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Extended Ionized Fe Objects in the UWIFE Survey

Yesol Kim^{1,2}*, Bon-Chul Koo¹, Tae-Soo Pyo^{3,4}, Dirk Froebrich⁵, Woong-Seob Jeong^{2,6}, Jae-Joon Lee², Yong-Hyun Lee^{1,7}, Ho-Gyu Lee², Hyun-Jeong Kim^{2,8}, Watson P. Varricatt⁹

² Korea Astronomy and Space Science Institute, Daejeon 305-348, Korea

³ Subaru Telescope, National Astronomical Observatory of Japan (NAOJ), National Institutes of Natural Sciences (NINS),

650 North Aohoku Place, Hilo, HI 96720, USA

⁴ School of Mathematical and Physical Science, SOKENDAI (The Graduate University for Advanced Studies), Hayama, Kanagawa 240-0193, Japan

⁵ University of Kent, Canterbury CT2 7NH

- ⁶ Korea University of Science and Technology (UST), 217 Gajeong-ro Yuseong-gu, Daejeon 34113, Republic of Korea
- ⁷ Samsung SDS, Olympic-ro 35-gil 125, Seoul, Republic of Korea
- ⁸ Department of Earth Science Education, Kongju National University, 56 Gongjudaehak-ro, Gongju-si, Chungcheongnam-do 314701, Republic of Korea

9 UKIRT Observatory, Institute for Astronomy, University of Hawaii, 640 North Aohoku Place, University Park, Hilo, HI 96720, USA

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ABSTRACT

We explore systematically the shocked gas in the first Galactic quadrant of the Milky Way using the United Kingdom Infrared Telescope (UKIRT) Wide-field Infrared Survey for Fe⁺ (UWIFE). The UWIFE survey is the first imaging survey of the Milky Way in the [Fe II] 1.644 μ m emission line and covers the Galactic plane in the first Galactic quadrant (7° < *l* < 62°; |*b*| \leq 1°.5). We identify 204 extended ionized Fe objects (IFOs) using a combination of a manual and automatic search. Most of the IFOs are detected for the first time in the [Fe II] 1.644 μ m line. We present a catalog of the measured sizes and fluxes of the IFOs and searched for their counterparts by performing positional cross-matching with known sources. We found that IFOs are associated with supernova remnants (25), young stellar objects (100), HII regions (33), planetary nebulae (17), and luminous blue variables (4). The statistical and morphological properties are discussed for each of these.

Key words: circumstellar matter - catalogues - surveys - infrared: ISM - ISM: kinematics and dynamics

1 INTRODUCTION

Understanding the role of shocks is essential for comprehensively studying the ecology of the Milky Way, since they transfer mass and kinetic energy into the interstellar medium (ISM), provide heavy elements for future star formation by destroying dust grains, and regulate star formation. Shock waves are one of the principal mechanisms of the interaction between stars and the ISM in galaxies, thereby playing an important role in the evolution of the Galaxy. Among the most powerful shock-driving sources are outflows and jets from young stellar objects (YSOs), stellar winds from massive OB stars, and supernova (SN) explosions. To understand the physics of the interactions as well as the nature of the shock-driving sources, observations of emission lines from the shocks are essential.

The [Fe II] $a^4 D_{7/2} \rightarrow a^4 F_{9/2}$ 1.644 μ m transition results in one of the brightest emission lines in near-infrared (NIR). It originates from one of the 16 levels of Fe⁺ that have a low excitation energy. Therefore they are easily excited in shocked gas, resulting in many lines, particularly in NIR. This emission line is thought to be bright in shock-excited gas; one suggested reason is that due to far-ultraviolet (FUV) radiation from the shock front, the Fe atom is in the form of Fe⁺ over extended regions (McKee et al. 1984, Hollenbach et al. 1989, Oliva et al. 1989, Koo et al. 2016). In contrast, in photoionized regions, Fe atoms are predominantly at higher ionization states, except when the ionizing radiation is hard enough that it can penetrate further into the interstellar cloud (Koo et al. 2016). Therefore, [Fe II] emission lines from shocked gas are stronger than those from photoionized regions; for example, [Fe II] 1.257 μ m / Pa β is over 0.1 in supernova remnants (SNRs) compared to 0.01–0.03 in Orion (Koo & Lee 2015; Mouri et al. 2000). Furthermore, the Fe abundance can be enhanced by shocks owing to grain destruction, making the [Fe II] lines stronger (Koo 2014; Greenhouse et al. 1991; Mouri et al. 2000 and references therein). These characteristics of [Fe II] make its lines extremely useful for studying interstellar shocks (e.g., Dinerstein 1995; Nisini 2008).

For example, the 1.644 μ m emission line as a tracer of shocked atomic gas enables us to study shocked regions in jets/outflows of YSOs (Nisini et al. 2002; Caratti o Garatti et al. 2006; Takami et al. 2006; Pyo et al. 2006; Pyo et al. 2009; Oh et al. 2016), planetary nebulae (Welch et al. 1999; Smith et al. 2005), supernova remnants (Koo et al. 2007; Lee et al. 2009; Lee et al. 2013), and nebulae of luminous blue variables (Smith 2002). Since NIR [Fe II] lines suffer less extinction than widely used optical emission lines such as H α ,

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^{*} E-mail:yskim916@gmail.com

[S II], and [O III], the NIR lines can give us information on deeply embedded regions inaccessible by optical lines.

Lee et al. (2014) conducted an unbiased [Fe II] 1.644 μ m narrowband imaging survey, which is called the United Kingdom Infrared Telescope (UKIRT) Wide-field Infrared Survey for Fe⁺ (UWIFE). The survey area $(7^{\circ} < l < 62^{\circ}; |b| \le 1^{\circ}, 5)$ is located in the first Galactic quadrant. This survey is the first unbiased, high-resolution [Fe II] survey of the Milky Way. It therefore enables us to discover more [Fe II]emitting sources and conduct a statistically meaningful investigation of Galactic [Fe II] line sources. Alongside [Fe II]-emitting Galactic SNR to study similar to [Fe II] line objects in nearby galaxies, the survey is expected to systematically detect low-brightness [Fe II] line sources from other kinds of [Fe II] emitters. Therefore it enables us to assess the level of contribution of each [Fe II]-emitting population. Further spectroscopic studies of new [Fe II] sources found in UWIFE can be used to derive critical densities in the range of $\sim 10^4 - 10^5$ cm^{-3} and temperatures up to 10^4 K (Pesenti et al. 2003), filling the gap in density between [S II] $\lambda 6731 \sim 10^4$ cm⁻³ and [O I] $\lambda 6300 \sim 10^6$ cm⁻³ (Osterbrock 1989). With other [Fe II] lines and emission lines such as [Fe II] 1.533 μ m, density diagnostics of ~10²-10⁵ cm⁻³ can be measured and line ratio diagrams with other [Fe II] lines (Pesenti et al. 2003) can help us understand the new parameter range.

Shinn et al. (2014) systematically searched for outflows from ultra-compact HII regions (UCHIIs), inferred [Fe II] outflow massloss rates, and discussed the travel time of the [Fe II] outflows using the UWIFE data. The statistical [Fe II] line study of Galactic SNRs in UWIFE and the UKIRT Wide-field Infrared Survey for H₂ (UWISH2; Froebrich et al. 2011) survey revealed a detection rate of 24 per cent for both surveys and suggested a relatively higher coincidence with mixed-morphology and/or radio-bright SNRs (Lee et al. 2019).

A comprehensive catalog of UWIFE sources will give an opportunity to compare shocked [Fe II] line objects with other tracers in previous large-scale Galactic plane surveys. Particularly, the UWIFE survey area is fully covered with the complementary survey, UWISH2 (Froebrich et al. 2011), which was carried out using UKIRT and the Wide-Field Camera (WFCAM, Casali et al. 2007). The catalog of extended H₂-emitting sources identified in UWISH2 (Froebrich et al. 2015) will be useful for the comparison of shocked molecular gas with higher excitation atomic gas. Also, the Isaac Newton Telescope (INT) Photometric H α Survey of the Northern Galactic Plane (IPHAS; Drew et al. 2005) and the UWISH2 survey can provide a chance to compare different outflow/shock tracers. Surveys tracing continuum sources in embedded regions such as the UKIRT Infrared Deep Sky Survey (UKIDSS) Galactic Plane Survey (GPS; Lucas et al. 2008) in the near-infrared, the Galactic Legacy Infrared Midplane Survey Extraordinaire (GLIMPSE; Churchwell et al. 2009), the Multiband Imaging Photometer for Spitzer Galactic Plane Survey (MIPSGAL; Carey et al. 2009) in the mid-infrared (MIR), and the Herschel infrared Galactic Plane Survey (Hi-GAL) (Molinari et al. 2010) in the far-infrared (FIR) were published.

Furthermore, the source catalog of various kinds of objects, namely, the catalog of UCHIIs from the Co-Ordinated Radio 'N' Infrared Survey for High-mass star formation (CORNISH, Hoare et al. 2012) and the catalog of Extended Green Objects (EGO, Cyganowski et al. 2008) can be good candidates to compare with [Fe II] sources, as well as emission line source catalogs, viz., catalogs of H α emission-line sources from IPHAS (Witham et al. 2008), and Molecular Hydrogen emission-line Object (MHO, Davis et al. 2010). In accordance with these catalogs and aims, we designate [Fe II] 1.644 μ m emission-line sources as ionized Fe objects (IFOs) and compile the first comprehensive catalog of Galactic extended

IFOs. The catalog includes basic physical properties of IFOs, such as coordinates (l, b), size, position angle, and flux. Information about possible counterparts and their distance is also included.

The organization of the paper is as follows. In Section 2, we describe the data reduction, the source identification, the photometry of the detected sources, and the procedure for searching for counterparts or exciting sources of IFOs. In Section 3, we first present the catalog of IFOs. The catalog contains the sizes and fluxes of IFOs as well as their counterparts. The IFOs are classified by their counterpart types. We then explore the statistics of the physical properties and the distribution of IFOs. In Section 4, we discuss the results of the individual types of IFOs. In Section 5, we summarize our paper.

2 DATA AND SOURCE CATALOG

2.1 UWIFE Survey Data

We have used the UWIFE survey data to search for extended IFOs in the Galactic plane. The UWIFE survey was carried out using WFCAM at UKIRT in 2012 and 2013 (Lee et al. 2014). The [Fe II] narrow-band filter was used, having a central wavelength of 1.644 μ m and an effective bandwidth of 0.026 μ m. The WFCAM hosts four Rockwell Hawaii-II HgCdTe 2 k × 2 k arrays, each covering 13.65 arcmin × 13.65 arcmin in area at a pixel scale of 0.4 arcsec. Four pointings of the telescope covered a contiguous area of 0.75 deg^2 (designated as 'tile', following the WFCAM terminology). Each pointing was composed of a set of dithered and microstepped observations, fully sampling the point spread function in good seeing conditions (<0.8 arcsec). The total integration time per pixel was 720s. The final [Fe II] images have a nominal 5σ detection limit of 18.7 mag for point sources, with a median seeing of 0.83 arcsec. For extended diffuse sources, the corresponding surface brightness limit is 8.1×10^{-20} W m⁻² arcsec⁻².

Lee et al. (2014) also produced continuum-subtracted [Fe II] images (hereafter [Fe II]-H images) by using the *H*-band images from the GPS. The continuum subtraction was carried out in two steps, i.e., point-like continuum sources were first removed in both [Fe II] and *H*-band images, and then the point source removed *H*-band images were subtracted from the point source removed [Fe II] images to remove extended continuum sources. The details of the observation and data processing procedure can be found in Lee et al. (2014).

All [Fe II] and [Fe II]-H images from UWIFE are available at the UWIFE web page ¹. The images consist of 220 tiles, where a single tile is a square of $54' \times 54'$ in equatorial coordinates. The tiles are arranged as 55 stripes of four consecutive tiles at constant declination along the Galactic plane, covering a region within the First Galactic Quadrant of $7^{\circ} < l < 62^{\circ}$; $|b| \lesssim 1^{\circ}5$ (see figure 1 of Lee et al. 2014). On the web page, the UWISH2 H₂ and GPS *JHK*-band images are also available.

2.2 Source Identification

In this study, we first aimed to identify IFOs in the continuumsubtracted images (hereafter, [Fe π]-H). We identified most of the IFOs through visual inspection and added several faint IFOs by mean of an automatic source identification, which uses the same algorithm as UWISH2 (Froebrich et al. 2015).

We focused on the extended sources in this study. Visual inspections were carried out twice for the whole survey area. We searched for all possible emission features and, for each feature, we defined an ellipse approximately surrounding the emitting area by eye. Then the central coordinates, radii, and P.A. of the ellipses are measured and listed in Table 1. All IFO candidates identified in the [Fe II]-H image were double-checked in both un-subtracted [Fe II] and GPS *H*-band images to confirm whether they were a real source or not. As the UWIFE and GPS observations were separated by several years, variable sources were seen as emission or absorption in the [Fe II]-H images. In particular, since artifacts with a negative digital number (DN) in GPS *H*-band resemble real sources in the [Fe II]-H image, we checked the position of all IFO candidates in the corresponding *H*-band data.

In addition, there are various kinds of artifacts in the [Fe II]-H images. Representative artifacts are: the residuals of bright stars, ghosts, cross-talks, cross stripes after star subtraction, and the diffraction pattern of bright stars (see Appendix A.1 for examples). Residuals of high proper-motion stars were also left in the [Fe II]-H images. We also excluded the features hampered by the artifacts from bright stars. The sources that show diffuse structures in both [Fe II] and H which are significantly brighter in [Fe II] compared to the GPS H-band, or the sources with a low probability of being scattered emission from dust seen in the GPS H-band, were selected as real sources.

Using the [Fe II]-H images, we conducted an unbiased automatic detection with the code used for identifying MHOs in UWISH2 (Froebrich et al. 2015) to benefit from its objectiveness. We adjusted the code to fit the specifications of UWIFE data: (1) Remove smallscale features (residual of star subtraction), determine the large-scale background level from a 40 arcsec scale median filter, and calculate its noise value. (2) Draw contours at the 1σ level in ds9² and identify the isolated contours as 'regions'. The level was determined empirically to include faint emission of IFOs. The low (1σ) level produces contours around the remaining point sources and noise peaks, but those 'false' regions are removed by a minimum size limit in the next stage. (3) Remove contours that are too small ($<4 \text{ arcsec}^2$) or near the image borders. (4) To avoid mistakenly identifying star residual as IFOs, remove contours smaller than 35 arcsec^2 if they are located within 3 arcsec to the Two Micron All-Sky Survey (2MASS) H-band stars brighter than 15 mag. This procedure was conducted for all UWIFE tiles except for tile 003, 080, and 196 due to the late release of the H-band data in the GPS survey.

All sources identified by the automatic detection were cross checked by visual inspection. We first examined whether the identified source from the code is an image artifact or not. Appendix A.1 shows some examples of the artifacts, including residuals of detector cross-talk and diffraction patterns from saturated stars. These nonastronomical sources can be easily distinguished by comparing them in the [Fe II] and H-band images and were removed from the catalog. We also rejected point-like sources (e.g., high proper motion stars, variables, [Fe II]-emitting stars, etc.) that are not considered in this paper. Note that the visual identification treats a group of clumpy structures as a single object (e.g., shells of SNR). On the other hand, the code identifies the substructures separately. We fitted each automatically-identified IFO with an ellipse and derived the geometrical parameters of the semi-major axis, semi-minor axis, and position angle. This process added 14 IFOs, and the complete catalog is presented in Table 1, which also provides their coordinates, sizes, fluxes, and counterparts.

2.3 Photometry

We conducted photometry of the IFOs in the [Fe II]-H images. Since our targets have an extended structure, we adopted aperture photometry. In the [Fe II]-H data, artifacts often have higher digital counts than IFOs. Therefore, masking artifacts is a crucial process. We masked the identified artifacts to prevent large uncertainties in the aperture photometry. The residuals of point sources (stars) brighter than 14th magnitude in the *H*-band (based on the 2MASS point source catalog, Cutri et al. 2003) were also masked. The size of the masking area was 6 arcsec in diameter, which is large enough to cover general residual patterns. When instrumental artifacts such as electronic cross-talk or diffraction patterns intruded on the aperture, we manually masked them to prevent any contamination.

In order to derive the total flux (F_{tot}) of the identified IFOs in a scientific unit (W m⁻²), we used the following equation :

$$F_{\text{tot}} = F_0 \cdot \left(\frac{DN}{t_{\text{exp}}}\right) \cdot 10^{-0.4 \cdot m_{\text{zpt}}}$$

 F_0 is the in-band flux of Vega falling in the [Fe II] filter (3.27 × 10^{-11} W m⁻², Lee et al. 2019), whereas t_{exp} and m_{zpt} are the net exposure time (60 s) and the zero-point magnitude of each image, respectively ('EXPTIME' and 'MAGZPT' in the image header). DN is the total digital number falling in the aperture corrected for the sky background. This local background of each source was estimated from a sky annulus with an inner and outer radius of 1.2 and 1.5 times the aperture. We took the mode of the sky values to further avoid the effect of any possible artifacts. The uncertainty of the flux is estimated considering the photometric calibration error from the uncertainty of the zero-point magnitude of ~0.06 mag, which corresponds to ~6 per cent of the total flux (Lee et al. 2019). The contribution of Poisson noise from aperture photometry and sky subtraction is negligible. The former is less than one-fifth, and the latter is less than one-tenth of absolute calibration uncertainty.

2.4 Search for Associated Exciting Sources

We have searched for the possible driving source(s) of IFOs via positional cross-matching with previously known sources: SNRs, HII regions, compact and ultra-compact HII regions, luminous blue variables (LBVs), planetary nebulae (PNe), and YSOs. IFOs associated with these sources are classified as SNR-IFO, HII-IFO, CHII-IFO, LBV-IFO, PN-IFO, and YSO-IFO, respectively. The rest of the IFOs are classified as 'unknown-IFO'. In the following, we describe the processes and catalogs employed for the search for the individual exciting source types.

SNRs have complex and filamentary structures often with a large spatial extent. Thus, a careful identification and the separation of genuine SNR-origin from mere superposition was required. We first selected IFOs located within the boundary of known SNRs, using the central positions and sizes of SNRs in the Galactic SNR catalog of Green (2019). We then referred to the references in the catalog and also SIMBAD³ for the multiwavelength morphology of SNRs for the confirmation of the association. If an IFO shows a coherent structure occupying a similar extent and/or its morphology implies a spatial correlation with the SNRs, we categorised it as an SNR-IFO. We also checked the area in SIMBAD for a possible superposition

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<sup>2</sup> https://sites.google.com/cfa.harvard.edu/saoimageds9
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of unrelated, superposed sources such as PNe along the same line of sight. An IFO without noticeable morphological correlation but positionally coincident with evident SNR emission was categorised as an SNR-IFO (e.g., IFO 38).

Diffuse HII regions also occupy a large spatial area and have complex morphology, so that a SIMBAD/VizieR query by IFO coordinate with an arcmin radius often returns various kinds of incidental sources such as sub-filaments of HII regions, jets/outflows from neighboring YSOs, and merely superposed sources along the line of sight. Therefore, keeping in mind that proximity alone does not necessarily guarantee a true correlation, a morphological correlation was also taken into account for identifying HII regions as a exciting source. If needed, a query with a larger angular scale was conducted to locate the diffuse HII region. We then compared the morphology of IFOs with that of HII regions obtained from high-resolution radio images (GPS; White et al. 2005, New-GPS; Helfand et al. 2006, and the H I, OH, recombination line survey of the Milky Way, THOR continuum; Beuther et al. 2016) and/or datasets from large-scale multi-wavelength studies (Fujita et al. 2021; Povich et al. 2009; Roshi et al. 2017). We also used small-scale surveys and targeted studies (see § 4.3). The IFOs with a positive correlation have been categorized as HII-IFOs. However, since the [Fe II] line emission from an HII region is inherently faint, morphological correlation with radio is occasionally hard to confirm. On the basis of this possibility, a few extended and faint IFOs have also been regarded as HII-IFOs although they do not have a clear morphological relationship with an HII region (see comments in \S 4.3).

We further explored whether IFOs are associated with compact, ultra-compact, or hyper-compact HII regions (CHII, UCHII, and HCHIIs) by querying VizieR within an arcmin-scale radius. Two comprehensive lists of UCHII regions were selected for the VizieR positional matching: the CORNISH UCHII region catalog (Kalcheva et al. 2018), which is appropriate for the comparison with the UWIFE survey data in terms of comparable high-resolution (1.5) and spatial coverage $(10^{\circ} < l < 65^{\circ}, |b| < 1^{\circ})$, and the catalog presented by Bronfman et al. (1996) which is a large-scale compilation of Infrared Astronomical Satellite (IRAS) FIR color-selected UCHII regions with higher Galactic latitude coverage ($|b| < 2^{\circ}$). The IFO positions were subsequently searched in SIMBAD to refer to targeted studies. We compared the [Fe II] line morphologies with available radio continuum images (see \S 4.2). When the IFOs show morphological correlation with radio structures or delineate the boundary of radio structures, they are classified as CHII-IFOs. IFOs having counterparts supposedly earlier or at a lower-mass evolutionary stage of an UCHII region (e.g., hypercompact HII region, UC HII precursor, ultra-compact embedded cluster which was suggested as a lowermass class of UCHII) are also included in this category (see § 4.2).

In order to identify IFOs associated with luminous blue variables (LBV-IFOs), the SIMBAD query was conducted with a radius criterion of 10 arcmin. But we noted that the list of LBVs and LBV candidates (hereafter cLBVs) has not been fully incorporated in SIMBAD, so we also used the catalog of (c)LBVs compiled by Nazé et al. (2012) which lists the coordinates of 68 (c)LBVs. As far as we know, this is the most comprehensive catalog of (c)LBVs. For example, Weis & Bomans (2020), in their review article of LBVs, presented a catalog, but it has a smaller number of (c)LBVs than Nazé et al. (2012), i.e., 47 versus 68. In the catalog of Nazé et al. (2012), twenty-two LBVs (including 19 candidates) are located inside the UWIFE area. There was also a [Fe II] survey of 9 LBVs by Smith (2002). Among the 9 LBVs, only one was located within the UWIFE survey area and it has been identified in our survey, too.

For IFOs associated with PNe (PN-IFOs), the SIMBAD query

was used with a radius criterion of 10 arcmin. We additionally compared the morphology of IFOs with multiwavelength data from references in SIMBAD. In order to incorporate recently discovered PNe and PN candidates that have not been updated in SIMBAD, we made use of the following databases and catalogs. We used the Hong Kong/AAO/Strasbourg H α (HASH) planetary nebula database which lists multi-wavelength data of newly found ~3500 PNe and PN candidates (Parker et al. 2016). The database includes three largescale catalogs of Galactic PNe; the Strasbourg-ESO catalog, the catalog of Galactic Planetary Nebulae version 2000, and the Macquarie/AAO/Strasbourg H α (MASH) catalogs, together with 159 new PNe from the related IPHAS survey and ~400 from the literature. A large number of unpublished, new PN candidates are accessible in this database, which are mostly (1) older, redder, and have lower surface brightness or (2) are more remote and small-scaled, faint PNe (Parker et al. 2016). When the counterpart is not a well-known source and is identified only in the HASH database, we checked the association using the references provided. There are PNe only detectable in NIR, so the recent study of PNe based on the UWISH2 data (Gledhill et al. 2018) was also checked for possible counterparts. This study complements faint or small-scale PNe previously undiscovered.

For the remaining IFOs, we made use of several large-scale catalogs of YSOs alongside catalogs for specific regions or targets. The large-scale survey of YSOs in four evolutionary stages (i.e., quiescent, YSO, protostellar, and massive star-forming stages, Urguhart et al. 2018) was used to find YSO-IFOs, keeping in mind the survey resolution (30 arcsec). The Infrared Array Camera (IRAC) red-source catalog was also used in the same manner (Robitaille et al. 2008) to locate YSO-candidate counterparts. When there was a positive match, we subsequently displayed their positions on the [Fe II]-H images with H₂ contours of UWISH2 data to confirm their association. H₂ images are useful since H2 emission is usually more easily excited, forming a series of knots between an IFO and the YSO that drives a H₂ outflow. When the positional match and morphological information could not pinpoint an obvious YSO counterpart, we listed up to two YSOs. Also used are small-scale survey catalogs to benefit from a deeper searches for YSOs. Kim et al. (2015) conducted a detailed survey of YSO candidates in the infrared dark cloud (IRDC) G53.2 region and investigated their evolutionary stages. Povich & Whitney (2010) investigated the M17 region where we have identified many IFOs, and the study provided the evolutionary stages of the YSOs. Ragan et al. (2009) covered multiple IRDC regions in the UWIFE survey area and a YSO Class with MIR color and distance information was provided. Other small-scale catalogs of YSOs available in Vizier were also used when available (\S 4.1).

Since Herbig-Haro (HH) objects are often bright in [Fe II] emission, we attempted to locate the [Fe II]-emitting HH objects separately from YSO-IFOs. 454 Galactic HH objects have been compiled by Reipurth (2000), who continuously updated the SIMBAD database to include newly found HH objects. We retrieved all HH objects in SIMBAD, up to HH 1213, which includes 3140 sub-structures (e.g., HH 250A and 250B). Firstly, we search for YSO-IFOs and unknown-IFOs within a radius criterion of 10 arcmin for a given HH object. When there was a match, we looked for a possible association of the IFO with HH object structures via multi-wavelength images (mainly $H\alpha$ from IPHAS, Witham et al. 2008). For example, IFO 195 which is associated with the parsec-scale HH 803 has a very compact, small-scale structure. It was originally categorized as an unknown-IFO since we could not find any associated source just based on positional proximity. However, when we plot the IPHAS H α and UWISH2 molecular hydrogen emission contours together, we could associate IFO 195

with the south-western tip of the series of aligned structures of HH 803 in H α and H₂ emission. Figure 1 shows the representative IFOs with respect to each counterpart.

3 RESULTS

3.1 Catalog of IFOs and their Statistical Properties

The full catalog of extended IFOs is presented in Table 1 and the description of each column of the catalog is as follows:

Column 1. IFO identifier : Designations of IFOs by a catalogue number in ascending order. When the IFO is identified only by a source detection algorithm, we marked them with an 'a' after its designation.

Column 2. IFO conventional designation : IFO full-name derived from Right Ascension and Declination (J2000) of the source center. It follows the 2MASS convention for the naming, i.e.: IFO JHH:MM:SS.SSS±DD:MM:SS.SS.

Column 3, 4. Galactic longitude (l) and latitude (b) : The center position of the source, in units of degree, in Galactic coordinates. For automatically identified IFOs, we adopt the geometric centre of the polygon by 2-dimensional Gaussian fitting of an ellipse.

Column 5, 6. Semi-major axis (r_1) and semi-minor axis (r_2) : Maximum semi-major and minor angular radius of the IFO in units of arcseconds.

Column 7. Position angle (P.A.) : The angle of the semi-major axis of an ellipse, in a counter-clockwise direction, from North to East in units of degree.

Column 8. Area : An area of an ellipse determined by the semimajor axis and semi-minor axis (Column 5, 6), in square arcseconds.

Column 9. F_{tot} : Total flux derived from summing up all flux inside an ellipse drawn from columns 5, 6. See the photometry section § 2.3 for details.

Column 10. Counterpart : Classification of the IFO indicating the most probable known object as follows: YSO-IFO - outflows or jets from an YSO or YSO candidate, HII-IFO - any outflows surrounding emission originated from the HII region, subdivided into HCHII, UCHII, CHII, and diffuse HII region, SNR-IFO - emission originates in SNR, PN-IFO - emission associated with PN/PN candidates, further classified into PN, PNc, and post-asymptotic giant branch (AGB), LBV-IFO - nebula structure around an LBV or LBV candidate, Unknown-IFO - multiple corresponding known object candidates or no possible known source in the vicinity,

Our IFO catalog contains 204 sources identified from 219 tiles, which is about 180 deg² in total. This number corresponds to an average surface density of ~1.1 IFOs per deg² in the first quadrant of the Galactic Plane (GP). This number should be regarded as a lower limit since our source identification methods were conservative. In general, the results of the manual and automatic search by the source detection algorithm were in good agreement. The 14 sources found only by the source detection algorithm, are marked with an 'a' after the IFO number in Table 1. They were either very faint or resembled artifacts. The majority of catalog sources are new discoveries of [Fe II] emission, and represent an order of magnitude increase in the number of extended [Fe II] sources in the first Galactic quadrant.

Table 2 presents basic statistics of IFOs for each counterpart type. We identified 100 YSO-IFO (87 YSOs, 13 HHs), 33 HII-IFO (22 CHII, 11 HII), 25 SNR-IFO, 17 PN-IFO, 4 LBV-IFO, and 25 IFOs without counterparts. Note that if a counterpart source has two distinct [Fe II] structures, they are counted as two separated IFOs which share a common counterpart (e.g., IFO 85 and 86 are from SNR G21.5-0.9 and are counted as 2 SNR-IFOs). Also, one SNR-IFO (IFO 7) is included in the number statistics in Table 2 but not used for flux statistics.

In total, 65 per cent of identified IFOs are related to star formation (49 per cent YSO- and 16 per cent HII-IFO), and 22 per cent are associated with evolved objects with 12 per cent of IFOs remaining as of unknown origin. Among them, YSO-IFO is the most frequent population showing [Fe II] emission. However, they account for only 1.6 per cent of the total [Fe II] flux. On the contrary, SNR-IFOs contribute 76 per cent of the total [Fe II] flux, though represent only 12 per cent of the IFOs by number. On average, the SNR-IFOs are 191 times brighter than the YSO-IFOs. The total flux of PN and LBV-type IFOs is similar, contributing 1 per cent of the total [Fe II] flux, albeit the number of PN-IFOs is 4 times larger. In order to understand the surface brightness of each type, the size and structure of the [Fe II] sources should be taken into account. In the next section, we will compare each counterpart's characteristics in more detail.

3.2 Flux and Size Distribution

In Figure 2a, we present the flux distribution of the IFOs. The flux distributions of the individual IFO types are shown in different colors. As mentioned above, some of the IFOs share the same exciting/driving source (e.g., 8 of 25 SNR-IFOs and 6 of 17 PN-IFOs). Bearing this in mind, we see that SNR-IFOs and HII-IFOs are bright with F_{tot} as large as ~10⁻¹⁴ W m⁻², while YSO, PN, and LBV-IFOs are much fainter, with a two-orders of magnitude smaller maximum F_{tot} . YSO and PN-IFOs appear in a similar flux range but the majority of PN-IFOs are brighter than YSO-IFOs. The unknown-IFOs are generally much fainter than the other types of IFOs.

Figure 2b shows the semi-major axis distribution of IFOs. IFOs appear in a wide range of sizes, from very compact, arcsecond-scale knots to large-scale objects up to ~47 arcmin in size. The distribution with respect to types is similar to that of the flux distribution, e.g., SNR-IFOs and HII-IFOs are large and bright while YSO-IFOs and PN-IFOs are small and faint. The radius range (<10 arcsec) of unknown-IFOs is similar to that of YSO-IFOs except for a few outliers. Although there are some exceptions and scatter, the overall fluxes and sizes seem to be proportional to each other. Especially for HII-IFO, the correlation coefficient of flux and size is 0.87. When divided into CHII and HII region sub-types, it is 0.52 and 0.83, respectively. The correlation coefficient of unknown IFOs is 0.99. In contrast the coefficient for SNR-IFOs is only 0.39.

Figure 2c presents the surface brightness distribution of IFOs. Unlike the flux and size distributions, the surface brightness distribution of each type shows slightly stratified distributions. Small IFOs appear to have a higher surface brightness in general, i.e., YSO-IFOs, PN-IFOs, and unknown-IFOs have higher surface brightness than HII-IFOs and SNR-IFOs. The reason for this might be due to the low surface filling factor of [Fe II]-emitting regions in the latter sources. For example, the IFO with the lowest surface brightness is SNR-IFO 117 (Kes 78). This SNR has a large size and the [Fe II] emission is patchy, apparent only around the northern and southern caps with a marginally detectable limb. For such sources, the true surface brightness of the [FeII]-emitting regions could be much greater. In Table 1, we made a note for IFOs with small surface filling factors.

3.3 Spatial Distribution

Figure 3 shows the distribution of IFOs in Galactic longitude and latitude. One can notice the Galactic longitude distribution is clus-

tered albeit the sky coverage is more or less homogeneous. The most outstanding overdensities are seen at $l \sim 16^{\circ}$ and $l \sim 51^{\circ}$. At $l \sim 16^{\circ}$, the dominant populations are YSO- and HII-IFOs, while at $l \sim 51^{\circ}$, they are unknown- and YSO-IFOs. Including other clustered IFOs in longitude, the dominant populations responsible for these peak distributions are YSO-IFOs, followed by HII- and unknown-IFOs. A detailed description of the individual peak regions will be presented later in this section. Note that there are also voids free of IFOs at $40^{\circ} \lesssim l \lesssim 50^{\circ}$.

The distribution of the whole population of IFOs in Galactic latitude shows a Gaussian-like distribution. The distribution yields an average latitude at $b = -0^{\circ}.12$ and standard deviation $\sigma = 0^{\circ}.65$. Some concentrations of YSO-IFOs are found at $b \sim -0.^{\circ}7$, 0° and $0.^{\circ}8$. The average latitude of YSO-IFOs is -0.08 ± 0.67 . The centroids of the HII- and SNR-IFO distributions are also below the Galactic plane with an average latitude of $b = -0.09 \pm 0.63$ and b = -0.27 ± 0.58 , respectively. The average latitude of unknown-IFOs is also less than zero, i.e., $b = -0.25 \pm 0.73$. For comparison, the average latitude of PN-IFOs is $b = 0.05 \pm 0.05 \pm 0.05$. A similar trend has been observed in the UWISH2 survey; the average latitude of the jets and photodissociation regions (PDRs) was -0.018 ± 0.01 and -0.017 ± 0.01 while that of the PN group was -0.01 ± 0.01 toward the Galactic mid-plane (Froebrich et al. 2015). The distribution of IFOs (excluding PN-IFOs) being slightly shifted to the negative latitude might be related to the 'bone' structure in the first Galactic quadrant. The bone structure refers to highly elongated, dense giant molecular filaments (GMF) that are the most probable tracer of spiral arm structure (Zucker et al. 2018). It is also worth noting the scarcity of IFOs at 0.9 < b < 1.5. The number of LBV-IFOs is too small for their distribution to have any statistical meaning.

Figure 4 shows the two-dimensional distribution of IFOs in Galactic longitude and latitude along with their flux distributions. Several IFOs in the same system (e.g., jet and counter-jet of an HH object) are shown as concentric circles, as in many cases they are only a few arcsec away from each other. On average, all populations show clustered distributions with some differences from each other, though the survey coverage is homogeneous. As well as the inhomogeneous distribution of IFOs, all populations except LBV- and unknown-IFOs have more sources toward the Galactic center ($l \leq 30^\circ$). About half of unknown-IFOs are located close to those of YSOs. In addition to the similar physical properties of YSO- and unknown-IFOs might originate from activities involved in YSOs.

The region relatively devoid of IFOs in the one-dimensional longitude and latitude distribution (Fig 3) turned out to form a large-scale 2-dimensional region; IFOs hardly exist toward $l \gtrsim 30^\circ$, $b \gtrsim 0.9^\circ$ and $35^\circ \lesssim l \lesssim 50^\circ$ near the Galactic mid-plane. This might reflect spiral arm structures and the sightline toward them, where we are seeing a shorter sightline toward the Galactic bar at $l \lesssim 30^\circ$. Above this Galactic longitude we are seeing the local arm branching from Perseus Arm and Sagittarius-Scutum Arm (line of sight tangential to $l \sim 45^\circ$) at a greater distance.

We have identified some areas rich in IFOs (upper panel of Fig 4), where in particular YSO and HII-IFO are major causes of overdensity. The respective regions are as follows.

(i) $l \sim 10^{\circ}2$, $b \sim -0^{\circ}3$: This region is coincident with the HII region G10.2–0.3, one of the three HII regions in the giant star-forming region W 31. The HII region is known to be very young (~0.6 Myr). At least four O stars are residing in it, where the brightest star W 31-1 showed permitted Fe II at 1.6878 μ m and brackett lines in the NIR

spectrum. In the *H*- and *K*-band spectra ($\lambda/\Delta\lambda \approx 3000$) the [Fe II] 1.644 μ m emission line was not detected (Blum et al. 2001).

(ii) $l \sim 12^{\circ}8$, $b \sim -0^{\circ}2$: This region matches with [MDF2011b] cl1, which encircles the O4-6 (super-)giant #23 (Messineo et al. 2015). This region is immediately east of the embedded protocluster W 33 Main which is located inside the massive star-forming complex W 33. The $K_{\rm s}$ -band spectroscopy of #23 showed that the extinction of the region is $A_{\rm K} = 1.20 \pm 0.03$ mag and the luminosity class is III-I. The Oe star #22 is located between W 33 Main and #23, with line identifications of Fe II 2.0895 μ m and H₂, an extinction of $A_{\rm K} = 2.87 \pm 0.07$ mag.

(iii) $l \sim 15^{\circ}$ 1, $b \sim -0^{\circ}$ 7: This over-density is coincident with one of the most massive star-forming regions, M 17. About a hundred O- and B-type stars are responsible for the emission and the system is quite young (<1 Myrs, Hanson et al. 1997). Bautista & Pradhan (1998) reported the detection of multiple iron species, including at 1.644 μ m.

(iv) $l \sim 16^{\circ}9$, $b \sim +0^{\circ}8$: Multiple compact IFOs are connected to the apex of pillars of creation located in M 16, an active star-forming region. At the tip of the apex, there are protostars in the pillar's EGGs ('Evaporating Gaseous Globules'), which are not yet hot enough to emit X-rays. Therefore, the IFOs in M 16 might be tracing some of the youngest protostars.

(v) $l \sim 25^{\circ}4$, $b \sim -0^{\circ}2$: The region corresponds to W 42, an obscured giant HII region. The closest nearby source is [BCD2000] W 42 1, an O5.5 star (Blum et al. 2000). There are several point-like sources that might be true [Fe II] sources or mere variables.

(vi) $l \sim 30.^{\circ}7$, $b \sim -0.^{\circ}0$: The IFO is close to one of the closest starburst regions, W 43. This giant H_{II} region has a central open cluster with massive stars.

(vii) $l \sim 49^\circ$ 1, $b \sim -0^\circ$ 6: Multiple HII- and YSO-IFOs are located in the vicinity of W 51, which is one of the most massive giant molecular clouds that is optically obscured. All large-scale representative structures, namely W 51 Main, IRS 1, and IRS 2, are bright in the [Fe II] 1.644 μ m line. Each structure shows a distinct star-forming phase as follows: W 51 Main - several UCHIIs are located. IRS 1 evolved HII region with a size of ~1 pc. IRS 2 - went through recent star formation, and an ~O3 star and a massive YSO were found (Barbosa et al. 2008). An LBV-IFO is also coincident with the region, which is a high-mass evolved star (P Cygni supergiant) with evidence for chemical enrichment (Clark et al. 2009).

(viii) $l \sim 53^{\circ}2$, $b \sim +0^{\circ}0$: Multiple YSO-IFOs coincide with an IRDC G53.2, which was formerly catalogued as three IRDCs in the *Midcourse Space Experiment (MSX)* dark cloud (MSXDC) catalog (Simon et al. 2006). The three IRDCs, viz. MSXDC G053.11+00.05, MSXDC G053.25+00.04, and MSXDC G053.31+00.00 harbor hundreds of YSO and YSO candidates, some of them in the vicinity of IFOs.

(ix) $l \sim 59^{\circ}4$, $b \sim -0^{\circ}2$: The IFOs are located in the central part of SH 2-87, a complex massive star-forming region. The three submillimeter clumps, SMM 1, SMM 2, and SMM 3 constitute this HII nebula. These three clumps are at separate evolutionary stages (Xue & Wu 2008), and two HII-IFOs were found in the vicinity of the hottest and most massive star-forming clump, SMM 1.

4 DISCUSSION

4.1 Outflows/Jets from Young Stellar Objects

Outflows/jets of YSO are composed of ejected and circumstellar swept-up material, and are recognized as an important signpost of recent star-forming activity. This phenomenon plays a key role in conventional disc accretion-outflow theories, the outflow being responsible for the removal of angular momentum and kinetic energy of accreting material that enables accreting material to overcome the centrifugal force and collapses to form a star (see theories of disk-wind; Pudritz & Norman 1983, X-wind; Shu et al. 1994, and observational studies; Ellerbroek et al. 2013 for reference).

Thanks to the development of IR instruments, previously undiscovered, highly obscured outflows have begun to be found in the near-infrared. The optical HH objects and their IR counterparts basically refer to the same phenomena, and only the conditions of jet and circumstellar matter differ. So far, molecular emission (e.g., MHO) has drawn attention in the NIR, alongside atomic/ionic lines in the optical, yet less attention has been brought to the [Fe II] lines in the NIR. The [Fe II] 1.644 μ m line, the brightest iron line in the H-K band, is reported to unveil a shocked region that is denser and/or more ionized than regions where optical lines are generated (Nisini et al. 2002). In this aspect, previous studies using frequently used molecular tracers, namely SiO, CO, and HCO⁺ in the sub-mm to mm, only revealed secondary outflows, tracing masses of low-density, distant (up to a few pc) outflows. Whereas the [Fe II] 1.644 μ m line from the jet is found to extend a few AUs to parsec-scales in the form of a dense irradiated jet (Reiter et al. 2015).

Most previous [Fe II] outflow studies are confined to certain types of objects or regions: specific star-forming regions (Orion; Takami et al. 2002, Carina; Reiter et al. 2016, Shinn et al. 2013) or a certain mass range of YSOs (Caratti o Garatti et al. 2006; Caratti o Garatti et al. 2015). Recently, outflow studies toward external galaxies, namely the Large Magellanic Cloud (LMC) and the Small Magellanic Cloud (SMC), became feasible (Reiter et al. 2019). These studies showed that the [Fe II] emission tends to be observed at the tip of the bipolar outflow and is rather collimated, compared to H₂ and H α which predominantly show the morphology of a 'wake' enclosing the [Fe II] emission (Reiter et al. 2015).

We have detected 100 YSO-IFOs (Table 3). Our result provides a large and comprehensive sample for the study of [Fe II] emission associated with YSOs. Figure 5 shows the example of identified YSO-IFOs, displaying UKIDSS *KHJ*-band RGB images to show how the YSO-IFOs reveal unique structures in comparison to hot dust continuum structures. YSO-IFOs show diverse morphologies, diverse compared to traditionally observed/expected [Fe II] features that are located at the tip of bipolar outflows and/or are highly collimated toward the driving sources (Caratti o Garatti et al. 2006; Reiter et al. 2016).

We classified YSO-IFOs into four morphological categories; bipolar, cometary, knot-like, and amorphous. A representative case of each category would be IFO 13-14, 125, 122, and 4 in Figure B.1, respectively. Bipolar YSO-IFOs are a textbook case of star formation, consistent with the accretion-jet theory with the aid of a magnetic field (Konigl 1982; Shang et al. 2020; Frank 1999). They typically show two lobes located on opposite sides of a central source, but some show two wakes, tips, and collimated bow-shock shapes, distributed laterally from the apparent YSO jet axis. The prototypical bipolar YSO-IFOs are IFO 13 and 14. The [Fe II] 1.644 μ m emission with bipolar morphology usually represents either the 'cap' of bow shock where an outflow collides with the ambient medium or dense, collimated jets. Cometary YSO-IFOs resemble a comet with a bright head around the driving source and a narrow faint tail-like structure. The prototypical cometary YSO-IFOs are IFO 125 and 131, both having well-defined conical structures. They are located at quite different distances, i.e., 4.7 and 1.1 kpc, and the extent of the associated conical structures has very different linear scales, i.e., ~45000 AU (10 arcsec) and 5000 AU (5 arcsec). For the wide-angle tails of cometary morphology, it is possible that either (1) the jet is bending and/or precessing (Paron et al. 2016) (2) a cavity structure is revealed (Hsieh et al. 2017) (3) a multiple systems presence is implied (Fuente et al. 1998). Knot-like YSO-IFOs appear as knots, sometimes located symmetrically from a driving source along a certain axis. The representative knot-like YSO-IFOs, 122 and 123, are showing well-isolated compact features. These knot-like features might imply that the ejection of accreted material in the system is accompanied by sporadic bursts of accretion (Caratti o Garatti et al. 2015). Amorphous YSO-IFOs represent the remaining YSO-IFOs that are diffuse and do not have a definitive structure. The nature of the amorphous YSO is uncertain. The number of YSO-IFOs classified as bipolar, cometary, knot-like, and amorphous is 16, 18, 19, and 47, respectively.

The morphologies of YSO-IFOs are closely related to the nature of YSOs and their mass-loss histories (Caratti o Garatti et al. 2015; Paron et al. 2016). For example, the collimated and continuous jet morphology indicates a continuous ejection of accreting material from the accretion disc system (Reiter et al. 2016; Reiter et al. 2017). The overabundance of amorphous morphologies might suggest highly varying environments or multiple systems are affecting the outflow structure. But the morphology of YSO-IFOs might depend on environments as well as foreground extinction, so detailed studies are needed of the individual objects to confirm their nature. Thirteen YSO-IFOs are associated with HH objects (Table 4). Figure 6 shows a comparison of their [Fe II] and H α images.

YSO-IFOs constitute half the number of our cataloged sources, making YSO the most common IFO in the inner Galaxy. The number density of YSO-IFOs is 0.55 deg^{-2} . For comparison, the H₂ number density probed by UWISH2, which covered an almost identical area with a comparable surface brightness limit, is 2.15 deg^{-2} (Froebrich et al. 2015). The flux density of YSO-IFOs ranges (2–820) $\times 10^{-18}$ W m⁻² with a mean of 4.3×10^{-17} W m⁻². This range can be compared with the results of other surveys. Caratti o Garatti et al. (2006) targeted H₂-emitting low-intermediate luminosity Class 0/I YSOs and reported that among 23, 74 per cent were also detected in [Fe II]. For the newly observed 9 [Fe II] line jets in the reference, the flux range is $(2.8-27.0) \times 10^{-18}$ W m⁻². Caratti o Garatti et al. (2015) observed 18 intermediate- to massive-YSOs having H₂ and EGO counterparts, and the flux range is $(2.5-61.9) \times 10^{-18}$ W m⁻². Note that these fluxes are obtained from spectroscopic studies using a slit of width 1 arcsec. The majority of YSO-IFOs have flux densities comparable to those of previous studies. But a few sources are exceptionally bright. The number of YSO-IFOs brighter than outflows observed in Caratti o Garatti et al. (2015) is 10 per cent of the YSO-IFOs. Since these bright YSO-IFOs do not share certain morphologies and 40 per cent of them have RMS counterparts, they might be preferentially massive YSO outflows, which have simply not yet been identified due to the limited sky coverage of past [Fe II] observations. One possible speculation is that [Fe II] brightness does not strictly scale with driving source brightness or other outflow tracers, based on the target of previous studies, which tend to be bright IRAS sources accompanying outflows discovered in other tracers. This illustrates the importance of an unbiased study to correct our understanding of the characteristics of [Fe II] emitters.

The YSO-IFOs and jet-group MHOs of the UWISH2 survey can be compared one-to-one since the UWIFE survey area was fully covered by UWISH2. The spatial distribution of YSO-IFOs in Figure 4 shows a highly clustered distribution, accompanied by the high-latitude sources in $l \sim 15-30^{\circ}$ and the absence of YSO-IFOs in the Galactic mid-plane at $l \sim 40-50^{\circ}$. This characteristic distribution is also shared in jet-group MHOs (see Figure 8 in Froebrich et al.

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2015). As seen in Figure 5, about 85 per cent of YSO-IFOs accompany jet/PDR-group MHOs in the vicinity. For example, in the M 16 (Eagle nebula), 6 YSO-IFOs were identified, and a few hundreds of jet/PDR-group MHOs are also present. A detailed comparison of YSO-IFOs with jet/PDR-group MHOs discovered in the subsequent UWISH2 studies will be helpful for the comparison of different shock tracers (Ioannidis & Froebrich 2012a; Ioannidis & Froebrich 2012b; Froebrich & Makin 2016; Makin & Froebrich 2018; Samal et al. 2018).

We can compare our results with the results of the RMS survey where NIR spectra of YSO candidates have been obtained. In the common survey area $(10^\circ \leq l \leq 62^\circ, |b| \leq 1.5^\circ)$, there are 182 RMS sources, and among the 72 sources from which spectra have been obtained, 58 have [Fe II] line emission, though some of the detections could be confused with the Br 12 line. For comparison, only 17 of 182 RMS objects have been identified as YSO-IFO in our study (for some RMS sources, 2-3 IFOs correspond to one RMS source.) Among these 17 sources, the NIR spectra have been obtained for 8 sources, and [Fe II] lines were detected in 6 sources, i.e., [Fe II] lines were reported as non-detection for two sources in the RMS survey. We note that the non-detection for the two is based on a comparison of Br 11 and Br $12/[Fe_{II}]$ line strengths (Br 11×0.788 > Br $12/[Fe_{II}]$) and it might be possible that a weak [Fe_{II}] line is in fact present but missed by low spectral resolution, as the authors noted (Cooper et al. 2013). To assess this possibility, we checked the slit configuration (central position, position angle) in Cooper et al. (2013) and compared it with YSO-IFO morphology. For both IFO 72 and 141, the RMS slit intersects the driving source but does not include the bright part of extended YSO-IFO structures. Indeed, the authors tried to include extended structures inside the slit in imaging mode prior to spectroscopy mode, yet even narrow-band [Fe II] images of UWIFE without continuum subtraction turned out to severely hinder extended emission. Therefore, most YSO-IFOs apparently do not have RMS source counterparts, which is claimed to be a 90 per cent complete list of massive protostellar populations (Lumsden et al. 2013). This seems to suggest that most of YSO-IFOs are associated with low-mass star formation. It is also worthwhile to note that the majority of YSO-IFOs (87 per cent) are not associated with HHs, which suggests that the [Fe II] emission is tracing optically hidden star-forming regions.

4.2 Compact HII Regions

Compact and ultra-compact HII regions are the earlier stages of 'classical' HII regions. An UCHII region is a photoionized region with a diameter ≤ 0.1 pc and an electron density $n_e \gtrsim 10^4$ cm⁻³, embedded in a molecular cloud (Wood & Churchwell 1989). In this evolutionary stage, mass accretion of the central star is thought to be insignificant (Churchwell 2002; Zinnecker & Yorke 2007). A CHII region is a HII region in the intermediate phase between UCHII and classical HII regions, having a radius ≤ 0.1 pc and $n_e \gtrsim 10^3$ cm⁻³. The lifetime of UCHII and CHII is $\sim 2 - 4 \times 10^5$ yr (Davies et al. 2011, Mottram et al. 2011).

In UCHII and CHII regions, [Fe II] emission can be enhanced by the interaction of stellar wind with the ambient medium. Bloomer et al. (1998) detected enhanced shell-like [Fe II] emission along the periphery of the CHII region NGC 7538 IRS 2. The observed [Fe II] 1.644 μ m / Br γ ratio was 0.15, which is an order of magnitude greater than that of HII regions, and it implies that the [Fe II] line emission emanates from shocked stellar wind material. Shinn et al. (2014) searched for [Fe II] 1.644 μ m emission associated with UCHII regions employing the CORNISH UCHII catalog and the UWIFE survey data. Among the 237 UCHII regions in the survey area, five and one candidate were found to have associated [Fe II] emission features, which were suggested to be shock-excited by outflows from central YSOs. Kim et al. (2017) also reported the detection of [Fe II] emission from UCHII Monoceros R2. Hereafter, we refer to IFOs associated with CHII/UCHII regions or with HII regions in even earlier evolutionary stages as CHII-IFOs.

We have detected 22 IFOs associated with 16 UCHII/CHIIs (Table 5). Six IFOs (IFO 24, 25, 26, 97, 107, and 156) had been previously reported by Shinn et al. (2014). We have discovered IFOs associated with an UCHII precursor (IFO 137) and an ultra-compact embedded cluster (IFO 138), which are thought to be earlier progenitor or less massive populations (Molinari et al. 1998; Alexander & Kobulnicky 2012). Among the 16 UCHII/CHII regions with [Fe II] emission features, 10 are catalogued in CORNISH, which corresponds to 4 per cent of the 237 UCHII regions in the CORNISH catalog in the survey area. The detectability might be partly due to the large extinction in UCHII/CHII regions, which is typically A_V~30–50 or A_K~3–5 (Hanson et al. 2002). Indeed, the A_V of three UCHIIs with associated IFOs had been found to have relatively low extinction (A_V~9–20, Shinn et al. 2014).

Figure 7 shows the 22 CHII-IFOs. CHII-IFOs have diverse morphologies, e.g., jet-like, shell-like, and amorphous morphologies. A representative IFO with jet morphology is IFO 97, which appears as a collimated beam from the center to the boundary of the HII region. The jet appears to extend beyond the radio continuum boundary (see Figure 7), which might reflect a possible correlation with the boundary of the ionization front (Goddi et al. 2020). The representative IFO with a shell-like morphology is IFO 132. An exemplary CHII-IFO of amorphous morphology would be the IFO 138, having a diffuse structure either outside or inside of the HII region in the radio. The properties of a compact HII region have been rarely investigated in [Fe II] emission. Shinn et al. (2014) proposed that some IFOs identified in the vicinity of ultra-compact HII (UCHII) regions (IFOs 24-26, 97, 107, 156) are the 'footprint' outflow features of UCHIIs, i.e., the features produced by outflowing material ejected during an earlier, active accretion phase of massive young stellar objects, based on the morphological relation between the [Fe II] and 5 GHz radio features, the outflow mass-loss rate, the travel time of the [Fe II] features, and the existence of several YSO candidates near the UCHIIs. The newly discovered CHII-IFOs in this study might serve as a chance to investigate the origin of the [Fe II] emission in the vicinity of CHIIs.

4.3 HII Regions

HII regions are not expected to be bright in the [Fe II] lines, since in their photoionized regions, Fe atoms are predominantly in higher ionization states, and Fe atoms are thought to be mostly locked in dust grains (Koo et al. 2016). According to theoretical models of photoionized regions, the [Fe II] emission from an HII region is mainly emitted in the high-density partially ionized zones near ionization fronts, predominantly excited by electron collisions (Oliva et al. 1989; Bautista & Pradhan 1998). In the Orion nebula, for example, [Fe II] images exhibit filamentary structures and diffuse emission that might be associated with ionization fronts, together with some knotty features (Takami et al. 2002). Expanding HII regions can drive shocks, but the shock velocity is low ($\sim 10 \text{ km s}^{-1}$) so [Fe II] line emission is not expected to be enhanced (e.g., Mouri et al. 2000). The [Fe II] 1.644 μ m/Pa α ratio of the Orion is 0.013, which is more than two orders of magnitude smaller than those of SNRs (Oliva et al. 1989; Mouri et al. 2000). So Galactic HII regions have not been a popular target

of deep and high-resolution [Fe II] imaging (Kraus et al. 2006; Bally et al. 2022). The depletion of Fe atoms in the HII region, however, is uncertain. In the Orion nebula, it has been estimated that 90 per cent of Fe is locked onto dust grains (Baldwin et al. 1991; Baldwin et al. 1996; Osterbrock et al. 1992; Rodríguez 2002). But there are studies which showed that, in many HII and star-forming regions, Fe is not depleted as heavily as in the Orion nebula (Osterbrock et al. 1992; Peimbert 1993; Rodríguez 2002; Okada et al. 2008; Peimbert & Peimbert 2010). It has been suggested that some populations of dust grains might be easily destroyed by UV radiation from OB stars and Fe atoms are released into the gas phase (Okada et al. 2008; Peißker et al. 2020). For external galaxies, Alonso-Herrero et al. (2003) did an imaging study of the starburst galaxies M 82 and NGC 253 in [Fe II] 1.644 μ m and Pa α (1.87 μ m) lines, and, by comparing their intensity ratios, concluded that 6-8 per cent of [Fe II] line fluxes are due to HII regions. Mouri et al. (2000), Riffel et al. (2016), Hennig et al. (2018), and Fazeli et al. (2019) suggested that some of the [Fe II] emission from external galaxies could be due to HII regions based on their low [Fe II] $1.257 \mu m$ / Pa β ratios.

We have identified 11 IFOs associated with 4 HII regions (Table 6). All HII-IFOs are located in the well-known star-forming complexes W 31, M 17, and W 51. Figure 8 shows the 11 HII-IFOs. We can see that some IFOs appear as thin filaments elongated along the radio structure (e.g., IFO 55, IFO 62) or as diffuse amorphous emission structures within the radio structure (e.g., IFO 11 and 12), so the association of IFOs with HII regions is very likely. The filamentary structures might correspond to ionization fronts and/or boundaries of PDRs as in the Orion nebula. On the other hand, some IFOs are faint and diffuse, and they extend beyond the radio boundary of the HII regions, e.g., IFO 159 and 161, so their association is uncertain and needs to be confirmed.

4.4 Planetary Nebulae

Planetary nebulae represent a short-lived phase near the endpoint of low- to intermediate-mass star (1-8 M_{\odot}) evolution which is preceded by the AGB, post-AGB, and pre-PN phases. The circumstellar envelope of the AGB carbon star is considered highly Fe-depleted (Mauron & Huggins 2010), though Fe becomes abundant with time (Fe abundance is negatively correlated with the C/O ratio, Delgado-Inglada & Rodríguez 2014). In turn, PNe are not expected to be strong [Fe II] emitters, also having a Fe-deficit nature with <10 per cent existing in gas and the remaining probably enshrouded in dust grains (Delgado-Inglada & Rodríguez 2014). Meanwhile, in the context of environmental factors, PNe could be a [Fe II] emitter since it has a partially ionized zone where Fe⁺ is apt to exist, and at a certain point of its evolution, a low-velocity shock is expected to occur. In short, suitable ionization conditions and energy to excite Fe (Greenhouse et al. 1991) can be established in PNe, and its iron-depleted nature is a key factor to determine the existence of $[\mbox{Fe}\,{\mbox{$\sc n$}}]$ emission.

Besides the theoretical expectation, previous studies reported the detection of [Fe II] emission towards stellar objects in a variety of evolutionary stages: post-AGB (IRAS 16594-4656; Van de Steene & van Hoof 2003), pre-PN (M 1-92; Davis et al. 2005), and PN (Hubble 12; Welch et al. 1999, M 2-9; Smith et al. 2005, NGC 2440; Hora et al. 1999). Some authors suggested a circumstellar origin (e.g., Clark et al. 2014, Smith et al. 2005), especially Baan et al. (2021) reported the detection of [Fe II] emission revealing the interaction of an accretion inflow, which is composed of material ejected in earlier post-AGB and pre-PN circumstellar material, and stellar outflow.

Table 7 shows PN-IFOs. They are IFOs spatially coincident with PNe, PN candidates, and sources in earlier evolutionary stages such as

post-AGBs. Seventeen PN-IFOs are associated with 14 PNe; 5 PNe, 8 PN candidates, and one post-AGB candidate. For comparison, in a previous study, Lee et al. (2014) reported the detection of [Fe II] emission in six PNe among 29 known PNe. In the survey area, there are 296 HASH 'true' (131), likely (40), and possible (125) PNe, so that the detection rate is 4.7 per cent. If we limit the sample to the 'true' PN, the detection rate slightly drops to 3.8 per cent (i.e., 5 out of 131). This very low detection rate of PNe in [Fe II] emission (4.7 and 3.8 per cent) contrasts with the results in H₂, where detection rates are 30 and 21 per cent, respectively (for $10^{\circ} < l < 66^{\circ}$, |b| <1°5, Gledhill et al. 2018). It is interesting that even with an order of magnitude larger sample of PNe in this study, our result is somewhat consistent with the former [Fe II] and H₂ detection rates of 7 and 39 per cent derived from 41 PNe (Hora et al. 1999). The slightly higher detection rate of Hora et al. (1999) could be because their samples are either moderately sized or optically bright.

The number density of PN-IFOs is 0.07 deg⁻² within 180 deg² whereas it is 1.25 deg⁻² within 209 deg² in UWISH2 (Froebrich et al. 2015). However, unlike the previous argument (Kastner et al. 1996), not all [Fe II]-emitting PNe are seen in H₂ emission; we found 3 of our 14 PNe in Table 7 were absent from the list of PNe with H₂ emission. Also, the median flux of PN-IFOs is greater than that of the H₂-emitting PNe, i.e., 6.46×10^{-17} W m⁻² versus 4.53×10^{-17} W m⁻². Therefore, our result shows that the H₂-emitting PNe are not necessarily brighter than the non-H₂-emitting PNe in [Fe II] emission.

Figure 9 presents [Fe II]-H images of PN-IFOs. Note that there are three bipolar PNe, each of which possesses two associated IFOs (IFO 5 and IFO 6, IFO 8 and IFO 9, and IFO 129 and IFO 130). We classified the morphologies of PN-IFOs using the basic 'ERBIAS' classifier following Parker et al. (2006), where 'E'=elliptical, 'R'=round, 'B'=bipolar, 'I'=irregular, 'A'=asymmetric, and 'S'=quasi-stellar. Their sub-classifiers 'amprs' are also adopted to describe detailed morphology; the main object has a one-sided enhancement/asymmetry 'a', has multiple shells or external structure 'm', exhibits point symmetry 'p', has a well-defined ring structure or annulus 'r', or resolved internal structure 's'. An IFO can have several 'amprs' sub-classifications. The results are summarized in Table 7, where their morphologies in $H\alpha$ and H_2 are also listed (Parker et al. 2016; Gledhill et al. 2018). The H α morphologies are from the HASH survey, while the H₂ morphologies are from the UWISH2 survey. For the PN-IFOs without a counterpart in the UWISH2 PN catalog (IFO 50, 95, 188), we inspected the UWISH2 data and classified their morphology in the same format (see Table 7). Some PNe have different morphologies in the [Fe II], H₂, and H α emission, which implies a complex surrounding environment and/or complex mass-loss history.

The physical sizes of PN-IFOs have been derived for 10 PNe that have previously estimated distances (Table 7). The sizes of 4 IFOs associated with 'true' PNe range from 0.13 pc to 0.92 pc, and three of the PN-IFOs are larger than 0.9 pc. This contrasts with the majority of PNe in H α being \leq 0.2 pc (González-Santamaría et al. 2020). This seems to suggest that the [Fe II] emission preferentially traces large, bright PNe.

For example, in PNG 050.4+00.7, the size of the associated IFO (IFO 157) substantially exceeds the previously known size of the counterparts (2 arcmin and 19 arcsec, respectively).

The IFO has a partial 'S' shape elongated along the east-west direction, with IRAS 19194+1548 superposed at the western part. The structure becomes gradually fainter toward the west, therefore the angular size of the partial 'S' shape should be considered as lower limit. The implied physical scale of 3.1 pc largely surpasses the generally accepted size of PNe (one of the oldest and largest PNe,

the Helix nebula has an outermost size of 1.76 pc). The driving source is suspected to be in a symbiotic star system (Akras et al. 2019) and the updated size is compatible with the sizes of large shells/nebulae around symbiotic stars (McCollum et al. 2008).

4.5 Nebulae of Luminous Blue Variables

Infrared [Fe II] 1.644 μ m emission around prominent nebulosity of LBVs is thought to be ubiquitous. Smith (2002) (henceforth, S02) searched for [Fe II] 1.644 μ m emission in nine well-known LBVs and found the emission in 7 of them, resulting in a detection rate of 77 per cent. This high detection rate surpasses that of SNRs (i.e., 24 per cent, Lee et al. 2019), the population that is thought to provide the most adequate environment for the existence of [Fe II] 1.644 μ m emission. S02 could not pinpoint the essential condition needed for strong [Fe II] emission to exist. Shock heating and radiative heating as possible excitation mechanism of [Fe II] emission were suggested by the author.

Shock-excited [Fe II] emission can arise when the LBV's environment meets requirements such as (i) a large difference in the outflow speed between the stellar wind and pre-existing LBV nebula and (ii) a difference of velocities between the stellar wind and ejected shell created during S Doradus outbursts or giant eruption phases. This velocity difference of 50–150 km s⁻¹ (S02) is ascribed to weaker gravity in an active phase. When LBV evolves toward a cooler temperature (to a local temperature lower than 30,000 K), Hydrogen atoms and opacity-enhancing ions start to emerge on the surface, which is known as the 'modified' Eddington limit (Humphreys & Davidson 1994). The elevated opacity makes the outward radiation pressure stronger and overpowers the inward gravity force. The resultant lower effective gravity helps LBVs easily induce the aforementioned mass loss. In these S Doradus outbursts and giant eruption phases, the weaker gravity results in an ejected shell having a lower expansion velocity than normal stellar winds. The following post-eruption wind has a velocity higher than that of the aforementioned high mass-loss phase and eventually overtakes the ejected shell. Meanwhile, photoionized [Fe II] emission was reported from two hot (30,000 K) LBVs (AG Car and R 127, S02) which was attributed to their stronger UV flux.

We detected [Fe II] emission features associated with 3 LBVs (Table 8). So the [Fe II] detection rate of LBV nebula in our study is 14 per cent. If we include the 9 LBV samples of S02, the detection rate would be 29 per cent, i.e., 9 out of 30 LBV nebulae (HD 168625 duplicated in both studies). This new detection rate with a three-fold sample is lower than the previous study, making the general physical conditions of LBVs not particularly suitable for the [Fe II] 1.644 μ m line to arise but comparable to those of SNRs. The discrepancy in detection rates between this study and S02 might be due to the biased sample S02 used, which includes confirmed LBVs and candidate LBVs showing nebulosity in the Galaxy and the two most famous LBVs in LMC.

The [Fe II]-H images of identified LBV-IFOs are shown in Figure 10. Brief information about them is listed in Table 8. In the [Fe II] emission, all identified LBV-IFOs share an elliptical/circular morphology. This is similar to their morphologies at 8 μ m but the extent appears smaller. We note that for G26.47+0.02 (IFO 102, 103) the south-eastern diffuse structure was noticed in the [Fe II]-H image. But the possibility of it being an artifact prevented us from assigning it as an IFO. The morphological coincidence of this South-East structure, IFO 102 and 103 with respect to the prominent part of the 8 μ m nebula (Paron et al. 2012) implies the possibility of more extended, diffuse [Fe II] emission than seemingly identified. There are some new features revealed by [Fe II] emission: (1) IFO 65 - HD 168625 is

located at the center of optical/IR elliptical structures that are broken toward the north-east. In the [Fe II] emission, we see a complete circular structure, the center of which is offset toward the northeast. (2) IFO 162 - [KW97] 37-17 shows multiple shells in [Fe II] emission, forming together a much brighter elliptical structure than those in 8 μ m or optical. This possibly indicates that the LBV had several active erupting phases that manufactured bright [Fe II]-emitting shells one by one.

We found that all [Fe II]-detected LBVs in the UWIFE survey also accompany nebulosities at 8 μ m, but not vice versa. For example, we could not detect [Fe II] emission in three LBVs with 8 μ m nebulosity (HD 168607, AFGL 2298, and GAL 024.73+00.69). Thus, the question of whether the LBV nebula, on account of the preceding giant eruption, is a prerequisite for the [Fe II] emission remains unanswered (S02). More comprehensive LBV samples and constrained physical properties of LBVs are needed to understand the possible relationship between the existence of the [Fe II] 1.644 μ m line in LBV nebula and their past eruption histories.

4.6 Supernova Remnants

SNRs are the brightest objects in [Fe II] emission. In SNRs this line is mostly emitted from cooling gas behind radiative shocks. [Fe II] lines are strong in shocked gas because Fe abundance could be enhanced by shocks owing to grain destruction (Dinerstein 1995; Nisini 2008; Koo et al. 2016 and references therein). Before the UWIFE survey, a dozen Galactic and LMC SNRs had been observed in the NIR [Fe II] lines. The SNRs that are bright in [Fe II] emission lines may be divided into two groups: (1) middle-aged SNRs interacting with dense molecular (or atomic) clouds such as W 44 (Reach et al. 2005), 3C 391 (Reach et al. 2002), and (2) young SNRs interacting with the dense circumstellar medium (CSM) such as Cas A (Koo et al. 2018), G11.2-0.3 (Moon et al. 2009), RCW 103 (Burton & Spyromilio 1993), and W49B (Lee et al. 2019). Then Lee et al. (2019) (hereafter, L19) searched for [Fe II] emission at the positions of the SNRs in the catalog of Green (2014) using the UWIFE survey data and detected [Fe II] emission features toward 19 SNRs, more than half of which were new detections. In external galaxies, [Fe II] emission is used as a tracer of SNRs (Blair et al. 2014; Bruursema et al. 2014; Long et al. 2020), although strong [Fe II] lines may originate from sources ionized by X-rays, e.g., in active galactic nuclei (Mouri et al. 2000; Morel et al. 2002).

We detected 25 IFOs associated with SNRs. All these SNR-IFOs belong to the 19 SNRs in Lee et al. (2019) except one (Table 9). It is worthwhile to point out that Lee et al. (2019) searched [Fe II] emission at 79 SNRs of the Green's catalog that are fully covered by the UWIFE survey. Four SNRs partially observed in the survey (i.e., G7.0-0.1, G13.3-1.3, G28.8+1.5, G38.7-1.3) were not investigated, and our unbiased search resulted in the identification of a small [Fe II]-emitting patch inside the region of G28.8+1.5. Meanwhile, the Green's catalog of Galactic SNRs has been updated (Green 2019), adding a new SNR G53.4+0.0 (partially covered in the UWIFE) and rejecting four (G20.4+0.1, G21.5-0.1, G23.6+0.3, G59.8+1.2 that were reclassified as HII regions) in the survey area. None of the new or rejected SNRs showed [Fe II] emission features. So the new detection rate for fully covered SNRs is 25 per cent (19/75).

We note that Lee et al. (2019) compensated the [Fe II] line flux for the flux subtracted from the *H*-band by multiplying with 1.15, whereas the fluxes in Table 9 are observed fluxes. As presented in Lee et al. (2019), IFO 147 that matches W49B is the brightest SNR-IFO. The detailed results for the 19 SNRs can be found in Lee et al. (2019).

5 SUMMARY

We have presented the first comprehensive catalog of Galactic IFOs discovered in the UKIRT Widefield Infrared Survey for [Fe II] (UWIFE). It is the first Galactic catalog of extended [Fe II] line emission sources using an unbiased, large-scale survey. We have discovered many previously unreported [Fe II] 1.644 μ m line sources. Therefore, this catalog provides an opportunity to broaden the horizons of the study of the shocked regions of our Galaxy, especially with the synergy of the UWISH2 survey.

We have searched for extended IFOs in the inner Galactic plane $(7^{\circ} < l < 62^{\circ}; |b| \le 1.5)$. In order for the search to be efficient, we removed point-like continuum sources from the [Fe II] 1.644 μ m images using H-band images taken as part of the UKIDSS GPS survey. We identified most of the IFOs by visual inspection and added several faint IFOs with an automatic source identification which uses the same source detection algorithm as in UWISH2 (Freebrich et al. 2015). In total, 204 IFOs were identified. We measured the sizes and fluxes of these 204 IFOs and presented their properties. We have searched for the counterparts of the IFOs via positional cross-matching with previously known sources and found that the majority of IFOs are associated with supernova remnants, young stellar objects, HII regions, planetary nebulae, and luminous blue variables. We group IFOs by their counterpart types and discuss their statistical and morphological properties. The main results are summarized as follows.

(1) In the 180 deg² Galactic plane area of the 1st Galactic quadrant covered by the UWIFE survey (7° < l < 62°; $|b| \leq 1^{\circ}5$), we identified 204 IFOs. The identified IFOs are classified according to their counterparts: IFOs associated with young stellar objects (YSO-IFOs), HII regions (HII-IFOs), compact HII regions (CHII-IFOs), planetary nebulae (PN-IFOs), luminous blue variables (LBV-IFOs), and supernova remnants (SNR-IFOs). There are 100 YSO-IFOs, 11 HII-IFOs, 22 CHII-IFOs, 17 PN-IFOs, 4 LBV-IFOs, and 25 SNR-IFOs. We could not identify counterparts for 25 IFOs, and they are classified as 'unknown-IFOs'. The majority of IFOs are new discoveries that have never been revealed in previous [Fe II] line studies.

(2) The SNR-IFOs and HII-IFOs are the brightest IFOs, and they dominate the [Fe II] 1.644 μ m line flux in the Galactic plane. They contribute 96 per cent of the total [Fe II] 1.644 μ m line flux of the IFOs (2.6 × 10⁻¹³ W m⁻²); 76 per cent by SNR-IFOs and 20 per cent by HII/CHII-IFOs. The YSO-IFOs, PN-IFOs, and LBV-IFOs are generally orders of magnitude fainter, while the unknown-IFOs are the faintest.

(3) The average number density of IFOs is ~1.1 deg⁻². The number density is highly variable spatially, especially for the IFOs associated with objects in the early-evolutionary phase, e.g., IFOs associated with HII regions and YSOs. In Galactic longitude, there are prominent peaks at $l \sim 16^{\circ}$ and 51°, while there is a 'void' at $l \sim 40^{\circ}-50^{\circ}$ where the number of IFOs is very small. The spatial distribution in Galactic latitude is centered at $b=-0^{\circ}$ 12 with a standard deviation of 0°.65.

(4) The results on the individual types of IFOs are summarized below.

(i) YSO-IFOs

We detected 100 YSO-IFOs, which constitutes half of the IFOs in our catalog. Only seventeen of those are associated with the RMS sources, which represent massive YSOs. The YSO-IFOs might be preferentially tracing low-mass YSOs. On the other hand, the majority (87 per cent) of YSO-IFOs are not associated with HH objects, suggesting that the YSO-IFOs are revealing previously hidden, optically obscured outflows in star-forming regions. YSO-IFOs have diverse morphologies, and we have classified them into four categories; bipolar, cometary, knot-like, and amorphous.

(ii) HII-IFOs and CHII-IFOs

We have identified 11 IFOs associated with 4 HII regions (Table 6). Almost all HII-IFOs are located in the well-known starforming complexes, W 31, M 17, and W 51. Some HII-IFOs appear as either thin filaments or diffuse amorphous emission structures within the radio structure, so their association with the HII regions is very likely. But some are faint and diffuse and extend beyond the radio boundary of the HII regions, so their association is uncertain and needs to be confirmed. We also detected 22 IFOs associated with 16 CHIIs, including 6 previously reported (Table 5). Among the 16 CHII regions, ten are catalogued in CORNISH, which corresponds to 4 per cent of the 237 CHII regions in the CORNISH catalog in the survey area. CHII-IFOs have diverse morphologies: jet-like, shell-like, and amorphous.

(iii) PN-IFOs

We detected 17 PN-IFOs. They are associated with 14 PNe (i.e., 5 PNe, 8 PN candidates, and one post-AGB candidate; Table 7), which correspond to about 4.7 per cent of the PNe in the survey area. We have classified the morphologies of PN-IFOs following Parker et al. (2006) and compared them with those in H α and H₂. Some PNe have [Fe II] morphologies different from the H α and H₂ morphologies, which implies that the [Fe II] line reveals new substructures, possibly probing additional mass-loss histories. The physical sizes of some PN-IFOs are larger than 0.9 pc.

(iv) LBV-IFOs

We detected 4 LBV-IFOs, They are associated with 3 LBVs out of 22 LBVs and their candidates in the survey area (Table 8), so the detection rate of [Fe II] emission associated with LBVs in this study is 14 per cent. All LBV-IFOs share an elliptical or circular morphology. Some show multiple shells. We found that all [Fe II] detected LBVs in the UWIFE survey also accompany nebulosity at 8 μ m, but not vice versa.

(v) SNR-IFOs

We detected 25 SNR-IFOs. They are associated with 20 SNRs, which corresponds to 25 per cent of the 75 known SNRs in the survey area. The SNR-IFOs occupy 76 per cent of the total [Fe II] flux of IFOs, and the four brightest IFOs are SNR-IFOs. On the other hand, the lowest surface brightness IFOs are also SNR-IFOs, showing the patchy [Fe II] emission in SNRs. All SNRs with [Fe II] emission features except one (G28.8+1.5) have been previously reported by Lee et al. (2019). The detailed results on the [Fe II] emission on the 19 SNRs can be found in Lee et al. (2019).

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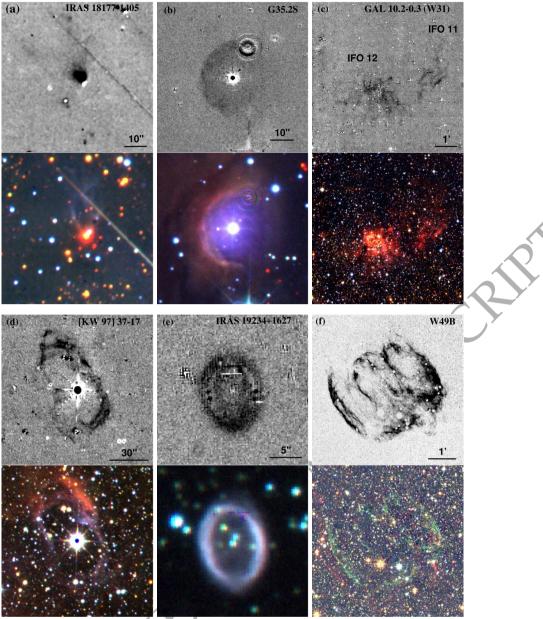


Figure 1. Continuum-subtracted [Fe II] and NIR three-color images of IFOs with various origins: (a) YSO outflow: IRAS 18177-1405; (b) compact HII region: G35.2S; (c) diffuse HII region: GAL 10.2-0.3; (d) LBV nebula: [KW 97] 37-17; (e) PN: IRAS 19234+1627; and (f) SNR: W49B. Grey-scale images in the upper rows are UWIFE [Fe II]-H images; Colour-composite images in the lower rows are R/G/B = *KHJ*-band images from the UKIDSS GPS survey. The units of the UWIFE [Fe II]-H images are DNs, with the darker colour denoting a higher DN. The UWIFE images of the panels (a) IRAS 18177-1405 and (d) [KW97] 37-17 are smoothed with a two-pixel Gaussian. In all images, North is at the top, and east to the left side. Note the following artifacts: panel (a) IRAS 18177-1405: diffraction spike from southwest to northeast; (b) G35.2S: crosstalk on the northwest edge of the source; diffraction spikes and an airy disk at the south; (e) IRAS 19234+1627: dead pixels on the north and southwestern part at the boundary of the source; (f) W49B: masked bright stars.

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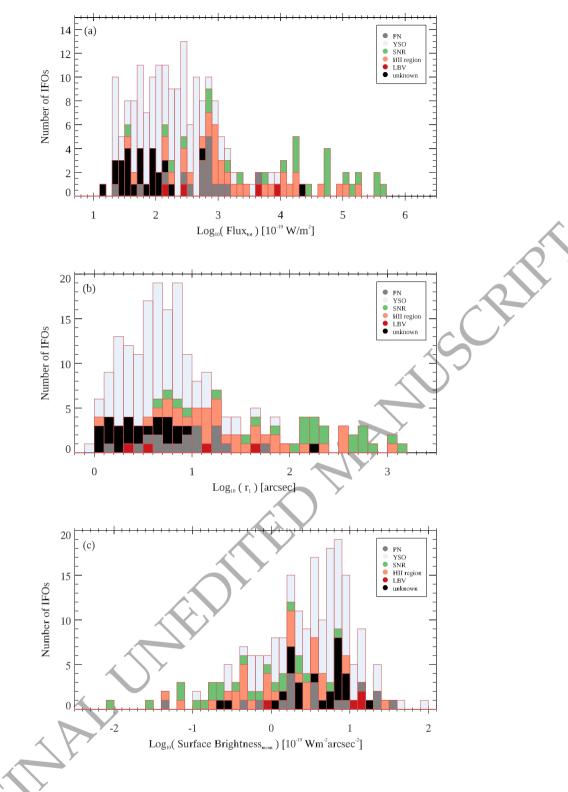


Figure 2. (a) F_{tot} distribution of IFOs. Note that the flux of a large-scale IFO 7 is excluded in this figure. (b) Semi-major axis r_1 distribution of IFOs. The semi-major axis of automatically-identified IFOs is the best estimate of the coordinate, semi-major, and minor axes from the best-fitting ellipse from IDL procedure 2dgaussfit. (c) Surface brightness distribution of IFOs. The counterparts of IFOs are presented in different colors.

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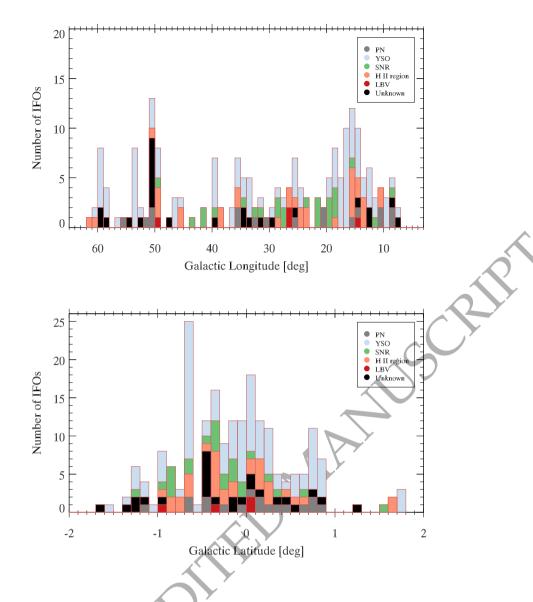


Figure 3. The spatial distribution of IFOs in Galactic longitude and latitude. The top panel shows the distribution of IFOs in Galactic longitude. The bottom panel shows the distribution of IFOs in Galactic latitude. IFOs are shown in accordance with their counterparts: YSO, HII region, PN, SNR, LBV, and unknown-IFOs.

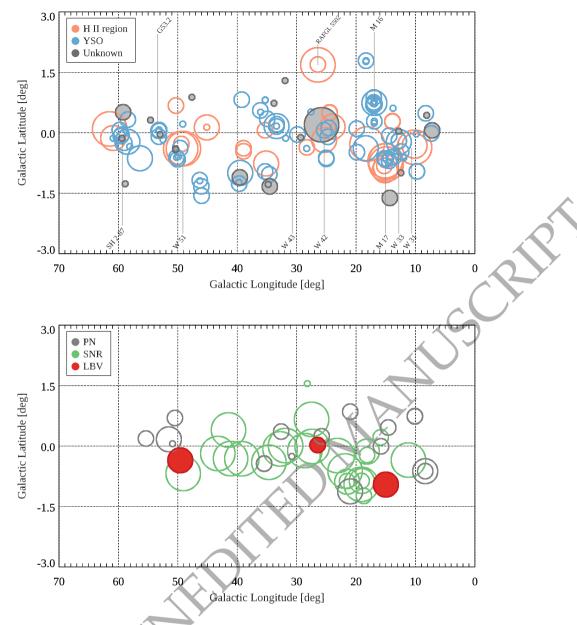


Figure 4. Two-dimensional distribution of IFOs. The top panel shows the spatial distribution of IFOs having counterparts in the HII region (orange), YSO (blue), and unknown (gray) categories. Each circle represents an IFO, and the size of each circle is proportional to its logarithmic F_{tot} (in order of 10^{-17} , 10^{-16} , 10^{-15} W m⁻²). Star-forming regions whose positions match those of IFOs in the distribution are labelled. Due to clustered IFOs, many circles overlap. The bottom panel shows the spatial distribution of IFOs with counterparts of PNe (gray), SNRs (green), and LBVs (red). Note that the flux of IFO 7 (i.e., SNR G8.7-0.1) is not provided, therefore excluded here.

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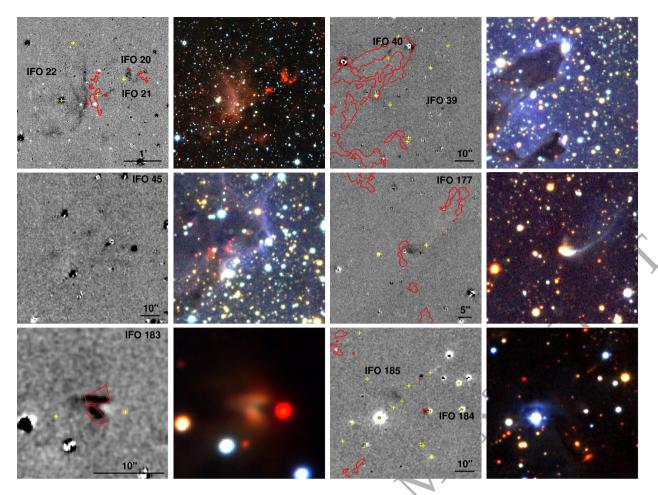


Figure 5. IFOs with YSO counterpart candidates in continuum-subtracted [Fe II] images as in Fig. 1. Only six representative IFOs are shown. The yellow crosses denote adjacent YSOs in the field of view, while the red contours are H₂ 2.12 μ m emission contours adopted from UWISH2. The right frames are three-color *KHJ* UKIDSS images of the same field of view. This figure is available in its entirety in the Appendix B.1.

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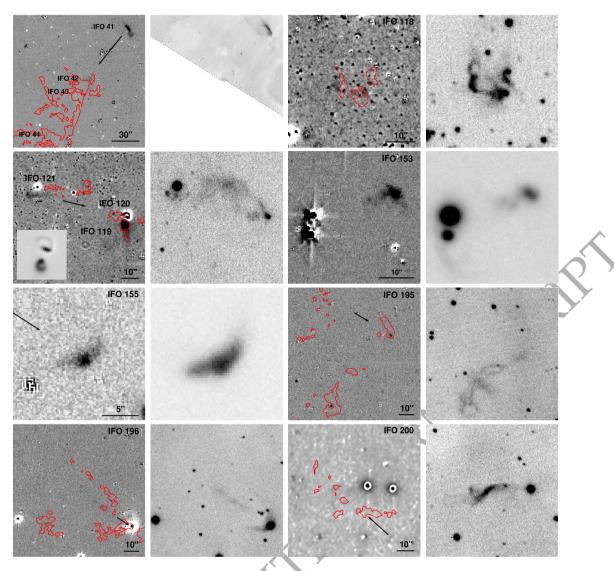


Figure 6. IFOs with HH counterpart candidates. The left panels show continuum-subtracted [Fe II] images as in Fig. 1. The right panels show H α in the same field of view. IPHAS images were used except for IFO 41–44 where the *Hubble Space Telescope (HST)* F657N image was used. Inset on the IFO 119–121 is a magnified [Fe II]-H image of the saturated star (West of IFO 120, North in the inset) and bright part of IFO 119 (South in the inset). Red contours are H₂ 2.12 μ m emission adopted from UWISH2. The black arrow points to the driving source of the HH object. When the driving source is out of the image field of view, the arrow points from the driving source to the IFO.

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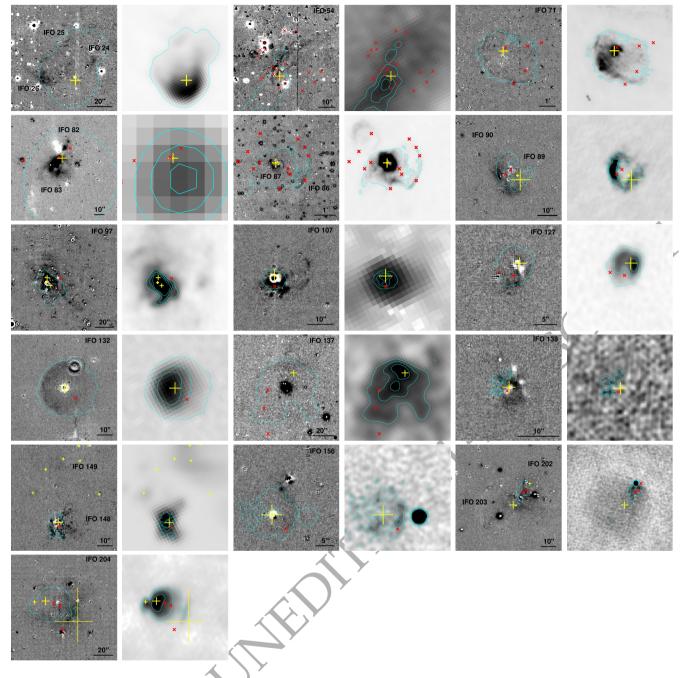


Figure 7. IFOs with CHII counterpart candidates. The left panels show continuum-subtracted [Fe II] images as in Fig. 1. The right panels show a radio continuum in the same field of view. Cyan contours on both images are the boundaries of CHIIs in the radio. The contours of IFO 24–26, 54, 71, 86–87, 97, 132, and 137 are from New-GPS 20 cm, IFO 89–90, 107, 127, 138, 148–149, 156, and 202–203 are from CORNISH 5 GHz, and IFO 82–83 are from the National Radio Astronomy Observatory (NRAO) Very Large Array (VLA) Sky Survey (NVSS). Only the radio image and contour of IFO 204 are from the old-GPS 20 cm. IFO 203 is a YSO-IFO inside the field of view. The yellow crosses in both panels are the same as in Fig. 5. The red cross shows the central position of the UWISH2 H₂ emission.

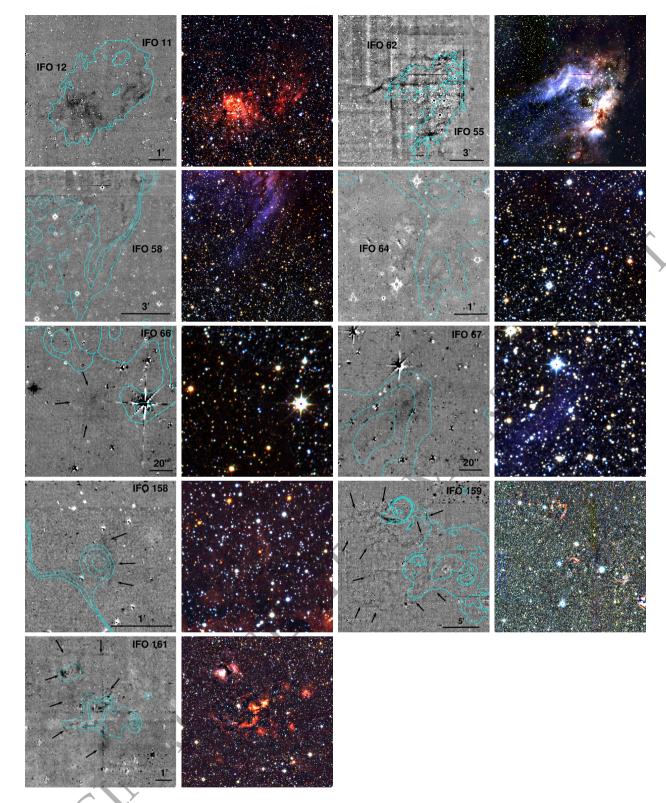


Figure 8. IFOs with Hu region counterpart candidates in continuum-subtracted [Fe II] images as in Fig. 1. Cyan contours are boundaries of HII regions in the radio continuum: IFO 11, 12, 55, 62 with New-GPS 20 cm data; IFO 58, 64, 66, 67 with GPS 90 cm data; 158, 159, 161 with THOR 1420 MHz continuum + VLA Galactic Plane Survey (VGPS) H I data. Black arrows point to the boundaries of IFO structures. The format for these images is the same as that of Fig. 1.

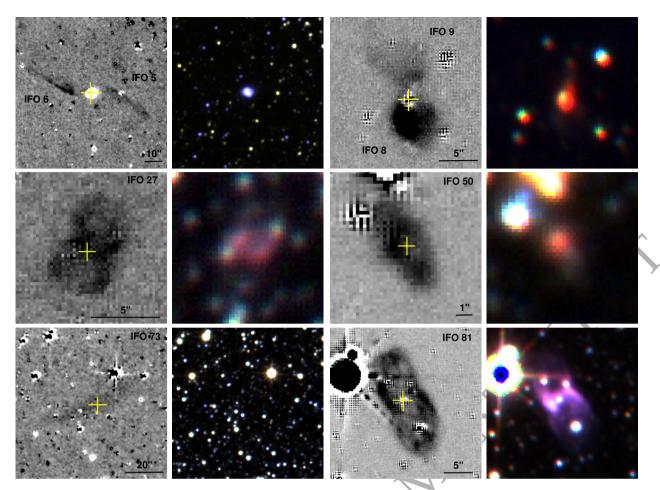


Figure 9. Continuum-subtracted [Fe II] images of IFOs with PN counterpart candidates. Only six representative IFOs are shown. The units on the UWIFE [Fe II]-H are DNs, with the darker colour denoting a higher DN. The right frames are three-color *KHJ* UKIDSS images of the same field of view. The corresponding source names for each IFO are shown. The yellow cross marks the central position of the counterpart. The images of IFO 73, 95, 112, 129, 157, and 164 are smoothed with a two-pixel Gaussian. In all images, North is at the top and east is on the left side. This figure is available in its entirety in Appendix B.2.

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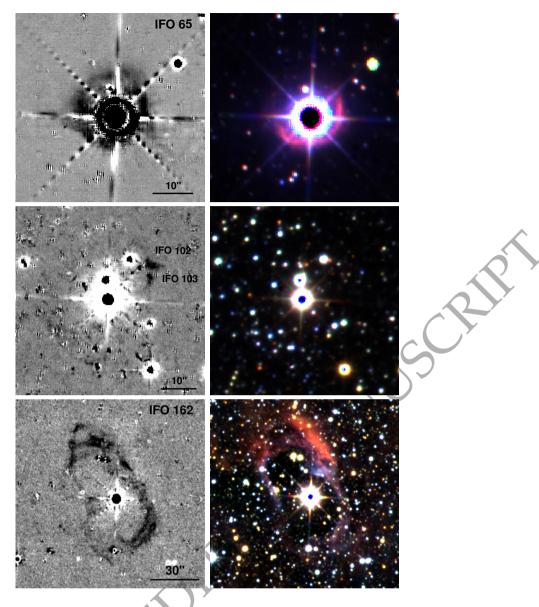


Figure 10. Continuum-subtracted [Fe II] images of IFOs having LBV counterparts. The right frames are three-color *KHJ* UKIDSS images of the same field of view. Note that there is a spike pattern around a bright star, coincident with IFO 65. The format for these images is the same as that of Fig. 1.

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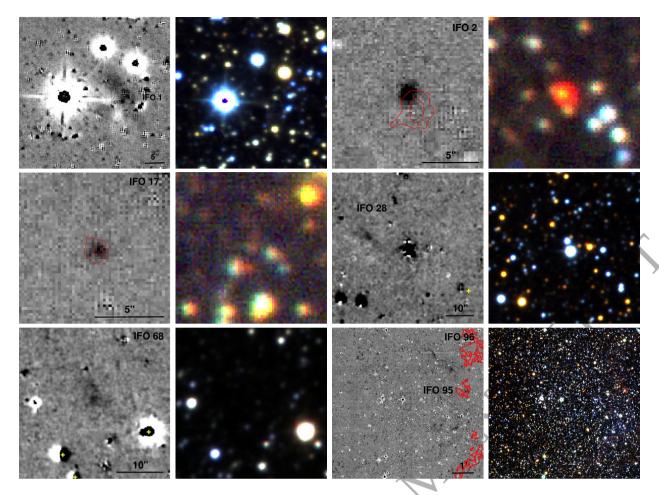


Figure 11. IFOs with counterpart candidates unknown in continuum-subtracted [Fe II] images as in Fig. 1. Only six representative IFOs are presented. The right frames are three-color *KHJ* UKIDSS images of the same field of view. The format for these images is the same as that of Fig. 1. This figure is available in its entirety in Appendix B.3.

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Table 1. Catalog of identified IFOs

ID19 UWIFE designation I h h No PE
[deg] [arcsc] [deg] [arcsc] [10 ⁻¹⁷ W m ⁻²] IF00007 118016321565-112456 51119 5435 2.3 2.0 84.7 5.88 - IF00007 1180121385-11350-21358 501604 2.6 1.8 157 1.42 2.25 YSO IF00047 118011-064-1950045 6.3221 4.0450 5.4 4.2 1.20 7.12 4.27 YSO IF00047 118021-373-210527.10 10.0550 6.0334 4.5 4.2 2.5 3.1 1.88 PN IF00007 118025.737-21054.10 10.1558 6.34 4.2 2.5 3.13.5 7.10 NI NN IF00101 118072.637-21054.10 10.13131<-0.9594
IF 00007 JB8021055-21432609 St 1119 +0.4376 2.3 2.0 0 14.4 0.899 - IF0 0007 JB8021398-2230550 8.2021 +0.48309 5.4 4.2 120 71.2 4.27 YSO IF0 0007 JB8016.46-190027.77 10.1035 +0.7314 180 -0.73 60 366.9 -0.741 31.58 PN IF0 0007 JB8056.397-22015.63 8.3394 -0.2320 4.4 4.2 25 9.33 6.30 PN IF0 0007 JB8056.397-22015.64 0.5333 -3.277 6.0 9.10 15.313.5 7.210 HI IF0 001 JB8056.372-20159.41 0.1331<-0.3379 6.3 4.2 10 15.313.5 7.211 HI IF0 001 JB8056.372-20159.41 0.1331<-0.3574 7.3 15.3 0.351 0.21 131 1.31 0.31 0.31 0.31 0.31 0.31 0.35 0.51 1.31 1.31 1.31 1.31 1.31
IF 00007 JB8021055-21432609 St 1119 +0.4376 2.3 2.0 0 14.4 0.899 - IF0 0007 JB8021398-2230550 8.2021 +0.48309 5.4 4.2 120 71.2 4.27 YSO IF0 0007 JB8016.46-190027.77 10.1035 +0.7314 180 -0.73 60 366.9 -0.741 31.58 PN IF0 0007 JB8056.397-22015.63 8.3394 -0.2320 4.4 4.2 25 9.33 6.30 PN IF0 0007 JB8056.397-22015.64 0.5333 -3.277 6.0 9.10 15.313.5 7.210 HI IF0 001 JB8056.372-20159.41 0.1331<-0.3379 6.3 4.2 10 15.313.5 7.211 HI IF0 001 JB8056.372-20159.41 0.1331<-0.3574 7.3 15.3 0.351 0.21 131 1.31 0.31 0.31 0.31 0.31 0.31 0.35 0.51 1.31 1.31 1.31 1.31 1.31
IF 0004 ¹¹ JB0212-398-22372.049 7.3338 -0.01604 2.6 1.8 157 14.7 2.25 YSO IF 00065 JB0214.089-19504.055 10.0984 -0.7341 180 7.2 60 407.1 3.15 PN IF 00067 JB052.378-213227.20 8.7390 -0.3223 1400 400.0 0 61572.18 - SNR IF 00007 JB054.037-20152.20 5.3303 -0.02320 4.5 4.4 9 25 9.3 3.80 PN IF 00007 JB054.037-20152.05 8.3303 -0.0232 4.6 4.9 25 9.3 3.4 0 3.6.3 0.01 YSO IF 00101 JB051.434-205738.7 9.7257 -0.9542 4.2 3.4 100 4.43 1.5.9 YSO IF 00105 JB112.64.21-9251.52 11.811 -0.3766 1.4 1.31 1.0 5.3 0.027 0.04 XSO IF 0015 JB112.64.21-9207.136.0 JB12.64.21 JB1.7
IFCO005 JIS011 064-19500.56 JOOP481 #0.7341 B.0 7.2 60 4071 31.55 PN IFCO007 JIS064 2772-21227.00 87900 -0.3293 H400 H400 H400 H400 H400 H5069 H5064 H5064.0377-201636 35344 H2 20 S3 J.300 PN IFC0100 JIS064.0377-201826.06 948449 -0.0258 J.4 L0 J.33 J.01 YSO IFC0101 JIS0105.472-201822.06 IJS033 -0.3374 G.6 J.0 J.83 J.7 L0.0 HII IFC0101 JIS112.032-10251.52 JIJS114 JJJS14 J.1
IFO 007 JIS051 464-195027.77 IOJ356 +0.731 I60 7.3 6.9 566.9 6.0.4 PN IFO 007 JIS067.378-21250 3.530 +0.6230 4.5 4.2 20 573.3 13.80 PN IFO 001 JIS072.3222.66 JIS034 -0.2322 6.1 30.3 9.0 150 S31.5 7.10 HII IFO 011 JIS072.378.76 7.057 -0.5622 5.0 3.8 4.0 3.6.3 9.01 S31.5 7.2.10 HII IFO 017 JIS075.378.76 7.057 -0.5642 4.2 4.10 7.0 4.8 TSO YSO IFO 017 JIS120.967-177.817.87 7.0570 -0.44 YSO JIS22.996-17.5751 JIS132.996-17.4752 JIS131 0 5.3 JIS12 JIS12.996-17.5751 JIS132.996-17.4750 JIS132.996-17.4750 JIS132.996-17.4750 JIS132.996-17.5750 JIS132.996-17.5750 JIS132.996-17.5750 JIS132.996-17.5750 JIS132.996-17.5750 JIS132.996-17.5750 JIS1444.44 JIS12.99
IF0007 ^b 1180627378-213227.20 87903 -0.3290 4.4 2 2 953 1.50 PN IF00007 118064.037-201826.5 8.3504 -0.6239 4.4 2 2 953 1.50 PN IF00107 118091.657.32-01822.96 10.1503 -0.2384 4.4 4.9 2.5 9.9 8.10 PN IF0011 11809.73-201822.96 10.1503 -0.3294 67.3 6.6 9.0 150 8.31.5 7.2.10 HII IF0013 118103.024-10515.52 11.811 -0.3706 8.8 170 4.4 8.59 9.00 9.00 NR IF0015 118112.42-161.411 13.700 7.1 1.5 60 8.0 0.44 YSO IF0017 118132.42-161.4114 13.700 7.4 90 19.9 4.79 YSO IF0017 118143.024-72-161.01.4144 13.8383 1.20604 8.3 1.00 8.3 0.5 9.0 1.57 YSO <
IFO008 J18060-088-2016.63 35394 -0.6322 6.1 4.9 25 939 6.10 PN IFO000 J18072.032-0260.66 94449 -0.0232 6.1 30.1 50.8 31.5 7.10 HII IFO011 J18092.579-201934.10 J105131 -0.3217 6.8 0 321.4.3 166.0 HII IFO012 J18092.579-201934.10 J105131 -0.3376 7.6 3.4 160 4.8 1.500 YSO IFO014 J18106.015-205748.39 9.7056 -0.9562 2.8 3.8 107 7.04 2.81 YSO IFO016 J18142.072-15501.73 J128432 -0.41842 1.33 2.1 110 2.1.7 0.64 YSO IFO013 J18148.077-15501.53 J28098 -0.2026 1.6 7.4 90 16.9 0.44 YSO IFO012 J18141521-1551.551 J28098 -0.2064 1.7 16 9.49 YSO IFO012 J181
IFO000 JIS060.088-22012.05 8.36205 -0.0228 4.3 4 0 3.3 0.01 YSO IFO0101 JIS0732.03-2016.05 9.8430 -0.0288 3.4 0 0.33 0.31 S 0.33 7.2.10 HII IFO011 JIS075.73-20182.06 0.15033 -0.3294 67.3 62.5 0.1121.31 JIS0.00 HII IFO013 JIS100.052-792.515.2 JIS111 -0.3573 JIS111 0.317 IO00.00 SRR IFO014 JIS112.62-16311.73 JIS206.62071 J.7 50 B.0 0.4 YSO IFO015 JIS1416.21-16311.2301 JIS2074 -0.06601 JIS 3 2.1 JIO 2.1 7.5 JIS JIO 4.5 IFO013 JIS1416.20-15205.501 JIS3020-0.2008 JIS3770 -0.06641 JIS 3 2.0 JIS 3 0.0 JIS 3 0.0 JIS 3 0.0 JIS 3 JIS 3 JIII 3 JIII 3 JIII 3 JIII 3 JIII 3 <th< td=""></th<>
IFO010 J18072.433-20260.66 9.8449 -0.0258 3.4 3.4 0 3.6.3 0.91 YSO IFO011 J18096.577-20182.56 10.533 -0.3217 6.80 050 150 831.5 72.10 HII IFO012 J18095.579-20193.410 10.1531 -0.3376 57.6 3.8 170 70.4 2.81 YSO IFO014 J18106.0344-20575.25 J1.811 -0.511.13 10.3476 3.14 11.0 5.11.1 0.51 0.53 0.53 0.54 5.7 IFO016 J18140.707-15050173 J198433 -0.62071 1.7 1.6 6.8 0.44 YSO IFO012 J18141.521-1552.051 J28098 -0.20641 1.7 1.6 6.8 0.44 YSO IFO021 J18141.521-1552.051 J28098 -0.20641 1.6 1.003 3.18 UCHII IFO022 J18141.521-1556.051 J28098 -0.20641 4.2 1.6 0.4 1.6 1.005 3.
IF 0011 1180016.373-201832.96 0.1503 0.250 873.1 72.10 HII IFO 013 118105.914-205738.76 0.95242 4.2 3.4 160 13214.3 160.00 HII IFO 015 118116.243-162515.52 11.811.1 0.9376.0 9.07 70.44 2.81 YSO IFO 016 11811.242-1611.154 13.707.04 2.81 YSO 9.07 70.99 YSO IFO 016 11811.242-1611.154 13.707.04 9.07 70.94 YSO IFO 017 1181.222.946-17758.22 12.80764 -0.0412 1.3 1.3 0 5.3 0.35 VSO IFO 017 11.8143.0208-12.20951.1 11.98582 -0.62071 1.7 1.5 60 8.0 0.44 YSO IFO 012 11.814.229.241.2051.1 11.286889. -0.2260 6.5 4.27 160 90.062 6.5.1 1.9 YSO IFO 022 11.814.229.41.2052.1 12.2081.1 1.0 8.3 1.0 1.0
IFO 013 J18105.01502578.76 97.627 -0.956.2 4.2 3.4 160 44.8 1.59 YSO IFO 015 J18112.024-1611.54 J370.7 0.4 2.81 YSO IFO 016 J1811.242-1611.54 J370.7 0.46864 3.5 2.8 90 30.7 0.94 YSO IFO 017 J18132.20.96-174758.22 1.2820.44 40.04152 1.3 1.3 0 5.3 0.35 - IFO 018 J1814.07.752-1850.11.3781.5 0.60201 3.3 2.1 110 2.1.7 0.64 N44 YSO IFO 021 J1814.52.21-7557.61 1.2840.56 -0.2664 3.3 1.20 2.90 4.75 YSO IFO 021 J1814.52.21-7561.65 J.280784 -0.2664 7.7 160 9068.2 69.50 YSO IFO 023 J1814.252.91-8153.57 J.24571 -0.2974 1.813.7718 40.250 1.0 1.00.3 3.18 0 1.057 1.00.46 0.551 7.7
IF0014 1181063.1015-205743.39 970056 -0.9320 5.9 3.8 170 70.4 2.81 YSO IF0016 118112.0623-125552 11.1811 131.1 05 511187 1090.00 SNR IF0017 11812.020-67.17582 12.304 1.0 2.17 0.64 YSO IF0019 11814.07.72-18510.173 11.98433 -0.62017 1.5 60 8.0 0.44 YSO IF0019 11814.057.72-1850.16 12.89826 -0.2604 10.7 8.3 122 279.0 1.57 YSO IF0021 11814.052.17.1555.16 12.89826 -0.2606 17.0 8.3 120 279.0 1.57 YSO IF0023 11814.922.16.156.0 12.8986 0.2206 1.0 0.36.7 0 0.55.1 7.1.6 9.55.1 7.1.6 9.55.1 7.1.6 9.0 7.6.0 UCHII IF0027 11814.52.1.196.16.025.94 14.35.90 0.6.0 10.0 3.0 10.0 3.0
IFO 015 11811242-01-61154 1317424 13181242-01-611154 137707 166086 33 1.0 5.11 0 5.07 100.00 NRR IFO 017 11812422-01-61731522 123306 1.1 1.1 1.5 1.0 2.1.7 0.64 YSO IFO 018 1181460.773-18205301 129852 -0.62017 1.7 1.5 6.0 8.0 0.44 YSO IFO 020 11814.132-175520.01 2.240784 -0.1604 8.3 7.4 90 192.9 4.7.9 YSO IFO 021 11814.1382-17557.01 1.240879 -0.46647 8.3 1.20 90.0 2.7.6 10 0.05.2 6.9.5 YSO IFO 022 11814.232-81-8156.057 1.383244 -0.2206 1.0 1.03 3.1.8 0.0 100 1.0.3 3.1.8 0.1507.9 6.60 UCHII IFO 025 1181812.02-61.0617.0 1.3.8444 0.200 0 1.551 YSO IFO 033 1.18152.0591.2002.5 1.
IF0016 1181212-24-164111.54 1377007 +0.69844 3.5 2.8 90 30.7 0.94 YSO IFO017 118122.096-174782-1123.044 10.9121 3.3 2.1 10 2.17 0.64 YSO IFO019 11814.08.077-2-185101.73 11.98582 -0.63071 1.7 1.5 60 8.0 0.4.7 YSO IFO021 11814.1521-175557.61 12.269436 -0.2664 10.7 8.3 120 279.0 1.5.7 YSO IFO022 11814.922.97-182508.51 12.39193 -0.46647 3.0 2.7 60 25.4 1.95 YSO IFO023 11814.322.1656.578 13.870 40.276 13.83234 40.2500 4.0 100 100.3 1.8 UCHII IFO024 118143.721-6125.68 13.8370 4.2578 13.870 4.3 50 102.6 -0.0 -7 1.90 7.4 0.90 7.4 0.91 7.5 1.91 1.91 1.91 1.92
IF 0017 J1811222096-17475822 J282064 40.0152 1.3 1.3 0 5.3 0.51 FO IFO 019 J1814078.073-185058.01 J198582 -0.62071 1.7 1.5 60 8.0 0.44 YSO IFO 020 J181415.12-17557.61 J28456 -0.2084 0.107 8.3 Z.7 1.60 90.65.2 0.507 YSO IFO 022 J181415.21-17557.61 J28456 -0.2084 4.0 160 10.03 3.18 UCHI IFO 023 J181422.23E-16497.70 J38244 4.0 160 10.03 3.18 UCHI IFO 024 J181426.32E-16497.70 J38244 4.020 0.00 150.79 6.60 UCHI IFO 025 J181627.693-18365.67 I2.45471 -0.931 3.3 9.0 4.17 4.66 YSO IFO 025 J181627.693-18365.67 I2.45471 -0.931 J1.7 4.4 0.80 YSO IFO 035 <tdj18174.5551-161207< td=""> J1.81575.61</tdj18174.5551-161207<>
IF0 019 J181408 073-ISS280 11.298582 -06.2071 1.7 1.5 60 8.0 0.4 YSO IF0 021 J181413.48-121-I75557.61 12.80436 -0.20684 10.7 8.3 7.4 90 19.29 4.79 YSO IF0 022 J181419.292-I756160 12.80898 -0.22602 67.6 4.27 160 90.68.2 69.0 YSO IF0 023 J181422.292-415208.51 12.3919 -0.4667 3.8244 4.0 160 10.0.3 3.18 UCHII IF0 023 J18142.292-4165070 13.8244 4.0 20.0 150.79 6.60 UCHII IF0 029 J181627.693-183653.67 12.45471 -0.99317 7.6 4.3 50 102.6 0.30 IF0 029 J18176.955-12160.31 13.668 -6.00717 3.8 3.5 90 41.2 48.4 3.5 10.2 1.0 3.1 4.0 3.8 4.0 1.40 3.8 5.0 1.17 1.6 8.9 YSO IF
IF 00 20 181415121-1557.61 12.907.84 -0.1960.4 8.3 7.4 90 912.9 1.57 YSO IFO 012 1181415.21-1557.61 12.908.6 -0.2064 10.7 8.3 120 27.90 1.57 YSO IFO 023 1181434.22-28-162306.51 12.3913 -0.46647 3.0 2.7 60 92.54 1.957 55.0 1.57 YSO IFO 024 1181434.22-16452.76 13.87207 4.02200 2.40 20.0 0 1570.9 6.06 UCHI IFO 025 1181437.31-16452.76 13.87270 4.023.0 8.0 60 32.5.7 9.40 UCHI IFO 028 1181627.693-183053.67 12.45414 -0.9317 7.6 4.3 50 10.2.6 9.00 UCHI IFO 028 1181627.693-183053.67 12.45471 -0.9317 7.6 4.3 50 10.2.6 7.3 1.0 9.0 1.4 0.43 YSO IFO 031 1181635.61-612124 14.440-0.07172<
IF 0021 IISI419.929-175616.05 I28088 -0.2200 67.6 42.7 160 9068.2 69.50 YSO IFO 022 IISI429.292-175616.05 I2.80898 -0.2200 67.6 42.7 160 9068.2 69.50 YSO IFO 023 IISI422.928-182306.51 IIS.39193 -0.46617 8.8244 40.200 100.0 150.79 6.60 UCHII IFO 024 JISI436.35-1465707 1.83244 40.200 150.79 6.60 UCHII IFO 027 JISI21.916-1602554 1.458529 -0.46128 4.5 3.9 160 55.1 7.16 PK IFO 029 JISI627.69-1805367 1.24471 -0.9317 7.6 4.3 50 10.2 6.0 5.1 7.16 PK IFO 029 JISI627.69-1802039 ISJSS 83 -0.00714 3.8 5.0 0 2.1 2.1 7.5 4.3 1.0 1.5 1.50 1.50 1.50 1.6 3.1 1.4 1.0 1.5
IF 00 02 II 81422 928-18208.51 I2.3093 -0.40647 3.0 2.7 160 9068.2 9.50 YSO IF 00 024 JI 81434 822-164514.38 JI SA718 0.22574 8.0 4.0 160 100.3 3.18 UCHII IF 00 25 ⁵ JI 81436 683-16450.70 JI S8234 0.2200 0 1507.9 6.60 UCHII IF 00 27 JI 81437.31-14652.67 JI SA771 7.6 4.3 0 16.0 3.0 8.0 0 3.51 7.16 PK IF 00 29 JI 81653.67 JI A44140 -0.07172 3.8 3.5 90 41.7 4.66 YSO IF 00 31 JI 8175.045-12080.50 JI JA2048 JI A40 3.8 JI A40 3.8 YSO 160 3.1 JI A41 3.8 YSO IF 0.032 JI B175.045-12084.20 JI JI A40 3.8 YSO IF 0.032 JI B183.55 JI JI A420 JJ JI JI S JI JI S YSO IF 0.032 JI B183.53 JI J
IFEO 023 JISJA22928-IRS208.51 I2.39193 -0.46647 3.0 2.7 60 25.4 1.95 YSO IFO 024 JISJA36821-664514.38 13.87718 +0.28764 8.0 4.0 160 100.3 3.18 UCHII IFO 026 ⁴ JISJA2156-01025.94 IASS23 +0.6252.54 IASS23 +0.612.5 IASS23 IASS23 IASS23 -0.72.5 0 2.12 2.11 YSO IFO 031 JISI750.953-11202.03.2 ISJS35 +1.7805 2.7 2.5 0 2.12 2.11 YSO IFO 033 JISI750.553.17 IASS23 1.03 0.8.1 0.54 YSO IFO 035 JISI837.058-1.3424.28 1.010 0.837 1.51 YSO
IFFO 024 IISI ISI ISI 1844 822-1651 45 13 ISI
IFO 026 ^b JI81437.731-I64326.78 JS87970 P0.27580 J3.0 8.0 60 326.7 9.40 UCHI IFO 027 JI8152.106-I60255.94 J4.58529 0.404128 45 3.9 160 55.1 7.16 N 55.1 7.16 N 50 0.26 0.30 - IFO 029 J181658.050-I62710.24 14.41440 0.007172 3.8 3.5 90 41.7 4.66 YSO IFO 031 J181755.445-10721.48 18.5638<-0.0071
IFO 027 JI81521.196-160255.94 I4.58529 +0.46128 4.5 3.9 160 55.1 7.16 PN IFO 028 JI81653.050-162710.24 I.41440 -00717 3.8 3.5 90 41.7 4.66 VSO IFO 030 JI81755.060-162710.24 I.41440 -00717 4.0 3.1 40 38.9 2.01 VSO IFO 031 JI81755.045-10272.10.03 JI.86538.050.72 1.7 1.4 90 7.4 0.43 VSO IFO 033 JI81875.445-12072.448 I8.31633 1.78705 2.3 2.0 90 1.4.45 0.48 YSO IFO 035 JI81825.990-16552.37 1.417066 -0.61195 3.1 2.4 1.20 2.3 4.89 YSO IFO 035 JI81837.058-134245.28 17.02271 +0.87917 1.2 1.0 4.5 0.23 YSO IFO 035 JI81847.407-150257.21 I.552388 +0.2933 +0.7797 1.2 1.0 6.4 5.1 1.30
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IFO 031 J181750.609–120802.39 I8.31833 +1.78972 1.7 1.4 90 7.4 0.43 VSO IFO 032 J181758.445–10274.48 I8.31833 +1.78895 2.7 2.5 0 21.2 2.11 YSO IFO 035 J181758.445–10274.48 I8.34208 +1.7052 2.0 1.3 0 8.1 0.54 YSO IFO 035 J181828.590-165523.72 14.17162 -0.6193 2.0 1.3 0 8.1 0.54 YSO IFO 035 J181837.058-134248.28 17.01527 +0.87651 6.4 5.1 130 1025 7.34 SNR* IFO 038 J181847.449-13502.70 16.23293 +0.77677 2.0 1.5 120 9.4 0.49 YSO IFO 044 J18183.830-13522.55 16.9189 +0.7767 2.0 1.5 120 9.4 0.49 YSO IFO 044 J18183.830-13526.39 16.91199 +0.72350 10.0 6.0 150 179.4 16.80 HH IFO 044 J18183.835-13526.231 16.91199 +0.72350
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IFO 042 JI81858.301-135236.39 16.91199 +0.72350 10.0 6.0 150 188.4 2.65 HH IFO 043 JI81858.835-135252.81 16.90897 +0.71943 4.0 30 140 37.6 0.23 HH IFO 044 JI81901.895-135252.81 16.90173 +0.70150 150 0.0 140 471.2 2.52 HH IFO 046 ^d JI81918.871-13452.91 17.03256 +0.75343 25.1 190.90 1498.2 4.14 YSO IFO 046 ^d JI81917.916-164355.78 14.43321 -0.69611 4.0 3.0 90 37.6 2.24 YSO IFO 047 JI8192.591-13411.45 17.12557 +0.76624 7.1 3.0 30 66.9 0.70 YSO IFO 050 JI8192.7.118-15121.1.6 15.79925 -0.0624 3.5 2.3 30 25.2 8.84 PN IFO 051 ^b JI8201.725-161018.05 15.0486 -0.65154 2.2 2.0 0 17.5 <t< td=""></t<>
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IFO 050 J181927.118-151211.16 15.79925 -0.00624 3.5 2.3 30 25.2 8.84 PN IFO 051 ^b J182019.871-161031.33 15.04081 -0.65134 2.2 2.0 0 13.8 1.33 YSO IFO 052 ^b J182020.767-161018.45 15.04566 -0.65282 2.8 2.0 0 17.5 4.05 YSO IFO 053 ^b J182021.725-161015.05 15.04831 -0.65757 2.3 1.7 30 12.2 1.05 YSO IFO 055 ^b J182028.170-161245.10 15.02369 -0.69815 250.0 100.0 130 78539.8 1257.00 HII IFO 056 J182023.784-160124.98 15.19905 -0.62538 7.6 3.9 0 93.1 0.63 YSO IFO 057 J182035.196-16192.63 14.9364 -0.77759 30.0 120 50.2 1.12 YSO IFO 058 J182035.224-140436.84 16.92057 +0.28355 1.9 1.8 90 10.7 0.85 YSO IFO 060 J182036.014-140344.82 16.92081
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IFO 054 ^b J182024.436-161126.80 15:03583 -0.67472 18.7 9.4 140 552.2 5.11 HCHII IFO 055 ^b J182028.170-161245.10 15:02369 -0.69815 25:00 100.0 130 78539.8 1257.00 HII IFO 056 J182032.784-160124.98 15:19905 -0.62538 7.6 3.9 0 93.1 0.63 YSO IFO 057 J182035.196-161942.63 14.93464 -0.77759 330.0 120.0 160 124407.0 473.00 HII IFO 059 J182035.224-140436.84 16.92807 +0.28355 1.8 90 10.7 0.85 YSO IFO 060 J182035.656-140409.72 16.92803 +0.28556 5.8 5.1 30 92.9 7.82 YSO IFO 061 J182036.014-140344.82 16.92803 +0.28754 3.3 3.3 0 34.2 0.54 YSO IFO 062 1182049.312-140353.86 15.10369 -0.69649 341.8 197.3 115 211860.0 875.00 HII IFO 062 ^b J182119.587-161224.78
IFO 055 ^b J182028.170-161245.10 15.02369 -0.69815 25.00 100.0 130 78539.8 1257.00 HII IFO 056 J182032.784-160124.98 15.19905 -0.62538 7.6 3.9 0 93.1 0.63 YSO IFO 057 J182035.196-161942.63 15.19359 -0.63521 8.0 2.0 120 50.2 1.1.2 YSO IFO 057 J182035.196-161942.63 14.93464 -0.7759 330.0 120.0 160 124407.0 473.00 HII IFO 059 J182035.224-140436.84 16.92807 +0.28555 5.8 5.1 30 92.9 7.82 YSO IFO 060 J182035.224-160434.82 16.93481 +0.28754 3.3 3.3 0 34.2 0.54 YSO IFO 061 J182036.014-140344.82 16.93481 +0.28754 3.3 3.3 0 34.2 0.54 YSO IFO 062 1182049.312-140353.86 16.95793 +0.28874 10.00 50.0 160 15707.9 58.27 HII IFO 065 ^b J182119.587-162224.78<
IFO 056 J182032.784-160124.98 15.19905 -0.62538 7.6 3.9 0 93.1 0.63 YSO IFO 057 J182034.306-160158.97 15.19359 -0.63521 8.0 2.0 120 50.2 1.12 YSO IFO 058 J182035.196-161942.63 14.93464 -0.77759 330.0 120.0 160 124407.0 473.00 HII IFO 058 J182035.224-140436.84 16.92803 +0.28555 1.9 1.8 90 10.7 0.85 YSO IFO 060 J182035.656-140409.72 16.92803 +0.28556 5.8 5.1 30 92.9 7.82 YSO IFO 061 J182036.014-140344.82 16.92803 +0.28556 5.8 5.1 30 92.9 7.82 YSO IFO 062 H82037.224-160828.36 15.10369 -0.69649 341.8 197.3 115 211860.0 875.00 HII IFO 063 J182049.312-140353.86 16.95793 +0.23896 2.6 2.4 30 19.6 0.60 YSO IFO 065 J182119.587-161224.78 <t< td=""></t<>
IFO 058 J182035.196-161942.63 14.93464 -0.77759 33.0. 120.0 160 124407.0 473.00 HII IFO 059 J182035.224-140436.84 16.92057 +0.28355 1.9 1.8 90 10.7 0.85 YSO IFO 060 J182035.224-140436.84 16.92057 +0.28355 5.8 5.1 30 92.9 7.82 YSO IFO 061 J182036.014-140344.82 16.93481 +0.28554 3.3 30 34.2 0.54 YSO IFO 062 ^b J182035.024-160828.36 15.10369 -0.69649 341.8 197.3 115 211860.0 875.00 HII IFO 063 J182049.312-140353.86 16.95793 +0.28564 2.6 2.4 30 19.6 0.60 YSO IFO 064 J18219.587-16224.78 14.97848 -0.95541 15.0 13.5 140 636.2 81.16 LBV IFO 066 J182121.701-160424.16 15.24737 -0.82163 18.2 16.2 0 926
IFO 059 JI82035.224-140436.84 16.92057 +0.28355 1.9 1.8 90 10.7 0.85 YSO IFO 060 JI82035.256-140409.72 16.92803 +0.28556 5.8 5.1 30 92.9 7.82 YSO IFO 061 JI82036.014-140344.82 16.93481 +0.28556 5.8 5.1 30 92.9 7.82 YSO IFO 062 ^b JI82036.014-140344.82 16.93481 +0.28754 3.3 3.3 0 34.2 0.54 YSO IFO 062 ^b JI82049.312-140353.86 16.95793 +0.28547 10.7 115 211860.0 875.00 HII IFO 064 JI82045.997-161934.88 14.97762 -0.85347 100.0 50.0 160 15707.9 58.27 HII IFO 066 JI82119.587-162224.78 14.97764 -0.85347 100.0 50.0 160 15707.9 58.27 HII IFO 066 JI82121.701-160424.16 15.24737 -0.82163 18.2 16.2 0 92
IFO 060 1182035.656-140409.72 16.92803 +0.28556 5.8 5.1 30 92.9 7.82 YSO IFO 061 J182036.014-140344.82 16.93481 +0.28754 3.3 3.3 0 34.2 0.54 YSO IFO 062 J182036.014-140344.82 15.10369 -0.69649 341.8 197.3 115 211860.0 875.00 HII IFO 062 J182049.312-140353.86 16.95793 +0.23896 2.6 2.4 30 19.6 0.60 YSO IFO 064 J182049.312-161934.88 14.97762 -0.85347 100.0 50.0 160 15707.9 58.27 HII IFO 065 J182119.587-162224.78 14.97848 -0.95541 15.0 13.5 140 636.2 81.16 LBV IFO 066 J182121.701-160424.16 15.24737 -0.82163 18.2 16.2 0 926.2 8.96 HII IFO 067 J182143.867-161209.80 15.15799 -0.92897 25.5 8.1 135 </td
IFO 061 J182036.014-140344.82 16.93481 +0.28754 3.3 3.3 0 34.2 0.54 YSO IFO 062 1182037.224-160828.36 15.10369 -0.69649 341.8 197.3 115 211860.0 875.00 HII IFO 063 1182049.312-140353.86 16.95793 +0.23896 2.6 2.4 30 19.6 0.60 VSO IFO 064 J18205.997-161934.88 14.97762 -0.85347 100.0 50.0 160 15707.9 58.27 HII IFO 065 J182119.587-162224.78 14.97848 -0.95541 15.5 10 636.2 81.16 LBV IFO 066 J182121.701-160424.16 15.24737 -0.82163 18.2 16.2 0 926.2 8.96 HII IFO 067 J182134.867-161209.80 15.15799 -0.92897 25.5 8.1 135 648.8 11.40 HII IFO 068 J182248.548-171548.32 14.32188 -1.61616 3.5 2.3 30 25.2 1.07 - IFO 069 J182434.8037-131345.15 18.14855
IFO 062 ^b I182037.224-160828.36 15.10369 -0.69649 341.8 197.3 115 211860.0 875.00 HII IFO 063 I182049.312-140353.86 16.95793 +0.23896 2.6 2.4 30 19.6 0.600 YSO IFO 064 I18205.97-161934.88 14.97762 -0.85347 100.0 50.0 160 15707.9 58.27 HII IFO 065 ^b J182119.587-162224.78 14.97848 -0.95541 15.0 13.5 140 636.2 81.16 LBV IFO 066 J182121.701-160424.16 15.24737 -0.82163 18.2 16.2 0 926.2 8.96 HII IFO 066 J182121.701-160424.16 15.24737 -0.82163 18.2 16.2 0 926.2 8.96 HII IFO 067 J182134.867-161209.80 15.15799 -0.92897 25.5 8.1 135 648.8 11.40 HII IFO 069 J182434.867-161209.80 15.15799 -0.92897 25.5 8.1
IFO 063 JI82049.312-140353.86 16.95793 +0.23896 2.6 2.4 30 19.6 0.60 YSO IFO 064 JI82056.997-161934.88 14.97762 -0.85347 100.0 50.0 160 15707.9 58.27 HII IFO 065 JI82119.587-162224.78 14.97848 -0.95541 15.0 13.5 140 636.2 81.16 LBV IFO 066 JI82121.701-160424.16 15.24737 -0.82163 18.2 16.2 0 926.2 8.96 HII IFO 066 JI82228.548-171548.32 14.32188 -1.61616 3.5 2.3 30 25.2 1.07<-
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IFO 066 J182121.701-160424.16 15.24737 -0.82163 18.2 16.2 0 926.2 8.96 HII IFO 067 J182134.867-161209.80 15.15799 -0.92897 25.5 8.1 135 648.8 11.40 HII IFO 068 J182228.548-171548.32 14.32188 -1.61616 3.5 2.3 30 25.2 1.07 - IFO 069 J182432.827-130950.81 18.17823 -0.13740 101.0 56.0 70 17768.8 21.50 SNR IFO 070 J182448.037-131345.15 18.14955 -0.22238 6.0 5.0 90 9.42 1.38 SNR IFO 071 J182459.449-131552.08 18.14002 -0.27977 13.0 90.0 60 36756.6 110.10 UCHII
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Table 1 (cont'd)

IFO #	UWIFE designation	l	b	r ₁	r ₂	PA	Area	Ftot	Counterpart
		[d	eg]	[arcs	ec]	[deg]	[arcsec ²]	$[10^{-17} \text{ W m}^{-2}]$	
IFO 073	J182619.105-101318.67	20.98261	+0.85302	19.9	7.4	120	462.6	6.64	PN
IFO 074	J182656.992-113210.92	19.89167	+0.10337	4.2	3.4	60	44.8	4.51	YSO
IFO 075	J182851.018-124415.55			67.4	27.4	15	5801.7	14.10	SNR
IFO 076	J182852.671-124311.10			16.4	5.5	0	283.3	2.55	SNR
IFO 077 ^a IFO 078	J182859.486-115026.04 J182919.659-124153.90			6.1 132.0	2.3 89.4	80 140	44.0 37073.3	3.45 192.00	YSO SNR
IFO 078 IFO 079	J182930.563-131350.84			8.7	3.6	70	98.3	1.89	SNR
IFO 080 ^b	J183314.281-100831.20			500.0		40	314159.2	627.00	SNR
IFO 081 ^b	J183328.975-110726.68			11.8	6.4	25	237.2	49.30	PN
IFO 082 ^a	J183330.115-050050.30	26.43603	+1.69464	6.8	3.5	165	74.7	6.73	UCHII
IFO 083 ^a	J183330.673-050110.94			15.4	12.0	114	580.5	150.00	UCHII
IFO 084	J183331.327-103257.93			35.0	17.0	50	1869.2	6.59	SNR
IFO 085 IFO 086	J183333.430-103402.86 J183404.384-071820.28			44.8 60.0	42.1 30.0	90 160	5925.2 5654.8	59.70 9.42	SNR UCHII
IFO 080 IFO 087	J183408.045-071801.82			12.7	7.6	30	303.2	1.72	UCHII
IFO 088	J183420.390-084722.27				400.0	10	753982.2	584.00	SNR
IFO 089	J183425.284-075448.33	23.95514	+0.14969	11.0	9.3	20	321.3	11.20	UCHII
IFO 090	J183426.772-075428.56	23.96285	+0.14677	1.1	1.1	0	3.8	0.32	UCHII
IFO 091	J183541.856-072203.61			15.0	8.0	140	376.9	3.06	YSO
IFO 092	J183648.912-071850.94 J183716.440-032958.39			2.3	1.9	20	13.7	2.13	YSO
IFO 093 IFO 094	J183716.440-032958.39 J183720.713-064200.69			4.0 2.0	2.3 1.7	10 30	28.9 10.6	0.39	SNR YSO
IFO 094 IFO 095	J183720.713-064200.69 J183730.398-061412.49			2.0 8.0	8.0	30 0	201.0	3.93	PN/UCHII
IFO 095 ^b	J183740.829-061452.41			180.0		0	101787.6	221.00	-
IFO 097	J183813.600-064815.32			25.2	8.0	45	633.3	25.60	UCHII
IFO 098^b	J183907.168-043230.84				400.0	20	628318.5	167.00	SNR
IFO 099	J183909.562-071927.89			4.0	3.0	0	37.6	2.05	YSO
IFO 100	J183911.798-072019.31			3.4	2.8	90	29.9	2.56	YSO
IFO 101	J183913.302-072057.12			1.8	1.5	130	8.4	1.12	YSO
IFO 102 IFO 103	J183931.338-054409.74 J183931.437-054414.64			3.3 2.4	2.3 1.4	80 0	23.8 10.5	3.07 1.27	LBV LBV
IFO 103 IFO 104	J183950.426-043037.60			4.5	2.0	0	28.2	0.20	YSO
IFO 105	J184120.333-045606.47			150.0		70	56548.6	274.00	SNR
IFO 106	J184358.299-035306.11			216.2		0	115534.0	197.00	
IFO 107	J184414.391-041754.32	28.28667	-0.36139	7.0	3.6	165	79.1	2.70	UCHII
IFO 108	J184422.810-041734.78			3.9	2.8	90	34.3	0.57	YSO
IFO 109	J184501.647-001716.48			2.6	2.1	90	17.1	0.37	-
IFO 110 IFO 111	J184515.462-031604.01			4.3 7.3	3.5 3.7	120 135	47.2 84.8	0.85	YSO
IFO 111 ^a	J184559.282-024502.58 J184829.526-021003.18			2.9	1.5	155	13.6	0.52	PN
IFO 112	J184927.068-005638.37			240.0		120	158336.2	3423.55	SNR
IFO 114 ^{ab}	J184933.121-003810.21			8.9	6.3	156	176.1	6.46	PN/HII
IFO 115	J184955.670-010153.39	31.84176	-0.13438	1.9	0.9	130	5.3	0.25	YSO
IFO 116 ^{ab}				5,5	2.1	68	36.2	0.83	-
IFO 117 ^b	J185125.777-000930.42				530.0		1232132.7	114.00	SNR
IFO 118	J185128.102+002840.15				8.0	170	216.1	1.02	HH
IFO 119 IFO 120	J185140.619+002850.89 J185141.136+002900.71			7.0 1.4	3.5 1.2	5 90	70.6 5.2	34.60 0.24	HH HH
IFO 120 IFO 121	J185144.114+002911.43			7.0	4.0	90	87.9	1.64	НН
IFO 121	J185249.992+022802.16			1.4	0.9	90	3.9	0.56	YSO
IFO 123	J185251.980+022804.91	35.29134	+0.80753	1.2	1.0	90	3.7	0.74	YSO
IFO 124	J185353.538+015714.24			3.9	2.8	60	34.3	1.87	YSO
IFO 125	J185516.571+030512.10			8.0	4.8	160	120.6	9.03	YSO
IFO 126 IFO 127 ^a	J185521.357+030154.61 J185534.205+021908.12			1.5	1.4 4.2	0 175	6.5 83.1	0.42 1.46	YSO UCHII
IFO 1274 IFO 128	J185534.205+021908.12 J185602.316+012139.70			6.3 1120.0			83.1 3025982.1	1.46 3942.00	SNR
IFO 128 IFO 129 ^b	J185737.231+020350.02			1120.0	11.0	0	3023382.1	6.54	PN
IFO 130 ^b	J185738.014+020332.58	35.47069	-0.43876	11.0	11.0	0	380.1	7.11	PN
IFO 131	J185808.531+010048.26			4.5	4.5	0	63.6	3.22	YSO
IFO 132	J185810.531+013656.88	35.13815	-0.76162	17.5	14.7	0	808.1	24.60	CHII
IFO 133	J185905.114+004833.51			2.1	1.4	0	9.2	1.60	-
	J185910.539+014013.31			5.0	3.1	130	48.7	1.56	YSO
IFO 135 IFO 136	J185923.204+010413.33 J190003.046+055926.63			2.8	2.8	0	24.6	0.39	-
IFO 136 IFO 137				26.6 35.0	13.0 18.0	170 100	1086.3 1979.2	3.29 8.31	YSO UCHII
IFO 137	J190403.633+050753.38			5.2	4.4	30	71.8	2.74	UCHII
IFO 139 ^b	J190404.180+052703.51			197.3		0	93037.4	618.00	SNR
1FO 140	J190540.231+074634.49			550.0		100	777544.2	1421.45	SNR
IFO 141	J190659.919+052253.12			5.4	5.2	90	88.2	12.20	YSO
IFO 142	J190731.328+052333.18			5.5	4.4	130	76.0	1.17	-
IFO 143	J190734.278+070829.06			170.0		115	64088.4	1691.00	SNR
IFO 144	J190813.552+052757.00	39.70977	-1.22650	1.6	1.4	90	7.0	0.23	YSO

Table 1 (cont'd)

IFO #	UWIFE designation	l [de	b eg]	r ₁ [arcs	r ₂ sec]	PA [deg]	Area [arcsec ²]	F_{tot} [10 ⁻¹⁷ W m ⁻²]	Counterpart
FO 145	J190816.446+052726.79	30 70784	-1 2/102	3.7	1.6	125	18.5	0.40	YSO
FO 146	J190816.782+052506.10			3.9	3.6	0	44.1	1.69	YSO
0 147	J191106.846+090604.55			160.0	150.0	120	75398.2	4739.00	SNR
O 148 ^a	J191327.650+105334.62			11.2	8.5	137	299.0	14.80	UCHII
0 149 ^a				3.2	2.4	105	24.1	0.48	UCHII
150	J191530.963+132747.36			1.7	1.4	120	7.4	0.29	-
0 151	J192026.005+111955.24	46.30789	-1.17527	5.6	3.9	120	68.6	2.25	YSO
0 1 5 2	J192029.411+111942.04	46.31118	-1.18928	1.3	1.1	90	4.5	0.27	YSO
0 1 5 3	J192029.485+110159.44	46.05061	-1.32806	7.5	5.3	90	124.8	8.71	HH
0 1 5 4	J192054.201+143031.29	49.16624	+0.21581	1.6	1.6	0	8.0	0.75	YSO
155	J192113.714+105232.92	45.99659	-1.56168	4.2	2.8	110	36.9	2.34	HH
156	J192127.938+154426.63	50.31742	+0.67543	4.5	2.6	30	36.7	1.58	UCHII
0 157	J192142.900+155351.18	50.48401	+0.69629	60.0	20.0	90	3769.9	1.55	PN
158	J192309.835+142912.63			40.0	15.0	10	1884.9	8.92	HII
) 159 ^b					1000.0		3769911.3	1647.09	HII
O 160 ^b	J192401.145+140105.48		-0.68118	580.0	430.0	30	783513.2	582.37	SNR
0 161	J192348.822+143137.35		-0.39670	350.0	210.0	115	230907.0	182.47	HII
162	J192348.169+143641.50			50.0	30.0	25	4712.3	45.50	LBV
D 163	J192354.032+143548.00			45.0	35.0	0	4948.0	5.76	YSO
164	J192451.838+155729.06			1.5	1.5	0	7.0	0.24	PN
0 165	J192516.759+144625.72			2.3	1.9	0	13.7	0.72	YSO
0 166	J192529.675+151646.36			1.1	0.9	0	3.1	0.20	-
167	J192531.202+151603.90			2.1	1.3	0	8.5	0.79	-
0 168	J192531.399+151556.79			0.8	0.8	0	2.0	0.13	-
169	J192532.882+151538.18			1.5	1.3	40	6.1	0.50	-
170	J192533.417+151616.62			1.1	1.1	0	3.8	0.26	(
0 171	J192534.199+151612.08			1.2	0.8	90	3.0	0.23	
0.172	J192534.538+151632.38			1.6	1.4	90	7.0	0.59	-
) 173 ^a) 174	J192540.546+163305.18 J192547.157+145145.84			7.0	5.8	16	127.5	11.50	PN
	J192557.625+150231.65			4.0 1.8	2.5	140	31.4	4.22	YSO
) 175) 176	J192557.848+150243.23			1.8	1.6 5.5	90 0	9.0 172.2	0.36	YSO YSO
0 177	J192852.403+171458.61			3.3	2.8	90	29.0	0.92	YSO
0 178	J192918.342+175615.42			15.0	10.0	140	471.2	4.95	YSO
178	J192918.342+175615.42 J192918.796+175723.68			3.7	10.0	140	4/1.2 22.0	4.95	YSO
D 180	J192918.790+175725.08 J192920.127+175716.54			25.0	8.0	80	628.3	4.41	YSO
D 181	J192920.506+175458.14			7.0	5.0	110	109.9	1.11	YSO
D 182	J192922.491+174442.54			4.6	3.5	0	50.5	0.57	-
) 183	J192931.617+175951.30			4.4	3.0	90	41.4	1.08	YSO
) 184	J192931.871+180058.11			1.7	1.4	90	7.4	0.25	YSO
) 185	J192932.874+180106.35			7.0	4.0	45	87.9	1.06	YSO
186 ^b	J193001.921+175455.44			5.4	3.3		55.9	3.15	YSO
D 187	J193120.744+192014.92			1.5	1.3	90	6.1	0.35	-
0 188	J193323.546+195647.07			20.0	18.0	40	1130.9	5.22	post-AGBc/YSO
) 189	J193831.665+202519.19			7.0	4.3	150	94.5	10.50	YSO
0 190	J193914.355+224021.52			7.0	6.0	¥40	131.9	3.75	YSO
0 191	J194014.058+232652.51			5.5	4.2	80	72.5	1.57	-
0 192	J194103.922+220340.80	58.08778	-0.34083	3.2	1.7	0	17.1	0.62	YSO
0 193	J194127.149+222739.58	58.47940	-0.22095	14.2	6.8	130	303.3	14.70	YSO
194	J194241.016+225417.72	59.00574	-0.24738	6.5	3.0	60	61.2	2.76	YSO
) 195	J194244.693+232250.36			3.0	3.0	0	28.2	0.65	HH
196	J194256.665+232435.17			29.0	18.5	40	1685.4	5.20	HH
197	J194306.295+231810.63			1.9	1.3	90	7.7	0.52	-
0 198	J194310.286+234358.03			4.9	2.9	60	44.6	2.83	YSO
199	J194310.930+234402.64			5.3	2.5	90	41.6	2.23	YSO
200	J194320.930+232952.89			10.5	8.0	150	263.9	1.34	HH
0 201	J194610.902+221559.08			7.1	2.5	120	55.7	0.96	-
0 202	J194620.335+243520.73			14.0	12.9	80	567.3	17.20	UCHII
203	J194621.675+243516.78	60.88413		1.3	1.3	0 140	5.3 4644.0	0.45 111.00	YSO UCHII / HII
204	J194646.921+251241.33			40.5	36.5				

^aIFOs marked with 'a' are identified only by an automatic detection method.

^bNote on the individual sources. IFO 7: Due to the complexity of the region, flux is not provided. IFO 25–26: The flux of the superposed part is allocated only to IFO 26. IFO 51–55: IFO 51–54 are located inside IFO 55. IFO 62, 98: The flux is derived for a partial region free from severe artifacts. IFO 65, 81, 114, 116, 186: missing flux due to 2MASS-bright star mask. IFO 80, 96, 117: Contaminated by an instrumental artifact. The pixels with DN > $\pm 3\sigma$ are masked for the flux measurement. IFO 129–130: Contaminated by an instrumental artifact. The pixels with DN > $\pm 3\sigma$ are masked for the flux measurement. IFO 139: Contaminated by an instrumental artifact. The pixels with DN > $\pm 3\sigma$ are masked for the flux measurement. IFO 139: Contaminated by an instrumental artifact. The pixels with DN > $\pm 3\sigma$ are masked for the flux measurement. IFO 139: Contaminated by an instrumental artifact. The pixels with DN > $\pm 3\sigma$ are masked for the flux measurement. IFO 139: Contaminated by an instrumental artifact. The pixels with DN > $\pm 3\sigma$ are masked for the flux measurement. IFO 139: Contaminated by an instrumental artifact. The pixels with DN > $\pm 3\sigma$ are masked for the flux measurement. IFO 159-160: The flux of the superposed part is allocated only to IFO 160. Note that there is an astrometry problem with certain continuum-subtracted [Fe I] images, where IFO 4, 8, 9, 73, 114, 155, 165, and 186 are located. Therefore, we determined the central positions of the IFOs based on the UKIDSS NIR image.

*IFO 38 is located within the SNR G15.9+0.2 domain but highly confined to a southwestern region (see fig. 1 of Sasaki et al. 2018 for an X-ray image of the SNR). Since there is no other possible counterpart in the SIMBAD query and the X-ray emission is coincident, we concluded that the SNR origin cannot be ruled out.

	Ν	Flux _{total}	Flux _{min}	Flux _{max}	Flux _{mean}	F ^{sb} mean				
YSO	100	4.3 (-15)	2.0 (-18)	8.2 (-16)	4.3 (-17)	6.6 (-19)				
CHII	22	5.2 (-15)	3.2 (-18)	1.5 (-15)	2.4 (-16)	4.0 (-19)				
ΗII	11	4.8 (-14)	8.9 (-17)	1.6 (-14)	4.3 (-15)	0.7 (-19)				
PN	17	1.4 (-15)	2.4 (-18)	4.9 (-16)	8.5 (-17)	7.6 (-19)				
SNR	25	2.0 (-13)	3.9 (-18)	4.7 (-14)	8.2 (-15)	1.3 (-19)				
LBV	4	1.3 (-15)	1.3 (-17)	8.1 (-16)	3.3 (-16)	9.7 (-19)				
Unknown	25	2.4 (-15)	1.3 (-18)	2.2 (-15)	9.7 (-17)	5.0 (-19)				
total/mean	204	2.6 (-13)	1.6 (-17)	4.7 (-14)	1.3 (-15)	5.3 (-19)				

Table 2. Statistics of IFOs

Note. — N: Number of IFOs in each type. Flux units are in W m^{-2} . F^{sb}_{mean}: Mean surface brightness of each type (flux divided by area) in W $m^{-2} \ arcsec^{-2}$. Note that one SNR-type (IFO 7) was not used for statistics of fluxes.

A

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candidates
· YSO
YSO or
with
Associated
IFOs /
Table 3.

IPO 003 YSO AGAL GOU7.33-00.016 IPO 003 YSO AGAL GOU7.33-00.016 IPO 004 YSO candidate XLUNES 108/219.38-21331.9 IPO 004 YSO candidate XLUNES 108/219.38-21331.9 IPO 004 YSO candidate XLUNES 108/219.38-21331.9 IPO 015 Shritem for YSO candidate SYTCIANC GO09.7612.00.9575 IPO 015 Shritem for YSO candidate SYTCIANC GO09.7612.00.9575 IPO 016 Shritem for YSO candidate SYTCIANC GO09.7612.00.9575 IPO 016 Shritem for YSO candidate SYTCIANC GO09.7612.00.9575 IPO 015 Shritem for YSO candidate SYTCIANC GO09.7612.00.9575 IPO 015 Shritem for YSO candidate SYTCIANC GO09.7612.00.9575 IPO 015 Shritem for YSO candidate SYTCIANC GO09.7612.00.9575 IPO 010 SYSO candidate ZMASS 11814081(6-186660) IPO 010 SYSO candidate ZMASS 1184.081(6-186660) IPO 010 SYSO candidate ZMASS 1184.0150 IPO 010 SYSO candidate ZMASS 1184.0150 IPO 010 SYSO candidate ZMASS 1184.0150 IPO 010 SYSO Candidate ZMASS 1184.01.711.182459.050 IPO 010 SYSO Candidate ZMASS 1181.794.945.12.711.1123.4509.12083 IPO 010 SYSO CANDIDATE C	Ż	IFO # YSO / YSOc Name N	Morphology	d [kpc]	Reference YSO Counterpart	Dist
YSO candidate JLWISE J180.219.38-21331.9 1 \times 1 \times 2 \times			¥	2.96	ro8/u18	u18
G009.7612-00.9575k $2.36^{+0.78}_{-0.88}$ $ro8/r09$ G009.7612-00.9575bro8G009.7612-00.9575b-ro8G009.7612-00.9575b-ro8stara2.90ro8/u18a2.90ro8/u18stara2.40^{+0.17}_{-0.15}b98stara2.40^{+0.17}_{-0.15}b98stara2.40^{+0.17}_{-0.15}b9875094-1208028, Class I/II YSOa2.40^{+0.17}_{-0.15}b9875094-1208028, Class I/II YSOa2.40^{+0.17}_{-0.15}b9875094-1208028, Class I/II YSOa2.40^{+0.17}_{-0.15}b9875094-1208028, Class I/II YSOa2.10ro8/r13/p1075094-1208028, Class I/II YSOa2.10ro8/r13/p1075094-1208028, Class I/II YSOa2.14c1375094-1208028, Class I/II YSOa2.14c1375094-1208028, Class I/II YSOa2.14c1375094-1208028, Class I/II YSOa2.14c1375094-1208028, Class I/II YSOa2.14c1375094-1208029, Stara2.14c1375094-1208028, Class I/II YSOa2.14c13750021 S-1 or S-2k2.14c13750021 S			а	ı	ro8	ľ
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$			k	$2.36^{+0.78}_{-0.88}$	ro8/r09	r09
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		Northern	p	00.00	ro8	ı
a 2.90 ro8/u18 a 2.40 $+0.17$ b98 star #23 star		Southern	þ		ro8	ı
a -1 -100		IFO 016 YSO AGAL G013.779+00.609	а	2.90	ro8/u18	u18
a $-40^{+0.17}$ b98 star a $-2.40^{+0.17}$ b98 star $-2.40^{-0.15}$ b98 star $+23$ $-2.40^{-0.15}$ m15 182459.0: Class I/II YSO $-2.41^{-0.15}$ ro83/v112/m16 $-2.41^{-0.15}$ ro83/v12/m16 $-2.41^{-0.15}$ ro83/v12/m16 $-2.41^{-0.15}$ ro83/v12/m16 $-2.41^{-0.15}$ ro83/v12/m16 $-2.14^{-0.15}$ ro83/v13/p10 $-2.10^{-0.15}$ ro83/c13/p10 $-2.10^{-0.15}$ ro83/c13/p10 $-2.14^{-0.13}$ ro83/c13/p10 $-2.14^{-0.13}$ ro83/c13/p10 $-2.14^{-0.13}$ ro83/c13/p10 $-2.14^{-0.13}$ ro83/c13/p10 $-2.14^{-0.13}$ ro83/c13/p10 $-2.14^{-0.13}$ ro83/c13/p10 $-2.14^{-0.13}$ ro83/c13/p10 $-2.14^{-0.13}$ ro83/c13 $-2.14^{-0.13}$ ro83/c13 $-1.98^{-0.05}$ ro83/c13 $-1.85^{\pm0.2}$ ro83/c13 $-1.85^{\pm0.2}$ ro83/c13 $-0.24^{-0.24}$ a $2.40^{-0.23}$ ro83/c13 $-2.40^{-0.23}$ ro83/c13 $-2.40^{-0.23}$ ro83/c13 $-2.40^{-0.23}$ ro83/c13 $-2.40^{-0.23}$ ro83/c13 $-2.40^{-0.23}$ ro83/c13 $-2.40^{-0.23}$ ro83/c13 $-2.40^{-0.23}$ ro83/c13 $-2.40^{-0.23}$ ro83/c13 $-2.40^{-0.23}$ ro83/c13 $-2.40^{-0.24}$ ro82/c13 $-2.40^{-0.23}$ ro83/c13 $-2.40^{-0.23}$ ro83/c13 $-2.40^{-0.24}$ ro82/c13 $-2.40^{-0.24}$		IFO 018 YSO candidate 2MASS J18140816-1850560	в	ı	ro8	I
W 33, IKS 3 hwing an $0.6.5$ start with the metricles $0.6.7$ start with the metricles 0.7 with the metricles 0.7 start w		IFO 019 YSO candidate 2MASS J18140816-1850560	в	ı	ro8	I
W 33, IRS I having an $0.65 + an 07.5$ or $08 \text{ star} \pm 33$ W 33, IRS I having an $0.65 + an 07.5$ or $08 \text{ star} \pm 33$ W 33, IRD 2011bj of l with envircles $0.67 \text{ star} \pm 33$ I. IRAS 18114-1825. Class I/IT e 20-0.151 I. RAS 18114-1825. Class I/IT e 2-141 is ro8/yu12/m16 W 33, RAS 1815-1208 Q 55, Class I/IT V50 is 3.00 m16 I. YASO IRAS 1815-1208 Q 52, 2.2MASS J18175094-1208028, Class I/IT V50 is 3.00 m16 I. YASO IRAS 1815-1208 Q 52, 2.2MASS J18175094-1208028, Class I/IT V50 is 3.00 m16 I. YASO IRAS 1815-1208 Q 52, 2.2MASS J18175094-1208028, Class I/IT V50 is 3.00 w16 I. YASO IRAS 1815-1208 Q 52, 2.2MASS J18175094-1208028, Class I/IT V50 is 3.00 w16 I. PW20101236, Class 0/I is 1.2MG 1815-1208 Q 52, 2.2MASS J181749-45-120751.1 a 3.00 w16 IPW20101236, Class 0/I is 1.2MG 1815-1208 Q 52, Class I/IT V50 is 2.10 m66(13/p10) IPW20101236, Class 0/I is 1.2MG 1815-1208 Q 52, Class 0/I is 1.2MG 1815-1208 Q 100 IPW20101236, Class 0/I is 1.2MG 1815-1208 Q 100 m16 IPW20101236, Class 0/I is 0.117 Q 100 m16 In the middle of multiple YSOs in M 16 In the widdle of multiple YSOs in M 16 In the widdle of multiple YSOs in M 16 In the widdle of column 2 of M 15 Intercompact leature in the crowded region of YI7. EB (extended bubble) is 1.2MG 100 m16 Into compact leature in the crowded region of M17, EB (extended bubble) is 1.2MG 100 m30 m15 Into Compact leature in the crowded region of M17, EB (extended bubble) is 1.2MG 100 m15 IAAS 18177-1405 aligned with IFO 059, 061, in M 16 Into Compact leature in the crowded region of M17, EB (extended bubble) is 1.2MG 100 m15 IAAS 18177-1405 aligned with IFO 059, 061, in M 16 IAAS 18177-1405 aligned with IFO 059, 061, in M 16 IAAS 18177-1405 aligned with IFO 059, 061, in M 16 IAAS 18177-1405 aligned with IFO 059, 061, in M 16 IAAS 1817		IFO 020 W 33, IRS 3 having an O6.5 star	а	$2.40^{+0.17}_{-0.15}$	b98	i13
W 33, [MDF20TIb] c11 which encircles O6-7 star #23 1181 A21:71-182459.0: Class I/T1 c c 2.41 0.065 1. RXS 1814-1723, Class I/T 1181 A21:71-182459.0: Class I/T1 c c 2.41 0.181 A21:71-182459.0: Class I/T1 c c 2.41 0.161 0.181 A11753, Class I/T1 1208 C c 2.14 0.050 0.1370 0.161 0.1 2MASS 11817-100.605 c 2.14 0.133 0.0 w116 0.1 2MASS 11817-1208 2.2, 22MASS 118175094-1208028; Class W1.2. ALLWISE J181749.45-120751.1 a 3.00 m116 0.12 MASS 18151-1208 2.2, 22MASS 118175094-1208028; Class M1.2. ALLWISE J181749.45-120751.1 a 3.00 w116 0.12 MASS 18151-1208 2.2, 22MASS 118175094-1208028; Class M1.2. ALLWISE J181749.45-120751.1 a 3.00 w116 m166 0.1 2MASS 18151-1208 2.2, 22MASS 118175094-1208028; Class M1.2. ALLWISE J181749.45-120751.1 a 2.00 w116 m166 0.1 2MASS 18151-1208 2.2, 22MASS 1181749.45-1207 1205 0.1 2004 0.1 2007 1205 0.1 2004 0.1 2007 1205 0.1 2004 0.1 1000 1200 0.1 1000 0.1 1000 0.1 1000 0.1 1000 0.1 1000 0.1 1000 0.1 1000 0.1 1000 0.1 1000 0.1 1000 0.1 1000 0.0 1000 0.1 1000 0.0 1000 0.0 1000 0.0 1000 0.0 1000 0.0 1000 0.0 1000 0.0 1000 0.0 1000 0.0 1000 0.0 0.			а	$2.40^{+0.17}$	b98	i13
1. If RAS 18114-1825 Class I, 2. J181421.71-182459.0: Class I/II closed contact contact the control of the model of multiple XSO RAAL Contact Contact and the model of multiple XSO RAAL Contact Contact and the model of multiple XSO RAAL Contact and the model of multiple XSO RAAL Contact and the model of multiple YSOs in M 16 c 2.1 c 2.1 c c 1.1 so RSV J12/m16TASS 18141-723, Class I/II 173094-1208028, Class I/II 175094-1208028, Class I/II 175094-1208028, Class I/II 120 a 3.00 $m16$ TASS 18151-1208 1.2 XMASS 18151-1208 a 3.00 $m16$ $m16$ PW20101 236, Class O/I 1.2 XMASS 18151-1208 a 2.10 $ro8/c13/p10$ PW20101 236, Class O/I 1.2 XMASS 18151-1208 a 2.10 $ro8/c13/p10$ PW20101 236, Class O/I 1.2 XMAS 18151-1208 a 2.14 $c13$ TI por Counta 2 of M1 6, either T-Tauri star [TSH2002] S-1 or S-2 k 2.14 $c13$ TI por Counta 2 of M1 6, either T-Tauri star [TSH2002] S-1 or S-2 k 2.14 $c13$ Ti por Counta 2 of M1 6 $m16$ k 2.14 $c13$ Ti por Counta 2 of M1 6 $m16$ k 2.14 $c13$ Proximity of Class O/I YSO [PW2010] 318 k 2.14 $c13$ Proximity of Class O/I YSO [PW2010] 318 k 2.14 $c13$ Proximity of Class O/I YSO [PW2010] 318 k 2.14 $c13$ Proximity of Class O/I YSO [PW2010] 318 k 2.14 $c13$ Proximity of Class O/I YSO [PW2010] 318 k 2.14 $c13$ Proximity o			а	$2.40^{+0.17}$	m15	i13
YSO AGAL G014414'00.069 cds. $M12$ ALLWISE 118175094-1208028, Class $M1$ YSO RAS 1814-1723, Class $M1$ buary is YSO RAS 18151-1208 2, 2. 2MASS 118175094-1208028, Class $M1$, 2. ALLWISE 1181749, 45-120751.1 a 3.00 m16 YSO RAS 18151-1208 a 2.10 ros8(c13/p10 PW2010) 236, Class $0M$ is the middle of multiple YSOs in $M16$ respectively a 2.10 ros8(c13/p10 ros			c	2.41	ro8/yu12/m16	yu12
Item S 1814+1723, Class I/II binaryk4.33c13/v181. YSO IRAS 18151-12082. 2.M.SS J18175094-1208028; Class I/II, YSO 3.00 m161. YSO IRAS 18151-12081. 2.MASS J18175094-1208028; Class I/II, YSO 3.00 w10YSO IRAS 18151-12082. 2.LLWISE J181749.45-120751.1 a 3.00 w10YSO IRAS 18151-12082. 2.M.SS J18175094-1208028; Class I/II a 3.00 w10YSO IRAS 18151-12082. 2.LLWISE J181749.45-120751.1 a 3.00 w10YSO IRAS 18151-12082. 2.LLWISE J181749.45-120751.1 a 2.10 rosk(13)p10YSO IRAS 18151-12081. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1			c	3.1	u18	u18
1. YSO IRAS 18151-12082. 2. 2MASS J18175094-1208028, Class JM1 YSOa3.00m16YSO IRAS 18151-12081. 2MASS J18175094-1208028; Class JM1, 2. ALLWISE J181749.45-120751.1a 3.00 w10PYO2010256, Class Of1. 2MASS J18175094-1208028; Class JM1a 2.10 ro8kc13/p10PW2010256, Class Of1. 2MASS J18175094-1208028; Class Ofa 2.10 ro8kc13/p10PW2010256, Class Of1. 2MASS J18175094-1208028; Class Ofa 2.10 ro8kc13/p10PW2010256, Class Of1. 6 either T-Tauri star [TSH2002] S-1 or S-2k 2.14 0.22 Edge of M 16 pillar V, RMS massive YSO G017.0332+00.7476Aa 2.14 0.22 Rear the edge of M 16 pillar V, RMS massive YSO G017.0332+00.7476Aa 2.14 0.02 Near the edge of M 16 pillar V, RMS massive YSO G017.0332+00.7476Aa 2.14 0.02 Spatially connected to Class Off YSO IPW2010] 411a 2.14 0.02 Feature connected to massive YSO G017.0532+00.7476Aa 2.14 0.02 Spatially connected to massive YSO G017.0532+00.7476Aa 2.14 0.02 Feature connected to class Off YSO IPW2010] 378a 2.14 0.02 Feature connected to massive YSO G017.0566+0.6826cc 2.14 0.02 Spatially connected to massive YSO G017.0566+0.6826cc 2.14 0.02 Ditto0.000.017.0666+0.6826cc 2.14 0.02 Spatially connected to massive YSO G017.0566+0.6826			k	4.33	c13/v18	v18
1. 2MASS J18175094-1208028: Class J01, 2. MLWISE J181749.45-120751.1 a 3.00 m16 YSO IRAS J8151-1208 a 3.00 v10 v10 Tyb Vol101 236, Class 0/I m16 a 2.10 ro8kc13/p10 IPW2010 236, Class 0/I m16 a 2.10 ro8kc13/p10 IPW2010 236, Class 0/I m16 c 2.14 c13 IPV2010 236, Class 0/I m16 k 2.14 c13 Ip of column 3 of M 16, either T-Flauri star [TSH2002] S-I or S-2 k 2.14 c02 Edge of column 2 of M 16 p11ar V, RMS massive YSO G017.0332+00.7476A a 2.14 c02 Near the edge of M 16 Pillar V, RMS massive YSO G017.0352+00.7476A a 2.14 c02 Proximity of YSO IPW2010J 411 c 2.14 c13 0.7 Pature connected to Class 0/I YSO IPW2010J 411 c 2.14 c02 Posimity of YSOs in M 16 filthet vicinity of YSOs in M 17 k 2.14 c13 Posimity of Oldson 0.6856 c 2.14 c13 0.7 Posimity of Toss 0/I YSO IPW2010J 411 c 2.14 <t< td=""><td></td><td></td><td>а</td><td>3.00</td><td>m16</td><td>m13</td></t<>			а	3.00	m16	m13
YSO IRAS 18151-1208 YSO IRAS 18151-1208 IPW2010] 236, Class 0/1 IPW2010] 236, Class 0/1 IPW2010] 236, Class 0/1 IPW2010] 236, Class 0/1 IPW2010] 236, Class 0/1 IP the middle of multiple YSOs in M 16 IP the middle of multiple YSOs in M 16 In the middle of multiple YSOs in M 16 In the middle of multiple YSOs in M 16 Tip of column 3 of M 16, either T-Tauri star [TSH2002] S-1 or S-2 Edge of column 3 of M 16, either T-Tauri star [TSH2002] S-1 or S-2 Edge of column 3 of M 16, either T-Tauri star [TSH2002] S-1 or S-2 Edge of column 2 of M 16 Near the edge of M 16 Pillar V, RMS massive YSO G017 03327+00.7476A Near the edge of M 16 Pillar V, RMS massive YSO G017 03327+00.7476A Proximity of Class 0/1 YSO IPW2010] 378 Eature connected to Class 0/1 YSO IPW2010] 411 in the vicinity of YSOs in M 17 Faature connected to massive YSO G017.0666+0.6826 Faature in the crowded region of YSOs in M 17 Spatially connected to massive YSO G017.0666+0.6826 Compact feature in the crowded region of M17, EB (extended bubble) Ditto c 2.14 c 2.13 Ditto c 1.98 $ro8/p09$ Ditto c 2.14 $ro5 1.060.31$ $ro8/c13$ Northern jet of IFO 060 b b 1.85 ± 0.2 $ro8/c13$ Northern jet of IFO 060 b b 1.85 ± 0.2 $ro8/c13$ Northern jet of IFO 060 c b b 1.85 ± 0.2 $ro8/c13$ Northern jet of IFO 060 c			а	3.00	m16	m13
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[PW2010] 236, Class 0/Ia2.10ro8/c13/p10In the middle of multiple YSOs in M 16in the middle of multiple YSOs in M 16i. 13i. 14c13In the middle of multiple YSOs in M 16i. ther T-Tauri star [TSH2002] S-I or S-2k2.14c13Tip of column 3 of M 16, either T-Tauri star [TSH2002] S-I or S-2k2.14t02Bege of column 3 of M 16modele of multiple YSOs in M 16i. 2.14t02Near the edge of M 16 Pillar V, RMS massive YSO G017 0332+00.7476Aa2.14t02Proximity of Class 0/T YSO [PW2010] 411a2.14t03Proximity of Class 0/T YSO [PW2010] 411a2.14t03The vicinity of YSOs in M 16a2.14t03Spatially connected to massive YSO G017.0666+0.6826k1.60±0.30siDittoa2.14c13g07So and the vicinity of YSOs in M 17a2.14c13Dittoa2.14c13g07So and the recowded region of YSOs in M 17k1.60±0.30siDittoa2.14c13siDittoa2.14c13siDittoa1.66±0.30sisiDittoa1.66±0.30sisiDittobb1.85±0.2ro8/c13Southern jet of IFO 060bb1.85±0.2ro8/c13Northern jet of IFO 060bb1.85±0.2ro8/c13Dittob1.85±0.2ro8/c13si </td <td></td> <td>[PW2010]</td> <td>а</td> <td>2.10</td> <td>ro8/c13/p10</td> <td>p10</td>		[PW2010]	а	2.10	ro8/c13/p10	p10
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In the middle of multiple YSOs in M 16K2.14c13Tip of column 3 of M 16, either T-Tauri star [TSH2002] S-1 or S-2k2.14t02Edge of column 3 of M 16column 2 of M 16k2.14t02Edge of column 2 of M 16massive YSO G0170332+00.7476Aa2.14t02Near the edge of M 16 Pillar V, RMS massive YSO G0170332+00.7476Aa2.14t02Proximity of Class 0/1 YSO [PW2010] 378a2.10c13/p10Proximity of Class 0/1 YSO [PW2010] 378a2.114c03/3Proximity of Class 0/1 YSO [PW2010] 411c2.14g07Fature connected to Class 0/1 YSO [PW2010] 411c2.14g07In the vicinity of YSOs in M 16c2.14c13g07Spatially connected to massive YSO G017.0666+0.6826c2.14c13g07Spatially connected to massive YSO G017.0666+0.6826c2.14c13g07In the vicinity of YSOs in M 17k1.60±0.30silittoc2.14c13Dittofeature in the crowded region of YI7, EB (extended bubble)c2.14c13siDittofromeb1.85±0.2roskp09littolittslittslittslittsDittofromfromb1.85±0.2roskp09littslittslittslittslittslittslittslittslittslittslittslittslittslittslittslittslittslittslittslit		,,	с	2.14	c13	66q
Tip of column 3 of M 16, either T-Tauri star [TSH2002] S-J or S-2k2.14 $t02$ Edge of column 2 of M 16Edge of column 2 of M 16k2.14 $t02$ Near the edge of M 16 Pillar V, RMS massive YSO G0170332+00.7476Aa2.14 $t02$ Near the edge of M 16 Pillar V, RMS massive YSO G0170332+00.7476Aa2.14 $t02$ Proximity of Class 0/I YSO [PW2010] 378a2.10 $c08/p10$ Feature connected to Class 0/I YSO [PW2010] 318a2.10 $c13/p10$ In the vicinity of YSOs in M 16c2.14 $g07$ Spatially connected to massive YSO G017.0666+0.6826c2.14 $g07$ Southact feature in the crowded region of YSOs in M 17k1.60±0.30siDittoftc1.98 $r08/p09$ Dittoftftft1.60±0.30siSouthern jet of IFO 060bh.85±0.2 $r08/r03$ Southern jet of IFO 060b1.85±0.2 $r08/r03$ Southern jet of IFO 060b1.85±0.2 $r08/r03$ Located at the edge of IRDC HEC G016.93+00.24a2.40siSouthern jet of IFO 060b1.85±0.2 $r08/r03$ Southern jet of IFO 060 </td <td></td> <td></td> <td>ч</td> <td>2.14</td> <td>c13</td> <td>66q</td>			ч	2.14	c13	66q
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Proximity of Class 0/1 YSO [PW2010] 378a 2.10 $ro8/p10$ Feature connected to Class 0/1 YSO [PW2010] 411c 2.10 $ro8/p10$ In the vicinity of YSOs in M 16a 2.14 $g07$ Spatially connected to massive YSO G017.0666+0.6826c 2.14 $g07$ Compact feature in the crowded region of YSOs in M 17k 1.60 ± 0.30 siDittok 1.60 ± 0.30 sisiDittomultiple YSO candidates in the northern region of M17, EB (extended bubble)c 1.98 $ro8/p09$ Dittomultiple YSO candidates in the northern region of M17, EB (extended bubble) c 1.98 $ro8/p09$ Dittomultiple YSO candidates in the northern region of M17, EB (extended bubble) c 1.98 $ro8/p09$ Dittomultiple YSO candidates in the northern region of M17, EB (extended bubble) c 1.98 $ro8/p09$ Dittomultiple YSO candidates in the northern region of M17, EB (extended bubble) c 1.98 $ro8/p09$ Nultiple YSO candidates in the northern region of M17, EB (extended bubble) c 1.98 $ro8/p09$ Dittomultiple YSO candidates in the northern region of M17, EB (extended bubble) c 1.98 $ro8/p09$ Nultiple YSO candidates in the northern region of M17, EB (extended bubble) c 1.98 $ro8/p09$ Dittomultiple YSO candidates in the northern region of M16 c 1.98 $ro8/p09$ Northern jet of IFO 060multiple YSO model a 2.40 a Located at the			а	2.14	ro8/c13	66q
Feature connected to Class 0/I YSO [PW2010] 411c 2.10 $c13/p10$ In the vicinity of YSOs in M 16Spatially connected to massive YSO G017.0666+0.6826 a 2.14 $g07$ Spatially connected to massive YSO G017.0666+0.6826 c c 2.14 $c13$ Compact feature in the crowded region of YSOs in M 17 k 1.60 ± 0.30 si Ditto k 1.60 ± 0.30 si Nultiple YSO candidates in the northern region of M17, EB (extended bubble) c 1.98 $ro8/p09$ Ditto b 1.85 ± 0.2 $ro8/p09$ Ditto b 1.85 ± 0.2 $ro8/p09$ Ditto b 1.85 ± 0.2 $ro8/r13$ Northern jet of IFO 060 b 1.85 ± 0.2 $ro8/r13$ Located at the edge of IRDC HEC G016.93+00.24 a 2.40 si			в	2.10	ro8/p10	p10
In the vicinity of YSOs in M 16 Spatially connected to massive YSO G017.0666+0.6826 Compact feature in the crowded region of YSOs in M 17 Ditto Multiple YSO candidates in the northern region of M17, EB (extended bubble) Multiple YSO candidates in the northern region of M17, EB (extended bubble) Ditto Southern jet of IFO 060 Northern jet of IFO 060 Northern jet of IFO 060 Located at the edge of IRDC HEC G016.93+00.24 Located at the edge of IRDC HEC G016.93+00.24			c	2.10	c13/p10	p10
Spatially connected to massive YSO G017.0666-0.6826 c 2.14 c 1.3 k 1.60 ± 0.30 si c 1.60 ± 0.30 si bitto Compact feature in the crowded region of YSOs in M 17 k 1.60 ± 0.30 si 1.60 ± 0.30 si Ditto Ditto Ditto Multiple YSO candidates in the northern region of M17, EB (extended bubble) c 1.98 r $0.87p09$ so 1.98 r $0.87p09$ Ditto Dit			a	2.14	g07	66q
Compact feature in the crowded region of YSOs in M 17 k 1.60 \pm 0.30 si k 1.60 \pm 0.30 si Ditto Ditto C multiple YSO candidates in the northern region of M17, EB (extended bubble) c 1.98 ro8/p09 Ditto 1.85 \pm 0.2 ro8/p09 b 1.85 \pm 0.2 ro8/p09 b 1.85 \pm 0.2 ro8/p09 Northern jet of IFO 060 b 1.85 \pm 0.2 ro8/c13 b 1.85 \pm 0.2 ro8/c13 b 1.85 \pm 0.2 ro8/c13 Located at the edge of IRDC HEC G016.93 \pm 00.240 si		Spatially c	с	2.14	c13	66q
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Ditto Multiple YSO candidates in the northern region of M17, EB (extended bubble) c 1.98 ro8/p09 Ditto Southern jet of IFO 060 b 1.85±0.2 ro8/p09 Southern jet of IFO 060 b 1.85±0.2 ro8/c13 Northern jet of IFO 060 b 1.85±0.2 ro8/c13 Northern jet of IFO 060 b 1.85±0.2 ro8/c13 b 1.85±0.2 ro8/c13 b 2.40 s i		Ditto	× k	1.60 ± 0.30	si	n01
Multiple YSO candidates in the northern region of M17, EB (extended bubble) c 1.98 ro8/p09 Ditto $a 1.98 ro8/p09$ Southern jet of IFO 060 $b 1.85\pm0.2 ro8/c13$ IRAS 18177-1405 aligned with IFO 059, 061, in M 16 $b 1.85\pm0.2 ro8/c13$ Northern jet of IFO 060 $b 1.85\pm0.2 ro8/c13$ Northern jet of IFO 060 $b 1.85\pm0.2 ro8/c13$ Located at the edge of IRDC HEC G016.93+00.24 $a 2.40 si$			Č	1.60 ± 0.30	si	n01
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Southern jet of IFO 060 b 1.85 ± 0.2 ro8/c13 b 1.85 ± 0.2 ro8/c13 b 1.85 ± 0.2 ro8/c13 b 1.85 ± 0.2 ro8/c13 Northern jet of IFO 060 a 2.40 m si		Ditto	а	1.98	ro8/p09	c16
IRAS 18177-1405 aligned with IFO 059, 061, in M 16 b 1.85±0.2 ro8/c13 Northern jet of IFO 060 b 1.85±0.2 ro8/c13 b 1.85±0.2 ro8/c13 Located at the edge of IRDC HEC G016.93+00.24 a 2.40 s i		IFO 059 Southern jet of IFO 060	e.	1.85 ± 0.2	ro8/c13	x19
Located at the edge of IRDC HEC $G016.93+00.24$ a 2.40 si		IFO 060 IRAS 18177-1405 aligned with IFO 059, 061, in M 16	<u>م</u>	1.85±0.2	ro8/c13	x19
				1.07±0.2	C12/001	417 10
			3		5	

IFO072 Class JIT YSO IRAS 1823-1308 0.325 (13) $0.$		ected PN in Froebrich et al. (2015) In the vicinity -064158.4. Multiple nearby YSOs candidate candidate lass III or more evolved YSO 43015.9 2R2 4258232818679065216 2R2 4258232818679065216 2R2 4258232818679065216 2R2 4258232818679065216 DR2 4258232818679065216 and Factor reported MSX6C G031.8380-00.1284, ne vicinity er vicinity	א פנפ פססנאספנט	3.40 12.60 3.42 3.57 3.50 3.50 3.50 3.50 3.50 3.50 2.01 6.21 - 4.80	ro8/c13/m16 c13 k21 e17 si ro8/k21 ro8/k21 ro8/k21 ro8/k21 ro8/k21 ro8/k21 ro8/k21 ro8/k21	u22 c13 c15 c15 c1 c1 c1 c1 c1 c1 c1 c1 c1 c1 c1 c1 c1
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Froebrich et al. (2015)a-k21Froebrich et al. (2015)b 3.42 $e17$ cinityk 3.57 sicinityc-scinityb 3.50 ros/k21cinityb 3.50 ros/k21teb 3.50 ros/k21or more evolved YSOa 2.20 or more evolved YSOa 2.20 or more evolved YSOa 2.20 or more evolved YSOa 2.01 0.05/138679065216a 2.00 S8232818679065216a 2.00 S8232818679065216a 2.00 S8232913400.8076k 4.80 ros/k21a 2.01 035.2913400.8076k 4.80 ros/k21 $0.35.291340.8076$ ksit to Westa 2.00 ros $0.35.291340.8076$ ksit to Westa 2.00 ros $0.35.291340.8076$ ksit to Westa 2.90 ros $0.35.291340.8076$ ksit to Westa 2.90 ros $0.35.291340.8076$ kros 0.560 110 ros 0.60 110 ros 0.60 110 ros 0.50 0.60 ros 0.60 110 ros 0.50 0.60 ros 0.60 110 ros 0.50 0.60 ros 0.50 0.60 ros <t< td=""><td></td><td> PN in Froebrich et al. (2015) in the vicinity 064158.4. Multiple nearby YSOs candidate candidate 10 more evolved YSO 43015.9 282 4258232818679065216 20437, [Fe II] detection reported MSX6C G031.8380-00.1284, ne vicinity </td><td>א אנא אסססנאסא</td><td>- 3.57 3.57 3.50 3.50 3.50 2.20 6.21 - 4.80</td><td>k21 e17 si ro8/k21 ro8/k21 ro8/k21 ro8/k21 ro8/k21 ro8/k21 ro8/k21</td><td></td></t<>		 PN in Froebrich et al. (2015) in the vicinity 064158.4. Multiple nearby YSOs candidate candidate 10 more evolved YSO 43015.9 282 4258232818679065216 20437, [Fe II] detection reported MSX6C G031.8380-00.1284, ne vicinity 	א אנא אסססנאסא	- 3.57 3.57 3.50 3.50 3.50 2.20 6.21 - 4.80	k21 e17 si ro8/k21 ro8/k21 ro8/k21 ro8/k21 ro8/k21 ro8/k21 ro8/k21	
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11 13 13 10 <t< td=""><td> IFO 099 North-western jet, aligned with IFO 100 & 101 IFO 100 Class I YSO candidate, previously reported as AGB GIFO 101 South-eastern jet, aligned with IFO 99 & 100 IFO 101 South-eastern jet, aligned with IFO 99 & 100 IFO 104 In the middle of ALLWMSE J183951.16-043113.8 Cl and semi-regular variable ASASSN-V J183948.07-0. IFO 108 Proximity of pre-main sequence star candidate Gaiaf IFO 111 Massive protostellar object [VEN2013] G029.8623-Giff 0111 Massive protostellar object [VEN2013] G029.8623-Giff 0115 Spatially coincident with H₂, which is connected to NSO candidate SSTGLMC G031.8361-00.1408 in the IFO 122 Shares a similar compact structure with IFO 123, aligned 120 Morehas to more cellar object [120 Coincident with flat-spectrum YSO candidate SSTGI PLO 124 Morehas to more cellar object </td><td>candidate lass III or more evolved YSO 43015.9 DR2 4258232818679065216 D.0437, [Fe II] detection reported MSX6C G031.8380-00.1284, ne vicinity</td><td>ע אנא אססס</td><td>3.50 3.50 3.50 3.50 2.20 6.21 - 4.80</td><td>ro8/k21 ro8/k21 ro8/m16/j18 v20 c13/a20 ro8/k21 ro8/k21</td><td></td></t<>	 IFO 099 North-western jet, aligned with IFO 100 & 101 IFO 100 Class I YSO candidate, previously reported as AGB GIFO 101 South-eastern jet, aligned with IFO 99 & 100 IFO 101 South-eastern jet, aligned with IFO 99 & 100 IFO 104 In the middle of ALLWMSE J183951.16-043113.8 Cl and semi-regular variable ASASSN-V J183948.07-0. IFO 108 Proximity of pre-main sequence star candidate Gaiaf IFO 111 Massive protostellar object [VEN2013] G029.8623-Giff 0111 Massive protostellar object [VEN2013] G029.8623-Giff 0115 Spatially coincident with H₂, which is connected to NSO candidate SSTGLMC G031.8361-00.1408 in the IFO 122 Shares a similar compact structure with IFO 123, aligned 120 Morehas to more cellar object [120 Coincident with flat-spectrum YSO candidate SSTGI PLO 124 Morehas to more cellar object 	candidate lass III or more evolved YSO 43015.9 DR2 4258232818679065216 D.0437, [Fe II] detection reported MSX6C G031.8380-00.1284, ne vicinity	ע אנא אססס	3.50 3.50 3.50 3.50 2.20 6.21 - 4.80	ro8/k21 ro8/k21 ro8/m16/j18 v20 c13/a20 ro8/k21 ro8/k21	
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$\begin{array}{cccccccccccccccccccccccccccccccccccc$	IFO 136 Flat spectrum YSO SSTGLMC G039.2199+00.8638.	. G039.2060+00.8818 in West	я	ı	r08/k21	
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3 10 and 13a 0.60 $s14$ 3 20 15 & IFO 151k 0.60 $t10$ SO 15 & IFO 151k 0.60 $t10$ at W 51 (or foreground, see k09)k 5.40 $s17$ 049.5851-0.3814a 5.40 $s17$ c 5.40 $s17$ $s17$ 049.5851-0.3814c 5.40 $s17$ 1456a 3.39 $c13$	IFO 145 Elongated and pointing toward YSO AGAL G039.70	08-01.237 and IFO 144	р	0.60	u18	
3 10 and 13a 0.60 $t10$ SO 15 & IFO 151k 0.60 $t10$ SO 15 & IFO 151k 5.40 $s17$ at W 51 (or foreground, see k09)k 5.40 $s17$ 049.5851-0.3814c 5.40 $s17$ c 5.40 $s17$ $s17$ 049.5851-0.3814c 5.40 $s17$ 1456a 3.39 $c13$	IFO 146 H α PN candidate, yet aligned with IFO 144, 145, H ₂	knots	а	0.60	s14	
SO 15 & IFO 151 k 0.60 t10 tt W 51 (or foreground, see $k09$) k 5.40 $s17$ 049.5851-0.3814 c 5.40 $s17$ c 5.40 $s17c 5.40 s17c 5.40 s17c 3.09 r17k 3.39 c13-1456 a 3.39 c13$		10] L673 10 and 13	а	0.60	t10	u18
tt W 51 (or foreground, see k09) k 5.40 s17 049.5851-0.3814 a 5.40 s17 c 5.40 s17 c 5.40 s17 c 3.09 r17 k 3.39 c13		L673 YSO 15 & IFO 151		0.60	t10	u18
049.5851-0.3814 a 5.40 817 c 5.40 817 k 3.39 c13 .1456 a 3.09 r17 c 3.09 c 13 c 13 c 13 c 13 c 13 c 13 c 13 c 13		0.2159 at W 51 (or foreground, see k09)		5.40	s17	
c 5.40 c 3.09 k 3.39 a 3.39		JERC G049.5851-0.3814	а	5.40	s17	
-1456 a 3.39 a 3.39 a 3.39 a 3.39		.5922,	c	5.40	s17	
	spectral index of flat (FS) according to k21					
.1456 k 3.39 c13 a 3.39 c13	IFO 174 Emerges from Class I YSO [RML2017] MC2 M105		с.	3.09	r17	
	IFO 175 Southern compact jet of massive YSO IKAS 1923(5+1456 10226 : 1156	K	3.39	c13 212	
		000000000000000000000000000000000000000	9		C17	

Table 3 (cont'd)				
IEO # YSO / YSOc Name	Morphology	q	Reference	
		[kpc]	YSO Counterpart	Dist
IFO 177 Diffuse structure in contact with YSO AGAL G052.488-00.172	С	1.60	u18	u18
IFO 178 Class1YSO 1 (\sim 10M _G) or 2 (\sim 5M _G) in k18	а	1.60	ro8/c13/k18	u18
IFO 179 In the proximity of Class I YSO SSTGLMC G053.1570+00.0735	а	1.60	ro8/k15	u18
IFO 180 Cloce to Class I YSO SSTGLMC G053.1612+00.0668 and multiple YSOs	а	1.60	ro8/k15	u18
IFO 181 Surrounding Class I YSO SSTGLMC G053.1266+00.0499	k	1.60	ro8/k15	u18
IFO 183 Coincident with MSXDC G053.25+00.04 MM6 & ISOGAL-P J192931.1+175954 (Class I)	а	1.60	k15	u18
Flat-spectrum YSO 2MASS J193	k	1.60	r08/k15	u18
IFO 185 SSTGLMC G053.2389+00.0552 (Class I), 2MASS J19293167+1800581 (FS)	а	1.60	r08/k15	u18
IFO 186 2MASS J19300219+1755001 (FS)	c	1	k15	1 3
IFO 189 Multiple compact structures surrounding ES-NW of Massive YSO MSX6C G056.3694-00.6333	а	6.40	c13	c13
IFO 190 Diffuse structure on South of Class II YSO SSTGLMC G058,4098+00.3279	a	2.80	ro8/k21	v13
IFO 192 The head of the cometary structure matches EGO G058.09-0.34, one of the low-mass EGOs		0.74	ro8/cy13	cy13
IFO 193 Two biconical structures, tails toward SE & W, Class I YSO SSTGLMC G058.4801-00.2205 at the center	nter b	6.15	ro8/k21	m21
IFO 194 The head of cometary structure corresponds to YSO candidate SSTGLMC G059.0069-00.2481	c	ī	ro8	ı
IFO 198 Aligned with star-forming region IRAS 19410+2336 and IFO 199	а	2.20	c13	113
IFO 199 Amorphous IFO points toward star-forming region IRAS 19410+2336	а	2.20	c13	113
IFO 203 Compact IFO at the East of biconical outflow S87, emerging from ${\sim}20~{ m M}_{\odot}$ pre-main-sequence object	a	2.20	b89	113
*Column 3. Morphology categories : b - bipolar, c - cometary, k - knot-like, a - amorphous. Column 4. Distance of counterpart in kpc. Column 5. References of counterpart classification and distance.	ance of counterpar	rt in kpc	. Column 5. Refer	ences of
*References : a20 - Areal et al. (2020), b18 - Bailer-Jones et al. (2018), b89 - Barsony (1989), b98 - Beck et al. (1998), b99 - Belikov et al. (1999), c13 - Cooper et al. (2013), c16 - Csengeri et al. (2016), cy13 - Cyganowski et al. (2013), e03 - Egan et al. (2003), e17 - Elia et al. (2017), g07 - Guarcello et al. (2007), i13 - Immer et al. (2013), j18 - Jayasinghe et al. (2018), k09 - Kang et al. (2009), k15 - Kin et al. (2015), k18 - Kim et al. (2018), k21 - Kuhn et al. (2021), I13 - Lumsden et al.	al. (1998), b99 - 1 al. (2017), g07 - C 2018), k21 - Kuhr	Belikov e Guarcellc 1 et al. (2	et al. (1999), c13 - et al. (2007), i13 021), 113 - Lumse	- Cooper - Immer len et al.
(2013), 116 - Li et al. (2016), m13 - Sánchez-Monge et al. (2013), m15 - Messineo et al. (2015), m16 - Marton et al. (2016), m21 - Mège et al. (2021), m96 - Molinari et al. (2016), n01 - Nielbock et al. (2001), p09 - Povich et al. (2009), p10 - Povich & Writney (2010), p16 - Paron et al. (2016), n09 - Ragan et al. (2009), p10 - Ragan et al. (2010), p10 - Ragan et al. (2009), p10 - Ragan et al. (2010), p10 - Ragan et al. (2010), p10 - Ragan et al. (2009), p10 - Ragan et al. (2010), p10 - Ragan et al. (2	al. (2016), m21 - on et al. (2016), r(Mège et 39 - Ragi	al. (2021), m96 - 1 m et al. (2009), r1	Molinari 0 - Rygl
et al. (2010), r17 - Retes-Romero et al. (2017), ro8 - Robitaille et al. (2008), s14 - Sabin et al. (2014), si - SIMBAD, s17 - Saral et al. (2017), t02 - Thompson et al.	3AD, s17 - Saral e	et al. (20	17), t02 - Thomps	son et al.
(2002), t10 - Tsitali et al. (2010), t15 - Traficante et al. (2015), t20 - Tian et al. (2020), u18 / Urquhart et al. (2022), v13 - Veneziani et al. (2013), v18 - Varricatt et al. (2018), v20 - Vionue et al. (2020), x19 - Xu et al. (2019), vu12 - Yuan et al. (2012)	8), u22 - Urquhart	et al. (2(122), v13 - Venezi	ani et al.
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objects
big-Haro
with Her
Associated
IFOs
Table 4.

		Tät	Table 4. IFOs Associated with Herbig-Haro objects			
HH Name d [kpc]	Exciting Source	Region	Comment	Morp.	Morp. Reference Type Dist	nce Dist
			Parsec-scale HH	. م	m82	
IFO 042 HH 216 2.14	N-HH	Eagle nebula	Parsec-scale HH Darsec-scale HH	م م	m82 m82	999 Poq
	,		Parsec-scale HH	p q	m82	66d
IFO 118 HH 722			Wrongly identified as HH 172 (Nikogossian et al. 2007)	а	c94	d92
			Binary. One of them is Class I YSO, $A_v \sim 25$ mag, bipolar envelope SE-NW side	а	s07	s87
IFO 120 GGD 30 1.70	GGD30IR	GM 2-30	Binary. One of them is Class I YSO, $A_v \sim 25$ mag, bipolar envelope SE-NW side	а	$^{\rm s07}$	$^{\rm s87}$
			Binary. One of them is Class I YSO, $A_v \sim 25$ mag, bipolar envelope SE-NW side	а	s07	s87
IFO 153 HH 32 0.20±0	0.20±0.03 AS353	Aquila Rift	T-Tauri binary, H α is coincident, [Fe II] detection reported (d03)	а	h74	r06
IFO 155 HH 250A 0.30	HH 250-IRS	Aquila Rift	Class I binary, bow-shock, $H\alpha$ detected. Launched 3500 yrs ago, adjacent to IFO 153	а	797	700
IFO 195 HH 803	>	\langle	SW of parsec-scale HH (7.5 pc), H α detected. L _{bol} =580 L \odot	k	c04	d92
IFO 196 HH 165 2.40	1548C27 IRS1		NE counterpart of the HH 803, very faint	а	c81	d92
IFO 200 HH 365	*		Central structure of parsec-scale HH, both perpendicular jet and curvature are identified	а	a97	d92

classification and distance .: a97 - Alten et al. (1997), b99 - Belkov et al. (1999), c04 - McGroarty et al. (2004), c81 - Craine et al. (1981), c94 - Cappellaro et al. (1994), d03 - Davis *Column 3. Distance of counterpart in kpc. Column 7. Morphology categories : b - bipolar, c - cometary, k - knot-like, a - amorphous. Column 8. References of counterpart et al. (2003), d92 -Dent & Aspin (1992), d97 -Devine et al. (1997), h74 -Herbig (1974), m82 -Meaburn & White (1982), r06 -Rice et al. (2006), s07 -Smith et al. (2007), s87 -Scoville et al. (1987), s97 -Sakamoto et al. (1997)

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Outer arc, East of cometary H II region Type Dist Diffuse filament filling inside, coincident with the boundary of cometary H II region K18 u18 Duffuse filament filling inside, coincident with the boundary of cometary H II region k18 u18 Outer arc, West of cometary H II region k18 u18 u18 Outer arc, West of cometary H II region k18 u18 u18 Outer arc, West of cometary H II region k18 u18 u13 Amorphous, compact feature sound hypercompact H II region k18 u13 Amorphous, compact feature south of UCHII south b96 113 Amorphous, diffuse feature south of UCHII b96 113 b96 113 Amorphous, diffuse feature south of UCHII b96 113 b96 113 Amorphous, structures on the UCHII b96 113 b96 113 Amorphous structures on the central region UCHIII b96 113 b96 b13 Amorphous structures encicling UCHII b00 k18 l13 Amorphous structures intercline for UCHII b00 k18 l13 Amorphous structures sucture northe center of UCHII b00 </th <th>Type Dist Type Dist Type Dist Type Dist Type Dist Type Dist filament filling inside, coincident with the boundary of cometary H II region k18 u18 filament filling inside, coincident with the boundary of cometary H II region k18 u13 shell-like features around hypercompact H II region k18 u13 bous, ciffuse features around hypercompact H II region k18 u13 bous, compact feature worth of UCHII bous, ciffuse features on the of UCHII bous, ciffuse features on the fold HII bous, ciffuse features on the fold HII bous, ciffuse features on the CHII bous structures encicling UCHII k18 k13 bous structures encicling UCHII bous structures encicling UCHII bous structures encicling UCHII k18 k13 bous structures encicling UCHII bous structures encicling UCHII k18 k13 bous structures in the central region of UCHII to West k18 k18 k13 bous structures in the central region of UCHII to West k18 k13 k13 k14 k18</th> <th>Type Dist Tryne Dist Type Dist The structures in the extructure structure in the North-East of UCHII Dist Type Structure Structure North-East of UCHII Dist Type Structure Structure Structure North-East of UCHII Dist Type Structure Struct</th> <th>Type Dist Type Dist The structures on the CHII Type Dist The structures in the count-East of UCHII Type Dist The structure structor bing from the center of UCHII Type Structure structor bing from the center of UCHII Type Structure structor bing from the center of UCHII Type Structure structures Type Structure structures Type Structure structures Type Structure structure structure structure structure structure model Type Structure structure structure structure structure structure model</th> <th>Type D Type D Kl8 1 Kl8 1 Kl8</th> <th>The set of conteary HI region Type Dist Tare, East of conteary HI region Type Dist Tare, West of conteary HI region K18 ul8 are, West of conteary HI region K18 ul8 are, West of conteary HI region K18 ul8 ple shellink features around hypercompact HII region K18 ul8 plots, diffuse features sound hypercompact HII region K18 ul8 phous, compact feature South of UCHII K18 ul9 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(2004), u18 - Urquinart et al.	of cometary H II region at filling inside, coincident with the boundary of cometary H II region to f cometary H II region to f cometary H II region to f cometary H II region te + amorphous structure around UCHII appet feature South of UCHII appet feature South of UCHII fillise feature South of UCHII fillise structures encircling UCHII threes, West of UCHII threes, Mest of UCHII threes, West of UCHIII threes, West of UCHIII, threes, West of 0.09 pc. three attructure. Single O9.5V star. 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B1. It is starts, most of them are early B1. It is starts, most of them are early B1. It is starts, most of them are early B1. It is starts, most of them are early B1. It is starts, most of them are early B1. It is starts, most of them are early B1. It is starts, most of them are early B1. It is starts, most of them are early B1. It is starts at a sources of spectral type of 00-B0 (d20) starts (2011, k18 - Katcheve et al. (2002), k11 - k1905, n01 - Niebock et al. (2001), s04 - Sewilo et al. (2003), k18 - Vacander & et al. (2001), n01 - Niebock et al. (2001), s04 - Sewilo et al. (2001), u18 - Urighhart et al Molinari et al. (1905), n01	ent filling inside, coincident with the boundary of cometary H II region k18 uuls at of conteary H II region k18 uuls k18 to conteary H II region k18 to conteary H II region k18 to compact feature not UCHII with the features around hypercompact H II region k18 to more accound hypercompact H II region k18 to more accound by the feature around the feature around the UCHII with the feature servicing UCHII with the boundary of UCHII with the features encircling UCHII with the tructures encircling UCHII with the feature south of UCHII with the tructures encircling UCHII with the feature south action of UCHII with the tructures encircling UCHII with the tructures encircling UCHII with the structures encircling UCHII with the structure south of UCHII with the structure in the central region of UCHII to West with the structure with the contral region of UCHII with the structure with the contral region of UCHII with the structure with the contral region of UCHII with the structure with the central region of UCHII with the structure with the central region of UCHII with the structure with the central region of UCHII with a redius of 0.09 pc. with a radius of 0.09 pc. with a radius so of 0.09 pc. with a radius so of 0.09 pc. with a structure with the west, compact structure superposed in the North with a radius of 0.09 pc. with a structure with the west, compact structure superposed in the North with a radius of 0.09 pc. with a radius of 0.01 4753 +0.003 412 + Alexander & with a radius of 0.09 pc. with a radius	ent filling inside, coincident with the boundary of cometary H II region k18 uul8 uul8 coincident with the boundary of cometary H II region k18 uul8 like features around hypercompact H II region k18 uul8 like structure around hypercompact H II region k18 uul8 uonphous structure around UCHII compact feature North of UCHII compact feature North of UCHII compact feature North and UCHII compact feature North East of UCHII south-Western jet k18 ul8 k13 tructures in the central region of UCHII hout be stated to be the central region of UCHII procensors. 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(198), p01- Nielbock et al. (2001), s04 - Sewilo et al. (2004), u18 - Urquhart et al. -, Molinari et al. (1998), p01- Nielbock et al. (2001), s04 - Sewilo et al. (2004), u18 - Vielwander et al. -, Molinari et al. (1998), p01- Nielbock et al. (2001), s04 - Sewilo et al. (2004), u18 - Urquhart et al. -, Molinari et al. (1998), p01- Nielbock et al. (2001), s04 - Sewilo et al. (2004), u18 - Urquhart et	 active compact features around hypercompact H II region ell-like features around hypercompact H II region ell-like features around hypercompact H II region e, diffuse feature South of UCHII compact feature North of UCHII compact feature South of UCHII compact feature South of UCHII contexes, West of UCHII by 66 113 by 66 113 by 66 113 by 61 114 contexes, West of UCHII contexes, West of UCHII contexes, west of UCHII contexes, west of UCHII contexes encloping the South-East of UCHII structures in the central region of UCHII + South-Western jet k18 113 structures in the central region of UCHII to West k18 113 structures in the central region of UCHII that the central region of UCHII structures in the central region of UCHII that structures in the central region of UCHII that structures in the central region of UCHII that structures in the central region of UCHII the structure structure in the West, compact H II region (radius : 0.14 pc) the structure structure structure superposed in the North k18 113 stinal sources of spectral type of 09-B0 (d20) k18 113 stinal sources of spectral type of 09-B0 (d20) k18 113 stinal sources of spectral type of 09-B0 (d20) k18 113 uCHII Go61, 4763, no01, s04 - Sewilo et al. (2009), al2 - Alexander 4 the et al. (1998), no1- Nielbock et al. (2001), s04 - Sewilo et al. (2004), utl8 - Urquhart et al. S - Molimari et al. (1998), no1- Nielbock et al. (2001), s04 - Sewilo et al. (2003), al2 - Alexander 4 	 A morphous structure around UCHII Compact features around hypercompact H II region Liffke Fatures around hypercompact H II region Compact feature North of UCHII Compact feature South of UCHII Compact features meloping the South-East of UCHII Contructions in the central region of UCHII Conture structures in the central region of UCHII Structures in the central region of UCHII to West A structures in the central region of UCHII Structures in the central region of UCHII to West A structure stretching from the center of UCHII Structures in the central region of UCHII Structures in the central region of UCHII to West Structure stretching from the center of UCHII to West State tenbedded cluster (UCE) with a radius of 0.09 pc. 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UCHII precursors, Mol 91C1–5, along the structure m98 s 13 bell-like structure in the West, compact structure superposed in the North s star star show of from the sectral type of O9-B0 (d20) ktl8 like structure in the West, compact structure superposed in the North s ission South of conteary UCHII, the spectral type of O9-B0 (d20) ktl8 like structure in the West, compact structure superposed in the North ission South of conteary UCHII, the spectral type of O9-B0 (d20) ktl8 - Moinari et al. (1998), p01- Niebock et al. (2001), s04 - Sewilo et al. (2003), k18 - Mexander & alter et al. (2020), ft1 - Froebrich & Ioannidis (2011), s04 - Sewilo et al. (2004), u18 - Urguhart et al. (2020), ft1 - Froebrich & Ioannidis (2011), s04 - Sewilo et al. (2004), u18 - Urguhart et al. (2020), h17 - Froebrich & Ioannidis (2011), s04 - Sewilo et al. (2004), u18 - Urguhart et al. (2020), h17 - Froebrich & Ioannidis (2011), s04 - Sewilo et al. (2004), u18 - Urguhart et al. (2020), h17 - Froebrich &	I-like + amorphous structure around UCHII s, compact feature North of UCHII tructures, West of UCHII and the structure south of UCHII eth-like structures of UCHII and the structures of UCHII and the structures of UCHII in or like structures of UCHII nor-like structures of UCHII s structures in the contral region of UCHIII is structures in the contral region of UCHIII s structures in the contral region of UCHIII is structures in the contral region of UCHIII to West structures in the contral region of UCHIII to West s structures in the contral region of UCHIII to West it the contral region of UCHIII to West it s structures in the contral region of UCHIII to West s thructure stretching from the center of UCHIII to West it s structures in the contral region of UCHIII to West it s structure stretching from the center of UCHIII to West it s structure stretching from the center of UCHIII to West it s structure is single O9.5V star. UCHII precursors, Mol 91CI-5, along the structure m98 z13 be ionizing stars, most of them are early-B. In the West, compact structure superposed in the North ission South of IFO 148 (Sision North of IFO 148) UCHII G061,4763+00.0892 in East, H II region G061,4758+00.0913 in West k18 113 (sision South of cometary UCHII, the spectral type of O9-B0 (d20) the et al. (2002), ft1 - Froebrich & Ioannidis (2011), k03 - Kolpak et al. (2009), a12 - Alexander 4 in et al. (2020), ft1 - Froebrich & Ioannidis (2011), s04 - Sewilo et al. (2004), u18 - Urquhart et a 8 - Molinari et al. (1998), n01 - Niebock et al. (2001), s04 - Sewilo et al. (2004), u18 - Urquhart et a	 I-like + amorphous structure around UCHII s, compact feature North of UCHII s, diffuse feature South of UCHII s, diffuse feature North-East of UCHII k, Rastructures encircling UCHII k and the structure structure arching the South-East of UCHII k and the structure North-East of UCHII k and the structure structure structure in the central region of UCHII k and the structure structure structure in the central region of UCHII k and the structure structure structure in the central region of UCHII k and the structure structure structure structure in the structure with a radius of 0.09 pc. k and the structure model. k and the off them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of them are early-B. k and be ionizing stars, non-point of	I-like + anorphous structure around UCHII s, compact feature North of UCHII s, compact feature North of UCHII attructures, West of UCHII structures, West of UCHII structures, West of UCHII structures encicling UCHII not-like structures encicling UCHII anot-like structures of UCHII + South-Western jet structures in the central region of UCHII + South-Western jet structures in the central region of UCHII not-like structures of UCHII s structures in the central region of UCHII s structure stretching from the center of UCHII to West s + knot-like feature South of UCHII s + knot-like feature South of UCHII ure, slightly limb-brightened, brighter at East. 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I-like + amorphous structure around UCHII 5, compact feature North of UCHII 5, compact feature North of UCHII 5, compact feature South of UCHII 5, compact feature south of UCHII 5, compact feature south of UCHII 5, compact features around UCHII 5, compact features around UCHII 5, compact features around UCHII 5, and the structures are neeroping the South-East of UCHII 5, structures are neeroping the South-East of UCHII 5, structures in the central region of UCHII 1, k18 113 structures in the central region of UCHII 1, west 5, structures in the central region of UCHII 1, west 5, structures in the central region of UCHII 1, west 5, structures in the central region of UCHII 1, west 5, structures in the central region of UCHII 1, west 5, structures in the central region of UCHII 1, west 5, structures in the central region of UCHII 1, west 5, structures in the central region of UCHII 1, west 5, structures in the central region of UCHII 1, west 5, structures in the central region of UCHII 1, west 5, structure stare, while interval 1, structure structure will 1, west 2, structure stars, most of them are early-B. The structure most 1, structure stars, most of them are early-B. The structure in the West, compact HI region (radius : 0.14 pc) fill 2, 13 and the structure most 1, 13 structure stars, most of them are early-B. The structure most 1, 13 structure stars, most of them are early-B. The structure most 1, 12 structure in the West, compact structure superposed in the North 1, 12 structure most 1, 13 structure superposed in the North 1, 14 structure most 1, 13 structure superposed in the North 1, 14 structure most 1, 13 structure superposed in the North 1, 14 structure most 1, 13 structure superposed in the North 1, 14 structure most 1, 13 structure superposed in the North 1, 14 structure most 1, 13 structure superposed in the North 1, 14 structure most 1, 13 structure superposed in the North 1, 14 structure most 1, 13 structure superposed in the North 1, 14 structure most 1, 13 structure 1, 1, 14 structure superpose
b96 b96 k18 k18 k18 k18 k18 k18 k18 k18 k18 k18	 s, compact feature North of UCHII s, diffuse feature South of UCHII s, diffuse feature South of UCHII bell-like structures, West of UCHII bell-like structures encircling UCHII bell-like structure North-East of UCHII bell-like structure North-East of UCHII bell-like structure stretching from the center of UCHII to West bell-like structure Single O9.5V star. UCHII to West bell-like structure. Single O9.5V star. UCHII precursors, Mol 91C1-5, along the structure m98 bell-like structure. Single O9.5V star. UCHII precursors, Mol 91C1-5, along the structure m98 central sources of spectral type earlier than B0.5 (v06) bell-like structure in the West, compact structure superposed in the North bell-like structure in the West, compact structure superposed in the North bell-like structure in the West, compact structure superposed in the North bell-like structure in the West, compact structure superposed in the North bell-like structure in the West, compact structure superposed in the North bell-like structure in the West, compact structure superposed in the North bell-like structure in the West, compact structure superposed in the North bell-like structure in the West, compact structure superposed in the North bell-like structure in the West, compact structure superposed in the North bell-like structure in the West, compact structure superposed in the North bell-like structure in the West, compact structure superposed in the North bell-like structure in the West, compact structure superpo	 s, compact feature North of UCHI s, diffuse feature South of UCHI s, diffuse feature South of UCHI structures, West of UCHI bell-like structures encicling UCHI structures in the central region of UCHII s structures in the central region of UCHII s structure in the structure in the North s the structure in the West, compact structure superposed in the North s ission South of EO 148 s of the structure in the West, compact structure superposed in the North s ission South of Contexpret classification and distance : a09 - Anderson & Bania (2009), a12 - Alexander & ente et al. (2020), ft1 - Froebrich & Ioannidis (2011), k03 - Kolpak et al. (2004), u18 - Urquhart et a 39 - Molinari et al. (1998), p0 - Nielbock et al. (2001), s04 - Sewilo et al. (2004), u18 - Urquhart et a 39 - Molinari et al. (1998), p0 - Nielbock et al. (2001), s04 - Sewilo et al. (2004), u18 - Urquhart et al 30 - Molinari et al. (1998), p0 - Nielbock et al	 s, compact feature North of UCHI s, diffuse feature South of UCHI s, diffuse feature South of UCHI s, another CHI s, another South of UCHI bell-like structures encicling UCHI s structures encicling UCHII s structures in the central region of UCHII to West s structure stretching from the center of UCHII to West s structure stretching from the center of UCHII to West s structure stretching from the center of UCHII to West s structure stretching from the center of UCHII to West s structure stretching from the center of UCHII to West s structure stretching from the center of UCHII to West s structure stretching from the center of UCHII to West s structure stretching from the center of UCHII to West s structure stretching from the center of UCHII to West s structure stretching from the center of UCHII to West s structure stretching from the center of UCHII to West s structure stretching from the center of UCHII to West s structure stretching from the center of UCHII to West s structure stretching from the center of UCHII to West ture slightly limb-brightened, brighter at East. 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(2000), al 2 - Alexander & end et al. (2000), the total structure structure superposed in the North initis of counterpart classification and dista	us, diffuse feature South of UCHII kills structures, West of UCHII kills structures encicling UCHII kills structures enveloping the South-East of UCHII kills structure structure structure structure in the central region of UCHII kills structure structure in the central region of UCHII to West kills will a structure structure structure for the central region of UCHII to West kills will be structure south of UCHII to West kills will be structure. Single O9.5V star. UCHII precursors, Mol 91C1–5, along the structure molg z13 shell-like structure. Single O9.5V star. UCHII precursors, Mol 91C1–5, along the structure molg z13 shell-like structure. Single O9.5V star. 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a Fuente et al. (2020), FtT - Froebrich & Ioannidis (2011), k03 - Kolpak et al. (2003), k18 - Kalcheva et al), m98 - Molinari et al. (1998), n01- Nielbock et al. (2001), s04 - Sewilo et al. (2004), u18 - Urquhart et al	50				
Fuente et al. (2020), FtT - Froebrich & Ioannidis (2011), k03 - Kolpak et al. (2003), k18 - Kalcheva et al m98 - Molinari et al. (1998), p01- Nielbock et al. (2001), s04 - Sewilo et al. (2004), u18 - Urquhart et al	SCR	CR		S	
Fuente et al. (2020), ftd - Floebrich & Ioannidis (2011), k03 - Kolpak et al. (2003), k18 - Kalcheva et al m98 - Molinari et al. (1998), p01- Nielbock et al. (2001), s04 - Sewilo et al. (2004), u18 - Urquhart et al	Scale			PIP	

	Reference Type Dist	r07 u12 r07 u12 p09 n01 p09 n01 p09 n01 p09 n01 k97 r03 f21 k95 f21 k95 f21 c09	
Table 6. IFOs Associated with HII Region or HII Region Candidates	Comment	 Diffuse structure in West of H II region Diffuse structure coincident with O stars/YSOs in the central region. UCHII G10.15–0.34 is embedded The South-Western large-scale structure of M 17 Diffuse filaments at the South of M 17 The North-Eastern large-scale structure of M 17 Diffuse filaments at the South of M 17 SO? Amorphous structure located in the extremity of M 17, star Gaia2 4097840529185958272 in West SO? Amorphous structure located in the extremity of M 17, star Gaia2 4097840529185958272 in West The elongated structure along the radio emission of H II region [KC97c] G015.1–00.9 Shell-like diffuse emission at the Western boundary of compact radio Large-scale, multiple filamentary structures in W 51B Large-scale, miscellaneous amorphous structures in W 51A 	
Tal	d Type [kpc]	а НІ 40.30 НІ 40.30 НІ 40.30 НІ 40.30 НІ 40.30 НІ 40.30 НІ 40.30 НІ 41 41 41 41 41 41 41 41 41 41	
	IFO #	IFO 011 G10.2–0.3 (W 31) 3.55 IFO 012 G10.2–0.3 (W 31) 3.55 IFO 012 G10.2–0.3 (W 31) 3.55 IFO 055 M 17 S 1.60 IFO 058 M 17 S (South) 1.60 IFO 062 M 17 N 1.60 IFO 064 M 17 S (South) 1.60 IFO 064 M 17 S (South) 1.60 IFO 066 M 17 EB ^b 1.60 IFO 067 [KC97c] G015.1–00.9 1.98 IFO 158 W 51A 5.40 IFO 150 W 51B 5.40	

^aIFO distances marked with 'a' are controversial values. Column 3. Distance of counterpart in kpc. Column 6 : References of counterpart classification and distance : c09 -Clark et al. (2009), f21 - Fujita et al. (2021), k95 - Koo et al. (1995), k97 - Kuchar & Clark (1997), 113 - Lumsden et al. (2013), n01- Nielbock et al. (2001), p09 -Povich et al. (2009), r03 - Russeil (2003), r07 - Roshi et al. (2017), u12 - Urguhart et al. (2012)

^bThe region M 17 EB (extended bubble) is defined in detail by Povich et al. (2009).

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Table 7

Ó	IFO #	PN / PNc Name	Type	р	Size	Mc	Morphology	gy		Reference	
				[kpc]	[bc]	[Fe II] H ₂	H_2	Ha ^a]	Distance	Distance Morphology	Type
	IFO 005 NGC	C 6537	PN	2.81 ± 0.45	0.49^{a}	$_{\mathrm{Bp}}$	Bmps Bmps	Bmps	3	1,2	'
	IFO 006 NGC	C 6537	PN	2.81 ± 0.45	0.43^{a}		Bmps Bmps	Bmps	ю	1,2	ı
	IFO 008 HR	DS G008.362-0.623	PNc	ı	<i>a</i> _	Bas	Bmps -		ı	1	4
	IFO 009 HR	DS G008.362-0.623	PNc	ı	-a		Bmps	ı	ı	1	4
	IFO 027 PNG	IFO 027 PNG G014.5+00.4	PNc	ı	I	в	В	S	ı	1,2	S
	IFO 050 SS1	0.0	063 PN	ı	I	Ia	1?	ı	ı	9	ı
	IFO 073 G02	20.9+00.8	PNc	ı	I	A	Is	Aa	ı	1,2	٢
	IFO 081 MM	IFO 081 M 1-51	PN	1.59	0.18	Bp^b	ı	В	8	2	ľ
	IFO 095 IRA	S 18348-0616	PNc/UCHII?	6.5	0.50	Ema	Ema	ı	18	9	20,19
	IFO 112 IRA	NS 18458-0213	PN	4.90	0.13	Bsa	\mathbf{Bs}	ı	6	1	I
	IFO 114 PN(3 032.1+00.1	PNc/HII?	4.90	0.42	Ia			6	ı	10,2
	IFO 129 IRA	AS 18551+0159	PNc	4.30 ± 0.50	0.45^{a}	Br	\mathbf{Bs}	В	11	1	4
	IFO 130 IRA	AS 18551+0159	PNc	4.30 ± 0.50	0.45^{a}	Br	\mathbf{Bs}	В	11	1	4
	IFO 157 PN(G 050.4+00.7	PNc/sym?	5.30	3.08	$_{\mathrm{Bp}}$	\mathbf{Bs}	В	6	1	12,
	IFO 164 PN(3 050.8+00.0	PNc	18.46 ± 2.59	0.26	I			17	ı	17
	IFO 173 IRA	S 19234+1627	Nd	4.70-9.50	0.31 - 0.64	4 Ears	Er	Emrs	13	1,2	I
	IFO 188 IRAS	AS 19312+1950	pAGBc/YSO? 2.42	2.42	0.46	Ams	\mathbf{As}		14	9	15.16

we showed the morphological classification of H α counterpart in HASH (Hong Kong/AAO/Strasbourg/H α ; Parker et al. 2016). For the *For the morphological classification, we adopted an 'ERBIAS' classifier (Parker et al. 2006 and references therein), and when listed, The 'ERBIAS' represents the main structure of PN by its elliptical, round, bipolar, irregular, and asymmetric or quasi-stellar morphology. The substructure is further classified into the sub-classifier 'ampirs', which explains asymmetry, multiple structures, point symmetry, ring, and internal structure. When no counterpart was detected, we marked '-'. Column 3. PNc: PN candidate, sym: symbiotic star candidate, Parker et al. (2016), 3 - Navarro et al. (2012), 4 - Froebrich et al. (2015), 5 - Miszalski et al. (2008), 6 - this study (UWISH2), 7 - Boissay Lumsden et al. (2013), 10 - Ferrero et al. (2015), 11 -Zhu et al. (2013), 12 - Sabin et al. (2014), 13 - Yang et al. (2016), 14 - Vickers et al. (2015), 15 - Nakashima et al. (2016), 16 - Cordiner norphological classification of the H₂ counterpart and H α classification of IFO 129, 130, and 173, we made use of Gledhill et al. (2018). and pAGBc: post-AGB candidate. Column 4. Distance of counterpart in kpc. Column 5. Physical scale of an IFO in the adopted distance. Column 7. References of distance, $H_2/H\alpha$ morphology, counterpart type in Column 3, respectively. Ref. 1 - Gledhill et al. (2018), 2 et al. (2016), 17 - Irabor et al. (2018), 18 - Cichowolski et al. (2018), 19 - Bronfiman et al. (1996), 20 - Kanarek et al. (2015) et al. (2012): Miscellaneous Emission Nebulae (MEN) list, 8 - Phillips (2004), 9 -

^aPart of bipolar lobes.

^bPN with quadrupolar morphology is included in the bipolar category considering the formation mechanisms of the two could be analogous; see Manchado et al. (1996) for details.

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IFOs

	LBV / LBVc Name	q	Reference	suce
		[kpc]	Type d	p
IFO 065 HD 168625	168625	1.55	5	4
IFO 102 26.47+0.02	7+0.02	≤6.5	-	-
IFO 103 26.4	26.47+0.02	≤6.5		-
IFO 162 [KW	[FO 162 [KW97] 37-17 (=LS1) 6.0, 2.5 ^{+2.4} _{-1.3}	$6.0, 2.5^{+2.4}_{-1.3}$	7	3,4

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References of counterpart classification and distance : 1 -Clark et al. (2003) : assuming 1.8 mag kpc⁻¹, 2 - Okumura et al. (2000), 3 - Clark et al. (2009) : observational and theoretical constraints + W51 membership + parallax, 4 -Bailer-Jones et al. (2018) : Gaia DR2 parallax, 5 - Hutse-*Column 3. Distance of counterpart in kpc. Column 4. mekers et al. (1994) MANUS

IFO #		R Name	d	F _{tot}	
10#	G-Name	Other Name(s)	[kpc]	$[10^{-17} \text{ W m}^{-2}]$	
IFO 007	G8.7-0.1	W 30	4.5	_a	
IFO 015	G11.2-0.3	_	4.4	1090.00	
IFO 038	G15.9+0.2	_	10.0	7.34	
IFO 069	G18.1-0.1	_	5.6	21.50	
IFO 070	G18.1-0.1	_	5.6	1.38	
IFO 075	G18.9-1.1	_	2.0	14.10	
IFO 076	G18.9-1.1	_	2.0	2.55	
IFO 078	G18.9-1.1	_	2.0	192.00	
IFO 079	G18.9-1.1	_	2.0	1.89	
IFO 080	G21.8-0.6	Kes 69	5.2	627.00	
IFO 084	G21.5-0.9	-	4.6	6.59	
IFO 085	G21.5-0.9	_	4.6	59.70	
IFO 088	G23.3-0.3	W 41	4.2	584.00	
IFO 093 ^b	G28.8+1.5	_	^c 3.4	0.39	
IFO 098	G27.8+0.6	-	2.0	167.00	
IFO 105	G27.4+0.0	Kes 73	8.5	274.00	
IFO 106	G28.6-0.1	_	9.6	197.00	
IFO 113	G31.9+0.0	3C 391	7.1	3423.55	
IFO 117	G32.8-0.1	Kes 78	4.8	114.00	
IFO 128	G34.7-0.4	W 44	2.8	3942.00	
IFO 139	G39.2-0.3	3C 396	8.5	618.00	\wedge
IFO 140	G41.5+0.4	_	4.1	1421.45	
IFO 143	G41.1-0.3	3C 397	10.0	1691.00	
IFO 147	G43.3-0.2	W49B	10.0	4739.00	$\mathbf{\mathbf{Y}}$
IFO 160	G49.2-0.7	W51C	6.0	582.37	ph an

Table 9. IFOs Associated with SNRs

*Distances are from Lee et al. (2019). See Lee et al. (2019) for original references.

^aDue to significant background errors, flux was not derived and not included in the statistics of fluxes.

^bDistance from Shan et al. (2018).

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^cPartially covered in the UWIFE survey.

Unknown-type
with
Associated
IFOs A
Table 10.

	Table 10. IFOs Associated with Unknown-type	
HO#	Comment	Reference
IFO 001 Amorphous structure elongated from NE to SW. The bright star is ALLWISE J180138.06–224227.8. a luminosity class of giant	Amorphous structure elongated from NE to SW. The bright star 15 arcsec East to the IFO is ALLWISE J180138.06–224227.8. a luminosity class of giant	s19
IFO 002 Compact IFO, H II region in the vicinity, H ₂ at South is slightly more extended	at South is slightly more extended	ı
IFO 017 Located in between late-type star [MHS2002] 196 and dark cloud SDC G12.804+0.055] 196 and dark cloud SDC G12.804+0.055	ı
IFO 028 Biconical structure in the North-East of IRAS 18134-1838, however, relation is uncertain	S 18134-1838, however, relation is uncertain	ı
IFO 068 An amorphous source in the middle of a possible evolved star J182227.66-171556.6 and	sible evolved star J182227.66–171556.6 and	m19
	South	r10
IFO 096 Spatially coincident with large-scale radio shell G25.8+0.2	ell G25.8+0.2	c18
	JI/16.3, H ₂ emission at North	ı
IFO 110 Amorphous IFO, possibly surrounding MIR source AllWISE J184515.66–031606.9 IFO 116 Amorphous IFO no well known sources in the vicinity	source AllWISE J184515.66-031606.9 he virinity	
Cometary IFO elongated North to	WISE J185905.19+004837.9 at the North	
	Amorphous IFO adjoining K-band source UGPS J185923.30+010415.0 which was not detected in J- and H-bands	ı
IFO 142 Bow-shock morphology with apex on NW si	Bow-shock morphology with apex on NW side, in between possible giant star at South and	s19
evolved/Class III YSO candidate at North		m16
IFO 150 Compact structure coincident with H ₂ , ALL	Compact structure coincident with H ₂ , ALLWISE J191530.41+132737.2 showing MIR photometric anomaly is located in the vicinity	$_{\rm S17}$
		ı
	iffed peak position	ı
IFU 108 A compact, faint knot in between IFU 10/ and 109 IEO 160 V and 11/20 Aiffinia IEO		I
	and IEO 179	
	and IFO 172	ı
IFO 172 Compact IFO, small-scale H ₂ in the vicinity		ı
	Amorphous IFO with the bright northern component coincident with MIR source GLIMPSE G052.9805-00.0394	ı
IFO 187 Knot-like IFO. Possible evolved star WISE J193120.72+192006.1 and	193120.72+192006.1 and	m19
	in South	s19
IFO 191 Diffuse elongated IFO from East to West. M	Diffuse elongated IFO from East to West. MIPSGAL source MG059.1989+00.5106 at North, MIR source ALLWISE J194013.97+232657.5	ν ι
IFO 197 Slightly elongated compact IFO, the center (the center of NGC 6823 is located at East	
	Cometary IFO with its South-Eastern head part coincident with ALLWISE J194611.21+221554.3.	s19
	S	
*Column 3. References of counterpart candidates : c18 - (2010), s17 - Solarz et al. (2017), s19 - Stassun et al. (2019)	*Column 3. References of counterpart candidates : c18 - Cichowolski et al. (2018), m16 - Marton et al. (2016), m19 - Marton et al. (2019), r10 - Roeser et al. (10), s17 - Solarz et al. (2017), s19 - Stassun et al. (2019)	0 - Roeser et a
*Counterpart candidates around IFO 166–172: 1: 2624 4: EGO G050.36-0.42 5: YSO candidate SSTC	*Counterpart candidates around IFO 166–172: 1: YSO candidate SSTGLMC G050.3746-00.4149 2: AGB candidate SSTGLMC G050.3756-00.4214 3: MHO 2624 4: EGO G050.36-0.42 5: YSO candidate SSTGLMC G050.3647-00.3944 6: YSO candidate SSTGLMC G050.3647-00.3979 7: YSO candidate SSTGLMC CONCOMPANY AND CANADA AN	1.4214 3: MH date SSTGLM
00.4095 11: YSO candidate SSTGLMC G0 00.4095 11: YSO candidate SSTGLMC G050.3741-00 serter MC G050.3755 00.4192	GUOU.338 /-00.4123 8: YSO candidate SST GLMC GUOU.36 /3-00.4089 9: YSO candidate SSTGLMC GUOU.3691-00.4096 10: YSO candidate SSTGLMC G050.3741-00.4083 12: YSO AGAL G050.376-00.421 13: YSO candidate SSTGLMC G050.3762-00.4205 14: YSO candidate SSTGLMC G050.3762-00.4205 14: YSO candidate sector MC G050.3752 00.4197	WC GUOU.3/U
2014.00.00.00.00.00.00.00.00.00.00.00.00.00		

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DATA AVAILABILITY

The data underlying this article are available to download from http://gems0.kasi.re.kr/uwife/.

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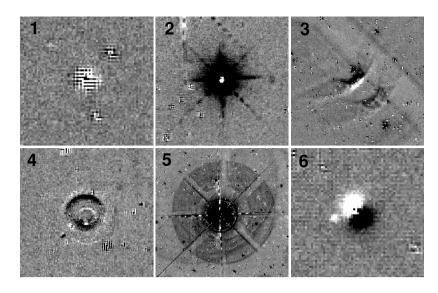


Figure A.1. Example of artifacts in the $[Fe \pi]$ -H image. 1) The residual of star subtraction shown as cross stripes 2) A variable and saturated star with a diffraction pattern 3) Arc-shape ghosts near a very bright star. The diffraction pattern of a bright star is superposed. 4) Electronic cross-talk near a bright star 5) Diffraction pattern of a bright star 6) High proper-motion star. (Black: bright, white: dark.)

APPENDIX A: EXAMPLES OF ARTIFACTS

APPENDIX B: THE UWIFE [FEII]-H AND GPS 3-COLOR IMAGES OF IFOS

, A

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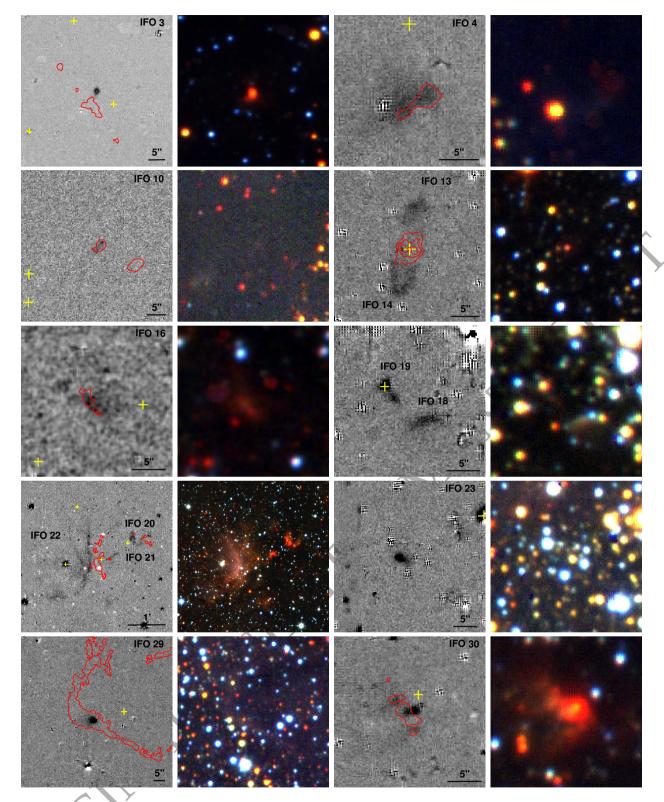


Figure B.1. IFOs with **YSO** counterpart candidates in continuum-subtracted [Fe II] and three-color *KHJ* UKIDSS images in the same field of view. The format for these images is the same as that of Fig. 1. Yellow crosses denote adjacent YSOs in the field of view. Red contours are $H_2 2.12 \mu m$ emission adopted from UWISH2.

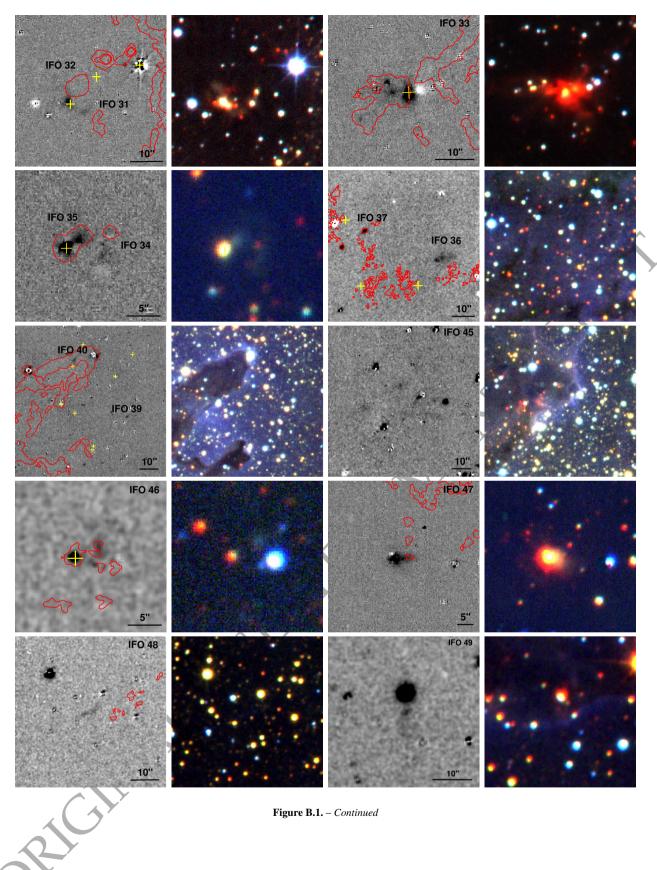
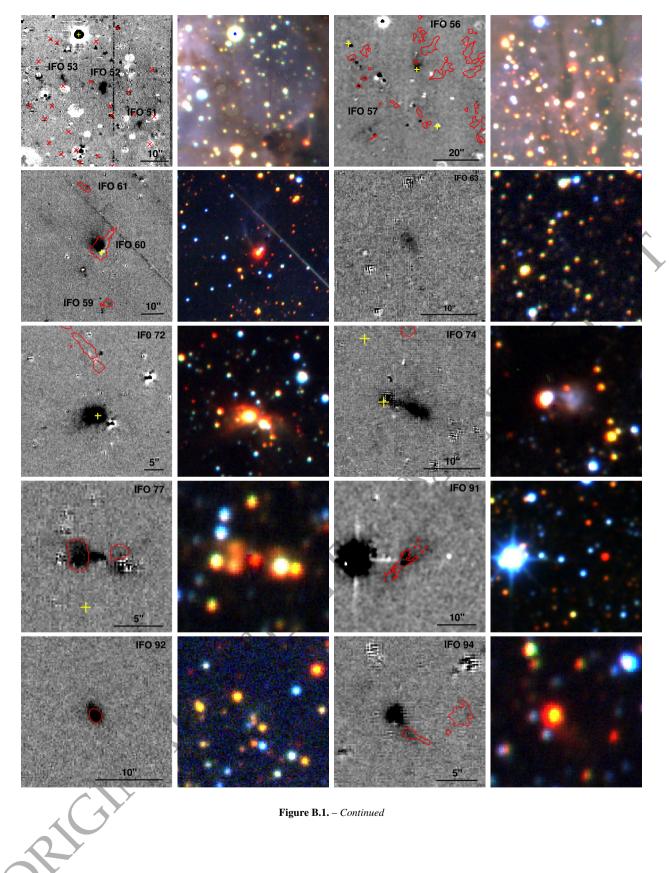


Figure B.1. – Continued



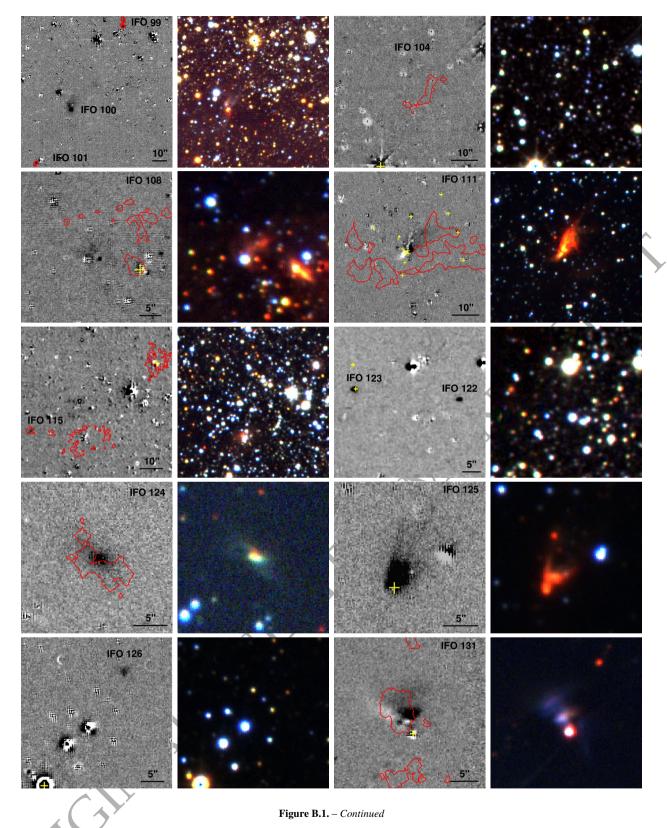


Figure B.1. – Continued

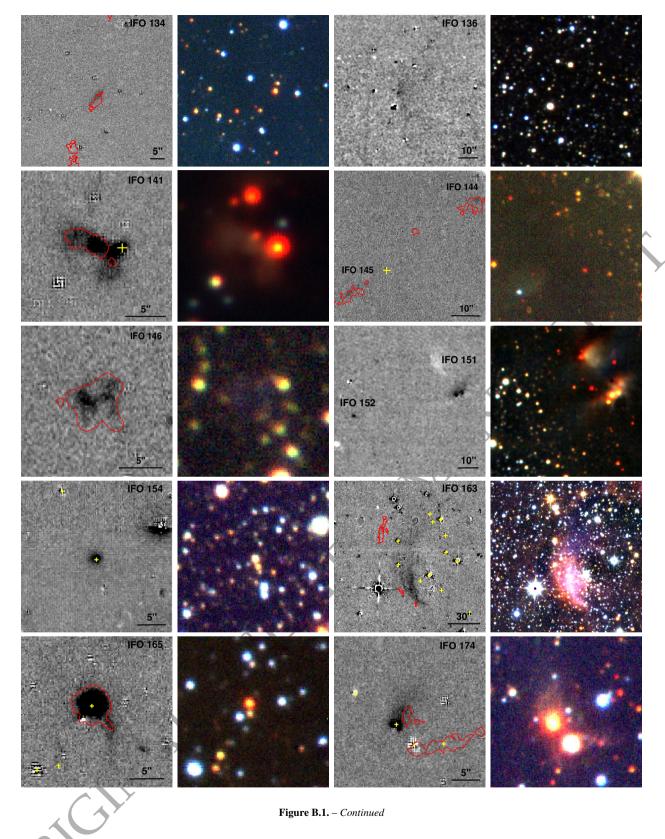


Figure B.1. – Continued

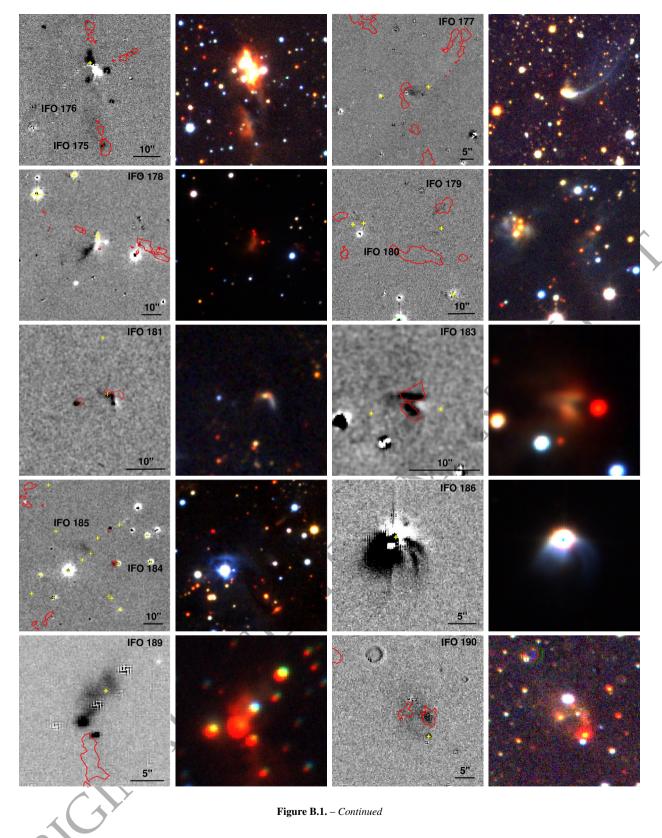
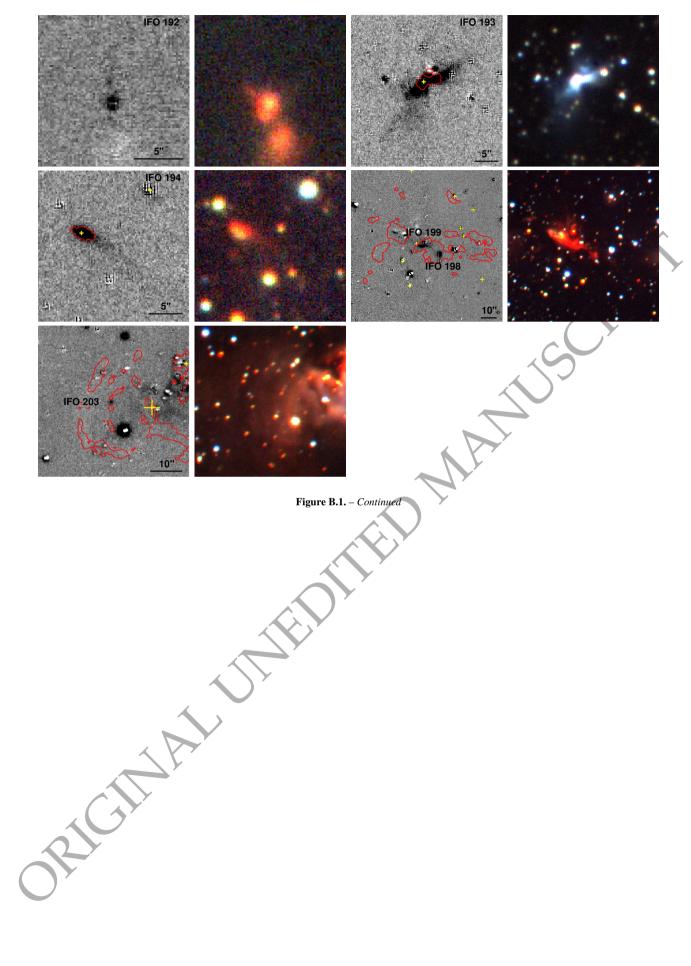


Figure B.1. – Continued



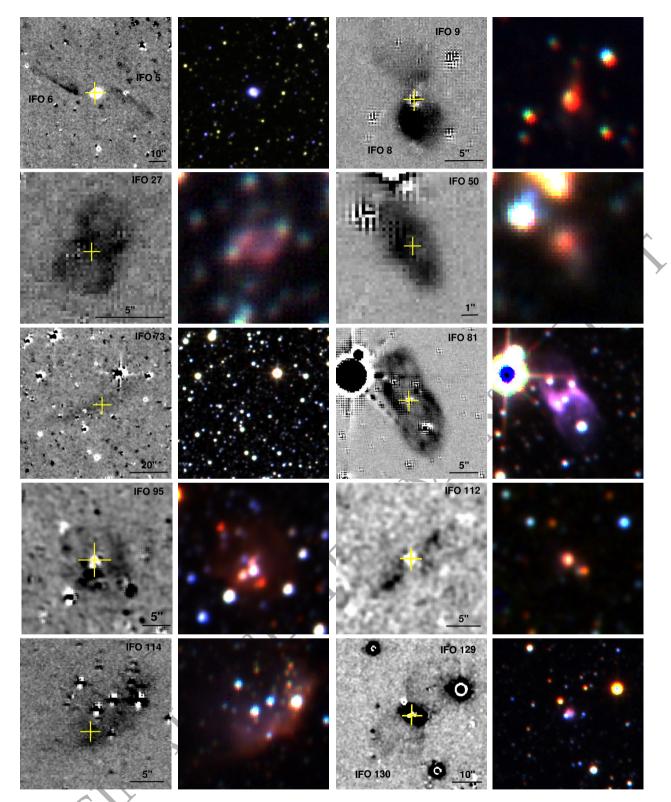
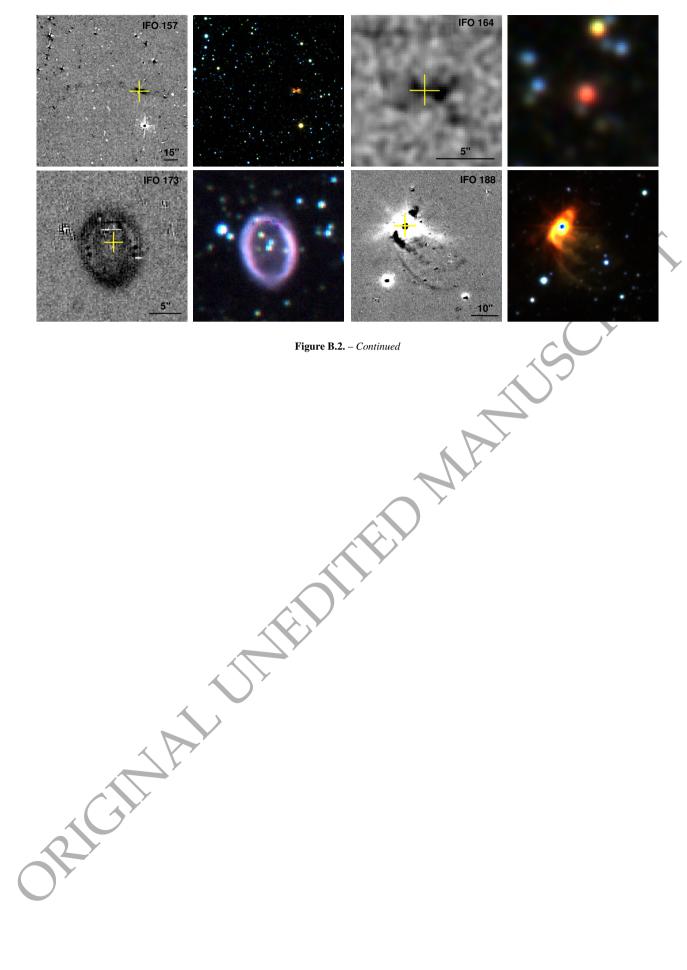


Figure B.2. Continuum-subtracted [Fe II] images of IFOs with PN counterpart candidates. The units on the UWIFE [Fe II]-H are DNs, with the darker colour denoting a higher DN. The corresponding source names for each IFO are shown. The yellow cross marks the central position of the counterpart. The images of IFO 73, 095, 112, 129, 157, and 164 are smoothed with a two-pixel Gaussian. In all images, North is at the top and east is on the left side.



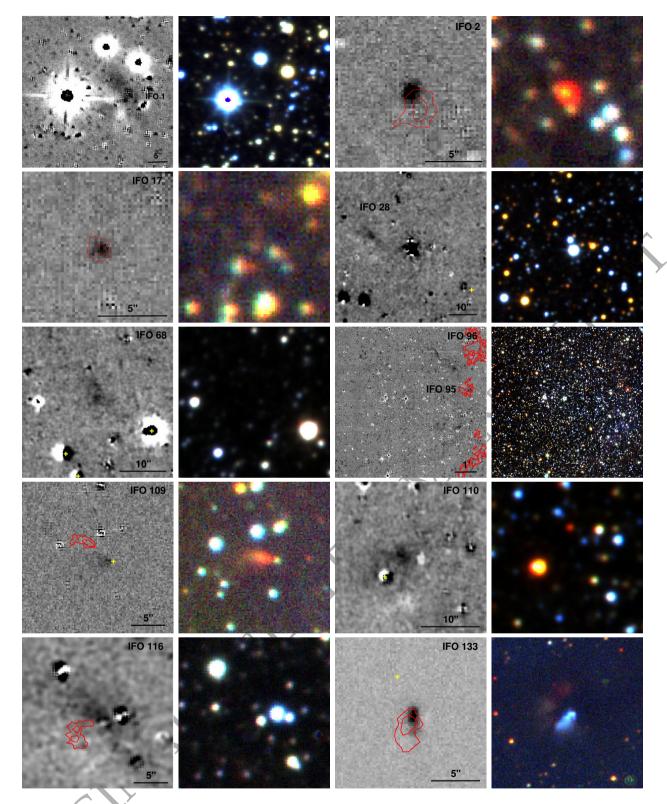


Figure B.3. IFOs with counterpart candidates unknown in continuum-subtracted [Fe II] images as in Fig. 1. IFO 95 is a PN-IFO inside the field of view. The format for these images is the same as that of Fig. 1.

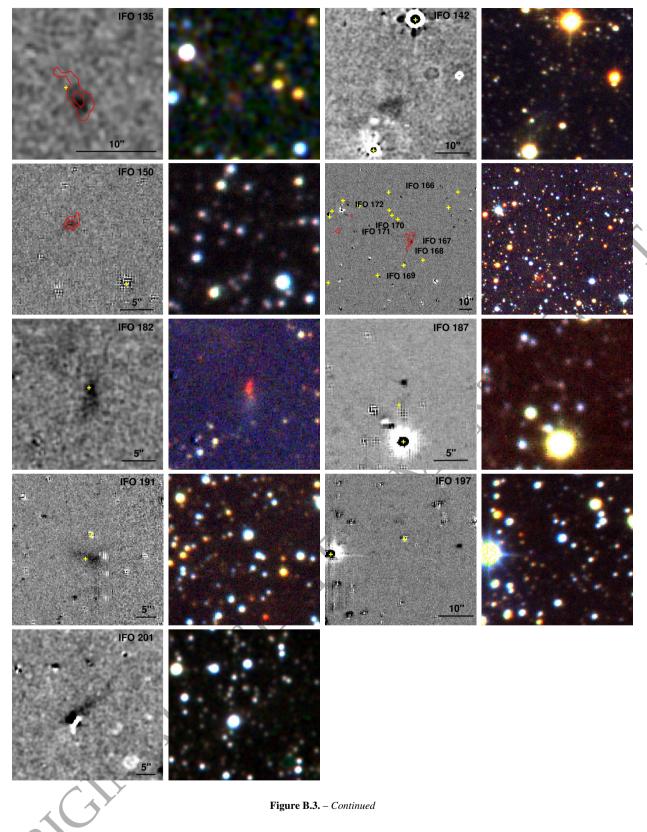


Figure B.3. – Continued