DISCOVERY OF YOUNG STELLAR OBJECTS AT THE EDGE OF THE OPTICAL DISK OF OUR GALAXY

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ABSTRACT

We report a discovery of young stellar objects associated with a molecular cloud at the edge of the optical disk of our Galaxy. This cloud is denoted as Cloud 2 in the list by Digel et al., and it is one of the most distant molecular clouds from the Galactic center known to date, with a probable distance of 15–19 kpc. We found seven red near-infrared (NIR) sources associated with this cloud. Based on our NIR observations and the far-infrared/radio data in the literature, we conclude that most sources are likely to be members of Cloud 2. The geometry of ionized gas, IRAS sources, and molecular cloud suggests that MR 1, an isolated early B-type star near Cloud 2, has triggered the star formation activity in Cloud 2. Our results show that ongoing star formation is present in Cloud 2 and that active star formation can occur in the farthest regions of the Galaxy, where the molecular gas density is extremely low, perturbation from the spiral arms is very small, and the metallicity is similar to that for irregular dwarf galaxies. Cloud 2 is an excellent laboratory in which to study the details of the star formation process in an environment that is similar to that in the early stage of the formation of the Galactic disk.

Subject headings: Galaxy: stellar content — infrared: stars — stars: formation

1. INTRODUCTION

Digel, de Geus, & Thaddeus (1994) found more than 10 molecular clouds possibly beyond the optical disk of our Galaxy in the direction to the Perseus arm (l ~ 130°). Their Galactic radius (R_g) is estimated at more than 20 kpc and as much as 28 kpc (see also Digel et al. 1996; Heyer & Terebey 1998). Because the distribution of Population I and Population II stars in the Galaxy has a sharp cutoff at around 18–20 kpc and 14 kpc, respectively (Digel et al. 1994 and references therein), these distant molecular clouds are potentially very interesting sites to investigate the star-forming process away from the Galactic disk with little or no perturbation from the spiral arms.

In such an outermost Galaxy region, the molecular gas surface density is much smaller than in spiral arms (Heyer et al. 1998; Heyer & Terebey 1998; Digel et al. 1996) and the H I surface density is one-fifth to one-tenth of that in the spiral arms (e.g., Wouterloot et al. 1990). Thus, the global star formation environment in the outermost Galaxy region is quite different from that in the spiral arms. Also, metallicity is very low in such a region. The metal abundance at R_g = 20 kpc is estimated at 12 + log (O/H) ~ 8.0, assuming the standard abundance curve (e.g., Smartt & Rolleston 1997). This metallicity is comparable to that of damped Lyα systems of higher metallicity (see Ferguson, Gallagher, & Wyse 1998 and references therein). Therefore, studies of star formation in the most Galaxy may reveal the details of the star formation process in an environment similar to that thought to exist during the early stage of the formation of the Galactic disk.

2 Smartt et al. (1996) derived an R_g of 15 kpc (heliocentric distance of 8.2 kpc) based on an LTE model of the optical spectrum. They suggested that a non-LTE model can make it larger up to 19 kpc (heliocentric distance of 12 kpc). Because the non-LTE model is more likely for stars like MR 1 with high effective temperatures as described by Smartt et al. (1996), we assume R_g = 19 kpc and a heliocentric distance of 12 kpc hereafter. The R_g of Earth is assumed to be 8.5 kpc.
lar clouds/H II regions known to date. The metal abundance of MR 1 is estimated at 12 + log (O/H) ~ 8.3 (Smartt & Rolleston 1997), which is comparable to that for irregular dwarf galaxies (e.g., ~ 8.4 for the Large Magellanic Cloud; Arnault et al. 1988).

Here we report a discovery of young stellar objects (YSOs) associated with Cloud 2 made during our near-infrared (NIR) studies. These sources could shed light on the star formation processes in such a low-density and low-metallicity environment as well as helping discern the distance to Cloud 2. We have made comprehensive NIR observations of Cloud 2 that include a wide-field survey, spectroscopy of detected infrared sources, and deep imaging for the purpose of detecting low-mass YSOs. The details of our study will be reported in subsequent papers.

2. OBSERVATIONS AND RESULTS

In October 1997, we made an initial NIR survey of Cloud 2 with the University of Hawaii's QUIST (Quick Infrared Survey Telescope) mounted at the UH 0.6 m telescope atop Mauna Kea. QUIST consists of University of Hawaii's QUIRC (Quick Infrared Camera), an NIR camera with 1024 × 1024 HgCdTe HAWAII array, and 25.4 cm Cassegrain telescope that provides a 25" field of view with one 1.5 pixel ~ 1 scale. The observing was done remotely from the Institute for Astronomy in Honolulu. The observations were partly affected by intermittent cirrus. Several standard stars from Elias et al. (1982) were observed at several air-mass positions for photometric calibration. We obtained images of a field centered on Cloud 2 in three NIR bands, J (1.25 μm), H (1.65 μm), and K (2.2 μm). The total integration times for each band were 36 minutes, 36 minutes, and 45 minutes, respectively.

We detected seven red sources associated with Cloud 2 with QUIST (Fig. 1). The coordinates and NIR magnitudes of all sources and MR 1 (Muzzio & Rydgren 1974) are summarized in Table 1. All of the NIR sources are associated with IRAS sources in Cloud 2: IRAS 02450 + 5816 for IRS 1; IRAS 02447 + 5811 for IRS 2, 3, 4, 5; and IRAS 02455 + 5808 for IRS 6&7 (Fig. 2a and Table 2). JHK photometry has been performed using IRAF APPHOT tasks. An aperture of 18" was employed. The resultant J − H versus H − K color-color diagram is shown in Figure 3.

We made follow-up K-band spectroscopy of IRS 1 and IRS 2 with the NIR spectrograph CGS4 at UKIRT in December 1997. IRS 1 and 2 are two bright sources near the northern and southern clumps of the molecular cloud, respectively (see Fig. 2). A 40 grooves mm ~ 1 grating that provides a spectral resolution of λ/Δλ = 900 was used. Because seeing was excellent, we used a narrow (0"5) slit with the tip-tilt secondary. Observing conditions were photometric. To achieve sufficient sampling, we took three exposures with one-third pixel shift between exposures. After basic reductions (e.g., sky subtraction and flattening), one-dimensional spectra were extracted with standard IRAF tasks. The standard star HR831 was used for the correction of atmospheric extinction and flux calibration. The Brγ absorption line in the standard spectrum was removed by interpolation before the extinction correction. The results are shown in Figure 4. When observing IRS 1, the humidity was so low and stable that we could clearly detect emission lines in spectral regions of significant telluric water vapor absorption. The details of this spectroscopy

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**TABLE 1**

| Name     | R.A. (2000)* | Decl. (2000)* | J* | H* | K* | J − H | H − K | Associated IRAS Source |
|----------|--------------|---------------|----|----|----|-------|-------|------------------------|
| IRS 1.....| 2 48 56.52   | 58 29 20.2    | 15.39 (0.09) | 14.10 (0.08) | 12.99 (0.06) | 1.29 (0.12) | 1.11 (0.10) | 02450 + 5816            |
| IRS 2.....| 2 48 28.89   | 58 23 33.5    | 15.42 (0.09) | 14.25 (0.09) | 13.01 (0.06) | 1.17 (0.12) | 1.25 (0.10) | 02447 + 5811            |
| IRS 3.....| 2 48 27.15   | 58 23 57.0    | 16.92 (0.44) | 15.98 (0.55) | 14.81 (0.34) | 0.94 (0.71) | 1.17 (0.65) | 02447 + 5811            |
| IRS 4.....| 2 48 35.38   | 58 23 37.3    | ...          | 15.16 (0.16) | 14.09 (0.13) | ...          | ...          | ...                    |
| IRS 5.....| 2 48 44.97   | 58 23 37.1    | 15.26 (0.07) | 14.08 (0.06) | 13.22 (0.06) | 1.18 (0.09) | 0.86 (0.09) | 02447 + 5811            |
| IRS 6.....| 2 49 24.18   | 58 21 58.1    | 14.90 (0.05) | 12.97 (0.03) | 11.35 (0.01) | 1.93 (0.06) | 1.61 (0.03) | 02455 + 5808            |
| IRS 7.....| 2 49 21.28   | 58 21 28.9    | 15.39 (0.07) | 13.34 (0.04) | 11.27 (0.01) | 2.05 (0.08) | 2.07 (0.04) | 02455 + 5808            |
| MR 1..... | 2 49 22.35   | 58 26 44.6    | 11.49 (0.01) | 11.17 (0.01) | 10.95 (0.01) | 0.32 (0.01) | 0.22 (0.01) | ...                    |

**Note.**—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

* Accuracy is ~ 0.2”, depending on the magnitude.

* In the QUIRC photometric system. The statistical uncertainty from IRAF APPHOT task is in parentheses. The uncertainty shown does not include any systematic uncertainty from color transformation and imperfect weather conditions, which could be 0.1–0.2 mag.

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**TABLE 2**

| Name         | 12 μm | 25 μm | 60 μm | 100 μm | Probable NIR Counterpart |
|--------------|-------|-------|-------|--------|--------------------------|
| 02447 + 5811| <0.27 | <0.25 | 0.72  | <4.47  | IRS 2, 3, 4, 5            |
| 02450 + 5816| <0.31 | <0.25 | 1.81  | 8.85   | IRS 1                    |
| 02455 + 5808| 0.46  | 1.15  | 3.27  | 7.73   | IRS 6, 7                 |

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* The 0.6 m telescope is not used. The QUIST telescope is attached to its equatorial mount.
will be described in a separate paper with results from our new CGS4 spectroscopy of additional Cloud 2 sources (N. Kobayashi & A. T. Tokunaga, 1999a, in preparation).

3. DISCUSSION

3.1. Near-Infrared Sources

Among all the detected sources in the observed field, the seven red sources are distinctively red as shown in the true color pictures (Fig. 1) and in the \((J - H)\) versus \((H - K)\) color-color diagram (Fig. 3). All of the red sources are associated with Cloud 2, and no other bright red sources were found apart from Cloud 2 in the surveyed field (Fig. 1). All sources except IRS 2 appeared to be point sources with the QUIST spatial resolution (\(\sim 2\)''). IRS 2 is discussed in more detail in §3.3.

The Five College Radio Astronomy Observatory (FCRAO) \(^{12}\)CO survey data (Heyer et al. 1998)\(^6\) show no foreground clouds in the direction of Cloud 2. However, a number of small foreground clouds are around Cloud 2 in the surveyed field: a small cloud in the local arm at 5' southward, another small cloud in the local arm at 10' eastward, a small cloud associated with the Perseus arm at 10' eastward, and a large cloud associated with the Perseus arm at 20' northward. Despite the existence of many foreground clouds in the surveyed field, we detected red sources only in the small area centered at Cloud 2. This result strongly suggests that all the red sources are physically associated with Cloud 2.

\(^6\) We obtained the FCRAO data electronically from the NASA Astronomical Data Center at http://adc.gsfc.nasa.gov/.
All seven sources show a large $H - K$ excess of more than 0.8. As shown in Figure 3, the $H - K$ excesses of the sources except IRS 4 are not caused by interstellar extinction but are caused by intrinsically large $H - K$ excess. YSOs, highly obscured late-type stars (e.g., OH-IR stars, protoplanetary nebulae [PPNs]), and active galactic nuclei (AGNs) are known to show large intrinsic $H - K$ excess from dust emission (e.g., Lada & Adams 1992 for YSOs; García-Lario et al. 1997 for late-type stars; and Hunt et al. 1997 for AGNs). Although it is difficult to distinguish between these three classes of objects solely from NIR colors, the red sources are most likely YSOs in view of the association with the molecular cloud.

The two brightest red sources, IRS 6 and 7, which, among the red sources, are most distant from Cloud 2 on the sky (Fig. 2a), might be foreground stars in view of their brightness (a few magnitudes brighter than other sources in Cloud 2; see Table 1) and relatively large angular distance from Cloud 2 (7'-8' from the CO peaks; see Fig. 2a). Also, they are located at the edge of one of the foreground molecular clouds in the Perseus arm. These two sources are associated with the bright IRAS point source, IRAS 02455 + 5808 but not resolved within the IRAS beam (1σ ellipse of 37'' × 10'' with P.A. = 59°). The IRAS color is typical for various kinds of objects (e.g., galaxies, YSOs, planetary nebulae) and does not reveal the nature of IRS 6 and 7 clearly. The pointlike appearance and extremely red NIR color ($H - K > 1.5$) suggest that they are at least Galactic stars. Further study is necessary to clarify the nature of these sources.
In Figure 3, MR 1 is located on a reddening vector from early-type stars. The visual extinction of MR 1 is estimated at about $A_v = 3$ to 4 mag from this color-color diagram. This is consistent with the estimate from $B$ and $V$ photometry of $A_v = 3.1$ mag (Muzzio & Rydgren 1974).

### 3.2. IRS 1

The $K$-band spectrum of IRS 1 (Fig. 4) shows three strong hydrogen recombination lines: $\text{Pa}_\alpha$ (1.875 $\mu$m), Br$\delta$ (1.945 $\mu$m), and Br$\gamma$ (2.166 $\mu$m). Those lines show a blueshift of about 100-200 km s$^{-1}$, suggesting IRS 1 is not an extra-galactic object. Also, our $K$-band spectrum shows that IRS 1 is unlikely to be an OH/IR star or a PPN because these objects do not usually show hydrogen emission lines. OH/IR stars show strong CO/H$_2$O absorption lines (T. Nagata, 1999, private communication) and PPNs usually show hydrogen absorption lines (Oudmaijer et al. 1995; Hrivnak, Kwok, & Geballe 1994). Although a few PPNs, possibly more evolved than most PPNs, are known to show NIR hydrogen emission lines like planetary nebulae (e.g., Aspin et al. 1993 for M 1-16; Thronson 1981 for AFGL 618), it is highly unlikely that such a rare source is located near an IRAS source in a molecular cloud (Fig. 2a). Instead, it is highly plausible that the NIR emission lines are signatures of an $\text{H II}$ region around YSOs. For the reasons above, we conclude that IRS 1 is a YSO physically associated with Cloud 2.

Assuming the Galactic radius of 19 kpc for IRS 1 (heliocentric distance = 12 kpc), the $K$-band absolute magnitude without any correction for extinction is $M_K = -2.4$ mag. This is comparable to those for high- to intermediate-mass YSOs such as Herbig Ae/Be stars (e.g., Hillenbrand et al. 1992). We estimate the spectral type of IRS 1 roughly at mid to late B from the $K$-band apparent magnitudes and distances for the Herbig Ae/Be samples in Hillenbrand et al. (1992).

### 3.3. IRS 2

IRS 2 is located at the southern peak of the CO molecular cloud as well as at the center of the error ellipse of IRAS 02447 + 5811 (Figs. 2a and 2b). IRS 2, 3, 4, and 5 form a cluster of red sources near the southern CO peak (Figs. 2a and 2b); IRS 2 is the brightest. The NIR color of IRS 2 shows that it is as highly extinguished ($A_V \sim 10$ mag) as IRS 1. IRS 2 appeared to be extended in the QUIST image with FWHM of $\sim 7''$ (Fig. 1b). We recently obtained deep $JHK$ images of Cloud 2 with higher spatial resolution and found that IRS 2 is a cluster of more than 20 red pointlike sources (N. Kobayashi & A. T. Tokunaga, 1999b, in preparation). This morphology strongly suggests that IRS 2 is a star cluster in or behind the molecular cloud. Further observations are necessary to clarify the nature of IRS 2 as well as of IRS 3, 4, 5.

### 3.4. Star Formation in Cloud 2

The ionized gas traced by H$\alpha$ emission extends from MR 1 toward Cloud 2. The peaks of the H$\alpha$ emission are between the molecular cloud peaks and MR 1 (de Geus et
al. 1993; see also Fig. 2a). Since IRS 1 is located at the center of the H\(\alpha\) emission, it also could be one of the major ionizing sources of this H II region. However, MR 1 is likely to dominate the ionization of the entire H II region because the number of ionizing photons from IRS 1 is expected to be much lower than that from MR 1, assuming a spectral type of mid- to late-B and B0–1, respectively, for IRS 1 and MR 1.

The IRAS source associated with IRS 1 (02450+5816) is located between the H\(\alpha\) peak and the northern CO peak of Cloud 2 (Figs. 2a and 2b). This pattern is typical for Galactic H II regions (e.g., Gatley et al. 1979 for M17); young OB stars photoionize the surface of an associated molecular cloud and make the warm dust region that is traced by IRAS 60/100 \(\mu\)m flux. IRAS 02450+5816 is not detected at 12 or 25 \(\mu\)m but only at 60 and 100 \(\mu\)m. Its [60]–[100] color temperature (about 30 K; assuming emissivity \(\epsilon_{\lambda} \sim \lambda^{-2}\)) is significantly lower than that for stars, planetary nebulae, single YSOs, or active galaxies (see, e.g., Walker et al. 1989). Also, IRAS 02450+5816 is cataloged with a “small-scale structure flag,” which denotes an association with a confirmed extended source (IRAS Point Source Catalogue 1988). These characteristics suggest that the IRAS source is a warm extended region adjacent to a molecular cloud rather than a single object with compact far-infrared emission. Judging from the low dust temperature (~30 K), the warm region is not a prominent photodissociation region (PDR) in a young star cluster (e.g., S140: Timmermann et al. 1996) but a less energetic one in a dark cloud such as \(\rho\) Oph (Liseau et al. 1999). This is consistent with the suggestion by Digel et al. (1994) that Cloud 2 is more like a dark cloud (e.g., Taurus dark cloud) than a large star-forming complex with OB star cluster (e.g., Orion molecular cloud complex).

The bolometric luminosity of IRAS 02450+5816 is estimated to be \(L_{IR} \sim 1000 \, L_\odot\) from the IRAS flux densities and assuming a 12 kpc heliocentric distance (Emerson 1988; Tokunaga 2000). Assuming a spectral type of B0 V–B1 V, the luminosity of MR 1 is expected to be \(L_{IR} \sim 10^4 \, L_\odot\) if all the emitting photons are absorbed entirely by the molecular cloud (see Fig. 2 in MacLeod et al. 1998). If we assume that the northern peak of Cloud 2 covers only 10% of the sphere centered at MR 1 (the cone of 60° apex angle), the observed IRAS luminosity can be explained by the ionization of MR 1. Although it is hard to estimate a precise solid angle from the current data, it is likely that MR 1 is the major ionizing source exciting the H II region and the PDR.

The IRAS source associated with the southern CO peak (IRAS 02447+5811) appears to have a small offset from the CO peak to MR 1 as is the case for the northern peak (Fig. 2b). Since the geometry of an ionizing source, ionizing gas, an IRAS source, and a molecular cloud is similar to that for the northern peak, IRAS 02447+5811 could also be a PDR associated with Cloud 2.

The NIR sources IRS 1–5 are located between the H\(\alpha\) peaks and the molecular cloud peaks near the IRAS sources (Figs. 2a and 2b). This geometry suggests that the photoionization of MR 1 triggered the formation of the NIR sources in Cloud 2. Thus, the star formation in Cloud 2 seems to be dominated by the single early B-type star MR 1. It is also interesting to consider how a single B-star, MR 1, was formed in the outermost Galaxy, but this is beyond the scope of this paper.
4. CONCLUSION

We have conducted a wide-field NIR search for YSOs associated with Cloud 2 as denoted by Digel et al. (1994). This cloud is one of the most distant molecular clouds from the Galactic center known thus far; the Galactic radius is estimated to be 15–19 kpc (Smartt et al. 1996). Although extended Hα emission is associated with this cloud, ongoing star-forming activity like that in the nearby star-forming molecular clouds has not been previously reported.

We have discovered seven very red NIR sources in and around Cloud 2 with wide-field imaging in the J (1.25 μm), H (1.65 μm), and K (2.2 μm) bands. Although foreground clouds in Perseus and local spiral arms are around Cloud 2 on the sky, we could not detect any red sources apart from Cloud 2 within the total surveyed area of roughly 900 arcmin square. Therefore, the detected red sources are very likely to be members of Cloud 2. Most of the sources show large $H-K$ excess ($H-K > 0.8$), indicating their YSO nature. We have also obtained a $K$-band (1.85–2.45 μm) spectrum of two of the infrared sources, IRS 1 and IRS 2, near the two CO peaks in Cloud 2. Strong hydrogen emission lines ($Br_\alpha$, $Br_\delta$, and $Pa_\alpha$) with a slight blueshift were detected for IRS 1, while emission or absorption lines were not detected for IRS 2 within the uncertainty. In view of the cloud association and the emission-line spectrum, we conclude that IRS 1 is a YSO physically associated with Cloud 2.

IRS 1 is associated with an IRAS point source with an extended feature (IRAS 02450 + 5816) near the northern CO peak of Cloud 2. This IRAS source has a low color temperature (∼30 K) and is located between an Hz peak and the CO peak, suggesting it is a photodissociation region. IRS 2 is associated with IRAS 02447 + 5811 on the southern CO peak of Cloud 2. IRS 3, 4, and 5 are located around this IRAS source. The overall distribution of ionized gas, IRAS sources, molecular cloud, and NIR sources suggests that MR 1, an early B-type star near Cloud 2, has triggered the formation of NIR sources in Cloud 2.

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REFERENCES

Arnault, P., Casoli, F., Combes, F., & Kunth, D. 1988, A&A, 205, 41
Aspin, C., et al. 1993, A&A, 278, 255
Bessell, M. S., & Brett, J. M. 1988, PASP, 100, 1134
Cao, Y., Terebey, S., Prince, T. A., & Beichman, C. A. 1997, ApJS, 111, 387
de Geus, E. J., Vogel, S. N., Digel, S. W., & Gruendl, R. A. 1993, ApJ, 413, L97
Digel, S., de Geus, E., & Thaddeus, P. 1994, ApJ, 422, 92
Digel, S., Lyder, D. A., Philbrick, A. J., Puche, D., & Thaddeus, P. 1996, ApJ, 458, 561
Elia, J. H., Frogel, J. A., Matthews, K., & Neugebauer, G. 1982, AJ, 87, 1029
Emerson, J. P. 1988, in Formation and Evolution of Low Mass Stars, ed. A. K. Dupree & M. T. V. T. Lago (Dordrecht: Kluwer), 193
Ferguson, A. M. N., Gallagher, J. S., & Wyse, R. F. G. 1988, AJ, 116, 673
Garcia-Lario, P., Manchado, A., Pych, W., & Pottasch, S. R. 1997, A&AS, 126, 479
Gatley, I., Becklin, E. E., Sellgren, K., & Werner, M. W. 1979, ApJ, 233, 575
Heyer, M. H., Brunth, C., Snell, R. L., Howe, J. E., & Schloerb, F. P. 1998, ApJS, 115, 241
Heyer, M. H., & Terebey, S. 1998, ApJ, 502, 265
Hillenbrand, L. A., Strom, S. E., Vrba, F. J., & Keene, J. 1992, ApJ, 397, 613
Hravnak, B. J., Kwok, S., & Geballe T. R. 1994, ApJ, 420, 783
Hunt, L. K., Malkan, M. A., Salvati, M., Mandolesi, N., Palazzi, E., & Wade, R. 1997, ApJS, 108, 229

IRAS Point Source Catalog, Version 2. 1988, Joint IRAS Science Working Group (Washington, DC: GPO)
Kulkarni, S. R., Blitz, L., & Heiles, C. 1982, ApJ, 259, L63
Lada, C. J., & Adams, F. C. 1992, ApJ, 393, 278
Liseau, R., et al. 1999, A&A, 344, 342
MacLeod, G. C., Scalise, E., Jr., Saedt, S., Galt, J. A., & Gaylard, M. J. 1998, AJ, 116, 1897
Muzzio, J. C., & Rydgren, A. E. 1974, AJ, 79, 864
Oudmaijer, R. D., Waters, L. B. F. M., van der Veen, W. E. C. J., & Geballe, T. R. 1995, A&A, 299, 690
Smartt, S. J., Duffin, P. L., & Rolleston, W. R. J. 1996, A&A, 305, 164
Smartt, S. J., & Rolleston, W. R. J. 1997, ApJ, 481, L47
Thronson, H. A., Jr. 1981, ApJ, 248, 984
Timmermann, R., Bertoldi, F., Wright, C. M., Drapatz, S., Drain, B. T., Haster, L., & Sternberg, A. 1996, A&A, 315, L281
Tokunaga, A. T. 2000, in Astrophysical Quantities, ed. A. N. Cox (Berlin & Heidelberg: Springer), 143
Walker, H. J., Cohen, M., Volk, K., Wainscoat, R. J., & Schwartz, D. E. 1989, AJ, 98, 2163
Wouterloot, J. G. A., Brand, J., Burton, W. B., & Kwok, K. K. 1990, A&A, 230, 21