AN EXTREMELY YOUNG MASSIVE STELLAR OBJECT NEAR IRAS 07029—1215

J. FORBRICH,1 K. SCHREYER, B. POSSELT,2 AND R. KLEIN2
Astrophysikalisches Institut und Universitäts-Sternwarte, Friedrich-Schiller-Universität, Schillergässchen 2-3, D-07745 Jena, Germany; forbrich@mpifr-bonn.mpg.de
AND
TH. HENNING
Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany

Received 2003 June 30; accepted 2003 November 3

ABSTRACT

In the course of a comprehensive millimeter/submillimeter survey of massive-star–forming regions, the vicinities of a sample of 47 luminous IRAS sources were closely investigated with the Submillimeter Common-User Bolometric Array and the MPIfR bolometers in order to search for massive protostellar candidates. A particularly interesting object has been found in the surroundings of the bright far-infrared source IRAS 07029—1215. Follow-up line observations show that the object is cold, has a massive envelope, and is associated with an energetic molecular outflow. No infrared point source has been detected at its position. Therefore, it is a very good candidate as a member of the long-sought group of massive protostars.

Subject headings: ISM: jets and outflows — stars: formation

1. INTRODUCTION

The study of the earliest stages of massive star formation (MSF) is one of the most exciting subjects of present research in this field. Whether the dominant formation process for massive stars is disk accretion (see, e.g., Jijina & Adams 1996) or coalescence (Bonnell, Bate, & Zinnecker 1998) is still an open question. However, the presence of outflows in regions of MSF favors the first scenario. Similarly to previous surveys (e.g., Beuther et al. 2002b; Mueller et al. 2002; Hunter et al. 2000), we have searched for MSF candidates located near bright IRAS sources using the Submillimeter Common-User Bolometric Array (SCUBA) and MPIfR bolometers (Posselt 2003; R. Klein et al. 2004, in preparation). Our focus was on objects unrelated to the IRAS sources themselves, looking for the earliest evolutionary stages, not yet seen in the near- to mid-infrared wavelength regime. Even if we do not yet know what the observational features of massive protostars are (Evans et al. 2002), their invisibility at near-infrared/mid-infrared wavelengths is a defining criterion. Near IRAS 07029—1215, an object with an IRAS luminosity of $L_{\text{IRAS}} = 1700 L_\odot$ (Henning et al. 1992) at its distance of $d = 1$ kpc, we discovered a deeply embedded object, Unidentified Young Stellar Object 1 (UYSO 1), powering a high-velocity bipolar CO outflow. The IRAS source is located in the bright HI region S297, illuminated by the B1 II/III star HD 53623 (Houk & Smith-Moore 1988). UYSO 1 is also located very close to the edge of a dark cloud.

2. OBSERVATIONS

CO ($J = 3 \rightarrow 2$) line mapping of UYSO 1 was carried out with the James Clerk Maxwell Telescope (JCMT)1 on Mauna Kea, Hawaii, in 1999 October. The facility receiver B3 (315–373 GHz) was used as the front end, and the Digital Auto-correlation Spectrometer (DAS) as the back end. With a total bandwidth of 250 MHz, centered on $v_{\text{LSR}} = +12$ km s$^{-1}$, the maps were obtained in position-switch mode with an off-position 10$^\prime$ to the east. Map sampling was at intervals of 10$^\prime$; the total on-off integration time was 10 minutes, the beam efficiency was $\eta = 0.63$, and the beam size was 14$^\prime$. In addition, SCUBA continuum observations at $\lambda = 450$ and 850 $\mu$m were performed with a total integration time of 46 minutes. Here, beam sizes were 8$^\prime$ and 14$^\prime$, respectively. Noise was minimized using the Emerson II technique, based on six different field scans with different chop throws (Emerson 1995). In 2003 March, additional CS ($J = 2 \rightarrow 1$), CS ($J = 5 \rightarrow 4$), SiO ($J = 2 \rightarrow 1$), and, especially, H$_2$CO ($J = 3_03 - 2_02)/(J = 3_{22} - 2_{21})$ observations were obtained at the IRAM 30 m telescope using the B100, B230, A100 and A230 receivers. The raster map sampling was the same as for the JCMT observations, although a smaller range of offset positions was observed. The center position is shifted southward by 6$^\prime$4 compared to the JCMT map. The data were obtained in position switch mode; integration time at each offset was 6 minutes. All line observations together with the observing parameters are summarized in Table 1. We used the CLASS software developed by the Grenoble Astrophysics Group for line data reduction, including zero-order baseline subtraction, and GAIA for the SCUBA data.

3. RESULTS

The POSS$^4$ view in Figure 1 shows the environment of IRAS 07029—1215. The overlain SCUBA map at 850 $\mu$m displays UYSO 1 as a compact emission peak at $\alpha_{(B1950.0)} = 07^{h}02^{m}51^{s}$,
\[ \delta_{[B1950.0]} = -12^\circ14'26'', \] between S297 and the dark cloud. In addition to this, two dusty filaments are visible at 850 \( \mu \)m. The eastern filament contains the IRAS point source position, and the western one is located inside the dark cloud.

UYSO 1 is still invisible at near- and mid-infrared wavelengths: no infrared point source in the \( \lambda = 2.2-20 \mu \)m range is visible in Two Micron All Sky Survey (2MASS) and Midcourse Space Experiment (MSX) images (see Fig. 2a and 2b), but some faint “reflected” light can be seen in the 2MASS \( K_s \)-band image. It cannot be ruled out, however, that this is captured H\(_2\) line emission, e.g., tracing cloud surfaces and outflows. Neither the IRAS, 2MASS, nor MSX infrared survey point source catalogs had detections at the UYSO 1 position. There is, however, an MSX point source inside the reflected light south of UYSO 1.

The CO map in Figure 2c is a close-up view of the dense dust core. The line wings, extending from \(-20 \text{ km s}^{-1}\) at \((0^\circ, -20^\circ)\) to \(+40 \text{ km s}^{-1}\) at \((0^\circ, 0^\circ)\) (see Fig. 3), can be clearly distinguished from well-determined baselines, extending from \(-40\) to \(+50 \text{ km s}^{-1}\). Lines are narrower in off-outflow positions. Figure 4 shows a comparison of the CO \((J = 3 \rightarrow 2)\) line

### Table 1

| Line             | Frequency (GHz) | Telescope | Date     | Beam Size (arcsec) |
|------------------|-----------------|-----------|----------|--------------------|
| CO \((J = 3 \rightarrow 2)\) | 345.79          | JCMT      | 1999 Oct | 14                 |
| CS \((J = 2 \rightarrow 1)\) | 97.98           | IRAM 30 m | 2003 Mar | 25                 |
| CS \((J = 5 \rightarrow 4)\) | 244.94          | IRAM 30 m | 2003 Mar | 10                 |
| SiO \((J = 2 \rightarrow 1)\) | 86.84           | IRAM 30 m | 2003 Mar | 29                 |
| H\(_2\)CO \((J = 3 \rightarrow 2)\) | 218.34          | IRAM 30 m | 2003 Mar | 12                 |

\(^{a}\) H\(_2\)CO \((J = 3_{00} \rightarrow 2_{02})\) and \((J = 3_{22} \rightarrow 2_{21})\).

\(^{5}\) The atlas image obtained as part of the Two Micron All Sky Survey (2MASS), a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the NASA and the NSF.

---

**Fig. 1.**—Surroundings of UYSO 1: POSS I, overlain by the 850 \( \mu \)m continuum from the JCMT. The box indicates the field of view of Fig. 2.
profile with the CS \((J = 5 \rightarrow 4)\) profile in the map center. CS \((J = 5 \rightarrow 4)\) is a high-density tracer with a critical density of \(n_{\text{crit}} = 7 \times 10^6 \text{ cm}^{-3}\).

Contrary to what could be expected from the 850 \(\mu\text{m}\) map, the CO data do not show a spherically symmetric structure. Instead, the envelope seems to be compressed toward the \(\text{H} \\Pi\) region east of it. The CO peak is roughly 10\(\prime\) off the SCUBA peak position. The line-wing map displays a bipolar outflow in the northwest-southeast direction, its origin being UYSO 1 at raster coordinates (0\(\hbar 00\), 10\(\hbar 00\)), taking the emission peak of the complete integrated line as its definition. The outflow is not clearly visible in the CS data, possibly because the average density is below the CS critical densities. Lines corresponding positions, however, have corresponding shapes. SiO \((J = 2 \rightarrow 1)\) could only be detected at the position (–10\(\hbar\), 16\(\hbar\)), in the outer regions of the redshifted outflow lobe. Possibly, this is due to a bow shock caused by the outflow colliding with the local interstellar medium. The detection at this position is at 6\(\sigma\). With the spatial resolution of the present observations, we cannot decide whether the bipolar outflow is composed of just one or several components (e.g., Beuther et al. 2002a). The SCUBA 450 \(\mu\text{m}\) map (see Fig. 2d) only shows a point source 6\(\prime\) to the north of UYSO 1, but the source is in between the two outflow lobes.

4. ANALYSIS

From the CO \((J = 3 \rightarrow 2)\) observations, the object mass and outflow parameters can be deduced. The mass derived from an integration of column densities can be compared to the virial mass. Line-wing analysis delivers physical parameters of the bipolar outflow, which are still dependent, however, on the unknown outflow inclination angle. The distance to UYSO 1,
assumed to be about the same as the distance to IRAS 07029–1215, was kinematically determined to be 1 kpc by Wouterloot & Brand (1989). However, while the distance to the illuminating star of S297, namely, HD 53623, was spectroscopically determined to be 2.2 kpc ± 25% by Neckel, Klare, & Sarcander (1980), Hipparcos measured a parallax for HD 53623 of \( \pi = 2.21 \pm 1.01 \) mas, corresponding to a distance of \( 450^{+380}_{-140} \) pc (Perryman 1997). Assuming the true distance is near the upper limit of this interval, we adopt a value of 1 kpc for the following mass estimates, in accordance with detailed studies of CMa R1 by Shevchenko et al. (1999) and de Zeeuw, Hoogerwerf, & de Bruijne (1999). The CO data analysis is depicted in Figure 2c, in direct comparison to 2MASS \( K_S \)-band data and the 450 \( \mu \)m continuum.

4.1. Temperature Determination

While the main beam temperatures \( T_{\text{mb}} \) of the highly optically thick CO lines already confine the kinetic temperature to the 40–50 K range, another estimate was obtained from \( H_2CO \) \( (J = 3_03 \rightarrow 2_02)/(J = 3_22 \rightarrow 2_21) \) data, following Mangum & Wootten (1993). Figure 5 shows the two \( H_2CO \) transitions for UYSO 1. The intensity ratio deduced from fitted Gaussians is 6, thus indicating a kinetic temperature of \( T = 40 \pm 5 \) K for a relatively wide range of densities.
4.2. Mass Determination

Assuming virial conditions, i.e., assuming that the observed line width is entirely due to motion in gravitational equilibrium, the total mass of the object can be estimated as described by Henning et al. (2000). Inside a sphere of 0.14 pc radius, corresponding to the 40% contour level (deconvolved with the 14′ beam) at 10 σ, and using the Gaussian fit result of $\Delta v = 3$ km s$^{-1}$, a virial mass of $M_{\text{vir}} = 180 M_\odot$ is obtained.

Following Henning et al. (2000), we derive hydrogen column densities from the CO ($J = 3 \rightarrow 2$) transition, assuming a relation of $N(H_2)$ (cm$^{-2}$) = $3 \times 10^{20} |T_{\text{D}}| dv$. A re-normalizing assumption is a conversion factor of CO ($J = 3 \rightarrow 2$) / CO ($J = 1 \rightarrow 0$) close to unity, as is frequently observed in massive-star-forming regions and can be explained by clumpy structure (Störzer et al. 2000). The gas mass of the cloud can then be determined as $M_{\text{gas}} = 2m_H\mu A(N(H_2))$, where $\mu = 1.36$ takes into account the interstellar mean molecular weight per H atom, and $A$ is the area occupied by the source.

Within the same area and to the same confidence level as the virial analysis, this leads to a different result for the cloud mass. With an average column density of $N(H_2) = 3.2 \times 10^{22}$ cm$^{-2}$, the resulting mass is $M_{\text{gas}} = 40 M_\odot$.

Another estimate for the total mass has been calculated from the continuum observations at $\lambda = 850$ μm. Assuming a dust temperature of $T_{\text{dust}} = 20$ K and optically thin conditions, $M_{\text{gas}} = F_p \kappa^2/(\rho_m(v)B(T_{\text{dust}}))(M_{\text{gas}}/M_{\text{dust}})$. Using an interpolated opacity of $\kappa = 1.97 \text{ cm}^2 \text{ g}^{-1}$ (thin ice mantles; Ossenkopf & Henning 1994), the result is $M_{\text{gas}} = 15 M_\odot$. The radius of the region taken into account here is 0.11 pc (at a distance of 1 kpc), slightly smaller than the 0.14 pc used here. In addition, the dust continuum emission traces only the high-density central regions, while the CO emission is collected along the line of sight throughout the low-density halo. Optically thick emission might further influence the estimate (see § 4.4). These two points at least partly explain the discrepancy.

Thus, the mass estimates based on line and dust emission are compatible when keeping in mind their respective limitations; they range between 15 and 40 $M_\odot$. The virial mass is much higher, which is certainly caused by an overestimation of line width due to optical thickness and turbulent motion in addition to the cloud not being in virial equilibrium.

4.3. Outflow Properties

The two line wings were analyzed to their respective 10% contour levels, corresponding to a 2 σ detection for the redshifted line wing and a 4 σ detection for the blueshifted line wing. The masses inside the two outflow lobes are again calculated by integration of H$_2$ column densities, resulting in $M_{\text{blue}} = 1.8 M_\odot$ and $M_{\text{red}} = 3.6 M_\odot$. The total outflow mass thus being $M_{\text{out}} = 5.4 M_\odot$.

The maximum projected velocities of the red and blue line wings are $v_{\text{proj},R} = 27.9$ km s$^{-1}$ and $v_{\text{proj},B} = 32.1$ km s$^{-1}$, respectively, the mean value being $v_{\text{proj}} = 30$ km s$^{-1}$. Together with the known distance and the outflow radial sizes, the dynamical timescale and the mass-loss rate can be obtained. With caution, the latter can be empirically converted to luminosity and spectral type, as well as the mass of an assumed central star. All values discussed hereafter are summarized in Table 2 for inclinations of $i = 10°$, 57.3° (the most probable value; Bontemps, Ward-Thompson, & André 1996), and 80°. When the apparent outflow velocity $v_{\text{proj}}$ and the apparent maximum outflow extension have been inclination-corrected to $v_{\text{out}}$ and $R_{\text{out}}$, the dynamical timescale can be calculated from $t_d(i) = R_{\text{out}}(i)/v_{\text{out}}(i)$. The resulting values range from $t_d(80°) \approx 500$ yr to $t_d(10°) \approx 1.5 \times 10^6$ yr. However, the timescale estimated in this way is not a good age indicator. Only a massive object can uphold mass outflow rates, $M(i) = M_{\text{out}}(i)/t_d(i)$, ranging from $M(10°) \approx 4 \times 10^{-4}$ $M_\odot$ yr$^{-1}$ to $M(80°) \approx 1 \times 10^{-2}$ $M_\odot$ yr$^{-1}$. They can be empirically transformed into the luminosity of the central object according to Shepherd & Churchwell (1996), Henning et al. (2000), or with a more comprehensive sample, Beuther et al. (2002c). Table 3 summarizes the resulting spectral types, masses, and luminosities (using data from Lang 1991). However, these properties of the central object can be better determined using the spectral energy distribution (SED; see § 4.4).

It may be interesting to consider the age of the neighboring H II region. Following Cernicharo et al. (1998), this age can be estimated (Whitworth et al. 1994). The size of S297, in the optical regime with a diameter of 7′ (Sharpless catalog), corresponds to a radius of only about 2.1 $\times 10^5$ AU, hence indicating that the nebula is rather young. Assuming a typical mean density of $10^3$ cm$^{-3}$ and the Lyman continuum flux for a B1 star from Thompson (1984), the resulting age is approximately $7 \times 10^5$ yr.

Regardless of the uncertainties in these age estimates, the H II region is likely to be older than UYSO 1. Possibly, this is an example of induced star formation, although this would need kinematic confirmation.

4.4. Spectral Energy Distribution

While the two measured continuum fluxes at 450 and 850 μm determined the cold dust emission, more data had to be obtained before the SED could be tentatively compared to the modeling results. Given the aim of determining the luminosity and mass of the central object, as well as obtaining a comparison to the mass determination, upper flux limits for short wavelengths helped to pin down the physical properties of the central object. As main support for the JCMT data, IRAS fluxes were used, determined at the position of UYSO 1 within beam sizes taken from the IRAS atlas maps. UYSO 1 is also unresolved on the IRAS HIRES maps. In addition, data for the definitely brighter nearby MSX point source, G225.4582−02.5939, and 2MASS detection limits set further constraints.

| TABLE 2 | UYSO 1 OUTFLOW PROPERTIES |
|---------|---------------------------|
| $i$ (deg) | $v_{\text{out}}$ (km s$^{-1}$) | $R_{\text{out}}$ (km) | $t_d$ (yr) | $M$ ($M_\odot$ yr$^{-1}$) |
|---------|---------------------------|
| 10........... | 30.5 | 1.4 $\times 10^{13}$ | 14600 | 3.7 $\times 10^{-4}$ |
| 57.3........... | 55.5 | 2.9 $\times 10^{12}$ | 1700 | 3.3 $\times 10^{-3}$ |
| 80........... | 172.7 | 2.4 $\times 10^{12}$ | 450 | 1.2 $\times 10^{-2}$ |

| TABLE 3 | OUTFLOW-INFERRED PROPERTIES OF ASSUMED CENTRAL STAR |
|---------|---------------------------|
| $i$ (deg) | $L$ ($L_\odot$) | Spectral Type | $M_{\text{star}}$ ($M_\odot$) |
|---------|---------------------------|
| 10........... | 10$^3$ | B4 | 6.5 |
| 57.3........... | 10$^4$ | B1 | 13 |
| 80........... | 10$^3$ | O9 | 19 |
Integrating the SED and using the flux limits at infrared wavelengths as the actual flux values leads to a luminosity of less than 1900 $L_{\odot}$, assuming spherical symmetry. A modified blackbody, to account for the dust optical depth, was fitted to the data: $S_\nu = B_\nu(T)\left[1 - \exp\left(-\kappa_\nu \tau\right)\right] \Delta \Omega$, with beam size $\Delta \Omega$ and dust opacities $\kappa_\nu \propto \nu^\beta$ (see, e.g., Hildebrand 1983). A good fit is obtained for $T = 45$ K and $\beta = 2$; however, fits with temperatures between 40 and 50 K agreed with the data within the uncertainties. With the aim of checking the consistency of existing data, the continuum emission was then modeled using the radiative transfer code developed by Manske, Henning, & Men’shchikov (1998). This is an accelerated version of the two-dimensional ray-tracing code developed for radiative transfer in disk configurations by Men’shchikov & Henning (1997). Due to insufficient parameter constraints, the code was used in its one-dimensional version only.

The limiting outer radius of the model could be estimated from the CO data to be $3.2 \times 10^4$ AU, taking the same area as for the mass estimation. Assuming an exponential for the density distribution of 2.0 with a dust-to-gas ratio of 1:150, the dust-to-gas ratio of silicates to carbon is 3:2. The inner model radius is determined by the dust sublimation temperature of 1500 K.

Figure 6 shows the results for an envelope mass of $M_{\text{env}} = 30 M_\odot$ and an assumed single central object in the B2.5 class. The optical depth at $\lambda = 500$ nm for the simulation runs is $\tau_{500 \mu m} \approx 6400$. Since the code becomes inaccurate for high optical depths, the computed SED is arbitrarily shown for $\tau \leq 1000$, corresponding to $\lambda > 10 \mu m$. At $\lambda = 850 \mu m$, the optical depth is $\tau_{850 \mu m} \approx 1$. Thus, the mass estimate from the dust emission in § 4.2 is a lower limit because of contribution from optically thick emission.

Both the simulation and the blackbody fit indicate the equivalent of an early B star as the central object. This finding is compatible with the result of the empirical outflow analysis for $i = 57.3^\circ$. The envelope mass in the simulation is compatible with the mass estimate from the CO \((J = 3 \rightarrow 2)\) data \((40 M_\odot)\), especially when keeping in mind that the modeled gas density only reaches $10^4$ cm$^{-3}$ at its outer radius, thus allowing for a slightly higher envelope mass when integrating further outward.

The authors are grateful to Remo Tilanus for his support during the JCMT observing run, as well as to R. Mauersberger for carrying out the Director’s Discretionary Time observations at the IRAM 30 m telescope in service mode. This research has made use of the SIMBAD database, operated at the Centre de Données Astronomiques de Strasbourg, France.

REFERENCES

Bernard, J. P., Dobashi, K., & Momose, M. 1999, A&A, 350, 197
Beuther, H., Schilke, P., Güeth, F., McCaughean, M., Anderssen, M., Sridharan, T. K., & Menten, K. M. 2002a, A&A, 387, 931
Beuther, H., Schilke, P., Menten, K. M., Motte, F., Sridharan, T. K., & Wyrowski, F. 2002b, A&A, 383, 892
Bonnell, I. A., Bate, M. R., & Zinnecker, H. 1998, MNRAS, 298, 93
Bontemps, S., Ward-Thompson, D., & Andrä, P. 1996, A&A, 314, 477
Cernicharo, J., et al. 1998, Science, 282, 462
Cernicharo, J., et al. 1998, Science, 282, 462
de Zeeuw, P. T., Hoogerwerf, R., & de Bruijne, J. H. J. 1999, AJ, 117, 354
Dorschner, J., Begemann, B., Henning, Th., Jäger, C., & Mutschke, H. 1995, A&A, 300, 503
Emerson, D. T. 1995, in ASP Conf. Ser. 75, Multi-fed Systems for Radio Telescopes, ed. D. T. Emerson & J. M. Payne (San Francisco: ASP)
Evans, N. J., II, Shirley, Y. L., Mueller, K. E., & Knez, C. 2002, in ASP Conf. Ser. 267, Hot Star Workshop III: The Earliest Phases of Massive Star Birth, ed. P. A. Crowther (San Francisco: ASP), 17
Fontani, F., et al. 2004, A&A, 414, 229
Henning, Th., Cesaroni, R., Walmsley, M., & Pfau, W. 1992, A&AS, 93, 525
Henning, Th., Schreyer, K., Launhardt, R., & Burkert, A. 2000, A&A, 353, 211
Hildebrand, R. H. 1983, QJRAS, 24, 267
Houk, N., & Smith-Moore, M. 1988, Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars, Vol. 4 (Ann Arbor: Univ. Michigan)
Hunter, T. R., Churchwell, E., Watson, C., Cox, P., Benford, D. J., & Roelfsema, P. R. 2000, AJ, 119, 2711
Hunter, T. R., Neugebauer, G., Benford, D. J., Matthews, K., Lis, D. C., Serabyn, E., & Phillips, T. G. 1998, ApJ, 493, L97
Jäger, C., Mutschke, H., Dorschner, J., & Henning, Th. 1998, A&A, 332, 291
Jimena, J., & Adams, F. C. 1996, ApJ, 462, 874
Lang, K. R. 1991, Astrophysical Data: Planets and Stars (Berlin: Springer)
Mangum, J. G., & Wootten, A. 1993, ApJS, 89, 123
Manske, Henning, Th., Schreyer, K., & Men’shchikov, A. B. 1998, A&A, 331, 52
Men’shchikov, A. B., & Henning, Th. 1997, A&A, 318, 879
Mueller, K. E., Shirley, Y. L., Evans, N. J., II, & Jacobson, H. R. 2002, ApJS, 143, 469
Neckel, T., Klare, G., & Sarcander, M. 1980, A&AS, 42, 251
Ossenkopf, V., & Henning, Th. 1994, A&A, 291, 943
Ossenkopf, V., & Henning, Th. 1994, A&A, 387, 931
Ossenkopf, V., & Henning, Th. 1994, A&A, 314, 477
Ossenkopf, V., & Henning, Th. 1994, A&A, 318, 879
Ossenkopf, V., & Henning, Th. 1994, A&A, 318, 879
Perryman, M. A. C. 1997, The Hipparcos and Tycho Star Catalogues, ESA SP-1200 (Noordwijk: ESA)
Posselt, B. 2003, M.S. thesis, Friedrich Schiller Univ., Jena
Shepherd, D. S., & Churchwell, E. 1996, ApJ, 472, 225
Shevchenko, V. S., Ezhkova, O. V., Ibrahimov, M. A., van den Ancker, M. E., & Tjin A Djie, H. R. E. 1999, MNRAS, 310, 210
Störzer, H., Zielinsky, M., Stutzki, J., & Sternberg, A. 2000, A&A, 358, 682
Thompson, R. I. 1984, ApJ, 283, 165
Whitworth, A. P., Bhattal, A. S., Chapman, S. J., Disney, M. J., & Turner, J. A. 1994, MNRAS, 268, 291
Wouterloot, J. G. A., & Brand, J. 1989, A&AS, 80, 149