THE MORPHOLOGIES OF ULTRACOMPACT H II REGIONS IN W49A AND SAGITTARIUS B2: THE PREVALENCE OF SHELLS AND A MODIFIED CLASSIFICATION SCHEME

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ABSTRACT

We have used Very Large Array (VLA) observations of the massive star-forming regions W49A and Sgr B2, obtained with resolutions from 270 to 004, to classify the morphologies of nearly 100 ultracompact (UC) H II regions. These high-resolution, multifrequency, multiconfiguration VLA observations motivate us to make several modifications of the existing morphological classification scheme for UC H II regions. In this work, we describe the modified morphology scheme and the criteria used in source classification. In particular, we drop the “core-halo” classification, add a “bipolar” classification, and change the shell classification to “shell-like.” We tally the percentage of each morphology found in the Sgr B2 and W49A regions and find broad agreement with the Galactic plane surveys in the distribution of morphologies for most types. However, we find that nearly a third of the sources in these regions are shell-like, which is a higher percentage by nearly a factor of 10 than found in the surveys of Galactic plane star-forming regions by Wood & Churchwell and Kurtz et al. This difference may be due to physical differences in the environments of these two extreme star-forming regions. Alternatively, differences in observational technique may be responsible.

Subject headings: H II regions — instrumentation: interferometers — ISM: individual (Sagittarius B2, W49N) — techniques: interferometric

1 INTRODUCTION

Wood & Churchwell (1989a, hereafter WC89) published the first survey of a new class of radio continuum sources in the Galaxy called ultracompact (UC) H II regions. These sources represent a subset of “standard” H II regions characterized by unusually small sizes (<0.01 pc) and high emission measures (>105 pc cm2), as derived from high angular resolution imaging observations with the Very Large Array (VLA) at 6 and 2 cm. WC89 systematically tabulated the physical properties of 75 sources found in regions at a variety of distances and placed them in five distinct morphological classes: cometary, shell, irregular, core-halo, and spherical/unresolved. The percentages of UC H II region morphologies found in this survey were 4% shell, 20% cometary, and the remainder (76%) irregular, spherical/unresolved, and core-halo sources. A subsequent survey of 59 additional regions by Kurtz et al. (1994, hereafter K94) extended these results and detected 75 more UC H II regions with a similar distribution of morphologies.

Wood & Churchwell (1989b) estimate the lifetime of an UC H II region (∼105 yr) from the comparison between the number of O stars within 2.5 kpc of the Sun (436; Conti et al. 1983) and the number of the 1646 embedded OB star candidates from the IRAS sample that one would expect to find within 2.5 kpc of the Sun if the sources were uniformly distributed in the Galactic disk (45). From this comparison, they determine that 10%–20% of the lifetime of an O star is spent in the UC H II region phase, in agreement with the estimate by Mezger & Smith (1976) that between 15% and 25% of all O stars are hidden by dust. Following the arguments of Wood & Churchwell (1989b), if there are approximately 1700 embedded OB stars in the Galactic disk, the surveys of WC89, K94, and the current work sample approximately 20% of the embedded OB stars in the Galactic disk.

In recent years, we have used the VLA to study radio continuum and radio recombination line emission from two of the Galaxy’s most luminous regions of massive star formation, Sgr B2 and W49A. Other luminous massive star-forming regions include the Arches, the Galactic center cluster, and NGC 3603. The observations of these “target-rich” regions, with resolutions from ∼2" to 004 (∼0.1–0.002 pc), have identified nearly 100 additional UC H II regions. The imaging observations of this new sample motivate us to make a modification to the UC H II region morphological classification scheme of WC89. In particular, we suggest the removal of the “core-halo” morphology, and we add a new “bipolar” designation. In this Letter, we describe these modifications to the classification scheme, the criteria used in the classification process, and we discuss the UC H II region morphologies found in Sgr B2 and W49A.

2 OBSERVATIONS

Our VLA radio continuum and recombination line observations of Sgr B2 and W49A have been presented and analyzed in a series of previous papers: 7 mm and 1.3 cm observations of Sgr B2 are discussed in De Pree et al. (1996, 1998) and Gaume et al. (1995); 7 mm, 1.3 cm, and 3.6 cm observations of W49A are discussed in De Pree et al. (1997, 2000) and Wilner et al. (2001); and further details of the high-resolution line and continuum imaging of Sgr B2 and W49A are given in De Pree et al. (2004) and C. G. De Pree et al. (2005, in preparation).

The VLA observations of these two massive star-forming regions have provided a large sample of UC H II regions suitable for morphological study. The sample has the following characteristics: (1) a total number of 97 sources, comparable to the WC89 and K94 surveys, (2) sensitivity to radio continuum structures on a wide range of size scales, (3) good emission measure sensitivity, resulting from long integration times on a large number of sources within just two fields of view, and

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(4) unambiguous relative size measurements within each of the two regions, as the sources within each region are associated and at the same distance.

3. RESULTS AND DISCUSSION

3.1. A Revised Morphological Scheme

We classified the morphologies of each of the UC H II regions detected in W49A and Sgr B2 using the highest angular resolution images available. Most of the sources can be placed in one of the morphological classes defined by WC89, but characteristics of the data prompt us to modify the WC89 classification scheme in three ways:

A new bipolar morphology.—There is a significant population of sources that exhibit a regular, previously uncategorized morphology, elongated along one axis. Churchwell (2002), in his recent review of UC H II regions, refers to a “bipolar” morphology, and we adopt that term here. The addition of the bipolar morphology is clearly needed to accommodate the presence of this class of sources.

Elimination of core-halo morphology.—With multiconfiguration VLA observations that are sensitive to emission at large size scales, it is apparent that many of the UC H II regions in Sgr B2 and W49A are associated with a faint shelf of radio emission (e.g., see the 3.6 cm images of W49A; De Pree et al. 1997). Recent studies of other, more isolated radio continuum sources in star-forming regions indicate that essentially all UC H II regions are associated with large-scale, diffuse emission, when observed with sufficient sensitivity (Kim & Koo 2003). Consequently, the “core-halo” designation is not a useful morphological discriminant in modern data sets of high quality. Instead, we prefer to concentrate on the morphology of the compact source within the extended emission.

Renaming “shell” morphology “shell-like.”—Many of the shell-like sources show considerable clumpiness and departures from circular symmetry in their brightness, while retaining a clearly identifiable and approximately circular edge-brightened structure. A slight revision in nomenclature to shell-like (SL) offers a better description of this morphology.

In summary, the revised UC H II region morphological types are (1) shell-like, (2) bipolar, (3) cometary, (4) spherical, (5) irregular, and (6) unresolved. The definitions of these morphologies (abbreviations in parenthesis) are as follows:

1. Shell-like refers to roughly circular sources that are not centrally peaked and are more than 50% complete around their perimeter, with no evidence of elongation away from the brightened edge. Figure 1a shows the SL source W49A/D.

2. Bipolar refers to sources with an axial ratio of at least 2 : 1. If radio recombination line data are available, then there may be evidence of a velocity gradient along the long axis. Figure 1b shows the bipolar source W49A/A1.

3. Cometary refers to sources with a bright edge and a tail that extends at least 1.5 times the width of the face. Figure 1c shows the cometary source Sgr B2 Main/I.

4. Spherical refers to sources that are symmetric, centrally brightened, resolved, and can be fit well by a two-dimensional Gaussian. Figure 1d shows the spherical source W49A/R.

5. Irregular refers to any spatially resolved source that does not fit in one of the specified categories. Figure 1e shows the irregular source Sgr B2 Main/F2.

6. Unresolved refers to sources that are symmetrical, centrally brightened, and can be fit well by a two-dimensional Gaussian that is comparable to the beam size. Figure 1f shows the unresolved source W49A/A2.

In Table 1 and Figure 1 are listed the percentage of sources found in each morphological class for the sources in the surveys of WC89 and

3.2. Bipolar Sources

The newly recognized class of bipolar UC H II regions is especially interesting. Kinematic evidence from radio recombination lines suggest that the bipolar morphology may be associated with the bipolar outflow phase of early stellar evolution. Several of the bipolar sources in W49A and Sgr B2 show velocity gradients along their long axis, or they show remarkably broad line widths (\( \Delta V_{\text{FWHM}} = 50 \text{ km s}^{-1} \)) that are not the result of pressure broadening (De Pree et al. 2004). The motions of the ionized gas, together with the elongation along one axis, suggest that ionized gas is flowing away from the young massive star at highly supersonic velocities. In addition, Garay et al. (2004) have observed a collimated stellar wind emanating from IRAS 16547 – 4247 and conclude that the thermal jet phenomenon may be common for high-mass as well as for low-mass stars.

3.3. Prevalence of Shells

Table 1 lists the percentage of sources found in each morphological class for the sources in the surveys of WC89 and
TABLE 1

| Morphology       | Sgr B2/W49 | WC89 | K94 |
|------------------|------------|------|-----|
| Shell-like       | 28         | 4*   | 1*  |
| Bipolar          | 8          |      |     |
| Cometary         | 14         | 20   | 16  |
| Core-halo        | 11         |      |     |
| Irregular        | 11         | 17   | 19  |
| Spherical        | 21         | 24   | 36  |
| Unresolved       | 18         | 19   | 19  |

* WC89 and K94 called this simply a shell morphology.
* WC89 and K94 did not include a bipolar morphology.
* WC89 and K94 included a core-halo morphology (16% of their survey sources); we eliminate this designation and instead concentrate on the morphology of the compact core (see text).

K94, and in the Sgr B2 and W49A sample. As indicated in Table 1, we find that 28% are shell-like, 8% are bipolar, 14% are cometary, and the remainder (50%) are spherical, irregular, or unresolved. In most respects, the findings of the three surveys are compatible within the uncertainties, which are generally dominated by counting statistics (and the subjective nature of the classification process). The frequencies of cometary, irregular, and unresolved morphologies are compatible. K94 find a marginally higher percentage of spherical sources than in the WC89 survey or the W49A and Sgr B2 sample. The bipolar morphology was not used by WC89 or K94, and we do not use the core-halo morphology; thus, we do not have percentages to compare for these two morphologies.

The only significant difference between the morphological classifications within Sgr B2 and W49A and those of WC89 and K94 is the much higher percentage of SL sources (28% vs. 3%), about an order-of-magnitude more frequent occurrence of sources in this class. The rarity of shell-like sources in the earlier surveys is surprising, considering the results of existing hydrodynamical models. Studies of the evolution of UC H II regions that examine the expansion of photoionization and stellar wind bubbles in dense molecular gas suggest that shell-like morphologies should be common (e.g., García-Segura & Franco 1996). The VLA observations of the Sgr B2 and W49A regions indicate that SL is the most commonly observed morphology in these regions, comprising approximately one-third of the sources.

There are several possible explanations for the striking difference in the percentage of shell sources found by WC89, K94, and the current work. Since the difference has clear statistical significance, it must result either from real physical differences in the populations of UC H II regions sampled or from selection effects related to differences in the observational strategies of the Galactic survey work (WC89 and K94) and the current work.

The star-forming environments represented by Sgr B2 and W49A are extreme and present differences from the typical Galactic plane star-forming environment. Since the WC89 and K94 surveys targeted isolated sources identified from IRAS 100 μm measurements, these surveys contained primarily isolated star-forming regions, rather than highly clustered, high source density regions like Sgr B2 and W49A. The difference in the percentage of shell-like sources could indicate that physical conditions in these highly clustered regions lead to a higher prevalence of this morphology. One possible explanation for the larger numbers of regular shell-like morphologies is that the molecular environments into which the UC H II regions expand are smoother, with fewer fluctuations in ambient pressure due to density, temperature, or turbulence that lead to the development of substantial asymmetries in the expansion phase.

The observing strategies and goals of WC89 and K94 differed from the current work. The WC89 and K94 surveys were comprised of short “snapshot” observations that targeted a large number of relatively isolated regions at the expense of the integration time on each region. The Sgr B2 and W49A surveys, by contrast, consist of observations of just two (crowded) pointings, which allowed for substantially longer integration times, better Fourier plane coverage, and higher sensitivity. Given data with lower sensitivity, many of the sources identified in Sgr B2 and W49A with SL morphology might have been classified as cometary or irregular. Likewise, sources classified by WC89 and K94 as cometary and irregular might (with better sensitivity and multiple VLA configurations) be classified as shell-like. Fey et al. (1992) show several examples of such changes in UC H II region morphological classification in light of data of higher quality and sensitivity to a broader range of spatial scales.

4. CONCLUSIONS

We have classified the morphologies of nearly 100 UC H II regions in the Sgr B2 and W49A regions. These results, taken together with previous work, suggest modifications to the UC H II region classification scheme, as follows:

1. VLA observations with sensitivity to a wide range of spatial scales detect faint extended radio continuum emission throughout massive star-forming regions, which makes nearly all compact sources appear with core-halo morphologies. As a result, we drop the “core-halo” designation from the UC H II region classification scheme.

2. A small percentage of UC H II regions have clear bipolar morphologies; in cases where recombination line data are available, the kinematics suggest directed ionized outflows originating from a young central source. This new “bipolar” morphological class is more common in W49A and Sgr B2 than the shell morphology was in the WC89 or K94 surveys.

3. We suggest that the shell classification should be modified to “shell-like” (or SL), in order to describe more accurately the appearance of these sources, many of which are clumpy or partially complete. The Sgr B2 and W49A regions exhibit ~10 times as many sources with shell-like morphologies as found in the WC89 or K94 surveys. Deep, multiconfiguration VLA observations of sources previously classified as cometary and irregular should determine whether or not this discrepancy is due to limitations of snapshot data.

The next step in this study is to utilize the morphological findings and derived physical parameters of the sources and their environments as inputs and constraints in hydrodynamic models of UC H II region evolution.

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