

## THE GALACTIC DISTRIBUTION OF OH/IR STARS

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Through systematic surveys (Johansson et al., Caswell and Haynes, Bowers, Baud, Caswell et al.) some 200 OH masers have been detected that are presumably associated with long period variables of very late spectral type ( $>M5$ ). Tentatively these stars will be called "OH/IR stars". They are characterized by their strong emission in the 1612 MHz line which shows a double peak due to the expansion of the shell surrounding these stars. The velocity difference  $\Delta V$  between the peaks is generally between 10 and 50 km s<sup>-1</sup>.

The distribution of these objects can be studied through a large fraction of the Galaxy. They show a strong concentration to the galactic plane, and a strong concentration to lower longitudes (cf. Figures 1 and 2). However, their longitudinal distribution reaches a maximum between  $\ell = 30^\circ$  and  $\ell = 15^\circ$ . The derivation of the (true) galactic distribution (Bowers, Baud) shows an increase in spatial density as  $R^{-4}$  for  $R > 4.5$  kpc, but a decrease in spatial density as  $R^{+7}$  for  $R < 4.5$  kpc. (Here  $R$  is the distance from the Galactic Centre). This decrease cannot be explained by observational selection. Its reality is supported by a discussion of the radial velocity distribution and by a more sensitive pilot survey made with the Effelsberg telescope. The derived density distribution in our Galaxy is similar to that of CO.

However, not all OH/IR stars belong to the *extreme* population I; about half of them have velocity dispersions, and presumably ages, comparable to early A-type stars. It is possible to separate them roughly into age groups by the velocity difference  $\Delta V$  between the two peaks in the spectra. Figure 3 indicates how the random motions decrease with increasing  $\Delta V$ . While among stars with  $\Delta V > 31$  km s<sup>-1</sup> there are only 2 with negative radial velocity and only 3 with  $V$  beyond the dashed curve the diagram for  $\Delta V \leq 26$  km s<sup>-1</sup> shows a great fraction outside these limits.

The variation in the velocity dispersion is also reflected in the **latitude distribution**: stars with small  $\Delta V$  show a wider distribution in  $z$  than those with large  $\Delta V$ , as indicated in the table:

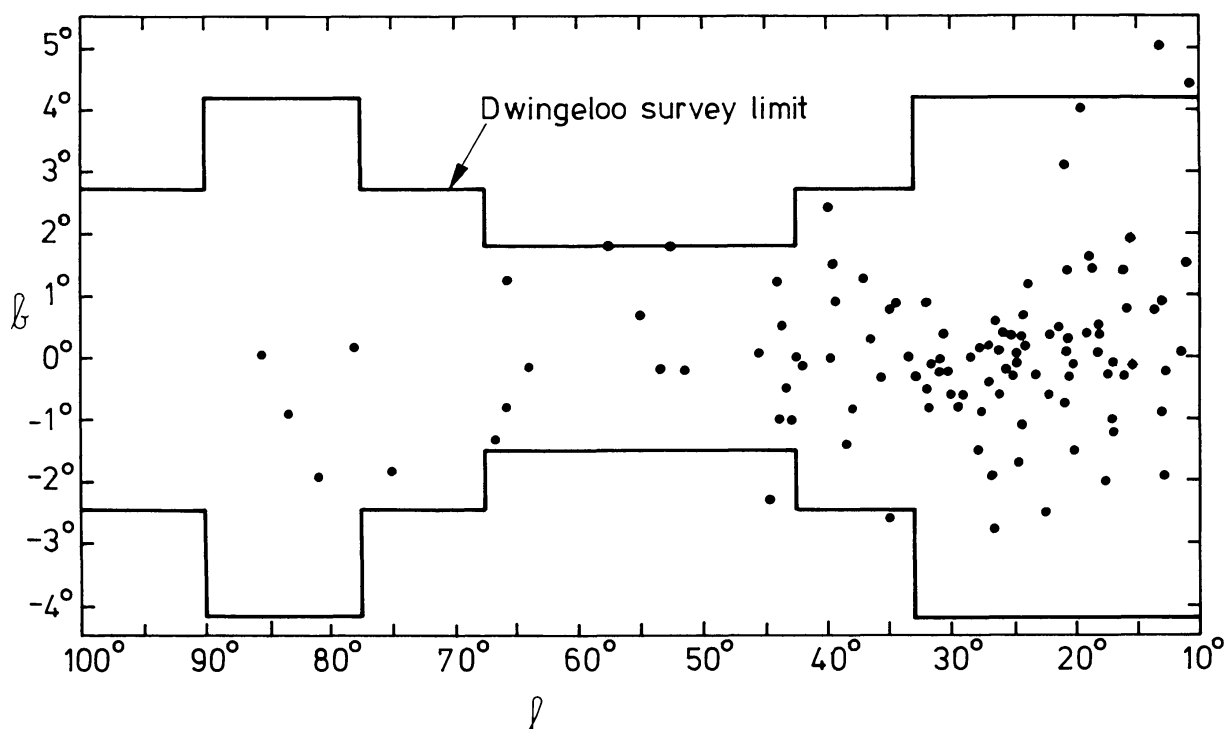


Figure 1. Distribution of representative sample of OH/IR sources with  $l > 10^\circ$  in galactic co-ordinates (Baud 1978).

| $\Delta V$<br>km s <sup>-1</sup> | $\langle  b  \rangle$<br>o | $\langle  z  \rangle$<br>pc | disp Z<br>km s <sup>-1</sup> | disp $\Pi$<br>km s <sup>-1</sup> | Age<br>y            |
|----------------------------------|----------------------------|-----------------------------|------------------------------|----------------------------------|---------------------|
| $\gtrsim 29$                     | 0.5                        | $\sim 60$                   | $\sim 8$                     | $\sim 10$                        | $\sim 10^7$         |
| $< 29$                           | 1.1                        | $\sim 140$                  | 10-15                        | $\sim 35$                        | $(1-2) \times 10^9$ |

For the small- $\Delta V$  stars the ratio of the velocity dispersions in the Z- and  $\Pi$ -directions appear to be less than 0.5 at  $R \sim 5$  kpc where most of the stars are situated. The quantity  $\Delta V$  appears to be correlated with the period (Dickinson *et al.* 1975).

The kinematic behaviour of the OH/IR stars appears to be similar to the behaviour of Mira-type stars, as analyzed by Feast (1963) but extended to much longer periods and sampled over a larger part of the Galaxy. Direct identification of a few OH/IR stars with oxygen-rich long period variables supports the view that OH/IR stars are a mixture of late type giants and supergiants - well evolved stars of masses  $\gtrsim 1.5 M_\odot$ , and ages  $\gtrsim 2 \times 10^9$  years.

The number of OH/IR stars increases strongly with decreasing luminosity  $L$ :  $N(L)dL \propto L^{-\alpha}dL$ , where  $\alpha$  is estimated to lie between 1.1 and 1.6, down to a cut-off at perhaps 1 Jy.

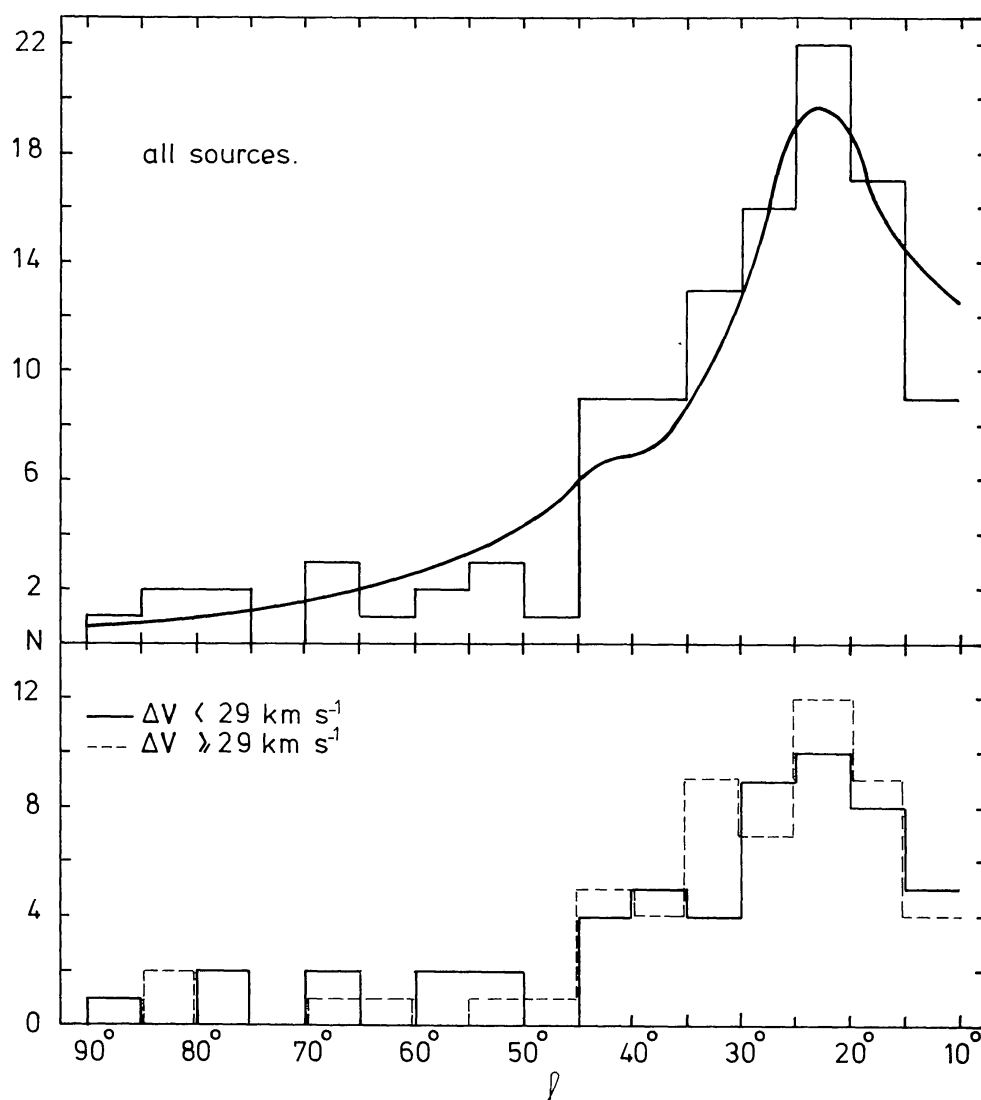


Figure 2. Longitude distribution between  $\ell = 10^\circ$  and  $90^\circ$  for all OH/IR sources (top) and for the sources with large and small  $\Delta V$  separately (bottom). The curve is the distribution predicted from a density model (Baud 1978).

The distribution of OH/IR stars near the galactic center is known very incompletely. A recent survey by Baud and others between  $358^\circ$  and  $14^\circ$  longitude has yielded 43 sources, mostly new. A new deep survey within  $1^\circ$  of the center is being made at Effelsberg. The density in the central region is generally low, but shows an increase within  $0.5^\circ$  from the center. For  $|\ell| < 5^\circ$  the radial velocities show a symmetric distribution around  $V = 0 \text{ km s}^{-1}$ , with an increasing dispersion for decreasing  $|\ell|$ . At  $\ell = 0^\circ$   $\langle v^2 \rangle^{1/2} \approx 130 \text{ km s}^{-1}$ . One object was found to have an exceptionally high velocity, of  $-343 \text{ km s}^{-1}$ ; it is situated at  $\ell = 0.3^\circ$ ,  $b = -0.2^\circ$  (Baud *et al.*). In the center region the kinematic

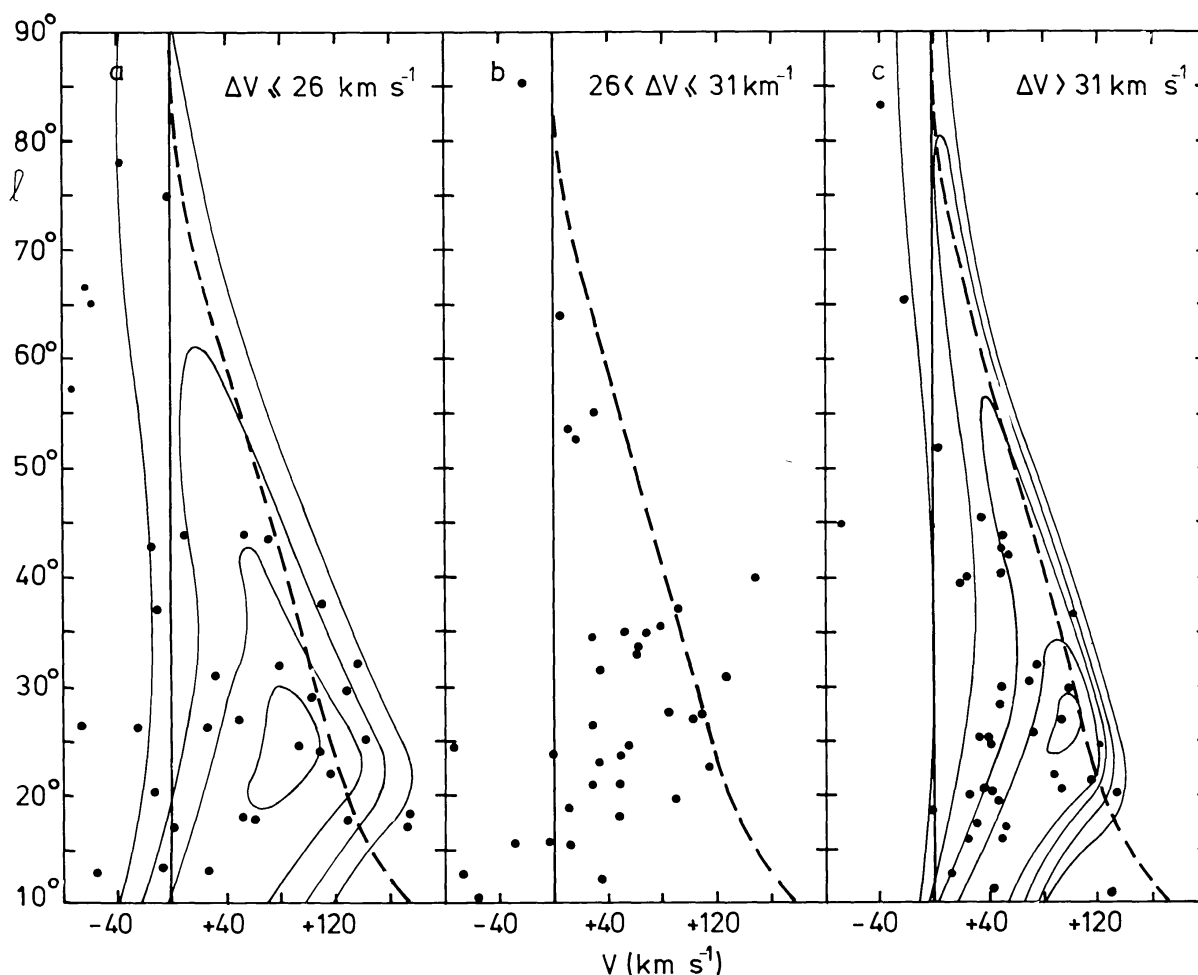


Figure 3. Radial-velocity distribution of OH/IR sources for three intervals of  $\Delta V$ , containing approximately equal numbers of sources. Thin drawn lines indicate model velocity distributions derived with dispersions of  $35 \text{ km s}^{-1}$  (a) and  $10 \text{ km s}^{-1}$  (c) of the velocity components  $\Pi$  in the direction towards and away from the galactic center. The dashed curve (Burton 1974) corresponds to the maximum radial velocities corresponding to pure rotation (Baud 1978).

properties of OH/IR stars of short and long periods are the same; differences are marginal.

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## DISCUSSION

**Bowers:** First, although I agree that the unidentified OH/IR stars with larger values of  $\Delta V$  may tend to be younger, this does not imply that stars with larger values of  $\Delta V$  ( $> 29 \text{ km s}^{-1}$ ) are necessarily supergiants. For example, there are identified OH Miras with  $\Delta V > 29 \text{ km s}^{-1}$ . From comparisons of the 1612-MHz profile structures of identified and unidentified sources, I have suggested that possibly  $\sim 10\%$  of the unidentified sources may actually be supergiant stars (Bowers, *Astr. Ap.* 64, 307; Bowers and Kerr, *Astr. J.* 83, 487). The good correlation in  $\ell, v$  space between the OH/IR stars with  $\Delta V > 29 \text{ km s}^{-1}$  and CO also does not imply that these stars are only  $\sim 10^7$  years old because it has been suggested that the massive molecular clouds are distributed in interarm regions and age estimates of a few times  $10^7$  to  $10^8$  years have been suggested for these clouds.

Second, if the period and  $\Delta V$  are correlated for the unidentified OH/IR stars, then the age of  $1\text{--}2 \times 10^9$  years, given for the stars with smaller  $\Delta V$  ( $\sim 20\text{--}29 \text{ km s}^{-1}$ ) is inconsistent with periods  $> 500$  days. The age-velocity dispersion relation used to estimate ages  $\sim 10^9$  year is only well known in the solar neighborhood, not at  $R \sim 5 \text{ kpc}$  where most of these unidentified sources are located. If, indeed, the periods of these stars are  $> 500$  days, it seems more likely that their ages do not exceed  $5 \times 10^8$  years, as indicated by Bowers (1978) based on a calibration of the period-age relation originally derived by Feast (*MNRAS* 125, 367). For this case I have suggested that most of the unidentified sources are a rare class ( $\sim 1\%$ ) of Mira variables which are not only relatively young but also relatively massive ( $\sim 2.5 M_{\odot}$ ), with extensive mass loss. Because of their rarity, it is no surprise that we find few of them in the solar neighborhood.

Third, I would like to make the general comment that frequency distributions as a function of galactic coordinates are strongly influenced by the sensitivity of the particular survey. Thus such diagrams must be considered cautiously when comparing results of different surveys. For example, both my survey and the Onsala survey showed that these sources are systematically below the galactic plane at  $l \simeq 25^\circ$  to  $30^\circ$ . I interpreted this to imply that the sources are systematically below the plane near the maximum in their radial density distribution. Although Baud's results do not show this deviation, his survey is of

higher sensitivity and thus is sampling a larger volume of the Galaxy in these directions. The deviation from the galactic plane for the mean  $z$ -height of these sources strengthens the result that they are concentrated in the 5-kpc annulus because such deviations are known for numerous other "young" species in this part of the Galaxy.

Finally, I would like to suggest that because these stars are likely progenitors of planetary nebulae, it seems probable that there is a subsystem of planetaries evolved from these stars with a density concentration at about 5 kpc from the galactic center. As with the unidentified OH/IR stars, however, such a subsystem should represent a very small percentage of planetary nebulae.

Oort: First point. The small average  $|z|$  for the stars indicates that they are young, not older than about  $10^8$  years. I agree that there is no reason to assume them to be still younger.

Second point. We do not know whether  $\Delta V$  is strongly correlated with period; wasn't this only a suggestion? The only criterion for estimating an age is the  $z$ -direction round  $R = 5$  kpc. It is true that Wielen's relation between age and  $\langle |z| \rangle$  is based on data at  $R \approx 8.5$ ; but Baud has estimated how the relation would change when going to  $R \approx 5$  kpc.

Third point. This was fully recognized by Baud, who made a special effort to take account of the differences in sensitivity and resolution of the different surveys. I do not see why the higher sensitivity of this survey could cause a systematic error at  $R = 5$  kpc.

As regard the planetary nebulae, I do not know of any sign of a concentration near  $R = 5$ . They are undoubtedly much older. Is there a good reason to think that the OH/IR stars would be their progenitors?

Burton: How do you measure from the data the quantity  $\text{disp } z$ ?

Oort: It was obtained firstly from a combination of the dispersion in  $b$  and  $z$  at the longitude of maximum density with a value of  $K_z$  estimated from a mass model of the galaxy, like Schmidt's model. It was independently inferred from the value of  $\text{disp } \pi$ , which may be estimated from  $\ell, v$  diagrams, in combination with an assumption concerning the ratio  $\text{disp } z / \text{disp } \pi$ .

Heiles: How does the large velocity dispersion in the galactic interior ( $R < \text{few kpc}$ ) arise?

Oort: It may well be of the same nature as the high velocities which are observed in the CO clouds; these reflect apparent expansion velocities in a tilted central disk.