The Arecibo Methanol Maser Galactic Plane Survey

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What is AMGPS?

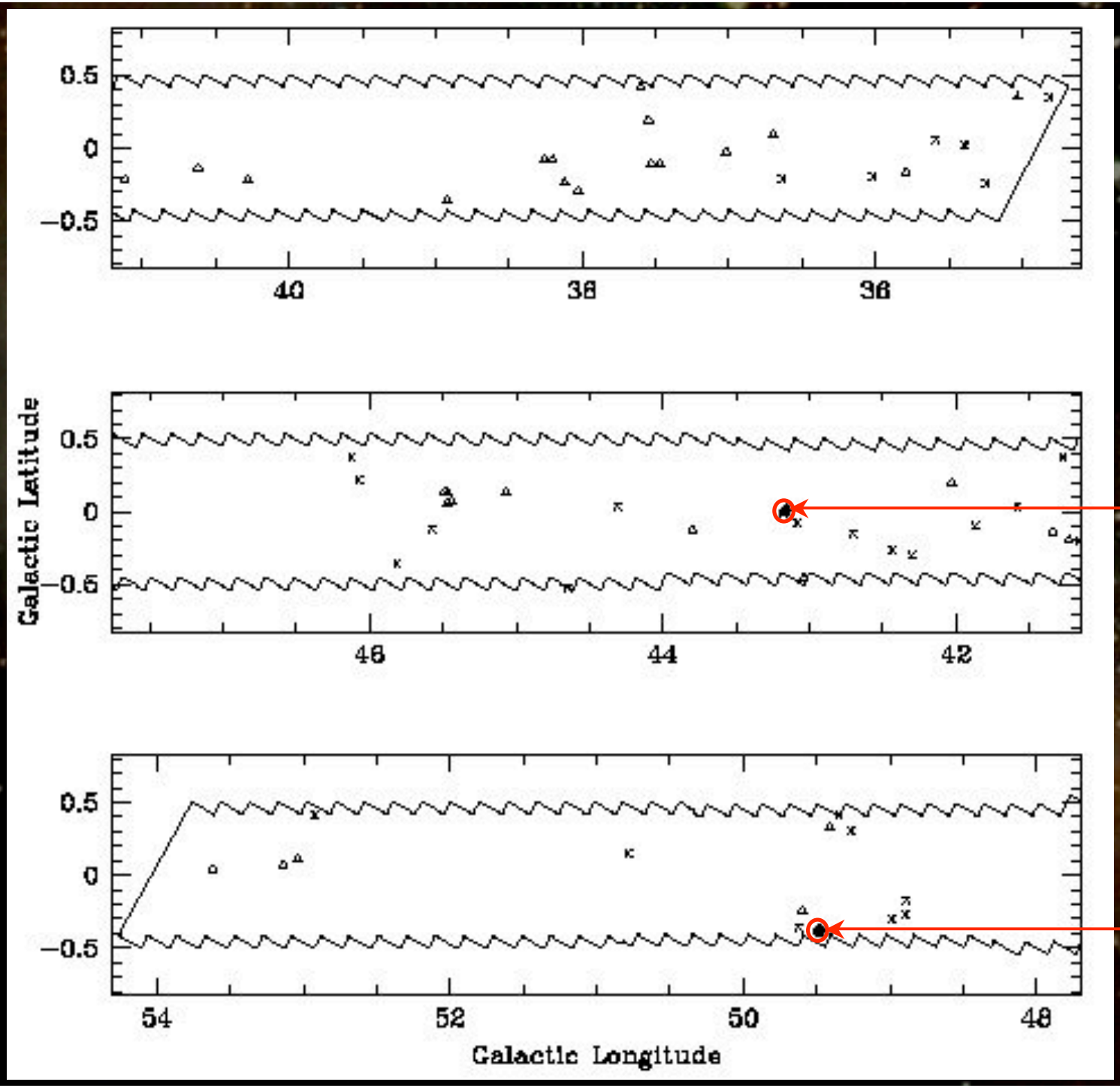
- The Arecibo Methanol Maser Galactic Plane Survey is a blind survey for 6.7 GHz methanol masers using the 305 m Arecibo radio telescope.
- The Arecibo radio telescope is equipped with the C-Band High receiver (6-8 GHz), which has a system temperature of 23-29 K and 28-34 K in two orthogonal linear polarizations.
- This coupled with the large gain of the telescope (SEFD ~ 5 Jy) makes it the most sensitive instrument to study 6.7 GHz methanol masers.

Survey Parameters

- The region surveyed nominally is $35° \leq l \leq 55°$, $|b| \leq 0.4°$.
- The bandwidth used covers the LSR velocity range of –70 to 110 km/s at 0.14 km/s resolution.
- The integration time was 0.5 sec with the telescope slewing at twice the sidereal rate (FWHM beamwidth ~ 40") .
- Candidate sources detected by automated matched filtering algorithms were re-observed with a 1 min position switched observation at a velocity resolution of 0.04 km/s.

Results

- AMGPS detected a total of 86 methanol masers, 48 of which are new detections.
- The peak flux density of the weakest and strongest sources are 0.11 Jy and 750 Jy respectively.
- Using simulations, we estimate the probability of detection of a source to be over 95% at the 3σ level.
  - Since the noise in a data cube is no larger than 0.09 Jy, we estimate the survey to be complete at 0.27 Jy.

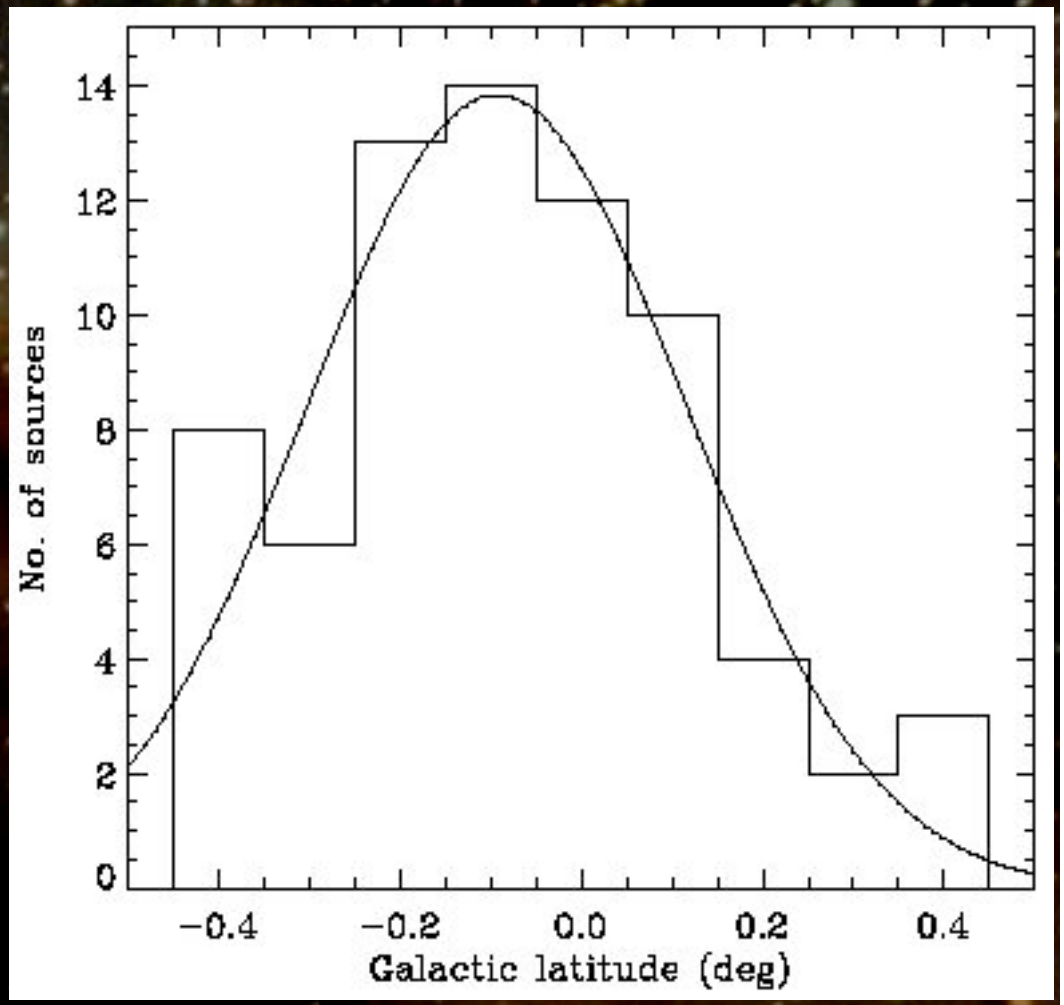

0.5
0
−0.5
40
38
36
Galactic Latitude
0.5
0
−0.5
46
44
42
W49N
0.5
0
−0.5
54
52
50
48
Galactic Longitude
W51

Distribution in the Galaxy

- In studying the distribution of methanol masers in the Galaxy, only sources that are stronger than 0.27 Jy, and which lie in the fully sampled region of the sky are selected.
  - These criteria give a sample of 72 methanol masers.

Latitude distribution

- A Gaussian fit to the latitude distribution has a mean of –0.09° and a FWHM of 0.49°.
- This is very similar to the distribution of all methanol masers detected prior to AMGPS.

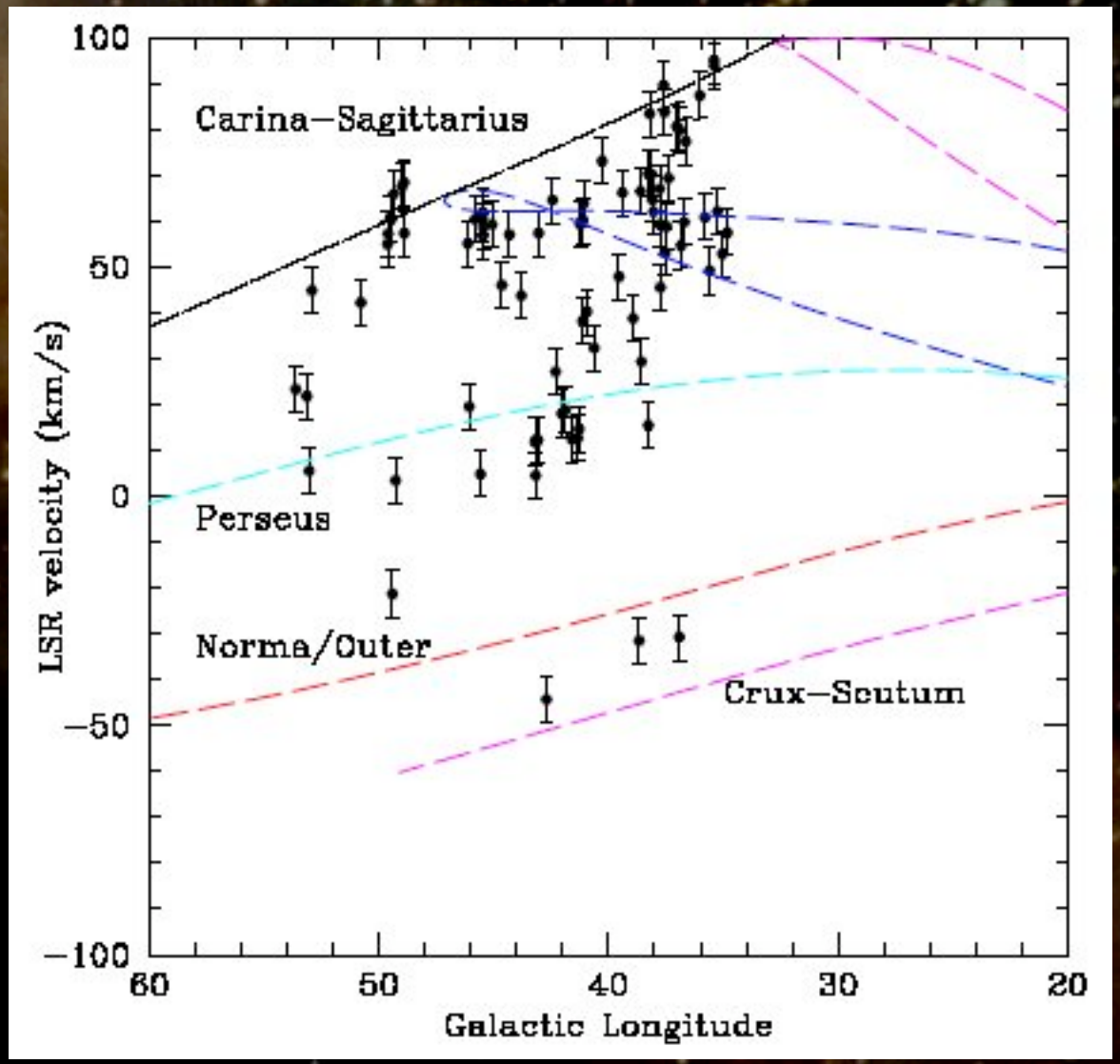


Latitude distribution

- It is to be noted that a significant number of methanol masers detected prior to AMGPS were from surveys targeted towards OH masers and HII regions selected from their IRAS colors.
- The width of the distribution is also similar to that of tracers of massive star formation such as ultra-compact HII regions.
- The close correspondence between the distribution of a blind sample with a sample tracing young massive stellar objects (MYSOs) suggests that methanol masers indeed trace massive star formation.

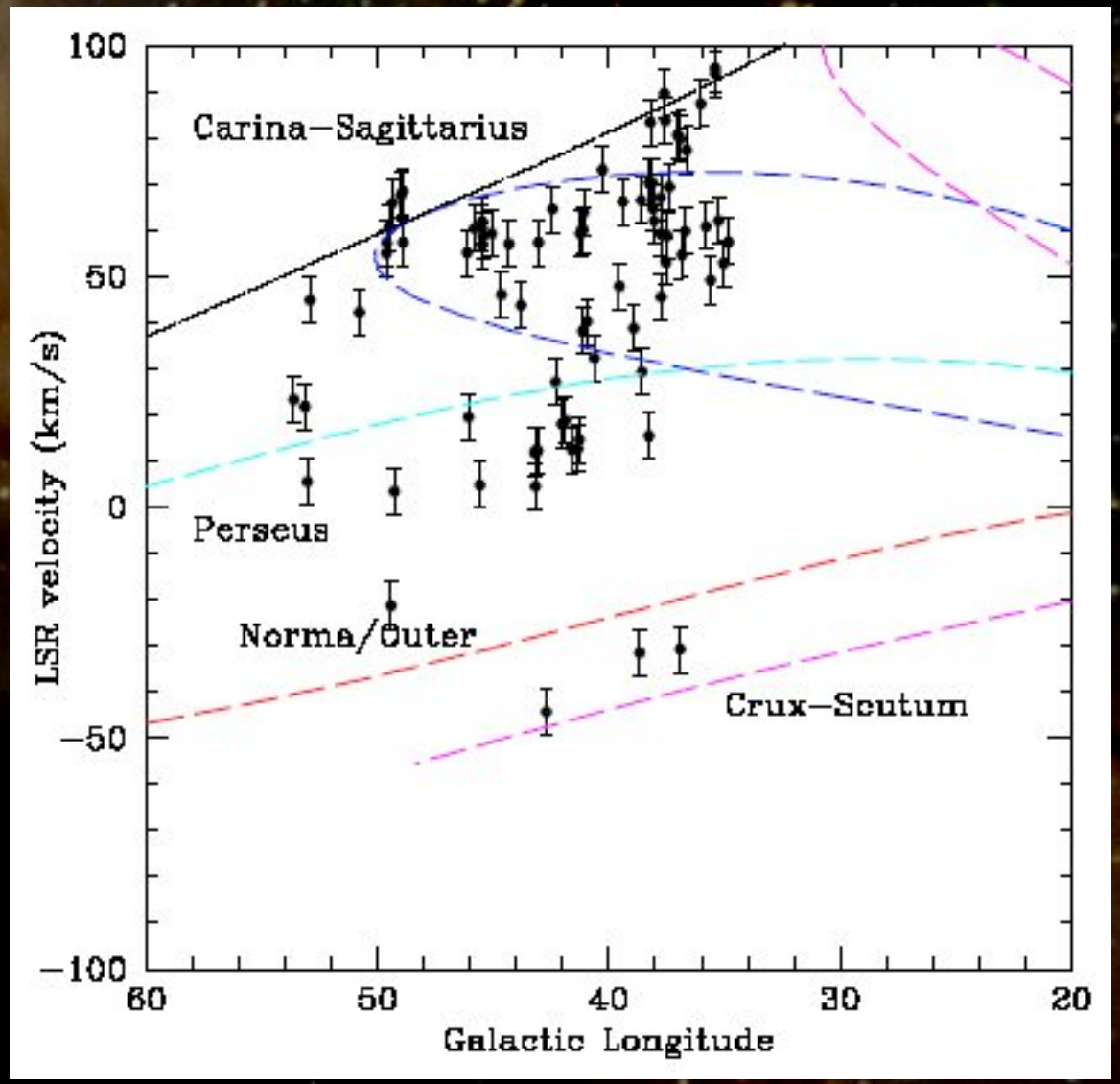
l-v diagram - I

- Spiral arm loci from NE2001 model of Cordes & Lazio (2002) and the Clemens (1985) rotation curve.



l-v diagram - II

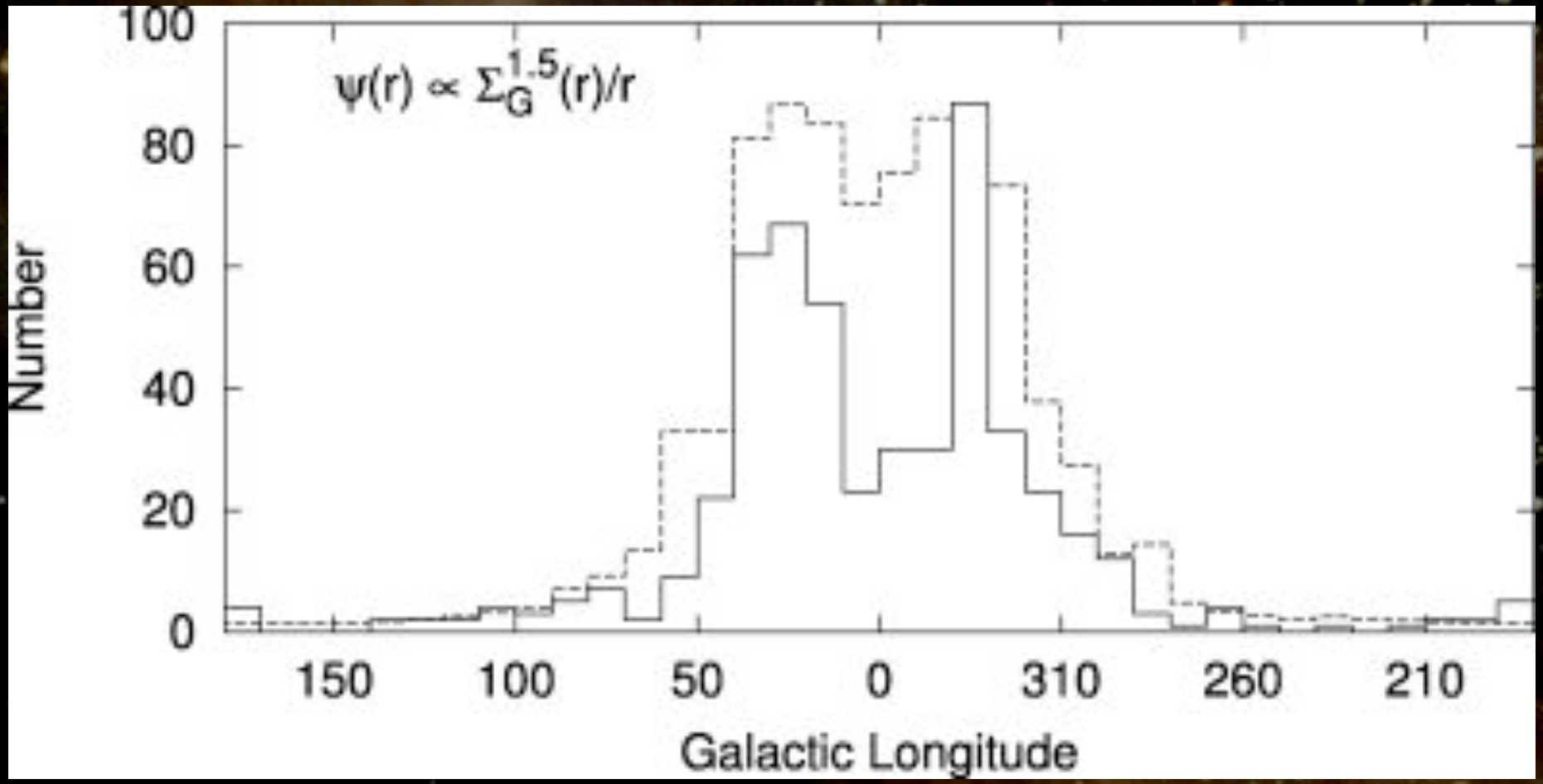
- Spiral arm loci from Vallee (1995) model and the Clemens (1985) rotation curve.
- The data are consistent with a tangent point of ~49.5° for the Carina-Sagittarius spiral arm, which also explains the decrease in source numbers for $l > 50°$



The total number of methanol masers

- The number of methanol masers in the Galaxy is estimated by van der Walt (2005).
- The steps followed are:
  - Estimate the number of stars in the mass range (m_1, m_2) from a star formation law $\psi(r)$ and an IMF.
  - Using a spiral arm model, one can then determine the relative distribution of massive stars as seen from the Sun as a function of Galactic longitude.
  - The distribution can then be scaled using the statistics of a survey to determine a *minimum* number of methanol masers in the Galaxy.
- The minimum number of methanol masers in the Galaxy is estimated to be around 850.

The total number of methanol masers



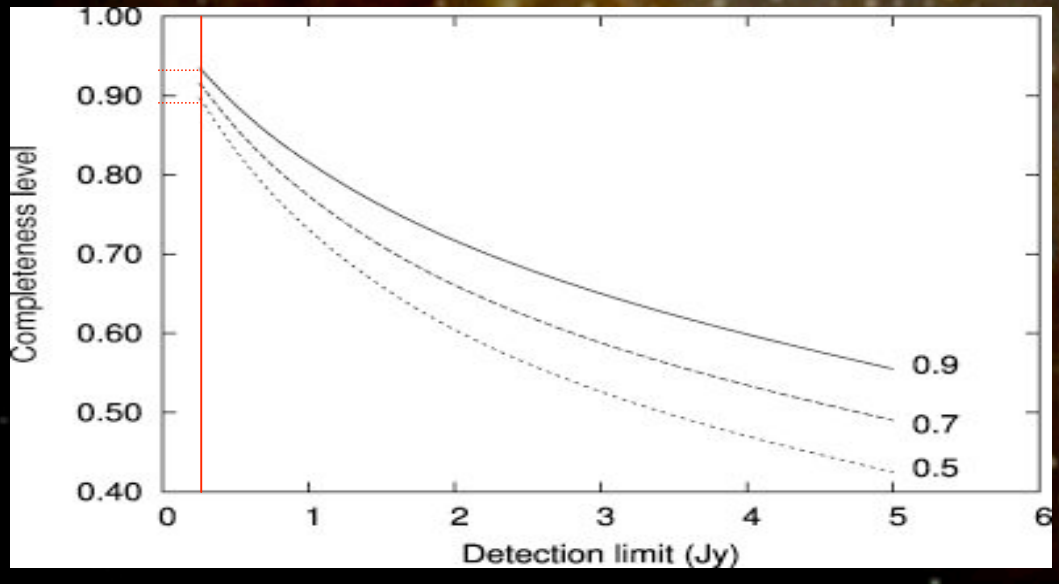
- The two peaks in first and fourth quadrants correspond to the molecular ring.

The total number of methanol masers

- Using the statistics of AMGPS which is an order of magnitude more sensitive than prior surveys, one can obtain a much better estimate for the number of methanol masers.
- Based on the number of methanol masers detected between longitudes of 40° and 50°, the minimum number of methanol masers brighter than 0.27 Jy is 1125.

The total number of methanol masers

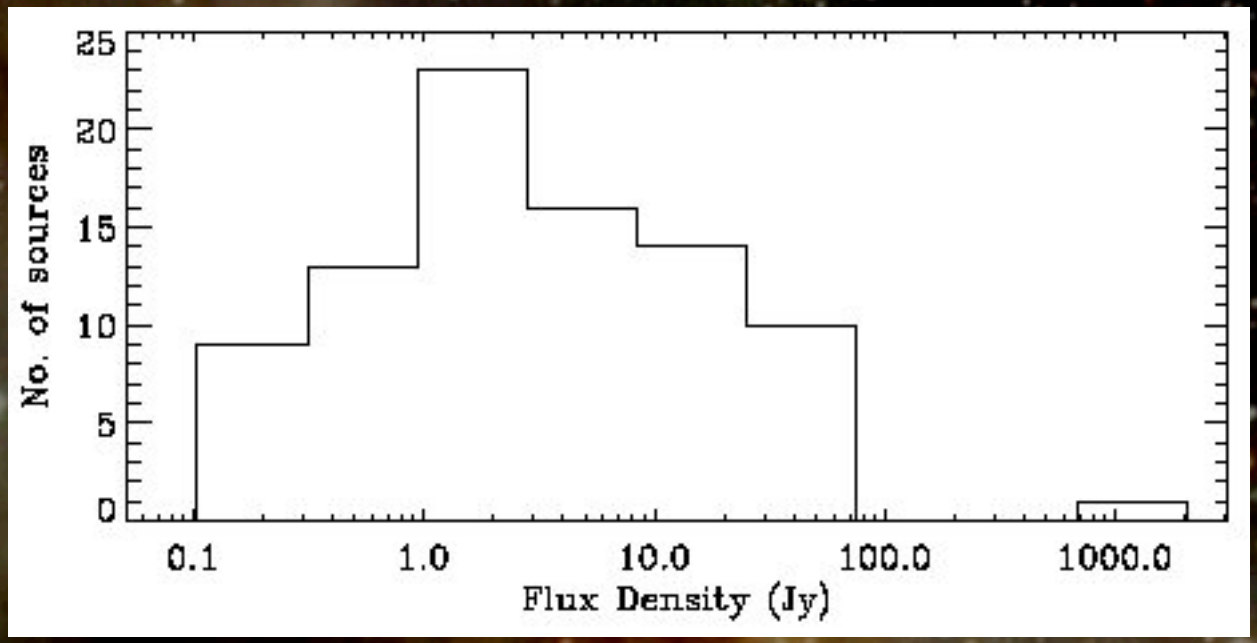
- van der Walt (2005) estimated the completeness of surveys as a function of flux density limit using simulations.
- The simulations require assigning distances to methanol masers, which is calculated kinematically, and is thus a function of the probability that a source is at the near or far distance.



The total number of methanol masers

- Based on the statistics between longitudes of 330° and 340°, the total number of methanol masers in the Galaxy is estimated to be 1200 ± 84.
- For a survey with a flux density limit of 0.27 Jy, the completeness is between 89% and 94%, which from the statistics of AMGPS gives the total number of methanol masers between 1197 and 1264.

The total number of methanol masers



- Note that only the last bin is affected by incompleteness.
- Thus the fall-off in the number of sources at low flux densities is probably real, and has implications on the sensitivity goal of future surveys.

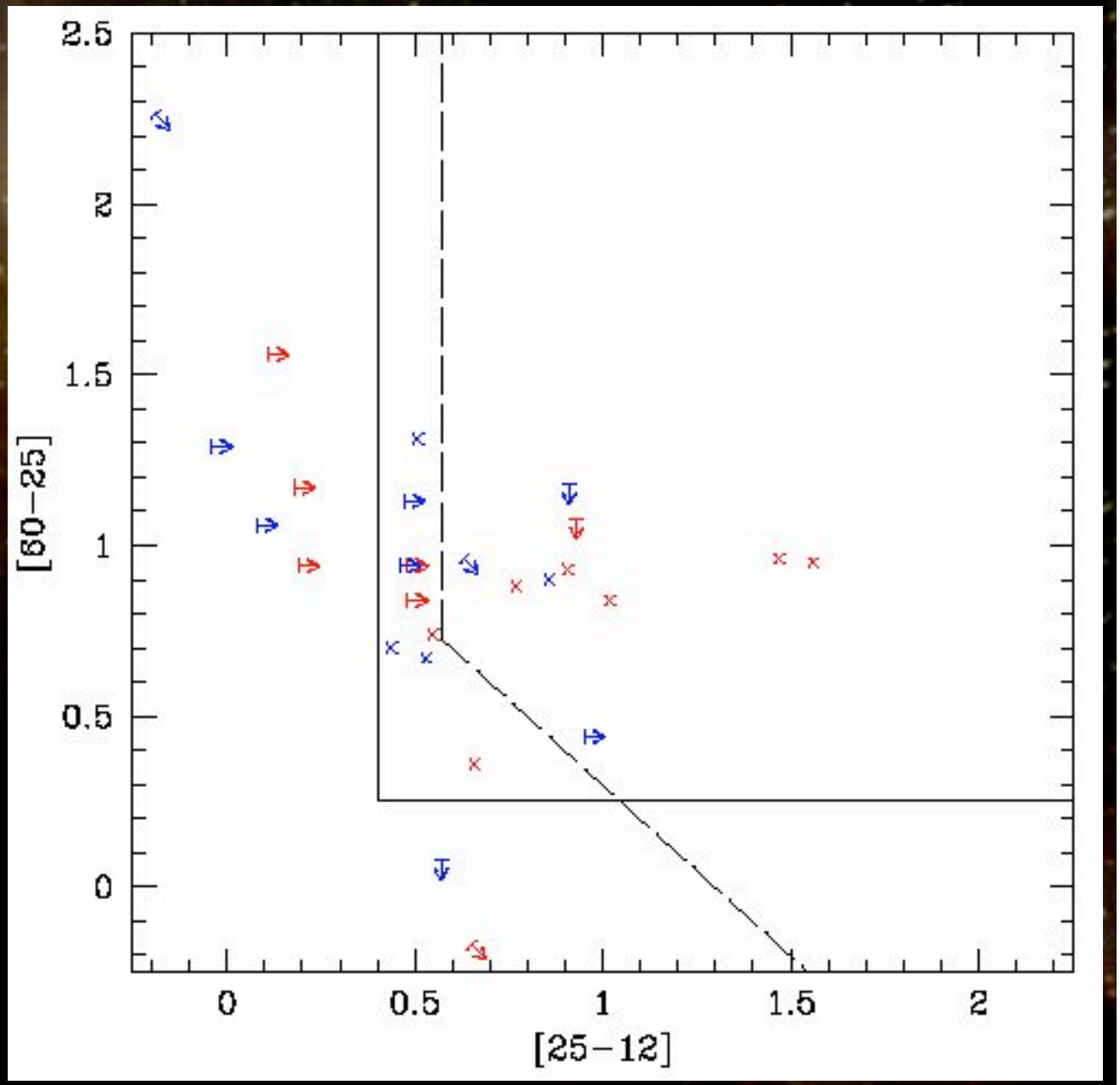
Multi-wavelength counterparts

- Due to the relatively large pointing error of the Arecibo telescope (7" rms), only a crude analysis of multi-wavelength counterparts can be done at the moment.
- Assuming that the pointing error has a Gaussian distribution (which is a good assumption although the pointing error is not exactly random), a search radius for counterparts is set to 23" (90% confidence level + 5" for associations).
- Sources in the W49N and W51 regions are excluded due to the high density of sources in these regions.

IRAS counterparts

- 26 out of 76 sources have IRAS point sources within 23".
- Out of these 26 sources, 5 and 6 sources respectively satisfy the Wood & Churchwell criteria, and Hughes & Macleod criteria for ultracompact HII regions.
- The message is that IRAS based searches for methanol masers will miss a significant number of methanol masers.
- Source confusion in the Galactic plane contributes to the small number of IRAS sources associated with methanol masers.

- Note that there is no segregation between new (blue) and old (red) detections.
- Thus, there is no evidence for IRAS sources associated with weak masers being different from those associated with bright sources.



MSX counterparts

- 41 out of 76 sources have MSX point sources within 23".
- 4 sources are associated clearly with MSX dark clouds, while the association is more uncertain for an additional 4 sources.
- Is the lack of counterparts for a significant fraction of the masers in part a sensitivity effect?
- It will be interesting to see how they correlate with the GLIMPSE catalog once better positions are obtained for the masers.

NVSS counterparts

- Only 7 sources have associated 1.4 GHz point sources (as seen in NVSS).
- The emission at long wavelengths is from thermal bremsstrahlung whose optical depth increases with wavelength.

$$\tau_\nu \sim \frac{0.08235}{\nu^{2.1} T_e^{1.35}} \int n_e^2 dl$$

- The lack of NVSS point sources associated with most methanol masers is most probably because any HII region associated with the maser is too compact and optically thick (high emission measure) at long wavelengths.

"Isolated" methanol masers

- Some methanol masers discovered in AMGPS have no tracer of star formation within 1' of the maser position.
- Are these masers tracing *very* early MYSOs, or are they associated with intermediate mass YSOs?
- The latter is unlikely (but not ruled out) based on a survey of 175 low and intermediate mass YSOs (Minier et al. 2003), who found no detections of methanol masers.

Conclusions

- The properties of methanol masers discovered in AMGPS are consistent with the picture that methanol masers are associated with early phases of massive star formation.
- There is no evidence for faint methanol masers having different properties compared to the bright ones.
- There is a significant population of methanol masers yet to be discovered, most of which reside in the Galactic ring.
- AMGPS discovered "isolated" methanol masers whose nature is not clear at the present moment.