The massive star forming complex W33 – Closer than expected?
Trigonometric parallax observations of water masers

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Massive Star Formation

Although massive stars have a strong impact on the Universe, their formation is still poorly understood.

Study star forming regions in detail

Observed quantity \( \text{distance } d \) \( \rightarrow \) Physical parameter

- Physical size \( \propto d \)
- Luminosity
- Mass \( \propto d^2 \)
- Spectral types
Kinematic Distances

Commonly used method to determine distances

Needed:

- Measurement of radial velocity from Doppler shifts
- Galactic circular rotation curve (e.g. from CO observations, Burton & Gordon 1978)

Problems:

- Near-far distance ambiguity
- Peculiar motions: local velocity deviations due to shocks, outflows...
**Trigonometric parallaxes**

**Definition**

Parallax: apparent movement of a source relative to a distant background due to the movement of the Earth around the Sun.

**Parallax signature with time**

![Diagram of parallax and angular offset over time](image)
Trigonometric parallaxes

- Parallax values in $\mu$as – mas range $\Rightarrow$ **high astrometric precision** needed
- Requires at least **one year of observations** to well sample the Right Ascension parallax signature
- Bonus: **Linear proper motions** of the source
- **Maser** sources used as targets for parallax observations
The Massive Star Forming Complex W33

Typical star forming regions along evolutionary sequence, from quiescent to highly active clouds

Dust emission at 870 µm (ATLASGAL survey, Schuller et al. 2009)
The Massive Star Forming Complex W33

Peculiar kinematic structure: two different velocity components from W33 A to W33 Main at 36 km/s and in W33 B at 58 km/s

- One connected star forming complex with large internal motions at a near-kinematic distance of 3.7 kpc
- Superposition of several independent star forming regions arranged along the line of sight
The Massive Star Forming Complex W33

Physical parameters

Size 16 pc
Luminosity $L \sim 2 \cdot 10^6 \, L_\odot$ (Stier et al. 1984)
Mass $M \sim (0.2–2) \cdot 10^6 \, M_\odot$ (Goldsmith & Mao 1983)
Spectral types O6 – B0 (Haschick & Ho 1983)
BeSSeL survey

Observations part of BeSSeL survey

BeSSeL survey will determine accurate distances and proper motions of up to 400 high mass star forming regions and reliably locate the spiral arms in the Milky Way.
Observations

- Observation of four water masers in W33 at 22 GHz with the VLBA
- Eight epochs from 2010 October to 2012 January total observing time per epoch: $\sim 7$ h
- Observation of two background quasars as position reference
- Masers in W33 Main and W33 A phase-referenced to maser in W33 B, yielding relative parallaxes
Parallax Determination

- Images of water masers and background quasars for each epoch
- Absolute position of strongest maser spot in W33 B relative to both background quasars
- Fit of positions with a sinusoidal parallax signature + linear proper motions in each coordinate
- Absolute positions of the strongest maser spots in W33 A and W33 Main masers = relative position to W33 B + position of W33 B relative to both background quasars
Parallax Determination

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Graph showing data points with color coding for velocity.
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Parallax of W33 B

![Graphs showing parallax offsets over epochs](image-url)
Parallax of W33 B

Parallax \( \pi = (0.416 \pm 0.028) \) mas
Parallaxes of W33 A and W33 Main
Parallaxes of W33 A and W33 Main

\[ \pi = (0.343 \pm 0.037) \, \text{mas} \]
Parallaxes of W33 A and W33 Main

$\pi = (0.343 \pm 0.037) \text{ mas}$

$\pi = (0.408 \pm 0.025) \text{ mas}$

(W33 Main)

(W33 A)

(W33 A)
**Parallaxes of W33 A and W33 Main**

- $\pi = (0.343 \pm 0.037) \text{ mas}$
- $\pi = (0.408 \pm 0.025) \text{ mas}$
- $\pi = (0.396 \pm 0.032) \text{ mas}$
Distance to W33 – Summary

- All parallaxes consistent with parallax of 0.416 mas within 2 $\sigma$
  $\Rightarrow$ Distance $d$ to W33 = 2.4 kpc ($\frac{2}{3}$ of near-kinematic distance)
  $\Rightarrow$ W33 is one connected star forming complex!

- W33 located in the **Scutum spiral arm**

- Physical parameters **overestimated**

  **Revised values**

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Outlook - Multi-wavelength observations of W33

- **Submillimeter Array**: 8 GHz spectra of five clouds in W33 at 230 GHz
- **Atacama Pathfinder Experiment Telescope**: 8 GHz spectra of six clouds in W33 at 280 GHz
- **Karl G. Jansky Very Large Array**: Radio continuum and H$_2$O, CH$_3$OH, and NH$_3$ spectral line observations of W33 Main at 22 GHz
- **IRAM 30 m Telescope**: $^{13}$CO and C$^{18}$O observations of W33 Main at 220 GHz
- Additional: Spitzer (3.6 – 24 µm), Herschel (60–600 µm), ATLASGAL (870 µm), and 330 MHz maps
THANK YOU FOR YOUR ATTENTION!
Internal Motions in W33

- Determination of proper motions for all maser spots in each W33 maser
- Average of proper motions $\Rightarrow$ one proper motion per maser
- Subtraction of overall motion of W33 complex $\Rightarrow$ internal motions of W33 clouds
Internal Motions in W33

[Diagram showing internal motions in W33 with a scale of 1 mas/yr and Jy/beam, indicating the positions of W33 A and W33 B.]