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

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

Different theories:

- **Accretion scenario** (e.g. Keto & Zhang 2010)
  - Upscaled version of low mass star formation

- **Coalescence model** (e.g. Bonnell et al. 1998)
  - Collisions and merger of protostars

- **Competitive accretion** (e.g. Bonnell et al. 2004)
  - Accretion in clustered environment
Why is the determination of accurate distances important?

Lots of physical parameters are dependent on distance $d$.

- Physical size $\propto d$
- Luminosity $\propto d^2$
- Mass $\propto d^2$
- Spectral types (number of photons) $\propto d^2$
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...
**Definition**

Parallax: apparent movement of a source relative to a distant background due to the movement of the Earth around the Sun.
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 (Declination signature much smaller)
- Bonus: Linear proper motions of the source
- Strong source needed that is detected in massive star forming regions: Masers
The Massive Star Forming Complex W33

Typical star forming regions

$L \sim 2 \cdot 10^6 \, L_{\odot}$ and $M \sim (0.2–2) \cdot 10^6 \, M_{\odot}$
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

W33 is either one connected star forming complex with large internal motions at a near kinematic distance of 3.7 kpc (corresponding to the radial velocity of 36 km/s), or a superposition of several independent star forming regions arranged along the line of sight.

Goal: Determine trigonometric parallaxes to water masers in W33
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

- Positions of water maser spots and background quasars from Gaussian brightness distribution fits for each epoch
- Absolute position of strongest maser spot in W33 B relative to both background quasars
- 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
- Fit of positions with a sinusoidal parallax signature + linear proper motions in each coordinate
Parallax Determination

- Positions of ground quasar distribution fits
- Absolute position of strongest maser spot in W33 B relative to both background quasars
- 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
- Fit of positions with a sinusoidal parallax signature + linear proper motions in each coordinate

![Graph showing positions and velocities](image)
Parallax Determination

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- Fit of positions with a sinusoidal parallax signature + linear proper motions in each coordinate
Parallax of W33 B

![Graph showing offset over epochs from 2011 to 2012.](image-url)
Parallax of W33 B

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

\[ \pi = (0.439 \pm 0.045) \text{ mas} \]
Parallaxes of W33 A and W33 Main

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\[ \pi = (0.360 \pm 0.026) \text{ mas} \]
Parallaxes of W33 A and W33 Main

\[ \pi = (0.439 \pm 0.045) \text{ mas} \]

\[ \pi = (0.360 \pm 0.026) \text{ mas} \]

\[ \pi = (0.409 \pm 0.050) \text{ mas} \]
Distance to W33

- All parallaxes consistent with parallax of 0.416 mas within 2 σ
  - Distance $d$ to W33 $= 2.4$ kpc ($\frac{2}{3}$ of near-kinematic distance)
  - Luminosity and Mass overestimated by factor of more than two
  - Revised values: $L \sim 8 \cdot 10^5 \, L_{\odot}$ and $M \sim (0.8–8) \cdot 10^5 \, M_{\odot}$
  - W33 is one connected star forming complex!

- W33 associated with a bright CO cloud at the same latitude with a mean velocity of 34.6 km/s, locating the star forming complex in the Scutum spiral arm
Proper Motion Determination in W33 B

- Positions of all maser spots, detected in at least three consecutive epochs, fitted with parallax and proper motion model, setting parallax parameter to 0.416 mas
- All proper motions fitted with model for expanding outflows, with position and proper motion of central driving source as free parameters

$$\mu_{*,x} = -8 \text{ km/s}, \mu_{*,y} = -26 \text{ km/s}$$
Internal Motions in W33

[Diagram showing internal motions in W33 with markers for W33 A and W33 B.]
Summary

- Successful determination of relative parallaxes in one star forming complex
- Trigonometric parallax distance to W33: 2.4 kpc, locating complex in Scutum spiral arm
- Clouds in W33 at same distance ⇒ W33 = one connected star forming complex
- Internal motions suggest that the complex will drift apart with time.