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.

Different theories:

Accretion scenario (e.g. Keto & Zhang 2010)	Coalescence model (e.g. Bonnell et al. 1998)	Competitive accretion (e.g. Bonnell et al. 2004)
Upscaled version of low mass star formation	Collisions and merger of protostars	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)

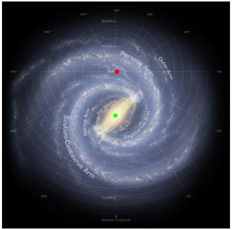


Illustration Credit: Robert Hurt, IPAC

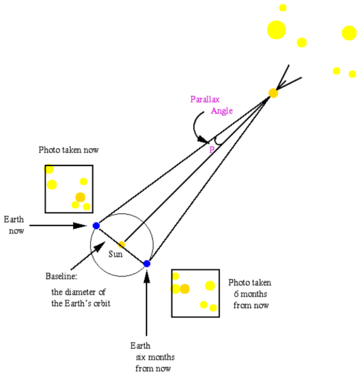
Problems:

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

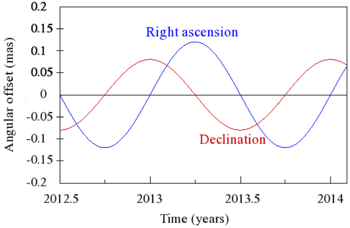
Trigonometric parallaxes

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

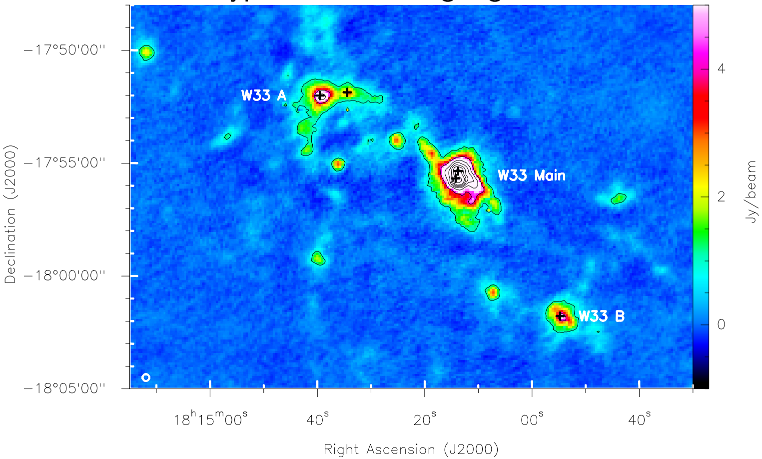


Trigonometric parallaxes

- Parallax values in μas – 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

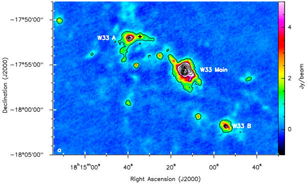
The Massive Star Forming Complex W33

Typical star forming regions



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

The Massive Star Forming Complex W33

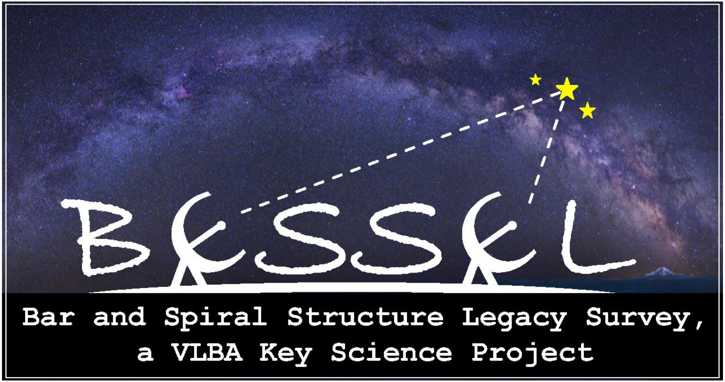


Peculiar kinematic structure: two different velocity components from W33 A to W33 Main at 36 km/s and in W33 B at 58 km/s

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

BeSSeL survey



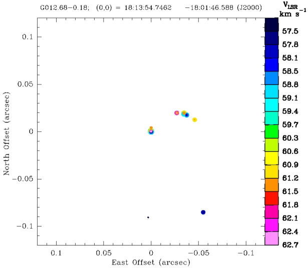
- Observations part of BeSSeL survey
- BeSSeL survey will determine accurate distances and proper motions of up to 400 high mass star forming regions and reliably locate the spiral arms in the Milky Way

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

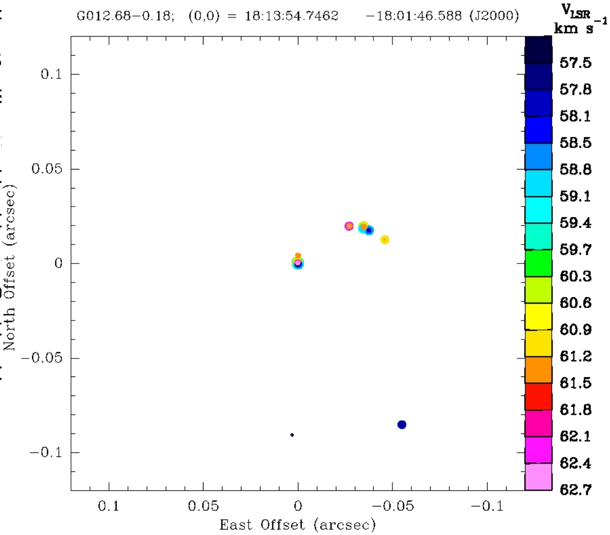
Parallax Determination

- 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 quas tribution fits
- Absolute po W33 B relat
- Absolute pc spots in W3 = relative p W33 B relat
- Fit of positic nature + lin dinate



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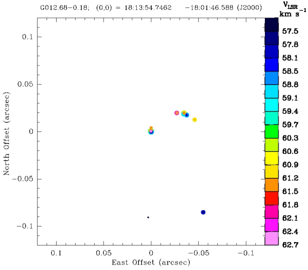
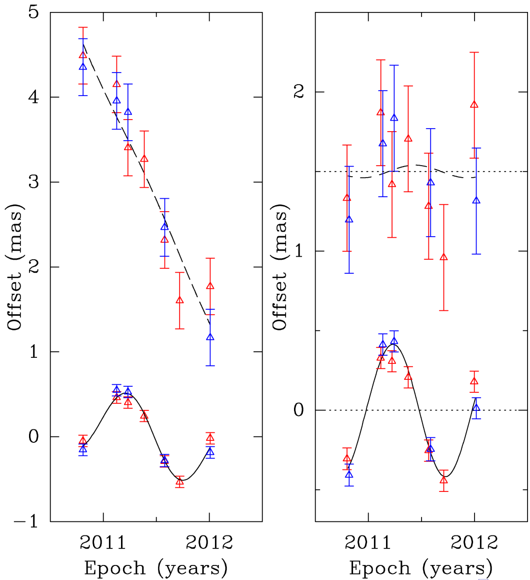
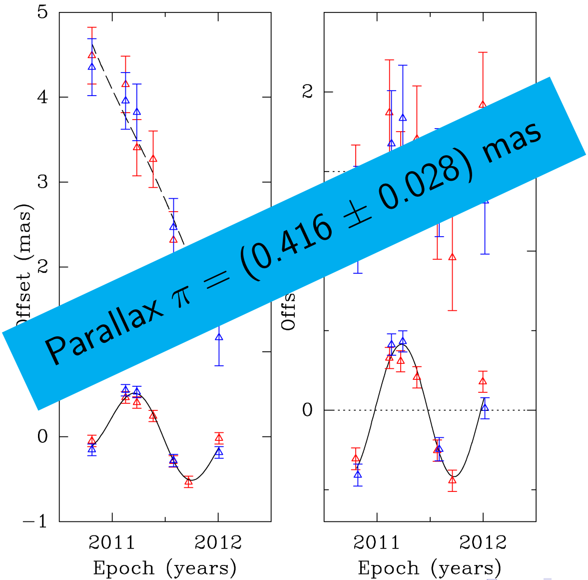


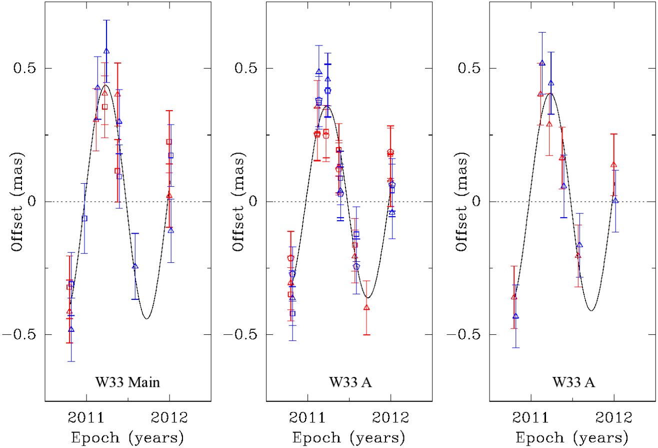
Parallax of W33 B



Parallax of W33 B



Parallaxes of W33 A and W33 Main



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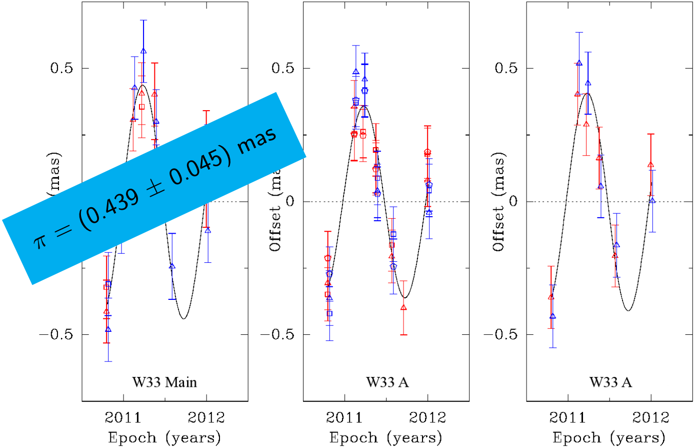

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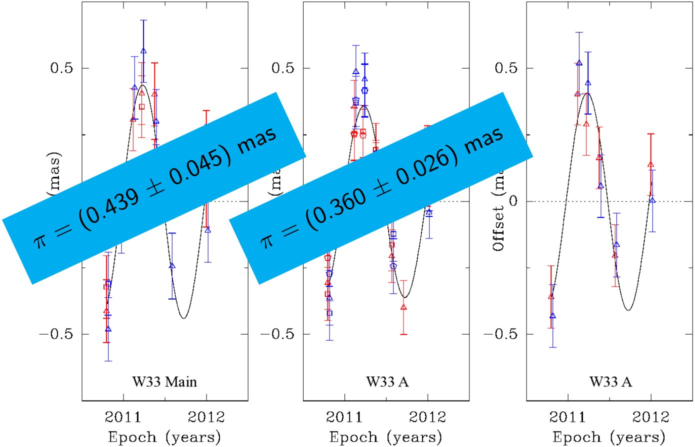
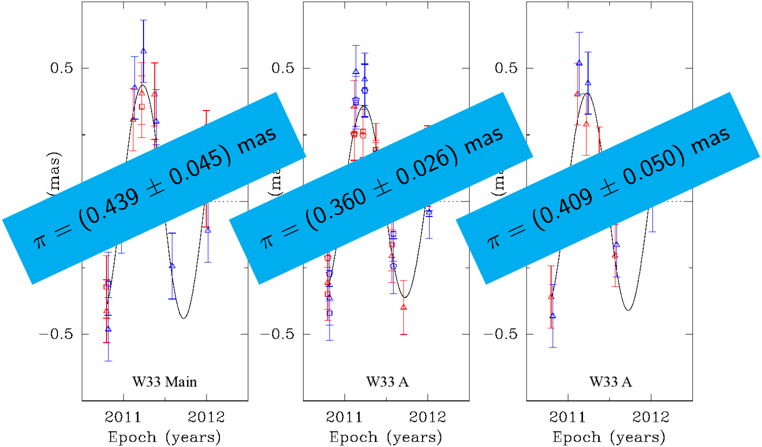


Parallaxes of W33 A and W33 Main



Distance to W33

- All parallaxes consistent with parallax of 0.416 mas within 2 σ

  $\Rightarrow$ Distance d to W33 = 2.4 kpc ($\frac{2}{3}$ of near-kinematic distance)

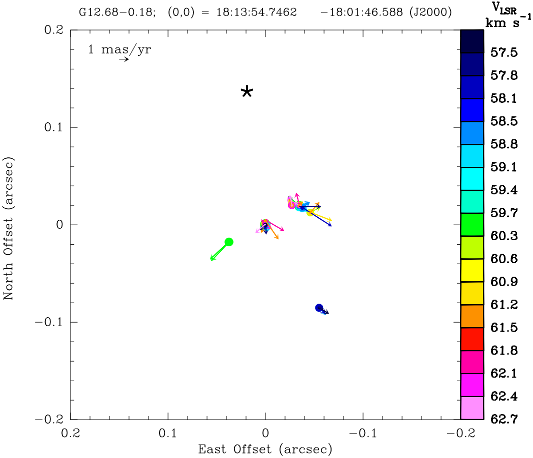
  $\Rightarrow$ Luminosity and Mass overestimated by factor of more than two
  Revised values: L $\sim 8{\cdot}10^5$ $L_\odot$ and M $\sim (0.8\text{–}8){\cdot}10^5$ $M_\odot$

  $\Rightarrow$ 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

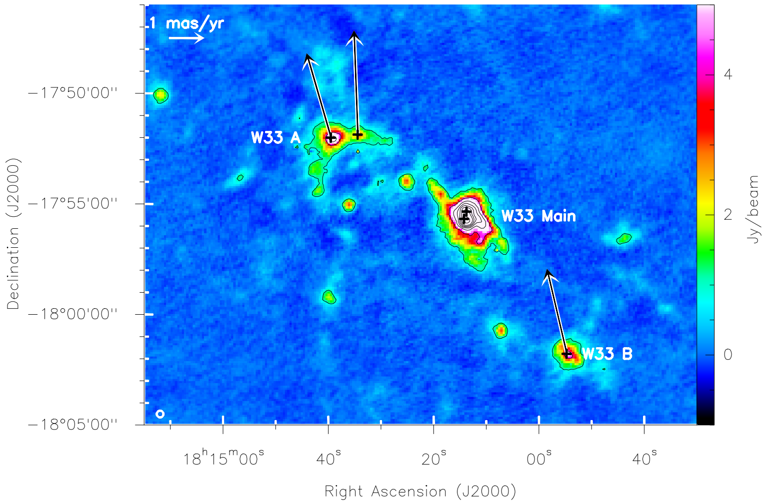
Proper Motion Determination in W33 B

- 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 km/s, $\mu_{*,y}$ = -26 km/s

Internal Motions in W33



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 $\Rightarrow$ W33 $=$ one connected star forming complex
- Internal motions suggest that the complex will drift apart with time.