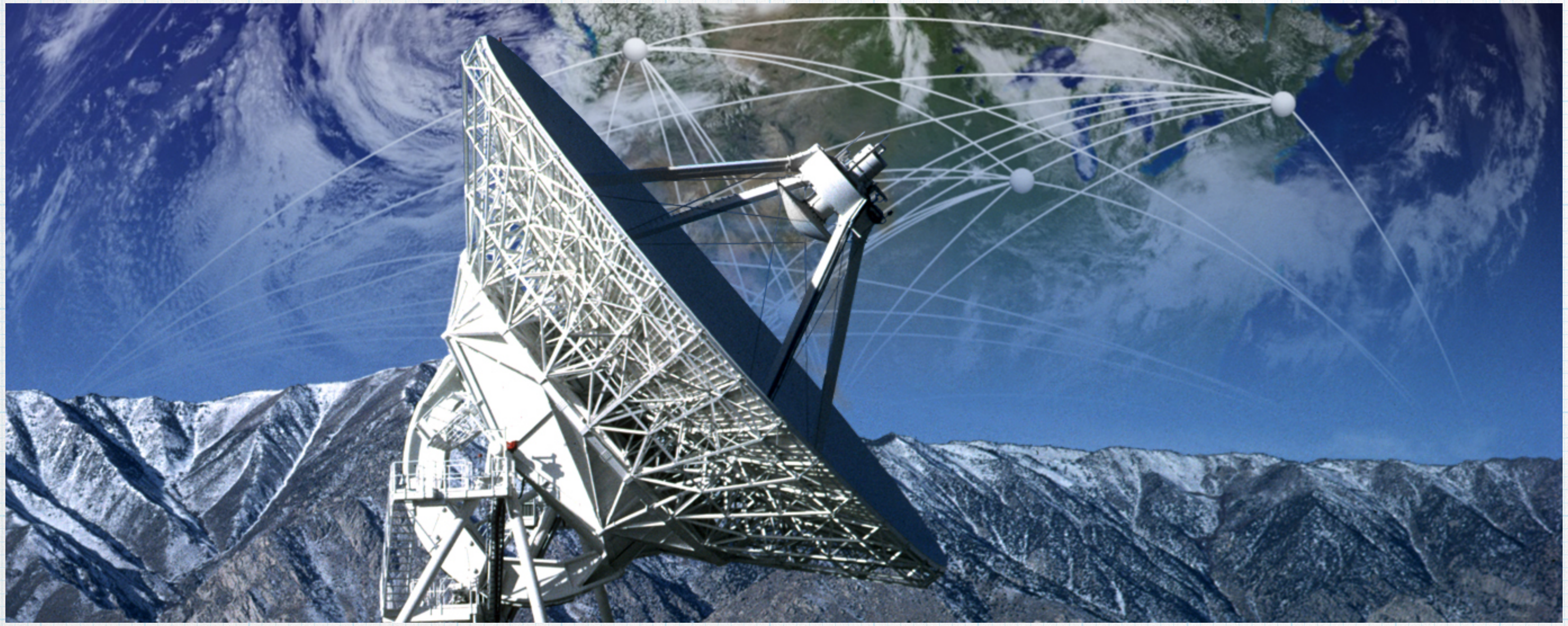
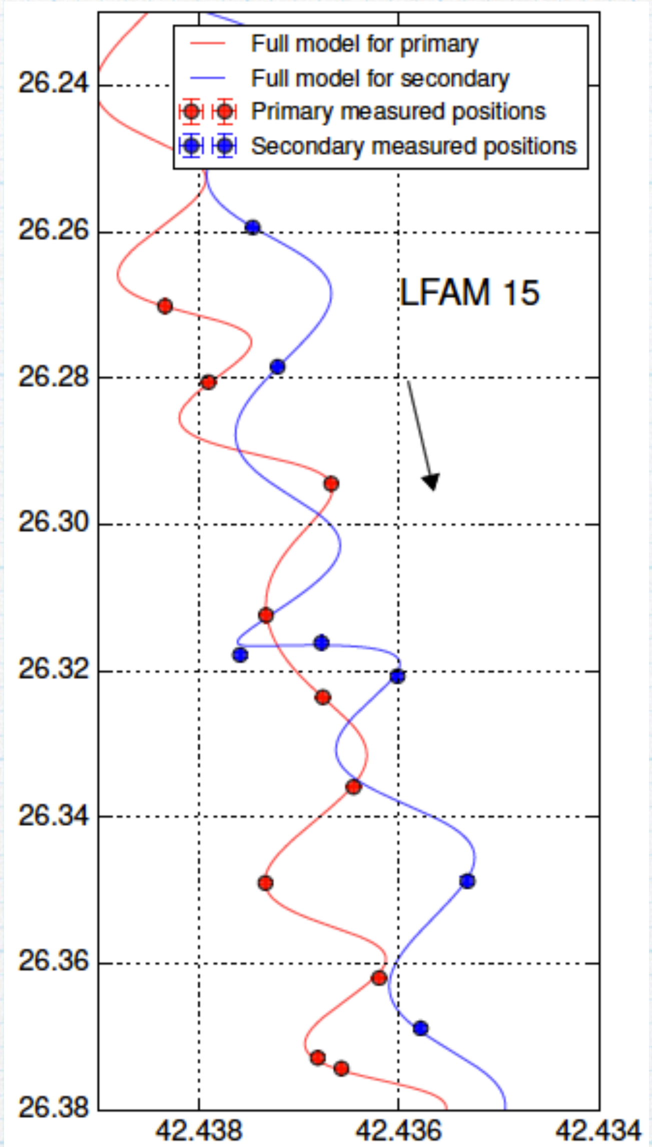
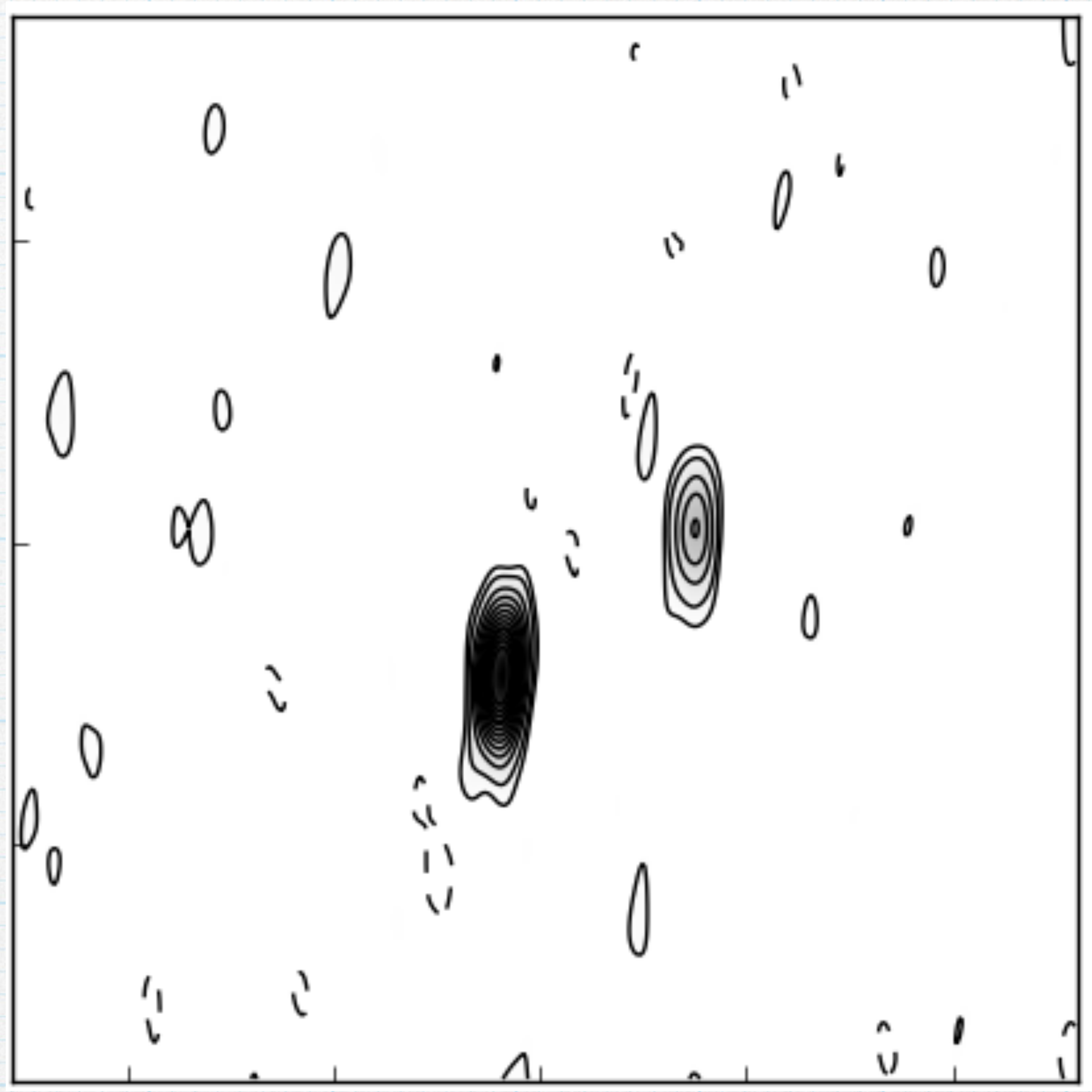
Stellar astrometry







Gisela N. Ortiz León
Max Planck Institute for Radio Astronomy, Bonn, Germany

Main collaborators: Laurent Loinard, Sergio Dzib, Phillip Galli, Marina Kounkel, Amy Mioduszewski, Luis F. Rodríguez.

235th Meeting of the American Astronomical Society, 4-8 January 2020

VLBI astrometry

* Astrometry means
  * Accurate stellar positions
  * Parallaxes → distances
  * Proper motions → transverse velocities
  * +radial velocities → 3D spatial velocities

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Radio waves immune to dust obscuration

* Use this information to derive 3-D structure of molecular clouds
* Identify multiple components within molecular clouds
* Study the kinematics of molecular clouds

VLBI astrometry

* Angular resolution:

$\lambda\,(\mathrm{cm})$	5	3	1	0.7	0.3	0.1
$\theta_{\mathrm{res}}\,(\mathrm{mas})$	1.2	0.72	0.24	0.17	0.07	0.02

* Absolute astrometric precision: $$\frac{1}{2}\frac{\theta_{\mathrm{res}}}{\mathrm{SNR}} \lesssim 50\ \mu\mathrm{as}$$

* Systematic errors contribution ~100-200 μas (continuum, low-elevation targets).
  * Main contribution by unmodeled atmospheric delays
  * Possible contribution from unmodeled motions from unseen companion.

VLBI sensitivity

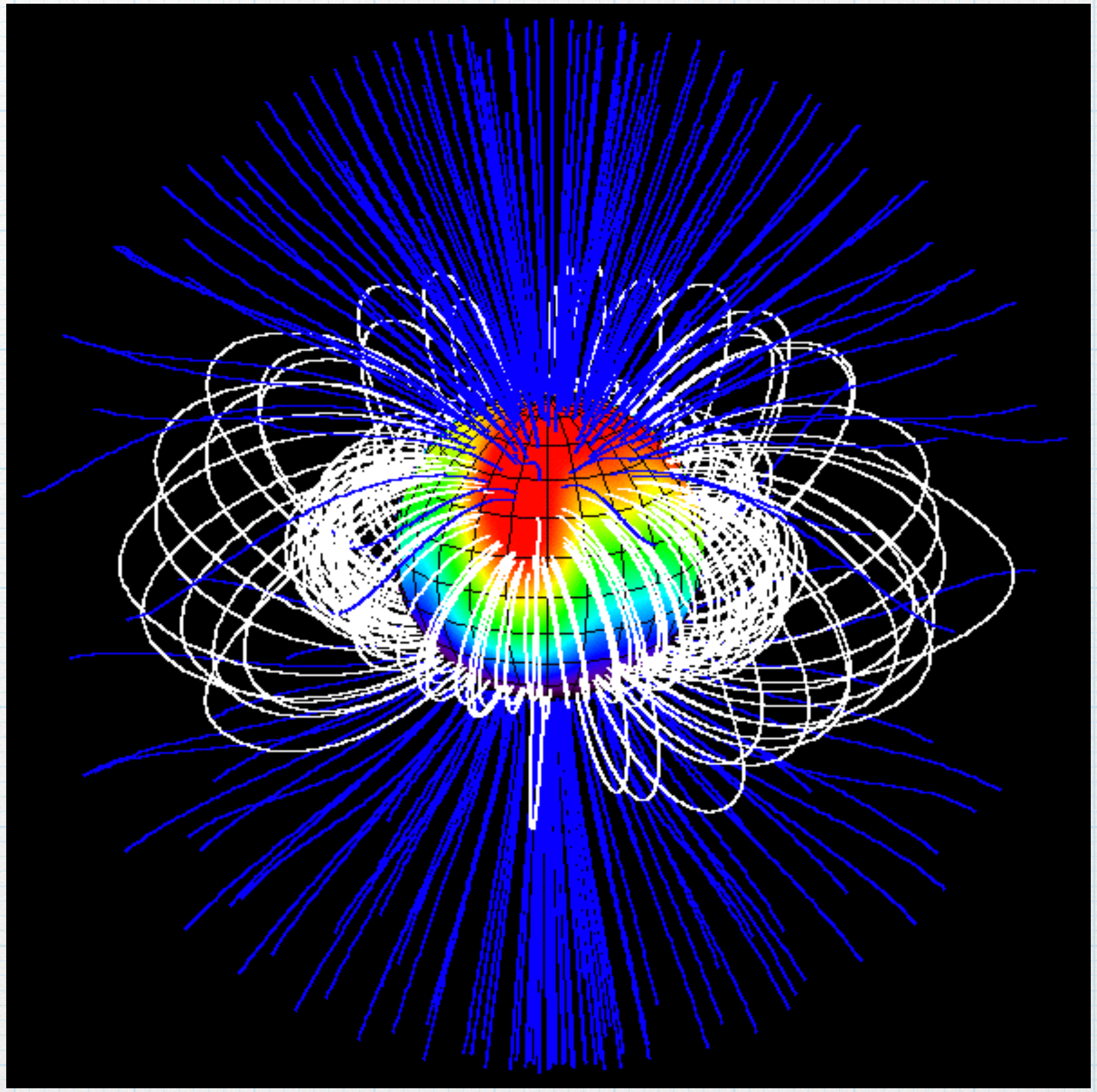
- VLBI sources must have non-thermal radio emission
- Brightness temperature sensitivity

$$T_b = 10^6 \left(\frac{S}{40\mu\text{Jy}} \right) \left(\frac{B_{\text{max}}}{8612\ \text{km}} \right)^2 \text{K}$$

- VLBI is sensitive only to compact, non-thermal radiation:
  - magnetic stars, masers → commonly found in SFRs
  - pulsars, AGNs

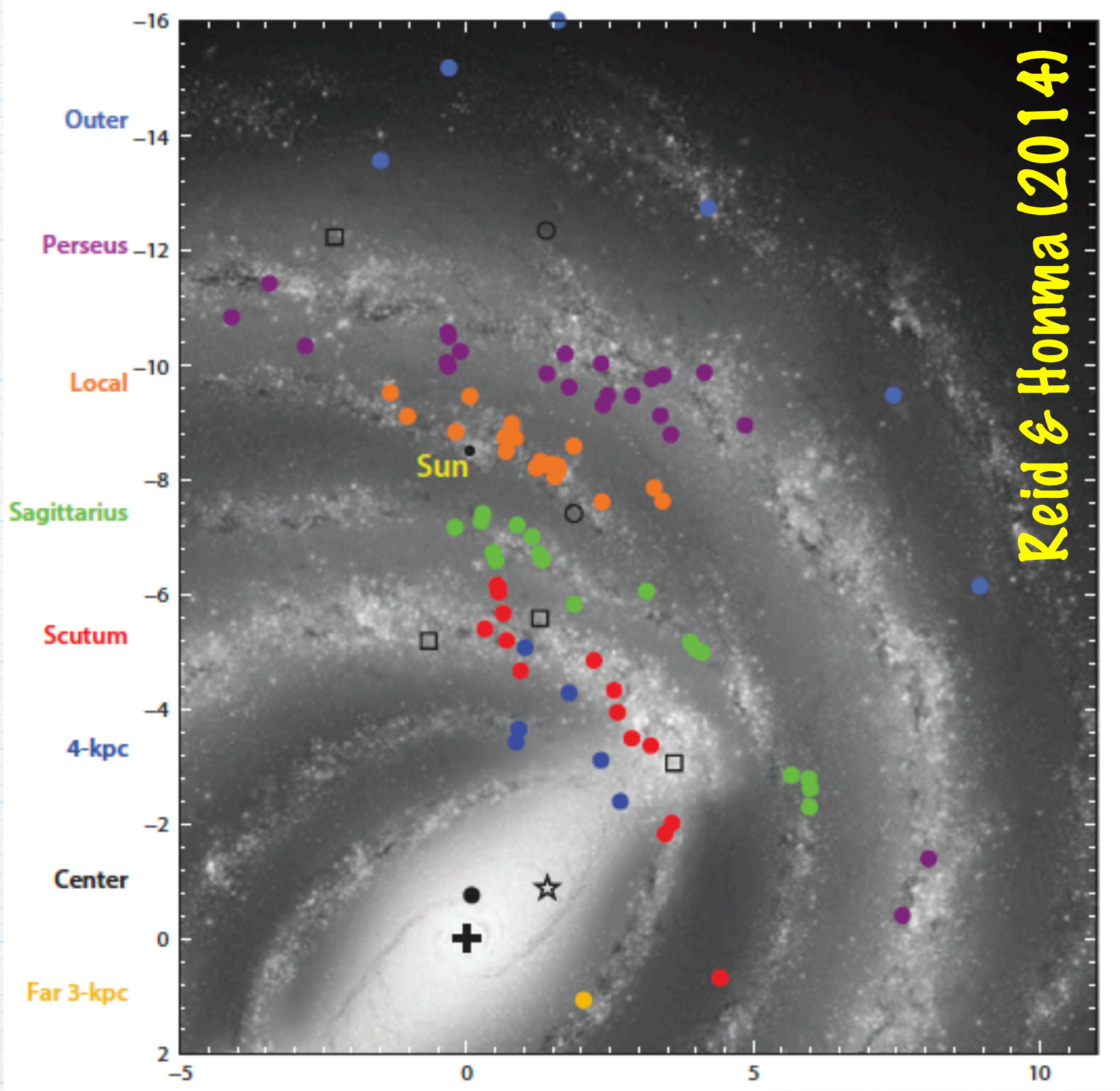
Non-thermal emission from young stars

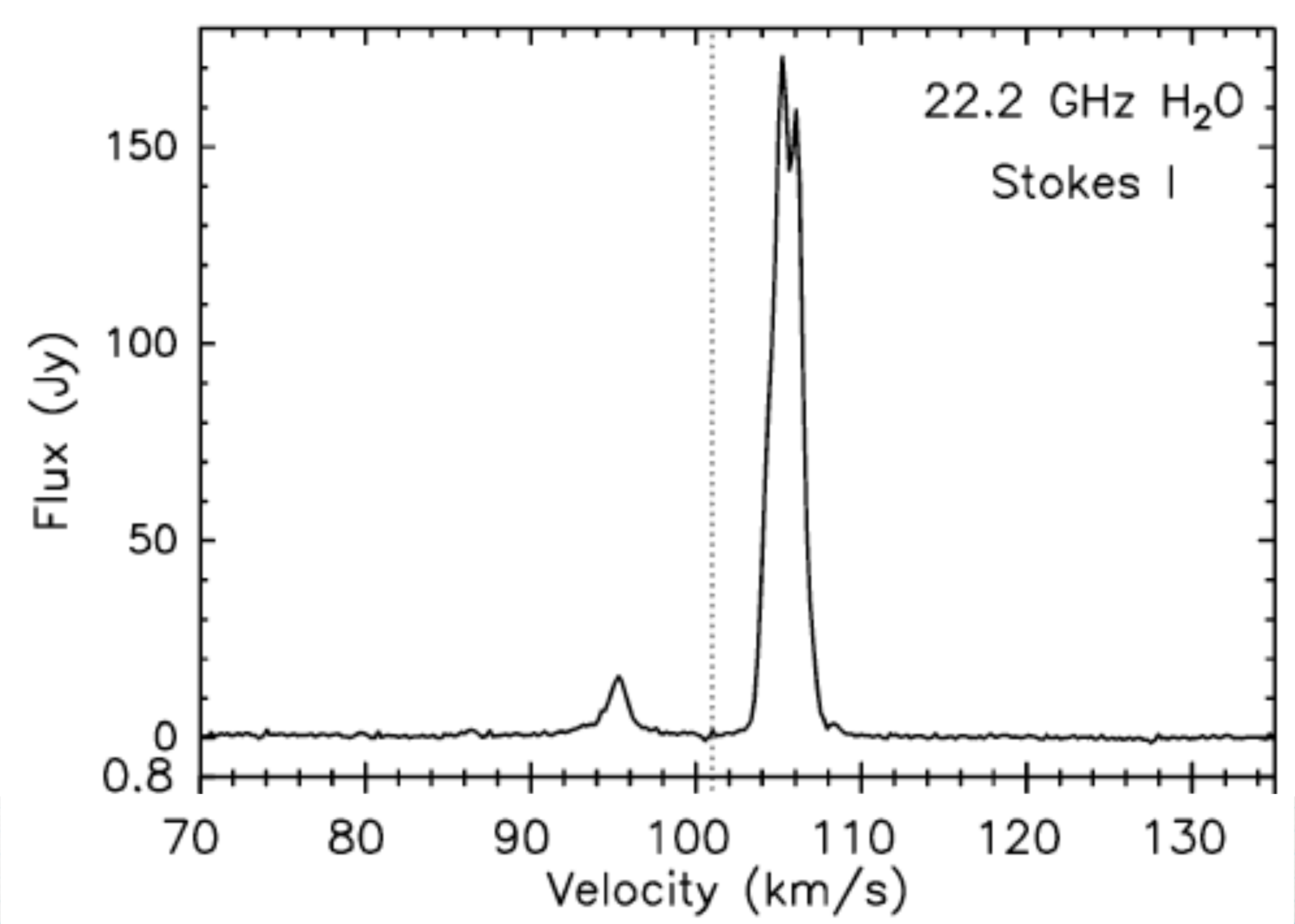
* Low-mass stars (10^5-10^7 yr) with magnetic activity are usually sources of compact, non-thermal (gyrosynchrotron) radio continuum emission.



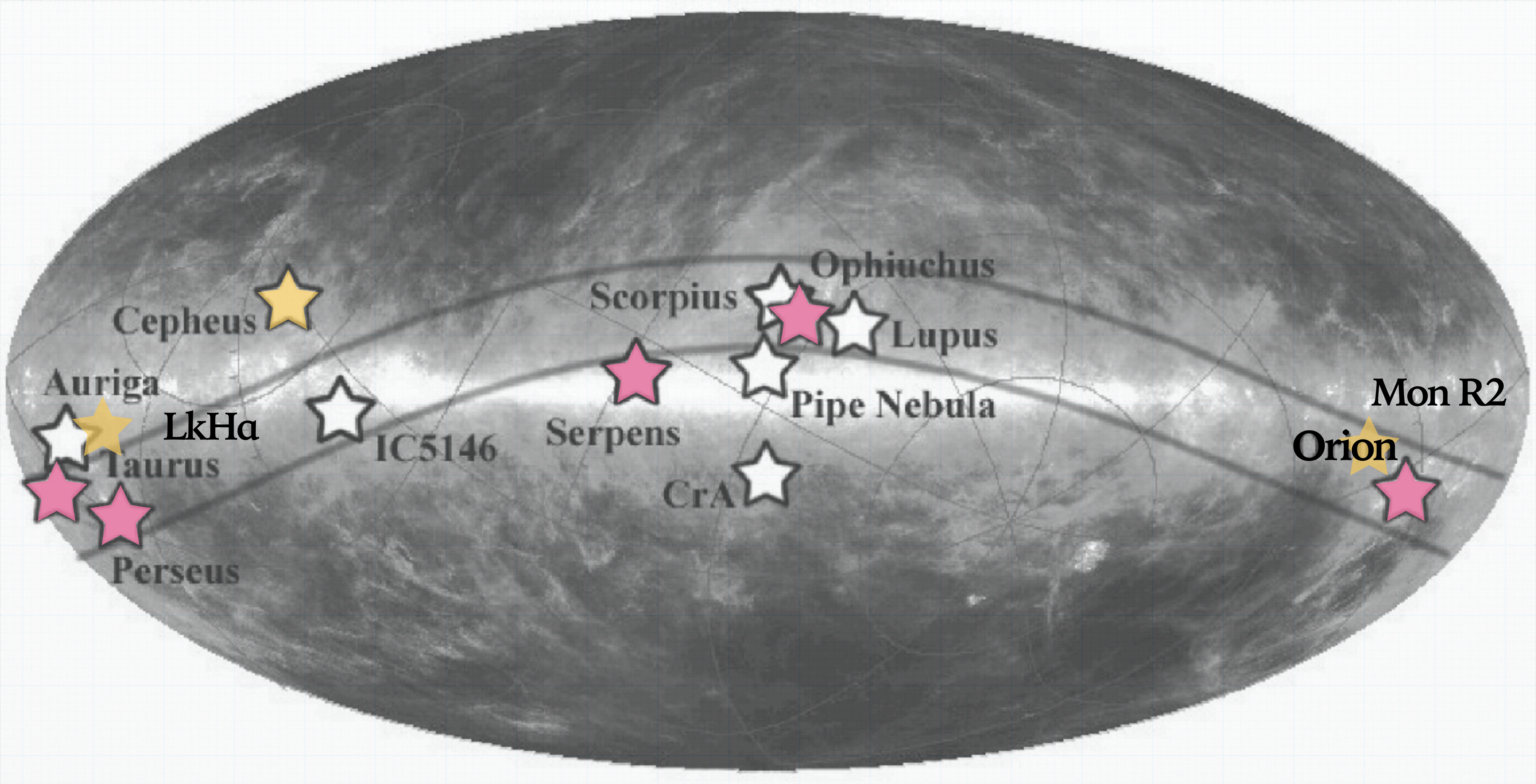
Non-thermal emission from young stars

* Maser lines
  * Methanol (CH_3OH, at 6.7 and 12.2 GHz) masers, excited by radiative pumping in the dusty environment around massive YSOs.
  * Water (H_2O, at 22 GHz) masers trace the shocked gas in jets and outflows in low- and high mass protostars.





GOBELINS - A VLBA astrometric survey of (embedded) young stars (Loinard, Dzib, Ortiz-León et al.)



Adapted from Ward-Thompson et al. (2007)

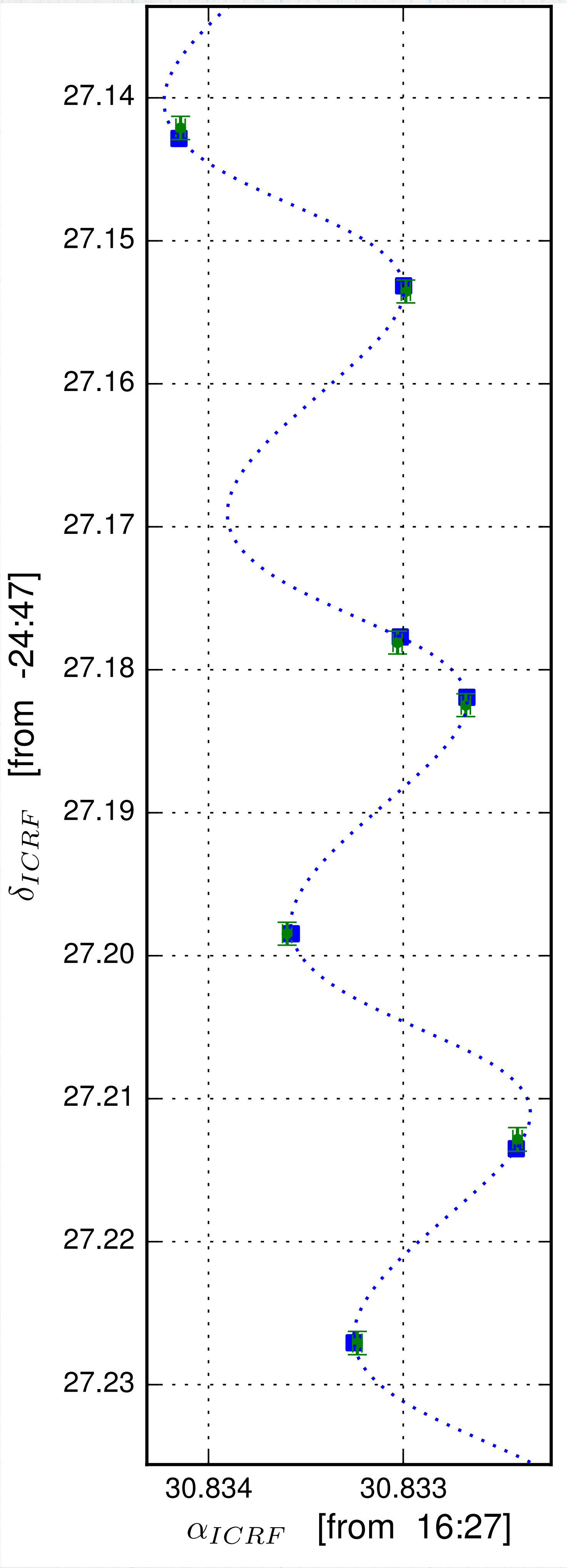
GOBELINS - A VLBA astrometric survey of (embedded) young stars (Loinard, Dzib, Ortiz-León et al.)

~270 YSOs observed, ~100 YSOs with good astrometry

Adapted from Ward-Thompson et al. (2007)

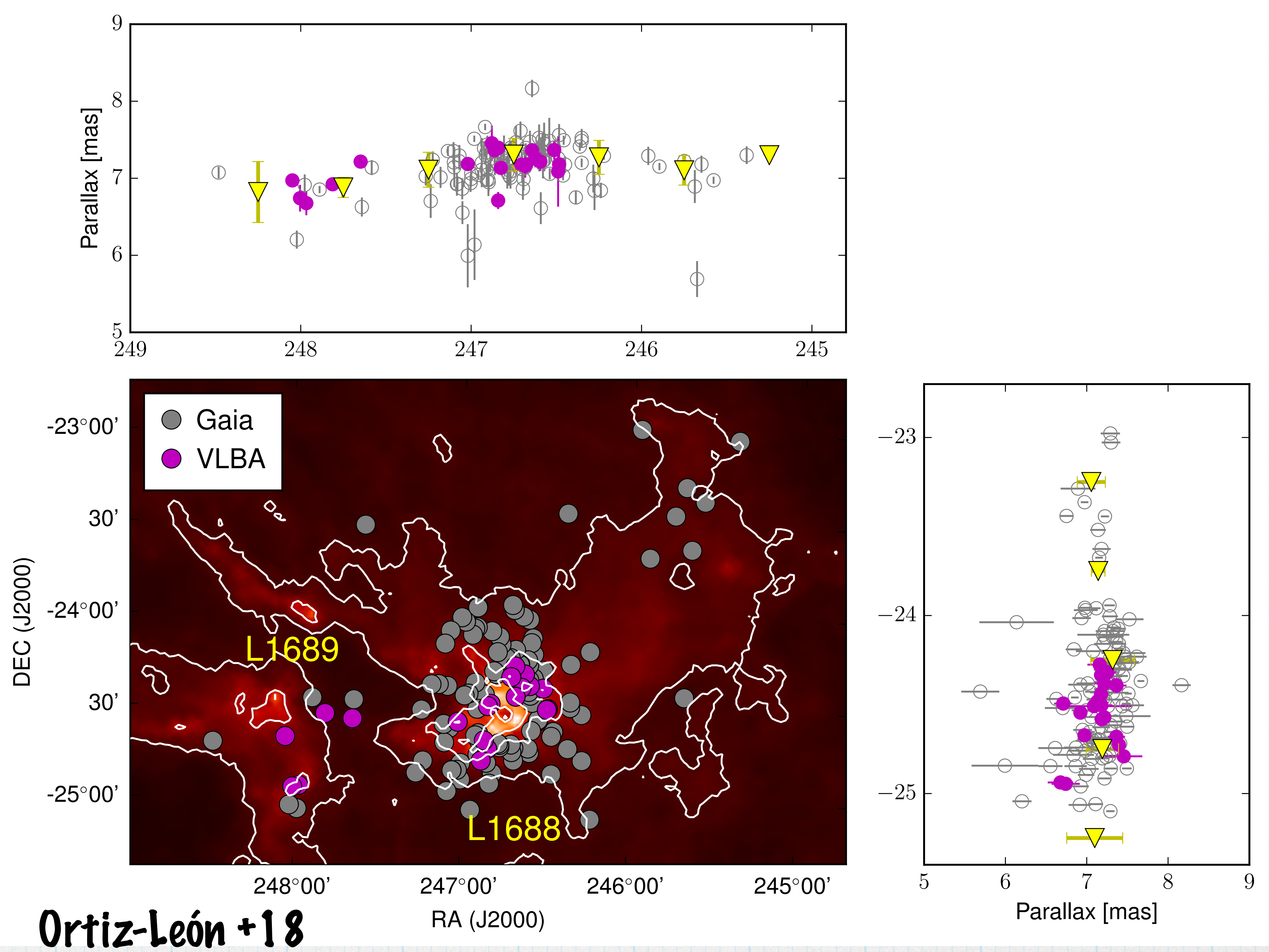
Taurus: L1495, L1513, L1519, L1531, L1534, L1536, L1551, BDN176.28-20.89
Perseus: IC348, NGC1333
Serpens: Main, W40
Ophiuchus: L1688, L1689
Orion: Trapezium, ONC, L1641, NGC 2024, σ Ori, NGC 2068

GOBELINS main results - Astrometry



Ortiz-León +17

- Single stars:
  - 5 free parameters.
  - Errors on parallax range from 0.2 to 3%
  - Systematics are the main source of error.

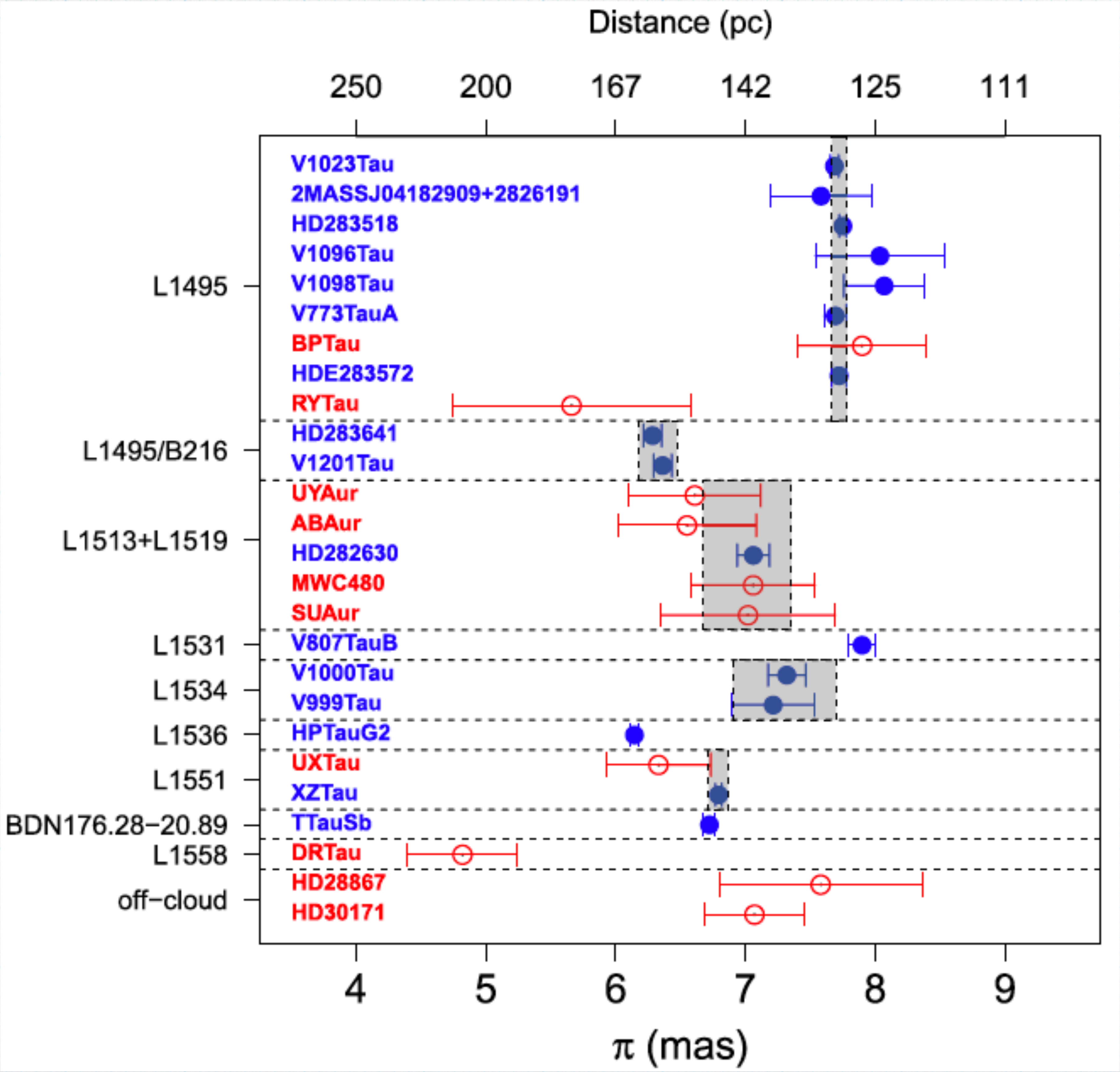


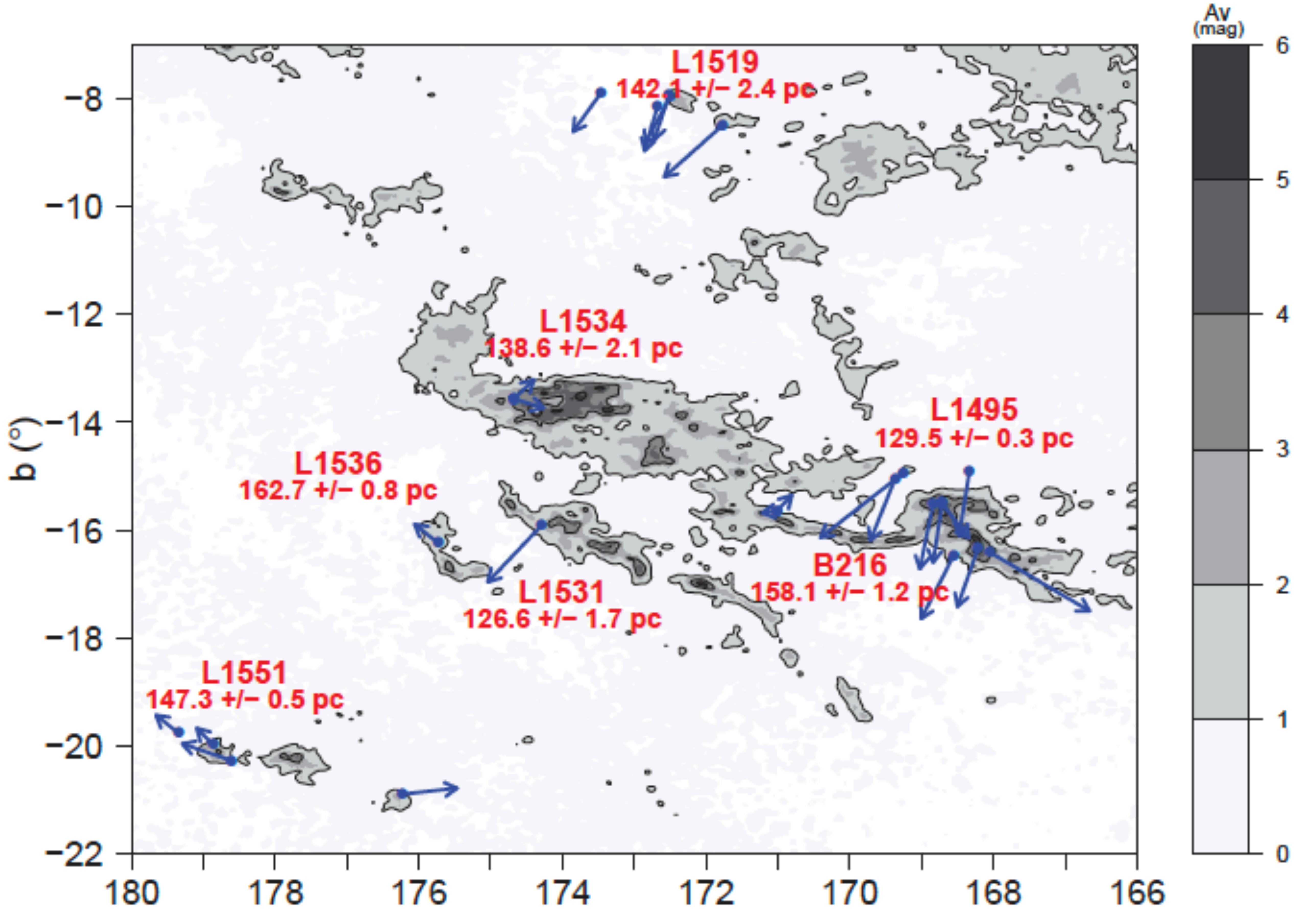
Ortiz-León +18

- Errors on proper motions are typically better than 0.2 mas/yr
  - At 140 pc this translates to ~0.1 km/s

Taurus - VLBA + Gaia DR1

* Parallax distances reveal important depth effects within the cloud.





Galli+ (2018)

Taurus - VLBA + Gaia DR1

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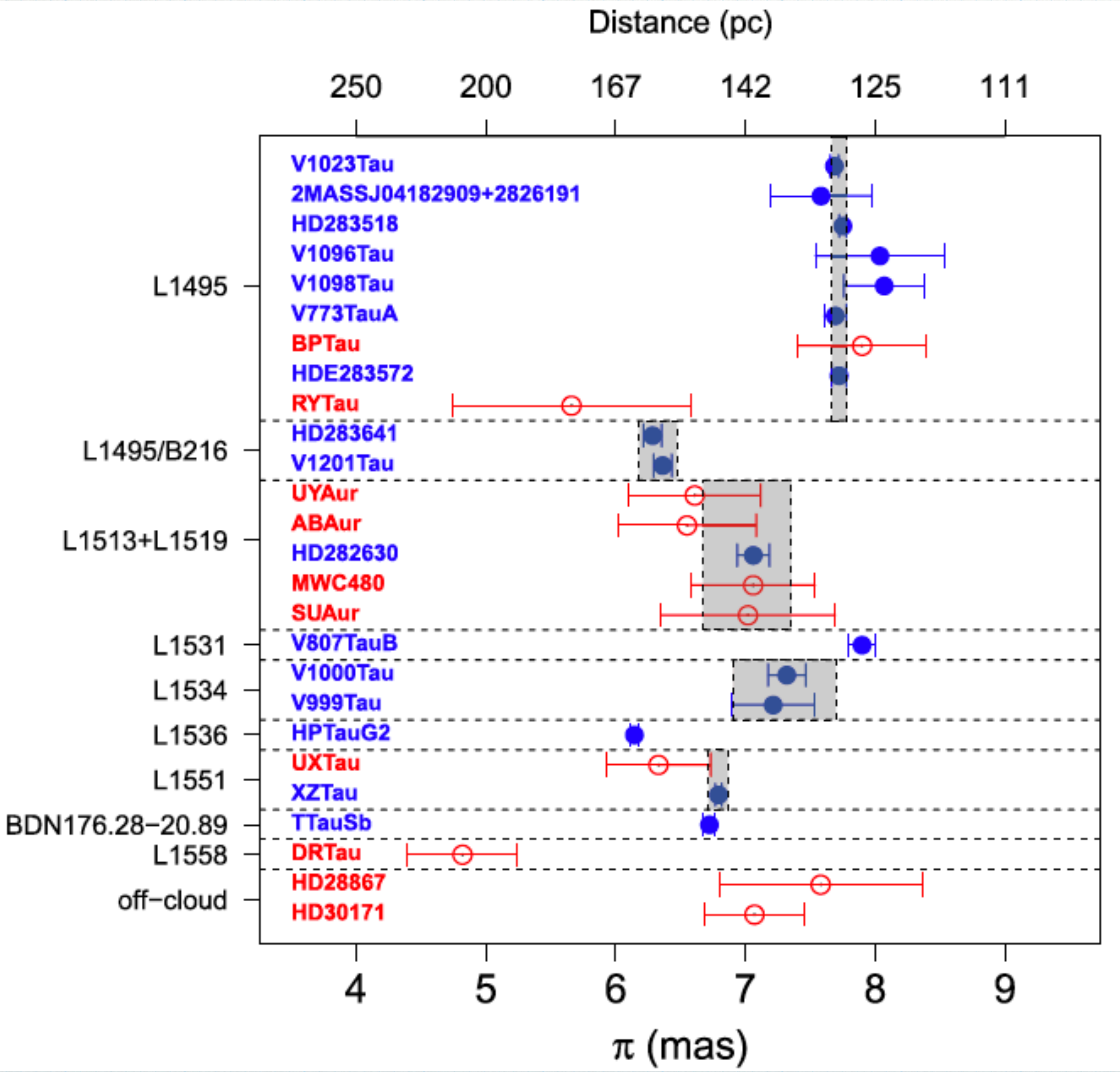
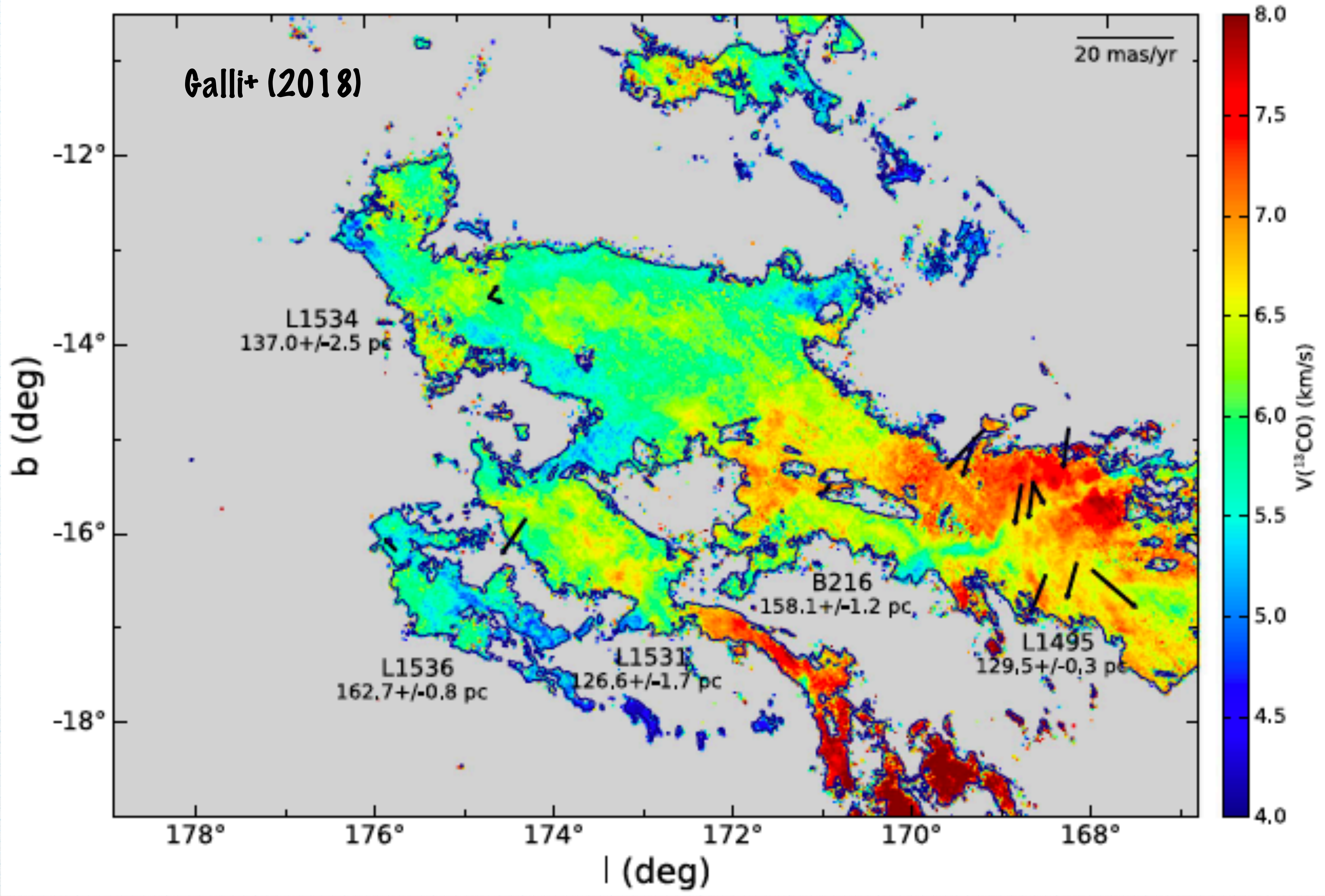
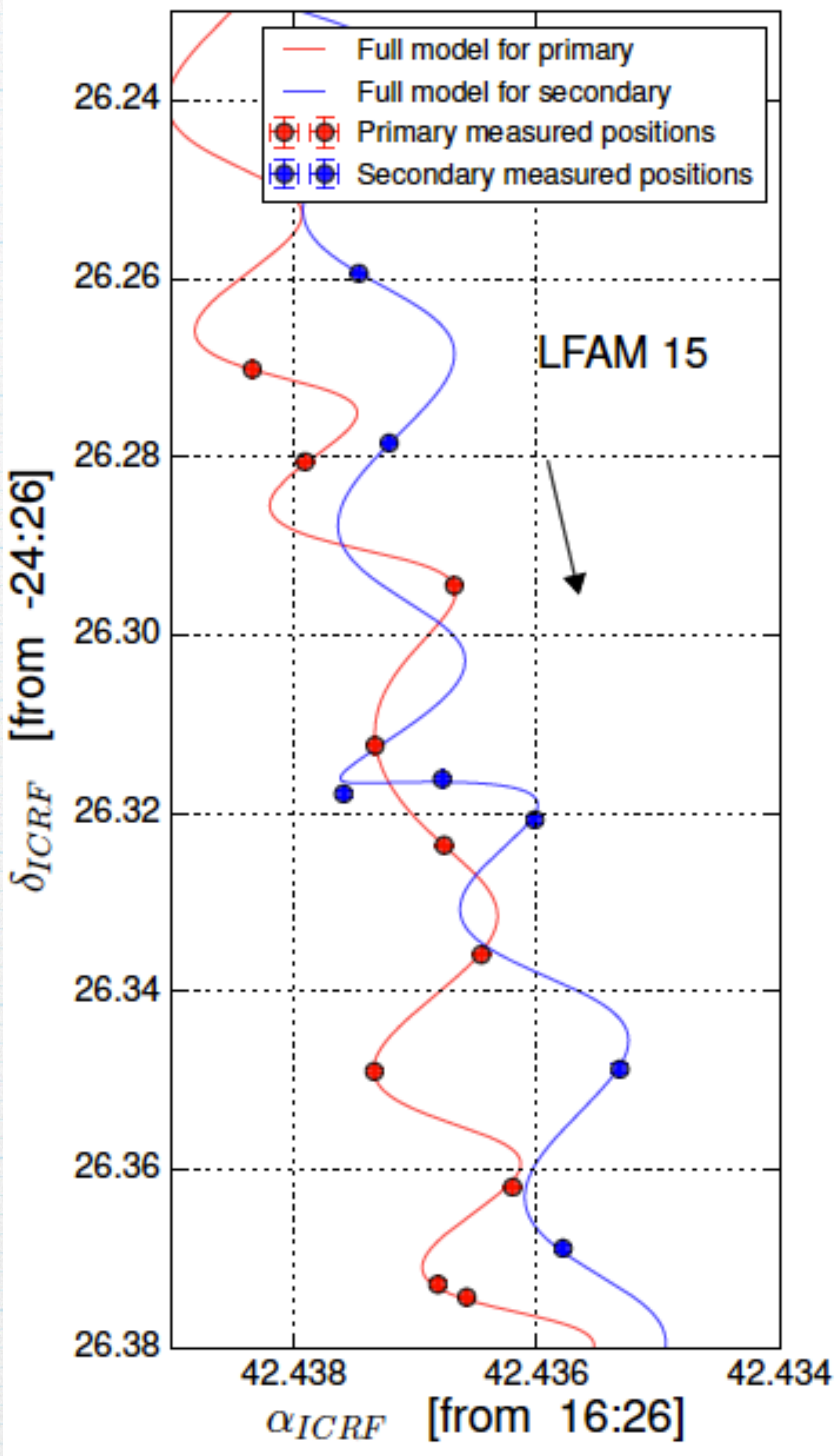


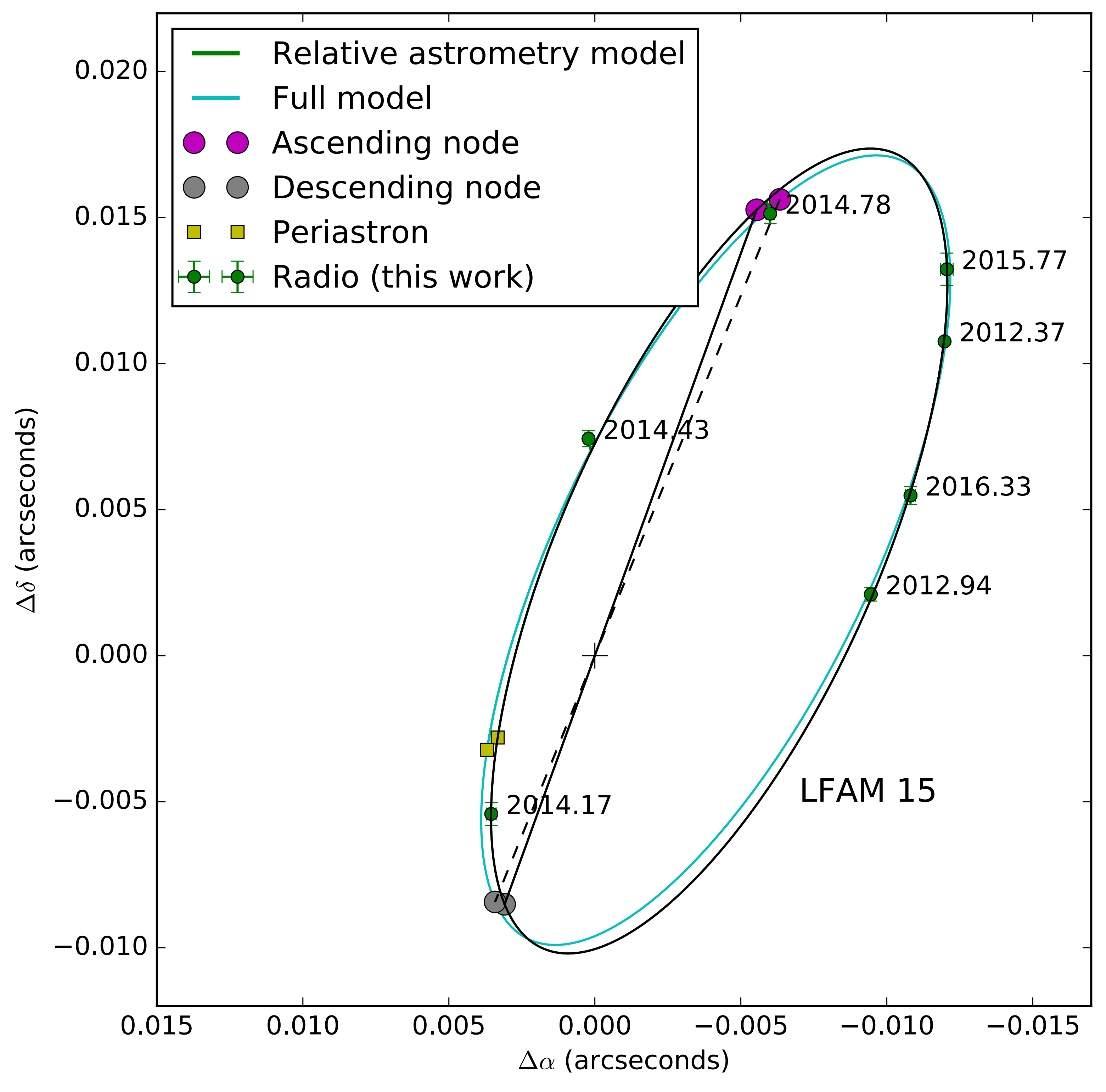


High angular resolution science - Astrometric binaries

* Excess of radio-bright binaries with separations below 10 au.

* Short-period binaries
  * Fit 5 astrometric parameters + 7 orbital parameters.

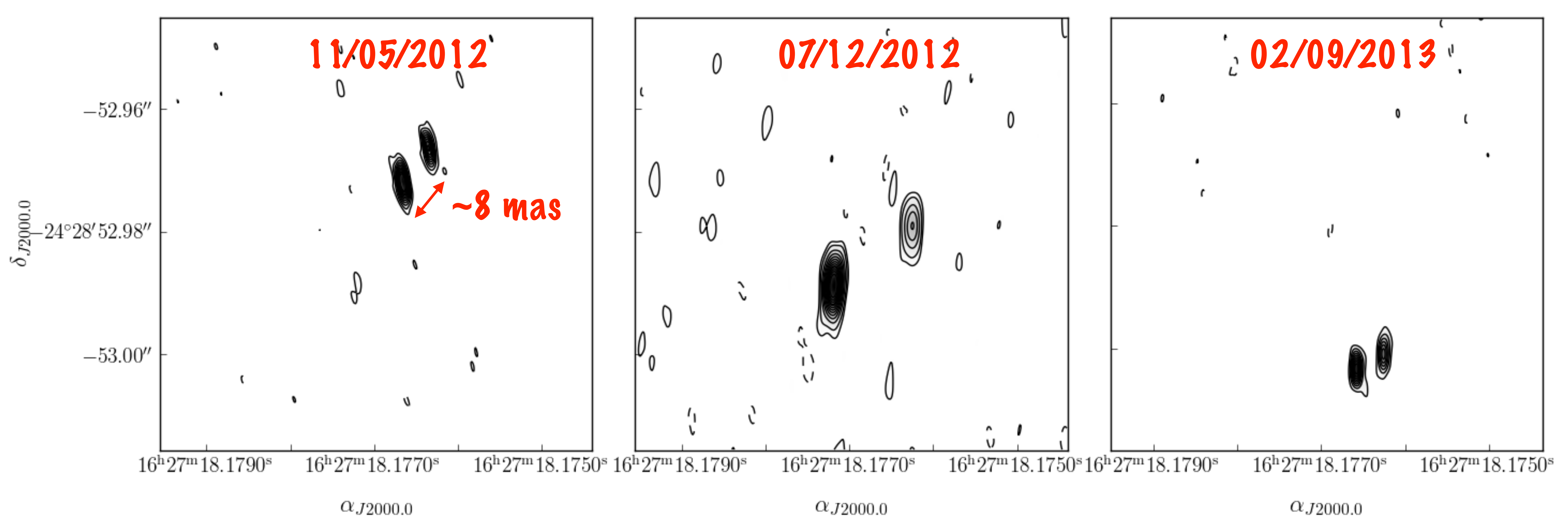




Ortiz-León et al. (2017)

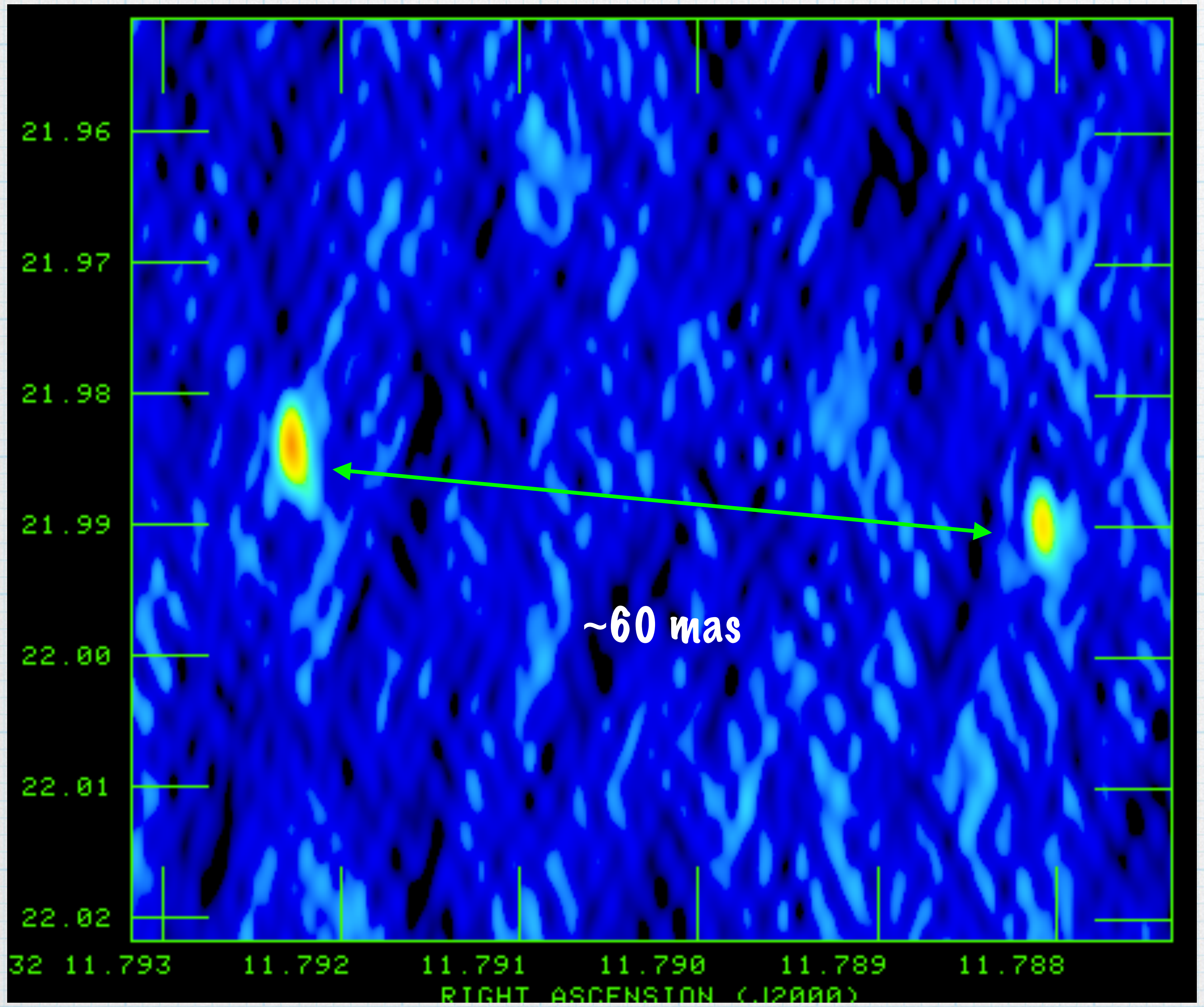
* **Dynamical** (individual) **masses** of very tight binary systems, with an accuracy of up to 2-5%.

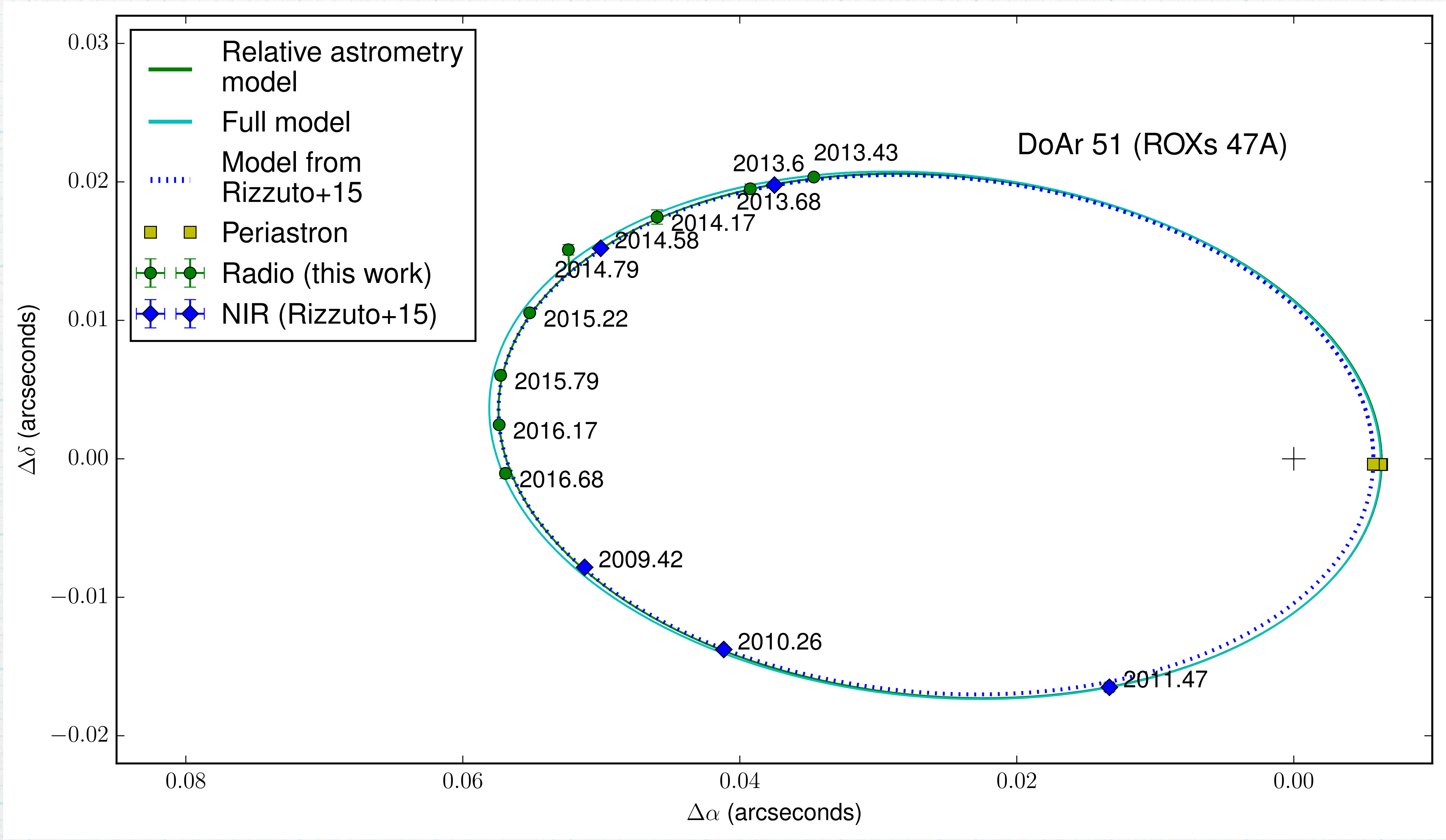
High angular resolution science - Astrometric binaries



High angular resolution science - Astrometric binaries

* Long-period binaries. Infrared data available. Fit to VLBA+IR data



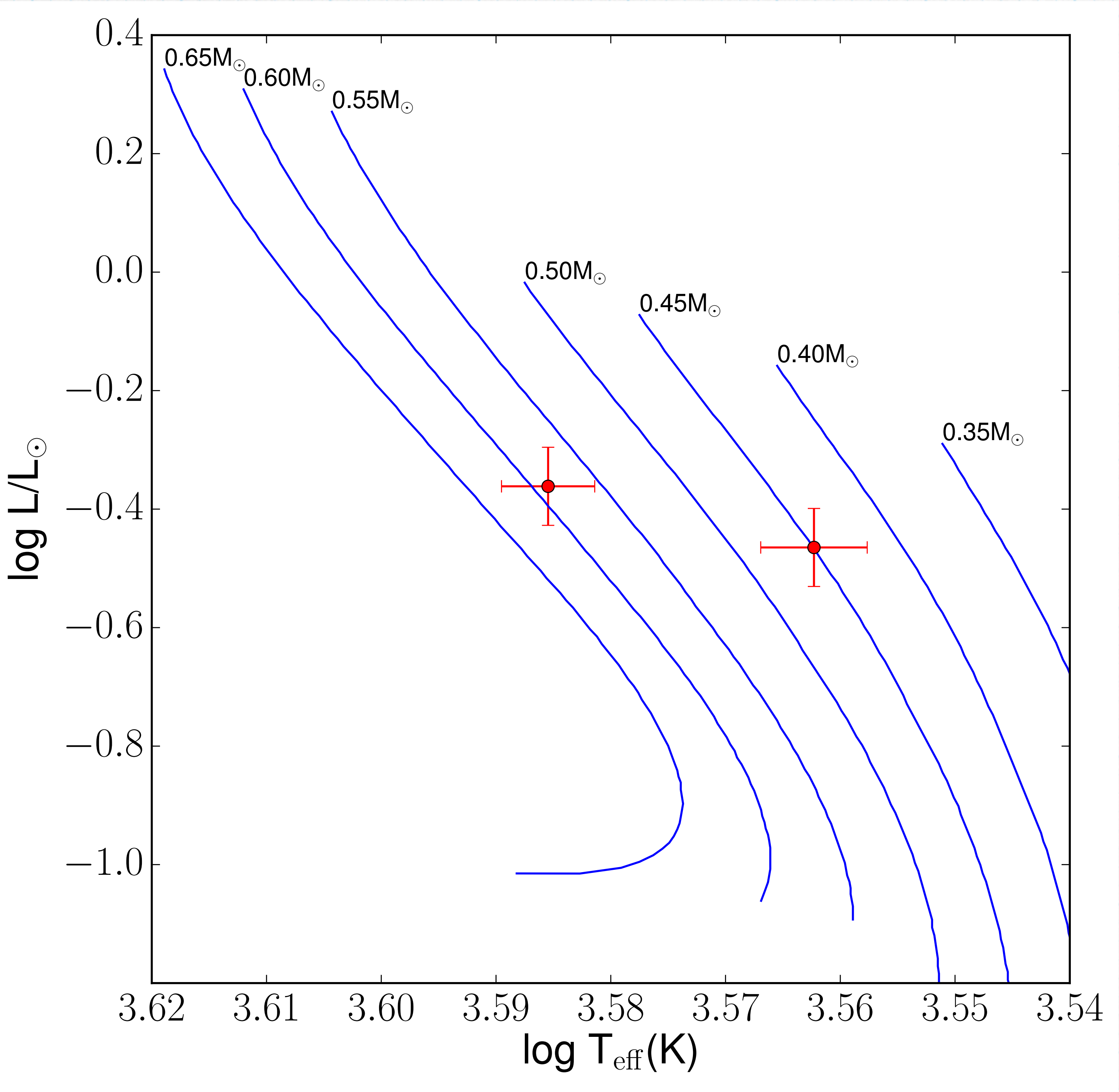


Ortiz-León et al. (2017)

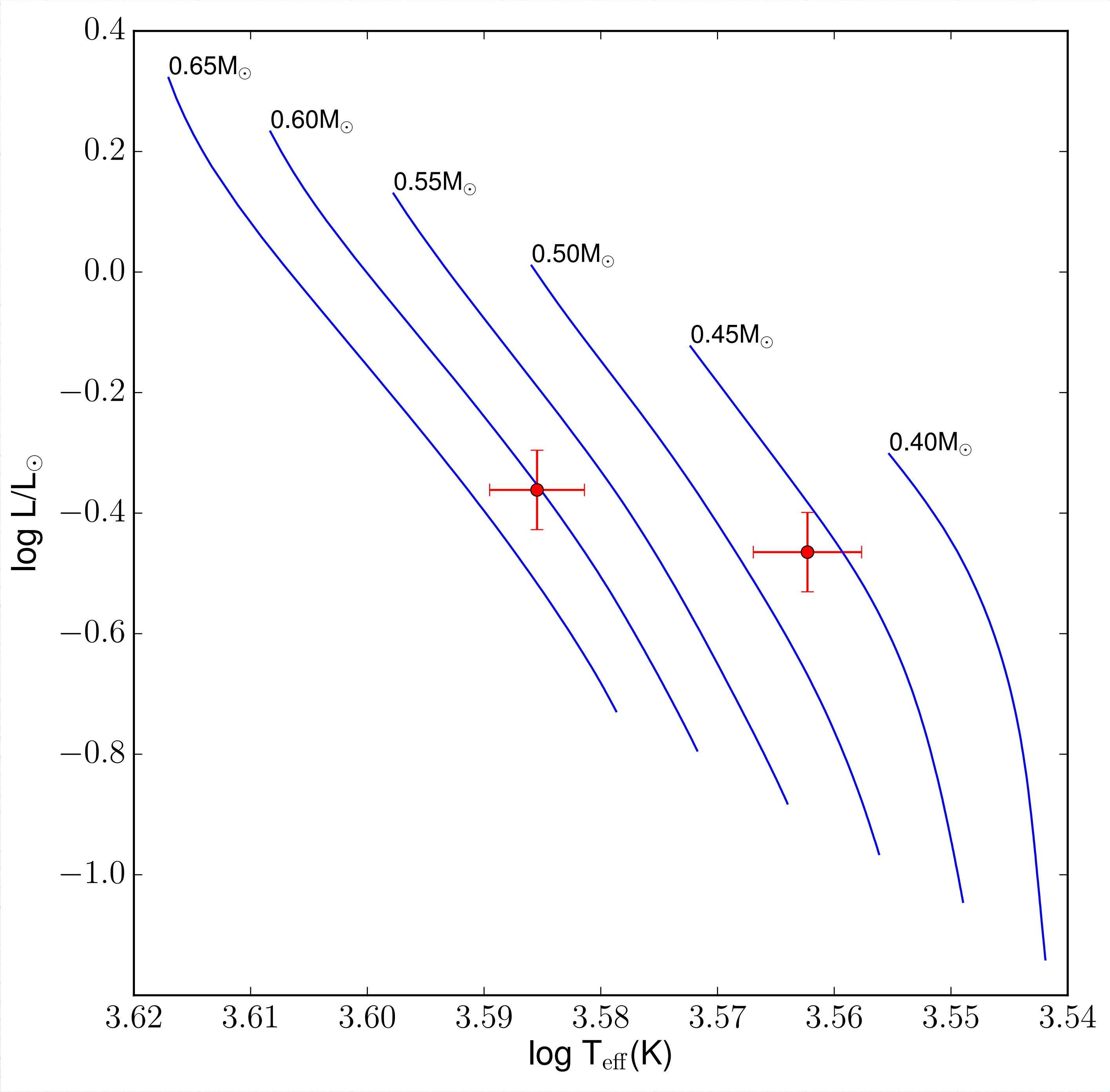
* Confirmed binaries
  * Ophiuchus 10
  * Serpens 2
  * Taurus 6
  * Orion 3
* Binary candidates
  * Orion 5
  * Ophiuchus 2
  * Serpens 1
  * Perseus 2

High angular resolution science - Astrometric binaries

* Dynamical masses of YSOs from VLBA astrometry (PI: Dzib, Ortiz-León + GOBELINS team)
  * 19 systems currently being observed



Models by Tognelli et al. (2011)



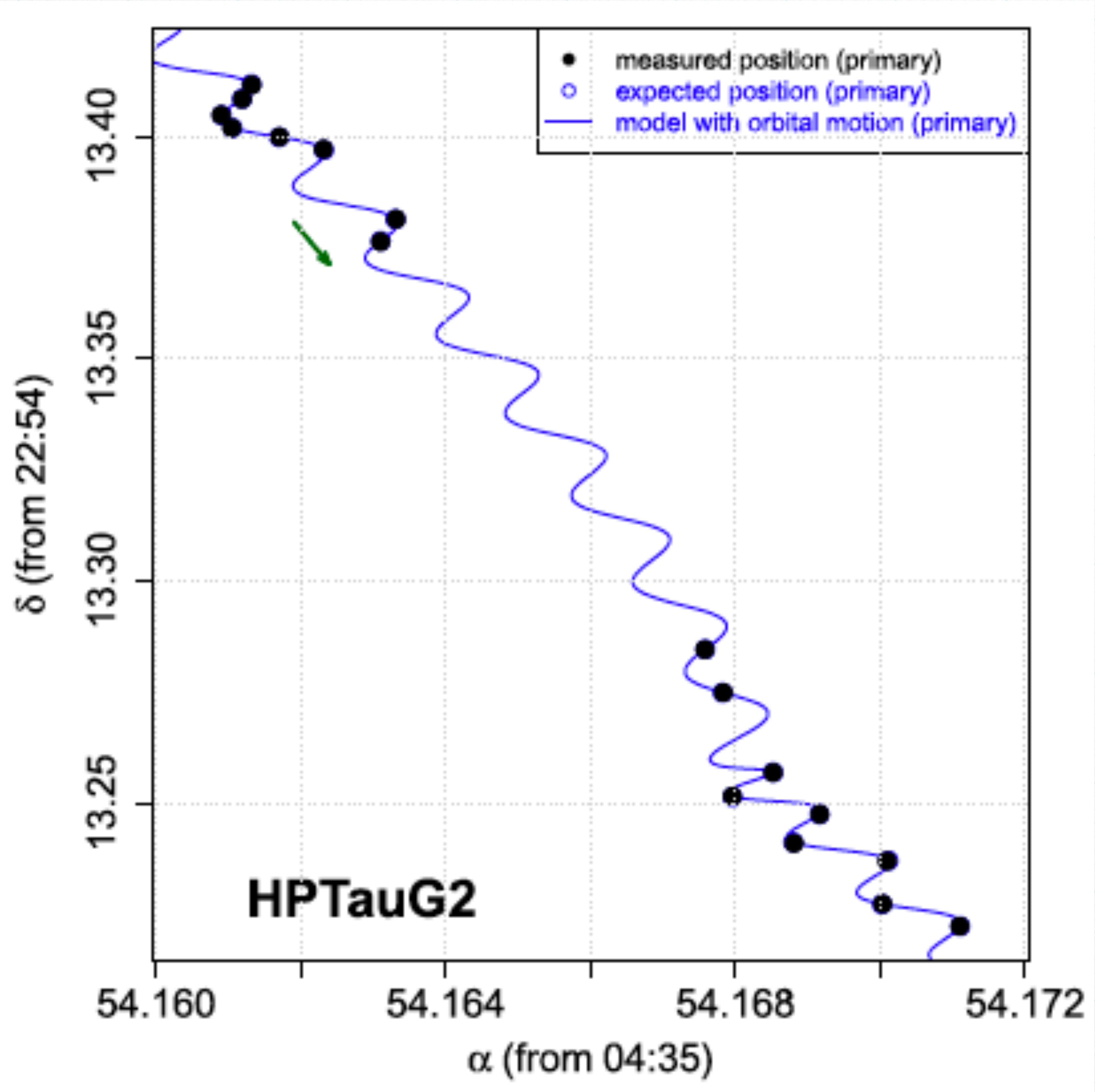
Models by Dotter et al. (2008)

~30% and ~70% larger than predicted

* Gaia will resolve all binaries (brighter than V=15) with separations above ~20 mas which have moderate magnitude differences between the components.

Comparison of predicted masses from PMS models with dynamical masses

High angular resolution science - Astrometric binaries

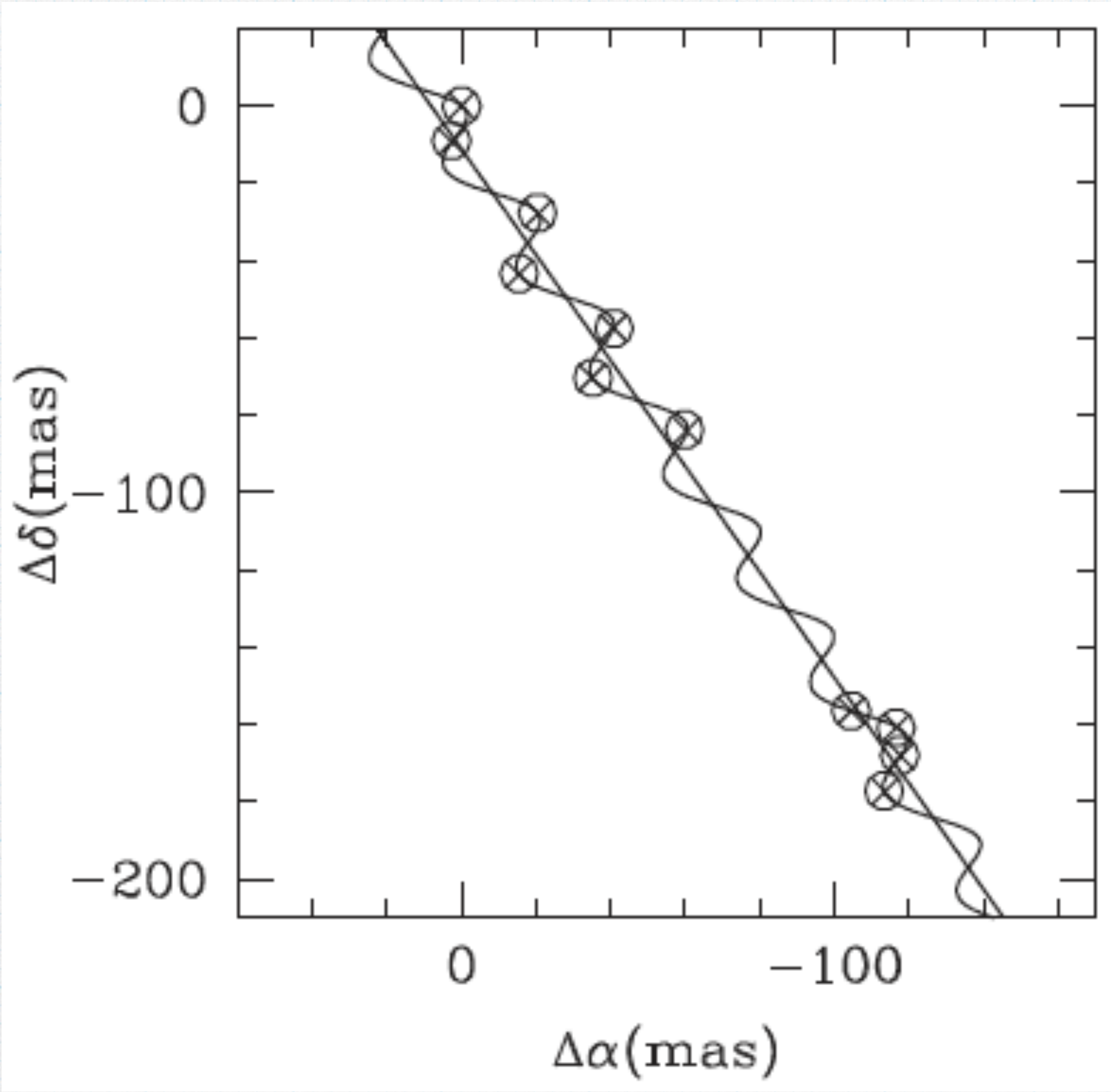


Galli+(2018)

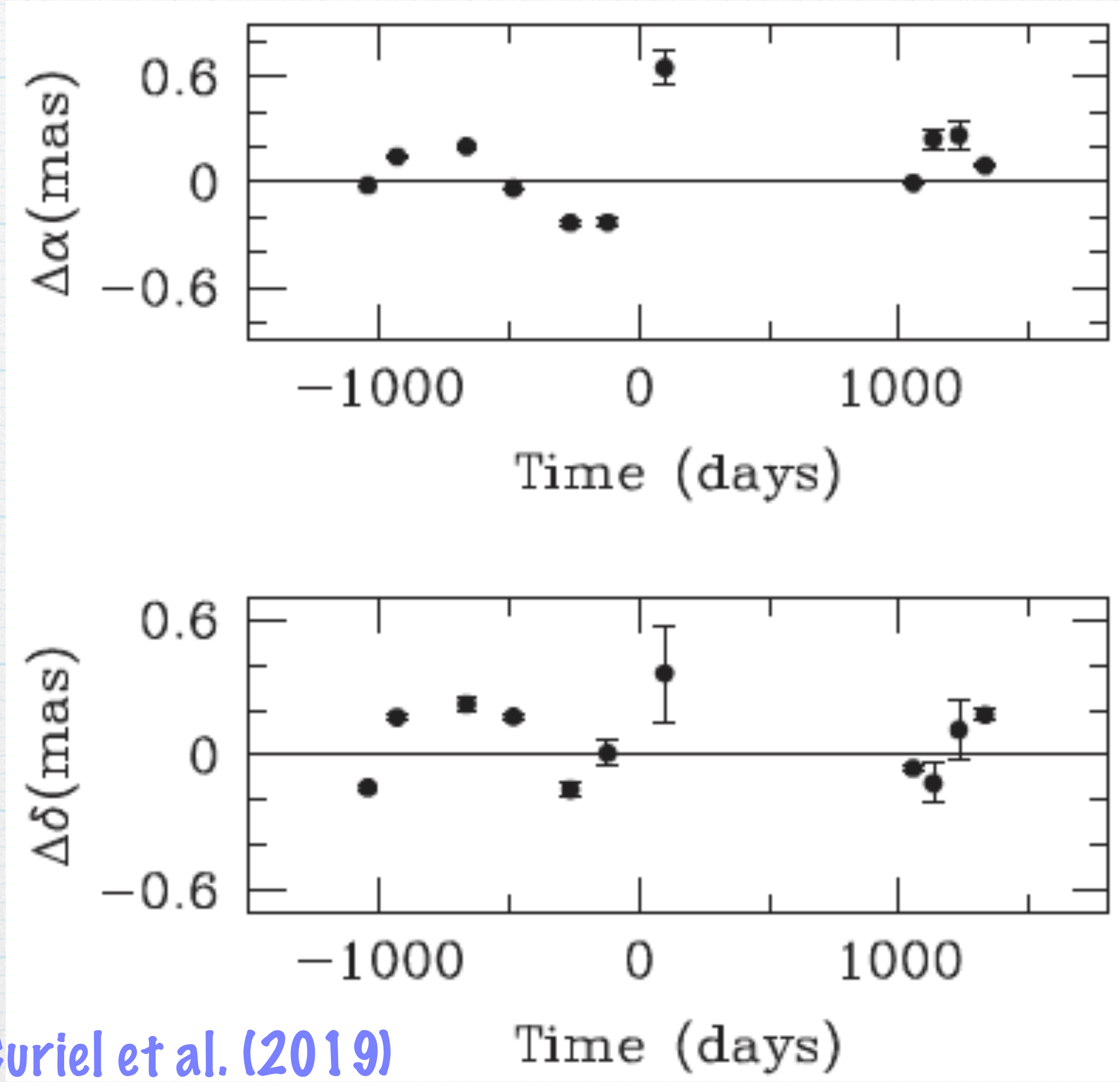
* Previously unknown companion detected by the astrometric signature of the host star.
* VLBA's potential to discover new hidden companions to pre-main sequence stars.

High angular resolution science - Sub-stellar companions

DoAr21: a weak-line TTauri star embedded in Ophiuchus

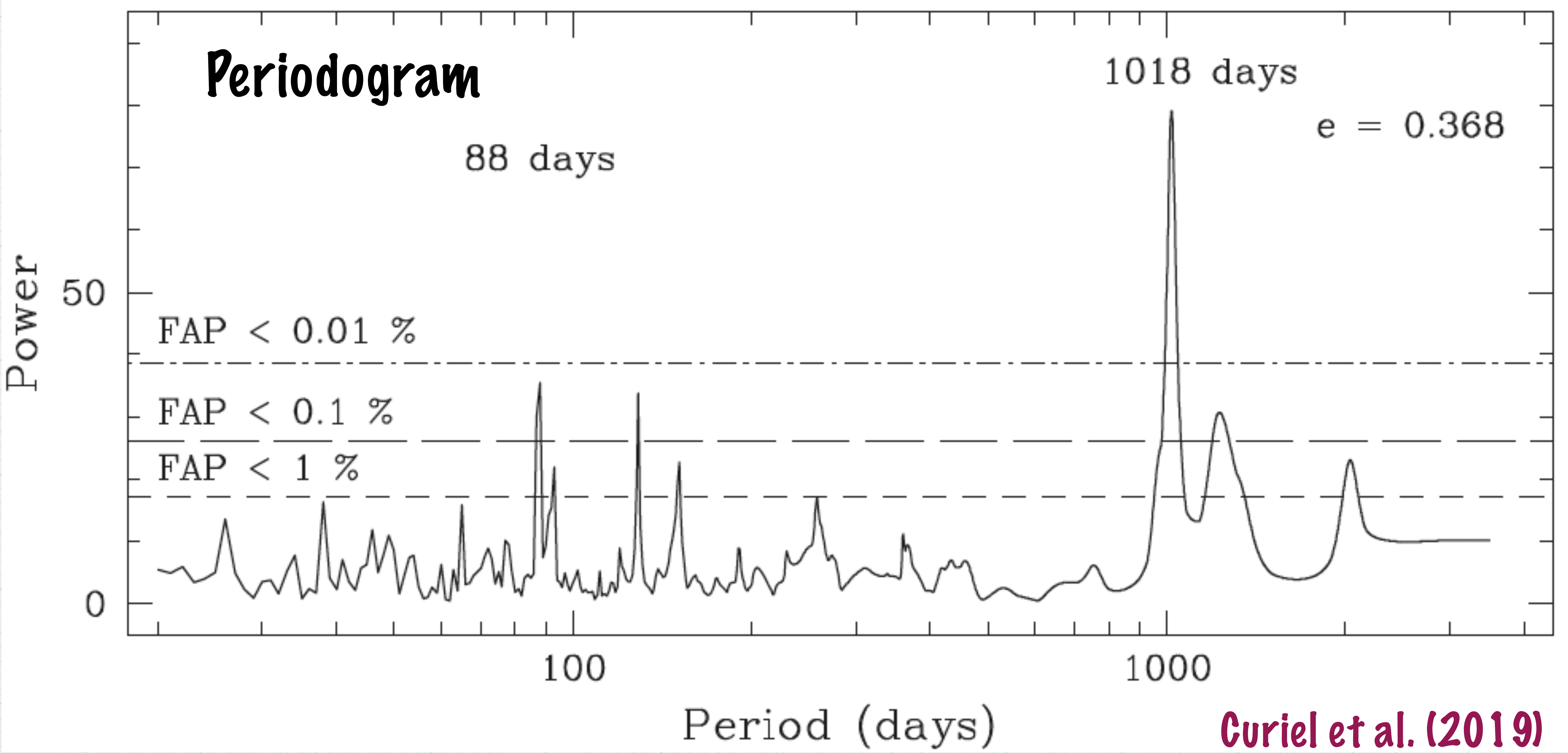


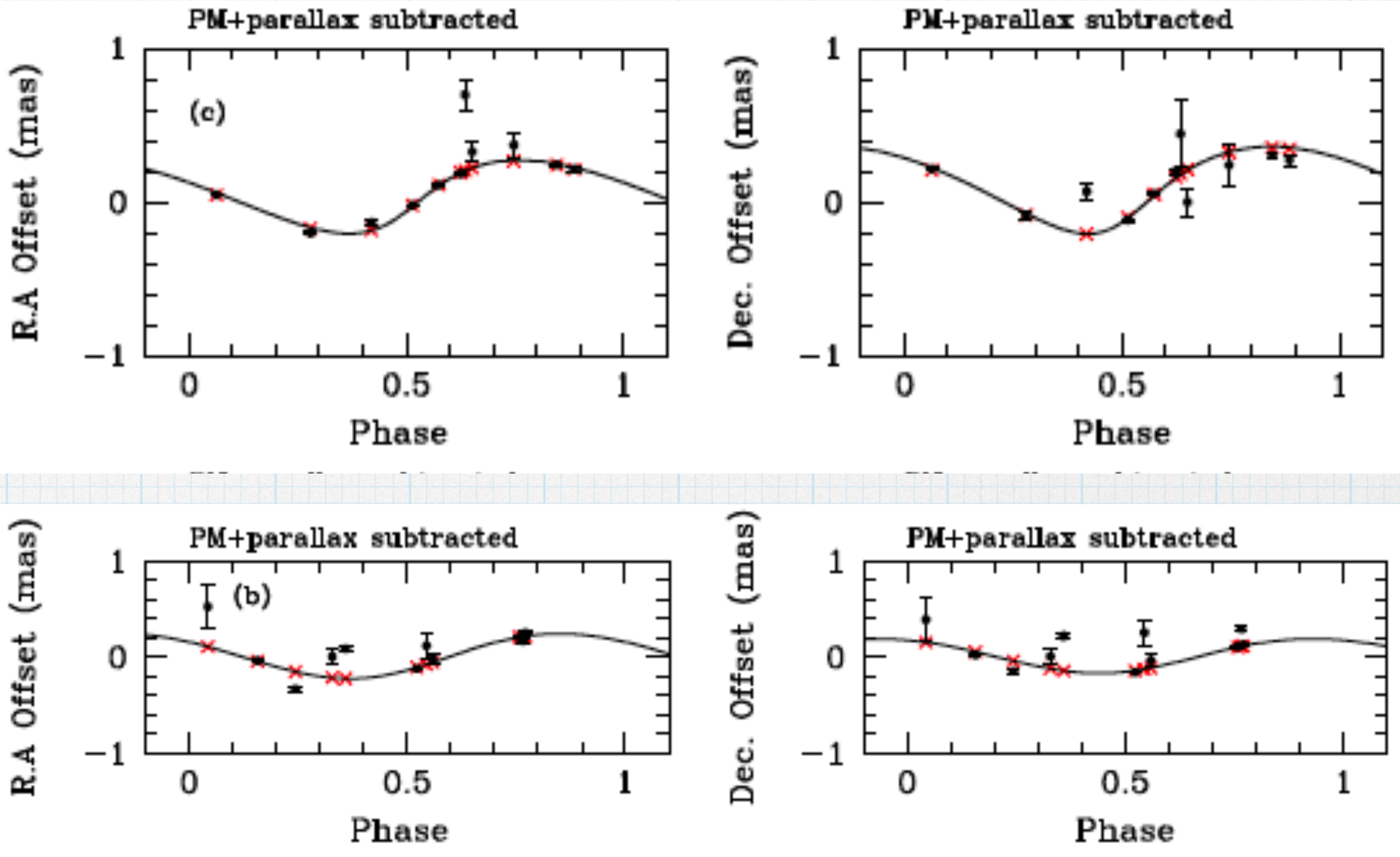
Astrometric fit residuals



Curiel et al. (2019)

High angular resolution science - Sub-stellar companions





* First case of a young star with one low-mass- and two sub-stellar companions
* M_{star}=2.04±0.70 M_{sun}; m_b=35.6±27.2 M_{jup}; m_c=44.0±13.6 M_{jup}

Science with the Next Generation VLA

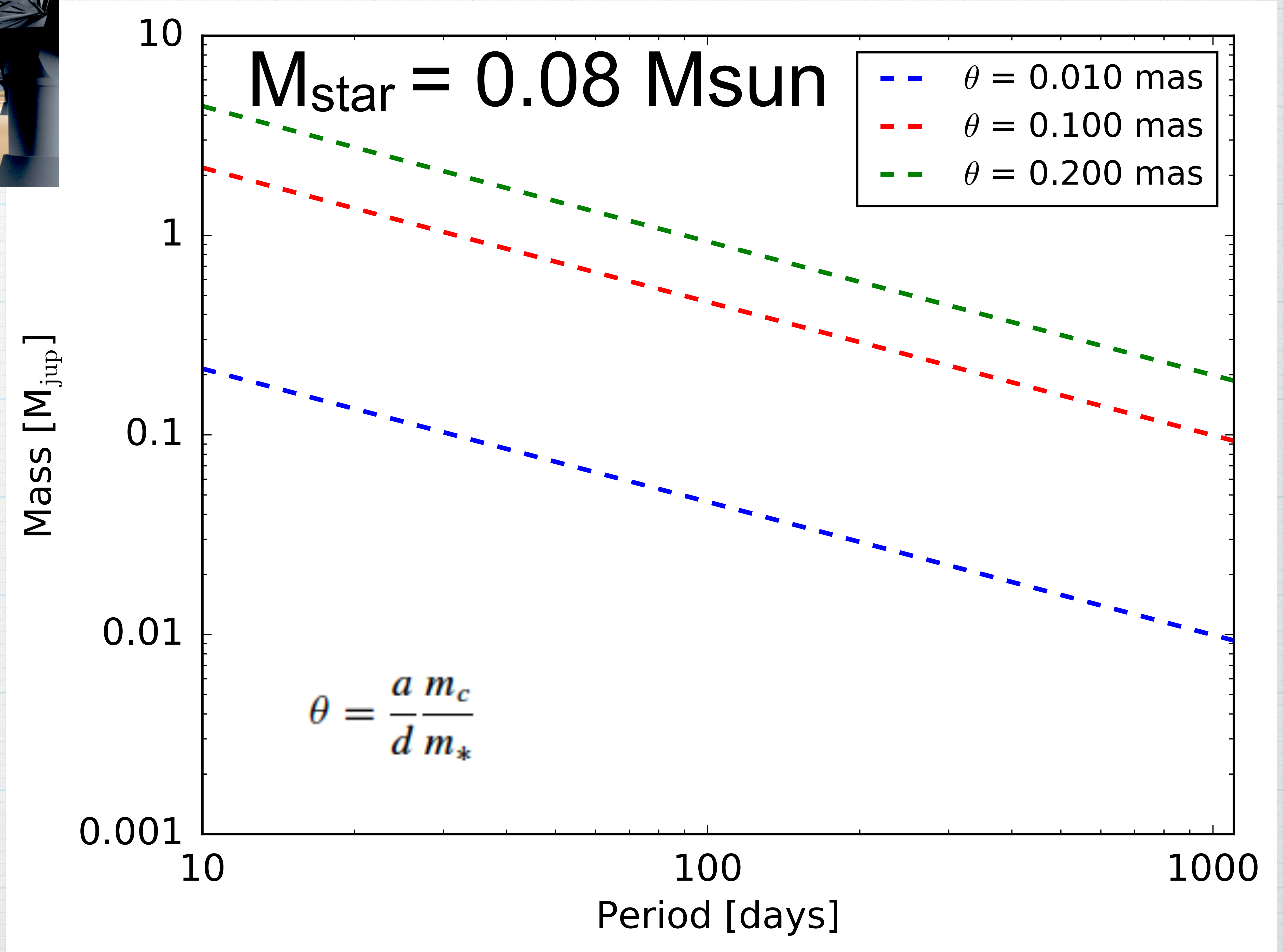
Long Baseline Array

1 μas astrometry accuracy

10x sensitivity of VLBA

- Potential to reveal planetary companions

The Next Generation Very Large Array is a design and development project of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.



Conclusion

High angular resolution enabled by long baselines play a key role in characterizing molecular cloud dynamics, very young binary systems and, in the future, will uncover planetary companions around low-mass stars

https://www3.mpifr-bonn.mpg.de/staff/gortiz/

@GiselaOrtizLeon