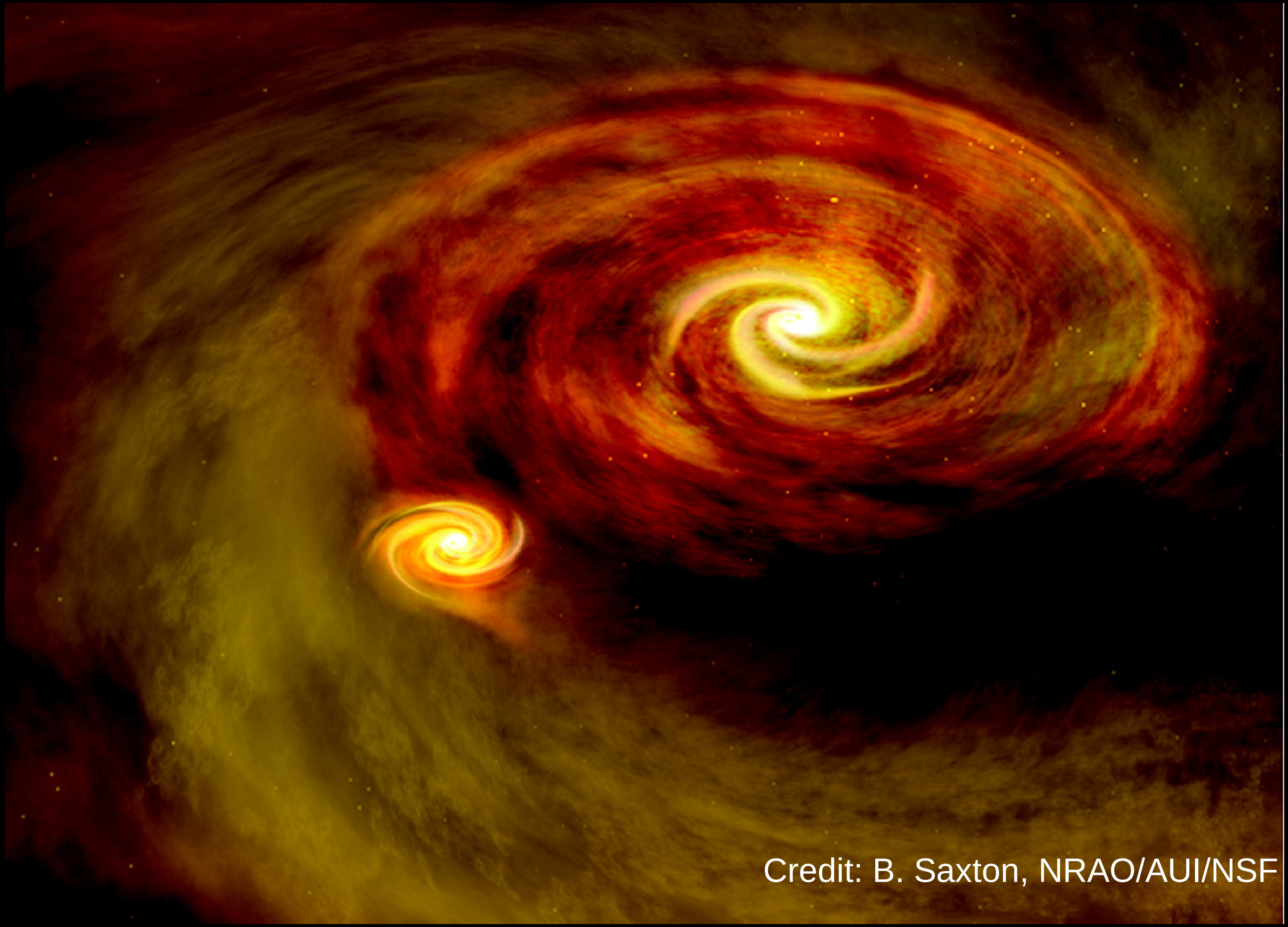
Resolving and characterising massive binaries at birth using high resolution techniques

Evgenia Koumpia, Postdoc fellow

UNIVERSITY OF LEEDS



René Oudmaijer, Rob Pomohaci (University of Leeds)
Willem-Jan de Wit (ESO Chile)

Binarity in high-mass star formation

Why study them?

- Significant influence on high-mass star formation and evolution
- **>** 80% of main sequence O stars are found in tight binaries or multiples (Chini et al. 2013, Sana et al. 2014)
- Observations and statistics for young massive stars are lacking

Proposed formation mechanisms

- Capture assisted by a disk in competitive accretion (Bally & Zinnecker 2005)
- Disk fragmentation (Krumholz+2009, Rosen+2016, Meyer+2018)
- Dynamical hardening (Dale & Davies 2006)
- Magnetic breaking (Lund & Bonnell 2018)

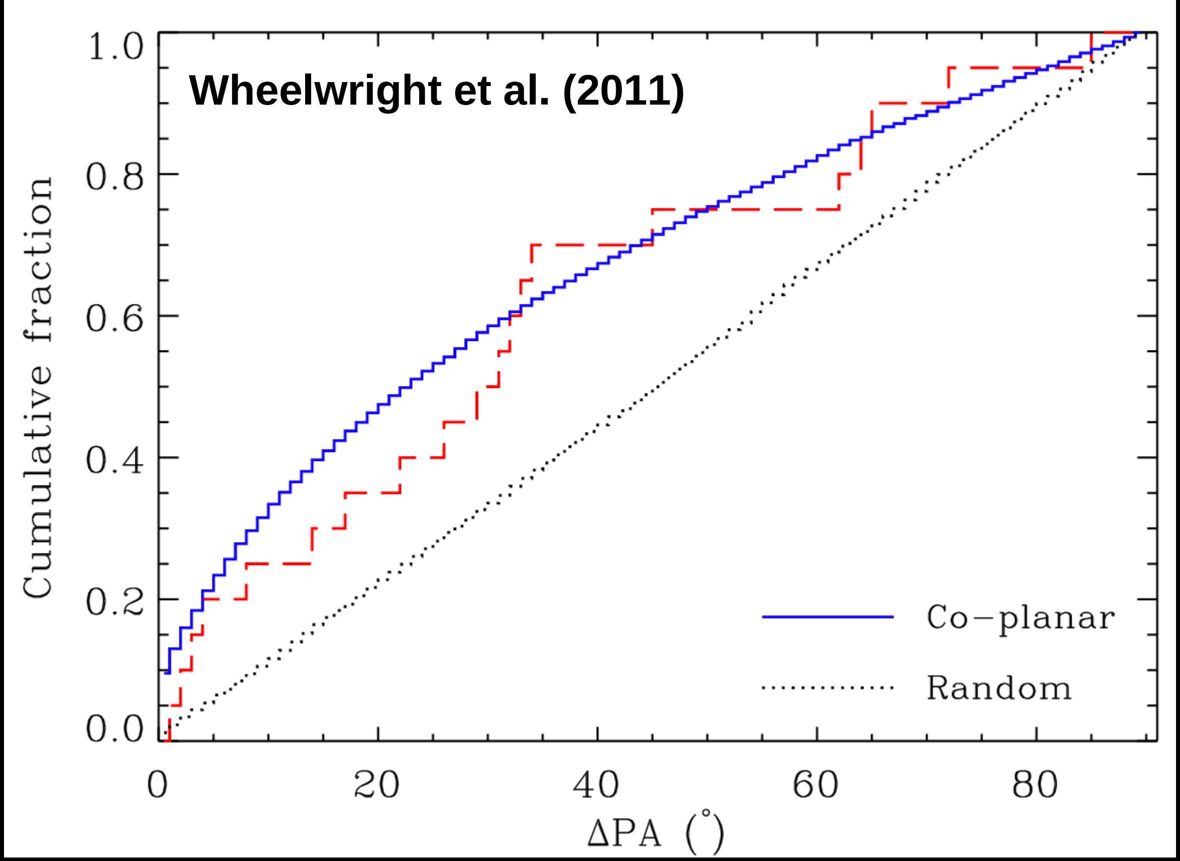
- **Note**: Different theories favor the formation of wider or of more compact binaries and of various mass ratios → Troubles predicting high-mass close binaries

Observational input not only will inform those theories (q, a) but will also help to distinguish among them

How can observations distinguish among theories?

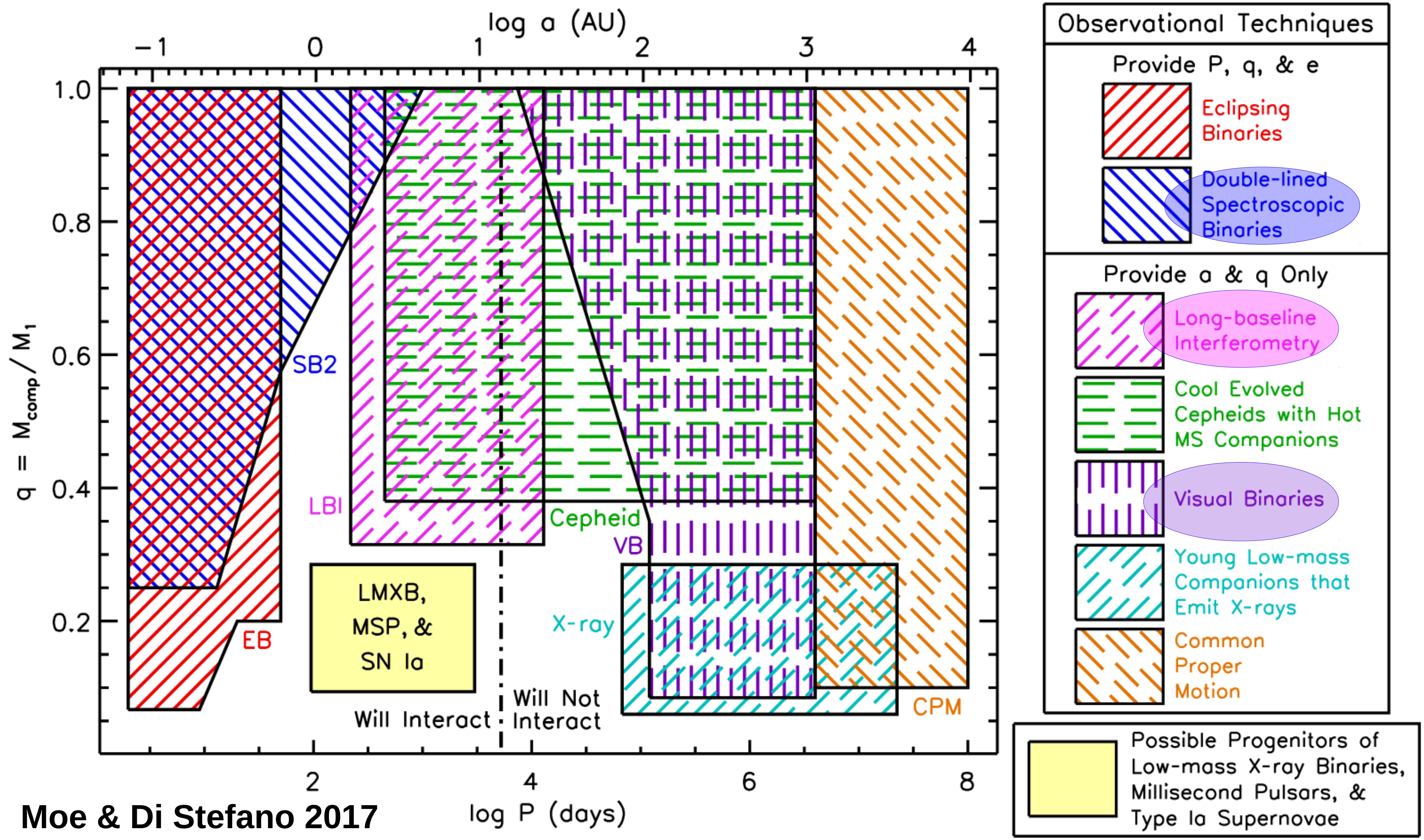
Example

• The disk fragmentation scenario favors co-planarity of the primary disks with binary orbits (Wheelwright et al. 2011)



• Kraus et al. 2017 found a massive protobinary (IRAS 17216-3801; 170 au) with the circumprimary disk is strongly misaligned w.r.t the binary separation vector

Observing binaries



Moe & Di Stefano 2017

Multiple techniques are required to cover the full range of the parameter space

The “LEEDS approach” - Observations

Visual binaries (wide)

Instrument: AO/K-band (2.2 micron) imaging (NaCo/VLT), θ = 0.12”

- Sample: 32 MYSOs (10-20 M⊙, L ~ 15000L⊙, d ~ 3.3 kpc, K < 10.5, taken from the RMS survey)

Long baseline interferometry (close)

Instrument: VLTI on Uts, θ = 1.3 mas

- PIONIER (H band; 1.6 micron) → Sample: 2 MYSOs (PDS 27, PDS 37)
- GRAVITY (K band; 2.2 micron) → Sample: 10 MYSOs

Spectroscopic binaries (compact)

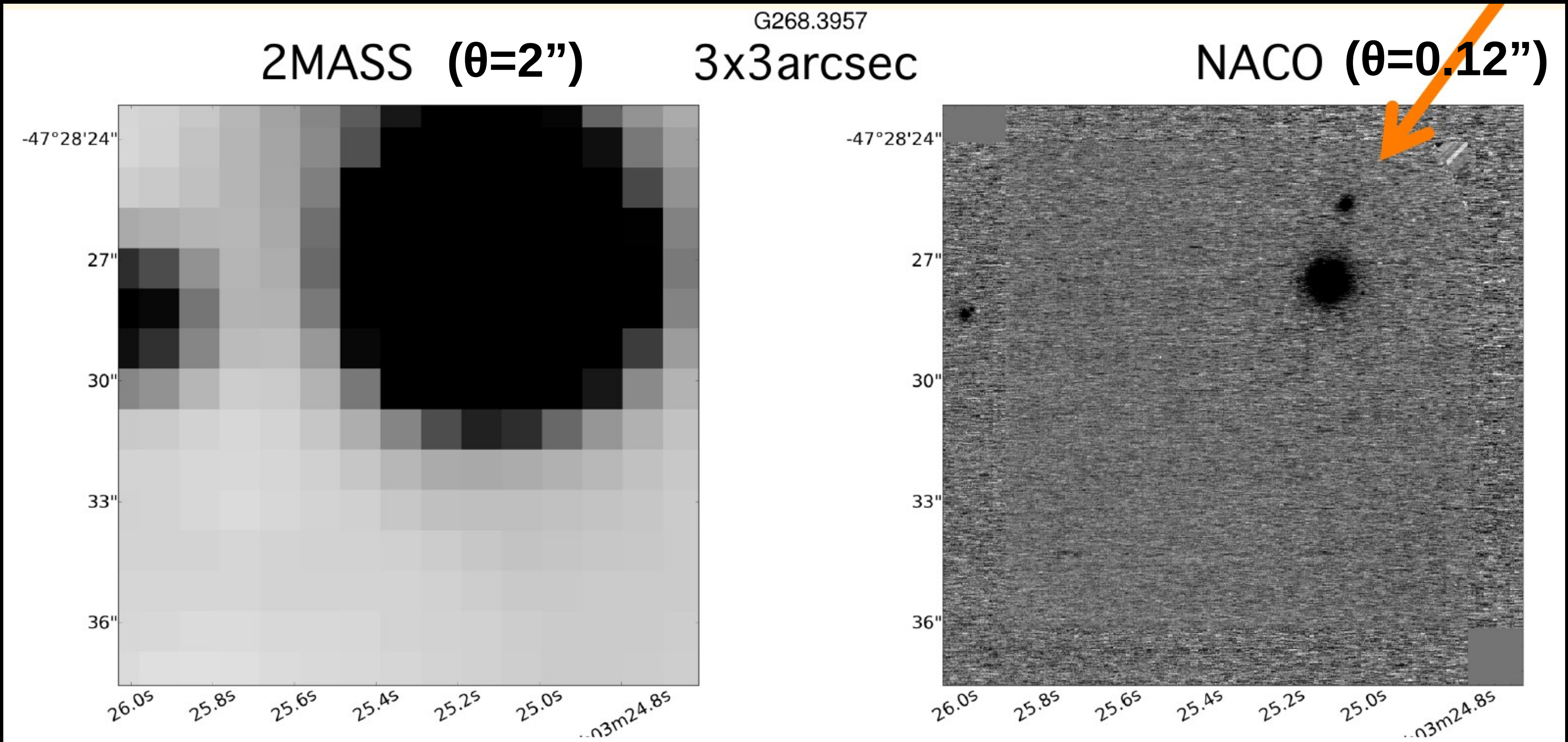
- Instrument: X-Shooter/VLT, K band; R ~ 10000
- Sample: 69 MYSOs, 1st and 2nd epoch spectra (awarded 30 hours)

We aim to combine those techniques in order to fill in the gaps in the parameter space and derive the young massive binary fraction

Visual high-mass binaries

Searching for MYSO binary companions

- Contrast of ΔK = 5 mag at 1-3” and ΔK = 3 mag at 0.3”
- Covered separations: 600 - 10,000 au
- Companions are observable for separations 1000 – 10000 au, q > 0.5 and similar brightness → multiplicity fraction of about 30% within 3”



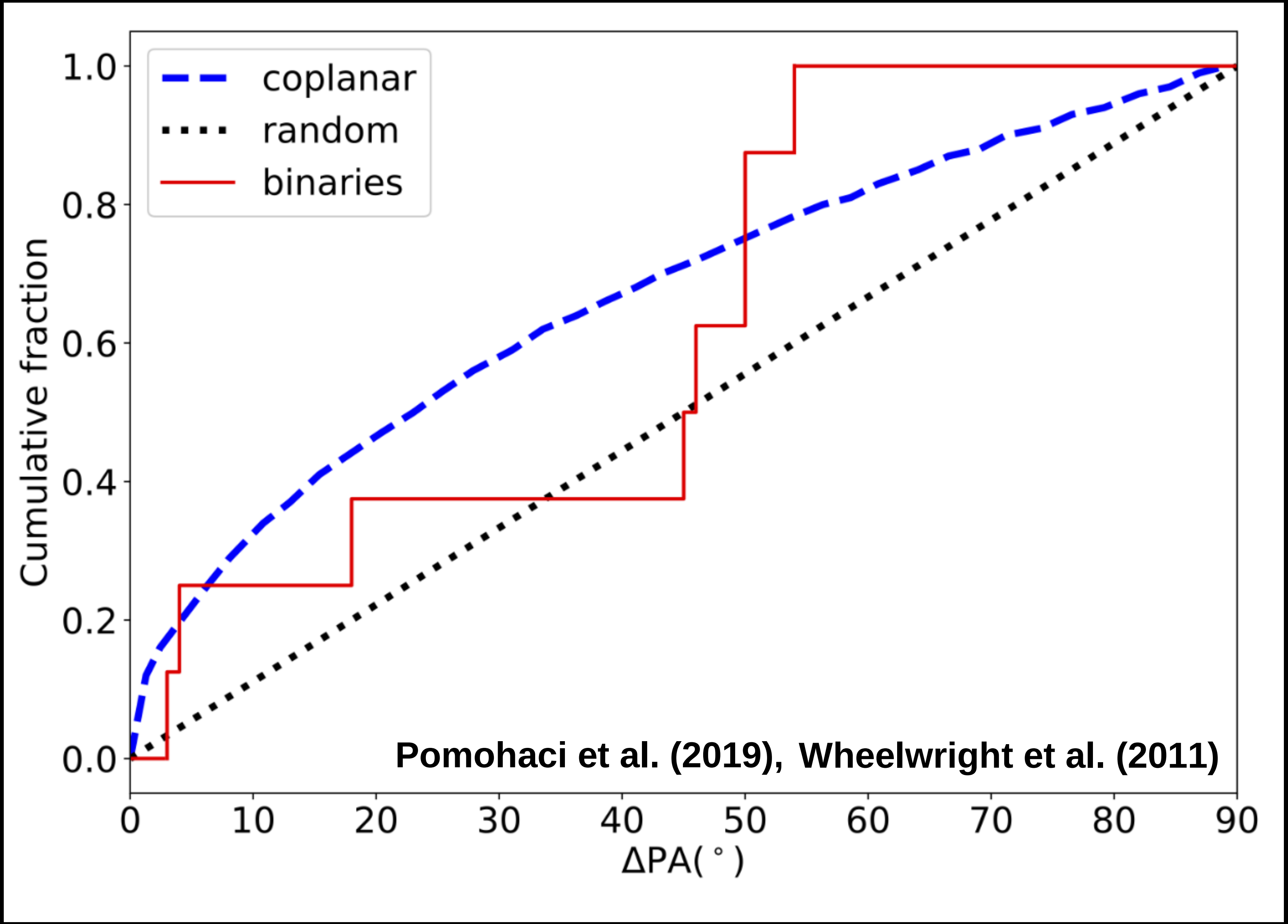
Pomohaci et al. 2019

NaCo/VLT survey -- Results

• Multiplicity fraction of MYSOs is found to be ~30% within 3” for the separation and mass ratios at which the NACO observations are sensitive to. Extrapolation shows higher percentages up to 100% for a wider separation and mass rate range.

• Crudely estimated mass ratios > 0.5 (lower limits) → larger than what is expected from randomly sampling the IMF, as the binary capture formation predicts, but higher accuracy is needed.

Orbits/disks orientations: coplanar vs random

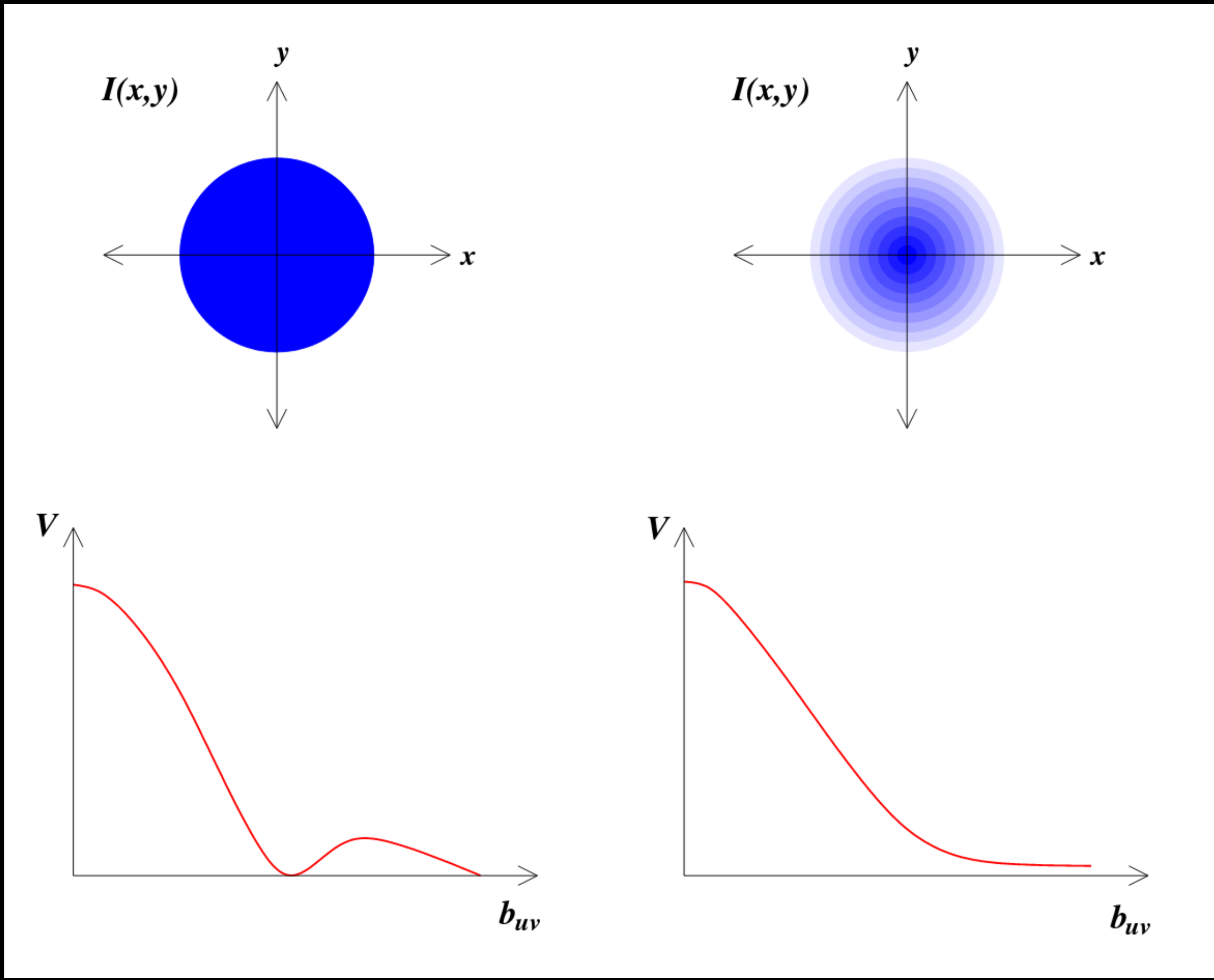


Insufficient amount of sources with disk orientation measurements → cannot safely differentiate between coplanar vs random orientations.

Long baseline Interferometry

What can NIR interferometry do for us?

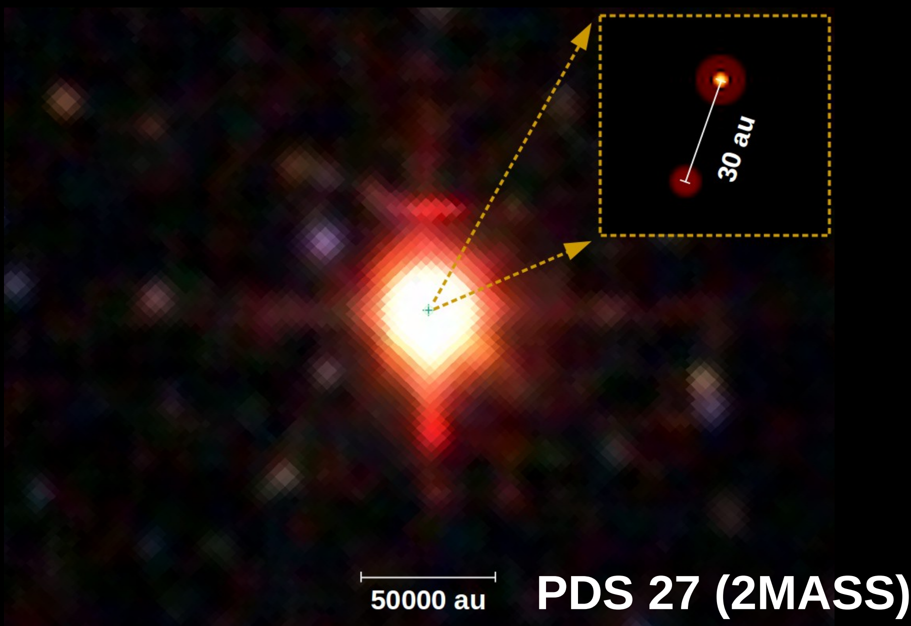
Depending on the brightness distribution of the emitting region:
a) **Visibility**: 1; unresolved, 0; resolved and, b) **Closure phases**: $\neq 0^{o}$ → flux asymmetries

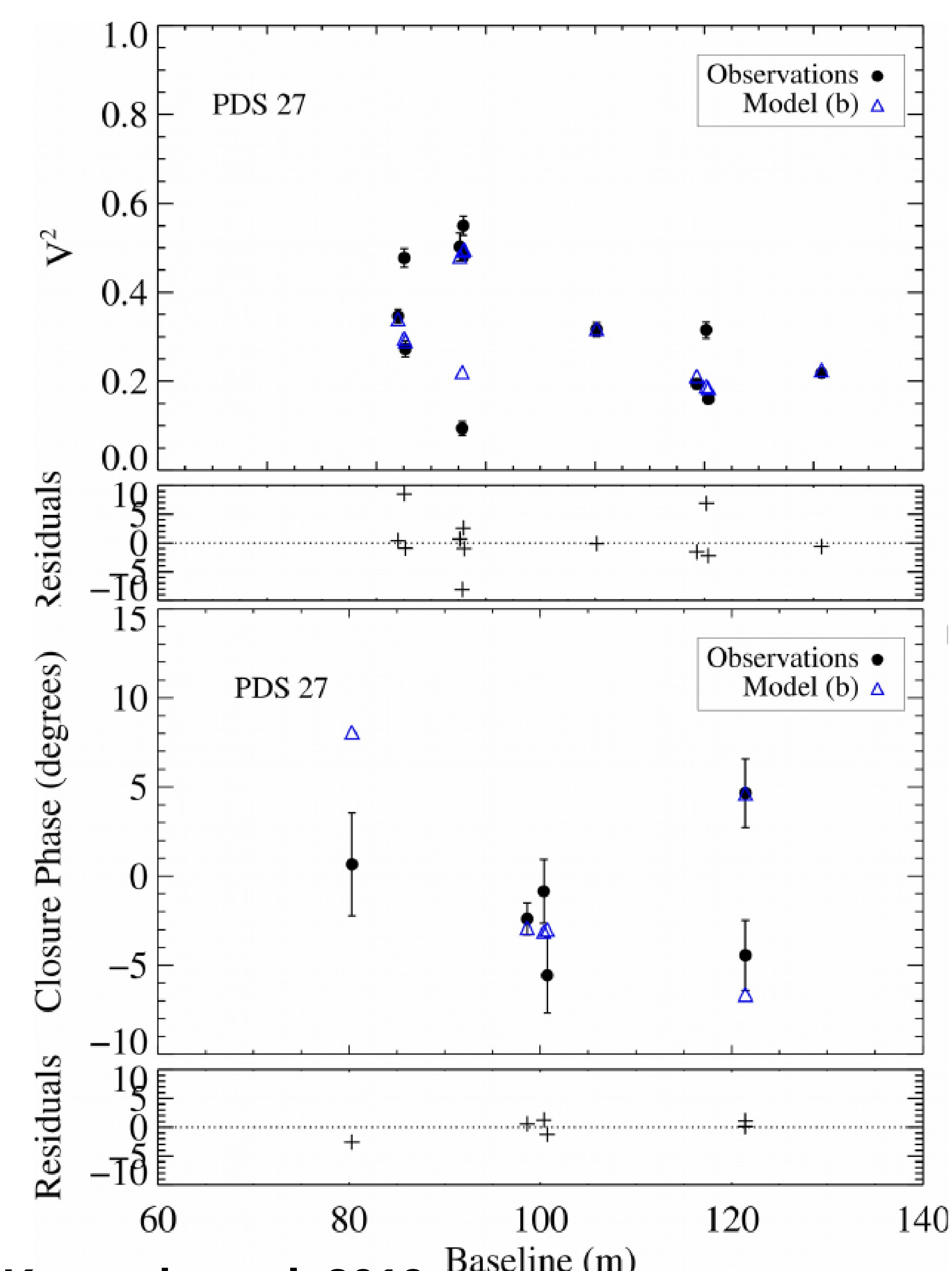


(Ilee & Greaves (2015))

Left) **Uniform disk** → **sinc-like** function in visibility
Middle) **Gaussian** → **smoothly declining** visibility curve
Right) **Binary** of equal brightness components → **sinusoidal-like** visibility curve

Discovering/resolving the tightest MYSO binary to date





Koumpia et al. 2019

PDS 27/37 -- Results

- We spatially resolve PDS 27 and PDS 37 for the first time, finding companions at 12 mas (30 au) and at 22-28 mas (42-54 au) respectively (Koumpia et al. 2019). These are two of the most **compact** and **massive** (>8 $M_\odot$) YSO binaries to date traced using thermal IR emission (see also Kraus et al. 2017, Zhang et al. 2019)

- The binary nature of PDS 27 is also supported by FORS2 spectroscopic observations (FORS2, X-Shooter/VLT) suggesting an orbital period of $\sim$10 years.

Take away points

• The first survey dedicated to multiplicity of MYSOs reveals a fraction ~30% (can be up to 100 %) (Pomohaci et al. 2019).

• PDS 27 and PDS 37 are the most compact and massive YSO binaries resolved to date. Using thermal IR emission we find physical separations of 30 au and ~50 au respectively (Koumpia et al. 2019).

• Complementary techniques on the youngest high mass binaries are important to cover the parameter space properly. Combined observations will distinguish among the formation theories and will quantitatively inform them.

– Co-planar vs random disk orientations in respect with orbit, can be used to support or not the disk fragmentation scenario.

– Accurate mass ratio (q) measurements can be used to support or not the binary capture formation scenario.

In progress & Future – Stay tuned!

NIR interferometric mini-survey

Instrument: GRAVITY/VLTI (K-band) (awarded time 15 hours on UTs; ongoing)

- ***Sample***: 10 MYSOs
- ***Aim***: determine the binary properties of MYSOs at intermediate separations (1-160au)
- ***Method***:

 - apply geometric models and image reconstruction techniques around Brγ and CO bandhead emission to a) detect the binaries b) characterize them

NIR Spectroscopic Survey

Instrument: X-Shooter/VLT (awarded time 30 hours / Oct. 2019- April 2020)
NIR, R ~ 10000 (30 km/sec))

- ***Sample***: 69 MYSOs, 37 of which 2nd epoch observations
- ***Aim:*** determine the fraction of close massive binaries (sub-au to few au separations)
- ***Method***:

 - RV measurements using the Brγ emission (2 micron)
 - Predicted periods range from days to 100s of days → combine with RVs within a 3 yr period