Accretion & Ejection processes in star formation
In theory and in practice
30 Nov – 2 Dec, 2022

Probing the multiplicity of young massive stars with NIR long baseline interferometry and high-resolution imaging

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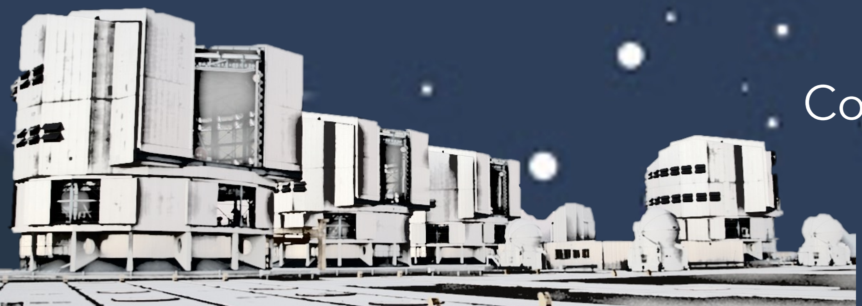
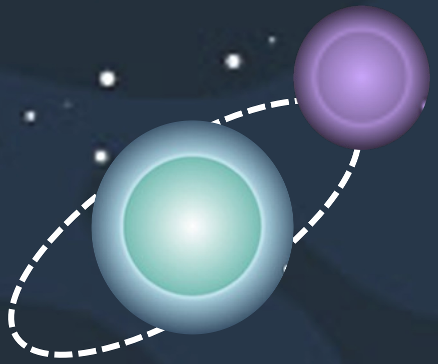
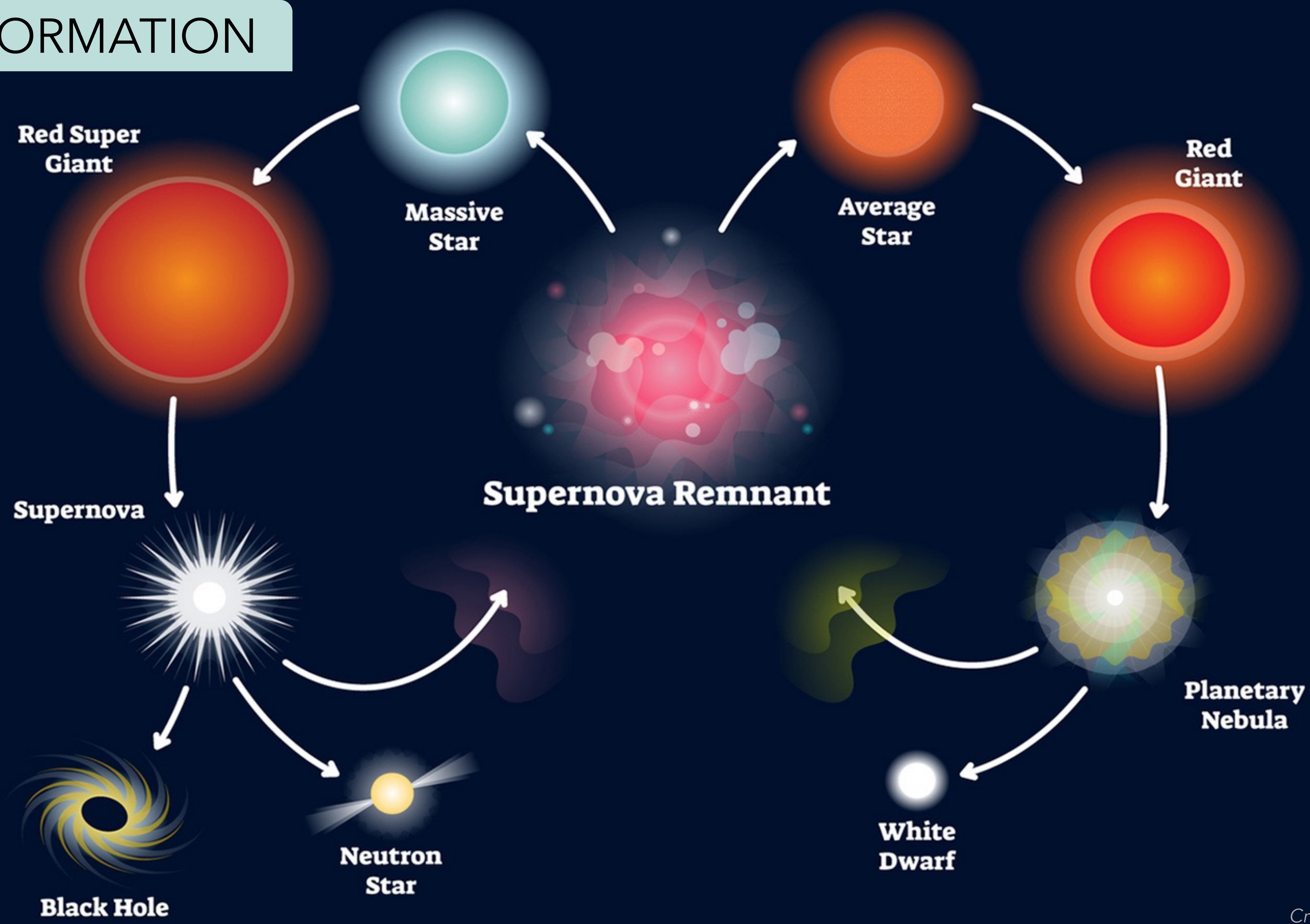




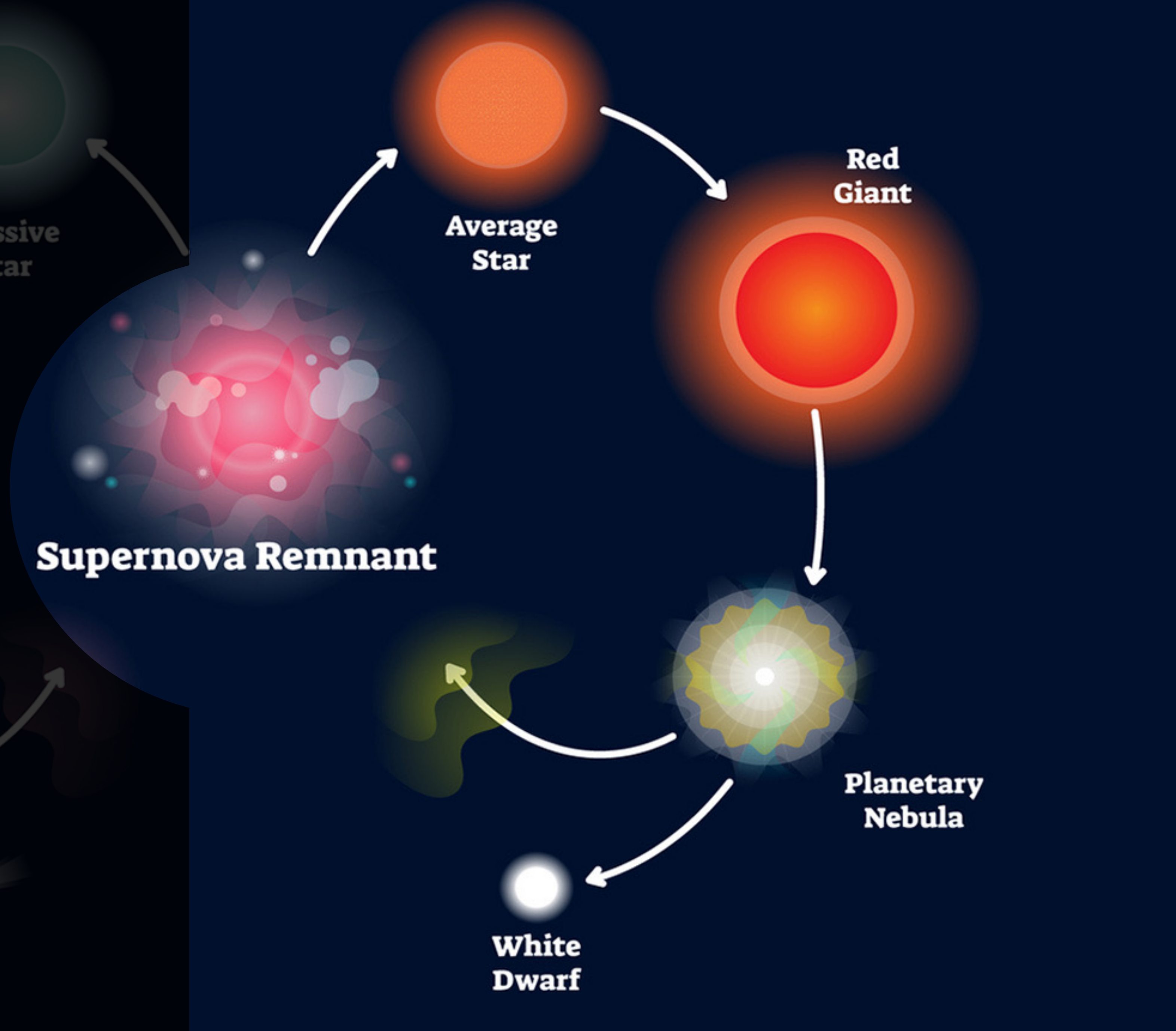
STAR FORMATION



Credit: VectorMine

LOW-MASS STAR FORMATION

- Sun-like stars
- Observational sequence of the formation process
- $\tau_{form} \sim 10^6 years$
- ~30-50% in multiple systems



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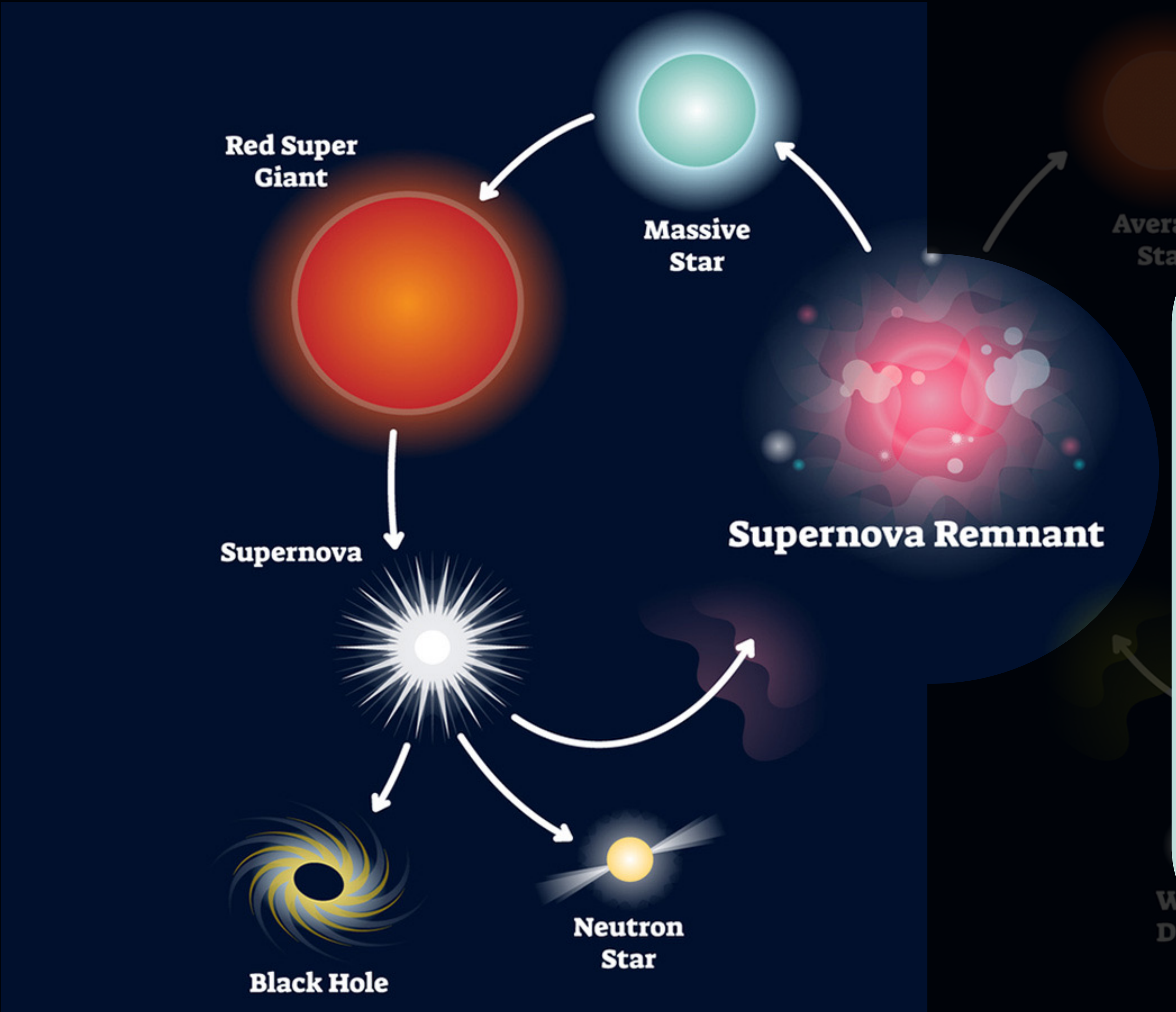


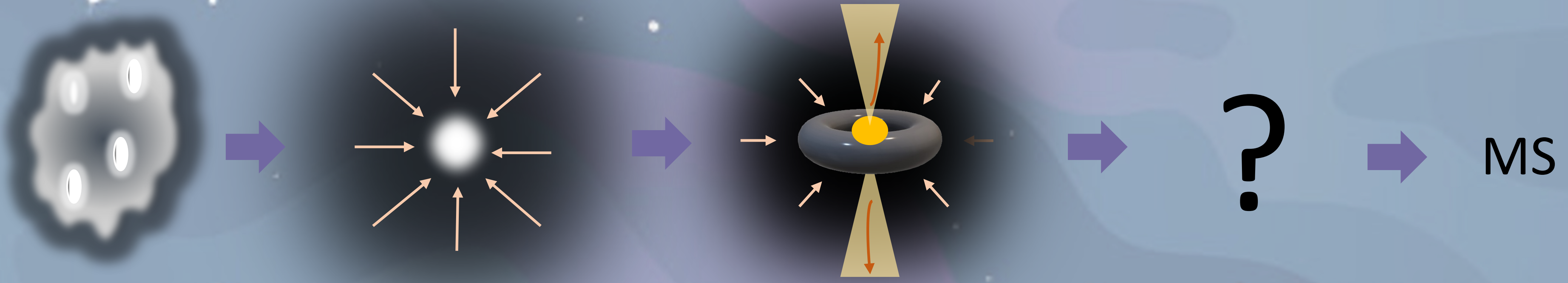
MASSIVE STAR FORMATION

- $M_{init.,star} \gtrsim 8\ M_{\odot}$
- Lifetime ~ few million years
- $\tau_{form} \sim 10^5 years$

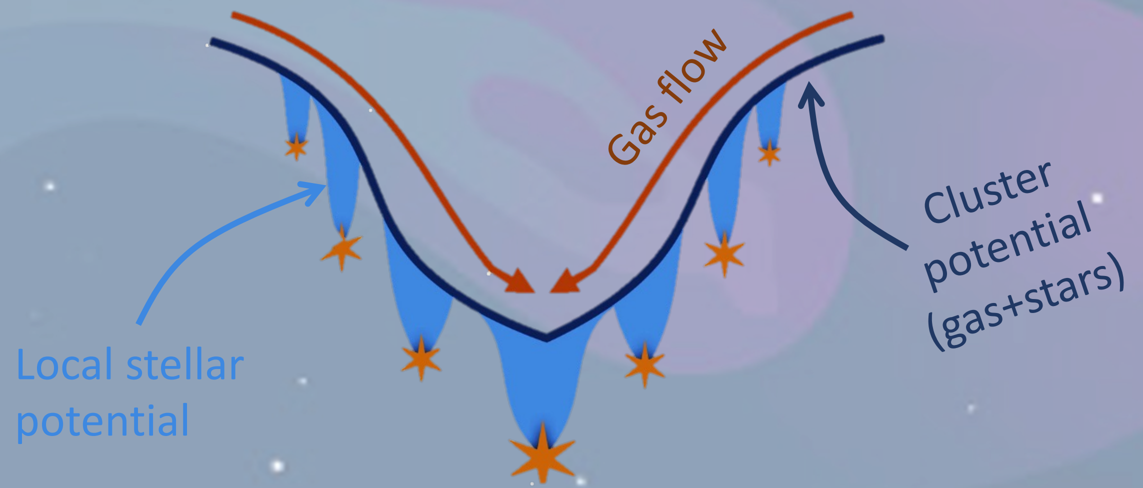
Credit: VectorMine

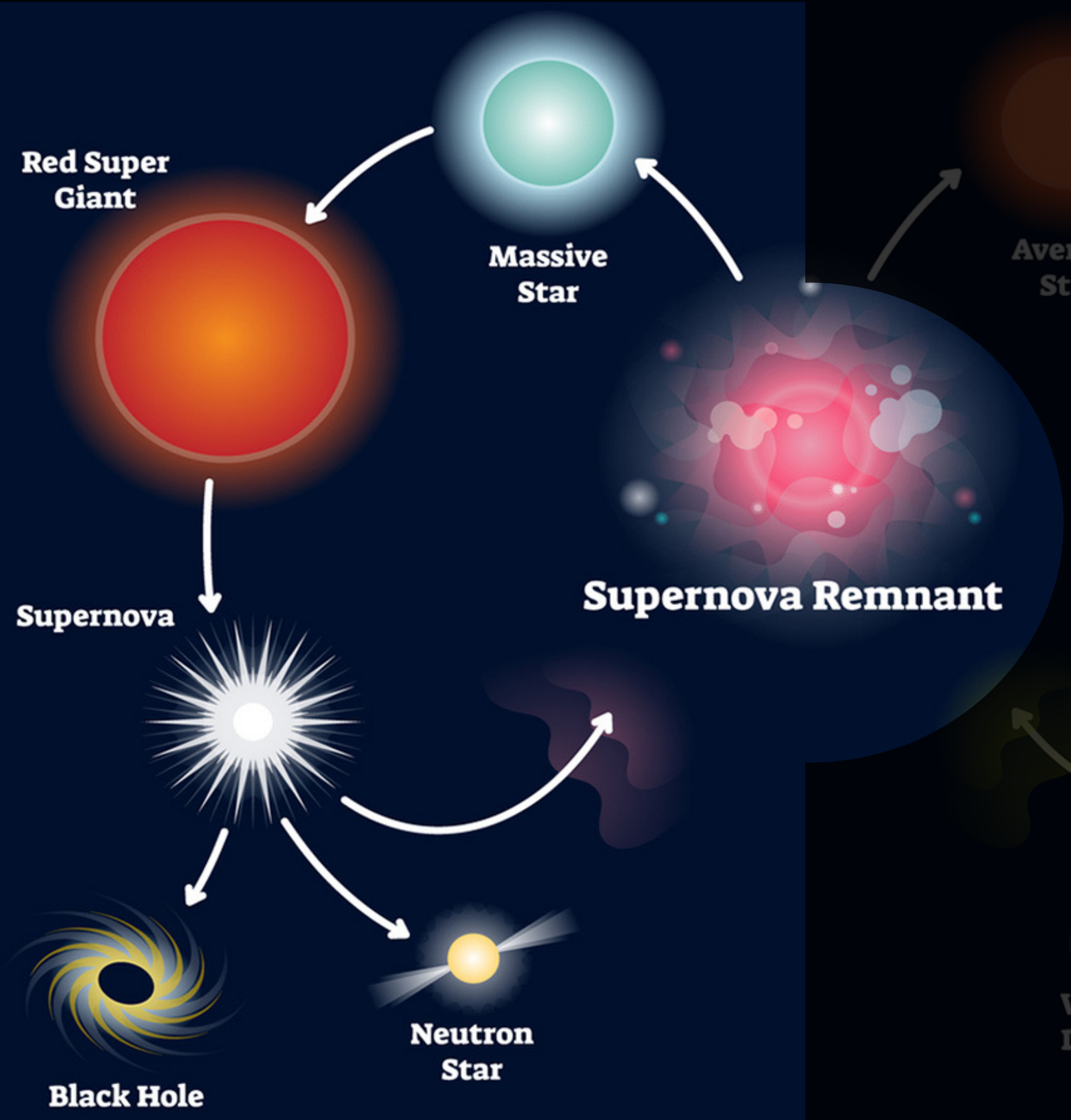
MASSIVE STAR FORMATION IN THE GENERAL CONTEXT OF STAR FORMATION

Monolithic Collapse



Competitive Accretion



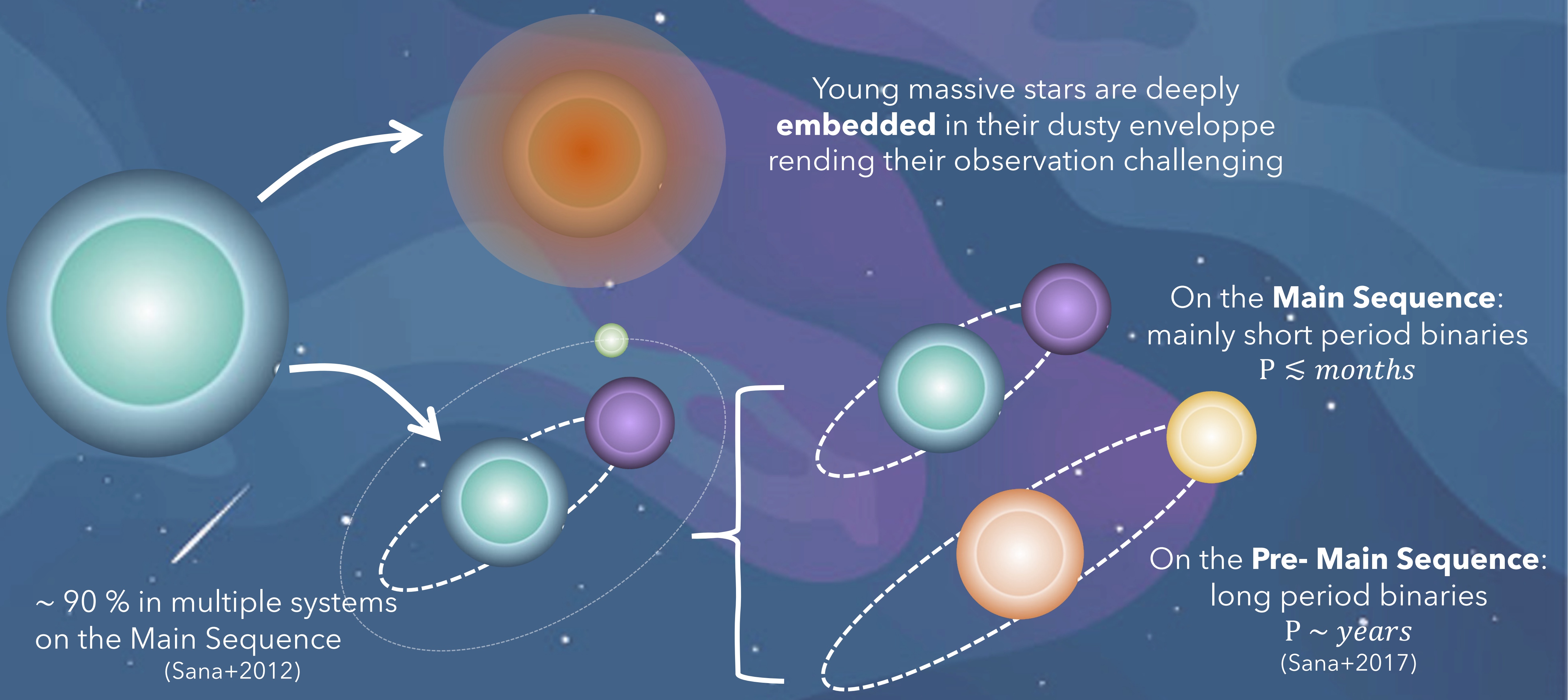


MASSIVE STAR FORMATION

- $M_{init.,star} \gtrsim 8\, M_{\odot}$
- Lifetime ~ few million years
- $\tau_{form} \sim 10^5 years$
- **More than 90% of OB stars are in multiple systems**

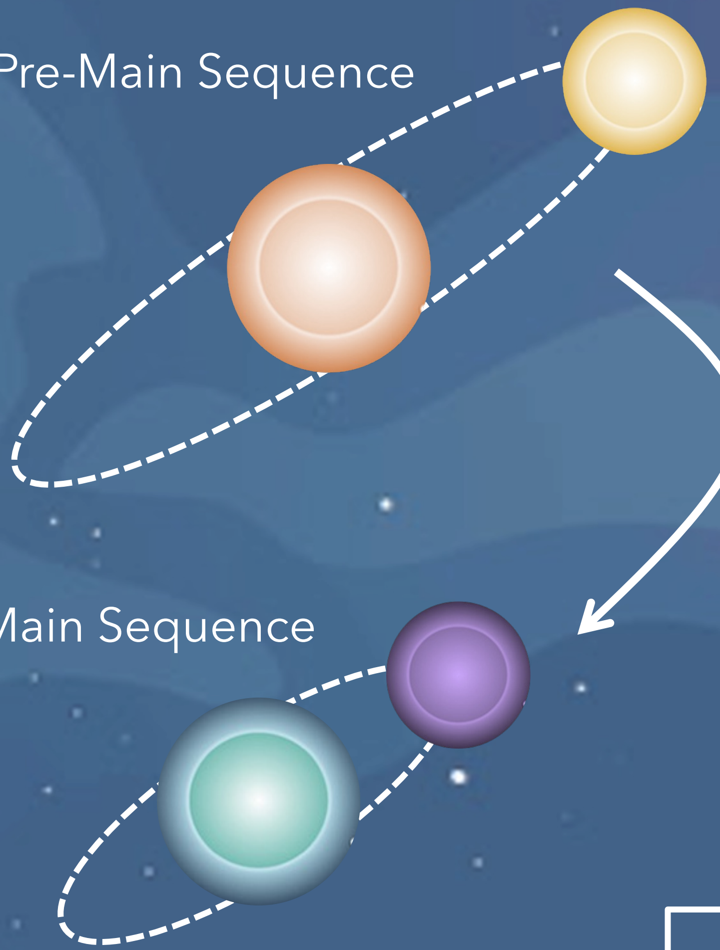
Credit: VectorMine

WHY MASSIVE STAR FORMATION IS STILL POORLY UNDERSTOOD?



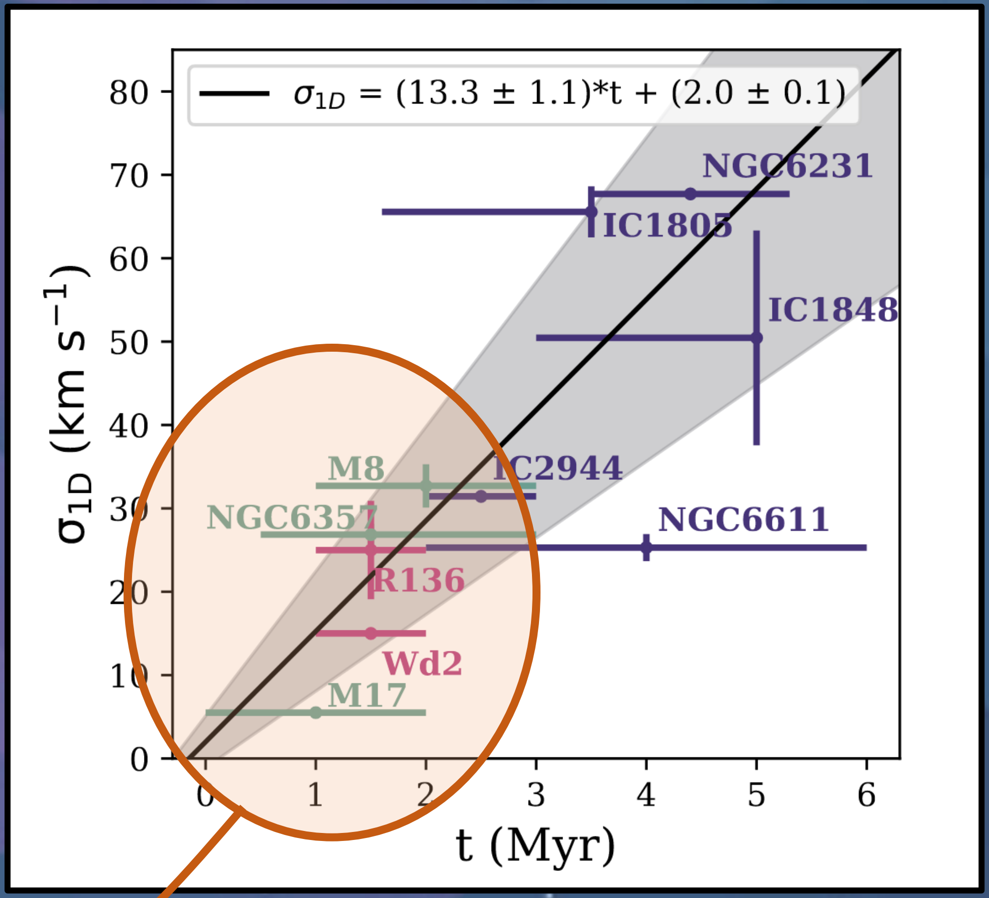
THE MIGRATION SCENARIO

Pre-Main Sequence



Radial velocity dispersion drops

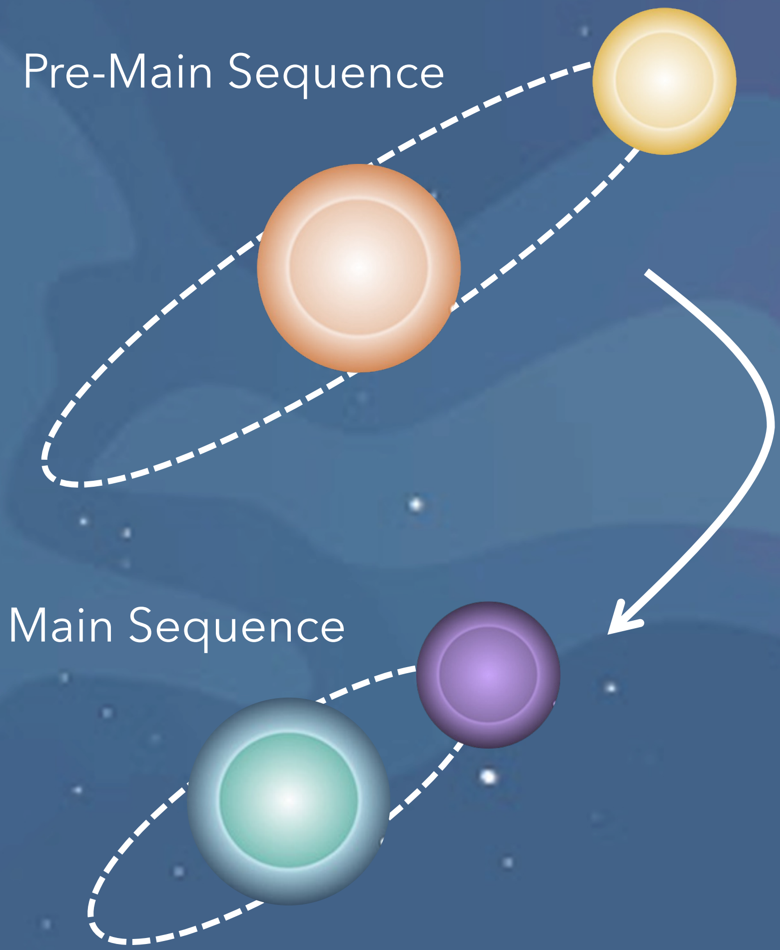
Main Sequence



(Ramirez-Tannus+2021)

Lack of short period binaries

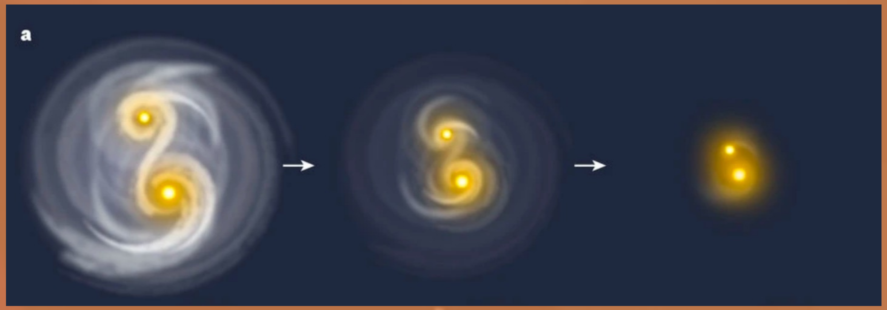
THE MIGRATION SCENARIO



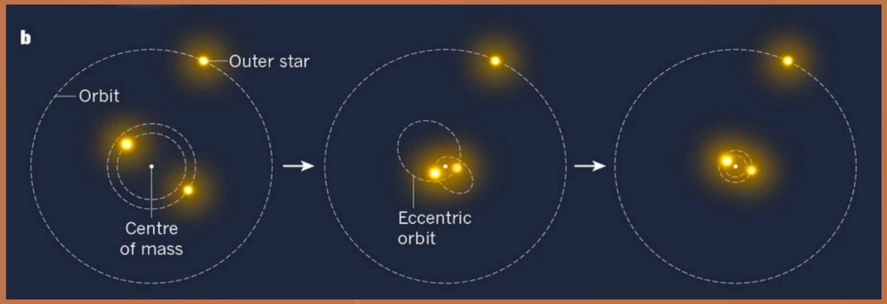
Binaries are born at larger separations

The system hardens on a time-scale of 2 Myrs or less

Through their interaction with gas

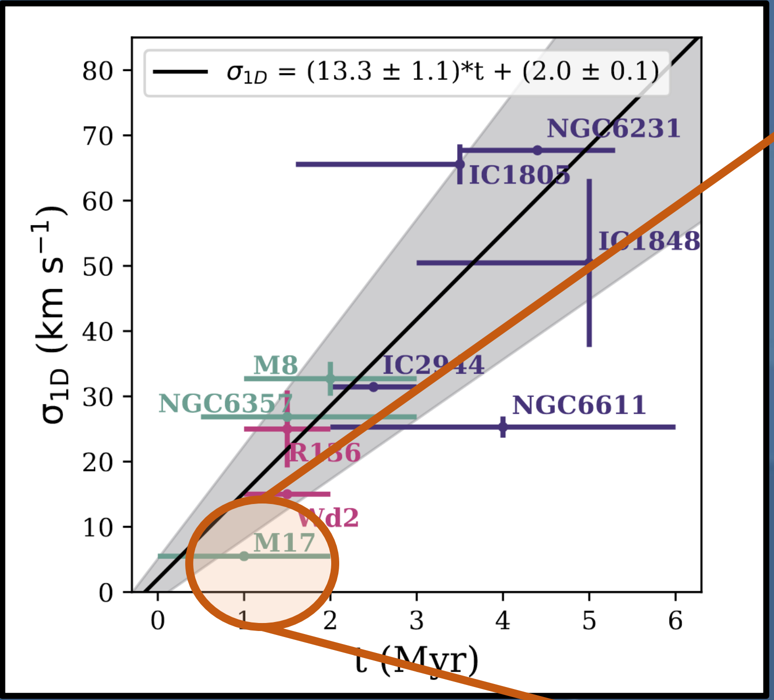


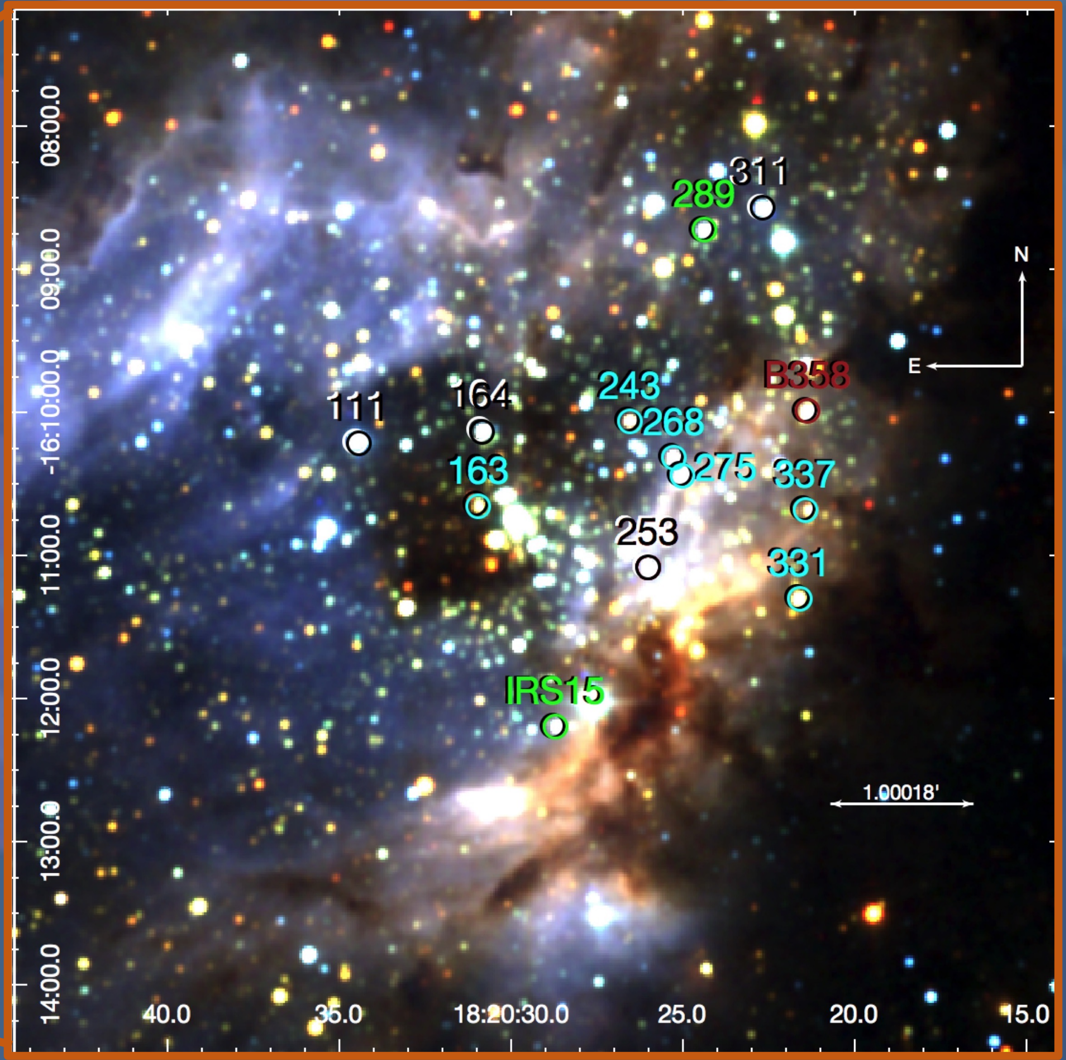
Through their interactions with (small) bodies in the accretion disk



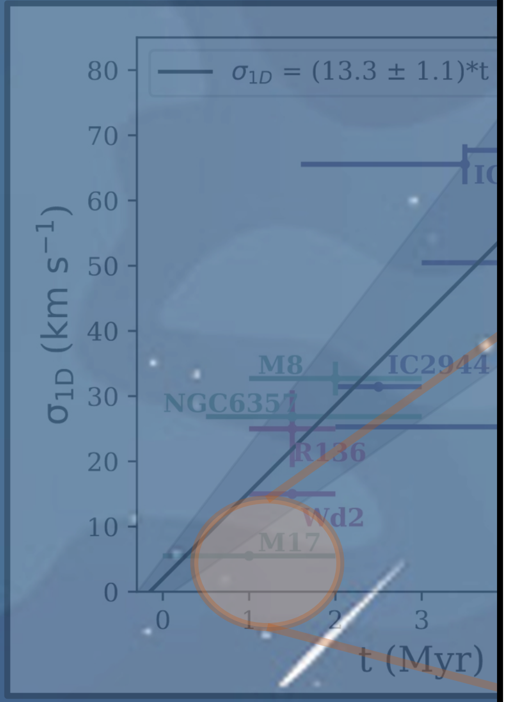
OBSERVING YOUNG MASSIVE STARS

1. Choice of the scientific object

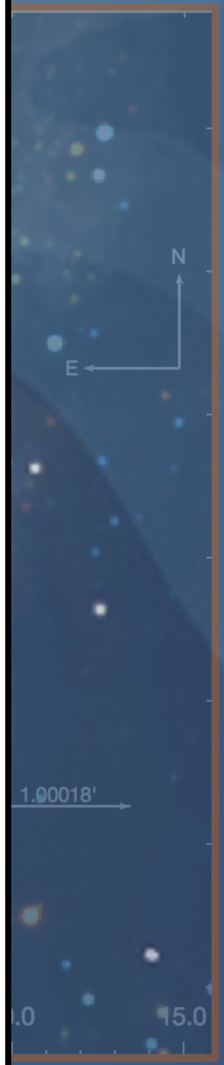




OBSERVING YOUNG MASSIVE STARS



Source	Emission lines	CO bandhead	NIR excess	Classification
B111	–	–	–	O star
B163	–	+	+	mYSO
B164	–	–	–	O star
B215	–	–	$*^a$	B star?
B243	+	+	+	mYSO
B253	–	–	–	B star
B268	+	+	+	mYSO
B275	+	+	+	mYSO
B289	–	–	$*^a$	O star?
B311	–	–	–	O star
B331	+	+	$*^a$	mYSO
B337	+	–	+	mYSO



OBSERVING YOUNG MASSIVE STARS

2. Choice of the instrument

Detecting young massive binaries

- Young massive stars are deeply embedded:

  → Infrared (IR)

- Resolving binaries from 1 mas to 100 mas to test for the migration scenario:

  → High-angular resolution

⇒ **Near IR (K-band) Interferometry with GRAVITY**

OBSERVING YOUNG MASSIVE STARS

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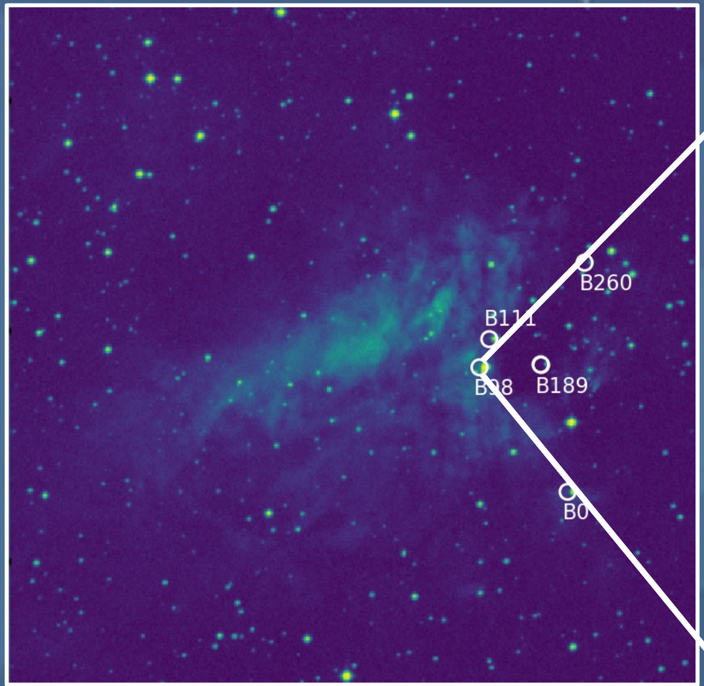
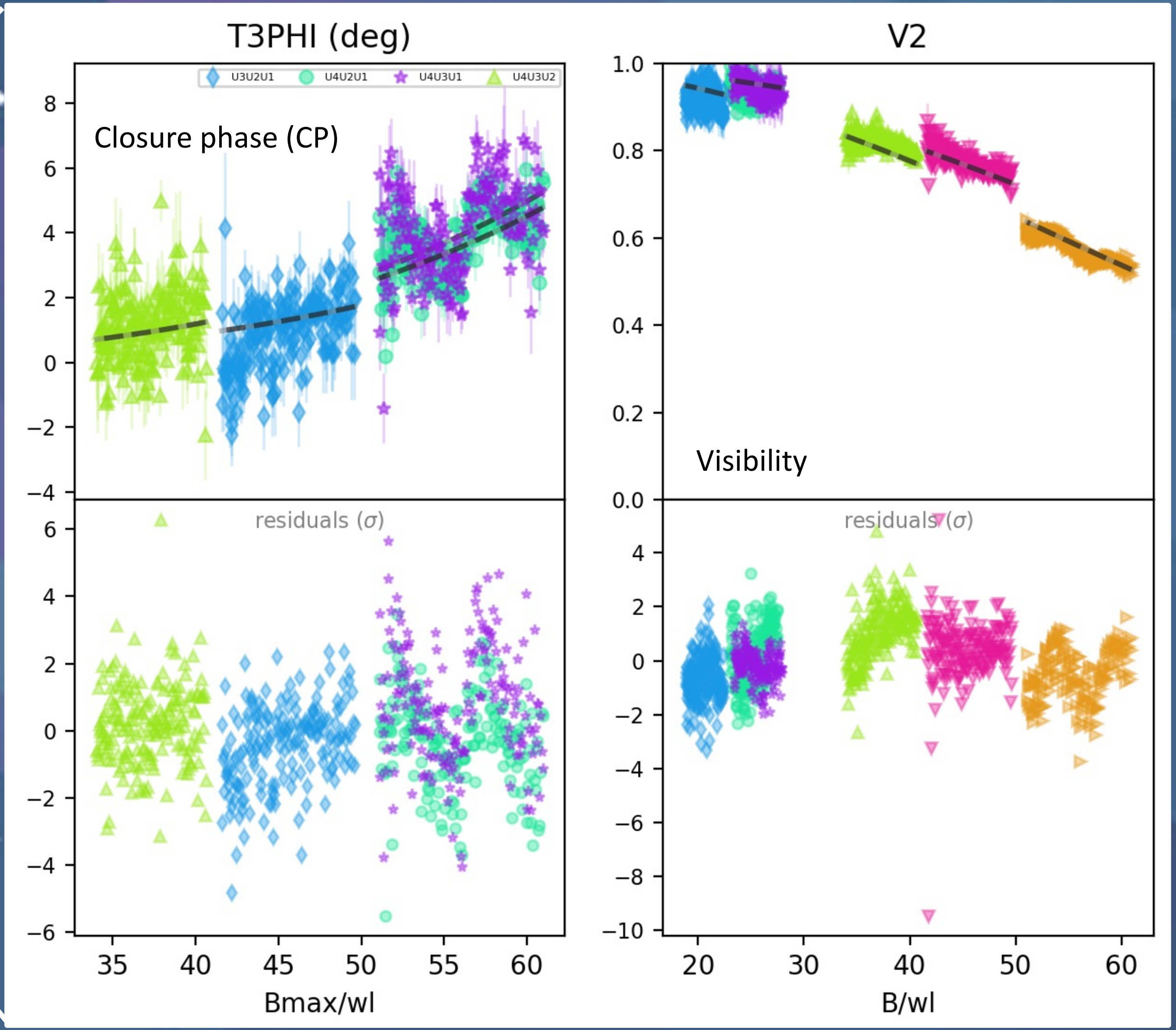
VLTI/GRAVITY+UTs

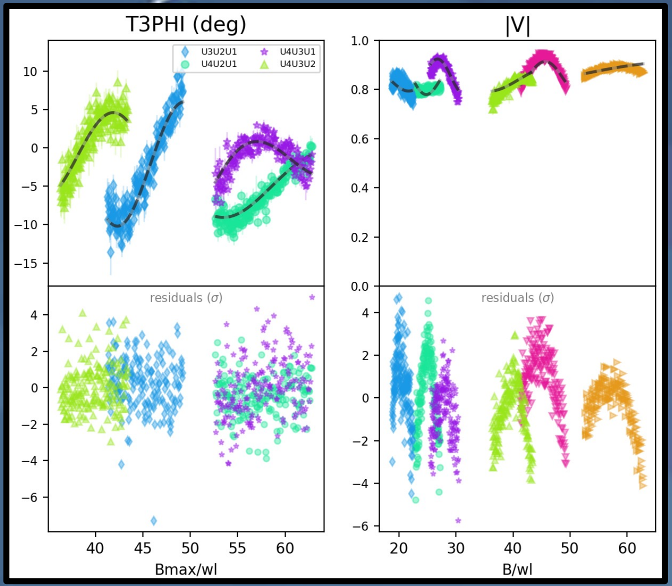
M17 and GRAVITY+UTs observations

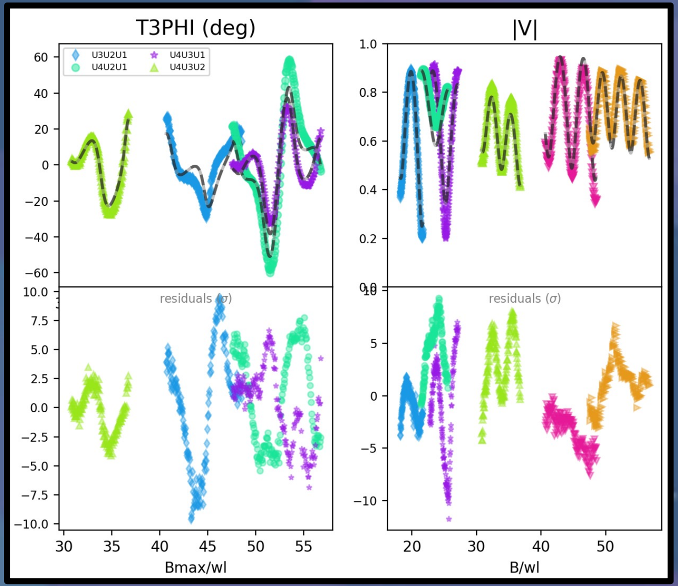


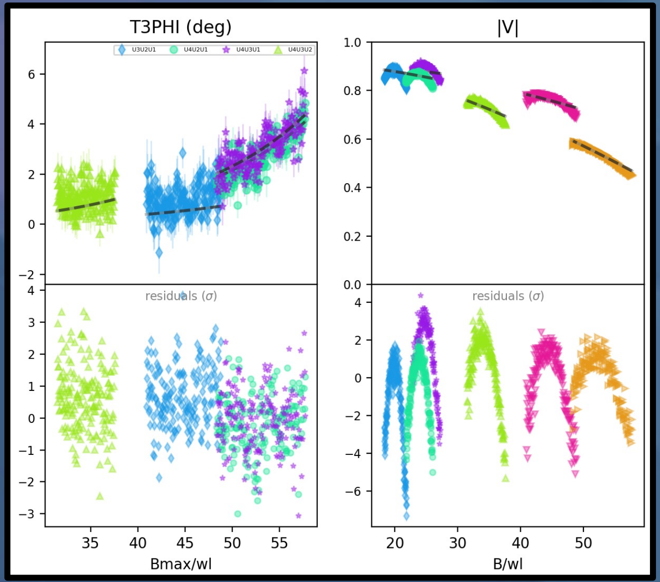


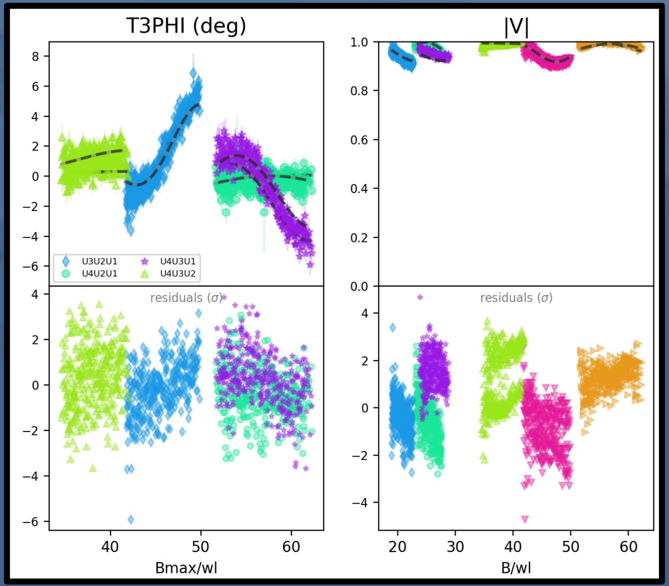
- 6 young O-stars
- $7 < K_{mag} < 9$
- Have reached the ZAMS
- 5 spectroscopic companions reported

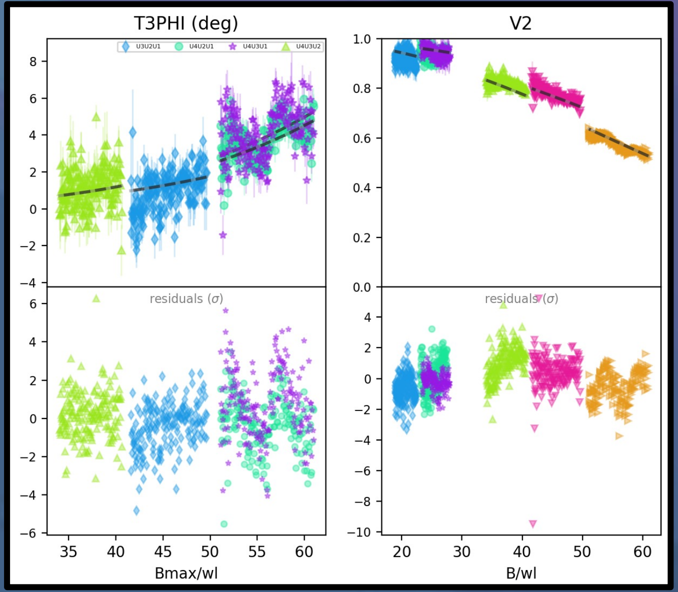
MODEL FITTING RESULTS

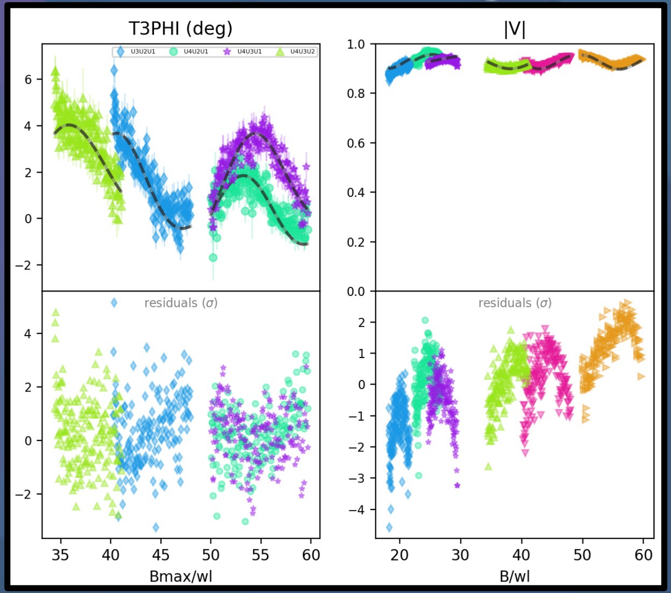






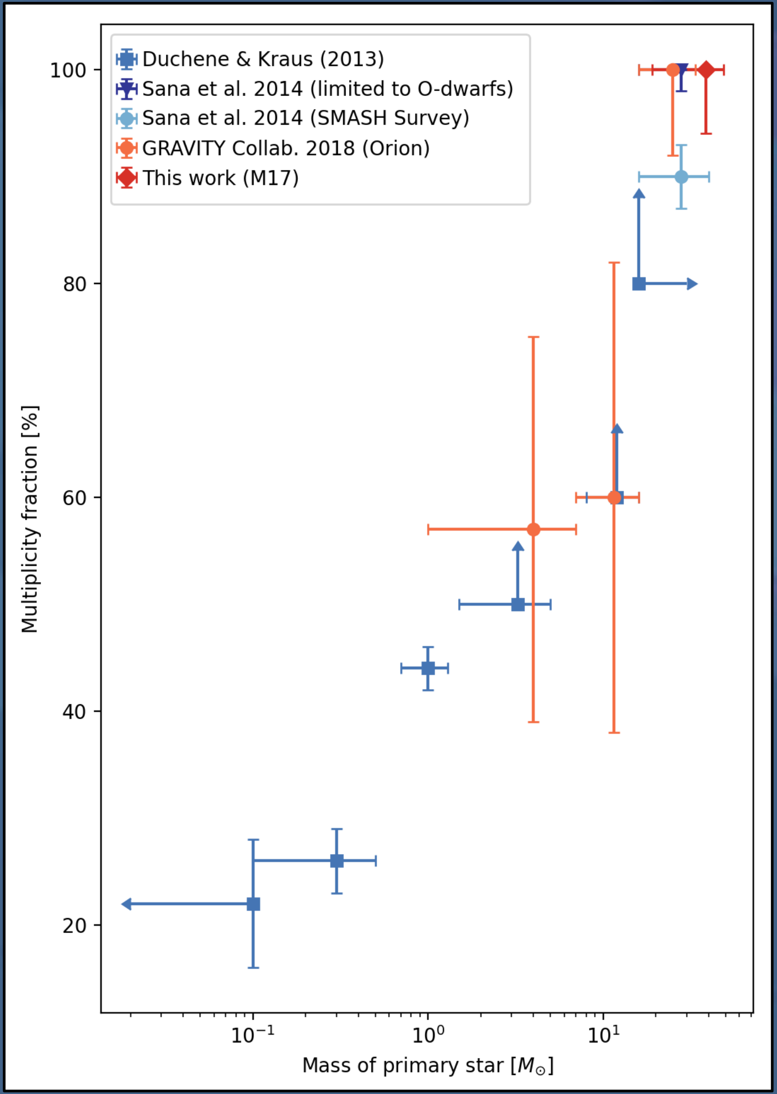






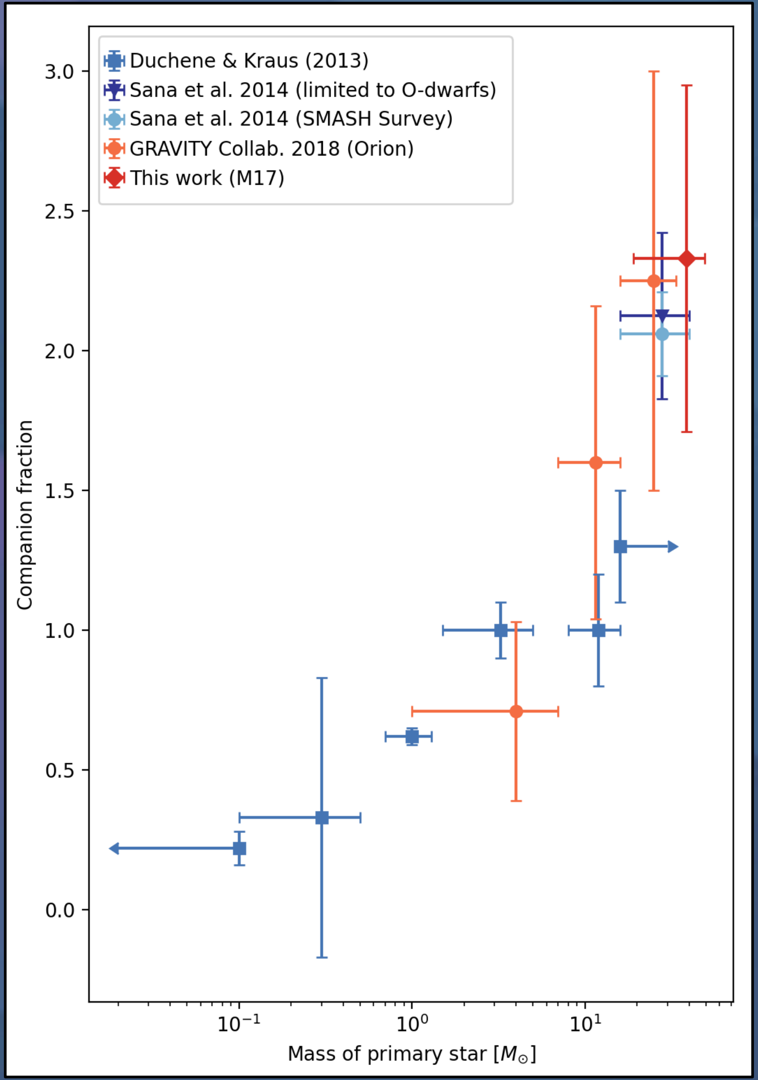
MULTIPLICITY RESULTS

- **ALL** of the sources are involved in a multiple system



Multiplicity fraction:
100%
94% at the 68% confidence interval

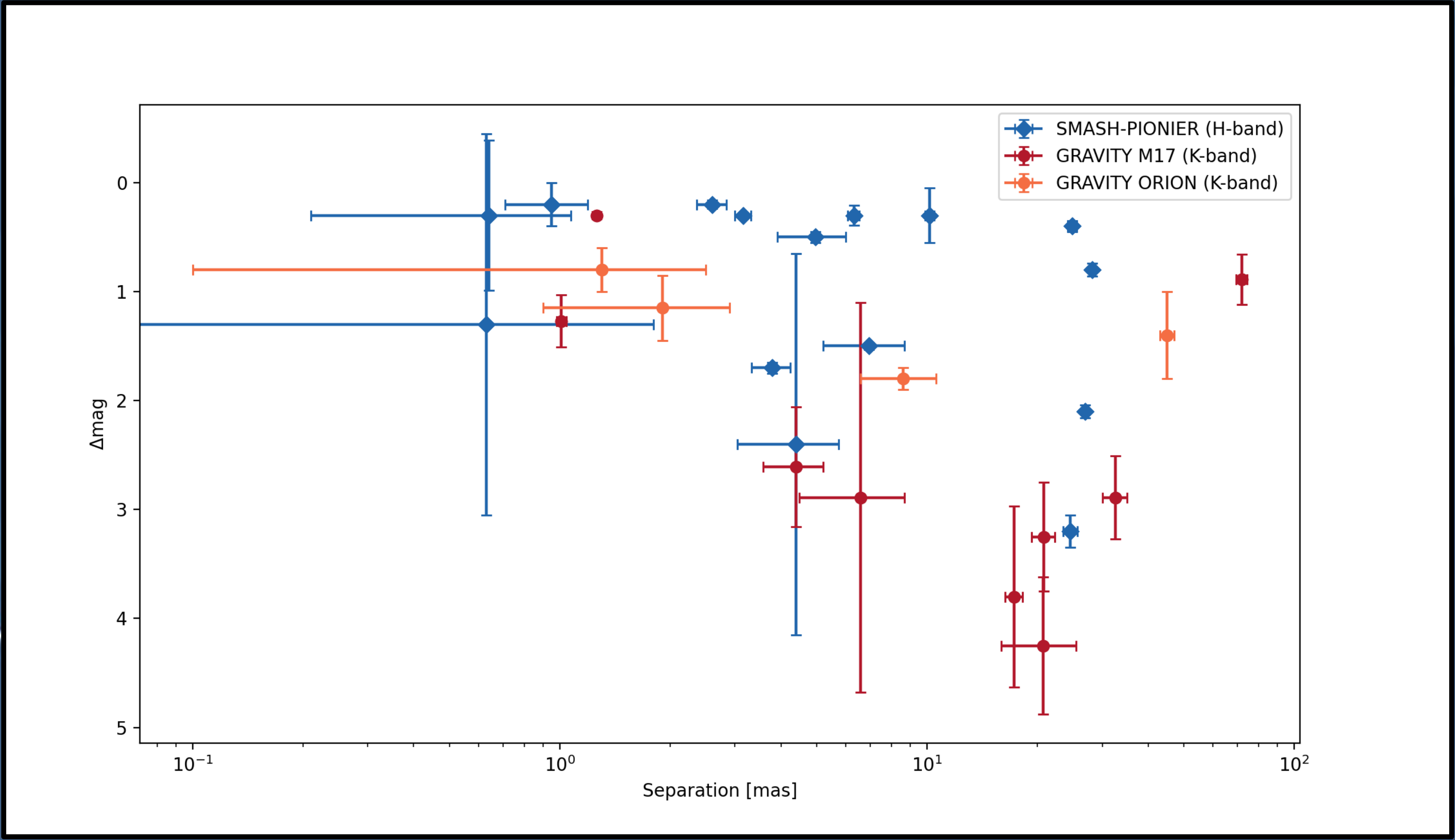
Companion fraction:
2.3 ± 0.6



Bordier+2022

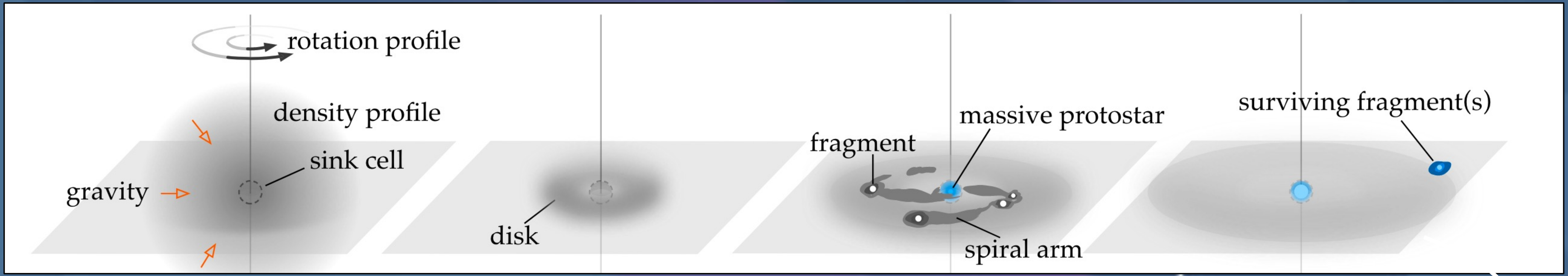
SEPARATION RESULTS

- **9 companions found between 1 and 120 au**

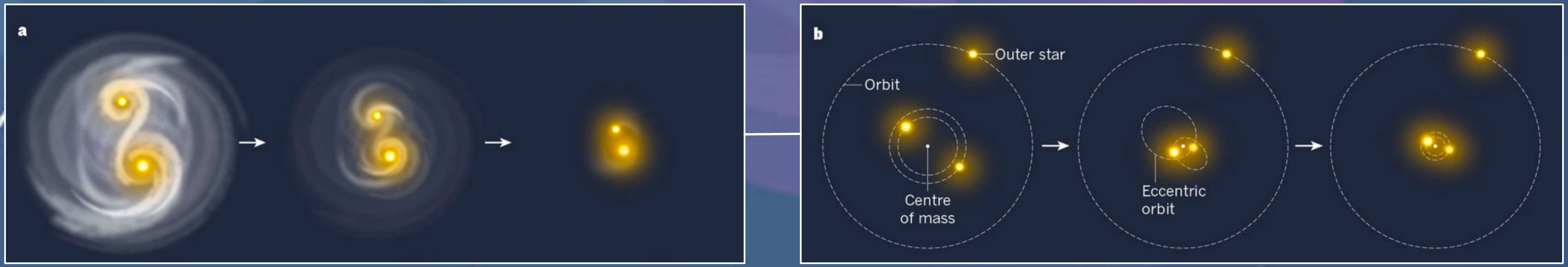


MIGRATION SCENARIO?

- Companions span a wide range of separations: 1-120 au around the primary star



Oliva+2020

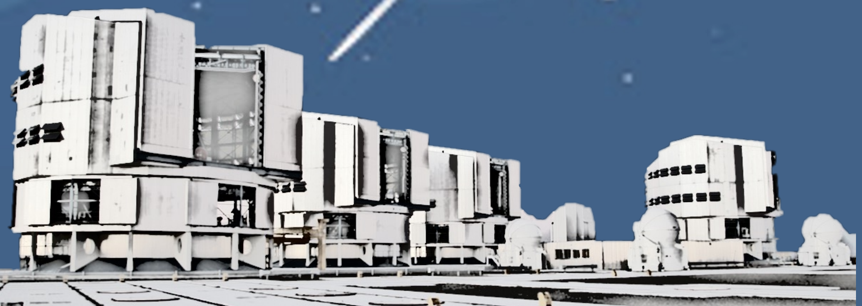


TAKEAWAYS

- 100% multiple systems at ZAMS, with 2.3±0.6 companions on average, at the traced scales (up to 120 au) , in the M17 star-forming region

- Despite the cluster environment and age, M17 shows consistency with the previous studies in terms of multiplicity and companion fraction, for the O stars populations.

- Disk fragmentation forms companions and provide a viable framework for migration. The models will be better constrained with more observations, especially among the youngest stars.



DOES THIS TREND EXTEND TO THE YOUNGER MASSIVE STARS?

FORMATION

PRE-MAIN SEQUENCE

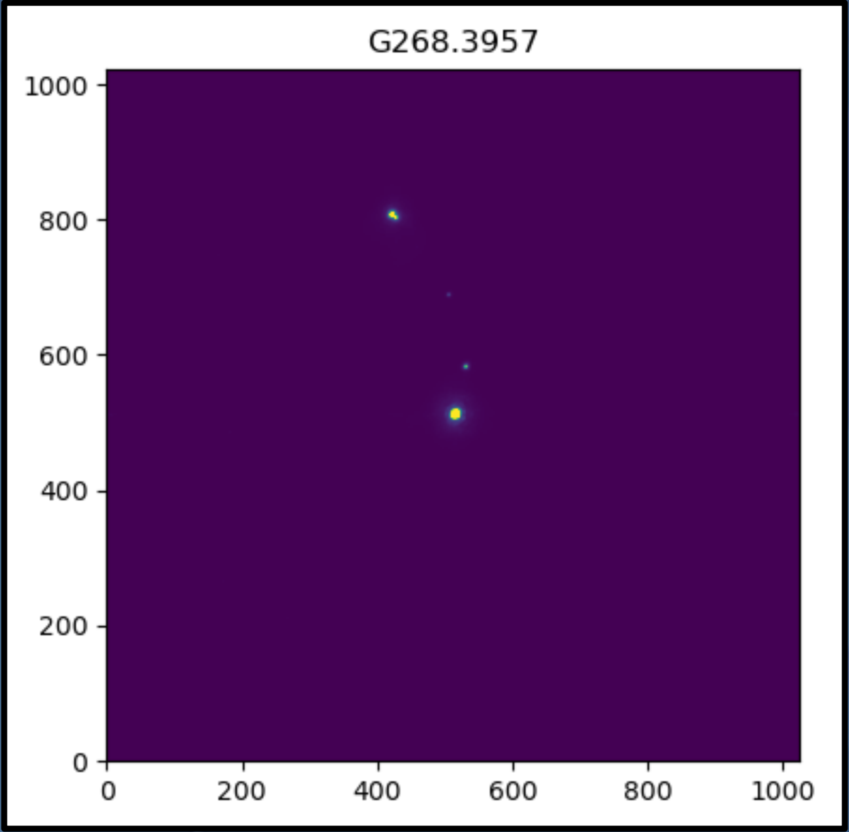
MAIN SEQUENCE

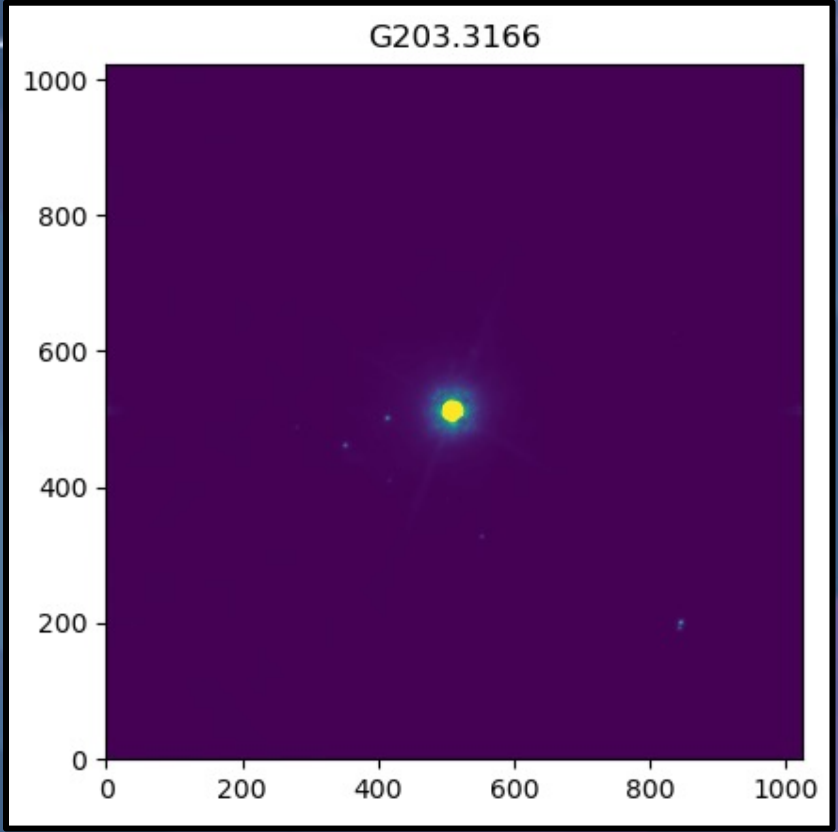
?

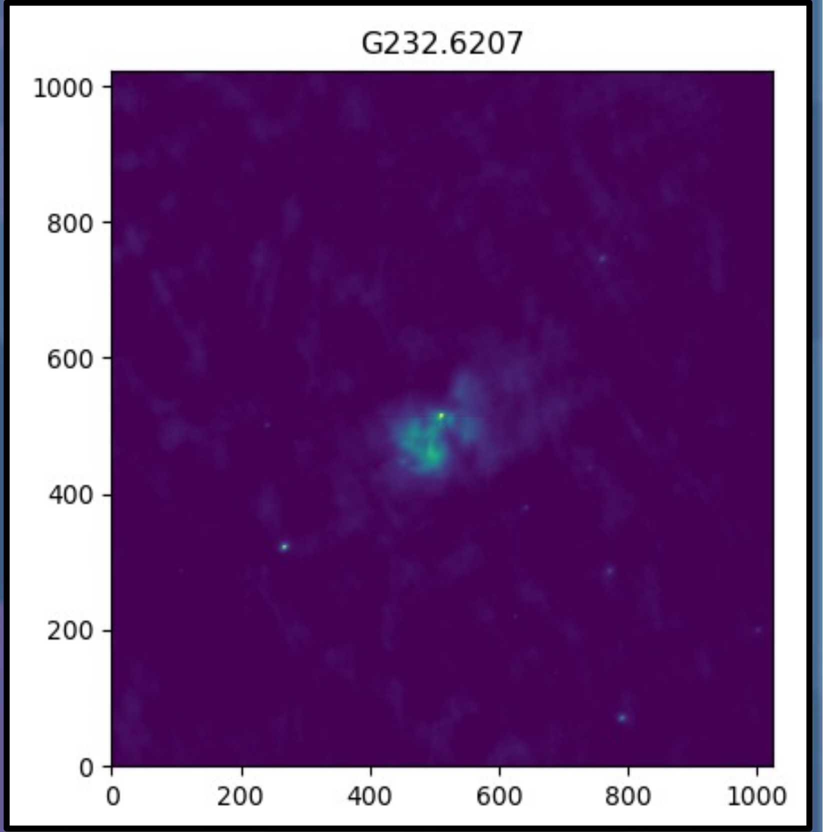
- Long-period binaries
  - $f_{multiple} > 94\ \%$ (sample of 6 stars)

- **Binary interaction** dominates the evolution of O-type star
  - $f_{multiple} > 90\ \%$ (sample of about 200 stars)
- Short-period binaries

NACO OBSERVATIONS OF 13 MYSOs

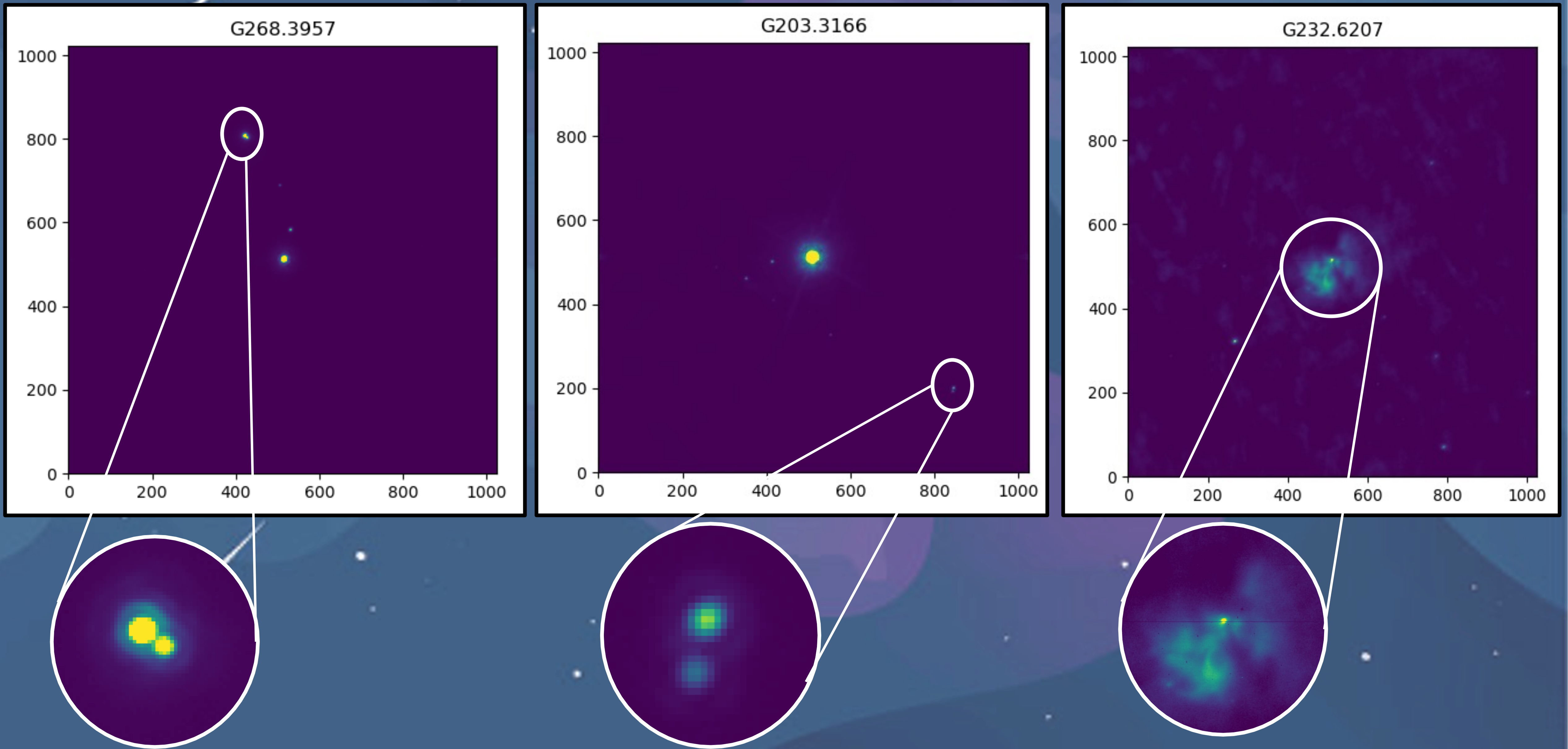






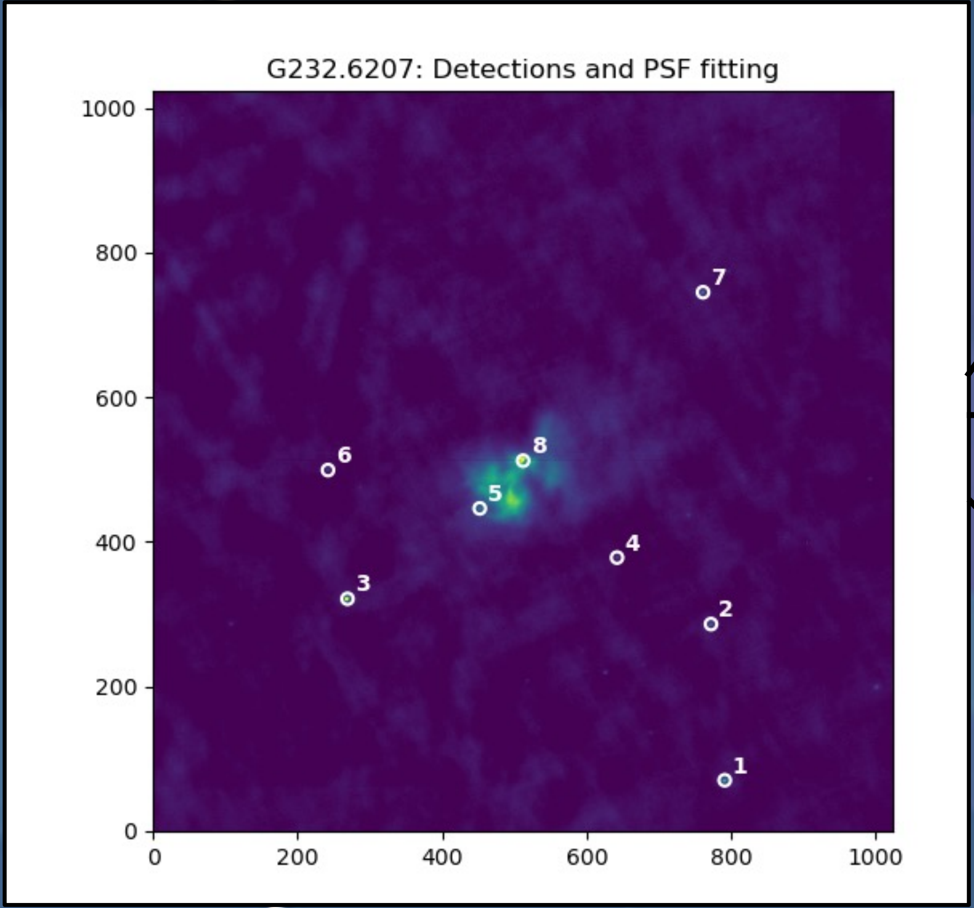
- IMAGING with CUBE Mode
- L'-band : $3.8\mu m$
- FOV: 28"×28" $\rightarrow 27\ mas/pixel$

NACO OBSERVATIONS OF 13 MYSOs



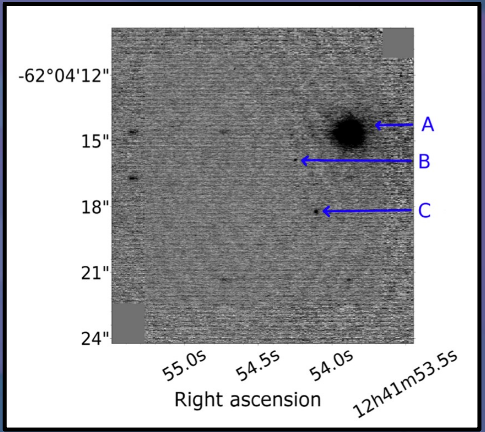
NACO OBSERVATIONS OF 13 MYSOs

PSF Fitting and analysis



- Likelihood of the detected sources to be bound to the central star
- Deriving the MF and CF for the probed separation range

Detection	x	y	Sep (as)	Sep (au)	flux_fit	Lmag	deltaMag
1.0	791.0	70.0	14.1	24039	4.43e+04	8.2	1
2.0	772.0	286.0	9.32	15843	2.16e+04	9	1.8
3.0	269.0	321.0	8.36	14215	7.81e+04	7.6	0.42
4.0	642.0	378.0	5.05	8586.2	1.15e+04	9.7	2.5
5.0	452.0	446.0	2.41	4102.2	4.1e+04	8.3	1.1
6.0	242.0	499.0	7.31	12432	9.97e+03	9.9	2.7
7.0	761.0	745.0	9.23	15683	2.56e+04	8.8	1.6
8.0	512.0	512.0	0	0	1.15e+05	7.2	0



- K-band AO imaging with NACO
- $f_{bin} = 53 \pm 9\%$

(Pomohaci+2019)

- K-band interferometry with GRAVITY
- $f_{bin,mYSO} = 17 \pm 15\%$

(Koumpia+2021)