A-Star Multiplicity and the Companion Mass Function
The Volume-limited A-Star (VAST) Survey

Robert De Rosa

University of Exeter

Thesis Advisor
Dr. Jennifer Patience

Patience, J.[1], Marois, C.[2], Song, I.[3], Schneider, A.[3], Graham, J.[4], McConnell, N.[4], Macintosh, B.[5], Bessell, M.[6]

[1] University of Exeter, [2] Herzberg Institute of Astrophysics, [3] University of Georgia, [4] University California Berkeley, [5] Lawrence Livermore National Laboratory, [6] Australian National University

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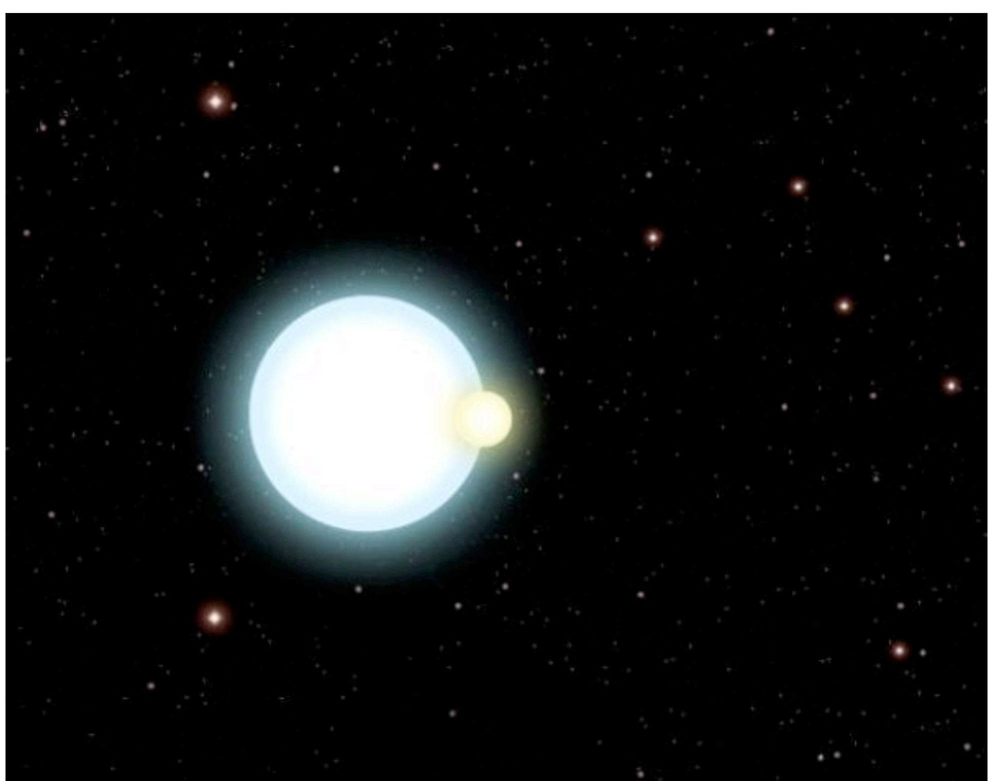
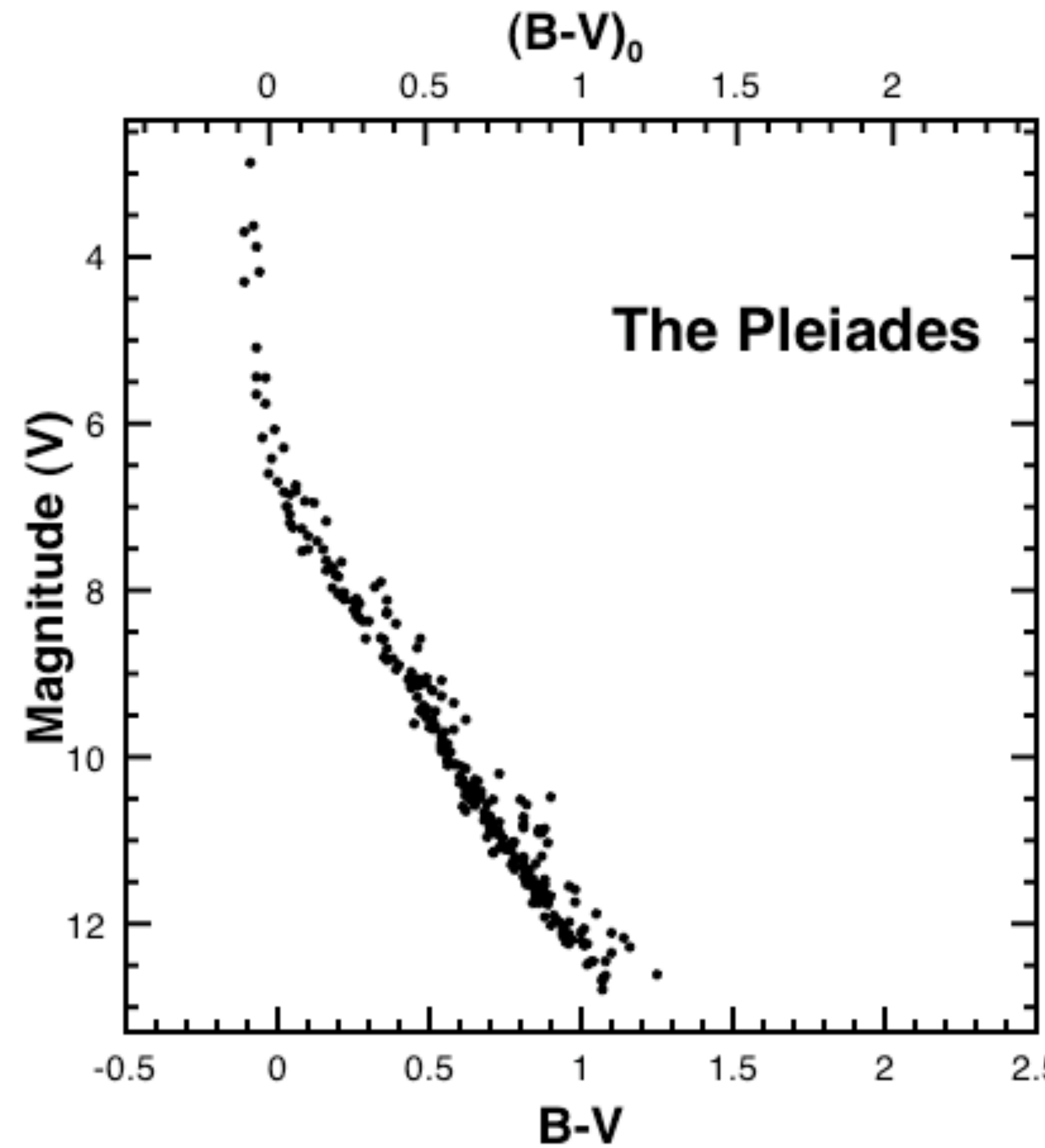
Motivation

- **Binaries are important**



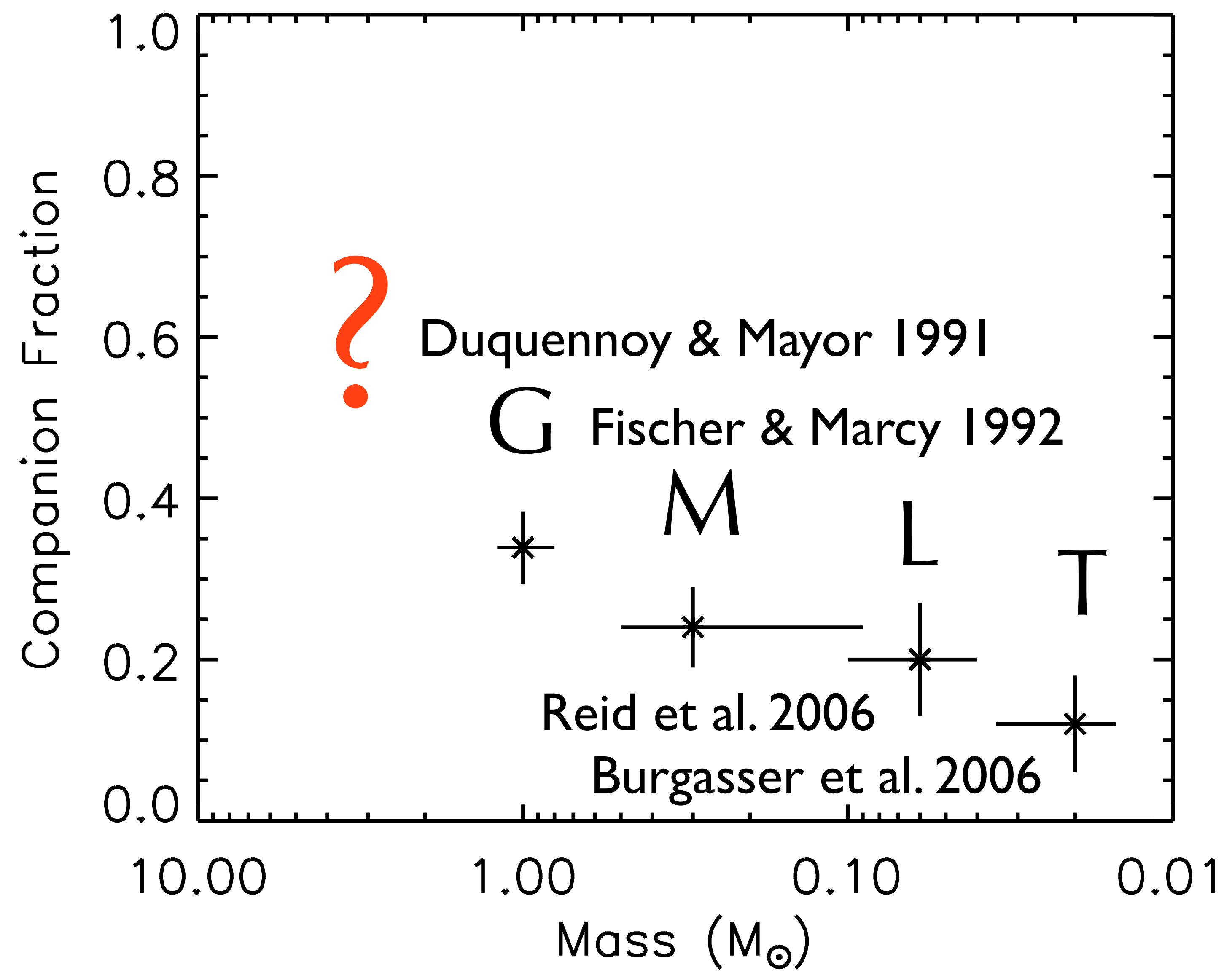
Eclipsing binary system



CMD of Pleiades cluster (Raboud et al. 1998)

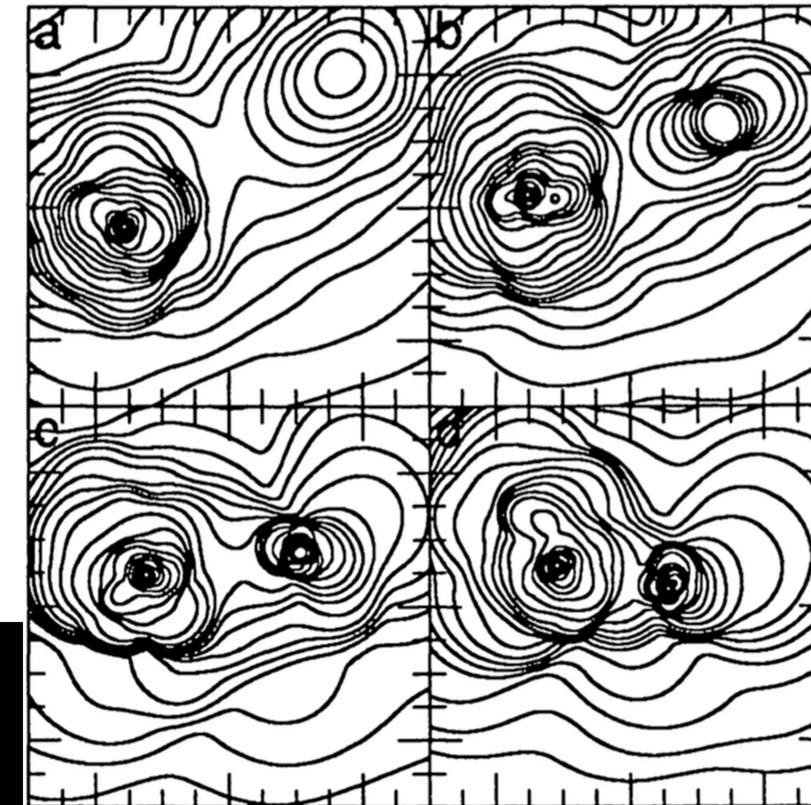
Motivation

- **Binaries are important**
- **Unconstrained multiplicity**

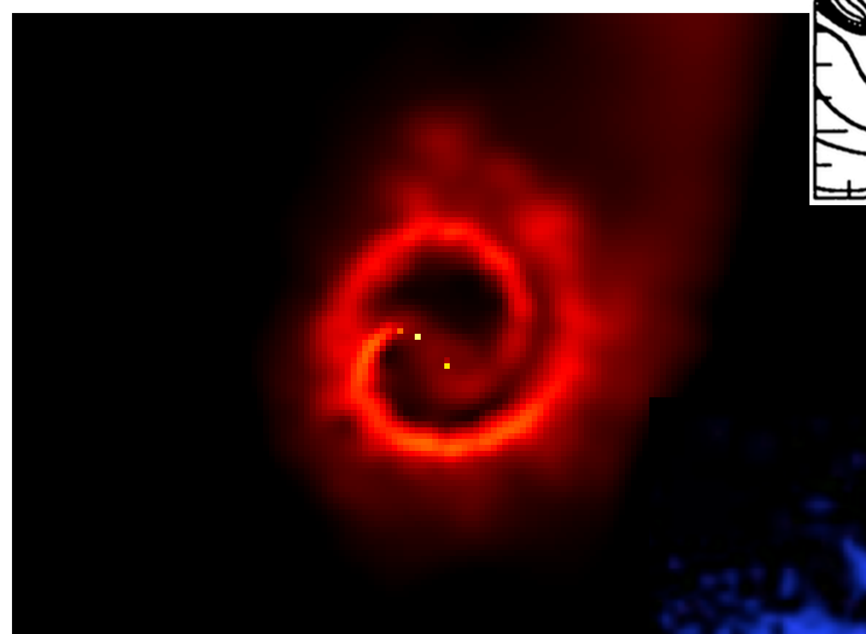


MOTIVATION

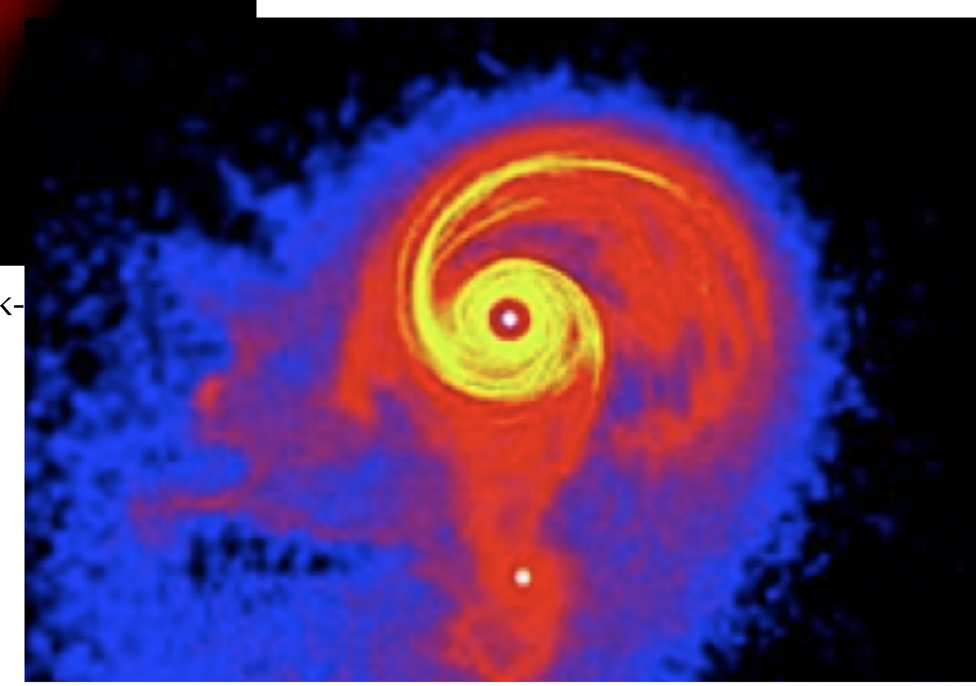
- **Binaries are important**
- **Unconstrained multiplicity**
- **Binary formation processes**



Core elongation and fragmentation
Bonnell & Bastien (1992)



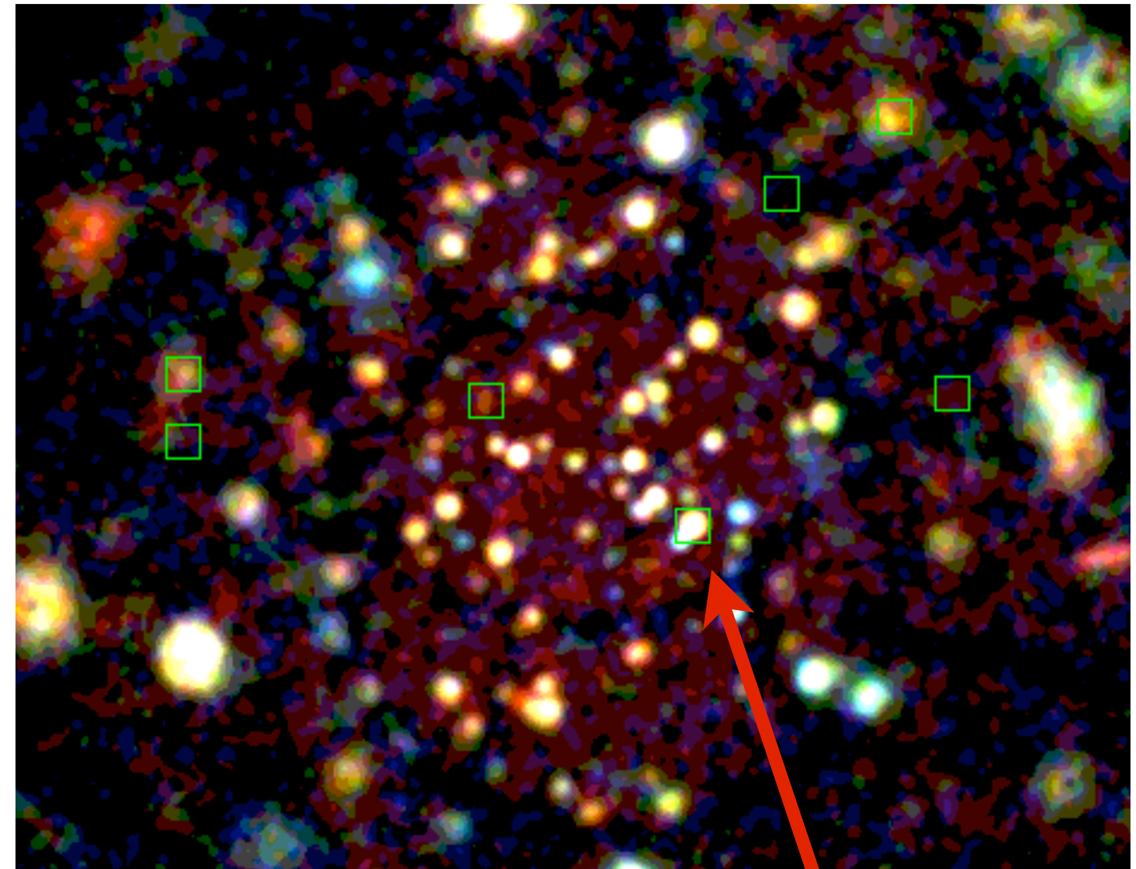
Formation of triple system through disk-assisted capture and fragmentation (Bate et al. 2003)



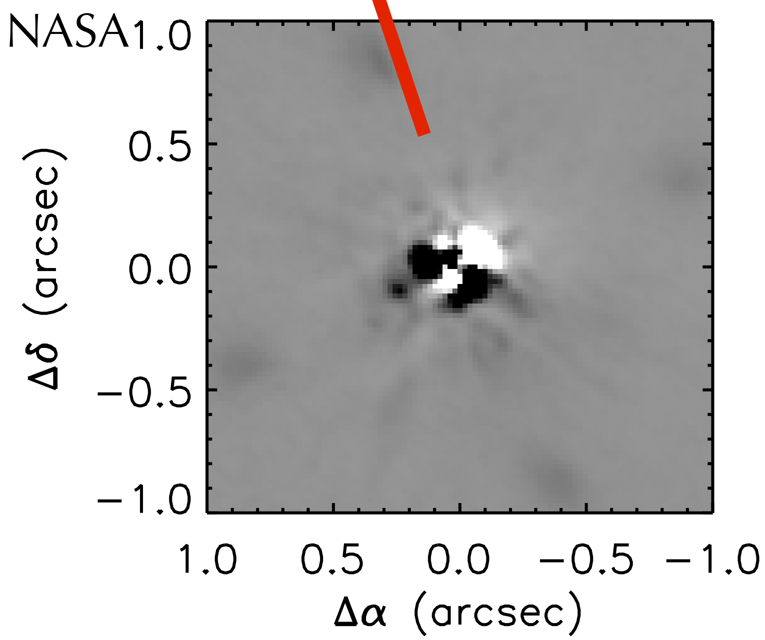
Effects of a potential capture event on circumstellar disks (Lodato et al. 2007)

Motivation

- **Binaries are important**
- **Unconstrained multiplicity**
- **Binary formation processes**
- **Unexplained X-Ray detection**



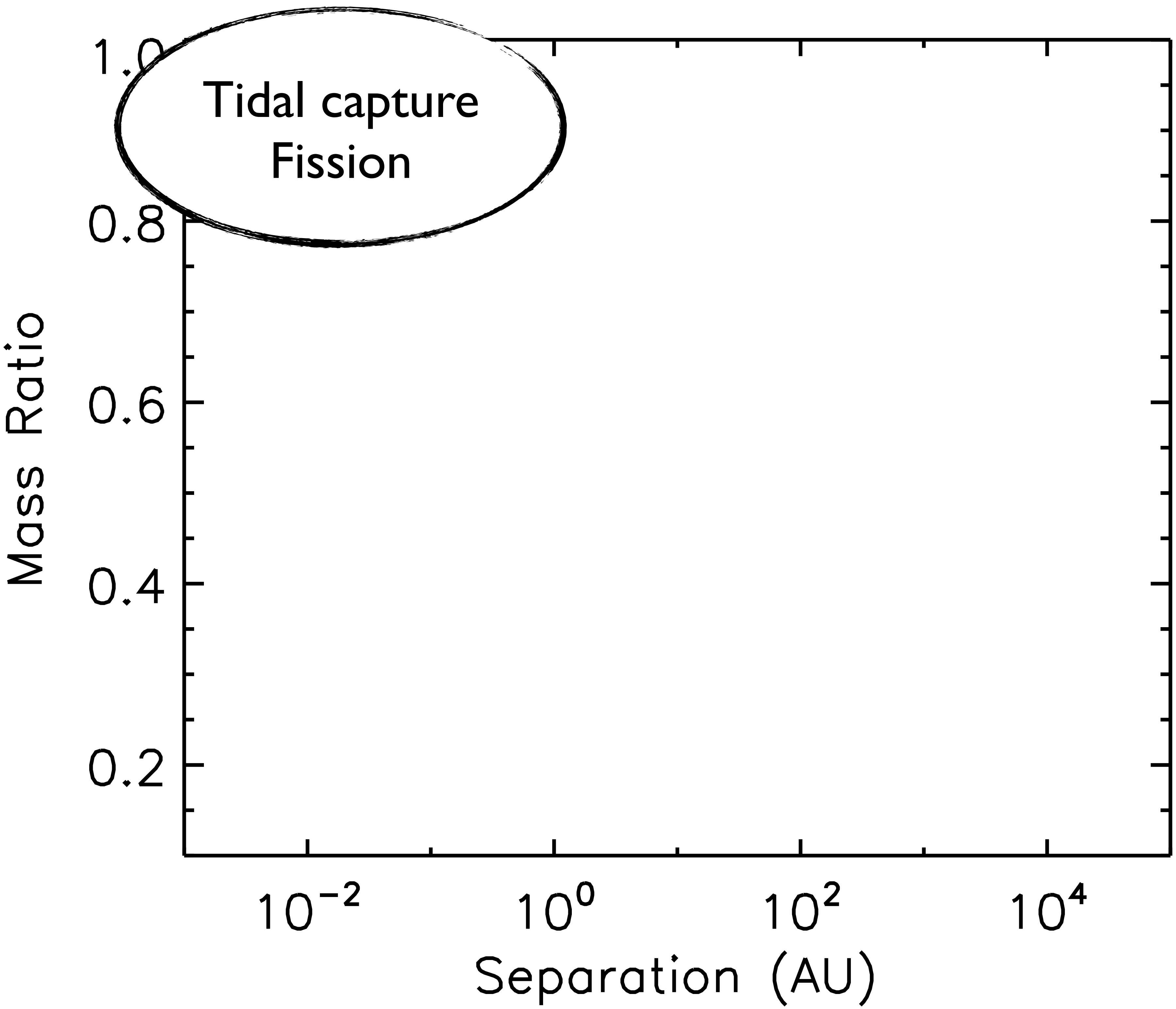
ROSAT Observations of the Pleiades
Credit: T. Preibisch (MPIfR), MPE, NASA



Newly resolved companion to Merope (B6)
De Rosa et al. 2010

BINARY FORMATION

Phase space cartoon -

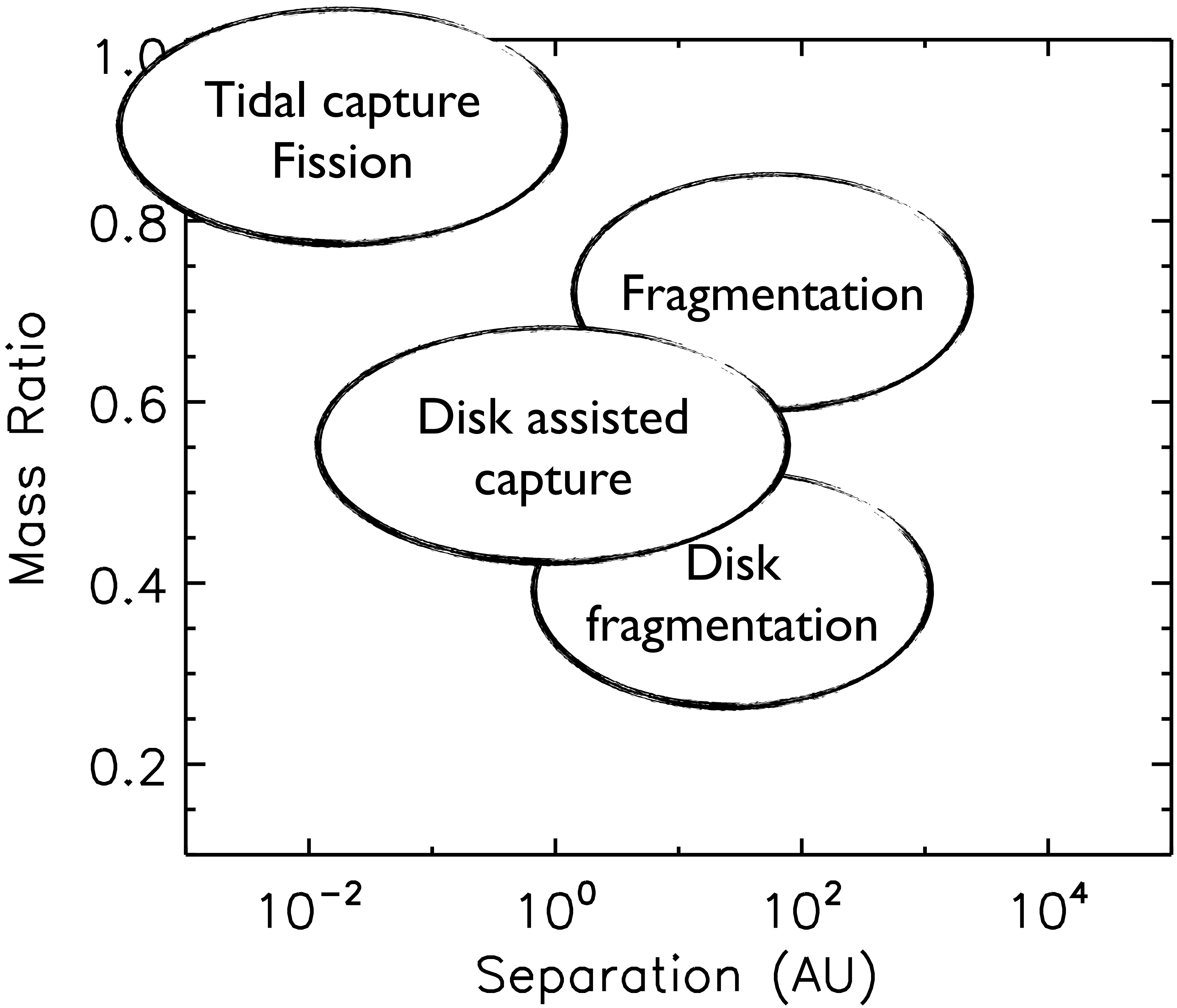


Mardling 1996

Roxburg 1966
Cazes 1999

Binary Formation

Phase space cartoon -



Mardling 1996

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McDonald & Clarke 1995
Bate, Bonnell & Bromm 2003

Stamatellos & Whitworth 2009
Kratter et al. 2010

Binary Formation

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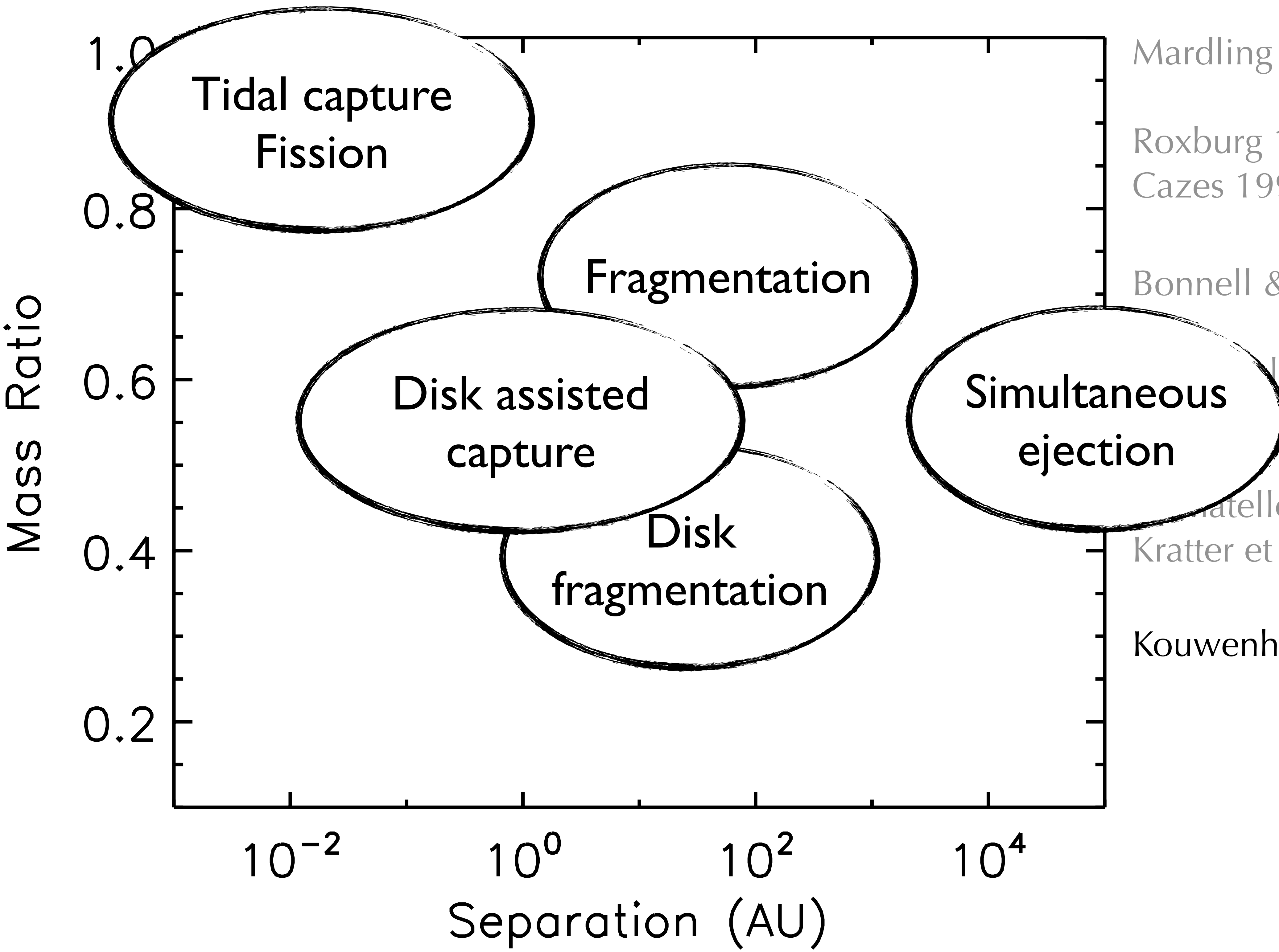

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BINARY FORMATION

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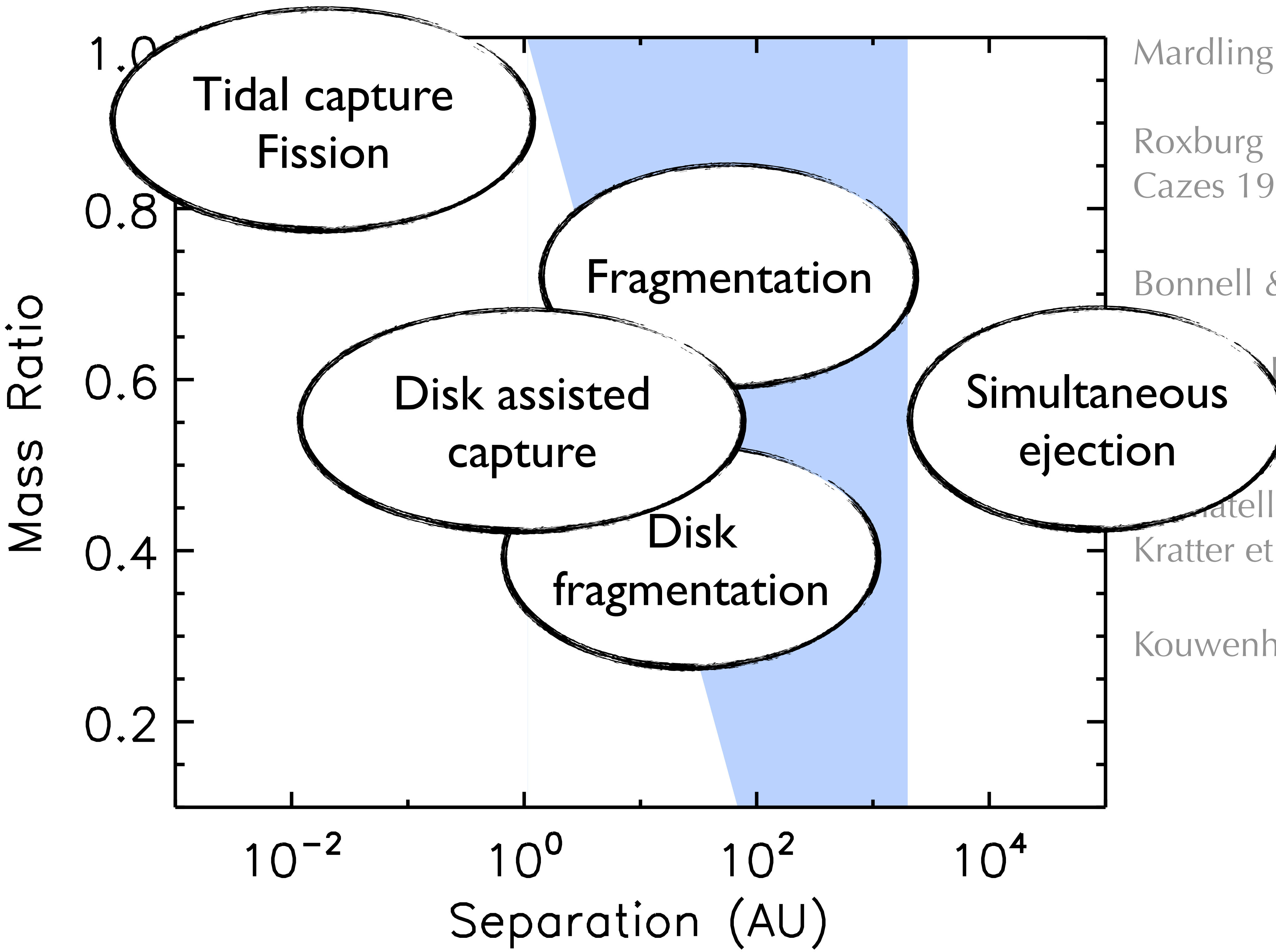

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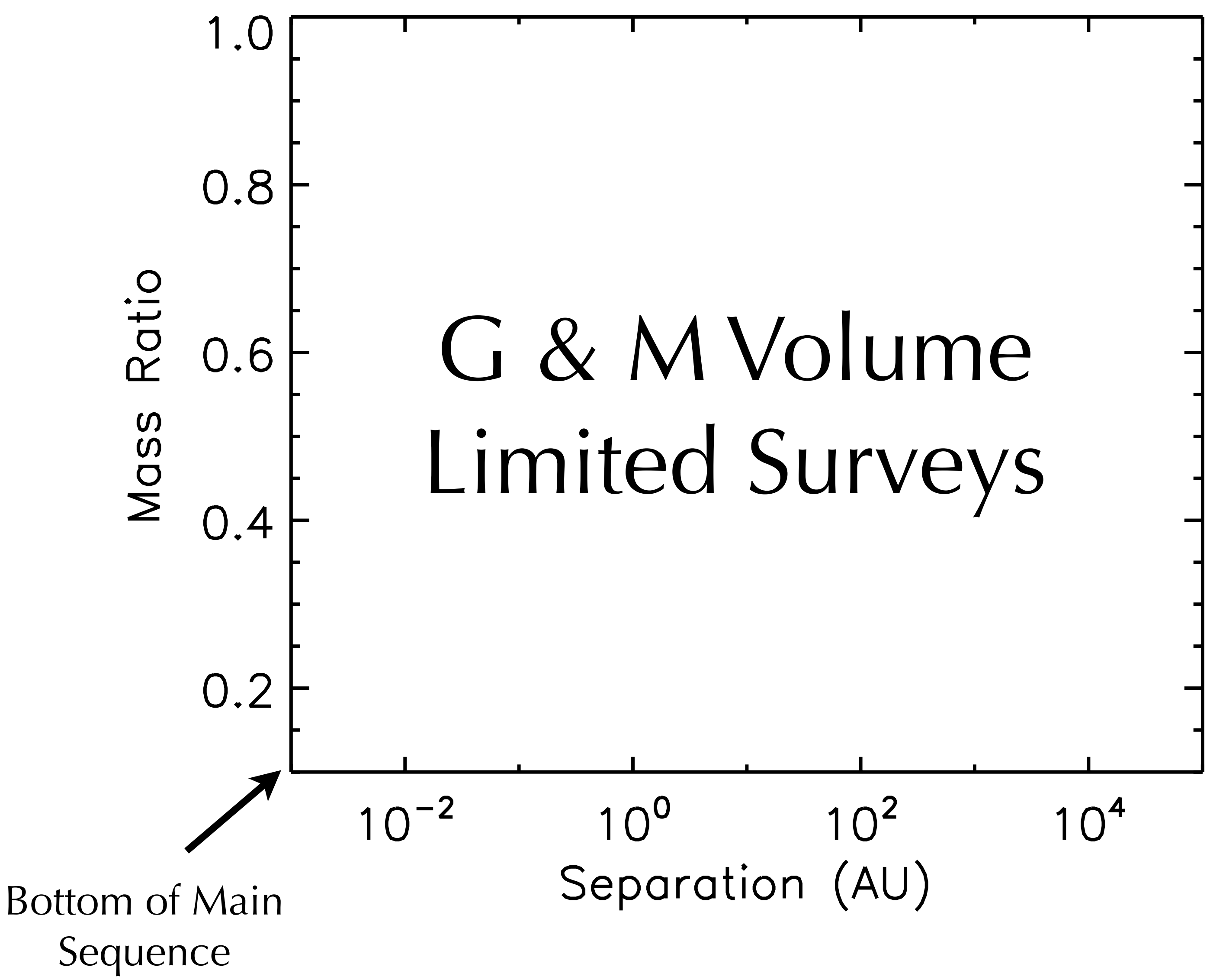
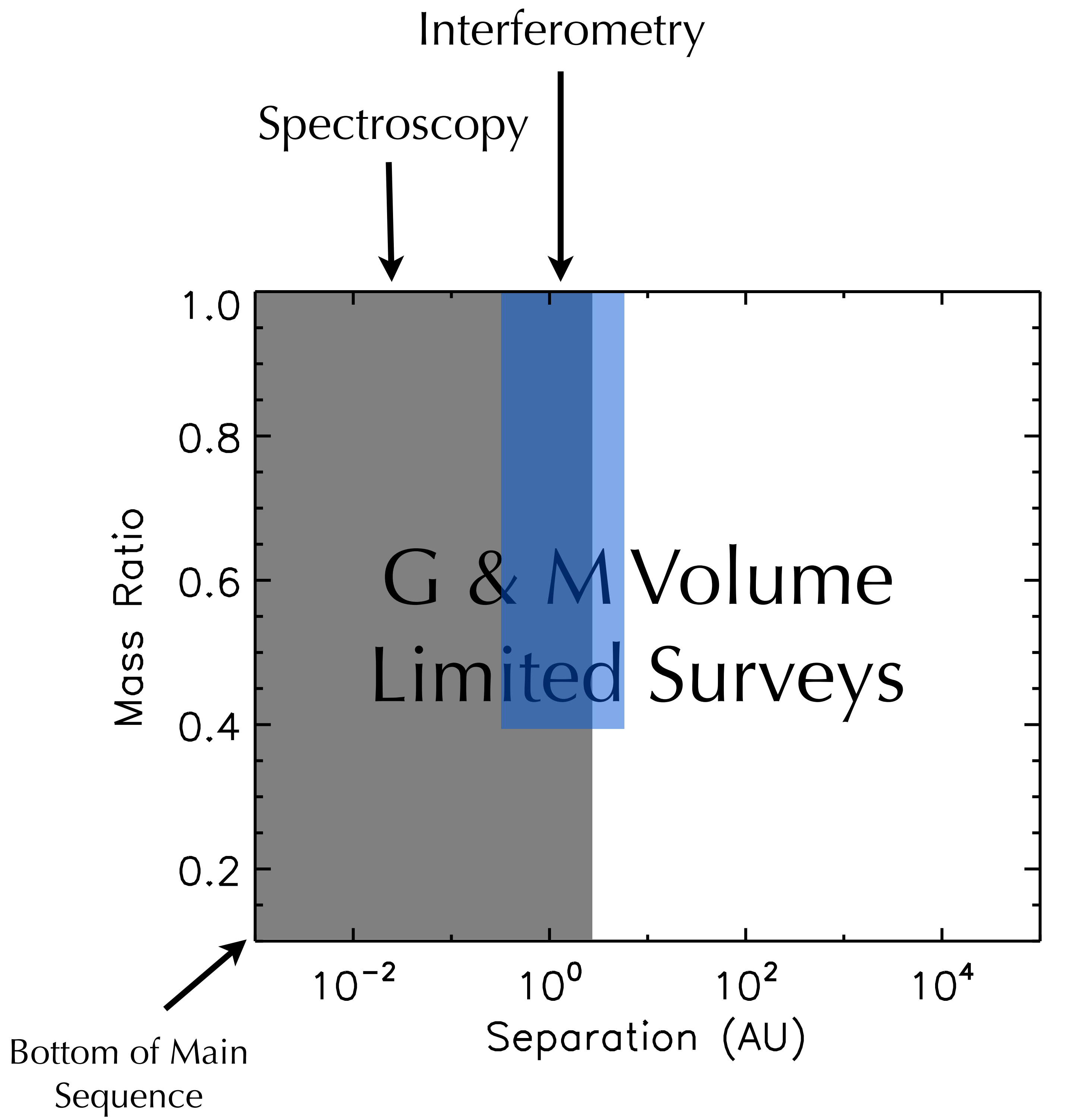
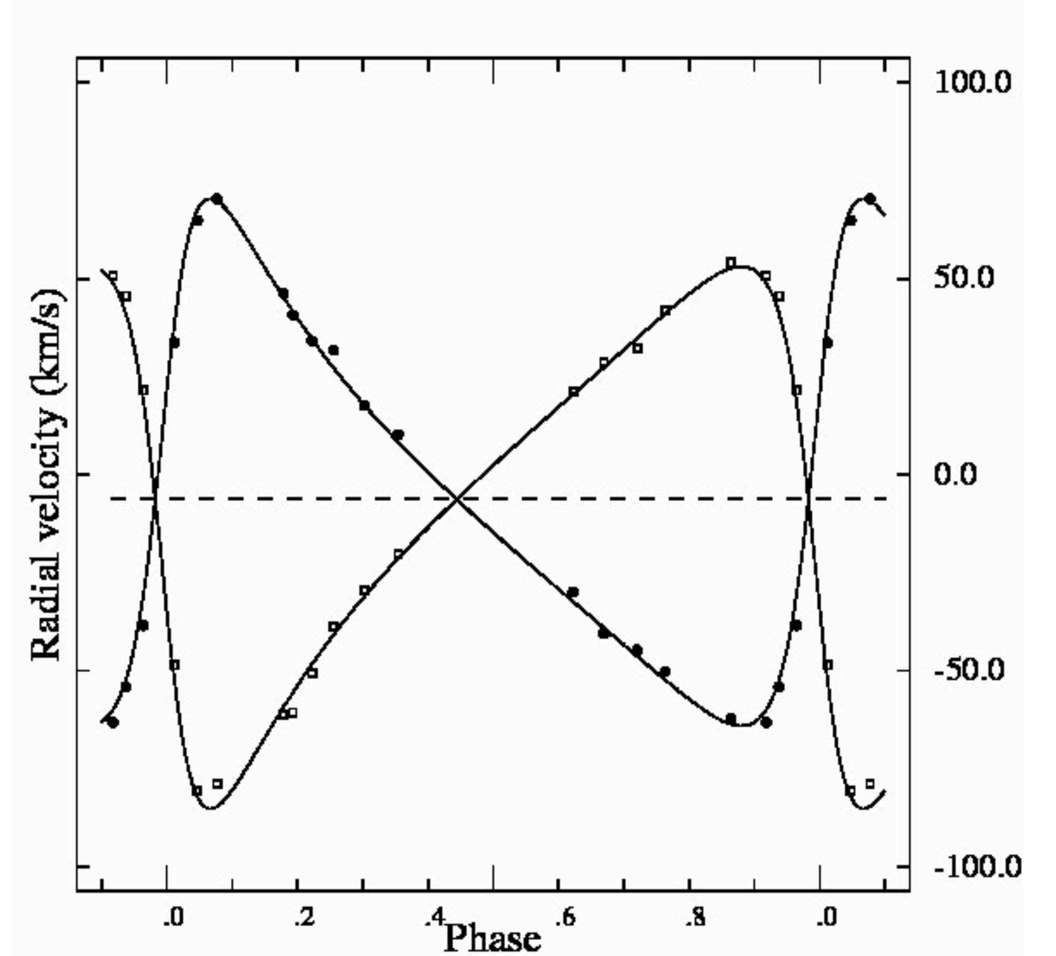
Techniques and Sensitivities

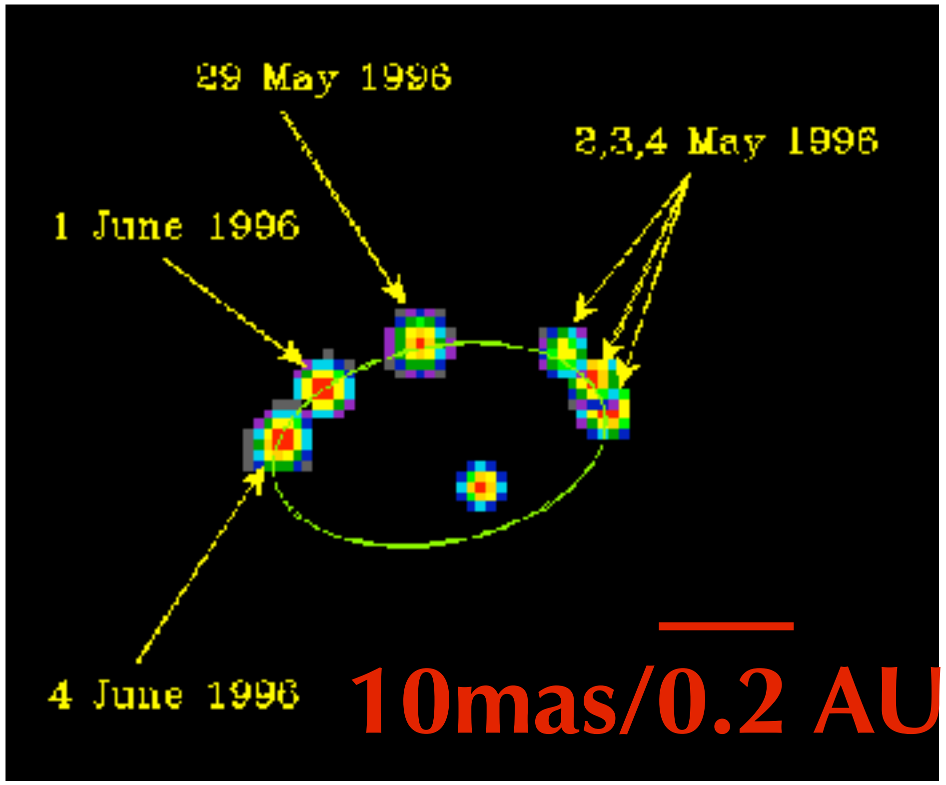


Techniques and Sensitivities



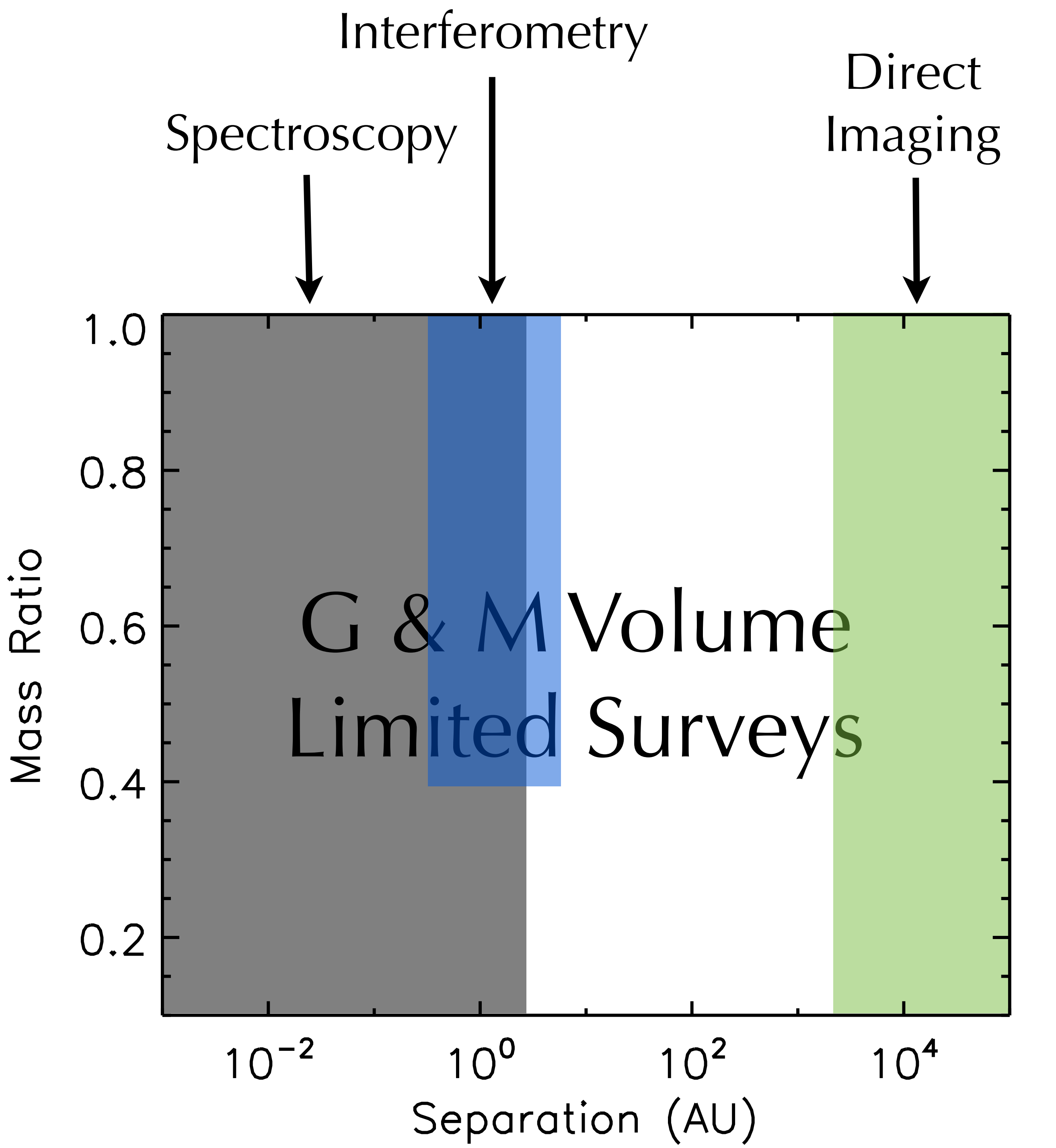


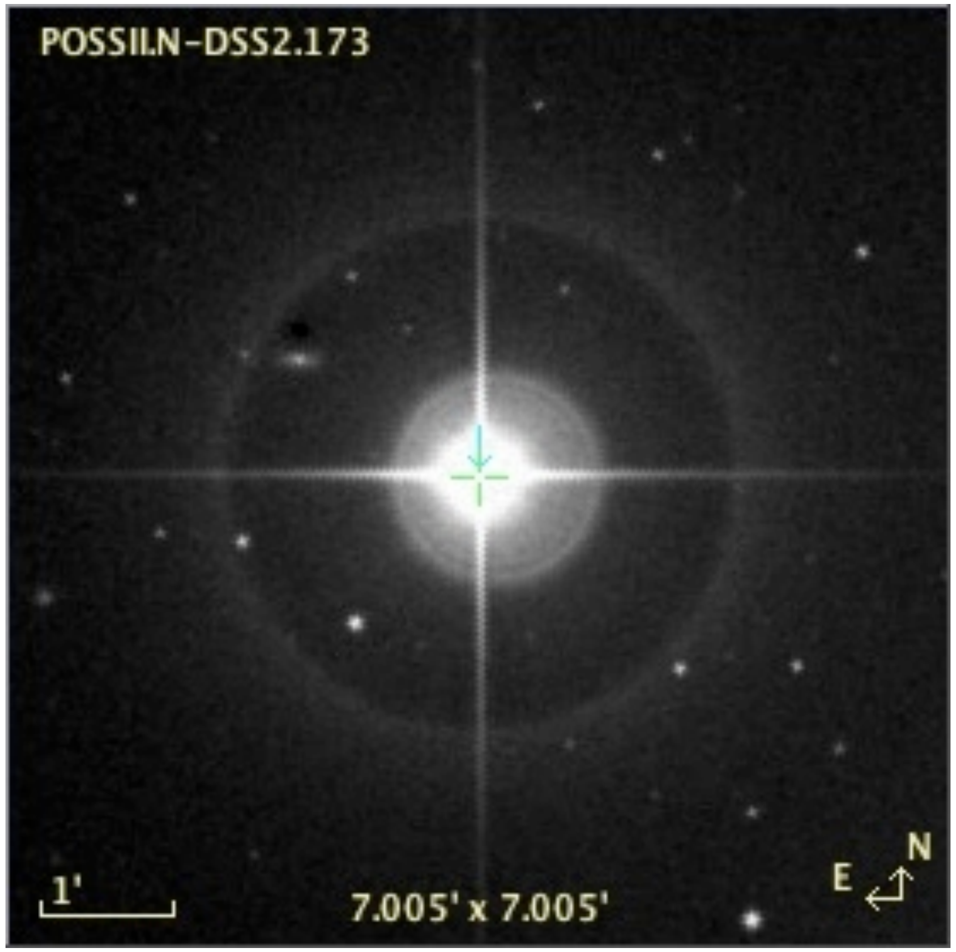
Radial Velocity of Mizar A (Pourbaix 2000)

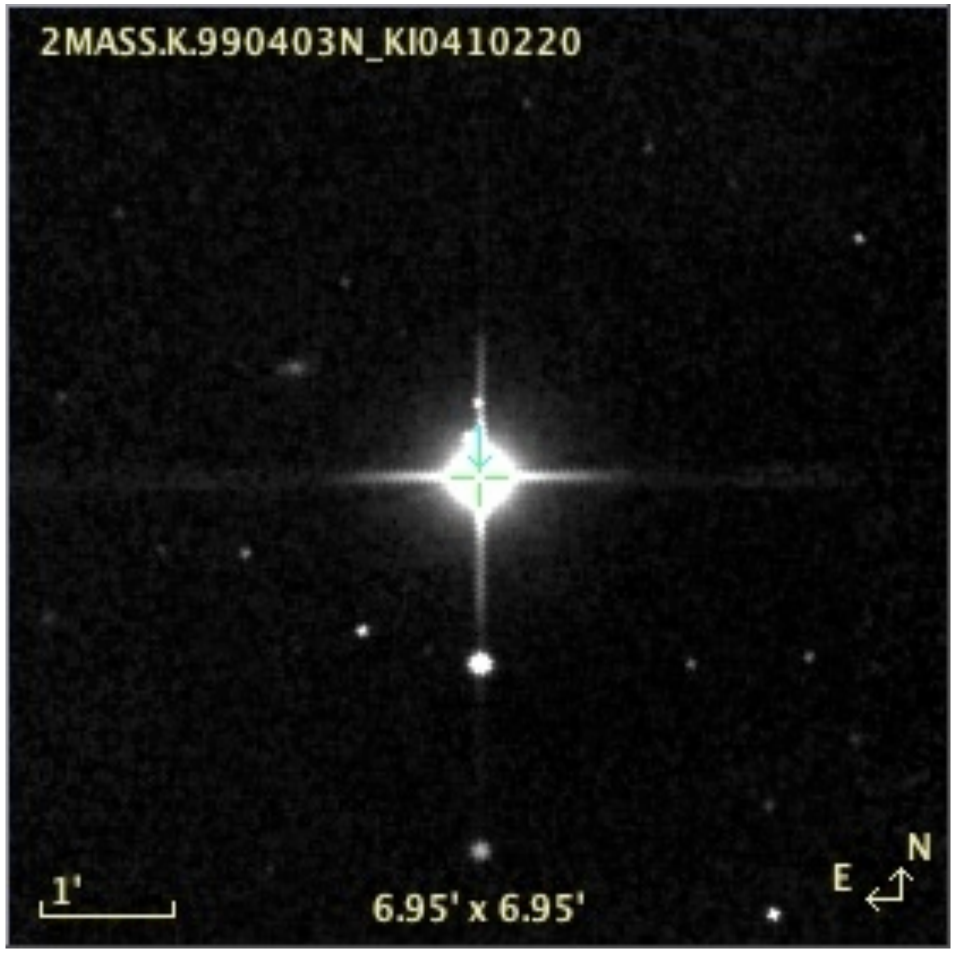


Interferometric observations of Mizar A
with NPOI (J. Benson)

Techniques and Sensitivities







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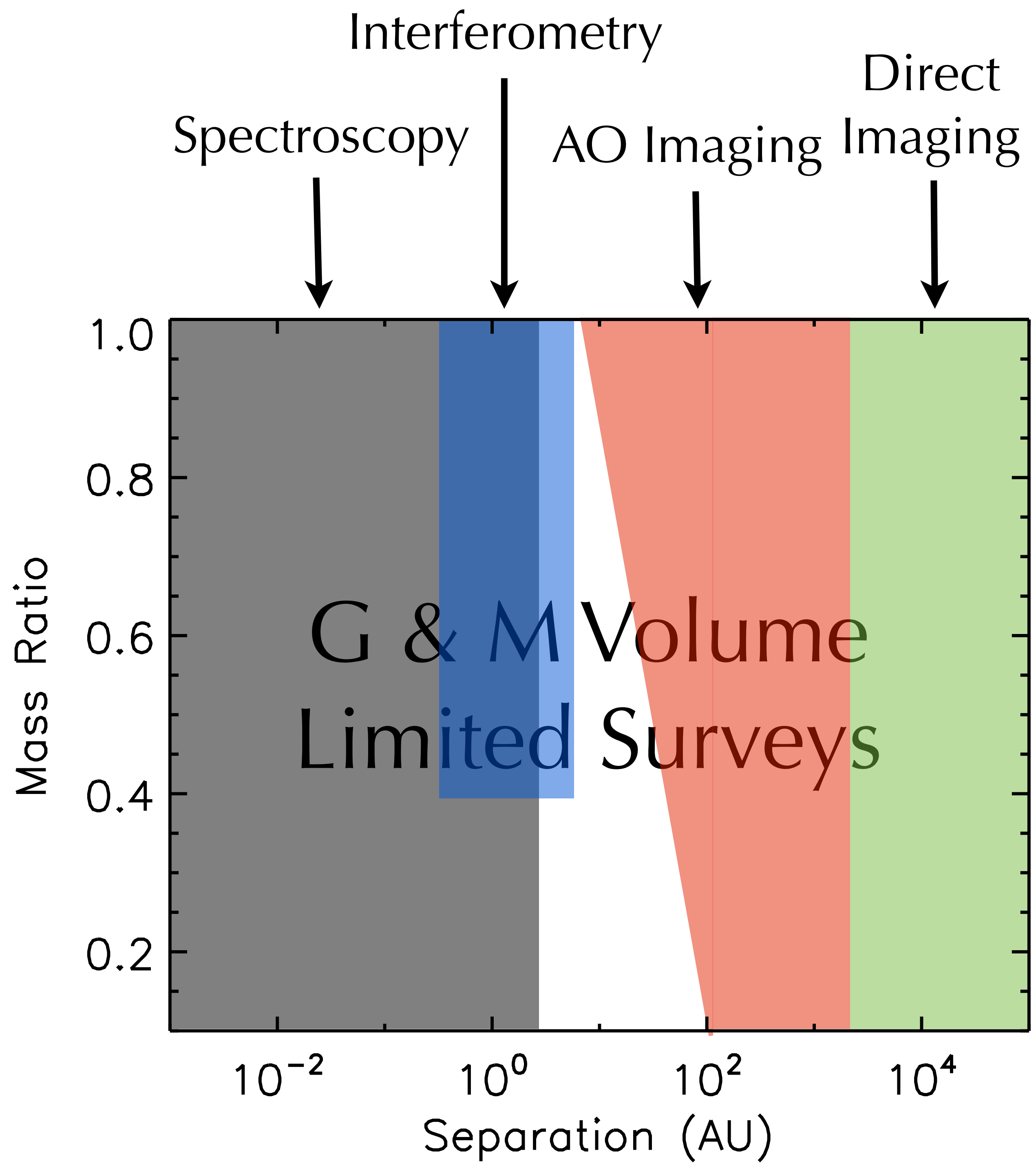

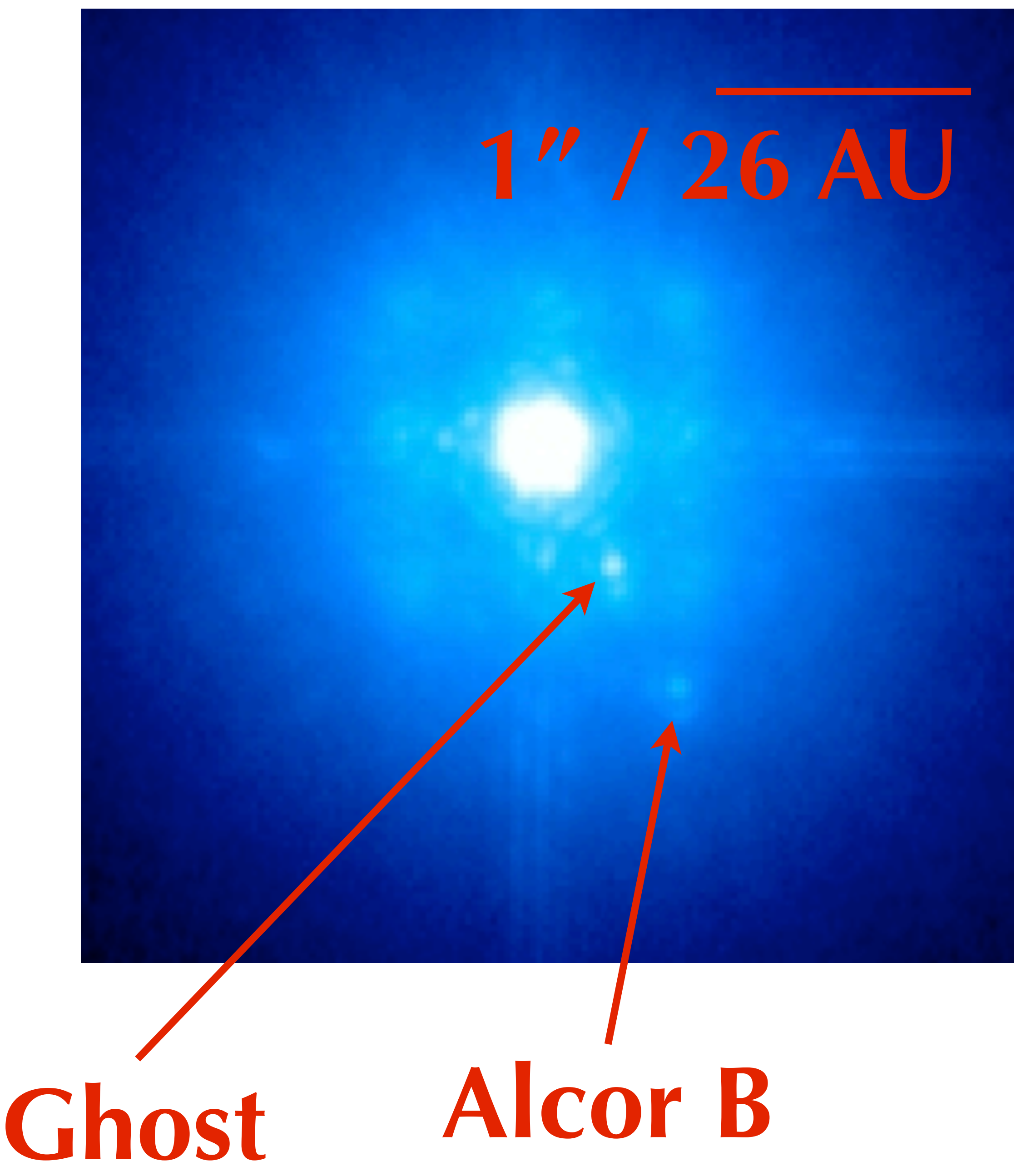

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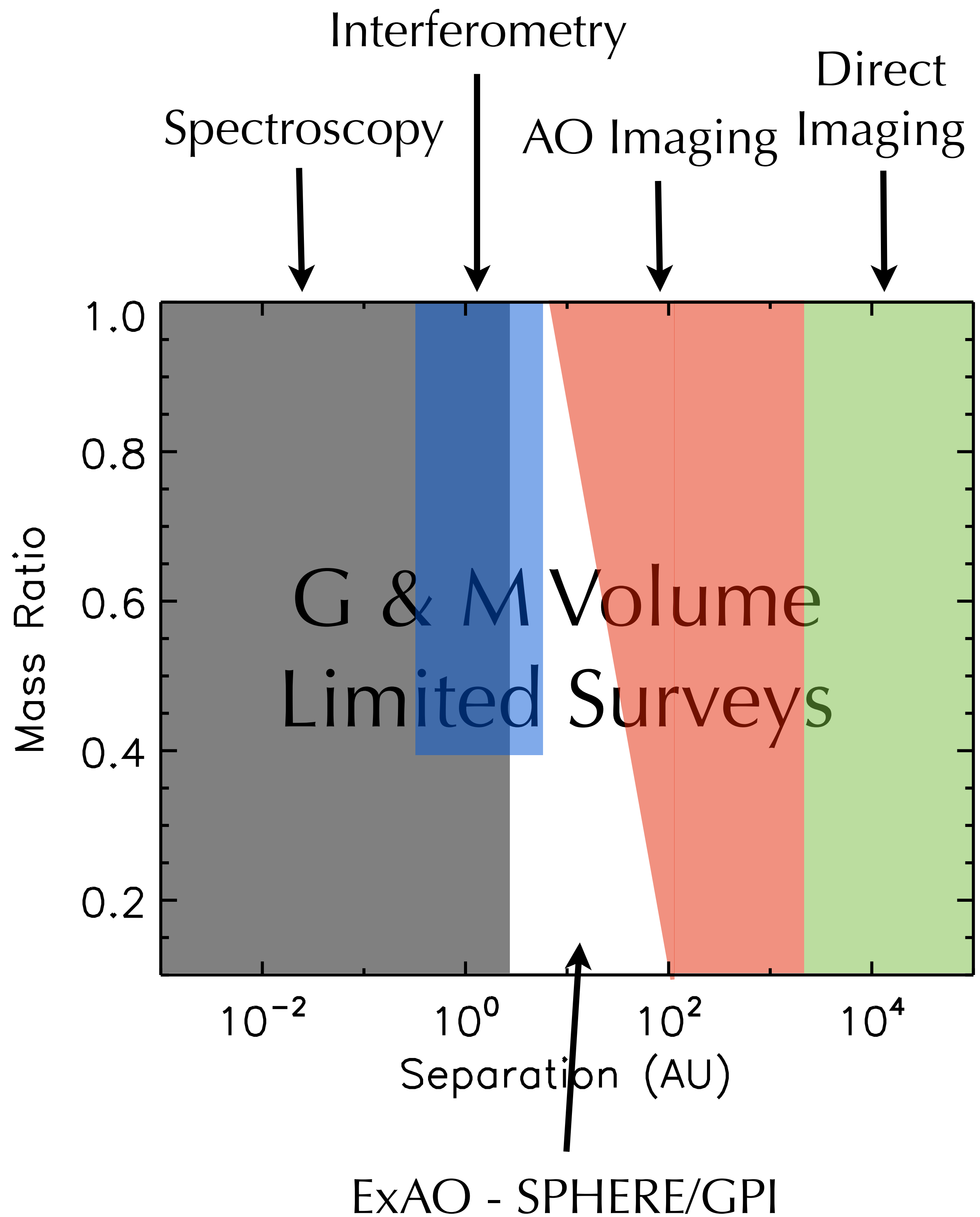
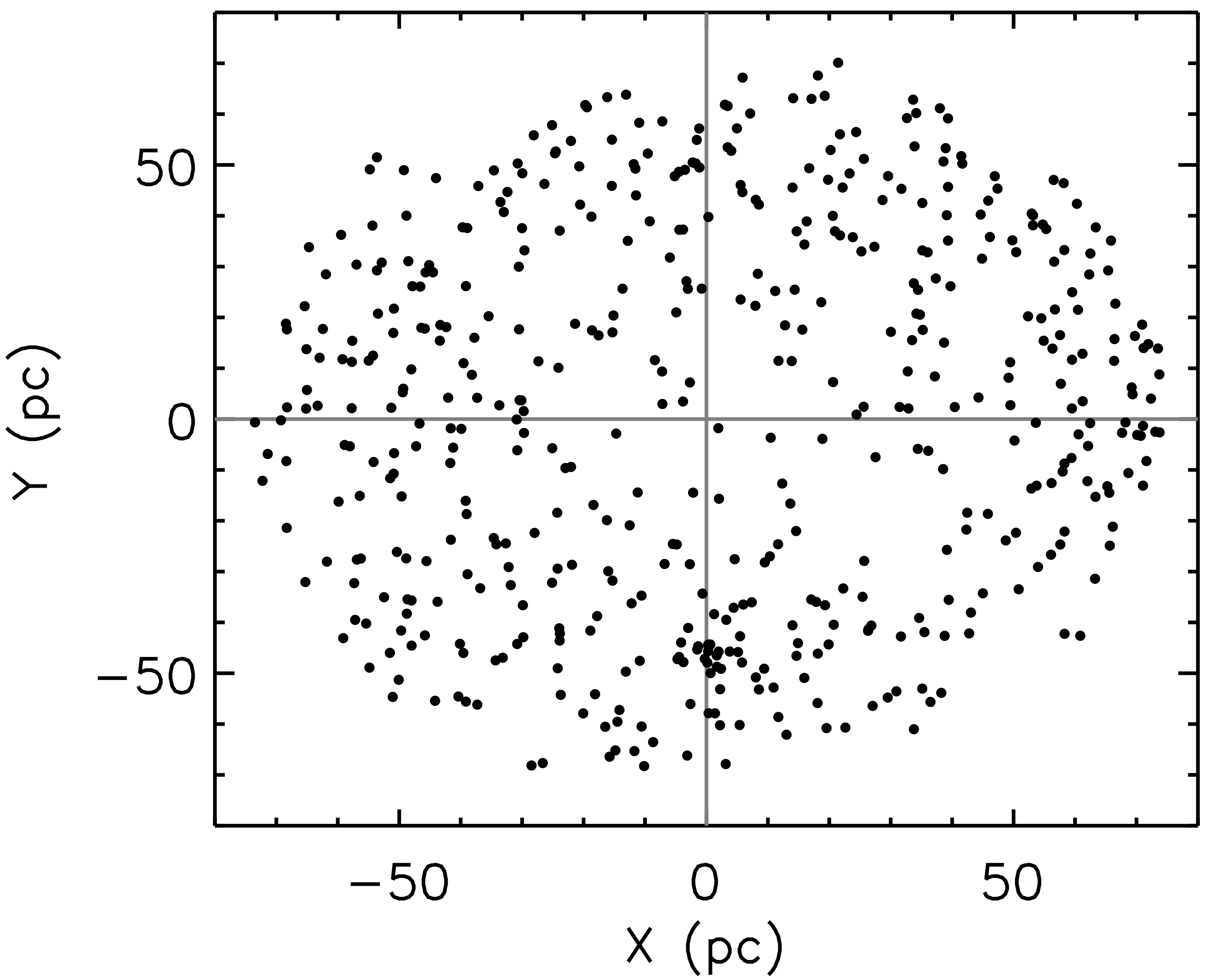
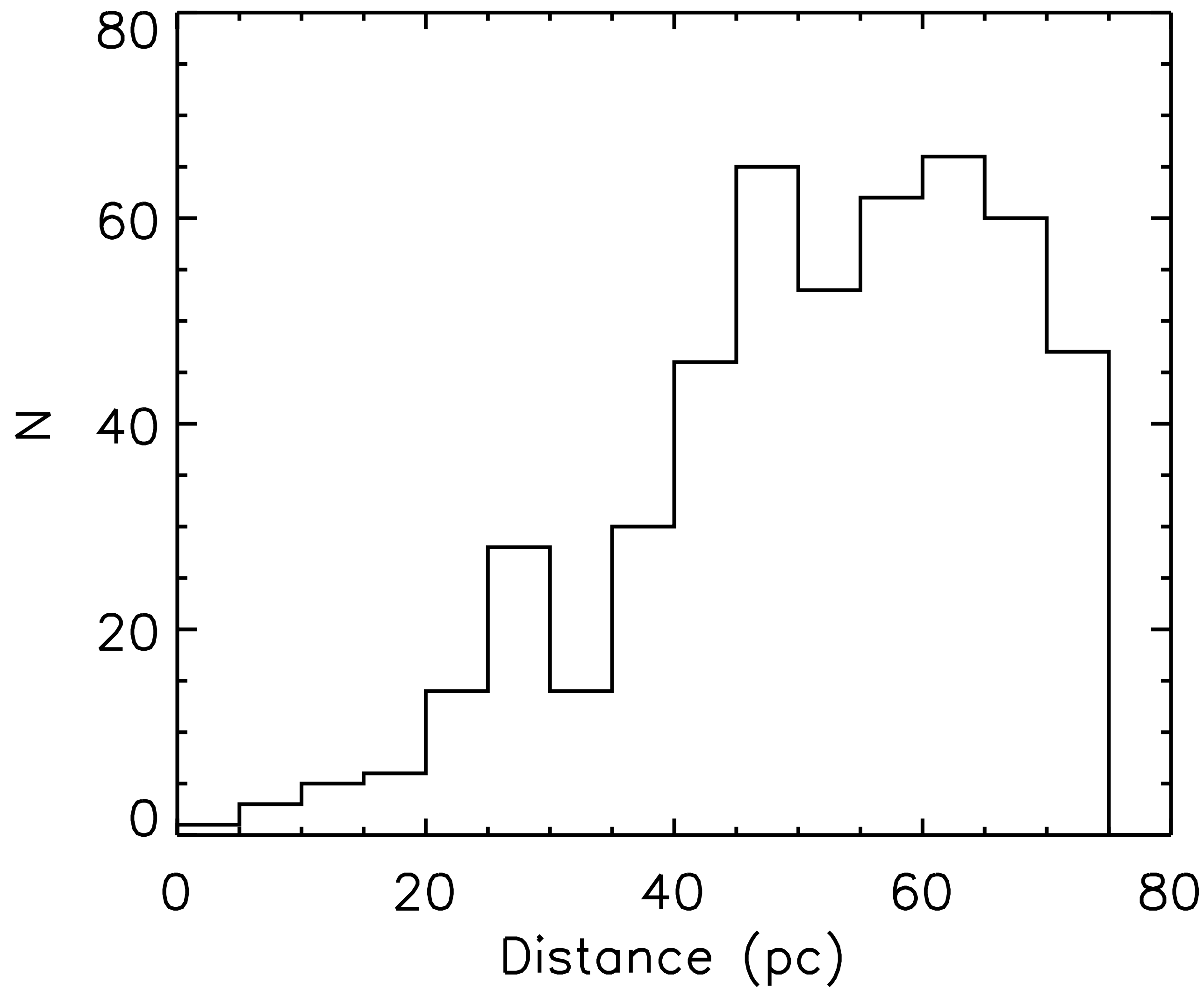


The Sample

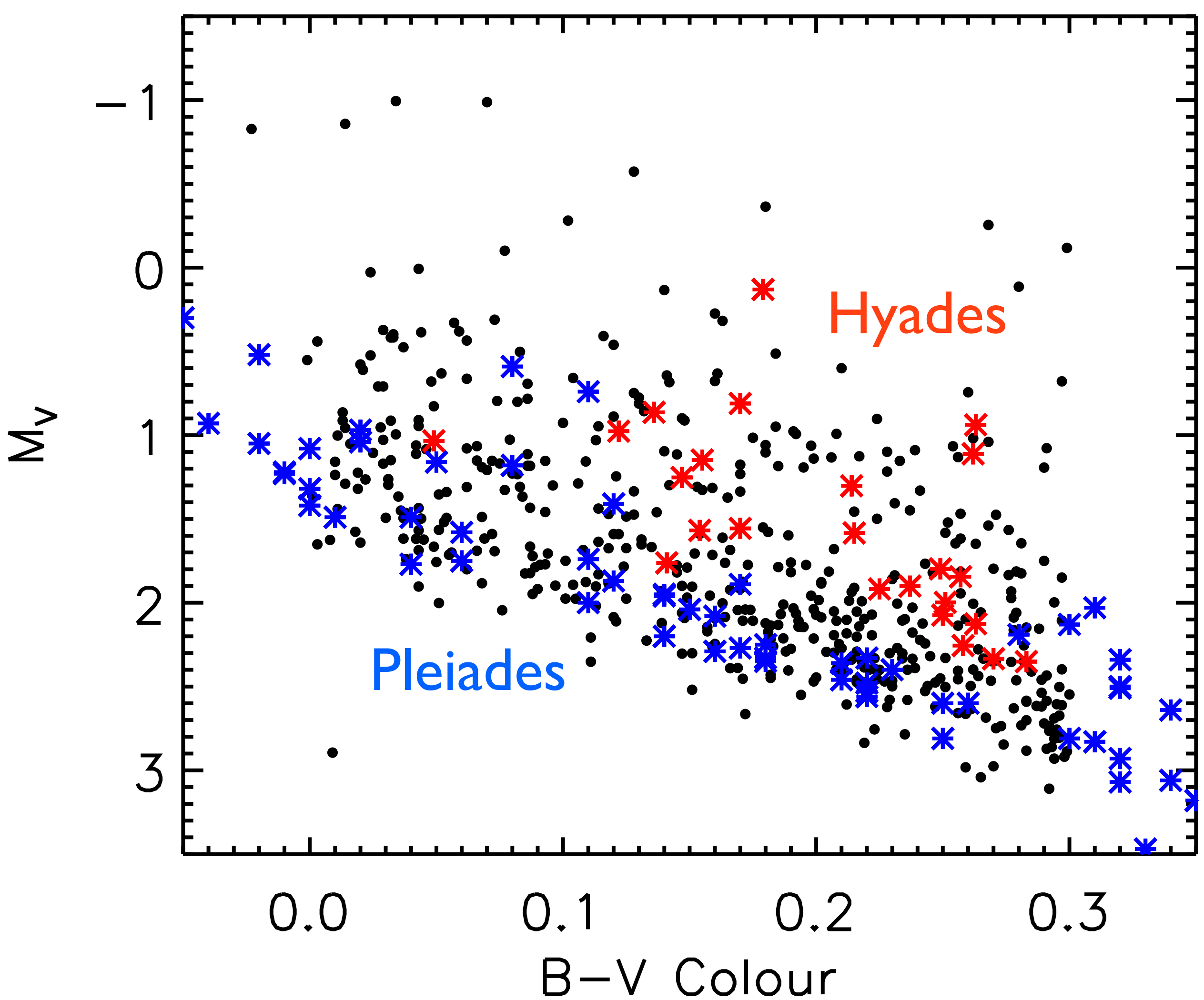
- **Volume-limited sample (D < 75 pc)**
- **500 stars from Hipparcos catalogue**





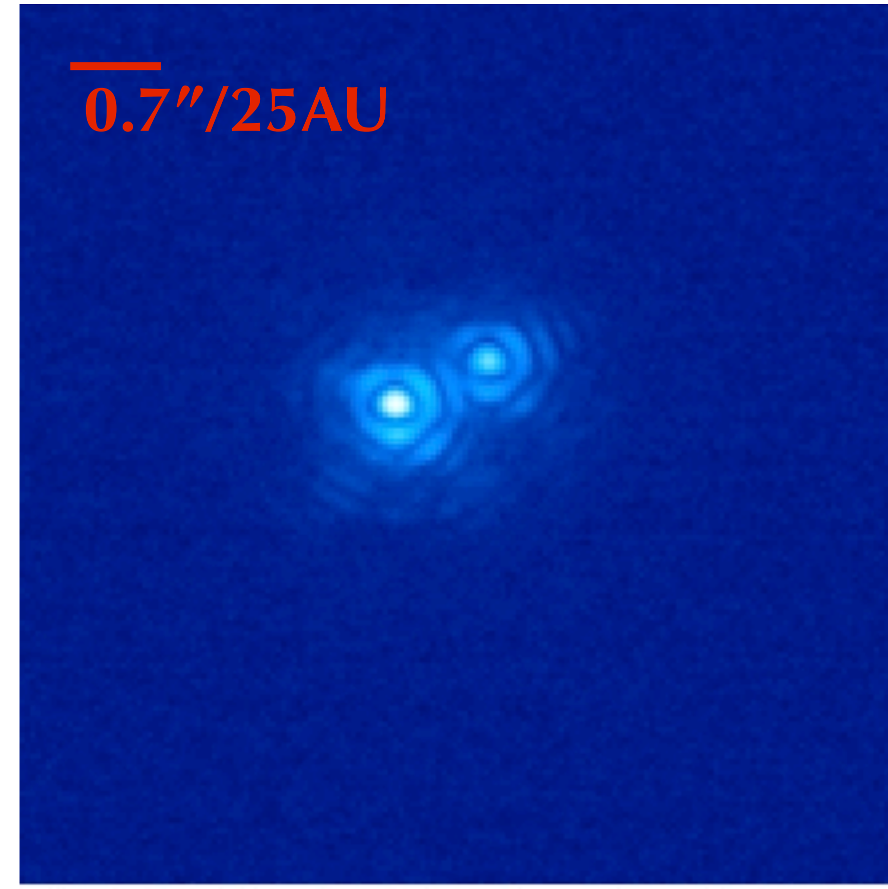
The Sample

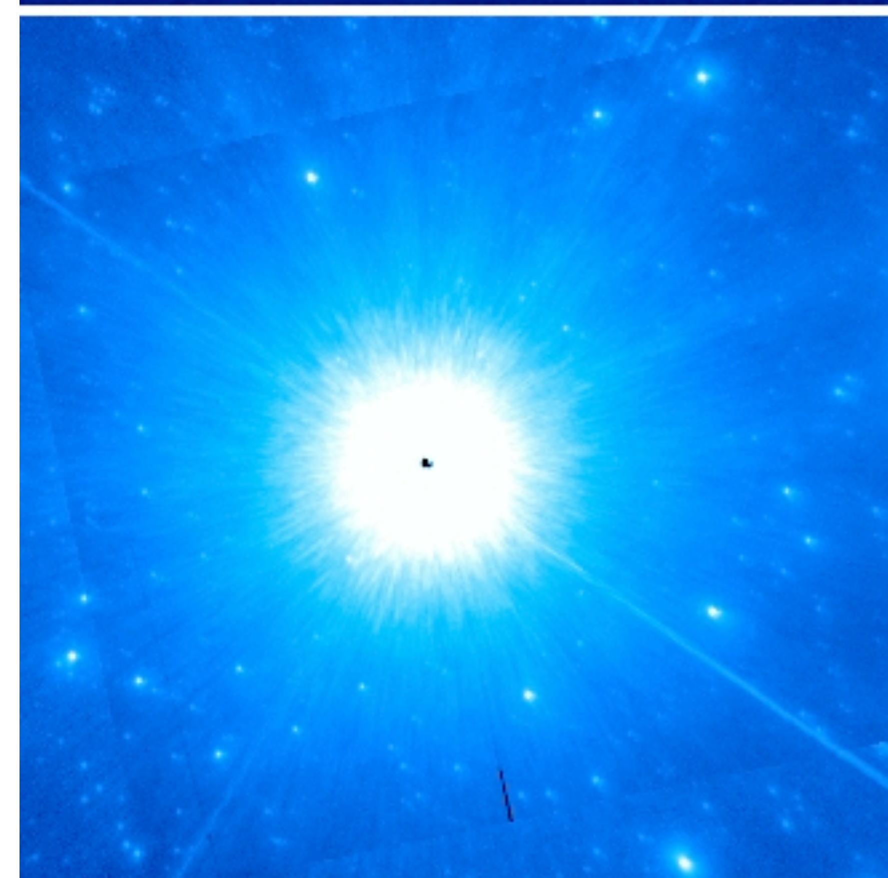
- **Volume-limited sample (D < 75 pc)**
- **500 stars from Hipparcos catalogue**
- **B-V between 0.0 and 0.3**

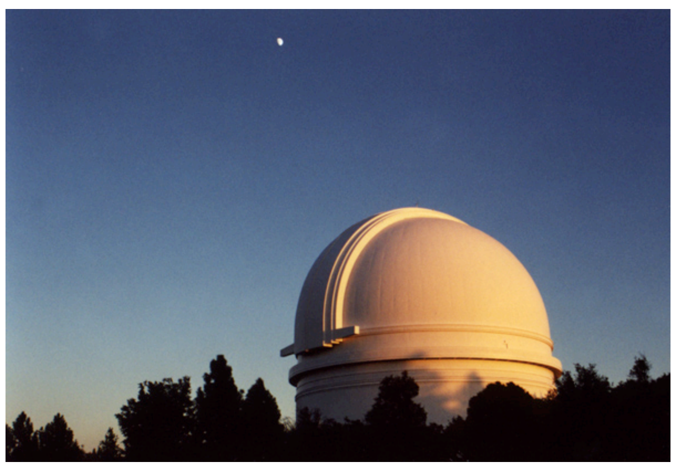


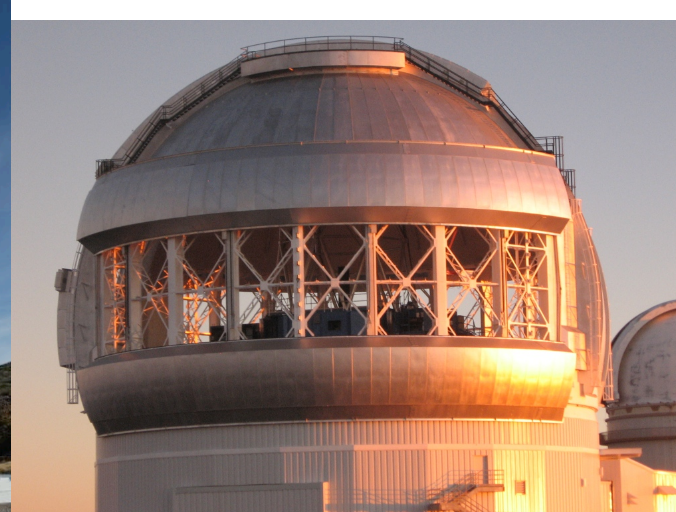
Observations

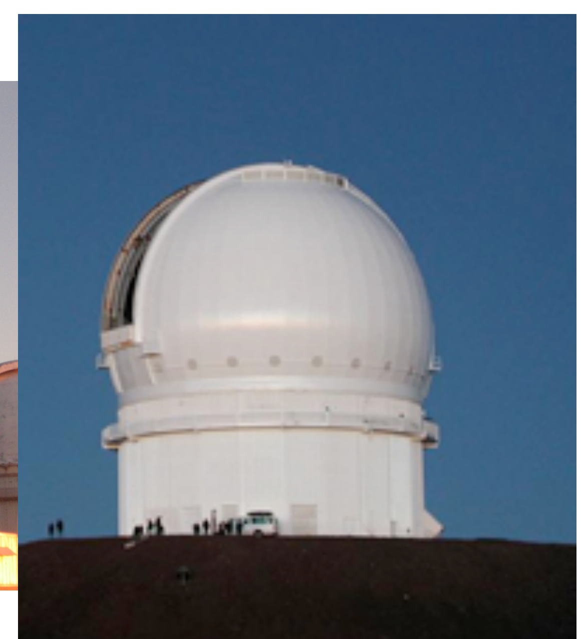
- **High-resolution AO data obtained at CFHT, Lick, Gemini, Palomar, WHT**





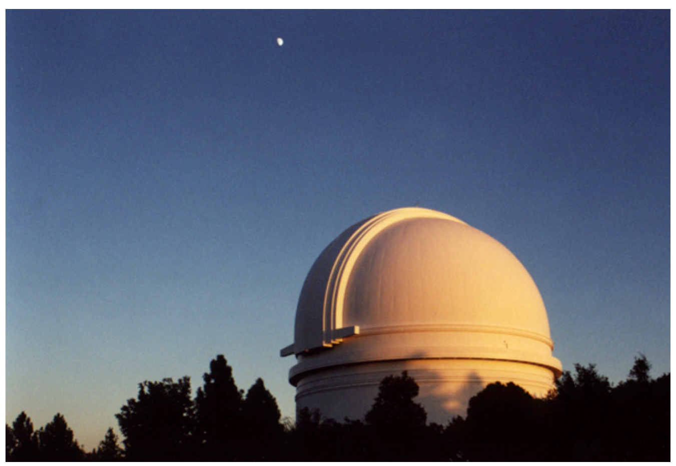


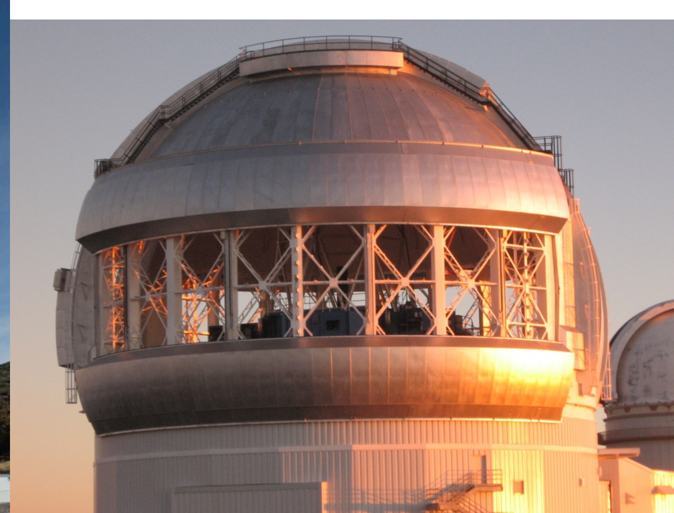


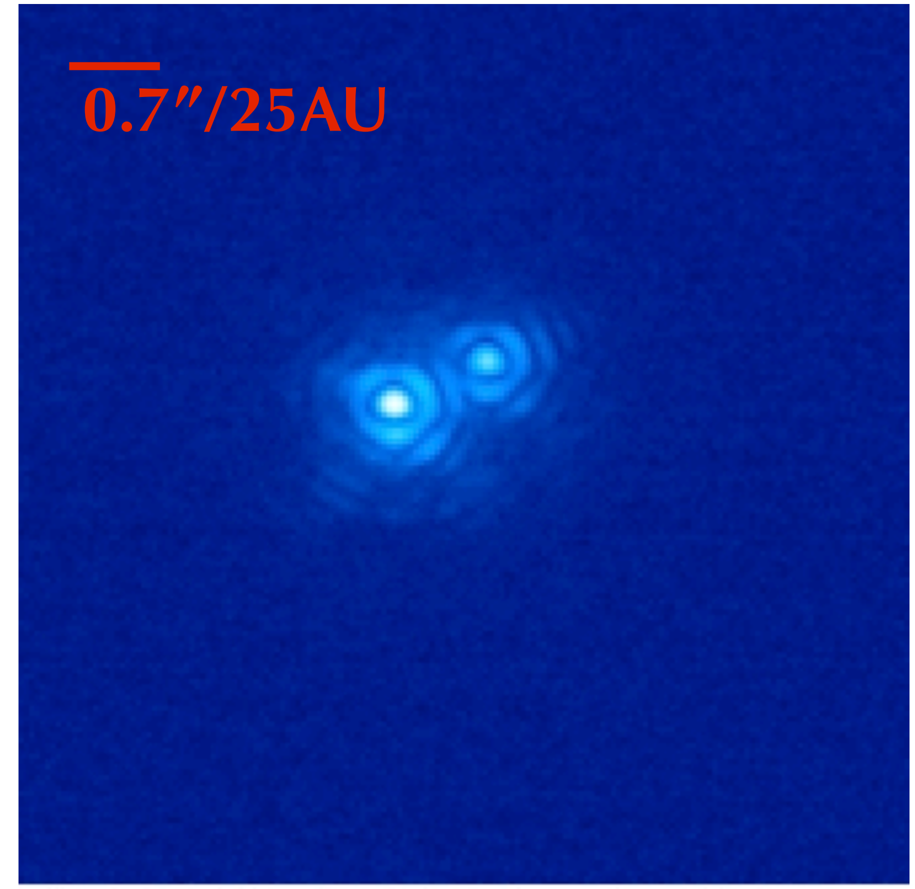


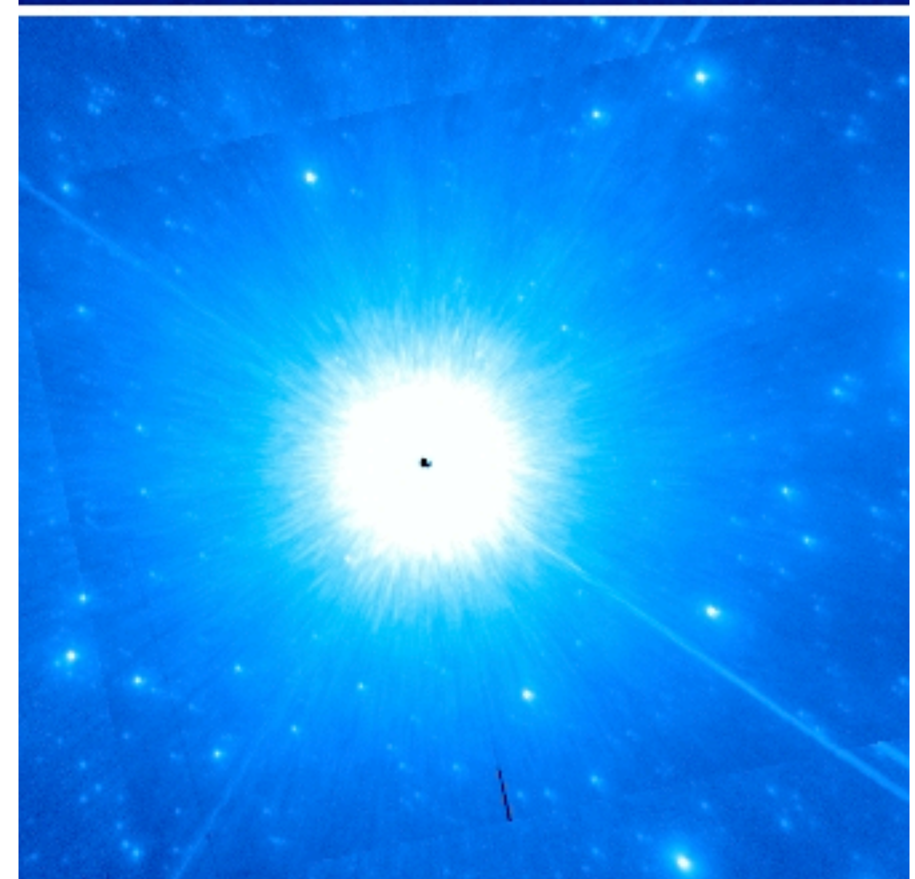
Observations

- **High-resolution AO data obtained at CFHT, Lick, Gemini, Palomar, WHT**
- **Complement with Washington Double Star Catalogue and all-sky surveys (2MASS etc)**



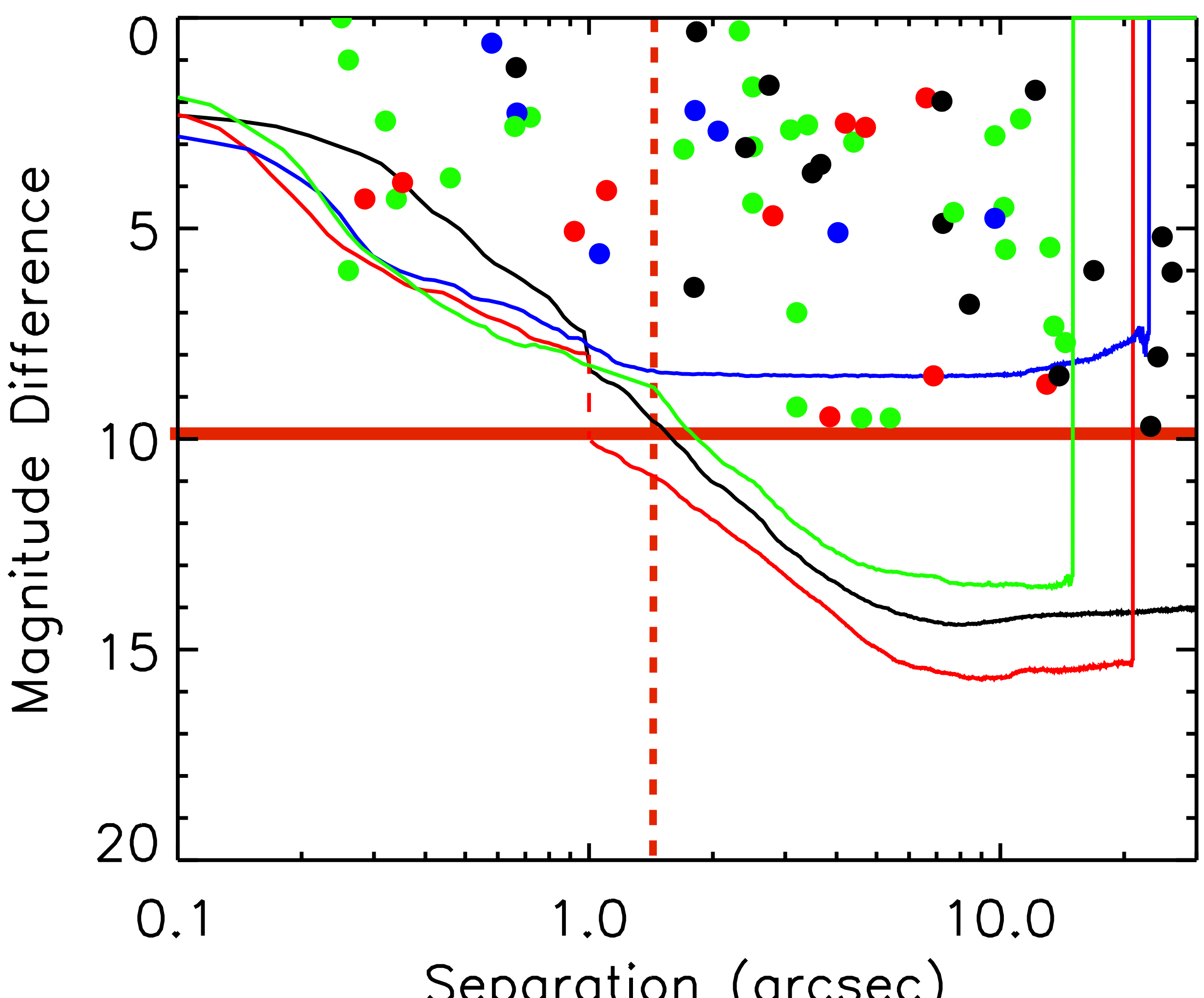


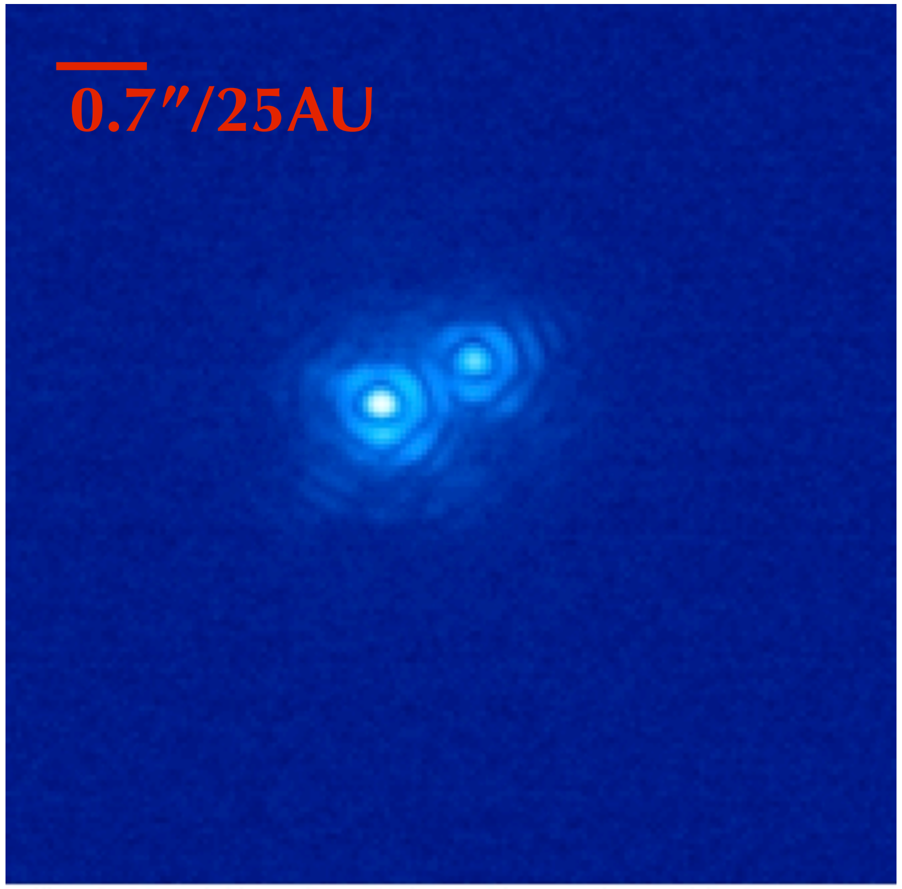


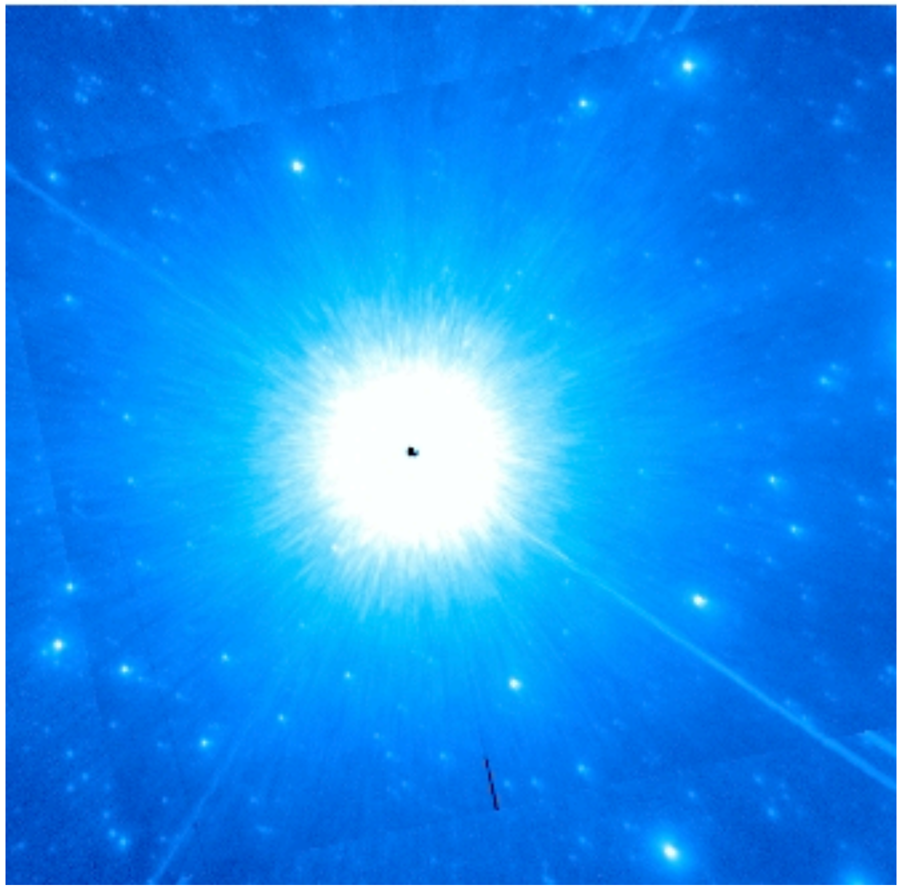


Observations

- **High-resolution AO data obtained at CFHT, Lick, Gemini, Palomar, WHT**
- **Complement with Washington Double Star Catalogue and all-sky surveys (2MASS etc)**
- **Sensitive to bottom of the Main Sequence beyond ~1.5″**

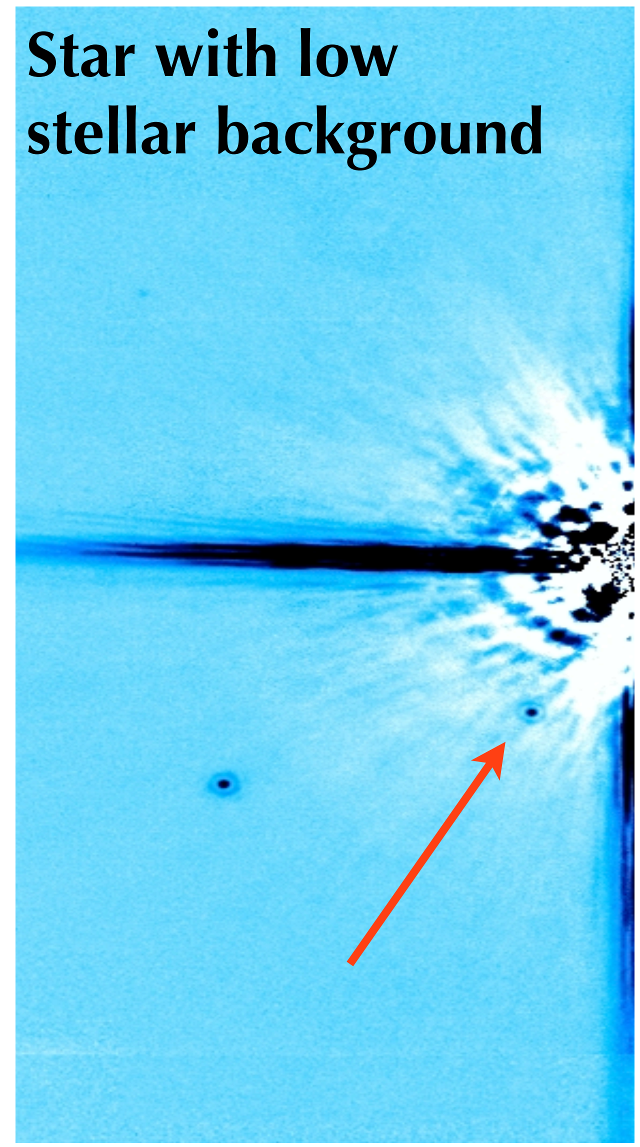


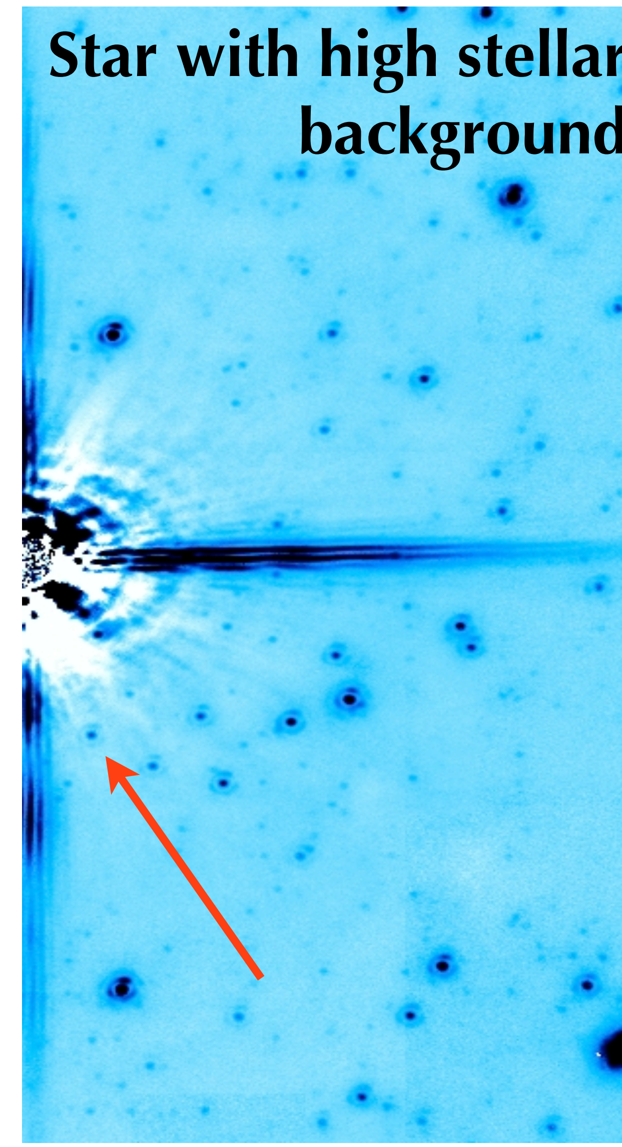




Multiplicity

- Used 2MASS (JHKs) source counts
- Reject candidates with background probability above 5%

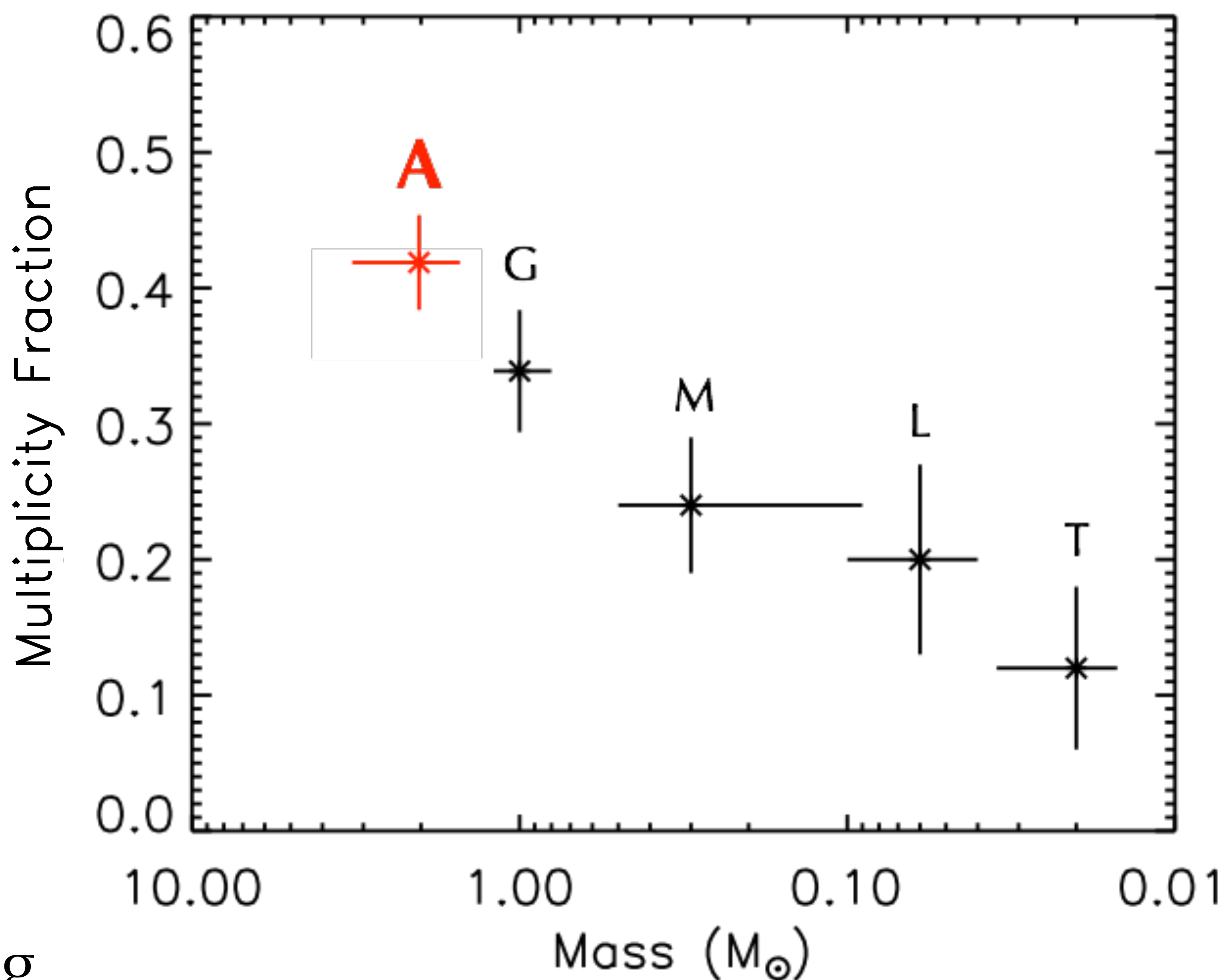




Companion Fraction

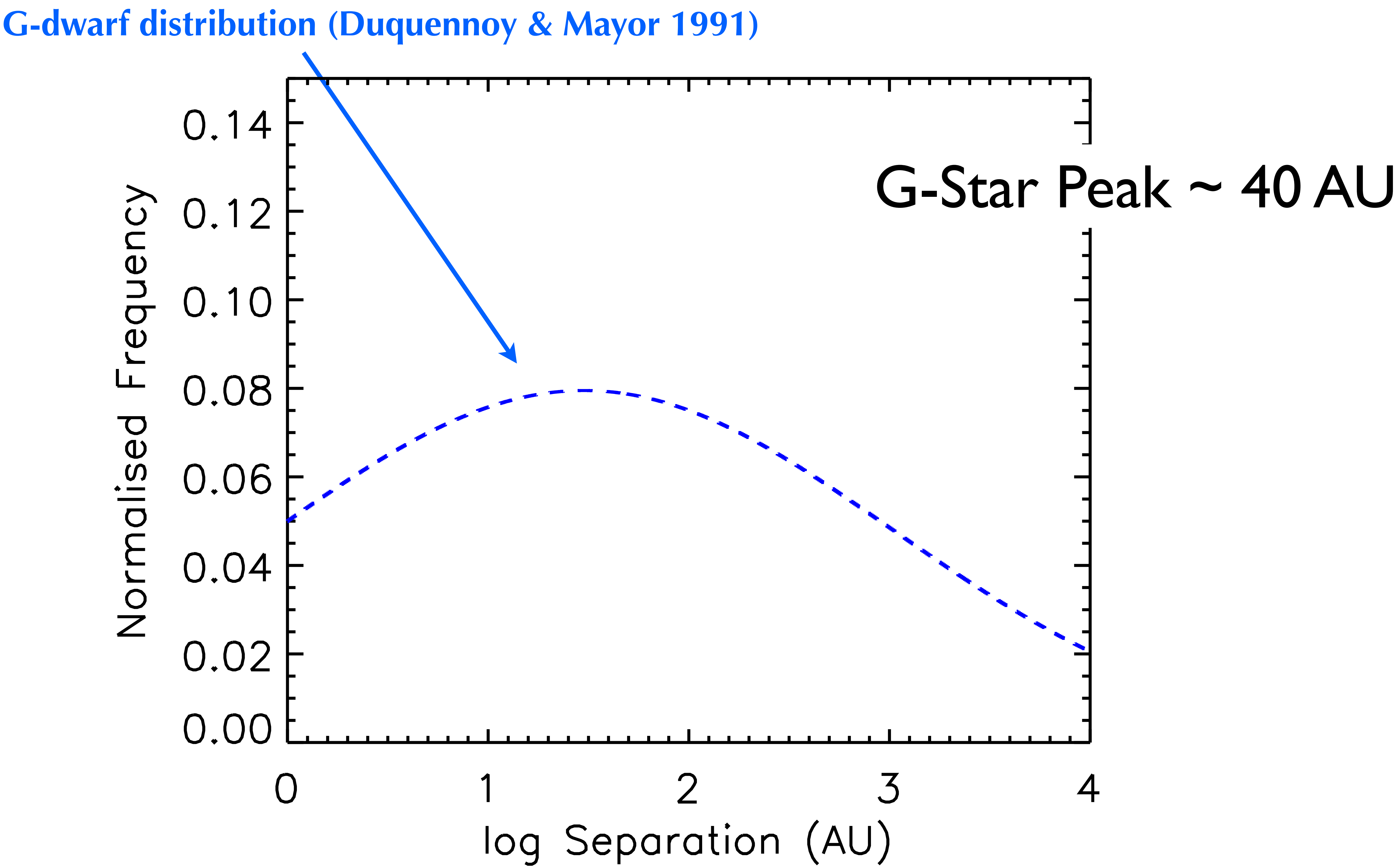
Of 349 stars observed:

~42% Multiplicity
108 Binaries
33 Triples
6 Higher-order

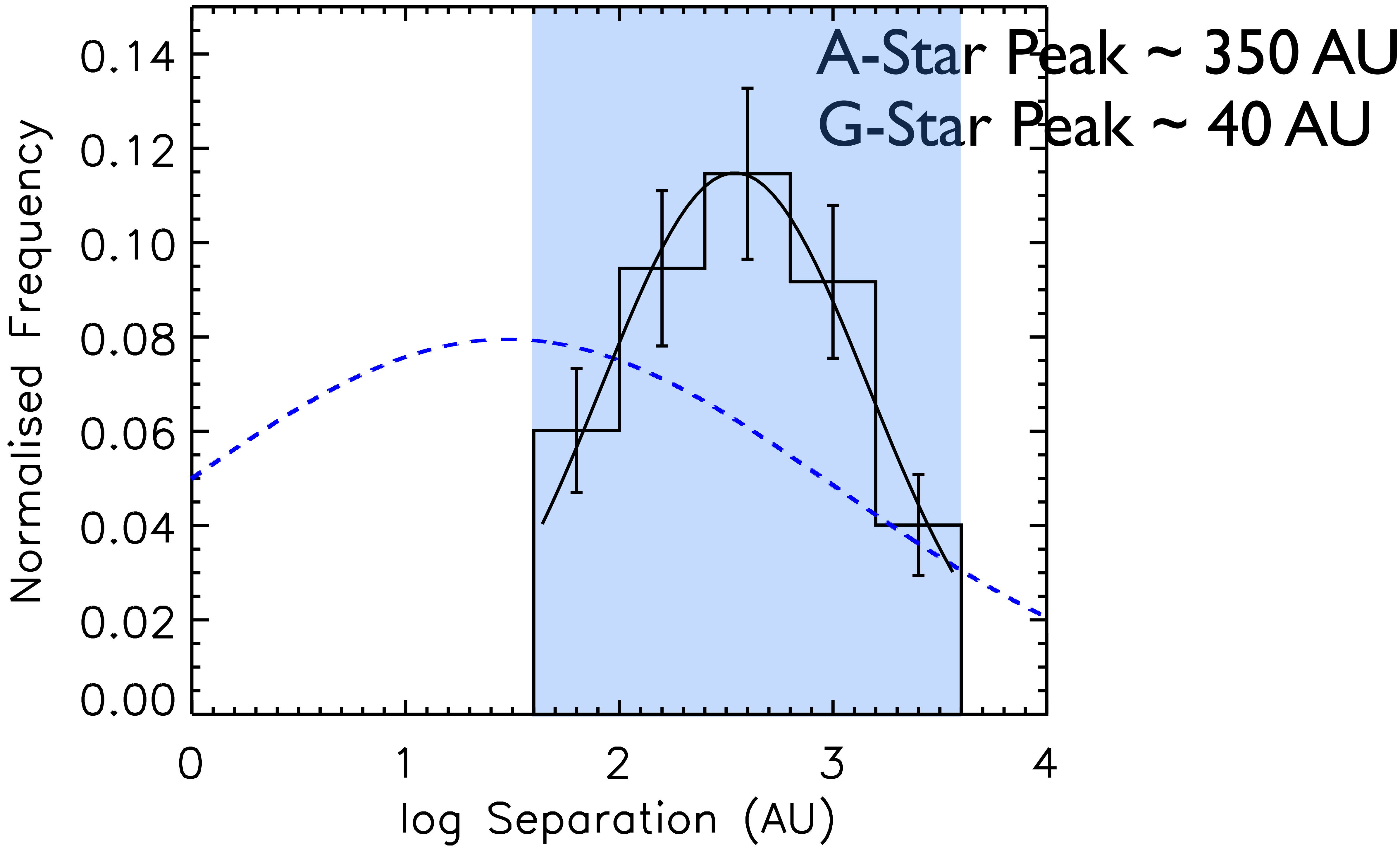


More efficient at forming, retaining companions?

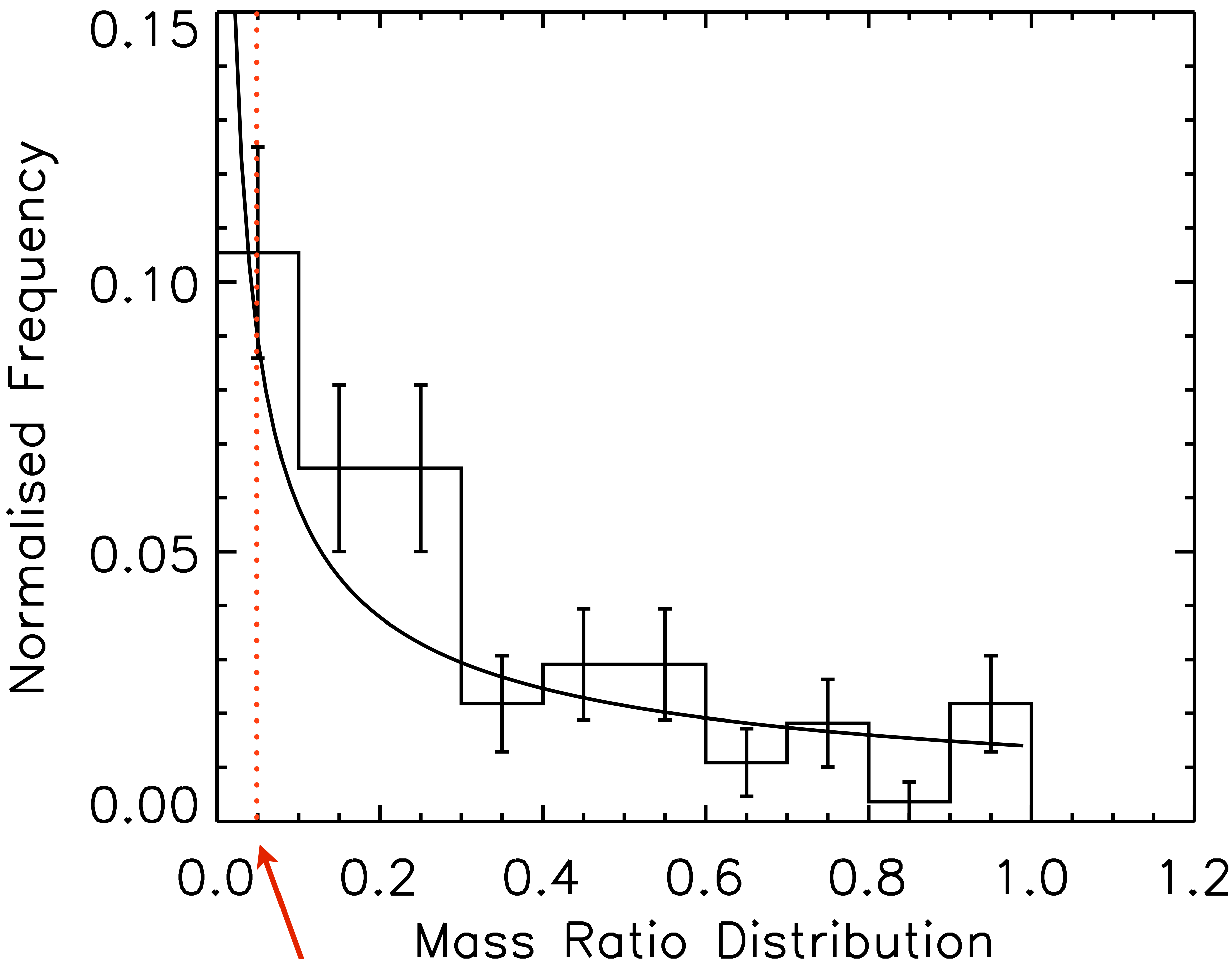
SEPARATION DISTRIBUTION



Separation Distribution



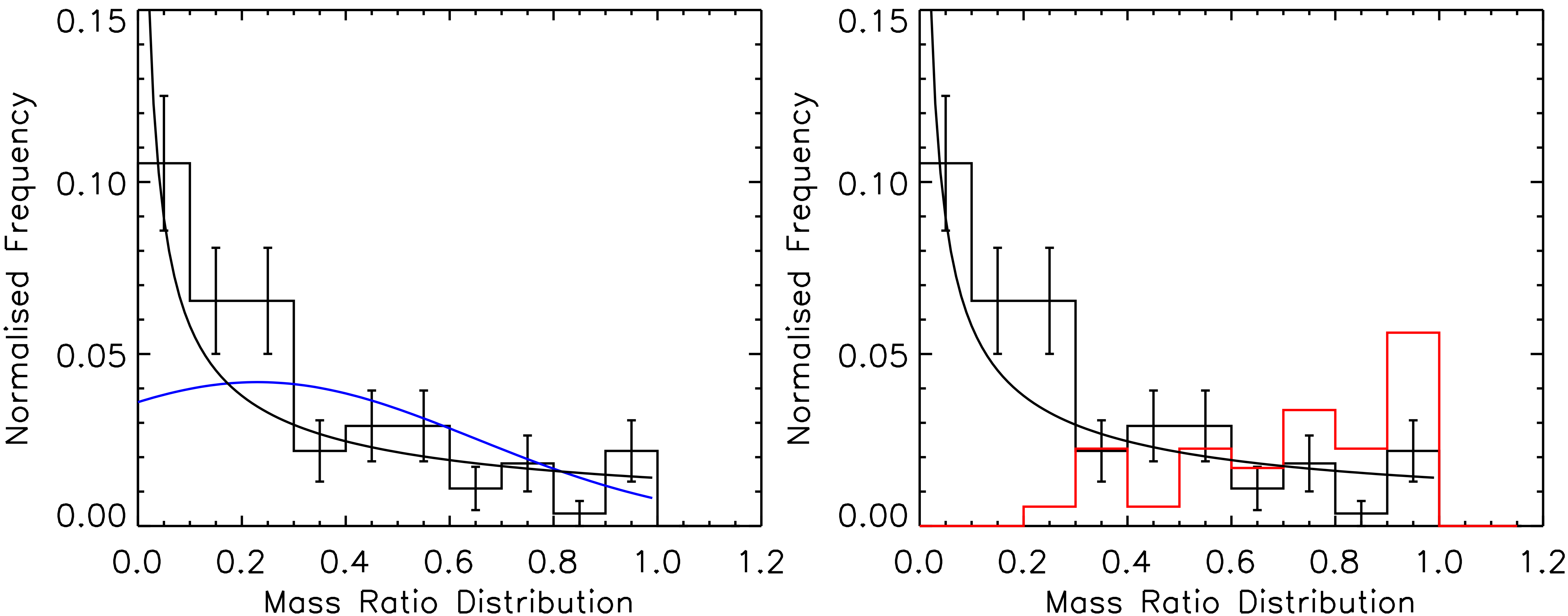
MASS RATIO DISTRIBUTION



Bottom of Main Sequence ($q_{25} \sim 0.05$)

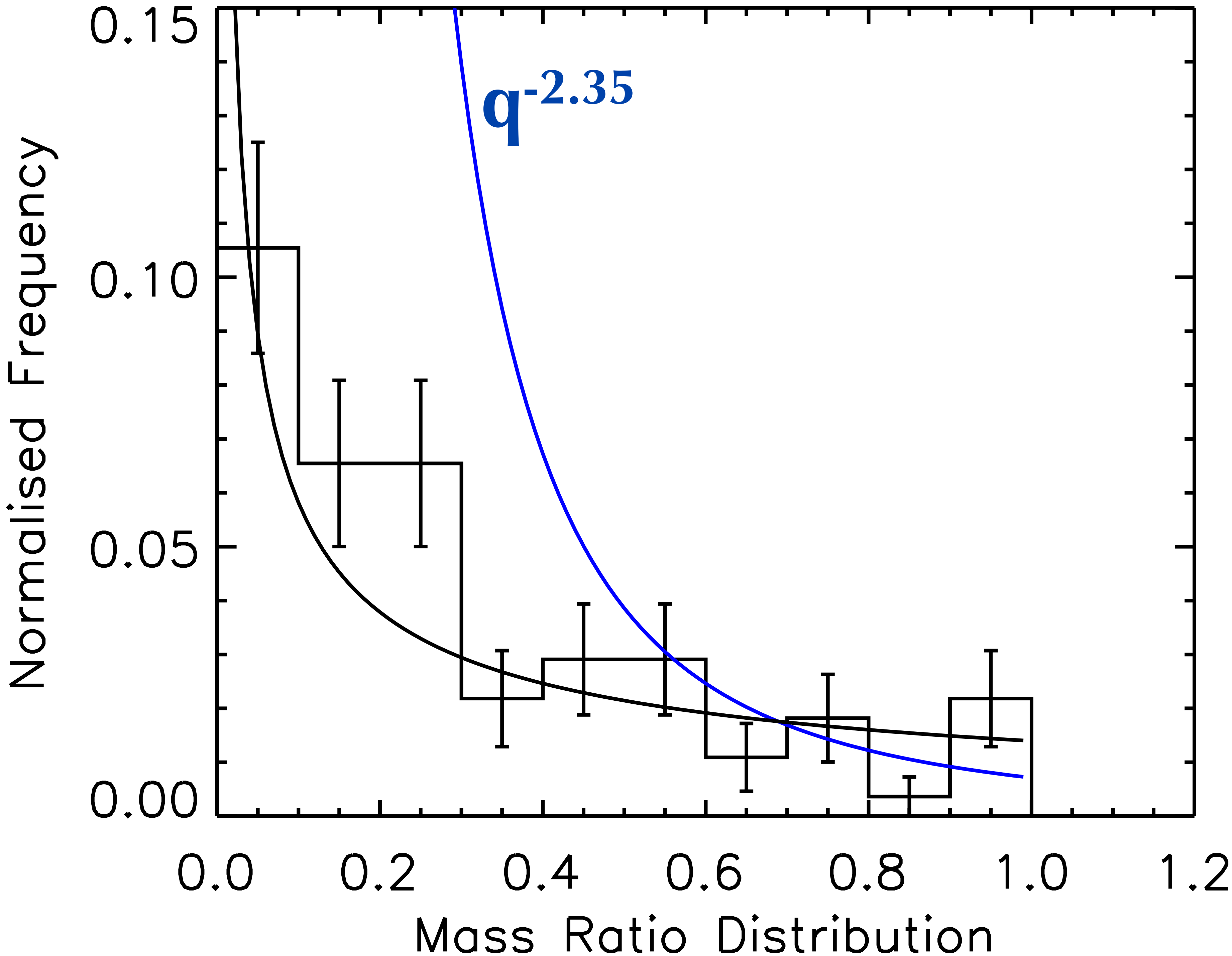
Mass Ratio Distribution

G-, M- dwarf distributions



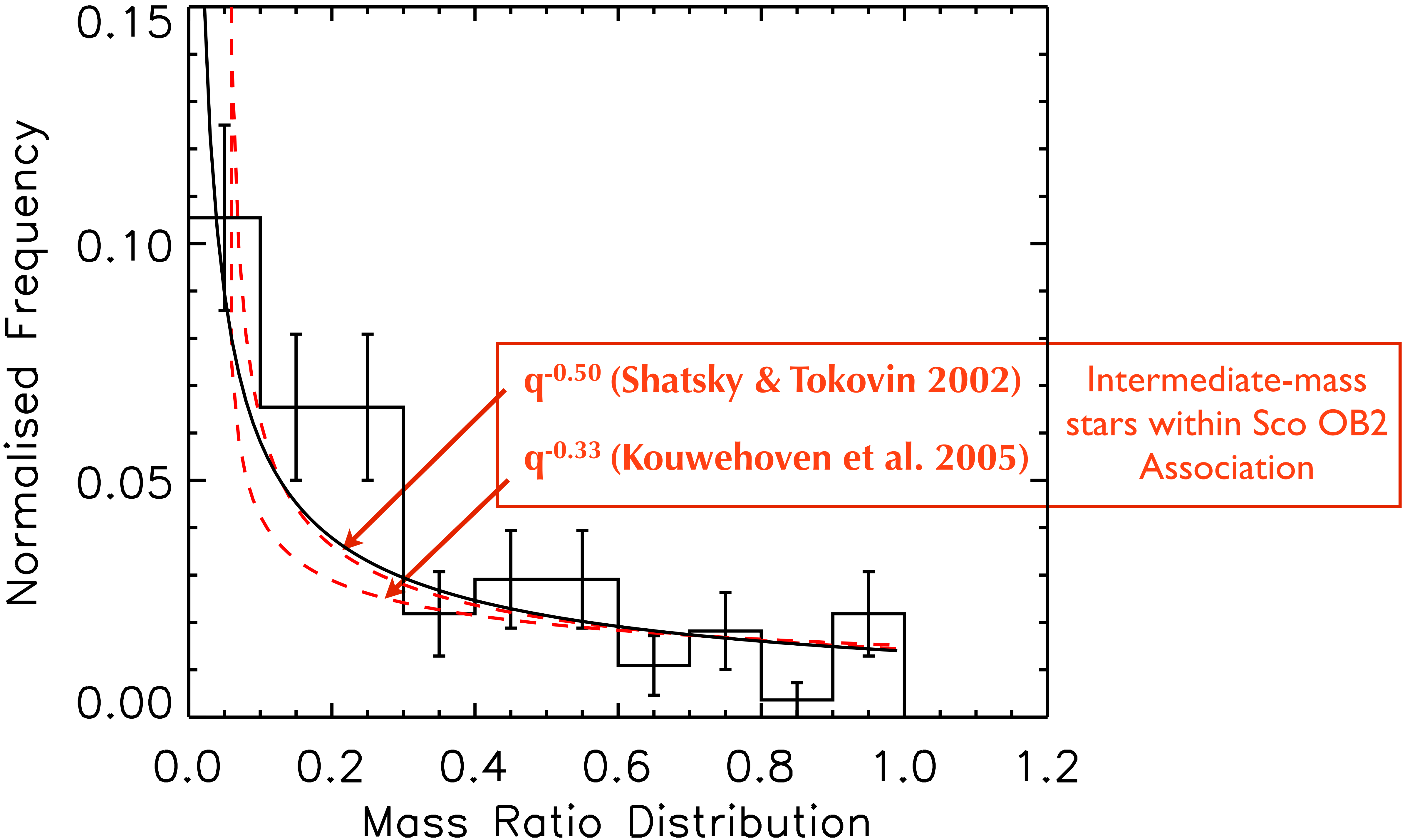
Mass Ratio Distribution

Random capture from the IMF?



Mass Ratio Distribution

Power Law?



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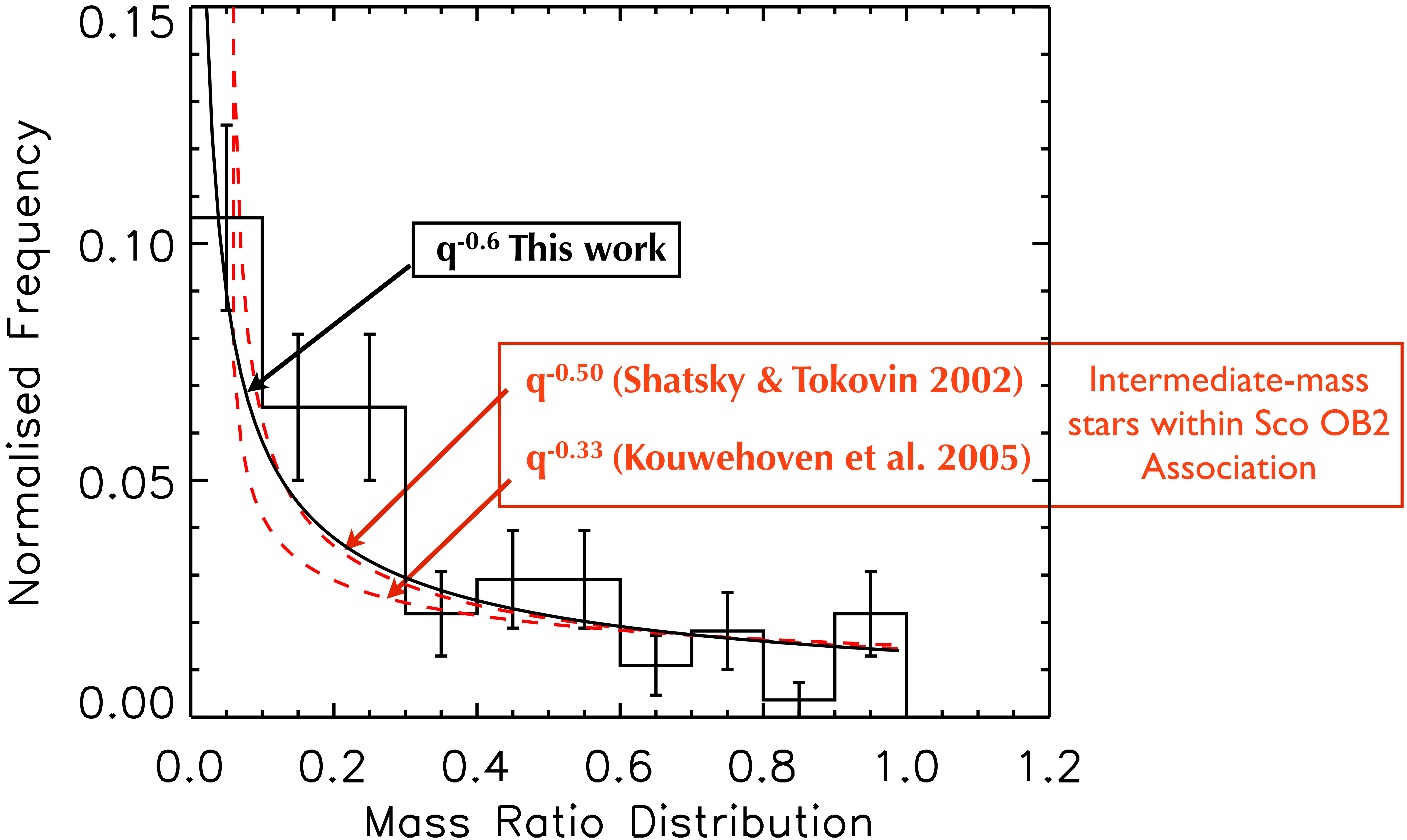
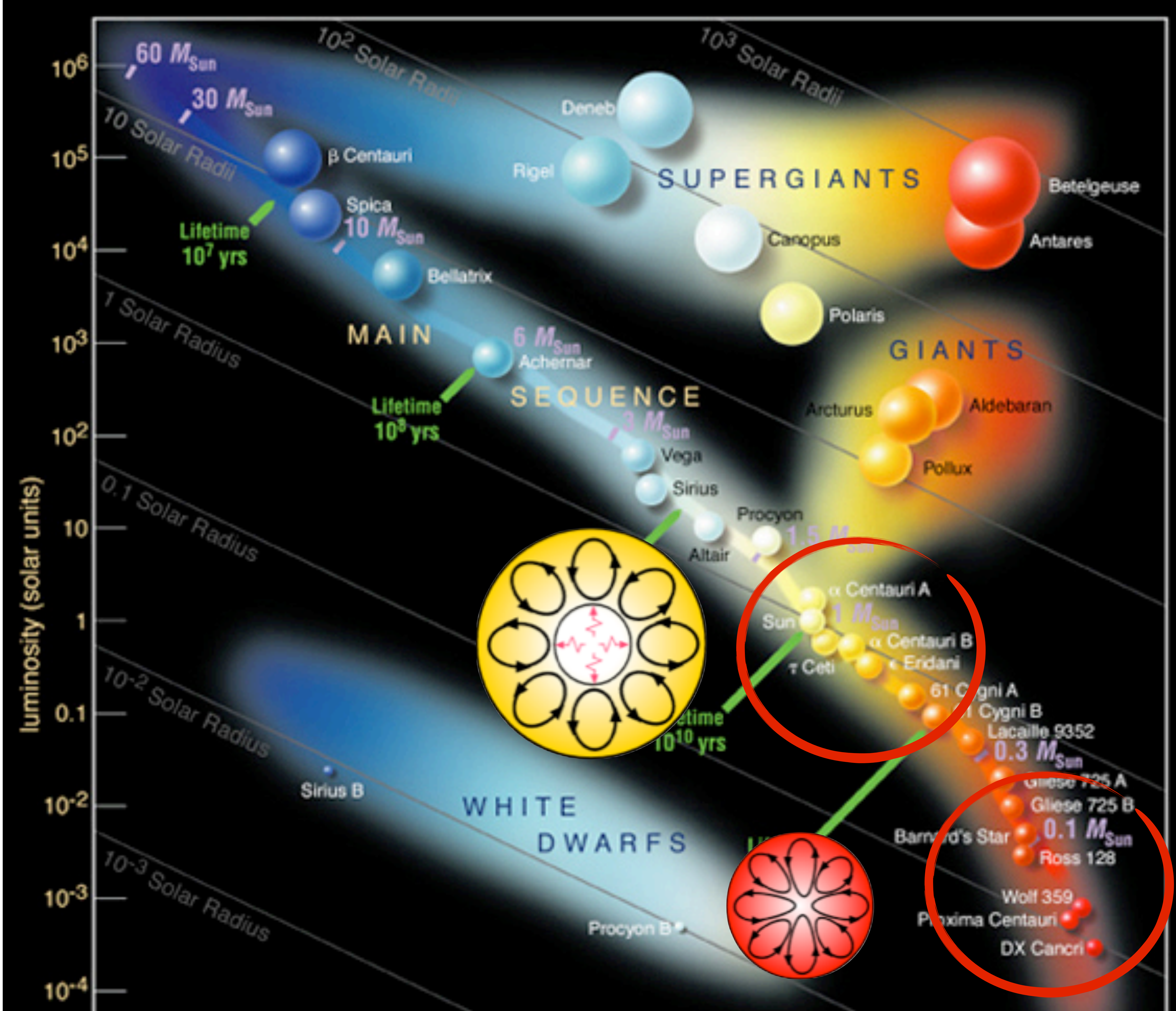
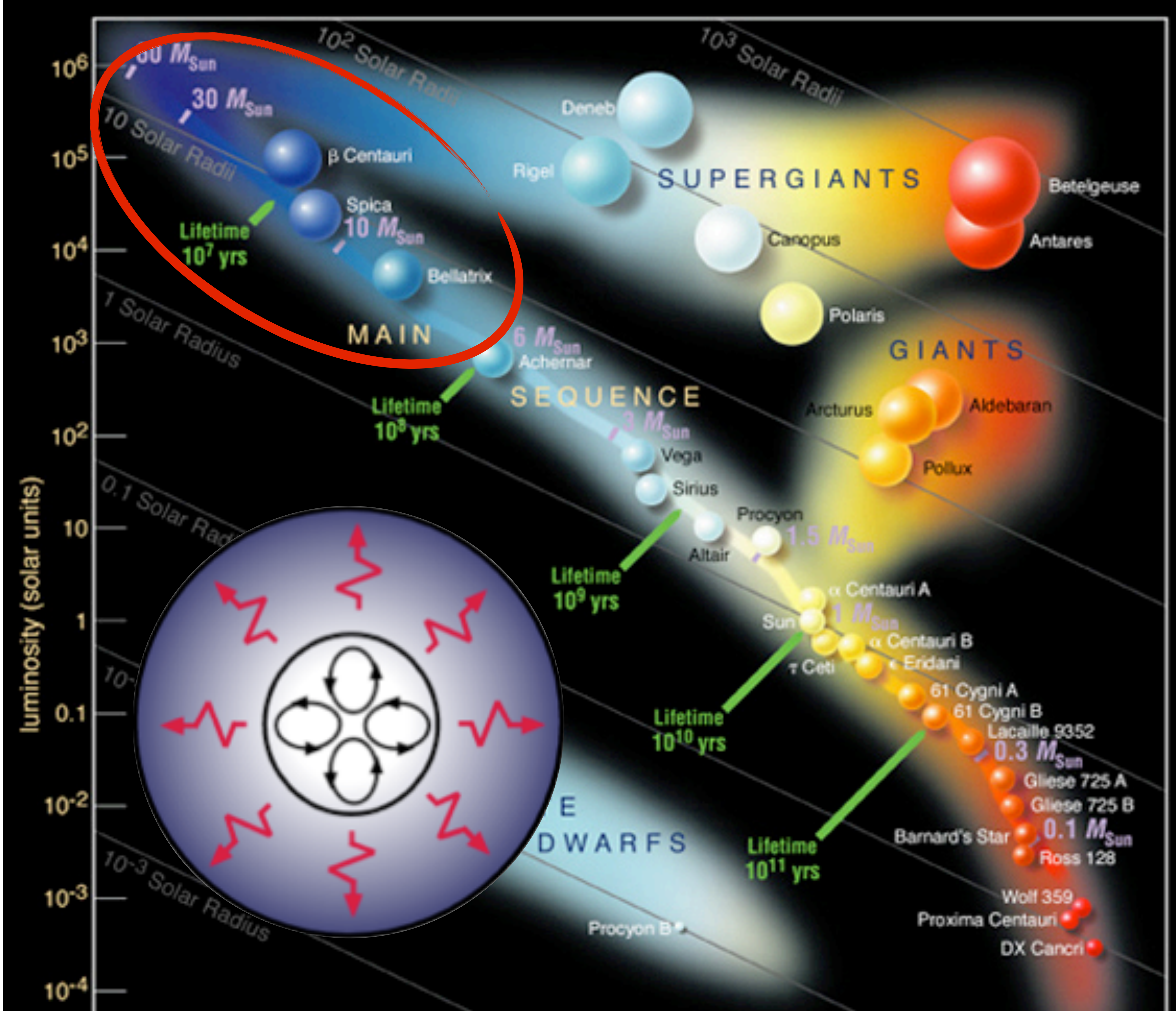


UNEXPLAINED X-RAY DETECTION

- **Late B- and early A-type stars shouldn't produce X-rays**
- X-rays typically generated by magnetic fields or strong stellar winds



luminosity (solar units)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^-2
10^-3
10^-4
60 M_Sun
30 M_Sun
10 M_Sun
6 M_Sun
3 M_Sun
1.5 M_Sun
1 M_Sun
0.3 M_Sun
0.1 M_Sun
10^2 Solar Radii
10^3 Solar Radii
10 Solar Radii
1 Solar Radius
0.1 Solar Radius
10^-2 Solar Radius
10^-3 Solar Radius
Lifetime 10^7 yrs
Lifetime 10^8 yrs
10^10 yrs
SUPERGIANTS
GIANTS
MAIN SEQUENCE
WHITE DWARFS
Deneb
Rigel
β Centauri
Spica
Bellatrix
Achernar
Betelgeuse
Antares
Canopus
Polaris
Arcturus
Aldebaran
Pollux
Vega
Sirius
Procyon
Altair
α Centauri A
Sun
α Centauri B
τ Ceti
ε Eridani
61 Cygni A
Cygni B
Lacaille 9352
Gliese 725 B
Ross 128
Wolf 359
DX Cancri
Sirius B
Procyon B



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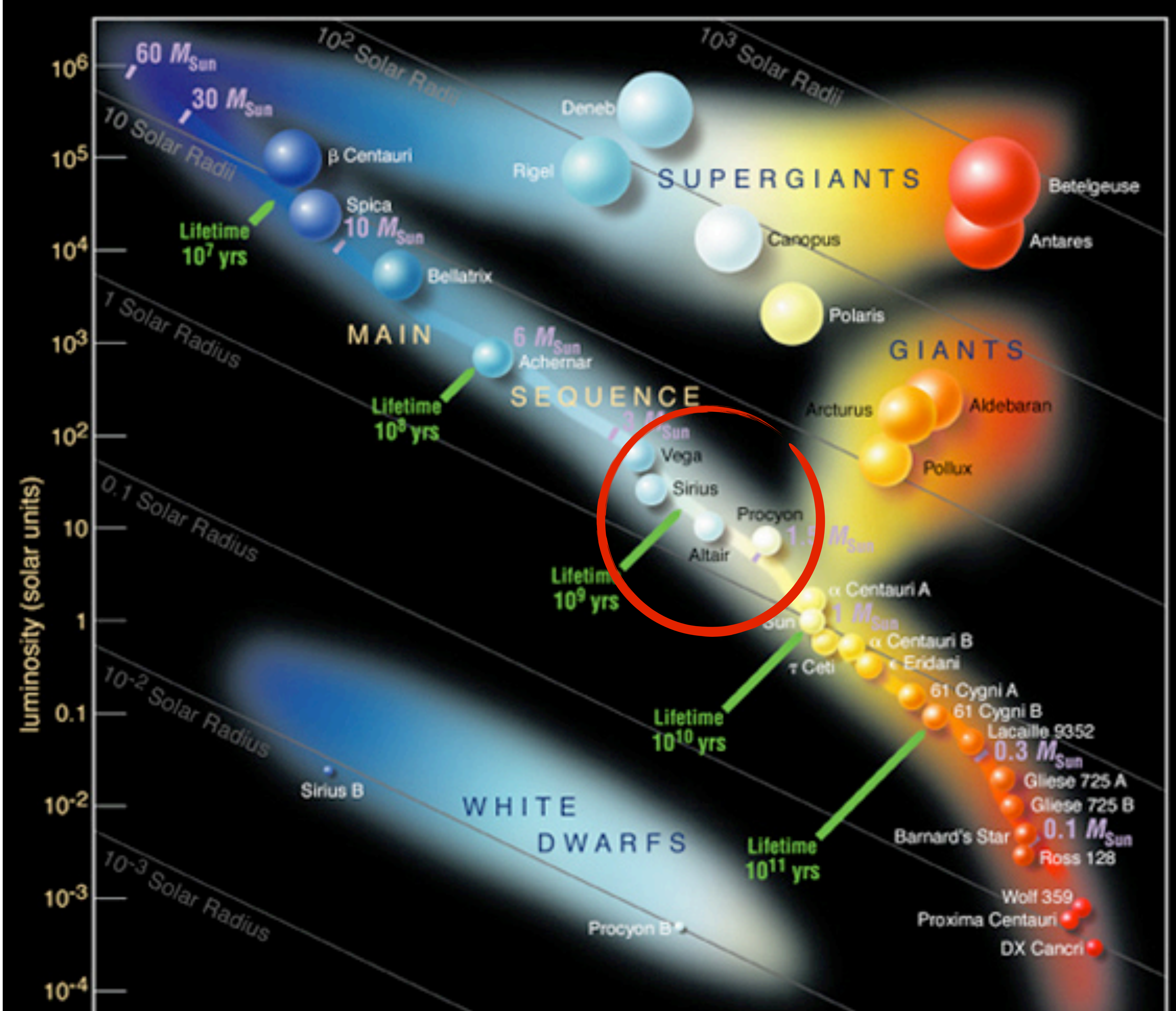

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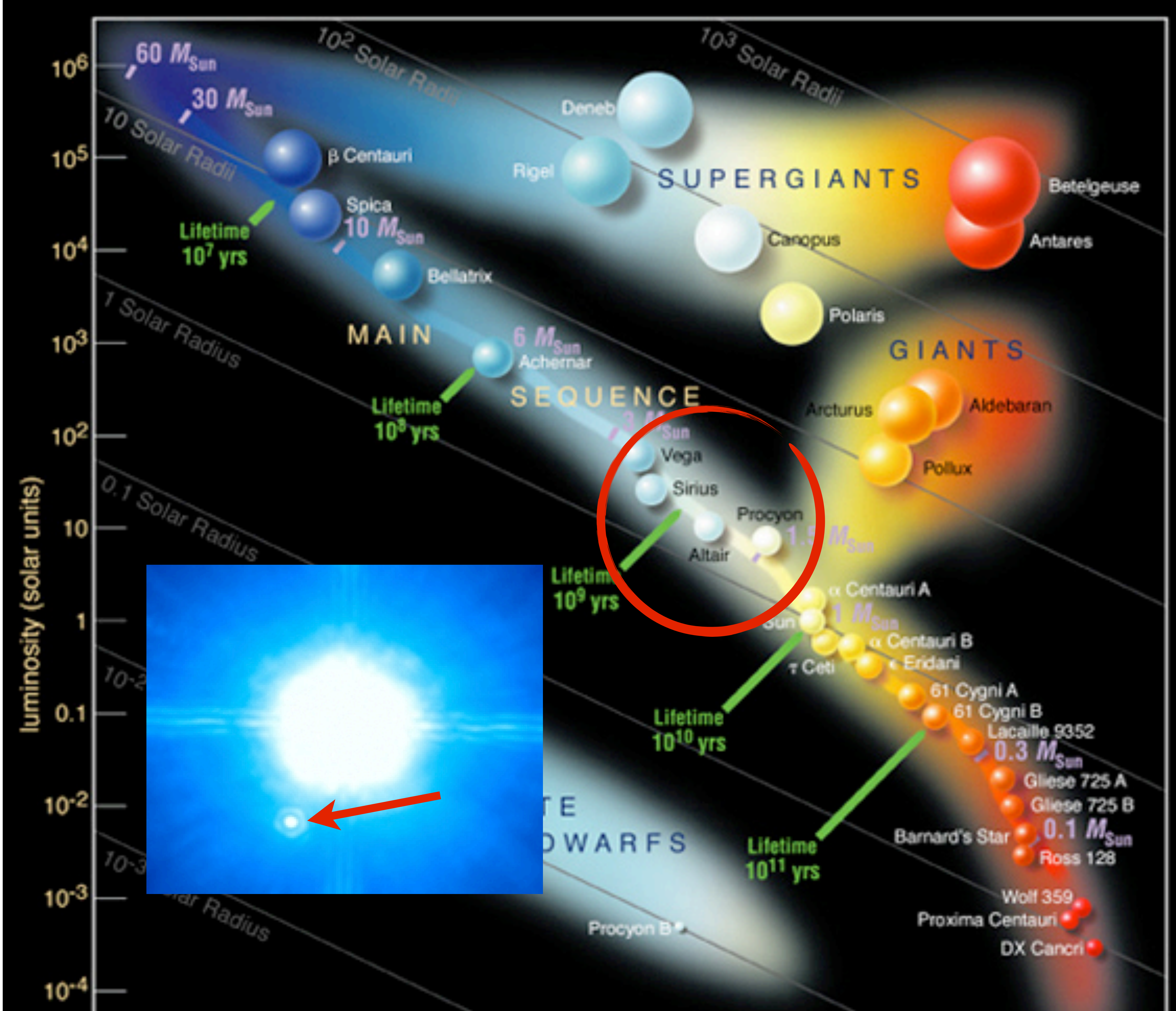

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Lifetime 10^{10} yrs
Gliese 725 A
Gliese 725 B
Barnard's Star
$0.1\ M_{Sun}$
Ross 128
Lifetime 10^{11} yrs
Wolf 359
Proxima Centauri
DX Cancri
Procyon B

Unexplained X-Ray Detection

- **Late B- and early A-type stars shouldn't produce X-rays**
- F/G/K/M - Magnetic field
- ***A - typically no generation mechanism***
- O/B - Strong stellar winds

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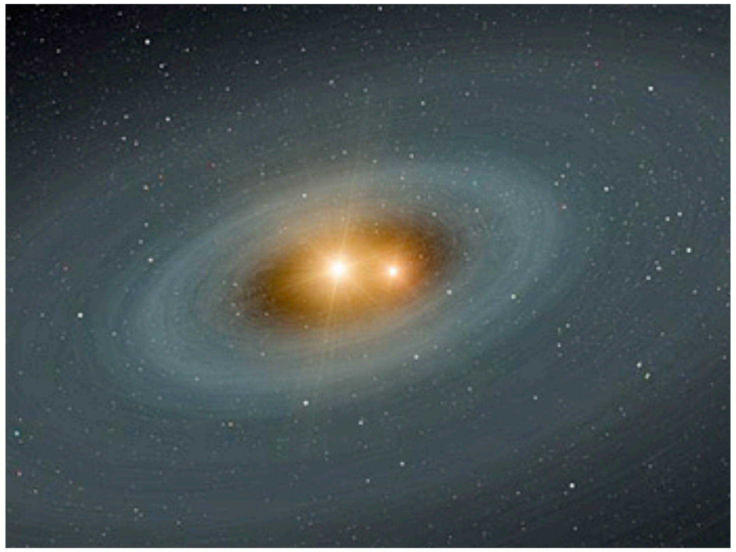
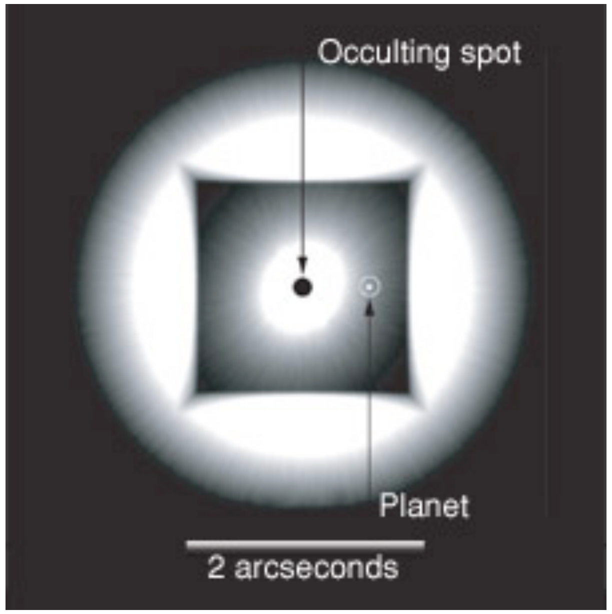
	X-Ray	**Control**
X-ray Active Companion	**58.7 ± 9.7%**	**20.0 ± 4.9%**

FUTURE WORK



Circum-binary disk (NASA/JPL-Caltech)



Extreme-AO Simulation (LLNL)

- Theoretical predictions of the intermediate-mass binary formation processes
- Influence of companions upon debris disks
- Interferometry/spectroscopy to probe tight separations
- Extreme-AO to search for brown dwarfs/giant planets within 10s of AU

CONCLUSIONS

- Multiplicity of A-type stars ~ 40%
- Peak of separation distribution at 350 AU
- Mass-ratio skewed towards lower-mass companions
- Unresolved low-mass companions likely source of X-ray emission