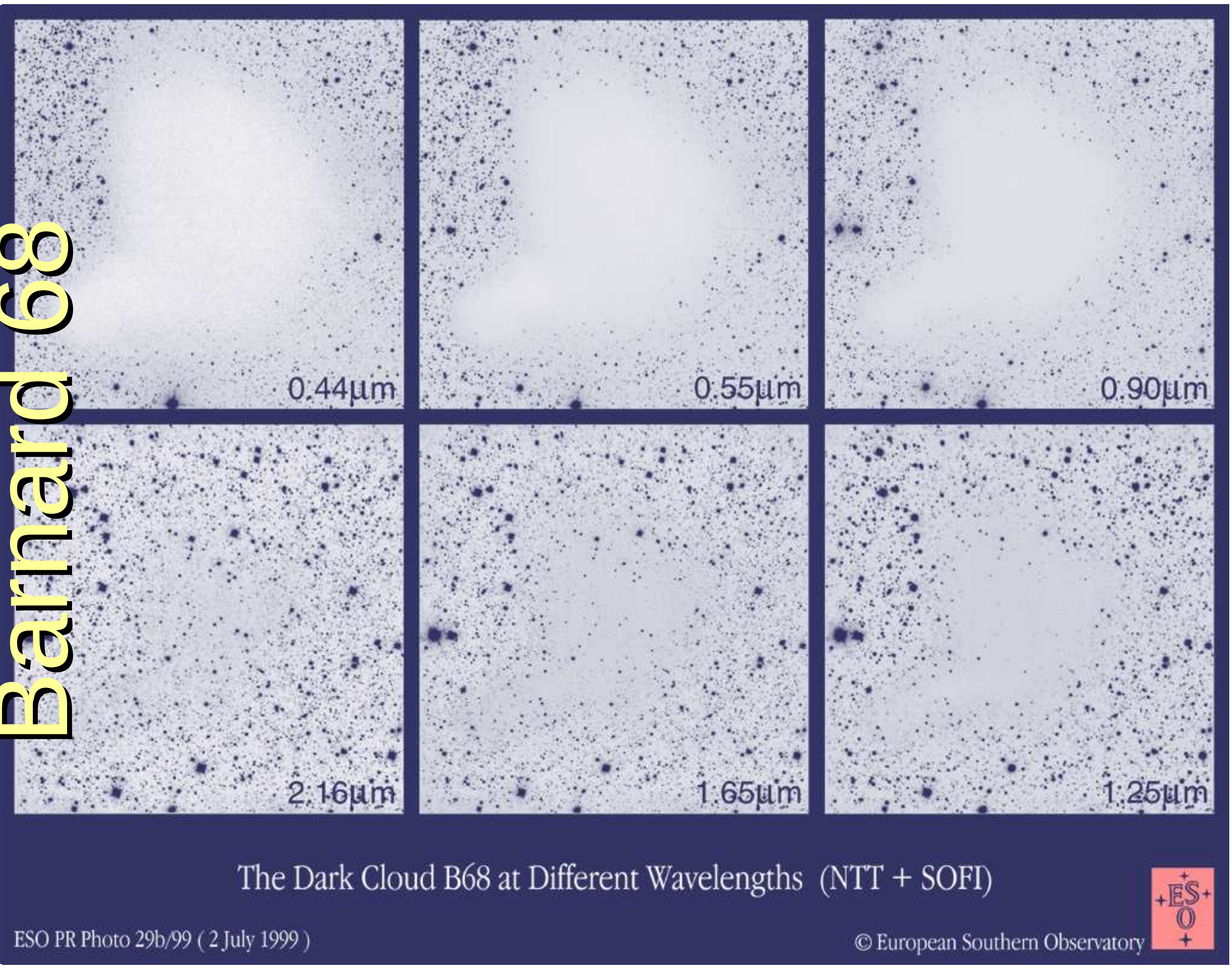
mini-course on

Star and Planet Formation

with, in order of appearance,

Marten van Kerkwijk	Ed Thommes
Norm Murray	Alexis Brandeker
Ray Jayawardhana	Pawel Artymowicz
Aleks Scholz	Yanqin Wu

Barnard 68



The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

ESO PR Photo 29b/99 (2 July 1999)

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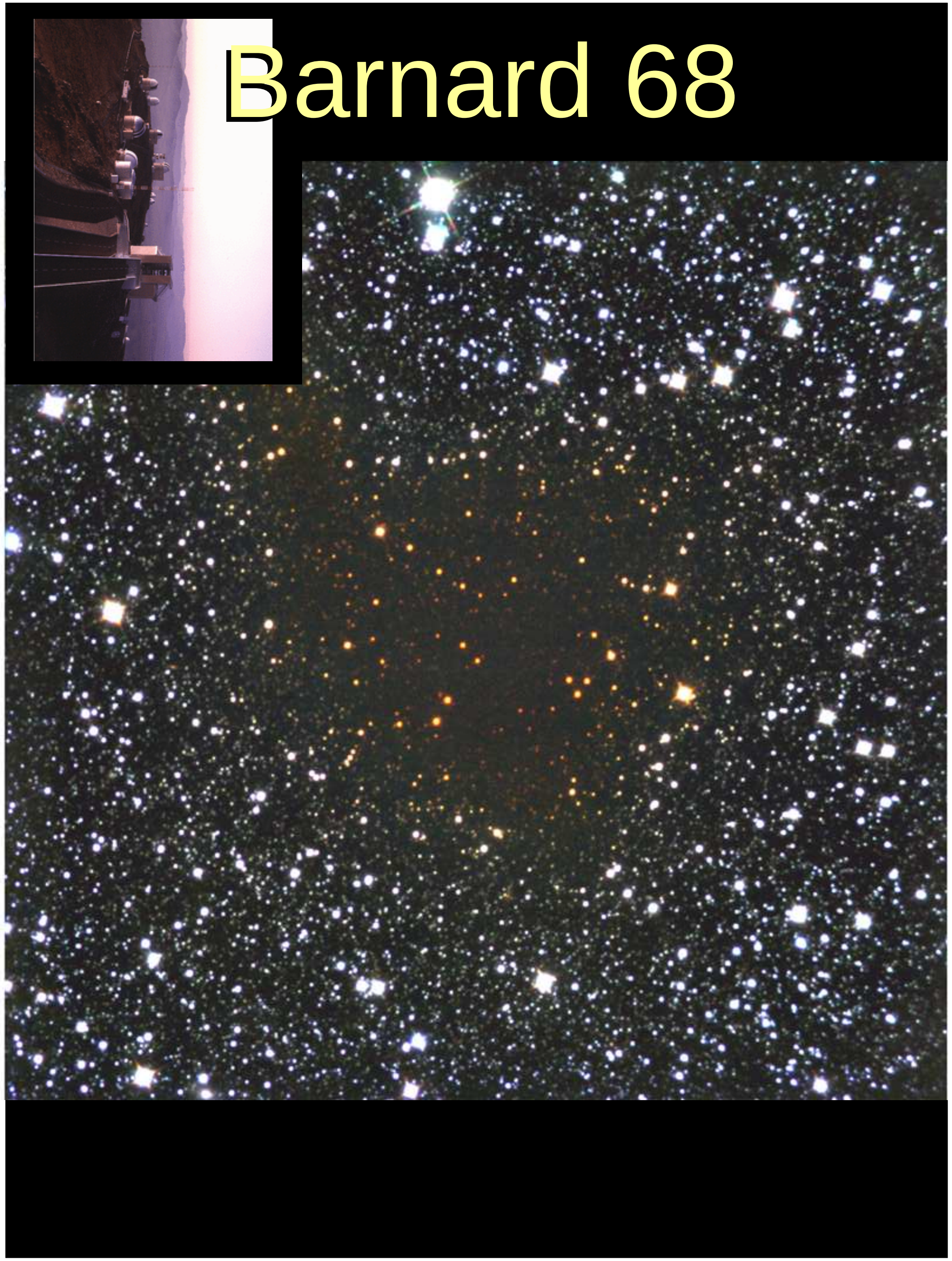
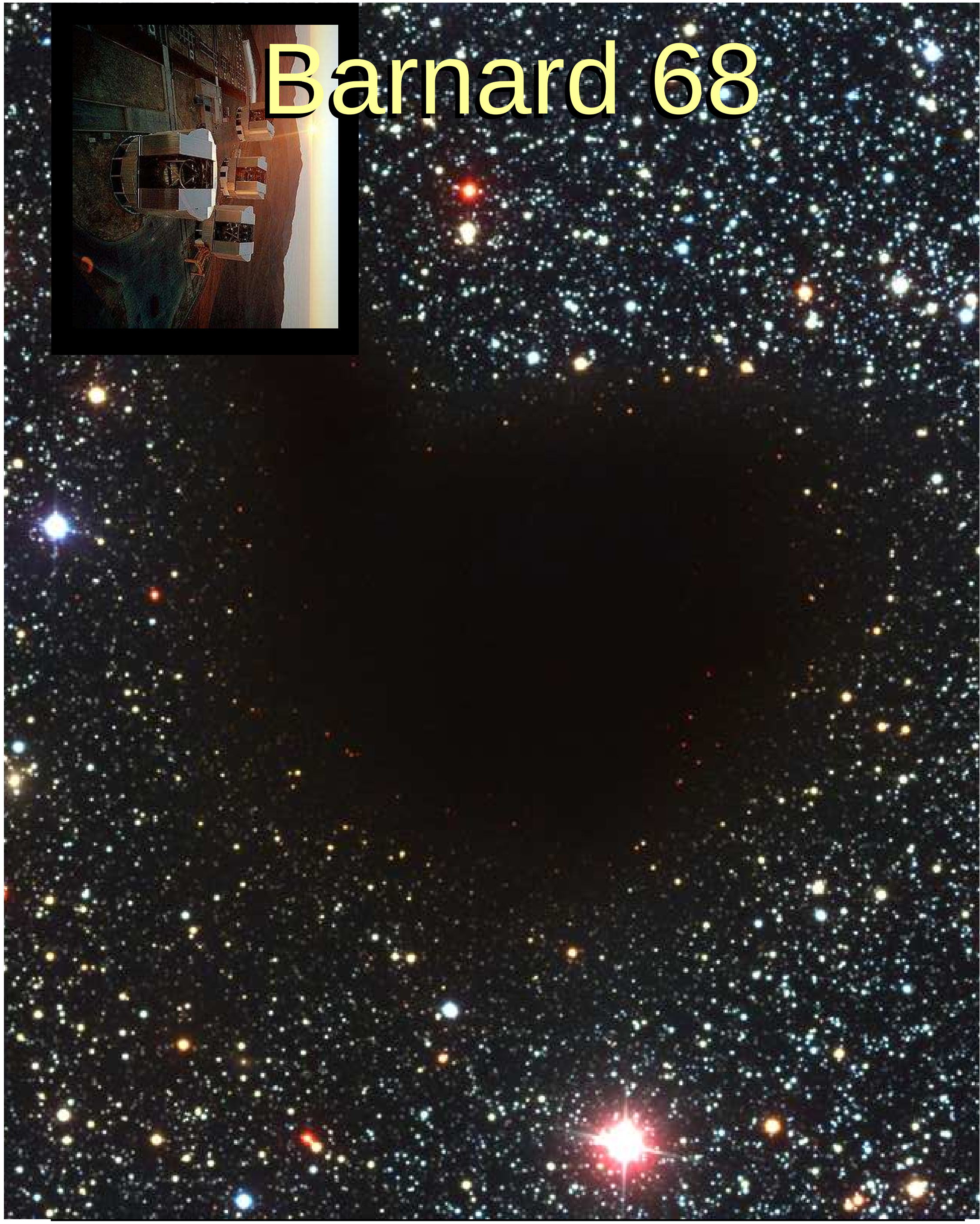
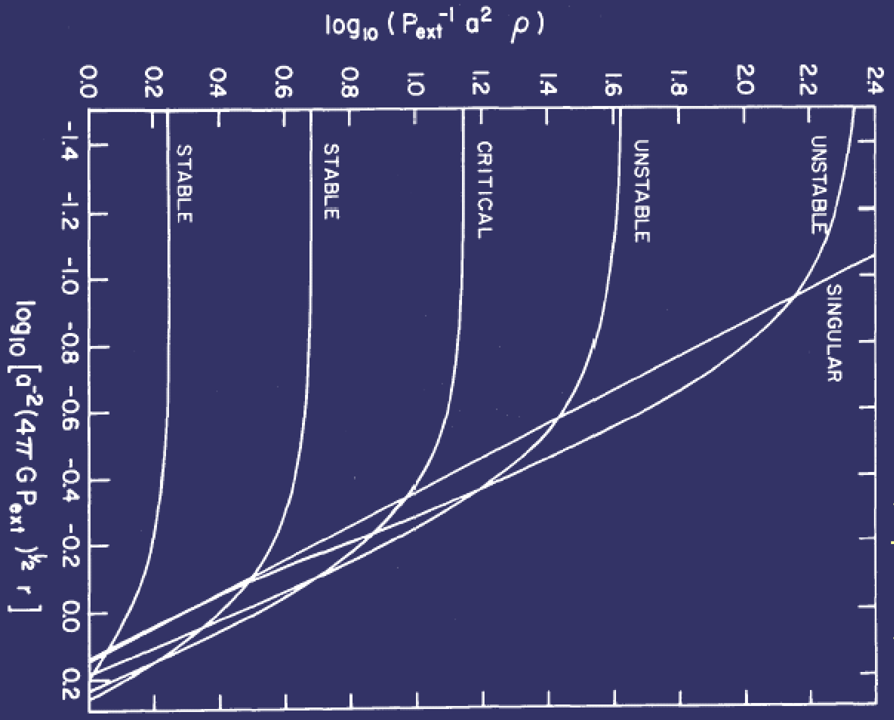

Barnard 68

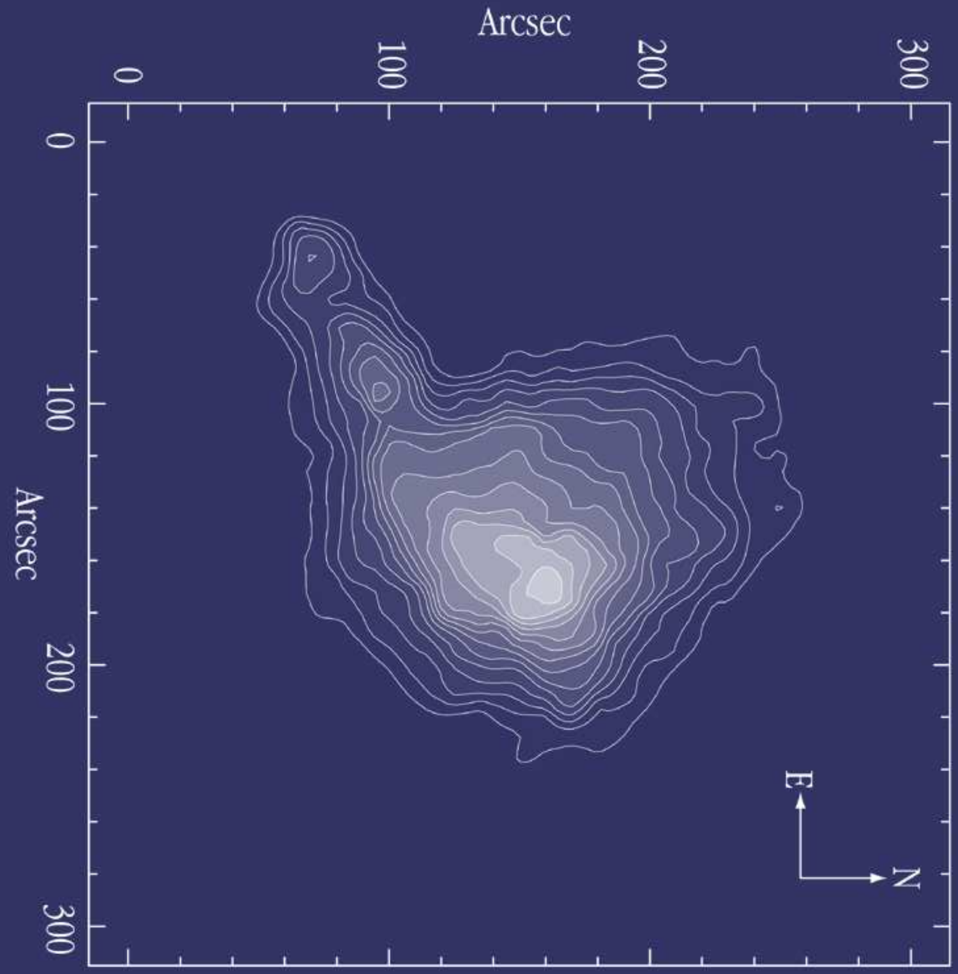

Barnard 68

Isothermal Spheres



Shu 1977, ApJ 214, 488

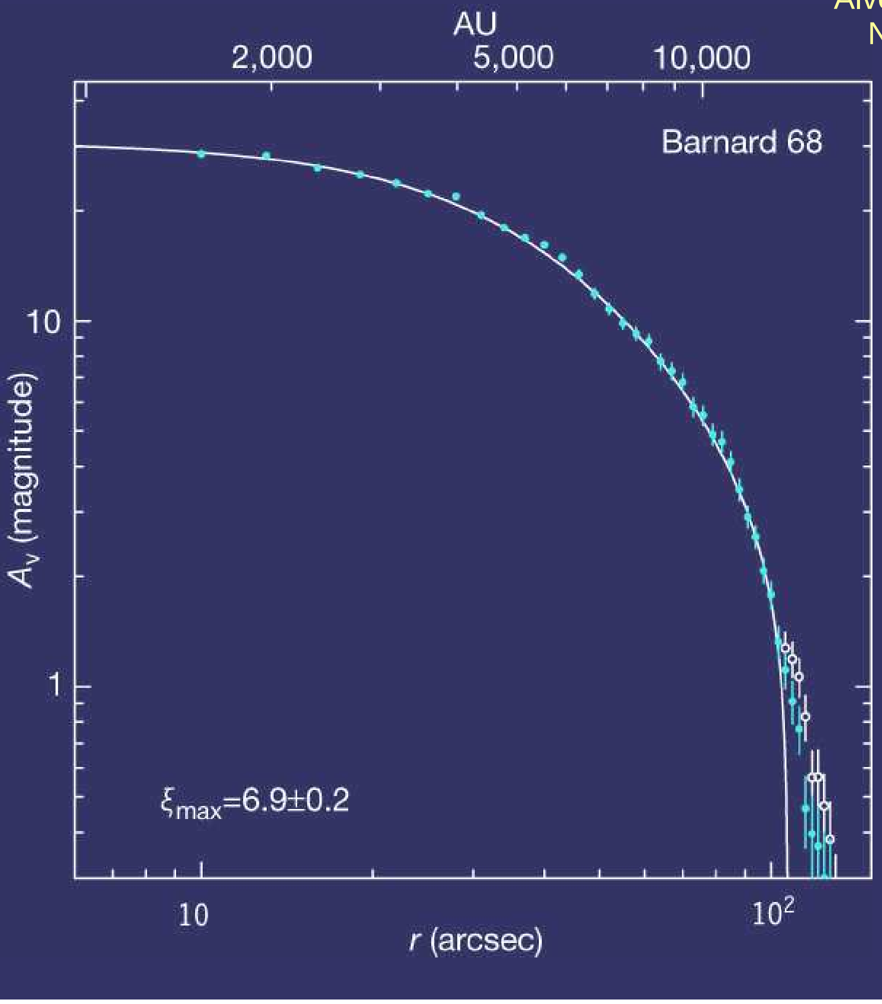
Barnard 68



Map of the Obscuration in the Dark Cloud B68

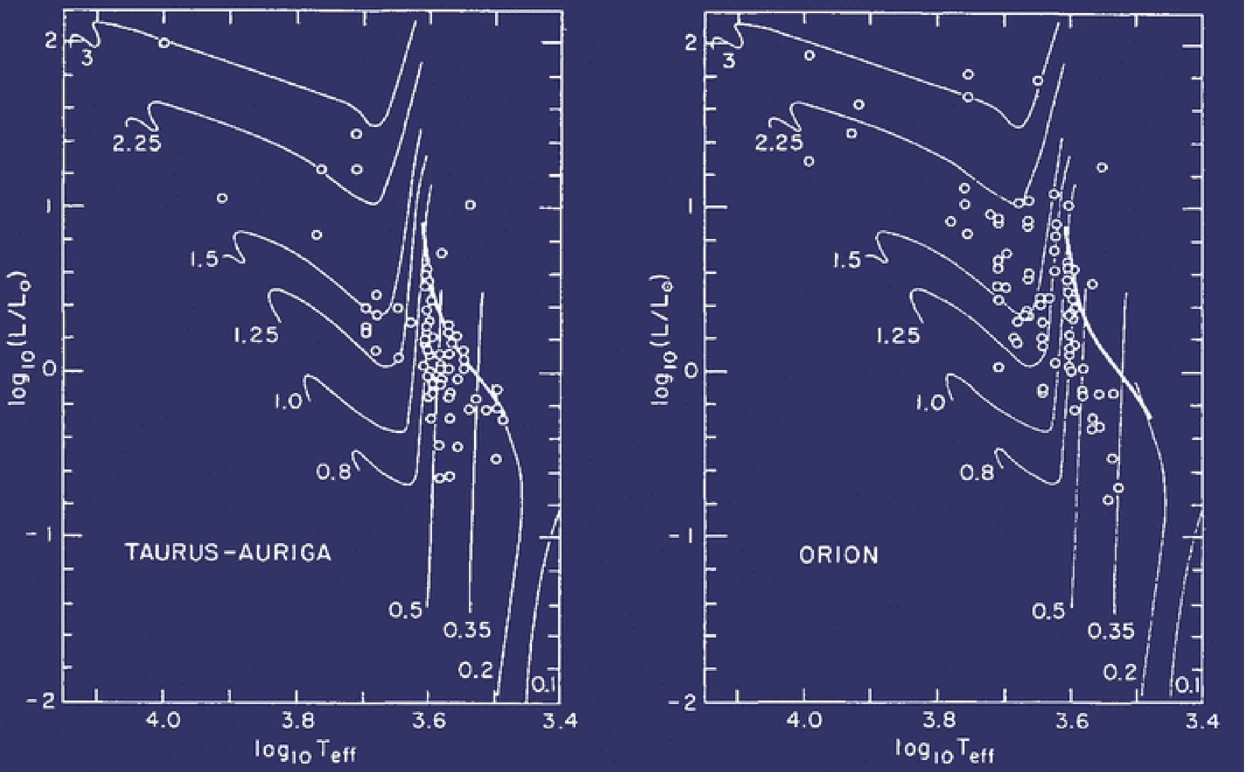
Barnard 68

Alves et al., 2001,
Nature 409, 159

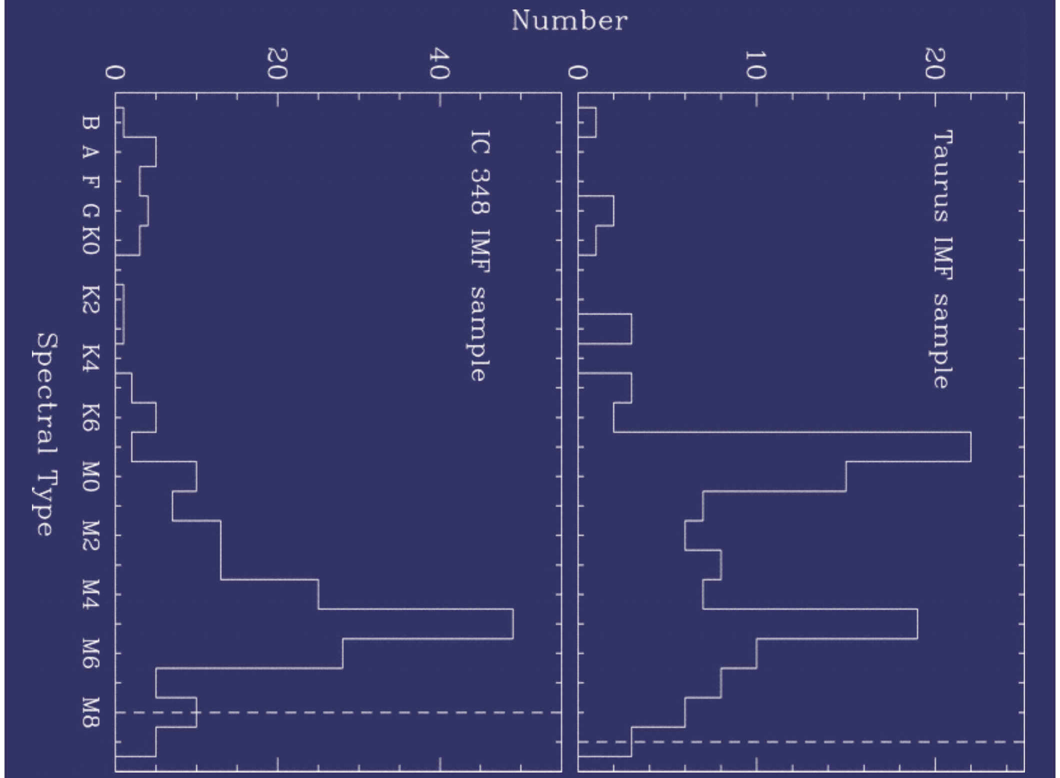


Stellar Birthline

Shu et al., 1987, ARA&A 25, 23

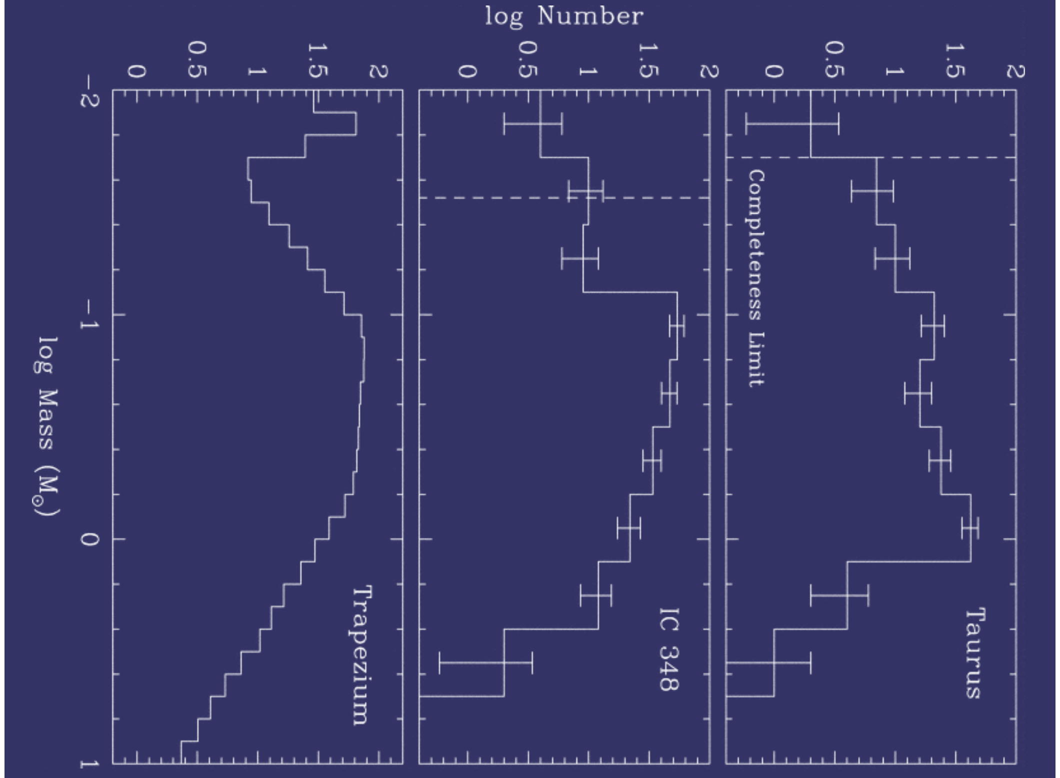


Initial Mass Function



Luhman, 2004,
ApJ 617, 1216

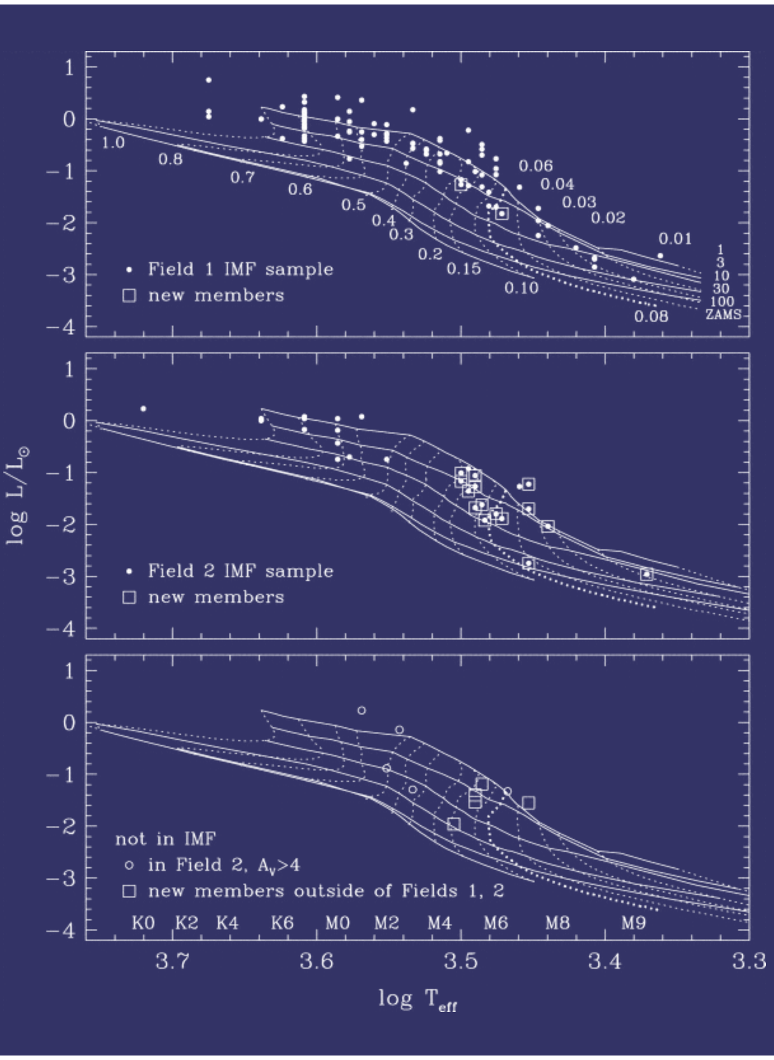
Initial Mass Function



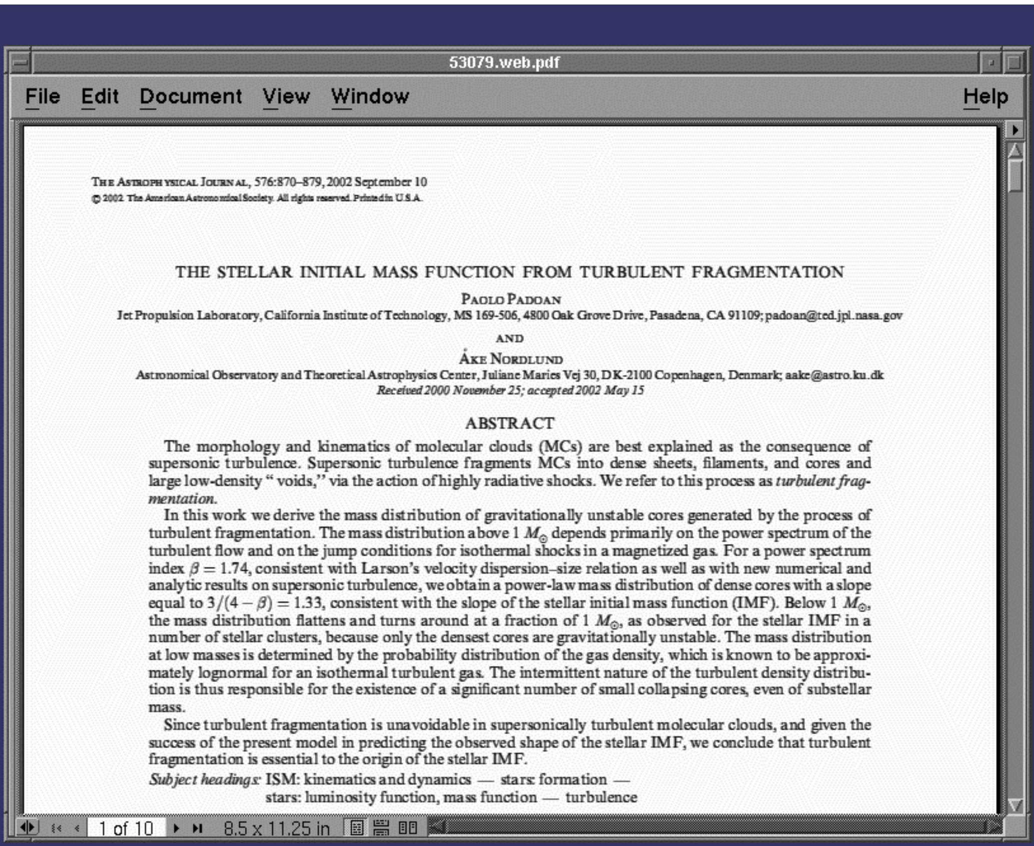
Luhman, 2004,
ApJ 617, 1216

Initial Mass Function

Luhman, 2004,
ApJ 617, 1216



Turbulent Fragmentation?



The Astrophysical Journal, 576:870–879, 2002 September 10

THE STELLAR INITIAL MASS FUNCTION FROM TURBULENT FRAGMENTATION

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ABSTRACT

The morphology and kinematics of molecular clouds (MCs) are best explained as the consequence of supersonic turbulence. Supersonic turbulence fragments MCs into dense sheets, filaments, and cores and large low-density "voids," via the action of highly radiative shocks. We refer to this process as *turbulent fragmentation.*

In this work we derive the mass distribution of gravitationally unstable cores generated by the process of turbulent fragmentation. The mass distribution above 1 $M_\odot$ depends primarily on the power spectrum of the turbulent flow and on the jump conditions for isothermal shocks in a magnetized gas. For a power spectrum index $\beta = 1.74$, consistent with Larson's velocity dispersion–size relation as well as with new numerical and analytic results on supersonic turbulence, we obtain a power-law mass distribution of dense cores with a slope equal to $3/(4 - \beta) = 1.33$, consistent with the slope of the stellar initial mass function (IMF). Below 1 $M_\odot$, the mass distribution flattens and turns around at a fraction of 1 $M_\odot$, as observed for the stellar IMF in a number of stellar clusters, because only the densest cores are gravitationally unstable. The mass distribution at low masses is determined by the probability distribution of the gas density, which is known to be approximately lognormal for an isothermal turbulent gas. The intermittent nature of the turbulent density distribution is thus responsible for the existence of a significant number of small collapsing cores, even of substellar mass.

Since turbulent fragmentation is unavoidable in supersonically turbulent molecular clouds, and given the success of the present model in predicting the observed shape of the stellar IMF, we conclude that turbulent fragmentation is essential to the origin of the stellar IMF.

Subject headings: ISM: kinematics and dynamics — stars: formation —
stars: luminosity function, mass function — turbulence

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Competitive Accretion?

Mon. Not. R. Astron. Soc. 339, 577–599 (2003)

The formation of a star cluster: predicting the properties of stars and brown dwarfs

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ABSTRACT

We present results from the largest numerical simulation of star formation to resolve the fragmentation process down to the opacity limit. The simulation follows the collapse and fragmentation of a large-scale turbulent molecular cloud to form a stellar cluster and, simultaneously, the formation of circumstellar discs and binary stars. This large range of scales enables us to predict a wide variety of stellar properties for comparison with observations.

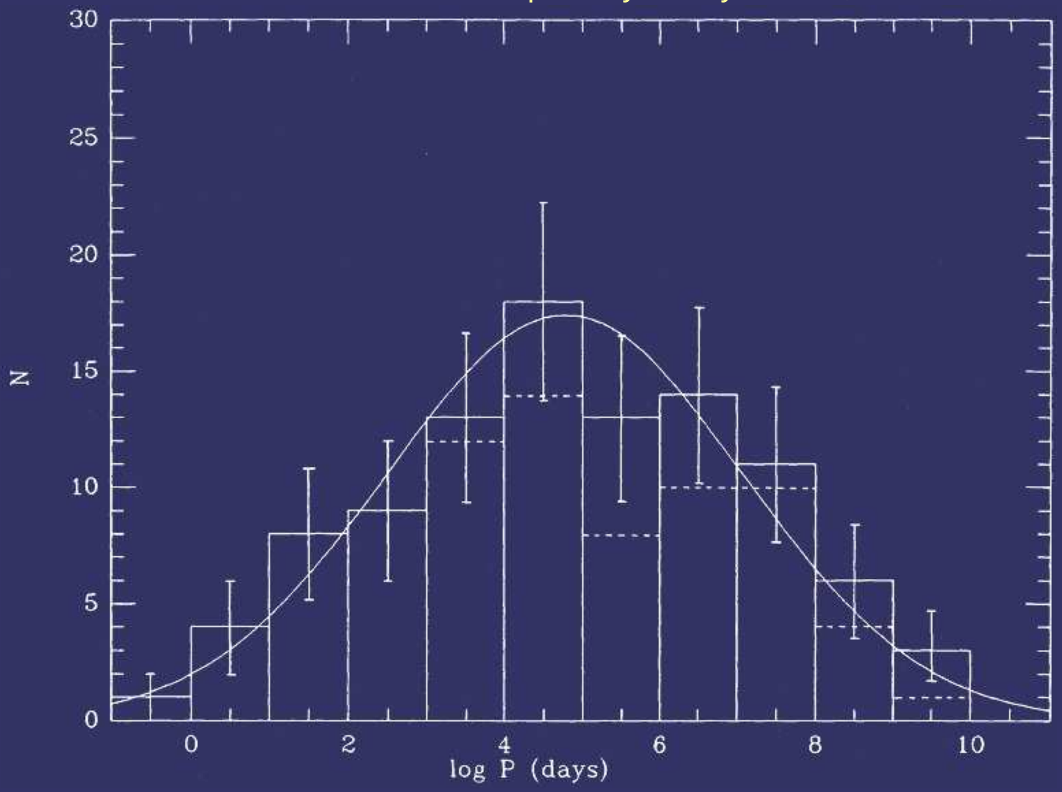
The calculation clearly demonstrates that star formation is a highly-dynamic and chaotic process. Star formation occurs in localized bursts within the cloud via the fragmentation both of dense molecular cloud cores and of massive circumstellar discs. Star–disc encounters form binaries and truncate discs. Stellar encounters disrupt bound multiple systems. We find that the observed statistical properties of stars are a natural consequence of star formation in such a dynamical environment. The cloud produces roughly equal numbers of stars and brown dwarfs, with masses down to the opacity limit for fragmentation (≈5 Jupiter masses). The initial mass function is consistent with a Salpeter slope ($\Gamma = -1.35$) above 0.5 $M_\odot$,

... Star formation occurs ... via the fragmentation both of dense molecular cloud cores and of massive stellar disks. ... the observed statistical properties of stars are a natural consequence...

BINARIES !

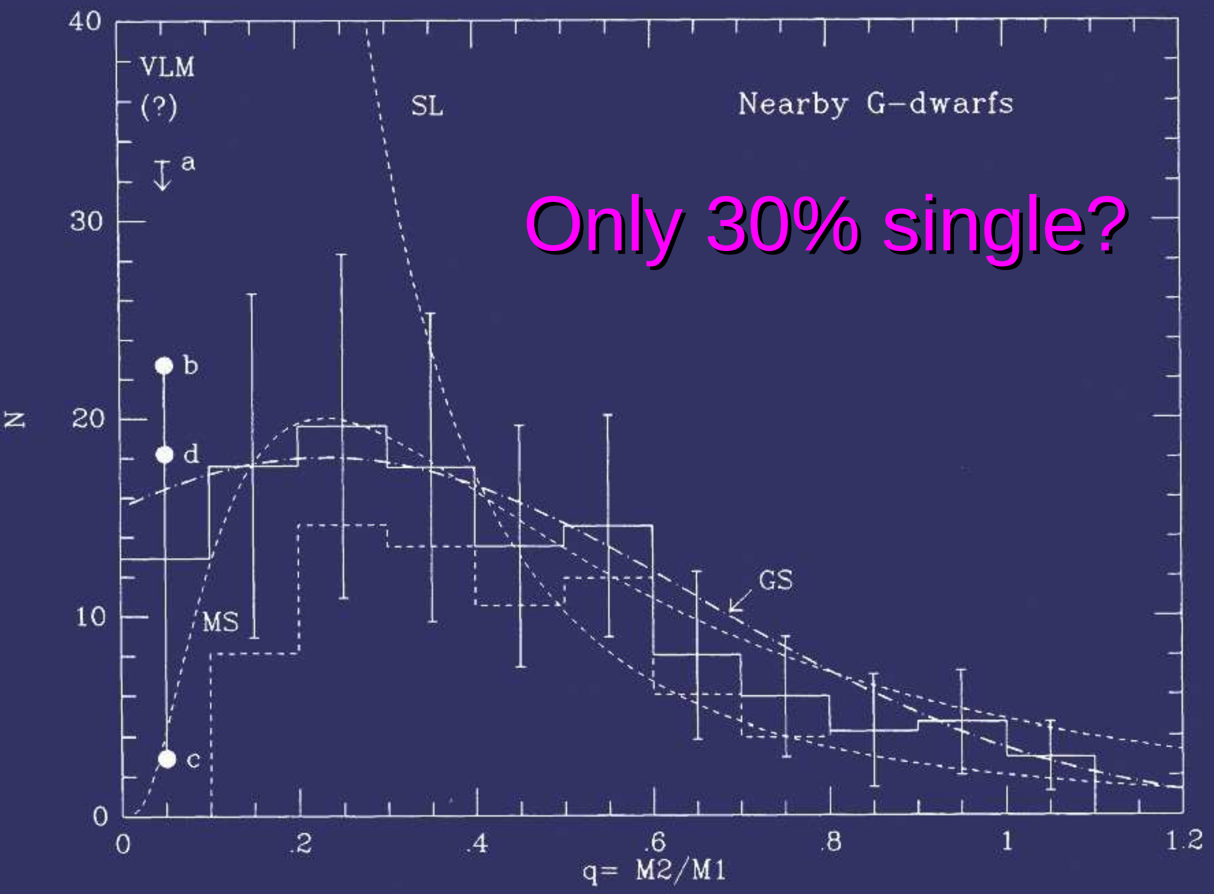
Period Distribution

Duquennoy & Mayor 1991, A&A 248, 485



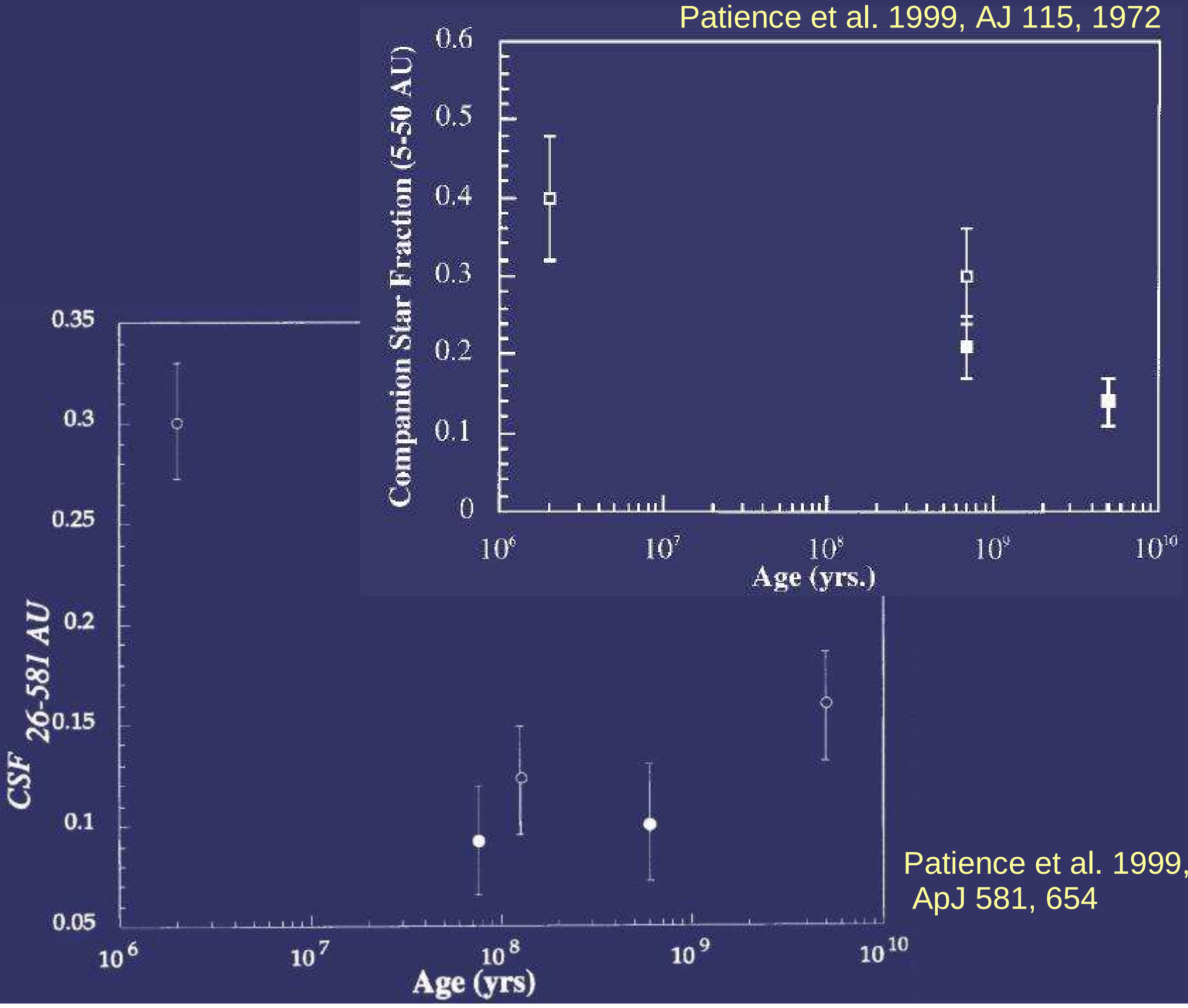
Mass Ratio Distribution

Duquennoy & Mayor 1991, A&A 248, 485



Only 30% single?

Companion Star Fraction

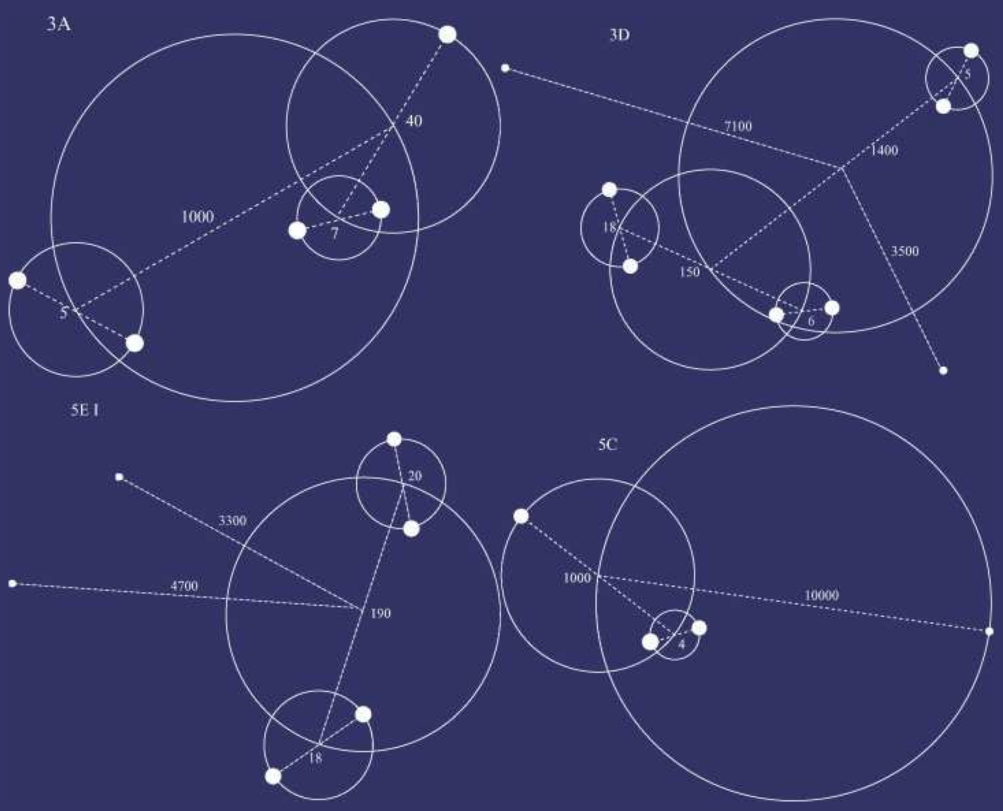


Patience et al. 1999, AJ 115, 1972

Patience et al. 1999, ApJ 581, 654

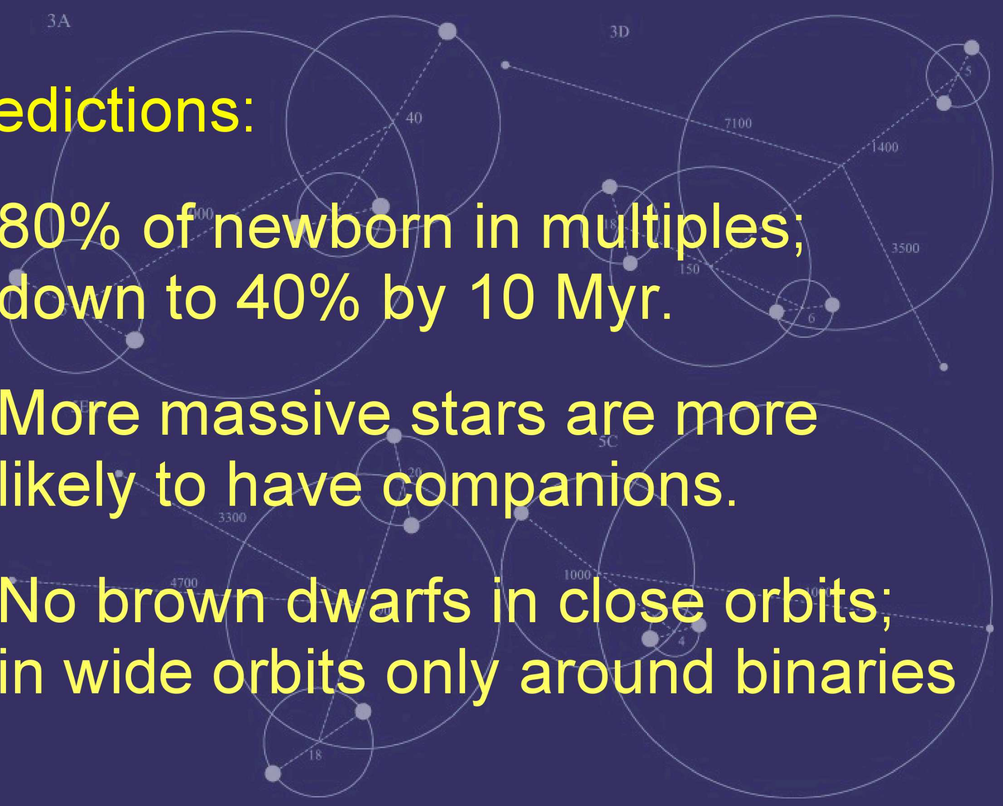
Initial Multiplicity

Delgado Donate et al. 2004, MNRAS, 351, 617



Initial Multiplicity

Delgado Donate et al. 2004, MNRAS, 351, 617



Predictions:

- 80% of newborn in multiples; down to 40% by 10 Myr.
- More massive stars are more likely to have companions.
- No brown dwarfs in close orbits; in wide orbits only around binaries

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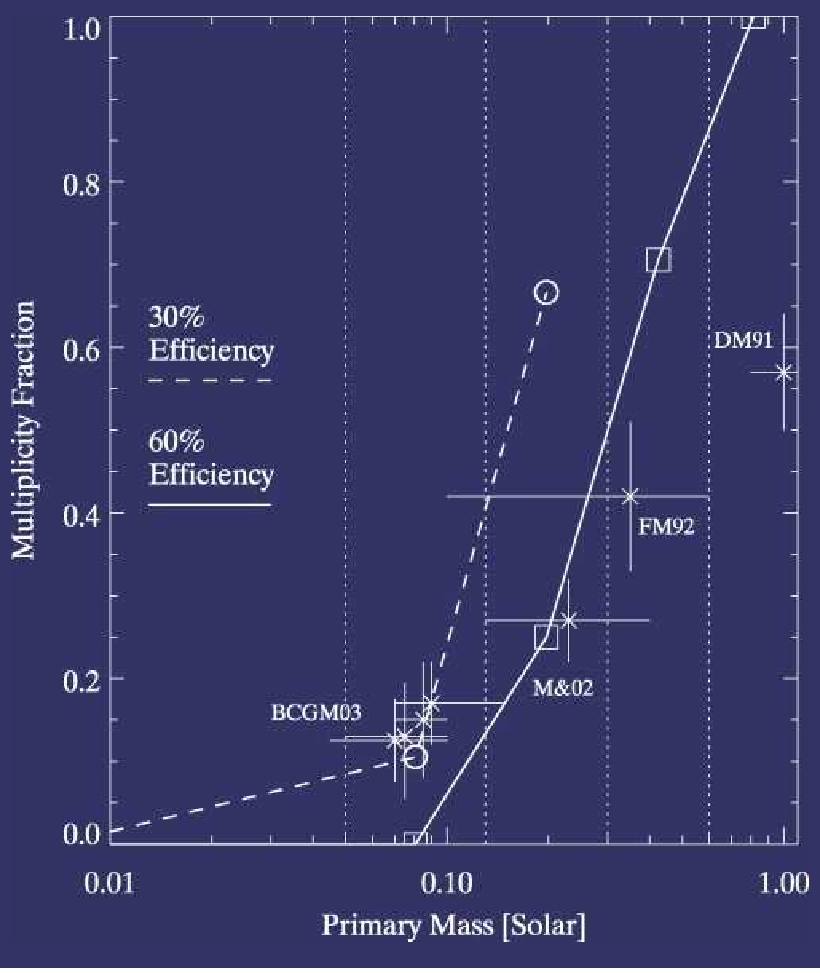
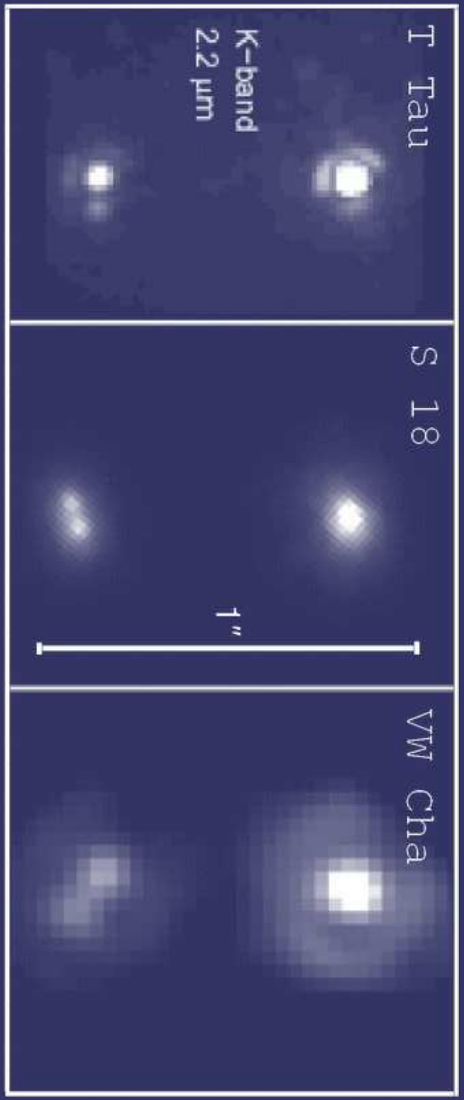
Multiplicity for diff. Mass

Delgado Donate et al. 2004, MNRAS, 351, 617

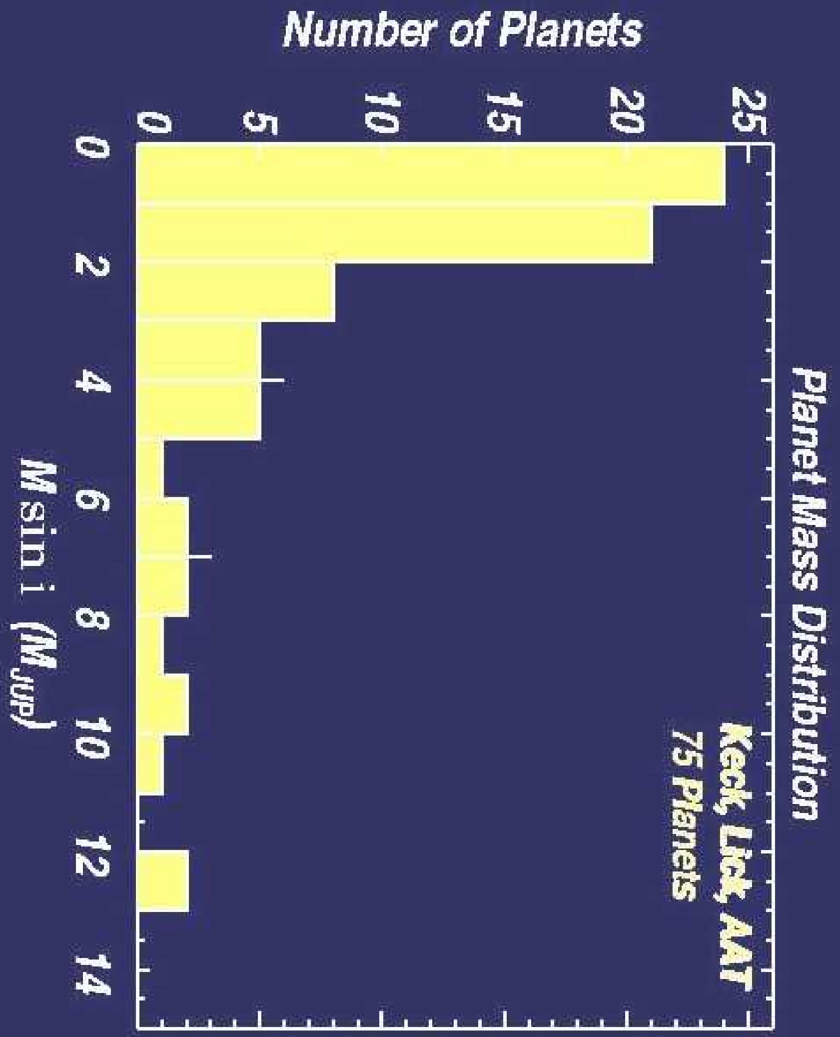


Many Multiples?



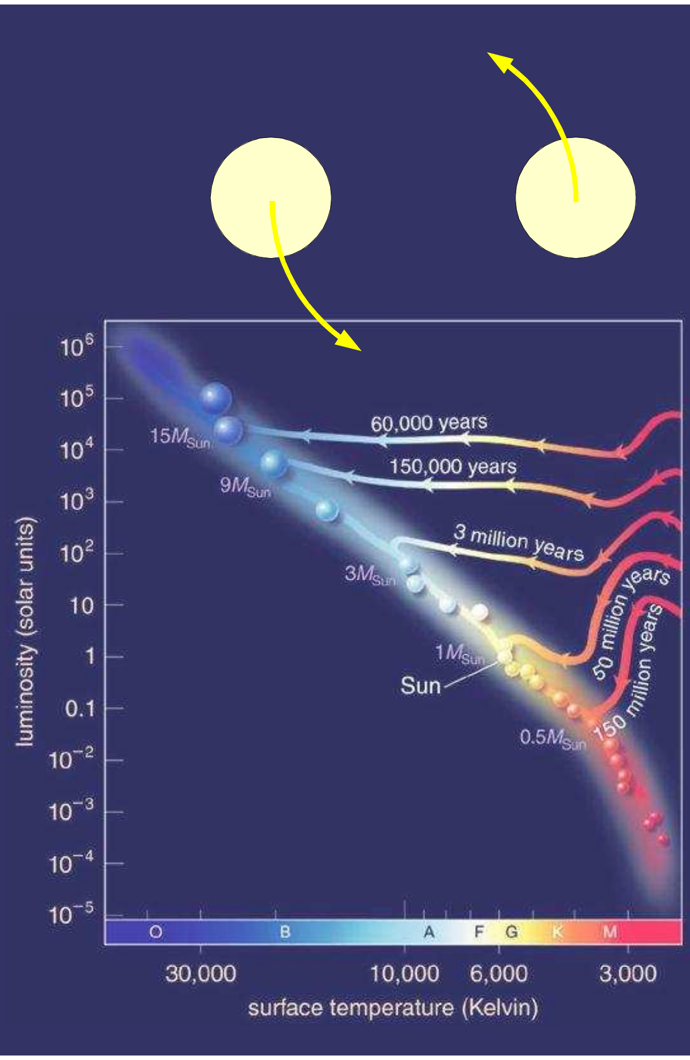
Brandeker 2003, IAUS, 221, 228

Brown Dwarf Desert



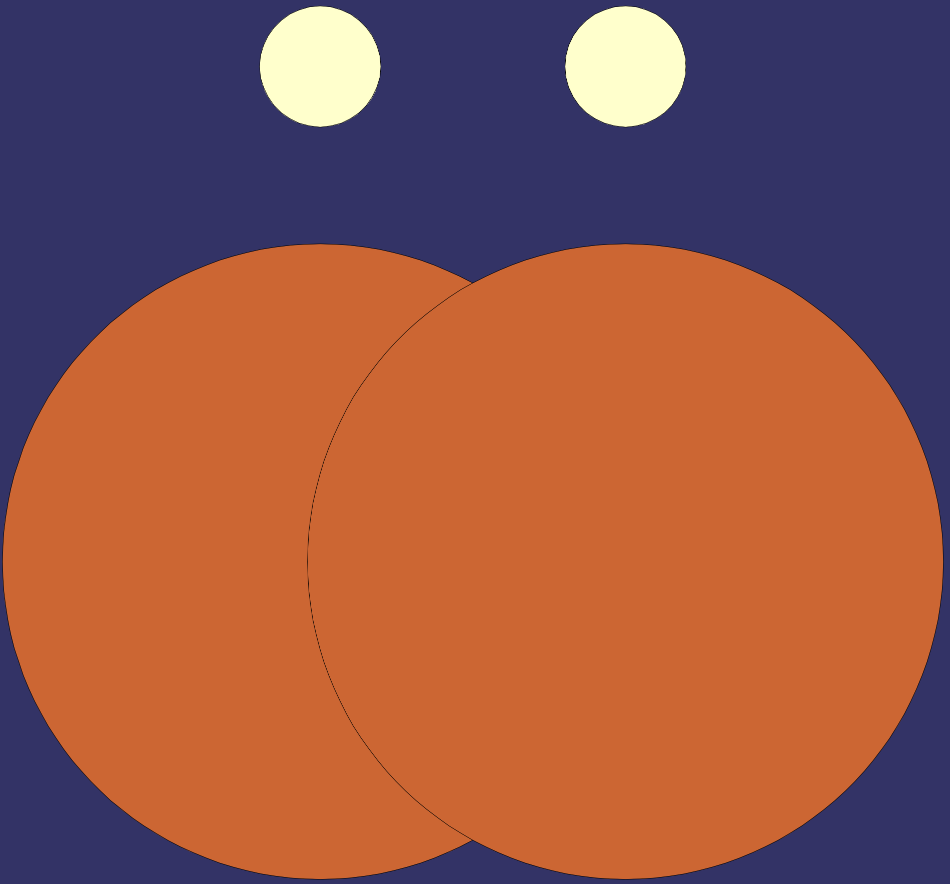
OBSERVE!

CLOSE BINARIES!



On main sequence

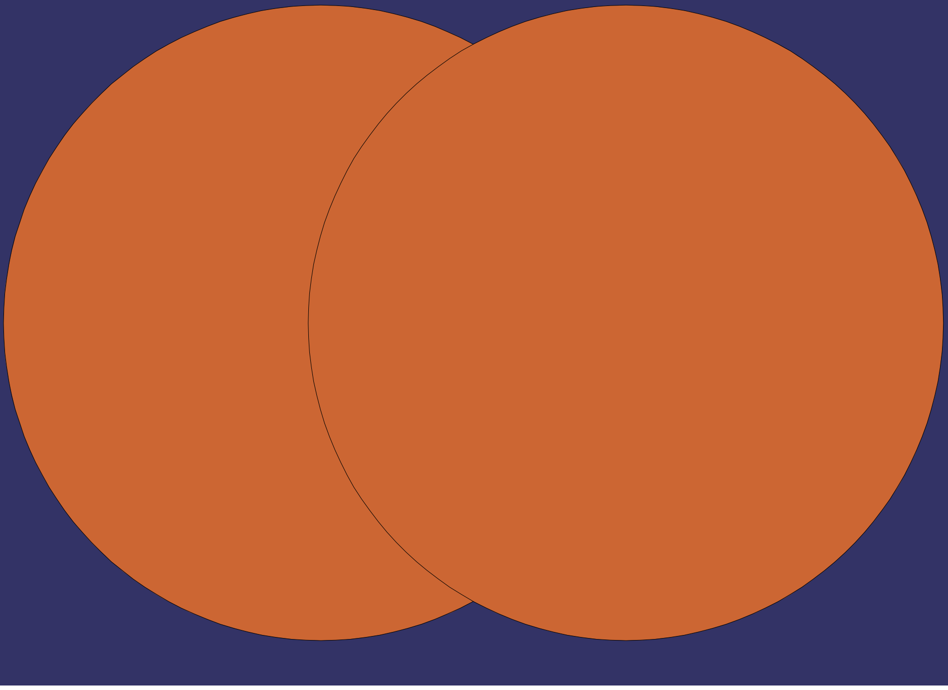
On pre-main sequence, up to factor ~5..10 larger!

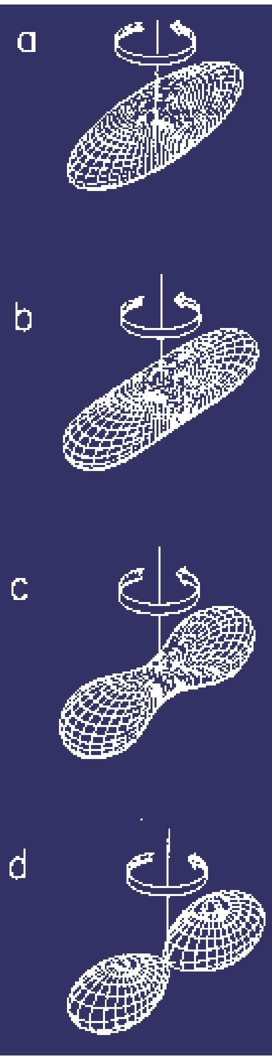


On main sequence

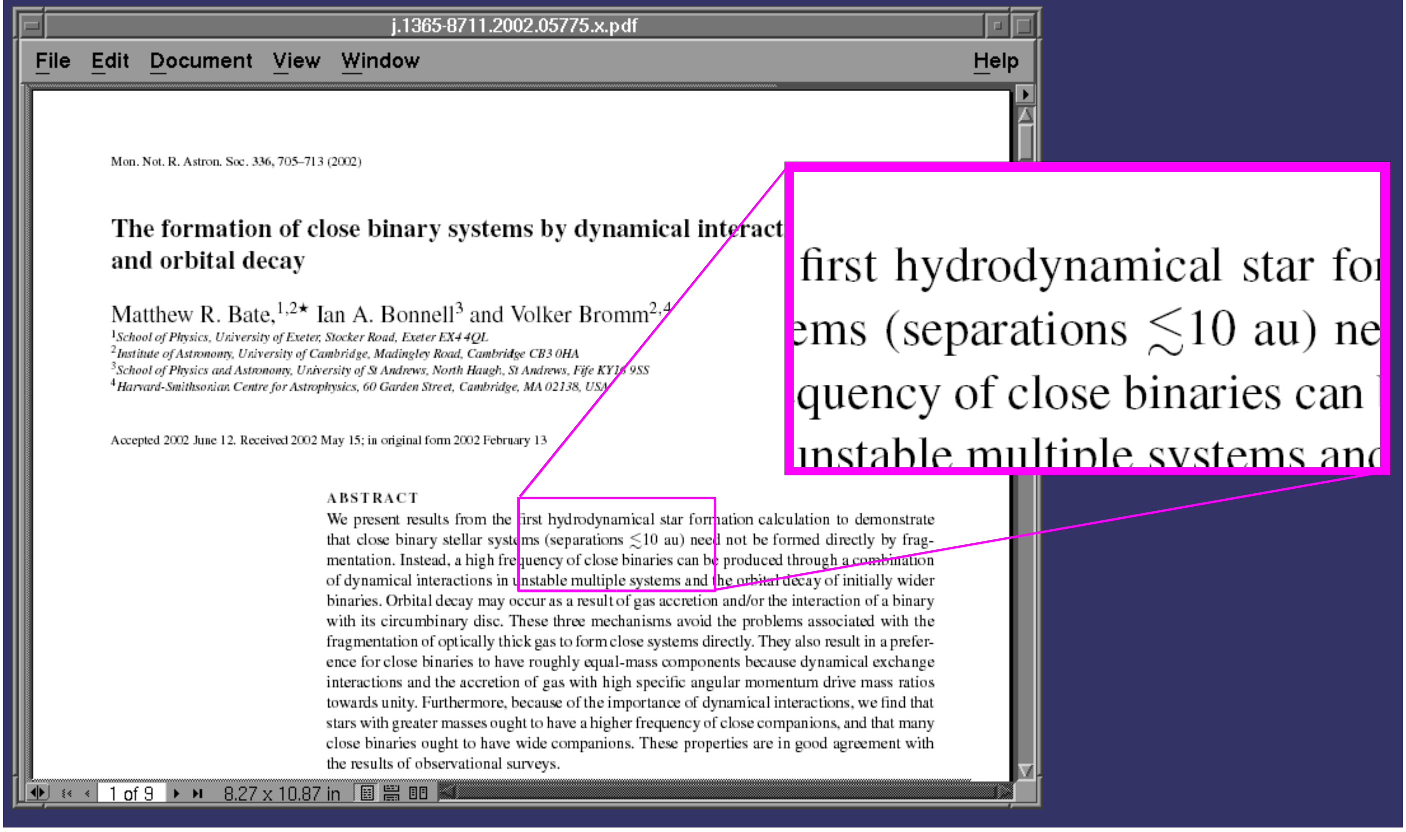
On pre-main sequence, up to factor ~5..10 larger!

Fission?





Unstable dynamics?



Mon. Not. R. Astron. Soc. 336, 705–713 (2002)

The formation of close binary systems by dynamical interact
and orbital decay

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Accepted 2002 June 12. Received 2002 May 15; in original form 2002 February 13

ABSTRACT

We present results from the first hydrodynamical star formation calculation to demonstrate that close binary stellar systems (separations $\lesssim$10 au) need not be formed directly by fragmentation. Instead, a high frequency of close binaries can be produced through a combination of dynamical interactions in unstable multiple systems and the orbital decay of initially wider binaries. Orbital decay may occur as a result of gas accretion and/or the interaction of a binary with its circumbinary disc. These three mechanisms avoid the problems associated with the fragmentation of optically thick gas to form close systems directly. They also result in a preference for close binaries to have roughly equal-mass components because dynamical exchange interactions and the accretion of gas with high specific angular momentum drive mass ratios towards unity. Furthermore, because of the importance of dynamical interactions, we find that stars with greater masses ought to have a higher frequency of close companions, and that many close binaries ought to have wide companions. These properties are in good agreement with the results of observational surveys.

first hydrodynamical star for
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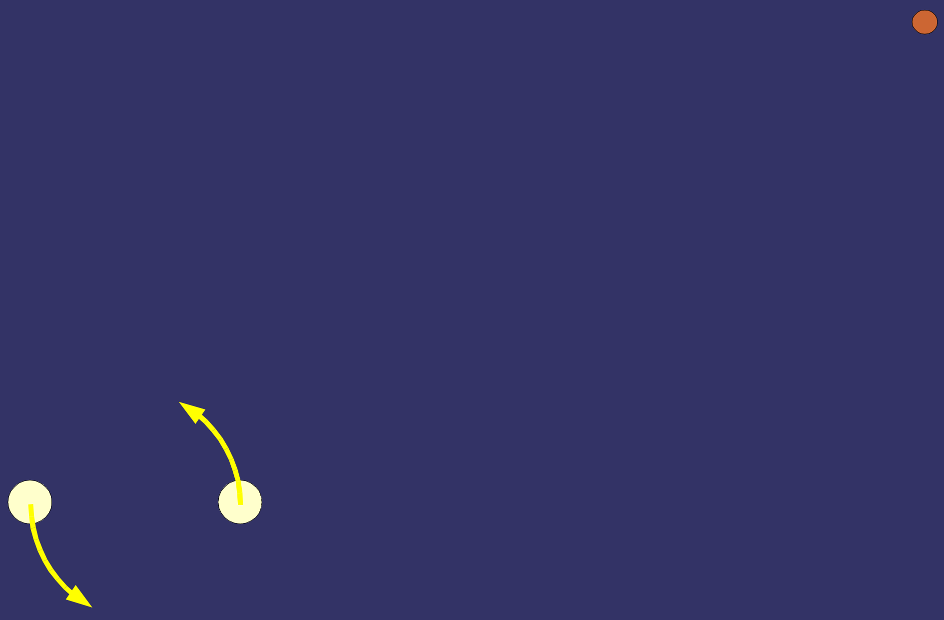
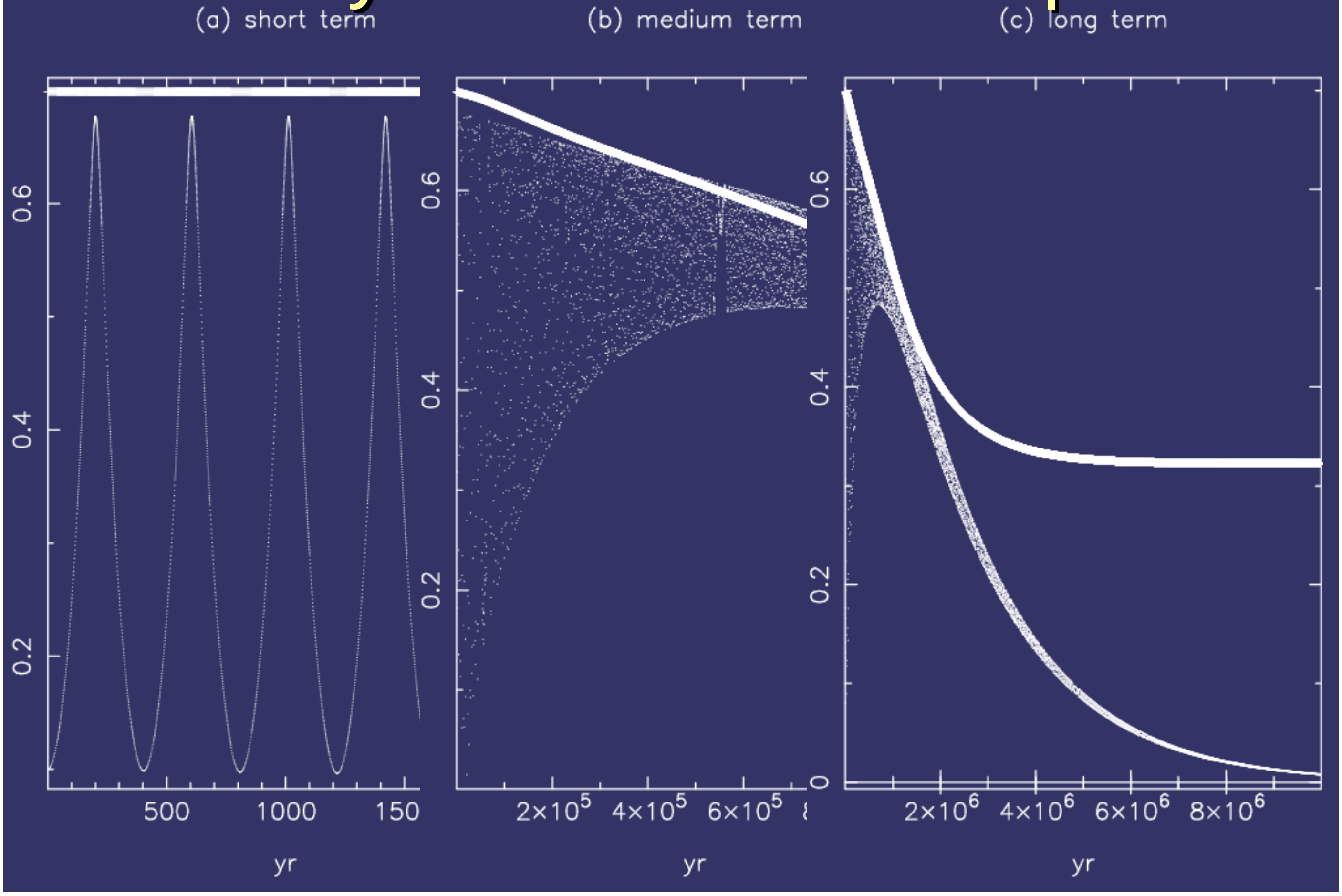
unstable multiple systems and

Stable dynamics?



Kozai cycles and tidal dissipation



Formation of Close Binaries in Triple Systems?

Third star induces Kozai cycle.
(can be after stars arrive on main sequence)

Tides take over once eccentricity becomes sufficiently high.

Prediction:
all close binaries are in triple systems!