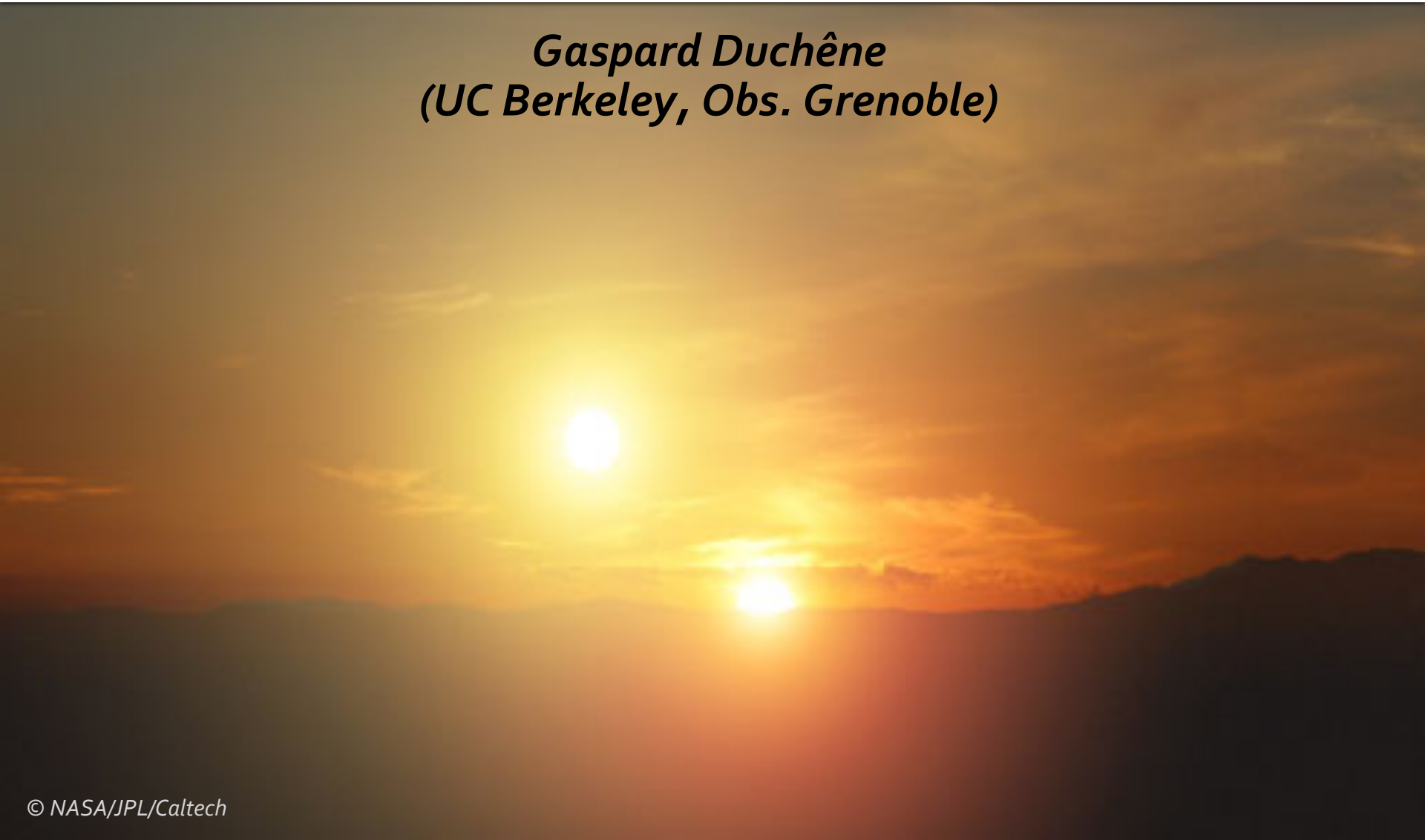
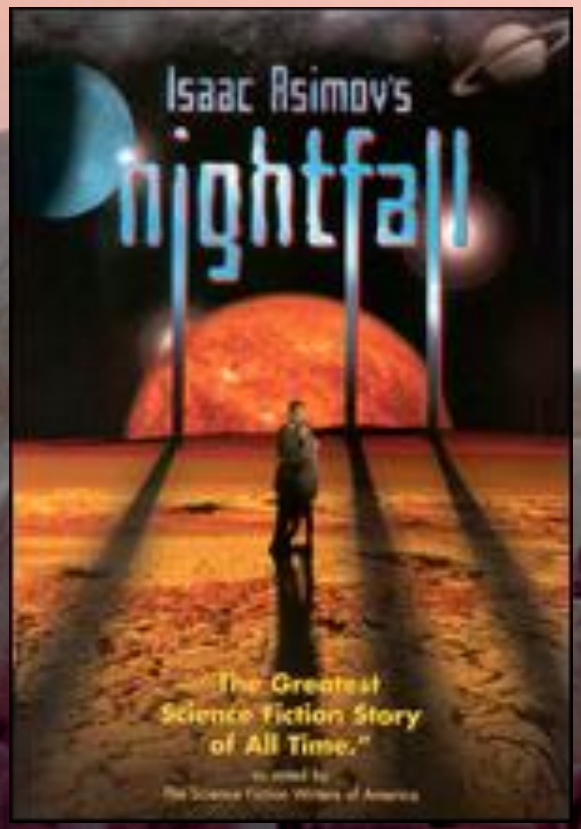
Planet formation & stellar multiplicity: (How) Can they coexist?

Gaspard Duchêne
(UC Berkeley, Obs. Grenoble)



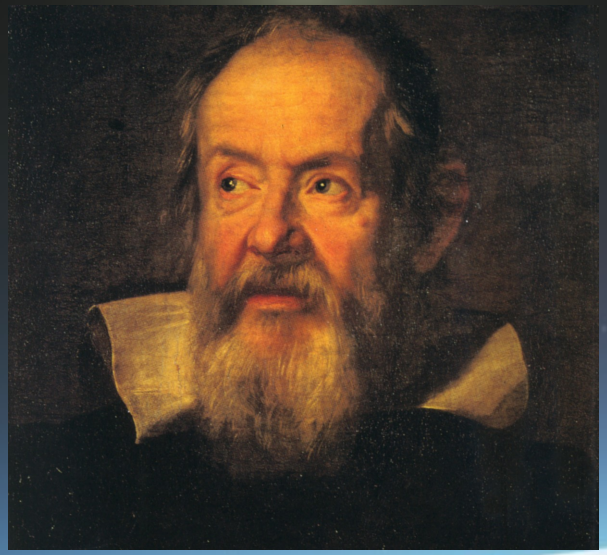
Planets in multiple systems? *Really??*



They must exist!

Stellar multiplicity: A long-known feature in the Galaxy

- Mizar known as a binary since 1617 (Galileo)



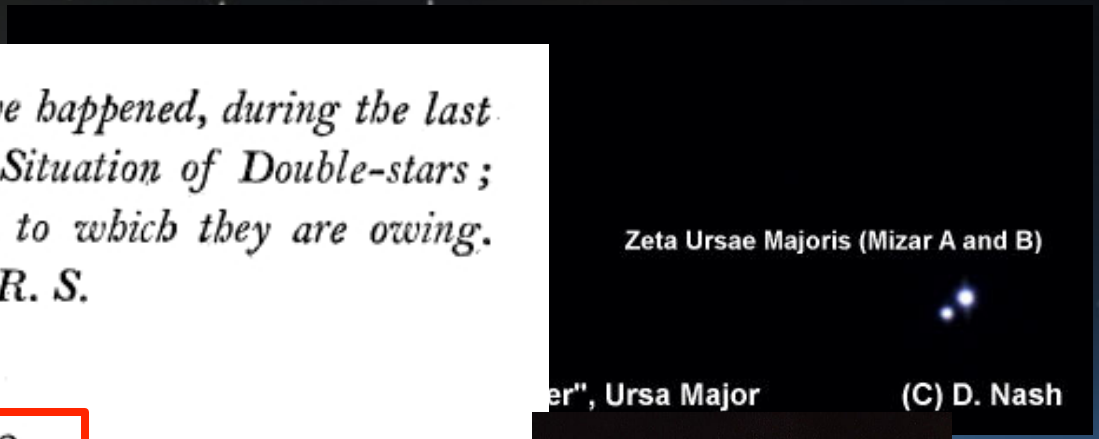
Stellar multiplicity: A long-known feature in the Galaxy

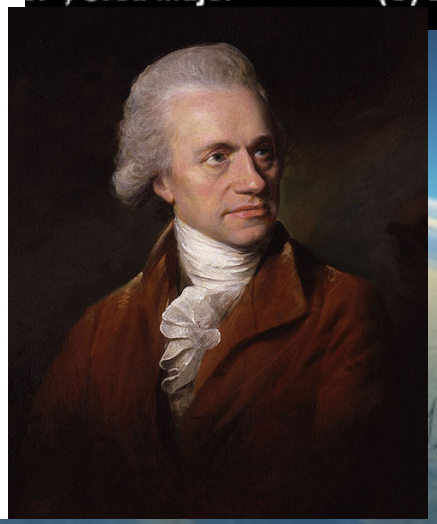
- William Herschel: binaries are physically bound!

XV. *Account of the Changes that have happened, during the last Twenty-five Years, in the relative Situation of Double-stars; with an Investigation of the Cause to which they are owing.*
By William Herschel, *LL. D. F. R. S.*

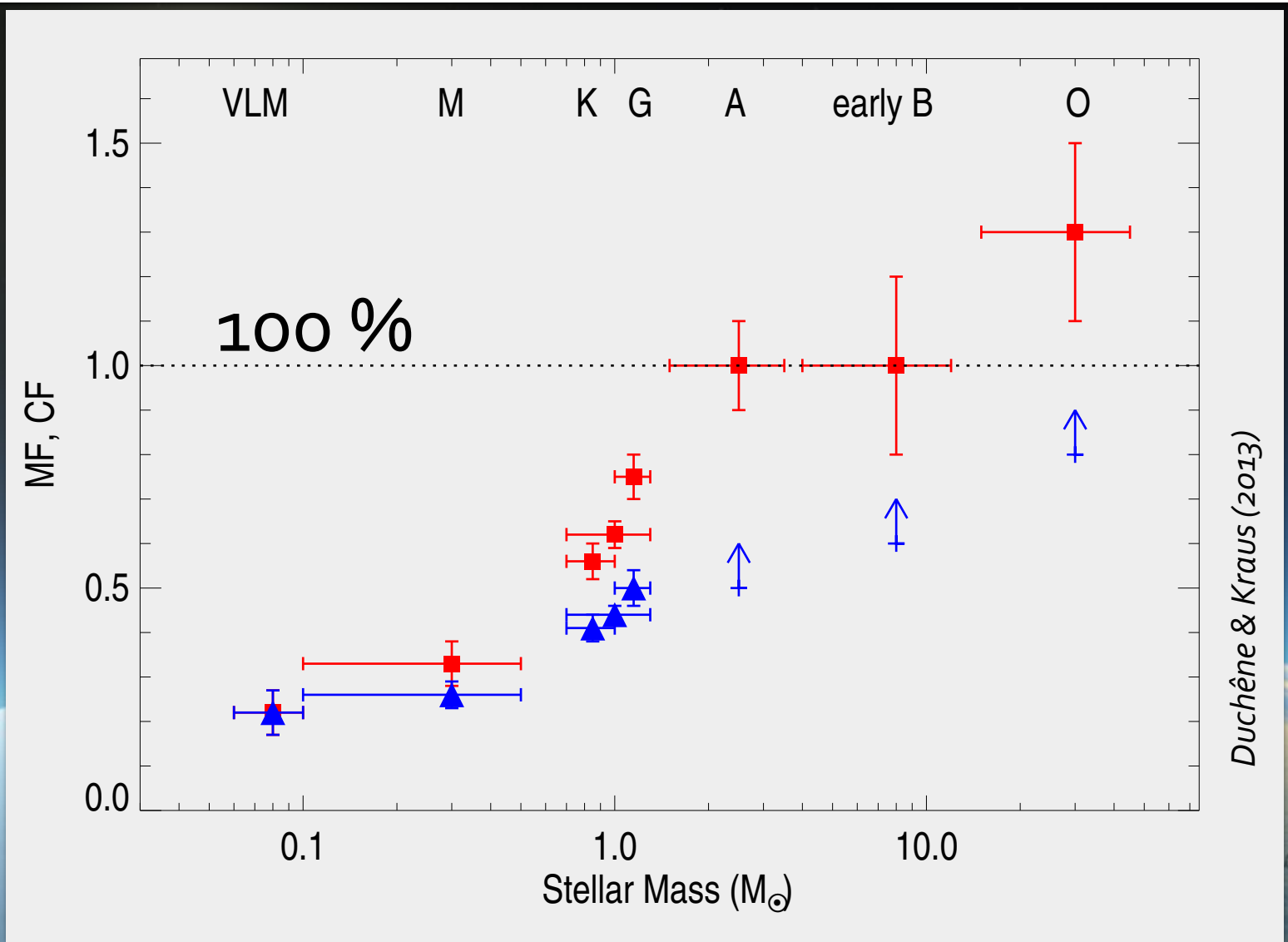
Read June 9, 1803.

istence of such binary combinations. I shall therefore now proceed to give an account of a series of observations on double stars, comprehending a period of about 25 years, which, if I am not mistaken, will go to prove, that many of them are not merely double in appearance, but must be allowed to be real binary combinations of two stars, intimately held together by the bond of mutual attraction.

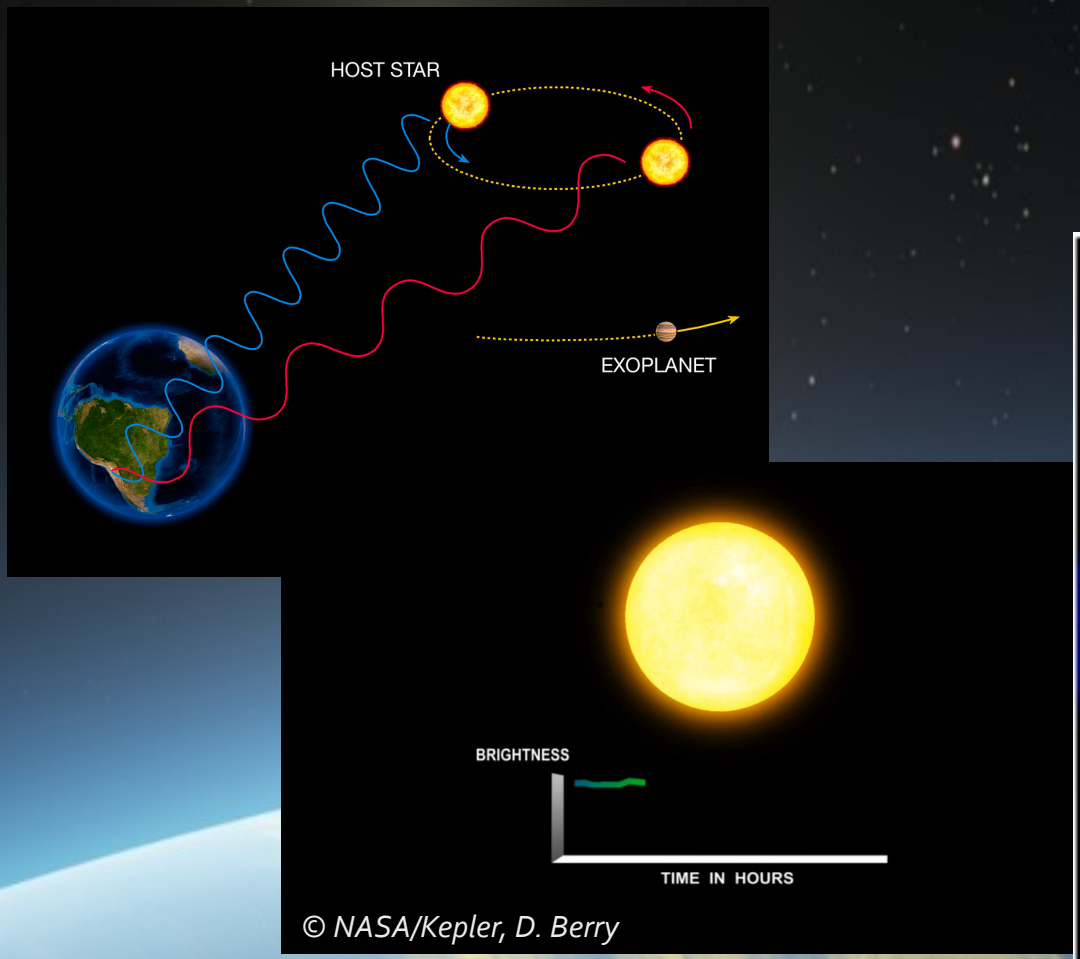




The modern view: Stellar multiplicity is pervasive

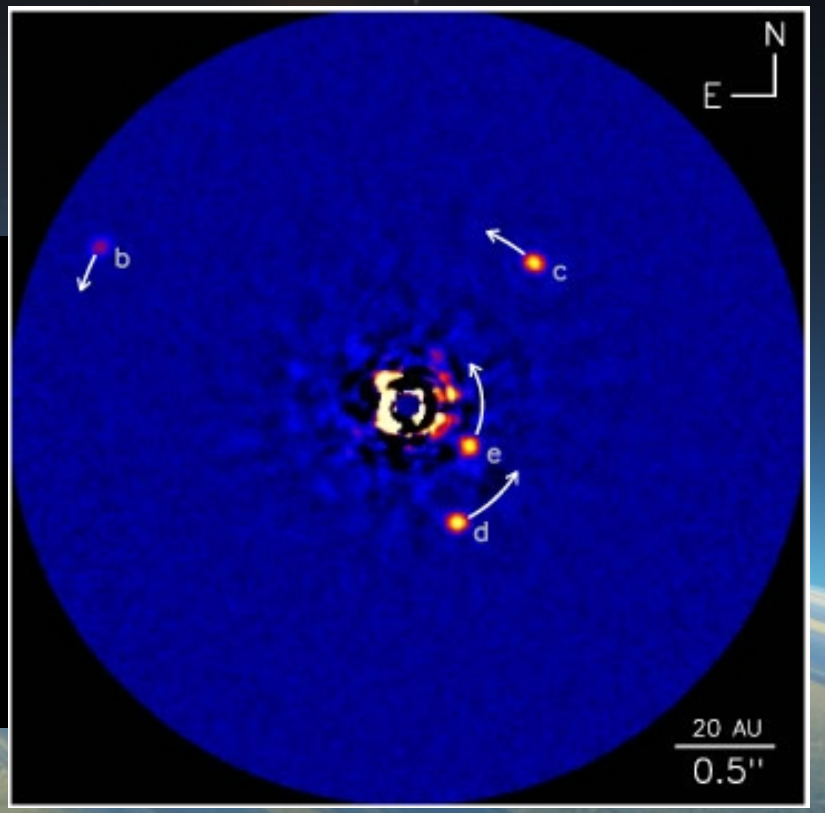


The discovery of extrasolar planets

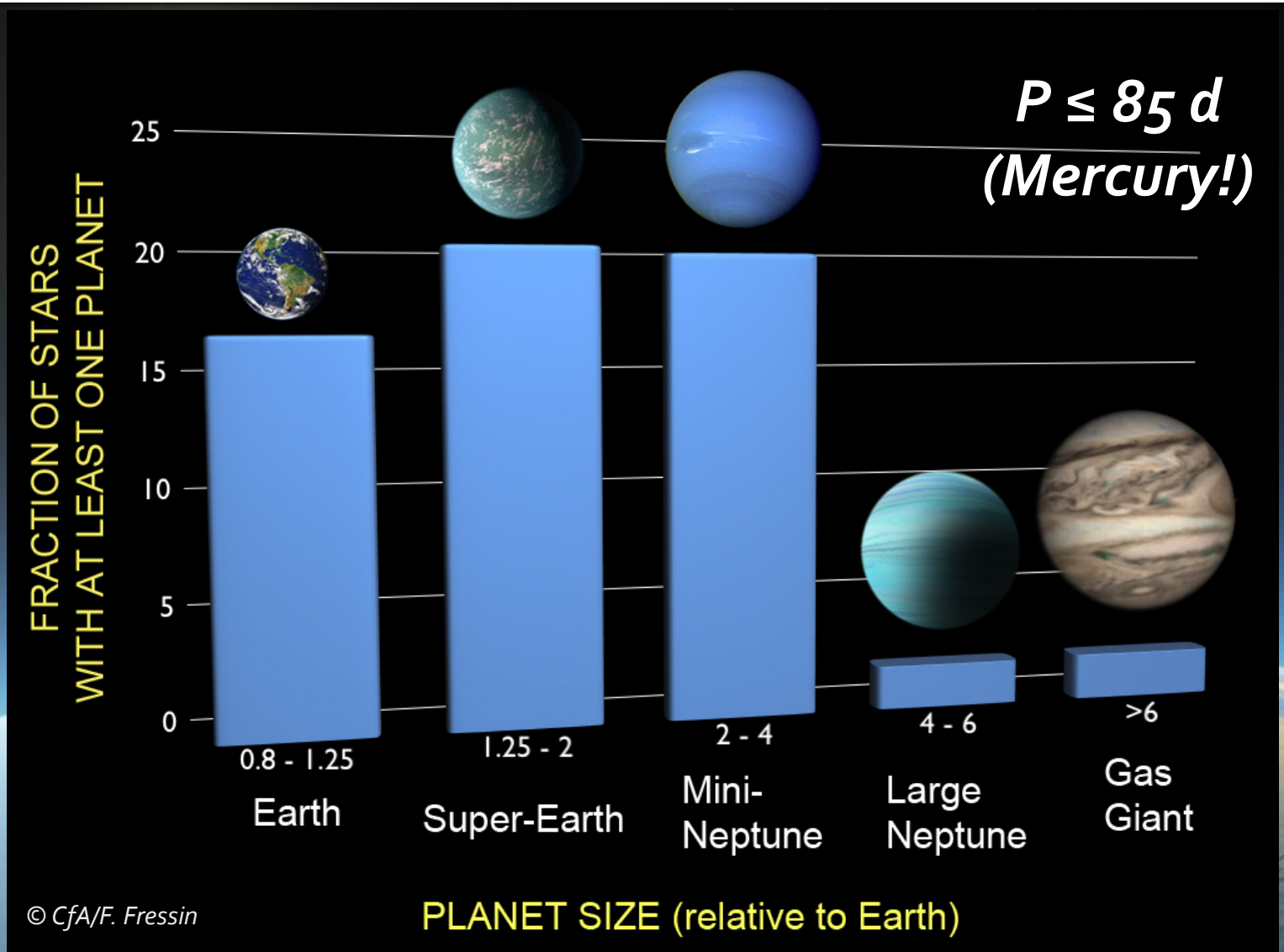


© NASA/Kepler, D. Berry

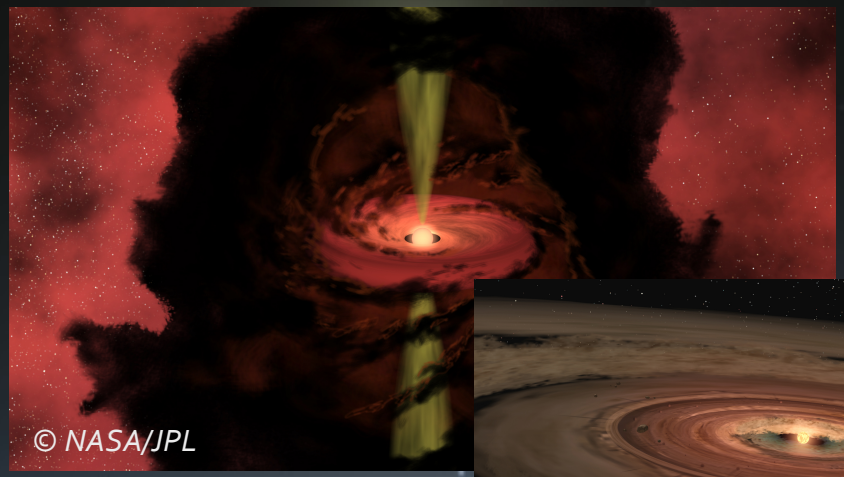
Marois et al. (2010)

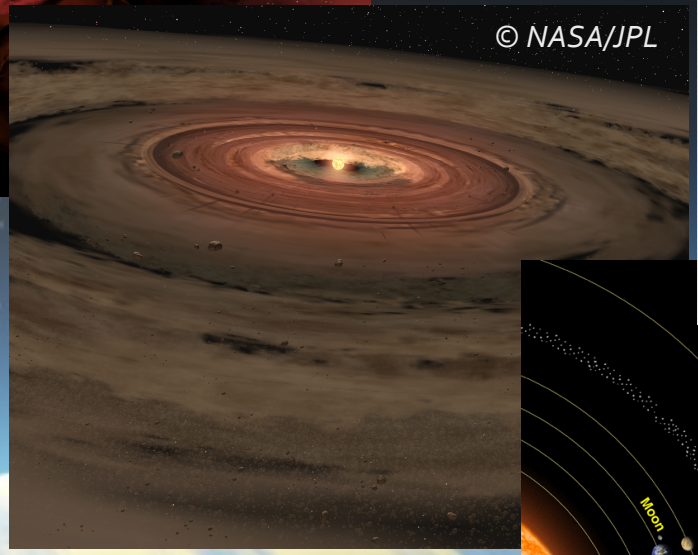


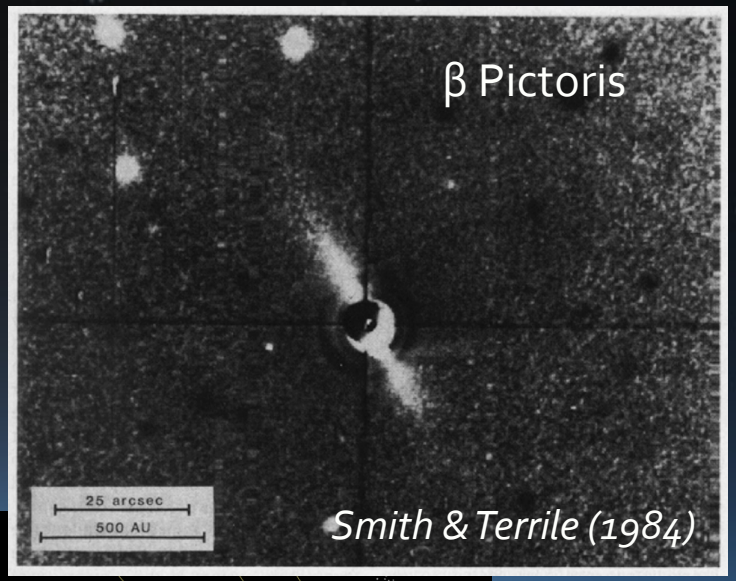
The modern view: Planetary systems are the norm!

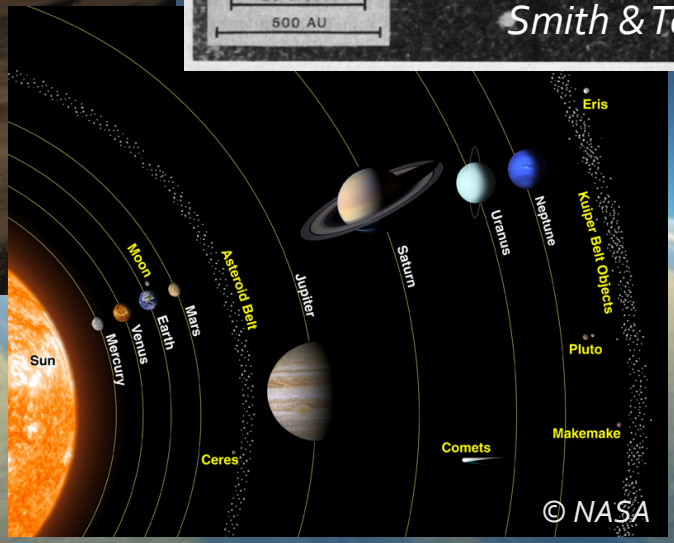


Planet formation in a nutshell

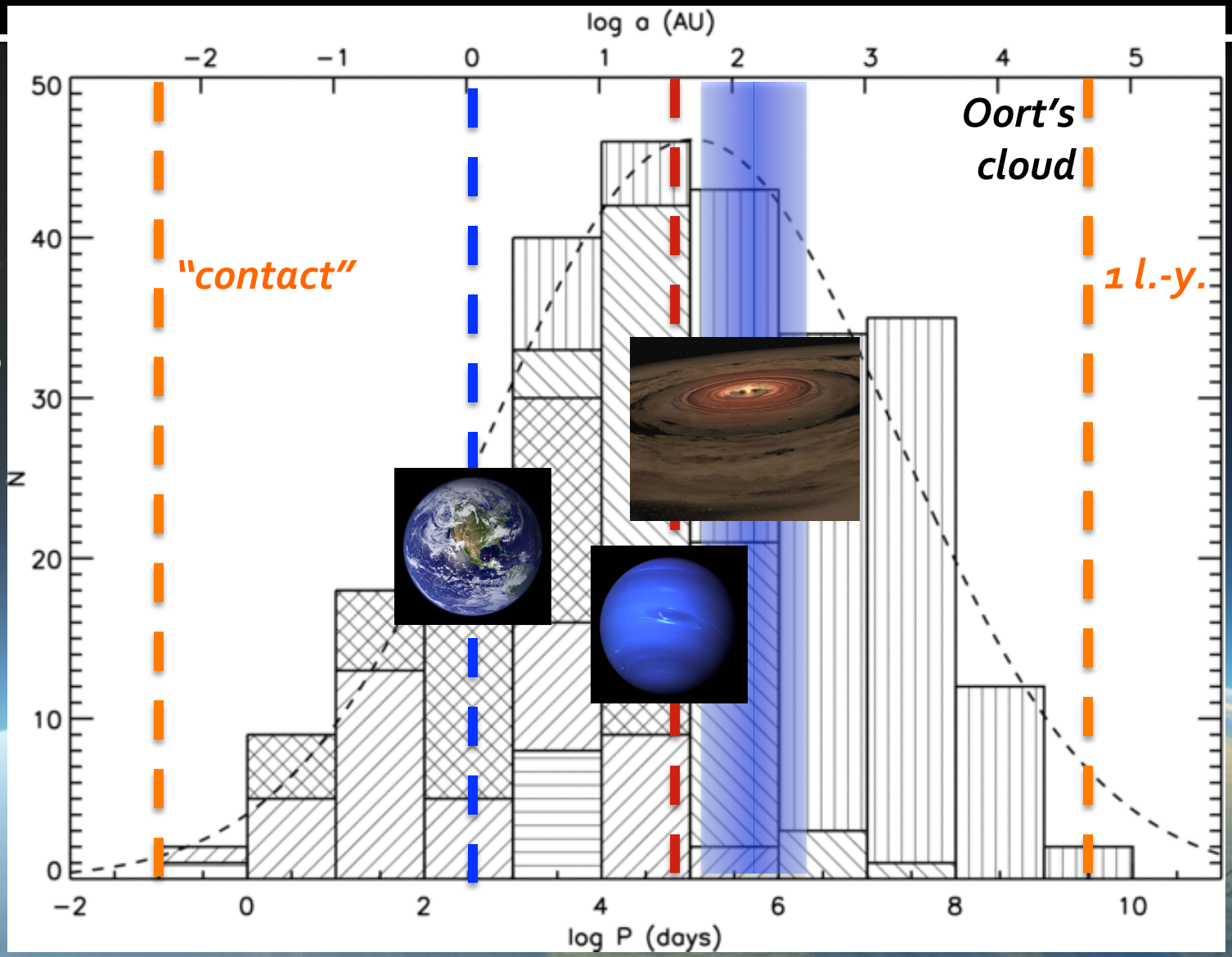








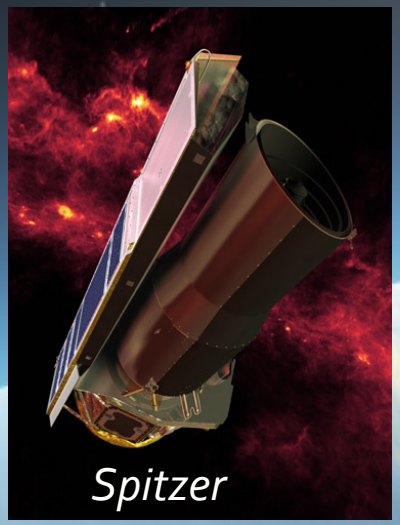
Typical dimensions

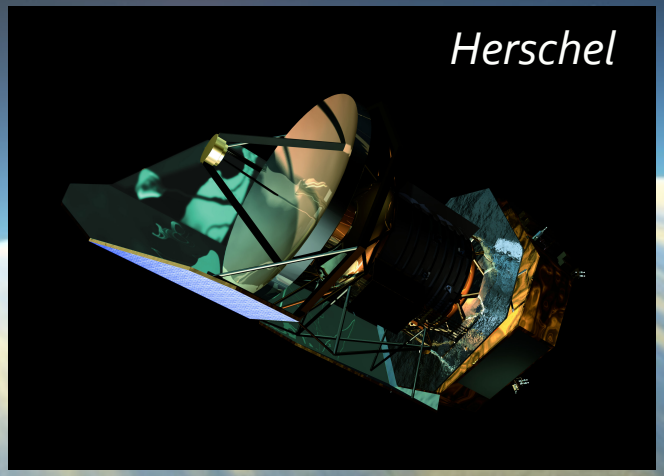


Raghavan et al. (2010)

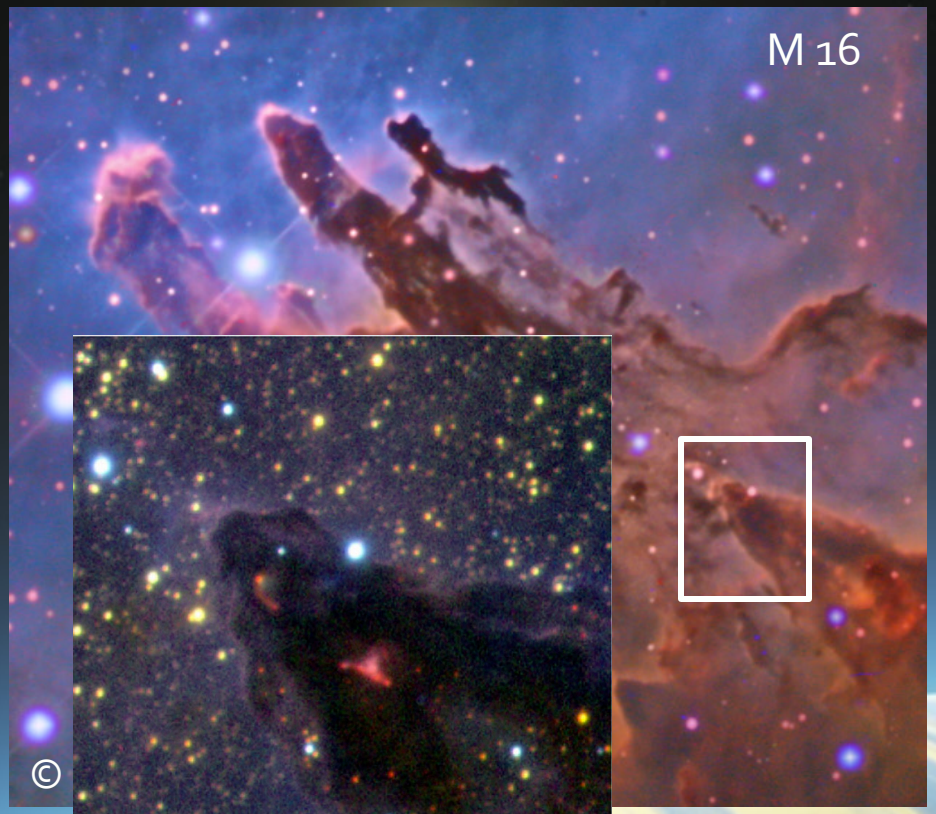
Some open questions

- *Do planets form in multiple systems?*
- *Is the planet formation process different in multiple systems compared to single stars?*

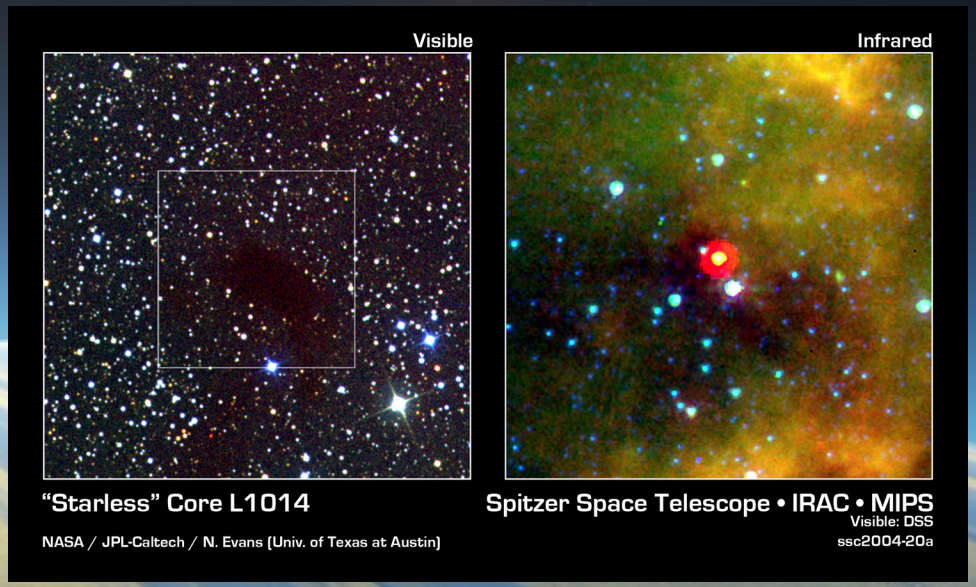




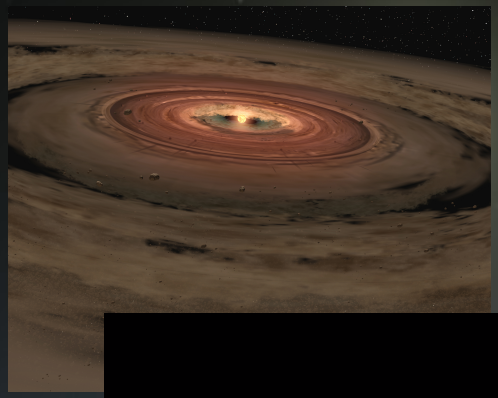
Finding young stars that are hosts to protoplanetary disks

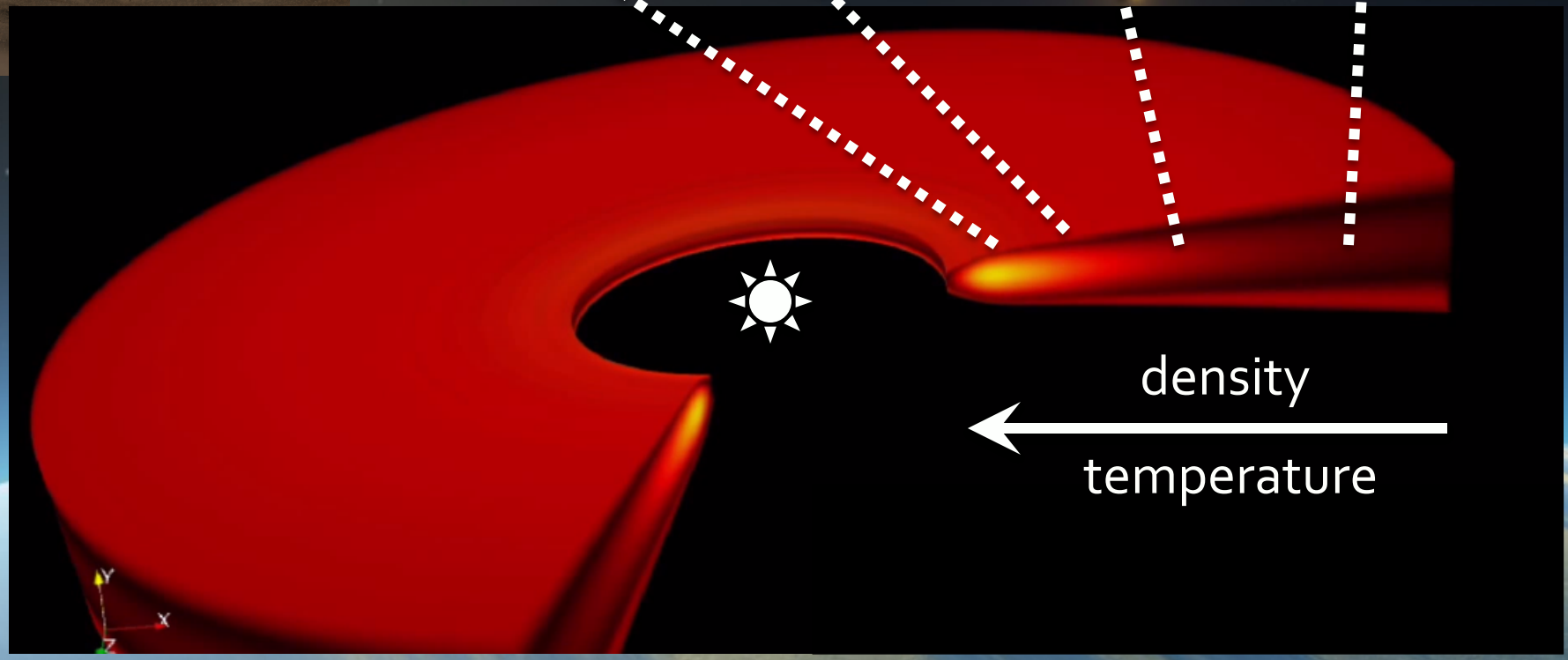


The power of infrared observations



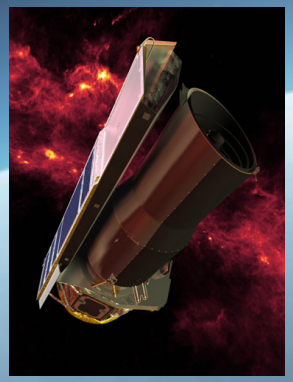
Studying protoplanetary disks

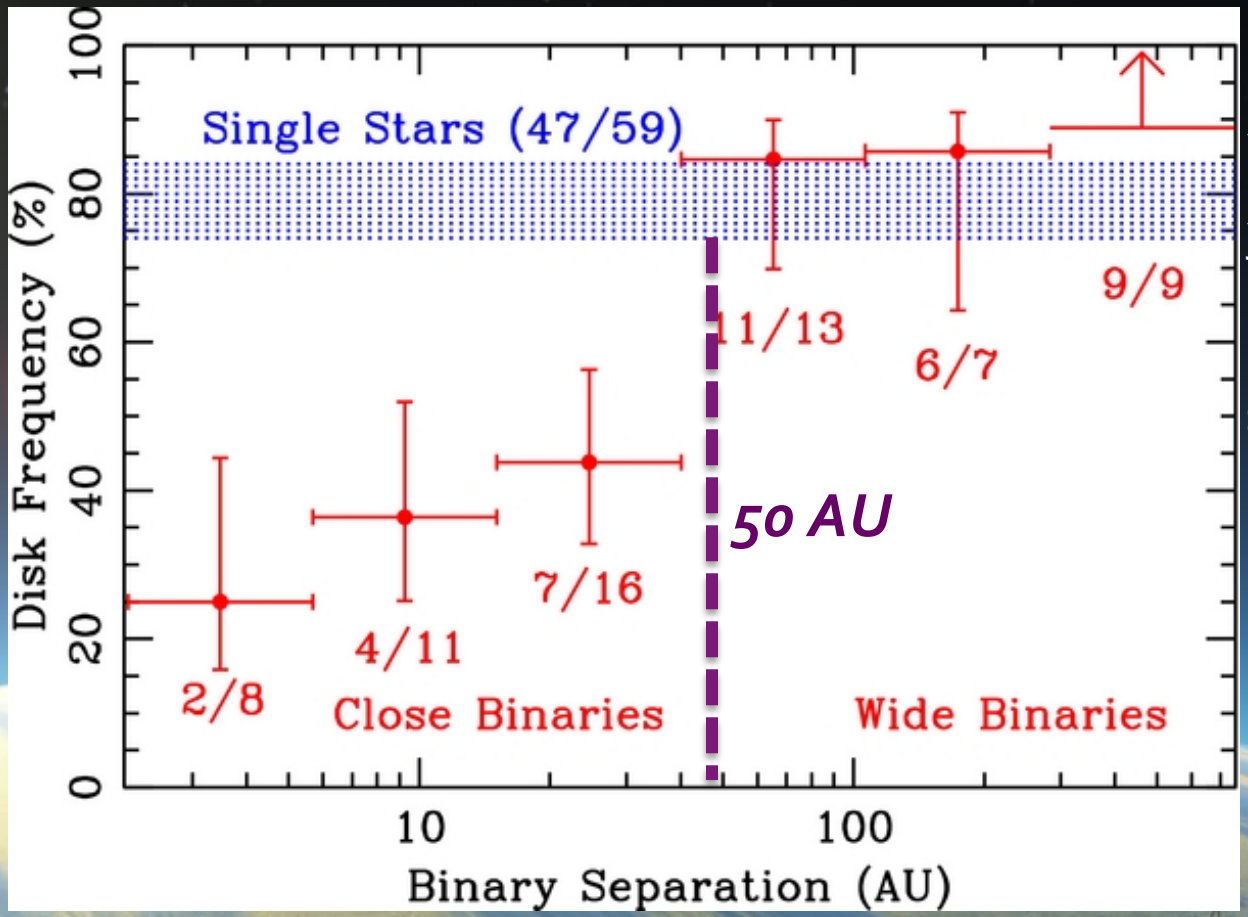




Primordial disks in binaries: frequency

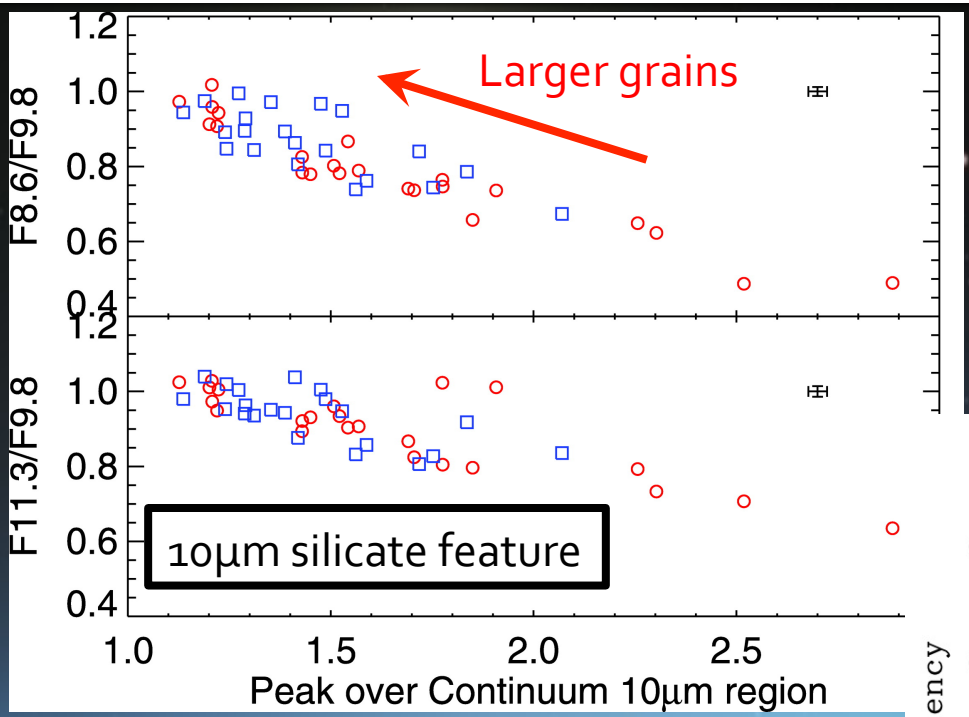
Disks in close binaries are less frequent (short-lived?)





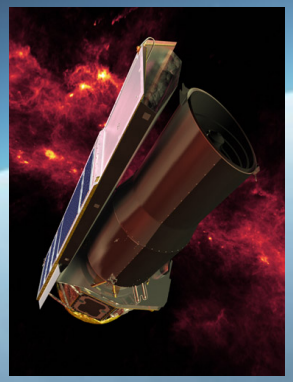
Kraus et al. (2012)

Inner regions: finer properties

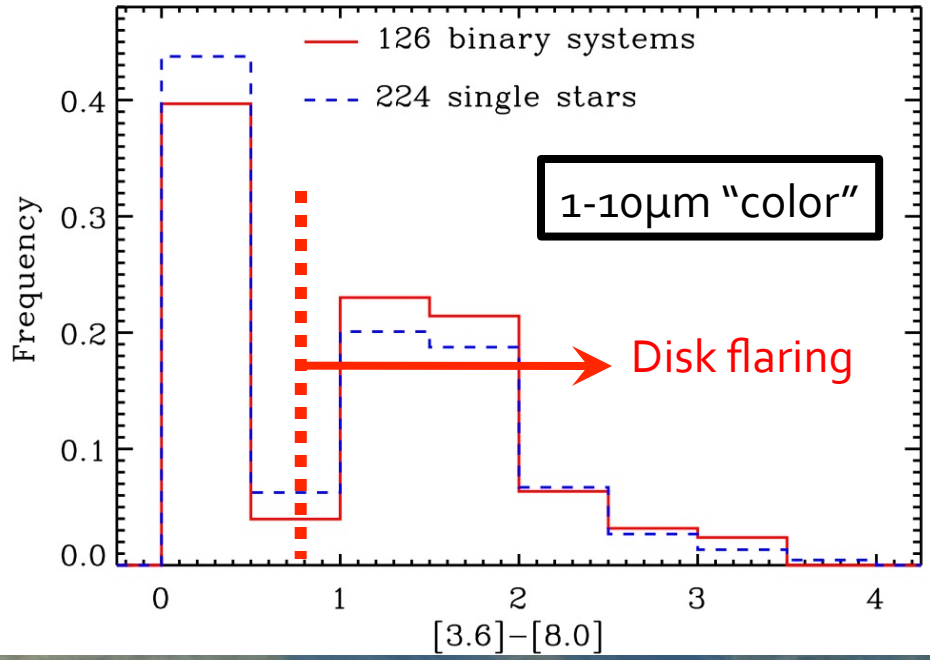


Pascucci et al. (2008)

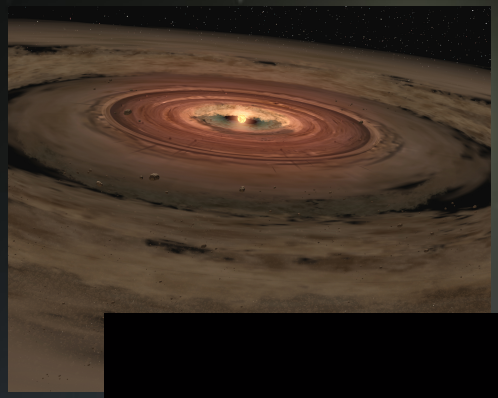
Disks in binaries have the same geometry and dust content as others

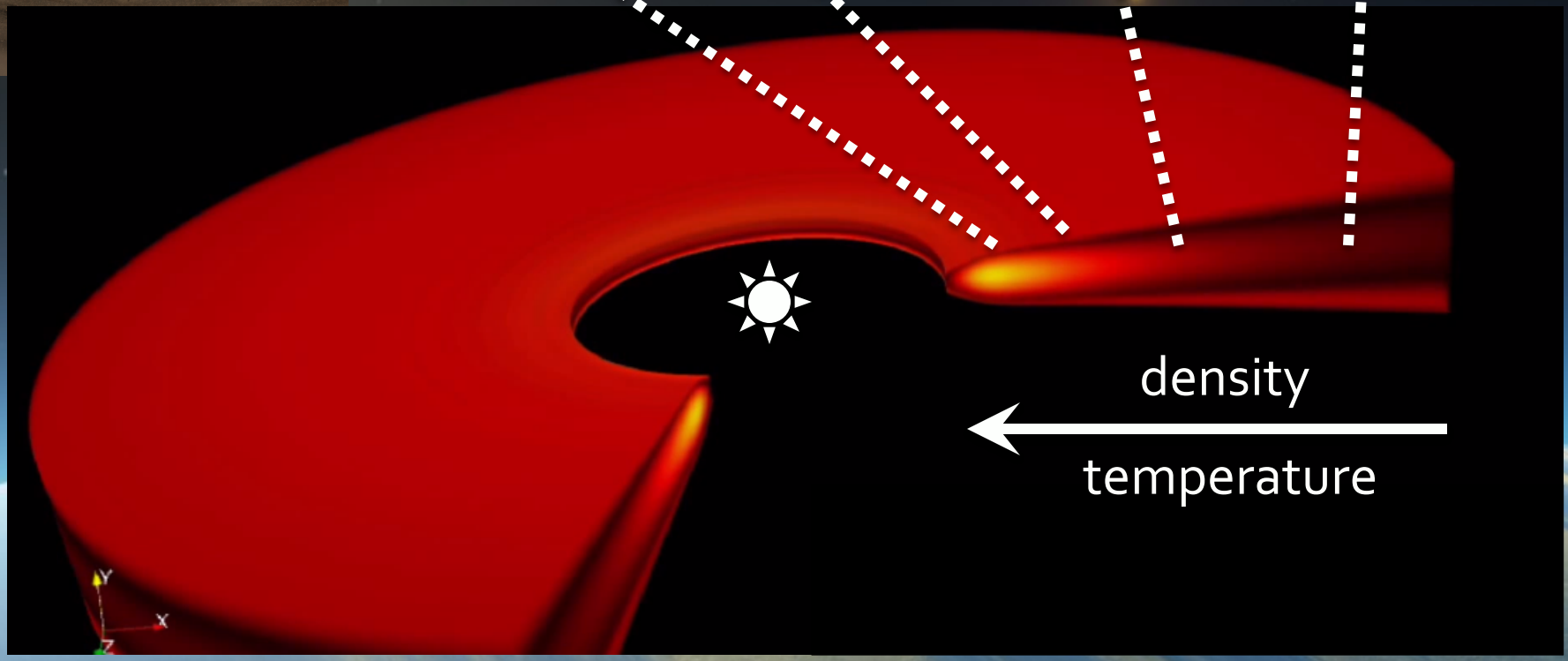


Cieza et al. (2009)



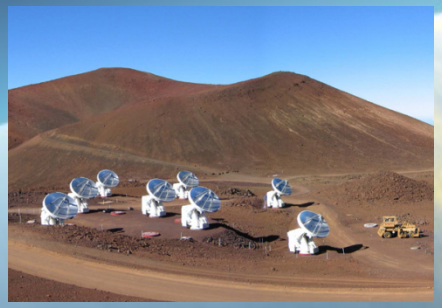
Studying protoplanetary disks

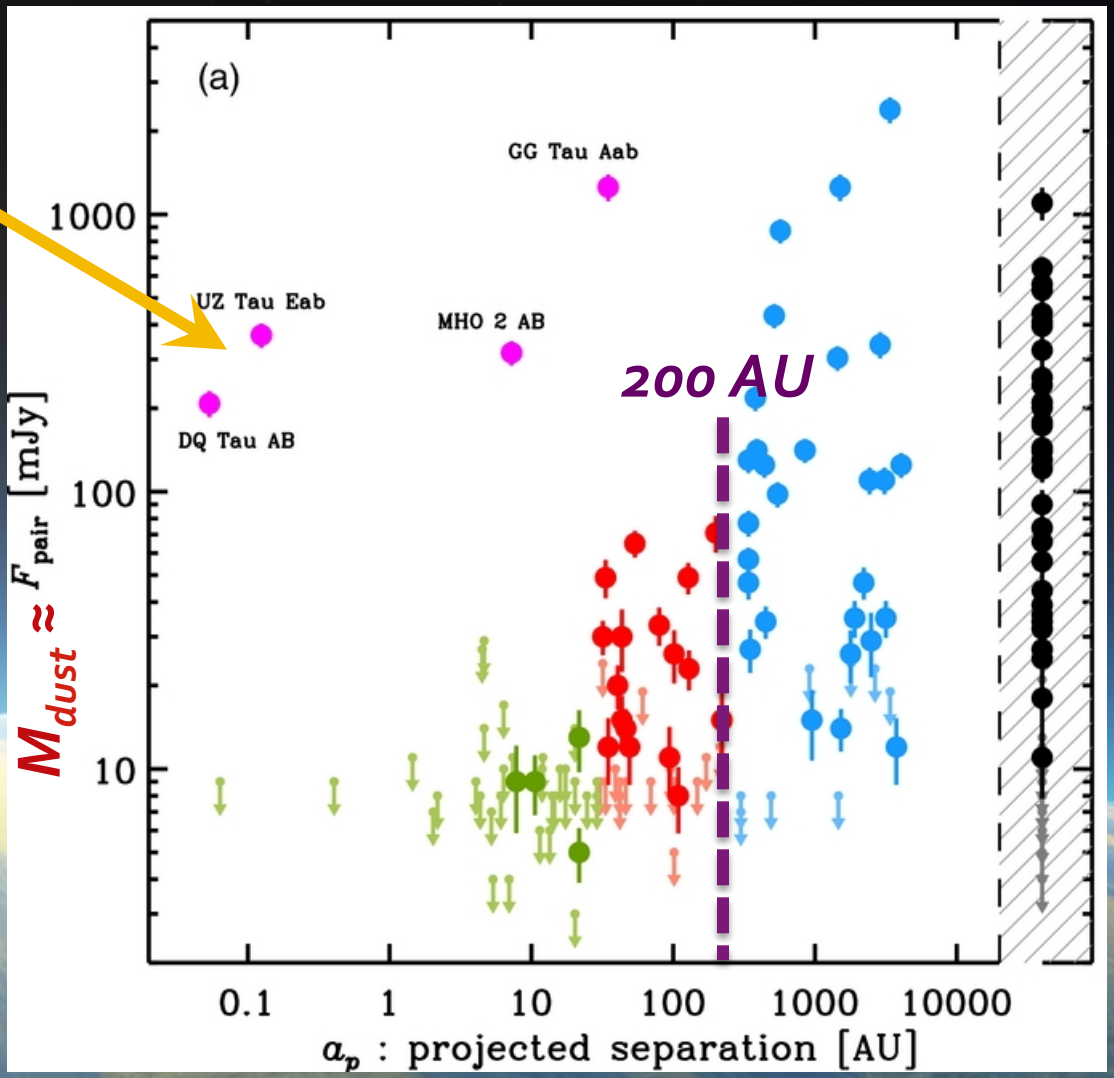




Total mass: the reservoir to form planets

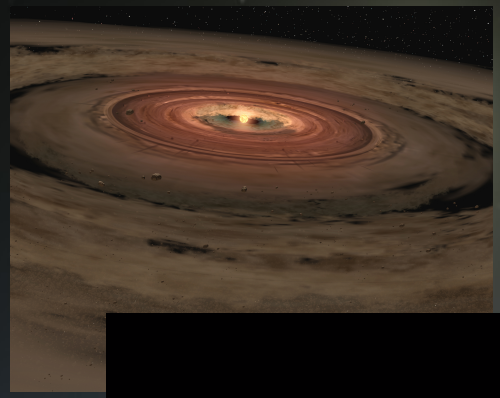
Disks in close binaries are more compact and (possibly) less massive





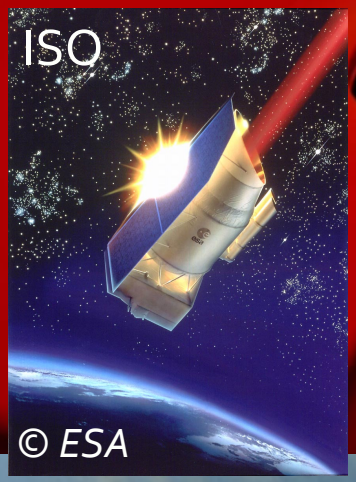
Harris et al. (2012)

Studying protoplanetary disks



Observing wavelength

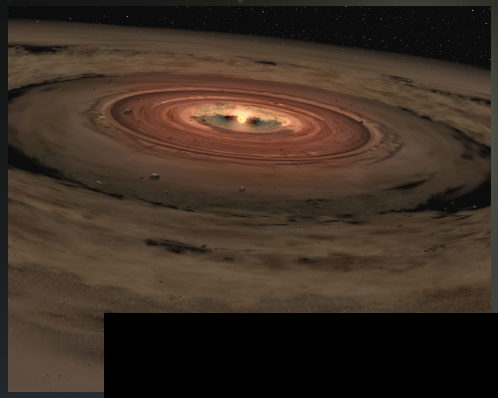
1-2 μm 10-20 μm 100 μm 1 mm



density

temperature

Studying protoplanetary disks



Observing wavelength

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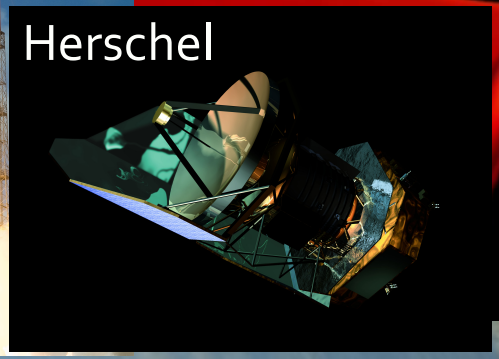

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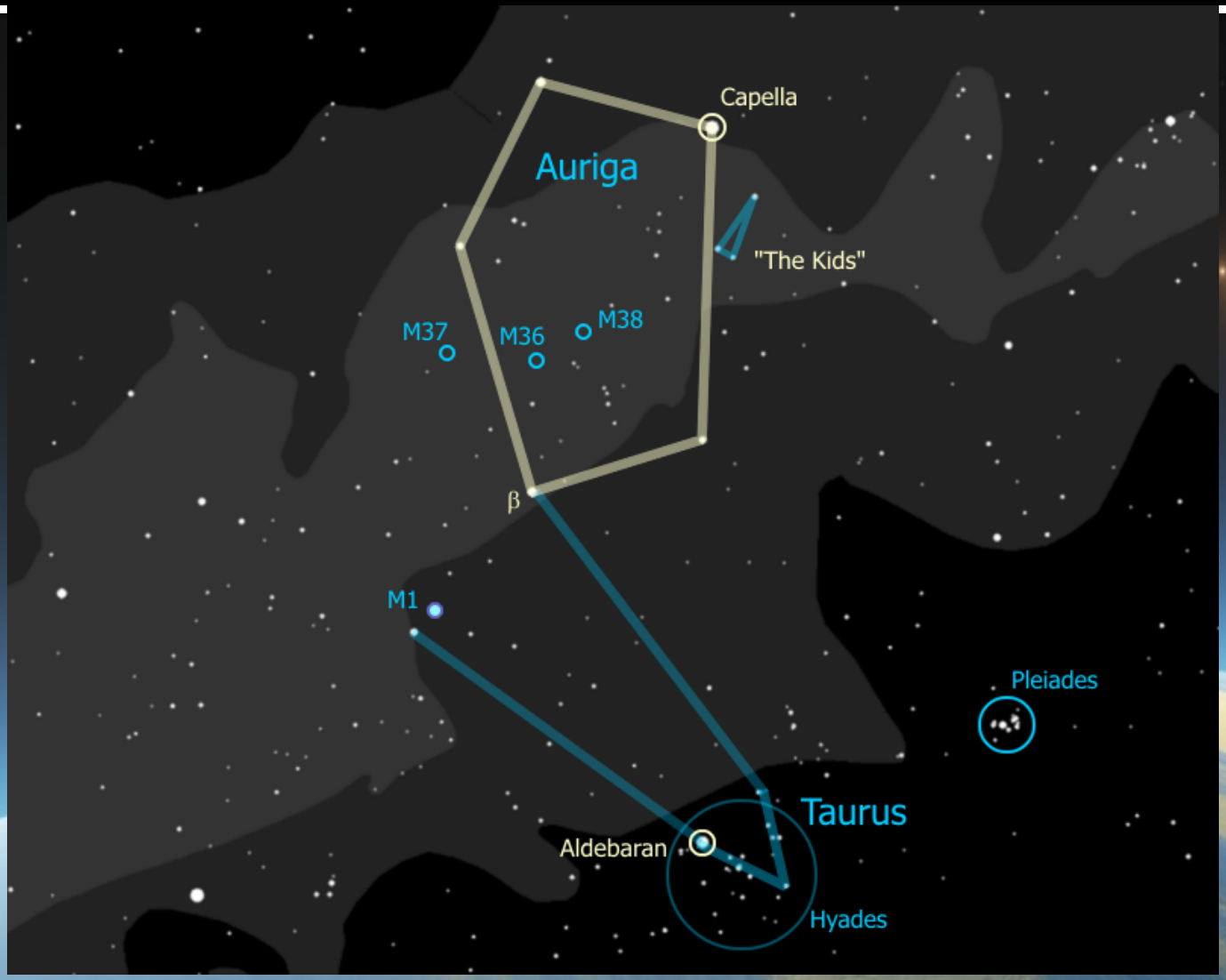
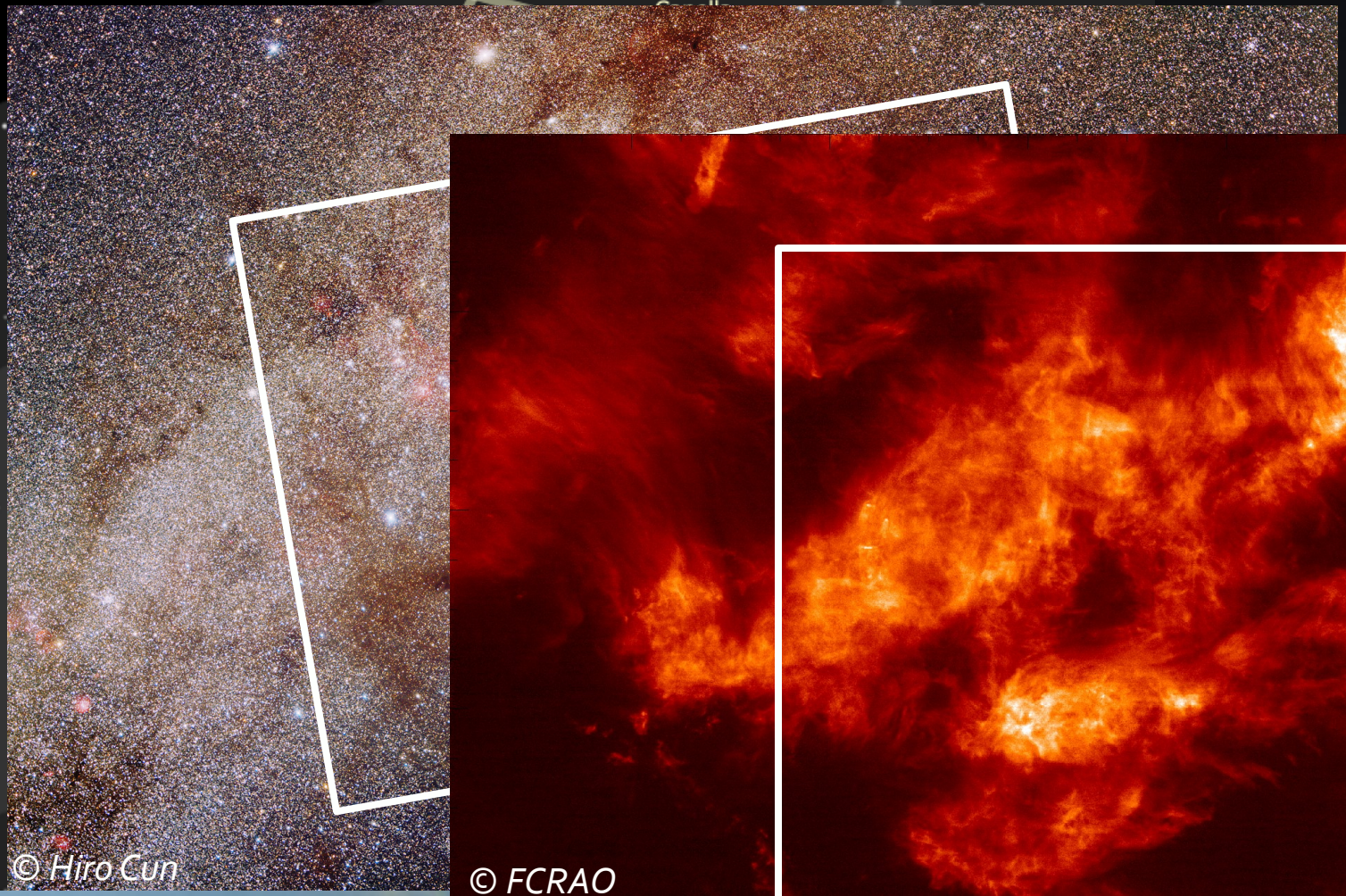
Focusing on the Taurus Molecular Cloud

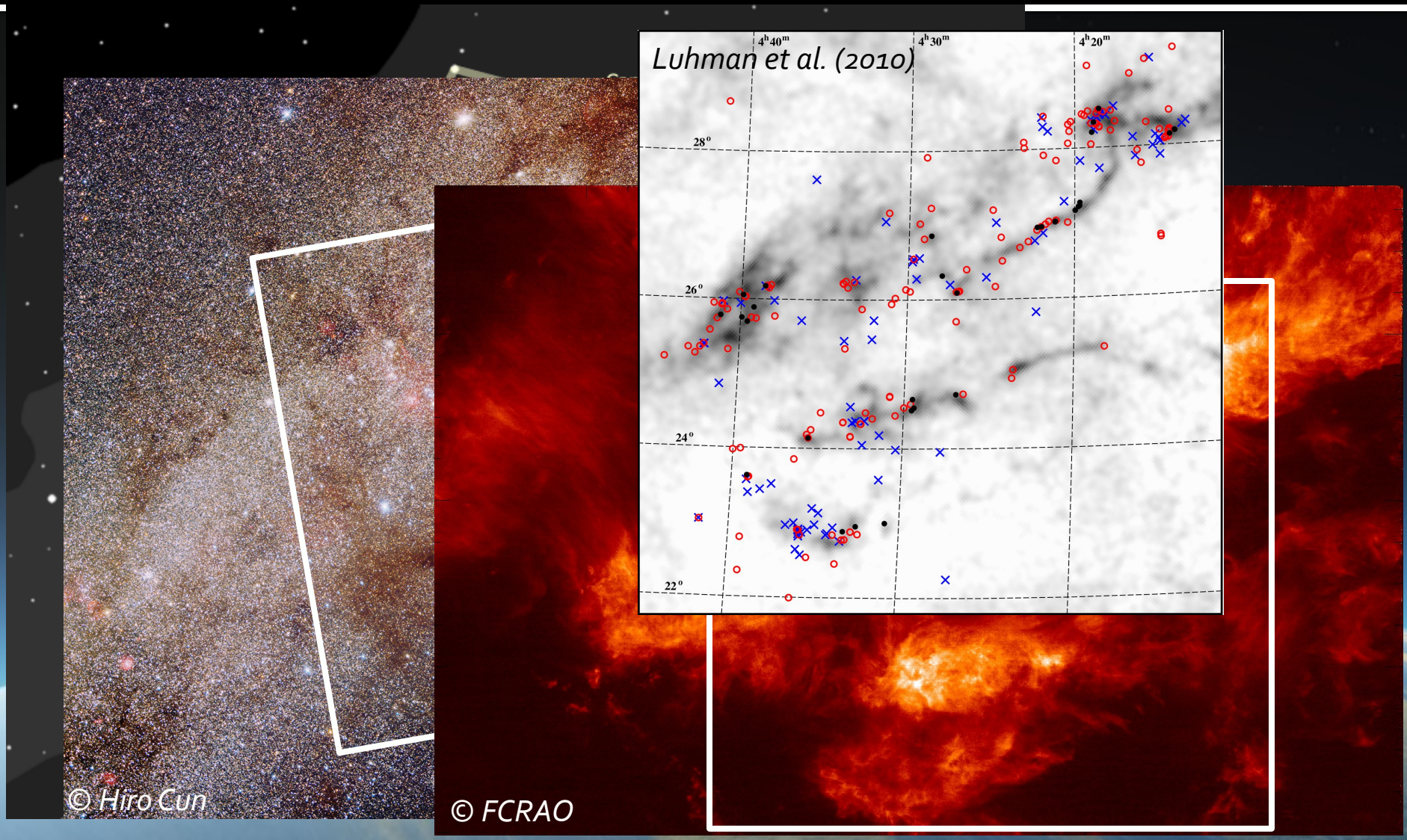


Focusing on the Taurus Molecular Cloud

Focusing on the Taurus Molecular Cloud

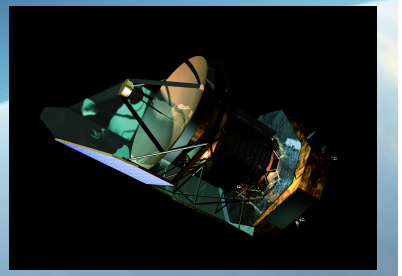


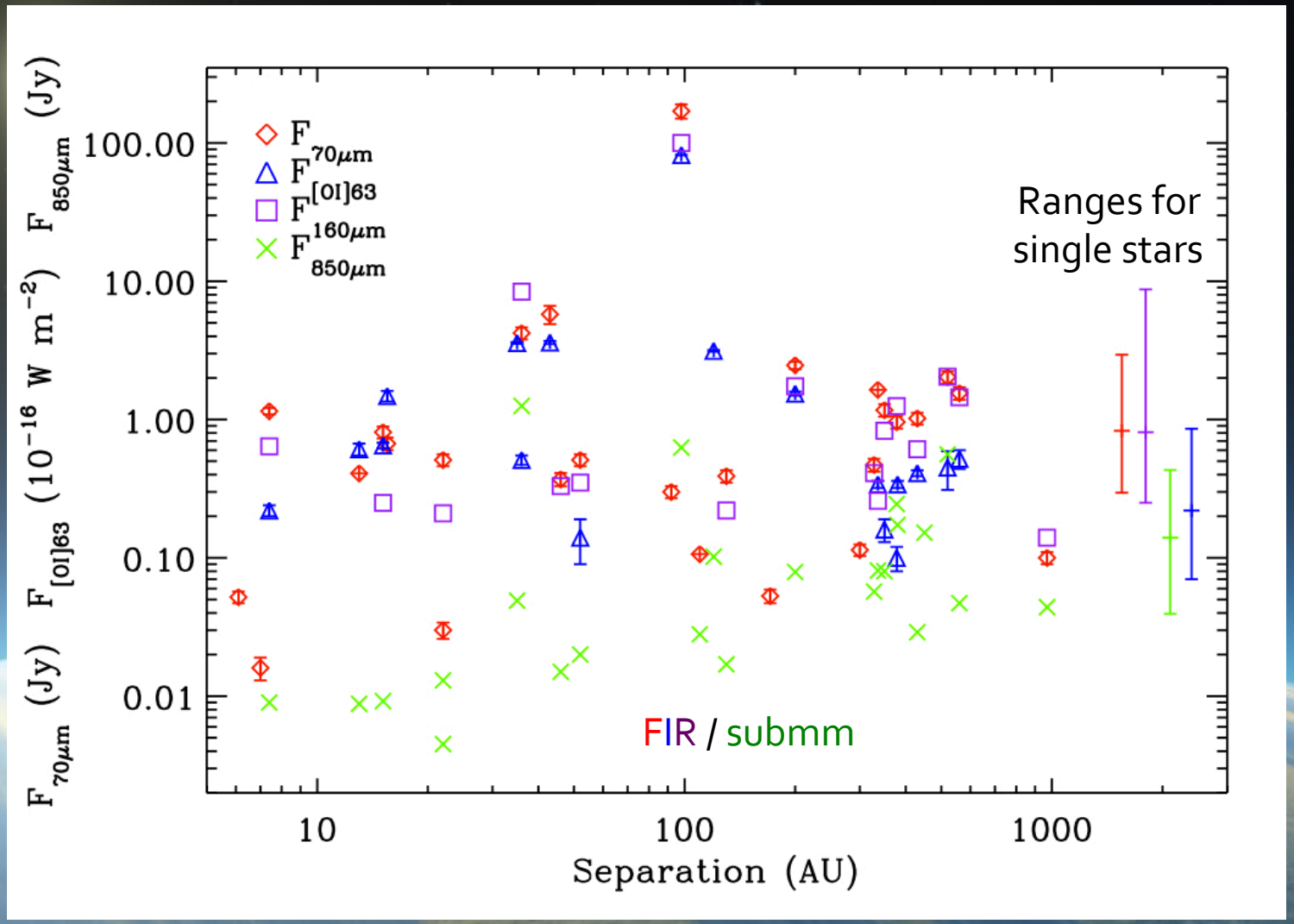
Focusing on the Taurus Molecular Cloud



The planet-forming region is unaffected by the presence of a stellar companion

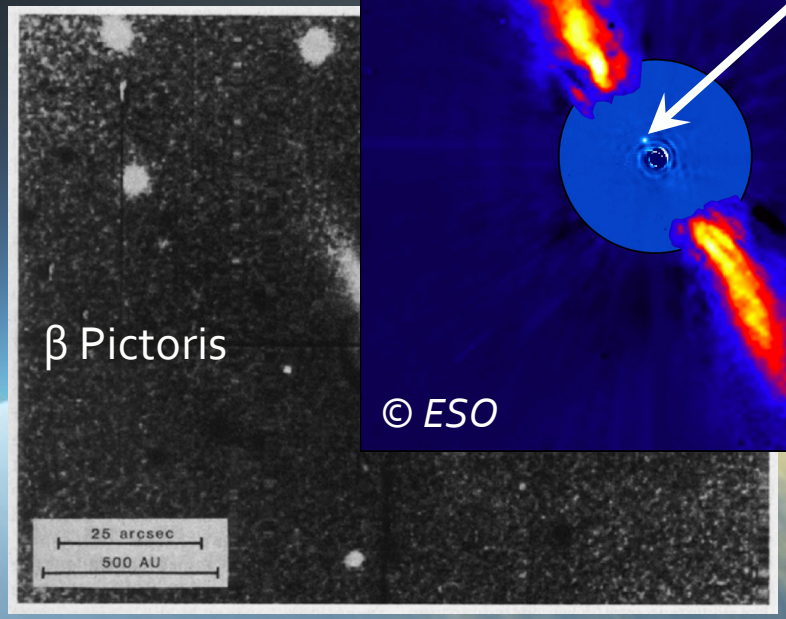
Howard et al. (submitted)



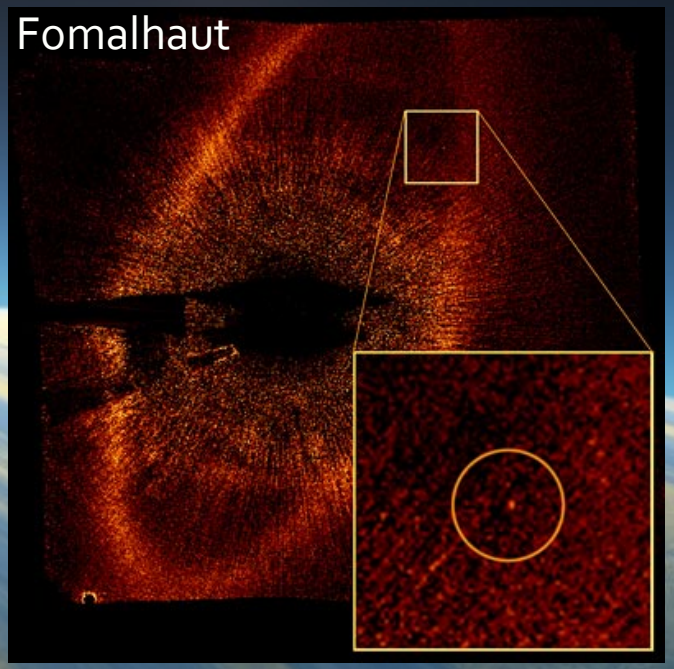


What are "debris disks"?

They are the equivalent of our zodiacal light, dust-rich disks replenished by continuous collisions between larger bodies, and are signposts for young planetary systems



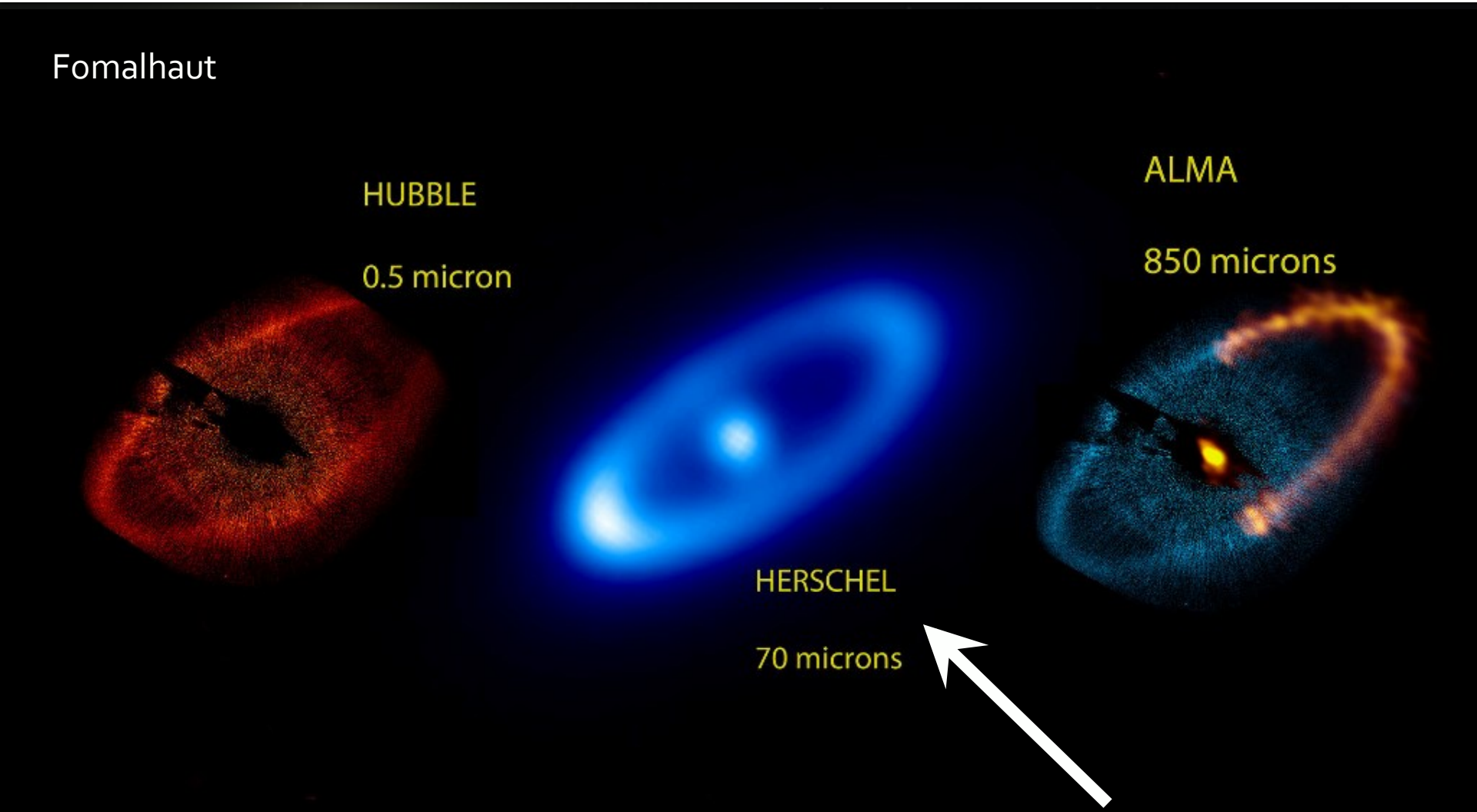
Smith & Terrile (1984)



Kalas et al. (2008)

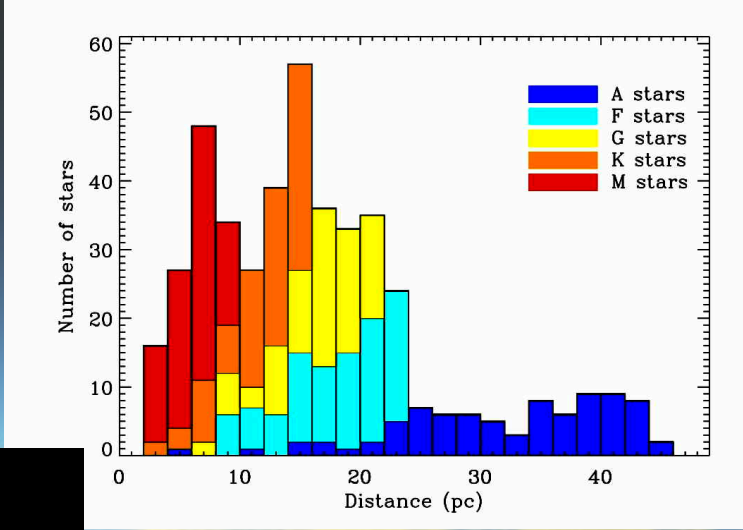
How to best probe debris disks

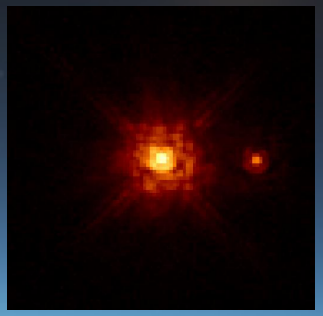
Fomalhaut

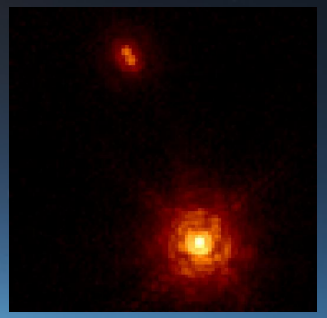


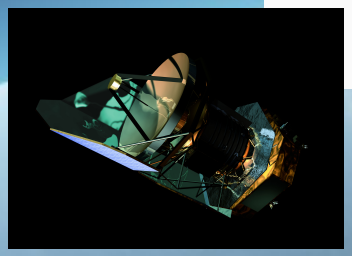
Debris disks in binaries

A systematic survey of ~450 nearby stars complemented by adaptive optics images from the Lick Observatory Shane Telescope

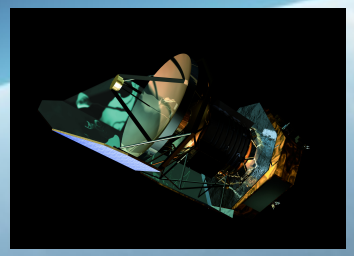


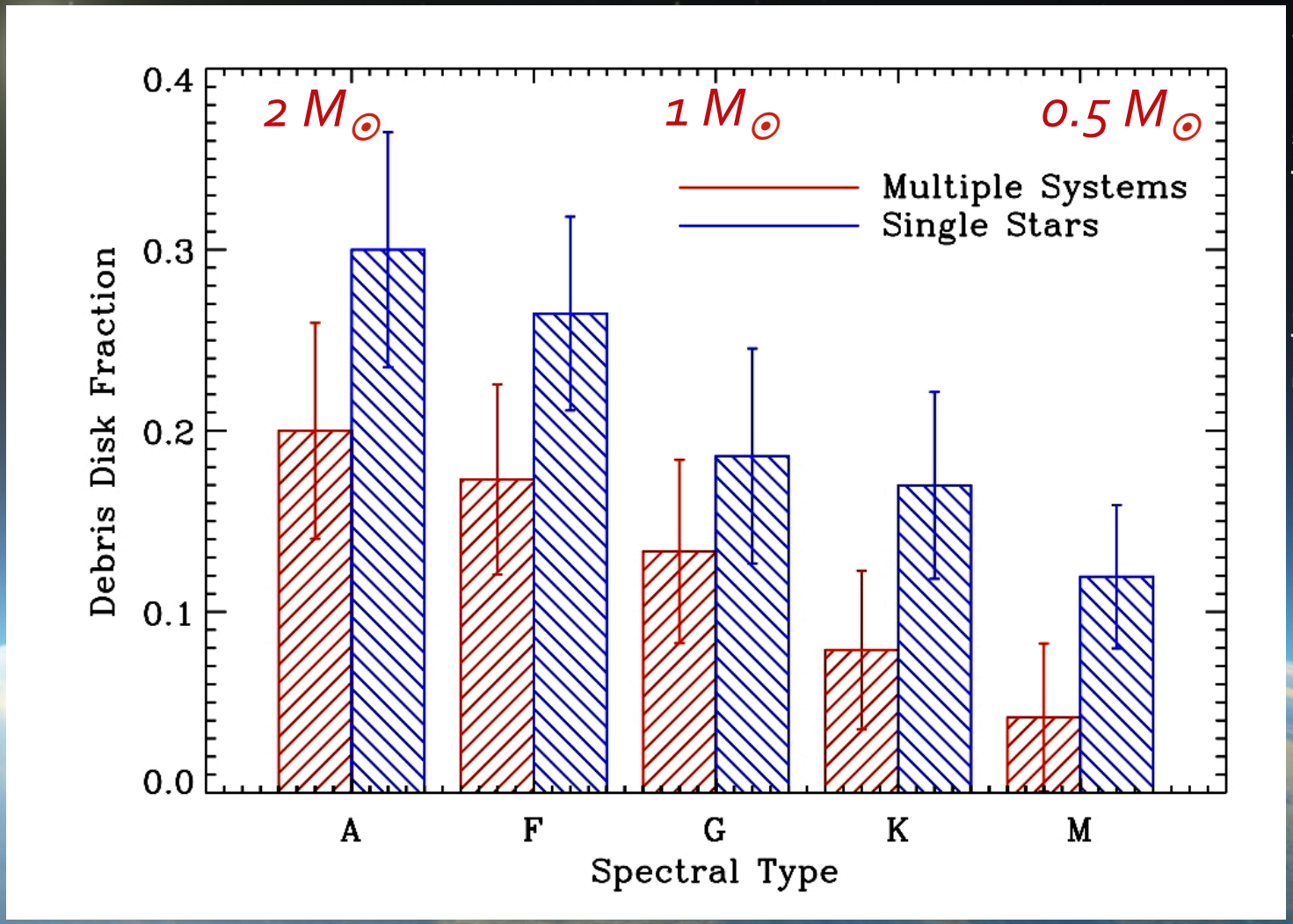






Debris disks are (slightly) less frequent in multiple systems

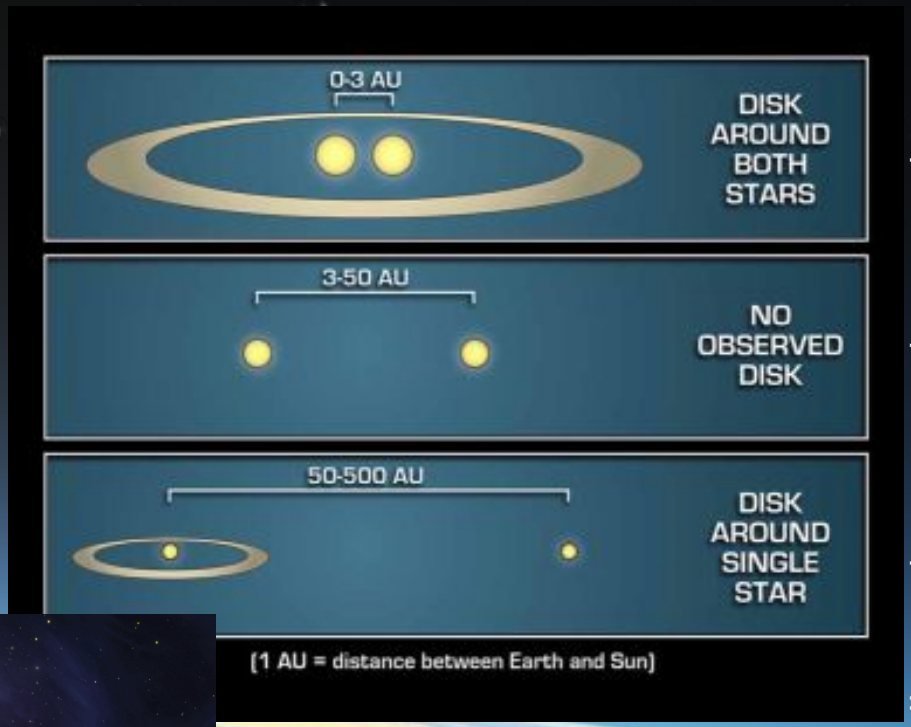




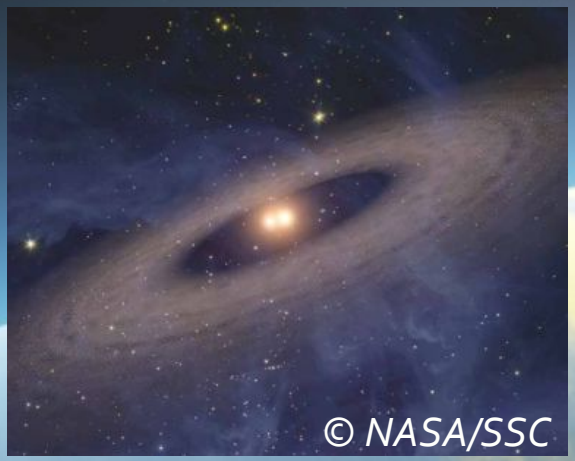
Rodriguez et al. (in prep)

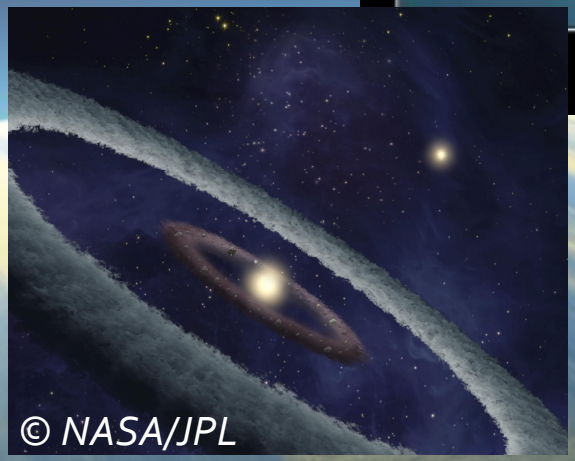
All binaries are not equally disruptive

Companions between ~5 AU and ~100 AU tend to quench the debris disk phenomenon (and planet formation?)



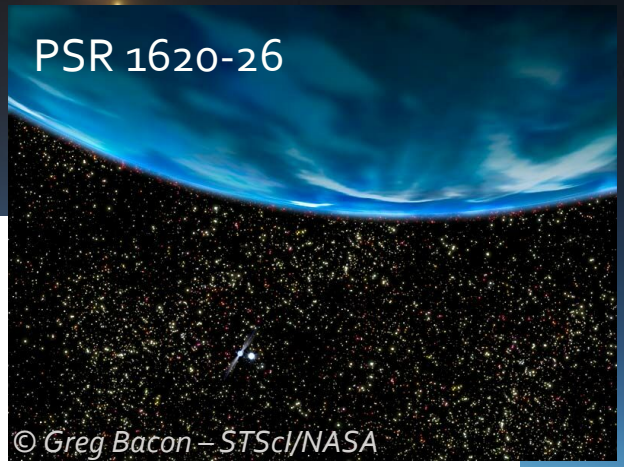
Trilling et al. (2006); Rodriguez et al. (in prep.)





Planets in multiple systems?

- Early surveys heavily biased *against* binaries, which severely hamper planet detection
- And yet…



THE ASTROPHYSICAL JOURNAL, 412:L33–L36, 1993 July 20

PSR B1620−26: A BINARY RADIO PULSAR WITH A PLANETARY COMPANION?

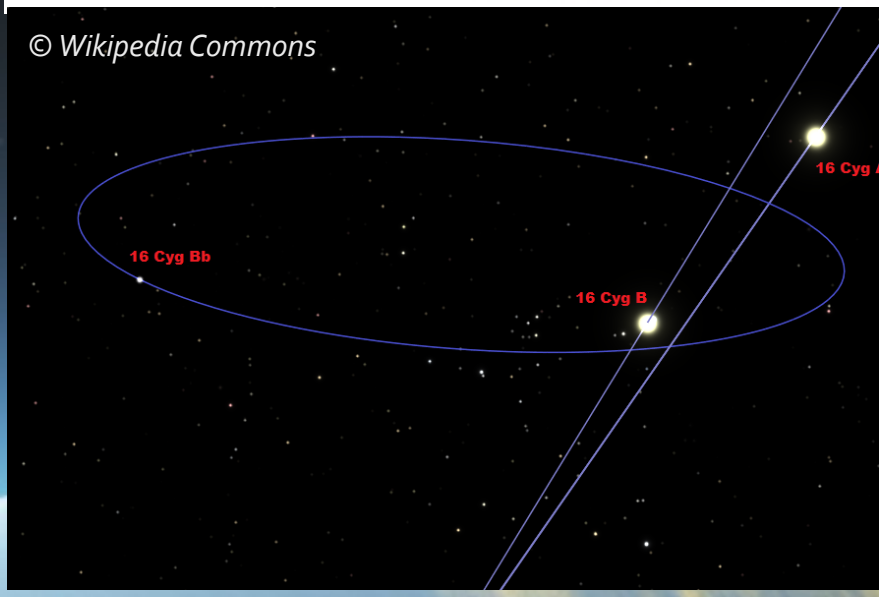
S. E. THORSETT
Owens Valley Radio Observatory, California Institute of Technology, MS 105-24, Pasadena, CA 91125
AND
Z. ARZOUMANIAN AND J. H. TAYLOR
Joseph Henry Laboratories and Department of Physics, Princeton University, Princeton, NJ 08544
Received 1993 March 11; accepted 1993 May 4

Planets in multiple systems?

THE ASTROPHYSICAL JOURNAL, 483:457–463, 1997 July 1

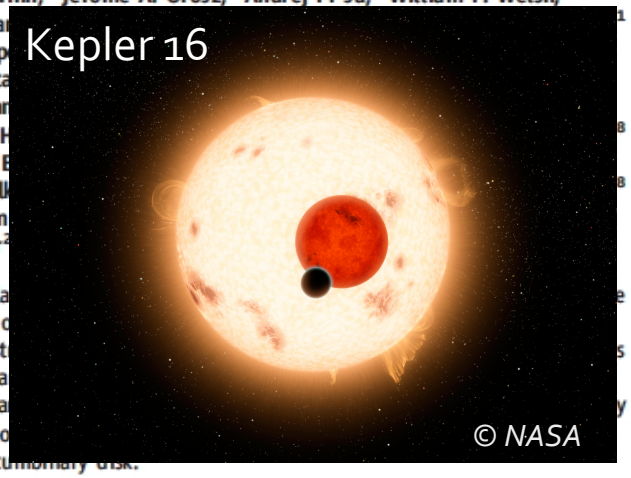
THE DISCOVERY OF A PLANETARY COMPANION TO 16 CYGNI B

WILLIAM D. COCHRAN AND ARTIE P. [illegible]
McDonald Observatory, University of Texas at Austin, Austin, TX 78712; wdc@[illegible]
AND
R. PAUL BUTLER[1] AND GEOFFREY W. [illegible]
Department of Physics and Astronomy, San Francisco State Unive[illegible]
gmarcy@etoile.berkeley.edu, paul@further.be[illegible]
Received 1996 November 21 ; accepted 1997 J[illegible]



Kepler-16: A Transiting Circumbinary Planet

Laurance R. Doyle,[1]* Joshua A. Carter,[2] Daniel C. Fabrycky,[3] Robert W. Slawson,[1] Steve B. Howell,[4] Joshua N. Winn,[5] Jerome A. Orosz,[6] Andrej Prša,[7] William F. Welsh,[6] Samuel N. Quinn,[8] David Latham[8] Jonathan J. Fortney,[12] Avi Shporer[13] Michael Rucker,[16] Natalie Batalha[16] Christopher K. Middour,[17] Jennifer R. Hall,[18] Elisa V. Quintana,[1] Matthew J. Holman,[8] Warren R. Brown,[8] Gilbert A. Esquerdo,[8] Perry Berlind,[20] Michael L. Calkins,[20] Edward W. Dunham,[23] William J. Borucki,[24] Derek Buzasi,[26] Debra Fischer[27]



We report the detection of a pla[illegible] Kepler spacecraft reveal transits [illegible] of the stars, giving precise const[illegible] comparable to Saturn in mass a[illegible] parent stars. The eclipsing stars a[illegible] orbit. The motions of all three bo[illegible] the planet formed within a circu[illegible]

A planet with two suns is a familiar concept from science fiction. However, the evidence for the existence of circumbinary planets—those that orbit around both members of a stellar binary—has been limited. A few good cases have been made for circumbinary

Planets in multiple systems?

THE ASTROPHYSICAL JOURNAL, 483:457–463, 1997 July 1

THE DISCOVERY OF A PLANETARY COMPANION TO 16 CYGNI B

WILLIAM D. COCHRAN AND ARTIE P.
McDonald Observatory, University of Texas at Austin, Austin, TX 78712; wdc@
AND
R. PAUL BUTLER[1] AND GEOFFREY W.
Department of Physics and Astronomy, San Francisco State Unive
gmarcy@etoile.berkeley.edu, paul@further.be
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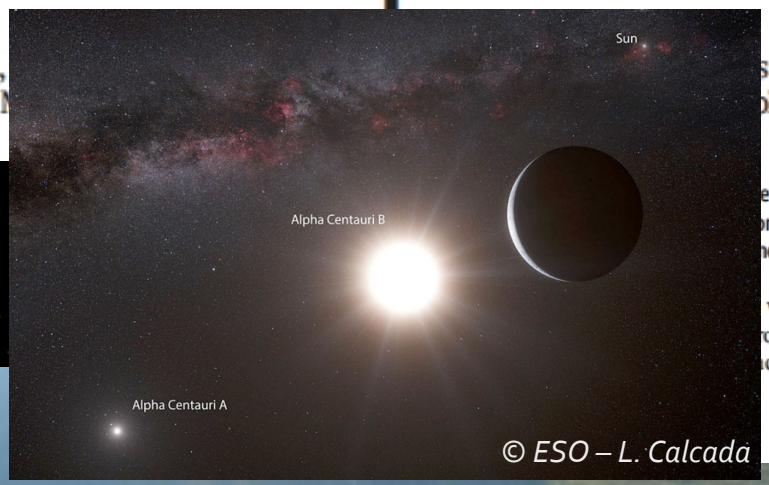
Jonathan J. Fortney,[12] Avi Shp
Michael Rucker,[16] Natalie Bata

Kepler 16

An Earth-mass planet orbiting α Centauri B

Xavier Dumusque[1,2],
François Bouchy[1,4],
san[1], Johannes Sahlmann[1], Willy Benz[3],
hane Udry[1]



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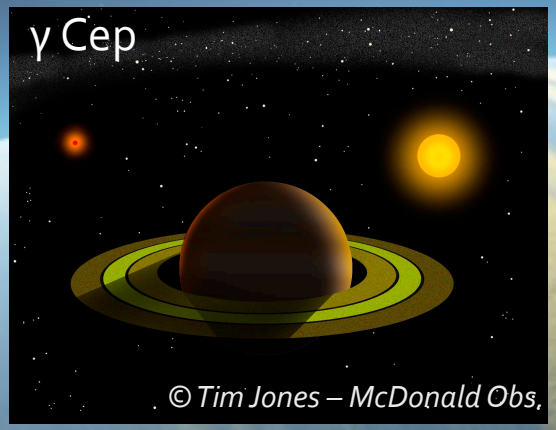
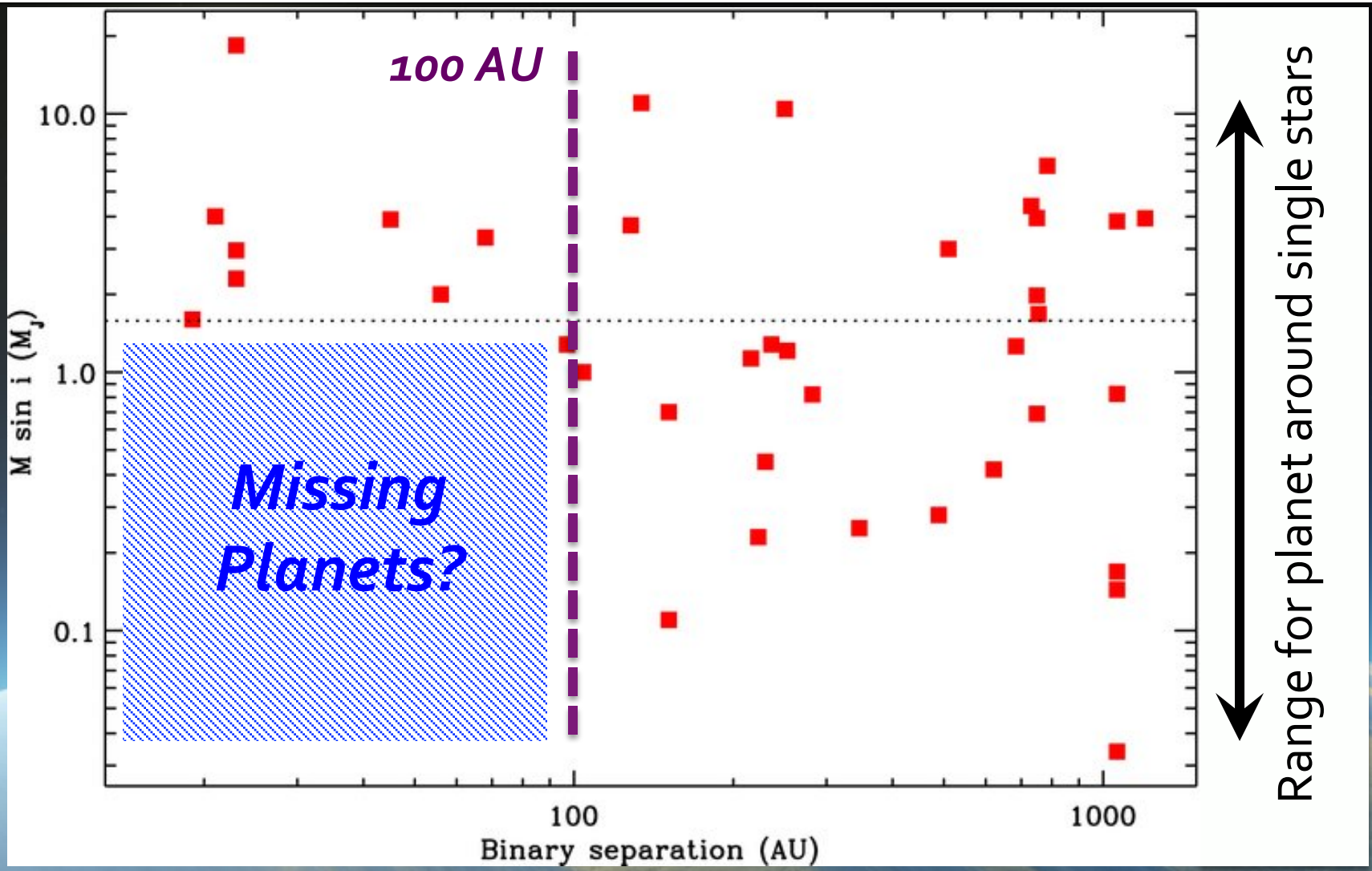
Exoplanets in binaries

- ~33% of known exoplanet hosts are binaries
- Most planets are found around primaries
  - Some exceptions (16 Cyg B), but fewer searches
- Tight binary systems (< 100 AU) show a deficit, but not a dearth, of planetary systems

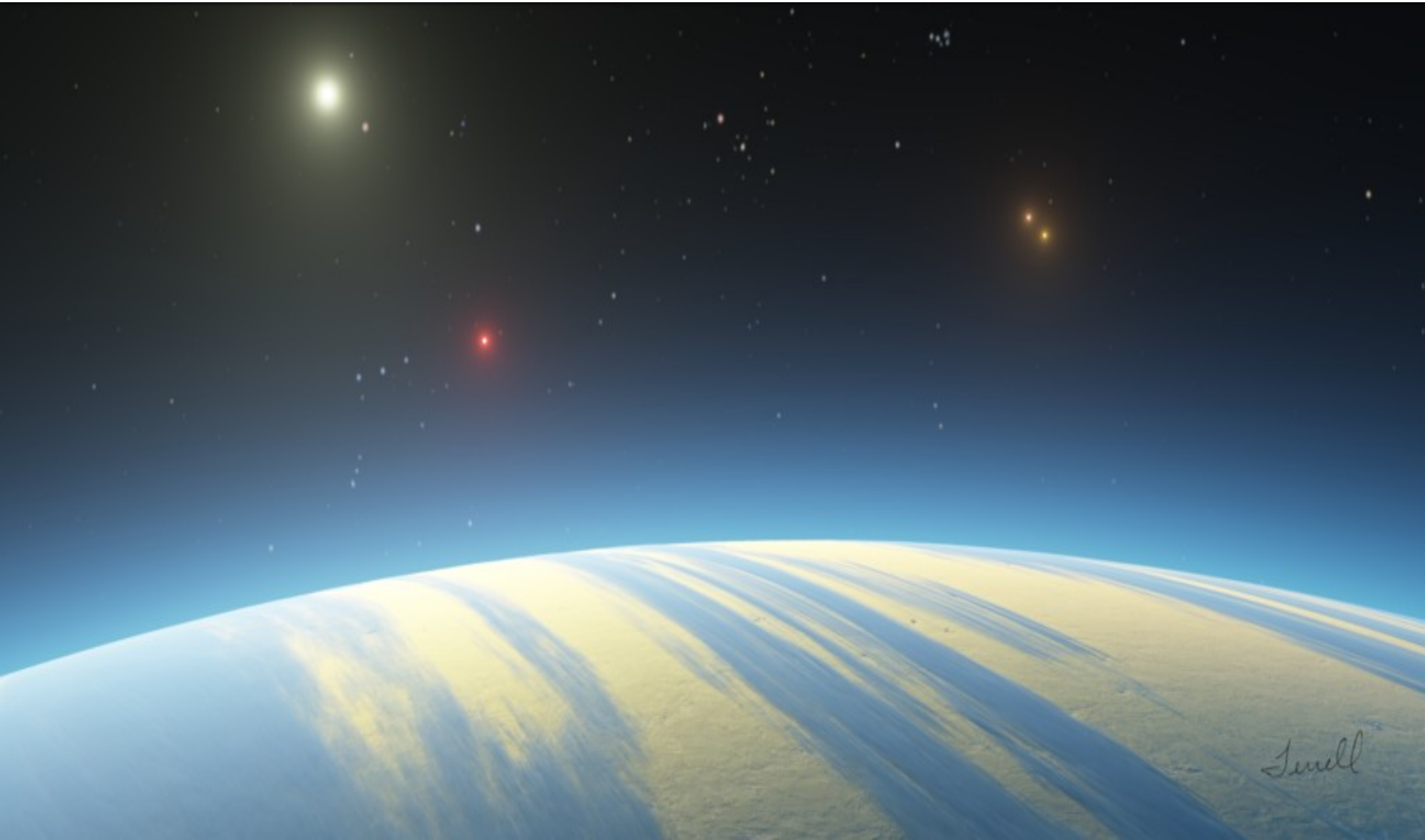


Planet: a=2 AU, e=0.2
Companion: a=20 AU, e=0.4

Close binaries only form high-mass planets



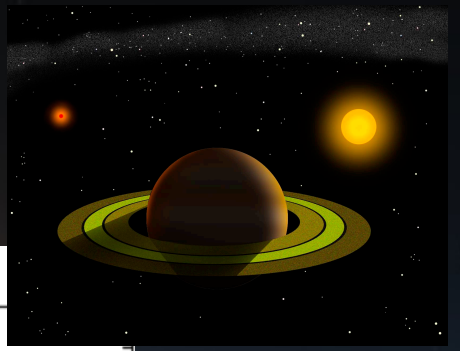
Back to the big picture…

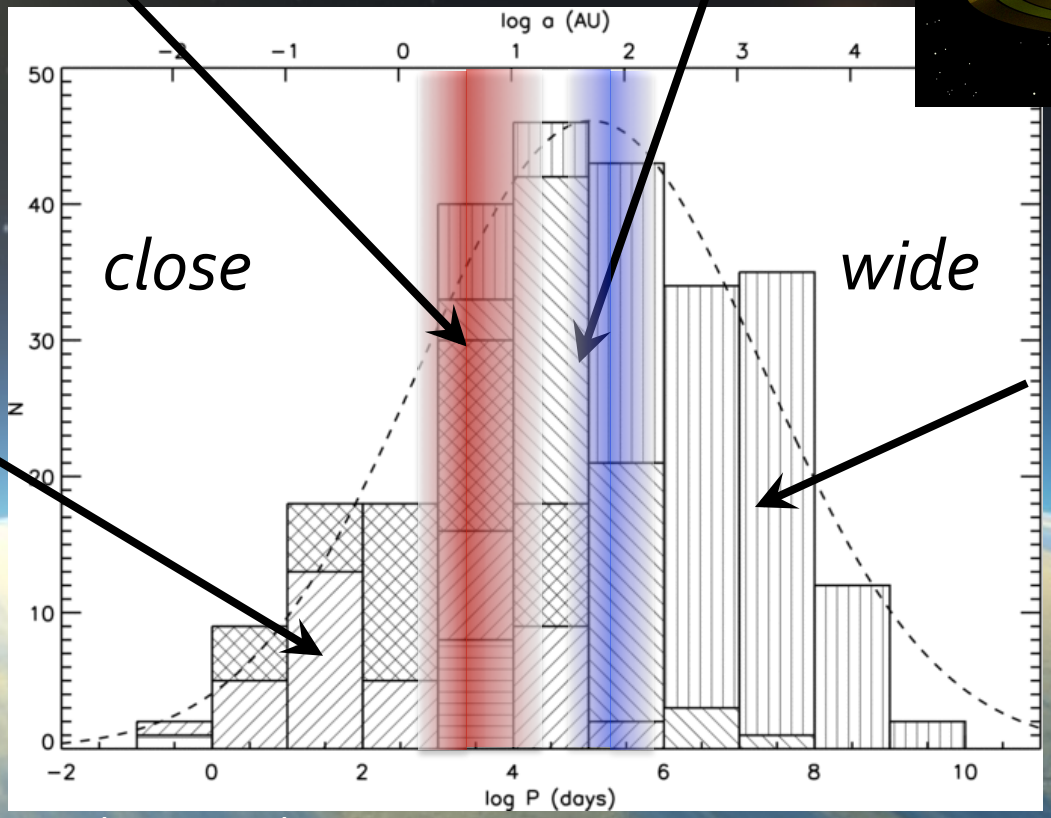


Planetary systems are common, yet diverse, in multiple stellar systems

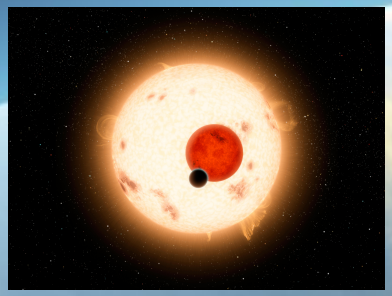
No man's land?

A "different" process

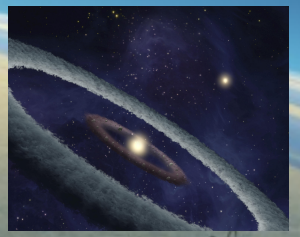




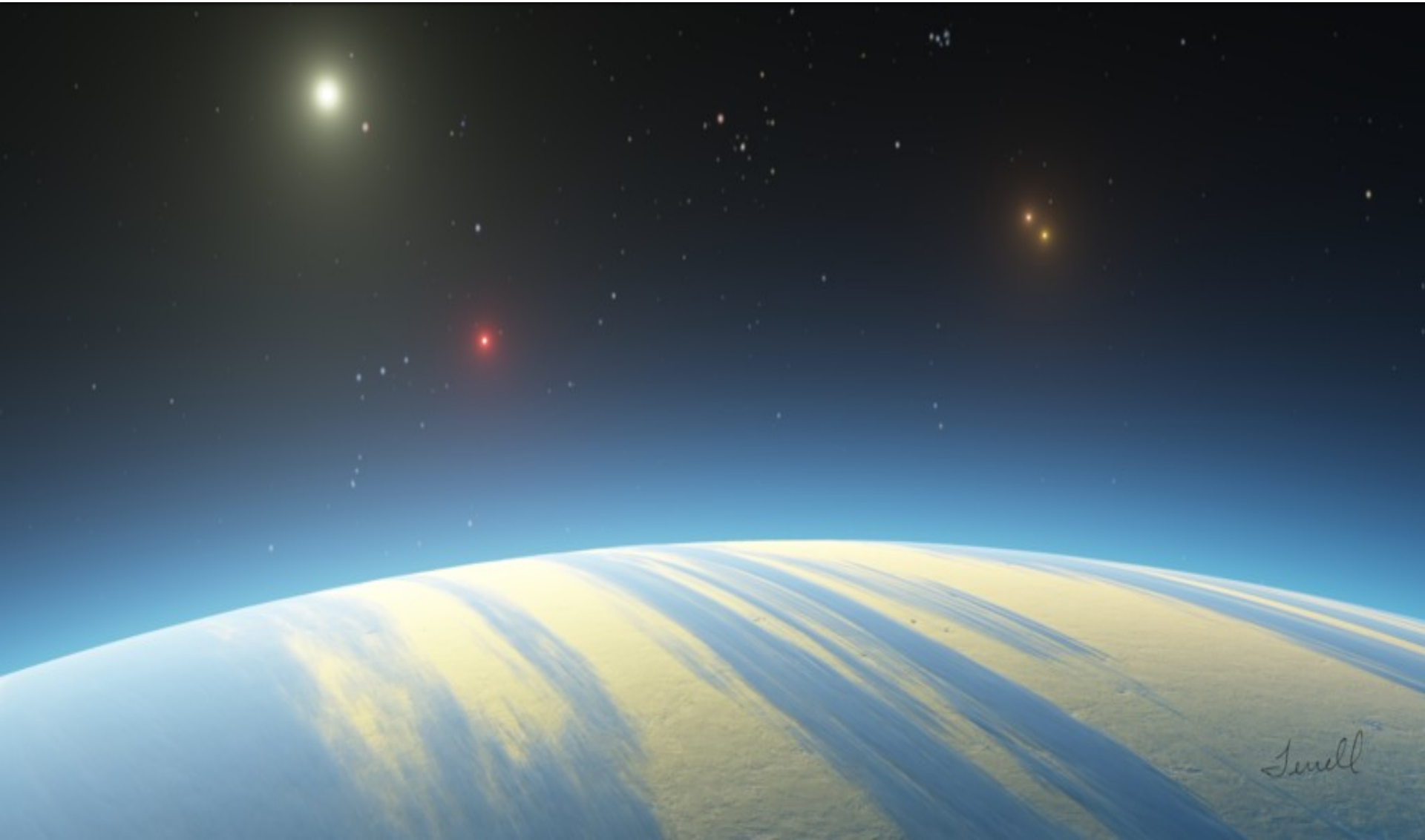
Quasi-normal process



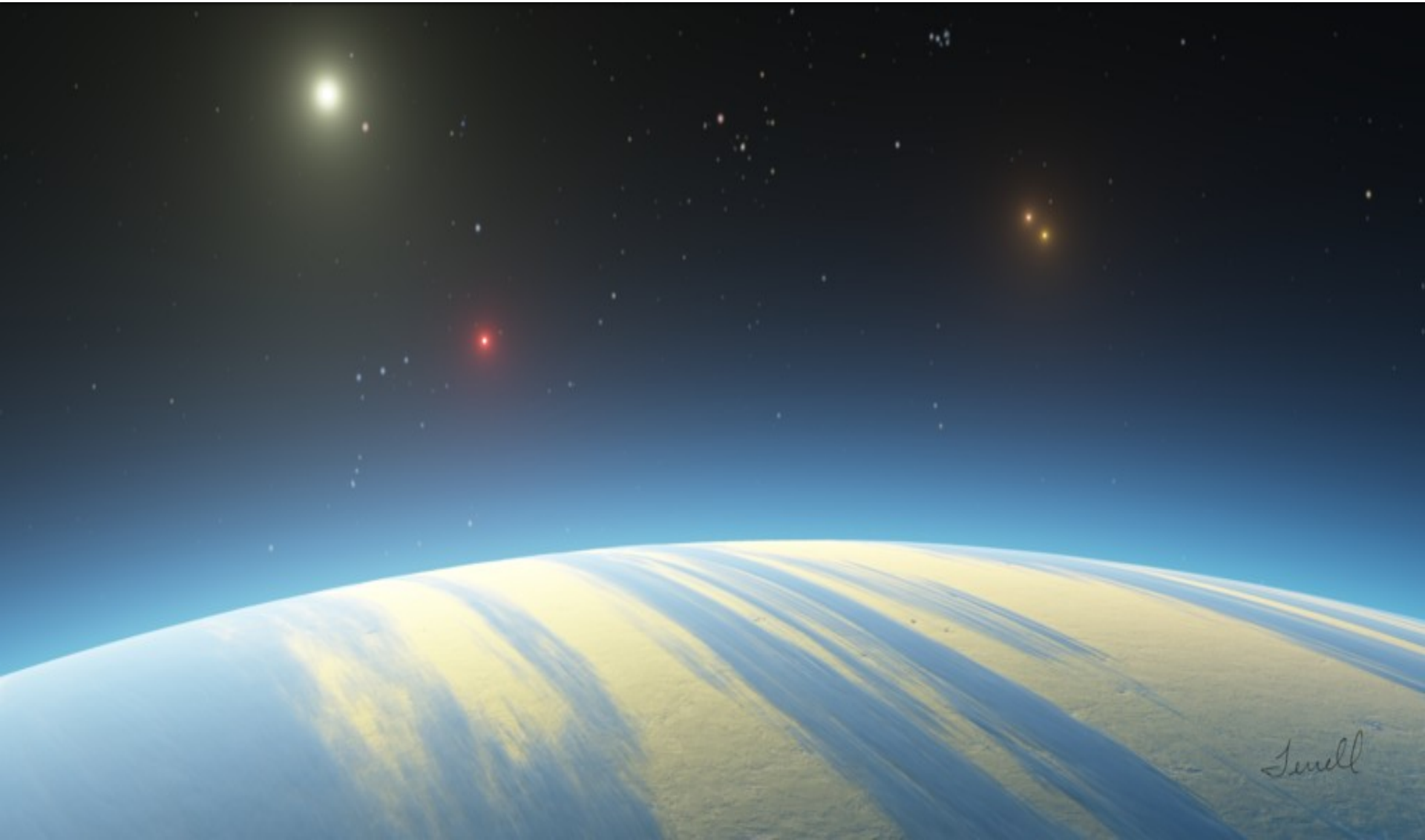
"Normal" process



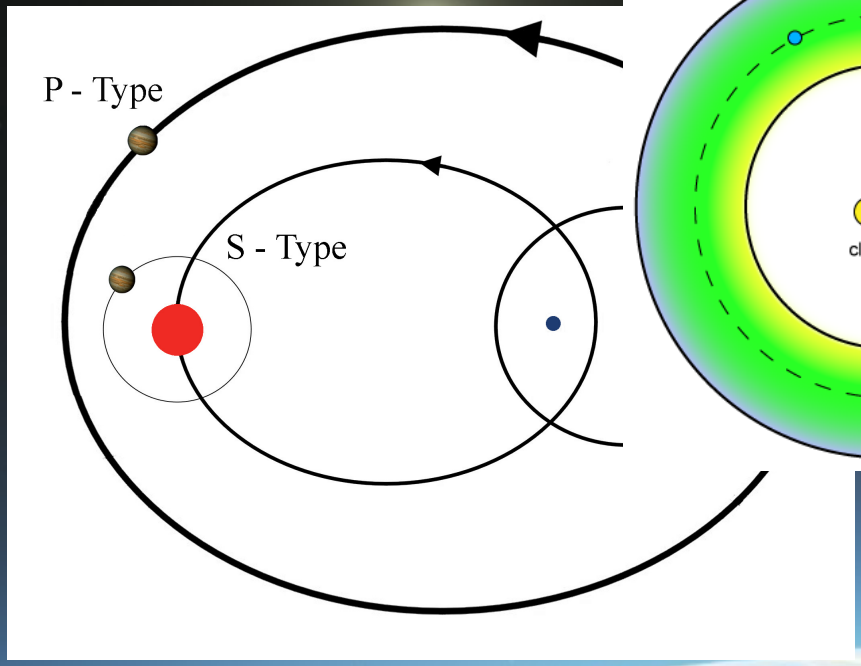
Raghavan et al. (2010)

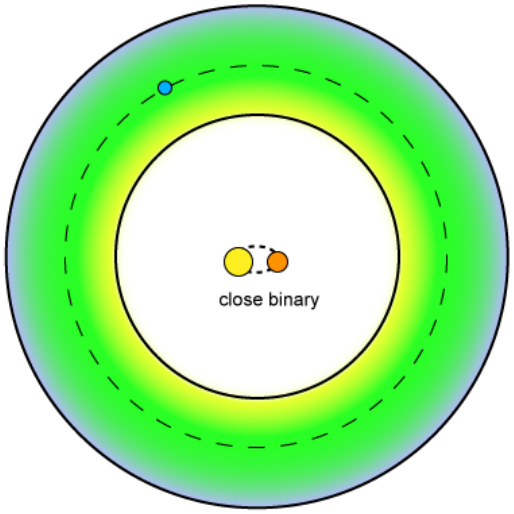


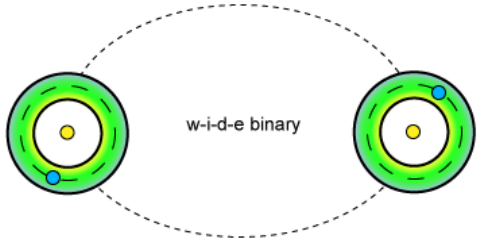
Extra slides



Planets in binary systems: possible orbits and habitability

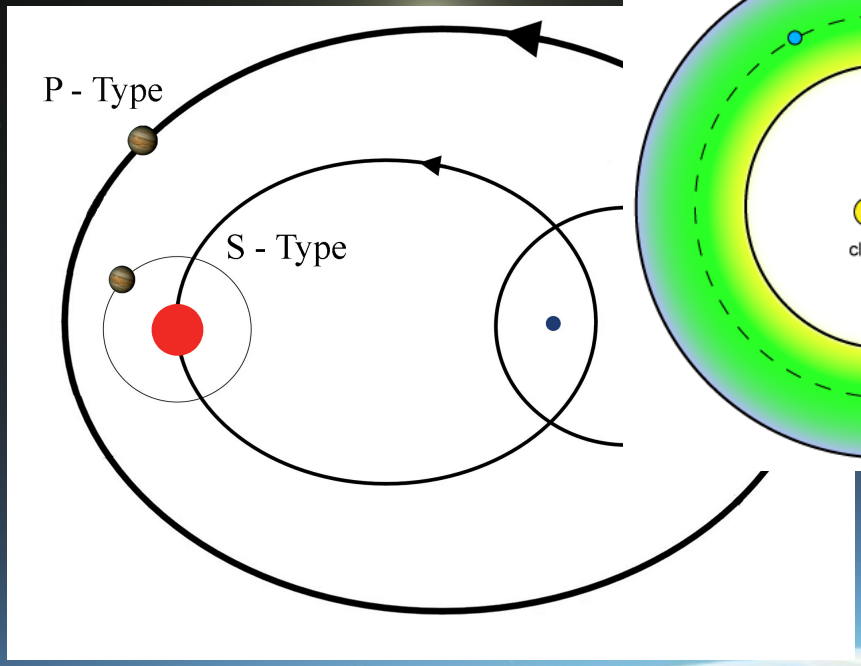


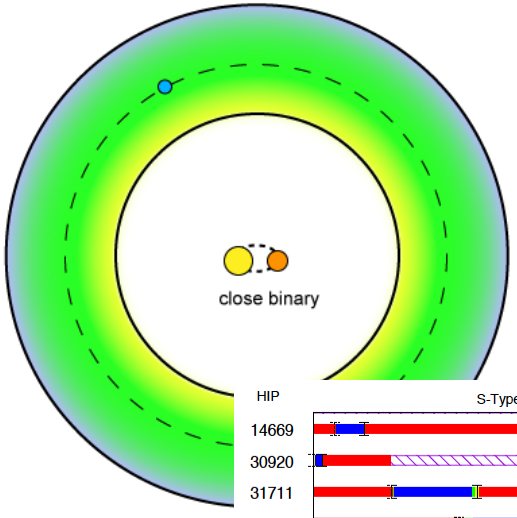


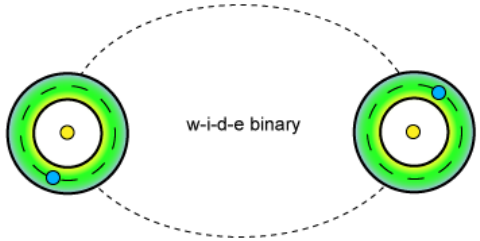


Habitable zones for stable planet orbits in binary systems
Left: A *circumbinary planet* (orbiting both stars in a close binary system).
Stable planet orbit is very large in comparison to binary star separation.
Right: A wide binary system, where star-star distance remains very large in comparison to stable orbits of the planets.
(These drawings are NOT to scale!)

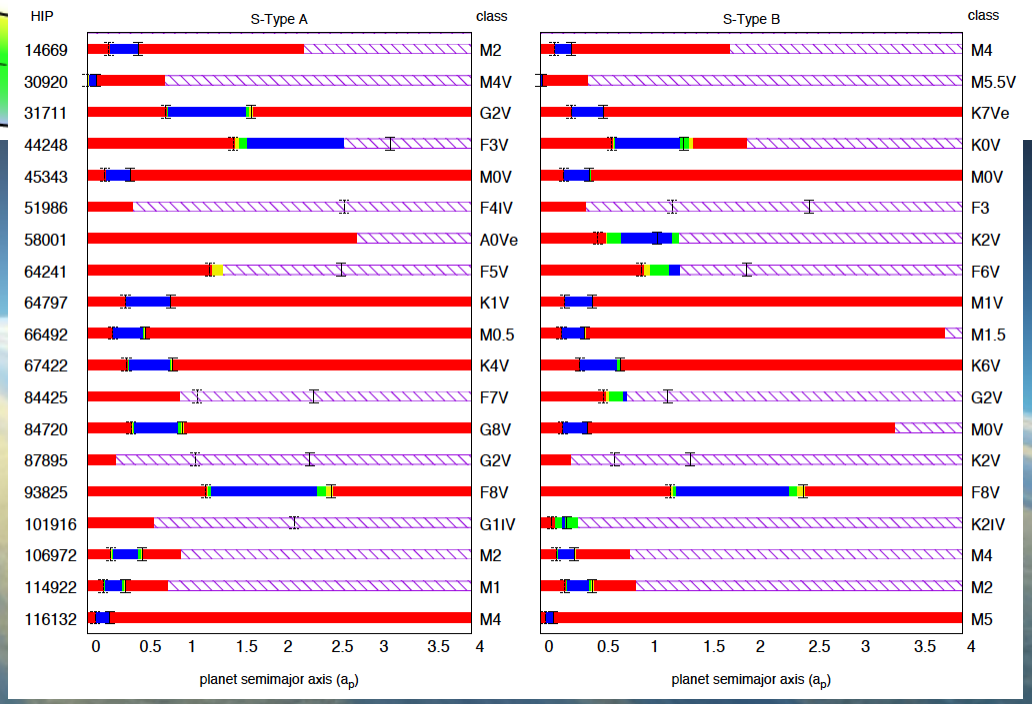
Planets in binary systems: possible orbits and habitability







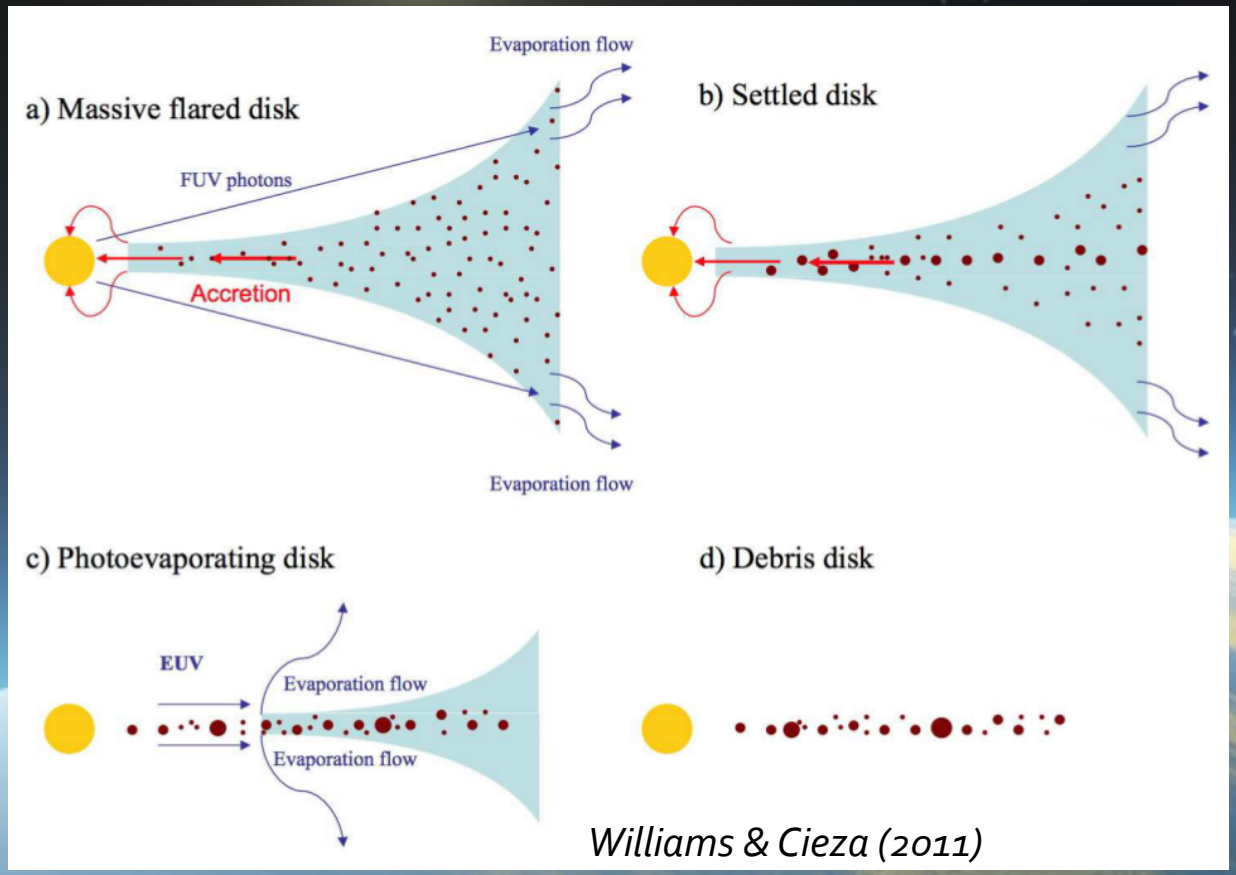
Habitable zones for stable planet orbits in binary systems



Eggl et al. (2012)

Planet formation scenarios

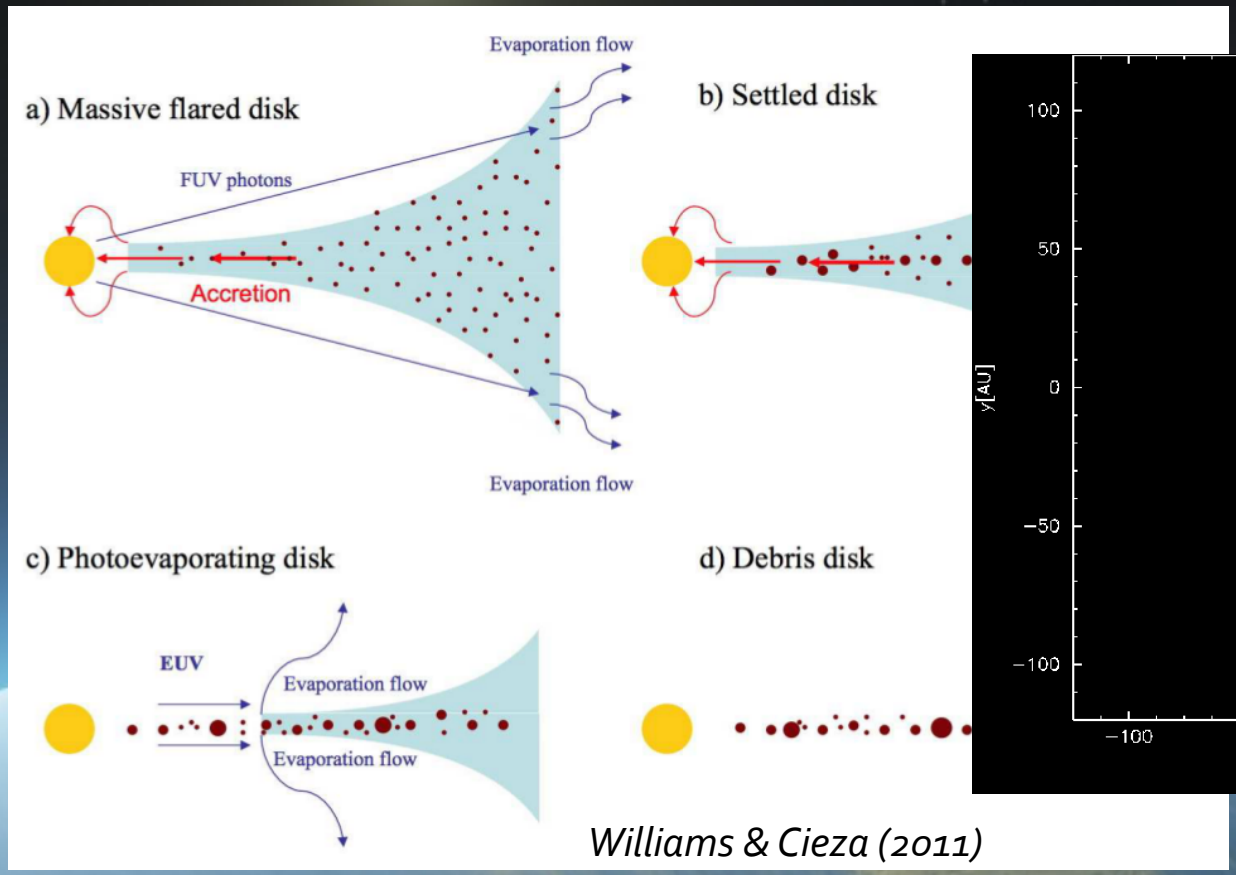
- A gradual build-up



Williams & Cieza (2011)

Planet formation scenarios

- A gradual build-up … or a catastrophic event?



Williams & Cieza (2011)

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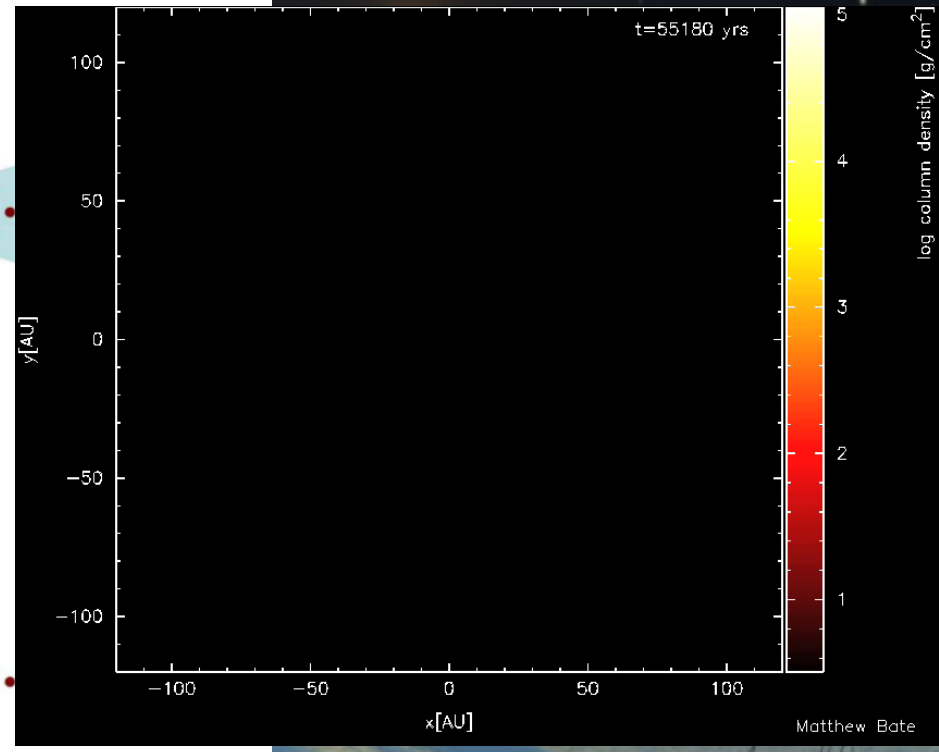
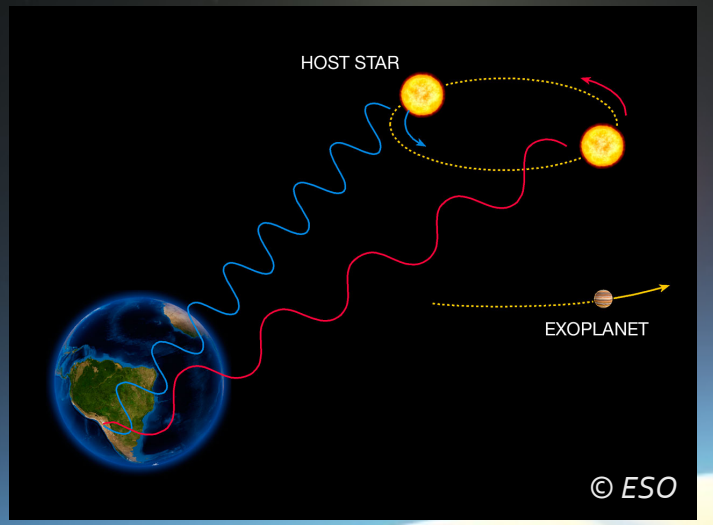
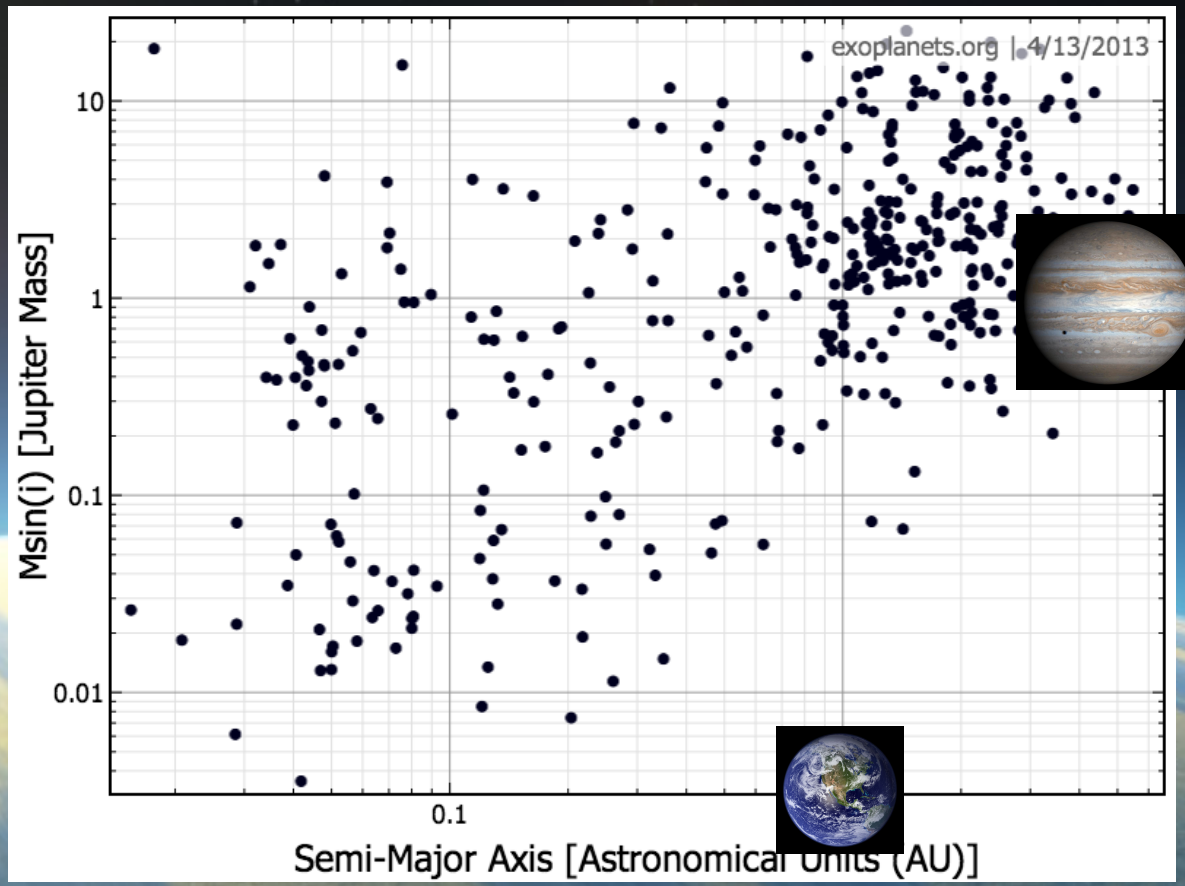


The discovery of extrasolar planets

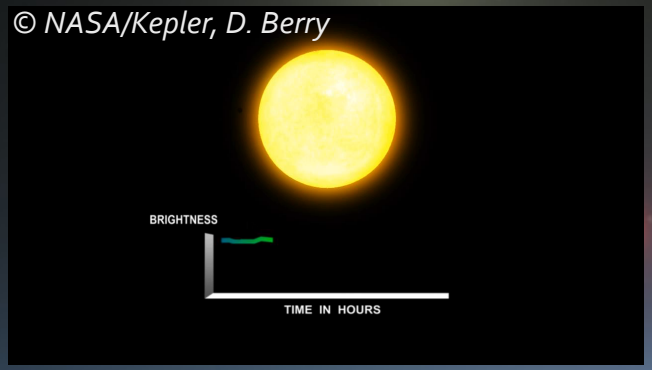
- The "old" way (~15yr): orbital wobble

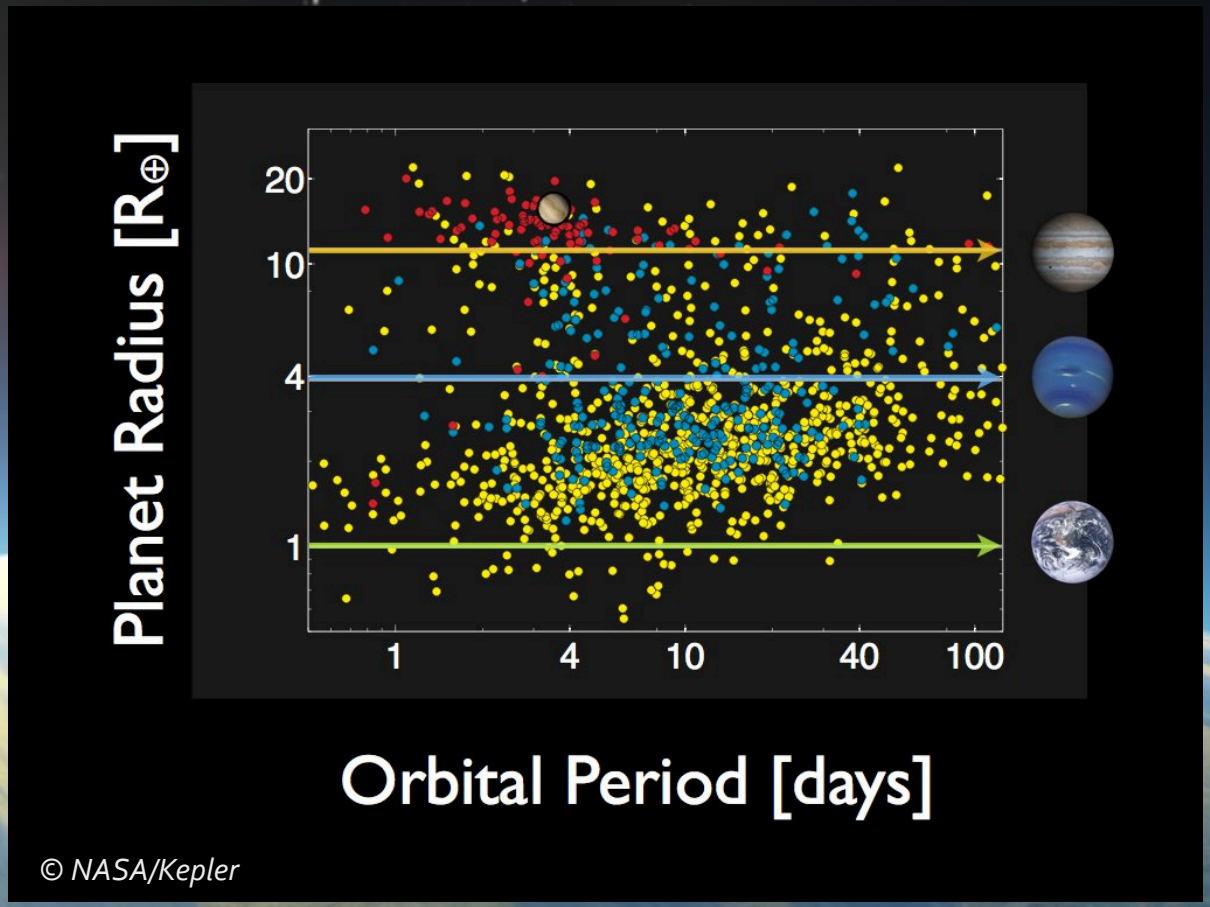




The discovery of extrasolar planets

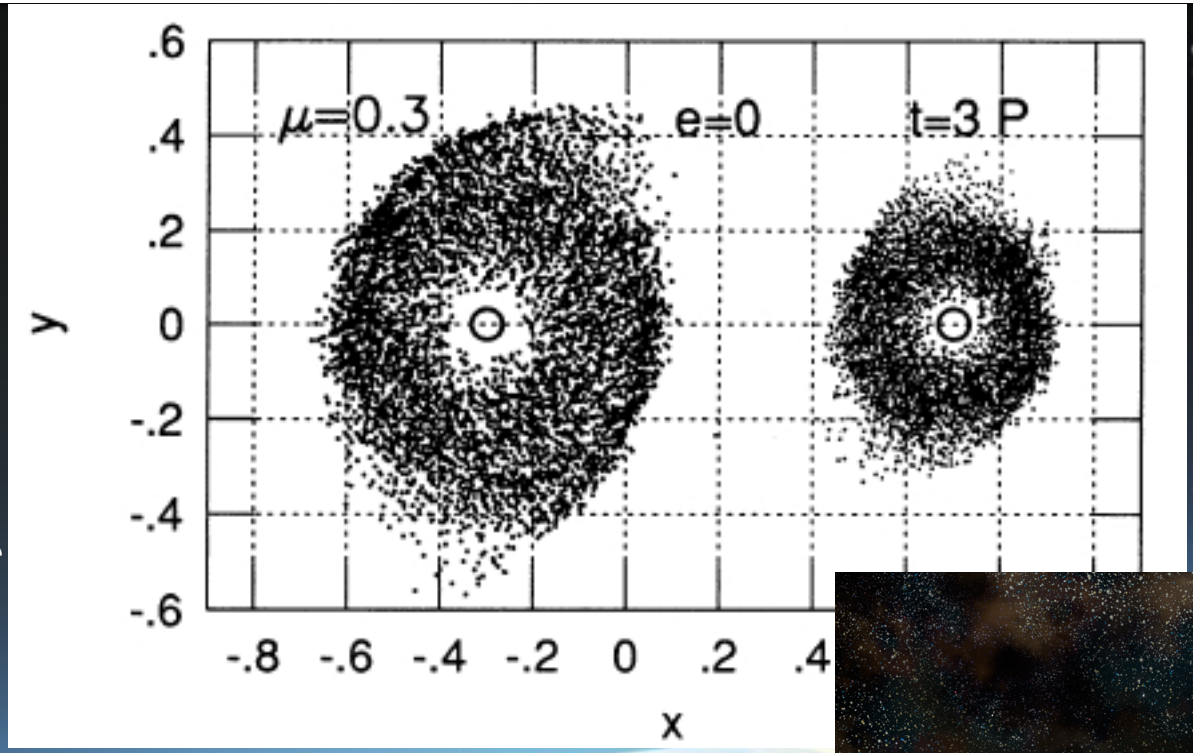
- The "new" way: transiting (eclipse) planets





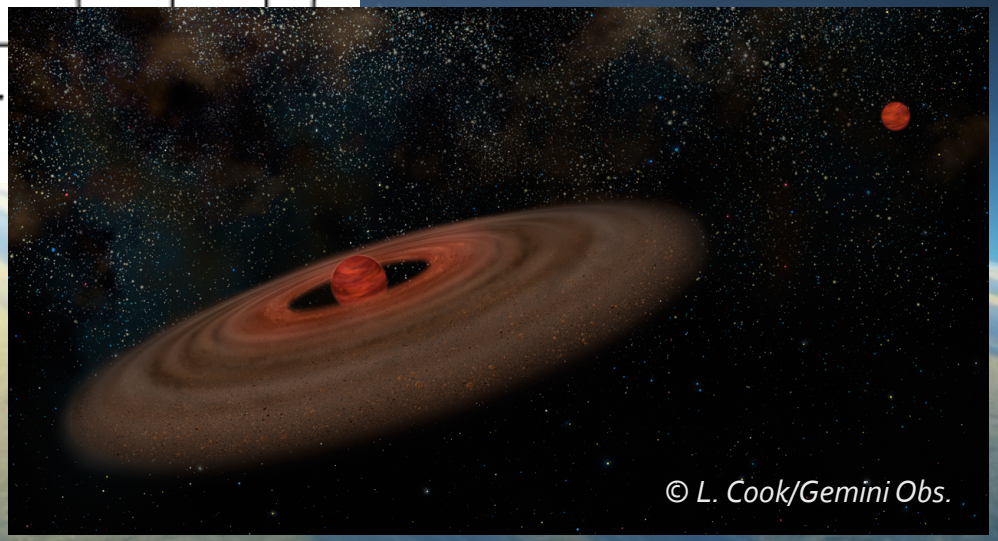
Kepler

A potentially disruptive influence



Artymowicz & Lubow (1994)

The companion truncates the outer parts of the disk



The power of Herschel: M78