NRC·CNRC

Herzberg Institute of Astrophysics

Three planets orbiting the nearby young star HR 8799

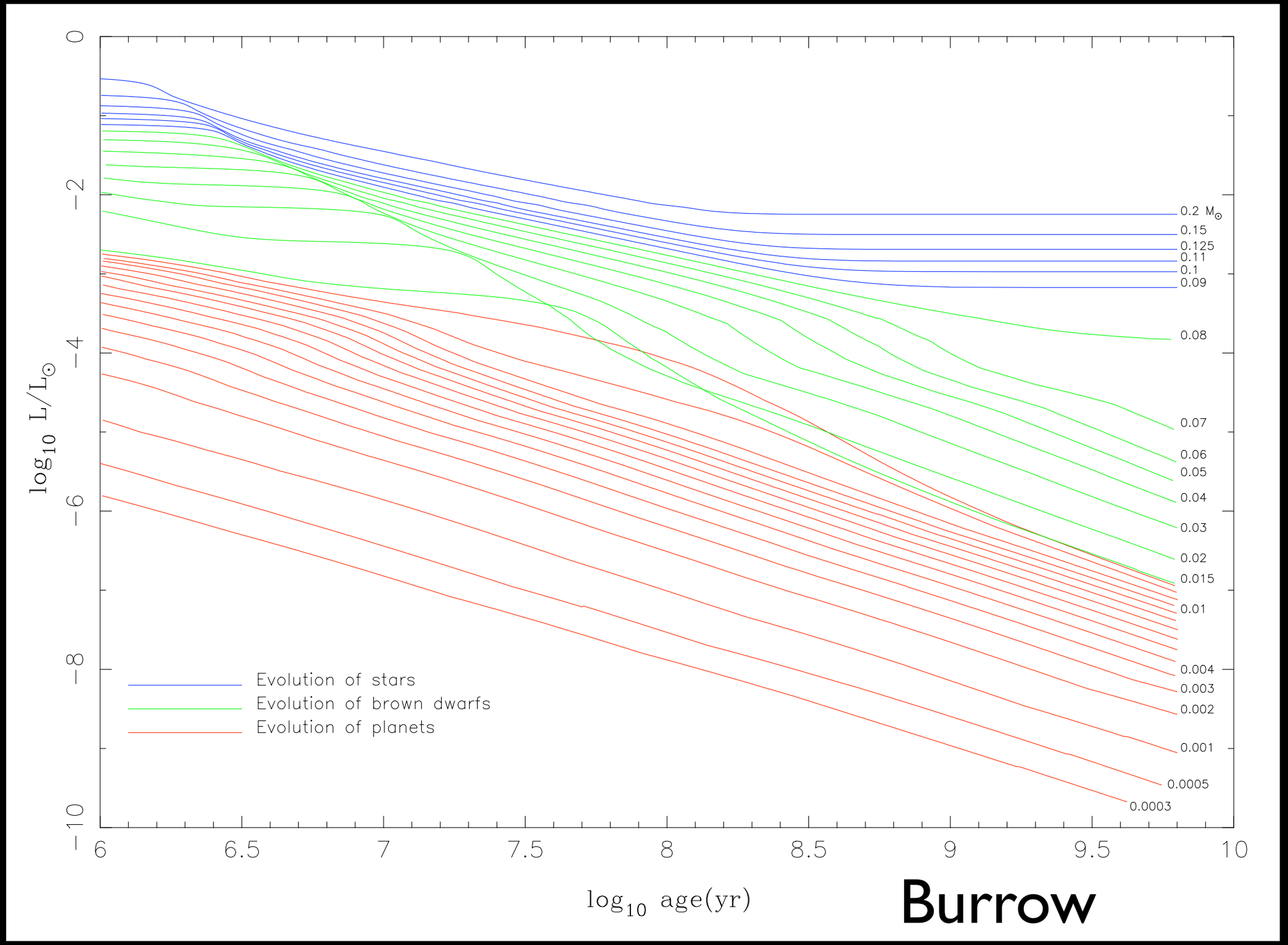
Christian Marois

Herzberg Institute of Astrophysics

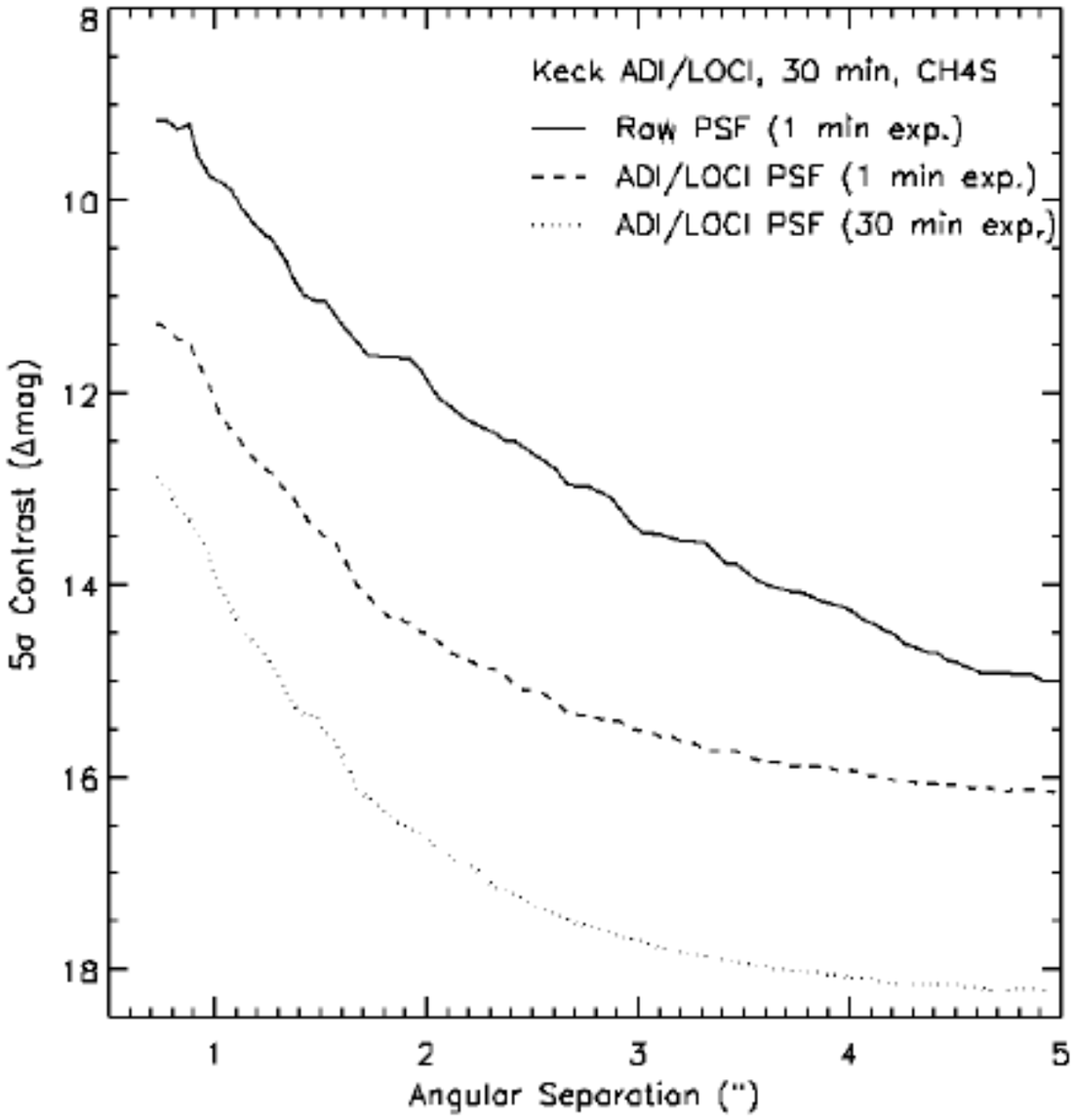
B. Macintosh, T. Barman, B. Zuckerman, I. Song, J. Patience, D. Lafreniere & R. Doyon

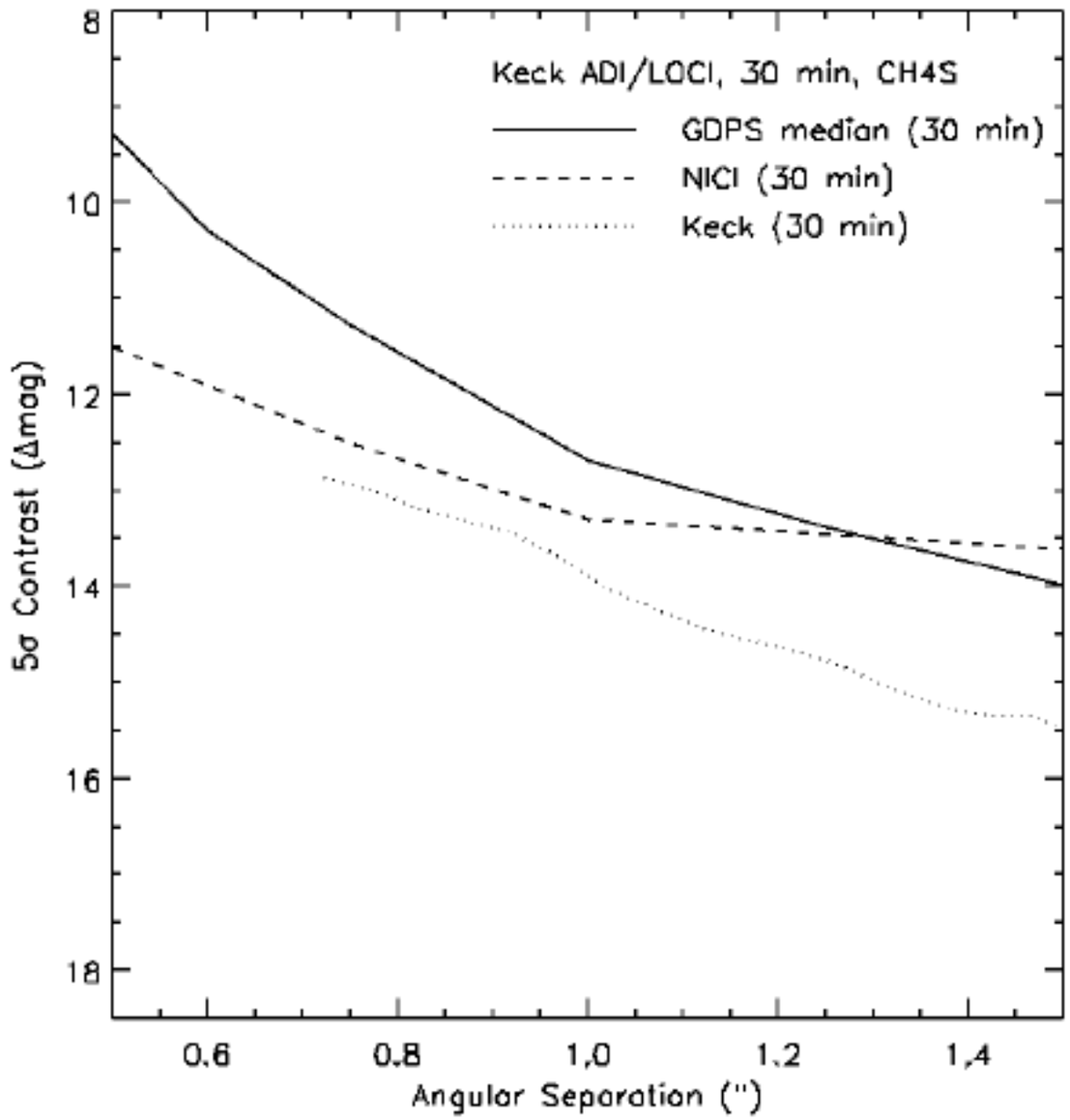
Pasadena AAS, June 2009

Searching for faint objects near bright objects

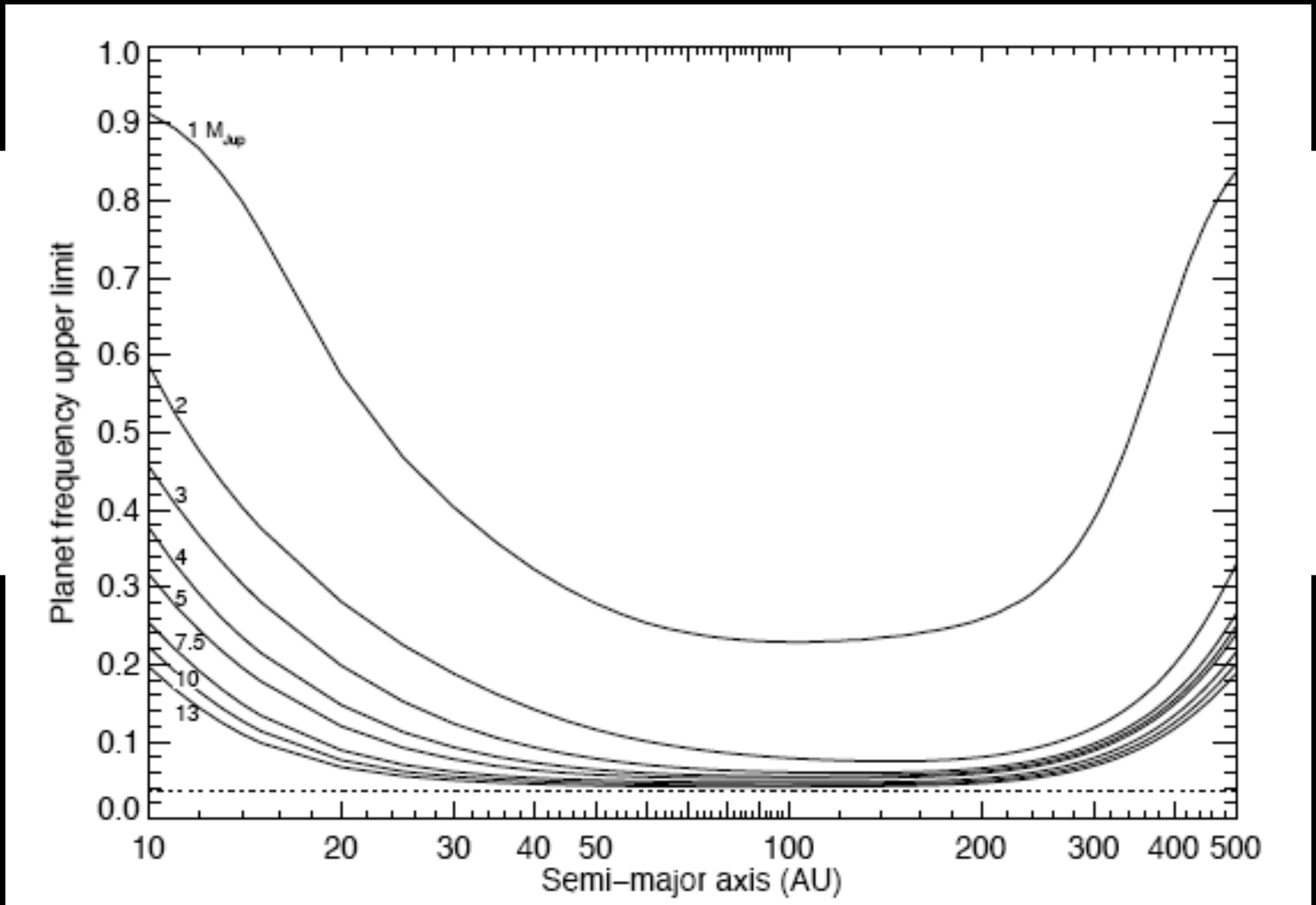


Select young & nearby stars to minimize contrast



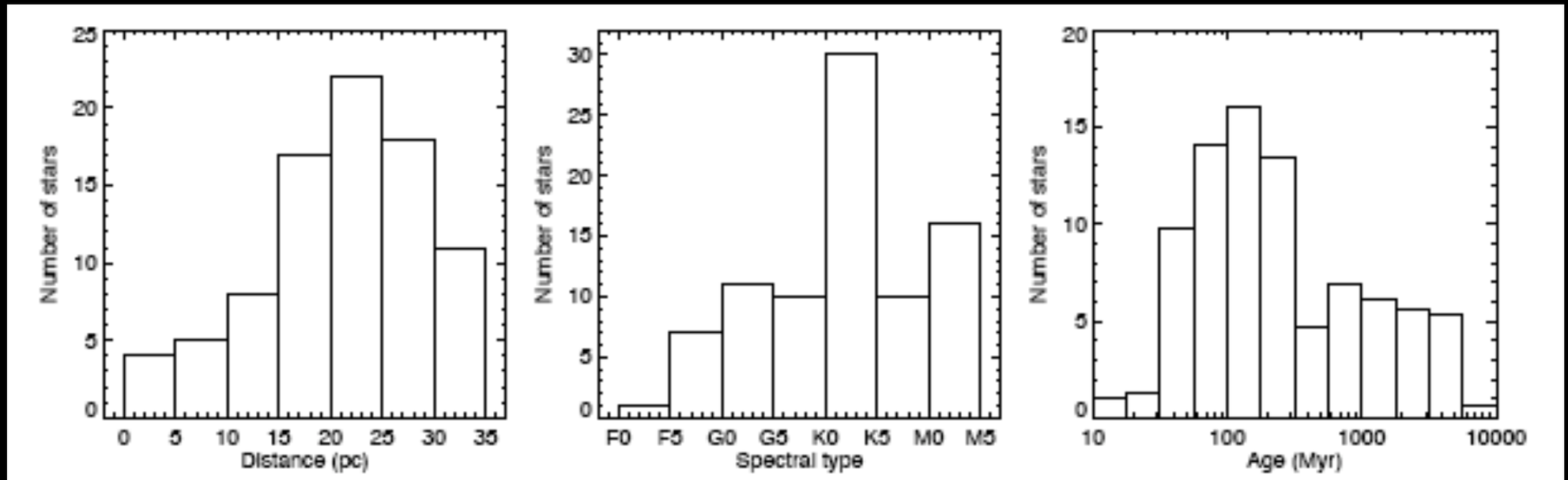


The first ADI Survey



No detection (Lafreniere et al 2007)

The 2nd ADI survey



- Remove "late-type" bias
- Focus an young nearby "massive" stars
- IR excess
- Low in HR diagram

Johnson et al. 2007 RV of evolved A-stars

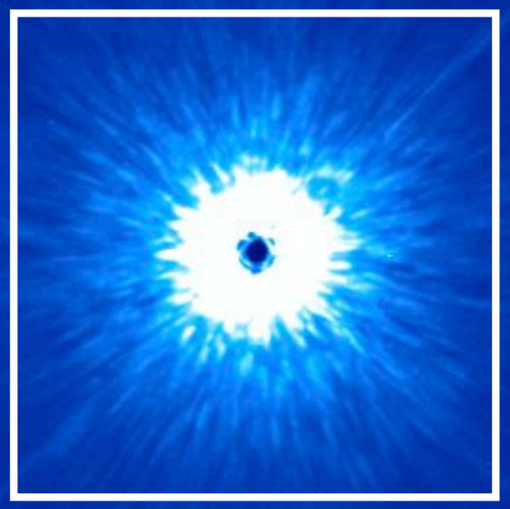
THE 2ND ADI SURVEY

HR 8799 Characteristics

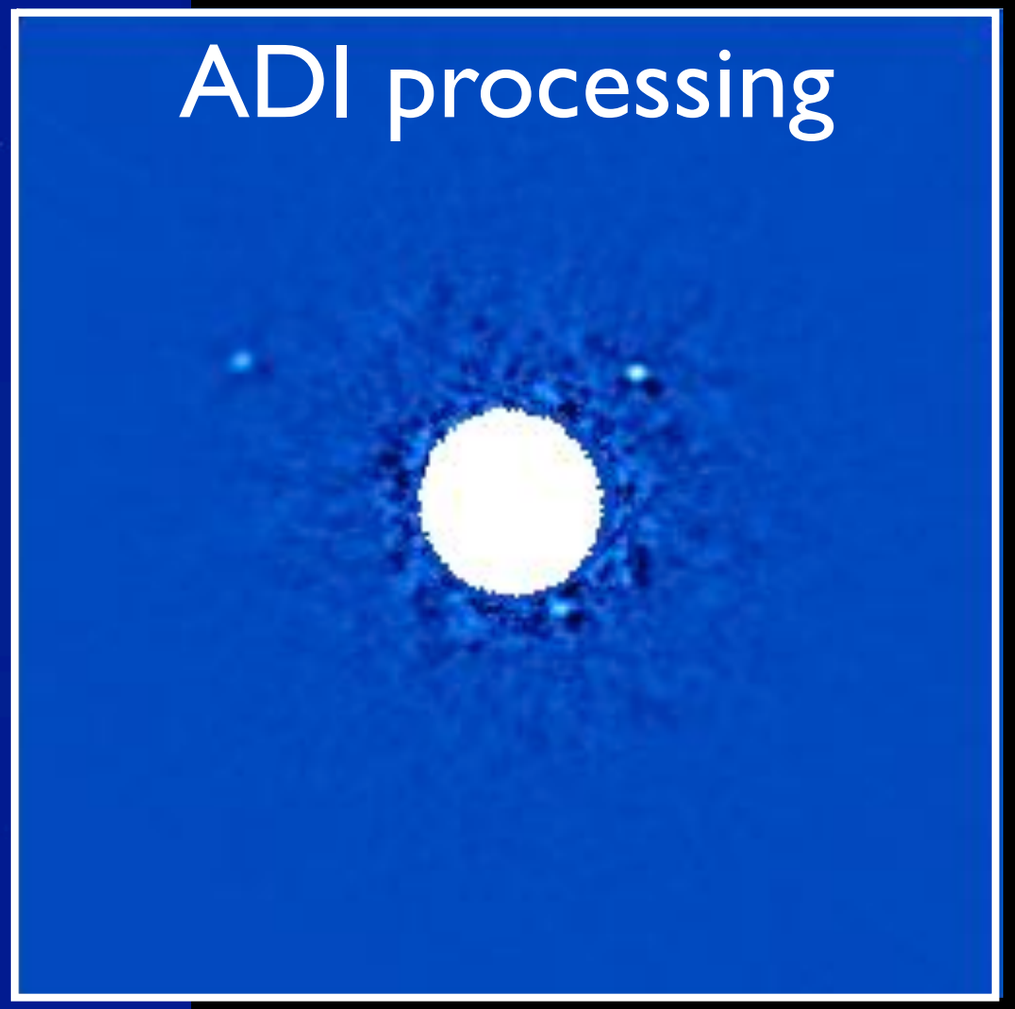
- A5V star
- V~6
- 39 pc (130 ly)
- Pegasus
- Lambda Boo, Gamma Dor and Vega-like star

Discovery made with Gemini North with Altair/Niri

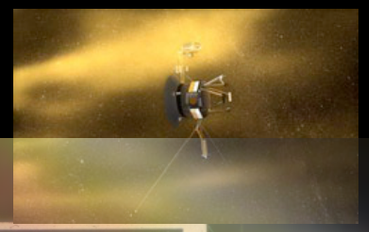
Gemini N, Altair/NIRI &10s K-band

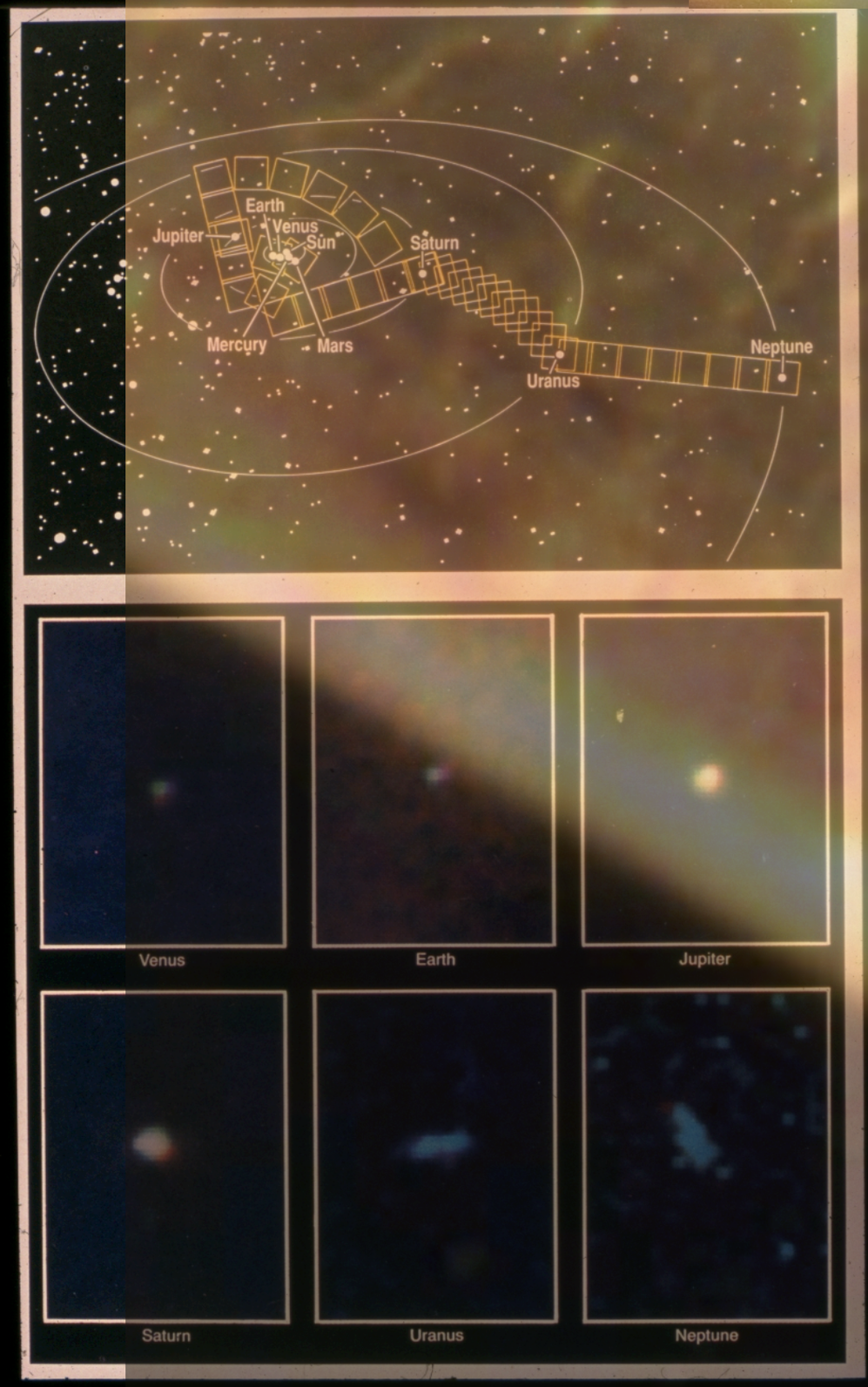


ADI processing

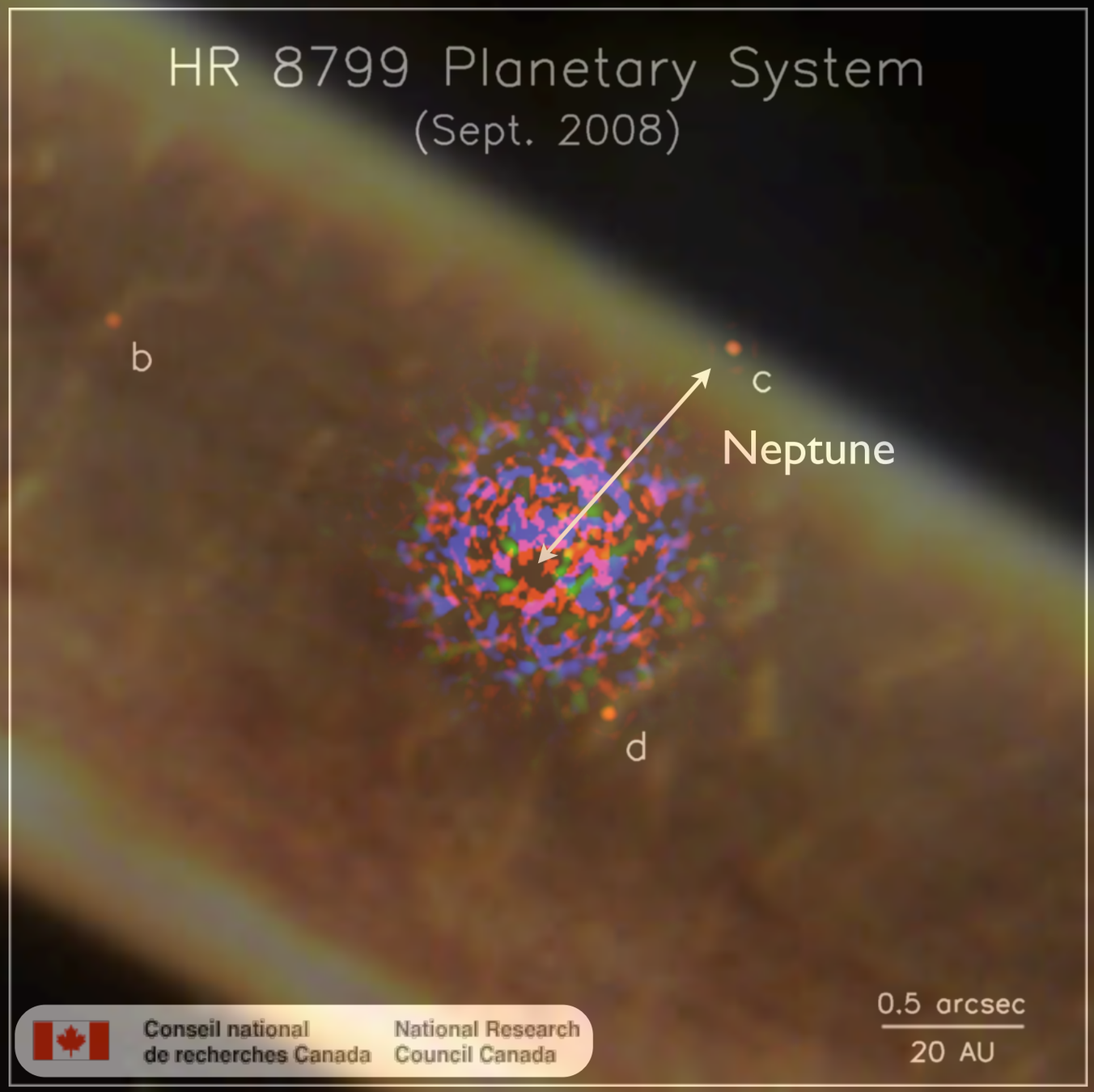


Voyager 1 (43 AU)
18 cm diameter





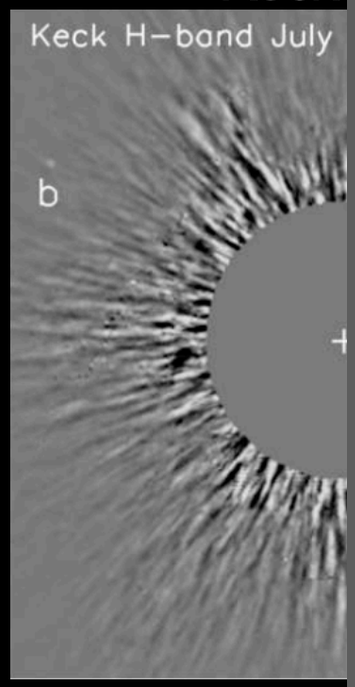
Keck 2 (130 ly), 10m diameter



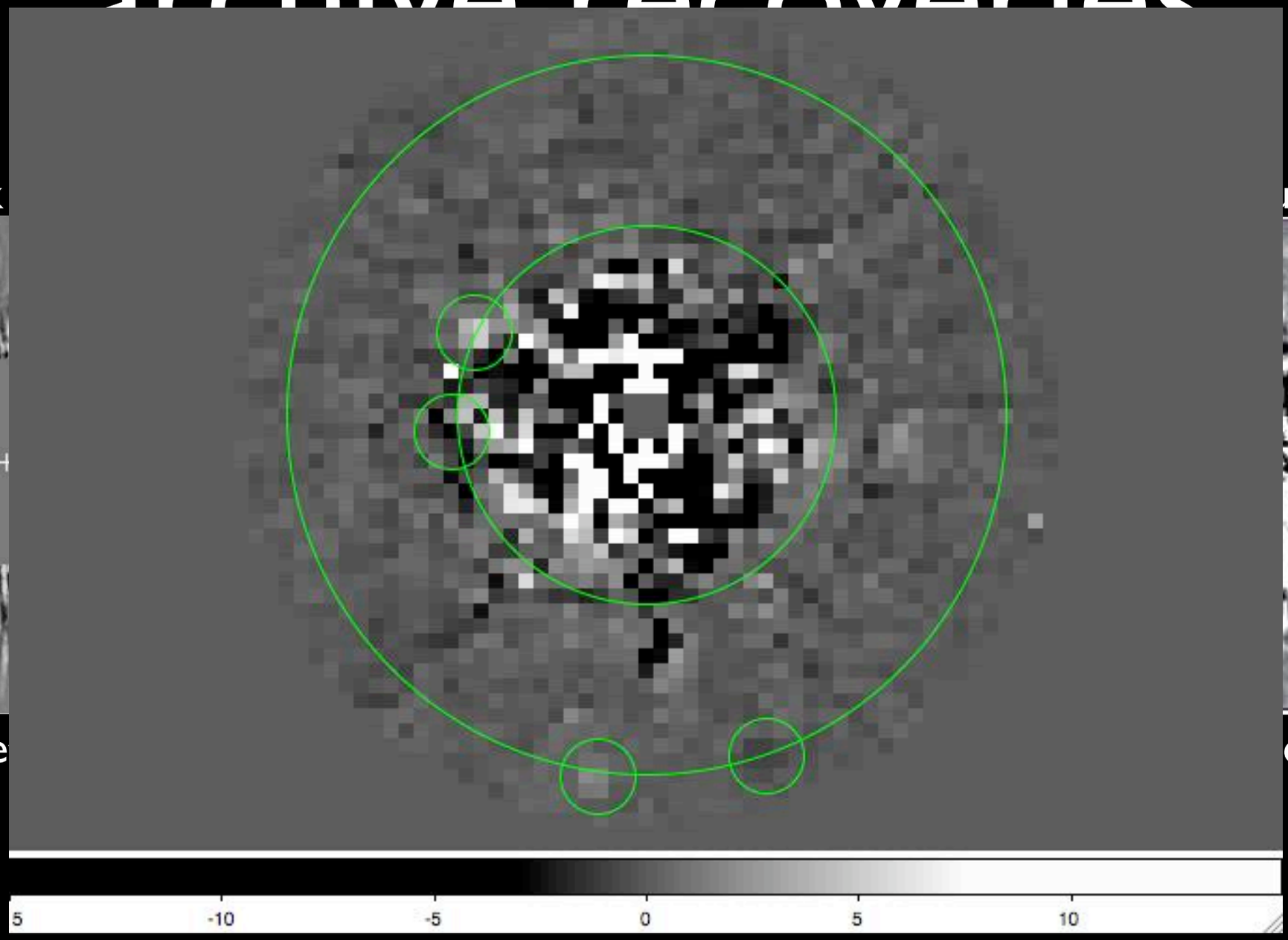
8 200 000 AU

A bunch of “archive recoveries”

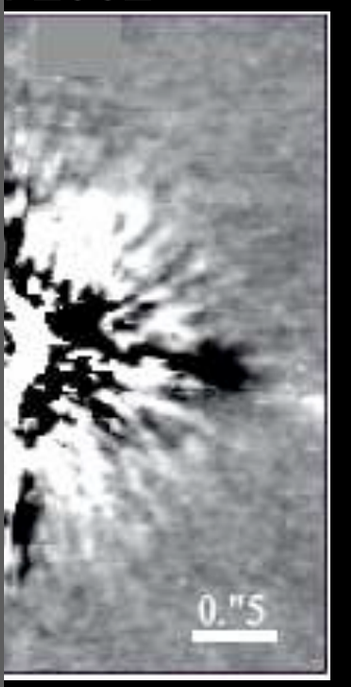
Keck



Marois e



u 2002

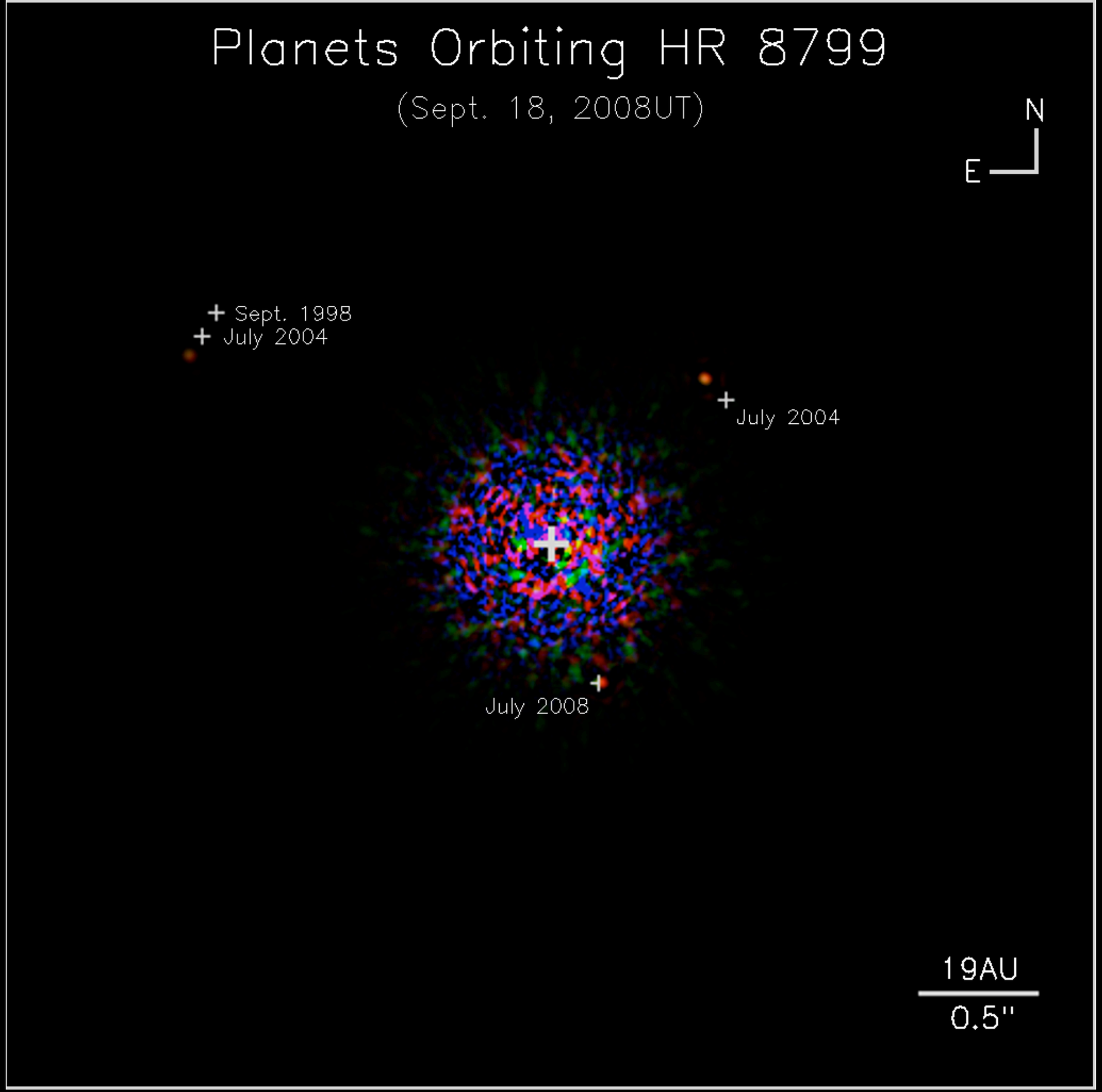


et al 2009

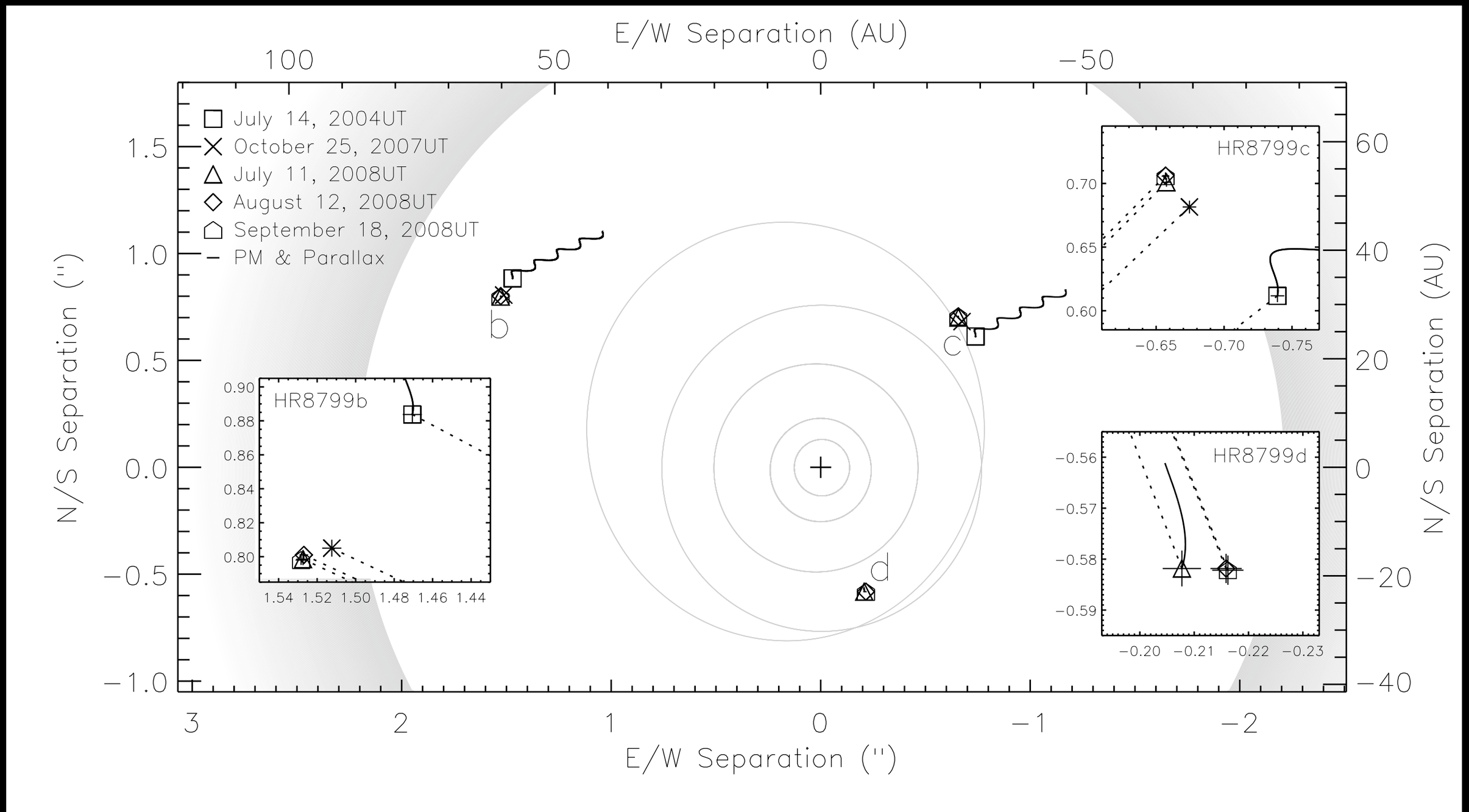
2 others in prep.

Planets Orbiting HR 8799

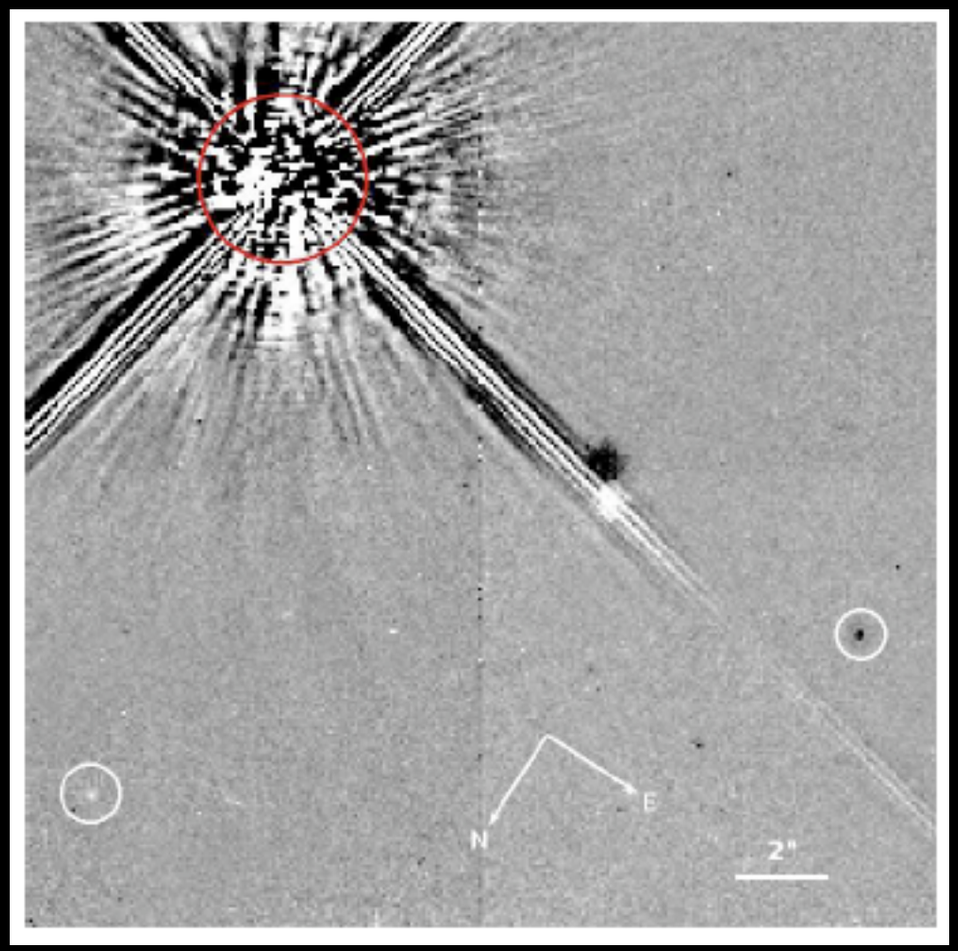
(Sept. 18, 2008UT)



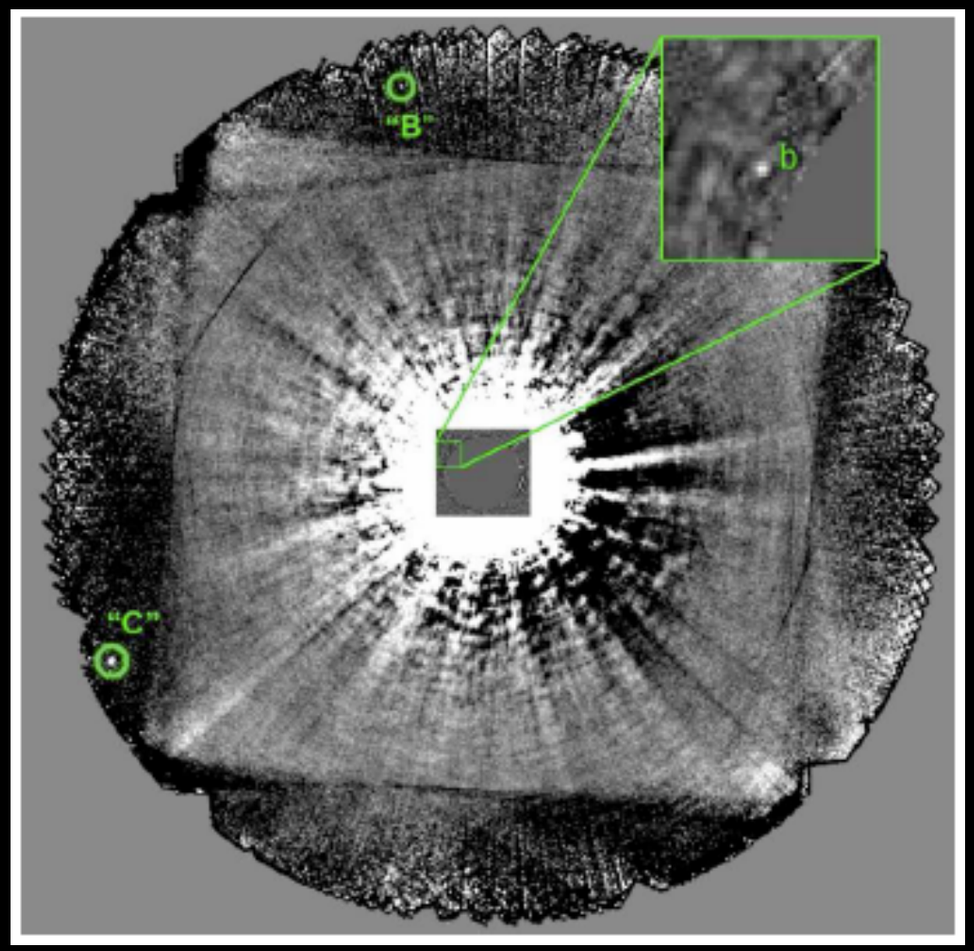
Conseil national de recherches Canada
National Research Council Canada


E/W Separation (AU)
100
50
0
−50
July 14, 2004UT
October 25, 2007UT
July 11, 2008UT
August 12, 2008UT
September 18, 2008UT
PM & Parallax
b
c
d
HR8799b
HR8799c
HR8799d
1.5
1.0
0.5
0.0
−0.5
−1.0
60
40
20
0
−20
−40
3
2
1
0
−2
E/W Separation (")
N/S Separation (")
N/S Separation (AU)

A search for a wide companion

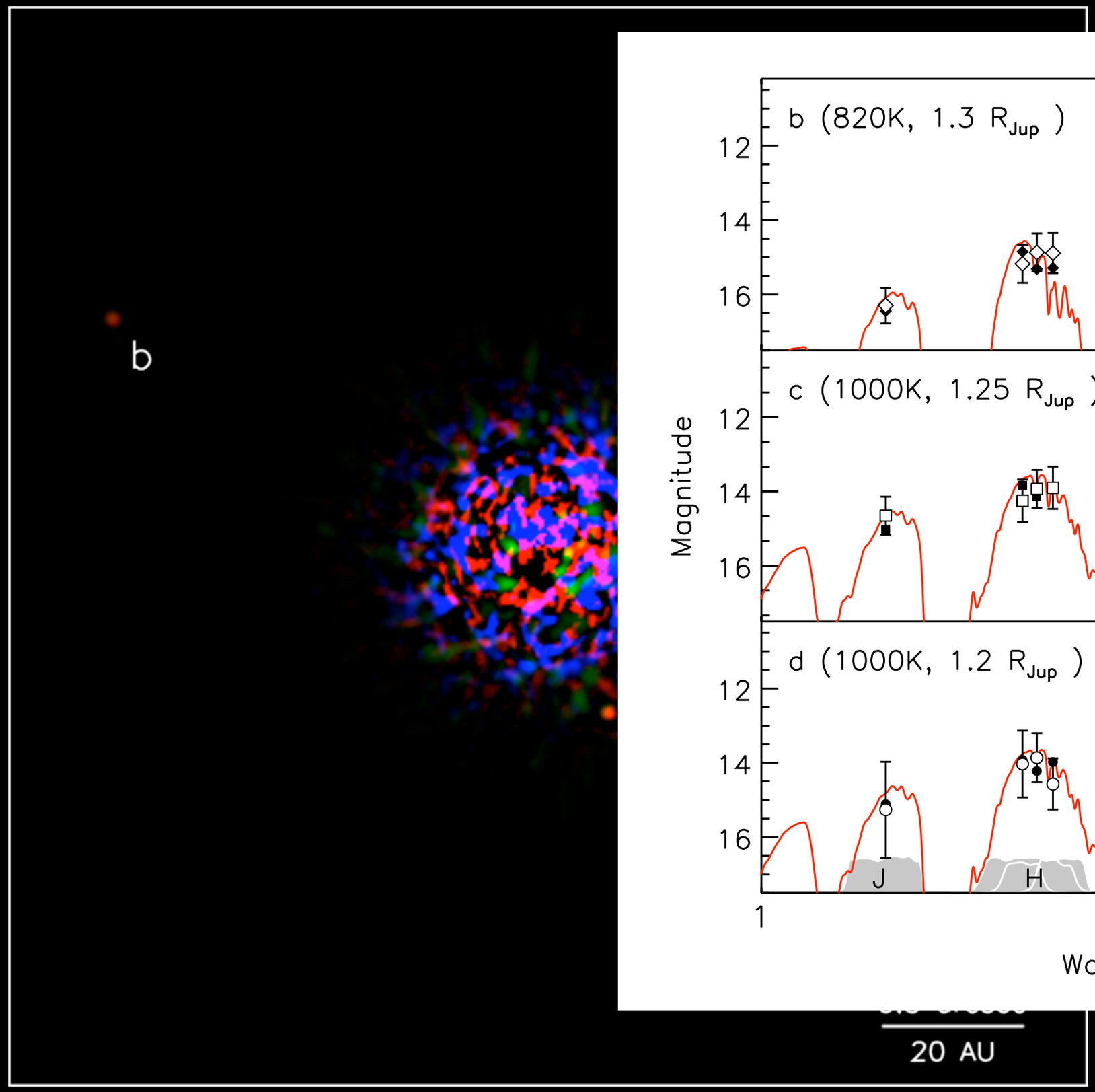


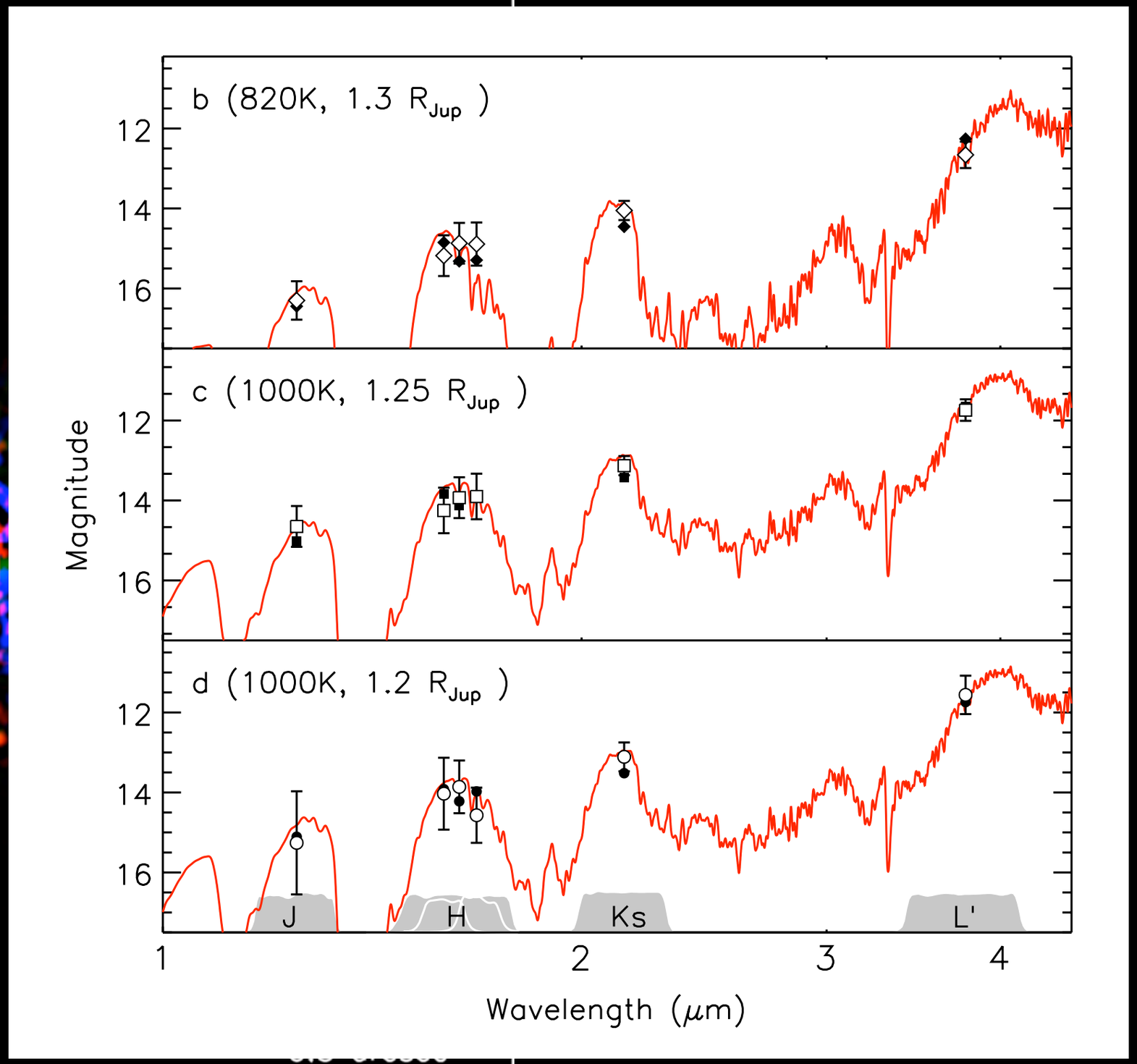
Lowrance et al. 2005



Close & Males 2009

Multi-band photometry @ Keck

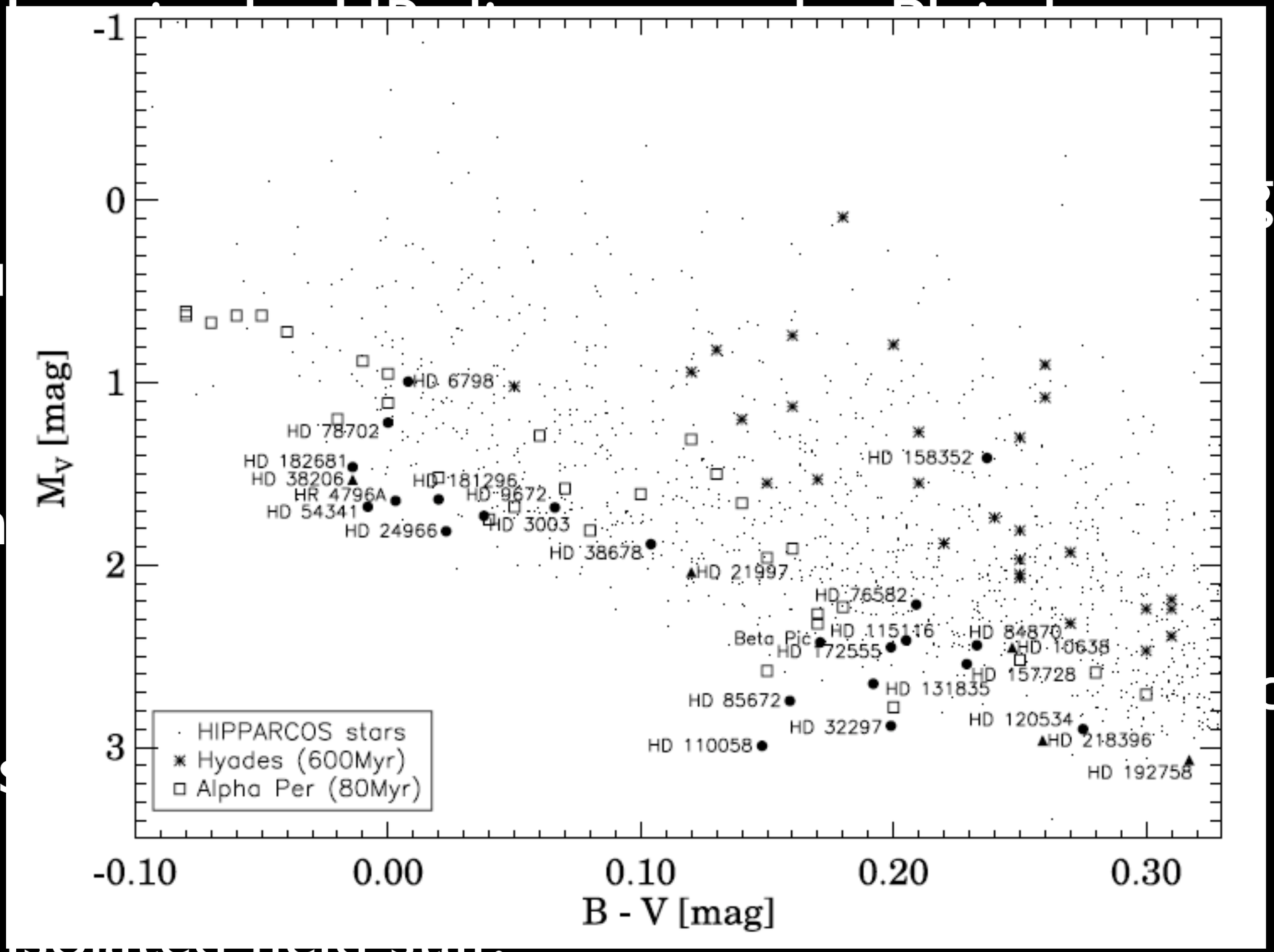




HR 8799 age?

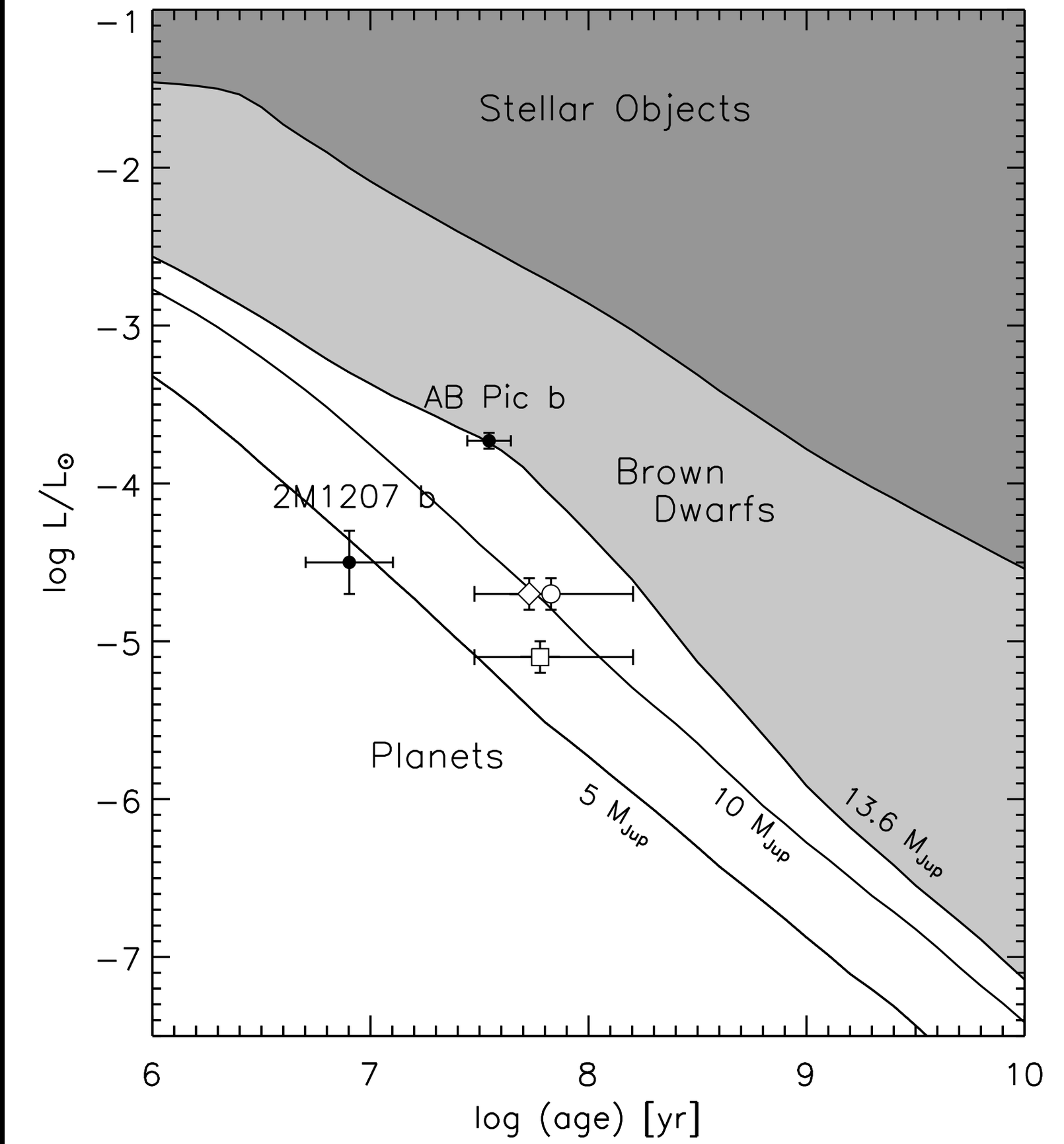
HR 8799 Age Estimation

- [illegible]
- [illegible]
- you[illegible]
- con[illegible]
- [illegible]der
- ages[illegible]
- isolated field star.



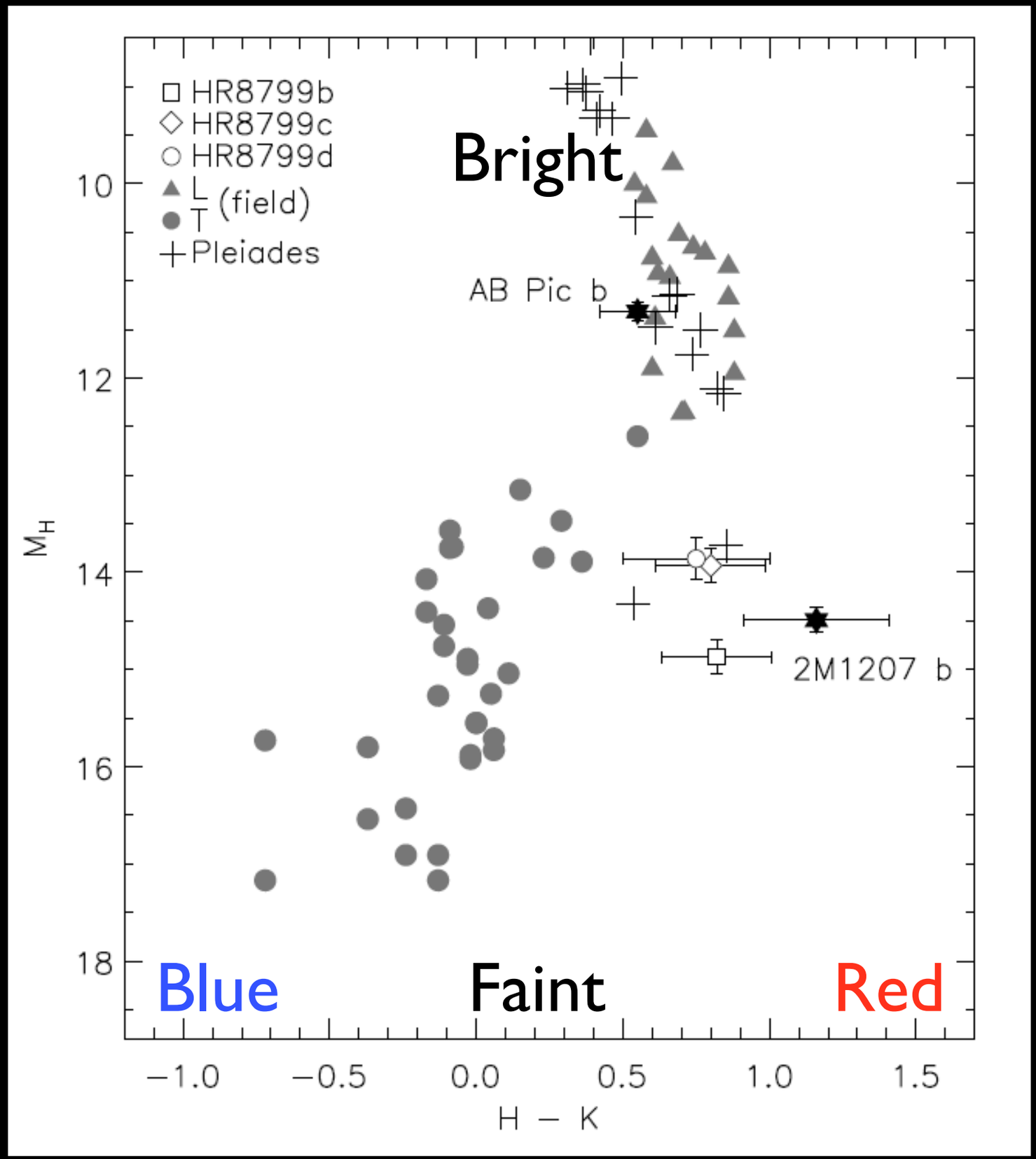
HR 8799 age = 30-160 Myr

Mass, radius & Teff estimations from cooling tracks



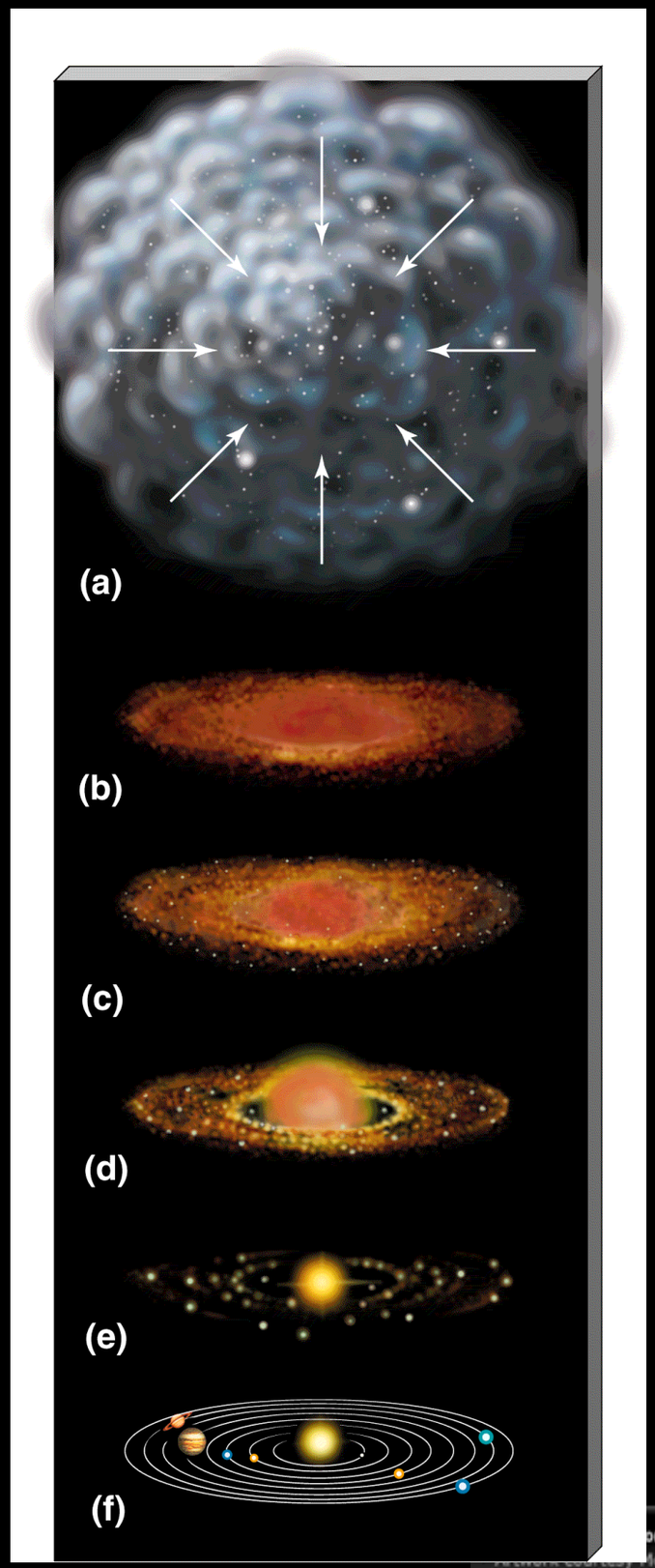
The 3 planet's colors are more consistent with Pleiades low mass ~11MJup objects and 2M1207b than field BDs.

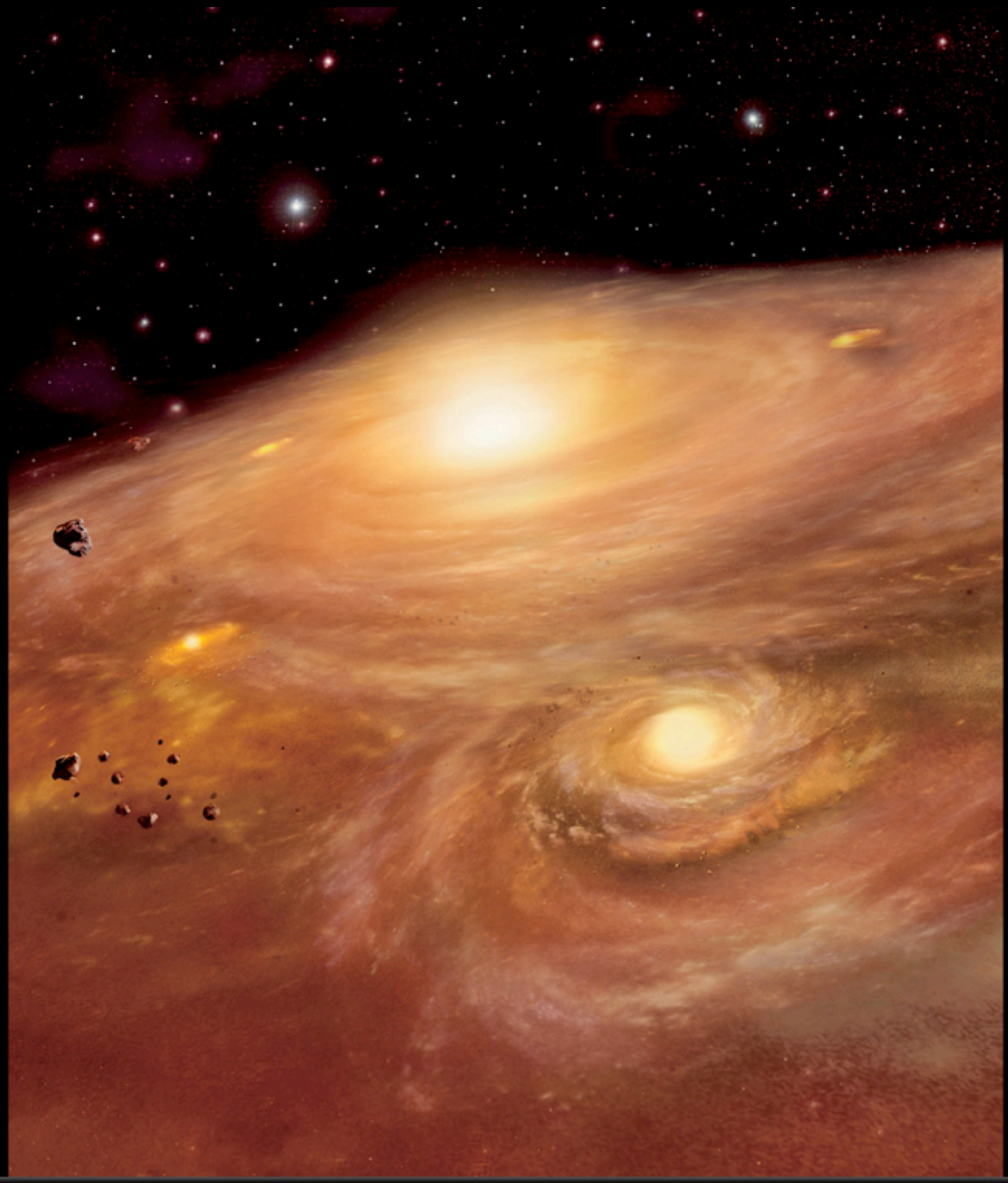
Physics untested - No corresponding objects in the field.



Planetary System Formation

Solar system



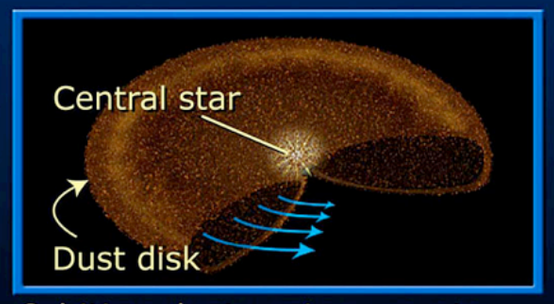


one theory of how gas-giant planets form

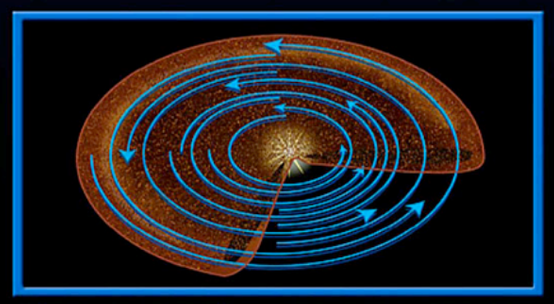
Moonrunner Design

Two Planet Formation Scenarios

Accretion model

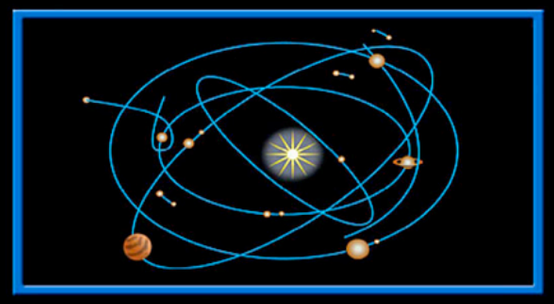


Orbiting dust grains accrete into "planetesimals" through nongravitational forces.



Planetesimals grow, moving in near-coplanar orbits, to form "planetary embryos."

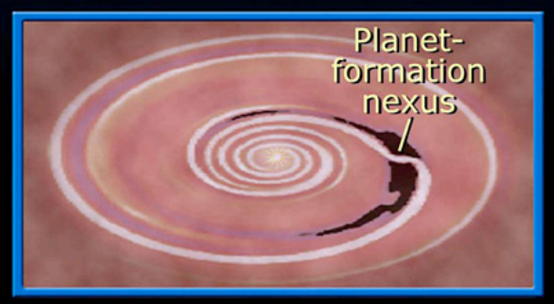
Gas-giant planets accrete gas envelopes before disk gas disappears.



Gas-giant planets scatter or accrete remaining planetesimals and embryos.

Gas-collapse model

A protoplanetary disk of gas and dust forms around a young star.



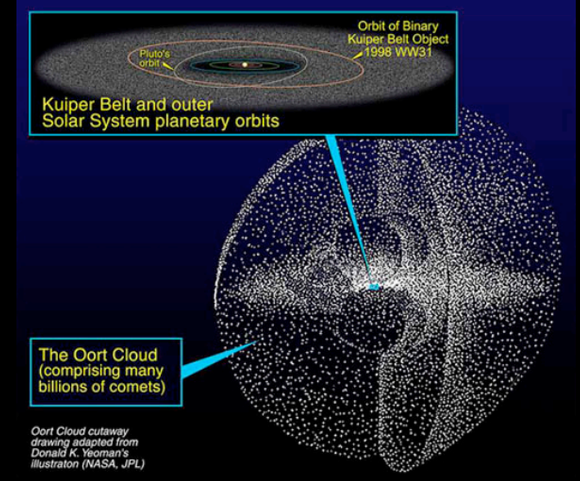
Gravitational disk instabilities form a clump of gas that becomes a self-gravitating planet.

Dust grains coagulate and sediment to the center of the protoplanet, forming a core.

The planet sweeps out a wide gap as it continues to feed on gas in the disk.

Solar system formation leftover vs HR 8799

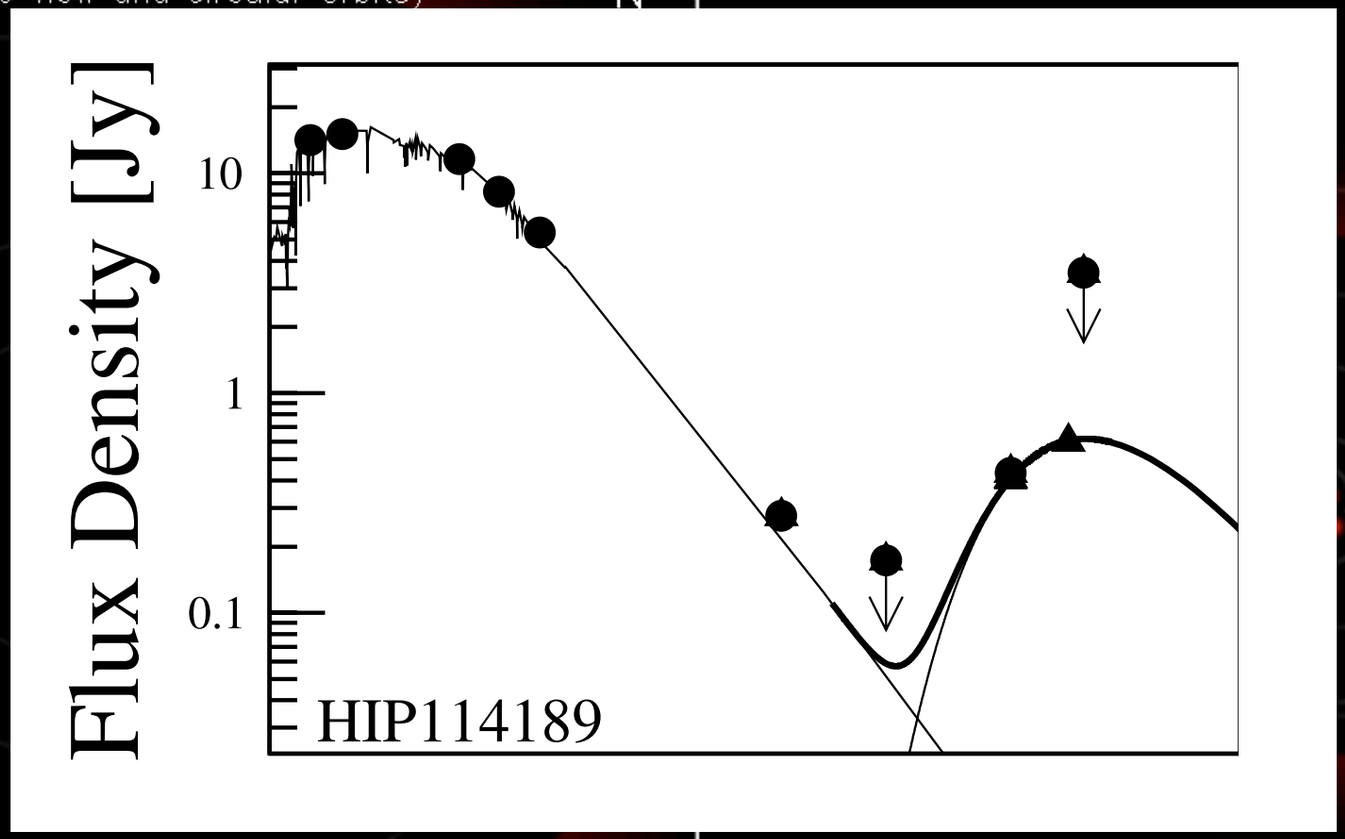
Spitzer IR excess, dust at ~10 AU (asteroid belt?) Chen et al. 2006
IRAS/ISO IR excess, dust at ~100 AU (Kuiper belt?) Rhee et al. 2007
Spitzer resolve dust emission, dust at ~1000 AU (Oort cloud?) Lu et al.



HR 8799 Planetary System

(assuming a pole view and circular orbits)

N



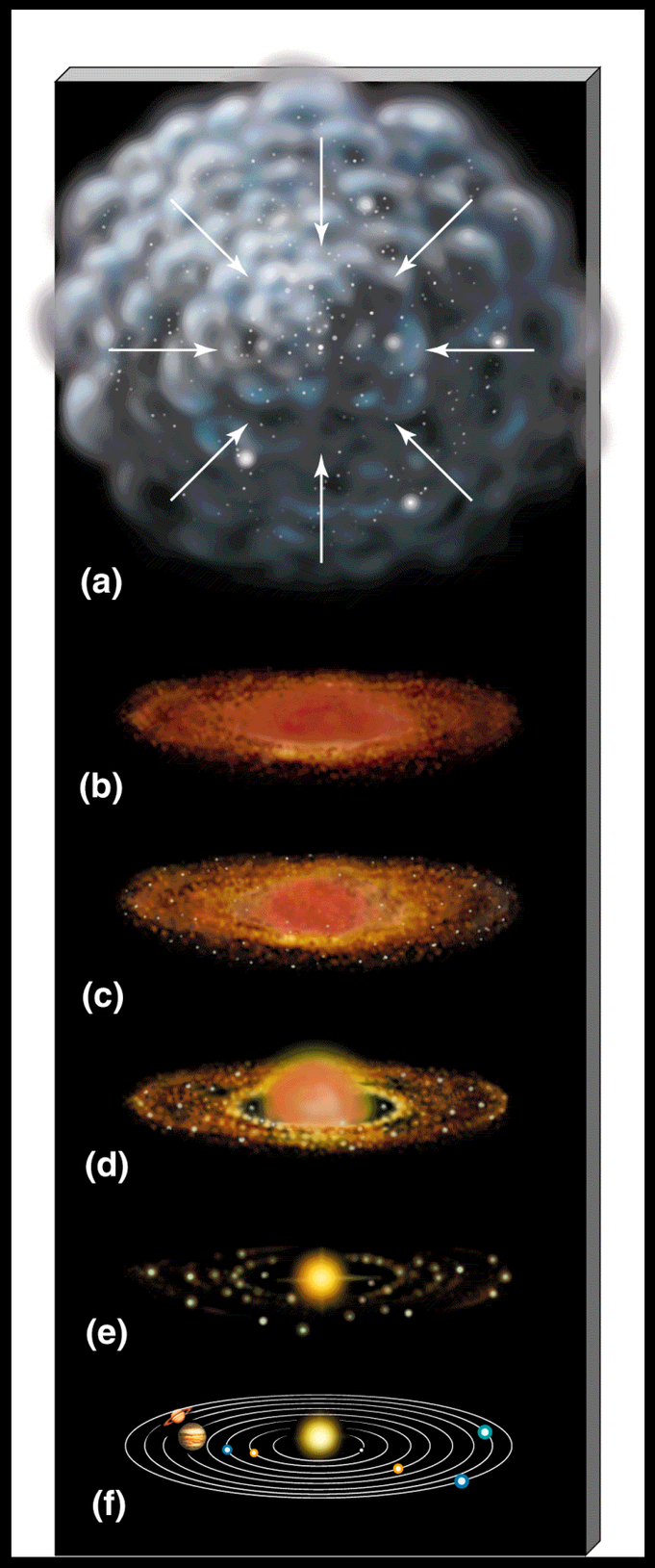
20 AU

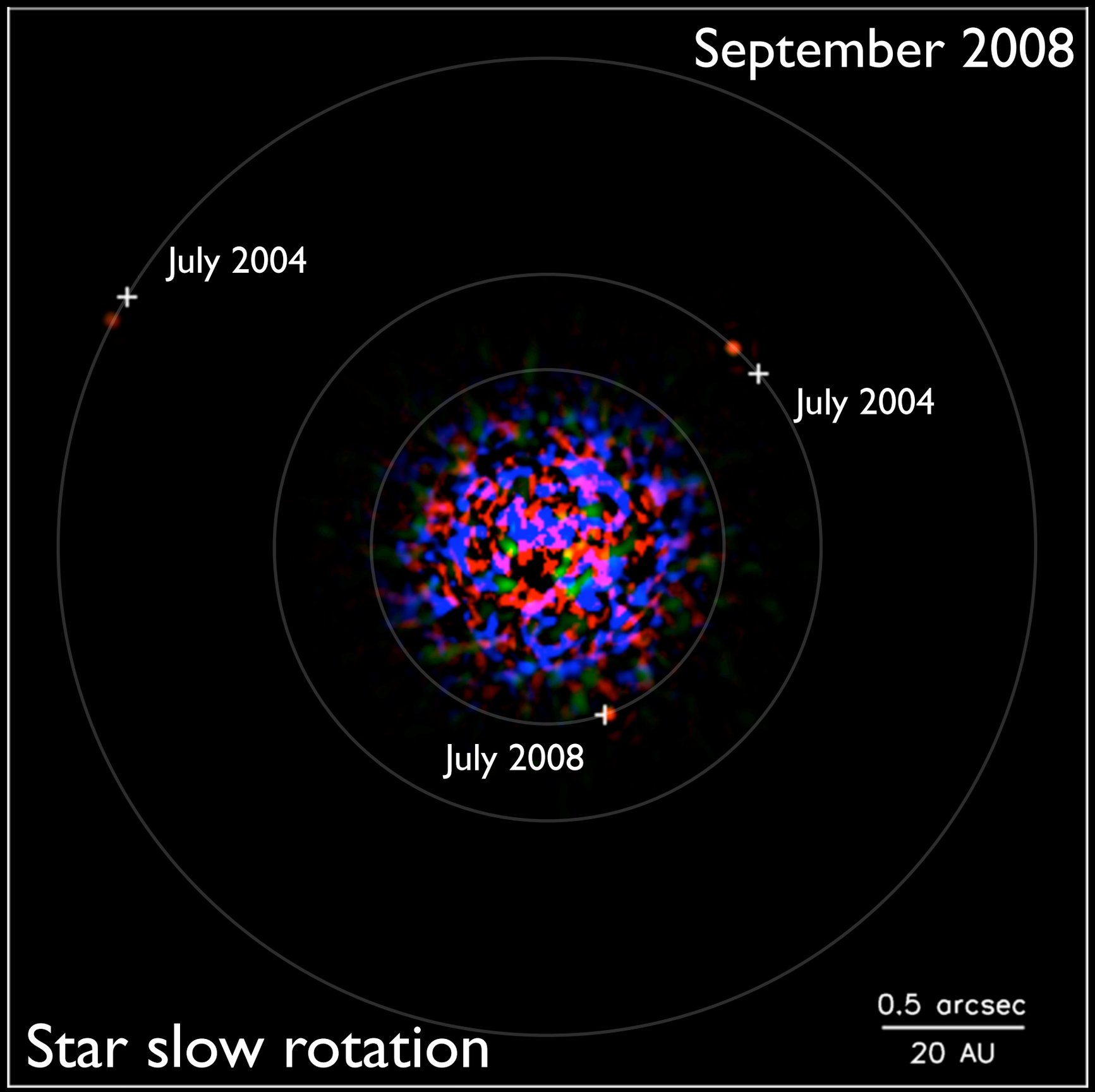
0.5 arcsec

Solar System

20 AU

HR 8799 planetary system probably formed in a disk





Star slow rotation

HR 8799bcd Characteristics

HR 8799	Separation (AU)	Period (years)	Temperature (K)	Radius (RJup)	Mass (MJup)
b	68	~460	820	1.30	7
c	38	~190	1000	1.25	10
d	25	~100	1000	1.20	10

Circular face-on

60 Myr

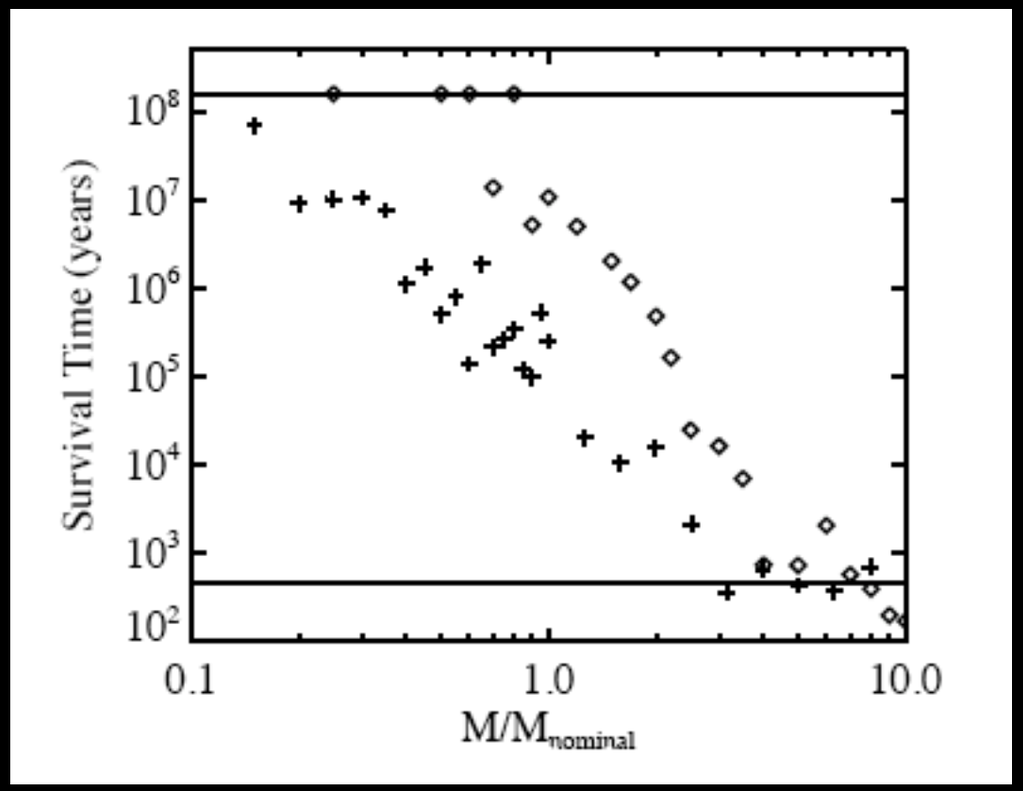
HR 8799bcd vs Radial Velocities

- Previous ADI GKM survey = NO DETECTION
- ~335 exoplanets known, 309 by RV - limited to ~5 AU.
- RV: 31 multi-planet systems, only 10 >= 3 planets (only ~3%)
- Planets are probably more likely around more massive stars.
- Multi-planet systems are also probably more likely at wide separations.

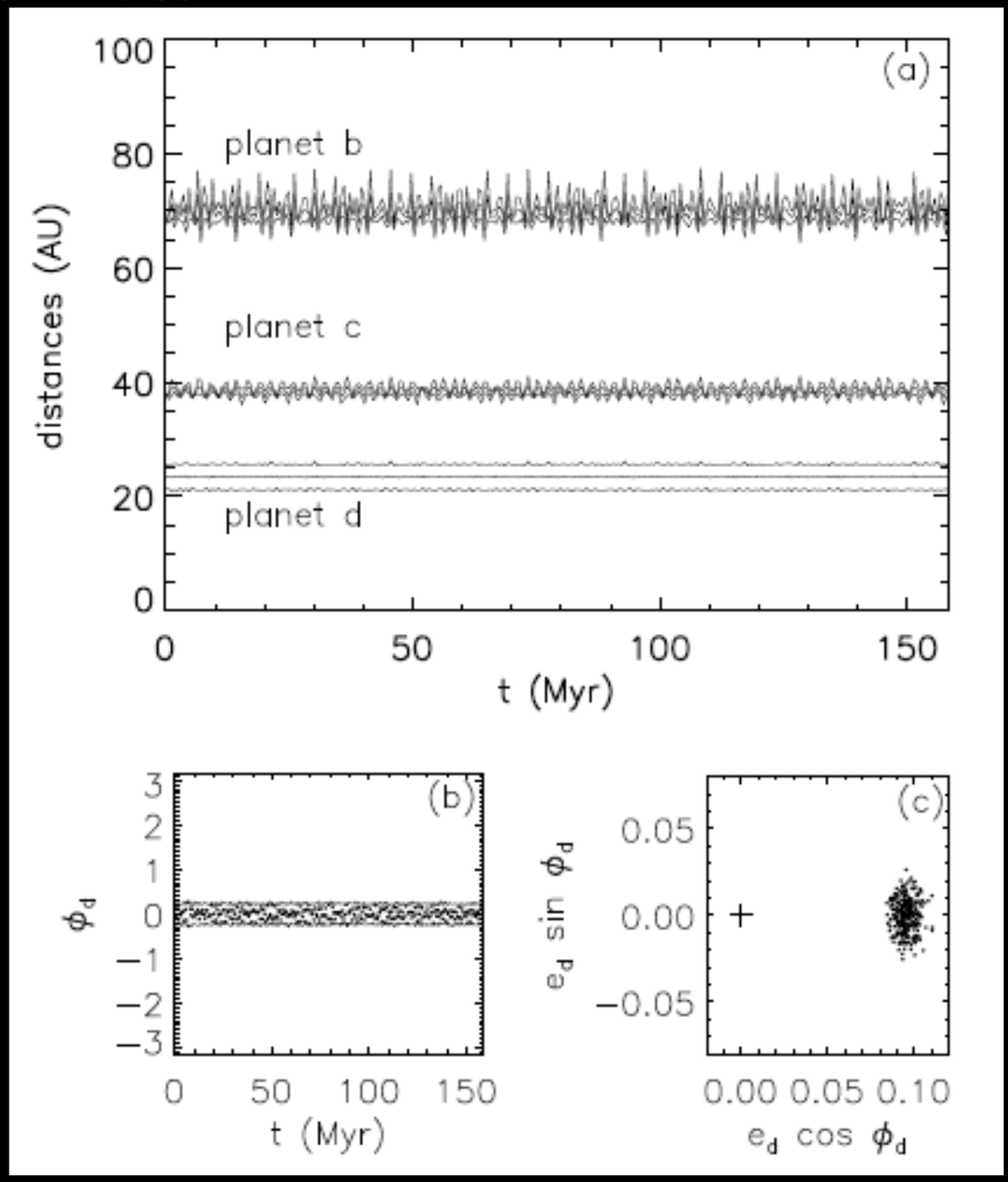
Dynamic Analysis

Fabrycky & Murray-Clay 2009

- Not perfectly face-on & not perfectly circular
- Non-resonance cases = masses need to be lower (< 2Mjup)
- 2:1 resonance for c & d: some cases stable for age
- 4:2:1 resonance: stable up to ~20 MJup & 60 Myr.



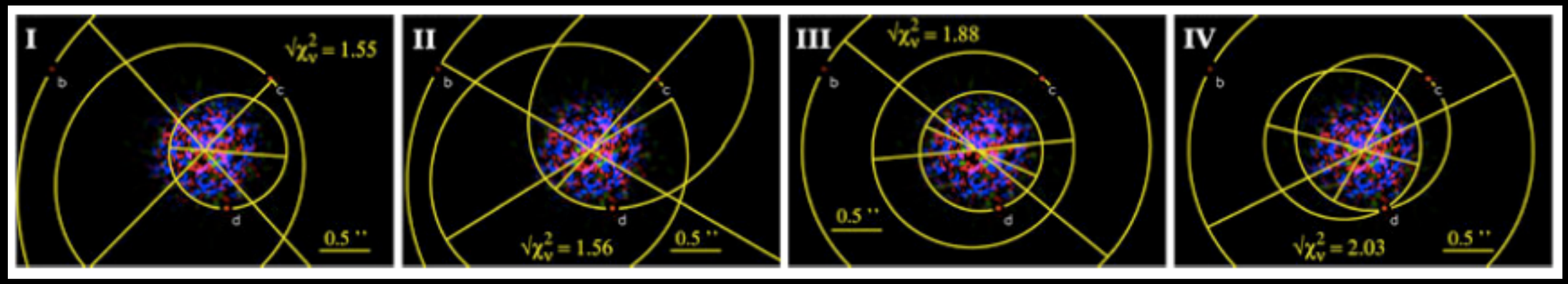
4:2:1 resonance



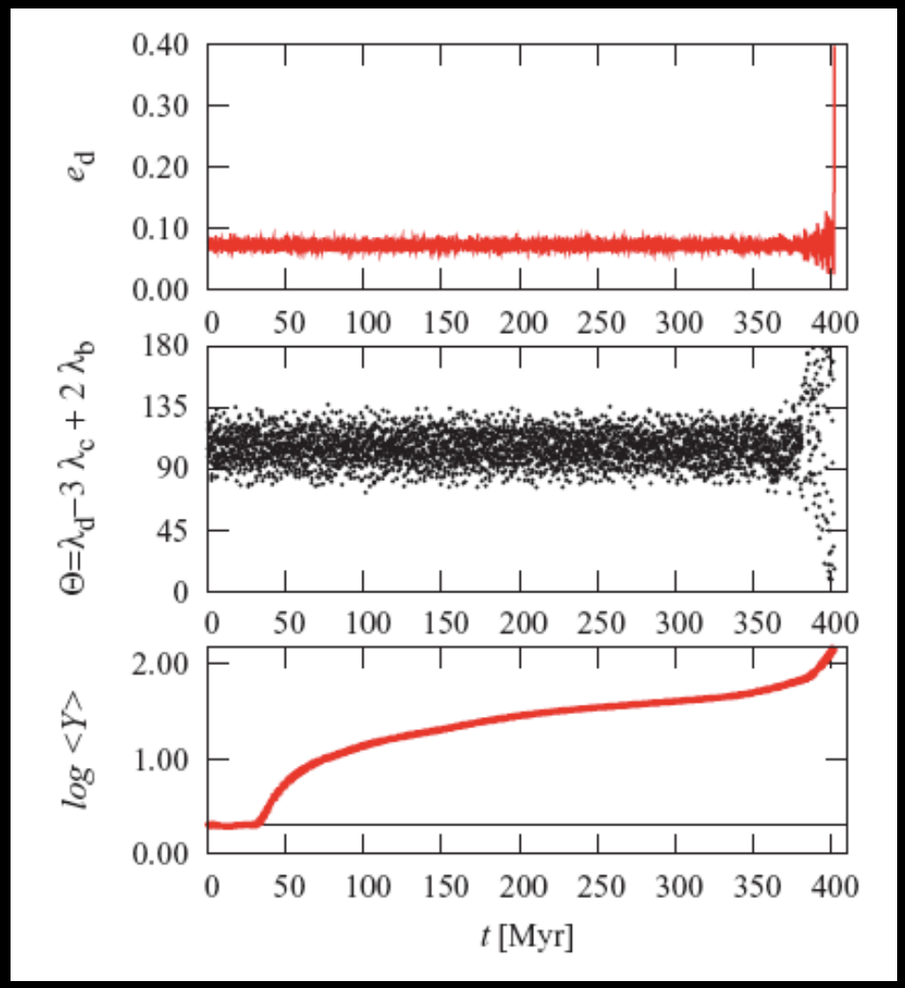
Younger age / model over predict mass / 4:2:1 resonance

Dynamic Analysis

Gozdziewski & Migaszewski 2009



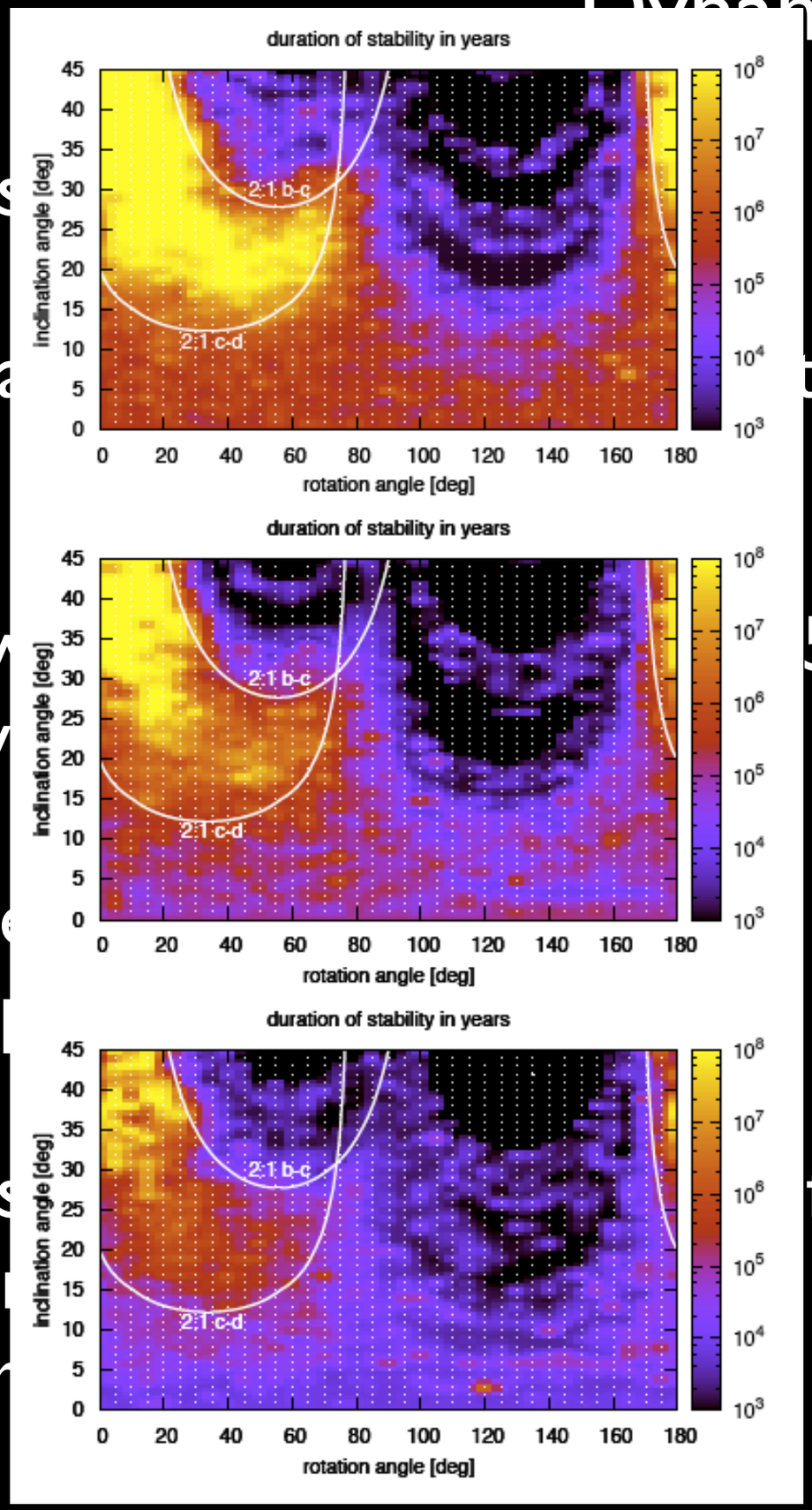
- Heavy mutual interactions
- Most likely 1:2:4 resonance
- Lower masses?
- 1:2:4 system may be unstable in a few 100 Myr.

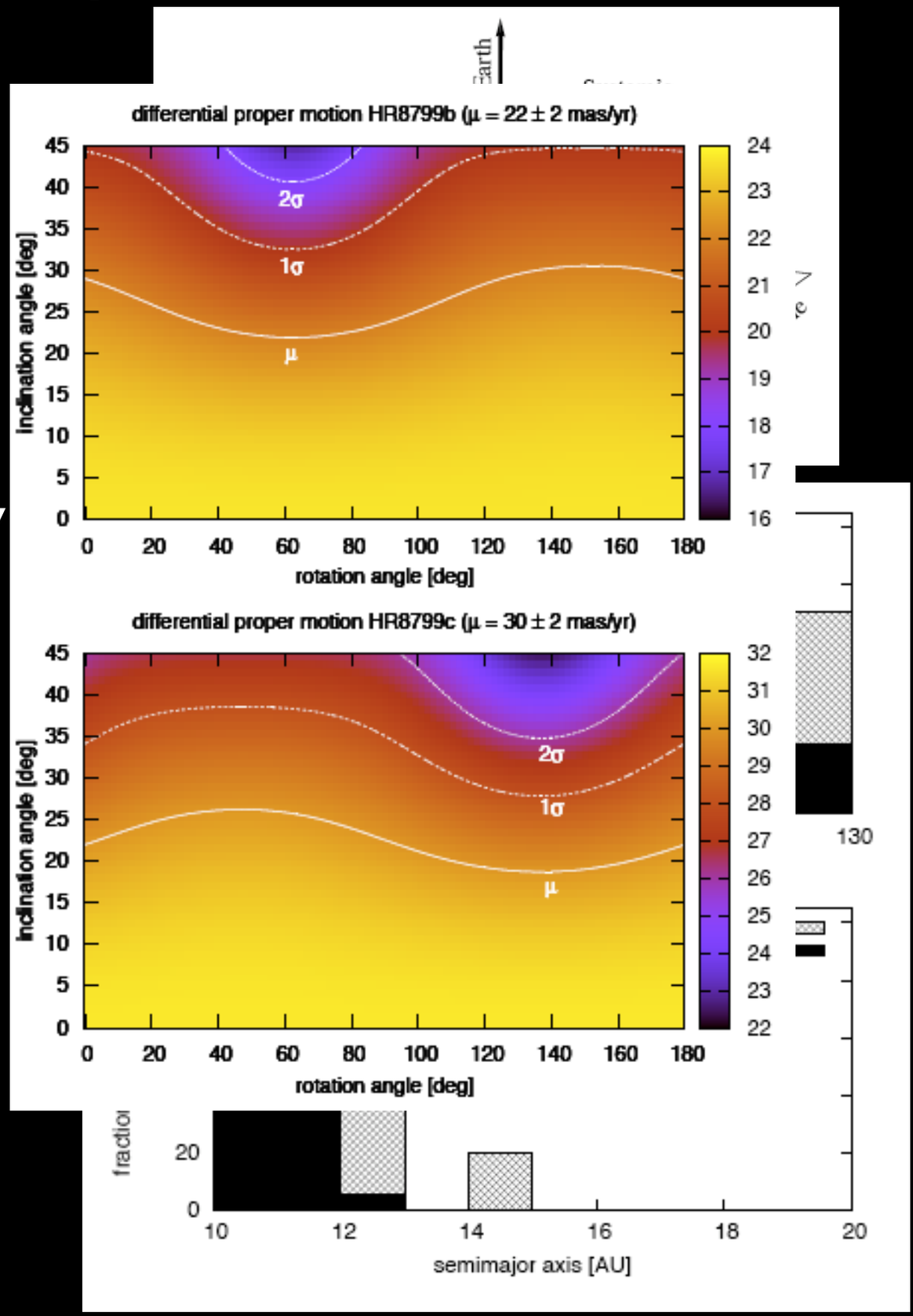


Dynamic Analysis

Reidemeister et al. 2009

- Dus
- Nea ts
- Low 50 My low
- Aste Kuip
- Dus for planet measur by IR



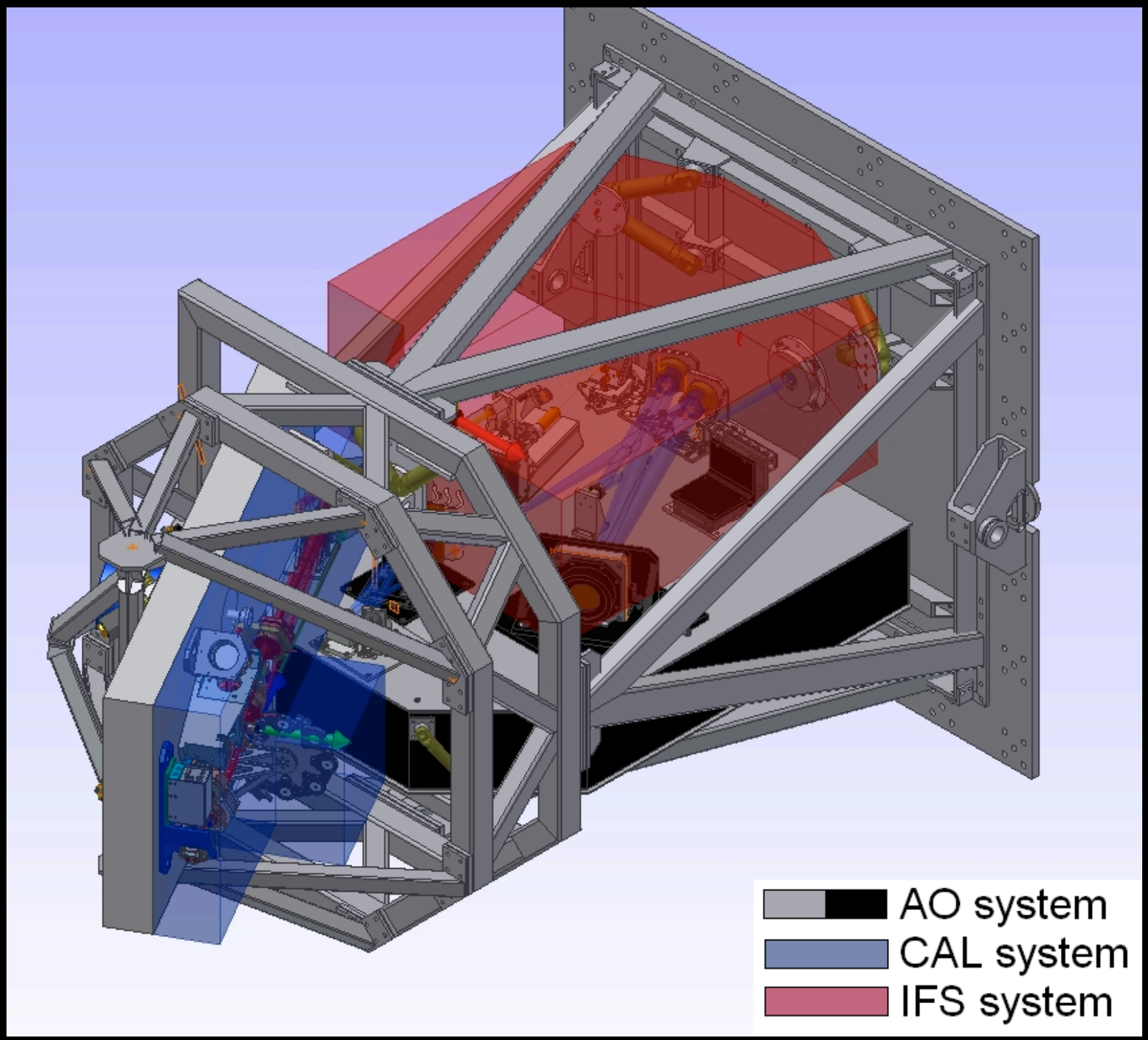


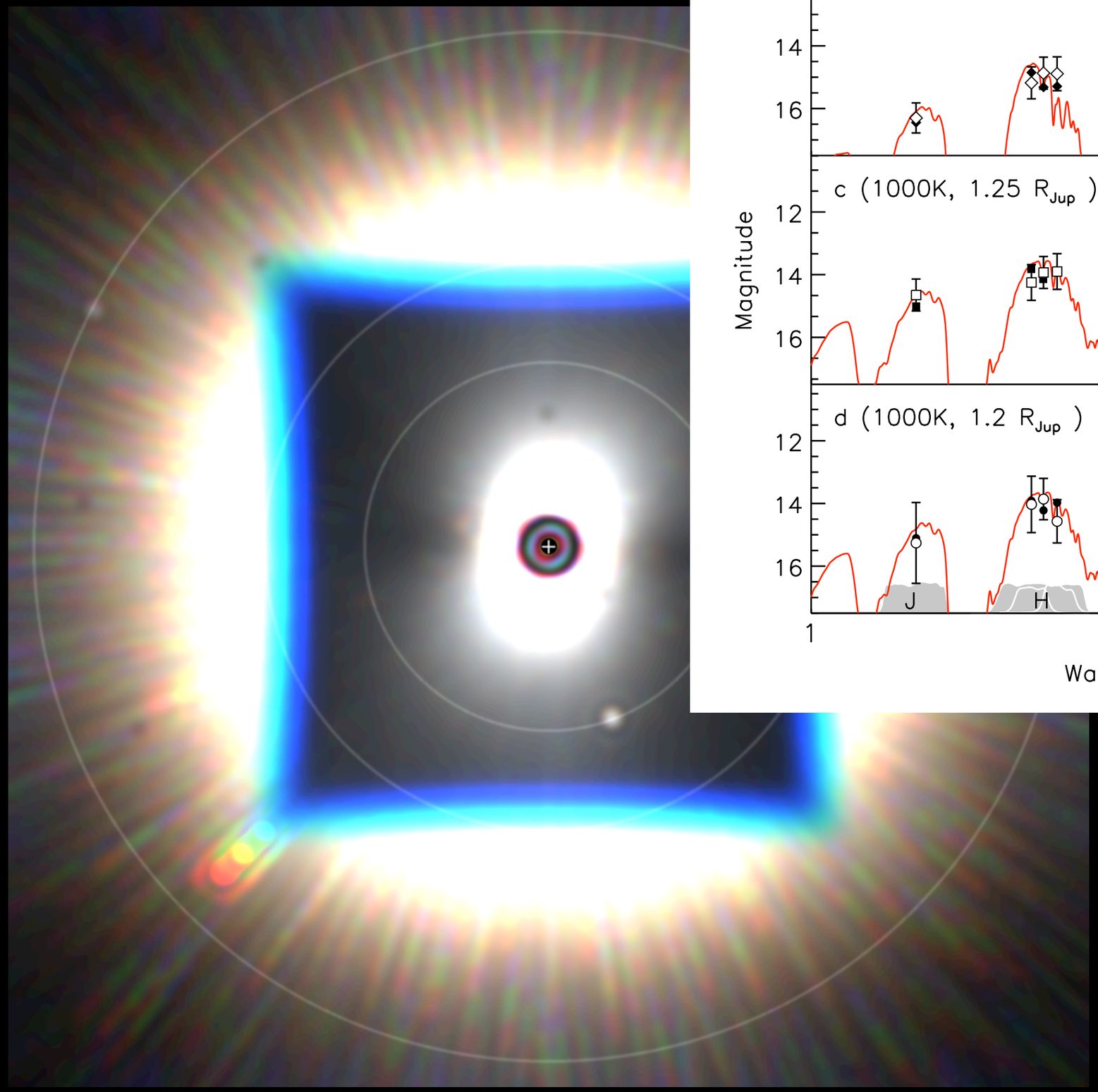
GPI Imaging of HR 8799

Gemini Planet Imager

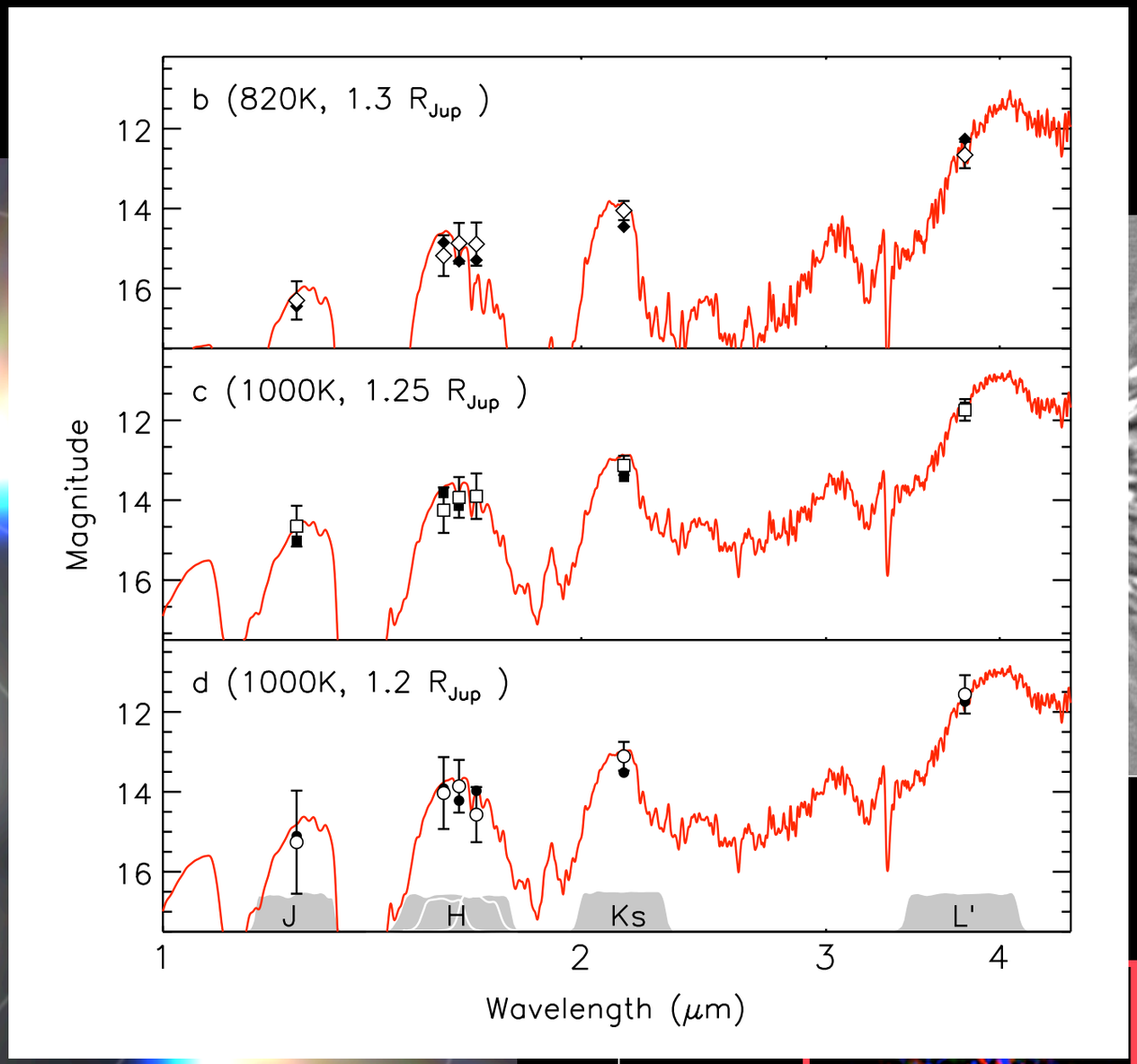
Imageur de Planètes pour Gemini

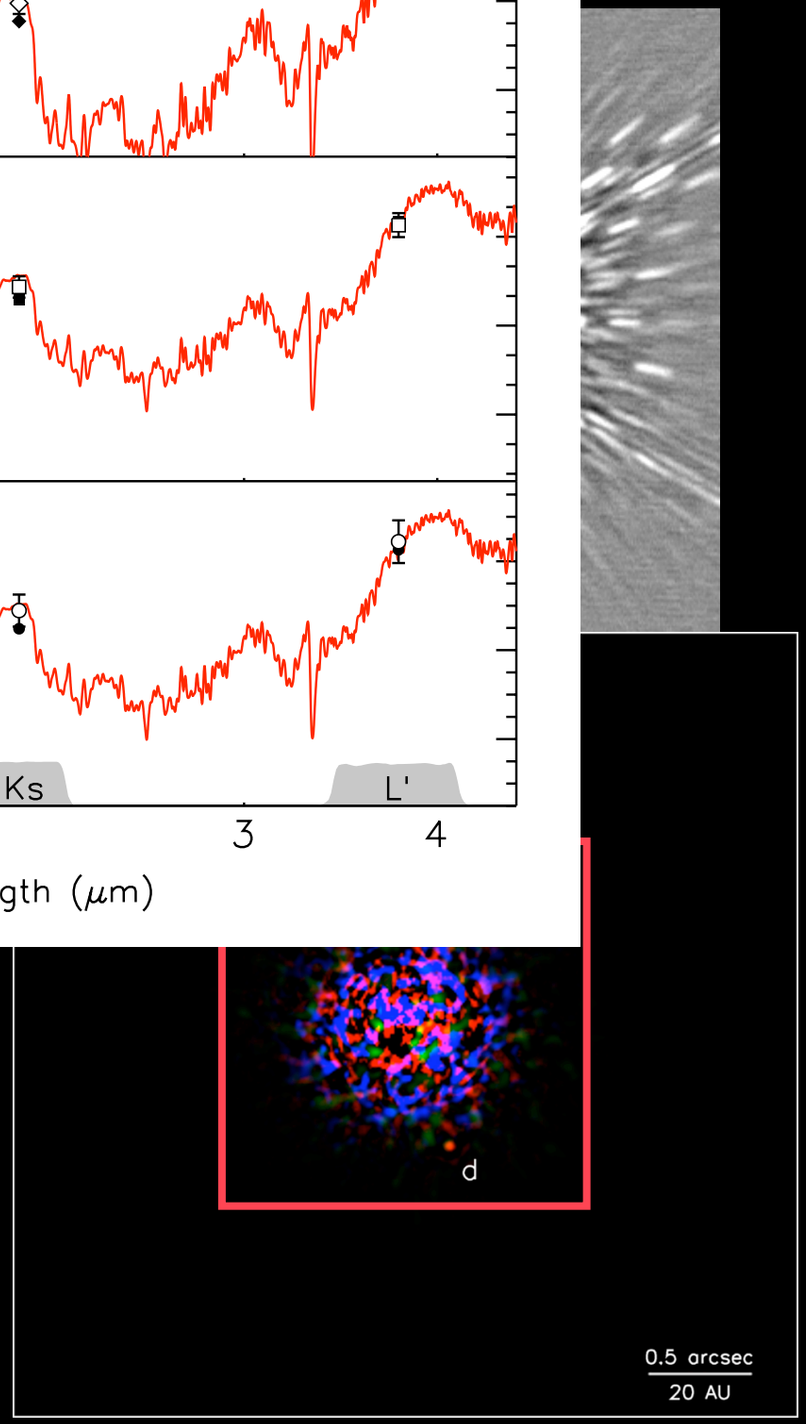
Conseil national de recherches Canada | National Research Council Canada





10s





20 minutes (ADI)

Conclusions

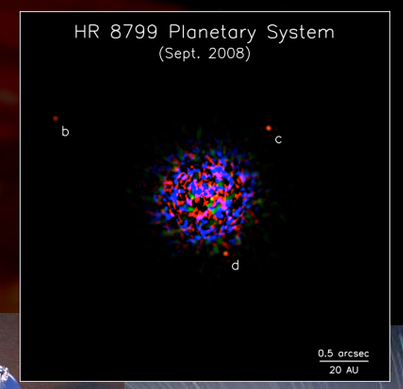
- HR 8799, first directly image of a multi-planet system. First at separation similar to the outer planets of our solar system.

- Peculiar star: Lambda boo, Gamma Dor & Vega-like.

- Cooling tracks: ~7-10 MJup from 25-70 AU, twice the SS size. ~800-1000K and 1.2 RJup. Supported by color - look like 2M1207b

- Evidences ~face-on orbits/~circular orbits/~coplanar/ star view ~ by the pole - formed in a disk.

- Dynamic simulations = lower masses & 4:2:1 resonance.



More to come...

Conseil national de recherches Canada
National Research Council Canada
CRSNG NSERC
Fonds de recherche sur la nature et les technologies Québec

NRC CNRC

Herzberg Institute
of Astrophysics

Science at work for Canada

National Research Council Canada

Conseil national de recherches Canada

Canada