Picturing the Extreme

Planetary Systems Revealed through Direct Imaging

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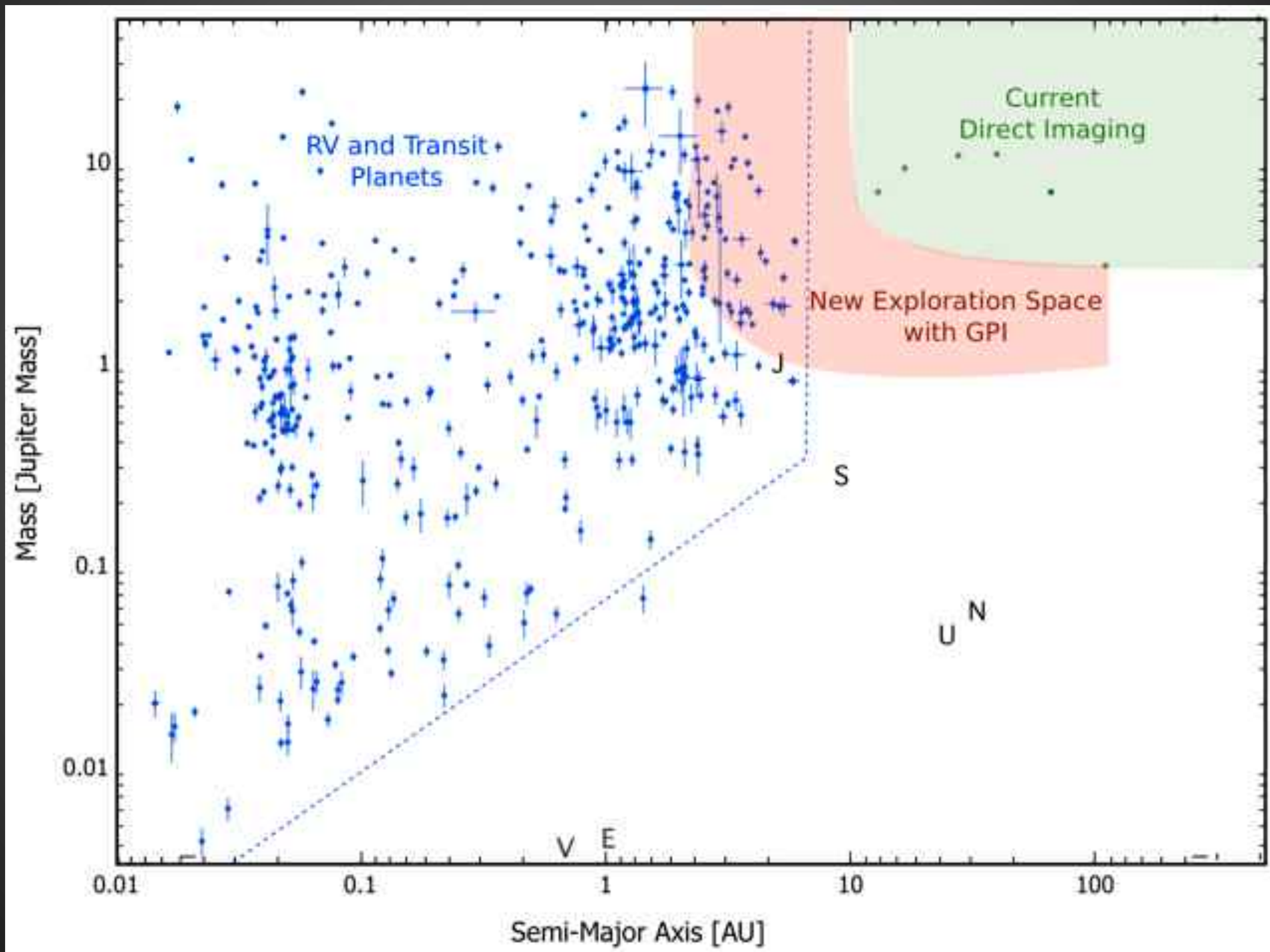
Extreme Solar Systems II

Collaborators: James Graham, Mike Fitzgerald, Mark Clampin, Bruce Macintosh, Matt Kenworthy, Eugene Chiang, Erik Mamajek, Ansgar Reiners, Andreas Seifahrt, Stefan Dreizler, The GPI Team

Discovery Space: Outer portions of planetary systems (long periods), A star (MS) planets, very young planets, face-on planets



Plot from Bruce Macintosh, James Graham & GPI Team

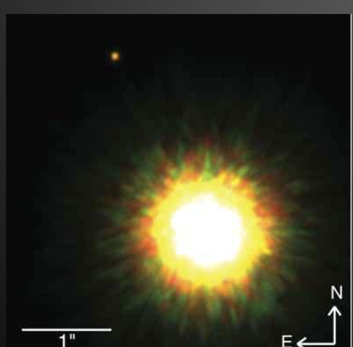
Direct imaging: remarkable progress & surprises too

GQ Lup

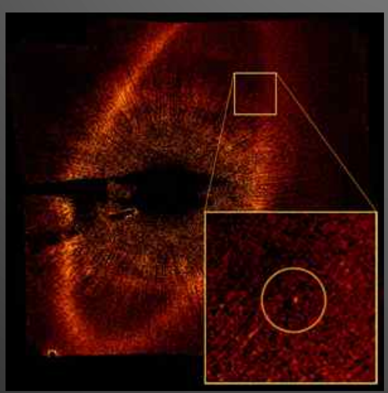
2M1207

AB Pic

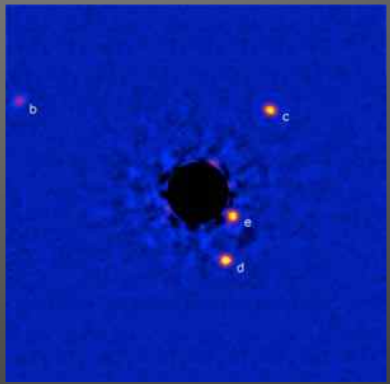
J1609
Lafreniere et al. 2008



Fomalhaut
Kalas et al. 2008

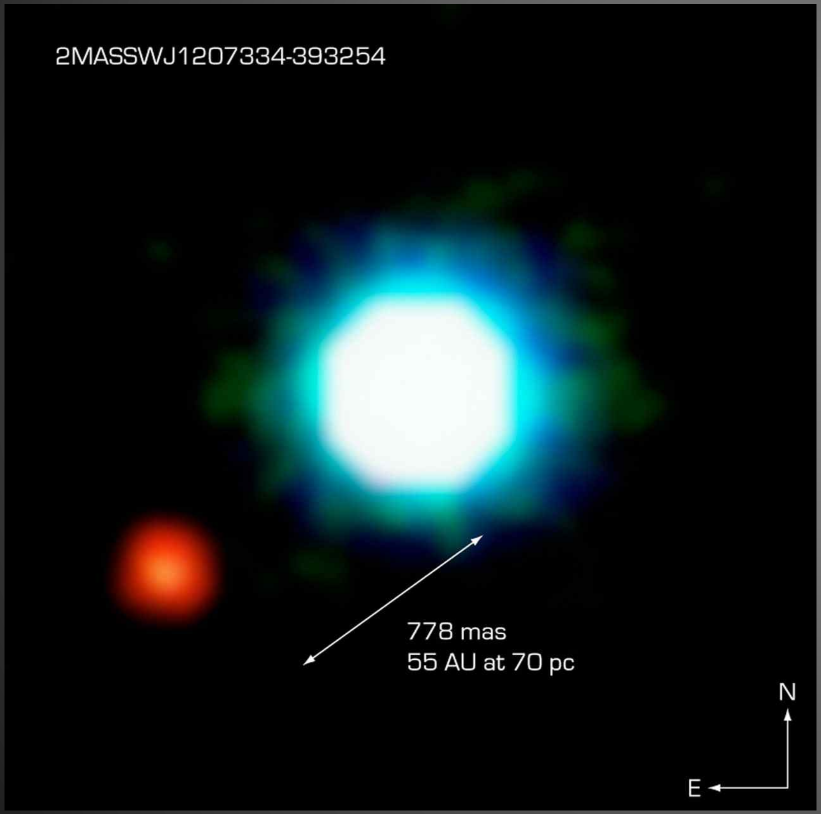


HR 8799
Marois et al. '08,'10

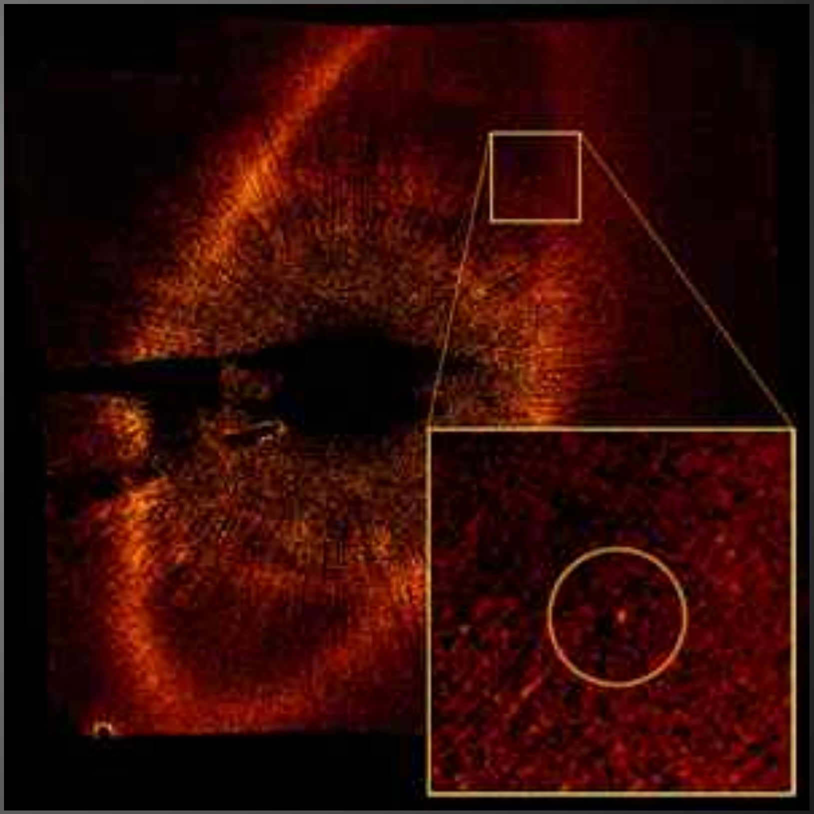


Beta Pic
Lagrange et al. 2009

Extreme separations



2M1207b: 55 AU from a BD host



Fomalhaut b: 119 AU from an A star

Direct detection planet candidates

Host	SpT	Distance (pc)	Separation (AU)	Mass (M_J)	Age (Myr)	Reference
Fomalhaut	A3V	7.69	119	<3.0	100 - 400	Kalas et al. '08
Beta Pic	A5V	19.3	8	7 - 12	8 - 20	Lagrange et al. '08
HR 8799	A5V	39.4±1.0	68,38,24,15	5-13	30 - 160	Marois et al. '08,'10
AB Pic	K2V	45.5±1.8	258	11 - 16	30 – 40	Chauvin et al. '05
2M1207	L2	52.4±1.1	54	2 – 10	2 – 12	Chauvin et al. '04
GQ Lup	K7	156 ± 50	100	4 – 39	<2	Neuhauser et al. '05
1RXJ160929	K7	145±20	330	6 – 11	4 - 6	Lafreniere et al. '08
CT Cha	K7	160±30	440	11 - 23	<2	Schmidt et al. '08

Visible light: Fomalhaut
Orbital motion: Fomalhaut, HR 8799, β Pic and GQ Lup

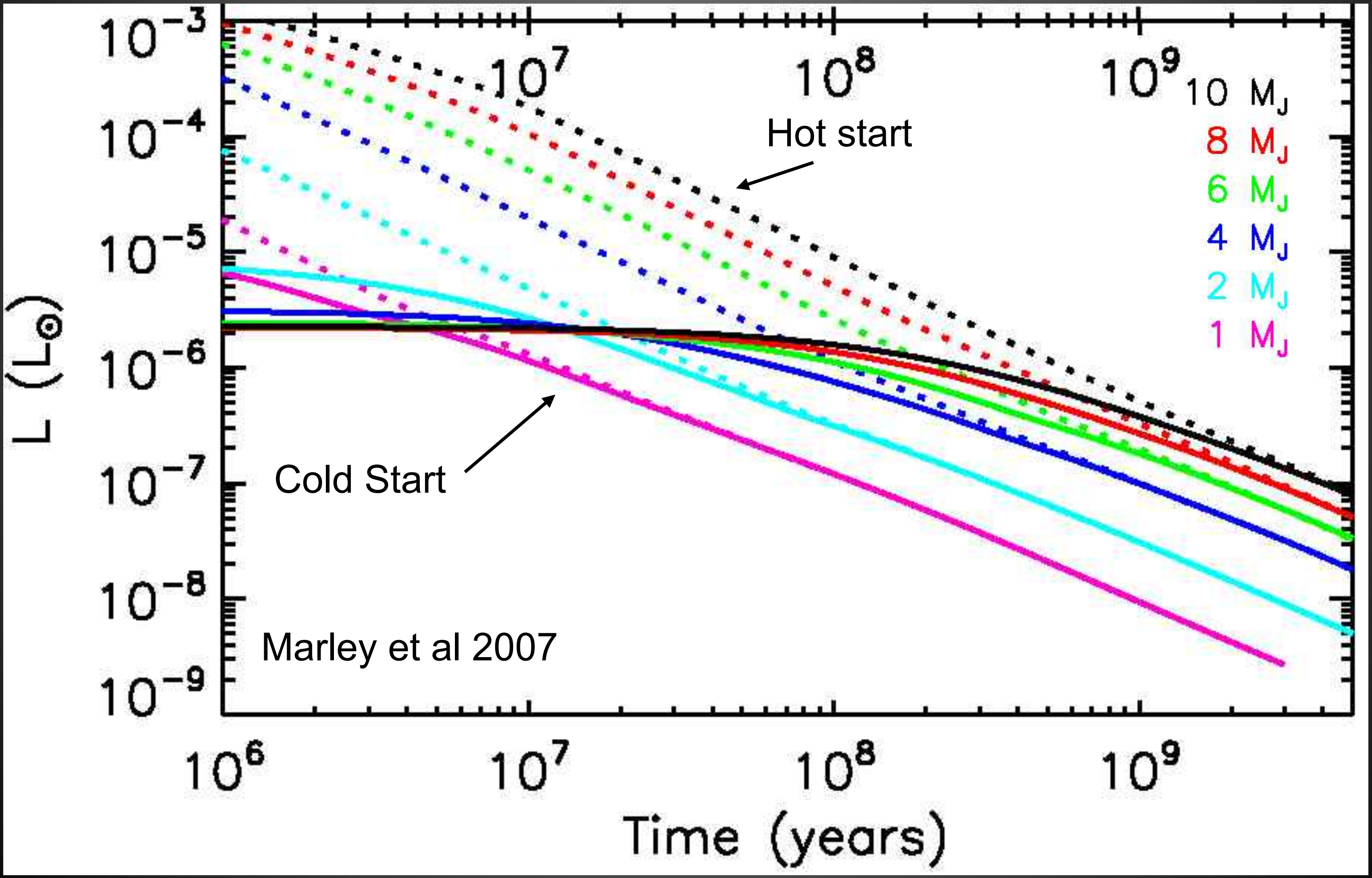
What is a planet? Formation matters?

Starting in 2011:
Gemini Planet Imager
And SPHERE

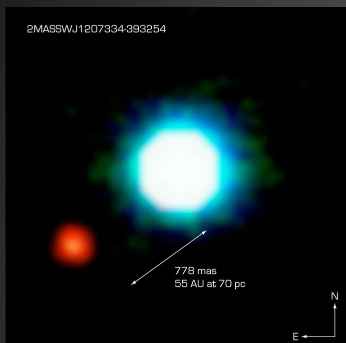
Mass estimate depends on models & age determination

How do planet form?
Hot Start vs. Cold Start

Ages?



Too extreme to be a “planet”?



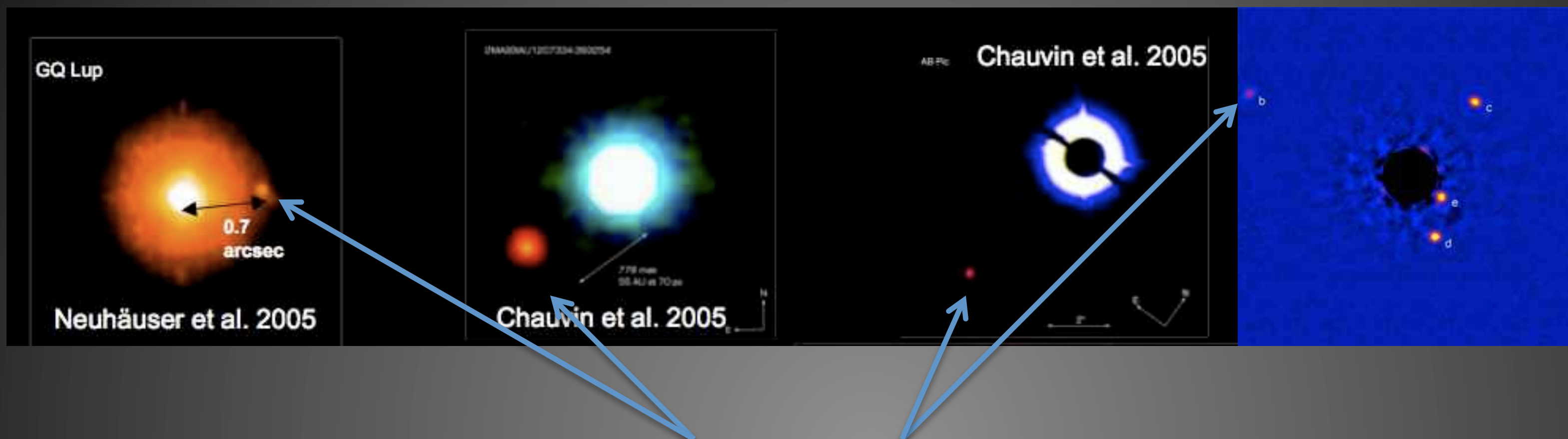
Host	SpT	D (pc)	ρ (AU)	M (M_J)	Age (Myr)	Reference
2M1207	L2	52	55	~8	2 – 12	Chauvin et al. ‘05

OBJECTS IN UNEXPECTED ORBITS

It has become apparent during recent announcements of images of exoplanets that circumstantial arguments are causing some scientists to reject the objects’ planetary status. The objects found so far have at least several Jupiter masses (Neuhäuser et al. 2005) and are seen 50–100 AU from their stars [or in one case, from a brown dwarf (Chauvin et al. 2005)]. Some astronomers reject these objects as planets because their distance from their host stars suggests that they may not have formed in the standard scenario (which is not thought to operate rapidly enough out there to beat the short lifetime of gas disks). They are being called “sub-brown dwarf binaries,” and similar names.

Basri & Brown 2006

Too extreme to be a "planet"?



Extreme core accretion?

08.04

Core Accretion at Wide Separations: The Critical Role of Gas

Ruth Murray-Clay[1], K. Kratter[1], A. Youdin[1]

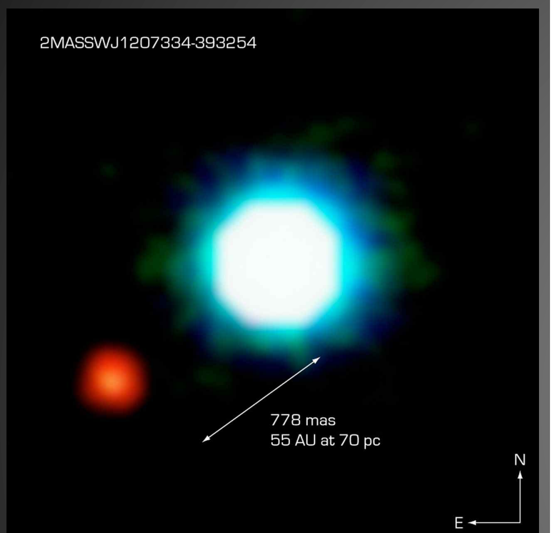
[1]*Harvard-Smithsonian Center for Astrophysics.*

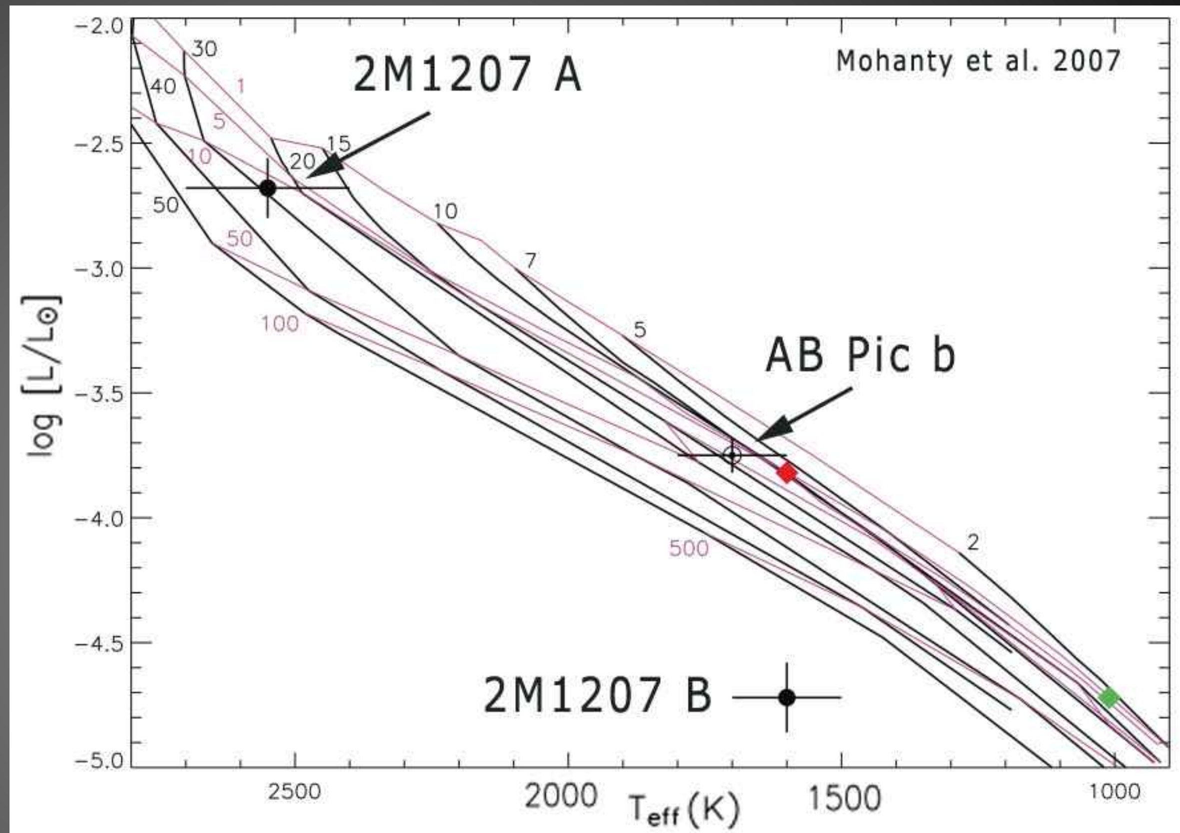
4:45 PM - 5:00 PM

Tuesday

"This process of drag-‐mediated gravitational focusing leads to fast growth, rendering core accretion plausible out to distances at which directly imaged planets have been observed."

Extreme Atmospheres, or Planetary Rings/Disks?



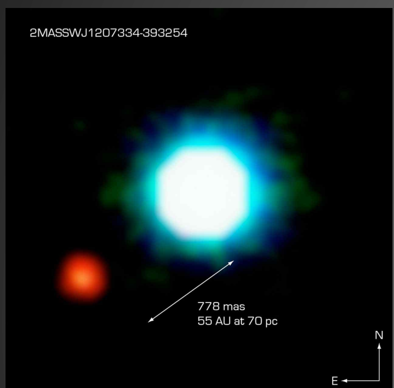


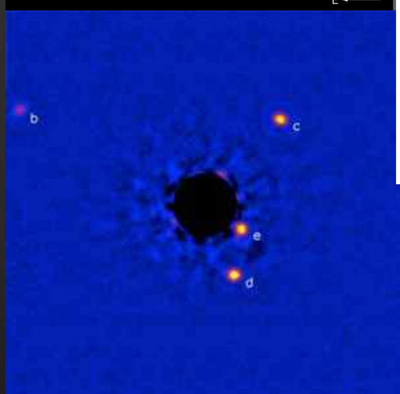
THE PLANETARY MASS COMPANION 2MASS 1207−3932B: TEMPERATURE, MASS, AND EVIDENCE FOR AN EDGE-ON DISK

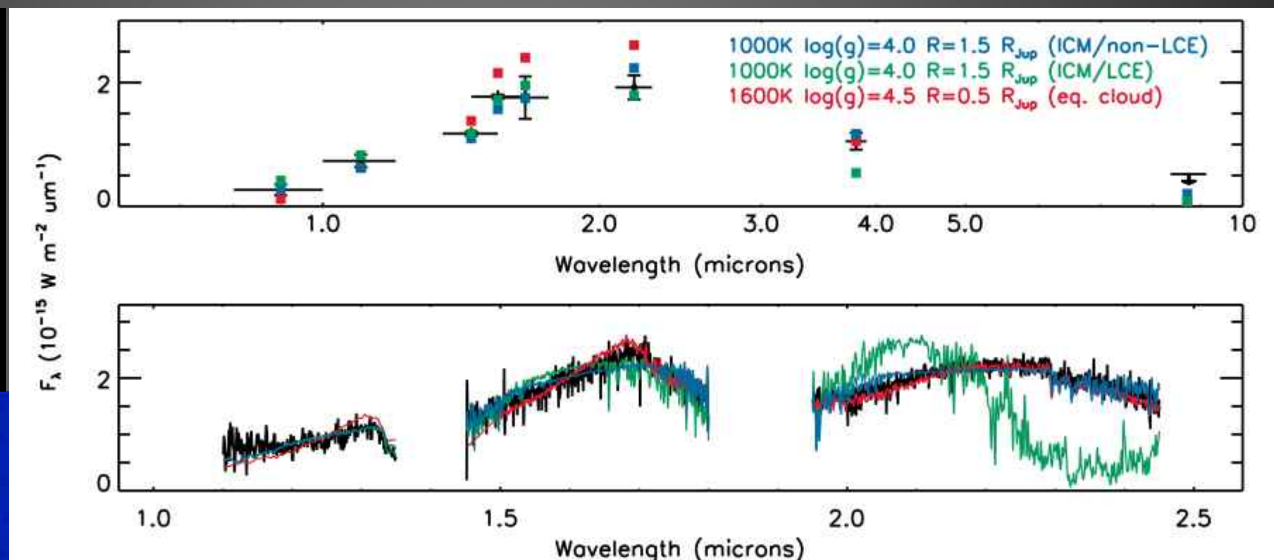
Subhanjoy Mohanty,[1] Ray Jayawardhana,[2] Nuria Huélamo,[3] and Eric Mamajek[1]

Extreme Atmospheres, or Planetary Rings/Disks?

Non-local equilibrium chemistry (non-LCE)
Intermediate clouds (ICM)
Low T_{eff} (1000 K), High N(CO) for 2M1207b







Barman et al. 2011

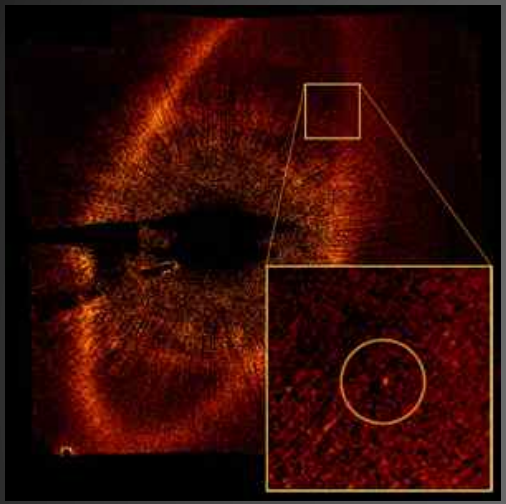
"The primary lesson… is that atmospheric clouds and chemistry can dramatically alter the spectral shape and potentially lead to errors in effective temperature as great as 50%."

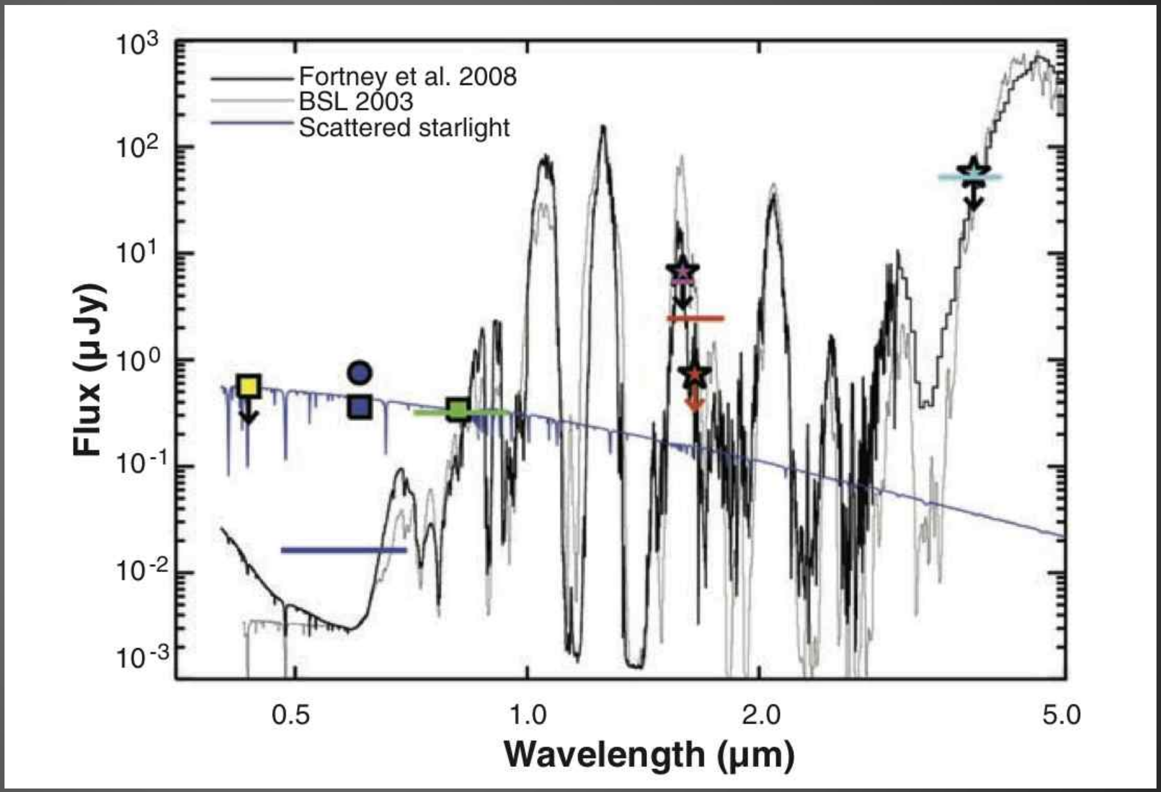
For HR 8799, see 2011 papers by Madhusudhan et al., Currie et al., Barman et al.

See Poster by Robert King et al.

Extreme Atmospheres, or Planetary Ring/Disks?

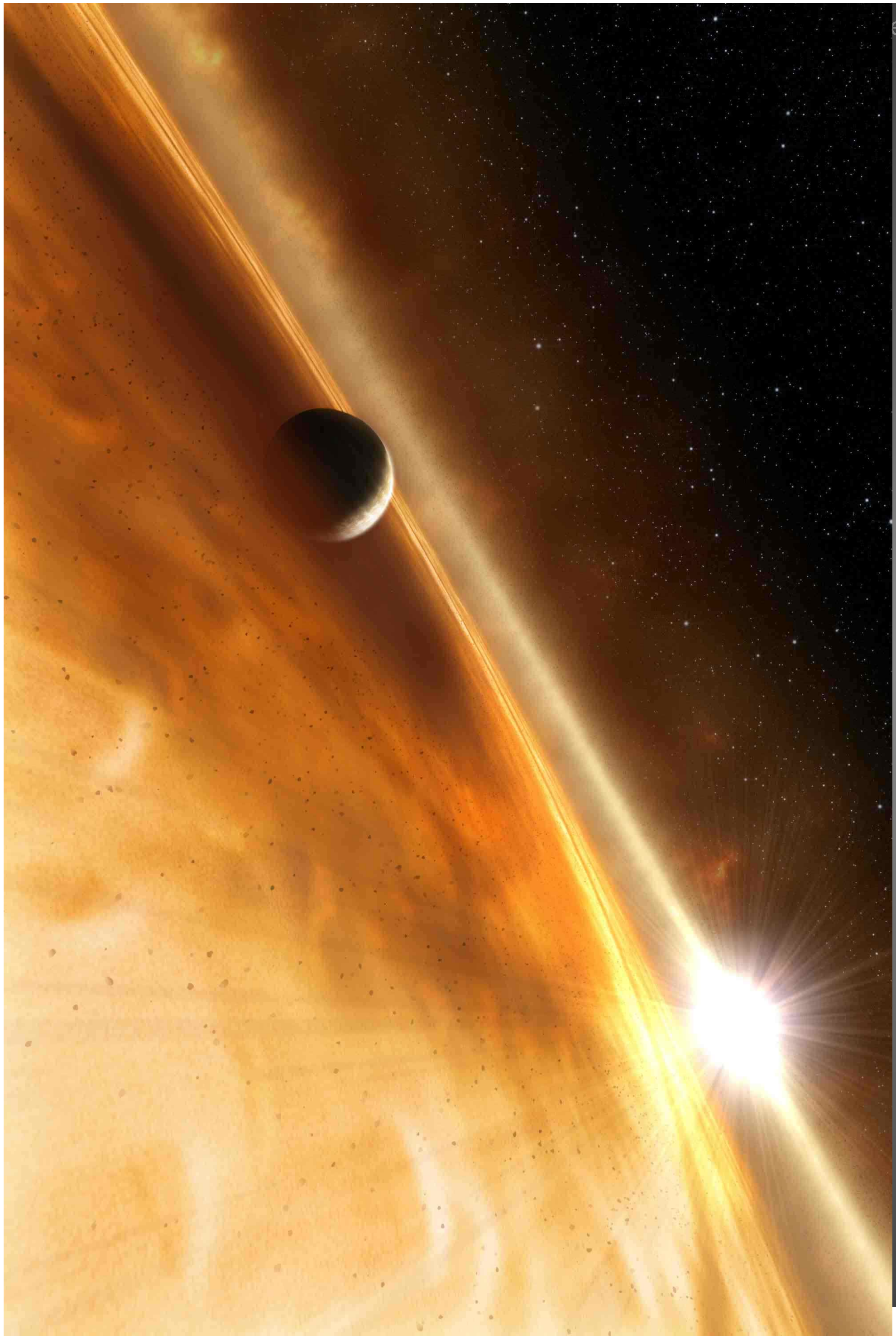
T_{eff} = 400 K, M = 1.7 – 3.5 M_J





Kalas et al 2008

- Detected at optical wavelengths (HST ACS & STIS)
- Not detected at infrared wavelengths (Gemini & Keck)
- Age is 400 Myr instead of 200 Myr? (Eric Mamajek)
- Optical light is reflected from circumplanetary rings?



Why is Fomalhaut b optically bright?

Circumplanetary disk

Kalas et al. 2008

Planet + 16 - 35 R_p rings

For comparison, Callisto at ~27 Jupiter radii

or

Irregular Satellite Cloud

Kennedy & Wyatt 2010, MNRAS, in press

see also

A Ringed Earthlike Planet

Arnold & Schneider 2004, A&A, 420, 1153

See also poster by Megan Shabram

Observations

Theory

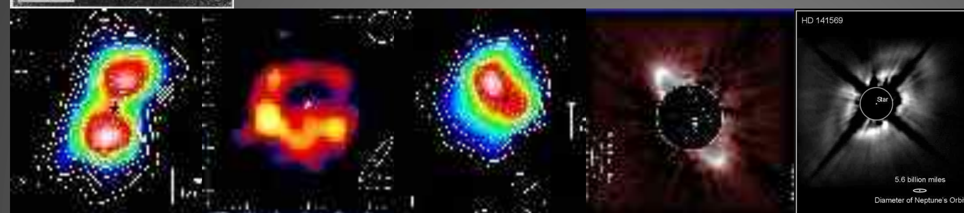
Many EXTREME debris disks

Planet-Disk dynamics give constraints on planet masses & orbital properties

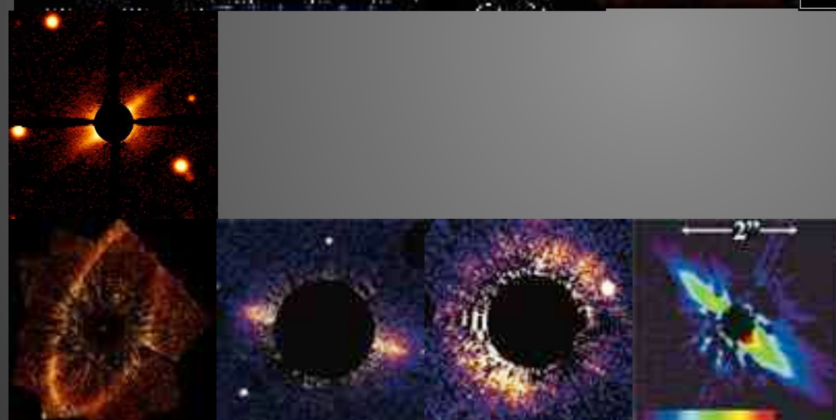
1700

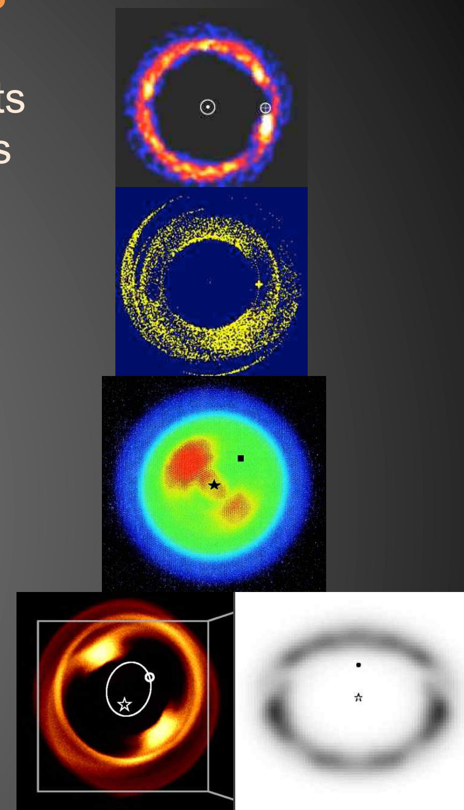
1984

1998

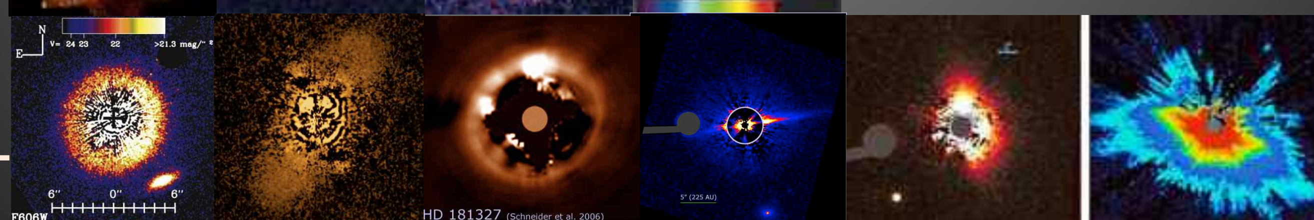


2004





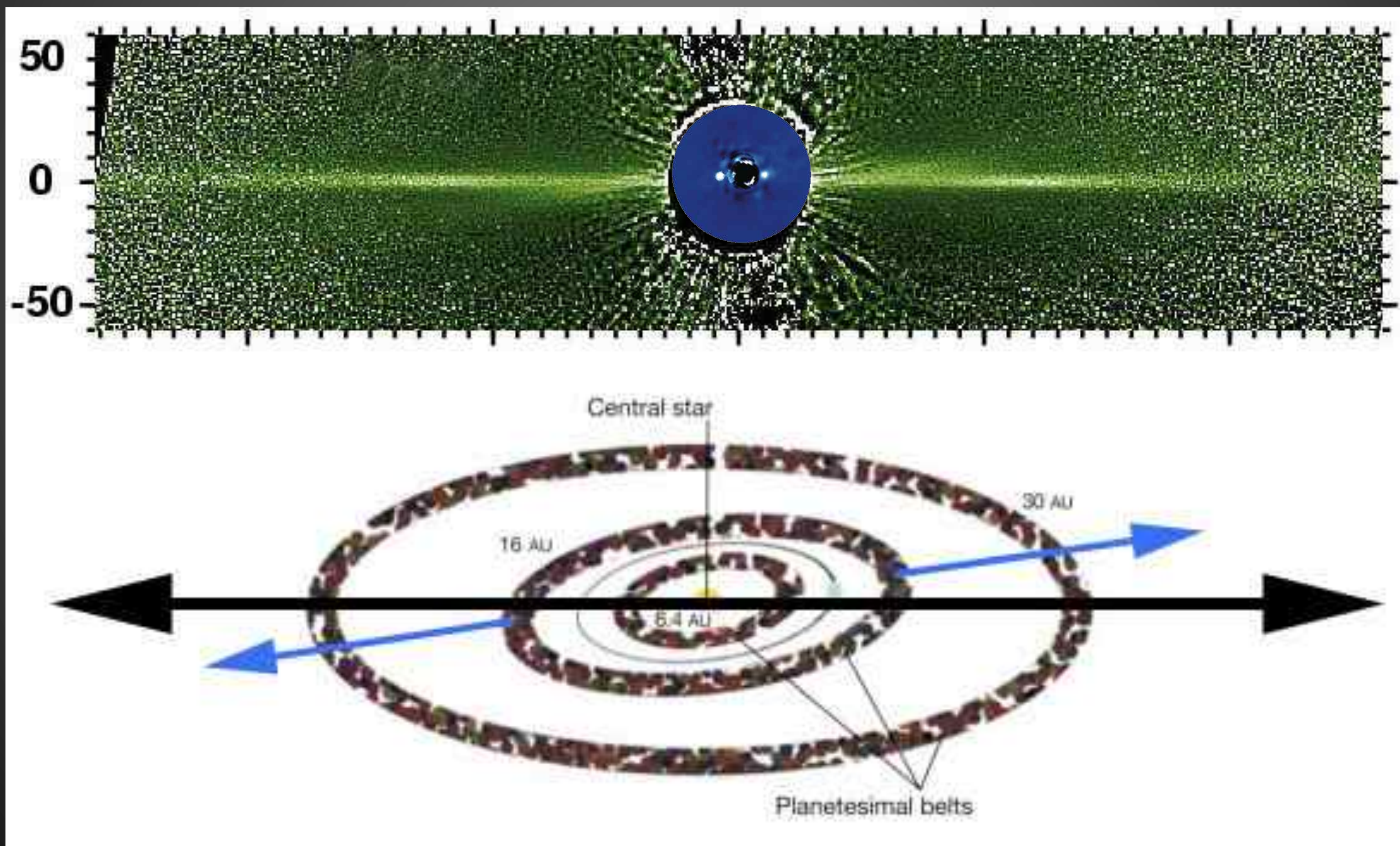
2007+



Fitzgerald talk Tuesday

Extreme Dynamics

- Is Beta Pic b responsible for the warp?
- If so, why is the planet plane inclined 5˚ away from the main disk midplane?



Okamoto et al. 2005

Extreme Adaptive Optics

Southern Hemisphere:	Gemini Planet Imager VLT/SPHERE
Northern Hemisphere	Palomar 1640 Subaru HiCIAO+SCeXAO Large Binocular Telescope

General Properties:

1) Extreme Strehl ratios, better than 85% at H
2) Extreme contrast; $\Delta H > 15$ mag at 0.5″ radius

Observations beginning 2012

Need “extremely” bright host stars (9^{th} mag or brighter)

Extreme Adaptive Optics Systems

2012 - 2015

Host	SpT	Dist. (pc)	Sep. (AU)	Mass (M_J)	Age (Myr)	Reference
Fomalhaut	A3V	7.69	119	<3.0	100 - 300	Kalas et al. '08
HD 182488	G8V	15	>14, >29	10 - 40	700 – 8700	Thalmann et al. '09
Beta Pic	A5V	19.3	8	6 - 12	8 - 20	Lagrange et al. '08
HR 8799	A5V	39.4±1.0	>68, >38, >24	5-11 7-13	30 - 160	Marois et al. '08
AB Pic	K2	47.3±1.8	258	11 - 25	30 – 40	Chauvin et al. '05
2M1207	M8	52.4±1.1	54	2 – 25	5 – 12	Chauvin et al. '04
GQ Lup	K7	140 ± 50	100	4 – 39	<2	Neuhauser et al. '05
1RXJ160929	G	145±20	330	6 – 12	5	Lefreniere et al. '08
CT Cha	K7	160±30	440	11 - 23	<2	Schmidt et al. '08

Direct Detections
Add 100+ rows from GPI and SPHERE results, also SEEDS, 1640, LBT, JWST

Gemini Planet Imager

gpi.berkeley.edu

When: Mid - 2012
Where: Gemini South
Who: PI Bruce Macintosh
How: High-order AO with coronagraphy
What: 0.9 – 2.4 μm, m_I < 9 mag stars, polarimetry, R~100 spectroscopy

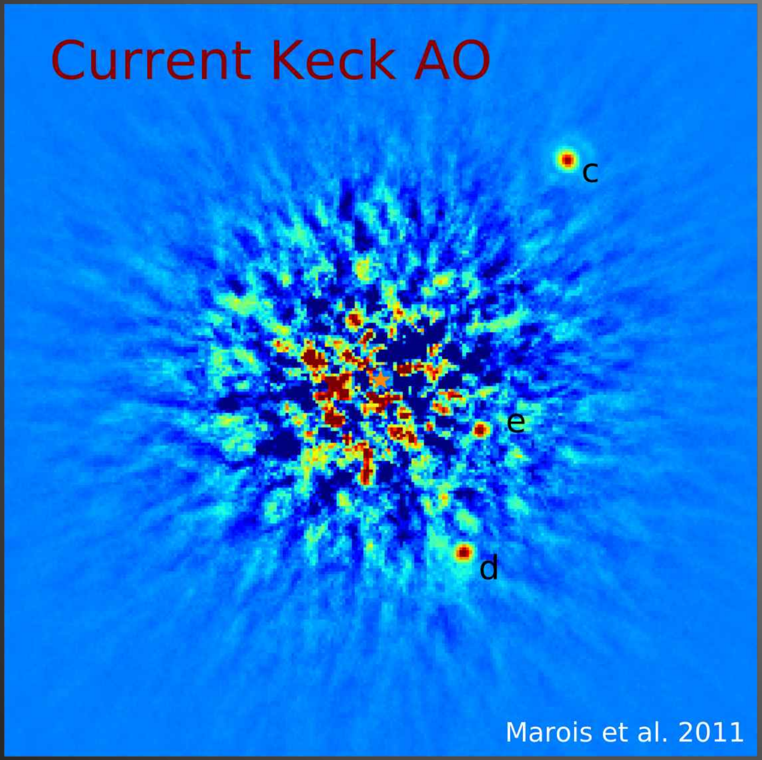
GPIES: GPI Exoplanet Survey

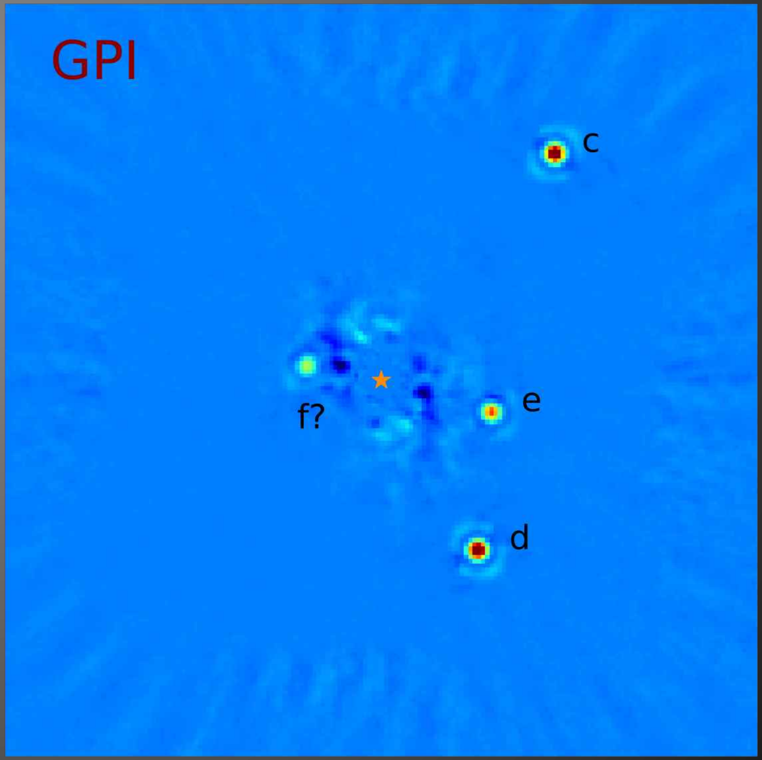
Talk by James Graham (Tuesday), Poster by Jeff Chilcote et al.

890 hours awarded for a 600 star planet survey

PI Bruce Macintosh (LLNL)

Expected detection rate: 4% - 8% (cold vs. hot start)
or 25-50 exoplanets





Direct imaging: Lessons being learned

- Most are >5 Jupiter masses in the 1-100 Myr age range, with 8 – 300 AU separations, often including debris disks.
- Flux & spectra anchor planet formation & atmosphere models, such as hot-start vs. cold-start, GI vs. core-accretion, chemistry, clouds, etc.
- Astrometry yields orbit estimates → planet masses given from dynamics, independently from atmosphere models
- Surveys using GPI, SPHERE, 1640, Subaru, LBT, JWST, etc. will transition the field from individual discoveries to statistically significant samples.

Many more results at the conference!

- Debris disks and their relationship to exoplanets
  - Jenny Patience et al. (poster), Debbie Padgett et al. (poster), Mike Fitzgerald et al. (oral, Tues PM), Karl Stapelfeldt (oral, Tues PM), Amaya Moro-Martin et al. (oral, Fri. AM), Torsten Lohne et al. (oral, Fri. AM), Rebekah Ilene Dawson (oral, Wed. AM), Etienne Morey (poster), Mark Booth (poster)
- Recent Direct Imaging Surveys
  - Eric Nielsen et al. (oral, Tues PM), Zahed Wahhaj (poster), Ray Jayawardhana et al. (oral, Tues PM), Markus Janson (poster), Arthur Vigan (poster), Heidi Karhonen et al. (poster), Sloane Wiktorowicz (poster)
- Planets in protoplanetary disks
  - Jane Greaves et al. (oral, Tues PM), Adam Kraus (poster)
- HR 8799
  - Quinn Konapacky et al. (oral, Tues PM), Sasha Hinkley et al. (poster)