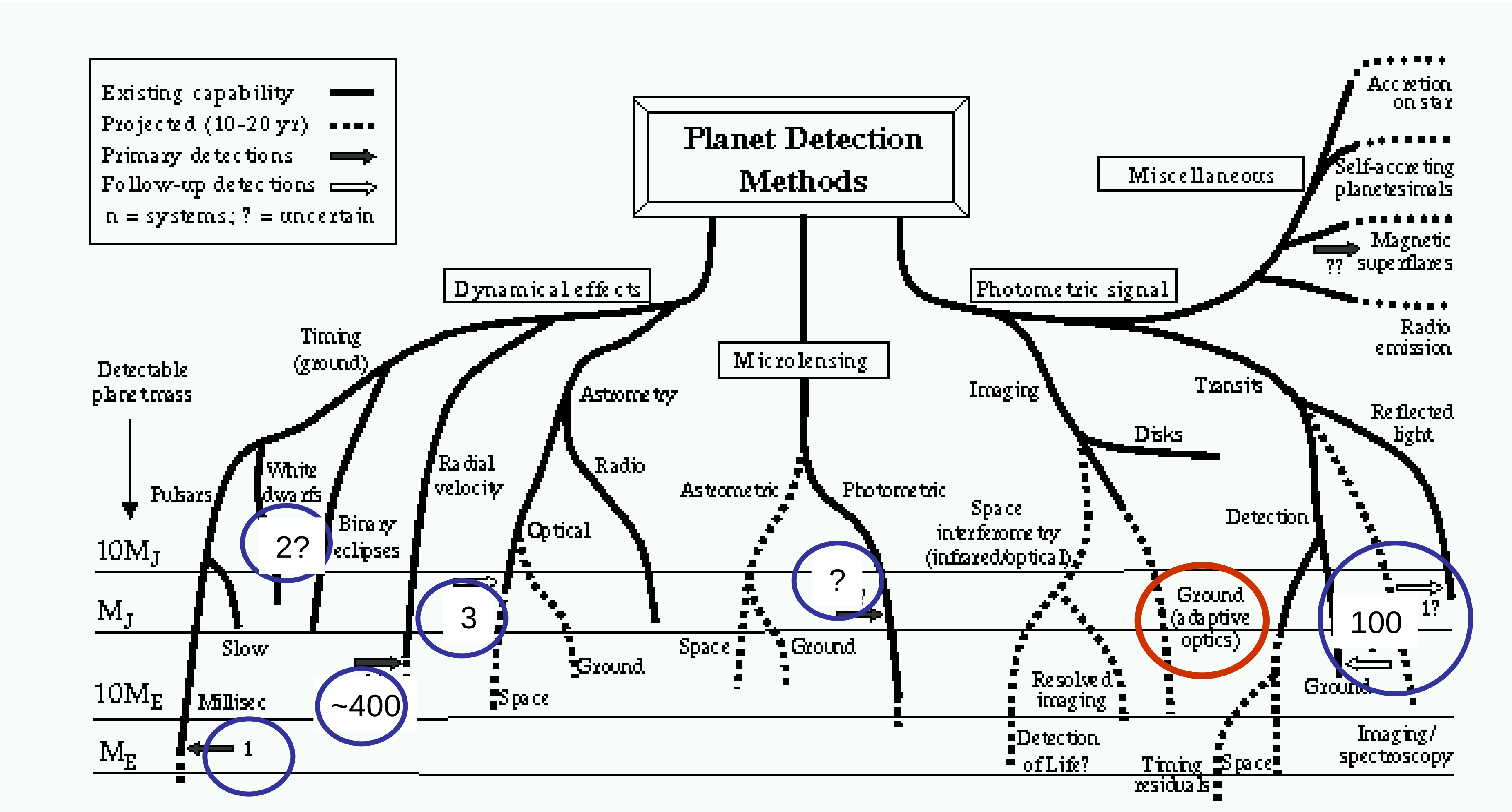
Direct detection of exoplanets

Ralph Neuhäuser

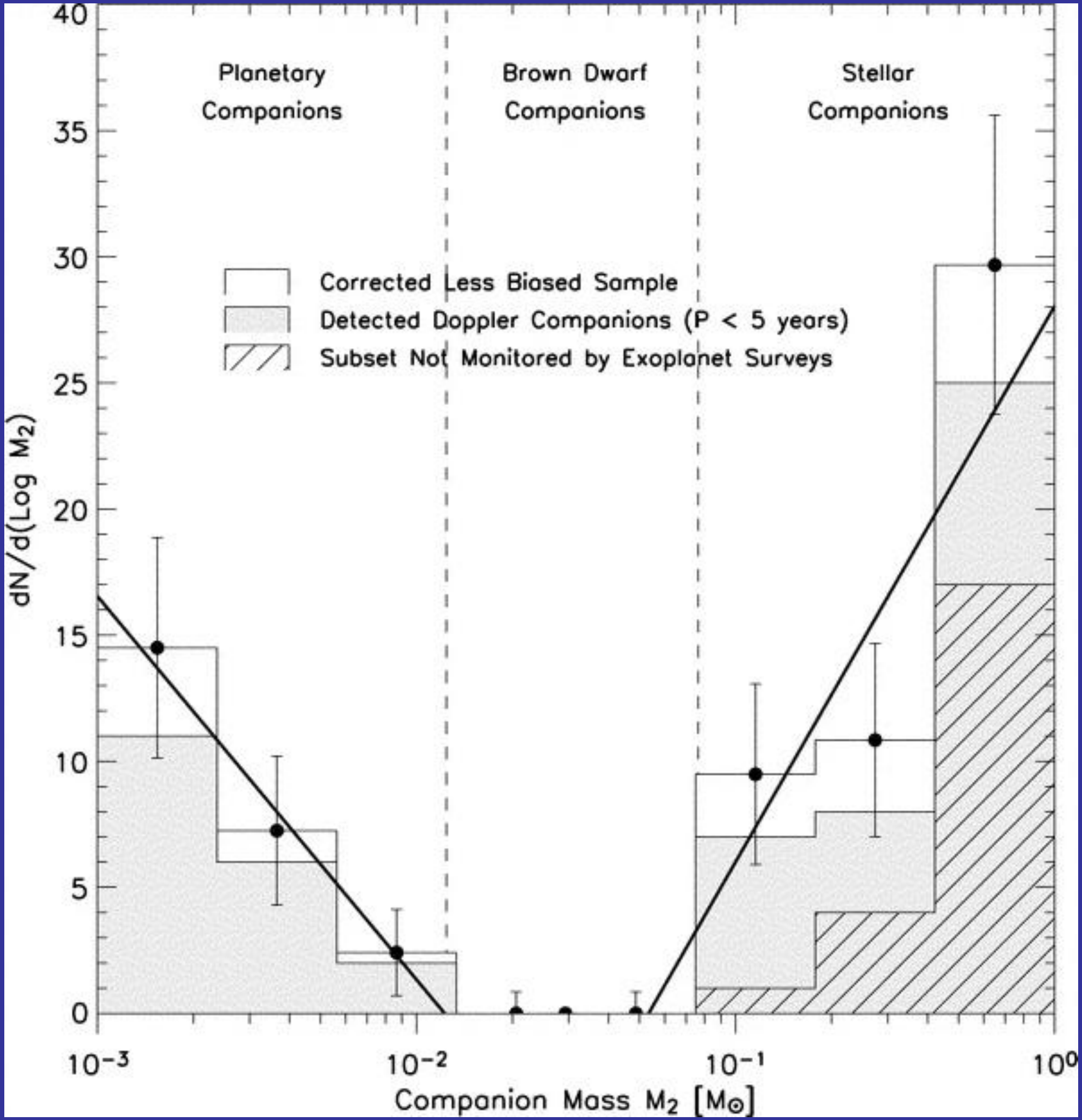
with Tobias Schmidt, Markus Mugrauer,
Christian Ginski, Christian Adam (U Jena), et al.

Astrophysikalisches Institut und Universitäts-Sternwarte
www.exoplanet.de www.astro.uni-jena.de
Friedrich-Schiller-Universität Jena

Methods for detection of extra-solar planets (exo-planets):



The brown dwarf desert: 20 to 50 Jup masses

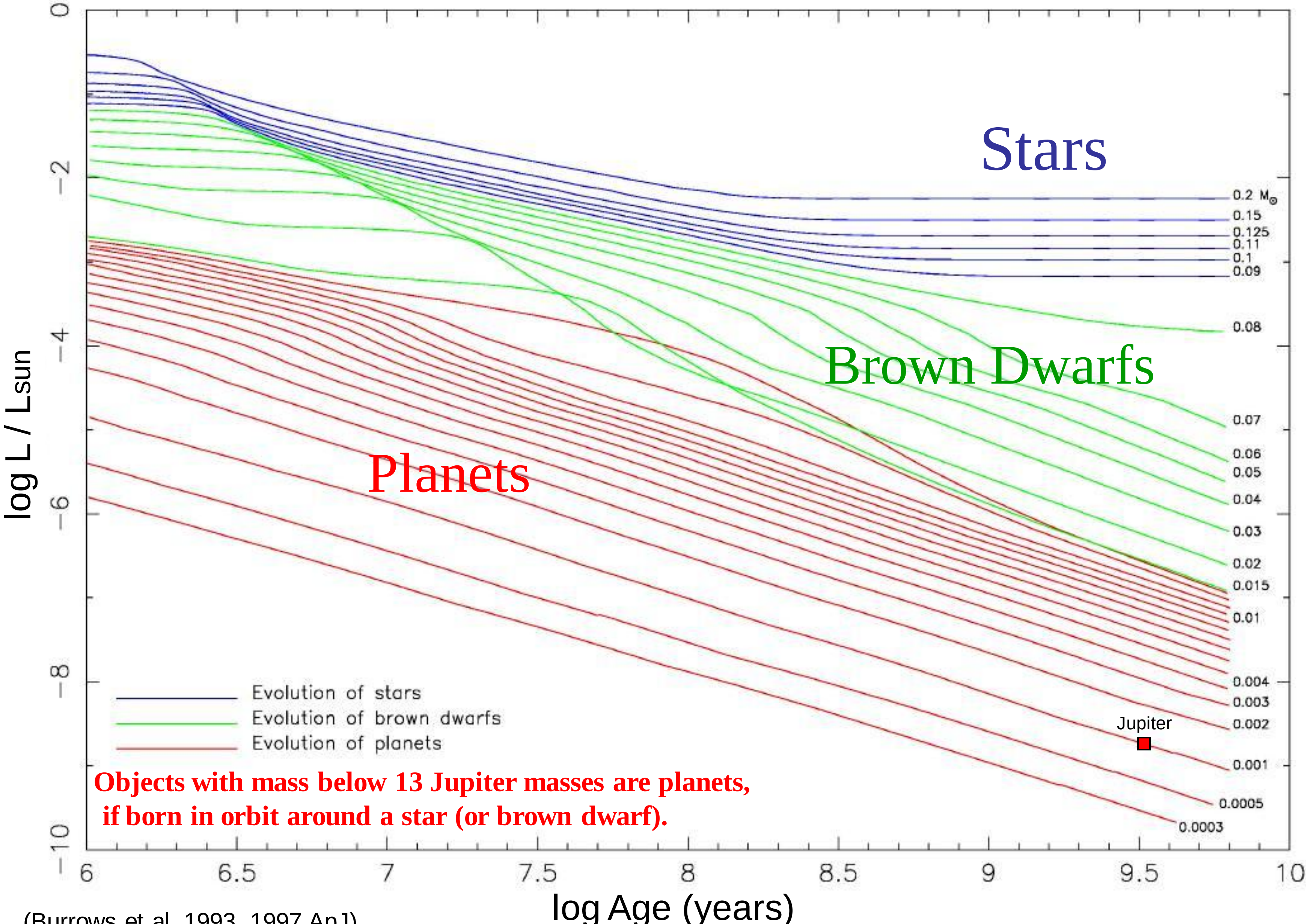


Grether & Lineweaver 2006:

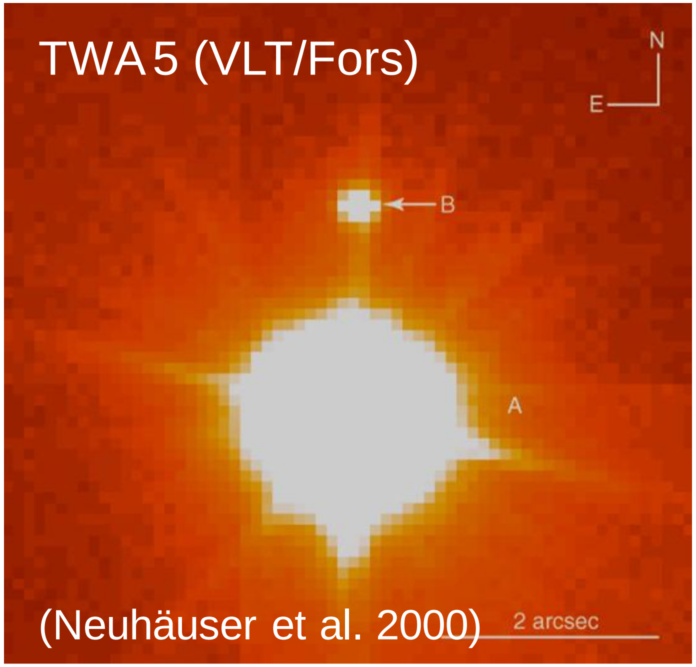
Bi-modal distribution !

Objects below <u>~ 35 Jup masses</u> form *differently*, i.e. planets …

Luminosity vs. age (stars, brown dwarfs, and planets)

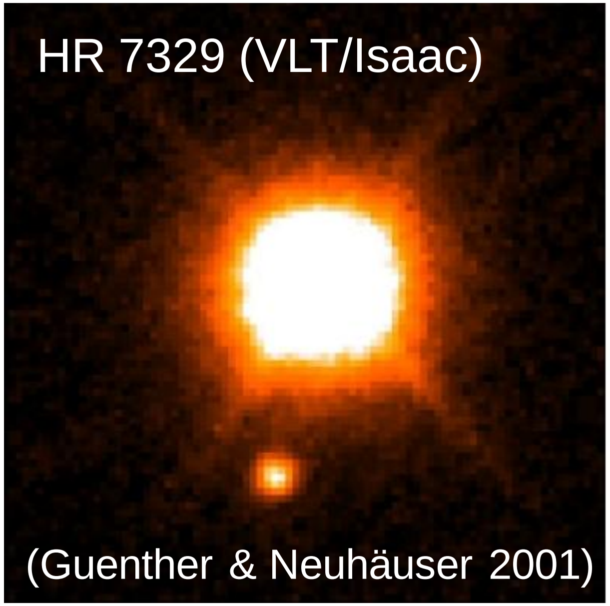


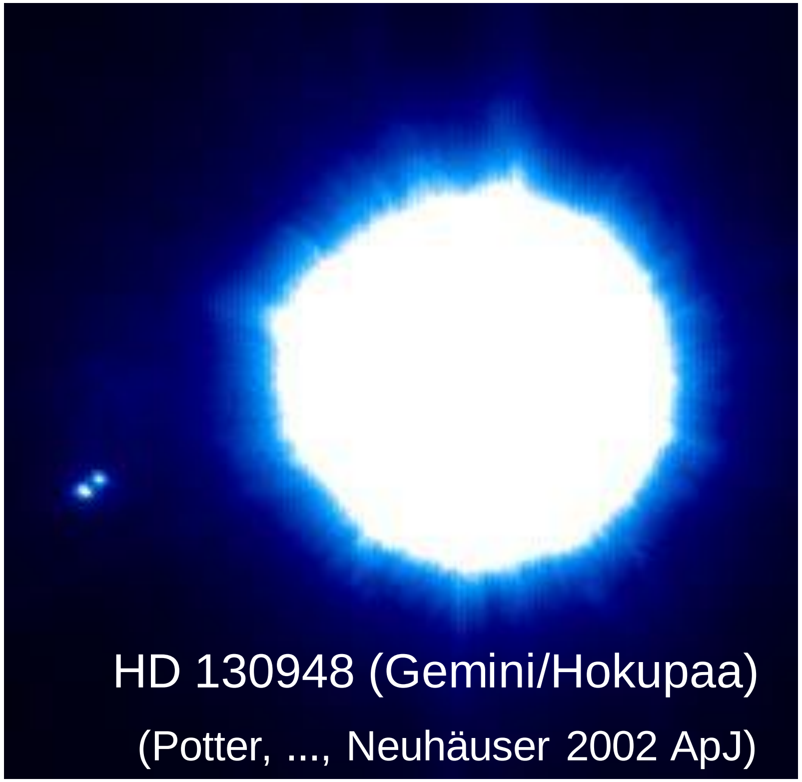
(Burrows et al. 1993, 1997 ApJ)



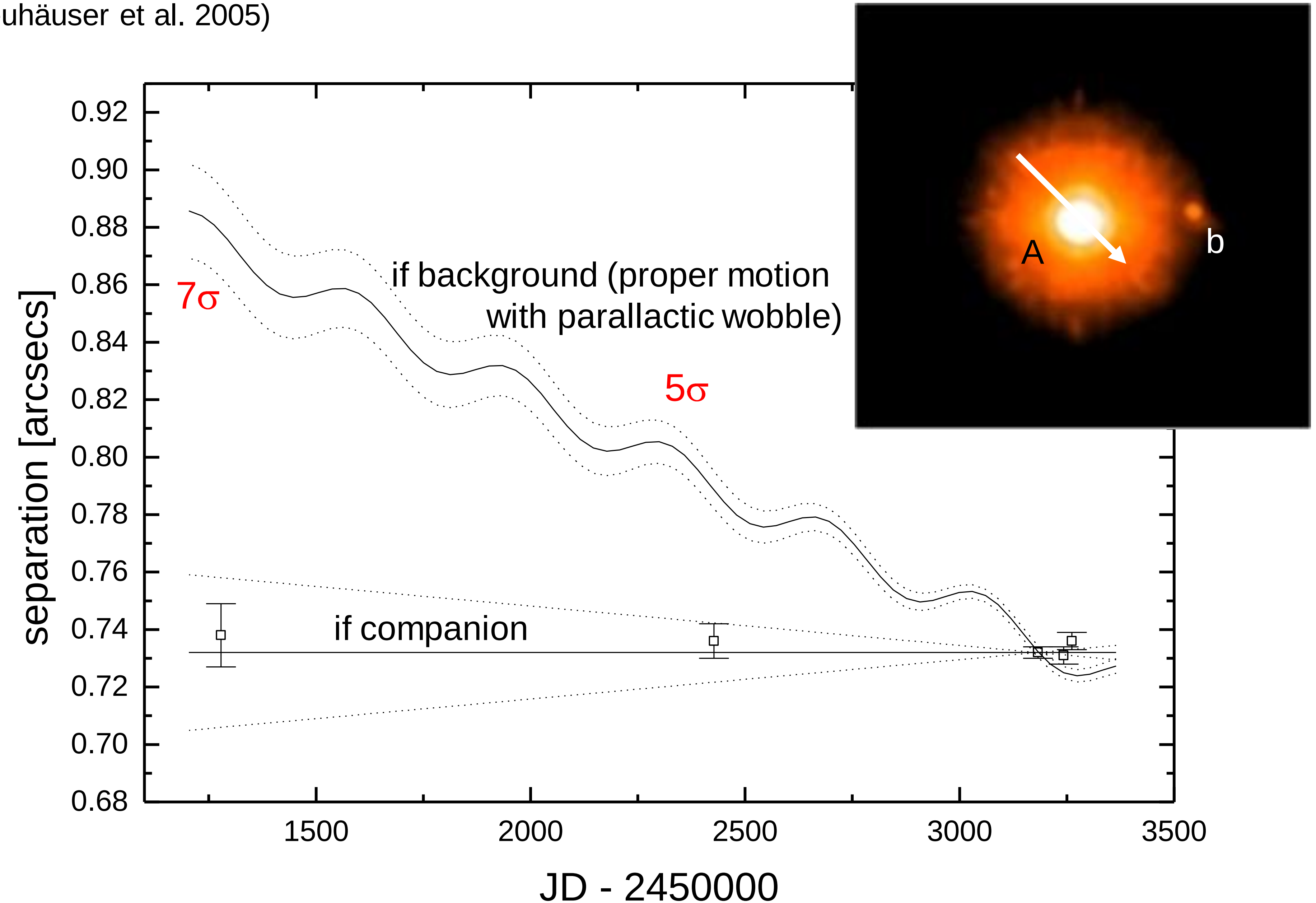
Brown Dwarf Companions !

(several brown dwarf companions, including the first three among pre-main seq. stars)





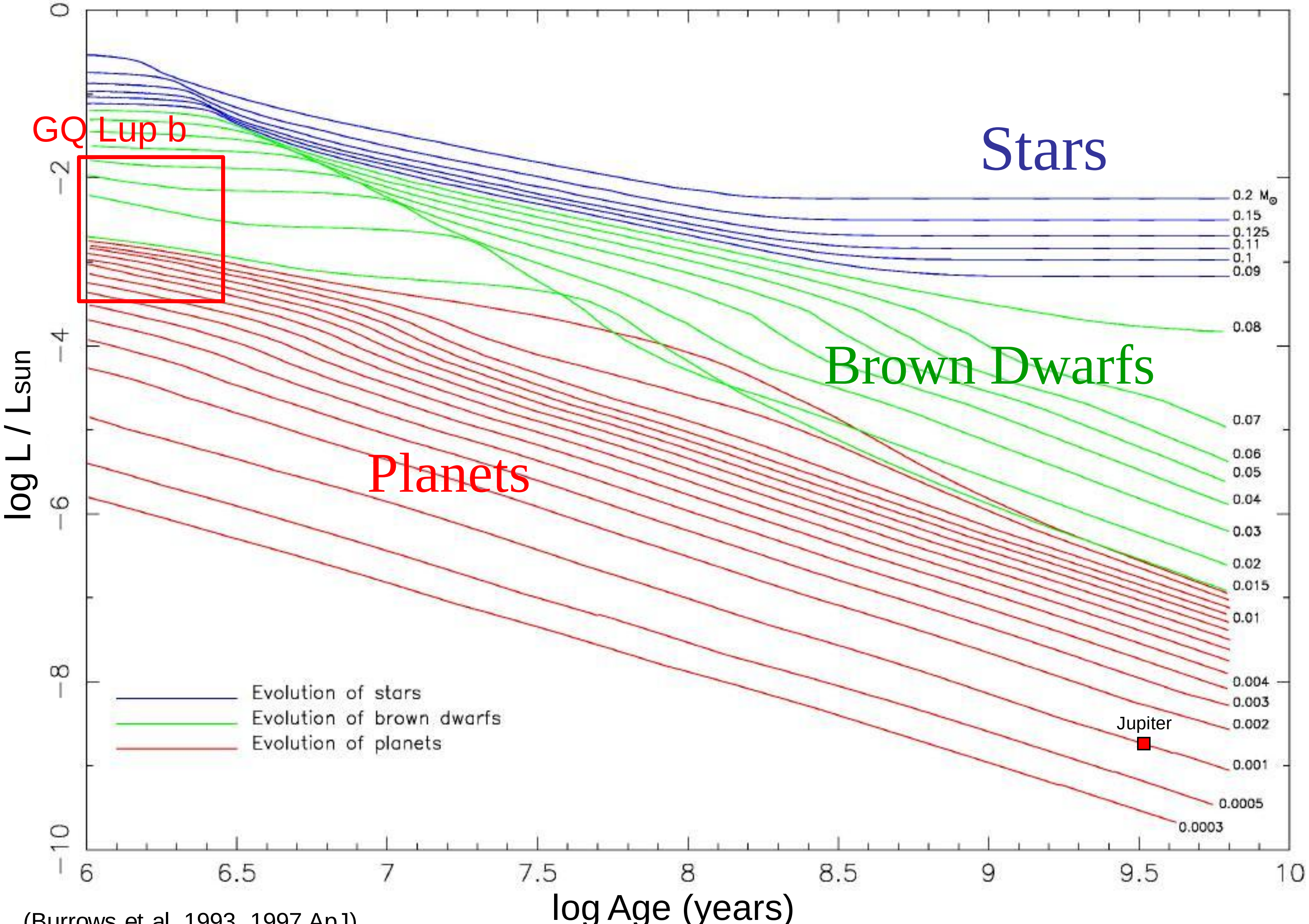
GQ Lup b: first planet candidate imaged directly
(Neuhäuser et al. 2005)



Models indicate a mass of 1 to 42 Jup masses
➔ Planet or brown dwarf (?)

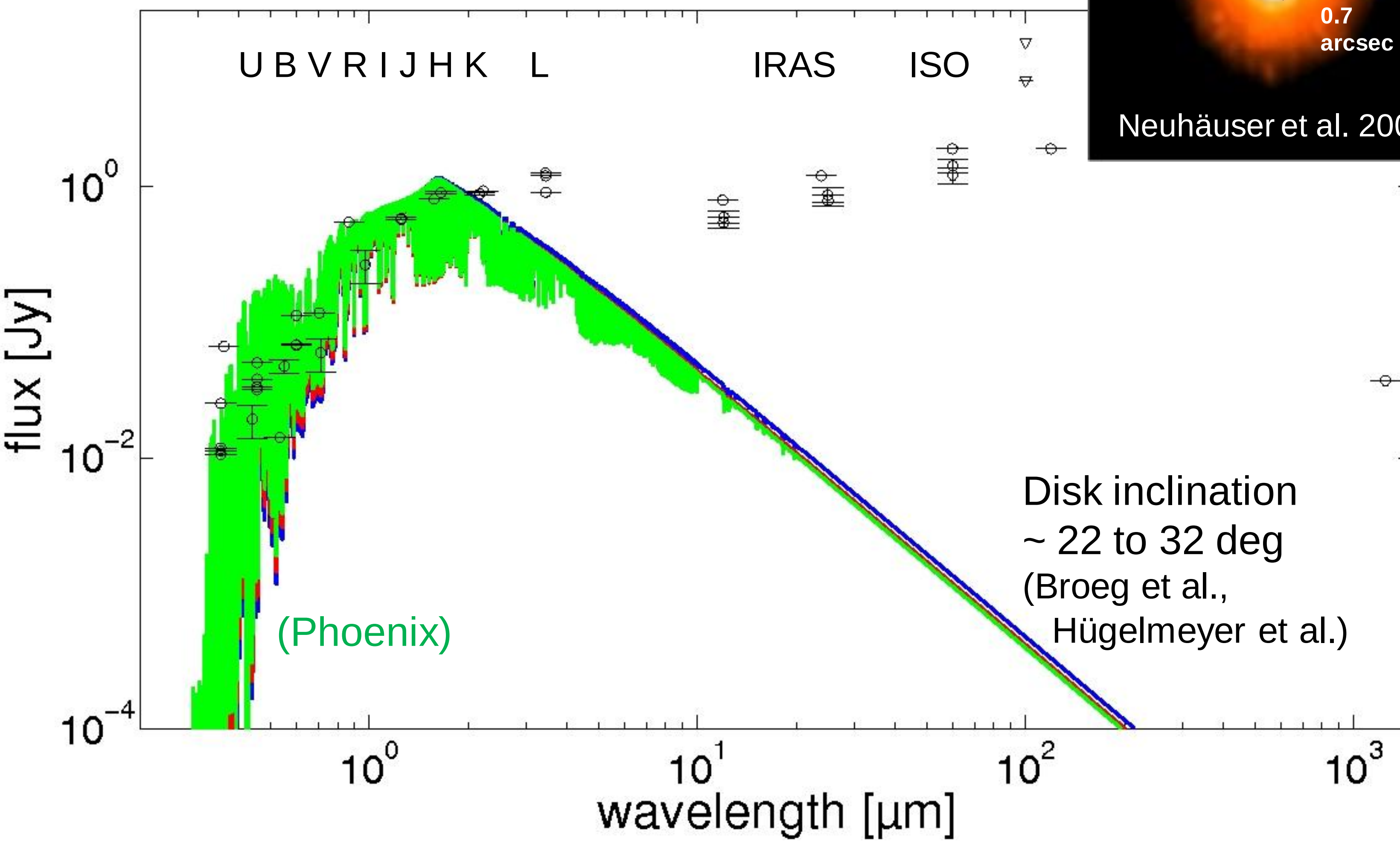
Common proper motion pair !

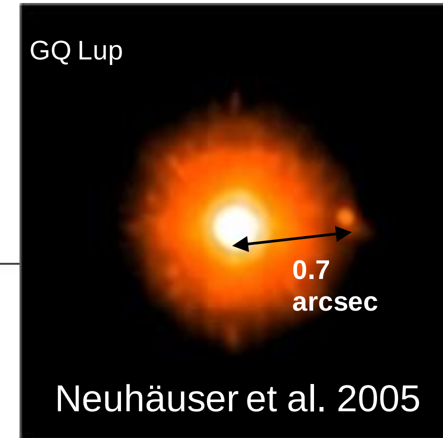
Hot start model



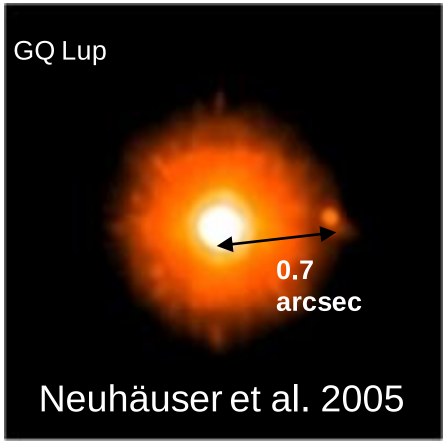
(Burrows et al. 1993, 1997 ApJ)

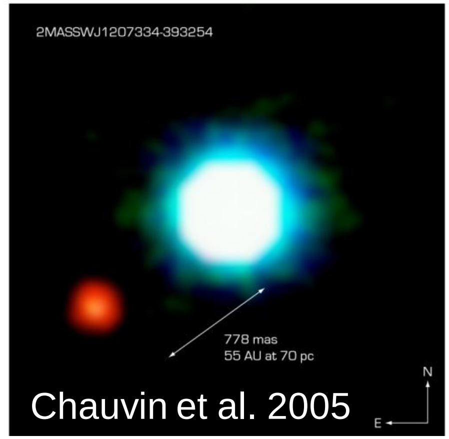
Classical T Tauri star GQ Lup
with planet candidate and
IR excess, i.e. (gas) disk

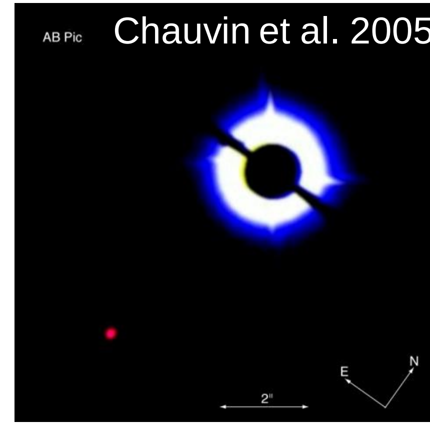


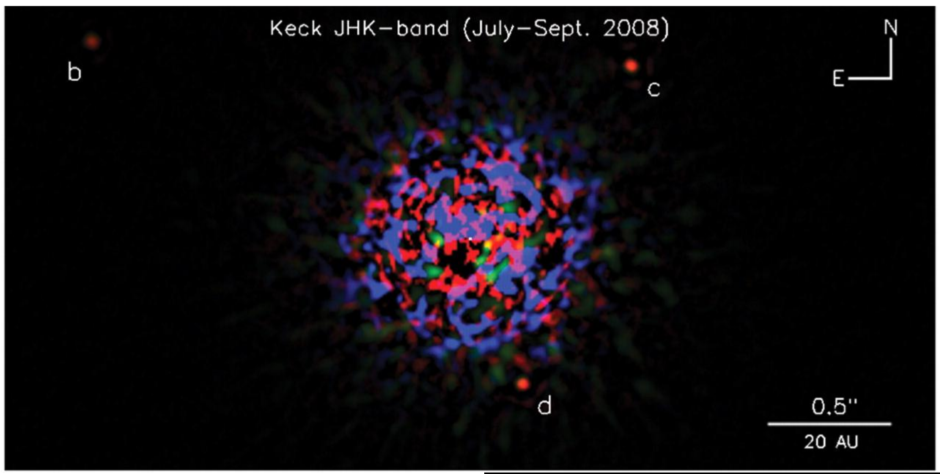


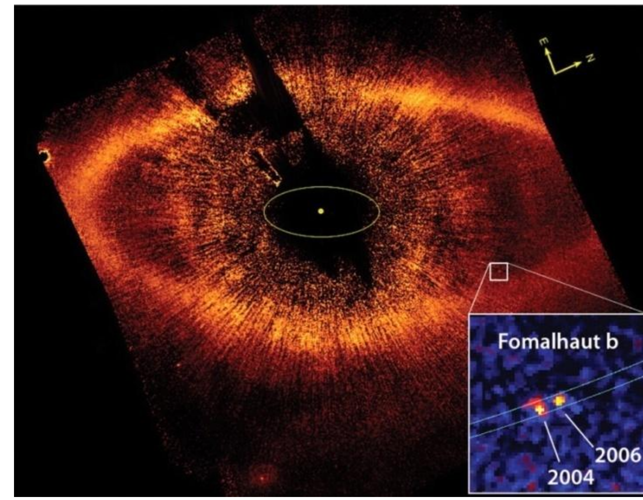
Strong IR excess in GQ Lup
➔ massive large disk (?) ➔ wide sub-stellar companions could form in disk instability (?)

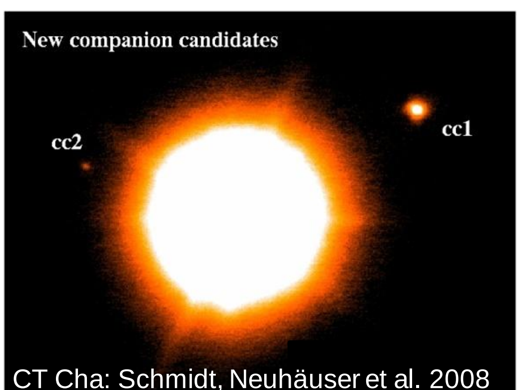

GQ Lup
0.7
arcsec
Neuhäuser et al. 2005

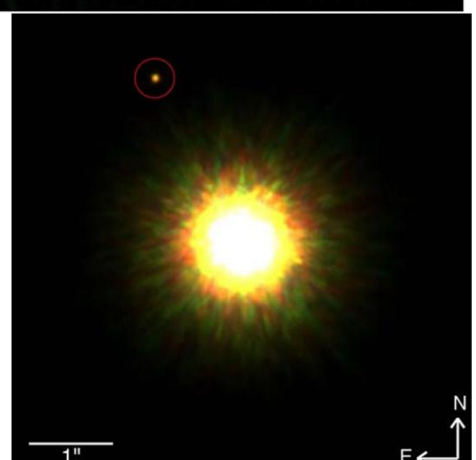

2MASSWJ1207334-393254
778 mas
55 AU at 70 pc
N
E
Chauvin et al. 2005

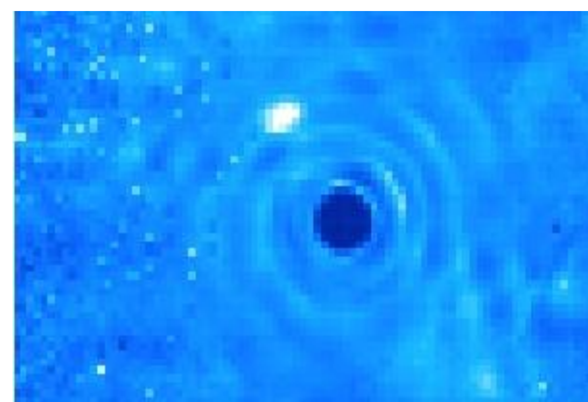

AB Pic
Chauvin et al. 2005
E
N
2"


Keck JHK−band (July−Sept. 2008)
N
E
b
c
d
0.5''
20 AU

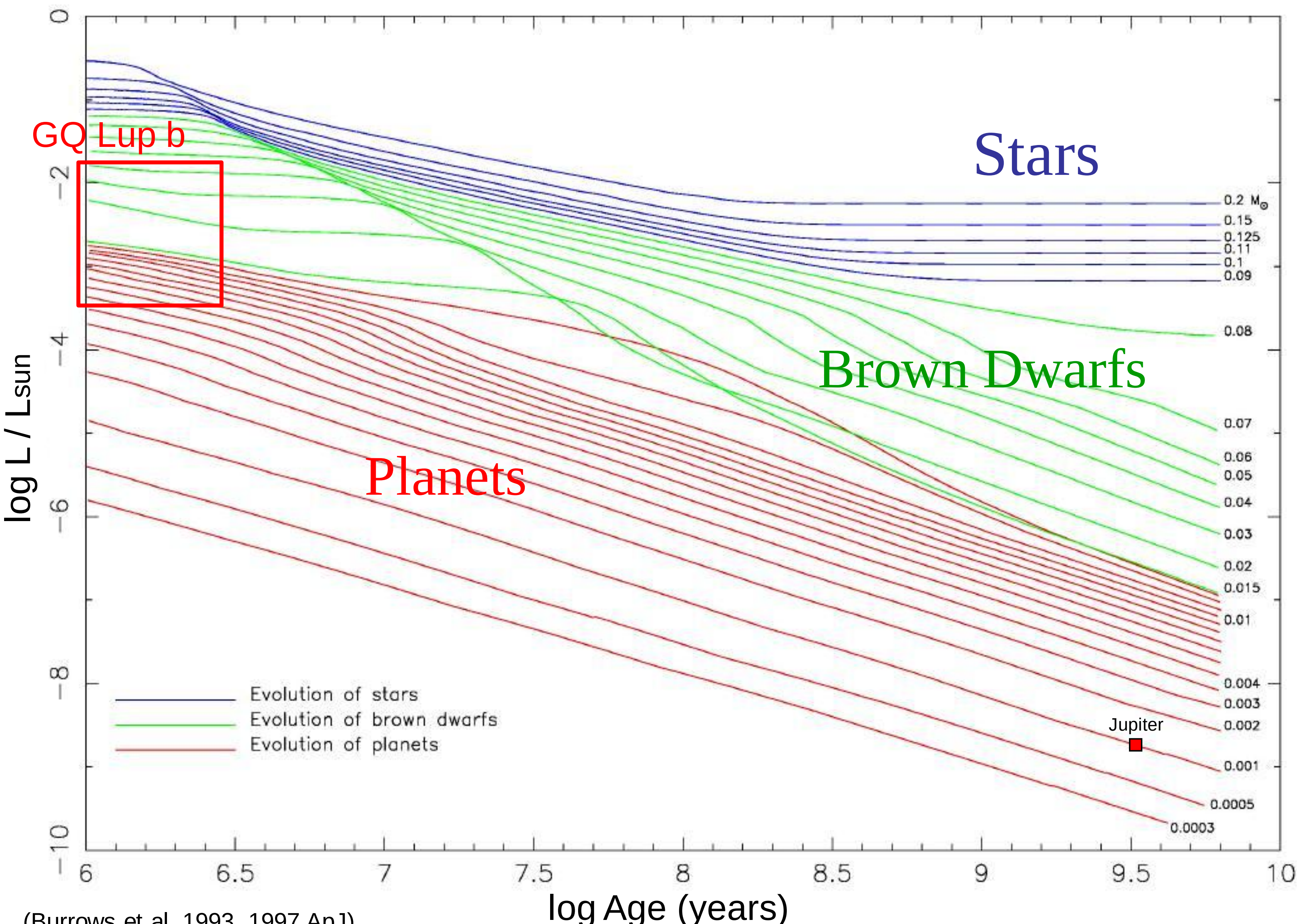

Fomalhaut b
2006
2004


New companion candidates
cc2
cc1
CT Cha: Schmidt, Neuhäuser et al. 2008


N
E
1"



Hot start model



(Burrows et al. 1993, 1997 ApJ)

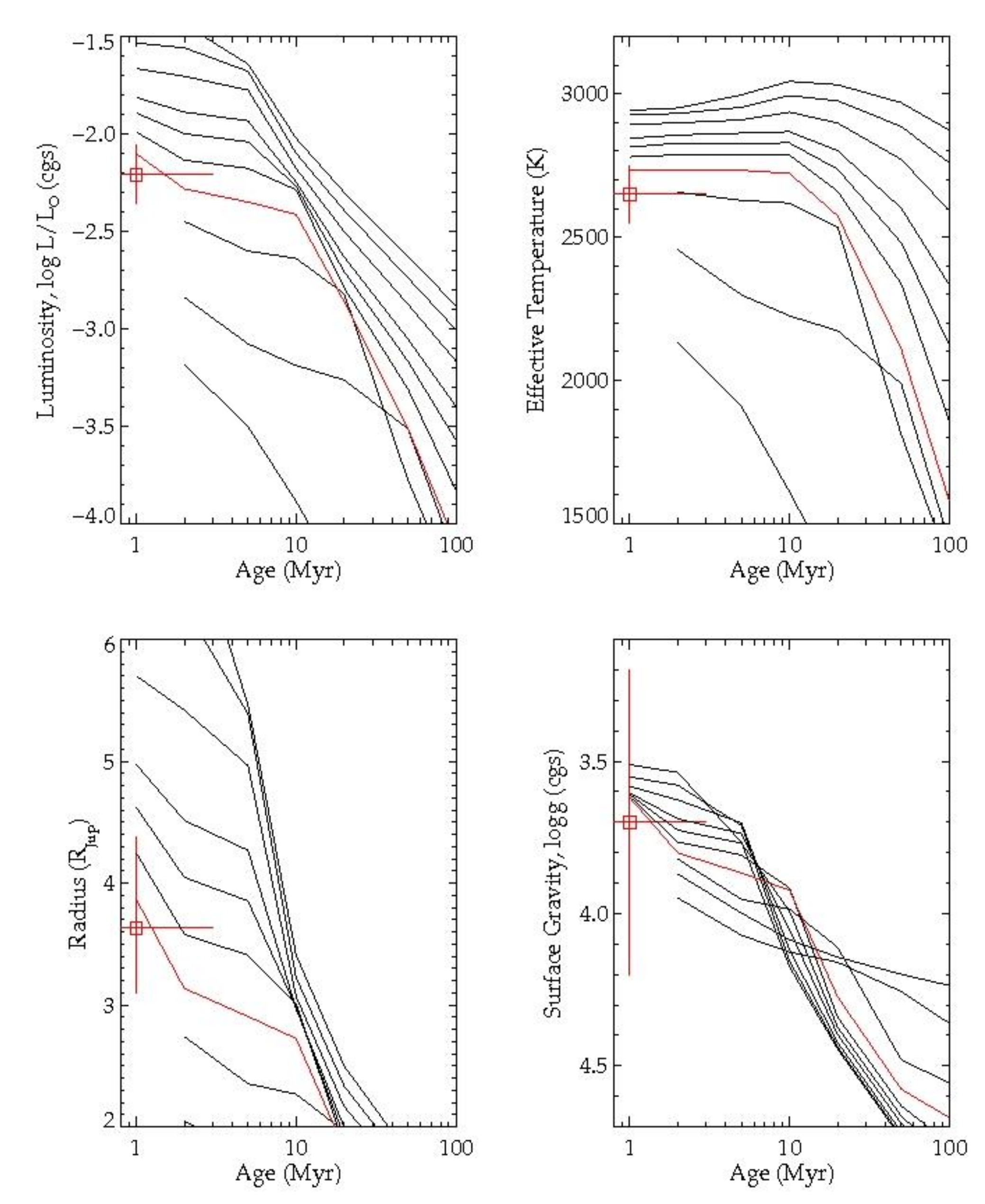
(Burrows et al. tracks for masses 10 to 70 M_jup)

Determination of mass

By comparison with
evolutionary models
& tracks (hot start)

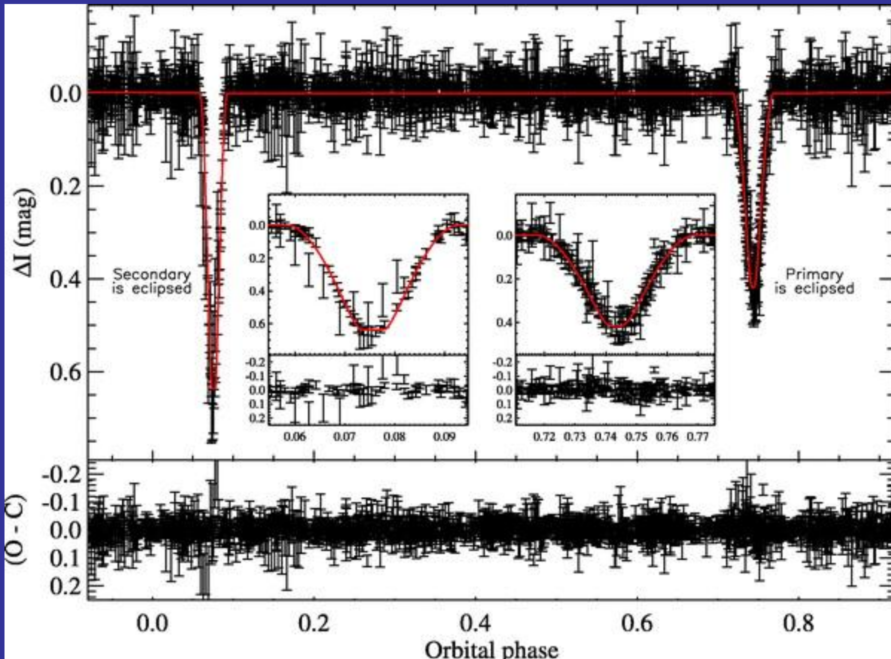
Observables:
Luminosity L
Temperature T
Gravity log g
Radius R
Age (of host star)

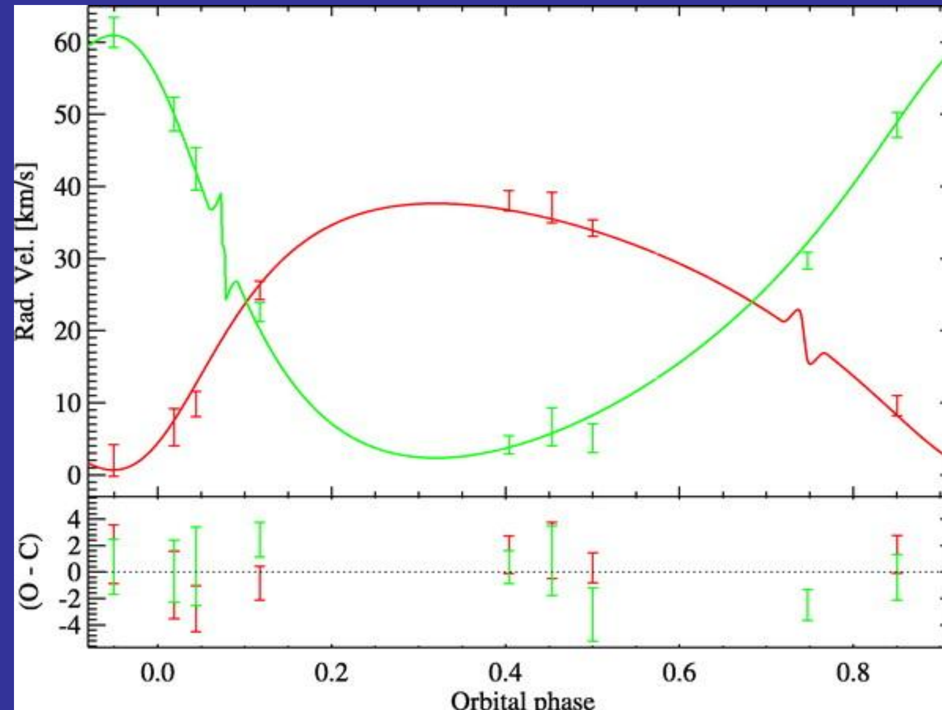
Model yields mass
of the companion



Example given here:
GQ Lup b and
Burrows et al. 1997 models
➔ 20-25 M_jup (4 to 36 M_jup), figure from Andreas Seifahrt PhD thesis (red: 25 Jup)

Calibrating tracks with eclipsing double-lined brown dwarf – brown dwarf binary (2M0535 in Orion region, i.e. few Myr)



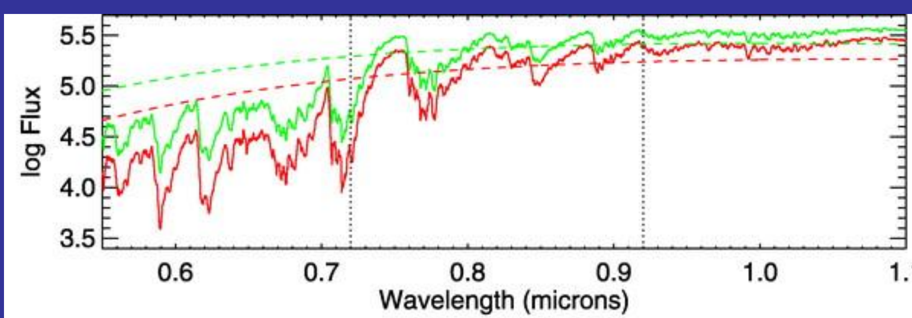


➔Masses from Kepler s 3rd law:

A has 59.5 4.8 M_jup but spots

B has 37.5 2.9 M_jup

(Stassun et al. 2007 Nat. & ApJ)



➔YETI goal: more eSB2 BD-BDs at different masses and ages

Observables:

Object name	Luminosity $\log(L_{bol}/L_\odot)$	Magnitude M_K [mag]	Temperature T_{eff} [K]	Age [Myrs]	References
Reference object (eSB2 brown dwarf - brown dwarf binary 2M0535):					
2M0535 A	-1.65 ± 0.07	5.29 ± 0.16	2715 ± 100	0.1-3	Stassun 07
B	-1.83 ± 0.07	5.29 ± 0.16	2820 ± 105	0.1-3	Stassun 07
Directly detected planet candidates:					
DH Tau b	-2.75 ± 0.10	8.31 ± 0.23	2750 ± 50	0.1-4	Itoh 05
GQ Lup b	-2.38 ± 0.25	7.67 ± 0.16	2650 ± 100	0.1-3	Neuh. 05
2M1207 A	-2.76 ± 0.05	8.35 ± 0.05	2425 ± 160	5-12	Chau. 05a
b	-4.75 ± 0.06	13.33 ± 0.12	1590 ± 280	5-12	Chau. 05a
AB Pic b	-3.76 ± 0.06	10.85 ± 0.11	2040 ± 160	20-40	Chau. 05b
CT Cha b	-2.68 ± 0.21	8.83 ± 0.50	2600 ± 250	0.1-4	Schmidt 08
1RXSJ1609 b	-3.57 ± 0.15	10.36 ± 0.35	early L	1-10	Lafr. 08
HR 8799 b	-5.1 ± 0.1	12.66 ± 0.11		30-1000	Mar. 08
c	-4.7 ± 0.1	11.74 ± 0.09		30-1000	Mar. 08
d	-4.7 ± 0.1	11.56 ± 0.16		30-1000	Mar. 08
Fom b	≤ -6.5	$M_H \geq 23.5$		100-300	Mar. 08
β Pic b		$M_{L'} = 9.8 \pm 0.3$		8-20	Lagr. 09

Model derived masses:

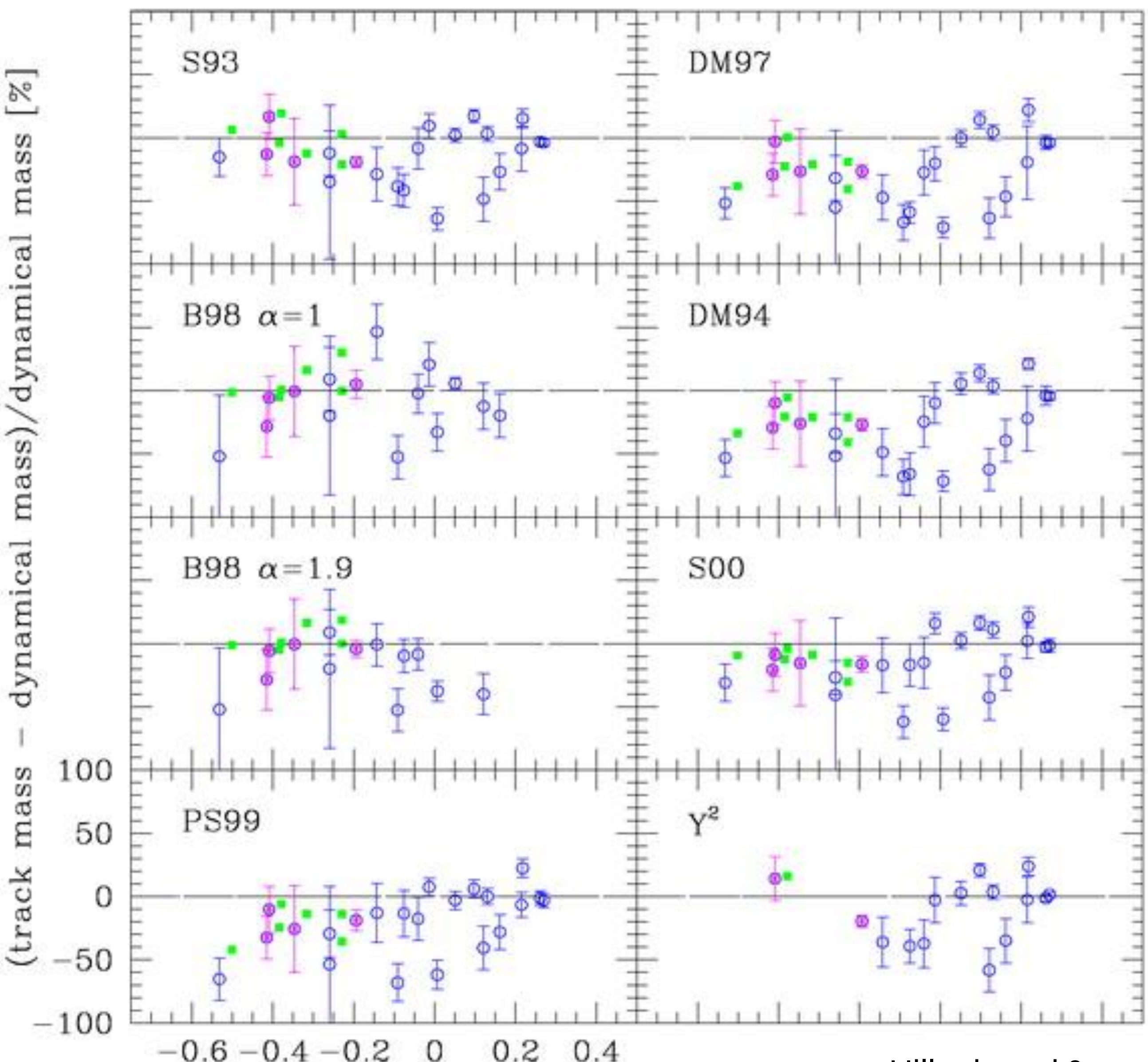
Object name	Burrows 1997 (L, age)	Chabrier 2000 (L, T, K, age)	Baraffe 2003 (L, T, K, age)	Marley 2007 ($\geq$ 10 Jup)	Baraffe 2008 ($\geq$ 10 Myrs)
Reference object (eSB2 brown dwarf - brown dwarf binary 2M0335):					
2M0535 A	50 (45-60)	55 (30-60)	50 (45-80)		
B	37 (33-46)	45 (40-50)	43 (40-65)		
Directly detected planet candidates:					
DH Tau b	14 (12-19)	11 (10-20)	10 (7-20)		
GQ Lup b	19 (16-30)	22 (12-30)	17 (12-32)		
2M1207 A	18 (18-19)	20 (17-23)	19 (15-21)		
b	4 (3-5)	4 (2-5)	3 (1-4)	3-5	4
AB Pic b	13.5 (13-14)	15 (11-20)	13 (11-20)		
CT Cha b	17 (11-23)	12 (8-25)	12 (6-30)		
1RXSJ1609 b	9.5 (4-14)	8 (3-13)	8 (3-12)	4-8	
HR 8799 b	5-30	$\leq$ 30	4-30	$\geq$ 5	$\geq$ 4
c	8-45	7-40	7-40	$\geq$ 7	$\geq$ 7
d	8-45	7-40	7-40	$\geq$ 7	$\geq$ 7
Fom b	$\leq$ 4		$\leq$ 3	$\leq$ 3	$\leq$ 2
β Pic b		6-10	6-12		

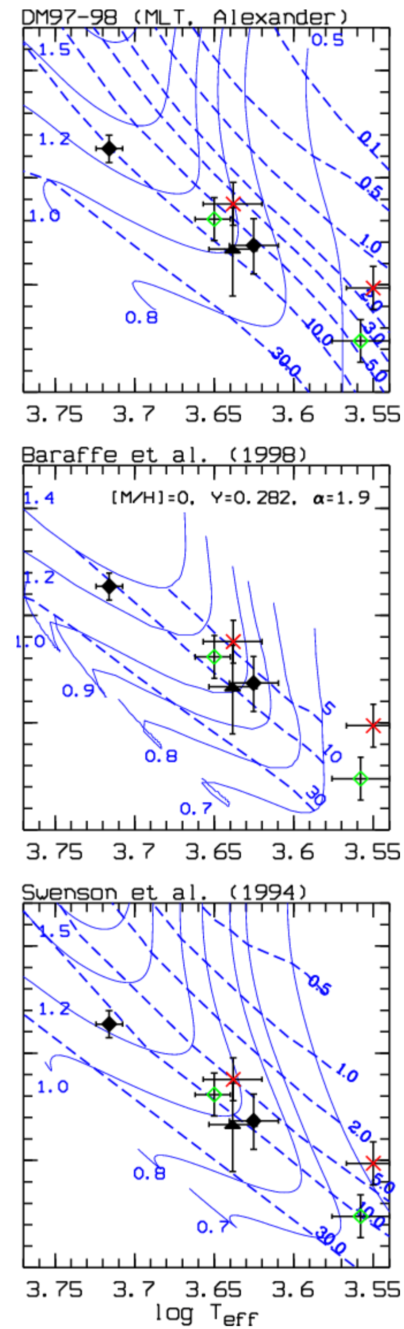
true 37.5 jup

(Schmidt, RN, Seifahrt, Conf. Proc., astro-ph)

Testing and calibrating

Test with 27 pre-main sequence stars





„no models predict consistent masses below 0.5 solar masses“

Hillenbrand & White 2004 ApJ

Problem:
Hot-start model tracks may not be valid for objects younger than ~ 10 Myrs

Needed:
Mass estimate without hot-start model tracks

Possible solution:
High-resolution JHK-band spectra
Fits to model atmospheres → temperature T, extinction A(V), and gravity g

Then, Mag, A(V), and distance give luminosity L

Then, L & T give radius R

and finally R & g give mass !!!

VLT Sinfoni near-IR spectra (observations / U Jena)
Drift-Phoenix model atmospheres (theory / U Hamburg)

CT Cha b
and Drift-Phoenix
(Helling, Hauschildt):

T= 2600 K   250 K

A_V= 5.8   0.8 mag

Log g = 4.0   0.5 dex

➔ Mag, A_V and distance give luminosity L

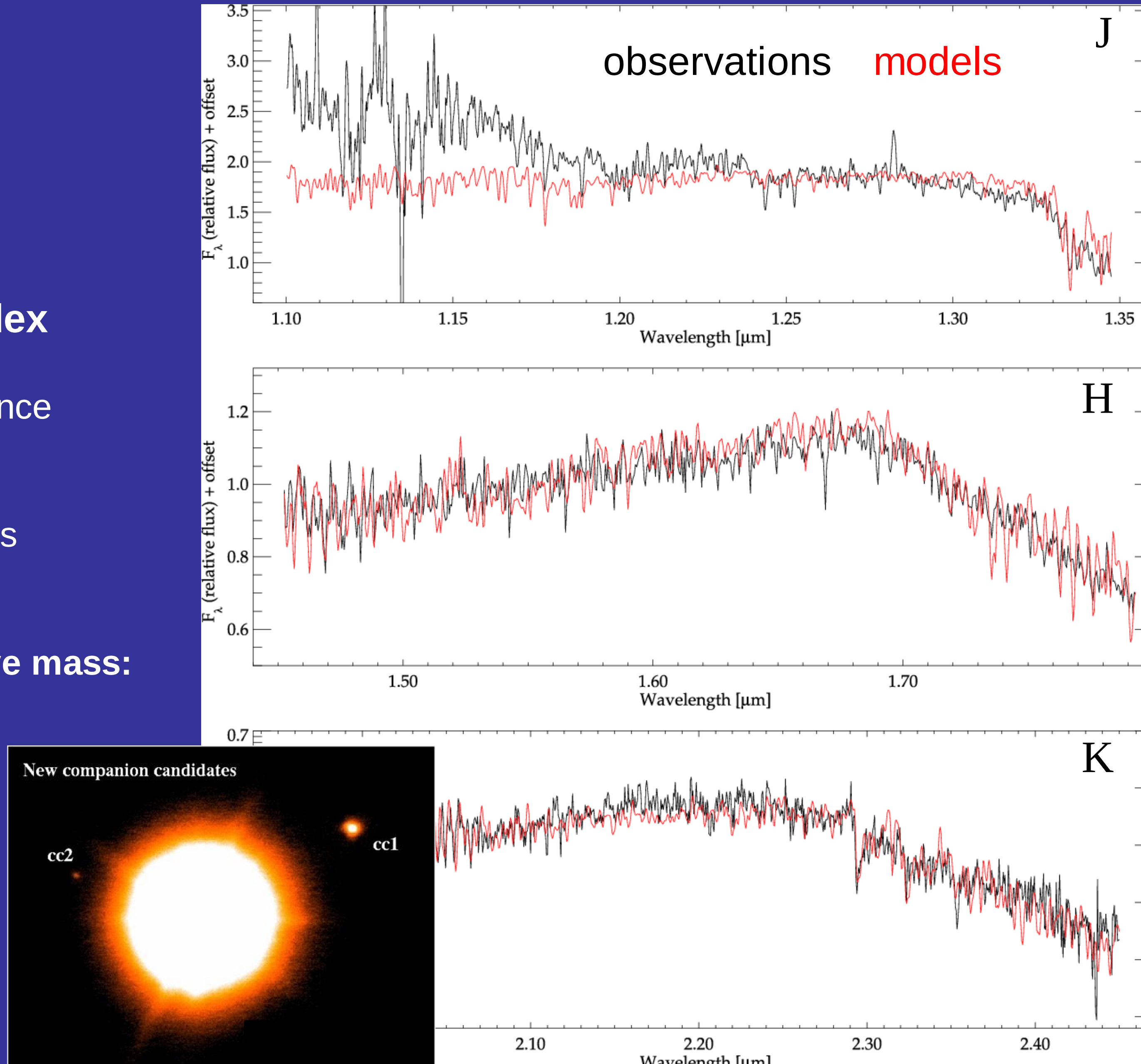
➔ L and T give radius (~ 2.2   0.7 R_jup)

➔ **L, T, R, and g give mass:**

~ 17   6 M_jup

(planet or BD ?)

Schmidt, Neuhäuser, et al. 2008 A&A



Conclusion:
Given the age ranges and all models,
Planet status is dubious in all cases but maybe Fomalhaut b and HR 8799 bcd

Problem:
Hot-start models differ a lot and may not be valid below ~ 10 Myrs

Solution:
Fitting higher-resolution spectra to model atmospheres → T, Av, and g
Mag, Av, and distance give luminosity L
L & T give radius R then Radius & gravity give mass

Problem here:
Gravity determination not yet precise enough (0.5 dex)

Direct imaging of planets can constrain and probe
→ Planet formation time-scale (youngest star with planet)
→ Migration scenarios (young exo-Jupiters at snow line ?)
→ Frequency of planets around (young) solar analogs
→ Is our solar system typical or not ?