Outstanding Brown Dwarf Questions

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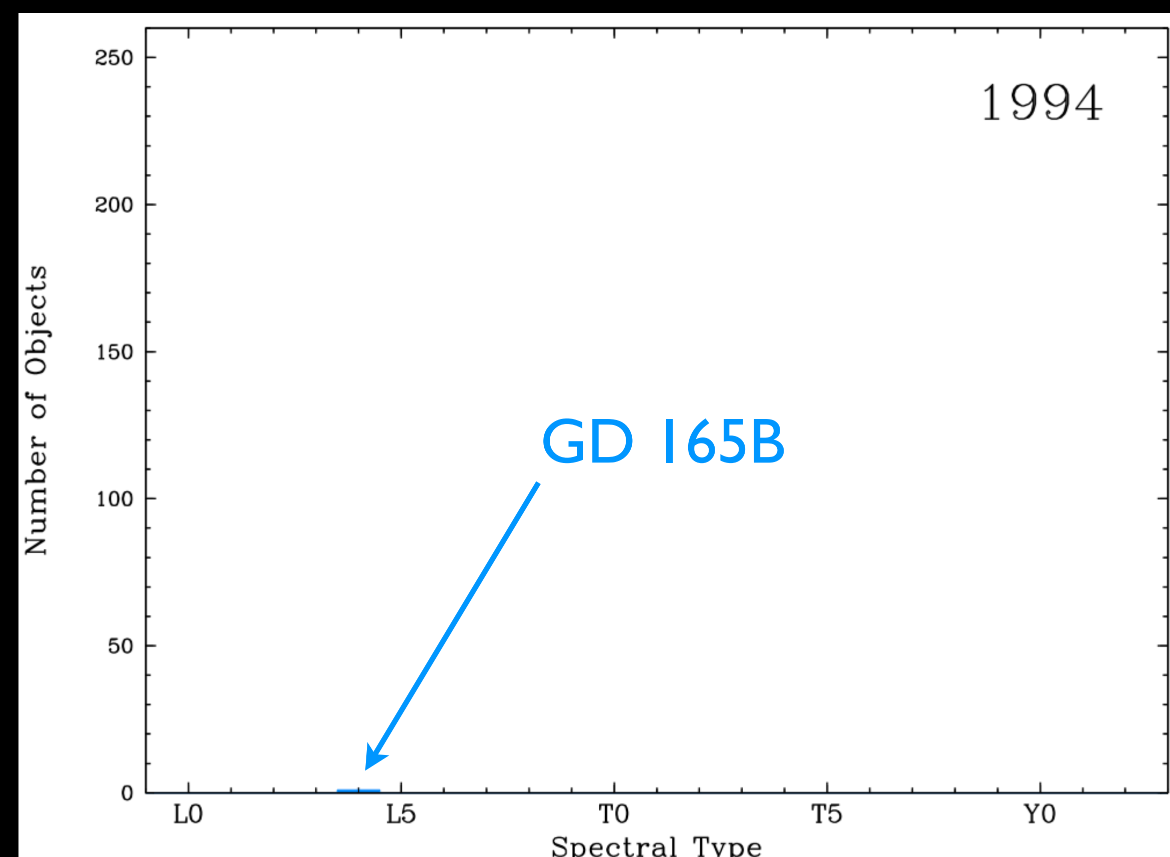
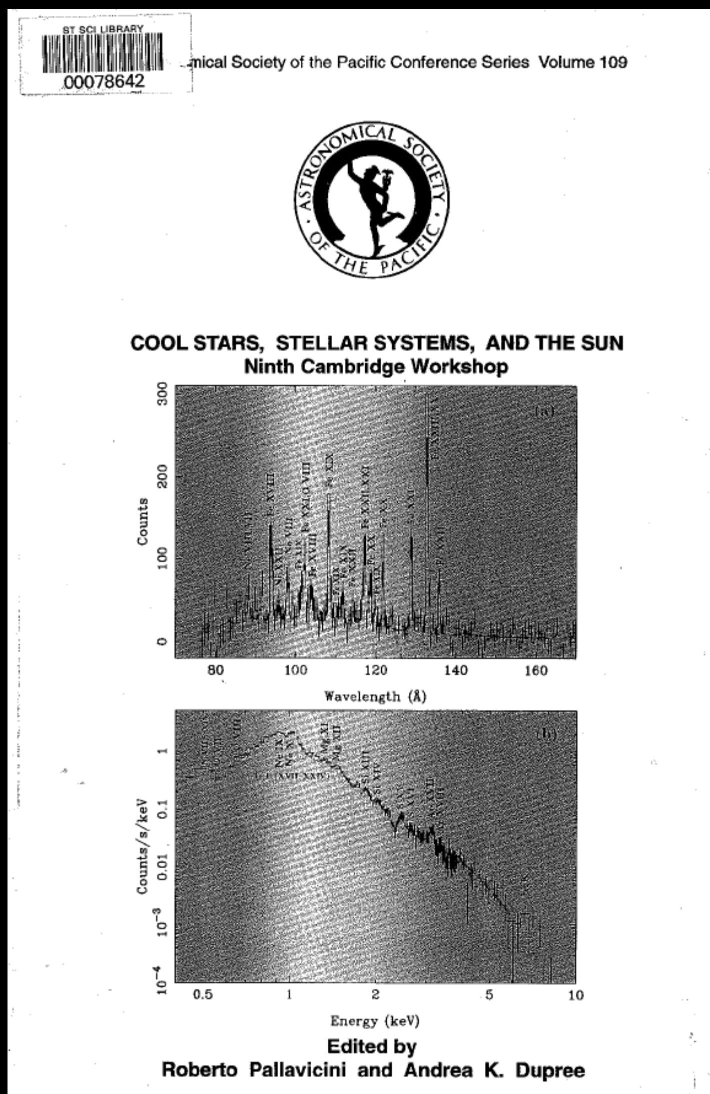
Artwork courtesy of ICE (IPAC Communications and Education)/R. Hurt

Once upon a time, the only question was "Do Brown Dwarfs Exist?"

1994



Gaia and the Unseen
The Brown Dwarf Question



...mical Society of the Pacific Conference Series Volume 109

COOL STARS, STELLAR SYSTEMS, AND THE SUN
Ninth Cambridge Workshop

Edited by
Roberto Pallavicini and Andrea K. Dupree

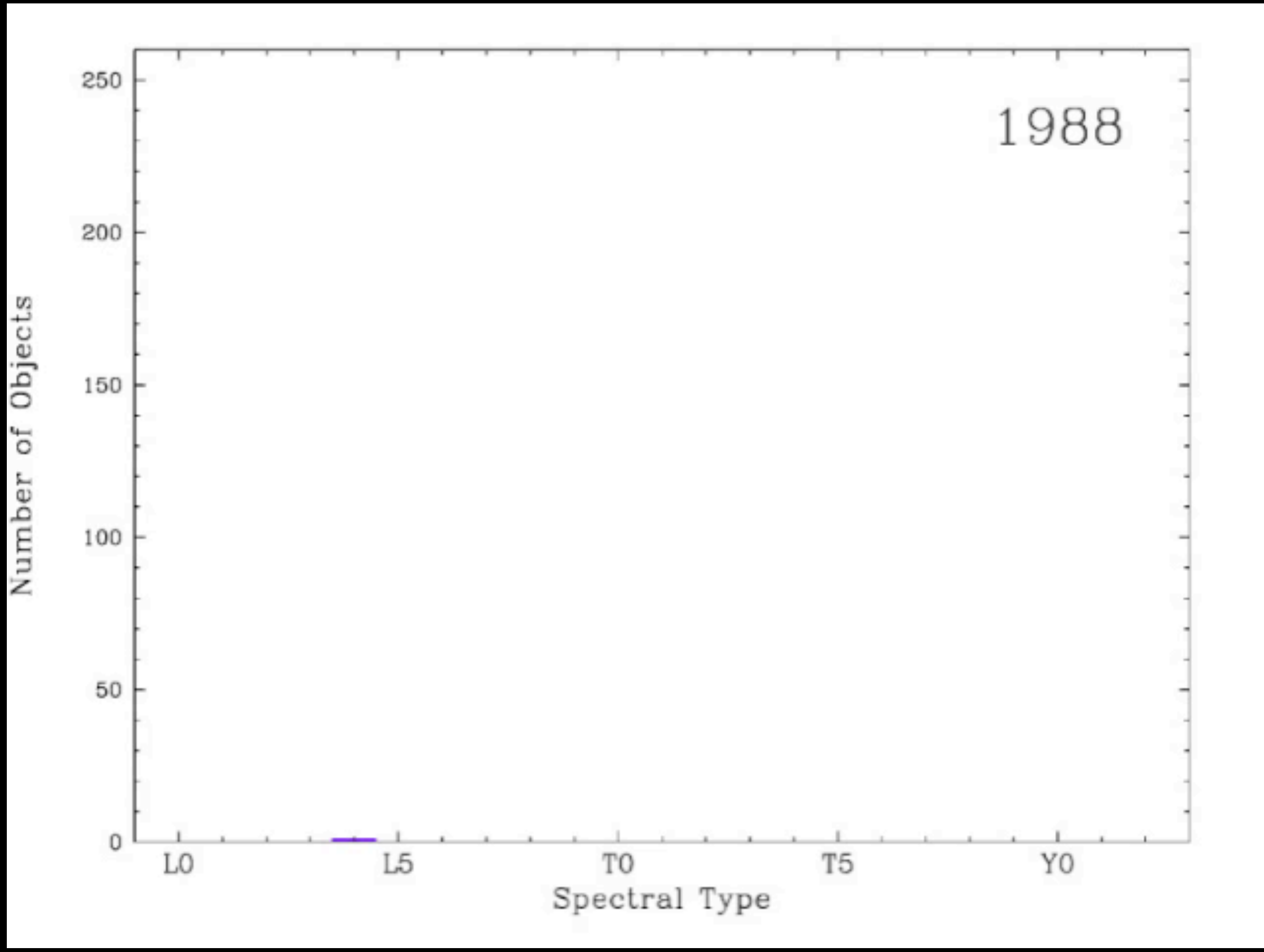
1995

That all changed a year later.

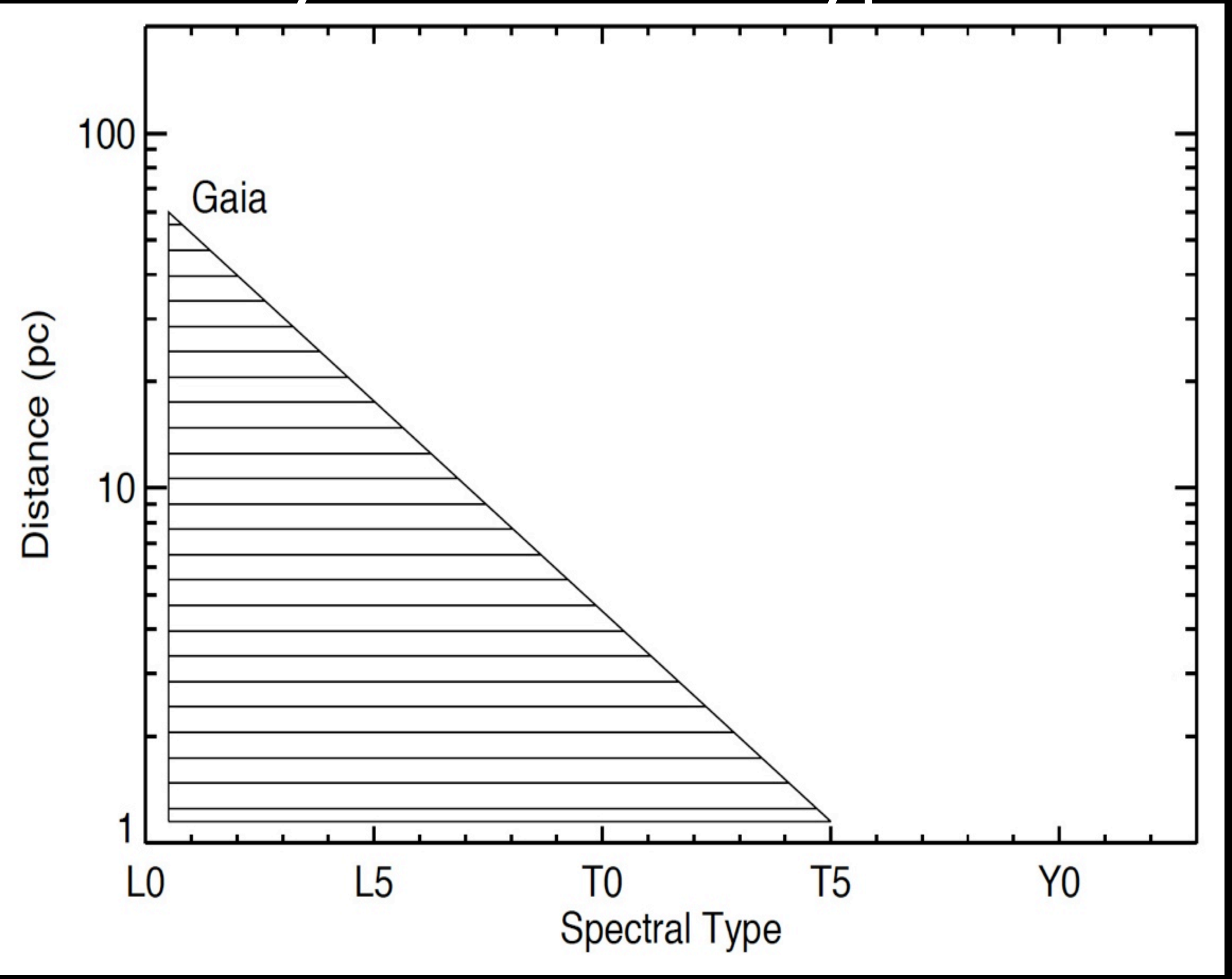
Geneva Obs. group announces 51 Peg b.

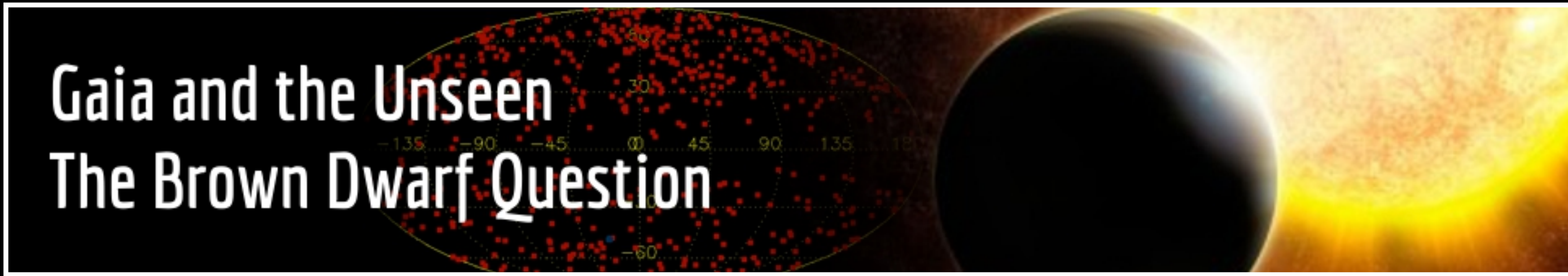
Caltech group announces Gl 229B.

The timeline of L, T, and Y discoveries; over 1500 now known



The approximate volume probed by Gaia at these types





To state them briefly, today's outstanding questions might be written as

How do brown dwarfs form?
What are their fundamental parameters?
What drives their atmospheric physics?
What aspects of BD science have we not foreseen?

1

How do brown dwarfs form?

ICE/T. Pyle

Partly depends upon definition!

Formation definition vs. mass definition

For the time being, lump brown dwarfs and planets together.

There are two main formation mechanisms

(1) From the collapse of an interstellar cloud

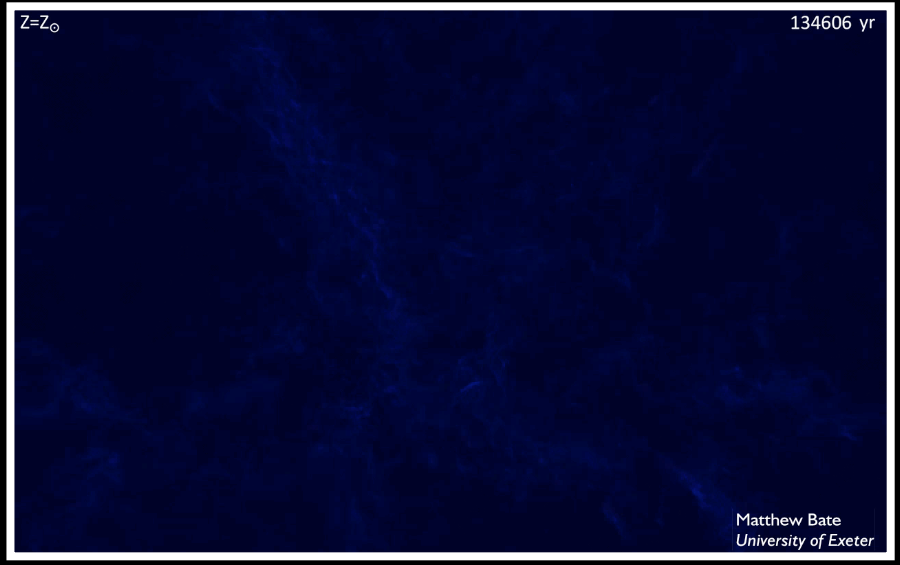
(2) From the evolution of a protoplanetary disk

Each of these mechanisms may have multiple branches

How important is the collapse of an interstellar cloud...

Turbulent fragmentation of gas

e.g., Padoan et al. 2005; Boyd & Whitworth 2005



Dynamical ejection of proto-stellar embryos

e.g., Reipurth & Clarke 2001; Bate & Bonnell 2005

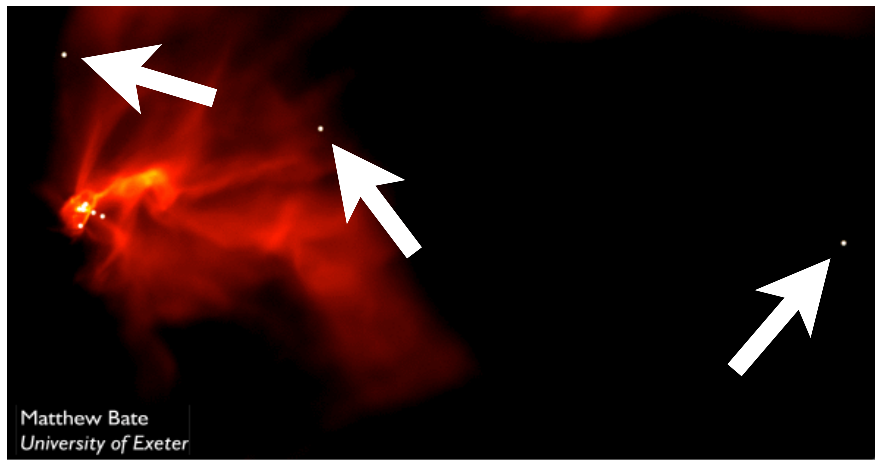
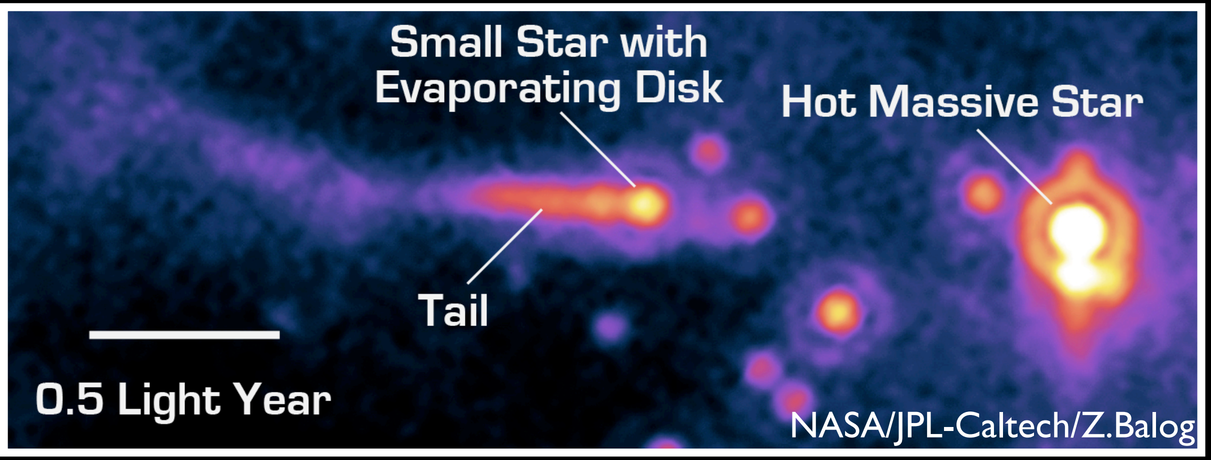
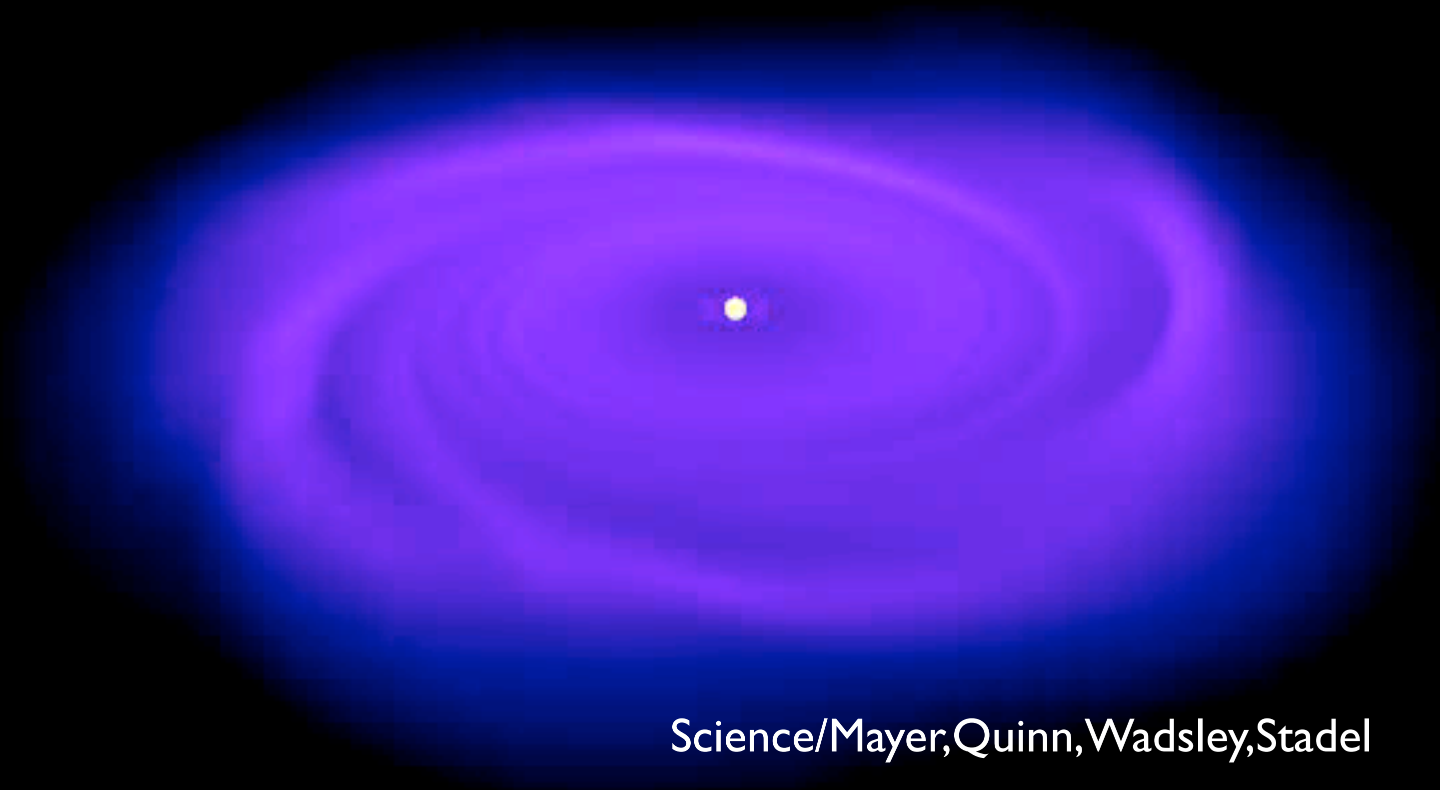


Photo-evaporation of embryos by hot stars

e.g., Kroupa 2001;
Whitworth & Zinnecker 2004

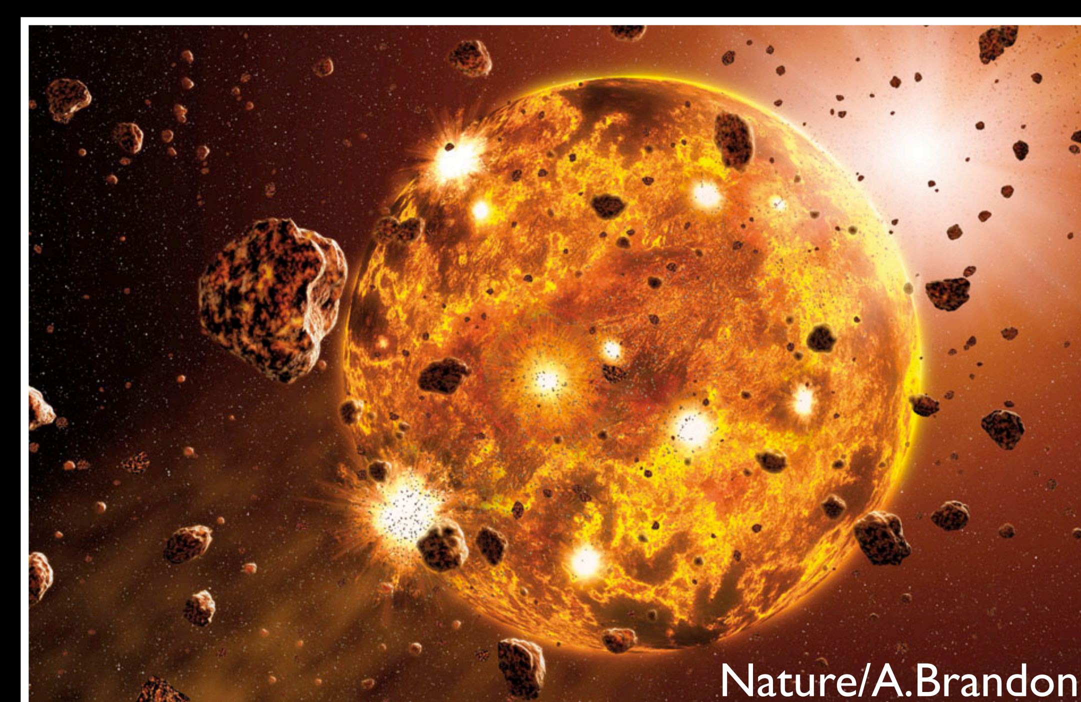


...vs. evolution of a protoplanetary disk?



Disk fragmentation

e.g., Goodwin & Whitworth 2007;
Basu & Vorobyov 2012



Core nucleation + gas accretion

e.g., Inaba et al. 2003;
Fortier & Benvenuto 2007

Which effect(s) is(are) dominant?

The incidence/tightness of binarity provides a clue as to whether ejection mechanisms play a big role.

The dominant effect may depend on environment:

> High-density star formation areas will have more dynamical interactions. Velocity dispersions of low-mass members are a strong clue.
>
> Regions with high-mass stars will have more photo-evaporation.

See also talk by Parker.

Which effect(s) is(are) dominant?

Kroupa et al. (2013)

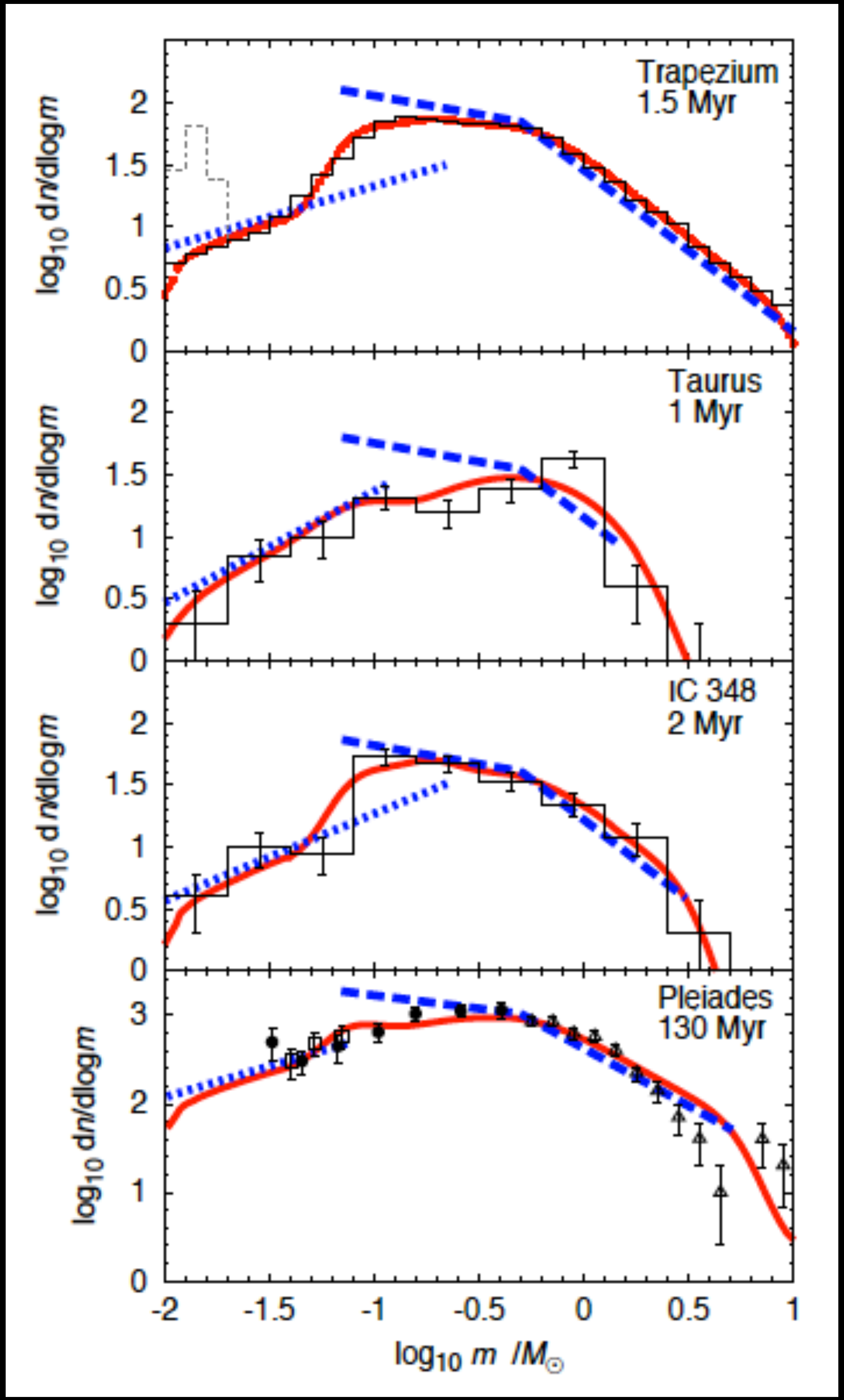
If BDs form primarily from gas fragmentation, they ought to follow the same binary pairing rules that stars do.

Simulations produce far too many wide BD-BD binaries; the observed distribution is very tight.

The observed incidence of star-BD pairs (the brown dwarf desert) disagrees with simulations assuming stars and BDs form via the same mechanism.

→ Like planets, BDs form from gravitationally pre-processed material.

(However, accretion disks around some BDs and indistiguishable spatial/velocity distributions in Taurus argue *for* a star-like birth process.)



Which effect(s) is(are) dominant?

Chabrier et al. (2014)

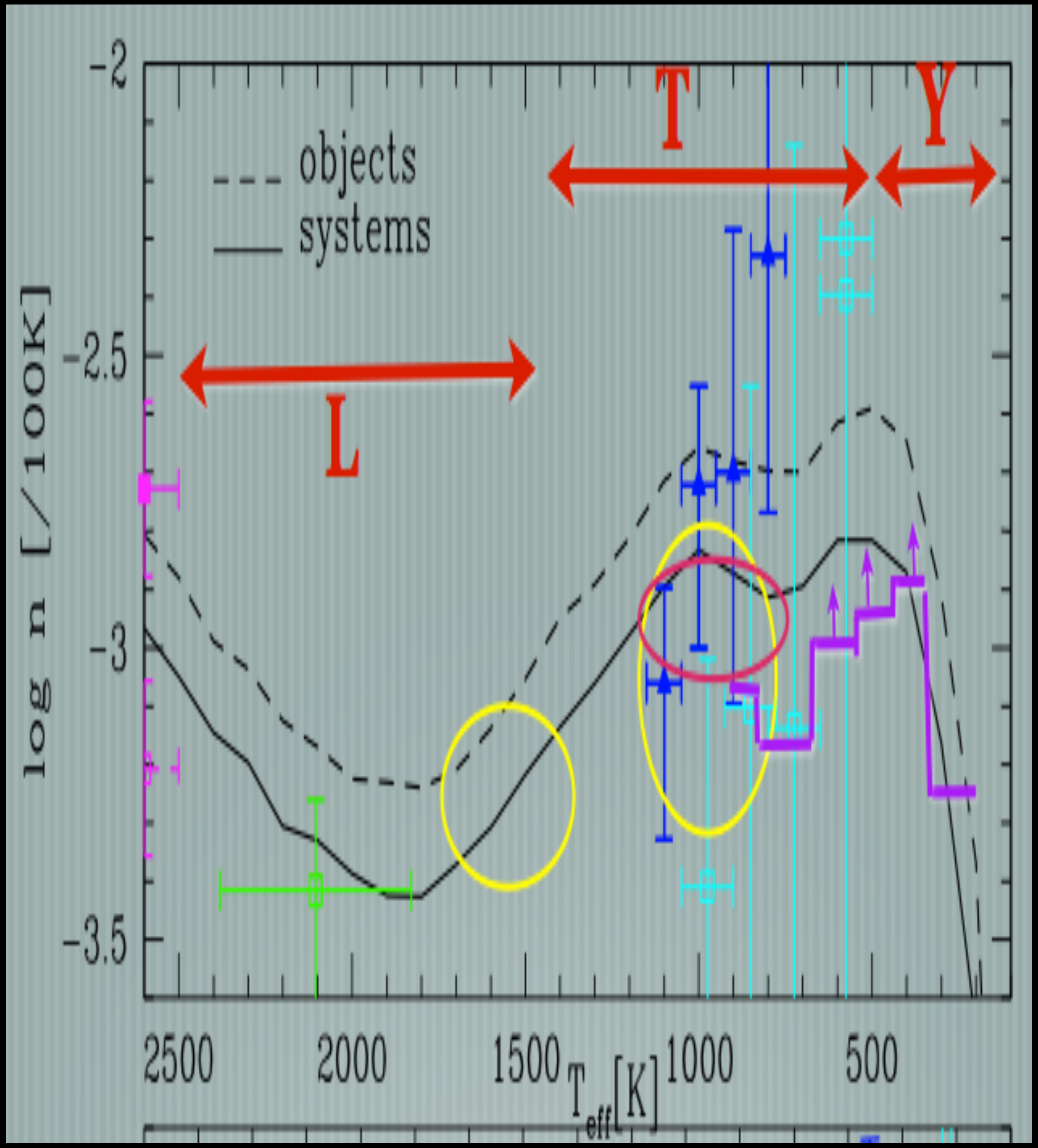
The BD mass function can be fit as an extension of the stellar power law + log-normal form.

BDs/stars share the same velocity/spatial distributions.

Given that the most weakly bound systems will not survive there is little evidence for differences in the binary distribution between stars and BDs. Also, wide BD+BD binaries, though rare, *do* occur.

The mass function of planets differs greatly from that of BDs, implying that planets and BDs do not form the same way.

Isolated brown dwarfs with disks are known, as is at least one pre-BD core.



→ BDs form the same way stars do.

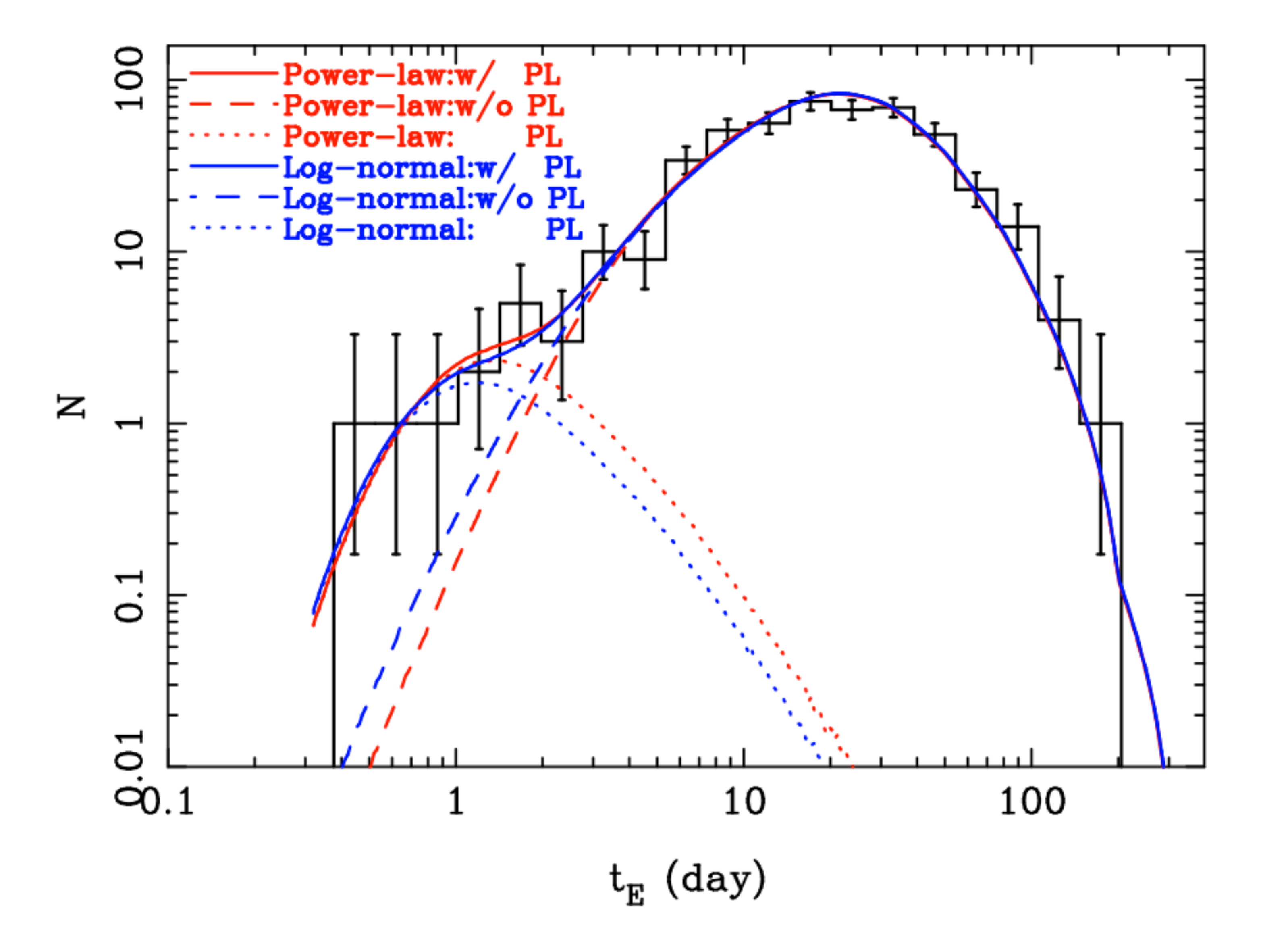
Which effect(s) is(are) dominant?

Sumi et al. (2012)

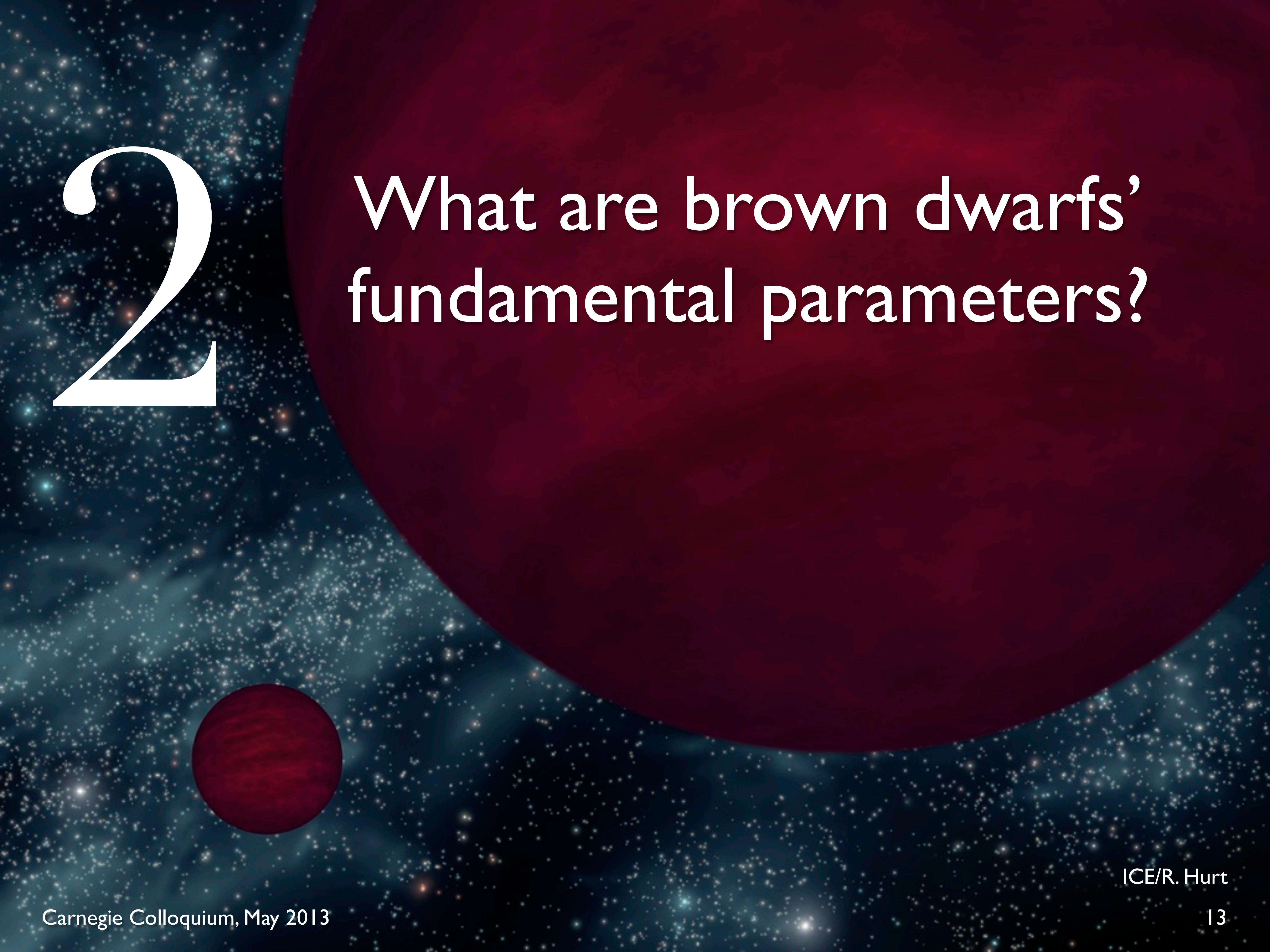
Microlensing results suggest that a vast population of sources with masses below ~10 M_{Jup} exist and are possibly solivagant planets.

A re-analysis by Quanz et al. (2012) suggests that at least some of these objects may instead by widely separated planets around M dwarf hosts.

Is this population real?



2 What are brown dwarfs' fundamental parameters?



ICE/R. Hurt

Gaia will provide 0.1-0.3 mas parallax precision for L dwarfs (Marocco et al. poster).

When combined with
Gaia G;
2MASS J, H, K_s;
WISE W1, W2, W3, W4
will result in exquisitely determined bolometric luminosities.

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L_{bol}

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R

T_{eff}

For transiting systems in which the individual component mags/spectra can be measured, L_{bol} and R provide model-independent measures of T_{eff} (see splinter session on model atmospheres).

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U,V,W

Gaia will provide v_{tan} values for L dwarfs to 10-30 m/s (Marocco et al. poster).

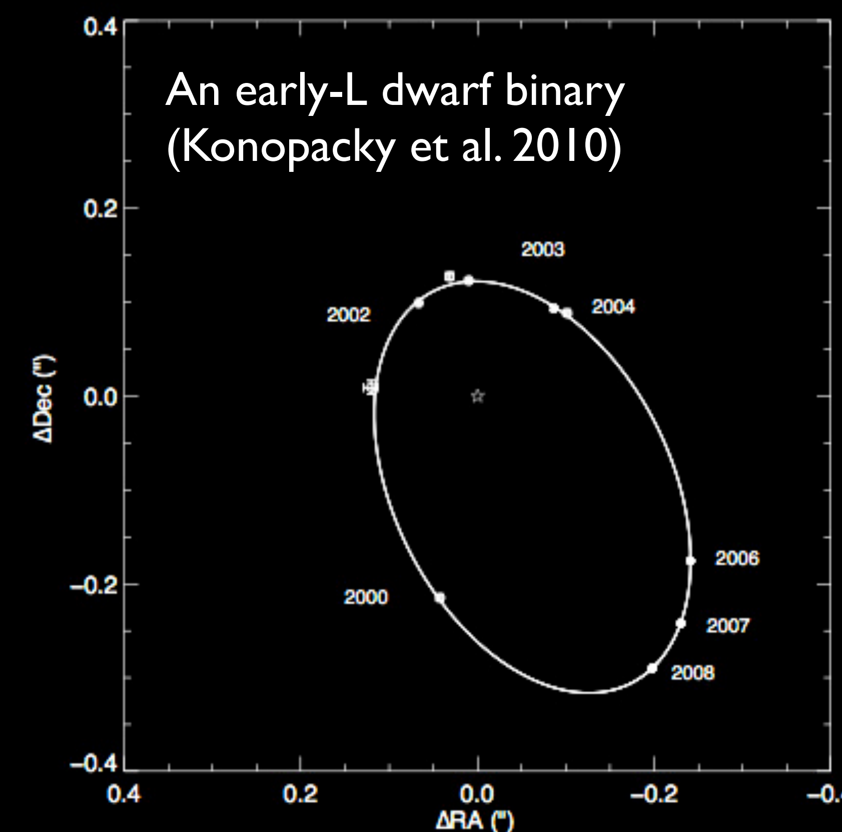
These will need to be combined with ground-based v_{rad} measures to produce space motions (see splinter session on moving groups).

M

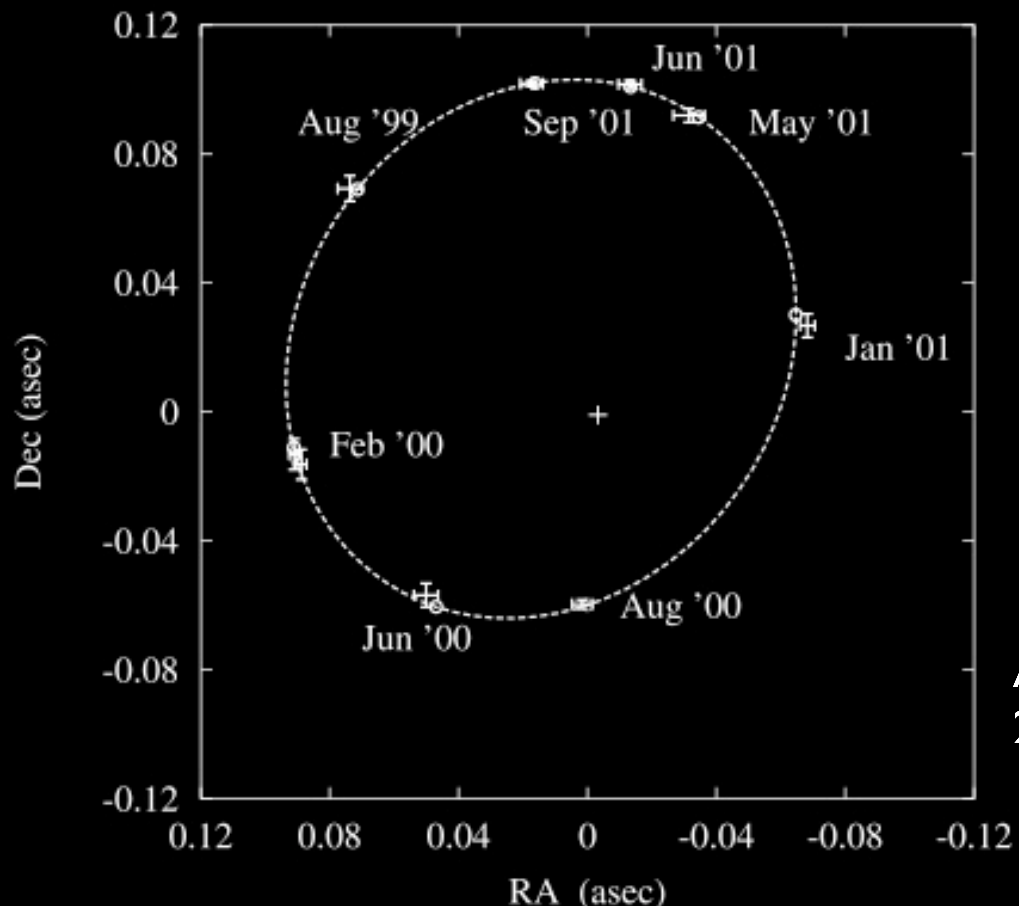
There are two ways of directly measuring mass

(1) Through dynamical interactions in binary systems
(See talk by Joergens)

There are few dynamical mass measurements for brown dwarfs so much more work is needed in this area (Konopacky 2013)



An early-L dwarf binary (Konopacky et al. 2010)



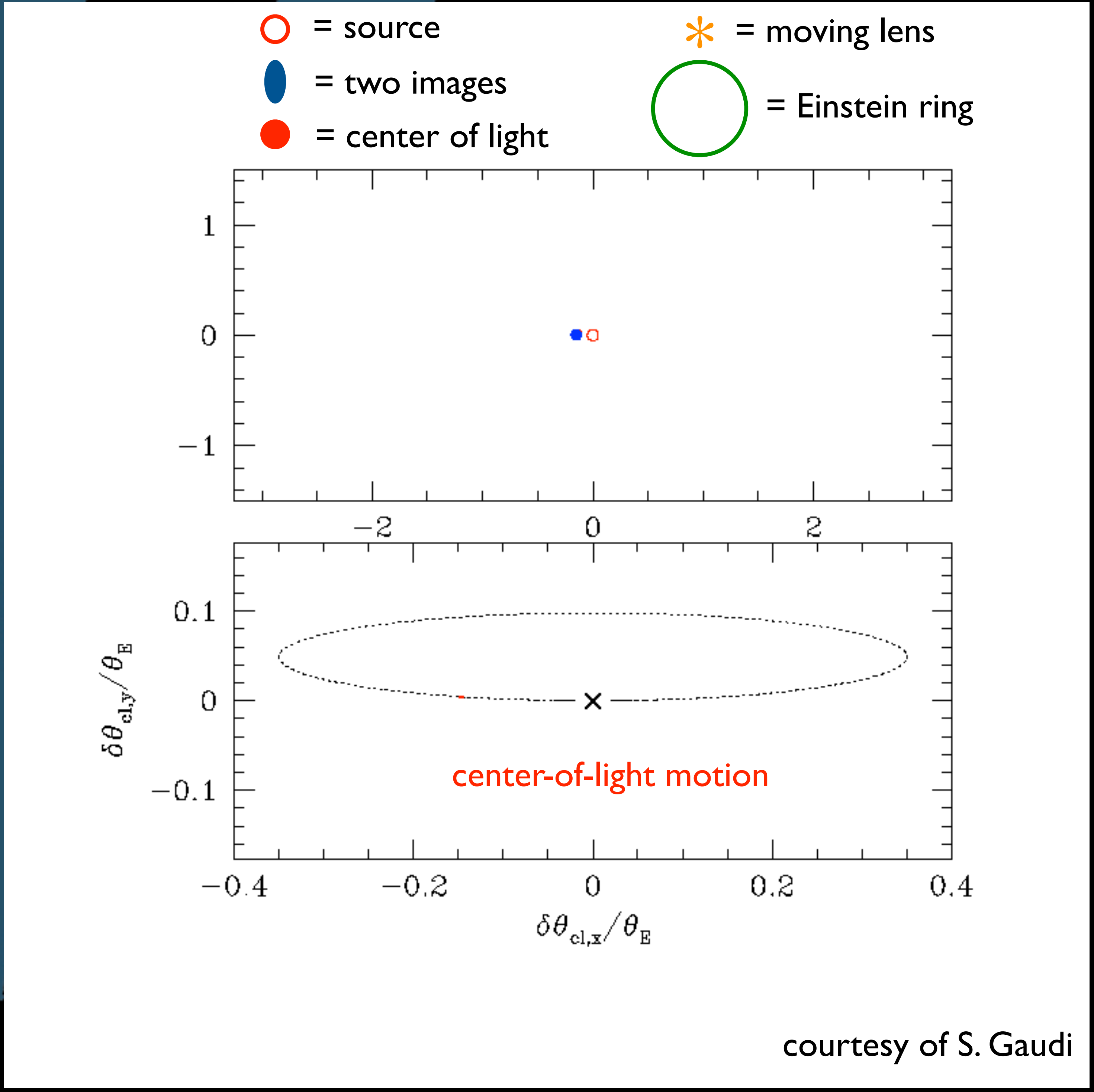
A late-M dwarf binary (Lane et al, 2001; Zapatero Osorio et al. 2004)

There are two ways of directly measuring mass

(2) Through microlensing of background objects
(See talk by Wyn Evans)

Gaia will uncover newly identified brown dwarfs against the Galactic Plane (see also talk by Beamin) whose future sky paths can be predicted with exceptional accuracy (see discussion in Cushing et al. 2014).

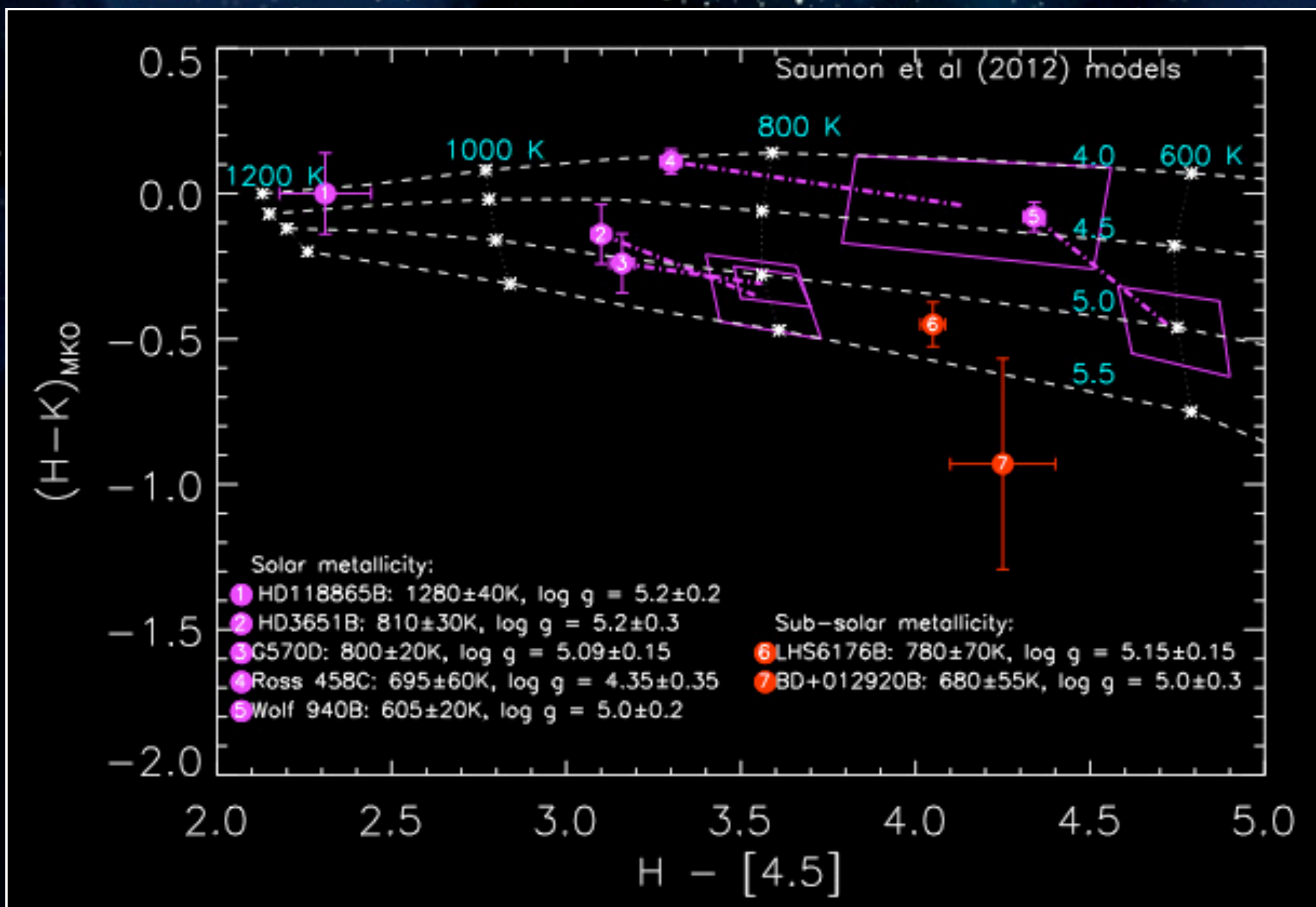
Future astrometric microlensing event by known objects are also being predicted (e.g., Proxima Cen by Sahu et al. 2014), and Gaia may be able to alert to unexpected events just beginning (Wyrzykowski & Hodgkin 2012).



Many brown dwarfs have now been cataloged as companions to main sequence stars whose ages are known.

These objects provide vital checks of the models:

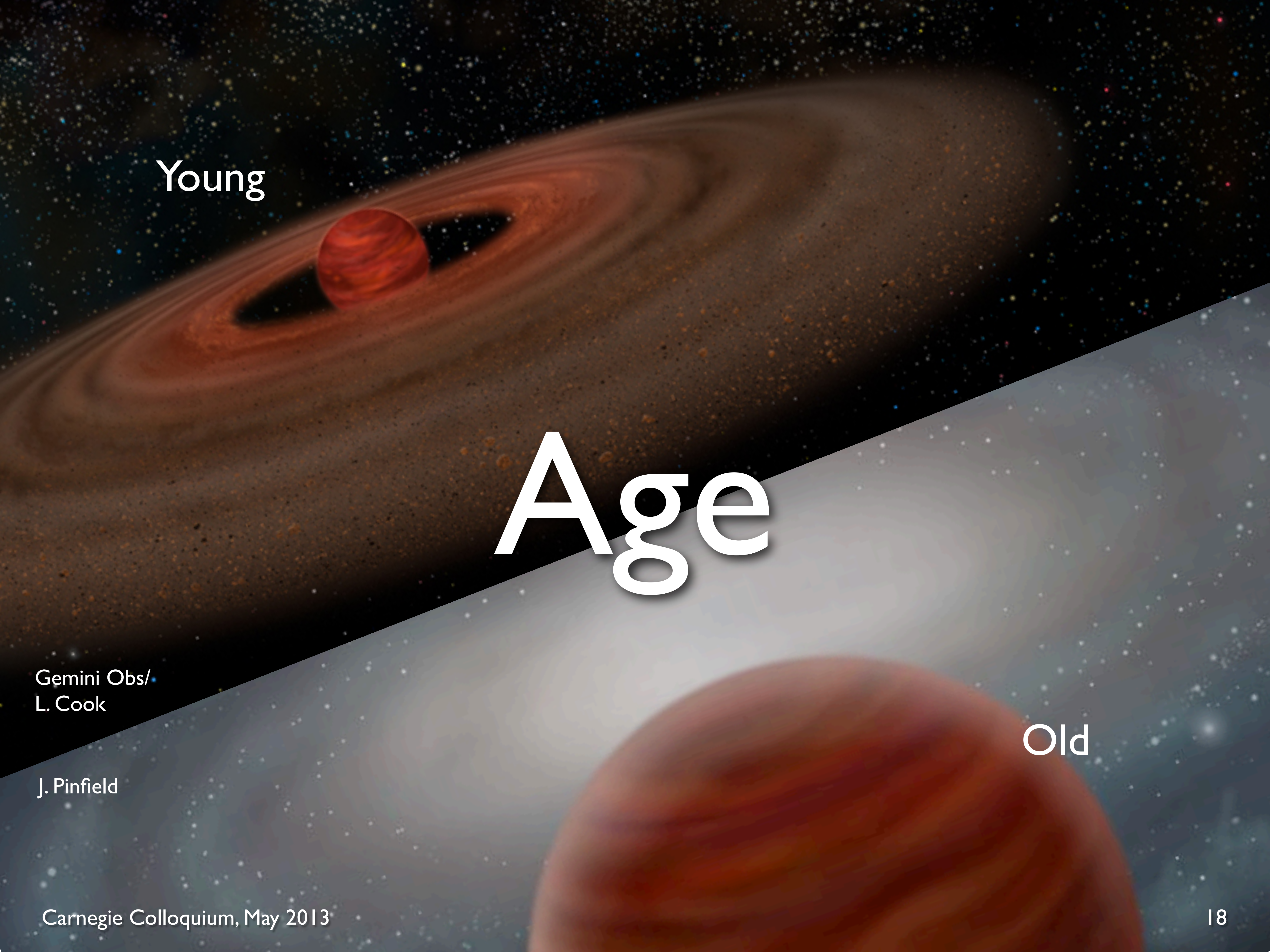
AGE



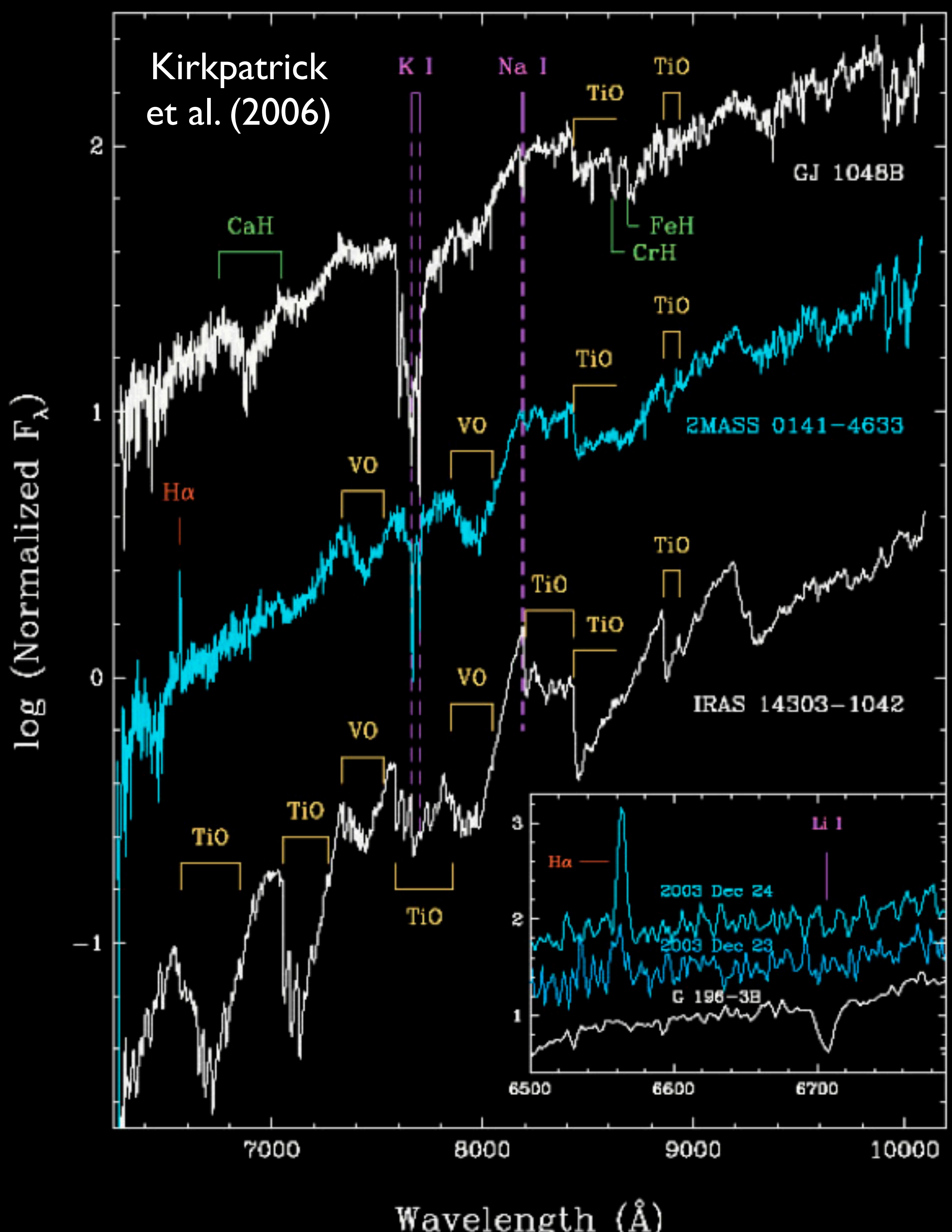
Burningham et al. (2013)

For companions to white dwarfs, see talk by Casewell.

J. Williams


Young
Age
Old
Gemini Obs/
L. Cook
J. Pinfield

Youth:



In the past, we've identified low-gravity (young) L dwarfs in the field and then tried to associate them with one of the nearby moving groups.

2MASS J0141-4633 was the first such solivagant field L dwarf.

It has a high probably of being a member of the Tucana-Horlogium Association (Gagne et al. 2014), at an age of 20-40 Myr.

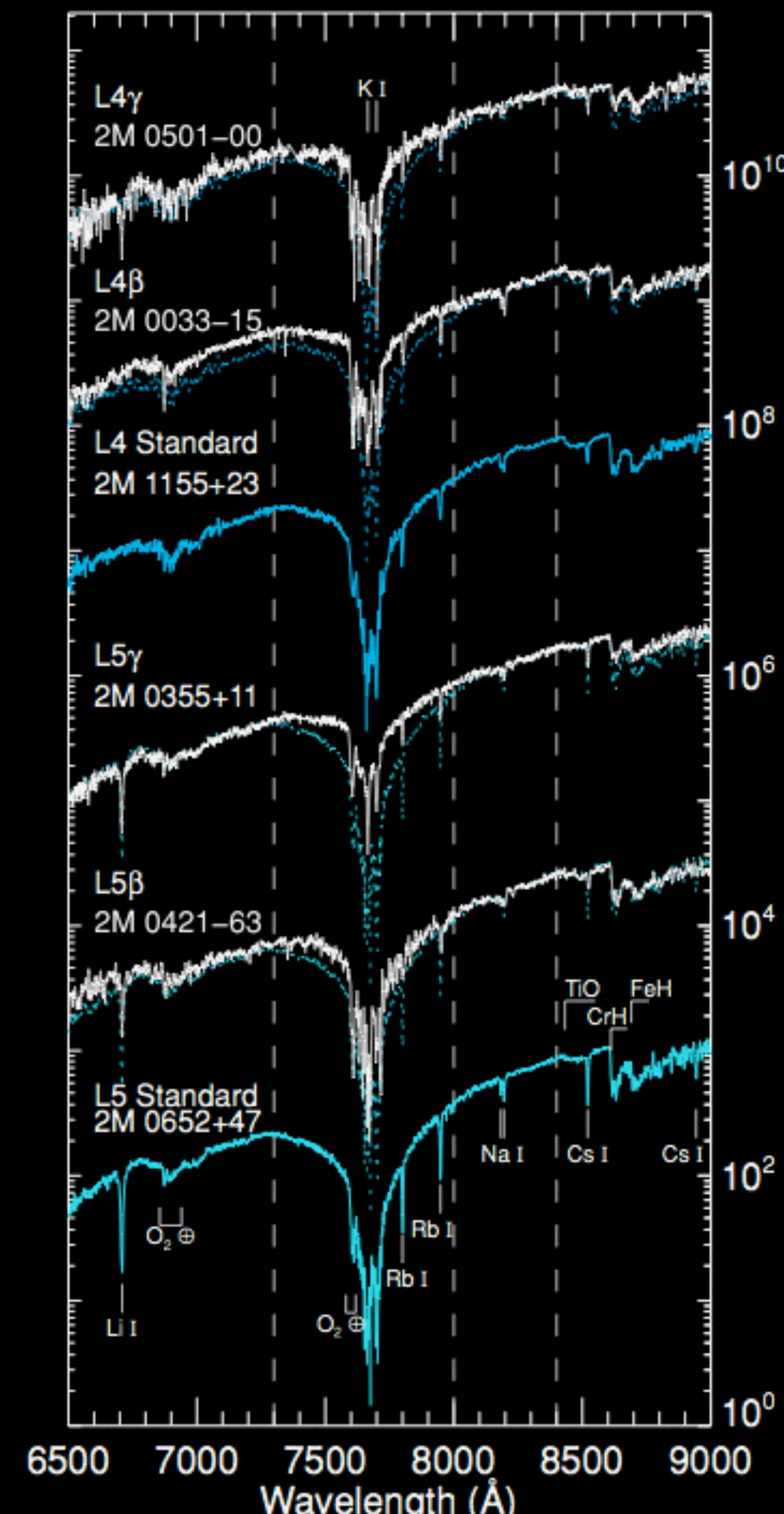
Since then, other teams have identified many more low-gravity L dwarfs in the Solar Neighborhood.

With the identification of many more examples, Cruz et al. (2009) established Greek letter suffixes to distinguish gravity types:

- α = normal gravity
- β = low-gravity features present
- γ = low-g features even more pronounced
- δ = low-g features even more extreme

The expectation was that this would be an age sequence:

- α >> 100 Myr
- β ~ 100 Myr
- γ ~ 10 Myr
- δ ~ 1 Myr



Group	Age (Myr)	# β's	# γ's
AB Dor	70-120	1	1
Argus	30-50	2	1
Tuc-Hor	20-40	1	9
Columba	20-40	0	3
β Pic	12-22	0	2
TW Hya	8-12	0	1

Data compiled from Gagne et al. (2014)

The separation of subtype with age is certainly not as clean as we'd hoped. Although the β's tend to be older, the γ's are scattered throughout the age range.

See splinter session on age determinations

With new Gaia data, we can use BANYAN-style membership probability techniques to

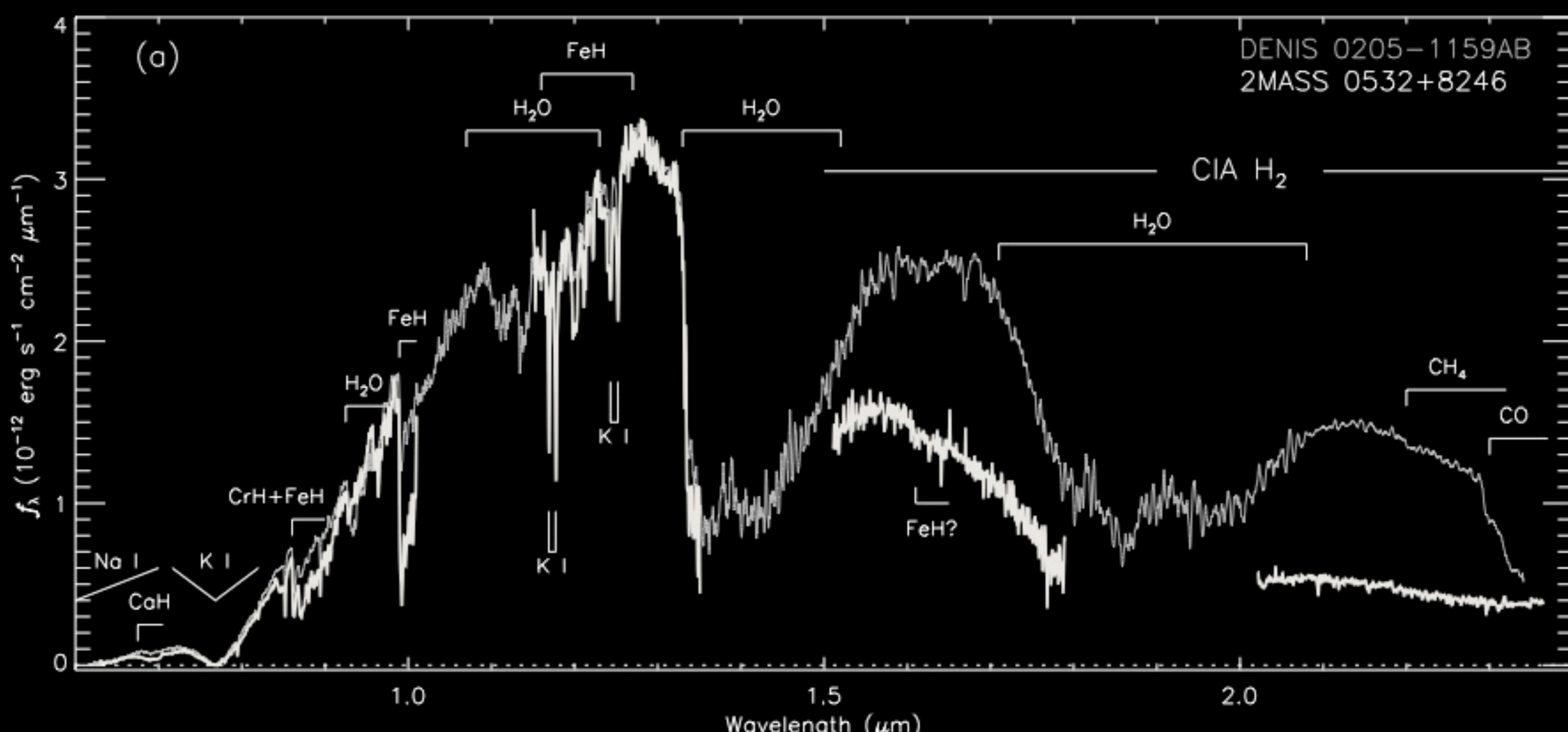
1) shore-up associations of known low-g objects
2) identify new members not yet recognized
3) even identify new moving groups all together

See talks by Mamajek and Malo

Old Age:

During a search for field T dwarfs, Burgasser et al. (2003) uncovered the first metal-poor L dwarf, 2MASS J0532+8246.

Object is believed to be a member of the halo population and falls below the hydrogen-burning limit (Burgasser et al. 2008).



New L and T subdwarfs are being discovered.

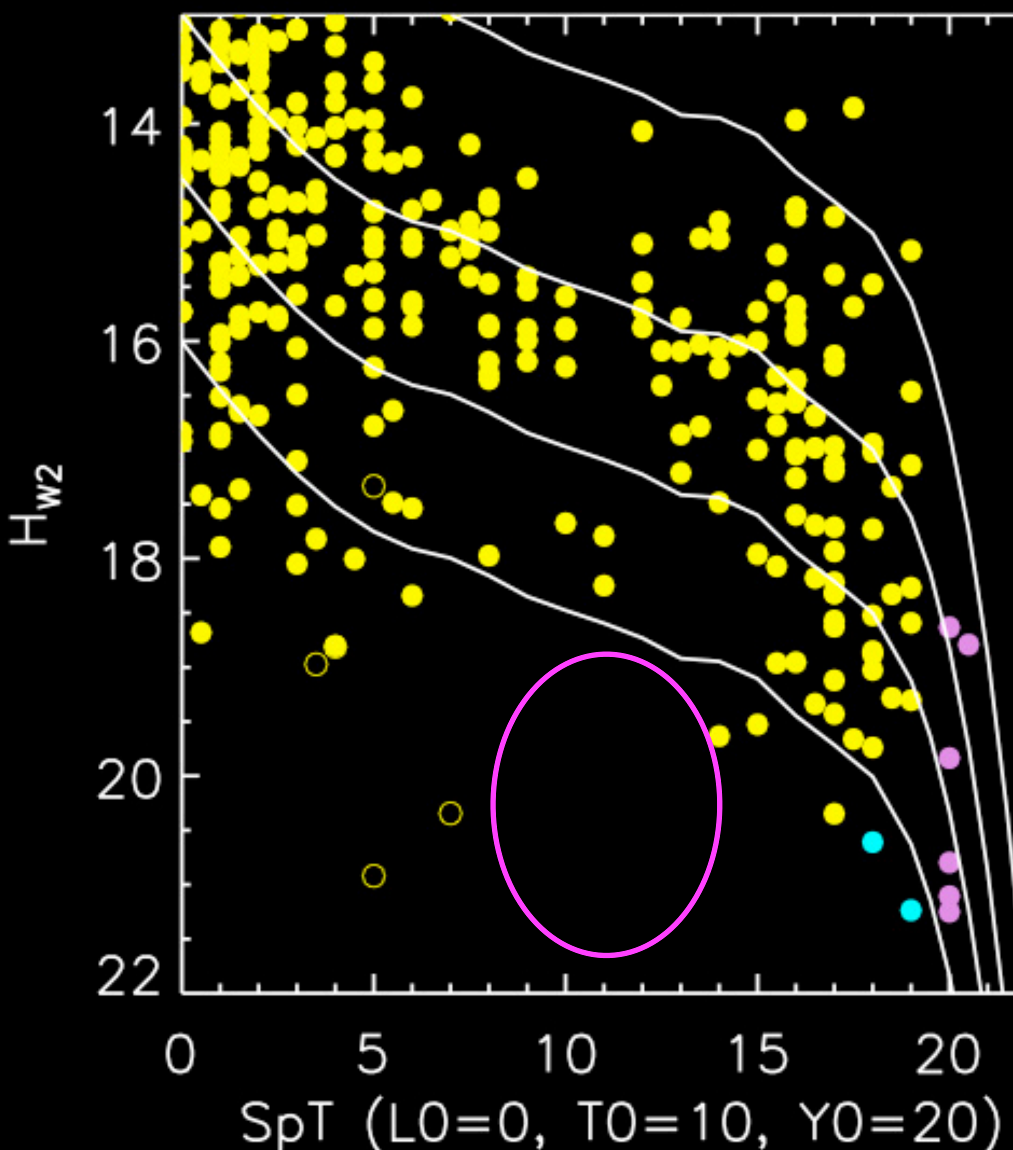
Because of their high kinematics, μ is a powerful tool in finding other examples.

Animation shows an artist's visible-light rendition of the motion of the early-L subdwarf WISE J2040+6959 over ~50 years.

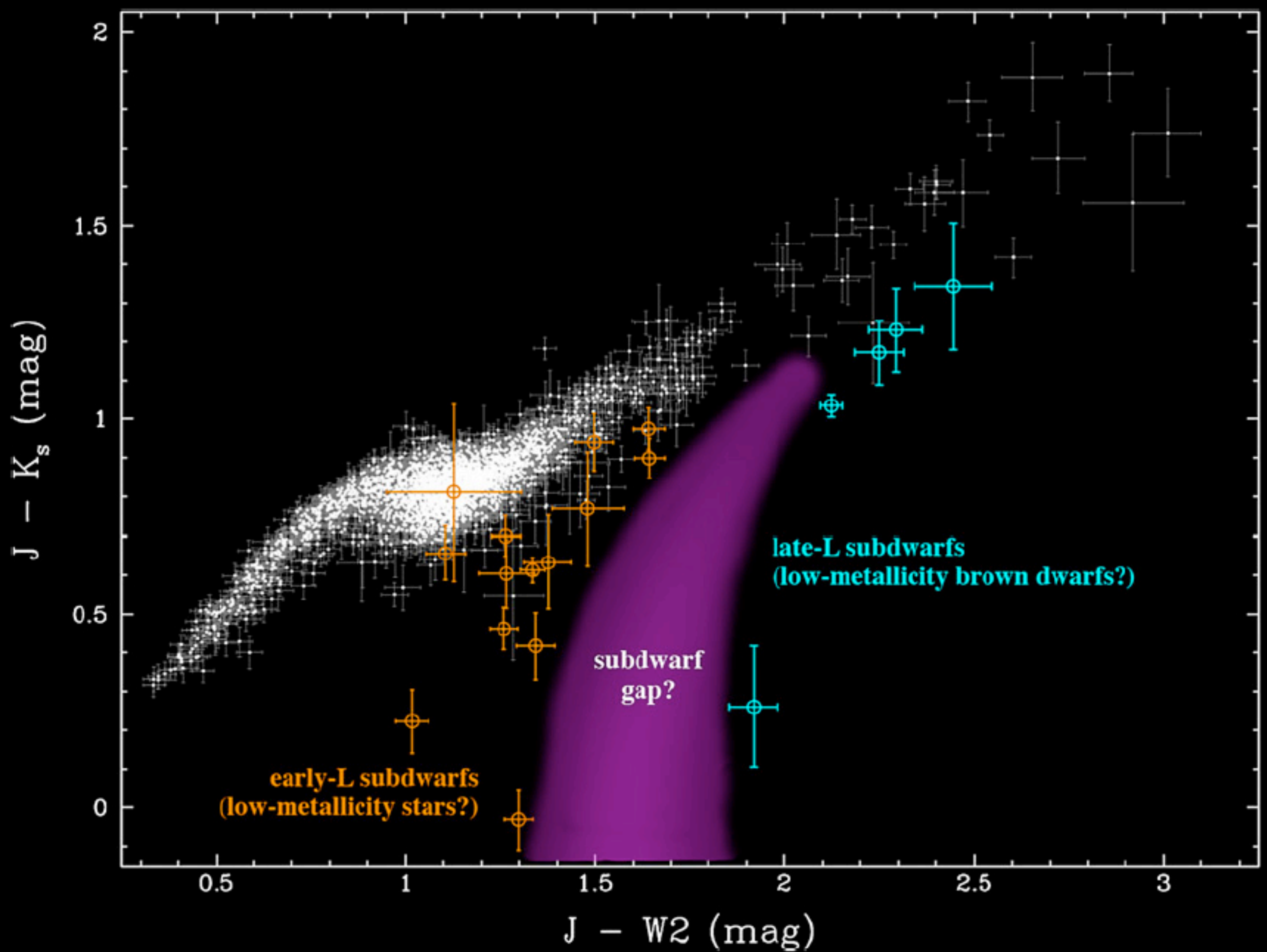
This object, moving at 2.3 arcsec/yr, was uncovered using motions measured by AllWISE.

Gaps in the spectral type distribution of subdwarfs are beginning to be seen.

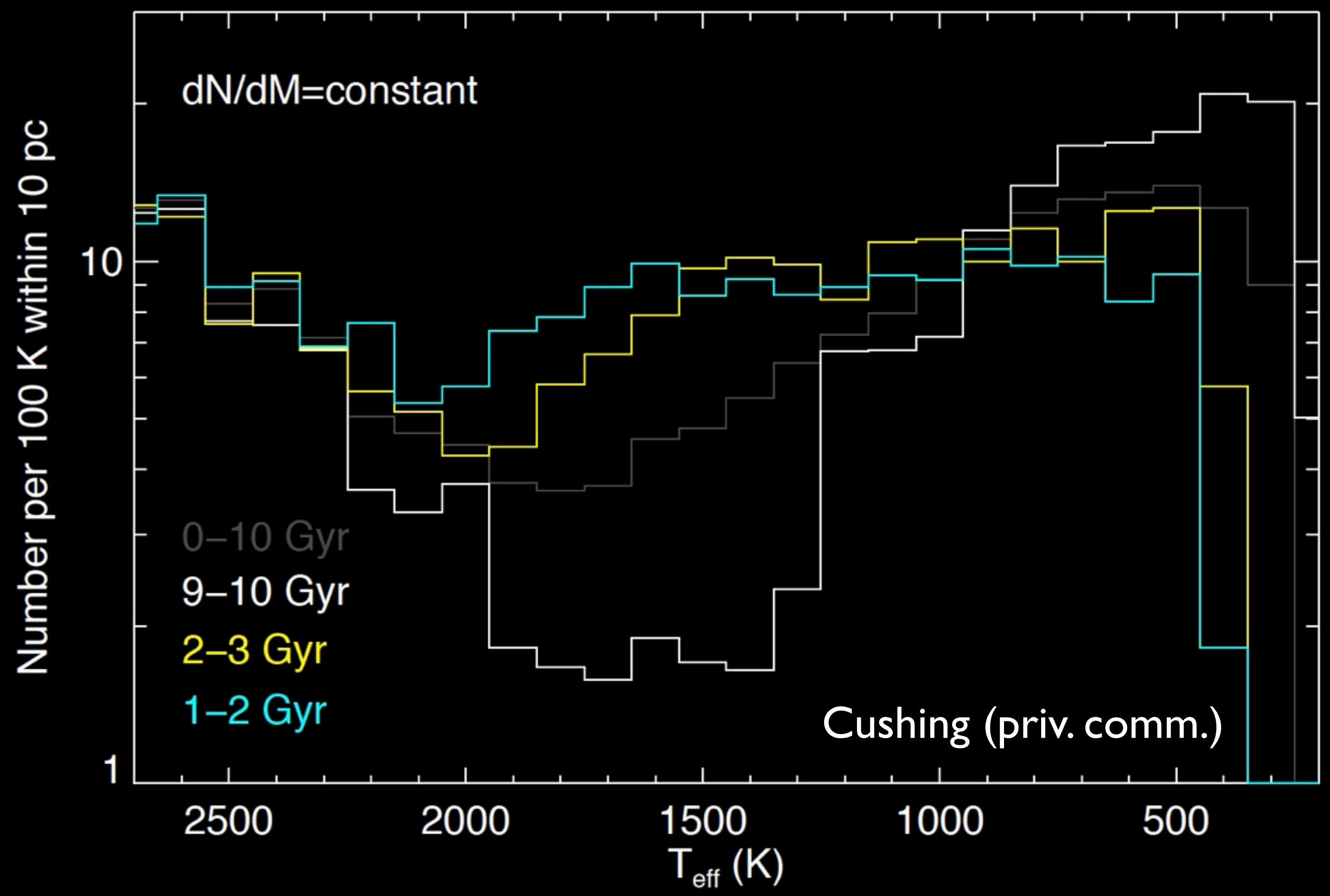
Pinfield et al. (2014)

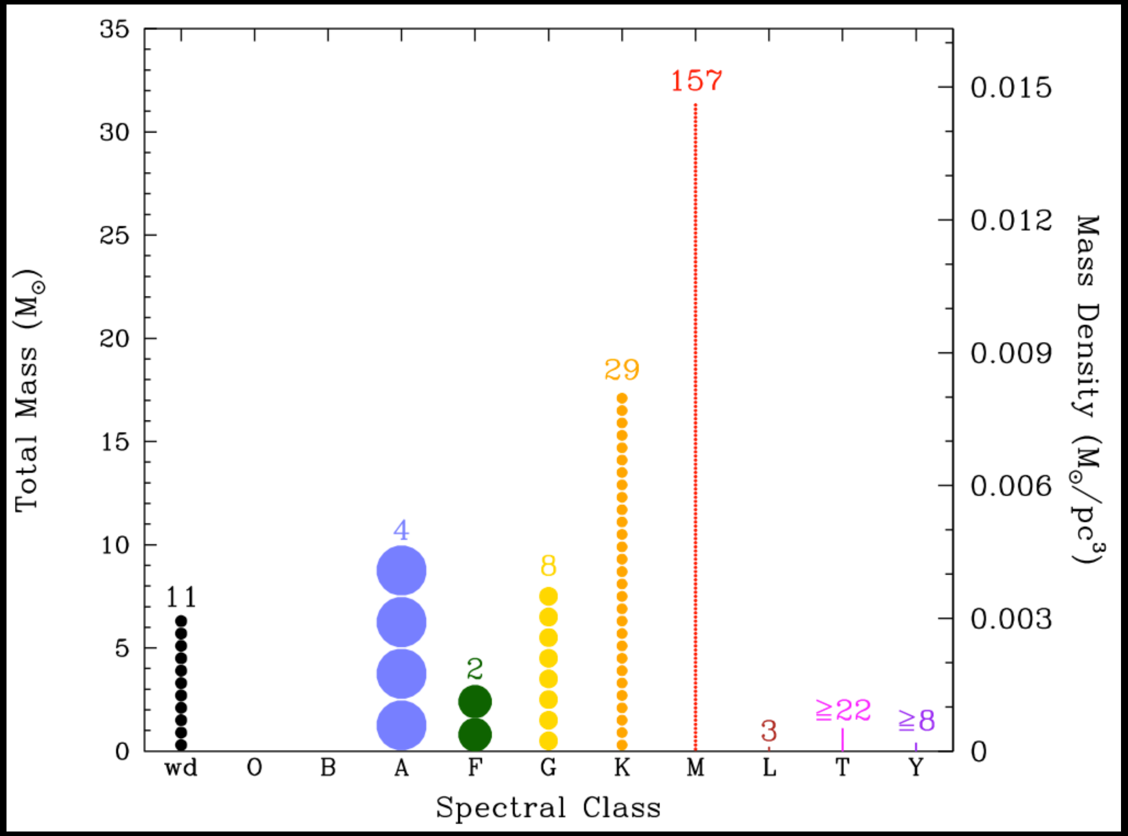


Kirkpatrick et al. (2014)



Can we map out this gap, as predicted by theory?





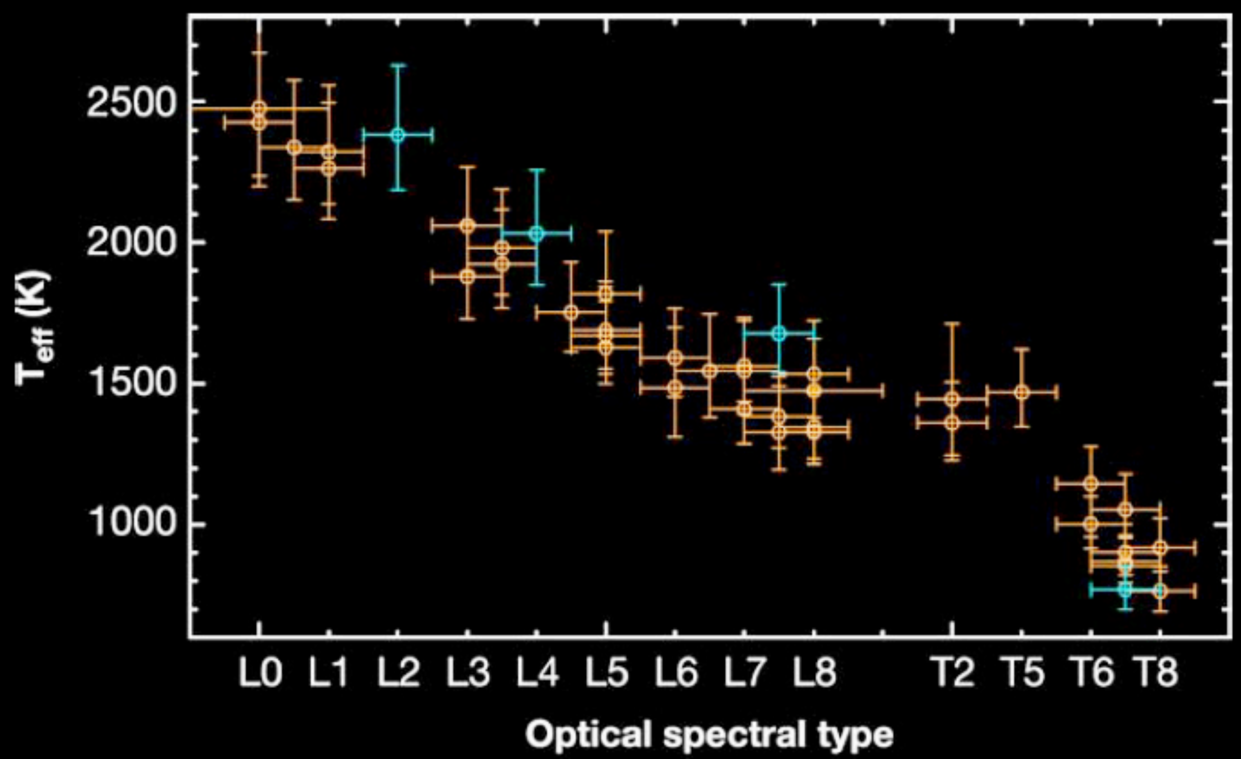
Gaia should be able to verify the drop on the high-temp side of the L subdwarf gap

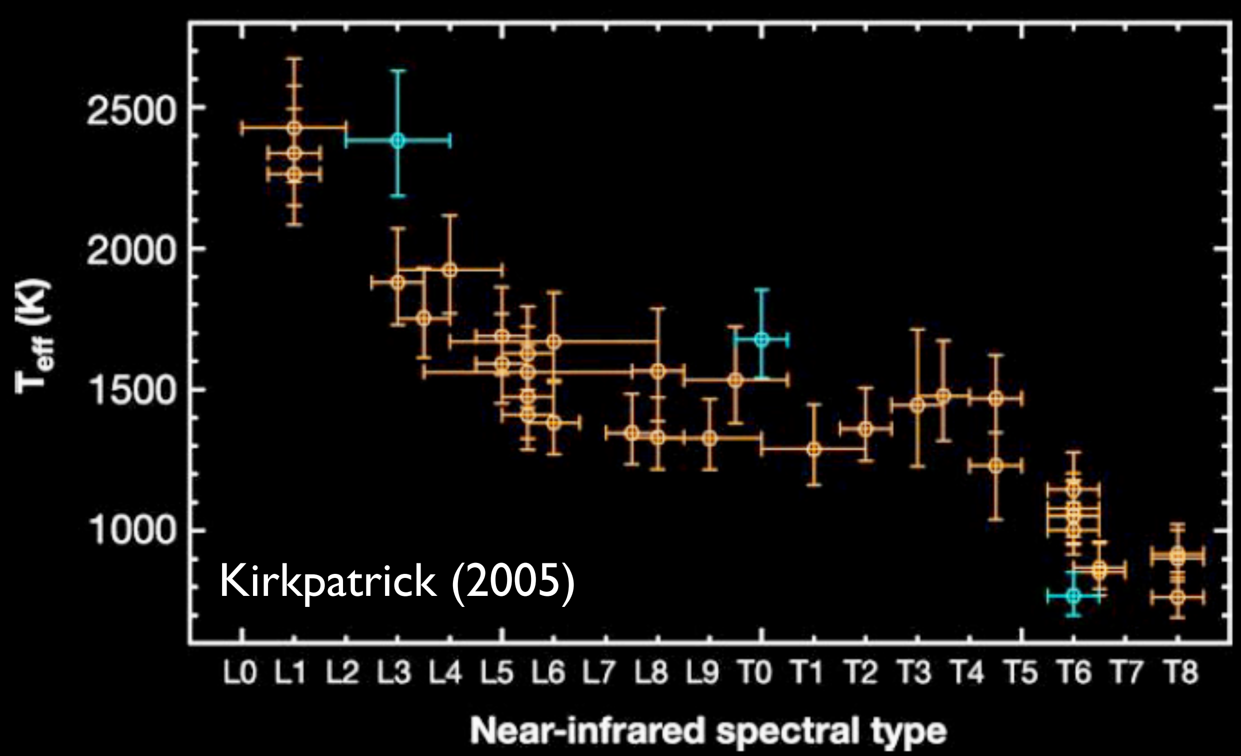
See also talk by Zhang.

3 What drives the atmospheres of brown dwarfs?

Tim Pyle, ICE

Is T_{eff} the parameter most influencing spectral type?





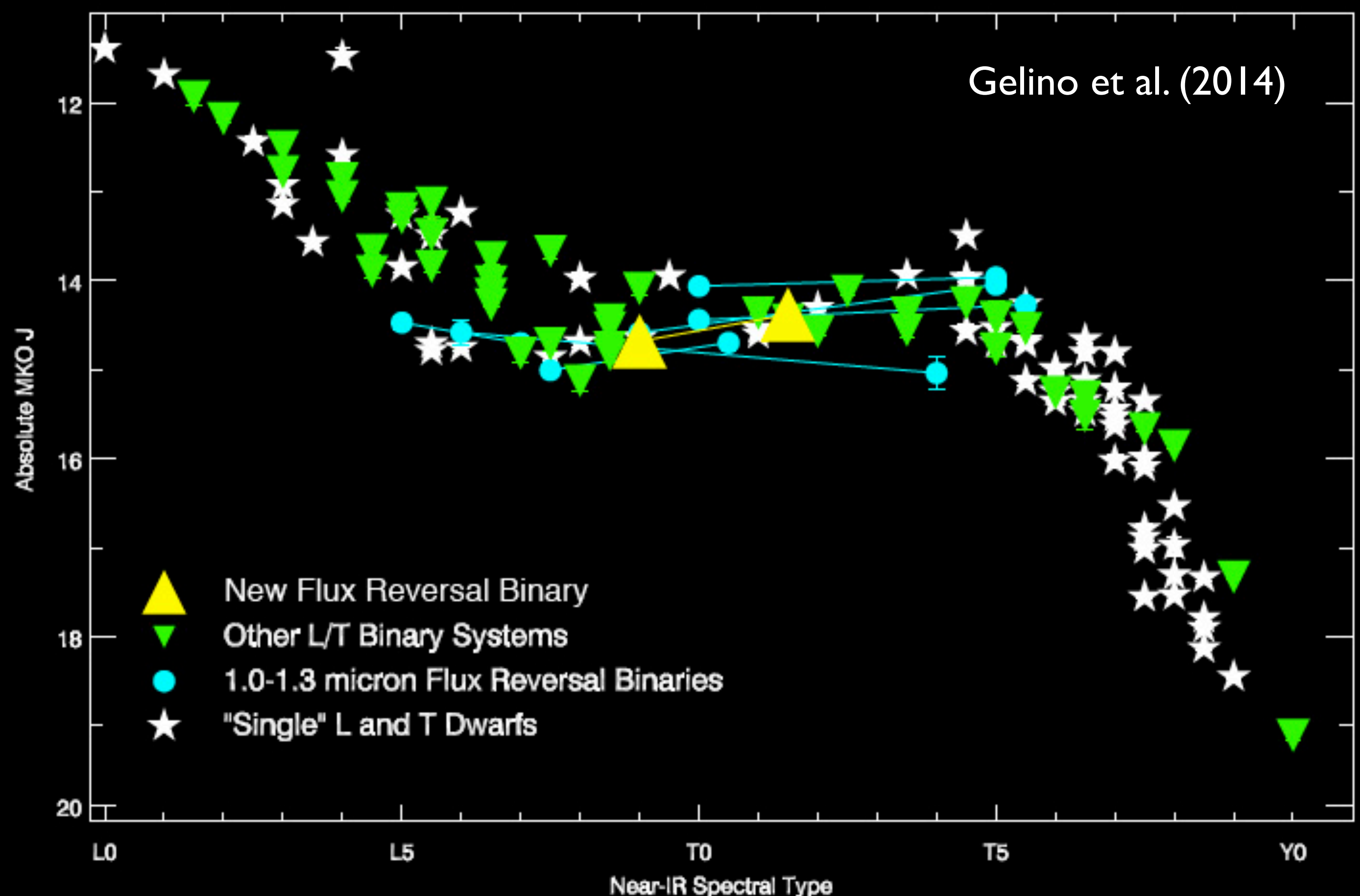
There is a nice correlation of spectral type with Teff in the optical (up until the L/T transition).

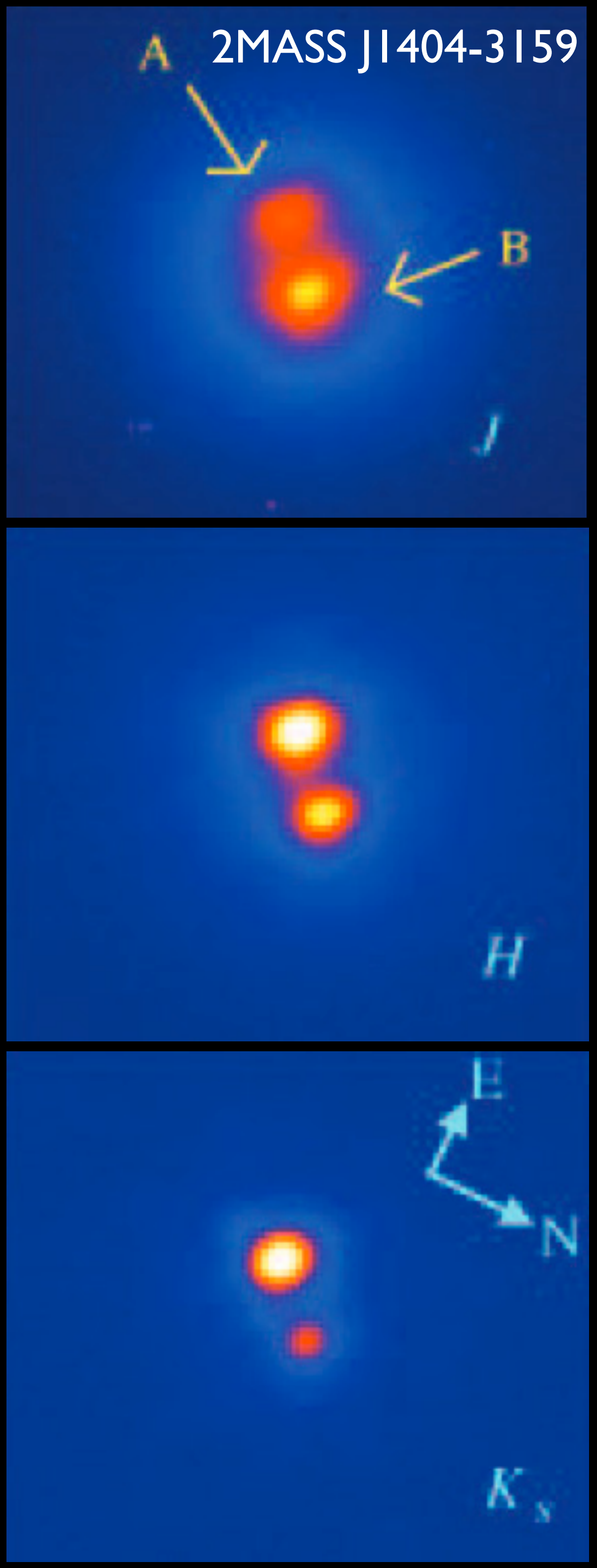
There is a strange flattening of the correlation at near-infrared types, however.

Cloud physics defines the spectral shape from mid-L to mid-T.

What's happening at the L/T transition?

The first "flip" binary was uncovered by Gizis et al. (2003). Six systems are now known. The cause for the J-band bump is likely due to patchy clouds allowing lines of sight to warmer layers below.

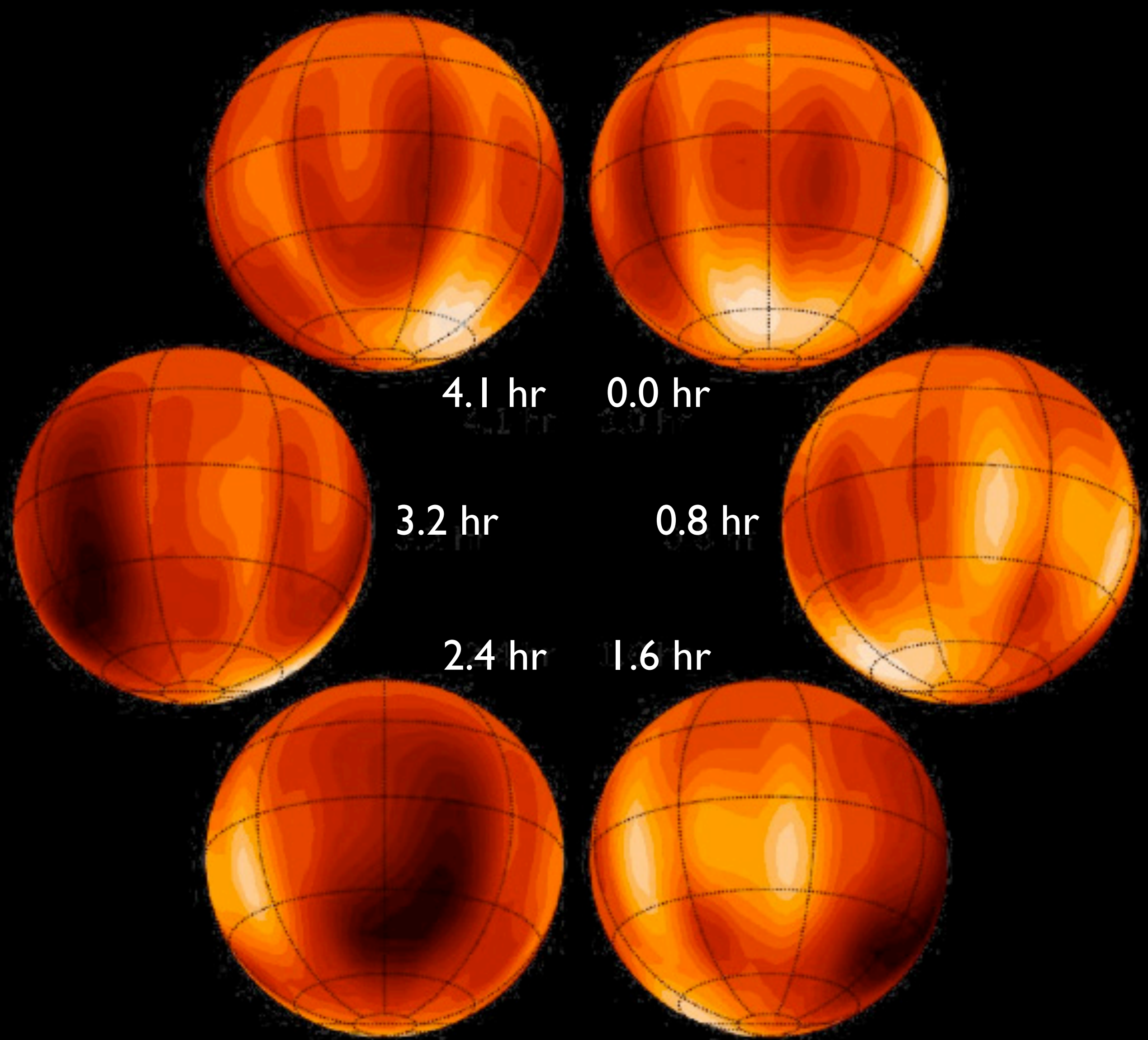




Looper et al. (2008)

How do we probe specifics regarding clouds?

Does cloud coverage fraction vary with time?
Are clouds banded or spotty?
Are there differences depending on orientation?

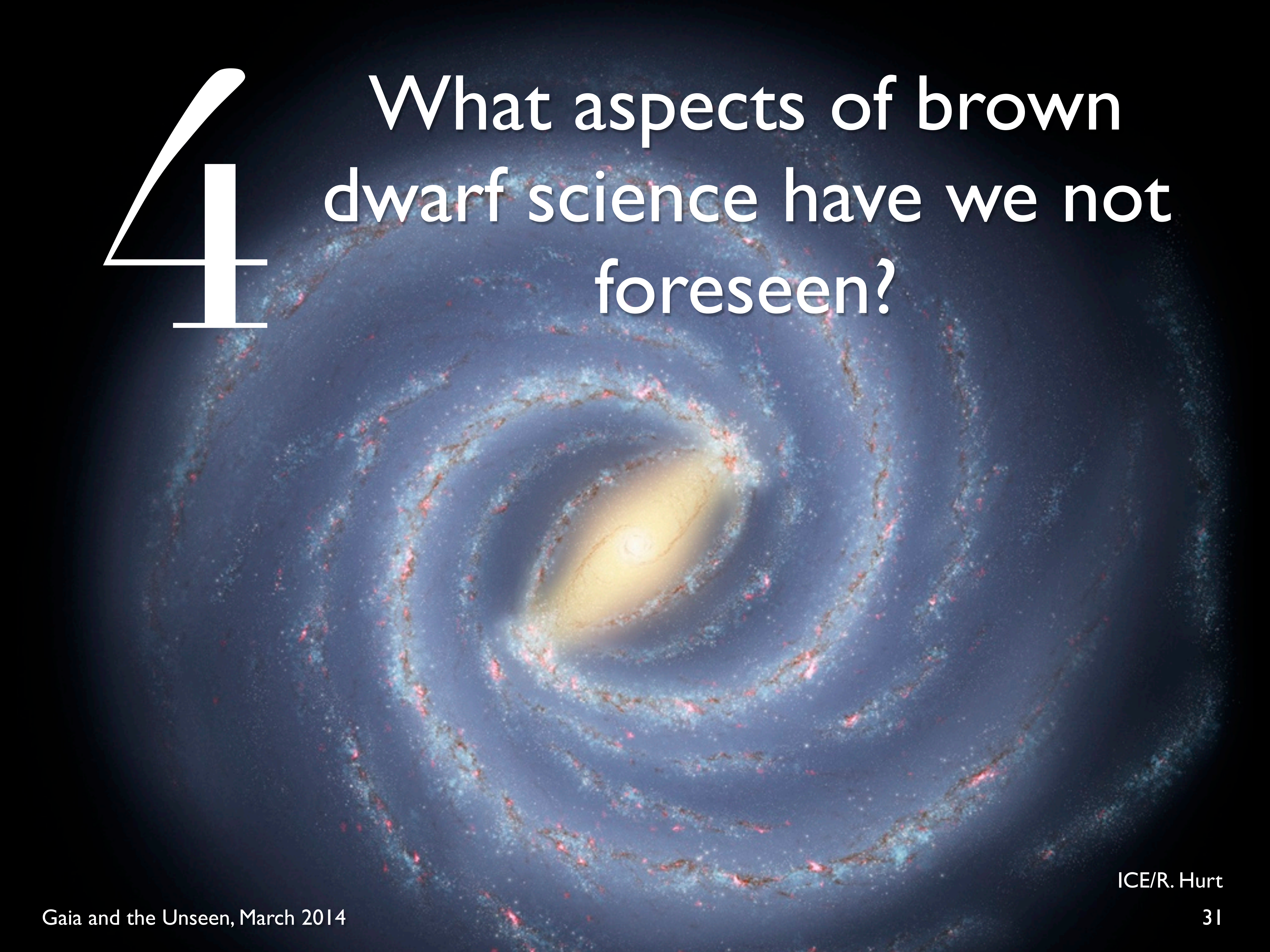


Crossfield et al. (2014)

Doppler imaging work by Crossfield et al. (2014) on the T0.5 dwarf WISE J1049-5719B (Luhman 16B), shows global spottiness and a near-polar bright spot.

Gaia will have photometric time series data on this system, the T1 dwarf e Ind Ba, and many L dwarfs. These visible-light studies can be paired with ground-based and/or Spitzer photometric monitoring and ground-based and/or HST spectral monitoring (see talk by Buenzli).

4 What aspects of brown dwarf science have we not foreseen?



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Possibilities

Very nearby objects that were missed before?

This is almost a certainty, especially in the Galactic Plane.

Rare BDs not previously recognized?

Quite likely for the L dwarfs, since most of the known objects have been selected via colors only.

New moving groups having only low-mass members?

If star formation has a low-mass-only mode, perhaps.

Others???


Thank you!