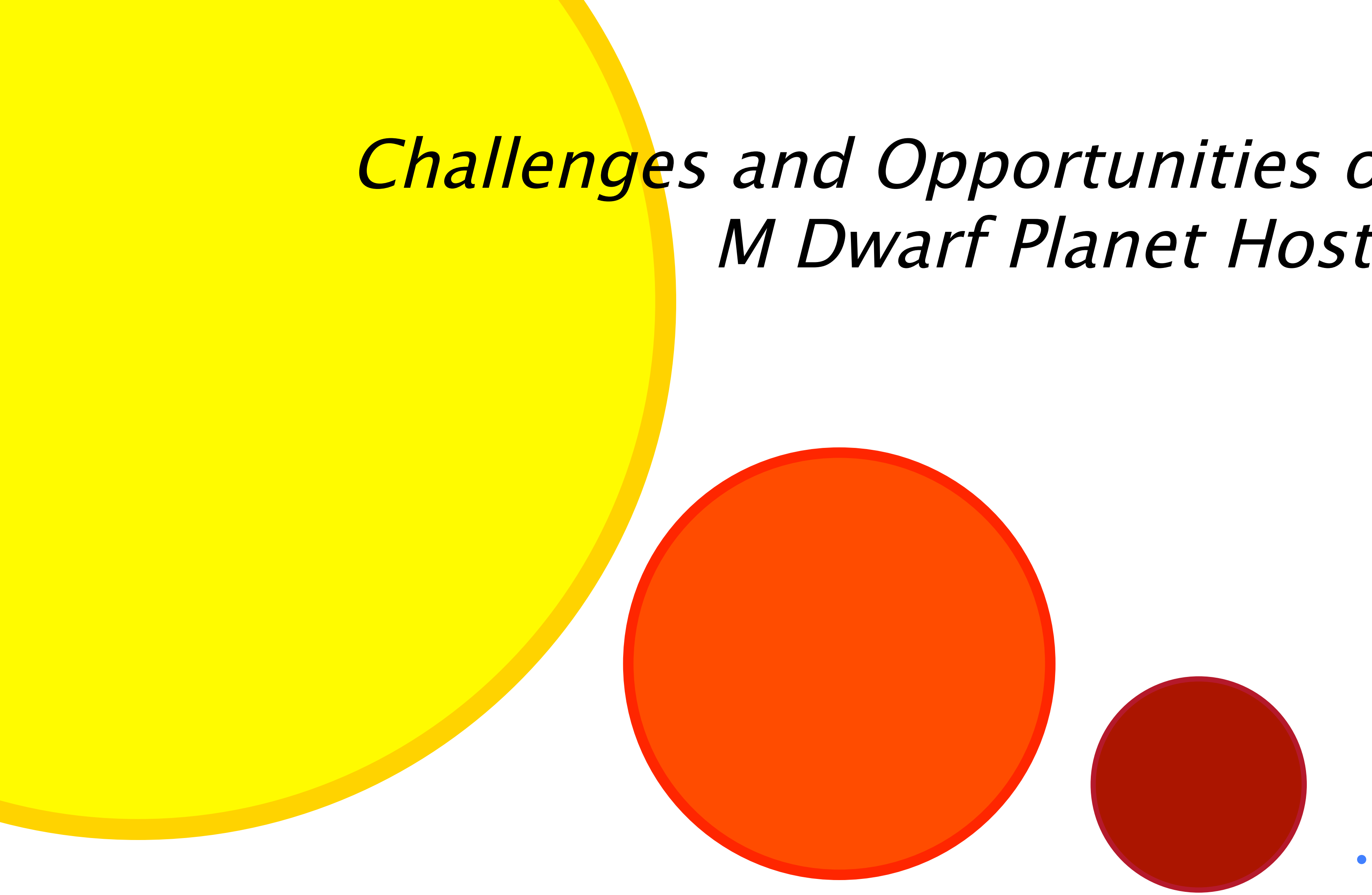
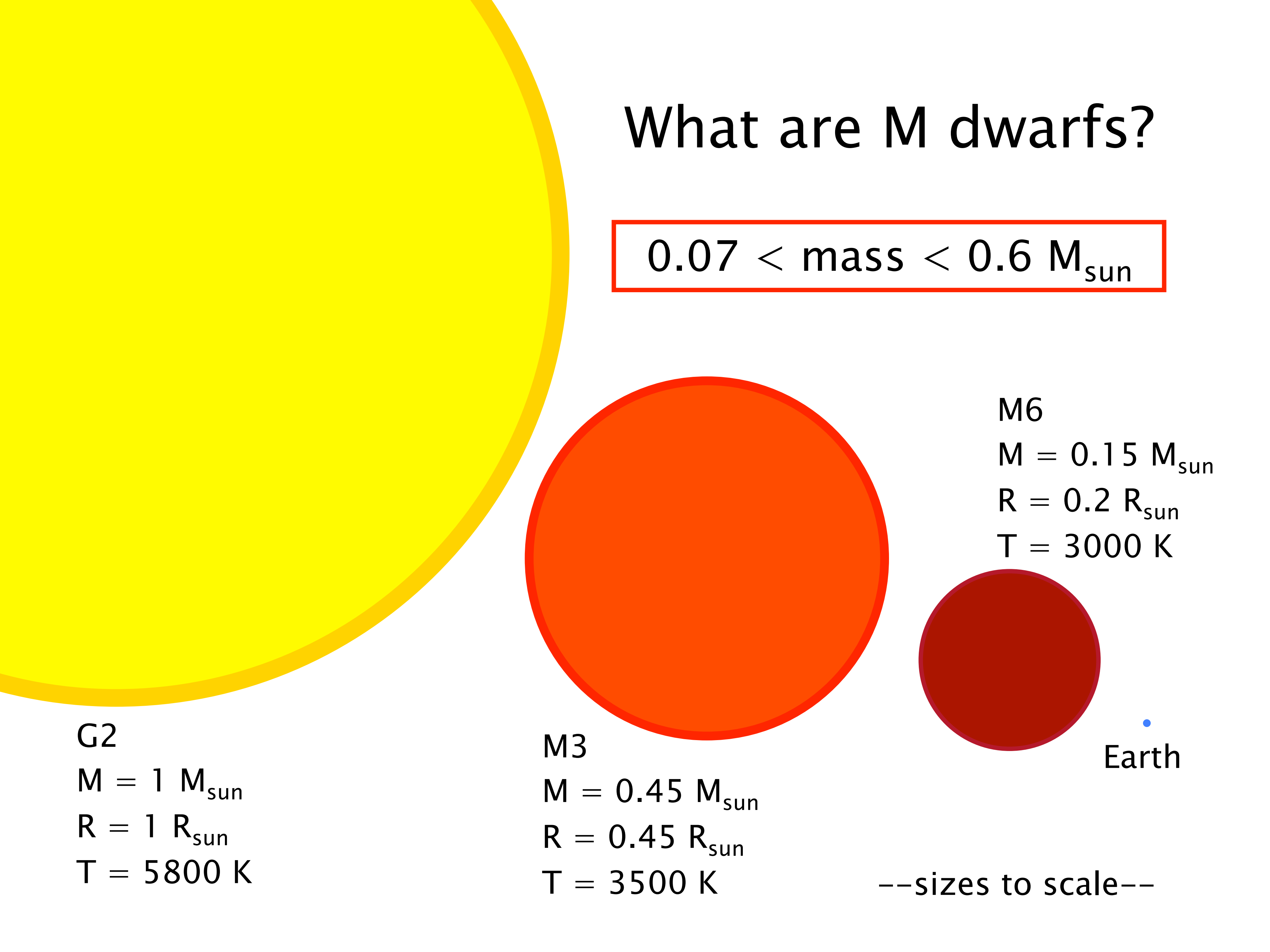
Challenges and Opportunities of M Dwarf Planet Hosts



Jacob Bean
Harvard-Smithsonian Center for Astrophysics

Outline

- Why M dwarfs?
- M dwarf challenges for planet detection and characterization
- Ongoing projects and highlights
- Future prospects


What are M dwarfs?
0.07 < mass < 0.6 M_{sun}
G2
M = 1 M_{sun}
R = 1 R_{sun}
T = 5800 K
M3
M = 0.45 M_{sun}
R = 0.45 R_{sun}
T = 3500 K
M6
M = 0.15 M_{sun}
R = 0.2 R_{sun}
T = 3000 K
Earth
--sizes to scale--

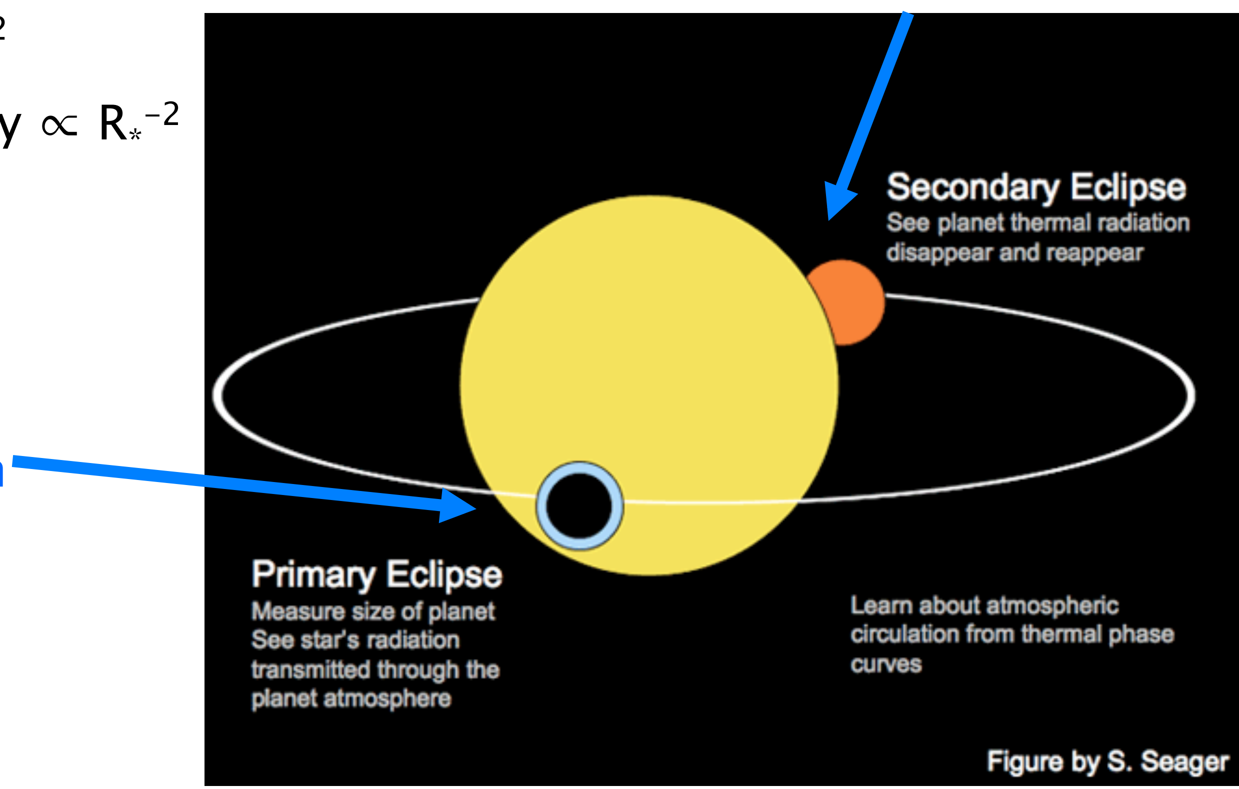
The shortcut to habitable planets

#1 Low-mass advantage for dynamical methods

RV signal $\propto M_*^{-2/3}$

Transit depth $\propto R_*^{-2}$

Transit Spectroscopy $\propto R_*^{-2}$



The shortcut to habitable planets

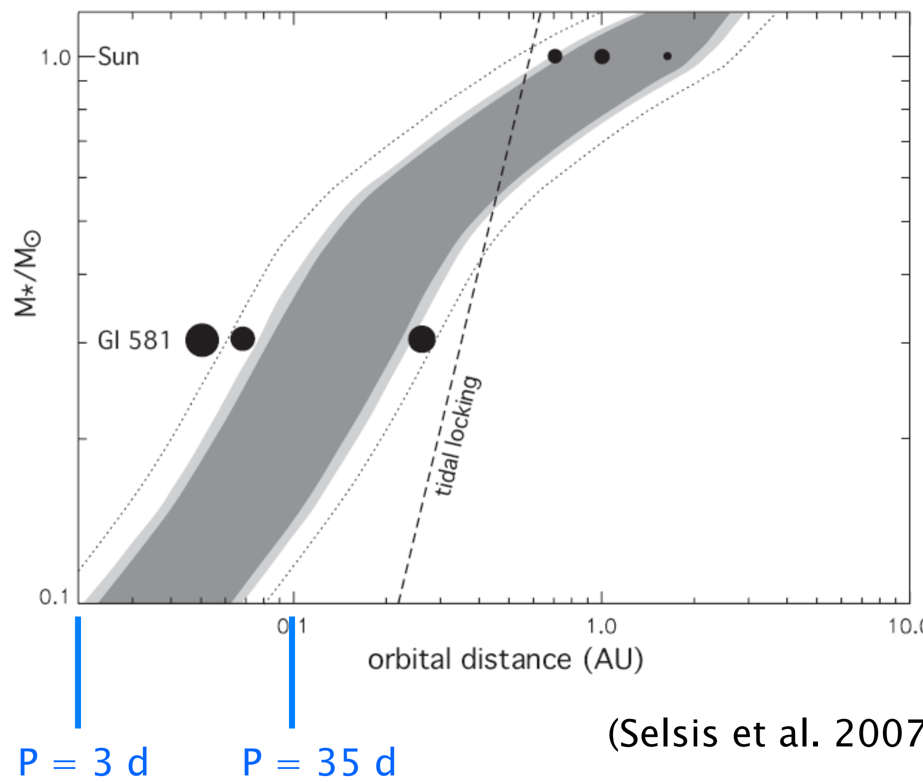
#1 Low-mass advantage for dynamical methods

#2 Low-mass brings in habitable zone (Kasting et al. 1993)

RV signal $\propto a^{-1/2}$

Transit probability $\propto a^{-1}$

Transit frequency $\propto a^{-3/2}$



(Selsis et al. 2007)

The shortcut to habitable planets

#1 Low-mass advantage for dynamical methods

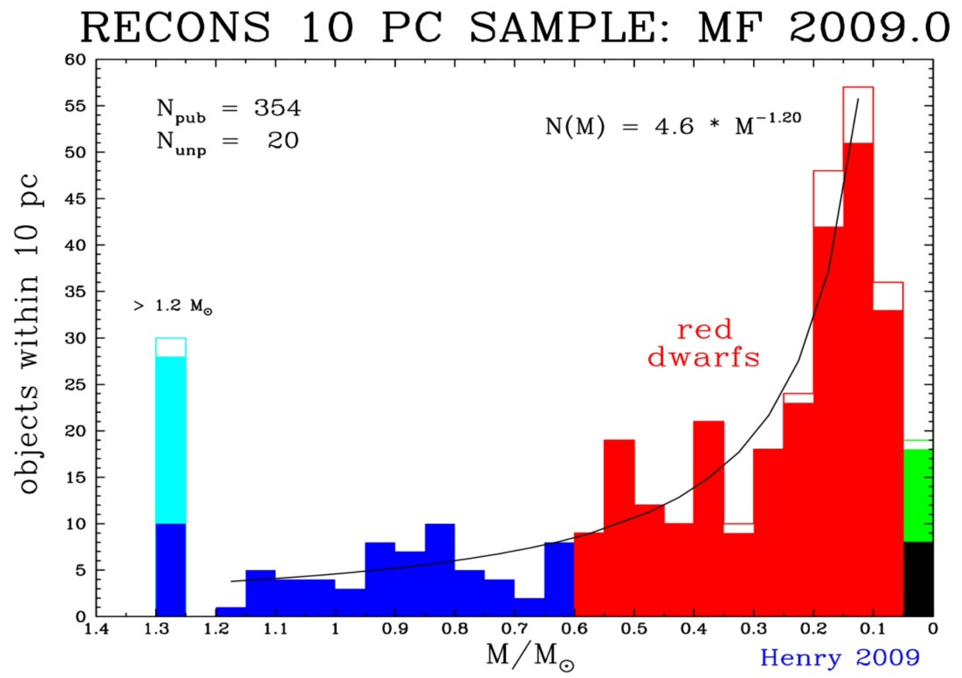
#2 Low-mass brings in habitable zone

#3 Low-mass stars most numerous

In the solar neighborhood:

75% M dwarfs, of which

50% $M_* < 0.2\ M_{sun}$



The shortcut to habitable planets

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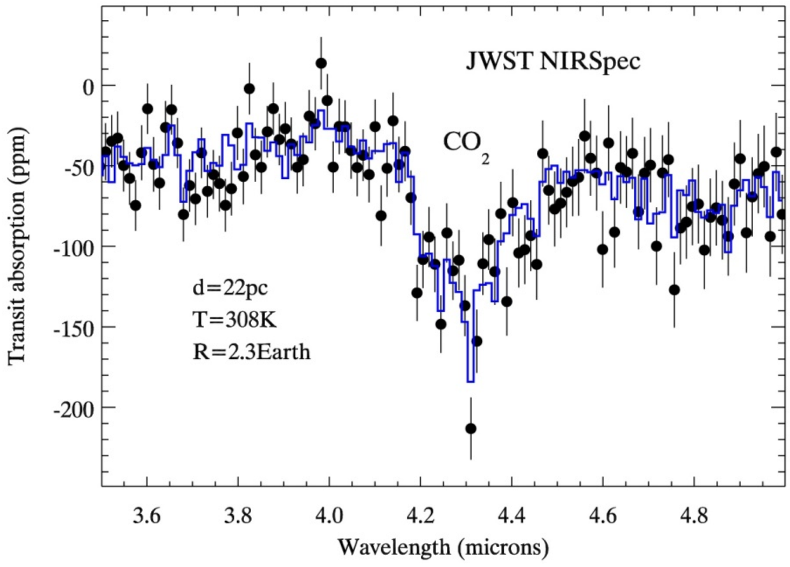
Best chance to find a transiting habitable planet around a nearby star, and study its atmosphere



(Deming et al. 2008)

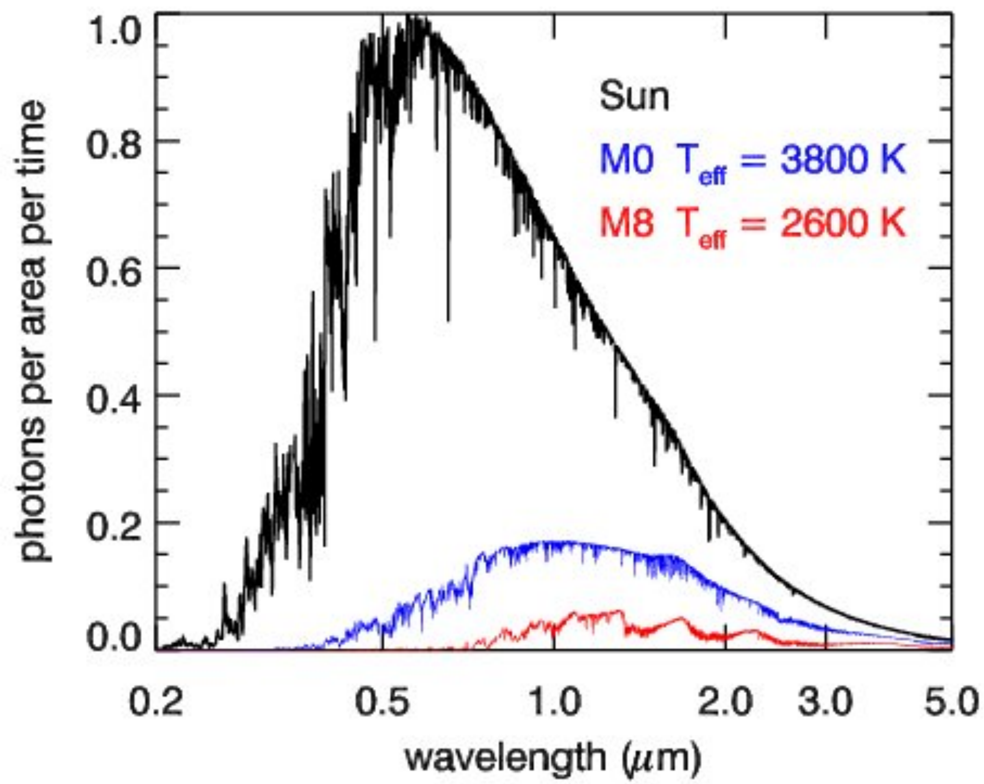
M dwarf firsts

- Planet-planet interactions (GJ876, Marcy et al. 2001)
- Firm astrometric detection (GJ876, Benedict et al. 2002)
- 1 of 3 RV Neptunes (GJ436, Butler et al. 2004)
- RV super-Earth (GJ876, Rivera et al. 2005)
- Transiting Neptune (GJ436, Gillon et al. 2007)
- Atmospheric study of a Neptune (GJ436, Demory et al. 2007, Deming et al. 2007)
- RV "habitable" planet (GJ581, Udry et al. 2007, Mayor et al. 2009, Vogt et al. 2010)
- Coplanarity in a normal system (GJ876, Bean & Seifahrt 2009)
- RV 2 M_{earth} planet (GJ581, Mayor et al. 2009)
- RV 4:2:1 resonance (GJ876, Rivera et al. 2010)
- Atmospheric study of a super-Earth (GJ1214, Bean et al. 2010)

M dwarf challenges

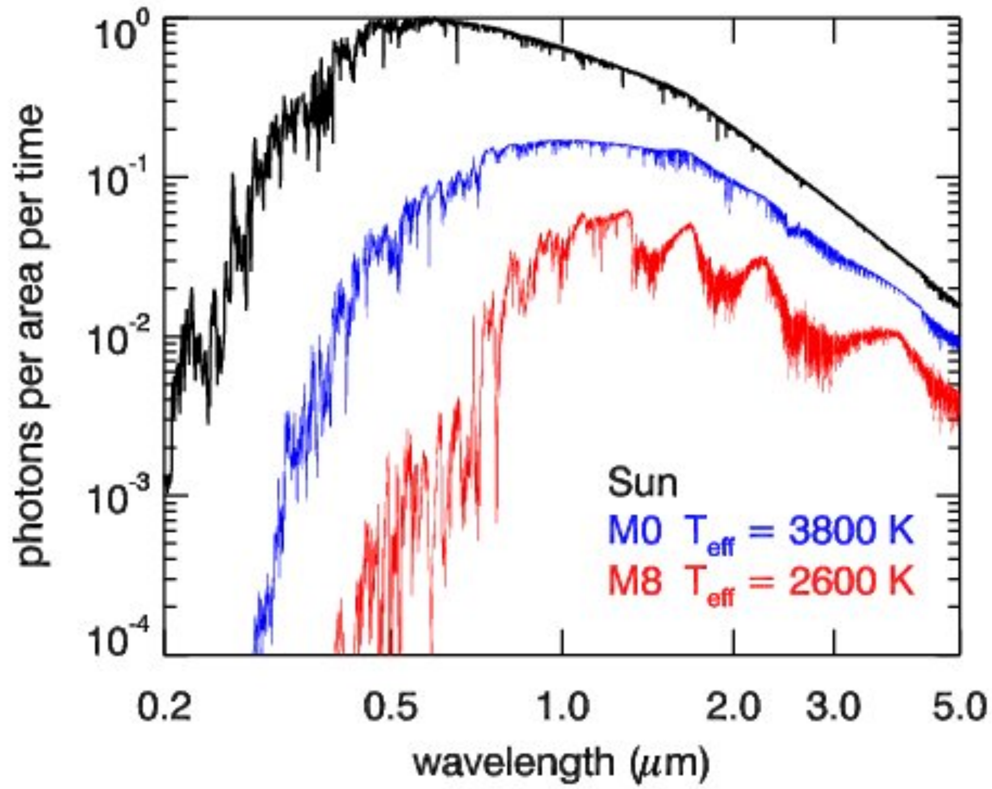
- Faintness
- Activity
- Difficult to measure/estimate accurate stellar parameters

M dwarf challenges: faintness



PHOENIX models courtesy P. Hauschildt et al.

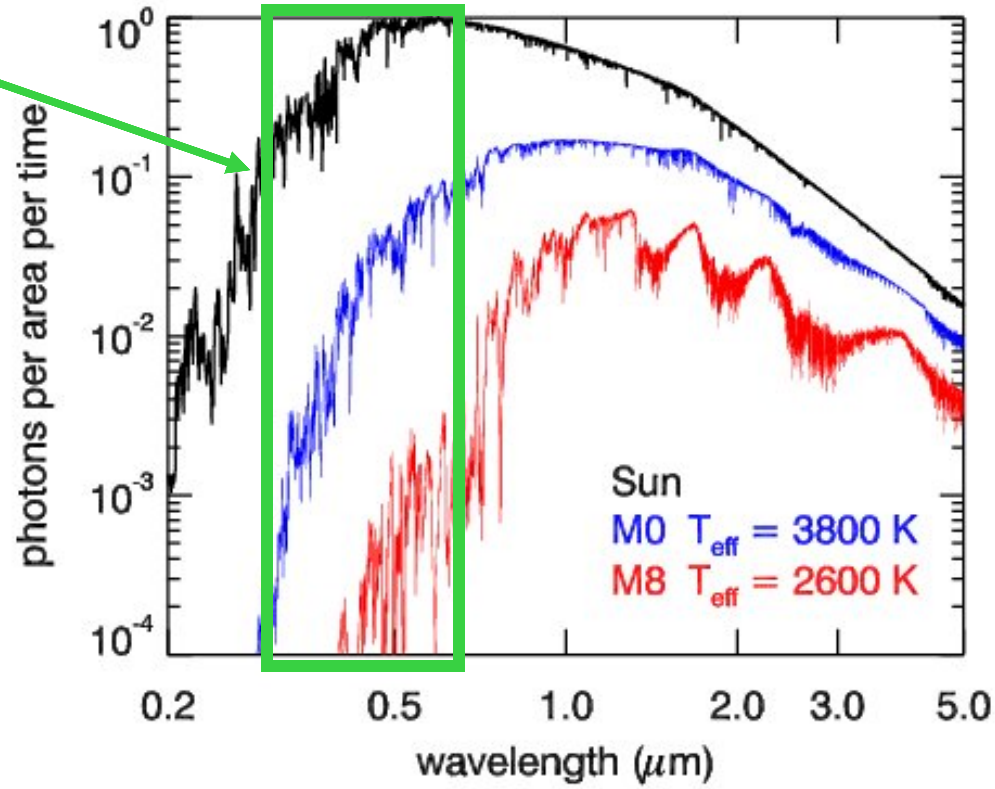
M dwarf challenges: faintness



PHOENIX models courtesy P. Hauschildt et al.

M dwarf challenges: faintness

normal RV and transit measurements



@ 10 pc

Sun V=4.8

M0 V=9.0

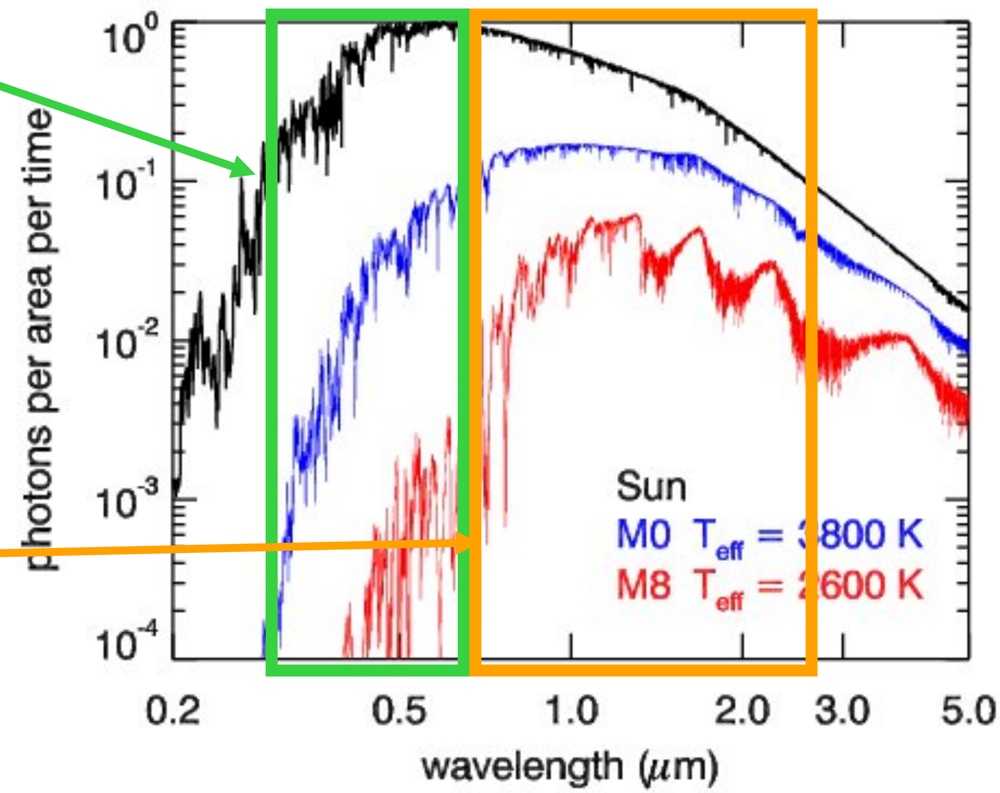
M8 V=18.7

PHOENIX models courtesy P. Hauschildt et al.

M dwarf challenges: faintness

normal RV and transit measurements

more flux in the red/NIR



but more challenging…

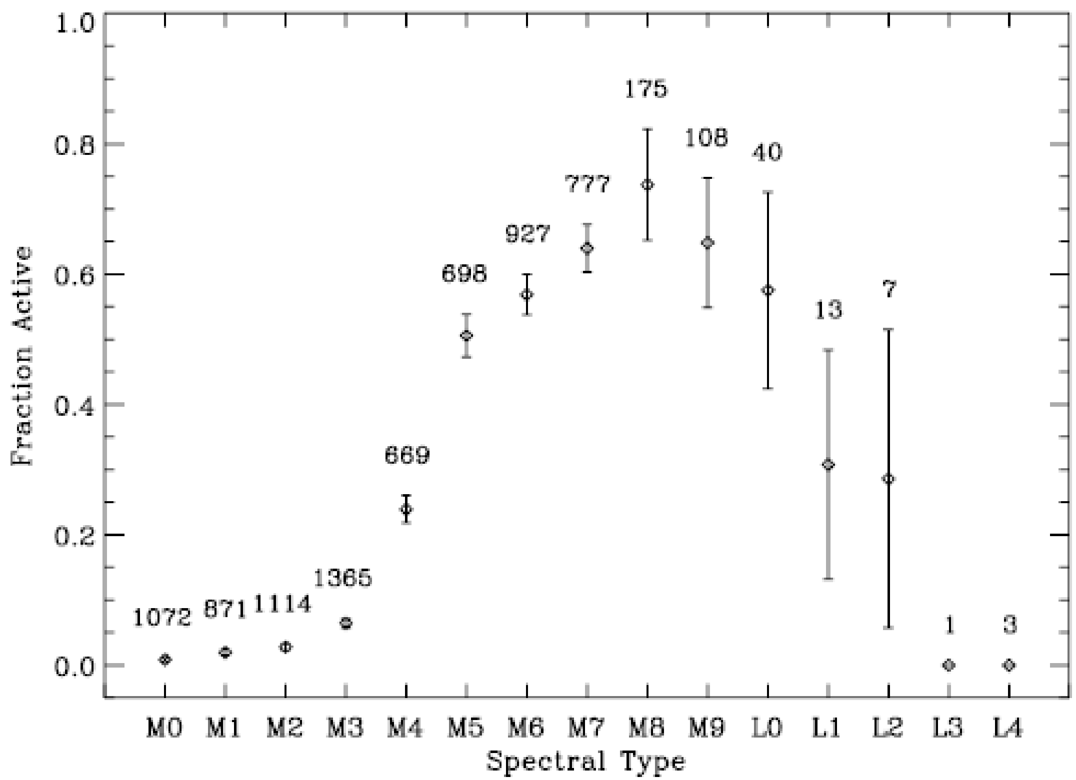
PHOENIX models courtesy P. Hauschildt et al.

M dwarf challenges: faintness

The (coupled) technical challenges of the NIR

- For RVs: spectrograph design, calibration, detectors, & tellurics
- For transits: few bright stars in a single pointing, bigger telescopes, detectors, RV follow-up

M dwarf challenges: activity

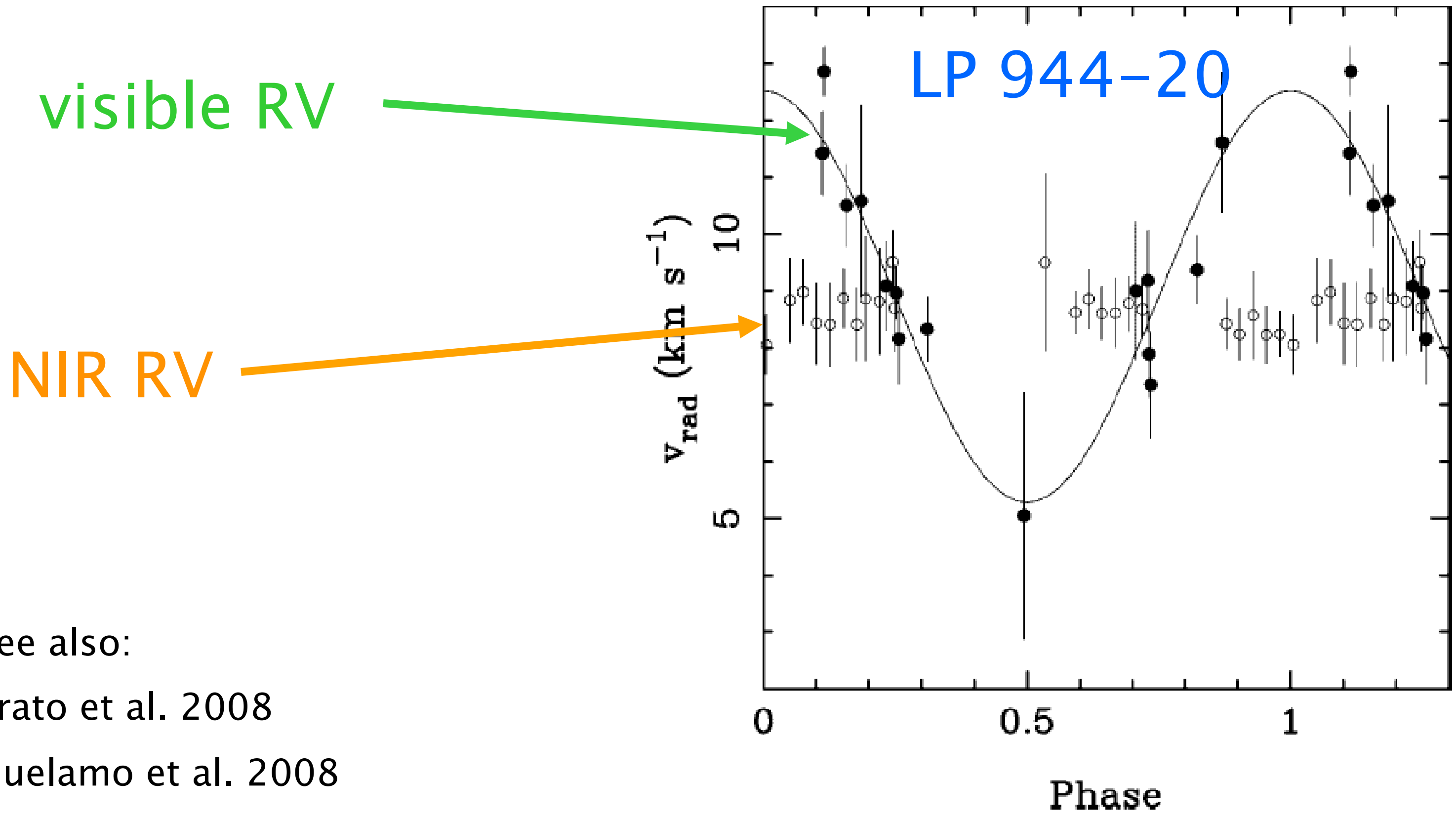


Leads to larger RV and photometric jitter

West et al. 2004

M dwarf challenges: activity

Partial solution is the NIR for RV



See also:

Prato et al. 2008

Huelamo et al. 2008

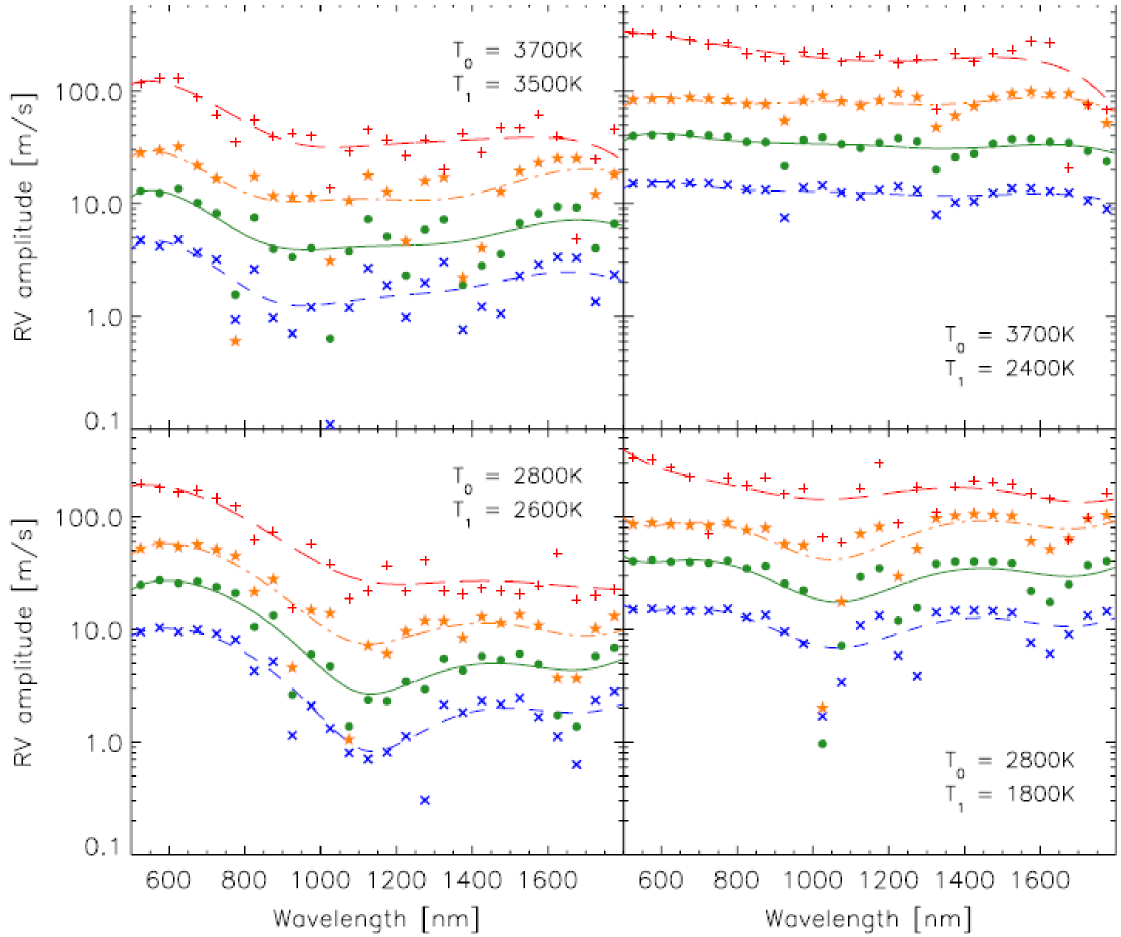
Figueira et al. 2010

Martin et al. 2006

M dwarf challenges: activity

NIR RV

- Depends on spot Temperature
- Maximum reduction reached around 1μm
- Contemporaneous photometry a good diagnostic – e.g., GJ674 (Bonfils et al. 2007)



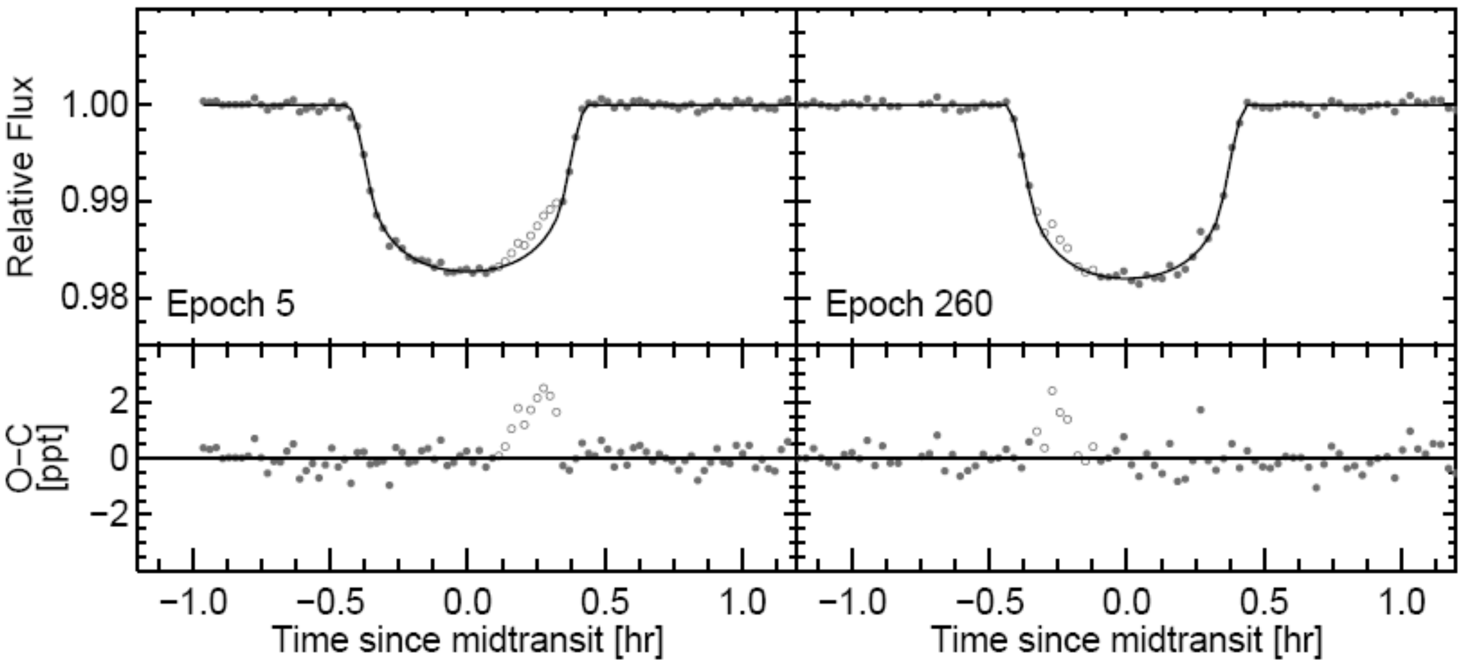
Reiners et al. 2010

See also Barnes et al. 2011

M dwarf challenges: activity

Photometry: occulted spots in transit

GJ1214b in r' band

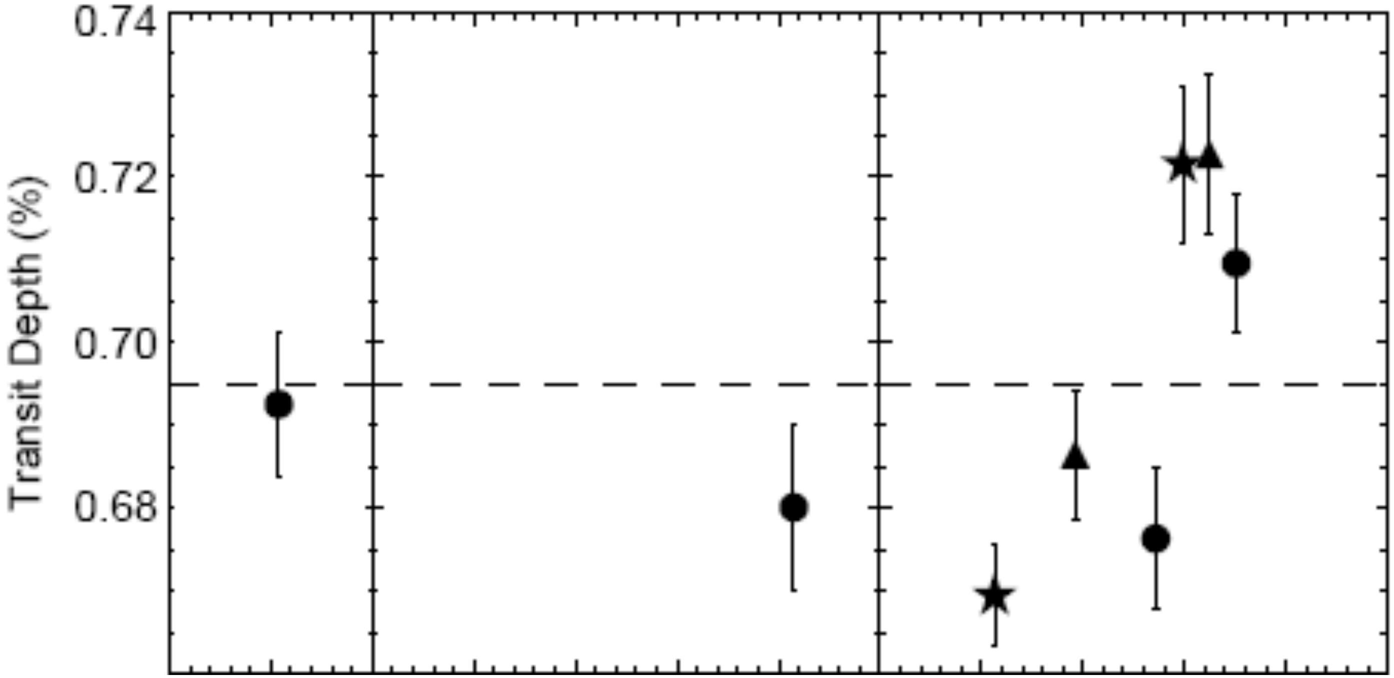


Carter et al. 2011b

M dwarf challenges: activity

Photometry: occulted spots in transit

GJ436b with Spitzer IRAC

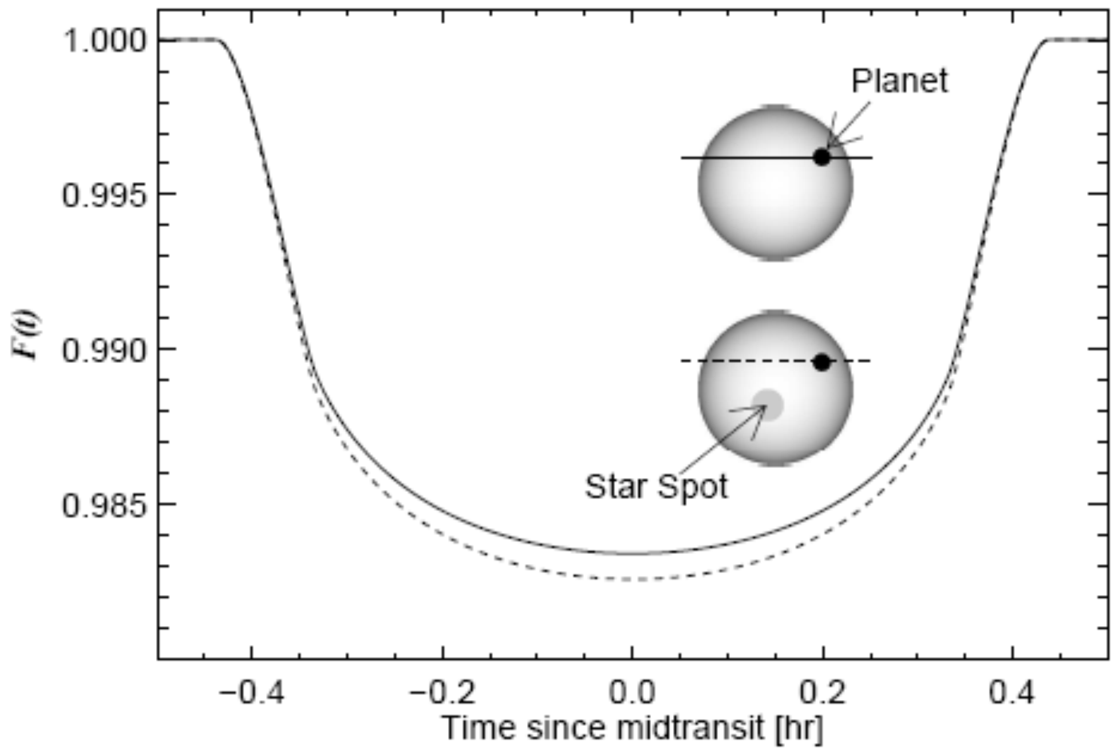


Knutson et al. 2011

M dwarf challenges: activity

Photometry: unocculted spots in transit

GJ1214b simulation

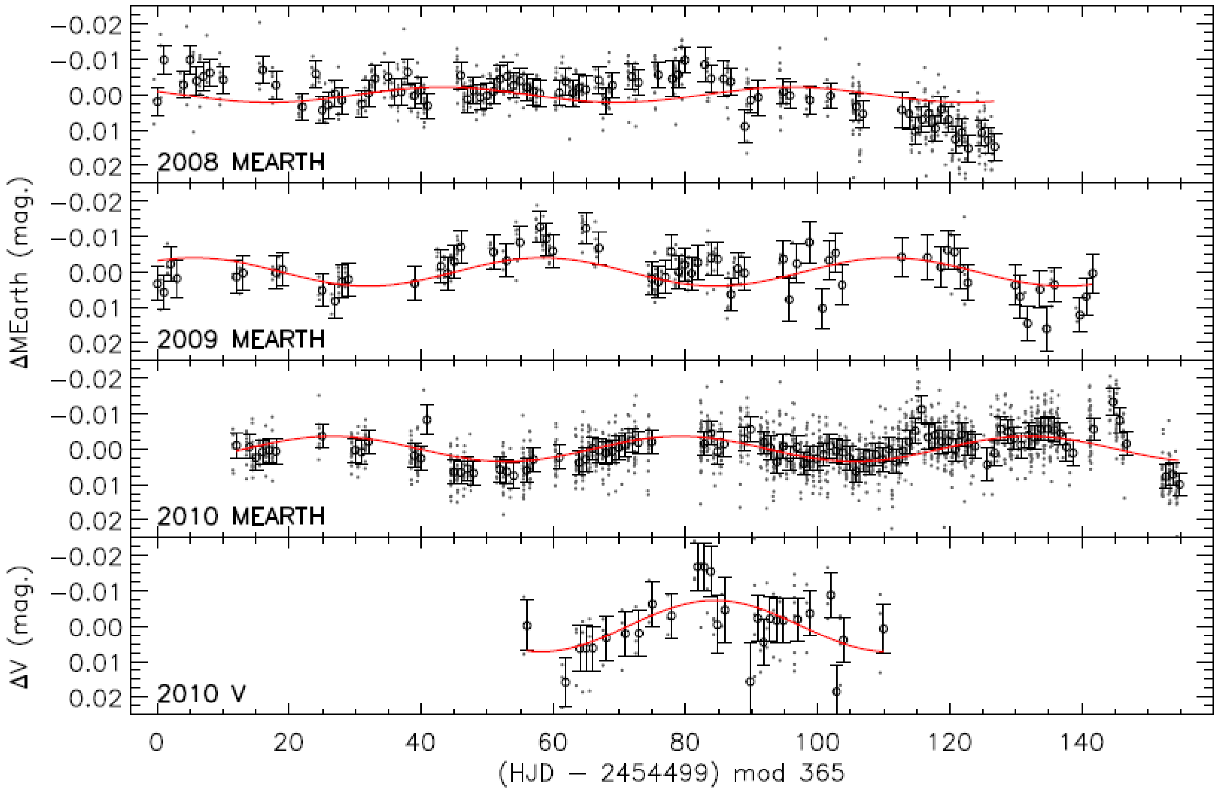


Carter et al. 2011b

M dwarf challenges: activity

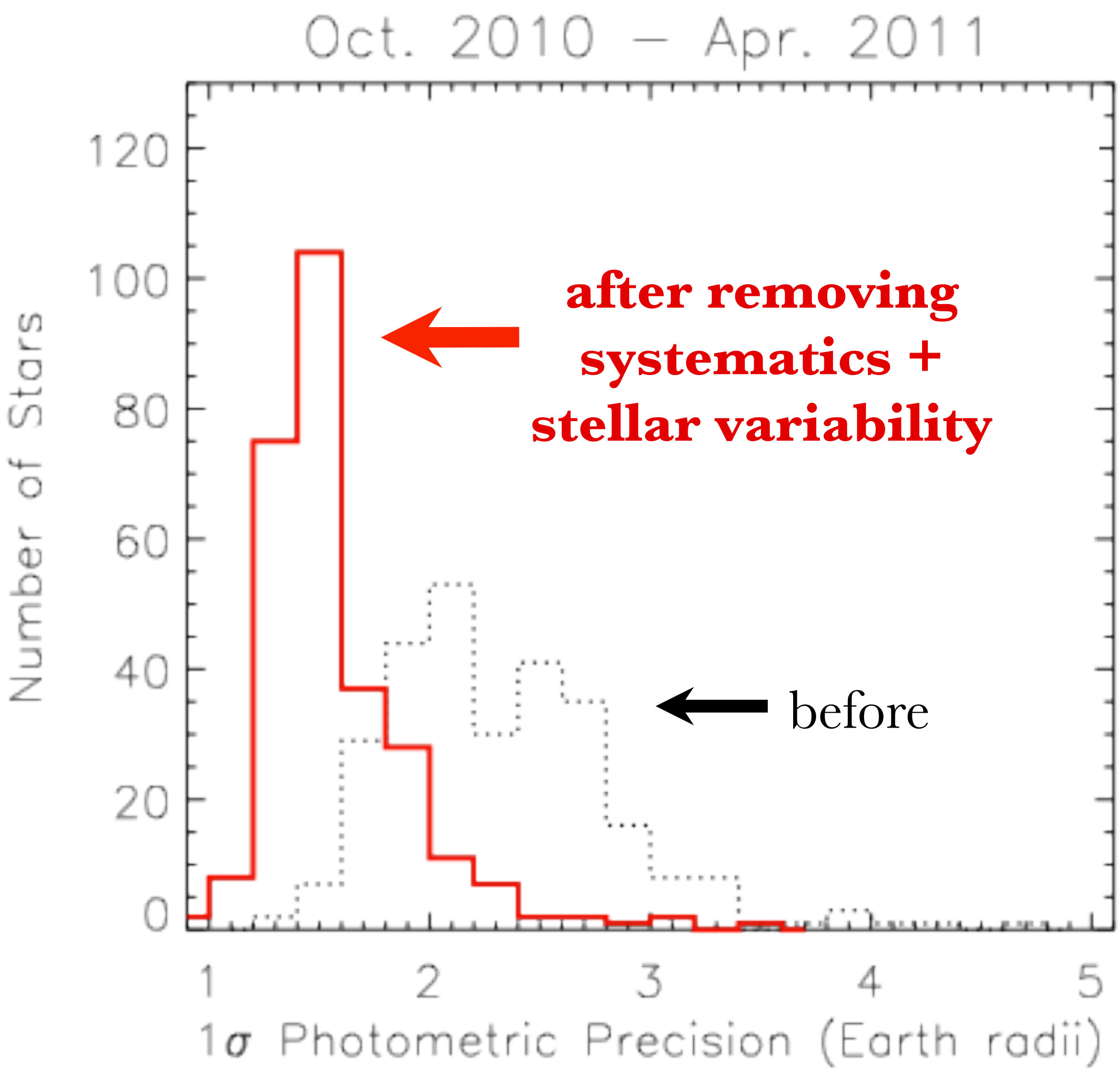
Photometry: long-term variability

GJ1214b



Berta et al. 2011

The MEarth Project



systematics and stellar variability can be corrected by decorrelation and filtering; simulations show the cost is 10-20% suppression of transit depth

slide from Z. Berta

M dwarf challenges: parameters

It is very difficult to estimate the masses, radii, and metallicities of field M dwarfs!

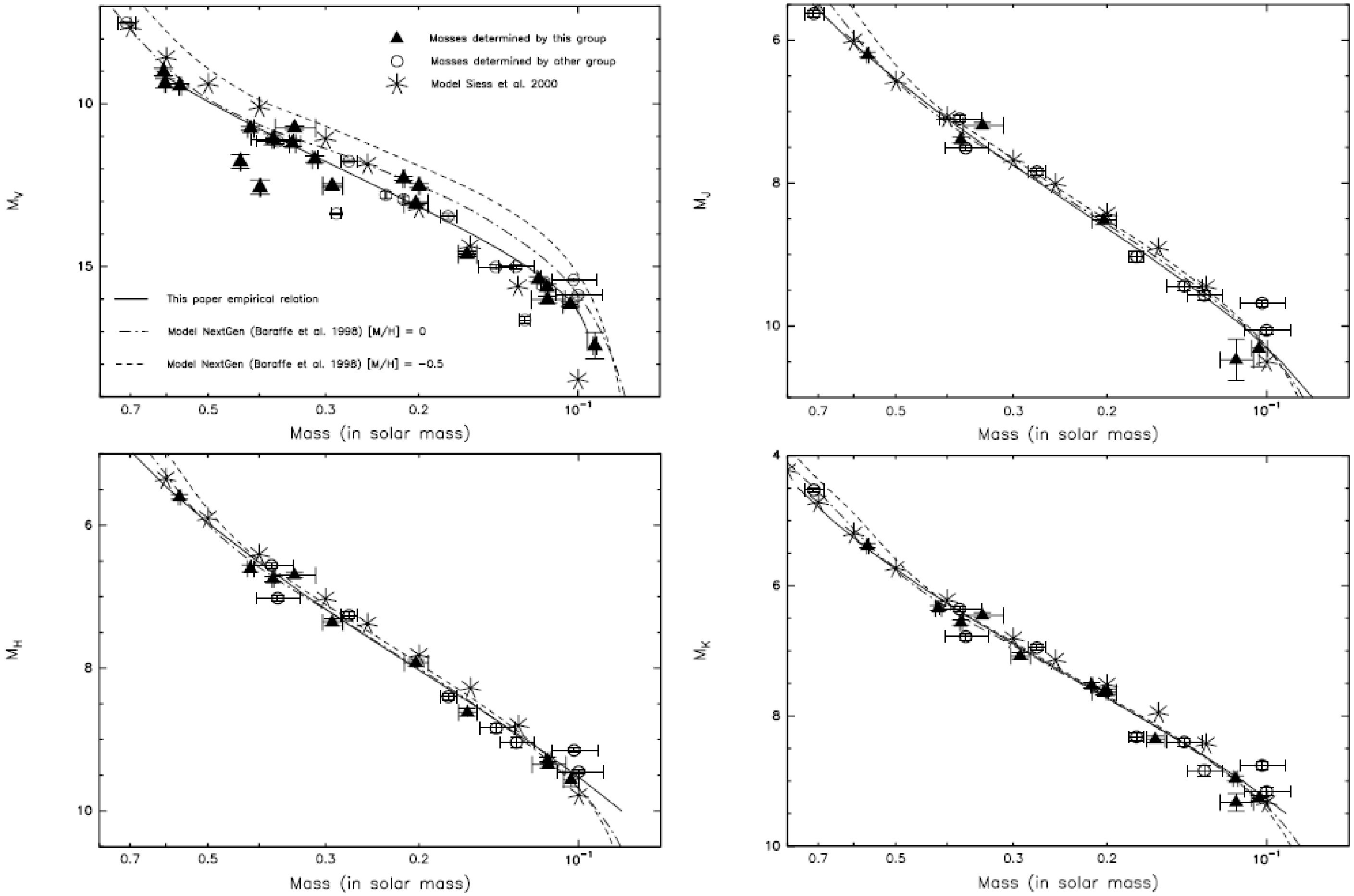
Impacts estimates of M and R for planets, study of correlations, and transit planet validation

The number one problem is the presence of significant abundance of molecules in their photospheres.

Enhanced activity and the fully convective nature of the latest objects are likely important secondary issues.

M dwarf challenges: parameters

The problem with mass

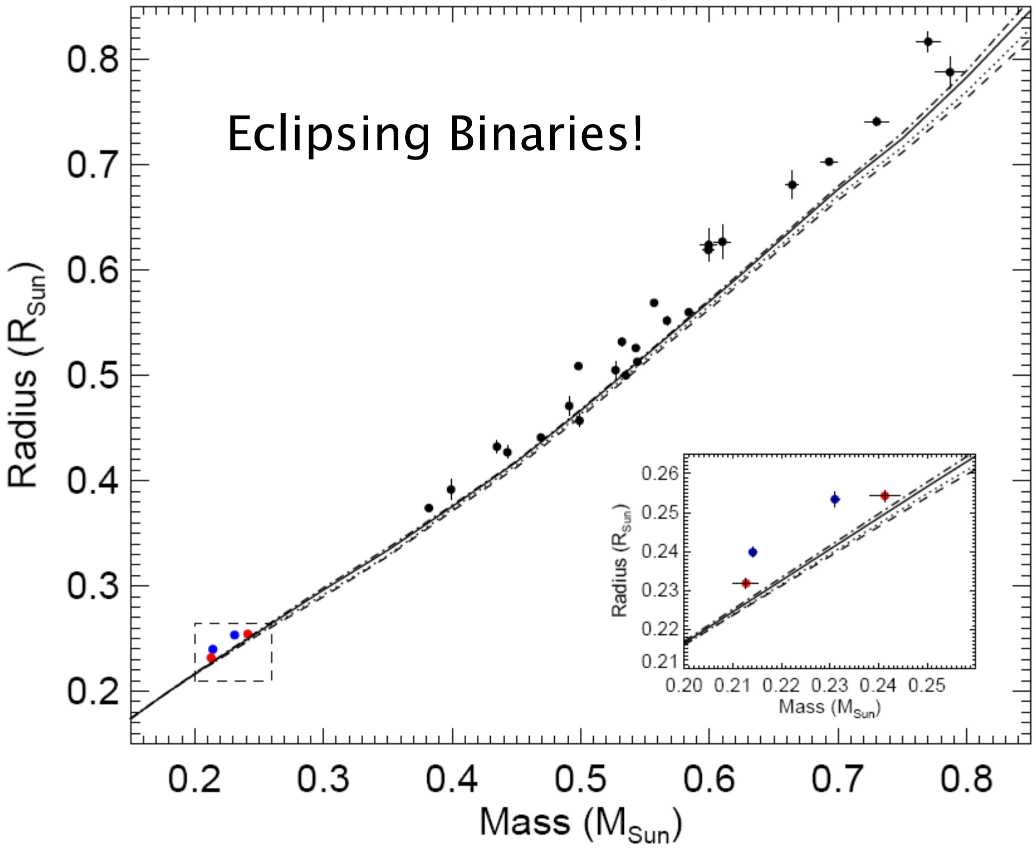


Delfosse et al. 2000

Models from Baraffe et al. 1998

M dwarf challenges: parameters

The problem with mass and radius

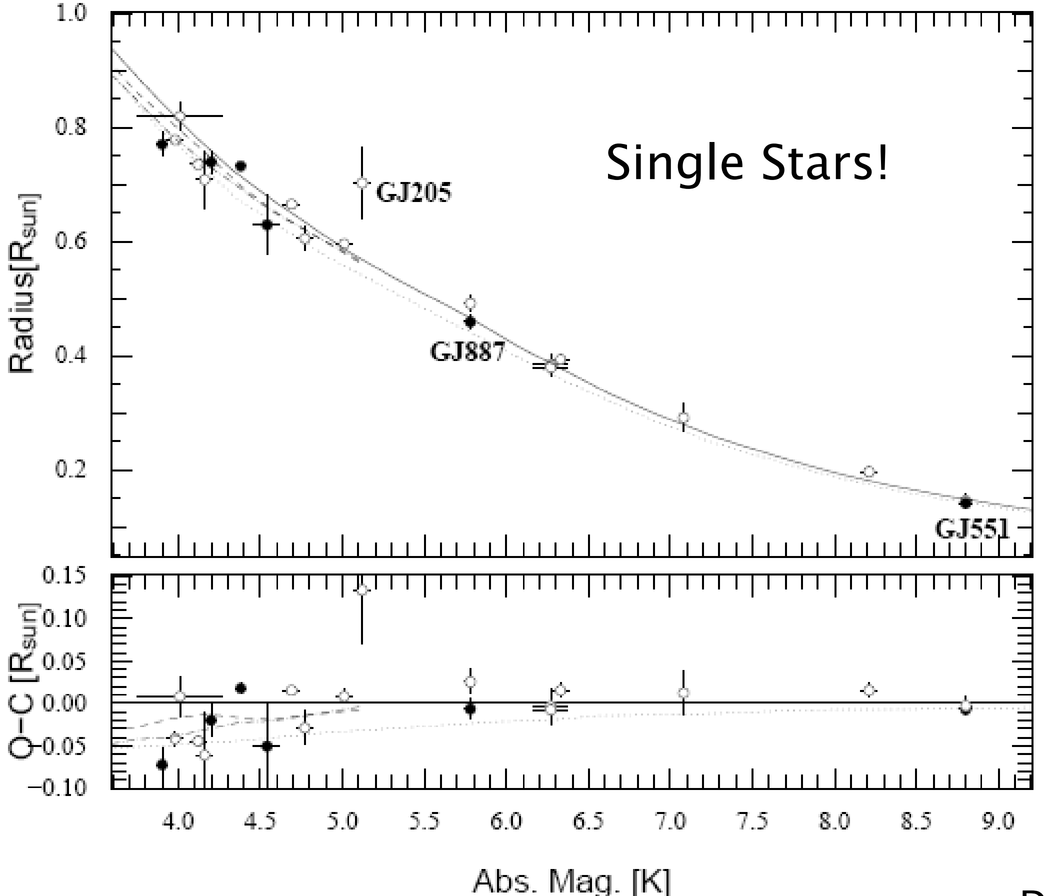


Carter et al. 2011a

Models from Baraffe et al. 1998

M dwarf challenges: parameters

The problem with radius – activity?



Demory et al. 2009

See also: Lopez-Morales 2007

Models from Baraffe et al. 1998

M dwarf challenges: parameters

GJ1214b as an example

Carter et al. 2011b

- Empirical M-L relationship + light curve:

$$\rho_* = 24.1 \pm 1.7 \text{ g/cm}^3,\ R_p = 2.65\ R_{earth}$$

- Theoretical isochrones + light curve:

$$\rho_* = 38.4 \pm 2.1 \text{ g/cm}^3,\ R_p = 2.27\ R_{earth}$$

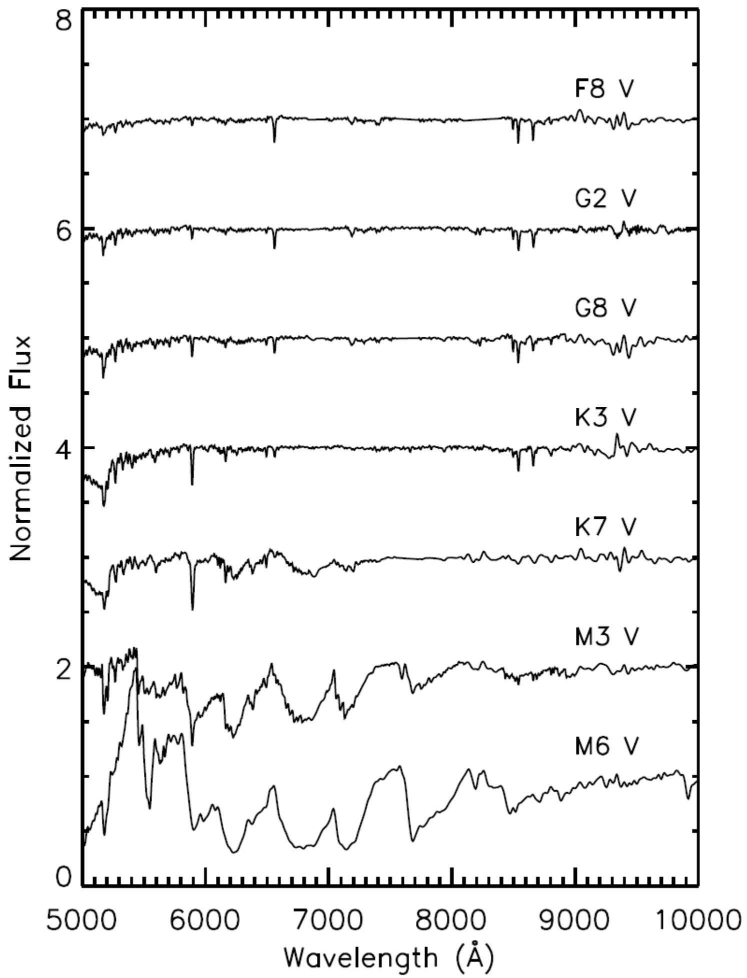
Resolution would require eccentricity at least 0.1

More work clearly needed!

M dwarf challenges: parameters

The problem with metallicity

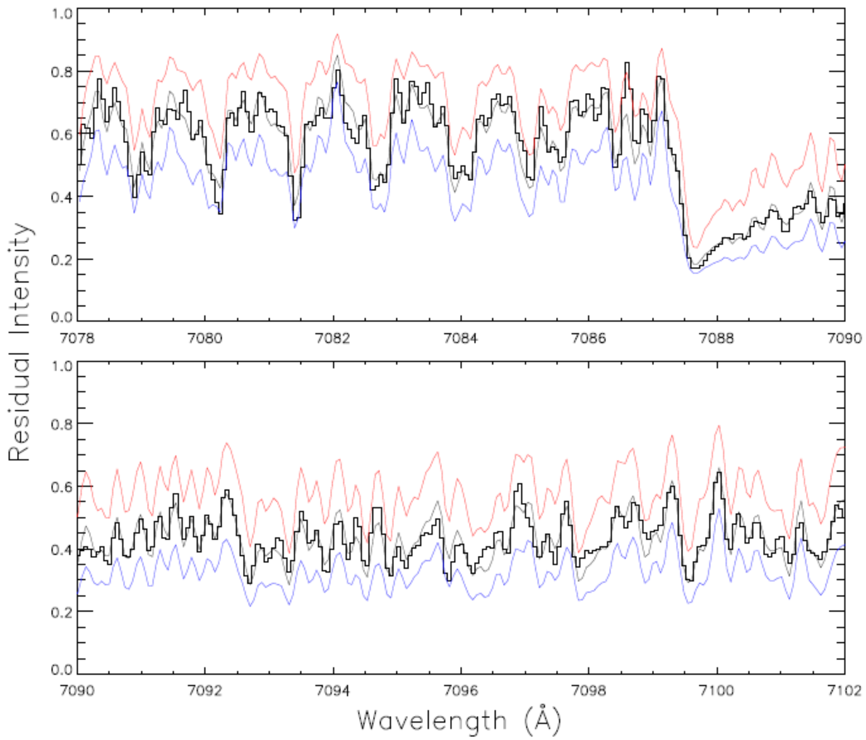
- Molecular features dominate the optical spectrum and prohibit clean equivalent width measurements
- Cool temperatures limit the range of atomic lines available, few are observable in the Sun
- Unreliable models mean that the objects must be fully characterized using photometry/spectroscopy and empirical relationships

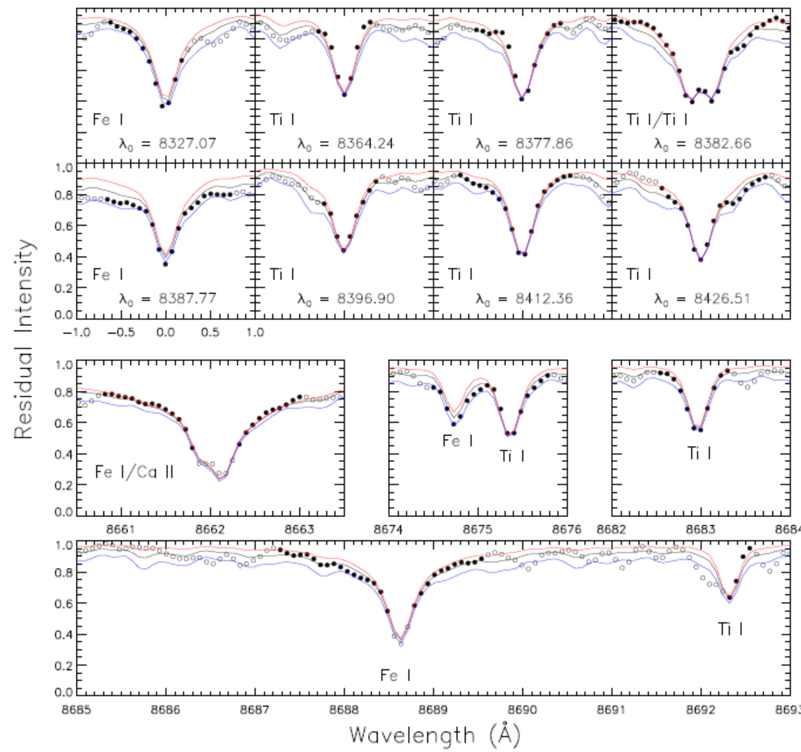


Spectra from Pickles 1998

M dwarf challenges: parameters

Spectral synthesis to 0.1 dex accuracy?





GJ876: [M/H] = −0.12

Improved model atmospheres and spectral analysis code

Bean et al. 2006a & Bean et al. 2006b based on Valenti et al. 1998

Subsequent work by Chavez & Lambert 2009 & Schmidt et al. 2009

M dwarf challenges: parameters

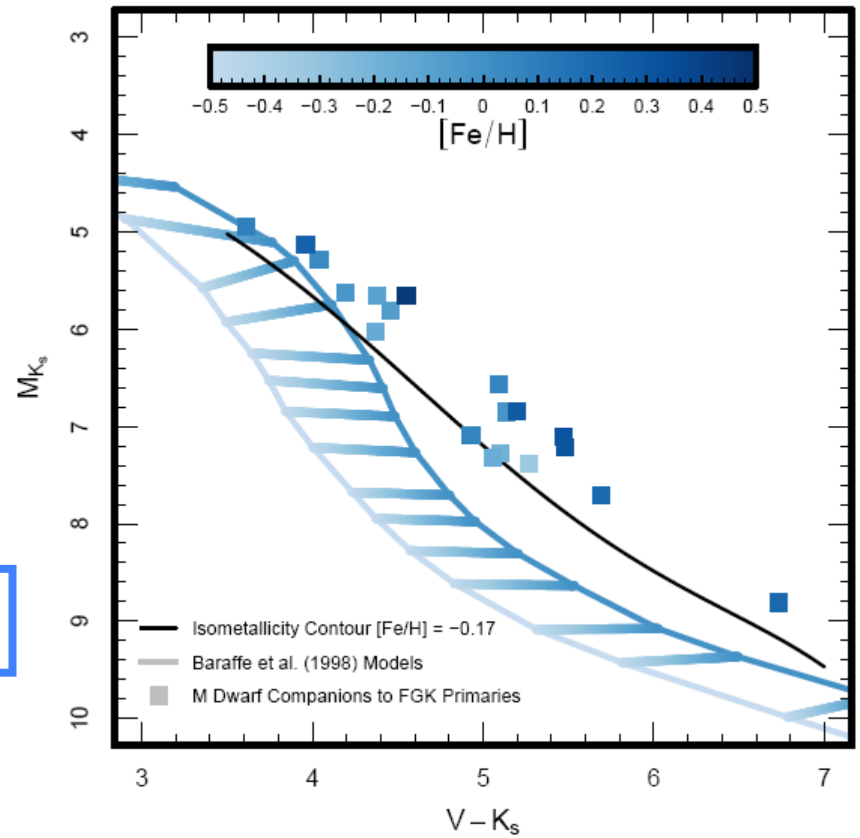
Photometric calibration of metallicity

Functions of $V-K$ and M_K:

Bonfils et al. 2005

Johnson & Apps 2009

Schaufman & Laughlin 2010

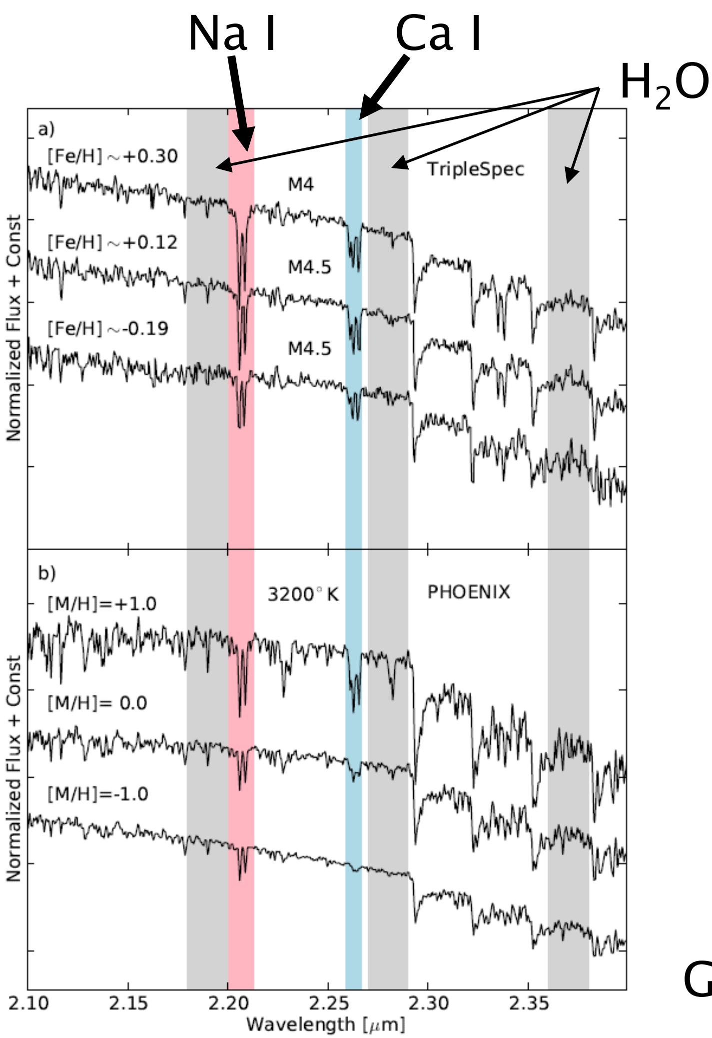


Accuracy is 0.2 dex

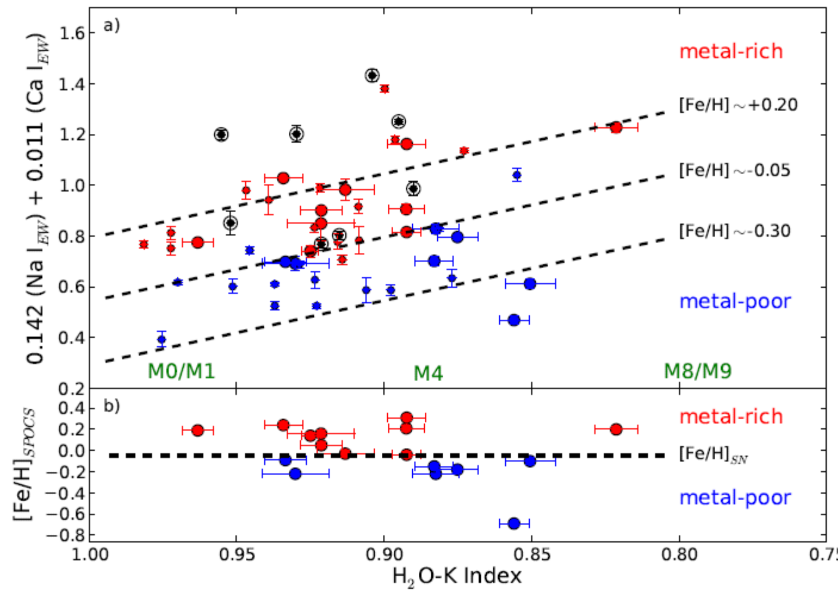
GJ876: [M/H] = +0.03, +0.37, +0.23

Schaufman & Laughlin 2010

M dwarf challenges: parameters



Low-res NIR indices



Accuracy is 0.15 dex

GJ876: [M/H] = +0.43

Rojas-Ayala et al. 2010

see related poster

M dwarf challenges: parameters

Final thoughts on metallicity

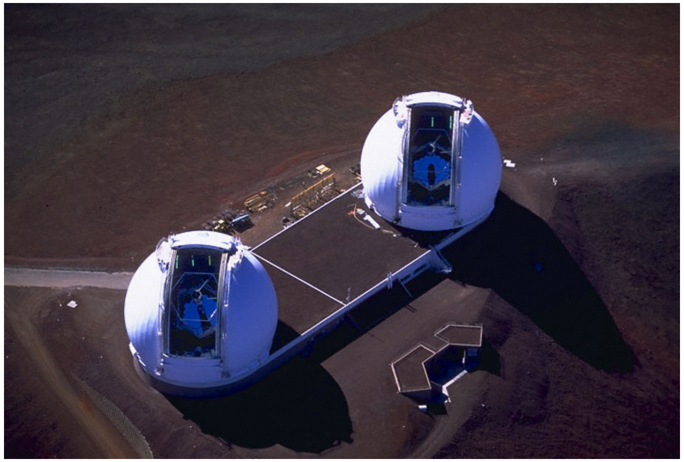
- Optical measurements should be re-visited with newly developed empirical calibrations of T_{eff} and avoidance of problem areas
- Investigating the NIR at high-resolution and using more sophisticated analysis techniques have a great potential, but beware NLTE effects
- Increasingly important as more planet surveys focus on these stars

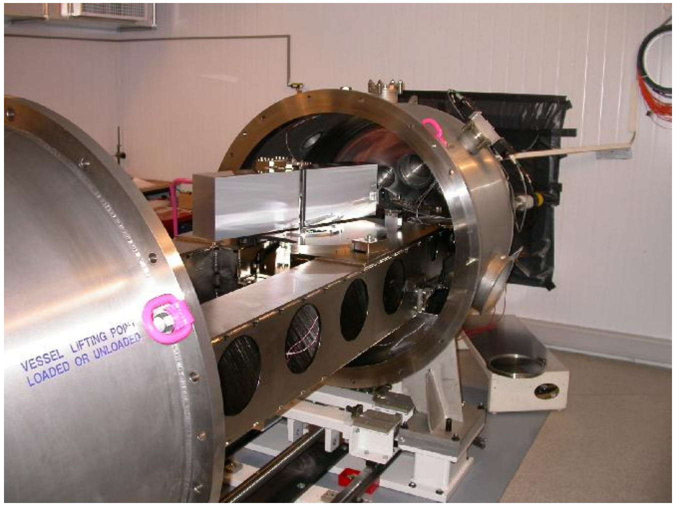
Ongoing projects and highlights

Ongoing projects and highlights

Optical radial velocity

- Discovery or confirmation of approximately 25 M dwarf planets
- Dearth of gas giants around M dwarfs: Endl et al. 2006, Johnson et al. 2007, Johnson et al. 2010
- Searches sensitive to very low-mass planets in the habitable zone around a few M dwarfs e.g., Endl & Kurseter 2008
- Very difficult to probe below 0.2 M_{sun}





Ongoing projects and highlights

NIR radial velocity

- Current state of the art is 5 m/s with VLT + CRIRES and ammonia cell
- CRIRES planet search running since 2009, 31 stars with $M < 0.2\ M_{sun}$ so far, proposed to continue and add 30 more
- New northern hemisphere survey using Subaru + IRCS since late 2010, 20 m/s precision, 23 additional stars (PI: Andreas Seifahrt)
- Other surveys with precision $\gtrsim$ 50 m/s

  Gemini + Phoenix + telluric calibration, Blake et al. 2007 – L Dwarfs!

  Keck + NIRSPEC+ telluric calibration, Blake et al. 2010 – more L dwarfs!

  Palomar + TEDI + ThAR and fibers, Muirhead et al. 2011

  IRTF + CSHELL + telluric calibration, Crockett et al. 2011
- Plus new gas cell development – see next talk
- Results: No planet detections, some candidates, no giant planet for VB10
- Limitation is tellurics, new level of precision will require new instruments

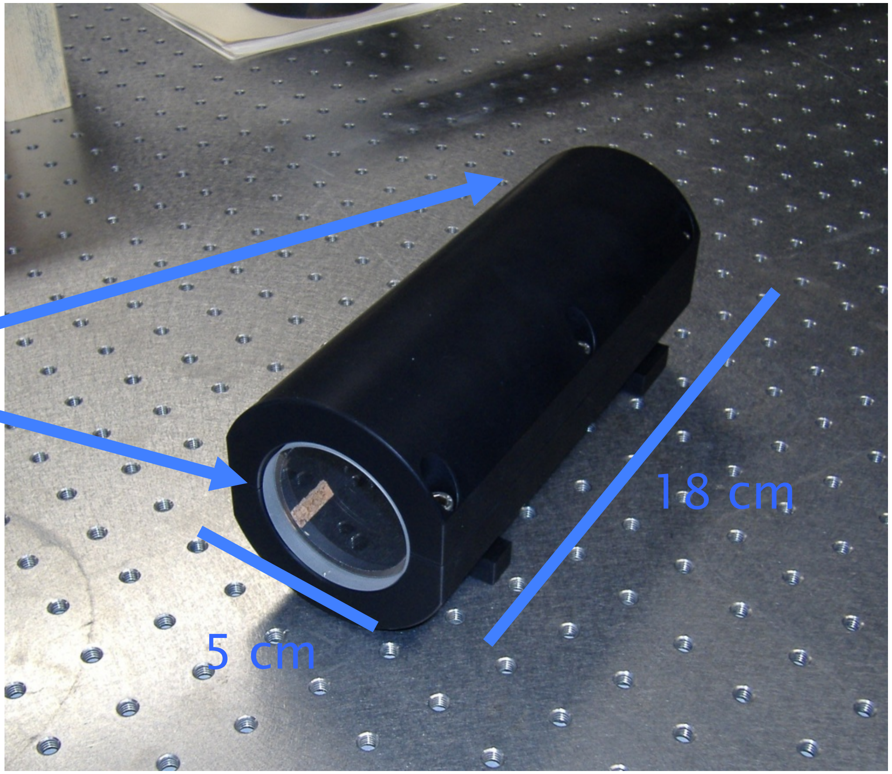
Ongoing projects and highlights

NIR radial velocity

CRIRES ammonia gas cell

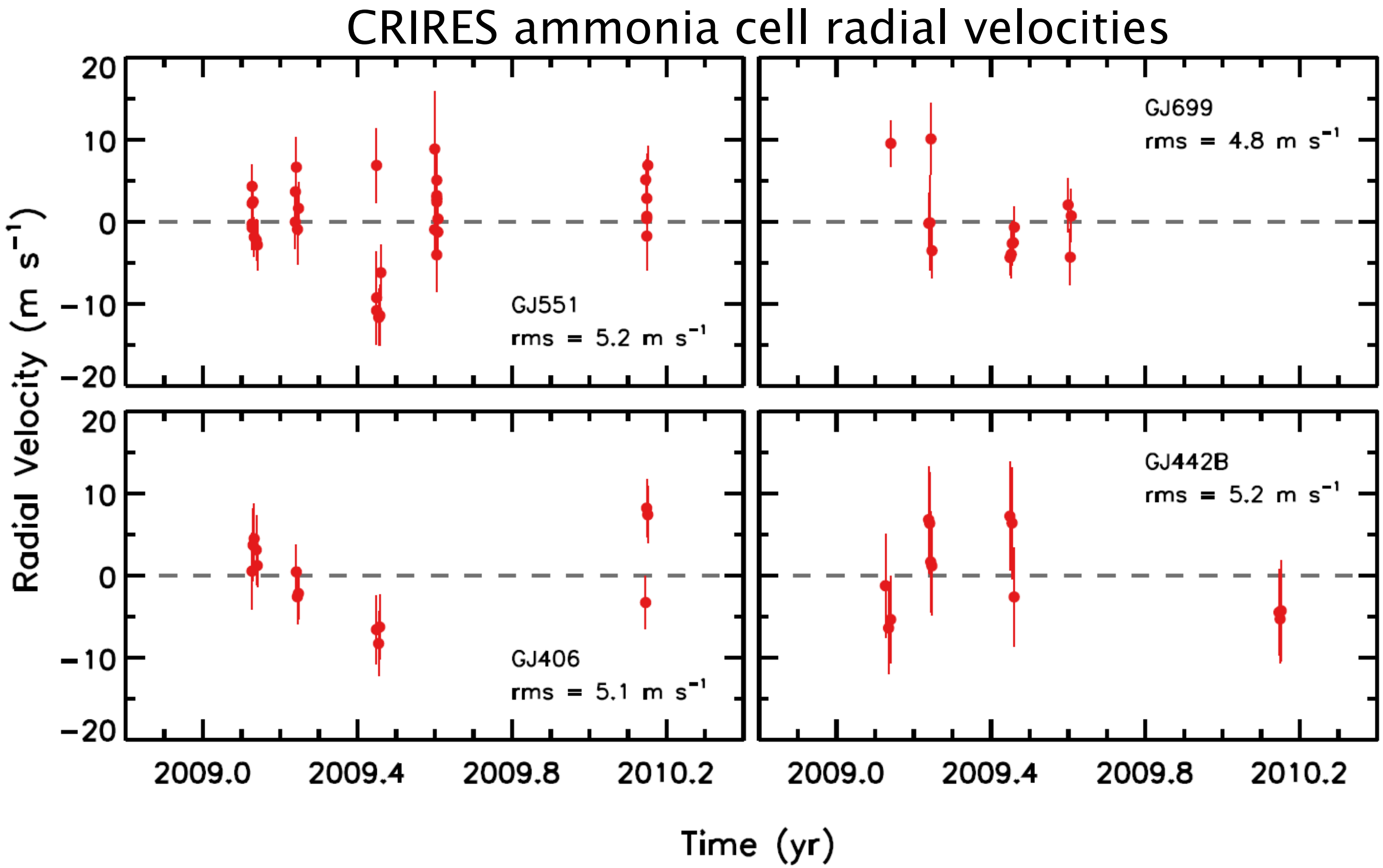
wedged windows to eliminate fringing

fixed pressure of 50 mbar at T=20 C



Ongoing projects and highlights

NIR radial velocity



Bean et al. 2010b

Ongoing projects and highlights

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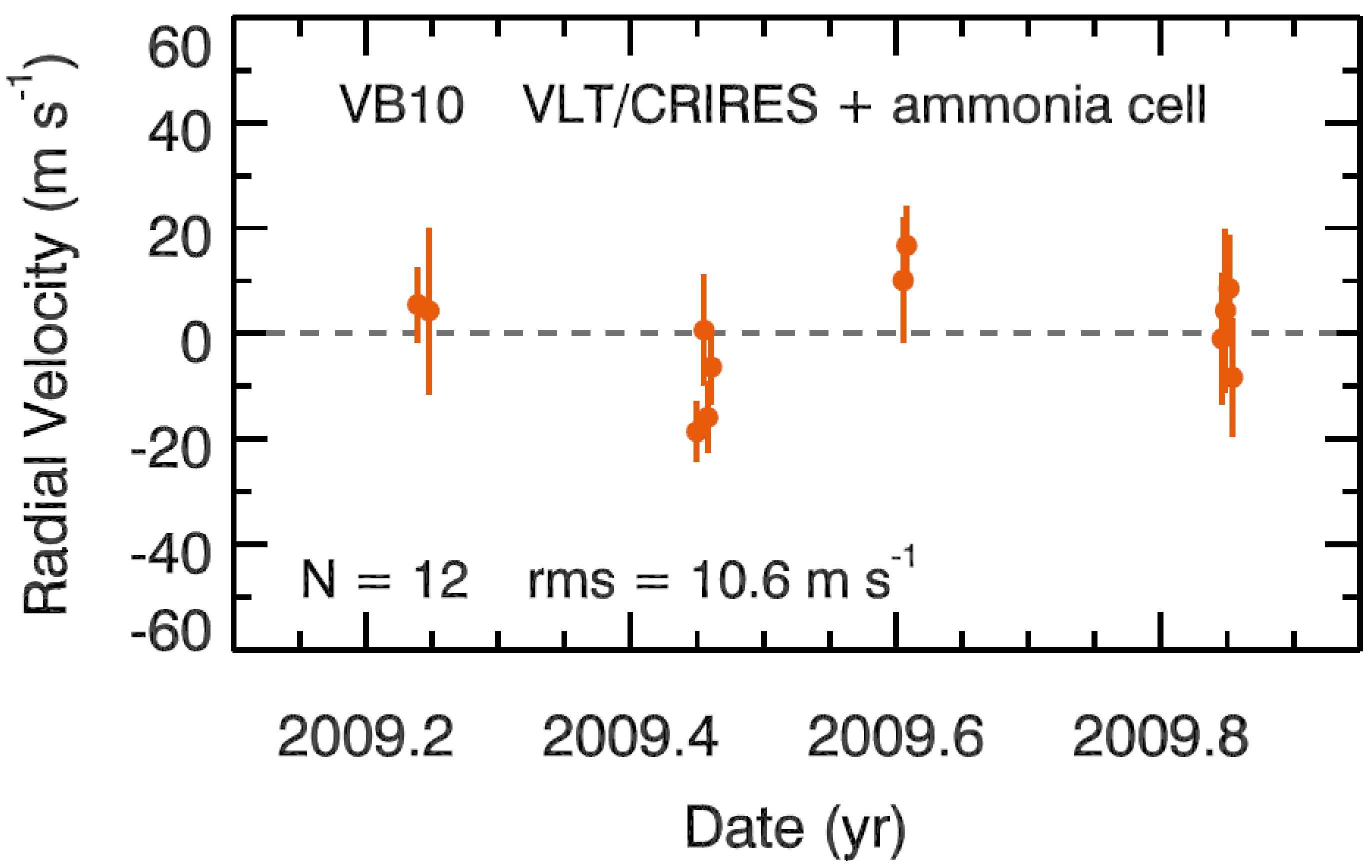

Bean et al. 2010a

Ongoing projects and highlights

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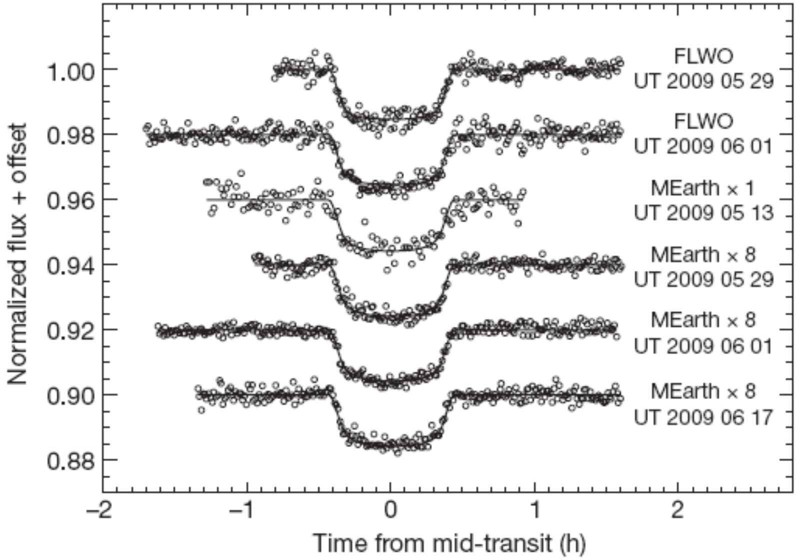
Ongoing projects and highlights

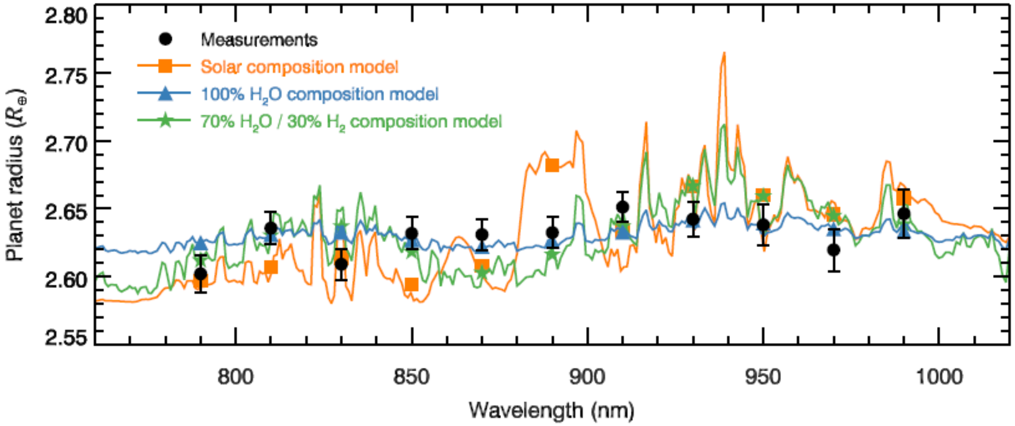
MEarth transit search

GJ 1214b



Charbonneau et al. 2009

Optimized for characterization!



Bean et al. 2010c

MEarth South coming soon

+

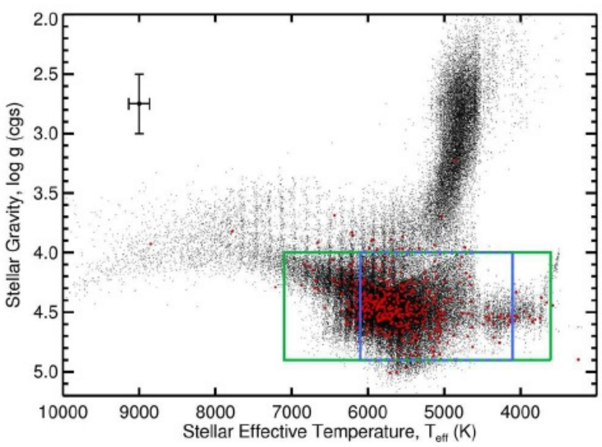
Désert et al. 2011

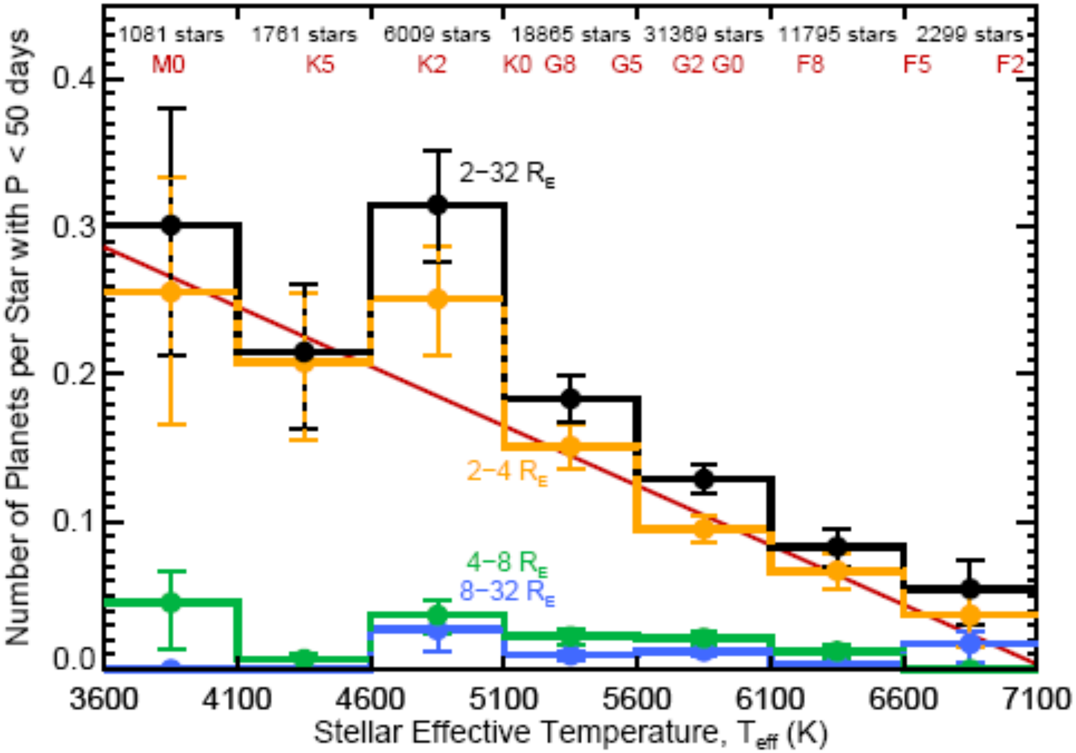
Croll et al. 2011

Crossfield et al. 2011

Also stellar astrophysics!

Ongoing projects and highlights





Howard et al. 2011

Select future projects

Future projects

CARMENES: optical and NIR RV to 1 m/s precision

Will enable the large-scale detection of planets down to a few times the mass of the Earth in the habitable zones of nearby M dwarfs

Telescope: Calar Alto 3.5m

Spectral coverage:
0.5 – 1.7µm with two stabilized spectrographs

Precision: 1 m s^{-1} in 15 min for J = 8.5 M6 dwarf

Survey 300 stars in a 600 night / 5 yr GTO program

PI: A. Quirrenbach, Heidelberg

Operational in 2014

see related poster

Future projects

All-sky transit surveys from space

Proposed NASA Explorer-class missions:

TESS – PI. George Ricker

ELEKTRA – PI. Chas Beichman

see related poster

Summary

The first potentially habitable planet that we will have a hope of studying the atmosphere of will be found around an M dwarf.

Significant advances in the characterization of M dwarfs will have an important impact on the field and will most likely not be driven by stellar theorists, but rather exoplaneteers with a bigger motivation.