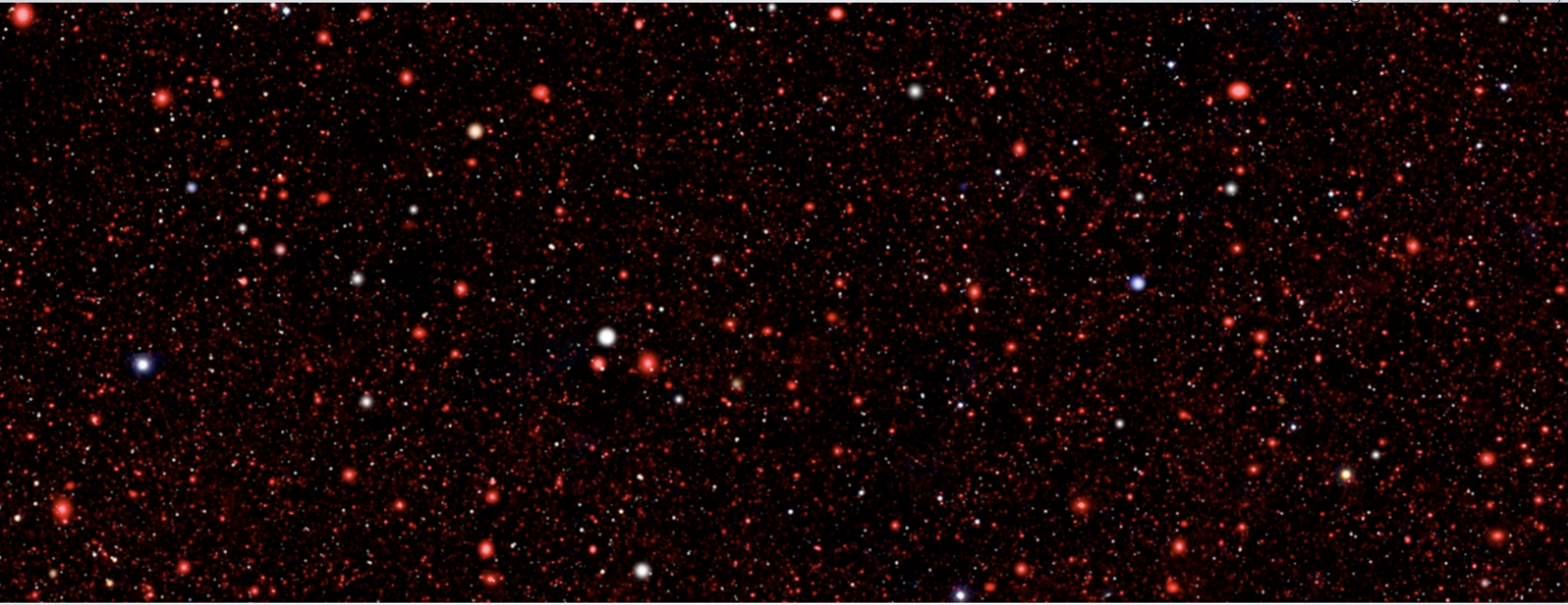
Credit: D. A. Aguilar & C. Pulliam(CfA)



THE SMALL STARS AND THEIR SMALL PLANETS

Bárbara Rojas-Ayala
IA-CAUP

Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA E DA TECNOLOGIA

instituto de astrofísica e ciências do espaço

The SOC suggested your name as an invited speaker for the session **"The precise characterization of stars with planets"**, and we would kindly ask you to give a review addressing in particular **M dwarfs** in this context.

precision | prɪˈsɪʒ(ə)n |

noun [mass noun]

the quality, condition, or fact of being exact and accurate: *the deal was planned and executed with military precision.*

Spectra

T_{eff}

[M/H]

Log g

Interferometry
+ parallax & SED

Binaries

Binaries

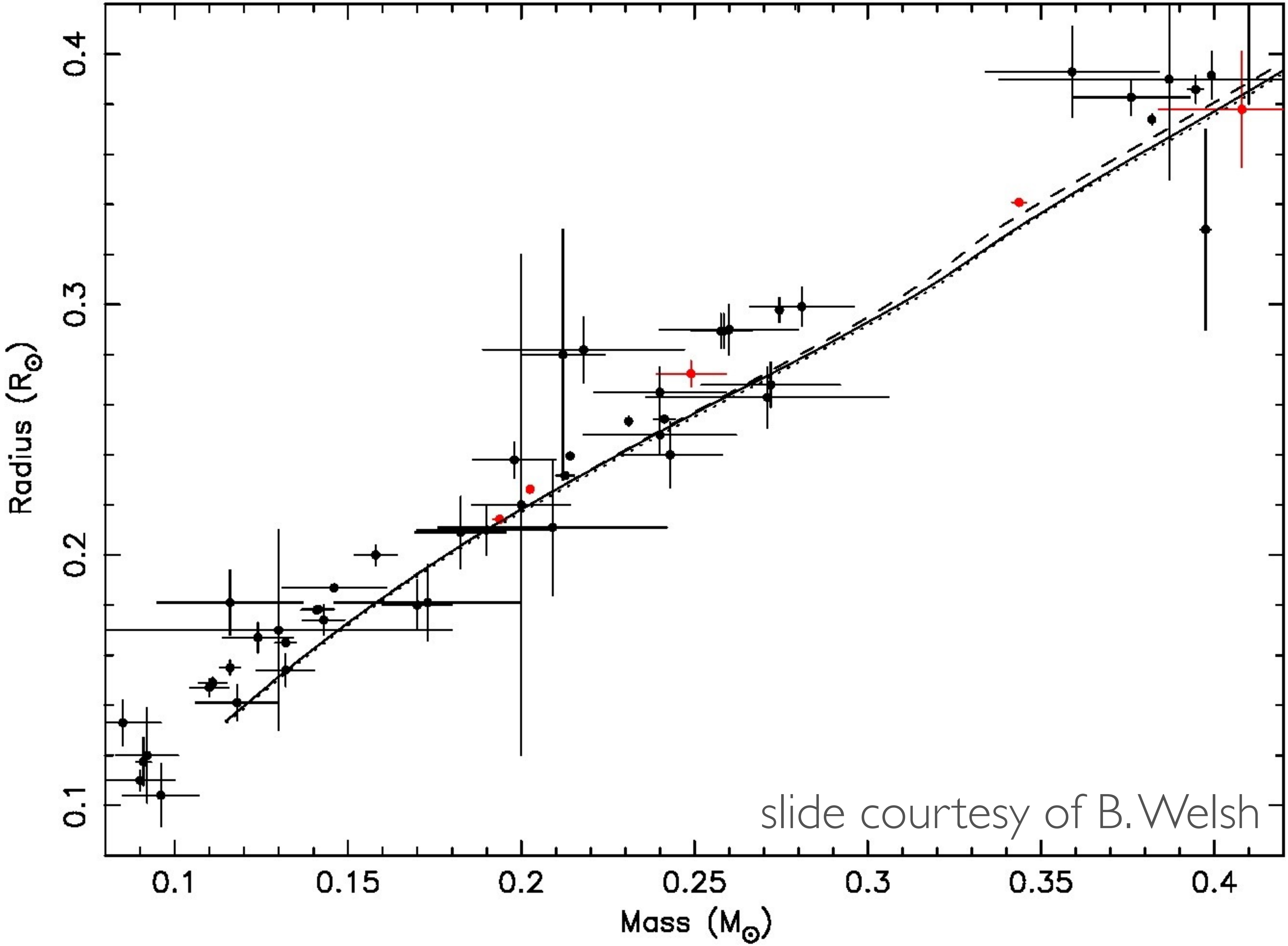
Binaries
Interferometry

M_{star}

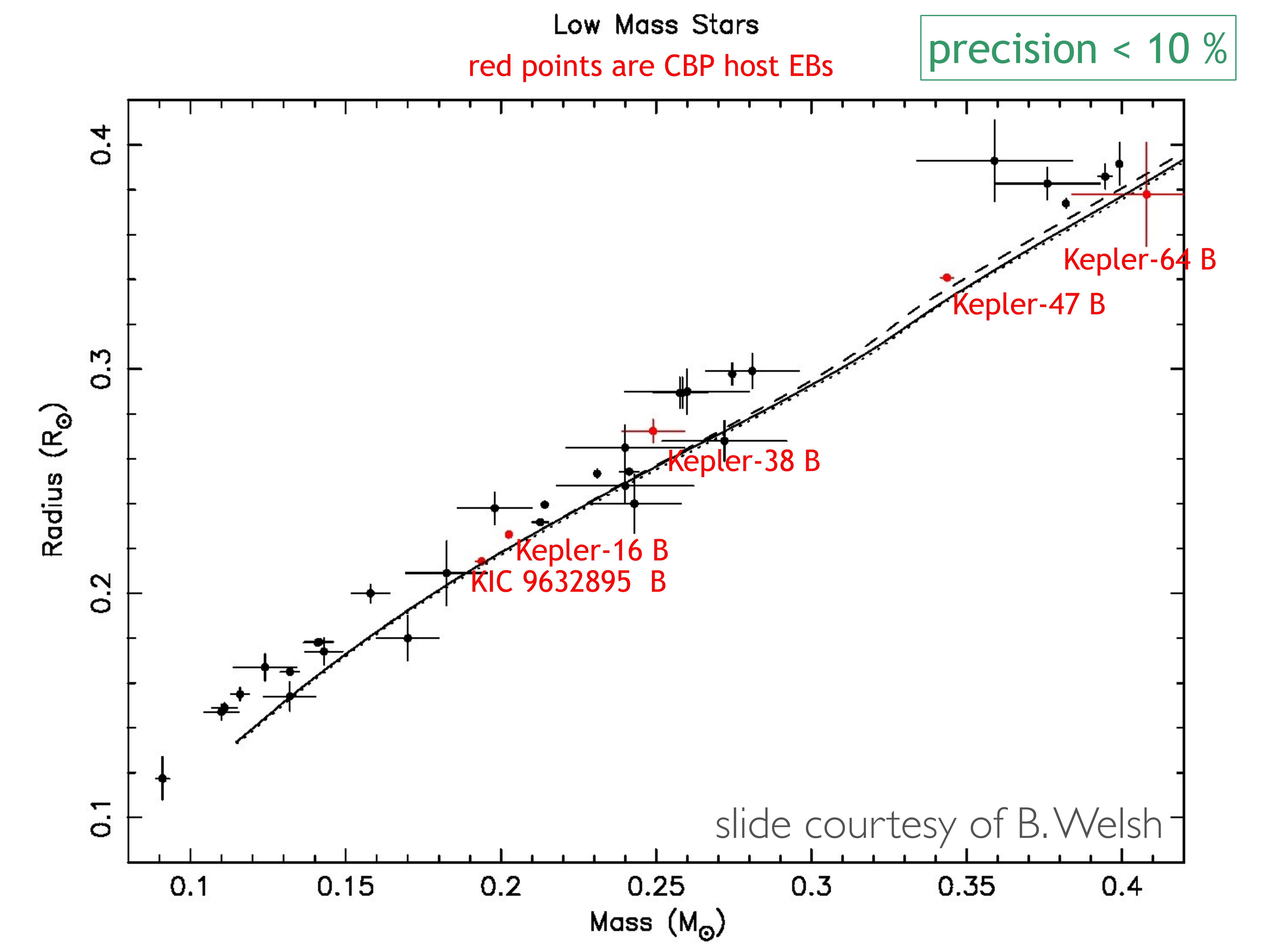
R_{star}

Low Mass Stars

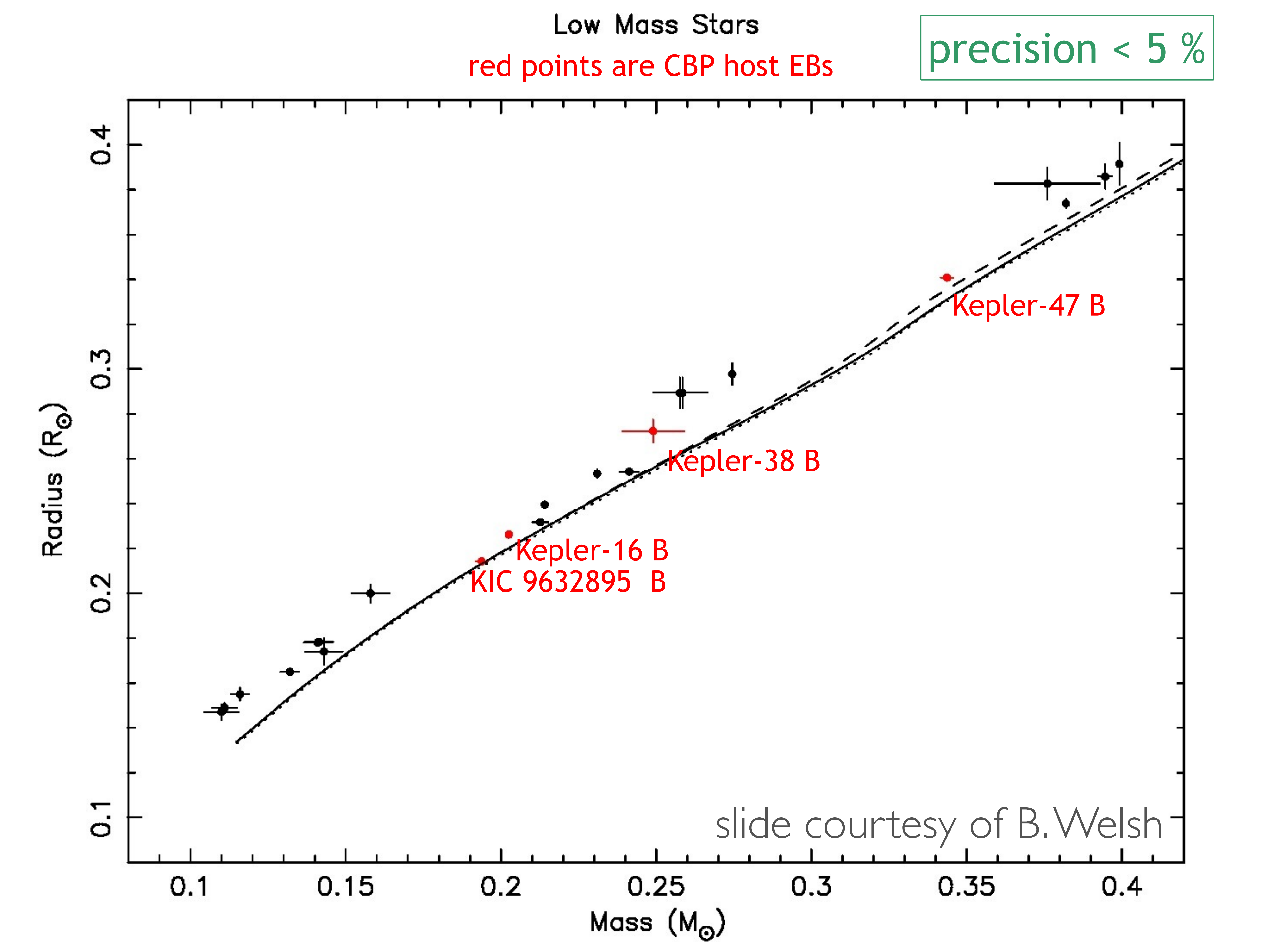
red points are CBP host EBs

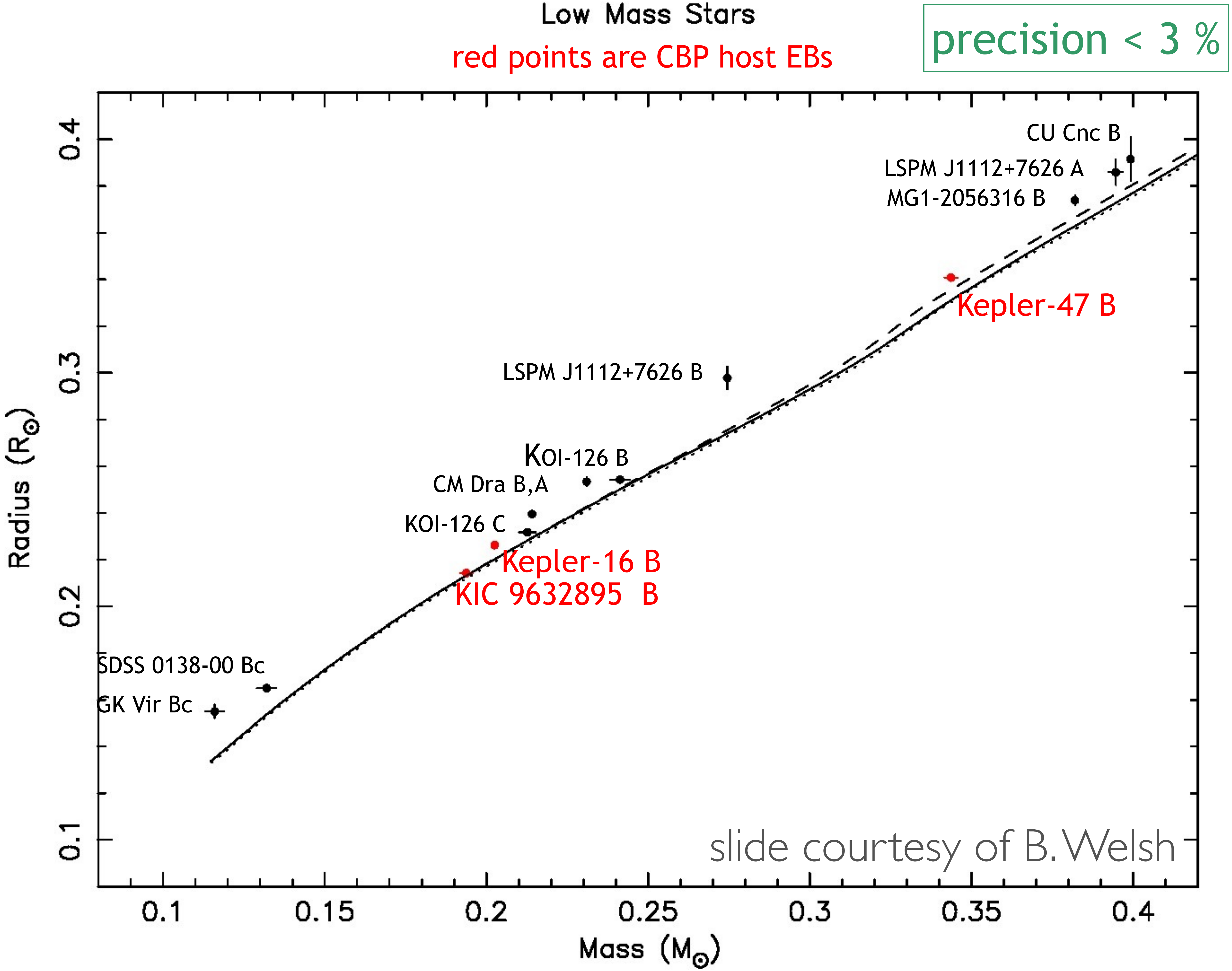


slide courtesy of B. Welsh

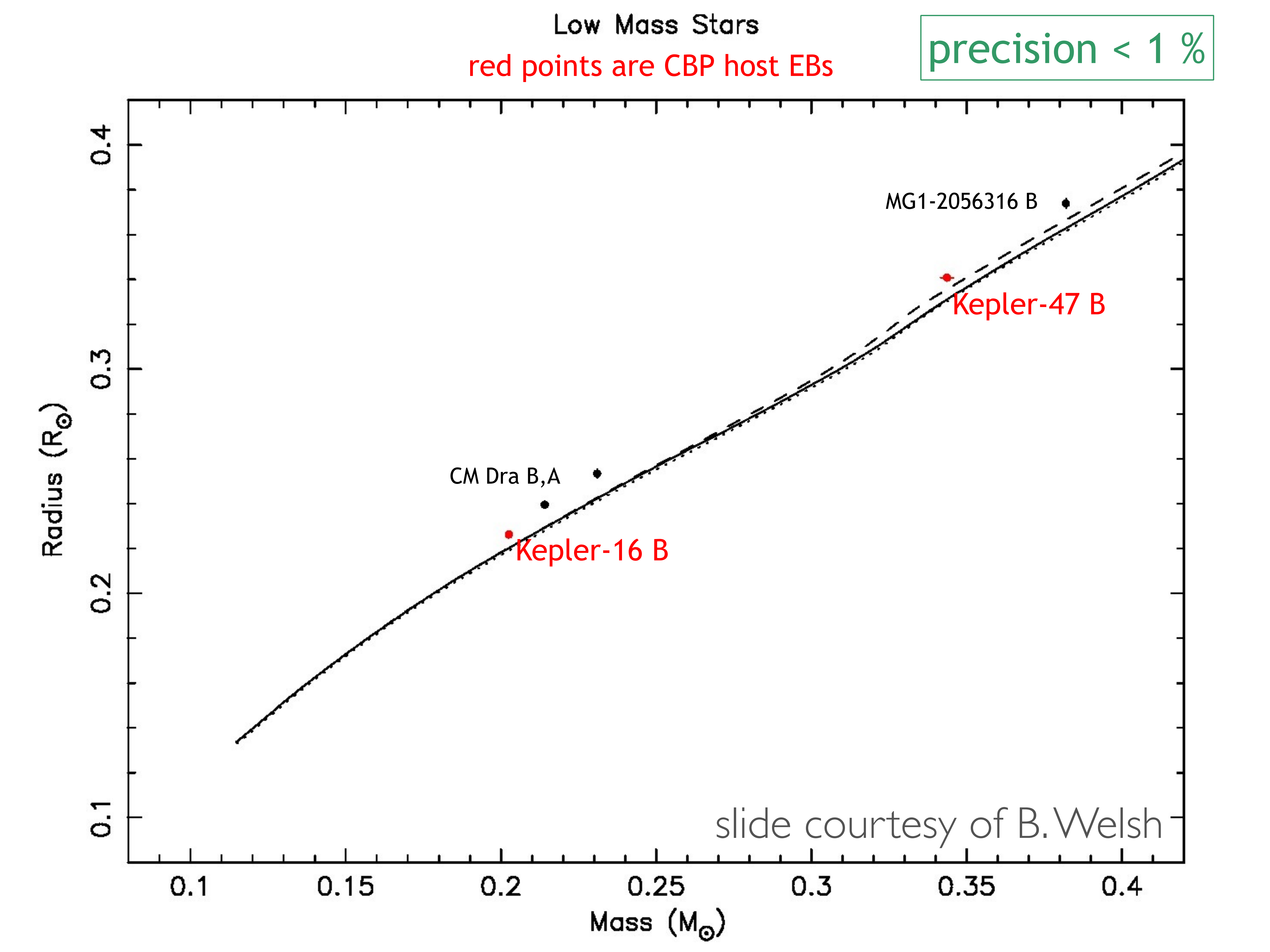


Low Mass Stars
red points are CBP host EBs
precision < 10 %
Radius (R☉)
Mass (M☉)
0.1
0.2
0.3
0.4
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Kepler-64 B
Kepler-47 B
Kepler-38 B
Kepler-16 B
KIC 9632895 B
slide courtesy of B. Welsh


Low Mass Stars
red points are CBP host EBs
precision < 5 %
Kepler-47 B
Kepler-38 B
Kepler-16 B
KIC 9632895 B
slide courtesy of B. Welsh
Radius ($R_\odot$)
0.1
0.2
0.3
0.4
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Mass ($M_\odot$)



Low Mass Stars
red points are CBP host EBs
precision < 3 %
CU Cnc B
LSPM J1112+7626 A
MG1-2056316 B
Kepler-47 B
LSPM J1112+7626 B
KOI-126 B
CM Dra B,A
KOI-126 C
Kepler-16 B
KIC 9632895 B
SDSS 0138-00 Bc
GK Vir Bc
slide courtesy of B. Welsh
Radius ($R_\odot$)
Mass ($M_\odot$)
0.1
0.2
0.3
0.4
0.1
0.15
0.2
0.25
0.3
0.35
0.4



Low Mass Stars
red points are CBP host EBs
precision < 1 %
MG1-2056316 B
Kepler-47 B
CM Dra B,A
Kepler-16 B
slide courtesy of B. Welsh
Radius ($R_{\odot}$)
Mass ($M_{\odot}$)
0.1
0.2
0.3
0.4
0.1
0.15
0.2
0.25
0.3
0.35
0.4

Kepler-16: Accurate Masses and Radii

	Parameter	Value and Uncertainty
	Star A	
0.50%	Mass, M_A ($M_\odot$)	$0.6897^{+0.0035}_{-0.0034}$
0.20%	Radius, R_A ($R_\odot$)	$0.6489^{+0.0013}_{-0.0013}$
	Mean Density, ρ_A (g cm^{-3})	$3.563^{+0.017}_{-0.016}$
	Surface Gravity, $\log g_A$ (cgs)	$4.6527^{+0.0017}_{-0.0016}$
	Effective Temperature, $T_{\rm eff}$ (K)	4450 ± 150
	Metallicity, [m/H]	-0.3 ± 0.2
	Star B	
0.33%	Mass, M_B ($M_\odot$)	$0.20255^{+0.00066}_{-0.00065}$
0.26%	Radius, R_B ($R_\odot$)	$0.22623^{+0.00059}_{-0.00053}$
	Mean Density, ρ_B (g cm^{-3})	$24.69^{+0.13}_{-0.15}$
	Surface Gravity, $\log g_B$ (cgs)	$5.0358^{+0.0014}_{-0.0017}$
	Planet b	
4.8%	Mass, M_b ($M_{\rm Jupiter}$)	$0.333^{+0.016}_{-0.016}$
0.34%	Radius, R_b ($R_{\rm Jupiter}$)	$0.7538^{+0.0026}_{-0.0023}$
	Mean Density, ρ_b (g cm^{-3})	$0.964^{+0.047}_{-0.046}$
	Surface Gravity, g_b (m s^{-2})	$14.52^{+0.70}_{-0.69}$

slide courtesy of B. Welsh

High Res, high SNR Spectra

T_{eff} [M/H]   Log g

Interferometry
+ parallax & SED

Binaries

Hard to calculate for M dwarfs
Complex atmospheres, faint objects, activity
Most of attempts have been done using FGK+M CPM systems
Need of alternative/exotic methods

Binaries

M_{star}

Binaries
Interferometry

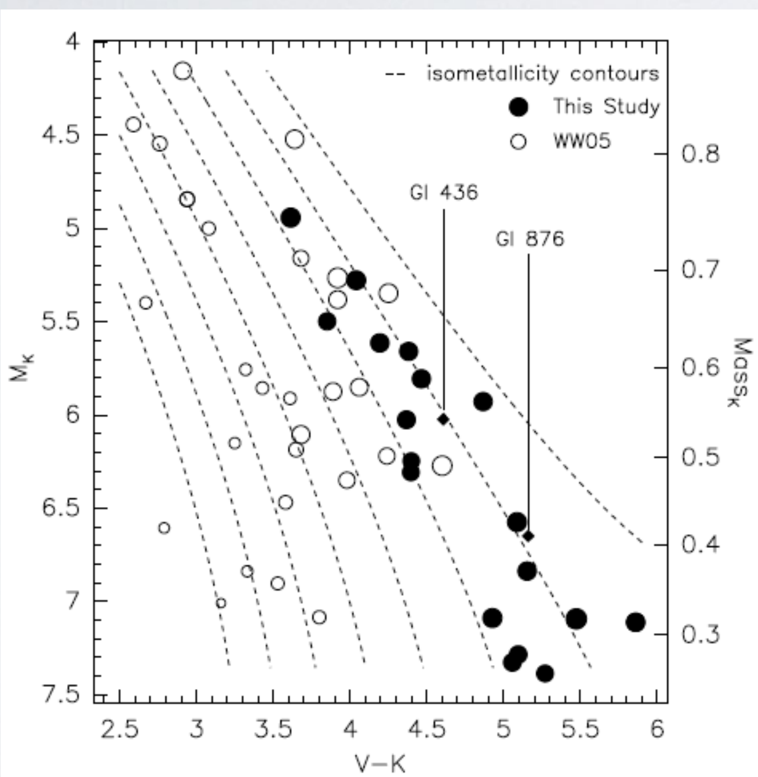
R_{star}

The planet-metallicity relation found for FGK stars motivated the development of [Fe/H] techniques for M dwarf hosts

[M/H] measurements rely on FGK+M CPM systems

Color-Magnitude

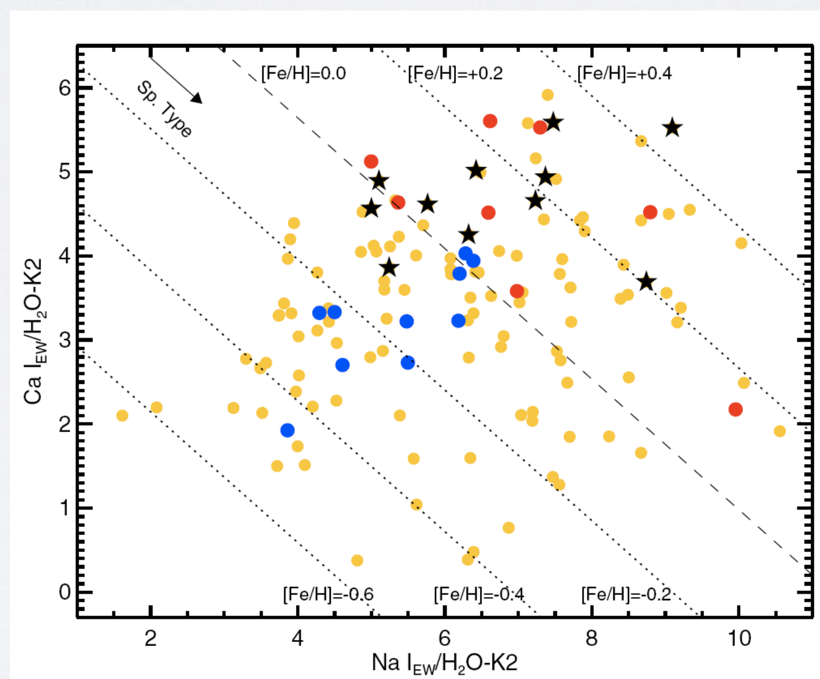
Neves et al. 2012
Schlaufman & Laughlin 2010
Johnson & Apps 2009
Bonfils et al. 2005



MK vs V-Ks

NIR “Modest Res”

Newton et al. 2014
Mann et al. 2012, 2014
Terrien et al. 2012
Rojas-Ayala et al. 2010, 2012

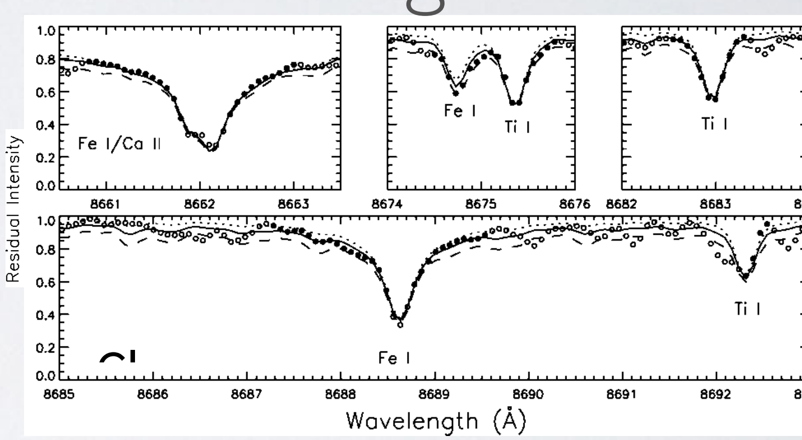


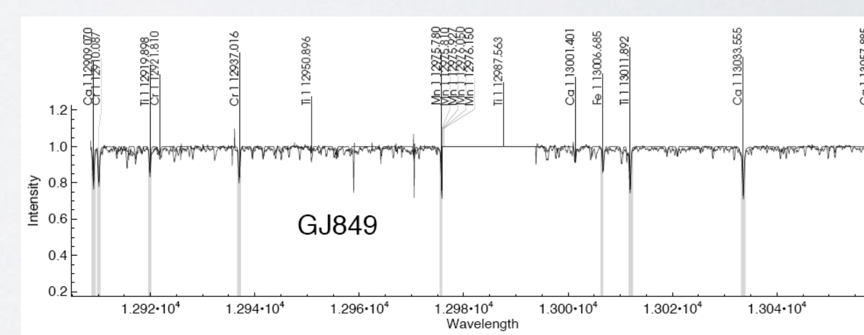
Ca, Na, Water in JHK

High Res

Neves et al. 2014
Bean et al. 2006
Önehag et al. 2011

Sara Lindgren’s talk





Fe I, Ti I, Ca I, etc

Check Session 5 for metallicity and planets!

Spectra
Models

T_{eff}

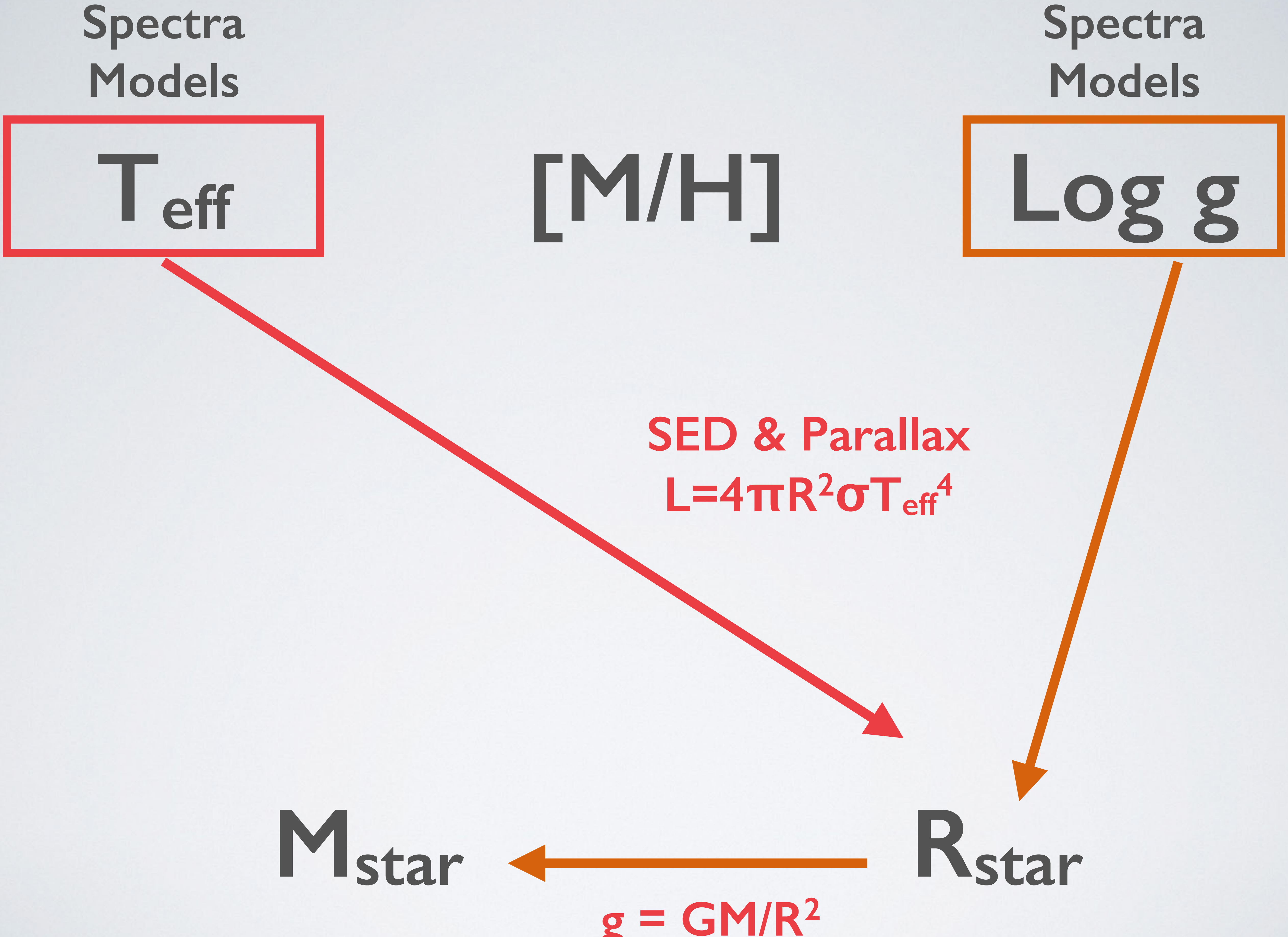
[M/H]

Log g

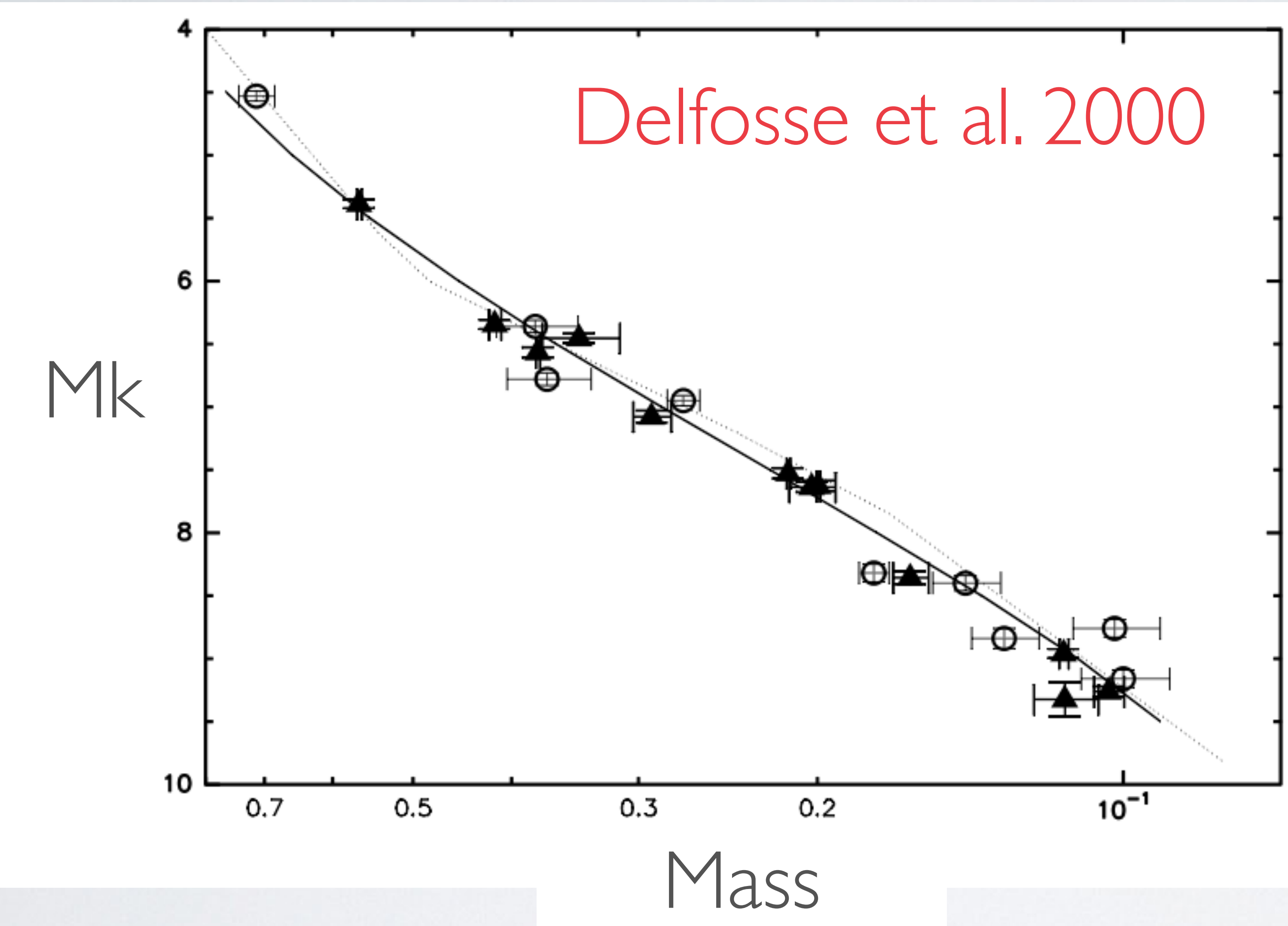
SED & Parallax
$L=4\pi R^2\sigma T_{eff}^4$

M_{star}

R_{star}



Spectra
Models
T_{eff}
[M/H]
Spectra
Models
Log g
SED & Parallax
$L=4\pi R^2\sigma T_{eff}^4$
M_{star}
R_{star}
$g = GM/R^2$



$$\log(M/M_\odot) = 10^{-3}\times[0.3 + 1.87\times M_V + 7.6140\times M_V{}^2 -1.6980\times M_V{}^3 + 0.060958\times M_V{}^4] \quad \text{for } M_V \in [9, 17]$$

$$\log(M/M_\odot) = 10^{-3}\times[1.6 + 6.01\times M_J + 14.888\times M_J{}^2 -5.3557\times M_J{}^3 + 0.28518.10^{-4}\times M_J{}^4] \quad \text{for } M_J \in [5.5, 11]$$

$$\log(M/M_\odot) = 10^{-3}\times[1.4 + 4.76\times M_H + 10.641\times M_H{}^2 -5.0320\times M_H{}^3 + 0.28396\times M_H{}^4] \quad \text{for } M_H \in [5, 10]$$

$$\log(M/M_\odot) = 10^{-3}\times[1.8 + 6.12\times M_K + 13.205\times M_K{}^2 -6.2315\times M_K{}^3 + 0.37529\times M_K{}^4 \quad \text{for } M_K \in [4.5, 9.5]$$

$$\log(M/M_\odot) = 10^{-3}\times[7.4 + 17.61\times(V-K) +33.216\times(V-K)^2 + 34.222\times(V-K)^3 -27.1986\times(V-K)^4 + 4.94647\times(V-K)^5 -0.27454\times(V-K)^6 \quad \text{for } V-K \in [4, 7]$$

Parallax + Johnson-Cousins-CIT

M_{star}

Used for RV host stars (SWEET-Cat)
Santos et al. 2013

Relations between [Fe/H] and Mass see V. Neves talk on Thursday

Spectra
Models

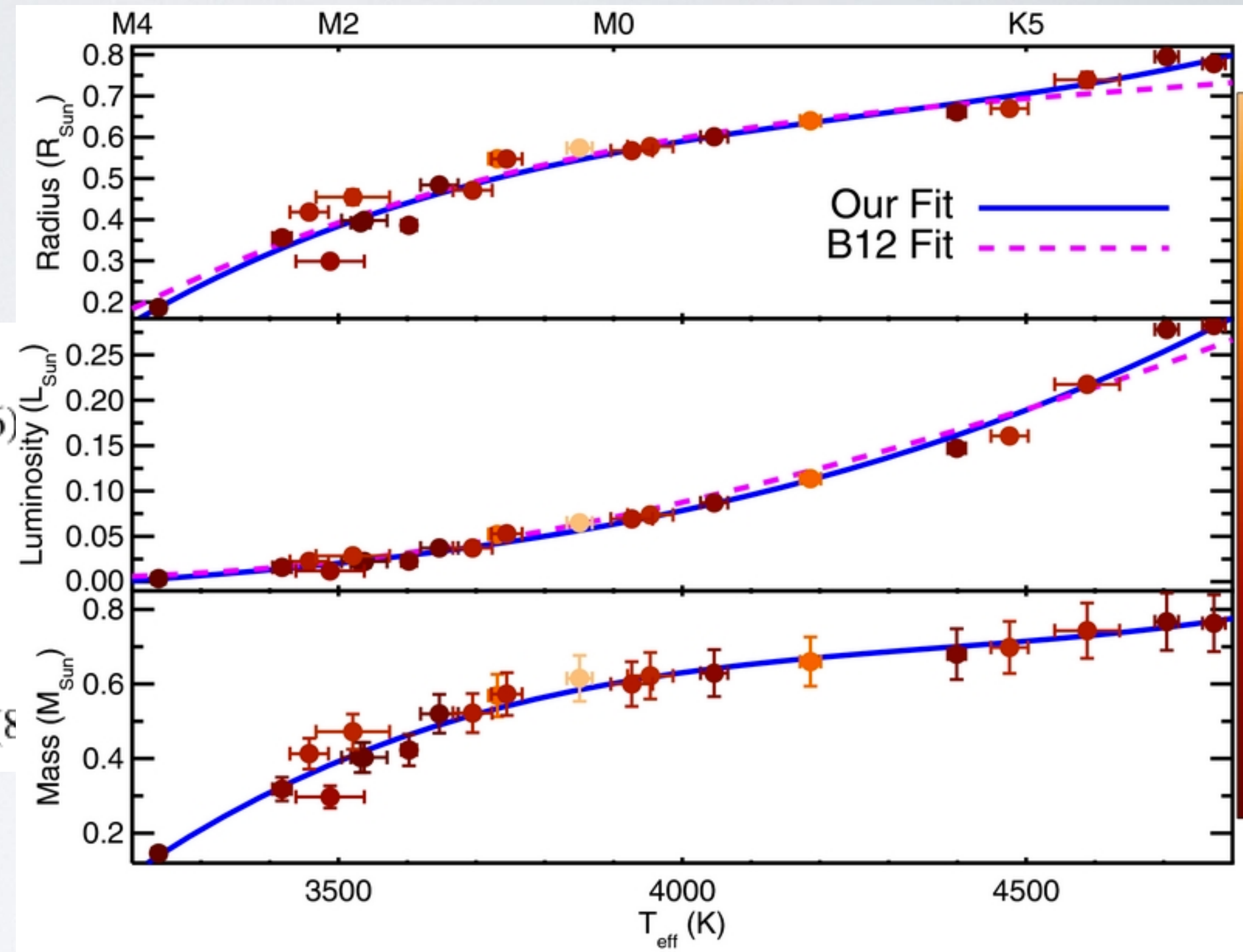
T_{eff}

Boyajian et al. 2012
Mann et al. 2013

$$R_* = -16.883 + 1.18 \times 10^{-2} T_{\rm eff} - 2.709 \times 10^{-6} T_{\rm eff}^2 + 2.105 \times 10^{-10} T_{\rm eff}^3, \quad (6)$$

$$L_* = -0.781 + 7.40 \times 10^{-4} T_{\rm eff} - 2.49 \times 10^{-7} T_{\rm eff}^2 + 2.95 \times 10^{-11} T_{\rm eff}^3, \quad (7)$$

$$M_* = -22.297 + 1.544 \times 10^{-2} T_{\rm eff} - 3.488 \times 10^{-6} T_{\rm eff}^2 + 2.650 \times 10^{-10} T_{\rm eff}^3, \quad (8$$



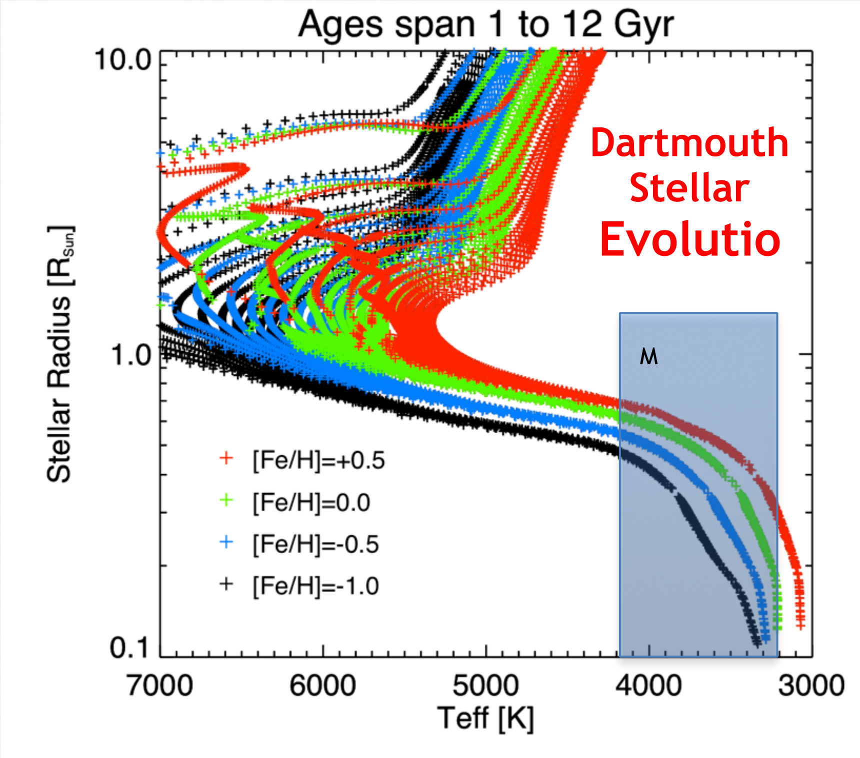
M_{star}

R_{star}

Spectra / Photometry

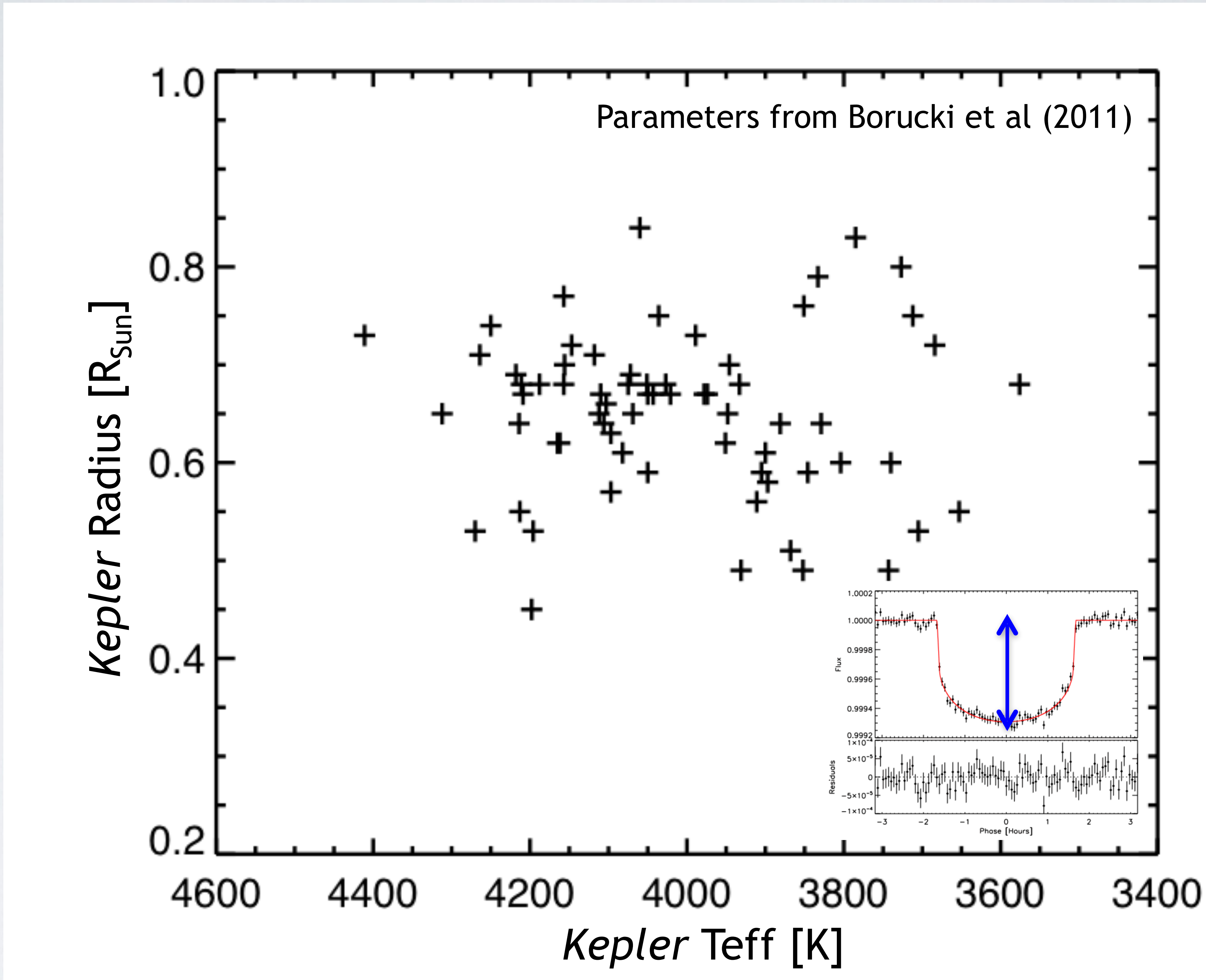
T_{eff} [M/H] Log g

Stellar evolution Models



M_{star} R_{star}

Borucki 2011: Low-mass stars with planet candidates!



$(R_{Planet}/R_{Star})^2$

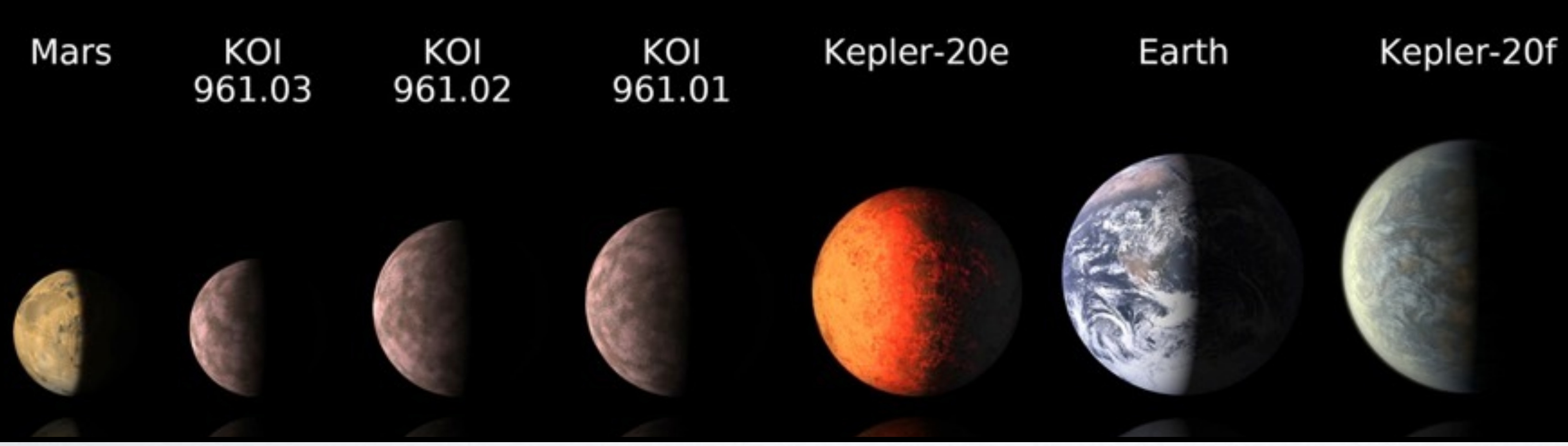
But the "photometric" parameters are not the expected ones :(

Characterizing the Cool KOIs

Phil Muirhead (BU)

- 3000 M dwarfs were observed by *Kepler*
- 100 show transit signals (The Cool KOIs)
- The Cool KOI Program is a *ground-based follow up* program of these stars to determine their stellar and planetary parameters:
  - Muirhead, Hamren, Schlawin, Rojas-Ayala, Covey & Lloyd 2012, ApJL (Cornell)
  - Johnson et al. 2012, AJ
  - Muirhead, Johnson et al 2012, ApJ
  - Swift et al. 2013, ApJ
  - Muirhead et al. 2013, ApJ
  - Muirhead, Becker et al. 2014 (last results)

Hamren (UCSC) Schlawin (Cornell) Rojas-Ayala (IA/CAUP) Covey (WWU) Lloyd (Cornell)

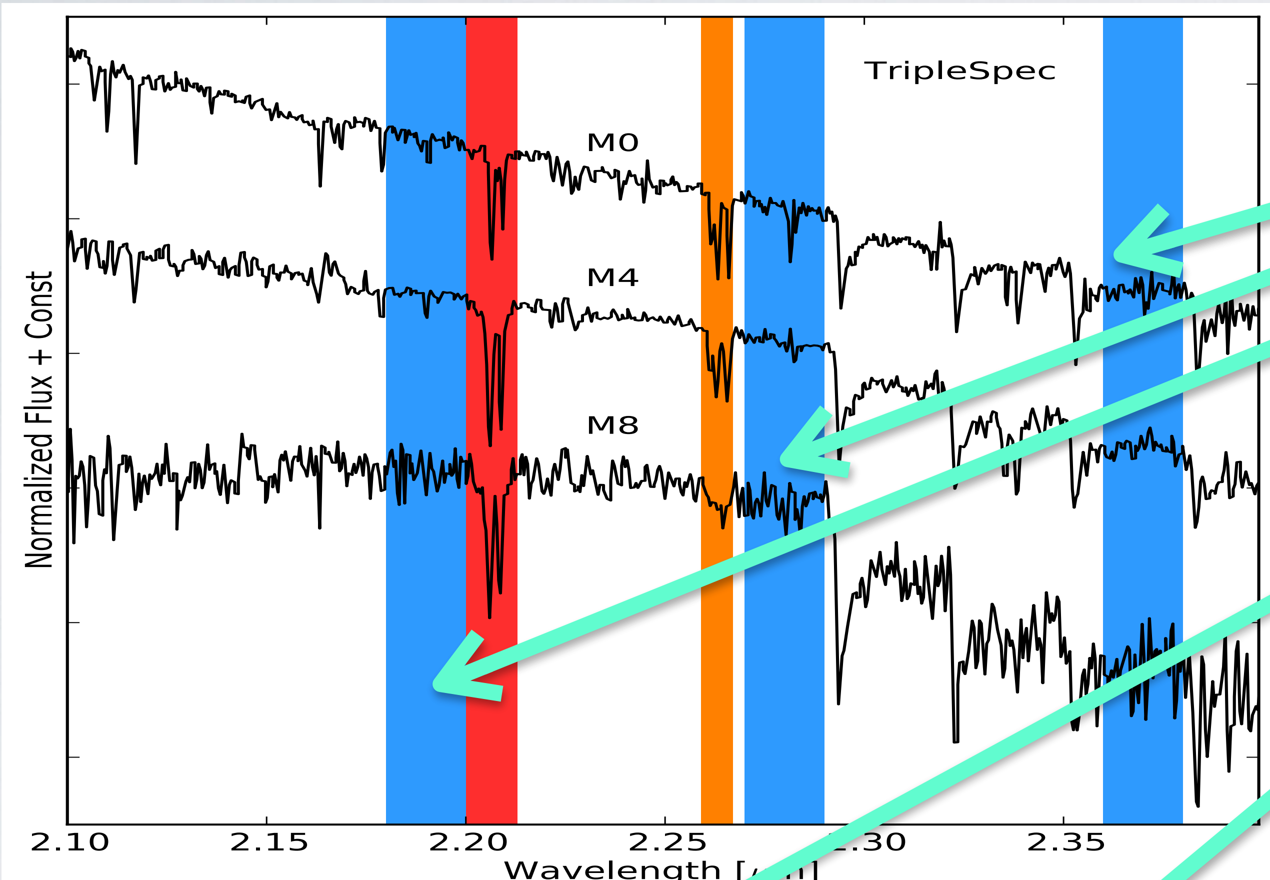


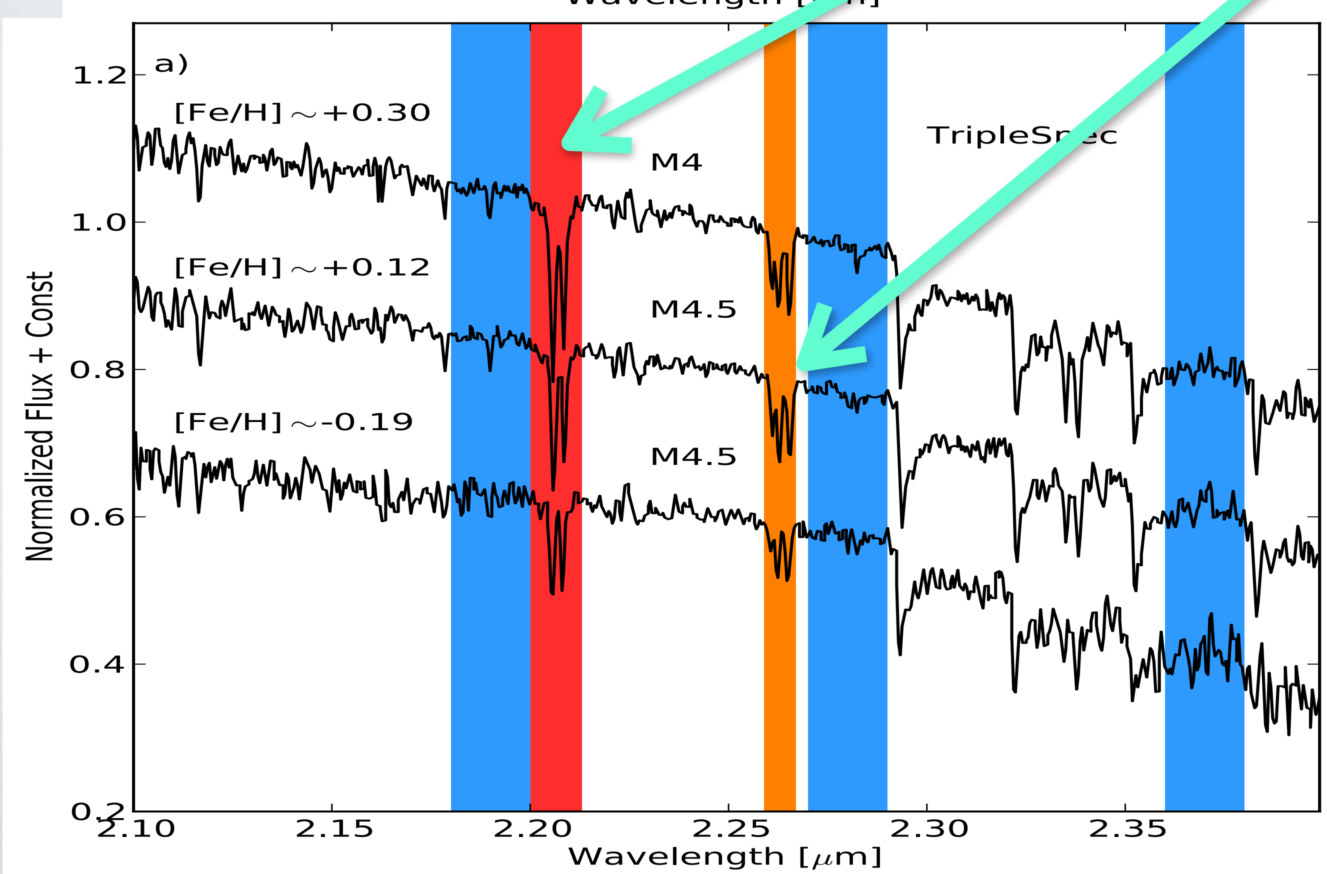
Juliette Becker
U of Michigan

slide courtesy of P. Muirhead

K-band Na I, Ca I and water reveal the metal abundance of M dwarfs

Rojas-Ayala et al. 2010, 2012

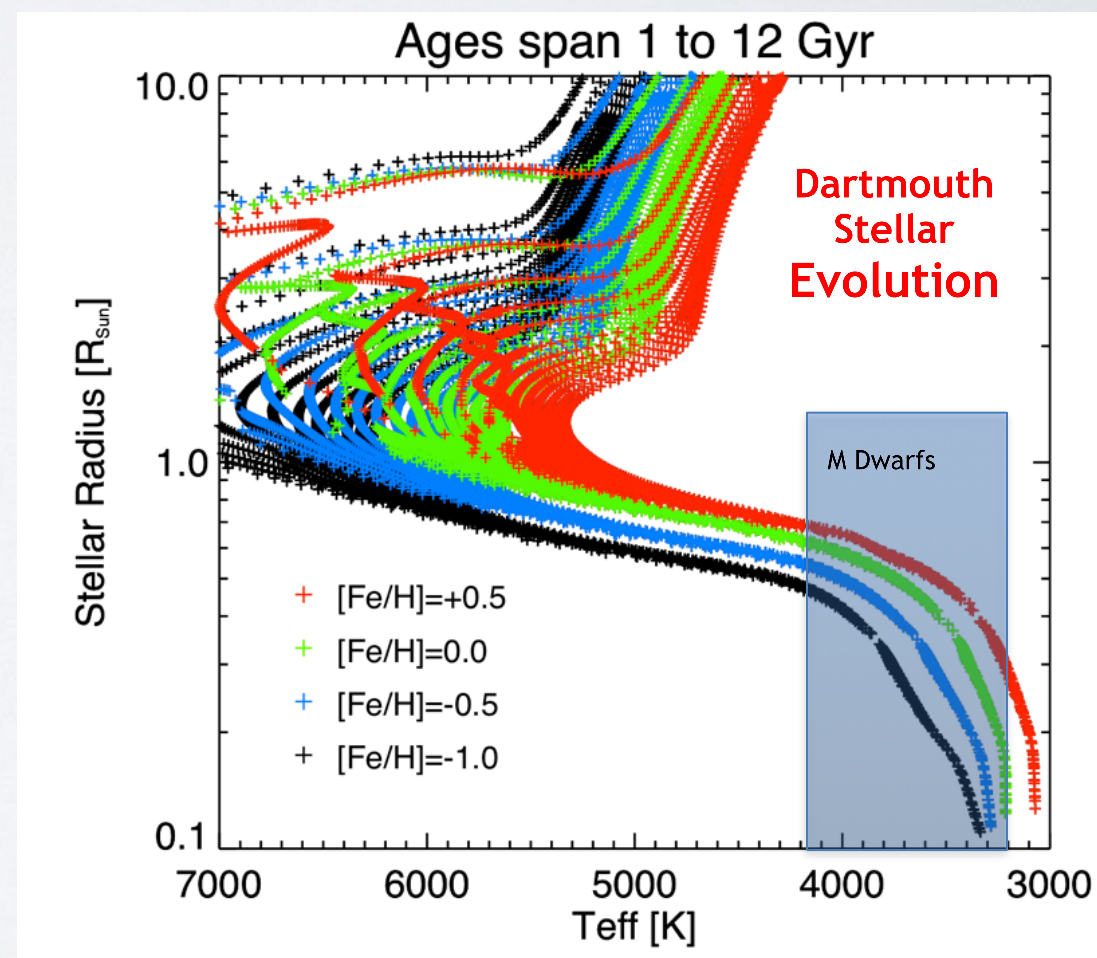


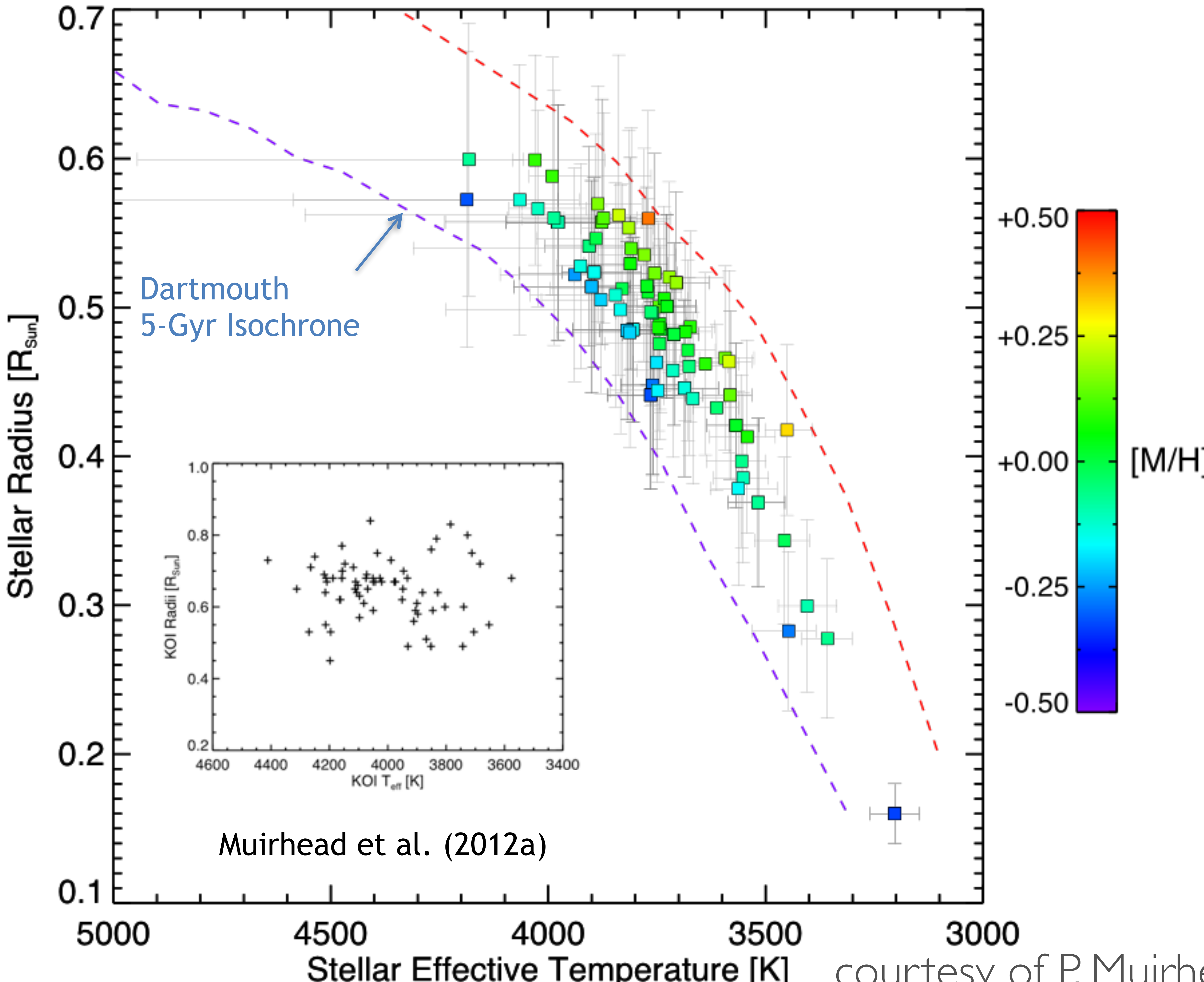


Deformation from H2O traces Teff

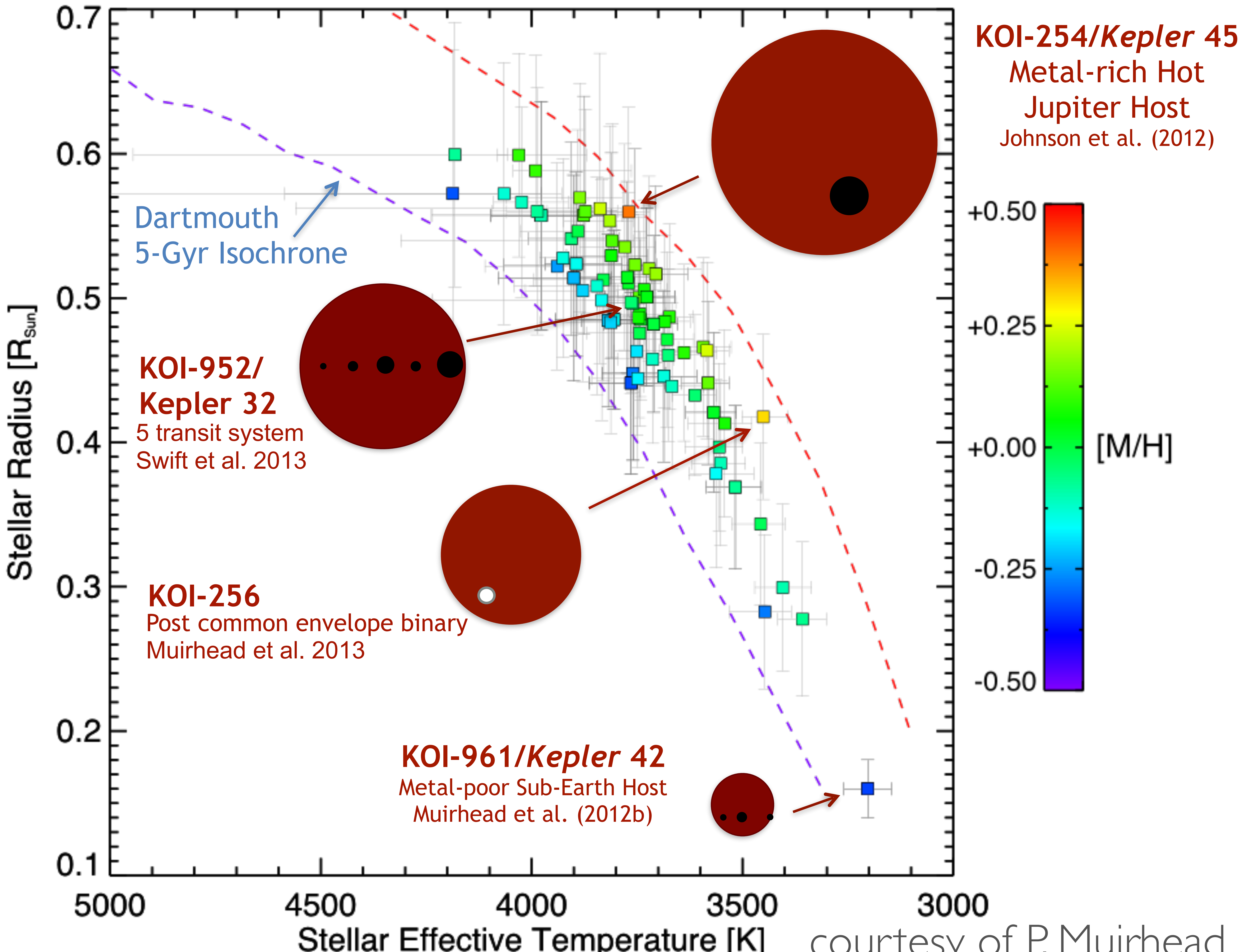
Na and Ca EW trace Metallicity

+





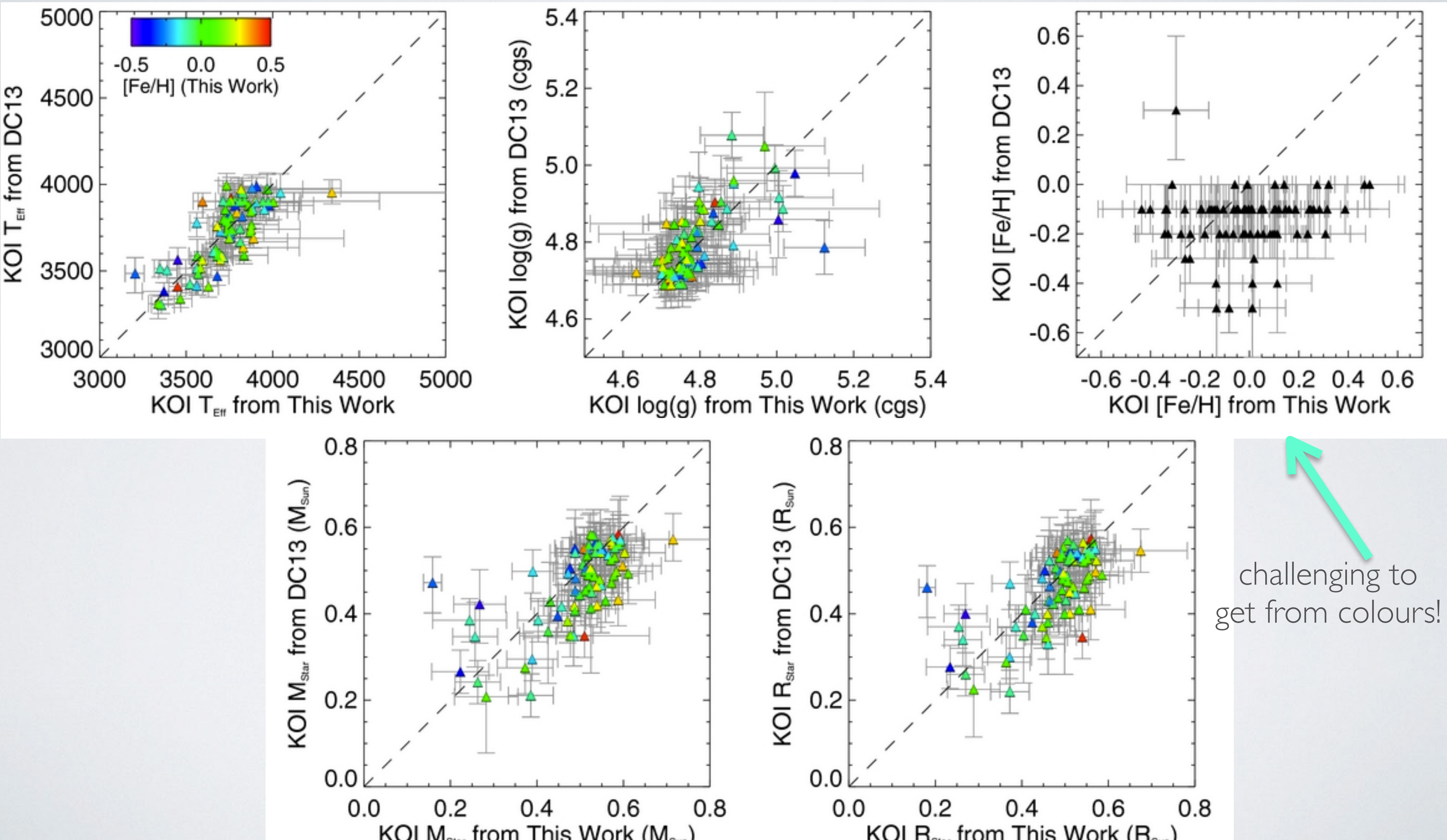
courtesy of P. Muirhead



courtesy of P. Muirhead

Considering the uncertainties, methods are in "agreement"

KIC+2MASS + Dartmouth Models photometry give lower masses and smaller radii than NIR+ 5 Gyr Dartmouth isochrones



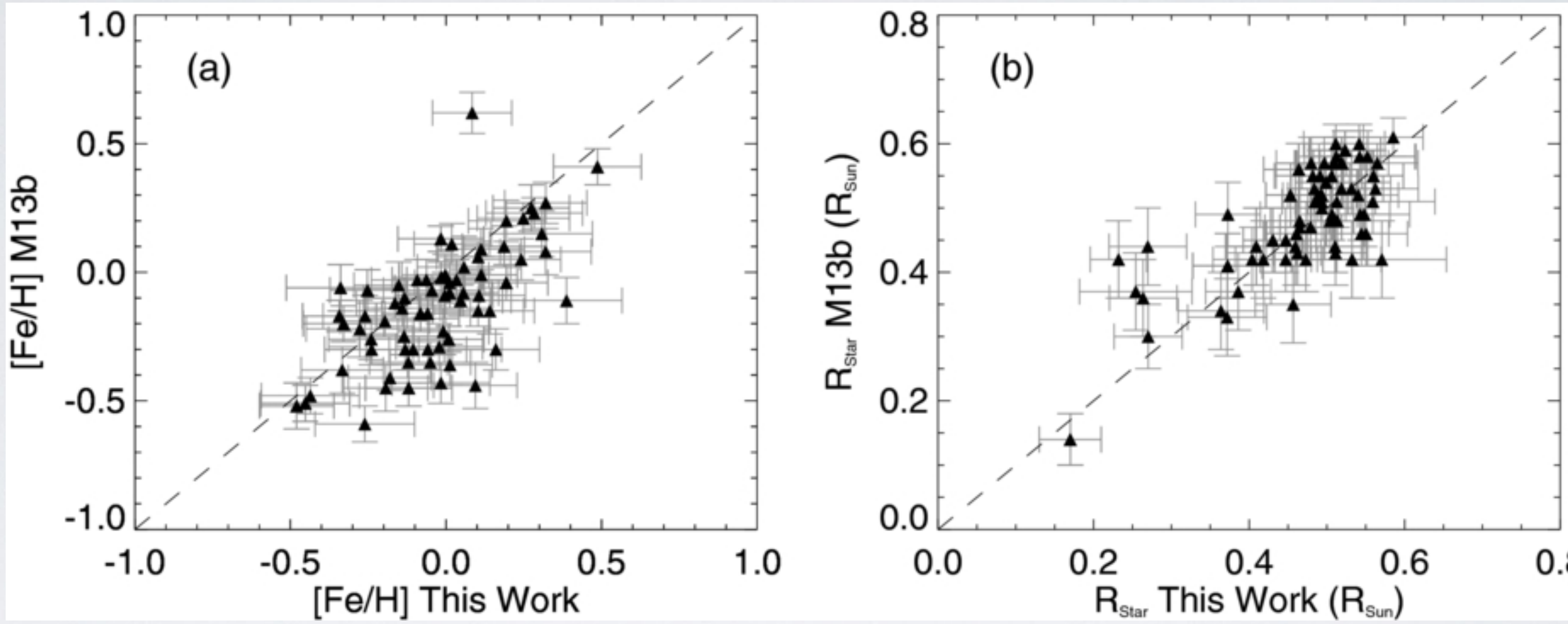
challenging to get from colours!

DC13: Dressing & Charbonneau 2013

Considering the uncertainties, methods are in "agreement"

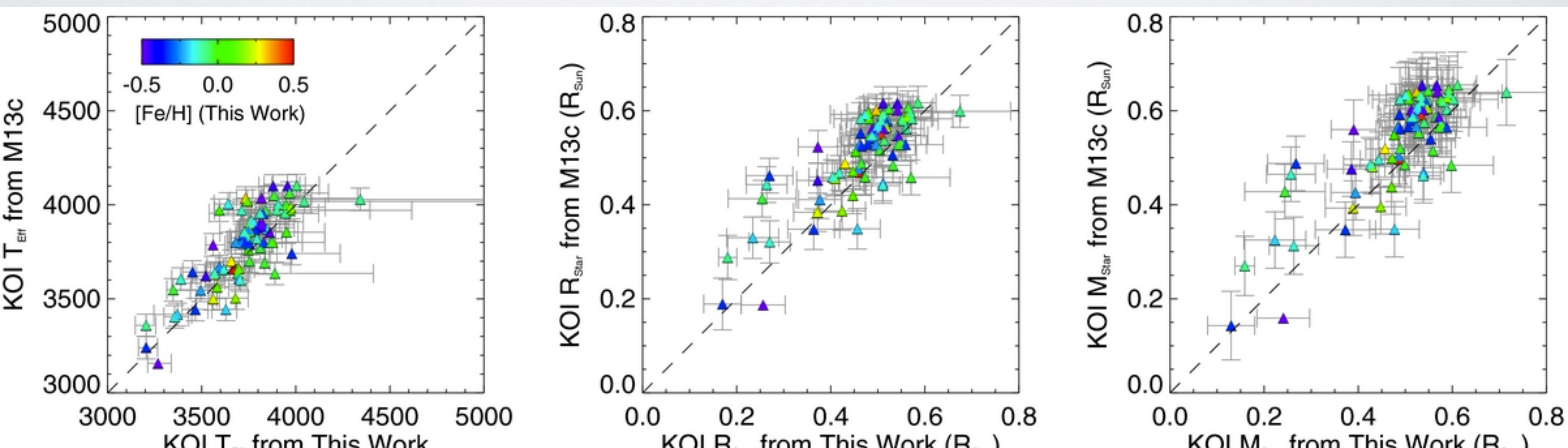
optical [Fe/H] + Teff (BTSETTL) + Teff-R relations from Boyajian et al. 2012.

Mann+13b



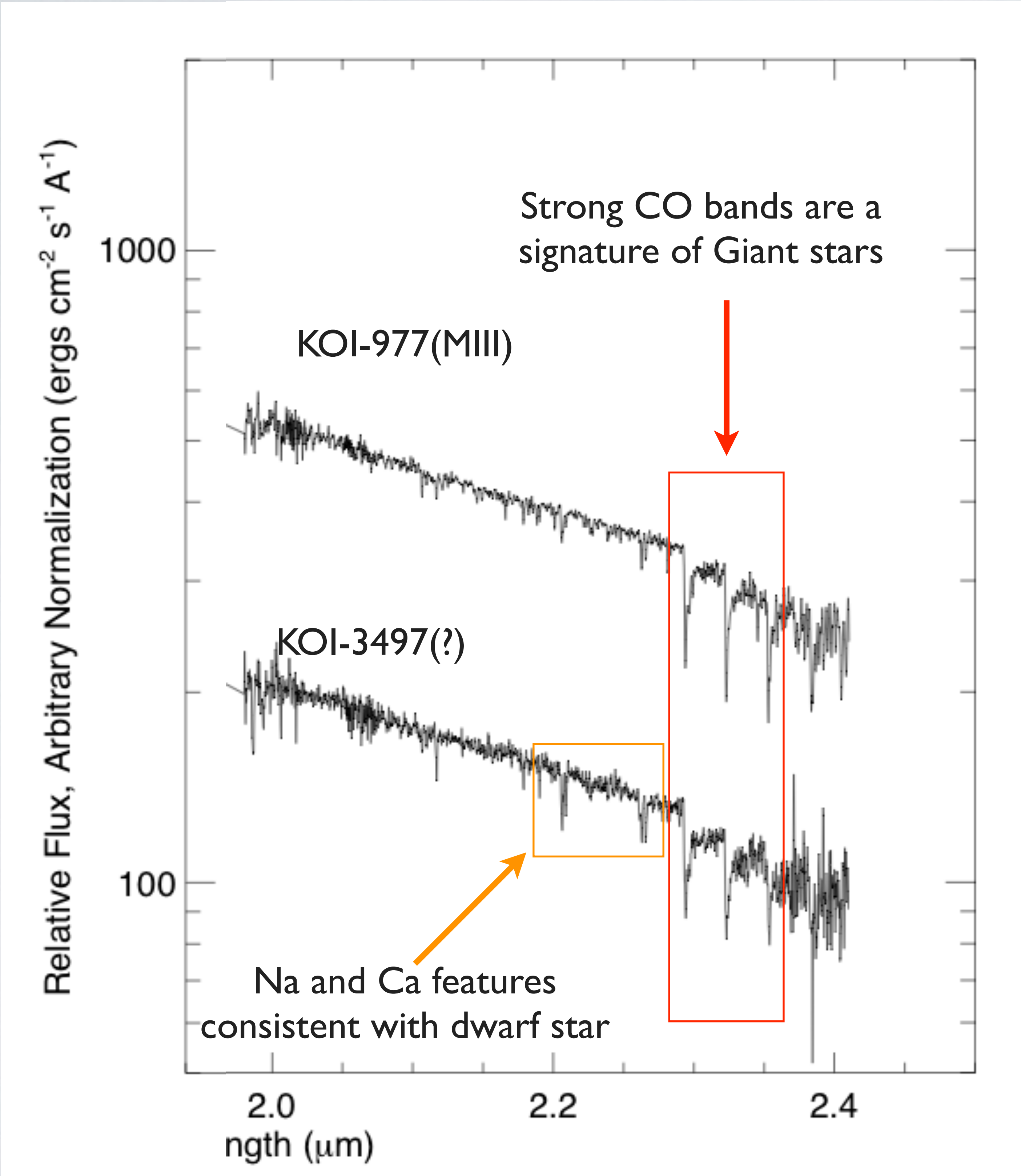
Teff (BTSETTL) + Teff-R relations + M-Teff relation

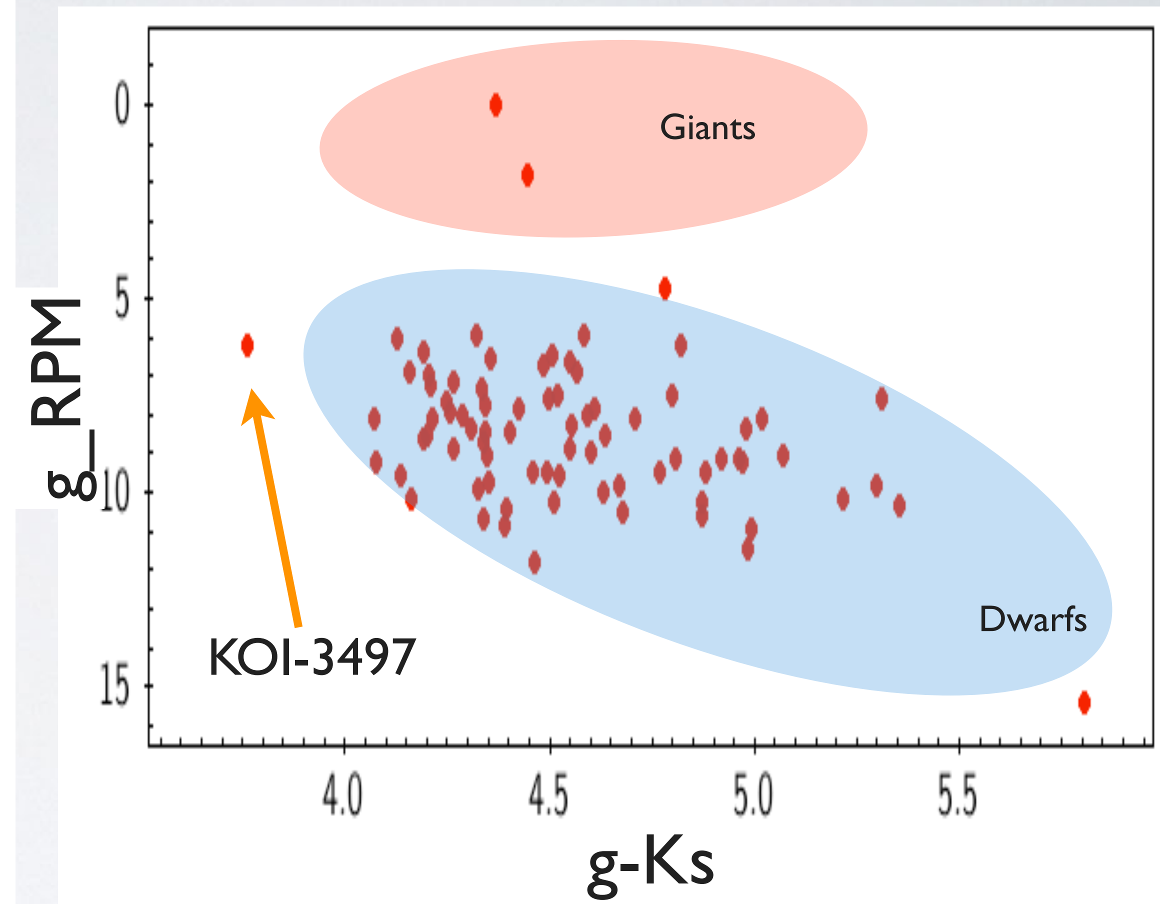
Mann+13c



CHARACTERIZING THE COOL KOIS: A FAKE GIANT

Muirhead et al. 2014





CHARACTERIZING THE COOL KOIS: A FAKE GIANT

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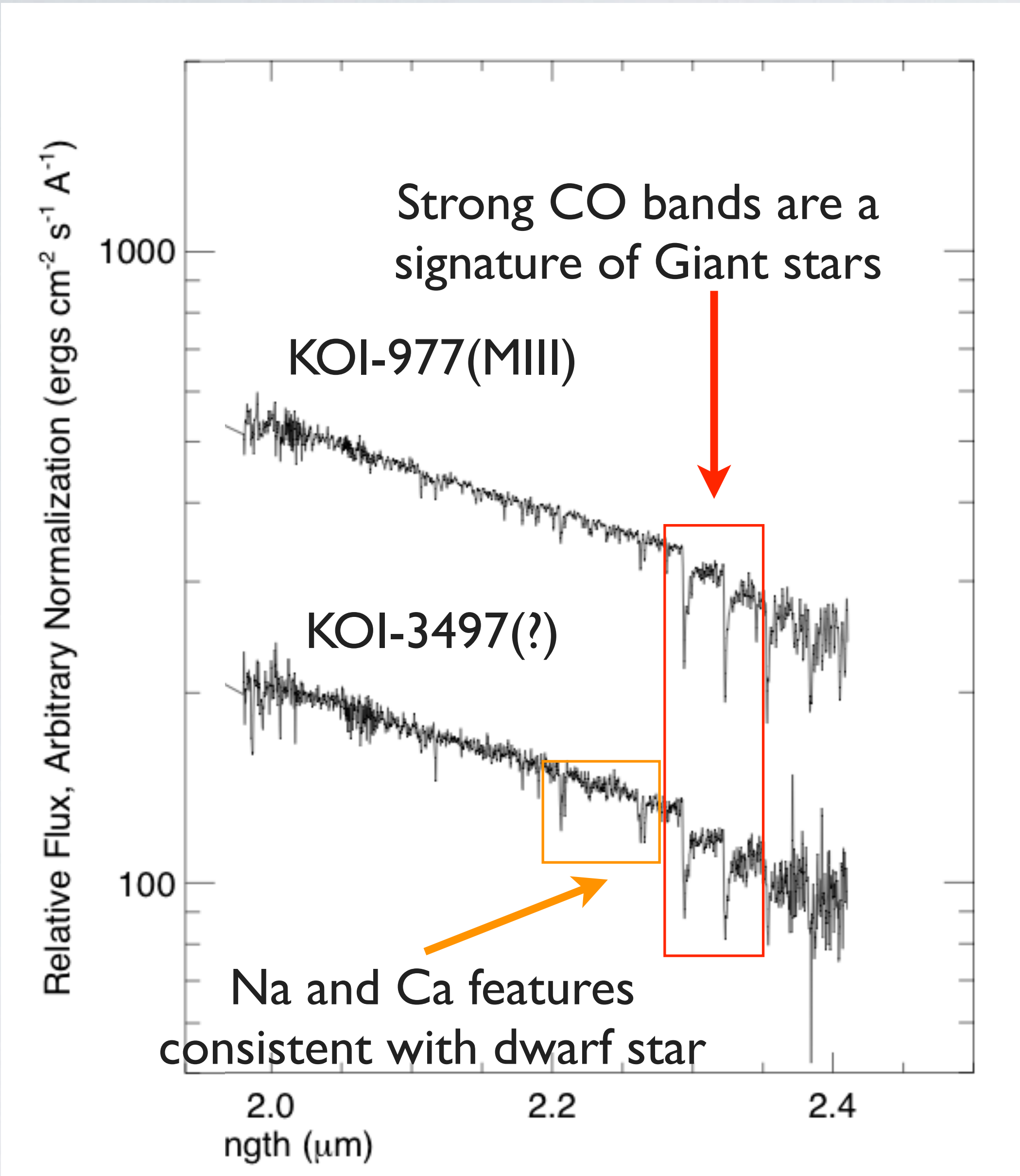
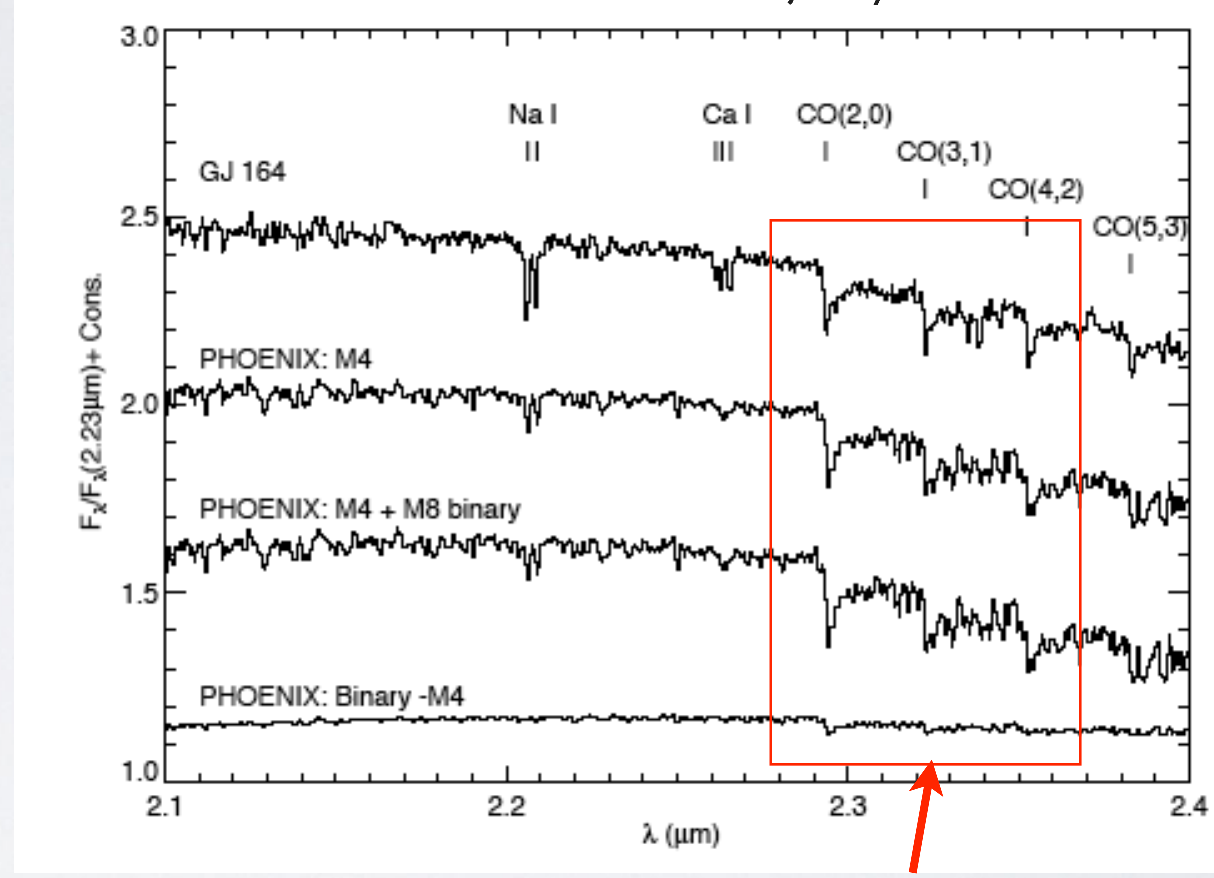
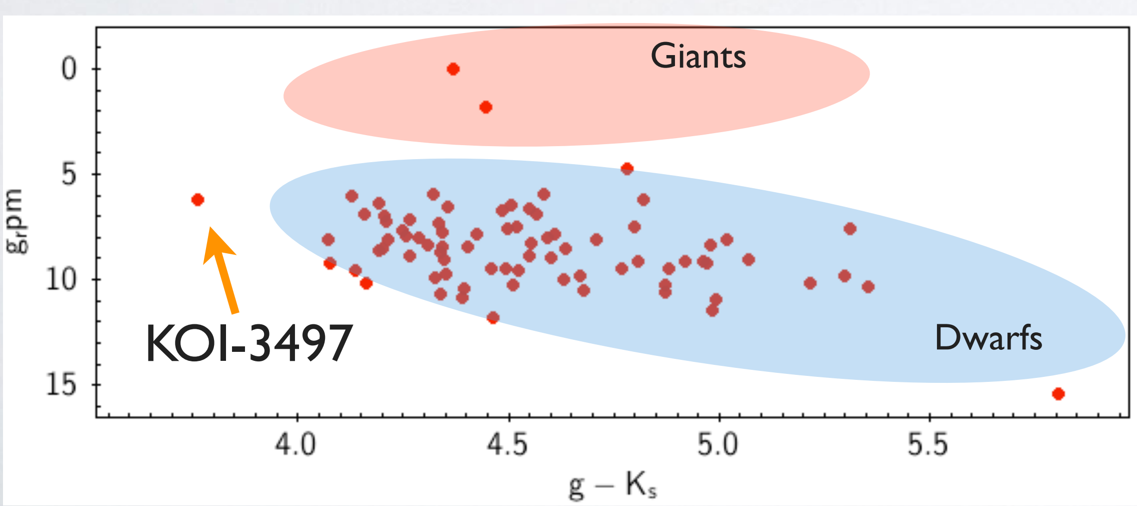
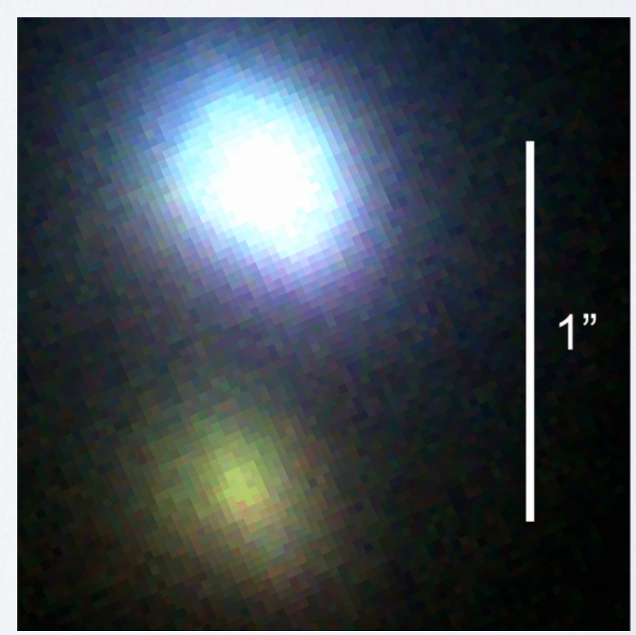


Martinache, Rojas-Ayala et al. 2009



early M + late M binary spectrum should exhibit stronger CO bands





KOI-3497: RoboAO Image reveals two objects within a 1 arcsecond diameter

Spectroscopic characterization of CARMENES target candidates

V. M. Passegger[1], S. Wende[1], A. Reiners[1], S. V. Jeffers[1], A. Lamert[1], A. Quirrenbach[2], P. J. Amado[3], J. A. Caballero[4], D. Montes[5], R. Mundt[6], I. Ribas[7] and the CARMENES Consortium

Preliminary Results

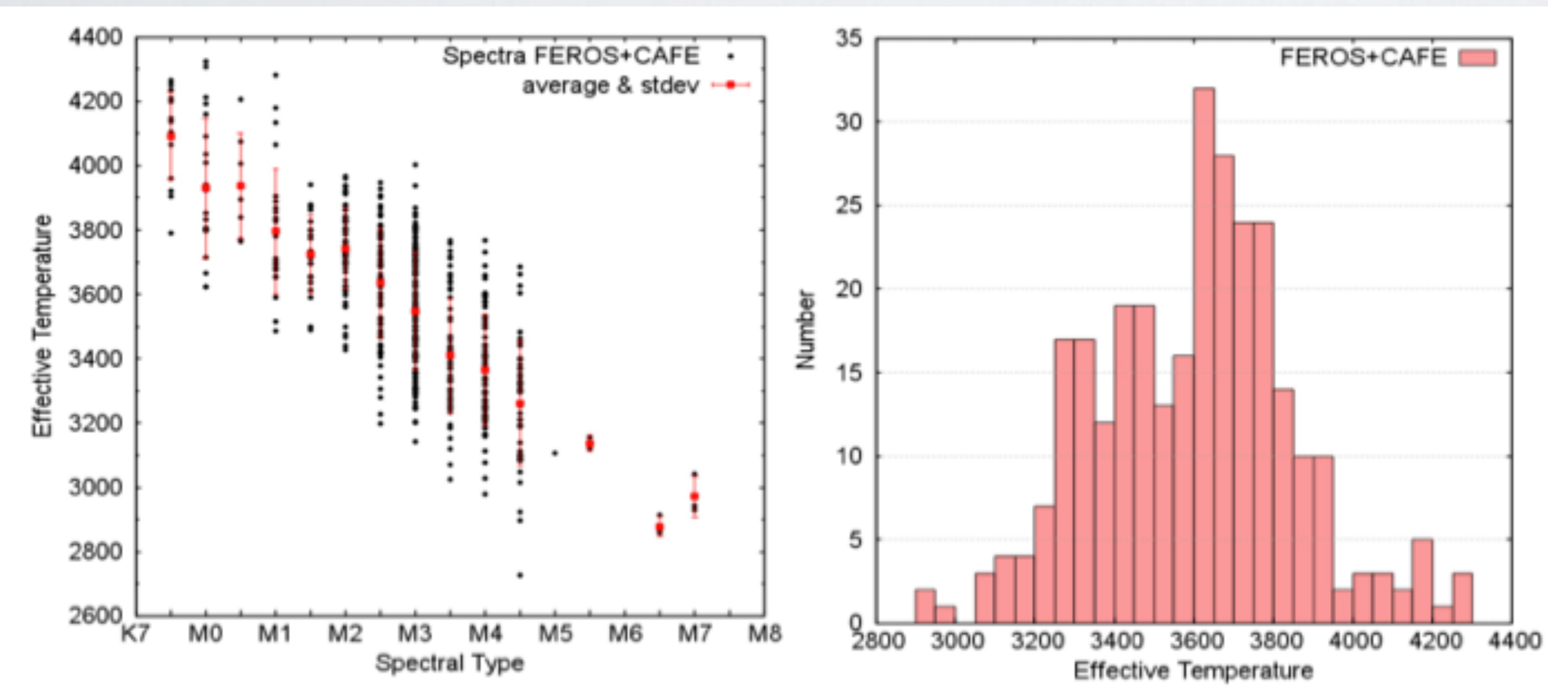


Figure 2: Spectral type-temperature relation together with average and standard deviation for each spectral type (from spectral indices [2], left) and temperature distribution of candidate sample (right).

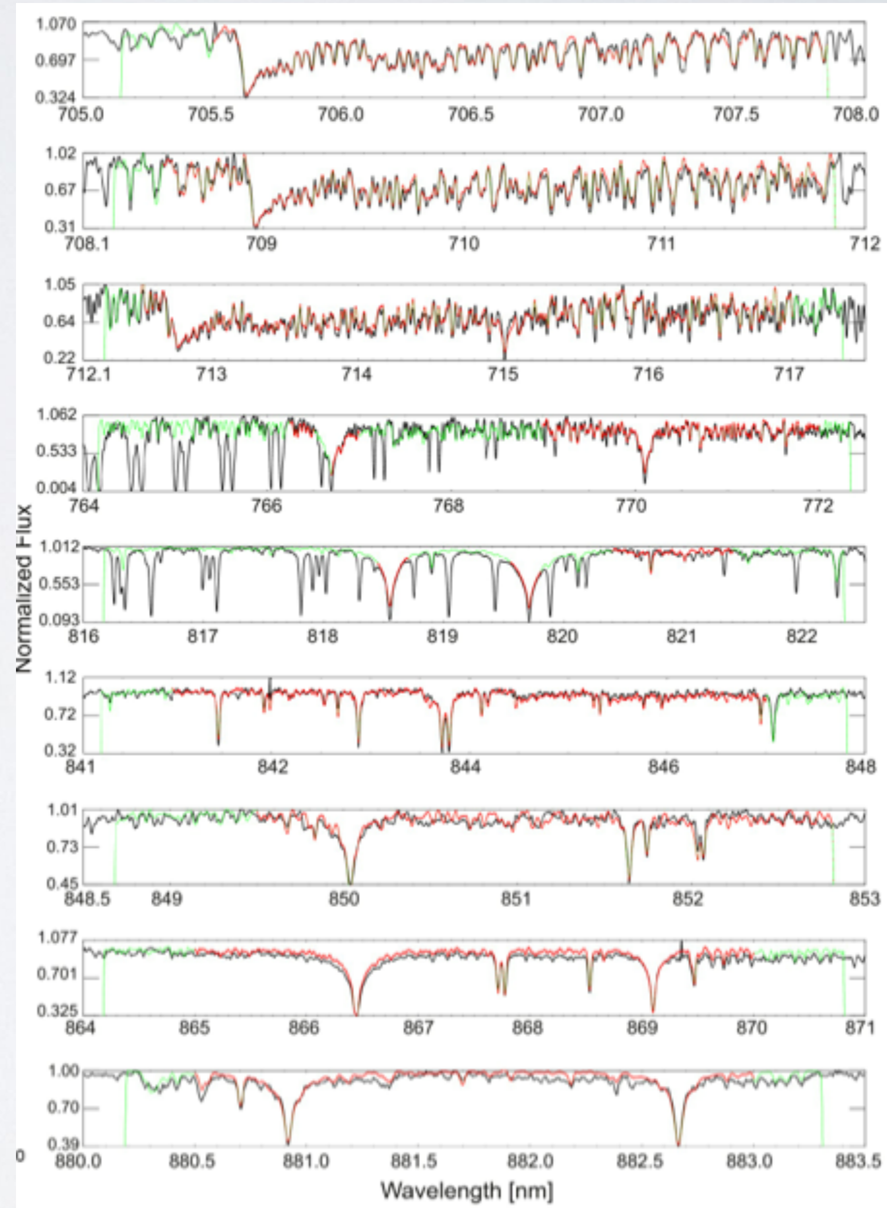
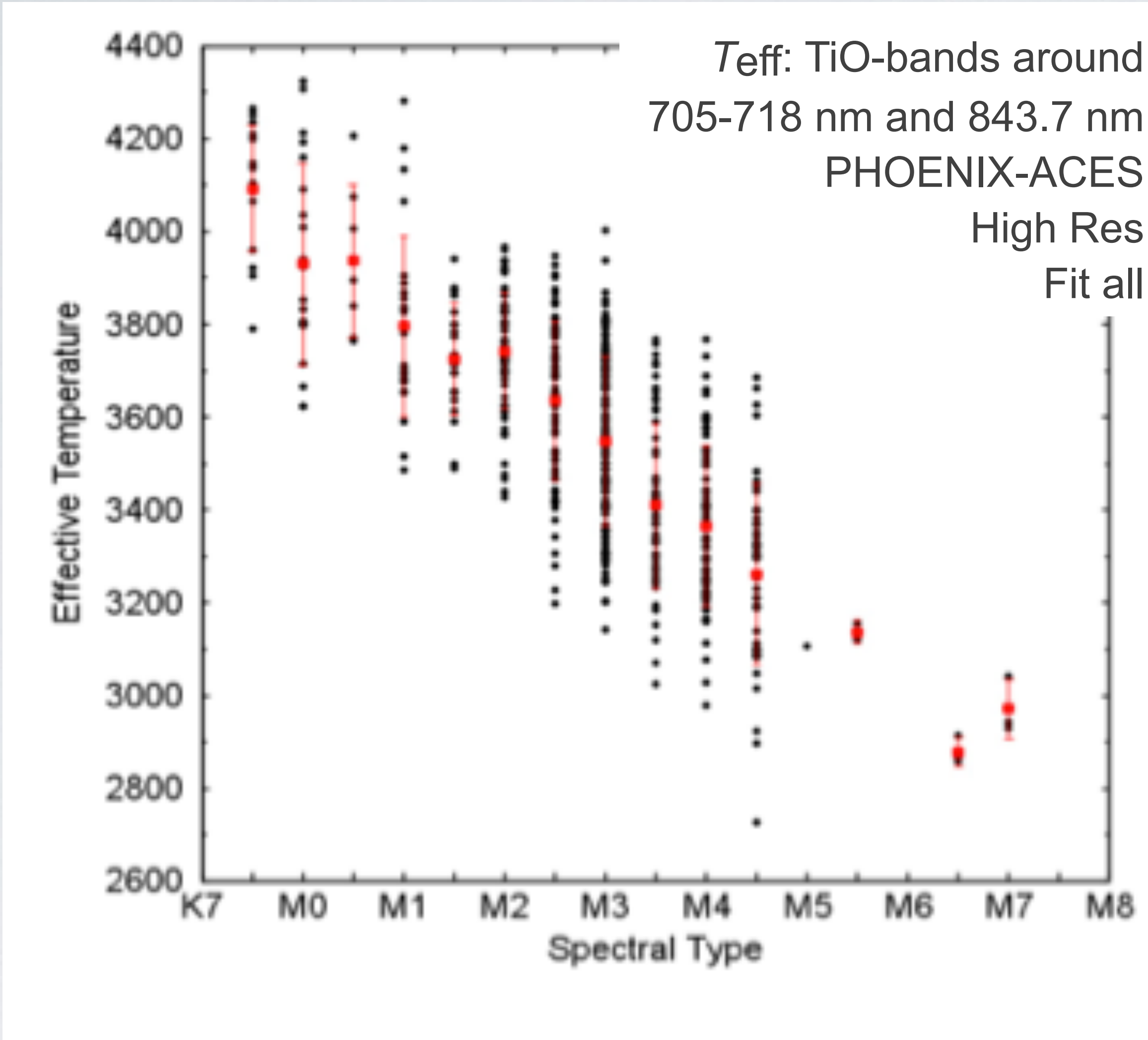


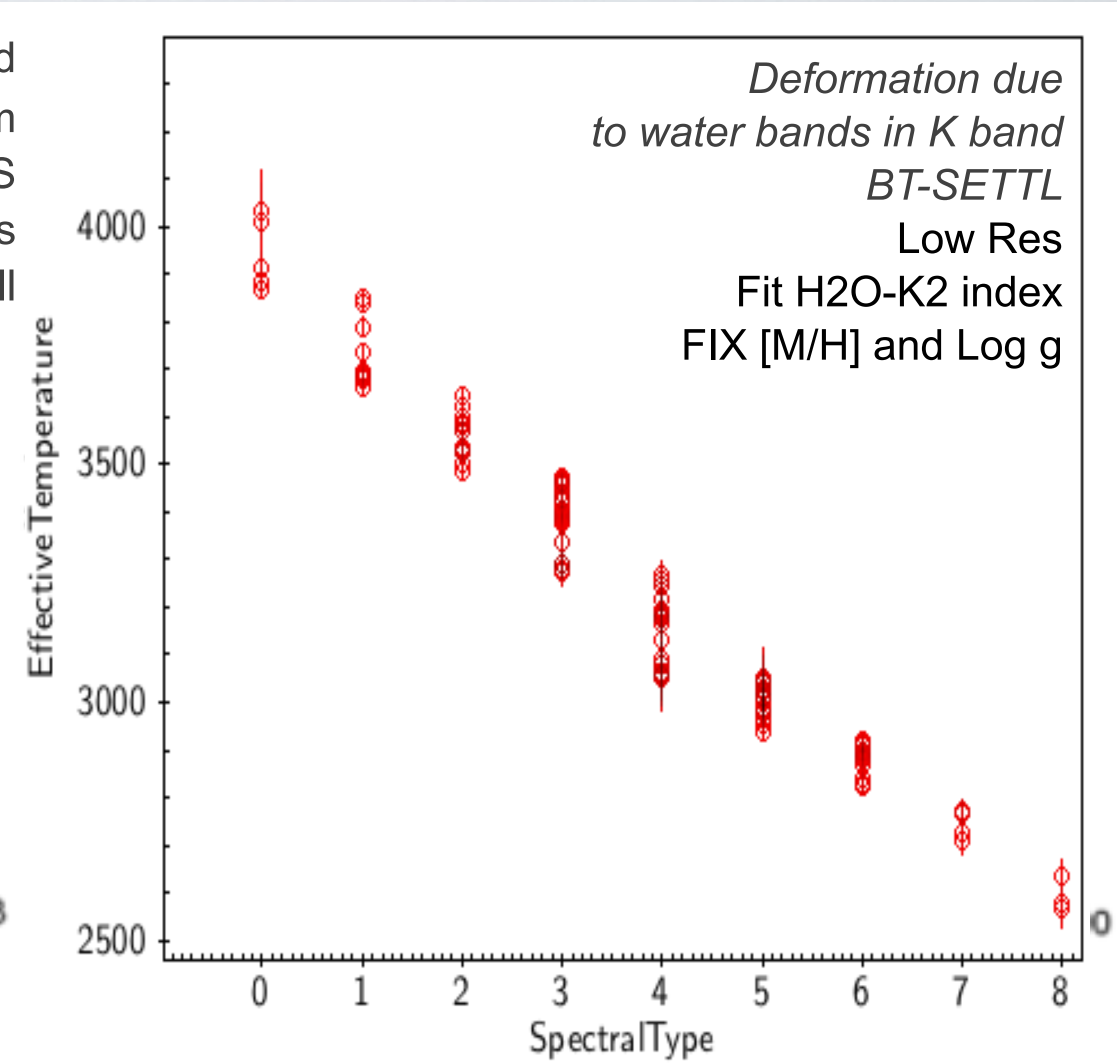
Figure 1: Spectrum of HD 285968 (M2V, black) and the best fit model (green: model outside fit region, red: model inside regions for χ^2-minimization).

Poster P6.2

Poster P6.2

Rojas-Ayala et al. 2012





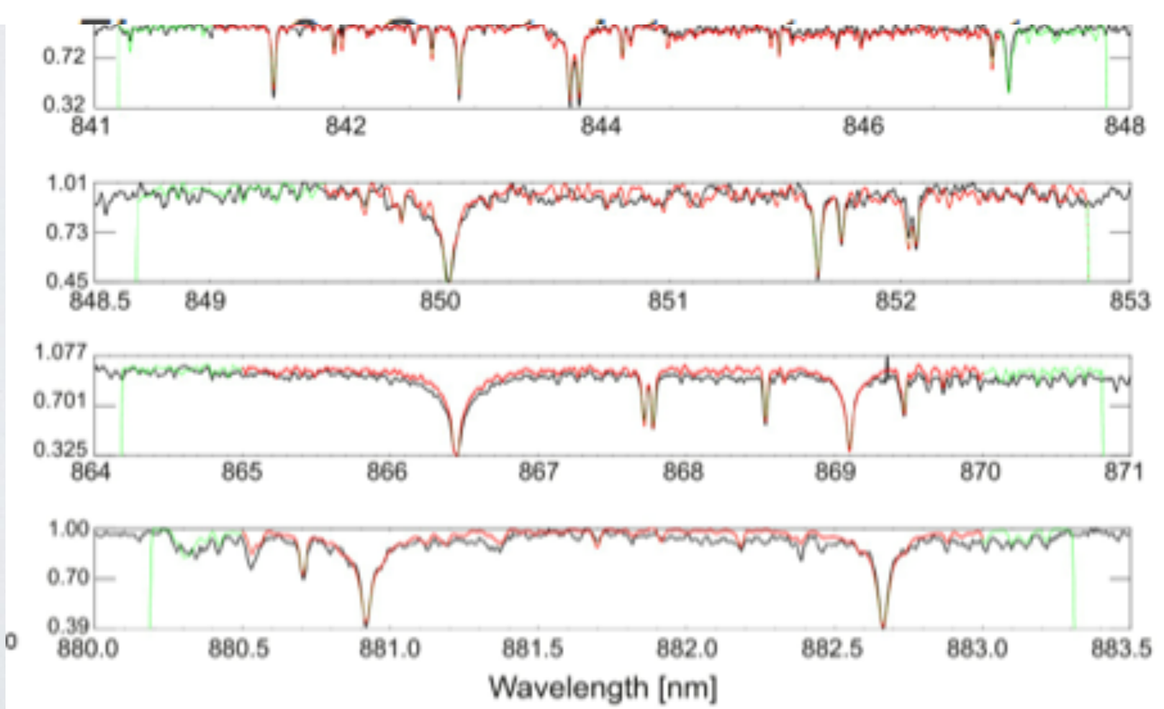
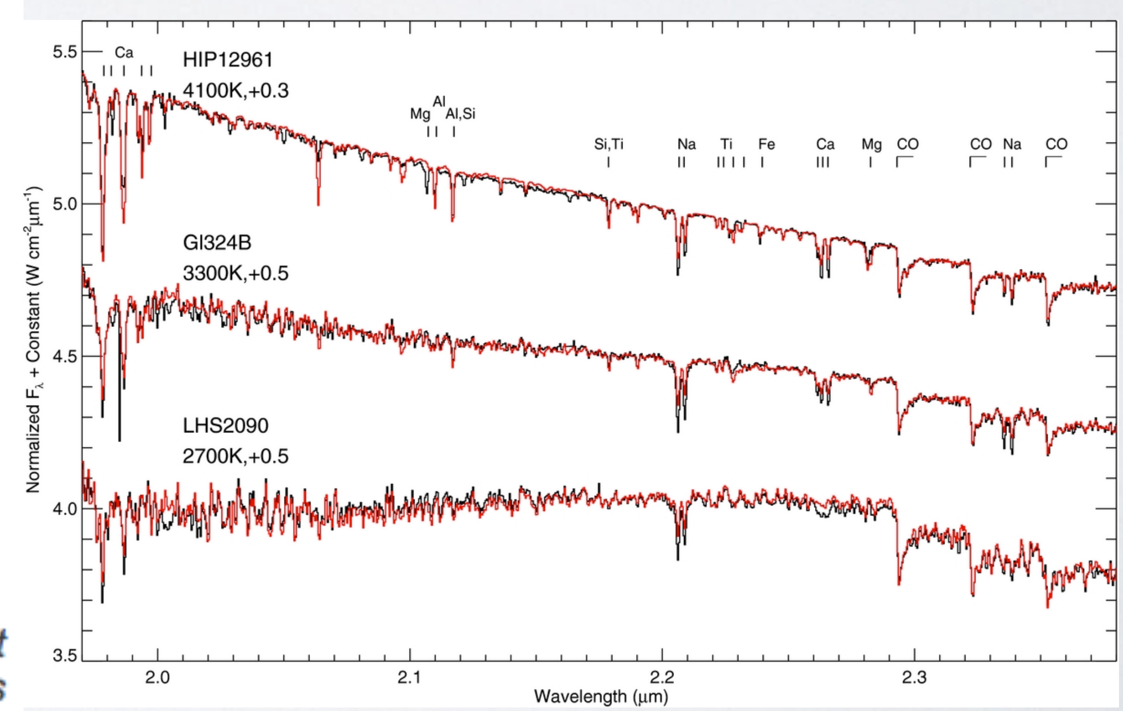


Figure 1: Spectrum of HD 285968 (M2V, black) and the best fit model (green: model outside fit region, red: model inside regions for χ^2-minimization).



Conclusions

- To get precise masses AND radii, look for planets around EB stars! (down to 1%) Interferometry for radii of bright M dwarfs (2-5%)

- Exoplanets era: alternative ways to obtain fundamental parameters for M dwarfs … it depends on the detection technique.

- More has to be done to improve the precision and the techniques. Agreement?
- [Fe/H] > 0.08 dex

- Teff >100K