Delicious Diameters of Dwarfs
(in particular, the juicy red ones)

Tabetha Boyajian
GSU / Hubble Fellow

In collaboration with a whole bunch of y'all

Radical **Radii** of Red Stars

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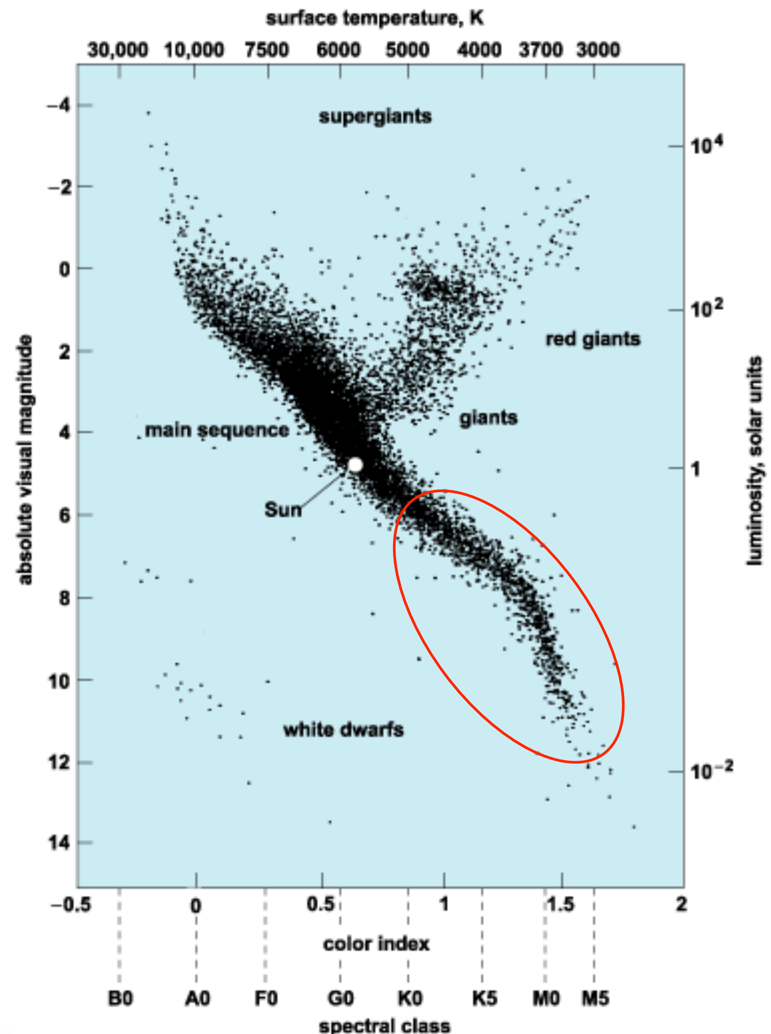
Interest and Motivation

- Fundamental properties of stars
  - Radius: $f(\theta, \pi)$
  - Temperature: $f(\theta, F_{BOL})$
  - Luminosity: $f(F_{BOL}, \pi)$
  - Mass
  - Age

> θ = angular diameter
> π = parallax
> F_{BOL} = bolometric flux

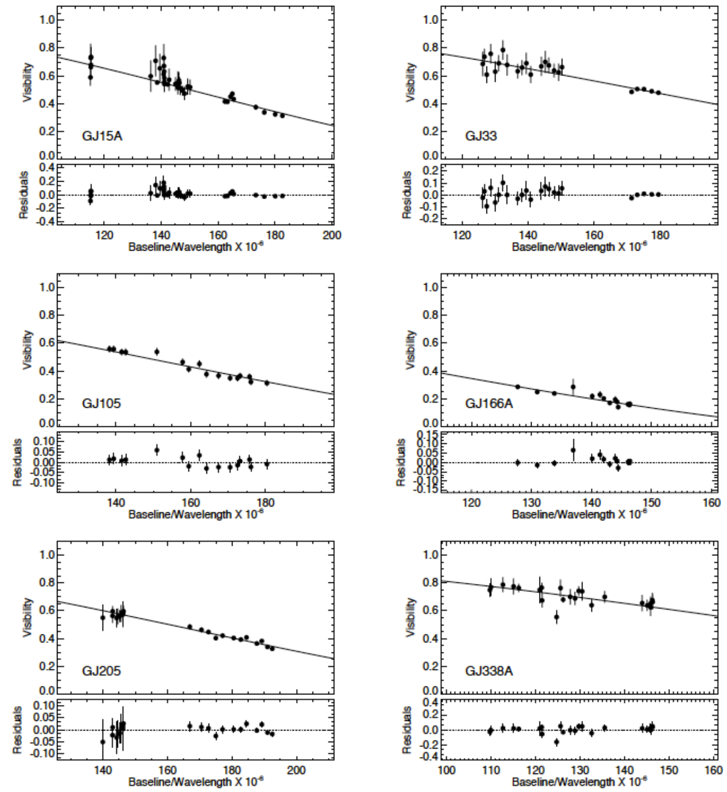
- A large & accurate set of data
  - Building empirical calibrations/transformations
  - Test atmosphere/evolutionary models: they are notoriously BAD
- Exoplanet environments



Data and Method

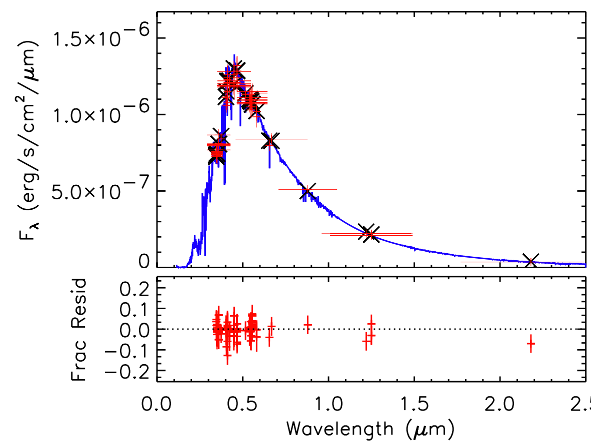
Interferometric Observations

- Observed a couple dozen KM dwarfs within ~10 pc over the past 3 years
- Use multiple wavelengths (*H* & *K*), baselines, and calibrators over several nights
- Fit calibrated visibilities to get ***angular diameter***



Spectral Energy Distribution Fits

- Collect flux calibrated photometry from literature and fit to spectral template to get ***bolometric flux*** and reddening



CH

R: $f(\theta, \pi)$

T: $f(\theta, F_{BOL})$

L: $f(F_{BOL}, \pi)$

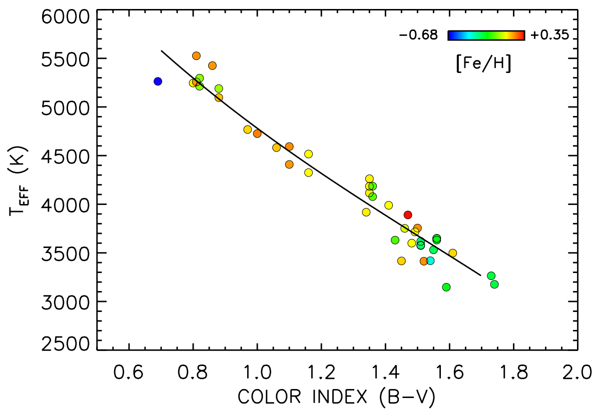
Tables of the measured properties of stars

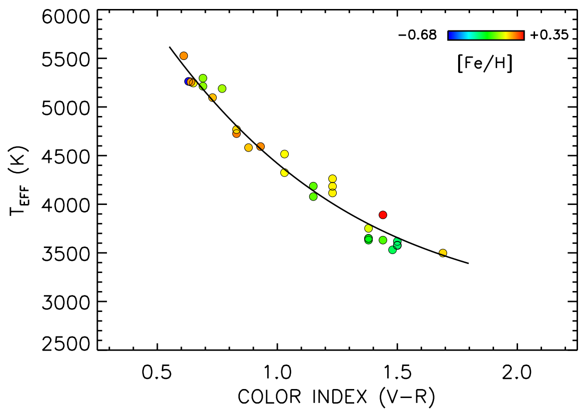
GeorgiaState

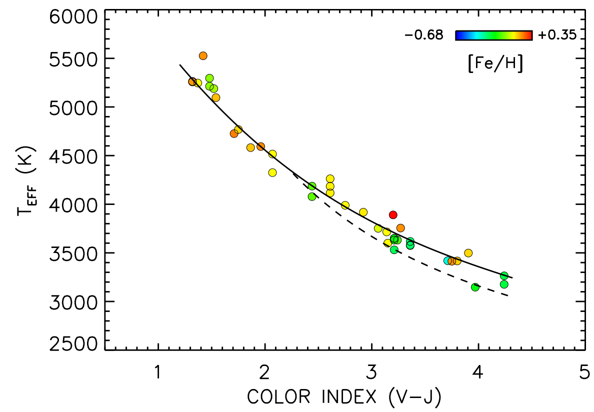
Some Cool Results

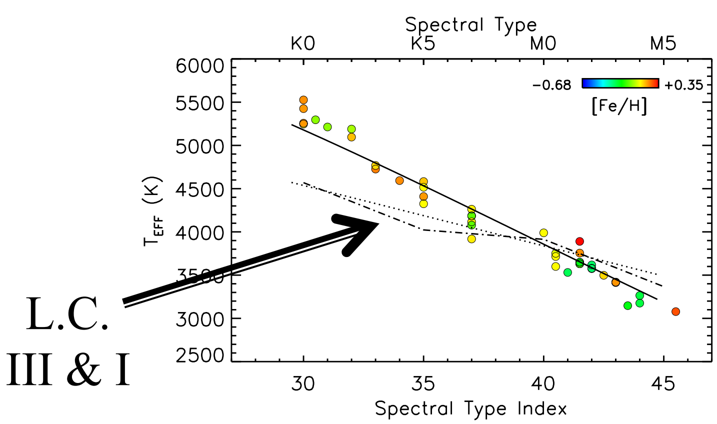
- Empirical relations
  - Color relations to T, R, and L (with Fe/H)
  - Global relations joining T, R, L, & M
- Single versus binary star properties
  - Mass-radius relations
  - Temperature-radius unrelations?
- Exoplanet characterization

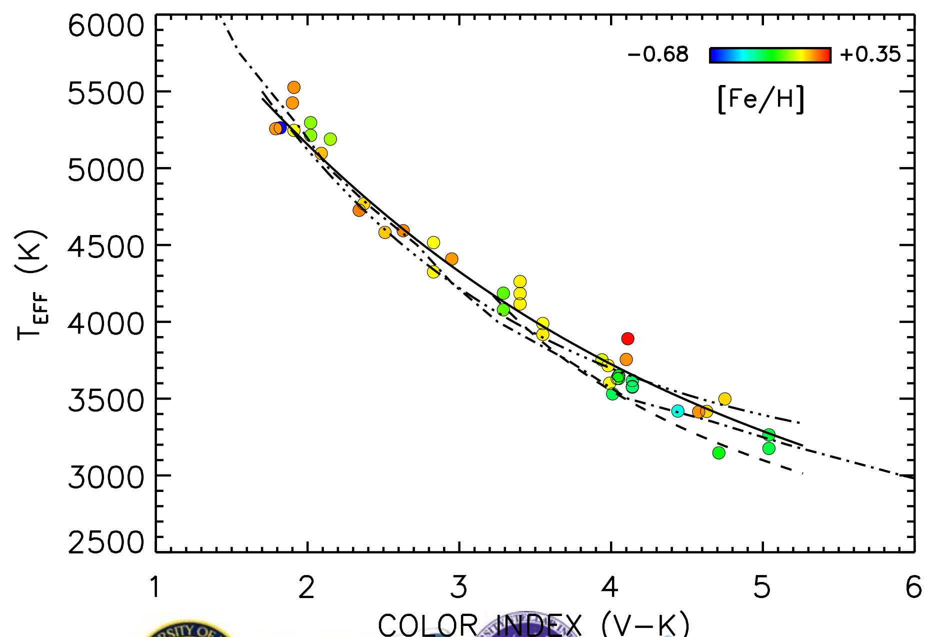
Color-Temperature Relations









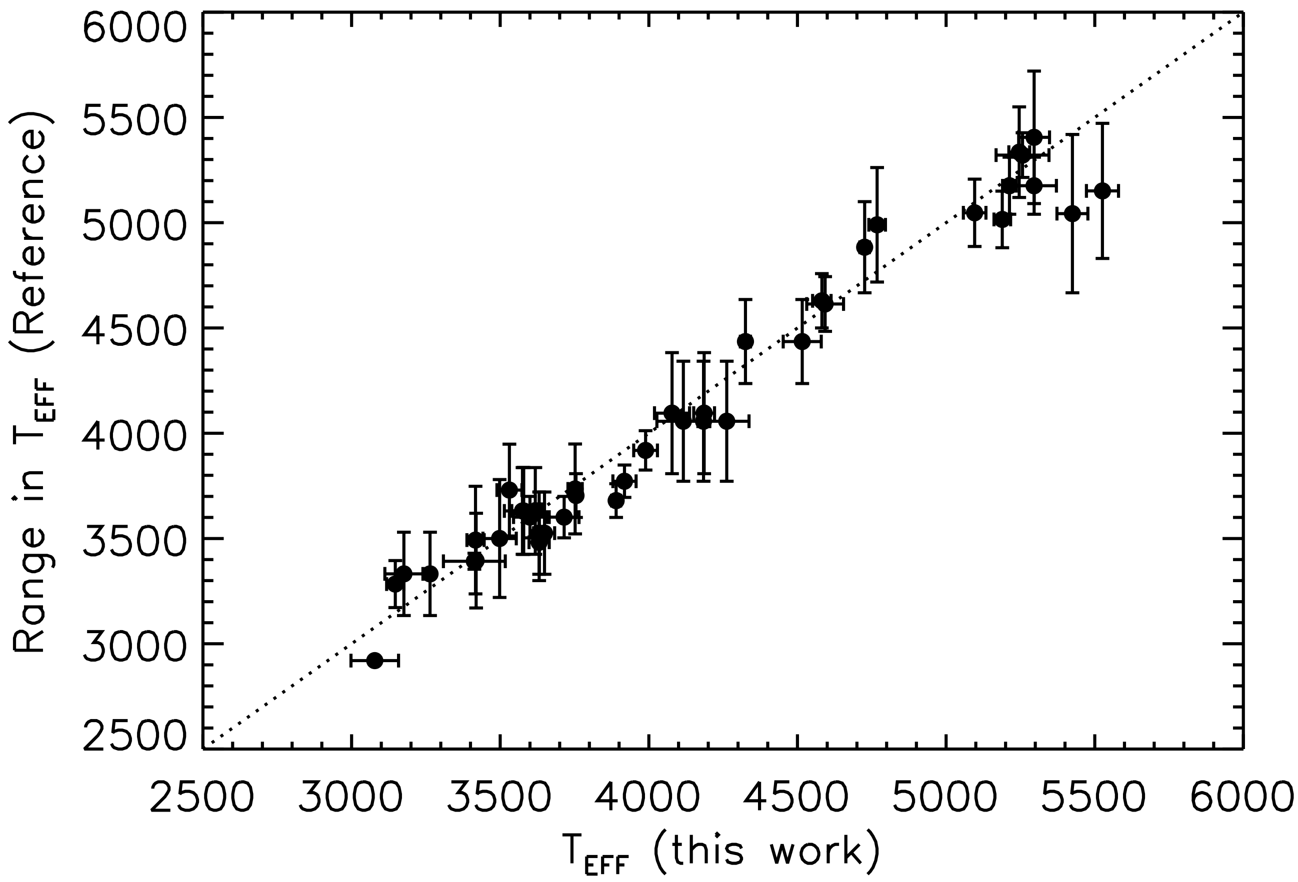


2nd order polynomial; average scatter ~70K

Solid line = our fit (all metallicities)

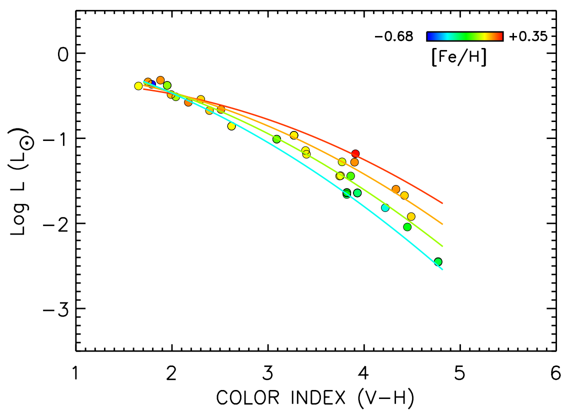
Dashed line = Casagrande et al. 2008 ([Fe/H]=0)

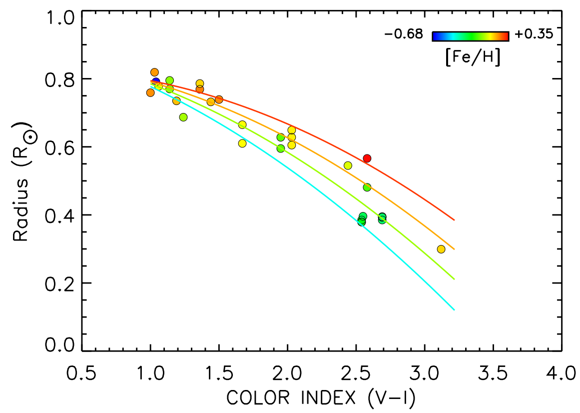
Comparing measurements of T_{eff}

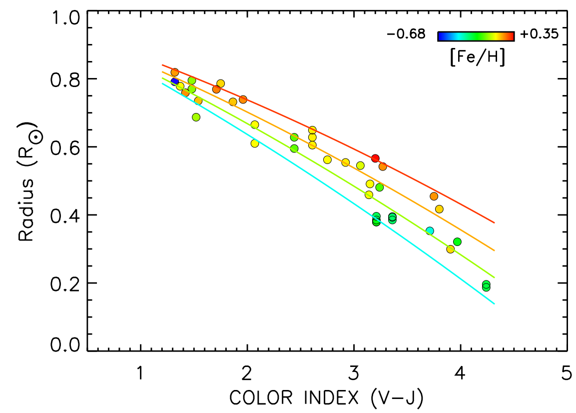


Color - Radius and Luminosity Relations

with metallicity!



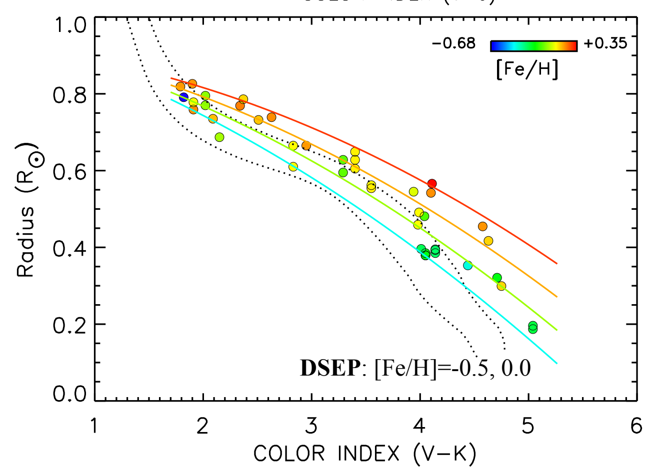




Solution found using a 2 variable 2nd order polynomial fit to color and [Fe/H]

→Average scatter ~0.03 $R_\odot$

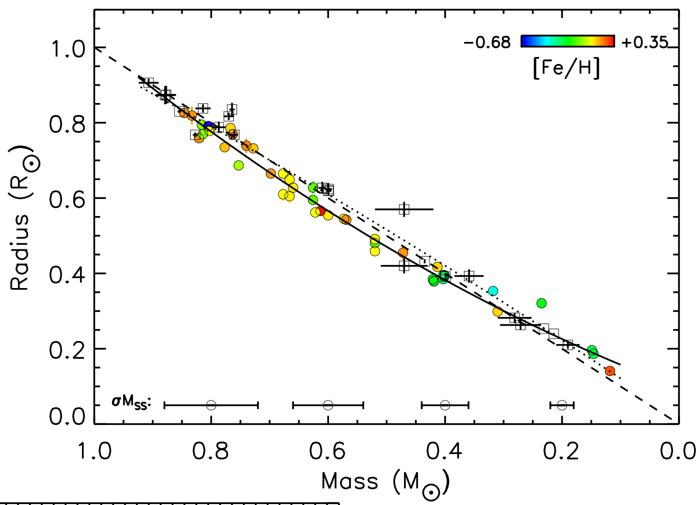
→Average scatter ~0.007 $L_\odot$

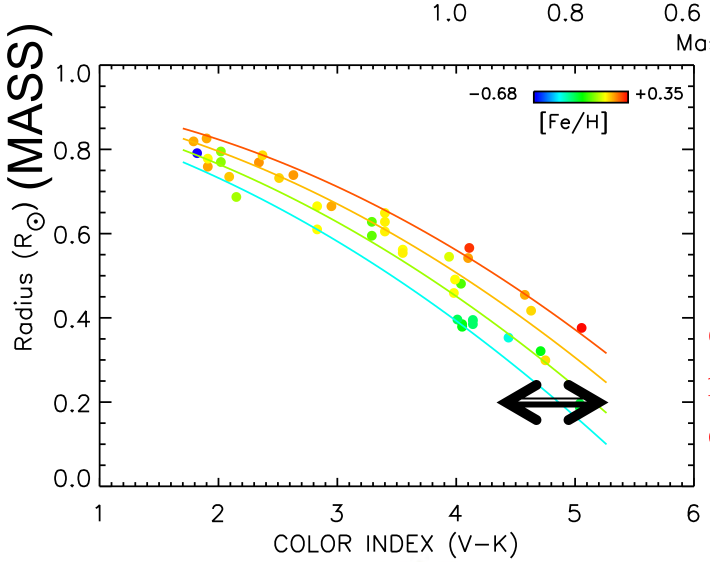


Plots:
The colored lines are solutions to the metallicity dependent fits, where the line color (red, orange, green, teal) represents our solution for an iso-metallicity line to [Fe/H] = +0.25, 0.0, −0.25, −0.5

Global Properties: Mass-Radius

"The most interesting boring plot ever"

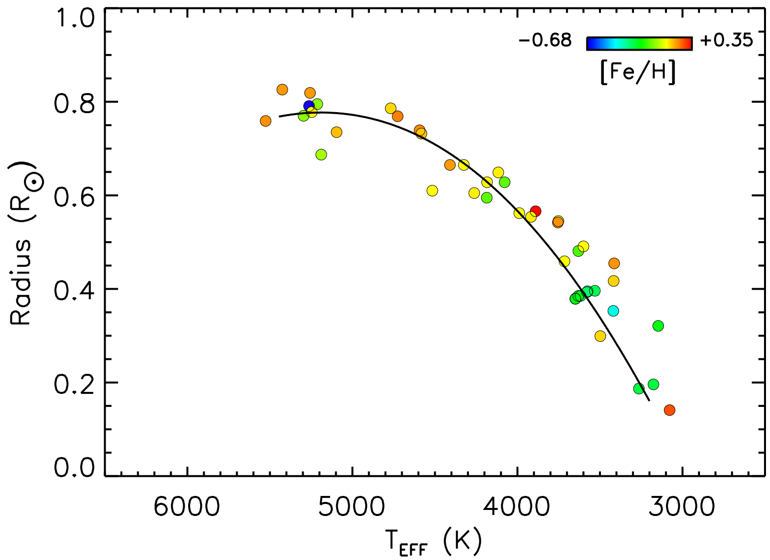




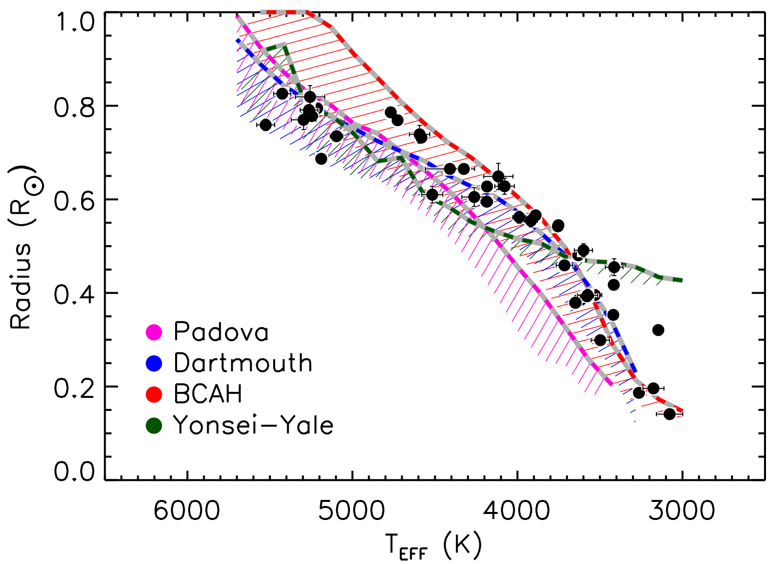
[Fe/H] does **not** effect radius (or mass) only the color index

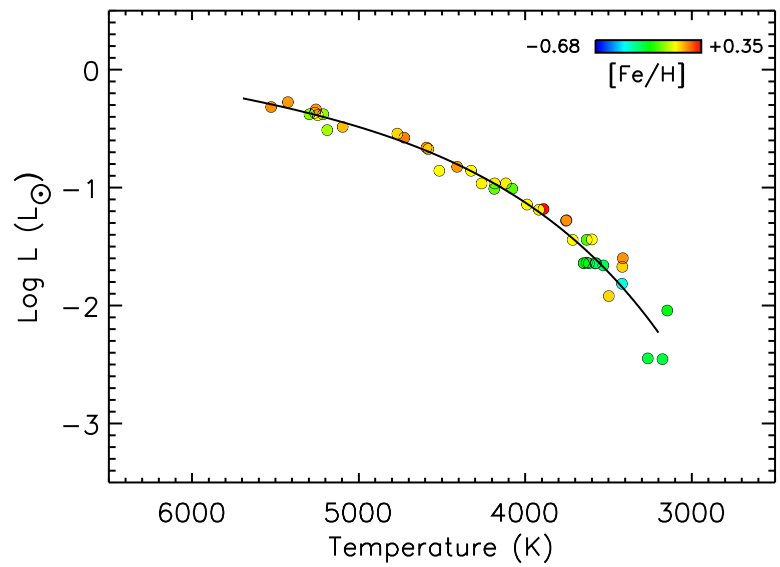
- Single and binary stars have comparable radii (solid and dotted lines, respectively)
- Fit to a 2nd order polynomial, but ~1:1 relation (dashed line)
- Relation does not appear to have a dependence on Fe/H

Global Properties: Radius-Temperature(-Luminosity)



- No (detectable) dependence on [Fe/H] on the temperature-radius plane
- Models predict that there is a [Fe/H] dependence
- The models are inconsistent and don't really do a good job anyway





This is not what you expect

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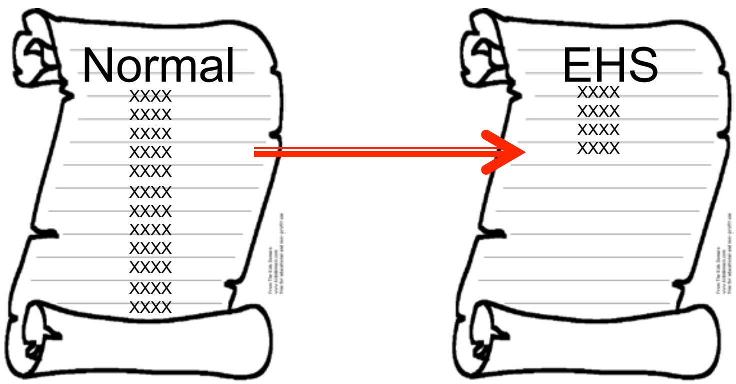
Exoplanet characterization

- Insights from Fundamental Stellar Parameters
  - Planetary astrophysics = f (stellar observables).
    Examples: planetary diameter, planetary mass, orbital period, inclination, eccentricity, orientation, etc.
  - Host star is primary energy source of the system.
  - Planetary formation, evolution.
  - Radiation environment & Habitable Zone (HZ).
- Similar but more focused approach & application
  - Near-IR interferometry: angular stellar diameter.
  - With trigonometric parallax: physical stellar diameter.
  - SED fit: stellar bolometric flux F_{BOL}.
  - From angular diameter and F_{BOL}: T_{EFF} and L.
  - From L, T_{EFF}: habitable zone.
  - Stellar physics determine planetary physics.

Targets

- Done or in progress
  - **GJ 581** (with 4/6 planets, some of which are in the Habitable Zone); von Braun & Boyajian et al. (2011a)
  - **GJ 436** (with a transiting planet); von Braun & Boyajian et al. (2012)
  - **55 Cnc** (with a transiting planet and a planet in the HZ); von Braun & Boyajian et al. (2011b)
- Soon
  - **GJ 876** (multi-planet system with some planets in the HZ)
  - … and many more



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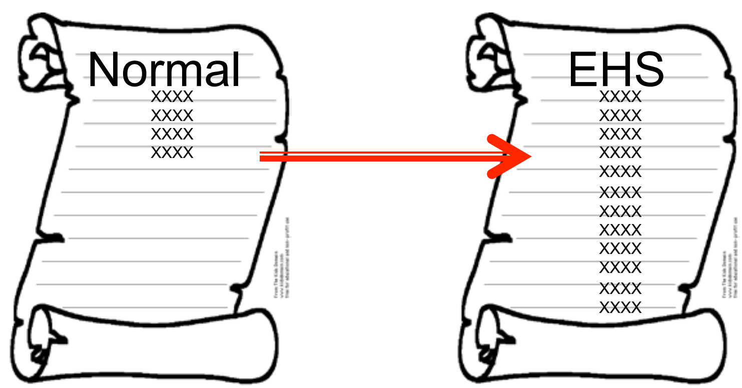


GJ 436 Results

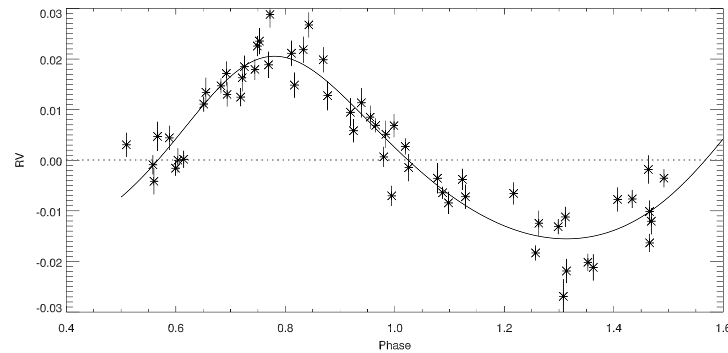
von Braun & Boyajian et al. (2012)

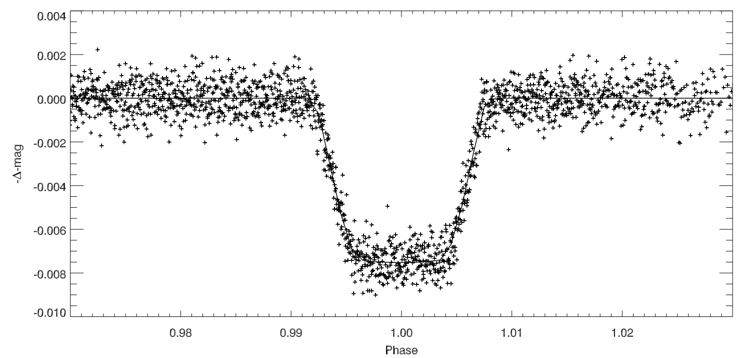
- Directly Determined Stellar Parameters

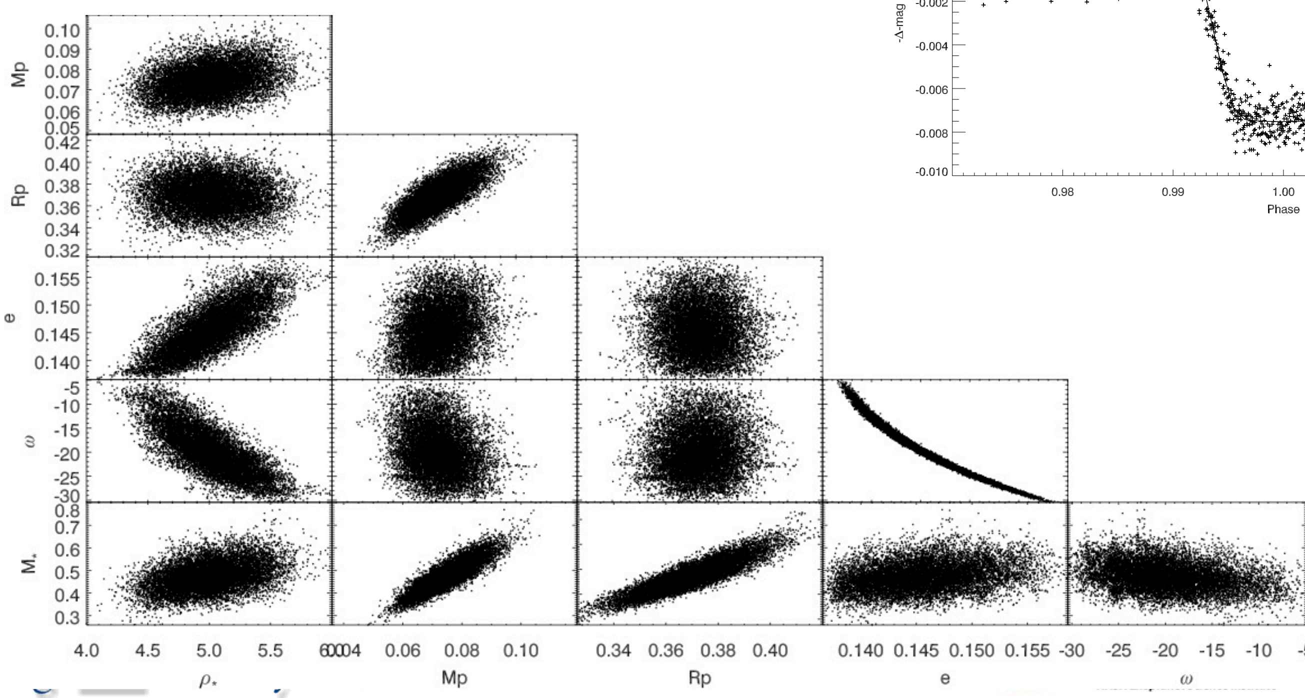
Parameter	Value (Uncertainty)
Spectral Type	M3 V
θ_{UD}(mas)	0.405(13)
θ_{LD}(mas)	0.417(13)
F_{BOL}(10^{-8} erg/s/cm^2)	0.787(5)
Radius (solar)	0.455(18)
Luminosity (solar)	0.0253(1)
T_{EFF}(K)	3416(54)
HZ boundaries (AU)	0.16—0.31
a_{Planet} (AU)	(b) 0.03

GJ 436 – Interpretation

1. MCMC: for selection of system parameters, create synthetic *V*, *R*, *K*, HST, and Spitzer IRAC-4 light curves – compare to literature data. Same for RV curves.
2. 10000 iterations. X^2 criterion to determine derived system parameters.
3. MCMC calculates correlations and error estimates.







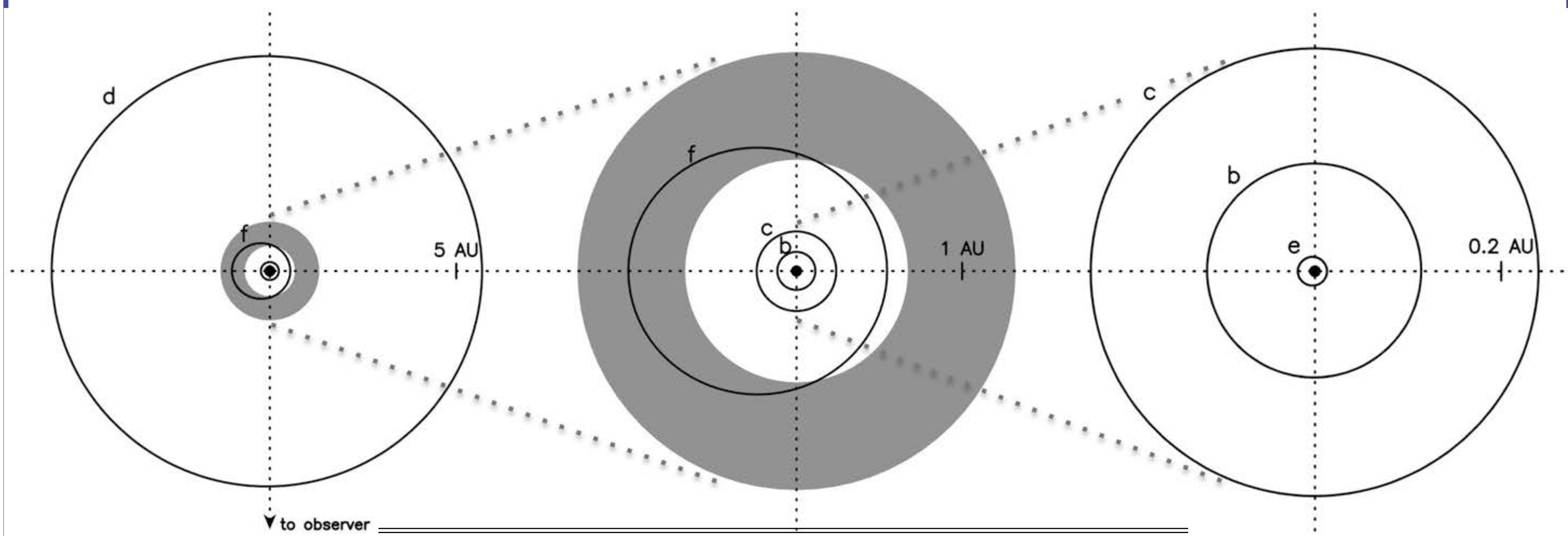
GJ 436**: Derived System Parameters

**no planet in HZ

Parameter	Symbol	Value	Units
Transit epoch (BJD)[a] . . .	T_0	$2454576.89848^{+0.00006}_{-0.00006}$	days
Orbital period[a]	P	$2.64389792^{+0.000000628}_{-0.000000608}$	days
Transit depth[a]	$(R_p/R_*)^2 \equiv \delta$	$0.0070^{+0.00005}_{-0.00005}$	
Transit duration[a,b]	t_T	$0.0419^{+0.00025}_{-0.00023}$	days
Impact parameter[a]	b	$0.86^{+0.004}_{-0.004}$	R_*
Secondary eclipse depth[a]	$\Delta f2$	$0.00046^{+0.000024}_{-0.000023}$	
Stellar reflex velocity[a] . .	K_1	$0.018^{+0.0009}_{-0.0008}$	km s^{-1}
Orbital semimajor axis . .	a	$0.029^{+0.0013}_{-0.0012}$	AU
Orbital inclination	i	$86.5^{+0.11}_{-0.12}$	degrees
Orbital eccentricity	e	$0.146^{+0.004}_{-0.004}$	
Longitude of periastron .	ω	$-21^{+5.4}_{-4.2}$	degrees
eccentricity × cos(ω)[a]	$e\cos\omega$	$0.136514^{+0.0002657}_{-0.0002674}$	
eccentricity × sin(ω)[a]	$e\sin\omega$	$-0.051953^{+0.0143786}_{-0.0118633}$	
Stellar mass	M_*	$0.472^{+0.0636}_{-0.0566}$	$M_\odot$
Stellar surface gravity . . .	$\log g_*$	$4.80^{+0.029}_{-0.029}$	[cgs]
Stellar density	ρ_*	$5.03^{+0.295}_{-0.289}$	$\rho_\odot$
Planet radius	R_p	$0.370^{+0.0149}_{-0.0145}$	$R_{Jupiter}$
Planet mass	M_p	$0.075^{+0.0076}_{-0.0072}$	$M_{Jupiter}$
Planet surface gravity . . .	$\log g_p$	$3.10^{+0.026}_{-0.027}$	[cgs]
Planet density	ρ_p	$1.48^{+0.116}_{-0.103}$	$\rho_{Jupiter}$

von Braun et al. (2012)

55 Cancri



Planet	K (ms^{-1})	$M \sin i$ (M_{Jup})	P (days)	a (AU)	e	ω (deg)
e	6.2(2)	0.0260(10)	0.736537(13)	0.01560(11)	0.17(4)	181(2)
b	71.4(3)	0.825(3)	14.6507(4)	0.1148(8)	0.010(3)	139(17)
c	10.2(2)	0.171(4)	44.364(7)	0.2403(17)	0.005(3)	252.(41)
f	5.4(3)	0.155(8)	259.8(5)	0.781(6)	0.30(5)	180.(10))
d	46.8(6)	3.82(4)	5169.(53)	5.74(4)	0.014(9)	186(8)

Habitable Zone

von Braun et al. (2011)

Orbital parameters Dawson & Fabrycky (2010)

55 Cancri – Press

Darth Vader's motherland discovered

Professor Kaspar von Braun and his colleagues at the University of California at Berkeley and the State University at San Francisco discovered another interesting exoplanet in the double star system 55 in the constellation Cancer. There is a great likelihood that there is some type of life on the planet. Now this discovery causes heated debates in the scientific world.