Accurate, Empirical Radii and Masses with *Gaia*: Eclipsing Binaries and Transiting Planets

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Know Thy Star Conference
October 11, 2017

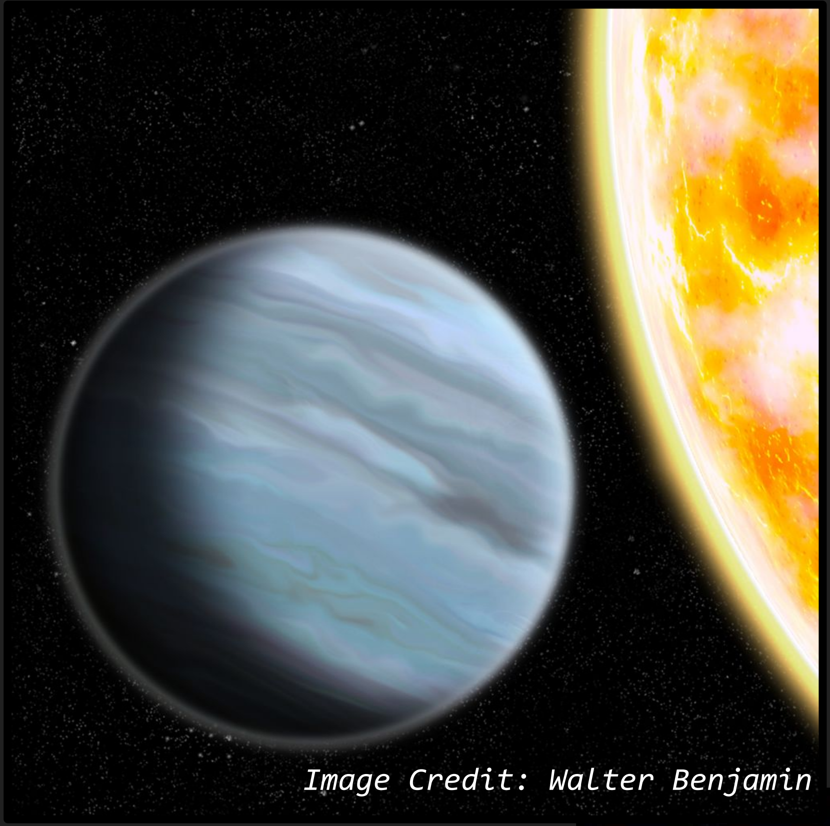
Image Credit: Walter Benjamin

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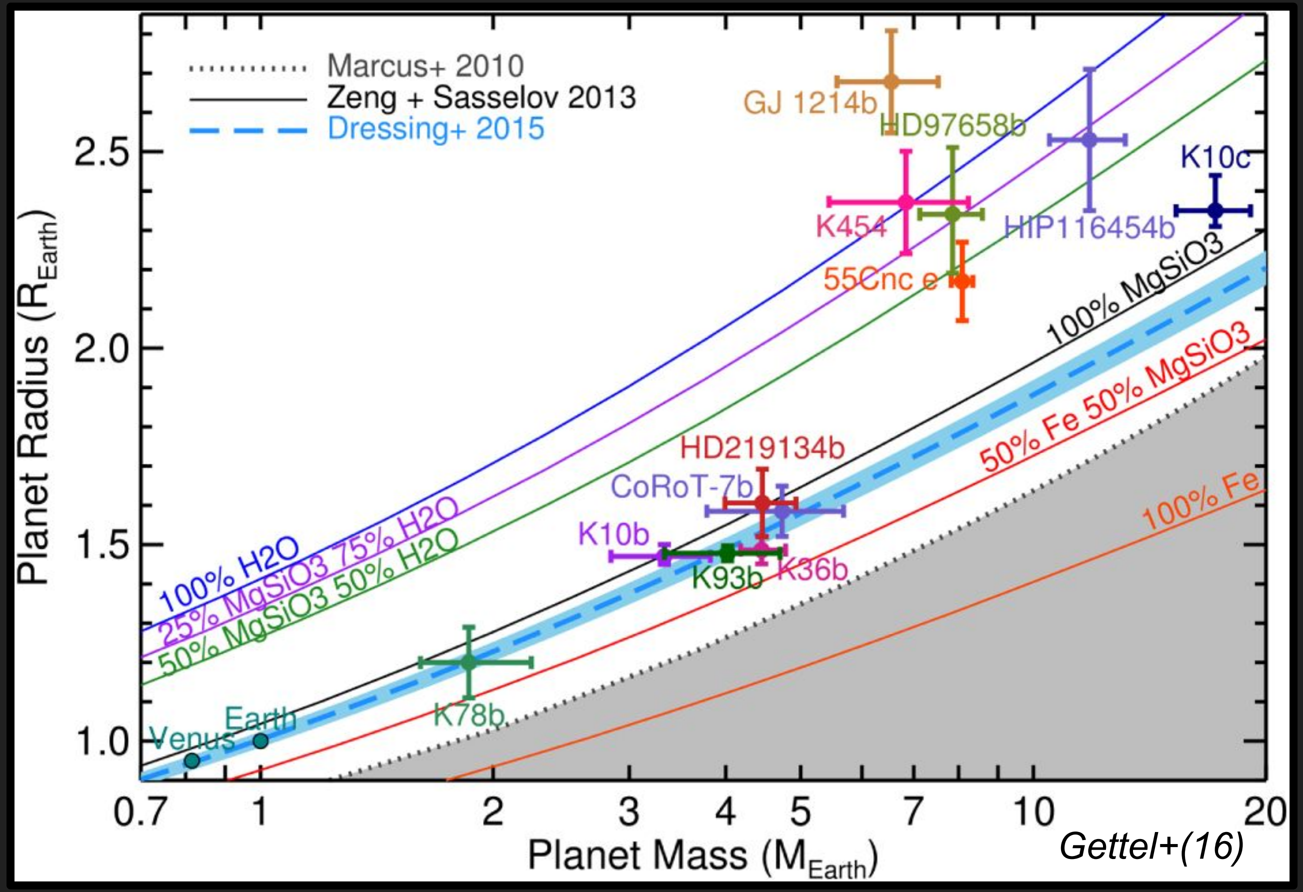
Know Thy Star, Know Thy Planet

Precise, accurate stellar characterization necessary for:

- Planet hunting
- Atmosphere studies
- Bulk compositions



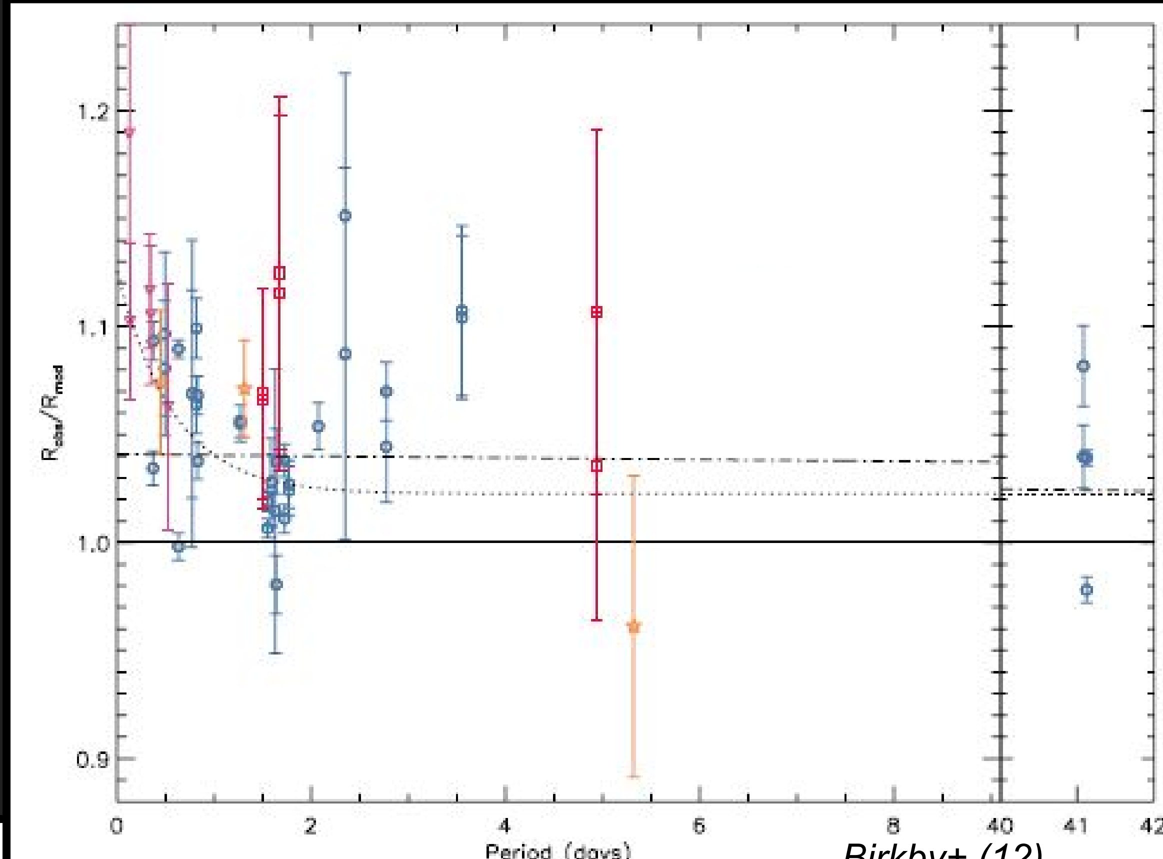
Gettel+(16)

M dwarf hosts:

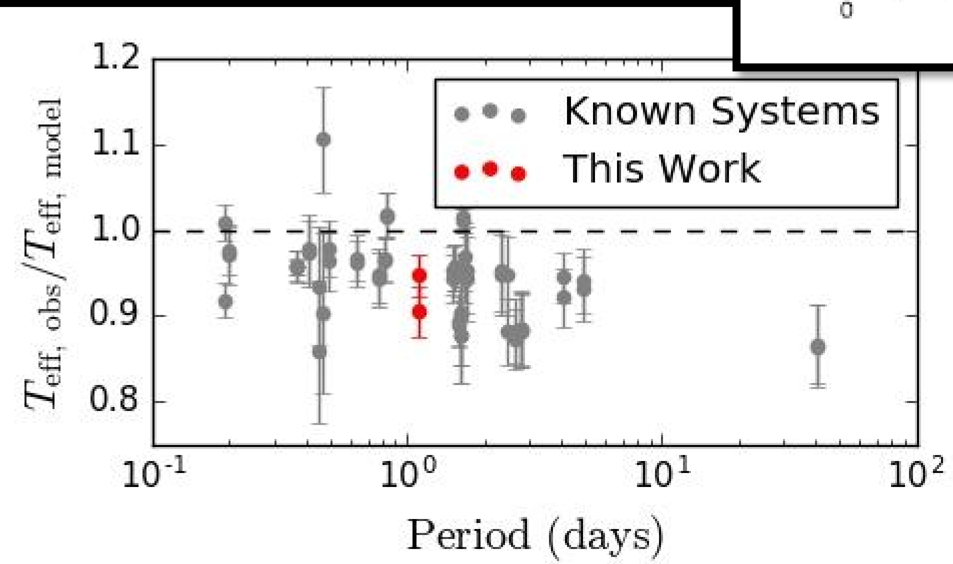
- MEarth measures <5% radius ratios -- accuracy matters
- Discrepancies between models and observations

M Dwarf Models: Too Small, Too Hot

- Underpredict radii by 5-10%
- Overpredict T_{eff} by similar amount



Birkby+ (12)

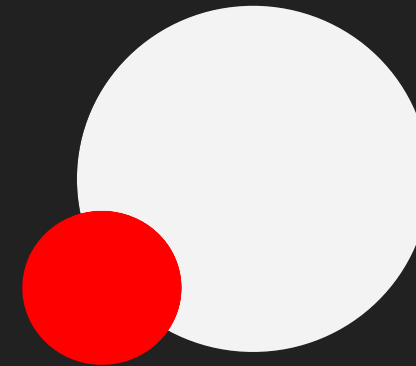


Lubin+ (17)

Two questions:

- What internal processes are models not capturing?
- What role do binary interactions have?

Characterizing Single-lined EBs



- Includes transiting exoplanet systems
- Hundreds found by transit surveys
  - Many more with TESS!

  → >100s of M dwarfs at interesting periods

Combine parallax, SED, eclipses, RVs for “model-independent” masses and radii

Parameters from Single-lined EBs

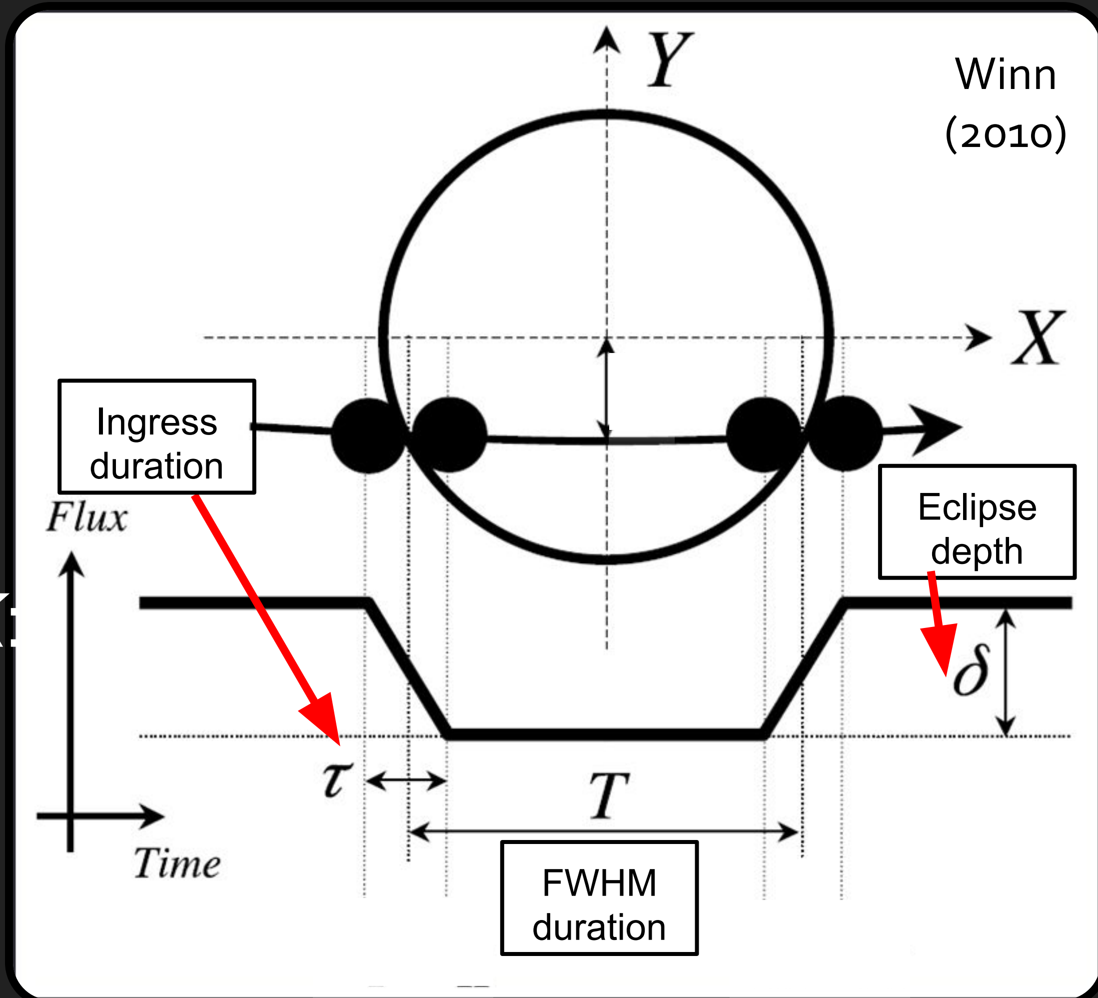
- Measure period *P*, depth δ, durations T, τ
  $\rightarrow$ $a/(R_1+R_2)$, R_2/R_1
  - Infer density ρ:

$$\rho \approx \frac{3\pi}{GP^2}\left(\frac{a}{R1}\right)^3 f(eccentricity)$$

- RV semiamplitude *K*:

$$M_2 = G^{-1/2}\frac{KP^{2/3}}{\sin i}M_1^{2/3} f(eccentricity)$$

No individual masses or radii; only combinations



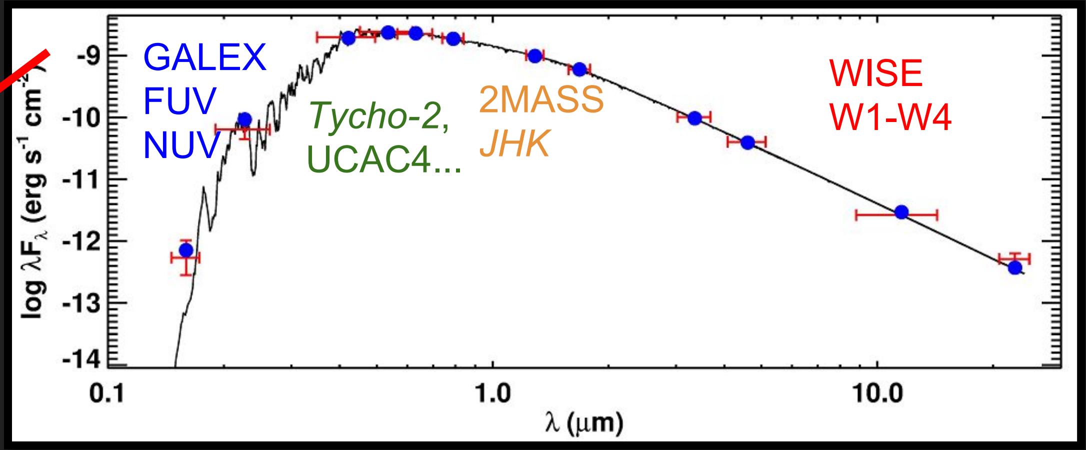
Gaia Parallaxes Give Stellar Radii

- Fit for (or measure) bolometric flux & extinction

$$R_1 \propto \frac{1}{\pi_p} \frac{F_{\rm bol}^{1/2}}{T_{\rm eff}^2}$$

Parallax *(Gaia)*

Effective Temperature (SED; spectra)



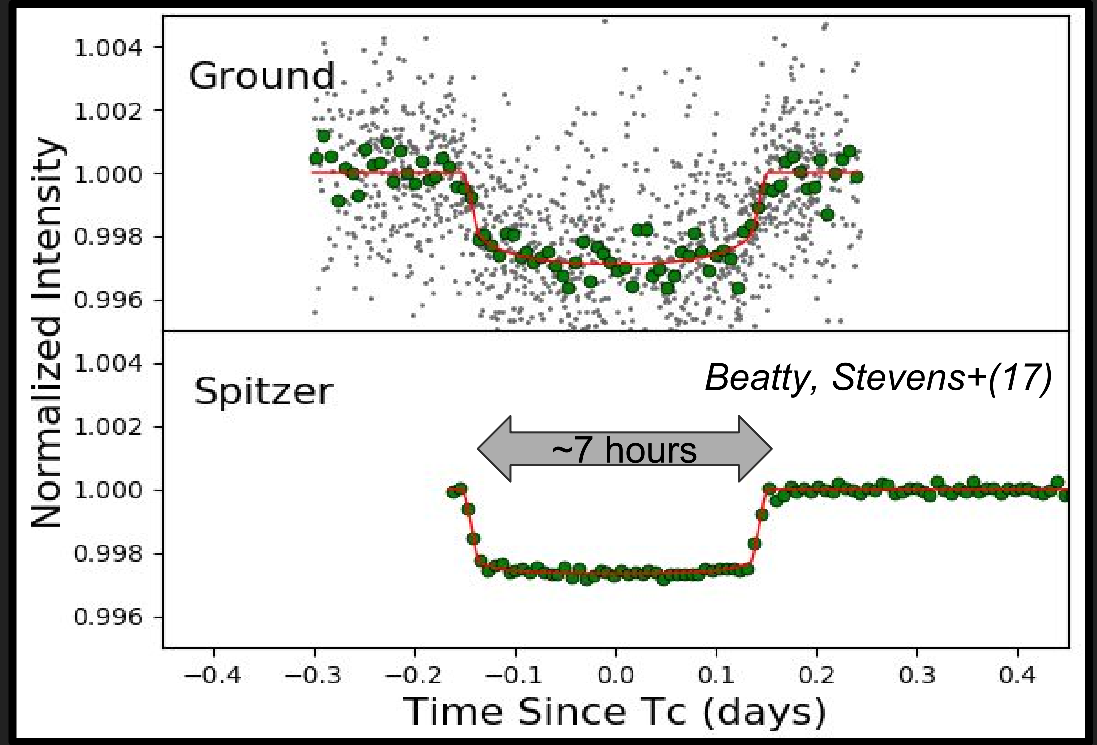
- Can be performed in bulk for bright stars*
  - GALEX, Tycho-2, UCAC4, 2MASS, WISE: All-sky & data already exist...

*e.g. Stevens, Stassun, & Gaudi (subm.)

Ex: KELT-11

(Pepper+16)

- Highly inflated Saturn around retired A star
- Can test stellar models & empirical relations:



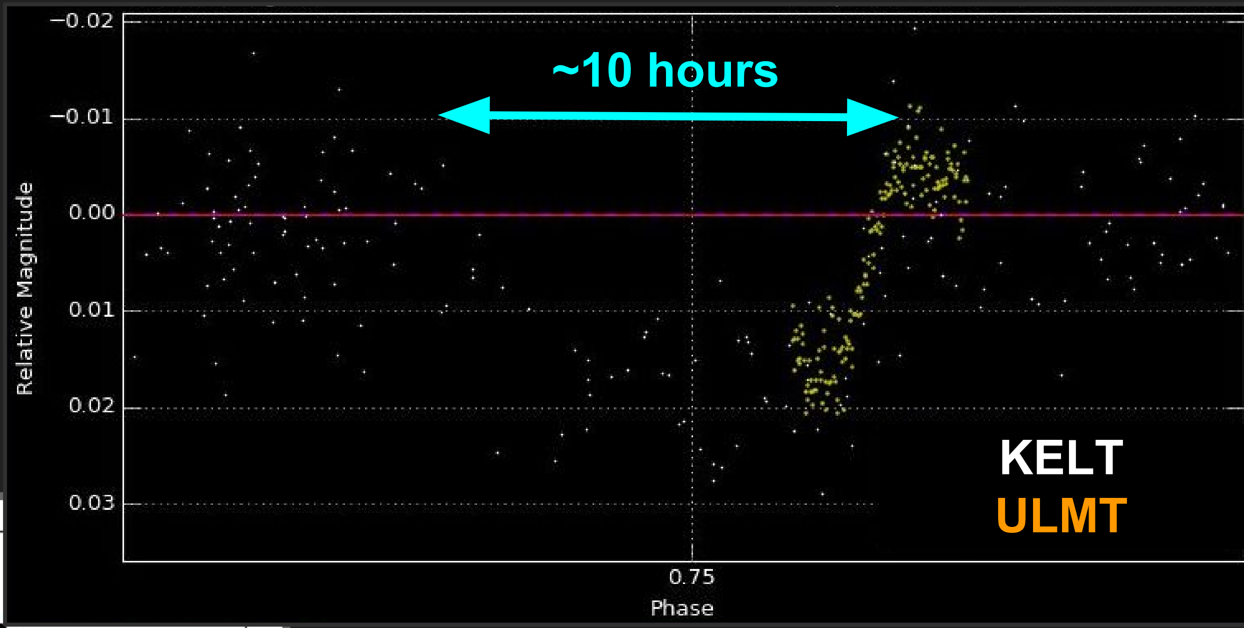
Parameter	Spitzer+Ground+Torres	Spitzer+Ground+Final *Gaia*
Stellar Mass ($M_\odot$)	1.44 ± 0.07	1.62 ± 0.05
Stellar Radius ($R_\odot$)	2.69 ± 0.04	2.790 ± 0.008
Planet Mass (M_{Jup})	0.171 ± 0.013	0.199 ± 0.019
Planet Radius (R_{Jup})	1.35 ± 0.10	1.45 ± 0.08

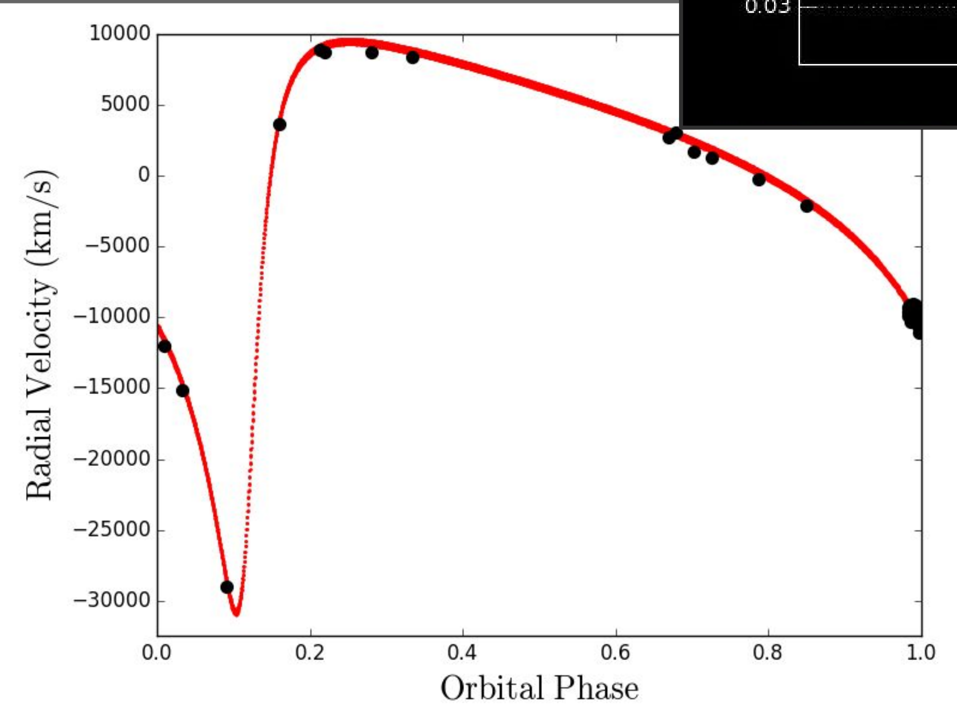
$>3\sigma$

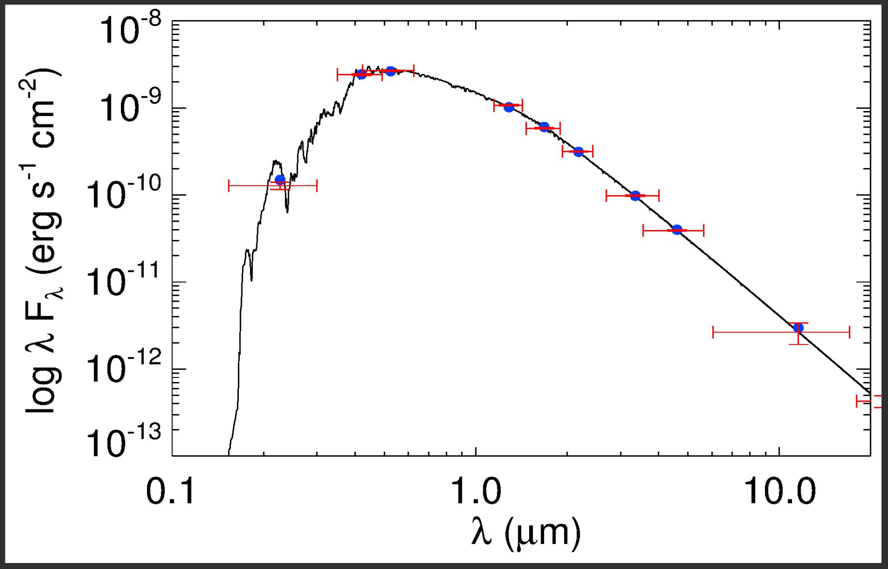
Ex: KELT F+M Binary

16.5-day orbit

~10-hour eclipse



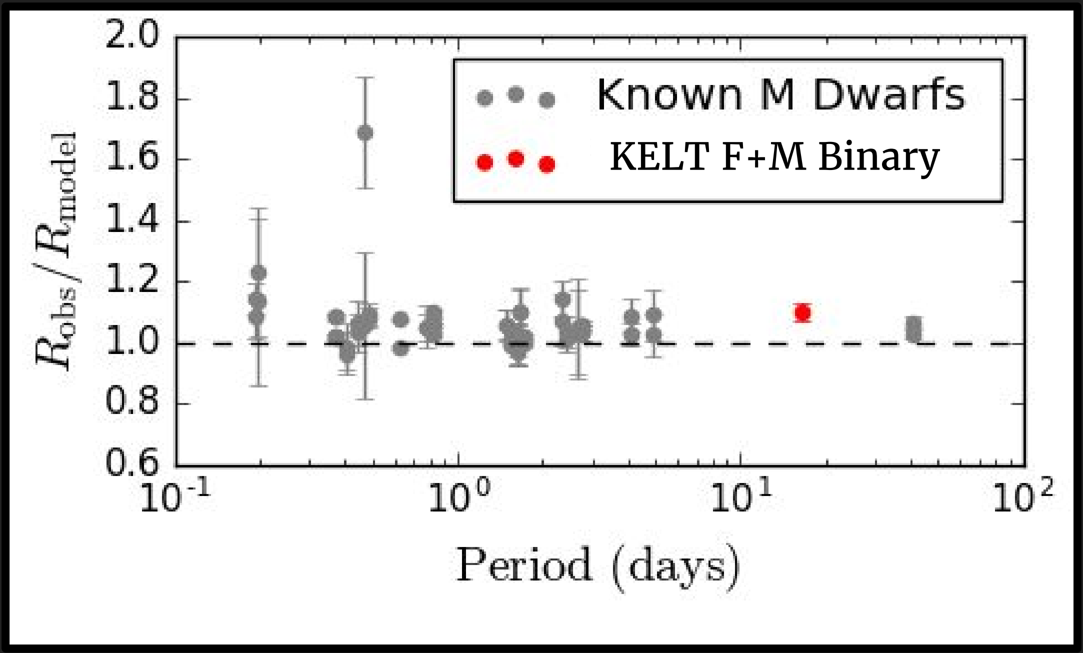




A Preliminary Result

Assuming <1% parallax:

- **R_1: 1.74 $R_\odot$ (1.1%)**
- **R_2: 0.23 $R_\odot$ (2.8%)**
- M_1: 1.74 $M_\odot$ (17%)
  - (16% density)
- M_2: 0.26 $M_\odot$ (10%)



The future is bright...

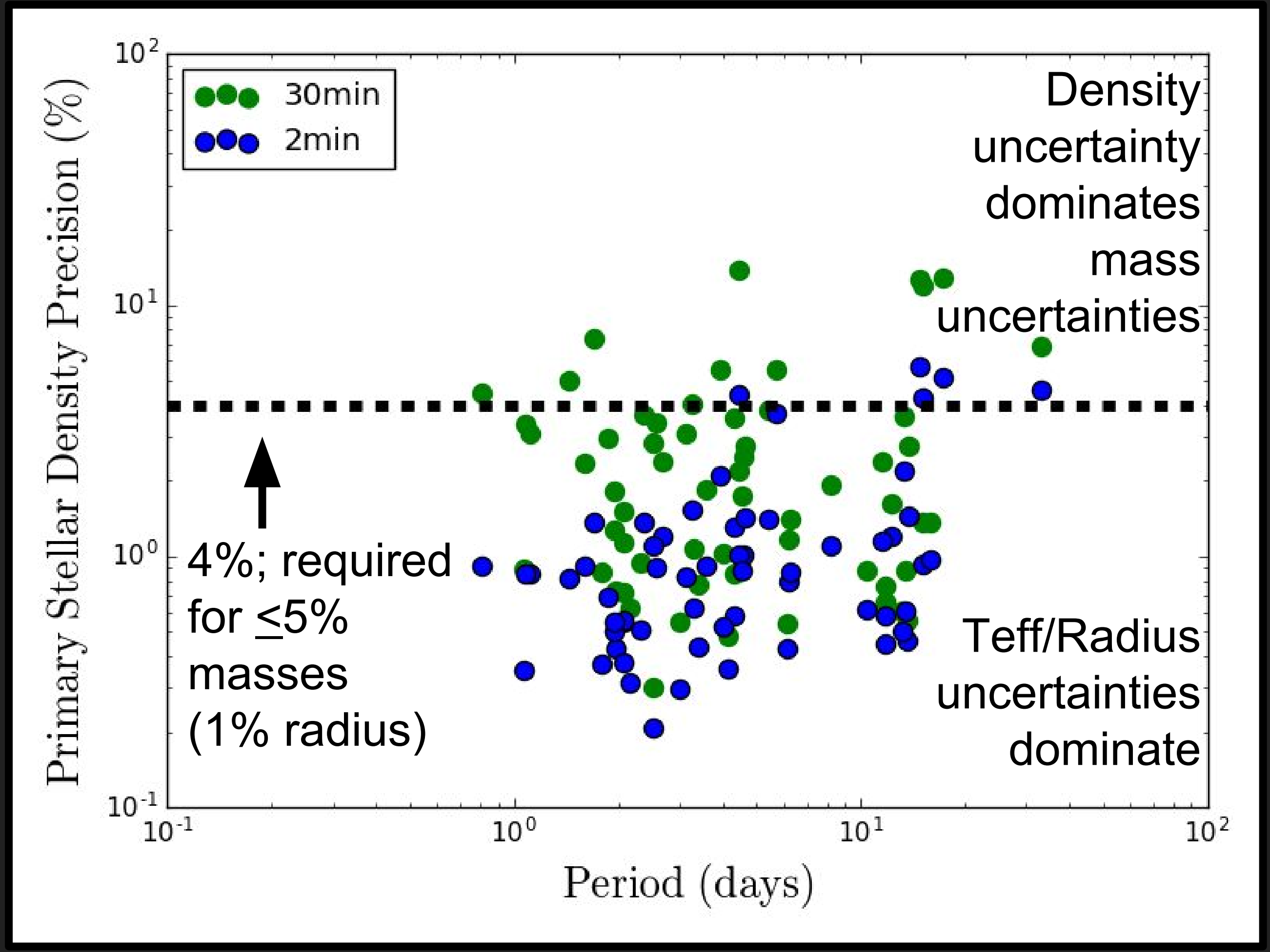
The Precision of TESS

Example F+M Binary: 1-2% density from eclipse

Flicker: log*(g)* to 0.1 dex

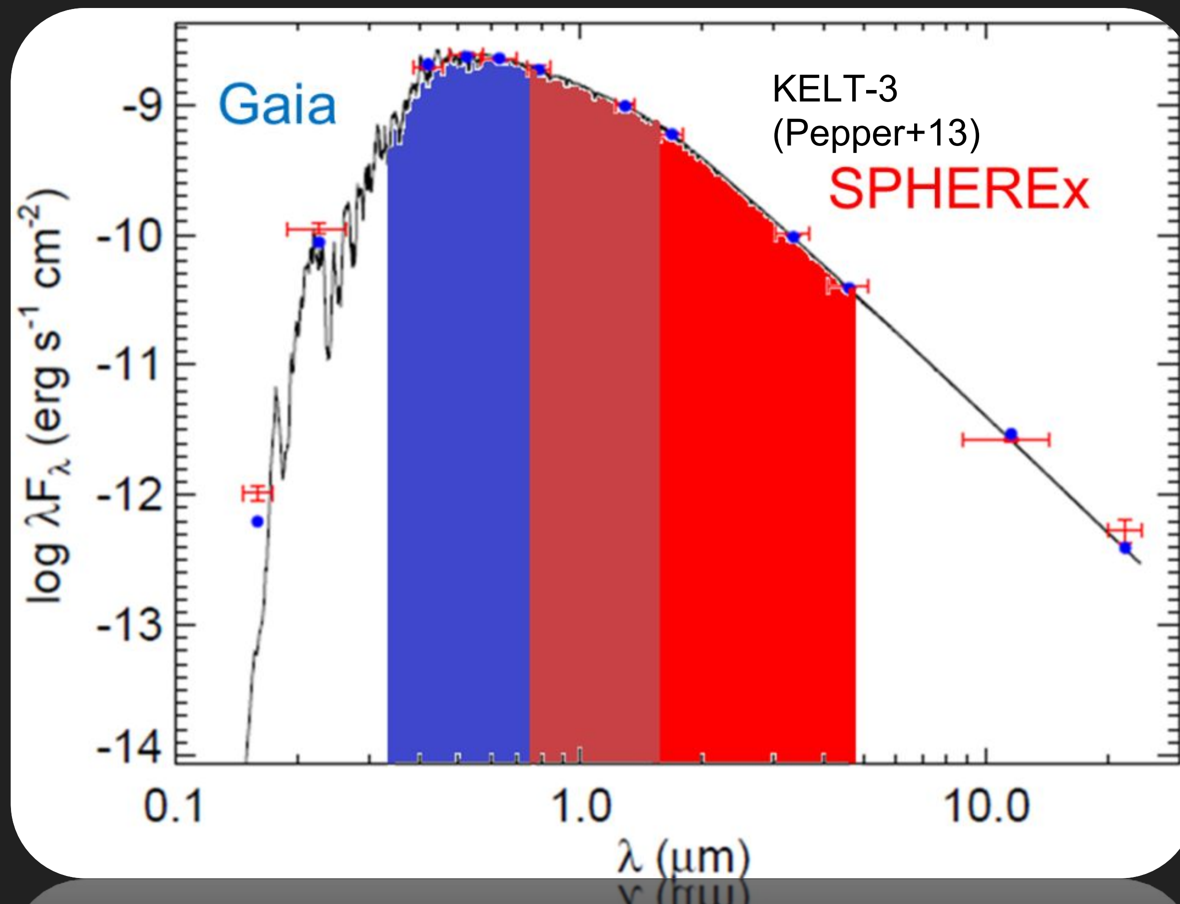
Granulation timescale: *g* to 4%

Secondary eclipses: T_{eff} to 1-2%



Precise SEDs with *Gaia* & SPHEREx

- *Gaia* (2020): 330-1050nm spectrophotometry
- SPHEREx* (2020s): 0.75-5µm
- ~All the flux from FGK dwarfs
- M dwarf SED peak



*Doré et al. (2016; (arXiv:1606.07039)

Ex: KELT-3 with SPHEREx

Now:

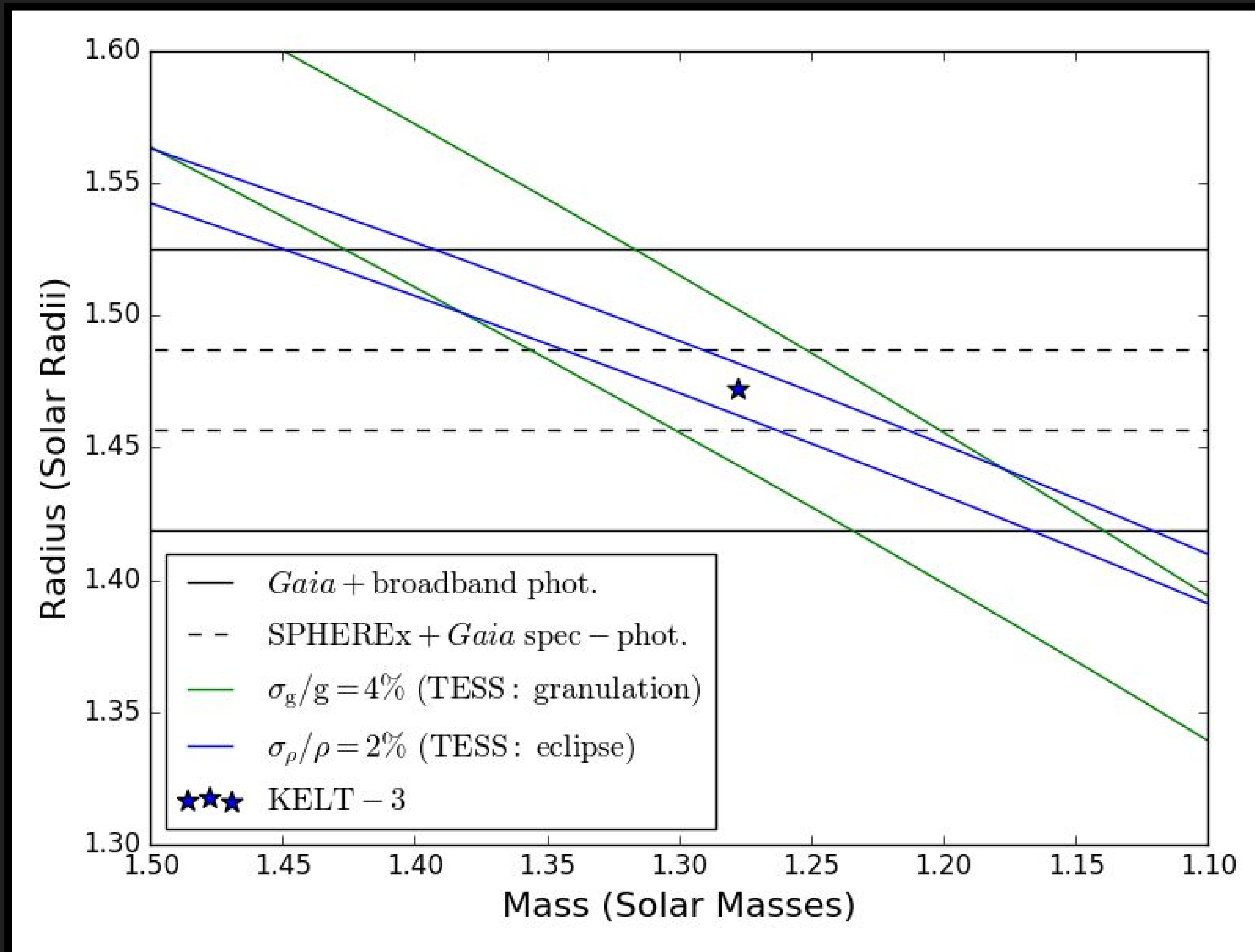
- 6% F_{bol}
- 4% R_1
- 14% M_*

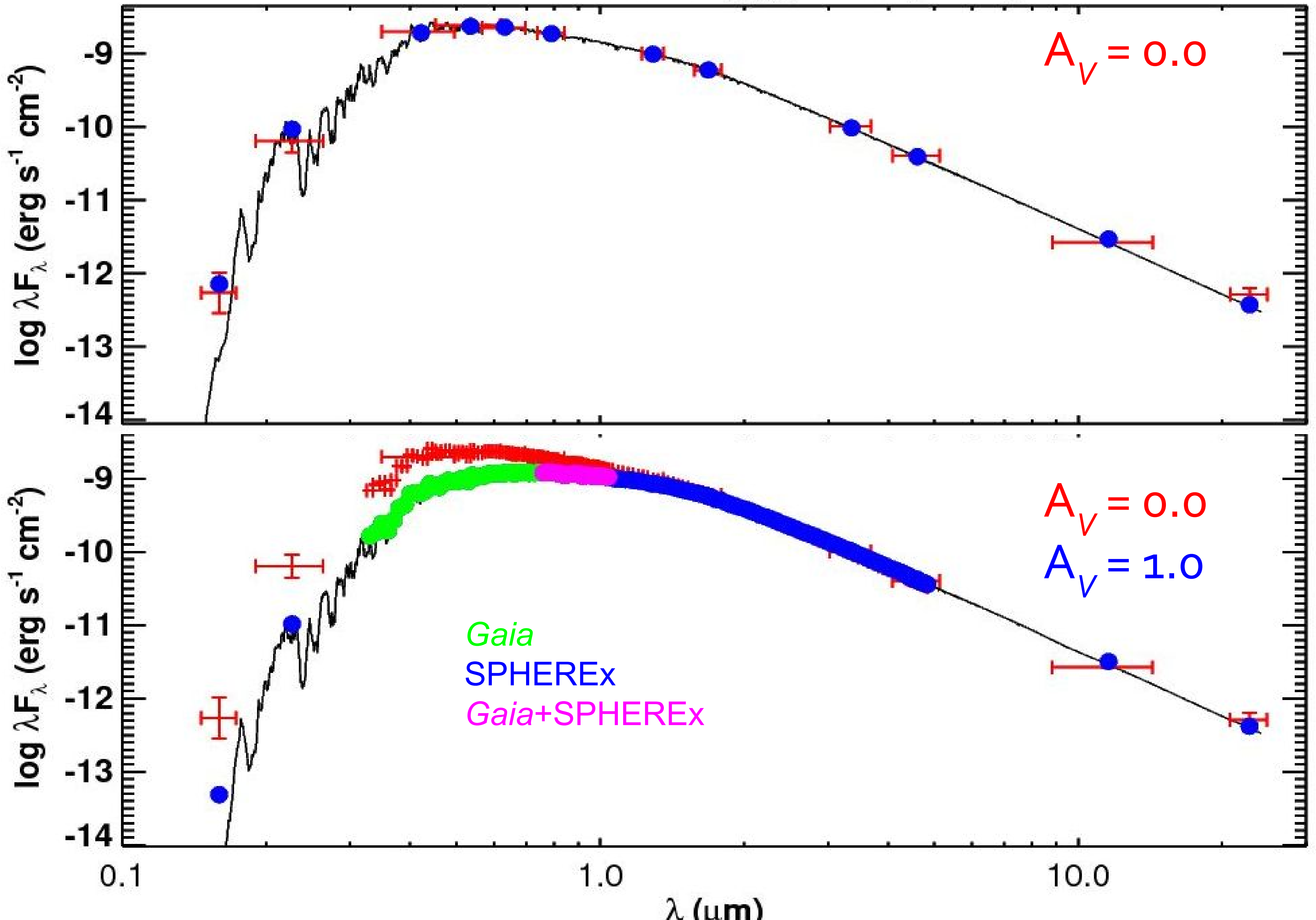
SPHEREx+ *Gaia*:

- <2% F_{bol}
- <1% R_1 (<0.1% T_{eff})

TESS:

- 2% density
- <4% M_*





Can measure extinction ("Cardelli-free!") with SPHEREx

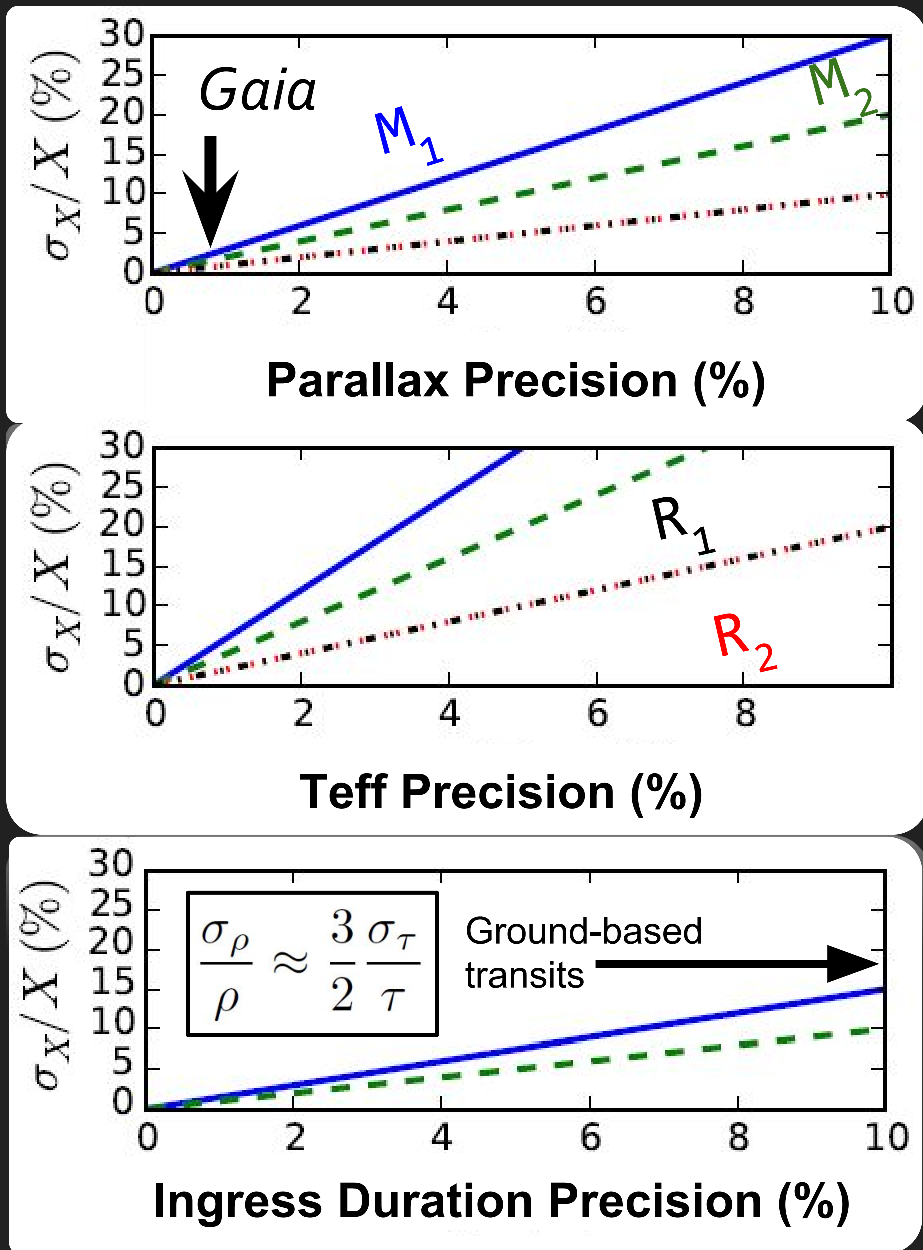
The Next Era of Precision Stellar Astrophysics

- From transit false positives to benchmark systems
  - Test stellar models & other measurement methods
  - Constrain planetary compositions
  - Probe star-planet relationships

- Expect major improvements in precision and accuracy
  - soon: *Gaia*, TESS, SPHEREx (Brendan Crill’s talk tomorrow)
  - later: PLATO, CHEOPS…

T_{eff} & Duration Dominate Errors

Stevens+ (in prep)



Gaia parallaxes contribute negligibly.

T_{eff} contributes significantly:

$$R_1 \sim T_{eff}^{-2}$$

$$M_1 \sim R_1^{3}$$

$$\rightarrow M_1 \sim T_{eff}^{-6}$$

Precise ingress durations: tough from the ground...