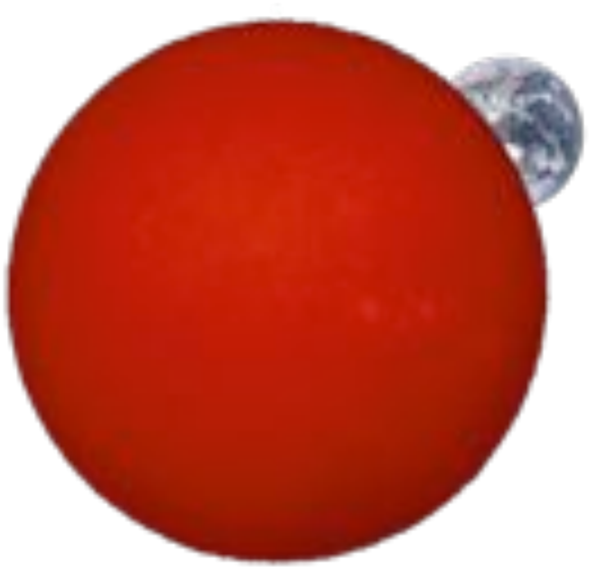
Precision Radial Velocities in the Near Infrared with TEDI

James Lloyd (Cornell University)



"Do there exist many worlds, or is there but a single world? This is one of the most noble and exalted questions in the study of Nature."

-Albertus Magnus
1193-1280

Outline

- ~~M dwarfs & Infrared RV~~

  Declare victory: 60/40 by talk emphasis

- Transits
- Accuracy, precision and efficiency
- TripleSpec Exoplanet Discovery Instrument

A brief history of Exoplanets

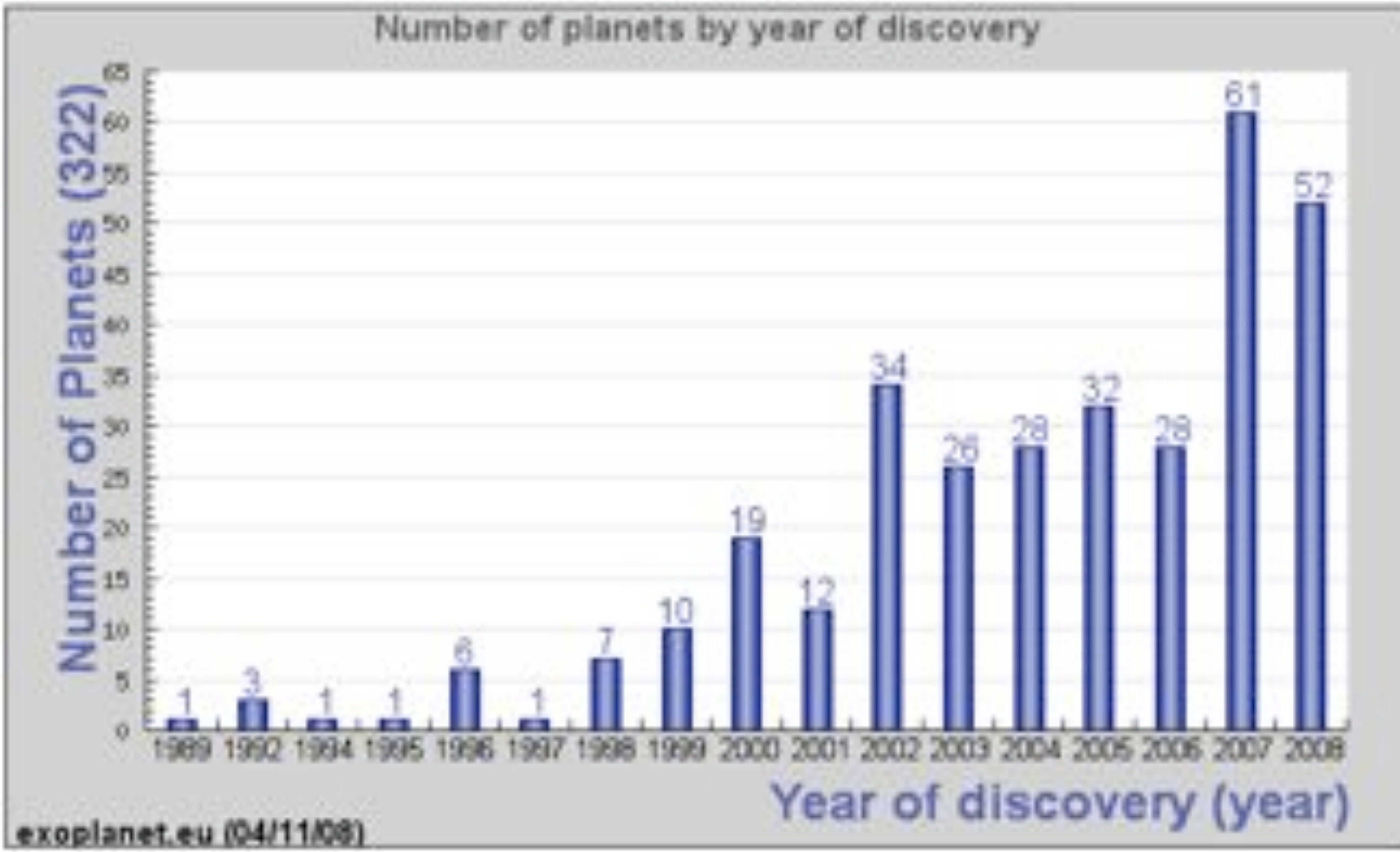
Giordano Bruno

De l'Infinito, Universo e Mondi (1584),

"Thus is the excellence of God magnified and the greatness of his kingdom made manifest; He is glorified not in one, but in countless suns; not in a single earth, a single world, but in a thousand thousand, I say in an infinity of worlds!"

Executed in 1600

Rate of Discovery

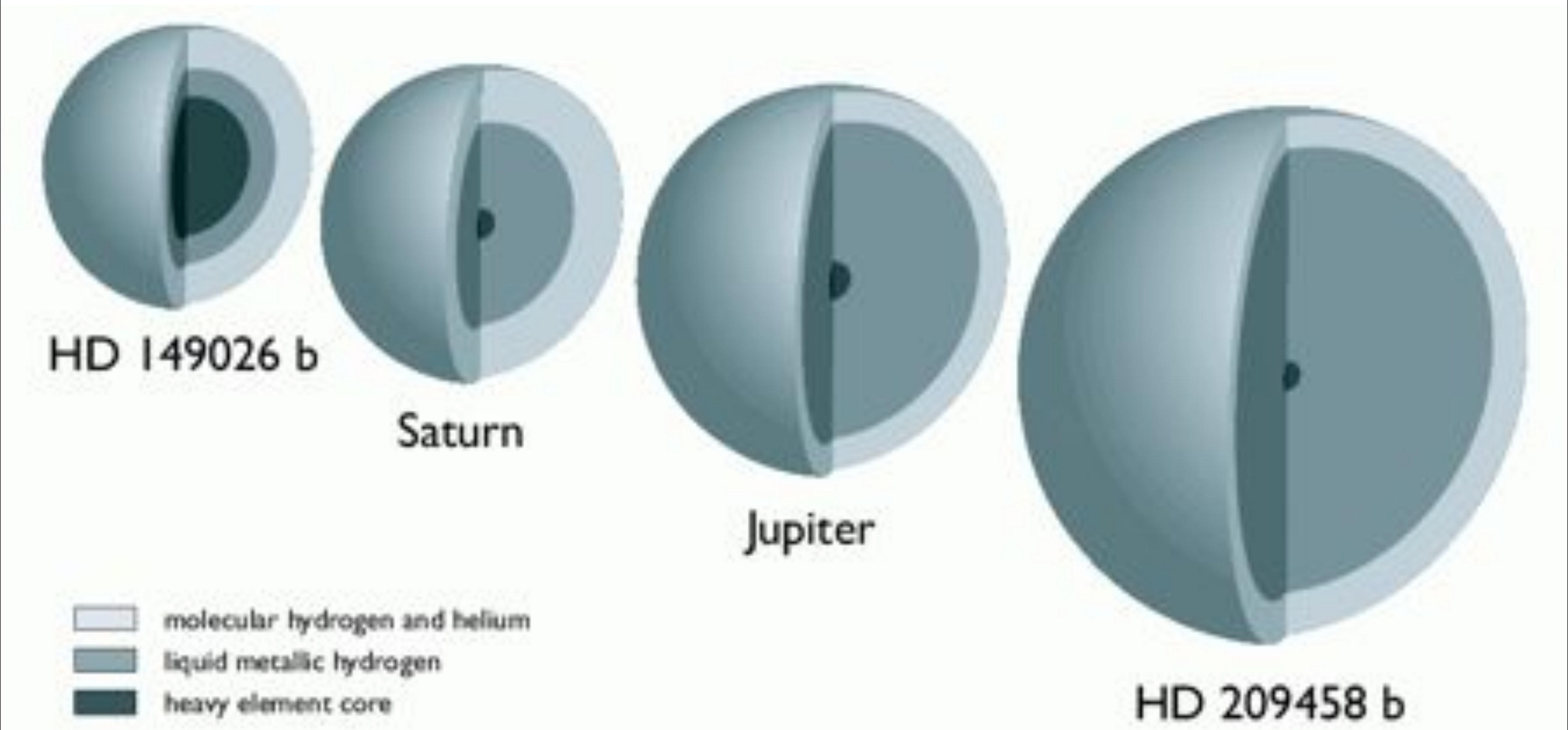


The Pothole of Comte's Positivism

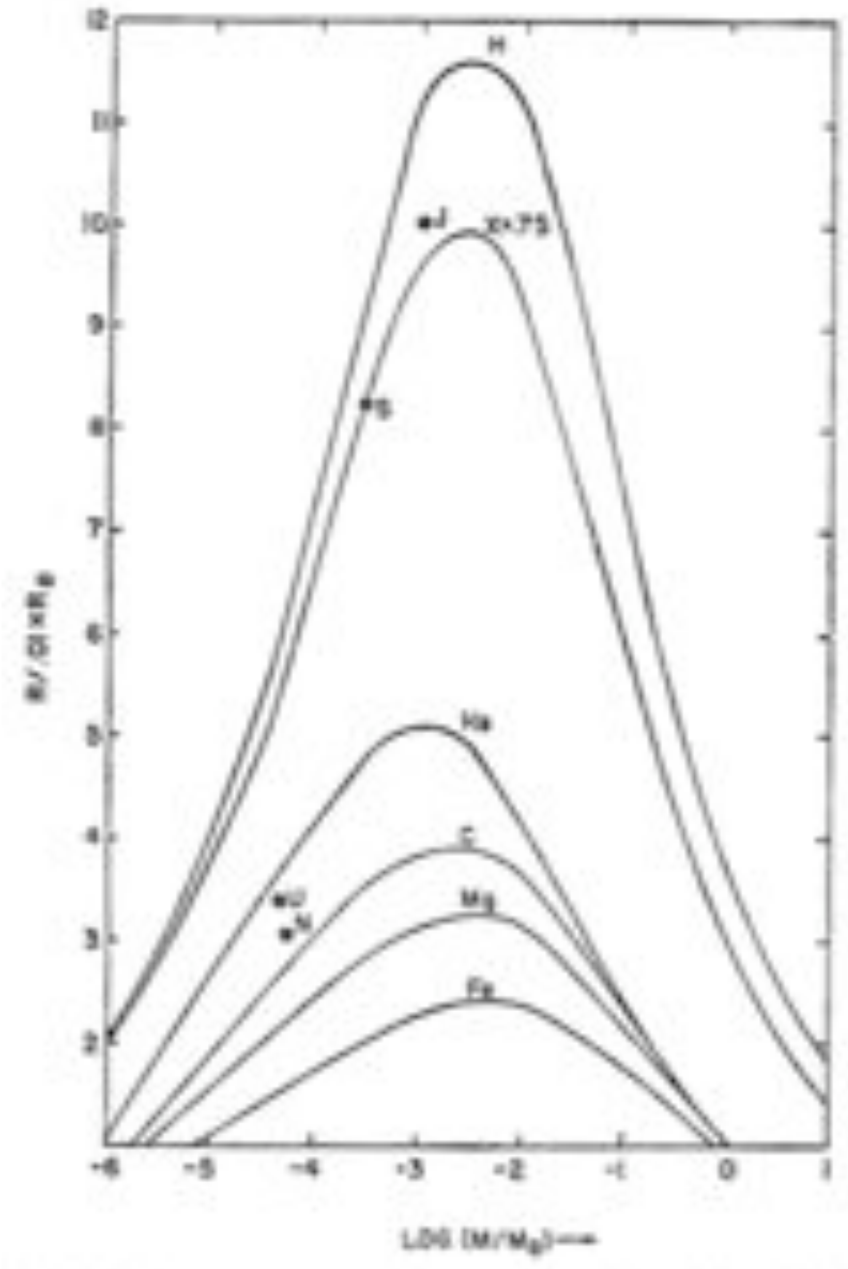
"we can determine the shapes, distances, sizes, and motions of celestial bodies, but never, by any means, will we be able to study their chemical compositions."

Auguste Comte, 1835

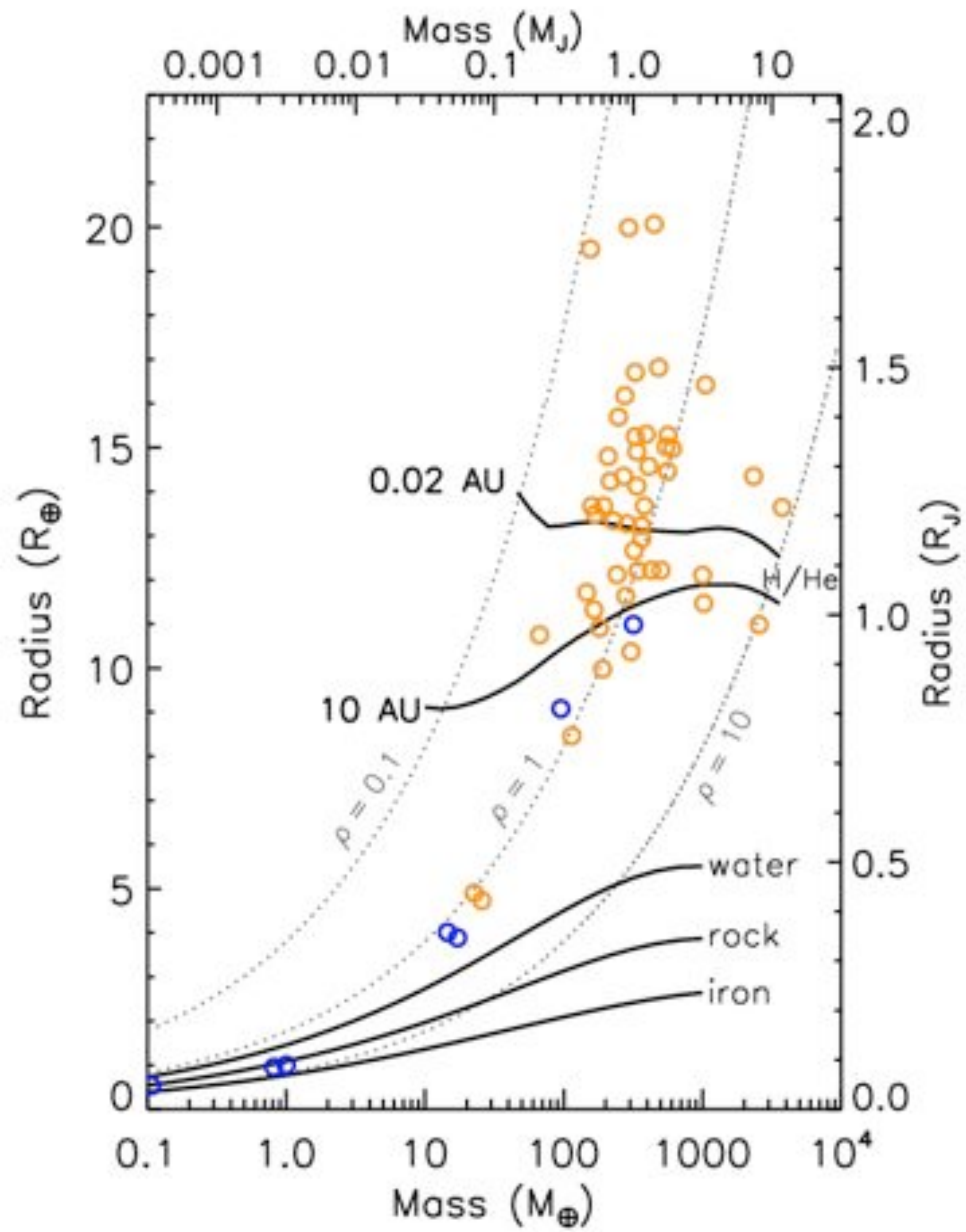
Mass + Size = Density



Transits ⇒ Astrophysics



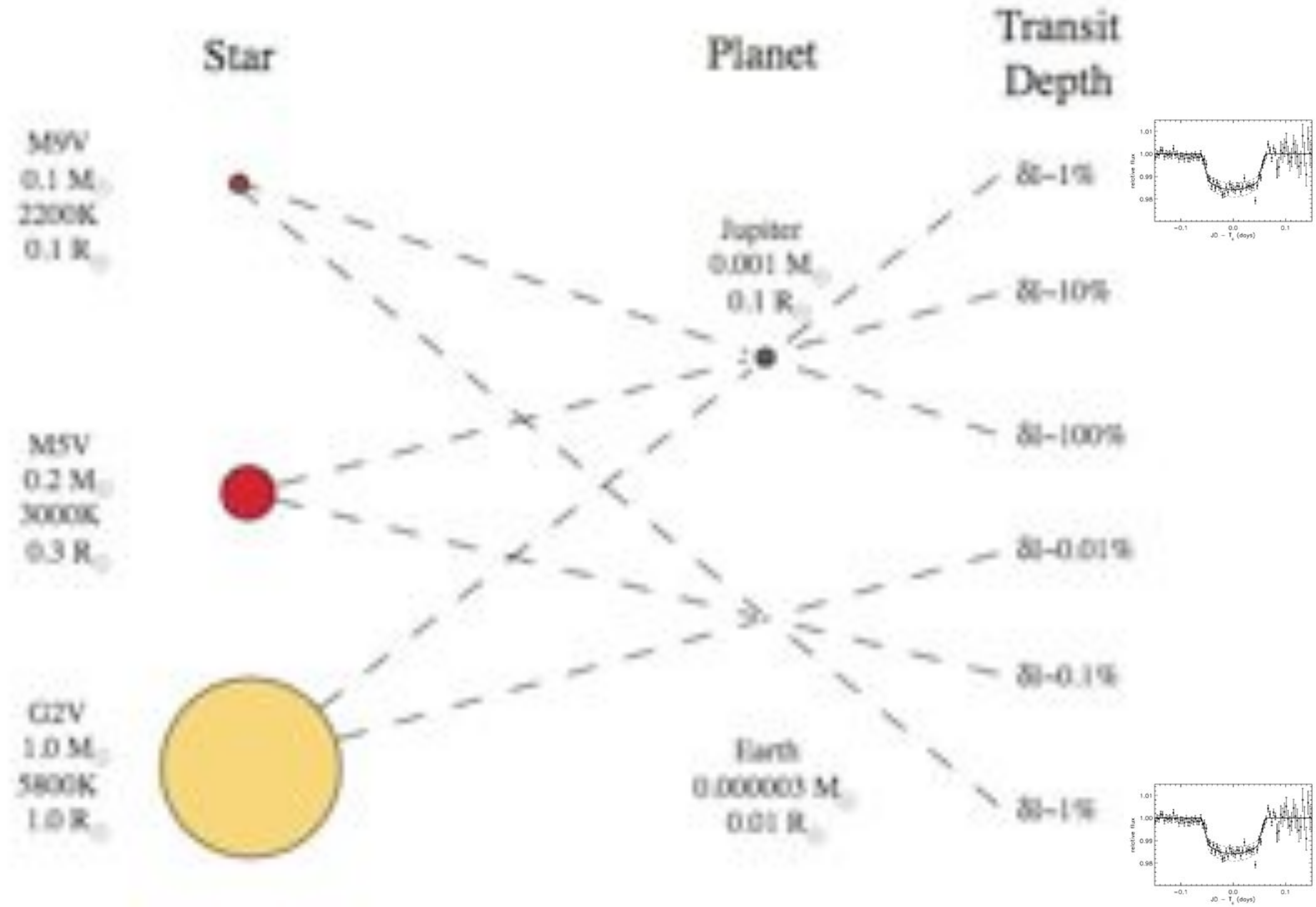
Zapolsky & Salpeter 1969



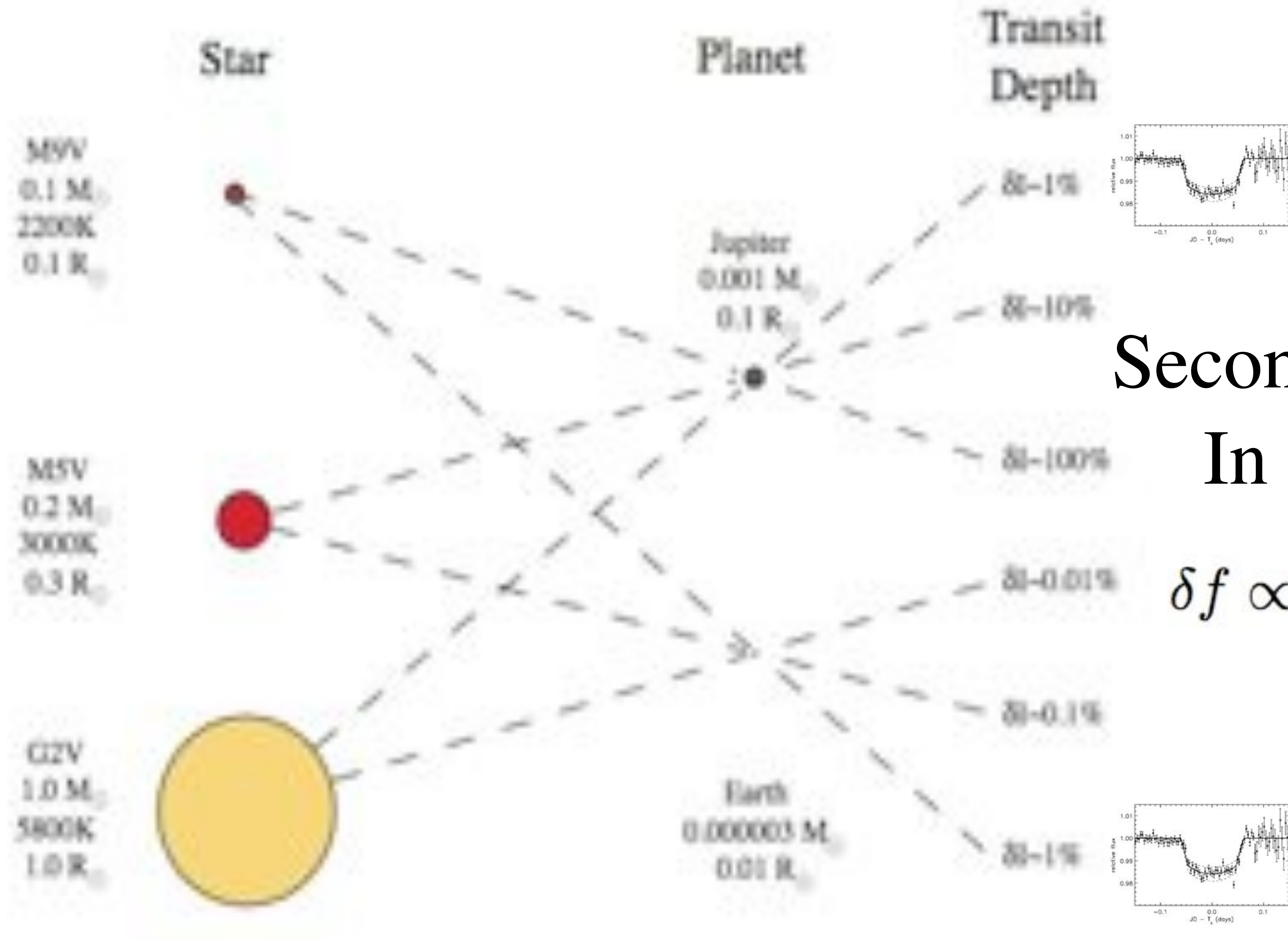
credit: J. Fortney


Star
M9V
0.1 $M_{\odot}$
2200K
0.1 $R_{\odot}$
M5V
0.2 $M_{\odot}$
3000K
0.3 $R_{\odot}$
G2V
1.0 $M_{\odot}$
5800K
1.0 $R_{\odot}$

Star
Planet
M9V
0.1 M
2200K
0.1 R
Jupiter
0.001 M
0.1 R
M5V
0.2 M
3000K
0.3 R
G2V
1.0 M
5800K
1.0 R
Earth
0.000003 M
0.01 R

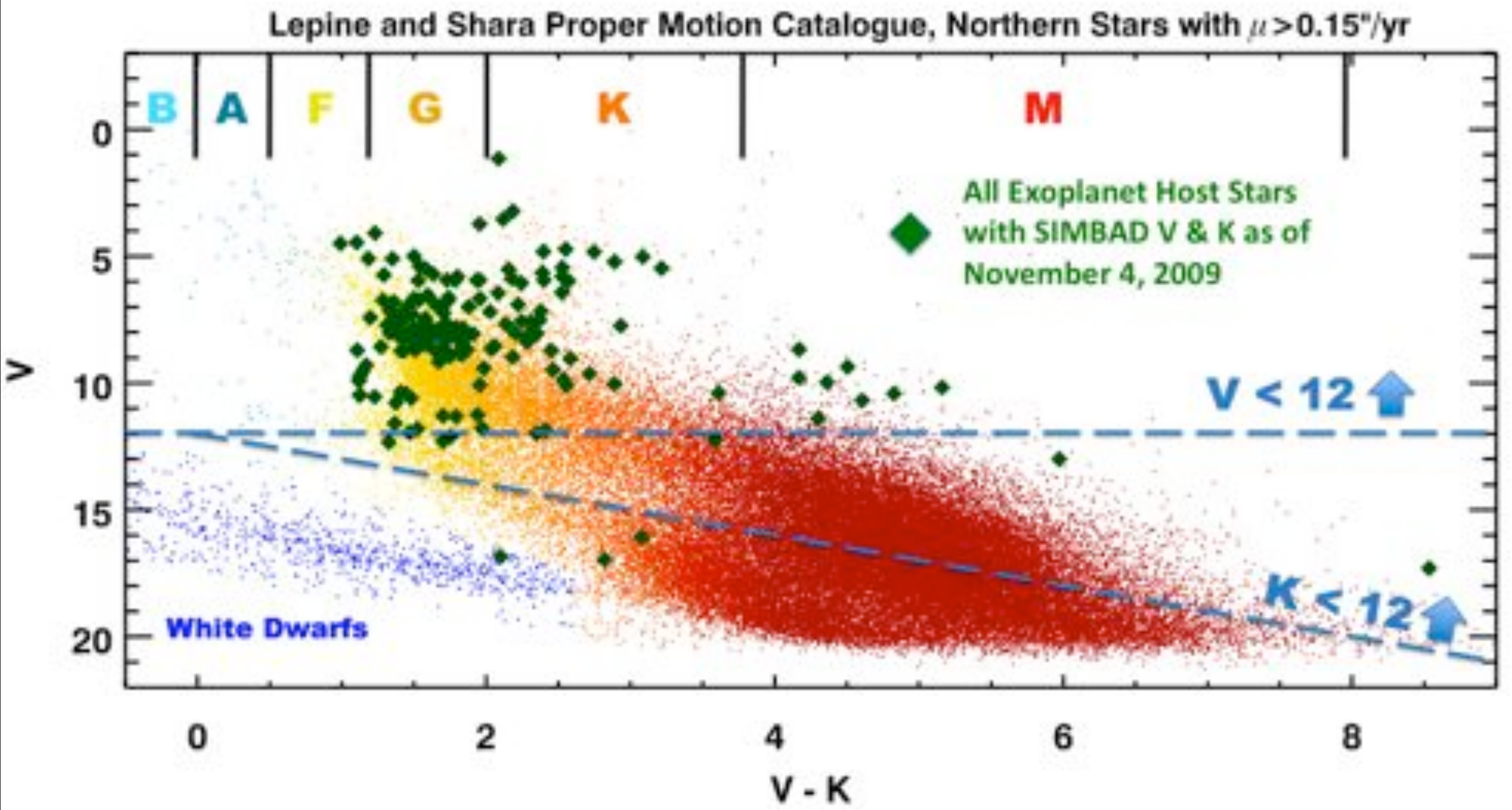

Star
Planet
Transit Depth
M9V
0.1 M
2200K
0.1 R
M5V
0.2 M
3000K
0.3 R
G2V
1.0 M
5800K
1.0 R
Jupiter
0.001 M
0.1 R
Earth
0.000003 M
0.01 R
δI~1%
δI~10%
δI~100%
δI~0.01%
δI~0.1%
δI~1%

Transiting planets around M-dwarfs enables detection of Earth-radius planets from the ground



Secondary Transit
In R-J limit:

$$\delta f \propto \left(\frac{R_p}{R_\star}\right)^2 \frac{T_p}{T_\star}$$

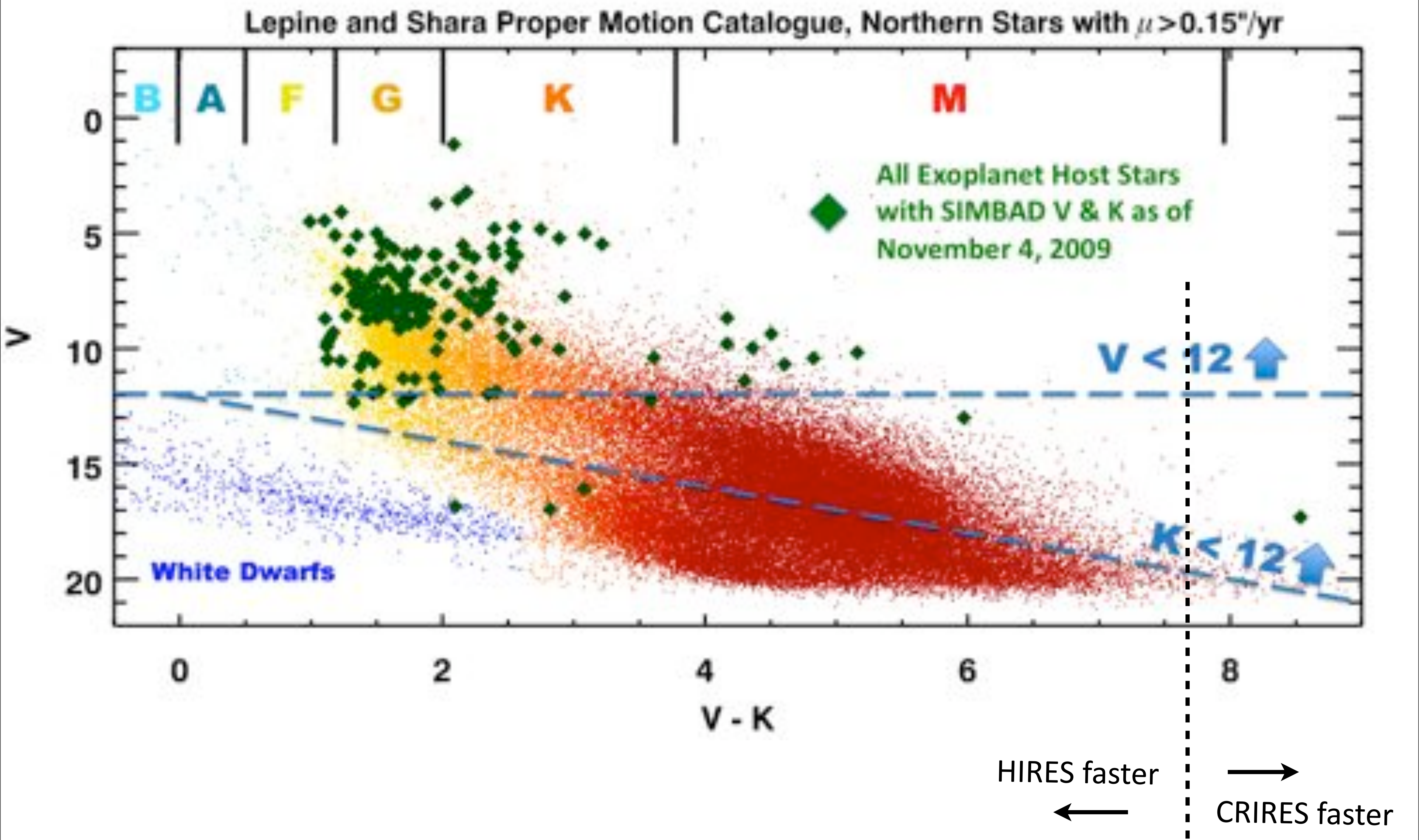

Lepine and Shara Proper Motion Catalogue, Northern Stars with μ > 0.15"/yr
B
A
F
G
K
M
All Exoplanet Host Stars with SIMBAD V & K as of November 4, 2009
V < 12
K < 12
White Dwarfs
V
V - K
0
5
10
15
20
0
2
4
6
8

Accuracy & Precision

- Kepler-4b: Keck/HIRES (Borucki et al 2010; Howard pers. comm.)
- V=12.8
- 3.6 m/s in 20 min

- VB10: VLT/CRIRES (Bean et al 2010)
- K=8.7
- 10 m/s in 2.5hr

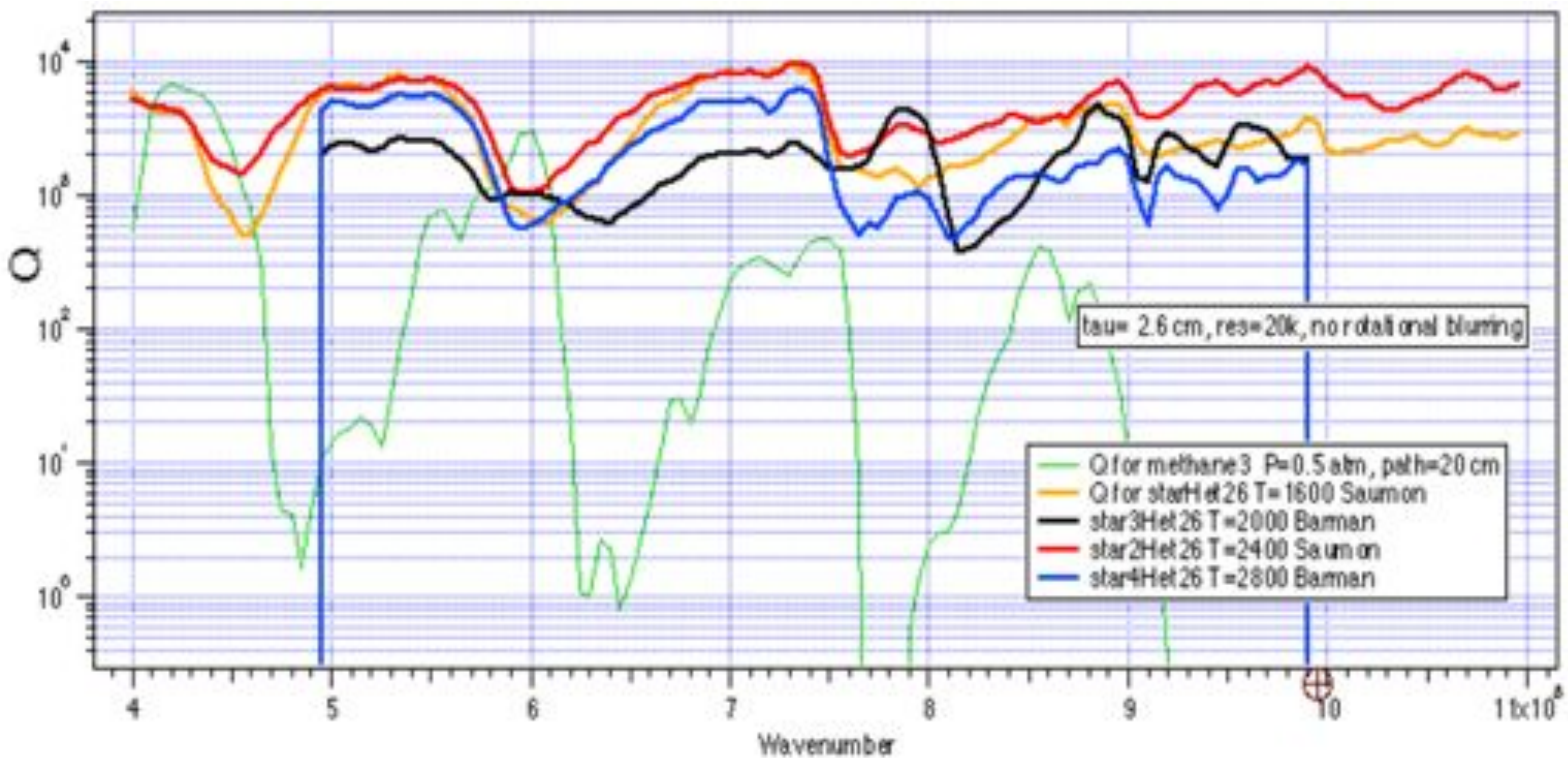
- equal speed on same star (m/s hr$^{-1/2}$) at V-K = 7.7



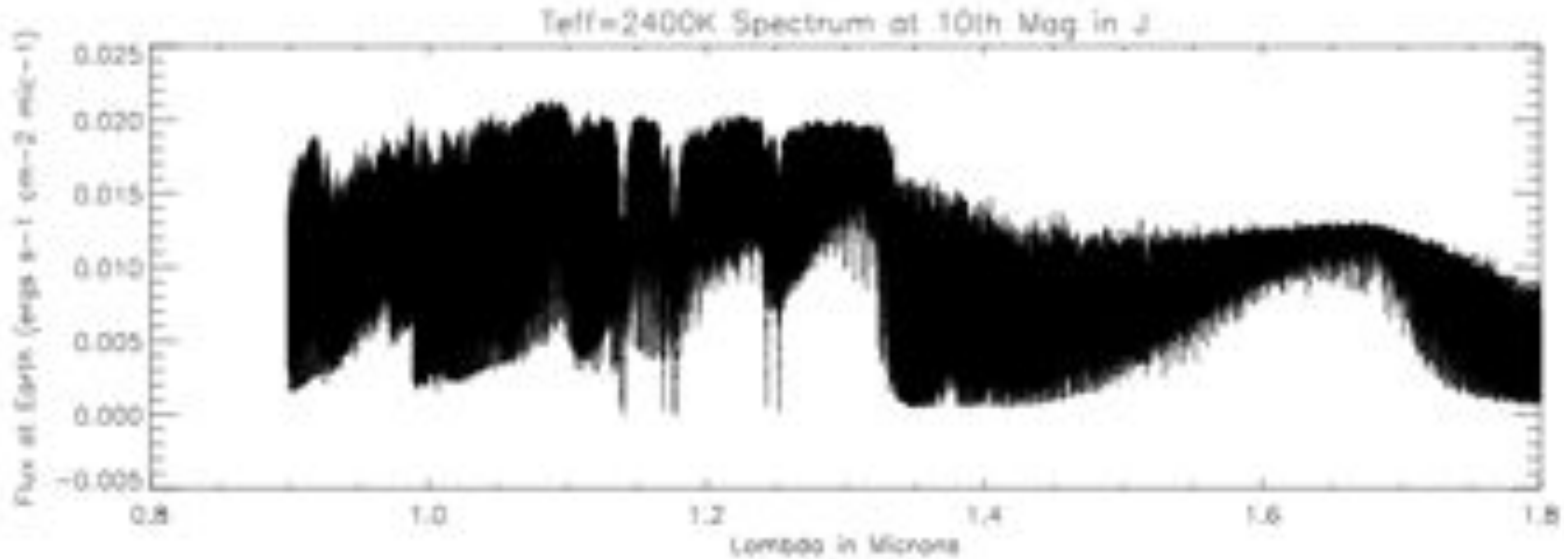
Lepine and Shara Proper Motion Catalogue, Northern Stars with μ >0.15"/yr
B
A
F
G
K
M
All Exoplanet Host Stars with SIMBAD V & K as of November 4, 2009
V < 12
K < 12
White Dwarfs
V
V - K
0
5
10
15
20
0
2
4
6
8
HIRES faster
CRIRES faster

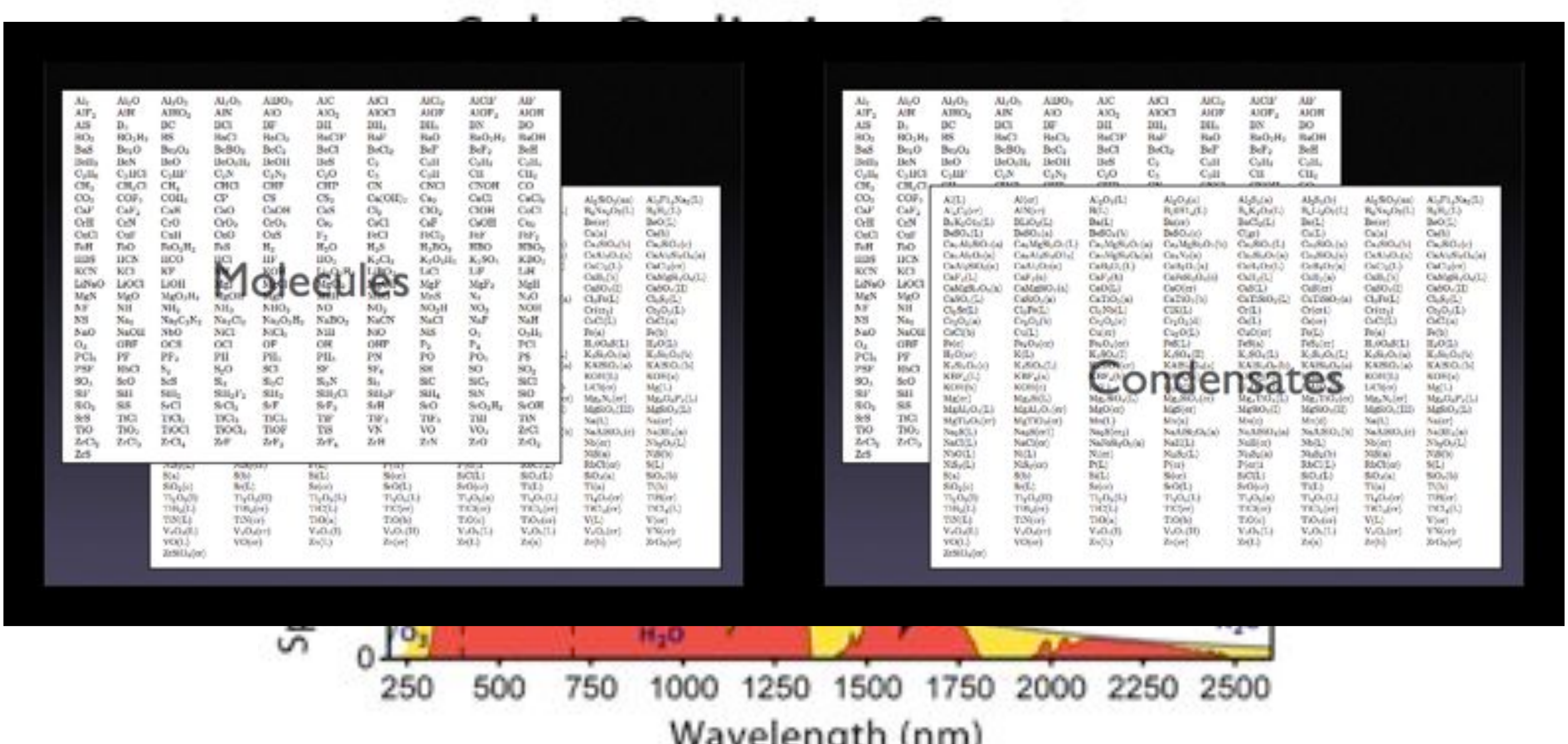
There is no gas cell analog of Iodine cell technique for M dwarfs

For calibration derived from an absorption cell, precision is set by the smaller of Q_{star} and Q_{abs}



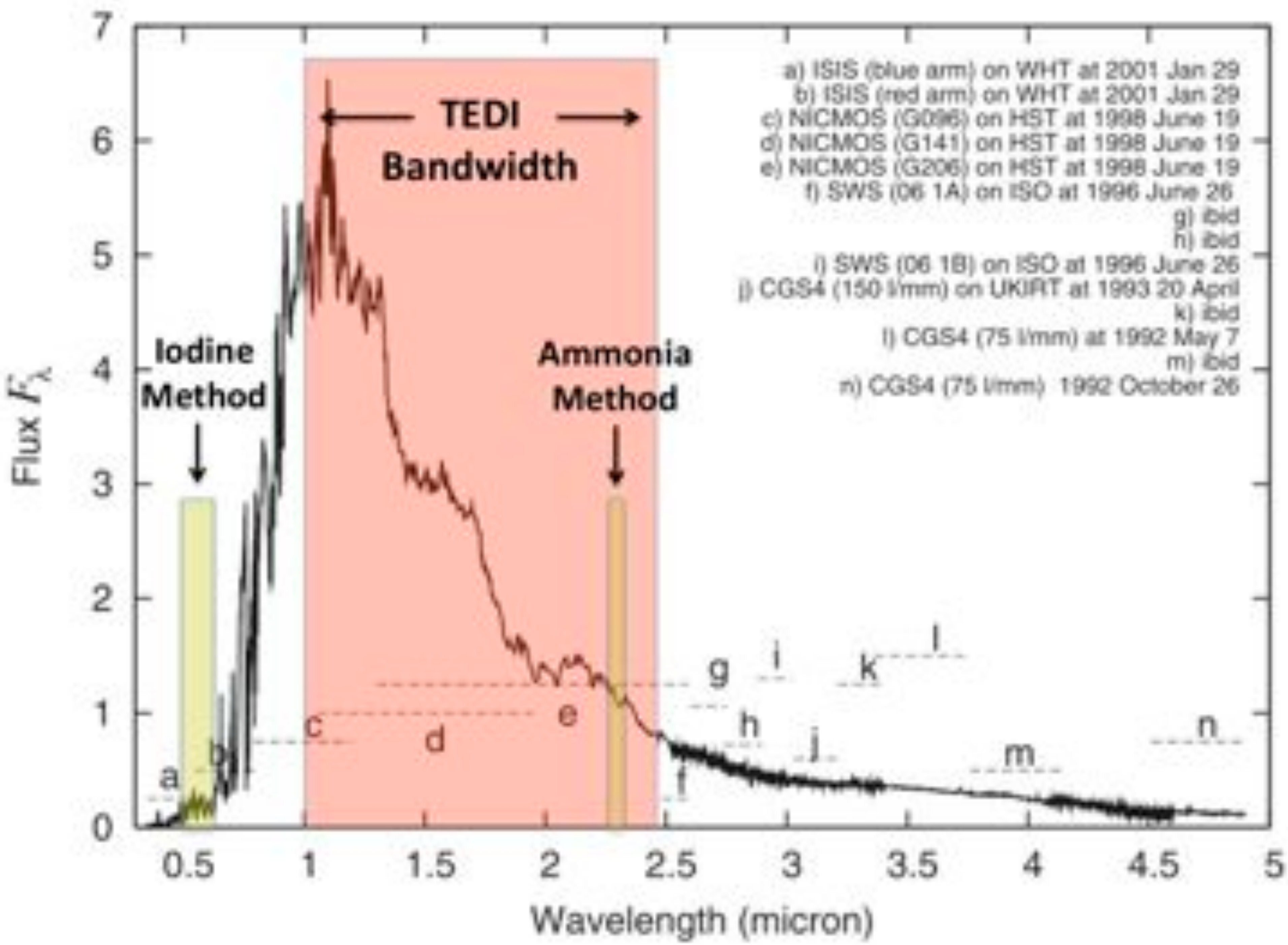
Line vs Continuum Opacity





TEDI

- Interferometer and a moderate-resolution spectrograph
- Large simultaneous bandwidth at high spectral resolution



Pavlenko et al. 2006

The TripleSpec Exoplanet Discovery Instrument: Precise Radial Velocities

Cornell Team:

Phil Muirhead, Kevin Covey, Katherine Hamren, James Lloyd

Berkeley Team:

Jerry Edelstein, David Erskine, Phil Andelson, David Kimber, Danny Mondo

+ others

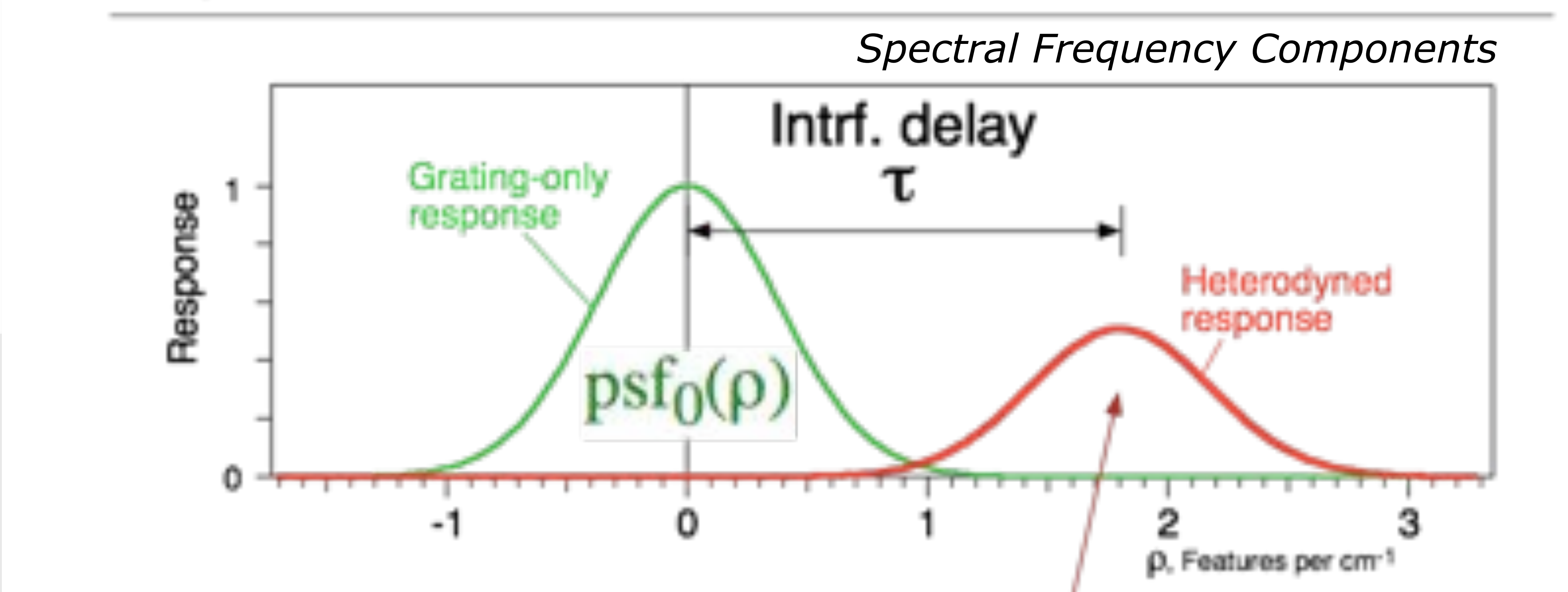
Think Picket Fence

Picket Fence

= Moiré
= Vernier Caliper
= Beat Frequency
= Spatial Frequency Heterodyning

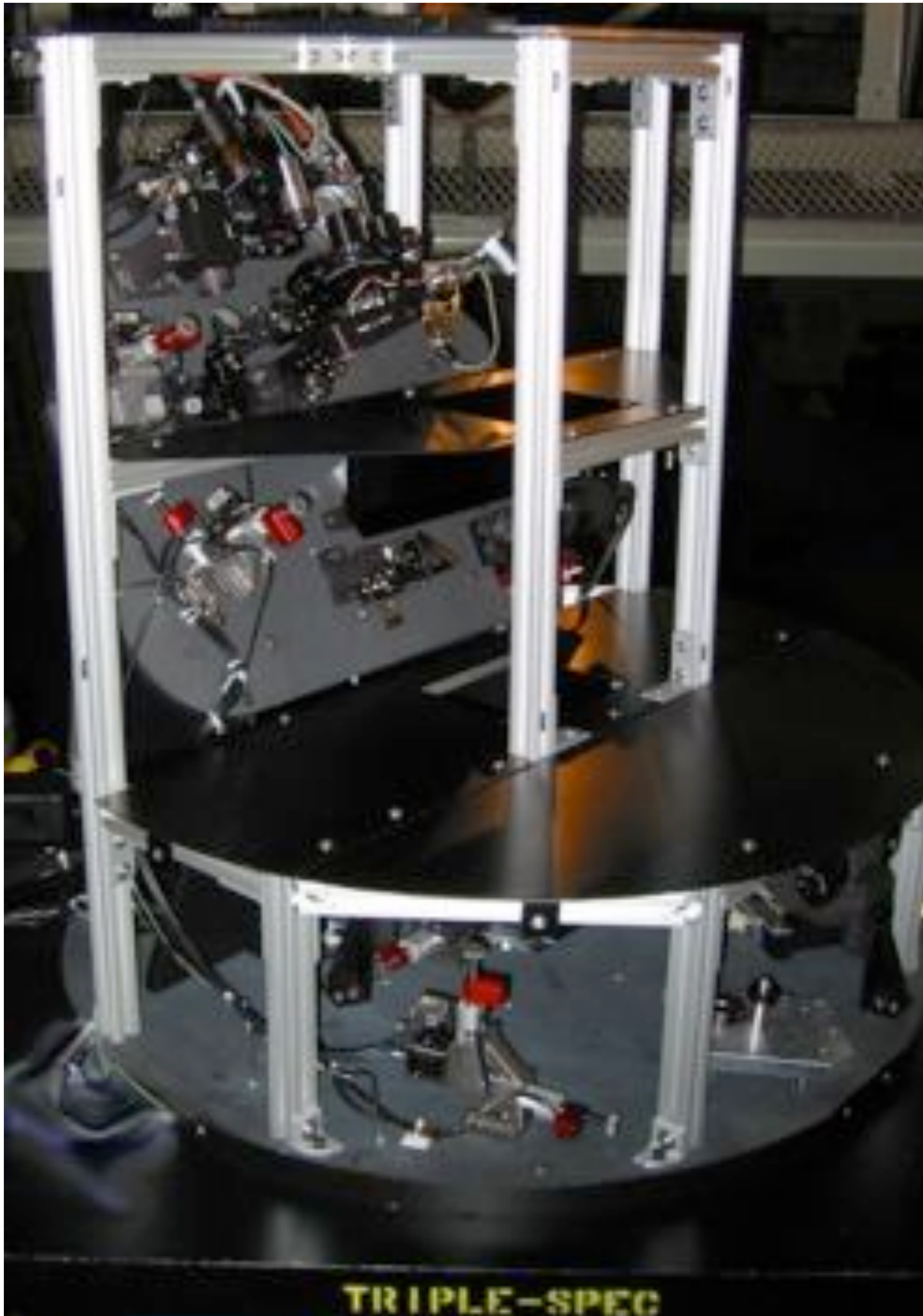
Moiré is a heterodyning effect

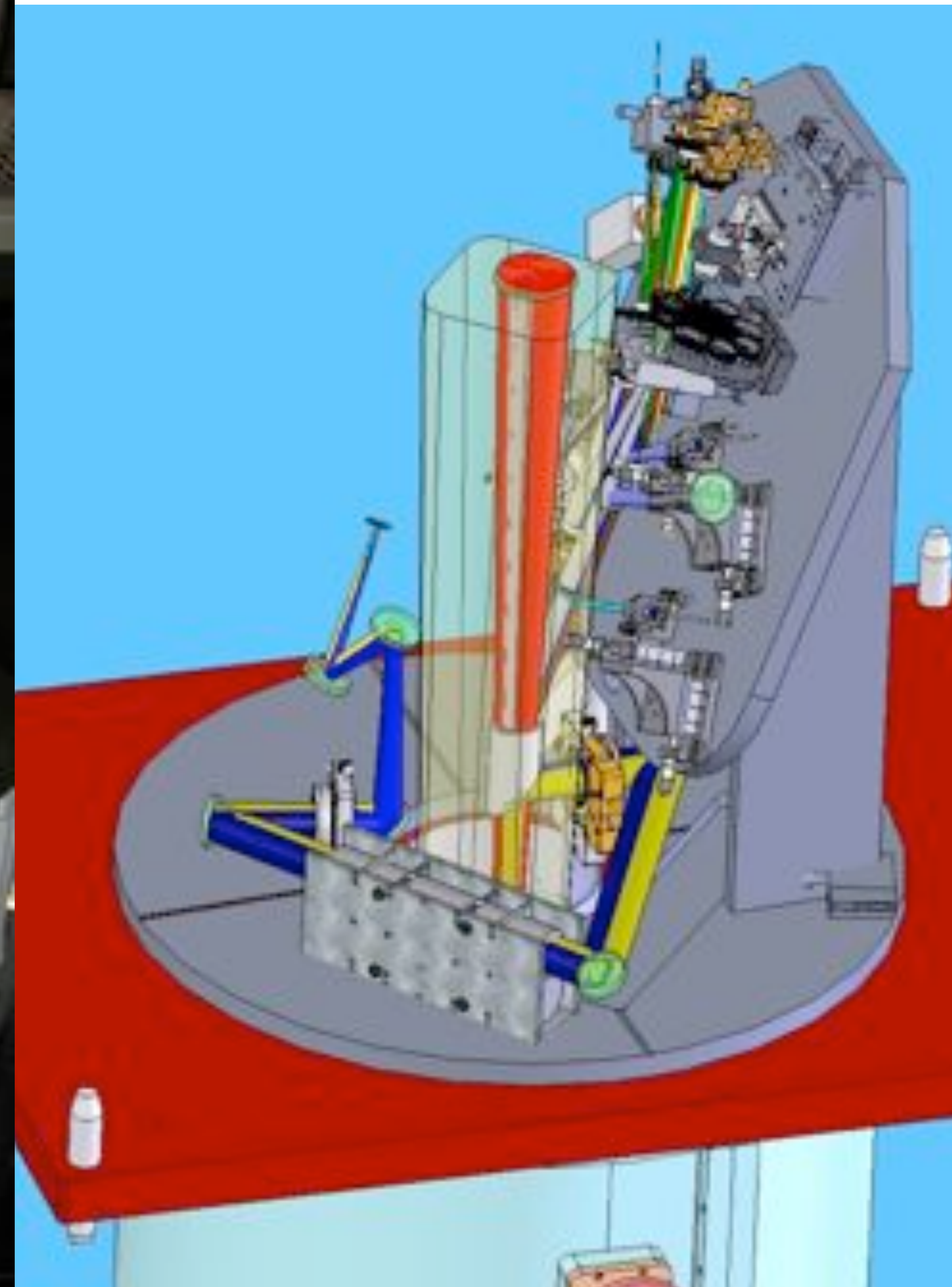
Heterodyning shifts grating response to higher details



Ordinary response $G(\rho) = psf_0(\rho)$

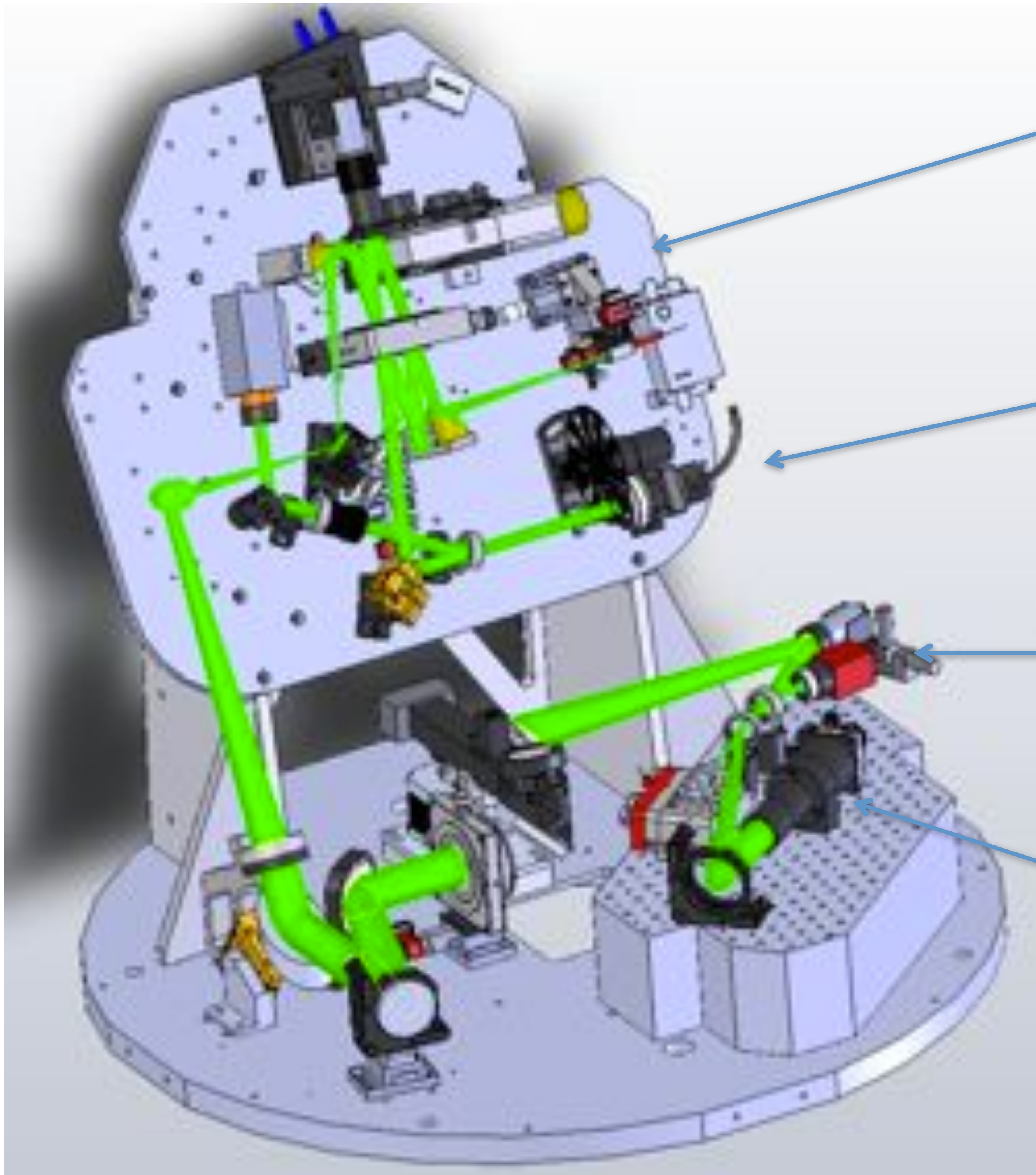
Fringing response $G(\rho) = (1/2)\ psf_0(\rho - \tau)$


TRIPLE-SPEC



First Fringes Dec 30 2007

TEDI: Post 2010 Upgrade



Variable delay interferometer, up to 4cm optical path diff
(Res boost up to 30k)

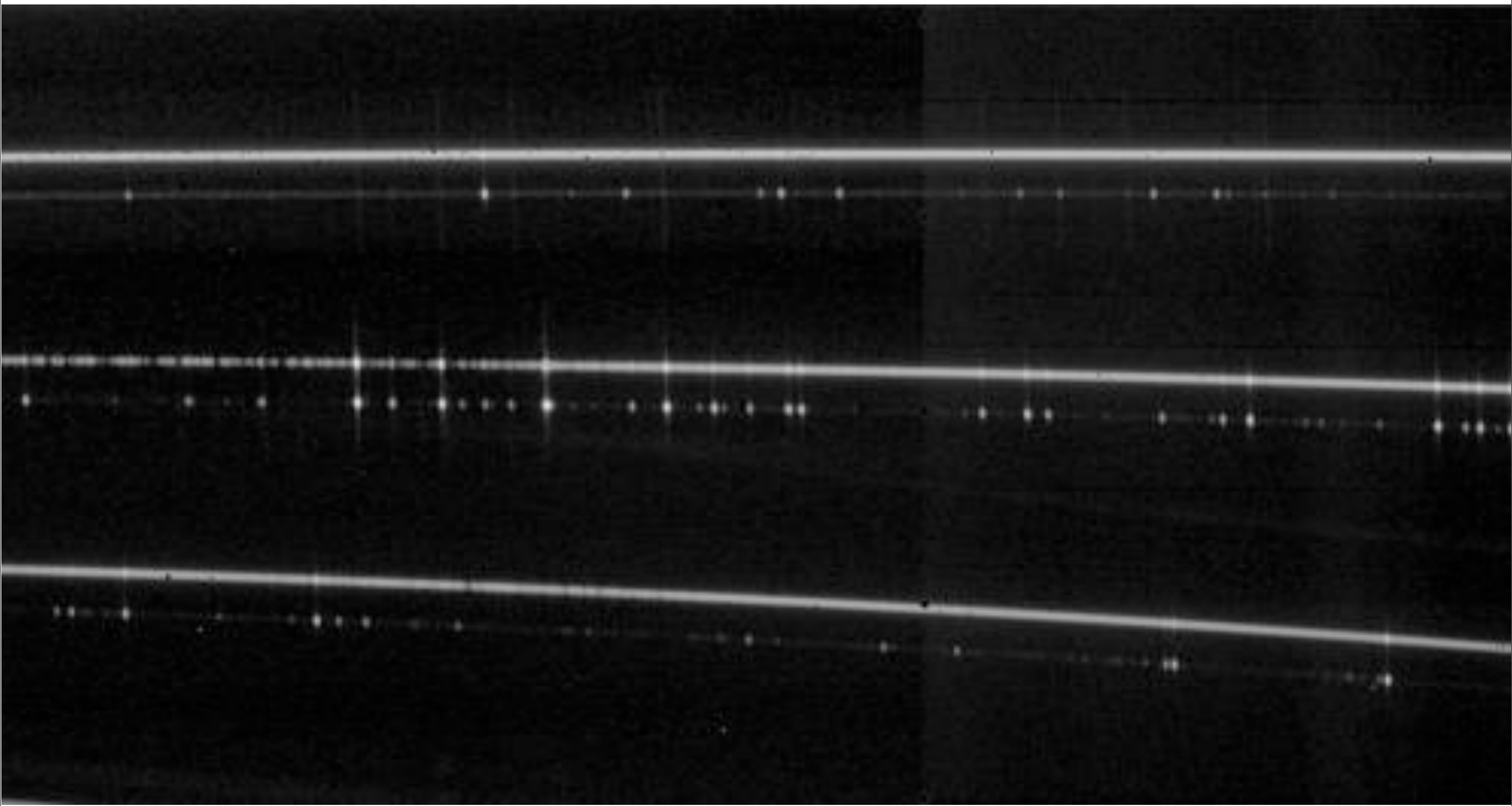
IR throughput monitor actively tracks system throughput

Visible light picked off by dichroic, guiding w/ high speed piezo

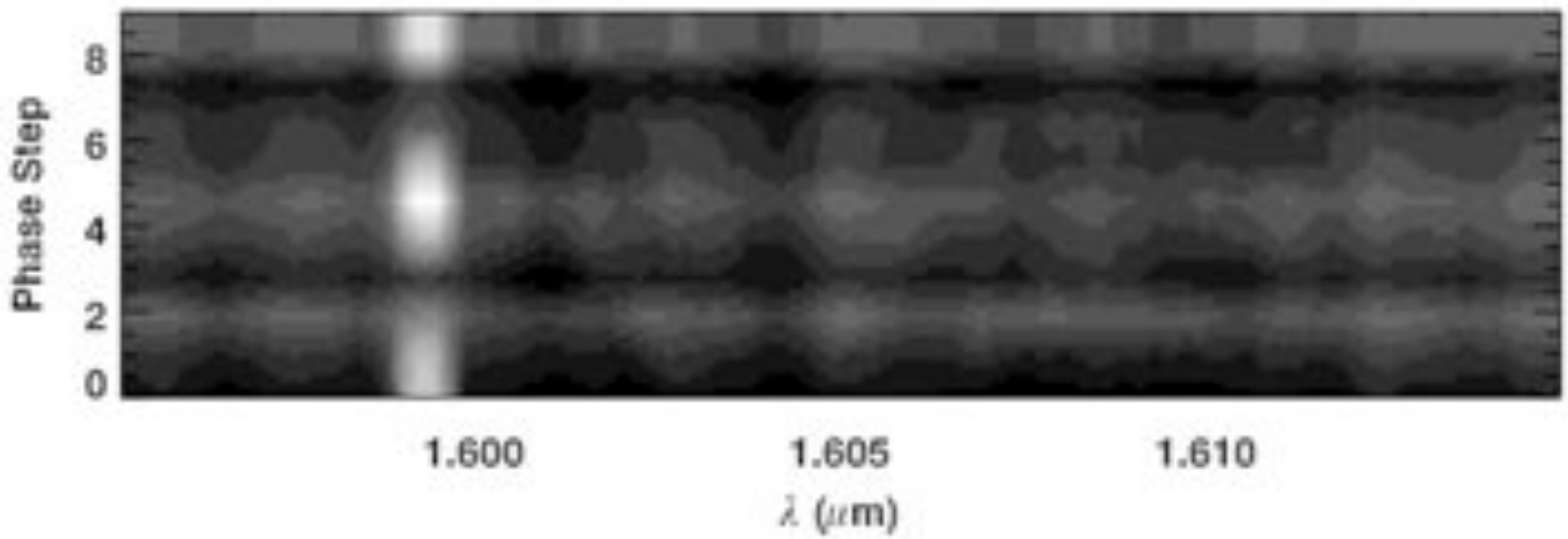
ThAr emission lamp injected into 2 fibers, calibrates interferometer delay/wavelength solution

to spectrograph

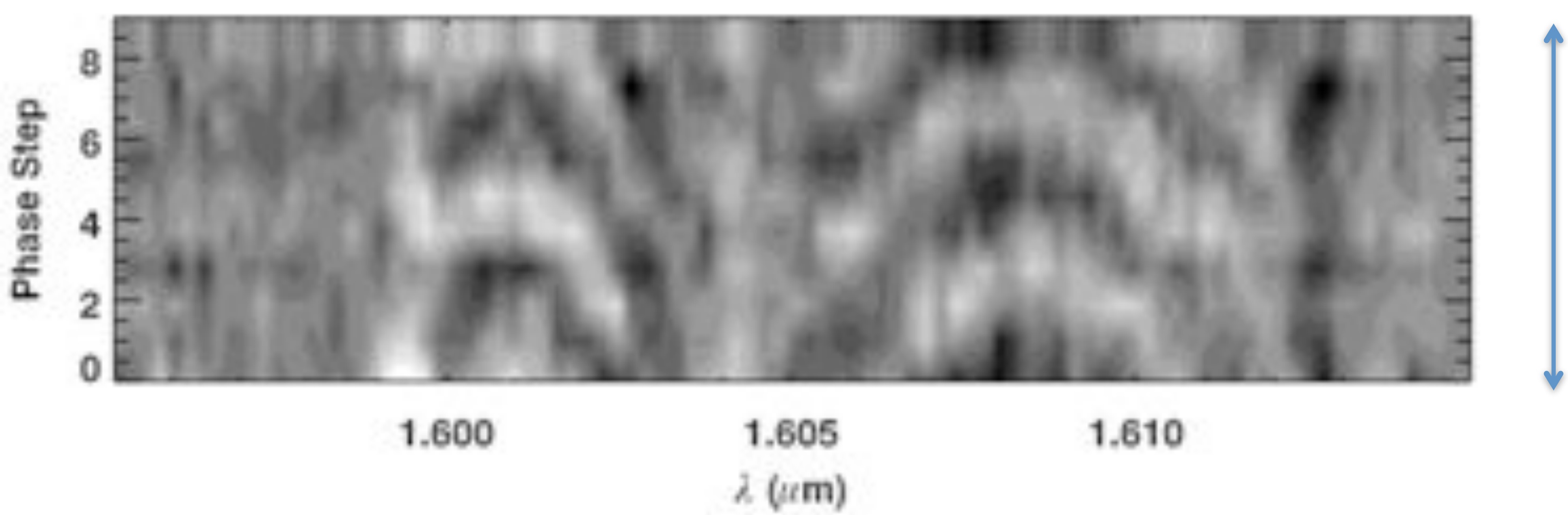
TEDI Data



TEDI Data

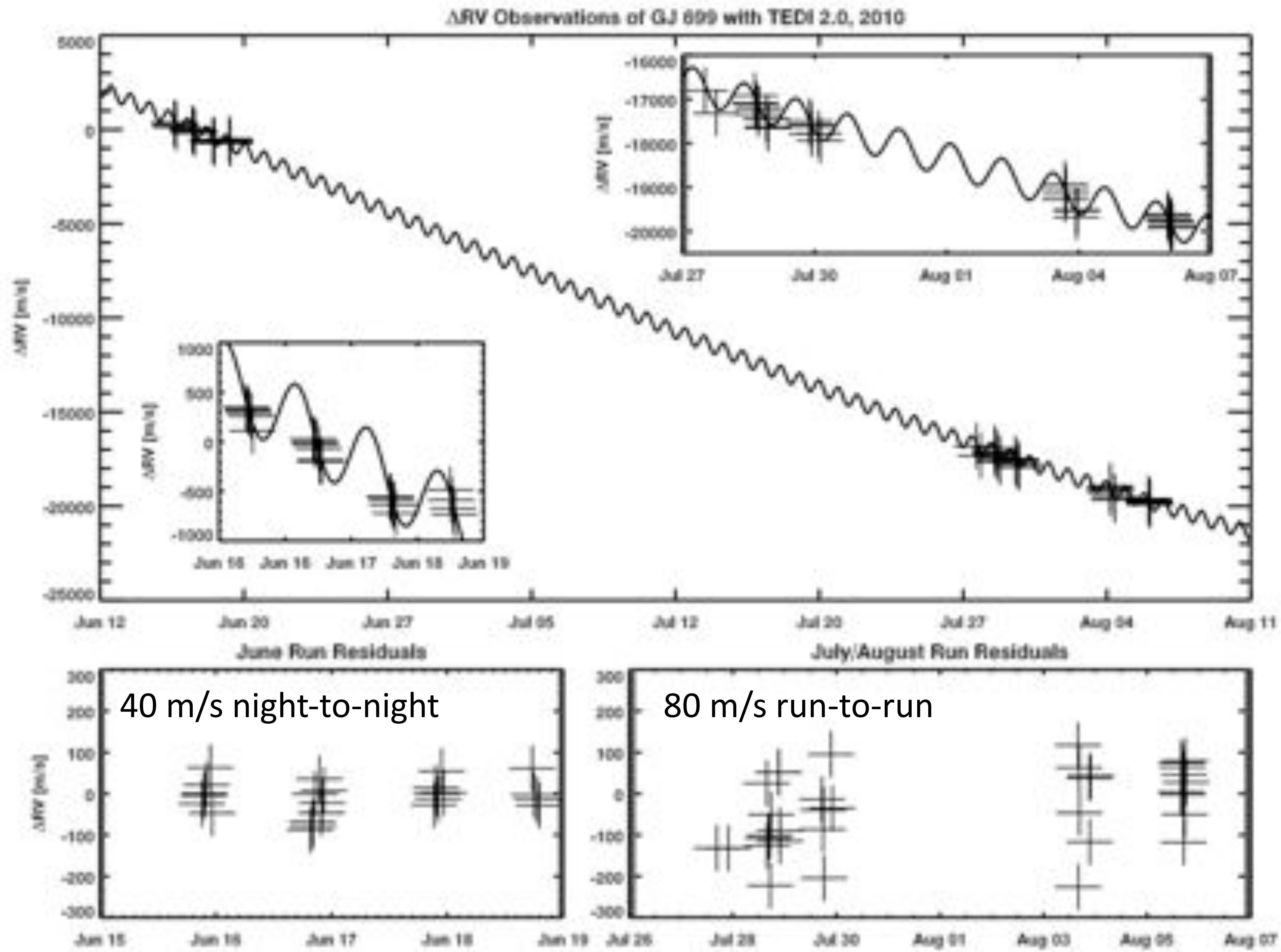


Use ThAr lines to get interferometer delays, then model and remove



Radial Velocity is proportional to shift vs phase

2 Runs with TEDI 2.0



Summary

- Accuracy, not just precision is critical for the M dwarf opportunity
- T-EDI is achieving ~20 ms $^{-1}$ intranight, 40 ms $^{-1}$ night-to-night, 80 ms $^{-1}$ month-to-month precision
- Accuracy is 12 m/s BarnardStar-Hale-decihr$^{-1/2}$
- = 1 philmuirhead $^{-1}$