Near IR Sensors and Precision Radial Velocities

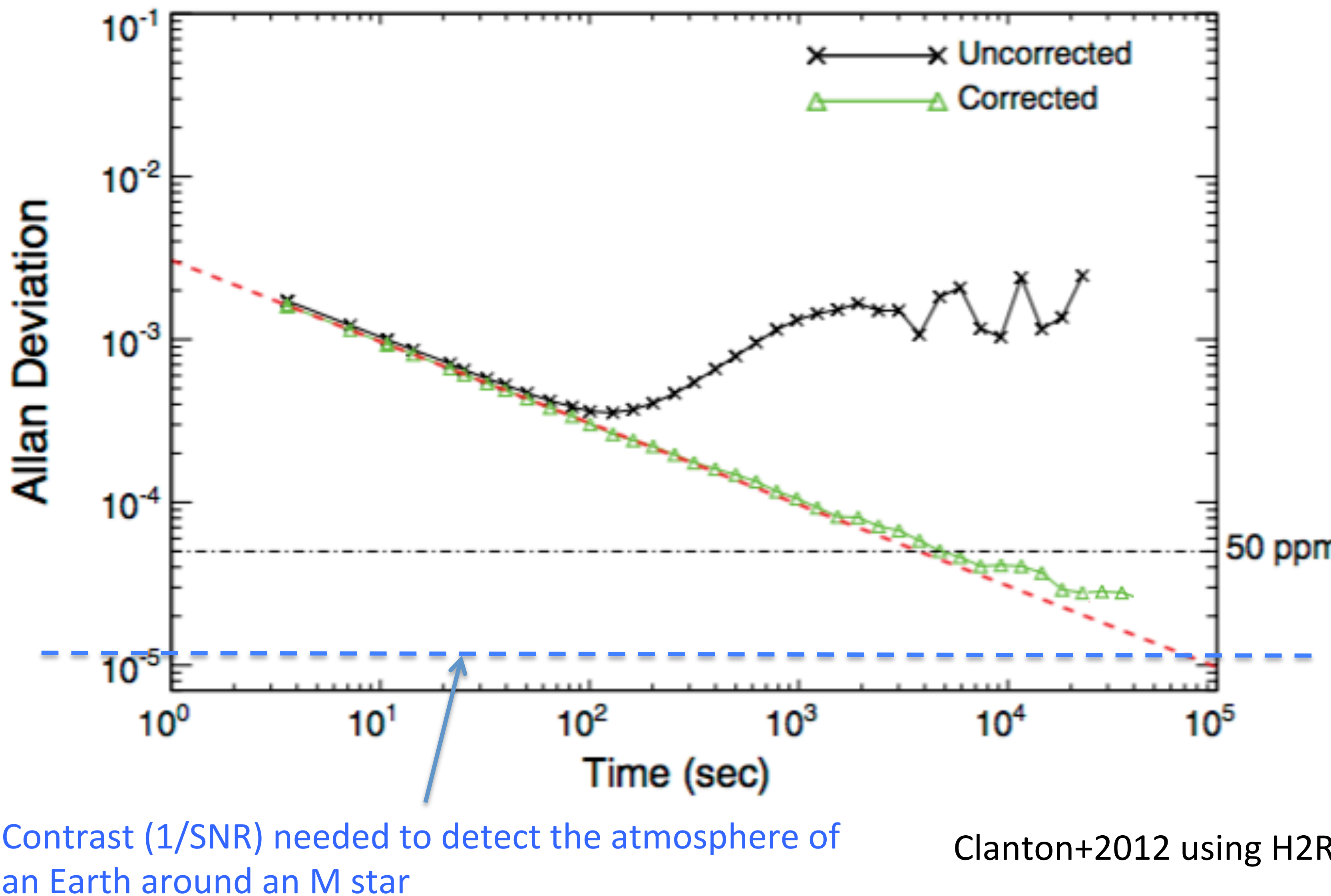
Gautam Vasisht (JPL)

Planets present weak signals

- Planet detection stresses capabilities of instruments and their detectors
  - Transits
  - Imaging
  - Astrometry
  - Radial Velocity

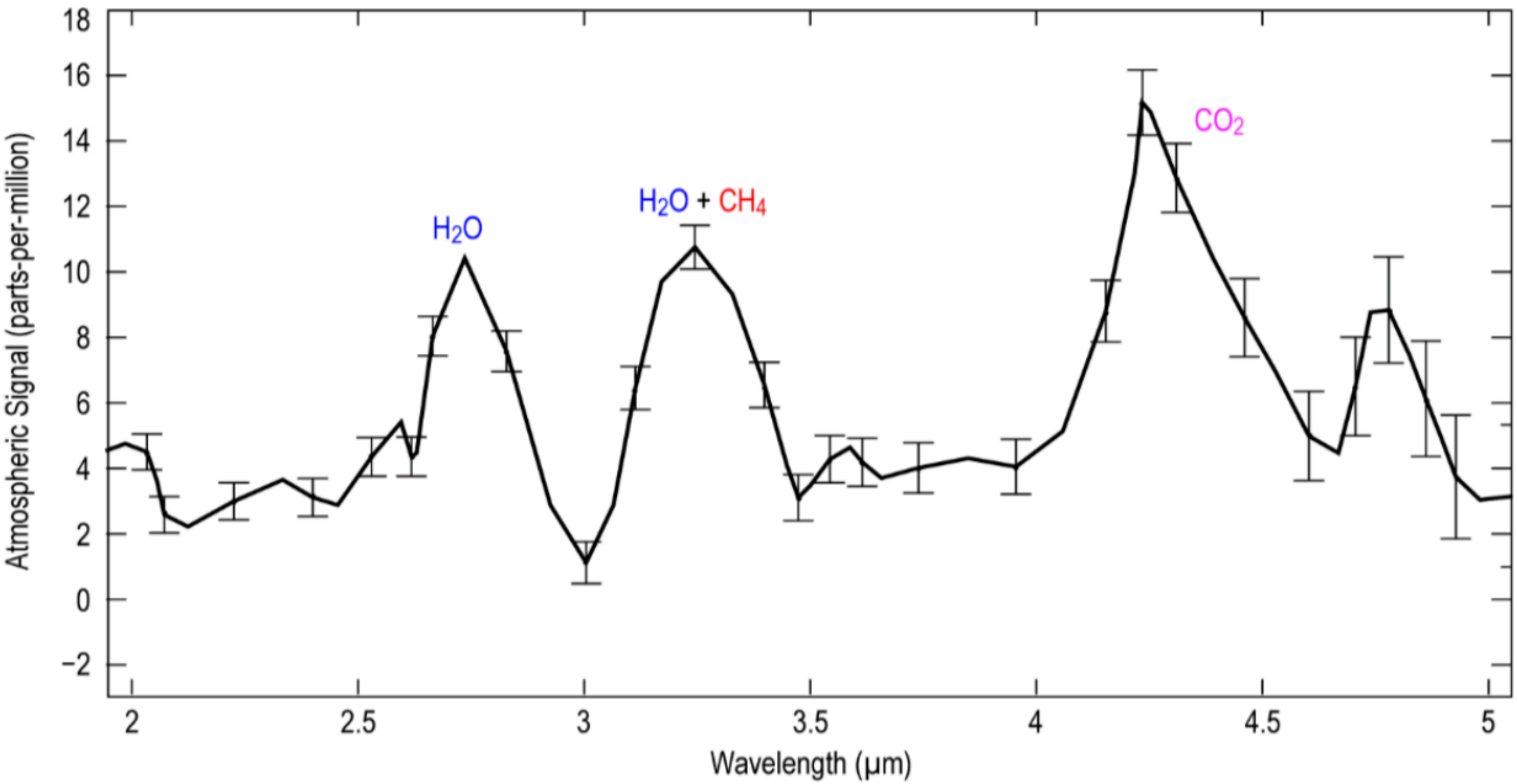
There's definitely a planet hiding under this muck

Transits: How well can we do the photometry?



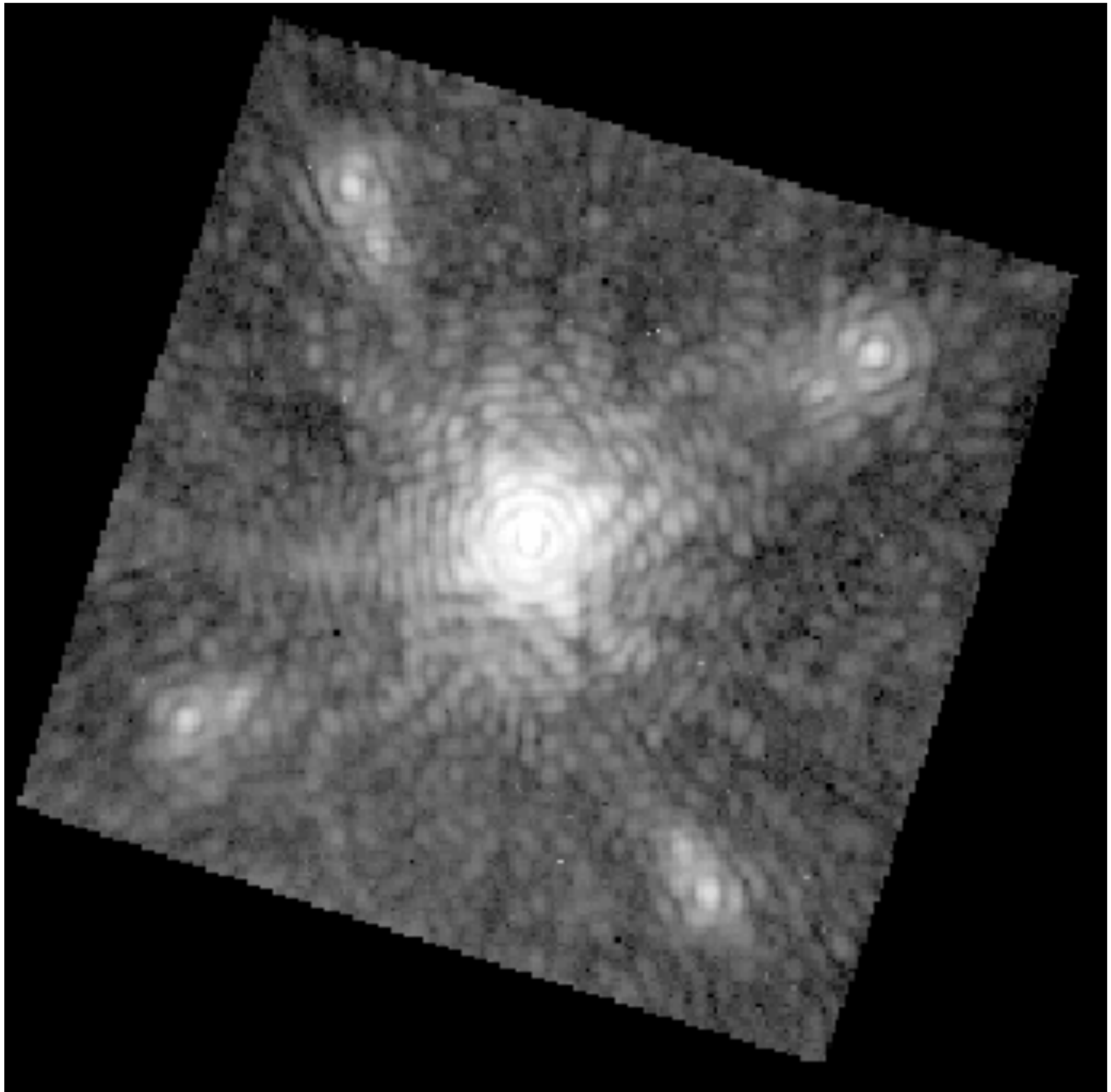
Clanton+2012 using H2RG

Spectroscopy requires 1 ppm



Earth 2.0 orbiting an M4V star Werner+2016 (LUVOIR)

Planet Imaging & PSF Reconstruction



P1640 IFS

Astrometry: measure position of target relative to background stars

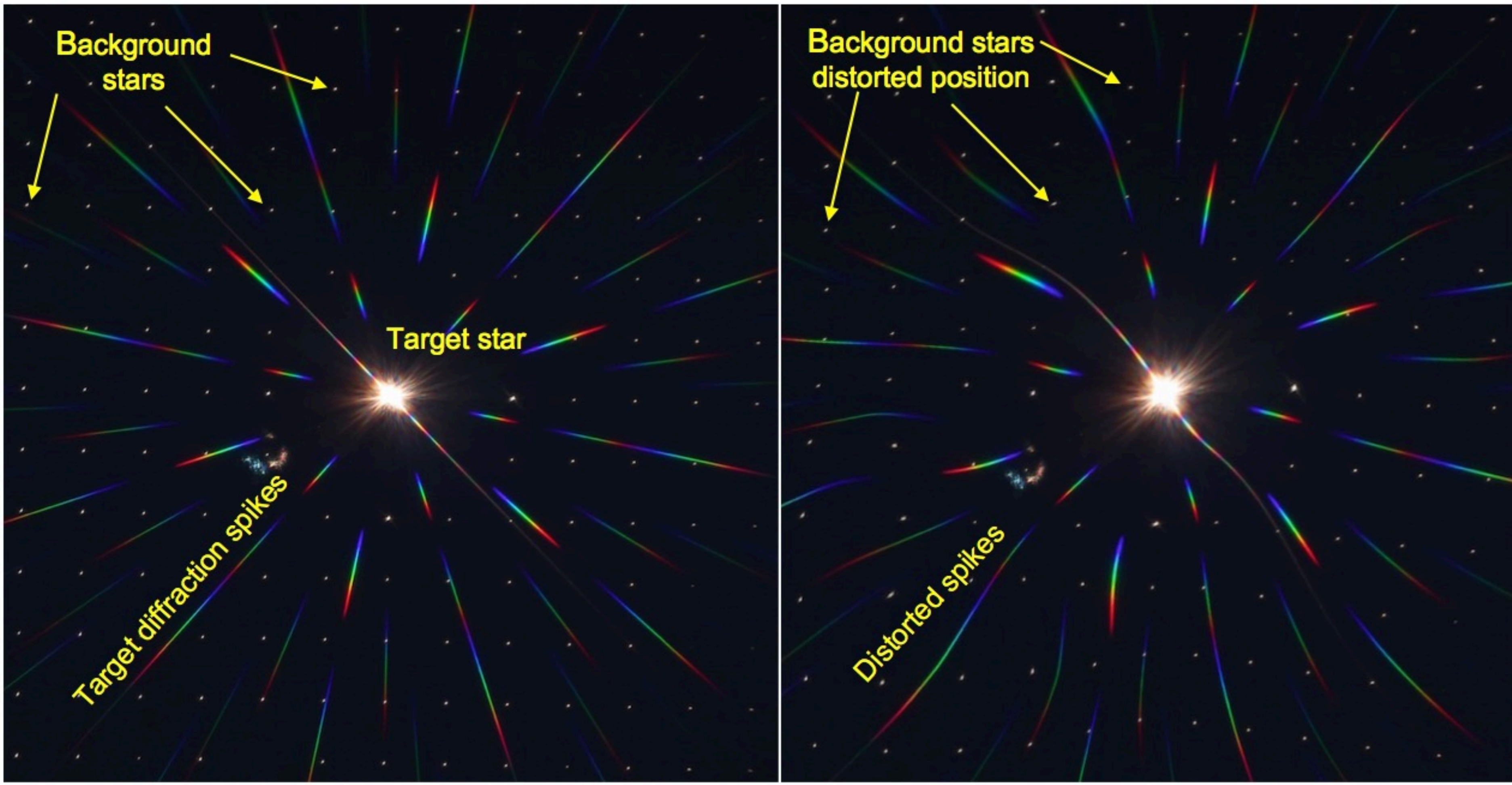
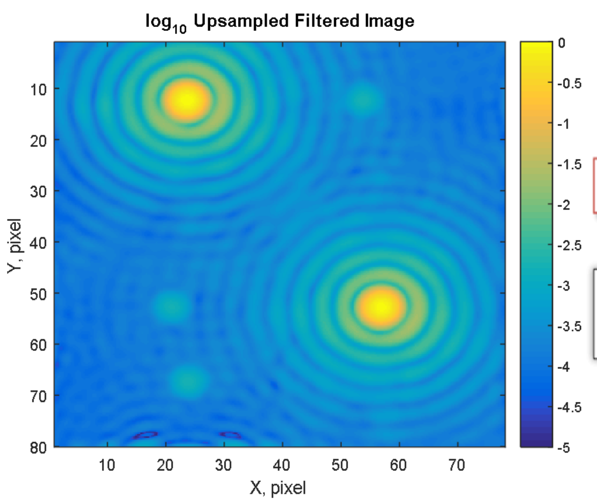
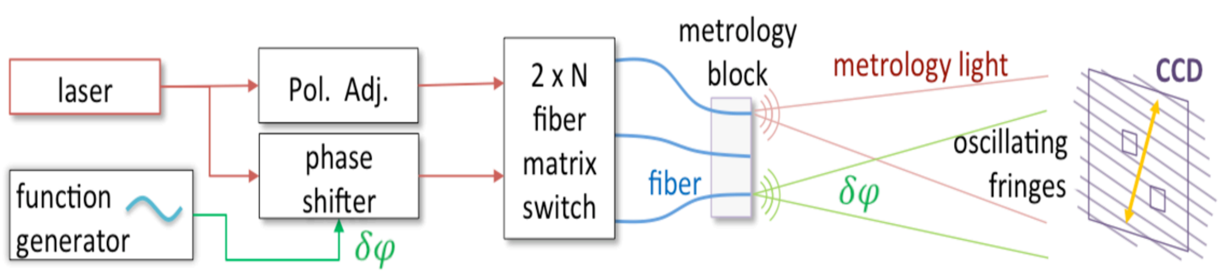
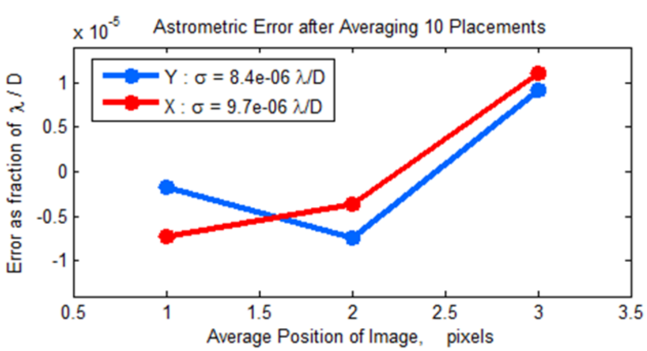


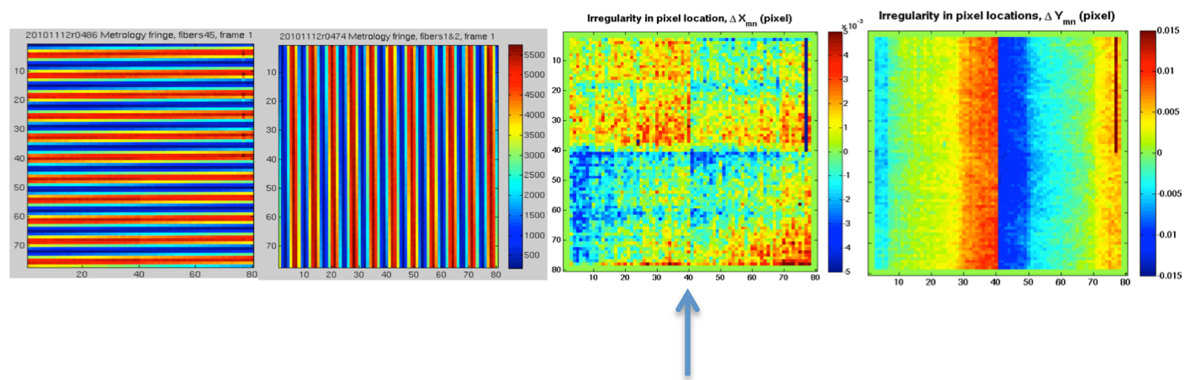
Image: E. Bendek

Narrow Angle Astrometry: Sensor Calibration at JPL



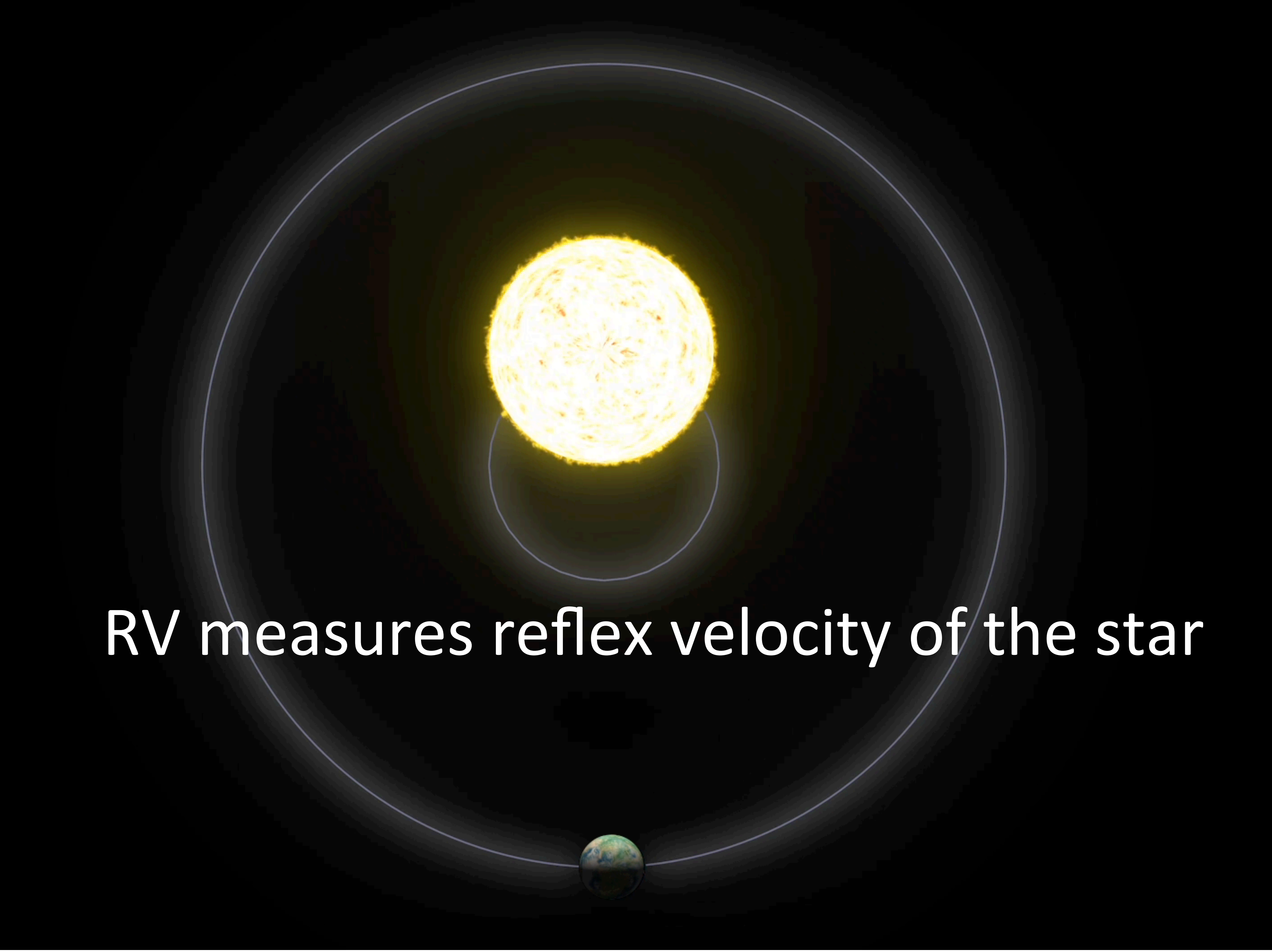




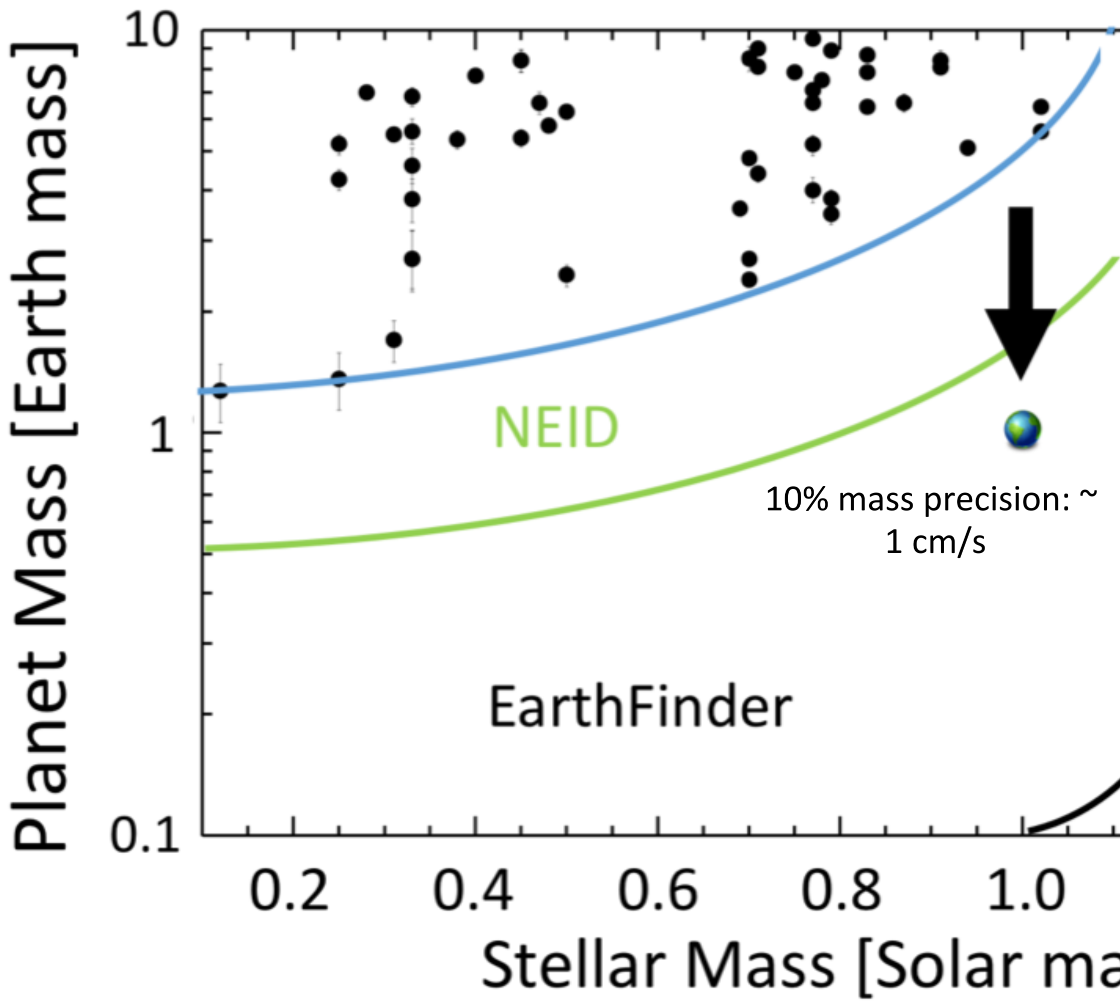


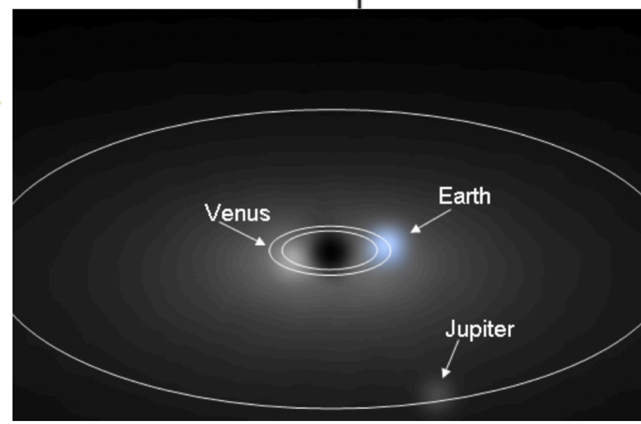
Map of irregularities in pixel location

Image: I. Hahn, C. Zhai


RV measures reflex velocity of the star

Discovery, mass and orbit characterization of planets. The ultimate prize is to find Earth-mass exoplanets orbiting nearby Sun-like stars





For a future flagship direct imaging mission, will we know a priori where and when to look? Either way, we still need mass for characterization!

Plavchan+2018

10 cm/s is a small shift in the focal plane

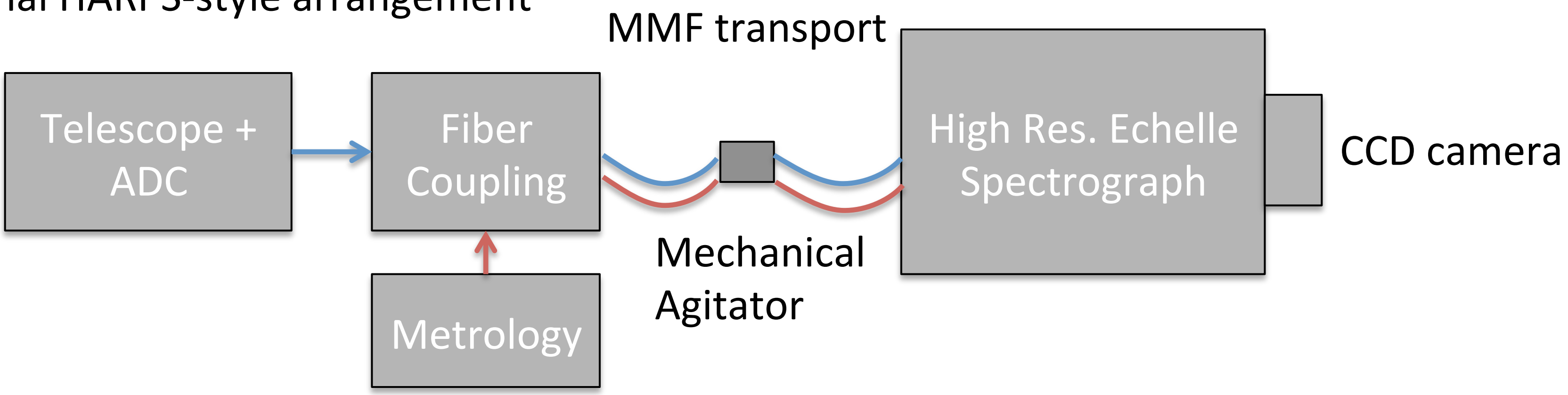
- Centroid to a fraction ~10^{-5} of a line width
- In a R=100,000 spectrograph with 3 pixel sampling:
  - 1 km/s = 1 pixel
  - 10 cm/s = 10^{-4} pixel = 18 Å
  - HgCdTe lattice block = ~7 Å

Worrying effects in HxRGs

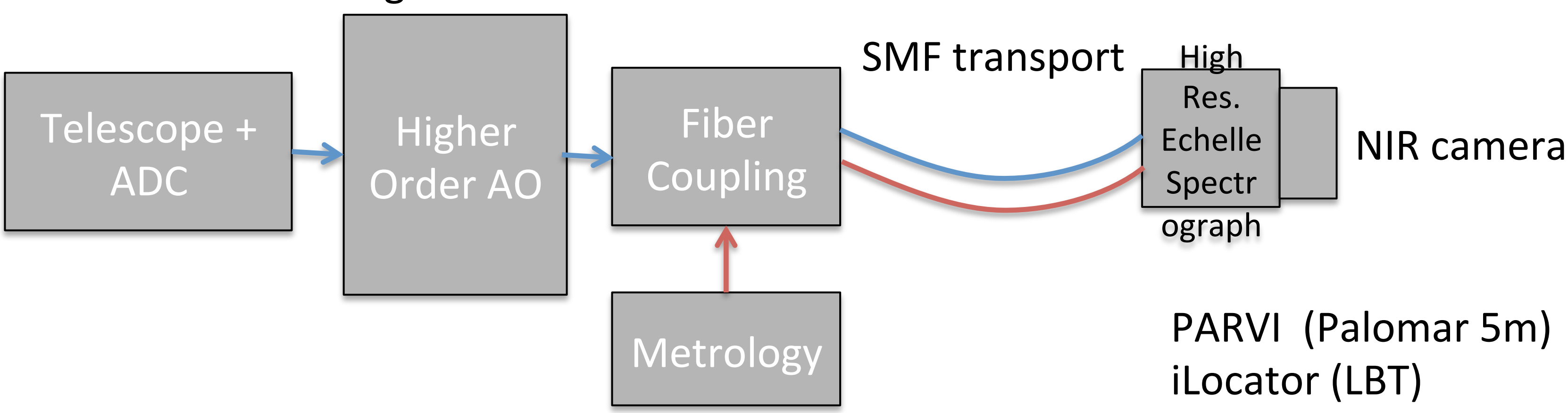
- Strange pixels
  - Get good at identifying and masking these pixels
- Pixel response function
  - QE, higher moments, pixel locations
- Non-linearity related changes PSF size
- Variable inter-pixel capacitance
  - Part of PSF for signal only
- Image memory

Two kinds of RV spectrographs

Traditional HARPS-style arrangement

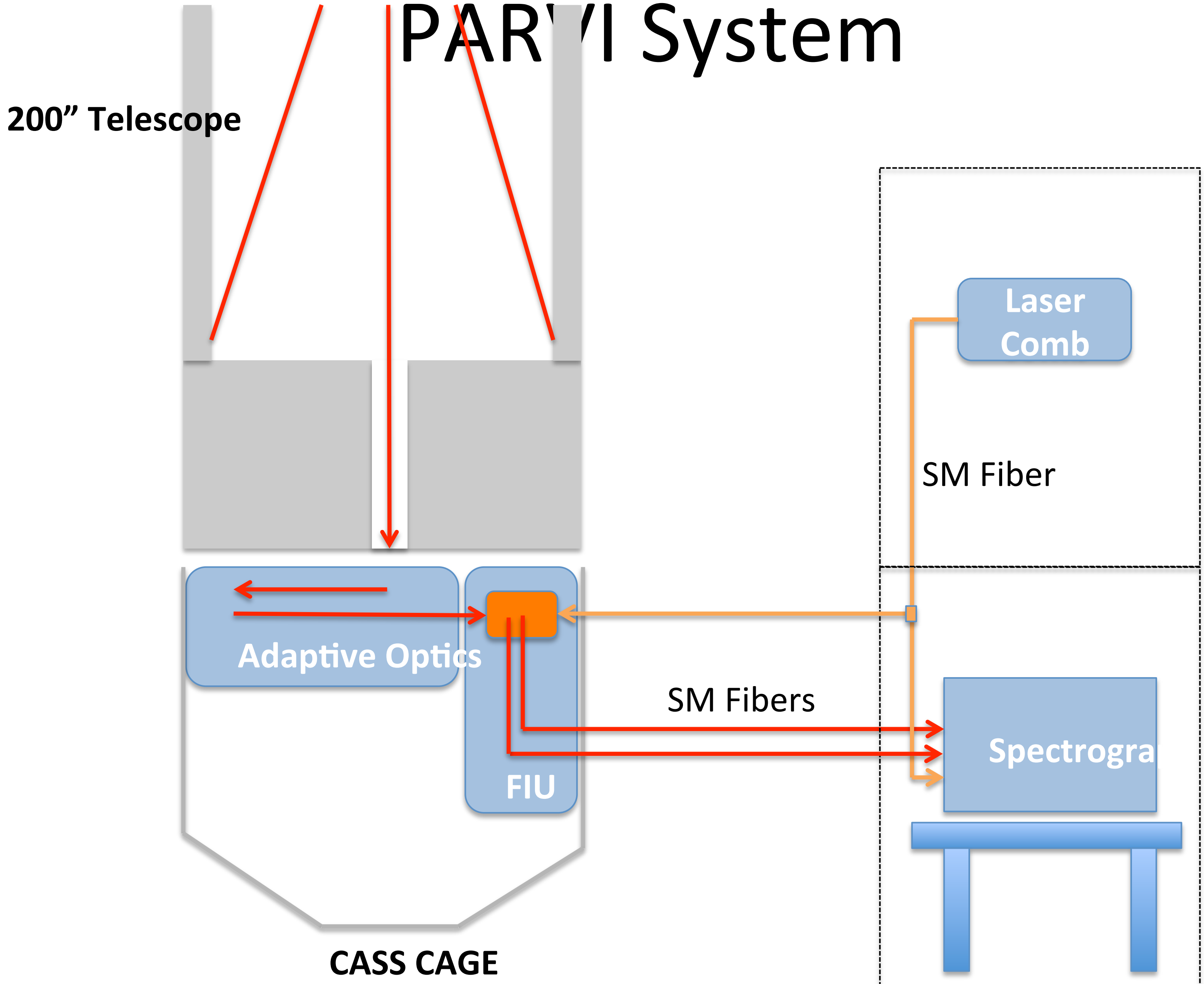


Diffraction-limited design with AO

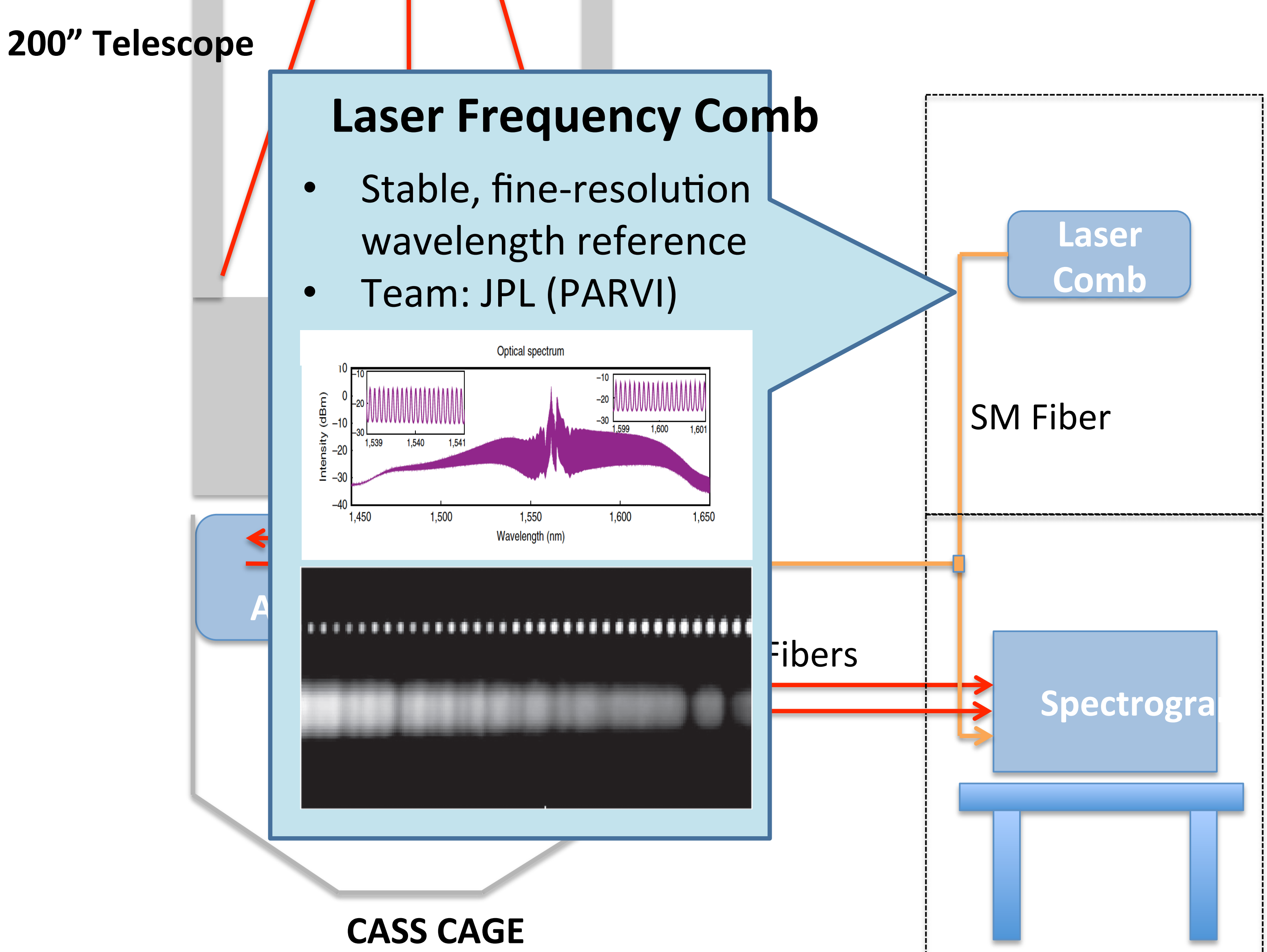


PARVI (Palomar 5m)
iLocator (LBT)
HISPEC (Keck)

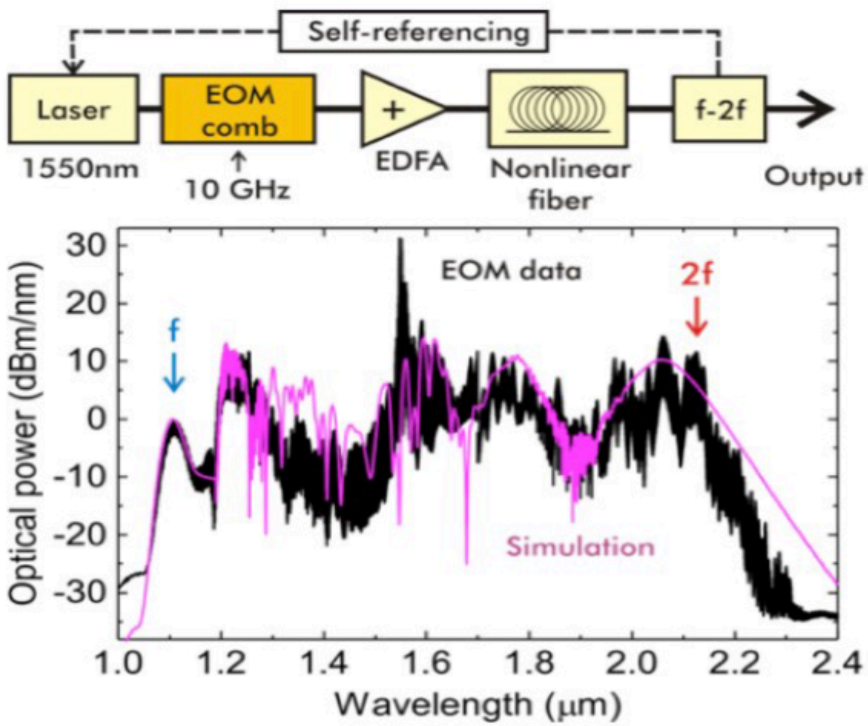
PARVI System

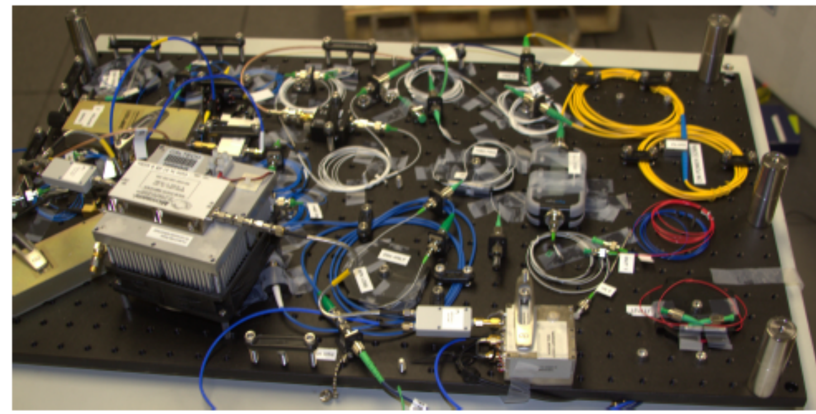


PARVI System



PARVI-OFC

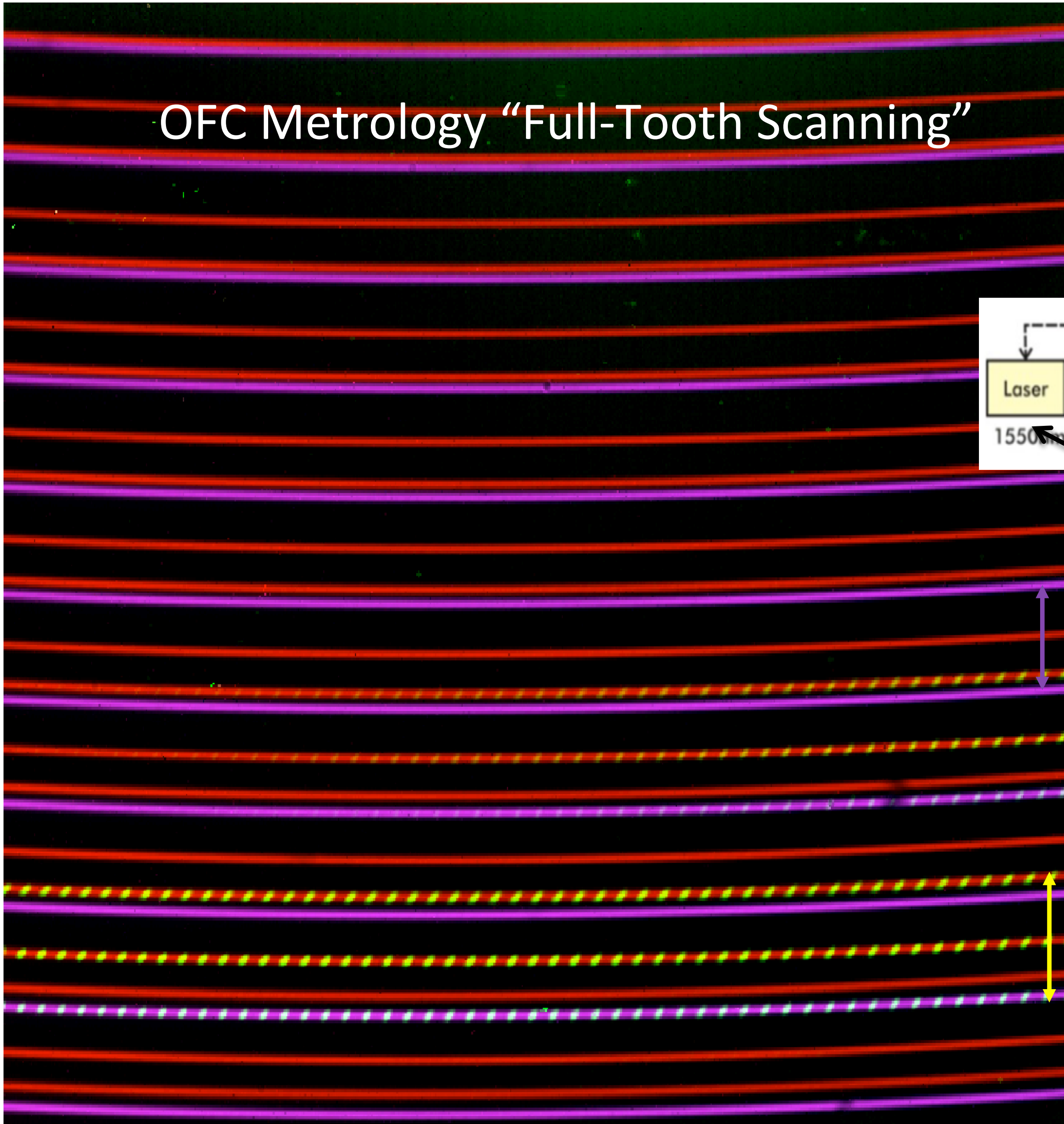




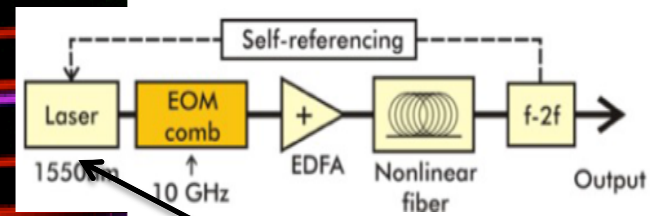
PARVI OFC jumble

PARVI uses an EOM comb with a highly non-linear fiber for "octave spanning" to enable *f-2f* self-referencing.

OFC Metrology "Full-Tooth Scanning"



Yellow (LFC) = Channel to Channel Spacing
PURPLE (Continuum) = Order to Order Spacing
RED (Continuum) = All Traces



Modulate 10 GHz

Order to Order Spacing

Channel to Channel Spacing

PARVI Instrument Error Budget

Instrumental Error (Uncalibratable)	17.2

Fiber & Illumination	5.0
Calibration source modal noise	0
Continuum modal noise	0
Near-field scrambling	0
Far-field scrambling	0
Stray light and ghosts	3
Polarization	4
Focal ratio degradation (science)	0
Focal ratio degradation (calibration)	0
Double scrambler mechanical drift	0
Fiber Fiber contamination	0
Reformater drift	0

Detector effects	15.4
Latent images	10
Pixel inhomogeneity/Non-linearity	10
Interpixel capacitance	6

Barycenter correction	3.3
Algorithms	1
Exposure midpoint time	3
PSF variation	1
Coordinates and proper motion	0

Reduction pipeline	5.0
Software algorithms	5

Instrumental Error (Calibratable)	31.4
Calibratable Error Contribution	4.7

Thermal-Mechanical	29.6
Thermal stability (grating)	9
Thermal stability (cross-disperser)	15
Thermal stability (bench)	12
Thermal stability (camera)	8
Optical elements (tilt)	10
Vibrational stability	2
Pressure stability	5
LN2 fill transient	15
Zerodur phase change	1
Optical elements (focus)	3

Detector effects	10.5
Pixel inhomogeneity	10
Electronic noise	1
Pixel location error	0
Detector thermal expansion	3
Readout themal transients	0
CTE	0

Total Instrumental Error 18.7 cm/s

Calibration Source (Uncalibratable)	5.4

Calibration Source (uncalibratable)	3.6
Wavelength stability	3
Photon noise	2

Calibration process	4.0
Software algorithms	4

External Error (Uncalibratable)	0.0

Telescope	0.0
Guiding errors	0
Atmospheric Dispersion Corr.	0
Focus	0
Windshake	0

General Parameter	Value
Calibration factor	0.85
On sky fiber diameter (")	0.06
Instr. Resolution	100000
Number of science slices	1

After calibration of thermal mechanical effects with the OFC metrology, the error-budgets are dominated by the HxRG

EarthFinder: EPRV from space

NASA has funded the Astrophysics Probe Study (< $ 1B); Plavchan et al.

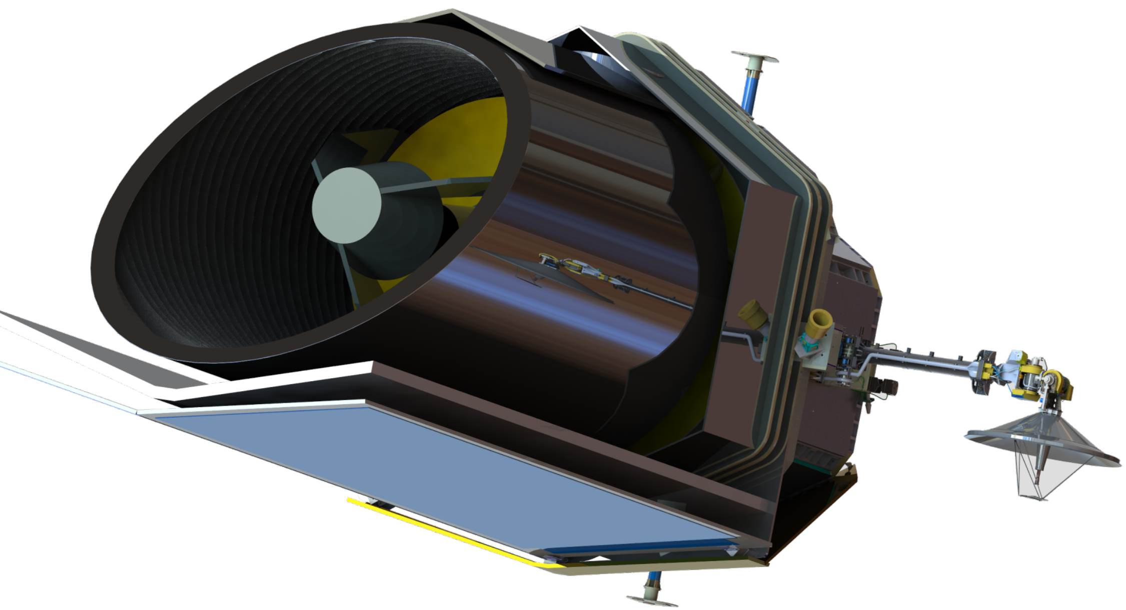


Image credit: Ball Aerospace

Payload

1.5 m telescope

Optical Spectrograph (R ~150,000)
Near IR Spectrograph (R ~ 150,000)
Near UV Spectrograph (R = 200, 4000)

L2 Orbit, 5 year mission

Survey 70 stars for Earth mass planets

Why Space? Tellurics: Atmospheric lines

From the ground, may introduce RV errors up to ~10 cm/s in the visible, & up to ~1 m/s in the NIR

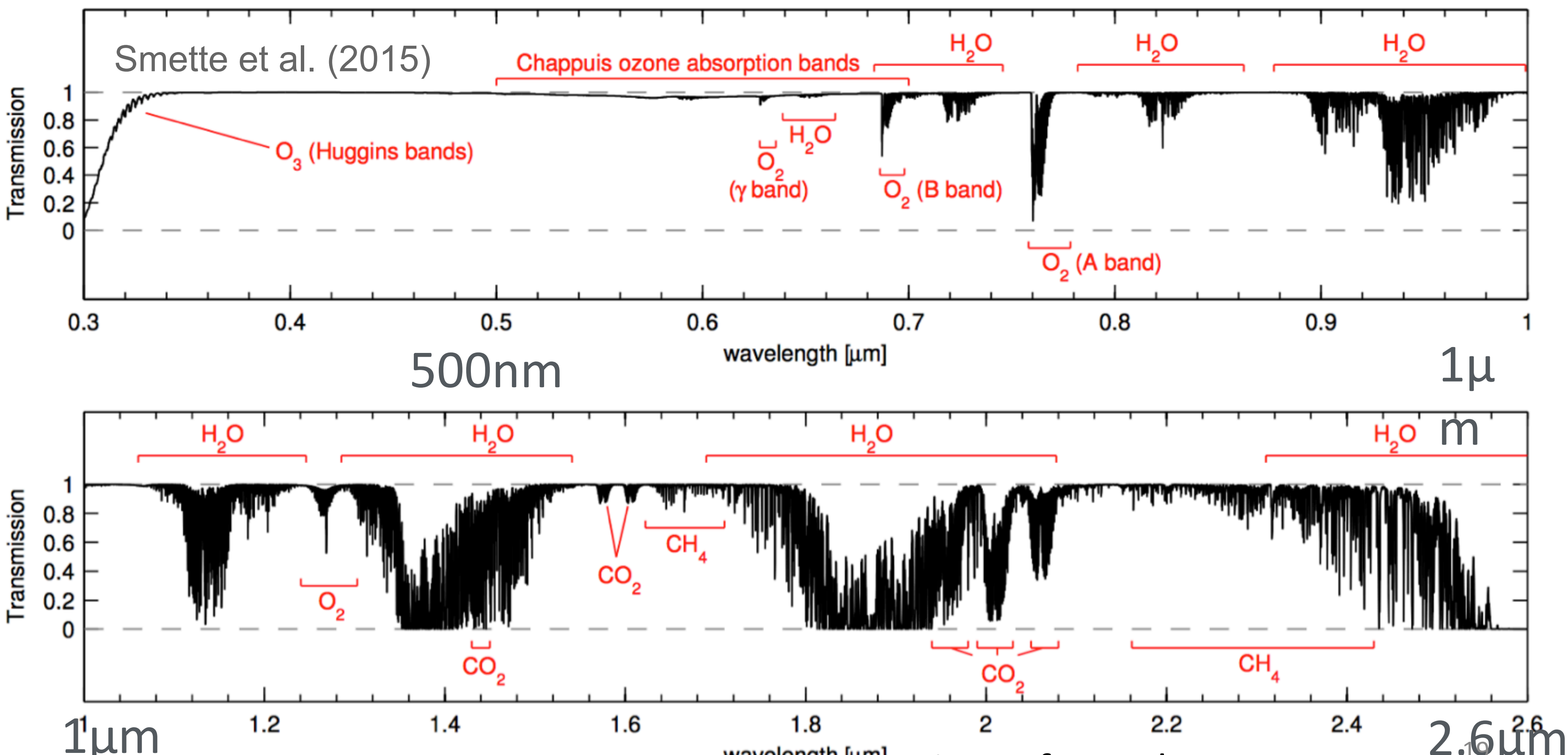
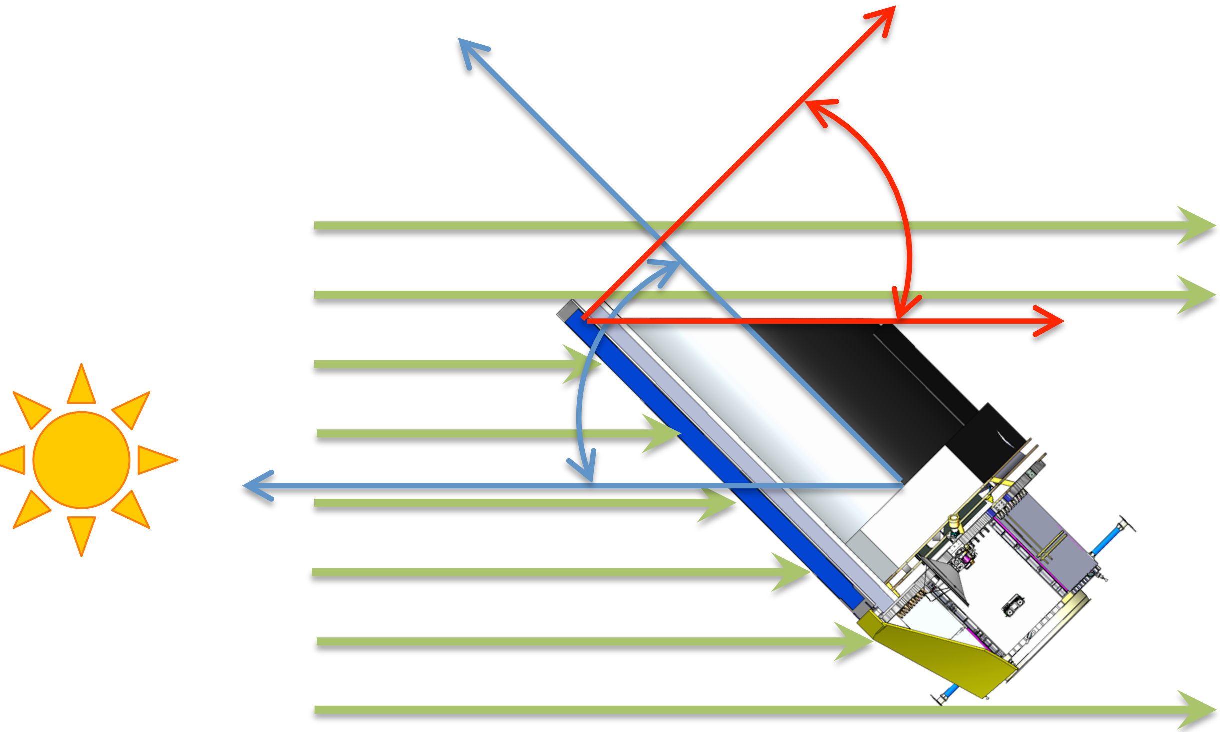
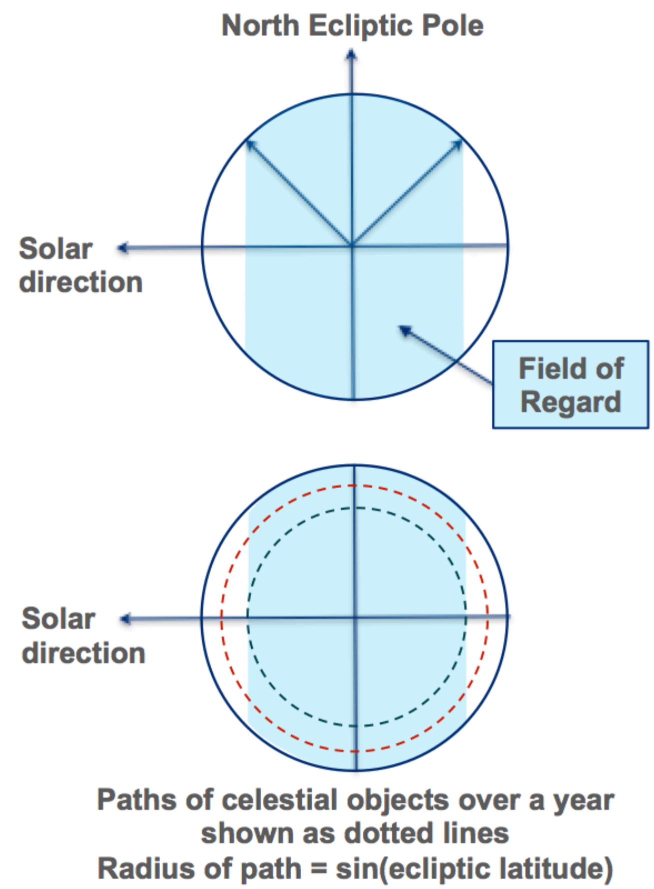


Figure from Sharon Wang

Why Space?
Cadence from L2 orbit





- Targets > 45° out of ecliptic plane are available all year
  - 70.7 % of celestial sphere
- Targets < 45 degrees out of ecliptic plane have two observing seasons
  - 90 days < season < 180 days

Credit: Ball Aerospace

Stellar Activity

Approaches under exploration for activity mitigation are all available from space:

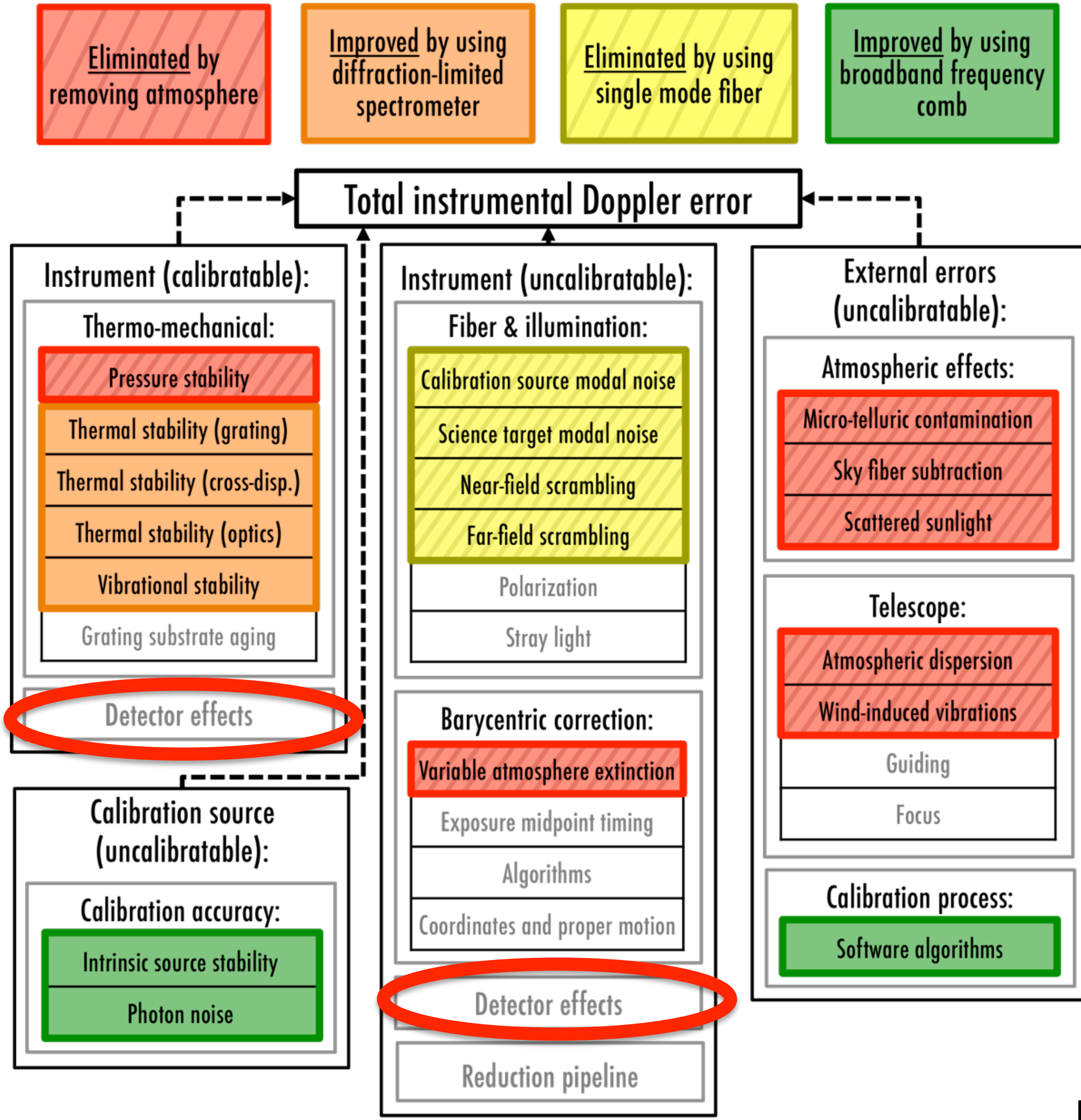
Cadence

Wavelength coverage

R~200k resolution

Line-by-line analysis

Simultaneous photometry



Many errors are eliminated or heavily improved by going into space

But the remaining errors are dominated by the CCDs and H4RGs !!

Based on Halverson+2016

Thanks