NASA's Work in Exoplanet Hunting Satellites and Robotic Servicing of Satellites

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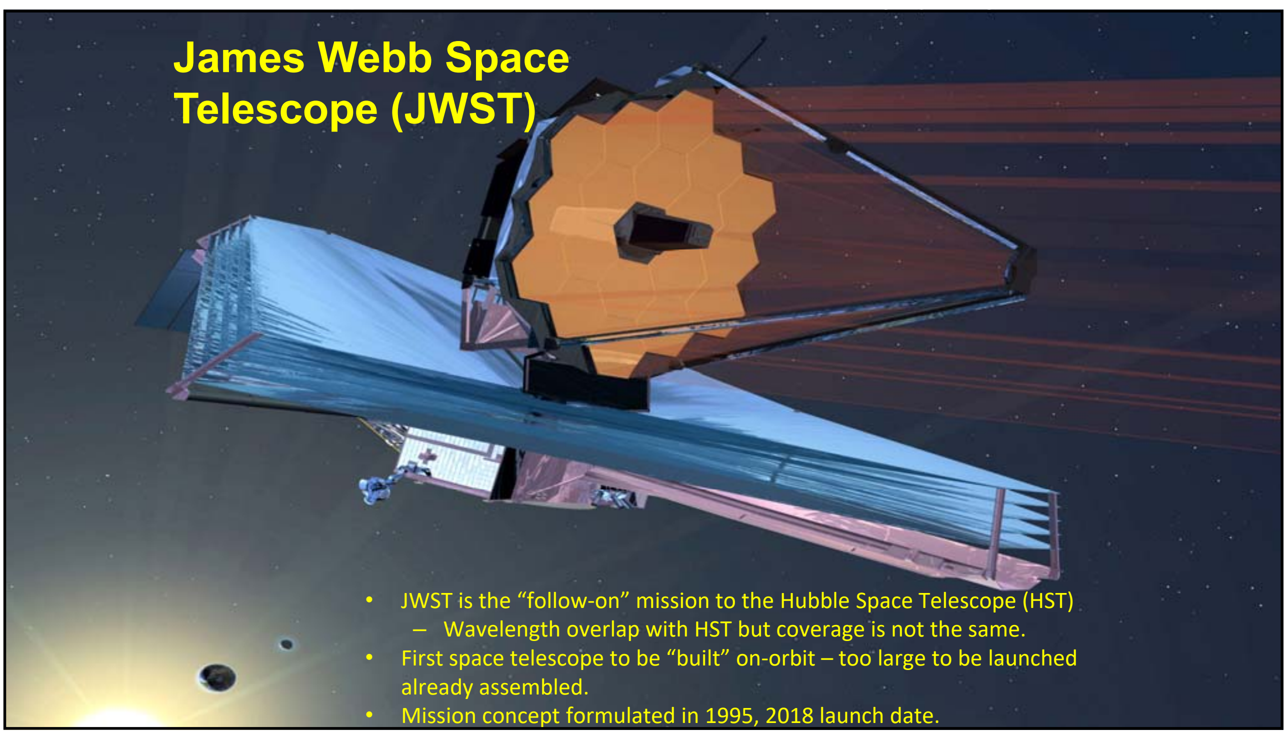
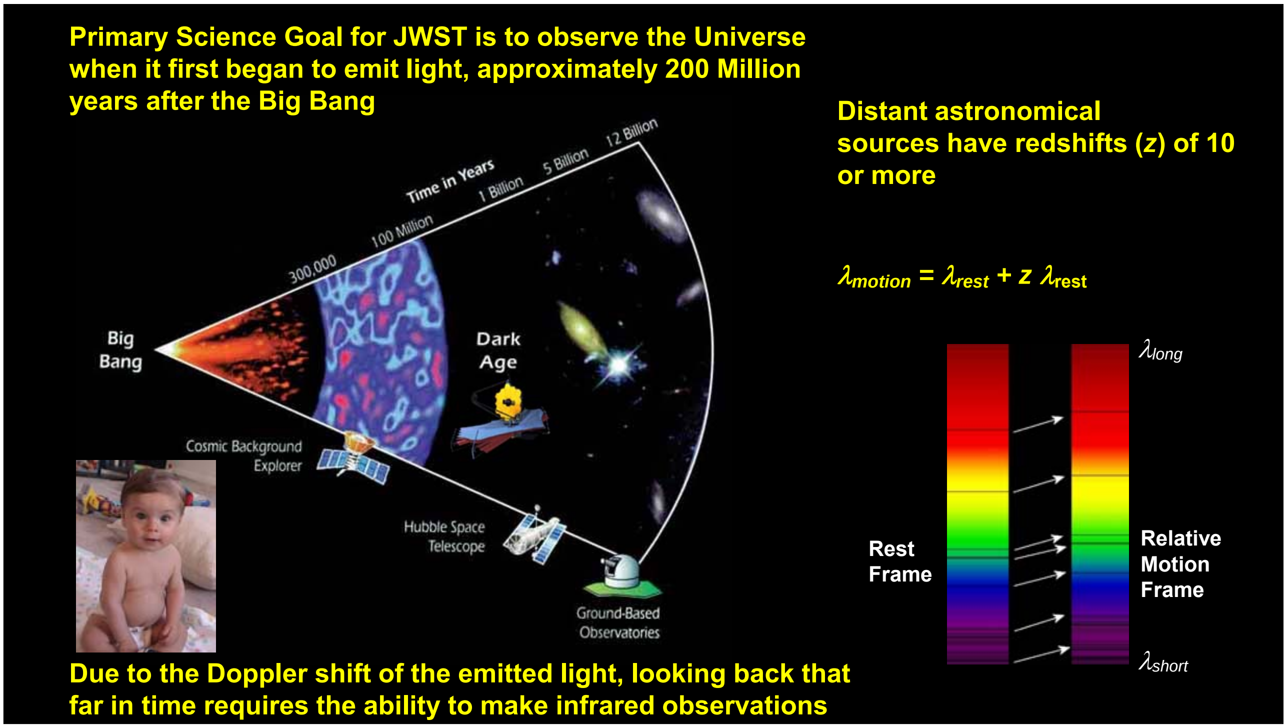
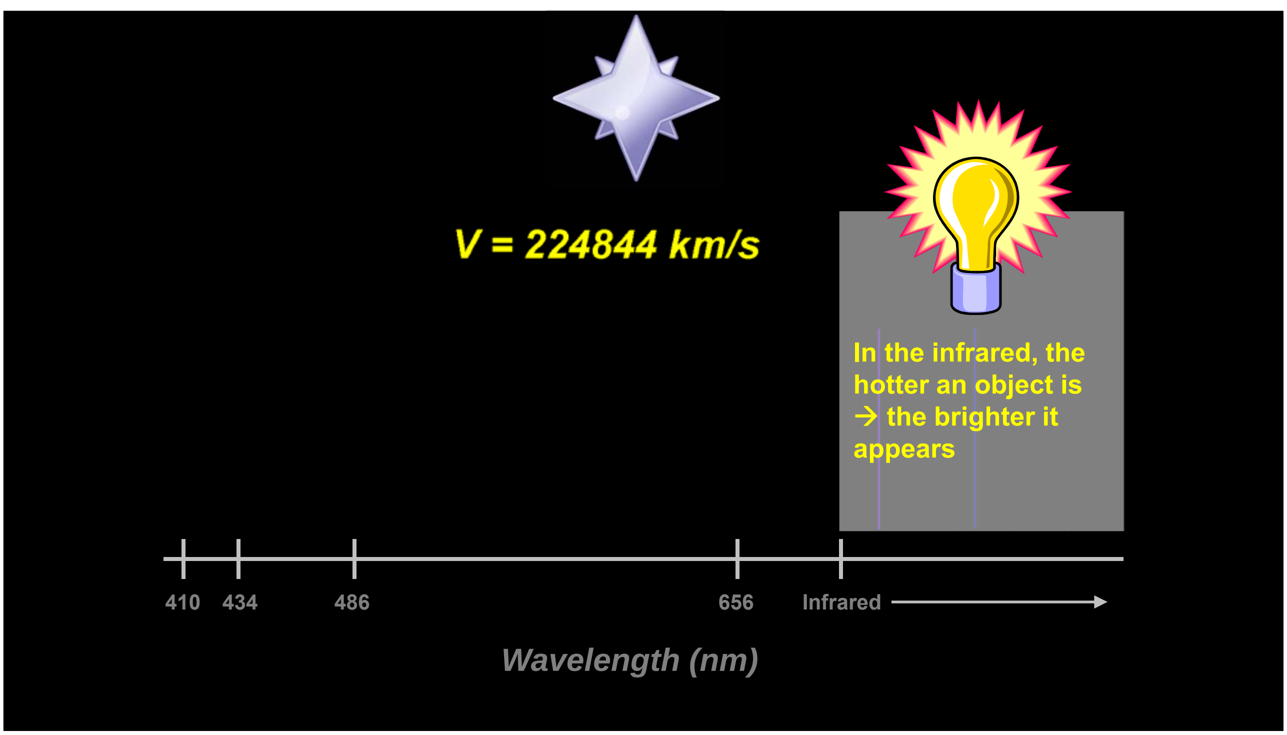
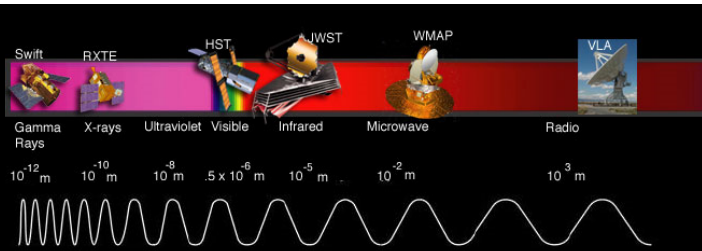
NASA Goddard Space Flight Center
March 26^{th} 2019

Ramapo College of New Jersey



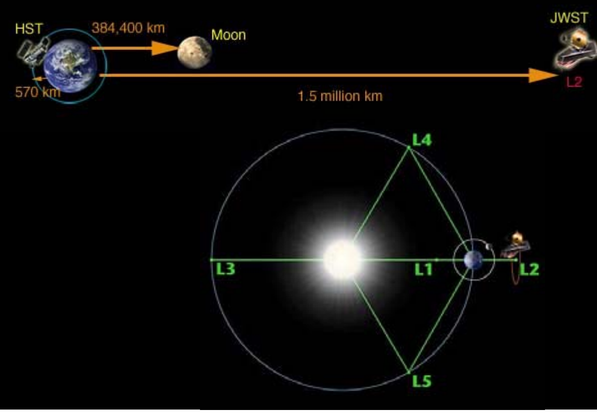

Primary Science Goal for JWST is to observe the Universe when it first began to emit light, approximately 200 Million years after the Big Bang
Time in Years
300,000
100 Million
1 Billion
5 Billion
12 Billion
Big Bang
Dark Age
Cosmic Background Explorer
Hubble Space Telescope
Ground-Based Observatories
Distant astronomical sources have redshifts (z) of 10 or more
$\lambda_{motion} = \lambda_{rest} + z\,\lambda_{rest}$
λ_{long}
Rest Frame
Relative Motion Frame
λ_{short}
Due to the Doppler shift of the emitted light, looking back that far in time requires the ability to make infrared observations


V = 224844 km/s
In the infrared, the hotter an object is → the brighter it appears
410
434
486
656
Infrared
Wavelength (nm)

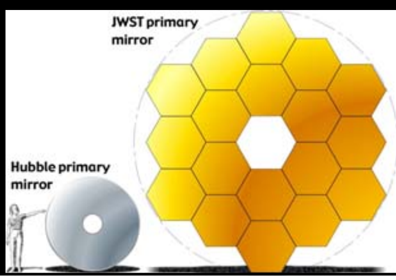


JWST covers the EM Spectrum from 0.6 to 25 μm

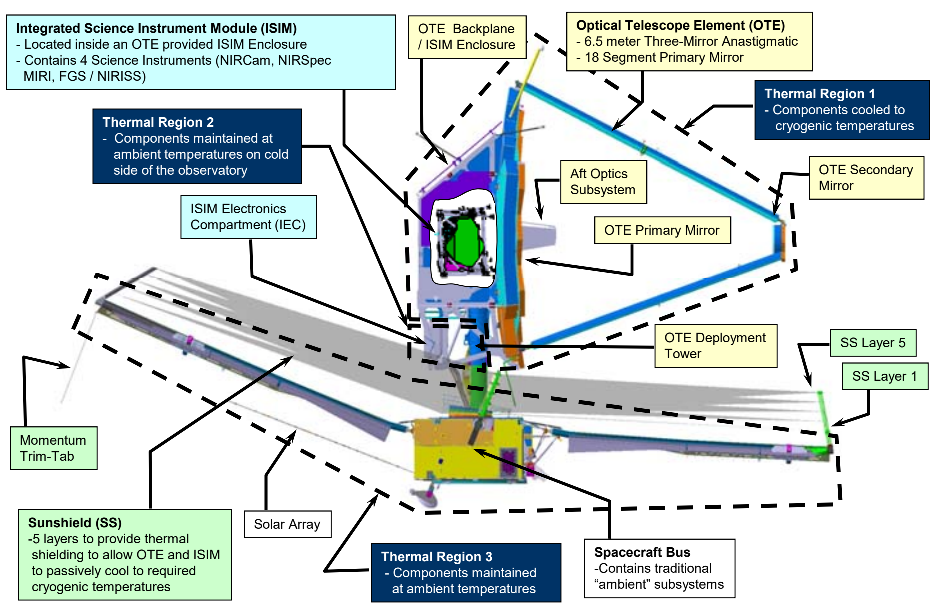
JWST orbits about the L2 point of the Earth-Sun System so that it can be passively cooled to 30-40 K



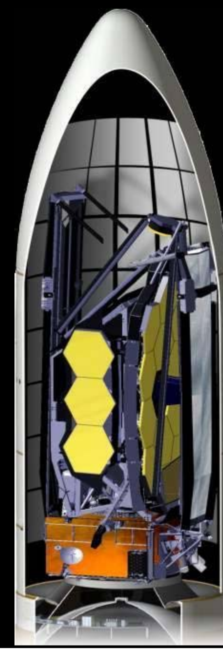
6.5 m segmented primary versus 2.4 m primary for HST ~7X HST's collecting area → increased sensitivity, higher spatial resolution



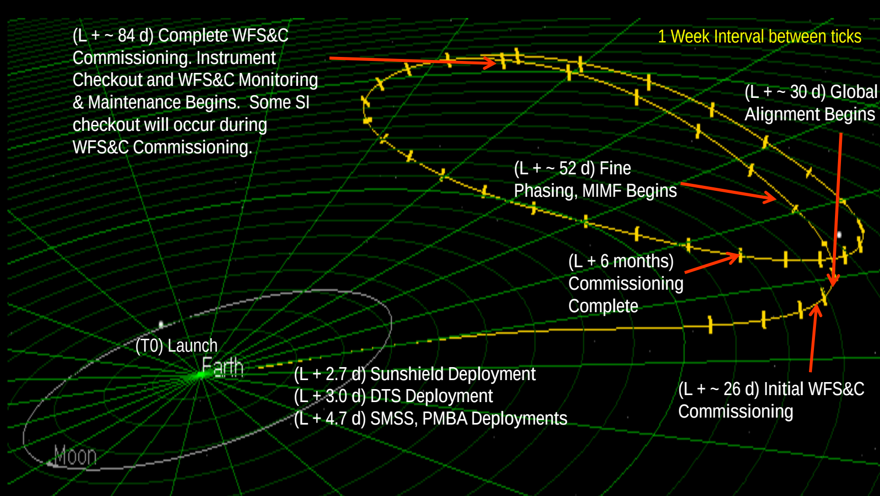
The JWST Observatory Elements and Regions



JWST – NASA's Transformer



JWST is Built (deployed) En Route

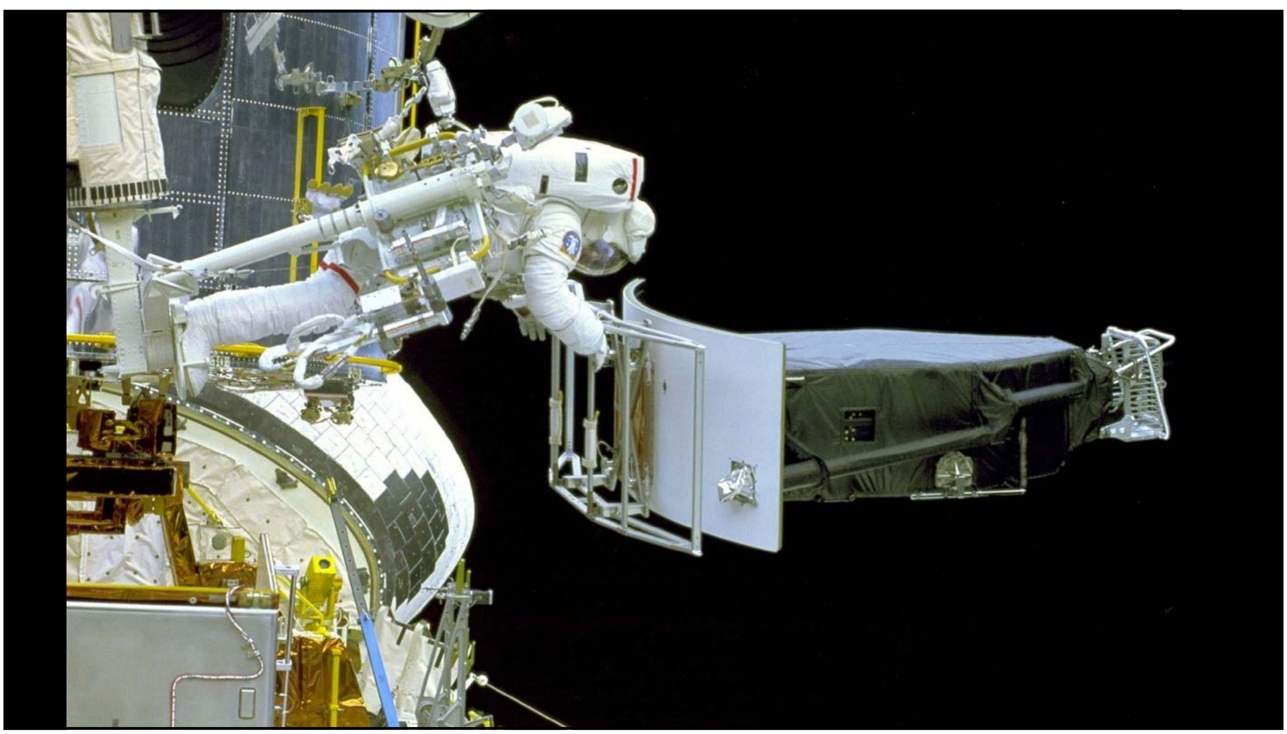


It takes a village…

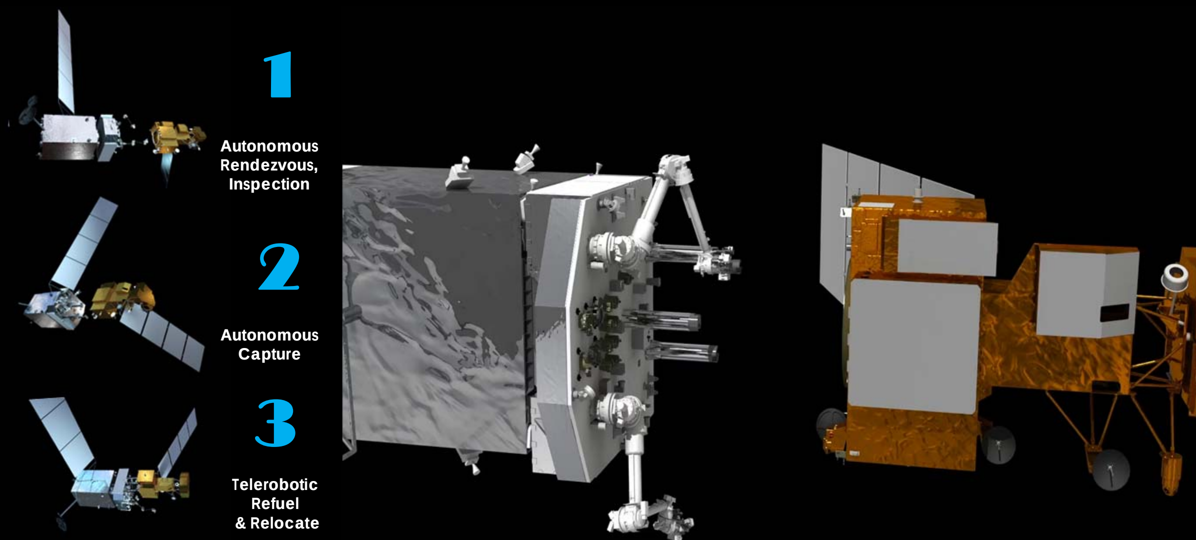
Why Servicing?

Satellite servicing allows us to maintain, repair, and upgrade our satellites in-orbit, drastically reducing the cost of conducting science and exploration

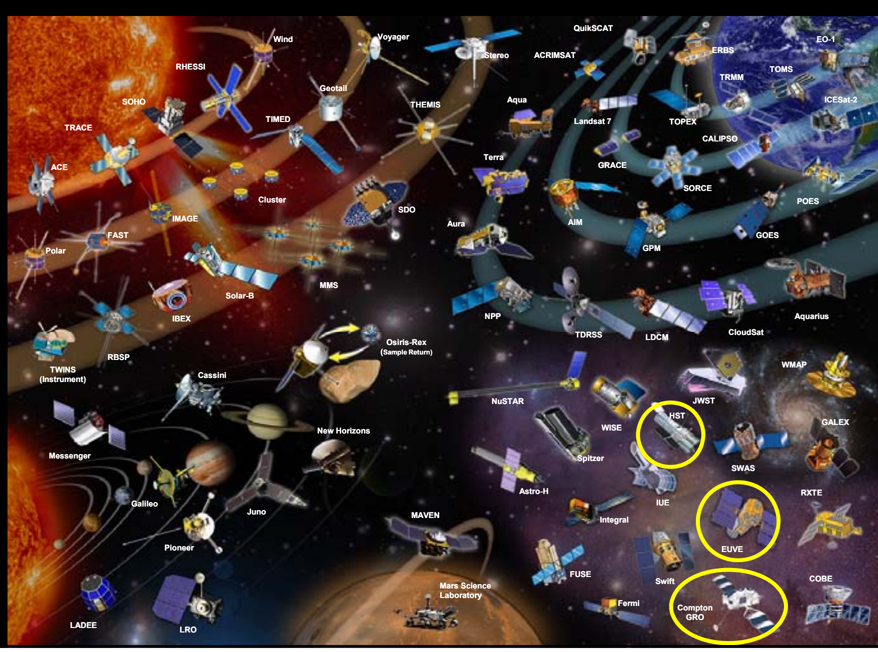
- **To expand our knowledge and understanding of the Earth and the universe**
  - Upgrades to critical satellites allow us to leverage technological advancements
- **To protect our national interests and maintain U.S. space leadership**
  - Servicing offers resilience in a dynamic threat environment
  - Satellite servicing helps America maintain and extend the lifespan of its key assets, and the technologies can be applied to key NASA missions
- **To provide economic and cost benefits**
  - Modularity and serviceability cut down on costs by delivering upgraded instruments and by extending satellites' lifespans



RESTORE-L



Era of One and Done



Project Description

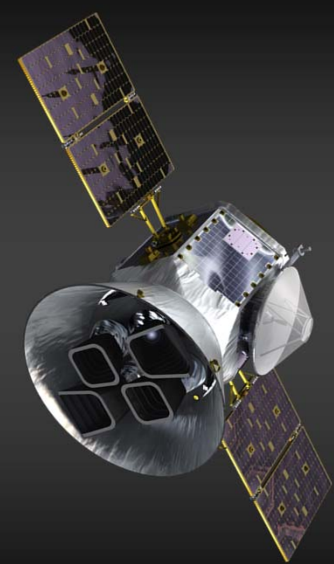
NASA's next Exoplanet hunter

Launched April 2018

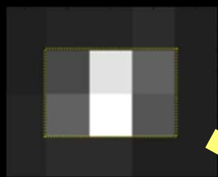
George Ricker (P.I.)

Massachusetts Institute of Technology

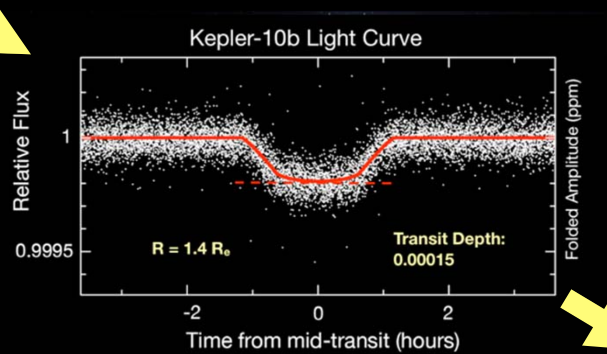
collaboration including:
NASA Goddard, NASA Ames, MIT Lincoln Lab, Orbital ATK, STScI, SAO, Harvard/Smithsonian, MPIA-Germany, Las Cumbres Observatory, Geneva Observatory, OHP-France, University of Florida, Aarhus University-Denmark, Harvard College Observatory, Vanderbilt University



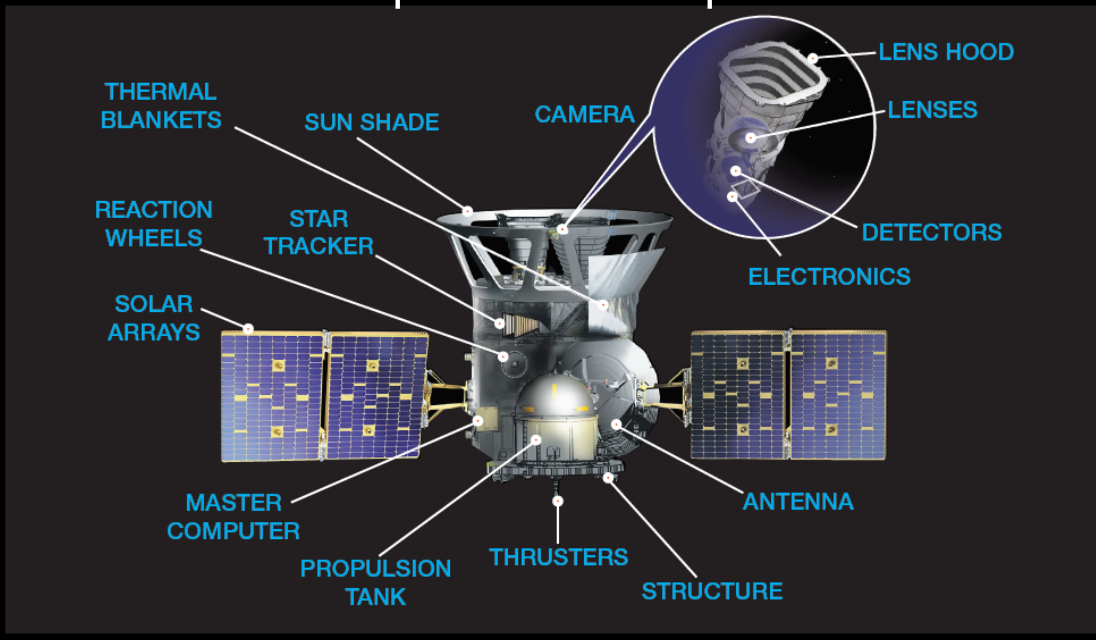
Transit Method



Turning Pixels into Planets

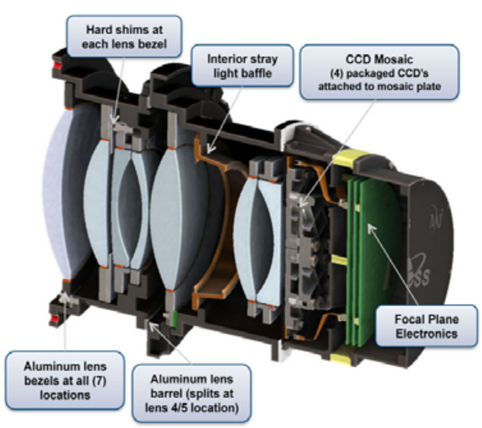


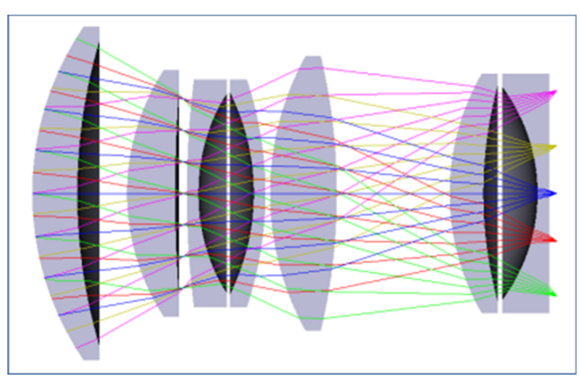
TESS Spacecraft Components



TESS Lens Assembly Characterization

- Contains 7 distance Ohara glasses
- Lens assembly is a Hybrid Petzval Design
- Operational Wavelength Range: 0.6 – 1.0 μm
- Operational Temperature Range: 183 – 213 K
- Index Characterization Wavelength Range: 0.42 – 1.1 μm
- Index Characterization Temperature Range: 120 – 300 K





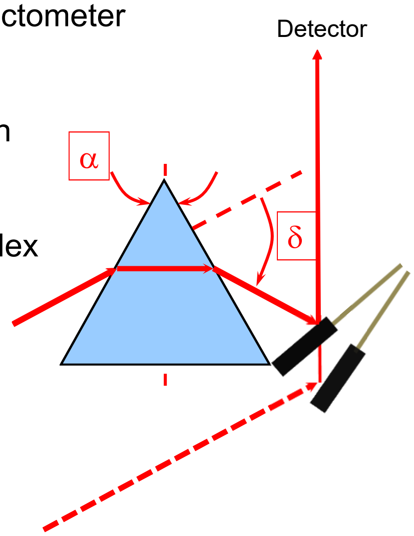
CHARMS Capabilities

- Absolute minimum deviation refractometer (in vacuum)
- Wavelength coverage: 0.35 to 5.6 µm
- Temperature coverage: 15 K (using LHe) to 340⁺ K (67 C)
- Single measurement ABSOLUTE accuracies as good as 5 x 10^{-6} at cryo (depending on material)
- Measures absolute refractive index, n(λ, T)
- Accurate values of thermo-optic coefficient, dn/dT, and spectral dispersion, dn/dλ, derived from measured n(T)

CHARMS: Operation and Capabilities

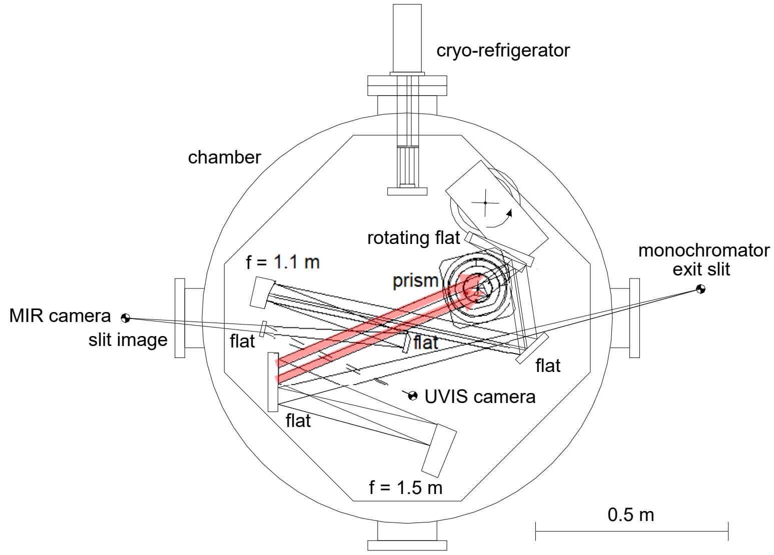
- CHARMS is a minimum deviation refractometer
- Five simple steps:

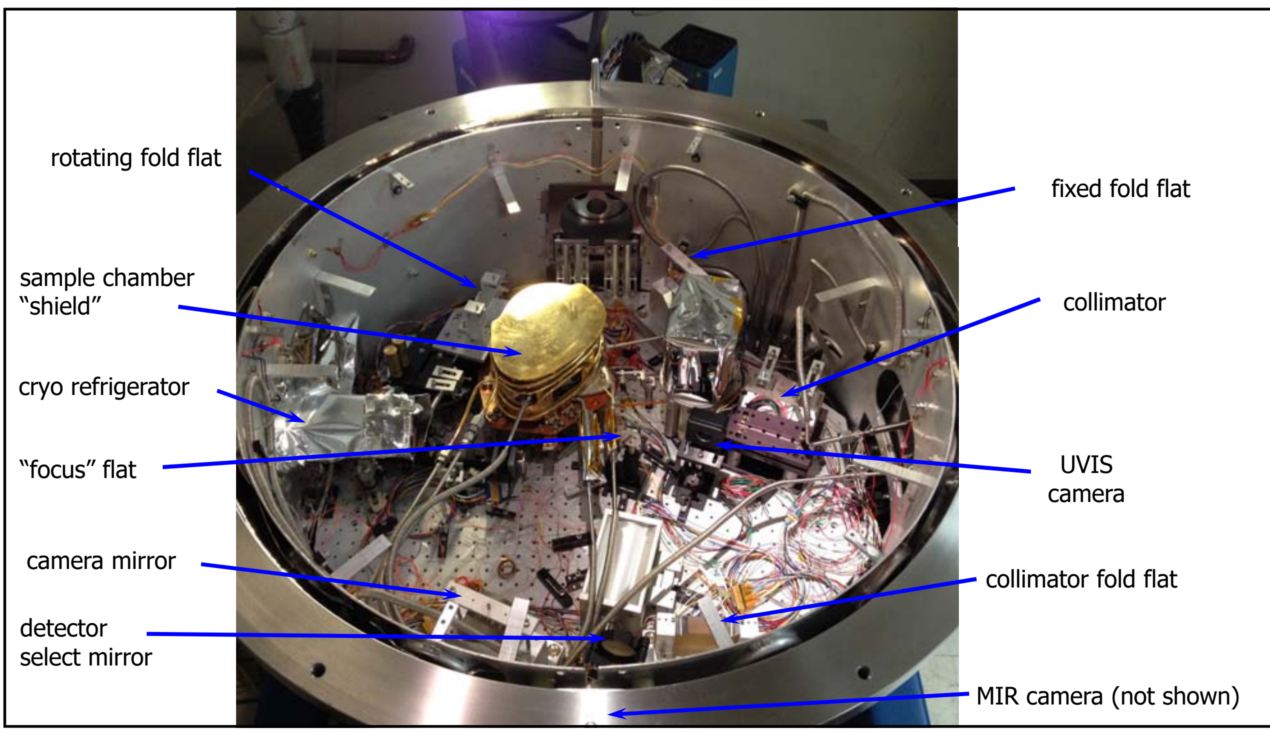
1. Measure the apex angle of the prism
2. Establish the condition of min deviation
3. Measure angle of undeviated beam
4. Measure angle of deviated beam
5. Compute deviation angle; compute index



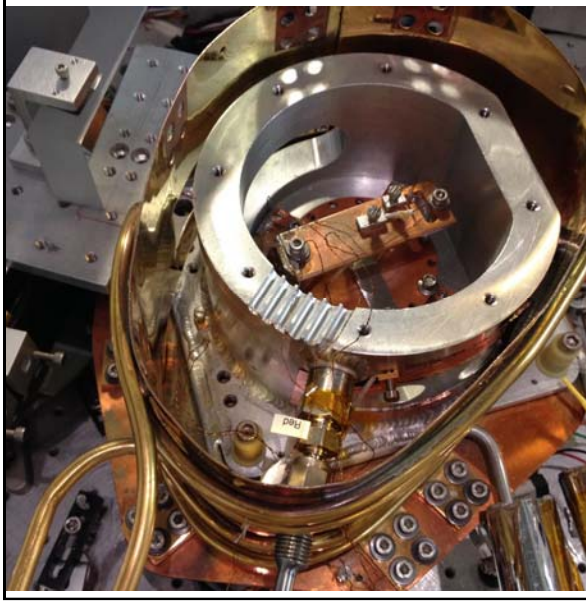
$$n = \frac{sin(\frac{\alpha+\delta}{2})}{sin(\frac{\alpha}{2})}$$

CHARMS optical layout

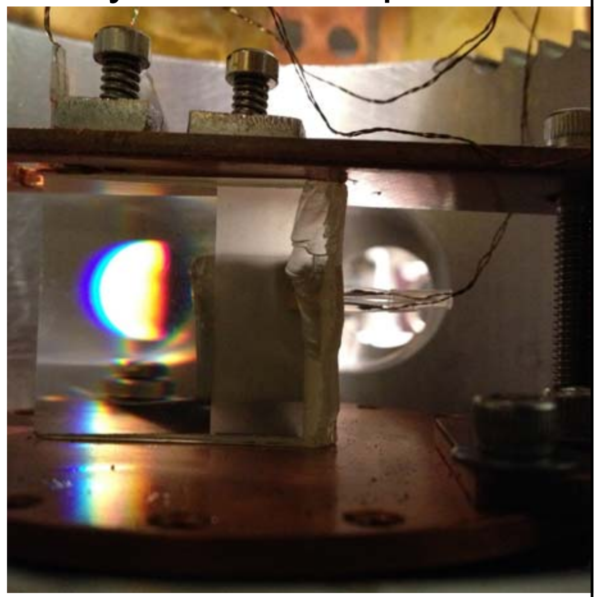




Top view of sample chamber

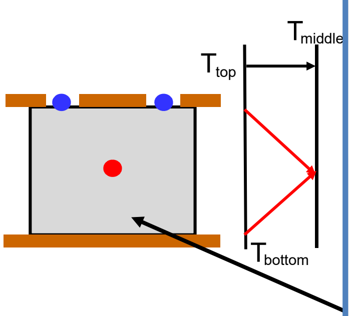


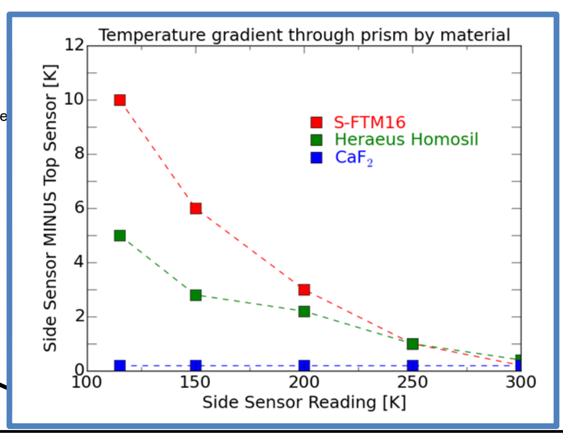
Eye level with prism

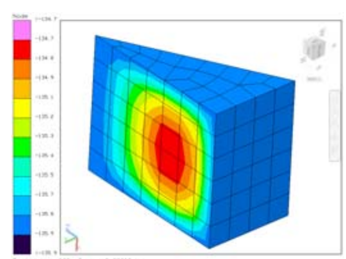


Sample Temperature, T

- sample sandwiched between two cryogen-cooled copper plates at essentially same T
- two T sensors on top of prism
- T_{sample} attributed to reading from sensor halfway up side of non-refracting face

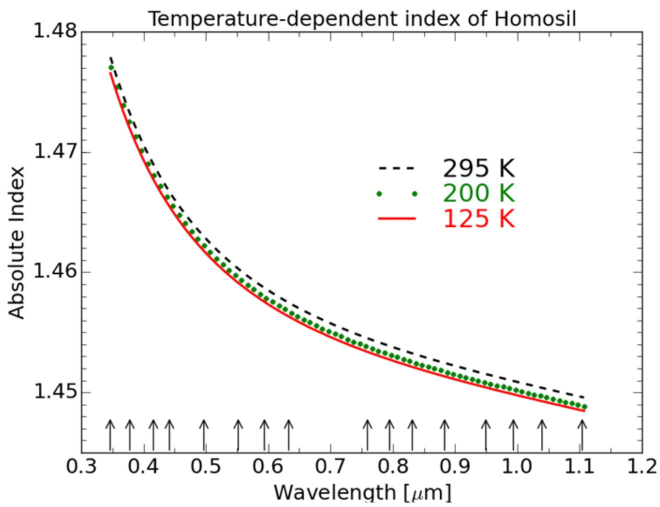






Courtesy of S. Scola – NASA LaRC

CHARMS Measurements of Heraeus Homosil



Sellmeier Equation

$$n^2(\lambda,T)-1 = \sum_{i=1}^{3} \frac{S_i(T)\cdot\lambda^2}{\lambda^2-\lambda_i^2(T)}$$

$$S_i(T) = \sum_{j=0}^{3} S_{ij}\cdot T^j$$

$$\lambda_i(T) = \sum_{j=0}^{3} \lambda_{ij}\cdot T^j$$

$$AAR = \frac{\sum_{k=1}^{n} |index_{measured} - index_{fit}|}{n}$$

Homosil_AAR = 2.04×10^{-6}

Example of Bookkeeping Error Budget

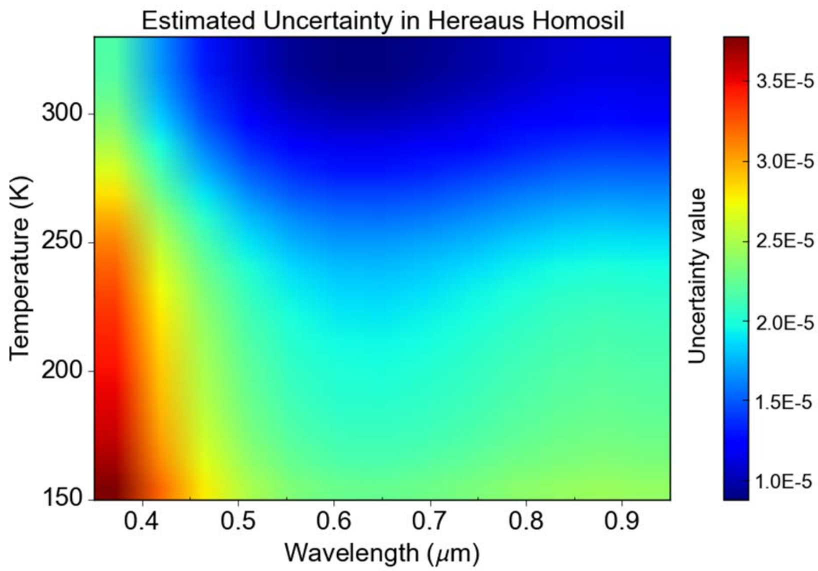
index n, apex α, deviation δ → dn/dλ, dn/dT, dn/dα, dn/dδ, dλ, dT, da, dδ → **dn**

					SENSITIVITIES								FOR SPECIFIED PRISM				FOR SPECIFIED PRISM				
index n	apex a	alpha	delta d		dn/dwv	dn/dT	dn/da	dn/d	dwv	dn(dwv)	dT	dn(dT)	da			dn(da)	dd			dn(dd)	dn r.s.s.
1.4574	10.0 deg	0.175 rads	4.595 deg	0.080 rads	0.00040/nm	0.000120/K	-2.64/rad	5.690/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-6.4E-06	0.00150 deg	5.4 sec	###	1.5E-04	1.7E-04
1.4574	20	0.349 rads	9.319 deg	0.163 rads	0.00040/nm	0.000120/K	-1.35/rad	2.786/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-3.3E-06	0.00150 deg	5.4 sec	###	7.3E-05	9.5E-05
1.4574	30	0.524 rads	14.321 deg	0.250 rads	0.00040/nm	0.000120/K	-0.93/rad	1.789/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-2.3E-06	0.00150 deg	5.4 sec	###	4.7E-05	7.4E-05
1.4574	40	0.698 rads	19.796 deg	0.346 rads	0.00040/nm	0.000120/K	-0.73/rad	1.267/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-1.8E-06	0.00150 deg	5.4 sec	###	3.3E-05	6.4E-05
1.4574	50	0.873 rads	26.038 deg	0.454 rads	0.00040/nm	0.000120/K	-0.63/rad	0.932/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-1.5E-06	0.00150 deg	5.4 sec	###	2.4E-05	5.9E-05
1.4574	58	1.012 rads	31.912 deg	0.557 rads	0.00040/nm	0.000120/K	-0.58/rad	0.730/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-1.4E-06	0.00150 deg	5.4 sec	###	1.9E-05	5.6E-05
2.6	10	0.175 rads	16.195 deg	0.283 rads	0.00040/nm	0.000120/K	-9.27/rad	5.588/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-2.3E-05	0.00150 deg	5.4 sec	###	1.5E-04	1.7E-04
2.6	15	0.262 rads	24.677 deg	0.431 rads	0.00040/nm	0.000120/K	-6.27/rad	3.603/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-1.5E-05	0.00150 deg	5.4 sec	###	9.4E-05	1.2E-04
2.6	20	0.349 rads	33.678 deg	0.588 rads	0.00040/nm	0.000120/K	-4.80/rad	2.569/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-1.2E-05	0.00150 deg	5.4 sec	###	6.7E-05	9.1E-05
2.6	25	0.436 rads	43.491 deg	0.759 rads	0.00040/nm	0.000120/K	-3.95/rad	1.910/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-9.7E-06	0.00150 deg	5.4 sec	###	5.0E-05	7.7E-05
2.6	30	0.524 rads	54.587 deg	0.953 rads	0.00040/nm	0.000120/K	-3.42/rad	1.429/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-8.4E-06	0.00150 deg	5.4 sec	###	3.7E-05	6.7E-05
3.4	10	0.175 rads	24.475 deg	0.427 rads	0.00040/nm	0.000120/K	-13.95/rad	5.479/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-3.4E-05	0.00150 deg	5.4 sec	###	1.4E-04	1.6E-04
3.4	14	0.244 rads	34.958 deg	0.610 rads	0.00040/nm	0.000120/K	-10.11/rad	3.734/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-2.5E-05	0.00150 deg	5.4 sec	###	9.8E-05	1.2E-04
3.4	18	0.314 rads	46.265 deg	0.807 rads	0.00040/nm	0.000120/K	-8.03/rad	2.707/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-2.0E-05	0.00150 deg	5.4 sec	###	7.1E-05	9.6E-05
3.4	22	0.384 rads	58.895 deg	1.028 rads	0.00040/nm	0.000120/K	-6.75/rad	1.994/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-1.6E-05	0.00150 deg	5.4 sec	###	5.2E-05	8.0E-05
4.0	10	0.175 rads	30.806 deg	0.538 rads	0.00040/nm	0.000120/K	-17.48/rad	5.377/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-4.3E-05	0.00150 deg	5.4 sec	###	1.4E-04	1.6E-04
4.0	12.5	0.218 rads	39.130 deg	0.683 rads	0.00040/nm	0.000120/K	-14.13/rad	4.134/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-3.5E-05	0.00150 deg	5.4 sec	###	1.1E-04	1.3E-04
4.0	15	0.262 rads	47.947 deg	0.837 rads	0.00040/nm	0.000120/K	-11.92/rad	3.267/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-2.9E-05	0.00150 deg	5.4 sec	###	8.6E-05	1.1E-04
4.0	17.5	0.305 rads	57.461 deg	1.003 rads	0.00040/nm	0.000120/K	-10.39/rad	2.608/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-2.5E-05	0.00150 deg	5.4 sec	###	6.8E-05	9.5E-05

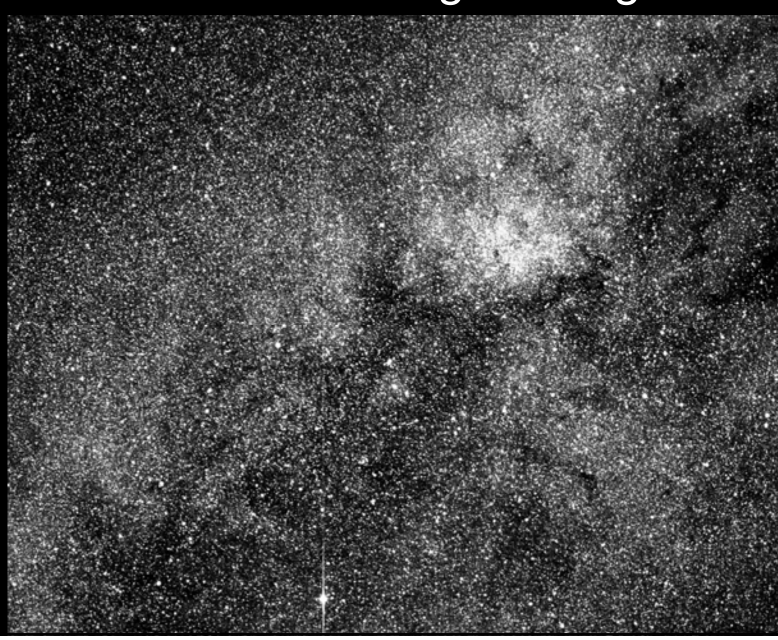
- uncertainty governed by all eight quantities in the red box <u>for each measurement</u> for a given specimen (green box)

so, a refractometer should <u>not</u>
list a single number for accuracy

Measurement Uncertainties



TESS: "First-Light" Image




Stay Tuned...
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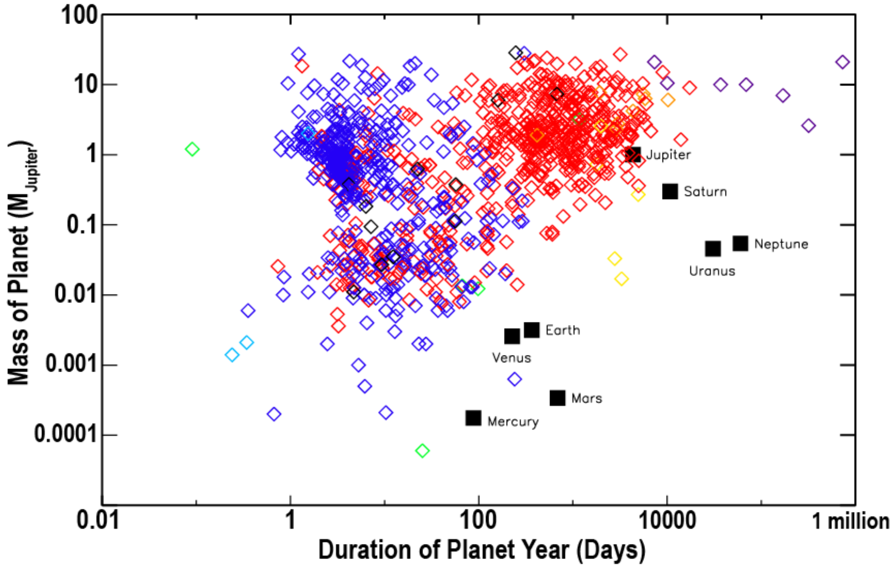
@NASATESS
@NASA_SatServ
@NASA_TESS & @TESSatMIT
Summer Internship Deadline is April 1st : https://intern.nasa.gov

Back Up

Rocky Worlds, Where Are (more of) You?



TESS: Library of Congress 35