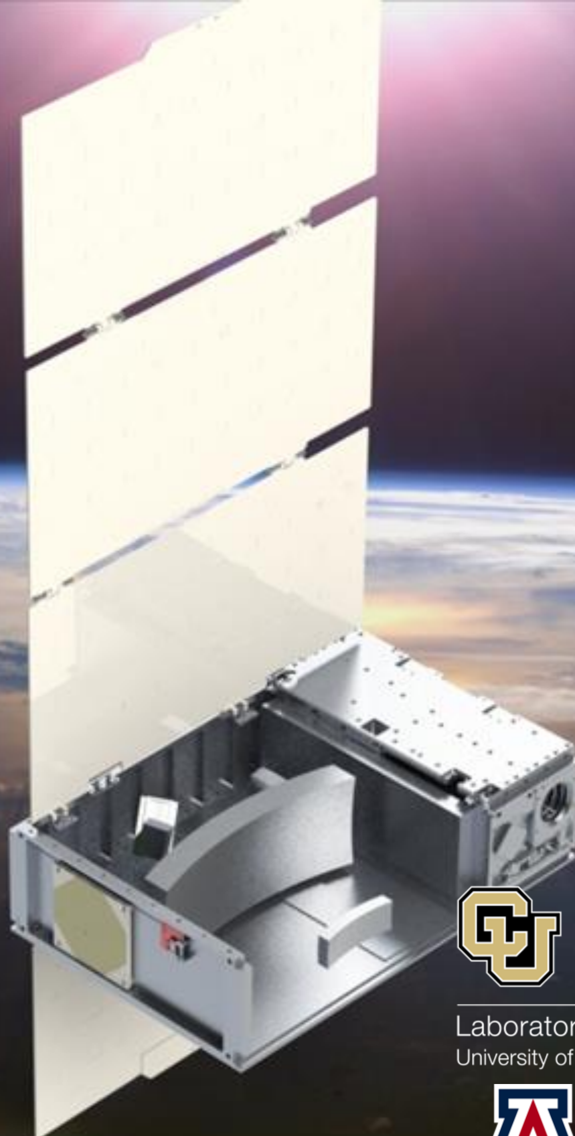
The Colorado Ultraviolet Transit Experiment (CUTE)

COPAG SiG2 splinter
AAS 8 January 2018



University of Colorado:
Kevin France (PI), Brian Fleming (PS), Rick Kohnert (PM), Nicholas Nell, Arika Egan, Kelsey Pool, Stefan Ulrich

United States:
Tommi Koskinen (UoA), Matthew Beasley (SwRI), Keri Hoadley (Caltech)

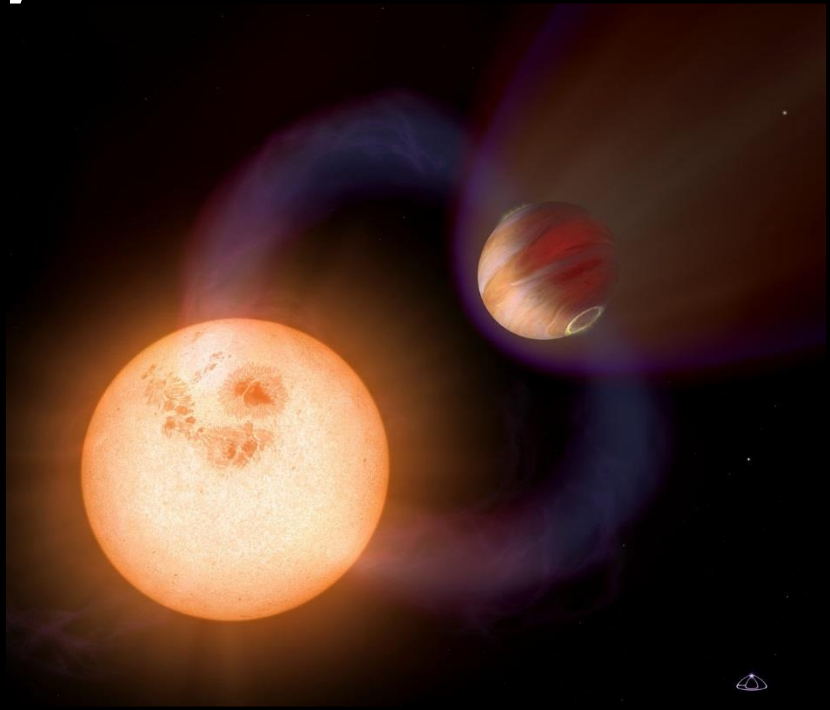
Europe:
Jean-Michel Desert (Amsterdam), Luca Fossati (ÖAW), Pascal Petit (UdT), Aline Vidotto (TCD)

LASP
Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

ARIZONA
SwRI
Université de Toulouse
ÖAW Austrian Academy of Sciences
Trinity College Dublin
The University of Dublin
BCT
NASA

Extreme exoplanetary systems: new regimes of planetary physics and star-planet interactions

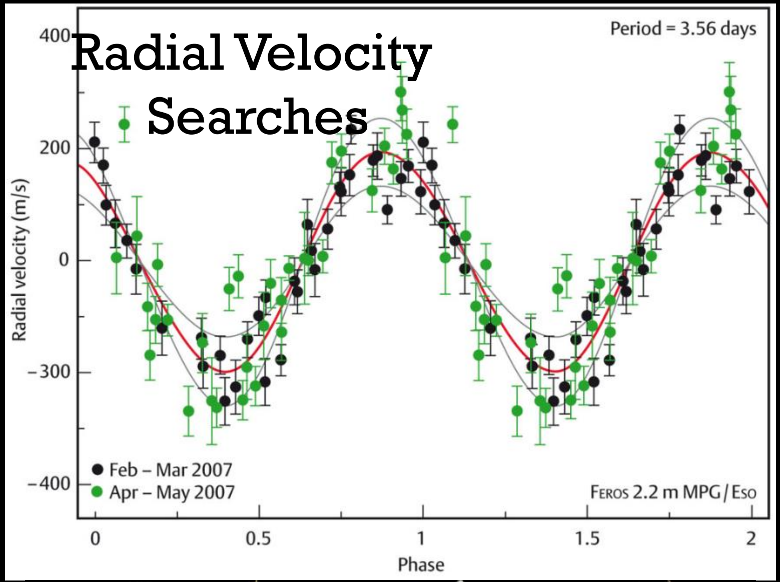
- **Introduction:**
- The detection and prevalence of exoplanetary systems
- Planet systems unlike the solar system
- Planetary atmospheres unlike the solar system

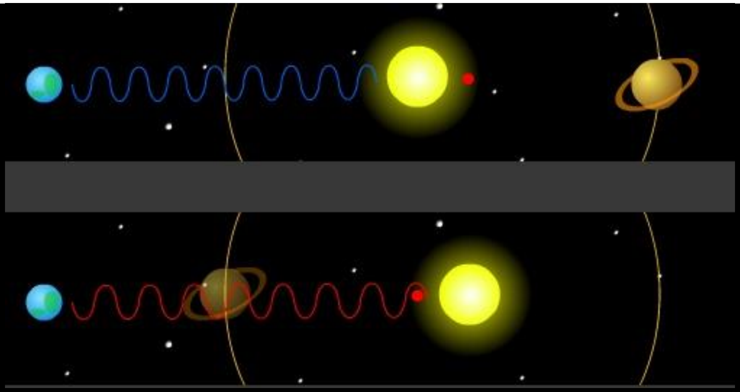


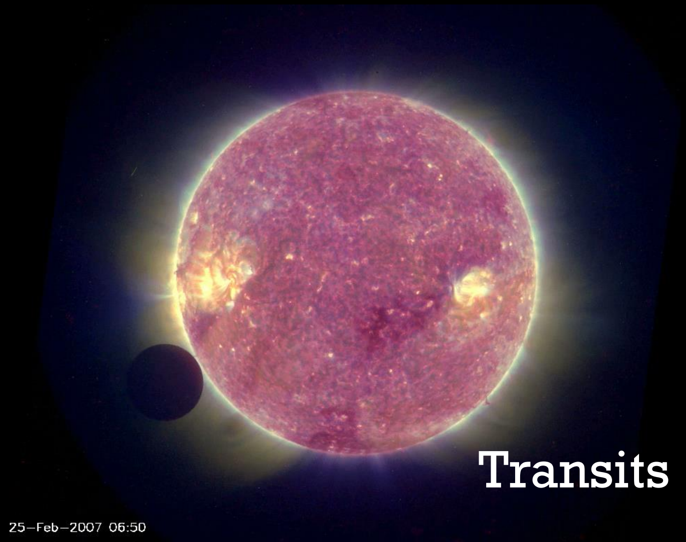
Extrasolar Planets:

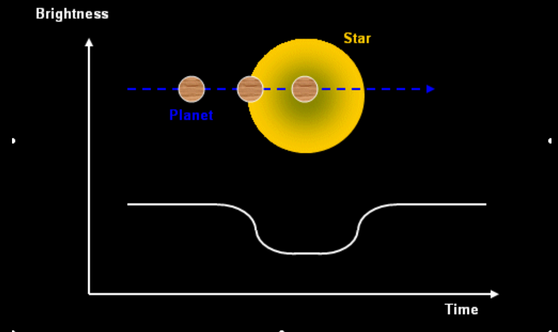
$N_{plan}(2018)$
~3500 Confirmed

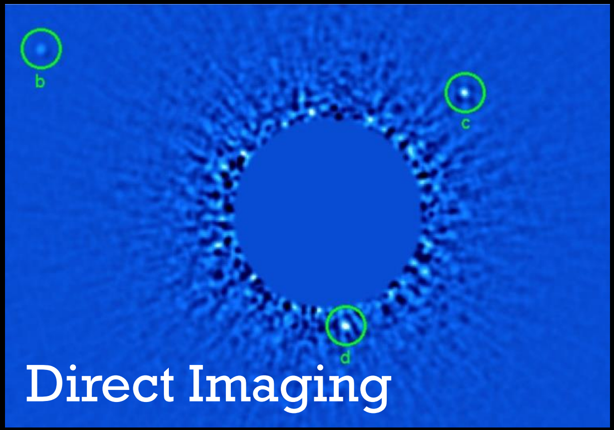
$\sim 175 \times N_{plan}(1999)$



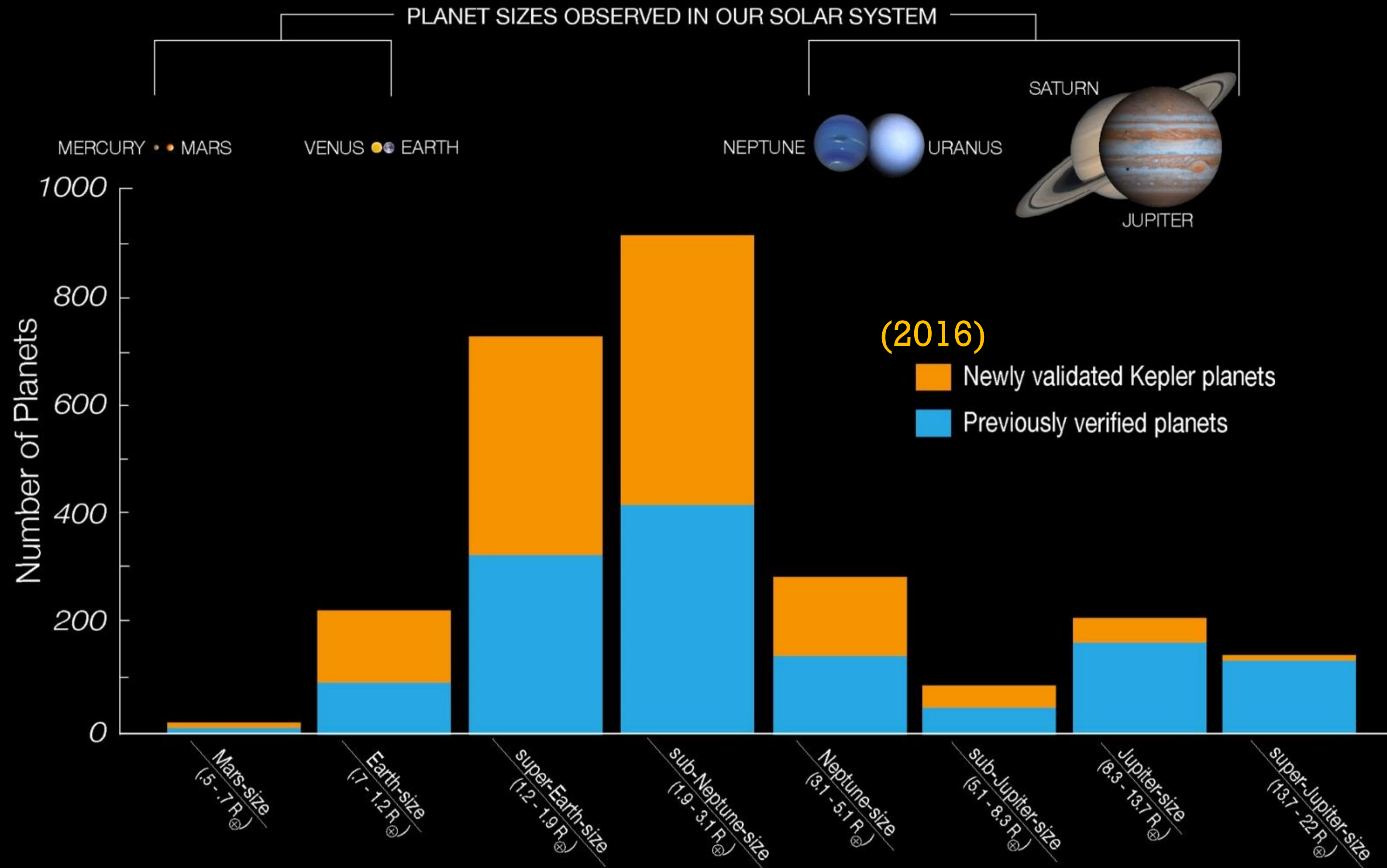






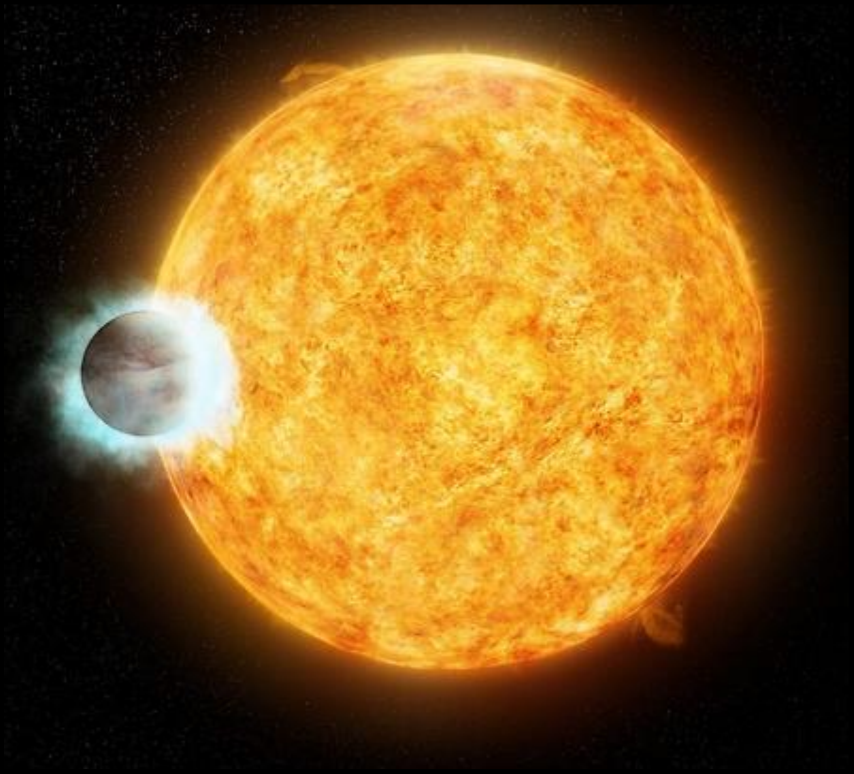


The Extrasolar Planet Zoo



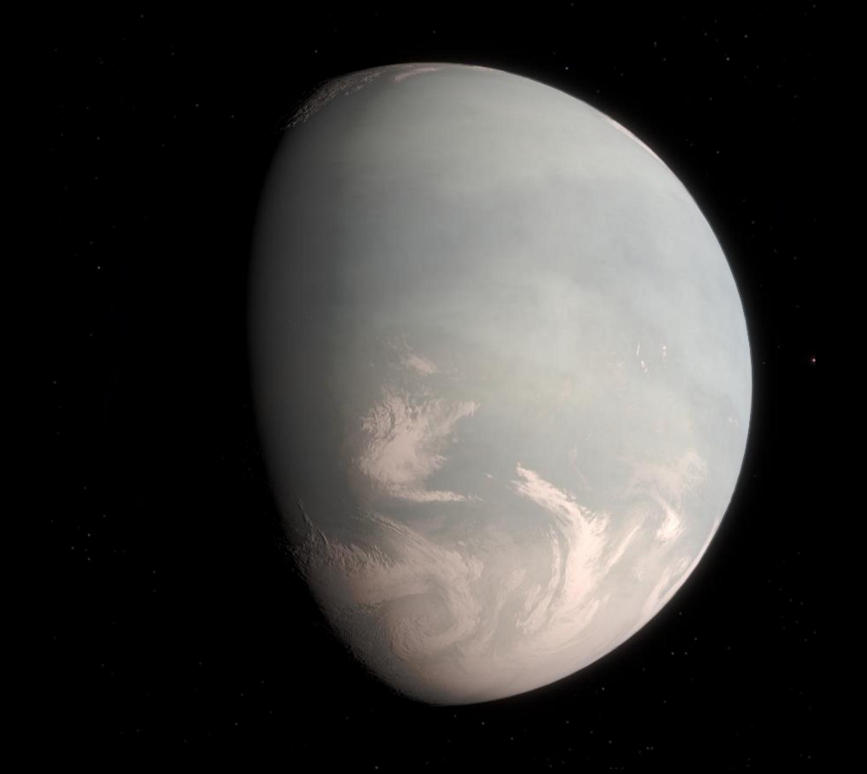
The Extrasolar Planet Zoo

Hot Jupiter



WASP-18b, solar-type host
$M \sim 10\ M_J$, $R \sim 1.1\ R_J$
$a \sim 0.02$ AU
$T_{eff} \sim 2400 - 3100$ K
(Hellier et al. 2009)

Super-Earth



GJ 832c, red dwarf host
$M \sin(i) \sim 5.2\ M_E$, $R \sim 1.7\ R_E$
$a \sim 0.16$ AU
$T_{eff} \sim 230 - 280$ K
(Wittenmyer et al. 2014)

Extreme exoplanetary systems: new regimes of planetary physics and star-planet interactions

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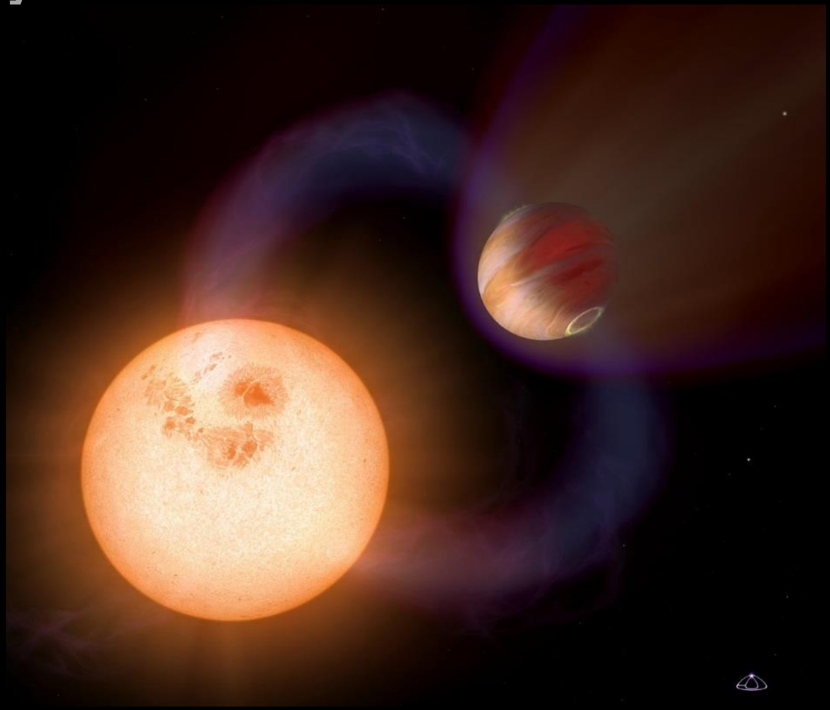
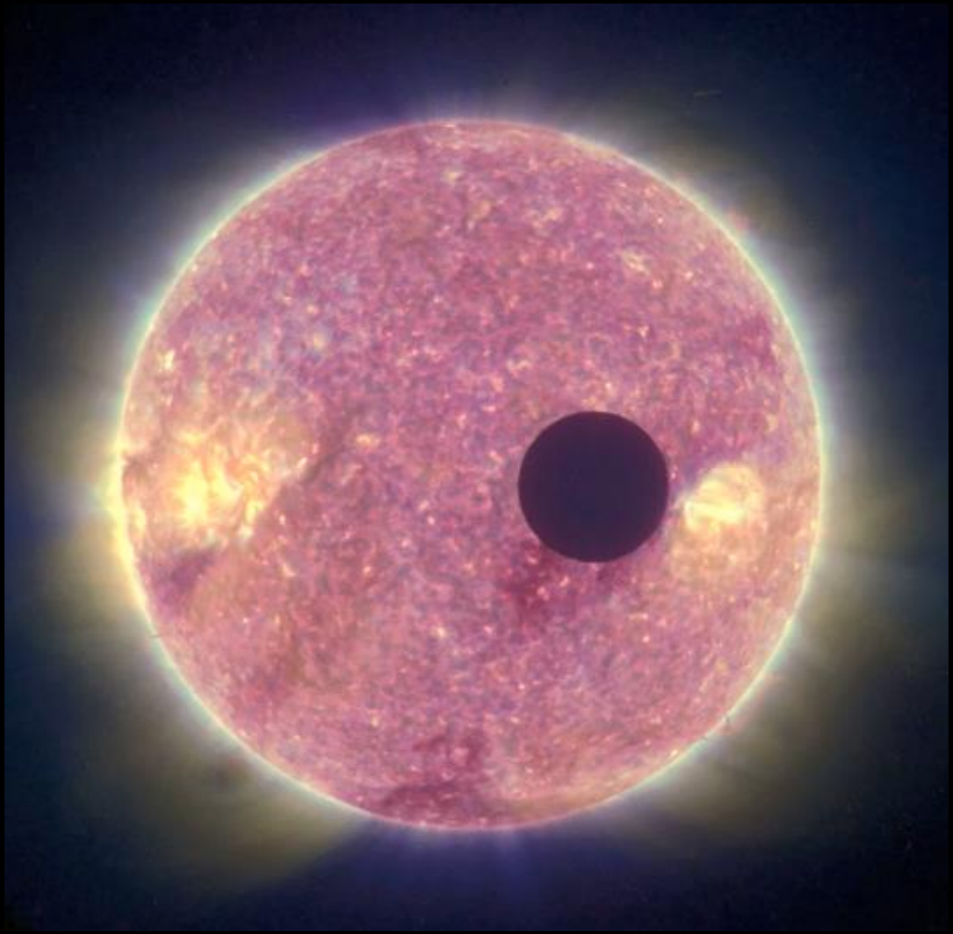


EXOPLANET ATMOSPHERES

- Narrow-band/spectroscopic transit analysis can probe absorption by specific atmospheric constituents



Occultation Depth = $(R_P / R_*)^2$

EXOPLANET ATMOSPHERES

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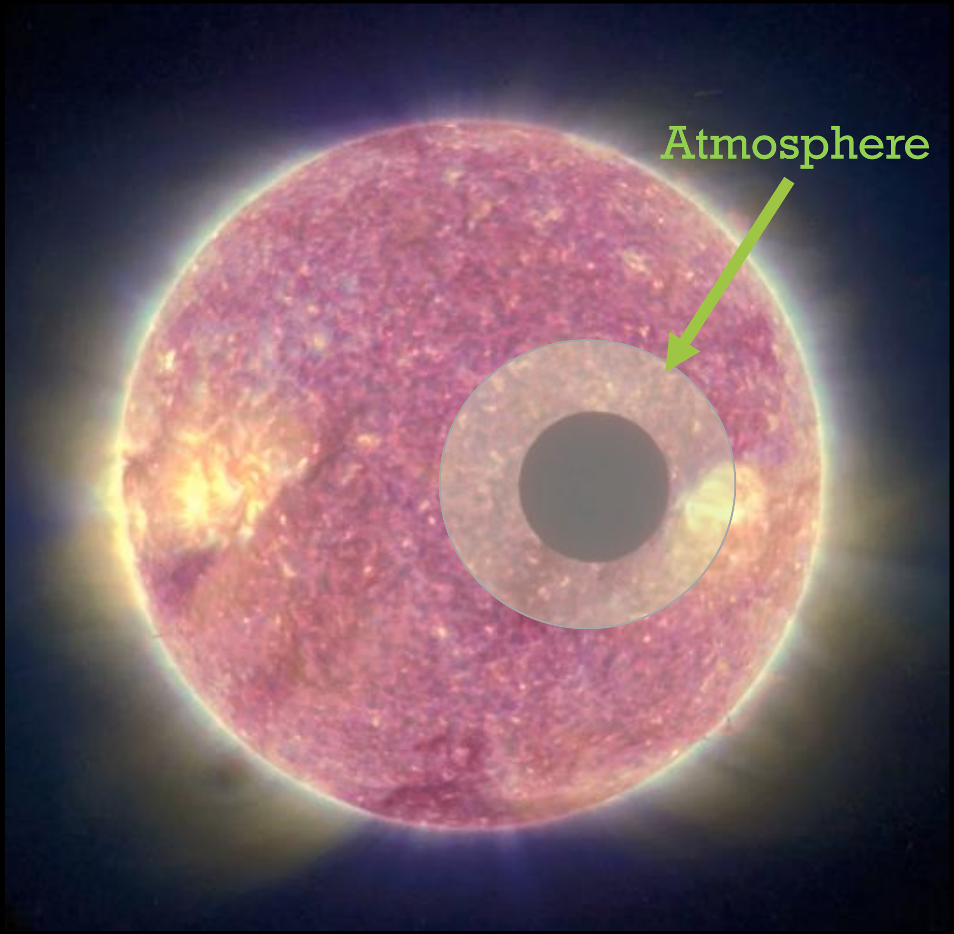


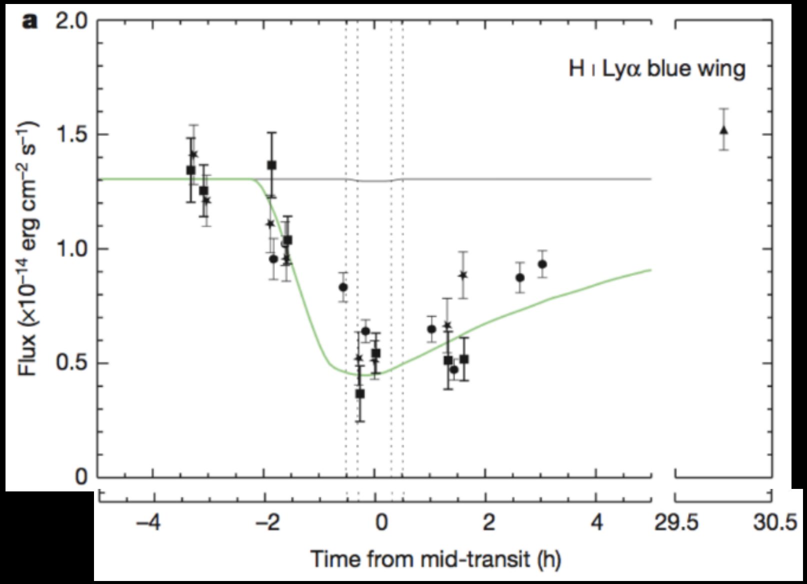
Occultation Depth = $(R_P(\lambda) / R_*)^2$

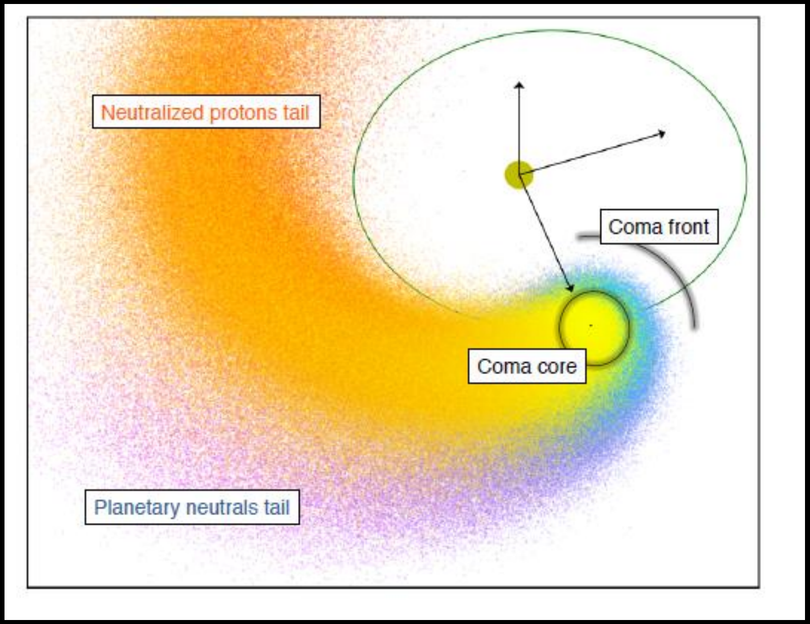
Transit Spectroscopy:
in-transit vs. out-of-transit

- Composition
- Temperature structure
- Velocity flows
- Mass-loss rates

Transit Spectroscopy of Short-period Planets

- **<u>EUV heating driving mass-loss from short-period planets</u>**
- Most spectacular example has been on the short-period Neptune-mass planet GJ 436b





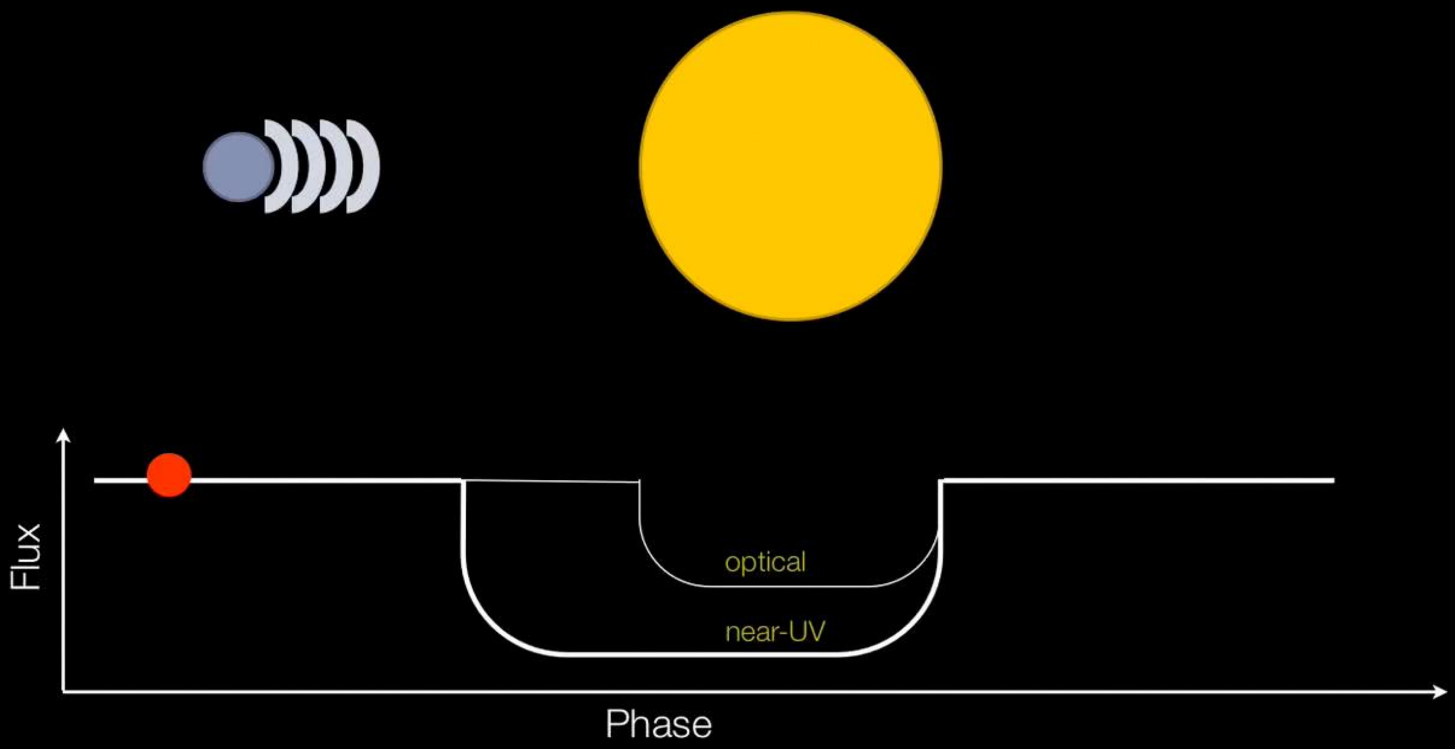
Hydrogen detected in the upper atmosphere of GJ436b (Kulow et al. 2014; Ehrenreich et al. 2015; Bourrier et al. 2016)

Transit depth ~ 50% (!)

(but no metal outflow – Loyd et al. 2017…or maybe there is…Lavie et al. 2017)

Slide credits Joe Llama – Lowell Obs

NUV Transit Spectra of WASP-12b: Early Ingress



Fossati et al. (2010); Vidotto et al. (2010)

Slide credits Joe Llama – Lowell Obs

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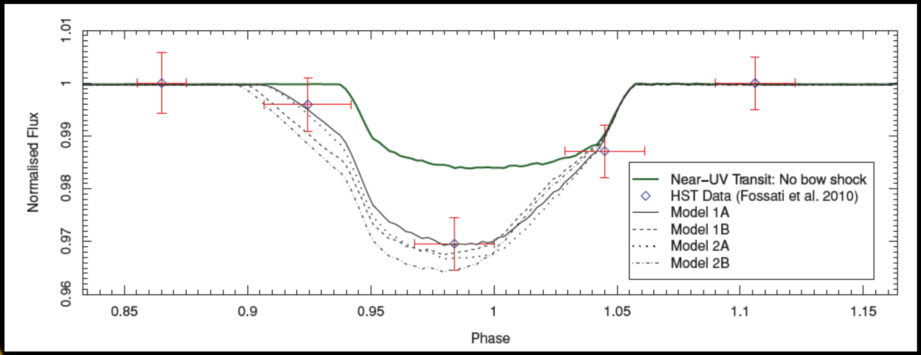
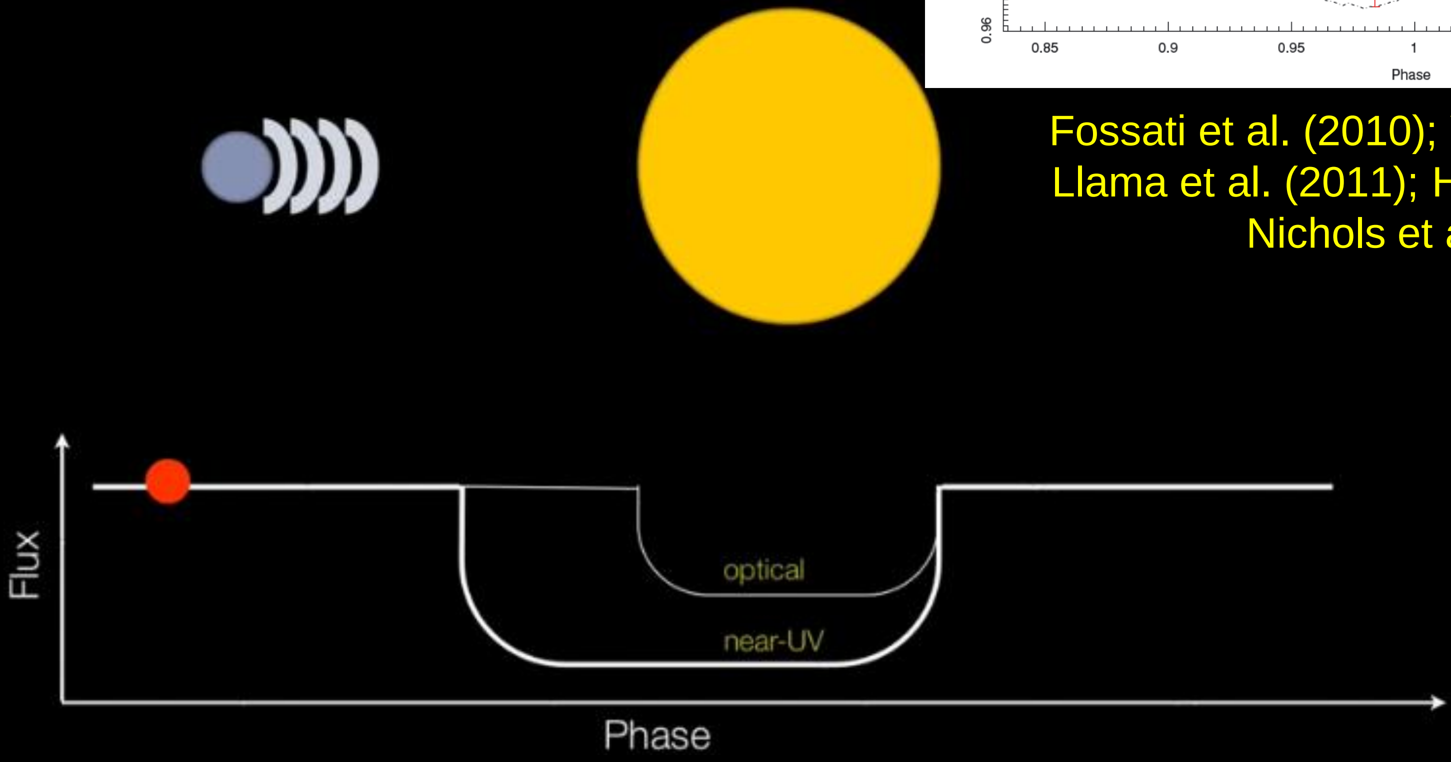


Fossati et al. (2010); Vidotto et al. (2010)
Llama et al. (2011); Haswell et al. (2012)
Nichols et al. (2015)



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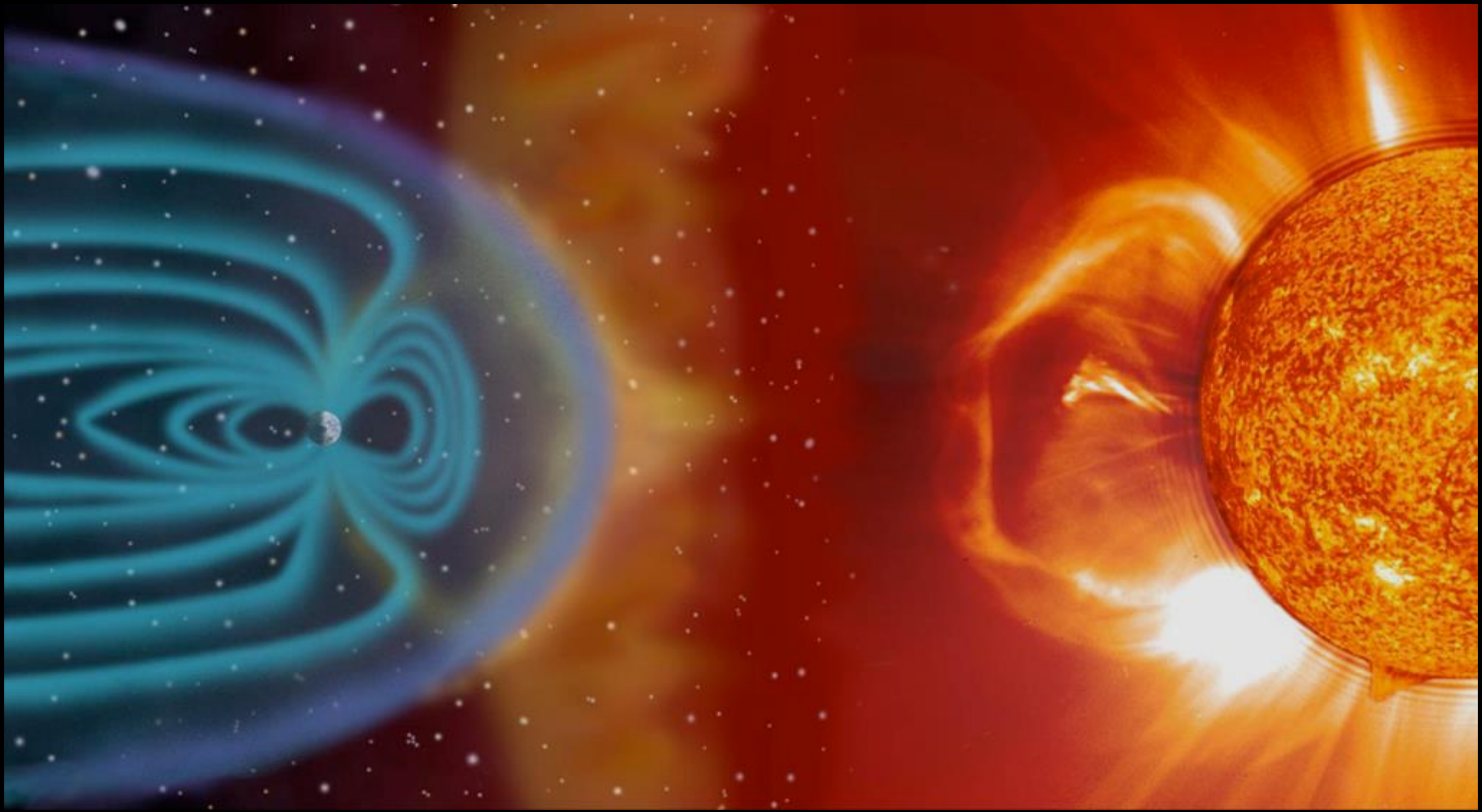


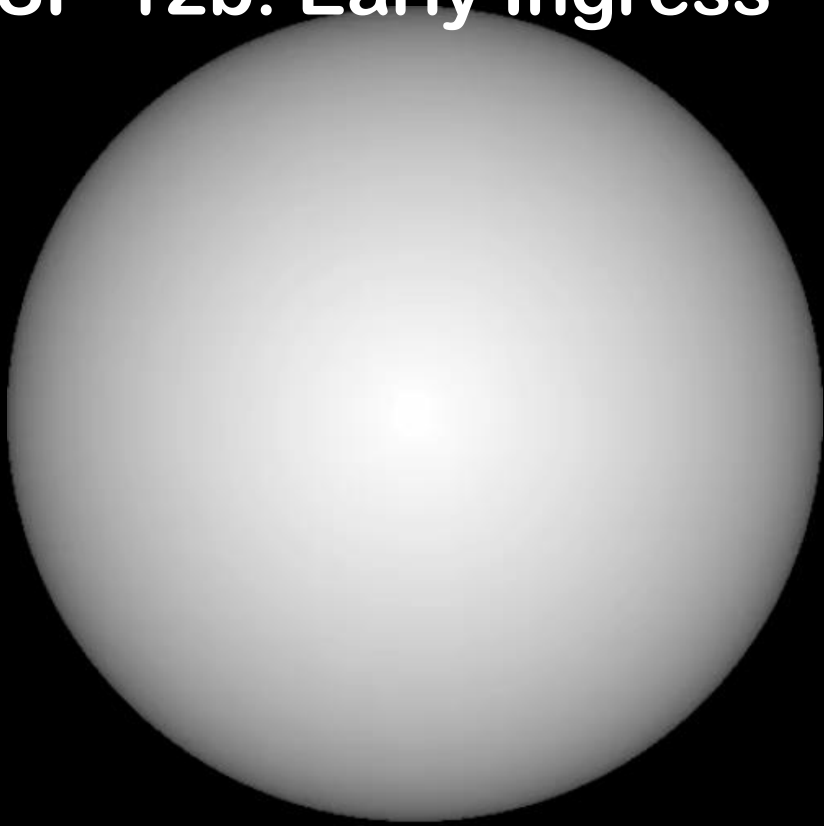
Interaction between stellar wind and planetary magnetic field may cause compression. (Vidotto et al. 2010, 2011)

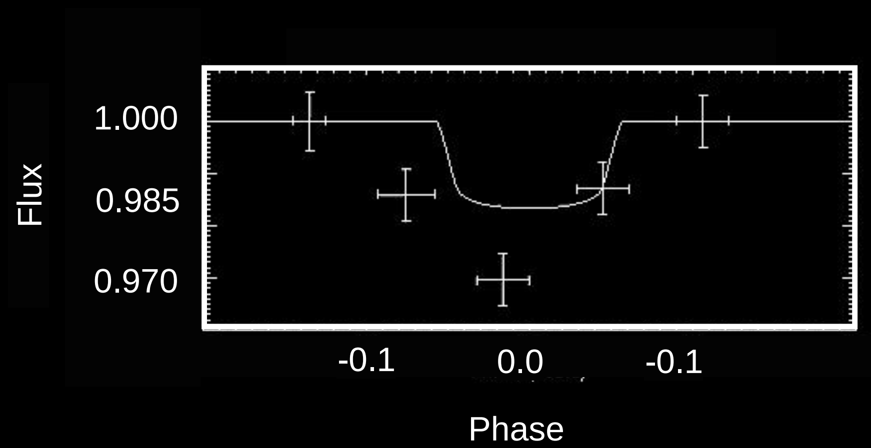
Interaction strength depends on relative velocity and coronal/wind density and temperature

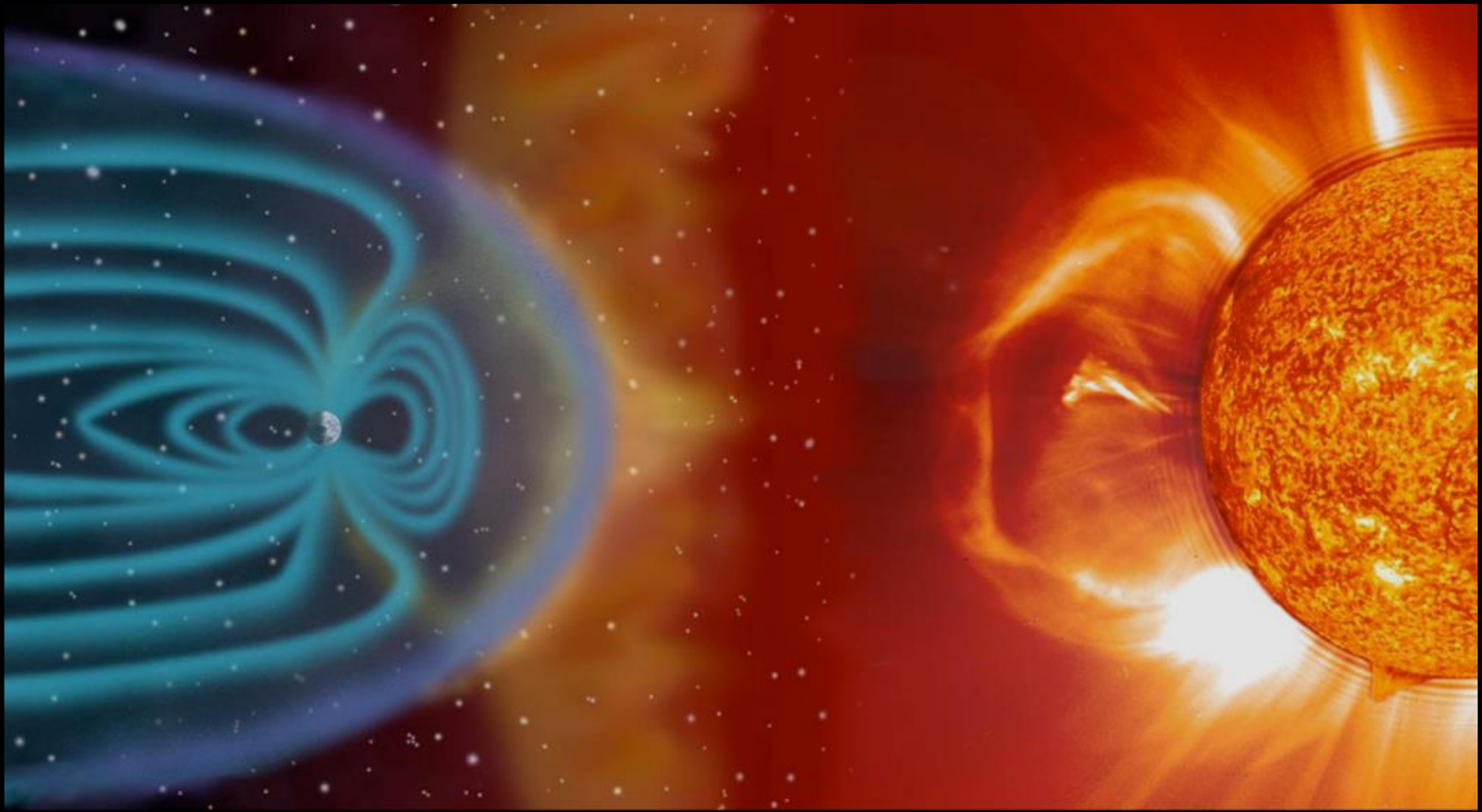
Slide credits Joe Llama – Lowell Obs

NUV Transit Spectra of WASP-12b: Early Ingress

- **Llama et al. (2011), Vidotto et al. (2010):**
  - Potential detection of a magnetic field around WASP-12b.
  - Magnetosphere protects the atmosphere to ~5 Rp.
  - Bp ~ 24 Gauss







Not the only interpretation:

- Hydrodynamic mass-loss may support an upstream shock (Lai et al. 2010)
- Accretion stream onto the star ahead of the motion (Bisikalo et al. 2013)
- Plasma torus from satellites (Ben-Jaffel & Ballester 2014; Kislyakova et al. 2016)
- CLOUDY modeling finds compressed stellar winds produce insufficient optical depth, arguing for the planetary mass-loss explanation (Turner et al. 2016)

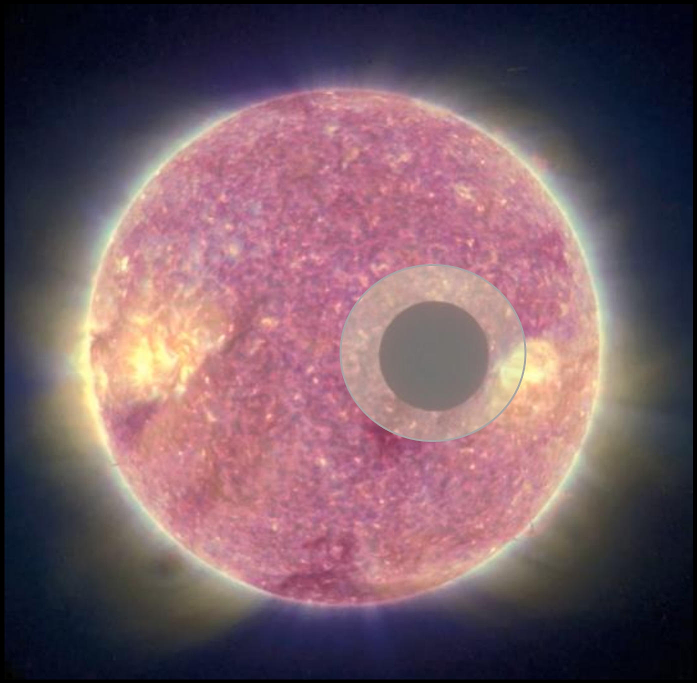
Extreme Exoplanet Atmospheres: challenges

- Rarely get the same transit result twice: time-variability in the star(?), planetary mass-loss rate (?), or apples-vs-oranges observations and data reduction algorithms

- Sample size of mass-loss measurements ~5, early-ingress observations ~1

- Stellar baseline for transit measurements

- Self-consistent modeling framework



Extreme Exoplanet Atmospheres: challenges

•Rarely get the same transit result twice: time-variability in the star(?), planetary mass-loss rate (?), or apples-vs-oranges observations and data reduction algorithms

→ multiple, consecutive transits, single data pipeline

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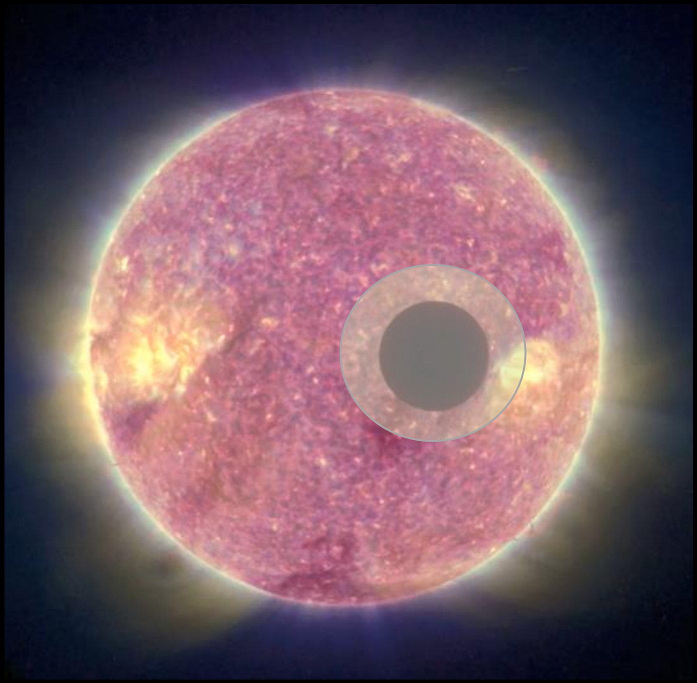

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Extreme Exoplanet Atmospheres: challenges

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→ **multiple, consecutive transits, single data pipeline**

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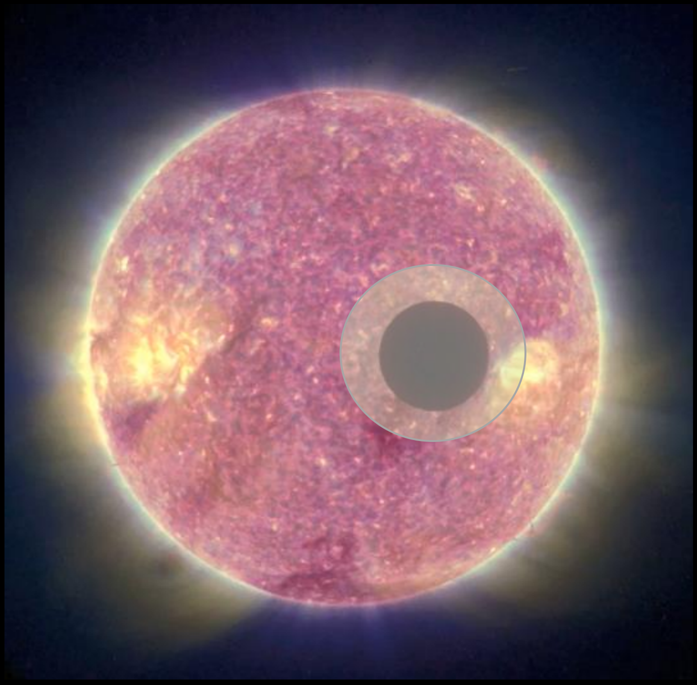
→ **dedicated platform**

- Stellar baseline for transit measurements



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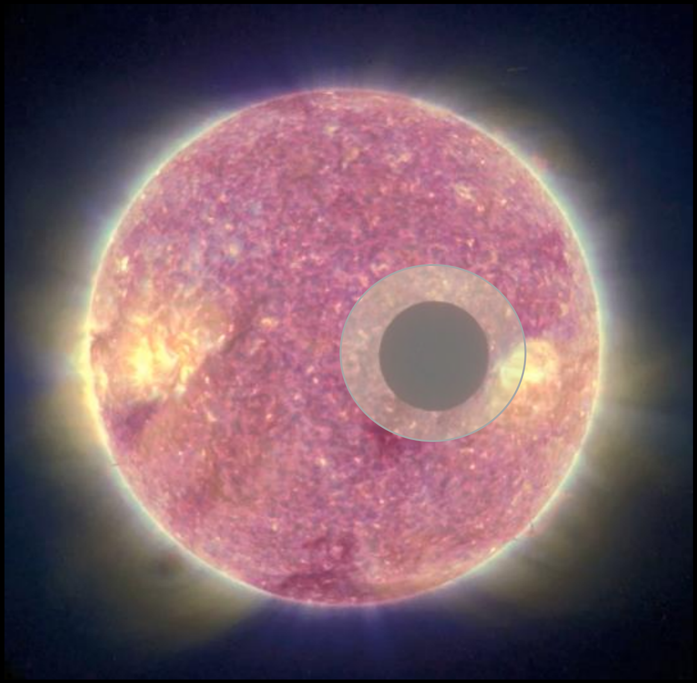
•Stellar baseline for transit measurements

→ **± 0.25 phase coverage**

•Self-consistent modeling framework



Extreme Exoplanet Atmospheres: challenges

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→ **multiple, consecutive transits, single data pipeline**

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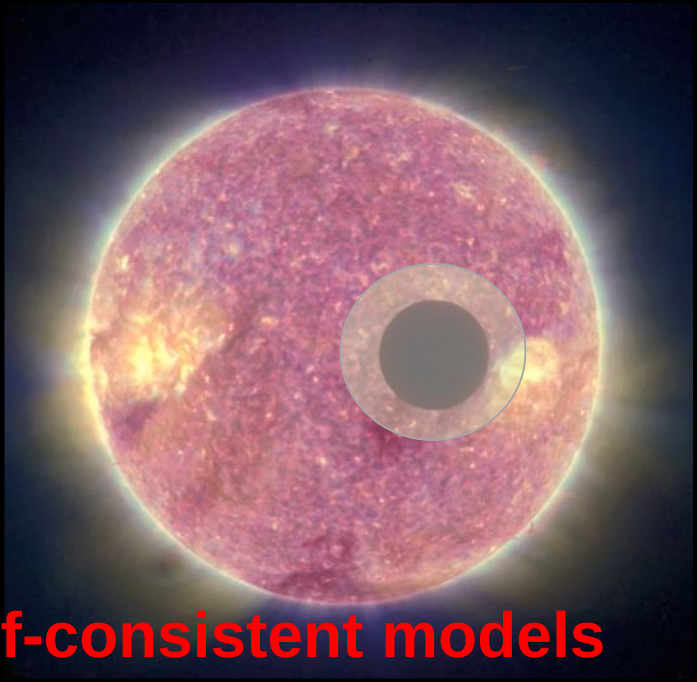
•Self-consistent modeling framework

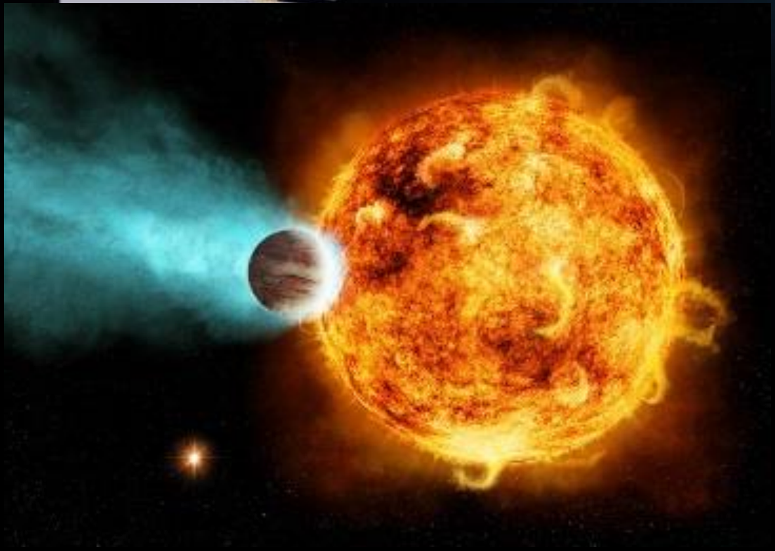


→ **state-of-the-art, physically self-consistent models**

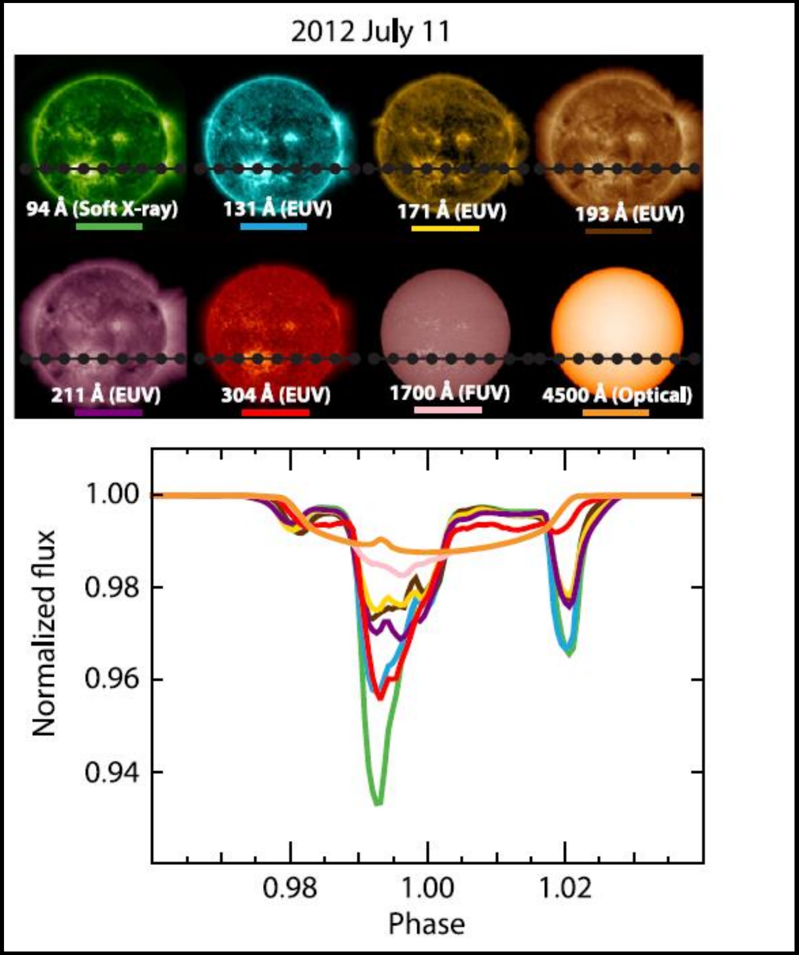
Colorado Ultraviolet Transit Experiment

Survey of ~12-24 short-period transiting planets around nearby stars:

1) Atmospheric mass-loss
2) Exoplanet magnetic fields?



CUTE: A NEW APPROACH TO ATMOSPHERIC MASS-LOSS MEASUREMENTS

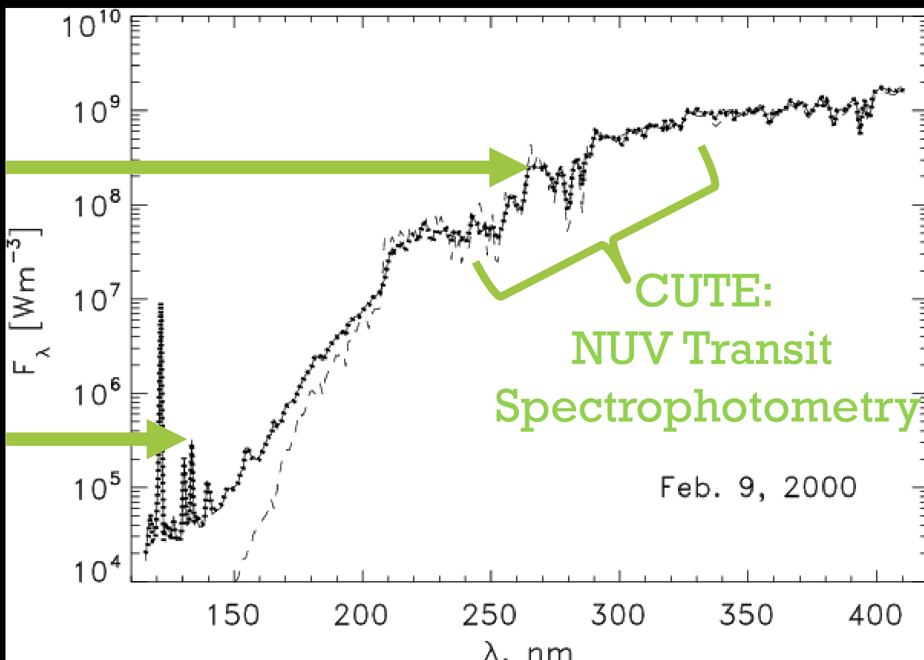


Llama & Shkolnik 2015, 2016

- Almost all detections of atmospheric mass loss have been carried out in the FUV (e.g. Vigal-Madjar+ 2004, 2013, Linsky+ 2010, Ben-Jaffel+ 2007, 2013, Kulow+ 2014, Ehrenrich+ 2015)
- Controversial interpretation due to low-S/N and uncertain chromospheric intensity distribution (e.g., Llama & Shkolnik 2015).
- The NUV has both a more uniform, mainly photospheric, intensity distribution AND an overall brighter background for transit observations.

CUTE: A NEW APPROACH TO ATMOSPHERIC MASS-LOSS MEASUREMENTS

Source: SDO



Krivova et al. 2006

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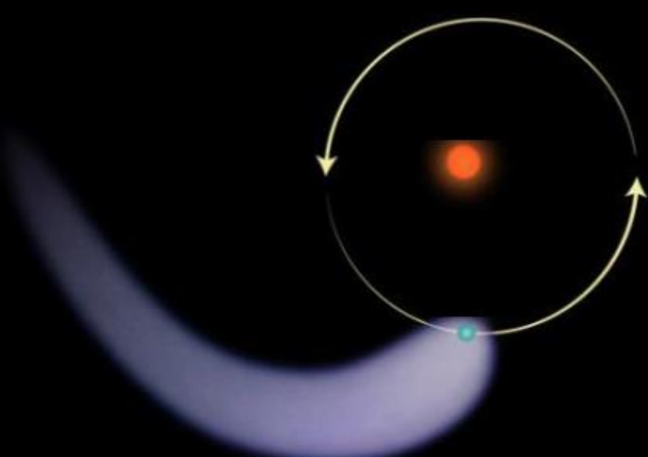
- Controversial interpretation due to low-S/N and uncertain chromospheric intensity distribution (e.g., Llama & Shkolnik 2015).
- The NUV has both a more uniform, mainly photospheric, intensity distribution AND an overall brighter background for transit observations, ~100-500x brighter.

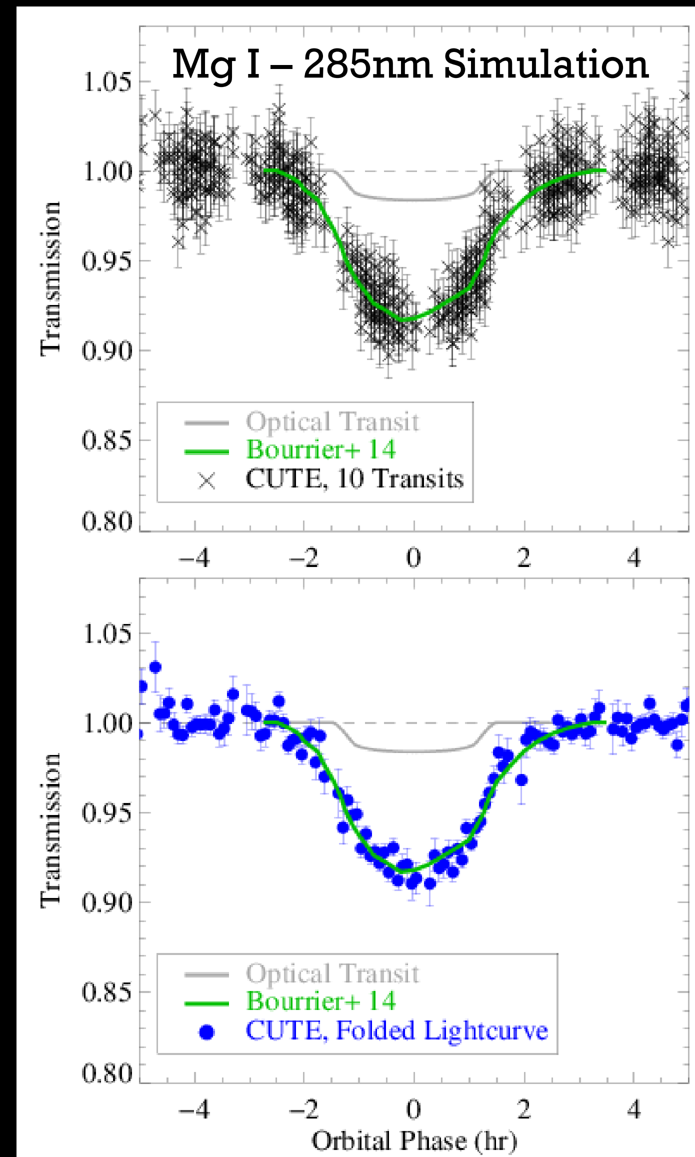
CUTE: A NEW APPROACH TO ATMOSPHERIC MASS-LOSS MEASUREMENTS

Survey of ~12-24 short-period transiting planets around nearby stars:

1) Atmospheric mass-loss & Variability

    -- heavy elements will be entrained in the rapid H & He outflow, getting ‘pulled’ out of the planet and into the circumplanetary envelope: **Mg, Fe, molecules, continuum absorption?**



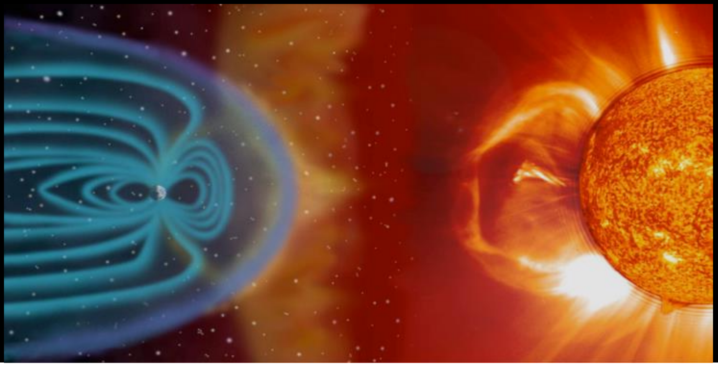


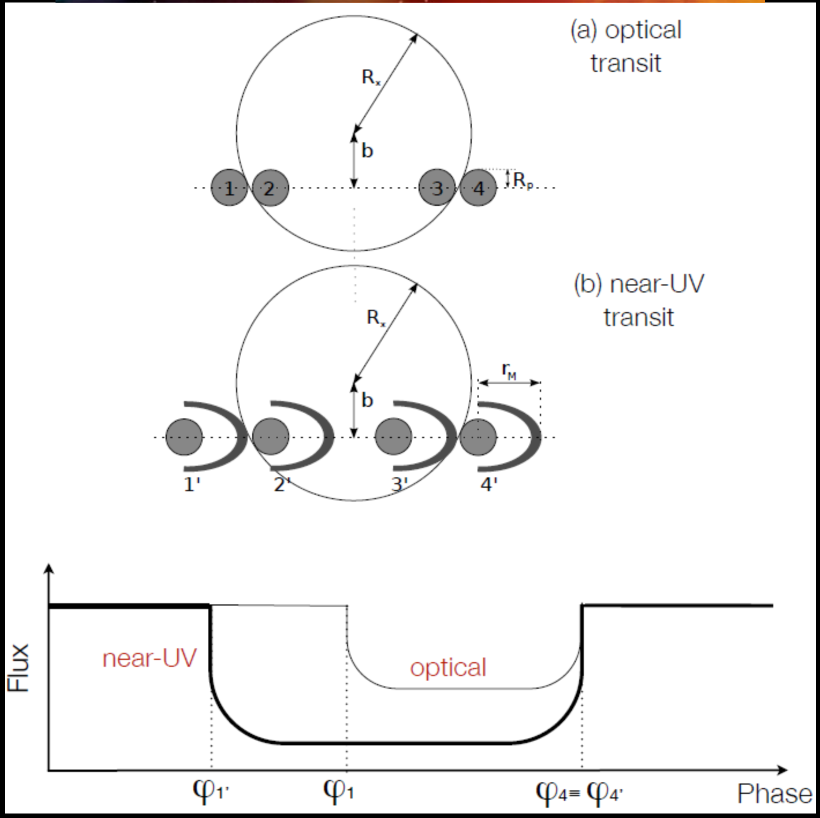
Survey of ~12-24 short-period transiting planets around nearby stars:

1) Atmospheric mass-loss
2) Exoplanet Magnetic Fields?

Light curve asymmetry to distinguish between magnetic and mass-loss supported bow shocks

Contemporaneous measure of stellar B-field enables calculation of planetary magnetic field -- potential to discover and quantify exoplanetary magnetism



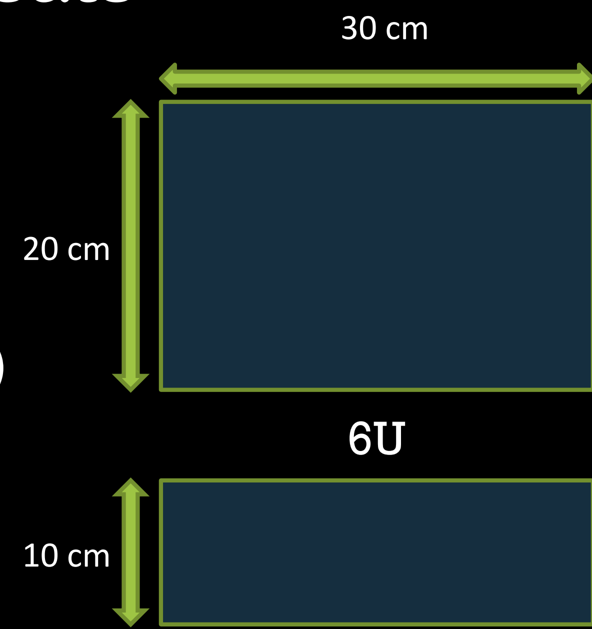


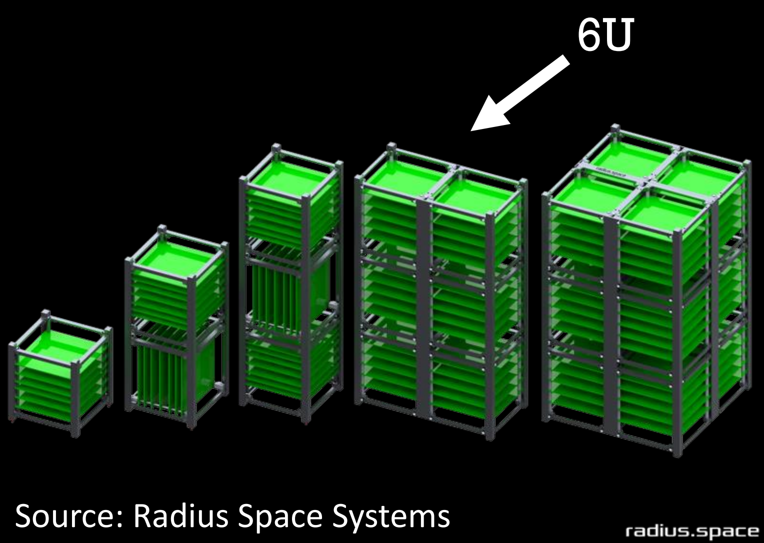
Vidotto et al. 2011

PI – France

DEDICATED SMALL SPACE MISSIONS: Astronomy with Cubesats

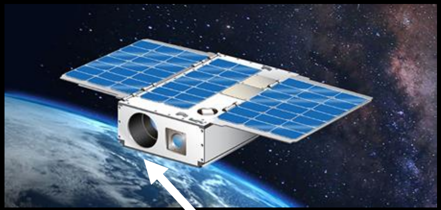
- CUTE: First NASA funded UV/O/IR astronomy cubesat
  - Halosat X-ray cubesat (P. Kaaret, Univ. Iowa)
  - More widely used in Earth observing, education, and solar physics (e.g. CSSWE, MinXSS – Mason et al. 2017)



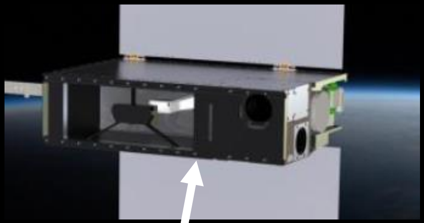


Source: Radius Space Systems

ASTERIA - JPL

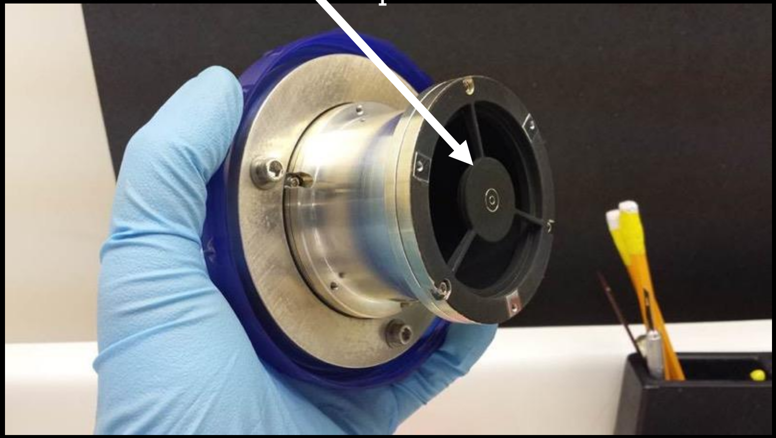


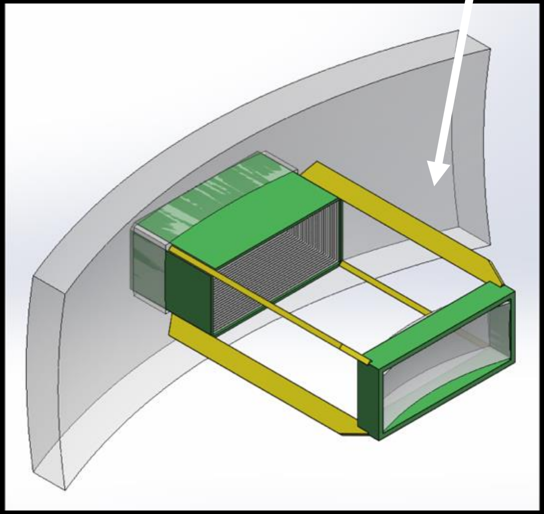
CUTE Telescope



See CUTE design overview in Fleming et al. (2017)

Source: Nu-Tek Precision Optics





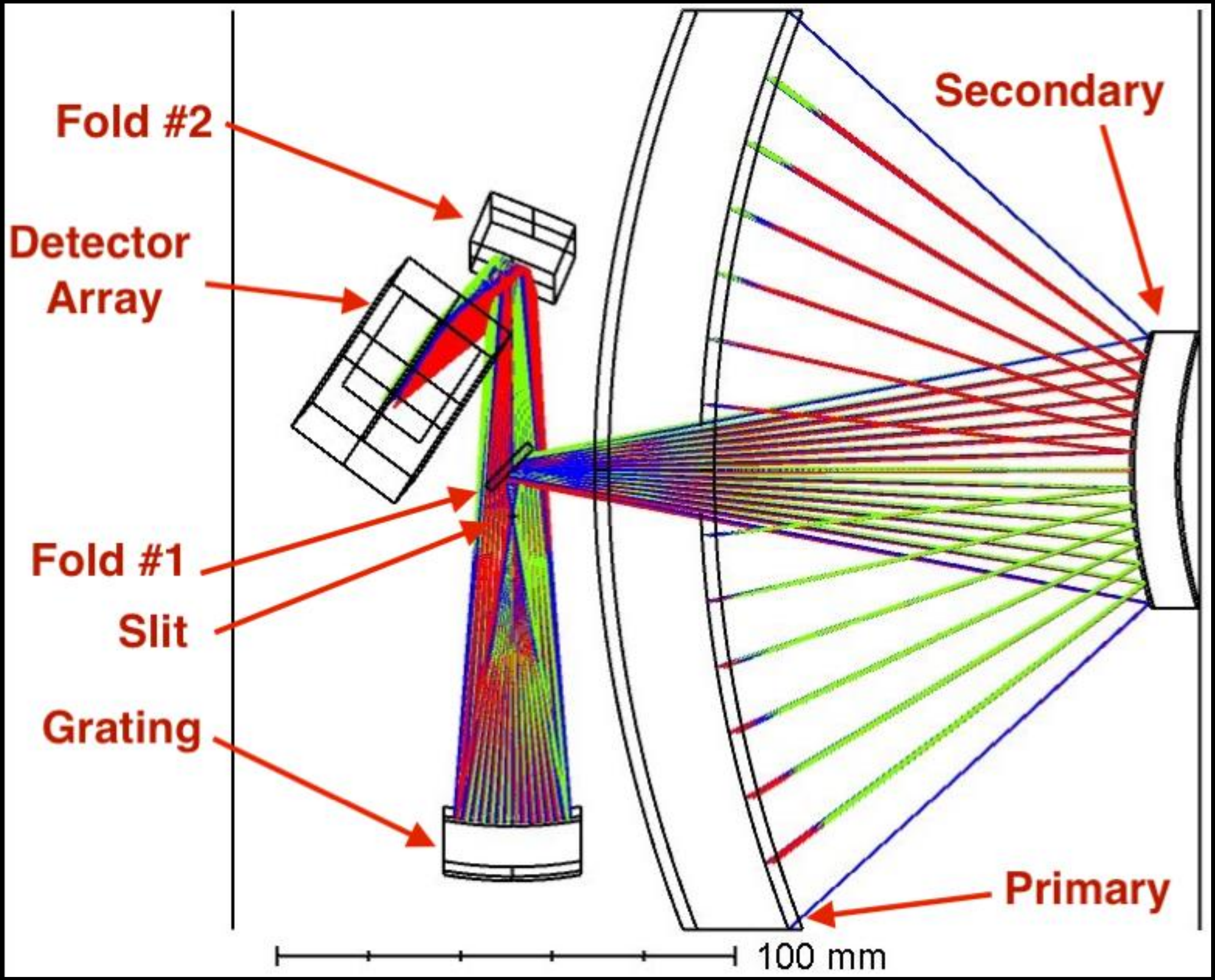
Geometric clear area for a 9cm Cassegrain: $A_T \sim$ **47 cm²**

Geometric clear area for a 20 x 8 cm cassegrain: $A_T \sim$ **152 cm²**

$A_{T,r}/A_{T,c}$ = **3.2x** more collecting area!

(requires robust scattered light control)

CUTE Science Instrument



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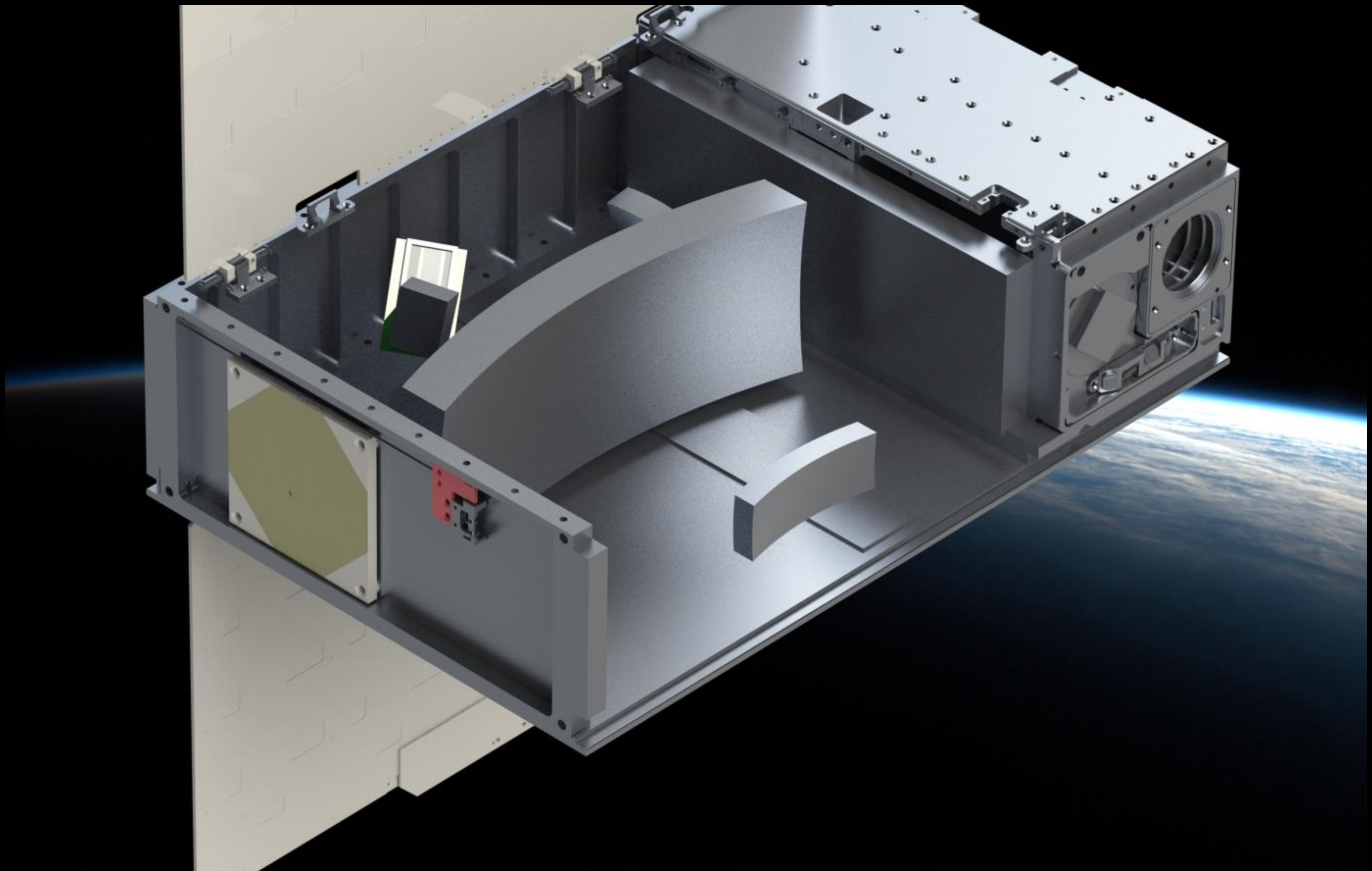
CUTE Science Instrument



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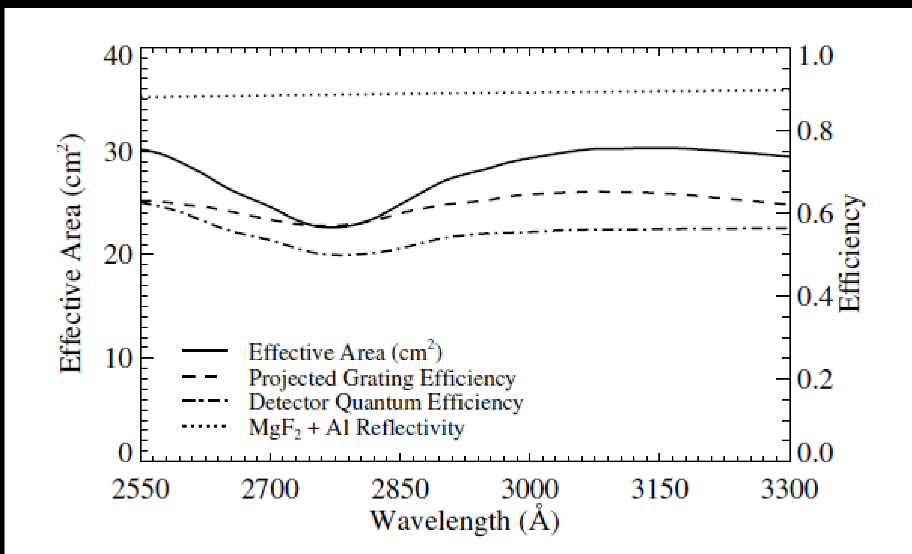
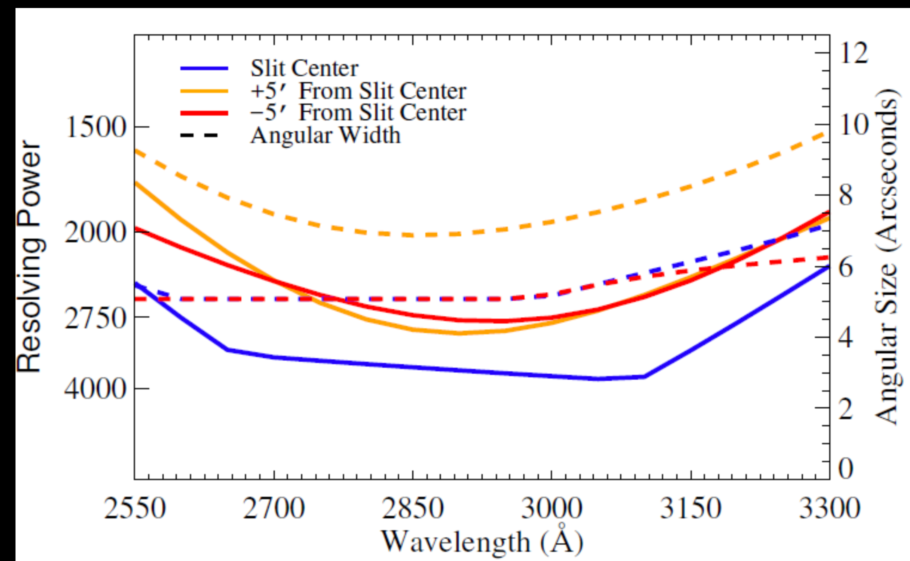
CUTE Predicted Performance





20 x 8 cm Telescope:

$A_{eff} = A_T\, R^5\, \varepsilon_{grat}\, QE_D$ = **25-30 cm^2**

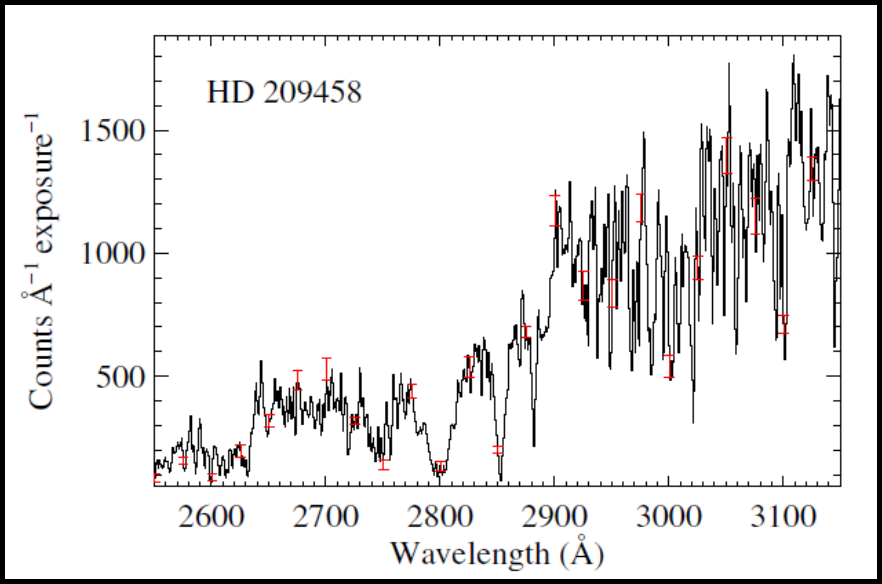
Performance relative to GALEX NUV Grism:

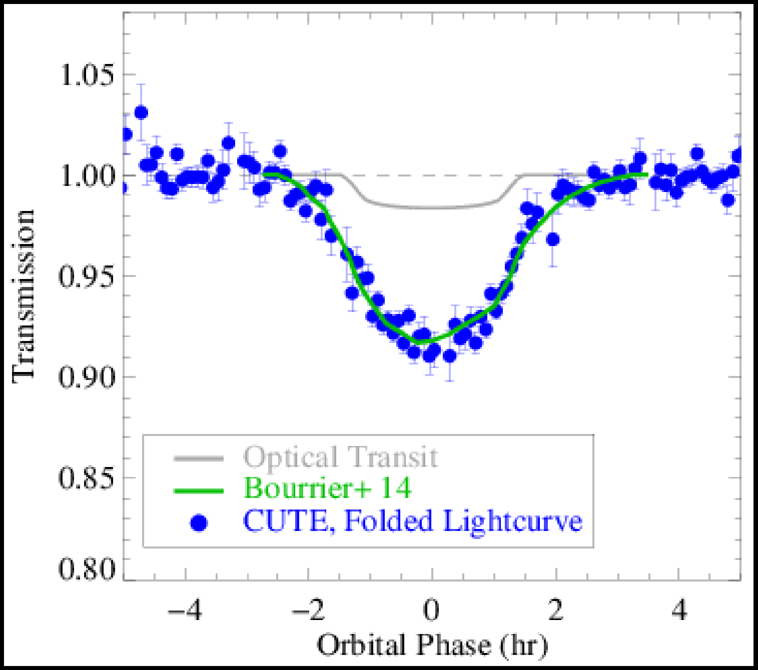
$A_{eff,CUTE}/A_{eff,GALEX}$ = ~60-70%

$R_{CUTE}/R_{GALEX,NUV}$ = 40x

Angular Resolution: Similar

CUTE Predicted Performance

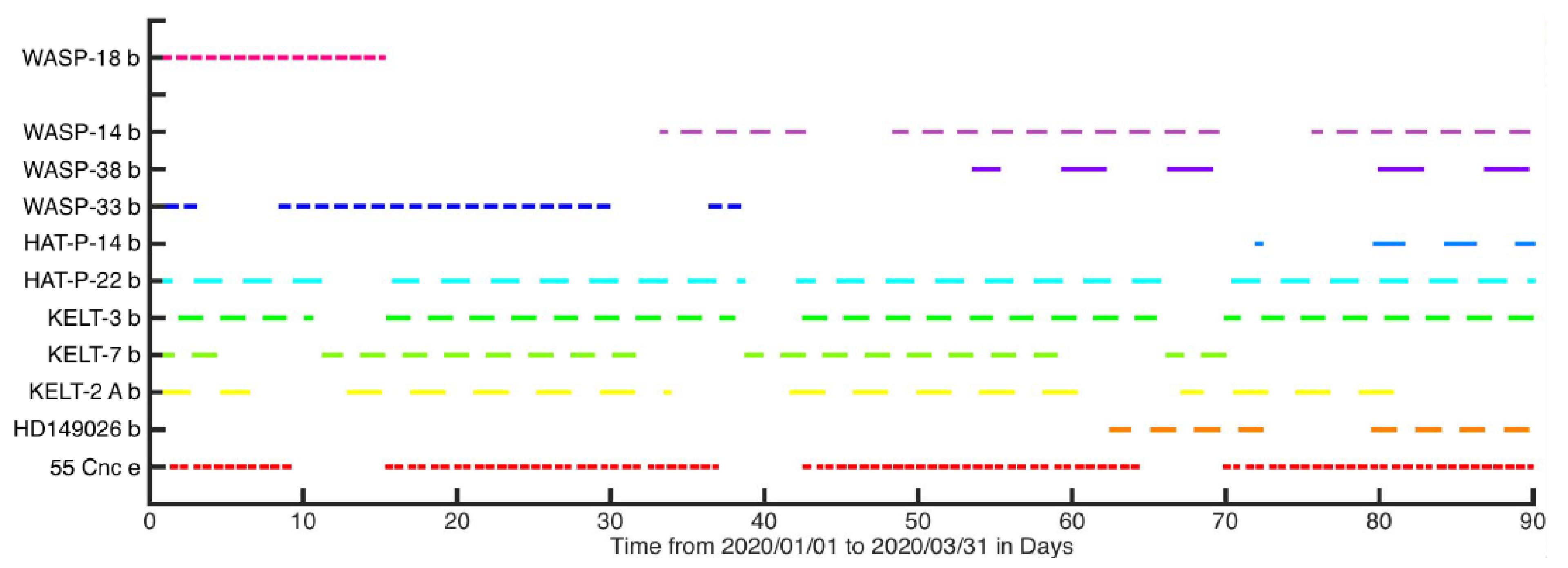




CUTE will achieve >3σ detections of transits as low as 0.1% depth for the brightest targets, and < 1% for all baseline targets with 5+ lightcurves per target:

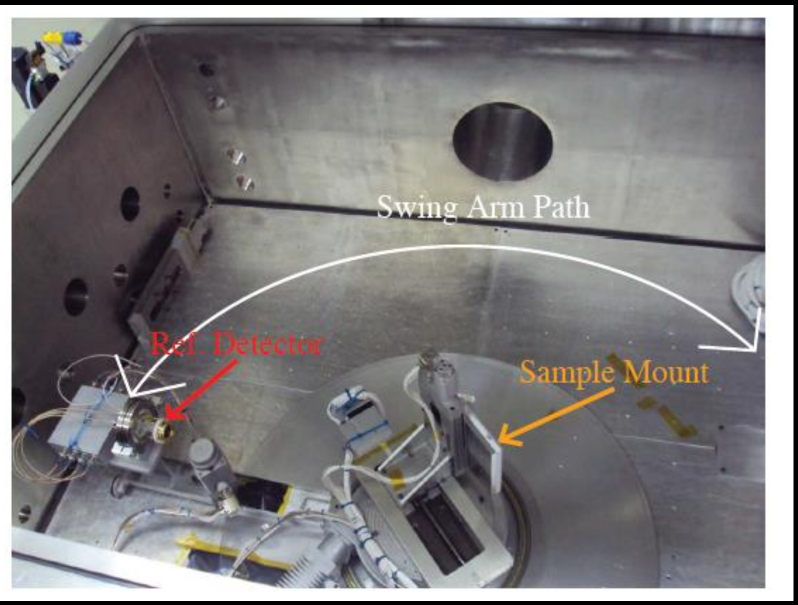
- Transit sensitivity to 0.7% depth for median target over 1 transit
- Capable of detecting geometric transit and atmospheric transit

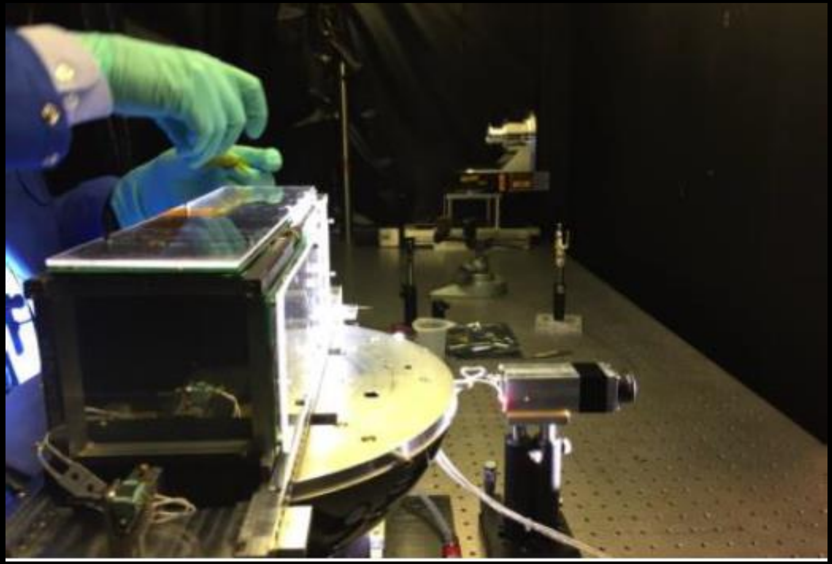
CUTE Example Target Visibility List



PI – France

CUTE Calibration and Operations at the University of Colorado

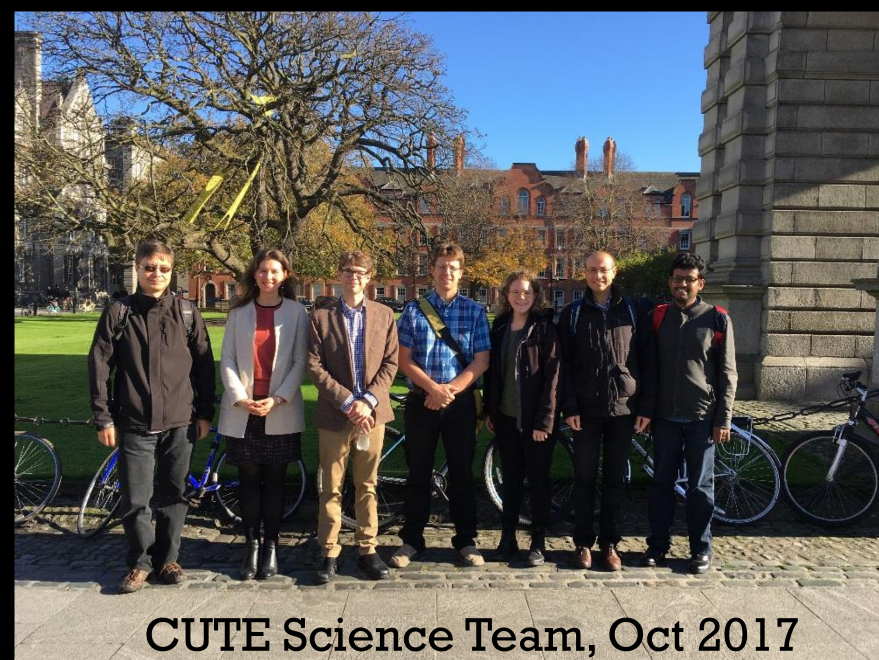




Student Training at the University of Colorado

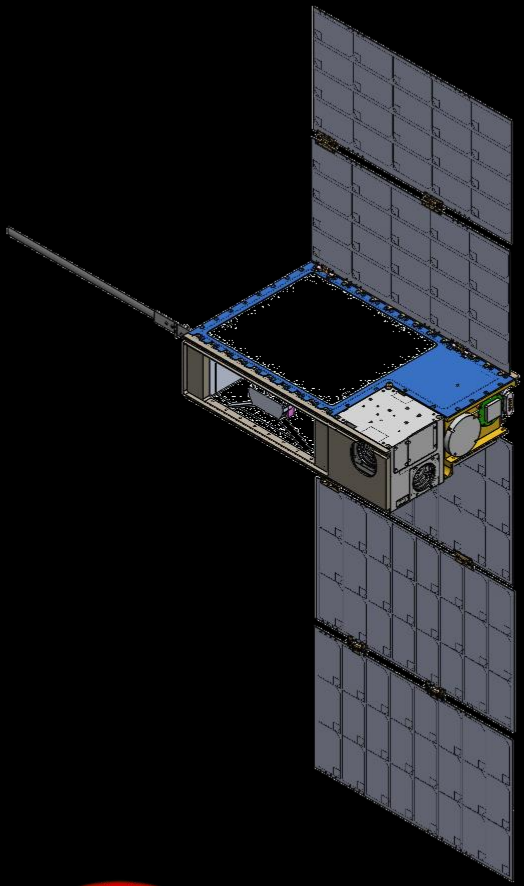
Hands-on training in space hardware

Suborbital Research Programs: end-to-end mission experience



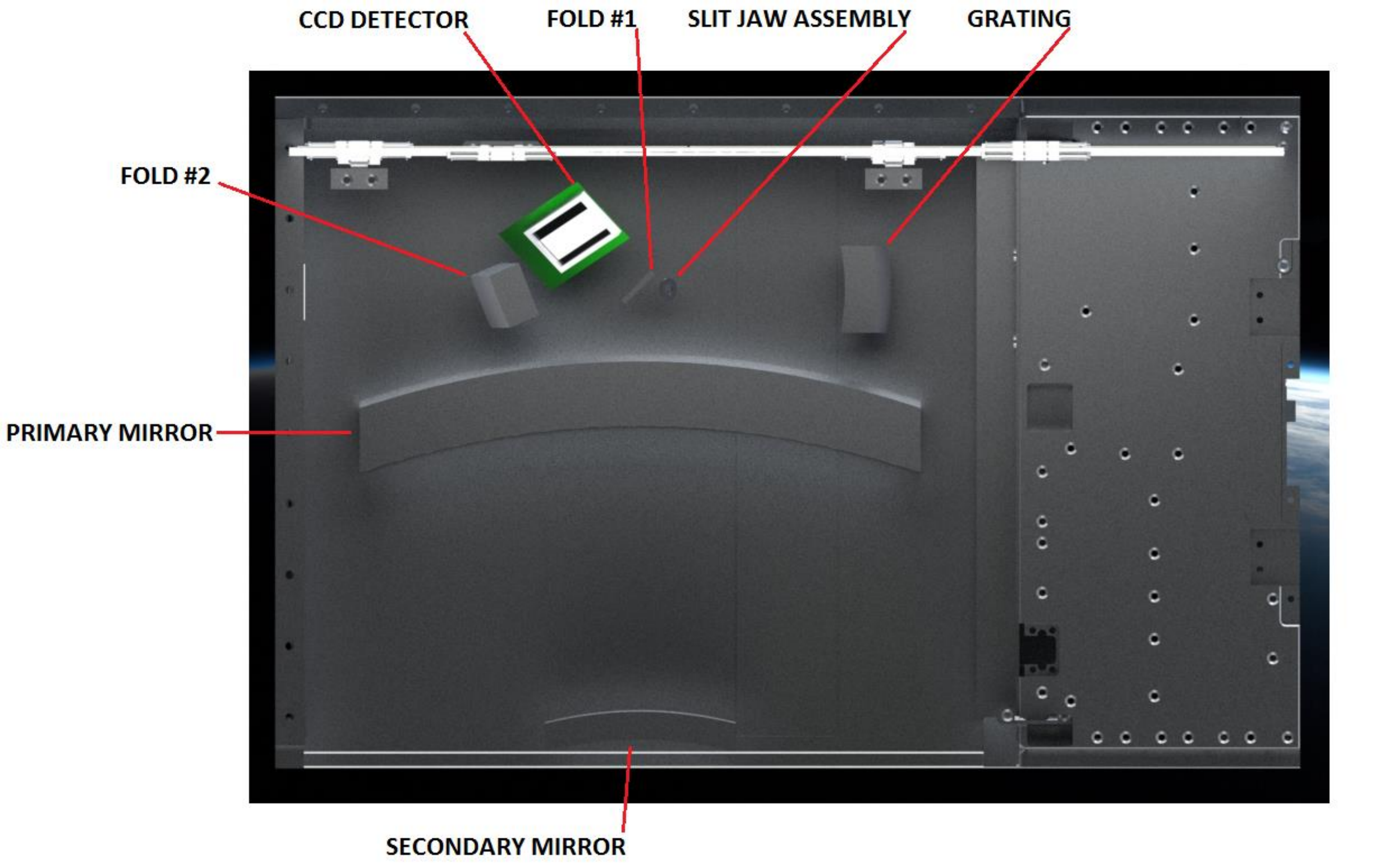
CUTE Science Team, Oct 2017

CUTE Status



- Proposed Roses D.3 APRA - March 2016
- Selected Feb. 2017
- Funding Started in July 2017
- First Science Team face-to-face meeting: Oct 2017
- Adorable logo creation: Winter 2017-18
- Launch Q1/Q2-2020
  - 7 Month Baseline mission:
  - 12 exoplanetary systems, 6-10 transits each
  - 12 – 20 additional systems in 12 month extended mission

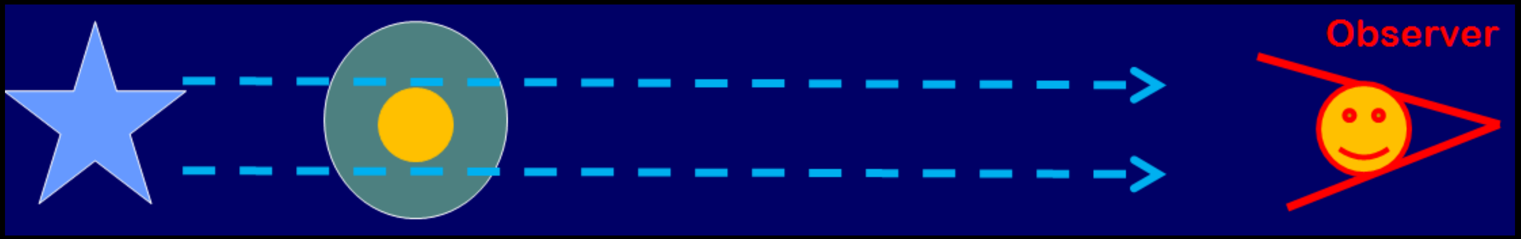
CUTE Science Instrument



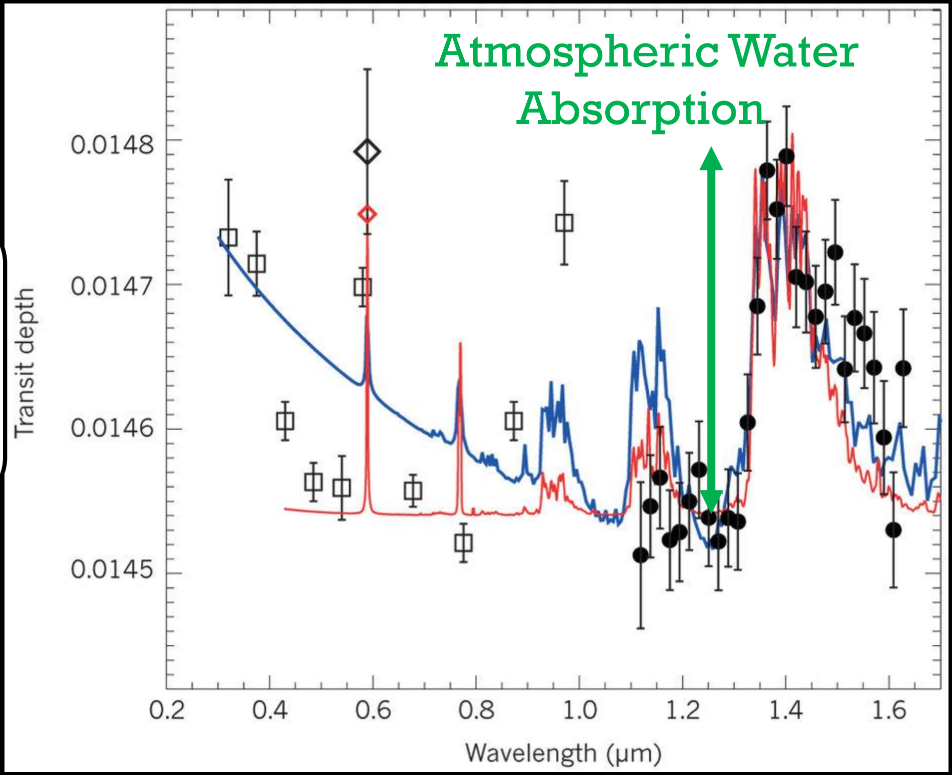
See CUTE design overview in Fleming et al. (2017)

EXOPLANET ATMOSPHERES

- Spectroscopic transit analysis can probe absorption by specific atmospheric constituents



Occultation Depth = $(R_P(\lambda) / R_*)^2$



Optical, NIR Transit of the HD 209458b

(Deming et al. 2013, see also Burrows et al. 2014, Sing et al. 2016)