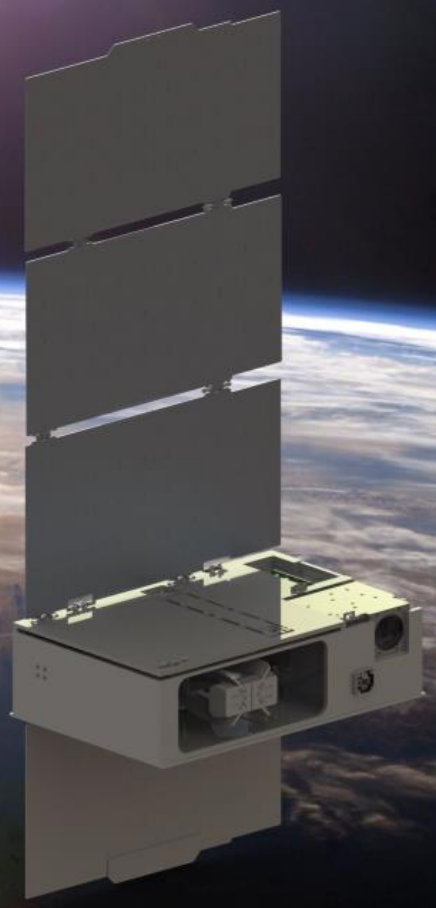
The Colorado Ultraviolet Transit Experiment (CUTE):

A cubesat to study the most extreme exoplanets



@CuteCubeSat

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

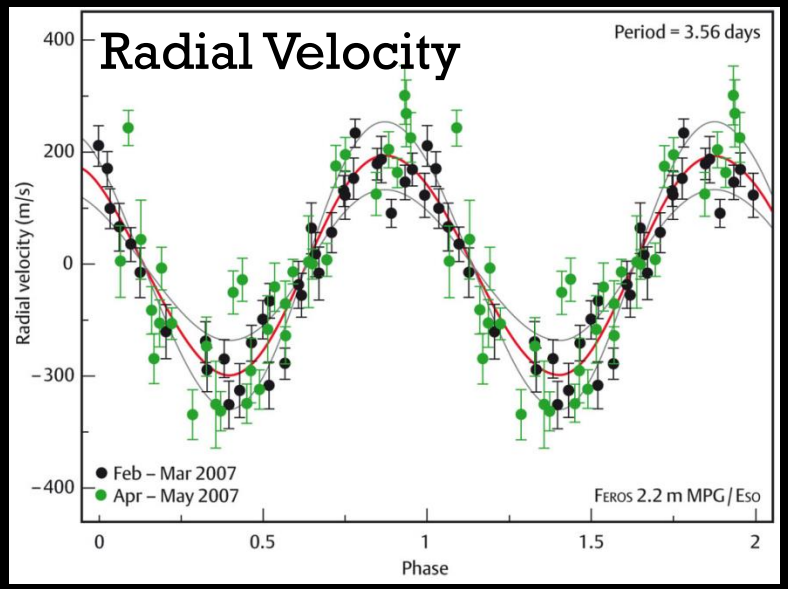
Kevin France – University of Colorado

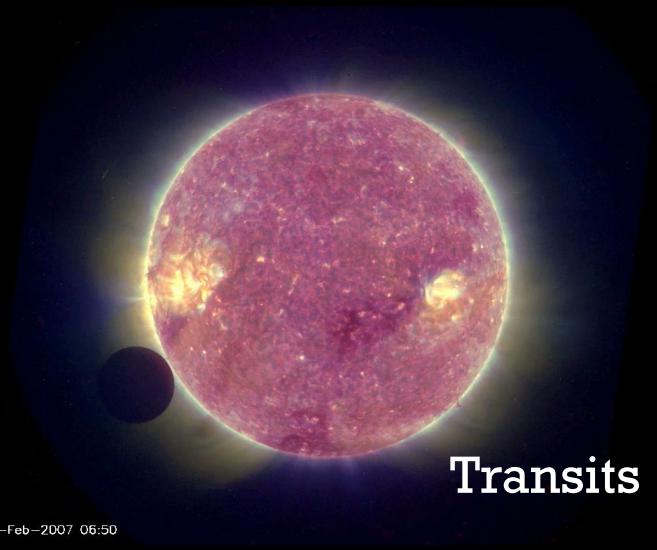
APAC Meeting, 15 March 2021

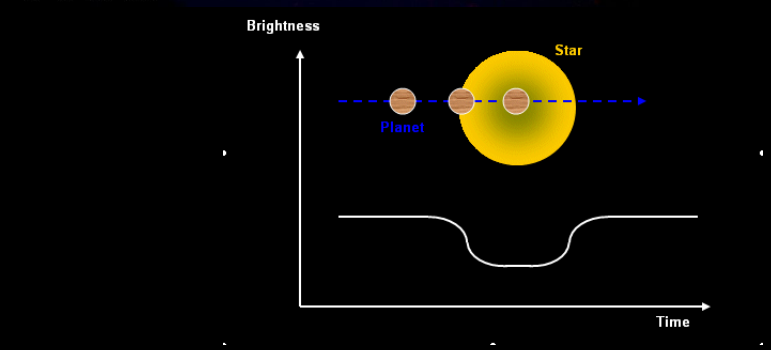
Extrasolar Planets:

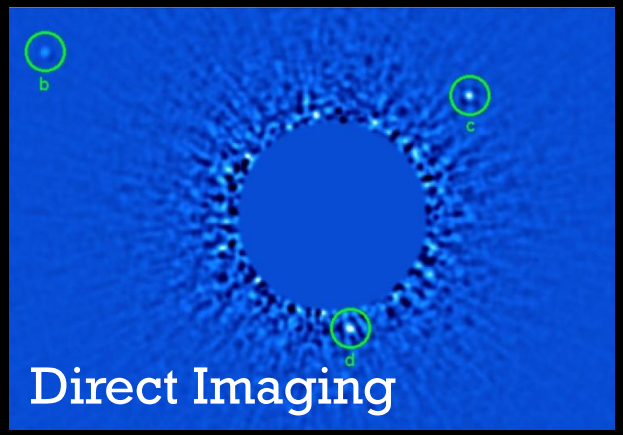
$N_{plan}(2021)$
~4300 Confirmed

~200 × $N_{plan}(1999)$



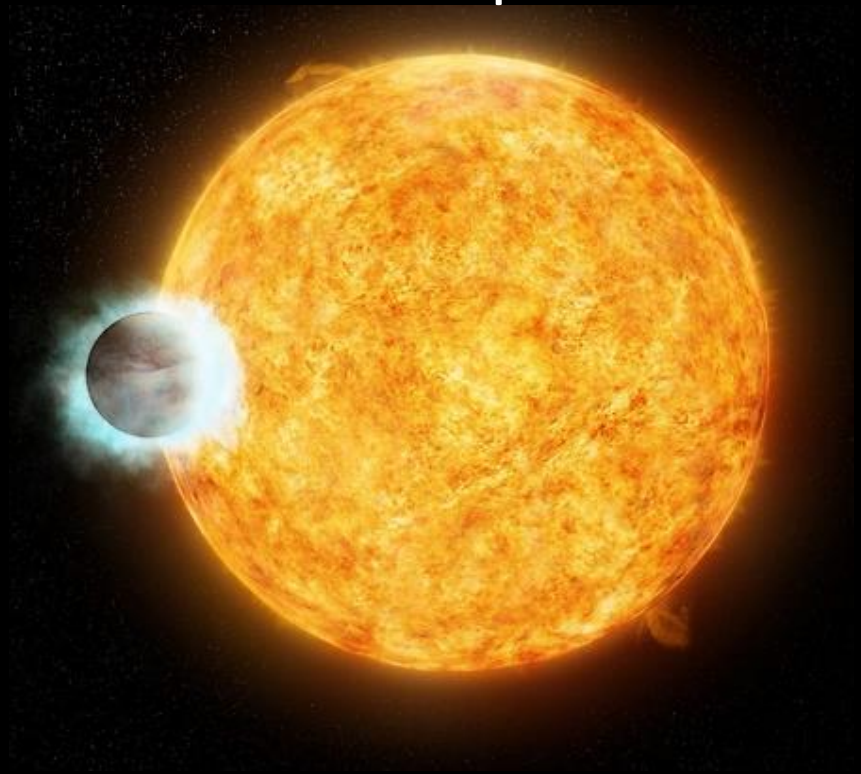






The Extrasolar Planet Zoo

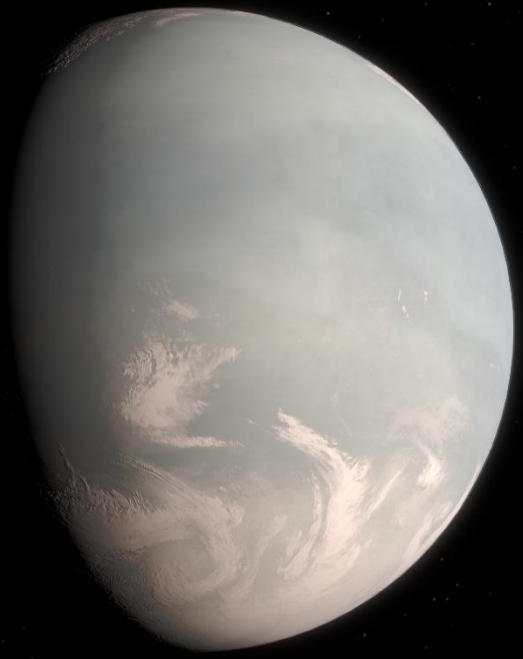
Hot Jupiter



WASP-18b, solar-type host
M ~ 10 M_J, R ~ 1.1 R_J
a ~ 0.02 AU
T_{eff} ~ 2400 - 3100 K

(Hellier et al. 2009)

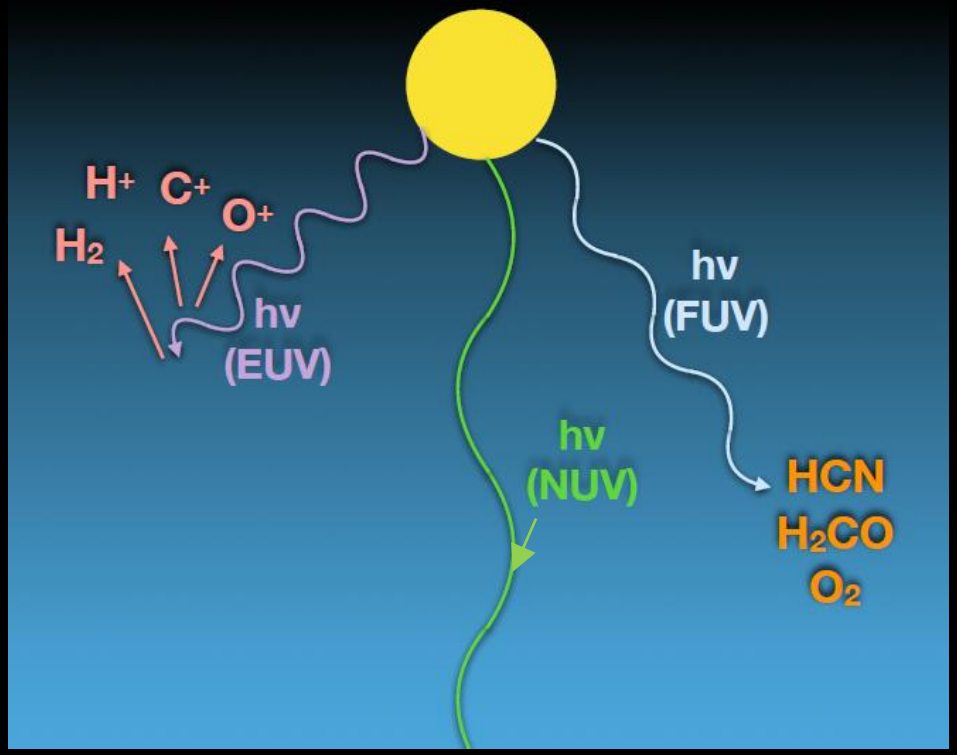
Super-Earth



GJ 832c, red dwarf host
M sin(i) ~ 5.2 M_E, R ~ 1.5 R_E
a ~ 0.16 AU
T_{eff} ~ 230 - 280 K

(Wittenmyer et al. 2014)

ATMOSPHERIC ESCAPE, NEAR AND FAR

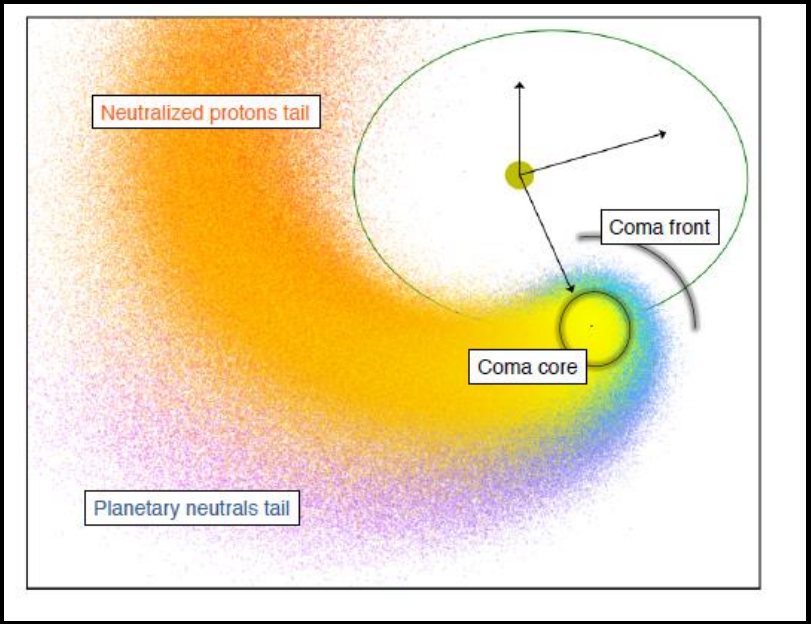


- Escape alters ~all planetary atmospheres
- The high-energy stellar emission dominates atmospheric photochemistry, ionization, and heating
- Exoplanets are laboratories for studying extreme mass loss that no longer operates in the solar system

Figure courtesy of
Paul Rimmer - Cambridge

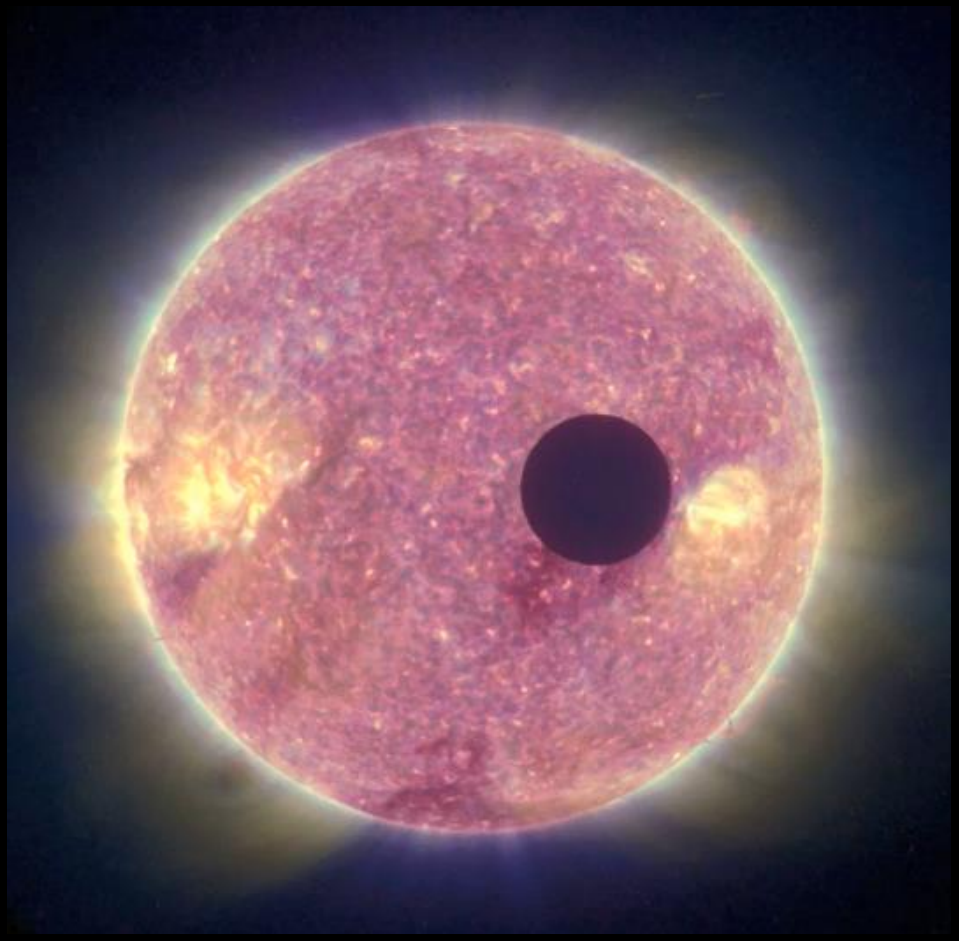
HOT JUPITER ATMOSPHERES

- **<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



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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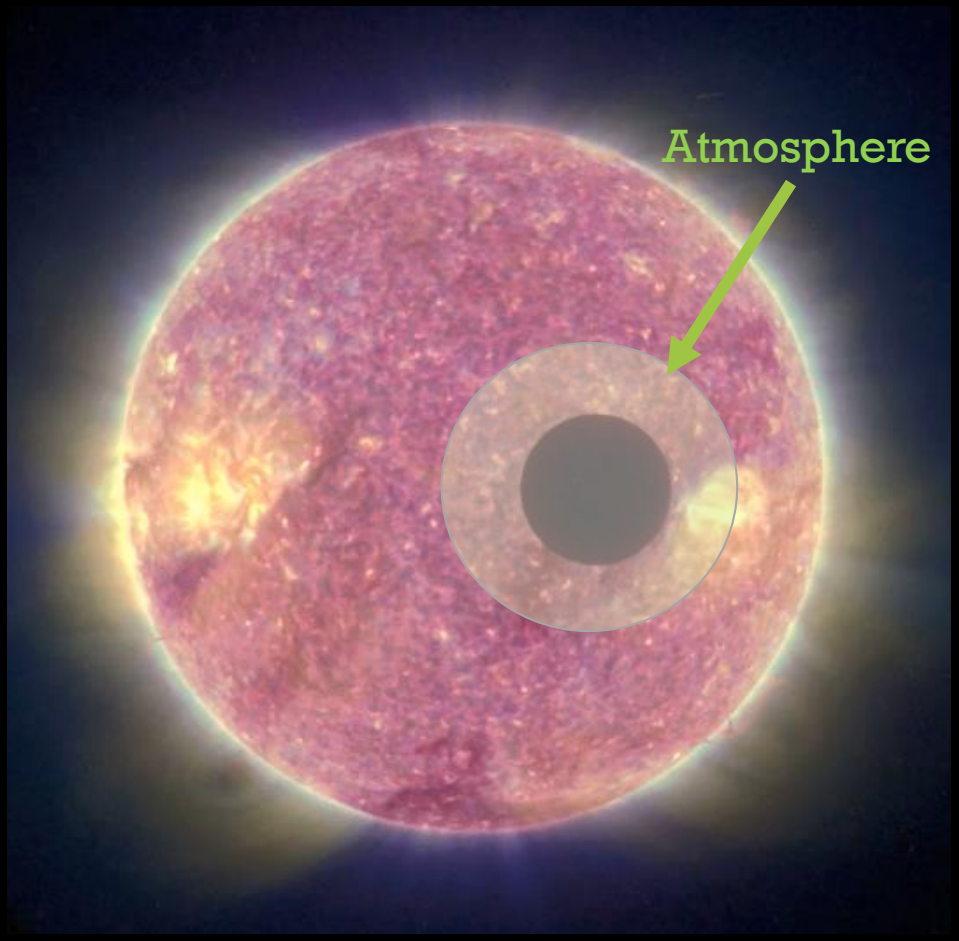

Occultation Depth = $(R_P(\lambda) / R_*)^2$

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

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

Transit Spectroscopy of Short-period Planets

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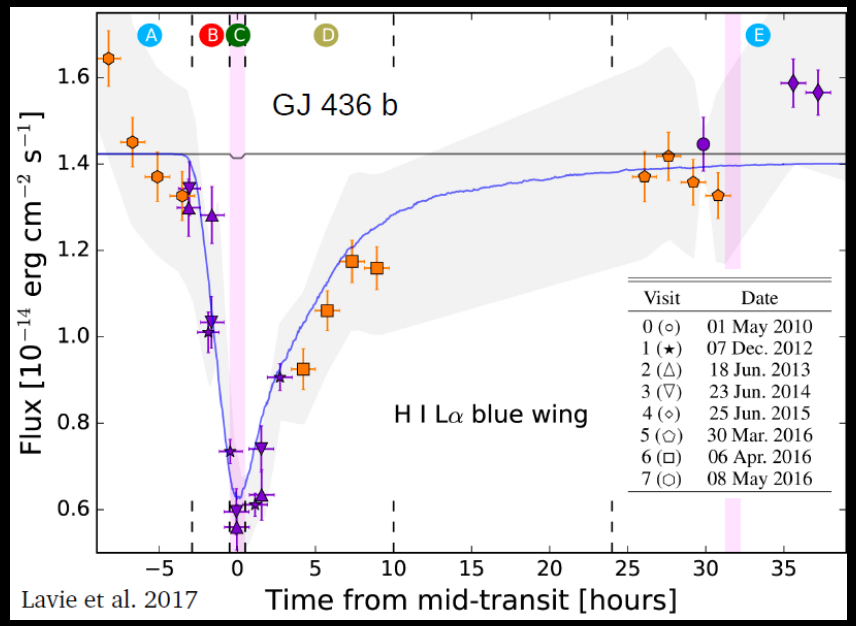
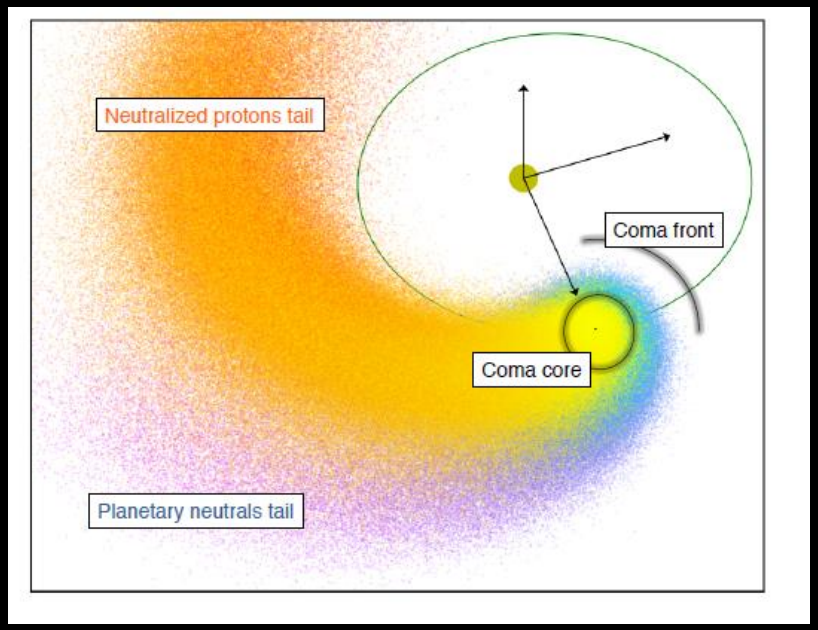




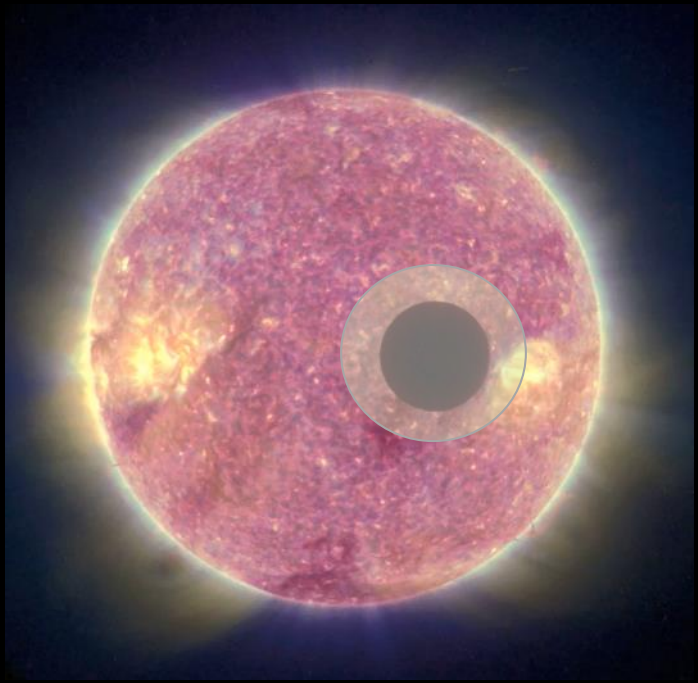
Hydrogen escaping from the upper atmosphere of GJ436b

(Kulow et al. 2014; Ehrenreich et al. 2015; Bourrier et al. 2016; Lavie et al. 2017)

Transit depth ~ 50% (!)

Extreme Exoplanet Atmospheres: challenges

- For the ~half-dozen Hot Jupiters measured with Hubble, we often find conflicting results, even on the same planet!



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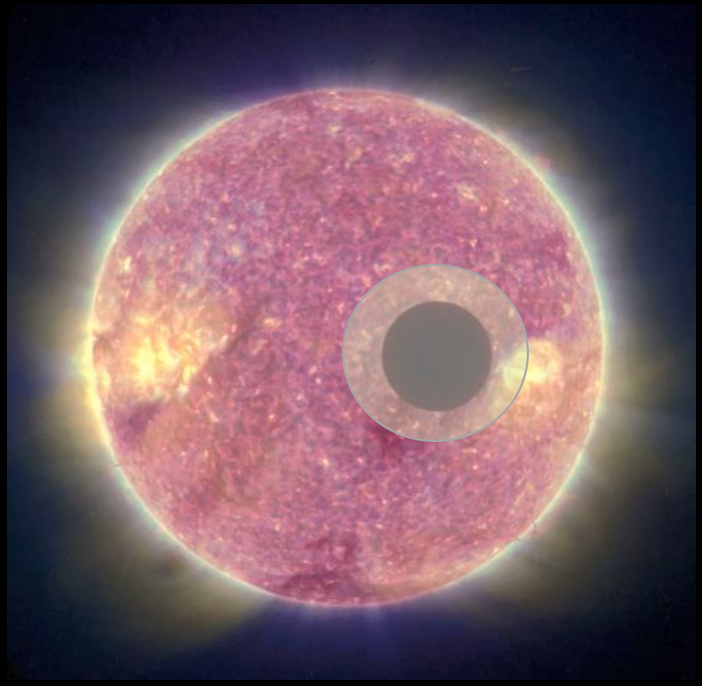
- Often discrepant results: time-variability in the star(?), planetary mass-loss rate (?), or apples-vs-oranges observations and data reduction algorithms



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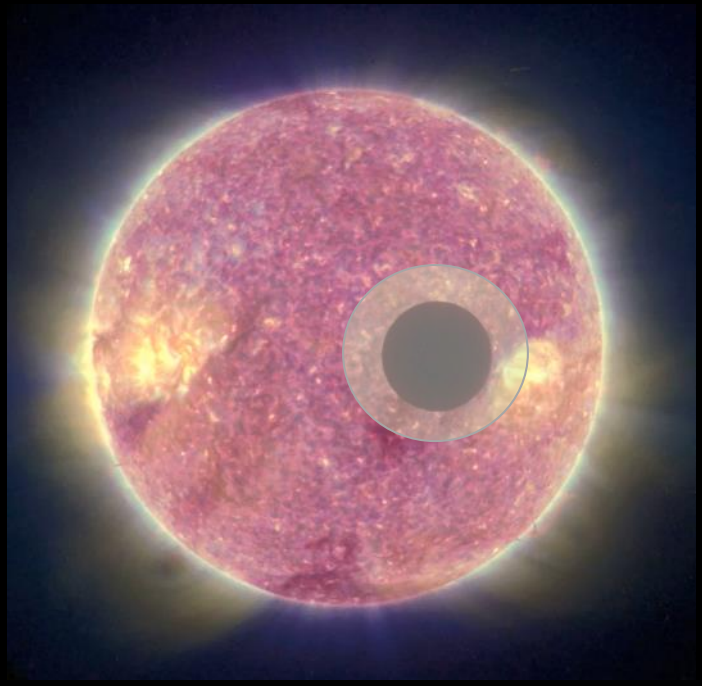
- Sample size of mass-loss measurements ~6, early-ingress ~1, late-egress ~2



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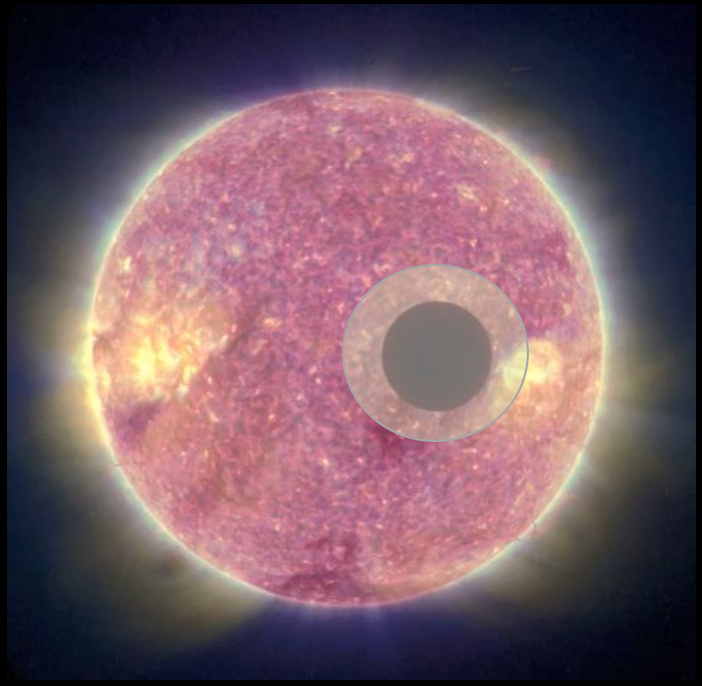

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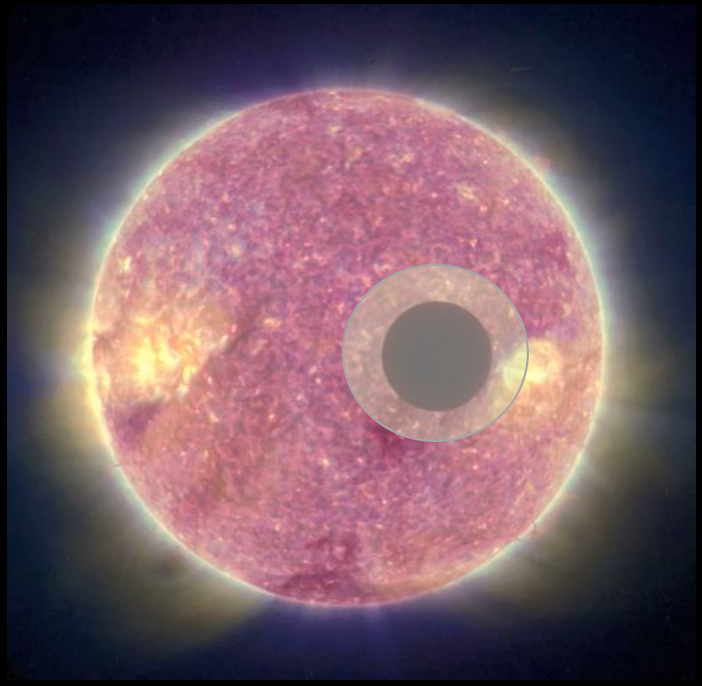
- Self-consistent modeling framework

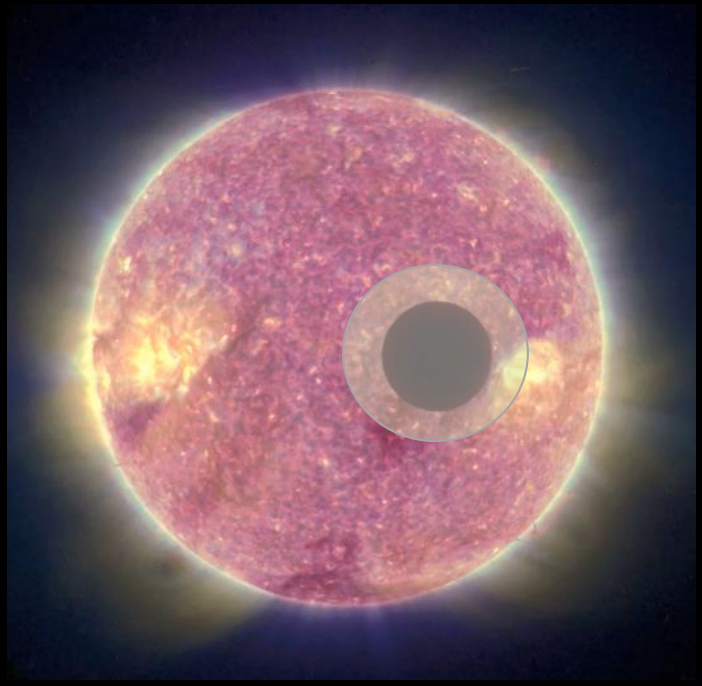


Extreme Exoplanet Atmospheres: challenges

- Often discrepant results: time-variability in the star(?), planetary mass-loss rate (?), or apples-vs-oranges observations and data reduction algorithms

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

- Sample size of mass-loss measurements ~6, early-ingress ~1, late-egress ~2



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  → **dedicated platform = more data**

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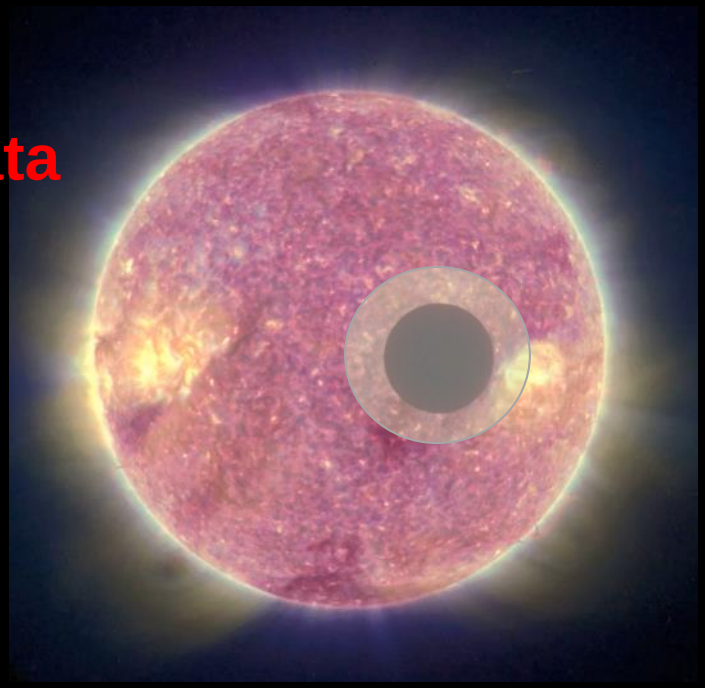

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  → **± 0.25 phase coverage**

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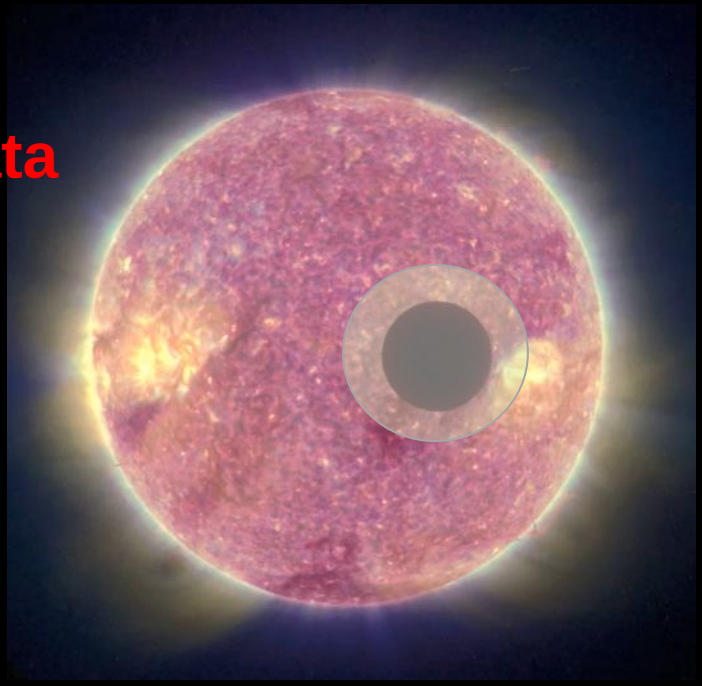

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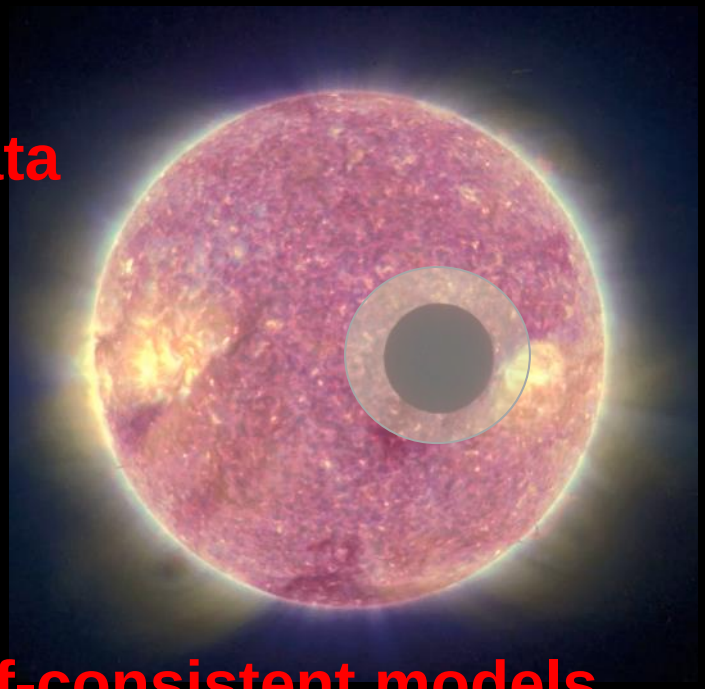
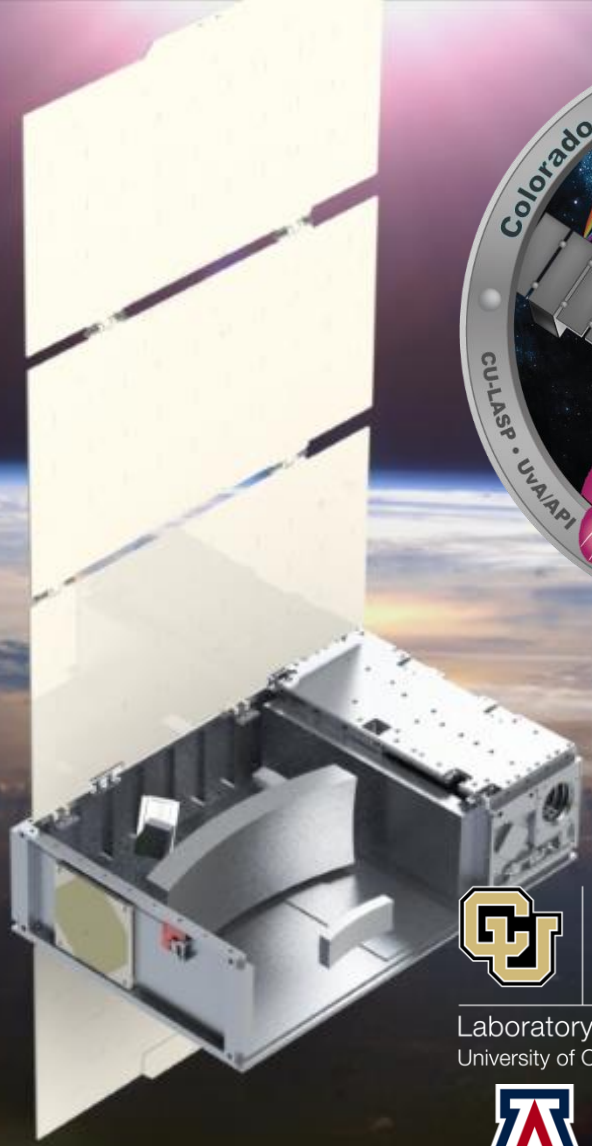
  → **± 0.25 phase coverage**

- Self-consistent modeling framework

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



Colorado Ultraviolet Transit Experiment (CUTE)



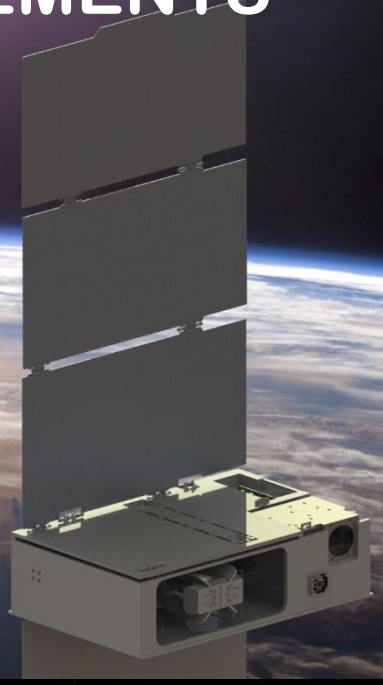
University of Colorado:
Kevin France (PI), Brian Fleming (PS), Arika Egan, Rick Kohnert (PM), Nicholas Nell, Stefan Ulrich, Nick DeCicco, Ambily Suresh, Wilson Cauley

United States:
Tommi Koskinen (UofA), Matthew Beasley (SwRI), Keri Hoadley (Caltech/Iowa)

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

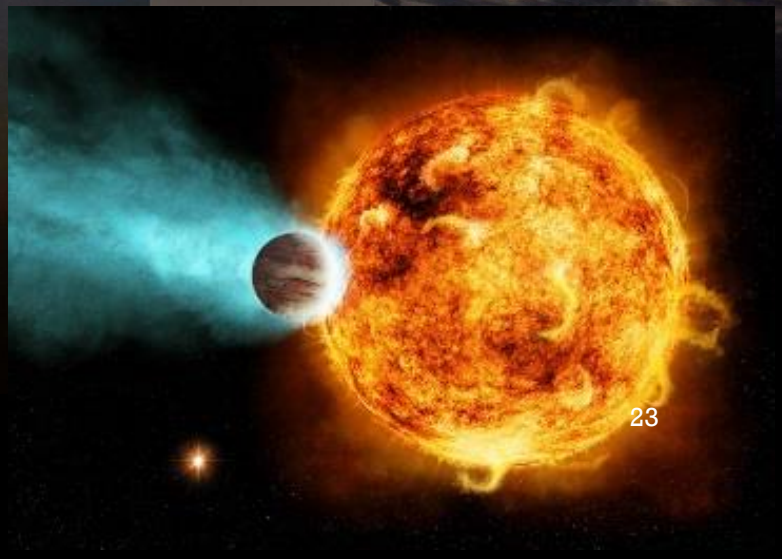
Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

CUTE: A NEW APPROACH TO ATMOSPHERIC MASS-LOSS MEASUREMENTS

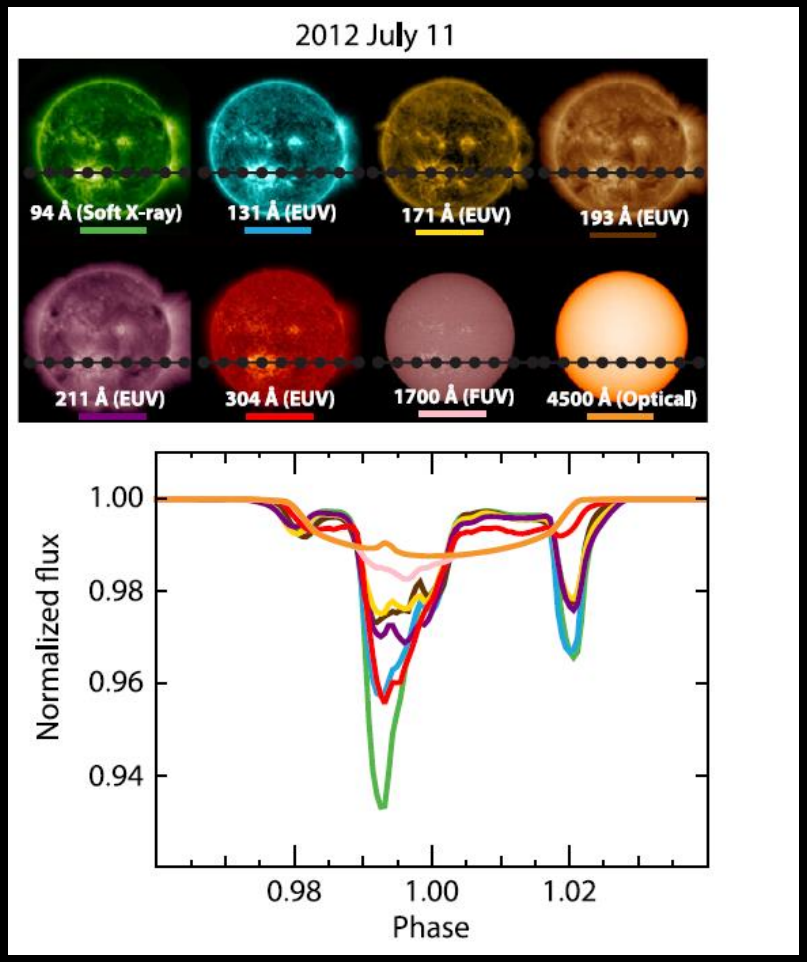


Survey of ~12-24 short-period transiting planets around nearby stars:

1) Atmospheric mass-loss rates
2) Escaping atmosphere composition



CUTE: A NEW APPROACH TO ATMOSPHERIC MASS-LOSS MEASUREMENTS

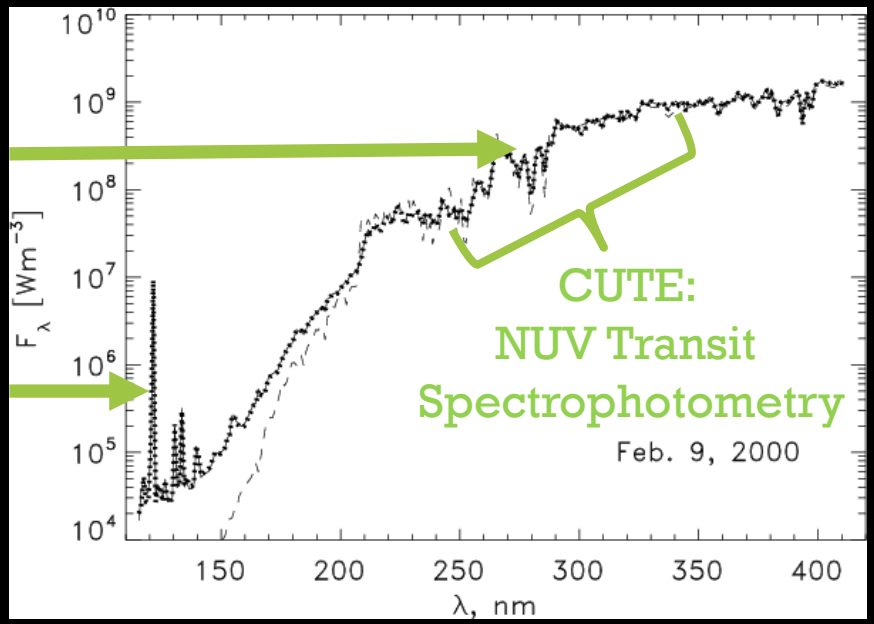


Llama & Shkolnik 2015, 2016

- **Most detections** of atmospheric mass loss have been carried out in the **FUV, Lyα** (e.g. Vidal-Madjar+ 2004, 2013, Linsky+ 2010, Ben-Jaffel+ 2007, 2013, Kulow+ 2014, Ehrenreich+ 2015, Bourrier et al. 2018)
- Controversial interpretation due to low-S/N and uncertain chromospheric intensity distribution (e.g., Llama & Shkolnik 2015).
- **The NUV has a more uniform, mainly photospheric, intensity distribution**

CUTE: A NEW APPROACH TO ATMOSPHERIC MASS-LOSS MEASUREMENTS

Source: SDO



Krivova et al. 2006

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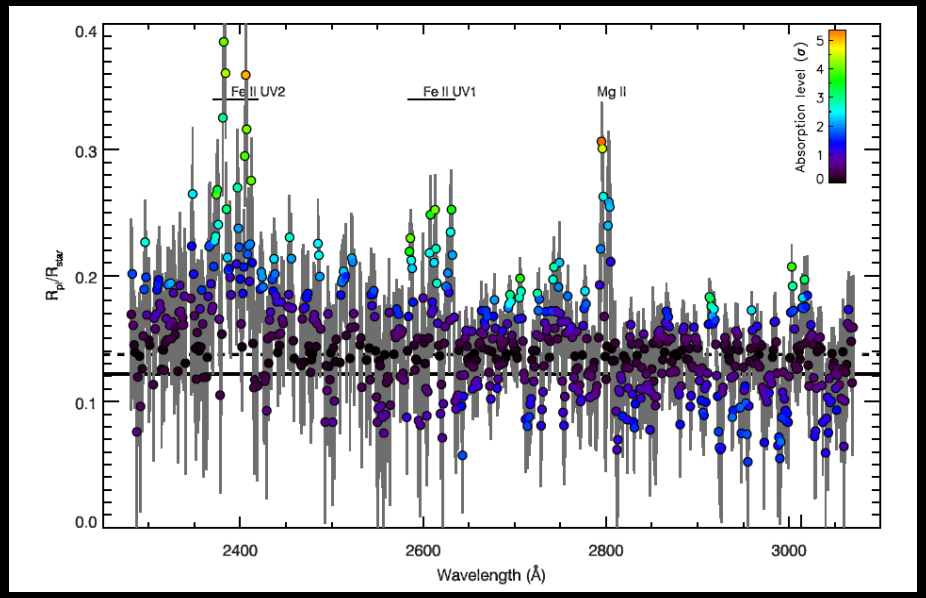
- Controversial interpretation due to low-S/N and uncertain chromospheric intensity distribution (e.g., Llama & Shkolnik 2015).
- The NUV has both a more uniform, mainly photospheric, intensity distribution AND an **overall brighter background for transit observations, ~50-1000x brighter.**

CUTE: A NEW APPROACH TO ATMOSPHERIC MASS-LOSS MEASUREMENTS

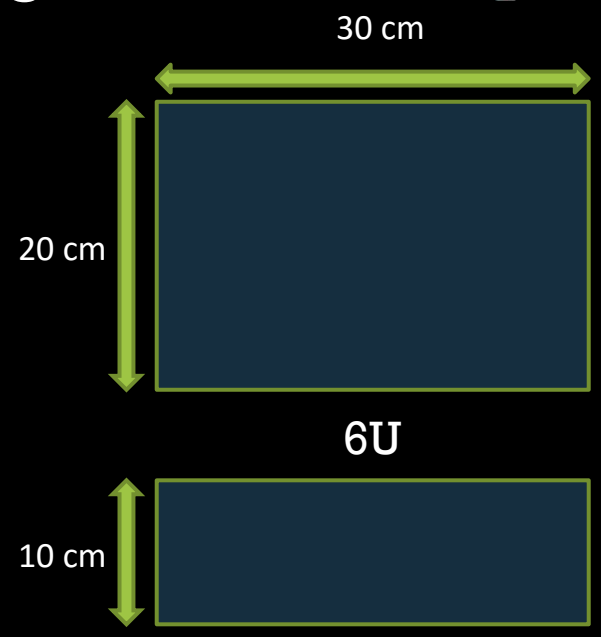


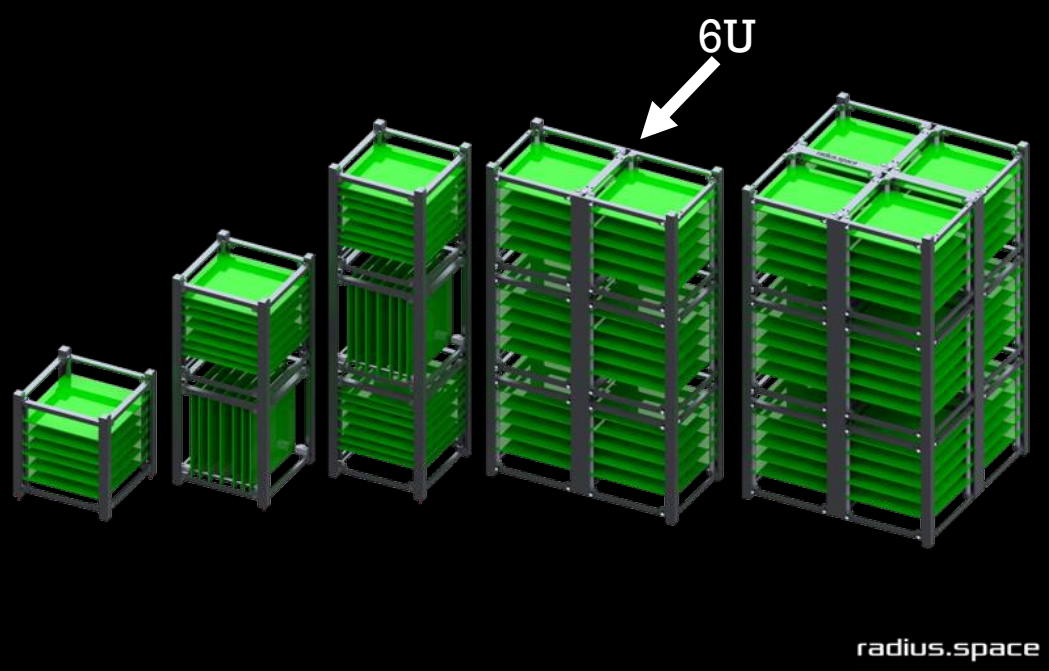
WASP-121b; Sing et al. 2019

- Brighter stellar flux enables spectroscopy in a correspondingly smaller platform
- <u>Spectroscopy</u> required to isolate escaping gas species

Astronomy with Cubesats: Dedicated Mission Architecture

- CUTE: First NASA grant 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)





ASTERIA - JPL

France et al. (2020)

Astronomy with Cubesats: Dedicated Mission Architecture

CUTE:

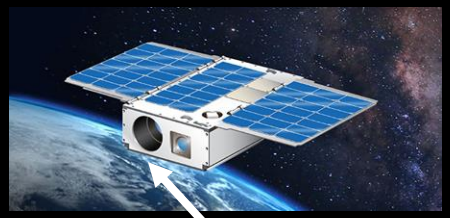
11.0 cm x 23.7cm x 36.2 cm

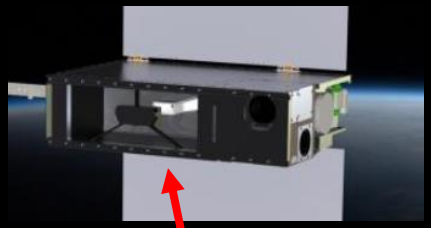
Family Size Cheerios available on Walmart.com:

7.8 cm x 23.9 cm x 34.4 cm

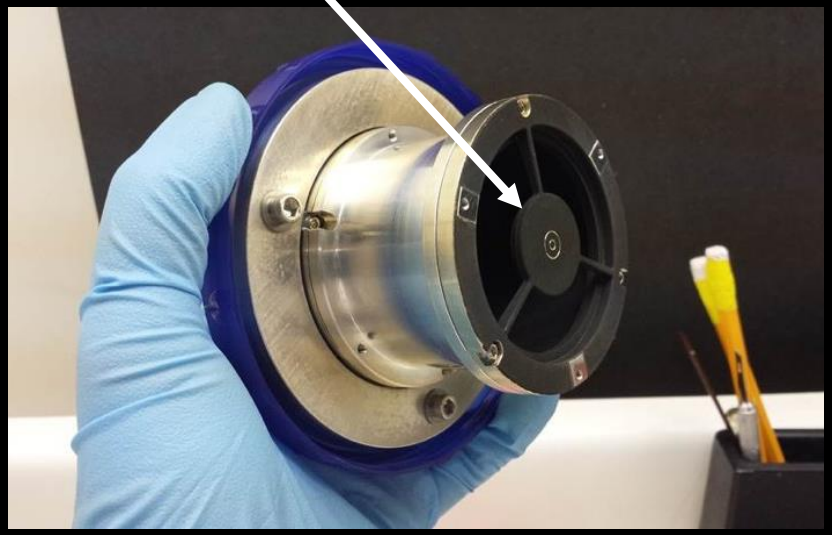
France et al. (2020)

CUTE Telescope

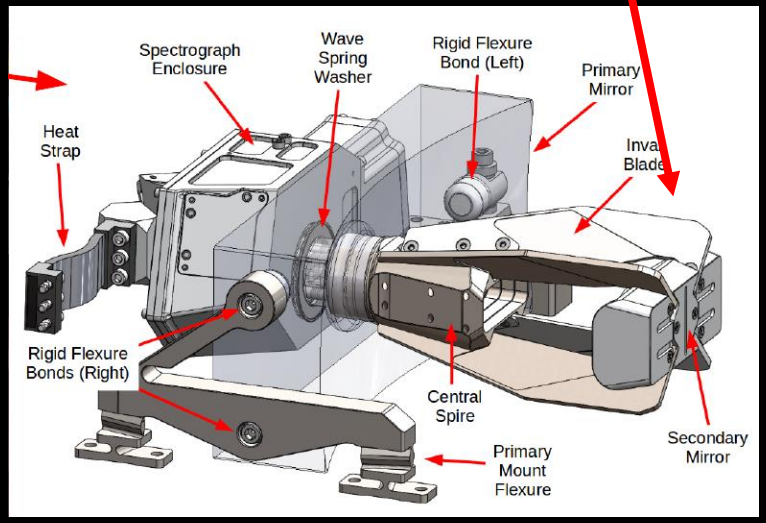




Source: Nu-Tek Precision Optics



See CUTE design overview in Fleming et al. (2018)



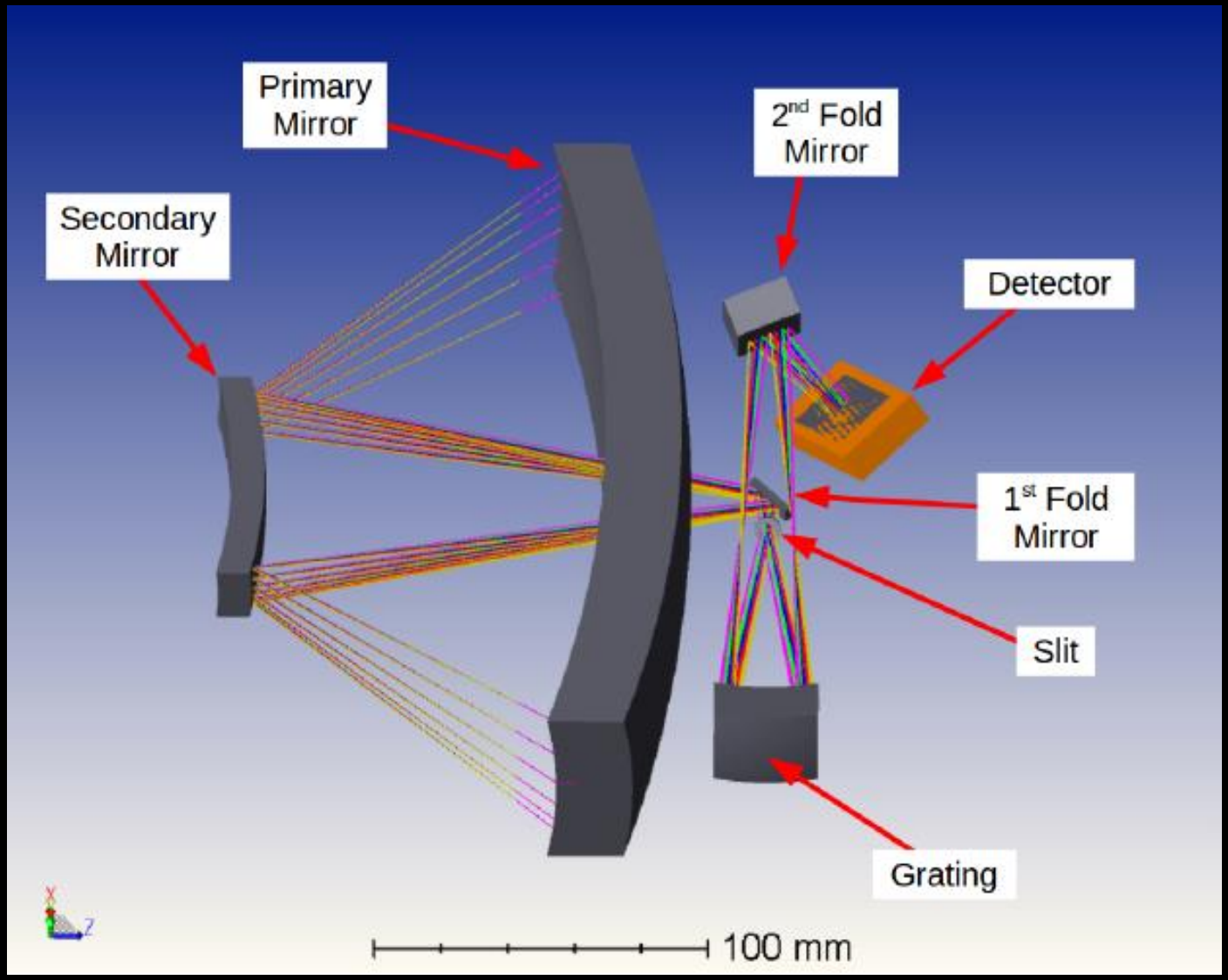
Geometric clear area for a 9cm Cassegrain: A_T ~ **47 cm²**

Geometric clear area for a 20 x 8 cm Cassegrain: A_{CUTE} ~ **140 cm²**

CUTE ~ **3 x** more collecting area

France et al. (2020), Egan et al. (2020)

CUTE Science Instrument



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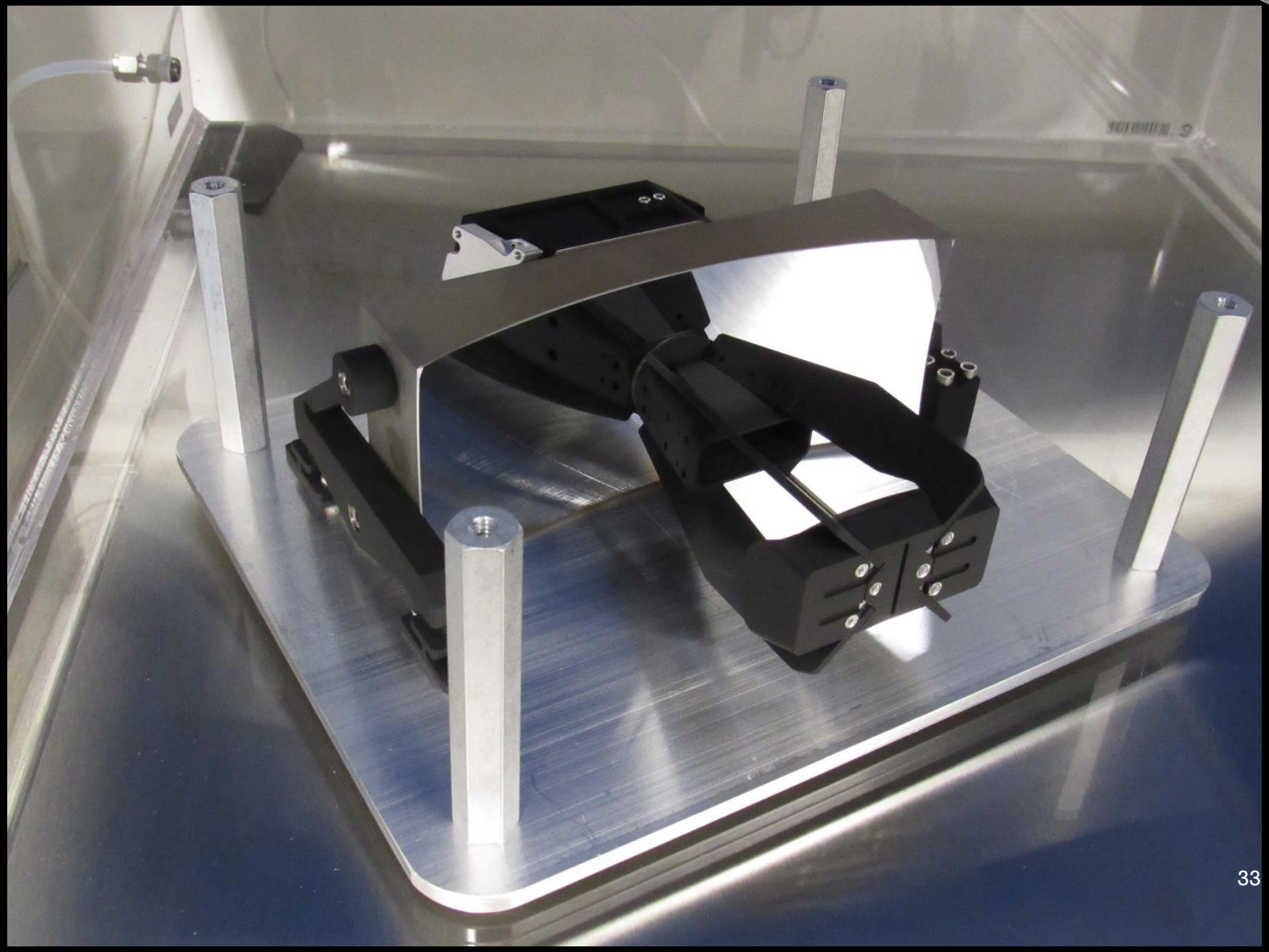
CUTE Telescope (Flight)



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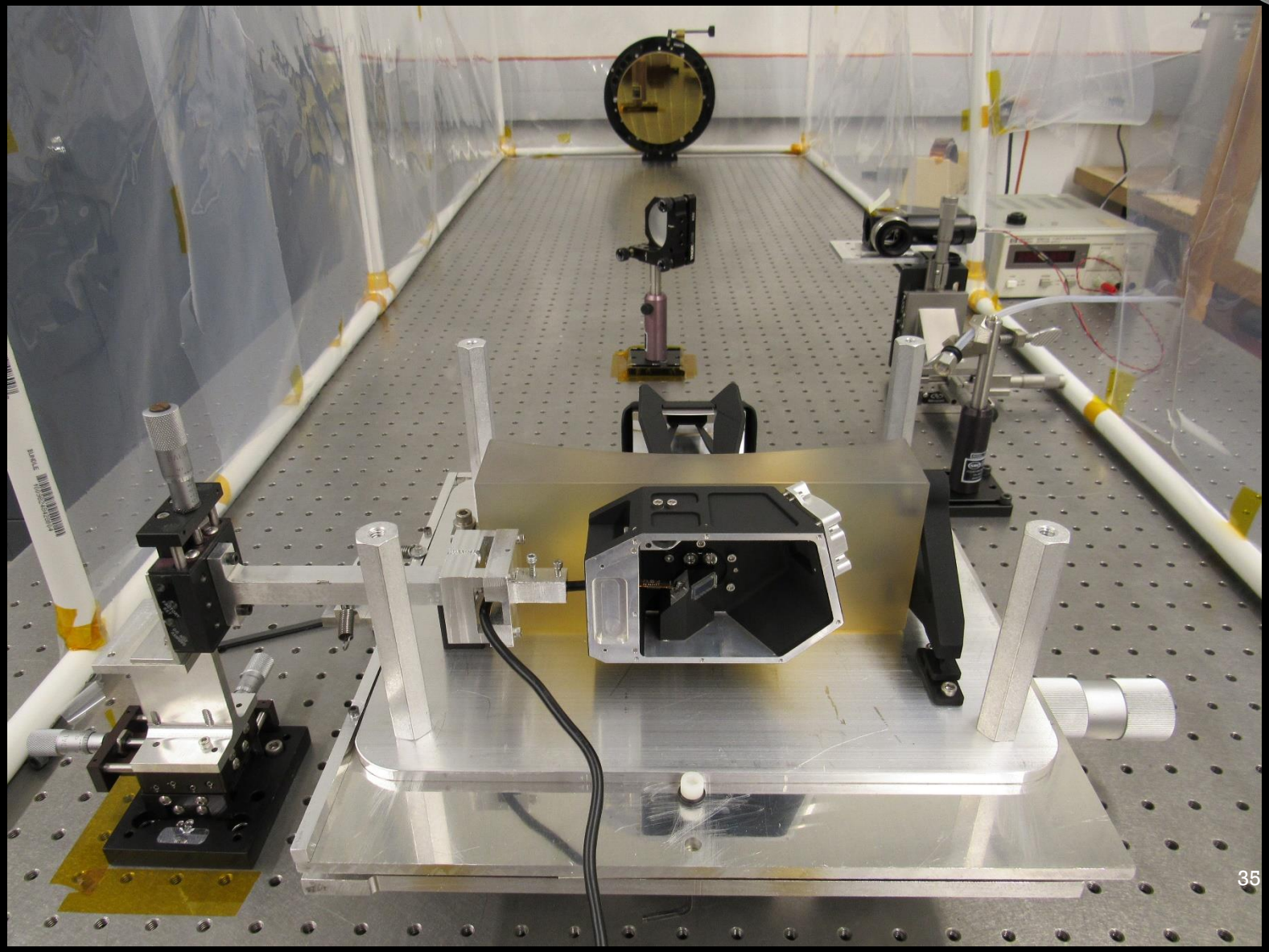


See CUTE design overview in Fleming et al. (2018); Egan et al. (2018)

CUTE Telescope (Flight)

See CUTE design overview in Fleming et al. (2018); Egan et al. (2018)

CUTE Operations: Student Ops Team

Student & PI Training Opportunities

Suborbital Research Programs: end-to-end mission experience

Hands-on training in space hardware

Dr. Ambily Suresh

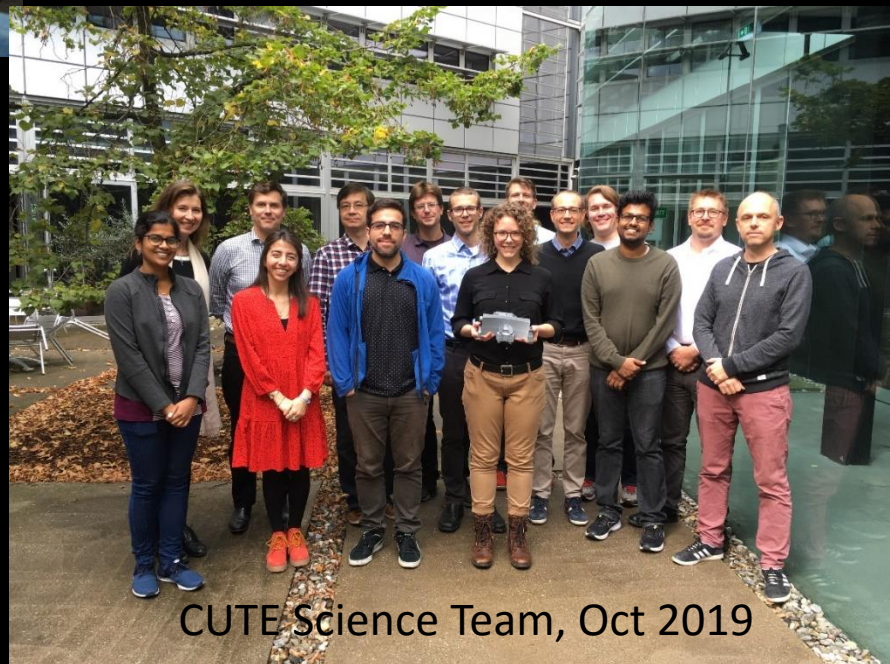
Arika Egan

Prof. Kevin France

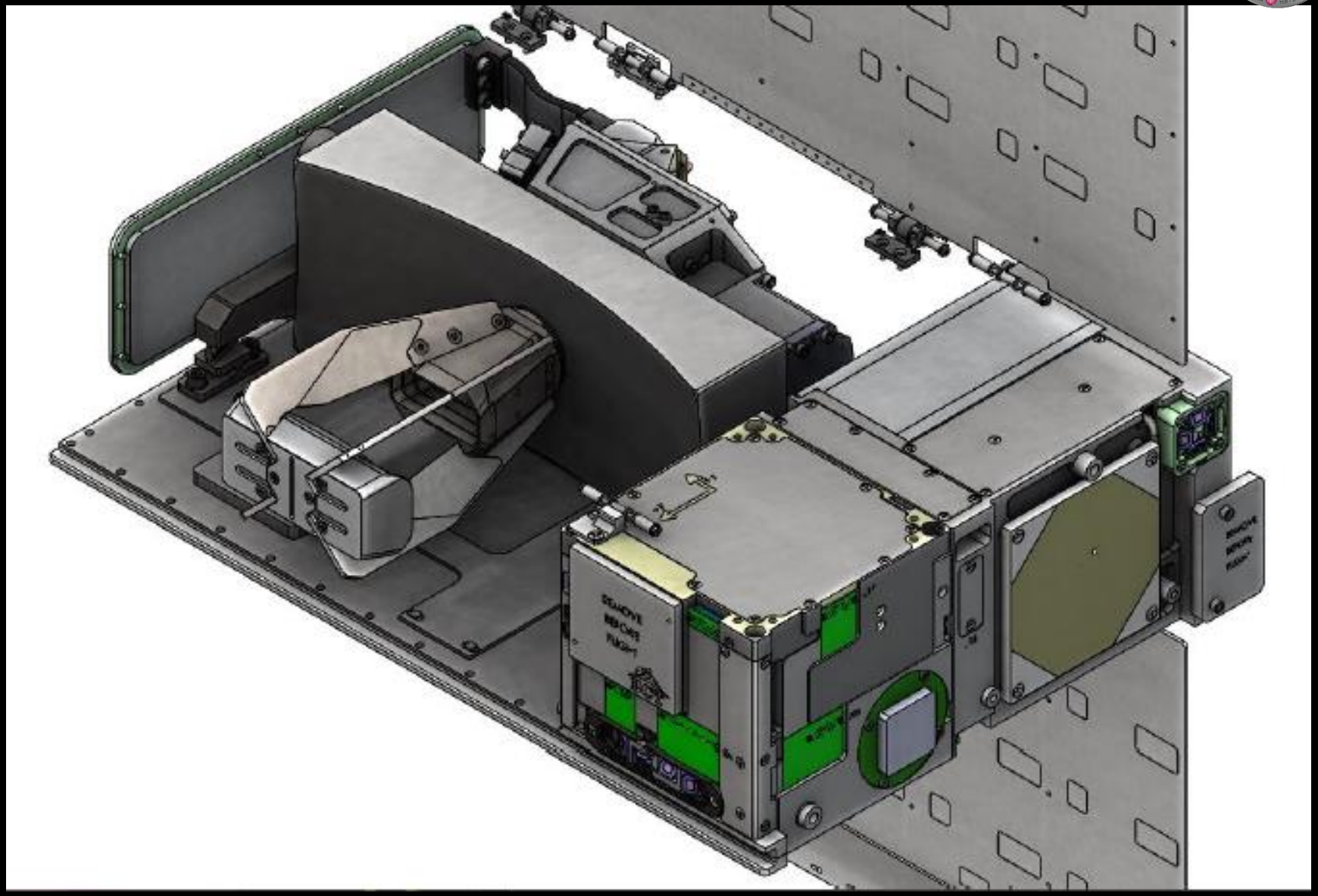
Stefan Ulrich

Nick DeCicco

Prof. Brian Fleming

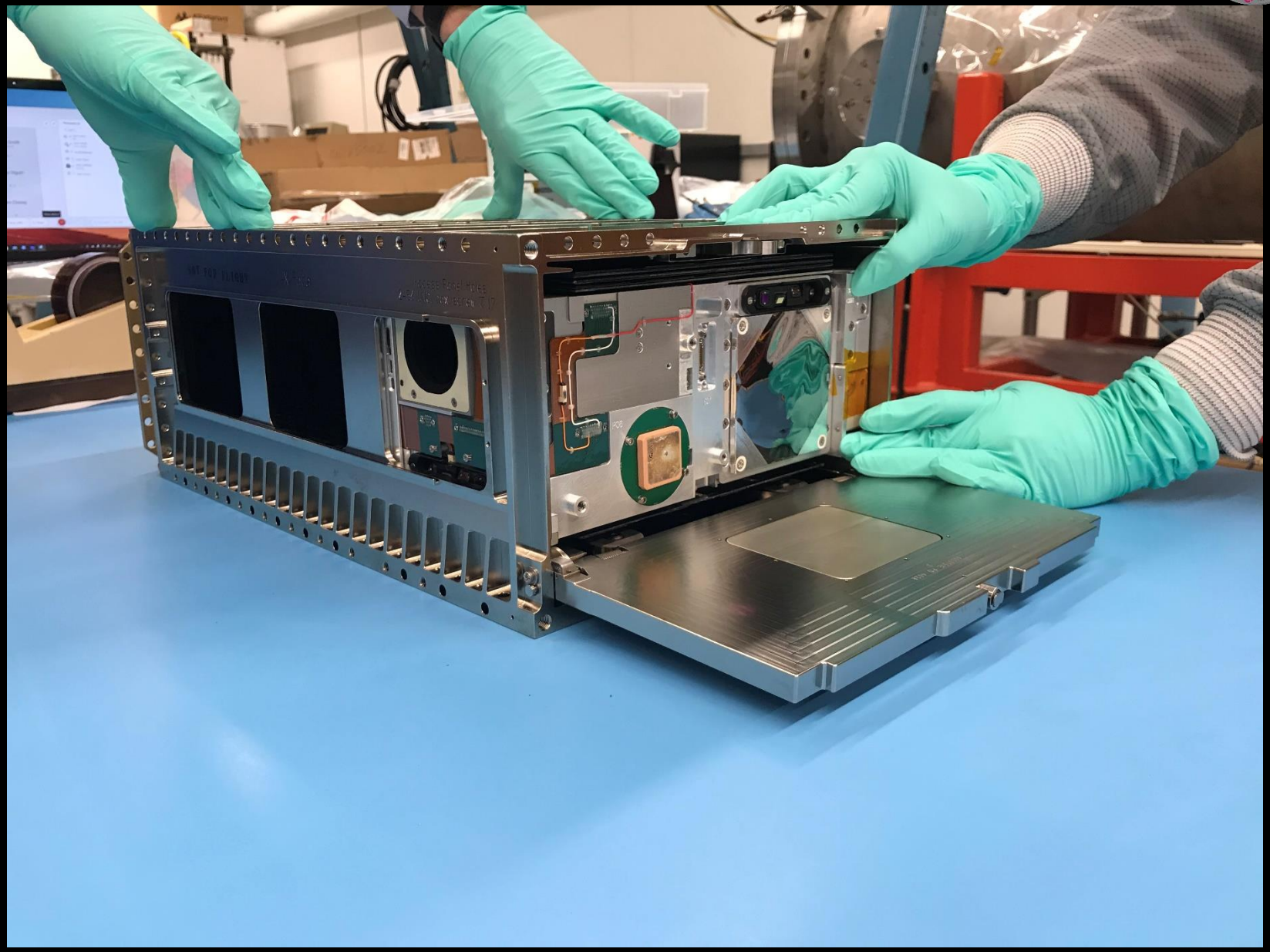

CUTE Science Team, Oct 2019

Integrated CUTE Science Instrument



See CUTE design overview in Fleming et al. (2018); Egan et al. (2018)

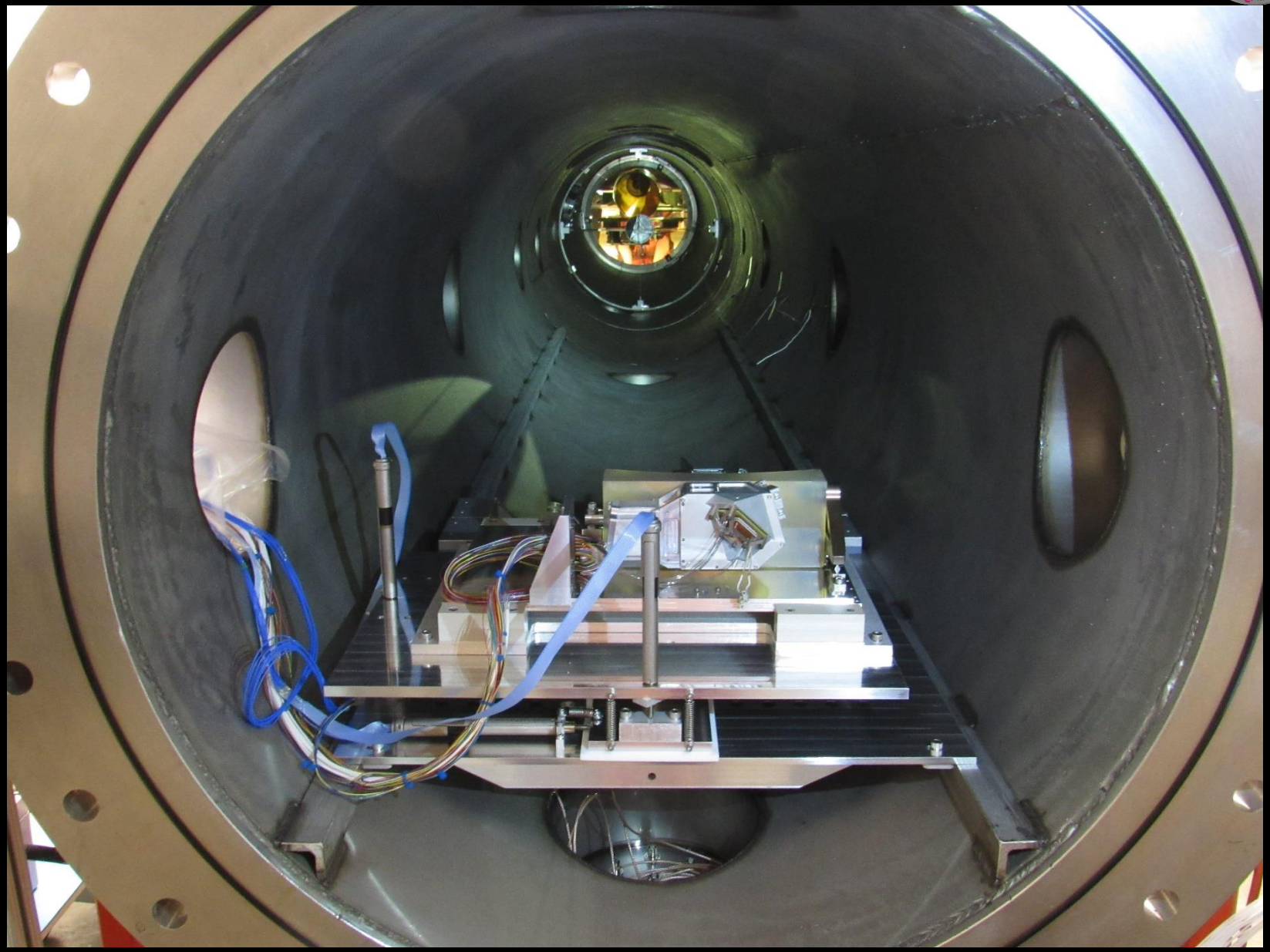
CUTE Spacecraft: Blue Canyon Technology



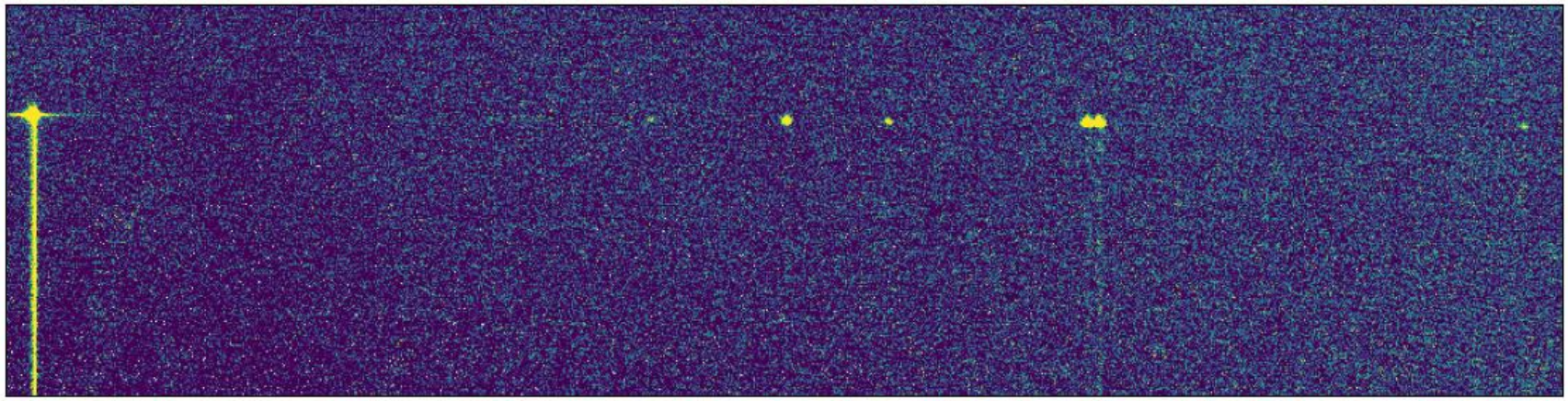
CUTE Spacecraft Testing

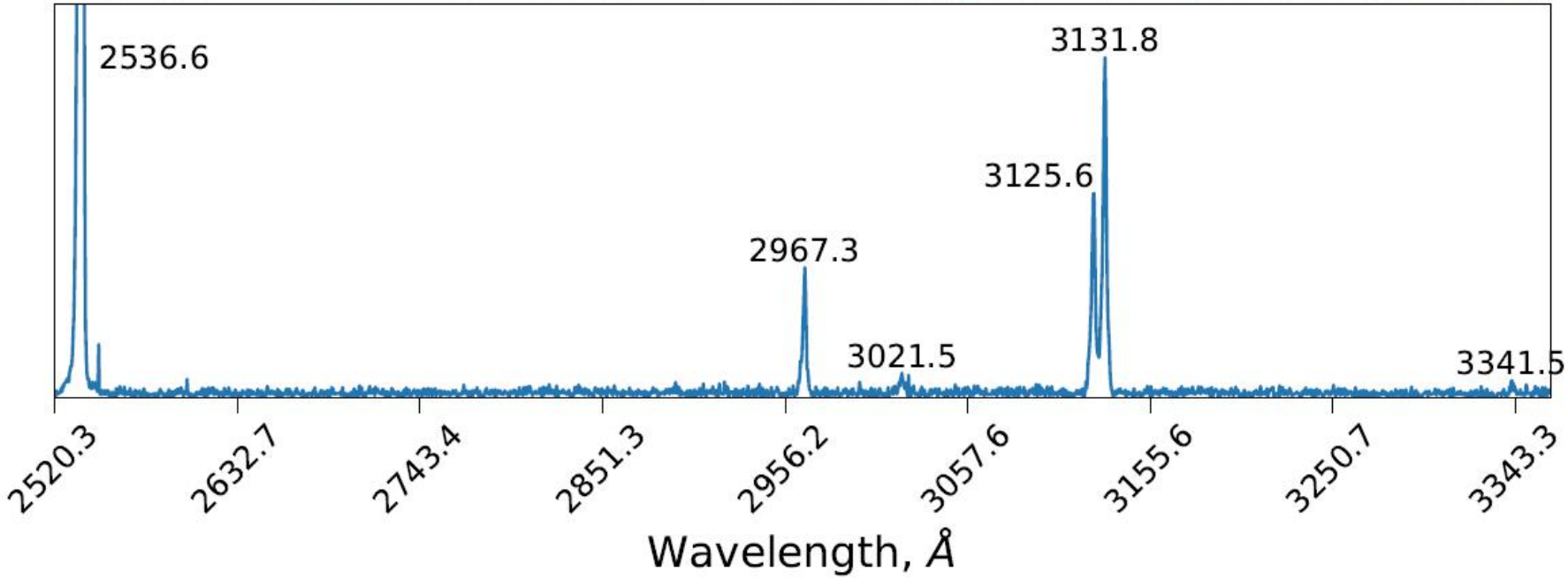
See CUTE design overview in Fleming et al. (2018); Egan et al. (2018)

CUTE End-to-End Testing

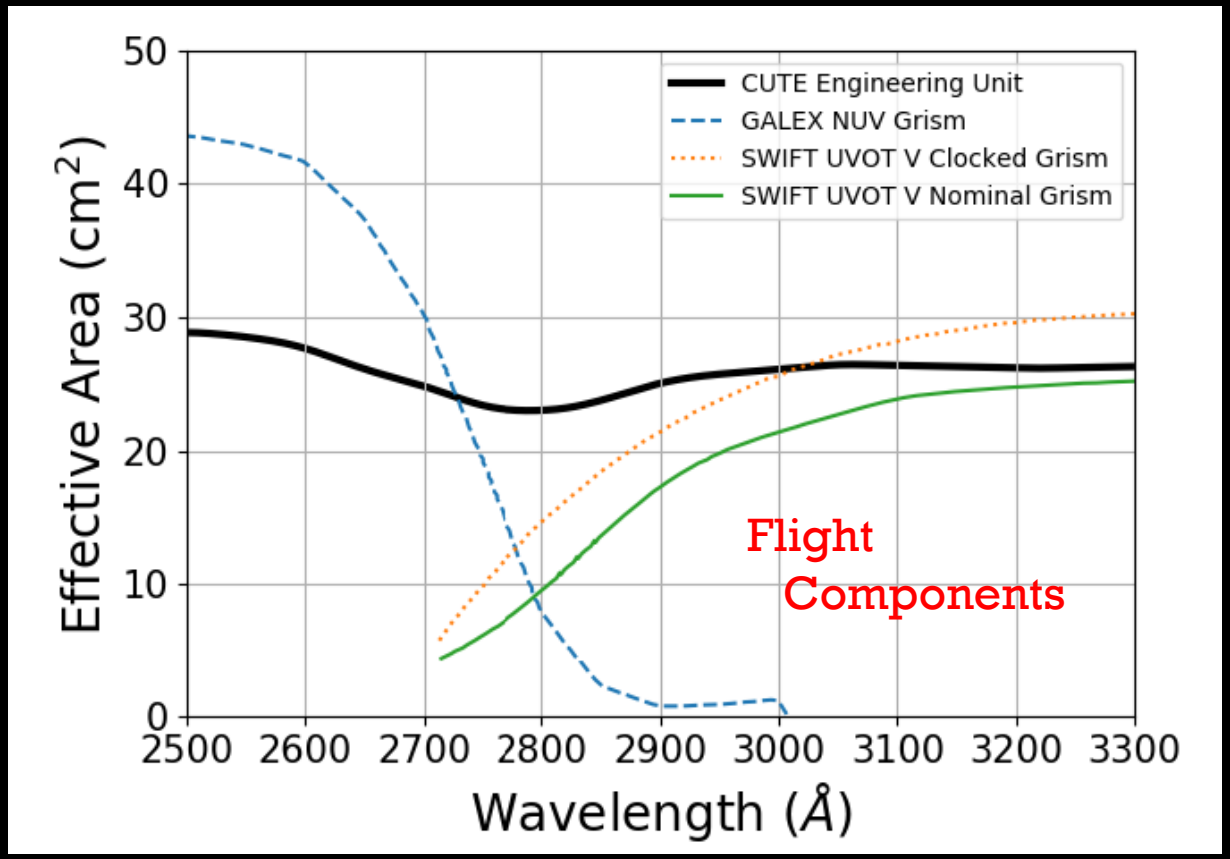


CUTE End-to-End Testing





CUTE Measured Performance

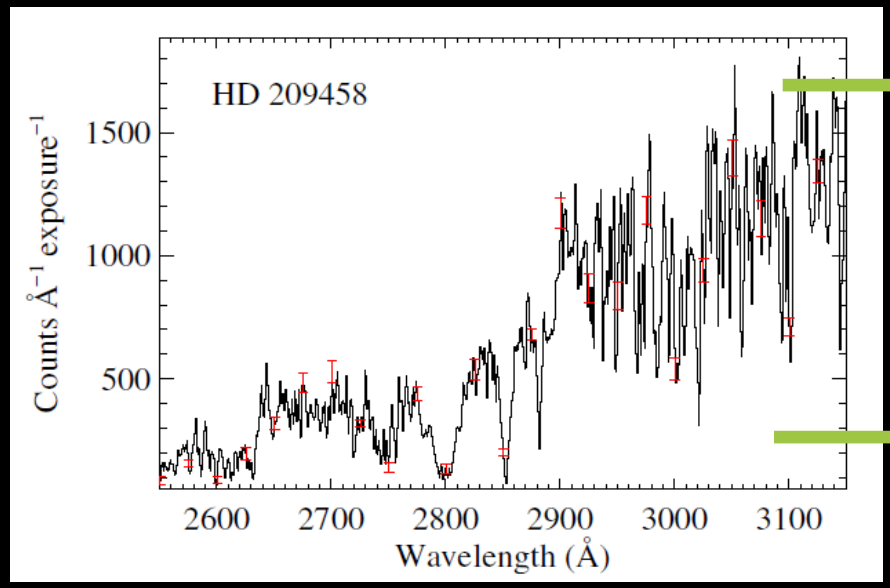


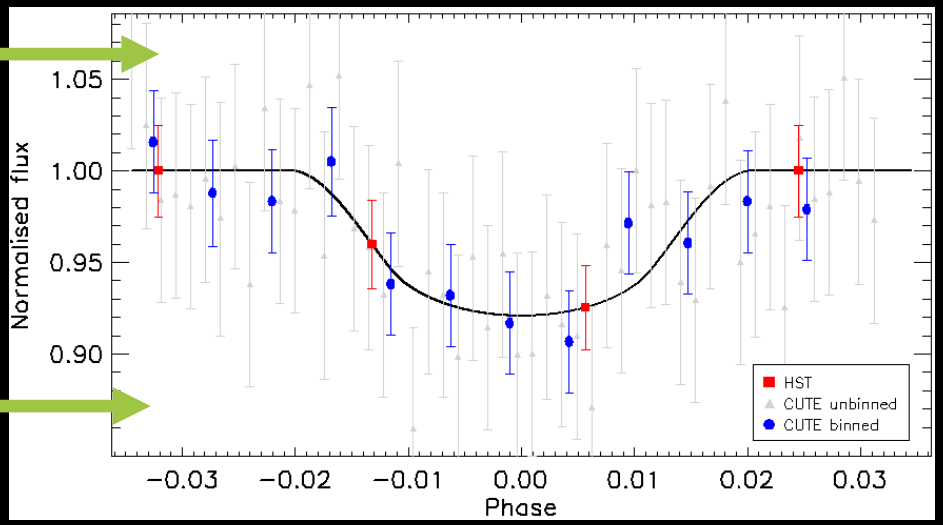
Instrument Sensitivity:

$A_{eff} = A_T R^5 \varepsilon_{grat} QE_D$ = **20-30 cm^2**

R ≈ **2000**

CUTE Predicted Science Data



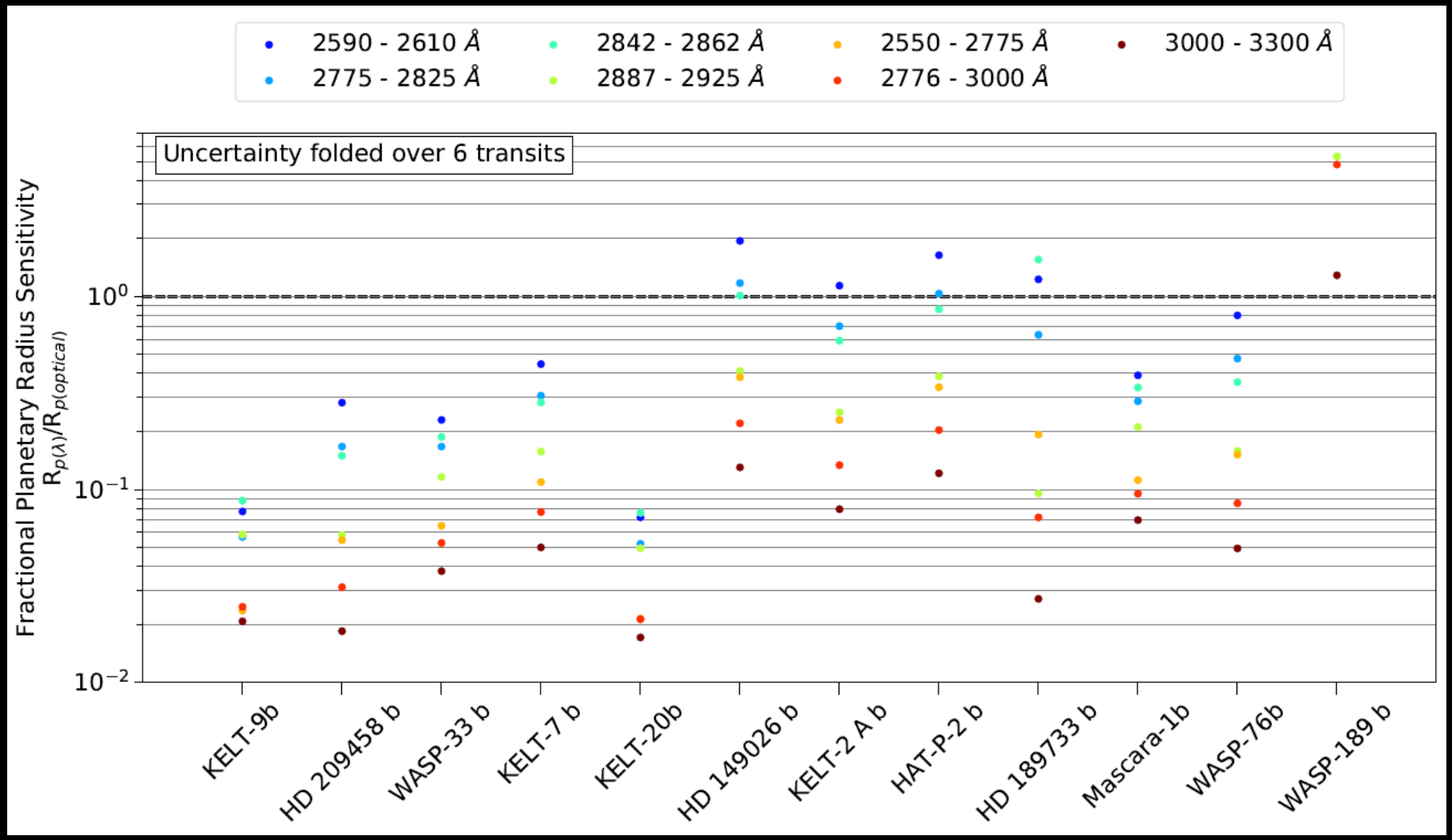


CUTE will achieve >3σ detections of transits as low as 0.1% depth for the brightest targets. Transit depths < 1% for all baseline targets with 5+ lightcurves per target.

Continuum transit sensitivity to 0.7% depth for median target over 1 transit

= Capable of detecting geometric transit and atmospheric transit

CUTE Predicted Science Data



= Capable of detecting geometric transit and atmospheric transit

Egan et al. (2020)

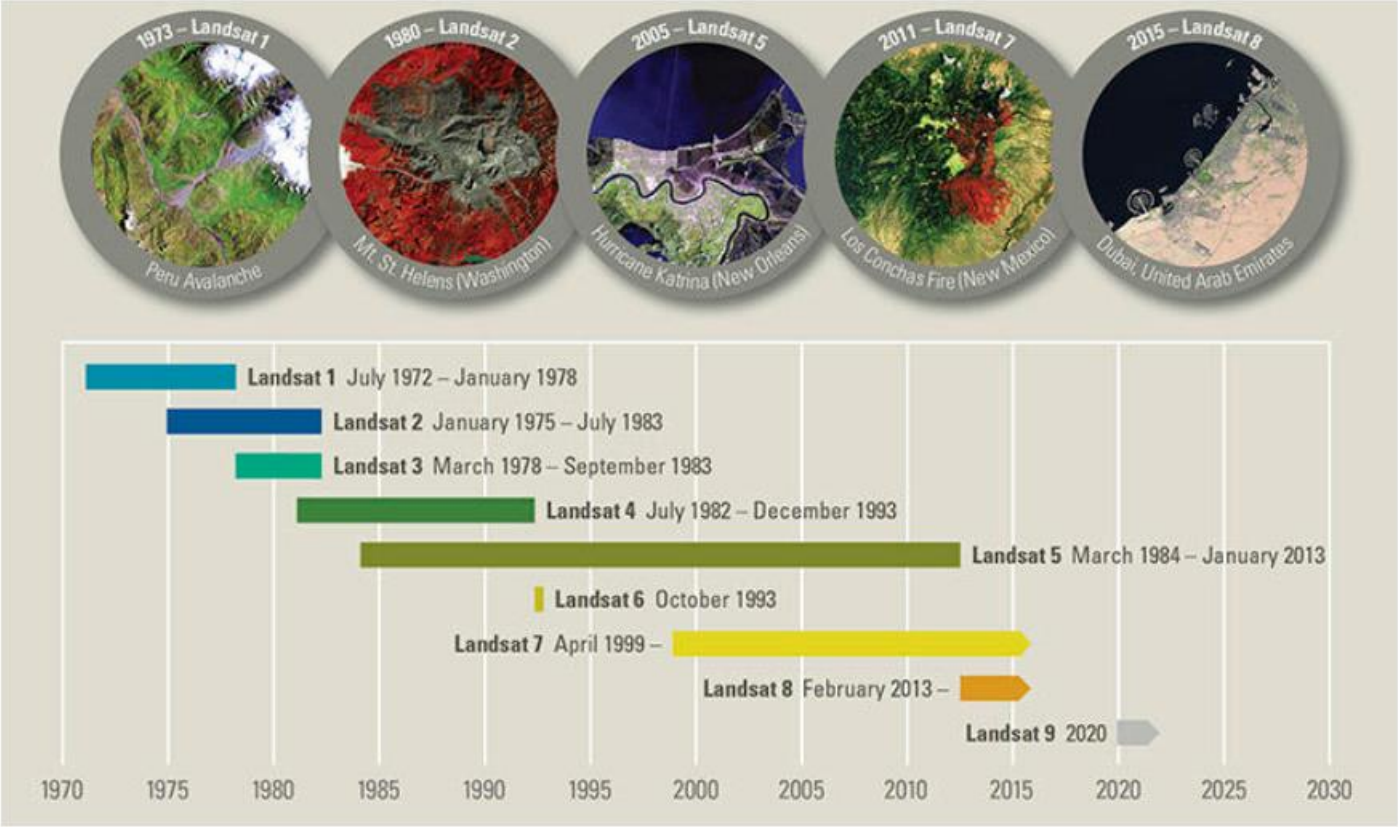
CUTE Status

When will the Landsat 9 satellite be launched?

Landsat 9—a partnership between the USGS and NASA—has a launch readiness date of December 2020.

Landsat 9 will be launched from Space Launch Complex 3E at Vandenberg Air Force Base in California and will be delivered into orbit by a United Launch Alliance Atlas V 401 launch vehicle.

Learn more: Landsat 9 Mission



CUTE

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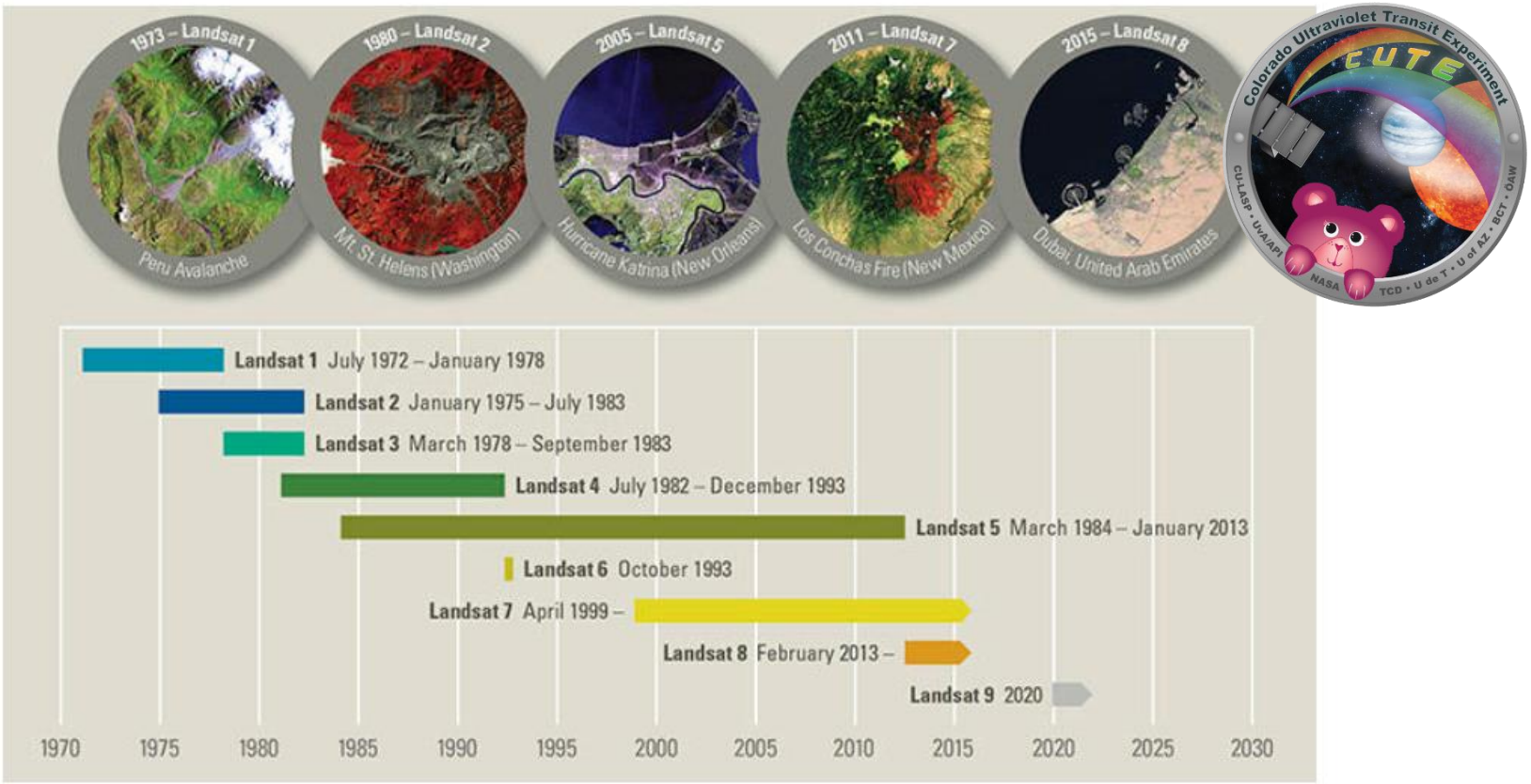


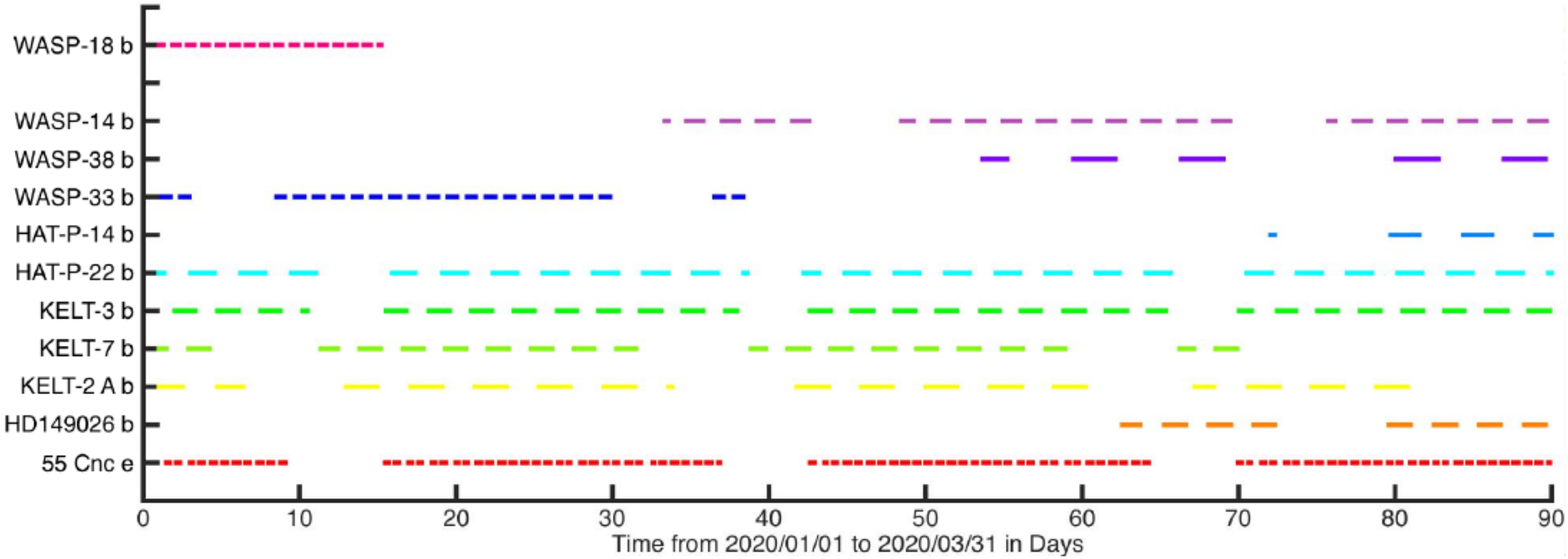
CUTE Status

- Proposed ROSES D.3 APRA - March 2016
- Selected February 2017, funded July 2017
- Science Team face-to-face meetings:
  Oct 2017, Nov 2018, Oct 2019, (Dec 2020)
- Assembly, test, calibration: almost complete
- Environmental Testing: April/May 2021
- Launch Late Q3-2021
  - 8 Month Baseline mission:
  - 12 exoplanetary systems, 6-10 transits each
  - 12 – 20 additional systems in 12 month extended mission

@CuteCubeSat

END

CUTE Example Target Visibility List



PI – France