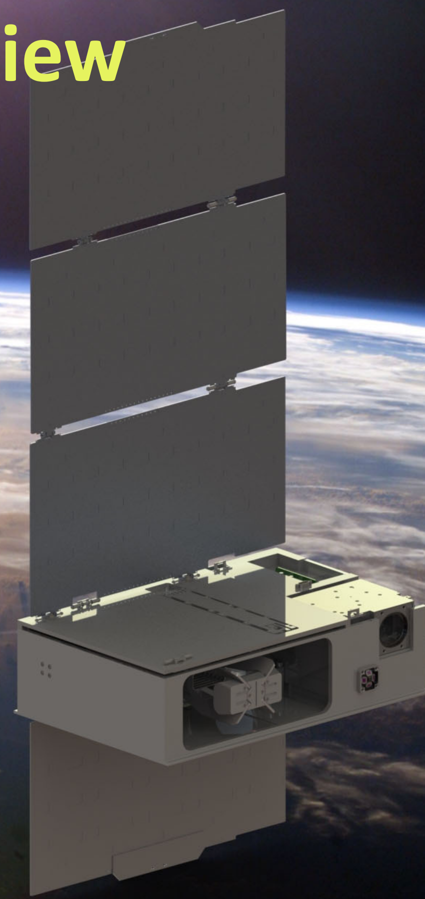
The Colorado Ultraviolet Transit Experiment (CUTE): Mission Overview and First Results

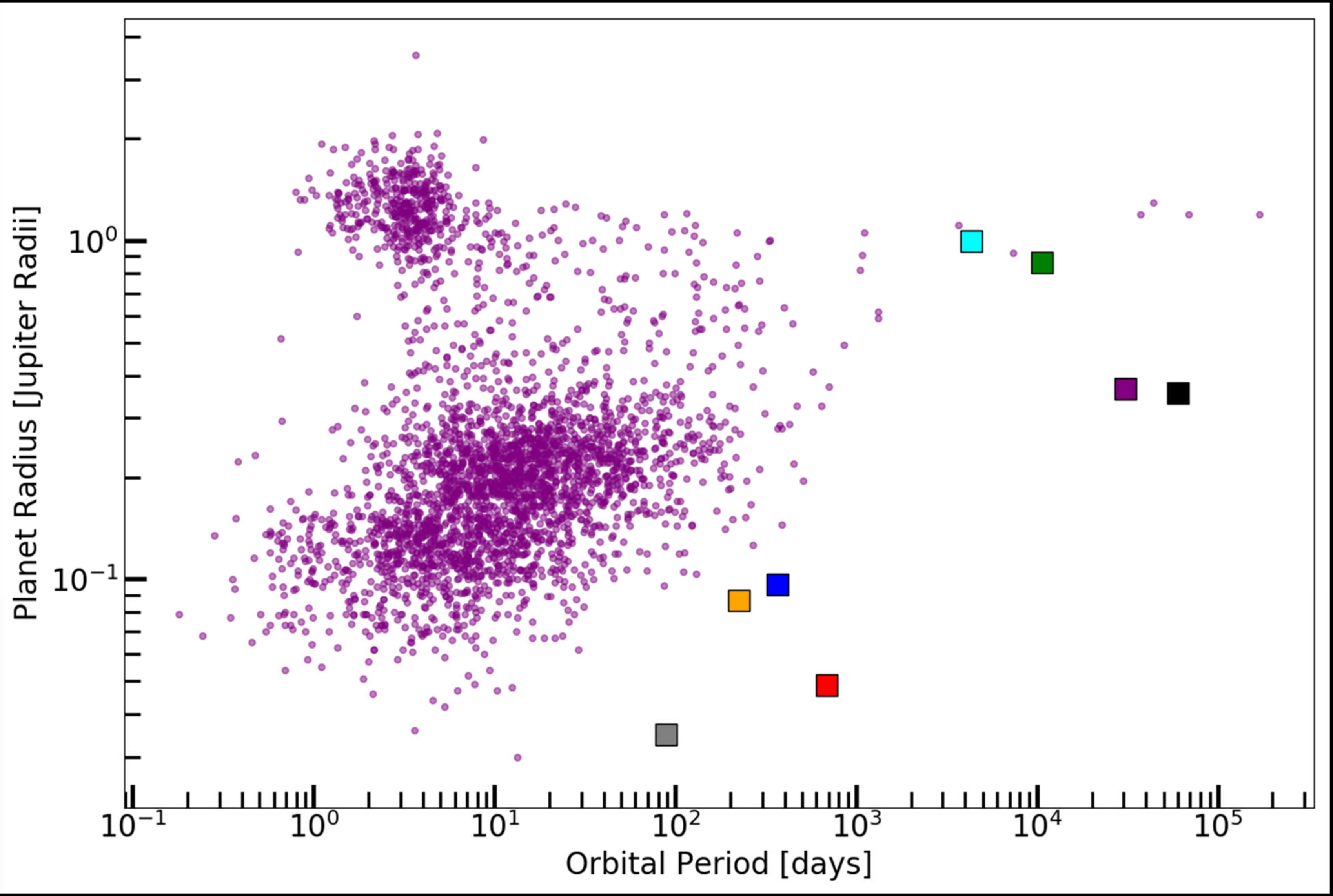


@CuteCubeSat

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

Kevin France – University of Colorado
NUVA 2022, 03 October 2022

The Extrasolar Planet Zoo



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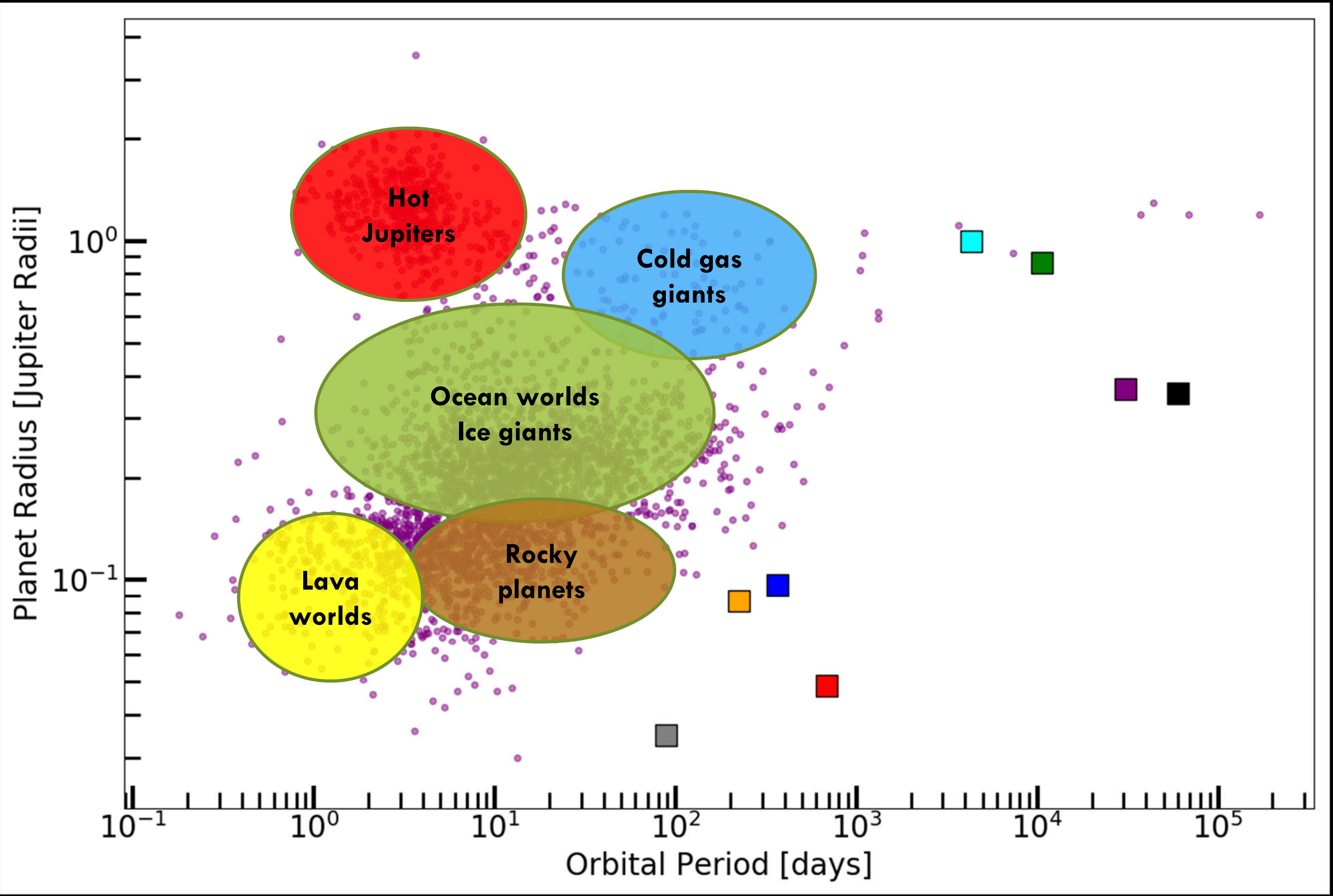
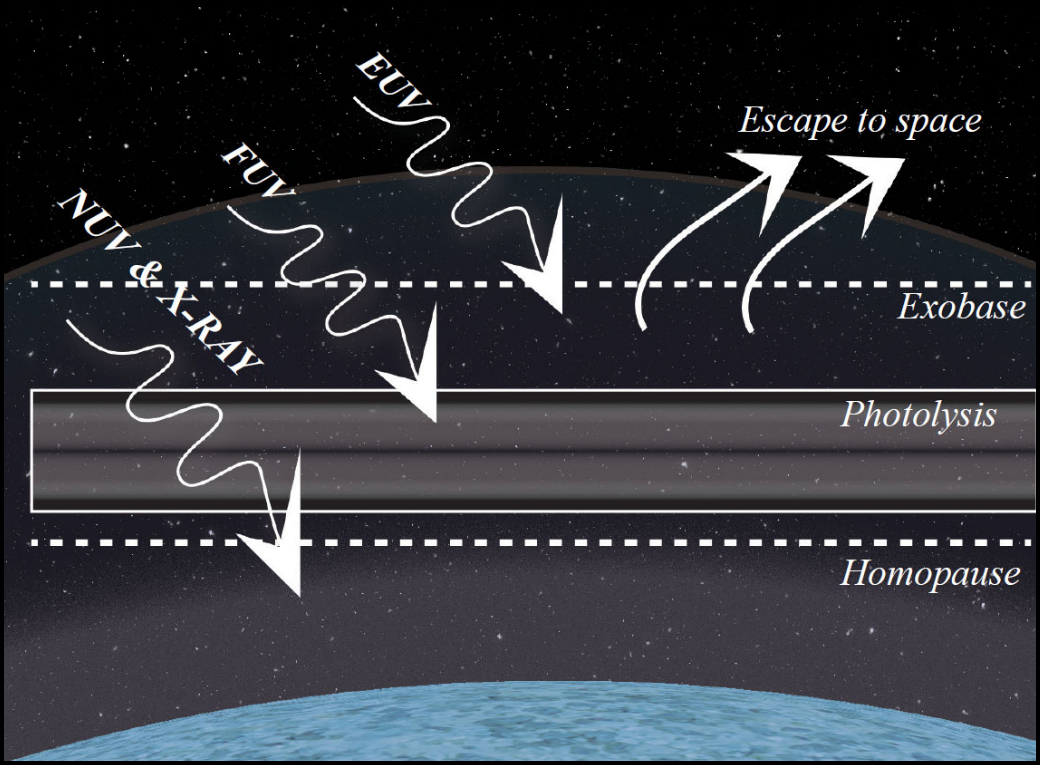


Short Period Planets and Atmospheric Effects

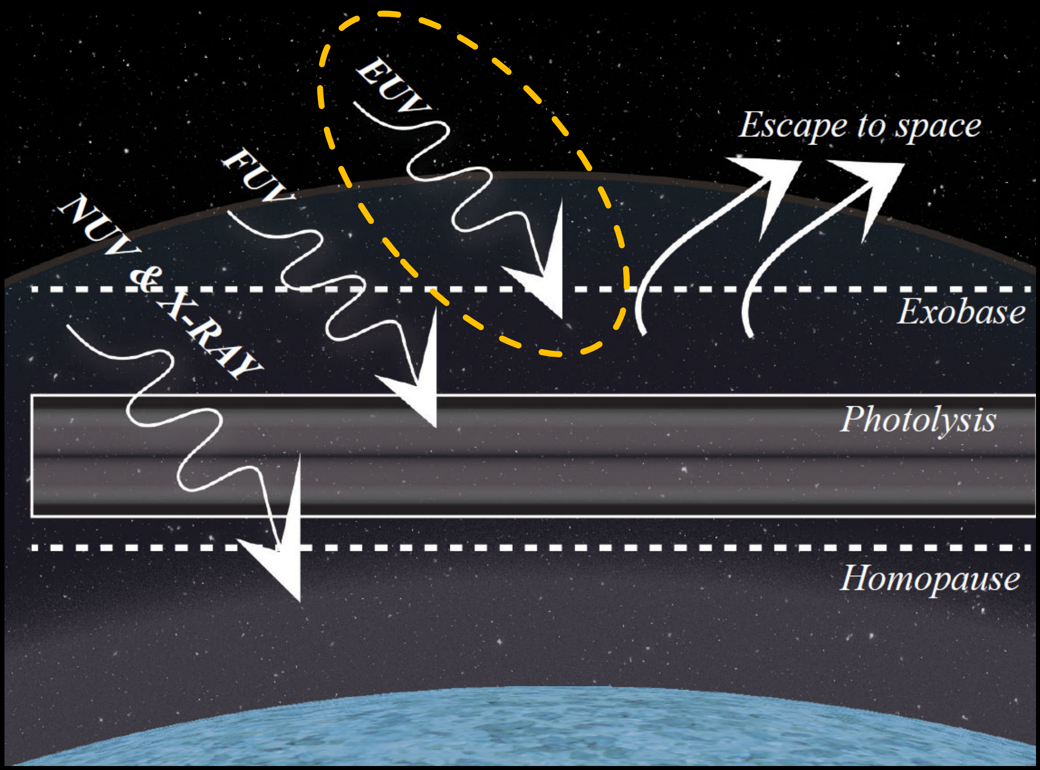


Adapted from France et al. 2019

- Photons of different energy play distinct roles, and all contribute to the observable signatures of that atmosphere

- The high-energy stellar emission dominates atmospheric photochemistry, ionization, and heating

Short Period Planets and Atmospheric Effects



Adapted from France et al. 2019

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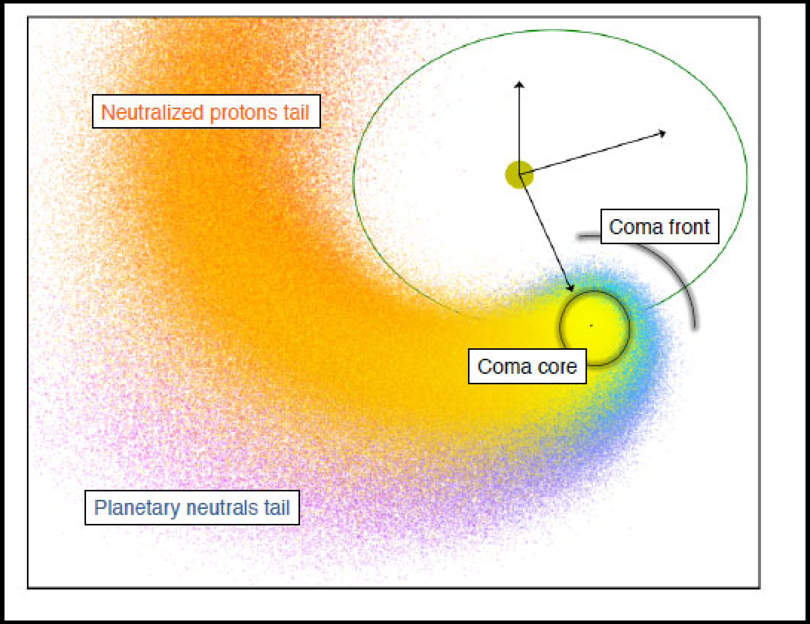
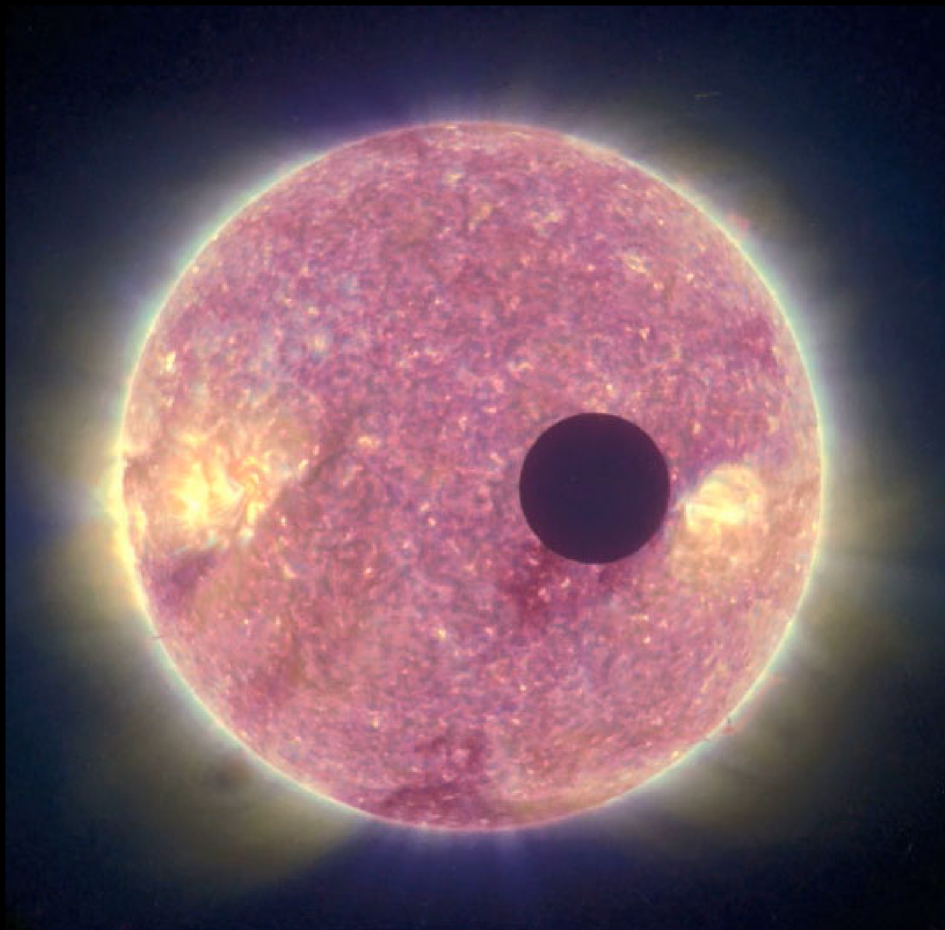
Short Period Planets and Atmospheric Effects

- Most spectacular example has been on the short-period Neptune-mass planet GJ 436b



Ehrenreich et al. 2015; Bourrier et al. 2016

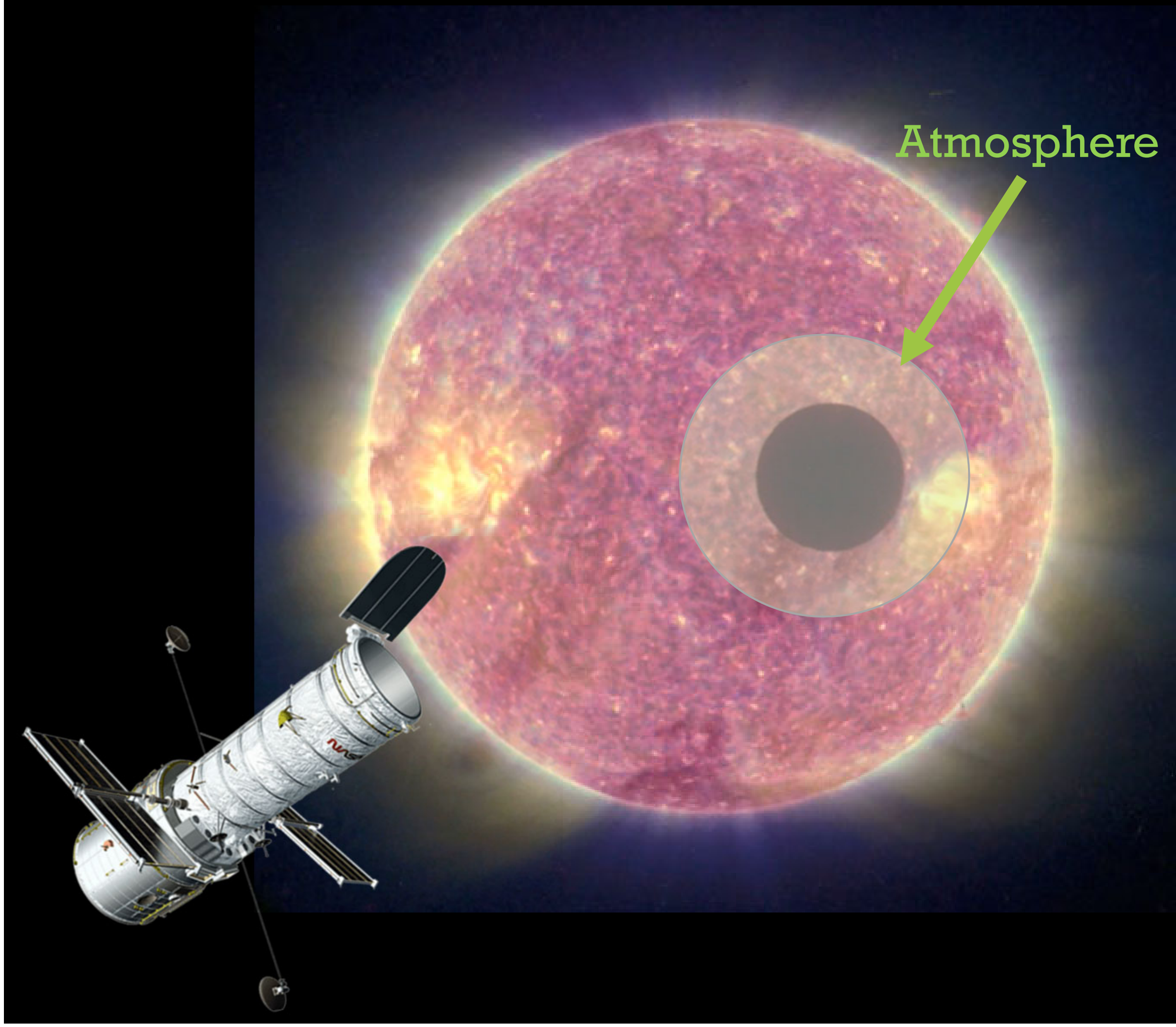
Short Period Planets and Atmospheric Effects



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

Short Period Planets and Atmospheric Effects

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



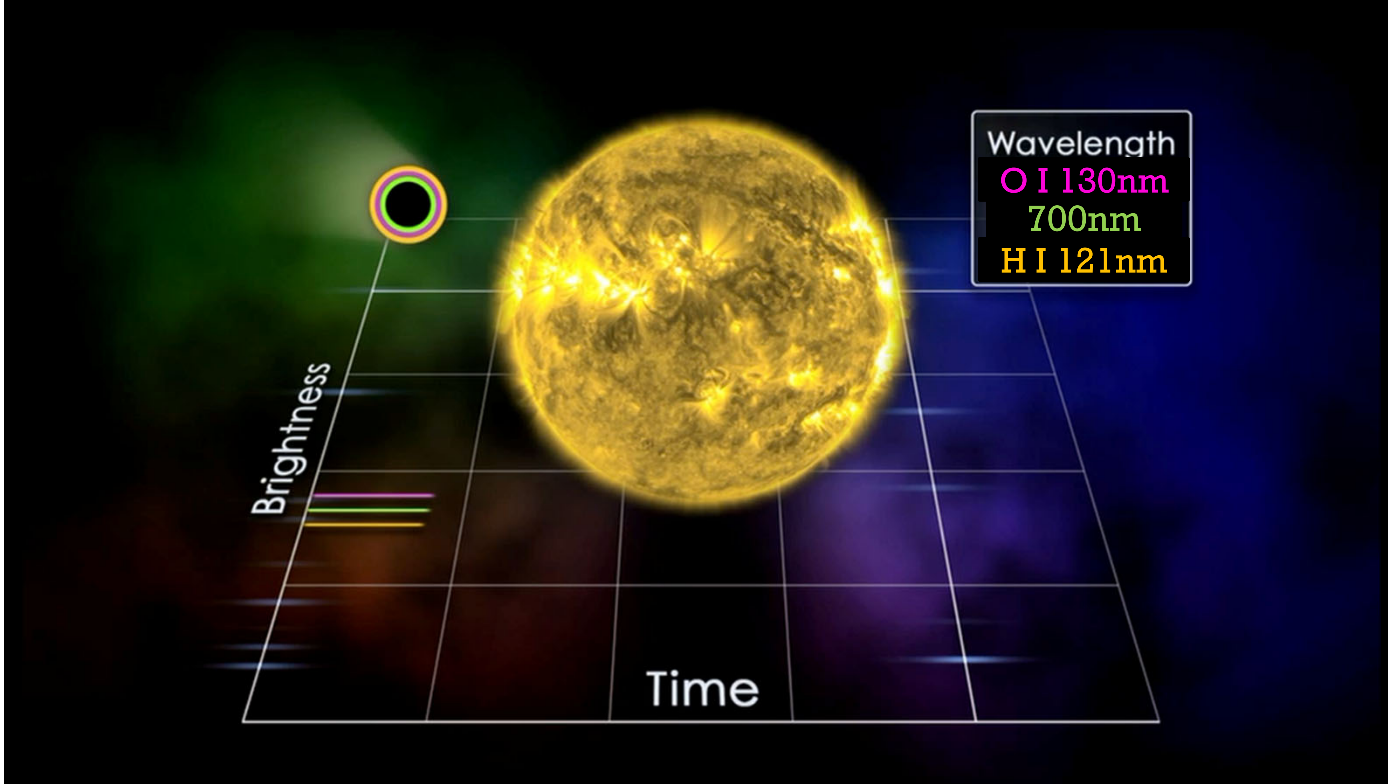
Occultation Depth = $(R_P(\lambda) / R_*)^2$

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

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

Short Period Planets and Atmospheric Effects

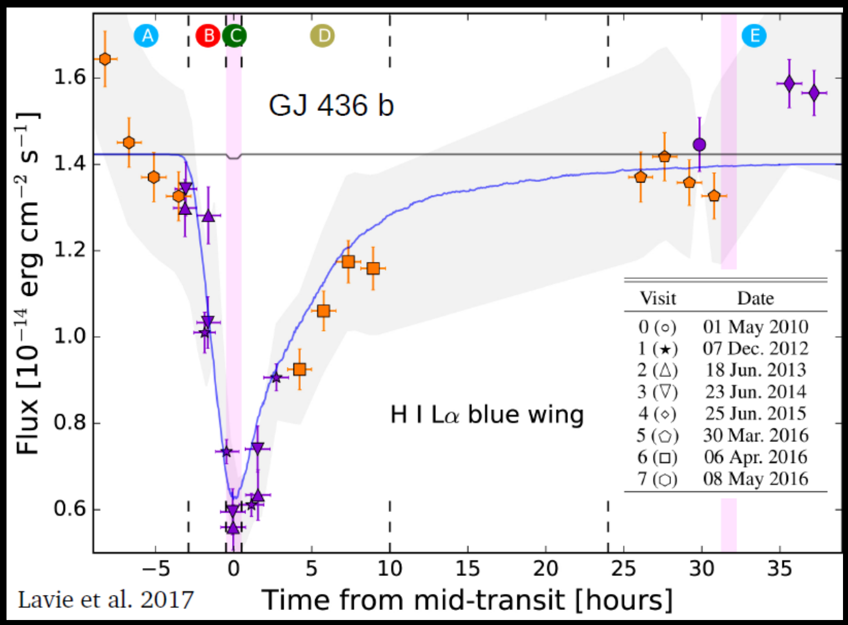
• Narrow-band/spectroscopic transit analysis can probe absorption by specific atmospheric constituents

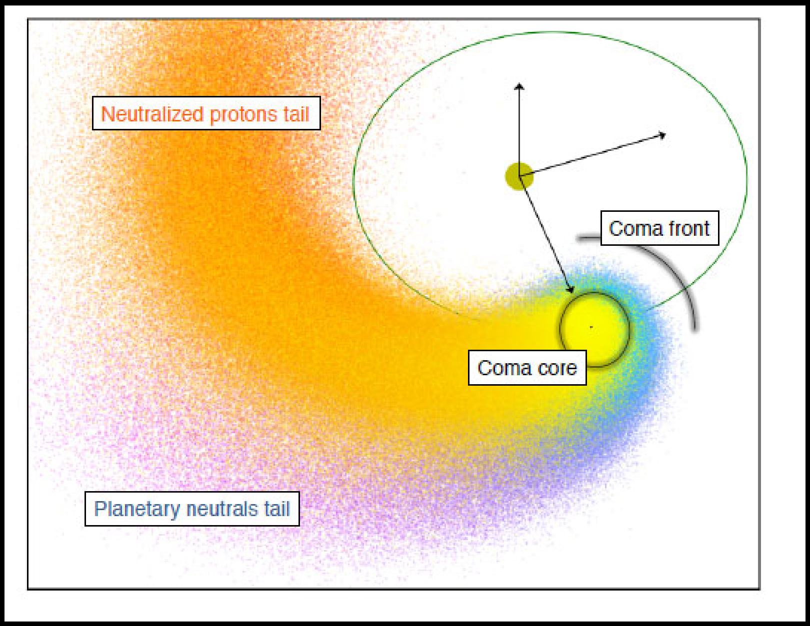


Occultation Depth = $(R_P(\lambda) / R_*)^2$

UV 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



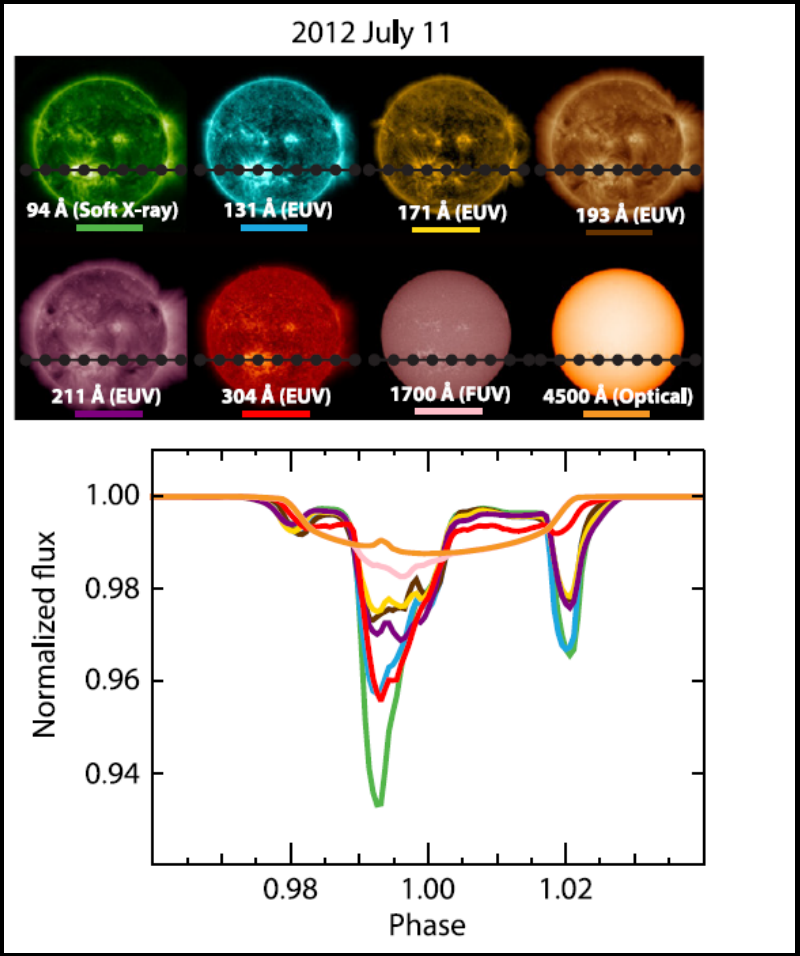


Hydrogen escaping from the upper atmosphere of GJ436b

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

Transit depth ~ 50% (!)

UV Transit Spectroscopy of Short-period Planets

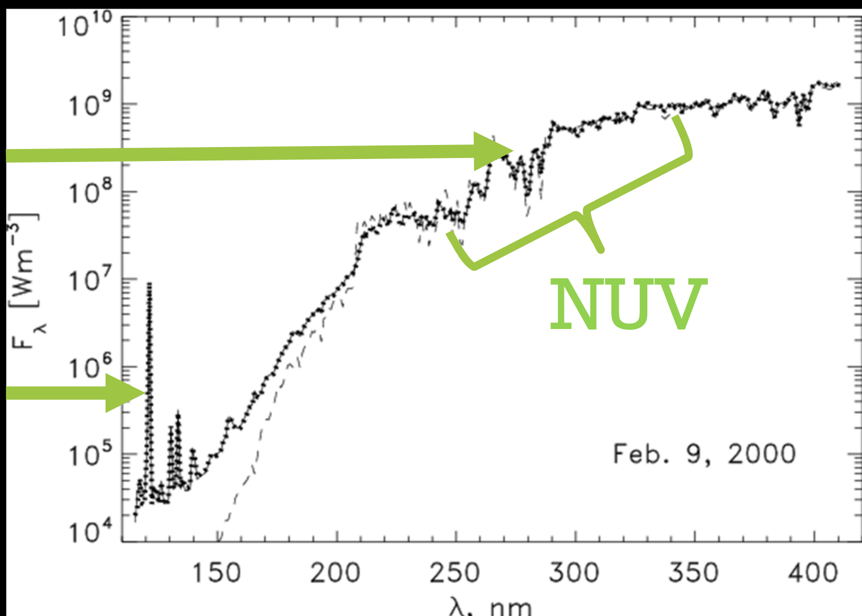


Llama & Shkolnik 2015, 2016

- **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).

UV Transit Spectroscopy of Short-period Planets

Source: SDO



Krivova et al. 2006

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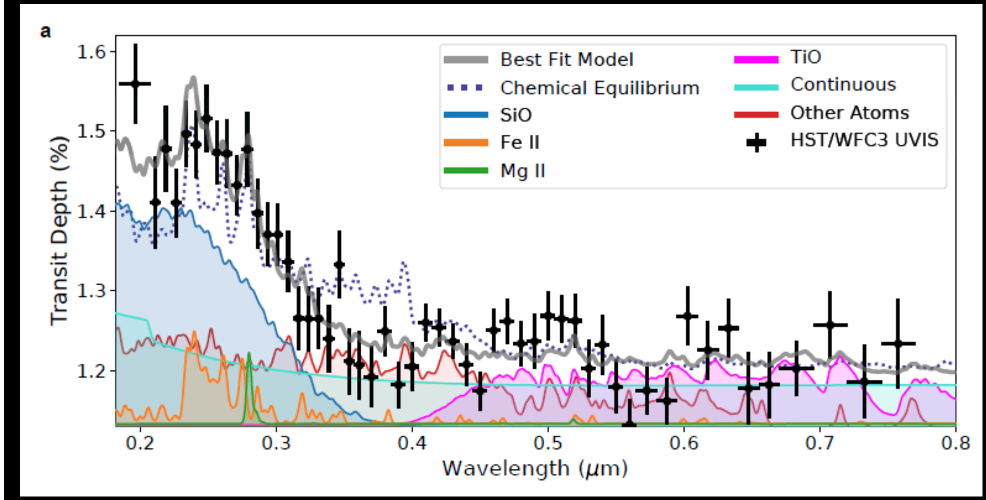
- Controversial interpretation due to low-S/N and uncertain chromospheric intensity distribution (e.g., Llama & Shkolnik 2015).
- **The NUV has a more uniform, mainly photospheric, intensity distribution** AND an overall brighter background for transit observations, ~50-1000x brighter.

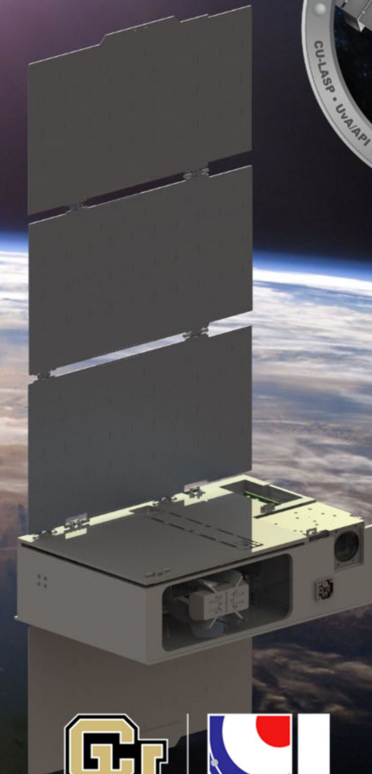
UV Transit Spectroscopy of Short-period Planets



WASP-178b; Lothinger et al. 2022

- Brighter stellar flux enables spectroscopy in a correspondingly smaller platform
- Spectroscopy required to isolate escaping gas species
- High-resolution not necessary to detect extended atmospheres (Sing et al. 2019; Lothringer et al. 2022)

Colorado Ultraviolet Transit Experiment (CUTE)

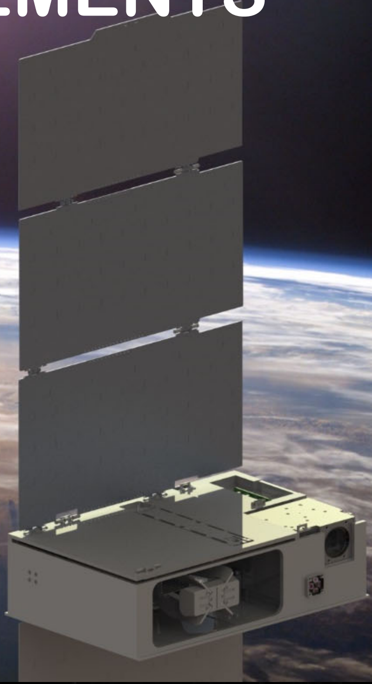


University of Colorado:
Kevin France (PI), Brian Fleming (PS), Arika Egan, Rick Kohnert (PM), Nicholas Nell, Stefan Ulrich, Nick DeCicco, Ambily Suresh, Wilson Cauley

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

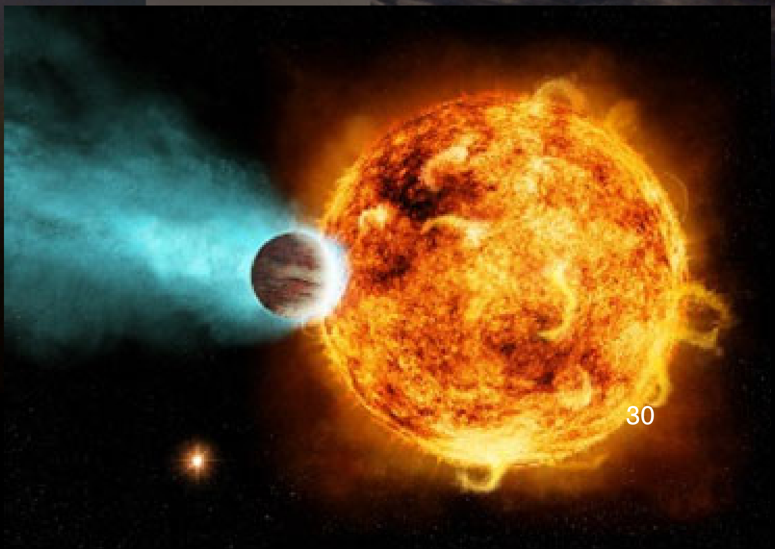
Europe:
Jean-Michel Desert (Amsterdam), Luca Fossati (ÖAW), Pascal Petit (UdeT), Aline Vidotto (TCD)

CUTE: A NEW APPROACH TO ATMOSPHERIC MASS-LOSS MEASUREMENTS

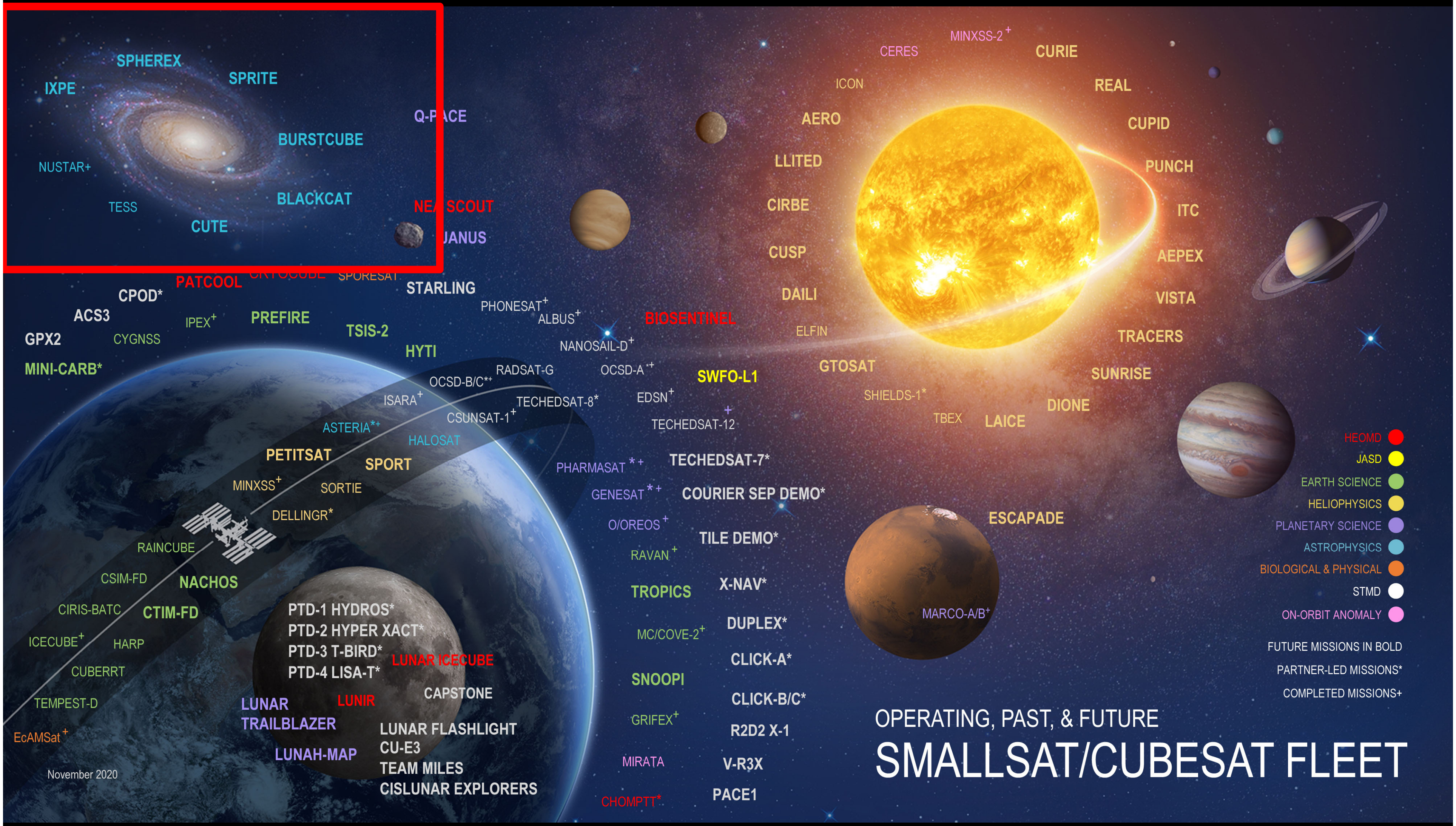


Survey of ~10 short-period transiting planets around nearby stars:

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

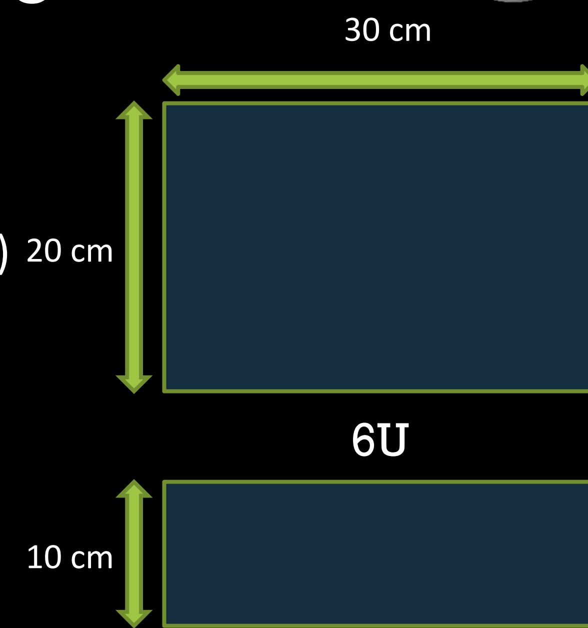


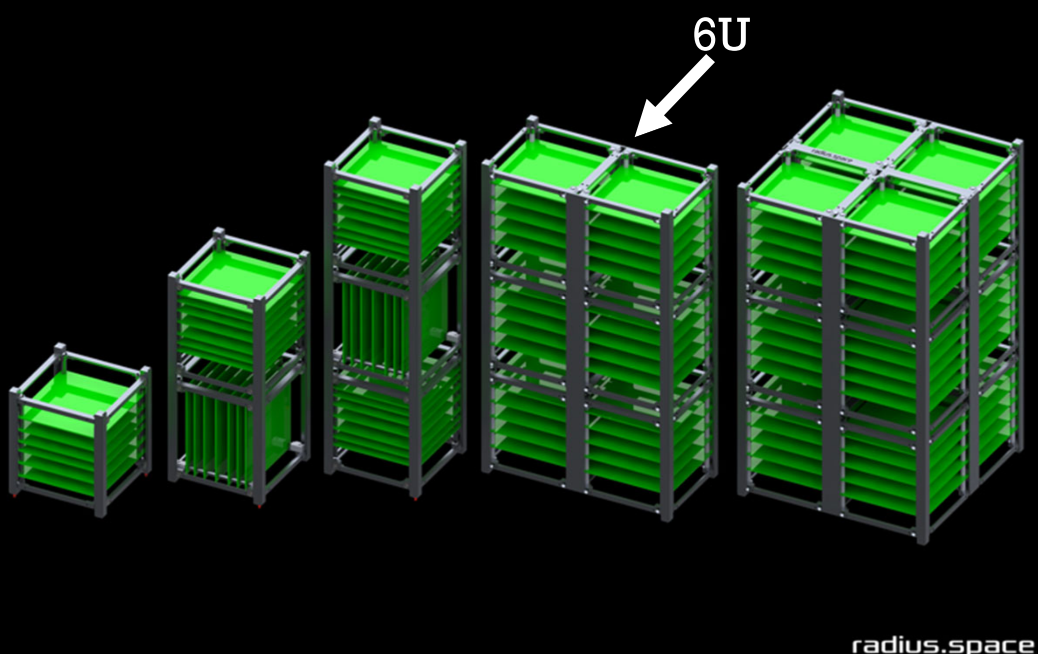
Astronomy with Cubesats: Dedicated Mission Architecture



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)





France et al. (2020)

ASTERIA - JPL

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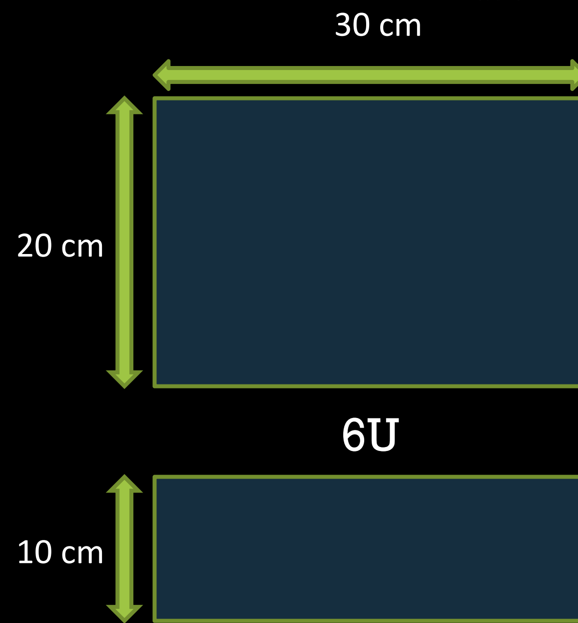

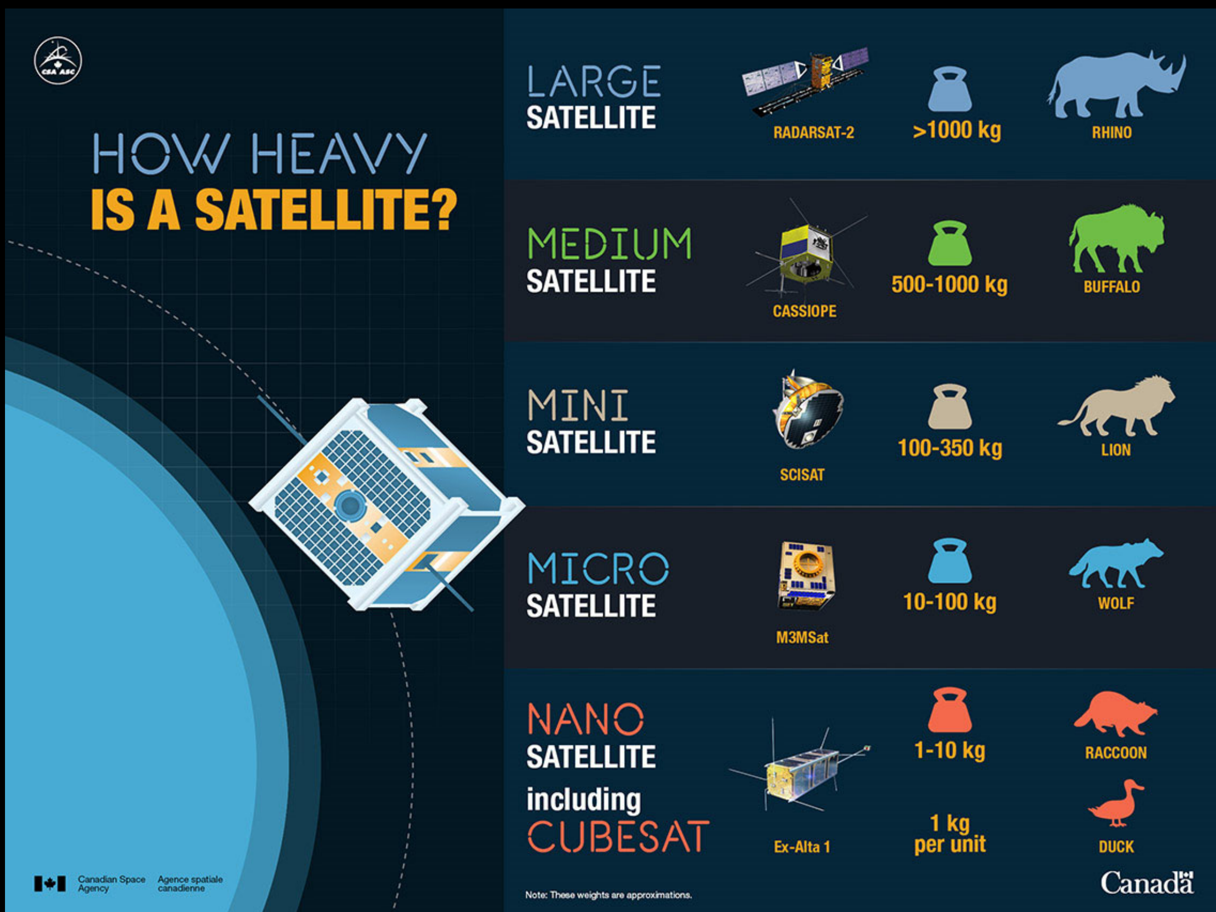

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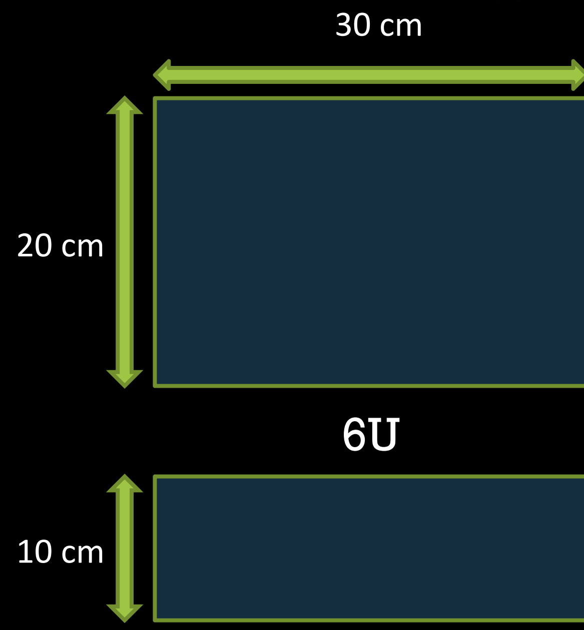
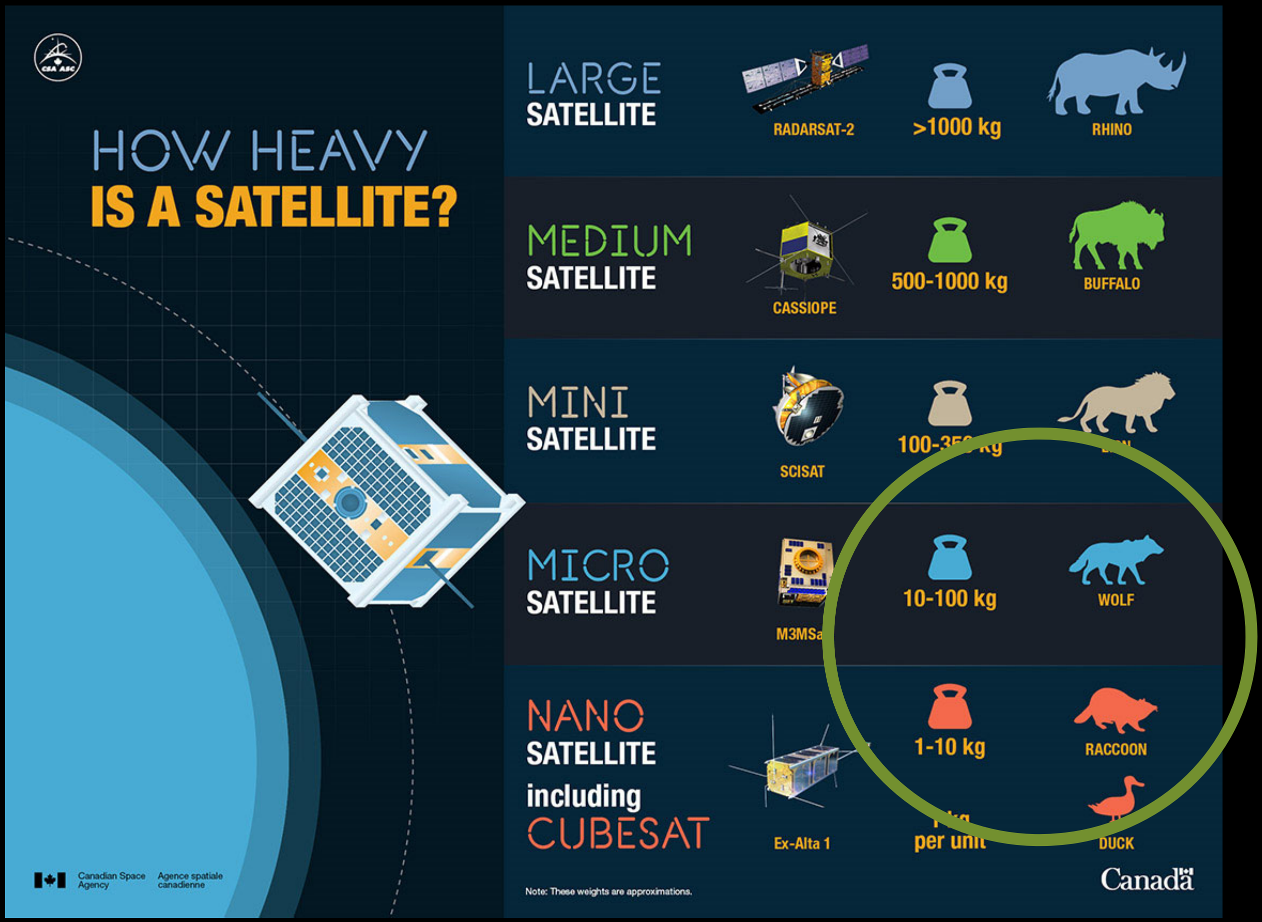




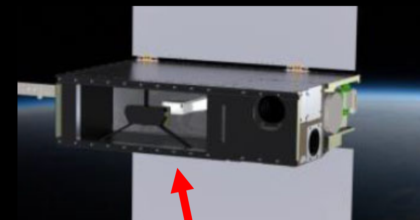
Astronomy with Cubesats: Dedicated Mission Architecture

CUTE:
11.0 cm x 23.7cm x 36.2 cm

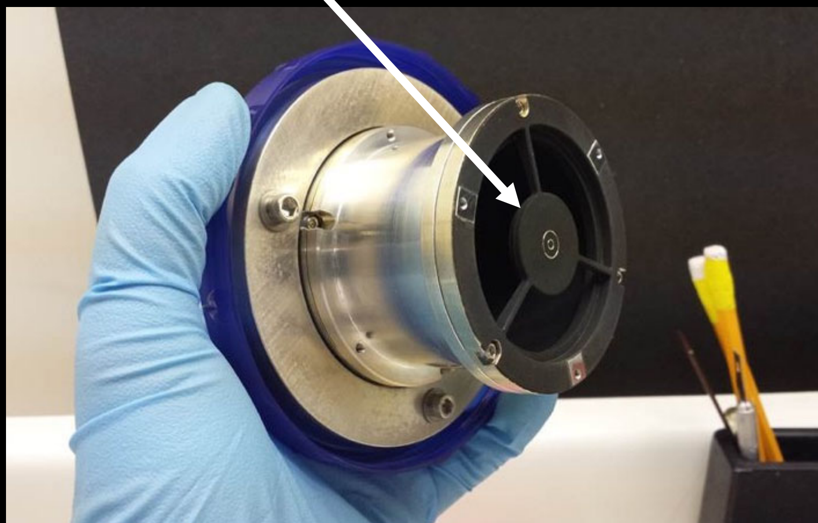
Family Size Cheerios available on Walmart.com:
7.8 cm x 23.9 cm x 34.4 cm

France et al. (2020)

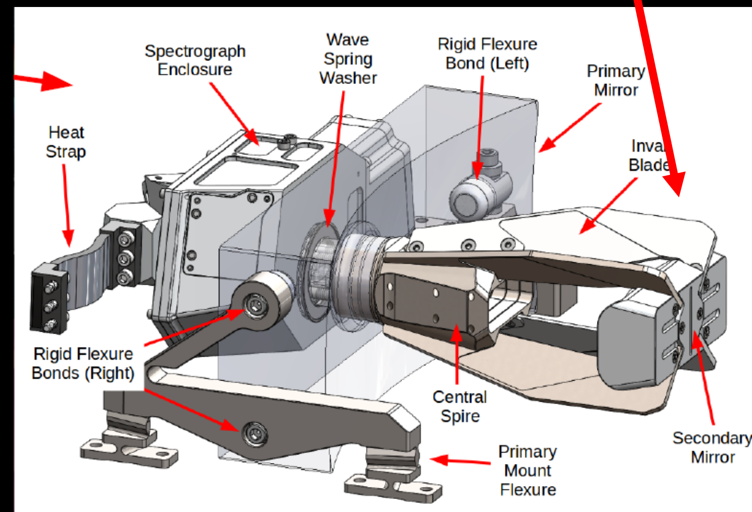
CUTE Telescope



Source: Nu-Tek Precision Optics



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



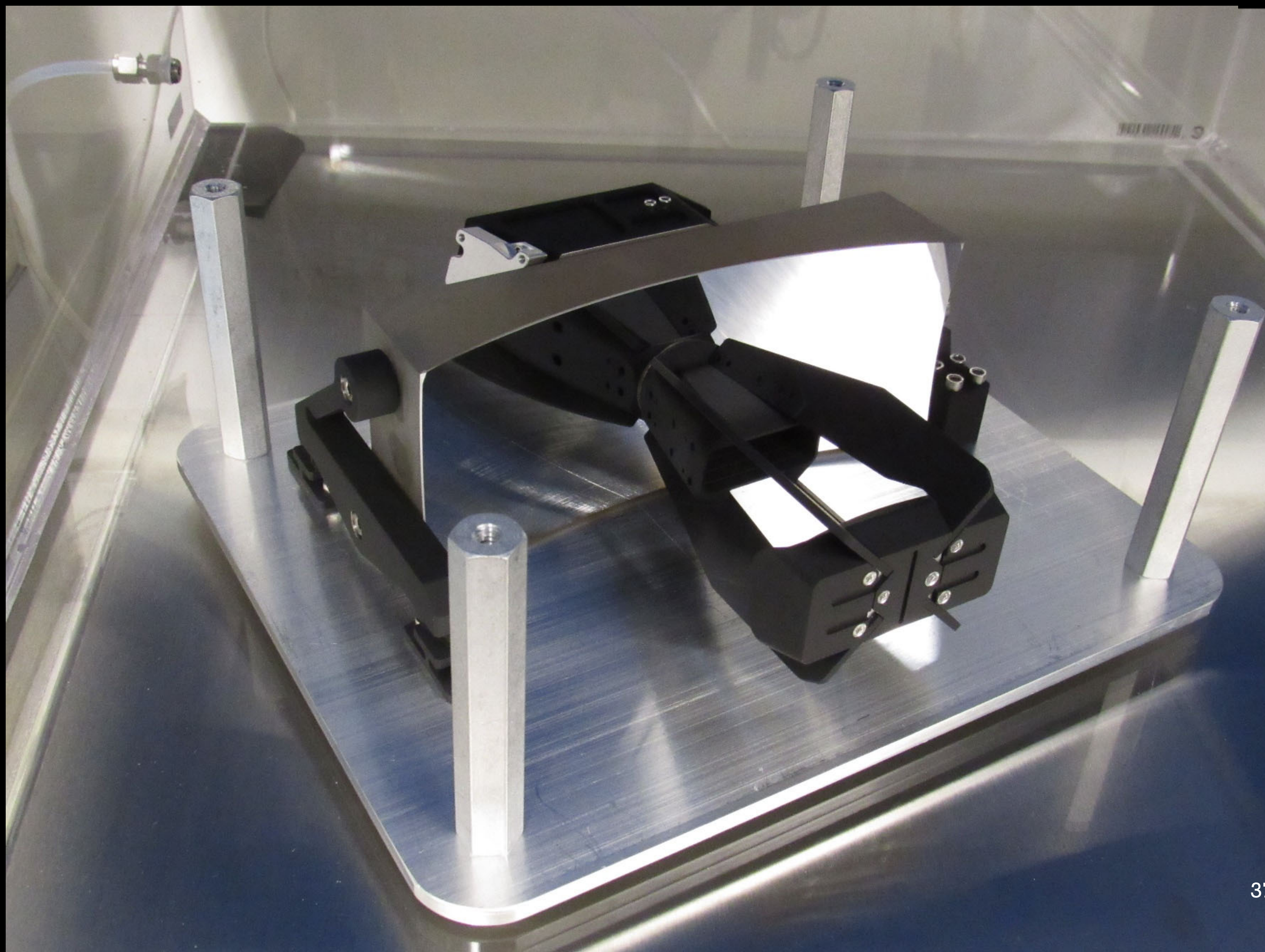
Geometric clear area for a 9cm Cassegrain: A_T ~ **47 cm²**

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

CUTE ~ **3 x** more collecting area

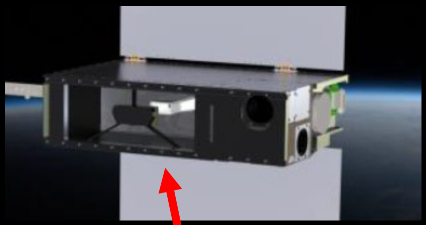
France et al. (2020), Egan et al. (2020)

CUTE Telescope (Flight)

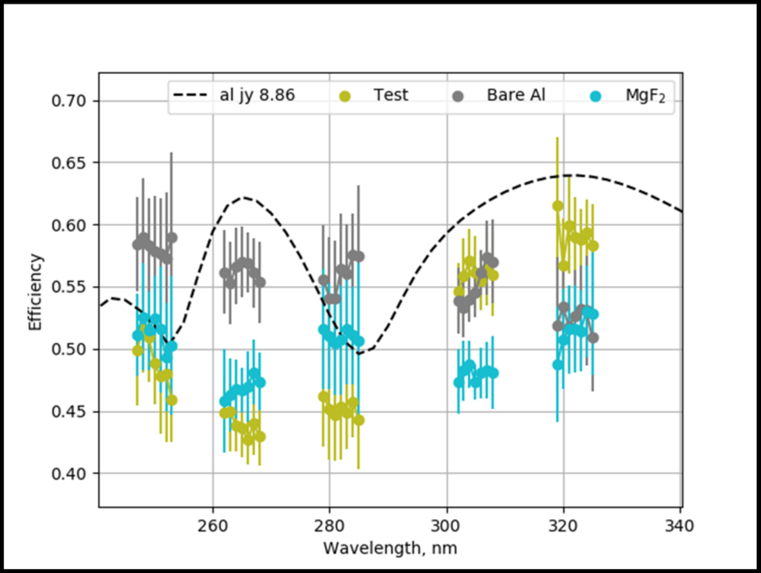


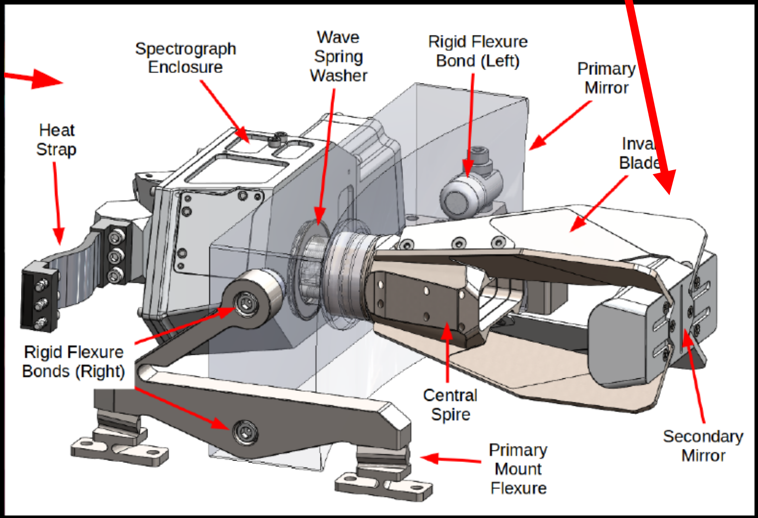
See CUTE design overview in Fleming et al. (2018); Egan et al. (2018)

CUTE Optical System



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





Diffraction grating from J-Y Horiba; bare Al coating

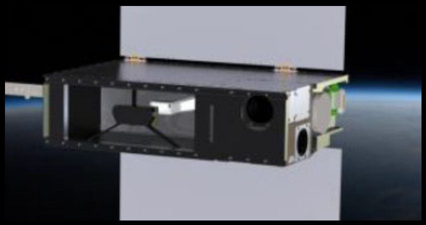
Geometric clear area for a 20 x 8 cm Cassegrain: A_{CUTE} ~ **140 cm²**

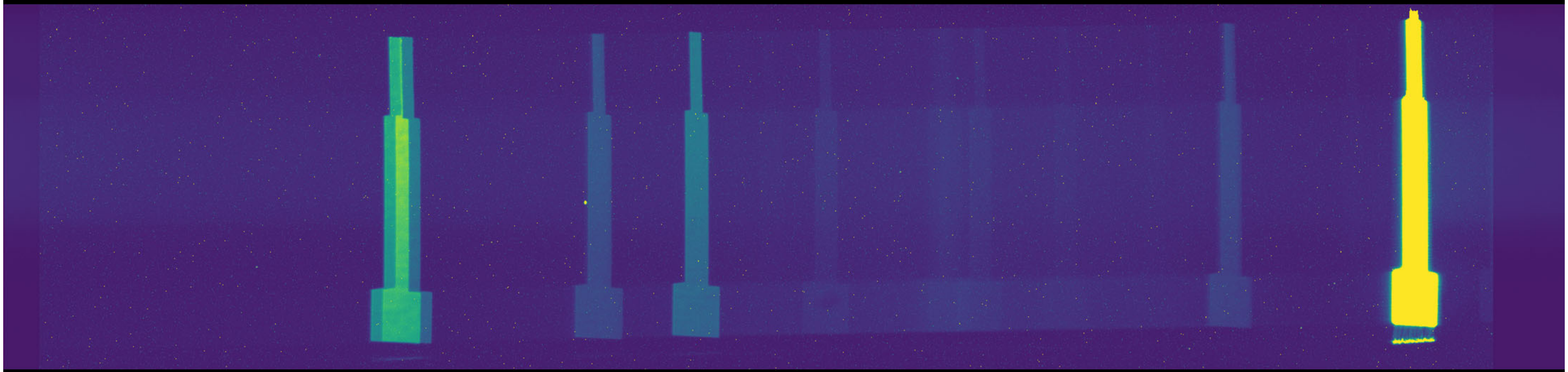
e2v CCD42-10 back-illuminated, UV-enhanced CCD detector. 2048 x 515 pixels, 13.5 micron square pixels

(Mars Science Laboratory ChemCham LIBS spectrometer)

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

CUTE Optical System



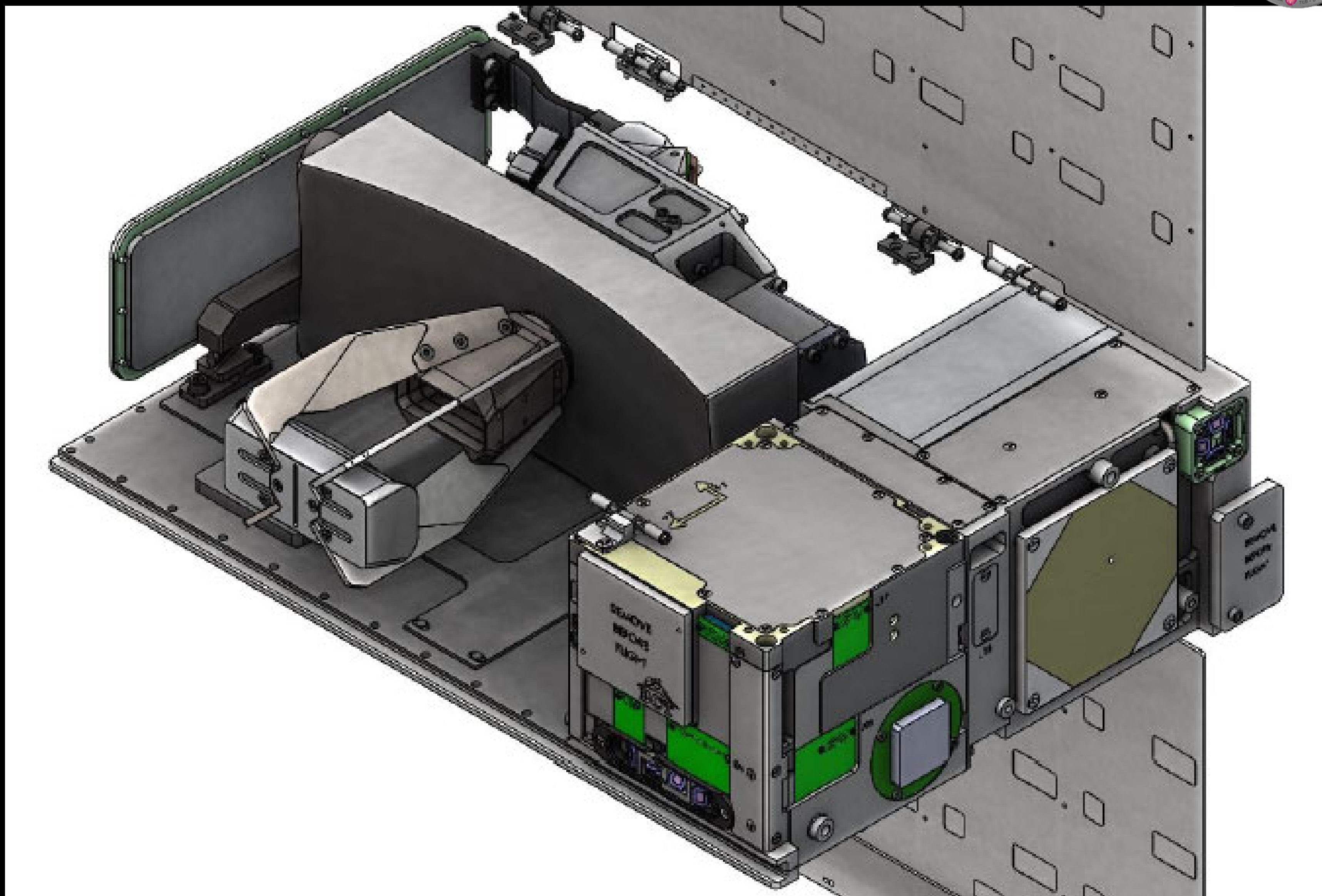


λ

Fully illuminated slit (30”, 60”, 120” x 18’)

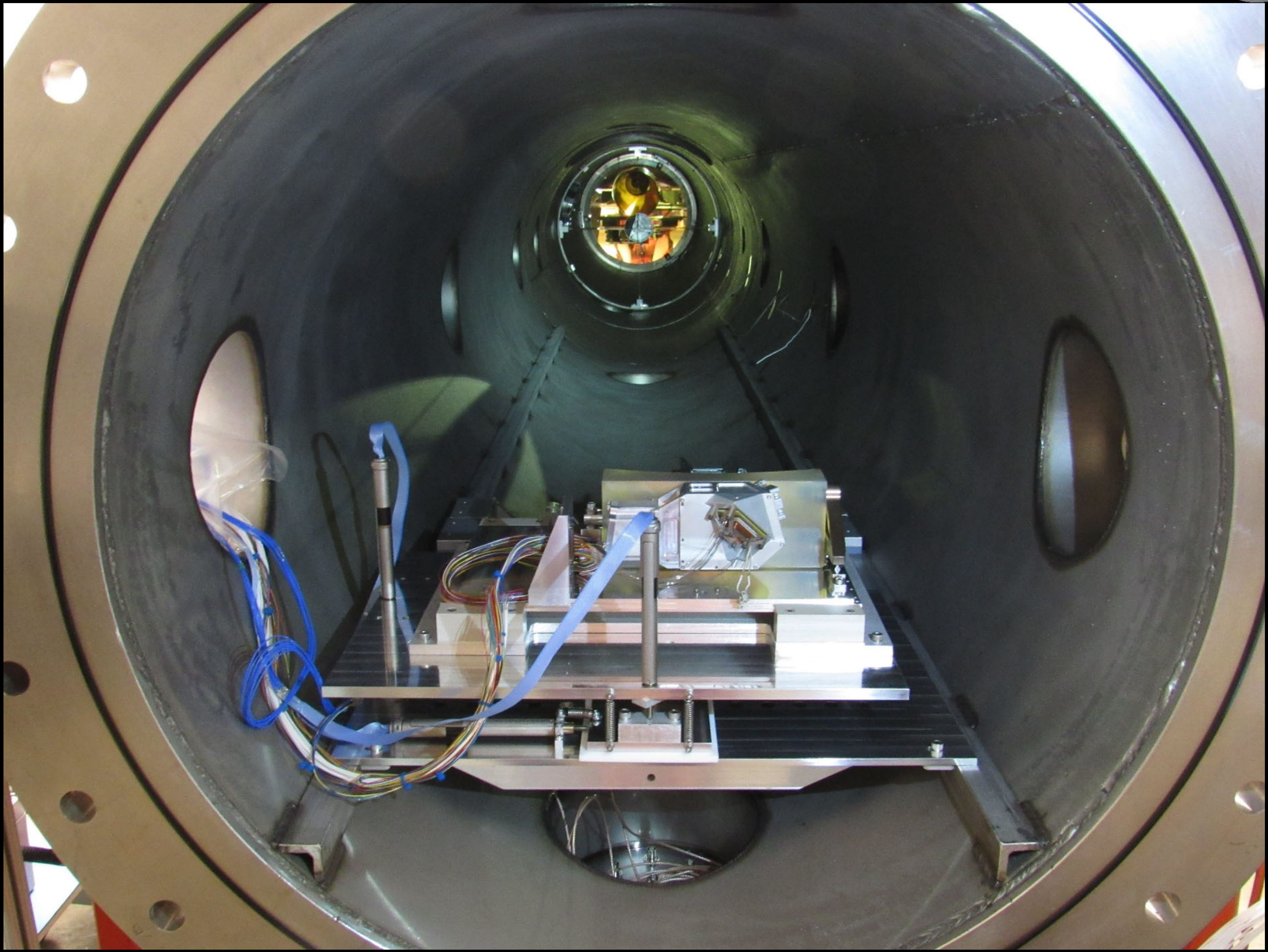
France et al. (2020), Egan et al. (2020)

Integrated CUTE Science Instrument



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

CUTE End-to-End Testing



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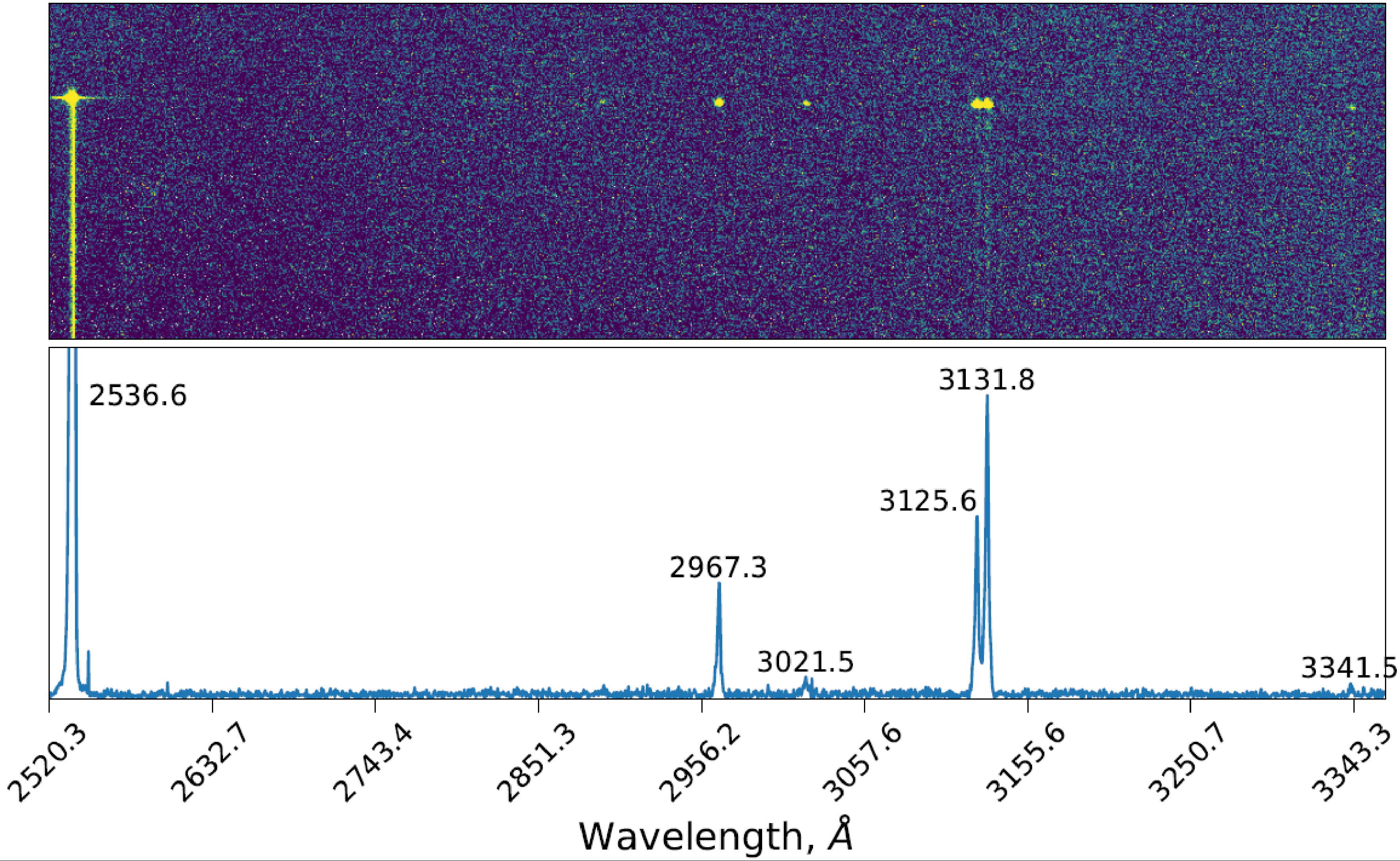

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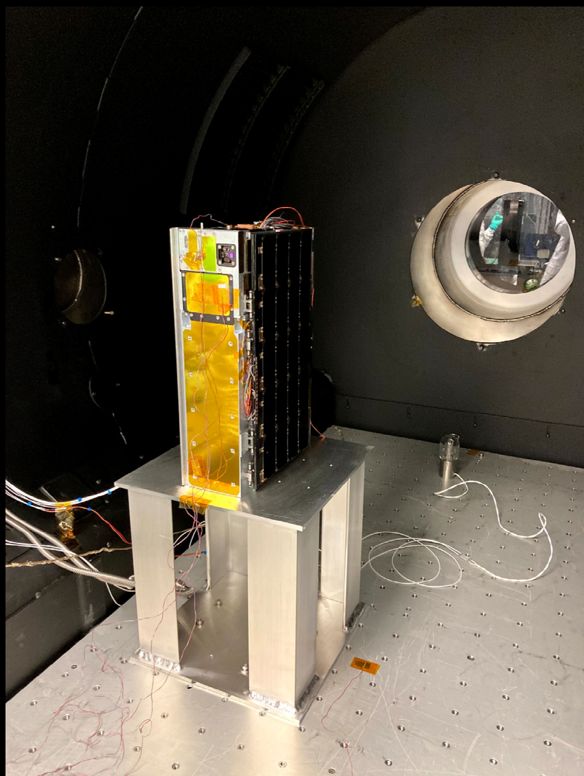

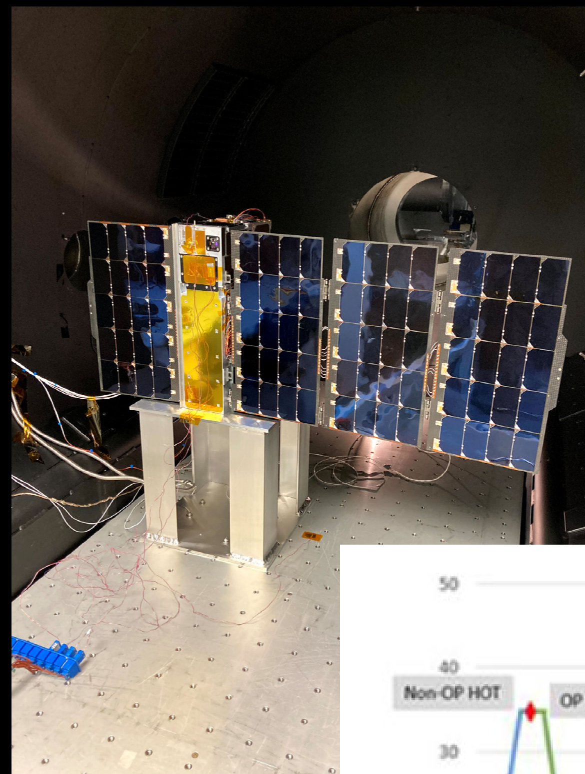

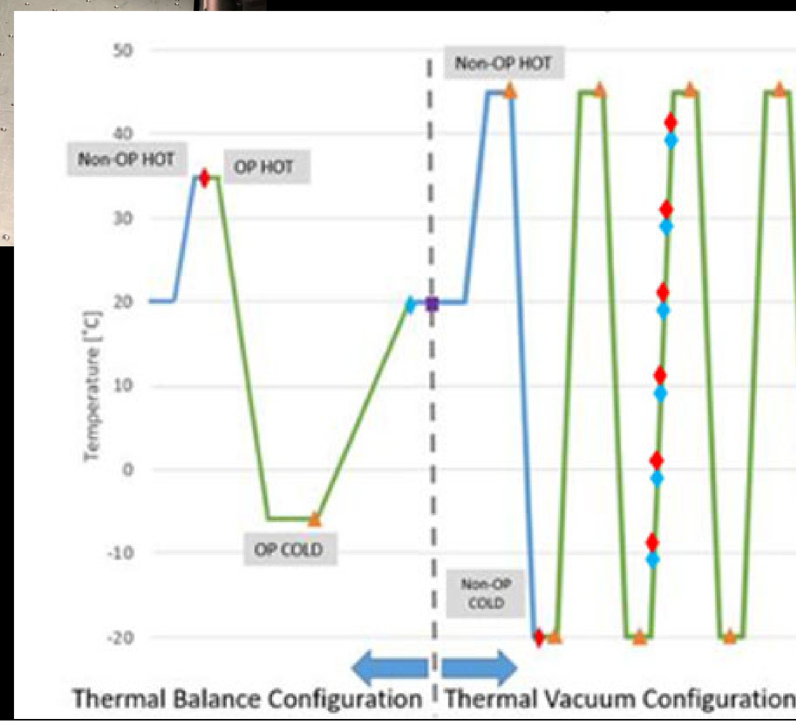

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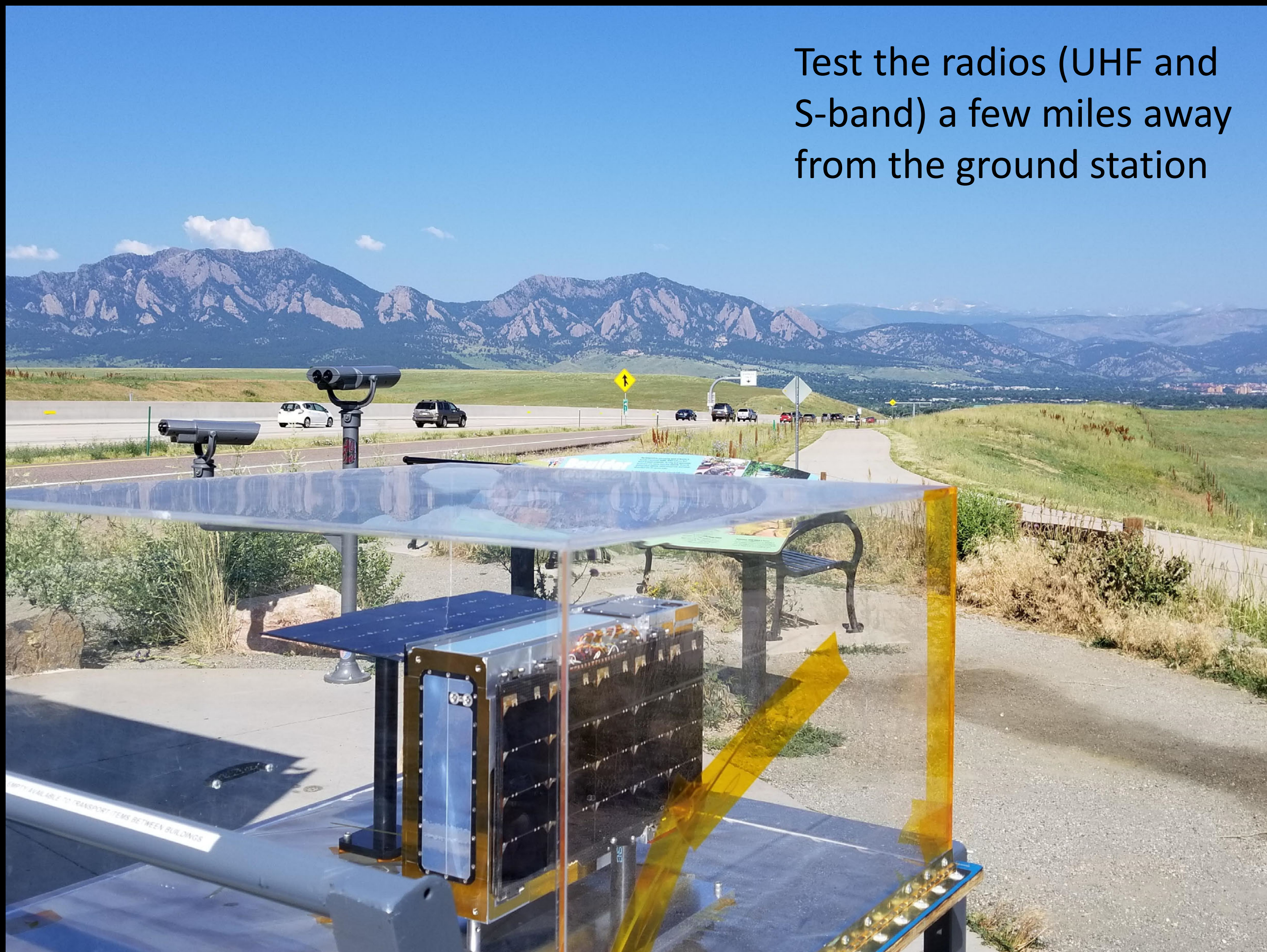
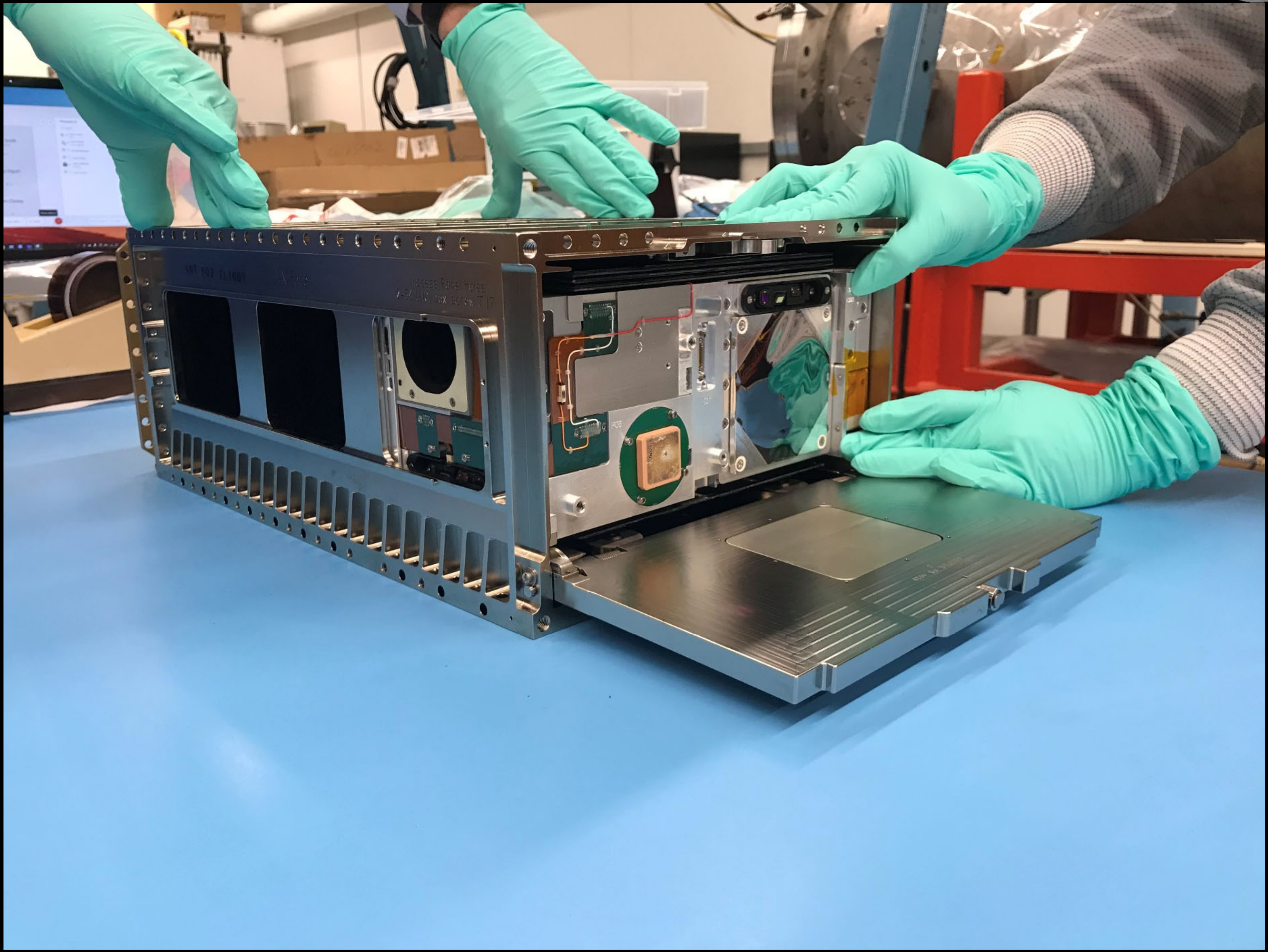


Test the radios (UHF and S-band) a few miles away from the ground station

Payload Dispenser

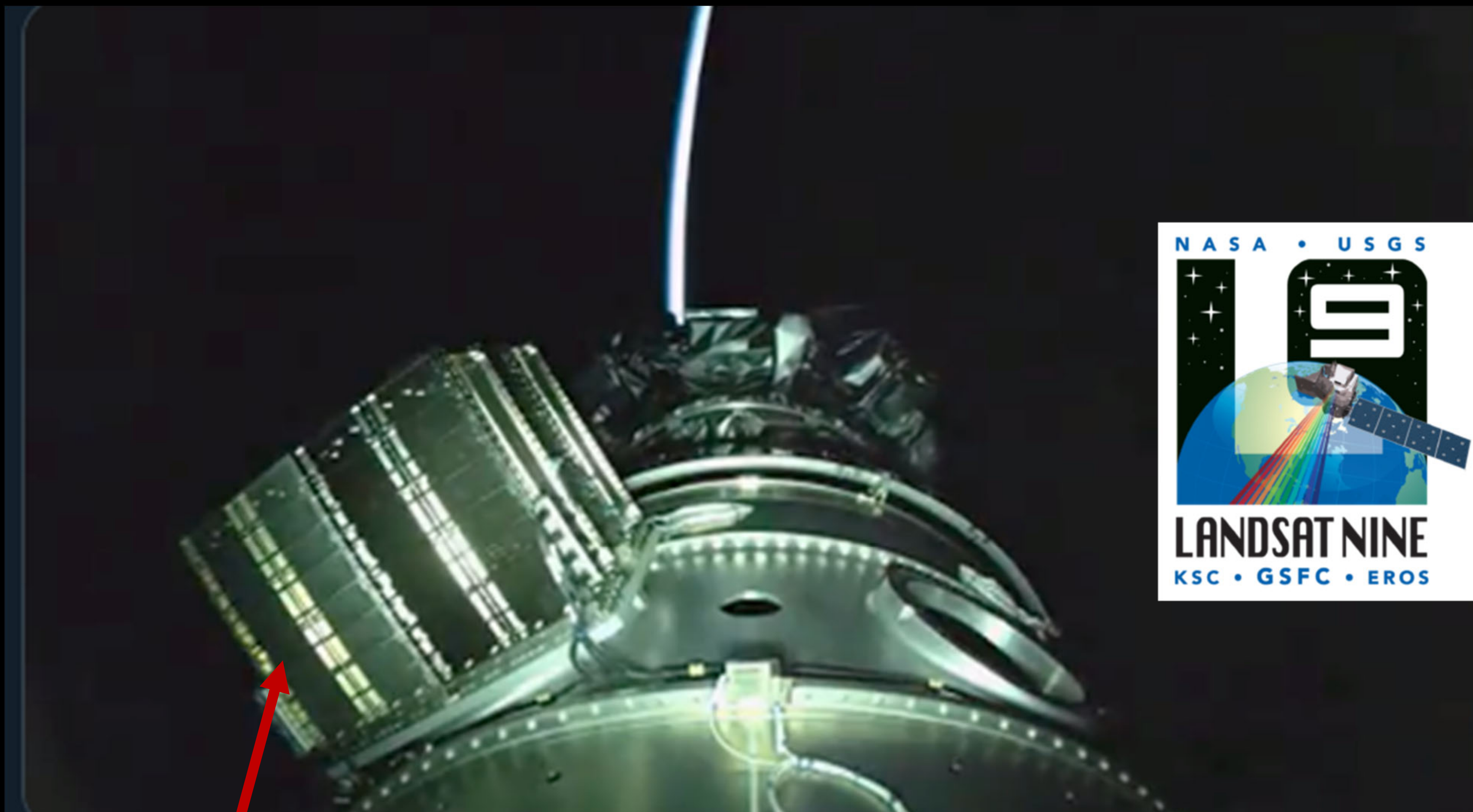


CUTE Delivery to Vandenberg SFB

(grad student) Arika Egan and (engineer) Nick DeCicco installing CUTE into the CubeSat dispenser

CUTE Launch, Sept 27 2021

CUTE Launch, Sept 27 2021



CUTE in dispenser

CUTE Contact, Sept 27 2021

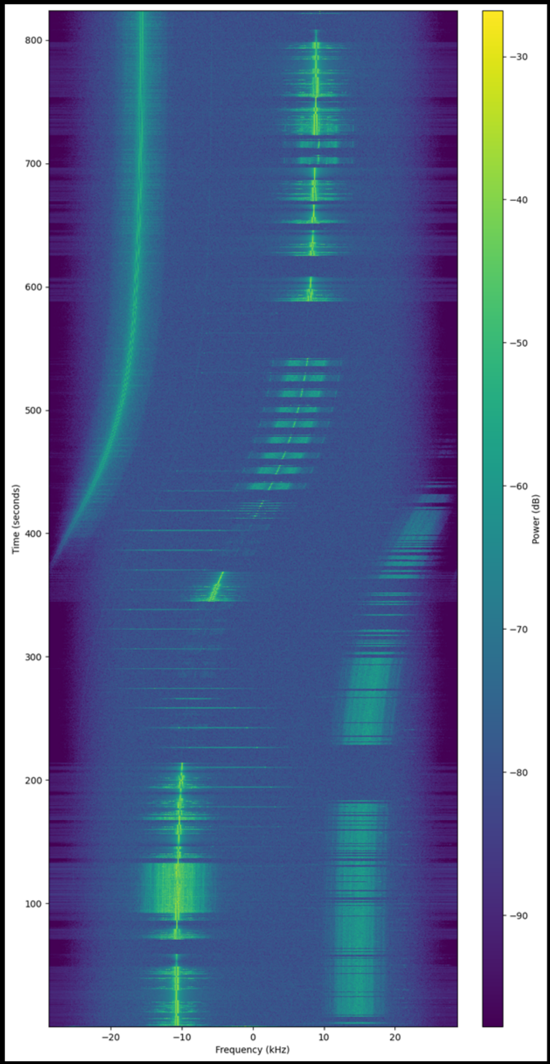
~1 hour post-deployment, SatNOGs ground stations found CUTE

CUTE beacons small identifying packets of info at 16s intervals

UHF: 437.72 Hz

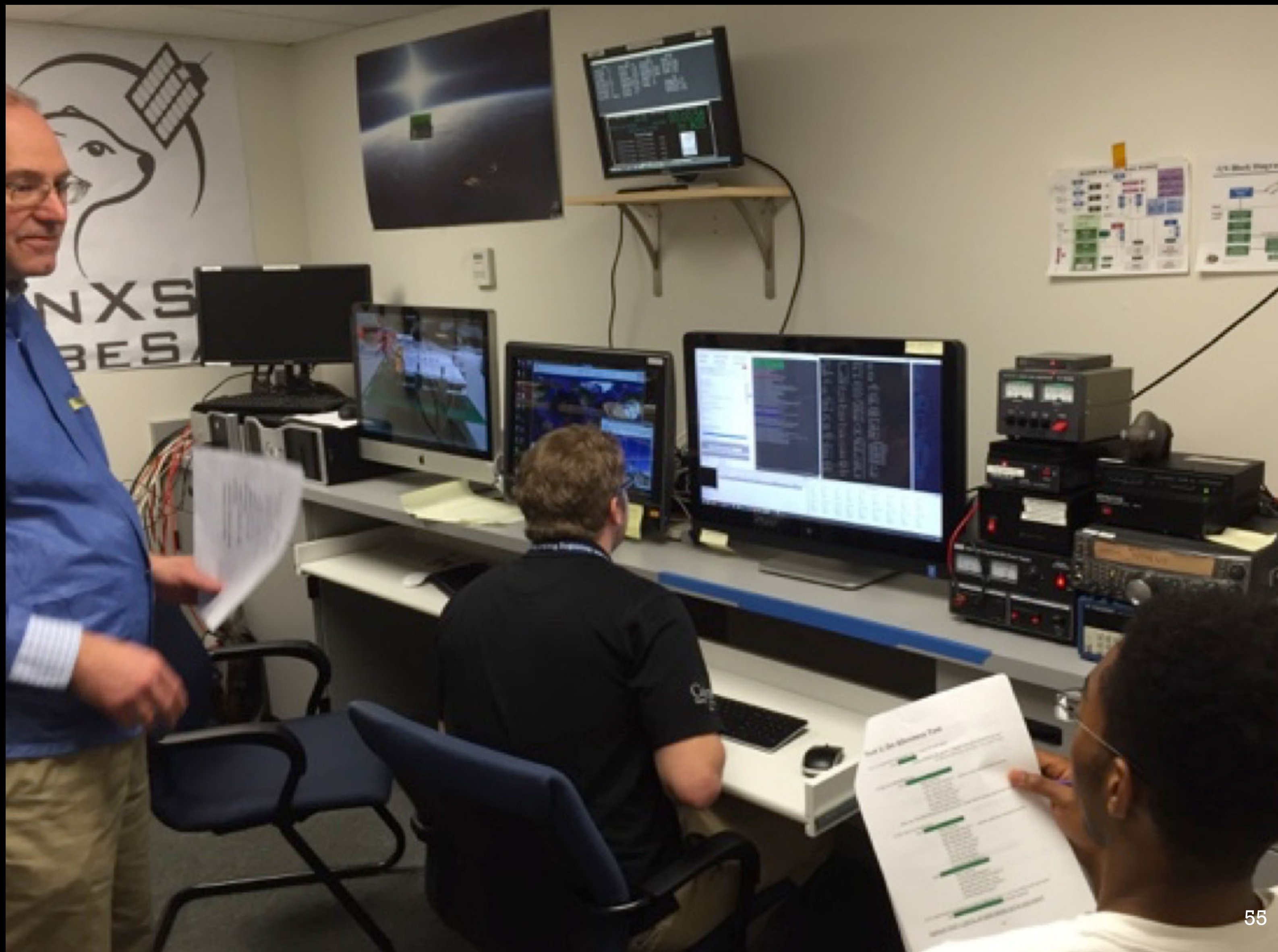
Several ground stations heard CUTE, and were able to calculate a two-line element (TLE)

Time

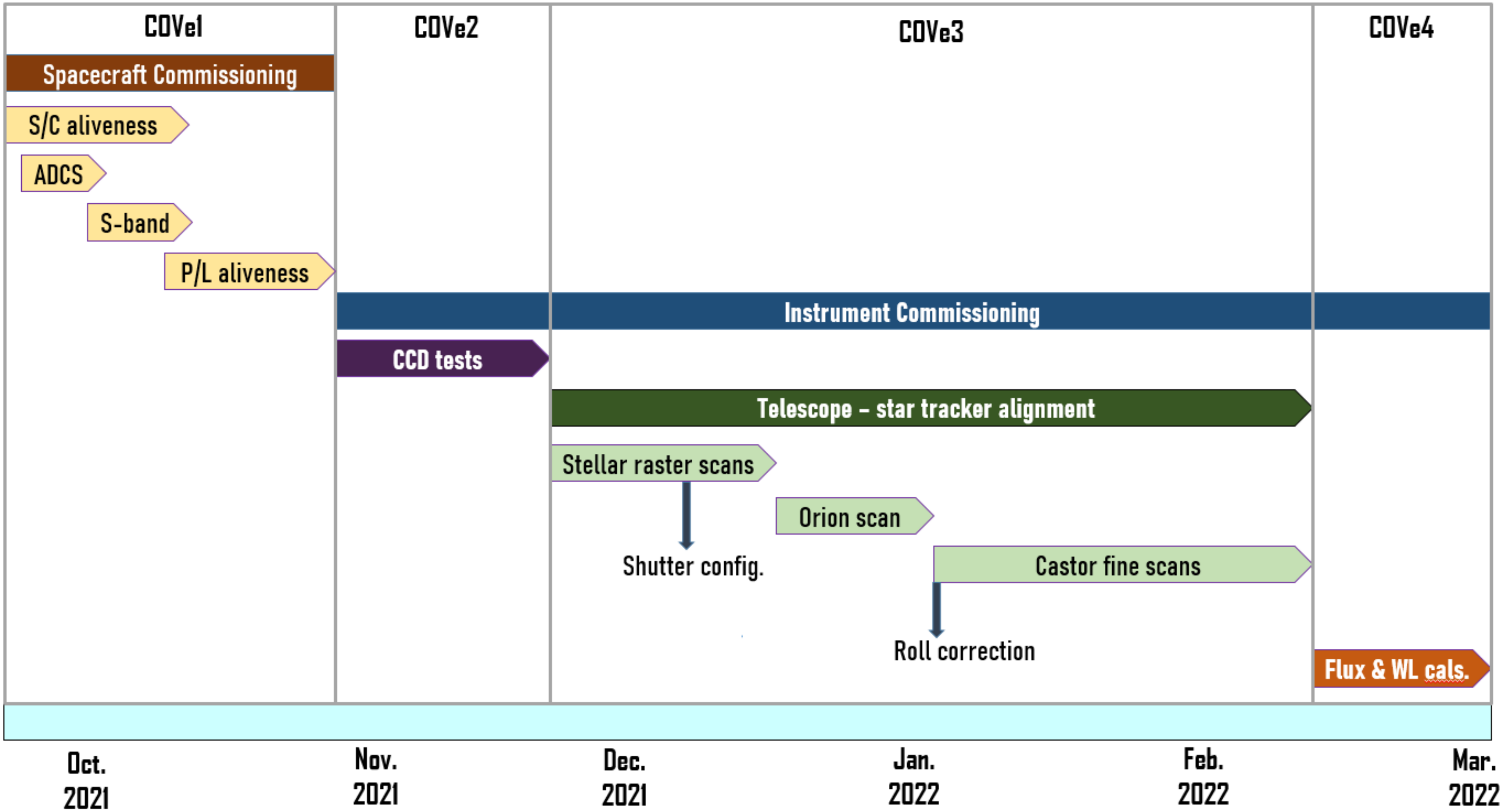


Frequency

CUTE Operations: Student Ops Team

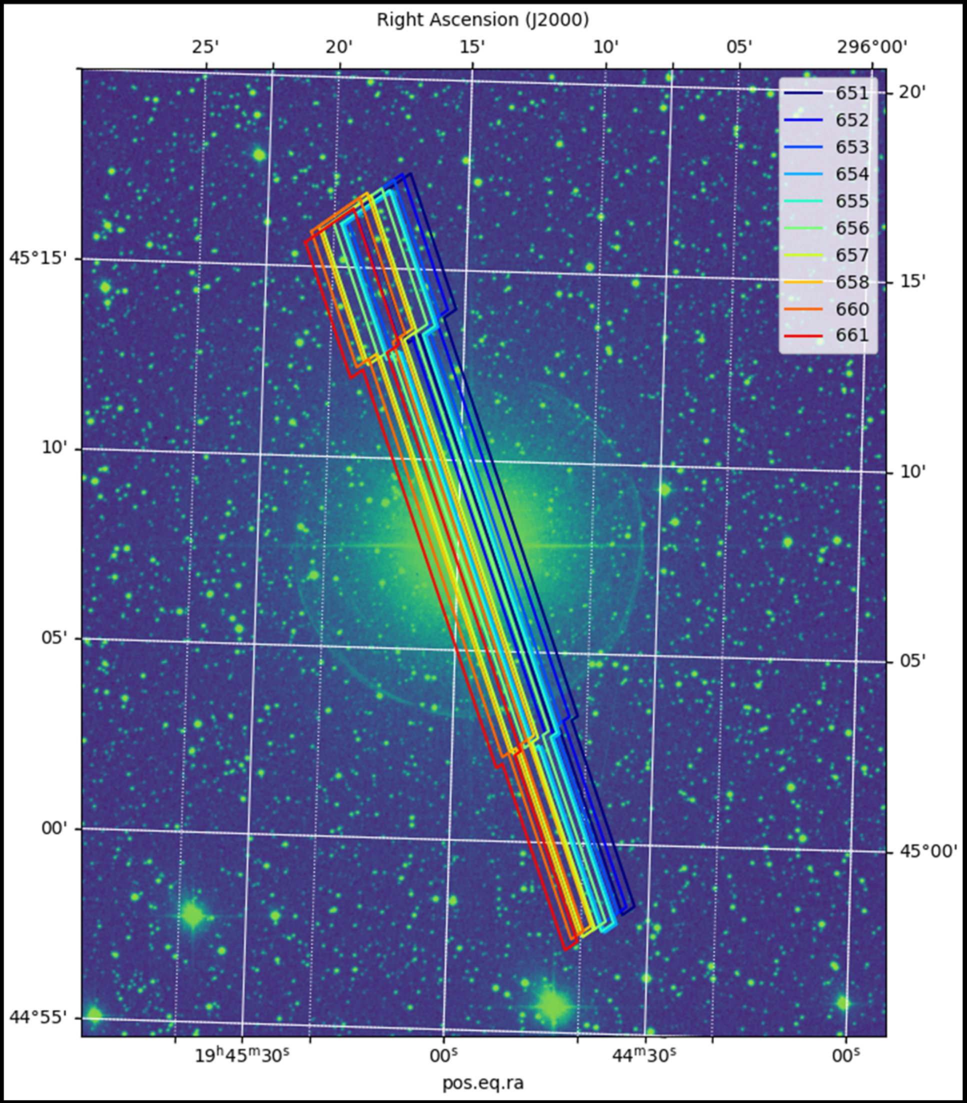


CUTE Commissioning Activities



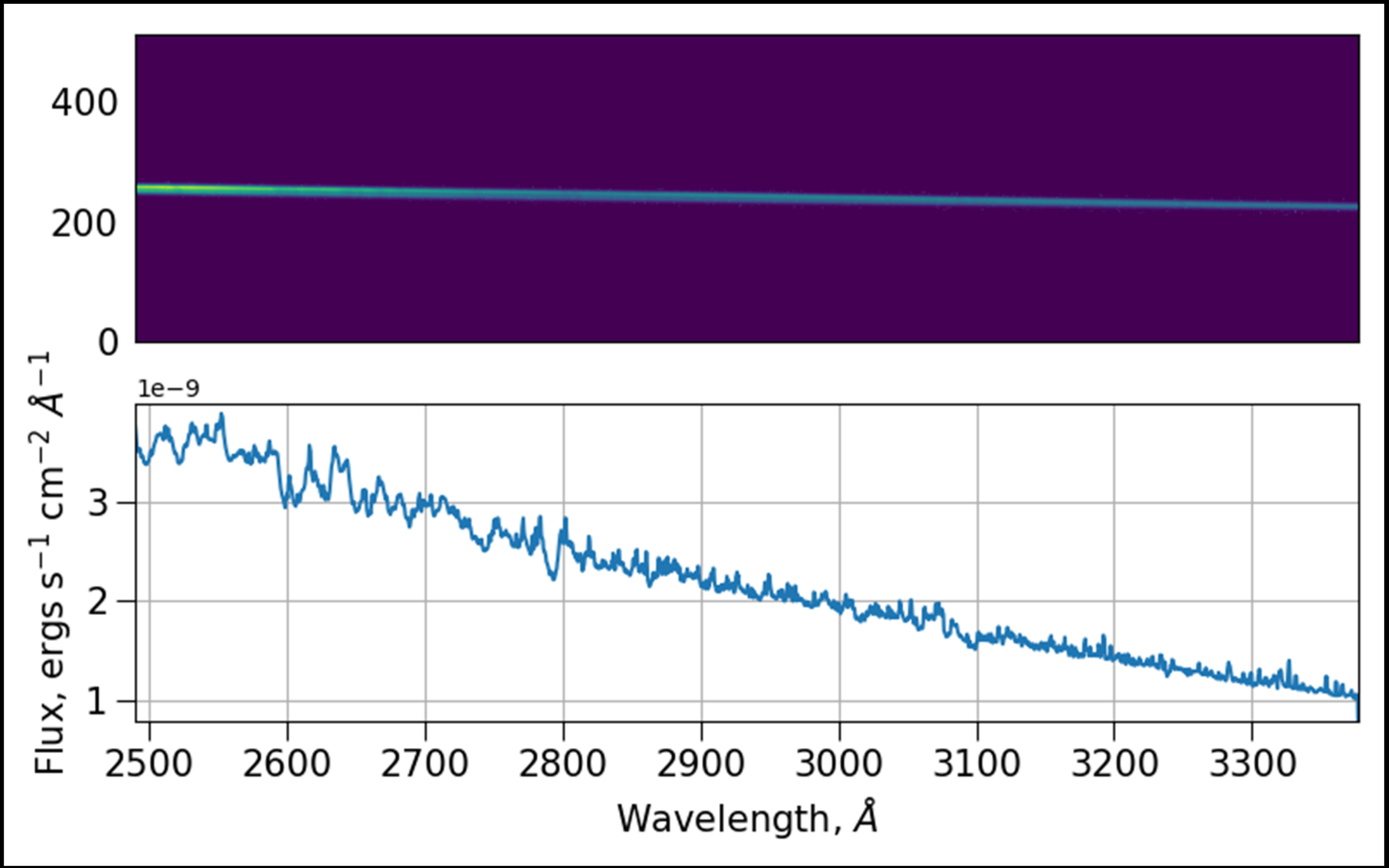
Suresh et al. (2022 –in prep)

CUTE Commissioning: Telescope/Star tracker Alignment



Suresh et al. (2022 –in prep)

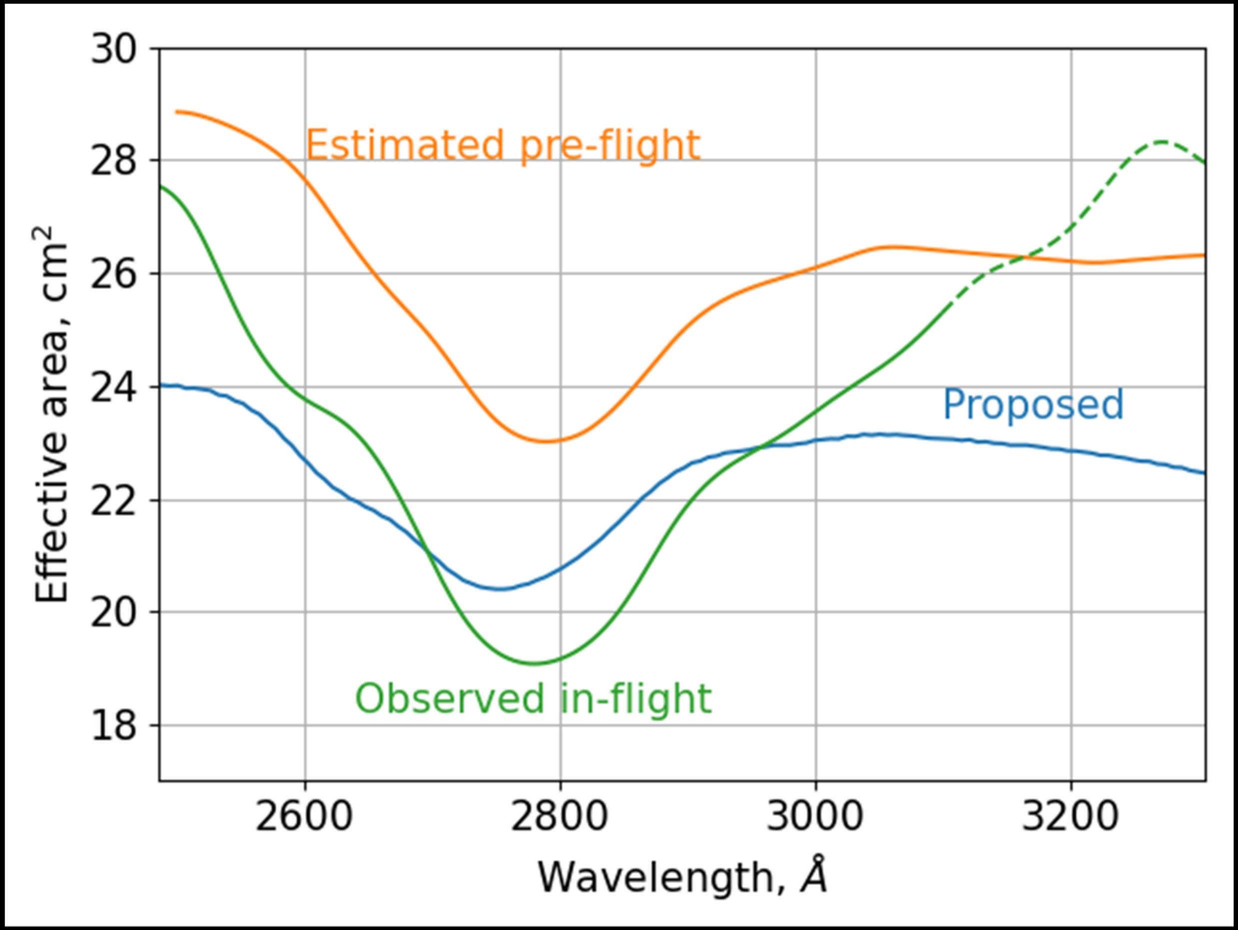
CUTE Commissioning: Measured Performance



Calibration spectrum of O4I ζ Pup

France et al. (2022 – submitted)

CUTE Commissioning: Measured Performance



Instrument Sensitivity:

A_{eff} = **19-28 cm²**

R ≈ **1000**

Egan et al. (2022 – submitted)

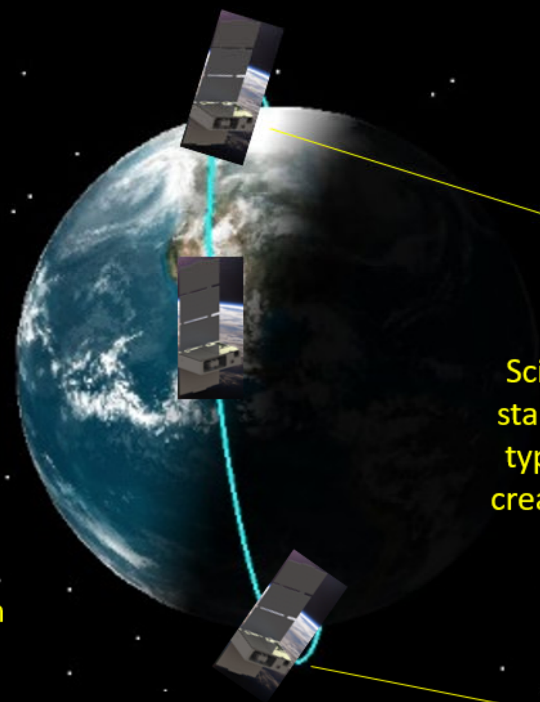
CUTE Observing Summary

Sun-Synch Orbit permits high-efficiency observing & positive power. Targets are seasonally available

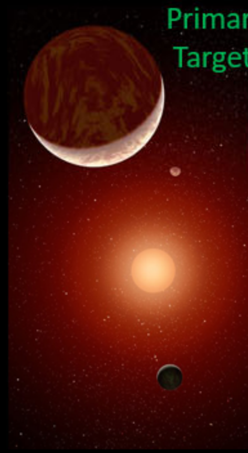
Primary survey will return to same target over the course 3 – 8 weeks to complete 6 – 10 orbit campaign

Instrumental dark and bias frames are acquired at similar temperature and illumination conditions as science observations. Data downlink over Boulder

Calibration targets acquired at approximately one-month cadence to monitor sensitivity and detector health.



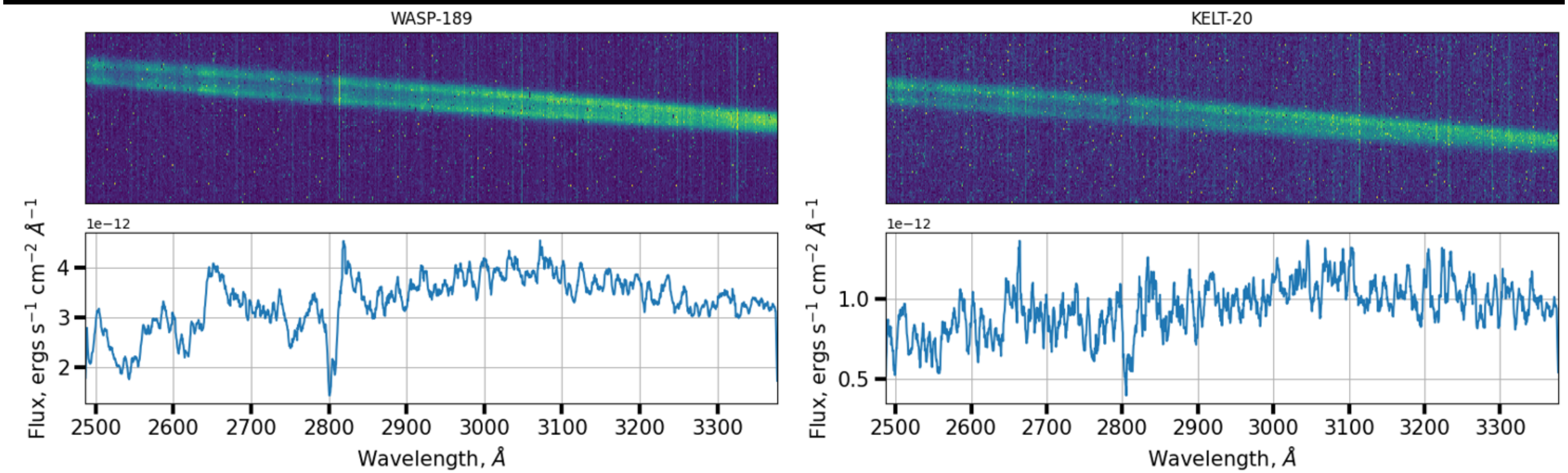
Targets: roughly anti-sunward



Science observing mode is staring. Exposure times are typically 5 min, lightcurves created over multiple orbits.

France et al. (2022 – submitted)

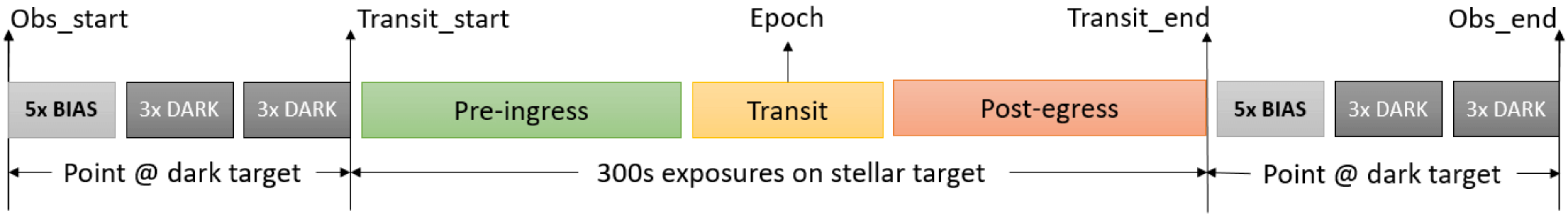
CUTE Science Spectra



- Mild defocus observed in cross-dispersion profiles
  - Result of unexpected final vibration test 2 weeks prior to delivering the spacecraft

France et al. (2022 – submitted)

CUTE Initial Science Data: WASP-189b



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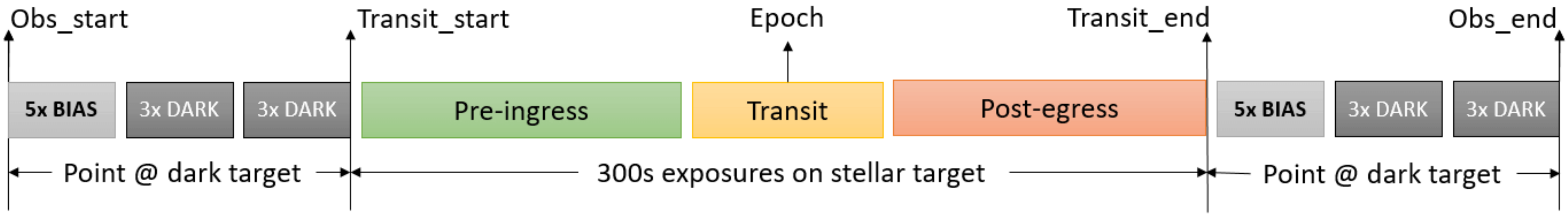
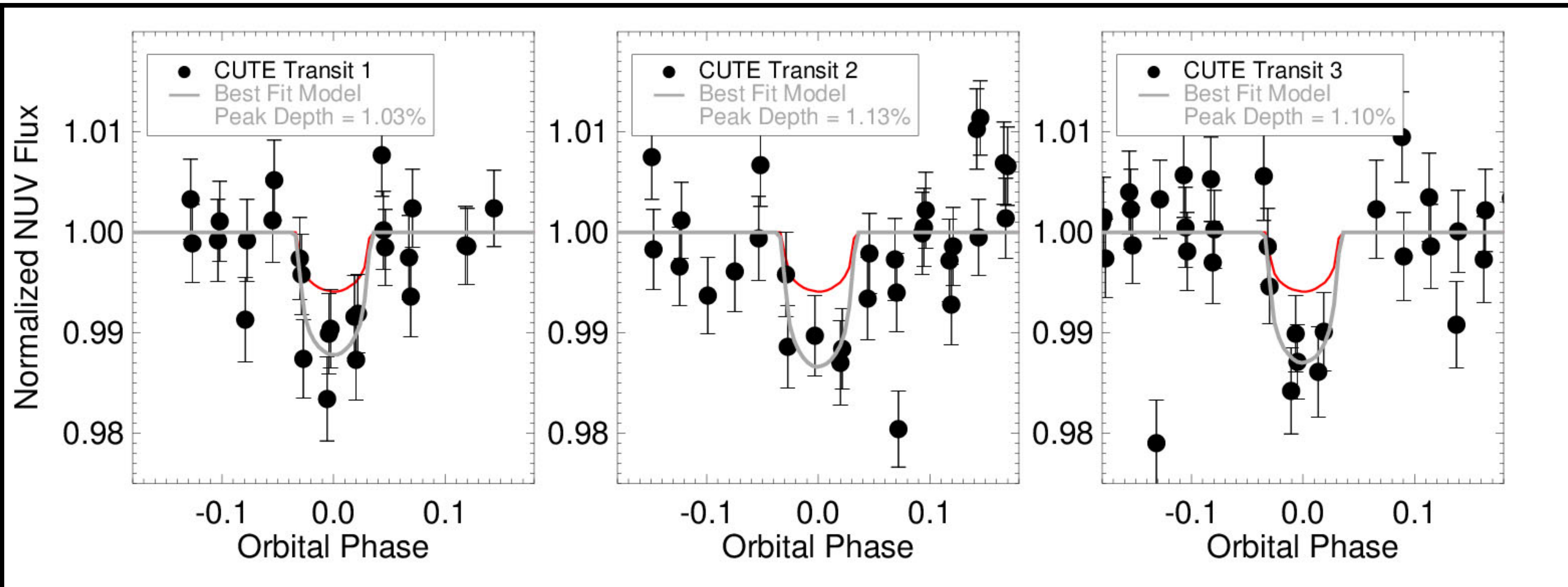




Three independent 2540 – 3300 Å light curves with initial processing pipeline. Best fit transit model is in gray, optical lightcurve from CHEOPS (Lendl et al. 2020) in red.

France et al. (2022 – submitted)

Student & PI Training Opportunities

Dr. Ambily Suresh

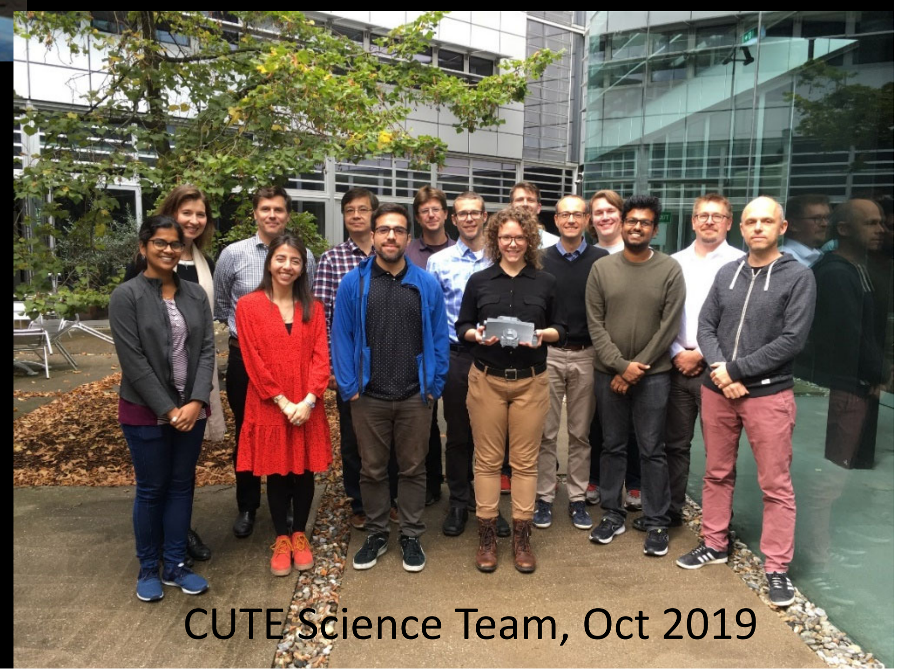
Arika Egan

Prof. Kevin France

Stefan Ulrich

Nick DeCicco

Prof. Brian Fleming



CUTE Summary

- Proposed ROSES D.3 APRA - March 2016, project start July 2017
- Launched Sept 27 2021
- 6U cubesat, R = 1000 NUV spectrophotometry
- Targeting ~10 Jovian planets orbiting nearby stars (V < 8)
- 170 ks of total science exposures acquired. Data archived at NASA NexSci, starting in 2023
- Mission overview and performance papers submitted, first science papers to be submitted in fall 2022

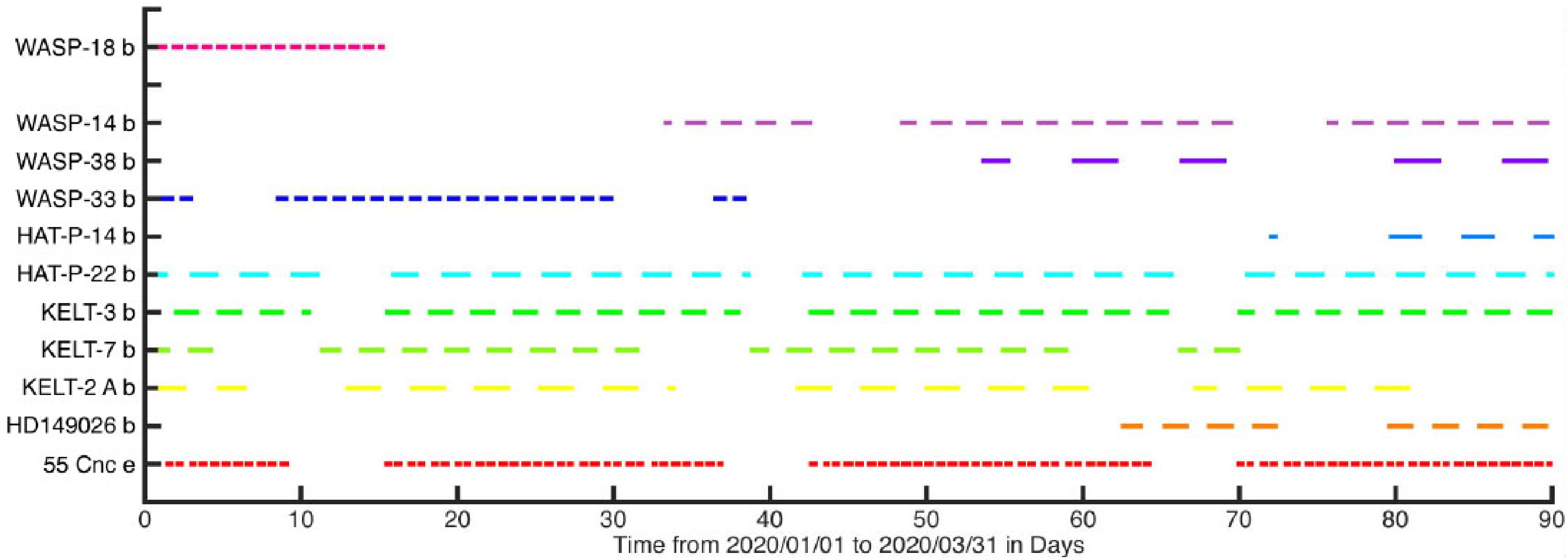
@CuteCubeSat

CUTE Lessons Learned

- Proposed ROSES D.3 APRA - March 2016
- Selected February 2017, funded July 2017
- TBD TBD

END

CUTE Example Target Visibility List



PI – France