The Colorado Ultraviolet Transit Experiment (CUTE):
A cubesat to study the most extreme exoplanets

Kevin France – University of Colorado
APAC Meeting, 15 March 2021
Extrasolar Planets:
\[ N_{\text{plan}}(2021) \]
\[ \sim 4300 \text{ Confirmed} \]
\[ \sim 200 \times N_{\text{plan}}(1999) \]
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
- $T_{\text{eff}} \sim 2400 - 3100$ K

(Hellier et al. 2009)

**Super-Earth**
- GJ 832c, red dwarf host
- $M \sin(i) \sim 5.2 \, M_E$, $R \sim 1.5 \, R_E$
- $a \sim 0.16$ AU
- $T_{\text{eff}} \sim 230 - 280$ K

(Wittenmyer et al. 2014)
• 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
HOT JUPITER ATMOSPHERES

• EUV heating driving mass-loss from short-period planets
• 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

\[
\text{Occultation Depth} = \left( \frac{R_p}{R_*} \right)^2
\]
EXOPLANET ATMOSPHERES

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

Occultation Depth = \left( \frac{R_p(\lambda)}{R_\star} \right)^2

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

• Composition
• Temperature structure
• Velocity flows
• Mass-loss rates
Transit Spectroscopy of Short-period Planets

- EUV heating driving mass-loss from short-period planets
- 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% (!)
Extreme Exoplanet Atmospheres: challenges

• For the ~half-dozen Hot Jupiters measured with Hubble, we often find conflicting results, even on the same planet!
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
Extreme Exoplanet Atmospheres: challenges

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• Sample size of mass-loss measurements ~6, early-ingress ~1, late-egress ~2
Extreme Exoplanet Atmospheres: challenges

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- Sample size of mass-loss measurements \( \sim 6 \), early-ingress \( \sim 1 \), late-egress \( \sim 2 \)

- Stellar baseline for transit measurements
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• Self-consistent modeling framework
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  → multiple, consecutive transits, single data pipeline

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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)
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
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).

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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

- Brighter stellar flux enables spectroscopy in a correspondingly smaller platform
- **Spectroscopy** required to isolate escaping gas species

WASP-121b; Sing et al. 2019
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)
Astronomy with Cubesats: Dedicated Mission Architecture

CUTE:
11.0 cm x 23.7 cm 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

Geometric clear area for a 9cm Cassegrain: $A_T \sim 47 \text{ cm}^2$

Geometric clear area for a 20 x 8 cm Cassegrain: $A_{\text{CUTE}} \sim 140 \text{ cm}^2$

CUTE $\sim 3 \times$ more collecting area

Source: Nu-Tek Precision Optics

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

France et al. (2020), Egan et al. (2020)
CUTE Science Instrument

See CUTE design overview in Fleming et al. (2018), Egan et al. (2018)
CUTE Telescope (Flight)

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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

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

See CUTE design overview in Fleming et al. (2018); Egan et al. (2018)
CUTE End-to-End Testing

See CUTE design overview in Fleming et al. (2018); Egan et al. (2018)
CUTE End-to-End Testing
CUTE Measured Performance

Instrument Sensitivity:

\[ A_{\text{eff}} = A_T R^5 \varepsilon_{\text{grat}} \text{QE}_D = 20-30 \text{ cm}^2 \]

\[ R \approx 2000 \]
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 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:

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

Egan et al. (2020)
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
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Learn more: Landsat 9 Mission
CUTE Status

• Proposed ROSES D.3 APRA - March 2016

• Selected February 2017, funded July 2017

• Science Team face-to-face meetings:

• 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
CUTE Example Target Visibility List

- WASP-18 b
- WASP-14 b
- WASP-38 b
- WASP-33 b
- HAT-P-14 b
- HAT-P-22 b
- KELT-3 b
- KELT-7 b
- KELT-2 A b
- HD149026 b
- 55 Cnc e

Time from 2020/01/01 to 2020/03/31 in Days