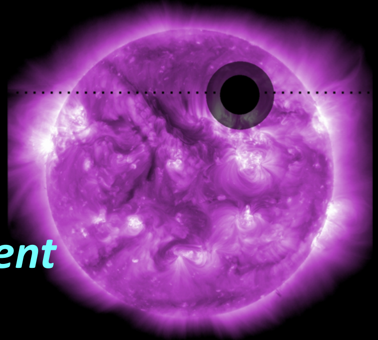
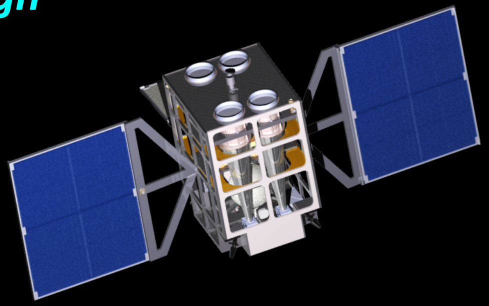
SEEJ: Smallsat Exosphere Explorer of hot Jupiters
PI: Scott J. Wolk



- ***The primary objective of SEEJ is to observe the maximum extent of the atmosphere of Hot Jupiters.***
    - SEEJ will perform high cadence monitoring transits of X-ray bright system detected by TESS.
    - SEEJ will measure the depth and shape of planetary transits of at least 7 Hot Jupiters at X-ray wavelengths (0.3-2.0 keV).
- ***SEEJ will also efficiently and effectively characterize the high energy flux of host stars***.
- *Need for SEEJ is **NOW**!*



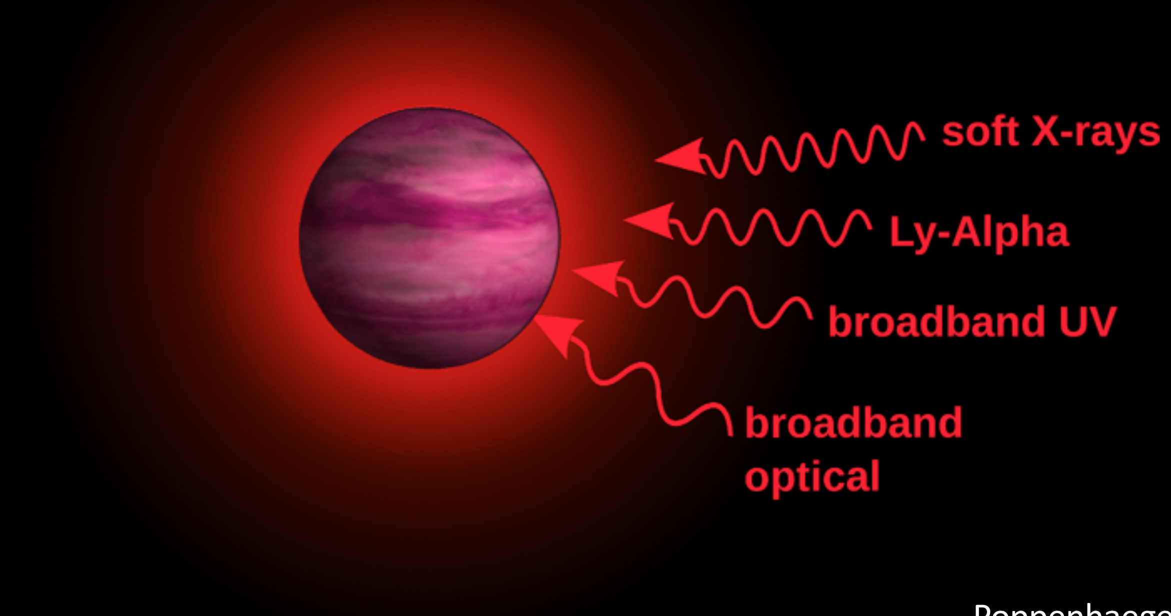
TEAM

Name	Institution	Role
Scott Wolk	SAO	Principal Investigator
JaeSub Hong	Harvard	Deputy PI
Martin Elvis	SAO	SOC Lead
Suzanne Romaine	SAO	MiXO Lead
Almus Kenter	SAO	CMOS Lead
Mark Stahl	MSFC	Lead System
Bruce Wiegmann	MSFC	Design Lead
Christopher Loghry	MOOG	Spacecraft Provider
Katja Poppenhäger	Potsdam	Science Lead
Jeremy Drake	SAO	Calibration Lead
Christopher S. Moore	SAO	Camera Lead
Vinay Kashyap	SAO	Simulations Lead

Measuring Exoplanet Atmospheres

How does the size of the exoplanet's atmosphere contribute to its mass loss?

- Planetary $\dot{M}$ depends on F_{XUV}
- Larger estimated mass loss than if the planetary atmosphere is not extended
- Direct measures of atmospheric height



Poppenhaeger et al. (2013)

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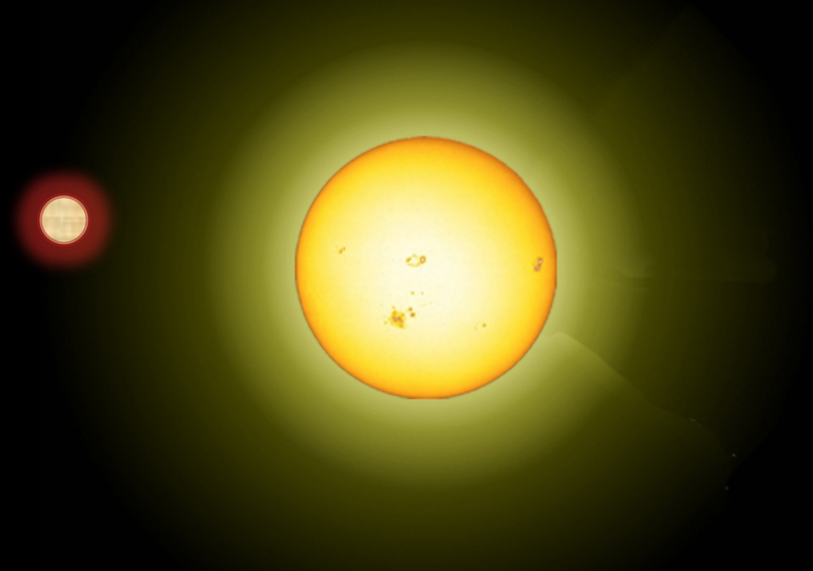

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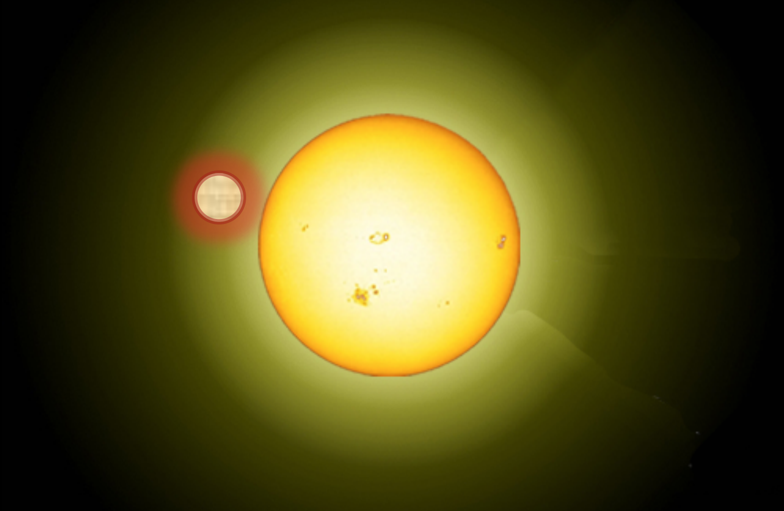

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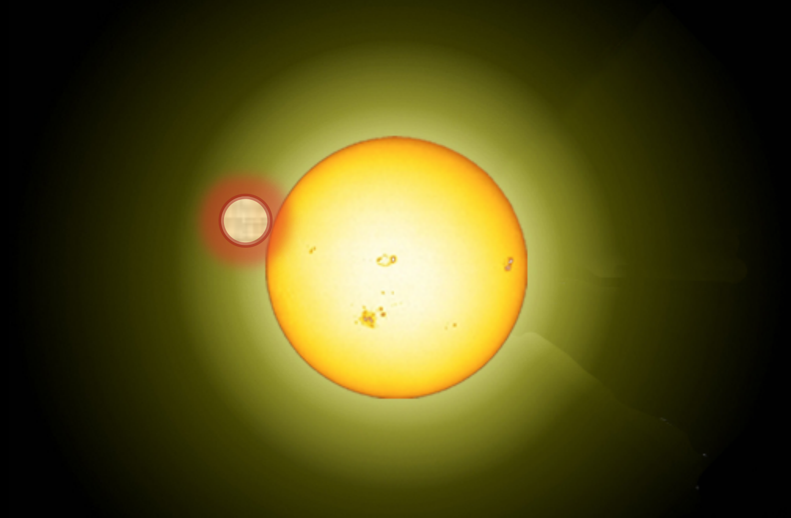

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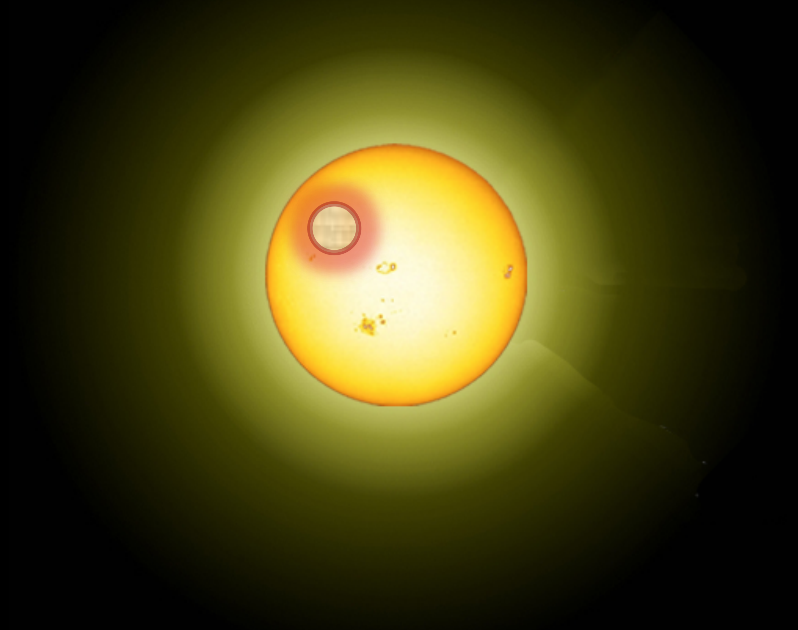

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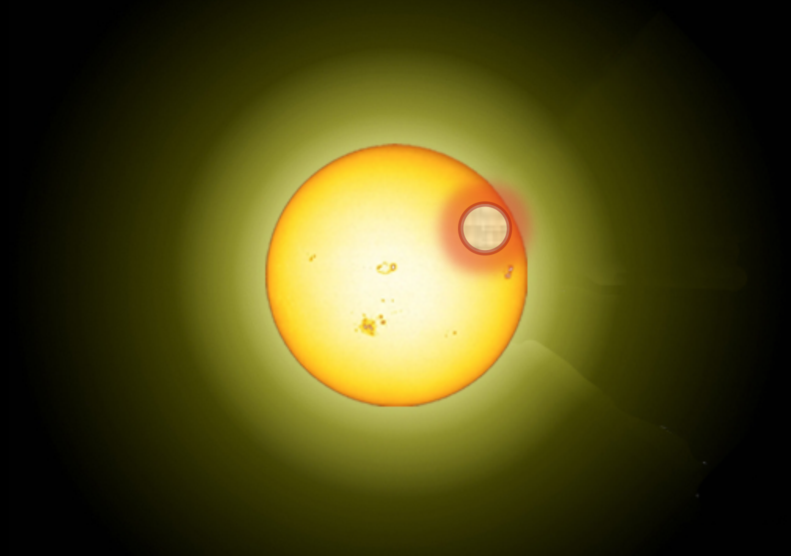

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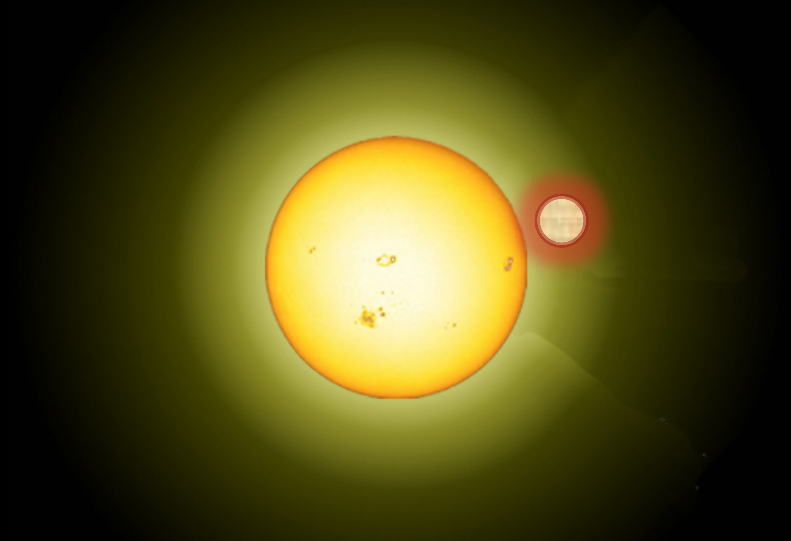

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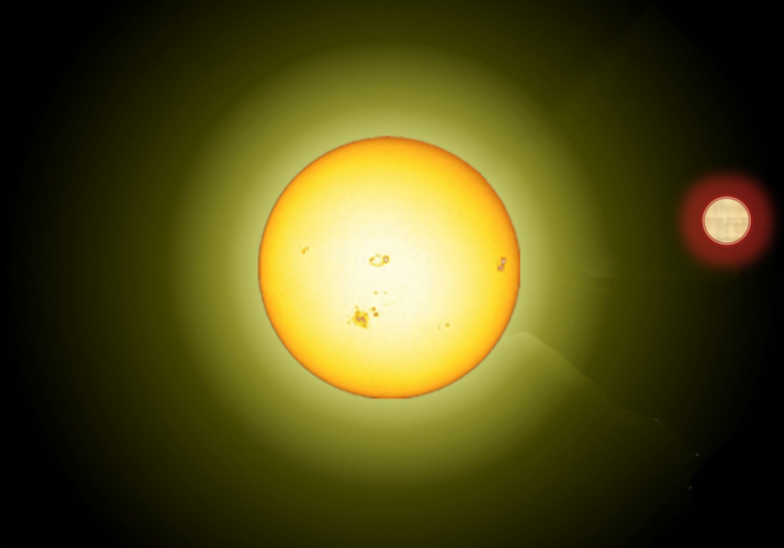
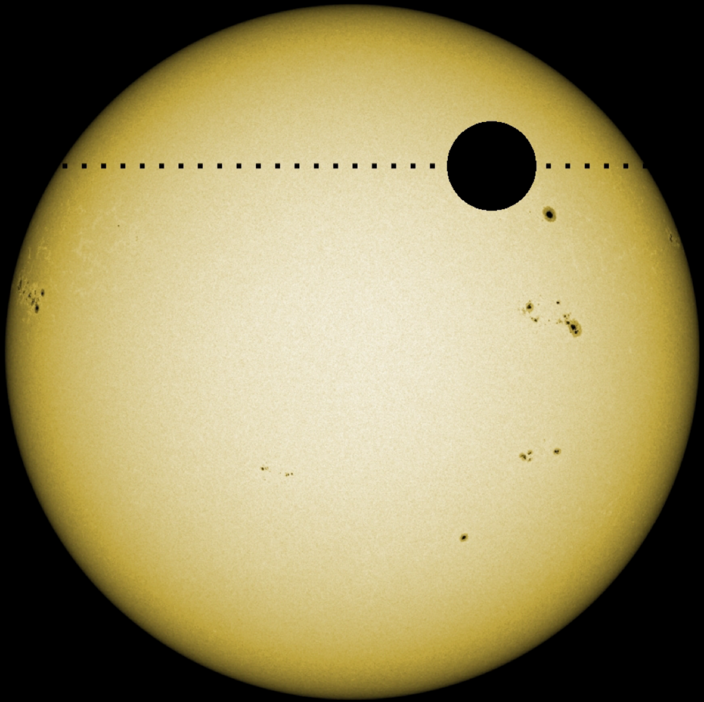
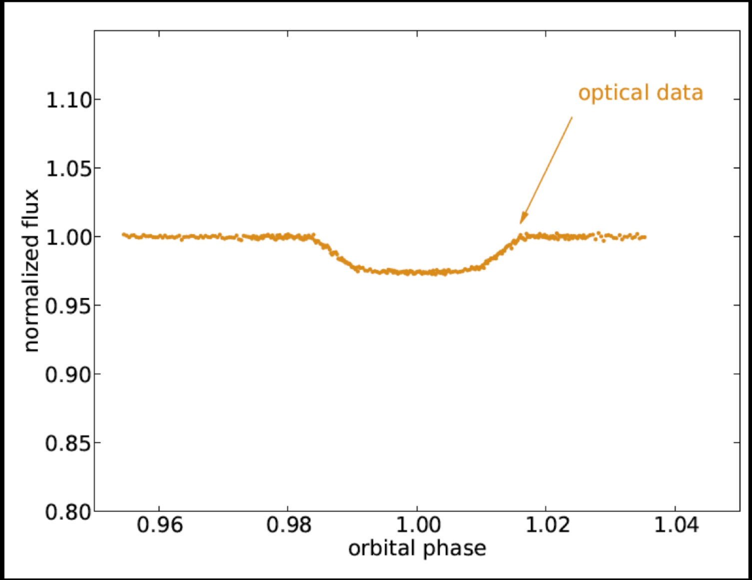


Transit of HD 189733





Chandra: 7 Transits
Poppenhaeger, Schmidt & Wolk (2013)

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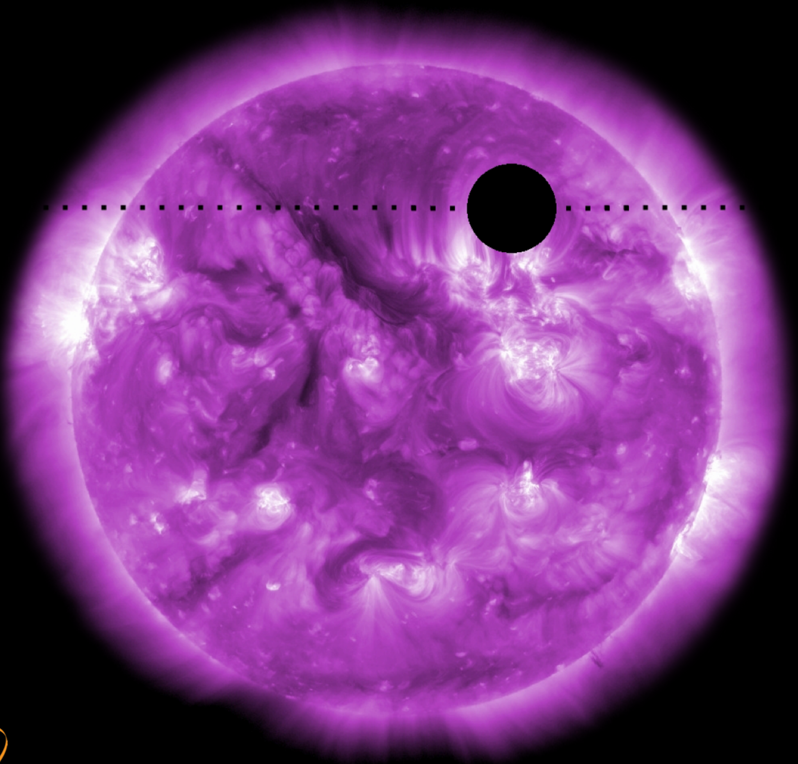

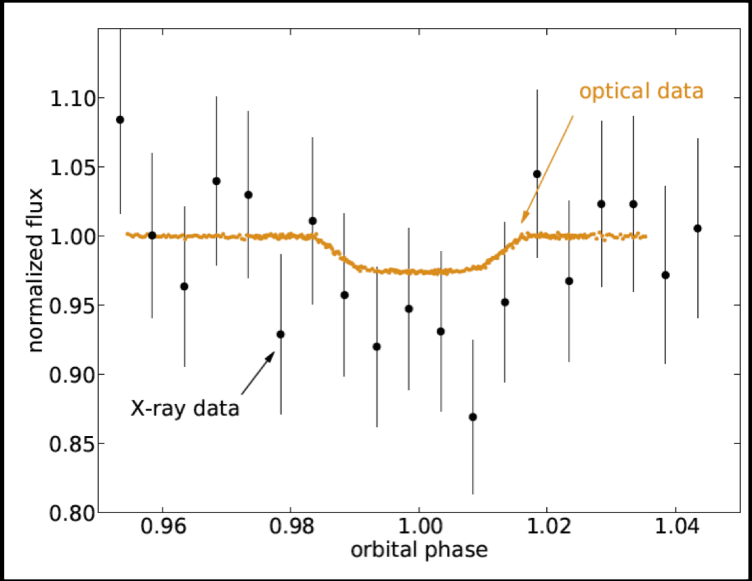

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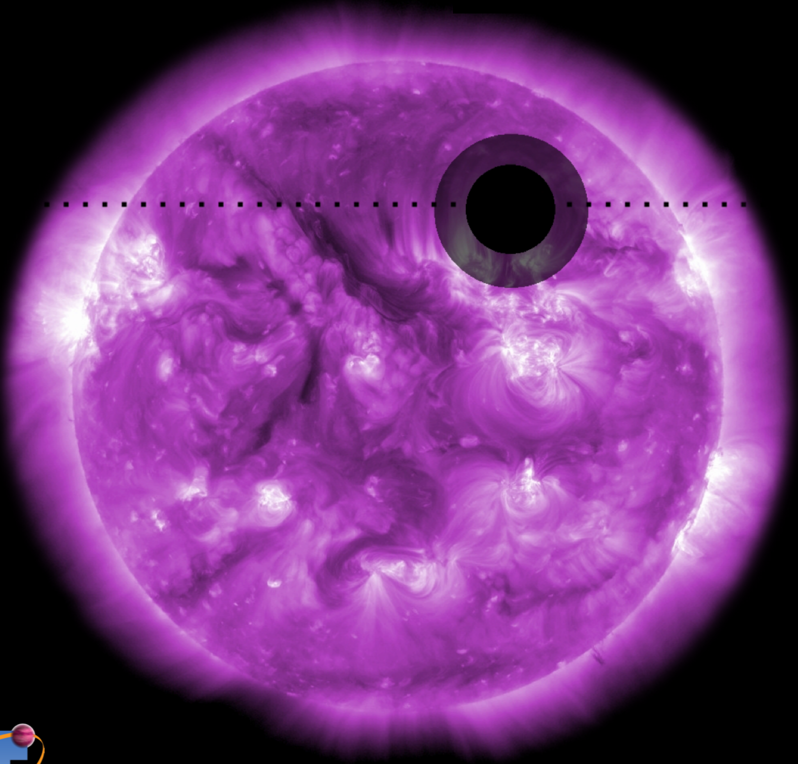

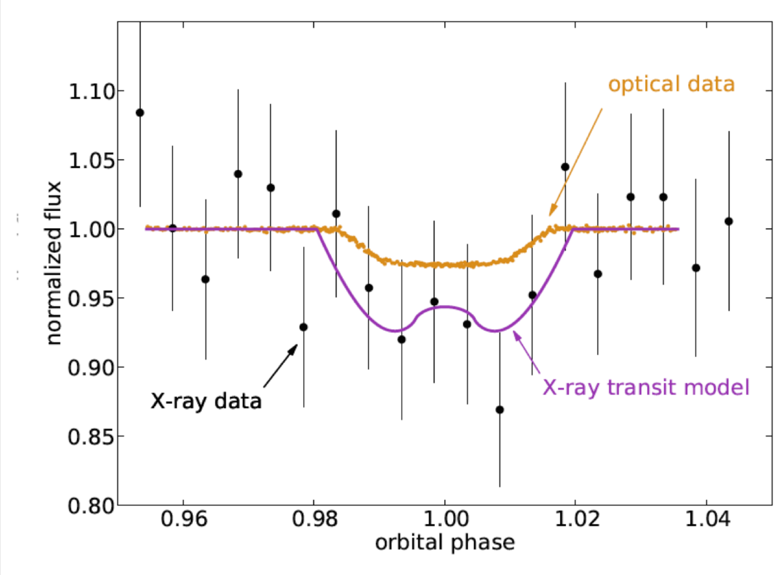

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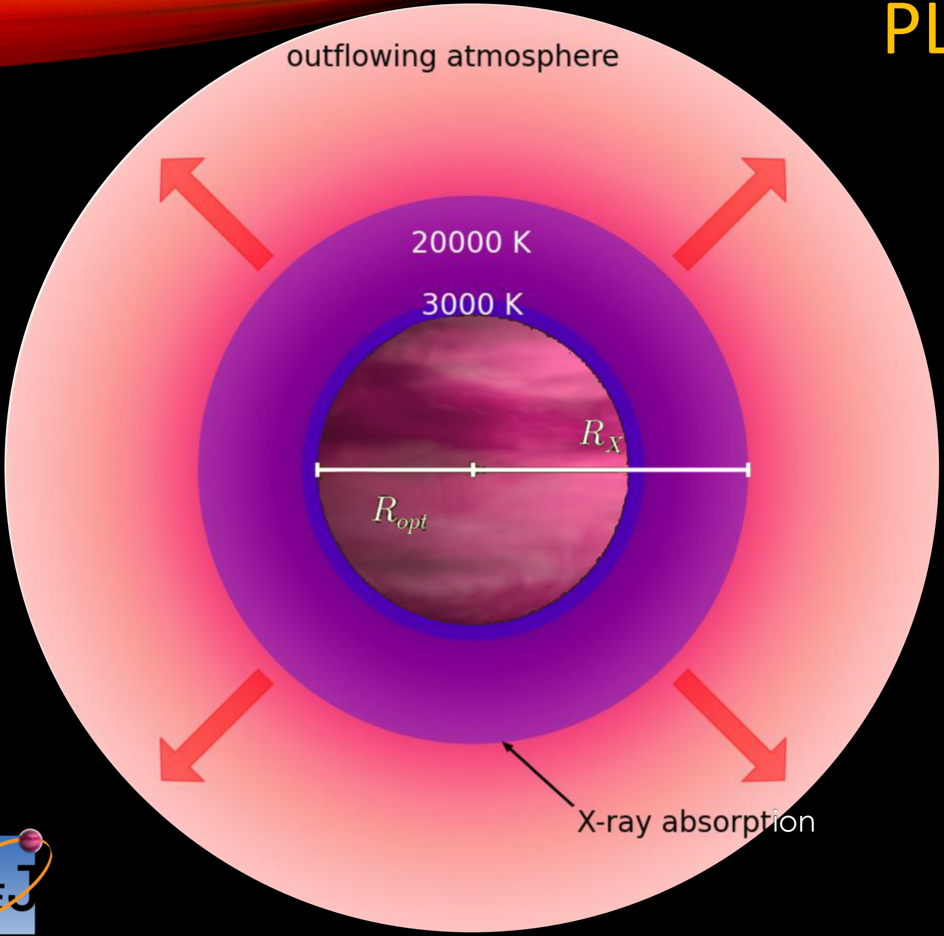
PLANETARY ATMOSPHERE: TOY MODEL



$H = kT/\mu_m g$

$\Delta D \sim 20 H R_{Pl}/R_*$

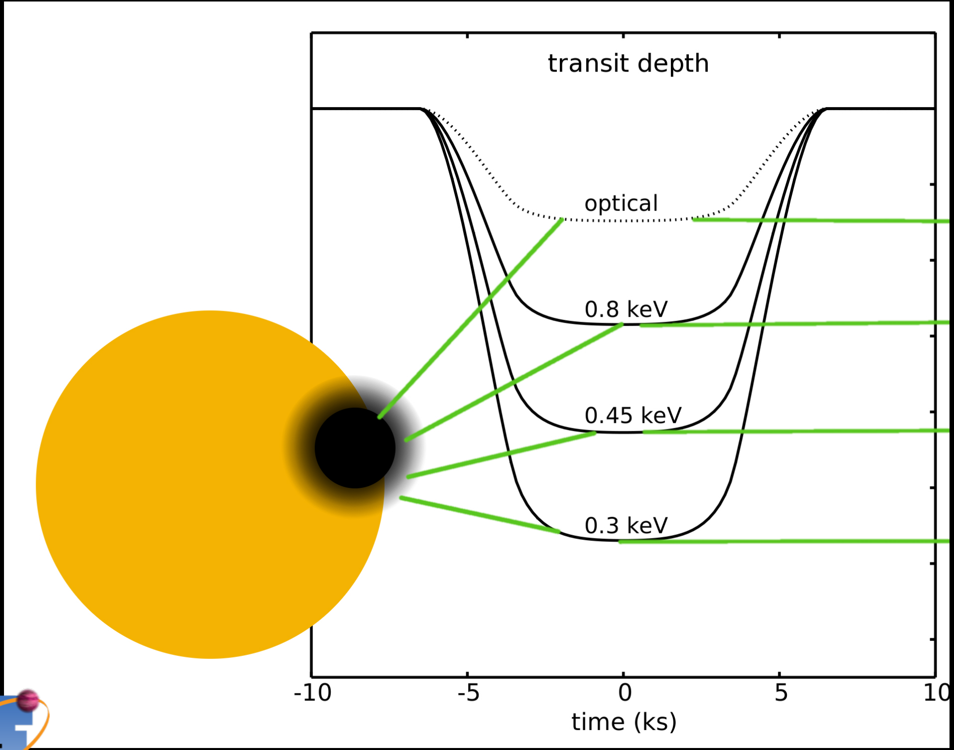
Miller-Ricci & Fortney (2010)

To be X-ray opaque at $1.75 R_{Pl}$:
Density > 10^{11} cm^{-3}

high-altitude temperature:
~ 20,000K

Poppenhaeger, Schmitt & Wolk (2013)

ENERGY SENSITIVITY AND RESOLUTION

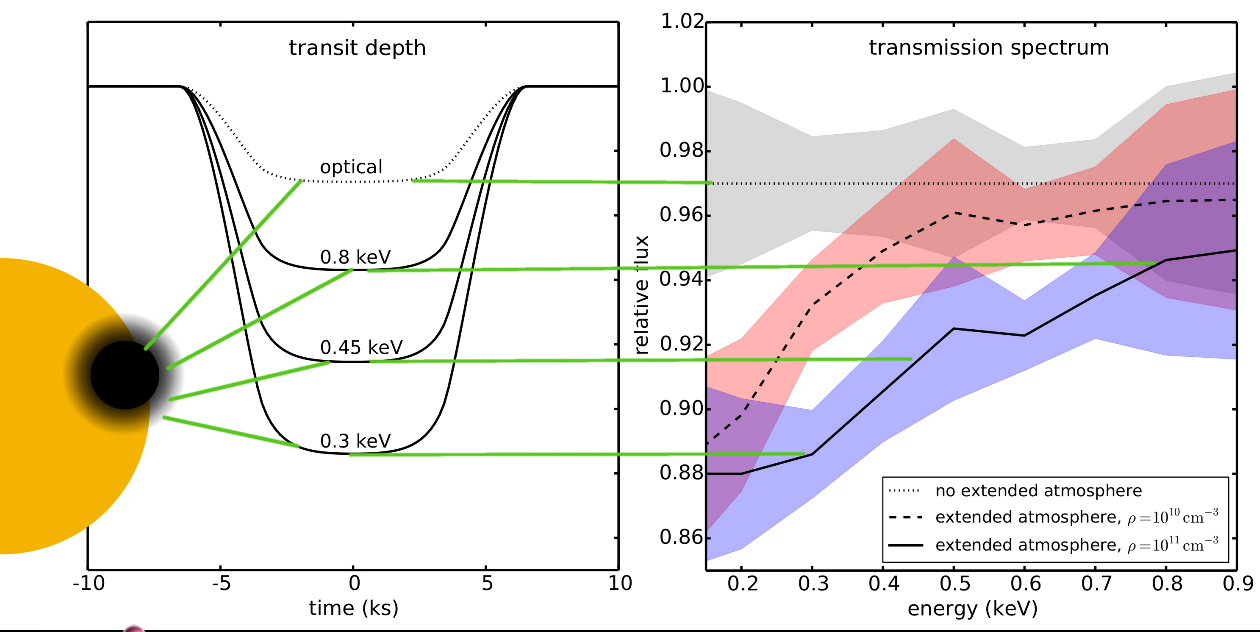


Hard X-rays (>2 keV) are highly penetrating and absorbed deep in the atmosphere, similar to optical photons.

In the soft X-ray regime, absorption is a strong function of energy.

The same transit can appear twice as deep at 300 eV as at 800 eV.

ENERGY SENSITIVITY AND RESOLUTION



The differential absorption can become even more pronounce if soft X-ray absorbing metals such as Oxygen, Nitrogen or Carbon are over-abundant in the atmosphere.

For example a 10x enhancement in Oxygen would double the eclipse depth at 580 eV.

OBJECTIVE: MEASURE EXOPLANETS' EXOSPHEREIC STRUCTURE

- X-ray bright candidates will be selected from TESS, eRosita and ROSAT.
- Observables: the depth, width and shape of the transit.
- In a year we can obtain ~ 50 transits of ~7 exoplanets .
- Measure Physical Parameters:
  - ΔD which leads to
  - Scale Height H which leads to
  - Exospheric temperature T
  - At Exosphereic density n
  - Asymmetries due to atmospheric blow-off
- The need for SEEJ
  - Transits are short and repetitive these kinds of observations are not well suited to multipurpose observatories.
    - Chandra/ACIS has very little low energy response.
    - XMM, SWIFT and XRISM are optimized for high energy.

X-ray Flare of HD 189733

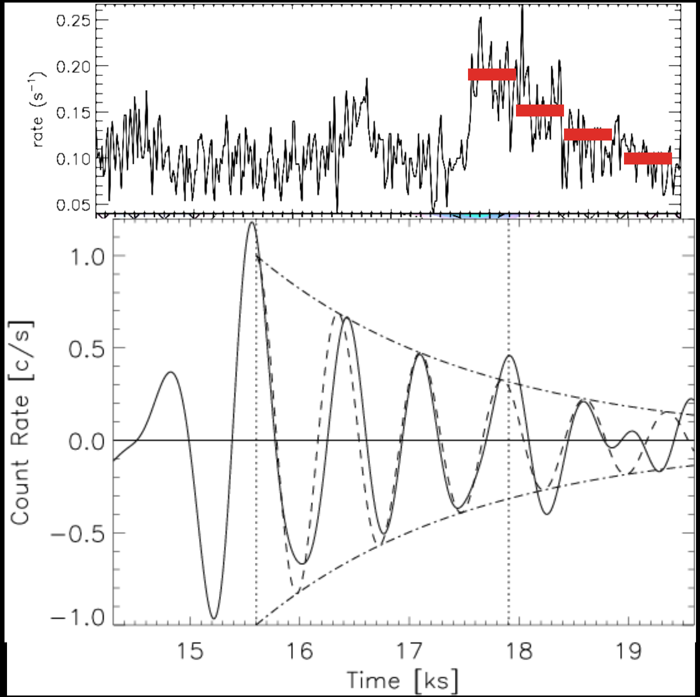
2D wavelet analysis of 2012 light curve
Description: A damped magneto acoustic oscillation in the flaring loop.

$\Delta I/I \sim 4\pi n k_B T/B^2$

T~ 12 MK
n: density=5×10^{10} cm^{-3}
(from RGS data)

B ⟶ 40-100 G

$\tau \sim L/c_s$
$c_s = \sim T^{0.5}$
τ= oscillation period ~ 4 ks
L=Const. X $\tau_{osc} N T^{0.5}$
L~5 R_*



Pillitteri et al. (2014)

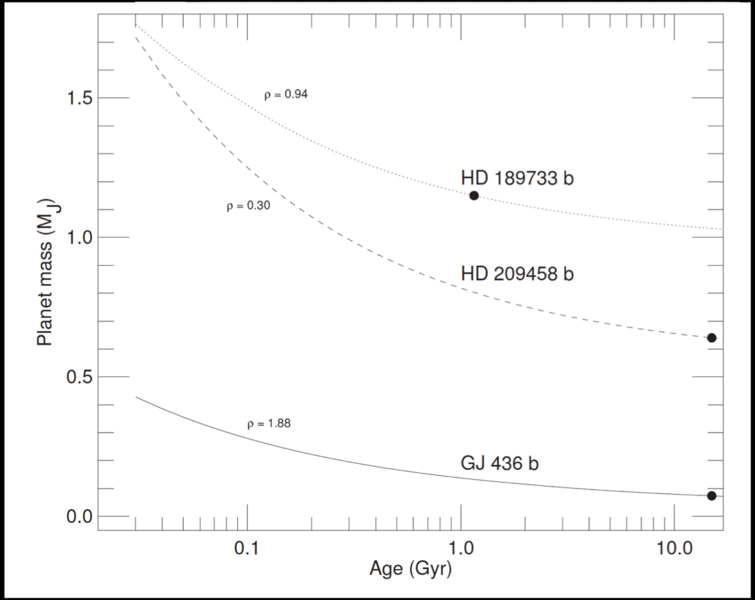
Implication of the wavelet analysis

THE CORONAL EMISSION OF STARS AFFECTS EXOPLANETS.

$$\dot{M} = \frac{4\pi\beta^3 R_p F_{XUV}}{GKM_p}$$

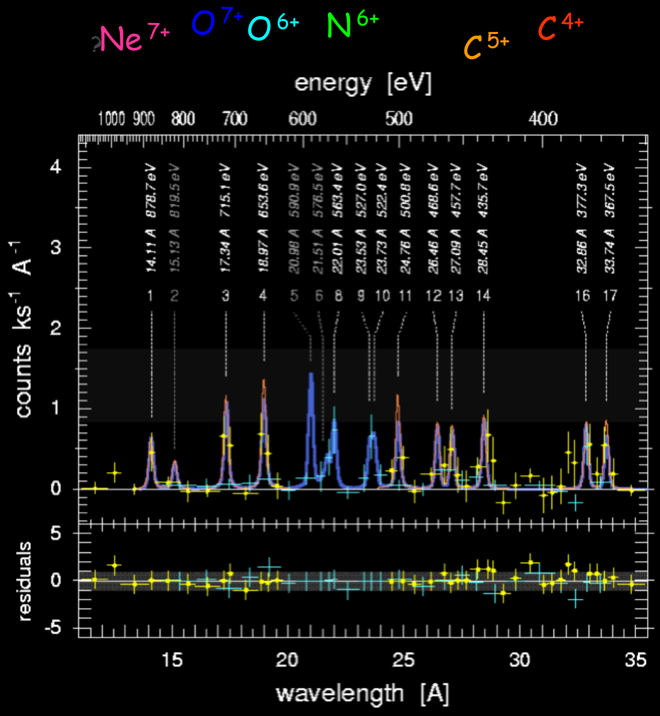
β Atmospheric inflation
K: Roche lobe overflow

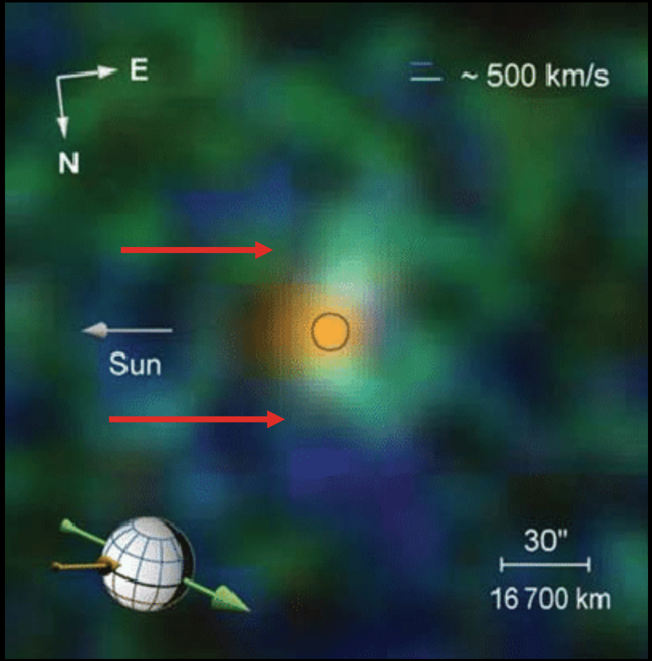
$$\dot{M} = \frac{3F_{XUV}}{G\rho}$$



Sanz-Forcada et al. (2011)

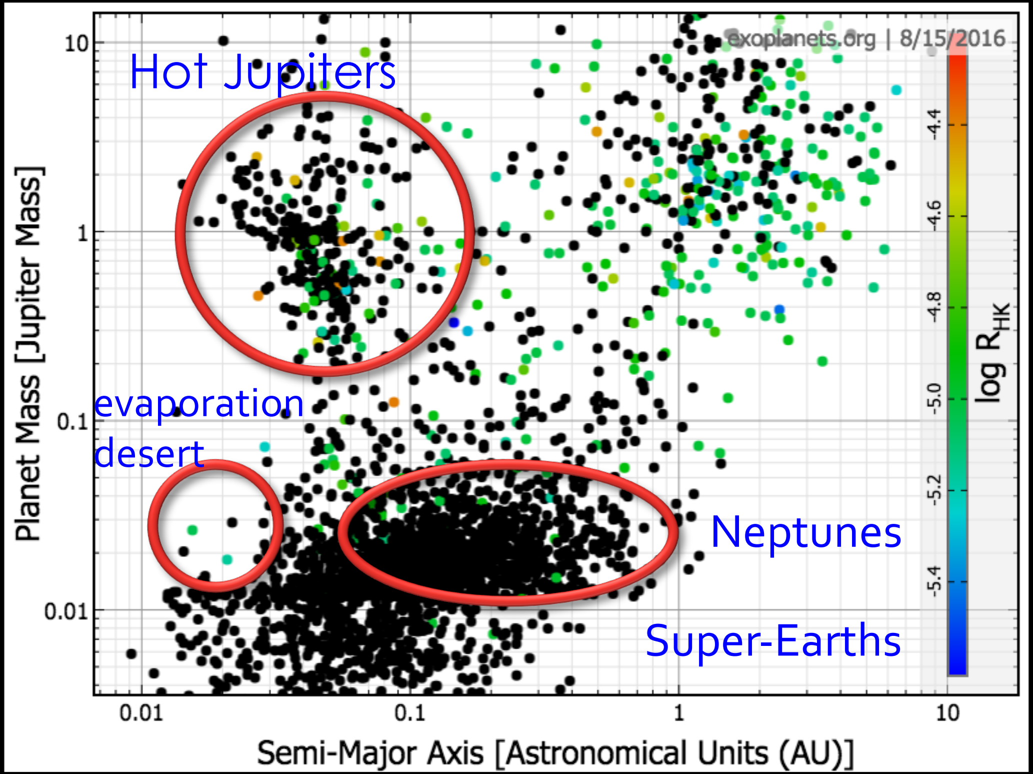
MARS IS CURRENTLY LOSING ATMOSPHERE





(Dennerl 2006)

THE EXOPLANET ZOO

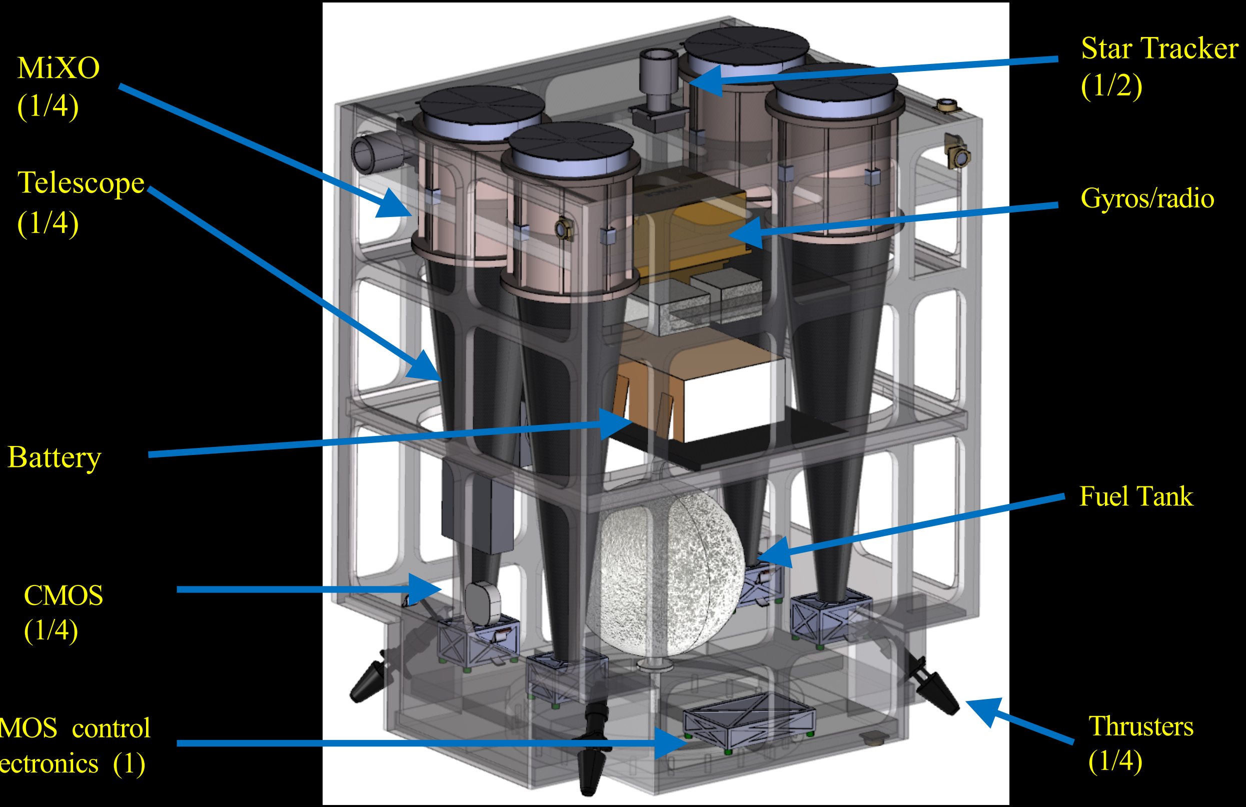


Scott J. Wolk

OBJECTIVE: MEASURE ACTIVITY OF THE HOST STARS

- Observable: Flux, Temperature of the host stars.
- Physical measurement: ~1.6 Msec exposure of ~ 7 exoplanet systems outside of transit.
- Physical Parameters:
  - Quiescent Temperature of plasma
  - Fractional Time in quiescence
  - Flare Temperature of plasma
    - Fractional time in flare
  - Current average fluence of XUV flux
    - Current mass loss rate
    - Cumulative mass loss
  - The need for SEEJ
    - Stars are highly variable, the bulk of the affecting flux only comes during flares.
    - Even in active stars is takes mega seconds of combined data to obtain good measures of mean flare rates, temperatures and energies.
    - No such comprehensive studies have been carried out on main sequence stars which are in addition subject to stellar cycles of unknown duration.

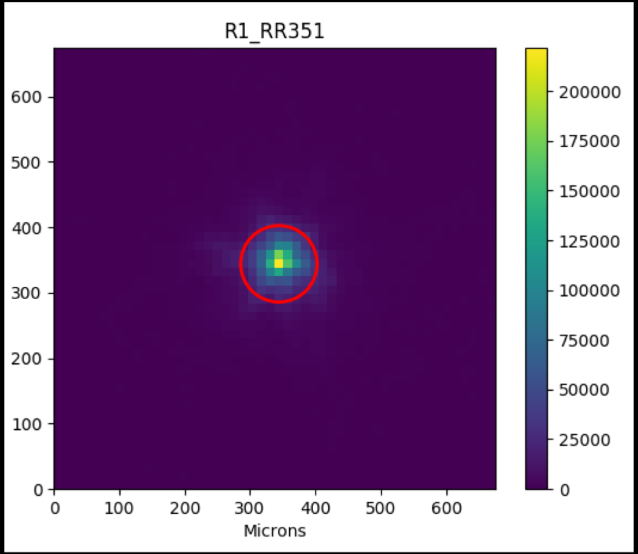
SPACECRAFT



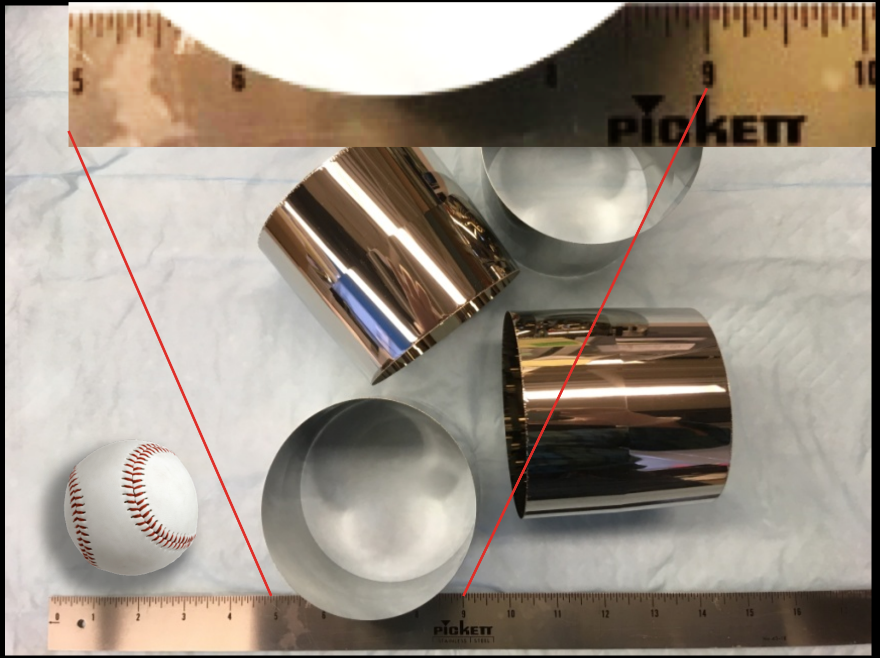
Vol: 28″x24″x38″ Mass 110 kg (dry)

MIXO

- MiXO (Miniature X-ray Optics) modules are composed of compact lightweight Wolter-I X-ray optics suitable for CubeSat/SmallSat missions.
- MiXO leverages the on-going development of electroformed Ni-alloy replication techniques to make Wolter-I X-ray optics with large area-to-mass ratios.



CCD image from 250 μm thick optic; measured HPD ~ 30 arcsec



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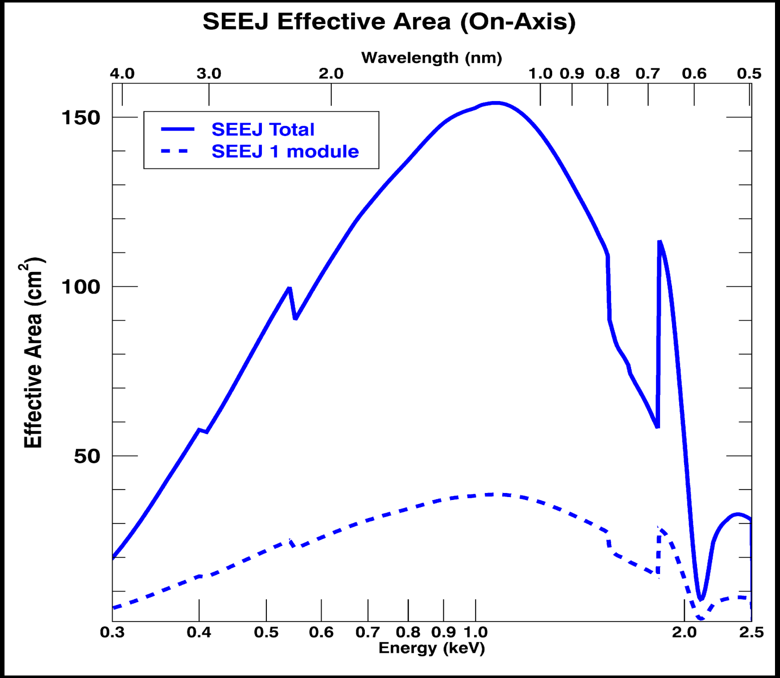
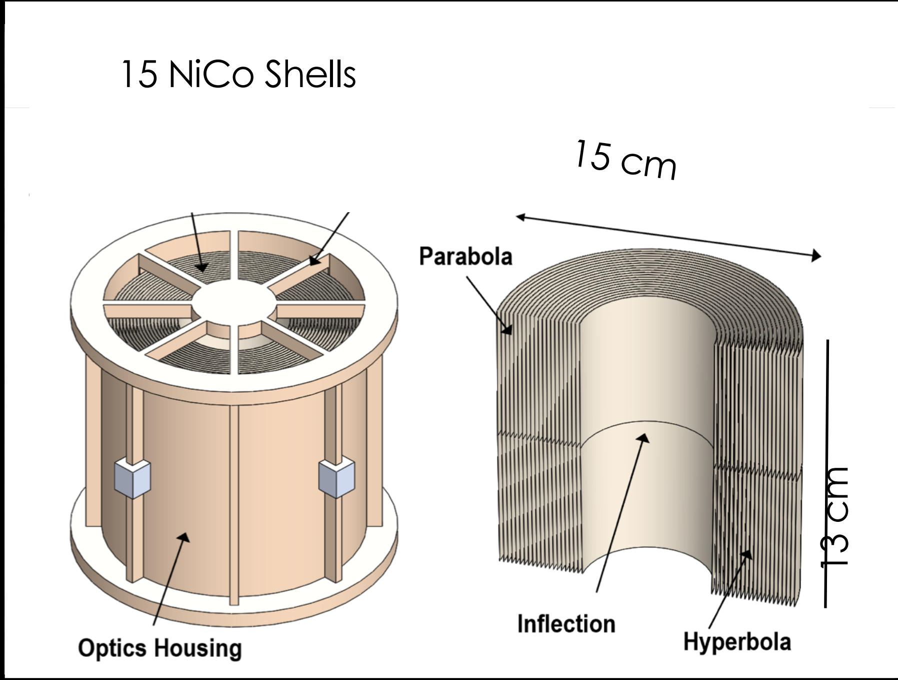
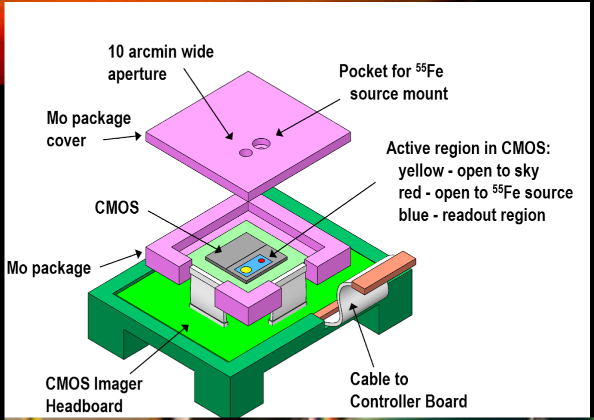
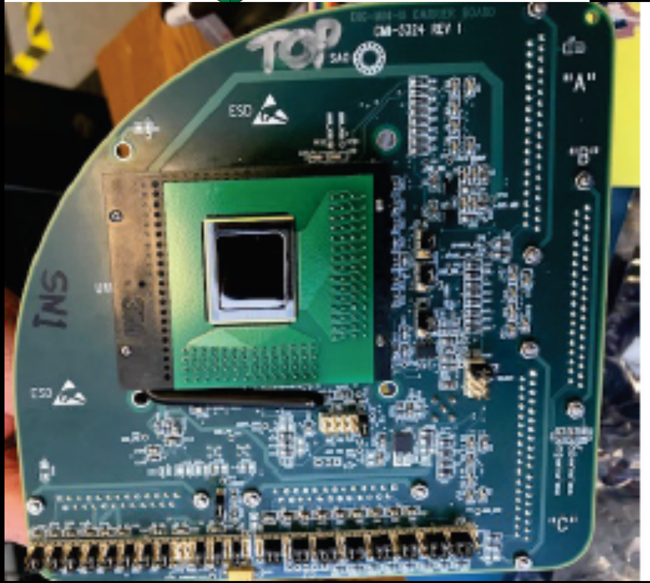


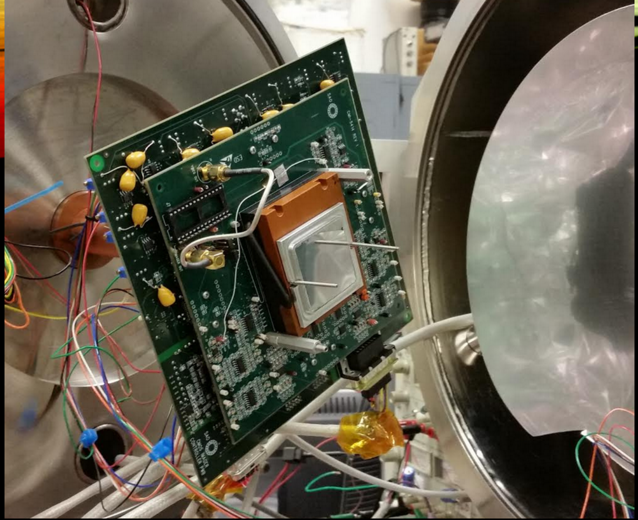


CMOS





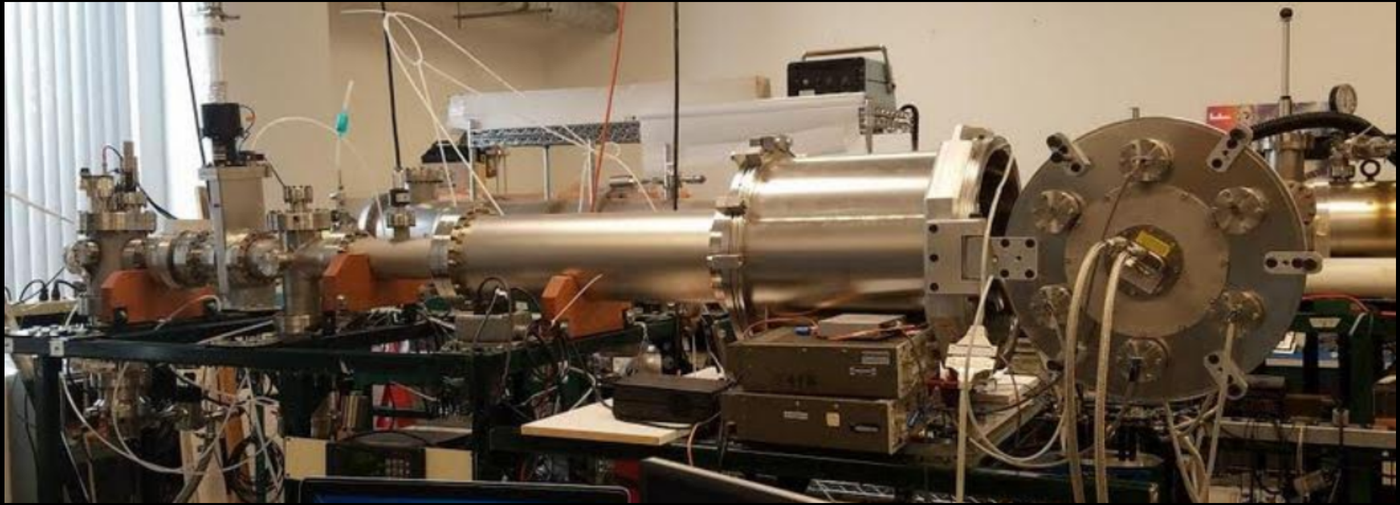
- CMOS are common in cameras and have flown on Parker Solar probe.
- Use of back-thinned CMOS devices for soft X-ray science is new.
- CMOS can be read out very quickly.
  - > 100 Hz
    - Can look at bright optical sources while maintaining sensitivity to soft X-rays.
- CMOS can also operate at high temperature (-20 C) relative to CCDs without significant noise. This lowers thermal requirements.



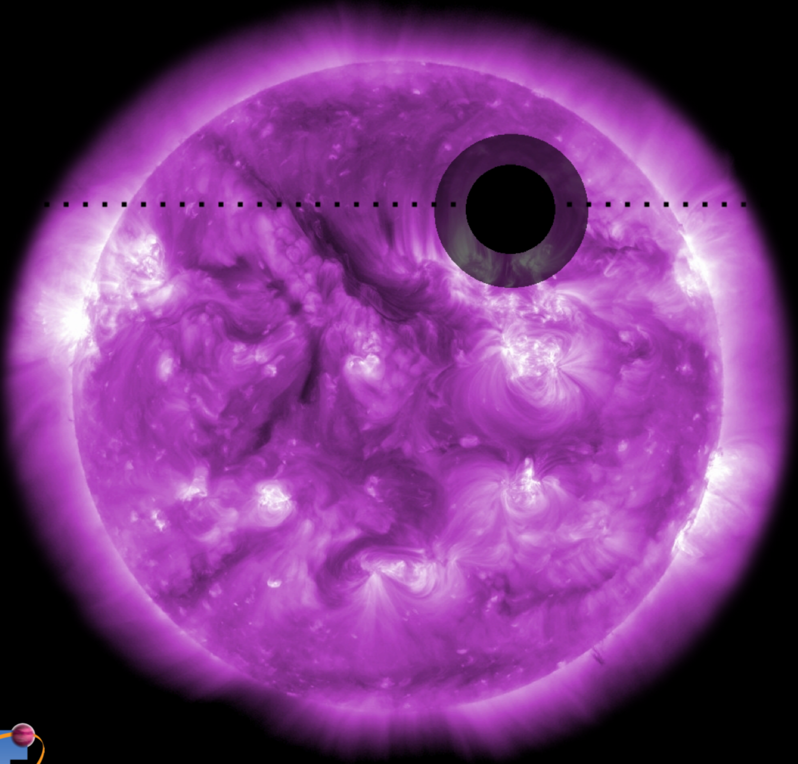
CMOS

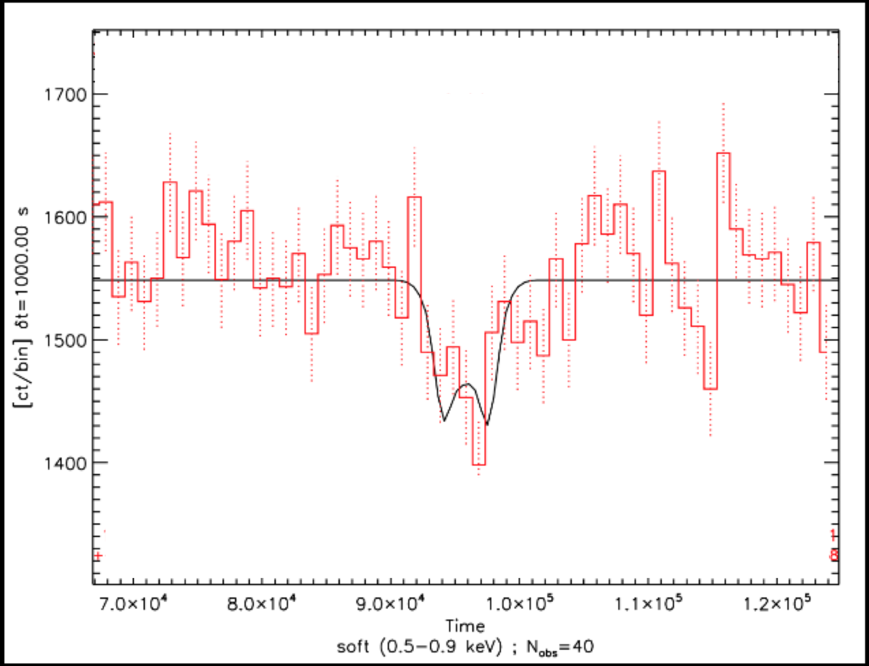
- *SAOCAM: SAO-Integrated Camera-Headboard*

- *SAO X-Ray Test Facility.*



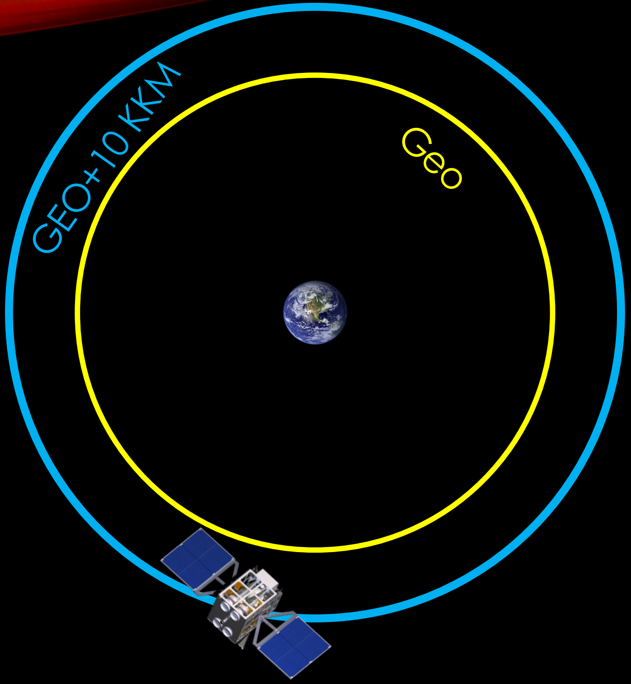
SEEJ Transit





SEEJ Simulation: 40 Transits

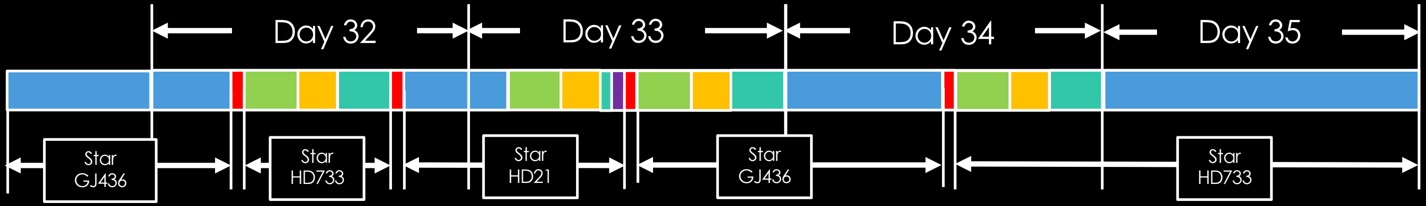
OPS CONCEPT



Rideshare to GEO and boost to GEO+10K circular orbit

GEO+10K orbit (~32hrs) provides nearly uninterrupted visibility while maximizing flight opportunities and limiting radiation.

- *Slew Time – 1 hr*
- *Pre-Transit Baseline Viewing – 4 hr*
- *Transit Viewing – 3 hr*
- *Post-Transit Baseline Viewing– 4 hr*
- *Extended Viewing Time (as needed)*



SEE-J

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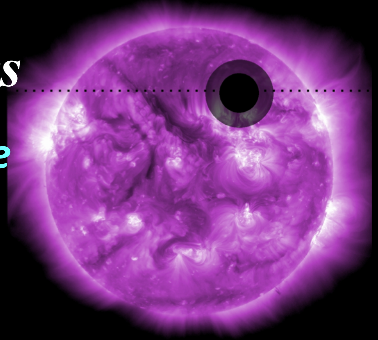
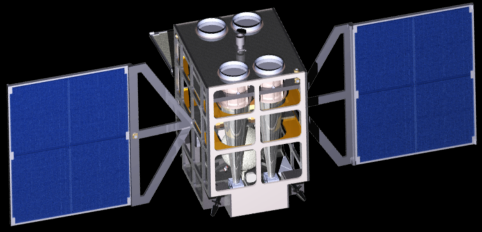


- ***The primary objective of SEEJ is to observe the maximum extent of the atmosphere of Hot Jupiters.***
- Using high cadence monitoring *SEEJ* will observe scores of transits of each TESS X-ray bright system detected.
- SEEJ will measure the depth and shape of planetary transits of at least 7 Hot Jupiters from 0.3-2.0 keV.
- ***SEEJ can efficiently and effectively characterize the high energy flux of host stars***.
    - *With new exoplanet systems being discovered monthly by TESS the need for SEEJ is now.*
- *Concept Design Study: total cost ~35M$*
- *Could launch by 2026*



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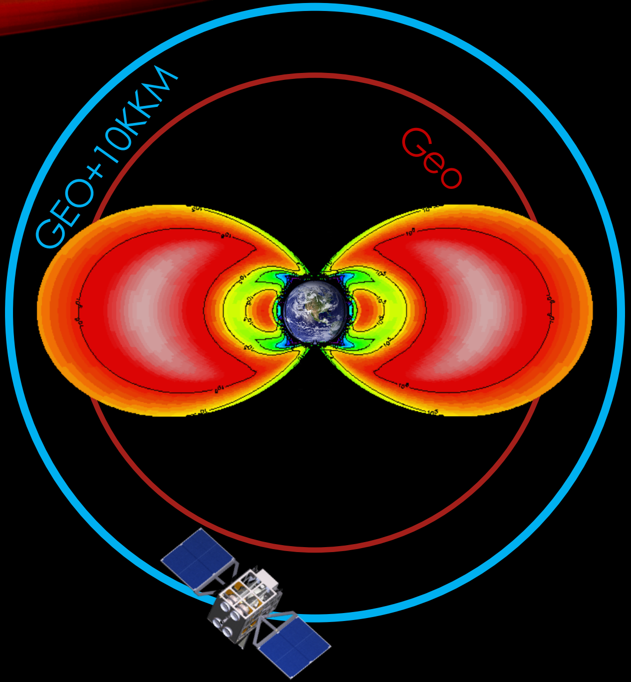

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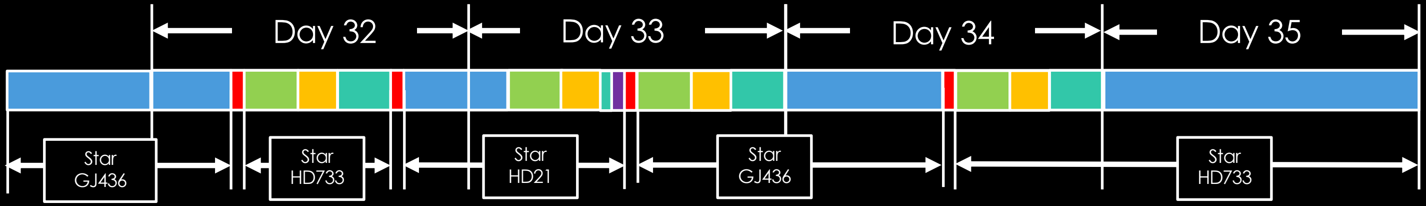
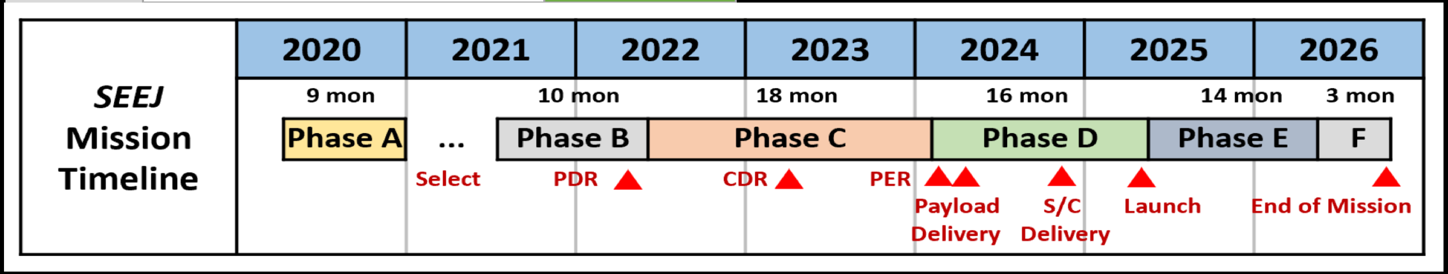


COST AND SCHEDULE

WBS #	WBS Element	Total
0	**SEEJ**	**$ 27.81**
1.0	Project Management	**$ 1.08**
2.0	Systems Engineering	**$ 0.71**
3.0	Safety and Mission Assurance	**$ 0.71**
4.0	Science/Technology	**$ 1.10**
5.0	Payload	**$ 9.77**
6.0	Flight System \ Spacecraft	**$ 12.40**
7.0	Mission Operations System (MOS)	**$ 1.01**
8.0	Launch Vehicle/Services	**$ -**
9.0	Ground Data System (GDS)	**$ -**
10.0	System Integration, Assembly, Test & Check Out	**$ 1.04**
11.0	Education & Public Outreach	**$ -**

		Total
	25% Reserves (A-D) + 15% Reserves (E-F) = ($6.86M)	**$ 34.67**

- Both parametric and notional bottom-up cost analysis were done.
- SEEJ can be done on time and on budget for the next SALMON call.



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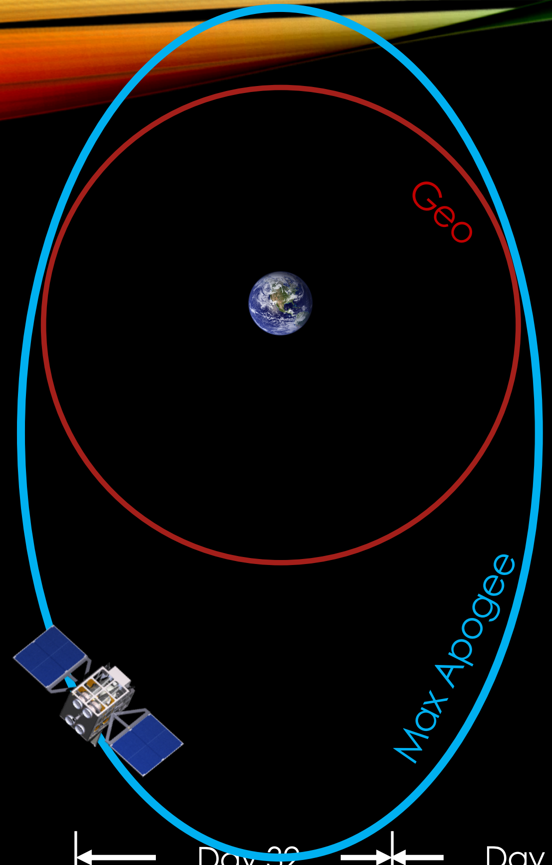

A maximum apogee orbit (35hrs) provides minimizes electron radiation for the bulk of the orbit, there may be some periods of high radiation at perigee.

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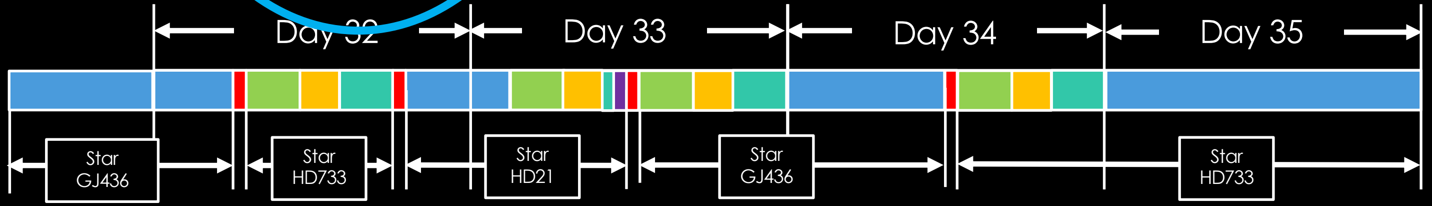

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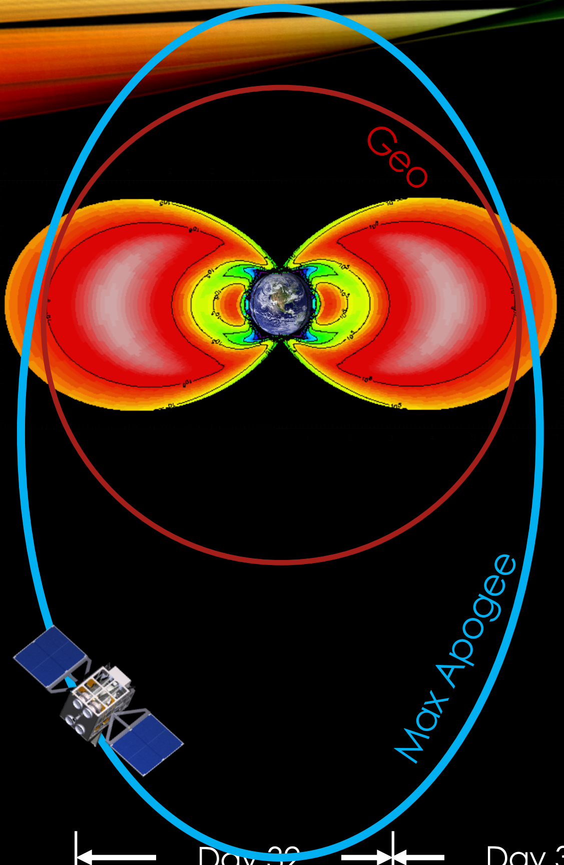

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