The Pandora SmallSat

Multiwavelength Characterization of Exoplanets and their Host Stars

Mission Update

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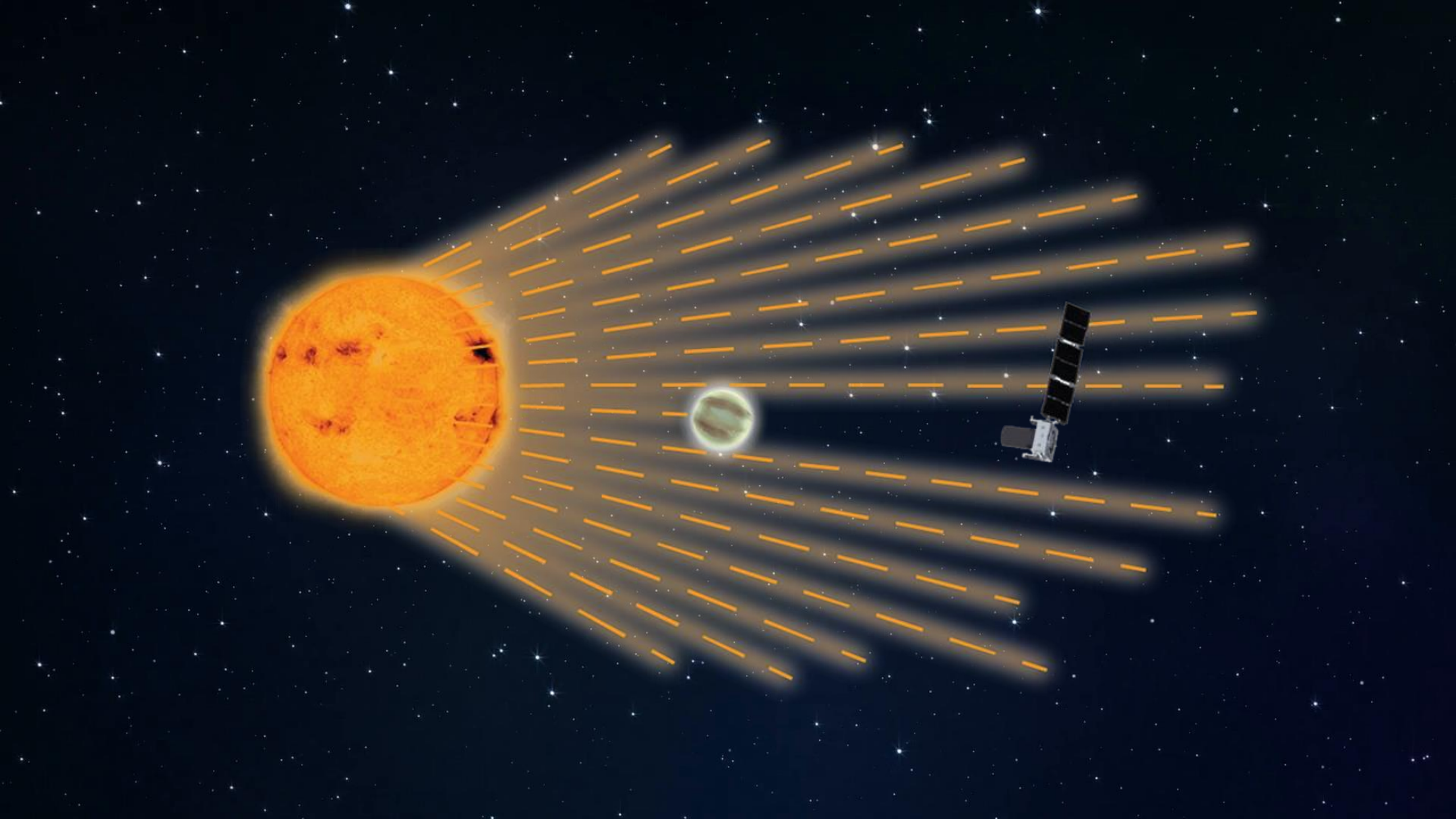
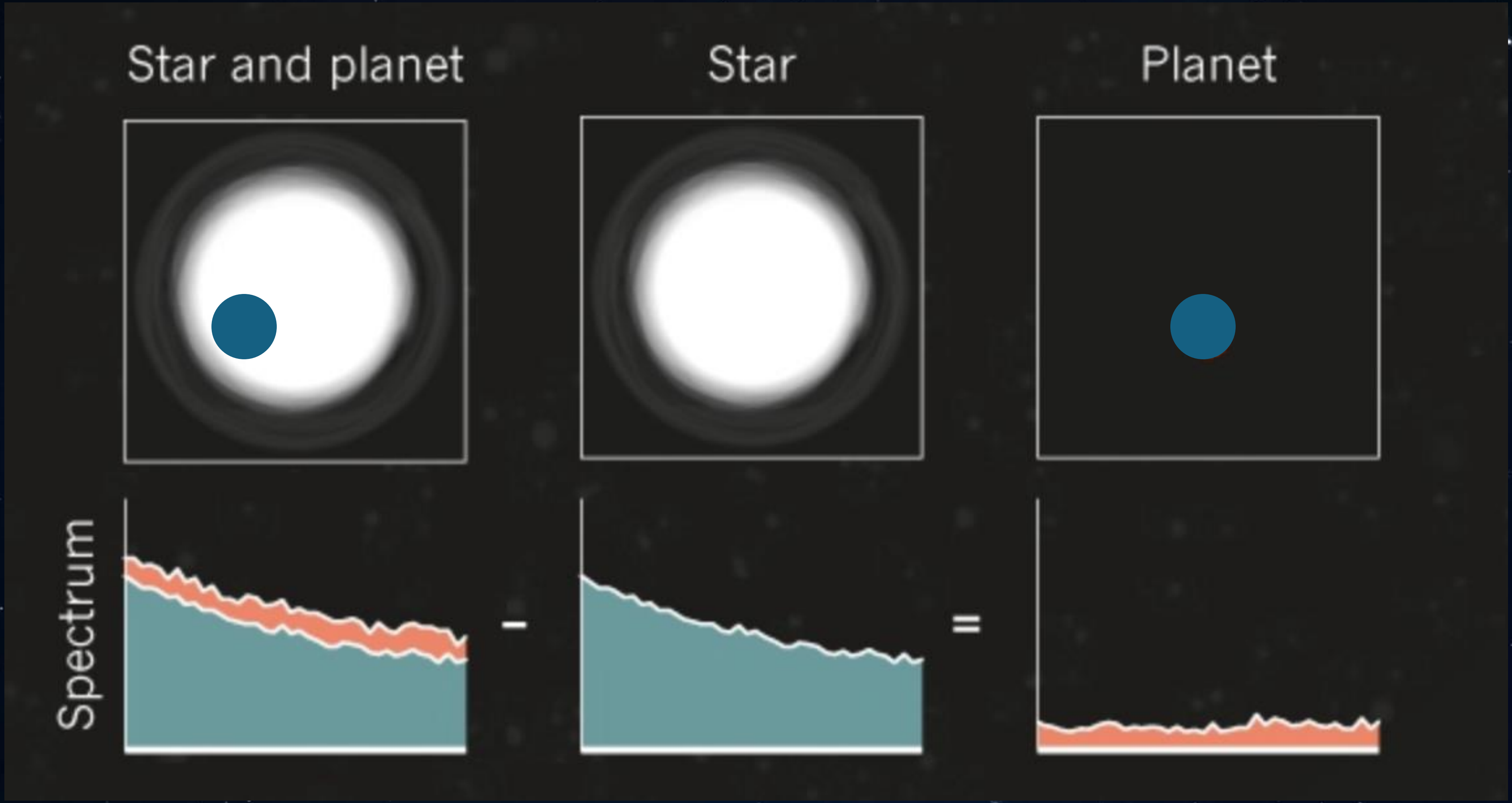
AAS 2025 National Harbor, MD

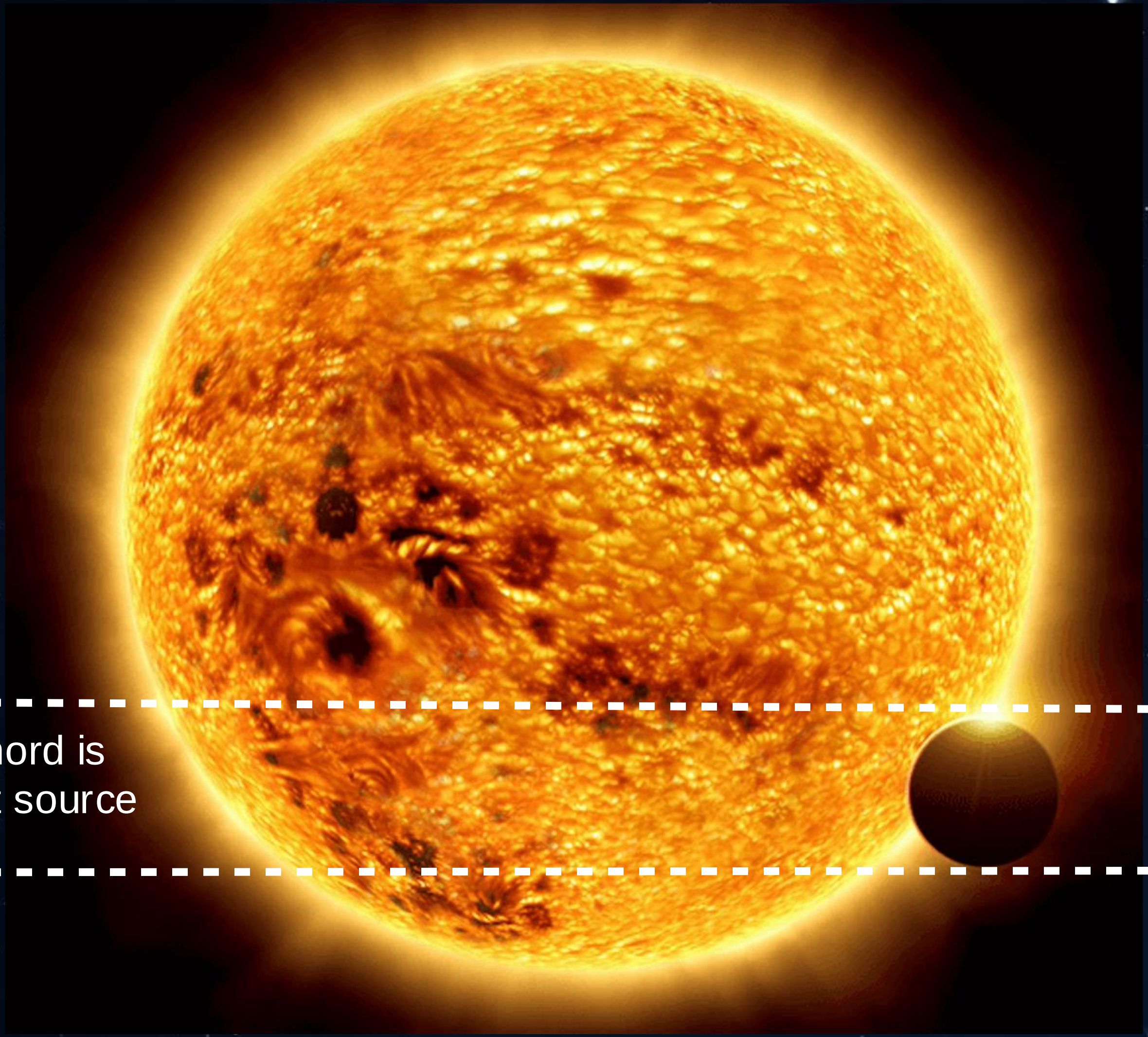


Exoplanet transmission spectroscopy is a differential measurement that assumes the emergent light (from the star) is a uniform source

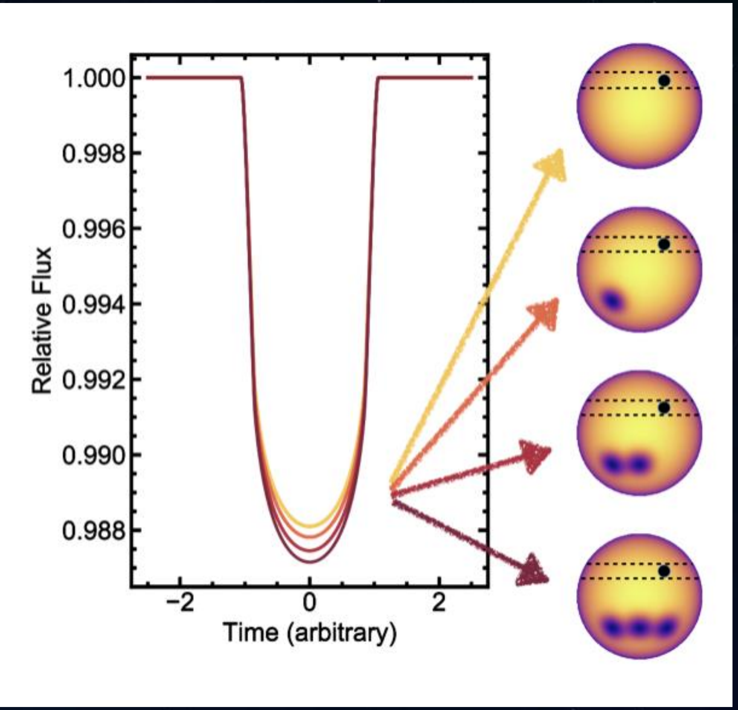


Brightness variations from star spots →stellar contamination

Full stellar disk
is *assumed*
light source



transit chord is
actual light source

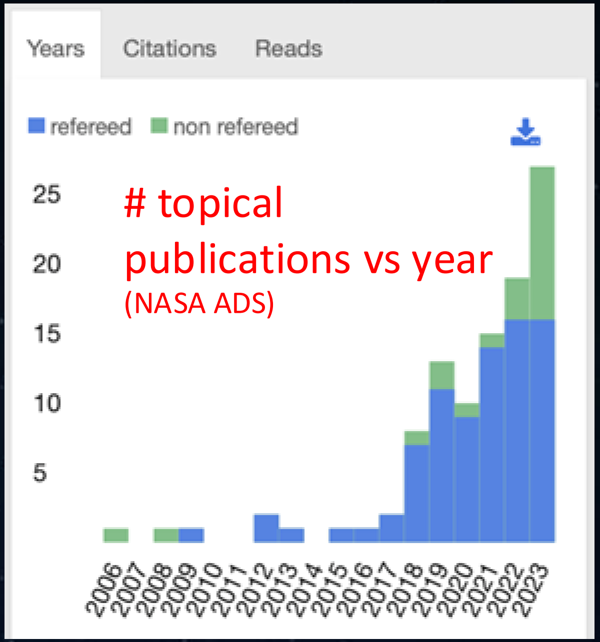


Stellar contamination can mask or mimic atmospheric features, like the presence and abundance of water!

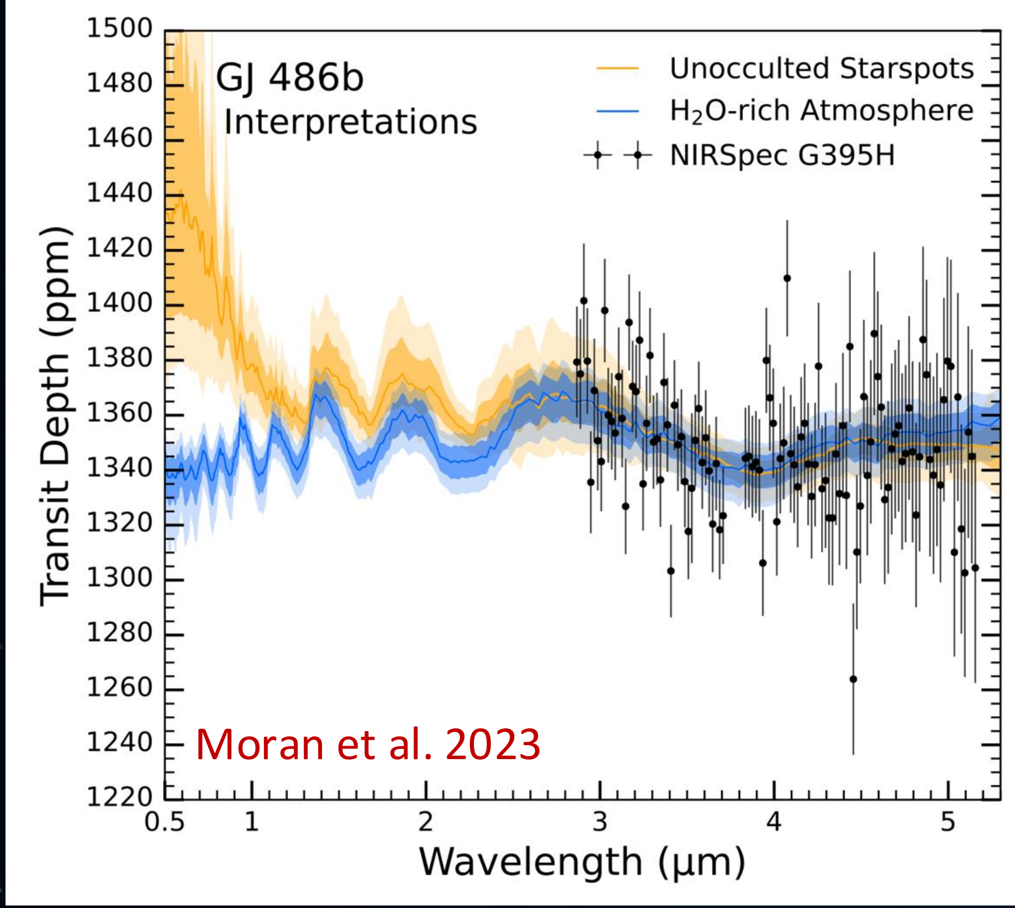
Pandora's Goal: Disentangle star and planet signals in transmission spectroscopy to reliably determine exoplanet atmosphere compositions.

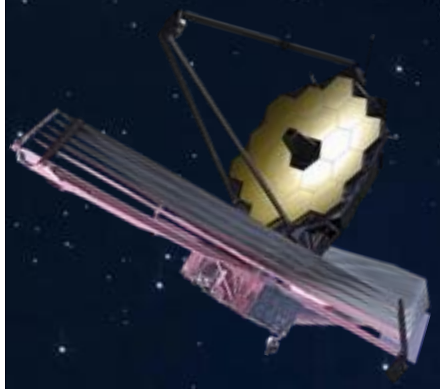
Stellar Contamination in the Literature

Early JWST science results display direct evidence of stellar contamination in spectra of Earth-size planets

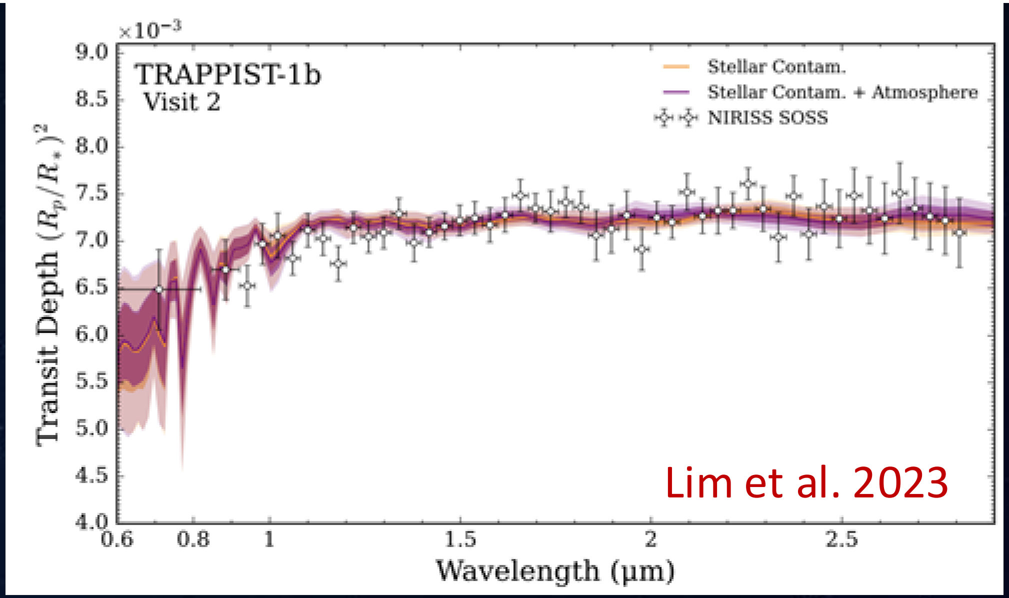


High Tide or Riptide on the Cosmic Shoreline? A Water-rich Atmosphere or Stellar Contamination for the Warm Super-Earth GJ 486b from JWST Observations





Atmospheric Reconnaissance of TRAPPIST-1 b with JWST/NIRISS: Evidence for Strong Stellar Contamination in the Transmission Spectra



Science Objectives

Pandora

L0: Determine the spot and faculae covering fractions of low-mass stars that host exoplanets and the impact of these active regions on exoplanetary transmission spectra

Ia. What are typical spot coverages of low-mass exoplanet host stars, and how do they vary with time?

Ib. How do stellar properties (size, mass, temperature) correlate with contamination, and how does the impact of contamination change with planet properties (size/mass/bulk density, orbital distance)?

L0: Identify exoplanets with hydrogen- or water-dominated atmospheres, and determine which planets are covered by clouds and hazes.

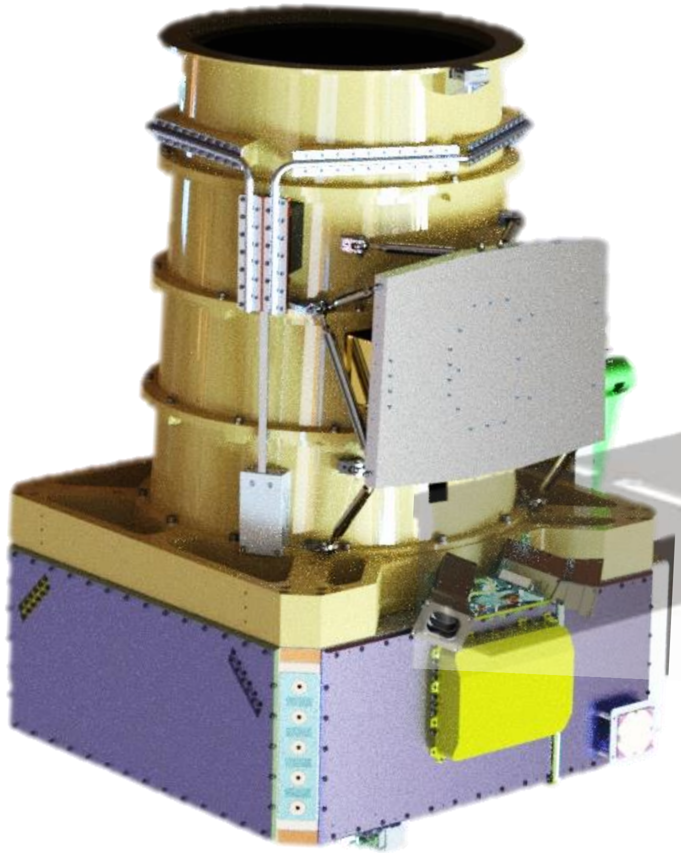
IIa. How does the atmospheric composition of planets vary with size/mass/bulk density, orbital distance, and host star properties?

IIb. Which prior transmission spectroscopy observations yield the same atmospheric results after correcting for stellar contamination?

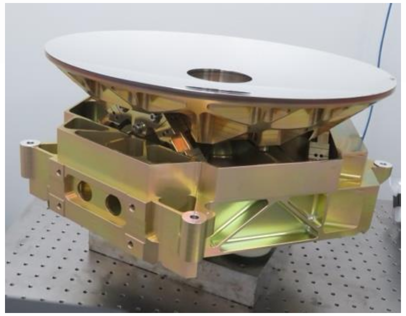
Pandora will observe at least 20 targets, 10 transits / target, 24 hours / transit
Pandora's targets include M/K dwarfs and Earth-to-Jupiter size planets

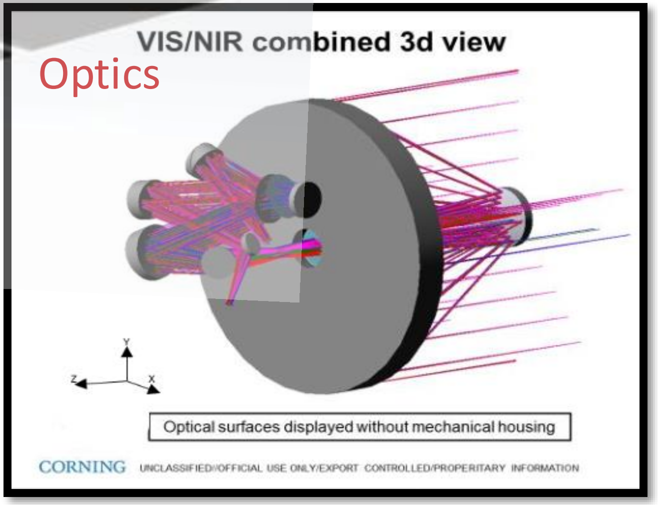
Pandora Observatory

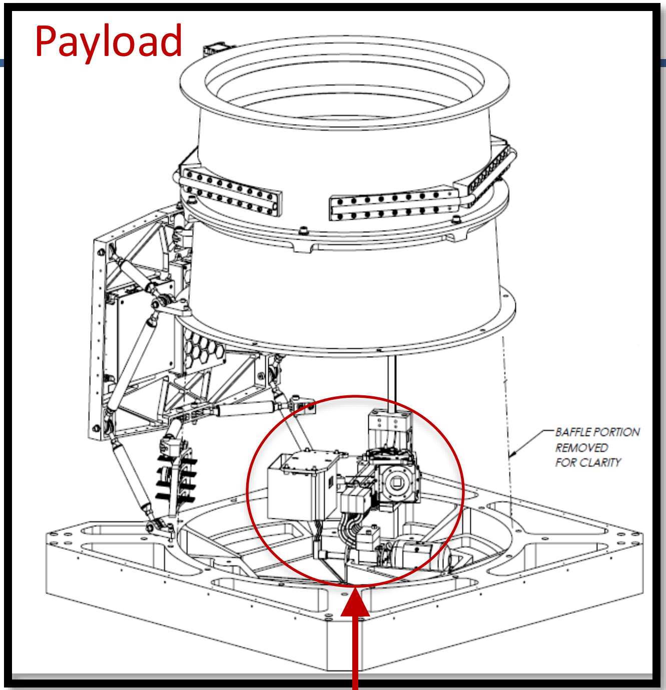
- All-aluminum 0.45-meter Cassegrain telescope design with relayed vis and IR paths.
  - VIS: 380-750nm
  - NIR: 870-1630nm
- Detectors:
  - VIS: sCMOS pco.panda
  - NIR: HAWAII-2RG
- Low-jitter active cryo system to cool IR to 110K ± 10 mK

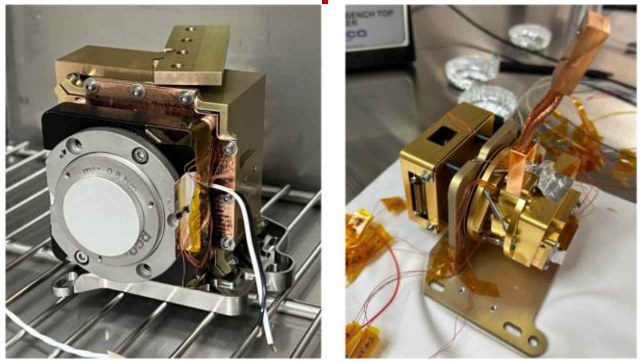


Pandora Observatory is an ESPA-Grande Class Satellite.





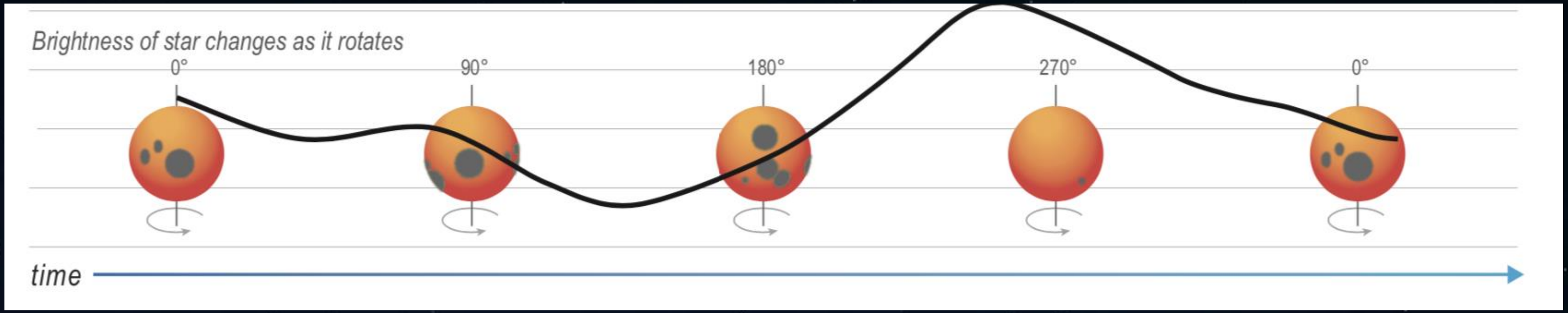




Detector Assemblies

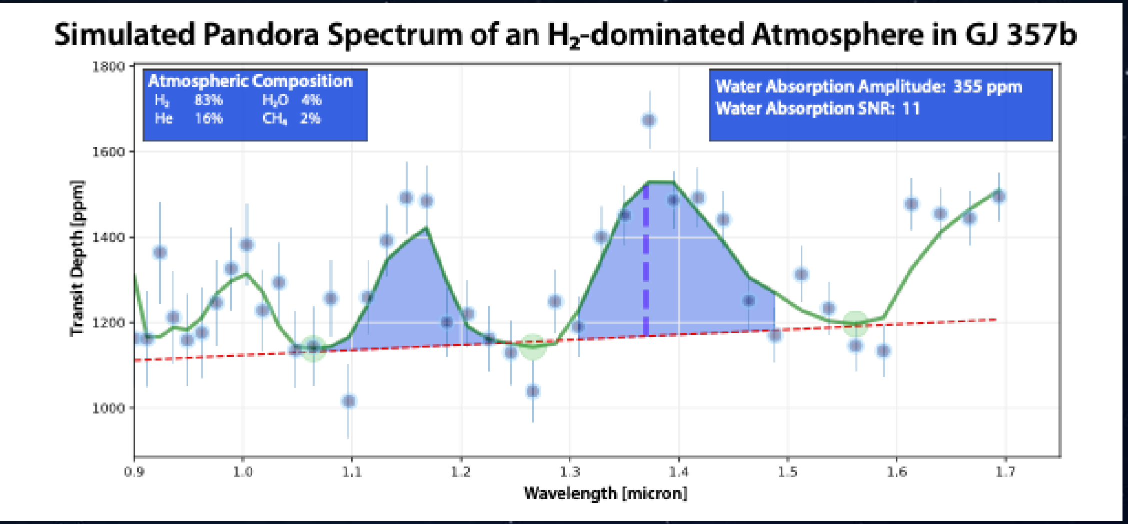
Visible Detector
(380-750nm)

Photometry captures stellar brightness over time

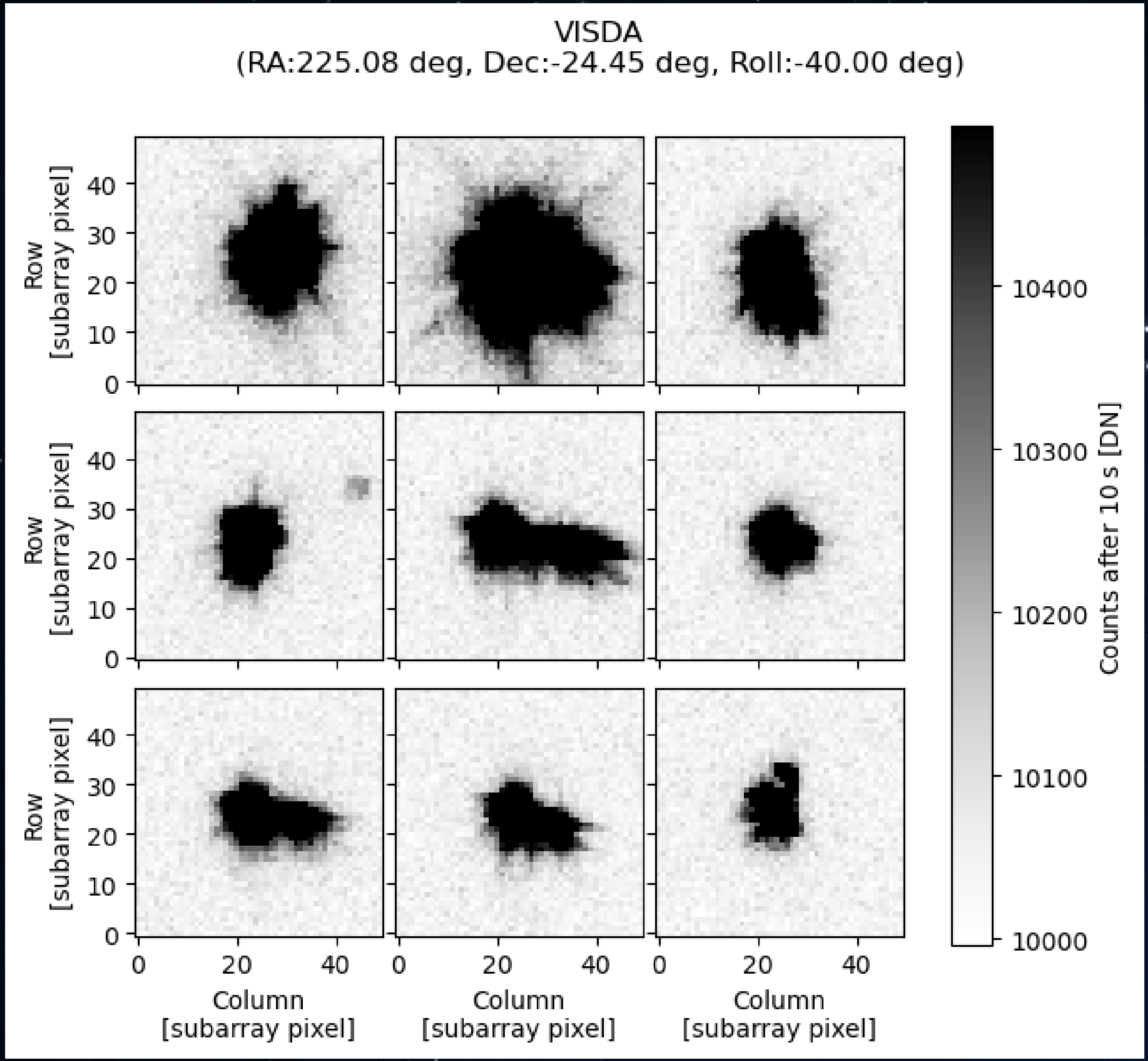


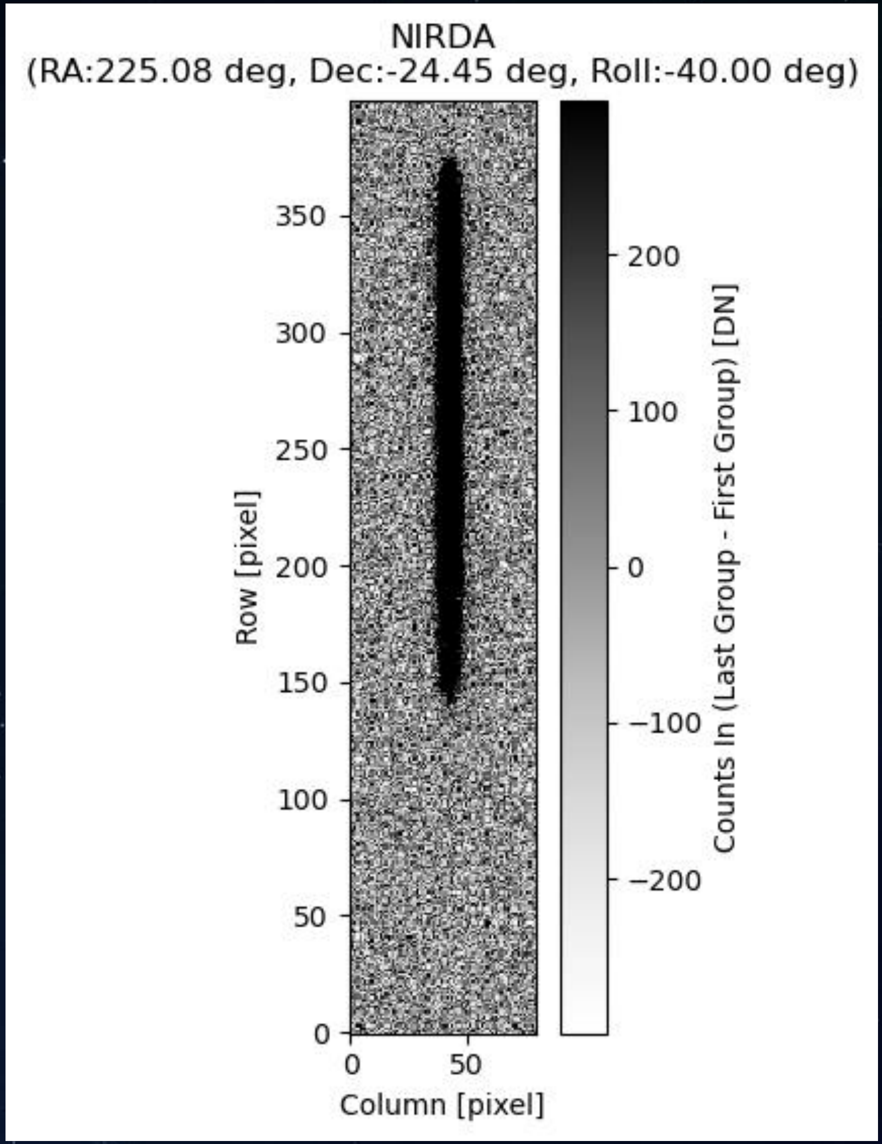
NIR Detector
(870-1630nm)

Simultaneous NIR spectroscopy captures variations in spectra over time



Together, the visible photometry + spectroscopy provides constraints on star spot coverage, which is needed to disentangle the star and planet spectra, **enabling robust measurements of the planet's true atmospheric makeup**


VISDA
(RA:225.08 deg, Dec:-24.45 deg, Roll:-40.00 deg)
Row [subarray pixel]
Column [subarray pixel]
Counts after 10 s [DN]


NIRDA
(RA:225.08 deg, Dec:-24.45 deg, Roll:-40.00 deg)
Row [pixel]
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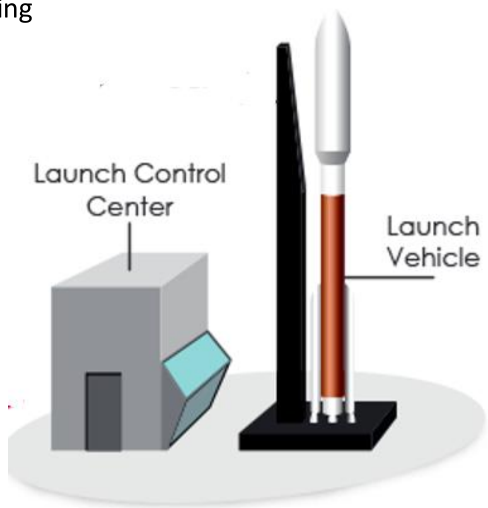
System Overview

Pandora

1.3 Launch Segment

Compatible with ESPA Rideshare User Guide; 24in Planetary System Adapter Ring



KSAT_LITE Ground Station Networks

1.1 Pandora Observatory

Sun-Synchronous, LEO Orbit
Altitude Range: 500 to 600km
Inclination: 97.0° to 97.8°

X-Band: Science Data & Telemetry, 5Mbps (downlink)
S-Band: TT&C, 1 Mbps (downlink), 100kbps (uplink)

1.2 Ground Segment

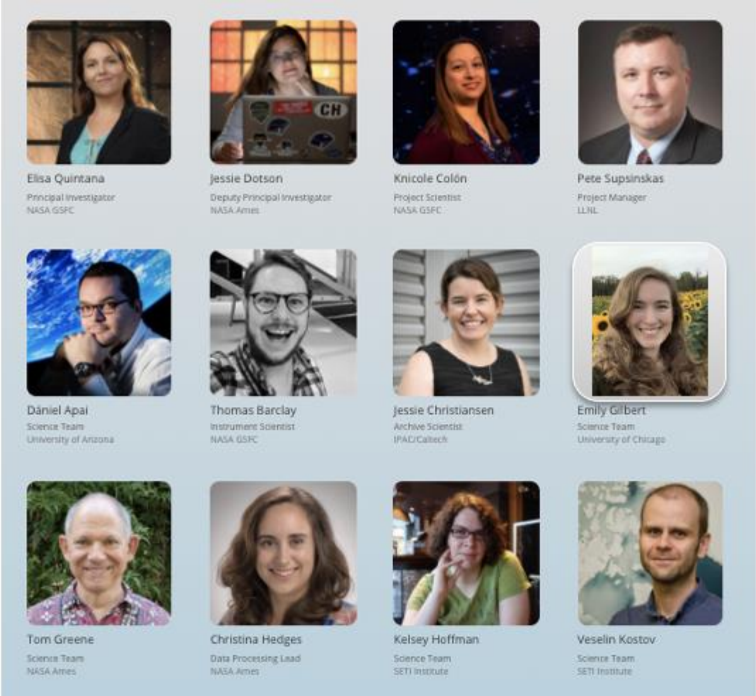
Mission Operation Center – University of Arizona
- TT&C System
- Science Observing Plans
- Payload Operations
- Image Capture System
- Housekeeping

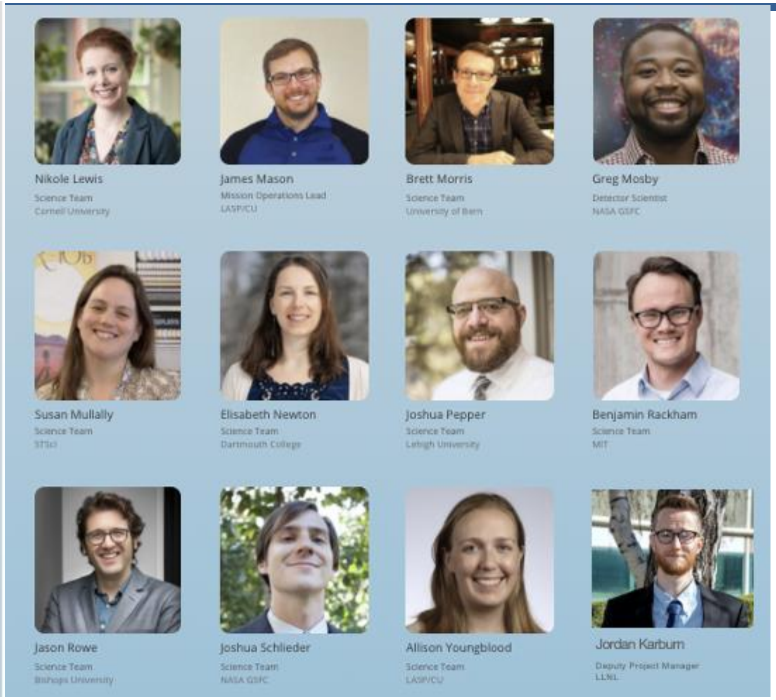
Science Operation Center – NASA Goddard Space Flight Center (GSFC)
- Science Observing Plans
- Target Planning

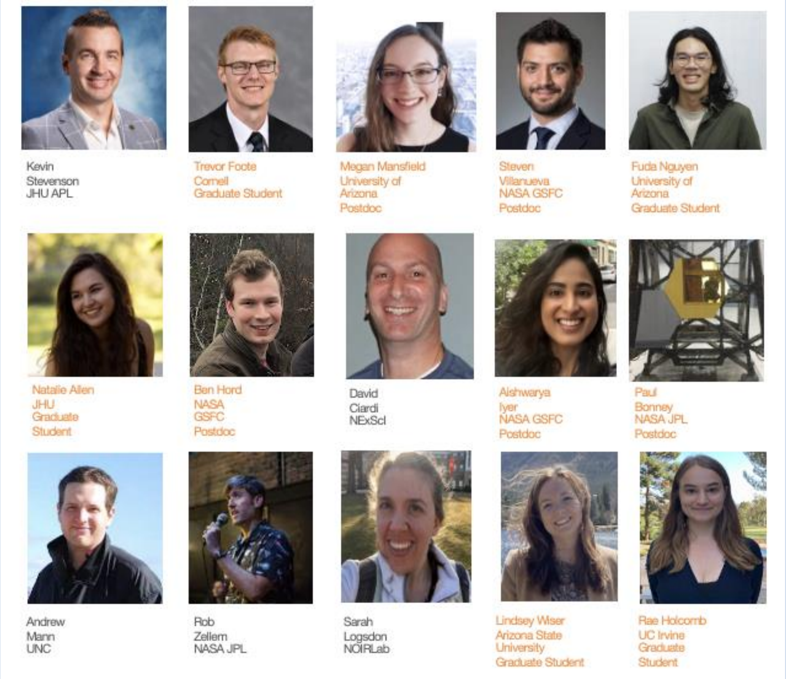
Data Processing Center – NASA Ames Research Center (ARC)
- Data Processing
- Data Management

Data Archive Center – IPAC/IRSA at CalTech
- Data Distribution
- Data Archiving

Mission Leadership and Science Team







15 "Contributors" added, with early career scientists highlighted in orange text

Early Careers on Pandora	#
Mission Team	6
Engineering Team	8
Graduate Student Shadows	4
Postdoctoral Researchers	6
Science Team	5
Undergraduate Interns	9

+ Lots of interns!

Pandora Science Working Groups

Pandora

Target Selection and Observing Strategy

SWG will assess potential targets, identify targets that maximize Pandora's science, and develop an optimum observing strategy.

Exoplanets

SWG will model exoplanet atmospheres in order to explore biases in inferred atmospheric properties when stellar contamination is not considered and identify water vs. H-dominated atmospheres.

Ground-Based Observations

SWG will coordinate photometric and spectroscopic ground-based exoplanet observations that add value to Pandora mission science.

Data Analysis

SWG will advise on pipeline algorithms, assess and provide feedback on prototype data products, review and document feedback on final data products.

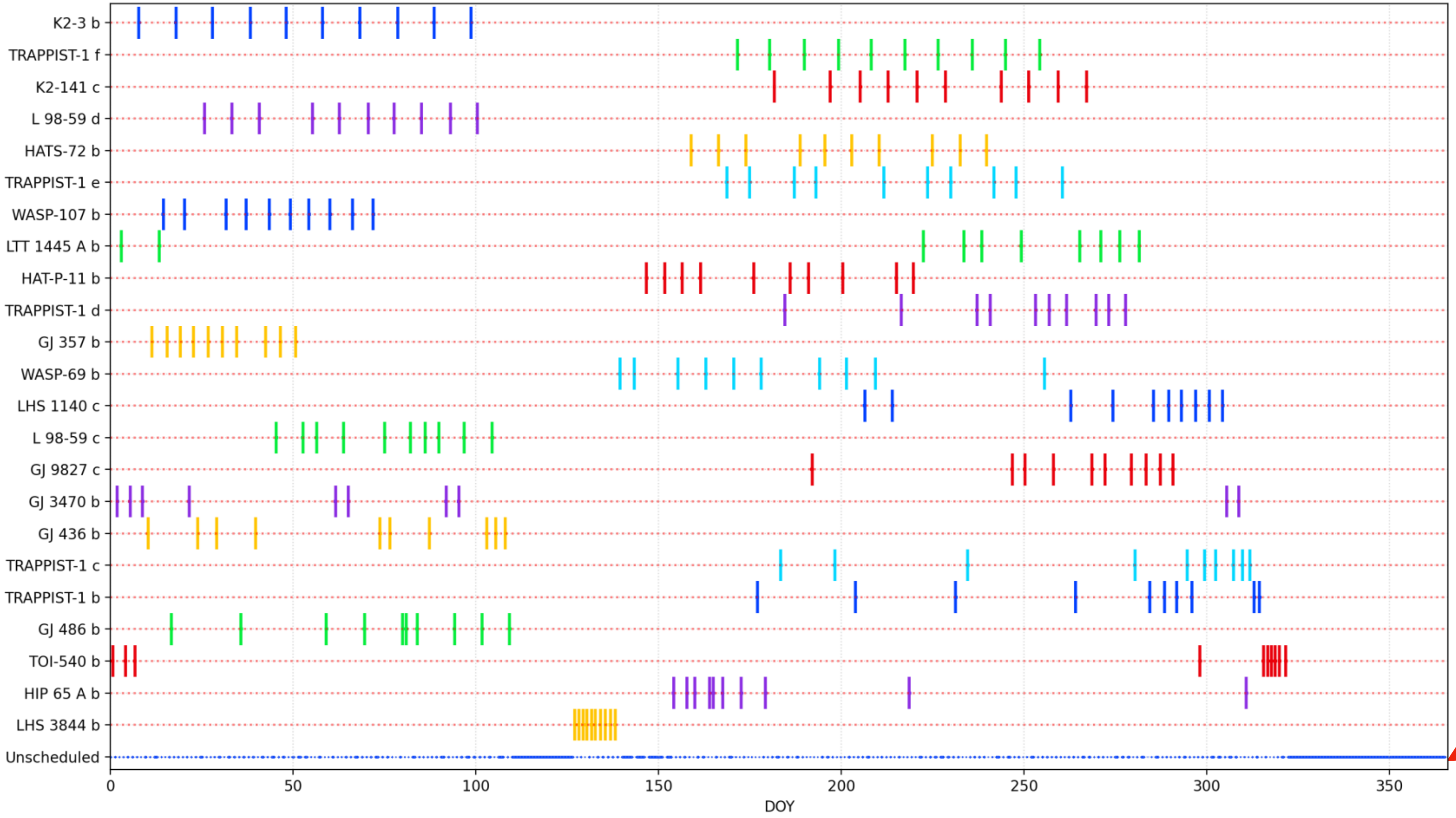
Stellar Contamination

SWG will develop and implement methodology to use multi-wavelength data to assess and constrain host star spots.

Auxiliary Science

SWG will identify and facilitate additional science investigations which can be pursued with Pandora without leveraging additional requirements or resources.

A year of Pandora science operations



Example target list for 20 Pandora target stars (with 23 Earth-to-Jupiter-size planets).

Tick marks are planned transit observations.

In this example, 135 days of unscheduled time remains available for schedule margin and auxiliary (bonus) science. We have built in functionality to populate the schedule with astrophysical targets.

See pandorasat.com for current target list + selection methodology

Pandora

Target List

The current list of science targets is given below (as of September 4, 2024). The Pandora target list will be updated as the mission launch date approaches.

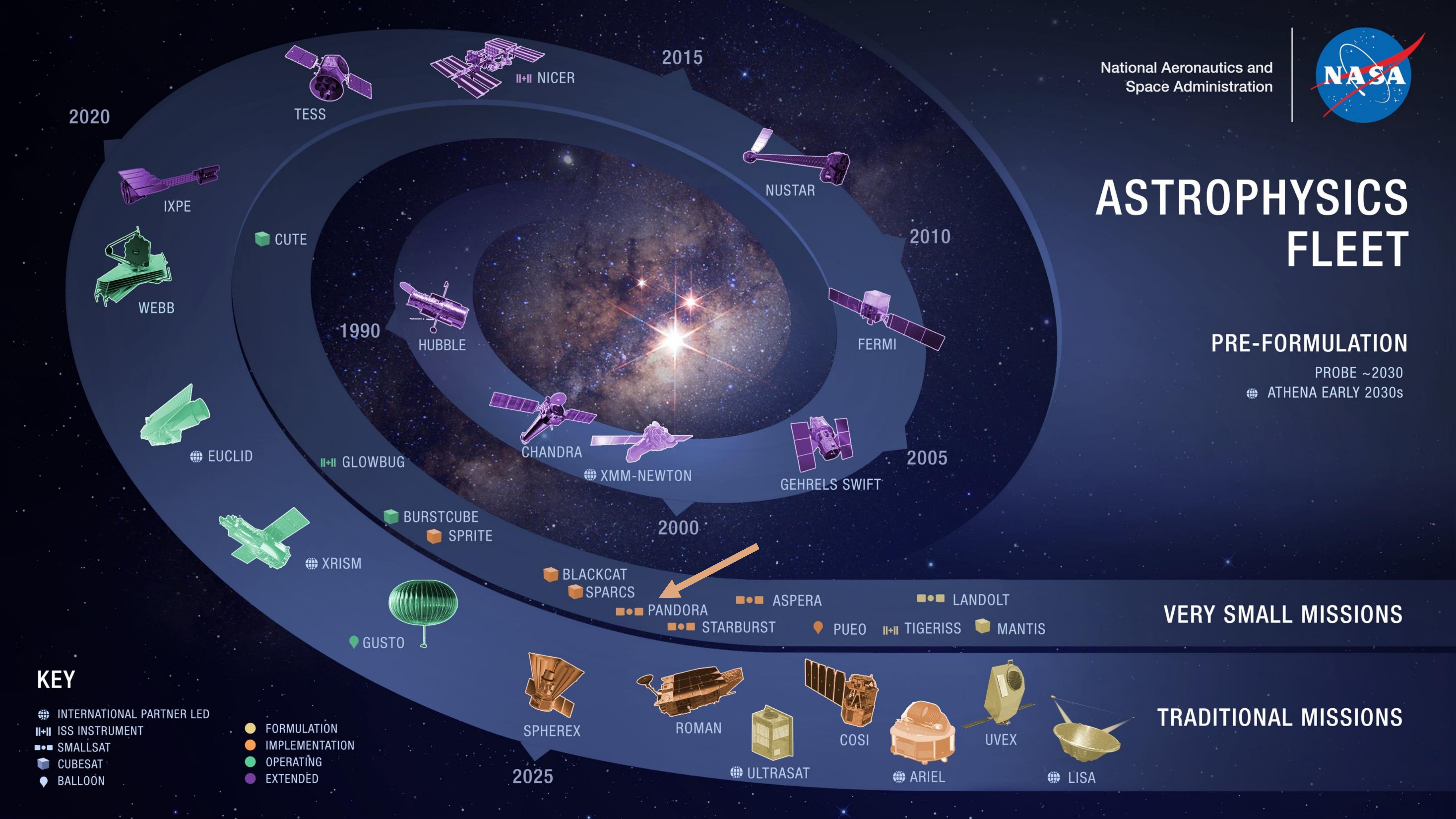
Star	Planet	RA	Dec	Vmag	Jmag	Spectral Type	Star Rotation Period [d]	Planet Radius [R_Earth]
WASP-69	b	315.026	-5.09486	9.873	8.032	K5	23.07	12.44
WASP-107	b	188.386	-10.1462	11.592	9.378	K6	17	10.54
HIP 65 A	b	0.185606	-54.8308	11	8.922	K4	13.2	22.75
TOI-3884	b	181.572	12.507	15.744	11.127	M4	nan	6
GJ 1214	b	258.831	4.96068	15.1	9.75	M4	124.7	2.74
WASP-177	b	334.797	-1.83443	12.312	10.654	K2	nan	17.71
WASP-80	b	303.167	-2.14444	11.841	9.218	M0	nan	11.2

Mission Status

Mission Lifecycle Phase

DEVELOPMENT	INTEGRATION	TESTING	DELIVERY	ON-ORBIT

Pandora Selection	1 Feb 2021
System Requirements Review	7 Sept 2021
Preliminary Design Review	19-20 Sept 2022
Critical Design Review	24-25 Oct 2023
Spacecraft Bus Delivery	Jan 2025
Pre-Environmental Review	14 March 2025
Flight Readiness Review/Pre-Ship Review	15 July 2025
Operations Readiness Review	8 Aug 2025
Initial Launch Capability	1 Sept 2025



National Aeronautics and Space Administration
NASA
ASTROPHYSICS FLEET
PRE-FORMULATION
PROBE ~2030
ATHENA EARLY 2030s
VERY SMALL MISSIONS
TRADITIONAL MISSIONS
1990
2000
2005
2010
2015
2020
2025
HUBBLE
CHANDRA
XMM-NEWTON
GEHRELS SWIFT
FERMI
NUSTAR
NICER
TESS
IXPE
WEBB
CUTE
EUCLID
GLOWBUG
BURSTCUBE
SPRITE
XRISM
GUSTO
BLACKCAT
SPARCS
PANDORA
STARBURST
ASPERA
PUEO
TIGERISS
LANDOLT
MANTIS
SPHEREX
ROMAN
ULTRASAT
COSI
ARIEL
UVEX
LISA
KEY
INTERNATIONAL PARTNER LED
ISS INSTRUMENT
SMALLSAT
CUBESAT
BALLOON
FORMULATION
IMPLEMENTATION
OPERATING
EXTENDED

More Pandora at AAS...

Mon 13 Jan	9:45 am	Hyperwall Talk (Tom Greene)
Wed 15 Jan	6:00 pm	Hyperwall Talk (Lindsey Wiser)
Thurs 16 Jan	9:00 am	Leveraging Pandora Smallsat Mission to Enhance Model Fidelity for M-dwarf Atmospheres (Aishwarya Iyer)
Thurs 16 Jan	10:15 am	Press Briefing (Benjamin Hord)
Thurs 16 Jan	1:15 pm	Hyperwall Talk (Knicole Colón)
Thurs 16 Jan	2:10 pm	NASA's Pandora SmallSat Mission: Multiwavelength Characterization of Exoplanets and their Host Stars (Benjamin Hord)
Thurs 16 Jan	2:20 pm	Planning Science Observations with the Pandora SmallSat (Tom Barclay)
Thurs 16 Jan	2:40 pm	TESS and Pandora: Understanding Stellar Activity and Exoplanet Host Stars in the Era of High-Cadence Photometry (Rae Holcomb)

+ Come visit us in the NASA booth area!

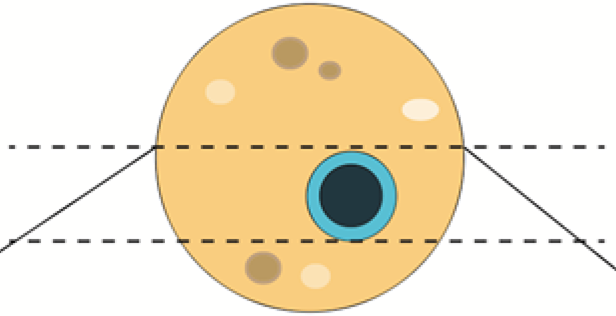
Mission At-A-Glance

Pandora

Pandora provides unique, continuous dual-band data to determine stellar photosphere properties and disentangle star and planetary signals in trans-mission spectroscopy.

Mission Overview

Launch Date	Mid-2020s
Payload	Telescope (0.45m)
Channels	Visible photometry IR spectroscopy
Orbit	Sun-sync LEO
Science Operations	1+ years



Wavelength: Visible channel ← simultaneous → IR channel

What do we measure?
- Visible channel: Time-varying star brightness (in visible band where stellar variability has high contrast)
- IR channel: Time varying spectrum (in IR band where water is strong molecular absorber)

What do measurements provide? Star spot and faculae brightness contrasts (from visible) and covering fractions (from Vis+IR) as a function of time & stellar rotation

What do we learn? Stellar atmosphere contribution to planetary spectrum + deeper understanding of stellar heterogeneity → Star-corrected planet spectrum revealing composition of intrinsic planetary atmospheres (water, hydrogen, clouds)

Why are the data unique? Pandora will produce the first long-duration dataset with simultaneous visible photometry and IR spectroscopy of exoplanets and their host stars.

Why Now? Pandora will inform JWST exoplanet transmission spectroscopy analyses, and operate concurrently with JWST.