NASA's Pandora SmallSat Mission:
Multiwavelength Characterization of Exoplanets and their Host Stars

Knicole Colón (NASA GSFC) *on behalf of the Pandora Team*

Know Thy Star, Know Thy Planet 2

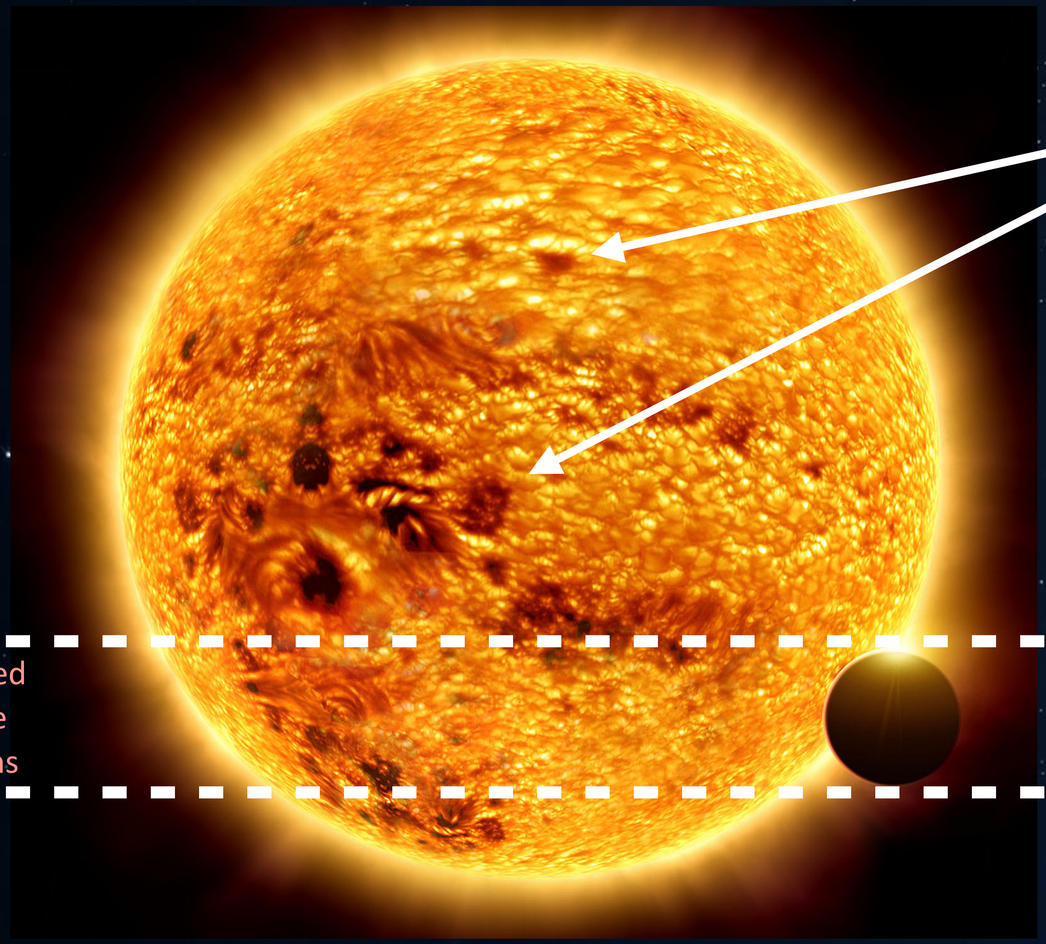
February 7, 2025

Principal Investigator: Elisa Quintana (GSFC)
Deputy Principal Investigator: Jessie Dotson (ARC)
Project Scientist: Knicole Colón (GSFC)
Deputy Project Scientist: Tom Barclay (GSFC)

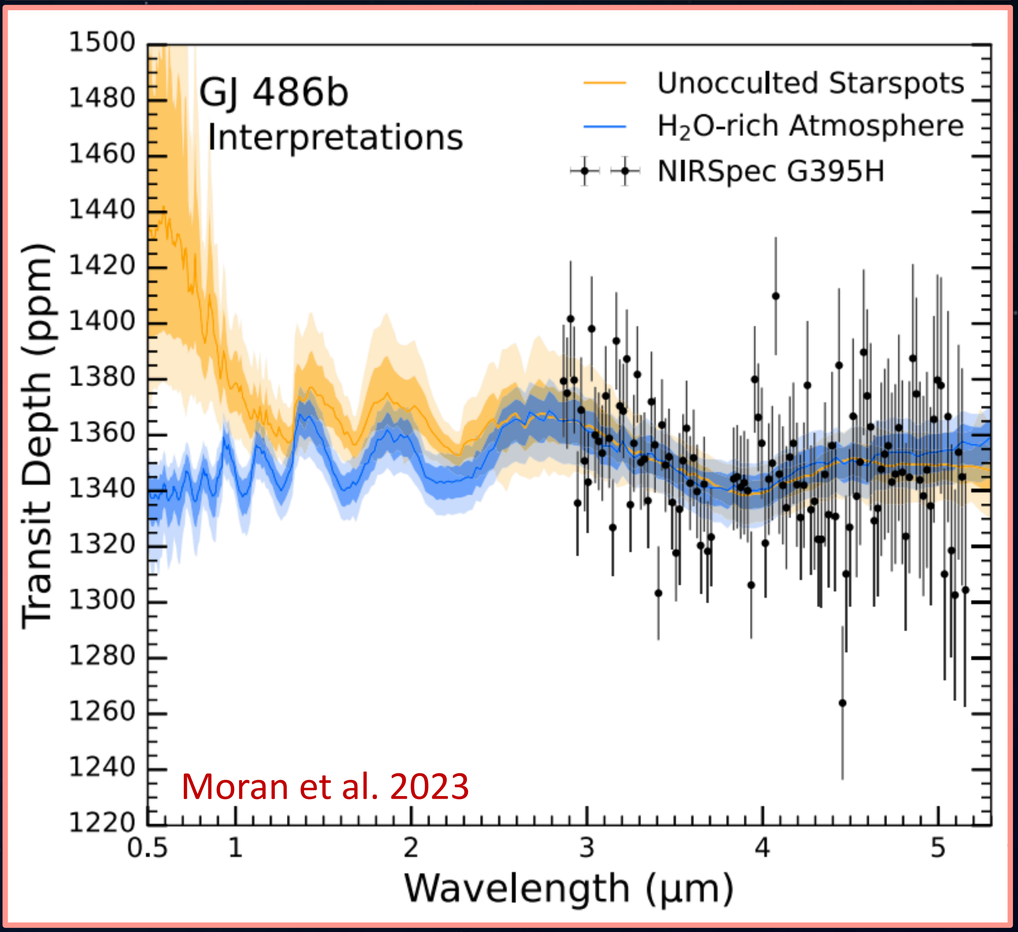
Project Manager: Pete Supsinskas (LLNL)
Deputy Project Manager: Jordan Karburn (LLNL)
Project System Engineer: Maricris Schneider (LLNL)

Pandora will address the timely problem of stellar contamination in exoplanet transmission spectroscopy

Stars are magnetically active, and dark/cool spots and bright/hot faculae regions can introduce brightness variations that evolve spatially and with time, leading to the Transit Light Source effect.



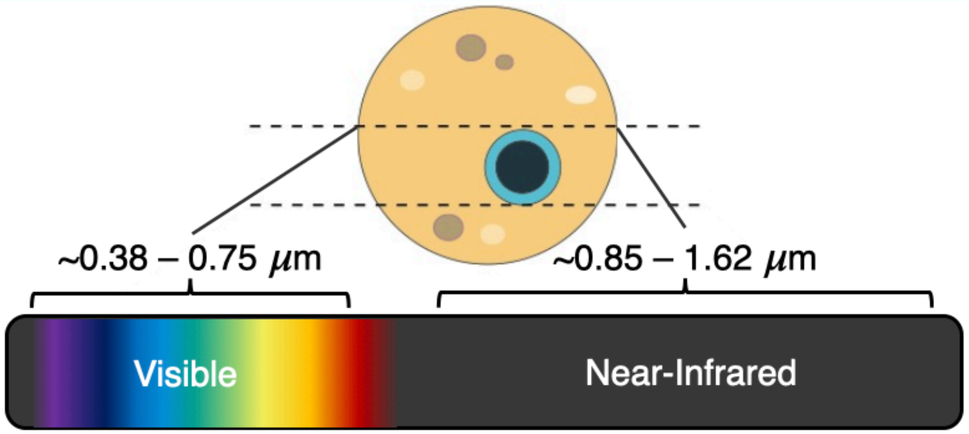
High Tide or Riptide on the Cosmic Shoreline? A Water-rich Atmosphere or Stellar Contamination for the Warm Super-Earth GJ 486b from JWST Observations



Pandora is a SmallSat designed to observe transiting exoplanets and their host stars with long time baselines and simultaneous visible photometry and infrared spectroscopy

Pandora will disentangle star and planet signals in transmission spectroscopy to reliably determine exoplanet atmosphere compositions.

At least 20 exoplanets will be observed 10 times, 24 hours each, spread across 1 year.



Mission Overview

Launch Date	NET Fall 2025
Payload	Telescope (0.45m)
Channels	Visible photometry IR spectroscopy
Orbit	Sun-sync LEO
Science Operations	1+ years

Orbit: 450-600km Dusk-Dawn orbit
Bus: BCT Saturn ESPA Grande
Payload: 45cm CODA 2.1 Design
Ground Stations: KSAT Lite

Science Objectives

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)?

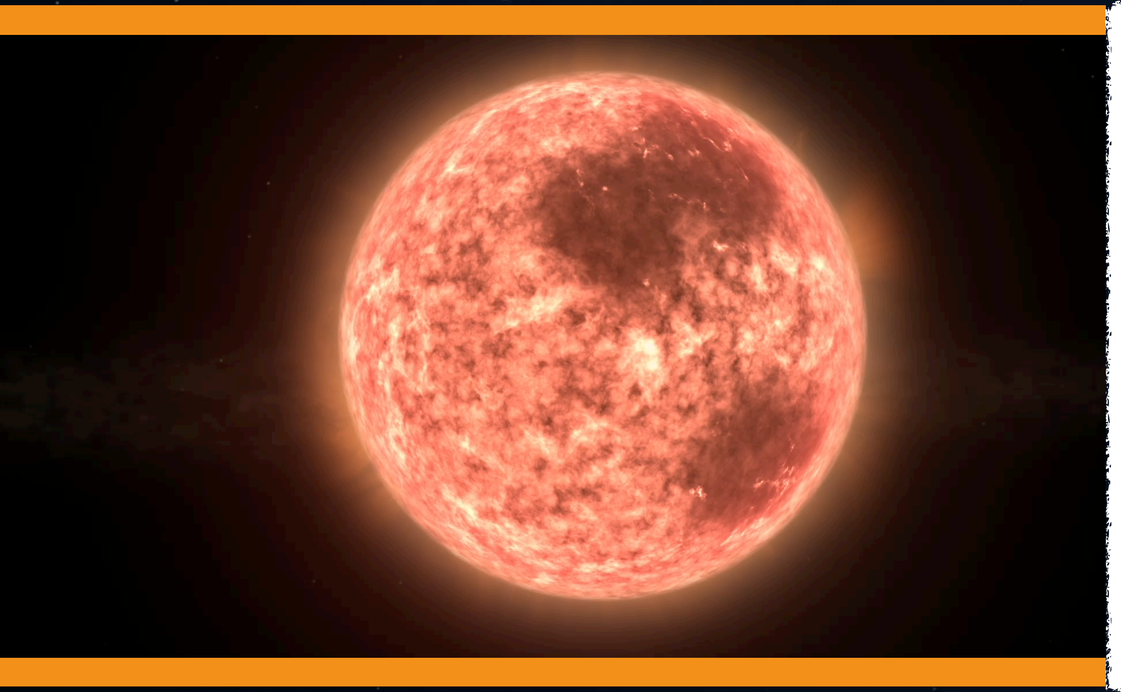
L0: Identify exoplanets with hydrogen- or water-dominated atmospheres, and determine which planets are covered by clouds and hazes.

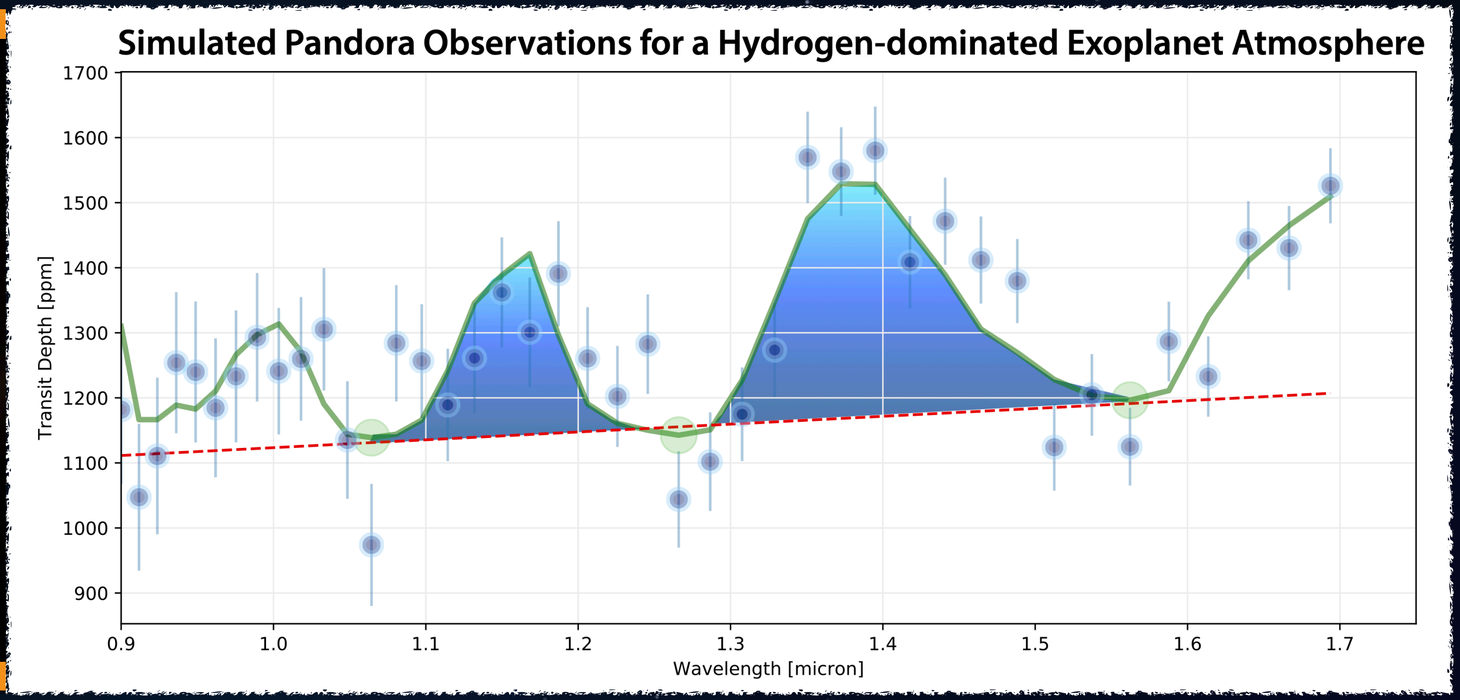
IIa. How does the atmospheric composition of planets vary with size/mass/bulk density, orbital distance, and host star properties?

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

Pandora simultaneous visible and near-IR observations will enable us to:

- Model the host star's spot fraction
- Measure how spot changes affect the star's spectrum
- Isolate the exoplanet atmosphere signal from the stellar signal
- Detect exoplanet atmospheric water and hazes (if present)





Credit: Daniel Apai

Pandora Mission Leadership & Science Team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Principal Investigator
NASA GSFC


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Deputy Principal Investigator
NASA Ames


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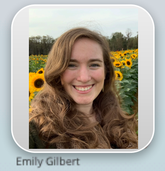
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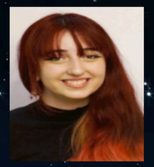
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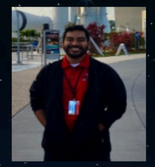
Undergraduate Student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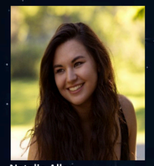
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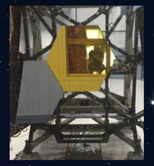
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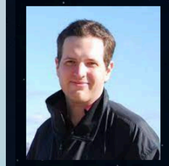
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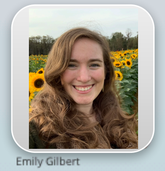
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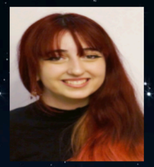
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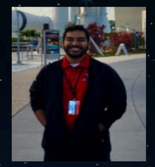
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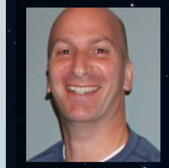
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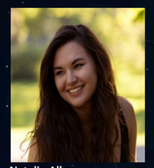
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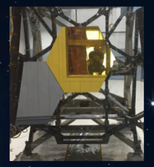
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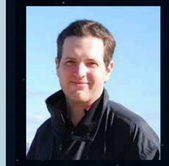
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Pandora Team Workshop (May 2024)

Pandora System Requirements Review (September 2021)

Pandora Team Workshop (May 2023)

Pandora's funded graduate student shadow program matches students with more senior mentors, to contribute to core mission activities

Emily Gilbert (NASA JPL)

- Graduate Student Shadow to the Pandora Project Scientist => NASA JPL Postdoc and Pandora Associate Project Scientist
- Tasks: (1) organization of science team activities and priorities and (2) Pandora representation at programmatic meetings

Lindsey Wiser (ASU)

- Graduate Student Shadow to the Pandora Deputy Principal Investigator
- Tasks: (1) development of Pandora commissioning plan and (2) coordination of Pandora scientific and public outreach

Trevor Foote (Cornell)

- Graduate Student Shadow to the Pandora Deputy Project Scientist => Newly Minted PhD!
- Tasks: (1) development of tools for optimizing Pandora's observing schedule and (2) Pandora detector testing in the laboratory

Rae Holcomb (UC Irvine)

- Graduate Student Shadow to the Pandora Science Data Processing Lead
- Tasks: (1) development of tools to process Pandora commissioning data and (2) applications of TESS stellar astrophysics measurements to Pandora

Pandora also provides opportunities for NASA Postdoctoral Program Fellows to make key contributions to mission development

Ben Hord
NASA Pandora Postdoctoral Program Fellow
Tasks:
- facilitating Pandora science target selection and prioritization
- developing planning and operations tools for use by the Pandora Science Operations and Data Processing centers

Aishwarya Iyer
NASA Pandora Postdoctoral Program Fellow
Tasks:
- developing improvements to stellar atmosphere model fidelity for Pandora science data analysis and interpretation
- contributing to coordination of ground-based observations of Pandora science targets

Pandora Science Working Groups

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.

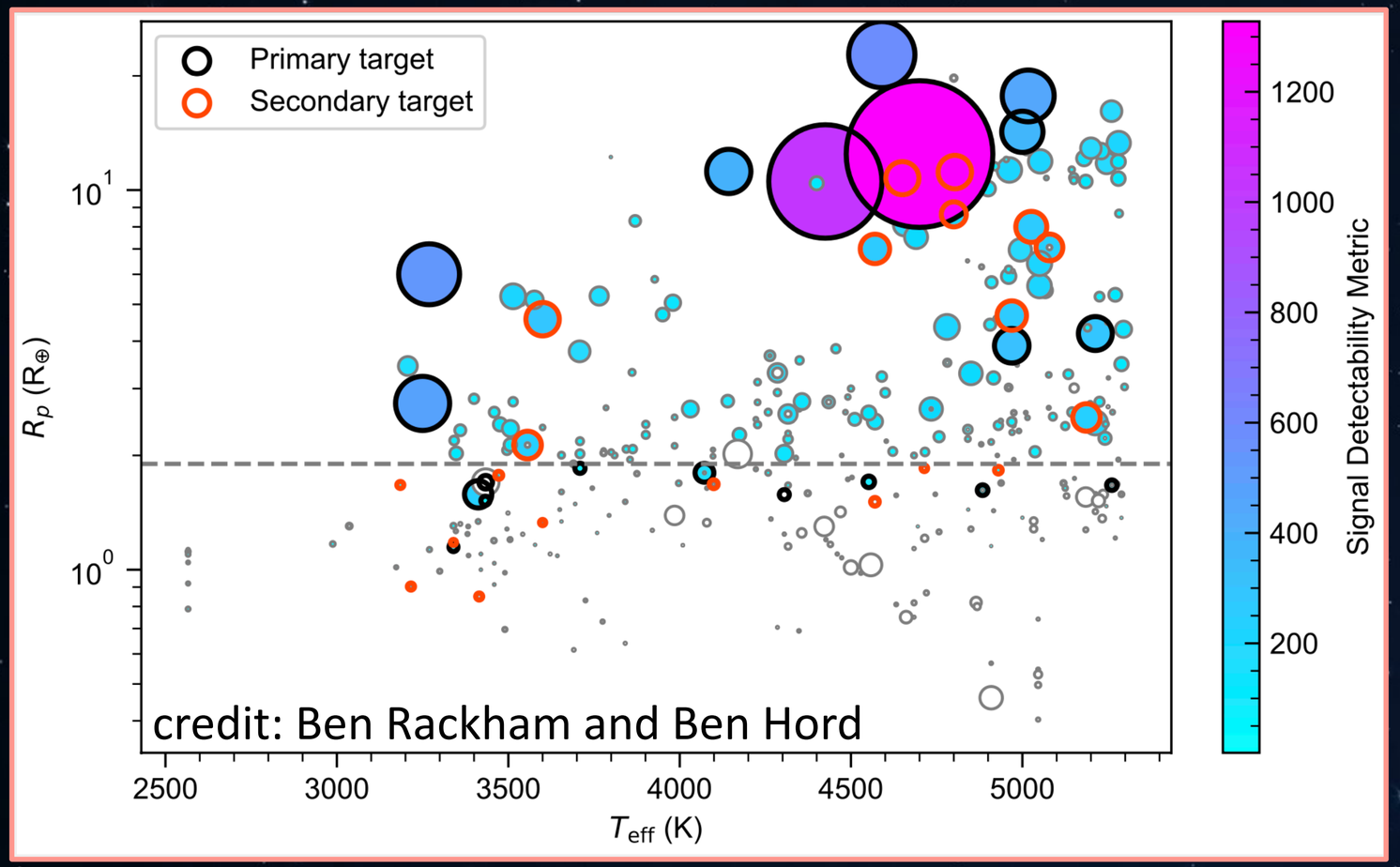
Auxiliary Science
SWG will identify and facilitate additional science investigations which can be pursued with Pandora without leveraging additional requirements or resources.

Pandora Target Selection Strategy

Our team has defined the "Signal Detectability Metric" that folds in stellar activity indicators, incorporating high cadence TESS measurements of rotational brightness modulation (which provides limits on the spot covering fractions of stars).

SDM = TSM * (1 + w * A)

- TSM = transmission spectroscopy metric
- A = peak-to-peak amplitude of variability
- w = weighting factor
  - w = 100 effectively doubles the metric for a star with A = 1%



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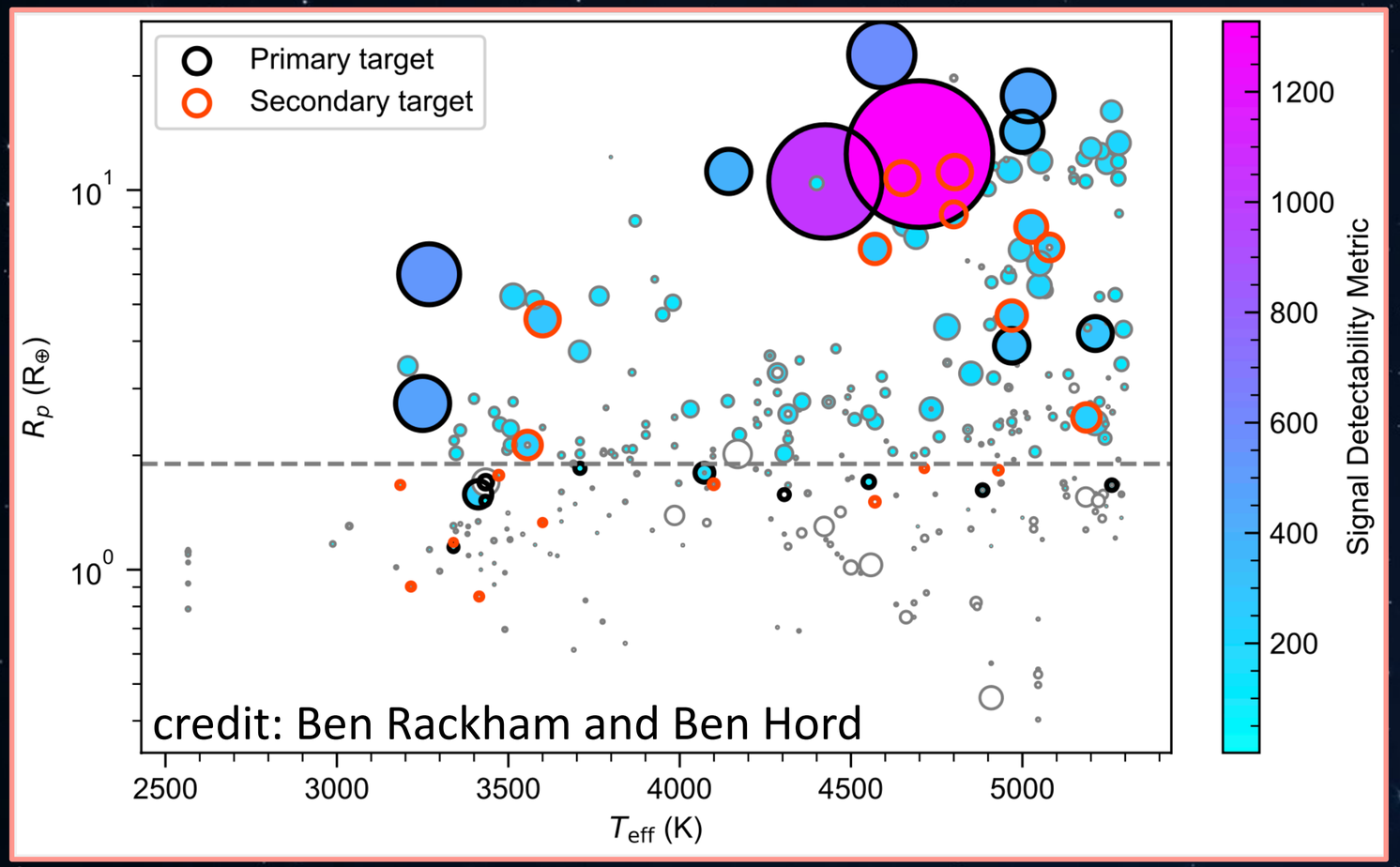
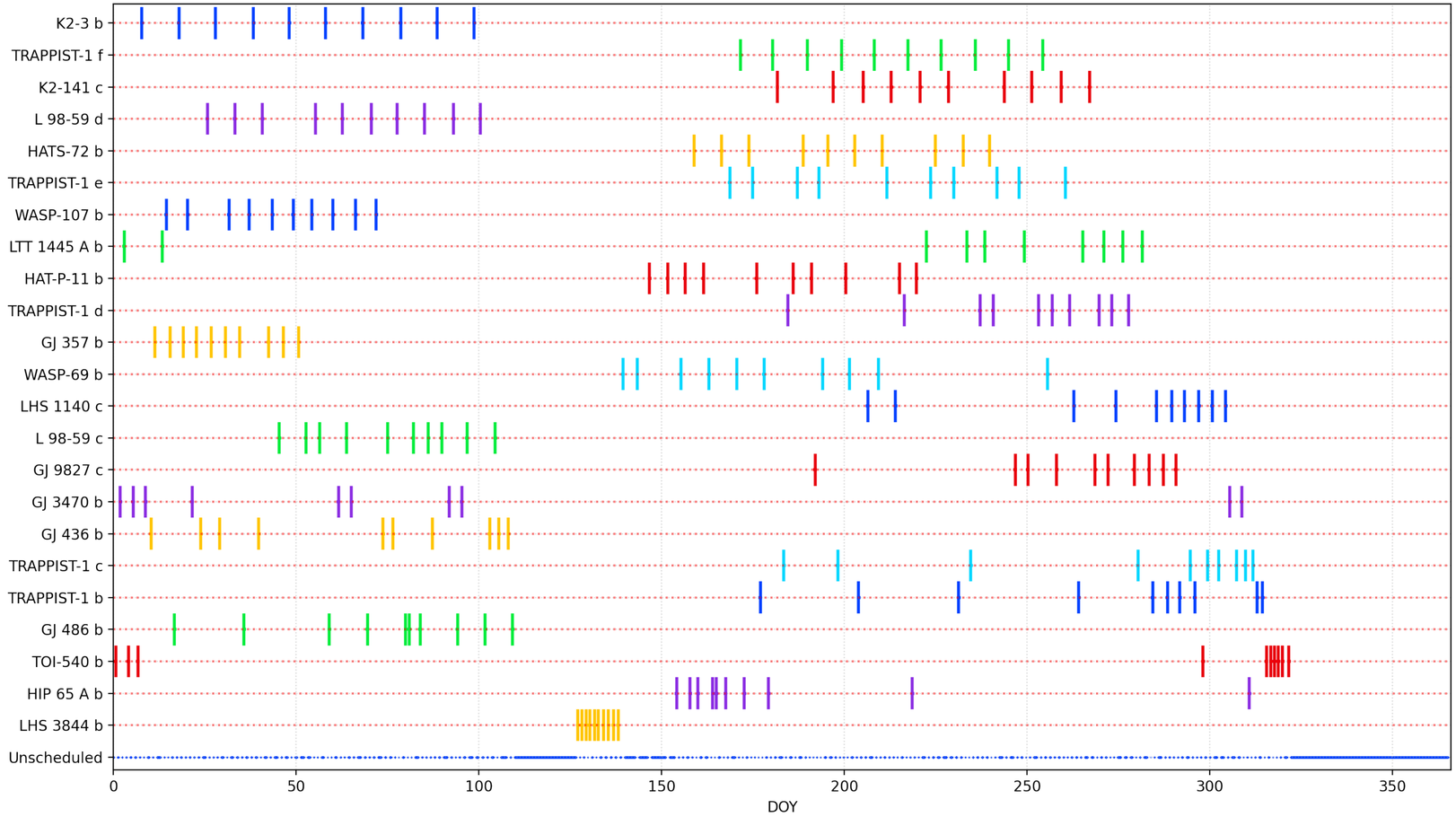


The target list is still evolving as we fold in additional information about the exoplanets and their stars

Further information can be found on our website at ***pandorasat.com***

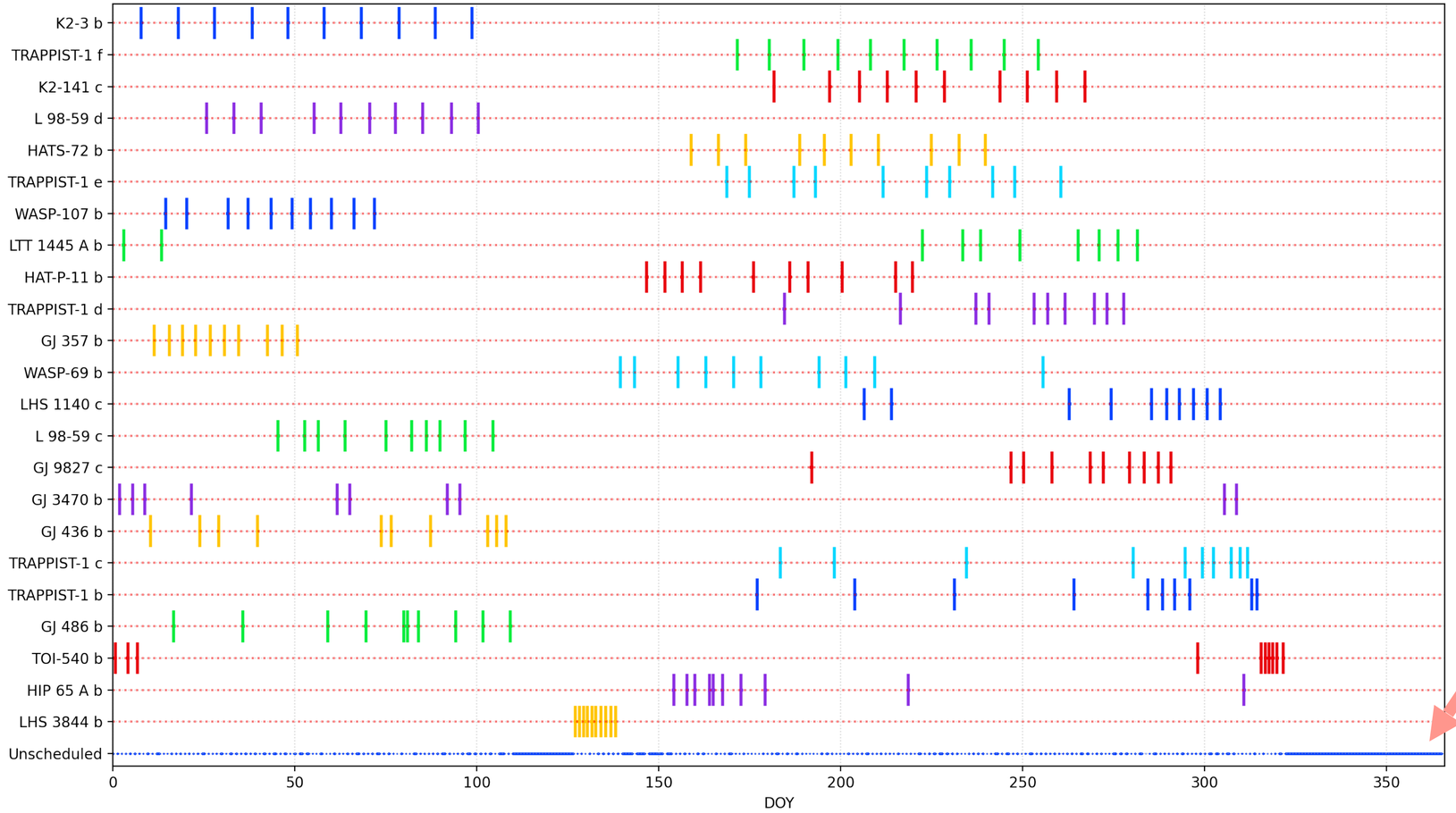
A Year of Pandora Observations



Example (*not final*) target list for 20 Pandora target stars (with 23 Earth-to-Jupiter-size planets).

Tick marks are planned transit observations.

A Year of Pandora Observations



Example (*not final*) target list for 20 Pandora target stars (with 23 Earth-to-Jupiter-size planets).

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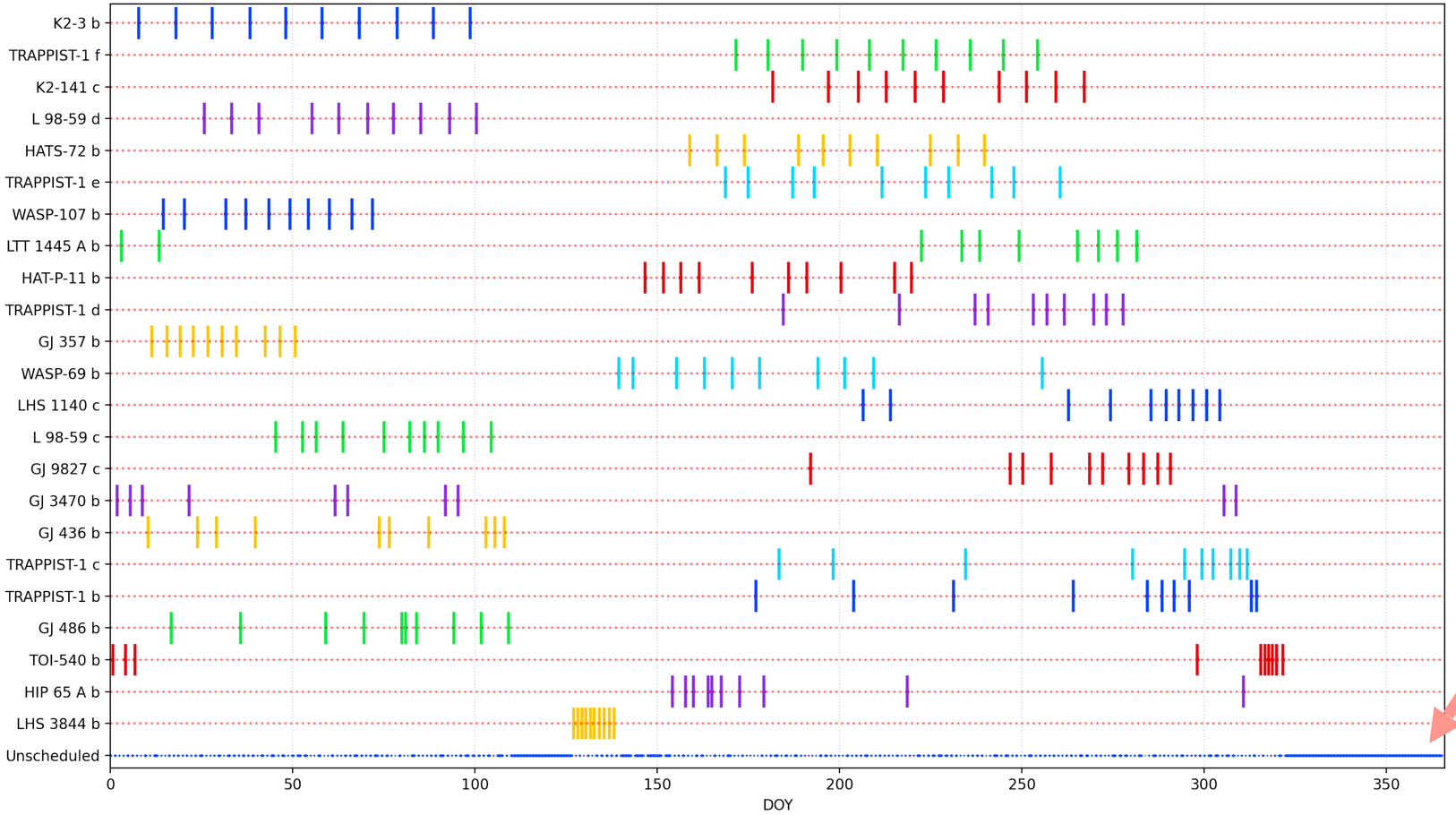
In this example, 135 days of unscheduled time remains available for schedule margin and **auxiliary (bonus) science**. We are currently developing a **DDT program** for the community to propose additional science targets.

A Year of Pandora Observations



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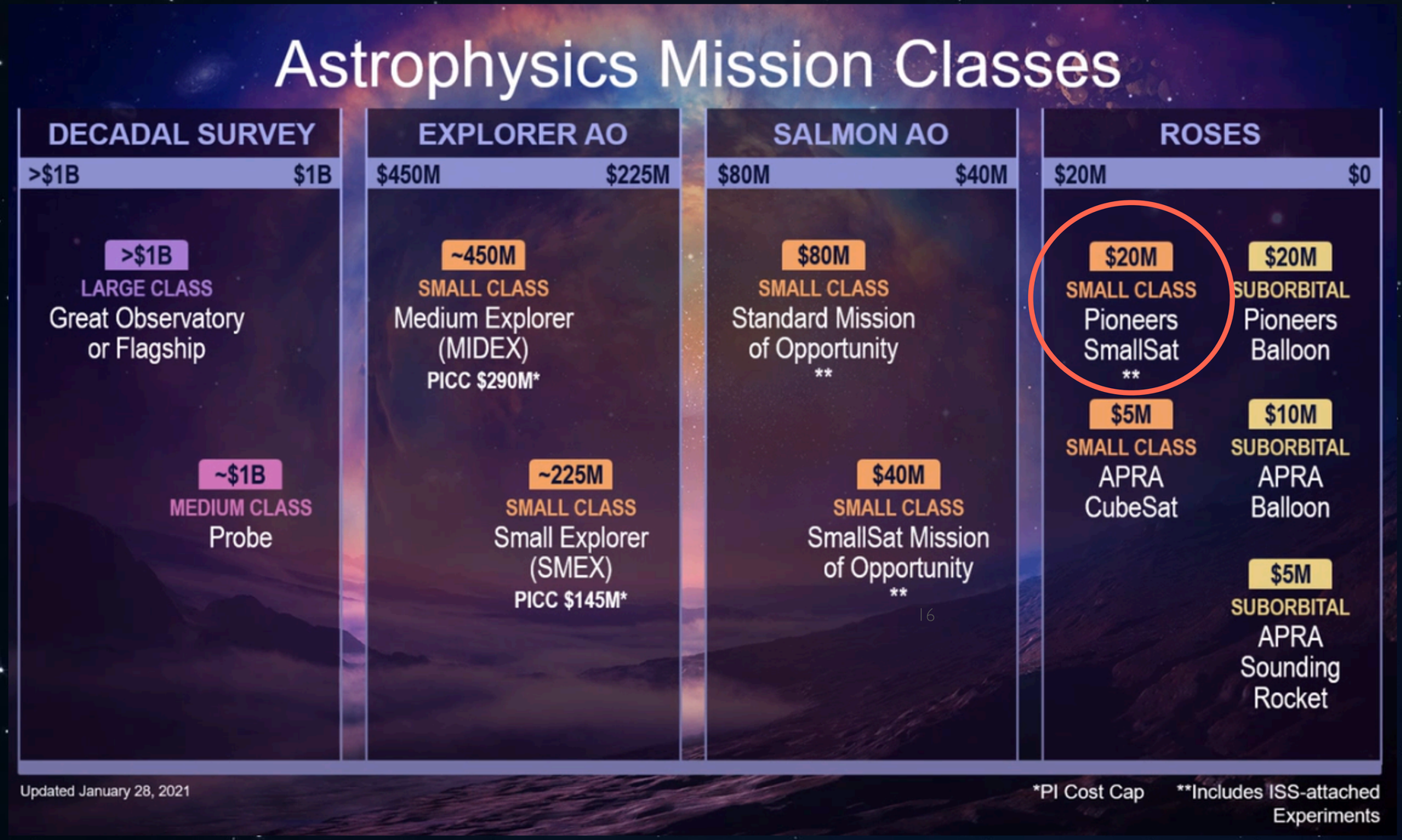
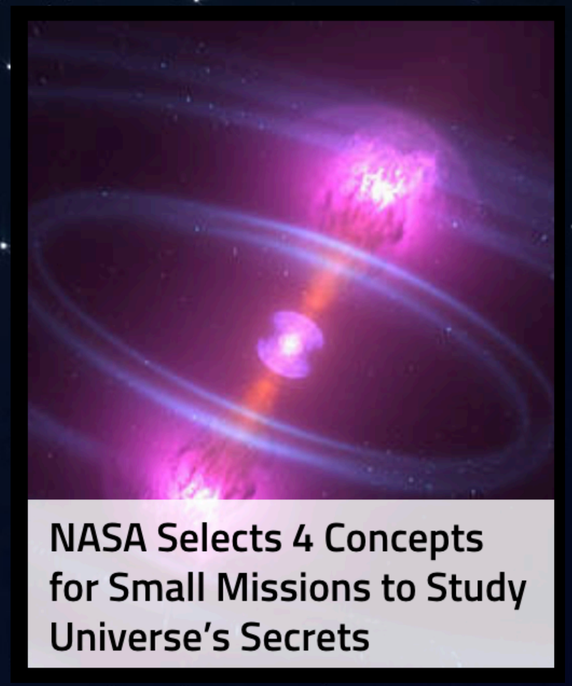
Data archiving nominally will occur within 3 months of data downlink, which includes calibrated images, light curves, and spectra. **Pandora data have no proprietary period.**

Pandora was selected as part of the inaugural class of NASA Pioneers missions in 2021

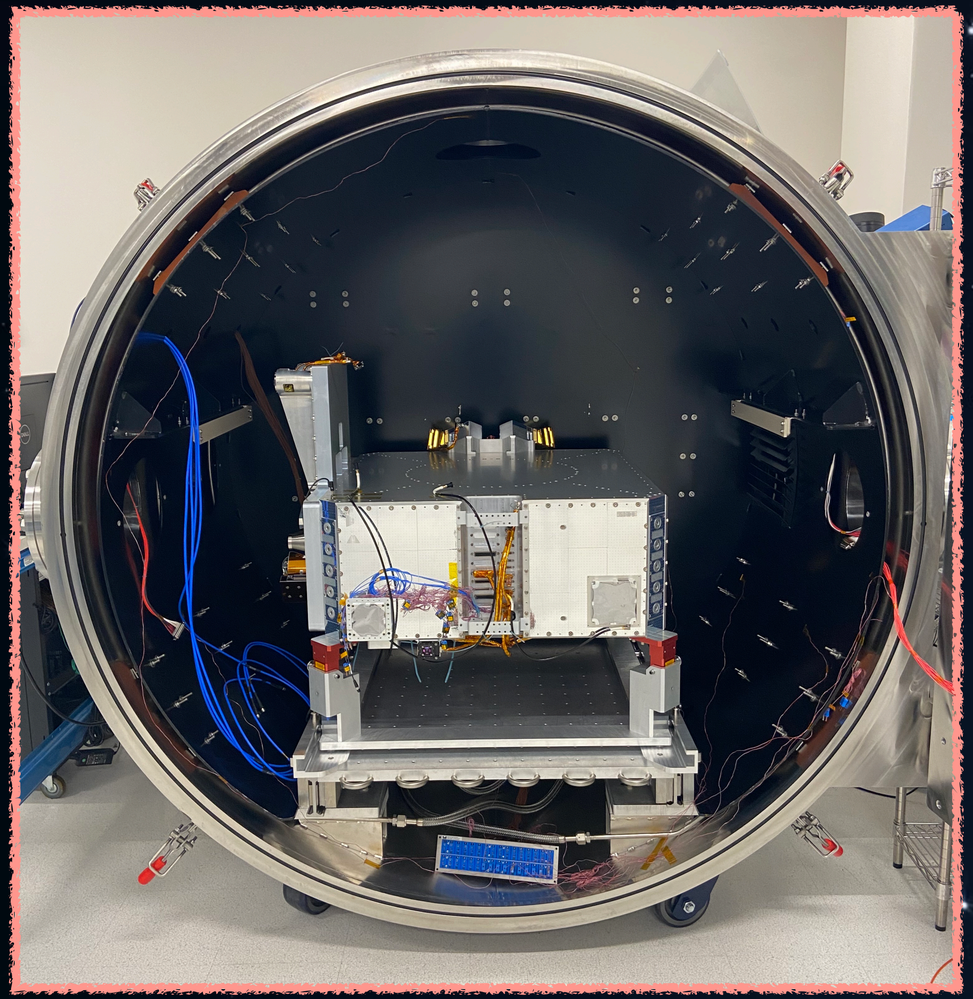




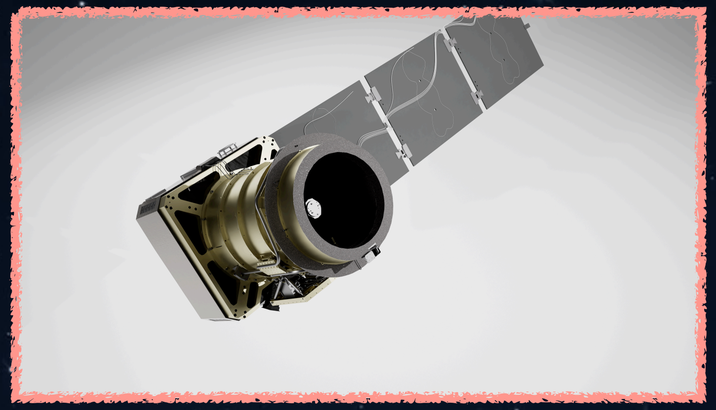
Pandora Mission Status

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 🚀

Pandora's spacecraft bus has been completed and the mission is on track for launch readiness in Fall 2025

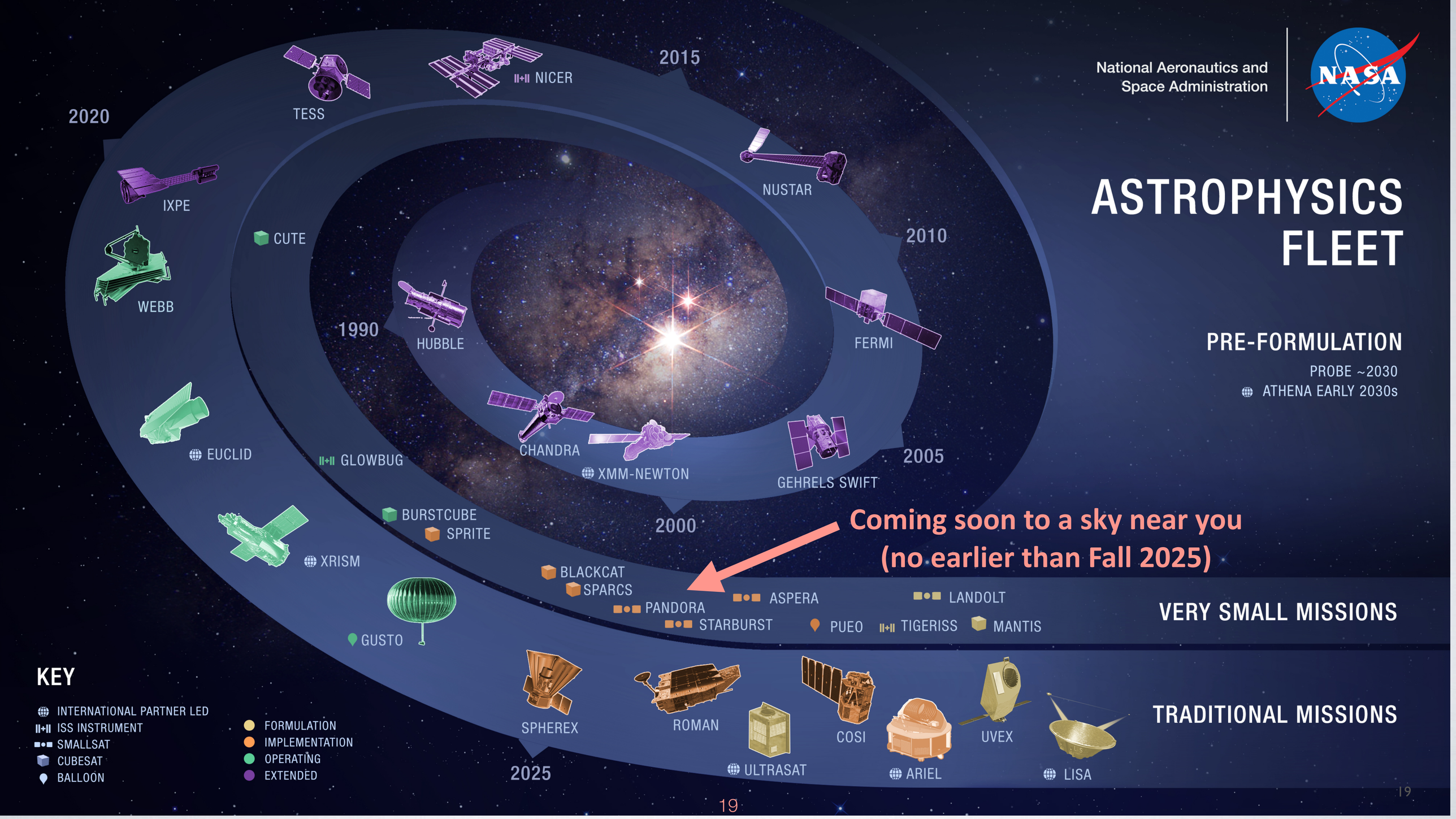


Pandora Spacecraft Bus
(Blue Canyon Technologies)



Pandora Observatory Rendering

Scale Model of Pandora Telescope at AAS
Fly Eagles Fly!


National Aeronautics and Space Administration
NASA
ASTROPHYSICS FLEET
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NUSTAR
IXPE
CUTE
WEBB
HUBBLE
FERMI
CHANDRA
XMM-NEWTON
GEHRELS SWIFT
EUCLID
GLOWBUG
BURSTCUBE
SPRITE
XRISM
GUSTO
BLACKCAT
SPARCS
PANDORA
ASPERA
LANDOLT
STARBURST
PUEO
TIGERISS
MANTIS
SPHEREX
ROMAN
ULTRASAT
COSI
ARIEL
UVEX
LISA
Coming soon to a sky near you
(no earlier than Fall 2025)
PRE-FORMULATION
PROBE ~2030
ATHENA EARLY 2030s
VERY SMALL MISSIONS
TRADITIONAL MISSIONS
KEY
INTERNATIONAL PARTNER LED
ISS INSTRUMENT
SMALLSAT
CUBESAT
BALLOON
FORMULATION
IMPLEMENTATION
OPERATING
EXTENDED

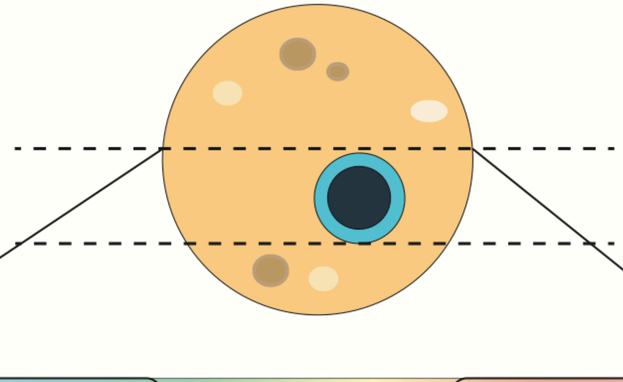
19

Mission At-A-Glance

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?

Time-varying star brightness (in visible band where stellar variability has high contrast)

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?

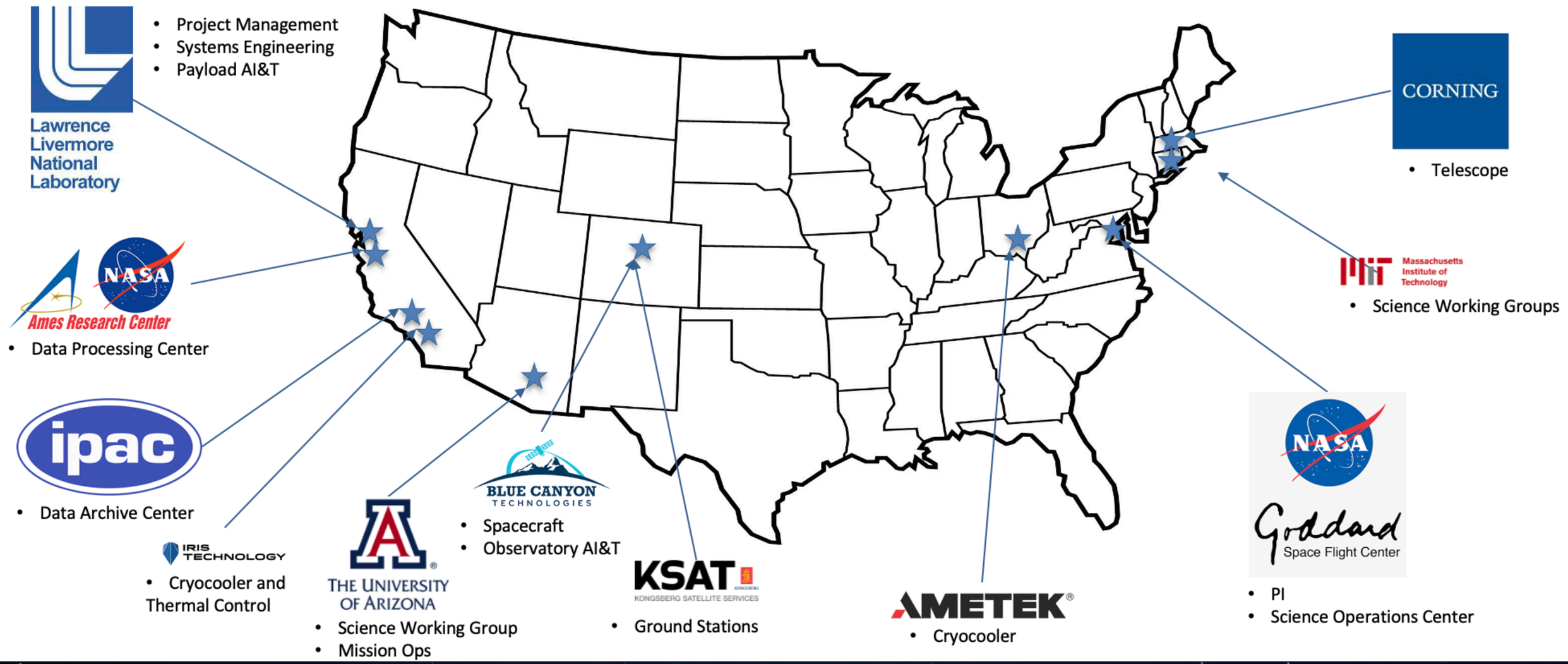
Pandora will produce the first long-duration dataset with simultaneous visible photometry and IR spectroscopy of exoplanets and their host stars.

Why Now?

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

EXTRA SLIDES

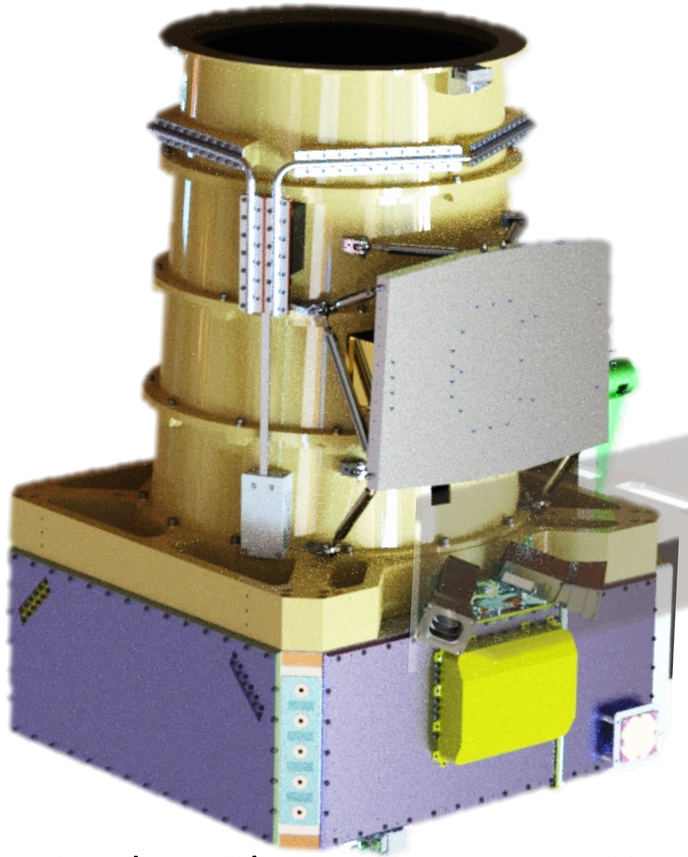
Pandora Mission Partners



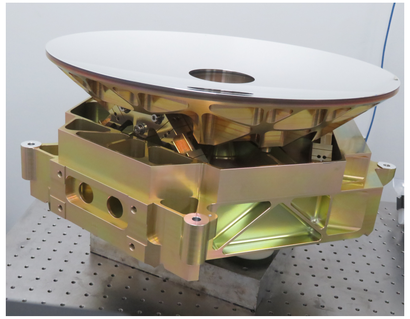
+ science team members at institutions across the US and Canada

Pandora Observatory

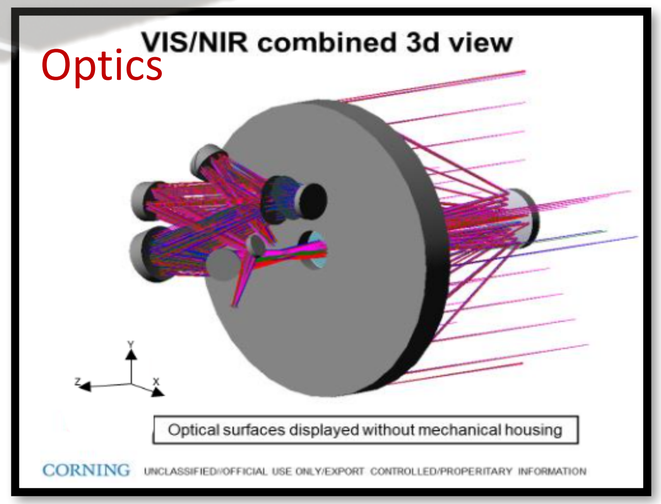
- All-aluminum 0.45-meter Cassegrain telescope design with relayed vis and IR paths.
  - VIS: 380-750nm
  - NIR: 850-1620nm
- Detectors:
  - VIS: sCMOS pco.panda
  - NIR: HAWAII-2RG
- Low-jitter active cryo system to cool IR to 110K ± 10 mK



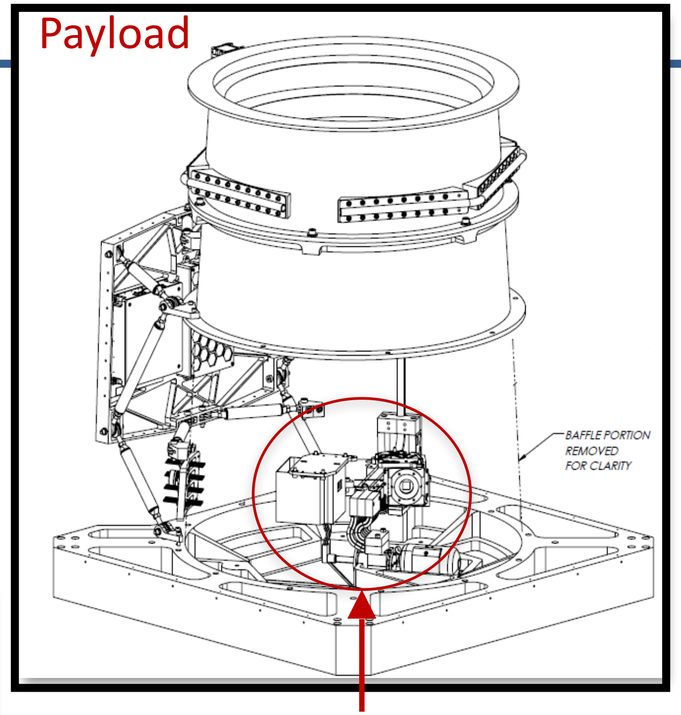
Pandora Observatory is an ESPA-Grande Class Satellite.



Optics



Payload



Detector Assemblies

System Overview

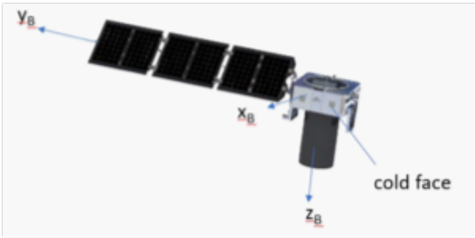
Pandora

KSAT_LITE Ground Station Networks

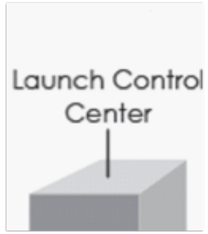
1.1 Pandora Observatory

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)



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



1.3 Launch 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)

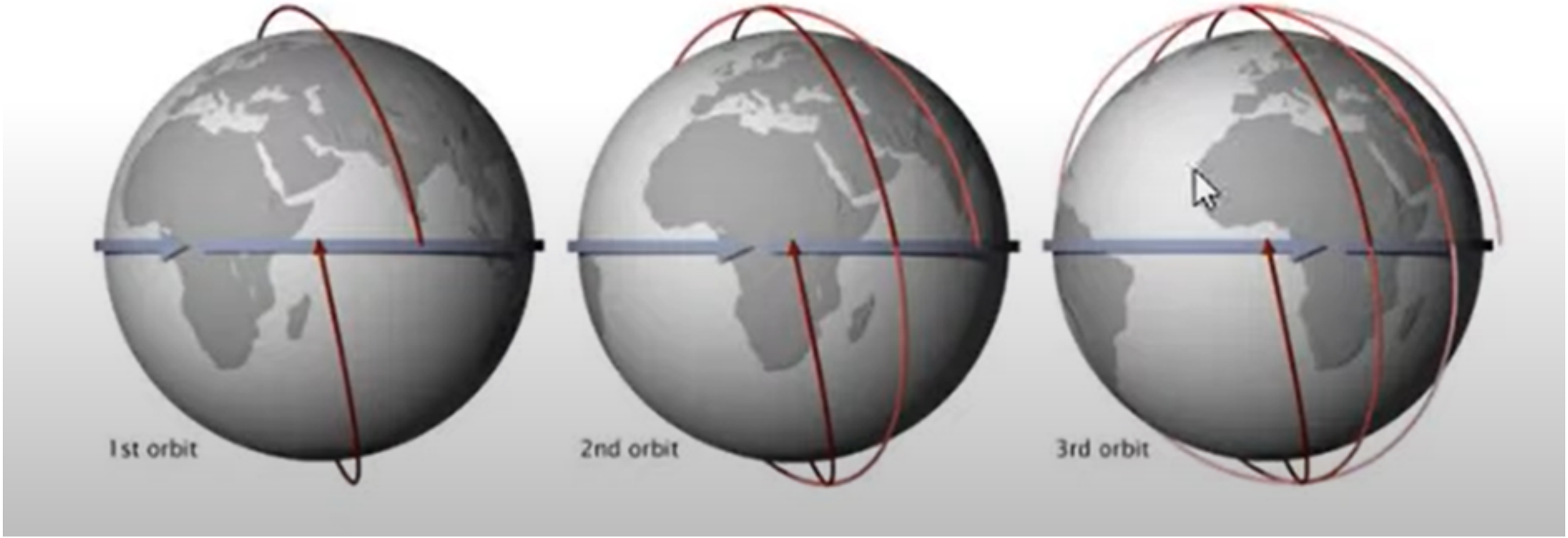
- Data Processing
- Data Management

Data Archive Center
IPAC/IRSA at CalTech

- Data Distribution
- Data Archiving

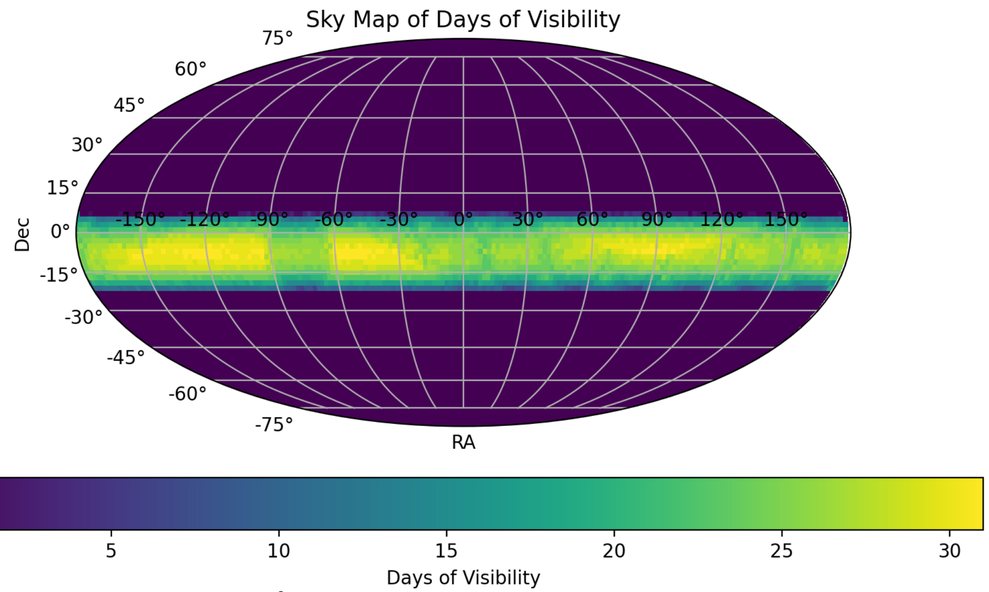
1.2 Ground Segment

Sun Sync orbit provides access to the full night sky



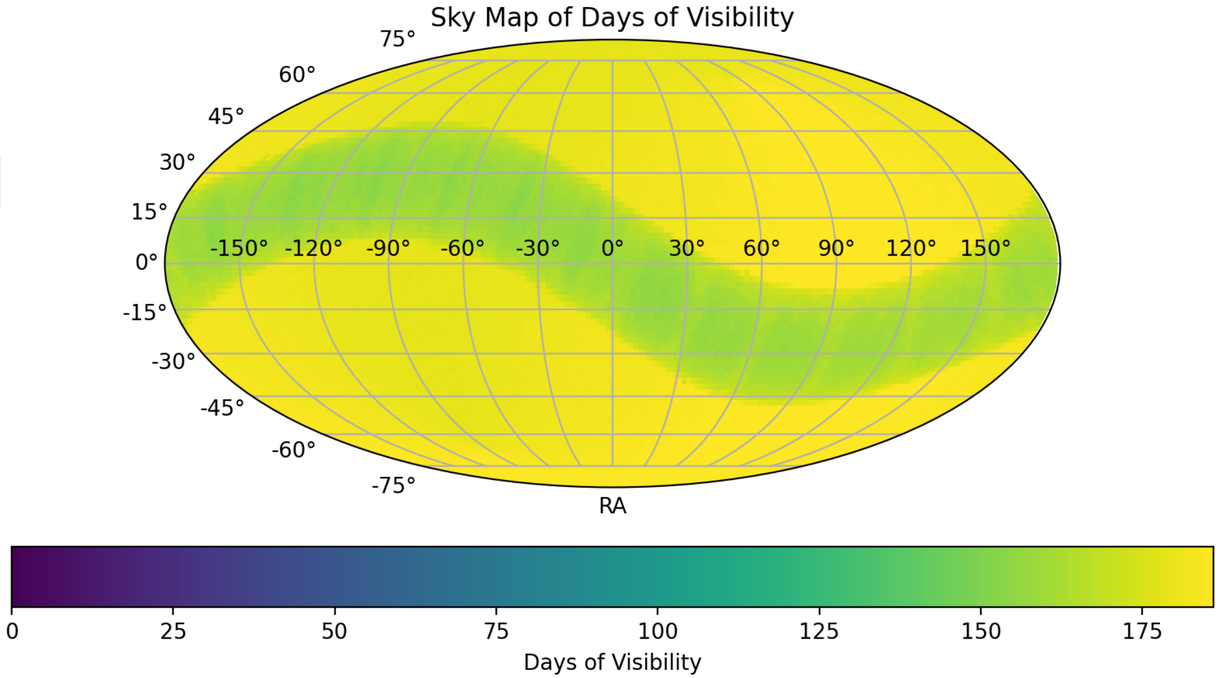
Direction of the sun

Sun Sync orbit provides excellent access to the full night sky

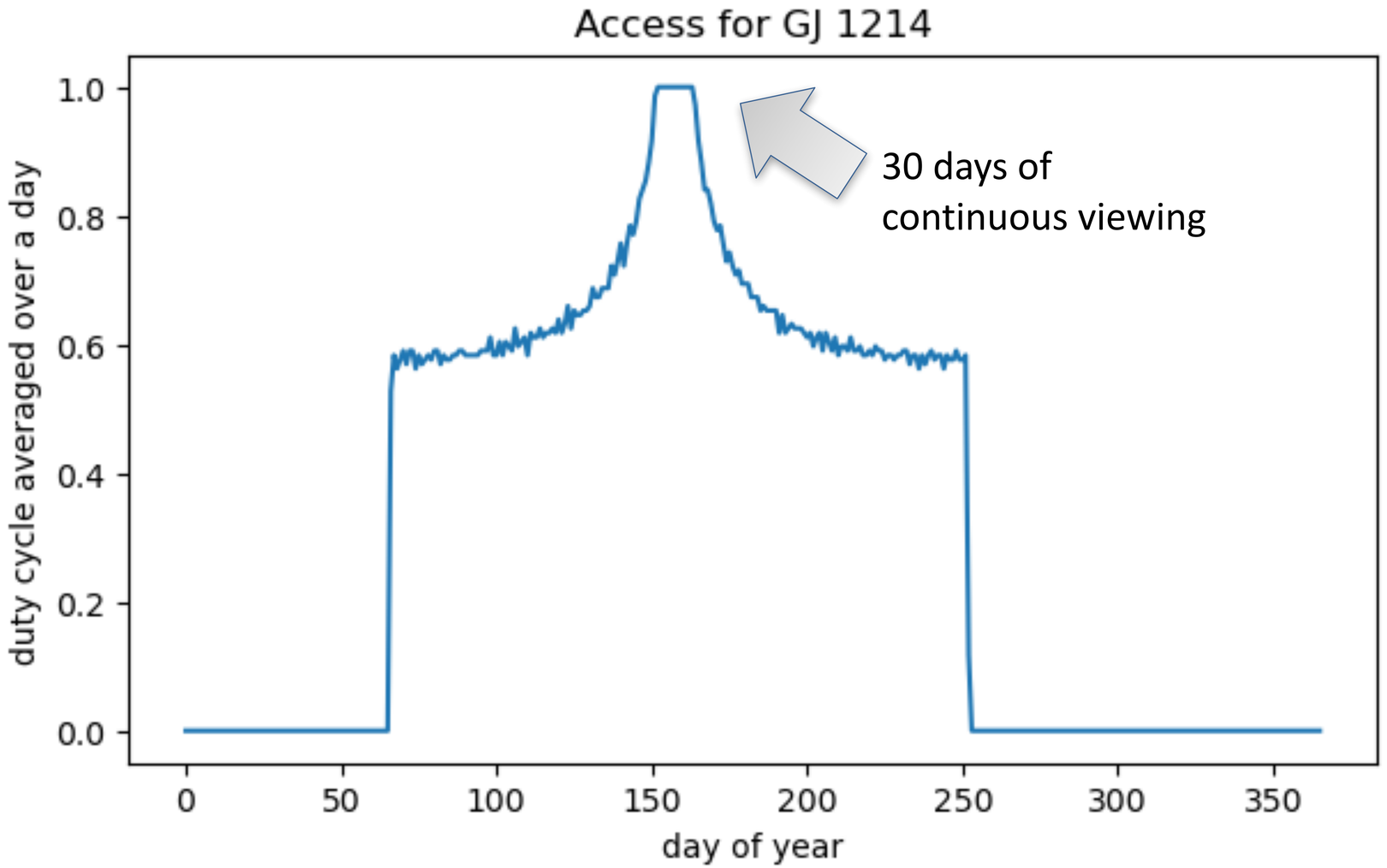


Continuous view days per year

>50 mins per orbit access in days per year

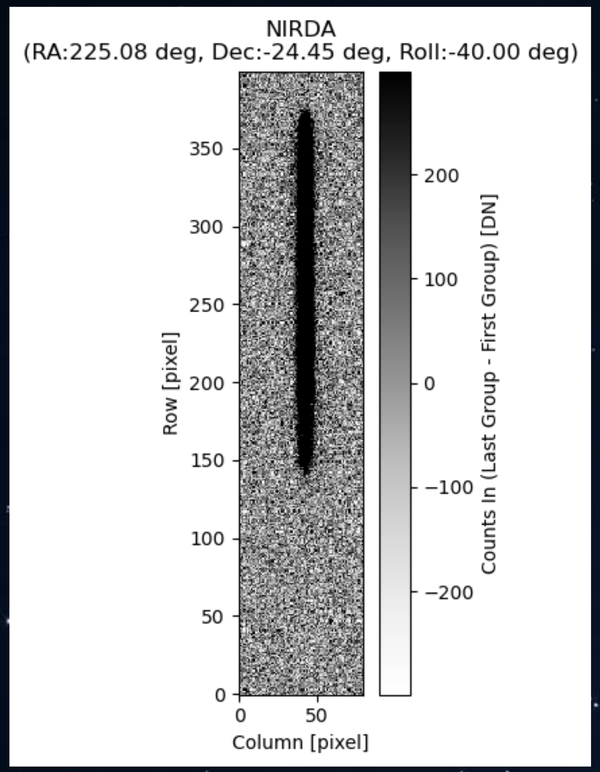


Sun Sync orbit provides excellent access to the full night sky



Pandora Science Data Simulations

Simulations of 3500K, jmag=9 star on VISDA (top) and NIRDA (right) with correct expectations of brightness and noise.



Pandora simulations generate realistic data for the visible and near-infrared detectors with:

- Accurate estimates of brightness and spectra for astrophysical targets (e.g. 3500K star, J=9)
- Full time-series modeling, capable of modeling any astrophysical spectral time-series (e.g. transits, spots, transmission spectra)
- Expected noise from dark, bias, read noise, sky background, thermal background
- Correct read out schemes (i.e. NIRDA read up the ramp, fowler sampling)
- Appropriate frame rates for VISDA (0.2s) and NIRDA (0.34s)
- Expectations of jitter and drift over time, given expected pointing stability.
- Expected distortions of the PSF as a function of space, wavelength, and temperature.

Further work will be undertaken to include effects such as non-linearity, saturation, as-measured flat fields, etc.

credit: Christina Hedges