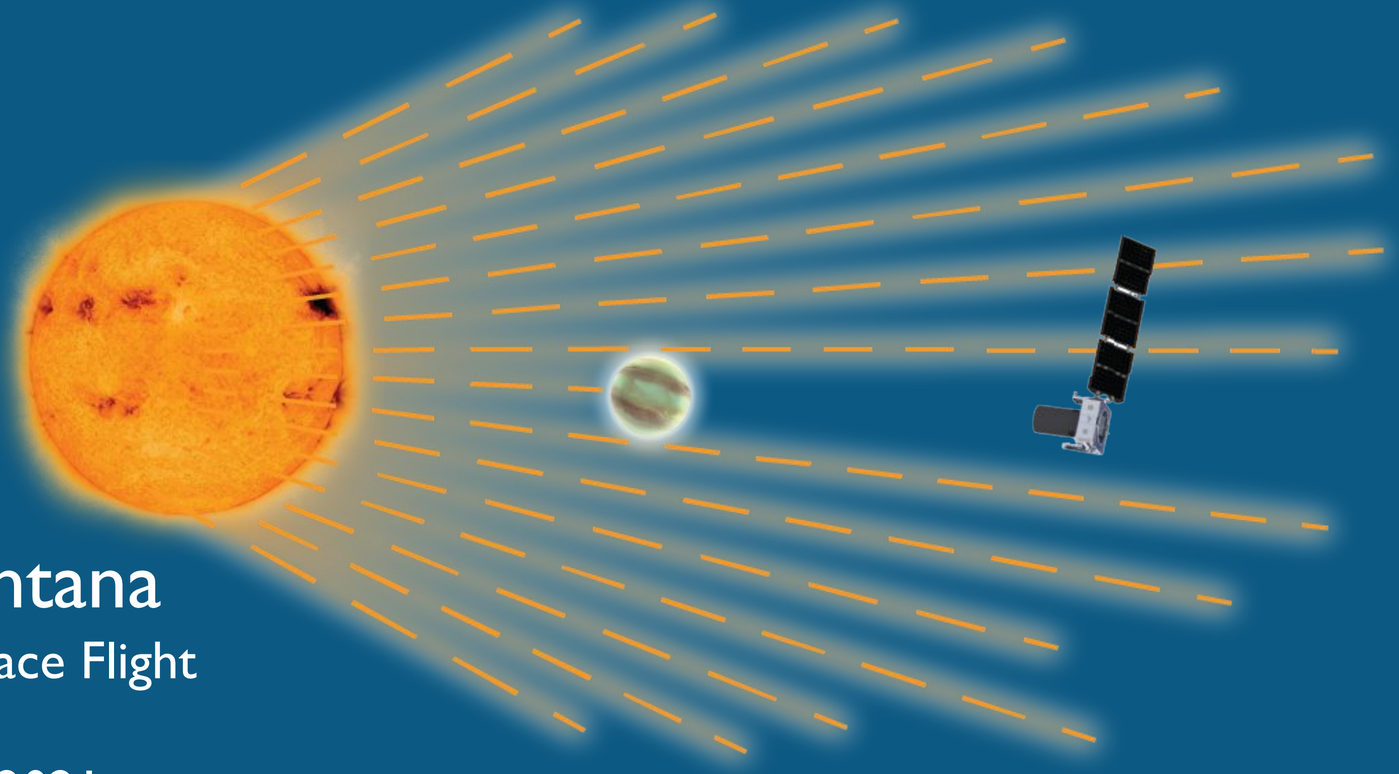
Pandora

Multiwavelength Characterization of Exoplanets and their Host Stars



PI Elisa Quintana

NASA Goddard Space Flight Center

APAC Oct 15, 2021

NASA Goddard Space Flight Center

Lawrence Livermore National Laboratory

Ames Research Center

ipac

The University of Arizona

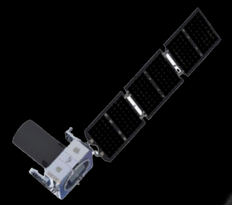
MIT

Exoplanets and the Search for Life

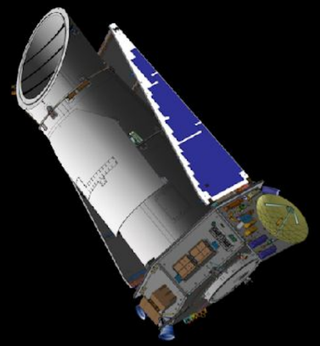
Exoplanet detection → demographics → characterization (compositions+atmospheres) → biosignatures

Hubble

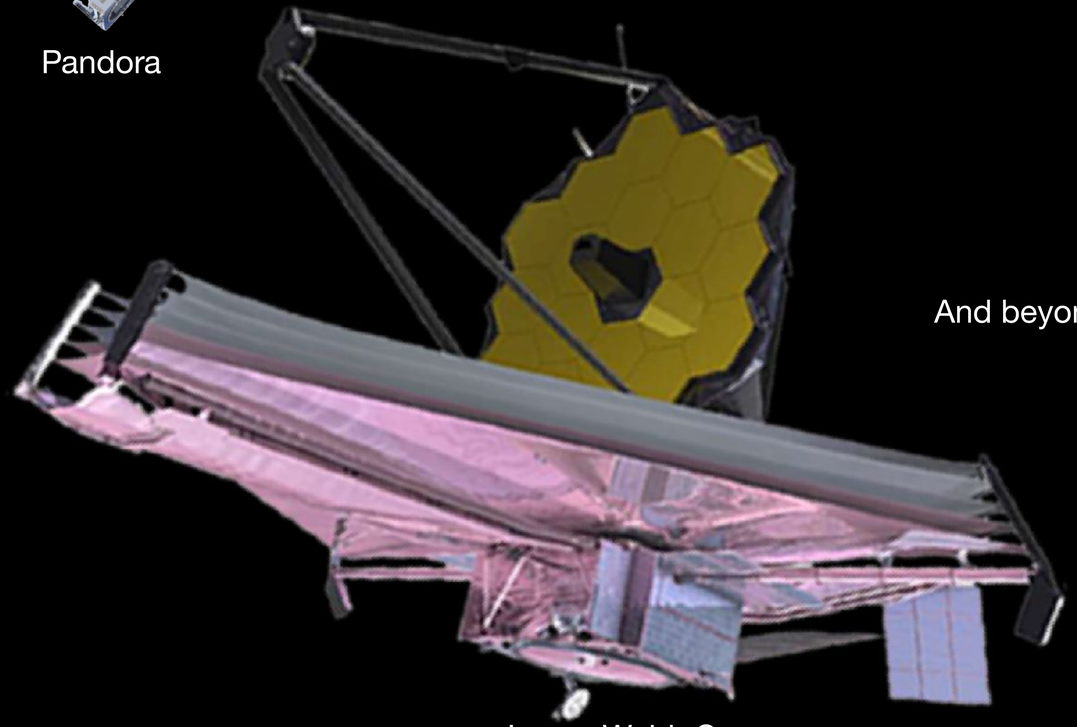
TESS



Pandora



Kepler



James Webb Space Telescope

And beyond…

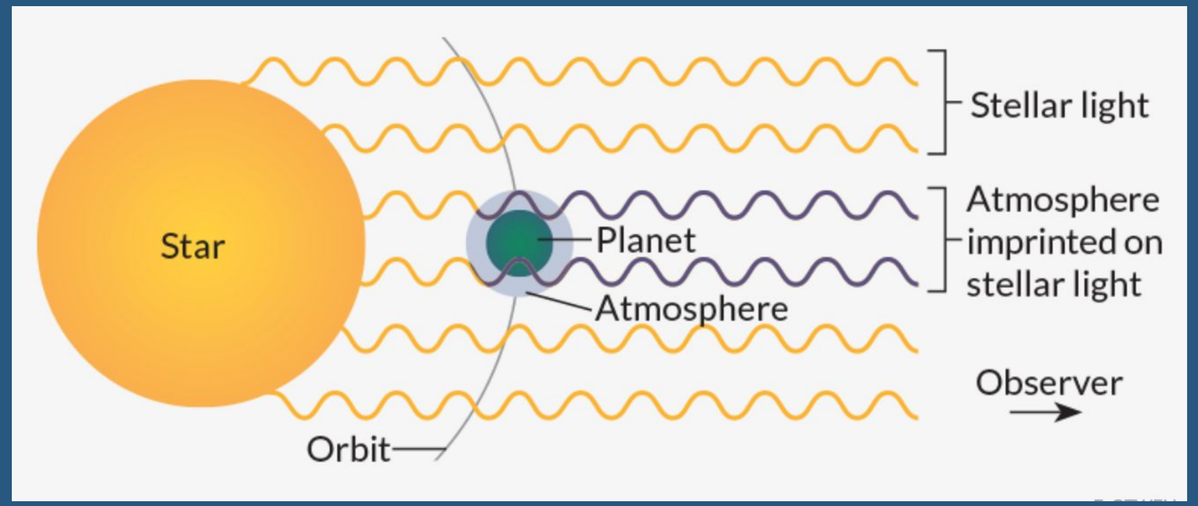
*Spacecraft not to scale

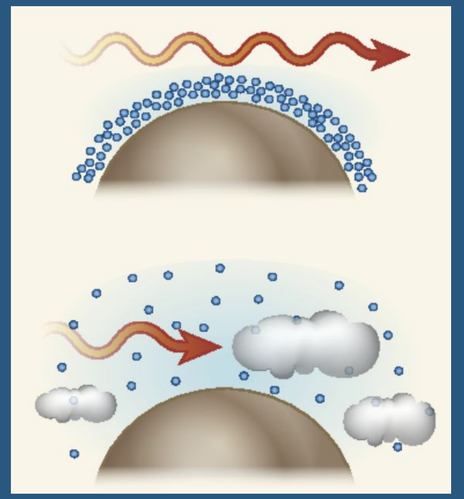
Why Pandora?

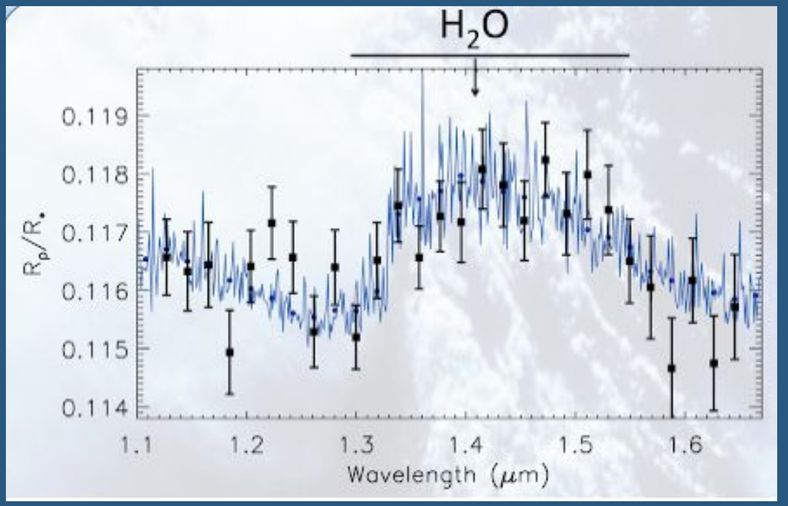
Pandora is a SmallSat mission that fills a gap in NASA's exoplanet roadmap.

Pandora's goal is to disentangle star and planet signals in exoplanet transmission spectra to reliably determine exoplanet atmosphere compositions.

Exoplanet transmission spectroscopy is a proven technique used to probe the atmospheres of transiting exoplanets and reveal their compositions (Seager & Sasselov 2000)

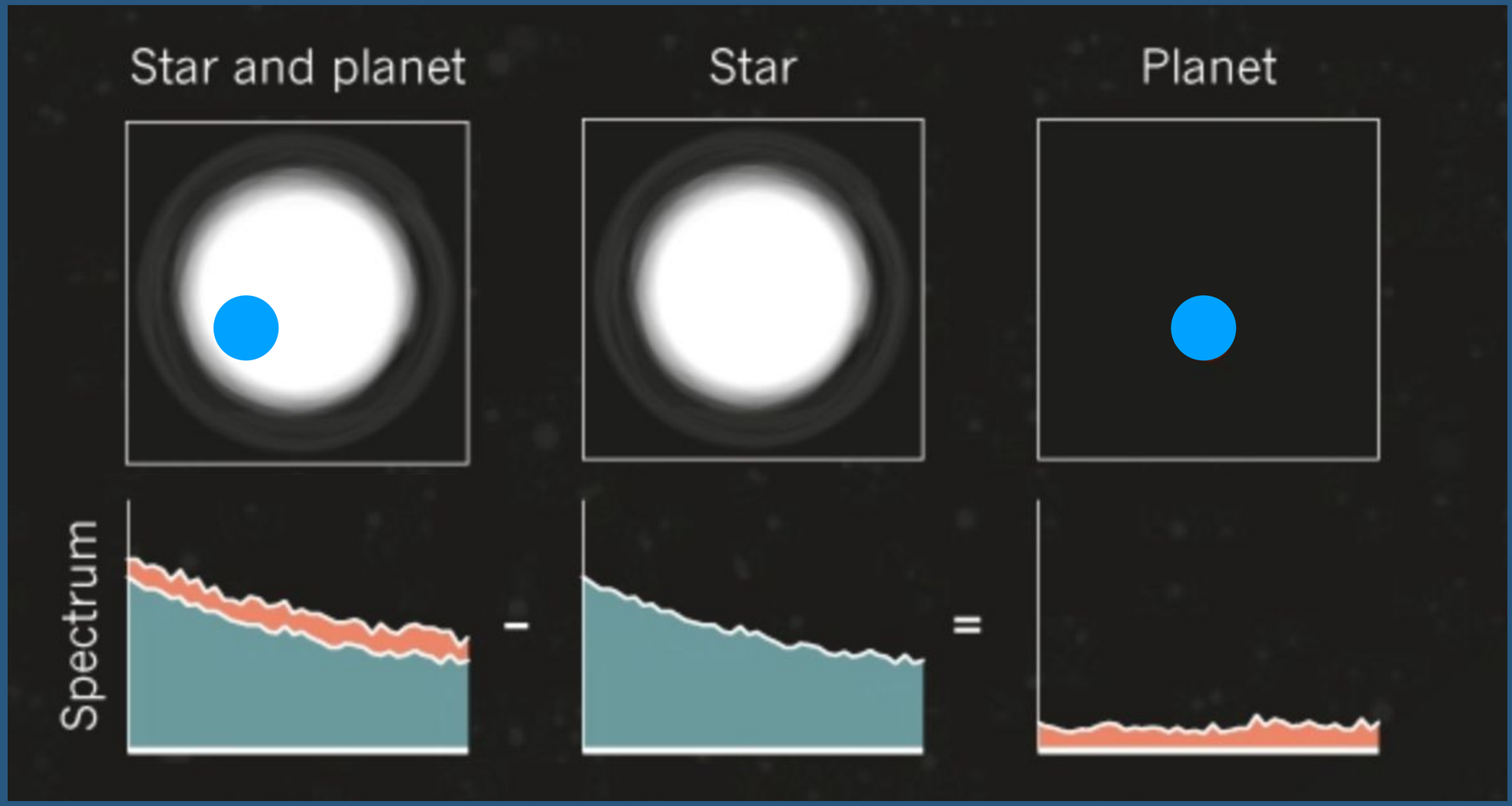






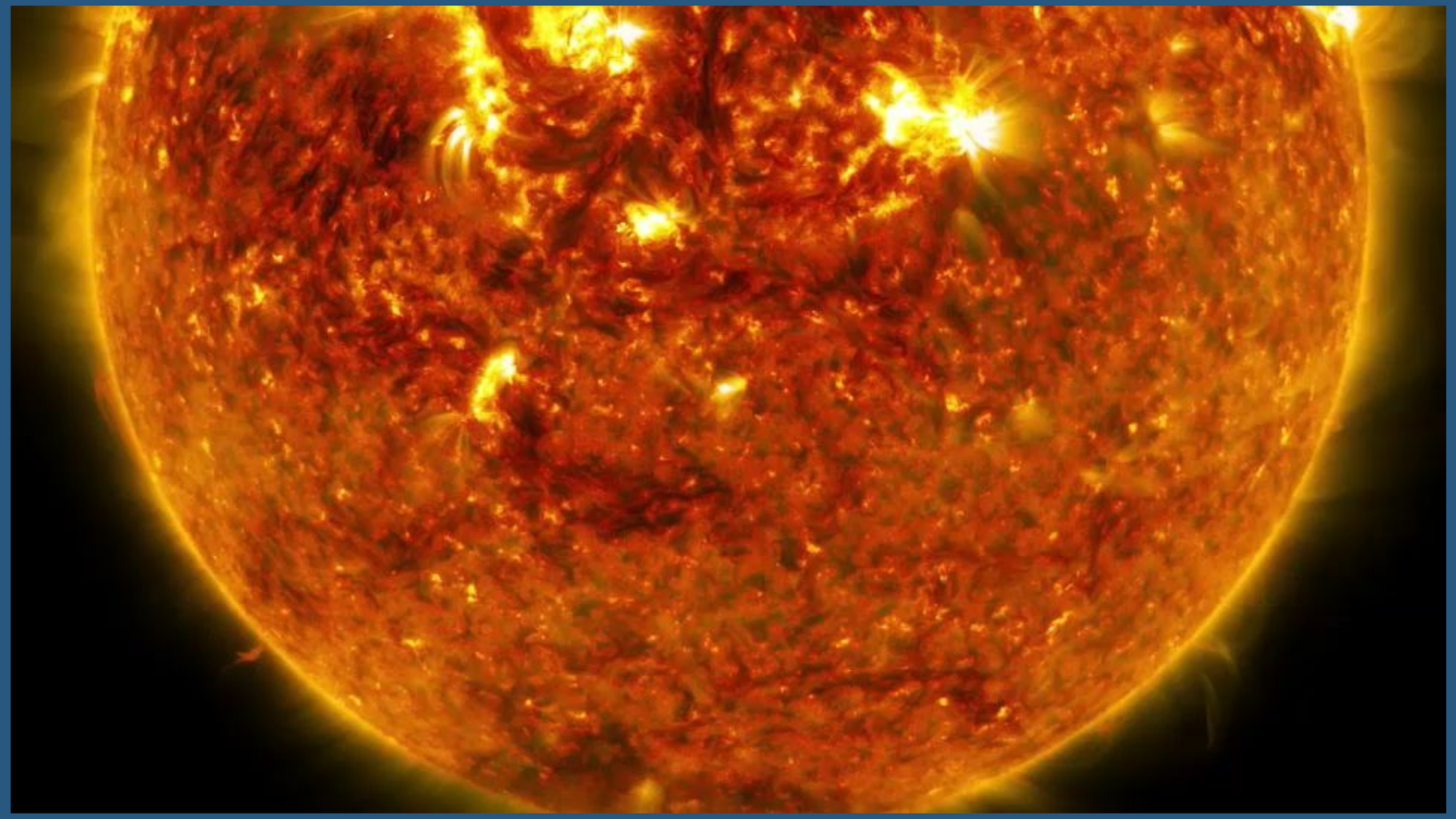
Exoplanet Transmission Spectroscopy

A differential measurement that assumes the star's spectrum is known and isn't changing, and can simply be subtracted from the observed (=star+planet) spectra



The Myth of a Perfect Star

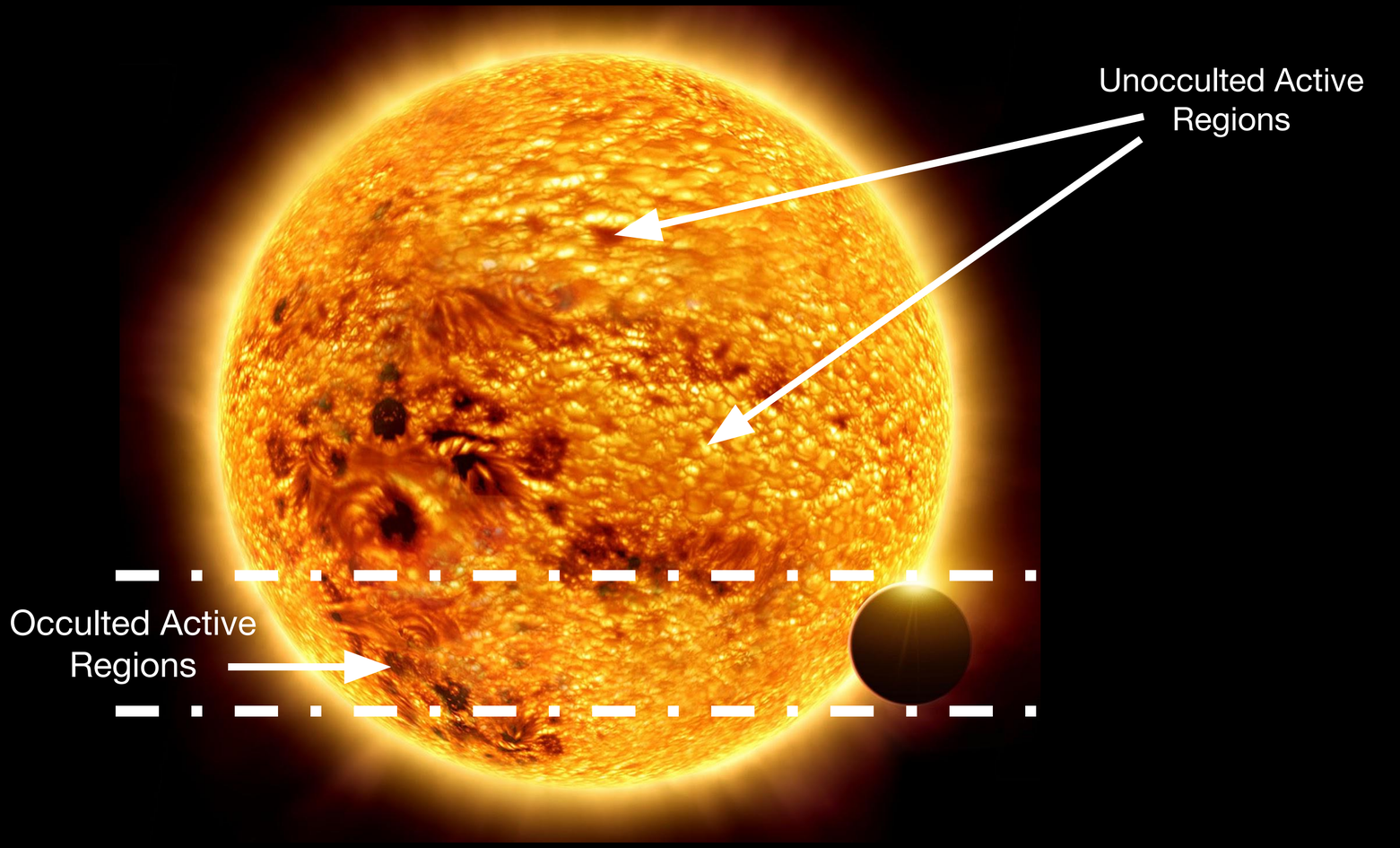
In reality, most stars are active, with dark spots and bright faculae regions that evolve spatially and with time (stellar rotation)



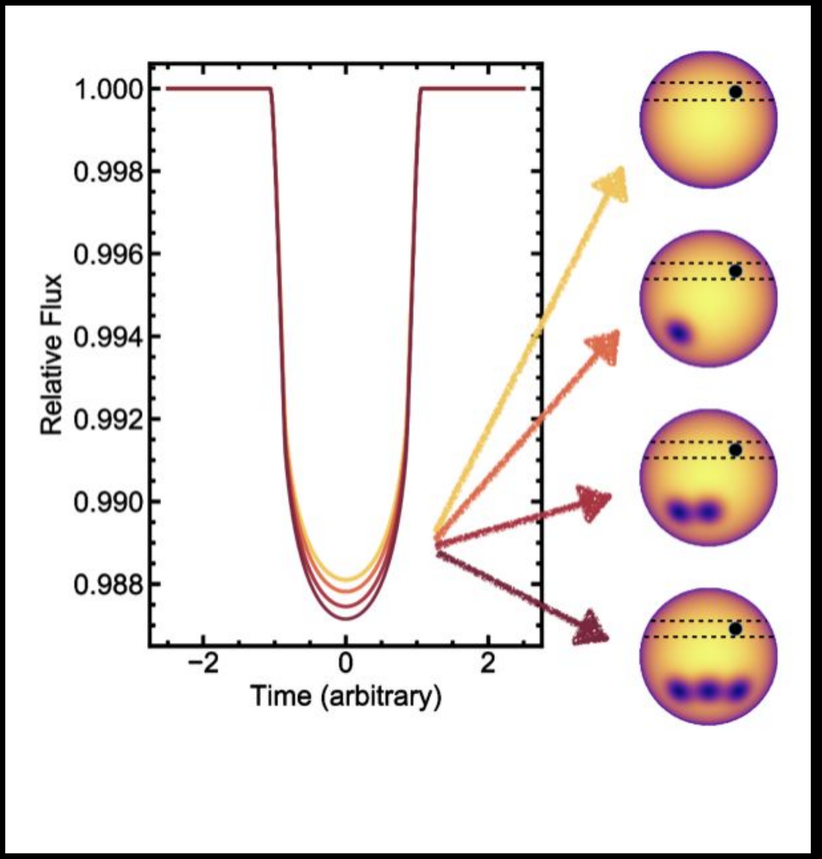
These brightness variations can be imprinted in the observed spectrum and can contaminate the inferred planetary spectra.

See D. Apai's description at https://distantearths.com/transit_lightsource_effect/

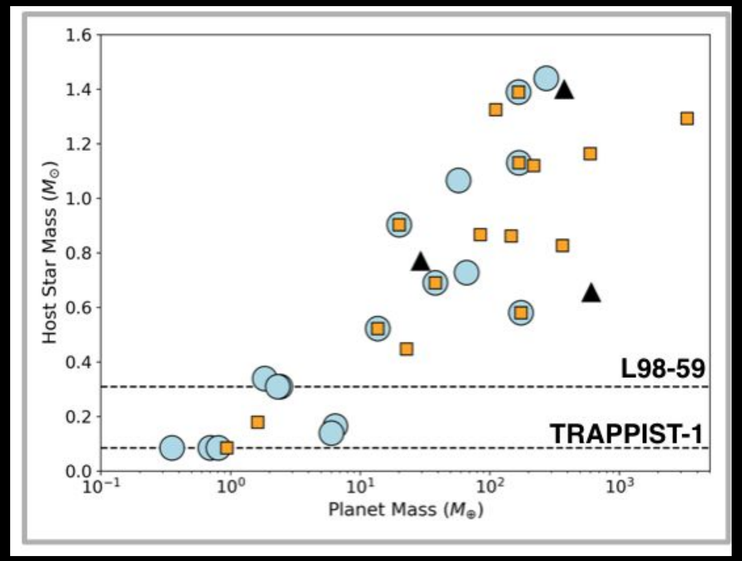
Spot-induced spectroscopic variations can mask or mimic planetary atmospheric features (like the presence and abundance of water!)



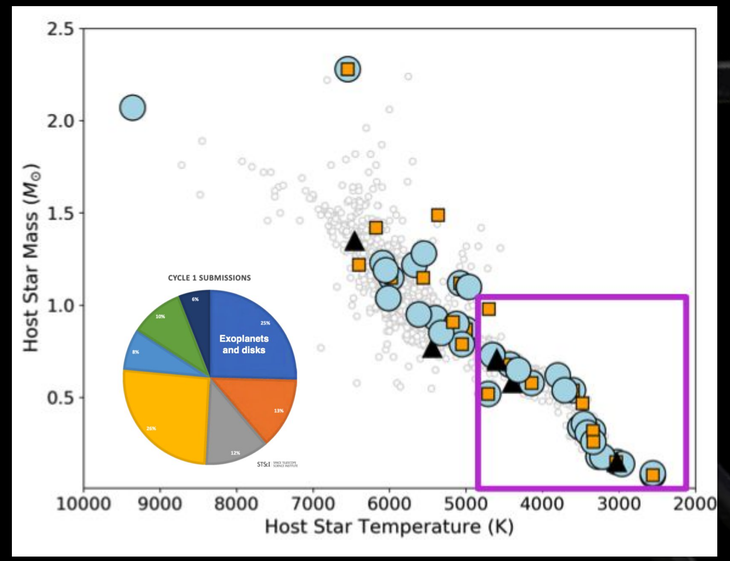
Transit Light Source Effect (Rackham 2018)



Exoplanet Transit Spectroscopy is a primary science case for JWST



30 transiting exoplanets
in JWST GTO+ERS programs



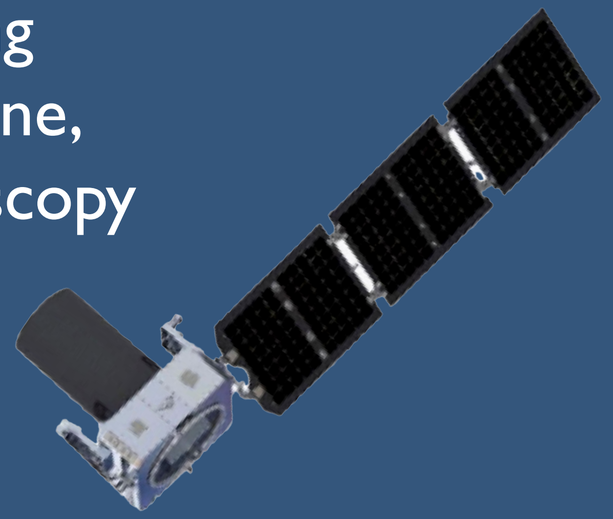
38 added for JWST GO Cycle 1

Correcting for starspots is most important for smaller planets (smaller signals), and smaller stars (highly active), i.e. those that JWST will observe

image: NASA

Pandora

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



Goal:

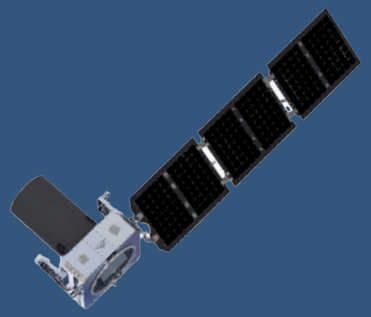
Disentangle star and planet signals in transmission spectroscopy to reliably determine exoplanet atmosphere compositions.

Unique capabilities:

Long duration baseline - observe 24 hours per transit [10 transits per planet]

Simultaneous visible photometry and NIR spectroscopy

Pandora



Objective I:

Determine the spot and faculae covering fractions of low-mass exoplanet host stars 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)?

Objective II:

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?

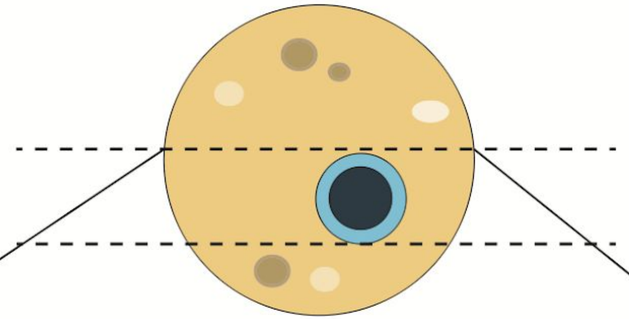
IIb. Which prior transmission spectroscopy observations yield the same atmospheric results after correcting for stellar contamination?

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?

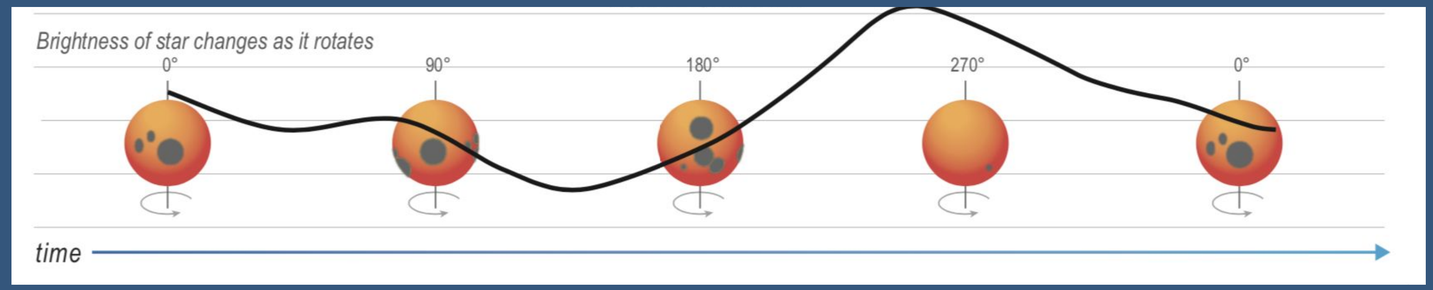
Pandora will produce the first long-duration dataset with simultaneous visible photometry and IR spectroscopy of exoplanets and their host stars.

Why Now?

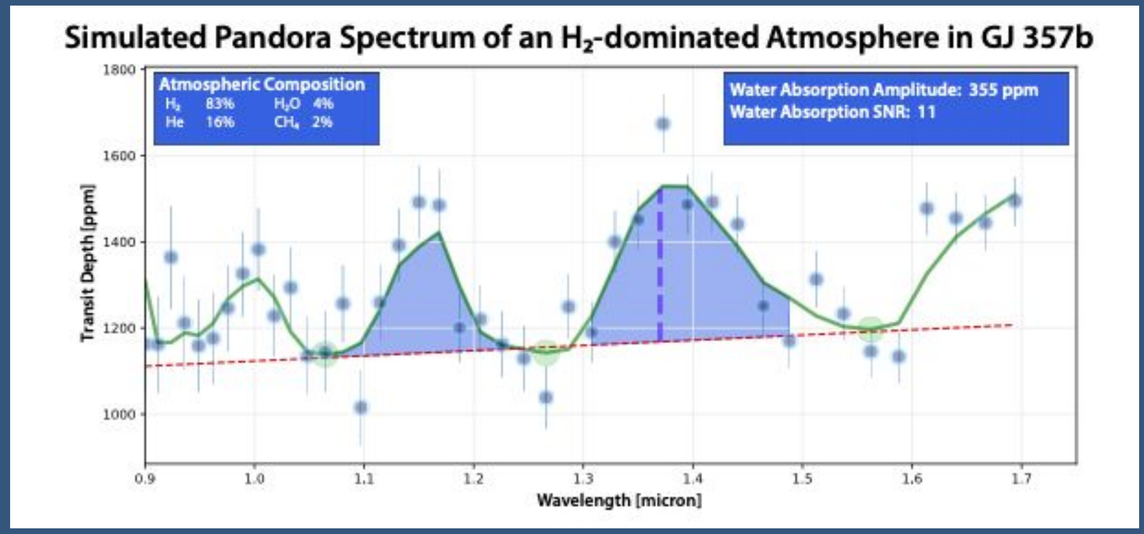
Pandora will inform JWST exoplanet transmission spectroscopy analyses, and operate concurrently with JWST.

Pandora's Observing Strategy

Visible photometry captures stellar brightness over time



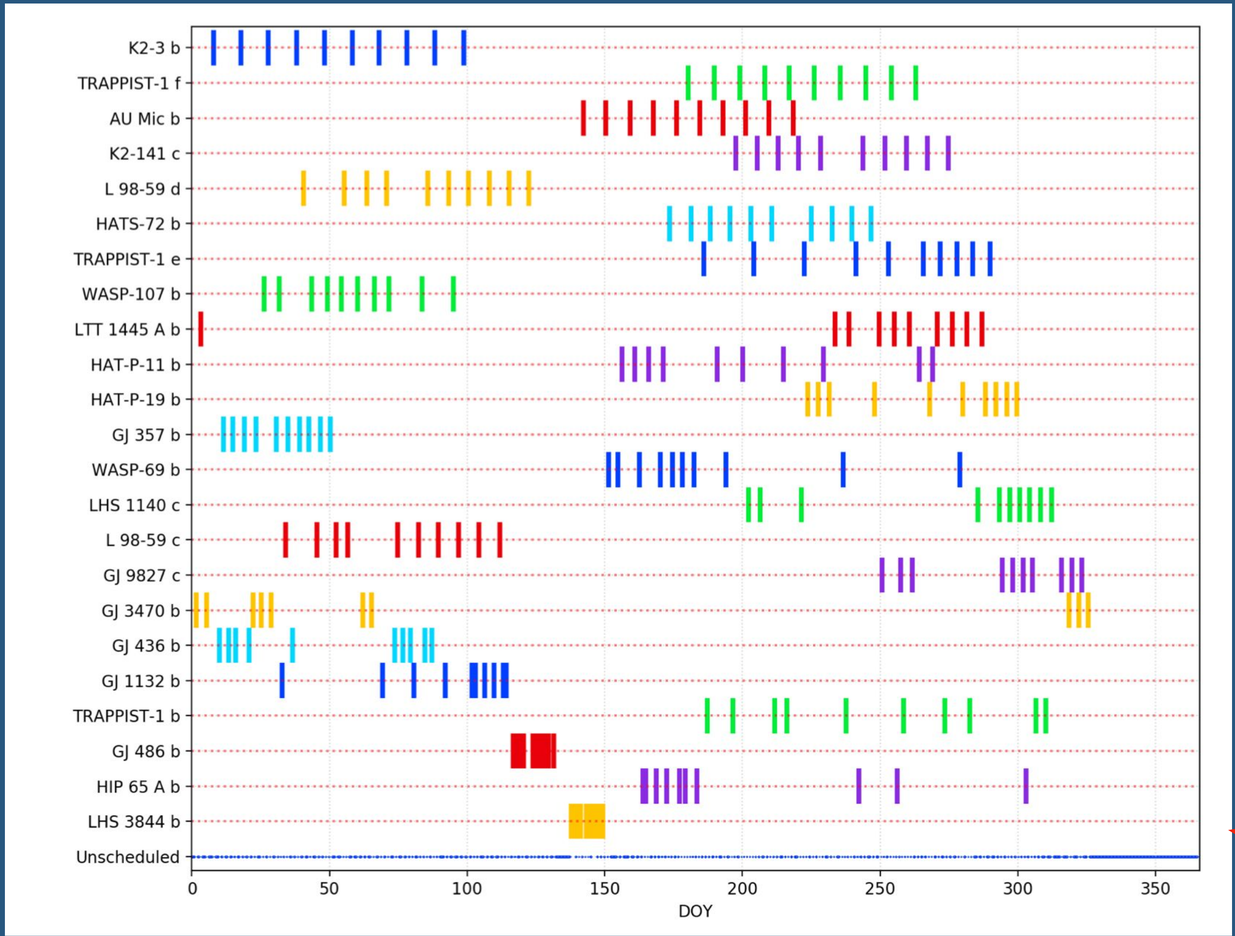
Simultaneous IR spectroscopy captures variations in spectra over time



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

Pandora's Notional Year of Operations

20 Pandora target stars (with 23 planets) shown below. Tick marks are planned transit observations for a notional year of science operations



Target Selection Trade Study:

- developed instrument simulators
- science team applied independent star and exoplanet atmosphere joint retrieval models
- signal-to-noise input into requirements
- software developed for "year in the life" of operations

135 days of unscheduled time available for schedule margin and auxiliary (bonus) science

Partnership with LLNL

Lawrence Livermore National Lab is co-leading and managing the Pandora mission.

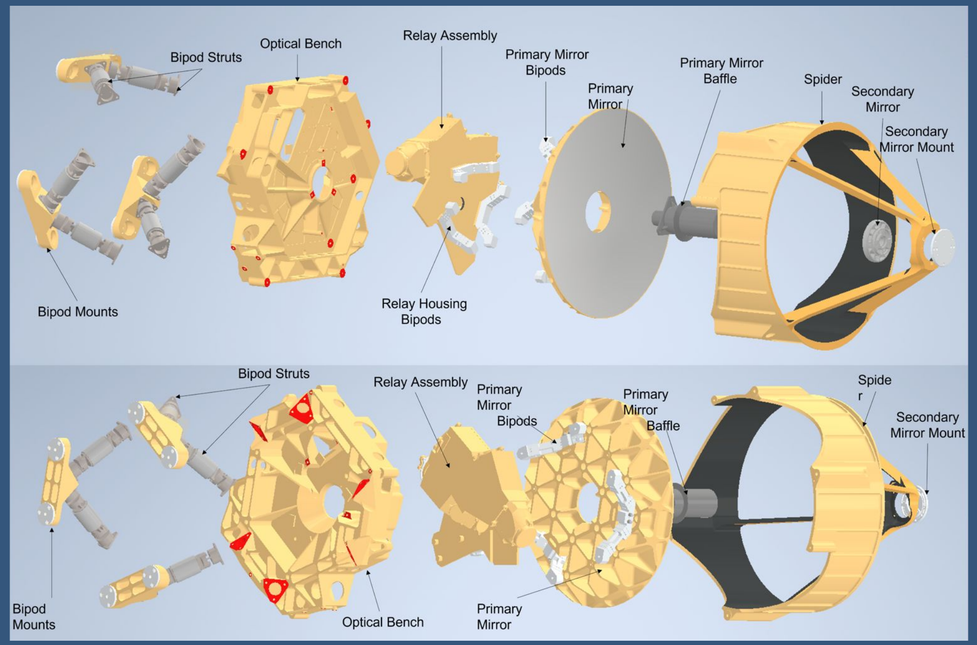
LLNL is responsible for the design and development of the payload

Pandora leverages technology investments from LLNL, including “CODA” telescope

Lawrence Livermore National Laboratory

Pandora Instrument Overview

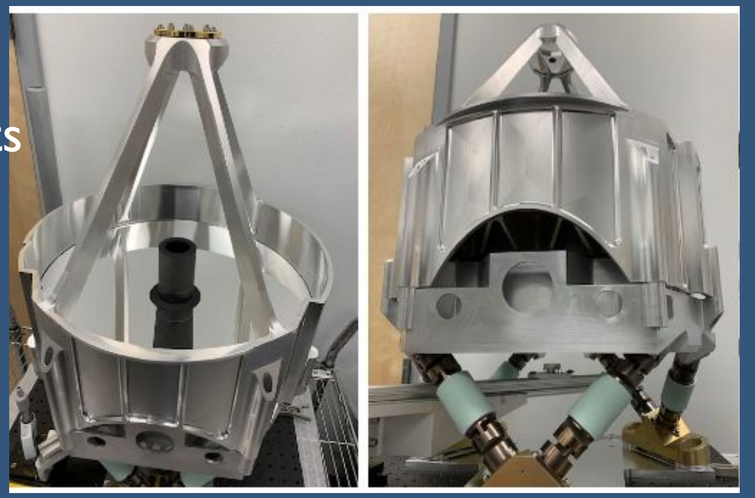
Pandora's single instrument: an all aluminum 0.45m relayed Cassegrain telescope "CODA"



LLNL's CODA Program Goal: Produce an inexpensive telescope that could be produced in large quantities for ESPA Grande class missions with minimal NRE

Features

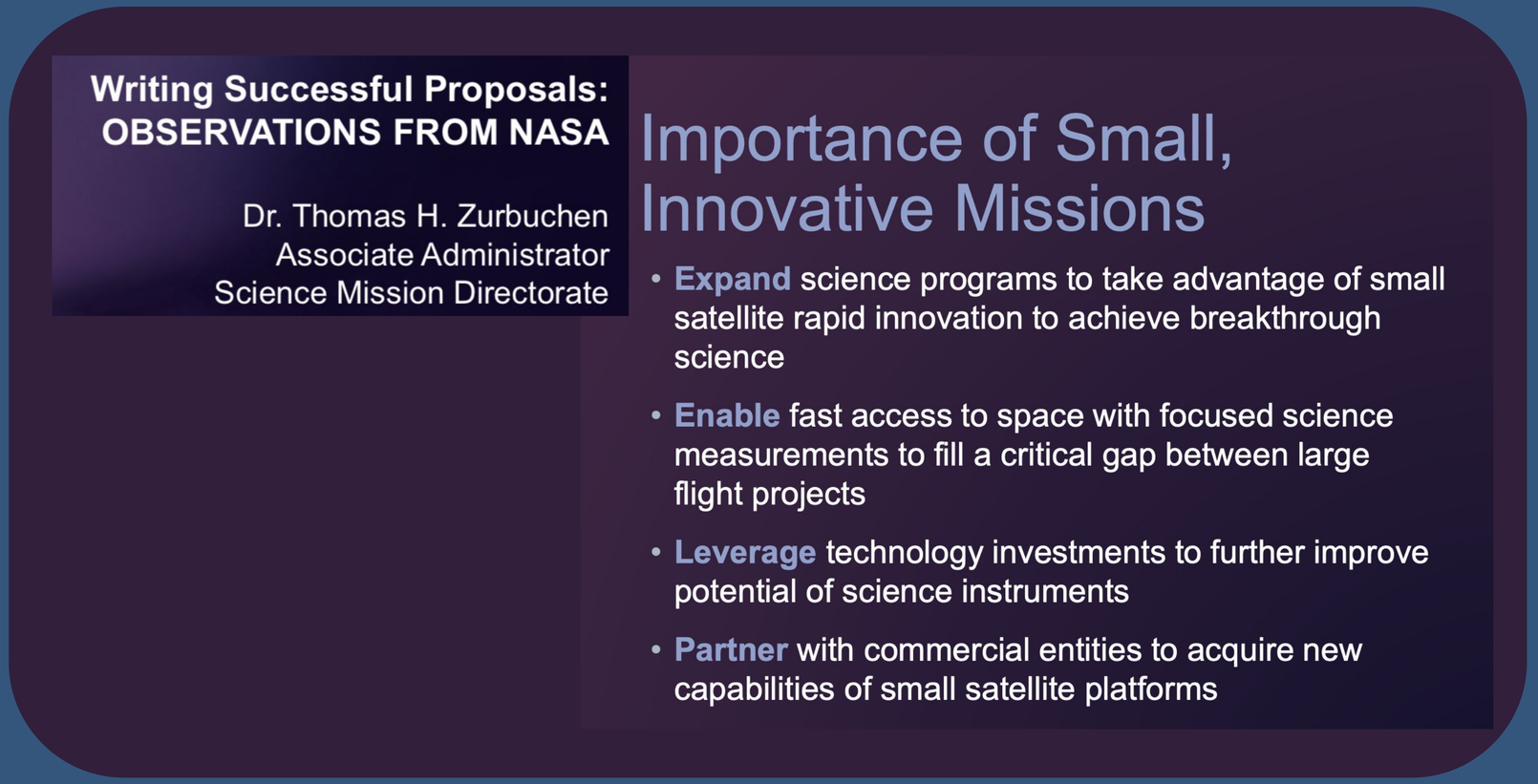
- Fabricated from readily available 6061 Aluminum
- Bulk materials allow for multiple sets of mirror to be produced quickly
- Flexible relay design allows for wide variety of detectors to be hosted
- Utilizes existing state of the art processes and coatings for optical elements



Optical relay assembly contains dispersion prism and dichroic, separates visible and NIR channels

- Visible Detector: Fairchild CIS2521
- NIR Detector: Teledyne H2RG

Leveraging Investments from Government and Commercial Entities

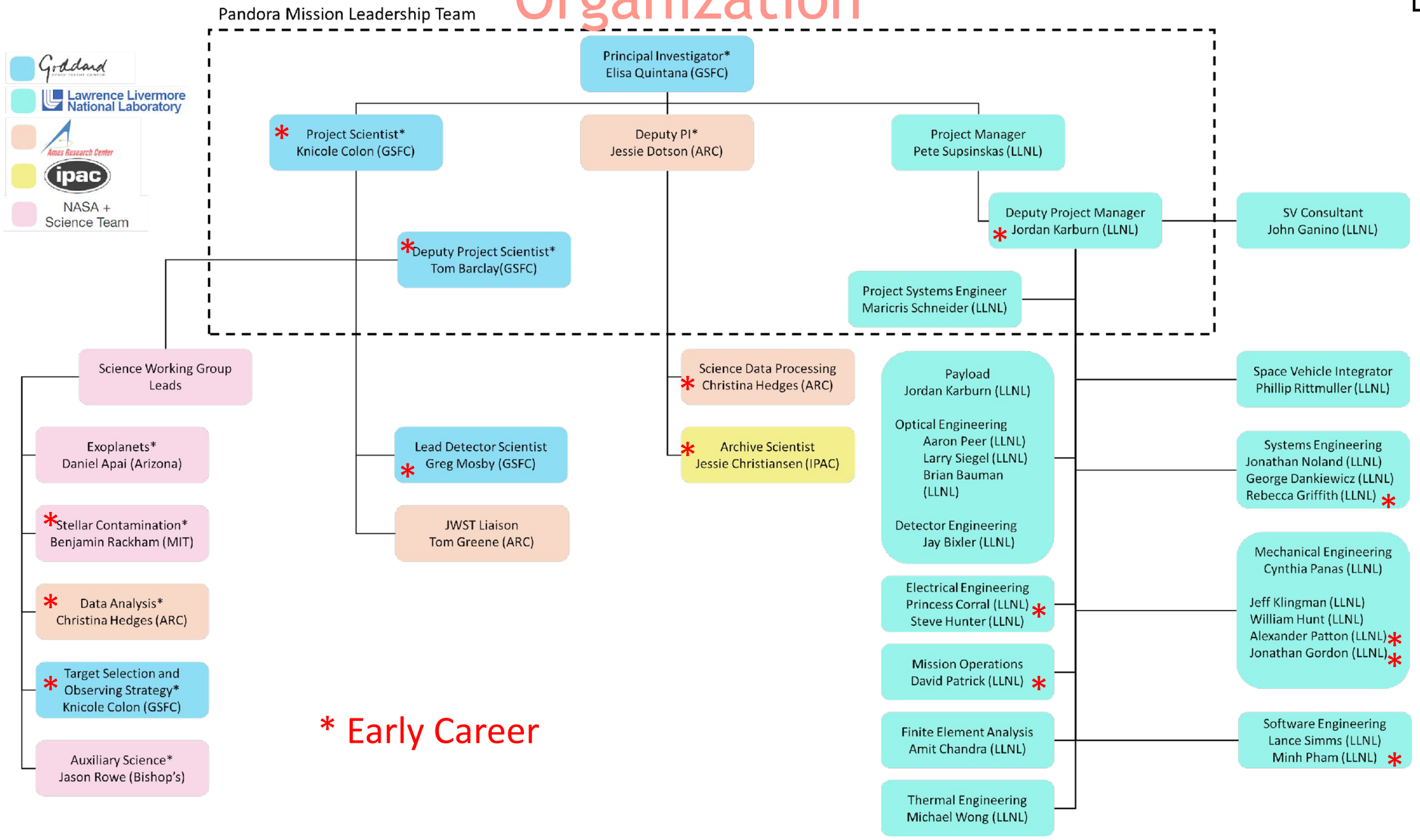


Pandora has partnered with LLNL, and thereby benefits from investments made by other gov agency programs

Pandora acquired donated JWST NIRCAM flight qualified spare (2.5 micron) detectors and SIDECAR

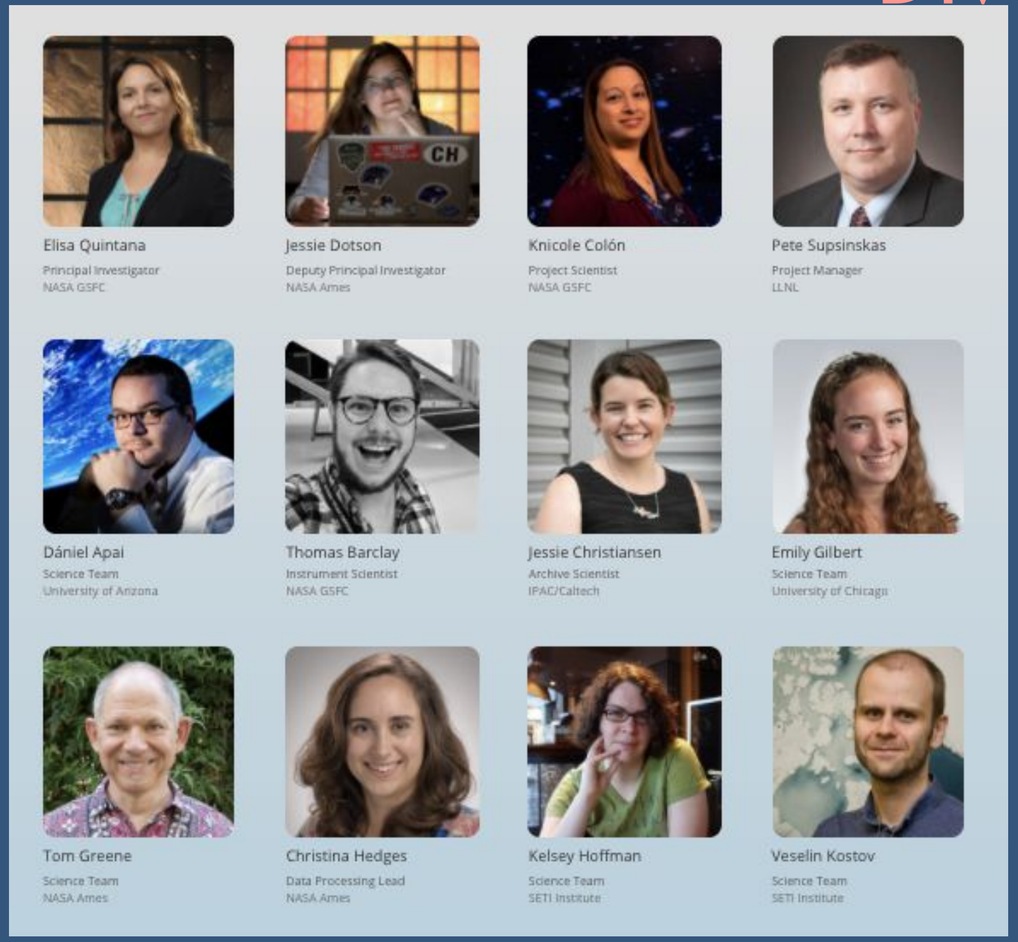
Pandora has partnered with commercial entities for spacecraft bus

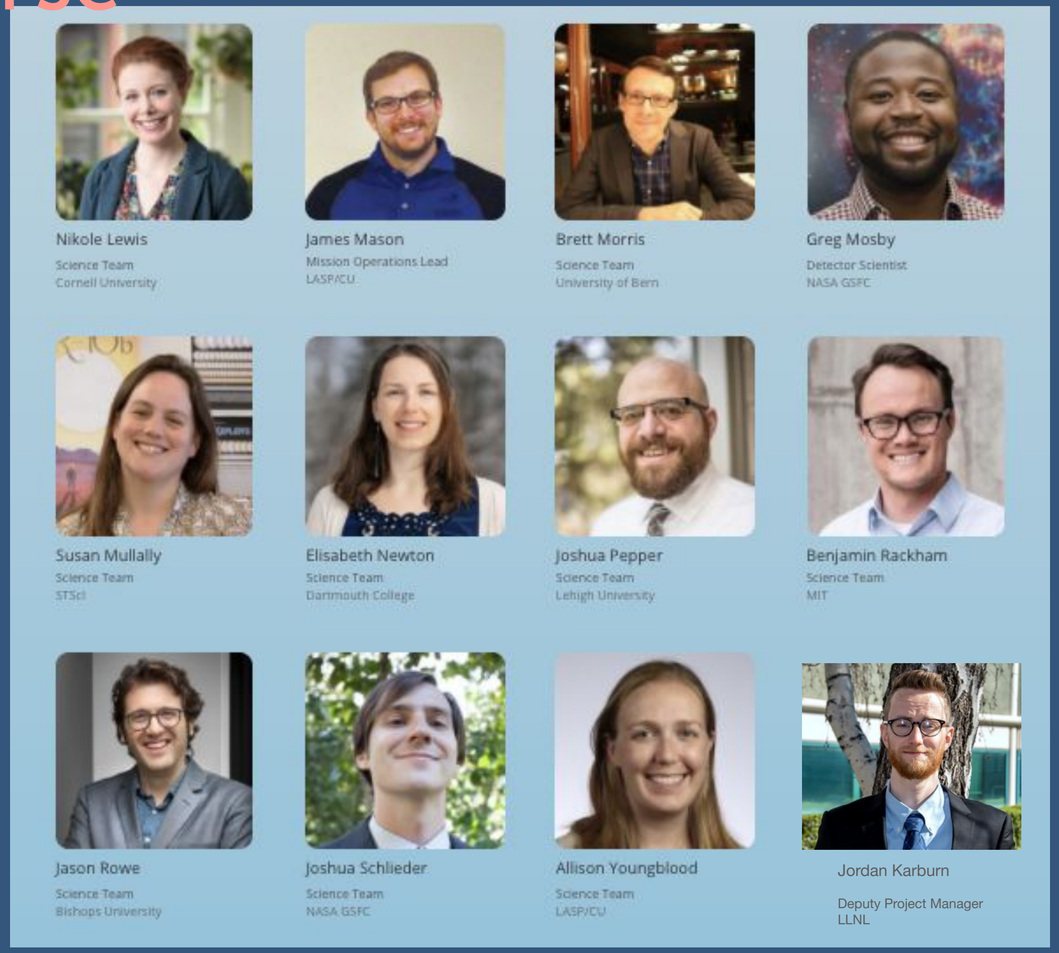
Pandora Team Organization



* Early Career

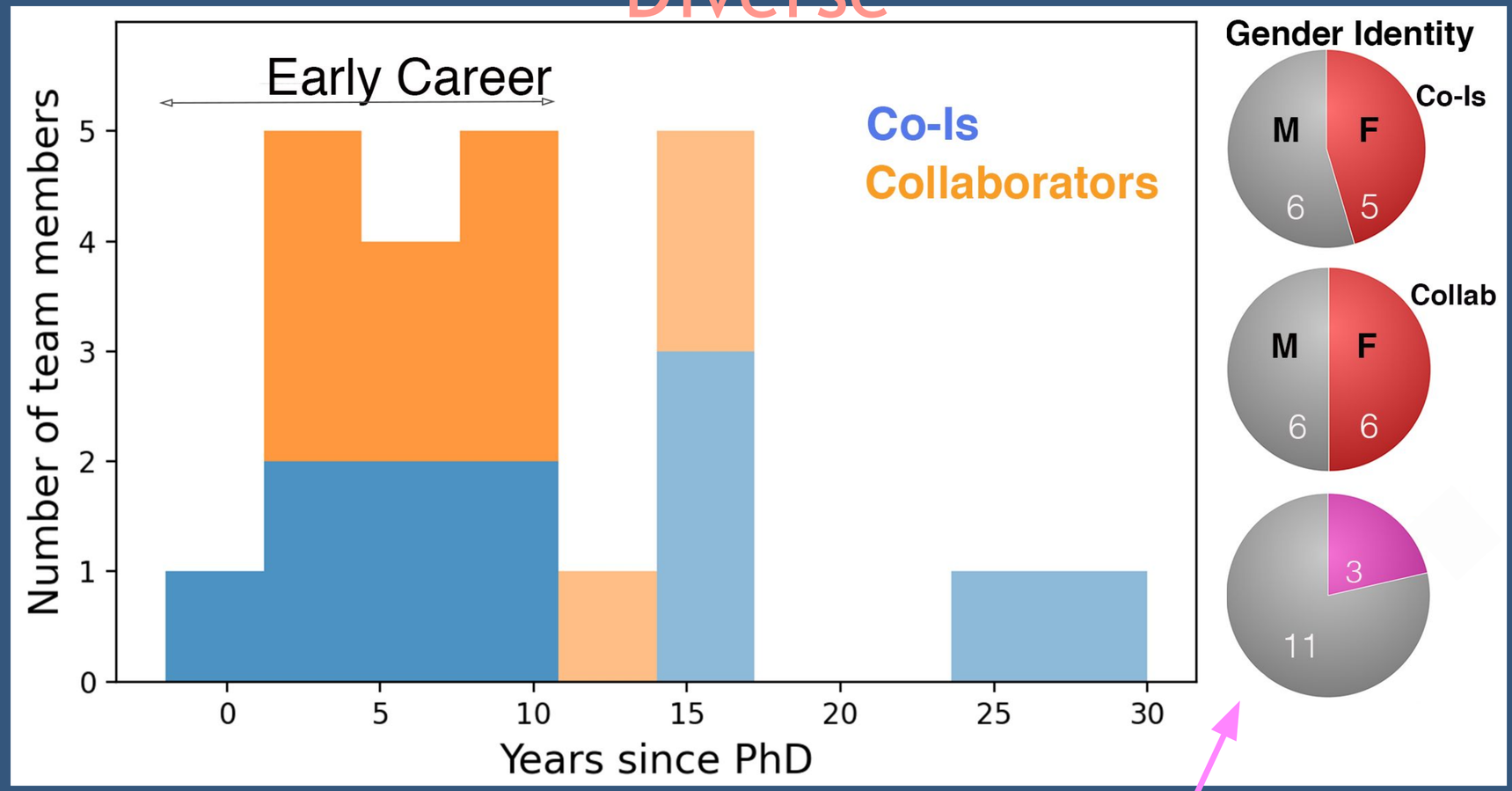
The Pandora Team is Diverse





- Shown above are mission leadership and science team
- Early Career Team Members in over half of science team roles (12 EC doctorates, 2 grad students in shadow position); Engineering (LLNL) includes 7 EC and summer interns
- Mentoring model matches experienced team member with EC

The Pandora Team is Diverse

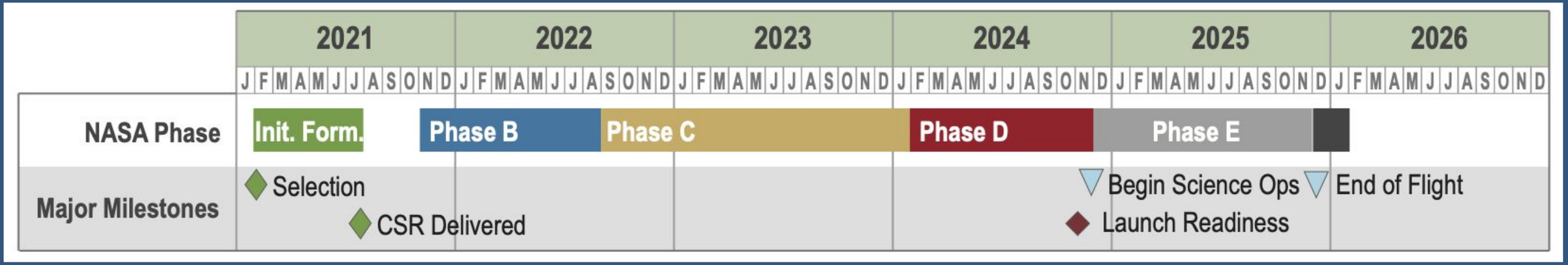


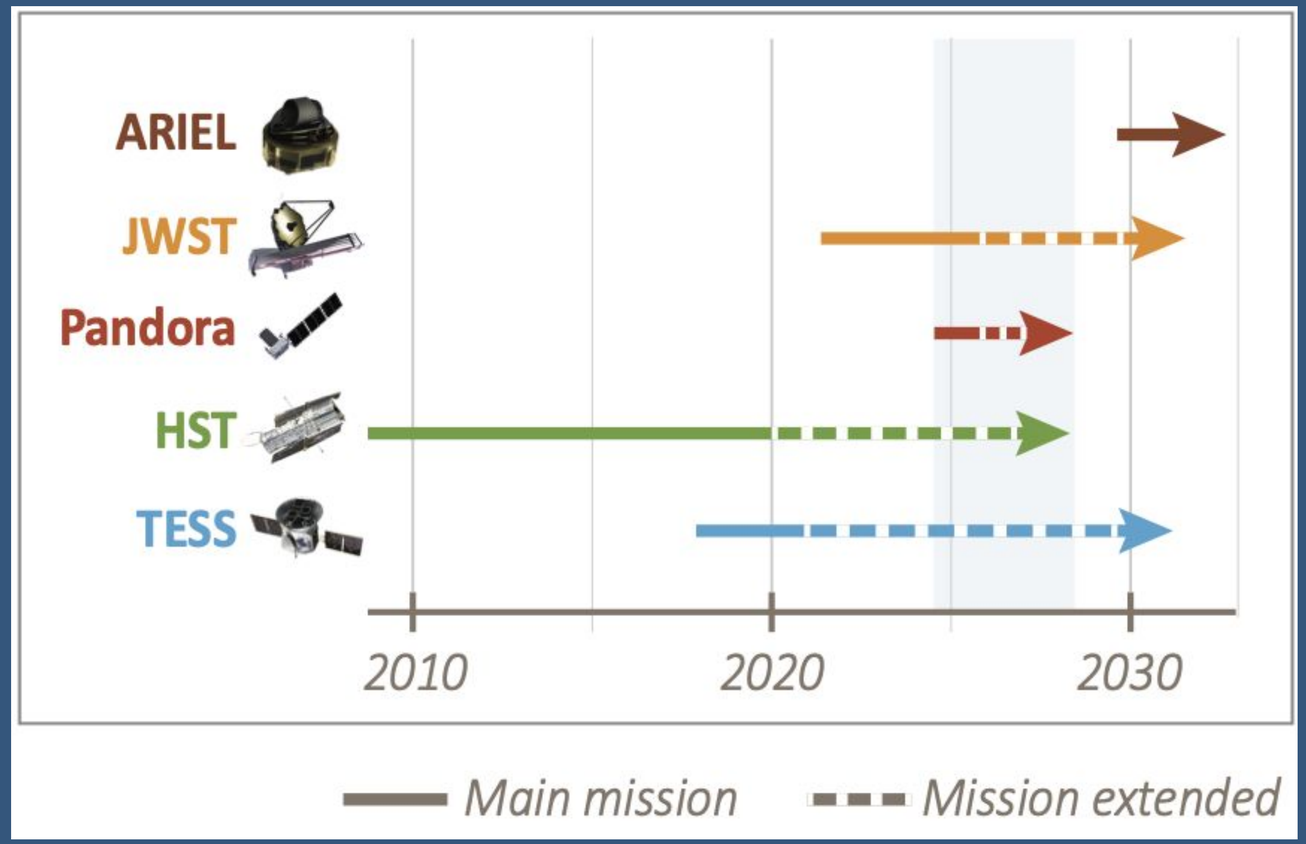
underrepresented minorities in leadership positions (PI, PS, Lead Detector Scientist)

Best practices already established:

- Team Code of Conduct
- Publication Plan
- Communications (internal/external)

Pandora Mission Timeline





Why now?

- Bounty of targets are being identified by TESS
- Pandora will be pathfinder for JWST, identifying benchmark targets & which are obscured by clouds
- Pandora will operate simultaneously with HST and JWST (Pandora provides complementary stellar characterization with long baseline)

Broad Community Support

Pandora addresses NASA's Key Goals and fills a gap in the ExEP's strategy plan

NASA's Astrophysics Themes
2010 NRC Decadal Survey: Science Frontier Discovery Area "Identification and characterization of nearby habitable exoplanets"
2014 NASA Science Plan: goal to "Discover and study planets around other stars and explore whether they could harbor life"
2018 NASA Strategic Plan: goal of "Searching for Life Elsewhere" by "Improving techniques and ideas for discovering and characterizing habitable and/or inhabited environments on these planets, coupled with an understanding of the potential false positives for habitability or life, will enable prioritization of exoplanets for targeted follow-up observations"
Exoplanet Exploration Program Office Science Gap List: (#SCI- 03) Spectral signature retrieval, "Early spectral detections have not withstood reanalysis"; "Systematic instrumental and stellar effects limit the ability to extract reliable spectra"; Capabilities needed: Ability to reliably extract physical parameters; calibration and mitigation studies like "studies on contamination of stellar photospheric heterogeneities as limitation to extraction of transiting planet spectra"
Exoplanet Science Strategy Plan from the National Academies: "An understanding of exoplanets is inextricably linked to an understanding of the stars they orbit. Moreover, the ability to detect planets and the precision with which researchers can determine their properties is often limited by knowledge of the star." "Heterogeneities on stellar photospheres are ubiquitous. At optical and infrared wavelengths, such regions of various temperatures, and thus differing local emission spectra, will corrupt the wavelength-dependent transit measurements of any planet", "These concerns also directly impact plans to search at infrared wavelengths for atmospheric biosignature gases in the atmospheres of HZ planets"

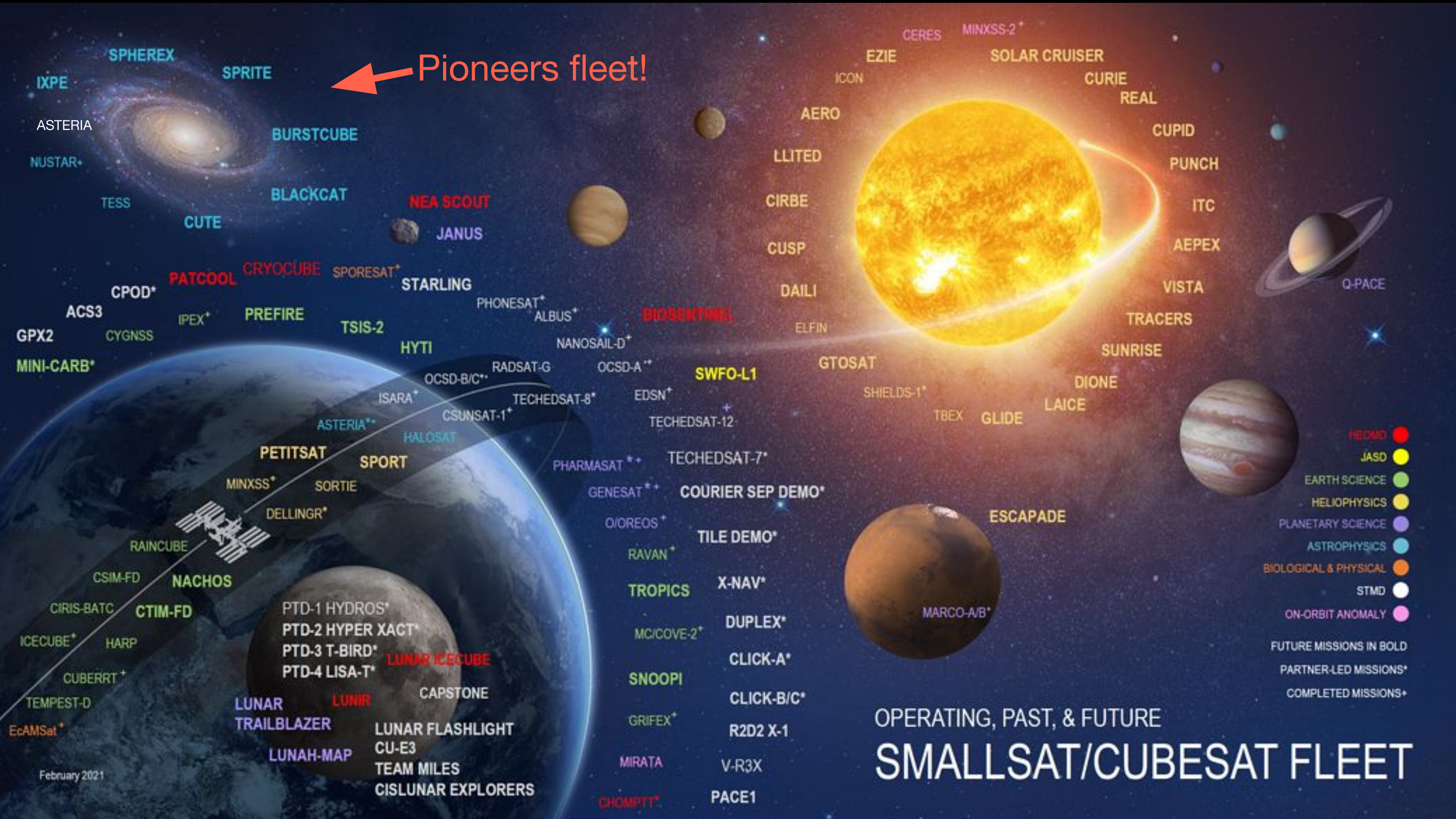
ExoPAG 21

The Effect of Stellar Contamination on Space-based Transmission Spectroscopy is the topic of Study Analysis Group (SAG) 21 of NASA's Exoplanet Exploration Program Analysis Group (ExoPAG).

Co-Chairs: Drs. Néstor Espinoza (STScI) and Benjamin Rackham (MIT)

Pandora Current Status

Feb 1, 2021	• Pioneers Selection • Pandora one of four selected projects • Funding for 6mo “Initial Formulation Phase”
Feb 1 - now	• Performed 8 trade studies • Developed L1-L2 Requirements • Write-up Concept Study Report (CSR) and Project Plan
Aug 2, 2021	• Submit Concept Study Report
Sept 7-8, 2021	• Gate Review: Systems Requirements Review & Site Visit (at LLNL)
★ NET Sept 30, 2021	• Gate Review Decision • No downselects of 4 Pioneers, but final approvals will be given


Pioneers fleet!
SPHEREX
SPRITE
IXPE
ASTERIA
BURSTCUBE
NUSTAR+
TESS
BLACKCAT
CUTE
NEA SCOUT
JANUS
PATCOOL
CRYOCUBE
SPORESAT+
CPOD*
STARLING
ACS3
IPEX+
PREFIRE
PHONESAT+
ALBUS+
BIOSENTINEL
GPX2
CYGNSS
TSIS-2
NANOSAIL-D+
HYTI
MINI-CARB*
OCSD-B/C*+
RADSAT-G
OCSD-A*+
SWFO-L1
ISARA+
EDSN+
TECHEDSAT-8*
ASTERIA*+
CSUNSAT-1+
TECHEDSAT-12
HALOSAT
PETITSAT
SPORT
PHARMASAT*+
TECHEDSAT-7*
MINXSS+
SORTIE
GENESAT*+
COURIER SEP DEMO*
DELLINGR*
O/OREOS+
RAINCUBE
TILE DEMO*
RAVAN+
CSIM-FD
NACHOS
TROPICS
X-NAV*
CIRIS-BATC
CTIM-FD
PTD-1 HYDROS*
PTD-2 HYPER XACT*
PTD-3 T-BIRD*
PTD-4 LISA-T*
MC/COVE-2+
DUPLEX*
ICECUBE+
HARP
LUNAR ICECUBE
CLICK-A*
SNOOPI
CUBERRT+
CAPSTONE
CLICK-B/C*
TEMPEST-D
LUNIR
LUNAR TRAILBLAZER
GRIFEX+
R2D2 X-1
EcAMSat+
LUNAR FLASHLIGHT
MIRATA
V-R3X
CU-E3
LUNAH-MAP
TEAM MILES
CHOMPTT*
PACE1
CISLUNAR EXPLORERS
February 2021
CERES
MINXSS-2+
EZIE
SOLAR CRUISER
ICON
CURIE
REAL
AERO
CUPID
LLITED
PUNCH
CIRBE
ITC
CUSP
AEPEX
DAILI
VISTA
Q-PACE
ELFIN
TRACERS
GTOSAT
SUNRISE
SHIELDS-1*
DIONE
TBEX
GLIDE
LAICE
ESCAPADE
MARCO-A/B*
HECMD
JASD
EARTH SCIENCE
HELIOPHYSICS
PLANETARY SCIENCE
ASTROPHYSICS
BIOLOGICAL & PHYSICAL
STMD
ON-ORBIT ANOMALY
FUTURE MISSIONS IN BOLD
PARTNER-LED MISSIONS*
COMPLETED MISSIONS+
OPERATING, PAST, & FUTURE
SMALLSAT/CUBESAT FLEET