STScI | SPACE TELESCOPE SCIENCE INSTITUTE

EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

The Exoplanet Characterization Toolkit

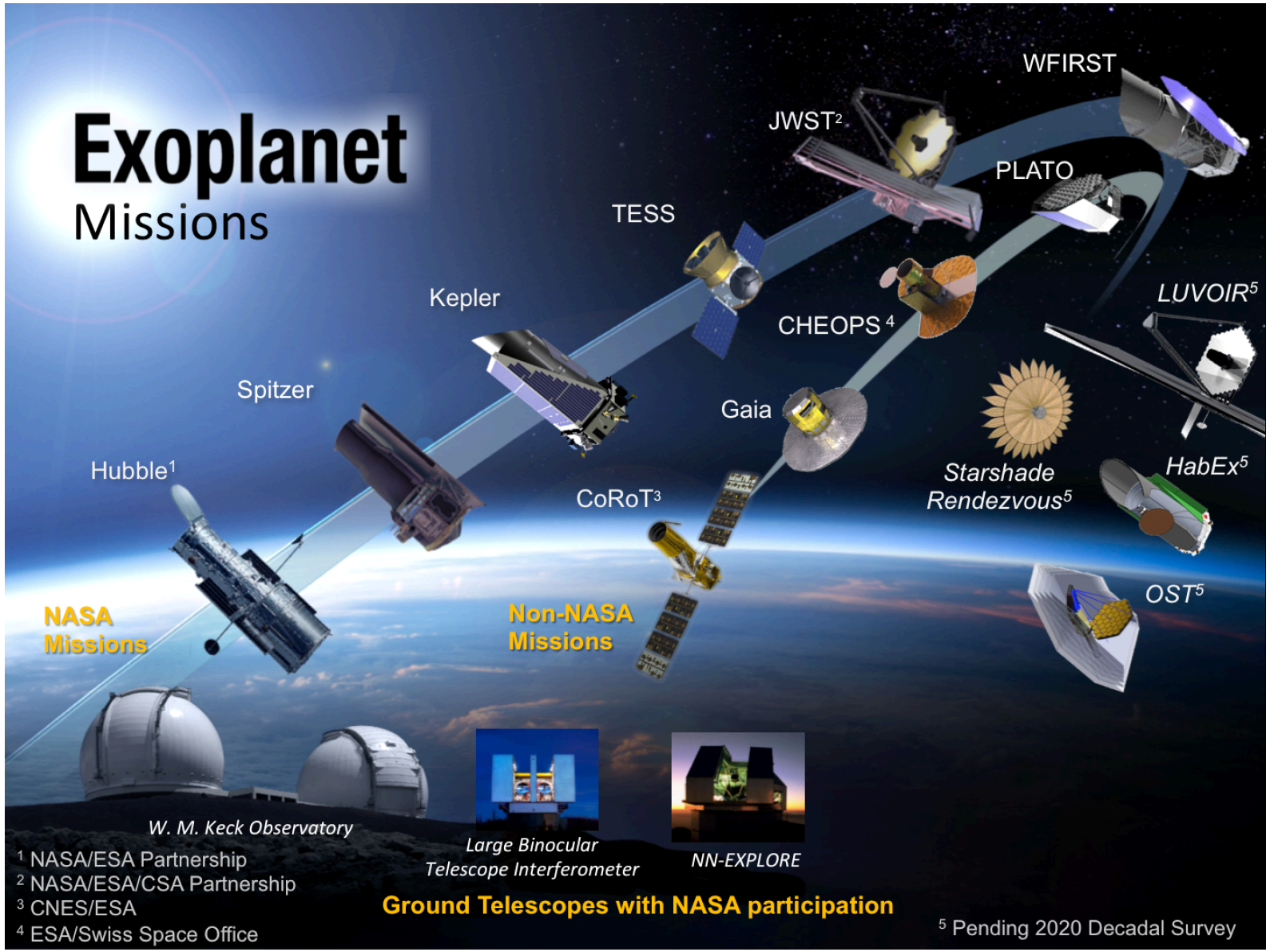
Presented By Kevin Stevenson
For the MAST Users Group

01/24/2018

What is ExoCTK?

The goal of ExoCTK is to provide the entire exoplanet community with a coherently packaged set of tools that enable the planning, execution, reduction, and interpretation of observations aimed at exoplanet atmospheric characterization.

Why ExoCTK?


Exoplanet
Missions
WFIRST
JWST[2]
PLATO
TESS
Kepler
CHEOPS[4]
LUVOIR[5]
Spitzer
Gaia
Hubble[1]
CoRoT[3]
Starshade
Rendezvous[5]
HabEx[5]
OST[5]
NASA
Missions
Non-NASA
Missions
W. M. Keck Observatory
Large Binocular
Telescope Interferometer
NN-EXPLORE
Ground Telescopes with NASA participation
[1] NASA/ESA Partnership
[2] NASA/ESA/CSA Partnership
[3] CNES/ESA
[4] ESA/Swiss Space Office
[5] Pending 2020 Decadal Survey

What's in ExoCTK?

- Transit light-curve fitting tools (TLC)
- Limb-darkening calculator (LDC)
- IFS exoplanet spectral extraction (IFS)
- Atmospheric forward models (AFM)
- Bayesian atmospheric retrieval (BAR)
- Planetary atmospheres libraries and tools (PAL)
- Transit Observation & Reduction Tools (TOR)

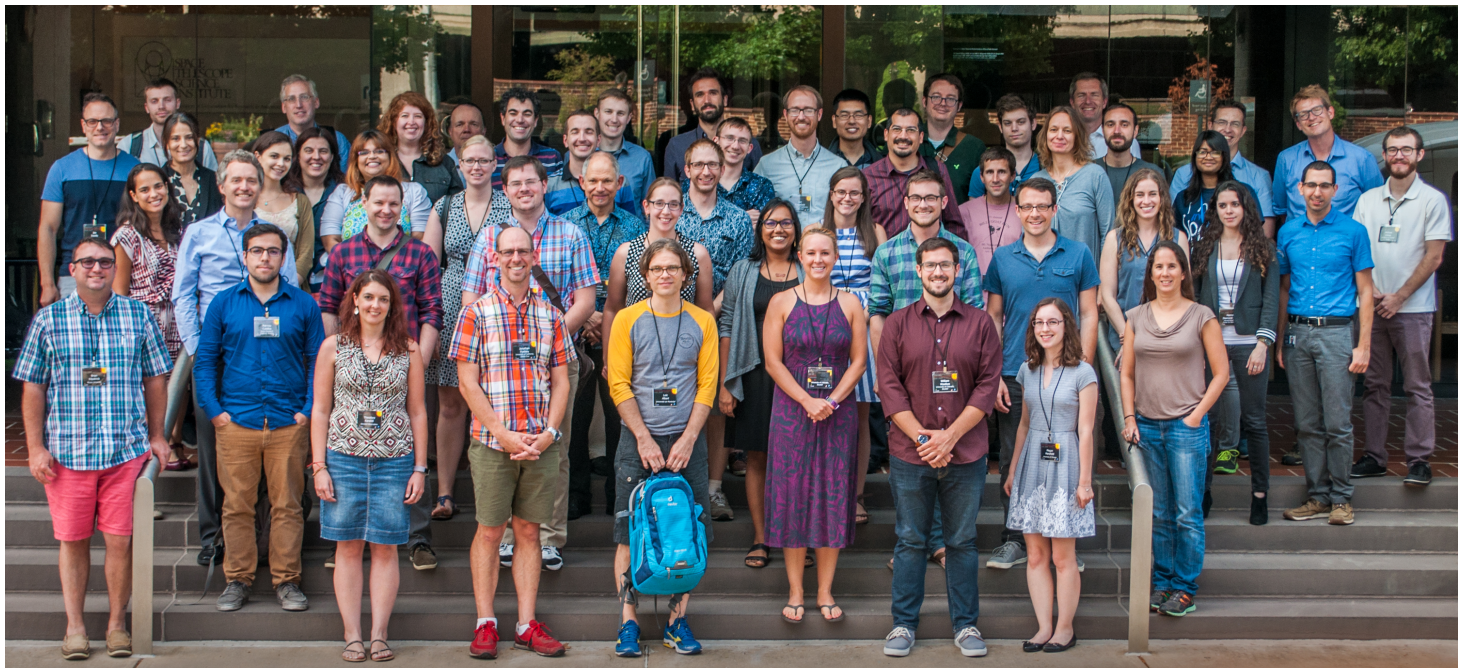
Who is ExoCTK?

Everyone!

- More than three-quarters of the code and data files currently in the ExoCTK repository have been contributed by individuals and groups outside of STScI, spanning several countries.

- ExoCTK has been presented to audiences at a variety of conferences and workshops and garnered enthusiastic support.

- Team at STScI consists of more than a dozen staff, postdocs, and students.



ExoCTK Team @ STScI

- Nikole Lewis (Co-PI)
- Kevin Stevenson (Co-PI, Project Manager)
- Jonathan Fraine (Deputy Project Manager)
- Natasha Batalha
- Giovanni Bruno
- Rafia Bushra
- Joe Filippazzo
- Jules Fowler
- Mike Fox
- Matt Hill
- Laurent Pueyo
- Abhi Rajan
- Jeff Valenti
- Hannah Wakeford

How does ExoCTK work?

- Leverages in house expertise in
  - Community software
  - Database maintenance
  - File formats

- ExoCTK uses I/O and file format requirements for inter-module compatibility
  - Incorporates a core module with common classes

- Automatically generates a Bibtex file with relevant citations
  - This is a requirement in our agreements with contributors

- Currently hosted using in-house computing resources
  - Will migrate to AWS, proposal for 1 year pilot program in preparation

How does ExoCTK work?

- All code is maintained on GitHub and is freely available
  - https://github.com/ExoCTK/ExoCTK

- Licensing restrictions
  - Use a standard 3-clause BSD license (unlimited redistribution, must reproduce copyright notice, cannot use name to endorse or promote other products)
  - Agreements reached with contributors is between STScI and that contributor

- Coding practices
  - Written in Python 3.5+
  - All code & documentation is required to be pep8 compliant (coding style)

When is ExoCTK?

- ExoCTK is maintaining an aggressive 2+ year schedule
- Ensure that the architecture and base modules are in place to facilitate sustainable growth and community contributions
- Will be ready in time to support JWST exoplanet observations
- ExoCTK is being leveraged to support goals of exoplanet DD ERS programs

Table 1. ExoCTK Milestones

Module	Jan-17	Apr-17	Jul-17	Oct-17	Jan-18	Apr-18	Jul-18	Oct-18
LDC	LDC-D1 LDC-D2	LDC-D3						LDC-D4
AFM				AFM-D1	AFM-D2	AFM-D3		
PAL		PAL-D4	PAL-D6	PAL-D5	PAL-D1	PAL-D2 PAL-D3		
TLC					TLC-D1		TLC-D2 TLC-D3	TLC-D4
BAR					BAR-D1 BAR-D2			BAR-D3
IFS	IFS-D1	IFS-D2		IFS-D3	IFS-D4		IFS-D5	IFS-D6 IFS-D7
TOR				TOR-D1 TOR-D2				
WEB			WEB-D1					

https://confluence.stsci.edu/display/ExoCTK/ExoCTK+Home

https://exoctk.stsci.edu

Live Demo!!!

Observation Planning

- Problem #1:
  - APT isn't set up to specify an observation with a given duration
  - Need to provide # of integrations (NINTS)
  - Determining the observation duration in APT is time consuming

- Problem #2:
  - Determining the number of groups (NGROUPS, up-the-ramp samples) without saturating the detector is non-trivial
  - Requires trial-and-error calculations with ETC
  - NIRISS/SOSS takes 2-3 minutes per calculation, time consuming

- Solution:
  - Given a specified observation duration and stellar magnitude, ExoCTK computes NINTS and NGROUPS for you (in a few seconds)

Observation Planning

Time-Series Observation & Reduction Tools

Input and Instrument Parameters:

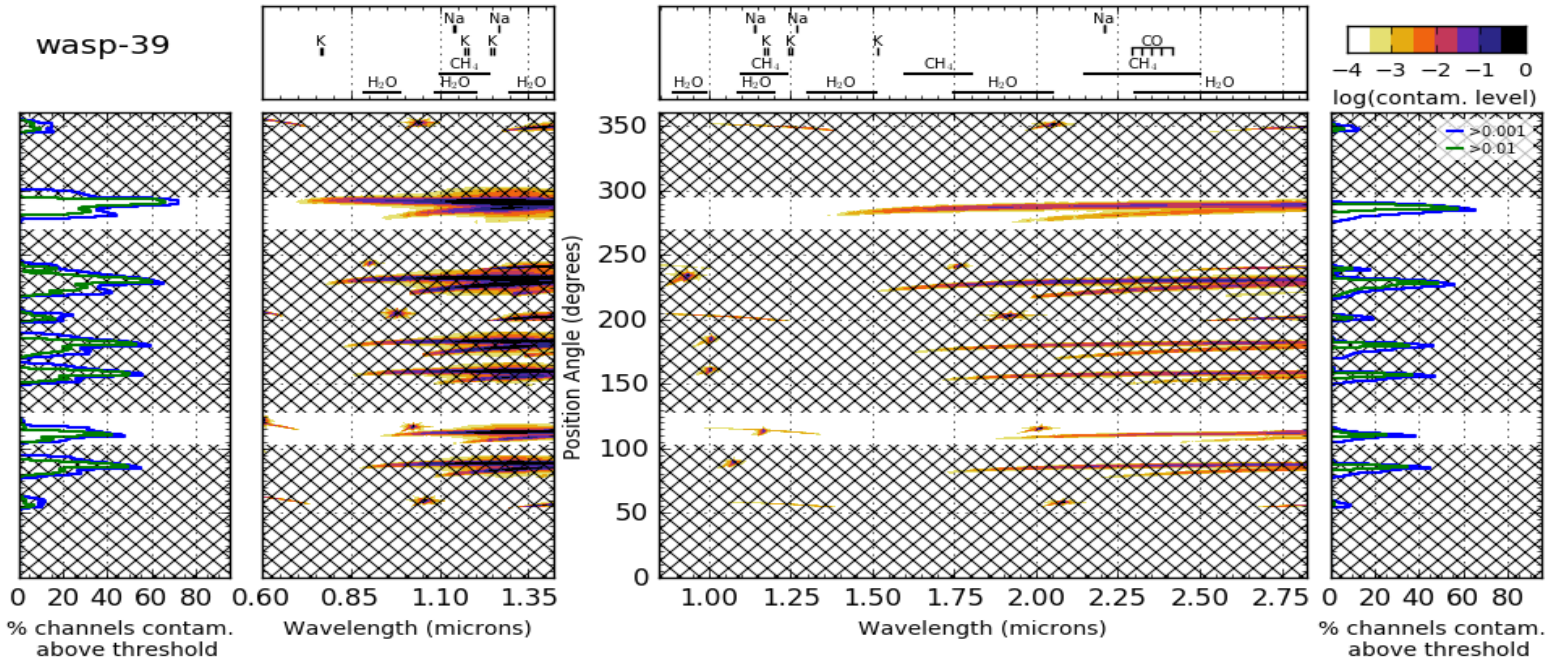
Rows	Columns	Amplifiers	Resets	Maximum Saturation Level (counts/s)	Frame Time (seconds per frame)	Transit Observation Time (hours)
2048	256	1	1	37500.0	5.491	5.49

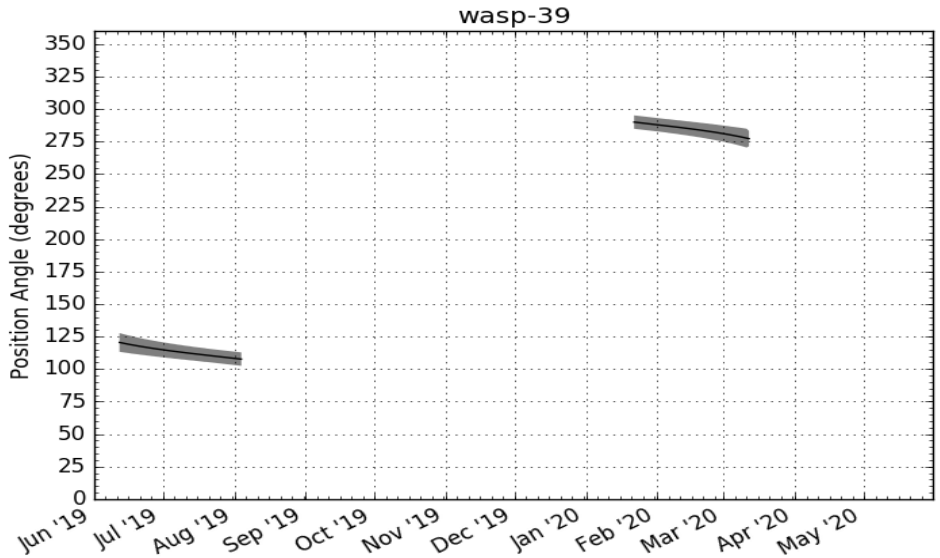
APT Ready Outputs and Useful Tidbits:

Integrations	Groups	Integration Time (seconds per group)	Photon Collection Time (hours)	Total Duration Time (hours)	Observation Efficiency
900	3	16.474	4.118	5.491	0.75

- Future functionality: NGROUPS for target acquisition
- Will be ready in time for Cycle 1

Observation Planning





- Contamination & Visibility Calculator:
  - Target overlap (NIRISS, NIRCam, MIRI) -> APT PA constraints
  - Observation start phase range -> APT timing requirements

Observation Planning

New Features:

1. Select from grid of planet models
2. Errors render on output page (don't worry though, pandas are still there)
3. New binning package
4. More flexible input variable options
5. Easily print out allowed input keys
6. Updated HST simulator

Check out docs: natashabatalha.github.io/PandExo

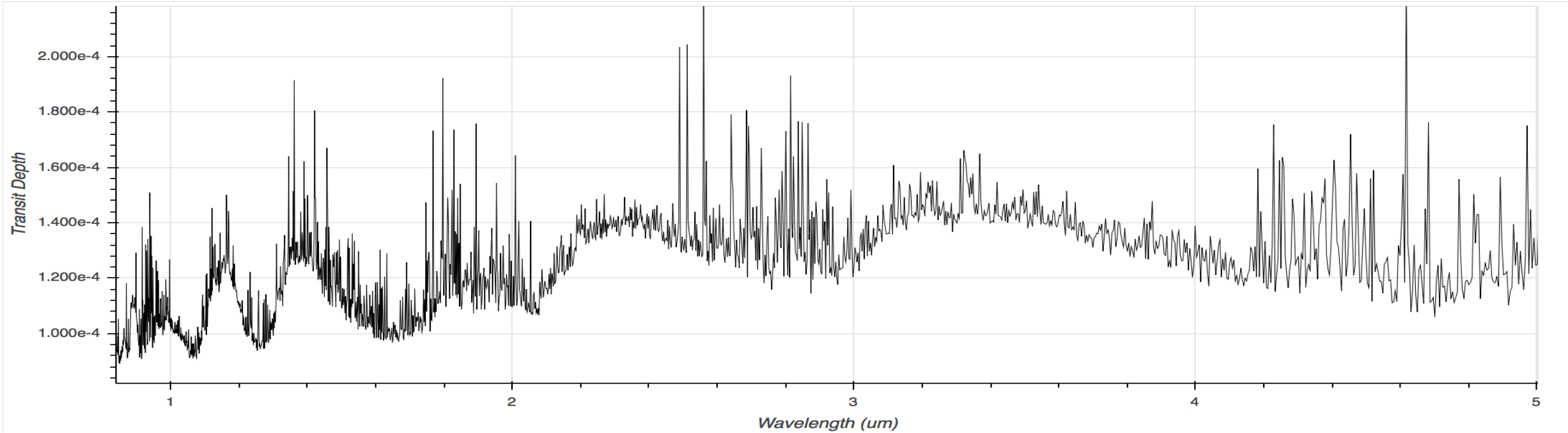
https://exoctk.stsci.edu

Forward Modeling

- Pre-generated atmospheric forward models
  - Gas giant exoplanets (Jonathan Fortney)
  - Super-Earths & brown dwarfs (Caroline Morley)
  - ATMO library (Jayesh Goyal, ~1E6 models)

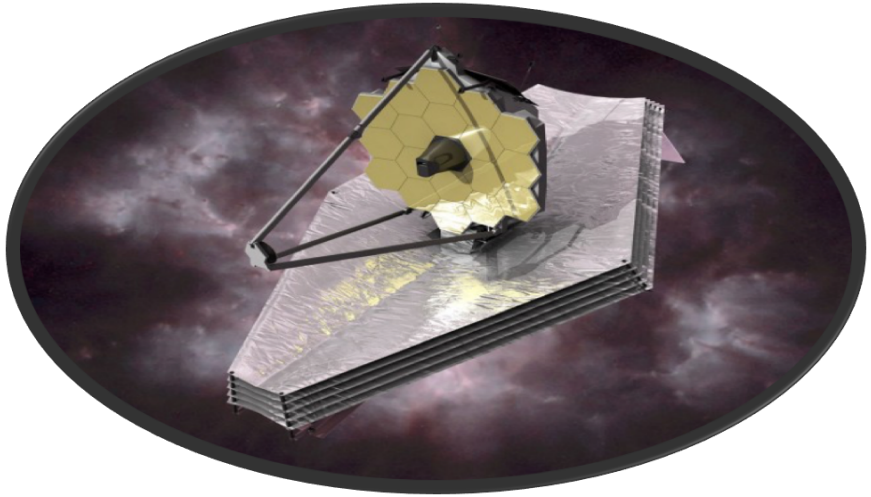
- Custom atmospheric forward models
  - ExoTransmit (Eliza Kempton)
  - CHIMERA (Mike Line)

Forward Modeling



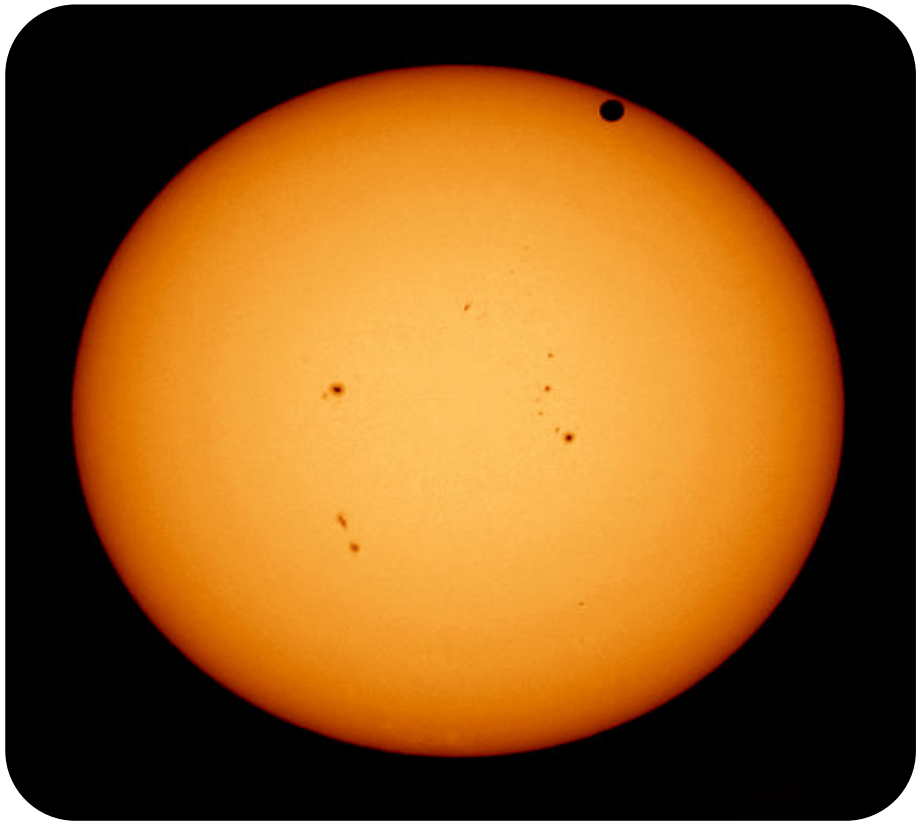
Data Reduction

- Convert time series of 2D integrations into time series of 1D spectra
  - Cosmic ray rejection
  - Background subtraction
  - Optimal spectral extraction



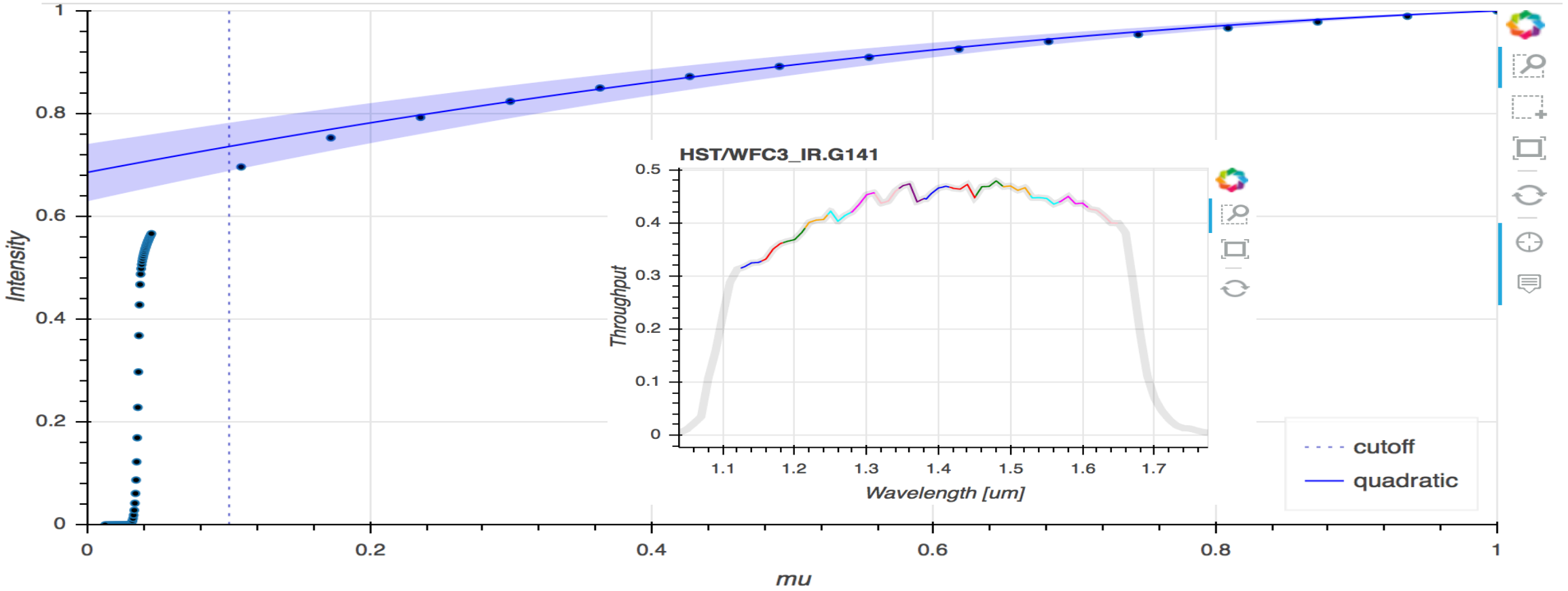
- We want everyone's JWST data reduction modules!!!

Limb Darkening



- Multiple stellar models
  - Phoenix, Kurucz
- Large assortment of filters/grisms
  - Spitzer/IRAC, HST/WFC3, JWST
- Select one or more LD models
  - 8 options (linear, quadratics, etc.)
- Interpolates model grids to determine best stellar model
- Will use stellar uncertainties to compute LD uncertainties

Limb Darkening



$\lambda_{\rm eff}$ (μm)	c1	e1	c2	e2
1.13971	0.121	0.011	0.221	0.017

https://exoctk.stsci.edu

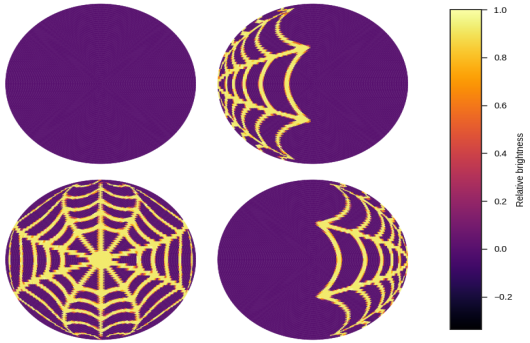
Light Curve Fitting

- Comprehensive library of physical and systematic model components
  - Ramps (time dependent)
  - IPSV (position dependent)
  - Unknowns (unknown dependent)

- Fit white and spectroscopic light curves
  - BATMAN (Laura Kreidberg)
  - SPIDERMAN (Tom Louden)
  - LMFIT

- Estimate uncertainties
  - MC^3 (Patricio Cubillos)
  - EMCEE (Dan Forman-Mackey)

- Generate transmission/emission spectrum



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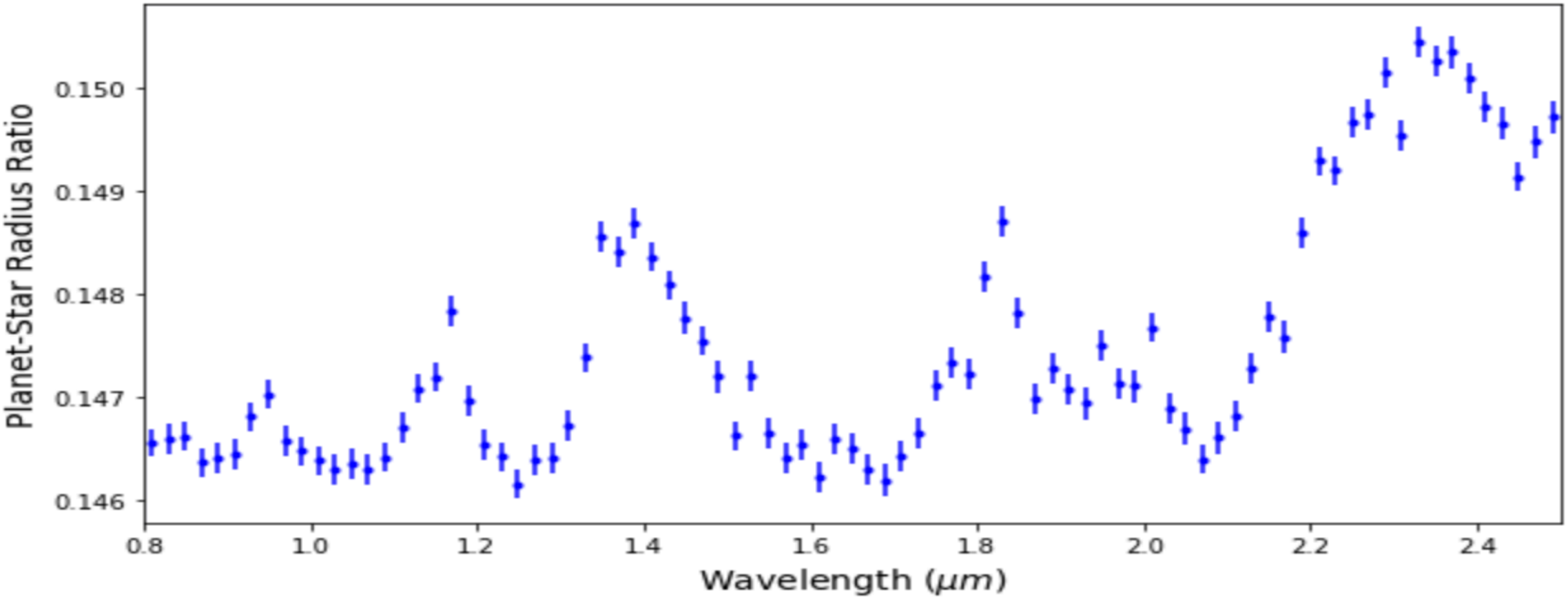
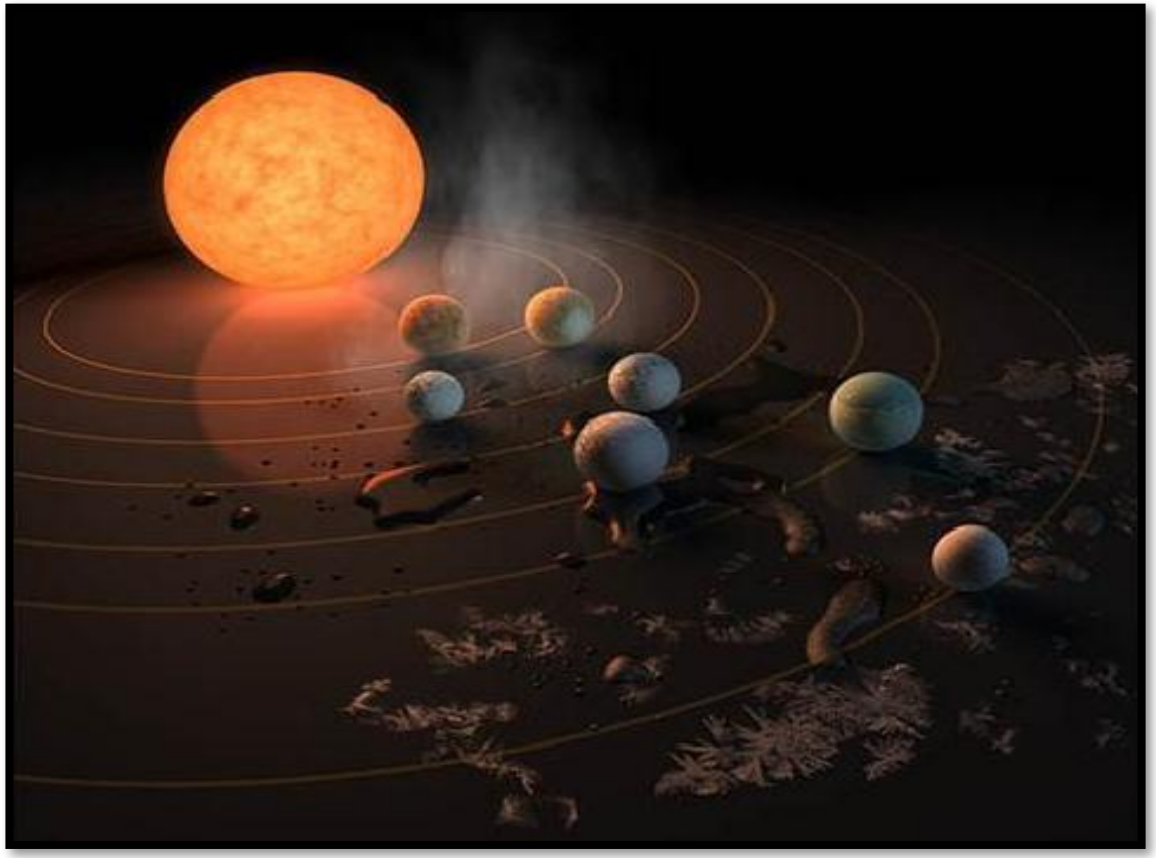
Light Curve Fitting



Atmospheric Retrieval

- Estimate physical parameter uncertainties under a Bayesian framework
  - CHIMERA (Mike Line)

- Example parameters
  - Molecular abundances
  - Thermal structure
  - C/O
  - Metallicity
  - Clouds



Atmospheric Retrieval