ASTR 405
Planetary Systems
Emission Spectroscopy

Fall 2025

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Supplementary Readings: **atmosphere.pdf** on Canvas

Exoplanet Atmospheres by Sara Seager and Drake Deming

Modules

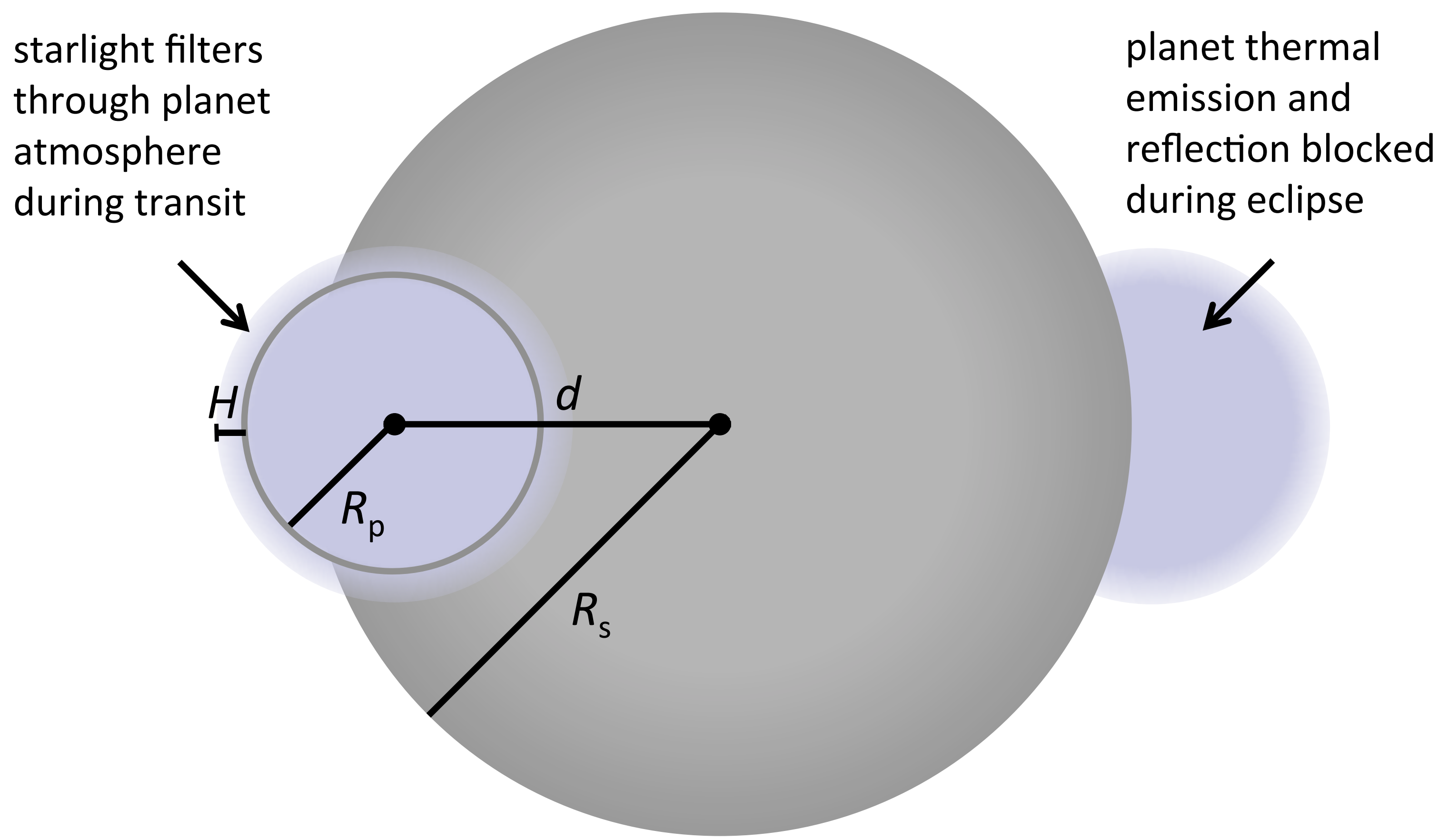
- Part I: Exoplanet Detection Methods
  - Explore the techniques astronomers use to discover planets beyond our solar system
- Part II: Exoplanet Demographics and Planet Formation
  - Investigate the statistical properties of exoplanets and theories of how planetary systems form
- **Part III: Exoplanet Atmospheres, Interiors, and Characterization**
  - **Examine methods for studying the physical properties and compositions of distant worlds**

Module III: Exoplanet Atmospheres, Interiors, and Characterization

- **Exoplanet Characterization**
  - Transmission, emission & phase curves → atmospheric composition, P-T profile
  - Rossiter–McLaughlin effect → spin–orbit angles
- **Atmospheric Physics**
  - Hydrostatic structure and P-T profiles
  - Thermodynamics: convection, lapse rate, and radiative balance
  - Composition and clouds: metallicity, C/O ratio, disequilibrium chemistry
  - Atmospheric loss and the cosmic shoreline
- **Planetary Interiors**
  - Giant planets: phase diagram of hydrogen, central pressure, Hot Jupiter radius inflation
  - Terrestrial planets: heat transport, cooling, and mass–radius relation

Emission Spectroscopy

Emission spectroscopy probes the atmospheres of exoplanets by measuring the planet's own thermal emission or reflected light, typically observed when the planet passes **behind** the star (secondary eclipse), rather than by the transmission of starlight through the planet's limb.



The geometry of a transit event, along with the geometry of the secondary eclipse that is used to derive planetary emission spectra (Kreidberg 17).

Secondary Eclipse Depth

The eclipse depth: $\delta_{\text{ecl}} = \dfrac{F_p}{F_\star + F_p} \approx \dfrac{F_p}{F_\star}$

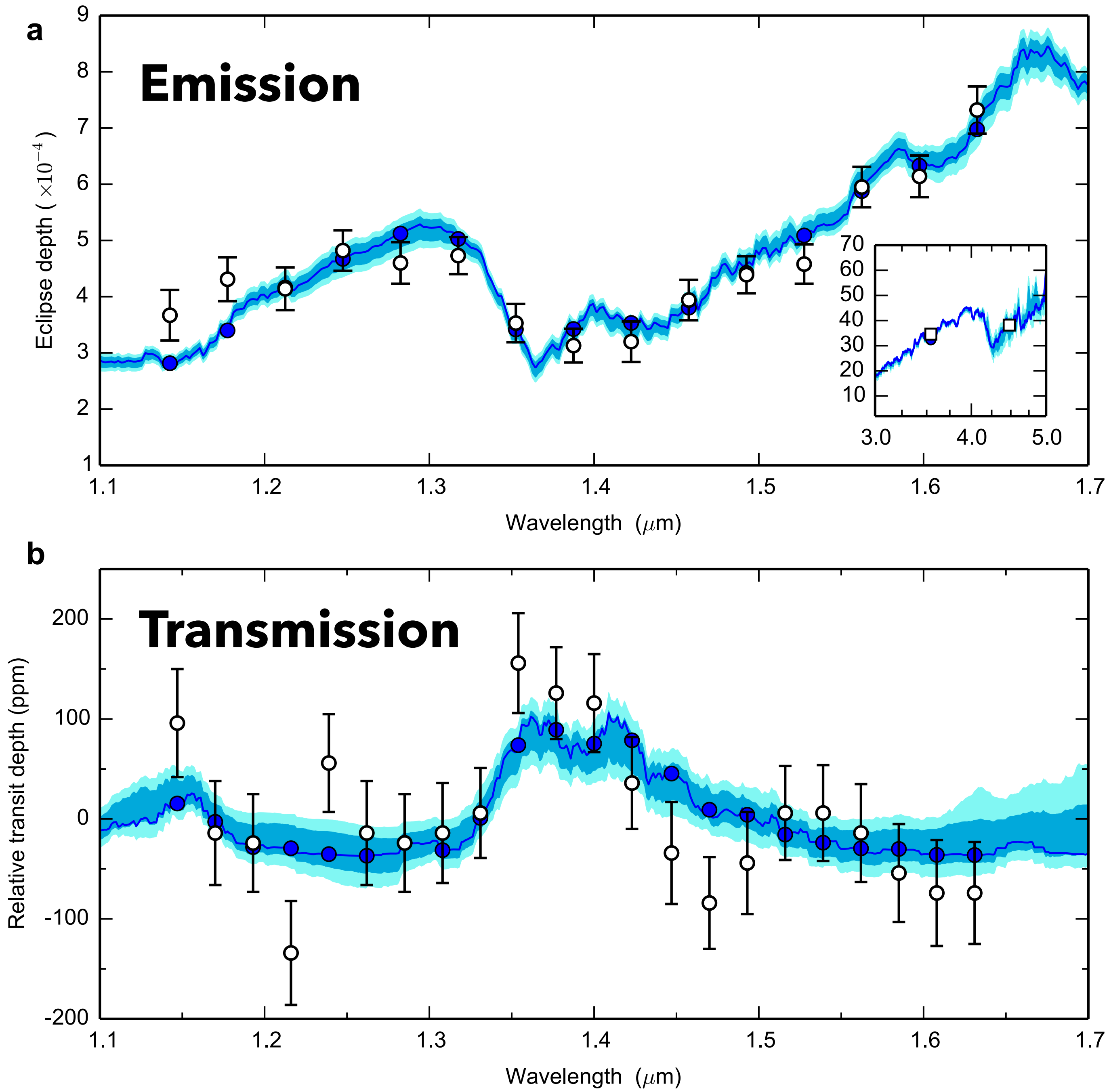
Assume blackbody emissions: $\delta_{\text{ecl}} = \dfrac{B_\lambda(T_p)\, R_p^2}{B_\lambda(T_\star)\, R_\star^2} = \dfrac{R_p^2}{R_\star^2} \dfrac{e^{hc/\lambda k T_\star} - 1}{e^{hc/\lambda k T_p} - 1}$

In Rayleigh–Jeans limit (long wavelengths): $\delta_{\text{ecl}} \simeq \left(\dfrac{R_p}{R_\star}\right)^2 \dfrac{T_p}{T_\star}$

Recall from the direct imaging lecture that planet equilibrium temperature $T_{\text{eq}} = T_\star \left[\dfrac{1 - A_{\text{B}}}{4f}\right]^{1/4} \sqrt{\dfrac{R_\star}{a}}$ where A_B is the Bond albedo and f is the heat redistribution factor

Emission and Transmission Spectrum of the Hot Jupiter WASP-43b by HST

Kreidberg 17

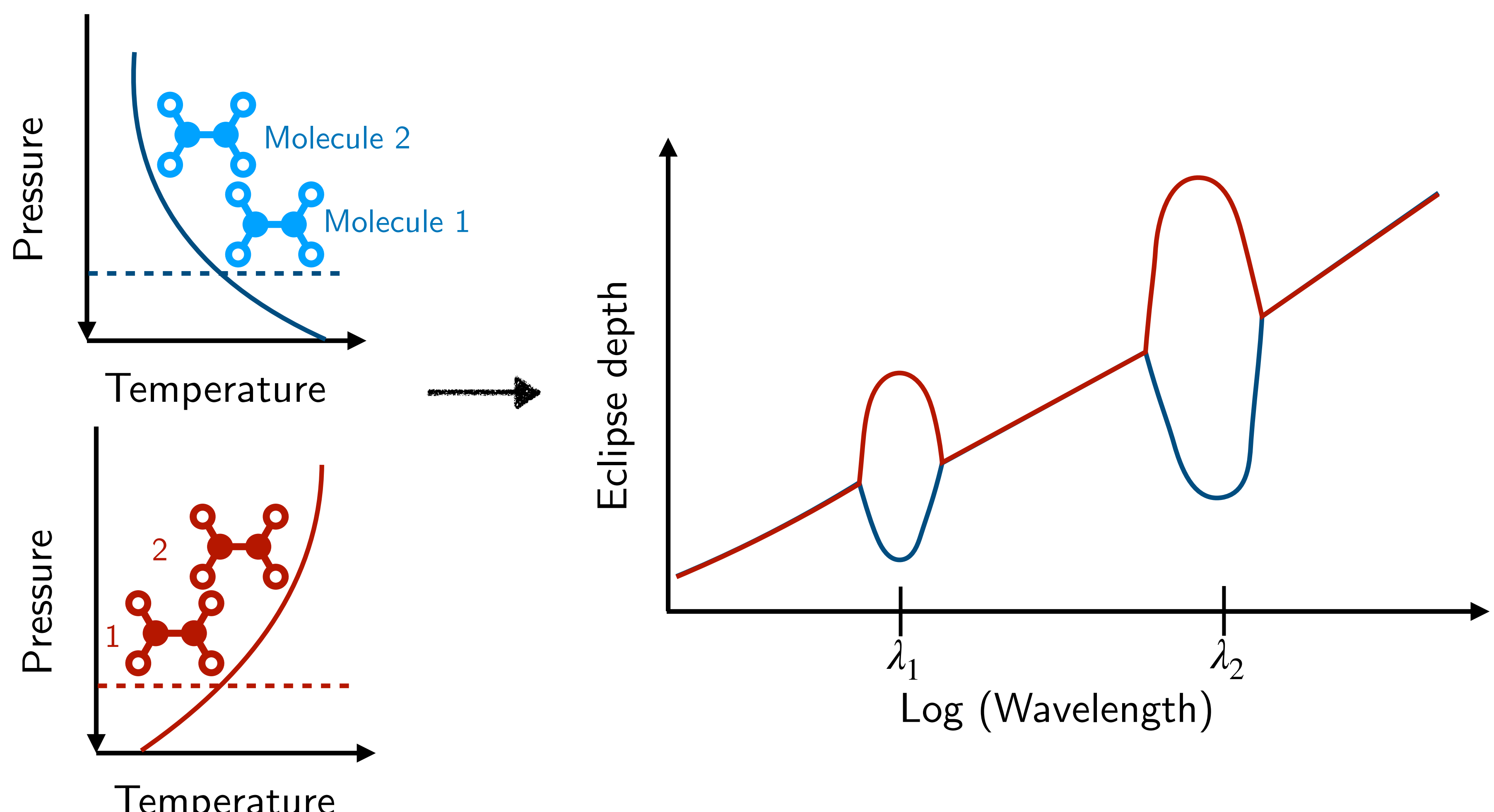


Emission spectrum (top) and transmission spectrum (bottom) of WASP-43b observed with the Hubble Space Telescope Wide Field Camera 3 instrument (inset on top shows observations with the Spitzer Space Telescope).

The spectral feature (bump) in the transmission spectrum at $1.4\ \mu\text{m}$ due to **water vapor** absorption, which also causes an absorption feature (dip) in the emission spectrum.

Absorption and Emission Features

- In **non-inverted** atmospheres (temperature decreases with altitude), molecular bands appear as **absorption** features (dips in eclipse depth) because cooler upper layers re-emit less flux at wavelengths where opacity is high.
- In **thermally inverted** atmospheres (temperature increases with altitude), molecular bands appear as **emission** features (bumps in eclipse depth) since hotter upper layers emit more strongly where opacity is high.
- **Isothermal atmosphere has no spectral features.**

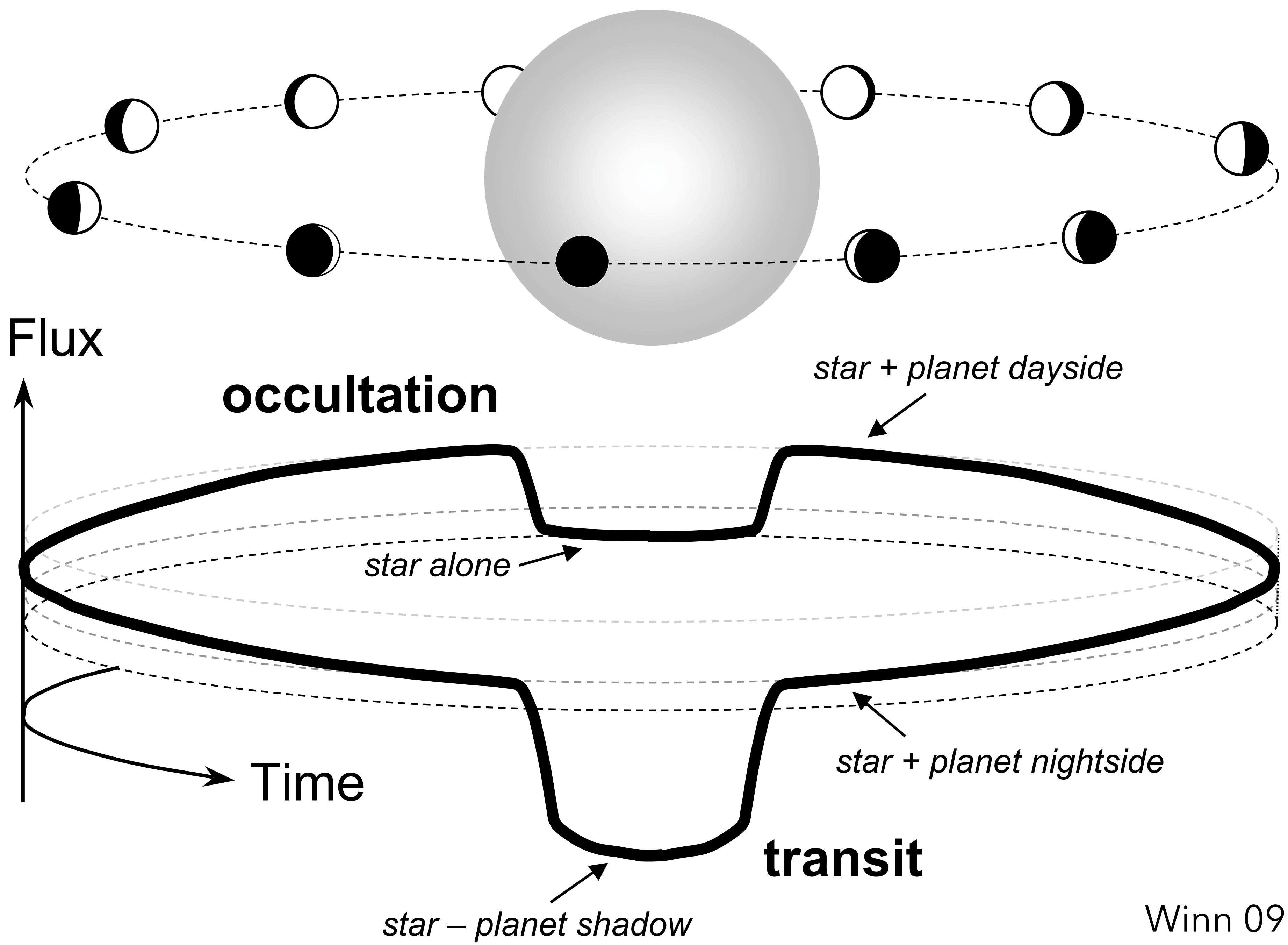


In-Class Activity

Planetary Spectrum Generator

psg.gsfc.nasa.gov/atmosphere.php

Phase Curves



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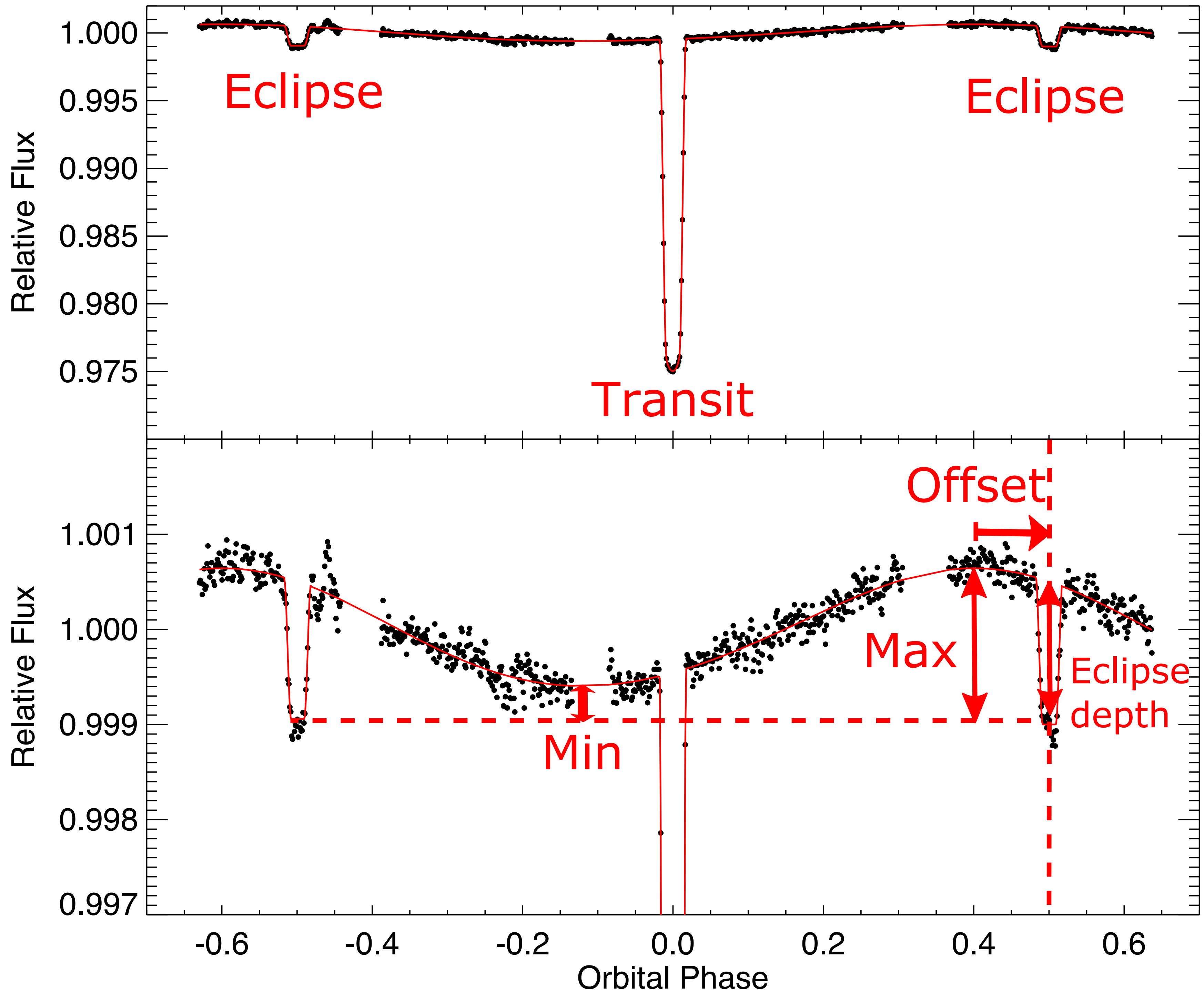
Phase Curves



Parmentier & Crossfield 2018