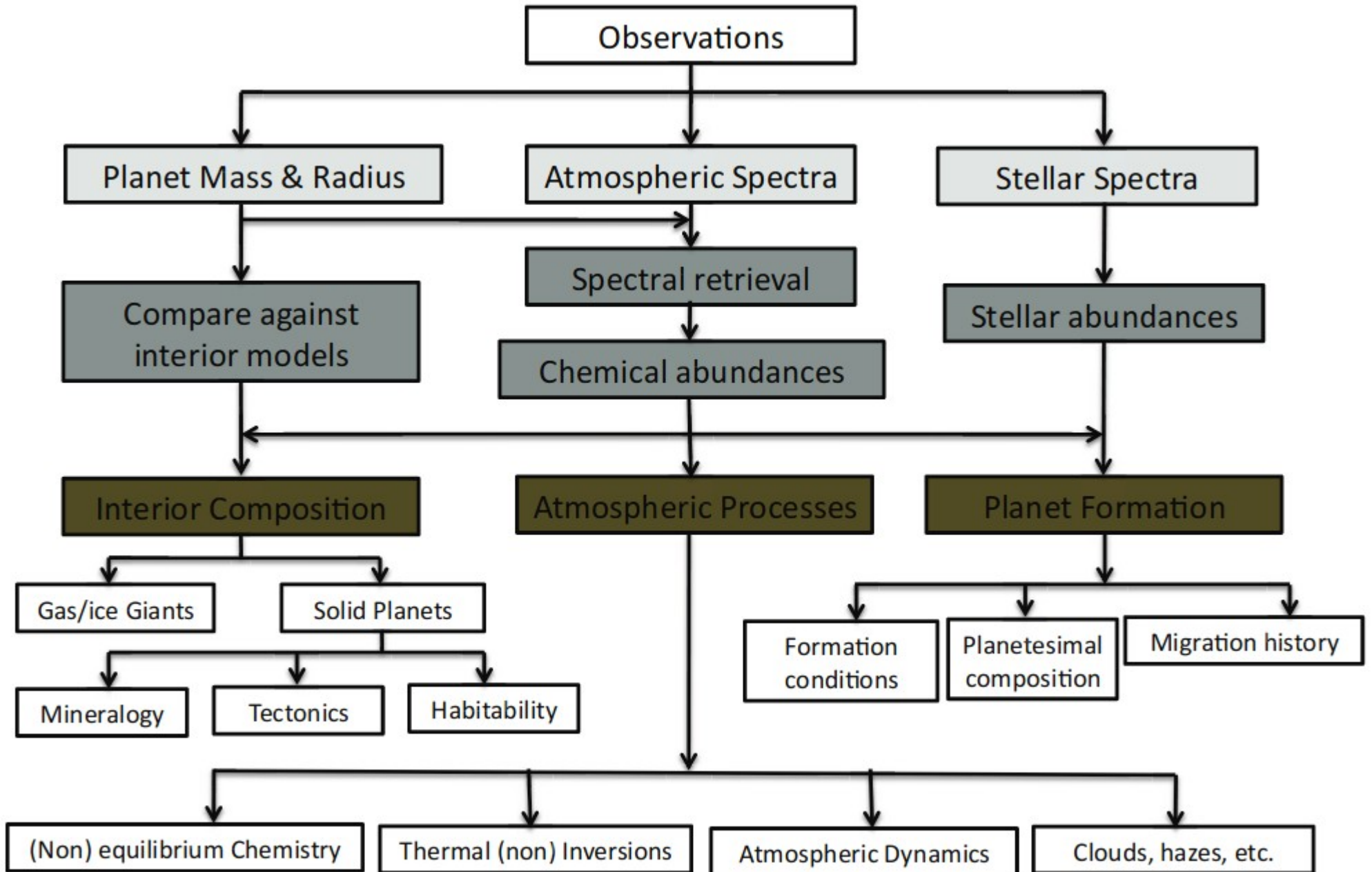
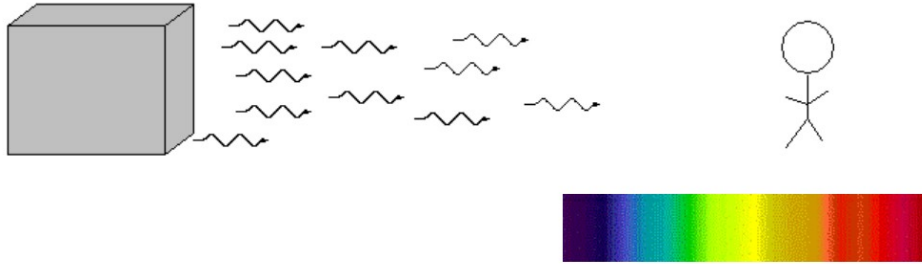


Exoplanet characterization and evolution

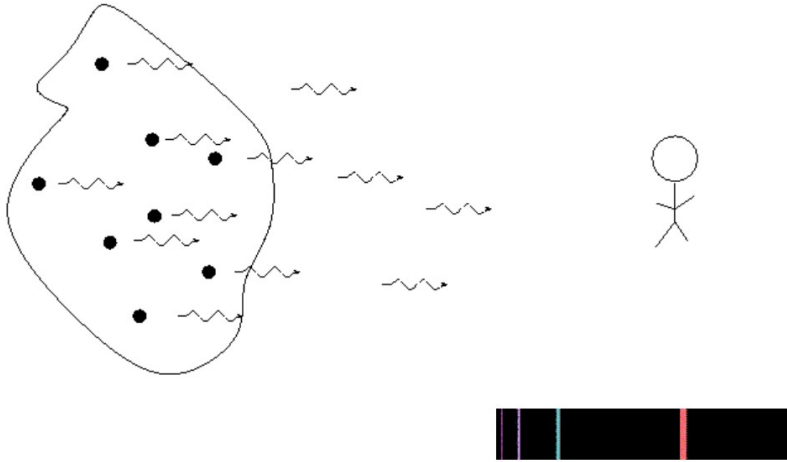
Exoplanet characterization



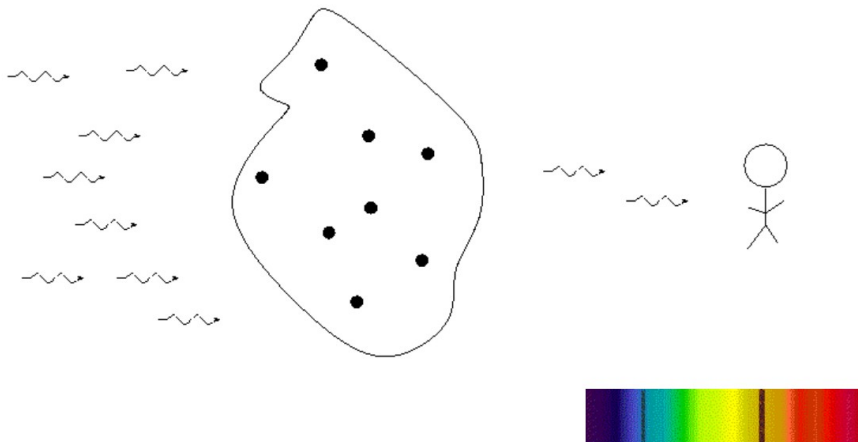
Reminder: types of spectra



dense:
blackbody



thin, warm/hot:
emission lines



thin, in front of light
source:
absorption lines

Atmospheres: transmission spectroscopy

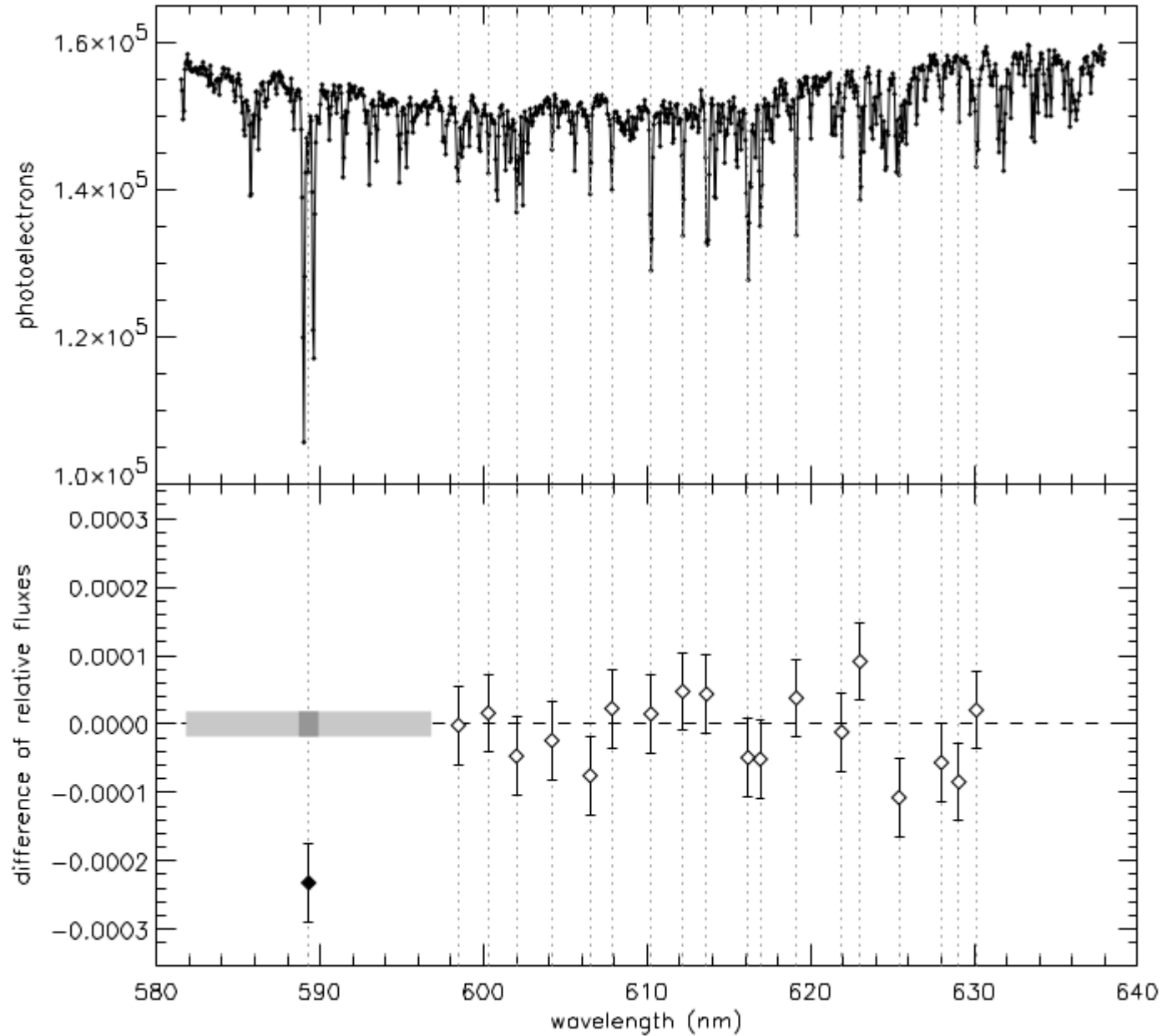
Observe:

Spectrum during transit, spectrum out of transit

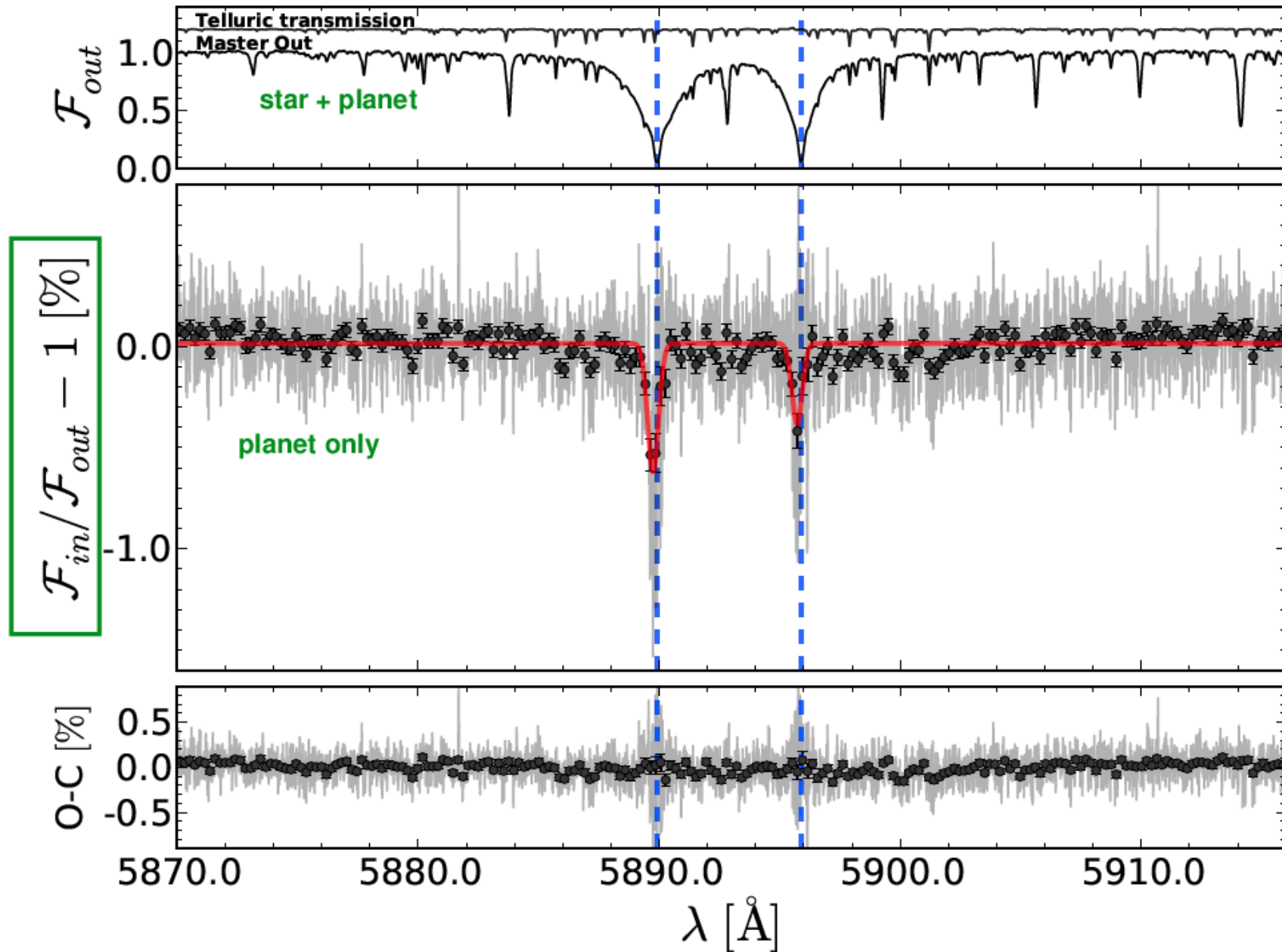
Subtract or divide spectra by each other.

Relative measurement, no absolute flux measurement.
But spectral lines corresponding to absorbers in the planet's atmosphere will be deeper.

Atmospheres: transmission spectroscopy



Atmospheres: transmission spectroscopy

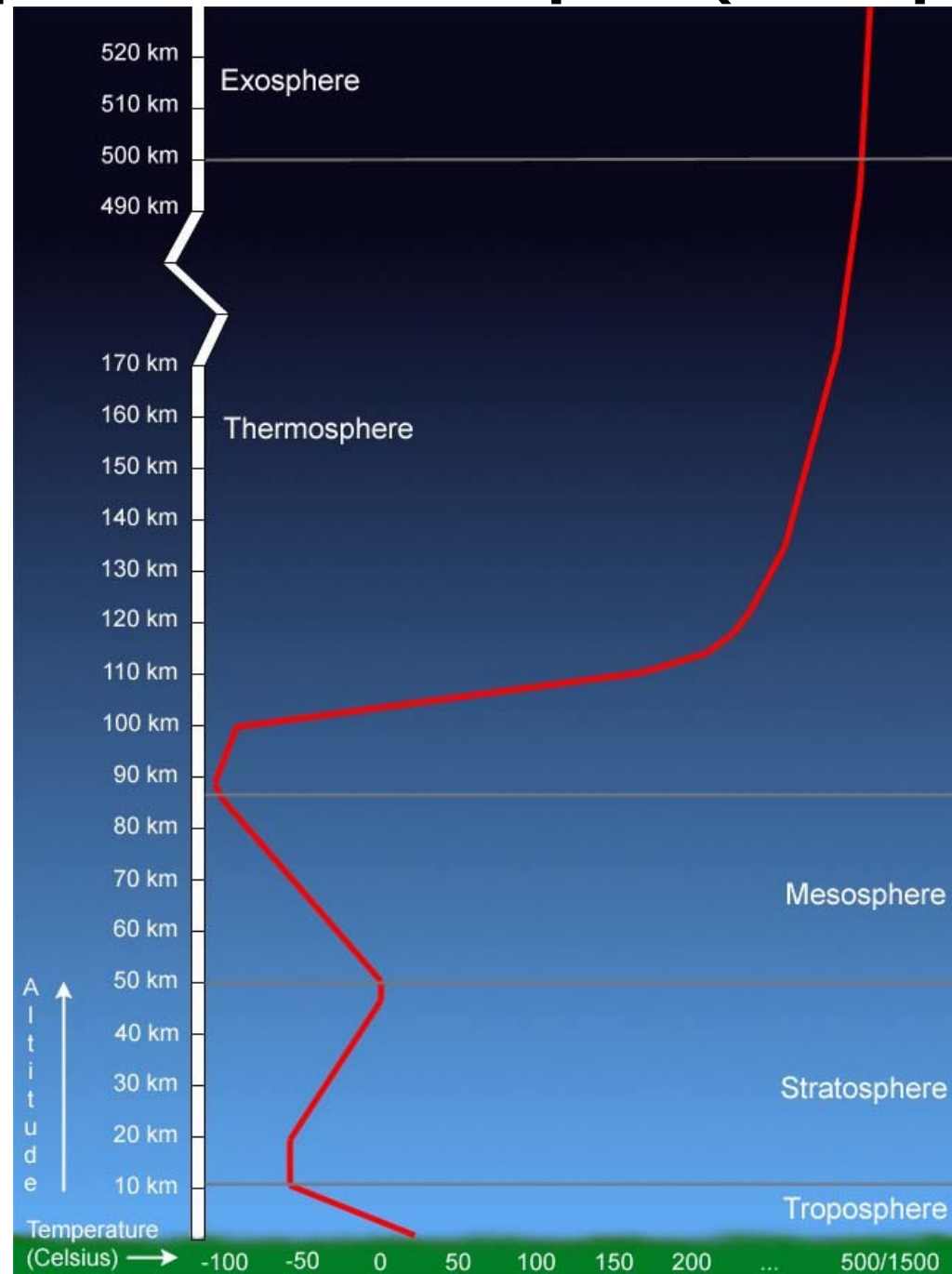


Atmospheric escape (evaporation)

Hot planets with gaseous atmospheres: can they evaporate?

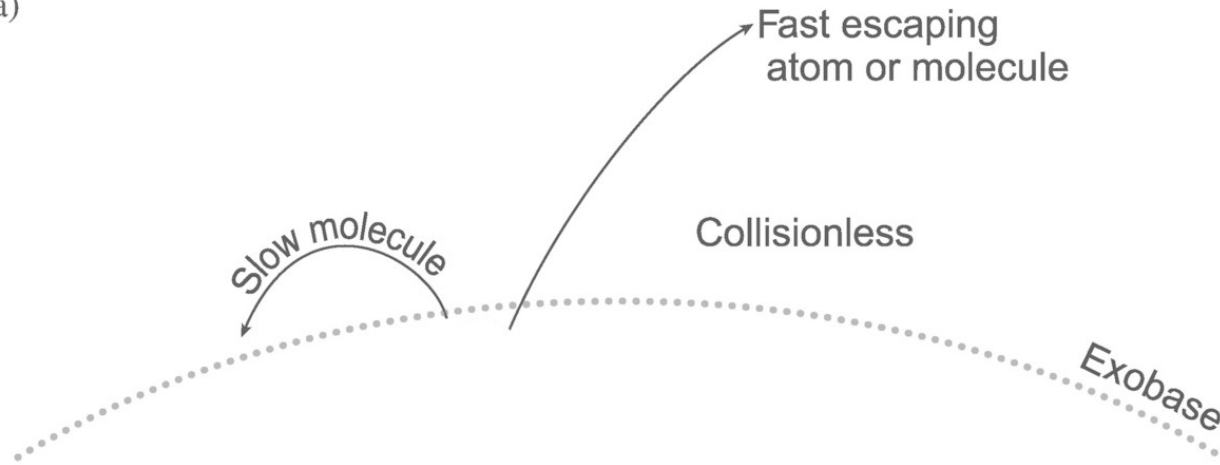
Calculation example: Jeans escape.

Atmospheric escape (evaporation)



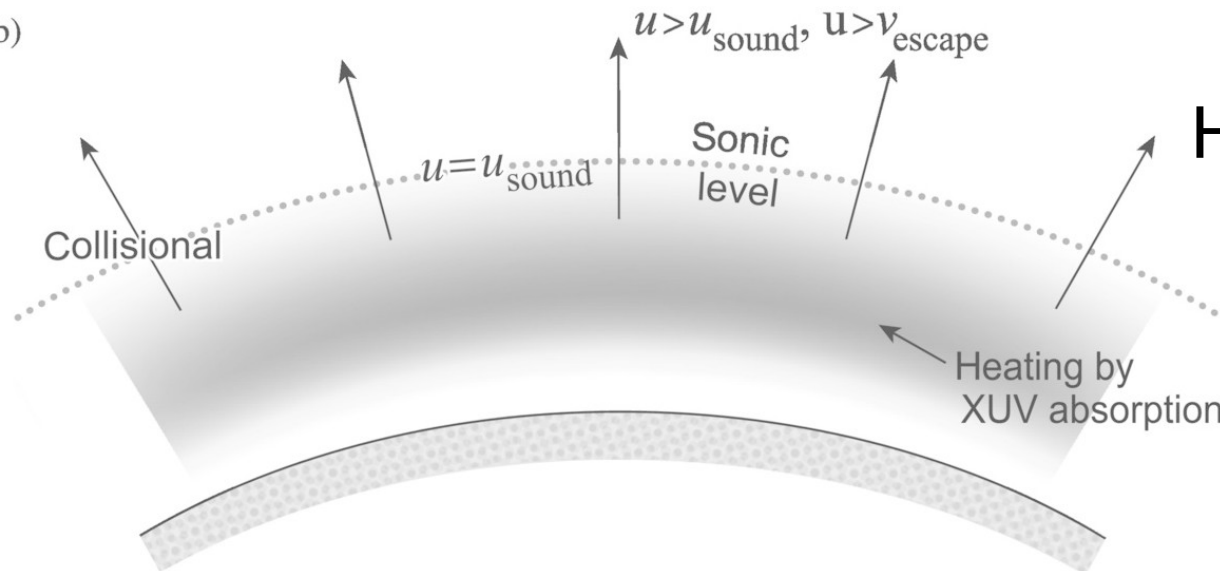
Atmospheric escape (evaporation)

(a)



Jeans

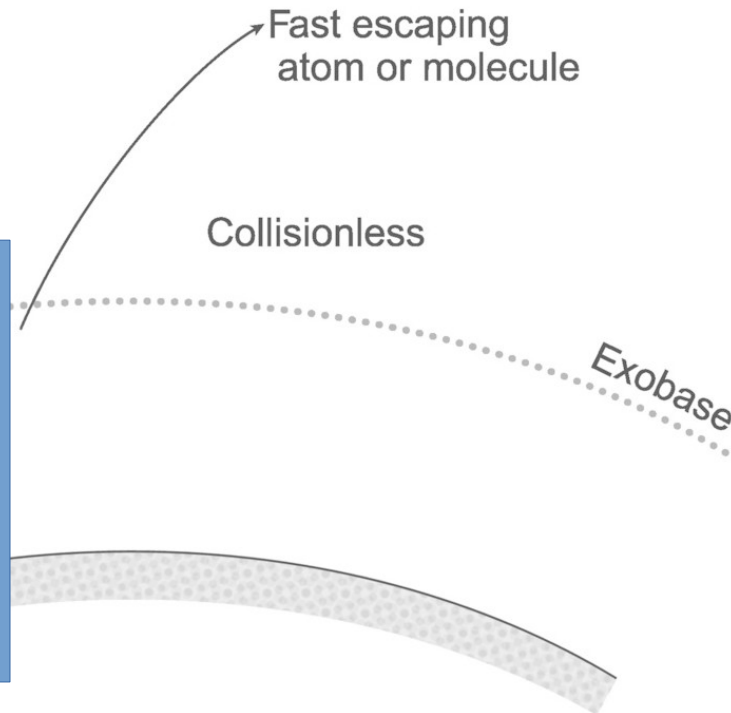
(b)



Atmospheric escape (evaporation)

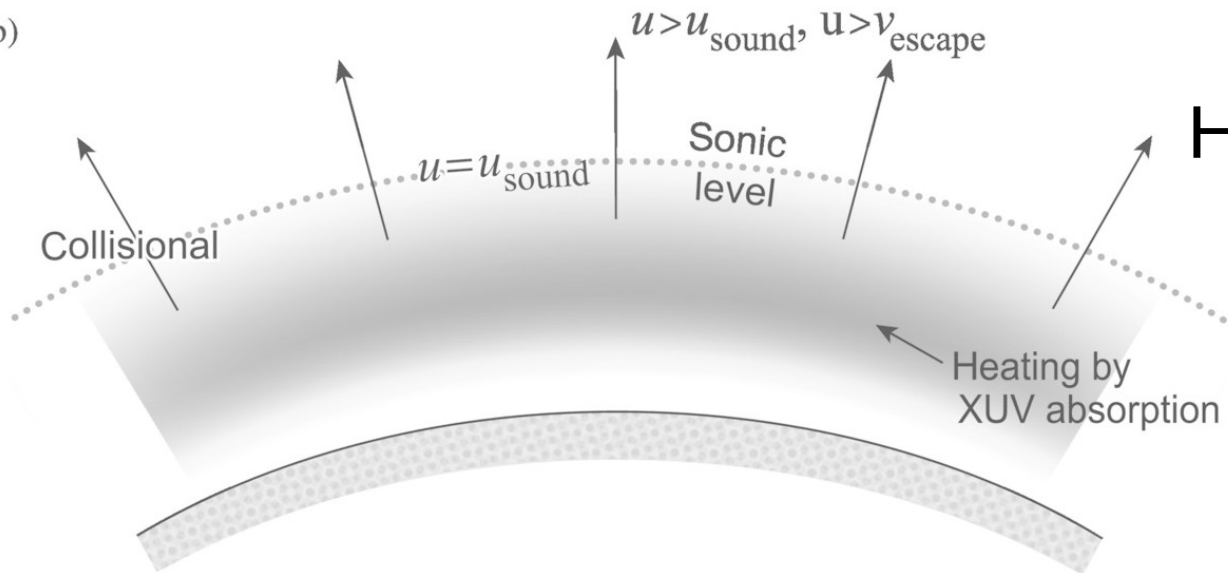
(a)

In the hydrodynamic regime, a layer of the atmosphere is heated by stellar photons, expands, and pushes the layers above it away as a streaming planetary wind.

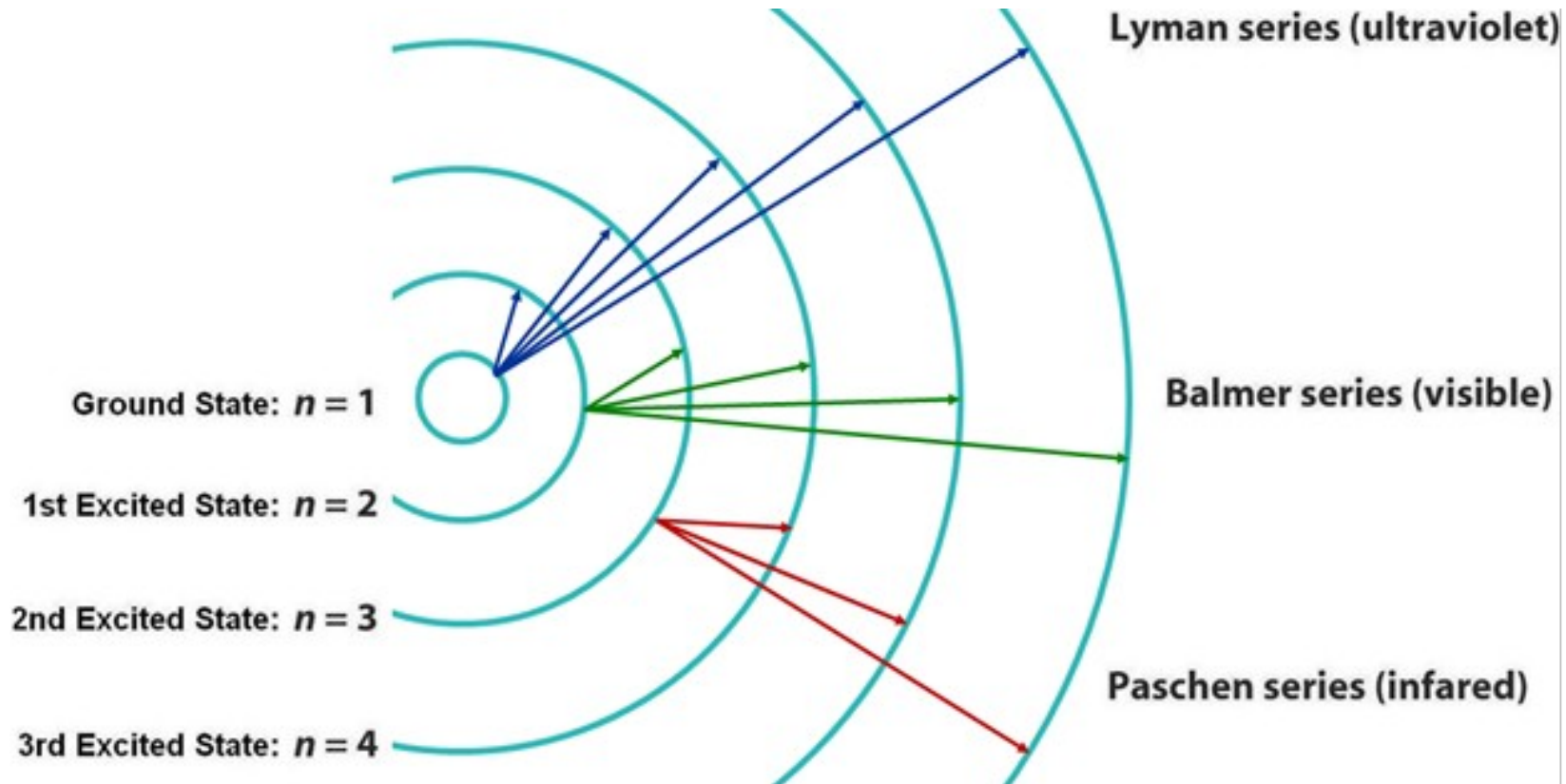


Jeans

(b)

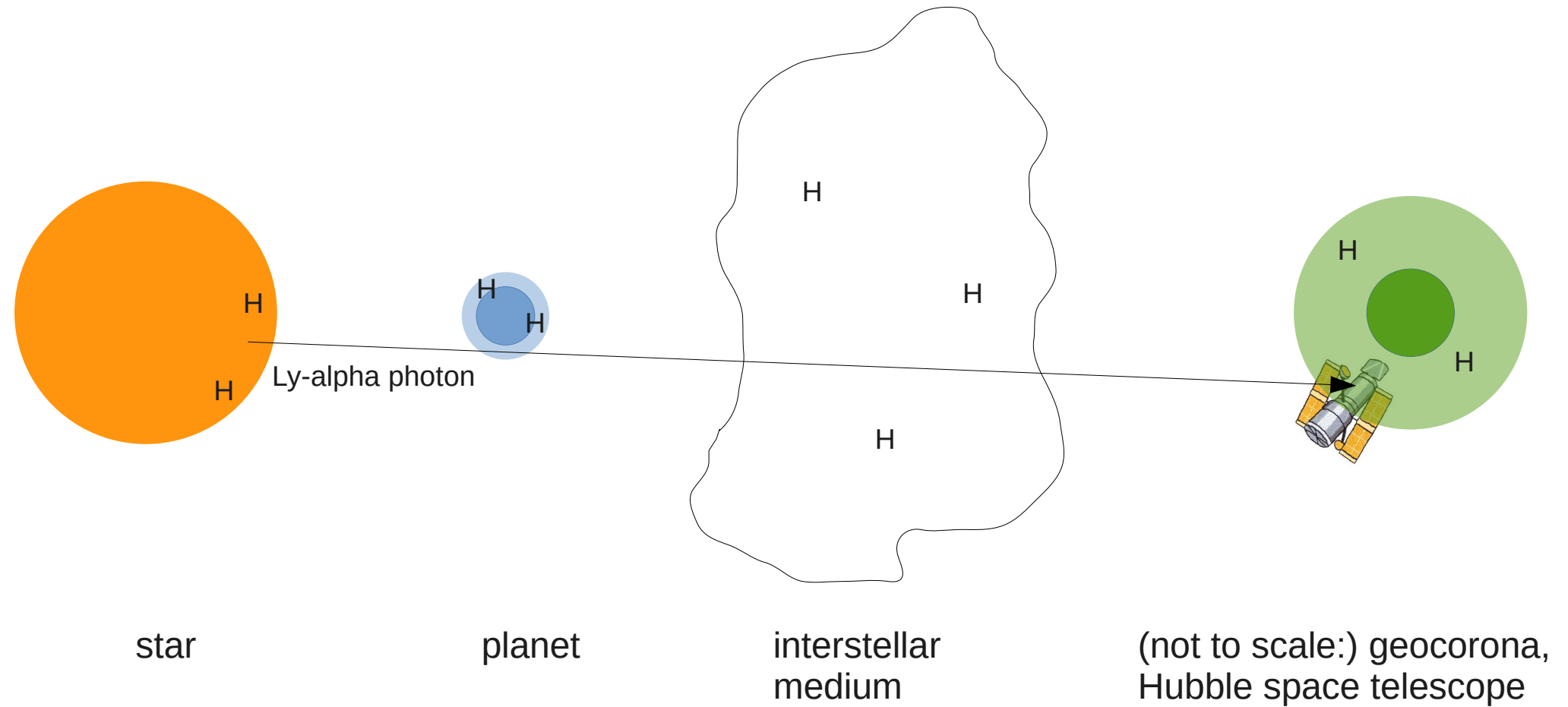


Atmospheric escape (evaporation)



Hydrogen Lyman-alpha line:
1216 Angstrom (121.6 nm), UV

Observe hydrogen (Ly- α)?



Atmospheric escape (evaporation)



Apollo UV image of earth: geocorona
Hubble orbit (height ca. 500 km) within geocorona

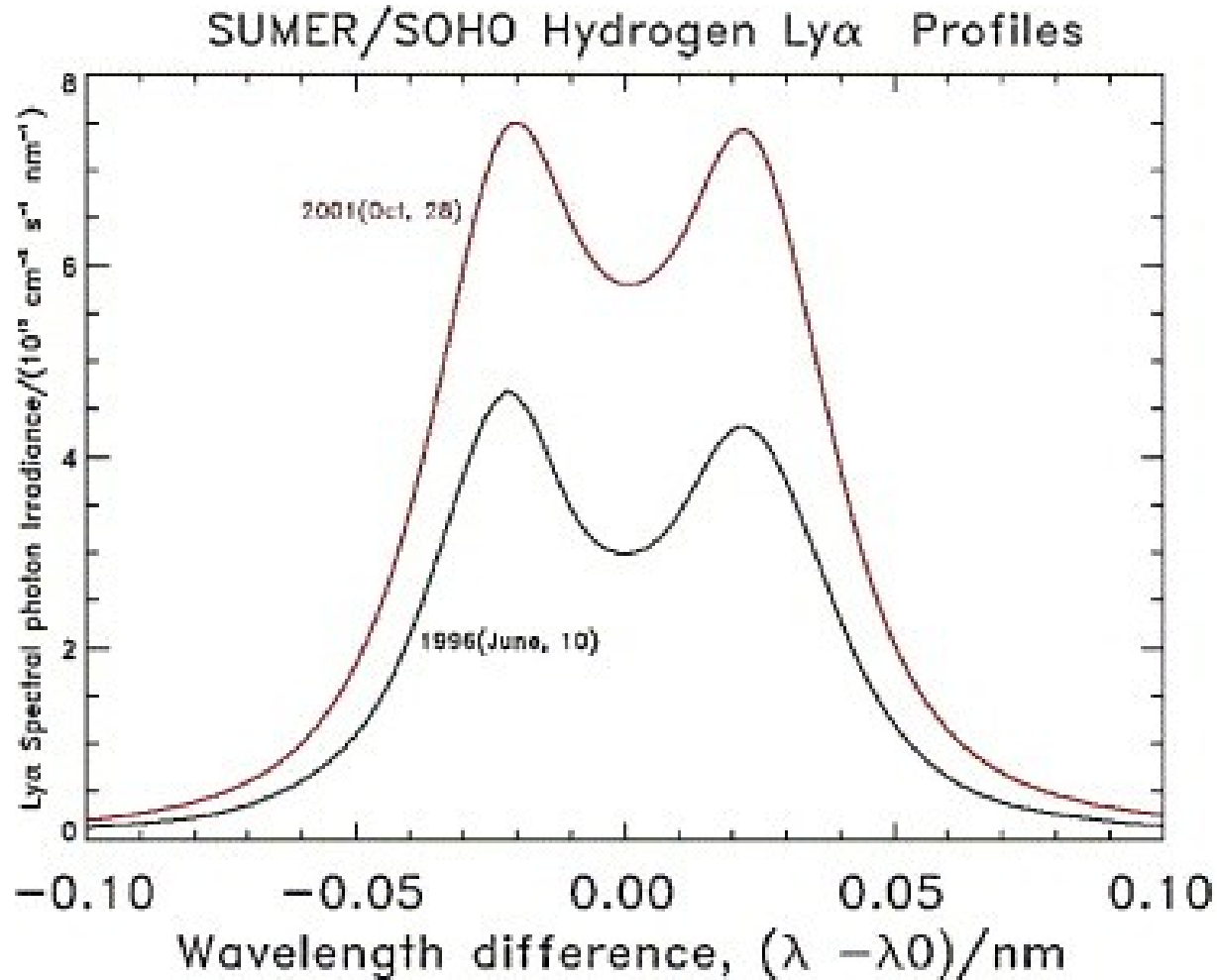
Atmospheric escape (evaporation)

What should a hydrogen Ly-alpha transit of a planet look like?

- stellar line profile
- absorption by planet
- absorption by ISM (hydrogen and deuterium)
- emission of geocorona
- instrumental profile of telescope

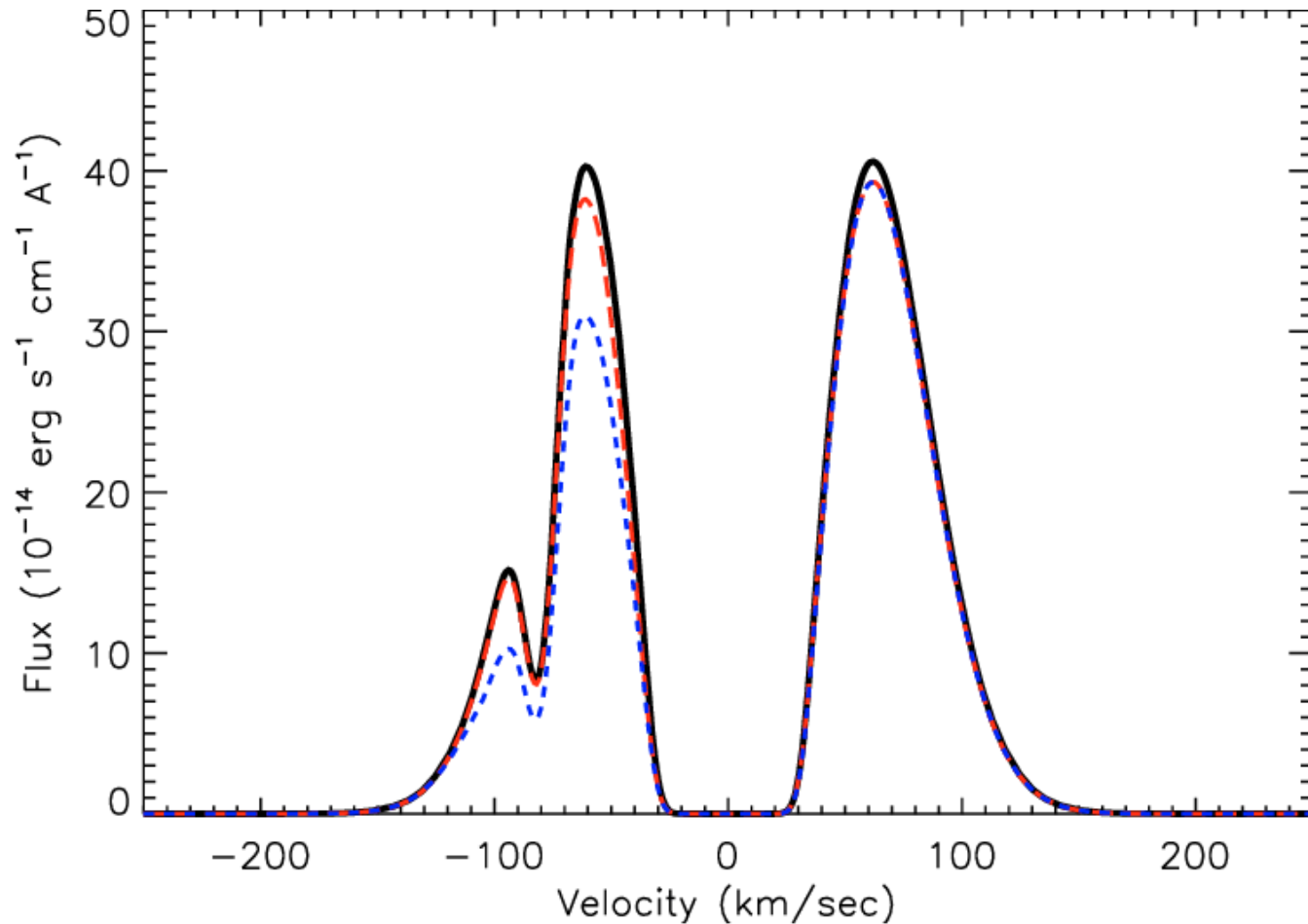
Atmospheric escape (evaporation)

Stellar line (take Sun as example):



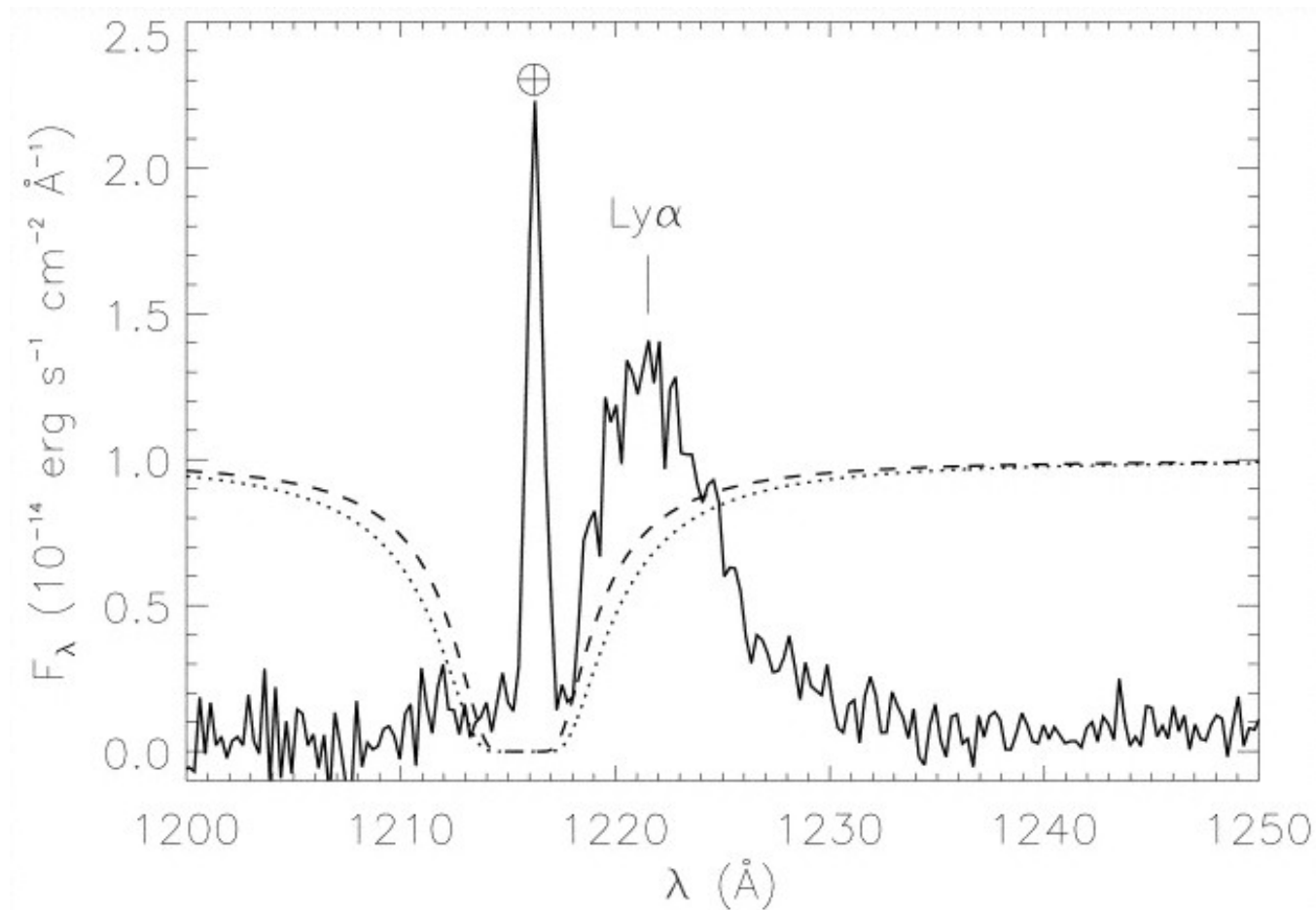
Atmospheric escape (evaporation)

ISM absorption:



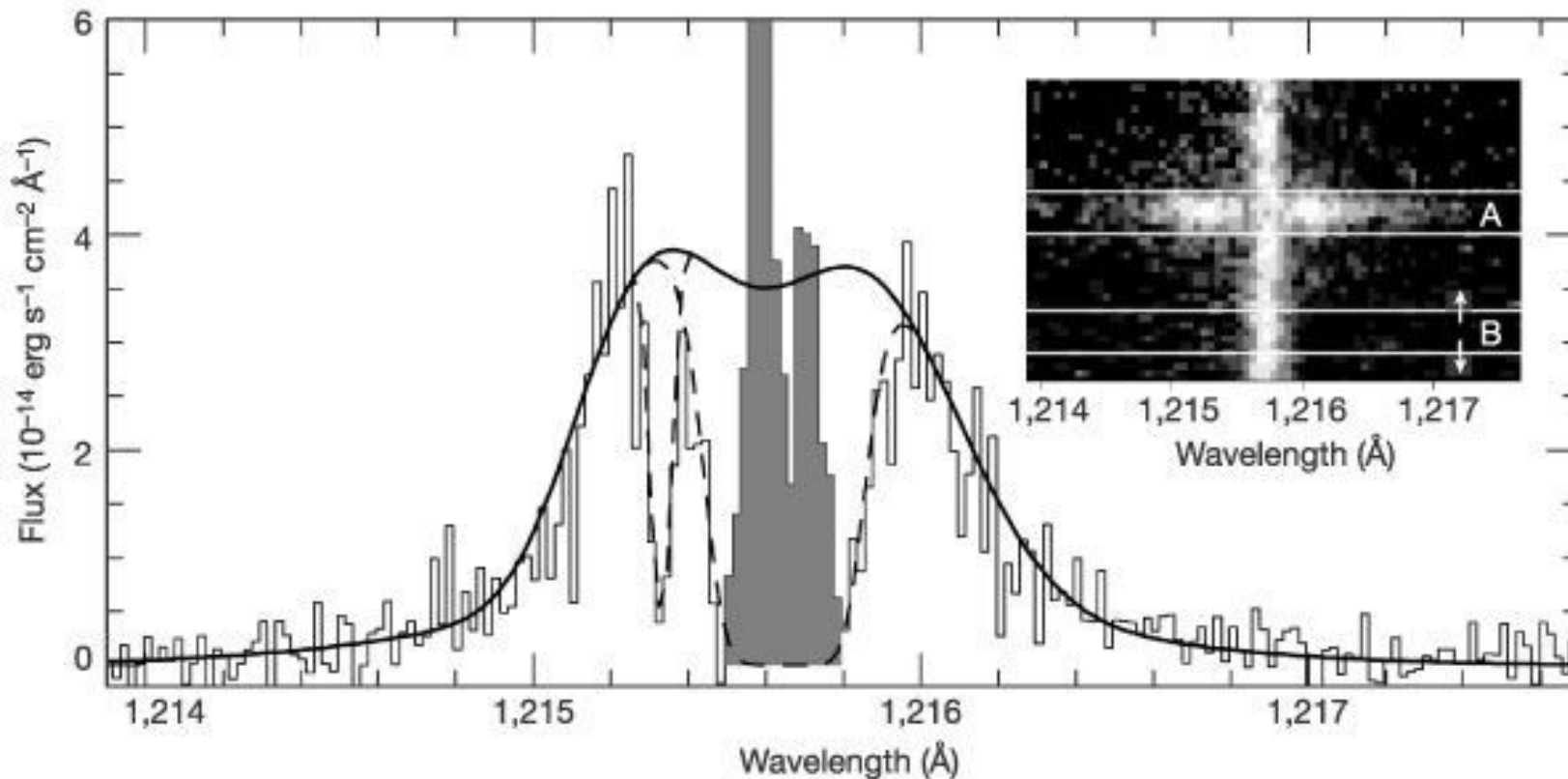
Atmospheric escape (evaporation)

geocoronal Ly-alpha line
(narrow):



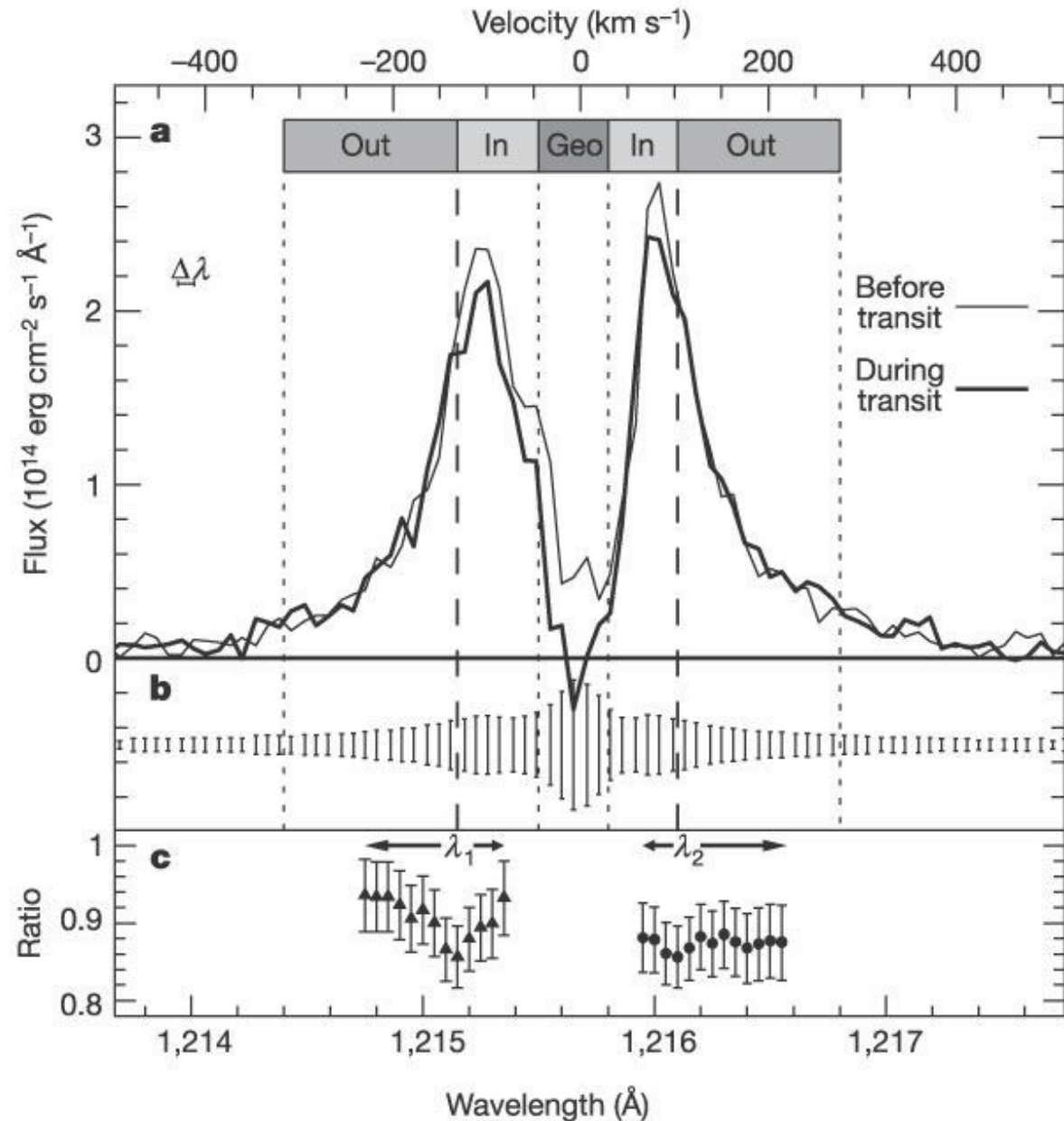
Atmospheric escape (evaporation)

Hydrogen Ly-alpha transit of Hot Jupiter HD 209458
(Vidal-Madjar et al. 2003):



Atmospheric escape (evaporation)

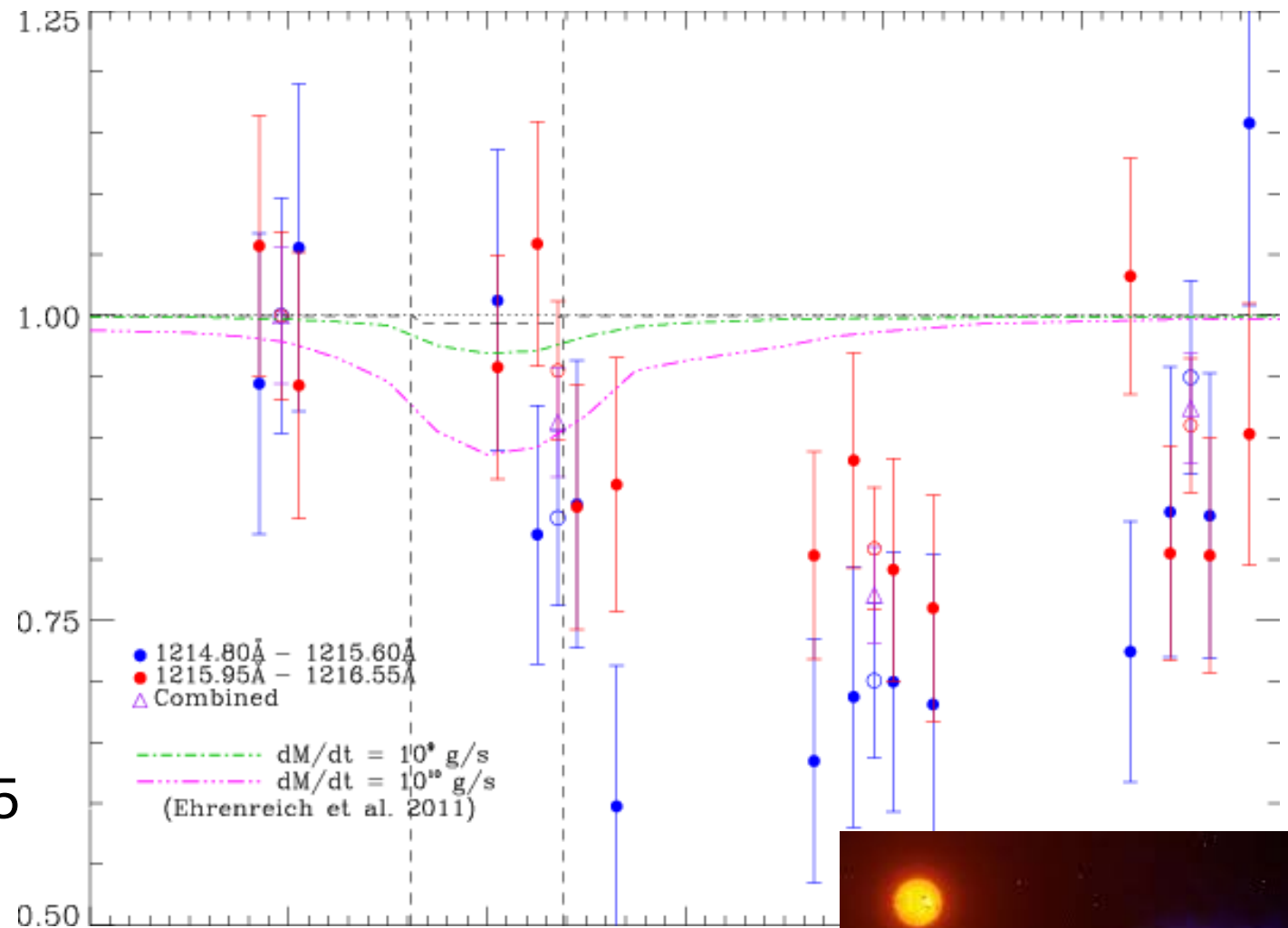
Hydrogen Ly-alpha
transit of Hot Jupiter
HD 209458 (Vidal-
Madjar et al. 2003):



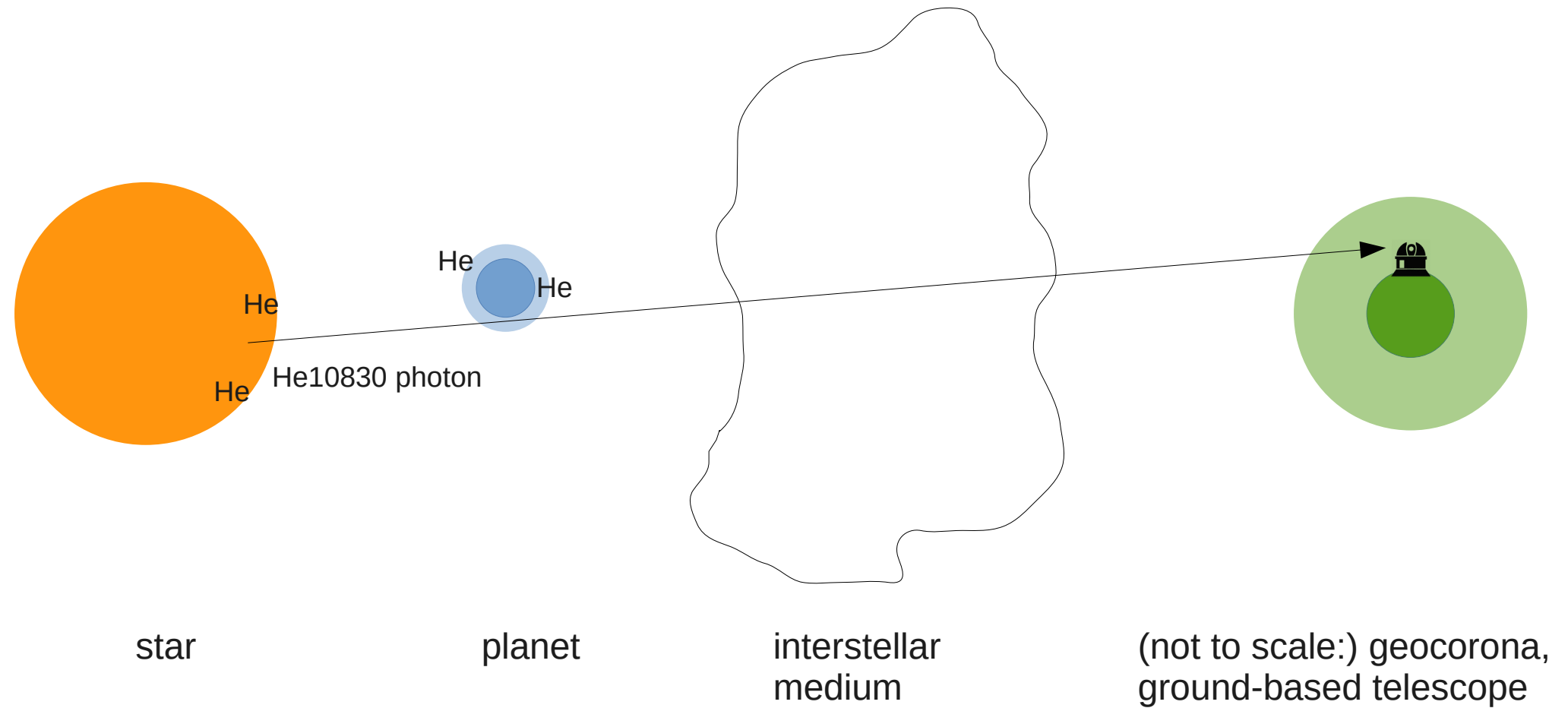
Atmospheric escape (evaporation)

Can also collect light curves only in relevant parts of line and plot that versus time:

Warm Neptune
GJ 436 b,
Kulow et al. 2014,
Ehrenreich et al. 2015



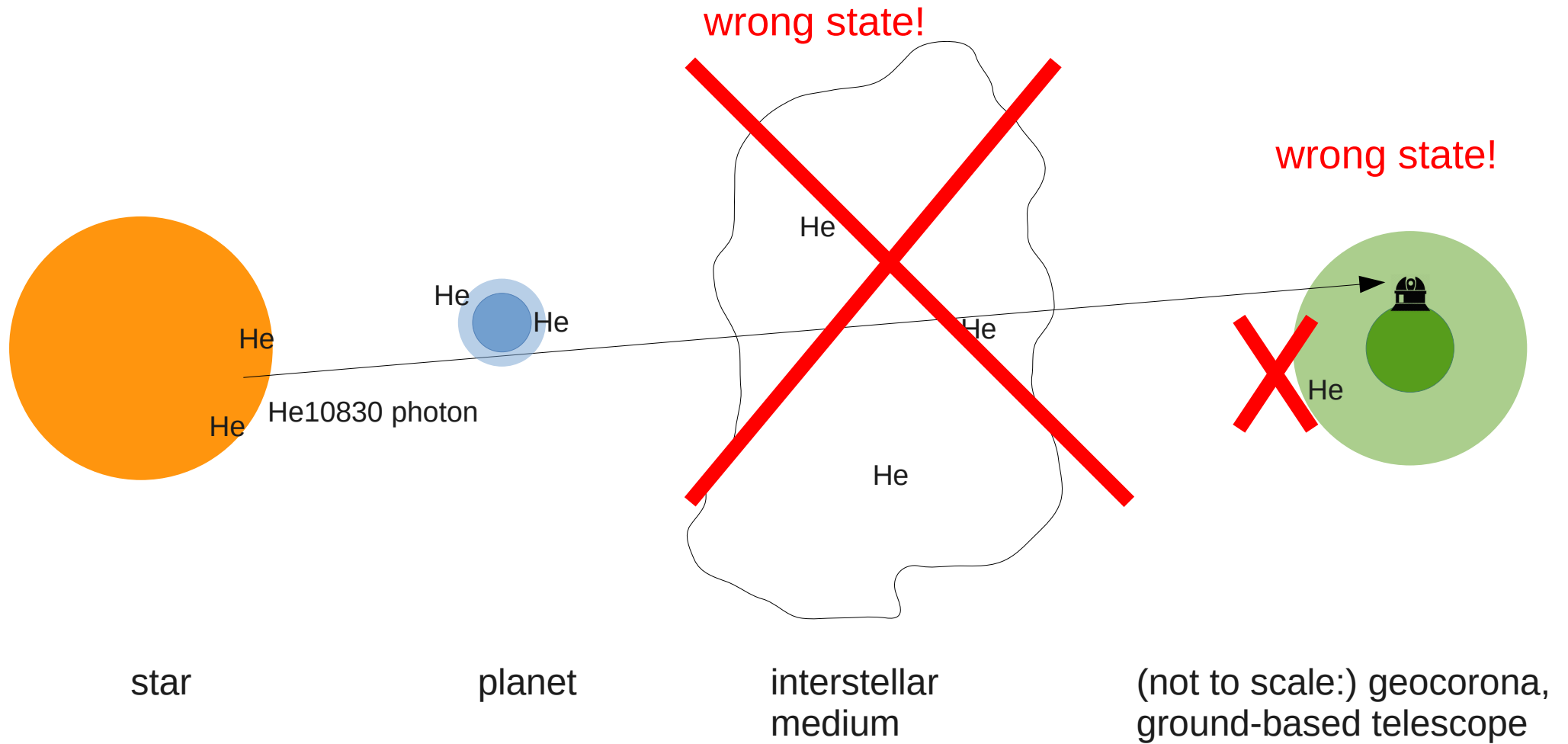
Enter: metastable He 10830 line



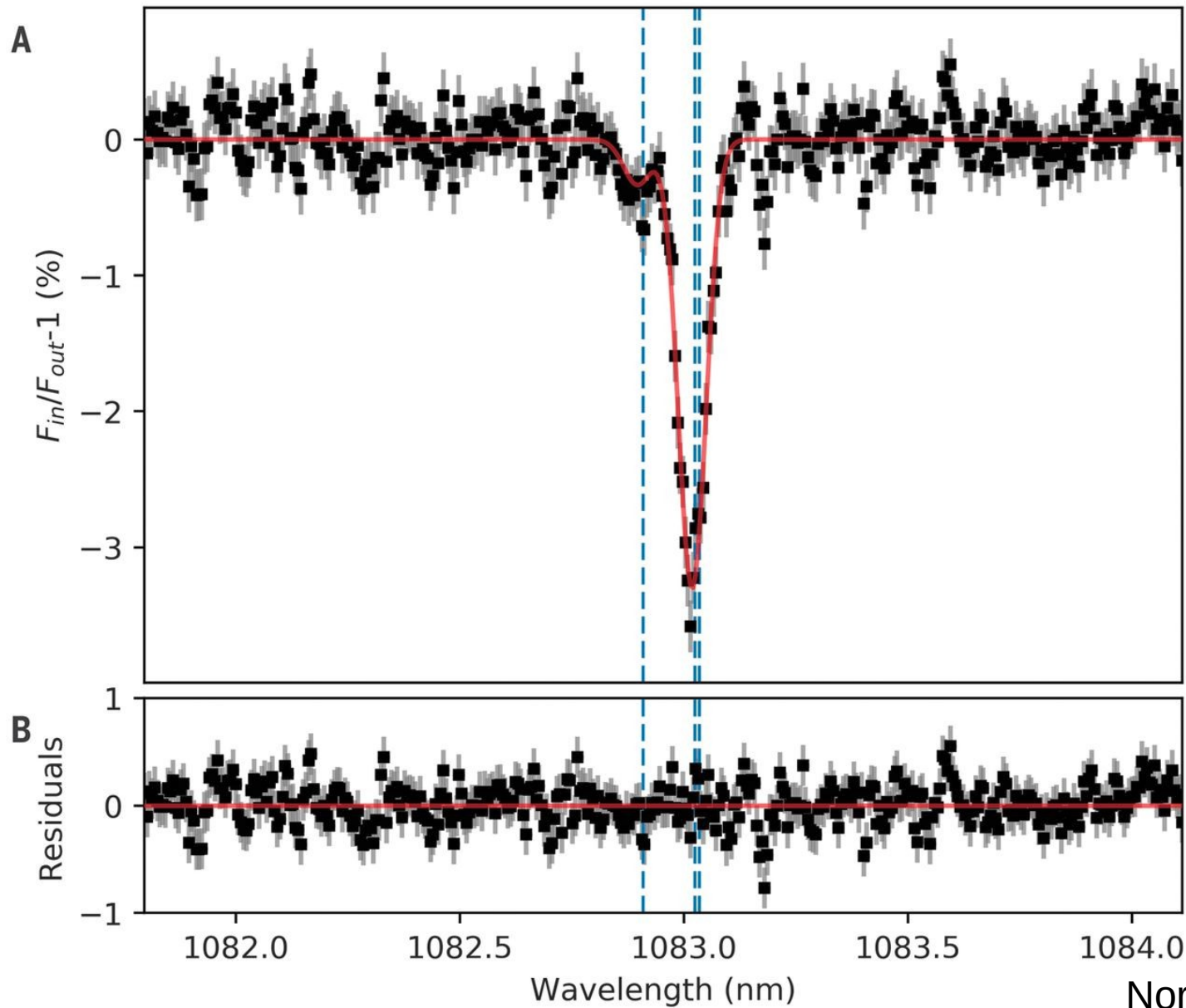
Enter: metastable He 10830 line

wrong state!

wrong state!



Evaporation tail: WASP-69 b



Nortmann et al. (2018)

Atmospheres: transmission spectroscopy

Measures **excess absorption** compared to a spectrally flat (“grey”) transit that reduces the flux by the same fraction everywhere in the spectrum.

