Probing the atmospheric properties of exoplanets through light curve analysis and using 1-D atmospheric models

Arvind Singh Rajpurohit (LAM, Marseille)
Olivier Damengeon (LAM, Marseille)
Magali Deleuil (LAM, Marseille)
Derek Hoemier (Univ. of Heidelberg, Germany)
France Allard (ENS, Lyon)

Scientific Context

- Precise and well tested models and numerical tools for very low mass stars and brown stars and brown dwarfs has been developed.

> Magneto-Hydrodynamics
> Radiative transport
> Information of molecules, dust, additional densities
> Detail Line profiles and Molecular opacities of interest
> Cloud physics

Very well tested and constrained (thanks to very precise data set available) for those regime.

- Such models and tools at such level of complexity and accuracy doesn't exist for exoplanets. (because of lower quality of exoplanets data set)

Scientific Approach and Compelling Questions for Hot Jupiter Atmosphere

Scientific approach :

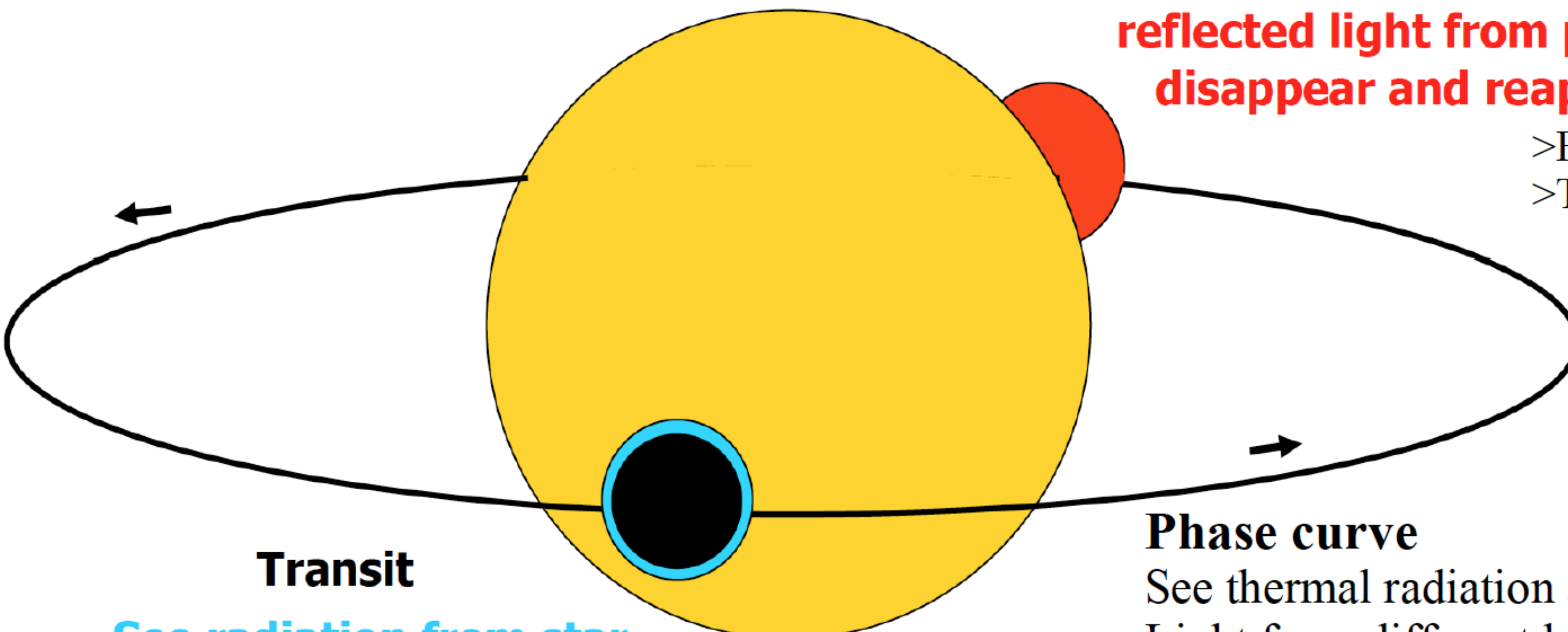
Modeling : Scale and adapt models developed for low mass stars for the case of Hot Jupiters and test them against exoplanets observations.

Observational Constrain : Transit, Secondary eclipse and Phase curves from CoRoT, Kepler, K2, CHEOPS, TESS and PLATO

Scientific Objective :

- How the irradiation affects the atmospheric structure ?
  Temperature distribution and dynamics, its chemistry, and the planets cooling and contraction
- Do their atmospheres have ~solar composition ?
  Or are they metal-rich like solar system planets
- How is the absorbed stellar energy redistribution in the atmosphere ?
  Hot Jupiters are tidally locked with a permanent day side
- What are the cloud and dust properties in the atmosphere of hot Jupiters ?
  How cloud impact the albedo (Kepler 7b)

What Do Different Types of Events Tell Us About the Planet's Atmosphere?



Secondary Eclipse

See thermal radiation and reflected light from planet disappear and reappear

>Emitting atmosphere τ~2/3
>Temperature structure

Transit

See radiation from star transmitted through the planet's atmosphere

> Planet radius
> Chemical composition of upper atmosphere

Phase curve

See thermal radiation and reflected Light from different longitude on the planetary surface

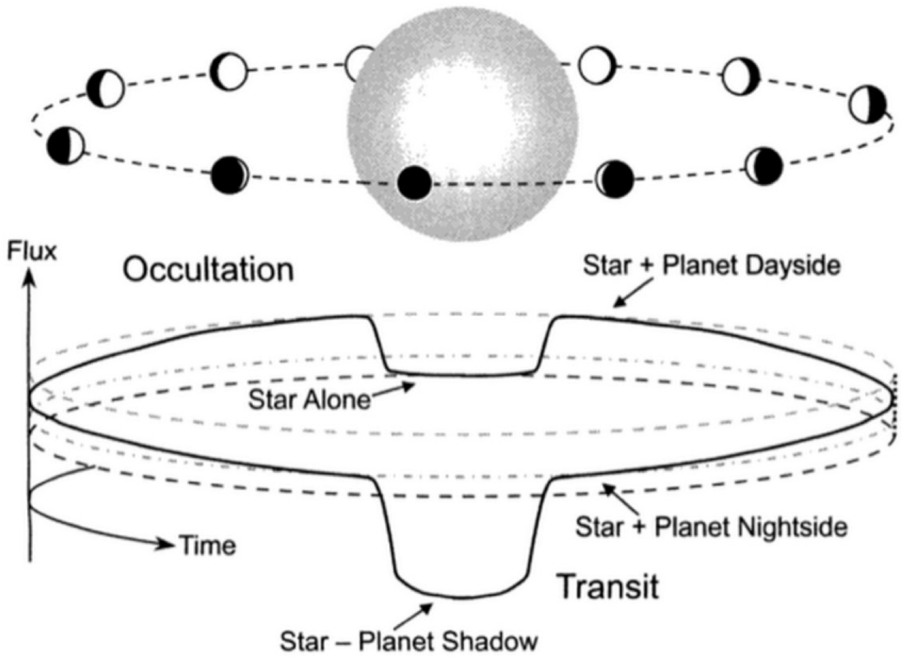
> Reflection spectra
> Albedo
> Scattering atmosphere

Properties of Hot Jupiter

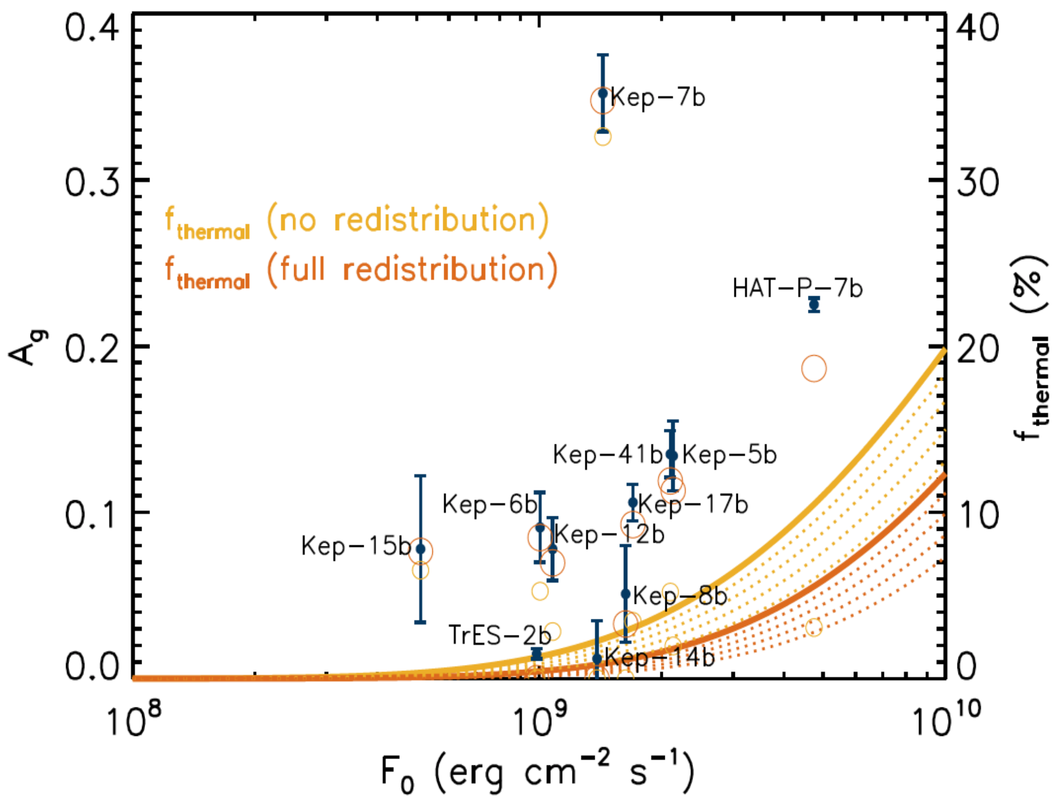
- Teff = 900-2500 K
- Major absorbers are H2O, CO, CH4, Na, K, H2 Rayleigh scattering
- Giant exoplanet atmospheres have the right condition to form condensates.
- High temperature condensate clouds may be present : MgSiO
- Scattered light at visible wavelengths
- Thermal emission at IR wavelengths

Atmospheric Properties

- Albedo gives us the energy budget of the atmosphere.
- Help to understand the vertical profile of absorb stellar flux.

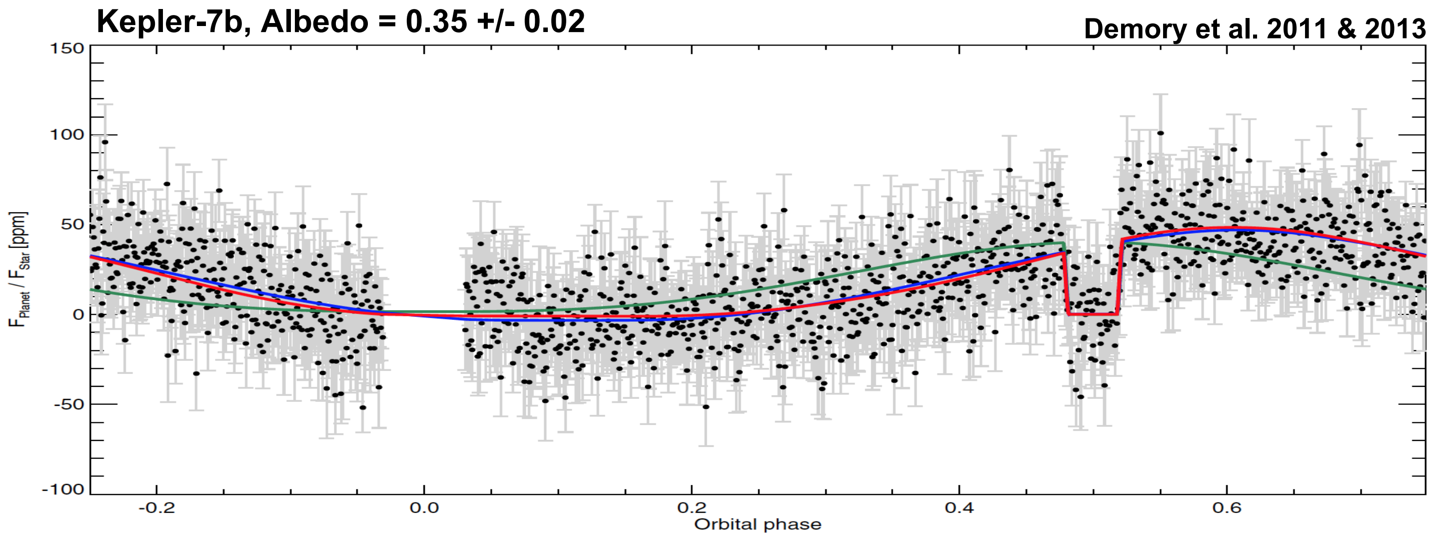


Heng & Demory 2013



No correlation with the stellar irradiation

Phase curve



- Phase curve shape reflects changes in the atmospheric circulation pattern as a function of depth in the atmosphere.
- Albedo could be primarily associated with the presence of clouds in irradiated atmospheres.
- A holistic modeling approach is needed to understand properties of the embedded cloud particles (which determine the albedo).

Large Range of Parameters

> Particle size distribution, composition, and shape

> Fraction of gas condensed

> Vertical extent of cloud

> Opacities

> Atmospheric circulation of heat redistribution

> Internal luminosities (mass and age dependent)

Why BT-Settl model atmosphere ?

- **Computed using the PHOENIX code and model updated for :**

(1) Updated H_2O line lists by Barber & Tennyson (BT2)

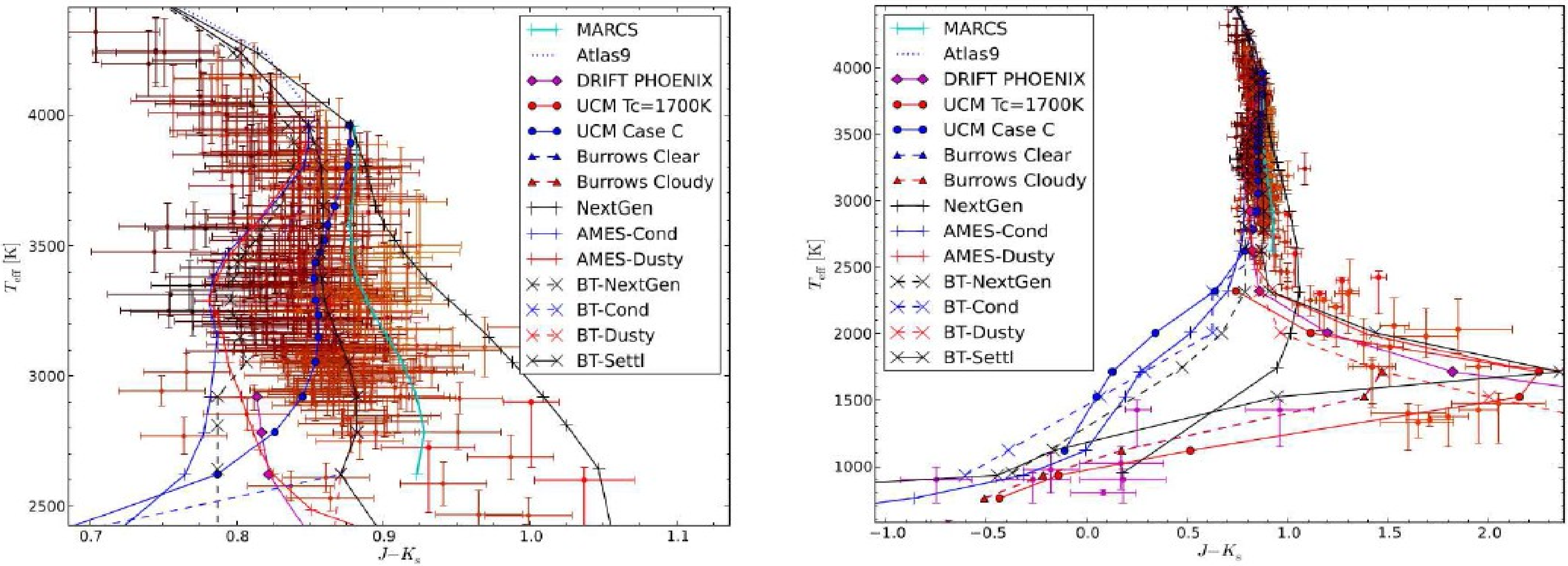
(2) Revised atomic and molecular opacities (TiO, VO).

(3) Cloud Physics, Dust formation and Green house effects.

(4) Absorptive properties of 600 different species.

(5) The solar abundances revised by Asplund et al. 2009.

BT-Settl Model



Allard et al 2013, Allard et al in preparation

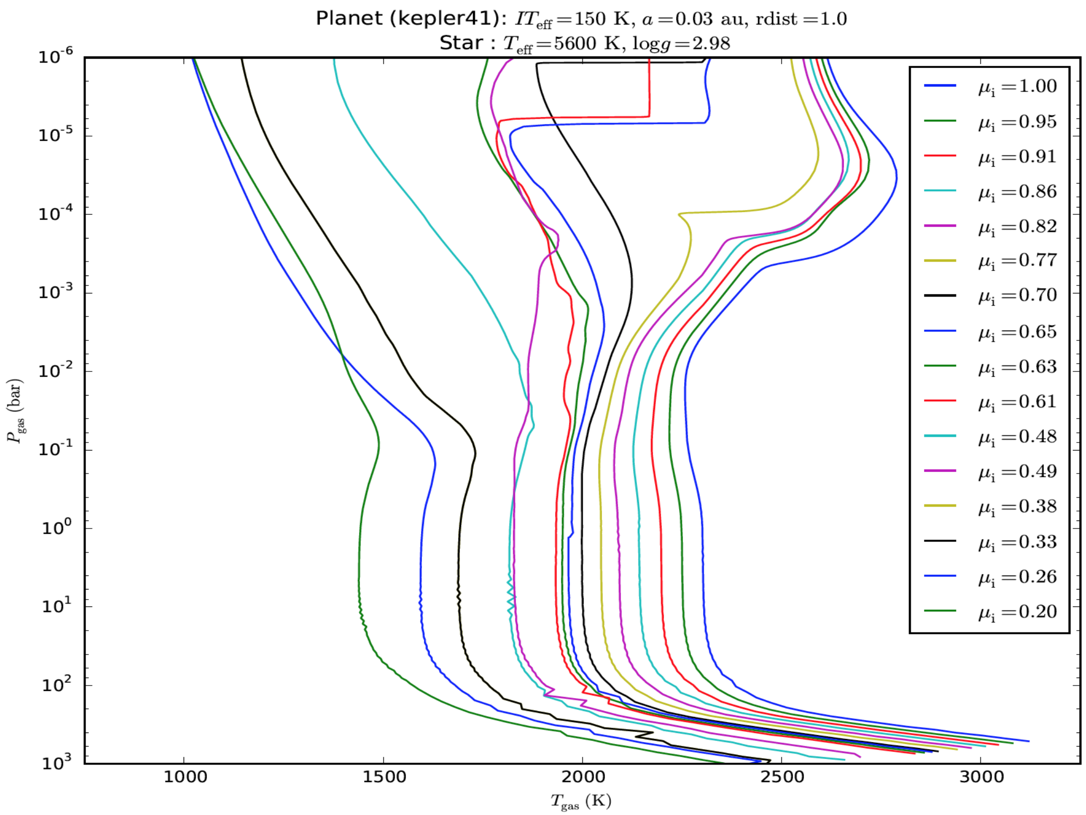
- **The region below 2900K is dominated by dust formation (Rajpurohit et al 2012).**

- **The BT-Settl models reproduce the redder infrared colors of young planets directly observable by imaging as an effect of their lower surface gravities.**

Methodology

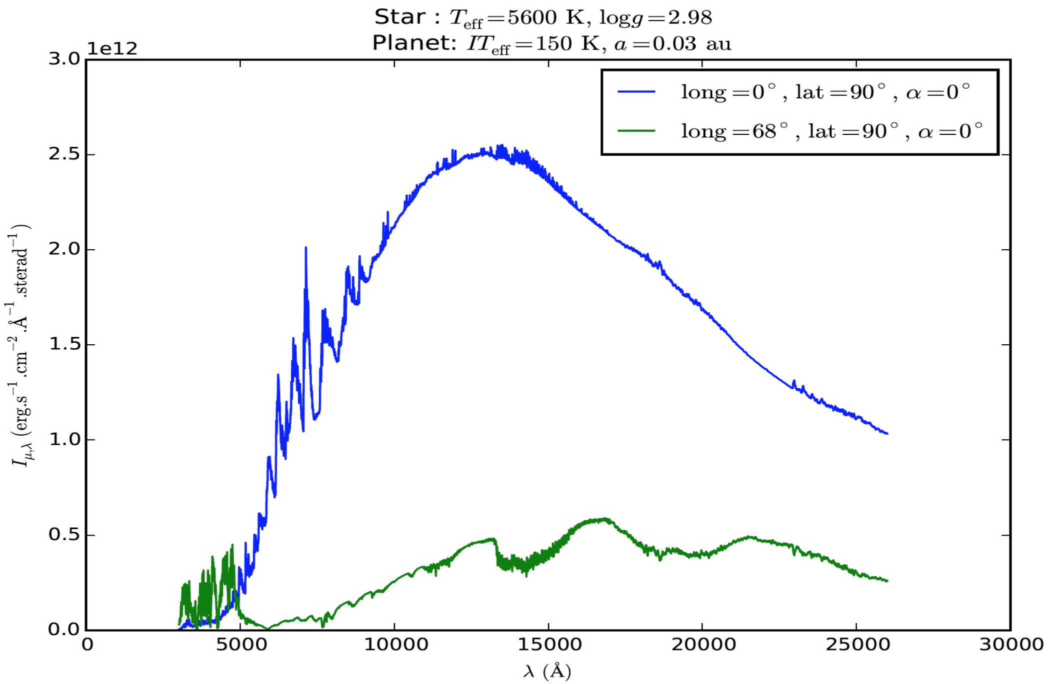
Using 1D PHOENIX radiative transfer code:

1. Calculate irradiation effects under varying incident angles.
2. Calculate theoretical phase fluxes using the PHOENIX atmosphere code to be compared to published phase curves and secondary of CoRoT and Kepler planets.
3. To explore the effect of grains and the clouds on the atmospheric profiles.



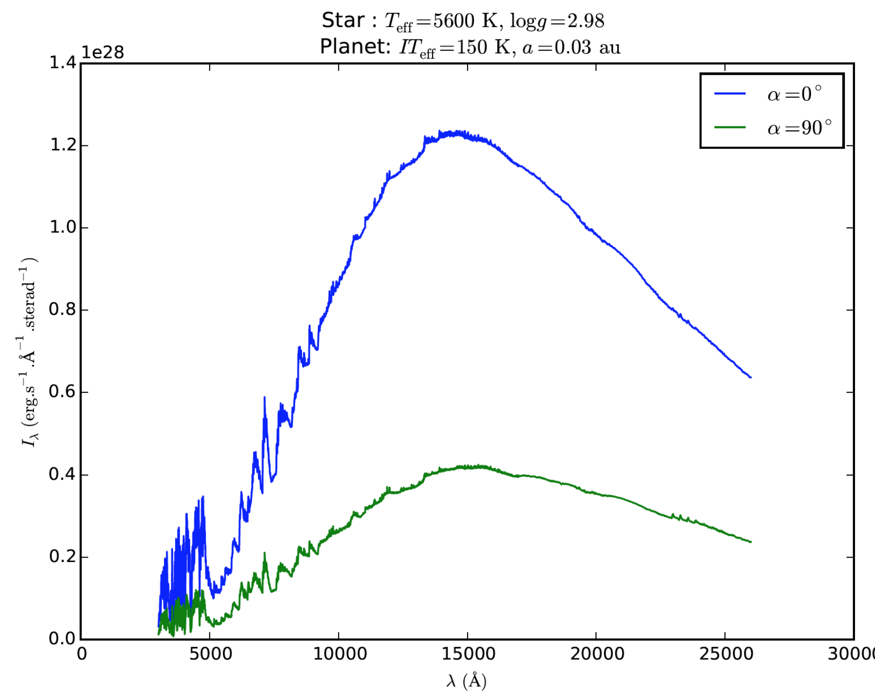
16 different incident angles on the planetary surface for Kepler 41b to represent the difference in isolation seen by different point of the dayside.

Kepler 41b

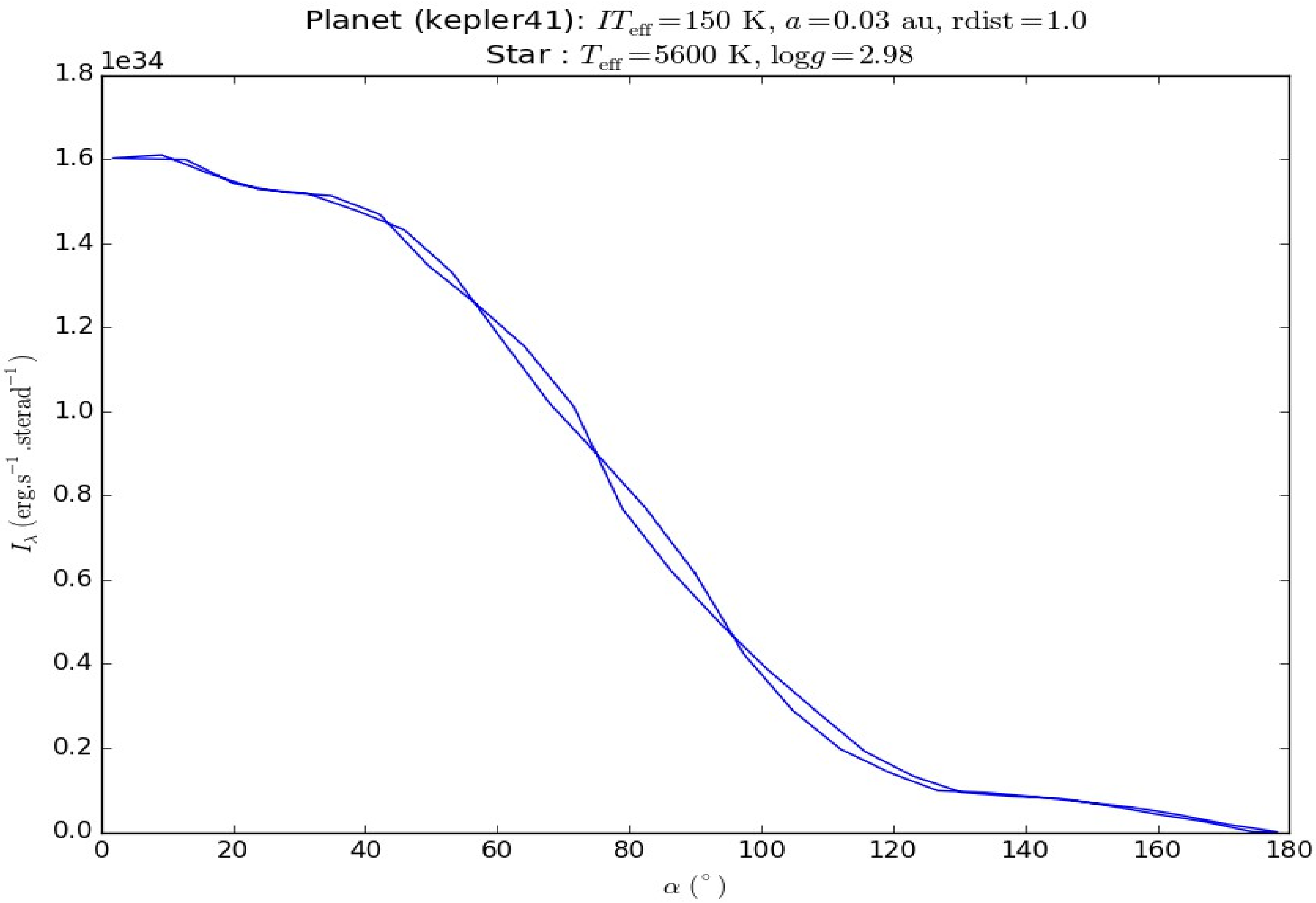


spectrum received from different points of the planetary surface defined by their longitude, latitude on the planetary surface and the phase angle of the planet

spectrum received from the whole planet at different phase angle



Kepler 41b



Phase curve obtained for kepler41b from 0 to 180 degrees and from 180 to 360 degrees

Ongoing work

- Compute day and night side grid of models (**BT-Settl**) for given sets orbital and atmospheric parameters.

> Equilibrium temperature
> Day and Night side temperature
> Redistribution factor
> Albedo

- Reproduce the phase light curve and the depth of the transits for individual planets for which we have phase light curves and precise photometry for ex. **Kepler 17b, Kepler7b CoRoT 2b and Kepler-412b** and compare our results with the published ones.

Conclusion

- Phase curves at very high precision open the possibility set constraints on the atmospheric properties (~ now 20 phase curve exists).

- We still lack the comparison of a significant sample of planets to atmosphere models that is required to explore in detail possible link between the albedo and the thermal and circulation atmospheric properties.

- Atmospheric circulation pattern yet not well understood because of lack of opacities and compositional gradients.