Climate variations on water-rich circumbinary planets and their impact on habitability

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Why study circumbinary planets ?

- Binary and other multi-star systems are fairly common and are therefore potentially interesting targets to look for habitable planets.
- Several circumbinary planets have already been discovered: Kepler-16b, Kepler-34b, Kepler-35b, Kepler-413b, …
- Compared to single-star circumbinary systems pose additional challenges to habitability.

Challenges for habitability

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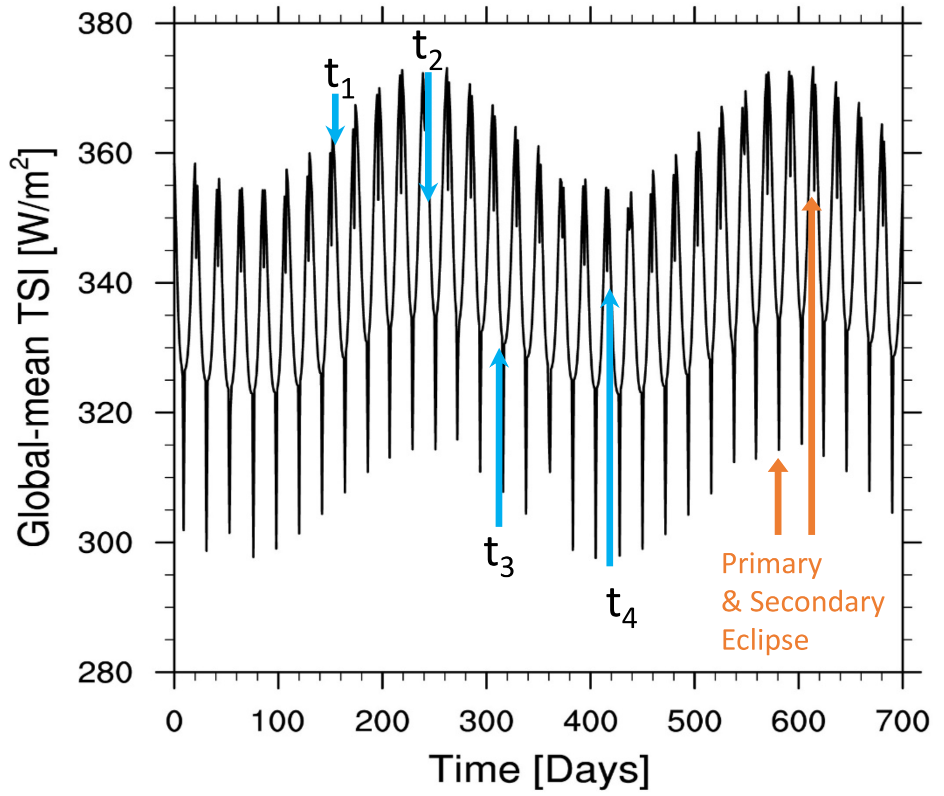
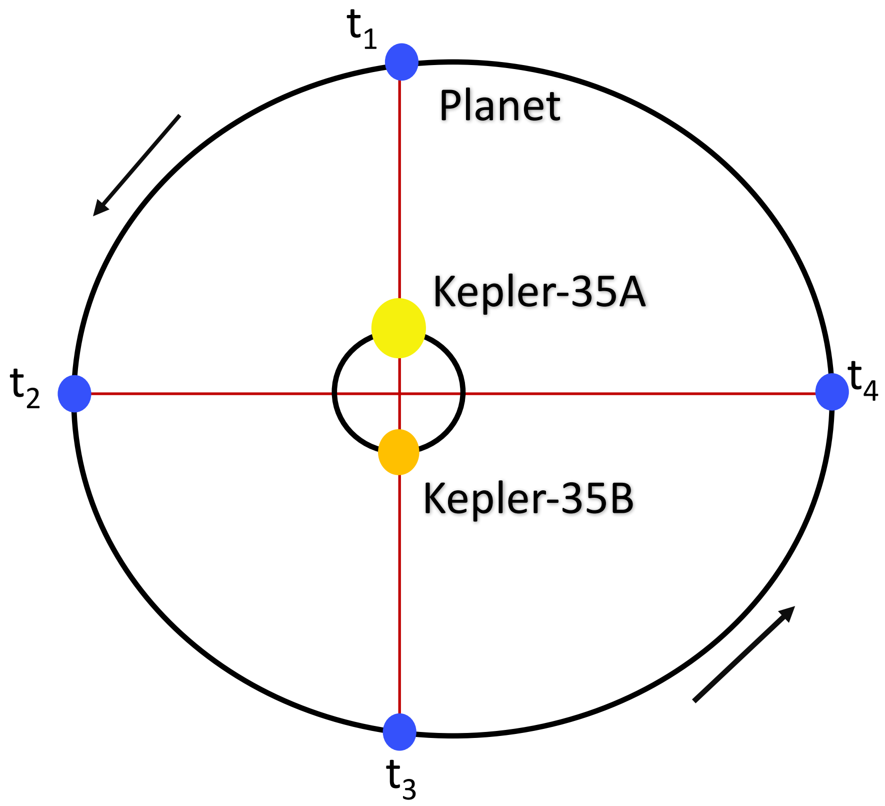
Periodic forcings:





TSI: Total Solar Irradiance (= Insolation)

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  The insolation of a planet in a circumbinary system changes continuously. ?

Previous studies

For high eccentricity planets:

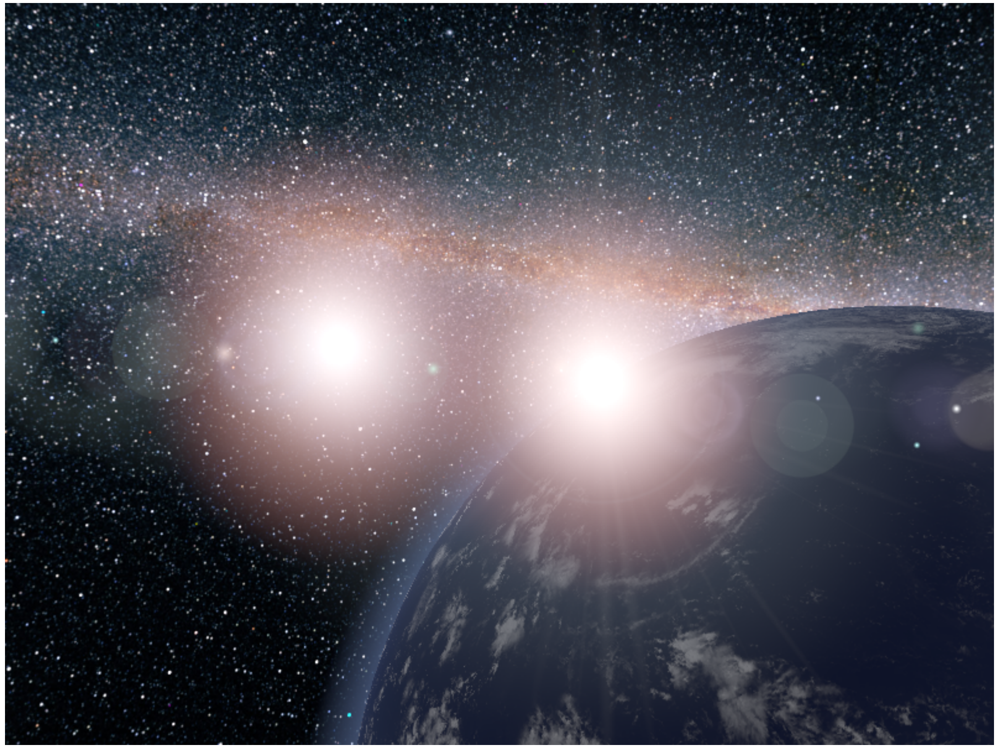
- Williams and Pollard 2002: Habitability depends only on the temporal mean insolation (3D Climate Model).
- Bolmont et al. 2016: The mean-flux approximation does not always hold (synchronous orbits, 3D Climate Model).

Circumbinary planets:

- Forgan 2014, 2016: Suggest that several binary systems have large habitable zones, depending on the eccentricity and the strength of the Milankovitch cycles (latitudinal energy balance model).
- Eggl et al. 2014: The gravitational interactions in the three-body system may constrain the habitable zone of binary star systems (evaluated based on a 1D radiative convective equilibrium model).

Motivation

1. Circumbinary planets receive a strongly varying amount of sunlight, and
2. this might influence the habitability of binary star system, but
3. this has only been investigated with simplified climate models.



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Therefore we performed the first simulations with a 3D climate model of a water-rich planet around a binary star.

Experimental setup

- We use a modified version of the atmospheric climate model ECHAM6 (Popp et al. 2016) coupled to a slab ocean.
- The GCM is coupled to an analytical orbit propagator for circumbinary planets (Georgakarakos & Eggl, 2015).
- We perform simulations of an aqua-planet setup (fully water covered planet) in a Kepler-35-like system with 0° obliquity and Earth-like parameters (mass, radius, etc.).
- We explore different orbits.

Fixed model parameters	Kepler-35A	Kepler-35B	aquaplanet
Mass	0.8877 M_{Sun}	0.8094 M_{Sun}	1.000 M_{Sun}
Radius	1.0284 R_{Sun}	0.7861 R_{Sun}	1.000 R_{Earth}
Effective temperature	5606 K	5202 K	-
Rotation period	-	-	1.000 P_{Earth}
Obliquity	0°	0°	0°

Experimental setup & Overview results

- For the same insolation the global-mean surface temperatures are very similar.
- The climate is somewhat colder in the Kepler-35 system in a priori cold climates.
- Therefore, the periodic variation do not substantially affect the habitability of the planet.

Semimajor axis	Mean insolation	Final state	Mean temperature	Albedo	Absorbed insolation
Kepler-35					
1.140 au	1.050 S_0	Moist Greenhouse	337.9 K	0.291	0.744 S_0
1.165 au	1.004 S_0	Earth-like	291.0 K	0.280	0.723 S_0
1.195 au	0.954 S_0	Earth-like	271.5 K	0.332	0.636 S_0
1.225 au	0.907 S_0	Snowball	196.5 K	0.735	0.240 S_0
Kepler-35, solar spectrum					
1.165 au	1.004 S_0	Earth-like	291.0 K	0.285	0.718 S_0
1.195 au	0.954 S_0	Earth-like	271.9 K	0.337	0.632 S_0
Sun:					
0.975 au	1.052 S_0	Moist Greenhouse	337.8 K	0.304	0.732 S_0
1.000 au	1.000 S_0	Earth-like	291.0 K	0.286	0.714 S_0
1.025 au	0.952S_0	Earth-like	272.8 K	0.337	0.631 S_0
1.050 au	0.907 S_0	Snowball	197.4 K	0.774	0.233 S_0

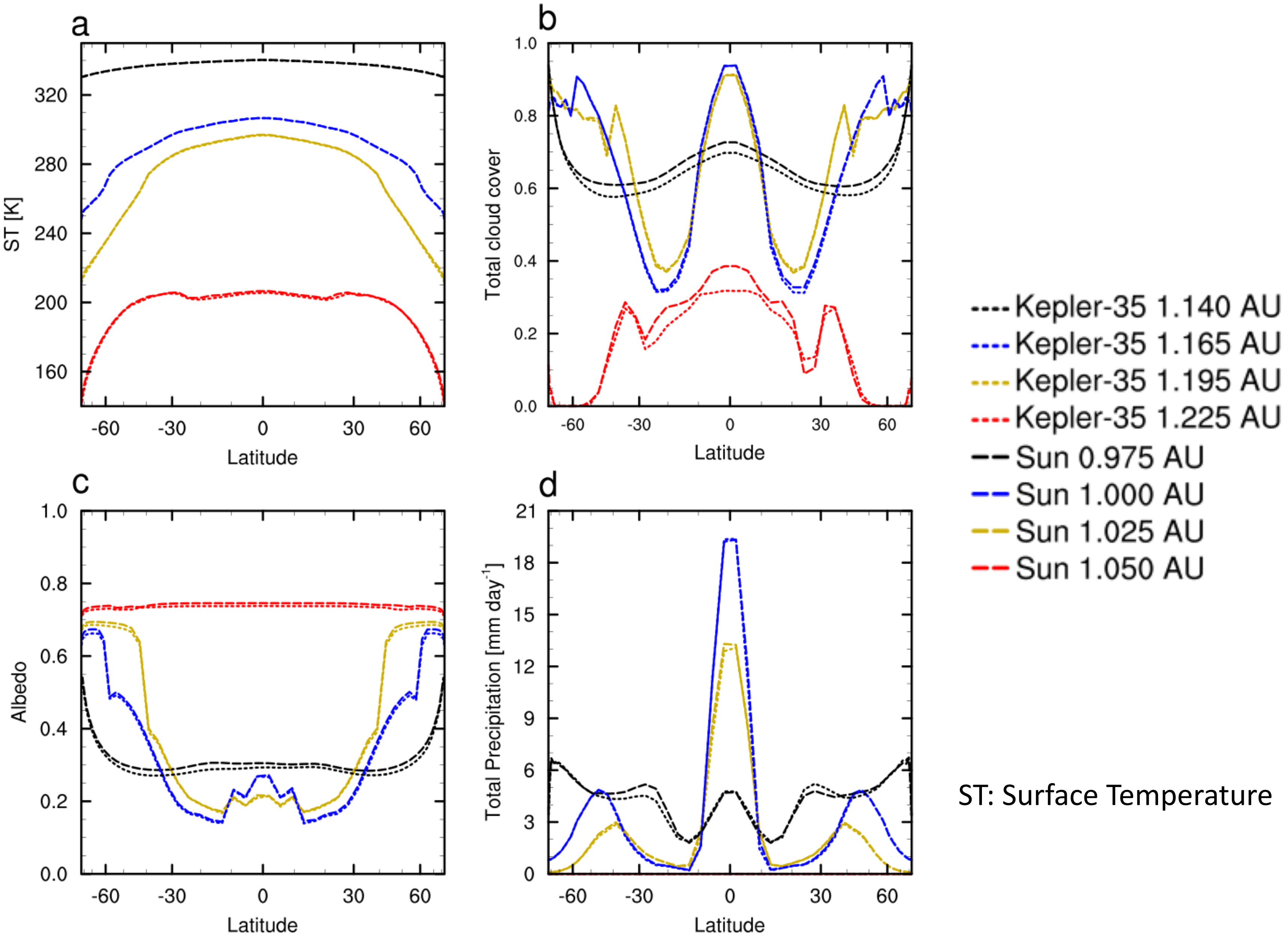
S_0 : Mean insolation on present-day Earth

Results published : *Popp & Eggl (2017), Nat. Comm. 14957*

Results

- The meridional structure of main climate indicators is similar in the Kepler-35 and our solar system in all states.

- The cloudiness and the albedo are somewhat lower in the Kepler-35 than in our solar system.

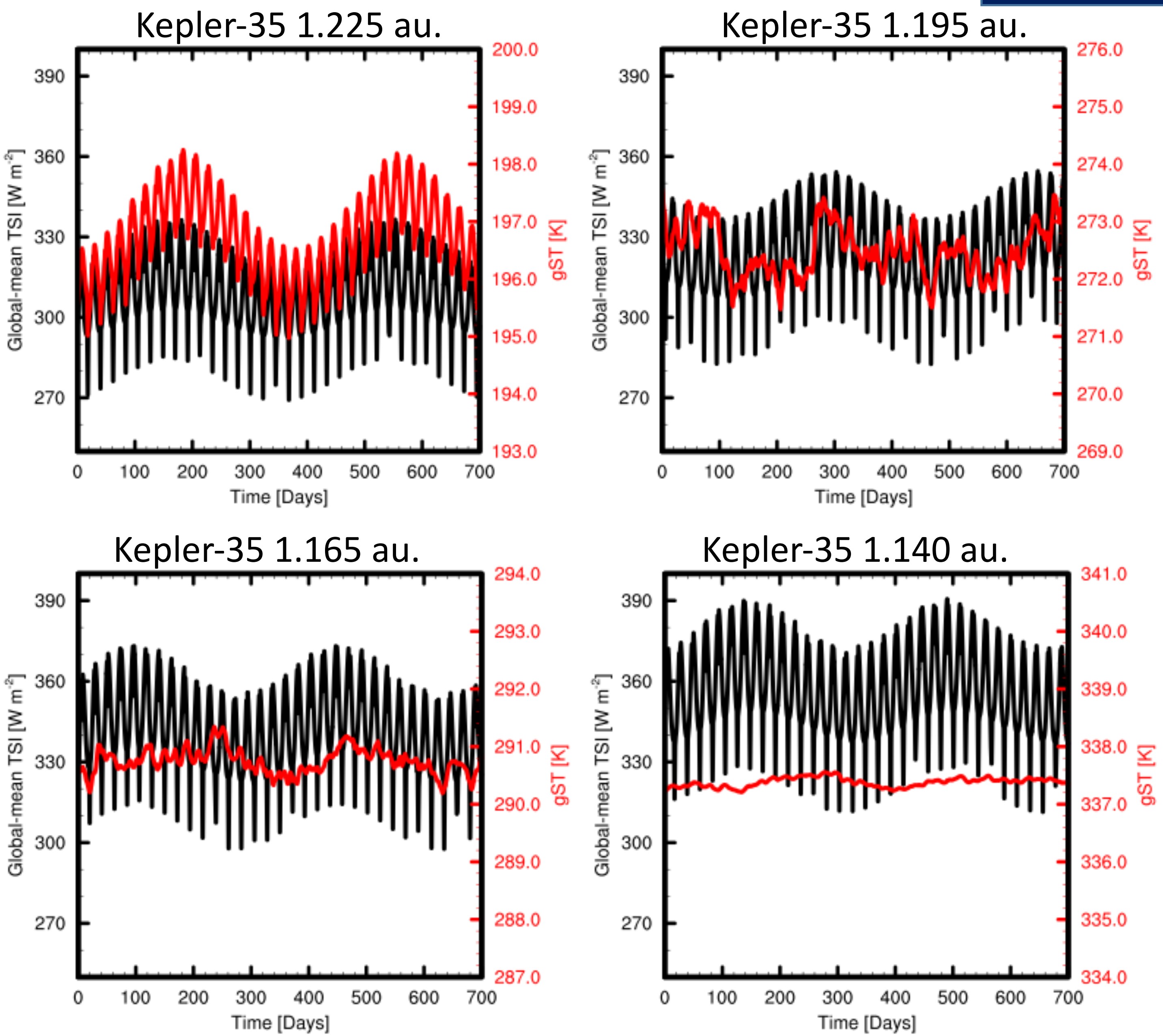


ST: Surface Temperature

Results published : *Popp & Eggl (2017), Nat. Comm. 14957*

Results

- However, on short time-scales the variations in surface temperature are clearly visible.
- The variations in surface temperature decrease with increasing mean surface temperature.
- The higher heat capacity of open water compared to sea ice, the ability to store more latent heat in warmer climates and the stronger feedbacks at higher temperatures all contribute to this effect.



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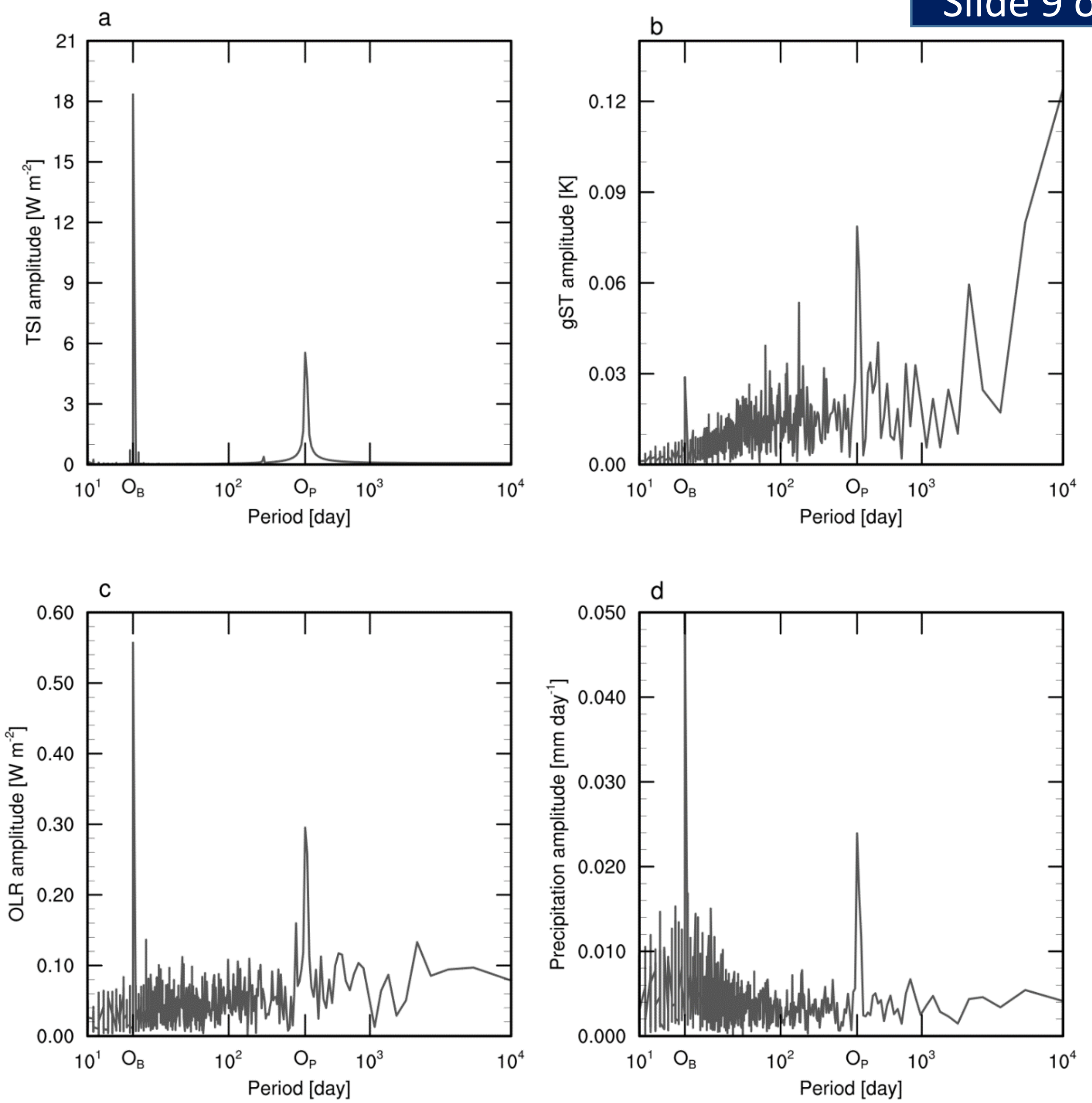
Results

- The variations in surface temperature from the orbital periods of the binary and planetary orbits show clearly in the spectra.

- For the surface temperature, the longer period with smaller period from the planetary orbit dominates the spectrum, whereas for the outgoing longwave radiation and the precipitation the shorter period with larger amplitude from the binary orbit dominates.



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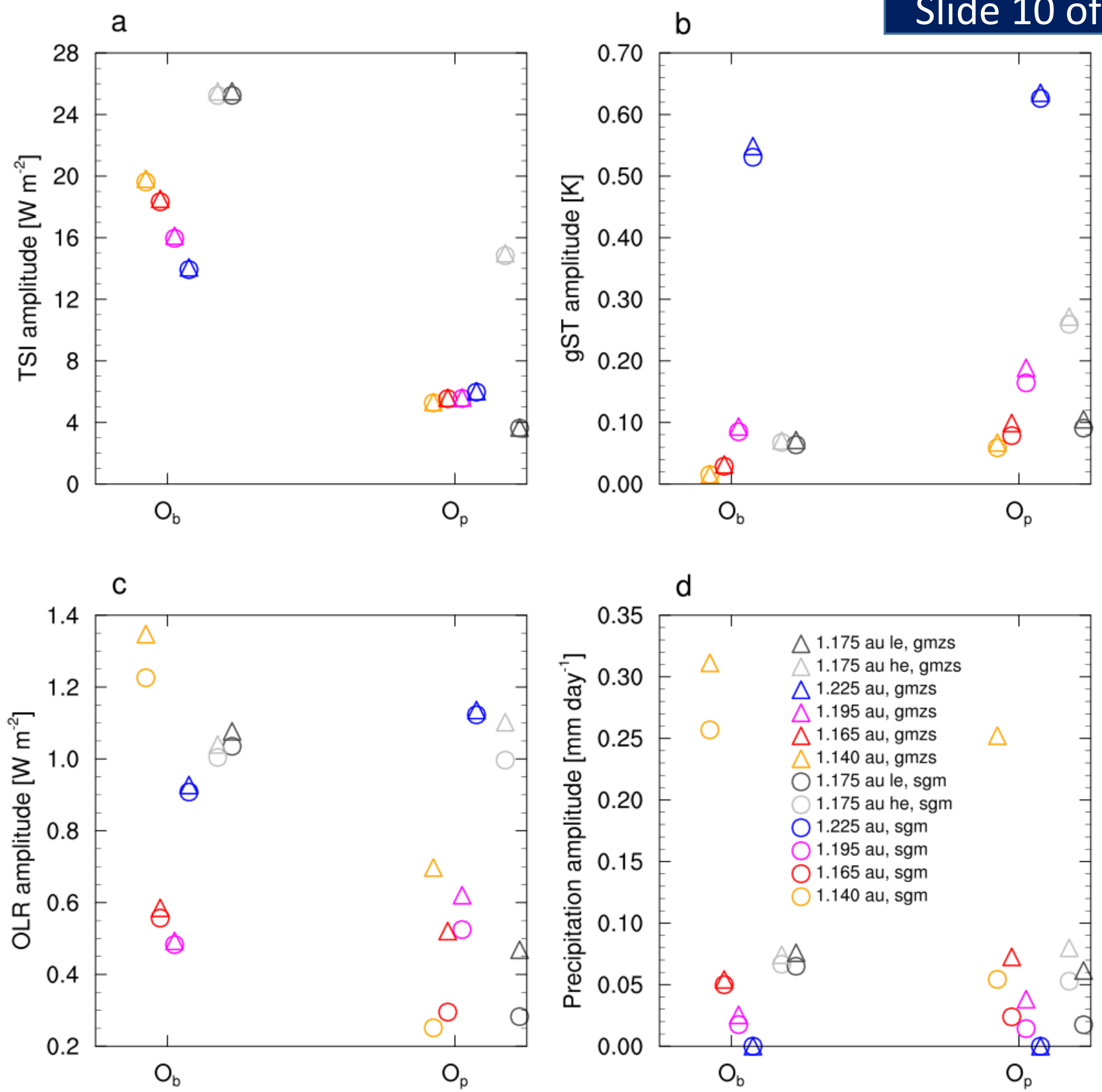
Results

- The amplitude of the response of a quantity increases with the period and the amplitude of the forcing.
- Which of the periods dominates the response depends on the quantity and on the climate state.
- In general the amplitudes of global-mean quantities are smaller than the global-mean of zonal-mean amplitudes.

Implications for observations:
Without knowledge of the climate-state the amplitudes of observables will be underestimated.



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Outlook

It appears that the periodic forcing experienced by circumbinary planets does not affect the mean climate much, because:

1. If the planet is close to the host stars the periods are too short to alter the climate.
2. If the planet is far from the host stars the amplitudes are too small.

Other parameters, such as the solar spectra have a larger influence on the climate.

Semimajor axis	Stellar spectrum	Slab ocean depth	Insolation	Surface temperature	Albedo
Our Sun					
1.000 au	solar	50 m	1.000	291.0 K	0.286
Kepler-35					
1.165 au	Kepler-35	50 m	1.004	291.0 K	0.280
1.165 au	solar	50 m	1.004	291.0 K	0.285
1.165 au	solar	2 m	1.004	288.6 K	0.294
Kepler-34					
1.670 au	Kepler-34	50 m	1.001	283.0 K	0.307
1.670 au	solar	50 m	1.001	290.9 K	0.286
1.670 au	solar	2m	1.001	287.6 K	0.299
Kepler-413					
0.552 au	Kepler-413	50 m	1.001	337.6 K	0.250
0.552 au	solar	50 m	1.001	290.9 K	0.286
0.552 au	solar	2m	1.001	287.7 K	0.298

Take home message

- The periodic variations in insolation on circumbinary planets clearly show on short time scales, but do not substantially alter the mean climate.

  → **Binary star systems similar to those studied here are excellent candidates to look for habitable planets.**

- Without knowledge of the planets climate, the amplitude of climate variations cannot be correctly inferred from distant observations (unless high resolution mapping would be possible).

  → **3D climate simulations of potentially habitable planets in circumbinary planets are crucial to estimate the planets' climate variations.**

- There are different time-scales and amplitudes involved in the climate response to periodic forcing experienced by circumbinary planets that lead to interesting short-term climate effects that are not yet understood.

  → **Studying these effects is not only important for a better understanding of climates on potential circumbinary planets, but also for the understanding of the response time-scales of the climate system in general.**

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Thank you !