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7 Summary

The concept of planets orbiting distant stars has long been used to fascinate and entertain in science fiction novels and films. However, in recent decades, extrasolar planets (or exoplanets) have left the realm of science fiction, and entered squarely into the realm of science fact.

After about 25 years of exoplanet discoveries, we now know of more than 3500 exoplanets. It is easier to detect exoplanets that have short orbital distances from their host stars, so the majority of these known exoplanets have orbits that are closer to their host stars than any planet in our solar system is to the Sun. In general, planets that are nearer to their host stars also have shorter orbital periods, so the closest of these exoplanets can have orbital periods of less than a day. These planets are at such short distances from their host stars, that they typically have temperatures on the order of 2000 °C. For comparison, the nearest planet to the Sun in our solar system is Mercury, which has an orbital period of 88 days and a day-side temperature of approximately 430 °C.

This thesis focuses on short orbital period planets that have mostly rocky compositions (in contrast to ‘gas giant’ planets like Jupiter). These ‘hot rocky exoplanets’ exhibit interesting properties due to their high temperatures that allow their composition to be studied in far greater detail than would be possible for cooler rocky planets.

7.1 Gas from hot rocky planets

Rocky planets that are close to their host stars are exposed to strong stellar winds and are heated to very high temperatures.

If they do not have thick atmospheres, they may be like extreme versions of Mercury, which has an exosphere (like a very thin atmosphere), that is produced by sputtering of its surface. This is when high energy charged particles from the Sun’s solar wind impact the surface material and cause atoms to be released. Elements like sodium, magnesium and calcium have been detected in the exosphere of Mercury. Considering that the exospheres of hot rocky exoplanets may be even

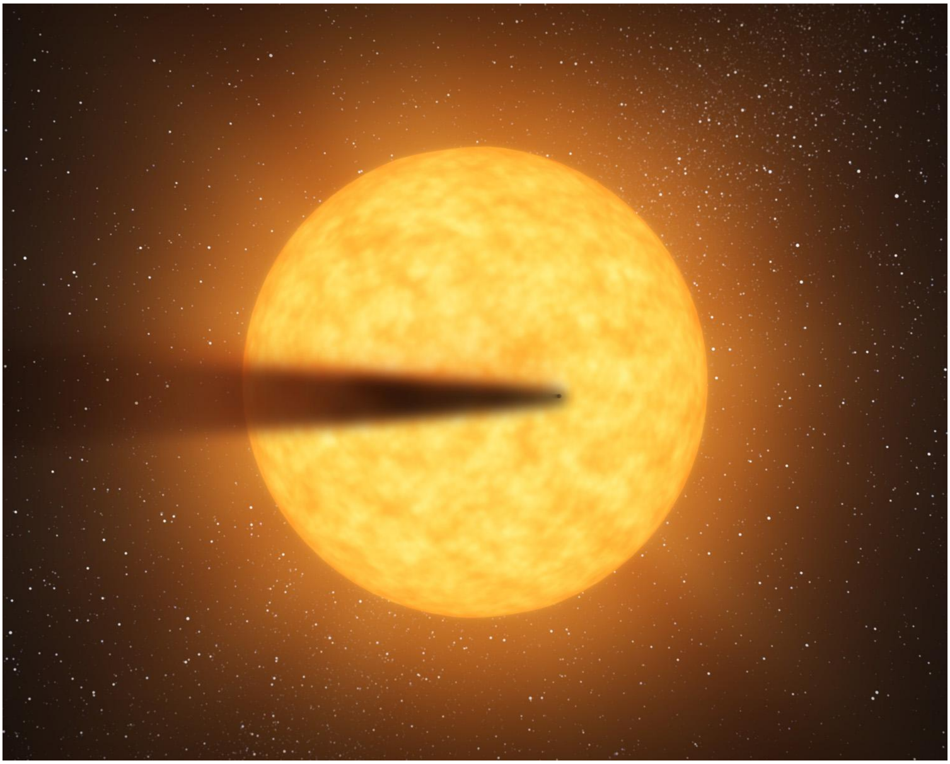

Figure 7.1: Artist's impression of the disintegrating rocky exoplanet, Kepler-1520 b. Image credit: NASA/JPL-Caltech - NASA Jet Propulsion Laboratory.

larger due to their shorter orbital distances from their host stars, they are also potentially detectable. It is also possible that their high temperatures will cause their surfaces to vaporise, producing atmospheres consisting of mineral vapours that can also potentially be detected.

In the most extreme cases, hot rocky exoplanets actively disintegrate and produce comet-like dust tails. An artist's impression of the disintegrating rocky exoplanet, Kepler-1520 b, is shown in Fig. 7.1. It is thought that the dust is lost from the planet as a result of its mineral vapour atmosphere expanding and cooling until some of the vapour can condense into dust grains and be dragged away from the planet by the remaining expanding gas. Additionally, volcanic activity may also play a role. Both the gas that is directly lost from the planet, and the gas that is produced by the sublimation of dust in the tail can potentially be detected.

In all of these cases the gas originates from the surface of the planet, so its composition must reflect the composition of the planet. Therefore, these objects offer us the possibility of gaining unprecedented insight into the composition of rocky planets. This information would greatly contribute to our understanding of how these planets formed and how they will evolve.

7.2 Observing exoplanet atmospheres

When light passes through a gas, unique wavelengths are absorbed by atoms or molecules in the gas. These absorptions are called spectral lines and depend on the composition of the gas. They can be studied with spectrographs which are instruments that disperse white light into its rainbow of constituent colours (or wavelengths). This technique allows the compositions of distant astronomical objects to be determined. When applied to exoplanets, it can be used to determine the compositions of their atmospheres. It can be most readily applied to exoplanets that transit (or pass in front of their host stars) as seen from Earth, because they allow us to observe how the star's light is changed by passing through the exoplanet's atmosphere. However, this is challenging because the host star and the Earth's atmosphere also imprint their own spectral lines, which are much stronger than the spectral lines from the planet's atmosphere. Therefore, it is necessary to remove the contributions of the host star and Earth's atmosphere to measure the contribution of the exoplanet's atmosphere.

This can be achieved by exploiting the fact that the exoplanet has a changing radial velocity during transit because at ingress (when it first moves in front of its host star), it will have a component of its velocity towards the observer and at egress (when it starts to move past the disk of its host star), it will have a component of its velocity away from the observer.

A relative velocity between a light source and an observer changes the wavelength of the observed light, due to the Doppler effect. Therefore, the changing radial velocity of the planet during transit will result in its spectral lines being shifted away from the lines of its host star and the Earth's atmosphere.

This technique is used in Chapter 2 of this thesis to search for sodium and ionized calcium in the atmosphere of the hot super-Earth, 55 Cancri e. While we were not able to make a definitive detection, we detected a strong signal of ionized calcium in only one of our data sets, tentatively suggesting that its exosphere may be variable, like the exosphere of Mercury.

It is also used in Chapter 5 of this thesis to search for gas around the disintegrating planet, K2-22 b. While we expect a large quantity of gas to be produced by the sublimation of its dust tail, we were not able to detect it. We argue that this is likely due to the gas atoms being significantly blueshifted by radiation pressure from the host star, caused by photons of light transferring their momentum to the gas atoms.

7.3 Dust tails

The dust tails of transiting disintegrating rocky exoplanets produce characteristic transit light curves that can be studied to constrain properties of the dust particles such as their average size and composition. This is very valuable information because it can give insight into the composition and geophysical processes of the planet. However, this information can only be inferred if the formation and evolution of the tails is understood, which depends on the orbital dynamics of their constituent dust particles.

The dust particles experience a radiation pressure, which acts to push them away from the host star and the host star's gravity, which acts to pull them towards the host star. For the dust particles in these tails, the star's gravity is somewhat stronger than the radiation pressure, so the overall force that acts on the particles is a reduced force towards the star, allowing them to stay in bound orbits.

Chapters 3 and 4 use a code to simulate transit light curves by building up a tail by ejecting virtual dust particles from the surface of a planet, letting the tail evolve under the influence of radiation pressure, then using a radiative transfer code to simulate the transit light curve that it would produce.

In Chapter 3, we use this code to derive some approximate constraints on the velocity with which the dust particles are ejected from the planet, potentially giving insight into the geophysical mechanism that causes the mass-loss. We also investigate how the amount of dust in the tail can affect the transit depth in different wavelengths and find that tails with more dust show less transit depth variation in different wavelengths, potentially explaining why only some multi-wavelength observations find such a variation.

In Chapter 4 we adapt this code to investigate how the orbital trajectories of the dust particles are affected by self-shielding within the tail, which is when dust particles on the edge of the tail facing the host star absorb some of the star's light, resulting in the particles deeper in the tail receiving less light and experiencing a weaker radiation pressure and reduced sublimation rate. We found that self-shielding can have a significant influence on the tail morphology in some cases and that dust compositions with fast intrinsic sublimation rates may be required to reproduce the observed lack of correlation between consecutive transit depths.