Irradiated brown dwarfs - hot Jupiter analogues?

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As brown dwarfs have atmospheres similar to those we see in Jupiter and in hot Jupiter exoplanets, irradiated brown dwarfs have been described as "filling the fourth corner of parameter space between the solar system planets, hot Jupiter exoplanets and isolated brown dwarfs". Irradiated brown dwarfs are however, rare. There are only about 22 known around main sequence stars, and even fewer that have survived the evolution of their host star to form close, post-common envelope systems where the brown dwarf orbits a white dwarf. These systems are however, extremely useful. The white dwarf emits more at shorter wavelengths, where the brown dwarf is brightest in the infrared, meaning it is possible to directly observe the brown dwarf – something that is extremely challenging for the main sequence star-brown dwarf systems.

BROWN DWARF DESERT

Despite there being a plethora of Hot Jupiters known, there are very few brown dwarfs discovered in similar orbits, a phenomenon known as the brown dwarf desert. This is thought to be caused by the difference in formation mechanisms, planets forming via core accretion around stars, but brown dwarfs forming via gravitational instabilty

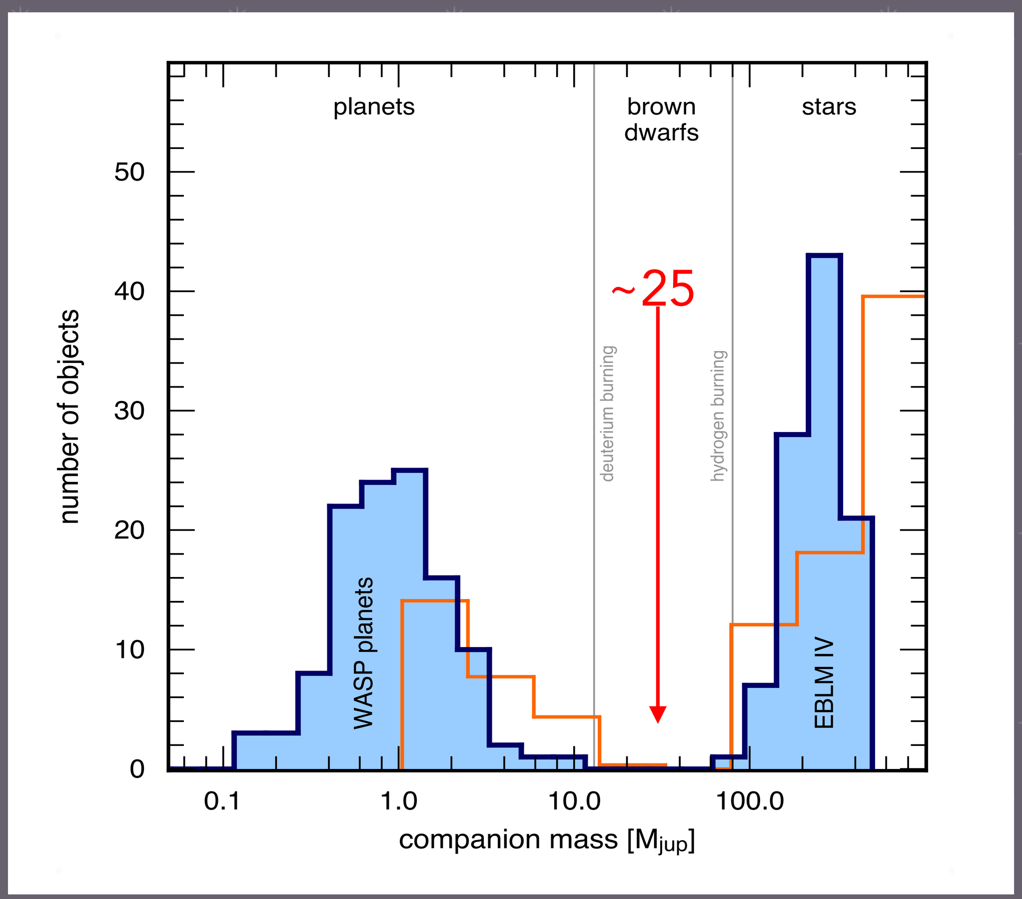

Figure 1: Brown dwarf desert (Triaud et al., 2017). Despite thousands of exoplanets discovered, and ~50% of sun like stars being part of a multiple system, there are only ~25 brown dwarfs orbiting main sequence stars within 3 AU (Carmichael et al., 2020).

ATMOSPHERES AND IRRADIATION

The brown dwarfs in these systems are highly irradiated leading to emission lines being seen from hydrogen, Ca I, Na I, K I, Ti I and Fe in the systems with white dwarfs hotter than 13000 K. The hottest primaries show fewer emission lines due to dissociation, but large day- night temperature differences of ~500 K (Casewell et al., 2015; 2018)

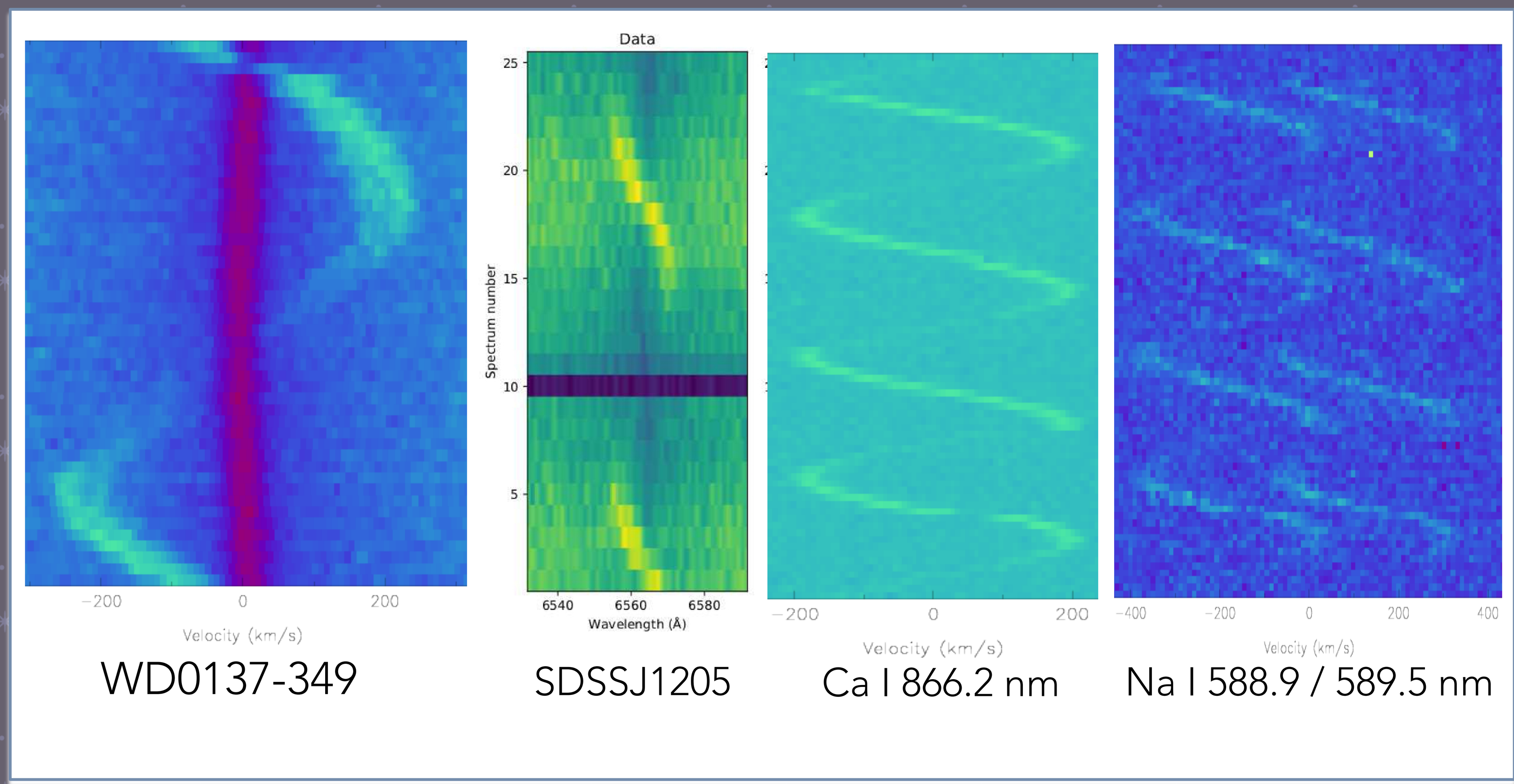

Figure 3: Halpha emission for WD0137 and SDSS1205 as well as Ca I and Na I emission from WD0137 (Longstaff et al., 2017; Parsons et al., 2017).

EVOLVED SYSTEMS

The evolved form of these systems, detached, post-common envelope white dwarf brown dwarf binaries however show huge potential for comparison to hot Jupiters. The periods are ~hrs, but the insolation is often similar to systems with a main sequence primary and a brown dwarf in an orbit of ~days.

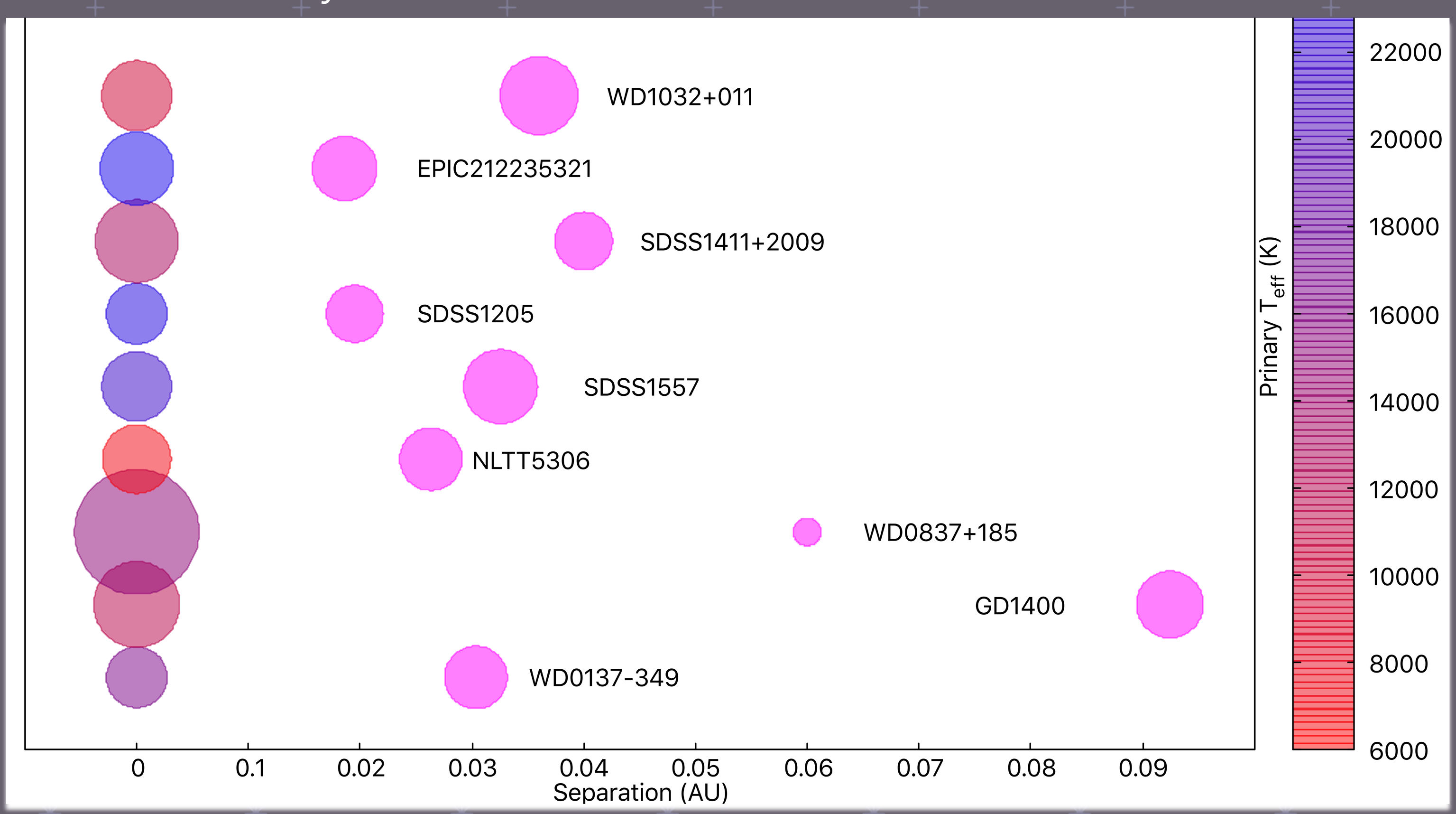

Figure 2:The known white dwarf-brown dwarf binaries. Periods range from 68 min (EPIC212235321) to 10 hrs (GD1400). The white dwarf effective temperature is represented by the colour. The pink circles are the brown dwarf secondaries. The size of the circles are proportional to the masses of the binary components.

BROWN DWARF INFLATION

Figure 4 shows that low mass brown dwarfs (<35 M_{Jup}) are generally inflated irrelevant of the insolation from their host star. Higher mass brown dwarfs are harder to inflate, and the majority are not. The brown dwarf WD1032+011B is eclipsing and nearly 70 M_{Jup}, and at least 5 Gyr old. Despite this, it is considerably inflated (Casewell et al., 2020a). Such inflation is not due to tidal deformation or rotation, as the white dwarf primary only has an effective temperature of 10000 K it is also unlikely to be due to the UV irradiation from the white dwarf.

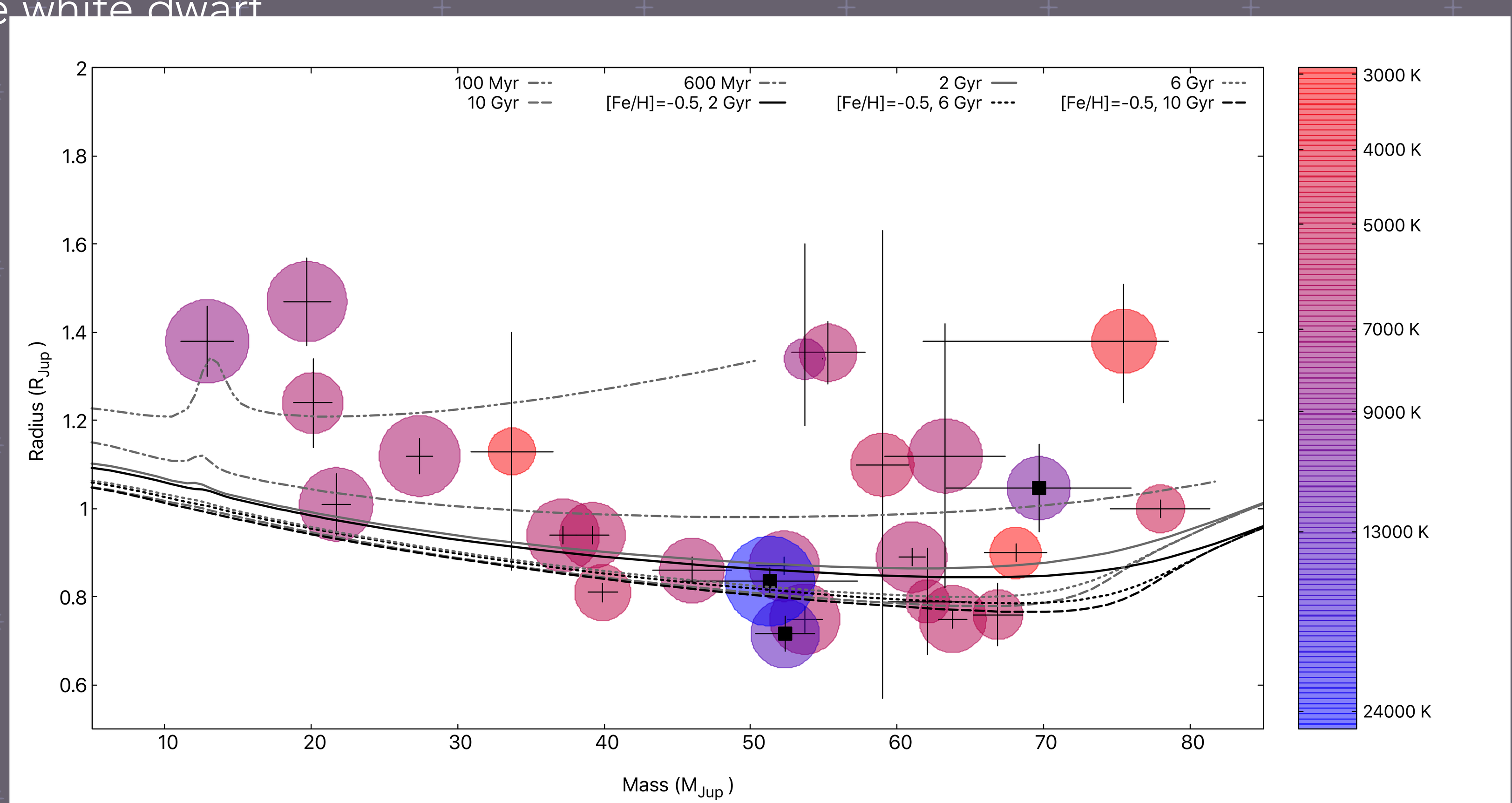

Figure 4: Mass-Radius relationship for all the known irradiated brown dwarfs. Colour is the effective temperature of the primary star, the circle size is proportional to the bolometric insolation. The 3 eclipsing systems with white dwarf primaries are plotted as squares. Adapted from Casewell et al., (2020b).

CONCLUSIONS

While there are only ~25 Main sequence-Brown dwarf binaries known, there are 9 known evolved forms of the binaries. With periods of only a few hours the brown dwarfs are tidally locked and often highly irradiated resulting in day-nightside temperatures of up to 500~K, and emission lines from the brown dwarf chromosphere. For a discussion of the modelling of these systems see Lee et al., (2020) and Lothringer & Casewell (2020).

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