TIGRE in pursue of a relation between the rotation velocity of stars and the physical properties of their exoplanets

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Introduction - exoplanets are weird beasts

As of today, the number of confirmed exoplanets is ~ 3700 in `http://exoplanet.eu/` (Schneider et al. 2011). Based on the information available, M_p, R_p, a_p and e_p, two important tasks are: 1) to determine their composition, 2) to understand how they formed.

So far what we found is puzzling! The exoplanets differ from the planets in the Solar System: 1) the majority are hot-Jupiters (HJs), super-Earths, and mini-neptunes; 2) their formation seems to involve migration.

Applying our own classification

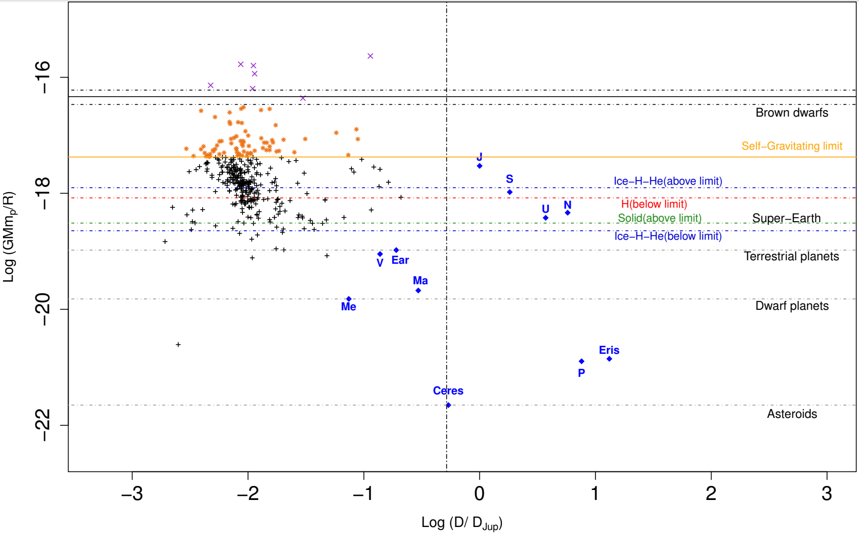

Fig. 1: Based on their Baryonic Gravitational Potential (BGP), we introduce a new classification criterion, the self-gravitating (SG) limit ($E_{binding} = E_G$), above which the composition of gas-giant exoplanets, with $M_C \geq 1.2 M_J$ and $R_C \sim 0.84 R_J$ (identify as SGE) could have massive envelopes of liquid metallic hydrogen (LMH).

SGE - hot-Jupiters or brown dwarfs?

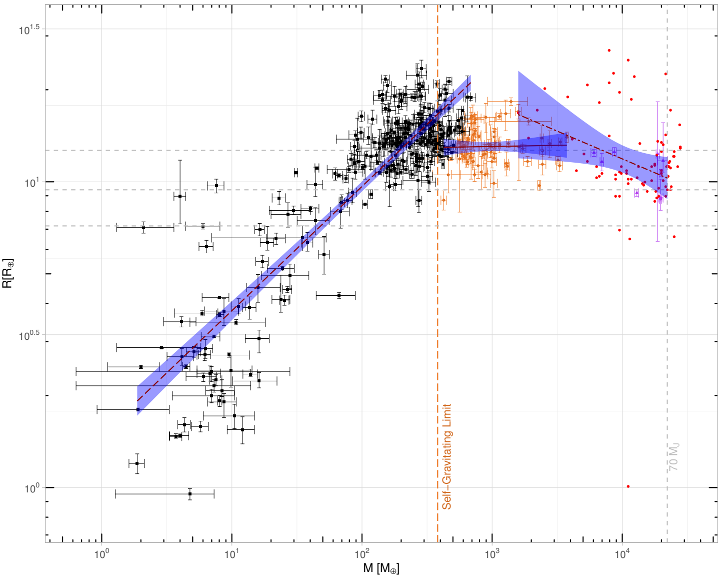

Fig. 2: Contrary to the HJs the SGE have a constant radius as the mass increases. In brown dwarfs (Bdws), the radius decreases with the mass. But what is the limit between the SGE and Bdws?

Model of exoplanets made of LMH, due to Hubbard et al.1997

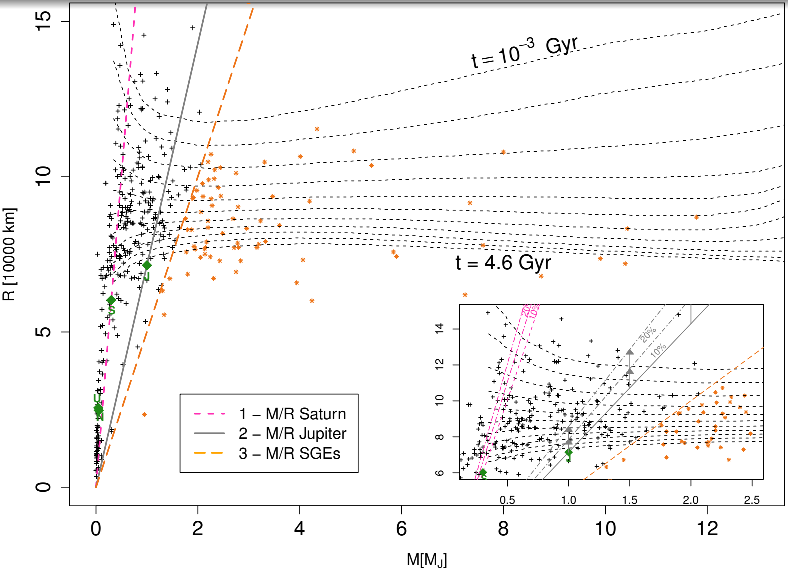

Fig. 3: Because LMH is incompressible, at different temperatures the radii of the SGEs are constant as the mass increases. Above the BGP corresponding to the SGE limit, we cannot explain the exoplanets in terms of HJ with inflated radii (by 10% to 20%).

Our analysis - What the rotation of stars can tell us about the formation of planets?

The importance of LMH in gas giant planets was confirmed by JUNO: 1) this produces stronger magnetic fields, 2) The solid core and LMH envelop have no sharp boundaries (Iron can be dissolved in LMH, Burrows & Liebert (1993)). The SGEs have more massive LHM than the HJs, which explains their different MRR. But very cold brown dwarfs could also have LMH (Flor-Torres et al. 2016). How can we distinguish between SGE and brown dwarf? Different formation processes?

Goal: to determine the velocity rotation of stars with exoplanets and search for possible relation with angular momentum of the orbit of exoplanets.

- Sample so far: 28 stars (21 HJs and 7 SGEs) observed with TIGRE using HEROS (R = 20000).
- Using **iSpec** (Blanco-Cuaresma et al. 2014) to determine $T_{eff}, \log g, [Fe/H], [M/H]$ by fitting synthetic spectra.
- Using the Vienna Atomic Line Data Base (VALD), the code SPECTRUM, the atmospheric model ATLAS and the solar abundance of Asplund et al. (2009).
- Concentrating on spectral range 585-876nm with higher S/N.
- Characteristics of the stars determined using a sample of 103 lines of Fe, Na, Ca, and H_α.
- Main problem - the rotation of low mass stars, $v \sin i$, are comparable to the velocity of the micro and macro turbulences (v_{mic}, v_{mac}); Once T_{eff} and $\log g$, are known, we fix v_{mic} and v_{mac} using empirical relations:

  Tsantaki et al. (2013)$^{(1)}$:

  $$v_{mic} = 6.932 \times 10^{-4} T_{eff} - 0.348 \log g - 1.437 \tag{1}$$

  Doyle et al. (2014)$^{(2)}$:

  $$v_{mac} = 3.21 + 2.33 \times 10^{-3}(T_{eff} - 5777) + 2.00 \times 10^{-6}(T_{eff} - 5777)^2 - 2.00(\log g - 4.44) \tag{2}$$

Discusion - v sin i vs. temperature

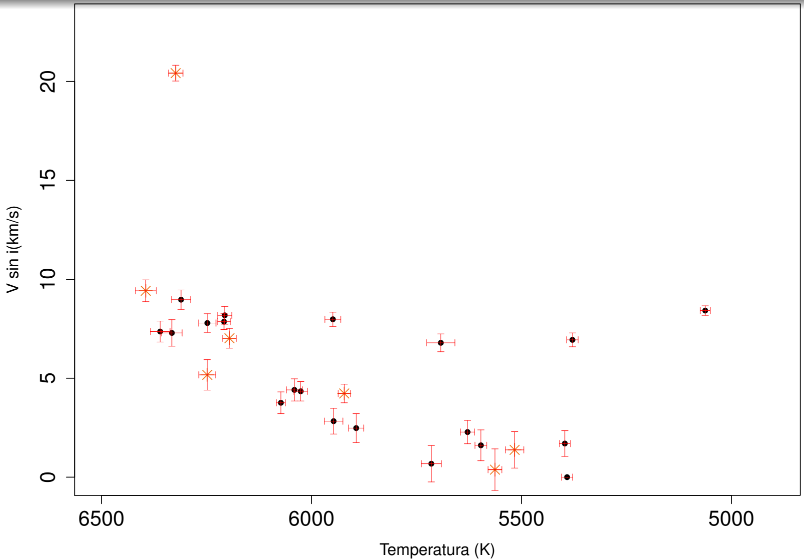

Fig. 4: *As expected, the rotational velocity of the stars increases with the temperature. This is observed for the host stars of SGE (stars) and HJ (black dots). Since the temperature decreases with the mass, v sin i varies with the mass.*

Discusion - Angular momentum of the host stars

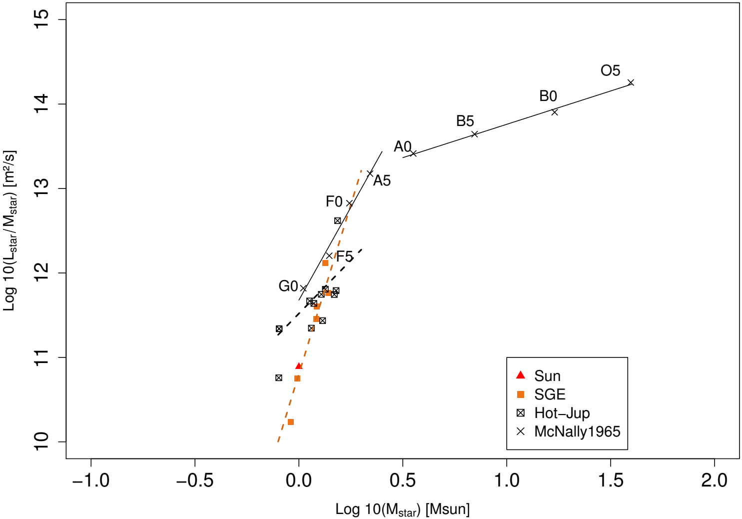

Fig. 5: *In Berget & Durrance (2010) found that stars hosting exoplanets have lower angular momentum per mass than MS stars with same spectral types. This is confirmed by our results. The SGE host stars show a larger variation in angular momentum than the HJ host stars, over the same range in mass. Considered as a whole, the variation with the mass could be steeper than determined by McNally in 1965.*

Discusion - Angular momentum of the exoplanets

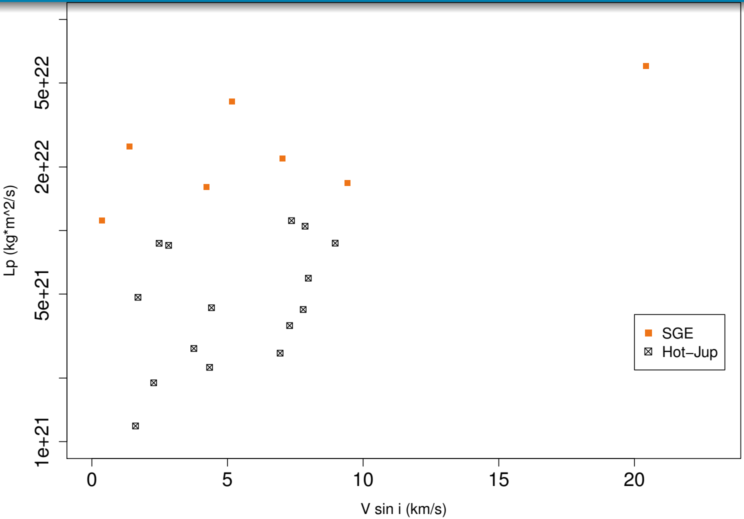

Fig. 6: *There seems to be a trend for the angular momentum of the planets to increase with the rotational velocity of their stars. This is consistent with an increase of rotational velocity with the mass of the stars, as suggested in Fig. 5. However, as the angular momentum of the planets increases, the relation with the velocity seem to disappear. In particular, the SGEs show higher angular momentum, despite their stars having comparable rotational velocities and following the same relation with the temperature (or mass).*

Discusion - Do SGE form as the HJ?

Angular momentum of the planets: $L_p = m_p\sqrt{GM_{hs}a(1-e^2)}$ where m_p is the mass of the planet, M_{hs} the mass of the host star, a the distance of the planet to its star and e the eccentricity of the orbit of the planet (G is the gravitational constant).

For the HJs and SGEs a is small due to migration. So, if *vsini* increases with M_{hs}, and $M_{hs} \gg m_p$, then we expect L_p to increase with M_{hs}. **But** SGEs (and some HJs) seem to have higher L_p than equation suggests.

According to Lin et al. (1996) two different mechanisms could be involved during migration *1- exchange of angular momentum between star and planet due to tidal interactions, 2 - Coupling of magnetic field of star with magnetic field of disk/planet.*

Migration implies a decrease in angular momentum of planet, dissipated by disk. Due to tidal effects, planet gains angular momentum from spin of star and migration stop. The planet is in equilibrium and its orbit is circularized ($e \rightarrow 0$). This explain higher L_p than expect based on spin of star.

But, why would the SGEs be different than the HJs, since both migrate and have comparable a?

More massive LMH envelope in SGE implies tidal interactions is less efficient (de Wit et al. 2016). Circularization process not complete.

Discusion - Do SGE form as the HJ?

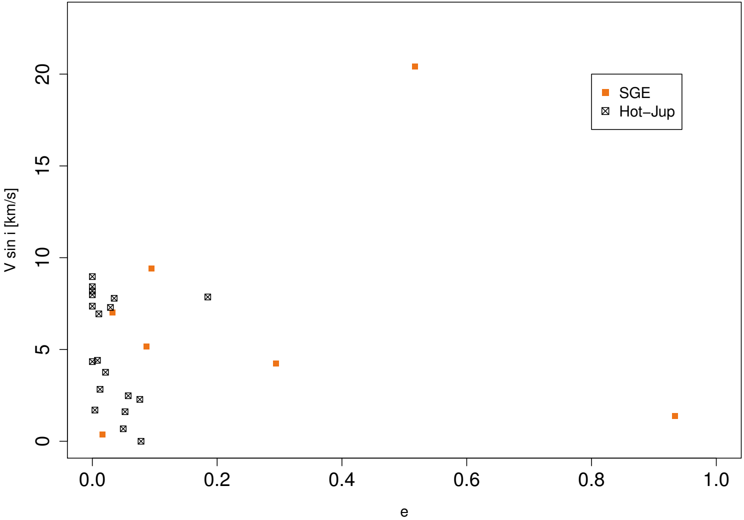

Fig. 7: *SGEs tend to have higher eccentricity than the HJ, which could be consistent with the LMH hypothesis. Could that produce higher L_p for SGEs than for the HJs? More massive envelopes of LMH in SGEs would also imply stronger magnetic fields, and thus stronger magnetic coupling between their stars and disks.* ***However, not clear how this higher produce higher L_p for SGEs.***

Conclusions

- The angular momentum of stars that host exoplanets seems lower than MS stars with comparable spectral type (Berget & Durrance 2010). This could suggest some sort of coupling between the spin of the star and the angular momentum of the planets.
- The rotation velocity of the star increases with its temperature (and, thus, possibly its mass).
- For the majority of the HJs the momentum of the exoplanet increases with the spin of the star (consistent with the spin increases with the mass).
- The SGEs have higher angular momentum for comparable spin for their stars as those with HJs.
- Two different mechanisms related to migration were consider (Lin et al. 1996): 1- exchange of angular momentum from the star to the planet, due to tidal interactions. This mechanism is complex, and does not necessarily explain the differences between SGE and HJ. The hypothesis of massive LMH making tidal interactions less efficient in SGE could be consistent with their higher eccentricity. 2- magnetic coupling between the stars and their disks. Here the massive LMH envelop in the SGE could play a more important role, due to their higher magnetic fields.
- So far, are results seem consistent with the LMH hypothesis for the SGEs, suggesting they form like the HJs through migration in comparable protoplanetary disks. BUT WE NEED MORE OBSERVATION WITH THE TIGRE.

To be continue!

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