Bloated Hot Jupiters: What can tides do?

- Tidal distortion: The **true** radius of transiting planets
- Tidal friction: An efficient bloating mechanism?

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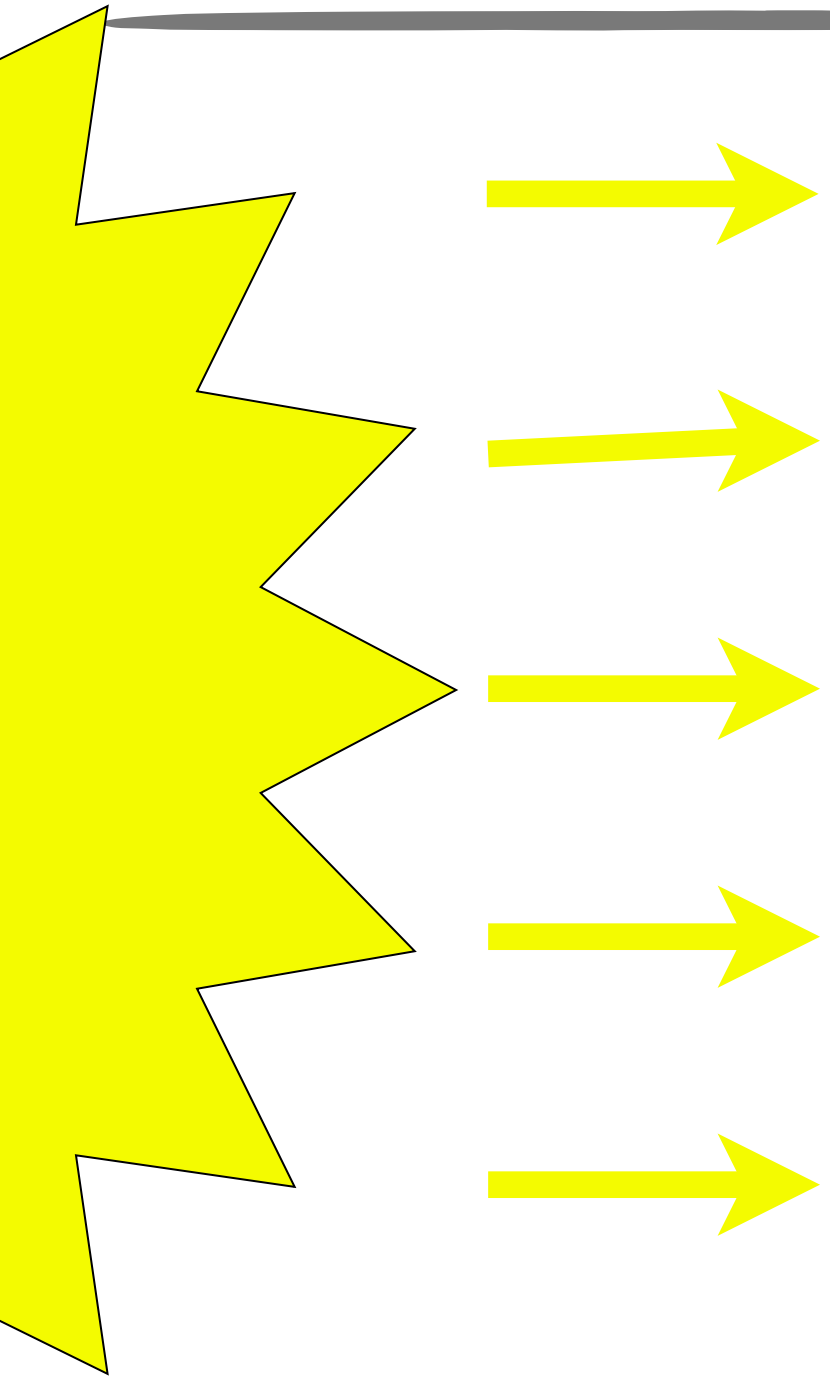
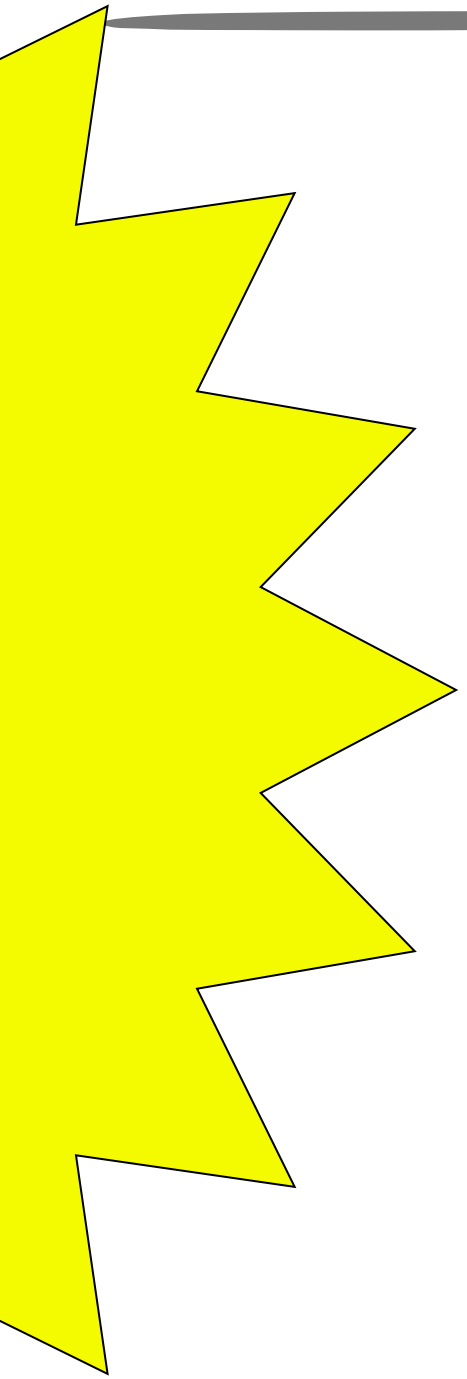
Effect of tidal distortion on transit measurements



$$\frac{\delta F_\star}{F_\star} = \frac{A_\mathrm{p}}{A_\star} = \frac{R_\mathrm{p}^2}{R_\star^2}$$

Effect of tidal distortion on transit measurements



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$$= \frac{R_{\mathrm{p,tr}}^2}{R_{\star,\mathrm{tr}}^2}$$

Tidal distortion

Observation-Theory comparison

Analytical computation of the true radius

Total energy

$$E = U + U' + W + W' + T + W_{\rm int}$$

Equilibrium set of equation

$$\left\{ \left. \frac{\partial E}{\partial x_{\rm i}} \right|_{M,J,...} = 0 \right\}_{x_{\rm i}=r_\star,{\rm shape}}$$

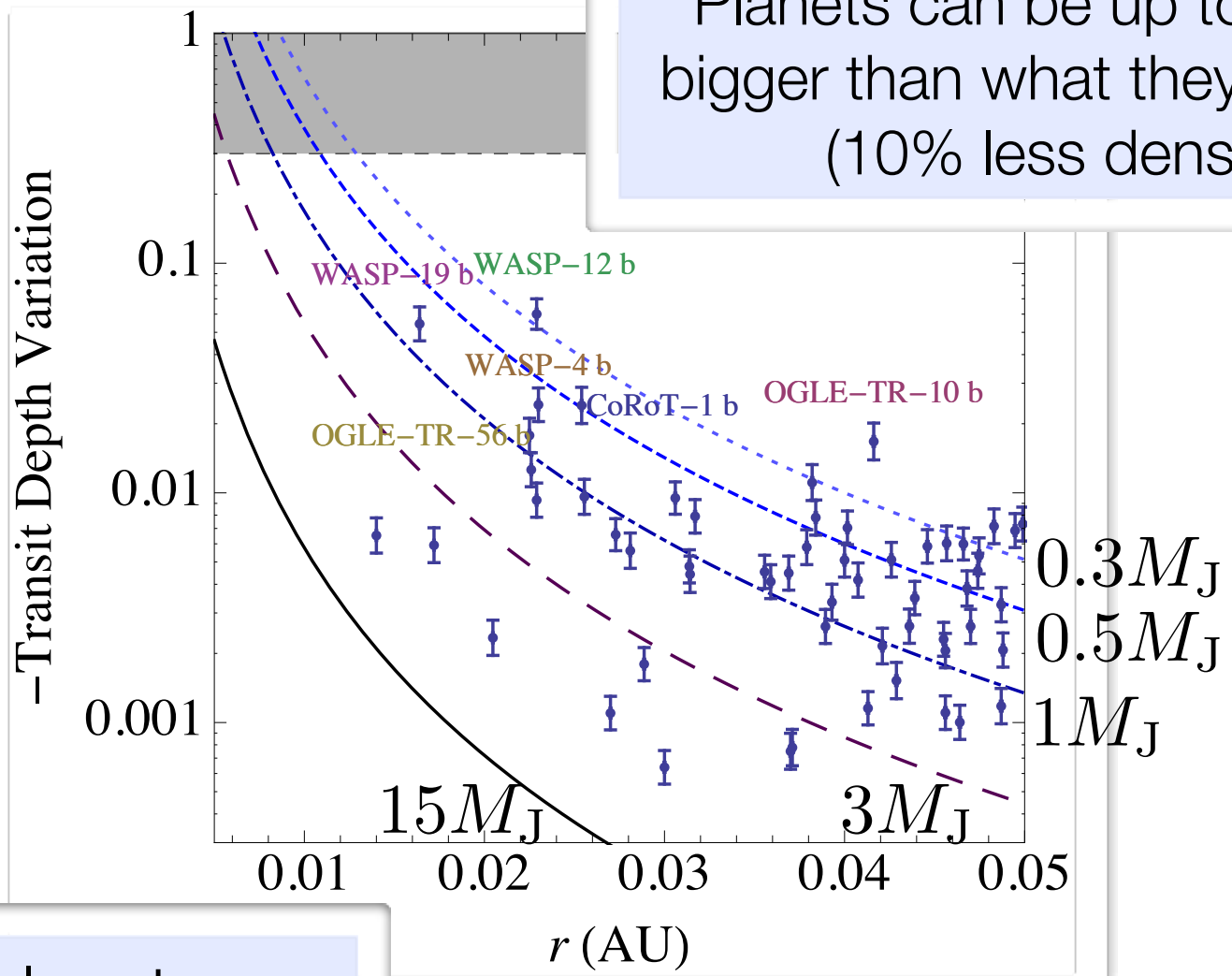
Linear regime: tides+synchronous rotation

$$\frac{R_{\rm p} - R_{\rm mes}}{R_{\rm p}} = \left(\alpha_{\rm rot} + \alpha_{\rm tid}\right) \frac{M_\star}{M_{\rm p}} \left(\frac{\bar{R}_{\rm p}}{r_\star}\right)^3 > 0$$

Lai et al. (ApJ 1994), Leconte et al. (A&A 2011)

A negative bias in the radius determination

Planets can be up to 3-4% bigger than what they appear (10% less dense)



Bloated planets are even more bloated!

Leconte et al. (A&A 2011)

Can tidal heating explain bloated planets?

Conclusion

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We don’t know much about tidal Dissipation!!!

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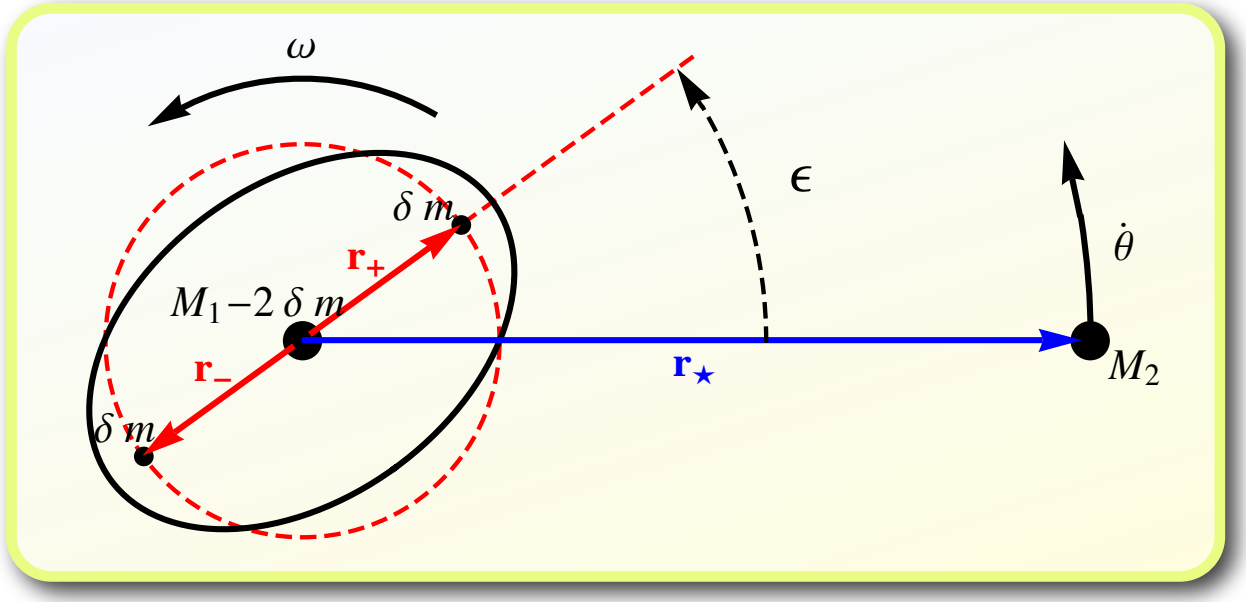
Conclusion

We don’t know much about tidal Dissipation!!!

One thing we do know is what an eccentric keplerian orbit is.

One main theory / Two main parametrizations



What is the freqency dependance of ϵ?

Constant phase lag

$$\epsilon = 1/Q$$

- Need perturbative developments:
  - ➡ Limited to low eccentricity and inclinations

Constant time lag

$$\epsilon = 2(\omega - \dot{\theta})\Delta t$$

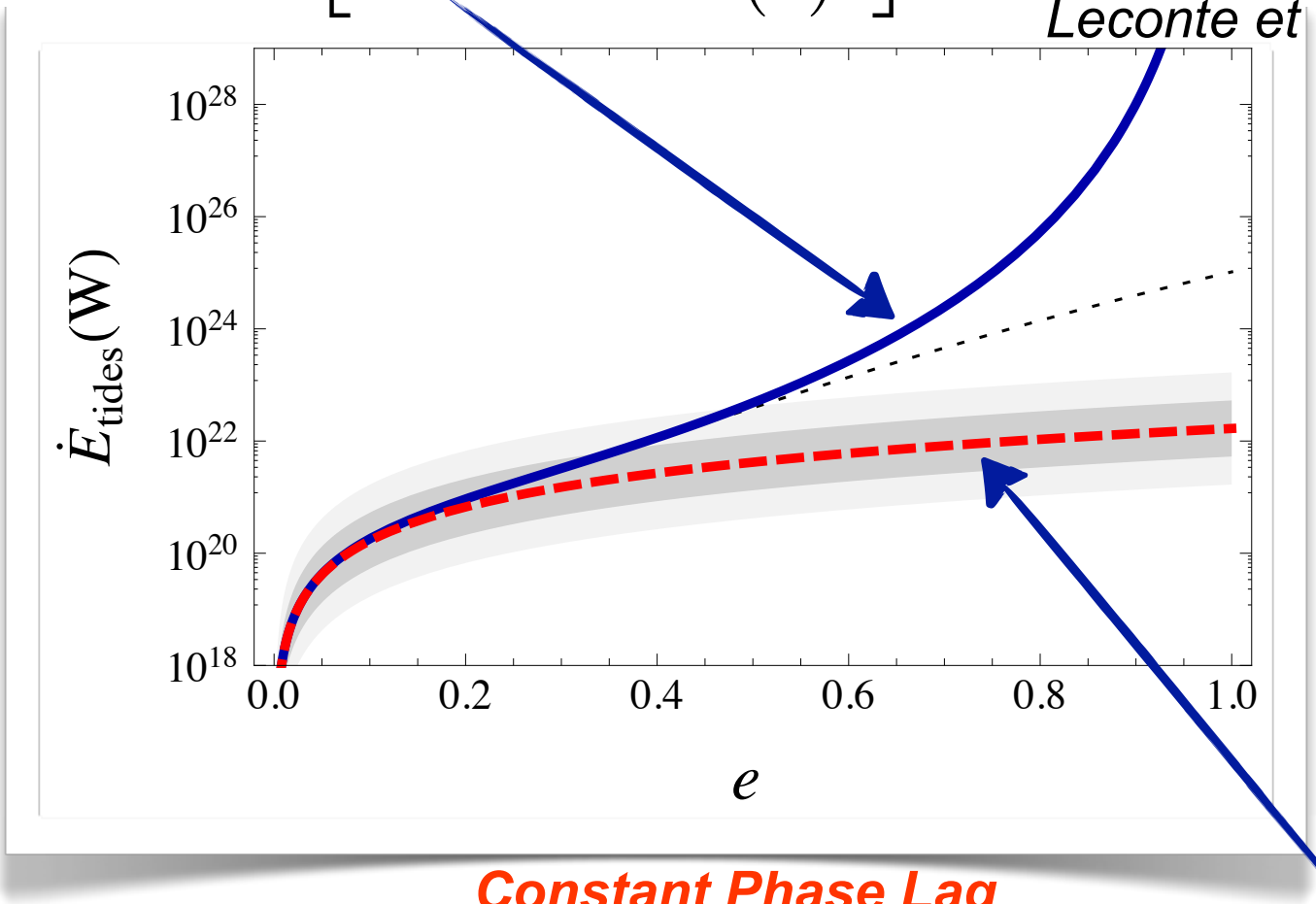
- Linear:
  - ➡ **Not** limited in eccentricity and inclination

Quasi circular model underestimates tidal heating

$$\dot{E}_{\rm tides} = 2K_{\rm p}\left[N_a(e) - \frac{N^2(e)}{\Omega(e)}\right]$$

Constant Time lag:

Levrard et al. (A&A, 2007)
Wisdom (Icarus, 2008)
Leconte et al. (A&A, 2010)



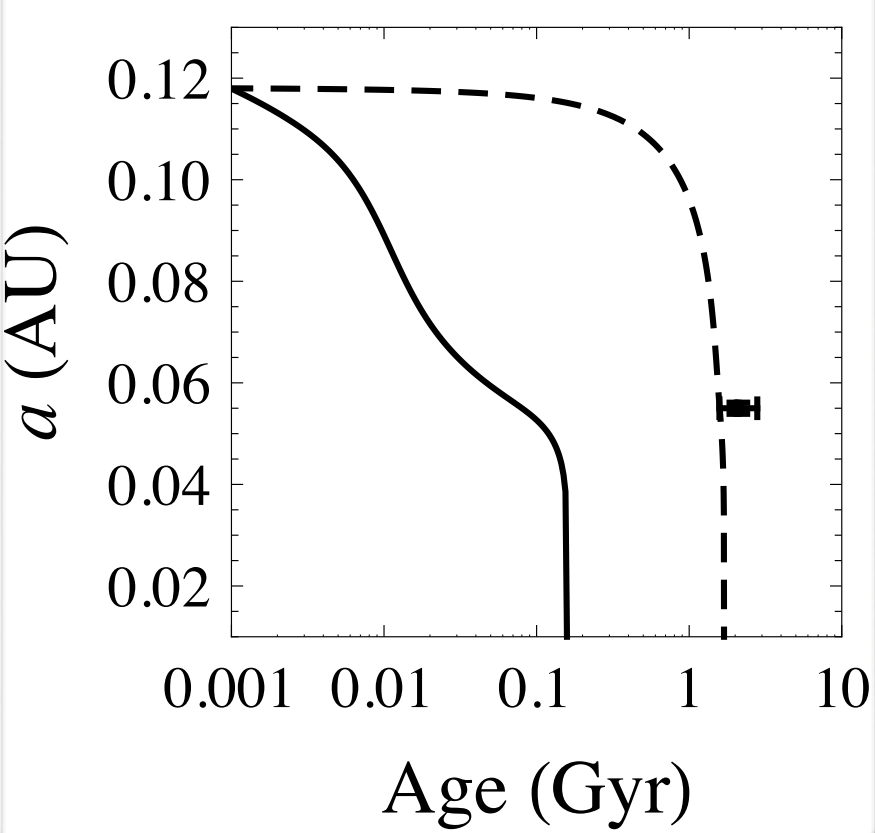
e^2 approx underestimates tidal heating by **orders of magnitude!**

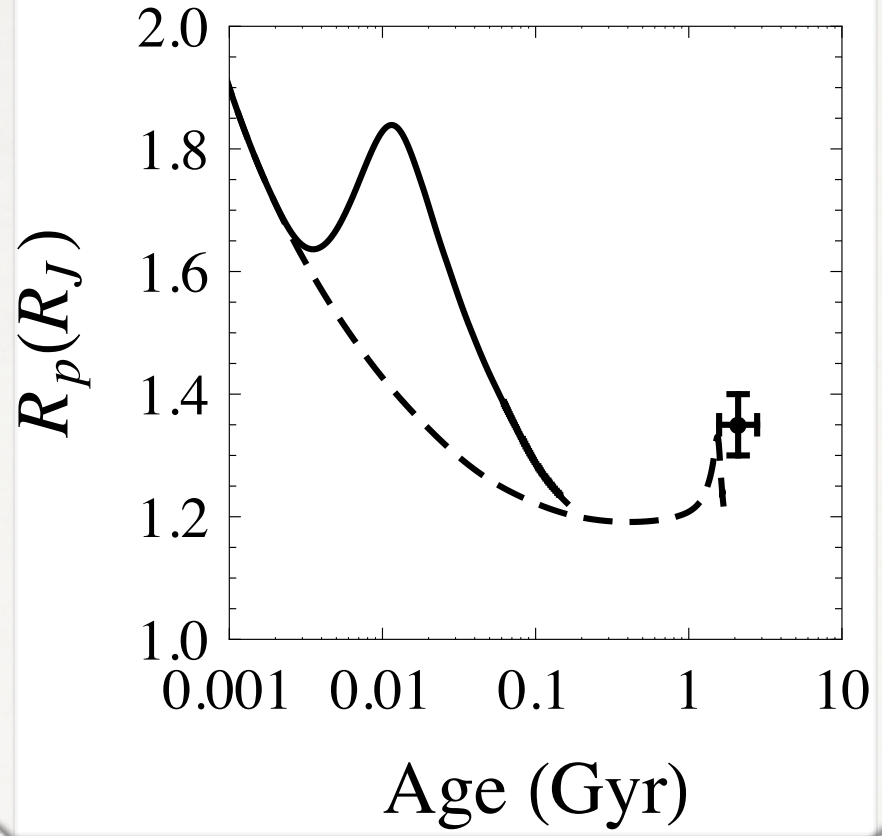
Constant Phase Lag

Jackson et al. (Apj, 2008)
Miller et al. (Apj, 2009)
Ibgui et al. (Apj, 2009)

$$\dot{E}_{\rm tides} = 7K_{\rm p}e^2$$

Comparison with the e^2 model

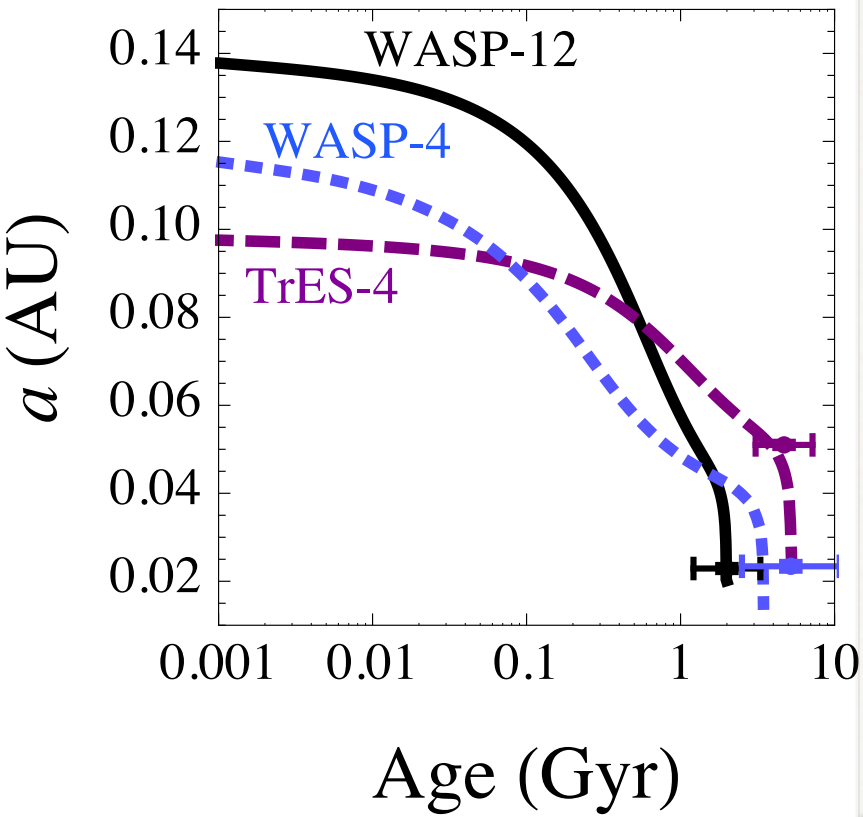


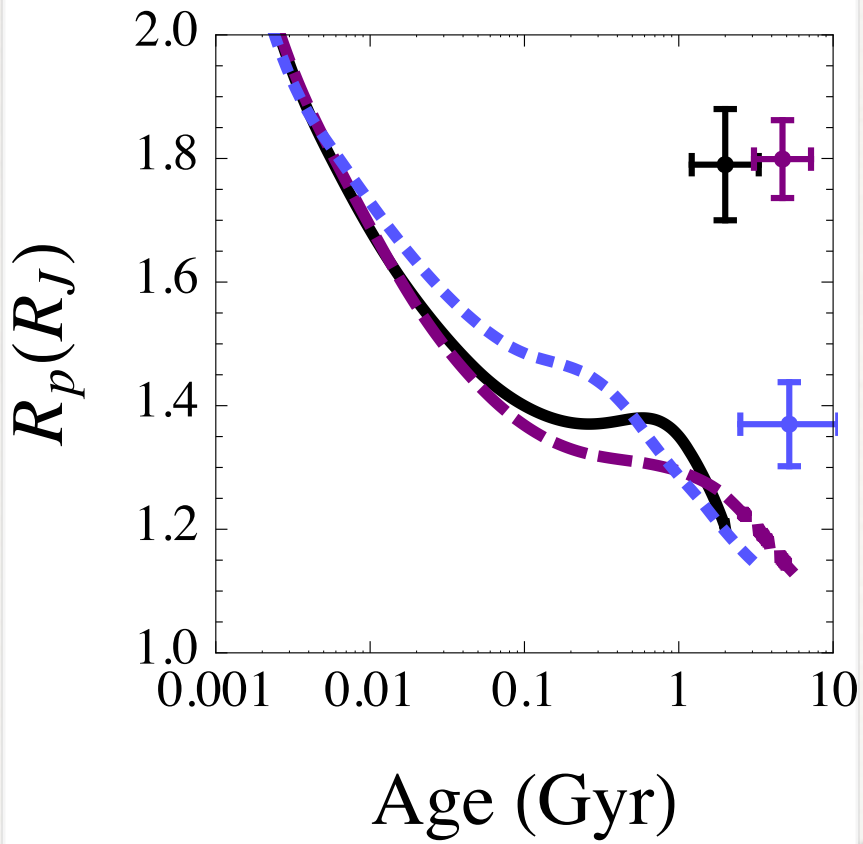


——— *Full Equations* ---------- *e^2 model*

With the full equations, tidal dissipation occurs **much earlier**

Most bloated planets: Tidal dissipation arises too early





Circularization occurs **too early** to heat the planet at a **late** epoch

Leconte et al. (A&A, 2010)

Conclusion

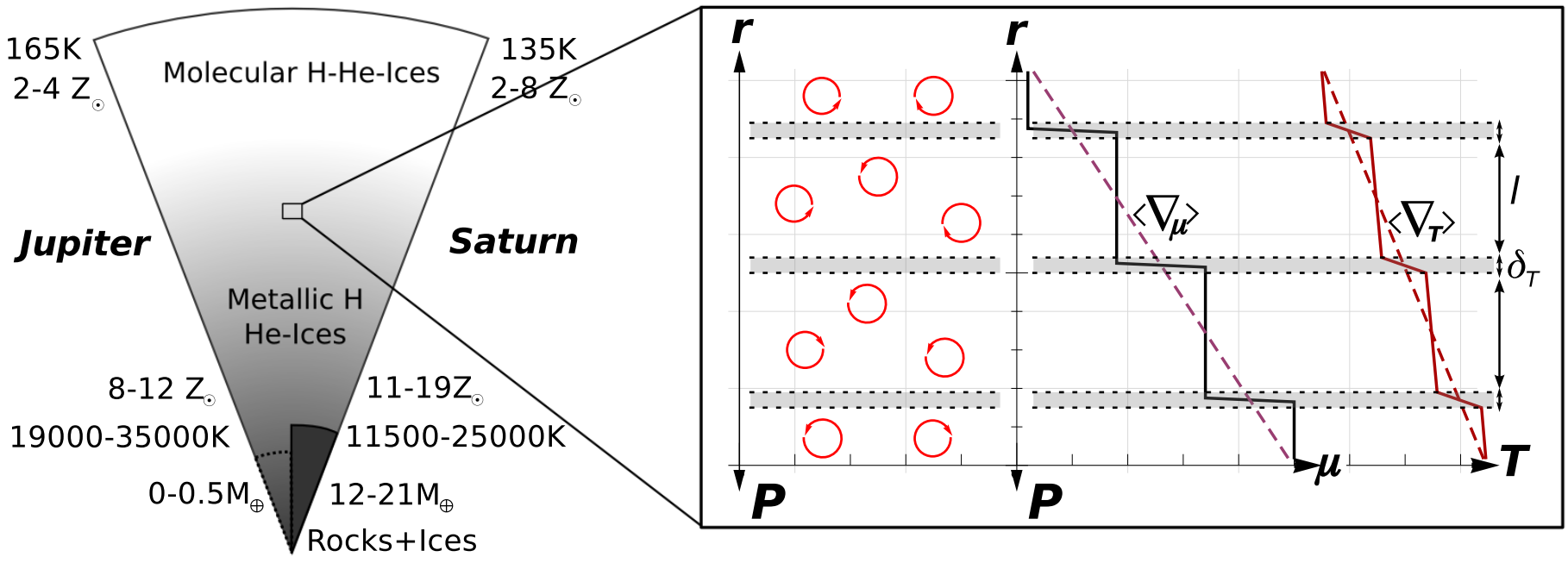
★Tidal distortion

- Bias in the transit data (up to 5-10% in transit depth)
  - ➡ Can be corrected analytically
- Planets are ***bigger*** than what they appear

★Tidal Heating

- eccentric orbits must be treated properly:
  - ➡ Complete formula or high order calculations needed
  - ➡ High orders are ***not*** mere corrections
- Not sufficient to explain most bloated exoplanets (for bodily tides in the 2 body problem), but has a significant contribution

Another possible bloating mechanism:
Double diffusive convection

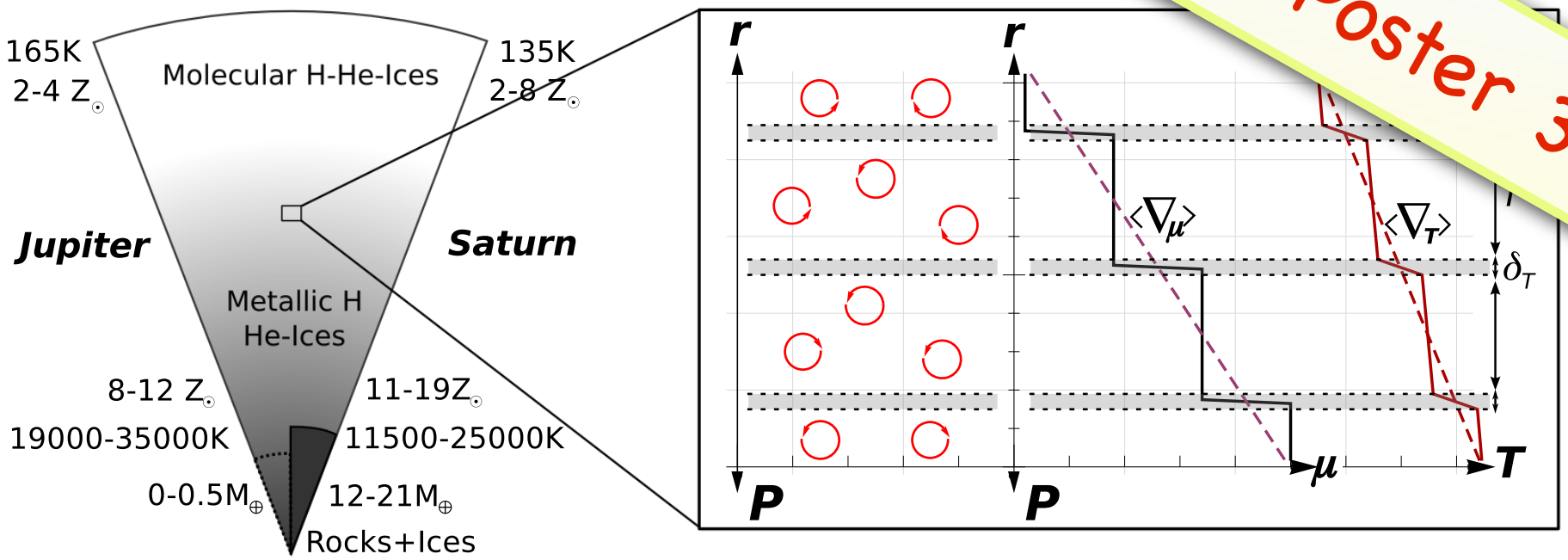


- Double diffusive convection impedes energy transport
  - *Possible absence of core in Jupiter!*

Leconte & Chabrier (Submitted)

Another possible bloating mechanism:
Double diffusive convection

See Poster 37.01



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Hut (A&A, 1981)
Levrard et al. (A&A, 2007)
Wisdom (Icarus, 2008)
Leconte et al. (A&A, 2010)
Hansen (Apj, 2010)

$$\frac{\dot{E}_{\rm tides}}{7K_{\rm p}e^2} = 1 + \frac{54}{7}e^2 + \frac{1133}{28}e^4 + \frac{31845}{224}e^6 + \frac{381909}{896}e^8 + O\left(e^{10}\right)$$

Jackson et al. (Apj, 2008)
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Does not come from a particular model. Due to the strong dependence to the orbital distance (r^{-6})

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