Structure and evolution of planets and their host stars

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On the structure and evolution of planets and their host stars – effects of various heating mechanisms on the size of giant gas planets

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Outlines

New methods for determination of metallicity (Z) and age (t) of the host stars.

- [Fe/H]? [O/H]?

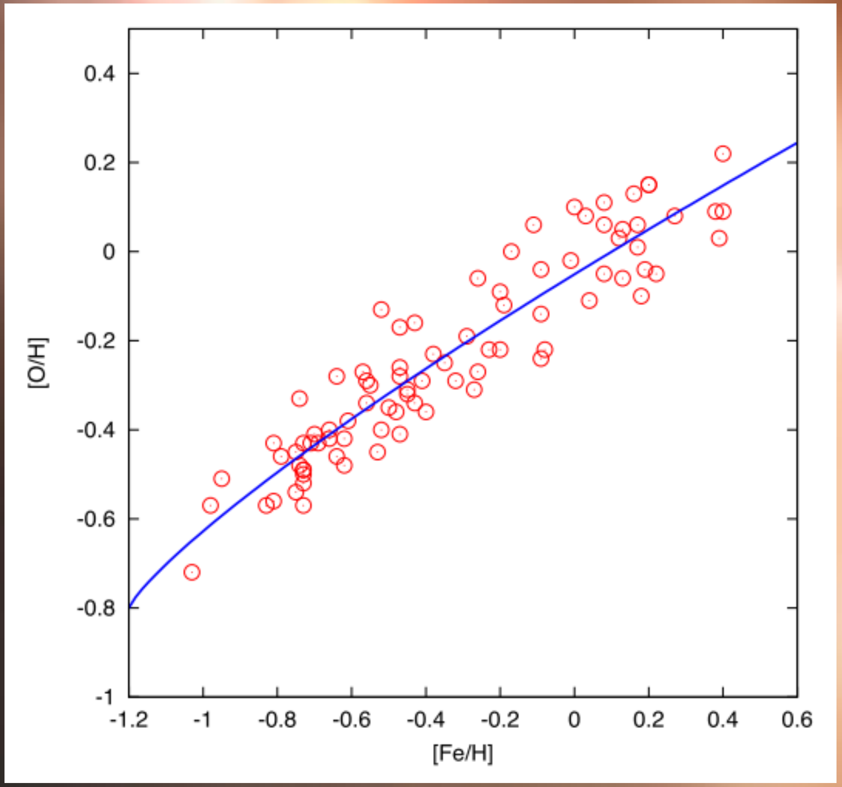
Heating processes in inflated planets (gas giants).

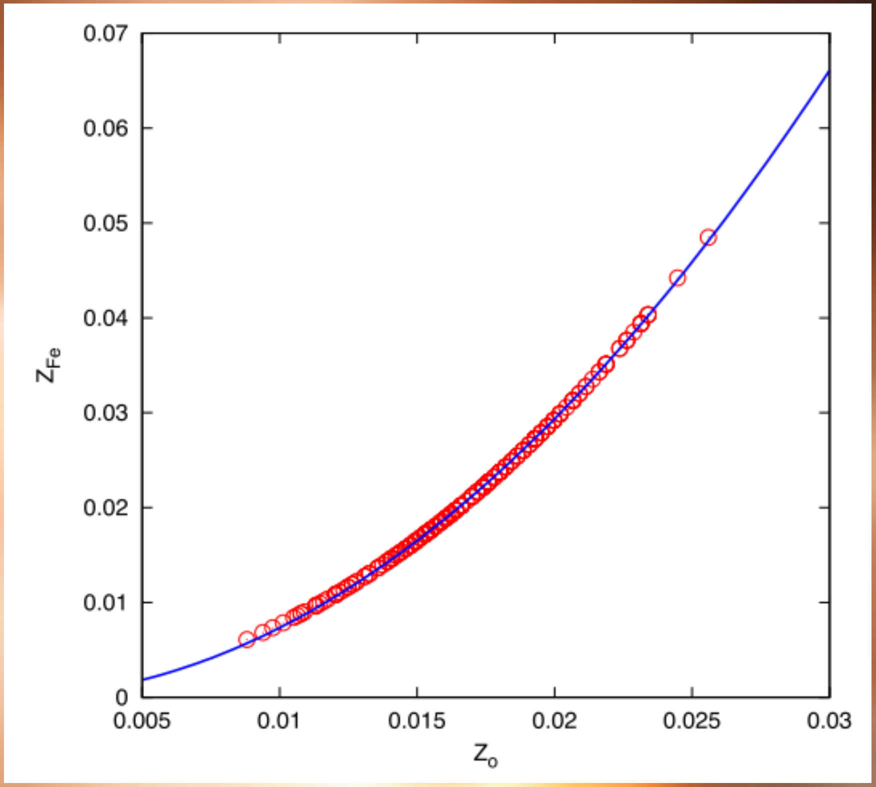
Data from TEPCat (Southworth 2011)

- Irradiation
- Tidal interaction
- Molecular dissociation
- Evaporation
- Effects of metallicity and cooling

Conclusions

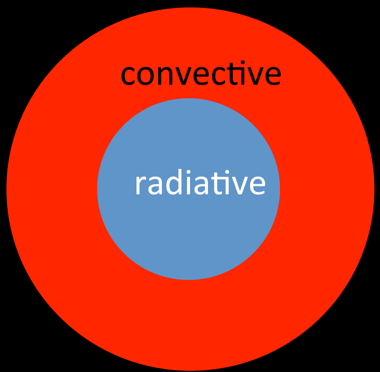
Metallicity from [Fe/H] or [O/H]?
Oxygen is the most abundant heavy element.





Edvardsson et al. (1993).

Stellar Mass-radius relation – Energy transfer in outer regions



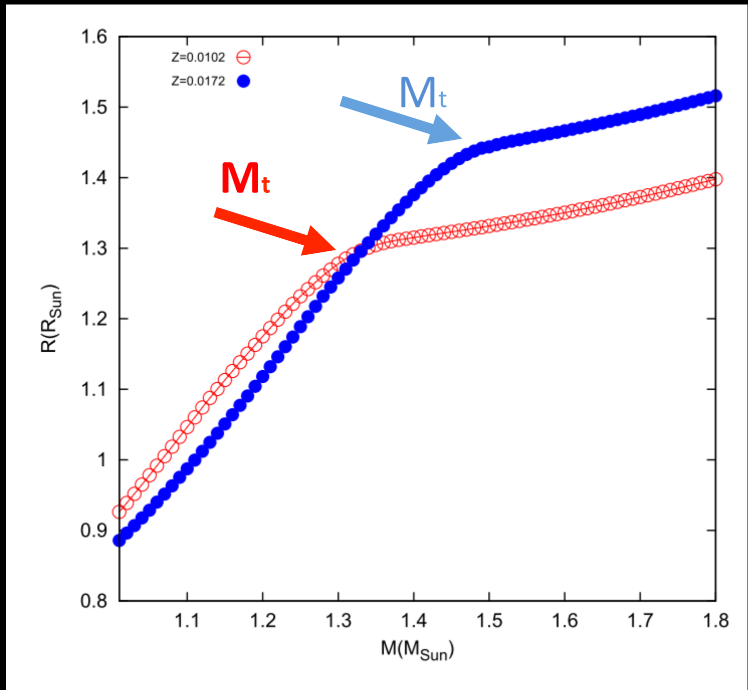
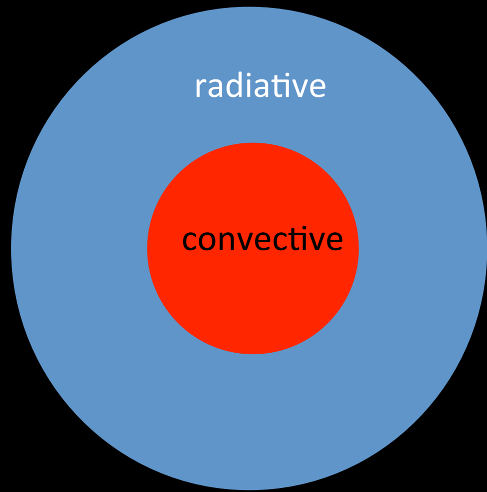


Figure 1. Stellar radius with respect to stellar mass.



Notes

1) **Two different slopes for $M < M_t$ and $M > M_t$.**
2) **M_t depends on metallicity.**
3) **Slopes do not depend on Z.**

Computation of Stellar Age:
ANKİ models

$$\frac{R(t)}{\mathrm{R}_\odot} = \frac{R_{\mathrm{ZAMS}}}{\mathrm{R}_\odot} + a(M, Z)t_{\mathrm{rel}}^{3/2}, \qquad t_{\mathrm{rel}} = \frac{t}{t_{\mathrm{TAMS}}}$$

$$a(M, Z) = 0.114b\left(\left(\frac{M}{8.8\,\mathrm{M}_\odot}\right)^5 + 1\right) + (0.222 - b)\left(\frac{M}{\mathrm{M}_\odot}\right)$$

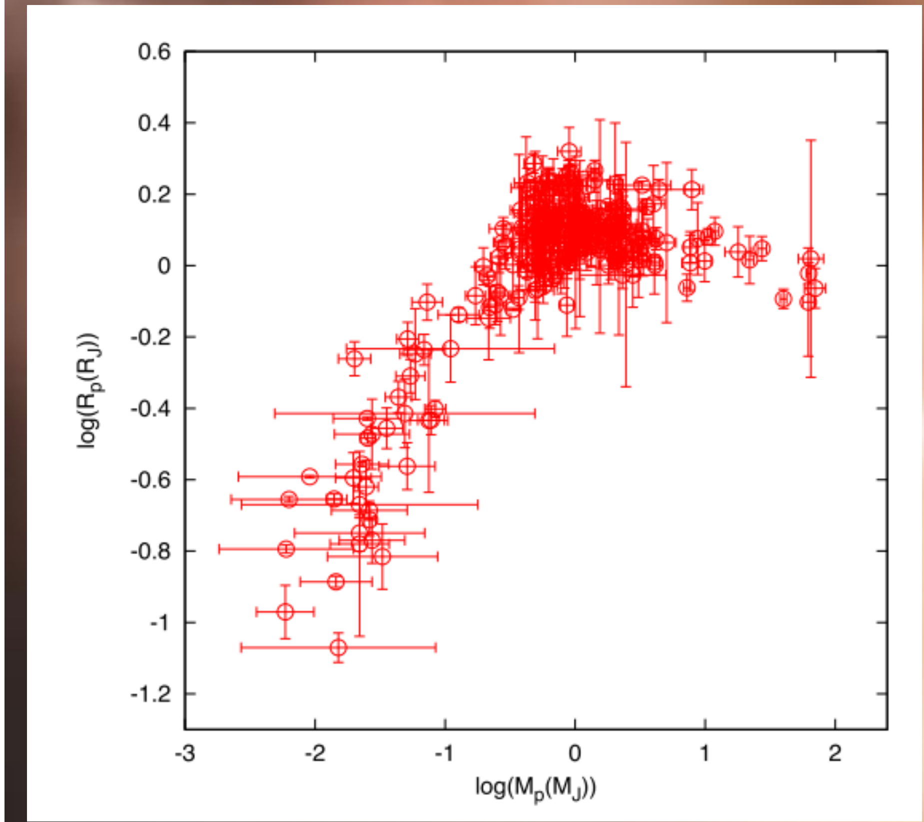
$$b(Z) = \frac{5.297}{3.139 + (Z/\mathrm{Z}_\odot)^{4.6}}.$$

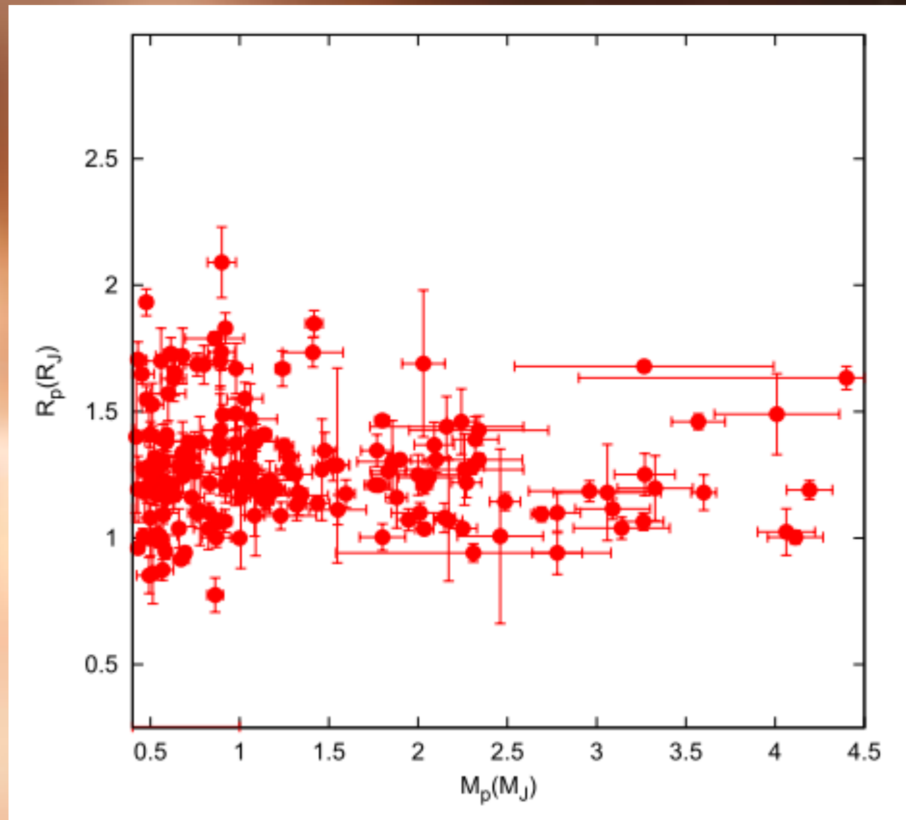
Maximum age from Z_{Fe} **is about 17-18 Giga years**

Maximum age from Z_o **is 11 Giga years**

Age of the Galaxy is 13.4 ±0.8 Giga years (Pasquini ve ark. 2004).

Mass-radius relation for Planets : TEPCat (Southworth 2011)





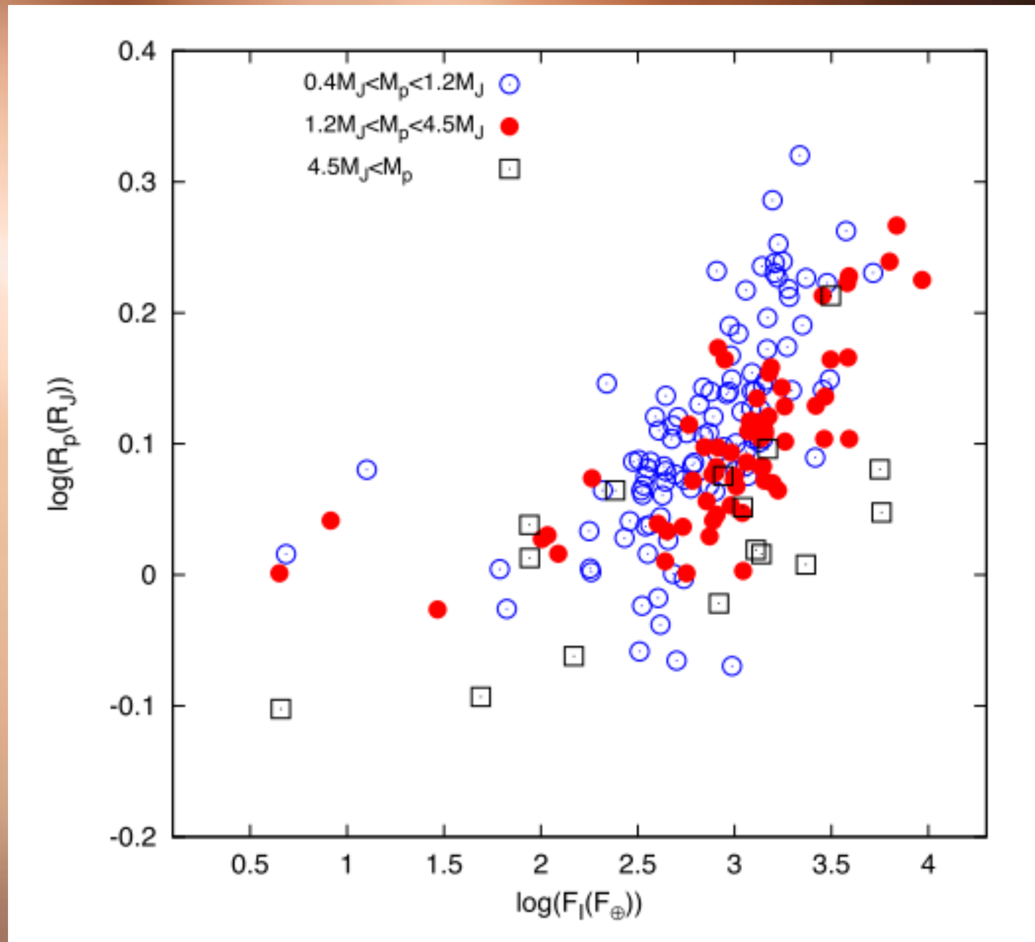
For Mp=0.4-4.5 Mj, radius is almost constant.

0.7 < R <2.1 Rj

Why planetary radii are so different?

Inflated Planets:
Effect of incident flux

Mass dependent



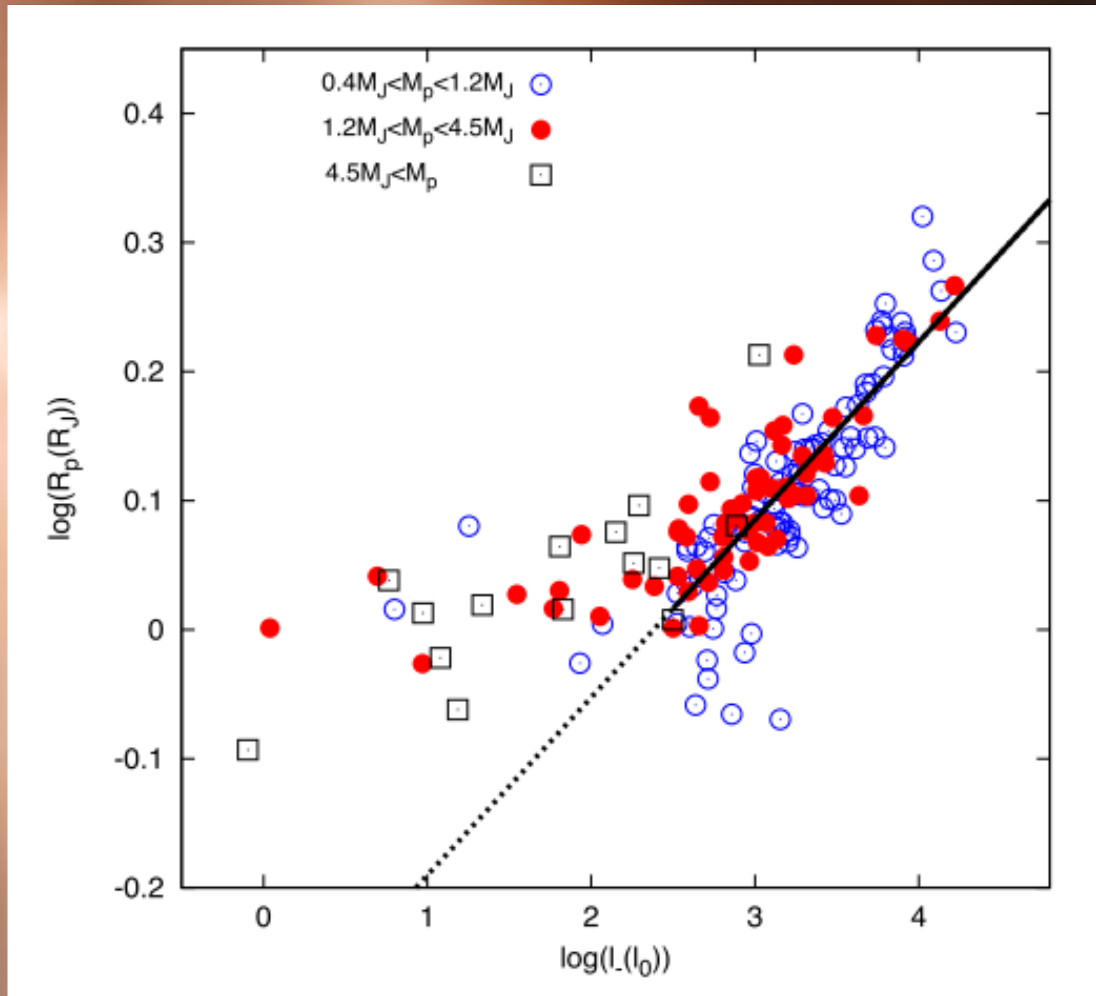
Inflated Planets:
Effect of irradiation energy per gram per second

$$L_{-} = \pi R_{\rm p}^2 F_{\rm I}.$$

$$l_{-} = L_{-}/M_{\rm p}$$

Mass independent relation between R and *l*_?

$$l_{-} = \frac{\pi F_{\rm I}}{M_{\rm p}/R_{\rm p}^2} \propto \frac{F_{\rm I}}{g_{\rm p}}.$$



$$\Delta \log\left(R_l\right) = 0.138(\Delta \log\left(l_{-}/l_0\right) - 2.5).$$

Inflated Planets: Molecular dissociation?

For a sphere:

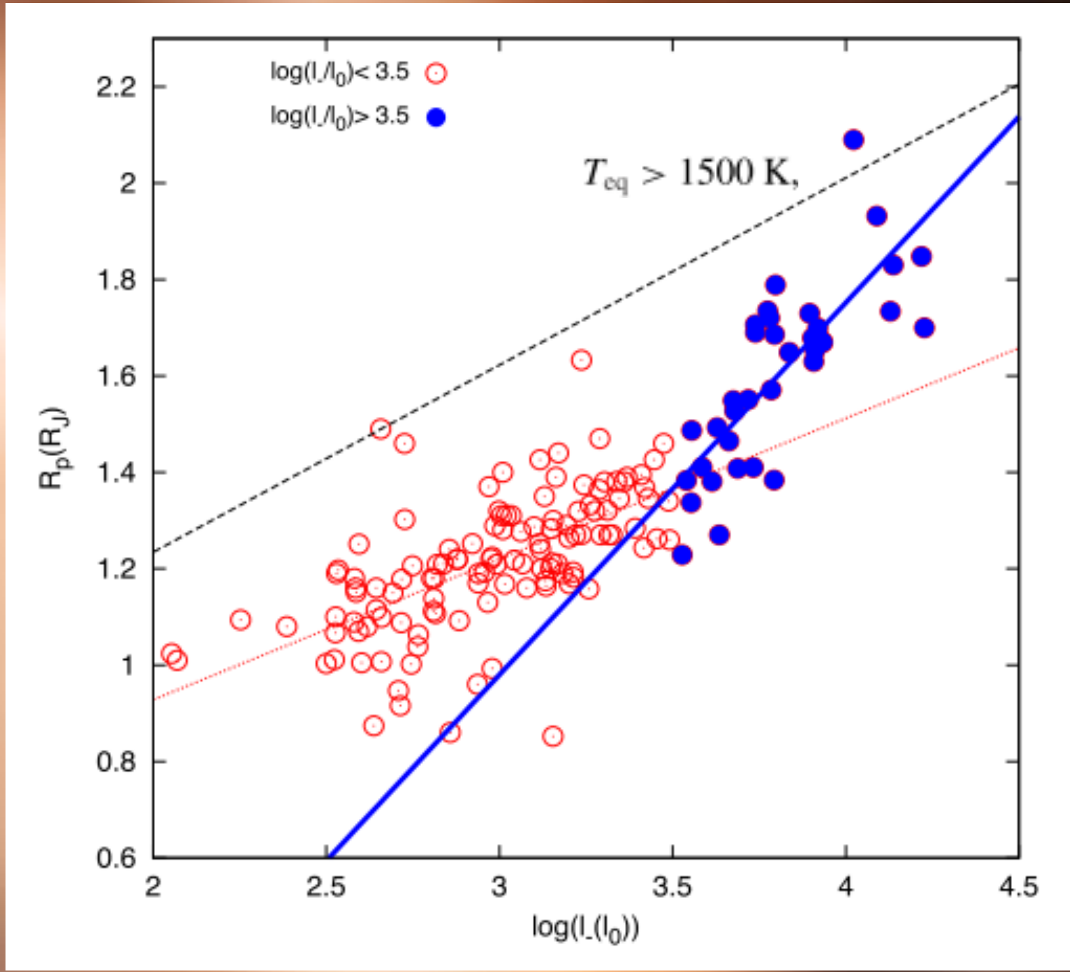
$$\frac{\Delta R}{R_i} = \frac{1}{3}\frac{\Delta V}{V_i}$$

If complete dissociation

$$n_f \approx 2n_i,$$

$$V_f \approx 2V_i,$$

$$R_f = R_i + \Delta R = 1.33 R_i.$$



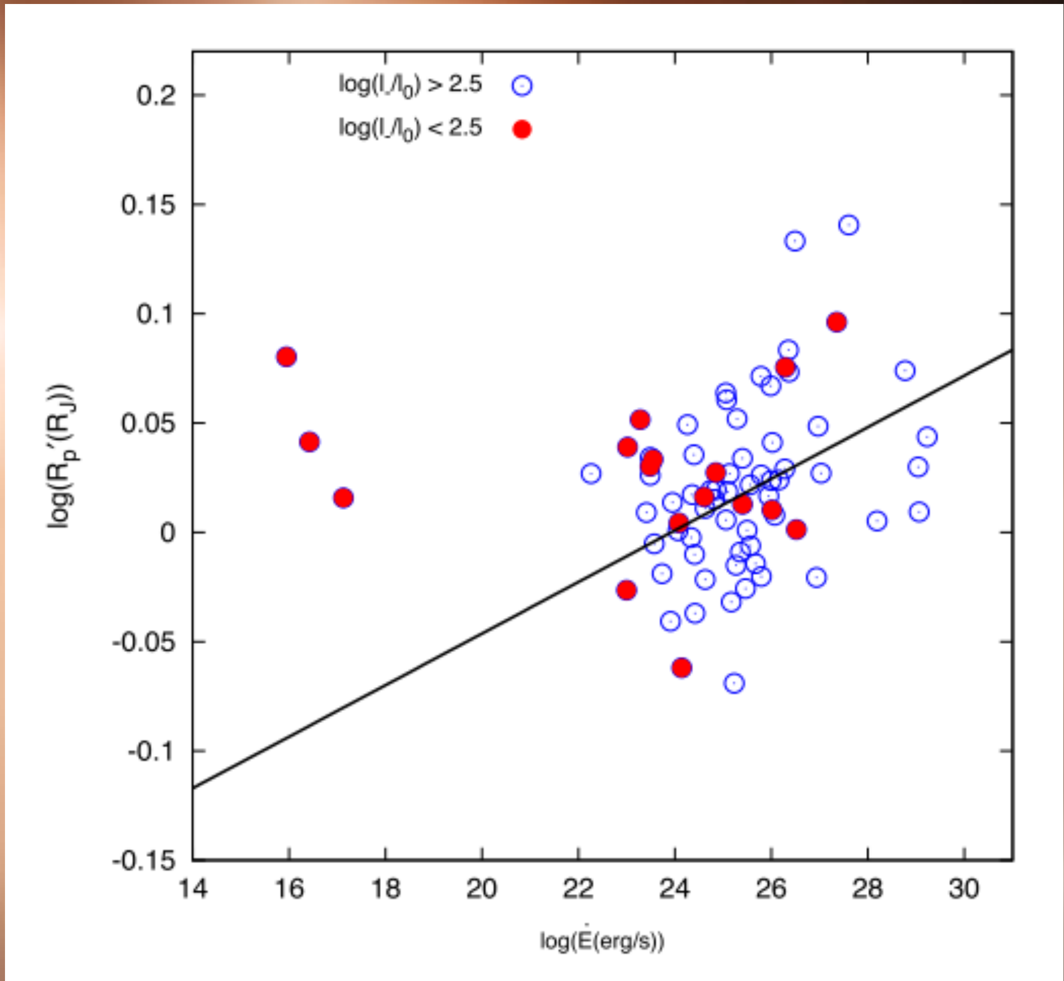
Inflated Planets: Tidal effect

Rate of energy converted from orbital energy to heat (Storch & Lai 2014)

Eccentricity (Knutson et al. 2014)

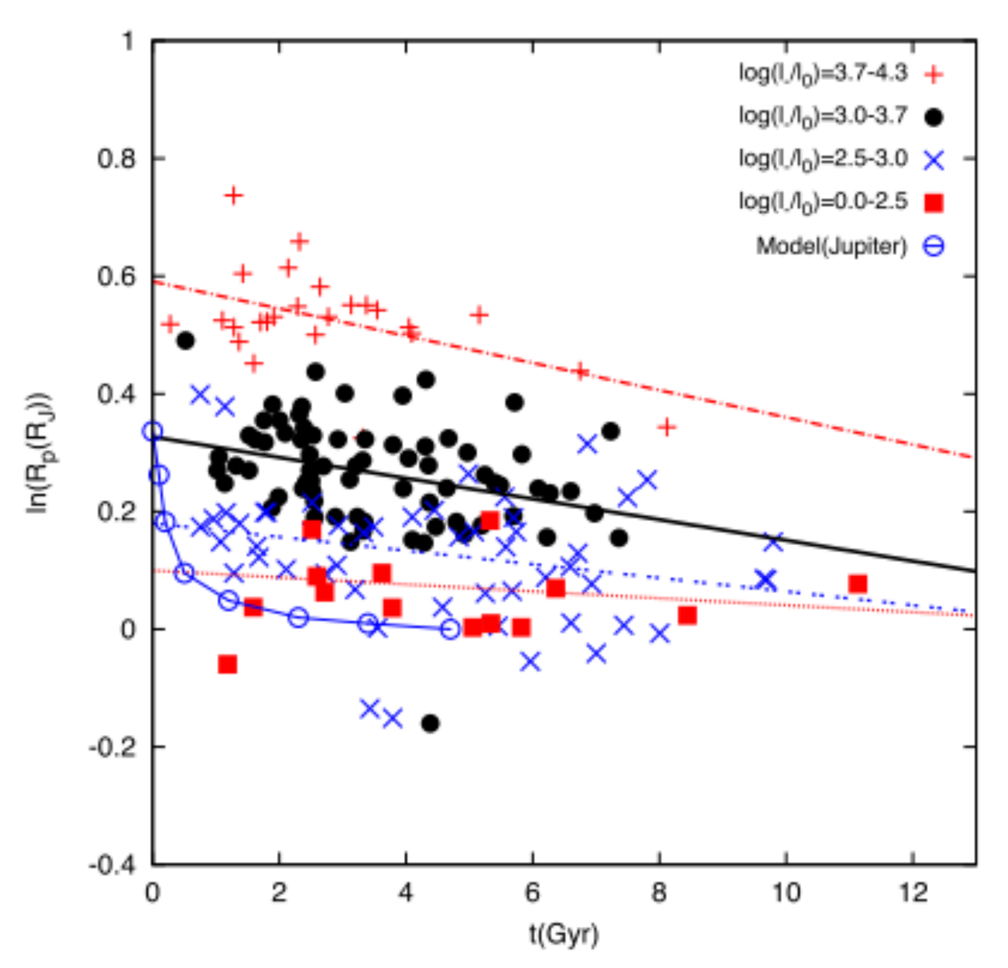
Effect of irradiation energy on R is subtracted.

R'_{p} is $R_{\mathrm{p}} - \Delta R_l$



Inflated Planets: Cooling

Cooling of Jupiter from Nettelmann et al. (2012)



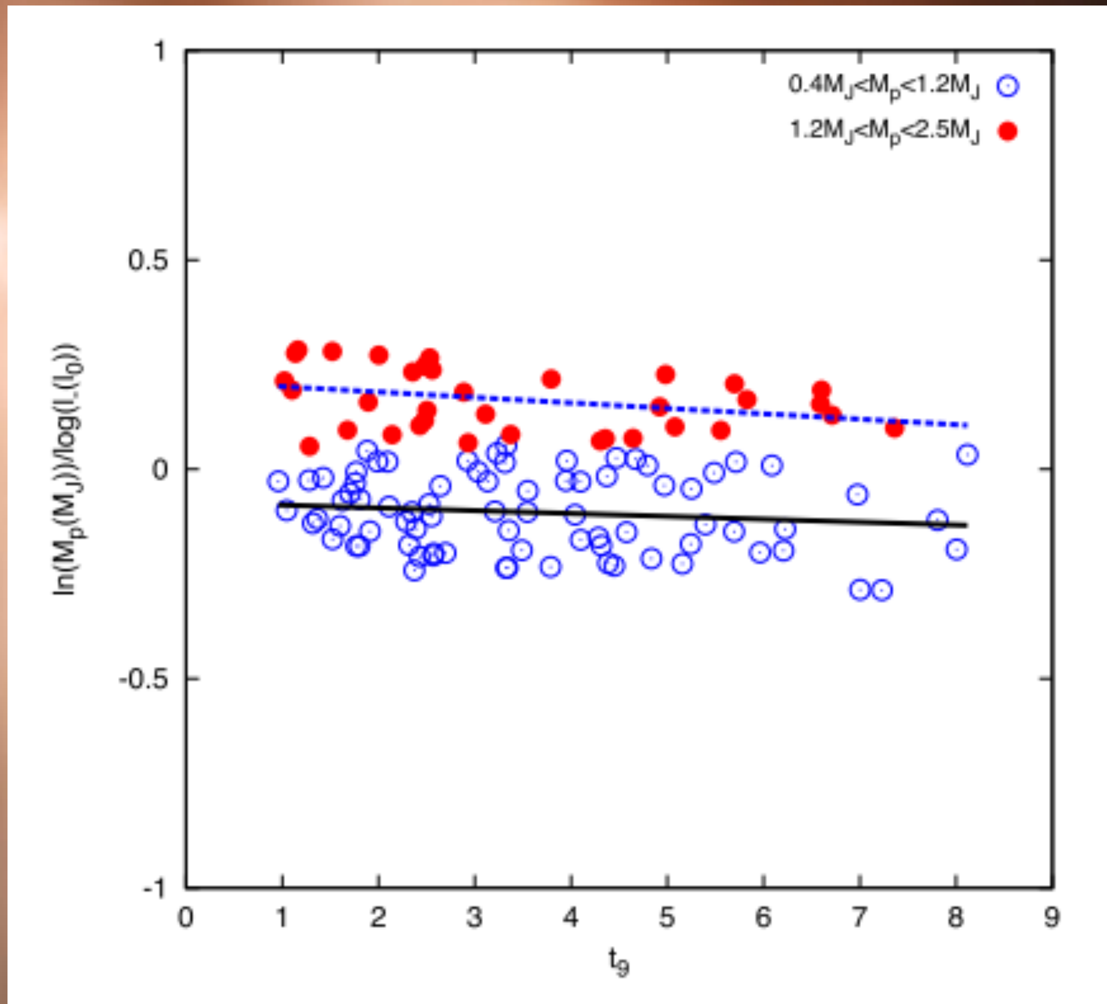
Inflated Planets: Evaporation

Mass-loss rates:

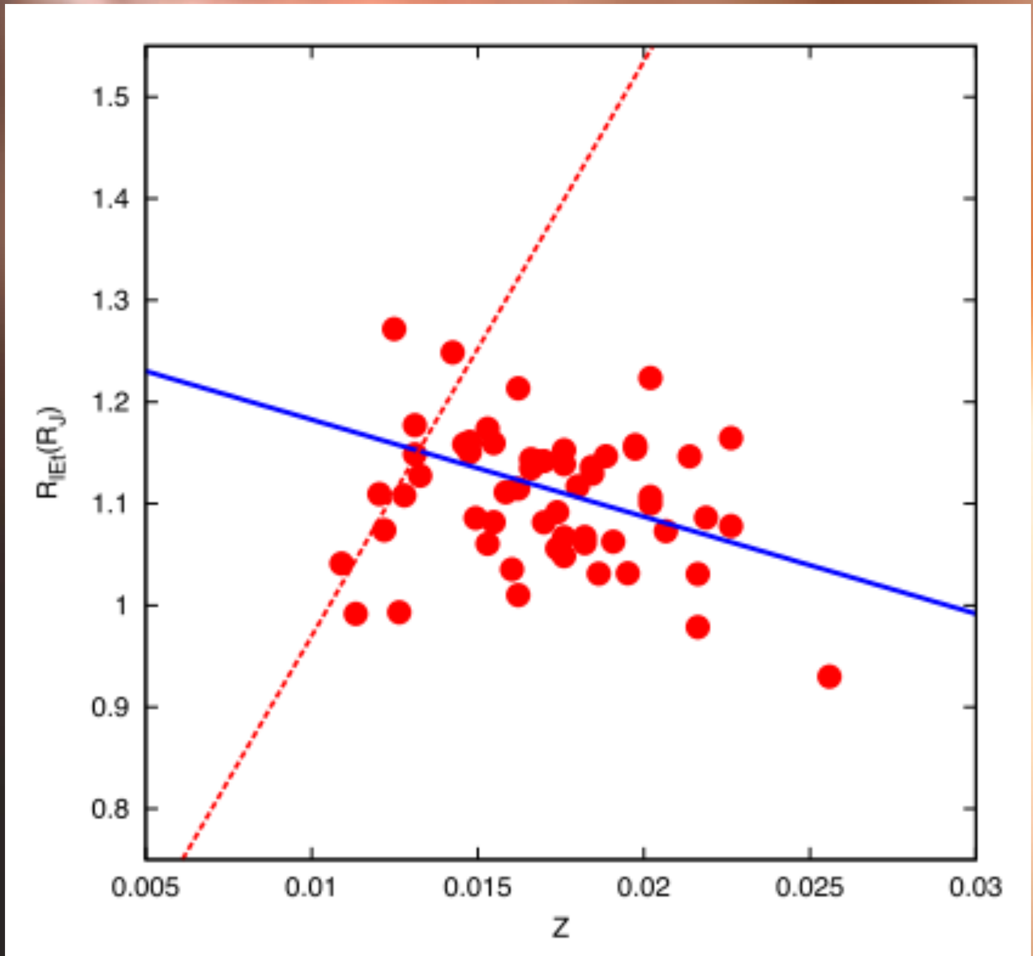
$$10^{11} - 10^{13} \text{ g s}^{-1}$$

$$10^{10} – 10^{12} \text{ g s}^{-1}$$

The mass loss for the most irradiated planets is about 5% in 1 Gyr.



Inflated Planets:
Effect of Metallicity



$$R_l = R_p - \frac{\Delta R_p}{\Delta \log(l_-)} \delta \log(l_-).$$

$$R_{lE} = R_l - \frac{\Delta R_l}{\Delta \log(\dot{E})} \delta \log(\dot{E}).$$

$$R_{lEt} = R_{lE} + \frac{\Delta R_{lE}}{\Delta t_9} \delta t_9.$$

Good agreement with the findings of Guillot et al.(2006) and Miller & Fortney (2011)

Conclusions

* New methods are developed for age and metallicity (Z) of the host stars.

* The mosf effective mechanism on planetary radius is irradiation energy (~ %30).

The relation between R and irradiation is mass independent, if we consider received energy per gram per second (I_).

* Tidal effect ~%10-15

* Cooling and metallicity incluence R.

*Evaporation seems to cause significant mass loss.

Further analysis is required.

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