Luminosities of young directly-detectable gas giants

Gabriel-Dominique Marleau

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## Overview

1. Uncertain theory + Unique observations = Great opportunity

2. Inferring $M$ and $S_i$ from $L$ and age

3. Population synthesis results

4. Bonus: Speculation

5. Summary and outlook
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Gas giant formation scenarios

- Core accretion $\rightarrow M_p \lesssim 30 M_J$, closer-in, higher $[\text{Fe/H}]$
- Gravitational instability $\rightarrow$ heavier, $\gtrsim 10$–$30$ au
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- Extremes: hot and cold starts; reality: continuum (?)

![Diagram](image)
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Given composition: $L = L(M, S)$
Direct imaging

- Probe far/closer in, CA–Gl boundary, interaction with disc, ...
- In particular: infant planets → remember birth process
  ! Caveat: Conversion from brightness to mass not trivial

![Diagram showing mass vs. semi-major axis for different detection methods and observational techniques.](image-url)
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![Diagram](image-url)

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Masses from direct observations

- Hot starts provide lower mass bound
  
  (e.g. Fortney et al. 2008; Marleau & Cumming 2014)

  \(\rightarrow\) Statistics (mass function) possibly skewed
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  ⭐ Turn this around → constraints on initial entropy

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Standard cooling tracks for gas giant planets

! Low entropy $\rightarrow$ long cooling time $t_{\text{cool}}$

- $t < t_{\text{cool}}: \approx$ remember initial entropy
- $t > t_{\text{cool}}: \approx$ power law

(Burrows & Liebert 1993; Arras & Bildsten 2006)
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Analytical approximation

$\Rightarrow$ Cooling curve with arbitrary $L_{\text{init}}$:

$$\frac{1}{L(t)} = \frac{1}{L_{\text{init}}} + \frac{1}{L_{\text{hot start}}(t)}$$

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$\rightarrow$ Map $(t, L)_{\text{obs}}$ point to $M_p(L_{\text{init}})$ curve (Marleau & Cumming 2014)

- General principle—valid for all sets of cooling curves
  
  (vary atmospheric grids, semi-convection, etc.)
**β Pictoris b**

- MCMC for $21 \pm 4$ Myr and $\log L = -3.90 \pm 0.07$
- Use RV constraints (here, small effect)
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- ★ Robust against age uncertainty

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**Bonnefoy, Marleau et al. (2014)**

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**β Pictoris b**

- MCMC for $21 \pm 4$ Myr and $\log L = -3.90 \pm 0.07$
- Use RV constraints (here, small effect), more dynamical modelling useful
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Mordasini et al., in prep.

Big $L$ spread ($\sim 1.5$ dex)

D-burning
$L_D \geq 5\% L_{\text{int}}$
$L_D \geq 25\% L_{\text{int}}$
$L_D \geq 50\% L_{\text{int}}$

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$!$ All have same opacity...
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\( \log \left( \frac{L}{L_{\odot}} \right) \)

\( T = 3 \times 10^6 \) yrs

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HD 100546 b: interpretation?

(Quanz et al. 2015)
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$T=1\times10^7$ yrs
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**A feature of the $L-t$ diagram?**

**Hot-start mass $\lesssim 25 \ M_J$**

(Neuhäuser & Schmidt 2012, updated)

**Cooling curves for 1–25 $M_J$**

(Marleau & Cumming 2014)
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- Lower density in cooling curves...
- ... if uniform mass function over deuterium-burning limit
- Speculative
  - See what surveys say!

(Marleau & Cumming 2014)
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- Application to $\beta$ Pic b: $S_i > 10.5$ (non-cold start)
- Population synthesis: tool for statistical comparison to theory
- Exciting future as close-in planets start being directly detected (SPHERE, GPI, CHARIS, etc.)
Summary and outlook

Thank you for your attention!

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