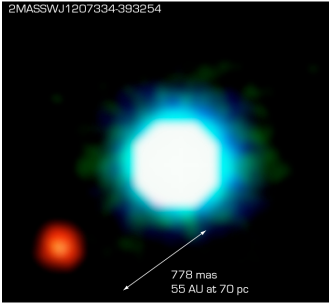
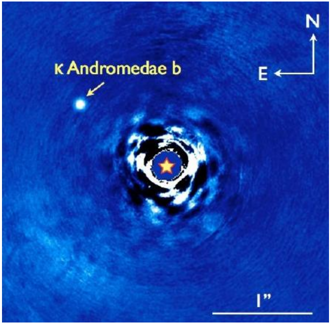
# Luminosities and magnitudes of directly-detectable exoplanets

G.-D. Marleau[1] C. Mordasini[1] F. Allard[2] M. Bonnefoy[3]

[1] MPIA (Heidelberg) [2] CRAL (Lyon, France) [3] IPAG (Grenoble, France)




Chauvin et al. (2004)




Bonnefoy et al. (2014)

# Overview

1. Motivation
   - Uncertainties in planet formation
   - Direct detections
2. Coupling structures to atmospheres
   - Calculating a planet structure
   - Overview of atmosphere models
   - Preliminary results
3. Summary and outlook

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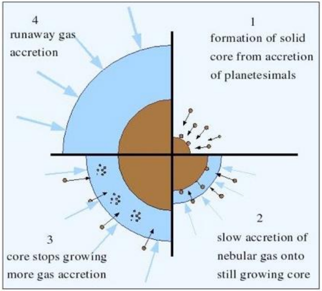
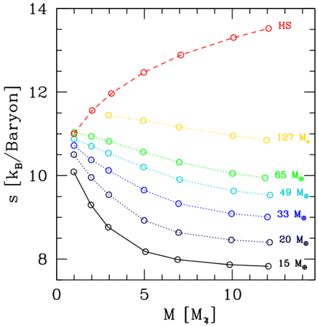
Two formation scenarios for planets in discs:

- Core accretion: closer-in, less massive, higher [Fe/H], colder?
- Gravitational instability: > tens of AU, heavier, hotter?




W. Benz




Mordasini (2013)

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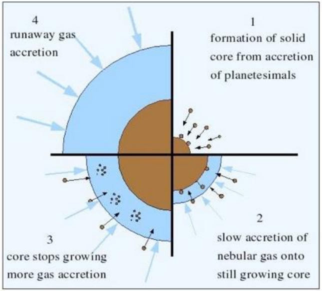
⋆ Compare statistics of observations with model predictions

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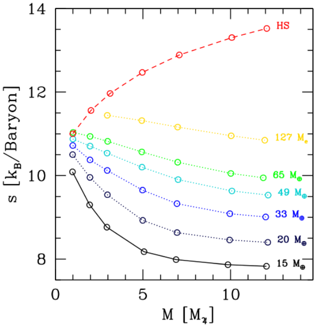


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Statistical study of a formation paradigm

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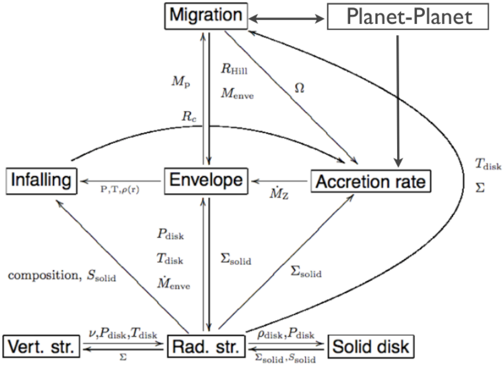


1. Disk migration
2. Planet planet interaction (n-body)
3. Planetesimal-envelope interaction
4. Gaseous envelope structure
5. Protoplanetary gas disk
6. Disk of planetesimals

Core accretion: C. Mordasini

# Contents

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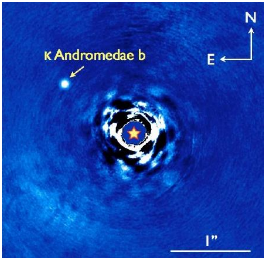
- Bias towards young, massive, and hot planets
- Short term: dramatic increase (GPI, SPHERE)

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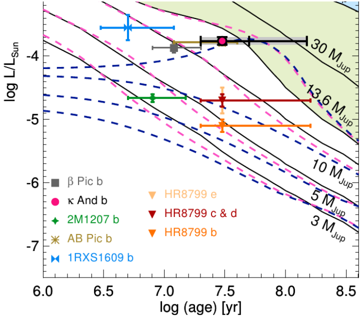


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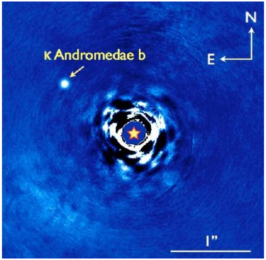


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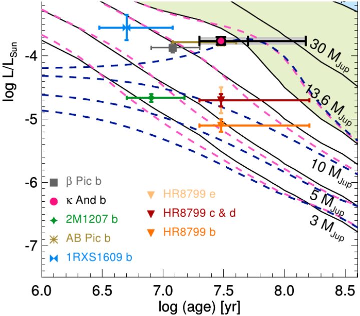


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⋆ "Real" atmospheres ⇒ correct (i) cooling and (ii) interpretation

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**How to couple**

Use atmospheres to obtain boundary conditions for inner structure

# Overview

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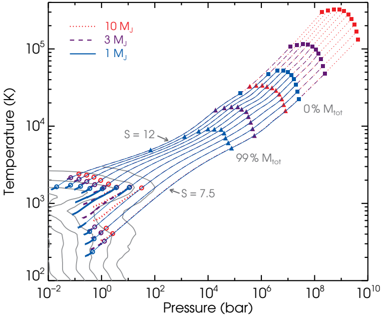
# Structure of gas giant planets

Structure of gas giants, from the centre:

1. Solid core/Dissolved metals
2. Convective interior
3. Radiative atmosphere



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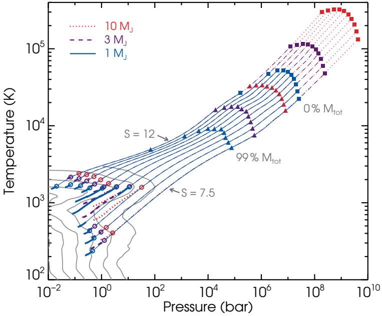

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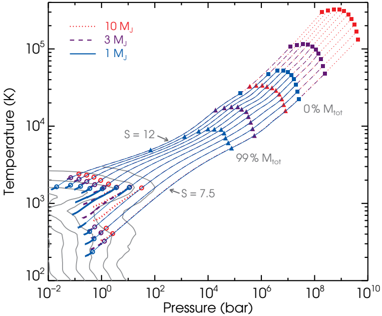

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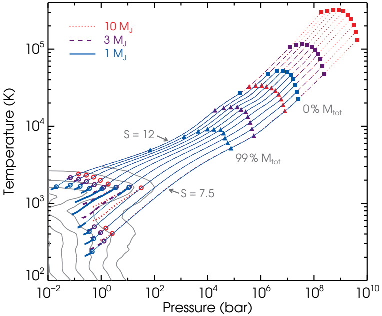

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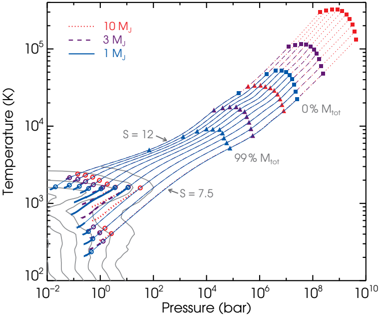
Connect just below atmosphere at $R_{\mathrm{couple}}$

- Neglect $\Delta M, \Delta R$ above $R_{\mathrm{couple}}$
- Interpolate ($P_{\mathrm{couple}}$, $T_{\mathrm{couple}}$) in $\log g$, $T_{\mathrm{eff}}$



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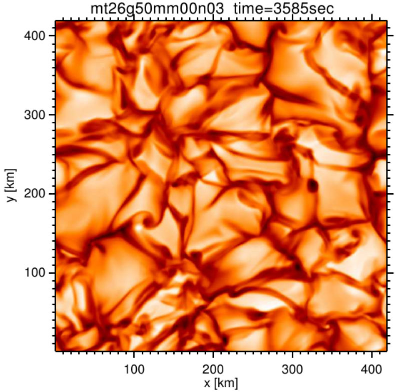
# BT-Settl atmospheres

- Spherical symmetry (1D)
- Radiative transfer solver
- Convection: MLT
- Clouds, mixing, diseq. chemistry




Freytag et al. (2010)

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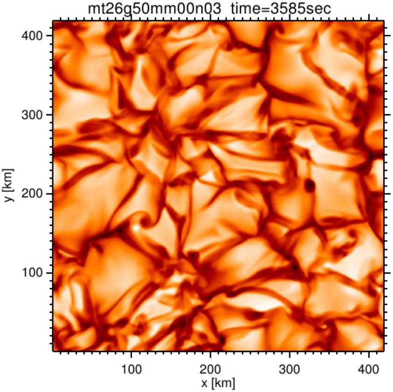
→ "See" F. Allard's talk

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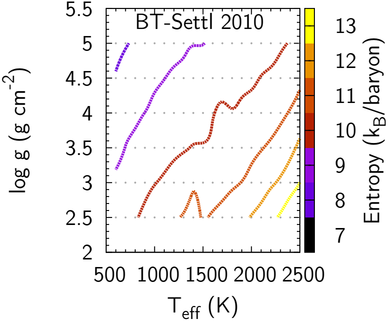


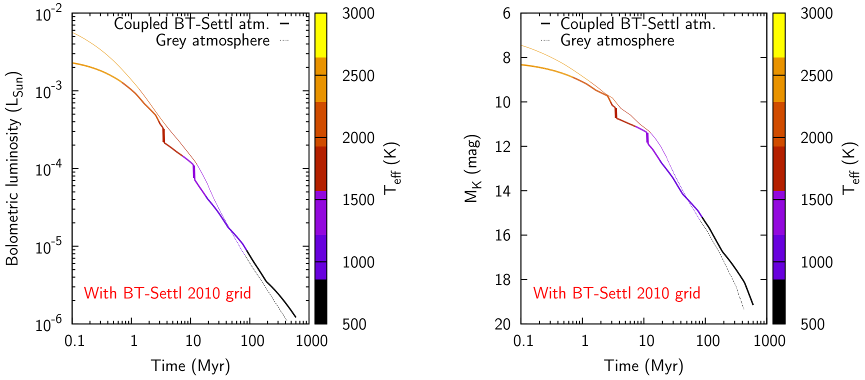

**For coupling purposes**

Atmosphere = Entropy($\log g$, $T_{\mathrm{eff}}$)

# Contents

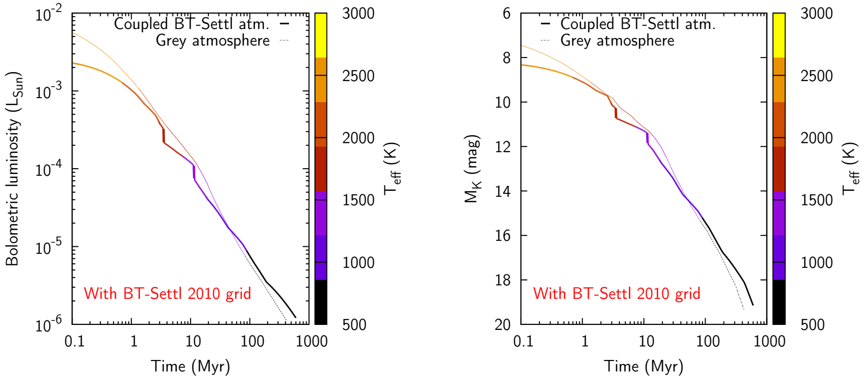
# Example

- $M_p = 10\ M_J$, warm start



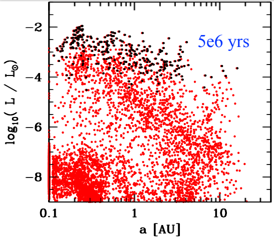
# Example

- $M_p = 10\ M_J$, warm start
- (Small) differences in cooling rate and magnitudes
- To do: check interpolation, use **BT-Settl** 2013 grid



# Population synthesis results (slide: C. Mordasini)

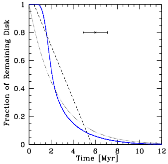
## *a-L diagram* CD745



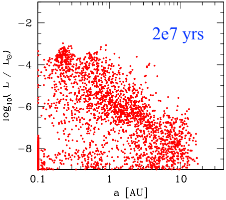

Formation phase: total L

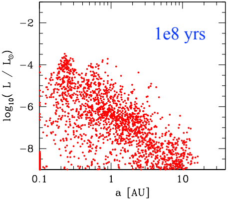
the most luminous ones are those still accreting.

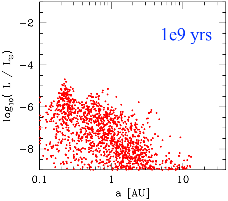
can also make similar plots for each obs. band.




Evolution phase: early on, still imprint from formation. Coupling important!



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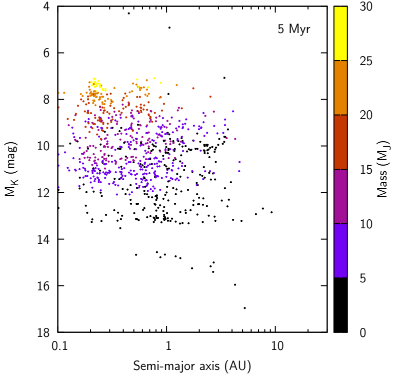

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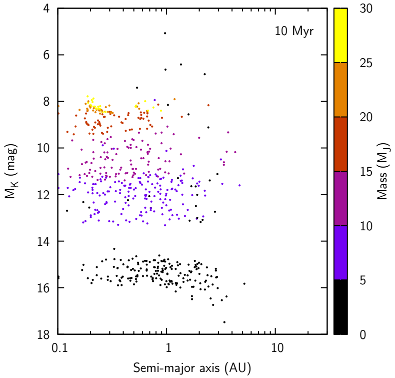

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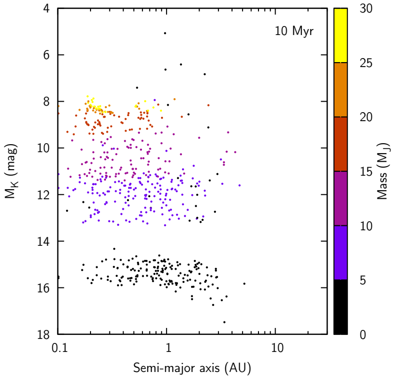


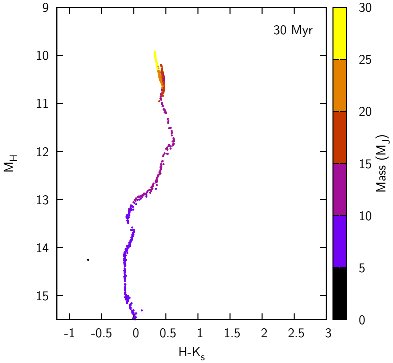

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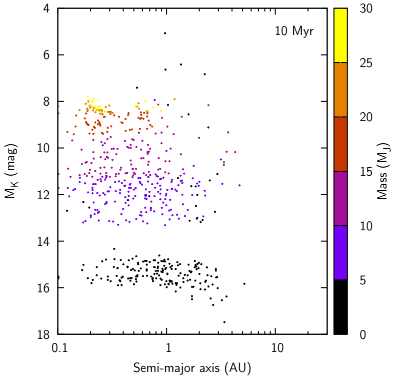


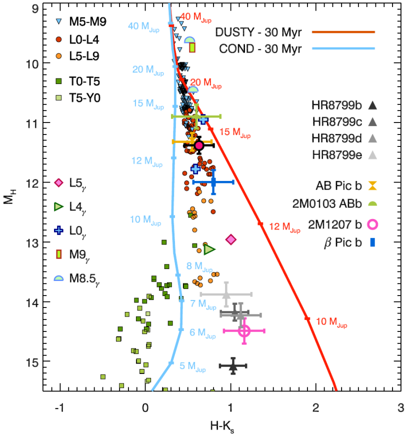

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- Need to accurately compute cooling of gas giant planets...
- ... and map their spectra to mass–initial luminosity constraints

**More accurate cooling planet curves**

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# Additional material

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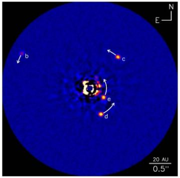
4. Information on the initial entropy

# Joint constraints on $M$ and $S_i$: from $L_{bol}$



## HR 8799 b

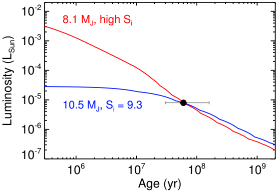


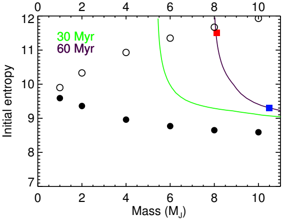

Marois et al., Zuckerman (2010)

- Hot-start masses
- Multiple system → dynamical info

→ Lower bound on $S_i$

- CA "too cold" by $\Delta S = 0.5$ but ok



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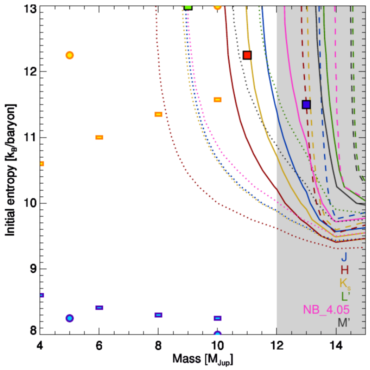


Bonnefoy et al. (2013)

- Atmospheric models: uncertain
- ⋆ Luminosities more robust