Understanding atmospheres across the Universe

ATMO

Pascal Tremblin

- 32 years
- 35 refereed articles (11 as first author)
- 450 citations
- Co-supervision: 2 PhD student, 2 master projects
- Expertise: atmospheric modeling, numerical simulation, HPC, comparison with observations

2009 — 2012 — 2015 — now

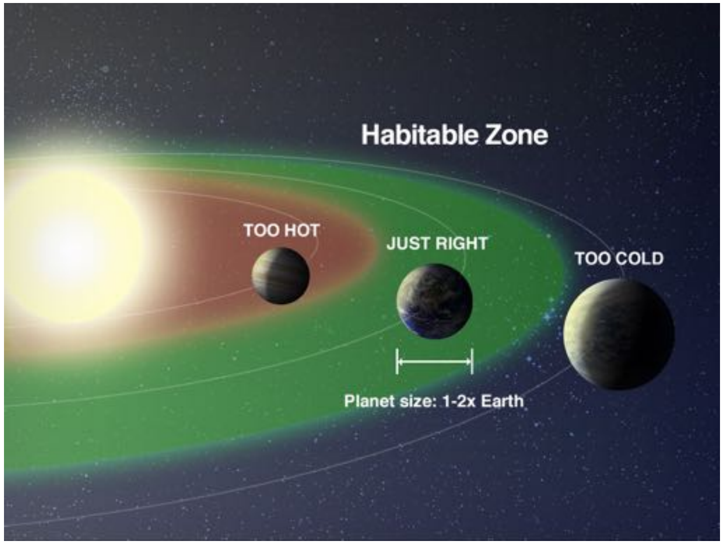
PhD: CEA Saclay
3D turbulent hydrodynamics

Postdoc: Exeter
Atmospheric model

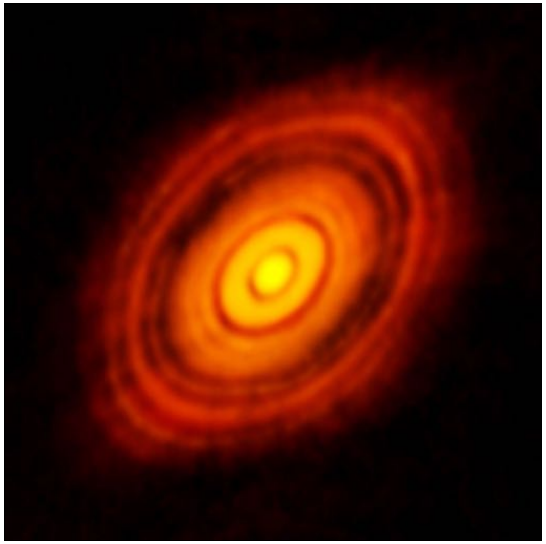
Permanent: Maison de la Simulation
HPC Hydrodynamics

Importance of exoplanet-atmosphere characterization

For habitability and bio-marker signature



For Location and processes for planet formation



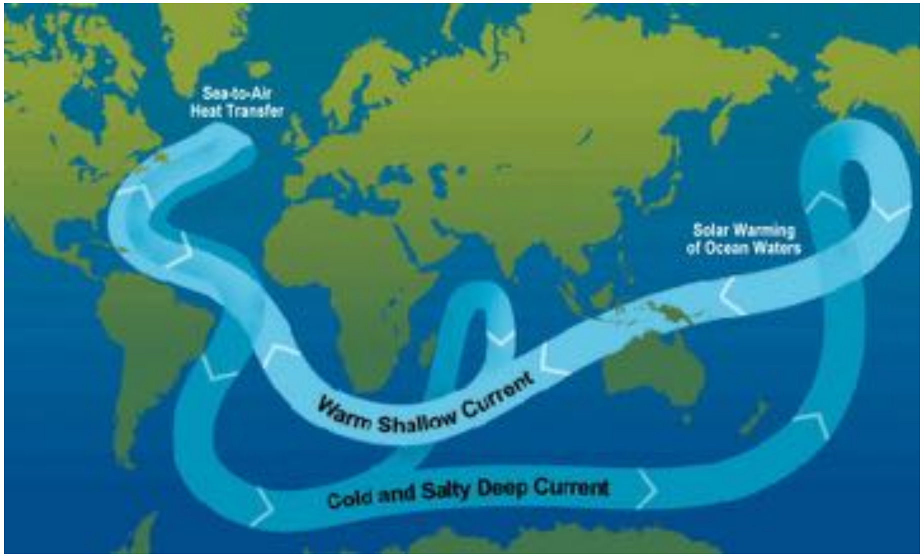
- Need to characterize exoplanet properties:
  - mass, radius
  - pressure/temperature profile
  - chemical composition

Importance of exoplanet-atmosphere characterization

Challenge 1:

- Why do exoplanets/Brown dwarfs emit stronger in the infrared than expected?

- Conventional scenario for 20 years: Clouds?
- Or fingering convection induced by chemical transition e.g. CO/CH4? (1D atmo: Tremblin et al. 2015,2016)



Thermohaline convection in Earth's oceans

Importance of exoplanet-atmosphere characterization

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Challenge 2:

- Why do irradiated exoplanets have inflated radii?

- No robust mechanism for 20 years (possibly magnetic fields)
- Or just circulation and vertical advection of potential temperature? (2D atmo: Tremblin et al. 2017)

Importance of exoplanet-atmosphere characterization

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Challenge 2:

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> ➢ Very promising but a lot of work still need to be done!
> ➢ Mandatory to have robust models to interpret observations

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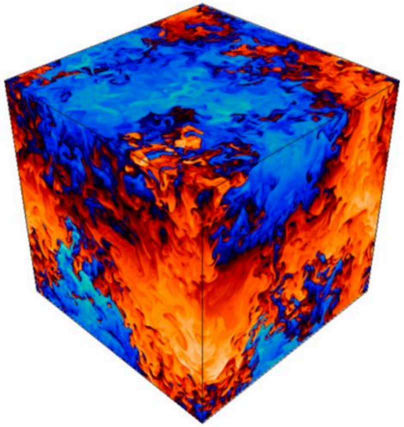
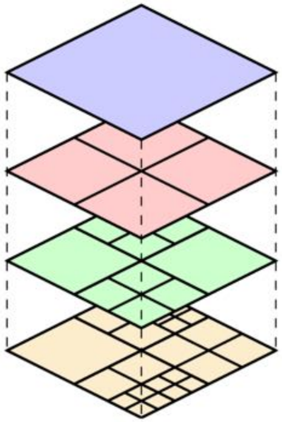
- Need a better understanding of the physical processes present in atmospheres: the ATMO project

WP1: Fingering convection in Ap/Bp star



Small-scale
Numerical simulation

WP2: Fingering convection in Brown dwarfs and non-irradiated exoplanets



Small-scale to large-scale
Adaptive Mesh Refinement

WP3: Fingering convection and circulation in irradiated exoplanets

Large-scale
Global circulation Model

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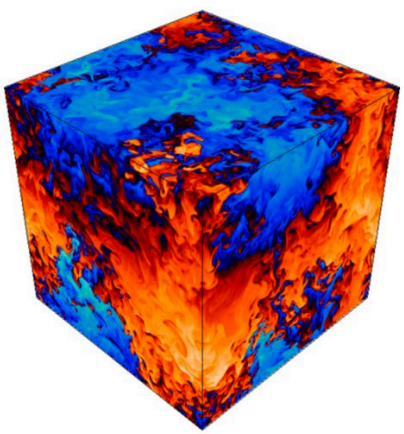
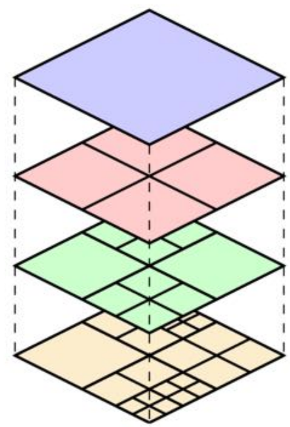
WP2: Fingering convection in Brown dwarfs and non-irradiated exoplanets

WP3: Fingering convection and circulation in irradiated exoplanets





WP1
Fingering convection in Ap/Bp star

State of the art
- application of the boussinesq model of Brown et al. (2013), Garaud et al. (2015)

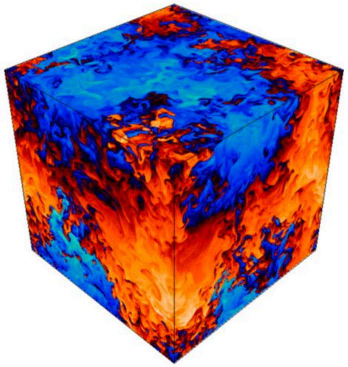
Challenges
- Stratification effect?
- Astrophysical regime? (viscous scale too small)

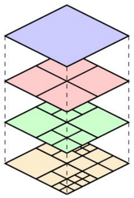
New approach
- Design a new robust hydrodynamic solver for stratified flow
- Take advantage of new HPC architecture to get closer to the astrophysical regime

WP1: Ap/Bp star

WP2: BDs/ exoplanets

WP3: Irradiated exoplanets





PI, Postdoc1, HPC Engineer

Applied maths breakthrough (coll. S. Kokh)
- Lagrange-remap solver
- Well-balanced for gravity
- High order with MOOD

GPUs/Xeon Phi with Kokkos library (Coll. P.Kestener)

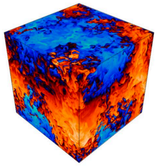
WP2
Fingering convection in Brown dwarfs and exoplanets

State of the art
- (1D) Fingering convection induced by chemical instabilities explains the spectral reddening (Tremblin et al. 2015,2016)

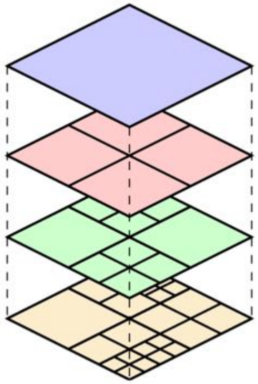
Challenges
- Is the 3D turbulent energy transport induced by fingering convection efficient enough?
- Is the extension of the turbulent zone big enough?

New approach
- Use Adaptative Mesh Refinement to resolve the small scale fingers and the extension of the turbulent region
- Dynamical study and parametrization of chemical instabilities for 1D model

WP1: Ap/Bp star

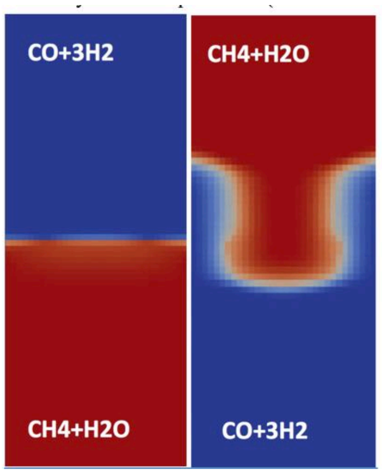


WP2: BDs/ exoplanets



WP3: Irradiated exoplanets

PI, PhD1, HPC Engineer



Preliminary result of the dynamical CO/CH4 instability

WP3
Fing. convection and circulation in irradiated exoplanets

State of the art

- 2D steady state circulation model expains the inflated radii (Tremblin et al. 2017)

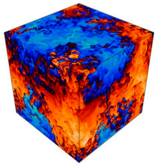
Challenges

- What about the 3D steady circulation?
- And the interplay with fing. convection?

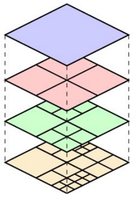
New approach

- Use the efficency of recent circulation model (Dynamico) to reach the 3D steady state
- Study fingering convection in a forced shear flow box model, extension of the parametrization for global models

WP1: Ap/Bp star

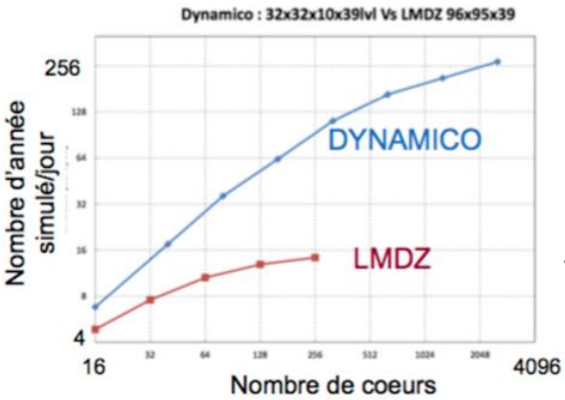


WP2: BDs/ exoplanets



WP3: Irradiated exoplanets

PI, PhD2, HPC Engineer



Scaling of the new cirulation model Dynamico

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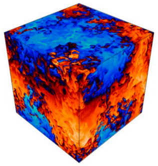
Highest risks WP1:
stratified hydro-solver

- Lagrange-remap -> low-mach solver
- Well-balanced gravity -> relaxation
- High order MOOD -> 2nd order scheme

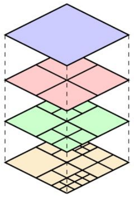
Lowest risks WP2/3:

- Parametrization of the instability
- Implementation in global 1D/3D atmospheric models

WP1: Ap/Bp star



WP2: BDs/ exoplanets



WP3: Irradiated exoplanets

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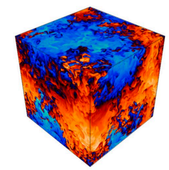
Deliverables

- An innovative solver for stratified hydrodynamics
- Parametrization of fingering convection for global models
- Produce exoplanets spectra, phase curves for future JWST/E-elt observations (PI associated to MIRI consortium)

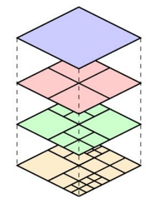
Transfer in other fields

- Application of the solver for oceanic dynamics

WP1: Ap/Bp star



WP2: BDs/ exoplanets



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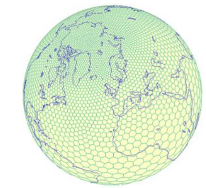


Team: Posdoc1, PhD1, PhD2

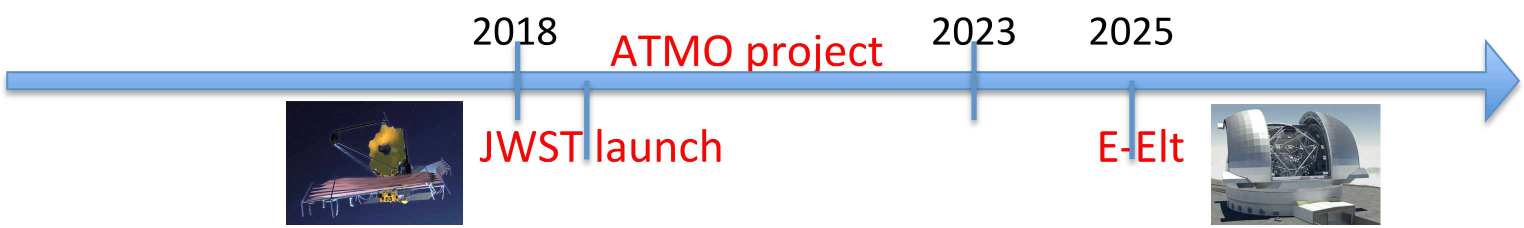
PI, HPC Engineer

(Host institute: CEA Salcay)

Budget:

Manpower (60%), HPC investments (11%)

Travel, publications (9%) Overheads (20%)



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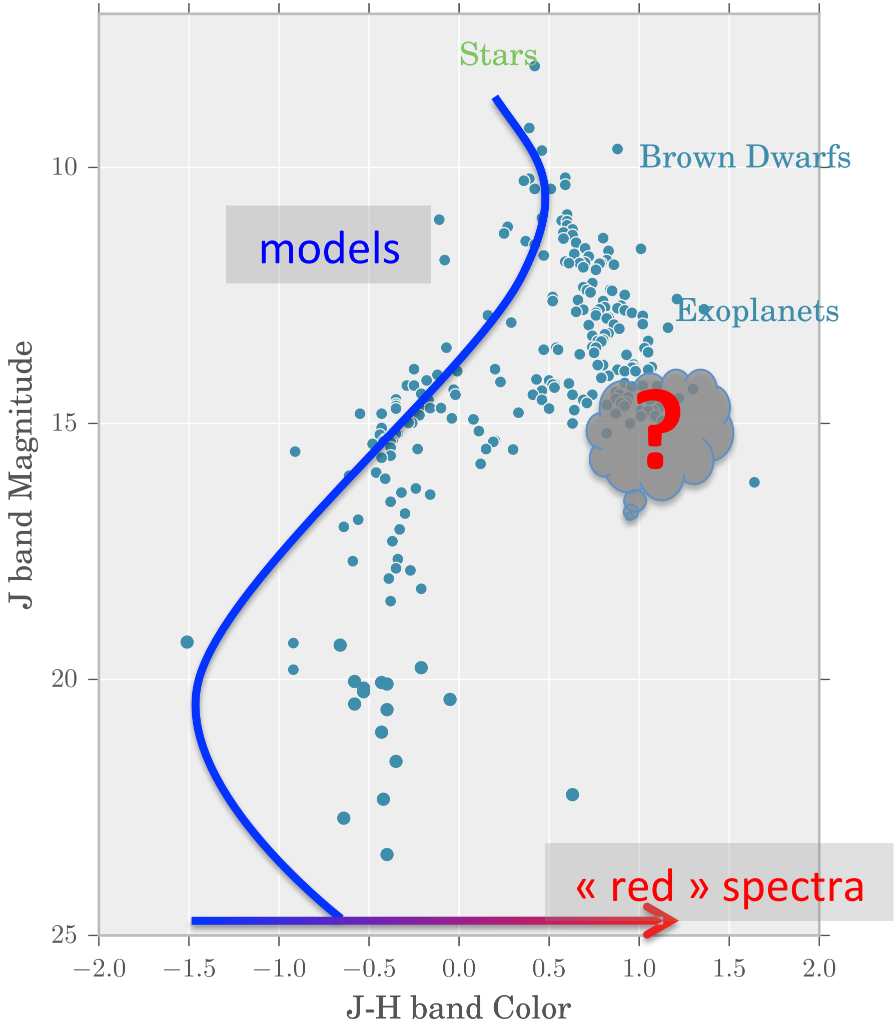

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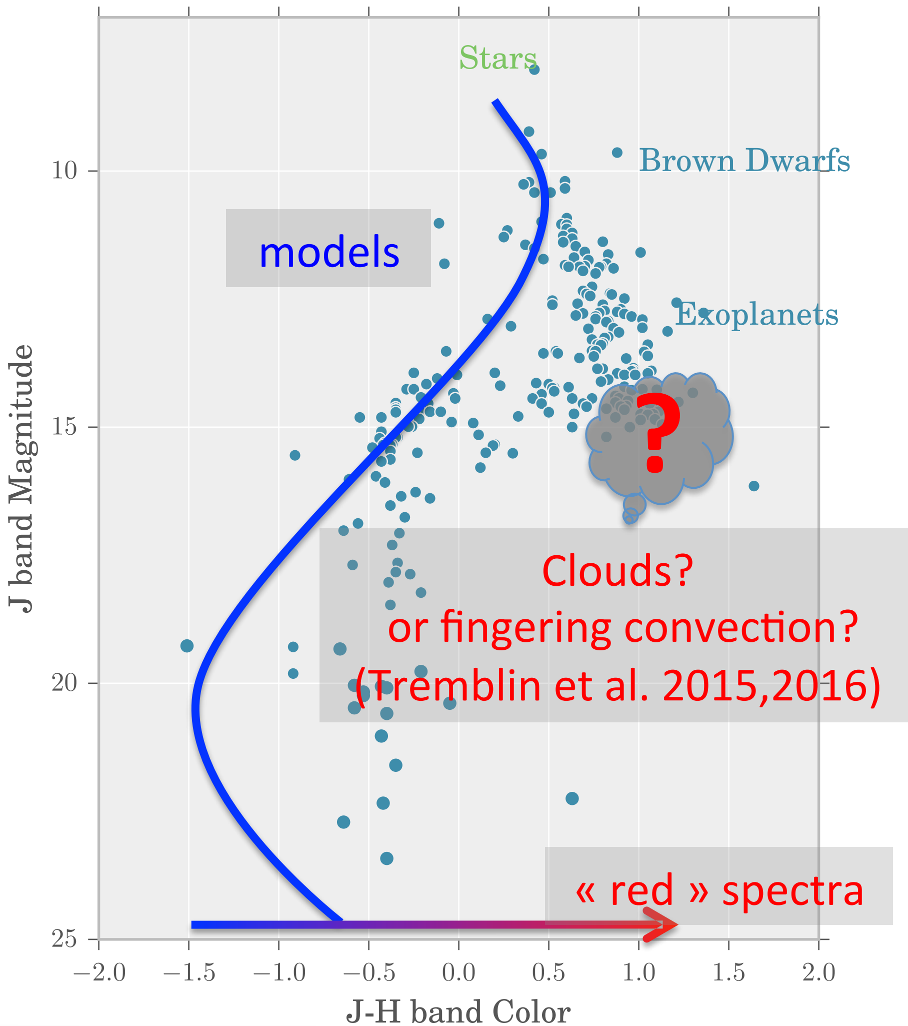

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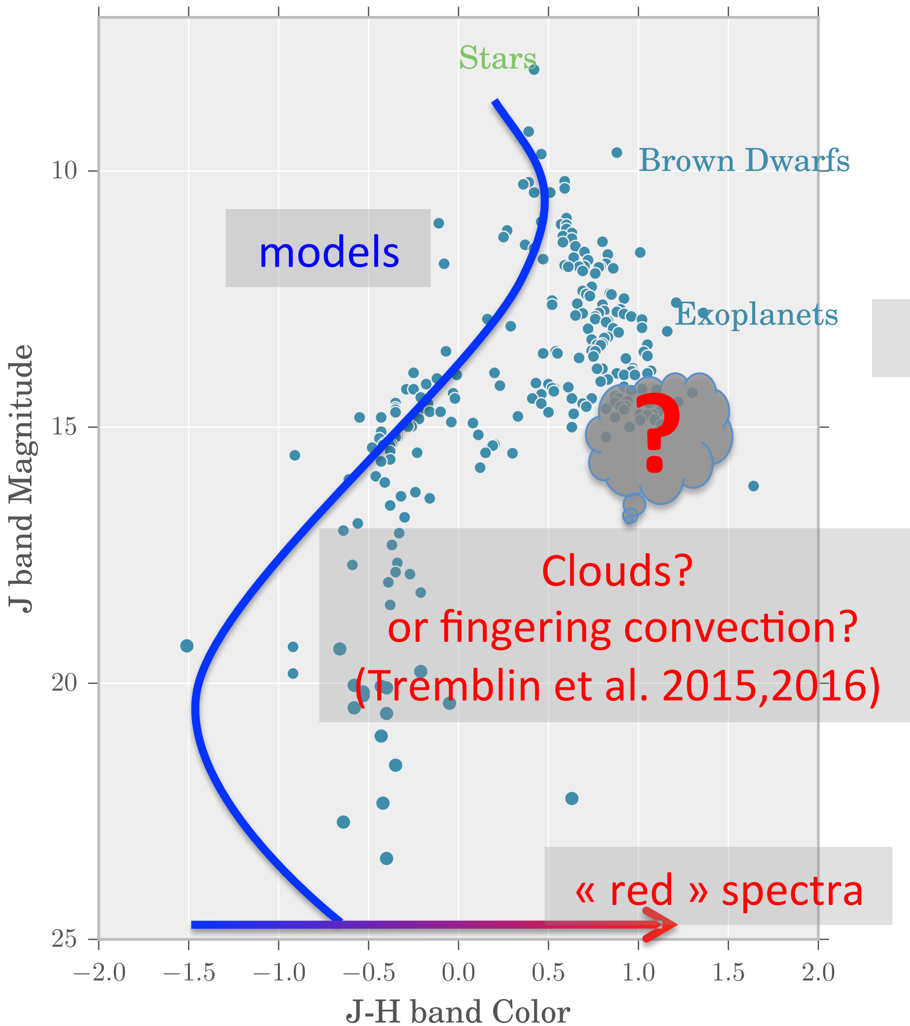

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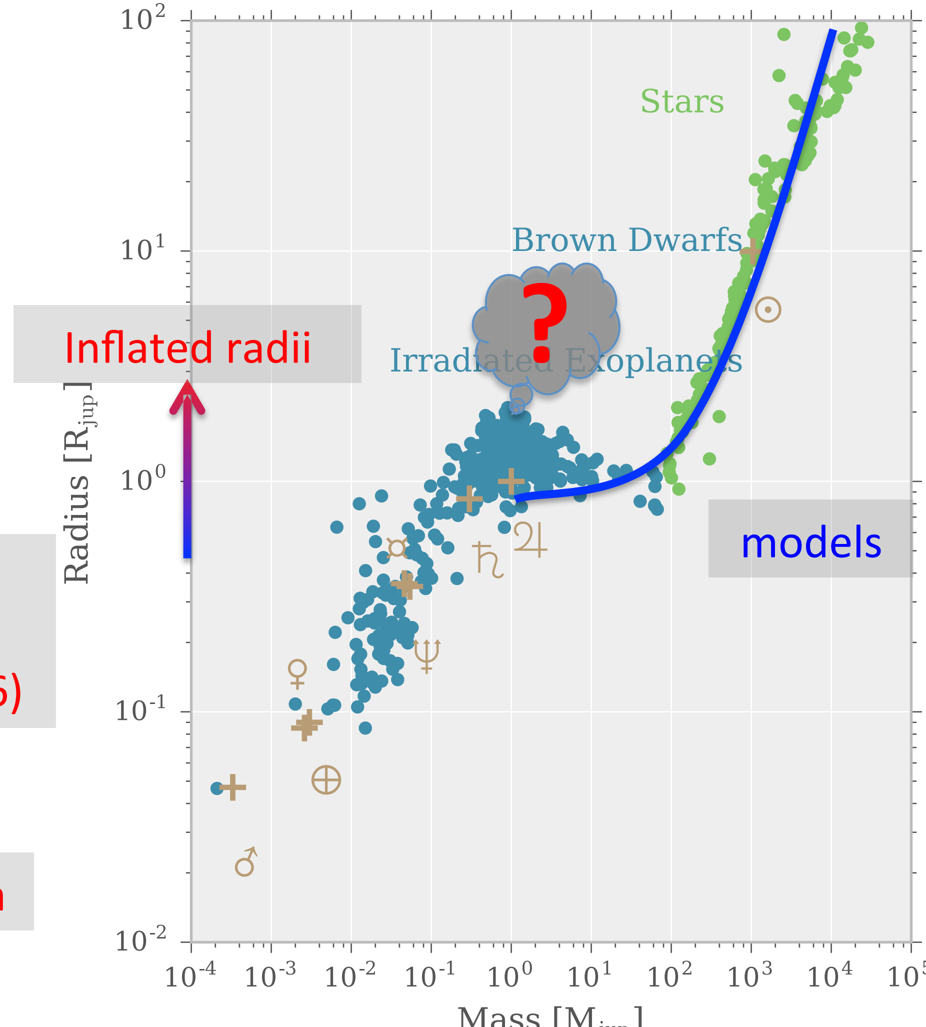

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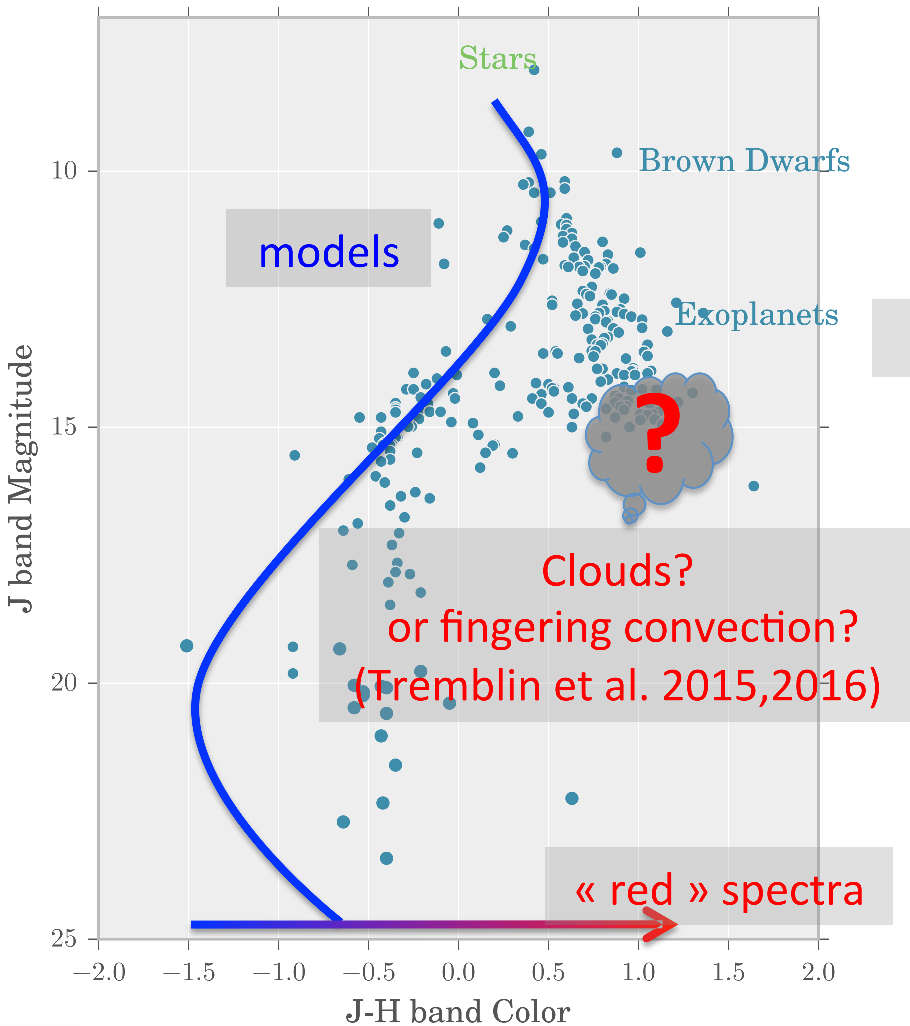

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