Radiation Hydrodynamics Simulation of Protostellar Collapse: Constraints on Brown Dwarf Formation Mechanisms

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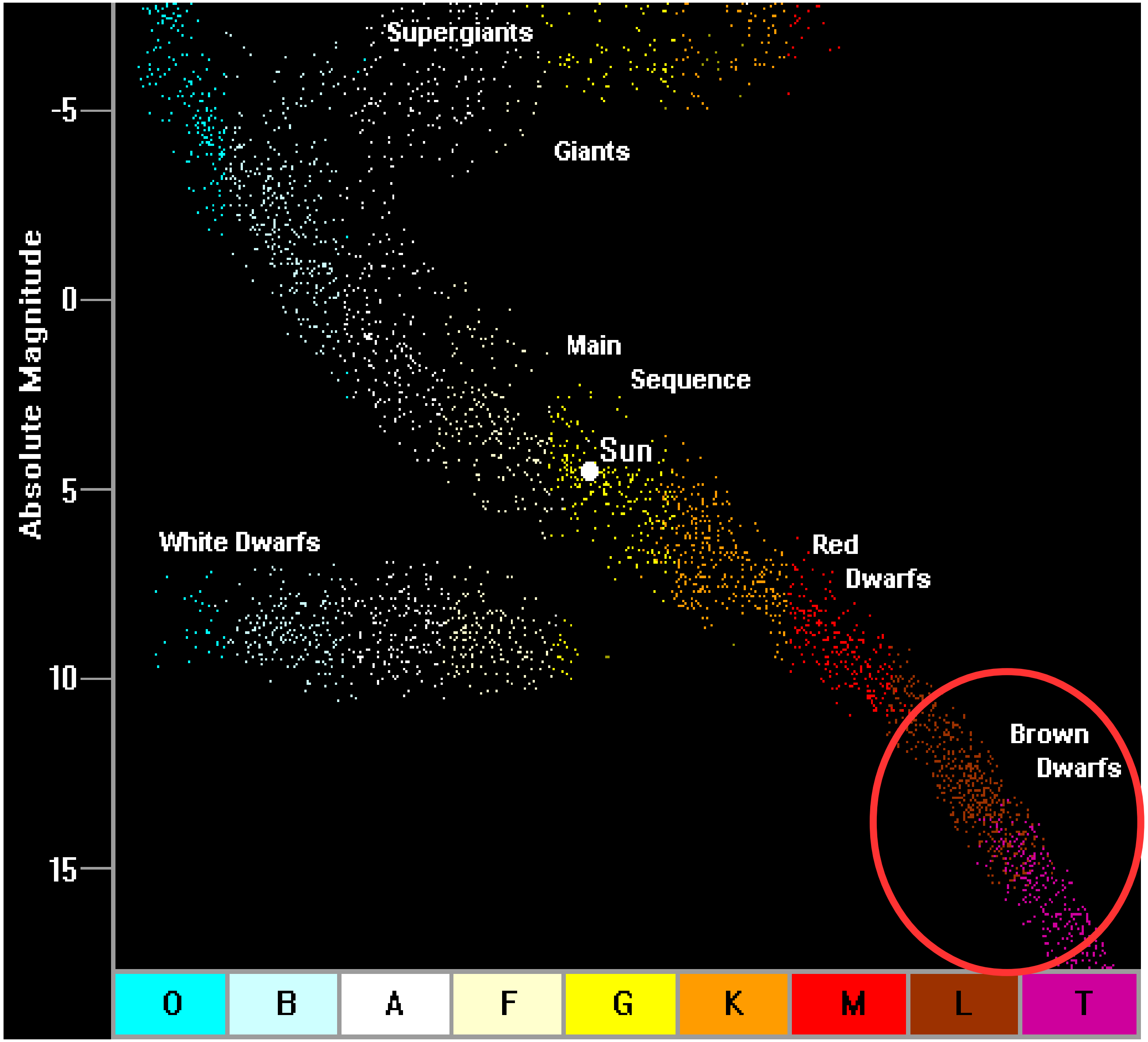
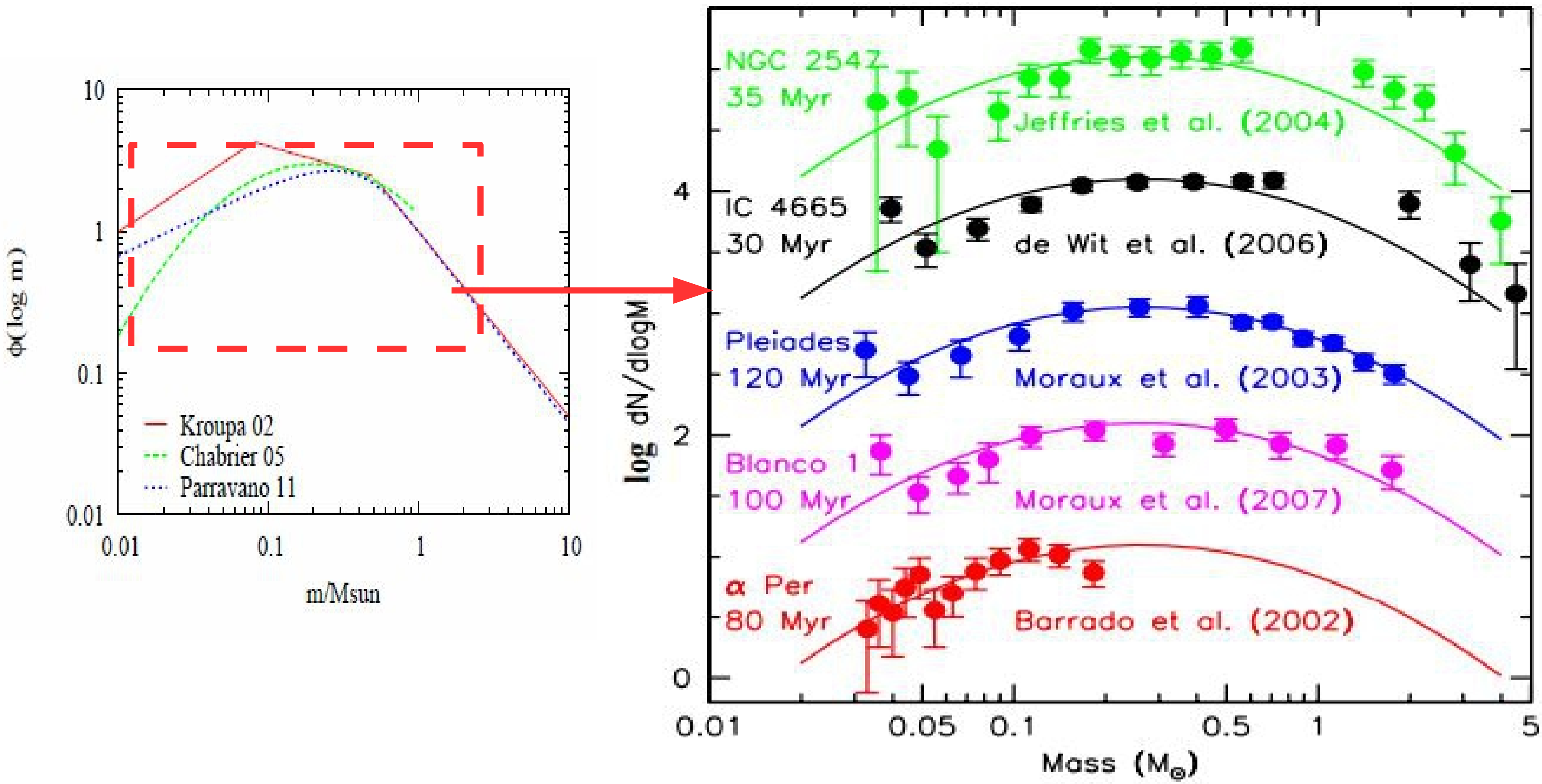
Brown Dwarfs: Definition

- Substellar object below the hydrogen-burning limit, but able to fuse deuterium
- Between ~13 and ~70 M_J
- Gravitational support: Electron degeneracy pressure
- Radius ~ 1 R_J
- "Failed star": Slow cooling over time



Brown Dwarf Mass Function



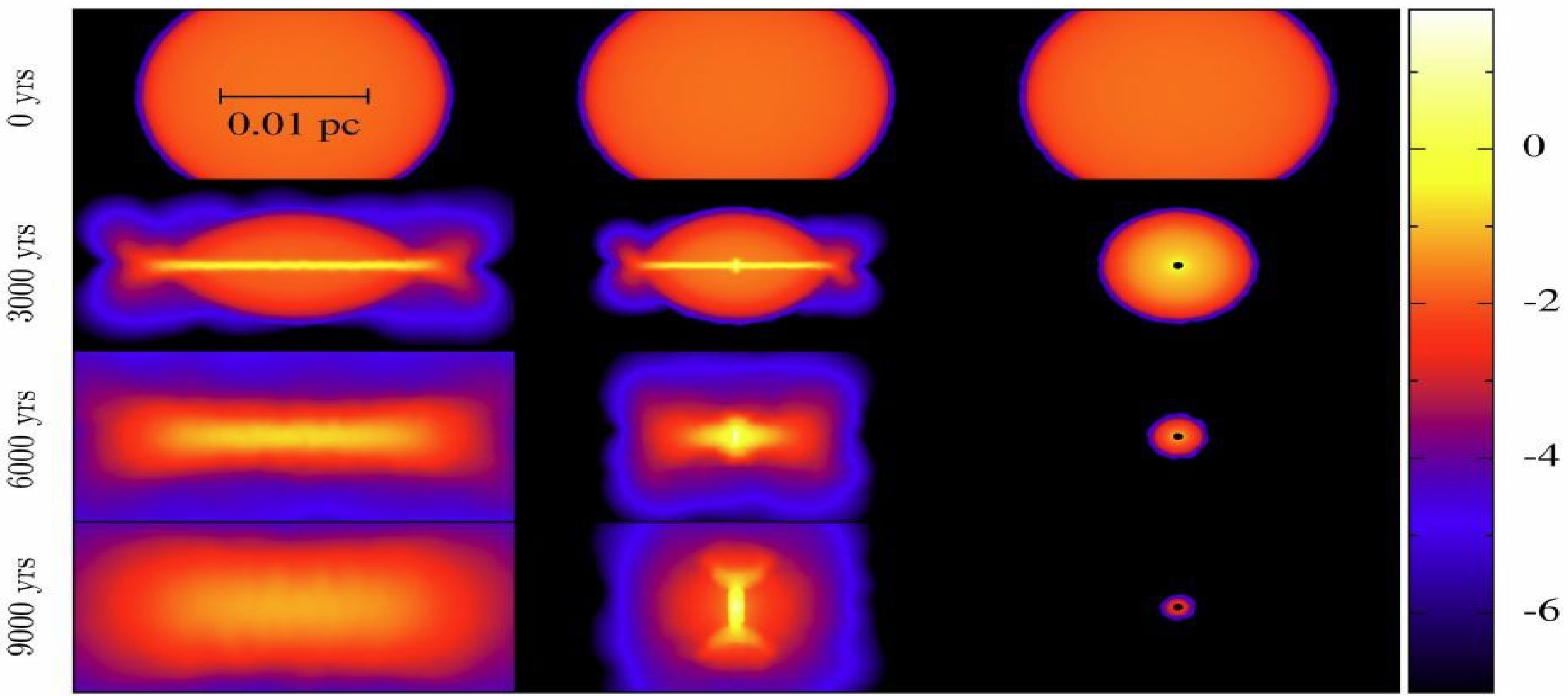
Jeffries (2012)

How to form Brown Dwarfs?

- Jeans Mass $M_J \sim \rho^{-1/2}\ T^{3/2}$
  - $M_J = 0.01\ M_\odot$, T=10 K -> Required density $10^7\ cm^{-3}$
- Typical observed high-density cloud: $10^4\ cm^{-3}$
- Possible formation scenarios:
  - Same as low-mass stars: Collapse and fragmentation of filaments
  - Alternative mechanisms specific to brown dwarfs
    - Turbulent compression
    - Competitive accretion and ejection
    - Gravitational instability in protoplanetary disks

Colliding Flows

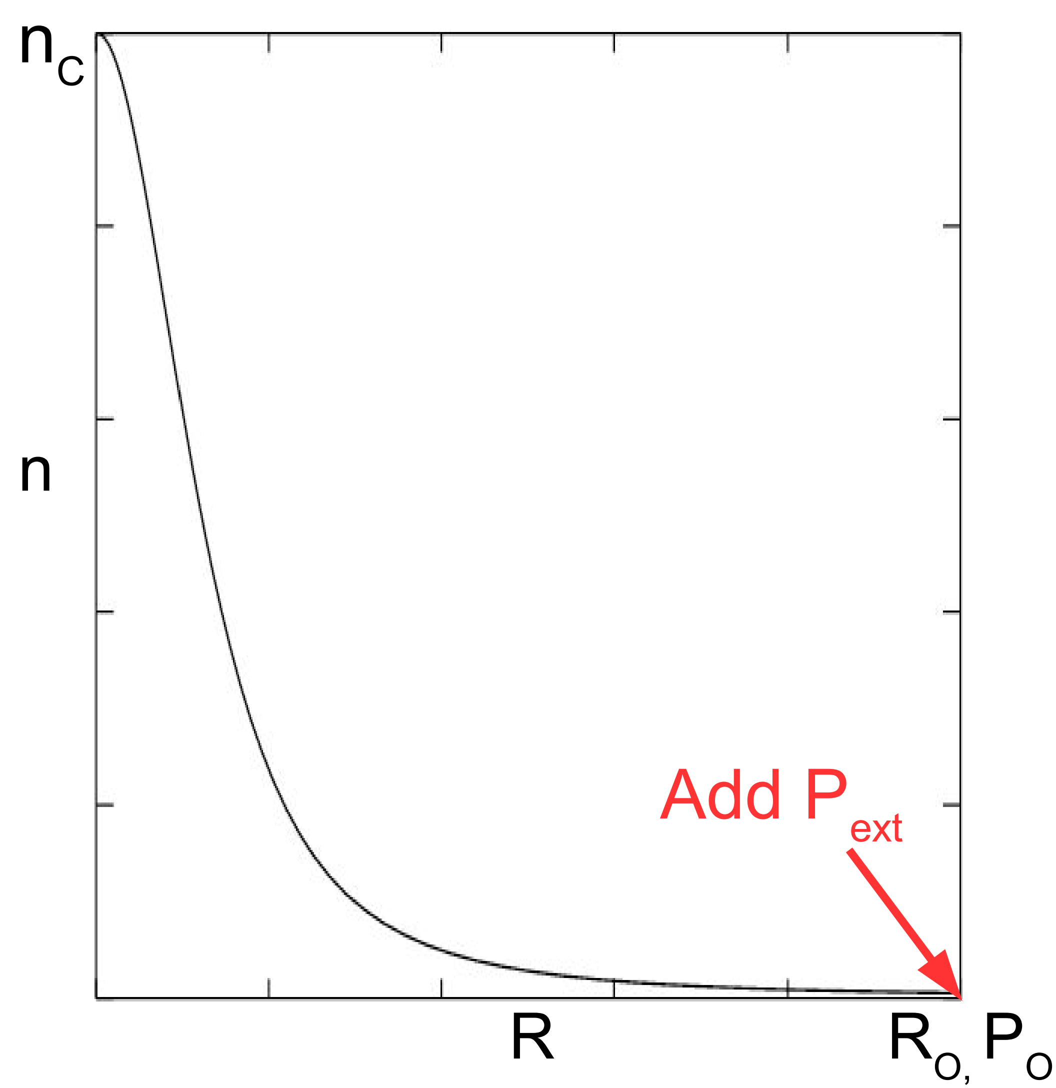
- SPH simulation of colliding flows with different degrees of convergence:



Lomax et al. (2016)

Simulation Setup

- Spherically symmetric RHD simulation
- Frequency-dependent radiative transfer: Newly developed method *(see forthcoming paper by Stamer&Inutsuka)*
- Bonnor-Ebert-sphere, central density n_C
- M (cloud mass) and n_C determine outer radius R_O and pressure P_O
- Gravitationally stable if: $M < M_{BE} = 1.18\, c_s^4\, P_O^{-1/2}\, G^{-3/2}$
- $P_{ext} = P_{ext,init} * \exp(-t / t_D)$
- 3 parameters: n_C, $P_{ext,init}$, t_D



Videos: Collapse vs. Oscillation

First Core Formation - Density Profile

Bounceback - Density Profile

Formation by Transient Compression

$M=0.06\ M_\odot$; $P_{ext}=P_{ext,init}*\exp(-t/t_D)$; O =success, X = failure

$n_C=10^4$

$\log(t_D)$ [years] \ $\log(P_{ext,init}/k_B)$	6	7	8	9
6	O	O	O	O
5	O	O	O	O
4	X	O	O	O
3	X	X	O	O

$R_O=5975$ AU

$t_{ff}=3\times10^6$ years

$M=0.06\ M_{BE}$

(very stable)

$n_C=10^5$

$\log(t_D)$ [years] \ $\log(P_{ext,init}/k_B)$	6	7	8	9
6	X	O	O	O
5	X	O	O	O
4	X	O	O	O
3	X	X	O	O

$R_O=2800$ AU

$t_{ff}=1\times10^6$ years

$M=0.17\ M_{BE}$

(quite stable)

$n_C=10^6$

$\log(t_D)$ [years] \ $\log(P_{ext,init}/k_B)$	6	7	8	9
6	X	O	O	O
5	X	O	O	O
4	X	X	O	O
3	X	X	O	O

$R_O=1325$ AU

$t_{ff}=3\times10^5$ years

$M=0.51\ M_{BE}$

(barely stable)

Required Conditions for Turbulent Compression

- Calculate minimum size of high-pressure region
- Necessary size = $R_O + v_{shock} * t_D$

$\frac{P_{ext,init}}{k_B}$	$n_C = 10^4$	$n_C = 10^5$	$n_C = 10^6$
10^8	7000 AU	3100 AU	2500 AU
10^7	9600 AU	3900 AU	
10^6	18000 AU		

Observation?

Summary

- Turbulent compression: A possible mechanism to explain brown dwarf formation
- We performed 1-D RHD simulations of gravitationally stable cores, compressed by external pressure
- Formation of brown dwarfs this way is possible, but difficult (requires very large-scale, coherent high-pressure region)
- If such large-scale turbulence exists, it should be observable