The Impact of Thermodynamics on Gravitational Collapse

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Introduction

Star formation occurs under a large variety of conditions:

- Milky Way-type molecular clouds
- starburst galaxies
- environments of supermassive black holes
- primordial minihalos

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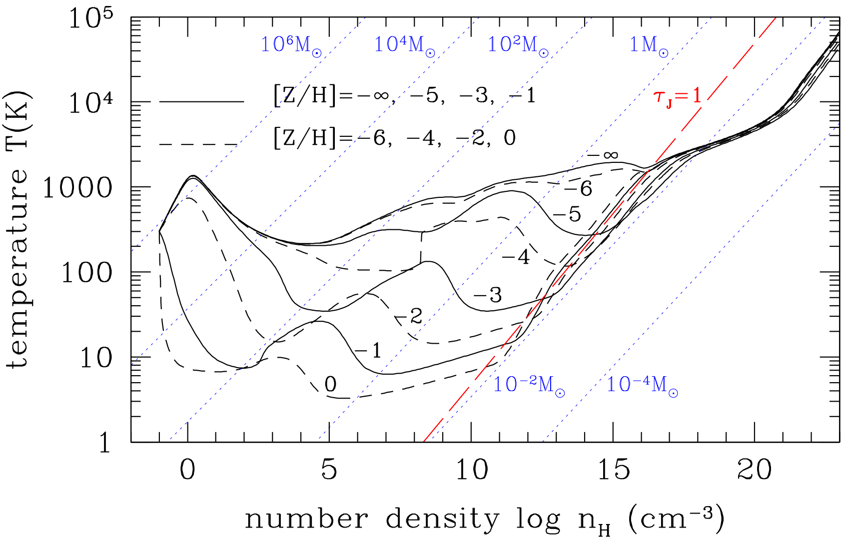
Thermodynamic response of gas to compression determined by:

- ambient radiation field
- cosmic ray flux
- overall metallicity

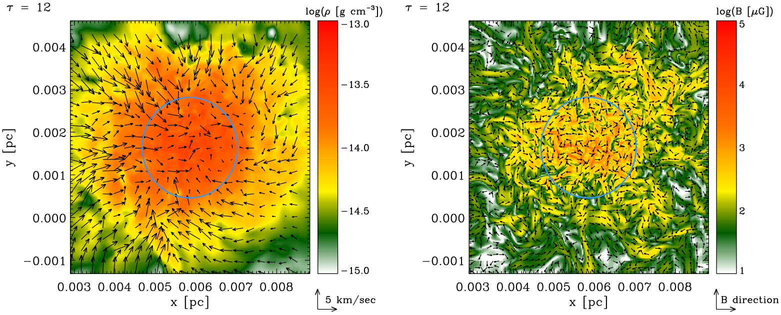
Primordial Thermodynamics



Omukai et al. 2005

Polytropic Collapse Calculations

- simplified collapse calculations: assume $\Gamma = 1.1$
- take Bonnor-Ebert sphere as model for primordial minihalo
- impose turbulent velocity fluctuations
- study magnetic field amplification by small-scale dynamo
- high Jeans resolution necessary



Sur et al. 2010

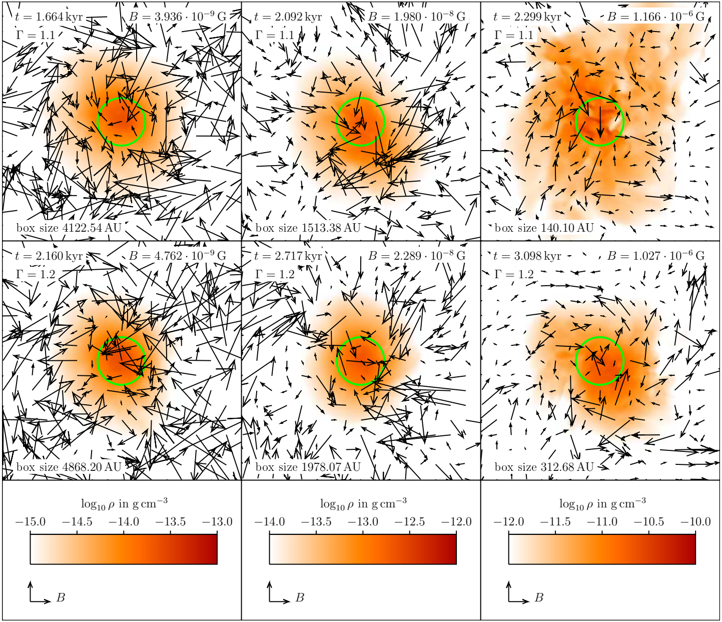
Influence of Polytropic Exponent

How does polytropic exponent Γ influence collapse behavior?

Collapse Simulations with FLASH

- collapse simulations for $\Gamma = 0.7, 0.9, 1.1, 1.2$
- resolution of 64 cells per Jeans length
- positive-definite MHD Riemann solver (Waagan et al. 2011)
- halo from Greif et al. 2011 as initial condition ($M \approx 100 M_{\odot}, \lambda_{\mathrm{J}} = 8000\,\mathrm{AU}, T_{\mathrm{mean}} = 710\,\mathrm{K}$)
- set up magnetic field with Kazantsev spectrum and $B_0 = 1\,\mathrm{nG}$
- follow collapse for up to 16 refinement levels

Density and Magnetic Field Structure



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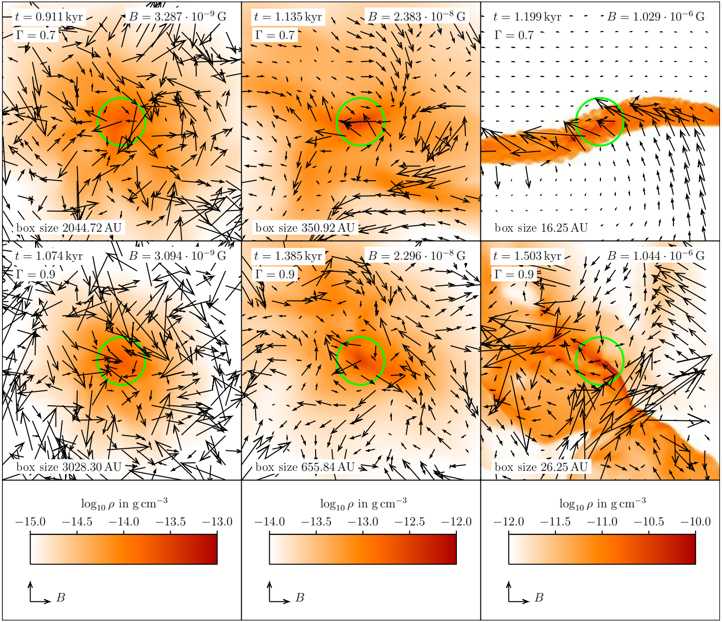


Density and Magnetic Field Structure

Significant differences between super-isothermal ($\Gamma > 1$) and sub-isothermal ($\Gamma < 1$) case!

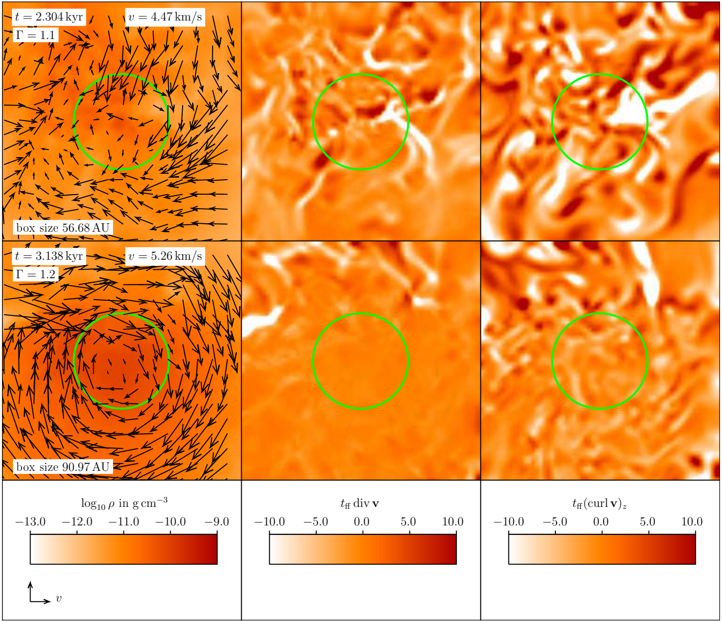
Super-isothermal collapse

- strong turbulence
- magnetic field highly tangled
- magnetic field efficiently amplified

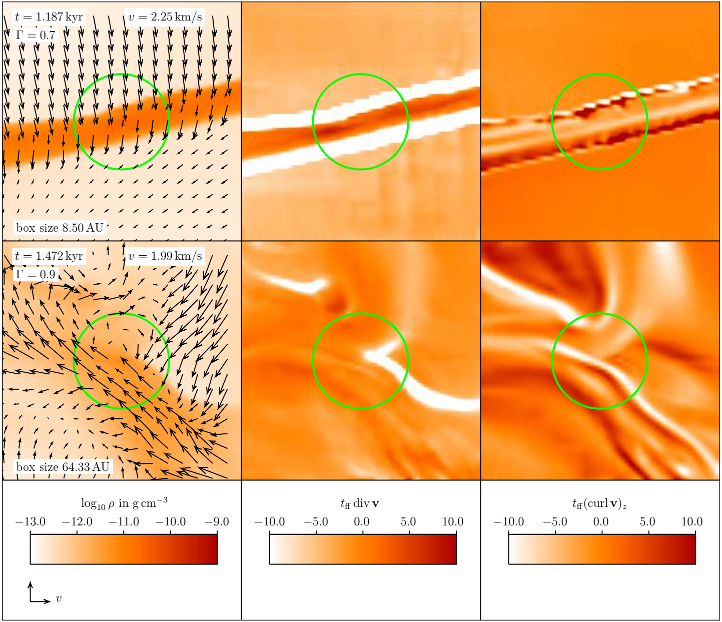
Sub-isothermal collapse

- collapse proceeds much more rapidly
- strong shocks and filaments form
- magnetic field lines are coherent on Jeans scale and beyond

Velocity Structure



Velocity Structure

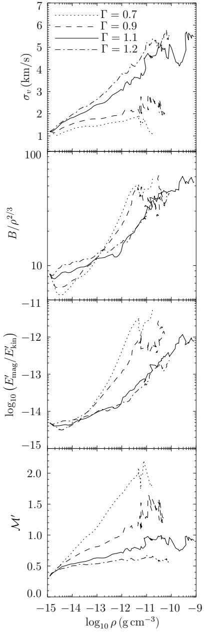


Velocity Structure

Differences also show up in velocity field:

- more small-scale structure in super-isothermal case
- even in the sub-isothermal case vortices near shocks form

Small-scale dynamo action possible!



- growth of turbulent velocity dispersion much weaker for sub-isothermal collapse
- all simulations show increasing $B/\rho^{2/3}$
- interpretation difficult for sub-isothermal runs

Conclusions

- Thermodynamics has significant influence on gravitational collapse.
- Super-isothermal collapse leads to strong turbulence and tangled magnetic field lines.
- Sub-isothermal collapse leads to pronounced shocks and filaments, magnetic field is coherent across Jeans volume and beyond.
- Magnetic field gets amplified beyond pure compression in all cases.