Max-Planck-Institut für Astrophysik

LMU TUM ORIGINS Excellence Cluster ESO Irz

MAX-PLANCK-GESELLSCHAFT

CN5 - Turbulence

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Frank Jenko, Harald Lesch

ORIGINS II meeting

October 18th, 2022

Steinwandel et al. 2020

Connector 5 – Turbulence in the interstellar medium

Highlights covering turbulent processes from stellar interiors to galaxy clusters

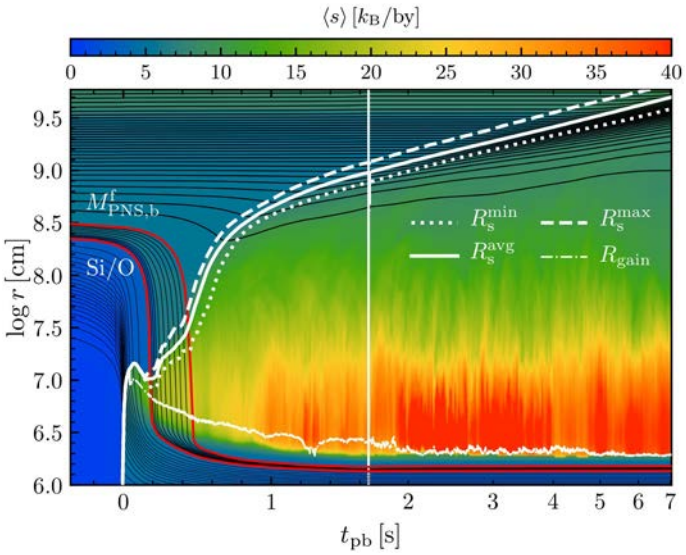
Turbulence in proto-planetary disks &
turbulent molecular dynamics in phase II

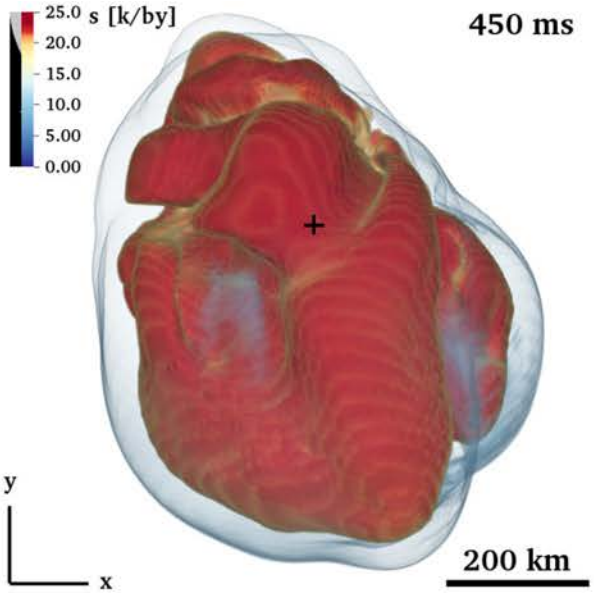
Large fraction of milestones have been addressed

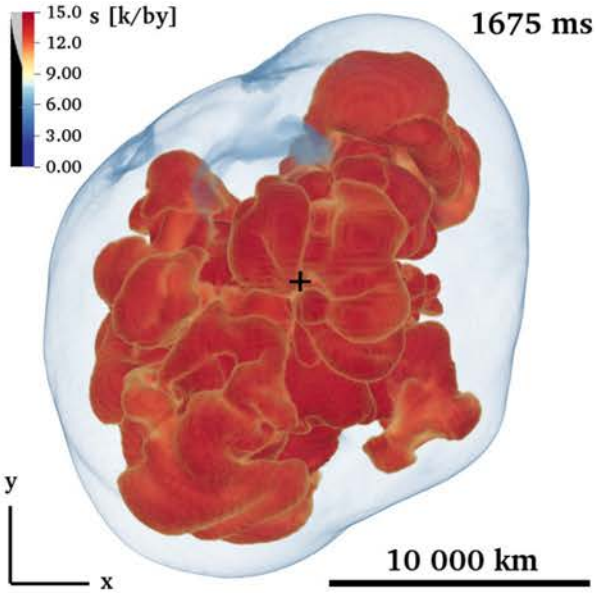
3D Supernova Simulations of ~19 M_{sun} Star From –7 Minutes to +7 Seconds

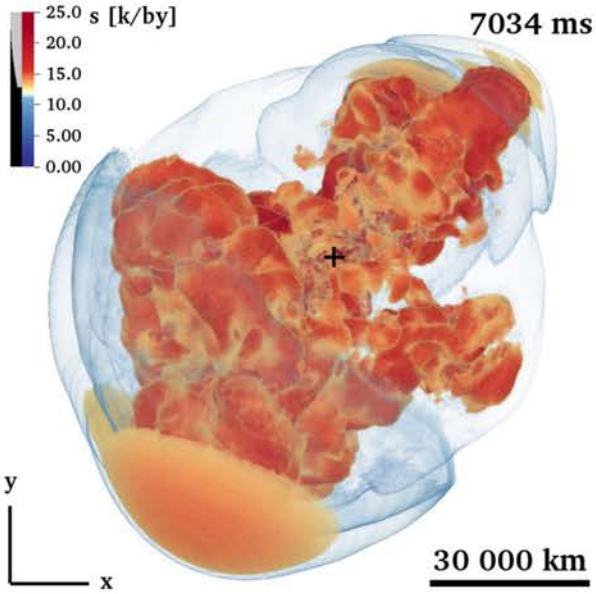
- First self-consistent 3D simulation from pre-collapse state through core bounce until 7 sec. into explosion.
- Successful supernova only with 3D initial conditions.
- Explosion energy (1 B), ^{56}Ni mass (< 0.086 Msun), neutron-star mass and kick in the ballpark of Supernova 1987A.

Bollig, Yadav, Janka, et al., ApJ, submitted (2020)



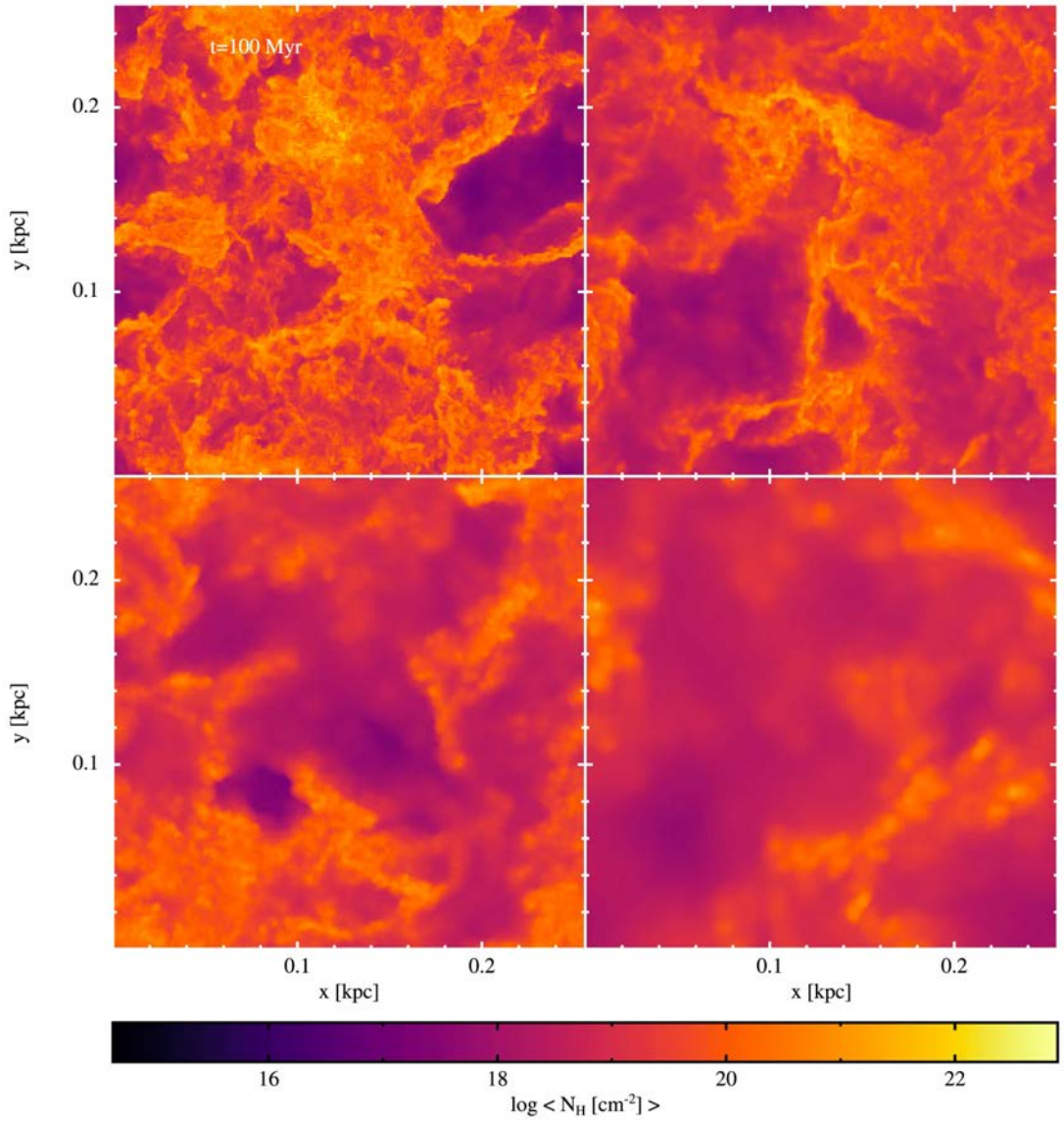






Turbulent multi-phase ISM in dwarf galaxies

The turbulent ISM at different resolutions

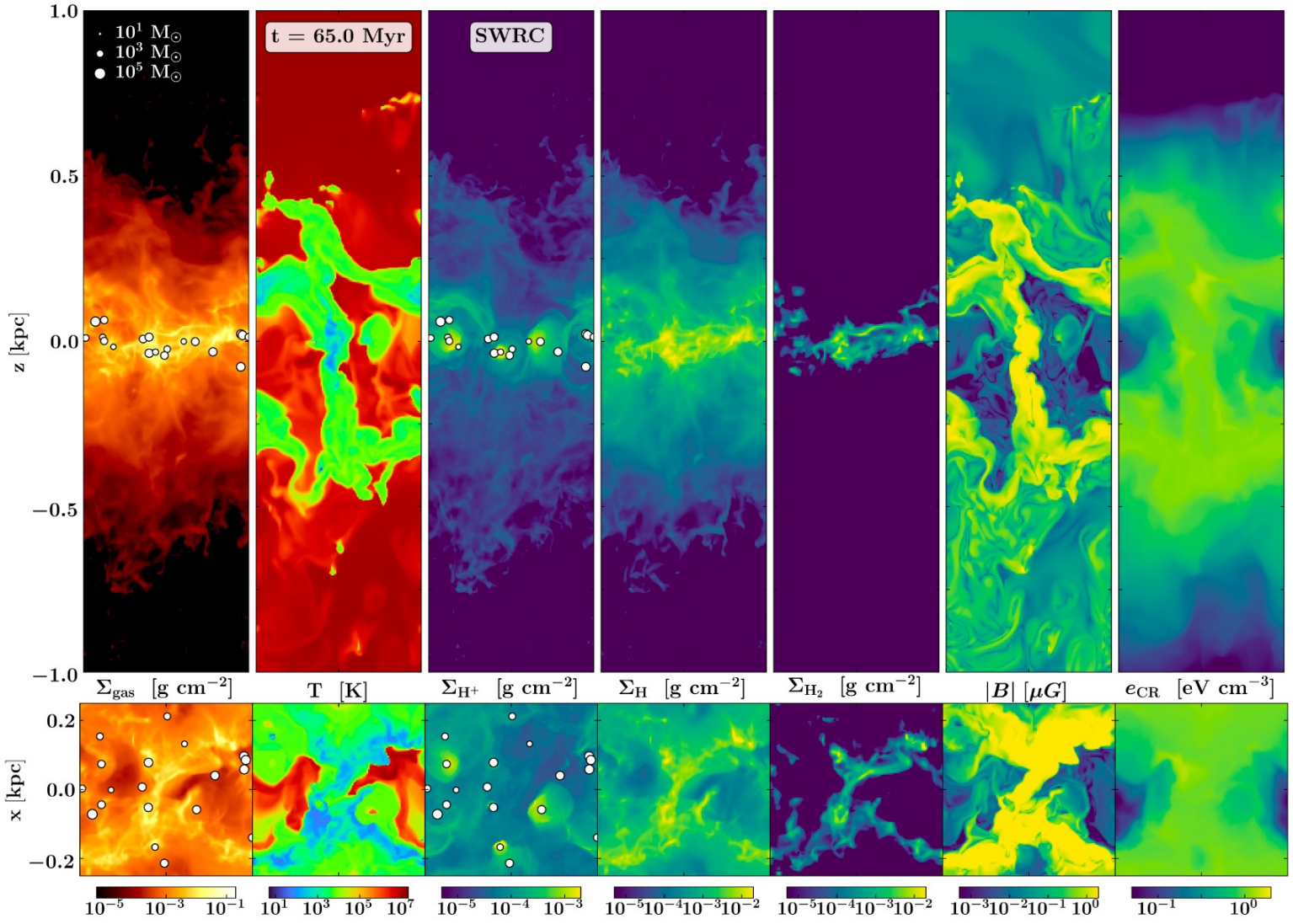


Steinwandel et al. 2020

Towards a complete model of the ISM with turbulent multi-phase gas, magnetic fields, radiation and cosmic-rays

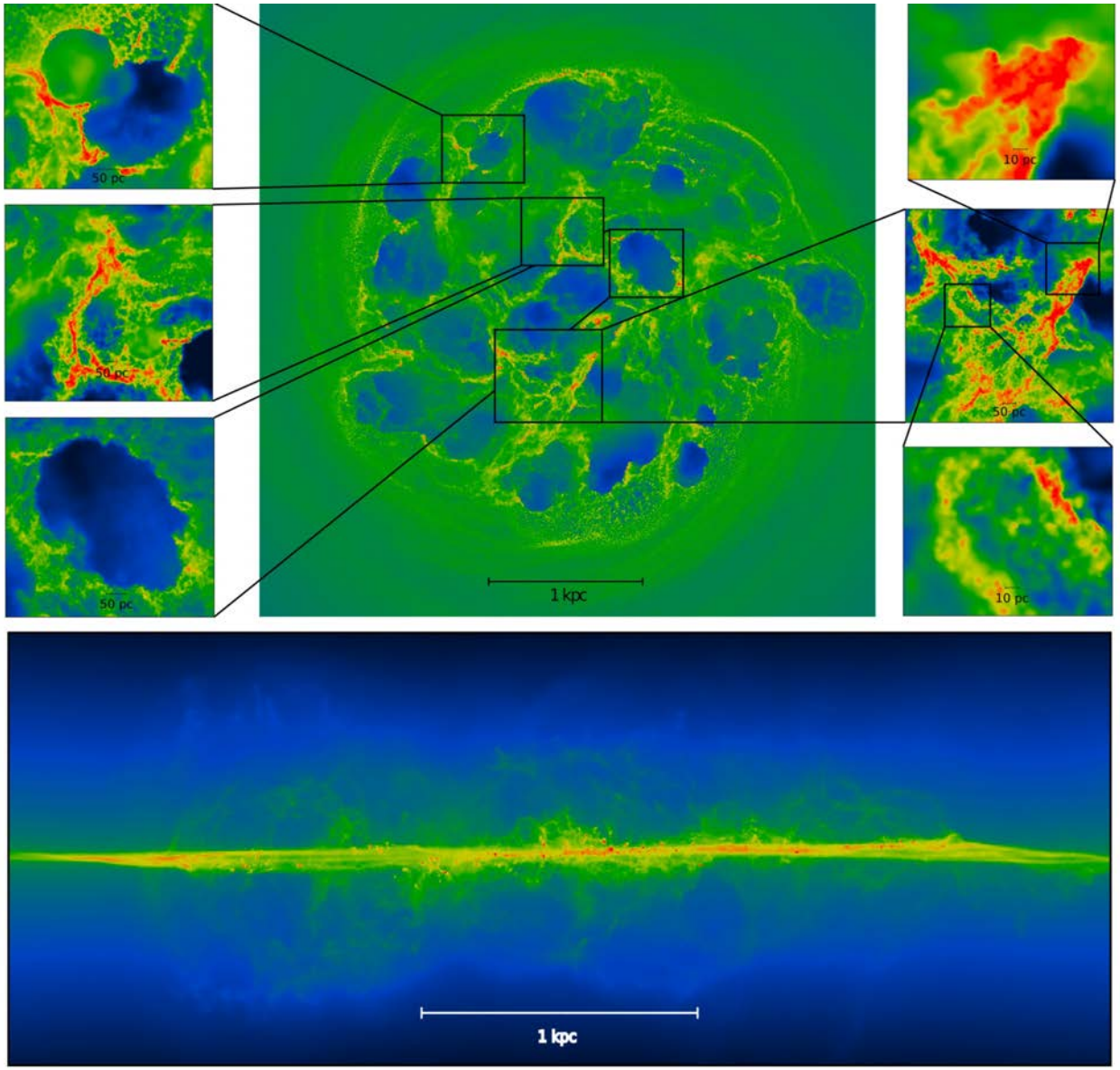
CN-5.3: Turbulence and CRs: from molecular clouds to dust to planet forming disks (PFDs)

CN-5.1: Microturbulent processes: acceleration and propagation of cosmic rays (CRs)



Rathjen et al.

Turbulent multi-phase ISM in dwarf galaxies



Hu et al. 2017, Steinwandel et al. 2020

CN-5.3: Turbulence and CRs: from molecular clouds to dust to planet forming disks (PFDs)

Colliding shocks in clusters

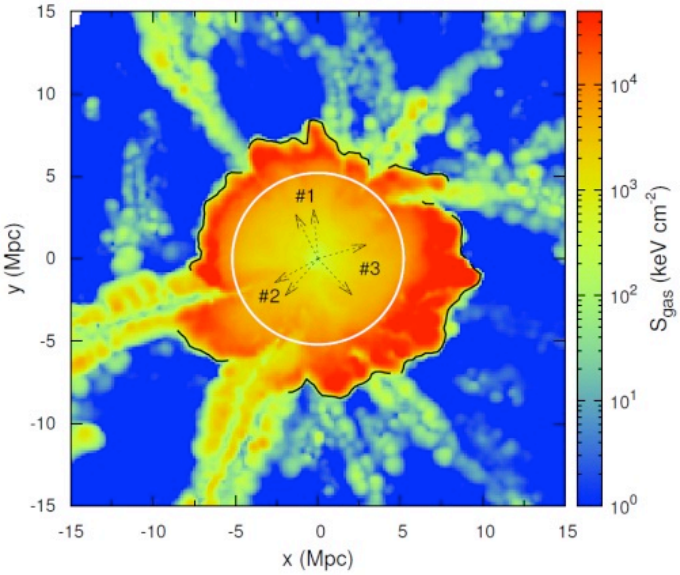
CN-5.2
Churazov / Dolag

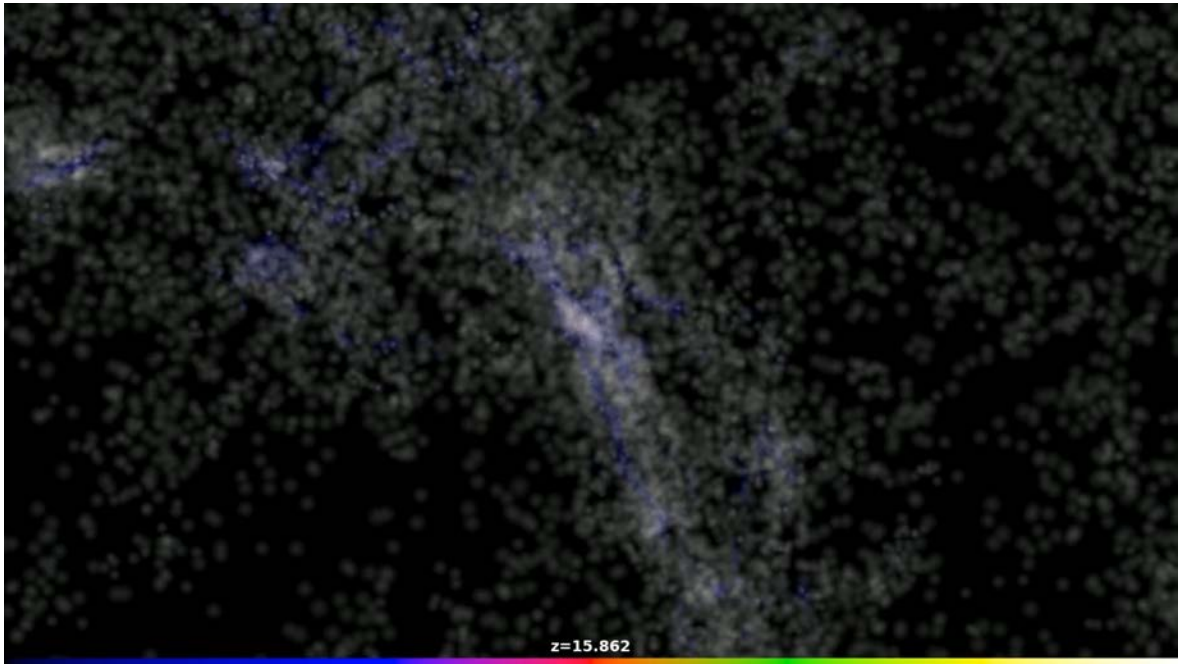
C·O·M·P·A·S·S

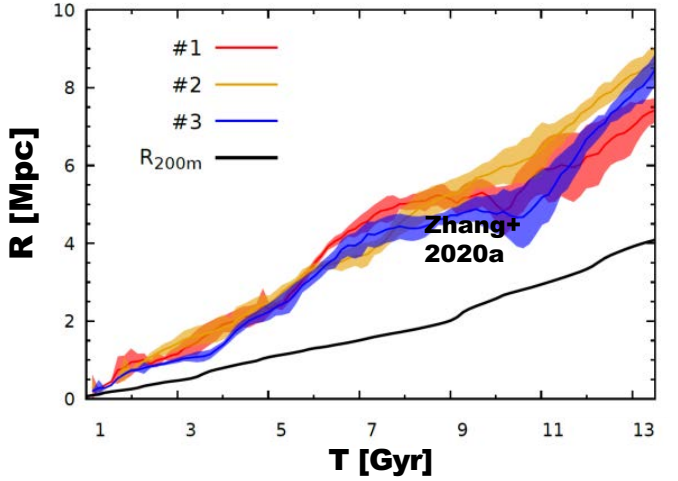
Through collisions with internal shocks, the virial shock is pushed far beyond the typical virial radius.

Why is this interesting?

- **Improving analytical models (RU-D)**
- **Baryon fraction as test of Cosmology (RU-C)**







Developing a Fokker-Planck solver for CRs

CN-5.1

Böss

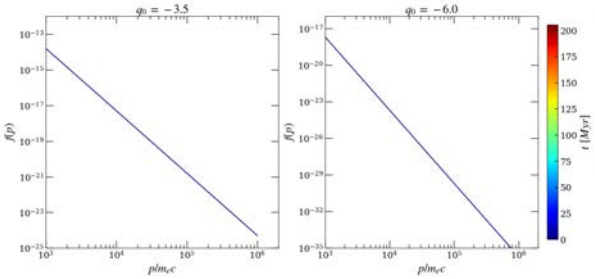
Lesch / Dolag

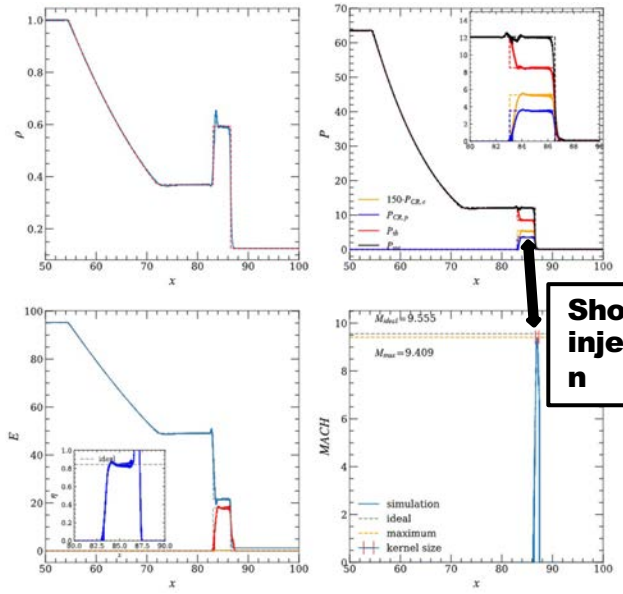
$$\frac{\partial f}{\partial t} + \underbrace{\mathbf{u}\cdot\nabla f}_{\text{spatial convection}} - \underbrace{\nabla\left(\boldsymbol{\kappa}\nabla f\right)}_{\text{spatial diffusion}} =$$

$$\underbrace{\frac{1}{3}\left(\nabla\cdot\mathbf{u}\right)p\frac{\partial f}{\partial p}}_{\text{momentum convection}} + \underbrace{\frac{1}{p^2}\frac{\partial}{\partial p}\left(p^2\left[b_\ell f + D_p\frac{\partial f}{\partial p}\right]\right)}_{\text{momentum diffusion + continuous losses}} - \underbrace{\frac{f(p,\mathbf{x},t)}{t_c(p,\mathbf{x})}}_{\text{catastrophic losses}} + \underbrace{j(p,\mathbf{x})}_{\text{source term}}$$

- **Shocks**
- **SFR**
- **AGN**

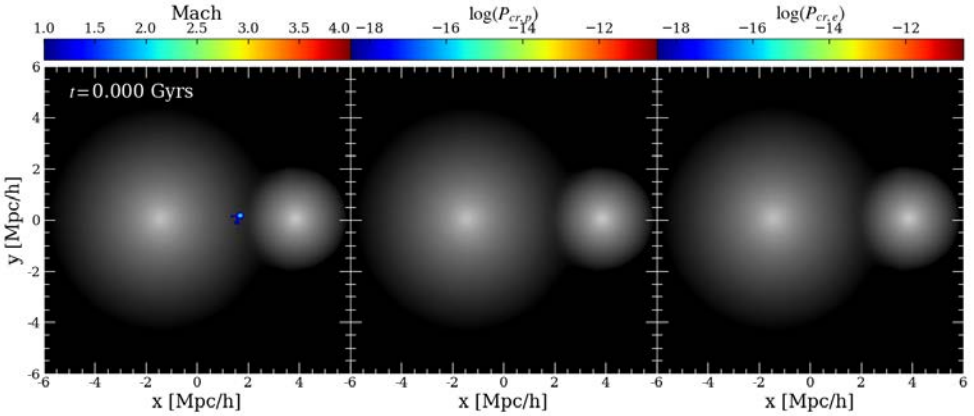
Cooling of CRe





Shock injection

Every resolution element in a simulation has to additionally evolve a sampled distribution fu

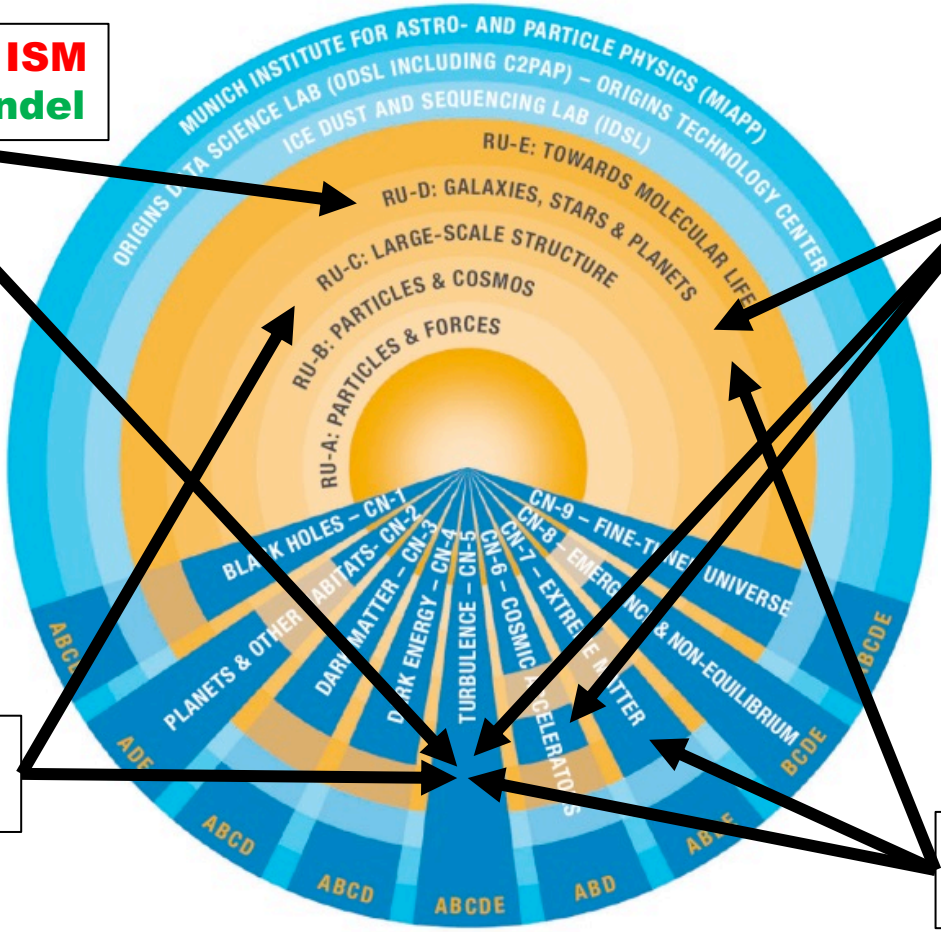


Böss et al. 2022

CN-5 Network in ORIGINS phase I

SN feedback in ISM
Naab / Steinwandel

CRs in ICM/CGM
Jenko / Dolag
Lesch / Böss



Shocks in ICM
Churazov / Dolag

Turbulence in SN
Janka / Yadav

... too many sub-units?

Connector 5 – Pros, Cons, Improvements & Suggestions

- "Turbulence" is very fundamental and should be continued
- Innovative and successful concept with great potential for interdisciplinary & cross-insitutional projects
- Easy onboarding of newly arriving researchers
- Insufficient funding for critical mass and non-funded projects jeopardize the whole connector concept
- More focus in Connectors in ORIGINS II?
- New connectors – Dust
- New connector - Relevance of fundamental ORIGINSII research for society