Importance of the initial conditions for star and star cluster formation

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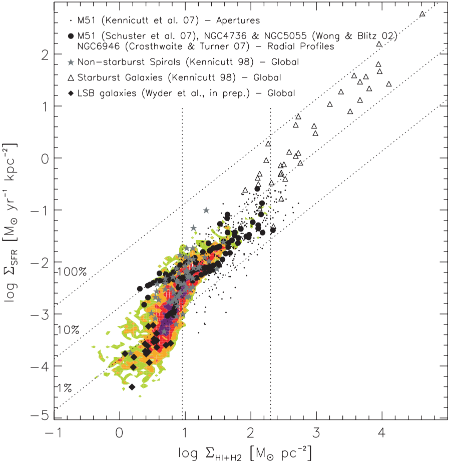
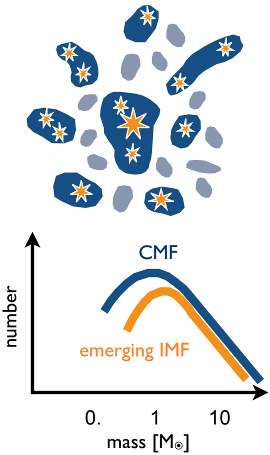
Star formation on different scales

star formation on Galactic scales



Bigiel et al. 2008

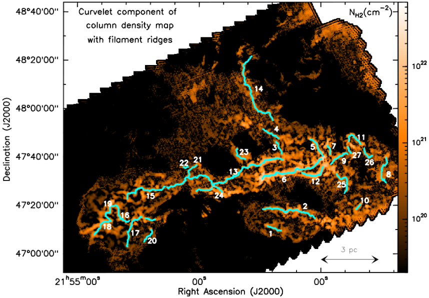
SF in dense cores



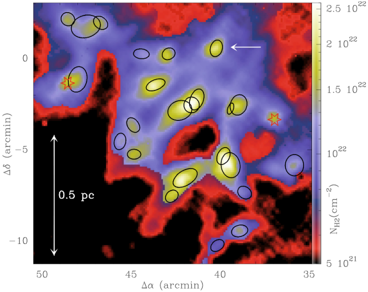
Offner et al. 2014

Star-forming Region

Arzoumanian et al. (2011)



Könyves et al. (2010)



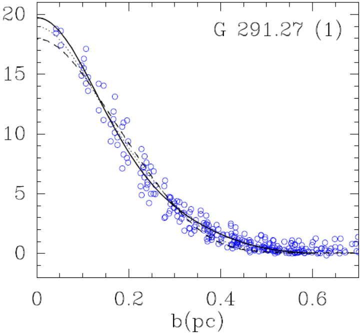
- very complex morphology
- filamentary structure
- turbulent motions

- critical / supercritical BE sphere
- trans- / supersonic velocity dispersion

difficult to use as initial conditions
use highly simplified conditions (not realistic)

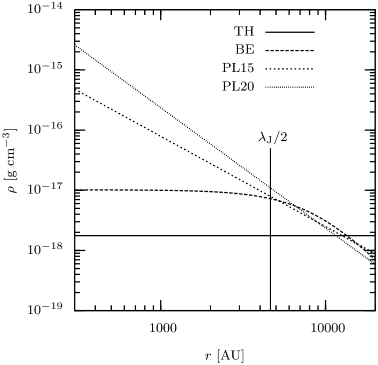
Core Density Profile (Observation)

Pirogov 2009



$\rho \propto r^{-p}, \qquad p = 1.6 \pm 0.3$

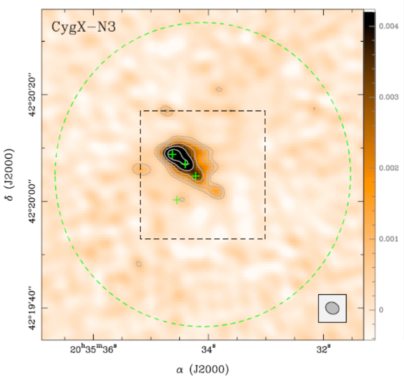
innermost part flattens

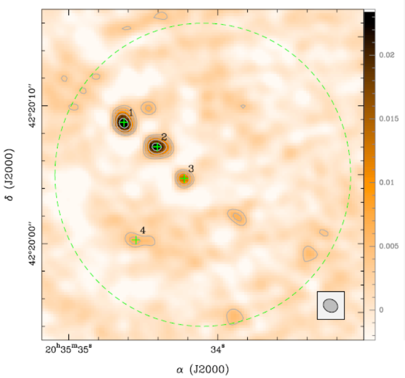


Fragmentation

Massive dense cores in Cygnus X (Bontemps et al. 2010)

3.5 mm and 1.5 mm observations, resolution limit: 1700 AU

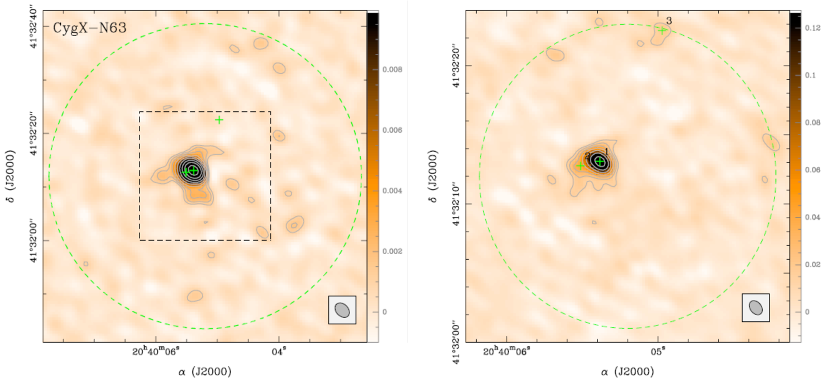




mass: $84\,M_\odot$, size: $20,000$ AU

Hidden Fragmentation?

Massive dense cores in Cygnus X (Bontemps et al. 2010)



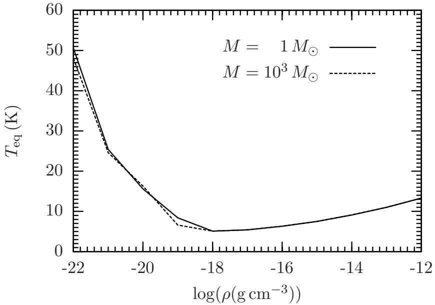
mass: $58\,M_{\odot}$, size: $20,000$ AU

Turbulence in the ISM

- *complex* gas motions with *turbulent* character
  Mac Low & Klessen (2004), Elemegreen & Scalo (2004), McKee & Ostriker (2007)
- $\sigma^2 = \sigma^2_\mathrm{therm} + \sigma^2_\mathrm{turb}$, where σ^2_turb dominates for cores $L > 0.01 - 0.1\,\mathrm{pc}$
- distinction between modes
  (simulations: Schmidt et al. (2009), Federrath et al. (2010)):
    - compressive modes $\vec{\nabla} \times \vec{v} = \vec{0}$
    - solenoidal modes $\vec{\nabla} \cdot \vec{v} = 0$
    - *measurements* via the widths of the pdf
    - connect widths to modes $\sigma^2 = \ln(1 + b^2\mathcal{M}^2)$
    - with $b = 1/3$: solenoidal modes & $b = 1$: compressive modes

Thermal properties of star-forming regions

- heating: compression, CR
- cooling: C, O, dust
- equilibrium temperature: $T_{\mathrm{eq}} \approx 10$ K

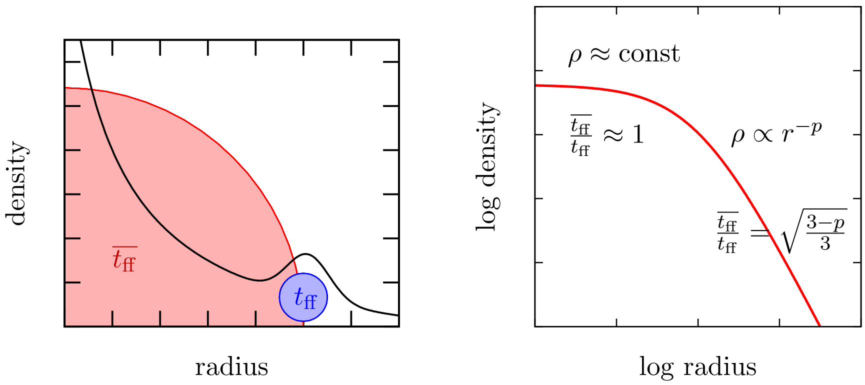


- high-mass star-forming regions: $T_{\mathrm{eq}} \approx 20$ K (Beuther et al. 2007)
- Jeans mass:

$$M_{\mathrm{J}} \propto \frac{T^{3/2}}{\rho^{1/2}} \sim 1\,M_\odot \tag{1}$$

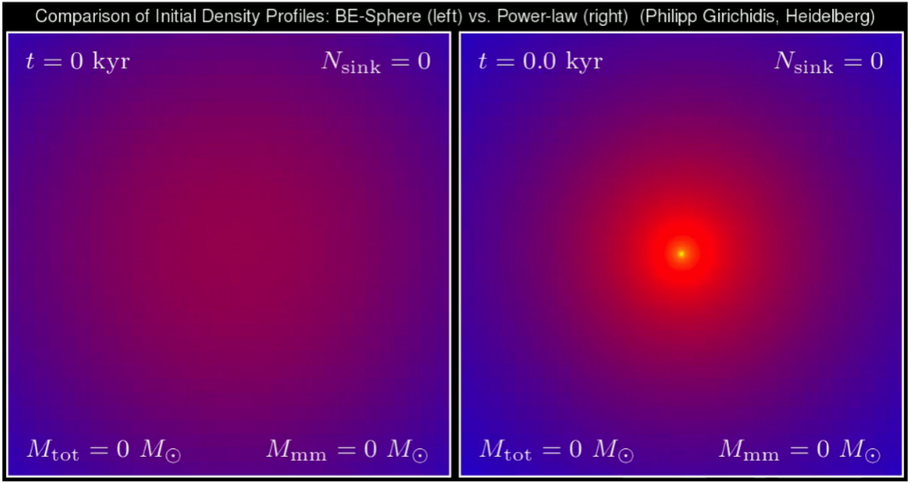
$\Rightarrow$ free-fall conditions

Collapse Time Scales



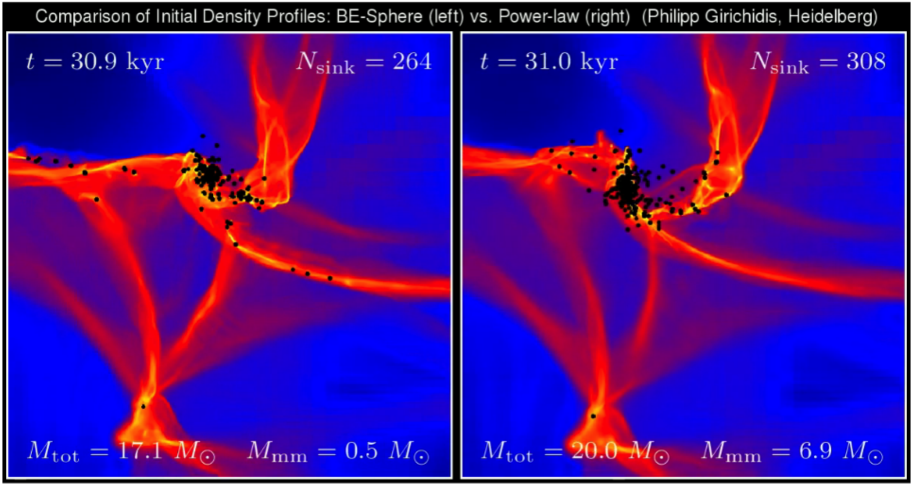
- free-fall times are similar, small perturbations can have effect

Impact of the initial density profile



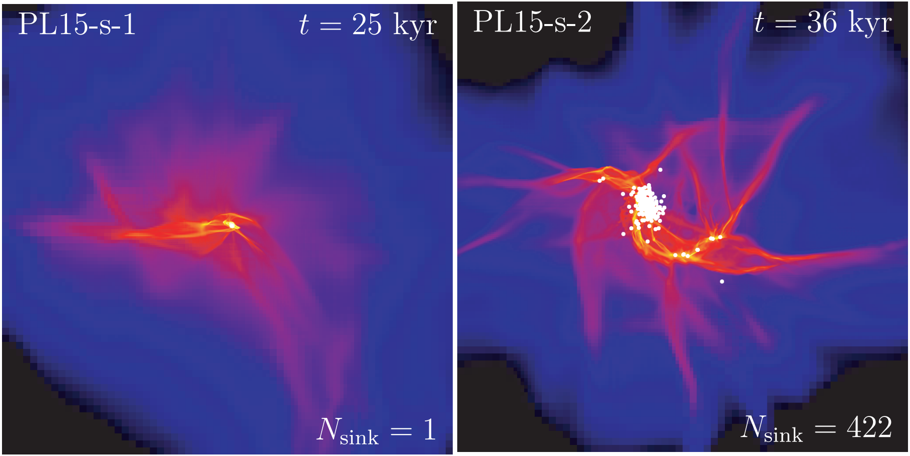
Girichidis et al. 2011

Impact of the initial density profile



Girichidis et al. 2011

Impact of the random seed

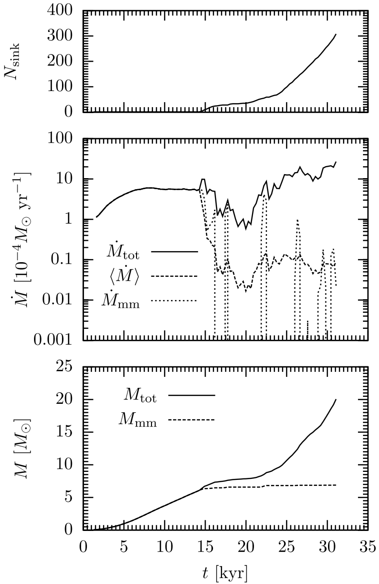


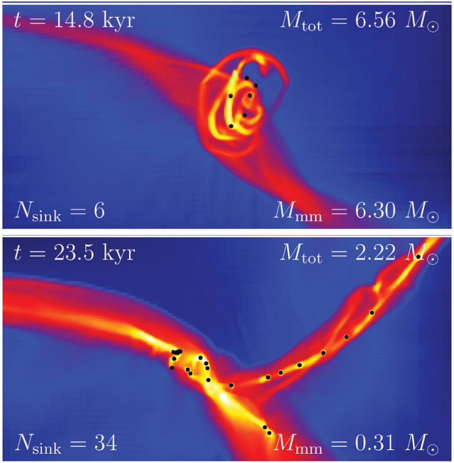
Girichidis et al. 2011

Global stellar differences

Run	t_{sim} [kyr]	$t_{\mathrm{sim}}/t_{\mathrm{ff}}^{\mathrm{core}}$	$t_{\mathrm{sim}}/t_{\mathrm{ff}}$	N_{sinks}	M_{max}
TH-m-1	48.01	0.96	0.96	311	0.86
TH-m-2	45.46	0.91	0.91	429	0.74
BE-c-1	27.52	1.19	0.55	305	0.94
BE-c-2	27.49	1.19	0.55	331	0.97
BE-m-1	30.05	1.30	0.60	195	1.42
BE-m-2	31.94	1.39	0.64	302	0.54
BE-s-1	30.93	1.34	0.62	234	1.14
BE-s-2	35.86	1.55	0.72	325	0.51
PL15-c-1	25.67	1.54	0.51	194	8.89
PL15-c-2	25.82	1.55	0.52	161	12.3
PL15-m-1	23.77	1.42	0.48	1	20.0
PL15-m-2	31.10	1.86	0.62	308	6.88
PL15-s-1	24.85	1.49	0.50	1	20.0
PL15-s-2	35.96	2.10	0.72	422	4.50
PL20-c-1	10.67	0.92	0.21	1	20.0

Accretion shielding

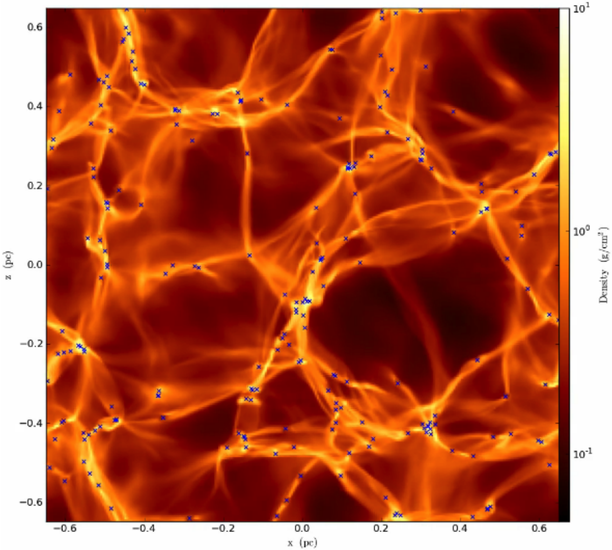




- central objects are shielded from accretion streams

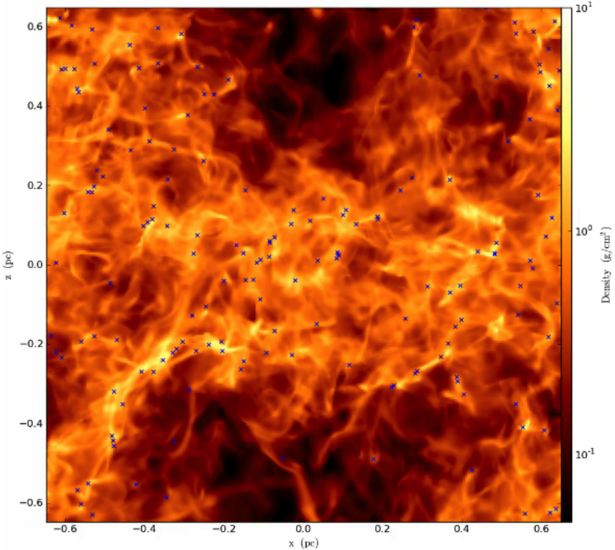
Impact of the strength of the turbulence

weak turbulent motions



Impact of the strength of the turbulence

strong turbulent motions



Conclusions

- concentrated density profiles abet the formation of massive stars
- compressive turbulence enhances cloud fragmentation
- weak turbulence favours filamentary star formation
- fragmentation leads to efficient accretion shielding

- star formation strongly depends on the immediate surroundings
  $\Rightarrow$ need to adapt the correct environmental conditions

ISM details on different scales

The SILCC project

Max-Planck-Institut für Astrophysik

Universität zu Köln

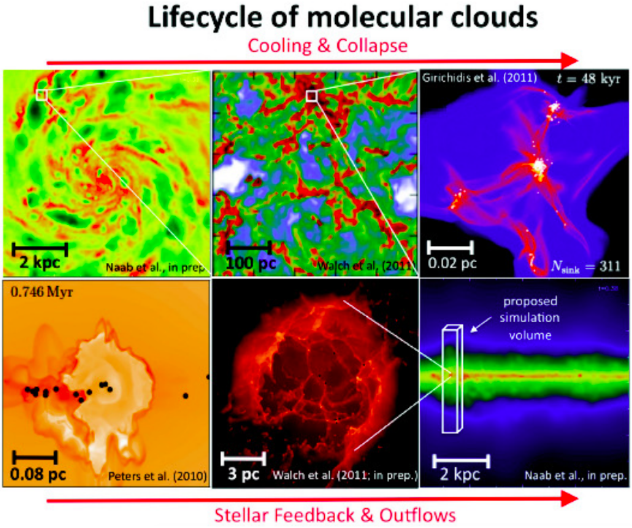
Astronomický ústav AV ČR

asu

Cardiff University

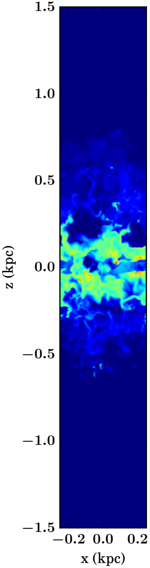
Universität Heidelberg

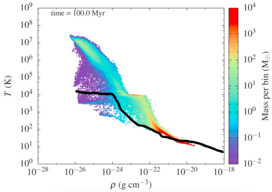
SILCC: SImulating the LifeCycle of molecular Clouds



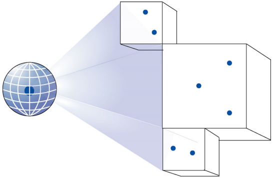
Setup for ISM simulations

- stratified box (deAvillez+2004, 2005, Kim & Ostriker+ 2013, 2014, 2015, Hennebelle & Iffrig 2015)
- external potential (ρ_*)
- **Magneto**hydrodynamics
- atomic, mol., metal cooling (follow H^+, H, H_2, C^+, CO) (Glover et al. 2012, Walch et al. 2015)
- shielding effects (high optical depth)
- feedback from stars (SNe)
- cosmic rays
- MW conditions: $10\,\frac{M_\odot}{\mathrm{pc}^2}$, $Z_\odot$



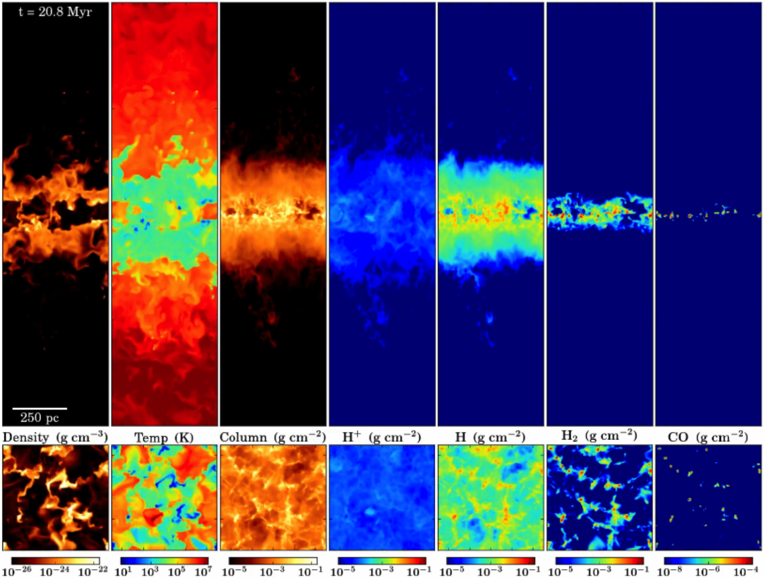


(Gatto et al. 2015)

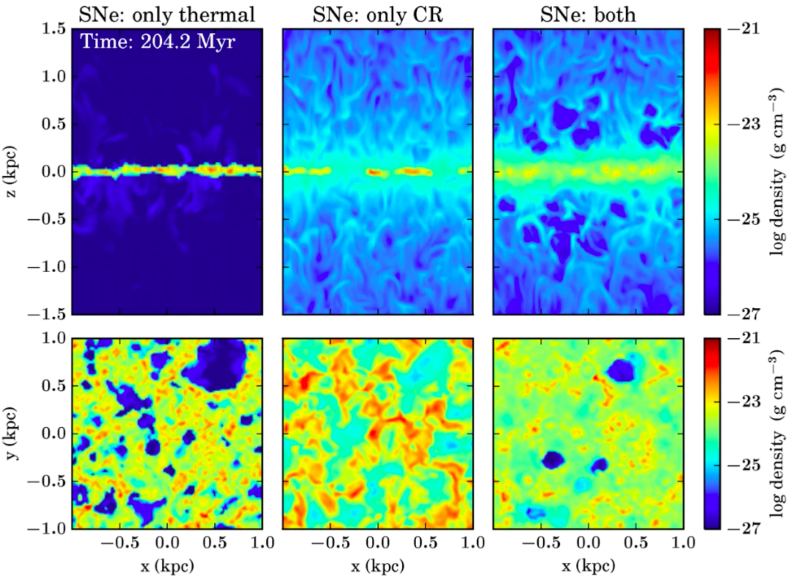


(Clark et al. 2012, Wünsch et al. in prep.)

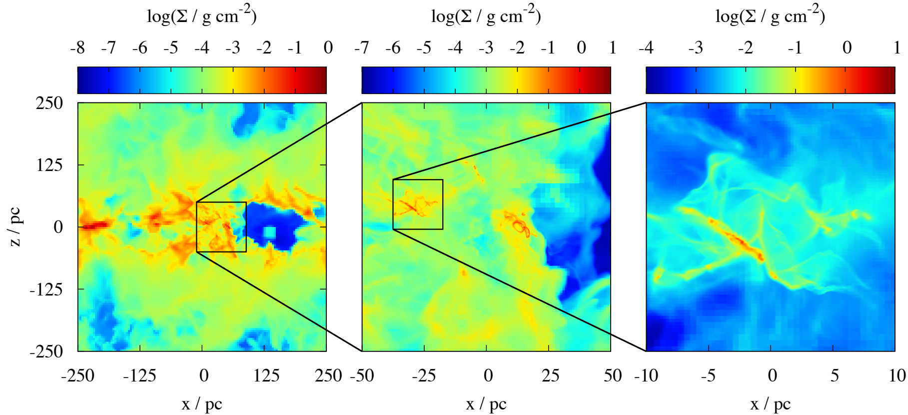
Stratified box sims (Walch et al. 2015, Girichidis et al. 2016a)



ISM simulations including CRs (Girichidis et al. 2016b)

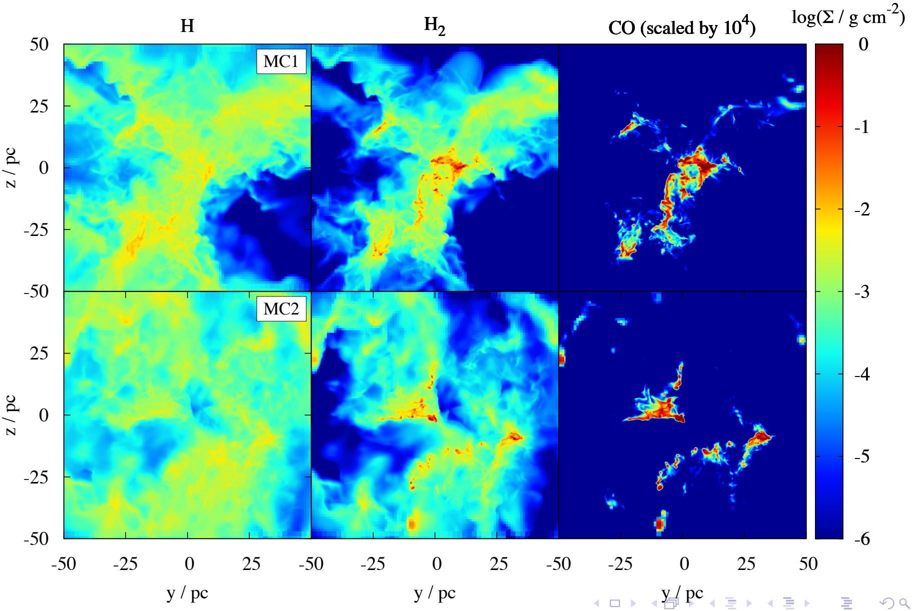


Zoom-in (resolution)

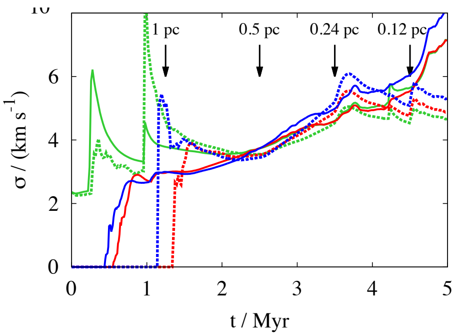


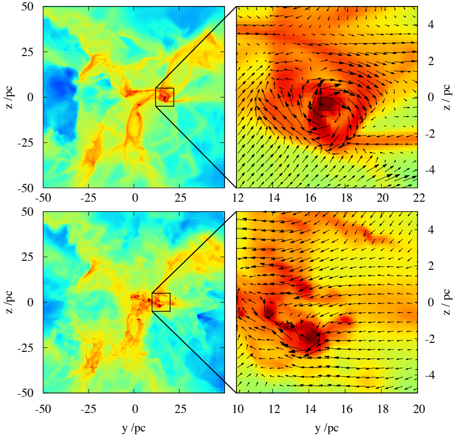
Seifried, PG et al. (in prep.)

Zoom-in (chemistry)



Zoom-in (dynamics)





determine self-consistent dynamics

Todo

As the initial conditions for immediate star formation matter:

- we need to follow the dynamics from MC formation down to cores
- we need chemical evolution for the proper cooling
- we need cosmic rays to account for the dynamical & thermal effects