# Chemical and dynamical evolution of the SN-driven ISM and the launching of outflows


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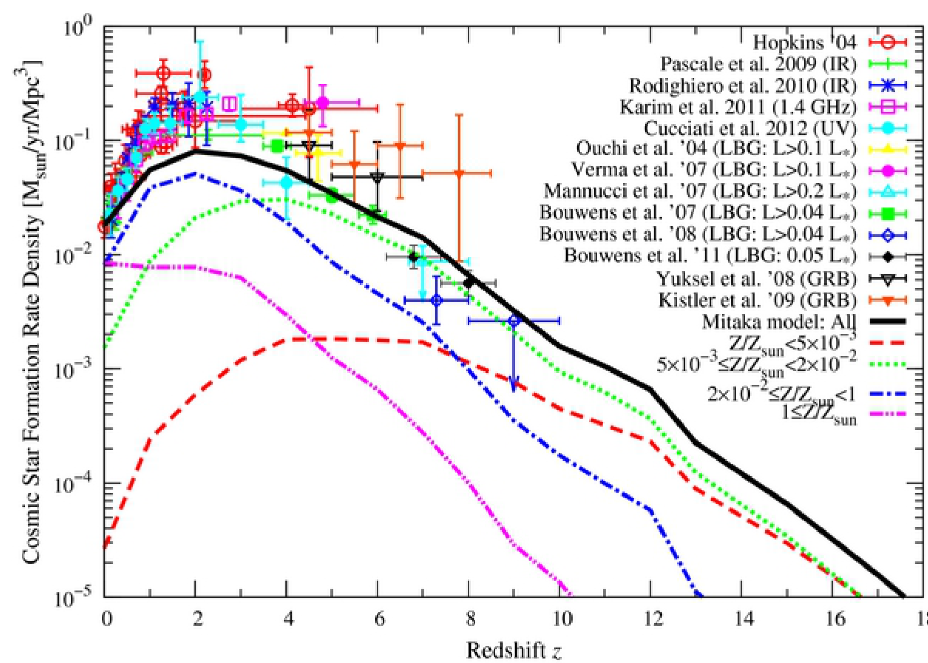
# Importance of ISM details

- Outflows are observed (mass-loading factors of a few)
- Smith+2005

- The structure in the ISM determines SFR (history)
- Inoue+2013



# Dynamical drivers in ISM

- Dynamical drivers from large to small scales (and back)
  - Gas accretion onto the galaxy
  - Gravitational instability in the disc
  - Thermal evolution, rapid cooling and pressure gradients
  - Gravitational collapse of cloud cores
  - Outflows from young stellar objects
  - Winds from massive stars
  - SN explosions
    - probably most energetic (GMC scales)
    - provide complex coupling between spatial scales

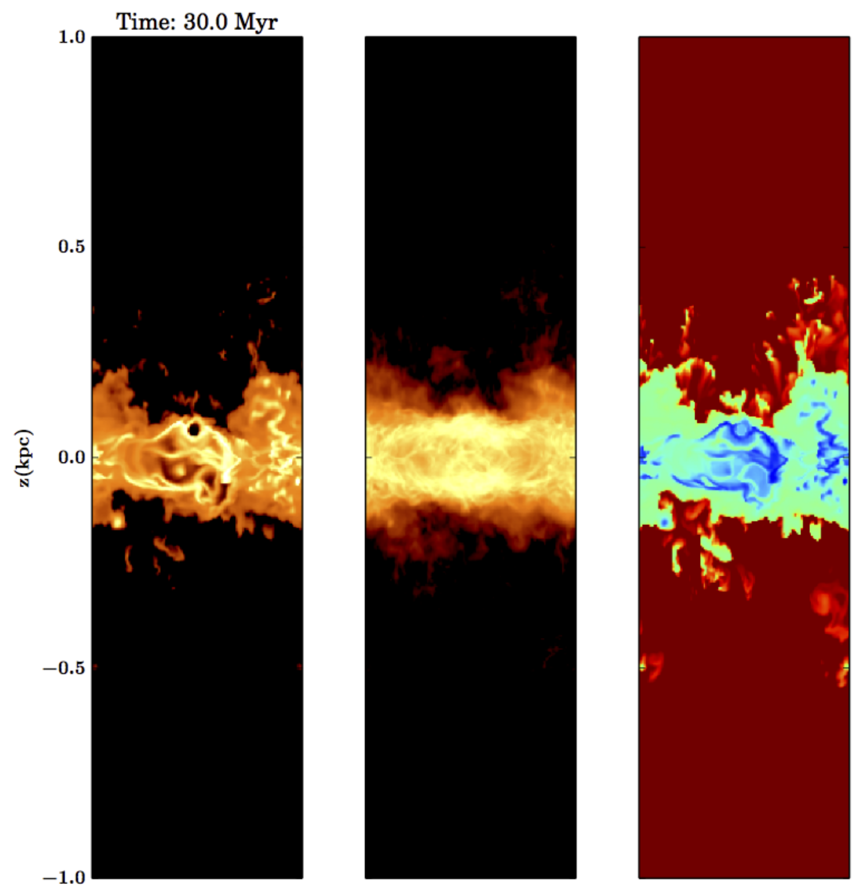
# Where do SNe explode?

- Stars form in dense regions
- Massive stars explode after a few Myrs as SNe
- Not much time for them to travel far away (except a few runaway stars)
- SNe explode in density peaks!?
- But: massive stars have side effects: ionisation, strong winds (WR winds)
- Clear out a region before exploding as SNe
- SNe explode in low density regions!?
- Stars form in clusters
- SNe are most likely clustered

- details of SN positions are tricky, keep as free parameter

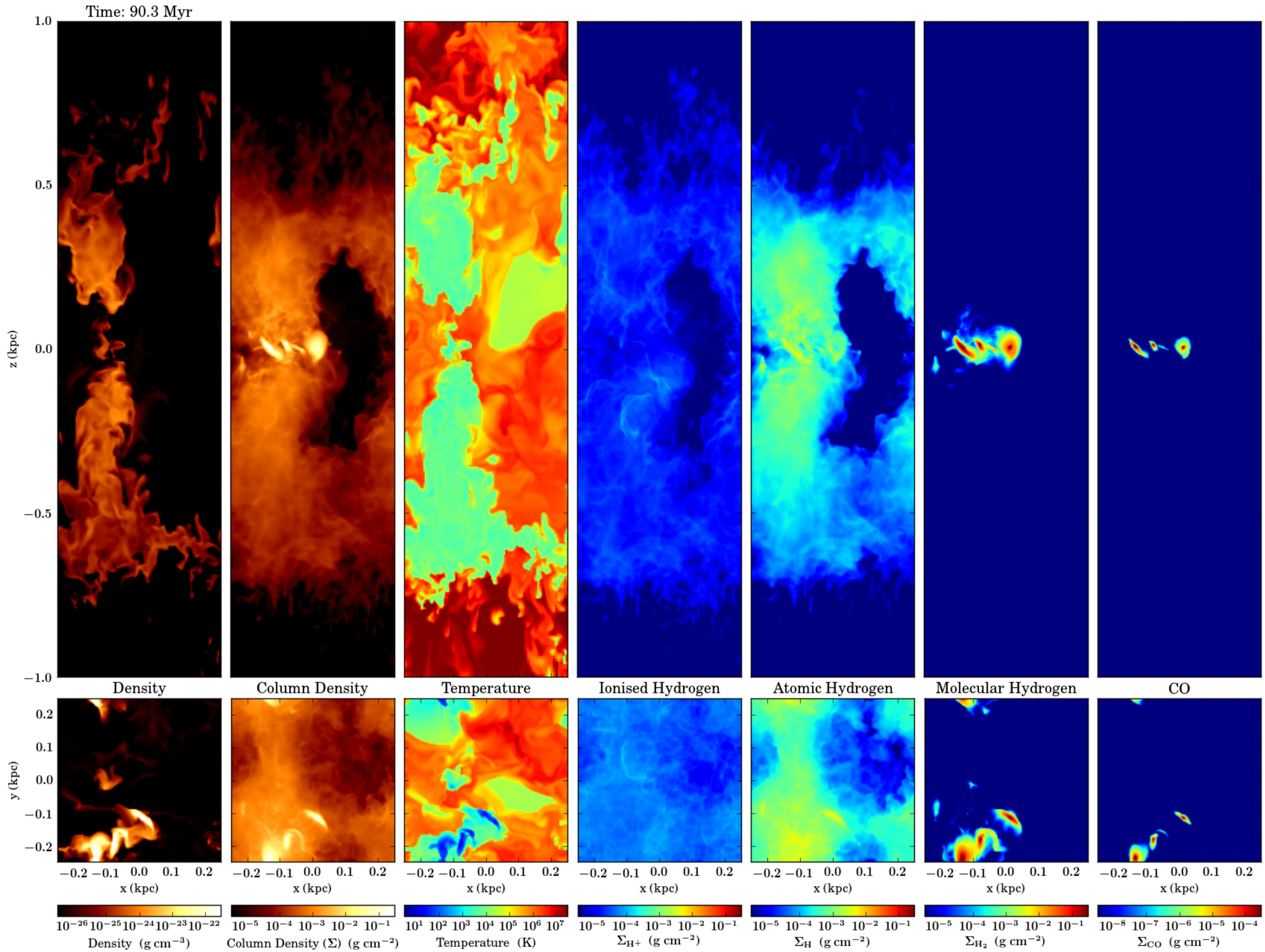
# Simulations of stratified discs with SNe

- Stratified disc 0.5x0.5x10kpc
- Include SNe at fixed rate (momentum and thermal energy), Gatto+2014
- Include chemical evolution (H+, H, H2, CO, C+) Glover+2012, Walch+2014
- Include shielding of the gas (attenuation of ISRF), TreeCol (Clark+2012)
- Neglect winds (Gatto+ in prep.)
- Neglect direct radiation
- Milky Way conditions (10 Msol/pc^2, solar Z)



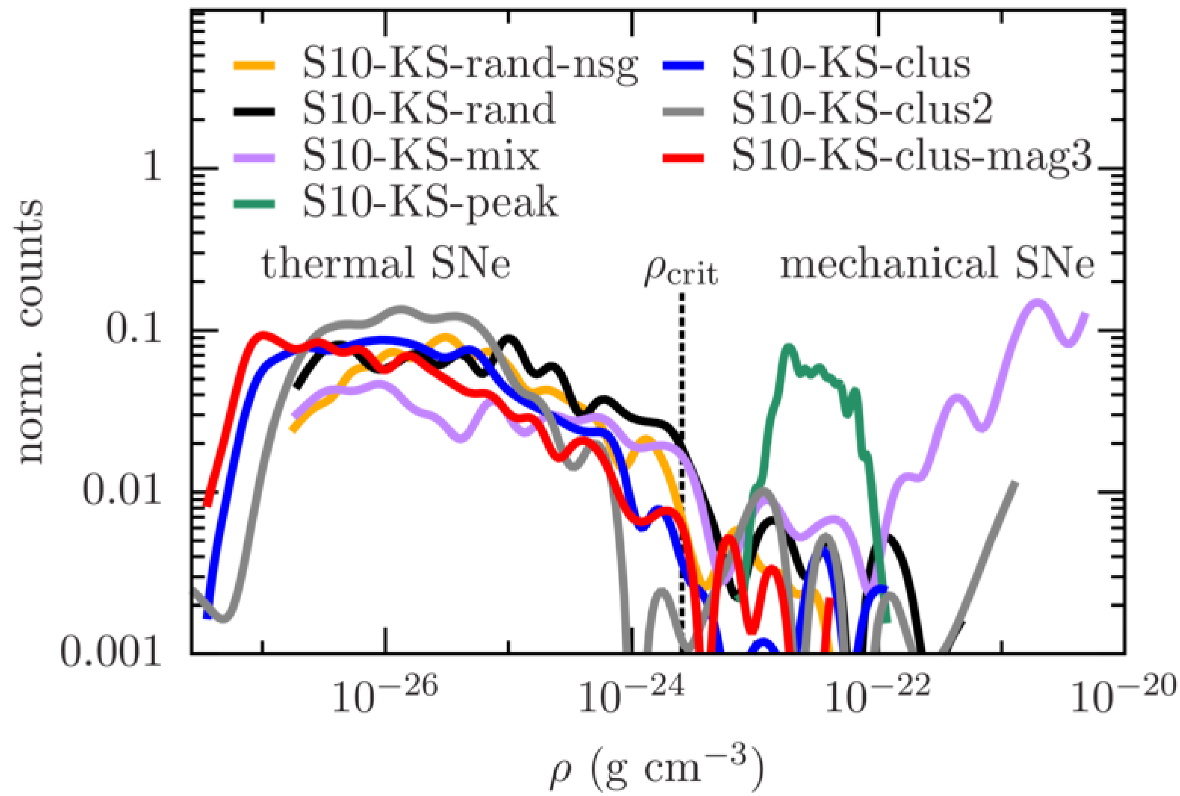

Walch+ 2014 (arXiv:1412.2749)
Girichidis+ 2015 (arXiv:1508.06646)

# Time evolution



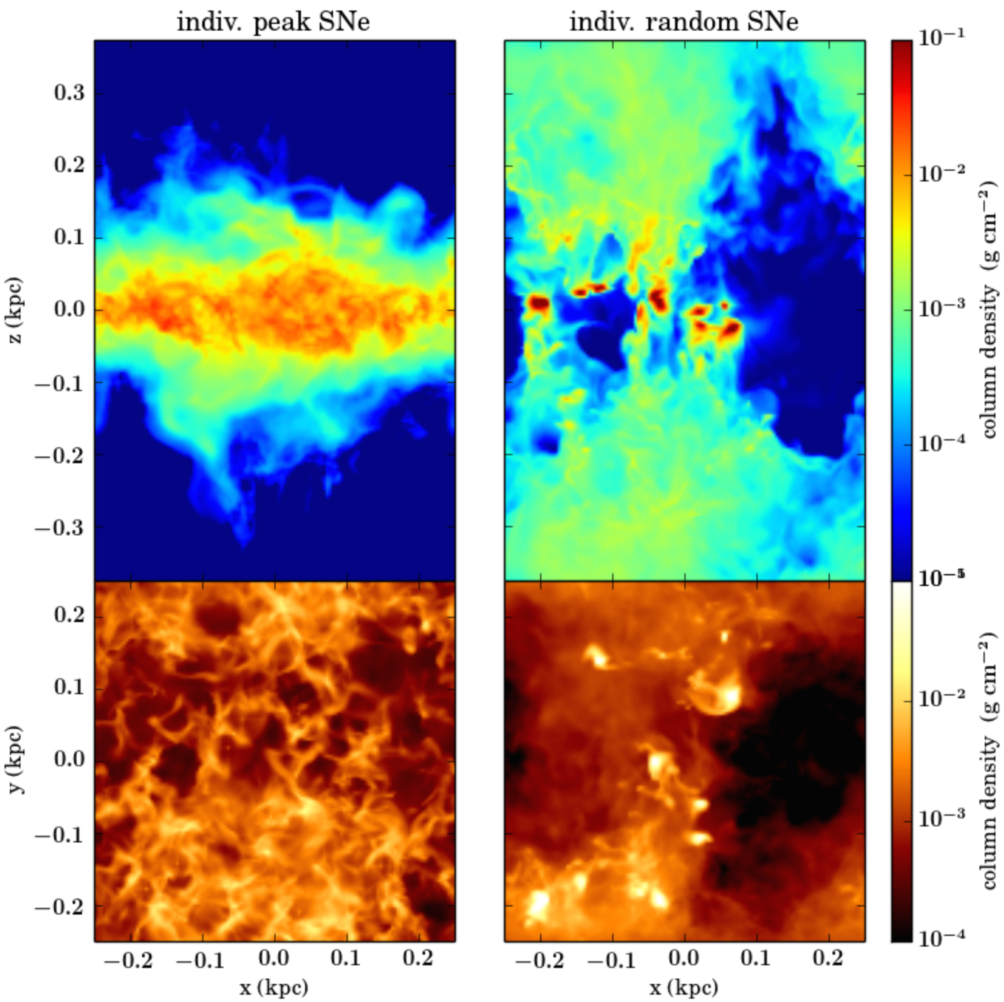
# SN environment in simulations

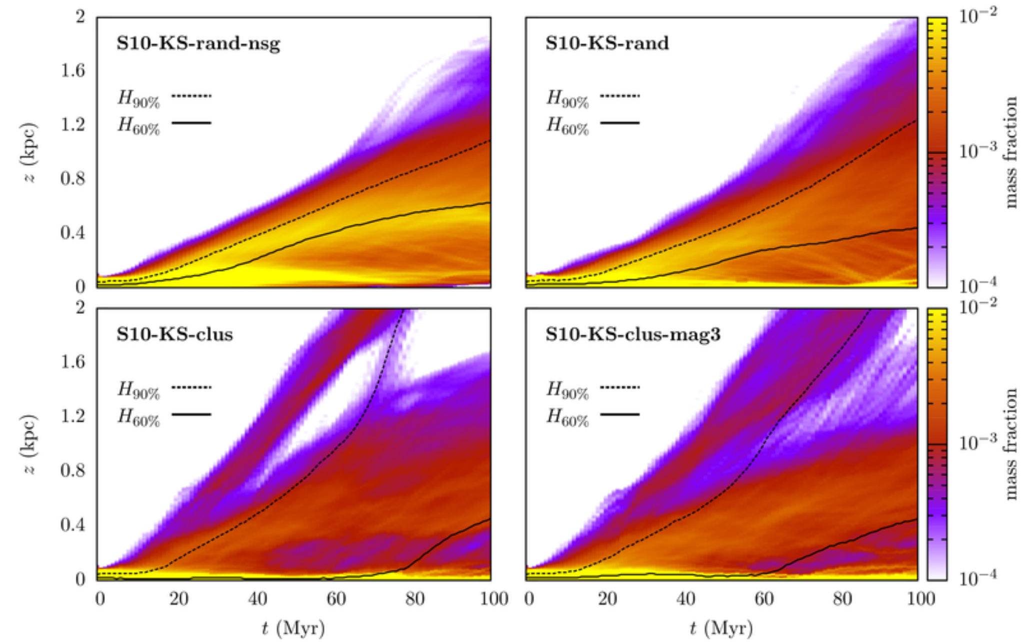
- Compare peak and random positions,
- Compare individual and clustered SNe
- Compare type II SNe (scale height 50pc), type Ia (scale height 300pc)




Girichidis+ 2015

# Overall disc structure



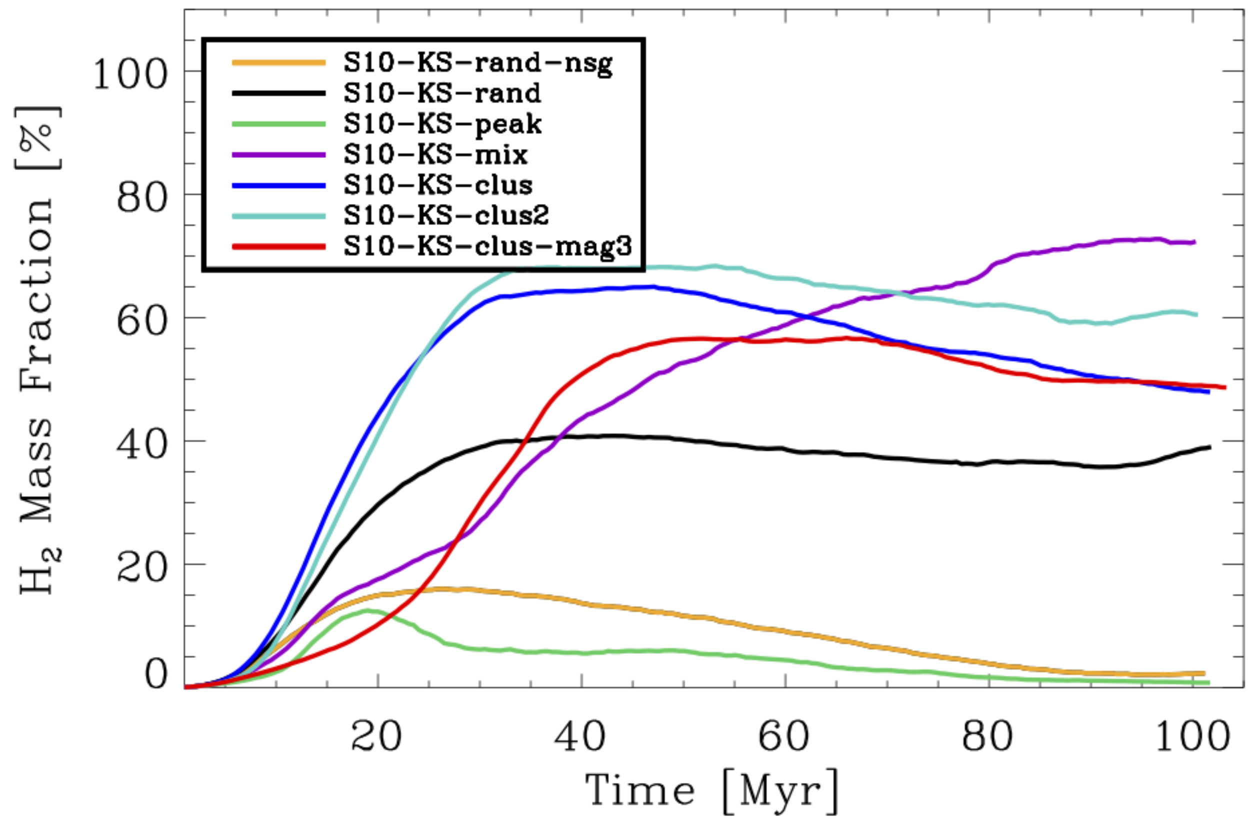




- SNe in density peaks form diffuse but compact disc
- Low-density SNe: clumps
- Individual SNe are less powerful than clustered SNe.

Girichidis+ 2015

# Chemical composition

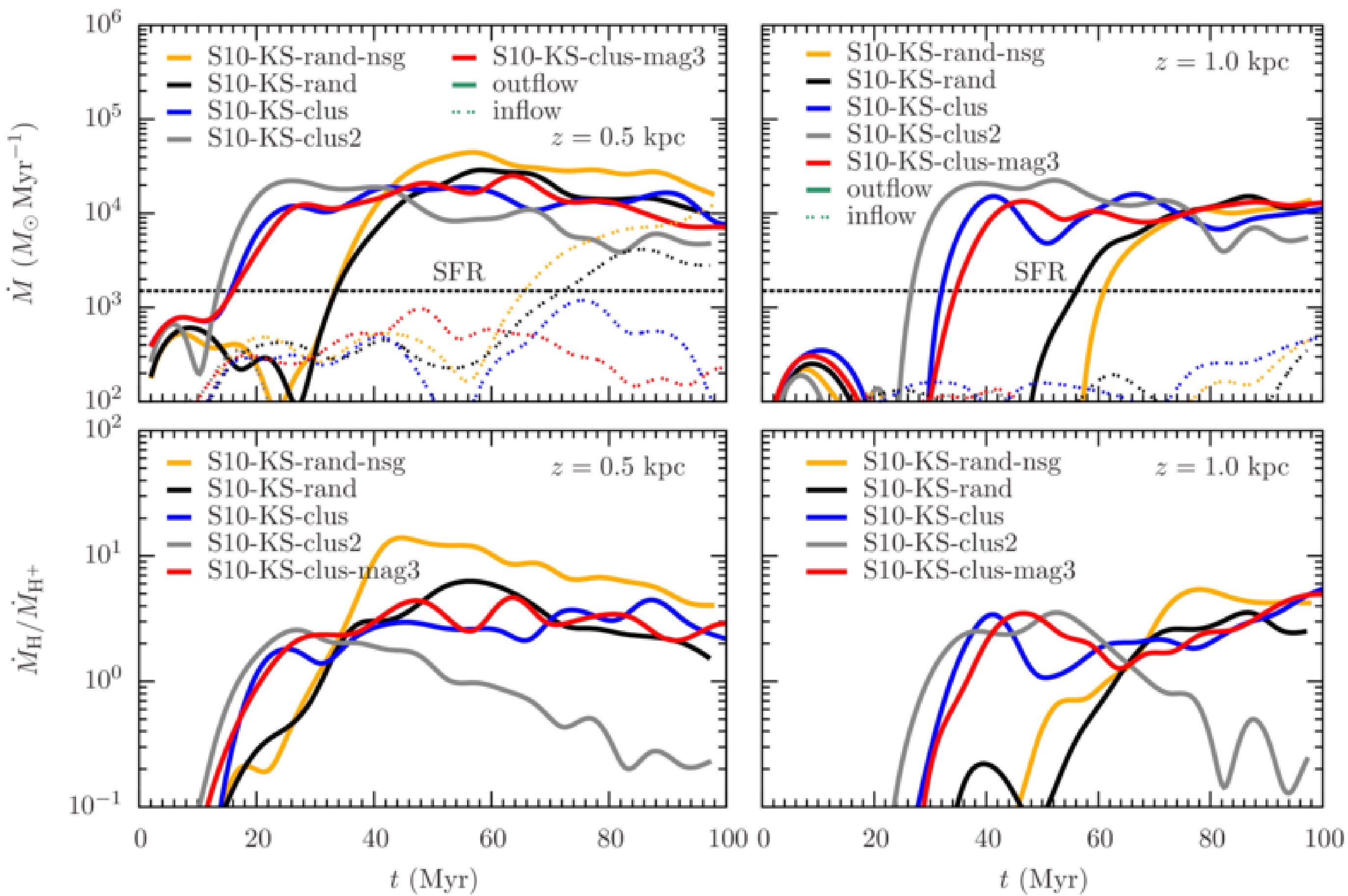
- Negligible fraction of mass in $H^+$
- $H_2$ mass fraction strongly depends on driving mechanism
- SNe in density peaks suppress $H_2$ formation




Walch+ 2014

# Outflow properties

- Strong outflows with mass loading factors of 10
- Composition varies with time and SN clustering



# Conclusions part I

- The positioning of the SNe w.r.t. the density is crucial

  SNe in peaks: little $H_2$ (few %), compact disc, no outflows

  SNe at random positions: more $H_2$ (40-60%), outflows

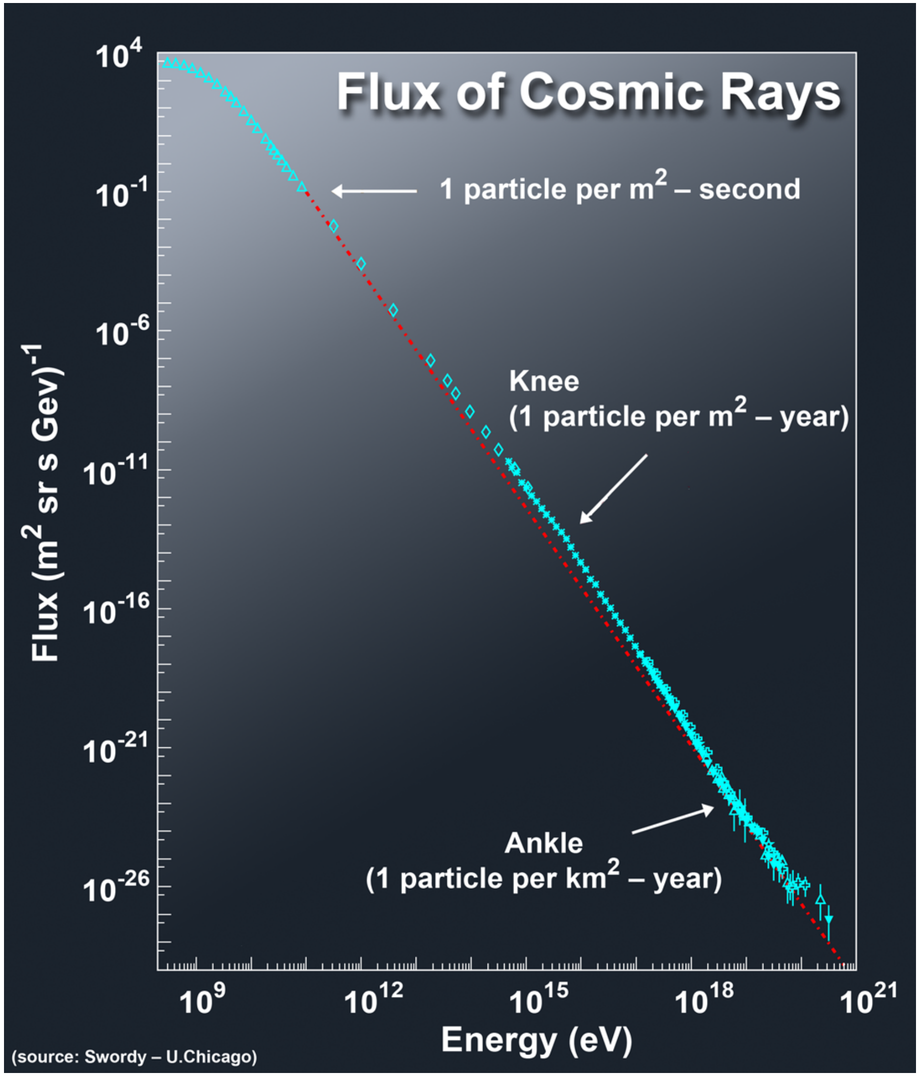
- Clustering of SNe: more coherent driving, enhances the formation of $H_2$

- Self-gravity is important, even in regions that are not gravitationally dominated or unstable

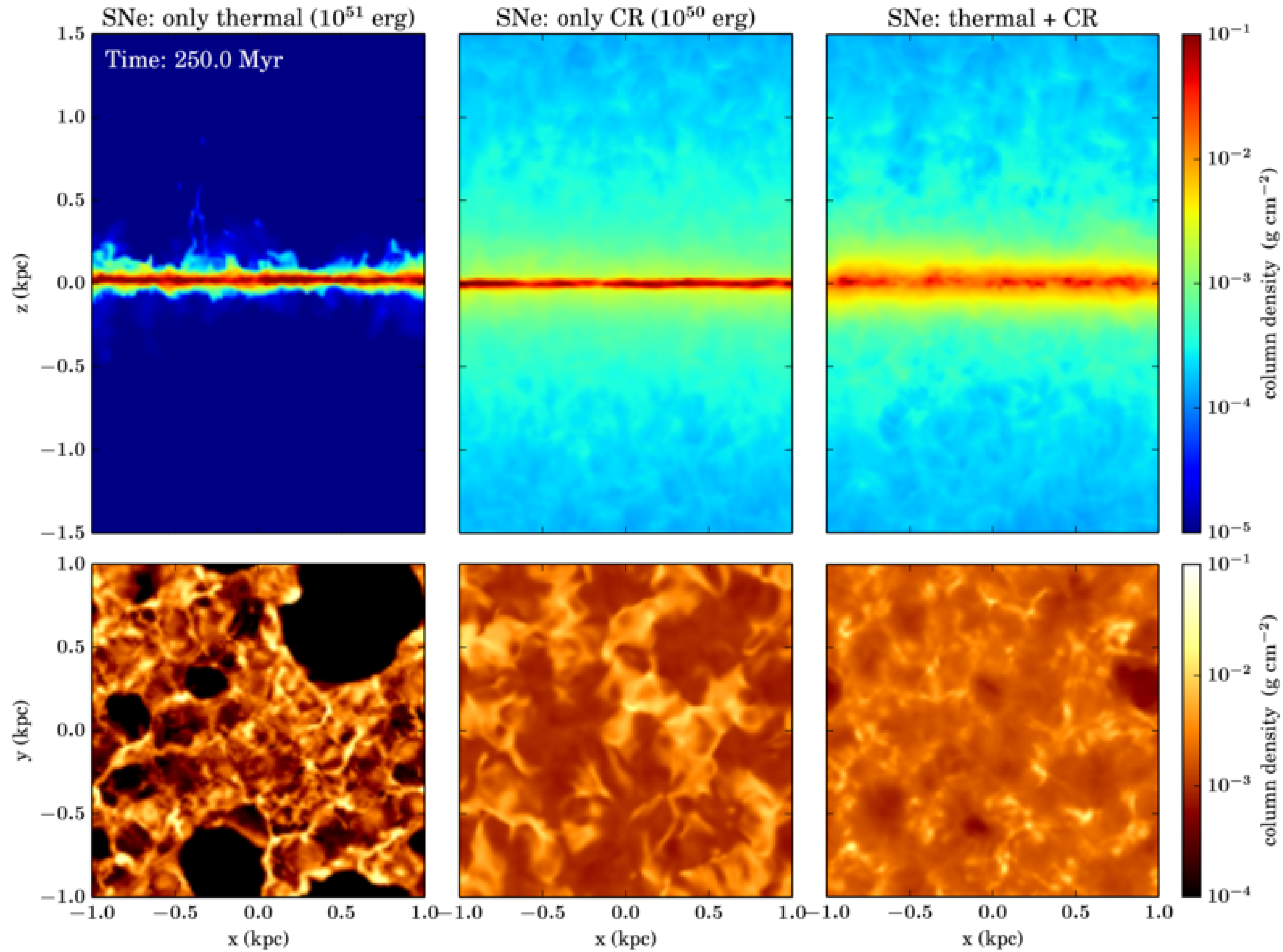
- Thermal SNe can drive outflows

# PART II: CRs in the ISM

- CRs: similar energy densities as turbulence and magnetic fields
- Galactic CRs generated mostly in SN remnants (DSA, Axford et al. 1977; Krymskii 1977;Bell 1978; Blandford & Ostriker1978; Malkov & OC Drury 2001)
- Efficiency: 0.01-0.3 of thermal SN energy
- CRs couple to gas via magnetic fields
- CRs are effectively a second relativistic fluid
- Advection-diffusion approximation

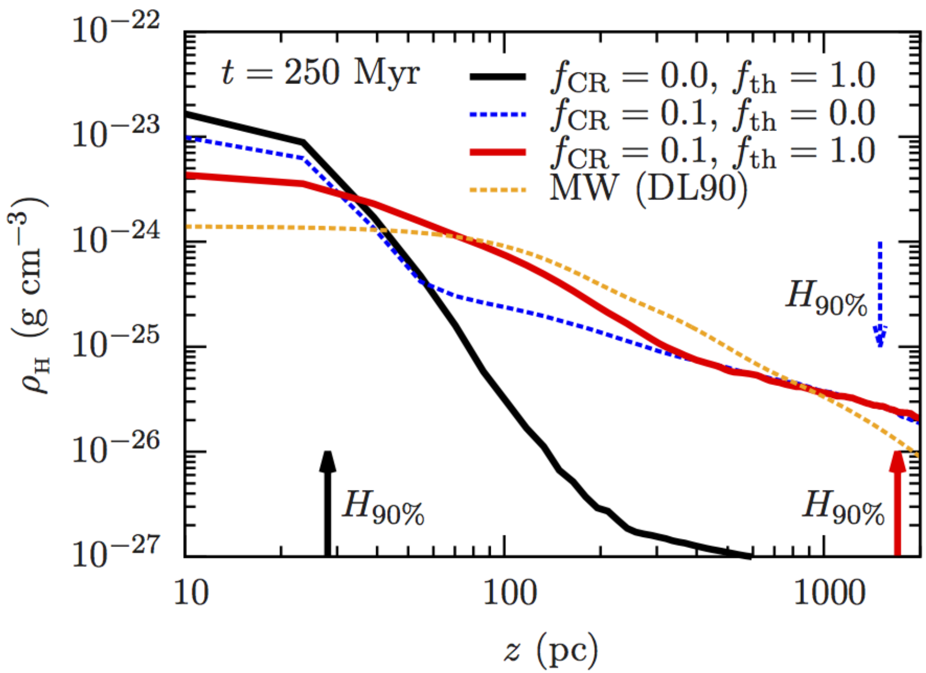


# CR effects on the disc structure

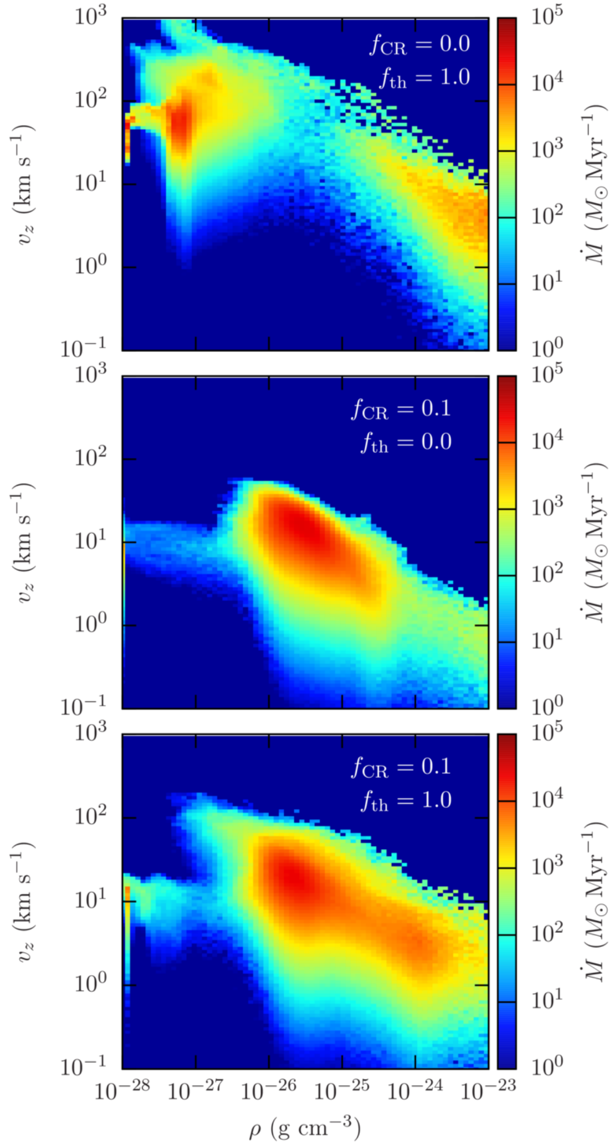


# Scale heights of the disc

- CRs quickly diffuse throughout the disk
- CRs do not cool efficiently
- Can build up a long-lived, large-scale pressure gradient
- Thicker disc with CRs
- Gas is lifted to heights of several hundred pc
- CRs allow for gradual lift, not like a hot SN shell



# Velocity and Density of the outflow




- Thermal SNe: fast expanding shells, fast outflows at low-density
- Type Ia SNe in high altitudes are not shielded and can ionise the outflows
- CRs: Slower outflows, very smooth and dense. Mainly atomic hydrogen.
- SNe embedded in this thicker layer of dense gas are less efficient in ionising the gas

# Summary

- Details of SN positions in ISM strongly determine chemical composition and outflow properties

  (a few parsecs are important)

- CRs thicken the disc and are likely to influence GMC formation
- CRs alone can drive and sustain outflows (mass loading > 1)
- CRs delay the formation of structures and dense gas

- What is more important SNe or CRs?