Max-Planck-Institut für
Astrophysik

MAX-PLANCK-GESELLSCHAFT

Outflows and the structure of the ISM in high-redshift galaxies

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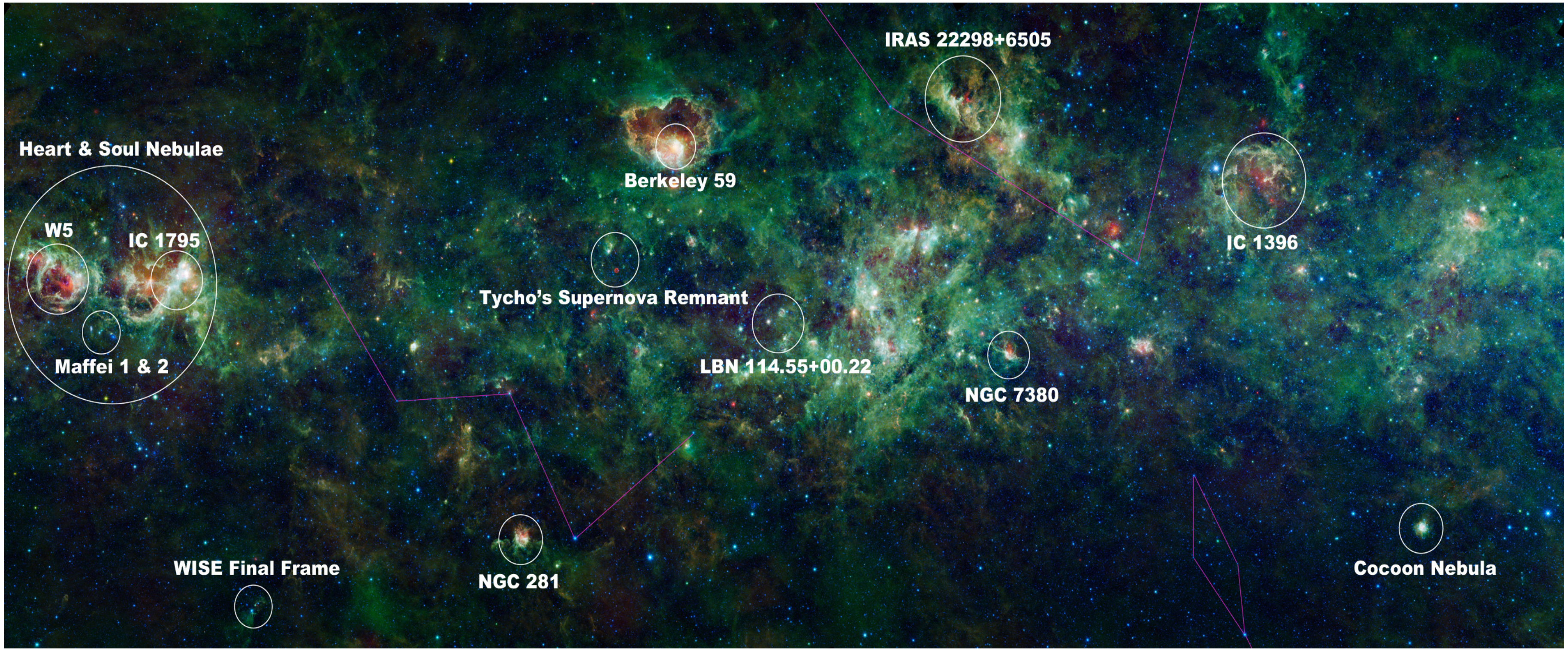
L. Tacconi, R. Genzel, S. Newman, PHIBBS team

Phases of the ISM – Heidelberg August, 1st

Star formation and feedback in the Milky Way

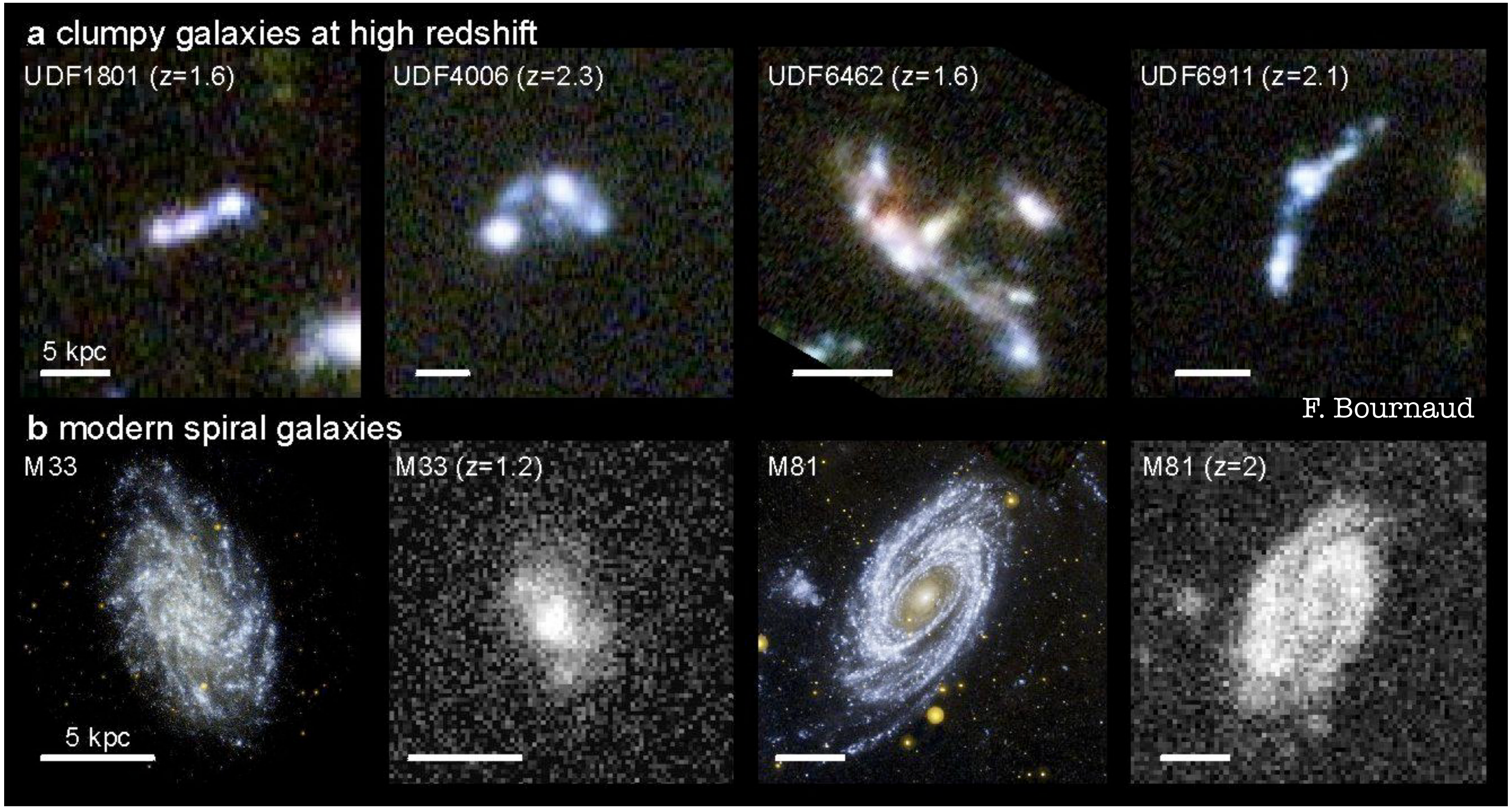


Can we better understand how massive stars impact the ISM and regulate galaxy formation by heating, enrichment, outflows etc.?

In the Milky Way the ISM can be studied in great detail

more than 5000 IR bubbles identified in the 'Milky Way project' based on Spitzer imaging

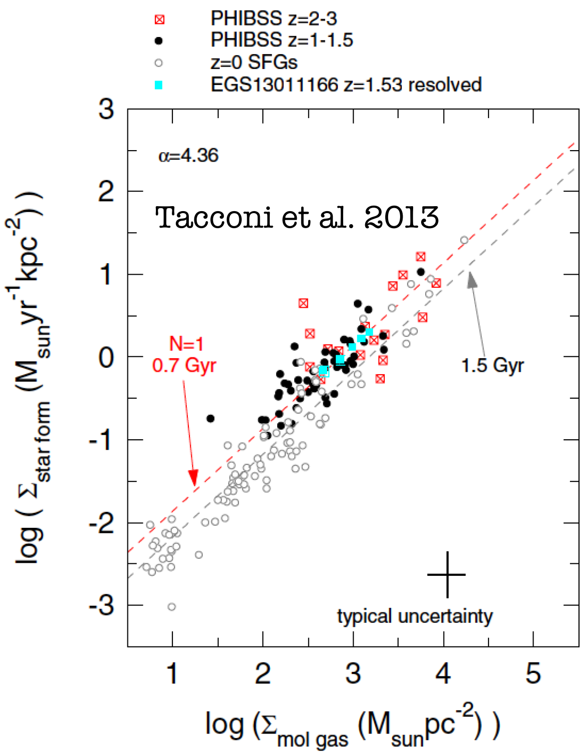
Star formation in high-redshift disks

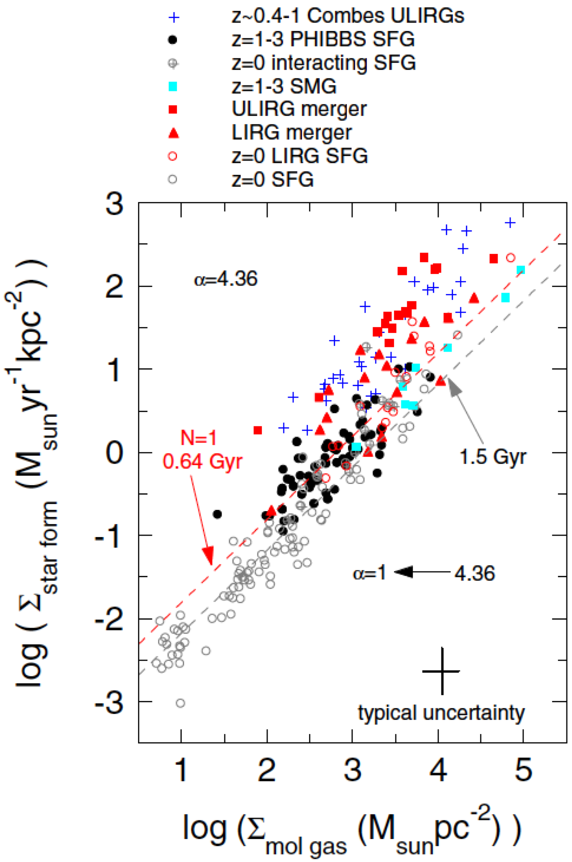


High-redshift star forming disks are more gas-rich (30% - 50%), have higher star formation rates, have higher gas dispersions, and can form stars in larger 'clumpy' sub-units (e.g. Elmegreen et al. Genzel et al. 2010, Tacconi et al. 2013)

Assume that similar physical processes are important in high- and low-redshift disks

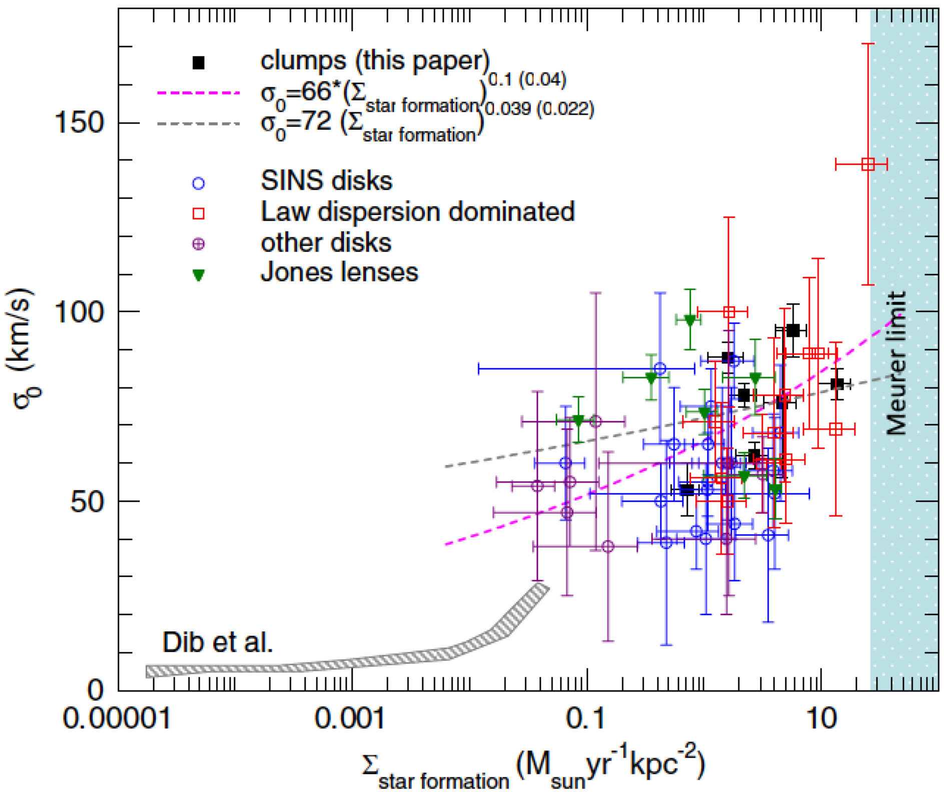
Star formation in high-redshift galaxies





- High-redshift star forming galaxies are gas rich ($f_{gas} \approx 0.3$-0.4) and fall on a 'linear' Kennicutt-Schmidt relation (e.g. PHIBBS survey, Tacconi et al. 2013)
- High-z galaxies - at the peak epoch of star formation - have higher gas surface densities and star formation rates than most low-z star forming disks

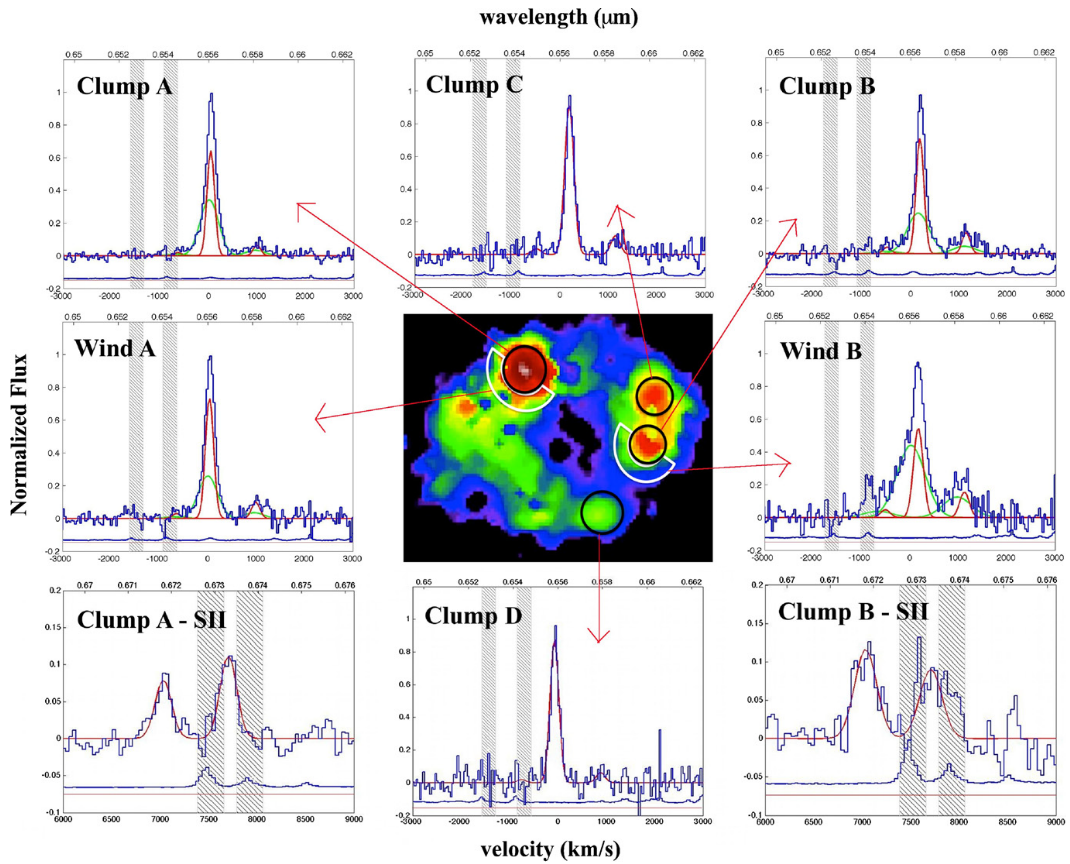
Gas kinematics in high-redshift star forming galaxies



Genzel et al. 2011

- Ionized gas in high-redshift disks has high velocity dispersion of 50 to 100 km/s (Forster-Schreiber et al. 2006, 2009; Genzel et al. 2006, 2009, Cresci et al. 2009, Wright et al. 2007, van Starkenburg et al. 2008, Epinat et al. 2009, Jones et al. 2010, Law et al. 2009)

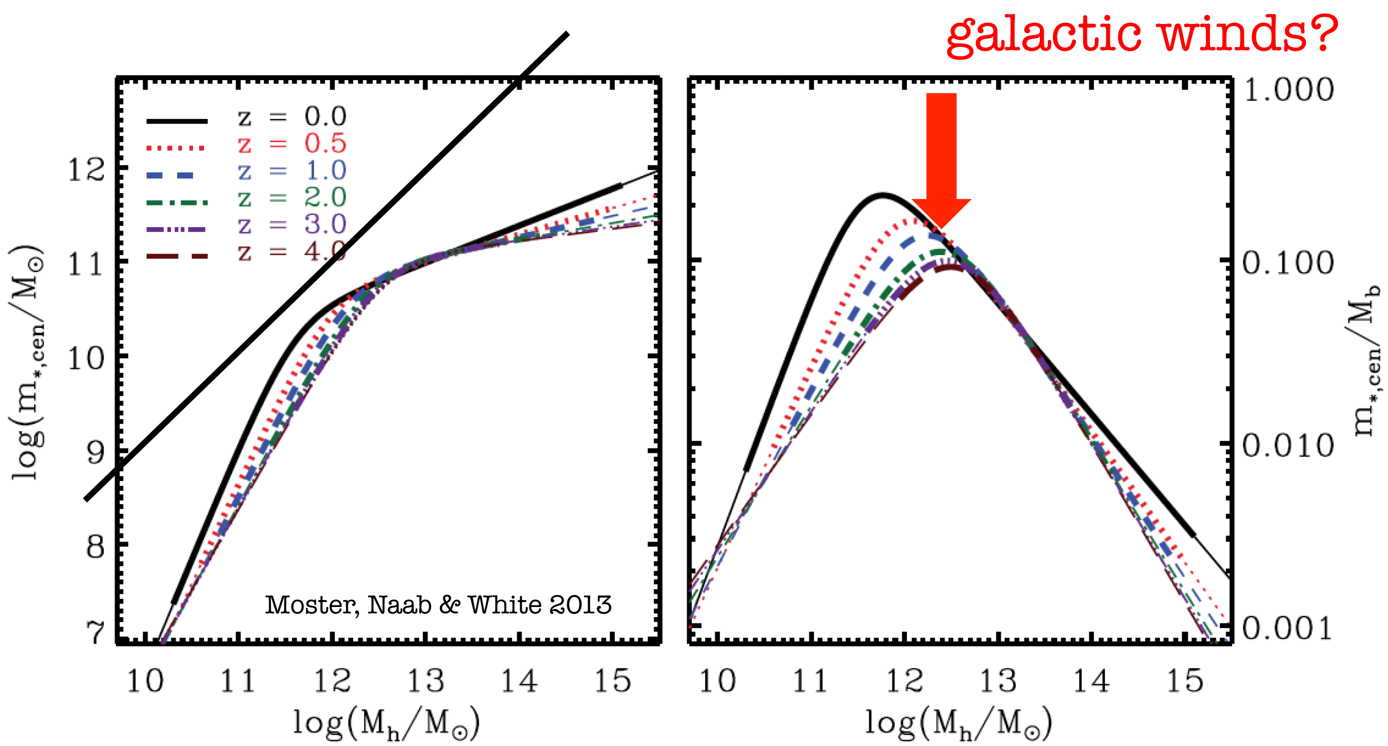
Winds in high-redshift star forming galaxies



Newman et al. 2012

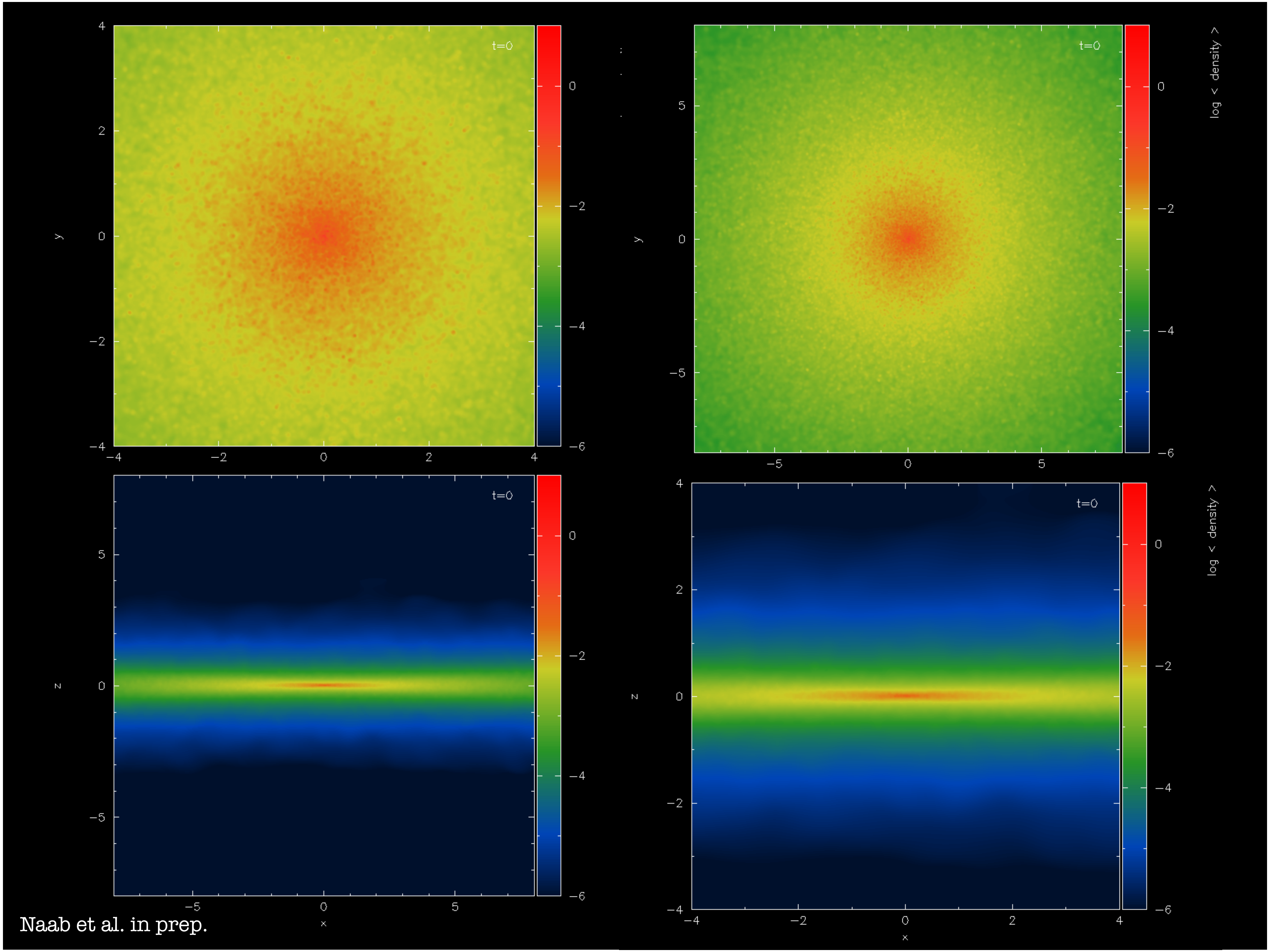
- Strong outflows in high redshift ($z \approx 2$-3) galaxies and enrichment with metals expelled to large (100kpc) radii (Steidel et al. 1996; Pettini et al. 2000, 2001; Weiner et al. 2009; Steidel et al. 2010)
- Outflow is spatially resolved at locations of high star formation – mass-loading 2 to 4 (Newman et al. 2012)

Independent constraints from abundance matching



- Abundance matching techniques - rank order dark matter halos by mass and match observed galaxy mass functions (Vale & Ostriker 2004, 2006; Conroy et al. 2006, Moster et al. 2010, 2013; Behroozi et al. 2010, 2013; Guo et al. 2010; CLF approach: van den Bosch et al. 2003; Yang et al. 2012, 2013)

- Models by Moster et al. including orphans and a proper treatment of sub-halos (Moster et al. 2010, Moster, Naab & White 2013)



Naab et al. in prep.

The SILCC Project

SImulating the LifeCycle of Molecular Clouds

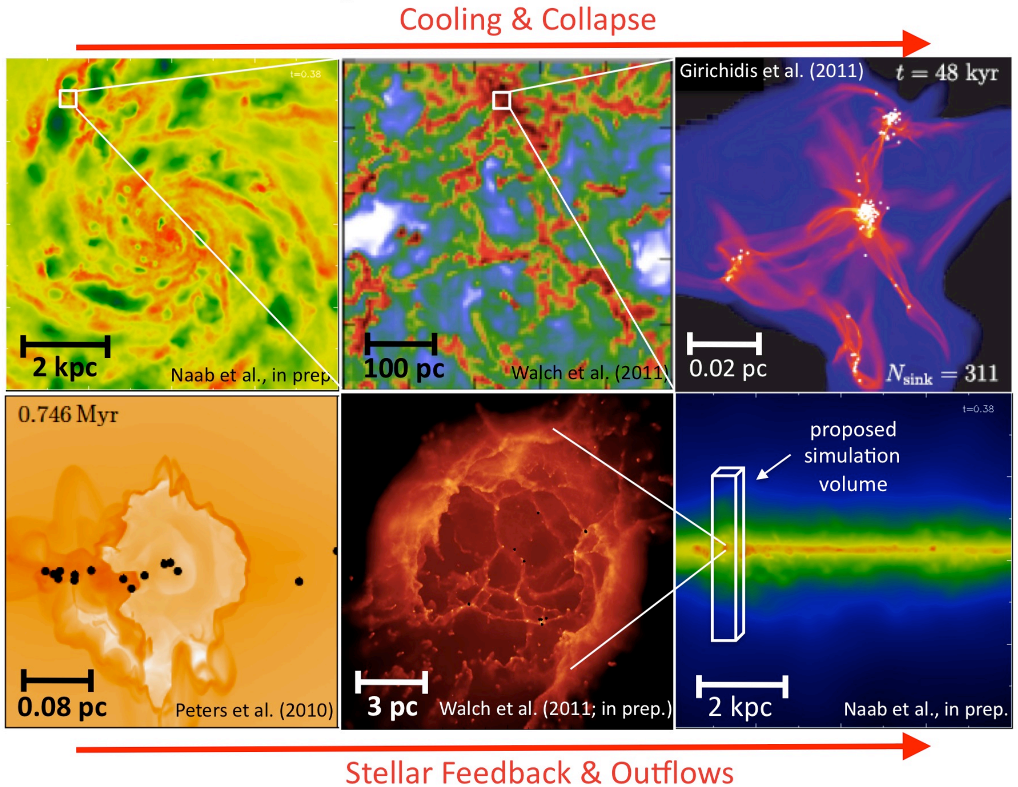
S. Walch, T. Naab, P. Girichidis, R. Klessen, S. Glover, S. Peters, R. Wünsch

AMR code FLASH 4 with...

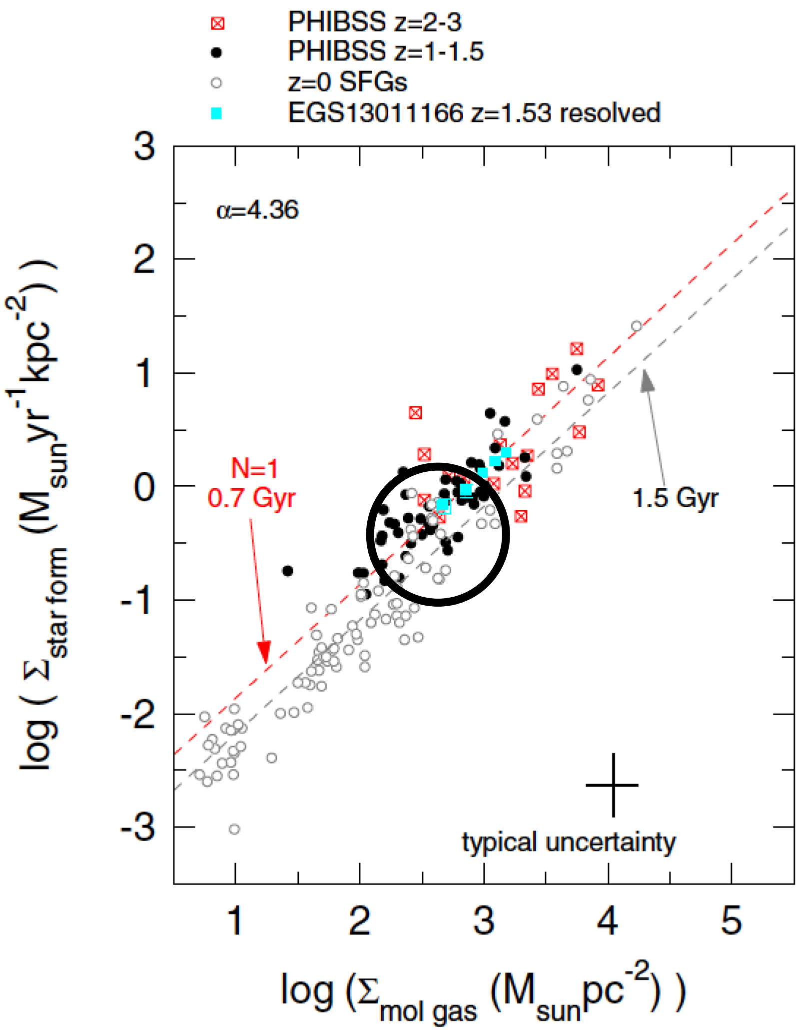
- tree self-gravity (Wünsch et al. in prep.)
- external potential
- ideal MHD
- heating & cooling, molecule formation (Glover et al. 2011)
- TreeCol (Clark et al. 2012)
- Sink particles with subgrid cluster/star model
- ionization, wind, and supernova feedback

42 million CPU-hours on SuperMuc@Leibniz-Rechenzentrum, Garching

Lifecycle of molecular clouds

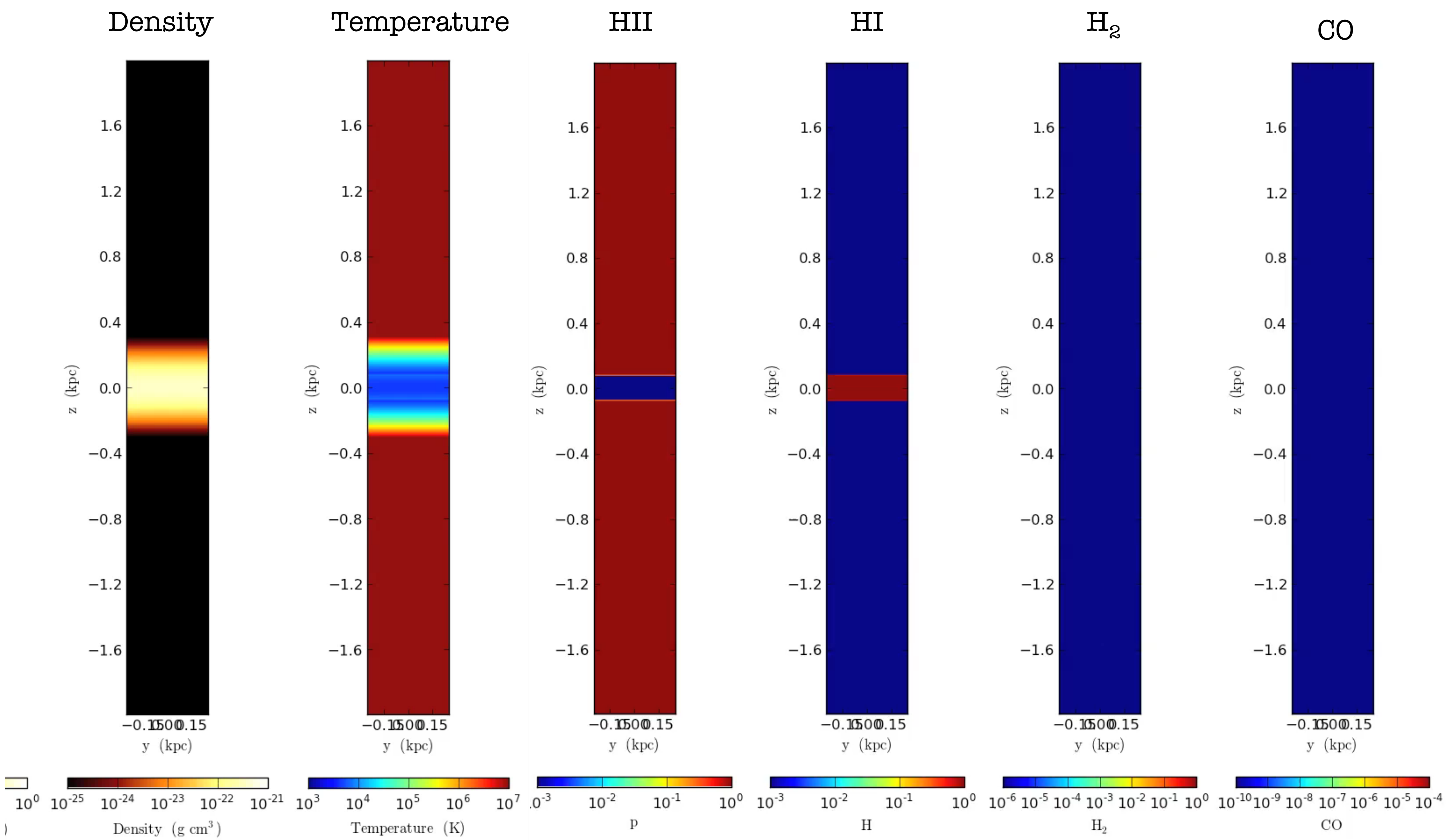


Feedback in dense environments...

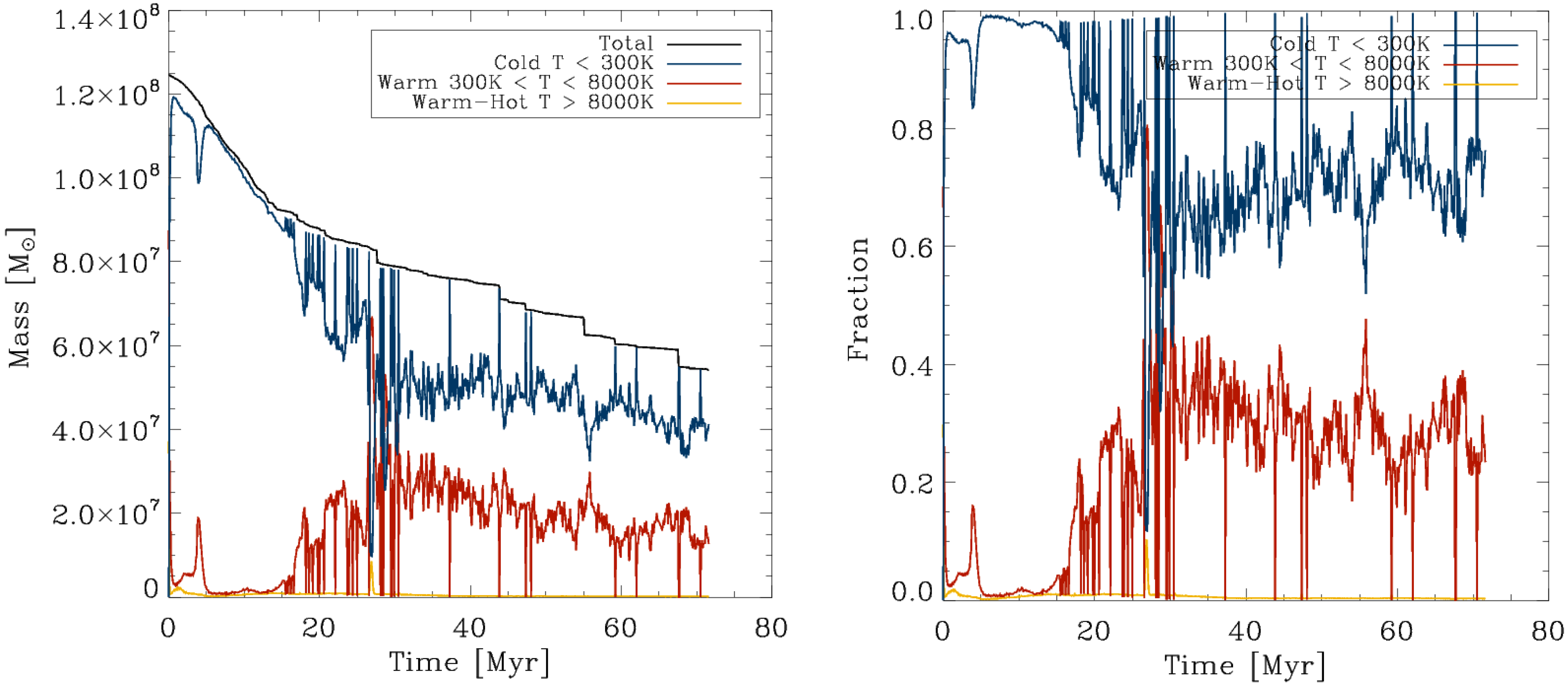


- Stratified disk with initial gas surface density of 500 $M_\odot/pc^2$
- Initial driving at 50 km/s
- Random supernova driving at a rate of 0.3 $M_\odot/yr/kpc^2$
- Follow dynamics, H_2 formation, outflows etc.

Feedback in dense environments...

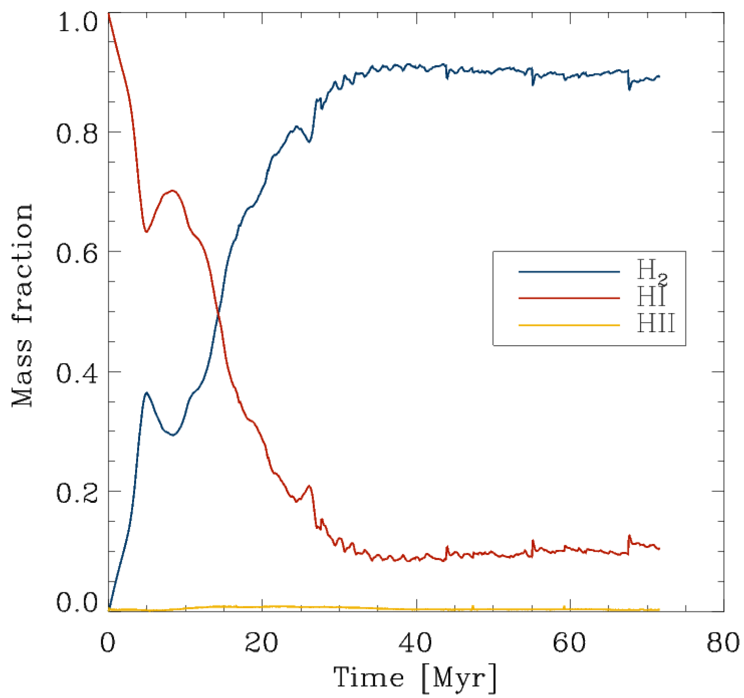


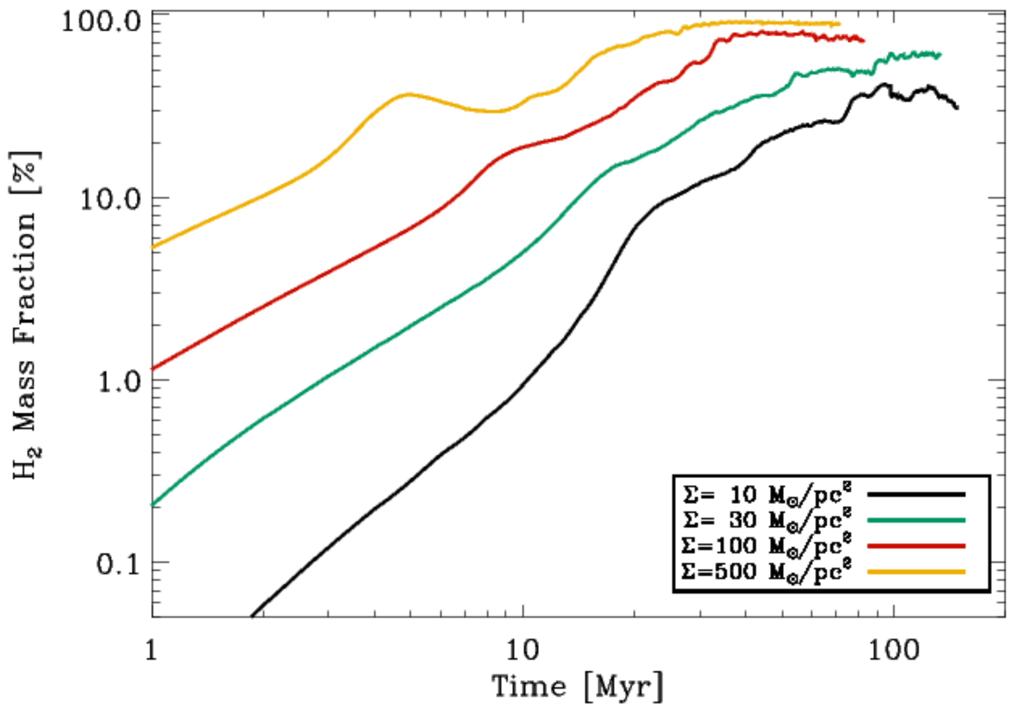
Gas phase evolution



- Significant mass-loss
- ISM is dominated by cold gas

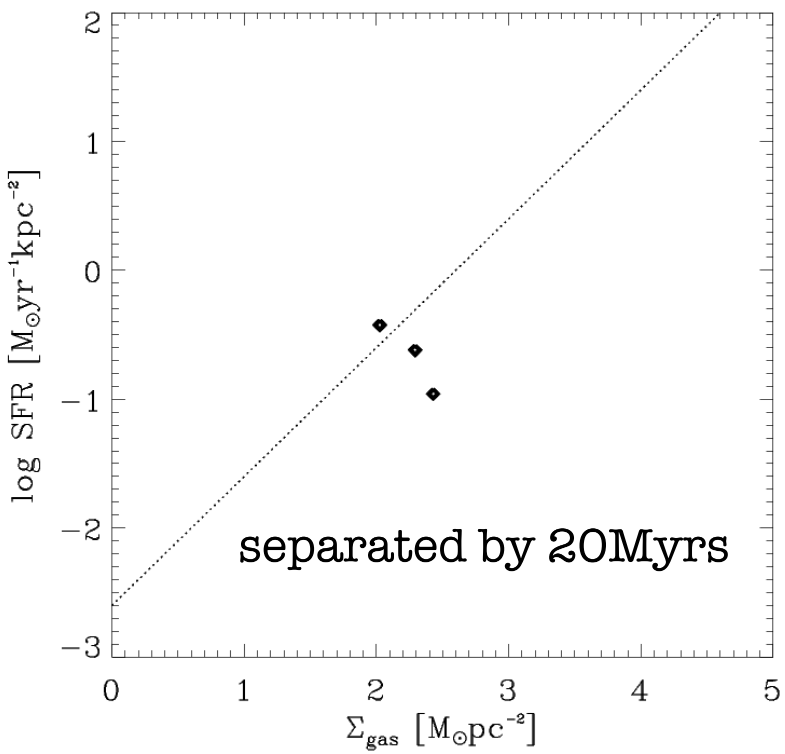
Gas phase evolution

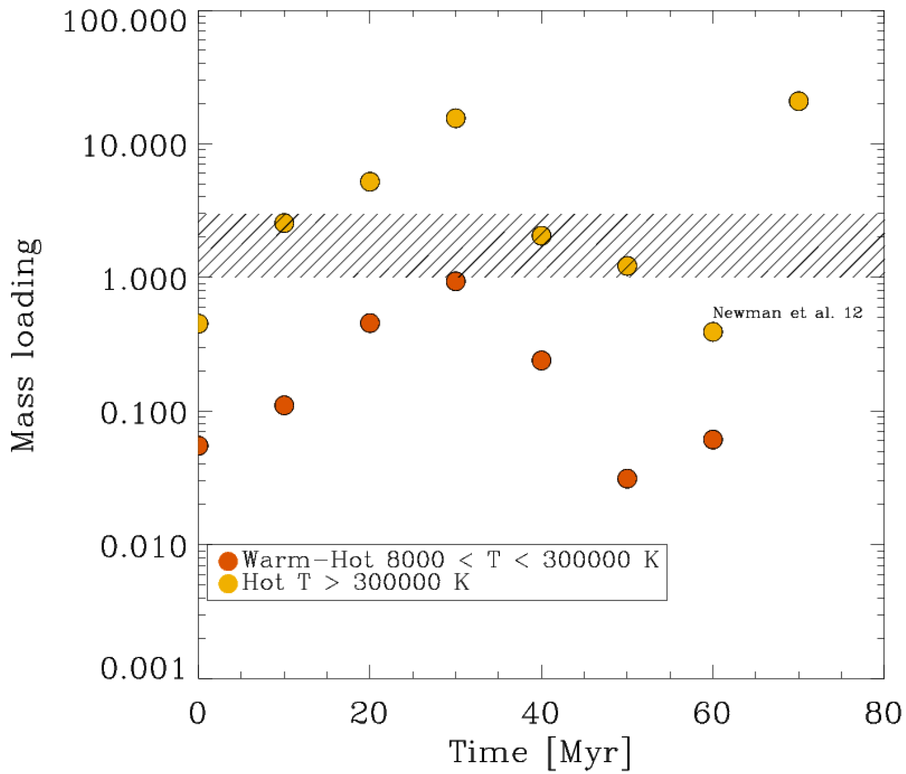




- At high surface densities gas becomes mostly molecular
- Robust trend: higher surface densities – higher H_2 fractions

Gas phase evolution





- Good match to the KS relation
- Mass loading (0.5kpc above and below the plane) is dominated by in hot (T > 300.000K) gas
- Loading is higher than in Creasey et al. 2013, puzzling...

Conclusions & Caveats

- SILCC simulations are a beautiful tool to investigate the evolution of the galactic ISM in (low- and) high-redshift galaxies
- Estimates for H_2 (and eventually CO) formation, outflow rates, dynamical and temperature structure of the multi-phase ISM

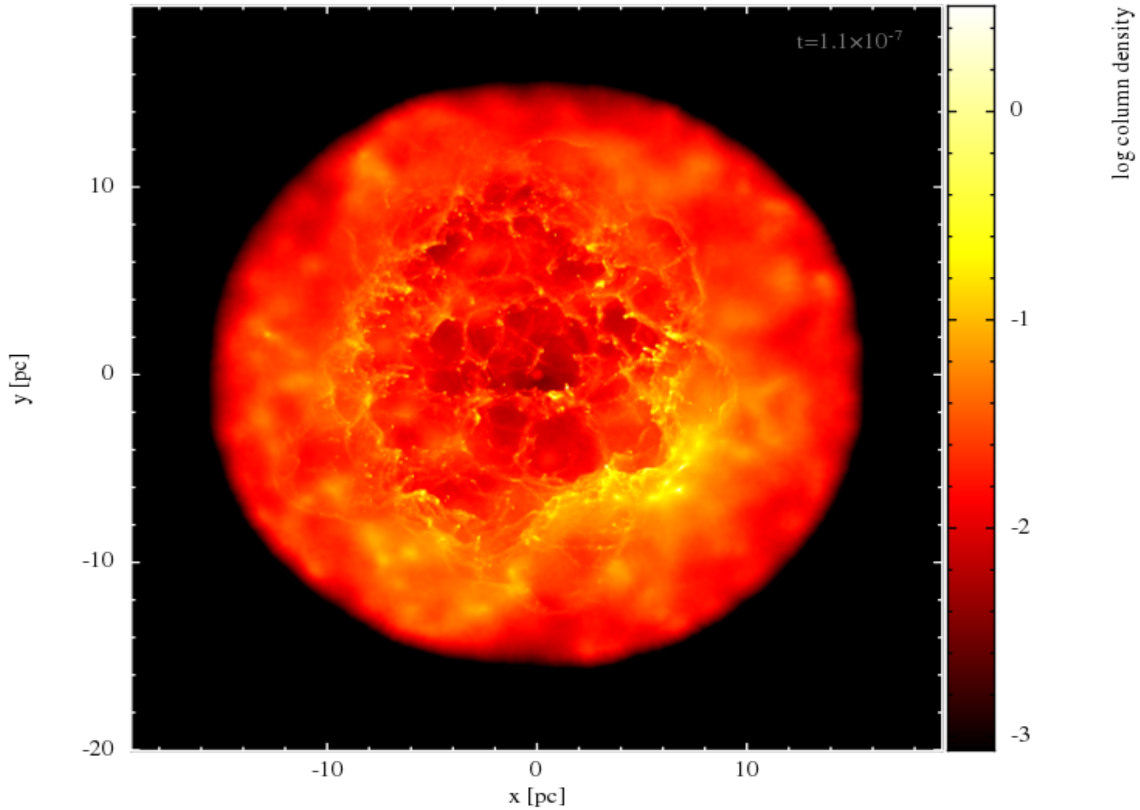
BUT…

- Test for numerical convergence – expensive but necessary
- Random driving is an over-simplification – include sinks with winds and SN (A. Gatto)
- Inclusion of ionizing radiation is necessary, see Walch et al. 2012 (C. Baczynski, T. Peters)
- Magnetic fields and a consistent treatment of cosmic rays are necessary (energy dependent advection and anisotropic diffusion implemented by P. Girichidis, stay tuned…)

HII regions in the Milky Way

- Ionization and winds from massive stars heat and shape the ISM – deposition of energy
- Theses processes shape the ISM before SN onset (Walch et al. 2012)

Sedov-Taylor blast waves in ionized clouds



- Sedov-Taylor blast waves (30% kinetic energy, 70% thermal energy) are well studied (e.g. Chevalier 1974, McKee & Ostriker 1977, Ostriker & McKee 1988)
- Significant fraction of the SN energy is radiated early – rapid onset of the snow plough phase – inefficient feedback, but pre-ionisation and cloud structure matters (Walch & Naab 2013)

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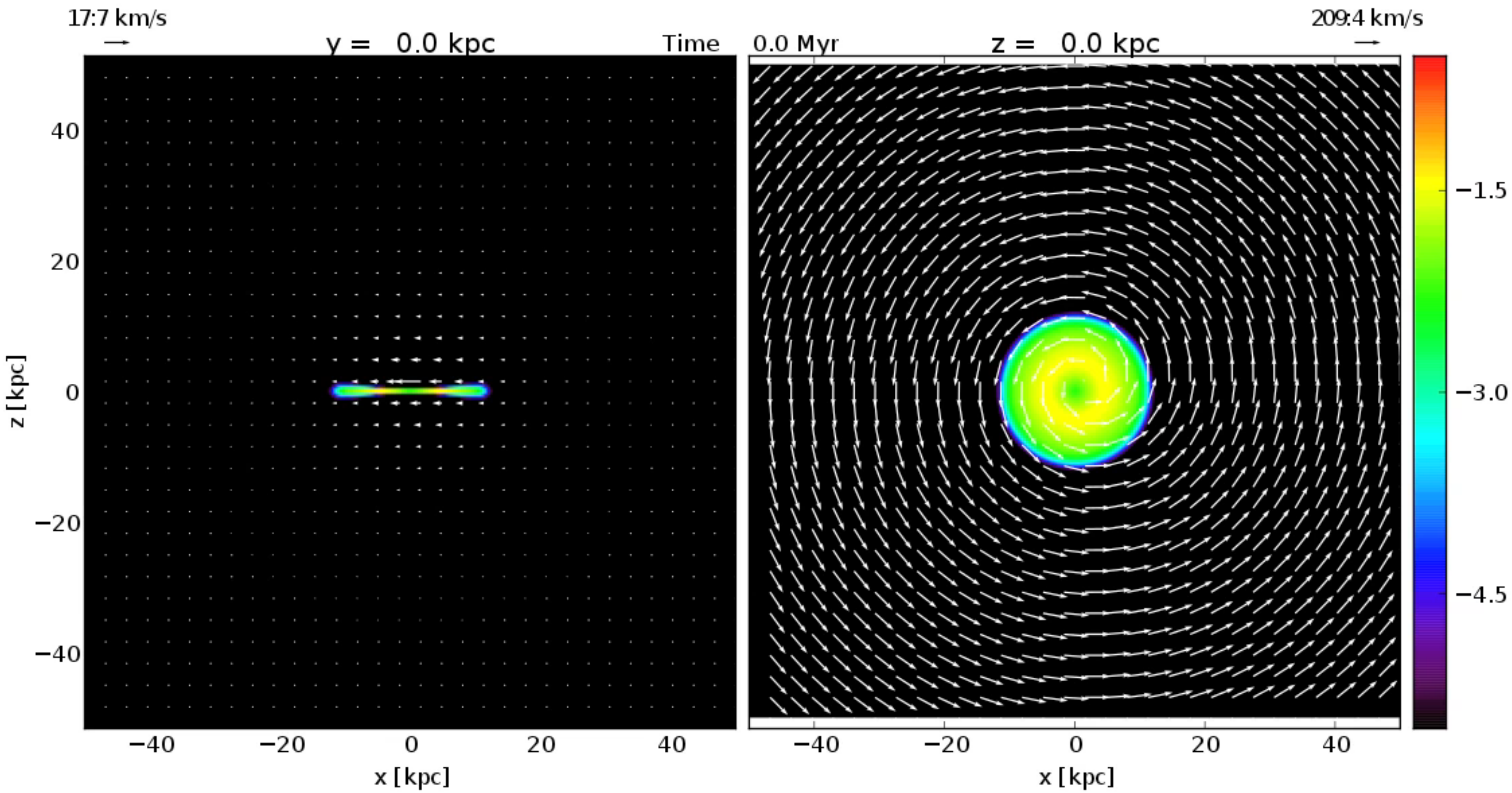
‘Cosmic ray driven’ winds - models



- Cosmic ray driven winds naturally drive bi-polar outflows with outflow rates similar to the star formation rate – even in the absence of thermal/kinetic input (e.g. Hanasz et al. 2009, Dorfi & Breitschwerdt 2012, Uhlig et al. 2012)

Hanasz, Lesch & Naab 2013