Stellar Feedback: Multiphase ISM and Galactic Outflows.

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Stellar Feedback

- Energy sources:
  - Supernova explosions.
  - Stellar winds.
  - Photoionization heating.

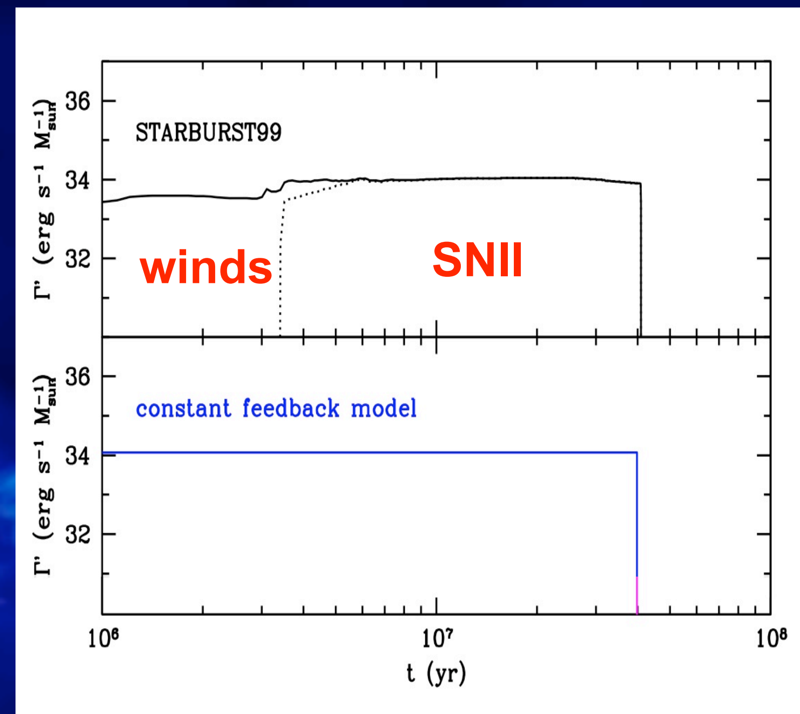
$$\frac{\partial e}{\partial t} = \Gamma - L$$

Feedback heating vs radiative cooling

$$\text{Heating rate:} \quad \Gamma = \rho_{\text{Stars}} \, \Gamma'$$

$$\text{Cooling rate:} \quad L = n_H^2 L'$$

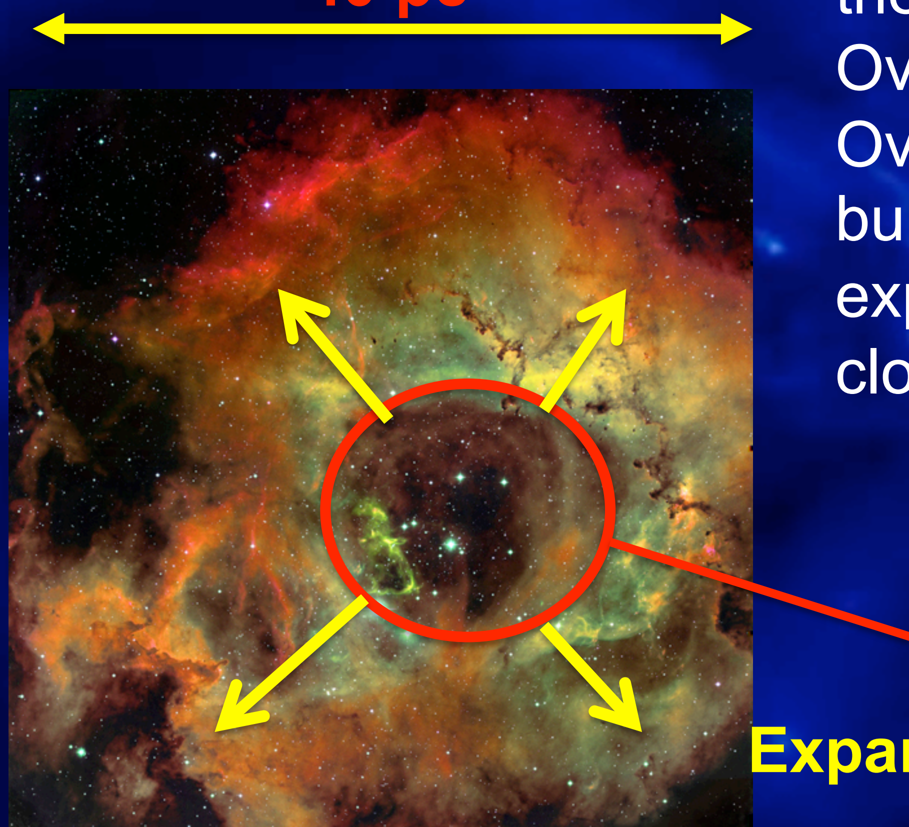
$$\frac{\partial e}{\partial t} = \Gamma - L$$



Ceverino & Klypin 2007

In the beginning…

Rosette Nebula



there was an
Overheated,
Overpressure,
bubble
expanding in a molecular
cloud

Our implementation

Ceverino & Klypin 2007

Kravtsov ART hydro code: Physical processes included:

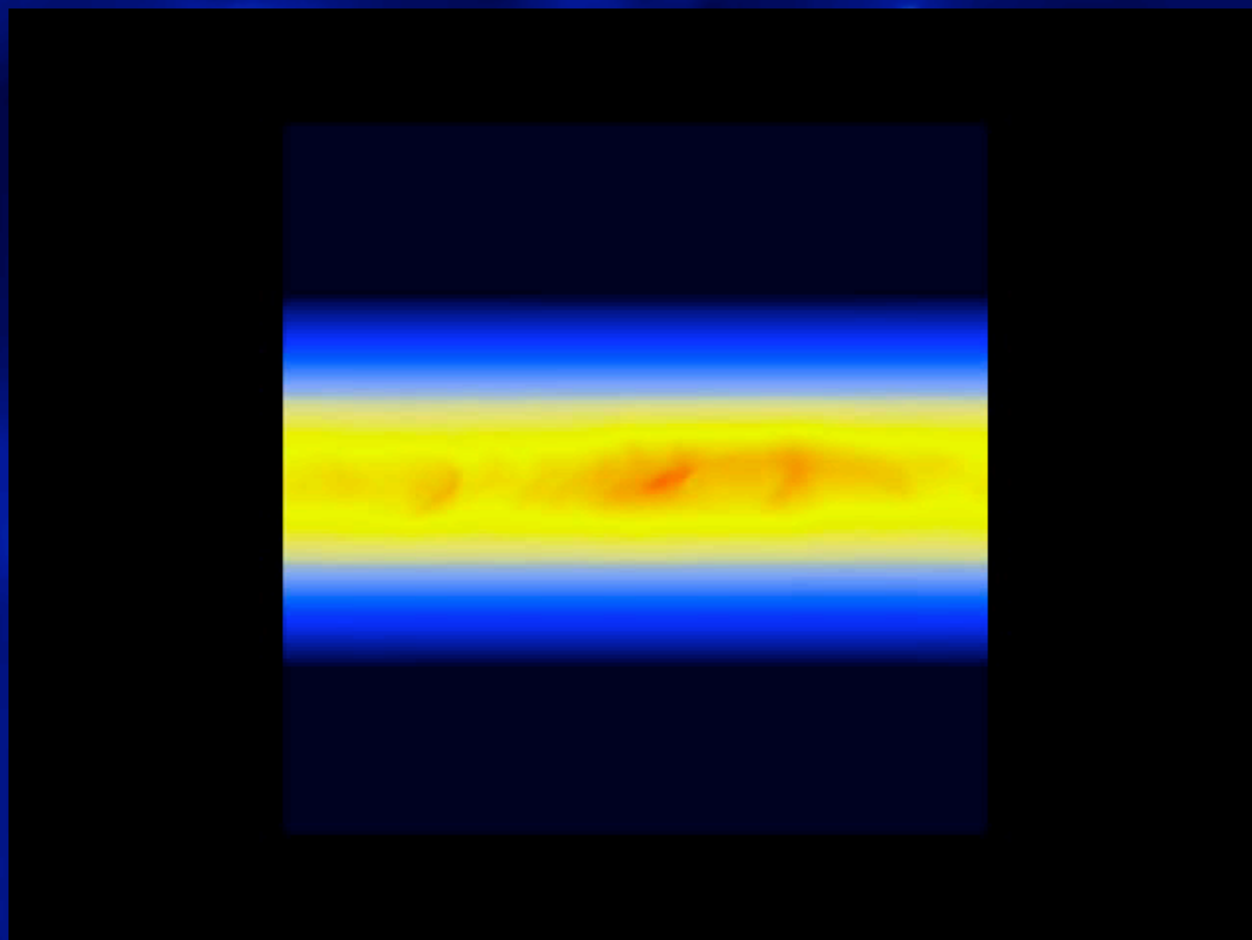
- AMR shock capturing hydro
- metallicity-dependent cooling + UV heating (Haardt & Madau). CLOUDY. Compton cooling
- Temperature range for cooling: 10^2K -10^8K
- Jeans length resolved with 4 cells
- Star formation rate proportional to gas density
- Energy release from stellar winds+ SNII +SNIa
- Thermal feedback: most * form at T< 1000K n>10cm^{-3}

- Runaway stars: massive stars move with exp(-v/17km/s)

A piece of a galactic disk

8 pc resolution

4 Kpc



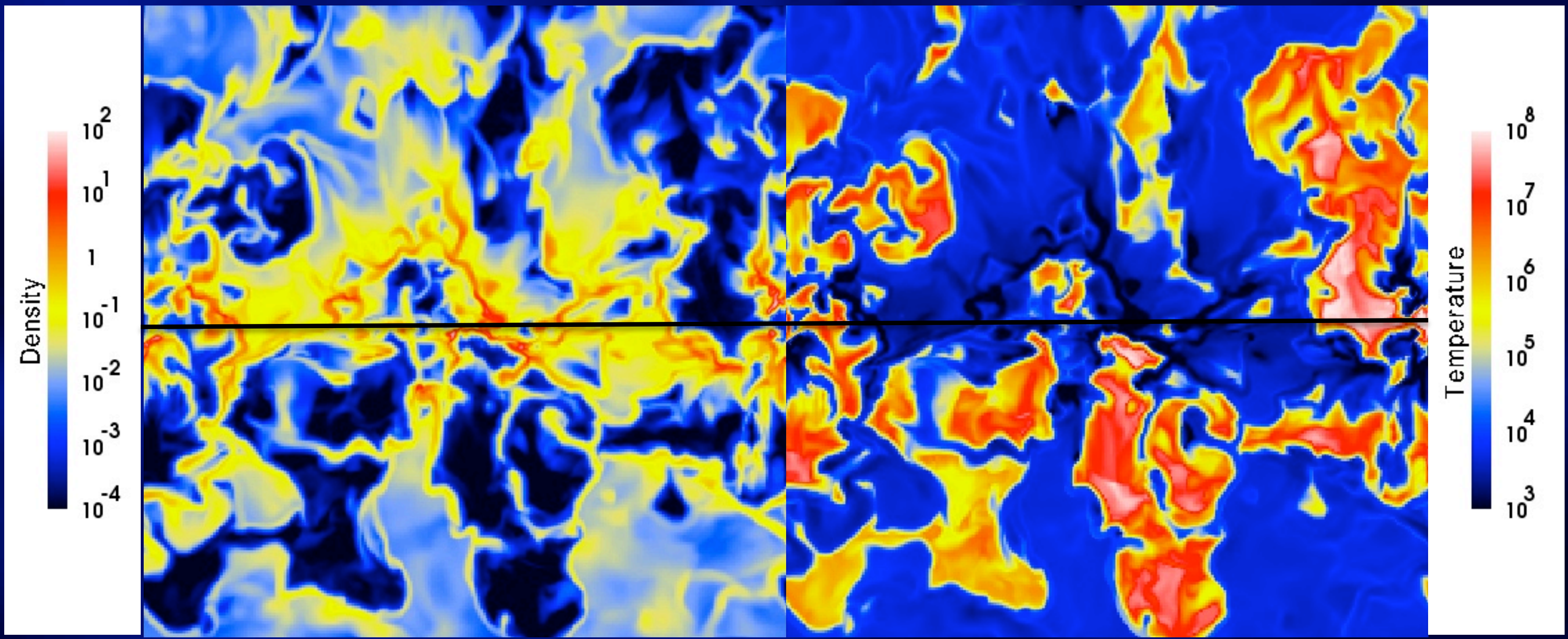
Projected density

(edge-on)

Super-bubbles and galactic chimneys

4x4 Kpc^2 Slices perpendicular to the disk plane

8 pc resolution



The effect of the stellar feedback in the ISM (Ceverino & Klypin 2007):

A multiphase medium: Cold ($T<10^3$ K) gas, Warm ($10^3 < T < 10^4$ K) and Hot ($T> 10^4$ K) gas.

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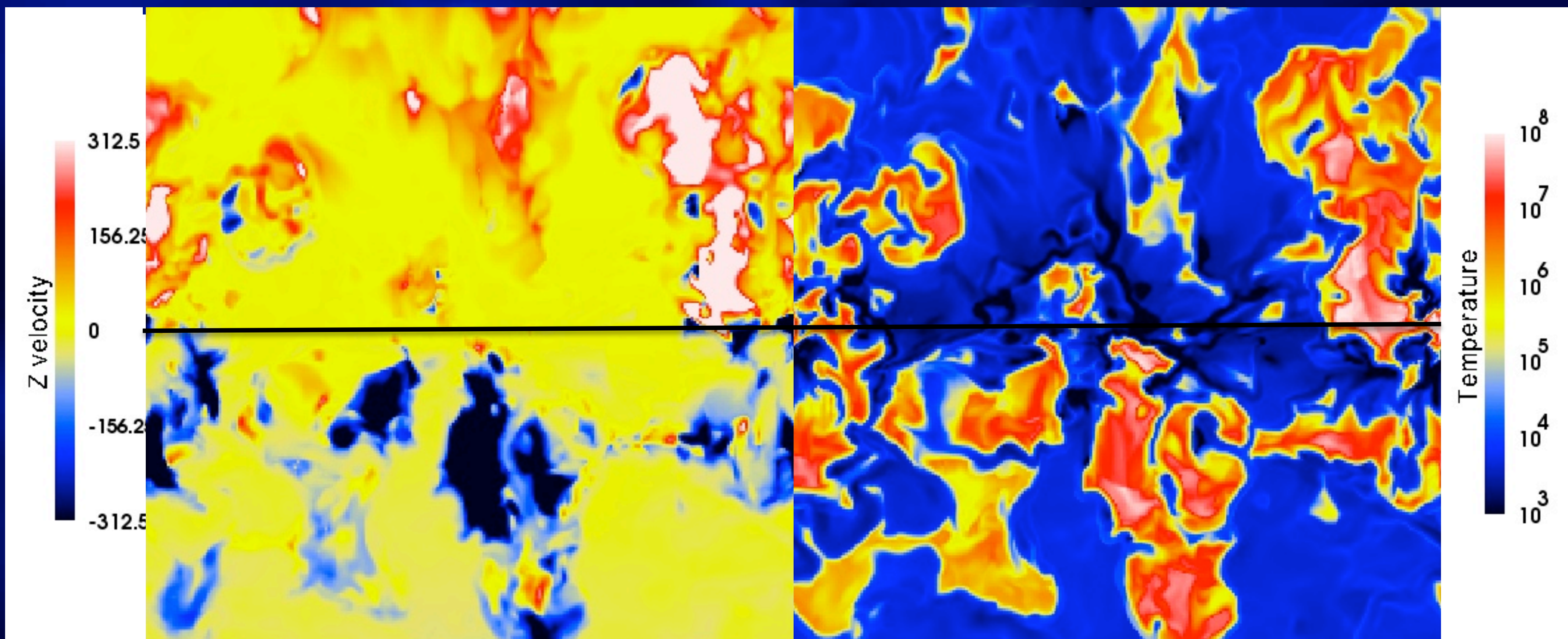

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Cosmology: formation of MW galaxy

z=3.5 MW progenitor. 45 pc resolution

Face-on view

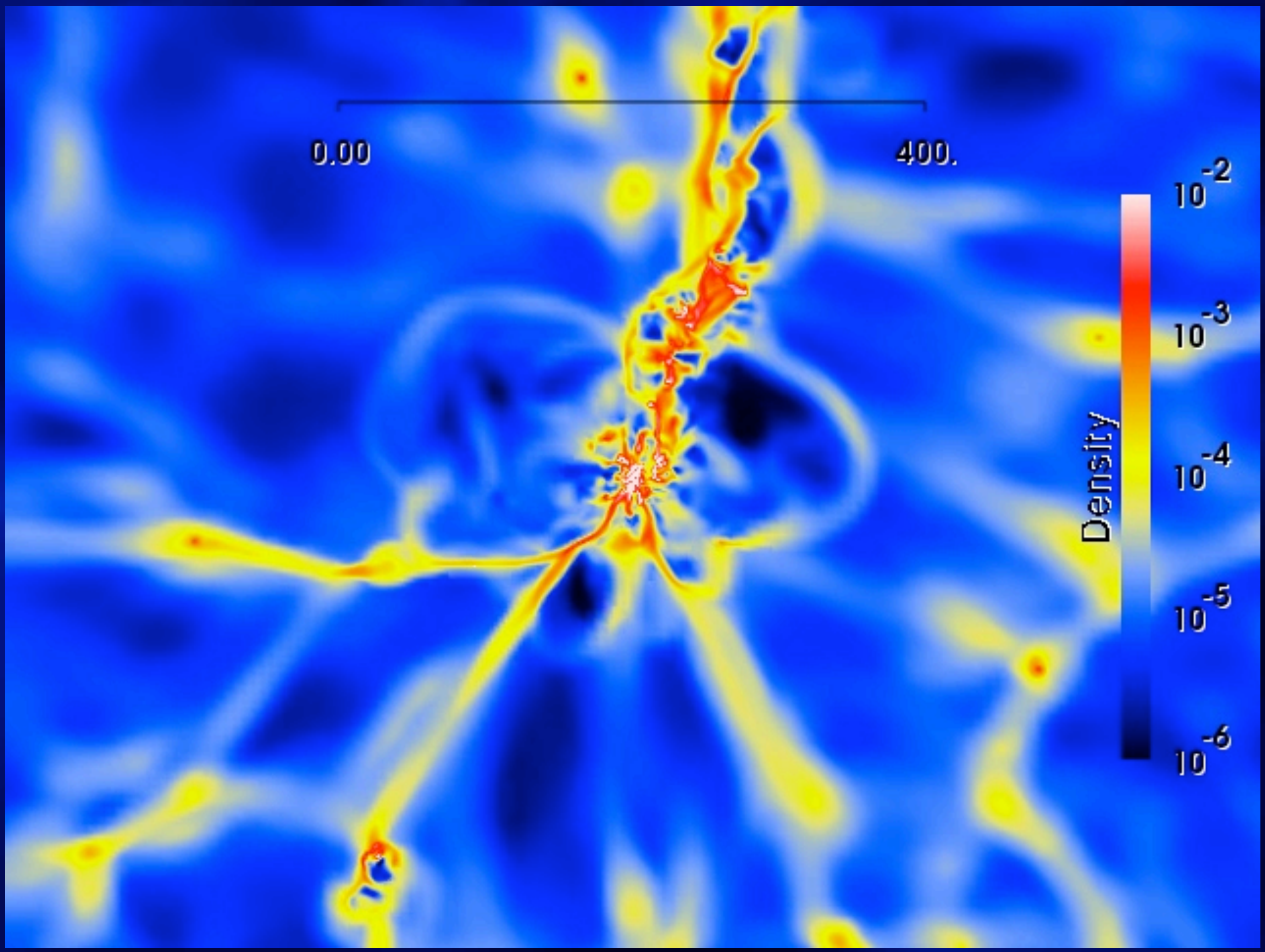
SFR =10Msun/year

Ceverino & Klypin 2007

400 kpc proper

Cold Flow regime

Slice of gas density

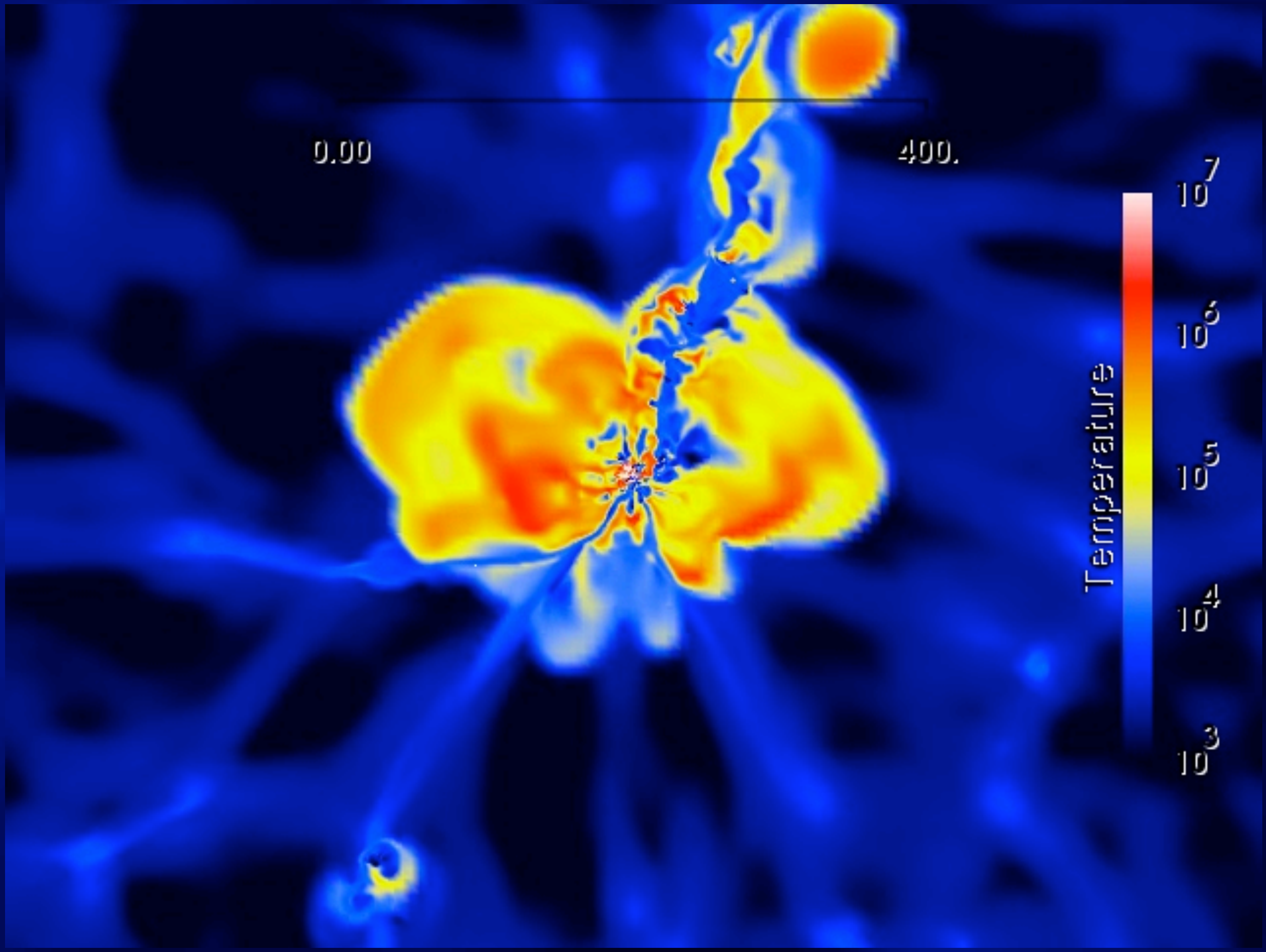


Ceverino & Klypin 2007

z=3.5 Major progenitor of MW. 45 pc resolution
Face-on view

400 kpc proper

Cold Flow regime



Slice of
temperature

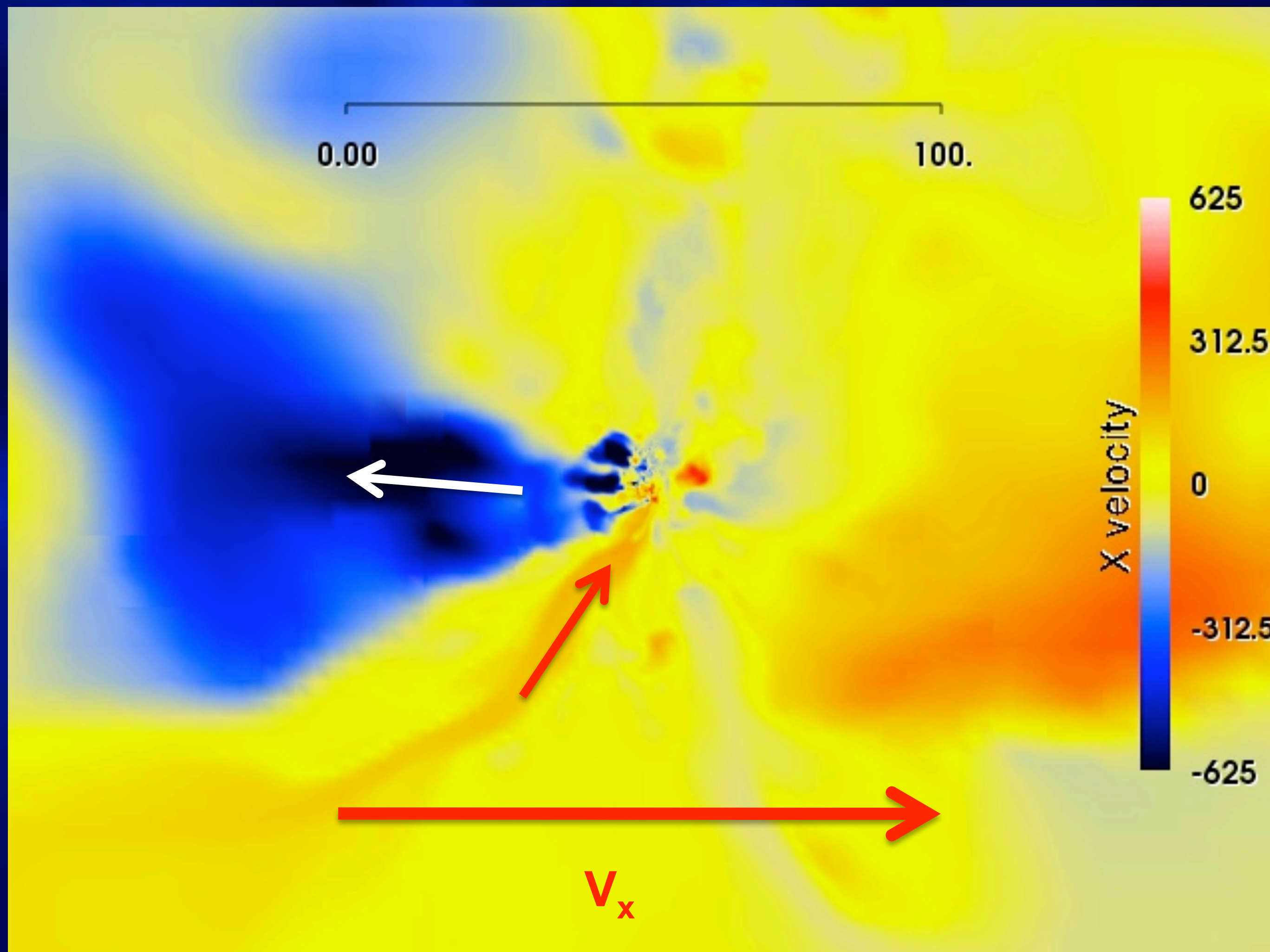
Ceverino & Klypin 2007

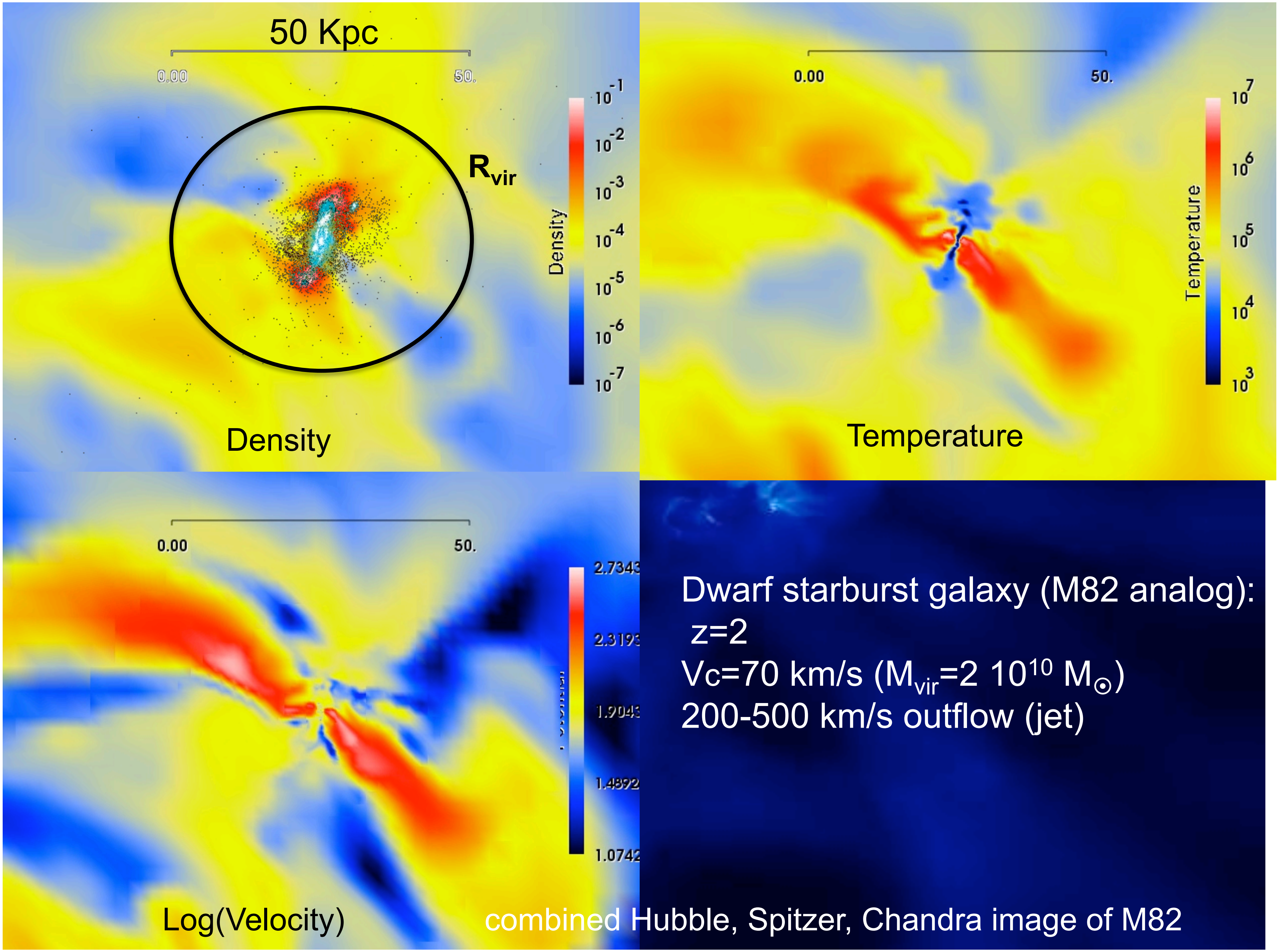
z=3.5 Major progenitor of MW. 45 pc resolution

Face-on view

100 kpc proper

Gas velocity
In the
horizontal
direction.

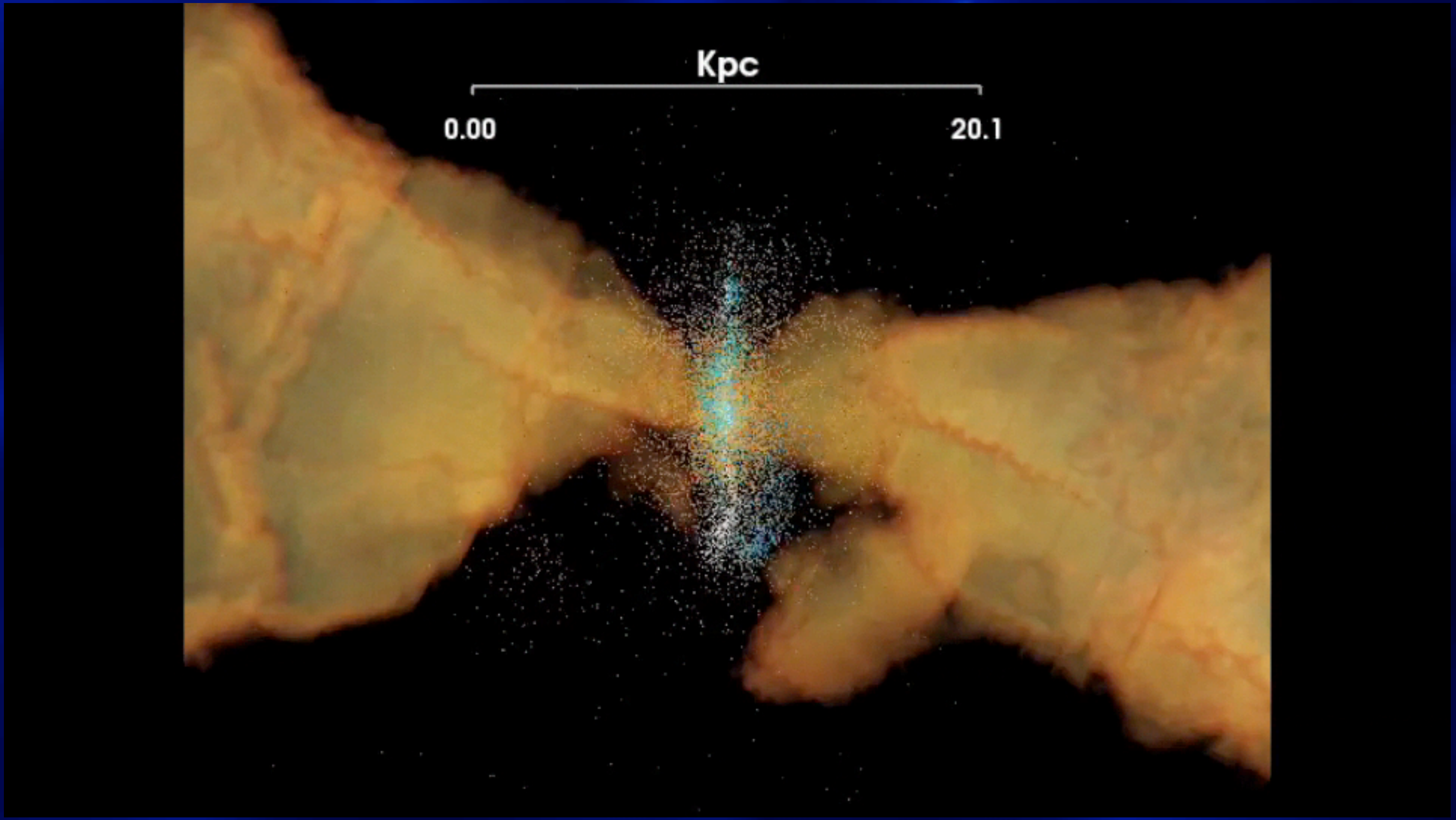




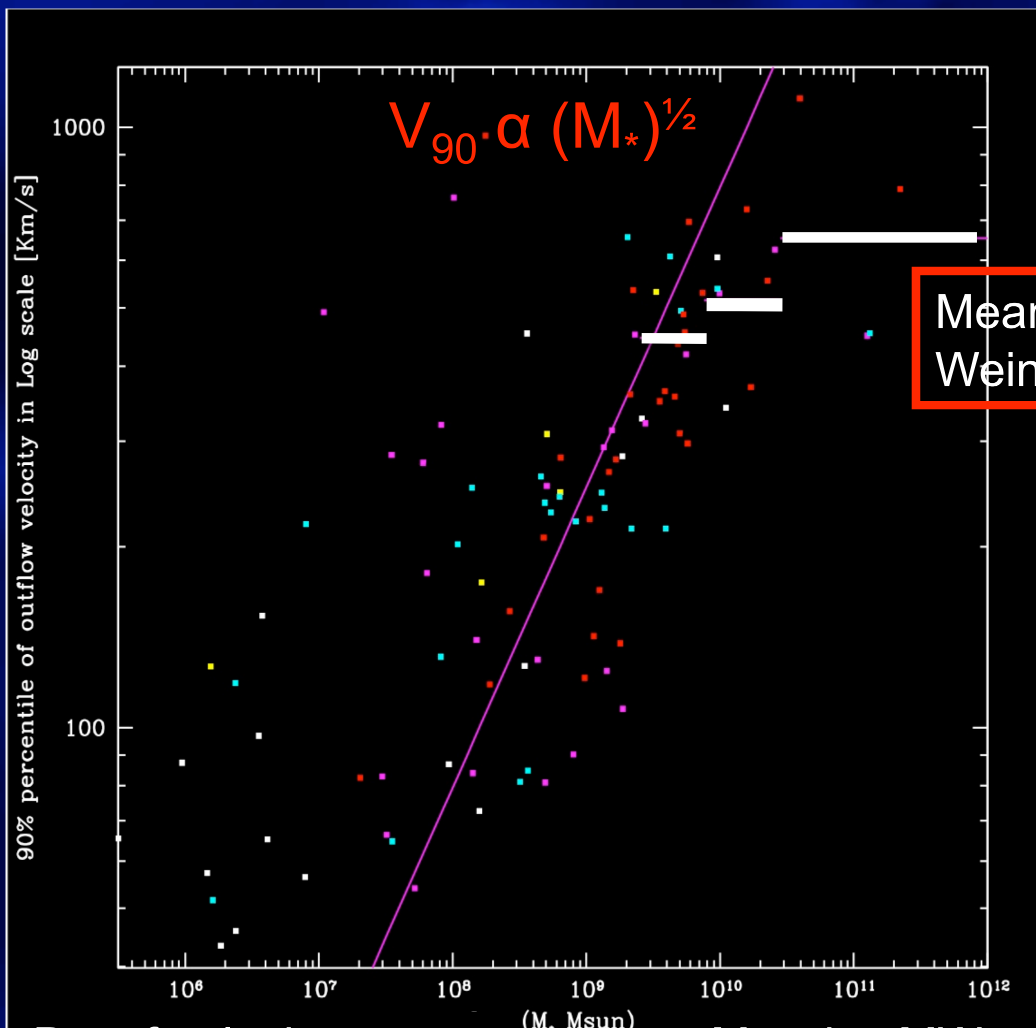
50 Kpc
0.00
50.
R_{vir}
Density
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Density
0.00
50.
Temperature
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
Temperature
0.00
50.
2.7343
2.3193
1.9043
1.4892
1.0742
Log(Velocity)
Dwarf starburst galaxy (M82 analog):
z=2
Vc=70 km/s (M_{vir}=2 10^{10} $M_{\odot}$)
200-500 km/s outflow (jet)
combined Hubble, Spitzer, Chandra image of M82

Outflows extend beyond the virial radius

Outflow mass ≈ $10^7 M_{\odot}$
Mass loss rate ≈ SFR



Maximum Outflow Velocity vs Stellar Mass

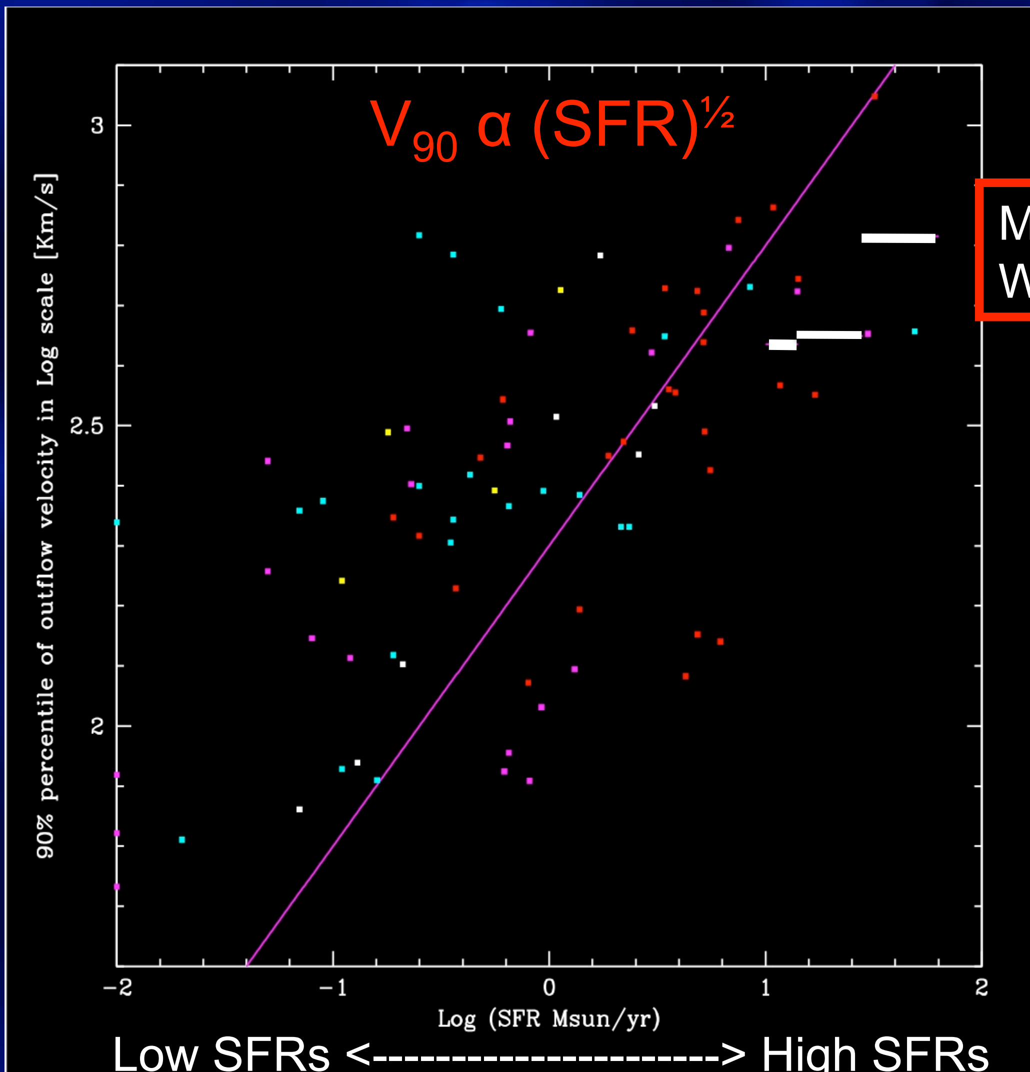


Dwarf galaxies <------------------> Massive MW-type galaxies

Mean properties from DEEP2 Weiner et al (2008). (1.3<z1.5)

- Galaxies at z=1.2-1.5
- Massive star-forming galaxies can have 1000 km/s outflows.

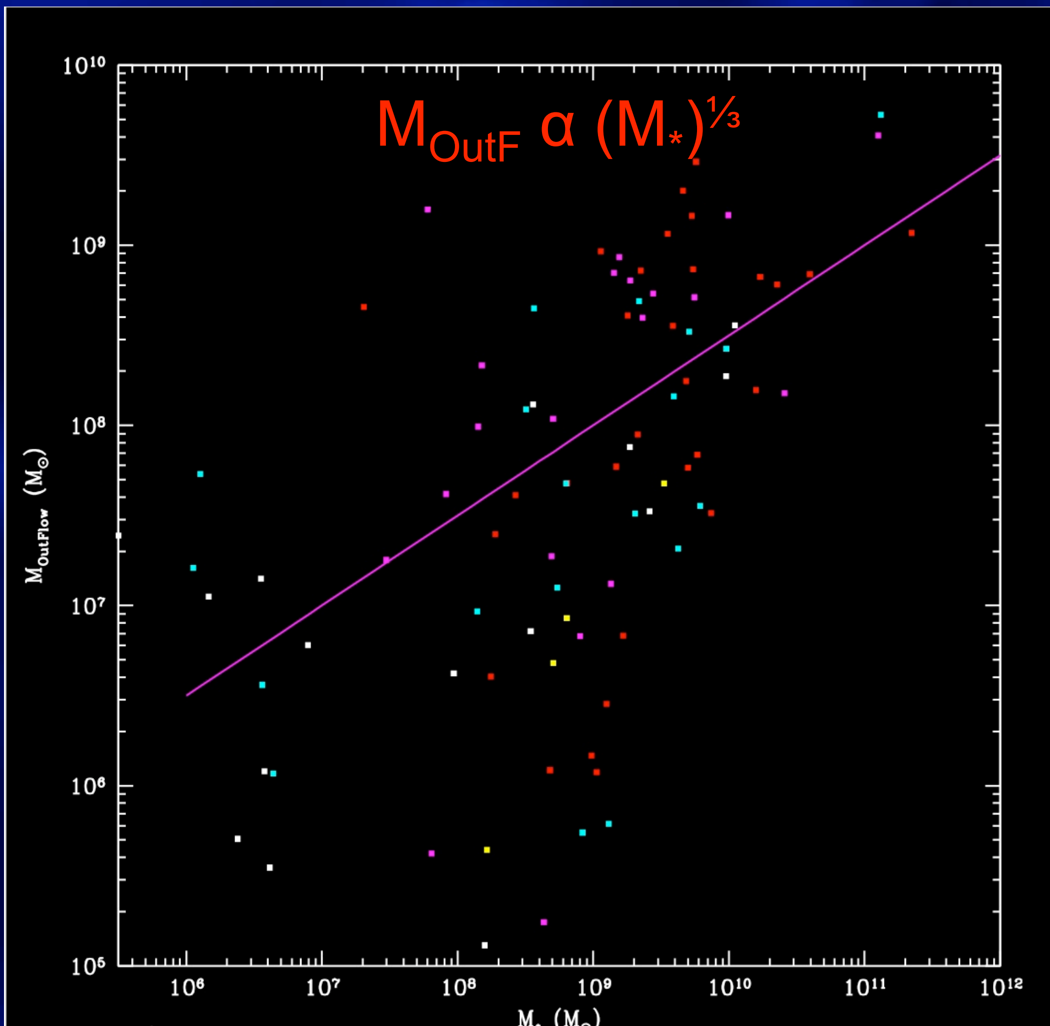
Maximum Outflow Velocity vs Star Formation Rate



Mean properties from DEEP2 Weiner et al (2008). (1.3<z1.5)

- Massive galaxies with SFR=10-100 $M_{\odot}$/yr can produce significant outflows of 500-1000 km/s

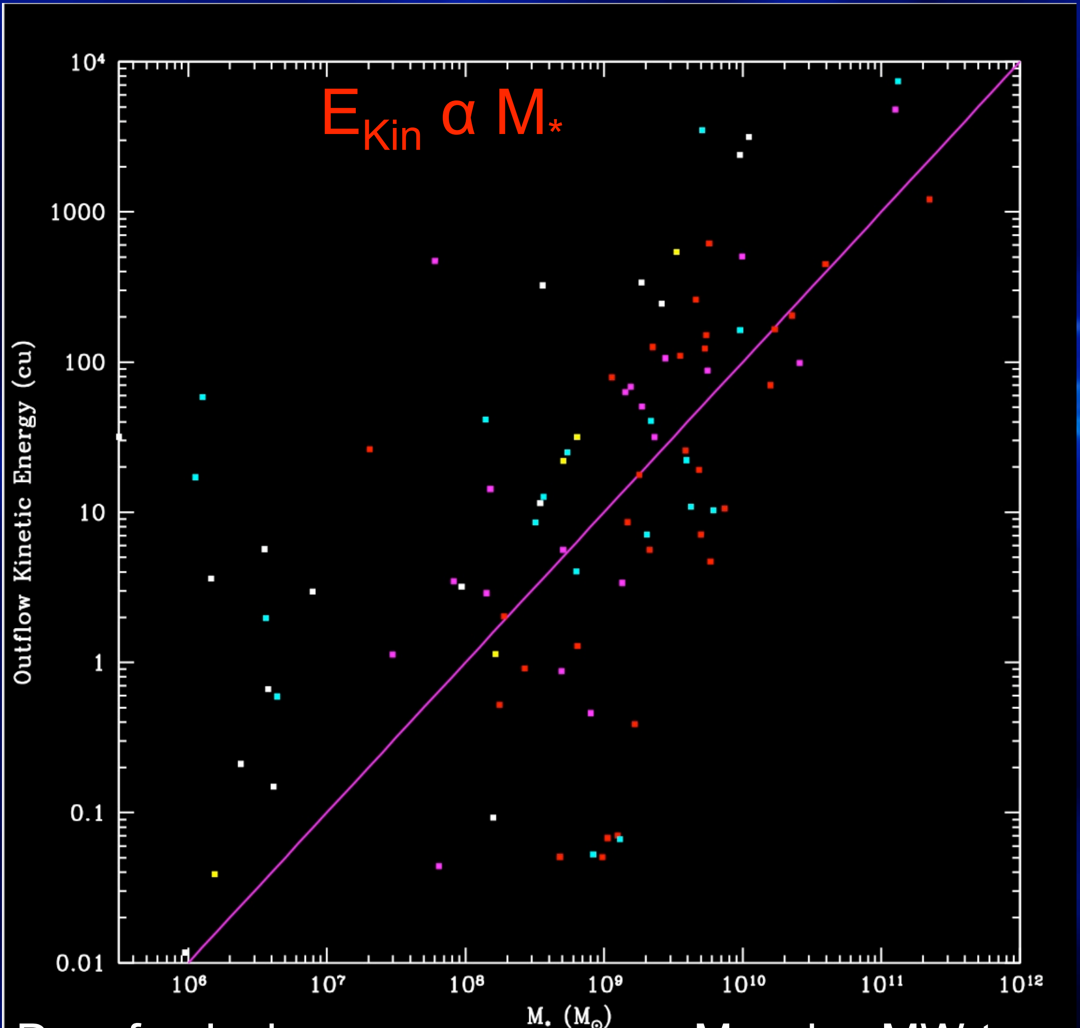
Outflow mass vs Stellar mass



Dwarf galaxies <------------------> Massive MW-type galaxies

- For Dwarf galaxies, a significant fraction of the baryons are lost.
- For massive galaxies, the mass in the outflow is a small fraction of the stellar mass.

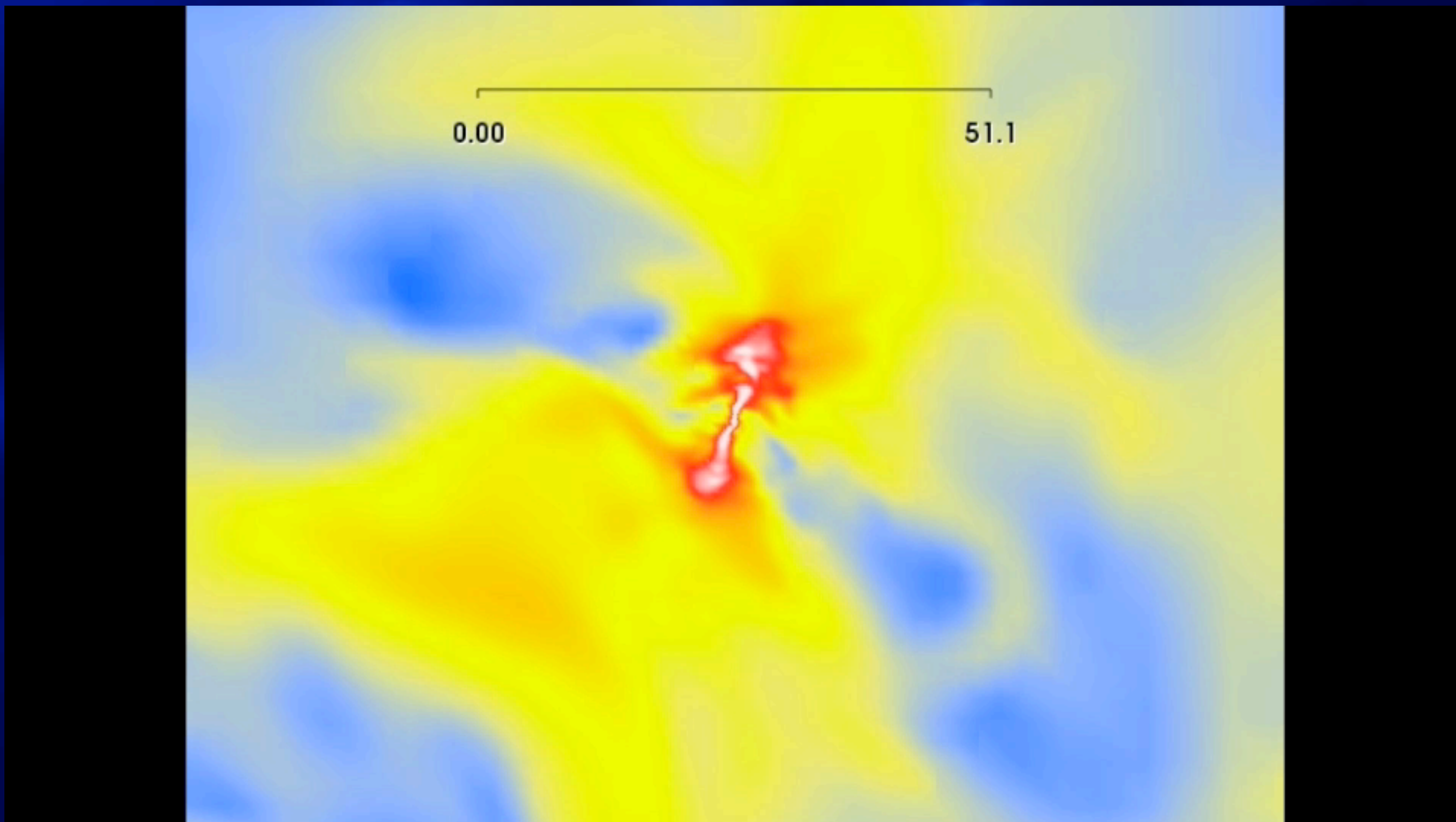
Outflow Kinetic Energy vs Stellar Mass



Dwarf galaxies <------------------> Massive MW-type galaxies

- The kinetic energy of the outflow scales linearly with stellar mass.

The effect of outflows extends much further



Conclusions

- Stellar feedback maintains a 3-phase ISM.
- It generates super-bubbles and galactic chimneys.
- Cosmological simulations with 30 pc resolution and more accurate models of stellar feedback produce naturally galactic outflows with properties similar to observed outflows at redshift 1-1.5.


THE END
(FIN)