PhEW: Physically Evolved Winds in Hydrodynamic Simulations

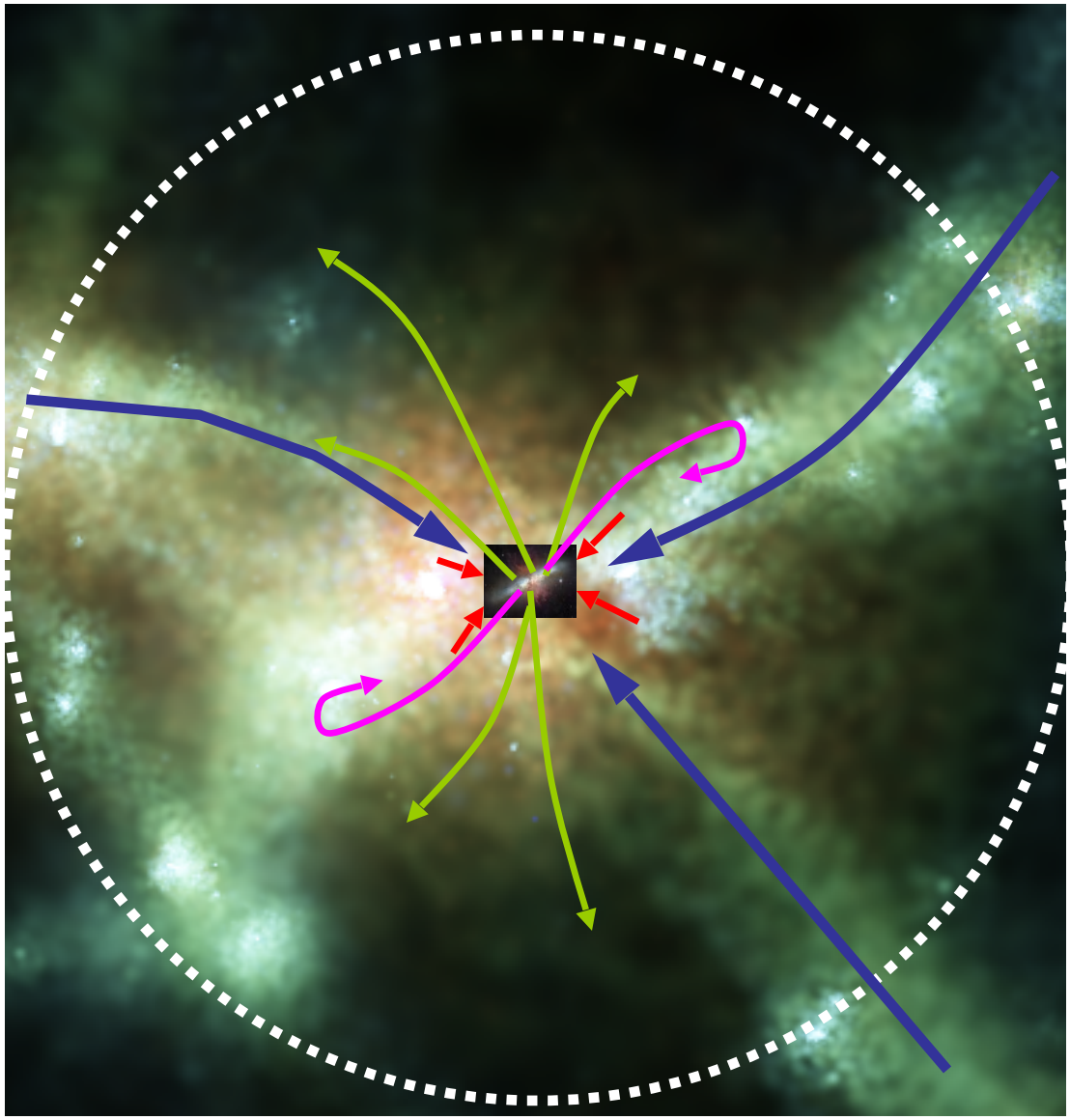
Shuiyao Huang

(UMass-Amherst)

Collaborators:

Neal Katz (UMass), *Romeel Davé (Edin.), Evan Scannapieco (ASU), Mark Fardal (UMass), Molly Peeples (STScI), David Weinberg (OSU)*

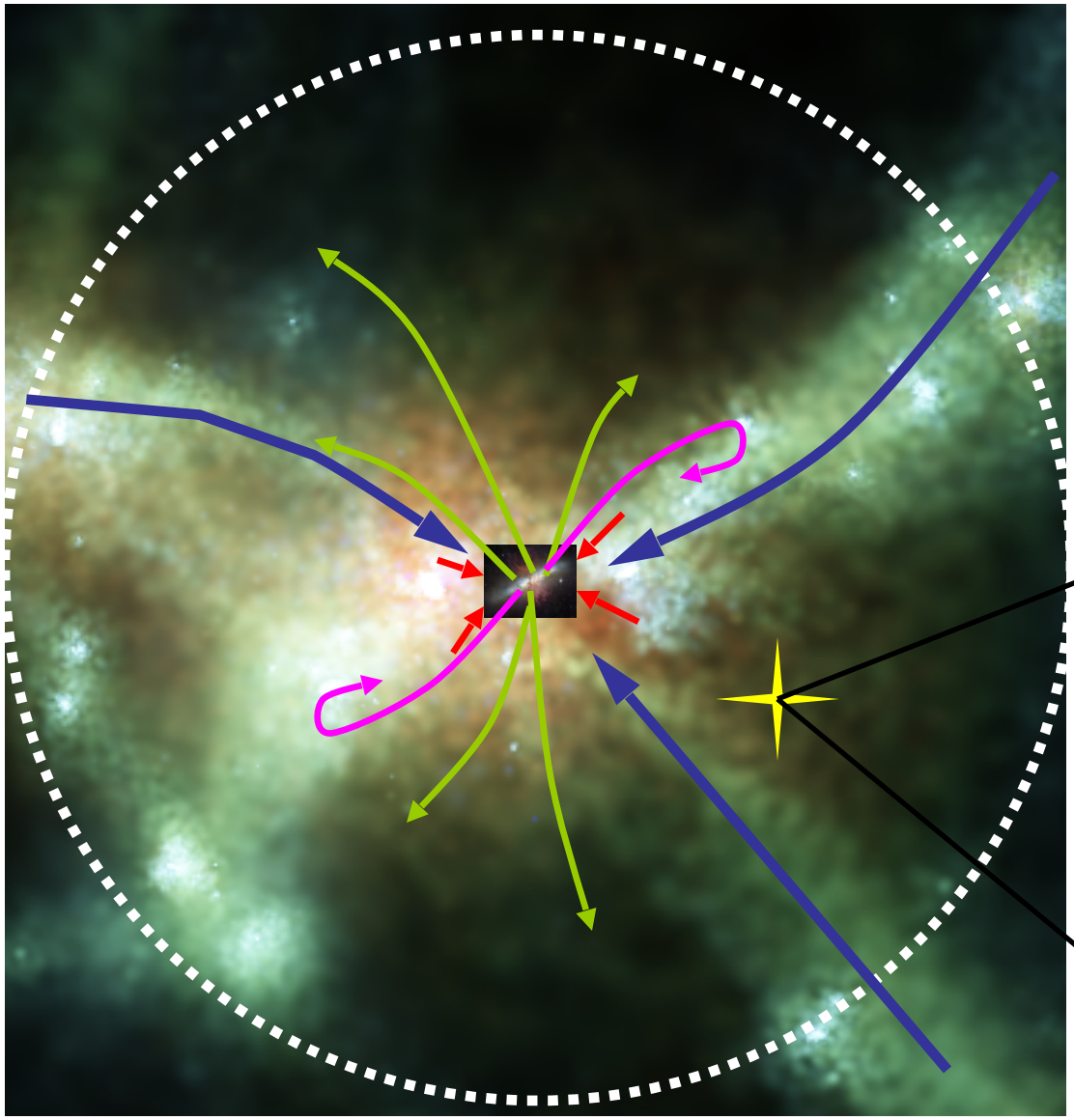
Cosmological Simulations and the CGM



The Baryon Cycling:

- Cold/Hot accretion
- Star formation
- Outflow
- Galactic fountain

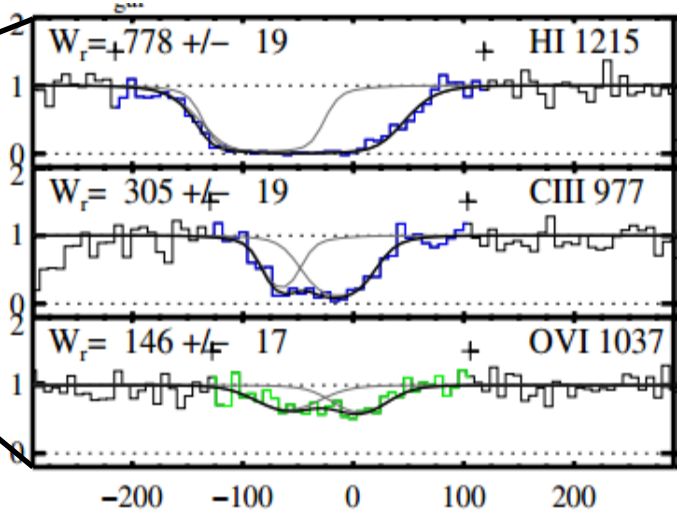
Cosmological Simulations and the CGM



The Baryon Cycling:

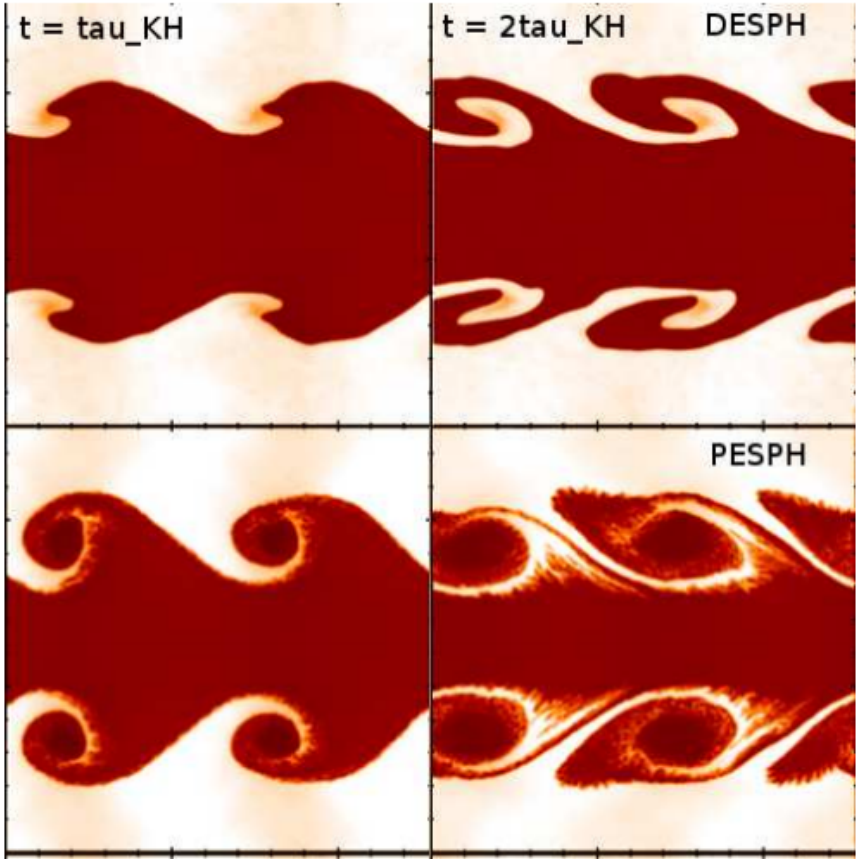
- Cold/Hot accretion
- Star formation
- Outflow
- Galactic fountain

Absorption Spectra:



Werk+, 2013

Traditional, old SPH

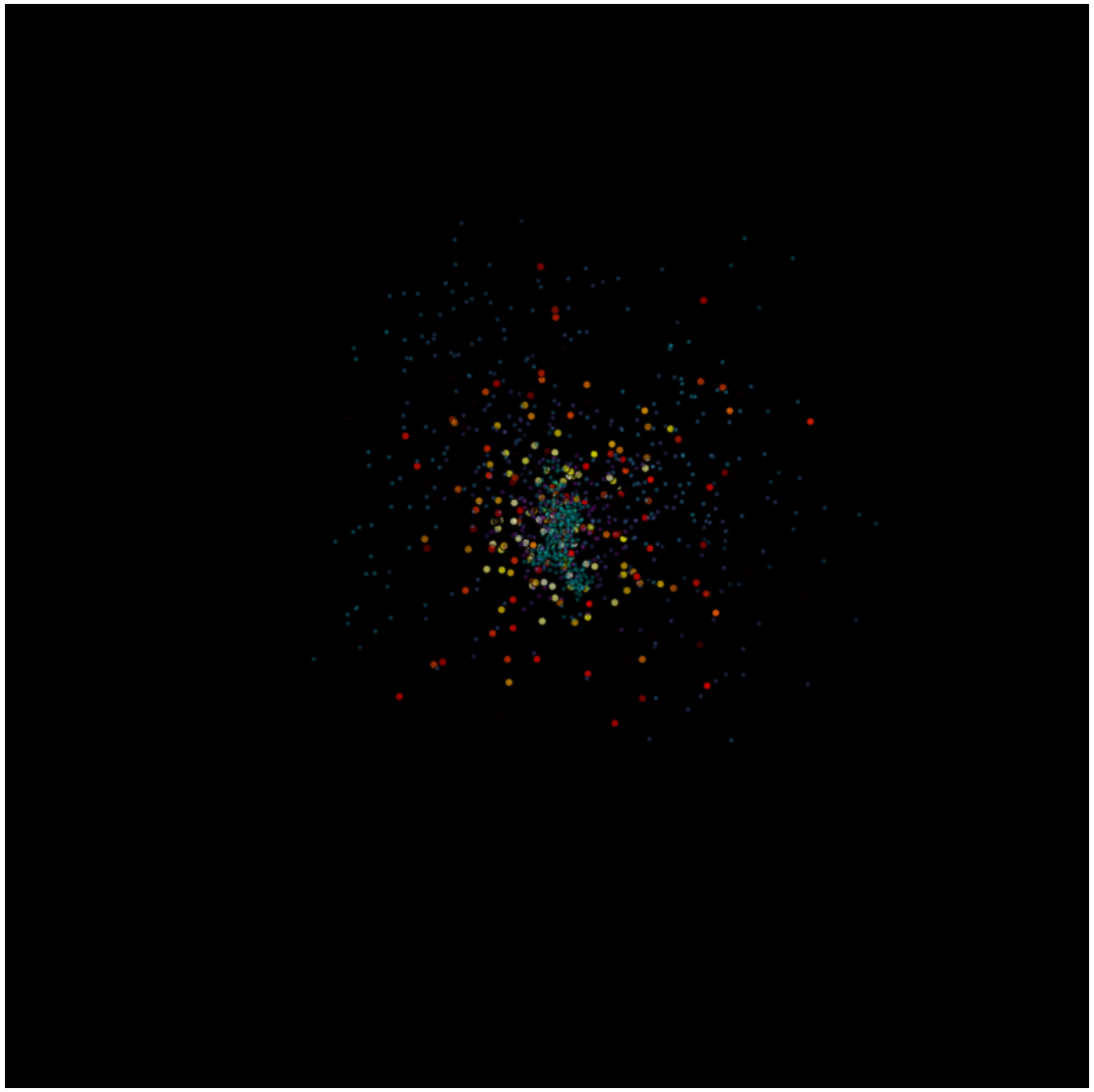


Updated, New SPH

- **Hydro codes: SPH, AMR, AREPO**
- **SPH had its problems, and was argued to have important consequences**
- **Recent developments on SPH:**

Pressure-Entropy SPH (Hopkins 13); artificial viscosity (Cullen & Dehnen 10); artificial conduction (Read & Hayfield 12), timestep limiter (Durier & Dalla Vecchia 12)

Feedback/Winds



Kinetic Feedback:

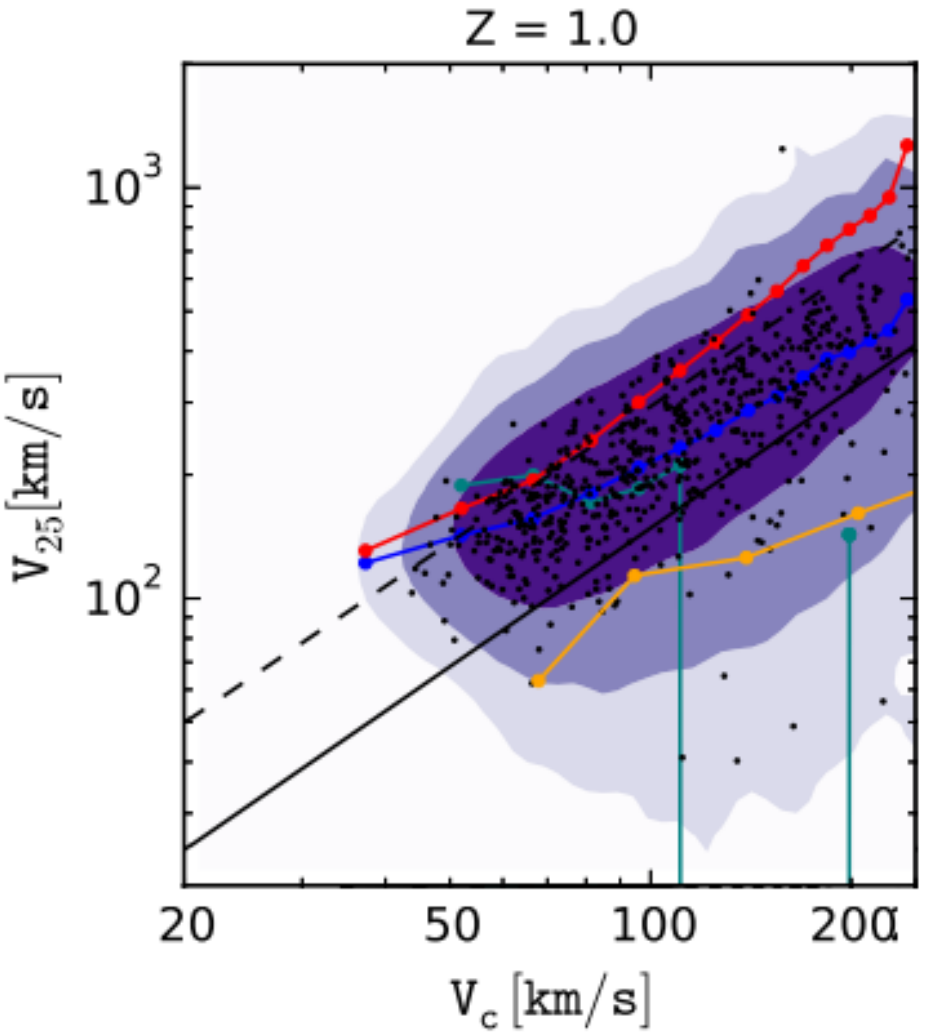
• *Wind launch*

- Eject wind particles stochastically. The outflow rate and wind speed are tuned to high-resolution simulations.

• *Wind propagation*

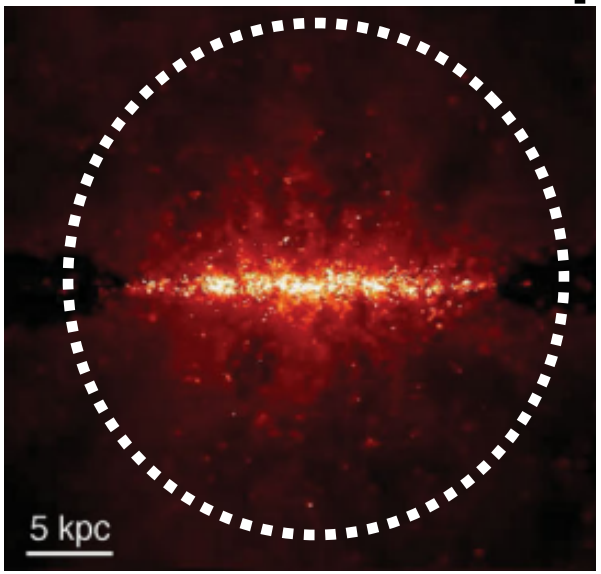
- Leave it to hydrodynamics

Calibrating Wind Speed

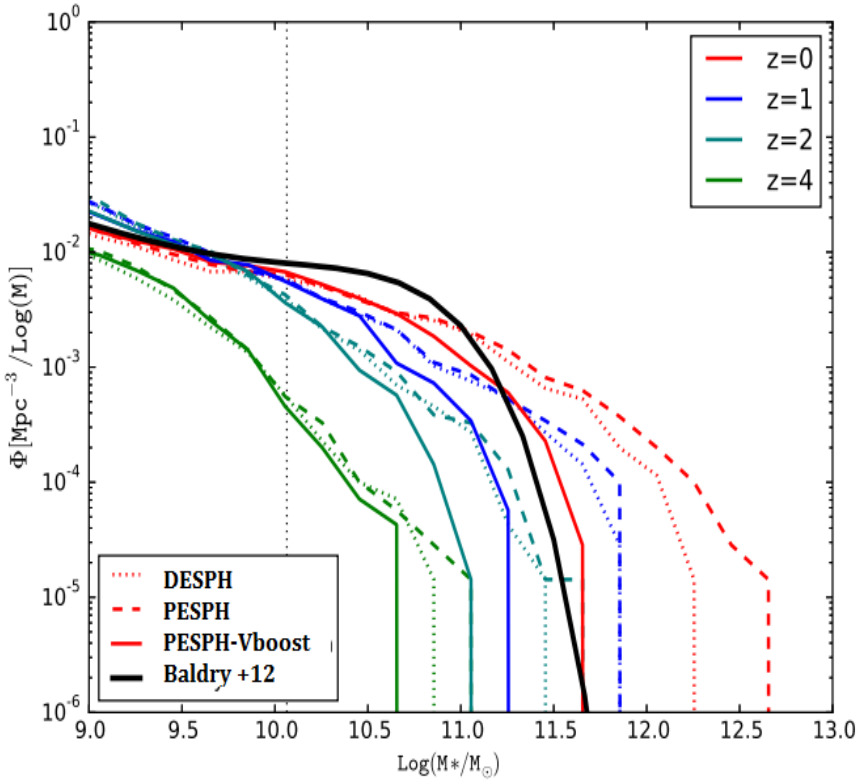


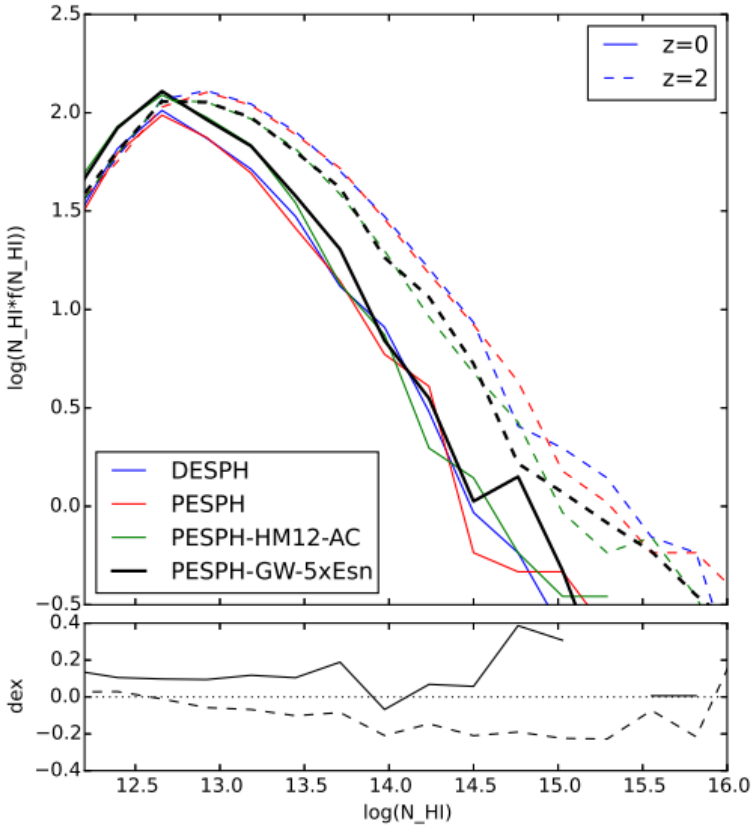
A boost in wind speed:

- Normalize to have V25 (wind speed at 0.25 Rvir) to scale with Vc like in Muratov +15 (FIRE)
- Previously, winds do not even make it out to 0.25 Rvir



Numerics V.S. Feedback





Many predictions are <u>very sensitive to</u> details of wind implementation

Numerical techniques have much less impact in most results

Cloud - CGM Interactions

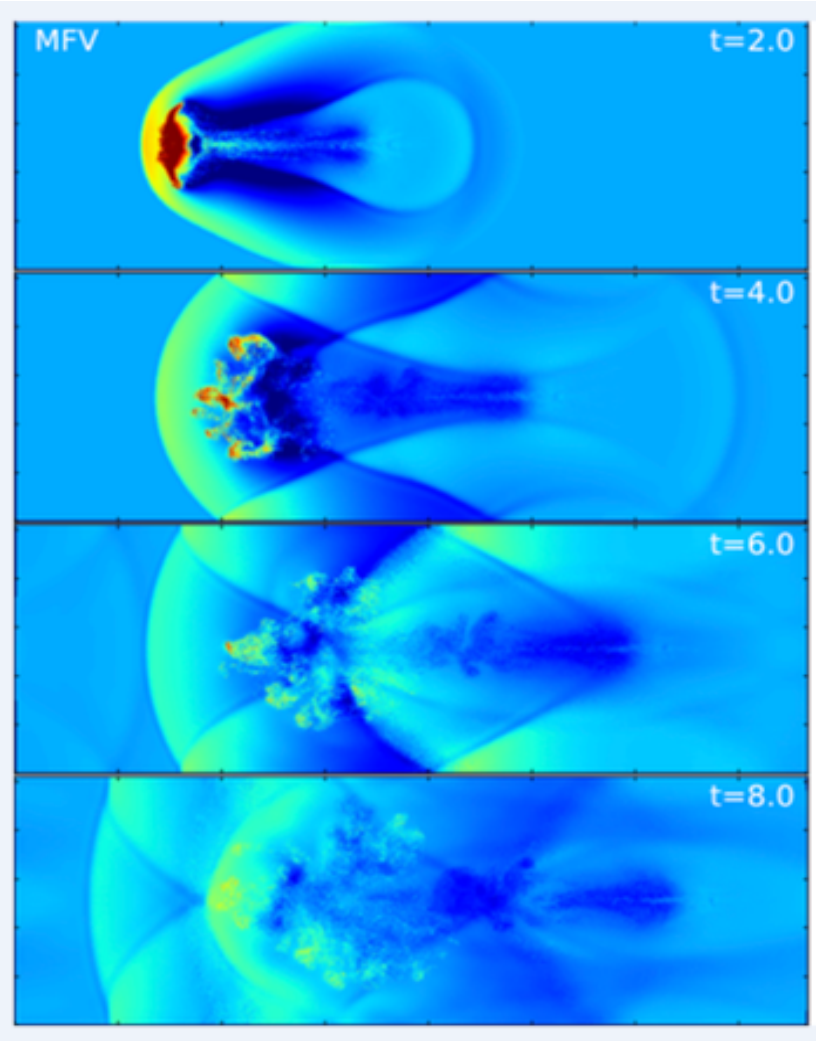
• Winds as individual particles do not represent hydrodynamics properly.

- In simulations, clouds are often destroyed quickly due to hydro instabilities

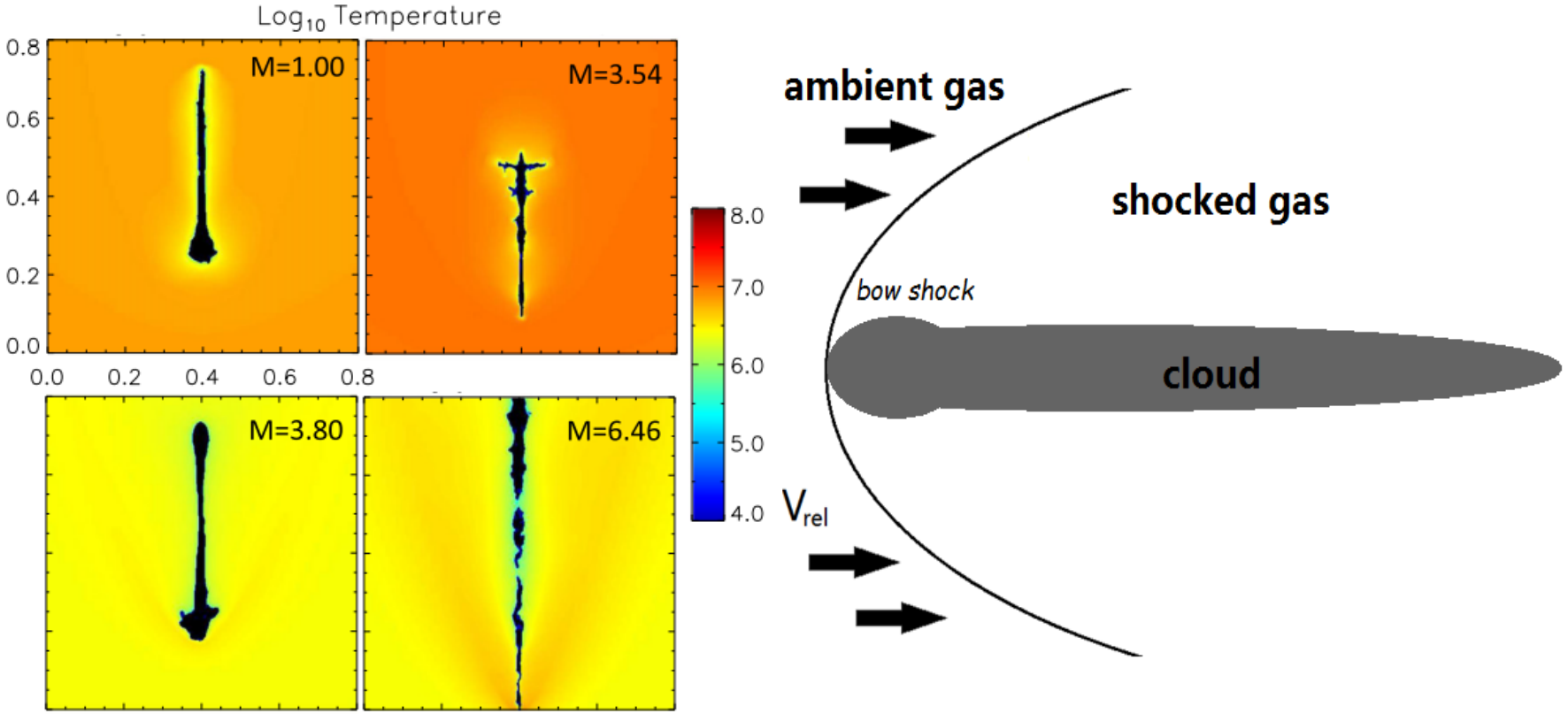
- Simulated clouds decelerate much slower. (Bruggen & Scannapieco +16, Schneider +17)

• Ignore important physics, e.g., mixing, conduction, magnetic field.

• Results are highly sensitive to resolution.



Cloud – CGM Interactions



Left: Thermal conduction stabilizes the cloud against fluid instabilities, over a wide range of physical conditions. (Bruggen & Scannapieco 2016)

Right: Illustration of the analytic model

The PhEW: Pheonomenologically Evolved Wind

PhEW particle:

- N identical, cylindrical cloudlets

- Particle evolution is represented by the collective motion of the cloudlets which is solved analytically

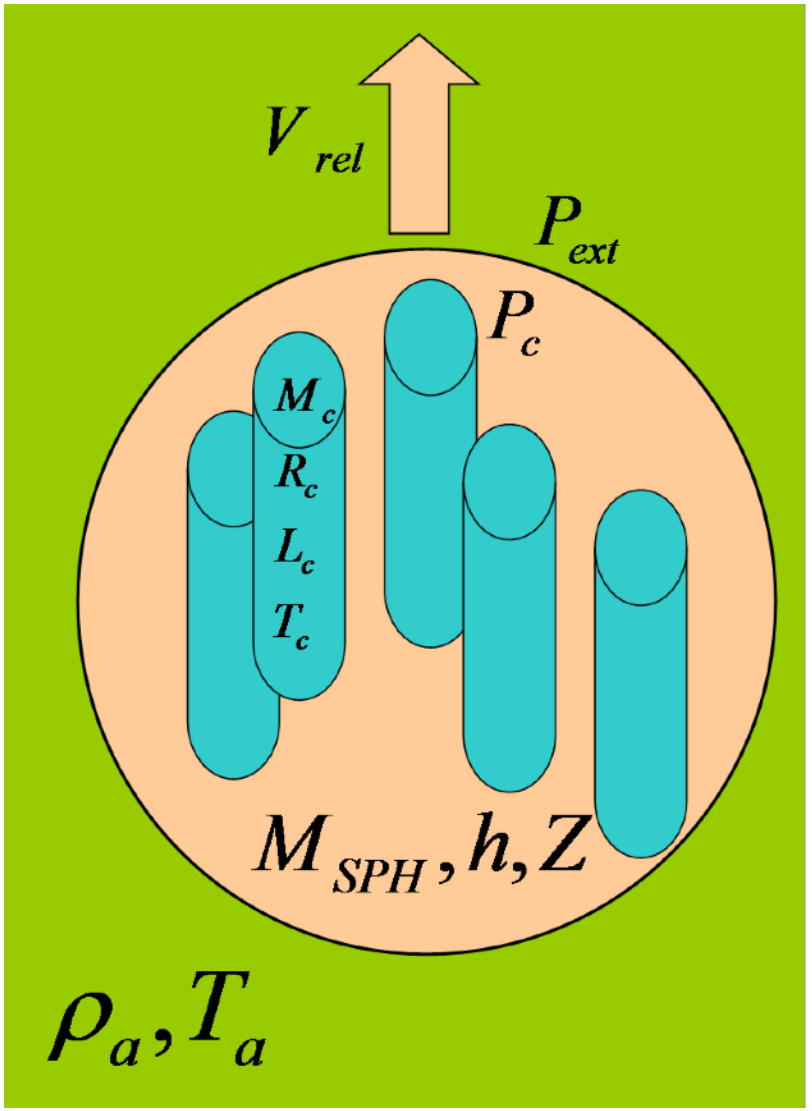
Advantages:

- Correctly represent physical assumptions

- Nearly independent of resolution and hydro technique

- Allows exchanges of mass and metals between wind and CGM

- Helps interpret CGM observations



SUMMARY

We introduce PhEW, an explicit, resolution-independent method of propagating galactic winds in cosmological simulations.

- Galaxy formation simulations are very sensitive to wind implementations
- Hydro techniques are much less important
- Common methods for wind propagation are unrealistic and potentially risky