Star Formation Simulations

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Approaching Exascale Meeting, LBL
March 21, 2014

The Big Problems in Star Formation (Simulations)

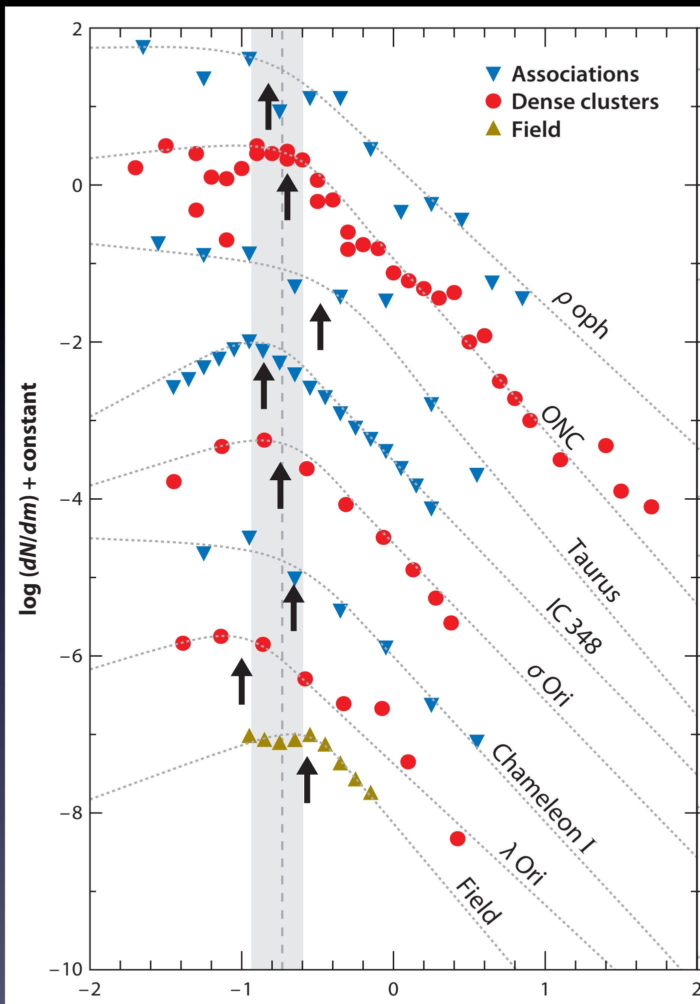
- What determines the stellar initial mass function, and does it vary?
- What controls the star formation rate within a galaxy?

Physical Ingredients

- MHD + gravity (all scales)
- Non-ideal MHD ($n >\sim 10^6$ cm^{-3})
- Radiative cooling by lines ($n <\sim 10^4$ cm^{-3})
- Radiative heating / cooling / pressure from dust-starlight interaction ($n >\sim 10^4$ cm^{-3})
- Feedback: ionization, jets, winds, Sne
- Chemistry (H_2, CO formation; $n <\sim 10^3$ cm^{-3})
- Dynamic range: $r_{GMC} / r_{\odot} \sim 10^9$, $t_{GMC} / t_{\odot} \sim 10^9$

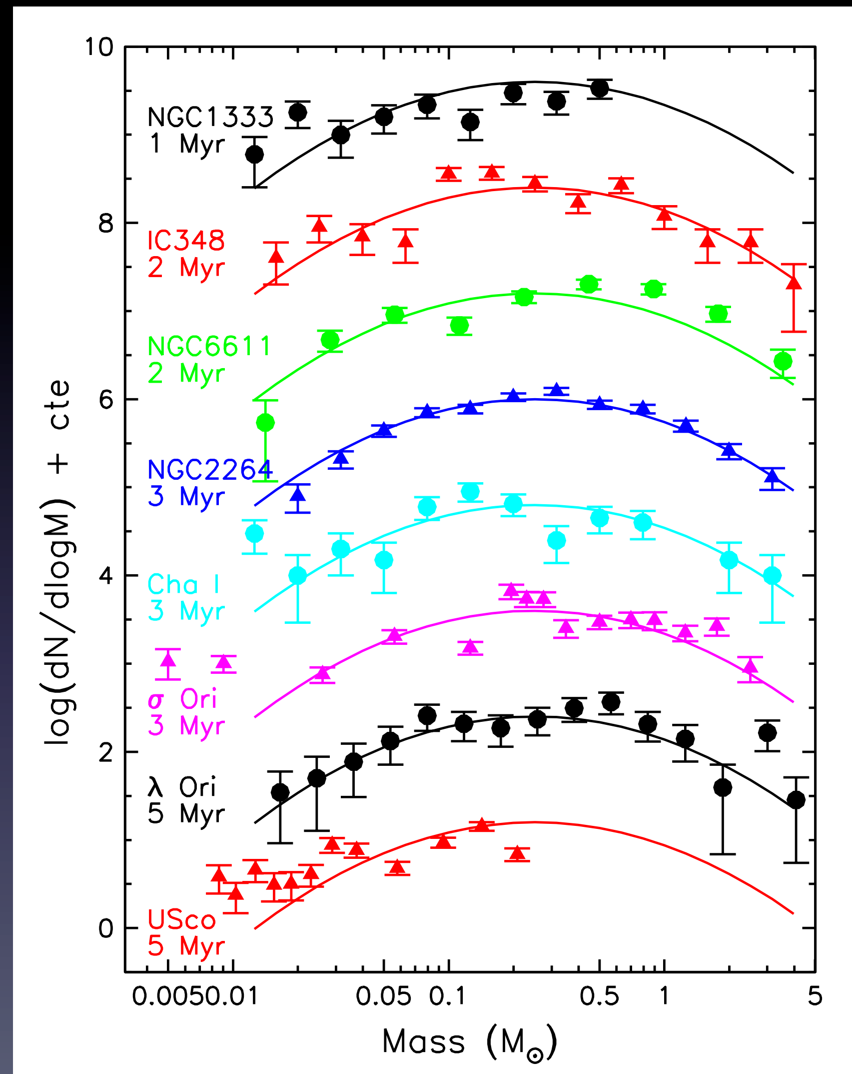
NO code includes all physics **OR** full dynamic range

The IMF: Observations



log M [$M_\odot$]

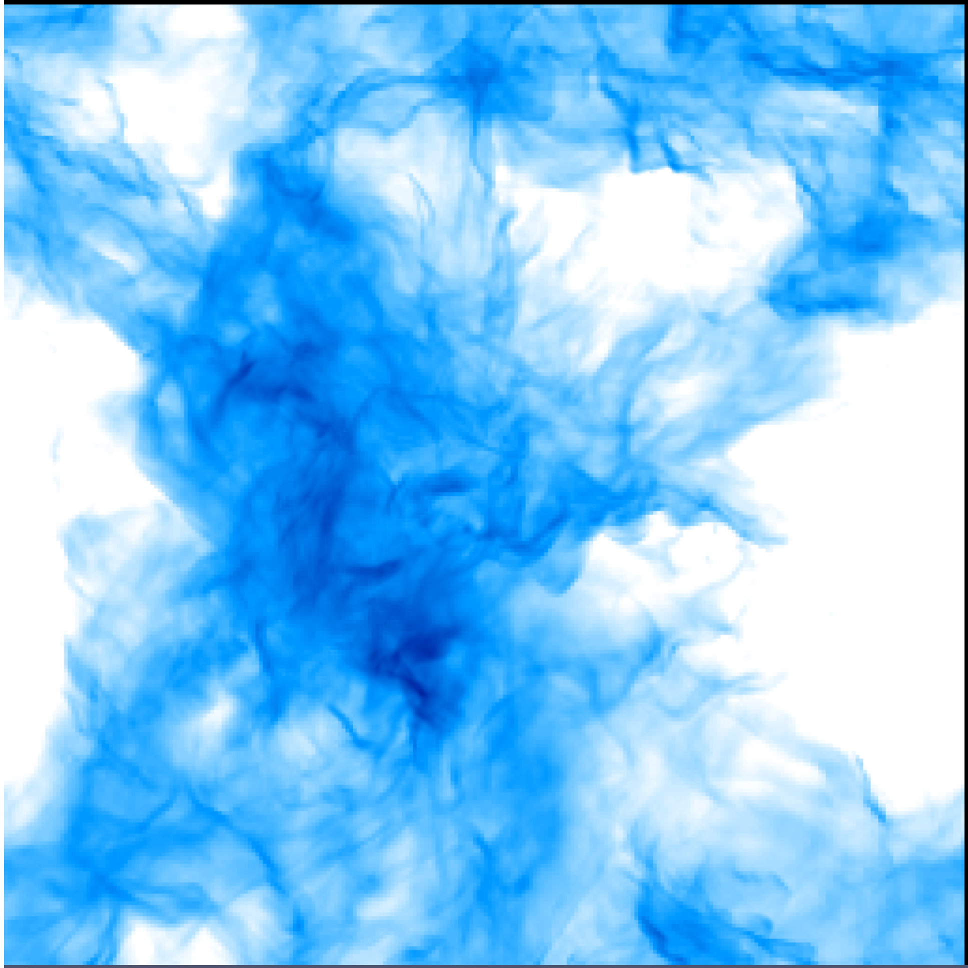
Bastian+ (2010)



Offner+ (2014)

IMF Origin Simulations I

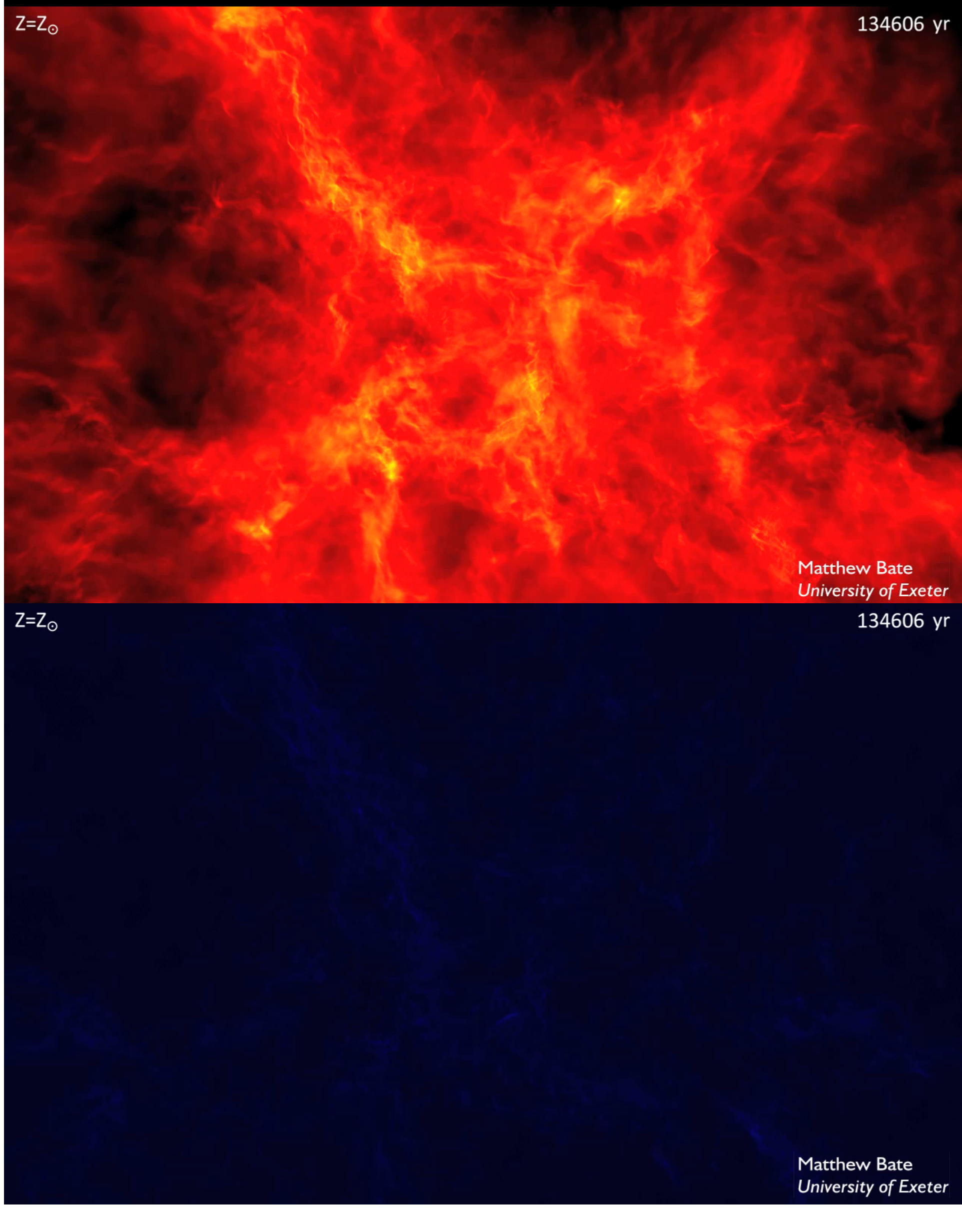
(Krumholz+ 2012)



1000 $M_{\odot}$ cloud, Σ ~ 1 g cm^{-2}, ~10 AU resolution, HD + gravity + dust RT + stellar radiation + jets, AMR - ORION

IMF Origin Simulations II

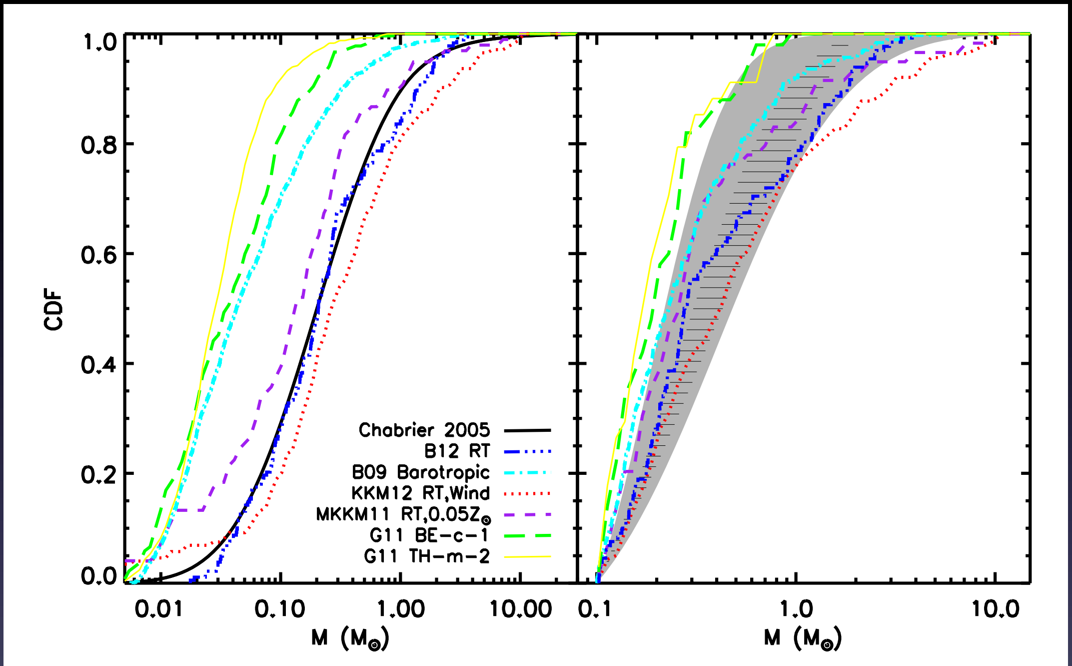
(Bate 2012)



- 500 $M_{\odot}$ cloud
- $\Sigma \sim 0.2$ g cm^{-2}
- ~0.5 AU resolution
- HD + gravity + dust radiative transfer
- SPH - Dragon

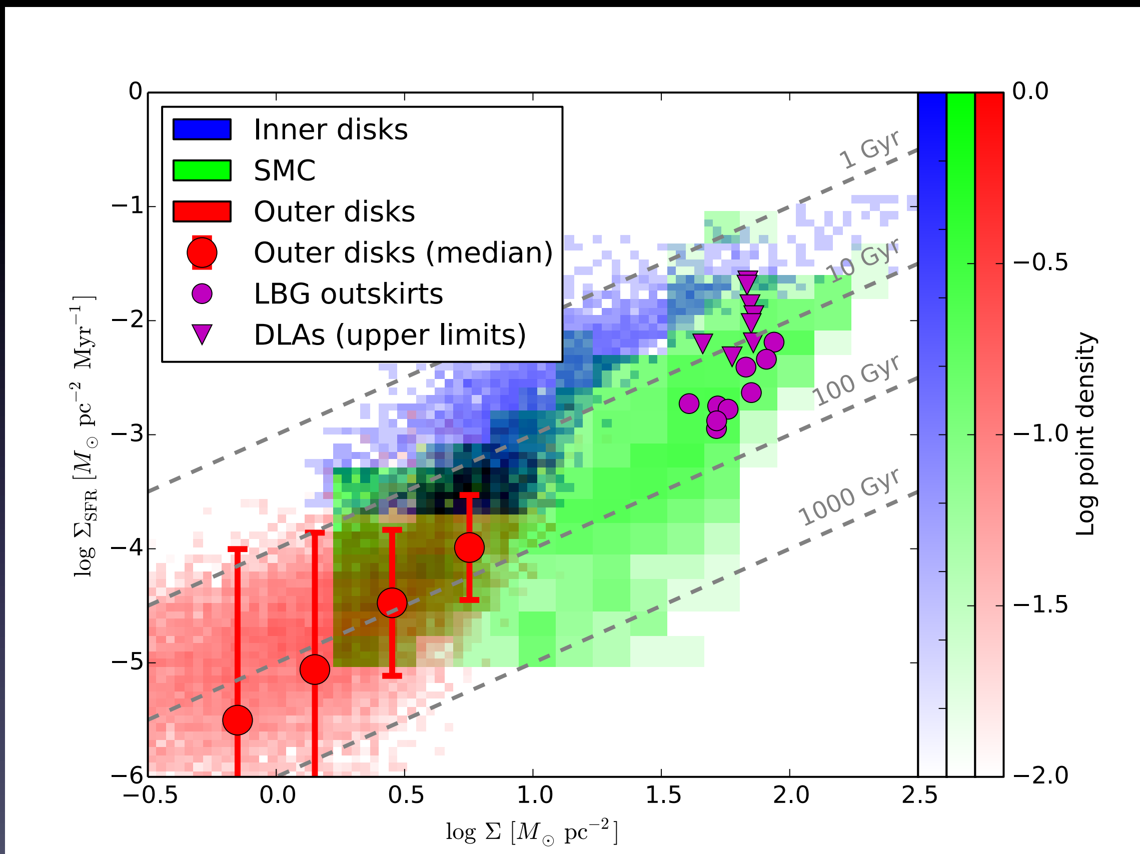
IMF Simulations: Results

- Need RT to get anything like right answer
- All else (e.g., metallicity, B fields, jets) matters at <~ factor of 2 level
- Dependence on environment still unknown



Comparison of IMFs from different simulations; black / gray = observed IMFs, red / blue / purple = simulations with RT, other colors = simulations without RT (from Offner+ 2014)

The SFR: Observations I



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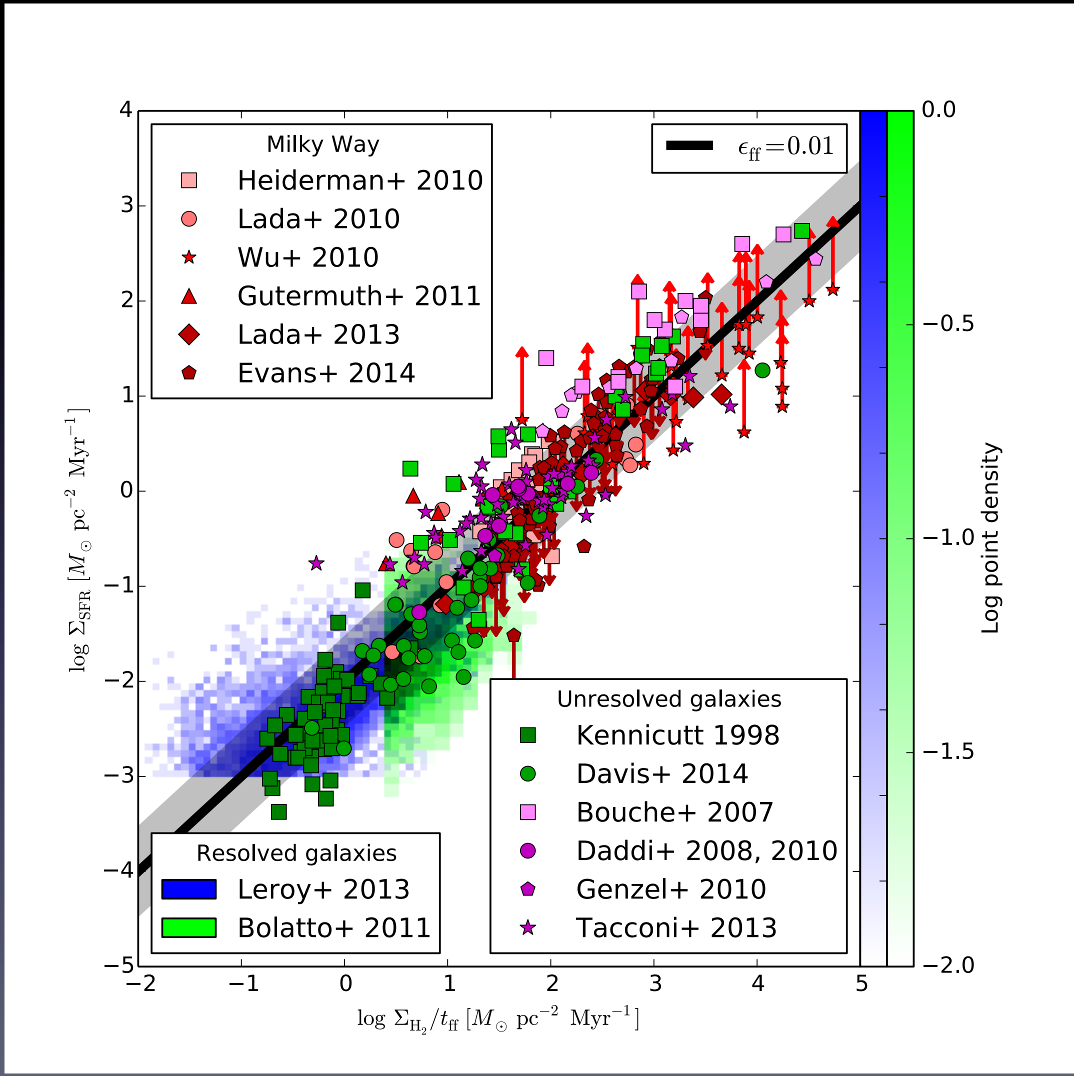
- SFR / area α Σ at high Σ, falls sharply at low Σ
- Linear regime is where gas is mostly H_2
- Transition Σ seems to depend on metallicity

The SFR: Observations II



- Molecular gas turns itself into stars at a rate $\epsilon_{ff} \sim 1\%$ of the mass per cloud free-fall time
- ϵ_{ff} seems universal across scales, environments

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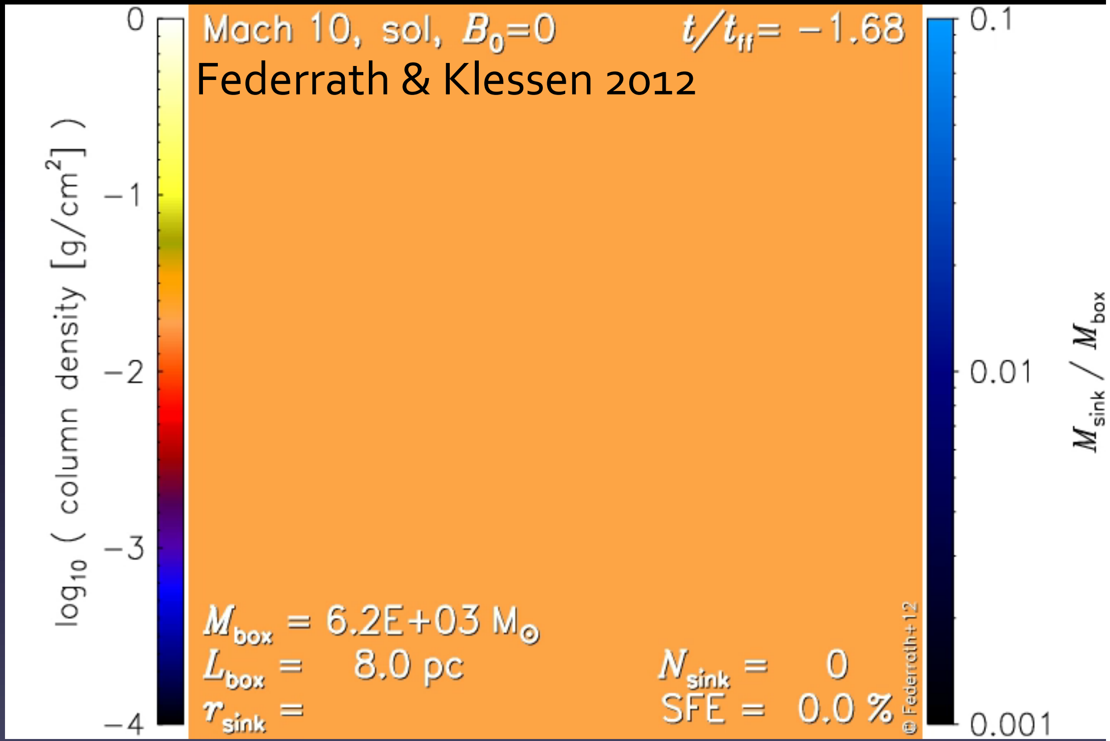
SFR Simulations: Turbulence

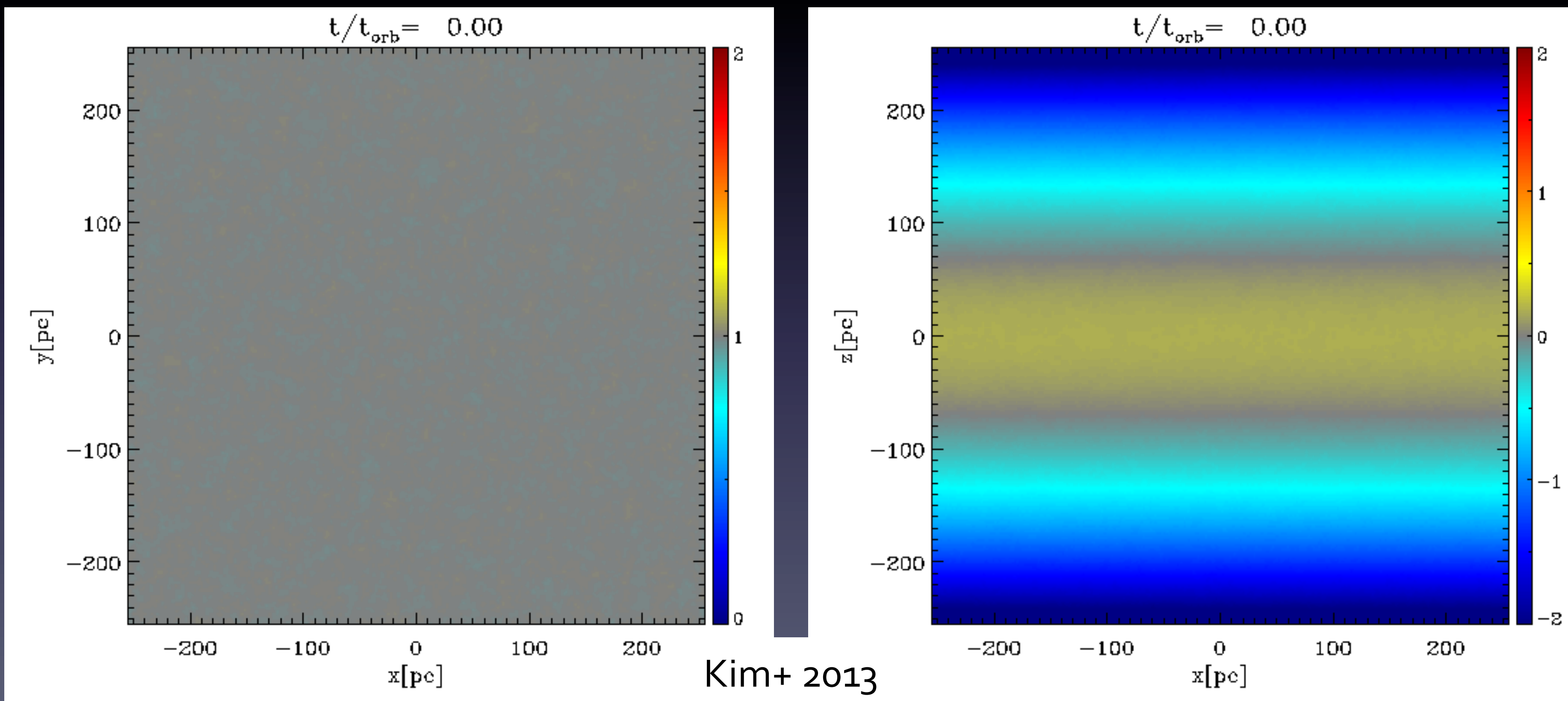
- Turbulence supports against collapse on large-scales, allows it on small scales
- Many models for $\epsilon_{ff}(\alpha_G, \mathcal{M}, \beta)$; all give $\epsilon_{ff} \sim 0.01 - 0.1$ for GMCs



MHD + gravity + sinks; no feedback; FLASH

- Turbulence must be maintained by external driving and/or feedback

SFR Simulations: Feedback on Galaxy Scales



Kim+ 2013

MHD + gravity + feedback shearing box; Athena

SFR Simulations: Status

- Still uncertain whether SFR is mostly set at local or galactic scales
  - Local: turbulence + local feedback may work, but need to show that turbulence can be maintained
  - Galactic: works if you set the SF feedback recipe right, but requires hand-tuning
- Metallicity- and phase-dependence still something of a mystery; probably related to role of dust in shielding against ISRF

Future Challenges

- Exascale will be very hard due to dynamic range in TIME; computational cost dominated by small volumes with short time steps
- Multiphysics a big challenge on specialized hardware; tasks include (M)HD, ray-tracing, sparse matrix solve, dense matrix solve…
- Probably need more accurate treatment of radiation hydro than we currently have
- Need to calibrate SF feedback recipes with first-principles simulations on small scales