Shine bright like a quasar: Feedback from radiatively-driven AGN Winds

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Rebekka Bieri

Collaborators: Yohan Dubois, Joakim Rosdahl, Alexander Wagner
Joseph Silk, Gary Mamon

Max-Planck-Institut für Astrophysik

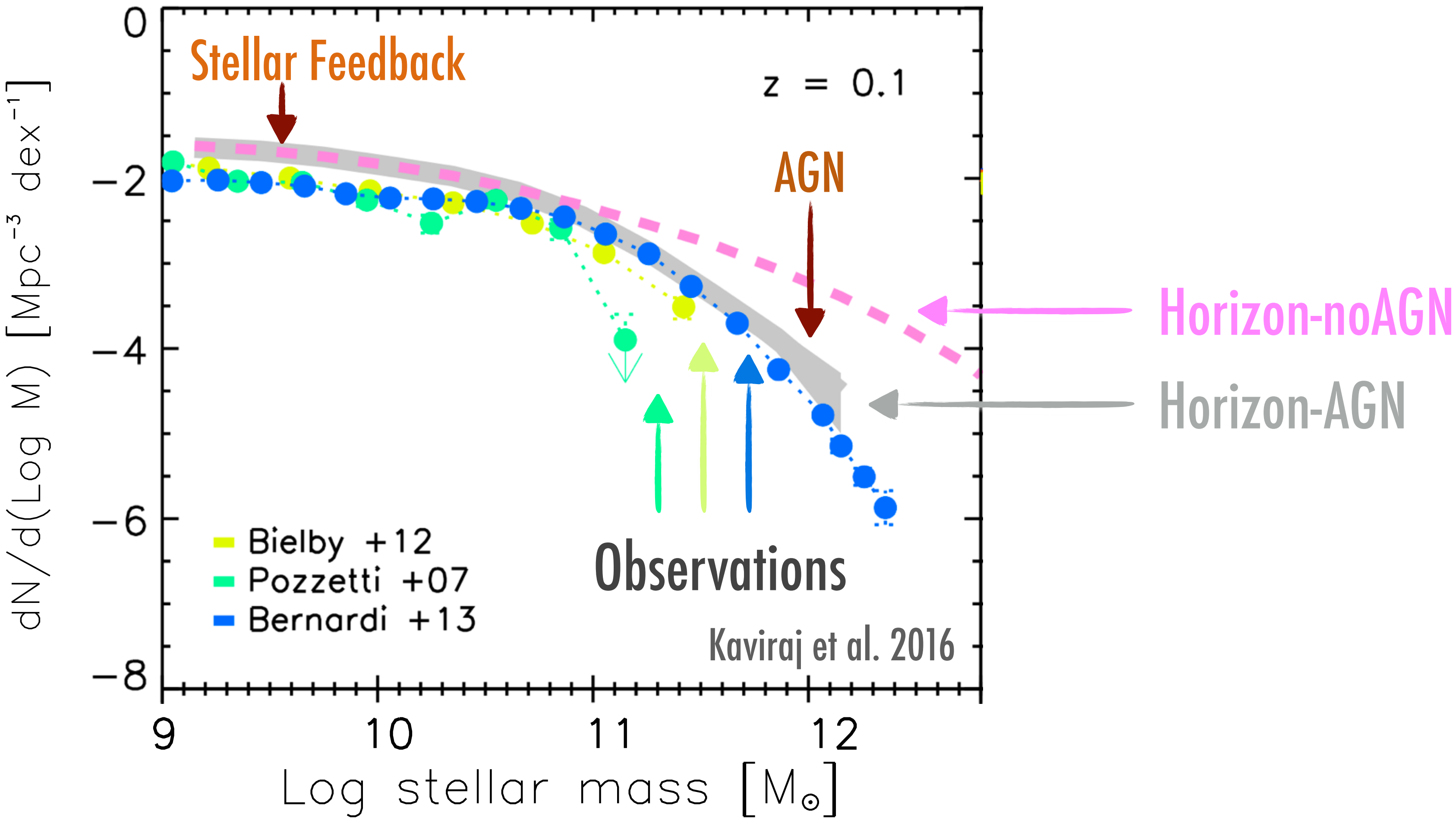
Institut Lagrange de Paris

IAP

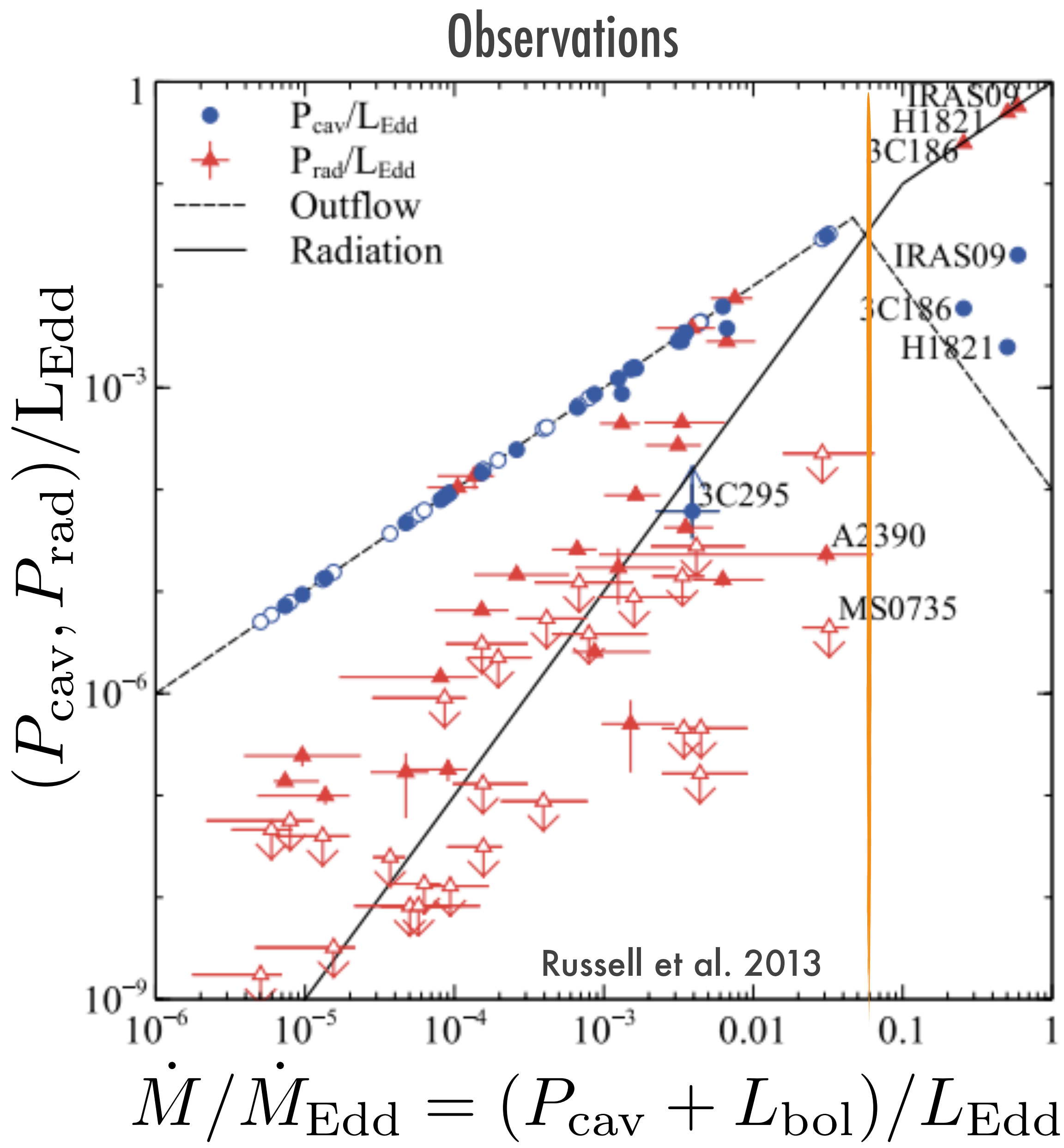
UPMC Sorbonne Universités

University of Oxford

Feedback from AGN



Two Main Modes of AGN feedback

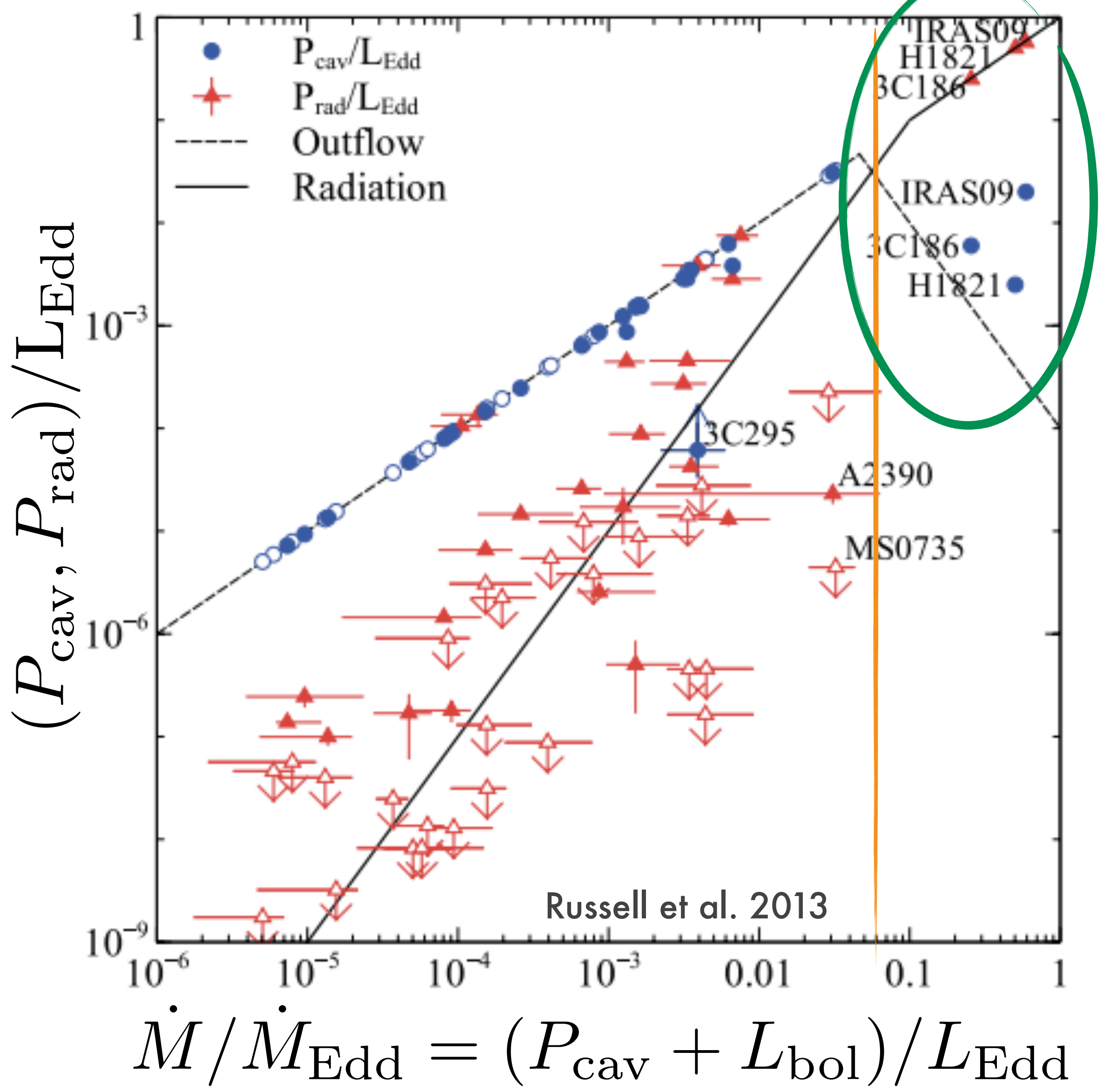


$$L_{\rm Edd} = \frac{4\pi G M_{\rm BH} c}{\kappa}$$

$$\dot{M}_{\rm Edd} = \frac{L_{\rm Edd}}{\eta c^2} = \frac{4\pi G M_{\rm BH}}{\kappa \eta c}$$

Two Main Modes of AGN feedback

Observations



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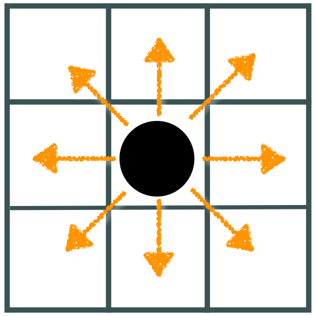
Quasar Feedback in Simulations

Heating of the surrounding gas

With thermal input



Modification of the internal energy

Increasing of the gas temperature by uniformly distributing the specific energy

Similar to: Di Matteo et al., 2005, 2008; Sijacki et al., 2007; Booth & Schaye, 2009; Teyssier et al., 2011

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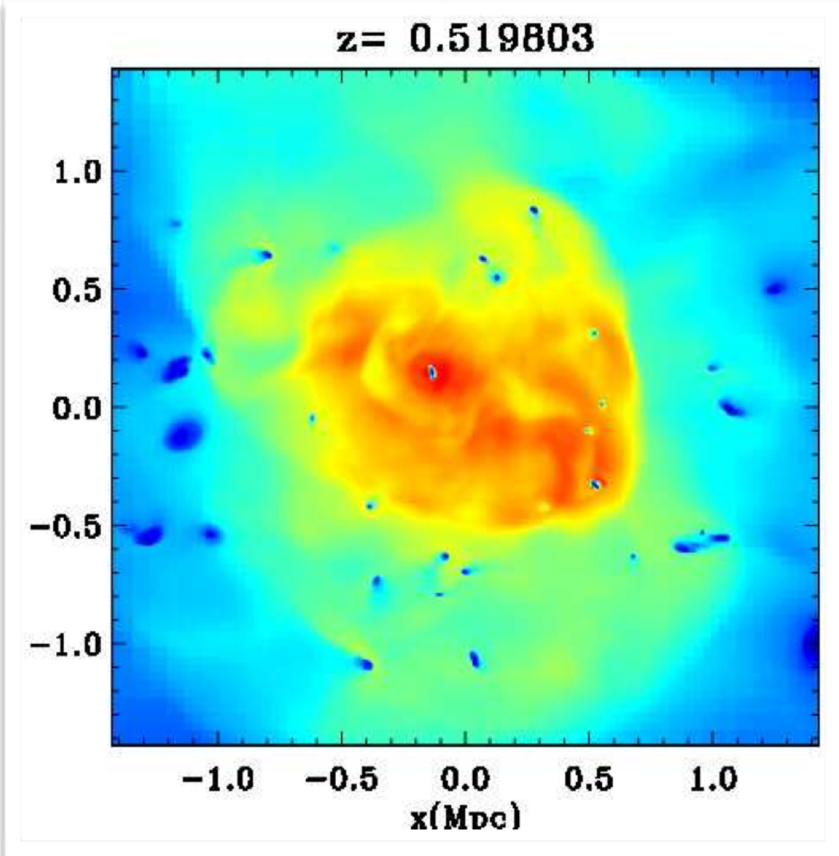

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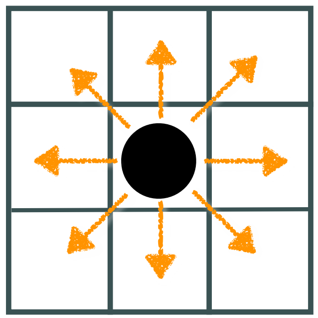

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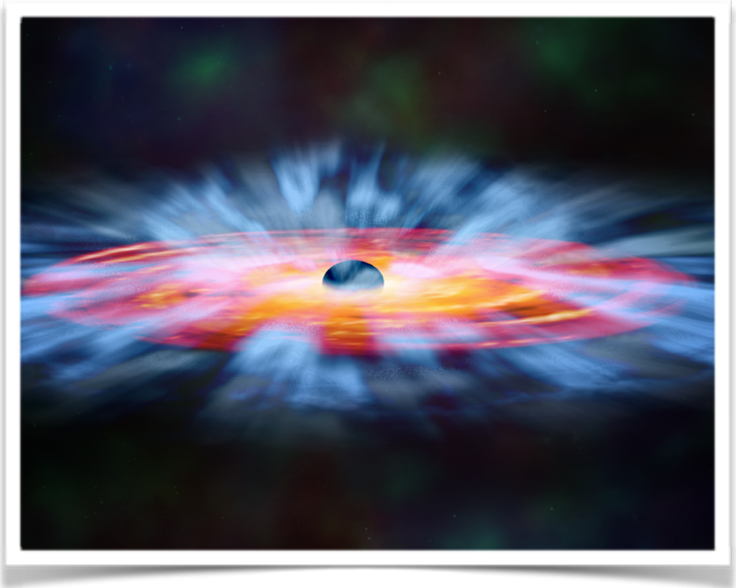
Modification of the internal energy

Increasing of the gas temperature by uniformly distributing the specific energy

Sub-grid models should rely on a number of assumptions regarding the coupling between the radiation and the gas:

- absorption of photons
- optical depth
- mean free paths
- self-shielding

Modelling a Quasar in a Multiphase ISM



- How efficiently do photons couple to gas?
- How does radiation couple gas and drive large-scale winds?
- Which photons are most relevant for driving a wind?

Bieri et al. 2016b; arXiv:1606.06281, accepted for publication in MNRAS

Radiation Hydrodynamics

- RAMSES-RT: Uses moment method to solve radiative transfer in RAMSES

(Rosdahl et al. 2013, Rosdahl & Teyssier 2015)

- Solves non-equilibrium evolution of ionisation fractions of HII, HeII, HeIII
- Radiation pressure + diffusion of multi-scattering IR radiation included
- Solar metallicities, assuming all metals are locked in dust
- Dust opacities $\kappa_{\mathrm{D,UV}} = 1000\,\mathrm{g\,cm^{-2}}$, $\kappa_{\mathrm{D,IR}} = 10\,\mathrm{g\,cm^{-2}}$, $\kappa_{\mathrm{D,\ IR,\ opt,\ UV}} = 0 \text{ if } T > 10^5\mathrm{K}$
- Reduced speed of light approximation $c_{\mathrm{red}} = 0.2\mathrm{c}$

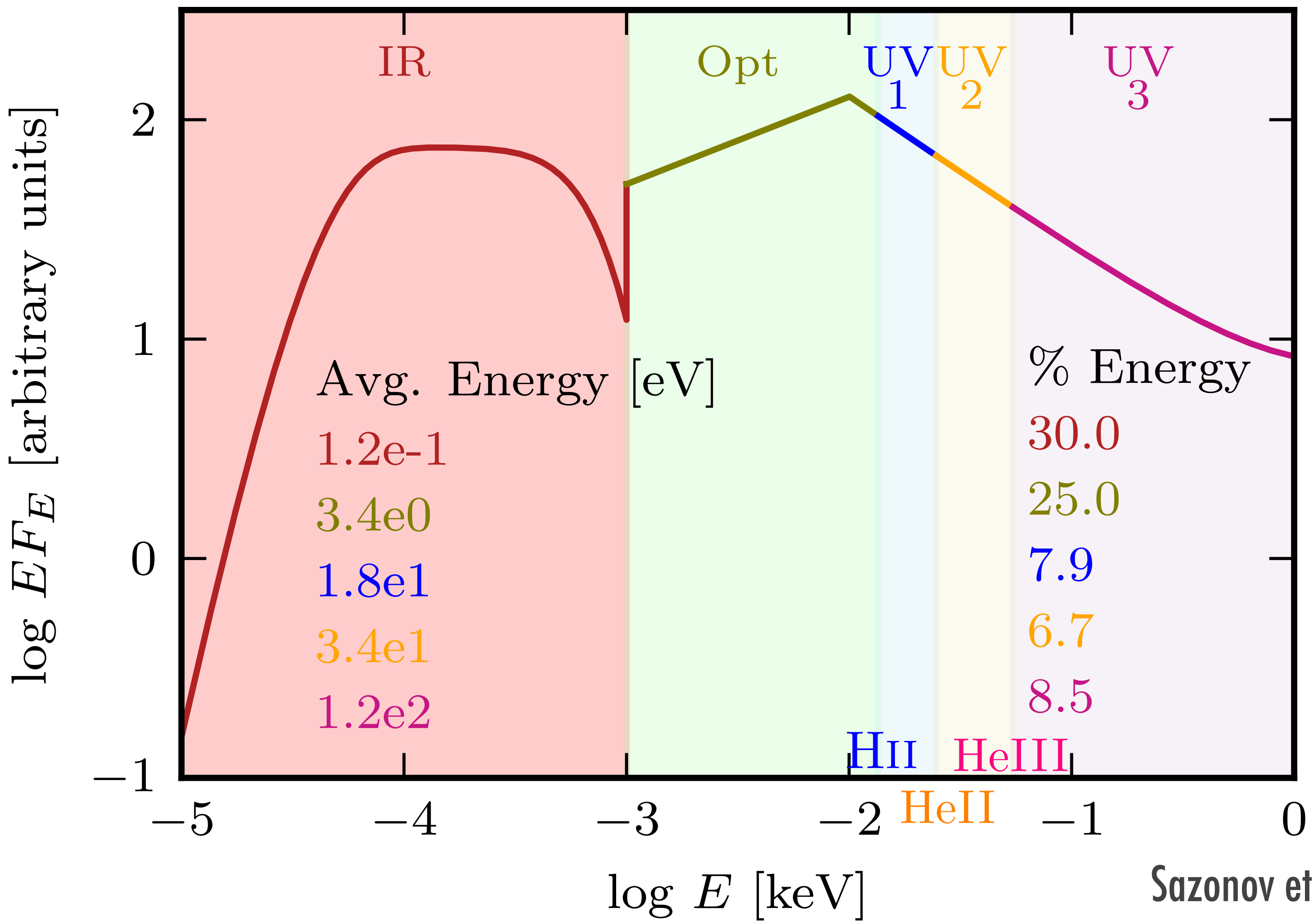
(Gnedin & Abel 2001)

- no gravity
- no cooling
- no time variability

Emission and propagation of photons and their interaction with the gas via the dust is self-consistently described

Quasar Spectral Energy Distribution

AGN luminosity: 10^{46} erg/s



Sazonov et al. 2004

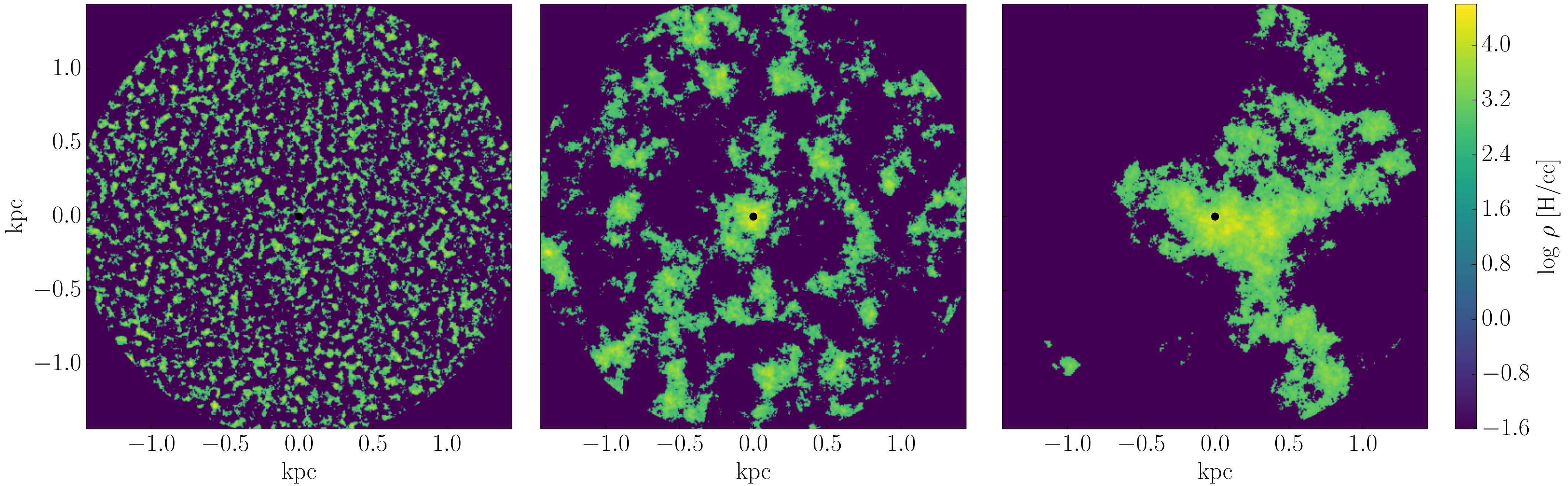
Setting Up a Disc

Galaxy radius: 1.5 kpc
Galaxy height: 0.2 kpc
Galaxy mass: 2.1 x 10^{10} M_{Sun}
5pc resolution in the galaxy

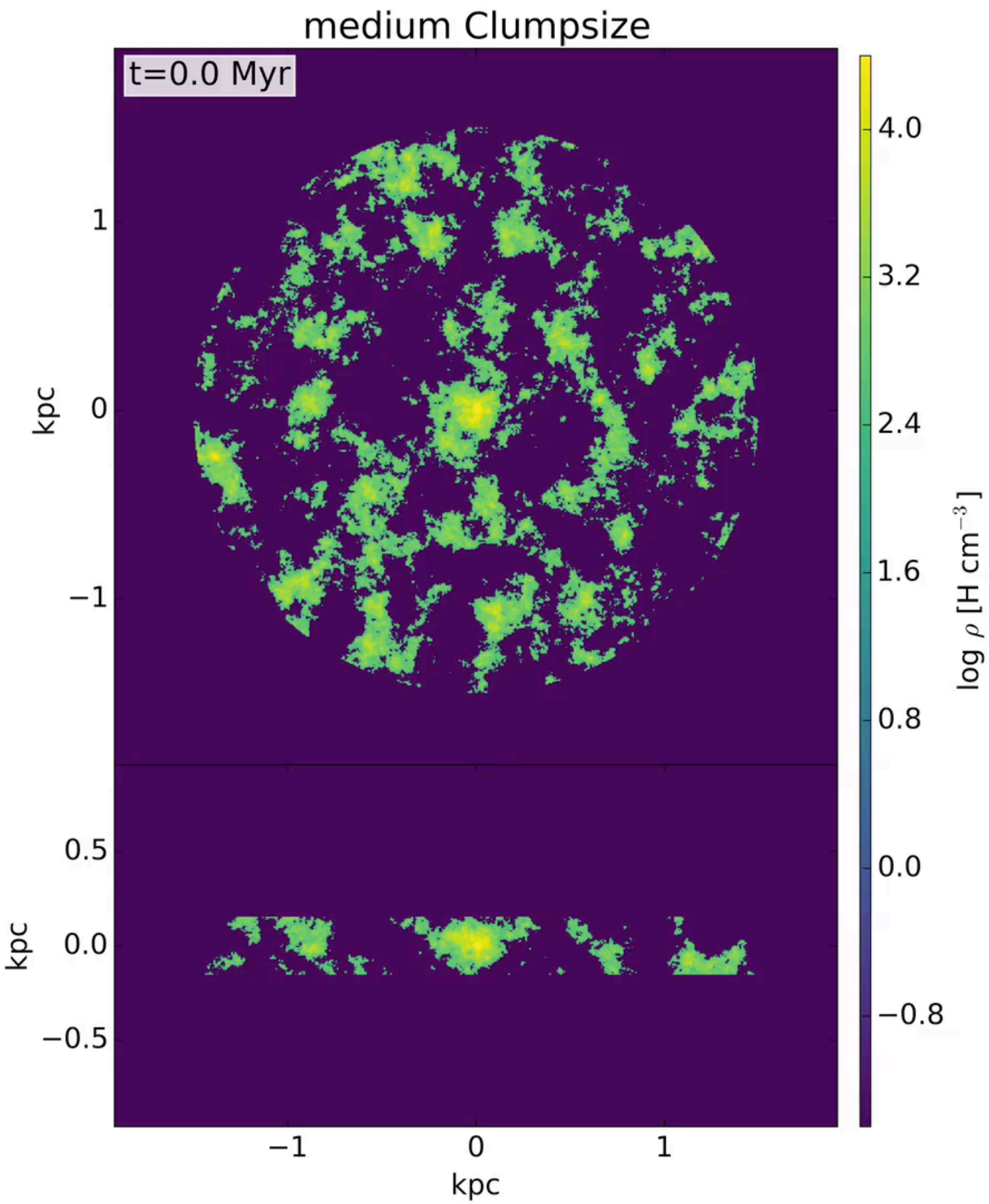
Log-normal pdf for gas density
Kolmogorov-like power spectrum (and different cloud size)
Initial conditions from Wagner & Bicknell (2011)

Realistic representation of a generic turbulent multi-phase interstellar medium (ISM) of a gas-rich high-redshift galaxy in terms of density structure and clumps size

smallC (L_{cloud} = 50pc) medC (L_{cloud} = 300pc) bigC (L_{cloud} = 1kpc)



Density Evolution Driven by Radiation



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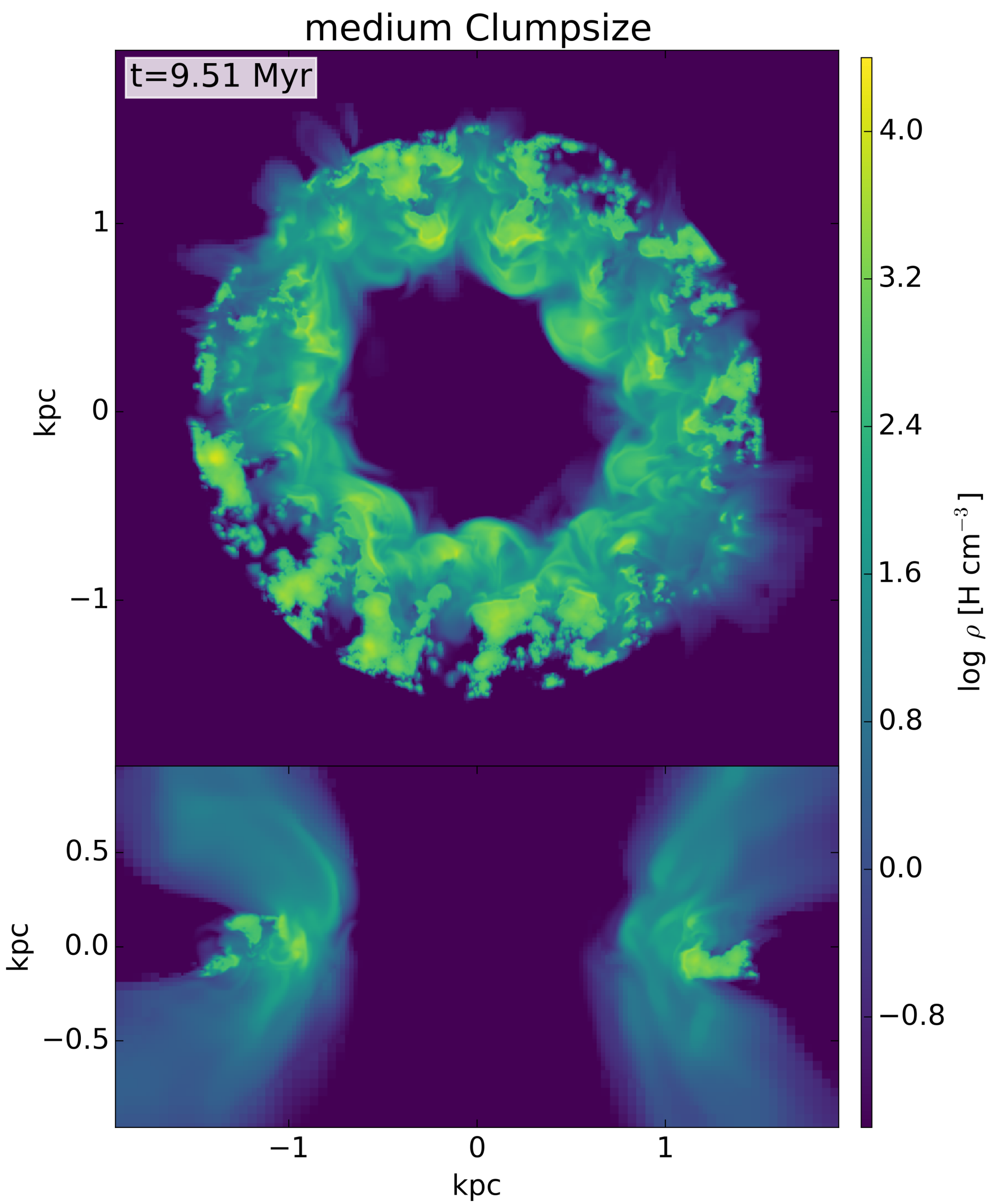
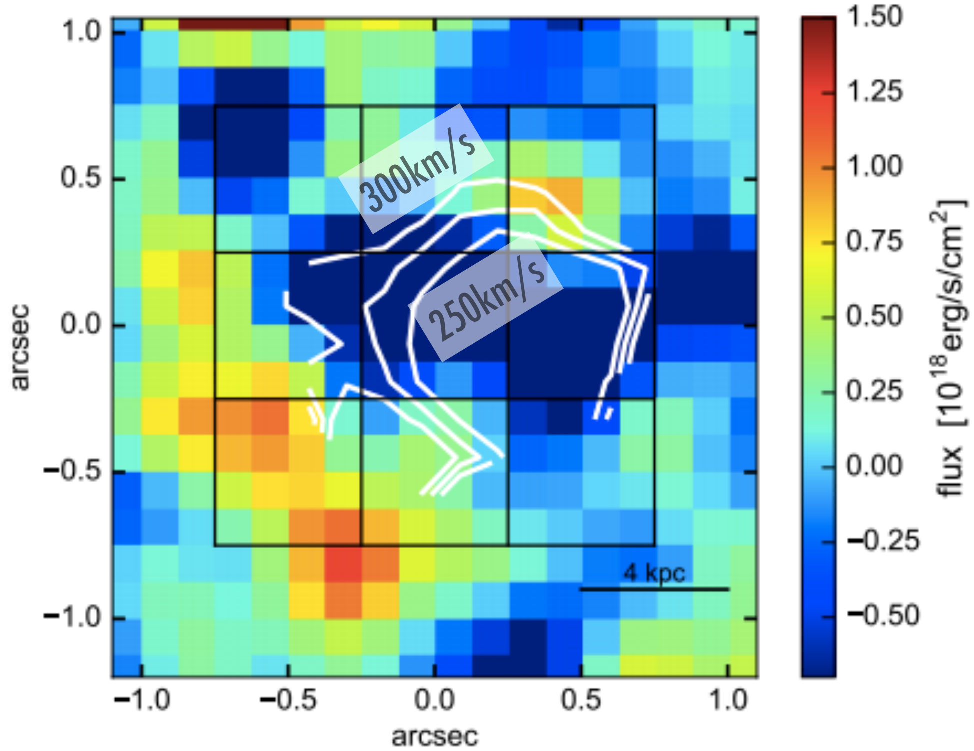
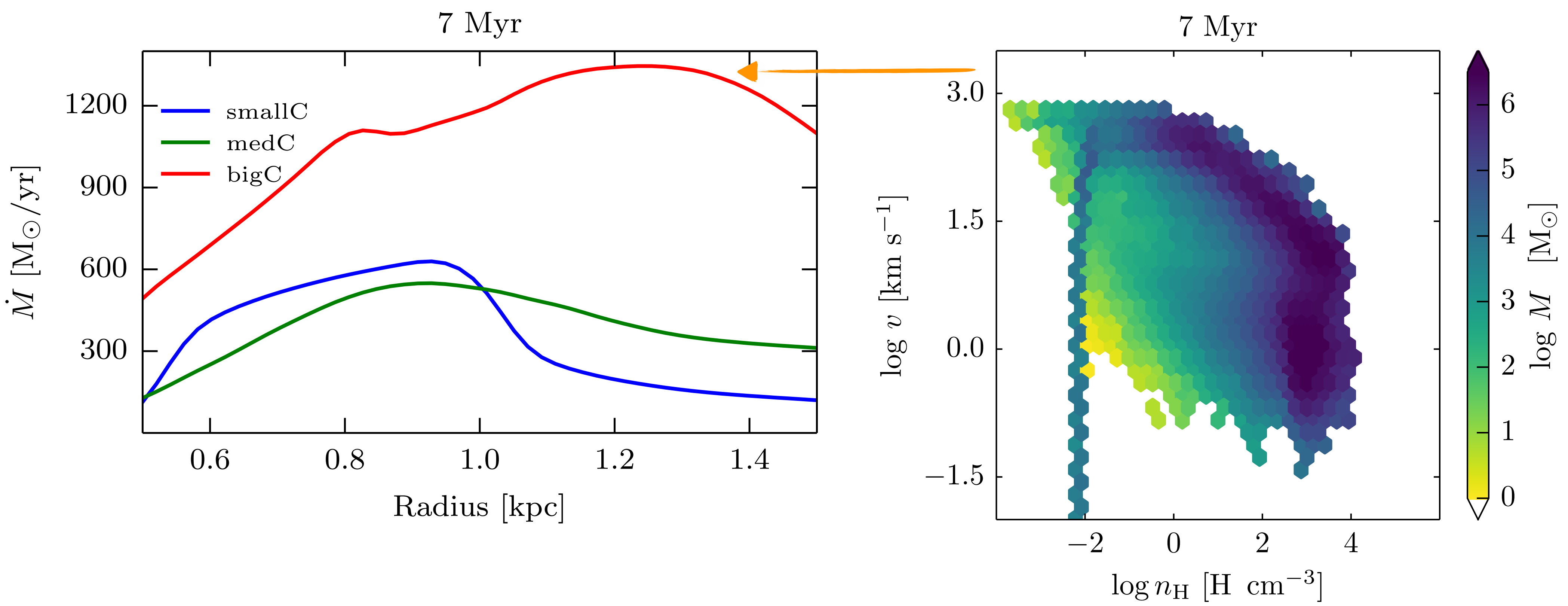




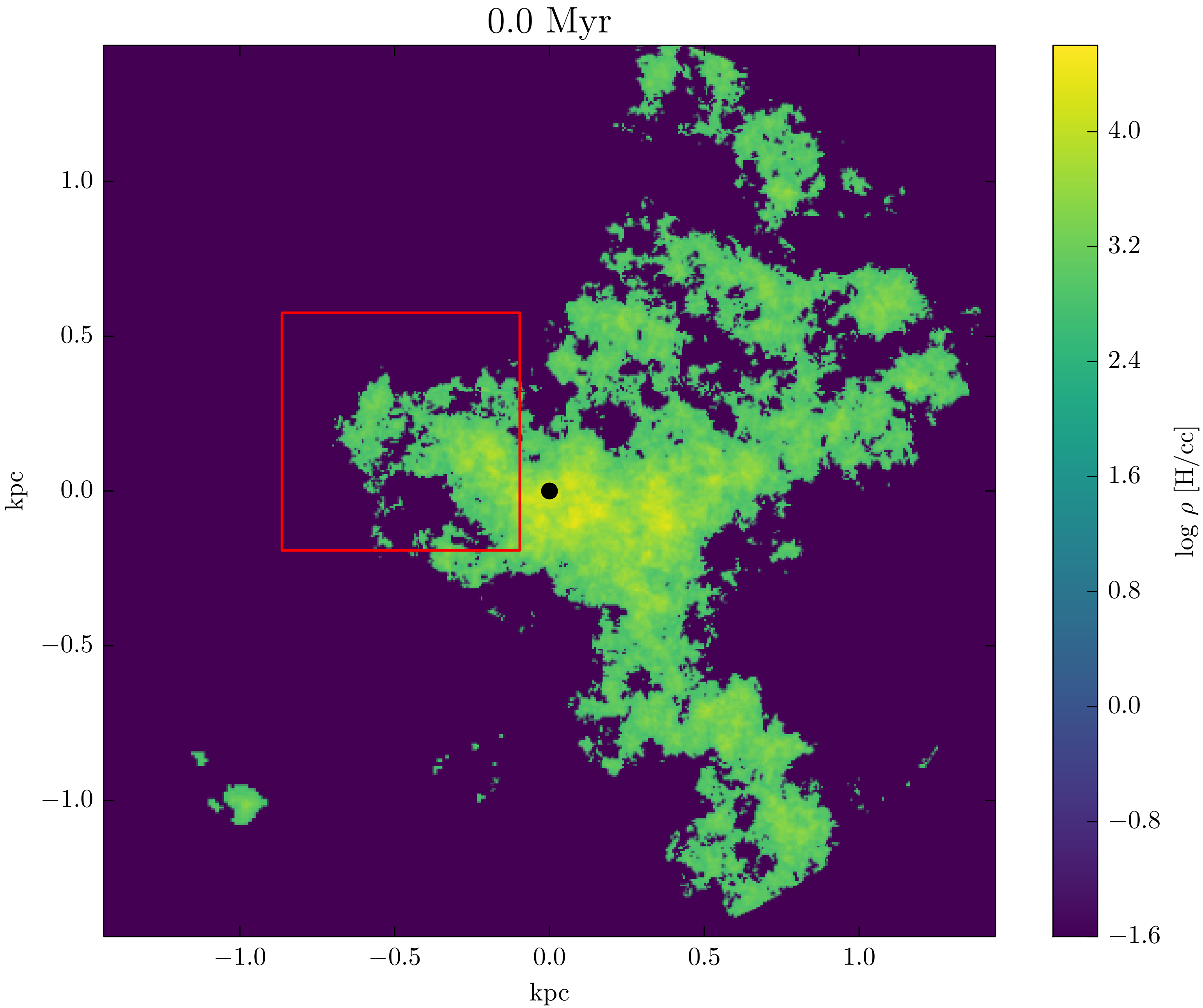
Carniani et al. 2016;
(SINFONI) Spectroscopic observation

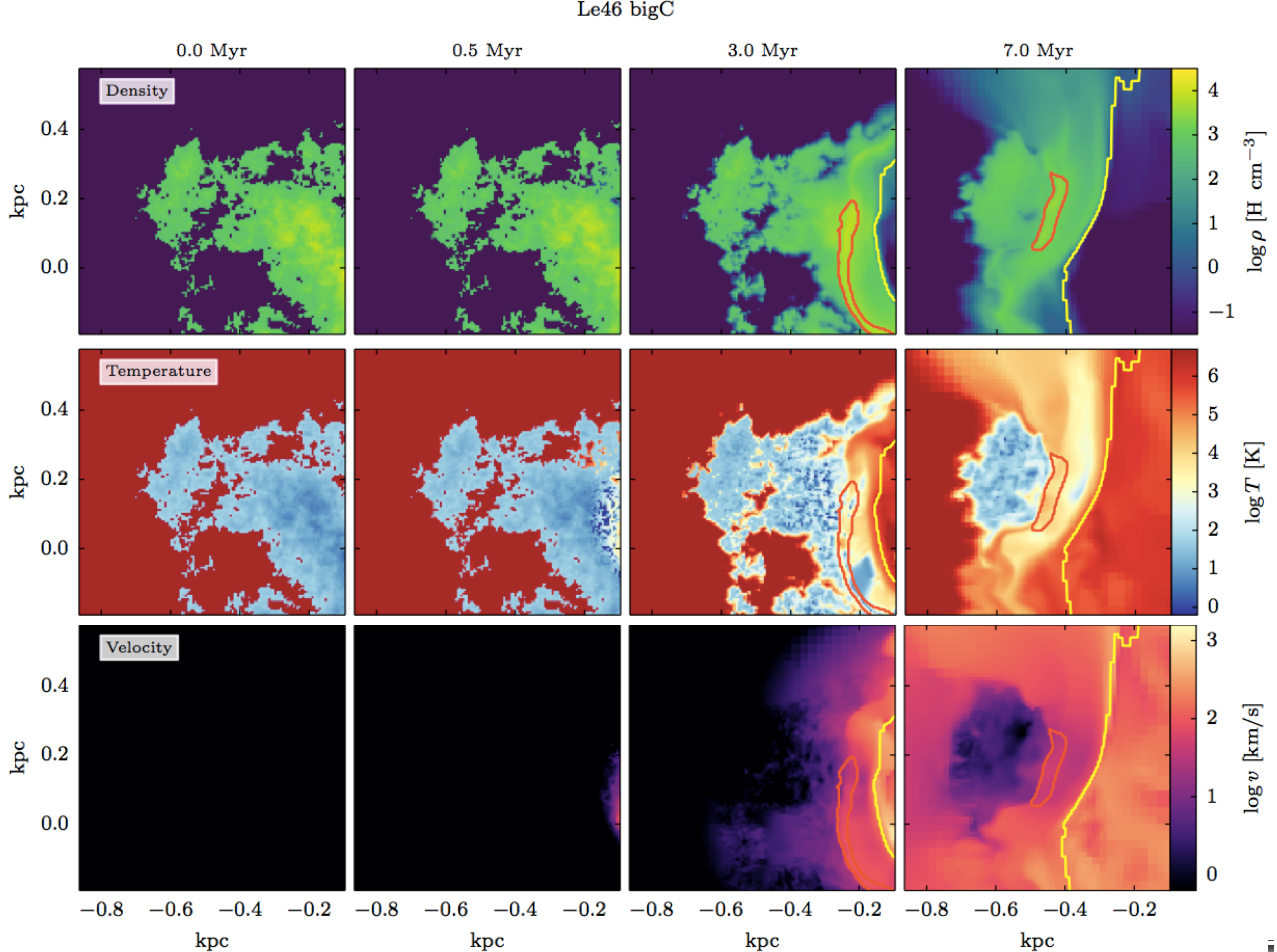
Large Velocities & Mass Outflow Rates



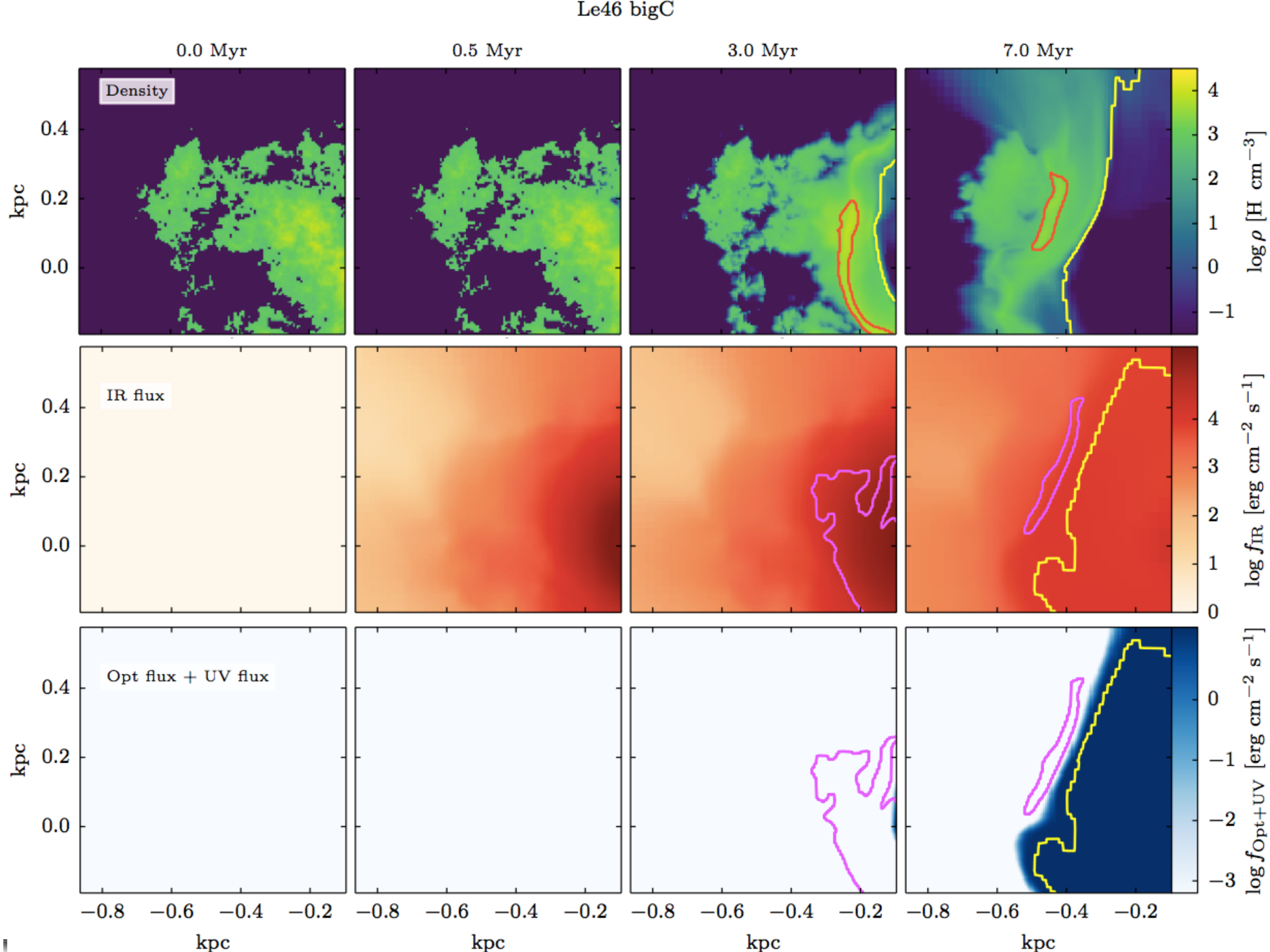
- Gas reaches velocities of up to 1000 km/s
- The highest velocity gas shows an anti-correlation with density.
- Mass outflow rates are up to 1000 M_{sun}/yr

How Does Radiation Drive a Wind?





Le46 bigC
0.0 Myr
0.5 Myr
3.0 Myr
7.0 Myr
Density
Temperature
Velocity
kpc
0.4
0.2
0.0
−0.8
−0.6
−0.4
−0.2
log ρ [H cm⁻³]
log T [K]
log v [km/s]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Density
IR flux
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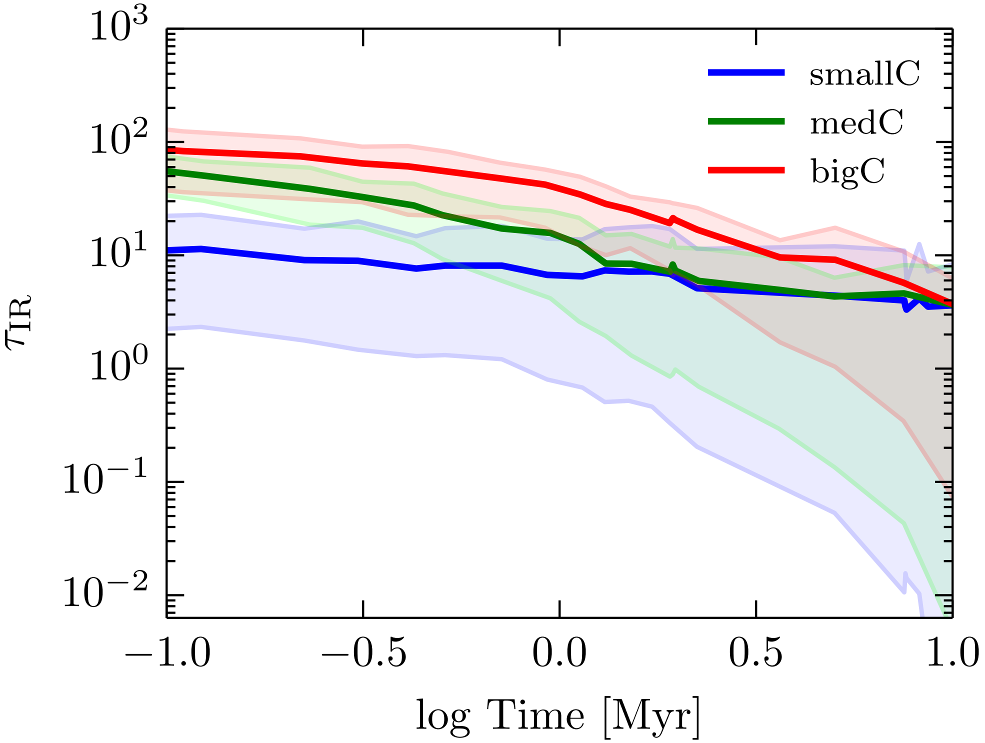
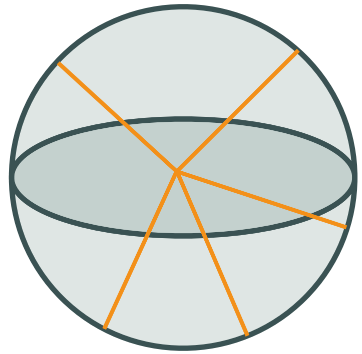
log ρ [H cm⁻³]
log f_IR [erg cm⁻² s⁻¹]
log f_Opt+UV [erg cm⁻² s⁻¹]

Optical Depth and Cloud Destruction

Optical depth



$$\tau_{\rm IR} = \int \rho \kappa_{\rm IR} \mathrm{d}l = \sum_{i \in \rm LOS} \rho_i \kappa_{\rm IR} \Delta l_i$$



500 uniformly distributed rays are cast to measure $\tau_{\rm IR}$

- Optical depths are between 10 and 100 depending on cloud size

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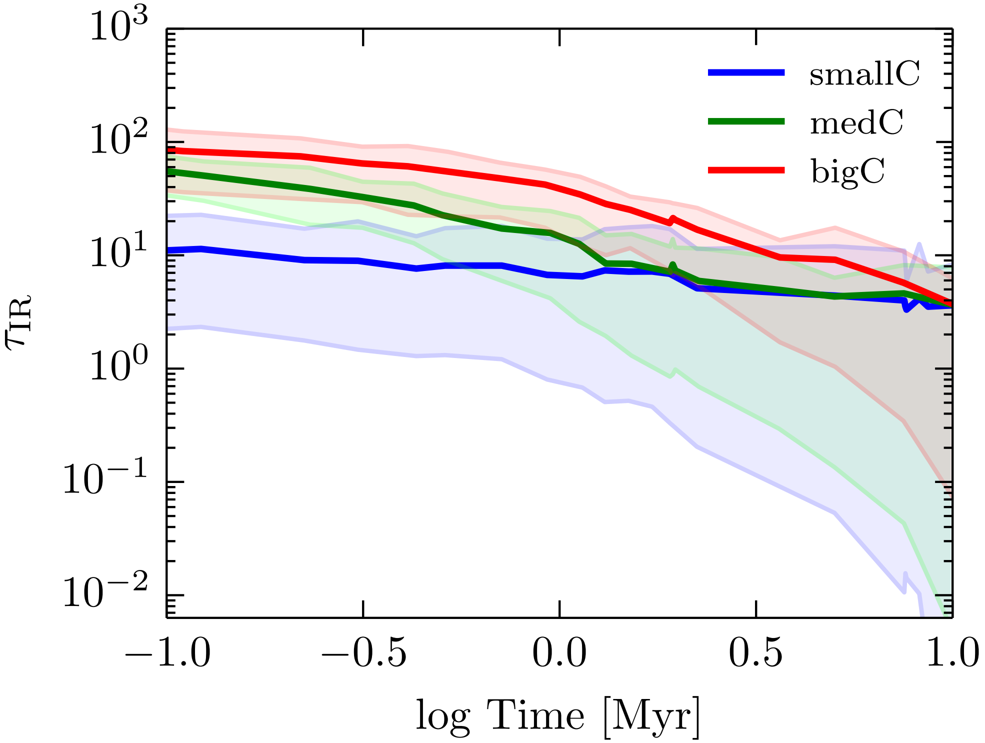
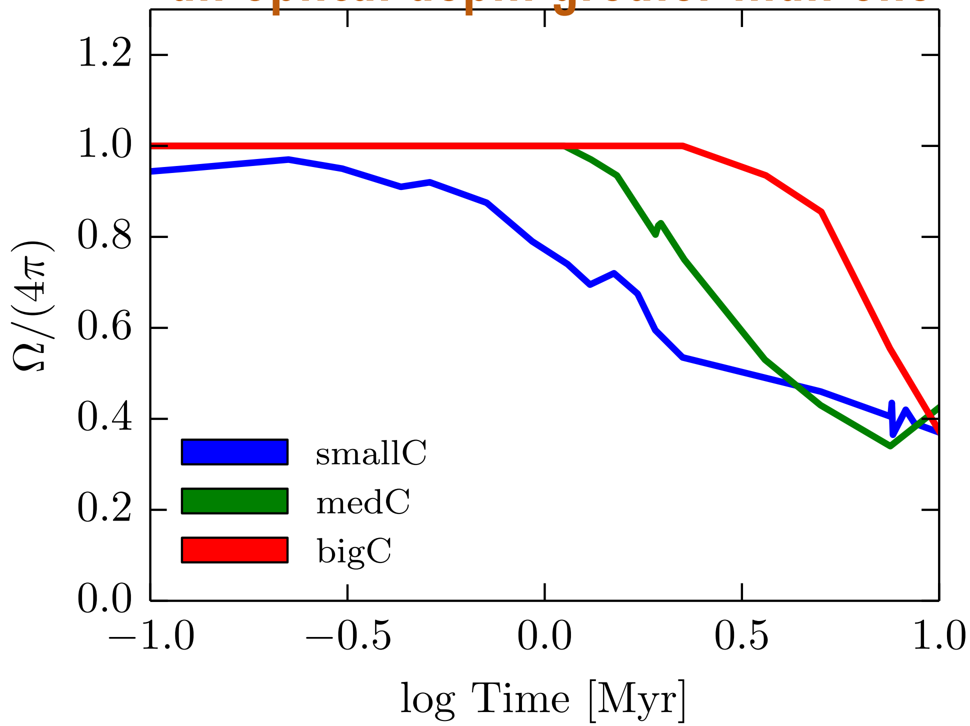
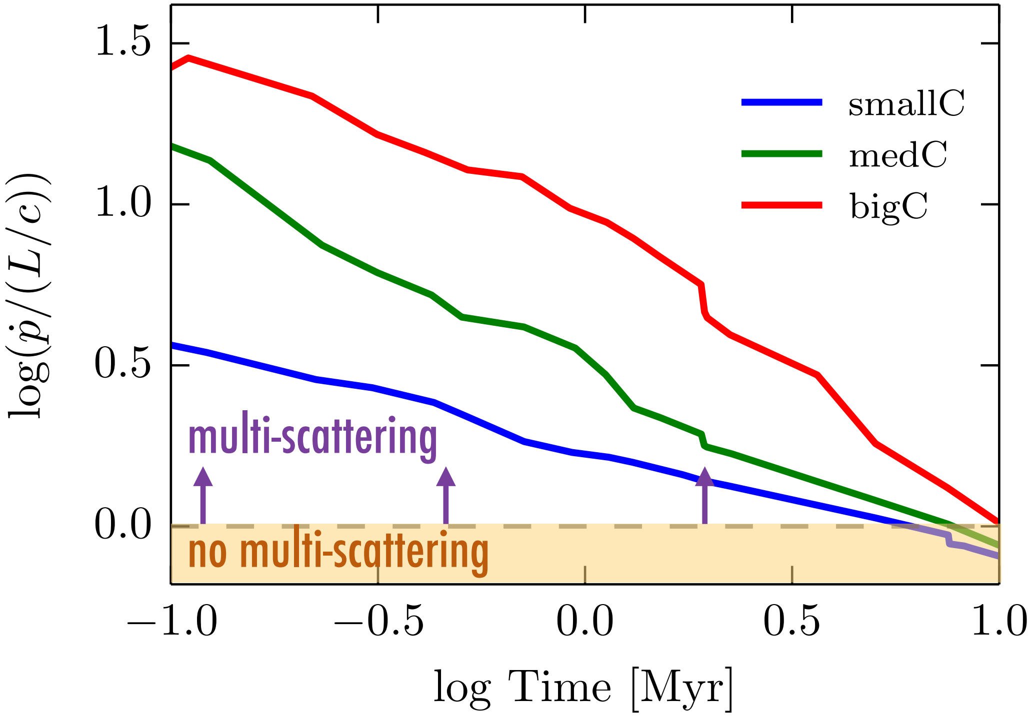


Fraction of solid angle covered by an optical depth greater than one



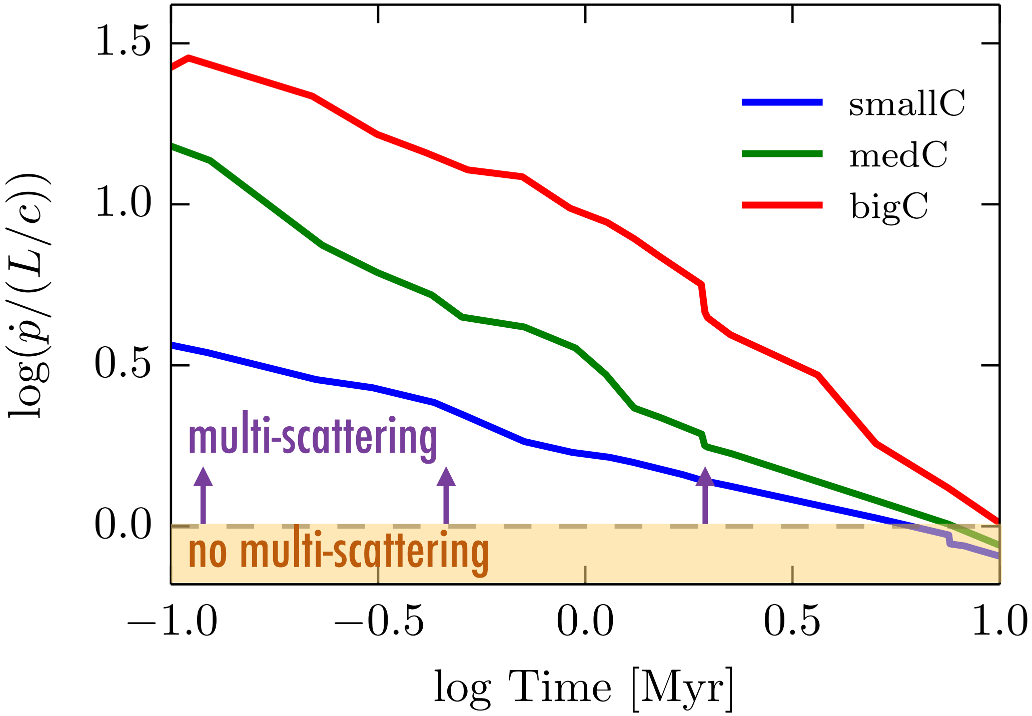
- Optical depths are between 10 and 100 depending on cloud size
- Covering fraction depends on cloud size but generally drops quickly

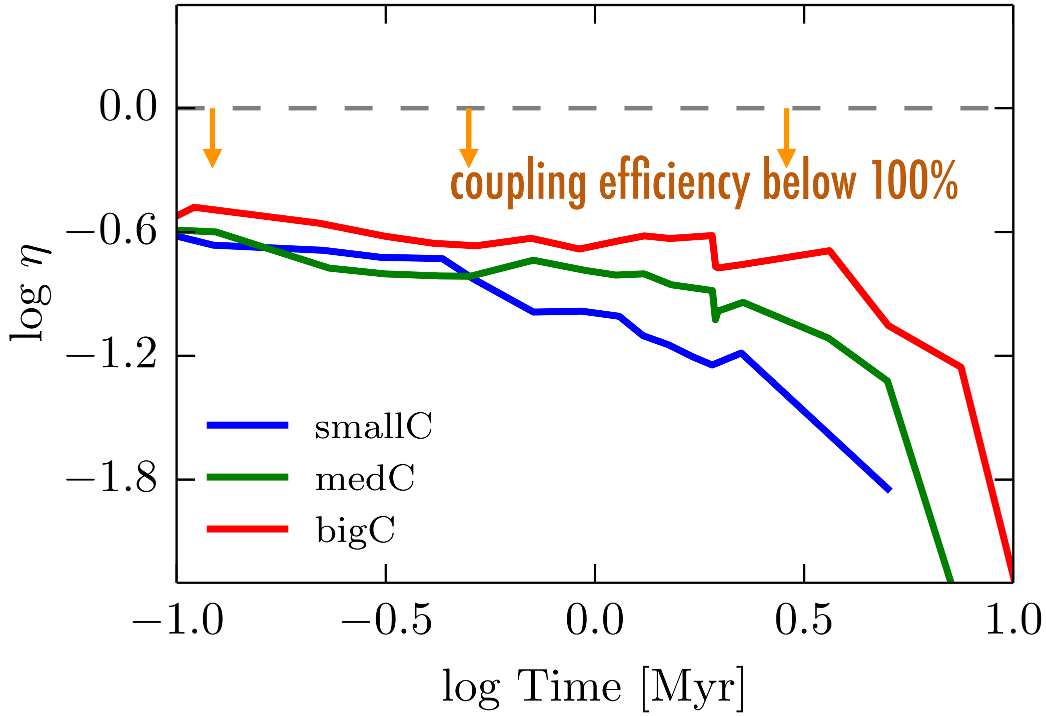
Mechanical Advantage



Mechanical Advantage

$$\dot{p} = (1 + \eta\tau_{\mathrm{IR}})\frac{L}{c}$$

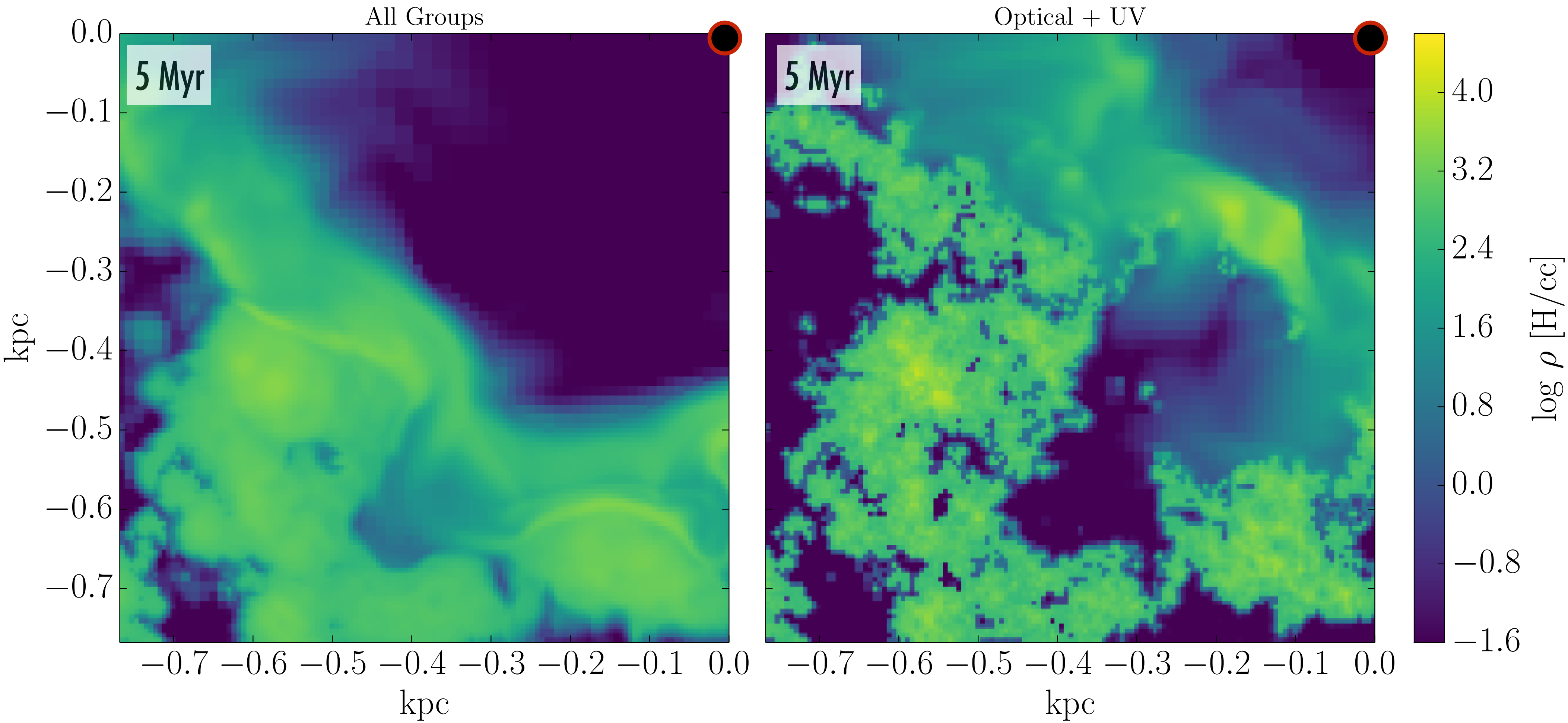


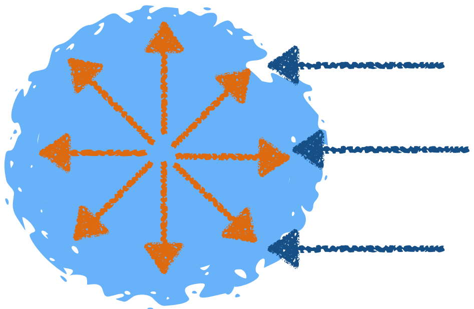


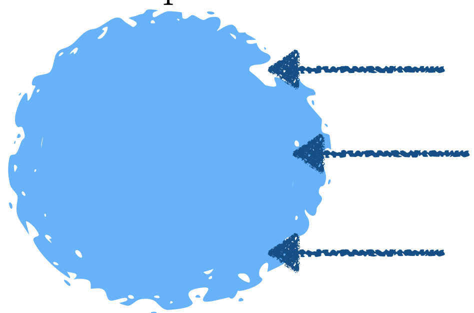
$\eta < 1$ momentum loss due to inhomogeneities in the gas

The non-uniform structure of the ISM and subsequent building of low density channels as well as destruction of central cloud leads to loss of momentum

How Does Radiation Drive a Wind?

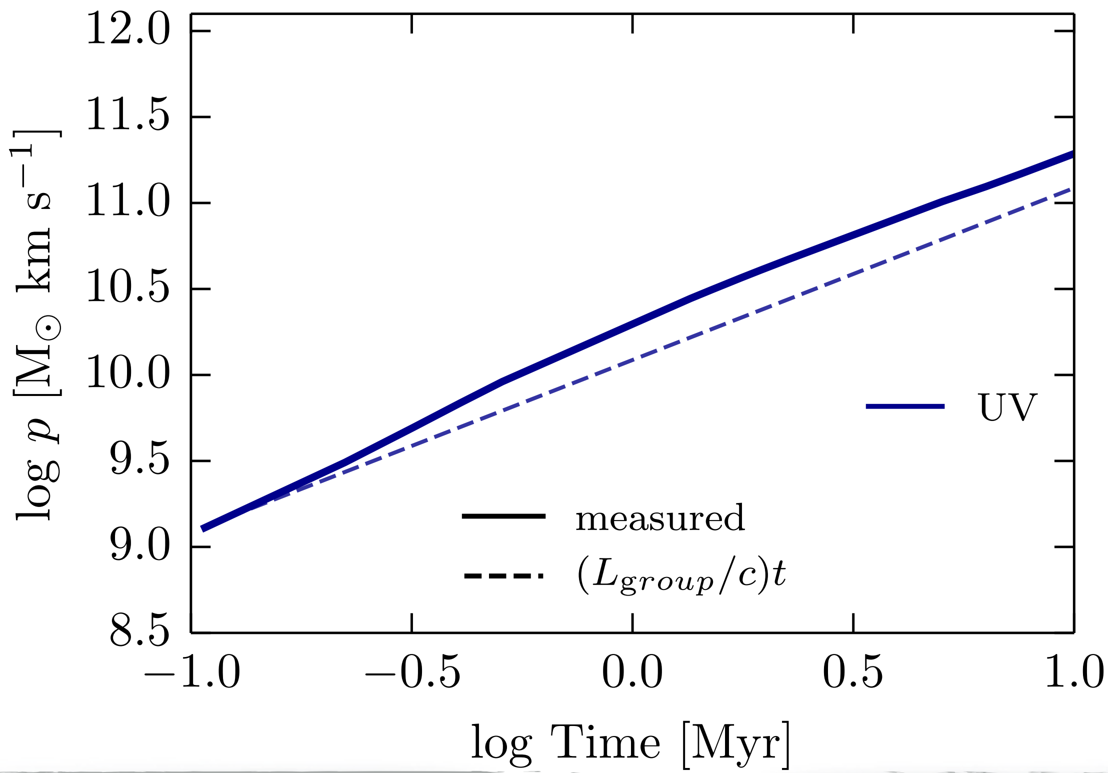






Mechanical Advantage From Groups

medC simulation



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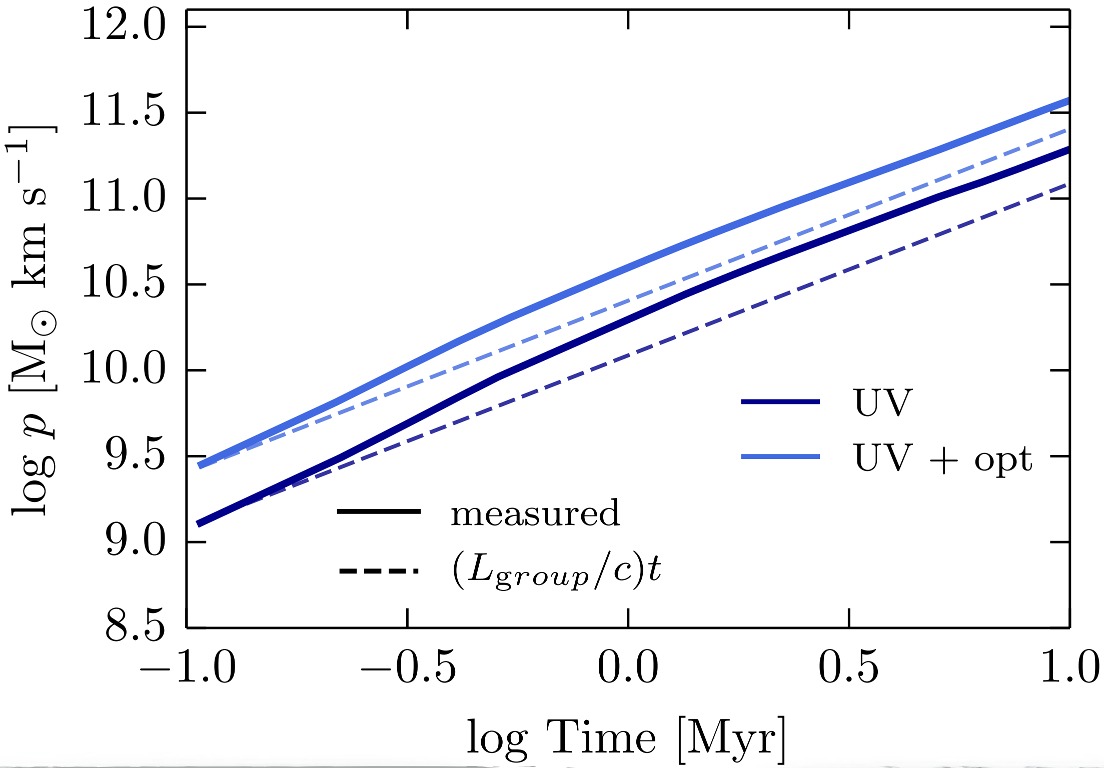

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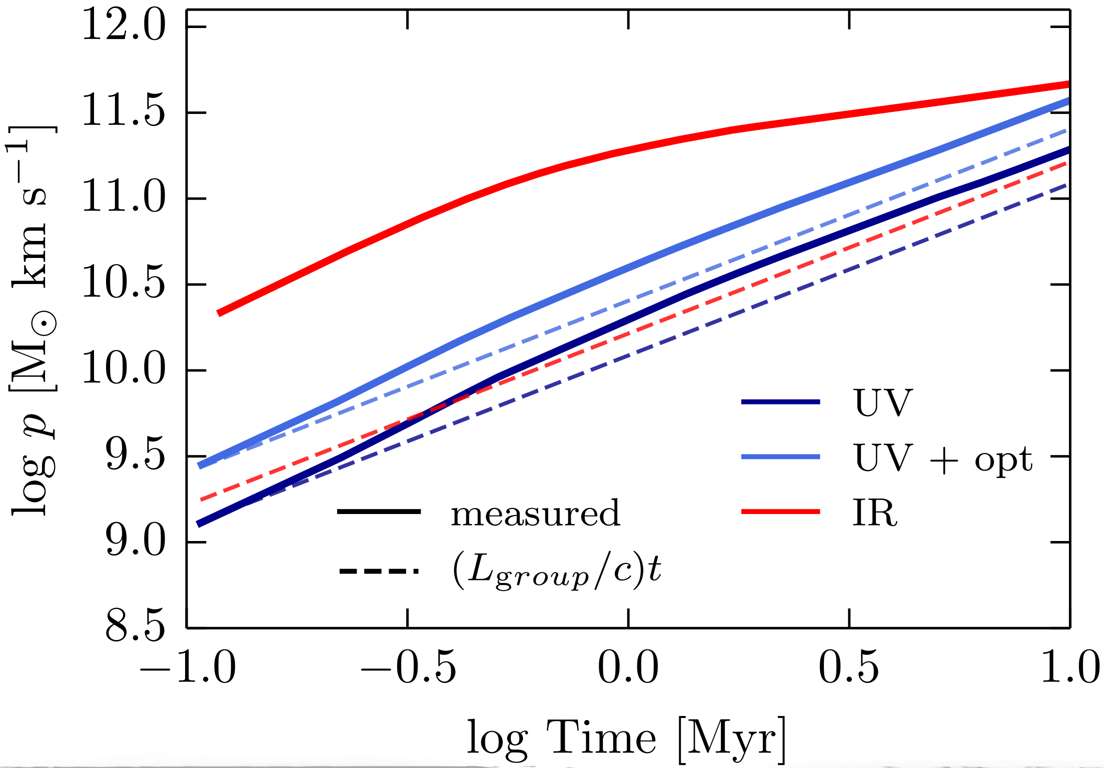

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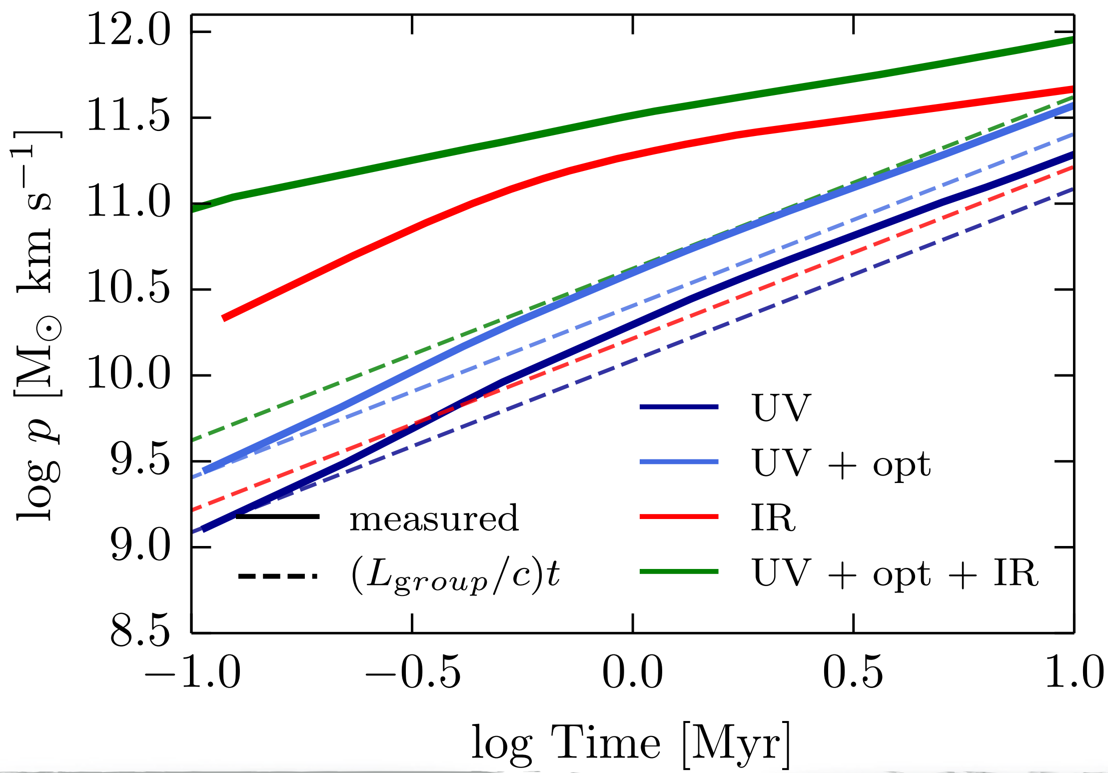

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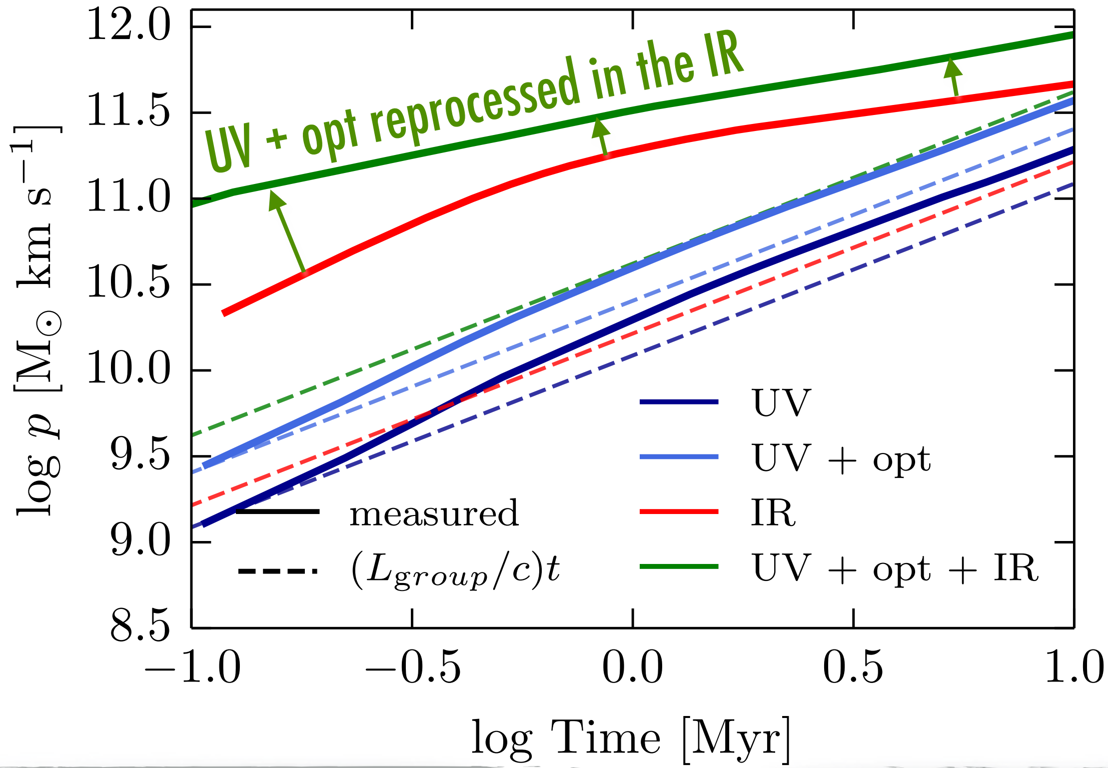

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Effect of Reduced Speed of Light

- Rationale: as long as the radiation travels faster then ionisation fronts, the results of RHD simulations are more or less converged with respect to the reduced speed of light
- ⚠ IR radiation is not photo-ionising ⟶ not obvious whether a reduced speed of light produces converging results, especially when IR trapping becomes important

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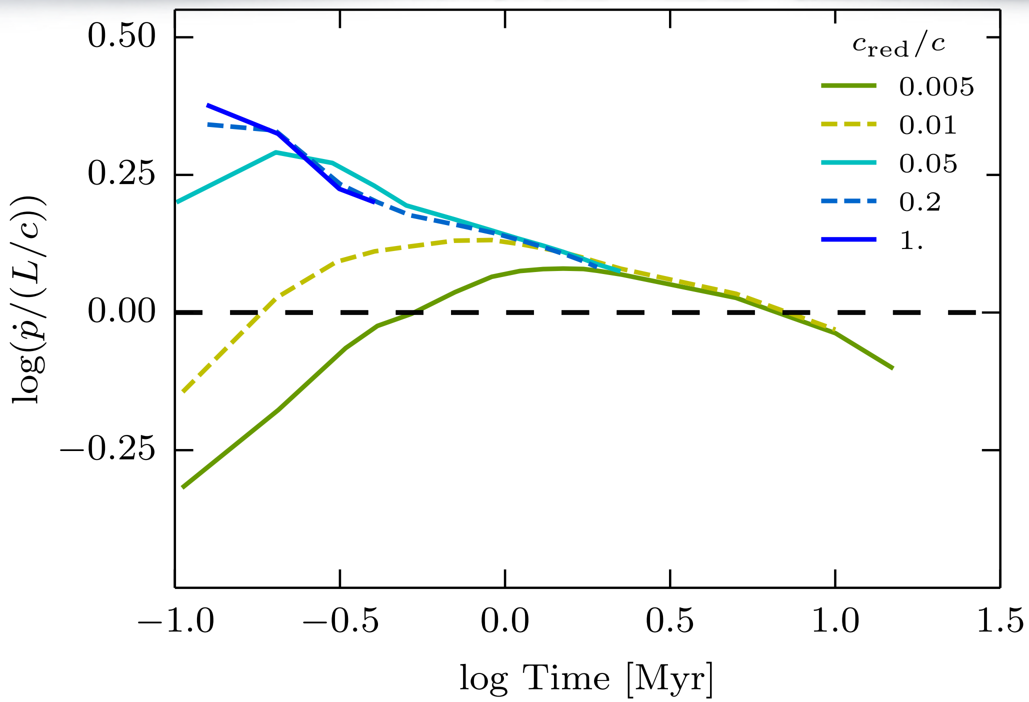

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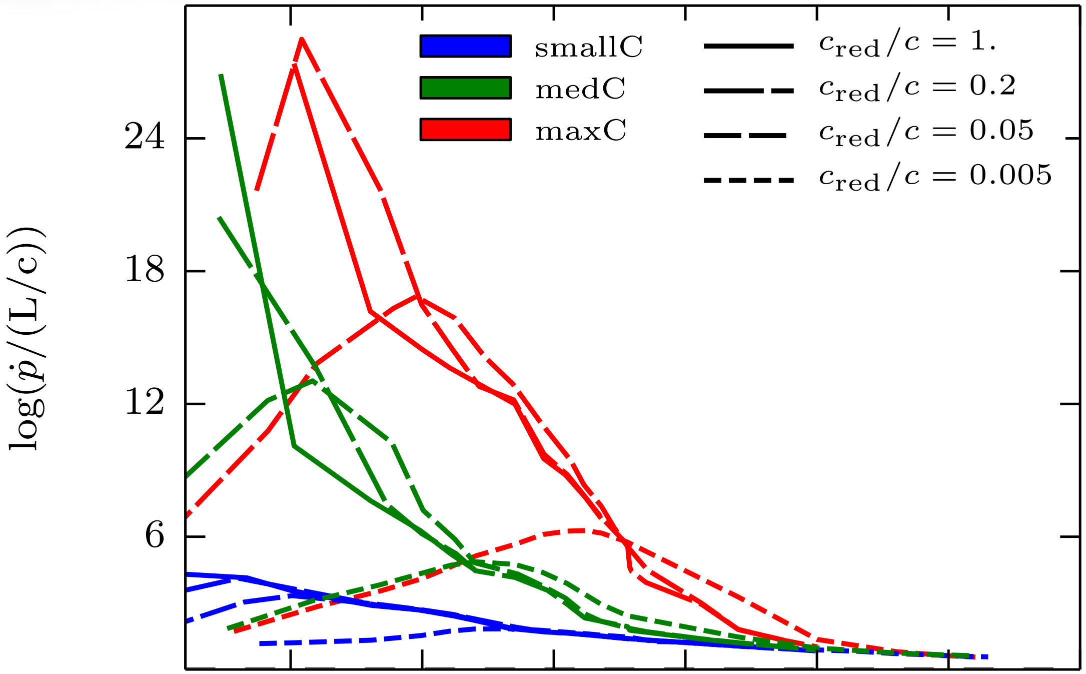

Choice of c_{red} has a significant effect on momentum transfer

Conclusion for Radiation Driven Quasar

- Mechanical advantage is smaller than theoretically inferred (10%)
- Radiation-driven feedback has most effect on galaxies with large clouds
- Radiation manages to drive a radiatively-driven wind mainly because of IR multi-scattering

(needs however to be confirmed with more realistic simulations)

- Be careful with your choice of reduced speed of light!