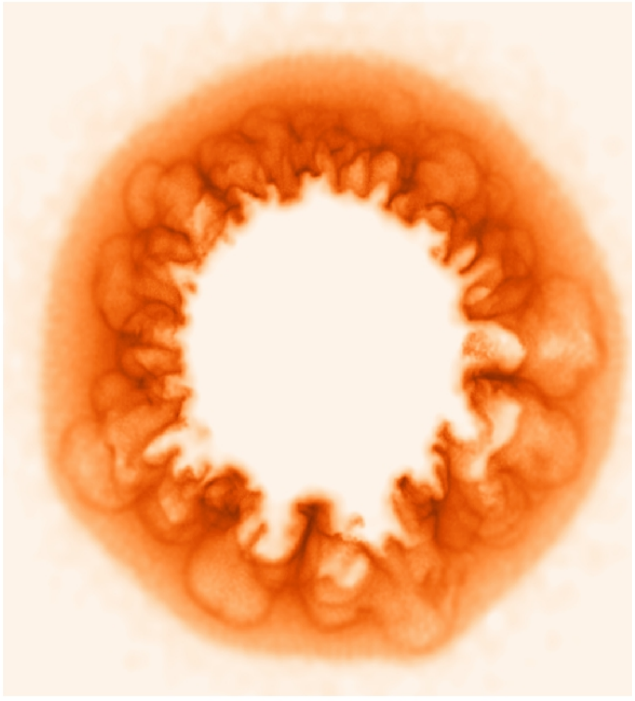
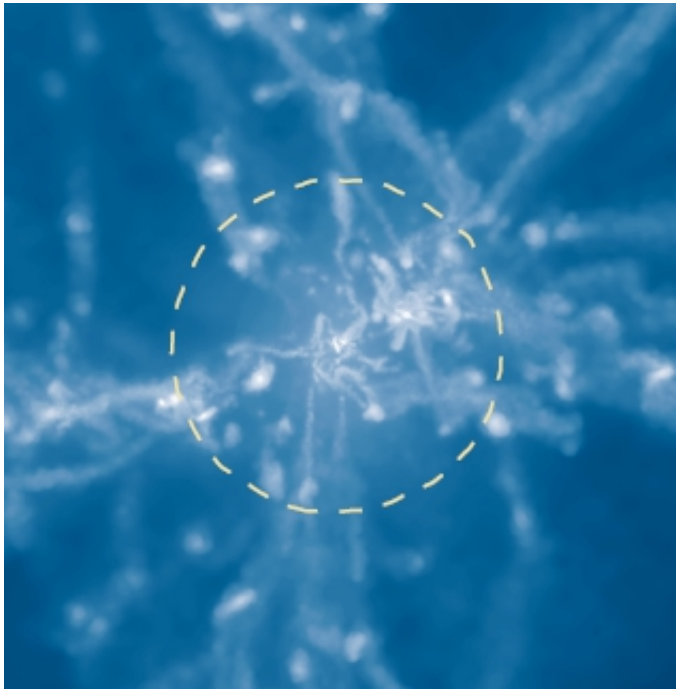
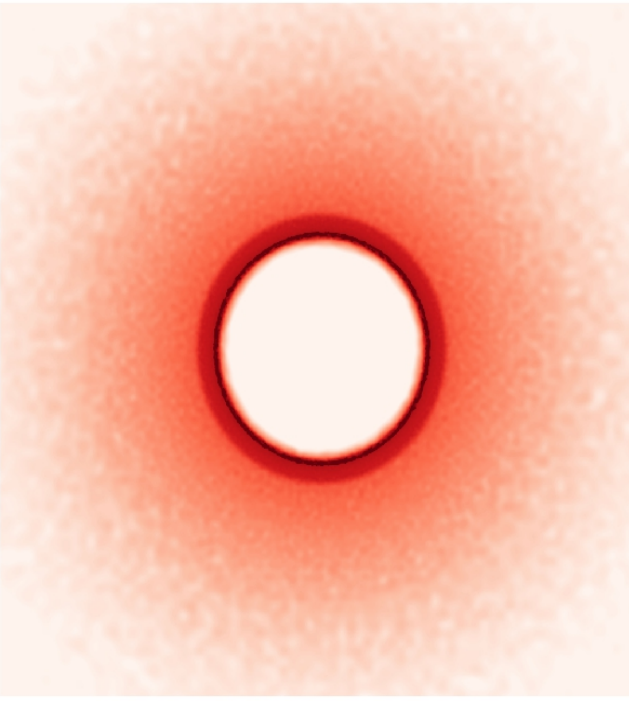
Feedback from AGN:

Energy- versus momentum-driven outflows

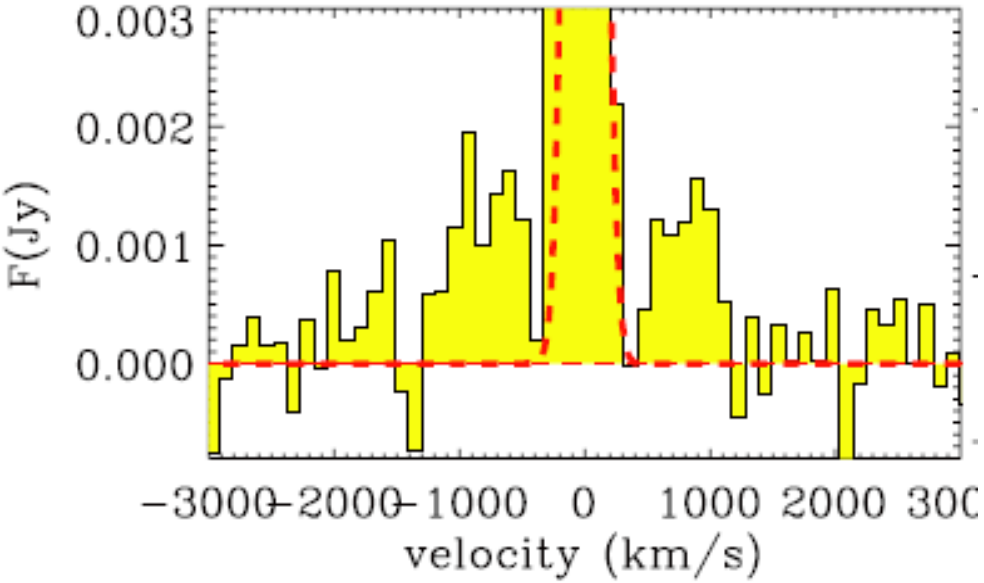
Tiago Costa

Debora Sijacki & Martin Haehnelt

Institute of Astronomy & KICC, University of Cambridge

Outflows driven by AGN

Cicone et al. 2014



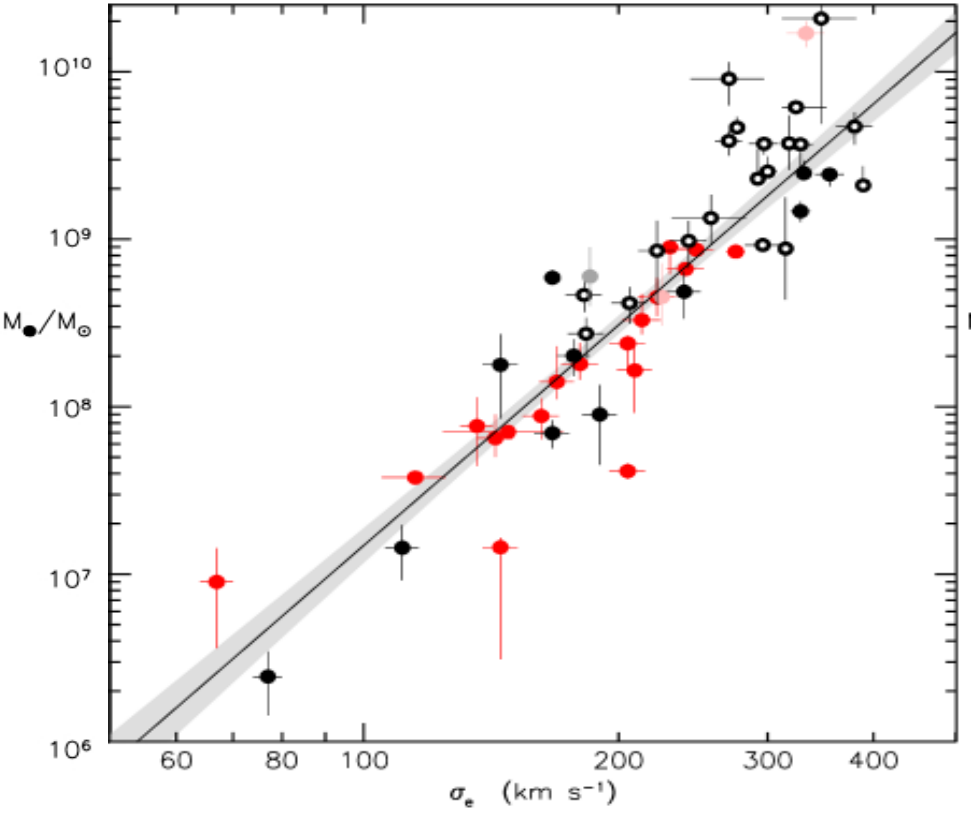
Molecular outflows from AGN:

Outflowing mass: ~ $10^{8\text{-}10}$ M_{sun}

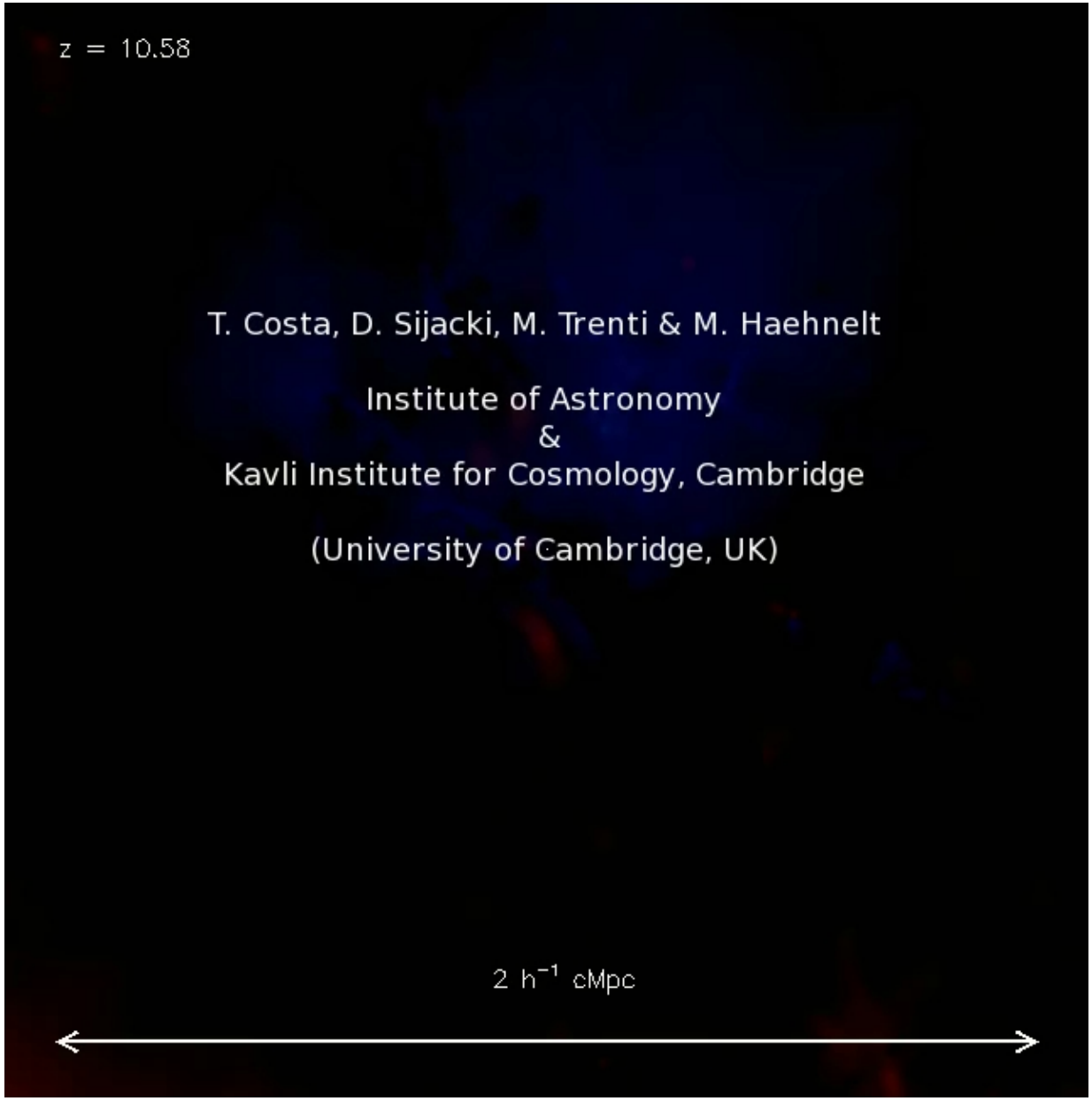
Momentum flux: ~ 20 L/c

Kinetic luminosity: ~ a few % L

Kormendy & Ho 2013

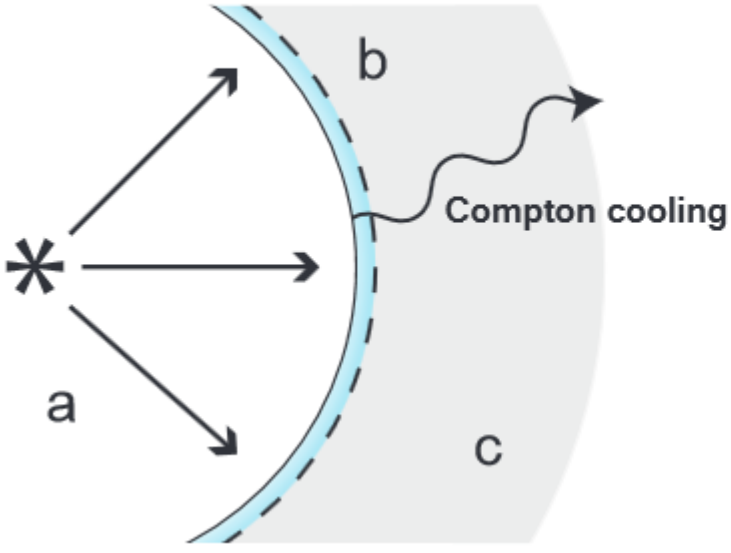


$M_{BH} \alpha \sigma^{4.3}$

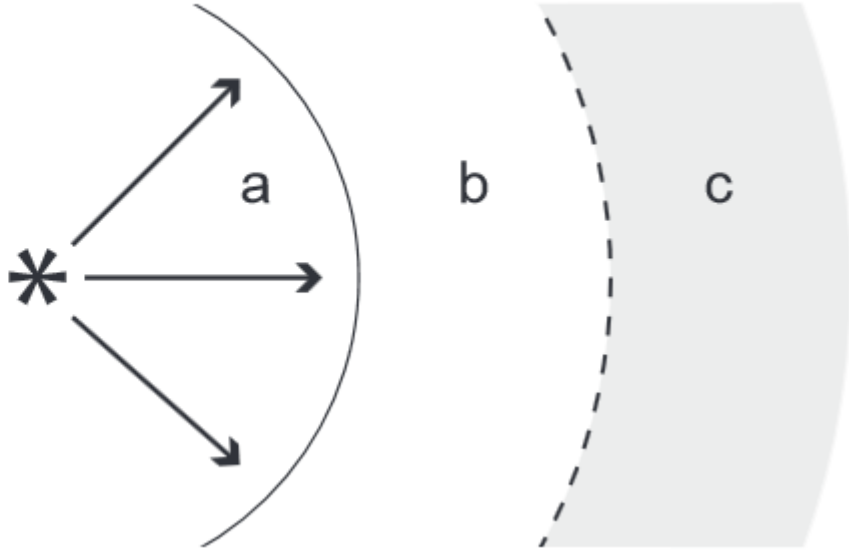

z = 10.58
T. Costa, D. Sijacki, M. Trenti & M. Haehnelt
Institute of Astronomy
&
Kavli Institute for Cosmology, Cambridge
(University of Cambridge, UK)
2 h^{-1} cMpc

Two limiting cases

Momentum-driven outflow



Energy-driven outflow



Shocked inner wind **radiates away** its thermal energy.
Gives

$$M^{\rm m}_{\rm final} \propto \sigma^4$$

Shocked inner wind **preserves** its thermal energy.
Gives

$$M^{\rm e}_{\rm final} \propto \sigma^5$$

Reproducing analytical solutions with AREPO

- Hernquist (static) potential with:

$$M = 10^{12}\,\mathrm{M}_\odot$$

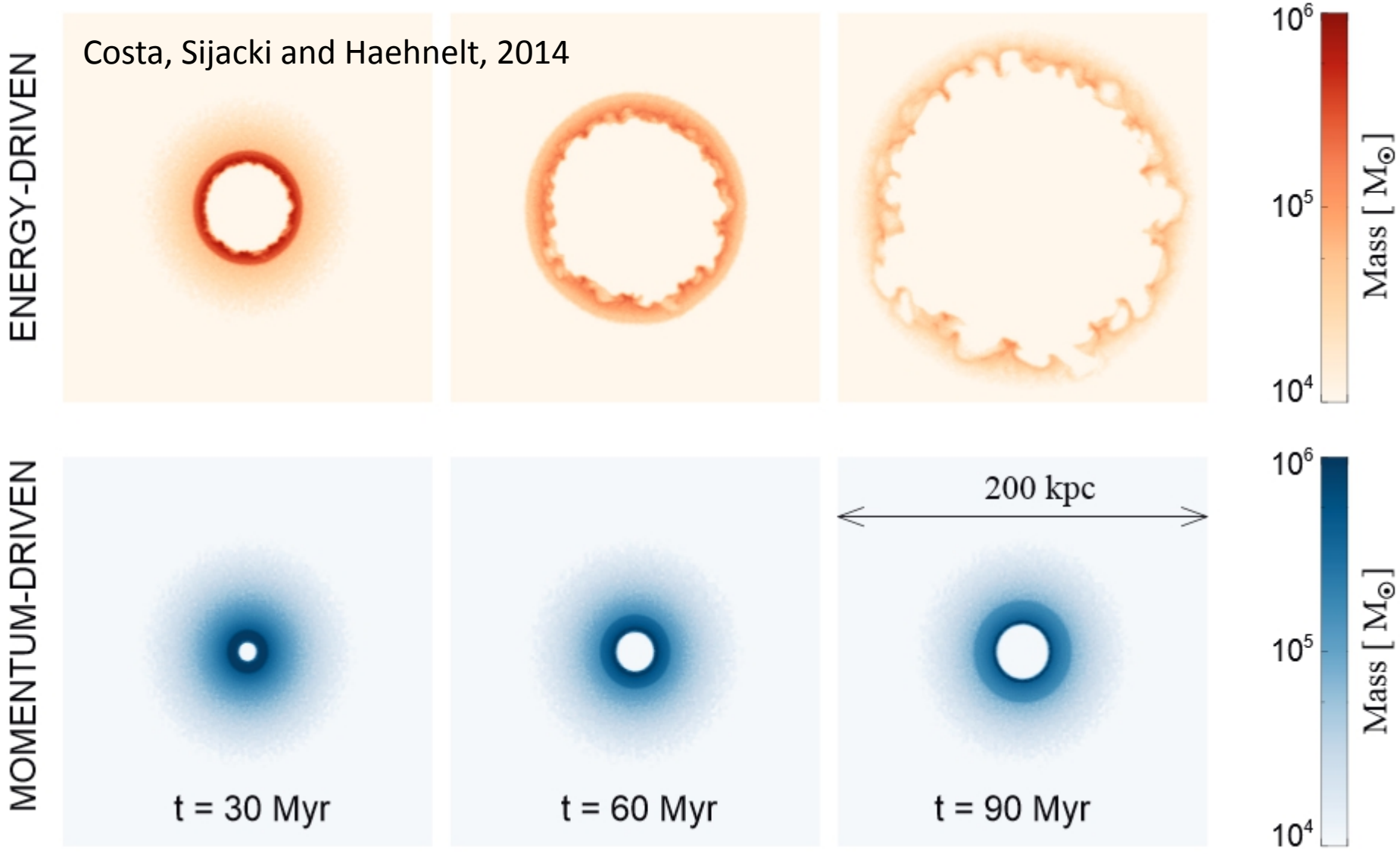
$$f_{\mathrm{gas}} = 0.17$$

- Gas at hydrostatic equilibrium.
- Explore range of BH masses:

$$5 \times 10^7\,\mathrm{M}_\odot \text{ to } 3 \times 10^8\,\mathrm{M}_\odot$$

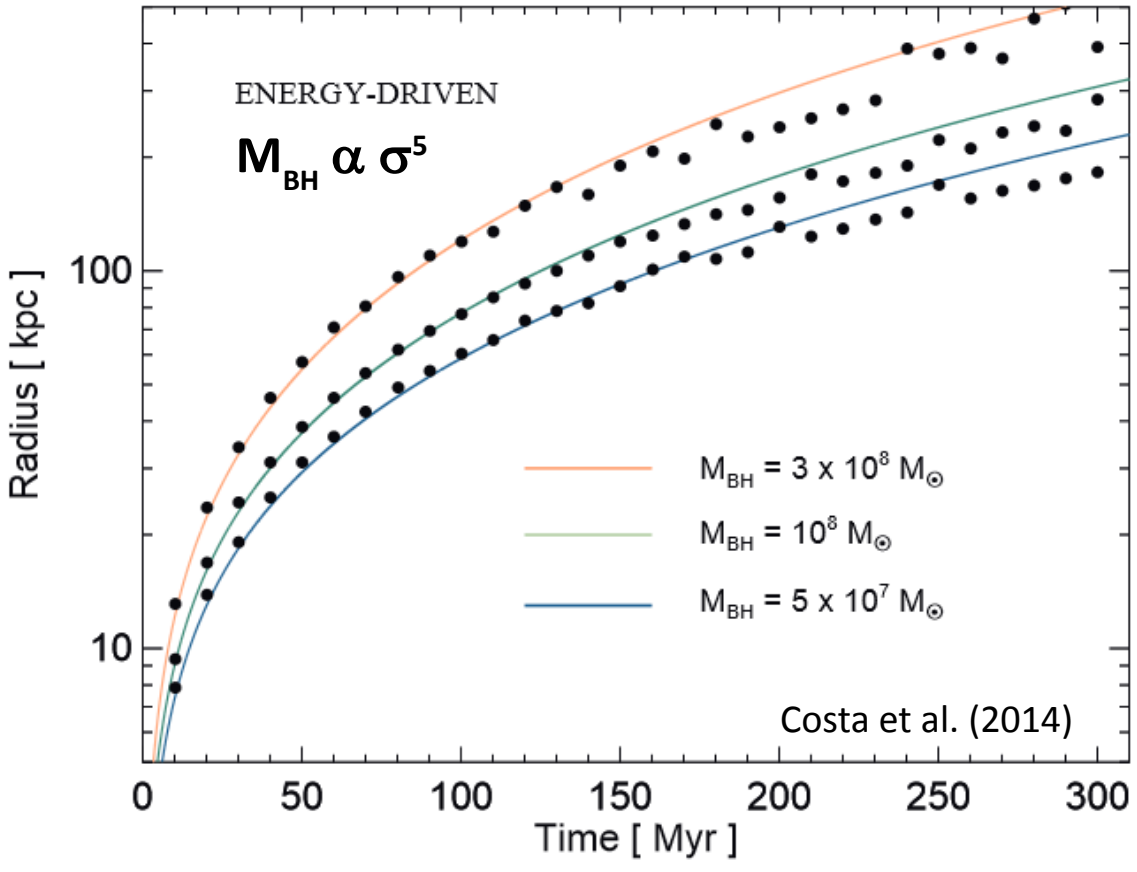
- Assume AGN is **constantly** emitting at its Eddington limit.
- Minimum cell size: ~ 7 pc
- Different resolutions: 10^5, 10^6, 10^7 cells.

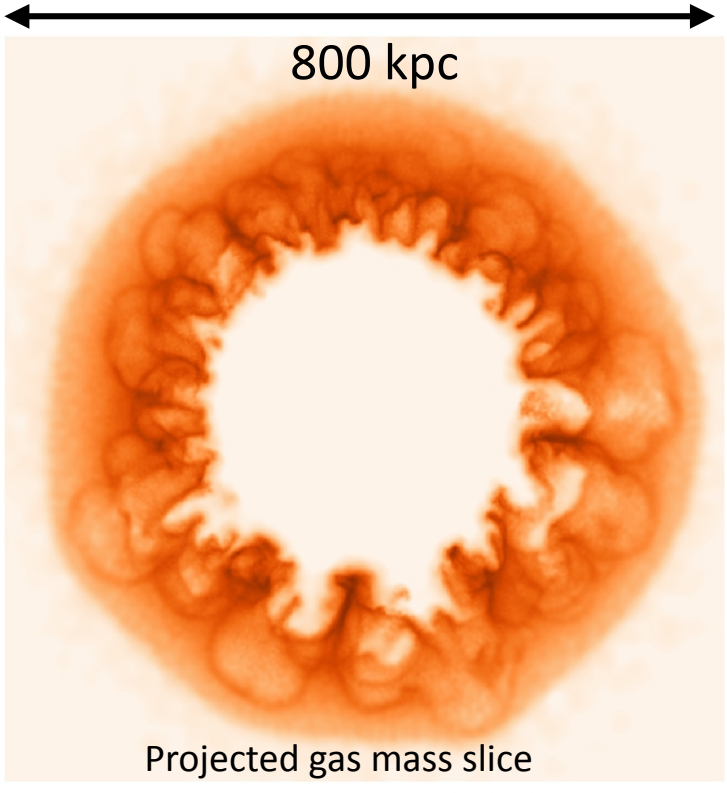
Dirac allocation, PI: Sijacki



Shell of shocked gas expands outwards as envisaged in models of spherical isolated haloes (Silk & Rees 1998, Fabian 1999, King 2003, Murray et al. 2005)

Energy-driven outflow

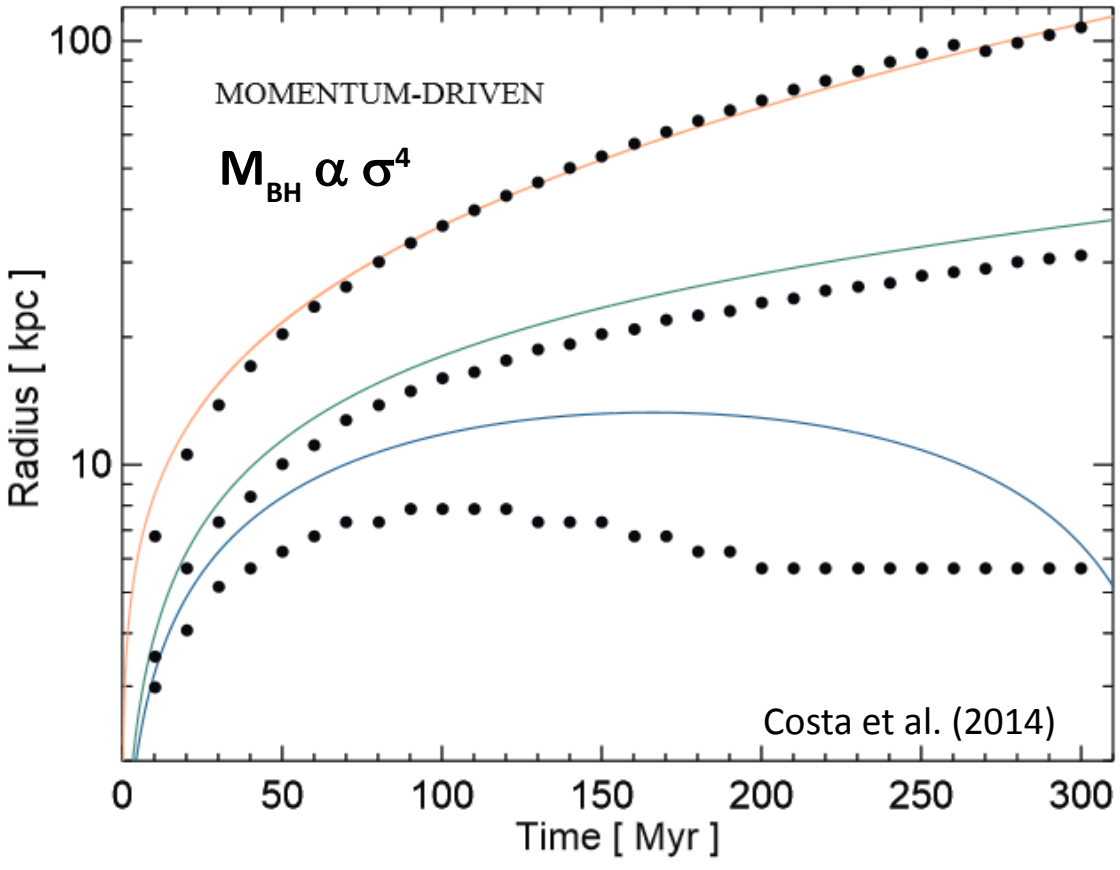


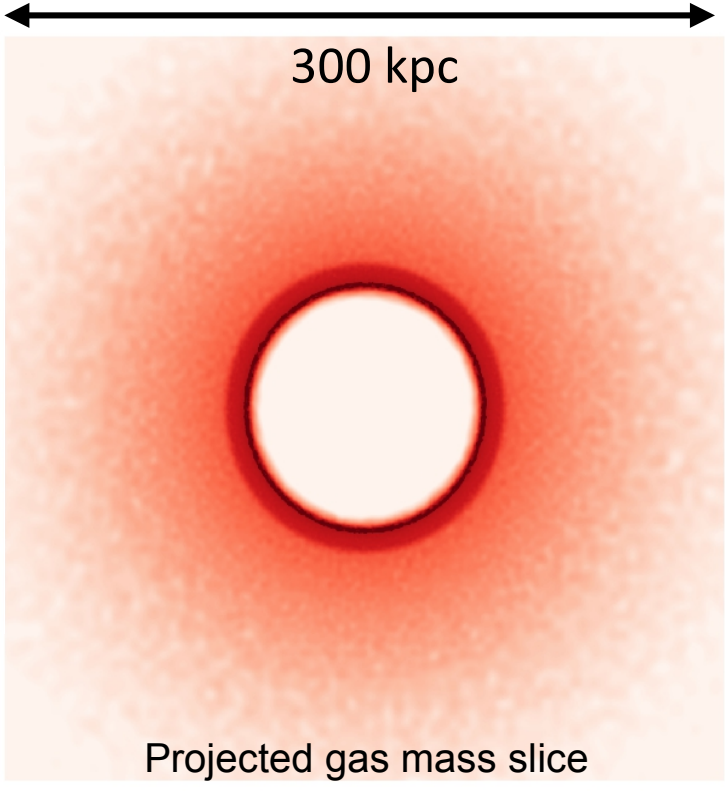


Costa, Sijacki and Haehnelt, 2014

Numerical and analytical wind solutions are in close agreement.
At late times, R-T instabilities develop and lead to disruption of the shell.

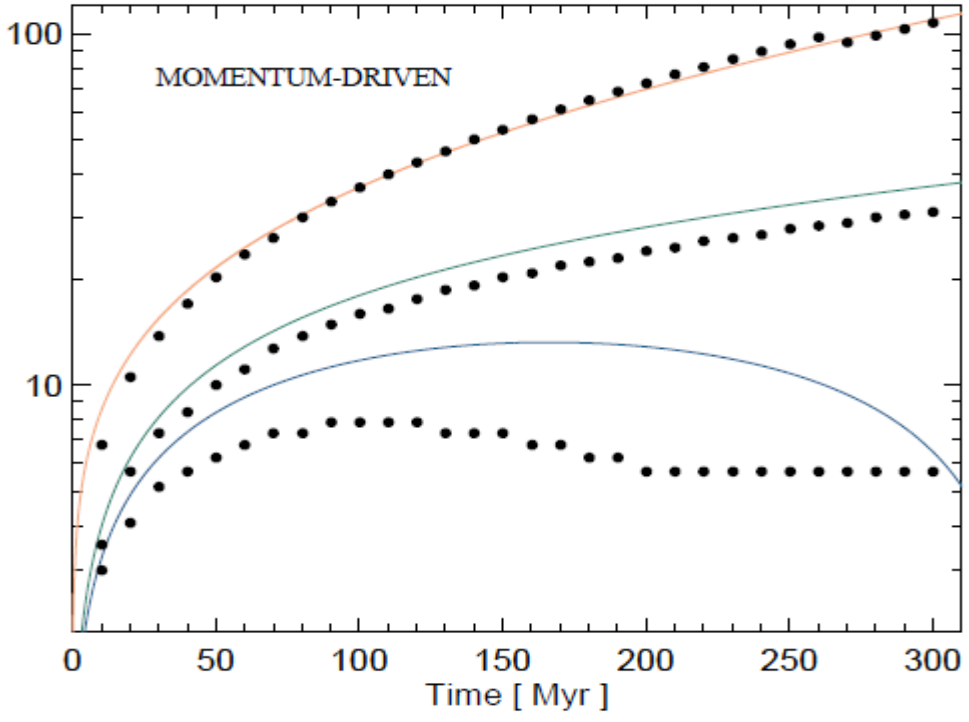
Momentum-driven outflow

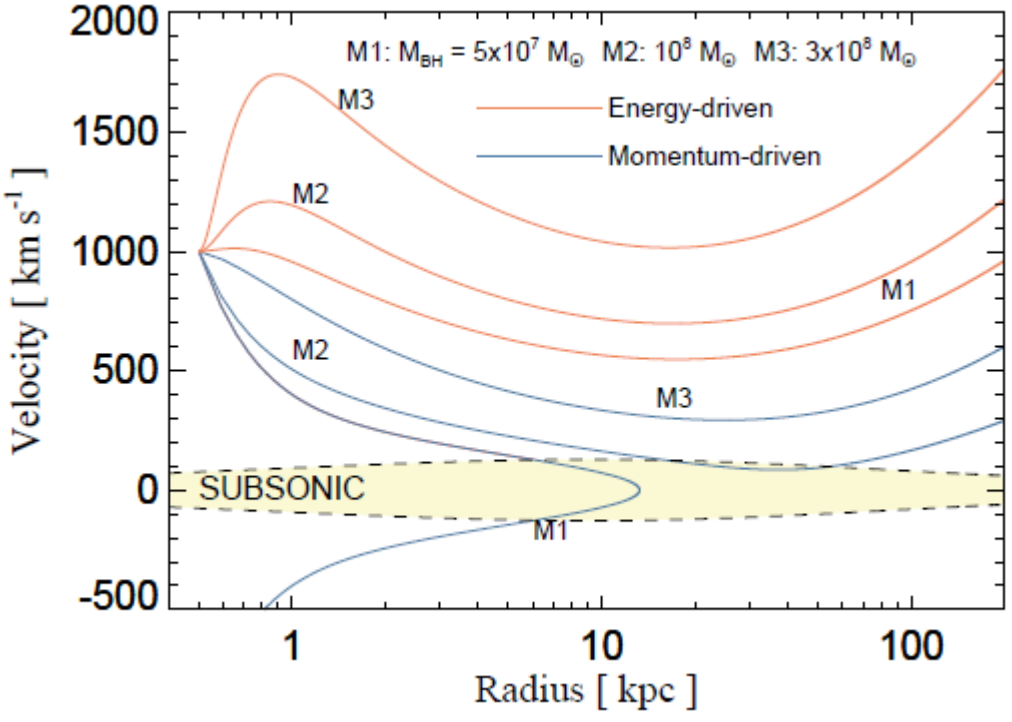




Costa, Sijacki and Haehnelt, 2014

Numerical and analytical solutions agree at **high black hole masses**.



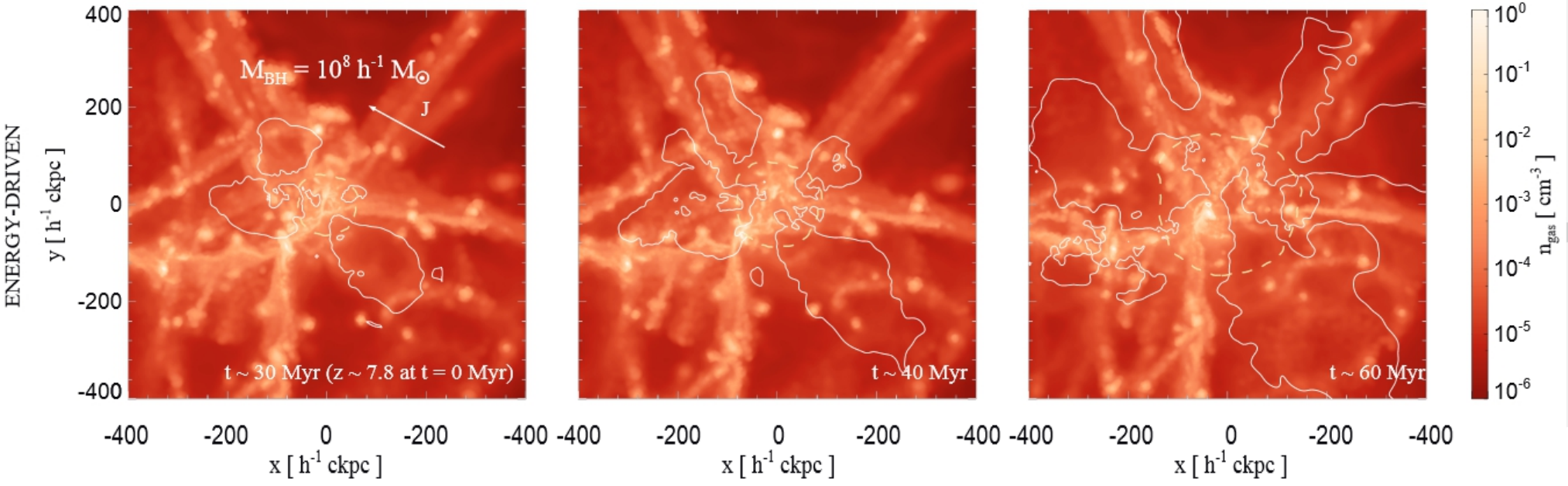


Cause of disagreement at lower black hole masses is confining pressure of halo gas in the subsonic regime.

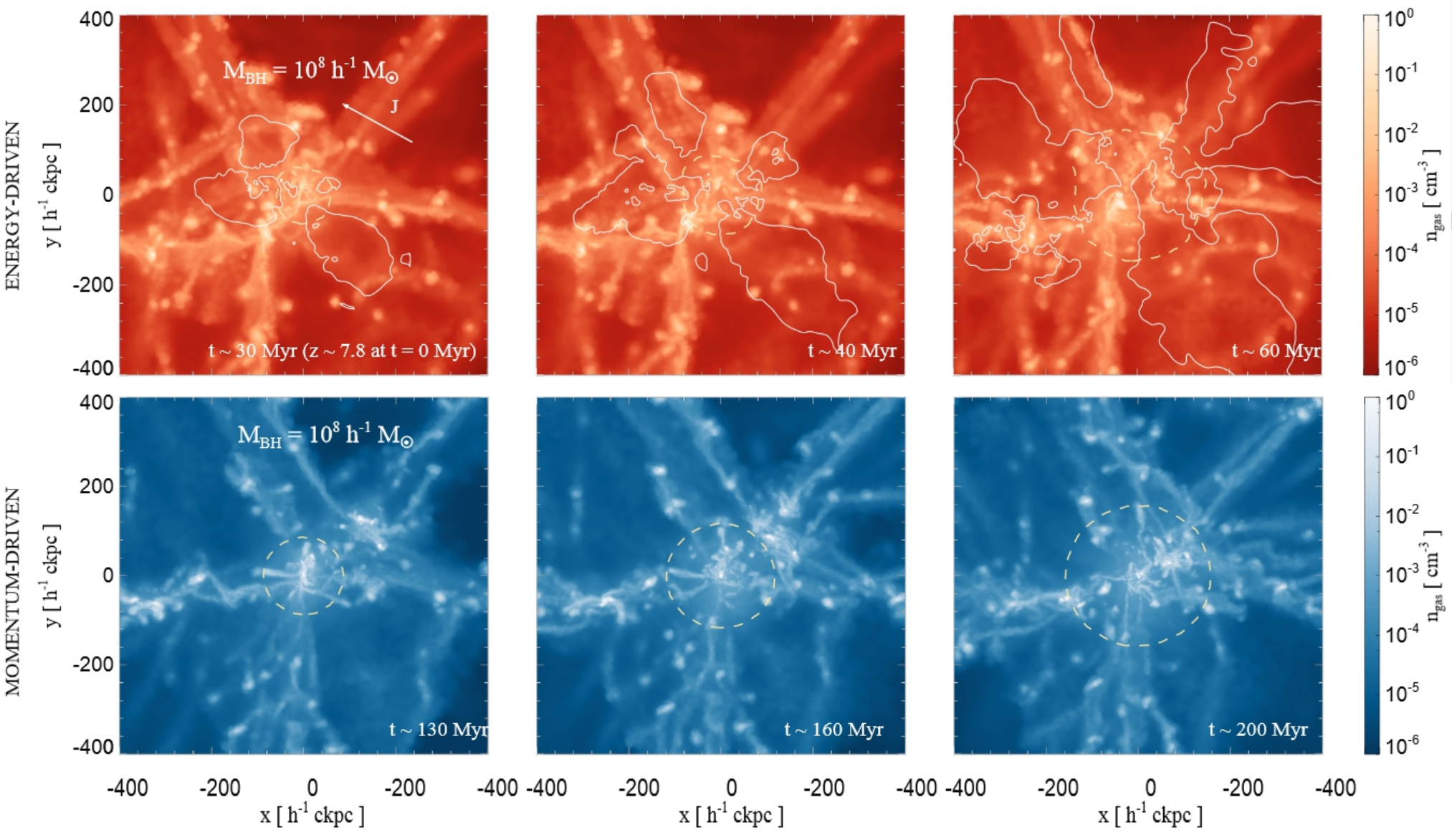
There is however a critical mass below which outflow solutions are bound.

$$M_\sigma \approx \left(\frac{f}{0.17}\right)\left(\frac{v_c}{200\,\mathrm{km\,s^{-1}}}\right)^4 10^8\,\mathrm{M}_\odot$$

cf. Fabian 1999, King 2003

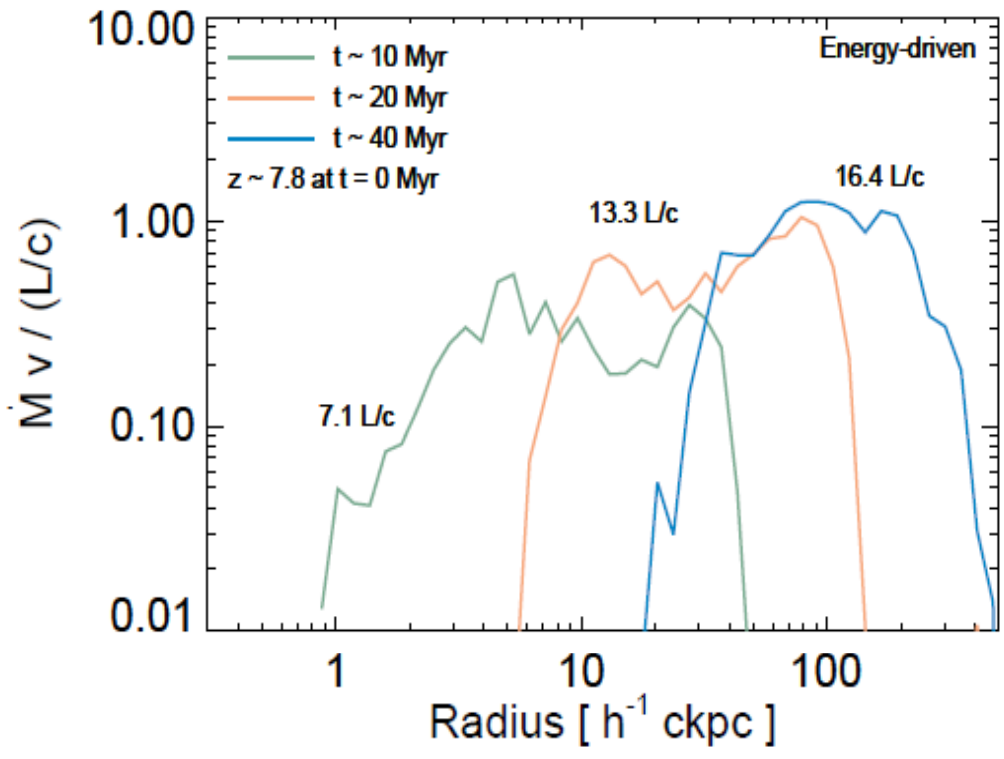


Anisotropic outflow escapes along paths of least resistance.
Geometry, velocity structure and spatial extent is greatly at odds with spherical models.

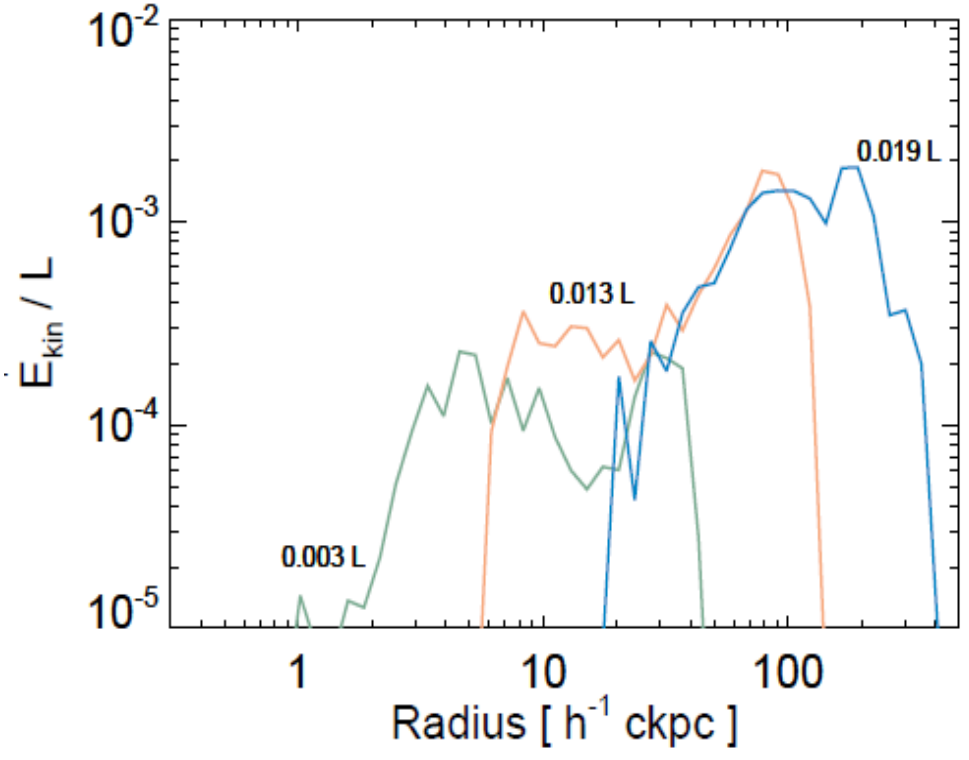


No significant momentum-driven outflow for M = M_σ.

MOMENTUM FLUX



KINETIC LUMINOSITY



Energy-driven outflows in cosmological simulations attain high momentum fluxes (>> L/c) and high kinetic luminosities (~2 % L) required to revert inflows.

Conclusions

- In an isolated potential, we verify that a momentum flux of L/c is sufficient to lead to a relation:

$$M_\sigma \approx \left(\frac{f}{0.17}\right)\left(\frac{v_c}{200\,\mathrm{km\,s^{-1}}}\right)^4 10^8\,\mathrm{M}_\odot$$

- A momentum flux >> L/c is however required to revert inflows of gas as predicted by cosmological simulations of BH growth.
- AGN-driven outflows must be **energy-driven** already at scales in the order of 50 pc.
- Large-scale energy-driven outflows are anisotropic and attain momentum fluxes ~ 15 L/c and kinetic luminosities of ~ 2% L.