Hydrodynamic Simulations of Black Hole Fueling and Feedback

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Massive Black Holes: Birth, Growth and Impact
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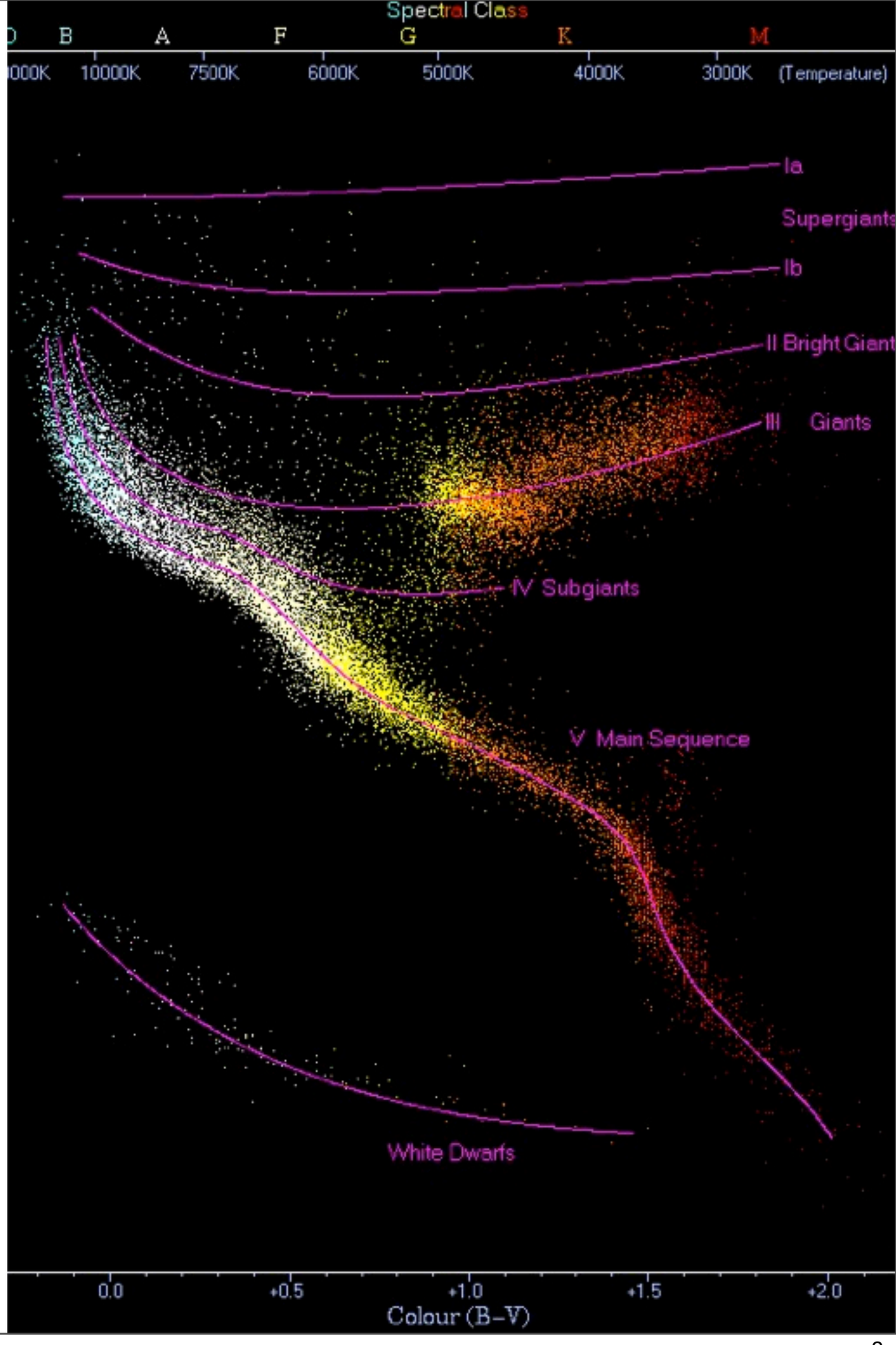
Nuclear Physics and Stars

- What if we tried to understand stars the way we try to understand galaxies and AGN?

$$\dot{e} = A\rho^{\alpha}T^{\beta}$$

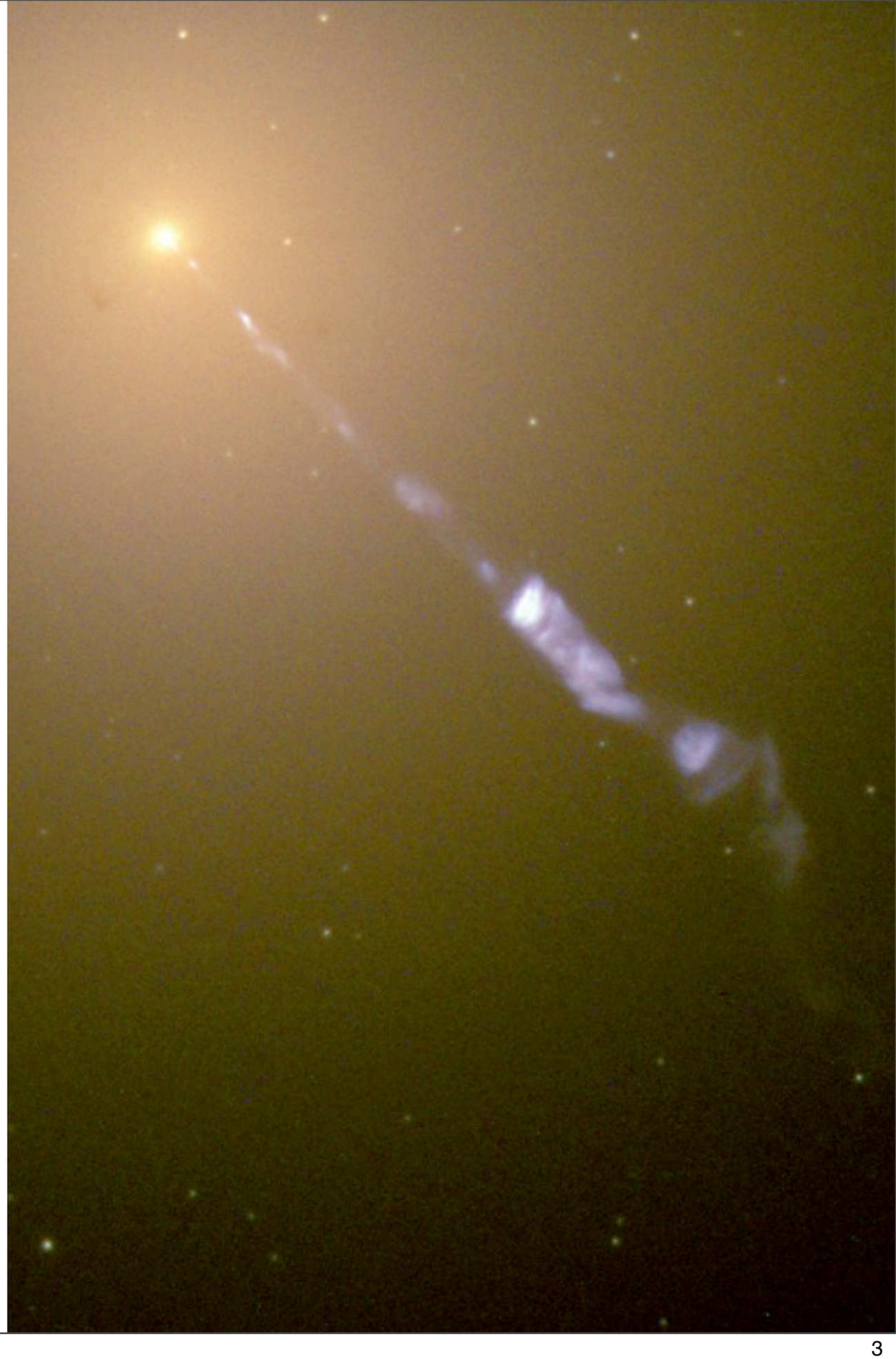
- Make tables of L, Teff as a function of alpha, beta, A.

- Are we finished?



“Nuclear Physics” of galaxies

- Not analytic
- Non-local (energy transport time less than dynamical time)
- Spatially inhomogeneous on all scales of interest
- Couples vastly different length scales
- Energy generation profoundly affects fueling

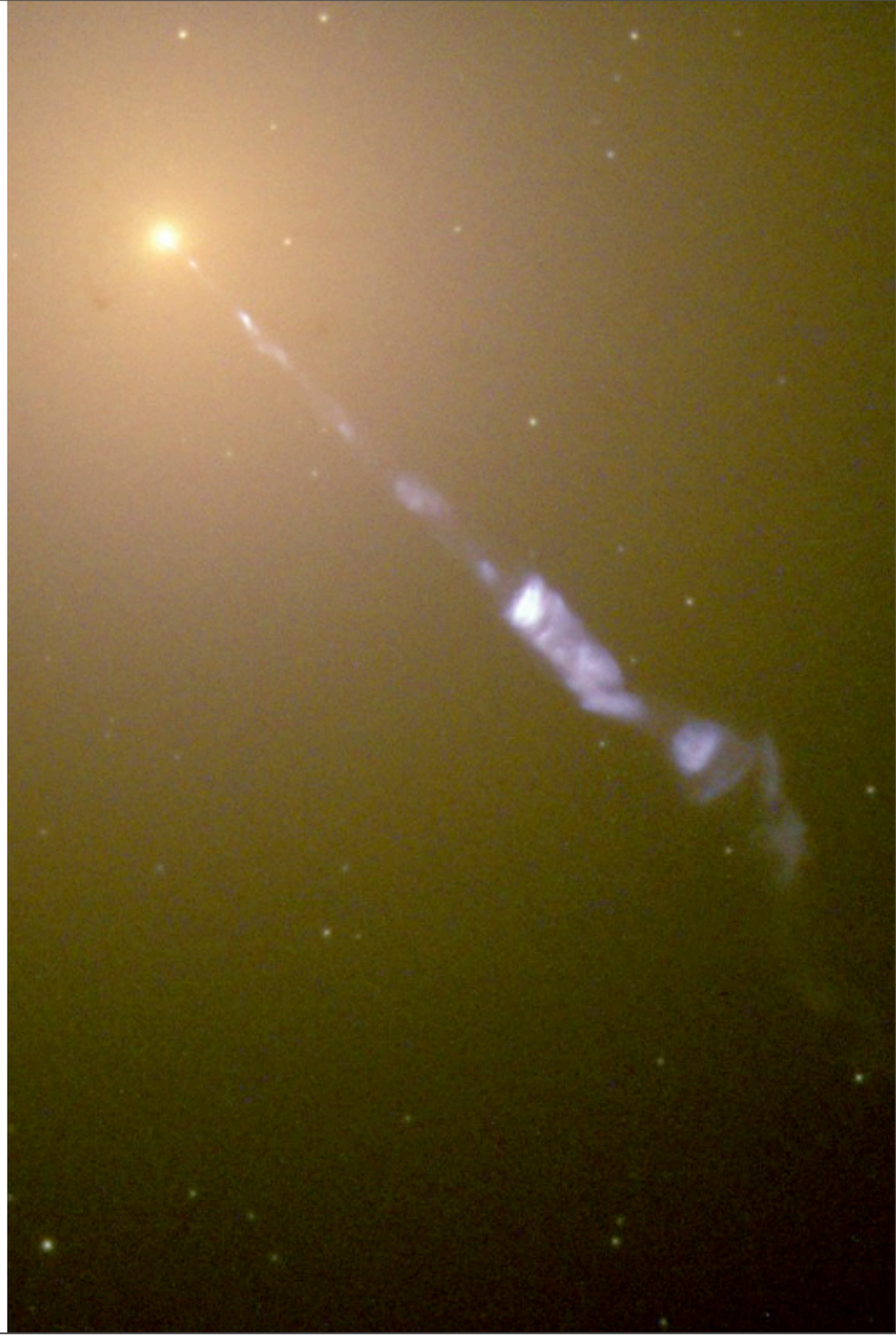


Issues

- Black Holes emit enough energy to unbind their host galaxy!

- If you have a problem, black holes can solve it! The issue is *coupling*

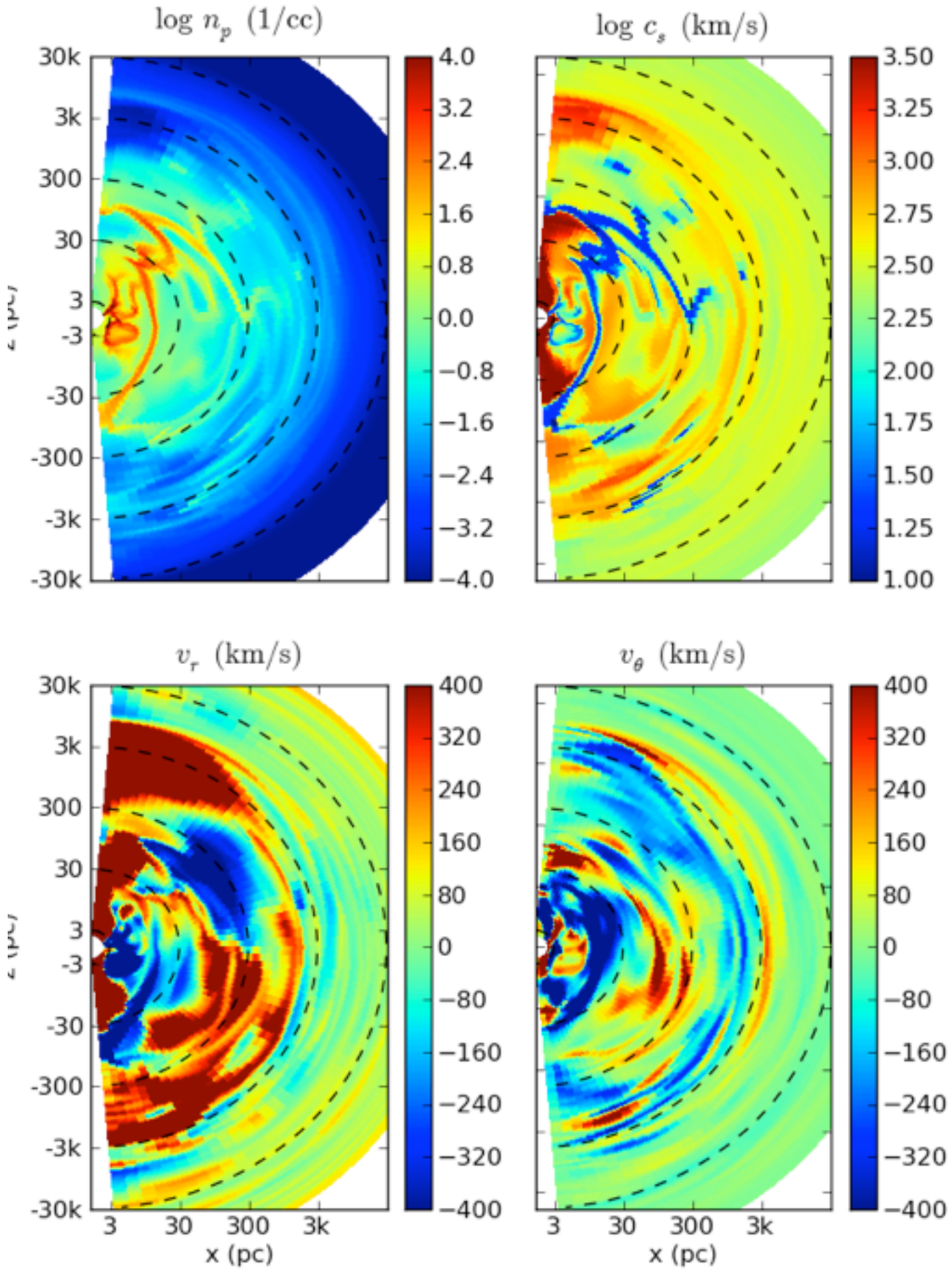
- We already know the basic physics (gravity, fluid dynamics, radiative transfer). The issue is *understanding complexity*



Basic Picture

- Early-Type Galaxy with initial population of stars, little gas
- Gas supplied by evolving stars, cools unstably, falls to center of galaxy
- Simulation domain 2.5 pc to 250 kpc, run for gigayear timescales

Novak et al ApJ 2011, arXiv:1007.3505

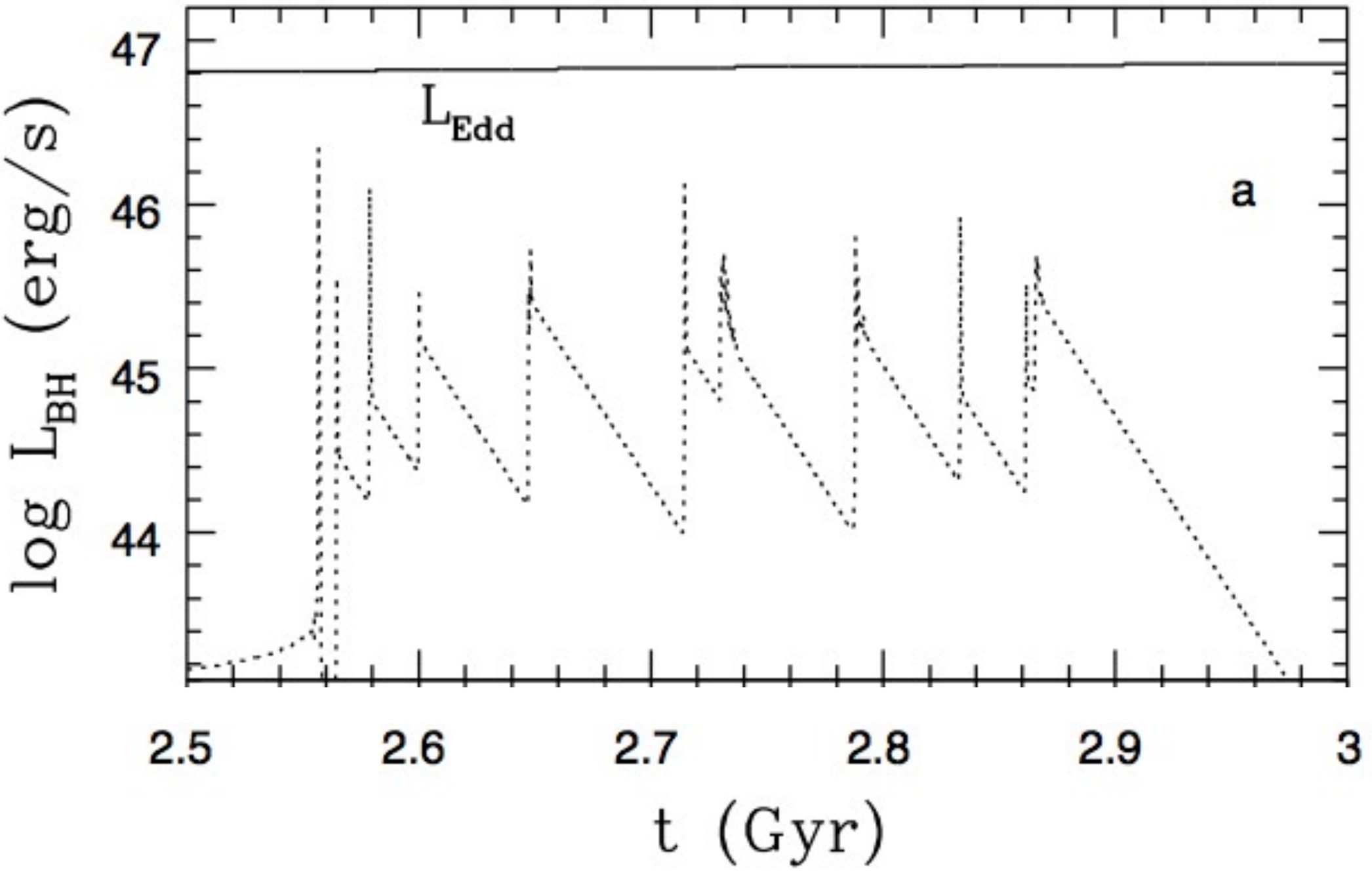


Physically Rich Feedback Model

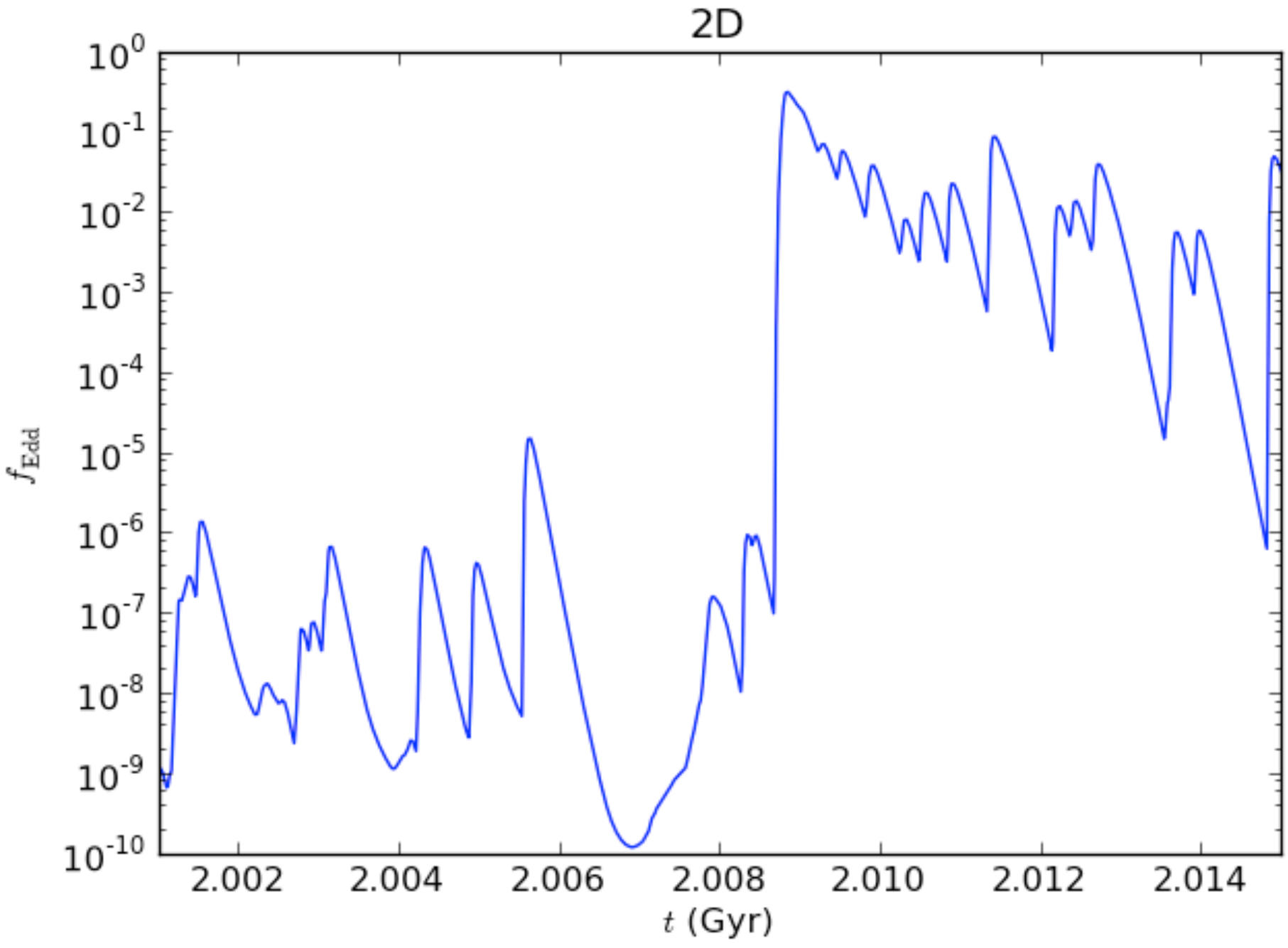
- Radiative and Mechanical Feedback via Energy and Momentum
- Mechanical Feedback via 10,000 km/s Wind driven off of (sub-resolution) Accretion Disk
- Radiative Transfer of AGN and Stellar Photons due to Dust Opacity
- Dust Destruction via Sputtering, Creation via Stellar Winds, Molecular Clouds
- Compton Scattering/Heating, Photoionization Heating/Opacity, Atomic Cooling, Bremstr.
- Star Formation, Supernovae

Novak, Ostriker + Ciotti arxiv:1203.6062

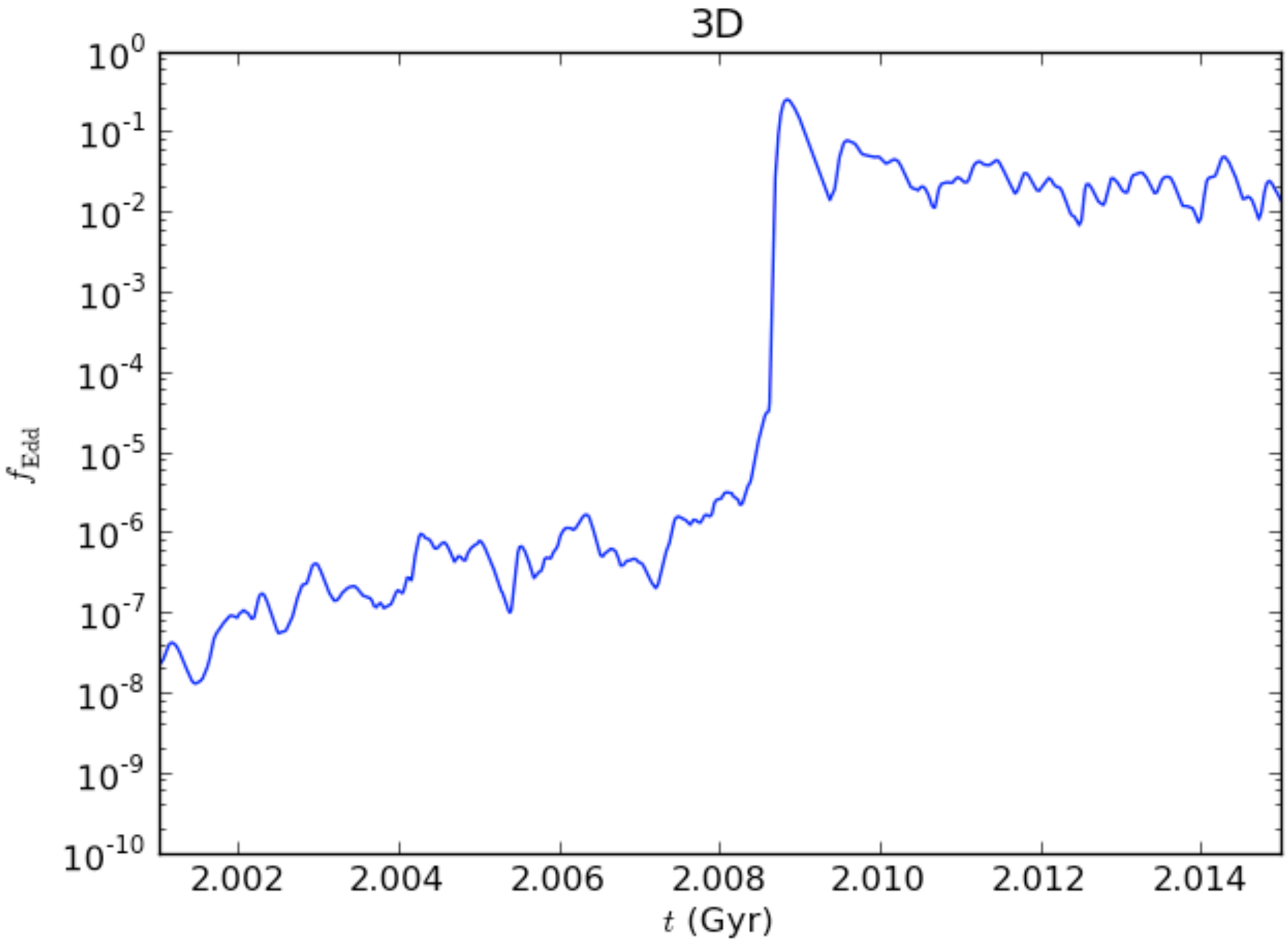
Black Hole accretion in a 1D galaxy



Black Hole accretion in a 2D galaxy

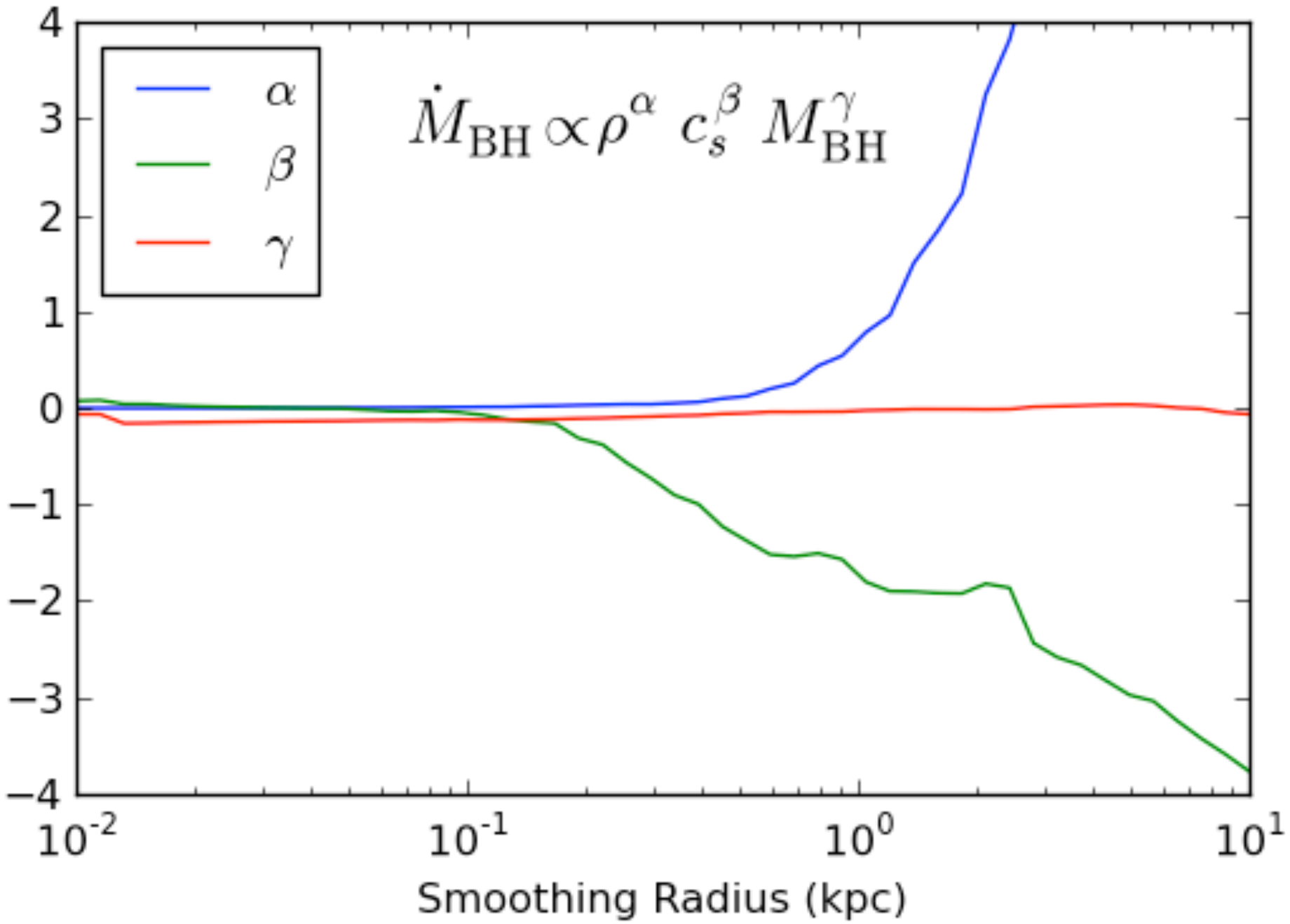


Black Hole accretion in a 3D galaxy



Accretion rate does not depend on small scale gas properties (... ?!?!)

Novak, Durier + Babul (in prep)



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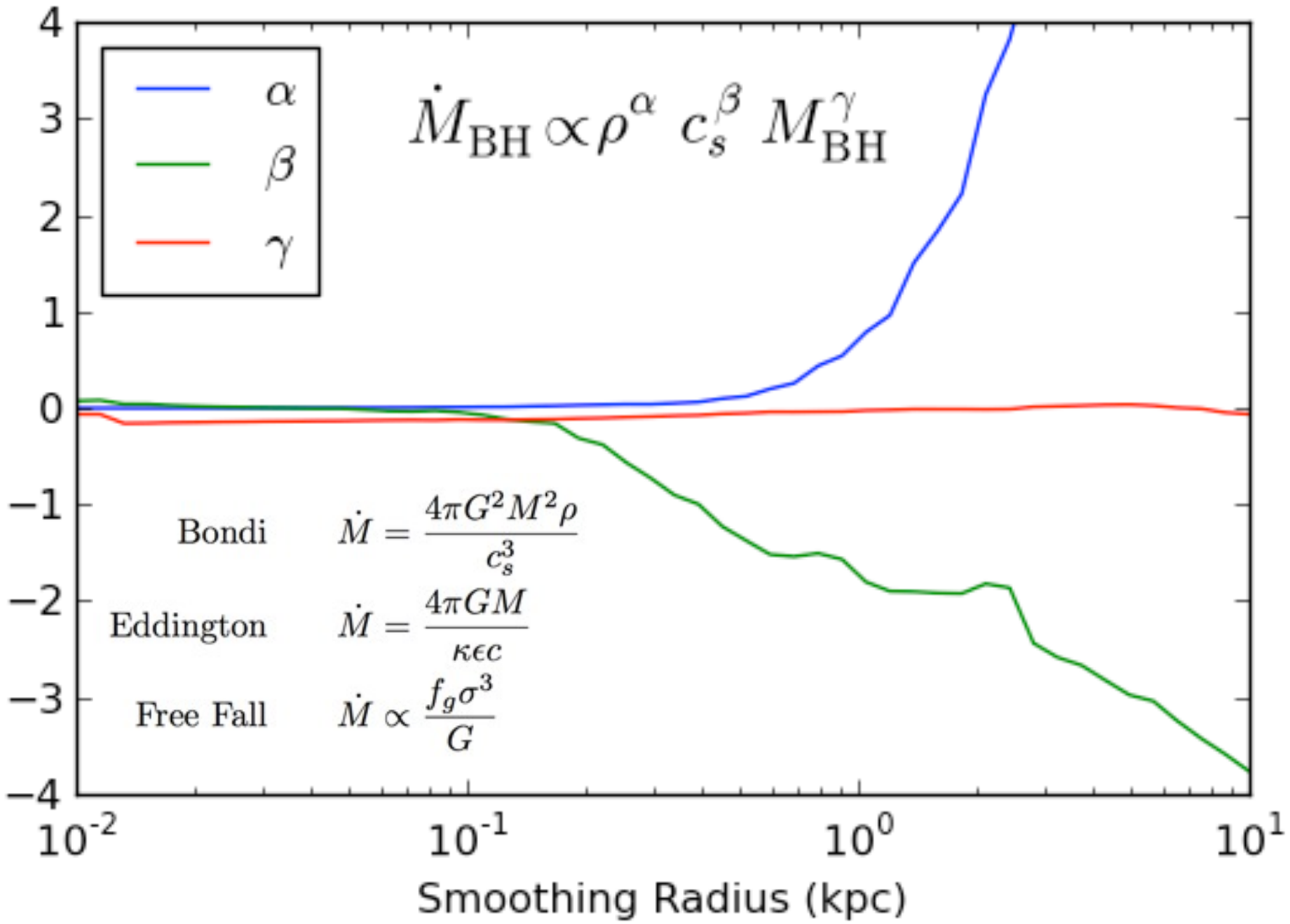

Conclusions

- We have implemented a physically rich AGN fueling and feedback model in order to work out the “nuclear physics” of galaxies
- 1D/2D/3D models are different in important, interesting, and comprehensible ways.
- Sub-resolution recipe based on these simulations suitable for use in lower resolution simulations coming soon (Novak, Durier + Babul in prep)
- Fueling does not seem to depend on small-scale gas properties, favoring free-fall limited accretion picture (e.g. Nixon et al, King, Begelman)