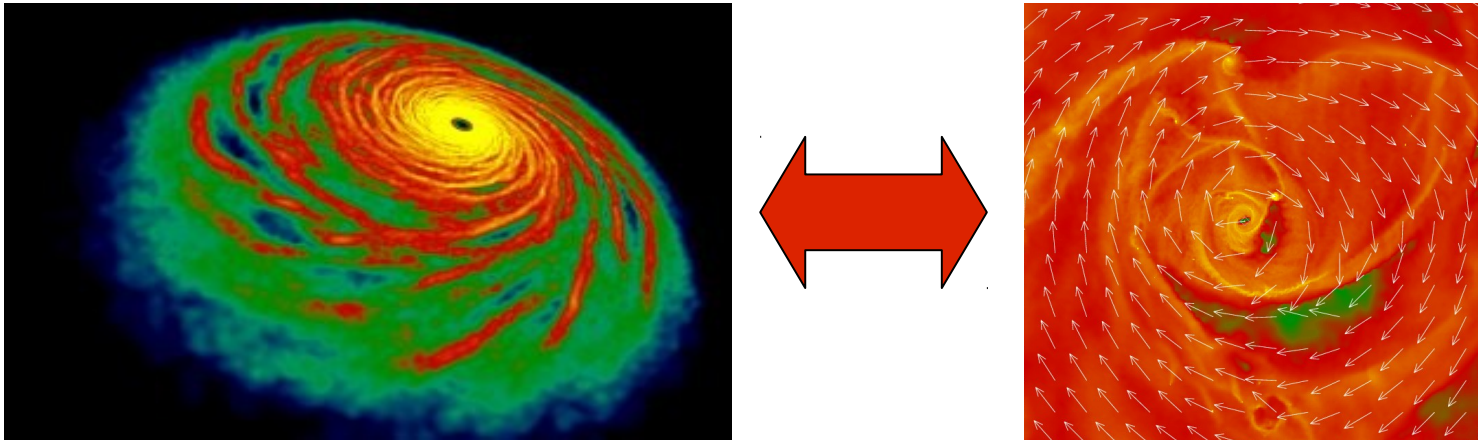
University of Leicester

AGN Feeding and Feedback Numerical Models



Chris Power, University of Leicester
in collaboration with
Alexander Hobbs, Andrew King & Sergei Nayakshin

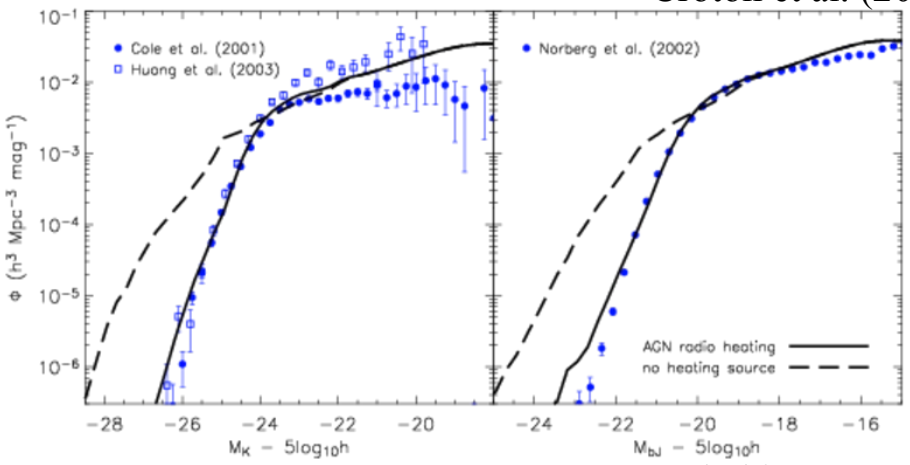
What I'm about to say...

- Model AGN feedback as a momentum-conserving outflow, locally...
    - Can explain observed M_{BH}-σ correlation.
- Modelling AGN feeding is much more challenging problem...
    - Bondi accretion is rarely a good description.
    - Angular momentum of accretion flow is important.
- Competition between black hole growth, star formation & feedback...
    - Stellar feedback as important as AGN feedback

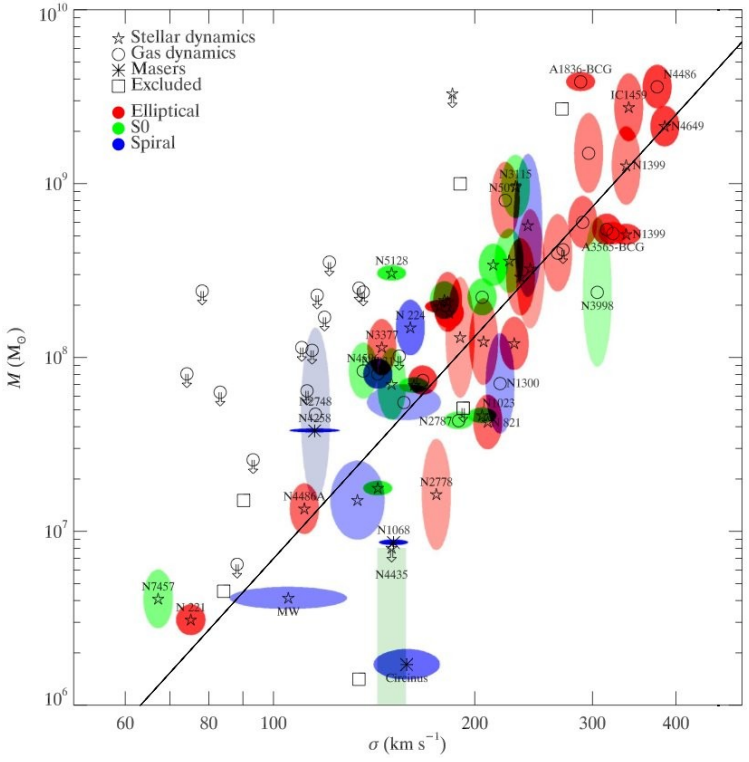
AGN Feedback is Important

- Accretion most efficient way to liberate rest mass energy.
  - $E_{acc}/E_{Bind} \sim 100$
- Expect AGN feedback to be important... but how?
- Regulates formation of massive galaxies (e.g. Bower et al. 2006, Croton et al. 2006).
- Natural explanation for observed M-σrelation (e.g. Fabian 1999, King 2003/05, Murray et al. 2005).

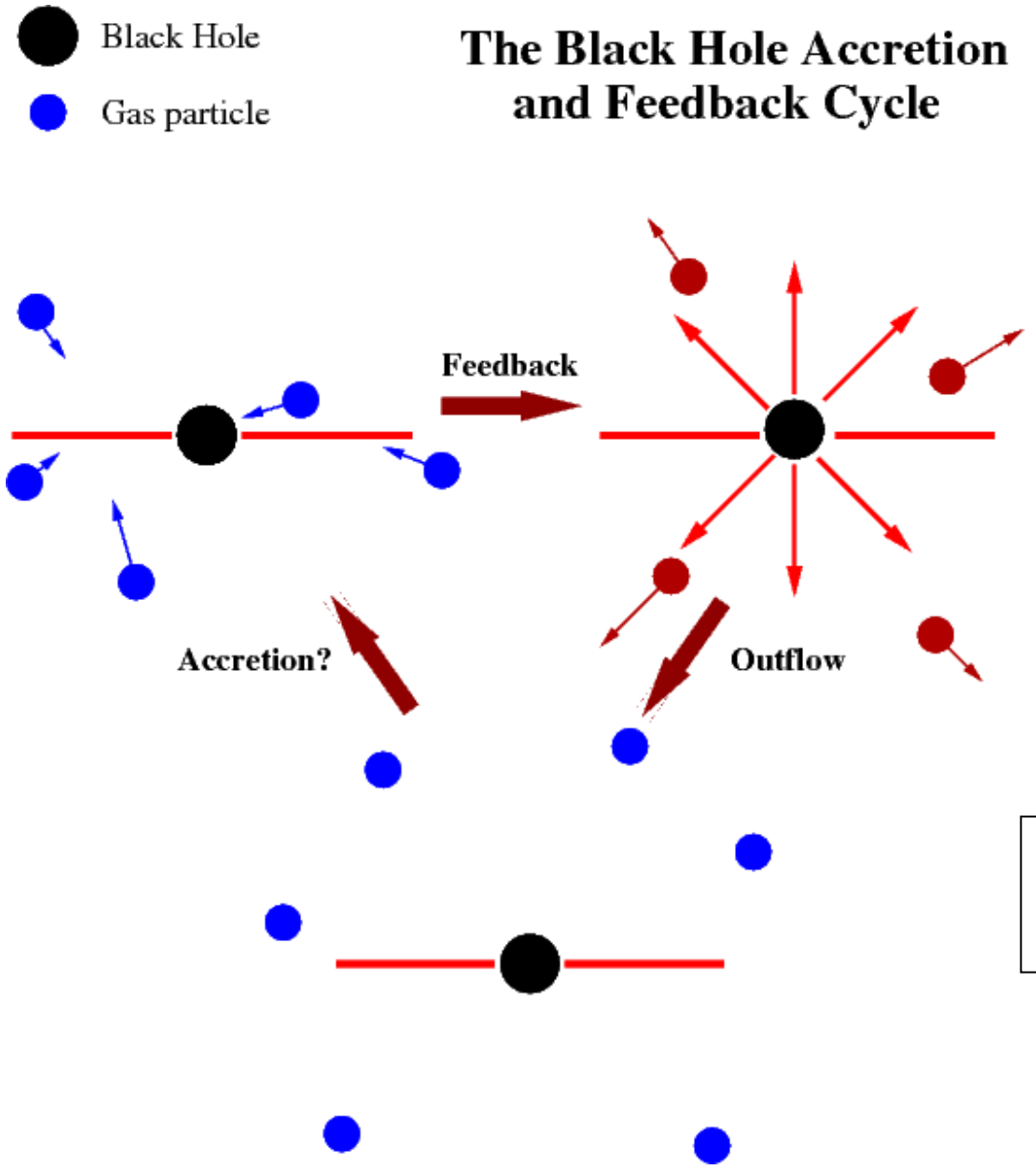
Croton et al. (2006)



Gultekin 2009



The AGN Feedback Cartoon



But how does it work??

Modelling AGN Feeding & Feedback

From Di Matteo et al. 2005

- **Problem :** cannot resolve relevant scales.
- Sub-grid models unavoidable.
  - Bondi accretion
  - Thermal feedback
- Reproduce observed scaling relations by construction.

<u>BUT...</u>

- **Problem:** unphysical models.
- Do current models tell us anything meaningful?

A Model for AGN Feedback

- Simple model : AGN outflow sweeps up ambient gas in galaxy, drives it outwards, possibly expelling it from potential.
- Silk & Rees (1998) : energy-conserving outflow – scales as σ^5 – unphysical – gas cools and radiates energy away!

- Fabian (1999), King (2003, 2005) : momentum-conserving outflow.
- King (2003) : Eddington-limited outflow, momentum flux is

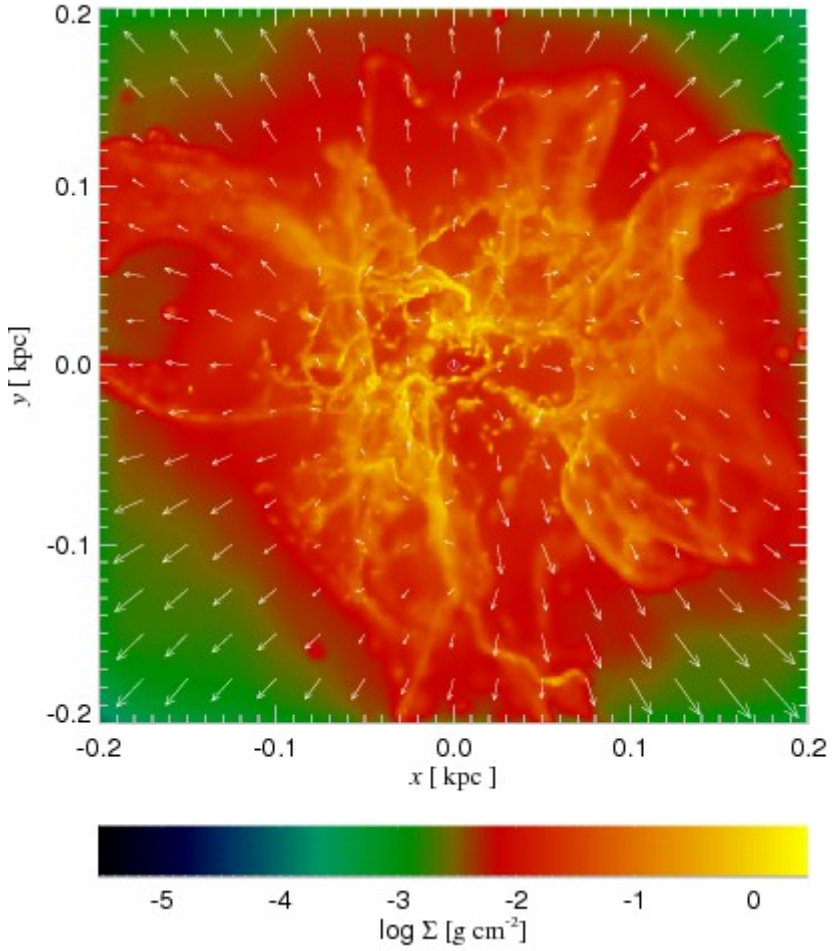
$$\dot{P}_{\rm SMBH} \approx \frac{L_{\rm Edd}}{c} = \frac{4\pi G M_{\rm BH}}{\kappa}$$

which implies

$$M_\sigma = \frac{f_g \kappa}{\pi G^2} \sigma^4$$

See Andrew King's talk tomorrow…

A Numerical Model for AGN Feedback



From Power & Nayakshin, in prep

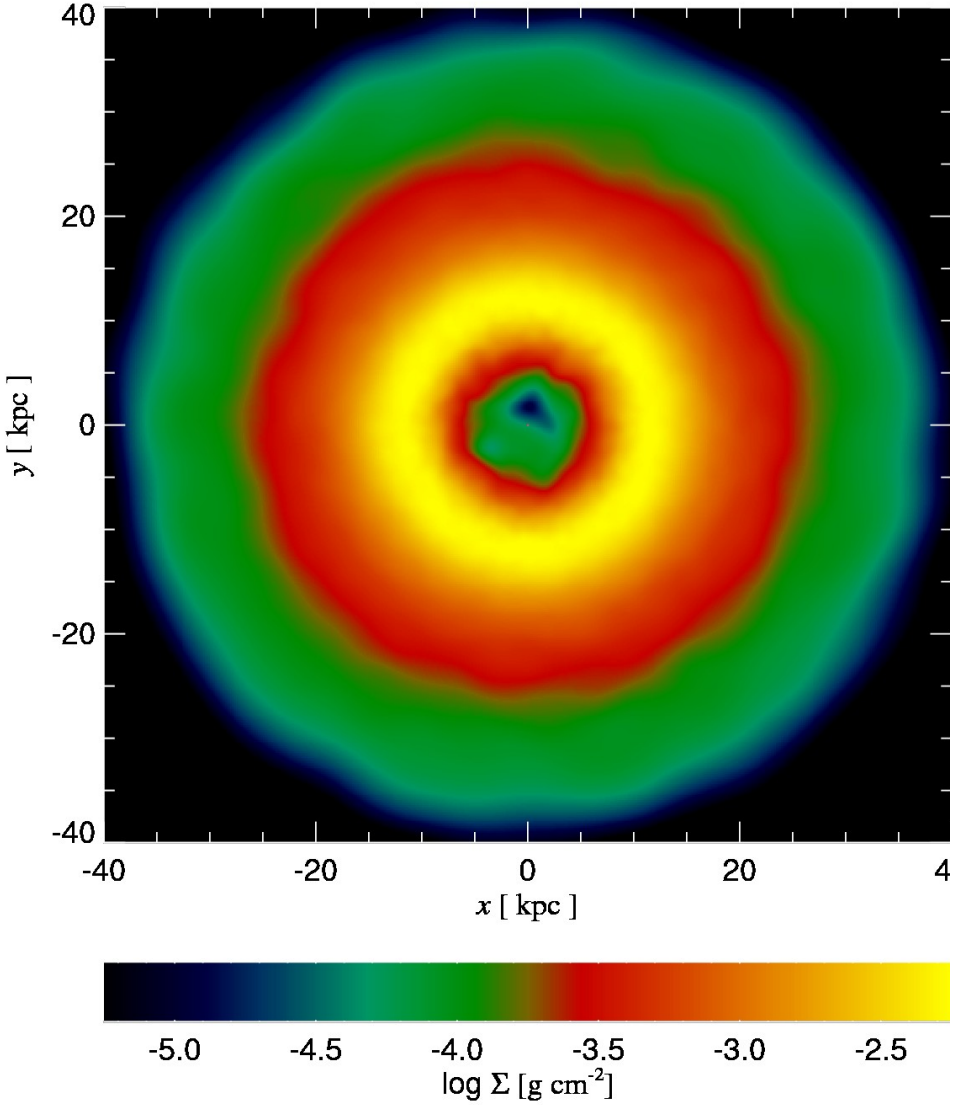
- Need to go beyond analytical arguments...
- Use Radiation Hydrodynamics in GADGET (Nayakshin, Cha & Hobbs 2009)

✓ Analytical models develop physical framework...

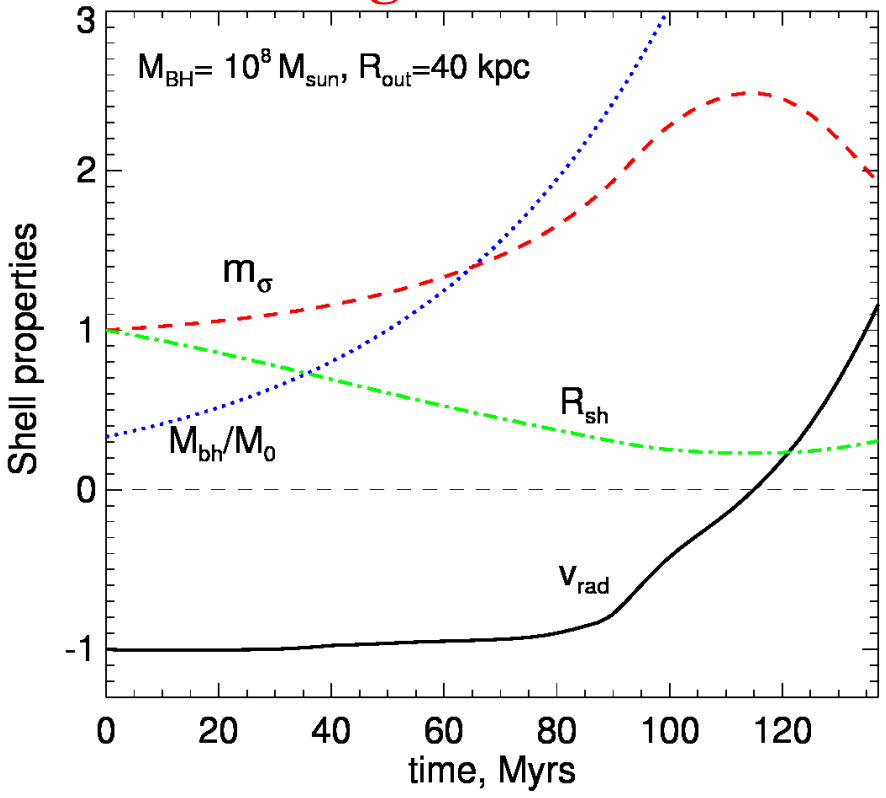
✓ Test ideas using controlled simulations...

✓Apply to astrophysically realistic situations.

Testing AGN Feedback



Eddington-Limited

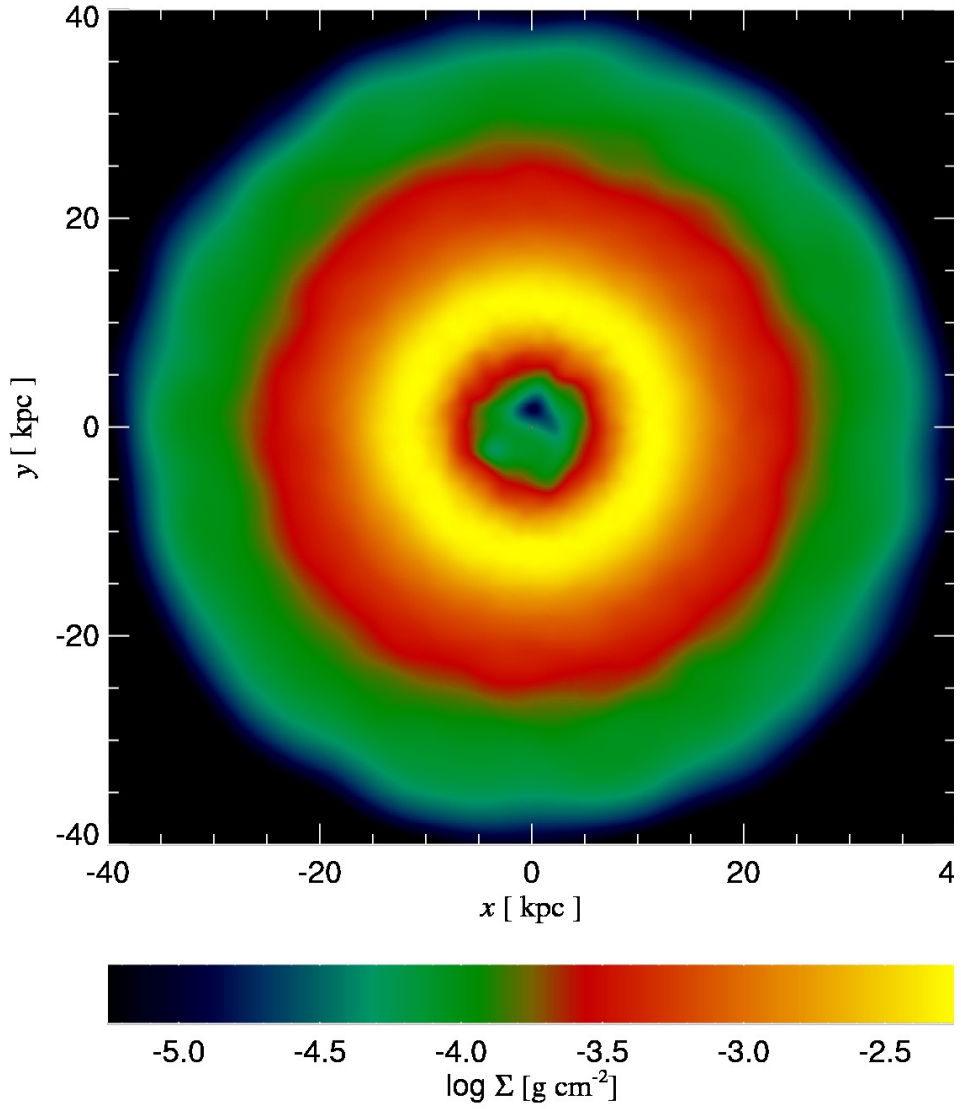


Radial Inflow: wind from BH expels infalling shell of gas.

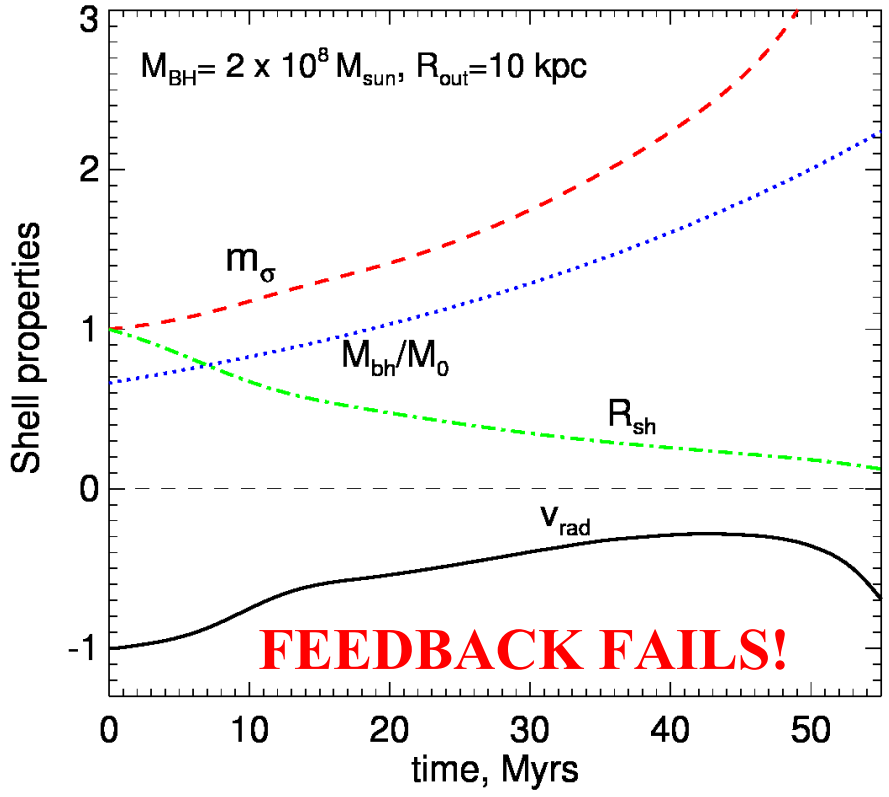
Recover M-σ... but how do we feed the AGN?

From Nayakshin & Power 2010

Testing AGN Feedback



Eddington-Limited



Radial Inflow: wind from BH cannot prevent infall, central regions become smothered.

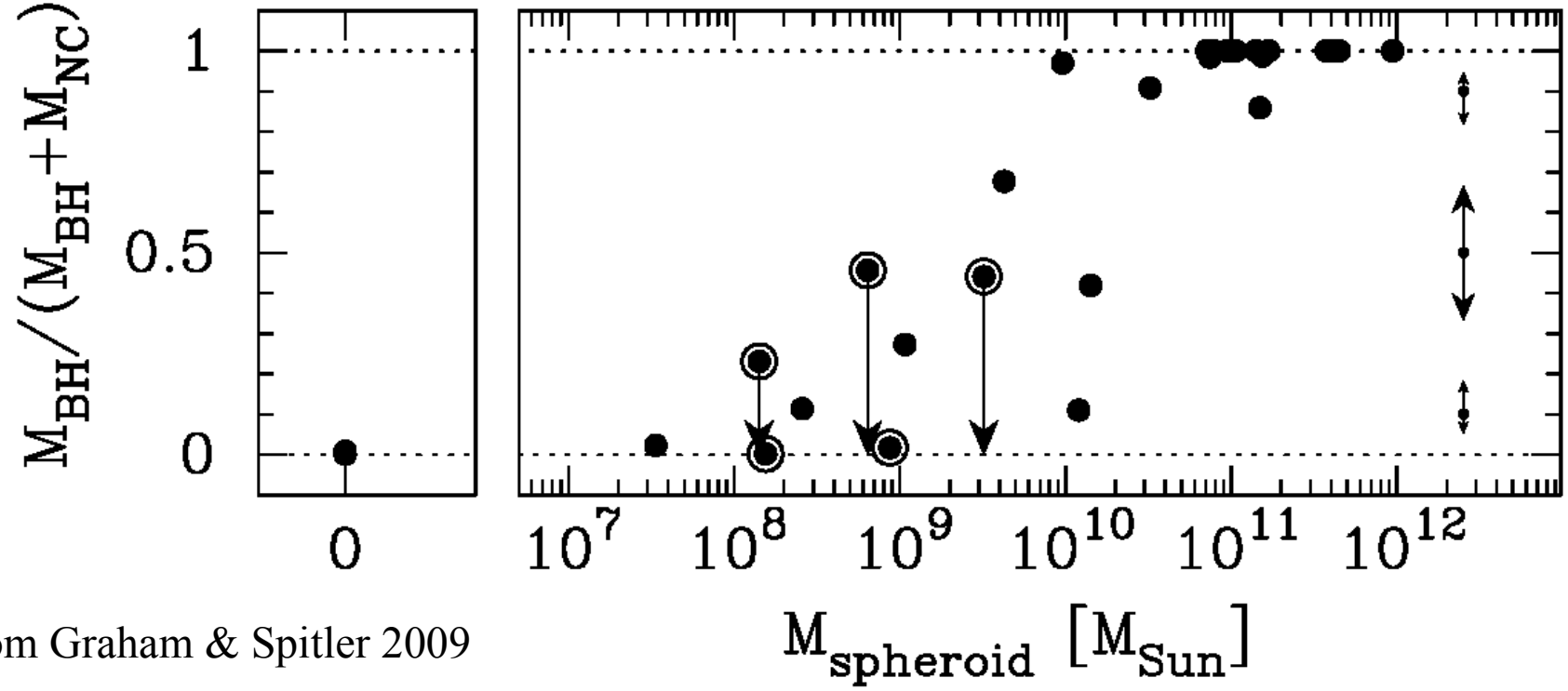
From Nayakshin & Power 2010

SMBH Growth & Star Formation

Nuclear star cluster growth preferred at expense of BH growth in low-mass galaxies – SF timescale shorter than Salpeter time.

Implications for low-mass end of the M-σ relation.

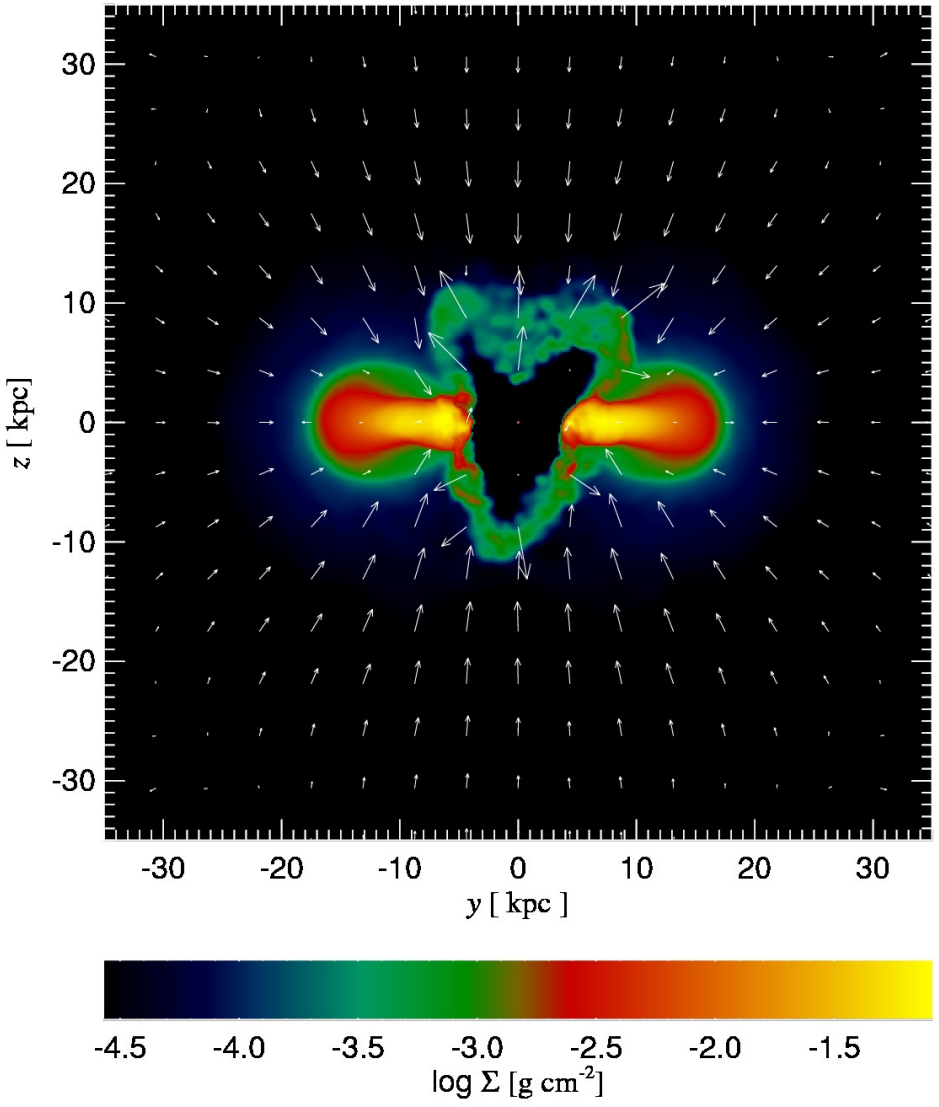
Nayakshin, Wilkinson & King 2009



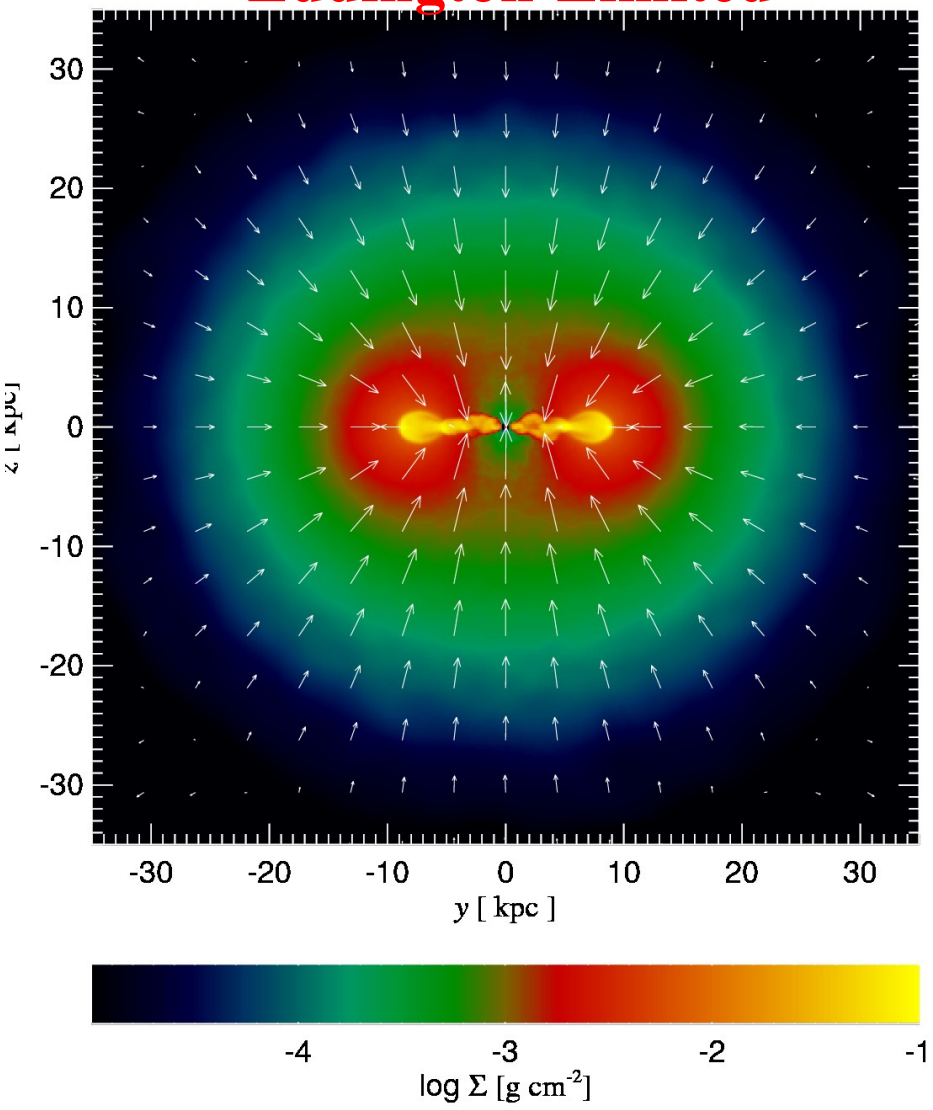
From Graham & Spitler 2009

Testing AGN Feedback

From Nayakshin & Power 2010



Eddington-Limited



Rotating Inflow : No longer recover M-σ, but can feed the AGN.

Linking AGN Feedback to Feeding

- How do we relate SMBH accretion rate to properties of accretion flow at 100 pc? 1 kpc? 10 kpc? (e.g Thompson et al. 2005, Hopkins & Quataert 2009, Levine et al. 2010)
- Distill complex physics into a simple estimator...
- Standard approach based on Bondi accretion (e.g. Springel et al. 2005, Booth & Schaye 2009)

$$\dot{M}_{\rm BH} = \frac{4\pi\,\alpha\,G^2\,M_{\rm BH}^2\,\rho}{(c_s^2+v^2)^{3/2}}$$

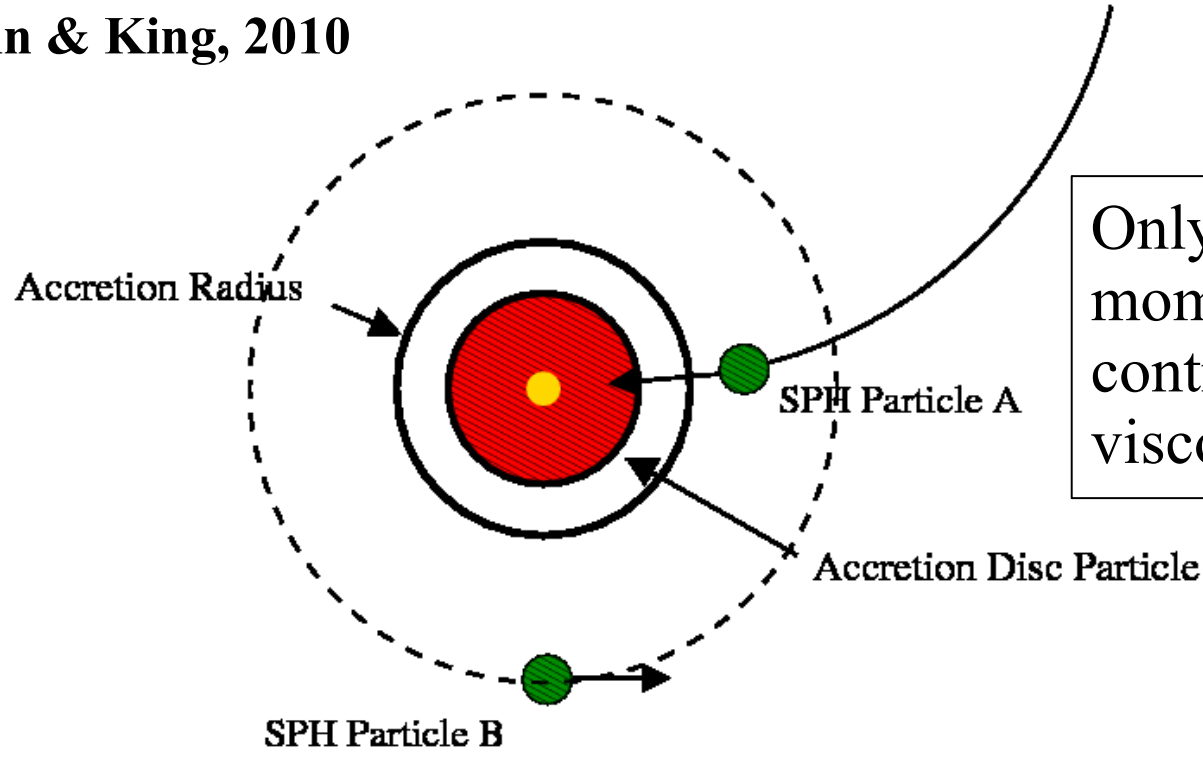
Bondi rate depends only on density & temperature; accretion is instantaneous.

but this is very unsatisfactory...

- **Problem 1 :** How do we define the Bondi radius? (Hobbs, Power, Nayakshin & King, Submitted)
- **Problem 2 :** Angular momentum is important...

Accretion Disc Particle Approach

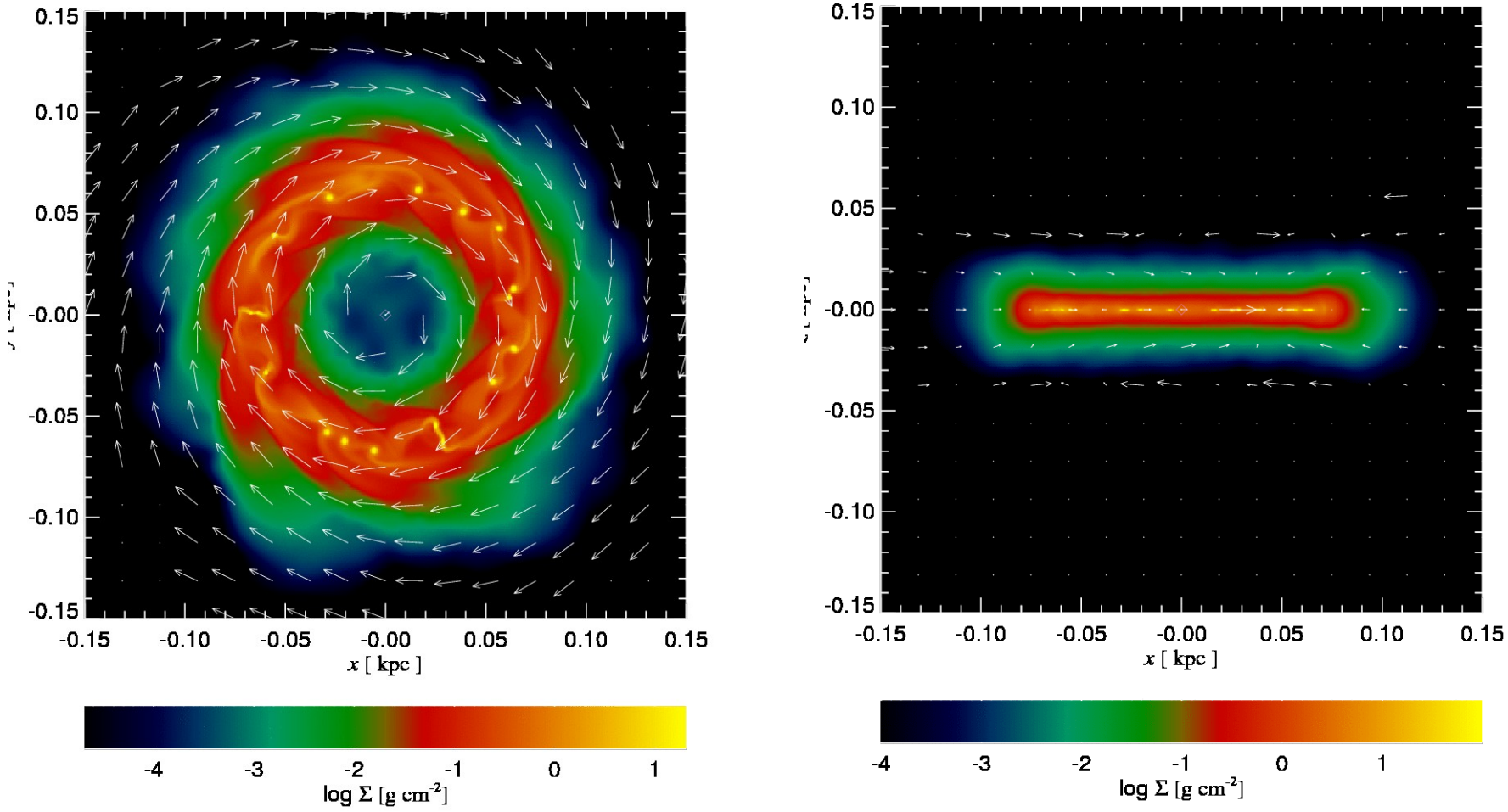
Power, Nayakshin & King, 2010
arxiv:1003.0605



Only lowest angular momentum gas can contribute, on a viscous timescale.

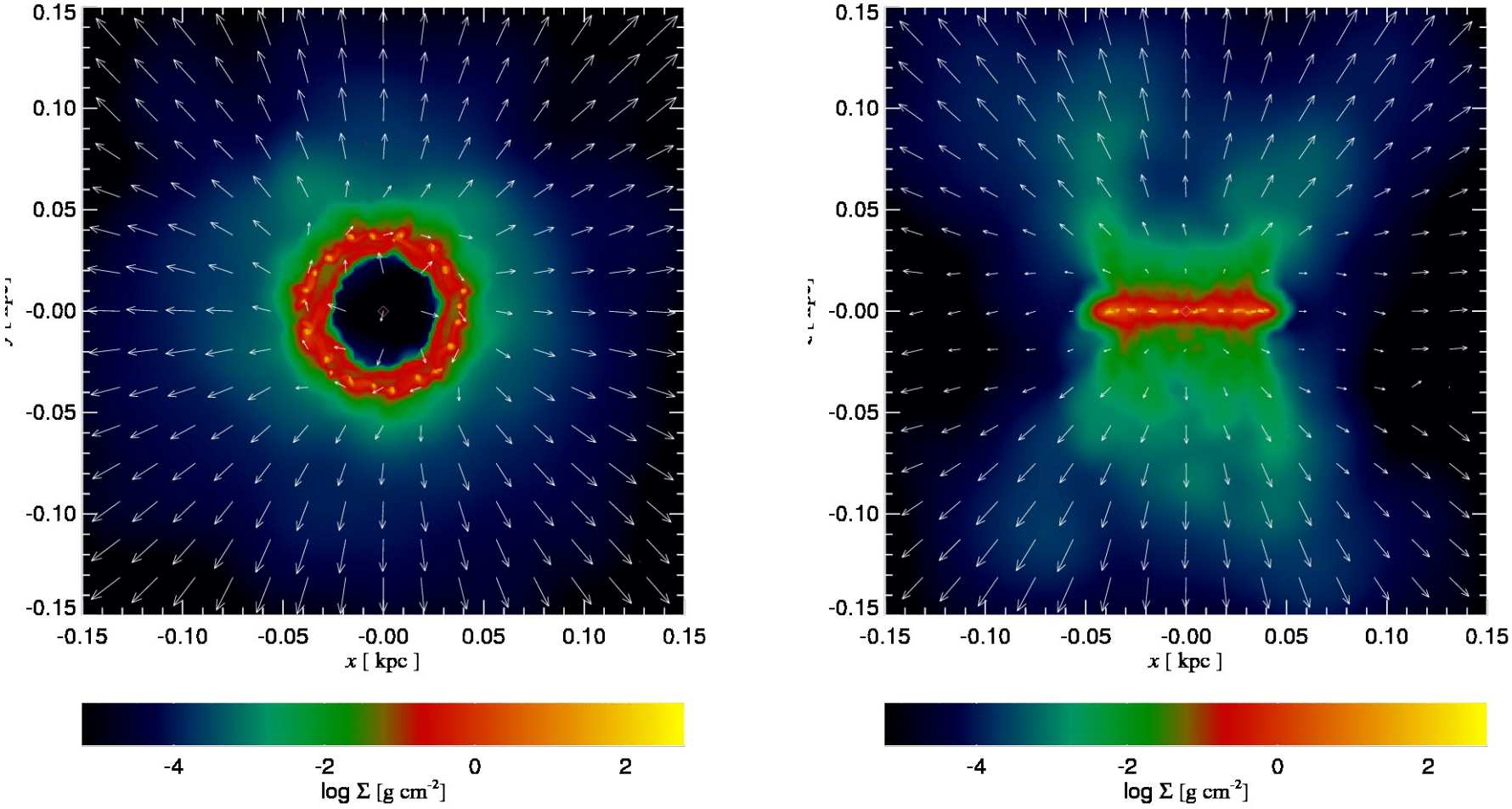
- Extension of sink particle method (Bate et al. 1995) – capture gas if angular momentum is sufficiently small.
- Adds to mass of accretion disc, BH fed on viscous timescale.
- Feedback proportional to accretion rate – Eddington limited.

Accretion Disc Particle



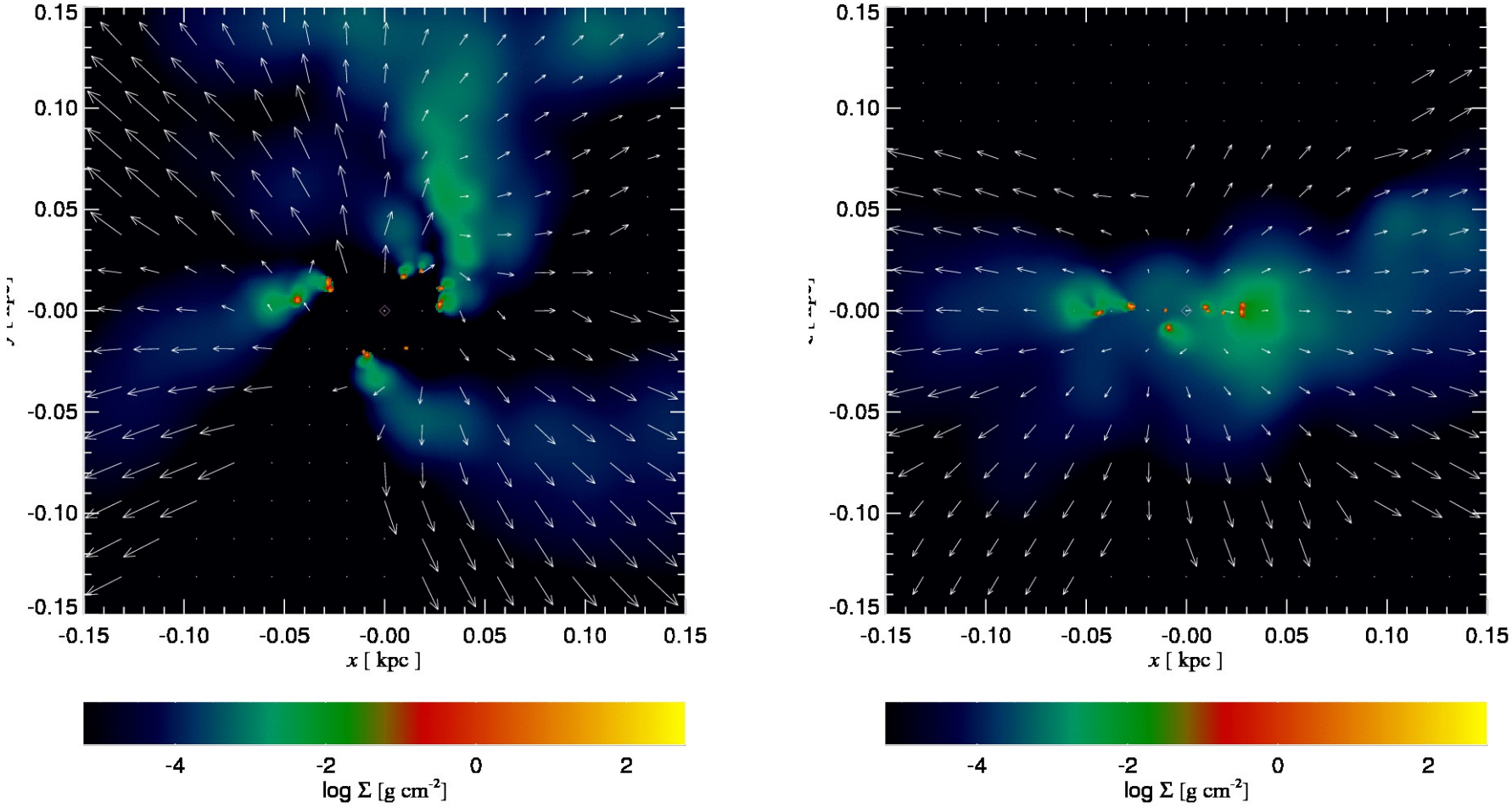
From Power, Nayakshin & King 2010

Early Times : Bondi



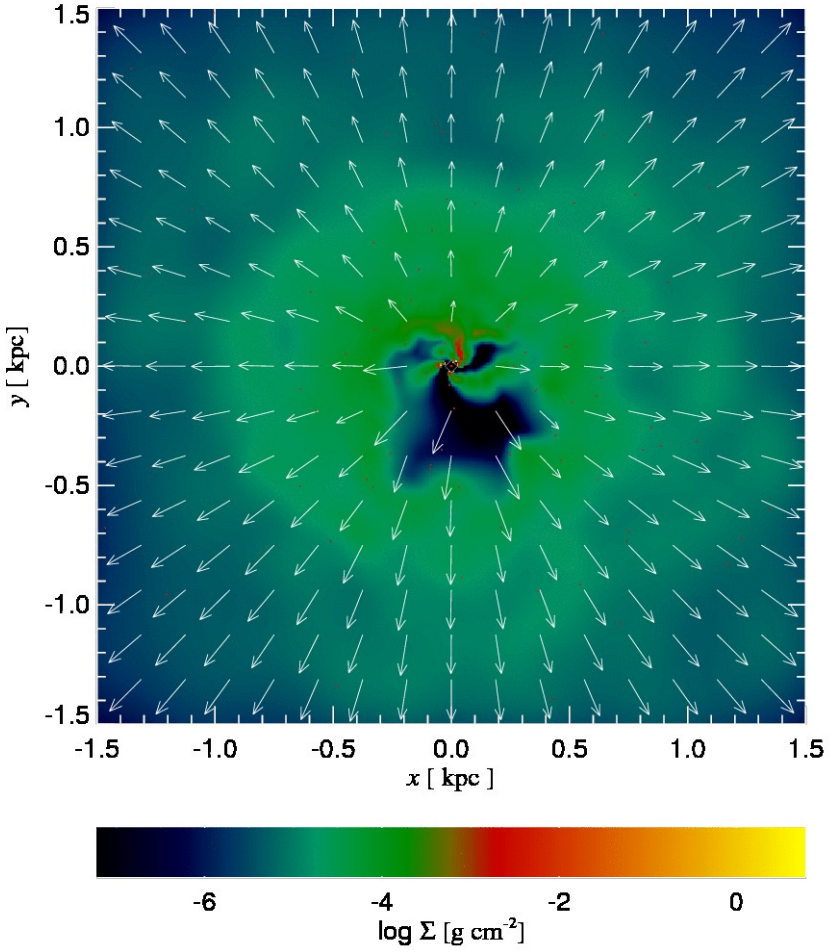
From Power, Nayakshin & King 2010

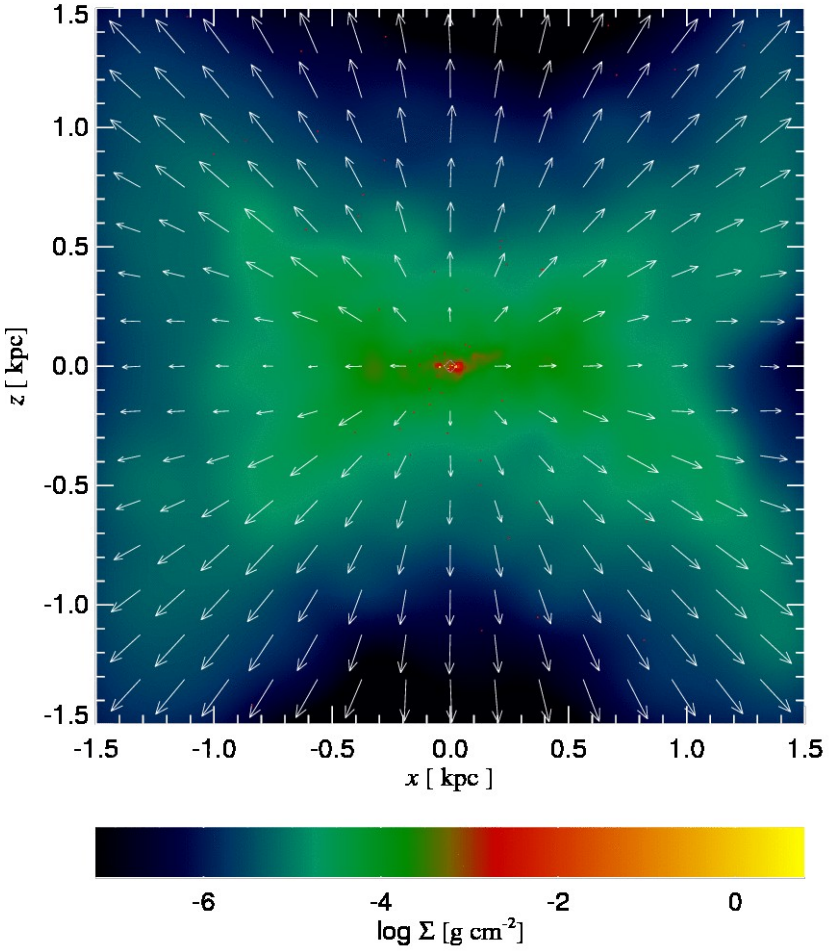
Late Times : Bondi



From Power, Nayakshin & King 2010

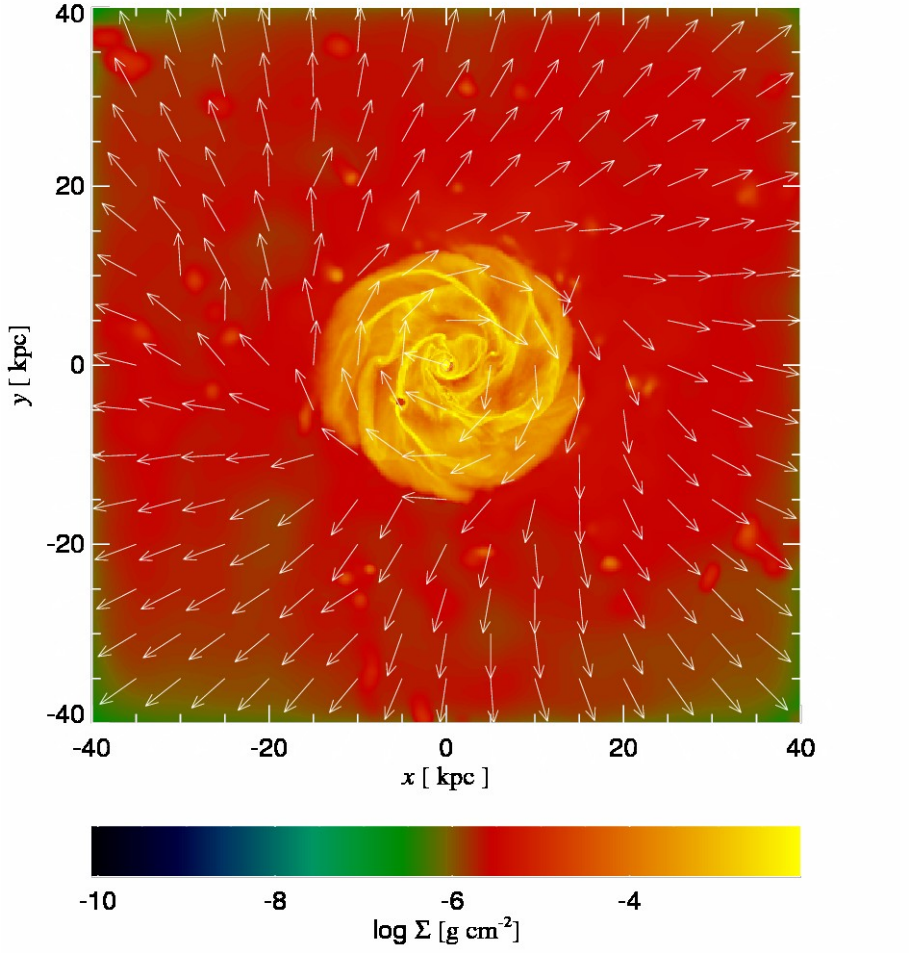
Late Times & Large Scales : Bondi

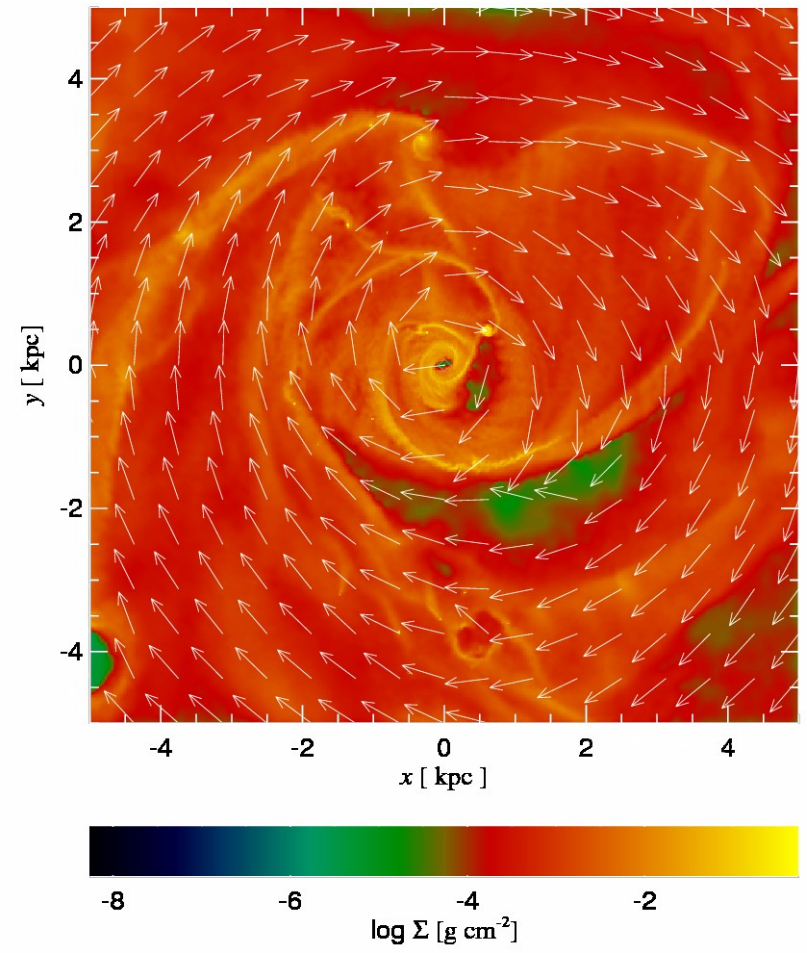




From Power, Nayakshin & King 2010

Modelling Galaxies I

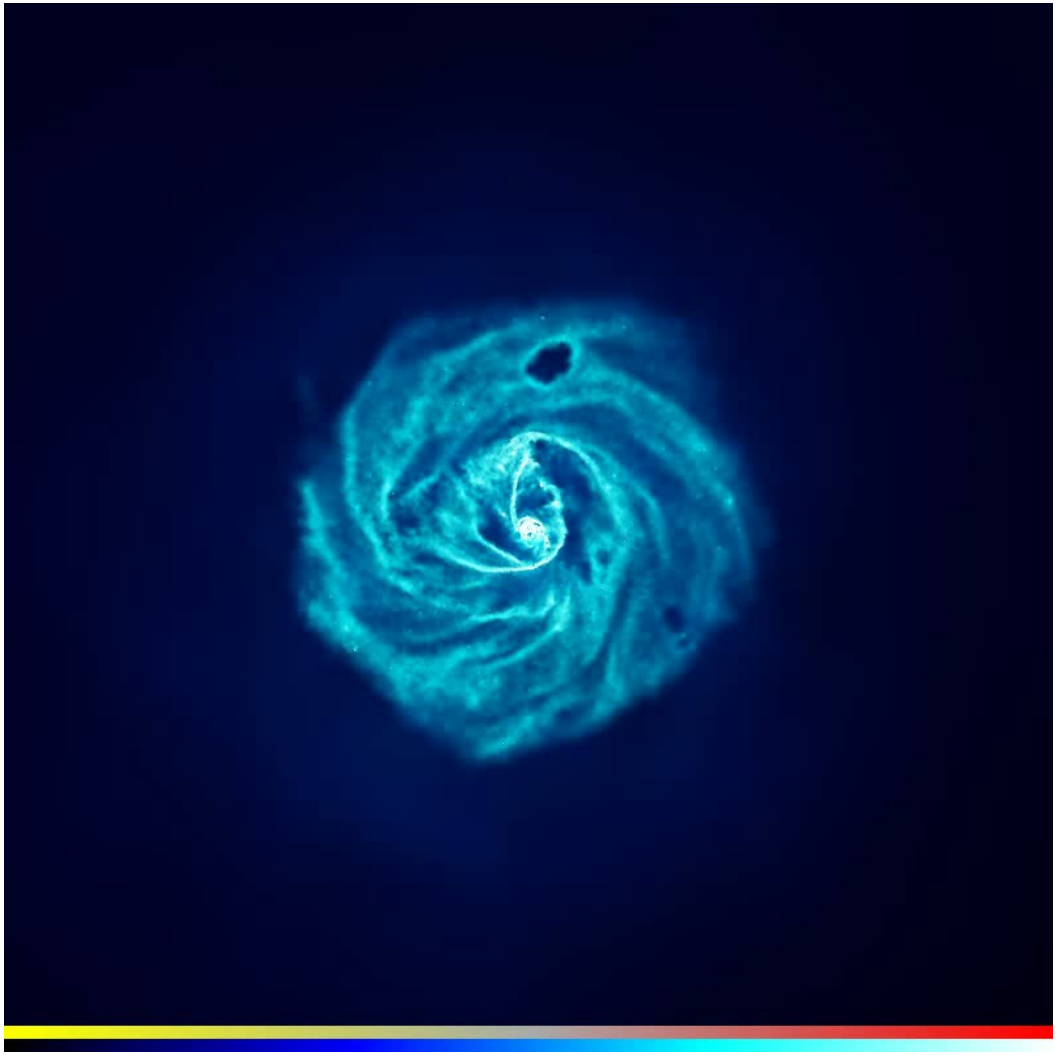




From Power, Hobbs & Read, In Prep

Look at SMBH fuelling in isolated galaxies.

Modelling Galaxies II



Power, Hobbs, Read, Nixon & Cole

Merger between MW & M31

Low accretion rate over ~7 Gyrs, but star formation and stellar feedback important.

M_{BH} - M_{Bulge} determined by stellar rather than SMBH feedback (Power, Zubovas, Nayakshin & King 2010).

What I've said...

- Model AGN feedback as a momentum-conserving outflow, locally...
  - Can explain observed M_{BH}-σ correlation.
  - Cannot explain M_{BH}-M_{Bulge} correlation (by itself).
- AGN feeding is much more challenging problem...
  - Bondi accretion is rarely a good description.
  - Angular momentum of accretion flow is important.
- Competition between black hole growth, star formation & feedback...
  - Stellar feedback as important as AGN feedback.
  - Underweight SMBHs in low-mass galaxies.
  - Can explain M_{BH}-M_{Bulge} correlation.