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AGN feeding: "the intermediate scale"

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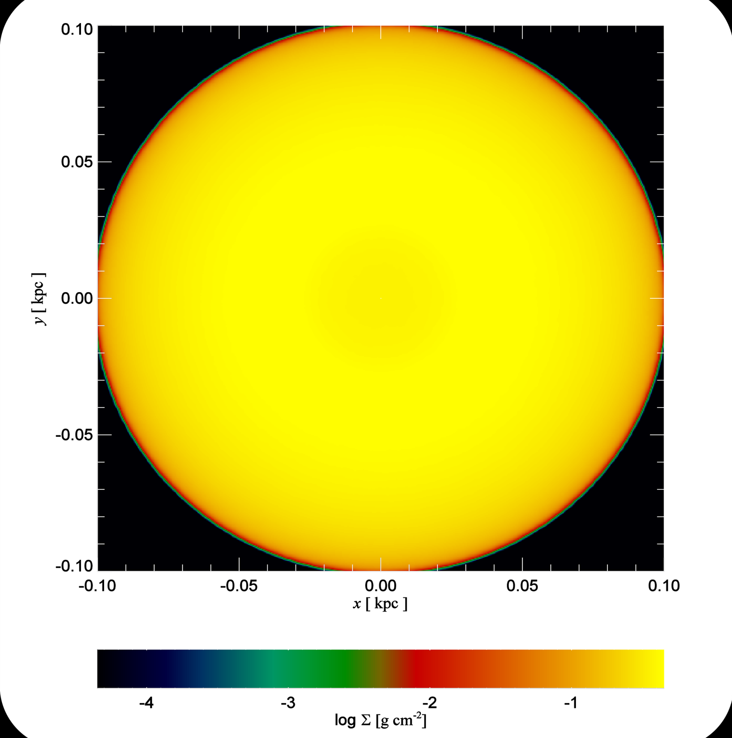
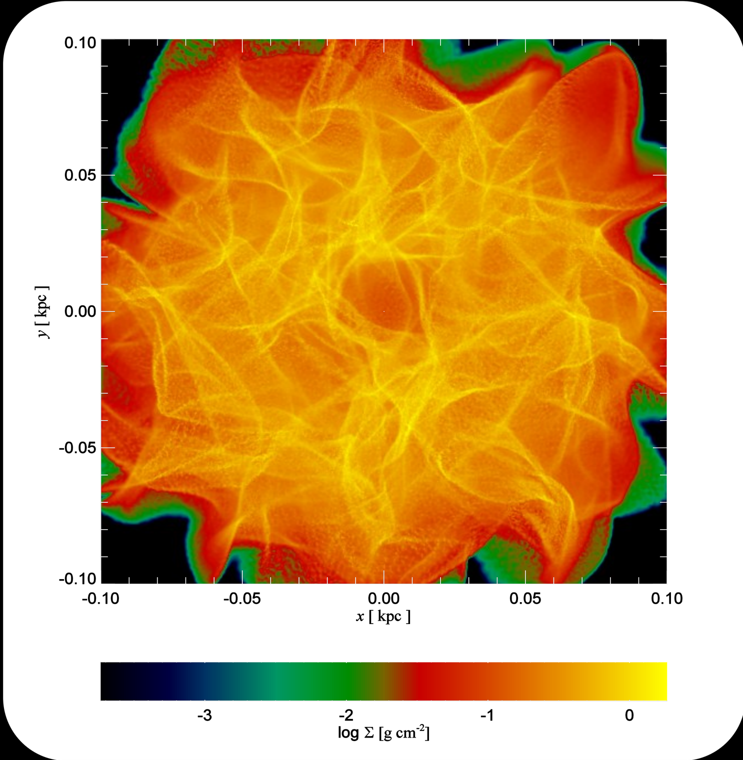
Abstract

The feeding of Active Galactic Nuclei (AGN) from the large-scale kiloparsec flow to the small-scale accretion flow is poorly understood. Here we take one of the first steps in modelling the dynamics of the gas at the intermediate scale, from the inner 100 pc of a galactic bulge to the inner parsec. We seed a spherically symmetric gaseous shell with supersonic turbulence, motivated by observations of supernovae feedback, and study the effect of varying the net rotation and turbulent velocities on the accretion rate. The shell infalls under the influence of a supermassive black hole (SMBH) at the centre of a static bulge potential. We find that in the presence of finite net angular momentum, supersonic turbulence significantly enhances the accretion rate onto the SMBH.



Motivation

In large-scale cosmological simulations, sub-grid models are needed to track the SMBH accretion rate. Often these are based on simplistic assumptions, e.g. Bondi-Hoyle accretion (Bondi 1952). An exploration of intermediate-scale flow is required to constrain these models. High redshift observations (e.g. Kurk et al. 2007) suggest a high accretion rate onto the central SMBH (~ 1 M_{sun} yr^{-1}). The requires rapid growth at or near the Eddington limit for a sustained period of time.

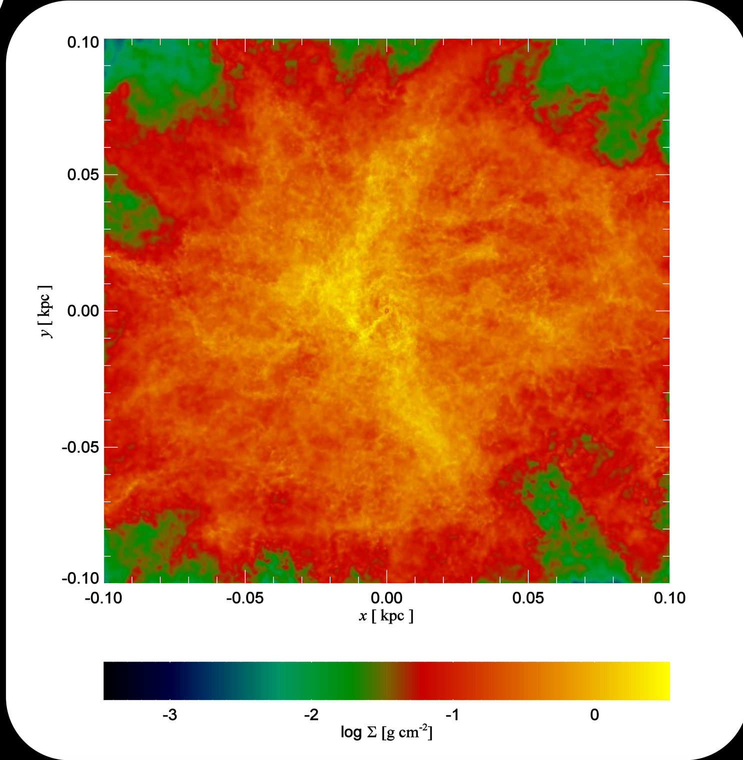


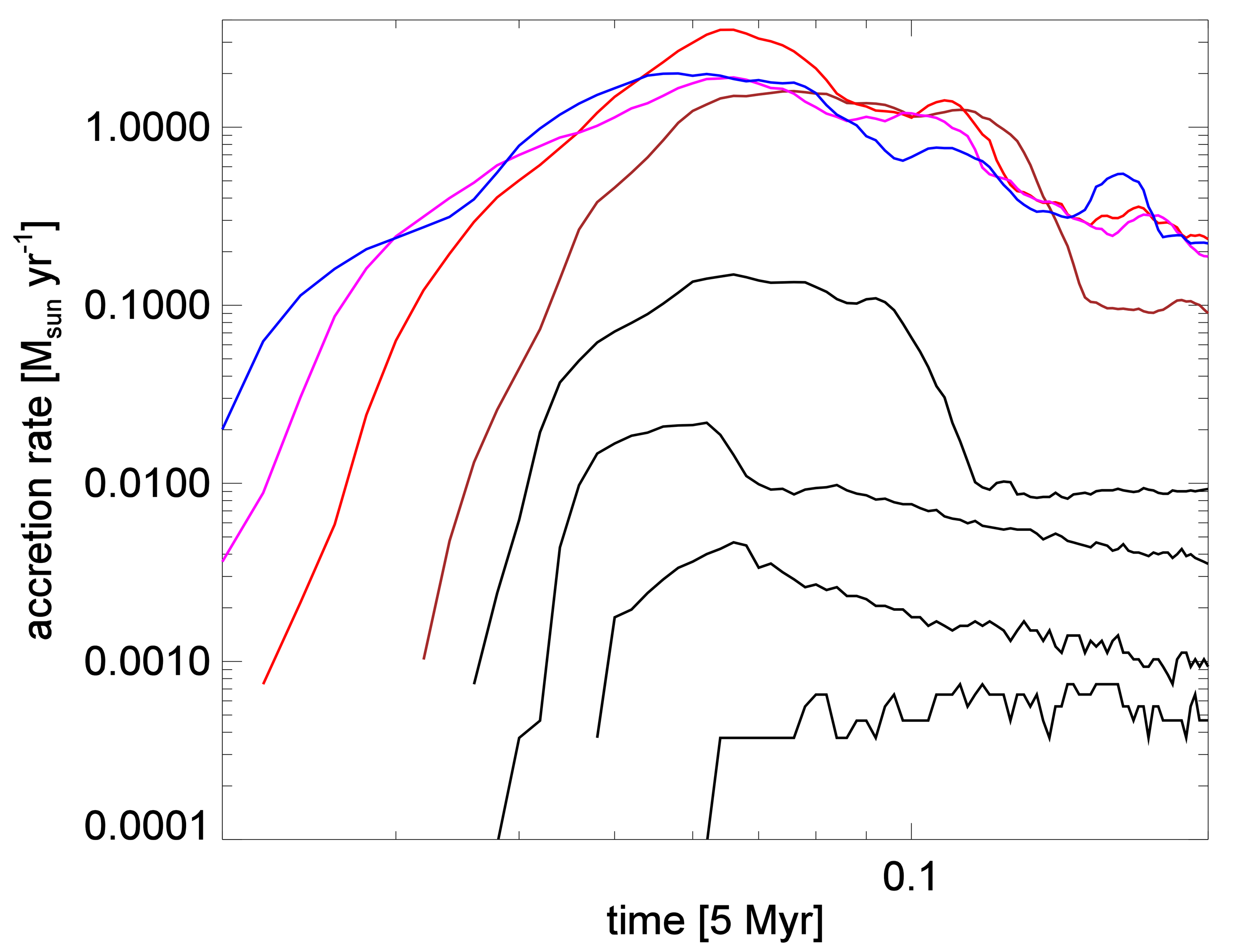
How do SMBHs grow so quickly?

One possible explanation for this is the action of supersonic turbulence, arising from supernova feedback in the bulge. The turbulence may drive the gas inwards through large-scale stirring at the dominant wavelength (~ tens of pc). This allows randomised feeding.

Results

We find that the accretion of gas onto the SMBH strongly correlates with the strength of the imposed turbulence. Depending on the rotation velocity, high turbulence can enhance the accretion rate by ~ 3 orders of magnitude (see Figure below).

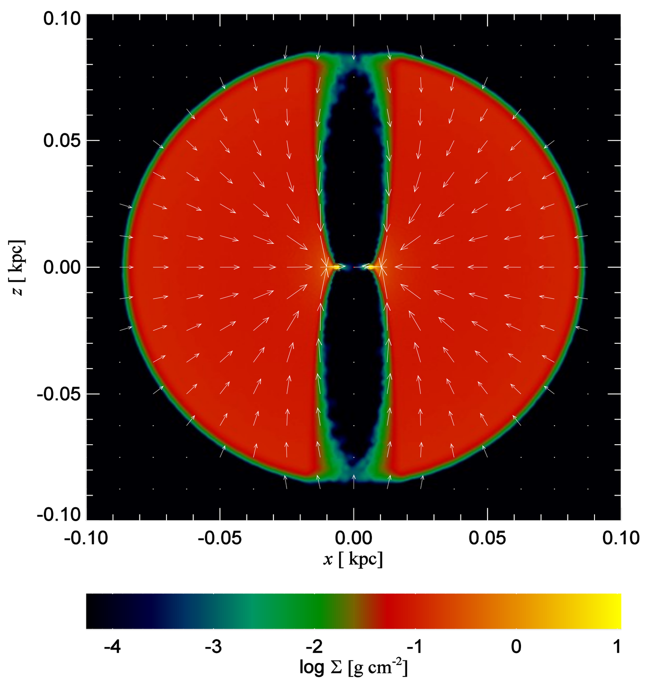




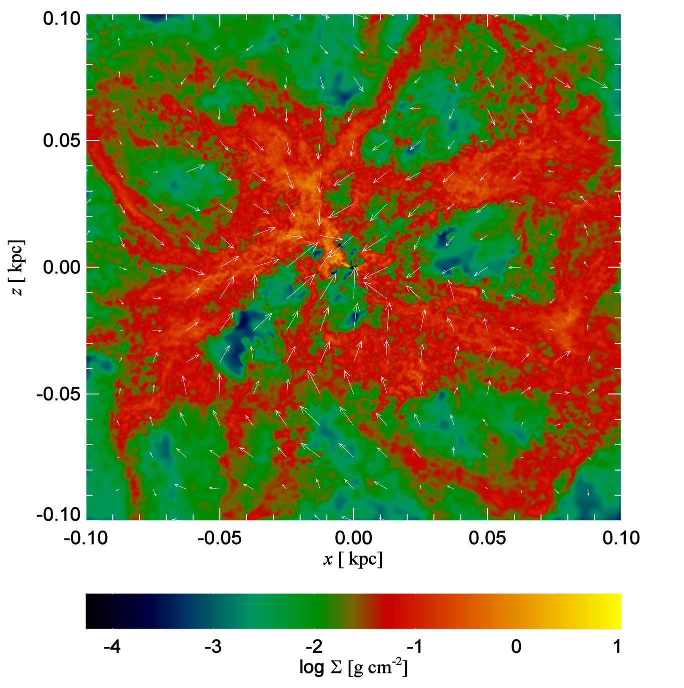
Accretion rate vs. time for simulations with v_{rot} = 100 km s^{-1} and varying strengths of turbulence. Key: from no turbulence up to v_{turb} = 60 km s^{-1} (black), v_{turb} = 100 km s^{-1} (brown), v_{turb} = 200 km s^{-1} (red), v_{turb} = 300 km s^{-1} (pink), v_{turb} = 400 km s^{-1} (blue)

The accretion trend with increasing turbulence saturates once the peak turbulent velocity (v_{turb}) becomes of the order of the rotation velocity (v_{rot}). Increasing the turbulence above this then leads to a decrease in the accretion rate.

Initial conditions



Side-on projected density of a slice of the shell without turbulence as it collapses, at t = 0.3 Myr. The shell has a net rotation velocity of v_{rot} = 60 km s^{-1} about the z-axis.



Side-on projected density of a slice of the turbulent shell at t = 0.3 Myr with v_{rot} = 60 km s^{-1}, $\langle v_{turb} \rangle$ = 200 km s^{-1}. The infall is dominated by random motions.

Uniform density, spherically symmetric thick gaseous shell extending from r = 30 - 100 pc, centered on the SMBH.

Velocity field: rotation (const v_ϕ) + turbulent spectrum

Kolmogorov turbulence: $P_v(k) \sim k^{-11/3}$ $\vec{v} = \nabla \times \vec{A}$

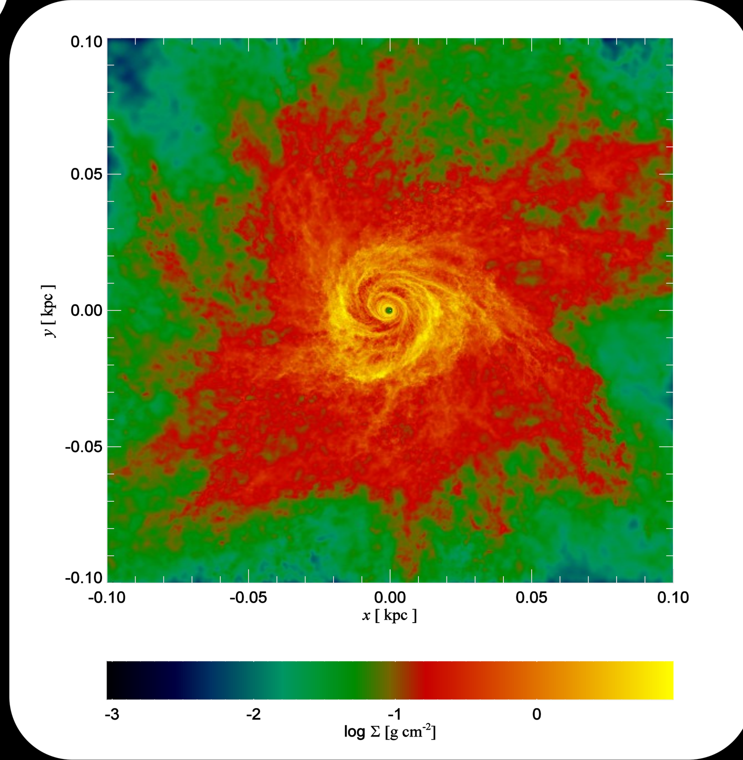
Gaussian random field $< |A_k|^2 >= C(k^2 + k^2_{\rm min})^{-17/6}$

Numerical method

- Smoothed particle hydrodynamics code GADGET-3 (Springel 2005) with no self-gravity
- External potential - Jaffe (γ = 2) cusp + core + SMBH:

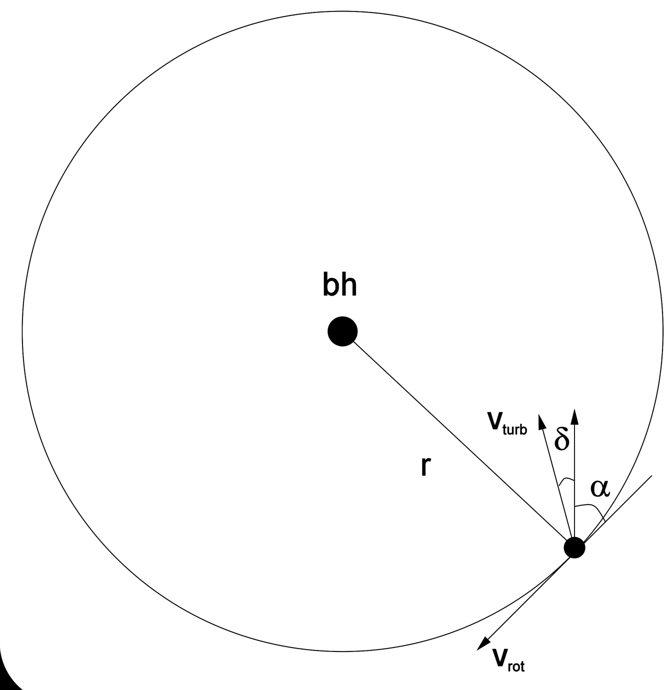
$$M(r) = M_{\rm bh} + \begin{cases} M_{\rm c}\left(\frac{r}{r_{\rm c}}\right)^3, & r < r_{\rm c} \\ M_{\rm c} + M_a\left(\frac{1}{r_{\rm c}+a} - \frac{1}{r+a}\right), & r \geq r_{\rm c}, \end{cases}$$

- M_c = 2x10^8 M_{sun} • r_c = 20 pc • M_a = 10^{11} M_{sun} • a = 10 kpc



- M_{SMBH} = 1x10^8 M_{sun}
- M_{shell} = 5x10^7 M_{sun}
- Accretion radius r_{acc} = 1 pc
- Isothermal at T = 10^3 K
- Adaptive smoothing lengths down to h_{min} = 2.8x10^{-2} pc
- Artificial viscosity with α = 1
- N_{sph} ~ 4x10^6
- m_{sph} ~ 12 M_{sun}

Analytical interpretation



For strong turbulence we can construct a "ballistic" theory for the dense regions of gas that form, and infall to the SMBH at nearly free-fall velocities. We assume a loss-cone model:

Mass in loss-cone:

$$M_{\rm lc} = \int_0^\infty \Omega_{\rm lc} f(v) dv$$

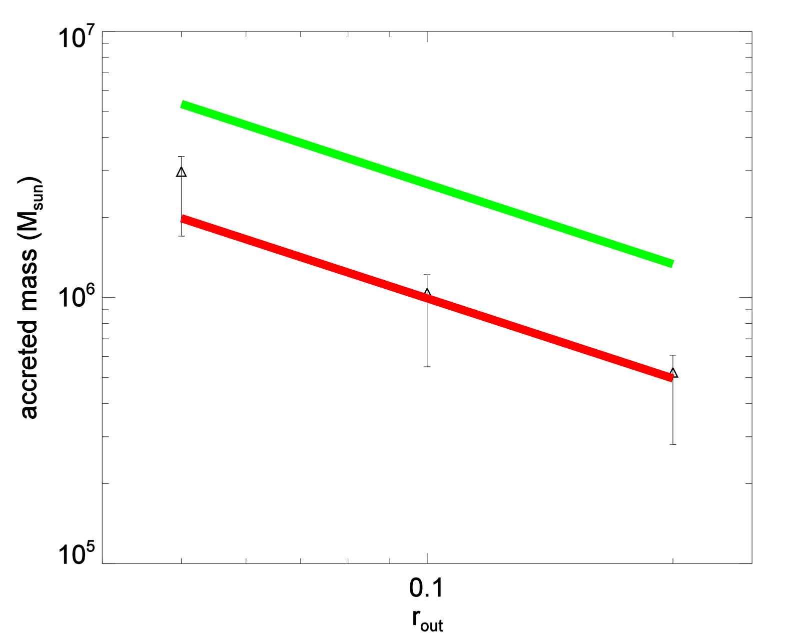
Accreted mass with high turbulence:

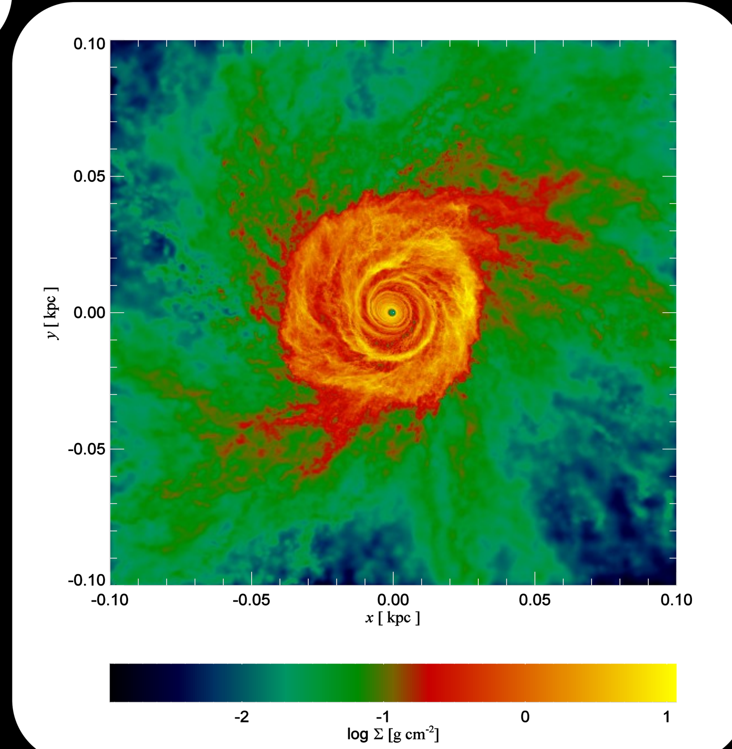
$$\frac{\Delta M}{M_{\rm shell}} \approx \frac{(2M_{\rm bh}r_{\rm acc})^{1/2}}{r_{\rm out}v_{\rm turb}}\left(1 + \frac{v^2_{\rm rot}}{v^2_{\rm turb}}\right)$$

where velocity dist. is fit by:

$$f(v) = \frac{4}{v^3_{\rm turb}\pi^{1/2}} v^2 e^{-(v/v_{\rm turb})^2}$$

Ballistic mode gives good analytical fit. Trend (red line) with r_{out} seen in Figure to the right:





Conclusions & key points

- In the presence of a finite net angular momentum, supersonic turbulence in the bulge can promote accretion.
- For supernovae-driven turbulence this points to a starburst-AGN connection (e.g. Heckman 2008, Chen et al. 2009).
- Increasing accretion trend with increasing turbulence saturates when peak turbulent velocity becomes of the order of v_{rot}.
- The effect of strong turbulence can be approximated by a "ballistic" mode of accretion with a loss-cone analytical approach.

References

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J. D. Kurk et al., 2007, *ApJ*, 669, 32
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