Why are the Sleeping Giants so Quiet: Rotating, Inflow/Outflow Solutions for Accreting Black Holes

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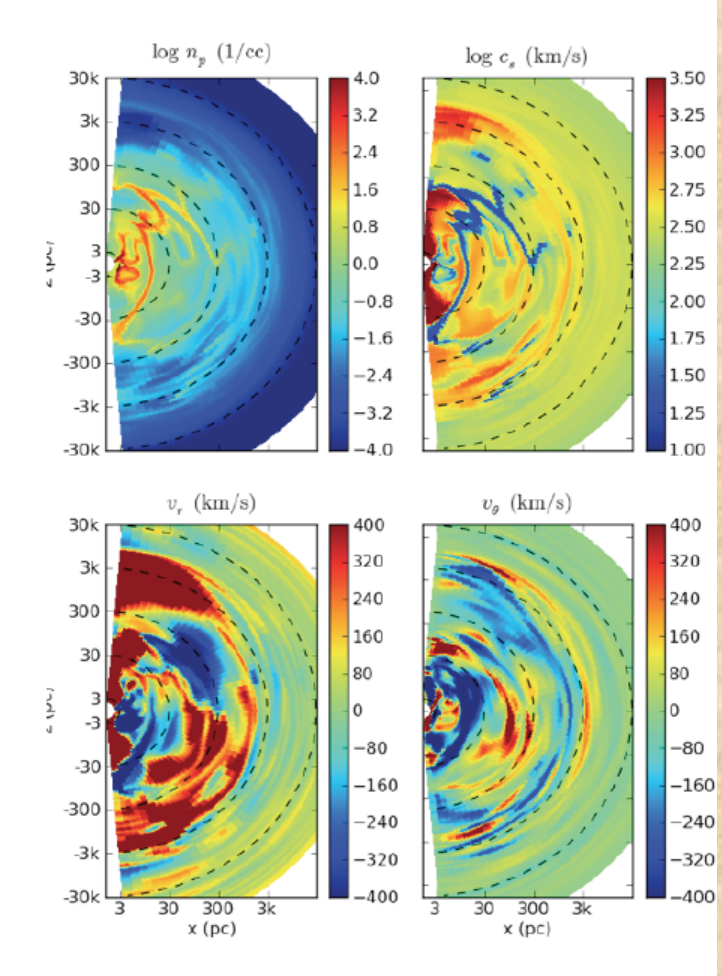


Overall Understanding

1) Bondi Accretion Flow assumes no rotation!
2) In the real case, rotation dominates the inner flow pattern and the generic case is "Inflow/ Outflow", ***with very low net inflow***.
3) Inflow at intermediate latitudes. A bi-conical wind at high latitudes and a viscous disc outflow in the equatorial regions.
4) Typical ***net*** inflow is 10^{-2} to 10^{-3} gross inflow.

Length Scales

$R_{bondi} = GM_{bh}/C^2 = 10^{20}\ M_8/T_6$ cm

$R_{centr} = j^2/(GM_{bh)} = 10^{16}\ j_{25}{}^2/M_8$ cm

$R_{schw} = GM_{bh}/c^2 = 10^{13}\ M_8$ cm

Note huge range of scales (typically):

$\boldsymbol{R_{bondi} >> R_{centr} >> R_{schw}}$

Some obvious implications

1) Absent transport processes there is ***no*** net accretion.[R_{centr} **>>** R_{schw}]-> Inflow, then bounce, then outflow, with inflow =~ outflow. Starting the calculation with strongly bound material misses essential physics.
2) [1/R_{schw} >>> 1/R_{bondi}] ->Small output of energy from inner parts of flow, if intercepted by outer parts of flow, can have huge effects.

Some Observational Notes

1) In our galaxy, M31 and M87 the inner accretion zone is ~ resolved in X-ray observations, so "Bondi flow" can be estimated.
2) Gas is hot – with net heating from AGN an important source of the energy.
3) Currently the net accretion flow is far below what would be computed from spherical Bondi flow.
4) Likely reason is rotation leading to "inflow/outflow" solution with small net inflow.

Some recent simulation results, all including radiative processes and passing through the Bondi radius.

1) Li, O & Sunyaev: For low inflow rates very, very low net accretion and luminosity is expected. That is $L/L_{edd} < 10^{-5}$ is expected and LF >> 1: Solutions are ***"RRIOS", Rotating, Radiating, Inflow/Outflow solutions.***
2) Yuan, Chao & O: For $L/L_{edd} \sim 1$, radiation output perpendicular to disk drives winds and heating at B radius causes episodic accretion. LF > 1
3) Novak *et al* galactic sims based on Proga *et al* radiative wind driving → BAL properties and feedback regulation of episodic BH growth.

Ap J.767, 105 (2013) Li, Ostriker & Sunyaev

Inflow at mid latitudes and outflow at poles and equator

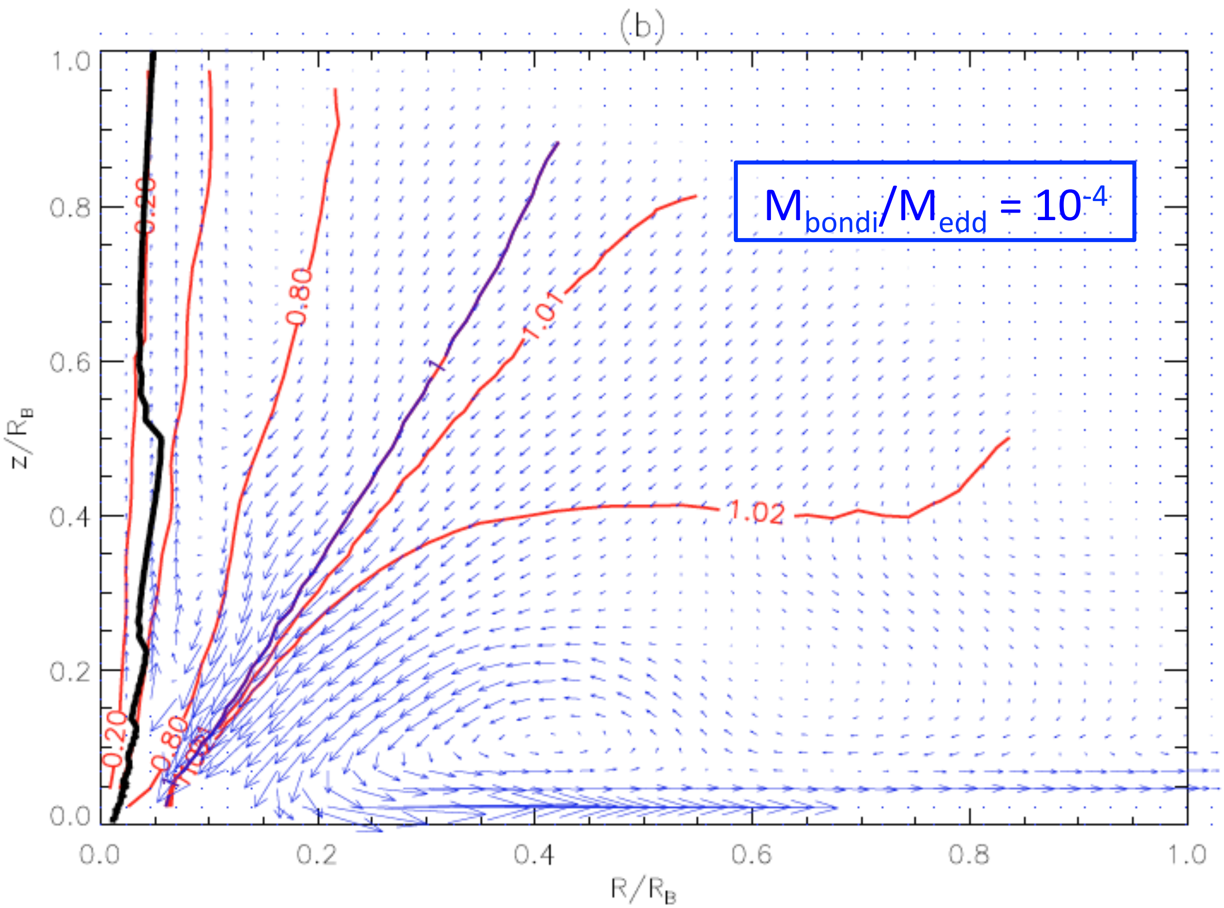
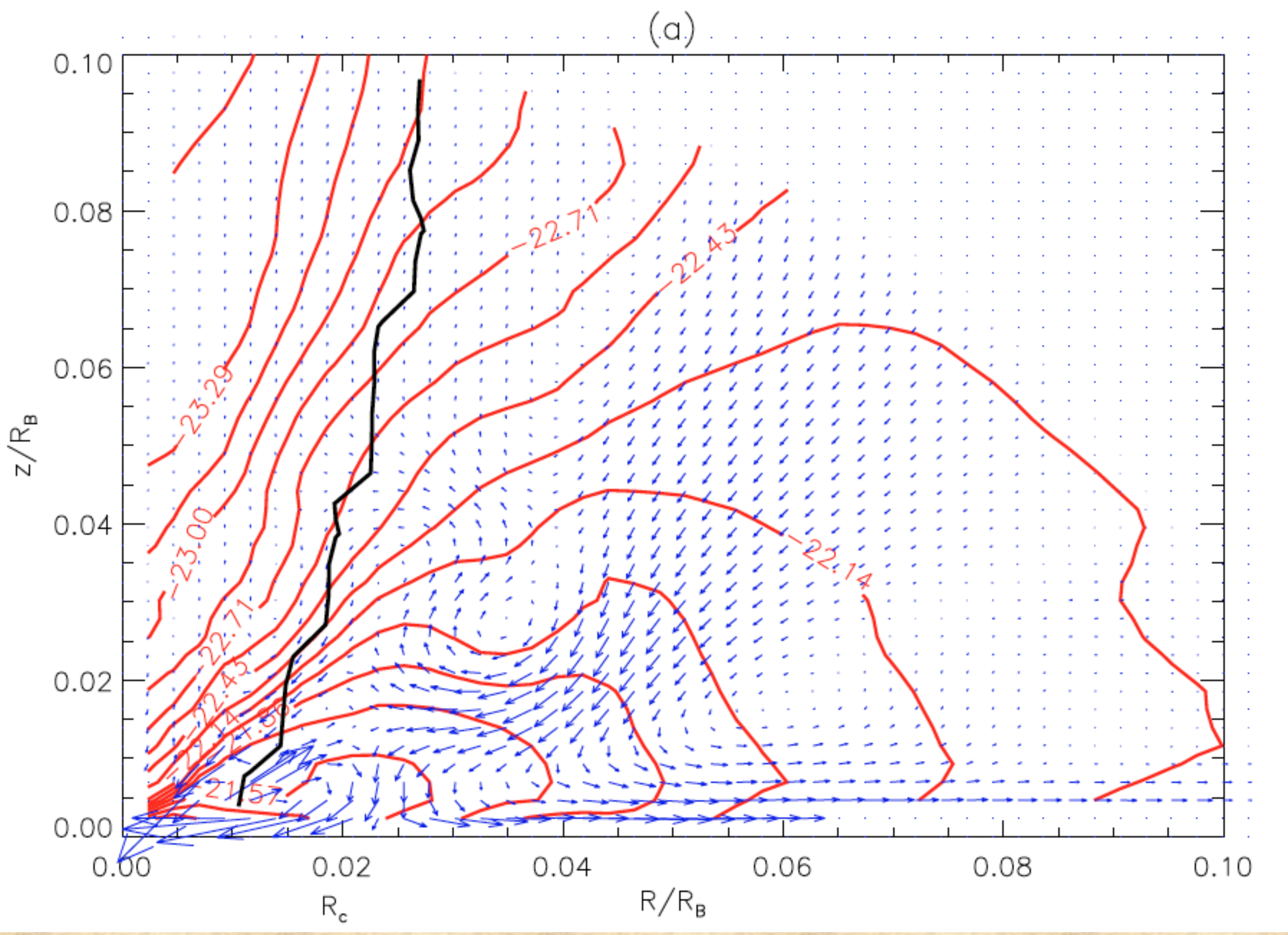
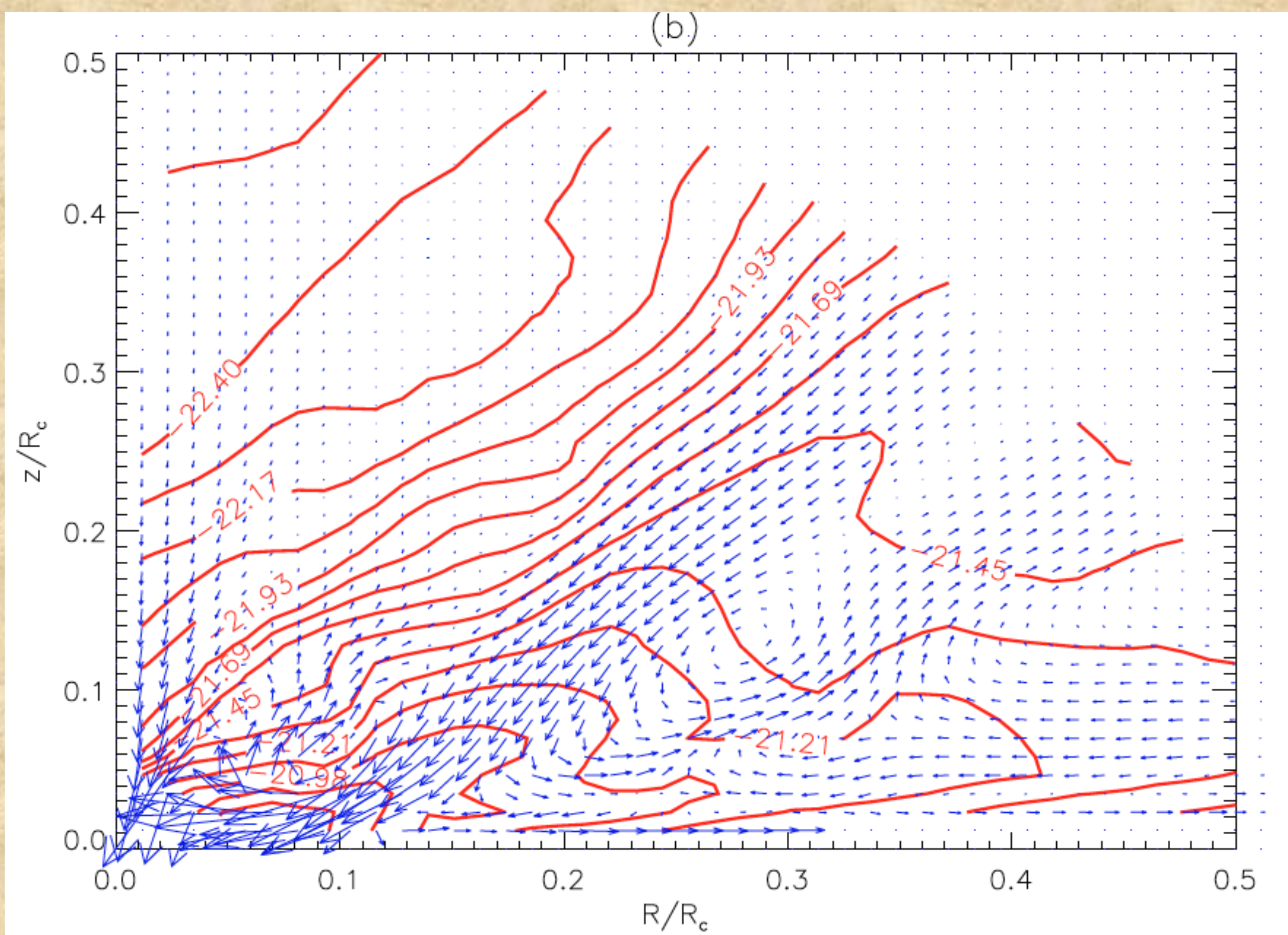


FIG. 2.— (a) The structure of the hot disk with angular momentum transport designed to mimic the MRI, shown interior to R_B in the low accretion limit where $\dot{M}_B/\dot{M}_{Edd} = 10^{-4}$. Cooling is negligible. Red contours are logarithmic contours of density, blue arrows indicate mass flux in the $R-z$ plane, and the black line demarcates the zero density surface in the adiabatic settling solution. Matter flows in through the Bondi radius and back out in disk and conical polar outflows. (b) Contours of specific angular momentum in units of $j_\infty = \sqrt{0.02}R_B c_{s,\infty}$ and blue vectors of angular momentum flux. The black line demarcates the zero density surface in the stationary solution, and the purple contour marks where the specific angular momentum $j = j_\infty$. Angular momentum of inflowing material is transferred to the equatorial outflow.

Closer: Within 0.1 Bondi radius to the centrifugal radius

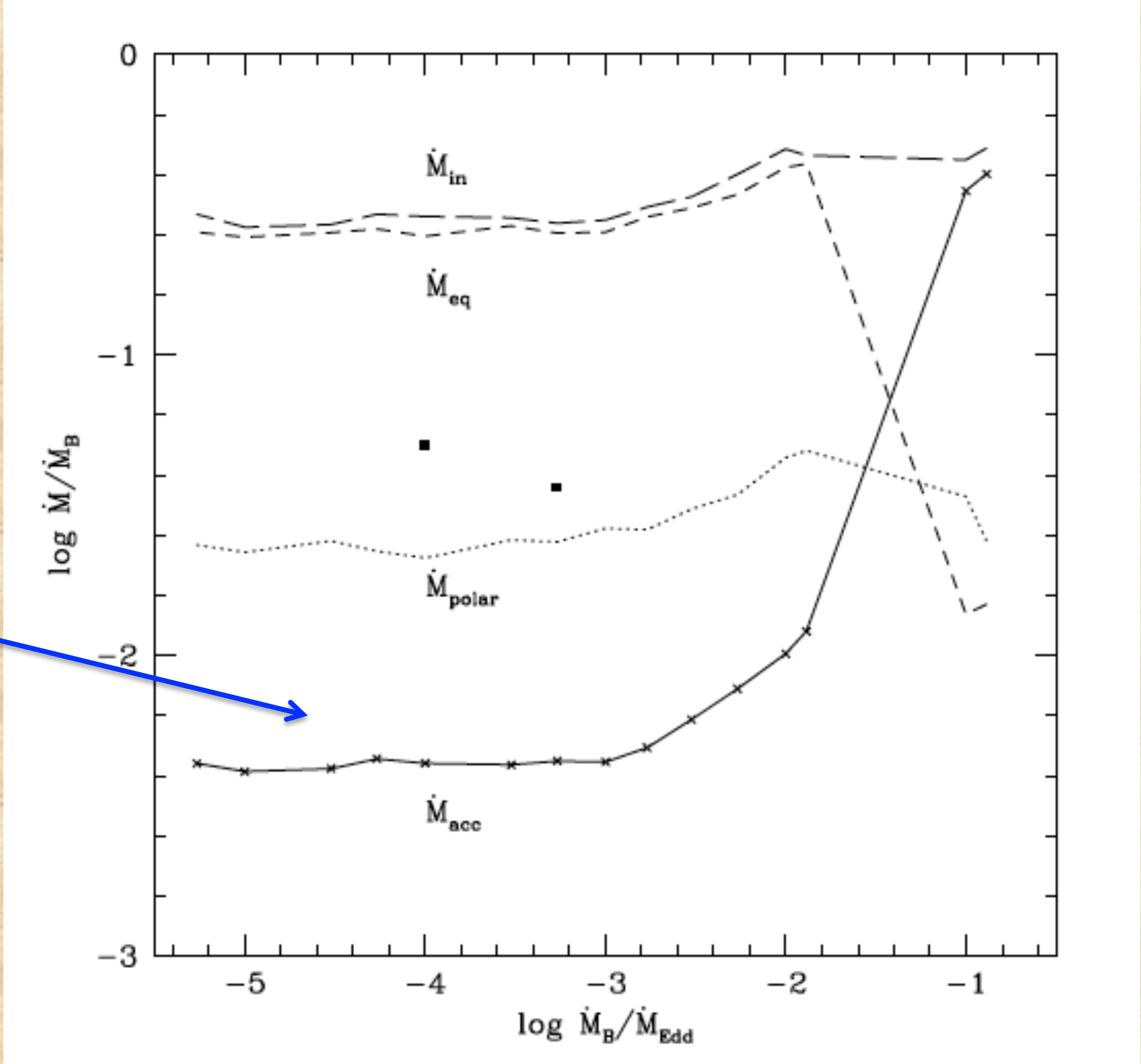


And closer: inside the centrifugal radius – solution is similar to “ADIOS” in this region.



"RRIOS", Rotating, Radiating, Inflow/Outflow solutions.

At low inflow rates the actual accretion is lower than the inflow by a factor of 250. Most matter flows out the poles and the equator

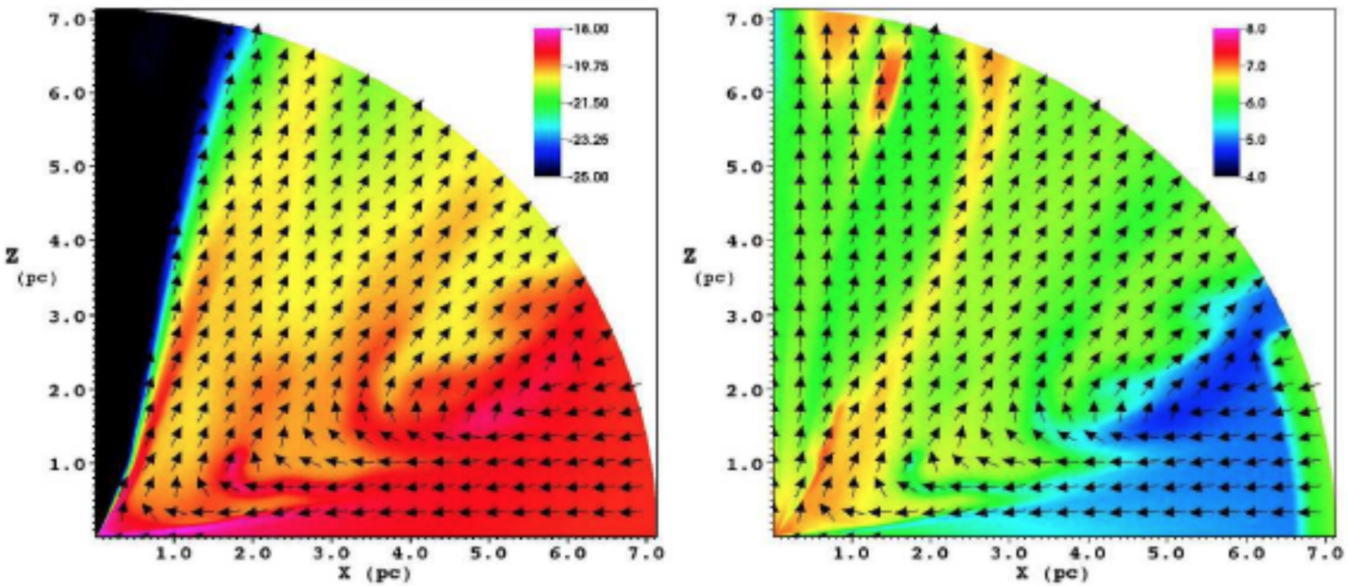


New Solution to Inflow Pb: RRIOS

- Two distinct domains of accretion of rotating flows: $M_{bondi}/M_{edd} < 10^{-1.5}$ or $> 10^{-1.5}$.
- Low inflow domain has *VERY* low net accretion and very high “Load Factor”. Very low luminosity – compatible with SagA*, M31, M87 and most observed BHs.
- High inflow domain qualitatively like Shakur-Sunyaev, standard solutions but requires treatment of radiative effects at the B radius.

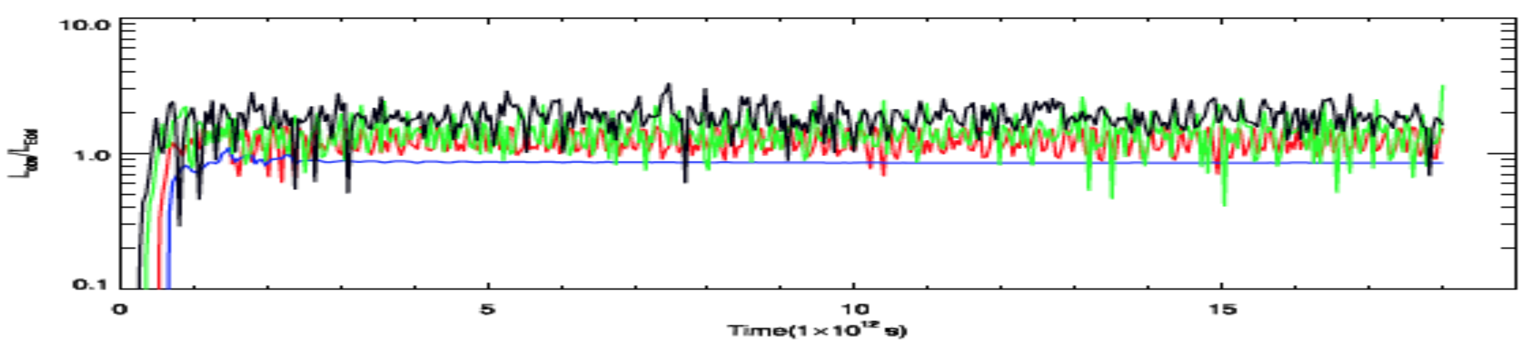
MNRAS 434,1721,(2013) Liu, Yuan, Ostriker, Gan &Yang

Inflow/Outflow at higher accretion rates w radiative driving



Density Temperature

Figure 7. Comparison of the logarithmic density (left) and temperature (right) contours between Model R7c (top panels) and Model R7c-X0 (bottom panels; with $\kappa_X = 0$). The arrows represent the direction of velocity vector but not its magnitude.



With radiative driving..

- Episodic accretion occurs with very small duty cycle. Most of the time the source is quiet, but most of the energy emitted at ~ Edd limit.
- Radiative momentum input in lines drives the winds.
- Presumably our galactic nucleus had such episodes in the past, if we are to account for the black hole mass.

MNRAS 427, 2734 (2012) Novak, Ostriker & Ciotti

Full Galaxy Sim (2D and later 3D), Proga radiative driving

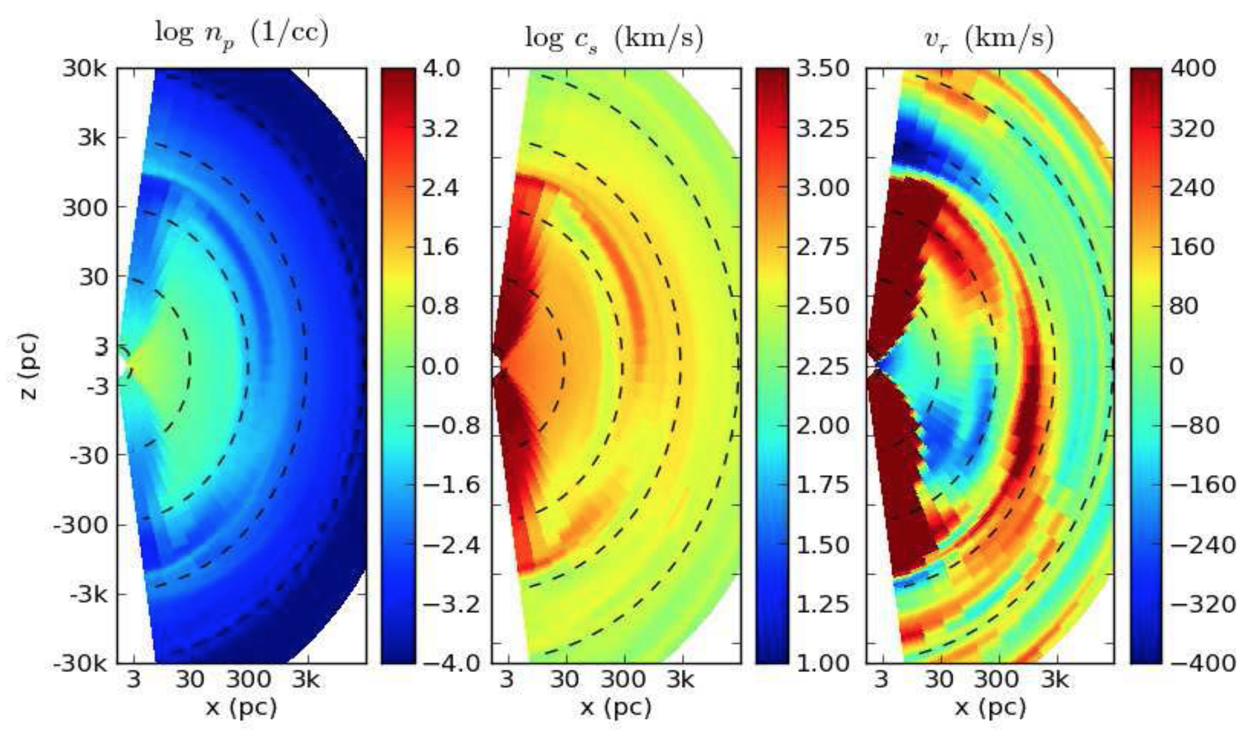
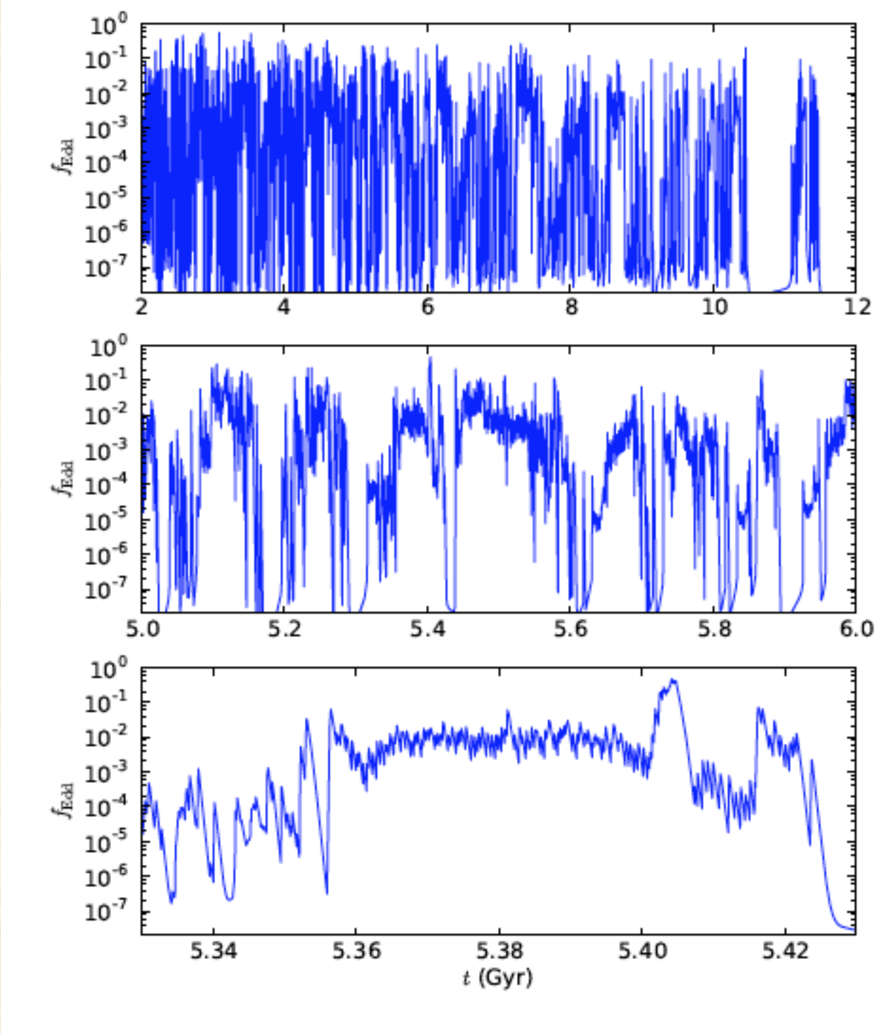
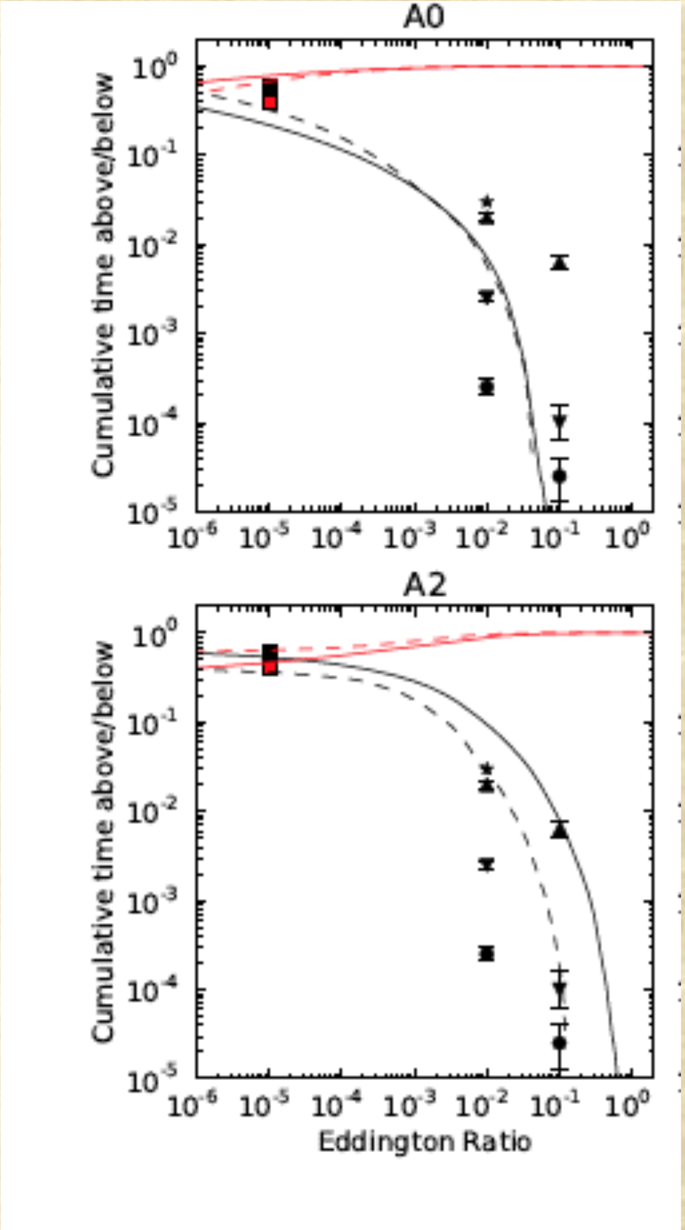


FIG. 3.— Simulation snapshot during an accretion event. A significant quantity of hot, outflowing gas injects energy and momentum into the interstellar medium at $r \simeq 1$ kpc.

Episodic accretion followed by outbursts that heat interior of galaxy and stabilize gas followed by cooling flows and repeated outbursts of BH growth and starbursts.

Fluctuating luminosity output with fraction of time at fraction of Eddington lum similar to observations





Conclusions: It is most important that computational domain include B region and that radiative heating and accecleration be included in self-consistent fashion. Then:

- At low inflow rate, accretion of rotating flow is very, very low (LF very high ~ 250) and luminosity is negligible. This is the normal state, with outflow essentially balancing inflow: RRIOS.
- For Bondi accretion rate more than several % of Eddington, there is a sudden switch to high efficiency but episodic accretion, with small duty cycle.
- If our galaxy is typical it spends 10^{-3} of time in high accretion, Seyfert, state.