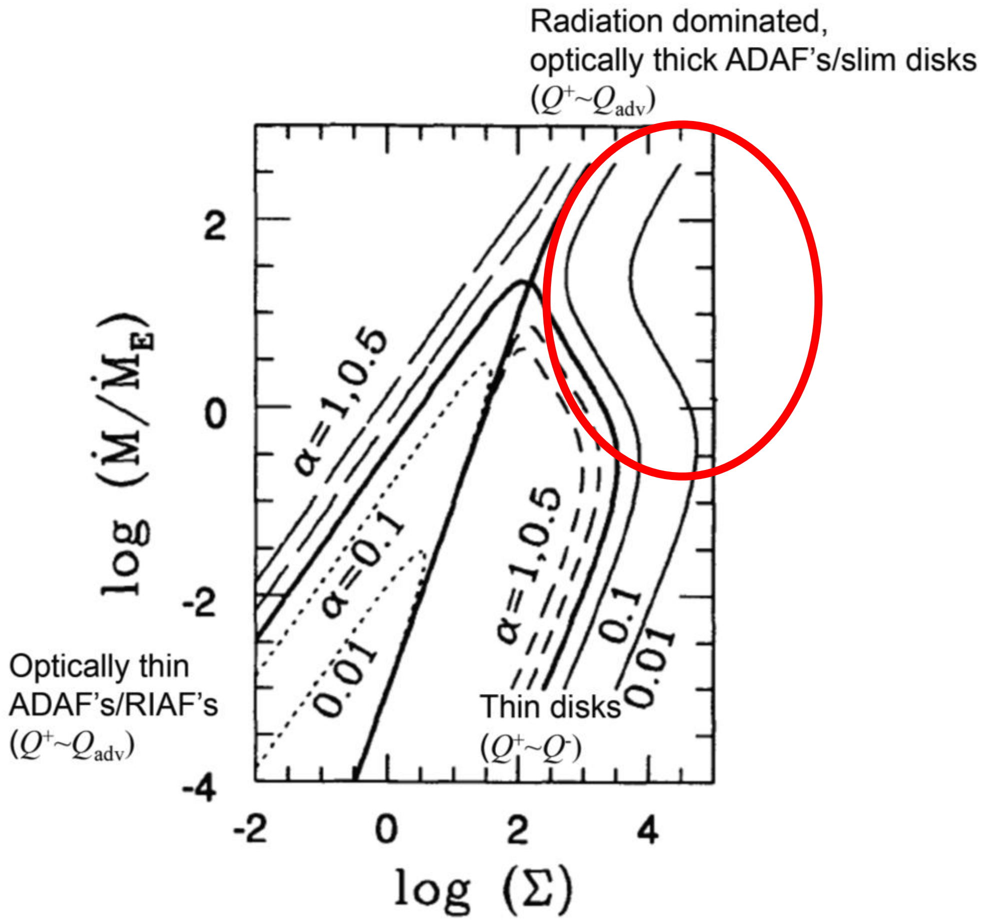
Issues in Radiation Dominated Accretion

Omer Blaes
UCSB

Massive Black Holes: Birth, Growth and Impact
KITP
August 9, 2013

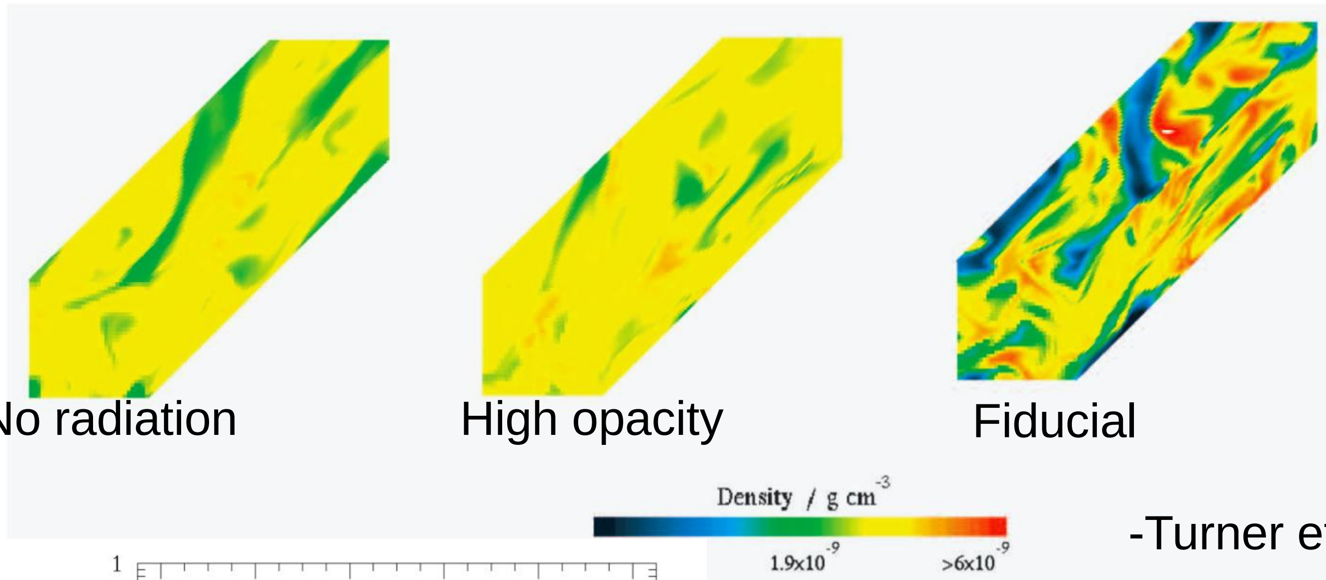


$$\frac{P_{\rm rad}}{P_{\rm gas}} \approx 10^7 \alpha^{1/4} (1-f)^{9/4} \left(\frac{M}{10^8 M_{\rm sun}}\right)^{1/4} \eta^{-2} \left(\frac{L}{L_{\rm Edd}}\right)^2 \left(\frac{r}{r_{\rm g}}\right)^{-21/8}$$

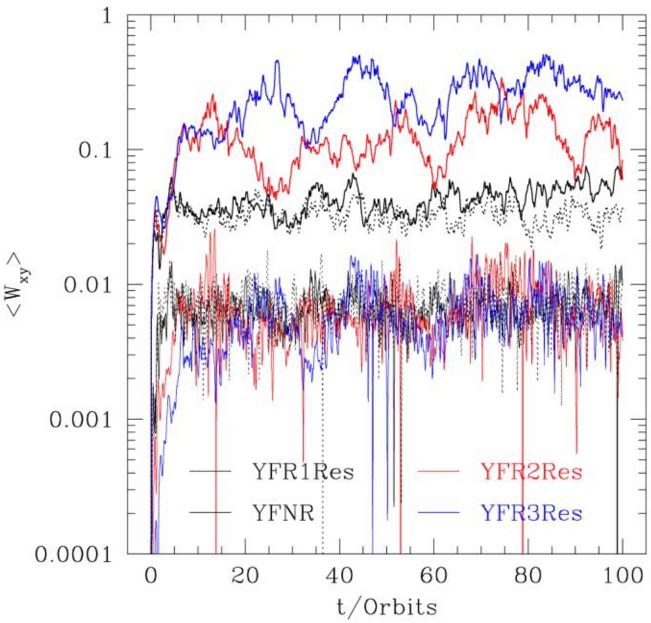
Important Roles that Radiation Can Play

- As the dominant power loss mechanism.
- As the dominant form of local thermal pressure (alters disk radial structure, fragile to compressible fluctuations).
- As a direct dissipation mechanism: radiation damping of compressible turbulence.
- As a mechanism for instability and variability.
- As a driver of outflows, both through heating of outer disk and direct radiation pressure (Proga's talk).

Compressibility and Radiative Damping in Radiation Dominated Plasmas (Agol & Krolik 1998)



-Turner et al. (2003)

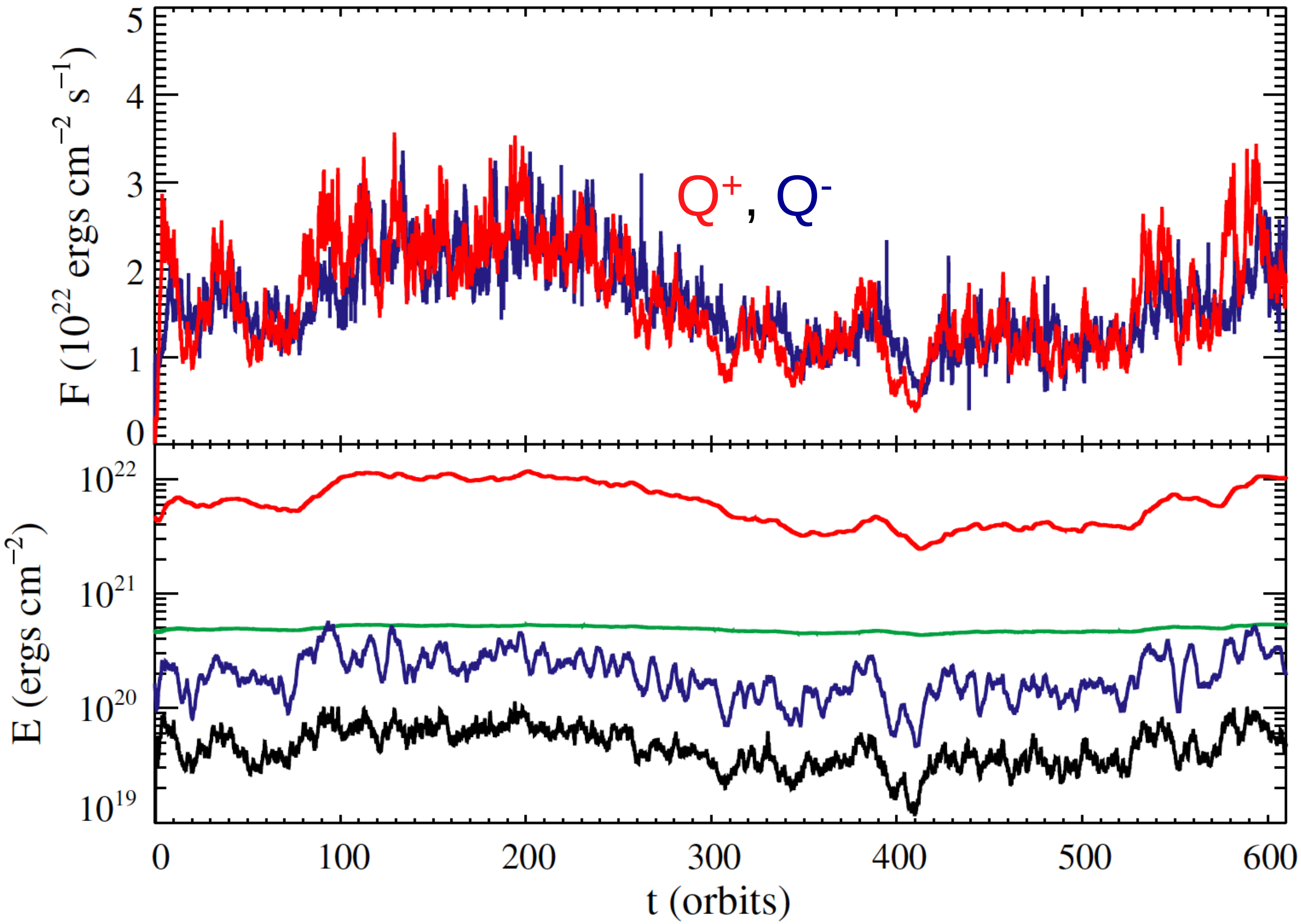


Maxwell stress

Reynolds stress

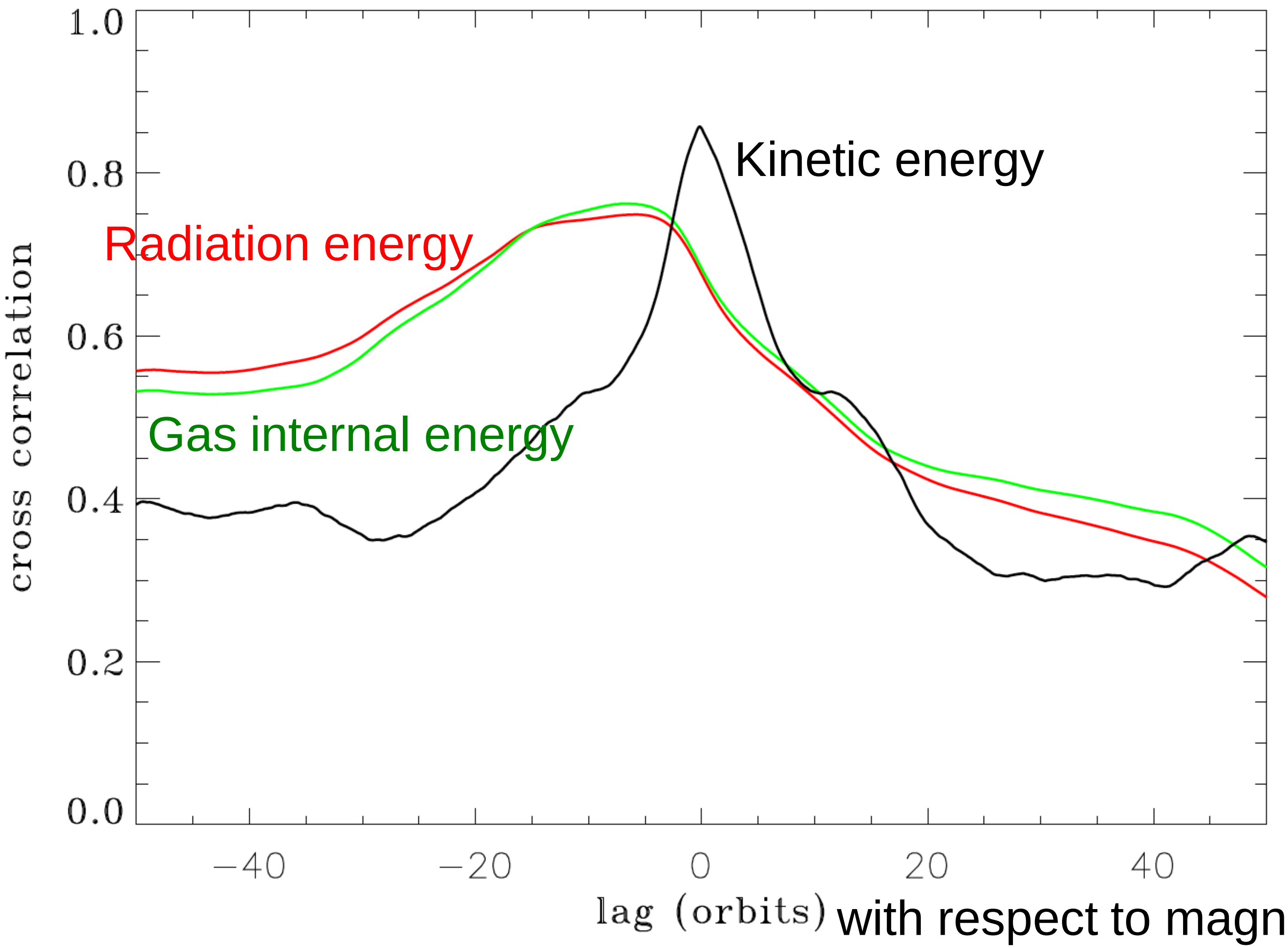
-Jiang, Stone, & Davis (2013)

Fluxes, Radiation, Gas Internal, Magnetic, and Turbulent Kinetic Energies in Local, Radiation Pressure Dominated, Shearing Box Simulations



No thermal instability! (Hirose et al. 2009, first shown by Turner 2004.)

Fluctuations in thermal energy are correlated to fluctuations in turbulent magnetic and kinetic energies, but with a LAG



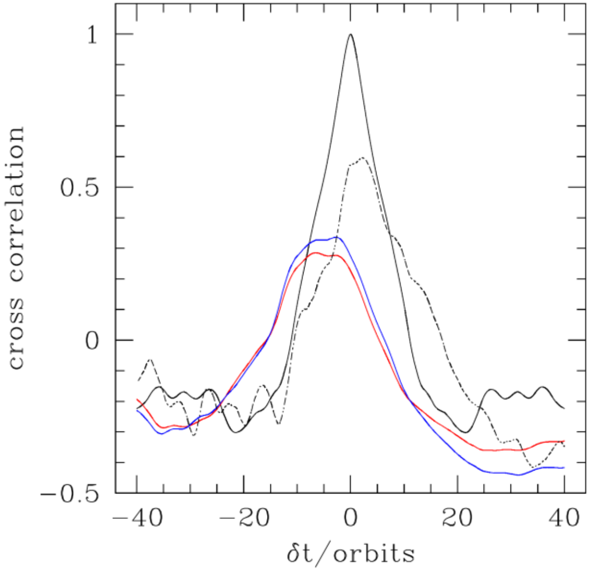
with respect to magnetic energy fluctuations

-Hirose et al. (2009)

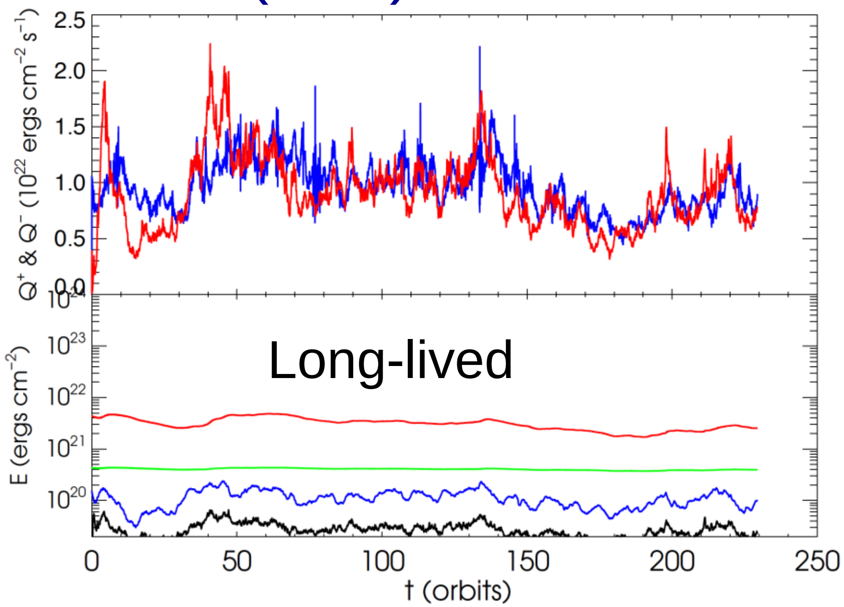
But Now Comes Athena (talk by Stone)

Even though Athena/VET can sometimes find thermal equilibria (generally at low Prad/Pgas>1), they are not very long-lived, and ***always*** eventually experience runaway heating or cooling.

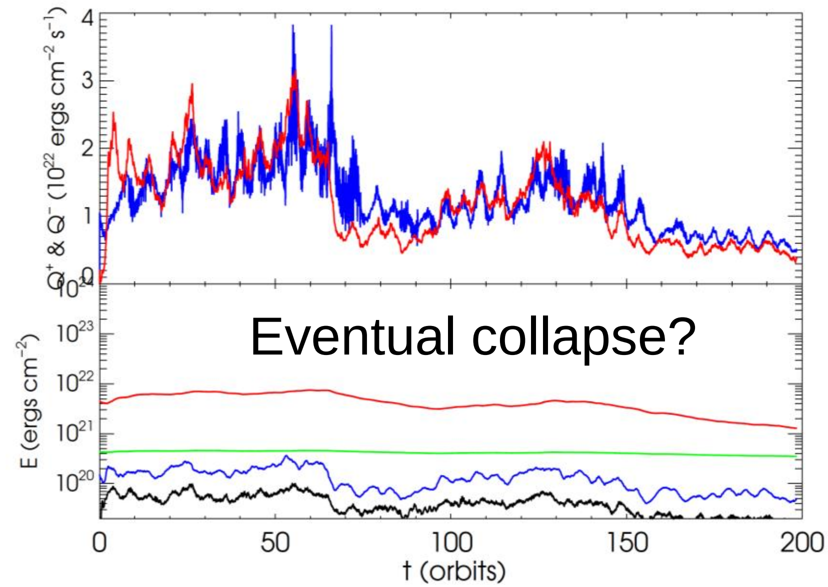
And they still see stress leading pressure with the same time delay as ZEUS:

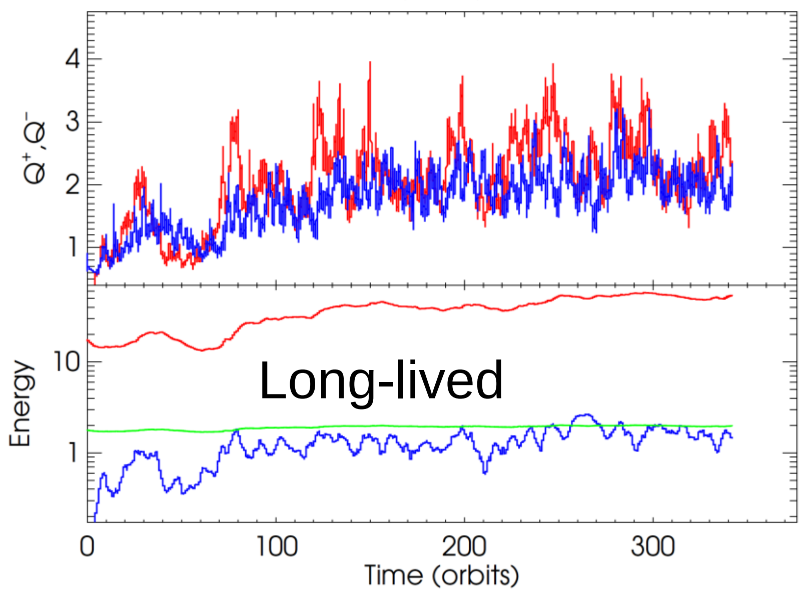


ZEUS (FLD) Narrow Box

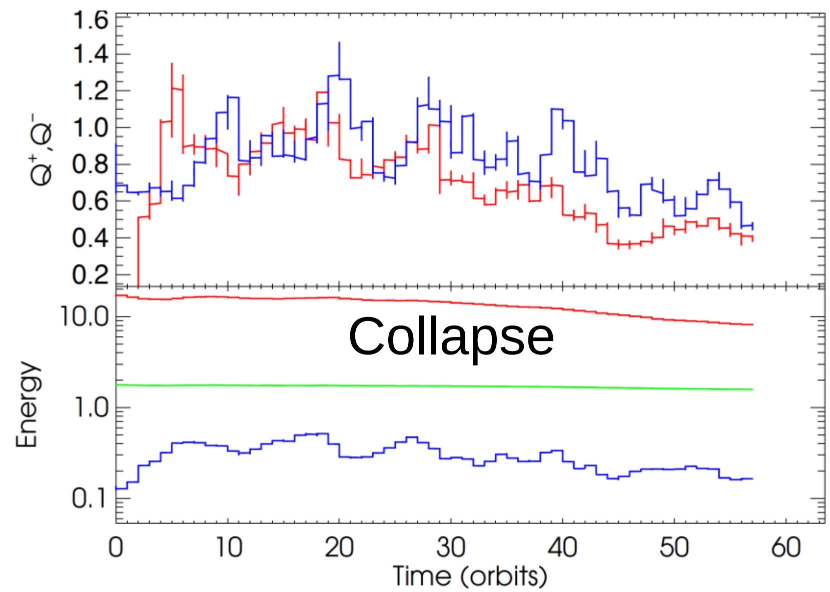


ZEUS (FLD) Wide Box

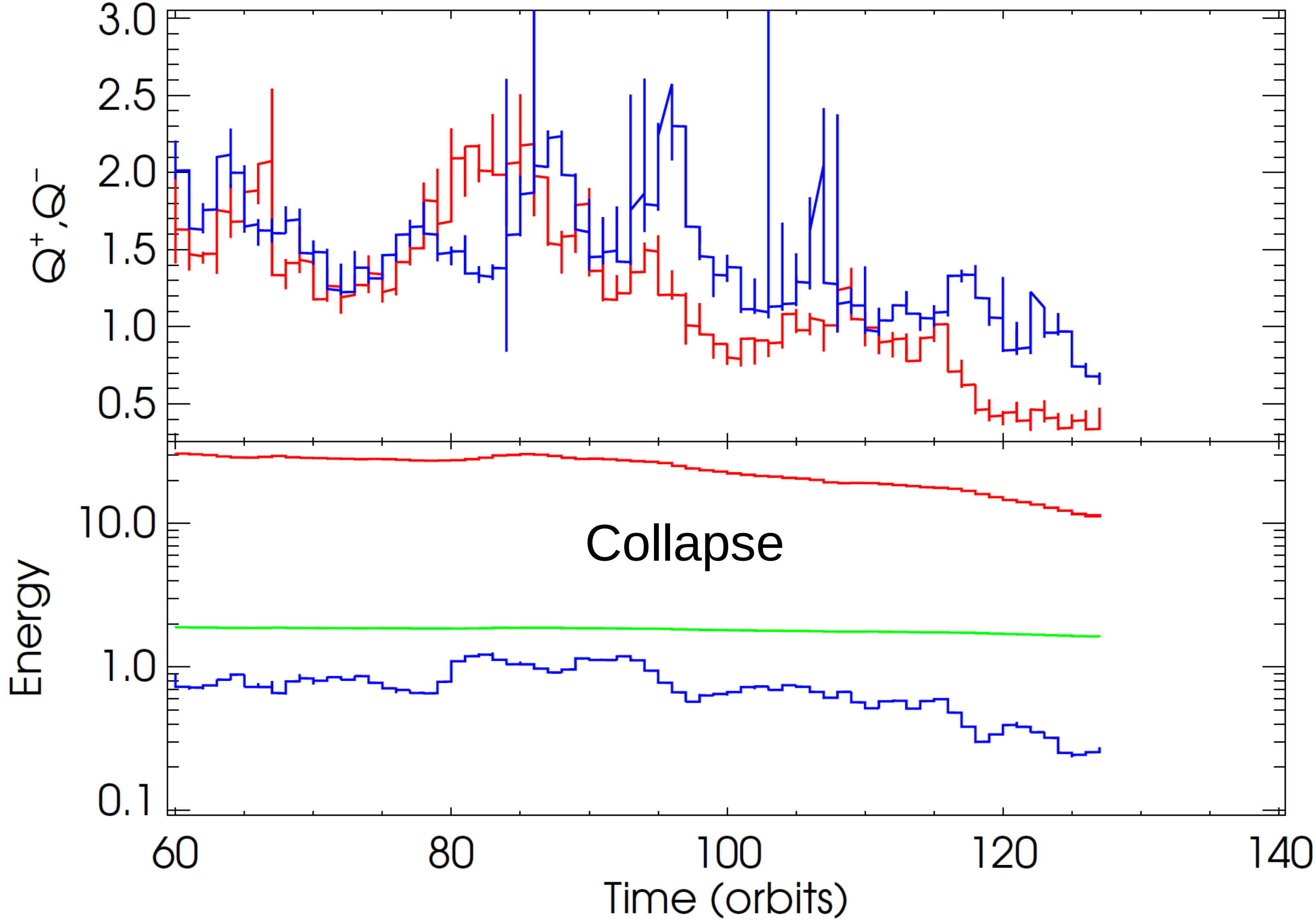




Athena (FLD) Narrow Box

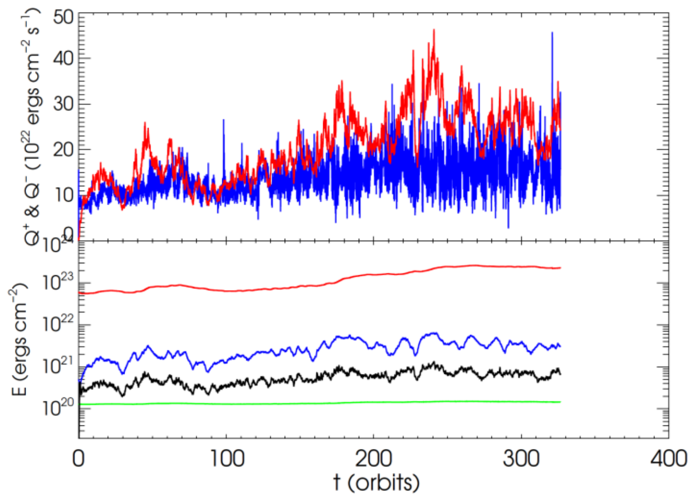


Athena (FLD) Wide Box

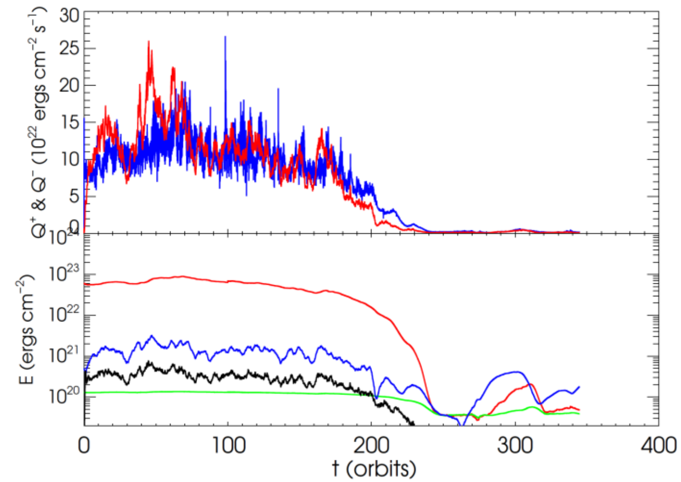


Athena (VET) Narrow Box

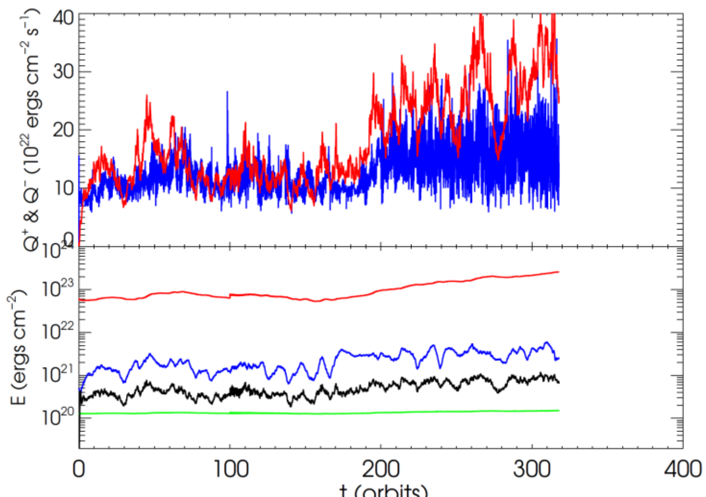
At high Prad/Pgas (~270), ZEUS simulations exhibit a variety of behaviors, even in a narrow box.



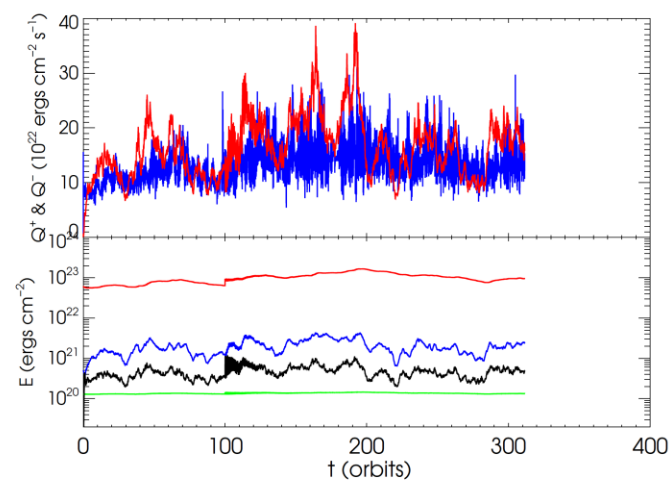
Fiducial – runaway heating



2% perturbations at 100 orbits - collapse

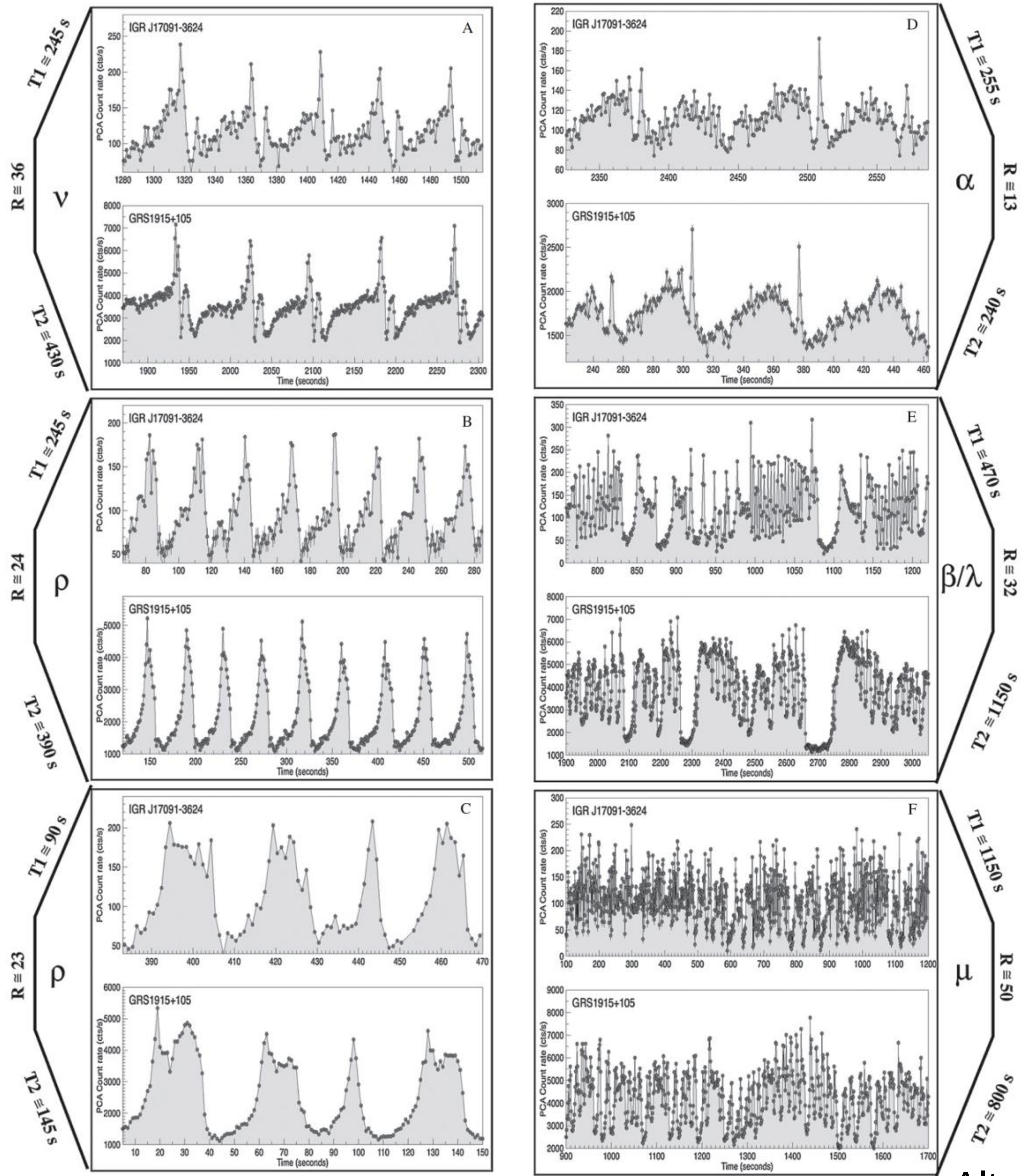


5% - runaway heating

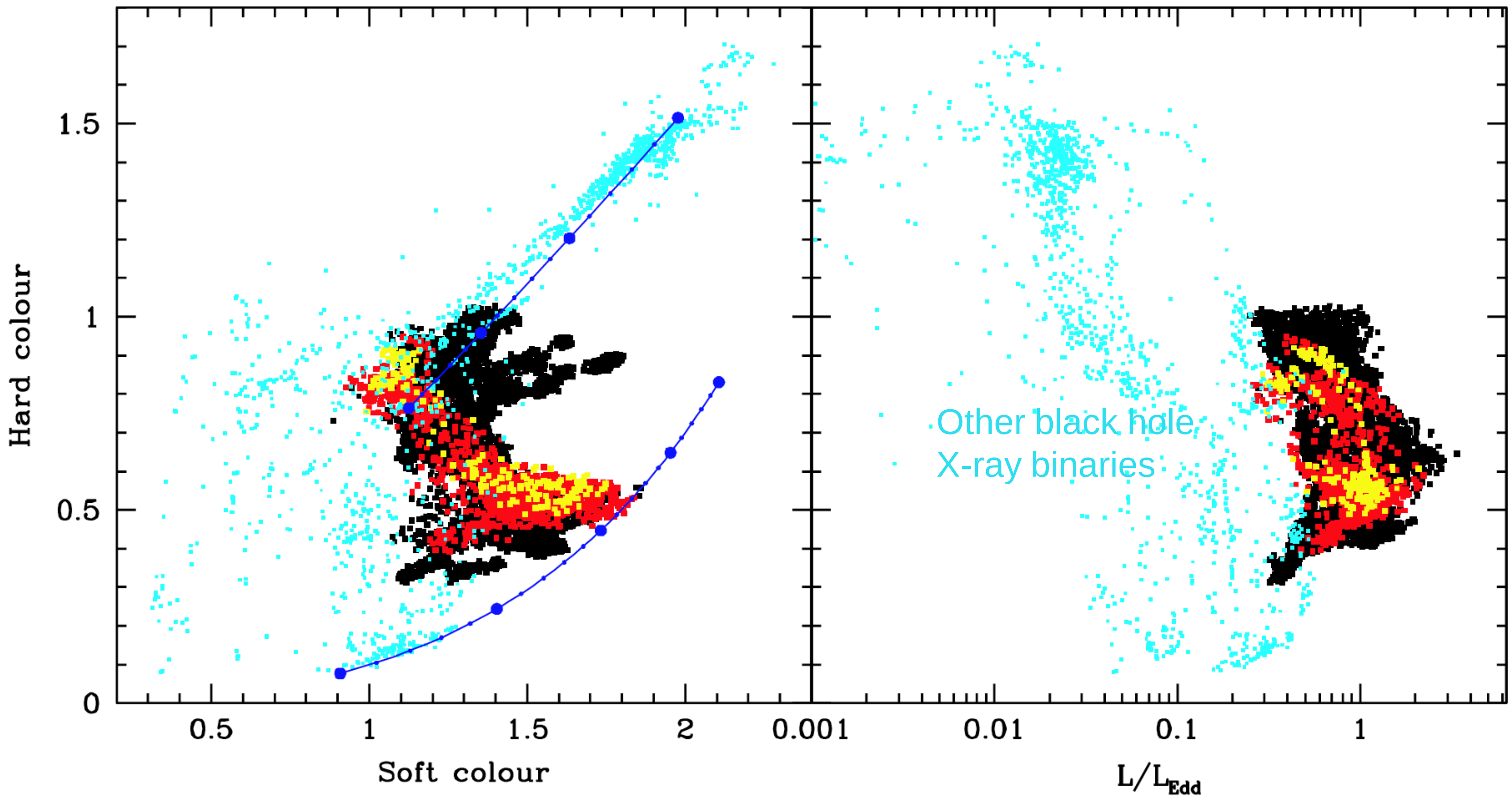


10% - long lived(!)

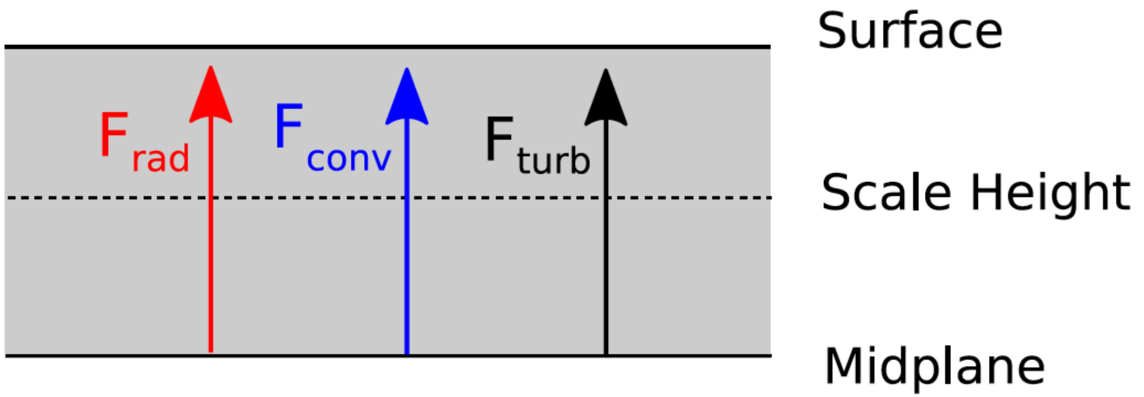
GRS 1915+105 and IGR J17091-3624

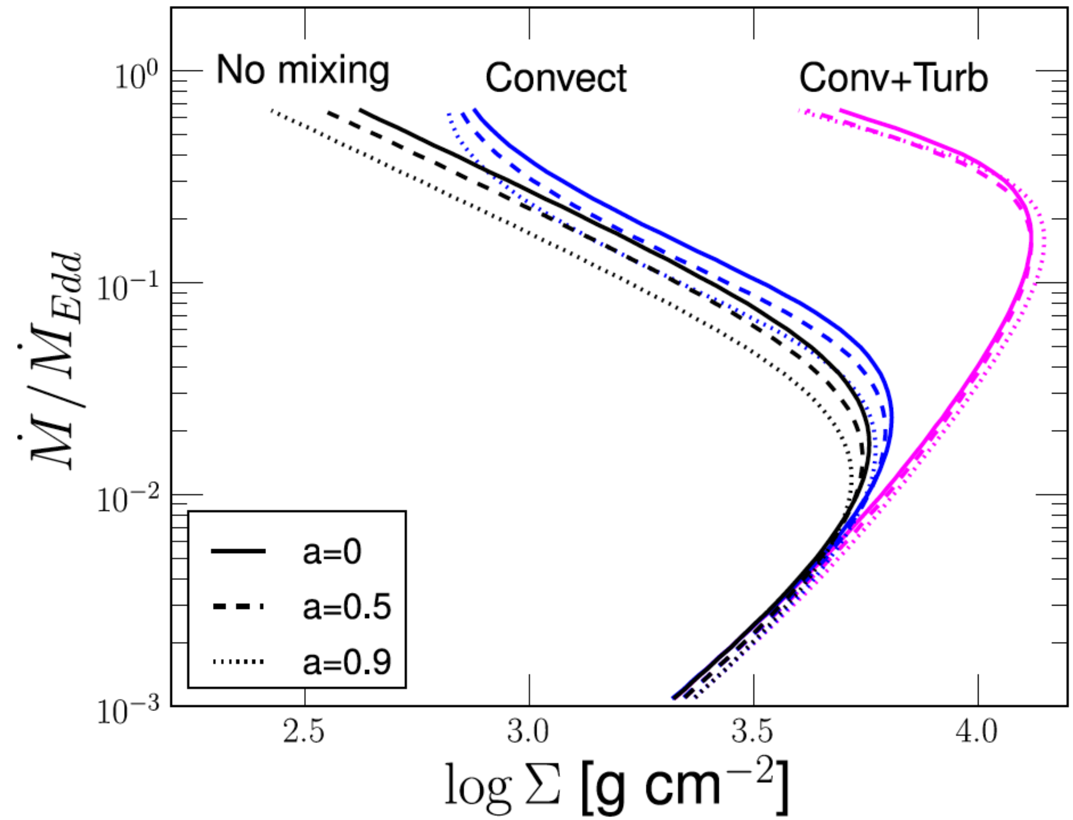


-Altamirano et al. (2011)



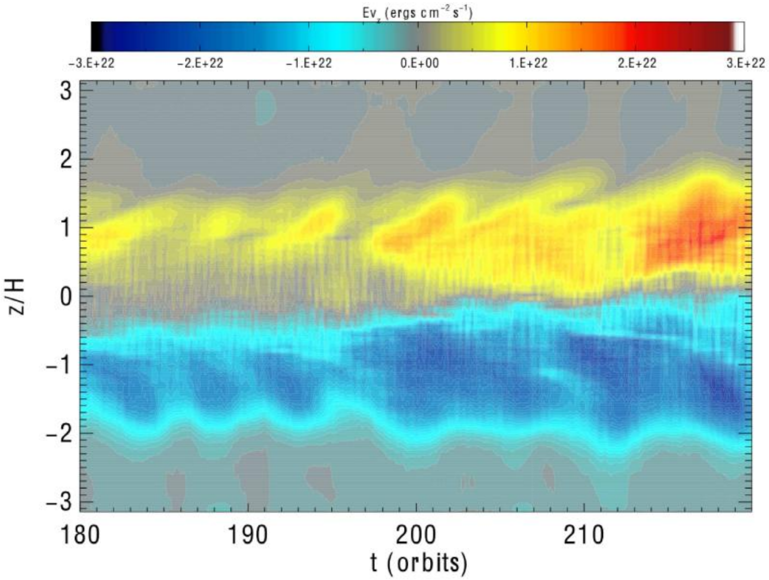
-Done, Wardzinski & Gierlinski (2004)



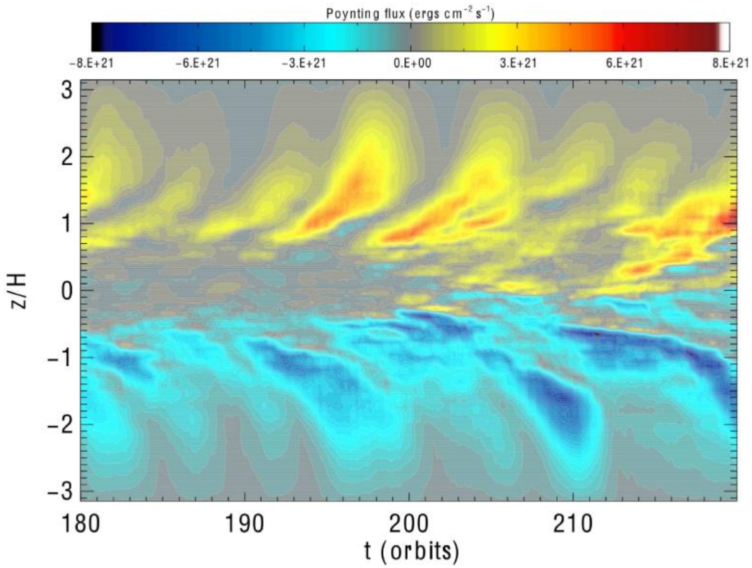


-Zhu & Narayan 2013

Advection of Radiation by Buoyant Magnetic Fields in the MRI Dynamo Can Be a Significant Heat Transport Mechanism



Radiation advection flux Ev_z, smoothed over two orbital periods.

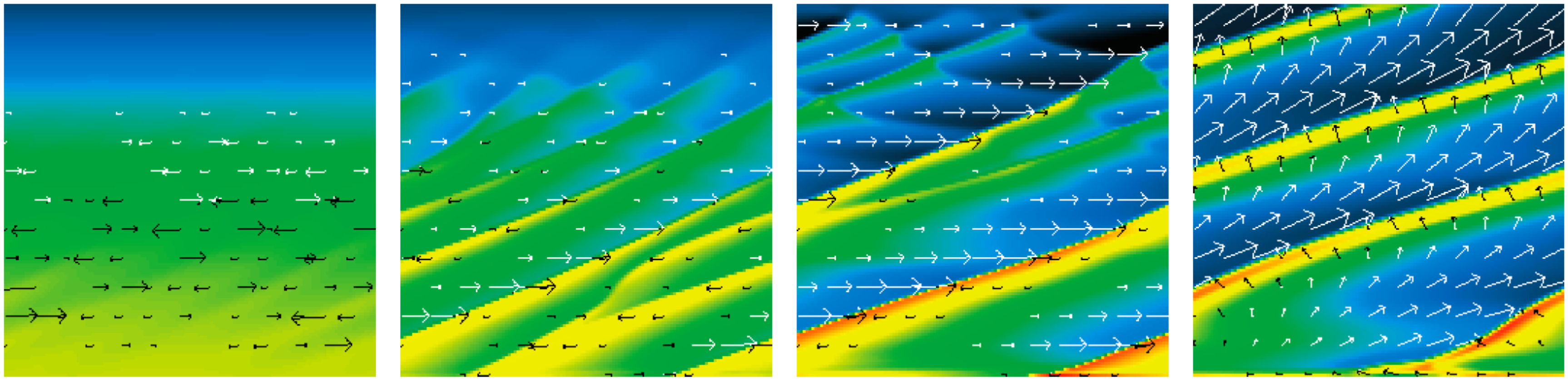


Poynting flux.

-Blaes et al. (2011)

BUT it never dominates diffusive flux, at least up to Prad/Pgas~100, in both ZEUS and Athena simulations.

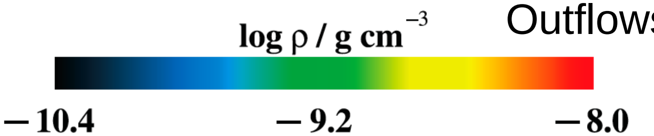
“Photon Bubbles” (Gammie 1998, Begelman 2001,…)



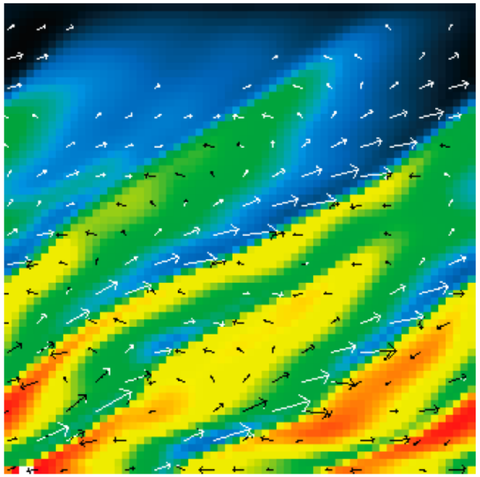
End of linear growth phase

Shock merger phase

Outflows



Or, if field is too weak to support the weight of the shocked material, buckling occurs.



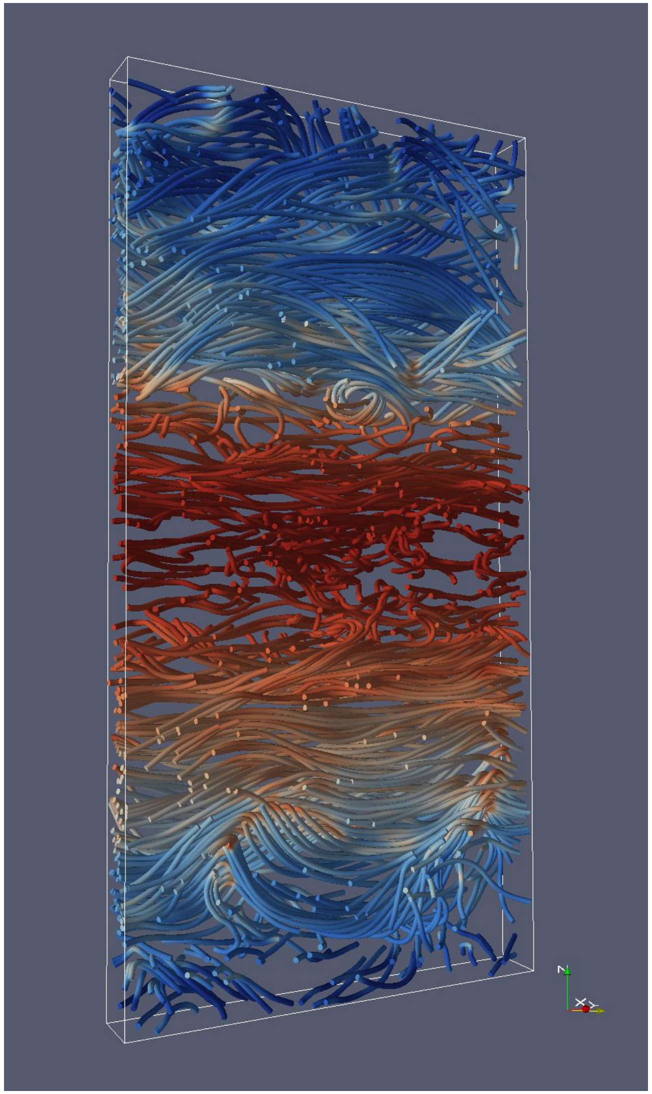
-Turner et al. (2005)

But so far MRI simulations always have vertical magnetic field gradients that buckle under the Parker instability. This may change at the higher levels of radiation pressure support in AGN.

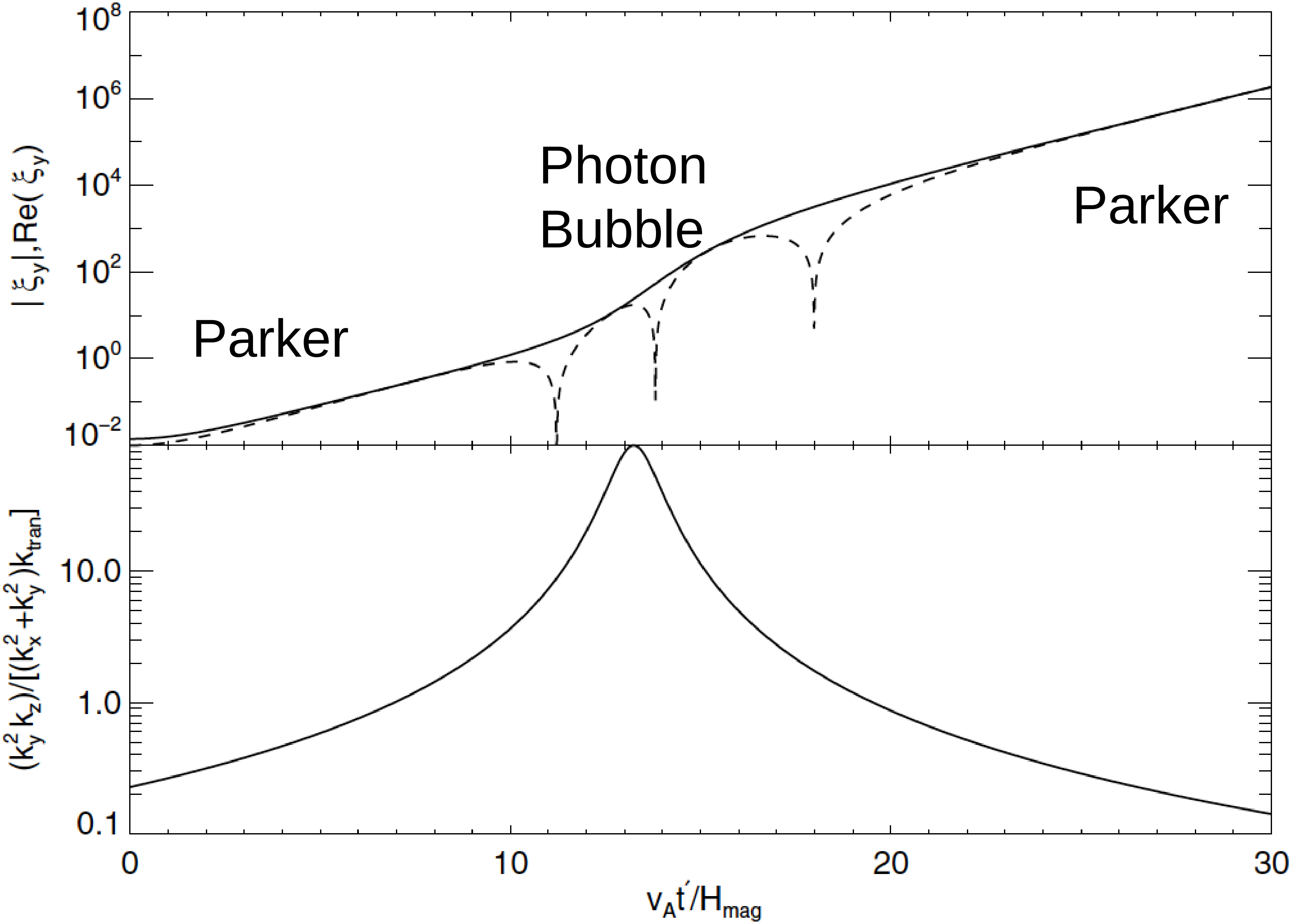
Parker

MRI turbulence in
midplane regions

Parker

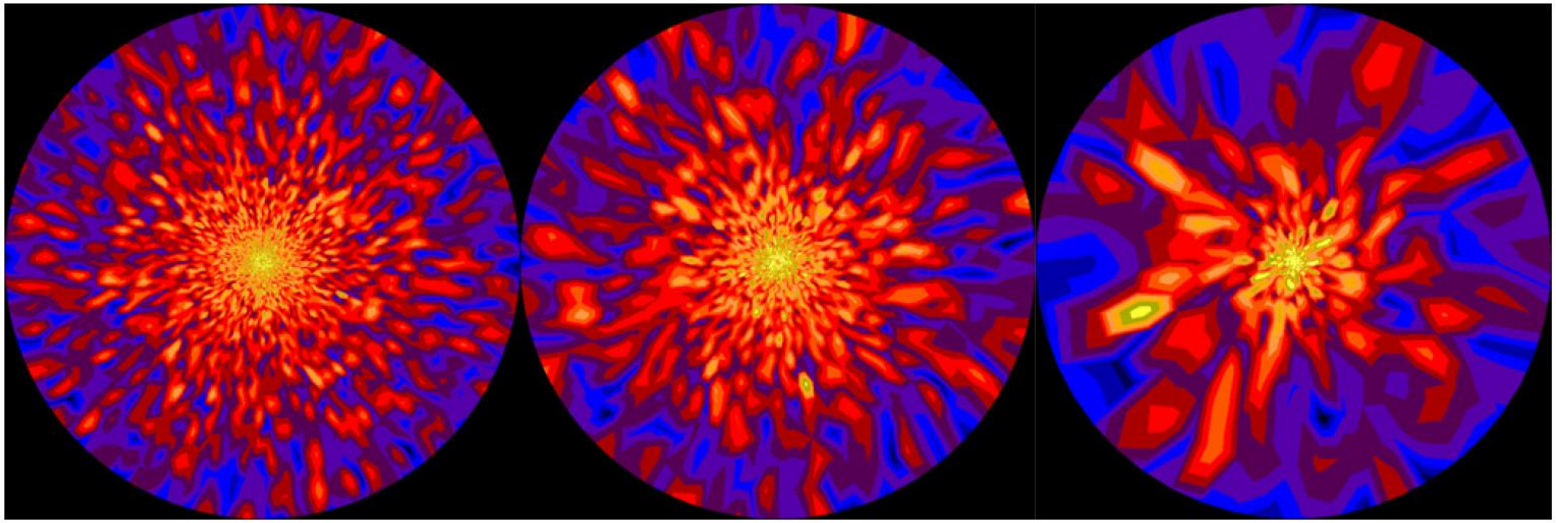


Photon Bubbles can Shear out to Parker Modes

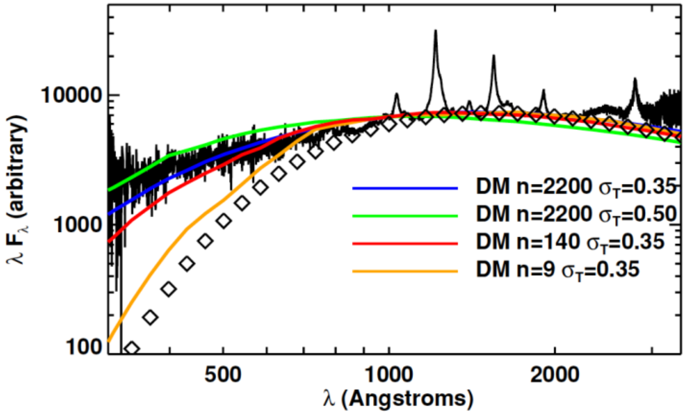


-Tao & Blaes (2011)

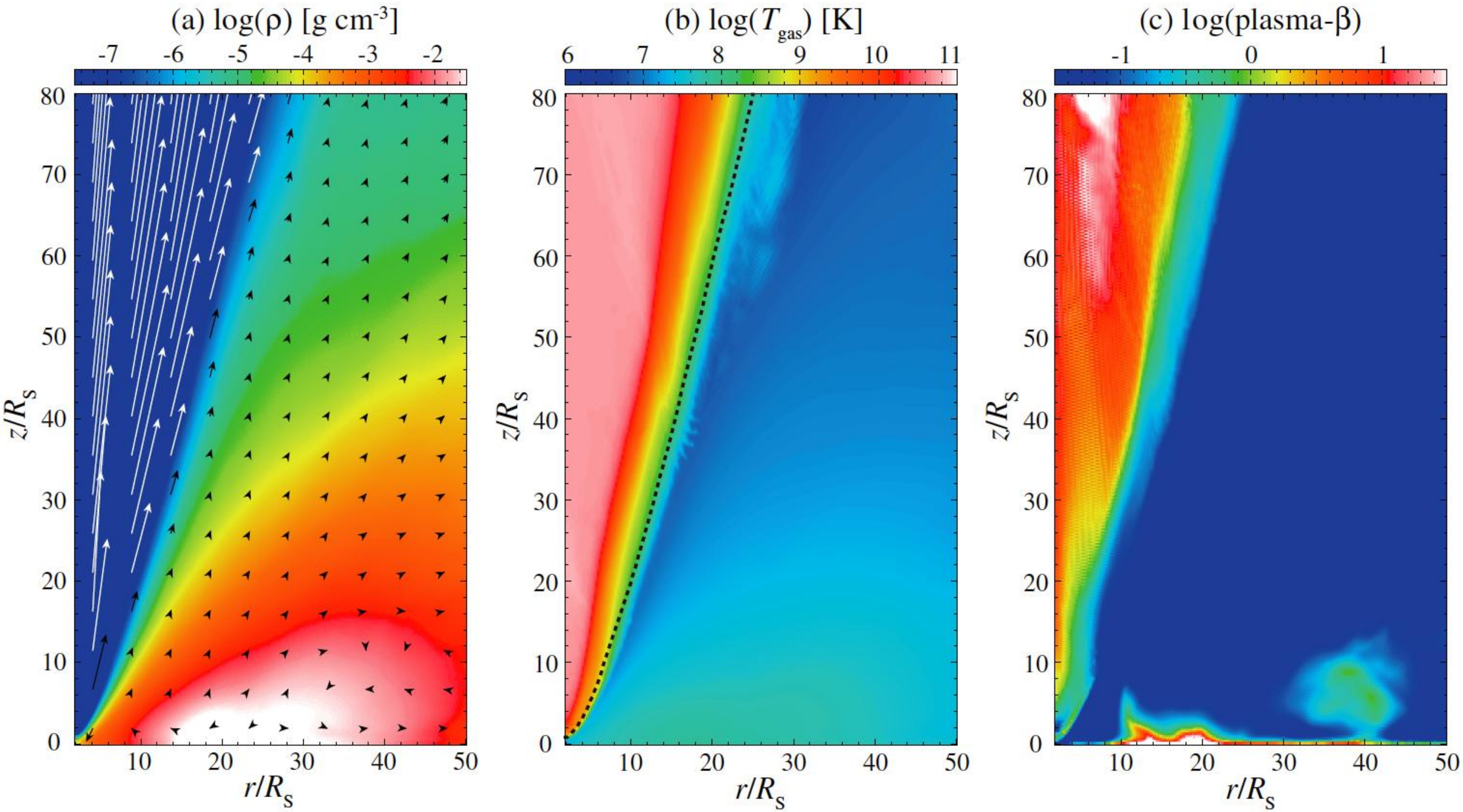
Inhomogeneous (in temperature!) Disks



-can simultaneously explain harder spectra, coherent variability, and larger microlensing sizes, compared to standard disk theory.



-Dexter & Agol (2011)



-Radiation MHD simulation of a super-Eddington accretion flow with a *radiatively* accelerated, magnetically-collimated outflow.
(Ohsuga & Mineshige 2011)

Conclusions

- Lots of distinct local physics unique to the radiation dominated regime: compressibility, radiation damping, photon bubbles (perhaps), radiation advection, turbulent Comptonization.

- Radiation pressure dominated regime does appear to be fragile to thermal runaways, though different codes give different results. Tentative ZEUS/Athena consensus:
  - -Narrow boxes with FLD give long-lived equilibria at Prad/Pgas~10
  - -Narrow boxes at Prad/Pgas~100 often run away.
  - -Narrow boxes with VET run away.
  - -Wide boxes run away.

- What is global outcome, and how does this manifest in lack of variability in X-ray binaries, except in GRS 1915+105 and IGR J17091-3624, which are probably near-Eddington?

- Even local simulations still a LONG way off from the regimes reached in nature. What is the disk structure in luminous AGN?

- Global simulations are the next frontier – and they are coming quickly!