AGN accretion and disk-jet coupling

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AGN accretion and disk-jet coupling: what should I talk about?
Not observations: many experts around

So theory.

disk-jet coupling: theory

Well, to be honest: there is no theory

So I have chosen a style „Inspiration” for my presentation.

disk-jet coupling: theory

But we have some hints for the necessary ingredients.

Jet presence: sources

Many astronomical systems with accretion disks develope jets. But not all.

- Protostars – accretion from environment – winds & jets (but not relativistic)
- Calaclysmic variables (white dwarf accretors) – accretion from binary companion – winds
- AGN – accretion from environment – winds & jets
- Galactic black holes/neutron stars – accretion from companion – winds jets
- Gamma-ray bursts – winds & jets

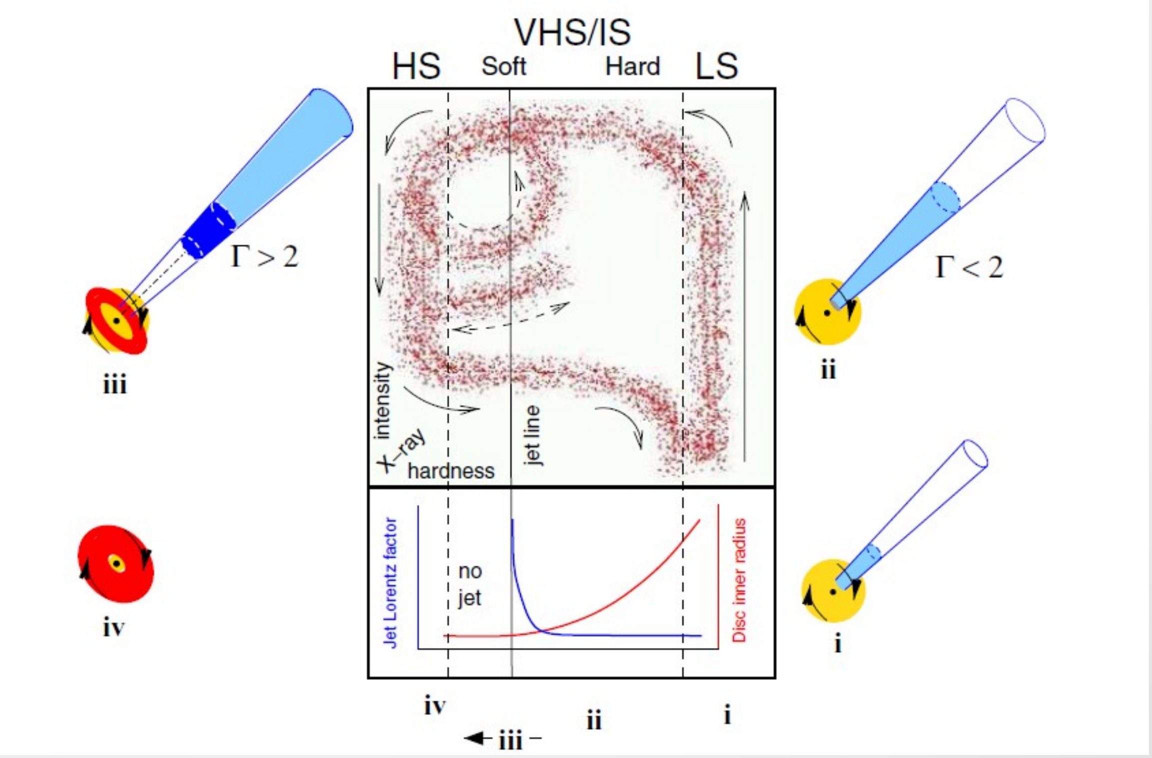
Nice example of a neutron star with jet: Circinus X-1Sell et al. (2010) Relativistic? Recent study suggests the presence of a supernova remnant instead of jet (Heiz et al. 2013)

Jet presence: conclusions

It is not quite proved that other objects than black holes can develop relativistic jets. If only blak holes have them, then extraction of energy from a rotating black hole might be a key element.

On the other hand, having a black hole is enough?

Jets in radio-quiet sources ?



Fender, Belloni & Gallo 2004

Basic accretion disk theory

Keplerian disks (Shakura & Sunyaev 1973):

- Specific angular momentum of a fluid element determines a radial position in a disk
- Angular momentum has to be transfered outward to allow the gas to move inward
- Half of the gravitational energy is retained by the fluid element, half is radiated away
- Stationary Keplerian disk have appearance which does not depend on the viscosity

$T\_eff^{4} = 3 G M Mdot/^{r3}$

- In order to be a Keplerian disk, the disk has to be geometrically thin (negligible radial pressure gradients)

Basic disk theory: bad news

The time-dependent behaviour of the Keplerian disk does depend explicitly on the prescription of viscosity:

tau_visc = 1/α (r/h)2 tau_dyn

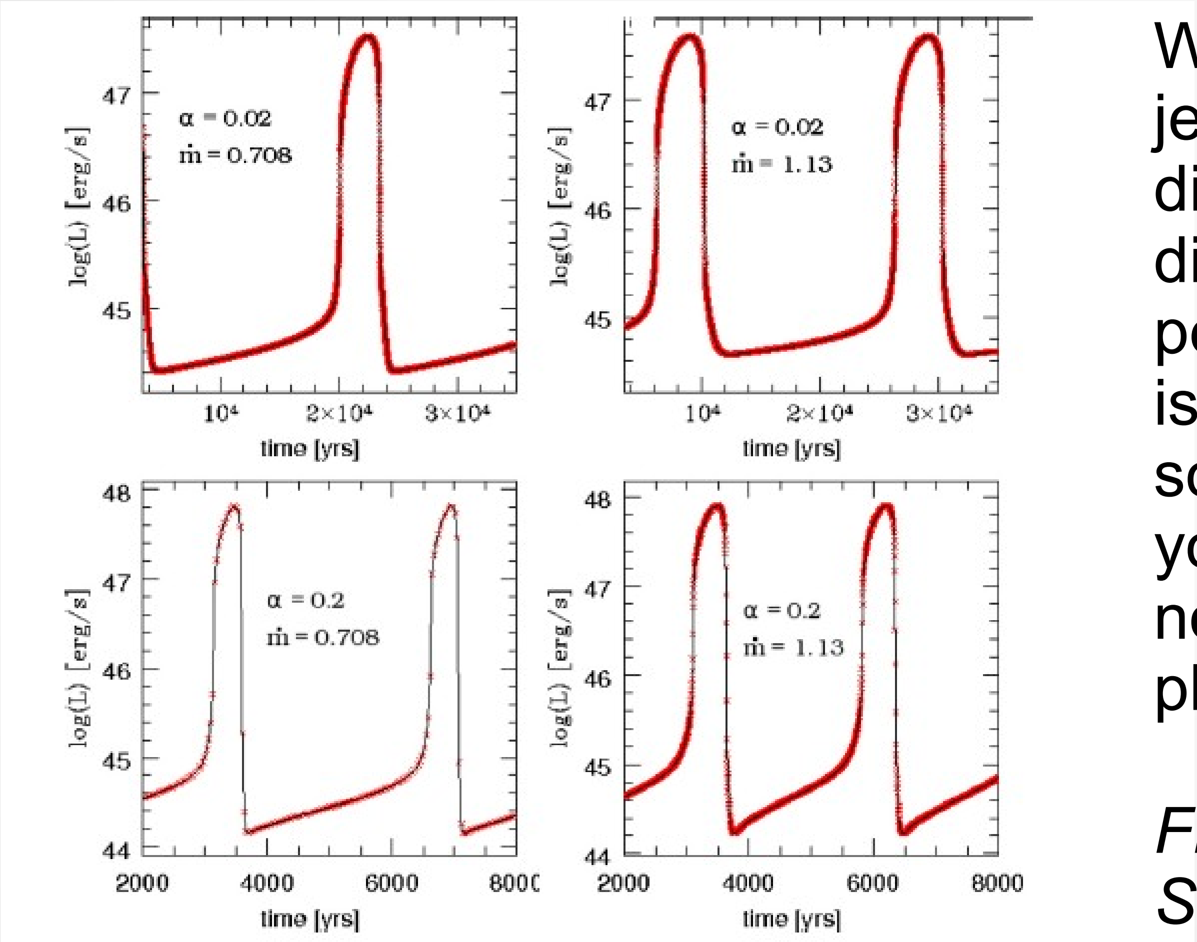
And standard Shakura-Sunyaev disks with α-viscosity are unstable:

- radiation pressure instability
- partial ionization instability

Observational support:

- Radiation pressure: heartbeat states in GRS 1915+105, IGR J17091–3624, GPS sources reactivation ?
- Ionization instability: CV dwarf novae, X-ray novae

GPS as young sources



We assumed that the jet responds to the disk state, and since disk changes periodically jet activity is also periodic, and sources seem always young, since we do not see the previous phase

From Czerny, Siemiginowska, Janiuk et al. 2009

Basic disk theory: good news

We now have a model of viscosity, and this is MRI (magnetorotational instability; Velikhov 1959, Chandrasekhar 1961; Balbus & Hawley 1991).

Numerical experiments indicate α of order of 0.01 – 0.1, depending on the radius and height.

Good news are short....

Basic disk theory: bad news

Numerical check for the presence of the radiation pressure instability:

- Turner 2004 – no instability
- Hirose, Blaes & Krolik 2009 – no thermal instability, possibly traces of viscous instability

Theoretical explanations of the absence of the radiation pressure instability:

- Stochastic aspect of the viscosity (Janiuk & Misra 2012)
- Time delays between the field generation and dissipation (Ciesielski et al. 2012)

But ...

Basic disk theory: bad news

But finally

Jiang et al. (2014) – radiation pressure instability obtained in MRI simulations!
Changes: new code (Athena instead of Zeus), larger grid

And

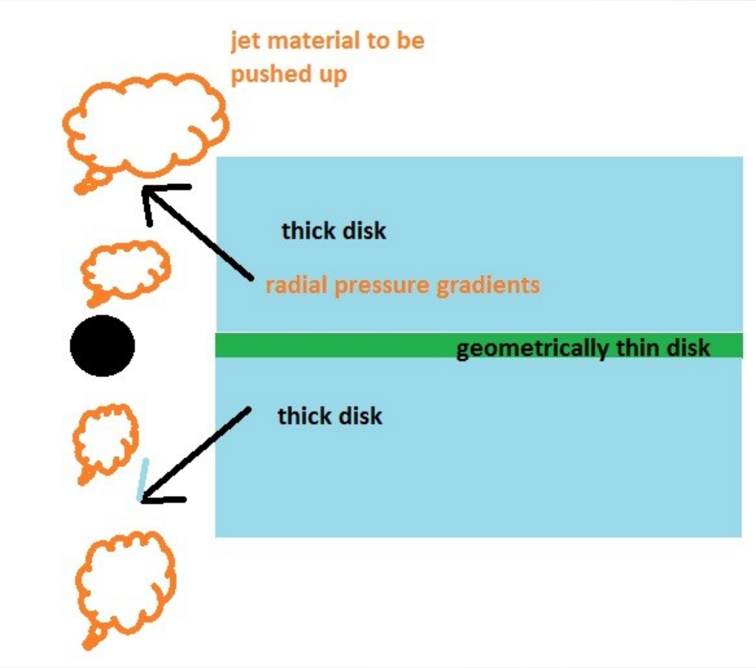
Mosr recent MRI modelling in partial ionization zone reveiled two states of the disk, as implied by alpha-viscosity models of partial ionization instability:
Hirose et al. (2014).

So may be good news? Or a fashion change?

Keplerian disks and jets

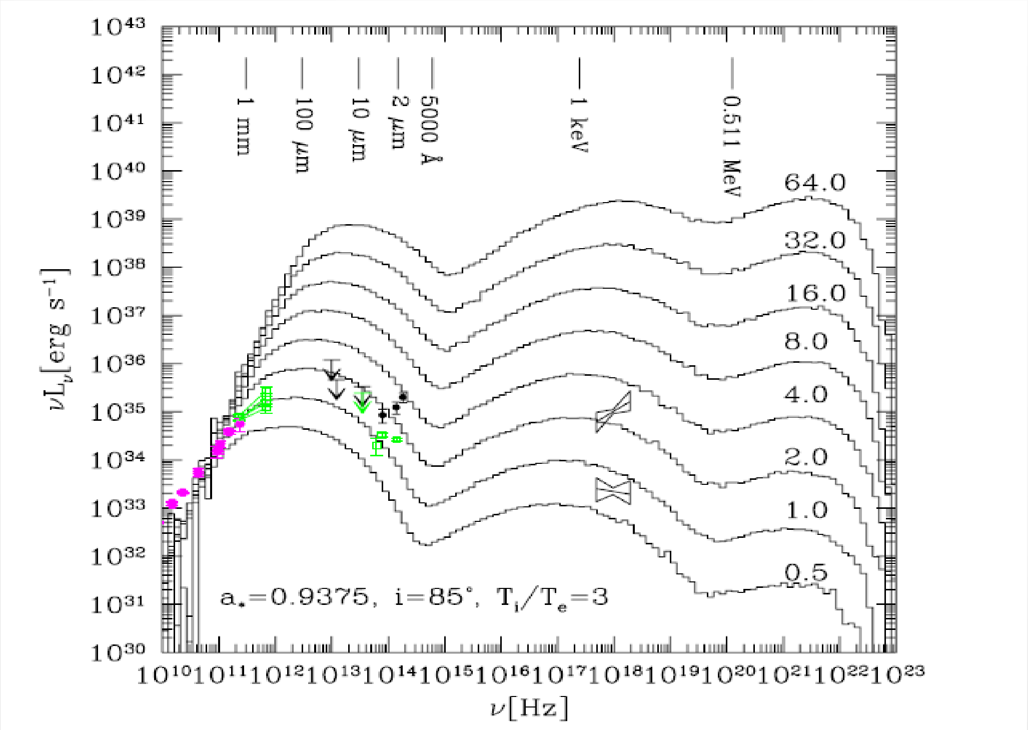
The general believe is that Keplerian disks are not capable of producing jets.

Arguments:
- Numerical simulations: geometrically thick disk is required
- Theoretical: need for high ram pressure close to the jet basis (black hole horizon) which cannot be provided by thin disk (low radial pressure gradient)



We do have other disk models:

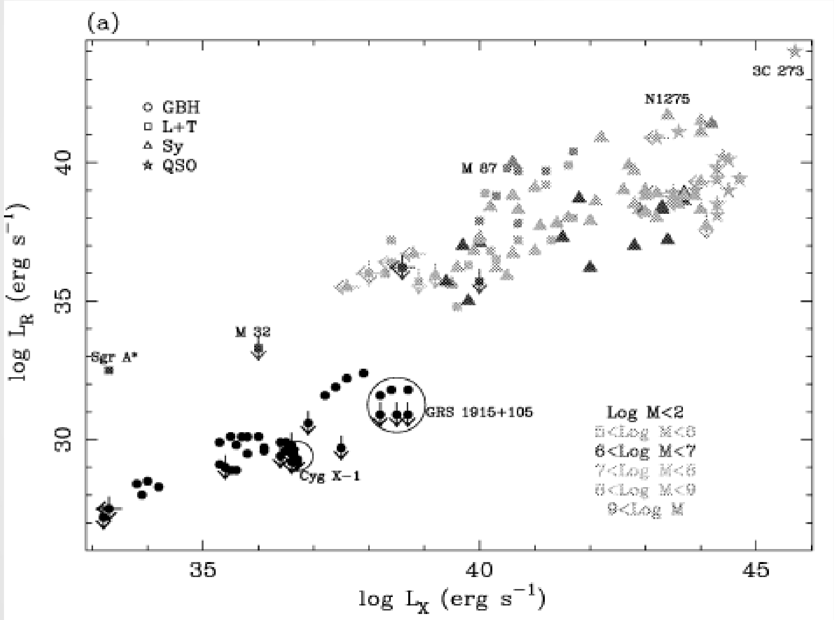
Alternative:
Geometrically thick, optically thin, sub-Keplerian flow (Ichimaru 1977, Narayan & Yi 1994), known as ADAF (advection-dominated accretion flow)
With further modifications (ADIOS, RIAF,CDAF, MDAF, ...).
Observational appearance:



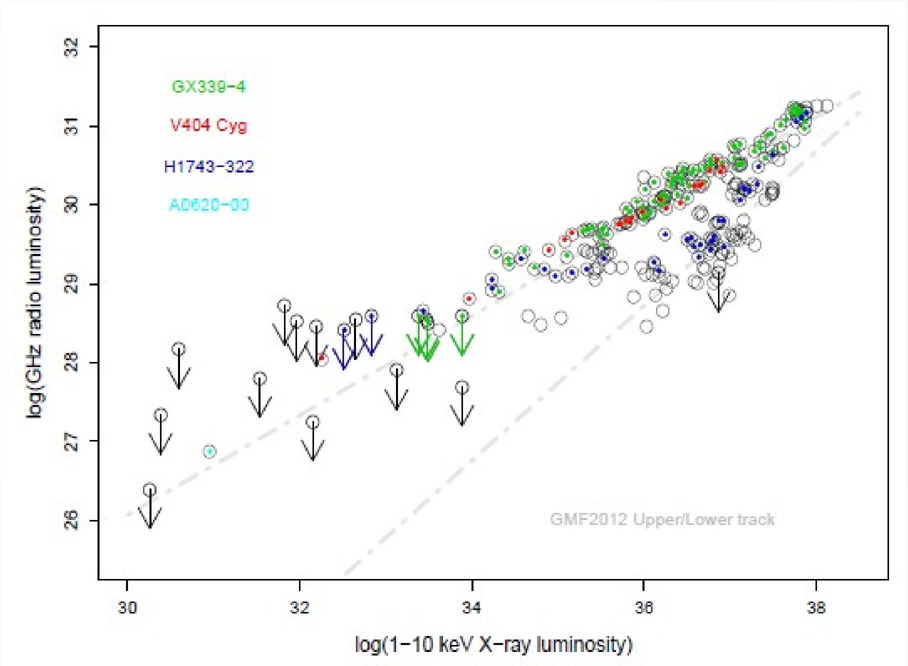
Broad band spectrum of various states of Sgr A, Moscibrodzka et al.*

Difficult aspects: ion-electron coupling, non-thermal electrons: i.e. radiative efficiency

ADAF and the Fundamental Plane

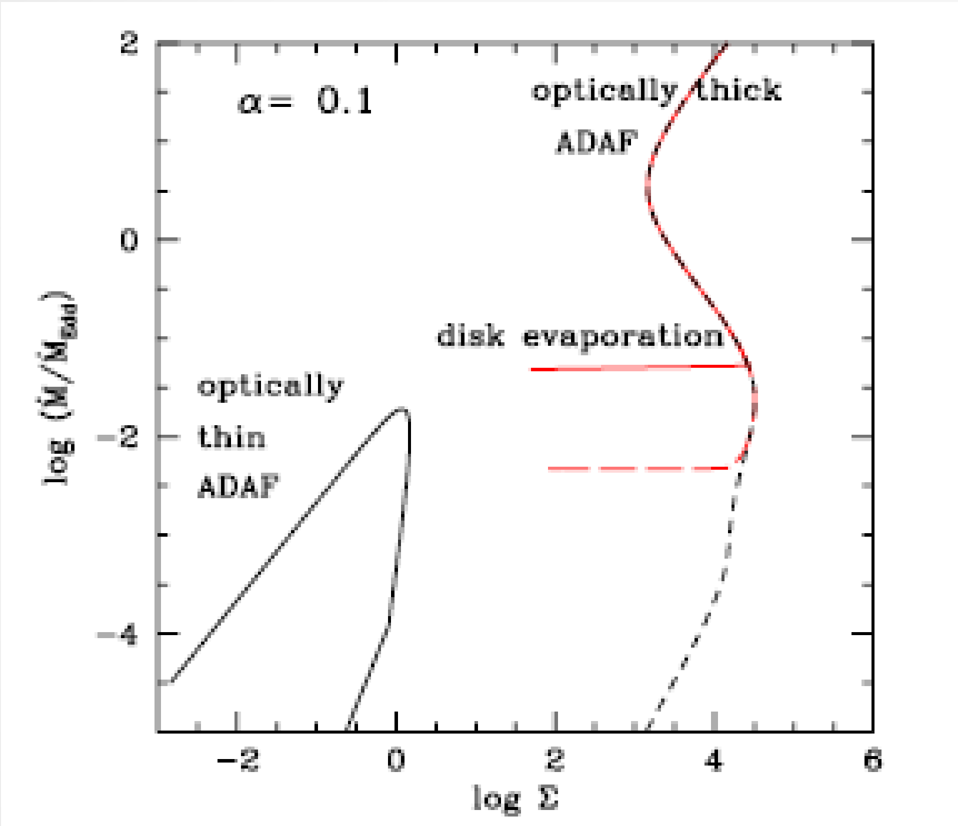


Merloni, Heinz & DiMatteo 2003



Recent picture for binaries: two tracks present? Fender & Gallo 2014

ADAF-SS transitions



Rozanska & Czerny 2000

The mechanism is based on electron conduction and radiative heating/cooling. However, it is not complete in the case of two-temperature plasma (ion conduction?).

ADAF-SS coexistence

Recent plot:

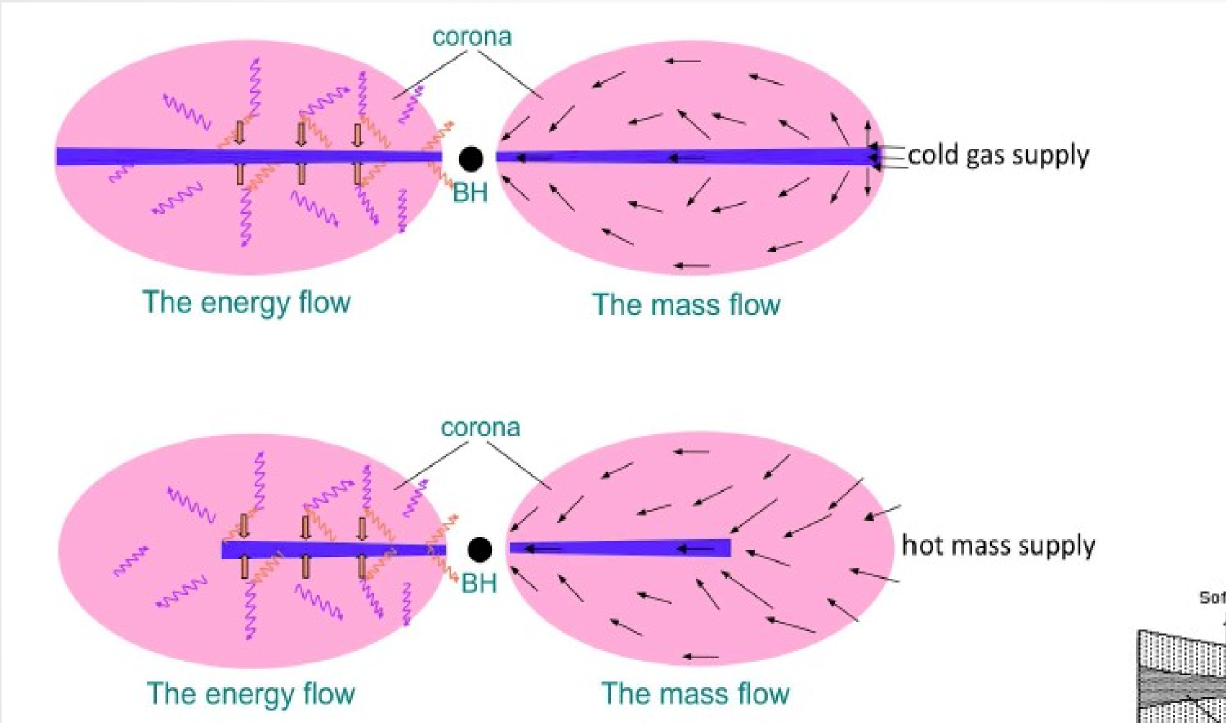
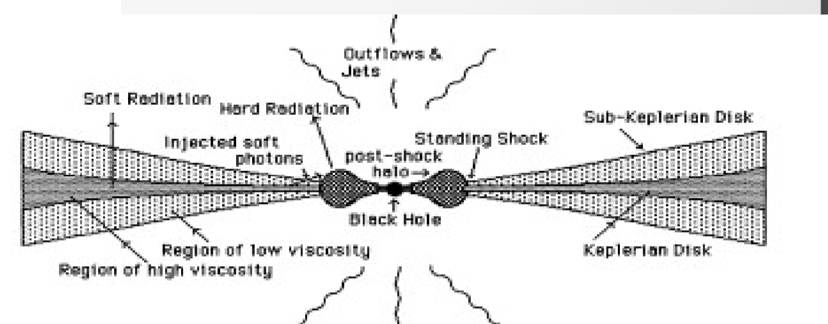


Fig. 1.—
A schematic description of the mass and energy flowing in the disk and corona w
Roche lobe overflow (upper) and hot, isotropically distributed gas supply (lower).

Liu et al. 2015)

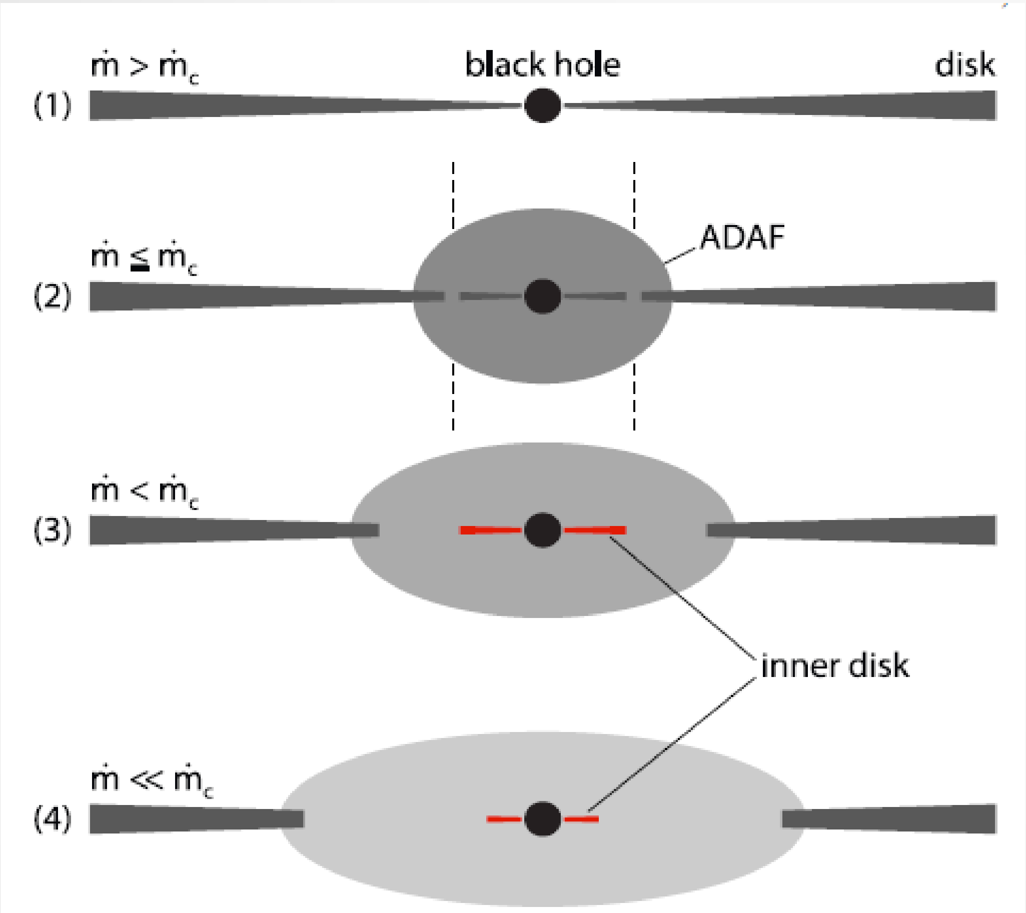
Actually, two-phase flow has been around for some time, e.g.

It is not yet well calculated, so the transition is not well



Chakrabarti & Titarchuk 1995

Inner cold disk



It is predicted by the model (but we know the model limitations), it might be seen in observations ??? Used in the paper to explain relativistic iron line in Seyfert 1 galaxies

Meyer-Hofmeister, E.; Meyer, F.2011

So does ADAF give us a jet?

No automatically.We need large scale magnetic fields to be put it. Simple standard ADAF does not generate them automatically.

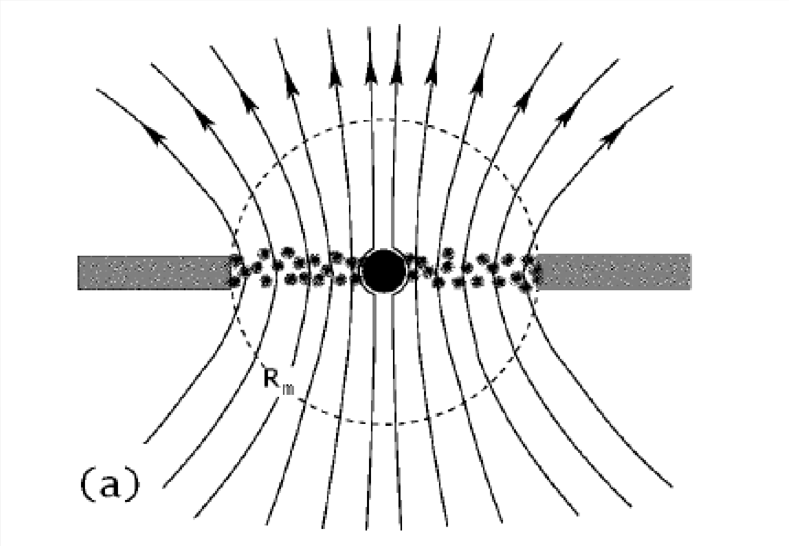
Typical MHD simulations do not produce large scale magnetic fields but small scale turbulent magnetic field, i.e. fields good for angular momentum transfert but not fo relativistic jet launching.

Two ideas how to produce those fields.

- Magnetic field line dragging
- Generation in situ by Cosmic Battery

Field dragging and MAD models

The idea dates back to Bisnovatyi-Kogan & Ruzmaikin (1974, 1976), further elaborated by Narayan, Igumenshchev & Abramowicz 2003, Sikora & Begelman 2013)



Narayan et al. 2003; field dragged by a cold disk

Sikora & Begelman (2013) point out the need for a hot (spherical ?) flow to dragg in the field.

Magnetized accretion disks

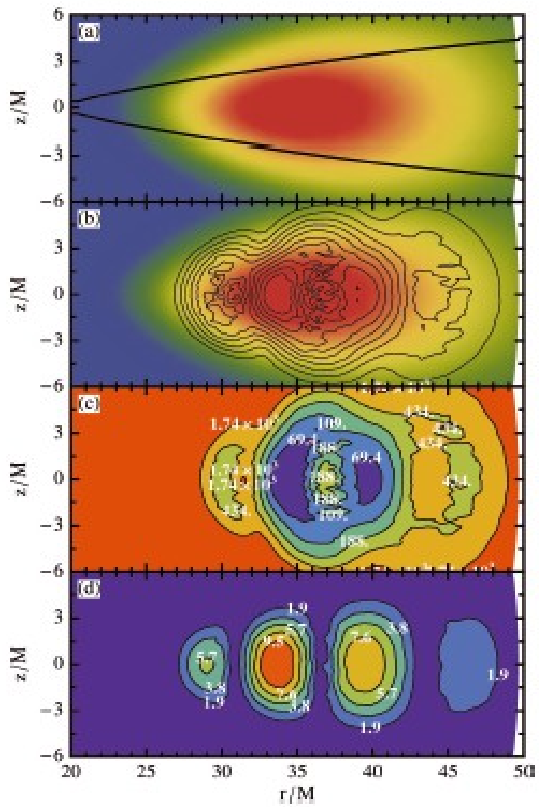


Figure 1. The initial state of the fiducial model (A0HR07) consists of weakly magnetized gas in a geometrically thin torus around a non-spinning ($a/M = 0$) BH. Colour maps have red as the highest values and blue as the lowest values. Panel (a): linear colour map of rest-mass density, with solid lines showing the thickness $|h/r|$ of the initial torus. Note that the BH horizon is at $r = 2M$, far to the left of the plot, so the torus is clearly geometrically thin. Near the pressure maximum $|h/r| \lesssim 0.1$, and elsewhere $|h/r|$ is even smaller. Panel (b): contour plot of b^2 overlaid on linear colour map of rest-mass density shows that the initial field consists of four poloidal loops centred at $r/M = 29, 34, 39, 45$. The wiggles in b^2 are due to the initial perturbations. Panel (c): linear colour map of the plasma β shows that the disc is weakly magnetized throughout the initial torus. Panel (d): linear colour map of the number of grid cells per fastest growing MRI wavelength, Q_{MRI}, shows that the MRI is properly resolved for the primary two loops at the centre of the disc.

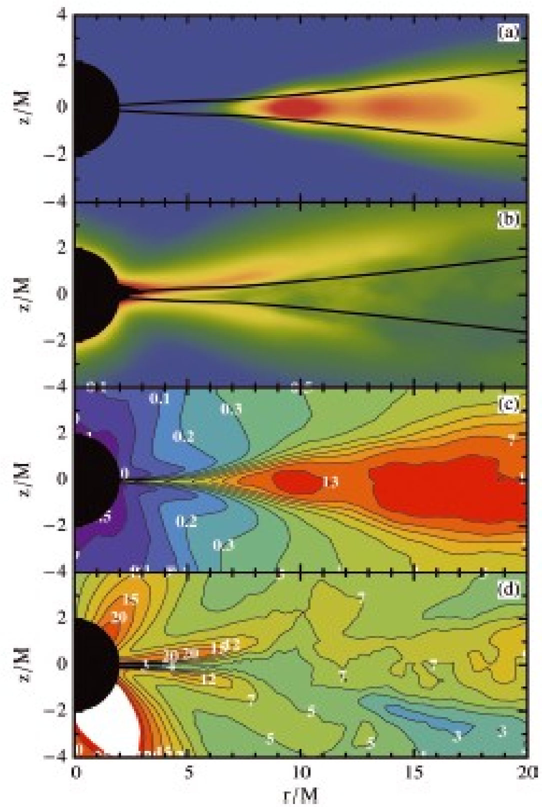


Figure 2. The evolved state of the fiducial model (A0HR07) consists of a weakly magnetized thin disc surrounded by a strongly magnetized corona. All plots show quantities that have been time-averaged over the period $12500M$ to $27350M$. Colour maps have red as highest values and blue as lowest values. Panel (a): linear colour map of rest-mass density, with solid lines showing the disc thickness $|h/r|$. Note that the rest-mass density drops off rapidly inside the ISCO. Panel (b): linear colour map of b^2 shows that a strong magnetic field is present in the corona above the equatorial disc. Panel (c): linear colour map of plasma β shows that the β values are much lower than in the initial torus. This indicates that considerable field amplification has occurred via the MRI. The gas near the equatorial plane has $\beta \sim 10$ far outside the ISCO and approaches $\beta \sim 1$ near the BH. Panel (d): linear colour map of the number of grid cells per fastest growing MRI wavelength, Q_{MRI}, shows that the MRI is properly resolved within most of the accretion flow. Note that Q_{MRI} (determined by the vertical magnetic field strength) is not expected to be large inside the plunging region where the field is forced to become mostly radial or above the disc within the corona where the field is mostly toroidal.

From Penna, McKinney, Narayan, Tchekhovskoy, Shafee & McClintock 2010

„We found that the assumed initial field geometry modifies the accretion flow"

Inflow/outflow from

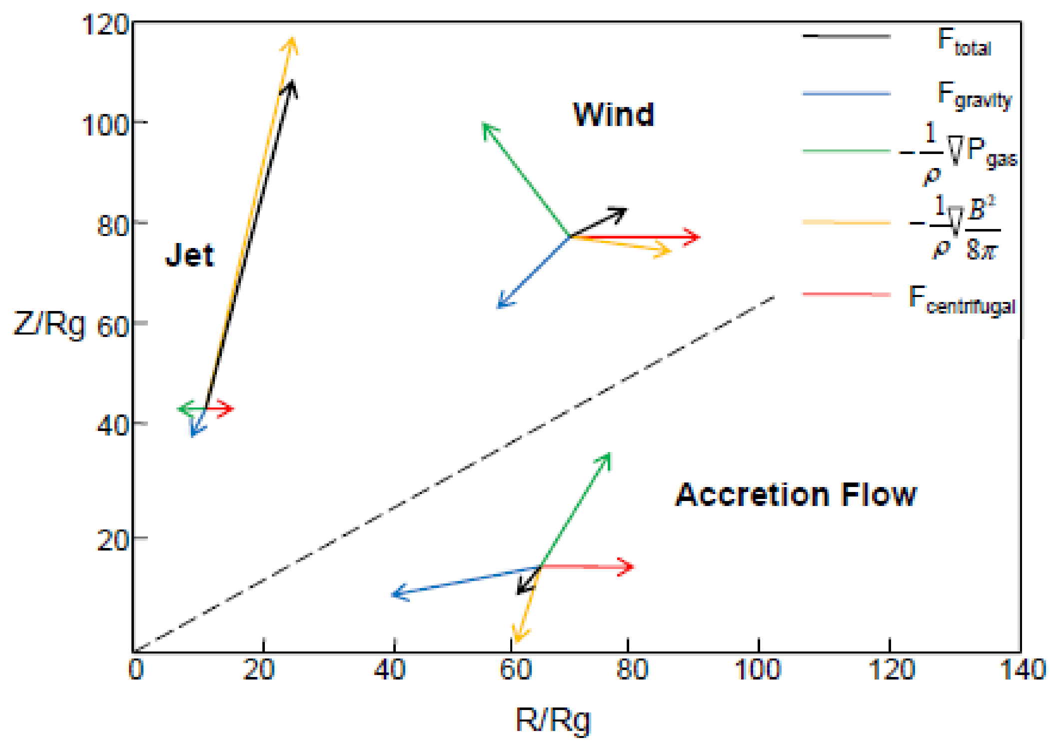


FIG. 13.— Force analysis at three representative locations corresponding to the disk jet, wind and the main body of the accretion disk. The arrows indicate force direction, whose length represents force magnitude.

Jet, wind and accretion in a single simulation (Feng et al. 2015)

But

- Jet is not relativistic
- Since the aim was to study winds, the simulation is designed so that the magnetic flux does not accumulatesignificantly around a black hole.

The result depends on the setup.

Cosmic batery

Idae dates back to Contopoulos & Kazanas (1998) further developed e.g. In Contopoulos et al. (2015)

Here the magnetic field is generated to to the difference of the radiation pressure actic on electrons and protons, relative motion of electrons and protons, subsequent electric field generation and finally generation of the magnetic field.

The mechanism gives large scale poloidal magnetic loops.

The authors performed nice numerical simulations but I could not copy a figure since it turned black (top secret) so read the paper.

During the jet conference in Krakow 2015 there was a lot of discussion whether this mechanism is efficient. Most people think it is not.

There is also Bierman batery (Biermann 1950) which operates due to the perpendicular electron and density gradients. For recent developments, see Schoeffler,[1] Loureiro,[1] Fonseca, Silva, 2014, Phys.Rev..

We need MAD. Do we need high spin?

Strong magnetic field expels the jet but we also need a source of energy. Do we take it from disk, or do we take it from the black hole rotation?

Blandord-Znajek mechanism: $L_{jet} \sim a^2 B^2$

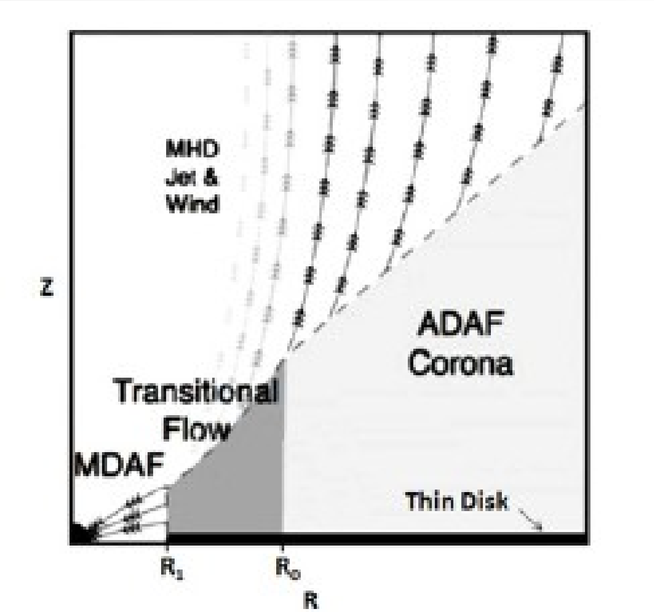
If so, we need $a > 0.5$ to have reasonable power.

The argument for the need of BZ is that if we have MAD or/and radial flow, with large pressure gradient/large ram pressure we push the plasma up efficiently but we have no spare energy to use (Marek Sikora, private communication).

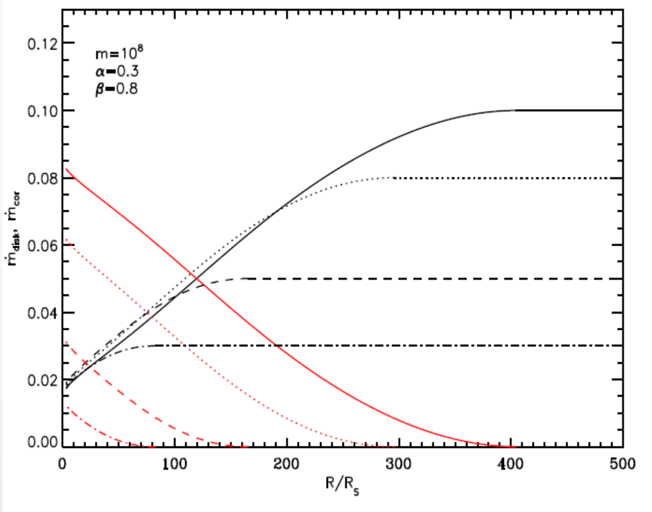
Does the sandwich model fails?

Going back to the turtle diagram by Fender et al.. Do we need an inner ADAF to have high state jet?

Recent discussion of fast magnetic field reconnection by Singh et al. (2015) suggests production of plasmoids **above** accretion disk (in the corona) but they need inner MDAF.



In the previous paper they did not nedd an inner MDAF. ..



Liu et al. 2015: accretion rate in the corona saturates at 0.02 Eddington.

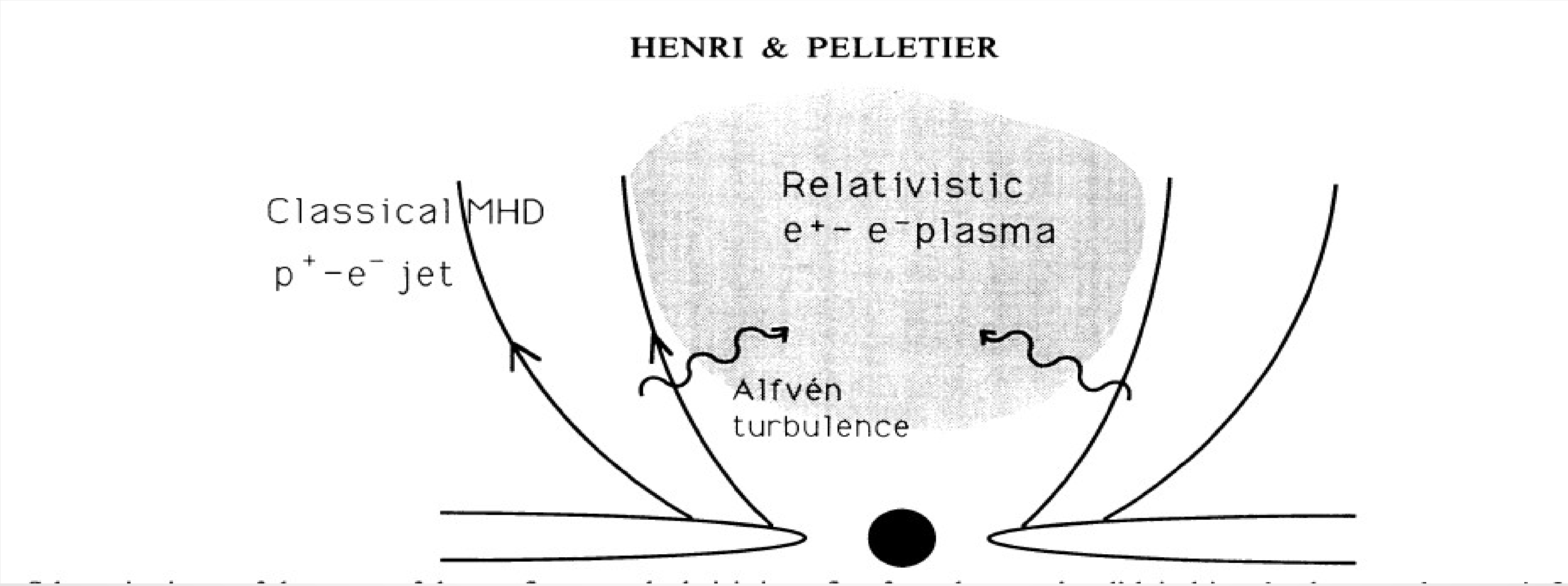
What do we see in radio-quiet sources?

The X-ray emission in radio-quiet sources comes from a very compact region:

- In radio-quiet quasars R_X ~ 10 R_g from microlensing
- In Seyfert galaxies like MCG -5-30-15 light-bending model advocated by Fabian requires compact region moving up/down roughly at the symmetry axis
- The size of the emitting region is not far from being pair-dominated although non-thermal cooling is a viable alternative
- In Sgr A* the flares come from a region of ~ 1 Rg

What do we see in radio-quiet sources ?

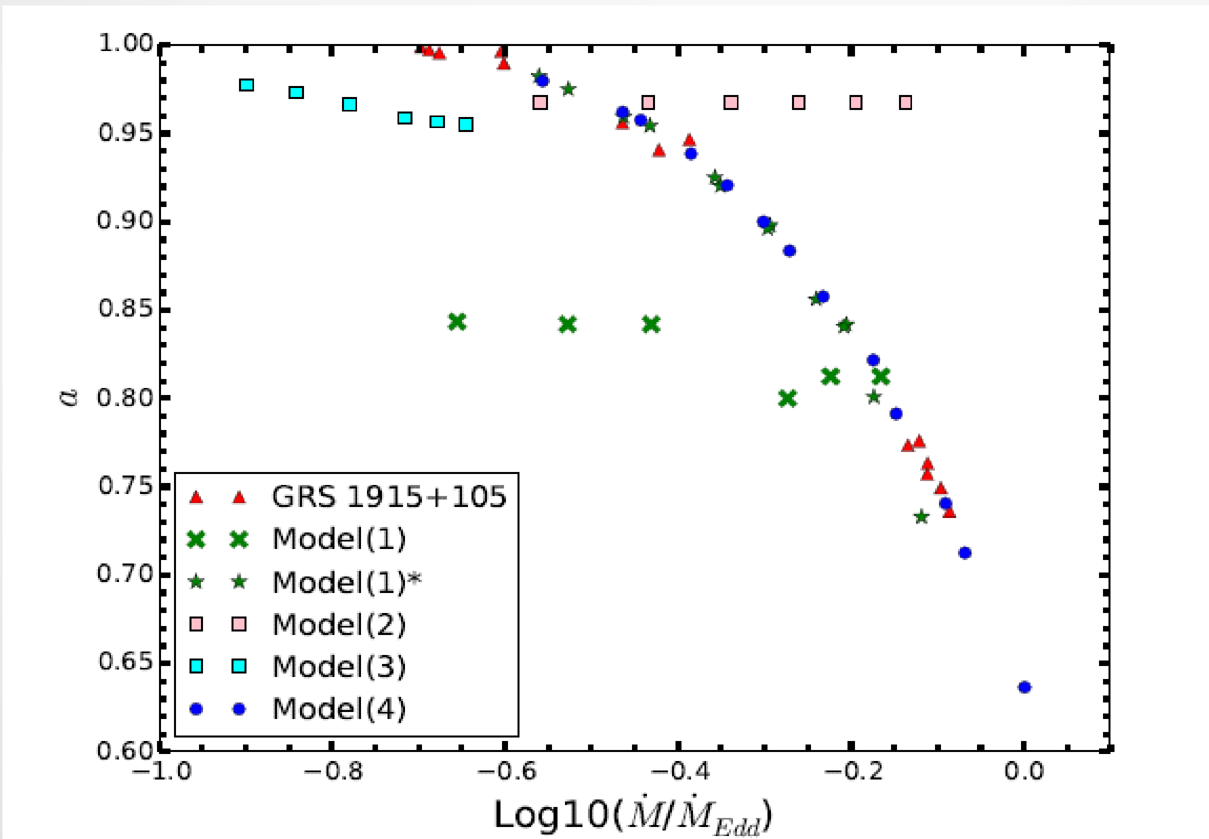
It all looks quite like the old picture of the pair-dominated jet basis by Henri & Pelletier 1991:



So plasmoid forms in the presence of the cold disk (reflection component in light bending) but is too weak or fails to extend or ….

How much we affect the radio-quiet sources by forming jet basis?

McClintock et al (2006) and Straub et al. (2011) discussed the apparent spin decrease with Eddington ratio in GRS 1915+105. We model that with an outflow.



You et al., in preparation

We can explain the effect as the rise in the inner disk cut-off radius with Eddington ratio, from ISCO to about 10 Rg. Strong outflow or energy drain

However, this is done for a specific disk hardening factor BHSPEC. Using different prescription we will lget much smaller effect (Straub et al., in preparation).

Summary

Necessary ingredients to cook a jrelativistic jet:

- Black hole
- Hot inner flow, persistent or temporary
- Large-scale magnetic field
- Large black hole spin

?

But how exactly to make it?

Magnetic field experts say that we are very, very far from understanding magnetized time-dependent plasma, and we cannot maje a jet without a magnetized plasma....