Black hole accretion

Feng Yuan (袁 峰)

Shanghai Astronomical Observatory
Chinese Academy of Sciences

Outline

- Chapter 1: Introduction to some basic concepts and Review of accretion models
- Chapter 2: The standard thin disk and slim disk
- Chapter 3: Hot accretion flow: dynamics & radiation
- Chapter 4: Hot accretion flow: applications
- Chapter 5: Wind and jet
- Chapter 6: AGN feedback

CAS "Taiwan Young scholar program"

- Visiting scholar: 3-6 months，30K CNY per month
- Postdoc: 2 years, 250 K CNY per year
- Deadline: Sept. 25
- Send me email if interested.

Chapter 5:
Winds and jets

5.1 Introduction: observation and theory of wind

Winds (Outflow): why important?

- Accretion physics
  - Outflow: exists or not? important ingredient of accretion physics
  - Crucial to explain observations of AGNs & BH binaries
- AGNs feedback
  - Outflow plays an important role in AGN feedback: momentum (Ostriker et al. 2010)
  - Need to constrain their properties: mass flux, velocity, density…

Observational evidences (I): cold disk

- blue-shifted UV/optical & X-ray absorption lines in AGNs
  - Typical v_{out} ~ several 1000 km/s → 0.2 c
  - Fraction of quasar with BALs to bright quasar ~ 0.15-0.2 (Reichard et al. 2003); ~0.5 for Seyfert 1 (Crenshaw & Kraemer 1999)
- Warm absorbers (WAs) observed in soft X-ray band
  - Detected in ~ 50 % Seyfert 1 galaxies
  - v_{out} ~ 100 - 1000 km/s, high mass outflow rate
- Ultra-fast outflow (UFOs) observed in hard X-ray band (Tombesi et al. 2010, 2011, 2012)
  - v_{out} ~ 0.03 – 0.4 c; highly ionized; high column density and mass outflow rate (higher than WAs)
  - Launched around 0.0003 − 0.03 pc

Observational evidences (II): hot accretion flows

- Low-luminosity AGN (Cheung et al. 2016, Nature)
  - They find evidence for wind in LLAGNs with, e.g., $L \sim 4 \times 10^{-4}\ L_{Edd}$
- Radio galaxy (Tombesi et al. 2010, 2014)
  - Blue-shifted iron absorption lines
  - Winds co-exist with jets
- Hard state of black hole X-ray binaries (Homan et al. 2016)
- But: still no good observational constraint on wind properties

Three Mechanisms of producing wind

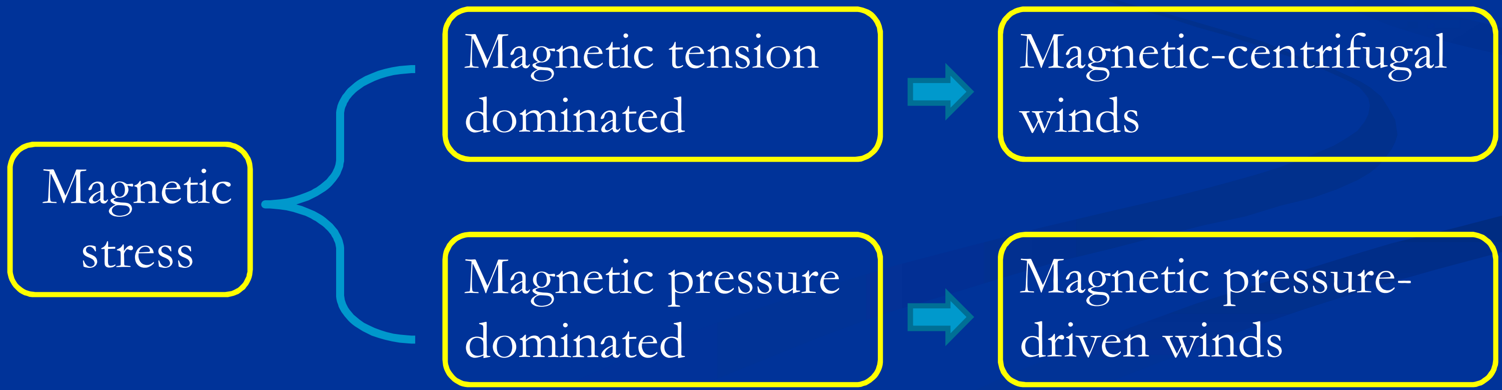
$$\rho\frac{D\mathbf{v}}{Dt}+\rho\nabla\Phi=-\nabla P+\frac{1}{4\pi}(\nabla\times\mathbf{B})\times\mathbf{B}+\rho\mathbf{F}^{rad}$$

- Thermal
- Magnetic
- Radiation

Reviews: Krolik (1999, book); Crenshaw (2003); Proga (2007)

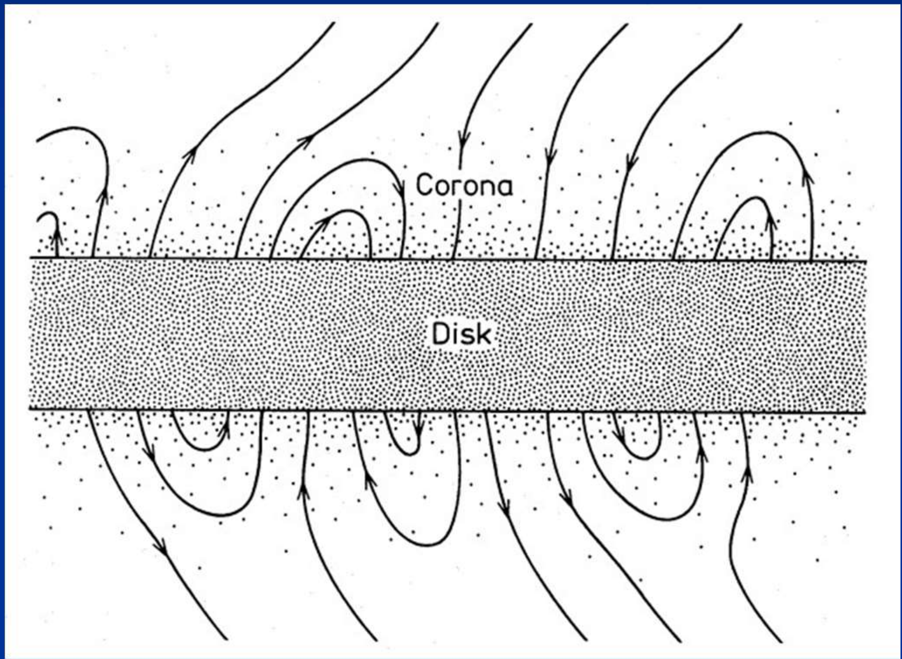
Magnetically driven

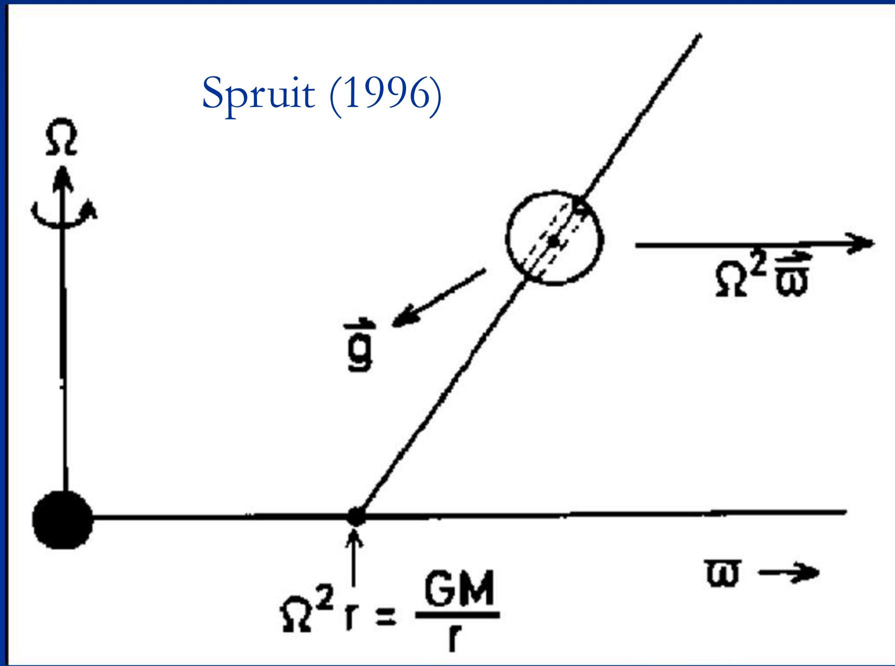
- Magnetic field always exists: the magneto-rotational instability (MRI; Bulbus & Hawley 1991) transfers the gas angular momentum outward
- So it potentially extracts materials out from the accretion disk and accelerates them to become outflows



Blandford & Payne mechanism

Blandford & Payne (1982)



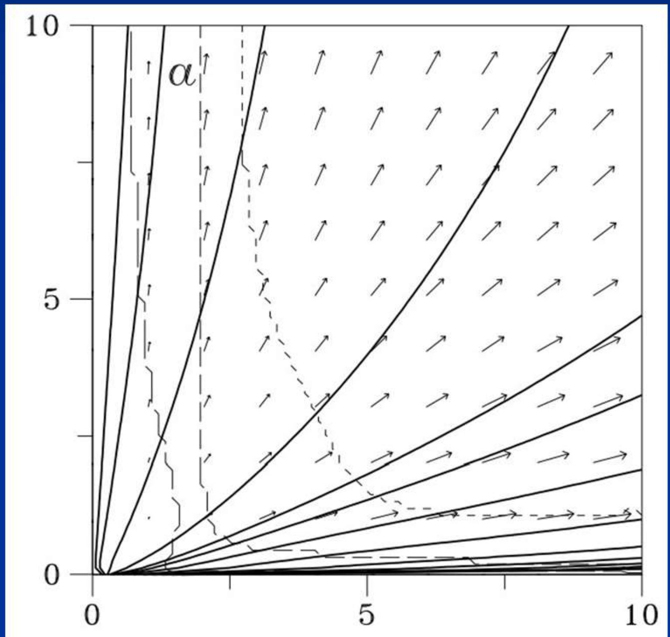


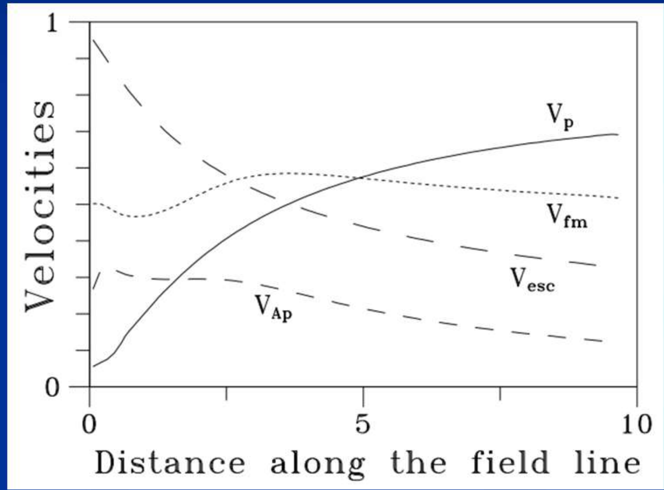
Main features of BP mechanism

- The poloidal component (Bp) of the field should have an angle > 30 degree relative to the rotational axis of the disk
- Bp > Bphi (the toroidal component)
- Open, ordered and larger scale magnetic field
  - Its origins is still unclear
  - Two possible mechanisms
    - MHD dynamo, but seems to produce only small-scale poloidal B field (e.g., De Villers 2005);
    - direct inward advection of larger-scale poloidal field (e.g., Cao 2011); however, Beckwith et al. (2009) found that large-scale poloidal field only exist close to the BH.

MHD simulations: fixed disk

Romanova et al. 1997; Ustyugova et al. 1995, 1999; Ouyed et al. 1999; Kato et al.2002…





* Assume there is such a large-scale poloidal field

- Treat the disk as the boundary (not self-consistently simulated)
- Don’t know how to push the gas into the field from the disk
- and determine the mass lost rate

Thermal mechanism

Begelman, McKee & Shields 1983

- X-ray heating: Compton heating and photoionization heating
- Escape (virial) temperature
  - Gas internal energy = local gravity potential
- When T_gas > T_esc (i.e., r > Rc), outflow appears
- Another requirement is the Compton heating time-scale should not be too long.

Features of thermal mechanism

- Thermal outflow is launched at radii far way from the BH; with weak velocity.
- The major defect is that the thermal outflow will quickly cool down as expanding when flow outward.
  - Need some heating sources to keep the outflow temperature
- Only effective when T > 10^7 K; when T < 10^7 K, the other two driven mechanisms become dominated.

5.2 (Radiation-driven) wind from thin disk

Radiation-driven: electron scattering

- For luminous quasar, the radiation momentum could match the momentum of outflows

$$\dot{M}_{out} v_{\infty} \sim L/c$$

- If gas fully ionized (high T), electron scattering is only contributor to radiation pressure
  - Outflow appears when $L > L_{Edd}$

- The required very high luminosity implies: electron scattering takes a minor role in driven AGN outflows

Radiation-driven: dust

- The opacity enhances greatly if dust exist and it couples well with the gas

$$\sigma_{dust} / \sigma_T = 10^{2-3}$$ (Mathis et al. 1977)

- The dust originates from outer part of accretion disk or torus; or from stellar evolution
- The dust exists only outside the sublimation radius

$$r_{min}^{dust} \approx 1.3(L/10^{46}\ \mathrm{ergs\ s^{-1}})^{1/2}(T/1500\ \mathrm{K})^{-2.8}\ \mathrm{pc}$$

(Barvainis 1987)

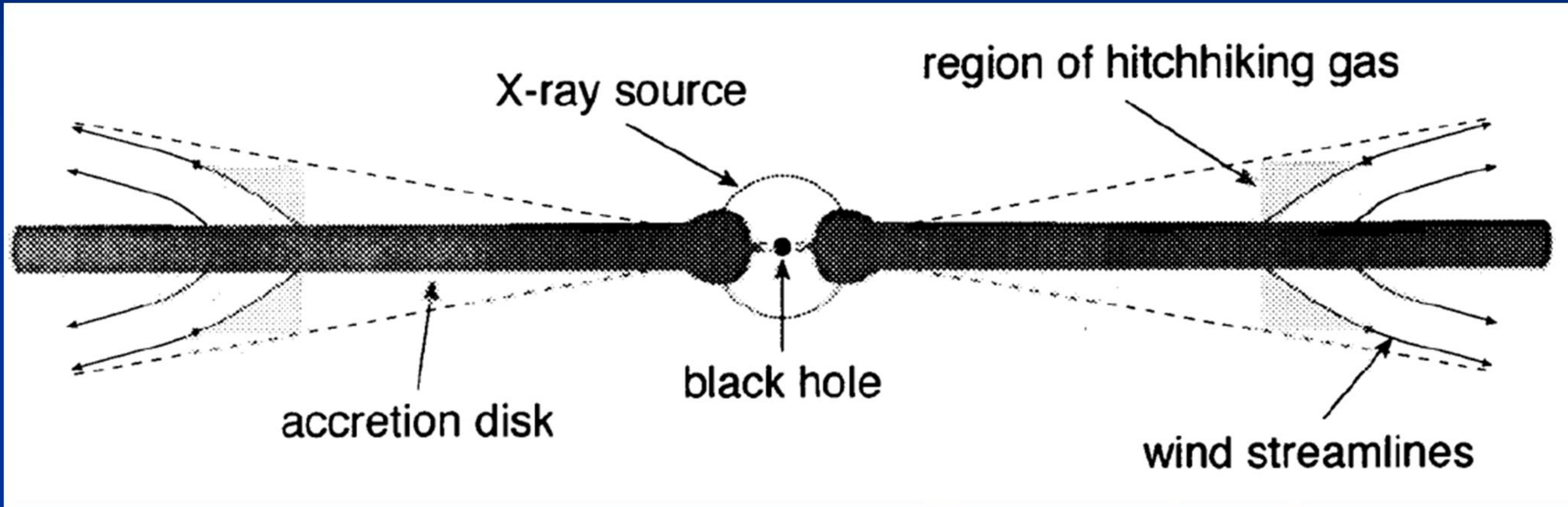
- Therefore, the dust wind only exist at large radii

Radiation-driven: line force

- For moderately ionized gas, there are many bound-bound transitions (line absorption) triggered by AGN UV (mainly) continuum
- Castor (1975) proposed a line force multiplier M_L : the magnification of line opacity relative to Thomson scattering opacity.
  - The value of M_L can be up to 2000 - 4000
- Murray et al. (1995) presented disk-wind driven by the UV radiation from the inner part of the accretion disk in order to explain the BALs

Disk-wind model

Murray, Chiang, Grossman & Voit (1995; MCGV95)



For M_{BH} =10^8 Msun , at r=10^16 cm, the gas is vertically accelerated by UV photons from local disk radiation, then radially accelerated by UV photons from the central regions of the disk.

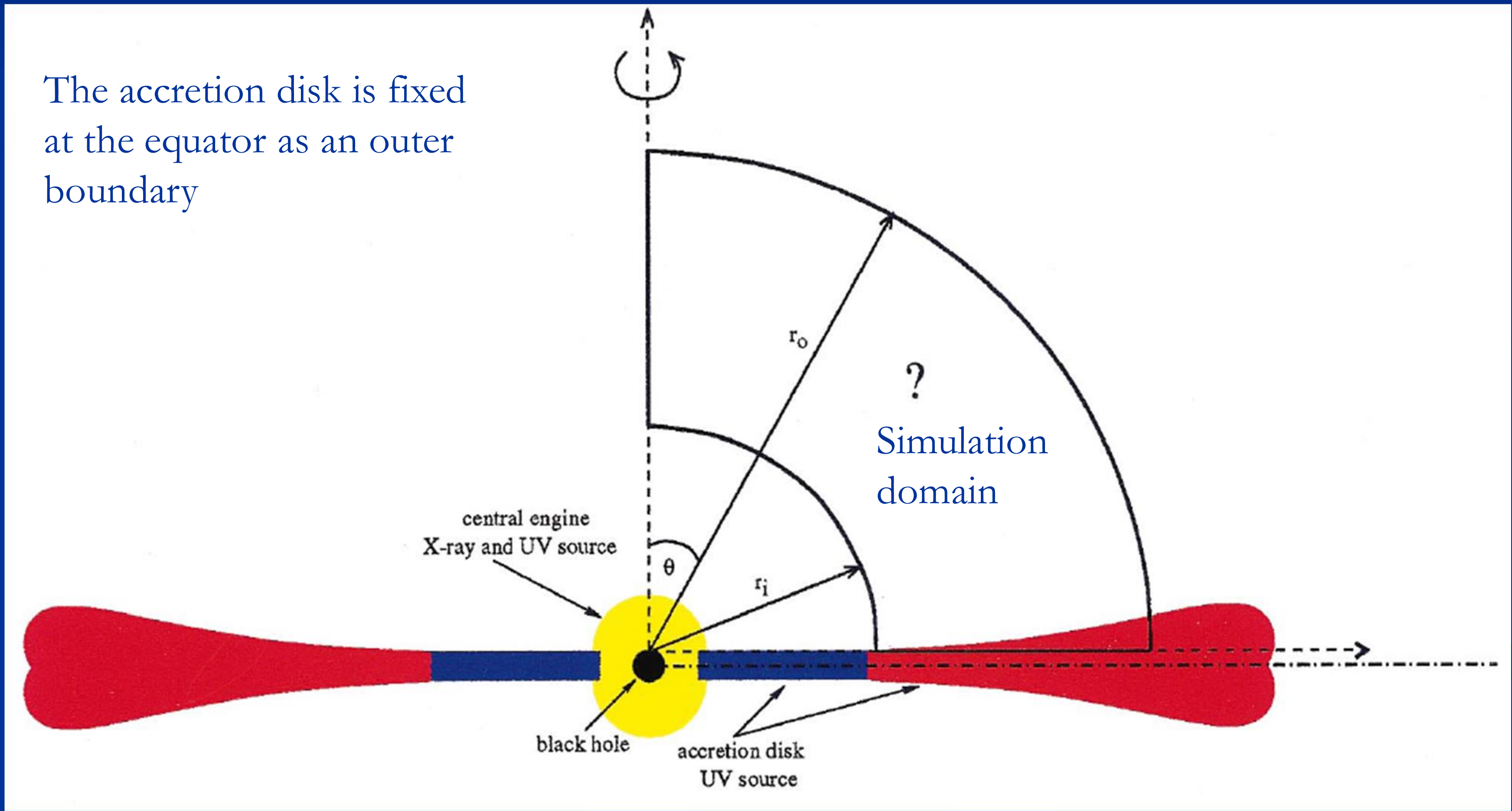
Disk-wind model: features

- "hitchhiking" gas is needed to protect the outflow gas not be over-ionized by X-rays
  - It should be optically thick to X-rays while optically thin to UV photons
- The wind streamlines has a 5 degree angle regard to the disk plane
  - It just covers ~ 10% sky which is consistent with the observations
  - If the line-of-sight is just traverse the outflow, blue shifted BALs and strong X-ray absorption lines will appear
  - As there are many resonance lines, so emission lines could be observed at most angles
- The wind is continuous

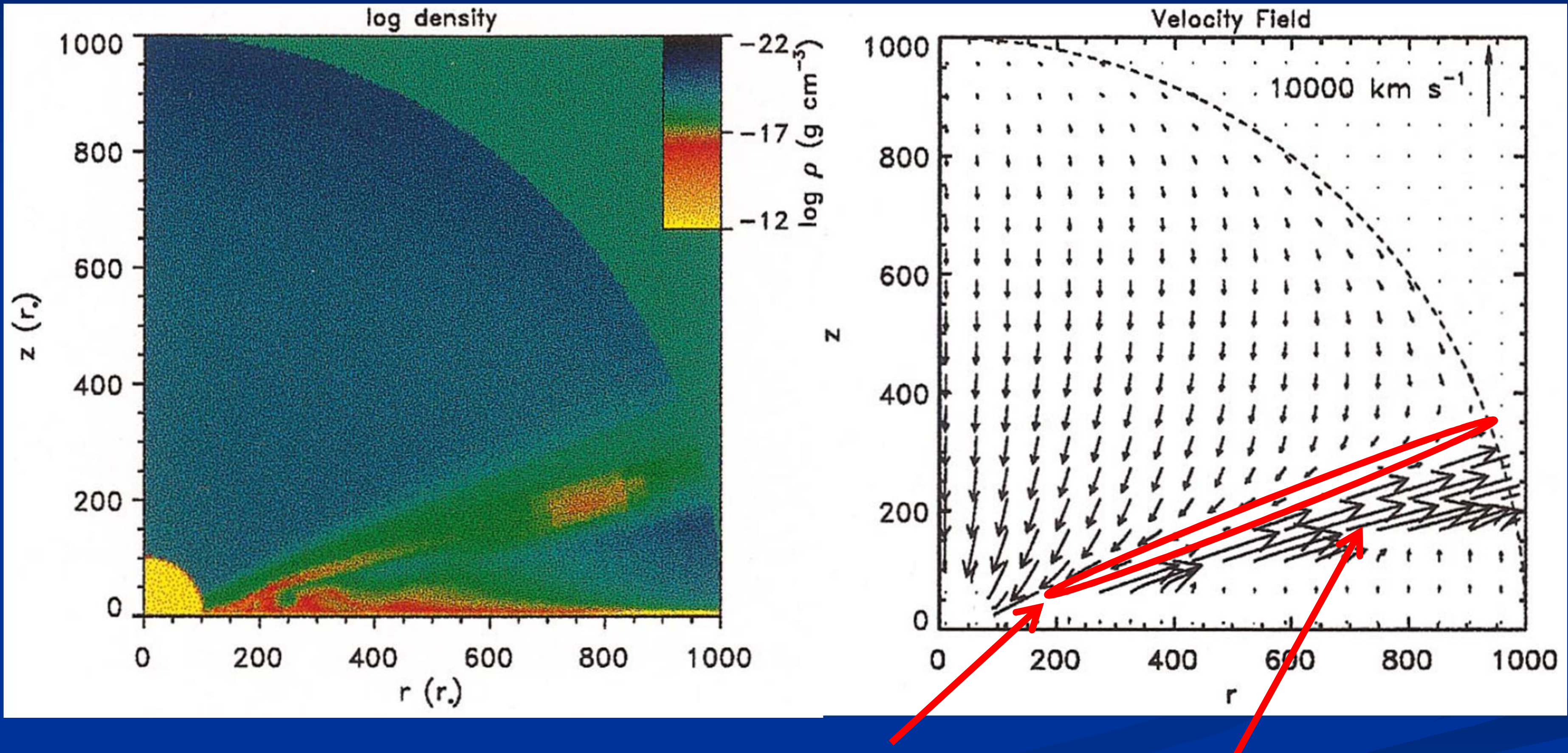
Disk wind: 2D HD simulation

Proga, Stone & Kallman 2000

- An extension of Murray et al. (1995)

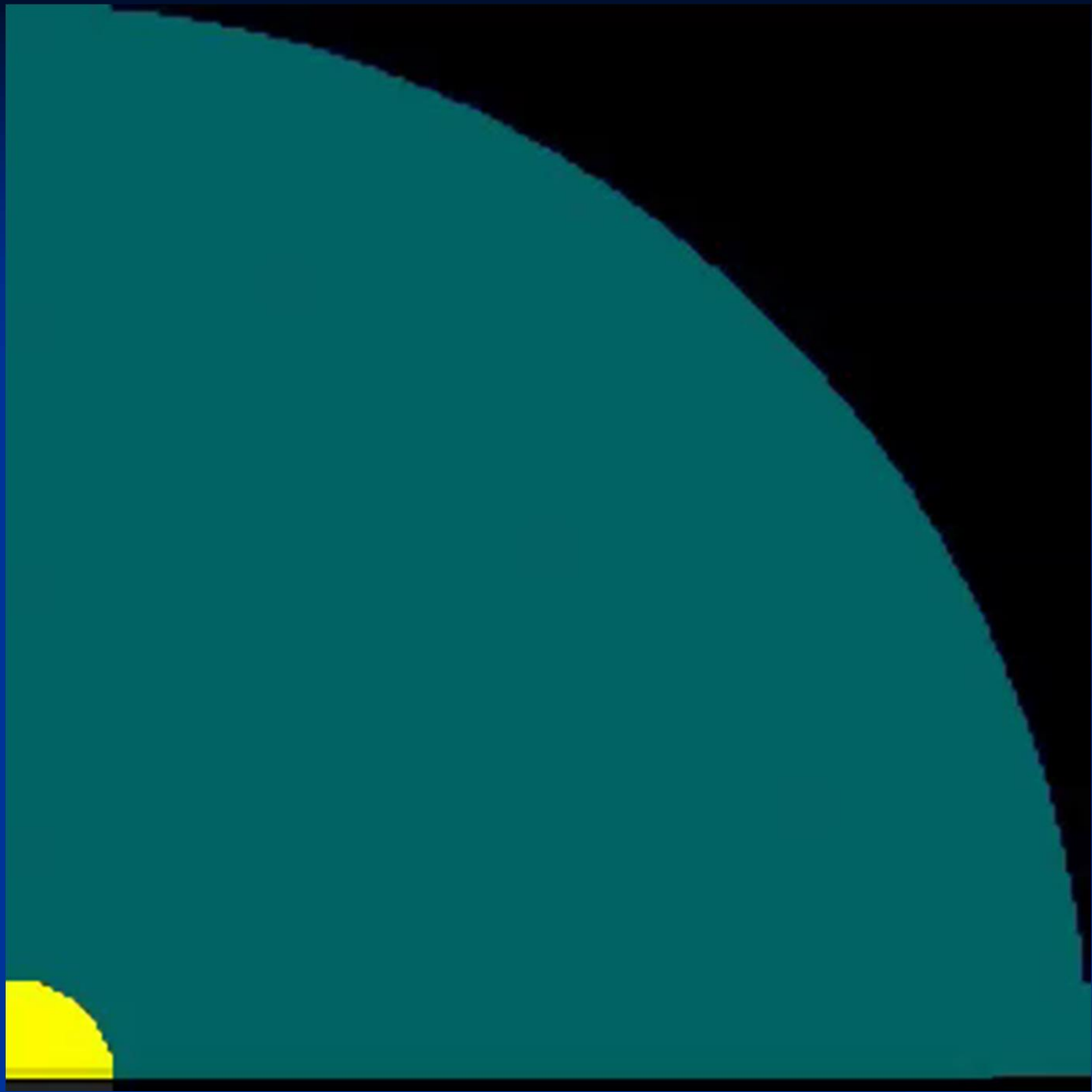


The Shielding gas appears self-consistently



Shielding gas shell

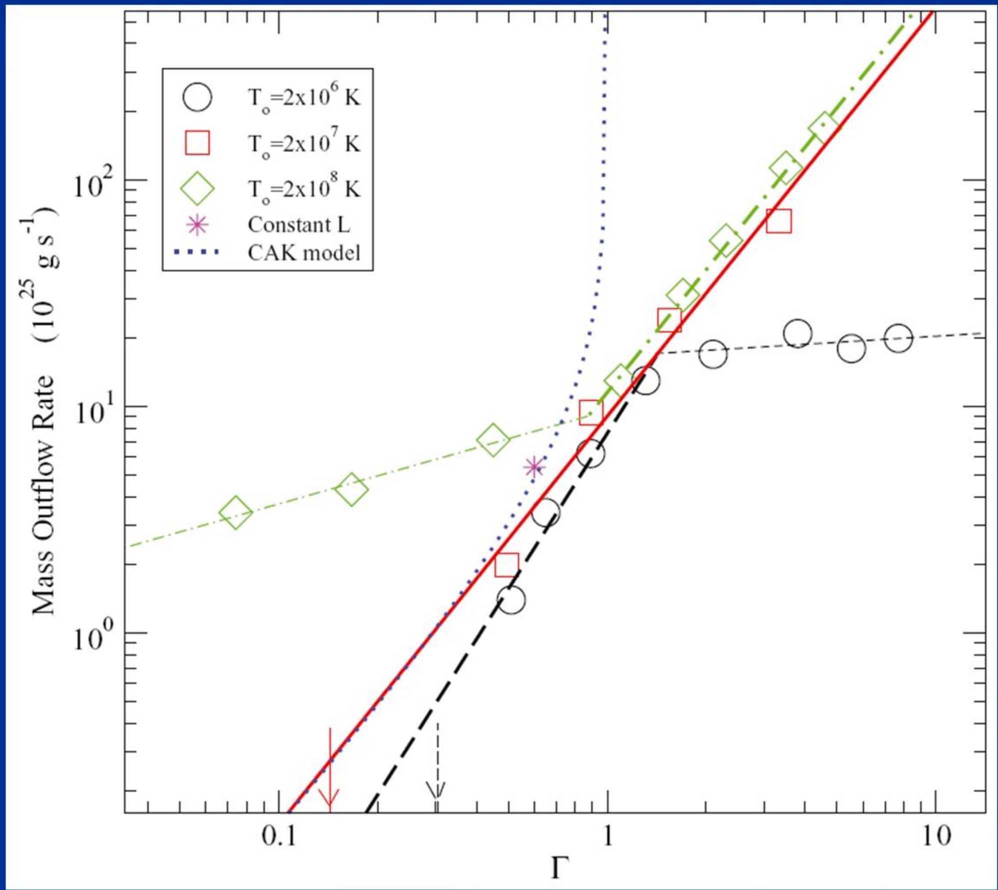
Fast line-driven outflows



Line-driven outflows on pc-scale

Kurosawa & Proga 2009

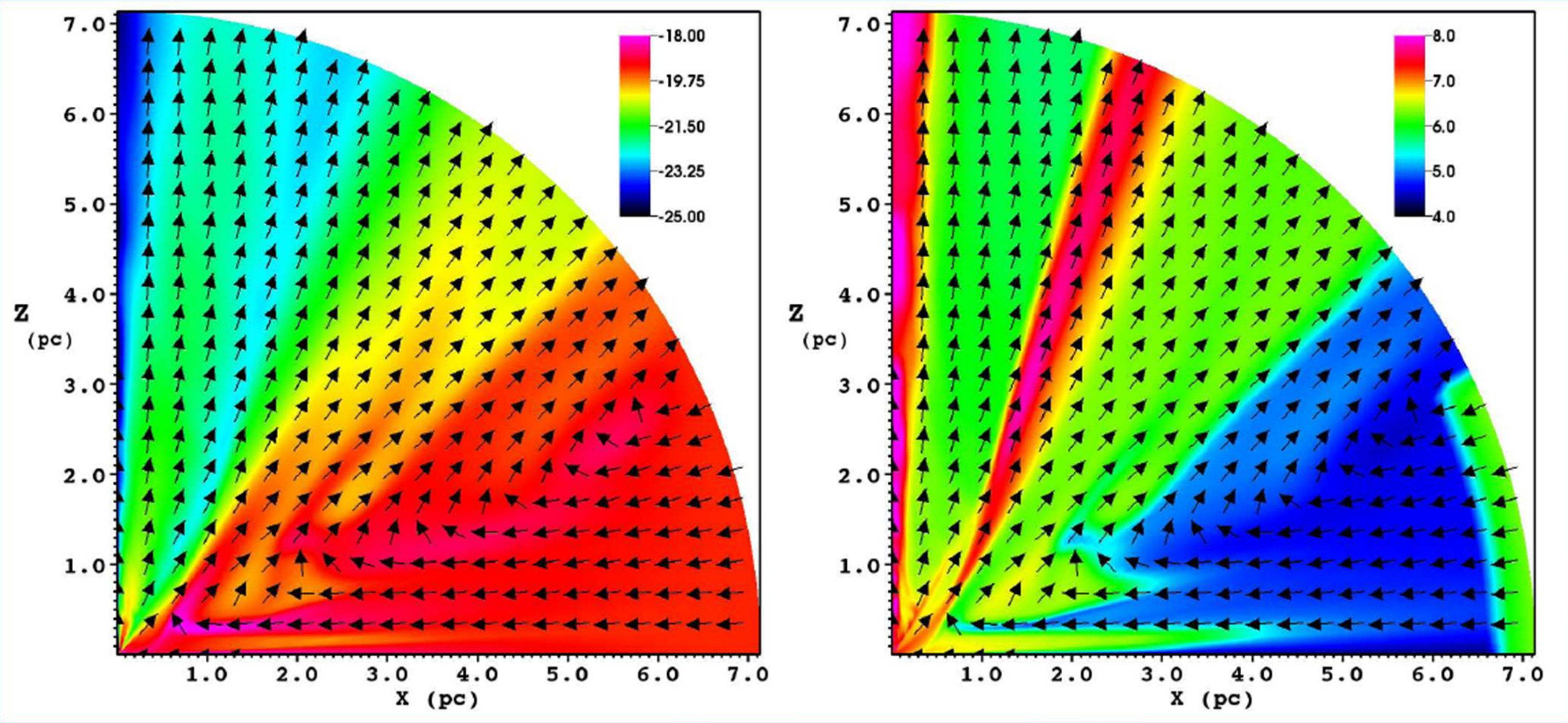
- the line-driven is also effective on pc-scale



Re-radiation effects

Liu, Yuan, Ostirker, Gan & Yang 2013

- This effect was ignored by previous works



The limitations of radiation-driven mechanism

- Effective only for luminous AGN
- not work well for sources with highly-ionized gas or low-luminosity sources
  - the highly-ionized UFOs are unlikely driven by Compton scattering as L is too low (Tombesi et al. 2013)
  - LLAGN; e.g., NGC 4151: L ~ 4%L_{Edd} (Kraemer et al. 2005)
  - 3C 111: Thomson scattering optical depth only ~ 0.05 (Tombesi et al. 2011)
  - NGC 3783: highly-ionized outflow; may be thermal-driven (Chelouche & Netzer 2005)
  - GRO J1655-40 (Miller et al. 2006, Nature; Neilsen & Homan 2012)

5.3: Wind from hot accretion flow

Accretion rate decreases inward

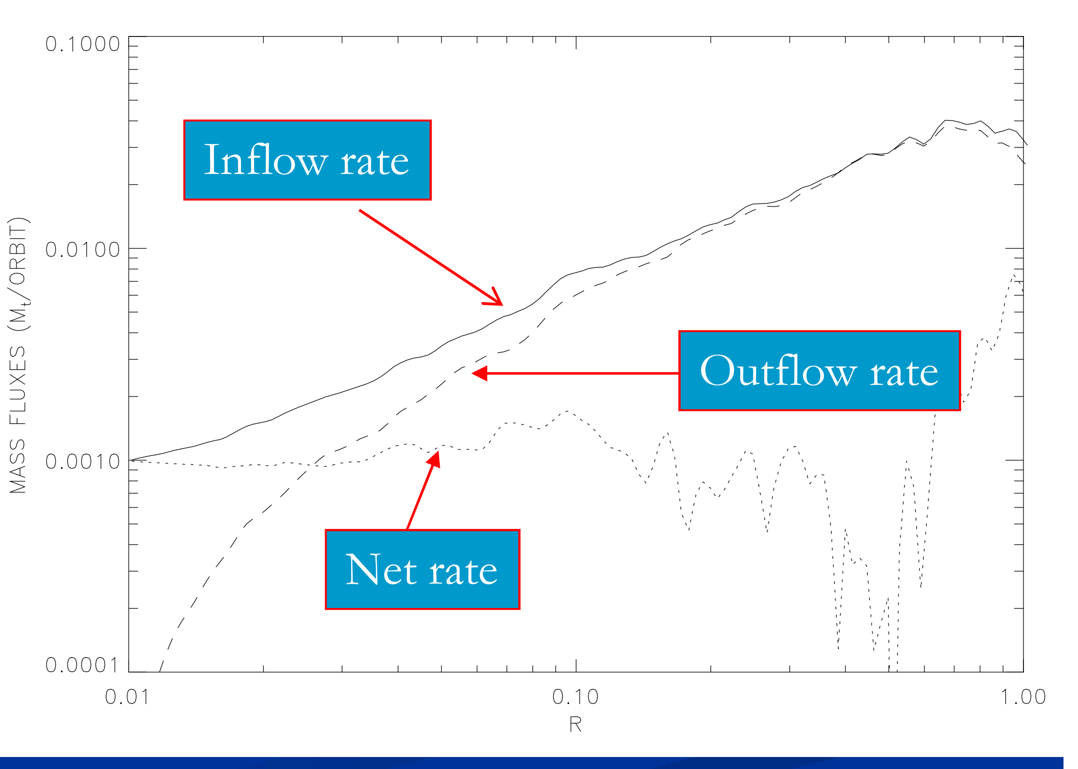
Stone, Pringle & Begelman 1999; Stone & Pringle 2001; Hawley & Balbus 2002; Machida et al 2003; Pen et al. 2003; Igumenshchev, Narayan & Abramowicz 2003; Pang et al. 2010; Yuan & Bu 2010; Yuan, Wu & Bu 2012; Li, Ostriker & Sunyaev 2013

$$\dot{M}_{\rm in}(r) = 2\pi r^2 \int_0^\pi \rho \min(v_r, 0) \sin\theta d\theta,$$

$$\dot{M}_{\rm out}(r) = 2\pi r^2 \int_0^\pi \rho \max(v_r, 0) \sin\theta d\theta,$$

$$\dot{M}_{\rm net}(r) = \dot{M}_{\rm in}(r) - \dot{M}_{\rm out}(r).$$

$$\dot{M}(r) = \dot{M}(r_{out})(r/r_{out})^{0.5-0.8}$$



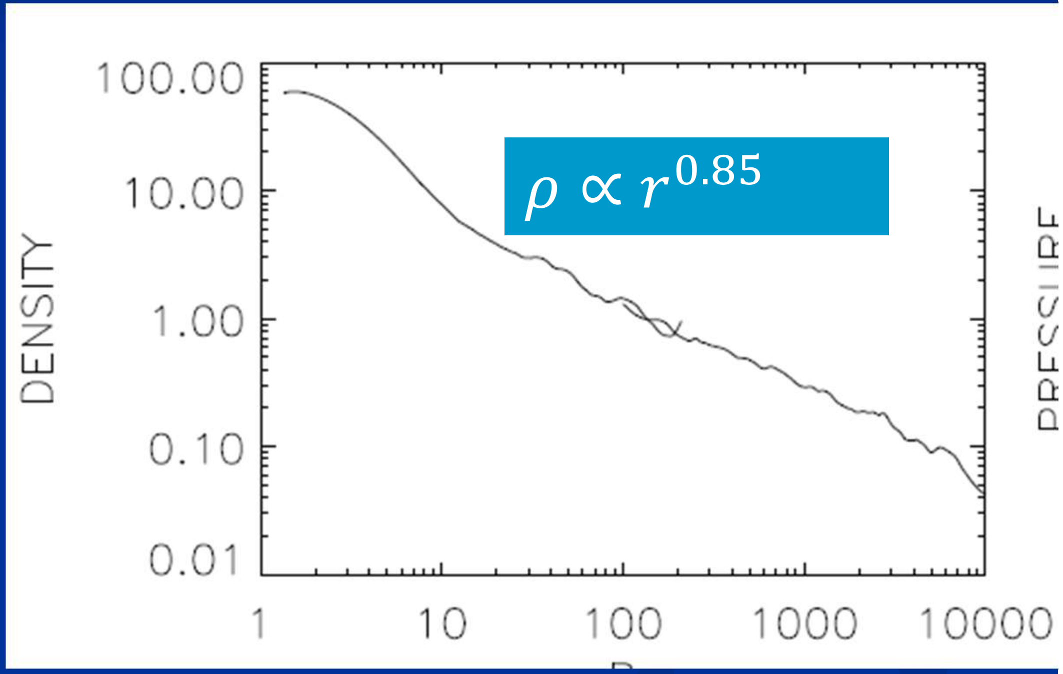
Stone, Pringle & Begelman 1999

Density profile flattens

If Mdot is constant, then:

$$\rho \propto r^{3/2}$$

When Mdot decreases inward →



Yuan, Wu & Bu 2012

Confirmed by Observations of Sgr A* & NGC 3115

Yuan, Quataert & Narayan 2003; Wong et al. 2011

- Chandra observations + Bondi theory give the Bondi rate:

$$10^{-5} M_{\bullet} yr^{-1}$$

(consistent with numerical simulation of Cuadra et al. 2006)

- High linear polarization at radio waveband requires innermost region accretion rate (rotation measure requirement):

$$(10^{-7} - 10^{-9}) M_{\bullet} yr^{-1}$$

- So $\dot{M}$ must decrease inward
- Density profile consistent with numerical simulation
  - Sgr A*: $\rho \propto r^{-1}$
  - NGC 3115: $\rho \propto r^{-1.03^{+0.23}_{-0.21}}$

Question:

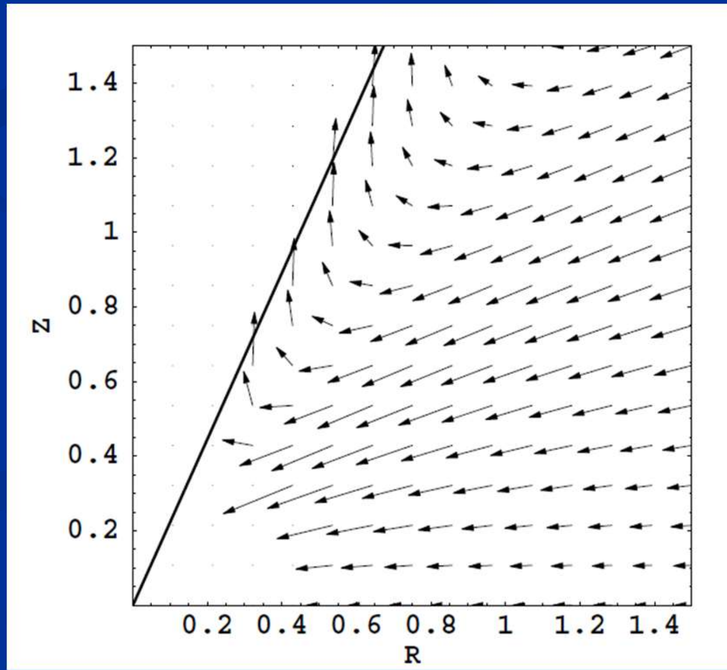
Why does Mdot decrease inward?

Two models have been proposed.

Scenario One: Outflow
(Adiabatic inflow-outflow solution; ADIOS)

Blandford & Begelman 1999; 2004; Begelman 2012

- Mass loss in outflow → Mdot decreases
- Self-similar solutions (ADIOS) constructed based on this assumption
- Origin of outflow:
  positive Bernoulli? no



Blandford & Begelman 2004

Model Two: Convection-dominated accretion flow (CDAF)

Narayan, Igumenshchev & Abramowicz 2000; Quataert & Gruzinov 2000

- Hot hydro accretion flow is convectively unstable
  - Because entropy increases inward (Narayan & Yi 1994)
  - It is true even when radiation is strong (Yuan & Bu 2010)
- A convective envelope solution is found
- Gas then circulates in convective eddies → Mdot decreases
- Debate on MHD flows: applicable to MHD flow or not?
  - No (Hawley, Balbus, Stone): dynamics of MHD flow is controlled by magnetic field & MRI
  - Yes (Narayan, Abramowicz, Quataert): there is a convection component in the instability criteria…

Which model is correct?

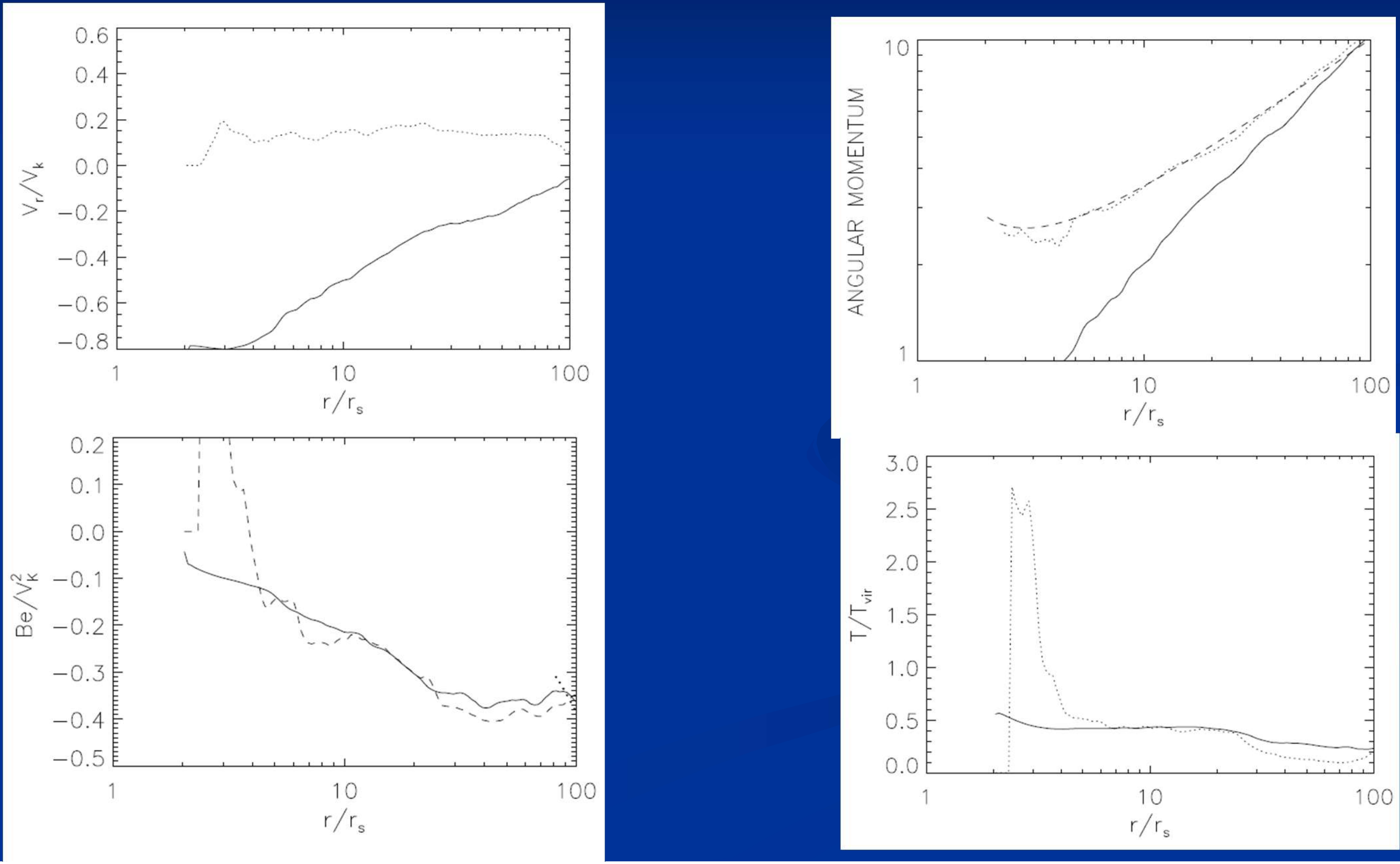
Yuan, Bu & Wu 2012

- If circular convective turbulence, we should expect: the properties of inflow & outflow roughly same
- So we systematically calculate the properties of inflow & outflow using simulation
- Analyze the convective stability of MHD flow
- Study the trajectory of ``test particles" to see whether they really escape

Conclusion: significant outflow exists
(see also Li, Ostriker & Sunyaev 2013)

Properties of inflow & outlow(MHD)

Yuan, Bu & Wu 2012



An MHD accretion flow is convectively *stable*

The Hoiland criteria:

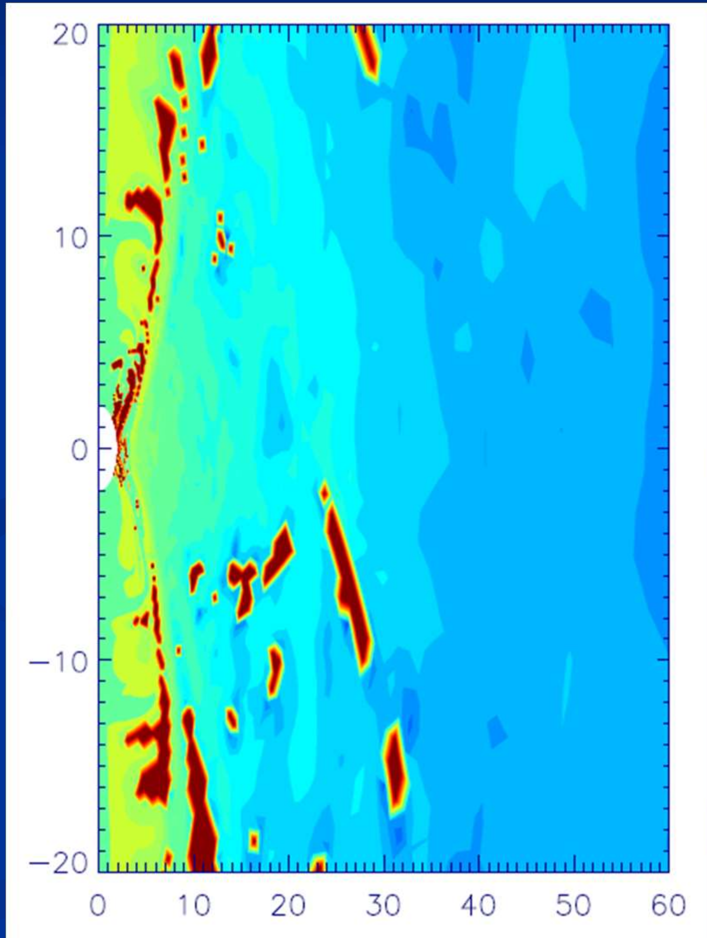
$$N_{\rm eff}^2 \equiv N^2 - \kappa^2 = \frac{3}{5\rho}\frac{\partial P}{\partial R}\frac{\partial \ln(P\rho^{-5/3})}{\partial R} - \kappa^2 > 0,$$

Here:

N is the usual Brunt-Väisälä frequency

$$\kappa^2 = 4\Omega^2 + d\Omega^2/d\ln R$$

Result:
Most of the region is convectively stable!

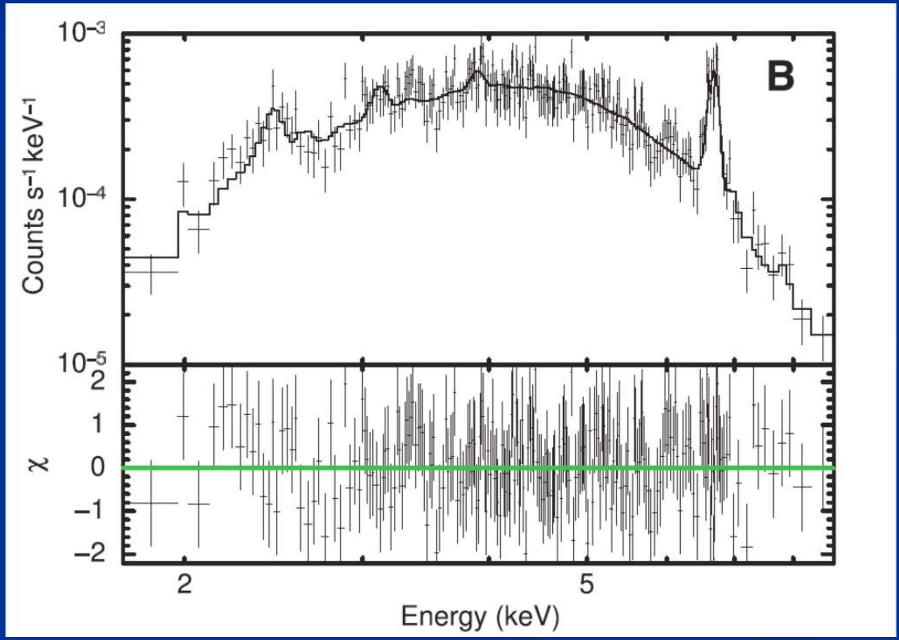


Yuan, Bu & Wu 2012

Outflow confirmed by new observations

Wang et al. 2013, Science

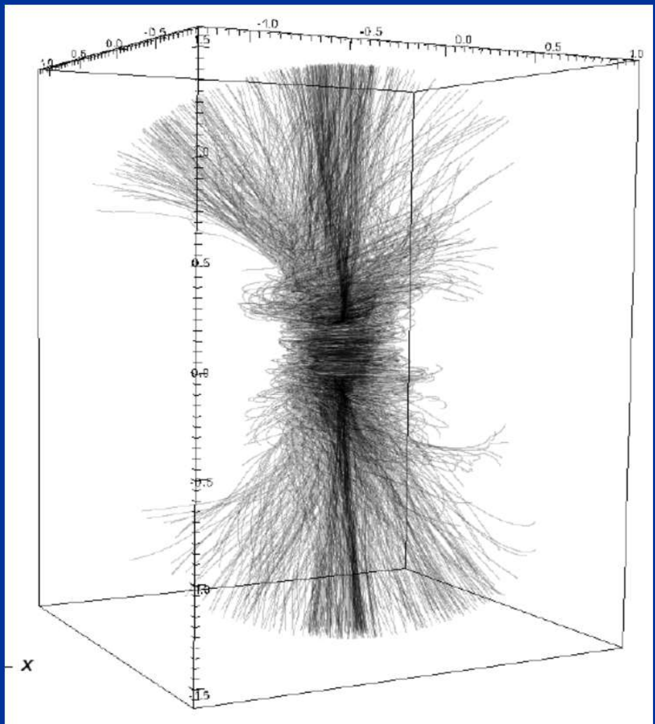
- 3Ms observation to the quiescent state of Sgr A* by Chandra
- H-like Fe Kα line profile fitting
  → flat density profile
  → strong outflow



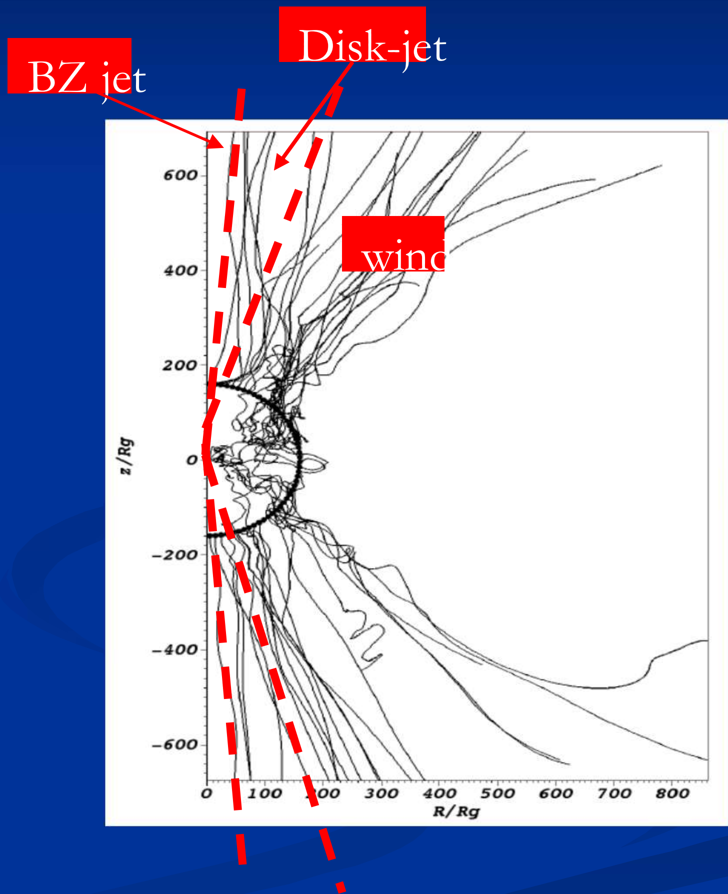
Main properties of wind: "Virtual particle trajectory" approach

Yuan et al. 2015

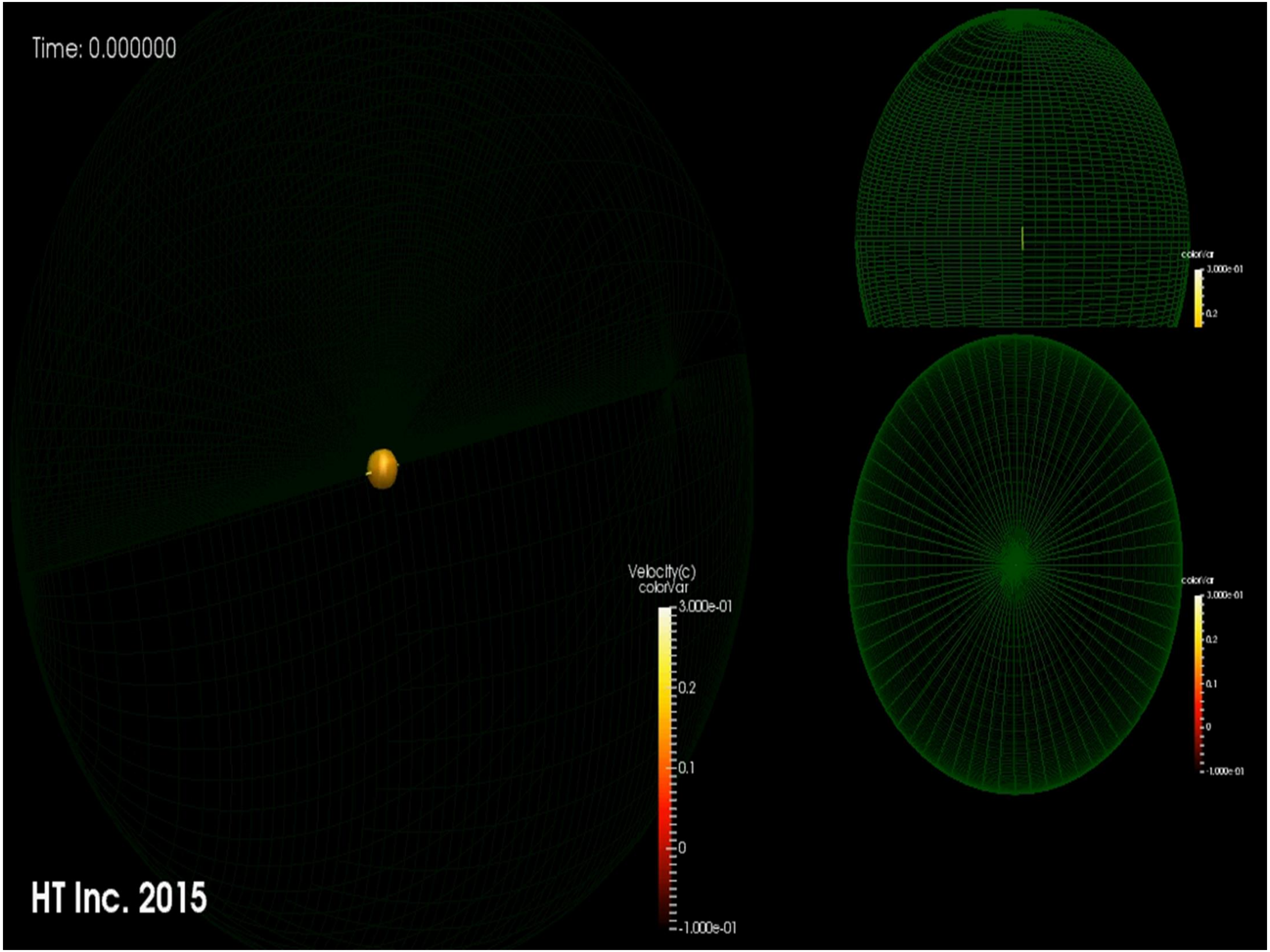
- Trajectory approach
  - different from streamline;
  - Based on *3D GRMHD* data



3D



2D



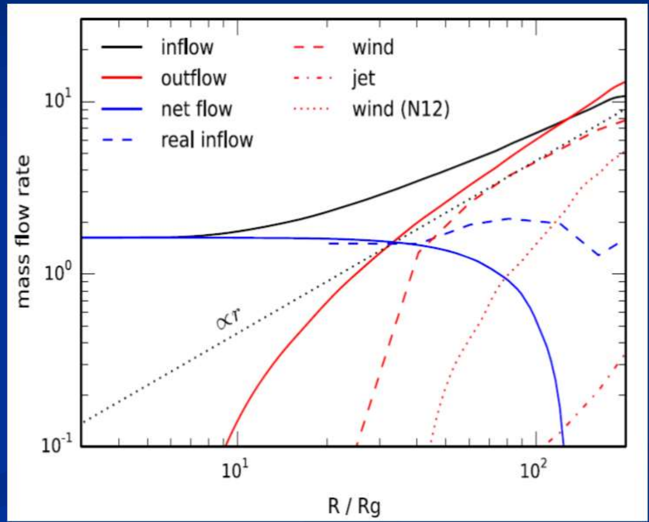
Time: 0.000000
Velocity(c)
colorVar
3.000e-01
0.2
0.1
0
-1.000e-01
HT Inc. 2015

Main properties of wind

Yuan et al. 2015

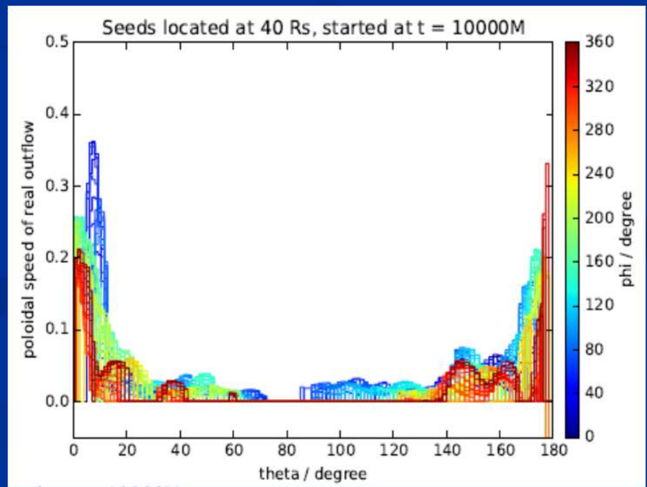
- Mass flux

$$\dot{M}_{wind} = \dot{M}_{BH}(r)\left(\frac{r}{20r_s}\right), \quad a = 0$$



- Poloidal speed:

$v_{term}(r) \sim 0.3 v_k(r)$



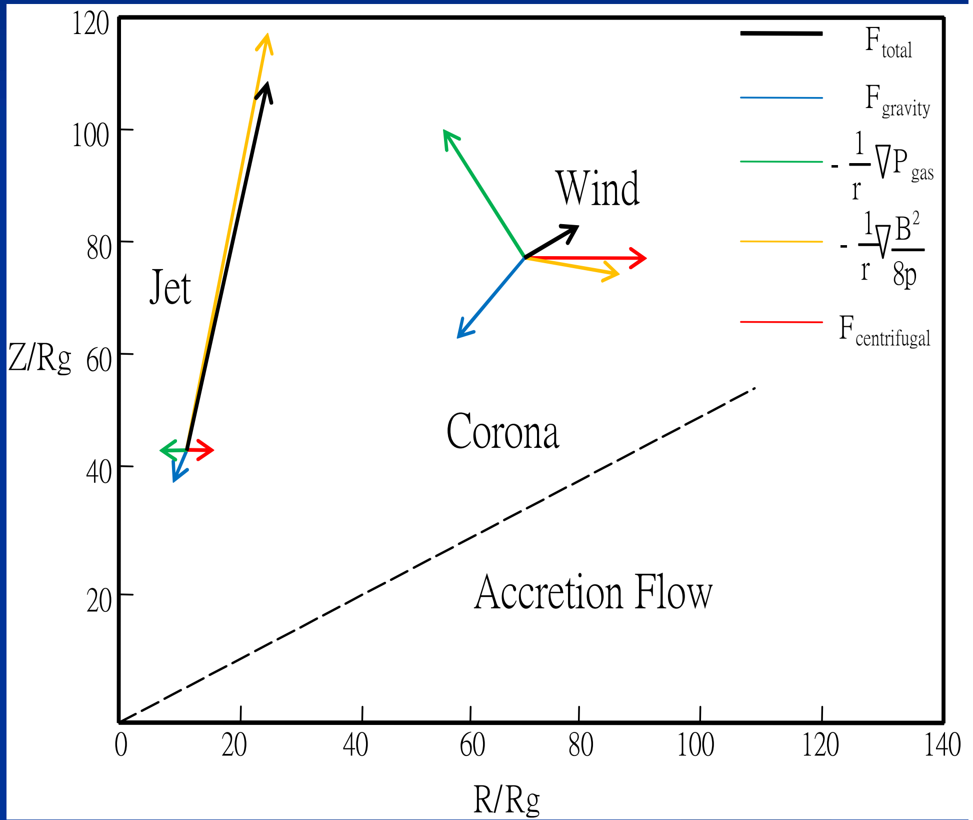
- Fluxes of energy & momentum (vs. disk jet)

$$\dot{E}_{wind} = \frac{1}{1000}\dot{M}_{BH}c^2$$

Mechanism of outflow production

Yuan et al. 2015

- Driving forces:
  - Centrifugal force
  - Gradient of gas & magnetic pressure



- Comparison with Blandford & Payne (1982)
  - BP82: large-scale field + only centrifugal
  - We don't have large-scale poloidal field, we have both centrifugal & magnetic force (since $\hat{v} \neq \hat{B}$!)

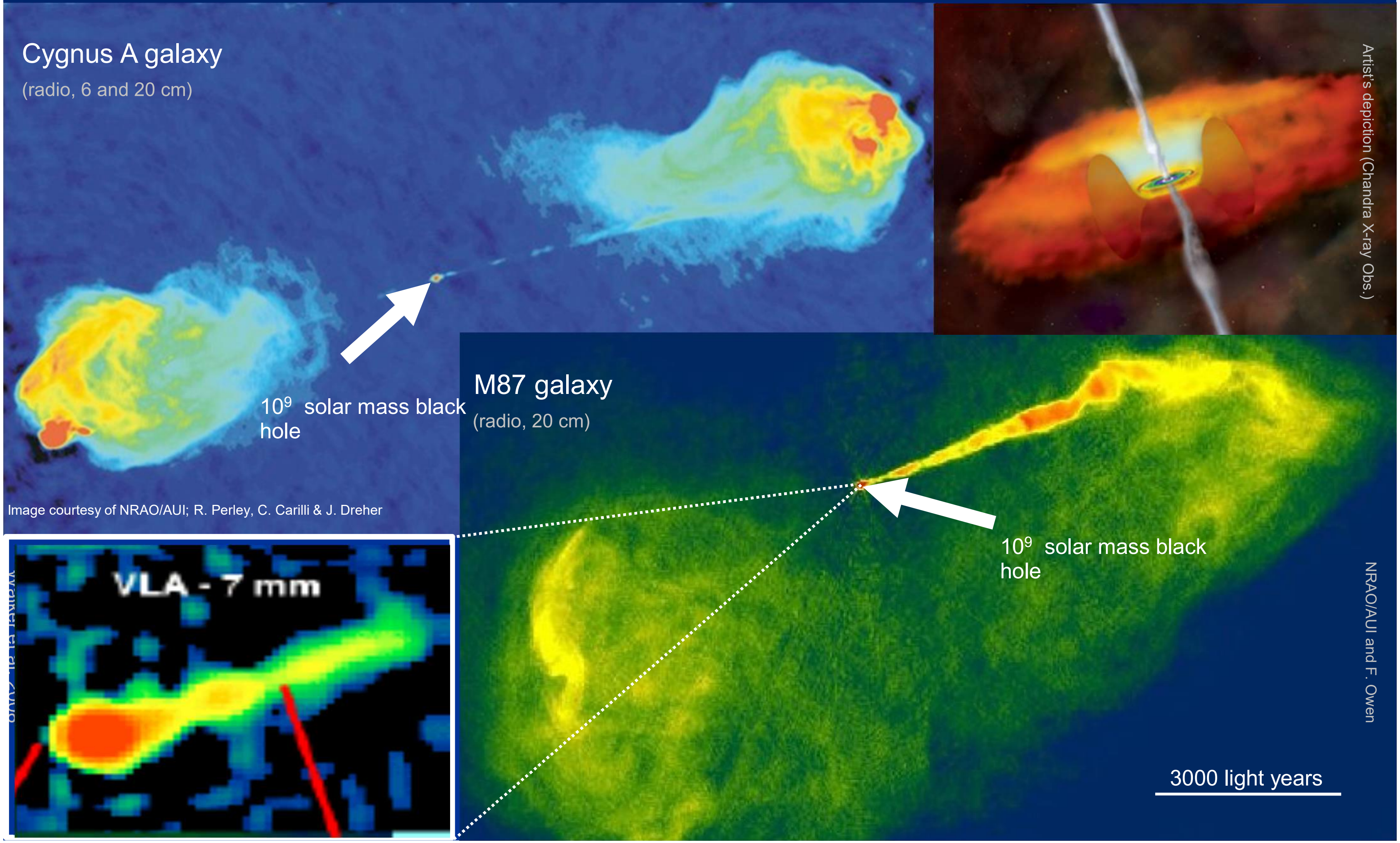
Wind vs. jet: summary

- Mass flux: wind >> jet
- Velocity: wind < jet
- Energy flux: wind < jet only for MAD & a=0.9
- Momentum flux: jet at most comparable to wind (?)

Given that the opening angle of wind >> jet,
Wind may be more important than jet in AGN feedback

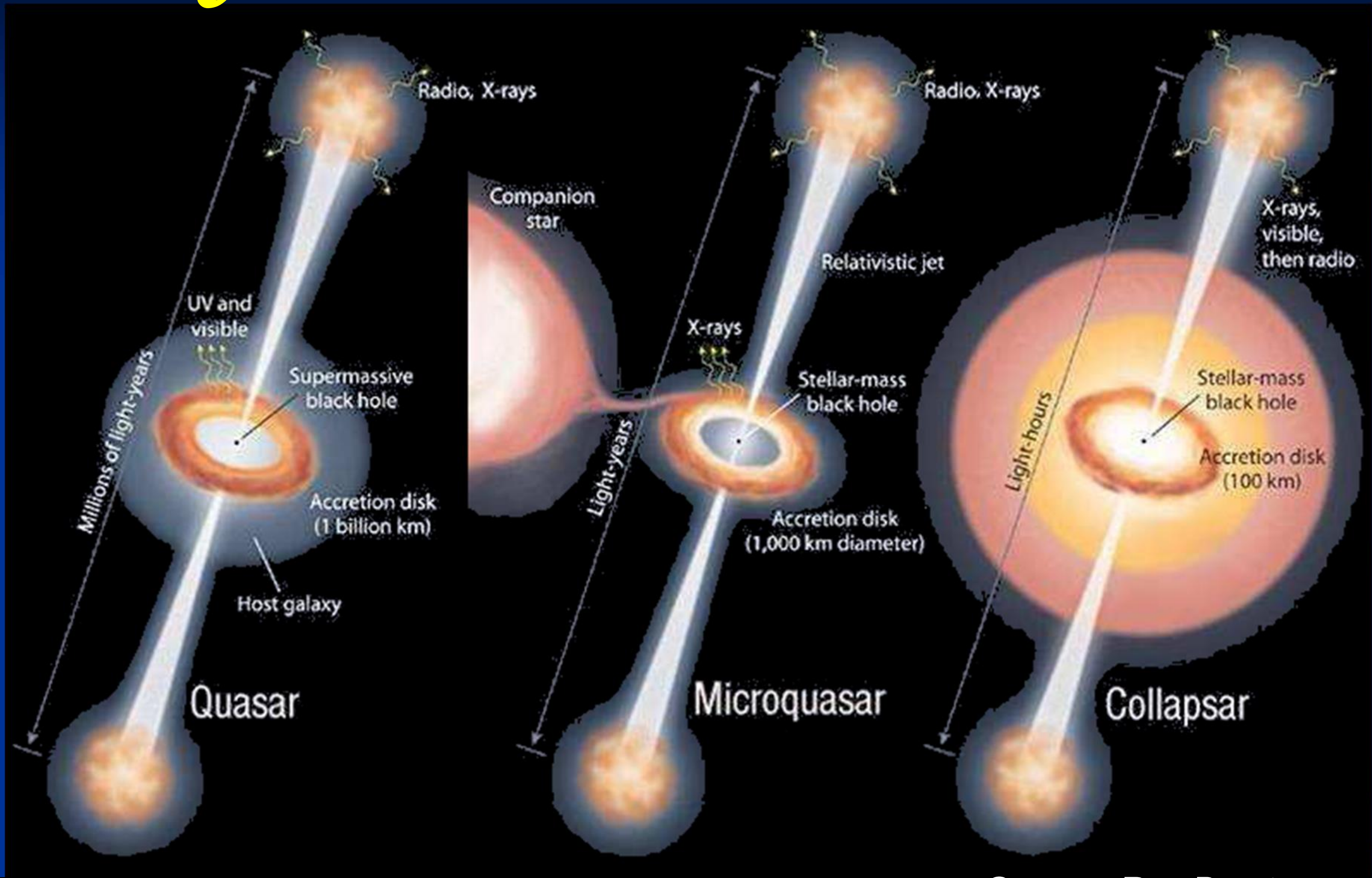
5.4 Jet (I): Continuous jet

Some images of jets



Jets from all scales

Mirabel & Rodriguez, 2002, Sky and Telescope



Active Galactic Nuclei
(e.g., M87,
M_{BH}=5 x 10^9 $M_\odot$)

Black Hole X-ray Binaries
(e.g., GRS 1915+105,
M_{BH}=15 $M_\odot$)

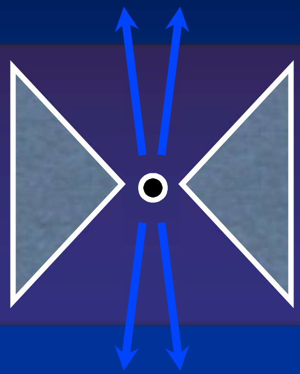
Gamma-Ray Bursts
($M_{BH} \simeq 5\ M_\odot$)

When Do We Observe Jets?

$\lambda = L/L_{\mathrm{edd}}$

$h/r \sim 1$

$\tau \gg 1$



Radiatively-Inefficient ✔ ?
(super-Eddington)

100%

10%

$h/r \ll 1$

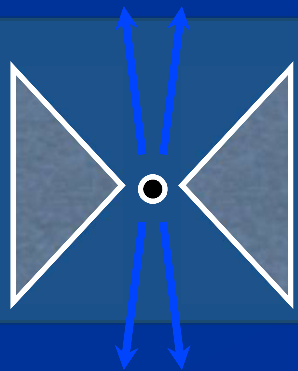
$\tau \gg 1$

Thin Disk

2%

$h/r \sim 1$

$\tau \ll 1$



Radiatively-Inefficient ✔
(sub-Eddington)

Three models of jet formation

Blandford & Znajek 1976; Blandford & Payne 1982; Lynden-Bell

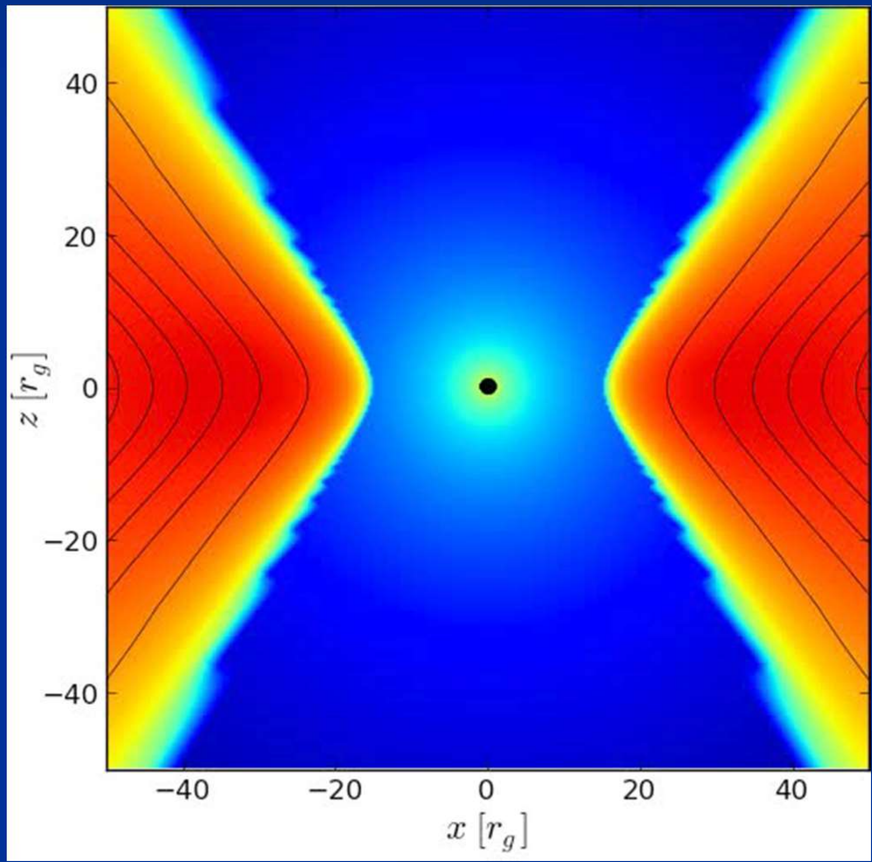
- Blandford & Znajek (1976).
  - Two key components: ordered magnetic field + BH spin
- Blandford & Payne (1982)
  - Large-scale B field
  - Magneto-centrifugal force
- Magnetic tower (Lynden-Bell 2003)
  - Gradient force of toroidal magnetic pressure

Question: which one is applicable?

GRMHD simulations of jet formation

Koide 1999; Hawley & Balbus 2002; McKinney 2005; McKinney & Blandford 2009; Tchekhovskoy et al. 2010, 2011; Sadowski et al. 2013…

- BZ model is confirmed
- BP model not yet



Consensus:

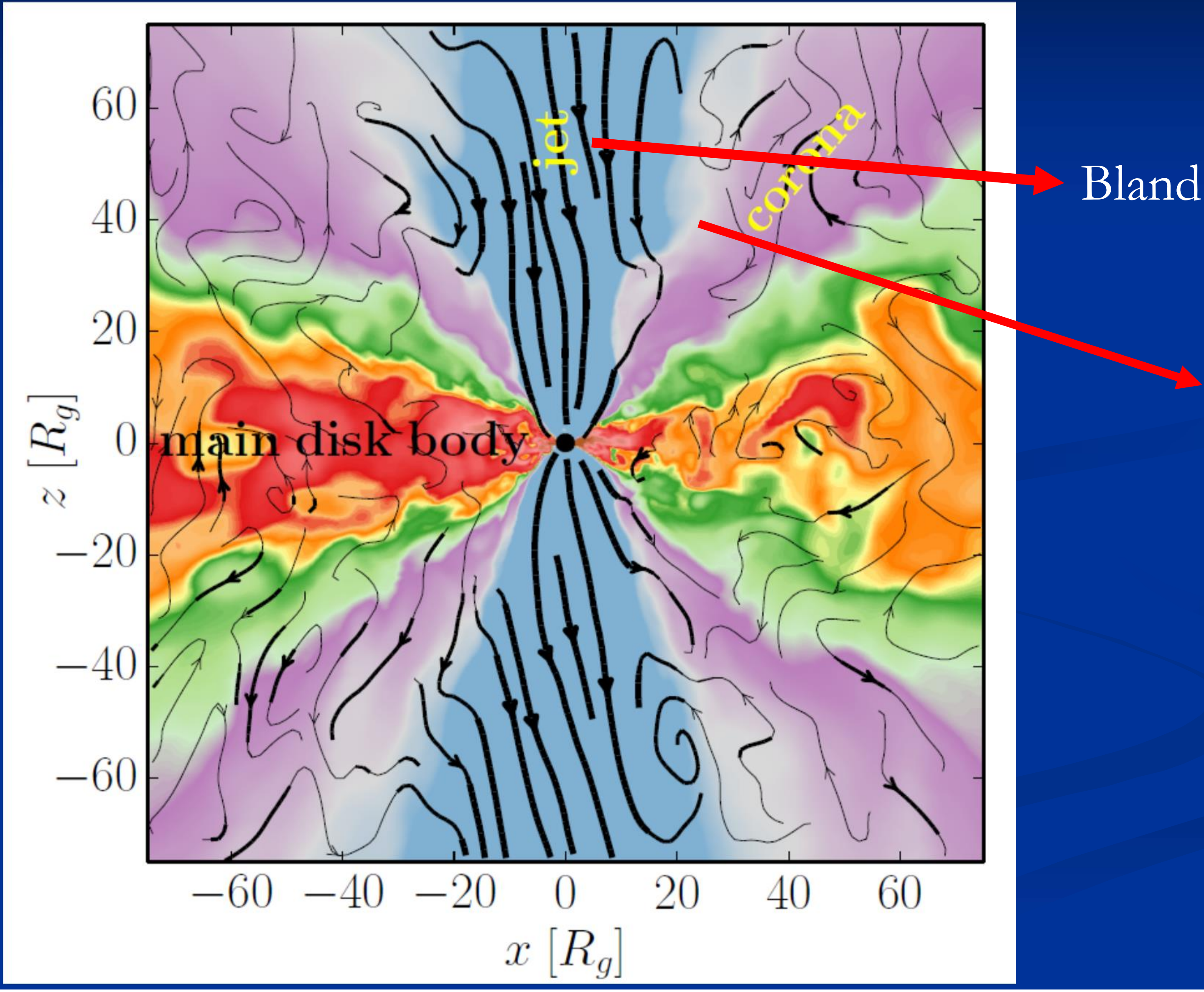
Large-scale poloidal B field is required!

Question:

*How about magnetic tower?

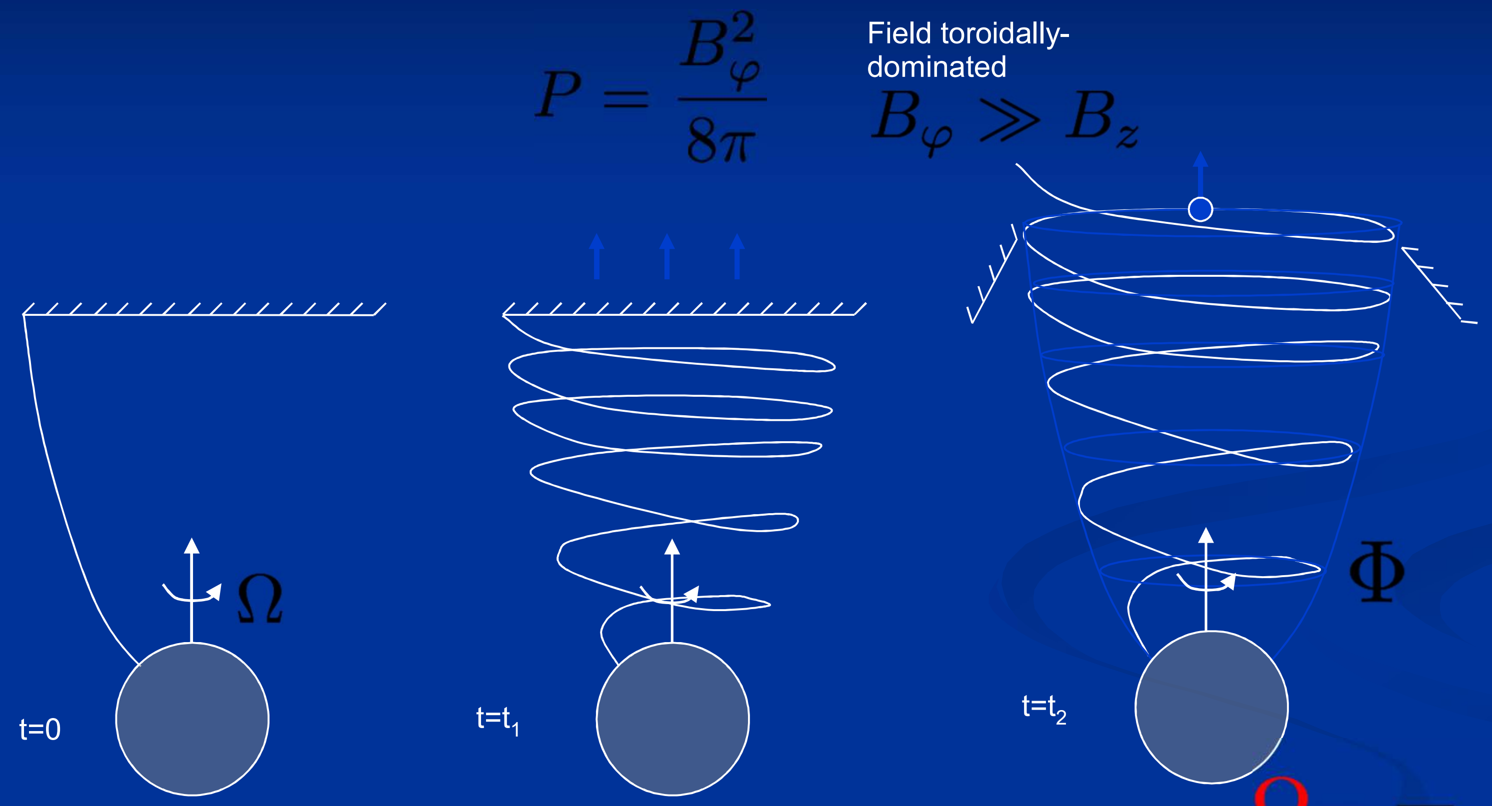
*Is BZ jet the observed one?

BZ jet and disk jet



Blandford-Znajek jet

How Do BZ Jets Work?



$$\Omega_{\mathrm{H}} = \frac{ac}{2r_{\mathrm{H}}}$$

Ergosphere; frame dragging by the rotating hole → toroidal field → Poynting flux

Power of BZ jet

Blandford & Znajek 1976; Tchekhovskoy 2010

- Two key components: ordered magnetic field at the horizon and rotation of BH

$$P_{\rm BZ} = \frac{\kappa}{4\pi c}\Phi^2\Omega_{\rm H}^2$$

Φ: magnetic flux threading the horizon;

Ω_H=ac/2R_H: angular velocity of the horizon; R_H=Rg(1+$\sqrt{1-a^2}$)

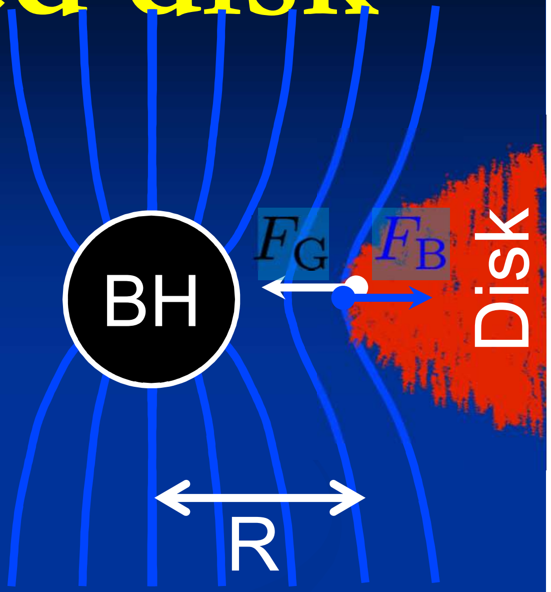
$\varkappa \approx 0.05$

- Prograde disk produces stronger jet than retrograde
- Requirement to the initial magnetic field: poloidal (bipolar or quadrupolar, not toroidal)

Magnetically arrested disk

Narayan et al. 2003; Igumenshchev et al. 2003

- "Usually", magnetic pressure smaller than gas pressure
- B flux can accumulate close to BH, due to advection
- Gravity limits BH B-field strength (Narayan+ 03; Tchekhovskoy et al. 2011):



$$\frac{B^2}{8\pi}4\pi R^2 \lesssim \frac{GM_{\rm BH}M_{\rm D}}{R^2}$$

$$B_{\rm max} \sim 10^4\,[{\rm G}]\left(\frac{L}{0.1L_{\rm Edd}}\right)^{1/2}\left(\frac{M_{\rm BH}}{10^9M_\odot}\right)^{-1/2}$$

Or: $$B_{\rm MAD} \approx \frac{\Phi_{\rm MAD}}{2\pi R_g^2} = 10^{10}\,m^{-1/2}\dot{m}_{\rm BH}^{1/2}\ {\rm G}$$

MAD (continue)

- when B ~ B_{max}, a magnetically-arrested disk (MAD) forms
- Why MAD is interesting? Only in this case, BZ jet power is larger than the disk-jet power (Livio, Ogilvie & Pringle 1999)

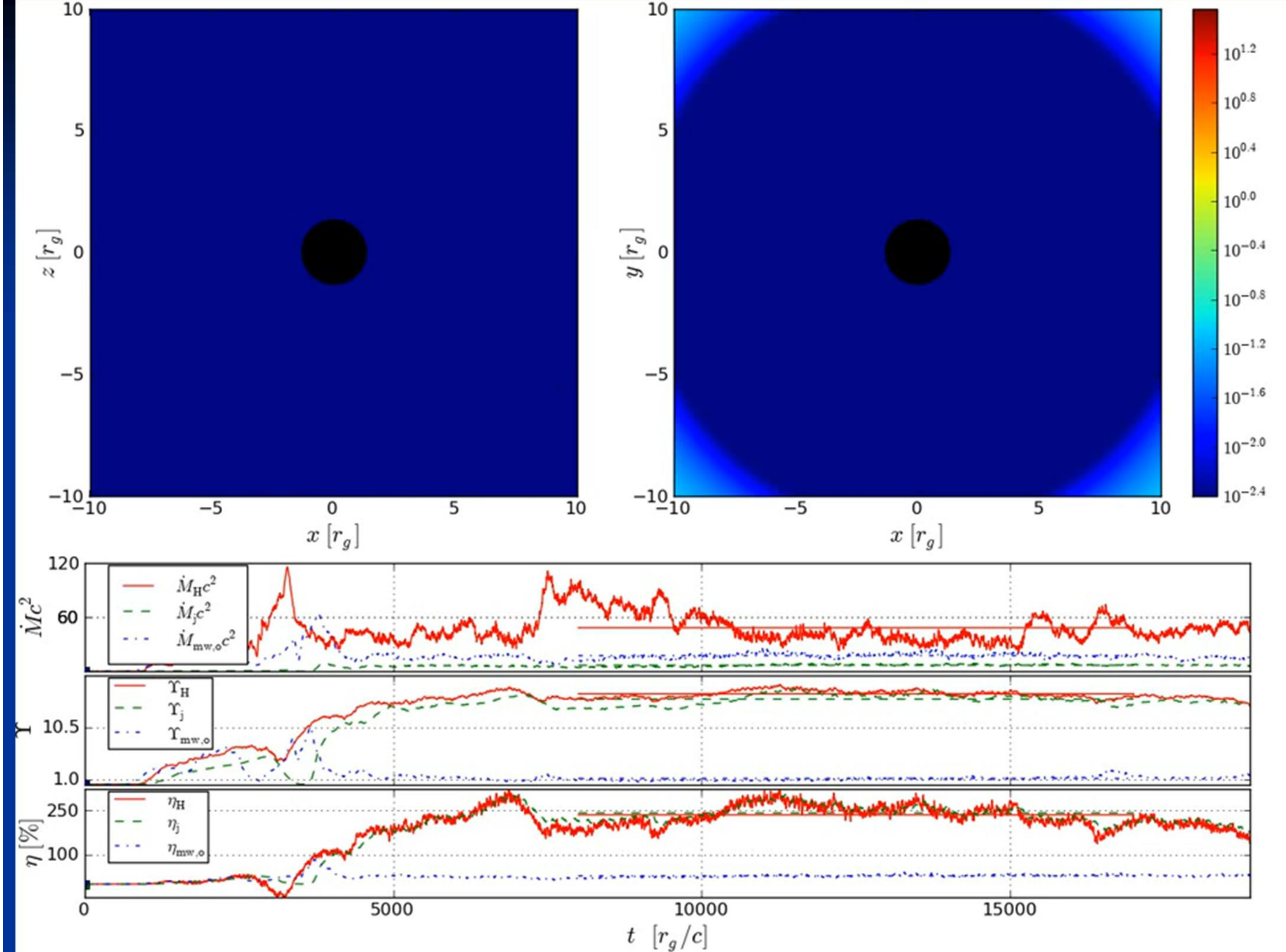
$$P_{\rm jet} \approx 2.5 \left(\frac{a_*}{1+\sqrt{1-a_*^2}}\right)^2 \left(\frac{\Phi}{\Phi_{\rm MAD}}\right)^2 \dot{M}_{\rm BH} c^2$$

Note BZ jet power can exceed accretion power!

- Whether MAD can be realized in nature? Unclear, depending on, e.g., microphysics

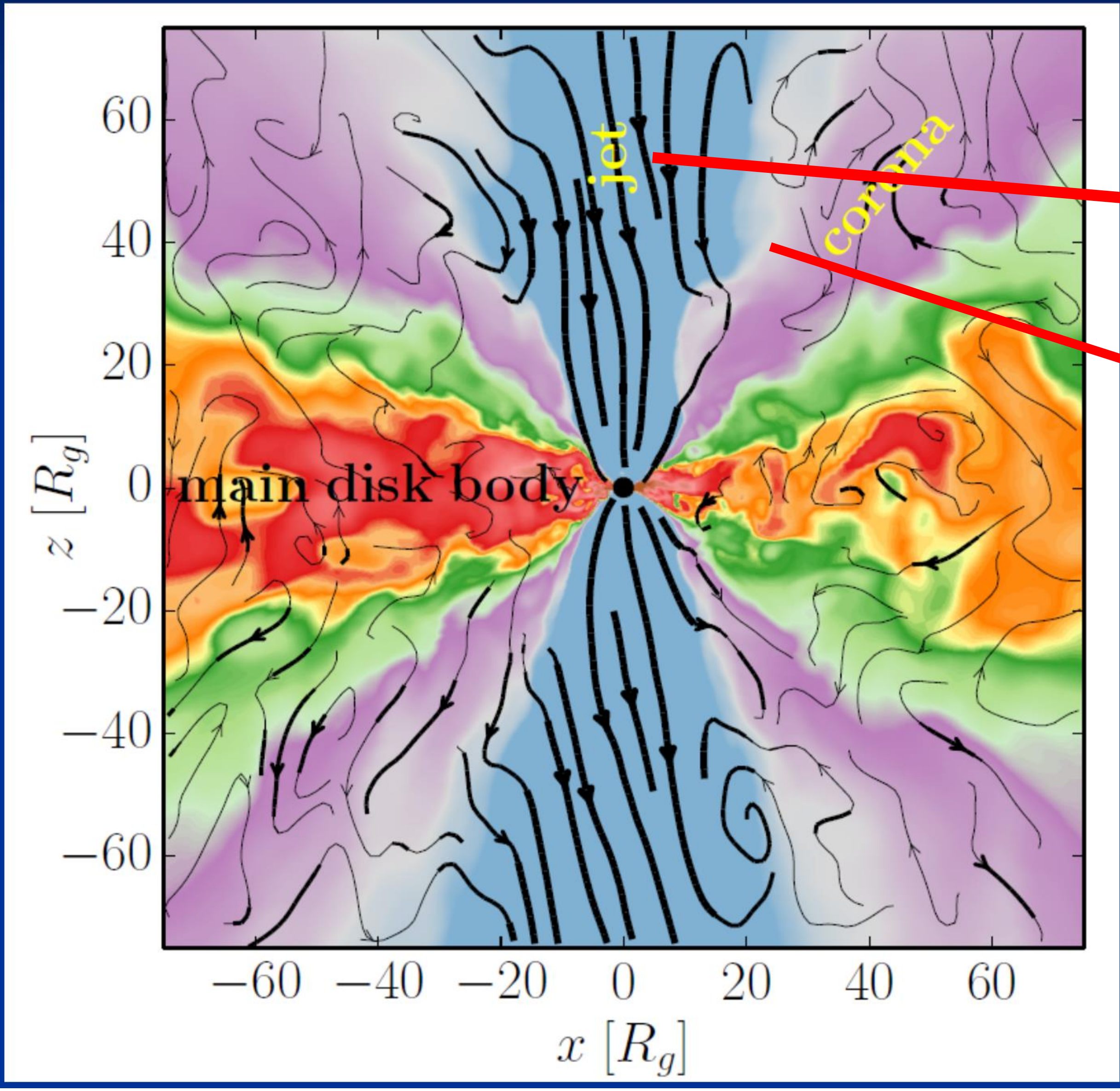
Mass loading in BZ jet

- The current best guess is that mass-loading occurs via pair creation through breakdown of a vacuum gap (Beskin et al. 1992; Hirotani & Okamoto 1998).



$z\ [r_g]$
$x\ [r_g]$
$y\ [r_g]$
$10^{1.2}$
$10^{0.8}$
$10^{0.4}$
$10^{0.0}$
$10^{-0.4}$
$10^{-0.8}$
$10^{-1.2}$
$10^{-1.6}$
$10^{-2.0}$
$10^{-2.4}$
$\dot{M}c^2$
$\dot{M}_{\rm H}c^2$
$\dot{M}_{\rm j}c^2$
$\dot{M}_{\rm mw,o}c^2$
Υ
$\Upsilon_{\rm H}$
$\Upsilon_{\rm j}$
$\Upsilon_{\rm mw,o}$
$\eta\ [\%]$
$\eta_{\rm H}$
$\eta_{\rm j}$
$\eta_{\rm mw,o}$
$t\ \ [r_g/c]$

Disk jets



Blandford-Znajek Jet

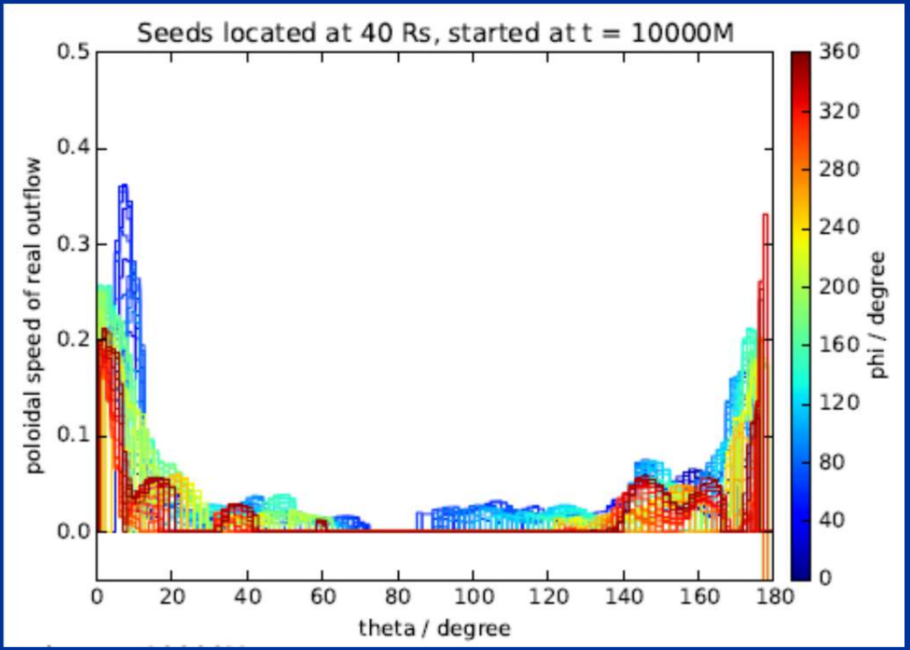
Disk-jet

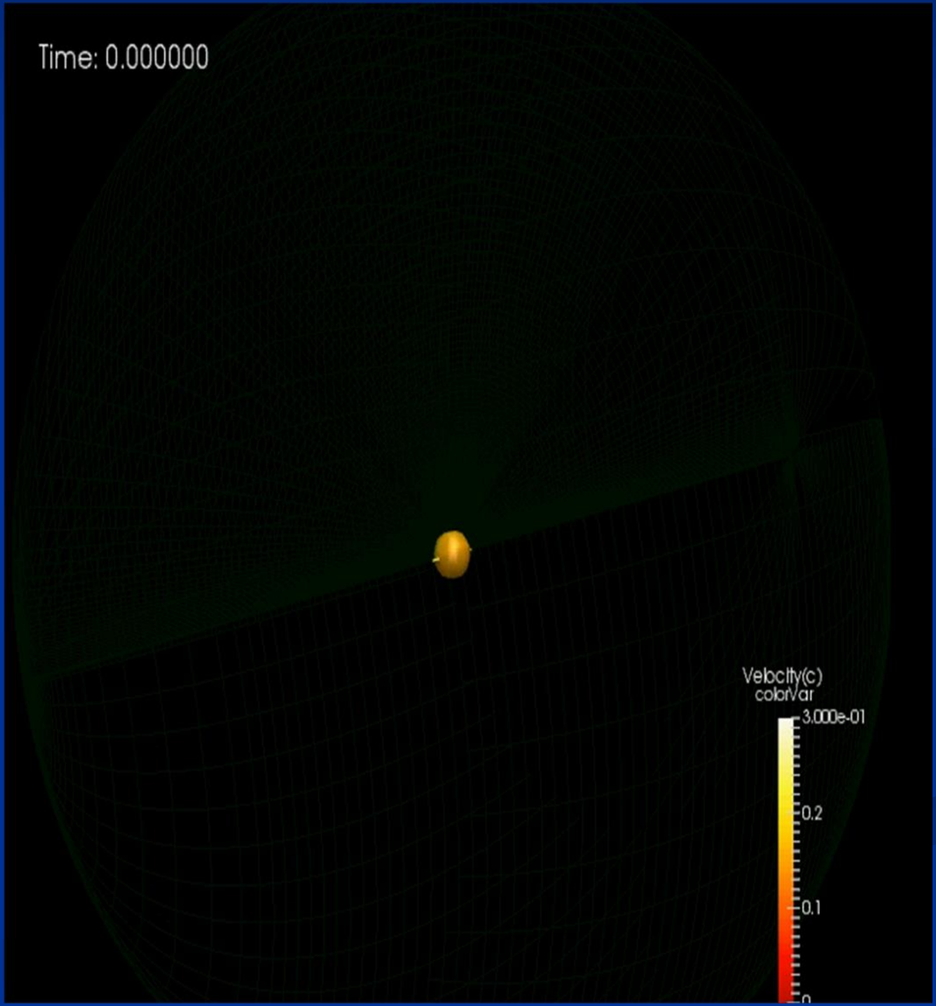
Yuan & Narayan2014, ARA&A

Courtesy: Sasha Tchekhovskoy

Disk-jet (magnetic tower) in simulations

Yuan et al. 2015; Yuan & Narayan 2014





Disk-jet (versus BZ jet)

Yuan & Narayan 2014; Yuan et al. 2015, 2016

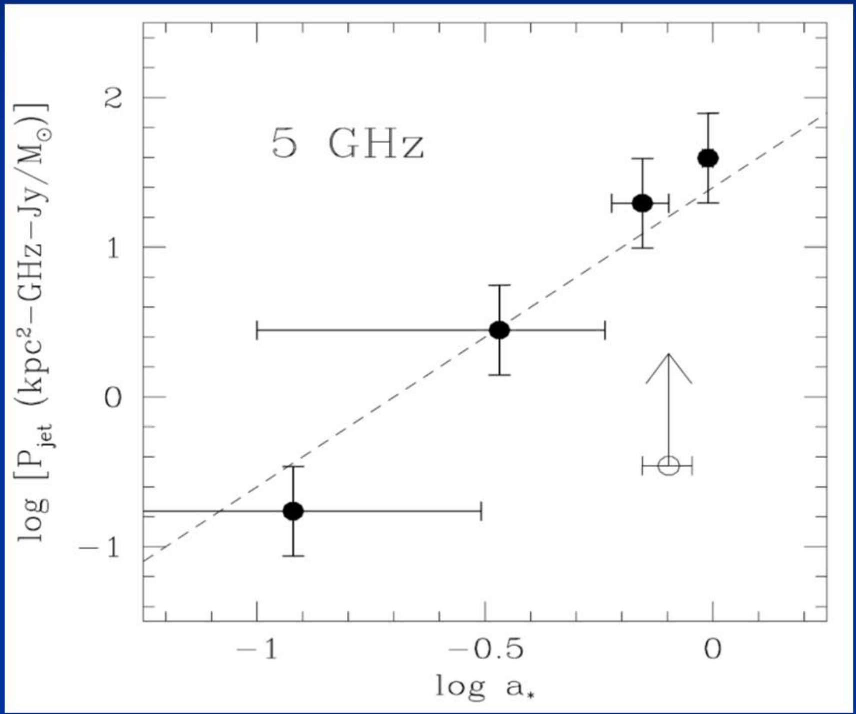
- Matter dominated
- Powered by the rotation of disk → so present even a=0
- Power of disk-jet vs. BZ jet?

  (Livio, Ogilvie & Pringle 1999)
- not powered by Blandford-Payne, but by the magnetic tower mechanism proposed by Lynden-Bell (gradient of the pressure of toroidal magnetic field)

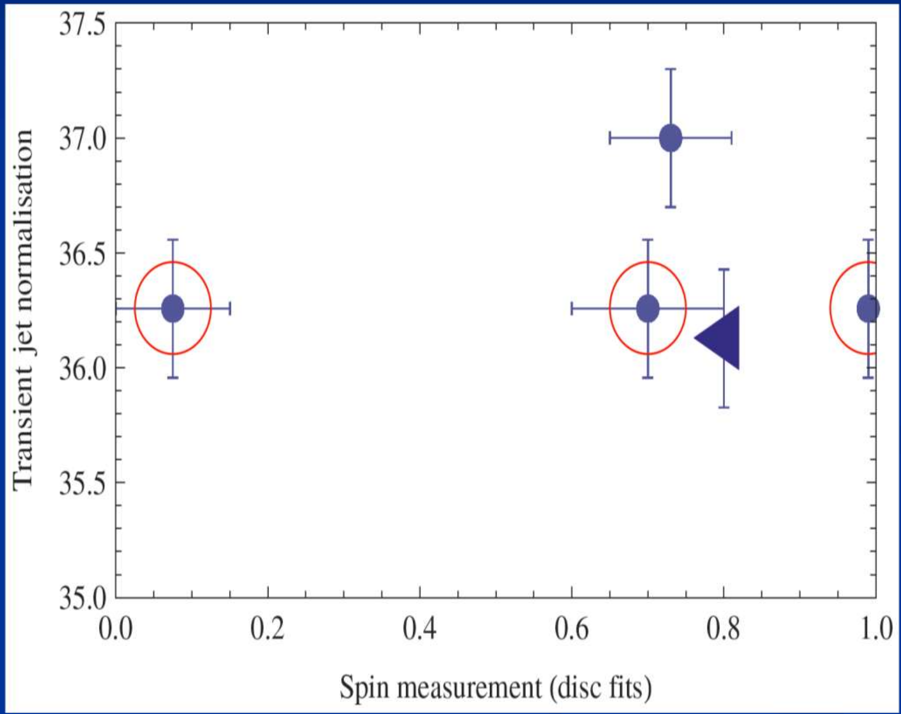
Question:

Disk jet & BZ jet, which one is associated with the observed jet?

Observation (I): Correlation between jet power & BH spin



Narayan & McClintock 2012



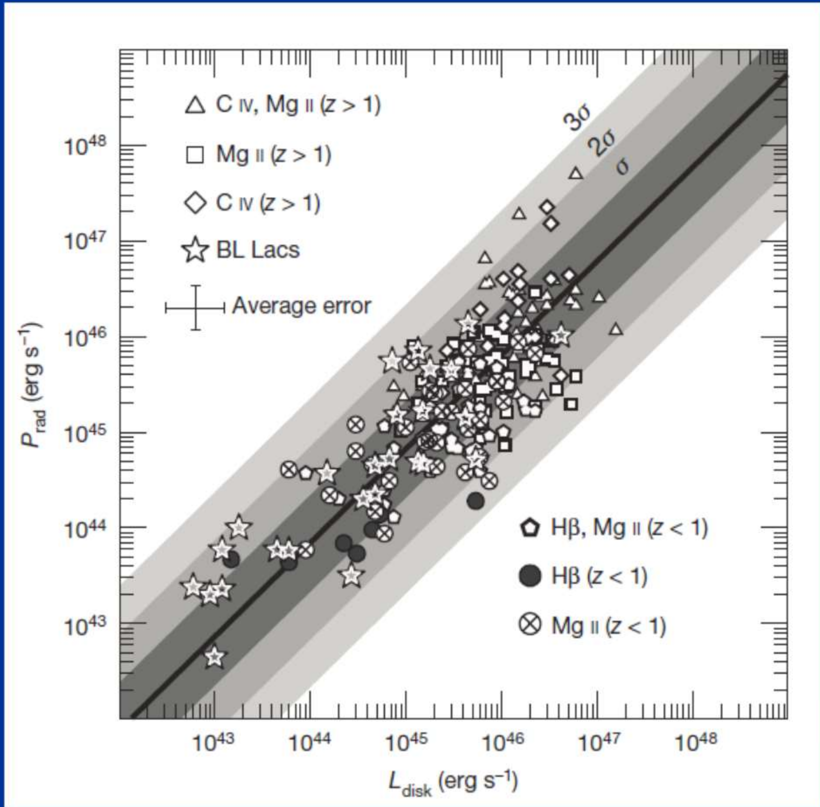
Fender, Gallo & Russell 2010; Russell 2013

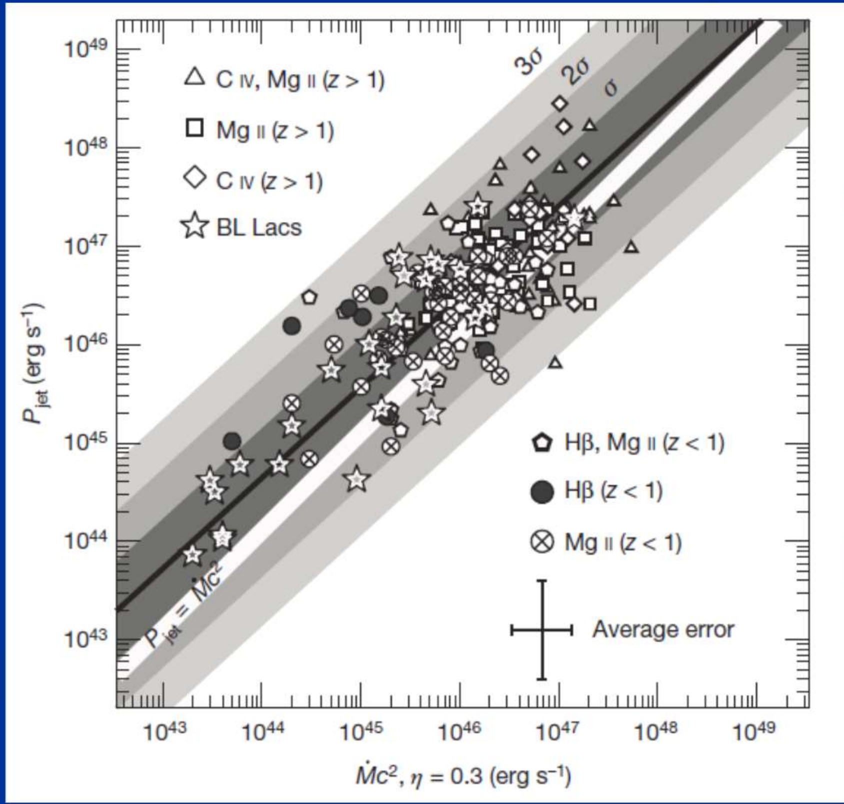
The main reason for the discrepancy: the estimation of jet power!

Observation (II): jet power vs. disk luminosity

Zamaninasab et al. 2013, Nature; Ghisellini et al. 2014, Nature

- L_disk vs. P_rad: $\log(P_{rad}) = 0.98\log(L_{disk}) + 0.639$
- So if P_jet =10P_rad, we have: P_jet> L_disk
- Consistent with the MHD simulation of jet formation from a MAD





Disk jet properties

De Villiers et al. 2005

Model	M_0	ΔM_i	ΔM_b	ΔM_u	f_M
KD0.........	156	24.9	1.14	0.17	0.007
KDI	258	36.1	2.70	0.60	0.017
KDP.........	291	17.9	1.86	0.87	0.048
KDE	392	14.4	8.35	4.78	0.33
KDPi	151	5.73	0.48	0.32	0.056
KDPlr......	291	10.2	0.88	0.87	0.085
SFR	741	285	8.76	1.36	0.005
SF0..........	1374	469	24.6	6.78	0.014
SFP..........	2308	427	72.3	30.2	0.071

Mass flux

$$f_M \equiv \frac{\Delta M_u}{\Delta M_i}$$

Model	a/M	$\eta_{\rm jet}$	$\eta_{\rm jet}/\eta_{\rm ms}$	$\dot{E}_{\rm (EM)}/\left(\dot{E}_{\rm (FL)} - \dot{M}_{\rm jet}\right)$
KD0................	0.0	0.002	0.03	0.06
KDI	0.5	0.013	0.16	0.34
KDP................	0.9	0.029	0.18	0.47
KDE	0.998	0.18	0.56	0.897

Energy flux

5.5 Episodic jet

What is episodic jet?

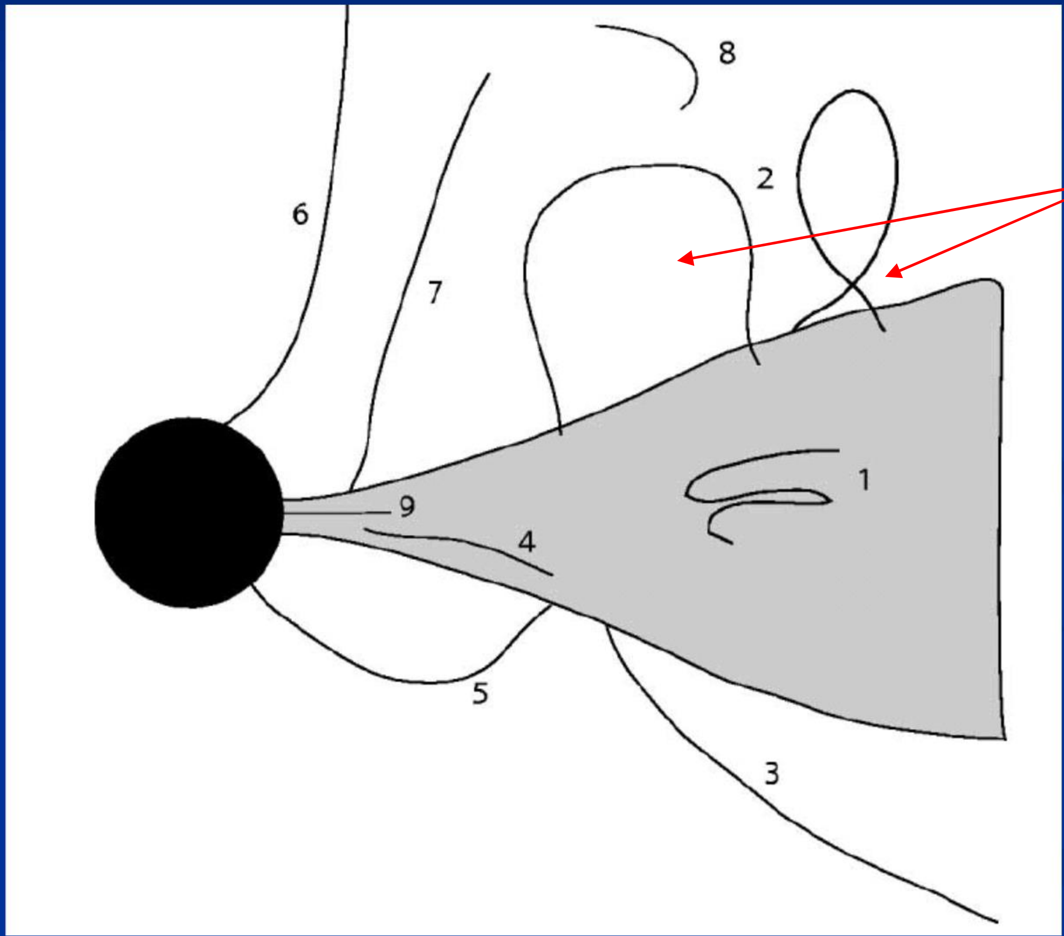
continuous jets	episodic jets
steady	episodic
optically thick spectrum	optically-thin spectrum
low polarization (<5%)	high polarization (~20%)
low velocity	highly relativistic

Fender & Belloni 2004, ARA&A

Two types of mass outflow in the Sun

- Solar wind
  - Continuous
  - Coming from region of *open* magnetic field
- Coronal mass ejection (CME)
  - Episodic
  - Coming from region of *closed* magnetic field
  - Speed up to 2000 km/s and beyond
  - Occurrence rate: from once a few weeks to several times per day

Magnetic field configurations in black hole accretion disk system

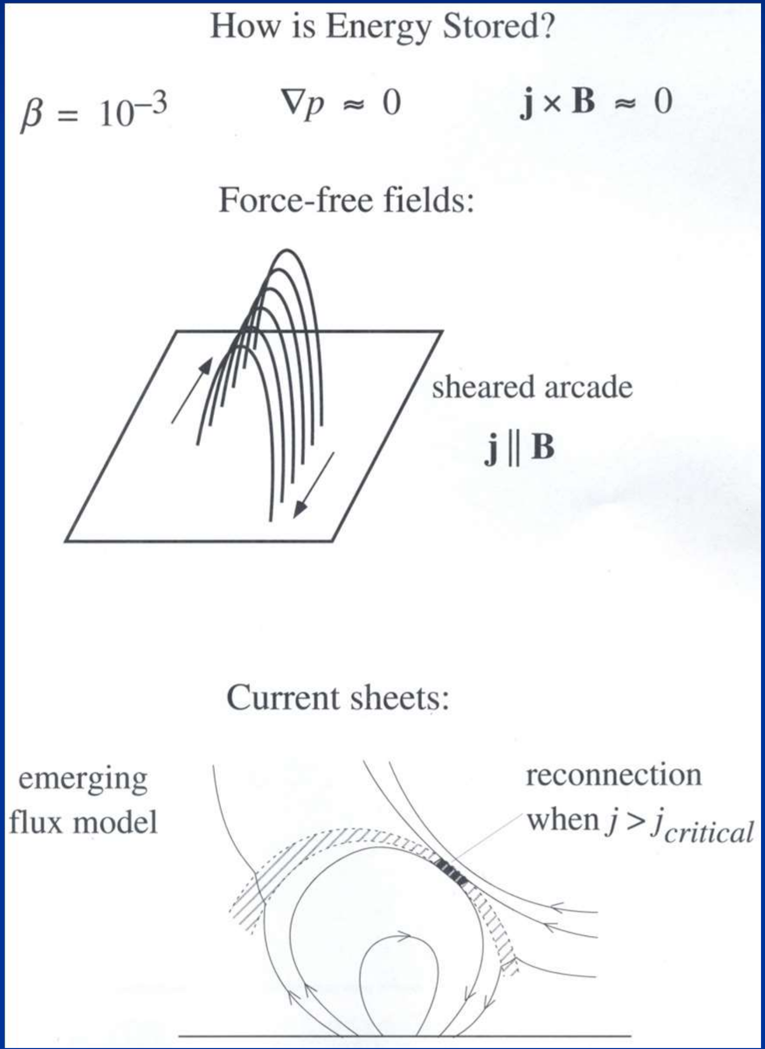


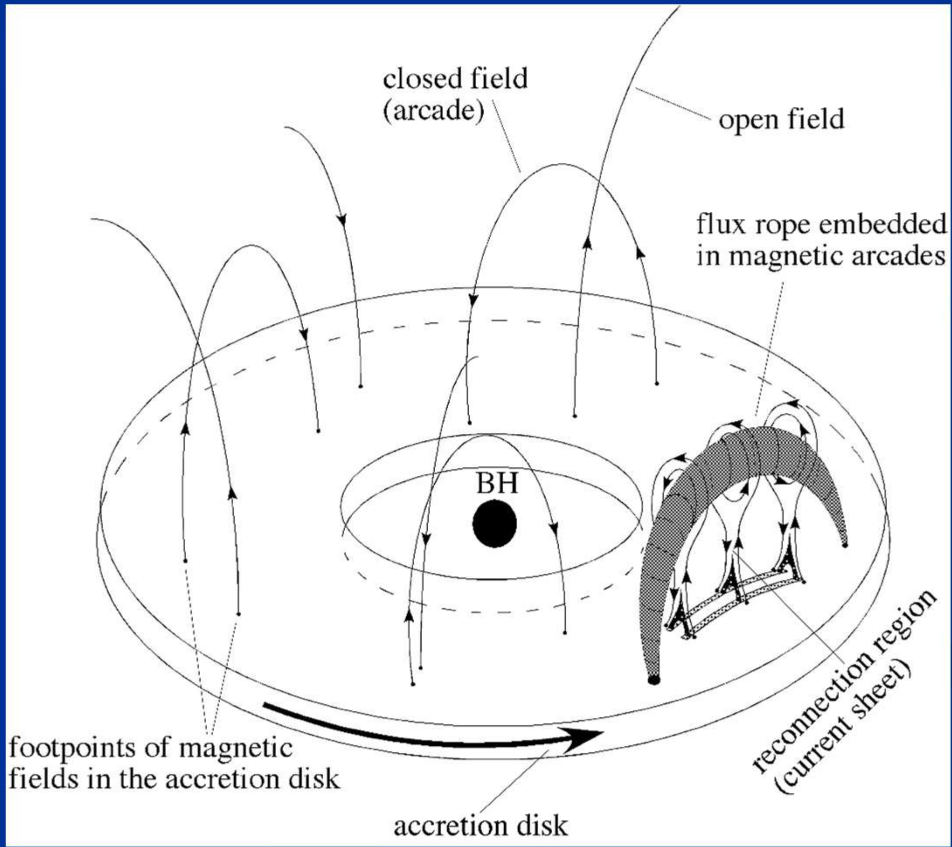
* Reconnection and flare
* Formation of flux rope

Blandford 2002

MHD model for episodic jet (I): Formation of flux rope

Yuan, Lin, Wu & Ho 2009

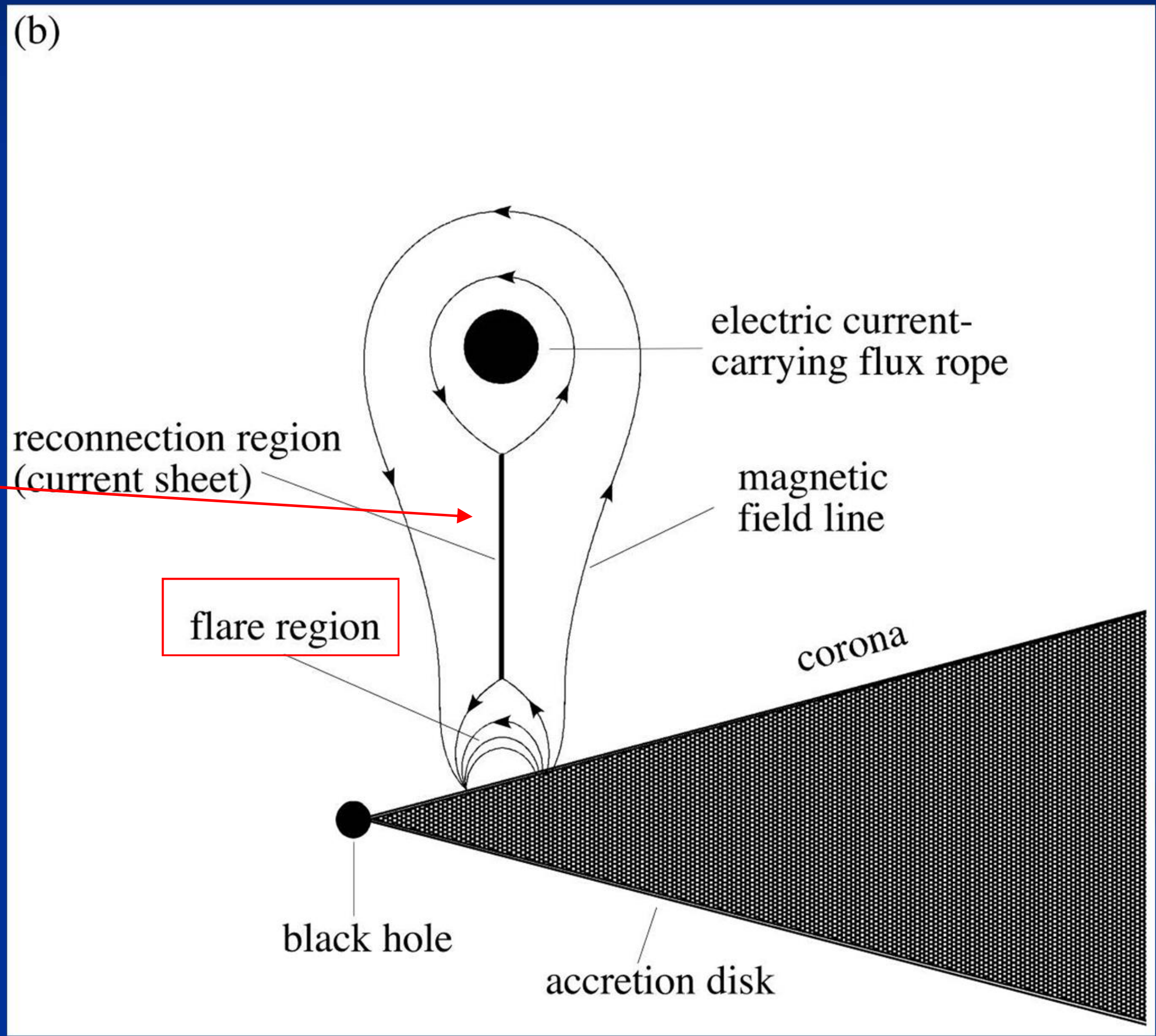




MHD model for episodic jet (II): Ejection of flux rope

Yuan, Lin, Wu & Ho 2009

Electron acceleration here!



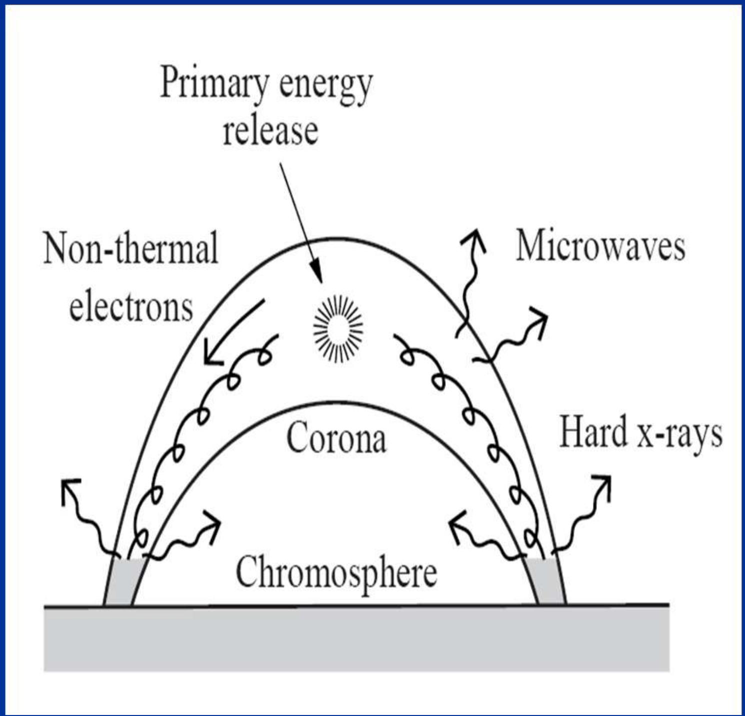
Collimation of jets: two possibilities

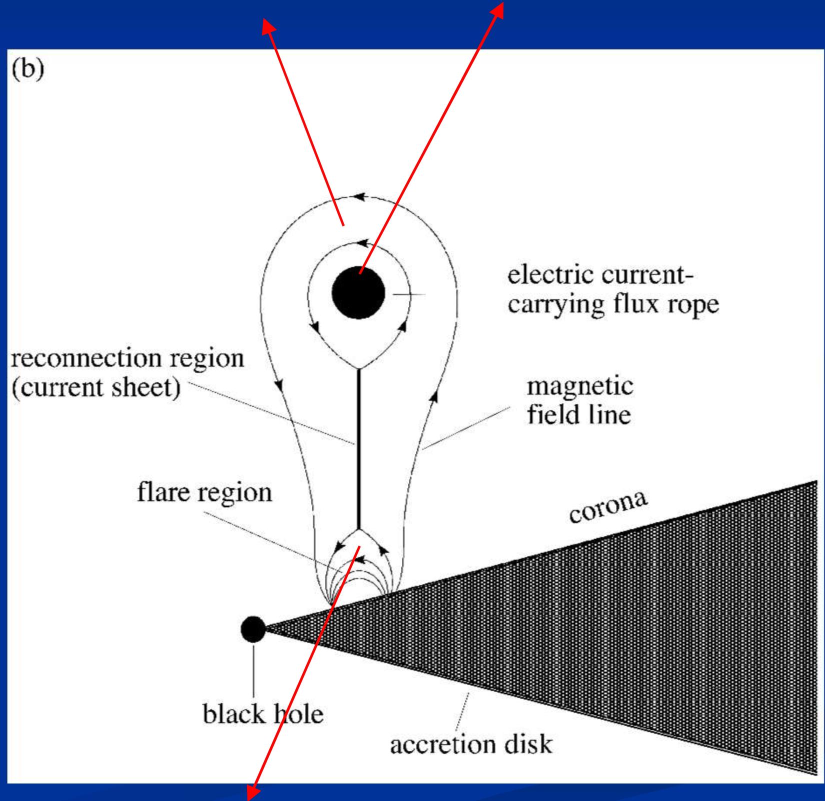
- Hoop stress of the toroidal magnetic field
- Pressure from the ISM

Episodic jets may be physically associated with flares, like the association between solar flare and CMEs

Modeling the Flares in BHs

synchrotron emission from shock or flux rope:
a) radio & submm flares? also IR & X-ray?
b) Time lags between different wavelengths



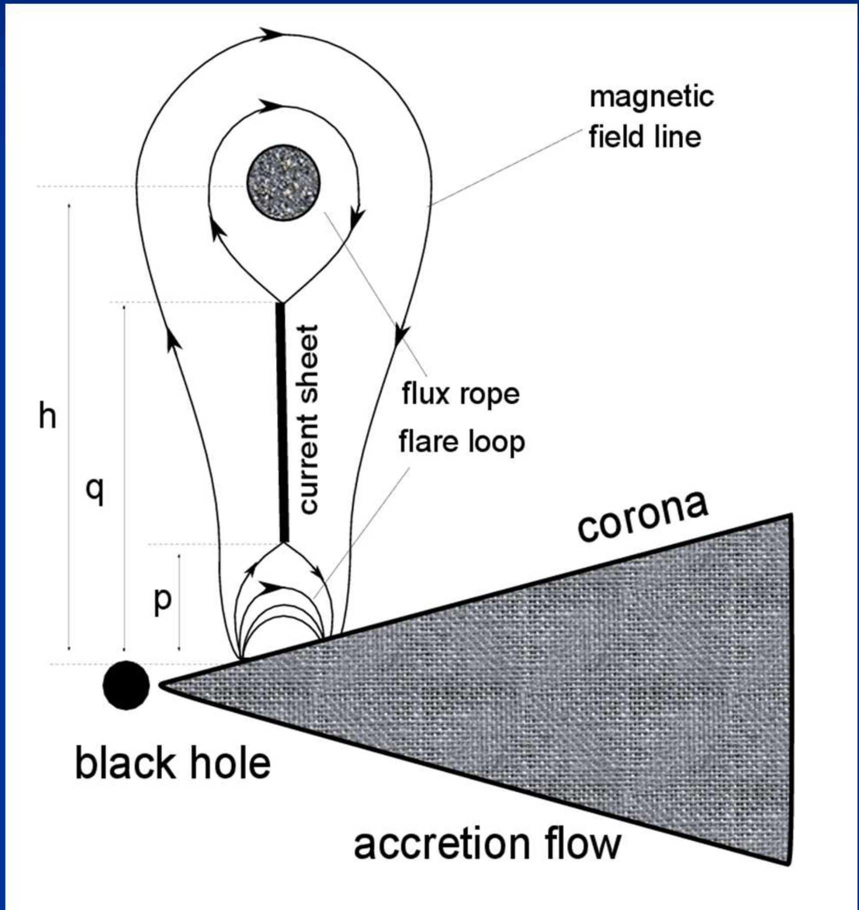


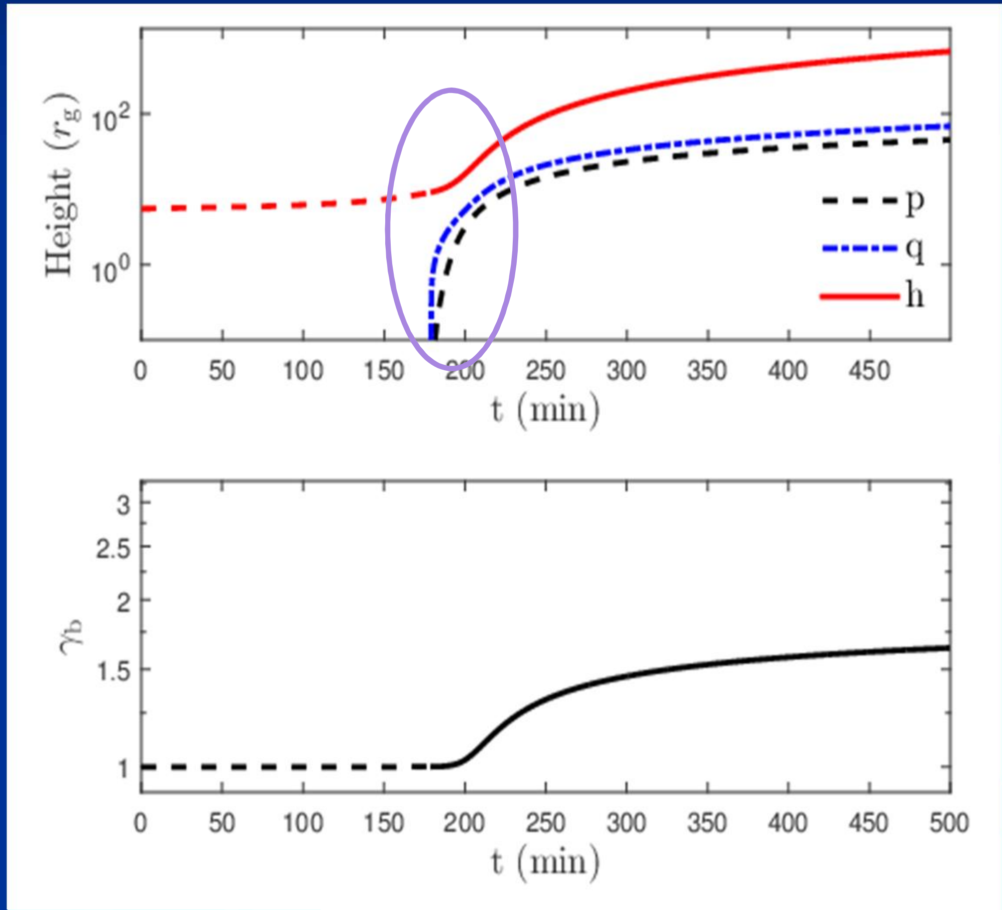
Standard model of solar flare
(Conduction; evaporation …)

synchrotron and/or SSC of electrons
accelerated by reconnection:
IR & X-ray flares?

Catastrophic dynamical evolution of the current sheet and flux rope

Li, Yuan & Wang 2017

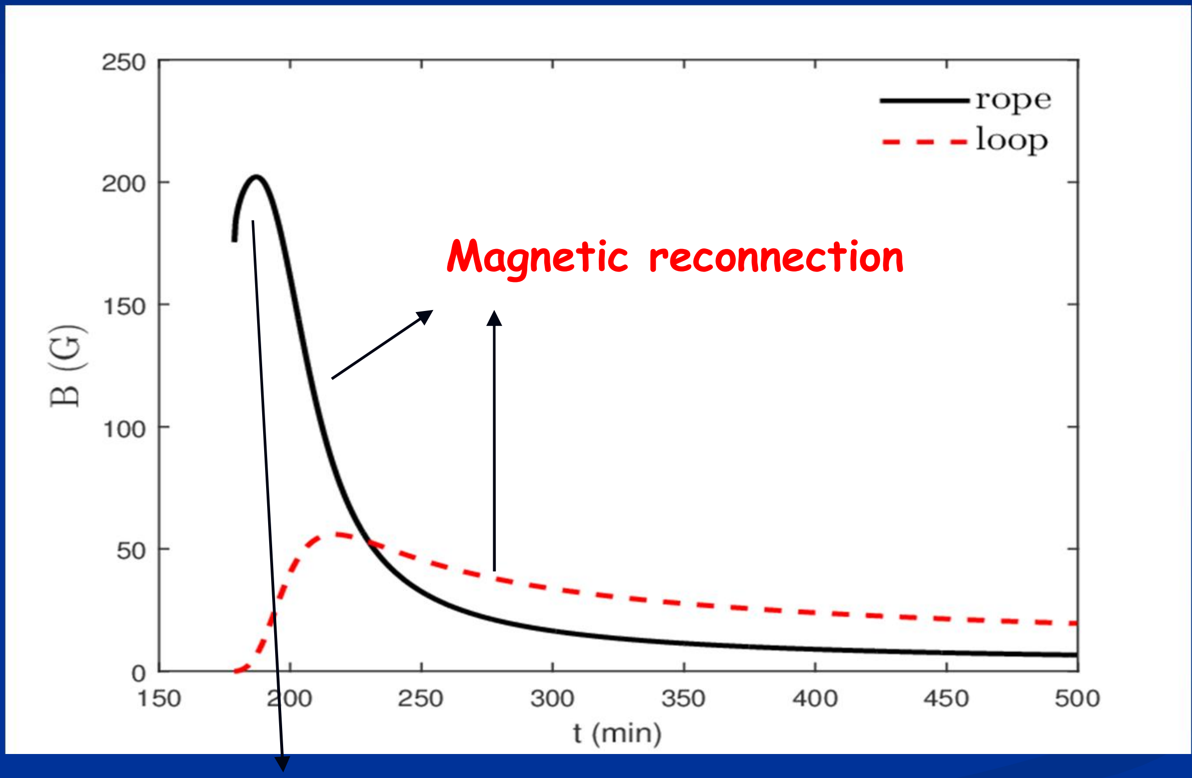




$$m\gamma_b^3 \frac{d^2 h}{dt^2} = \frac{1}{c}|\boldsymbol{I} \times \boldsymbol{B}_{\rm ext}| - F_g$$

Magnetic field evolution in the flare region

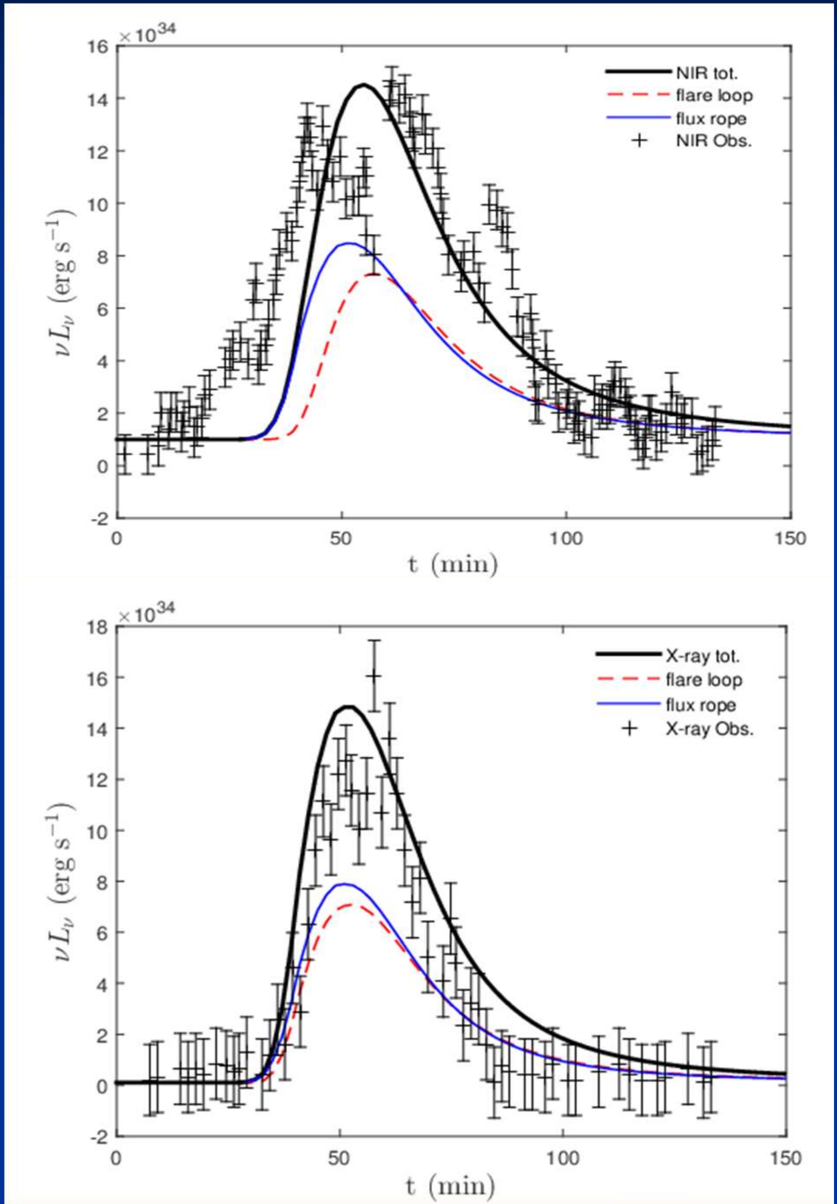
Li, Yuan & Wang 2017



$$B(\zeta) = \frac{2iA_0\lambda(h^2+\lambda^2)\sqrt{(\zeta^2+p^2)(\zeta^2+q^2)}}{\pi(\zeta^2-\lambda^2)(\zeta^2+h^2)\sqrt{(\lambda^2+p^2)(\lambda^2+q^2)}},$$

Magnetic field coupled with the dnyamical evolution of the flux rope.

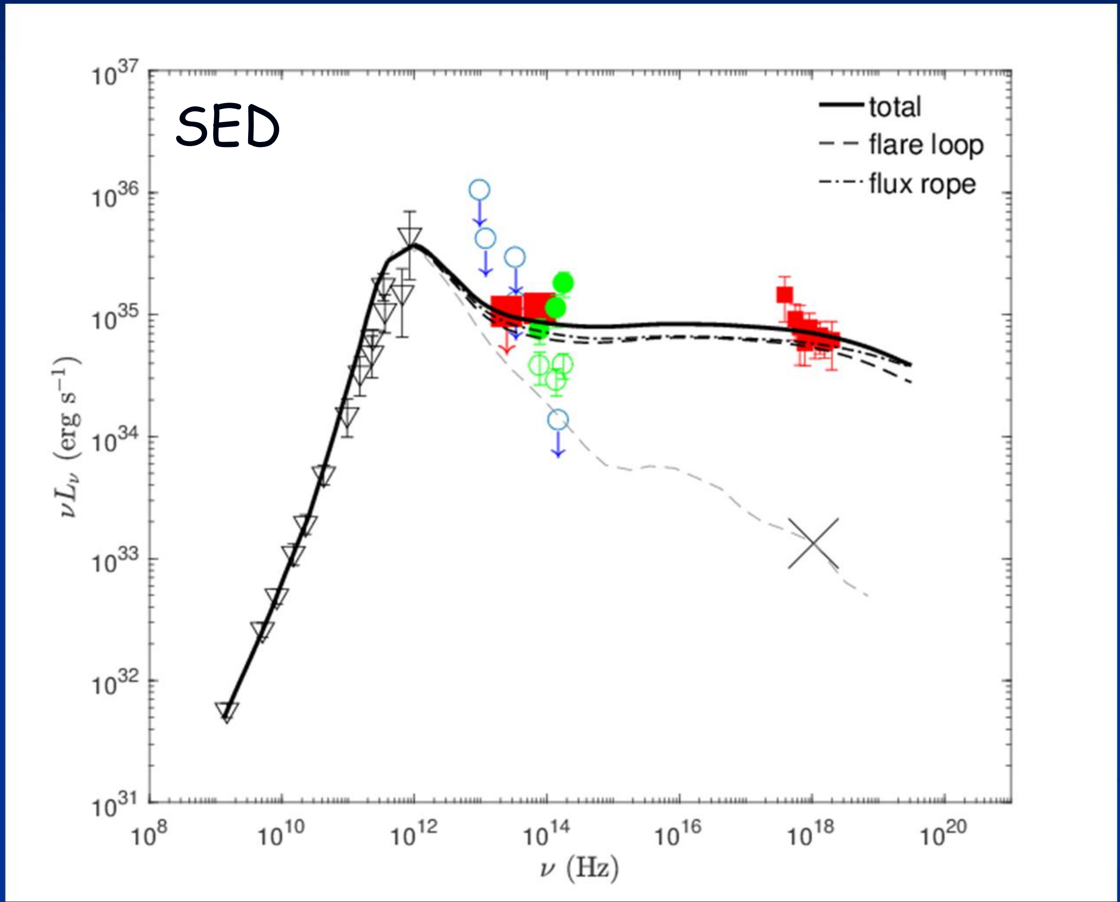
NIR and X-ray Light curves



Main features:

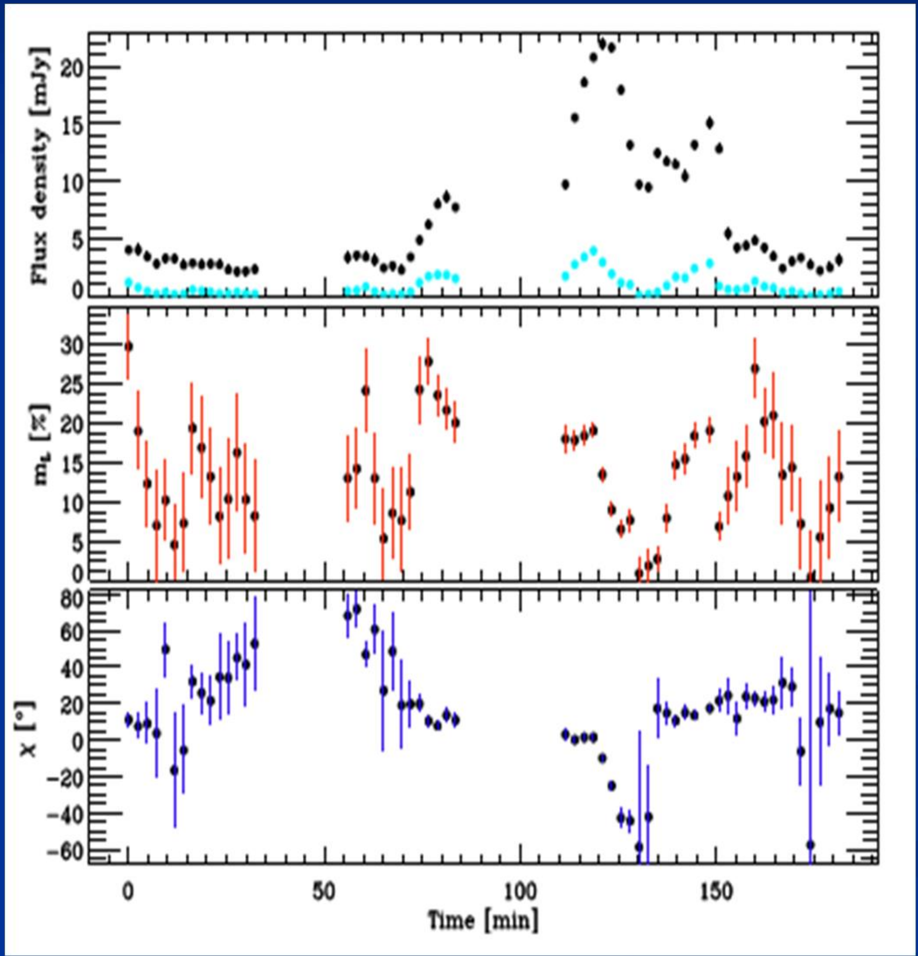
1. Simultaneous flaring
2. Quasi-symmetric profile
3. Amplitudes both in NIR and X-ray

Spectrum energy distribution



Synchrotron radiation in two flare regions (loop and rope) for each time at a given frequency.

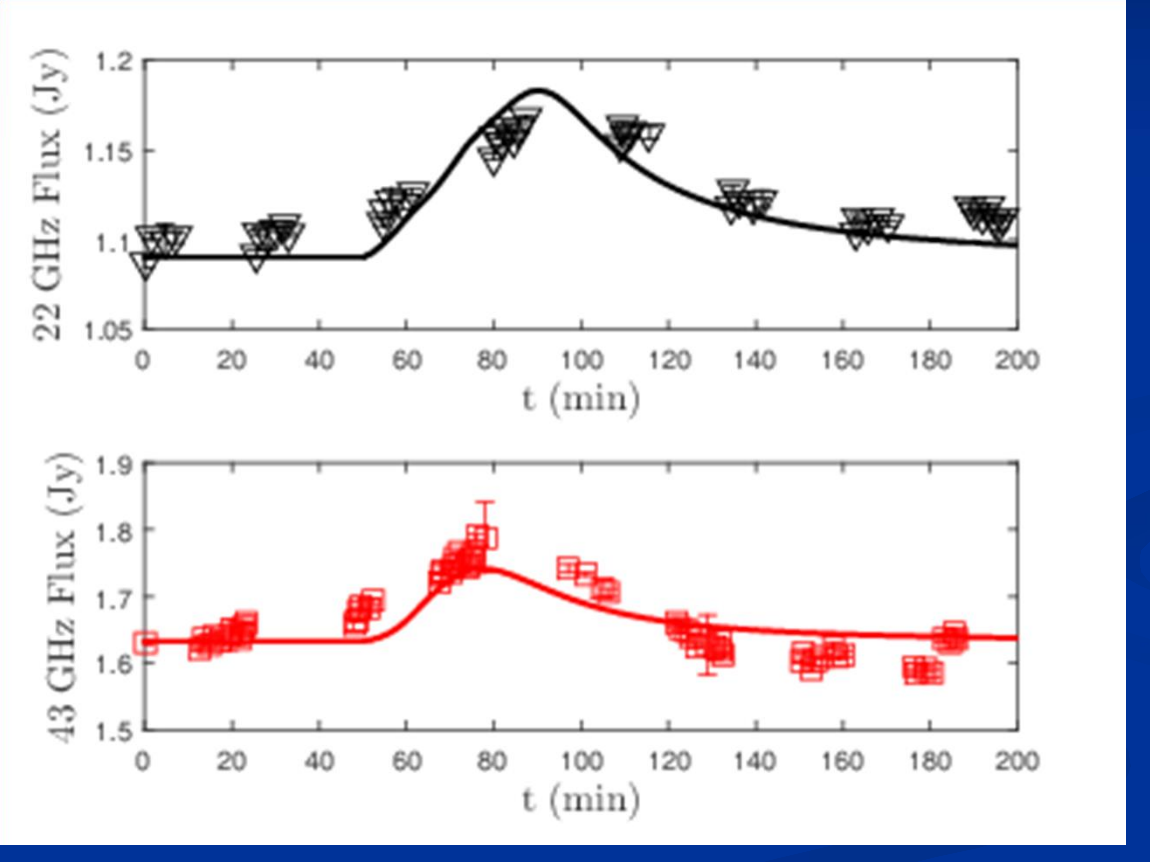
Ongoing works:
Polarization of NIR flares



Shahzamanian et al. 2015

NIR flares polarization fraction: ~ 20+/-10%, suggests a synchrotron origin for NIR flares

Ongoing Works: Radio Light Curves



Synchrotron light curves at different radio frequencies for expanding blobs of plasma.

Data from Yusef-Zadeh et al. 2006

Summary on jet formation: A lot of debates & unsolved problems….

- Jet powered by BH spin or rotation of disk?
- How Poynting flux transferred into radiation?
- Composition of jet? Leptons or also baryons?
- Nature of episodic jet?
- ……