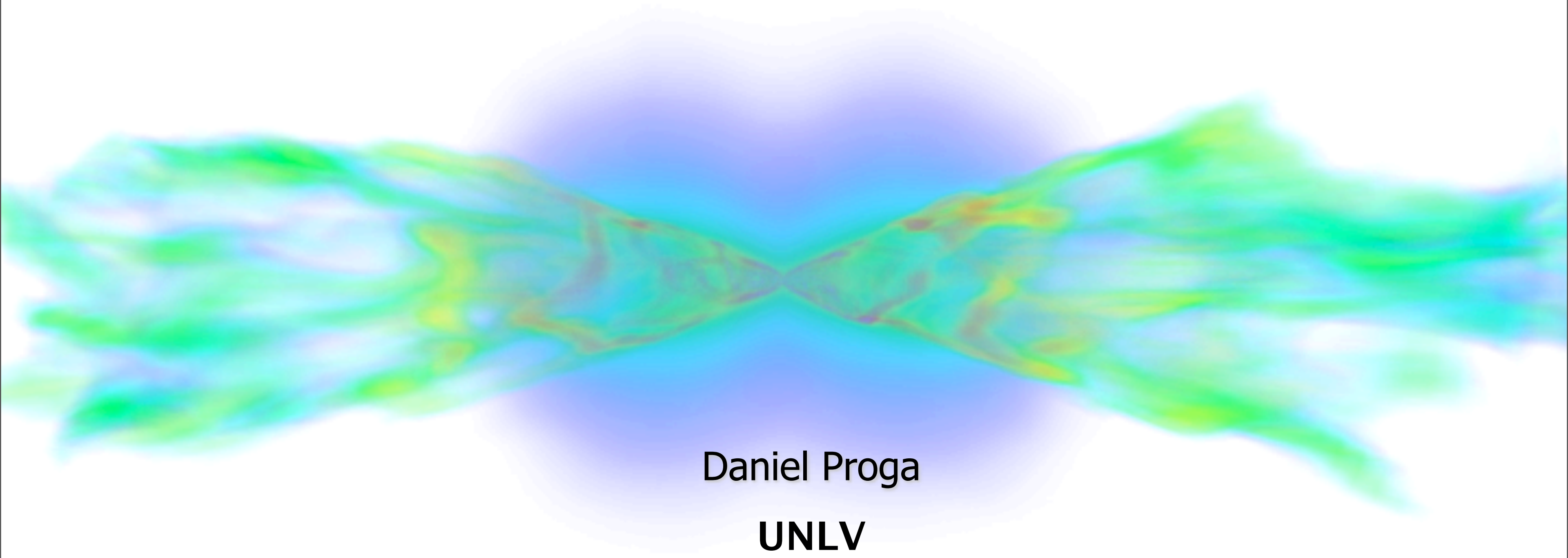
Winds from Disks and Tori



Daniel Proga

UNLV

Collaborators

- J. Stone, T. Kallman, J. Raymond, M. Begelman, J. Ostriker, **R. Kurosawa,** J. Drew, A. Janiuk, M. Moscibrodzka, B. Czerny, A. Siemiginowska, A. Dorodnityn, S. Sim, **S. Luketic**, **T. Waters**, and many more

OUTLINE

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1. Introduction

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2. Multidimensional, time-dependent simulations of disk winds driven by:

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3. Conclusions

What can drive an outflow?

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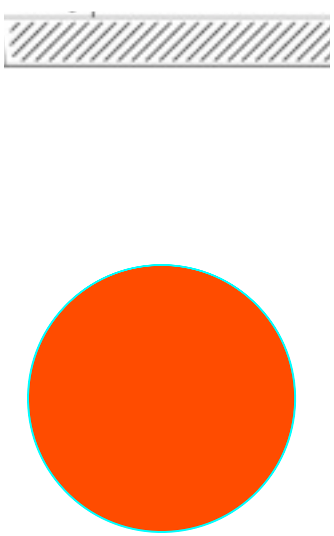
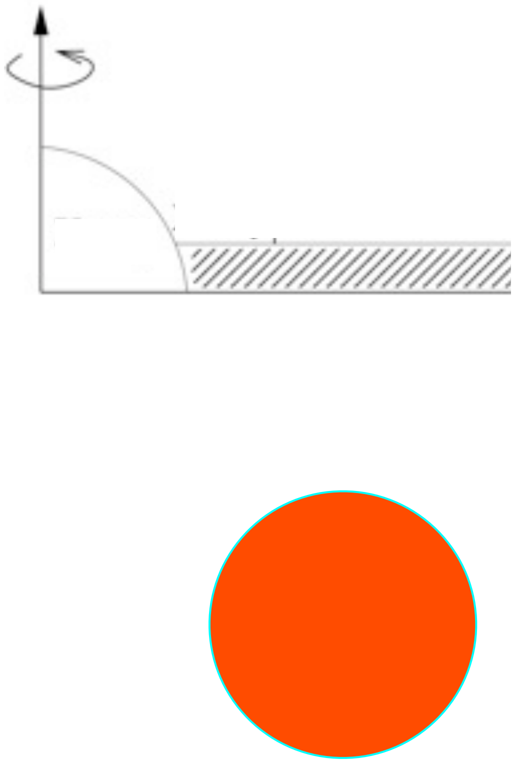
In most cases, rotation plays a key role (directly or indirectly) especially in AD.

Accretion Disks vs Stars



Accretion Disks vs Stars



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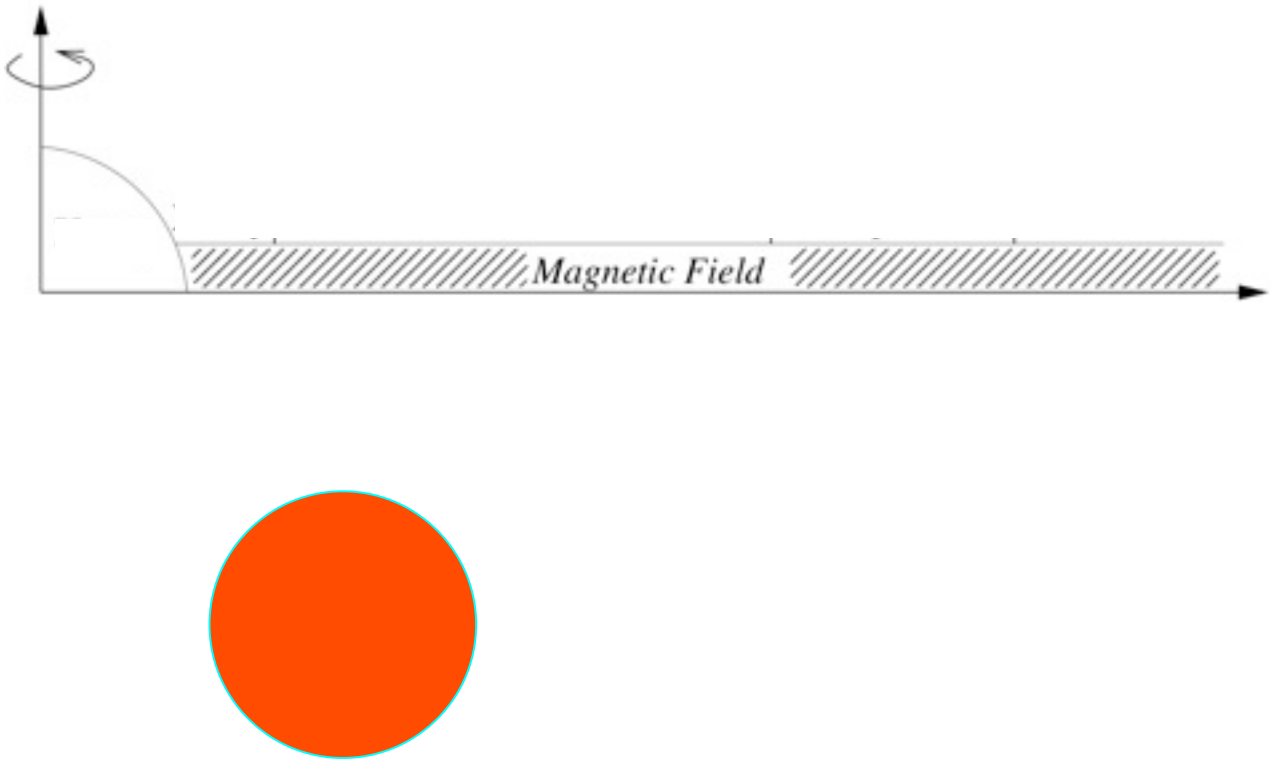

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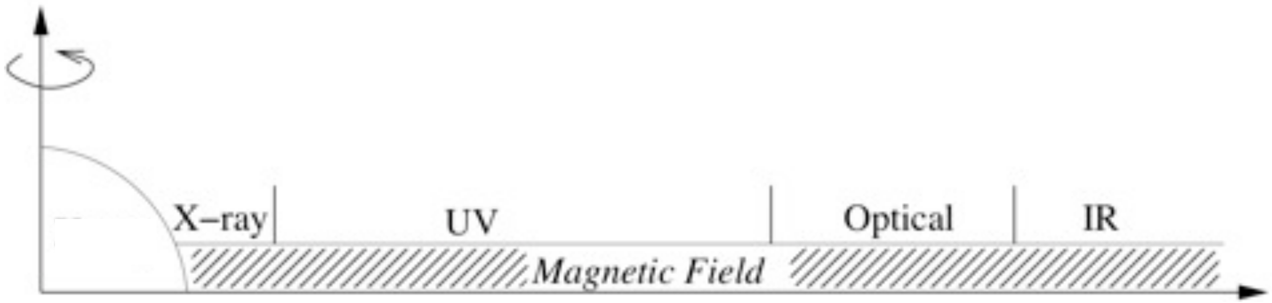

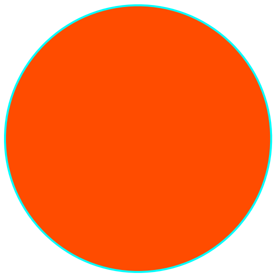

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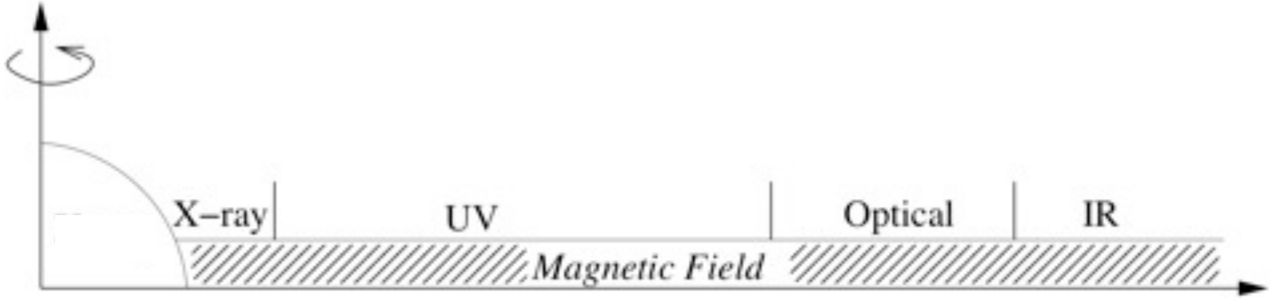
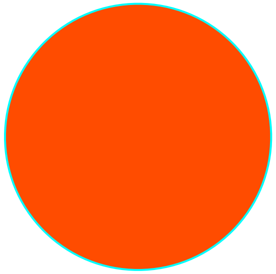
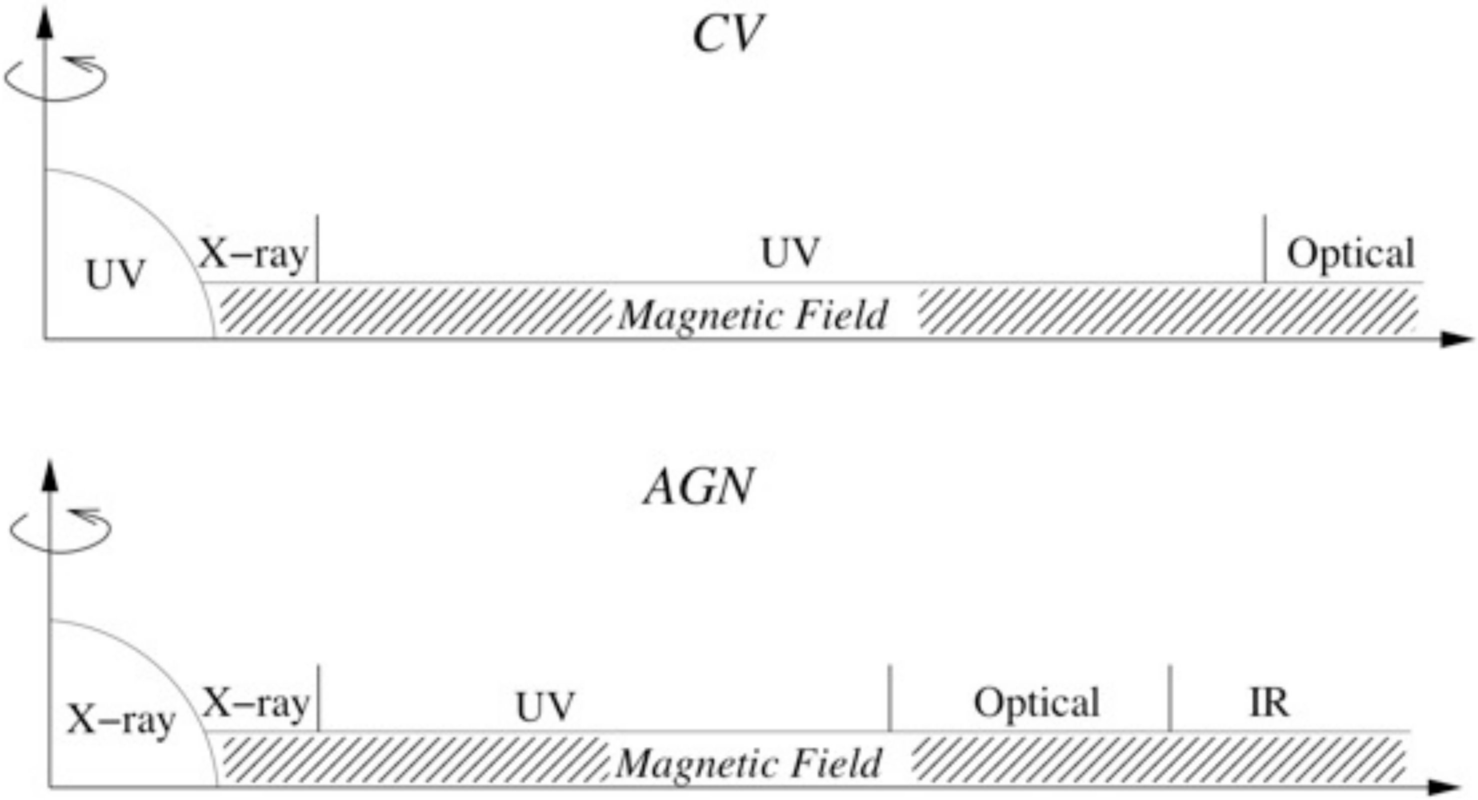




See a poster by Tim Waters

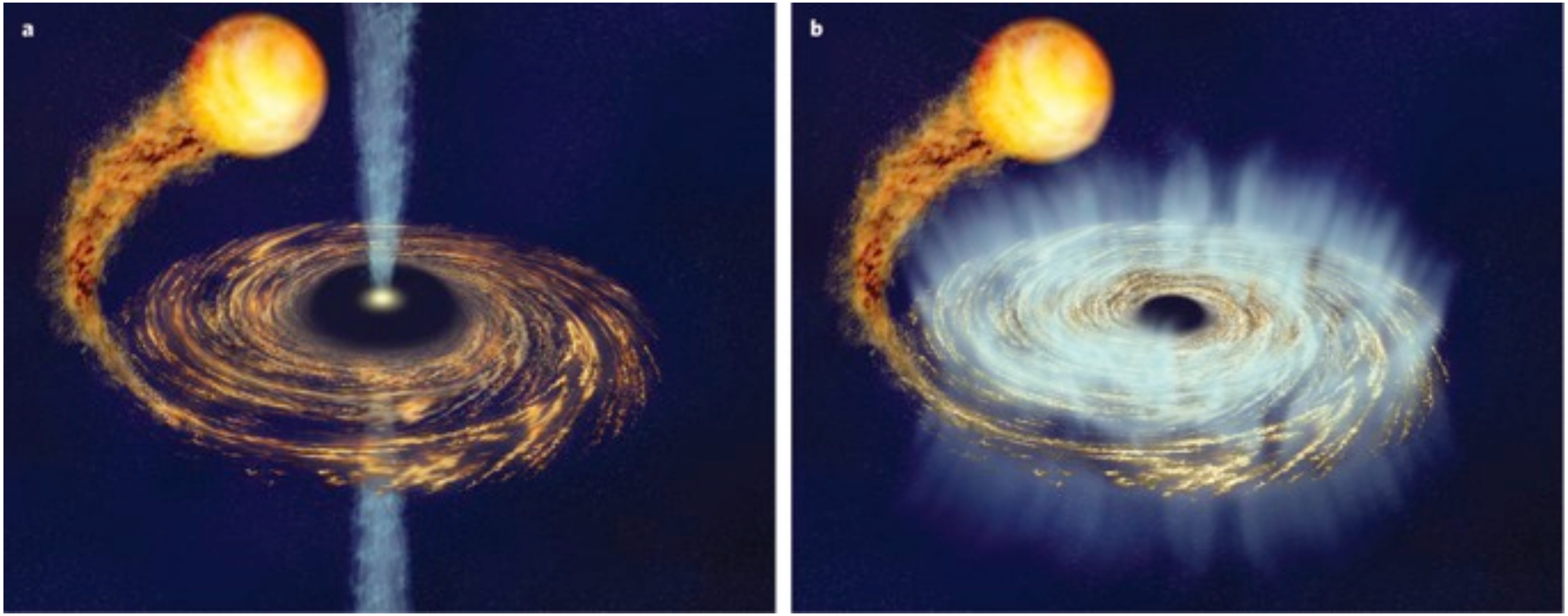
Accretion Disks in Various Objects

Two examples:



Thermal Disk Winds

GRS 1915-105



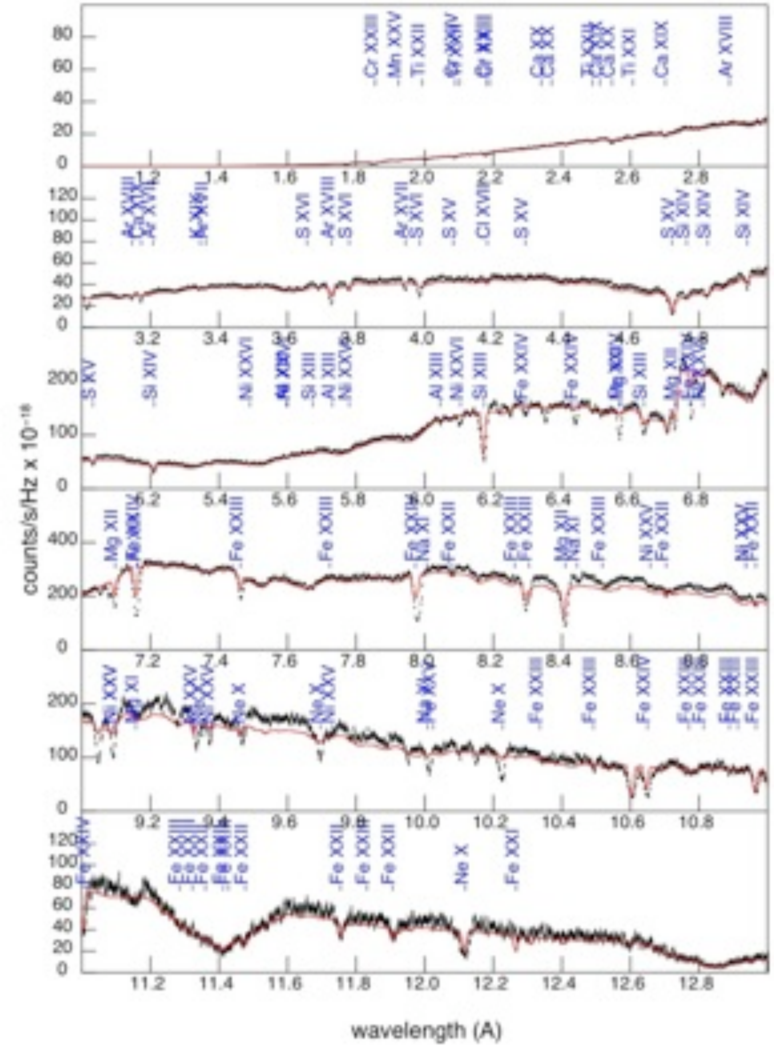
Neilsen & Lee (2009)

fig. from P's 2009 news & views

X-ray Transient Sources

- Most of the accretion energy is emitted in X-rays.
- The radiation energy is still too low to drive an outflow from the inner disk.
- But the radiation from the inner disk can heat up the outer disk.
- However, spectral features of disk winds have not been seen from these systems until recently (Schulz & Brandt 2002; Miller et al. 2006, 2008; Kubota et al. 2007; Neilsen & Lee 2009).
- Thank you “Chandra, XMM-Newton, and Suzaku” ... !!!
- IXO

GRO J1655–40

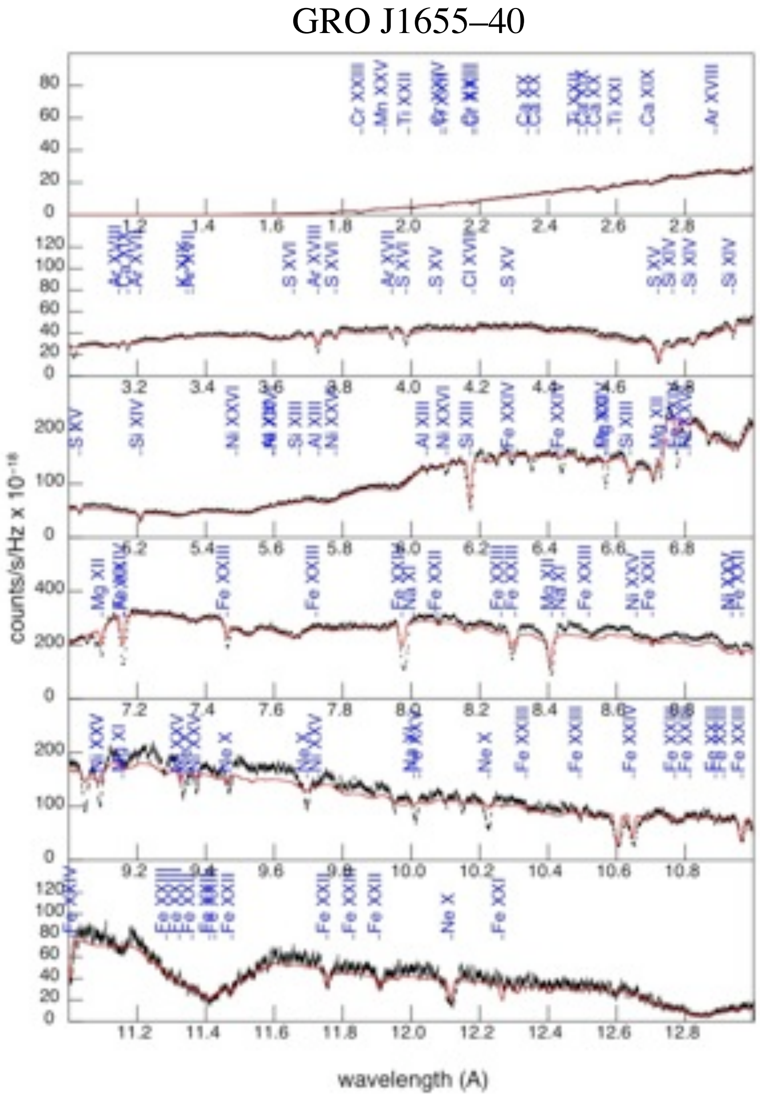


Observations: Miller et al. (2006)

X-ray Transient Sources

- Interpretation and spectral modeling: Miller et al. (2006, 2008), Netzer (2006), Kallman et al. (2009).
- Dedicated hydrodynamical simulations (Luketic et al. 2010)

$$R_{\rm IC} = \frac{G M_{\rm BH} m_{\rm p} \mu}{k T_{\rm IC}}$$


GRO J1655–40

Observations: Miller et al. (2006)

The equations of hydrodynamics

$$\frac{D\rho}{Dt} + \rho\nabla \cdot v = 0$$

$$\rho\frac{Dv}{Dt} = -\nabla P + \rho g$$

$$\rho\frac{D}{Dt}\left(\frac{e}{\rho}\right) = -P\nabla \cdot v$$

$$P = (\gamma - 1)e$$

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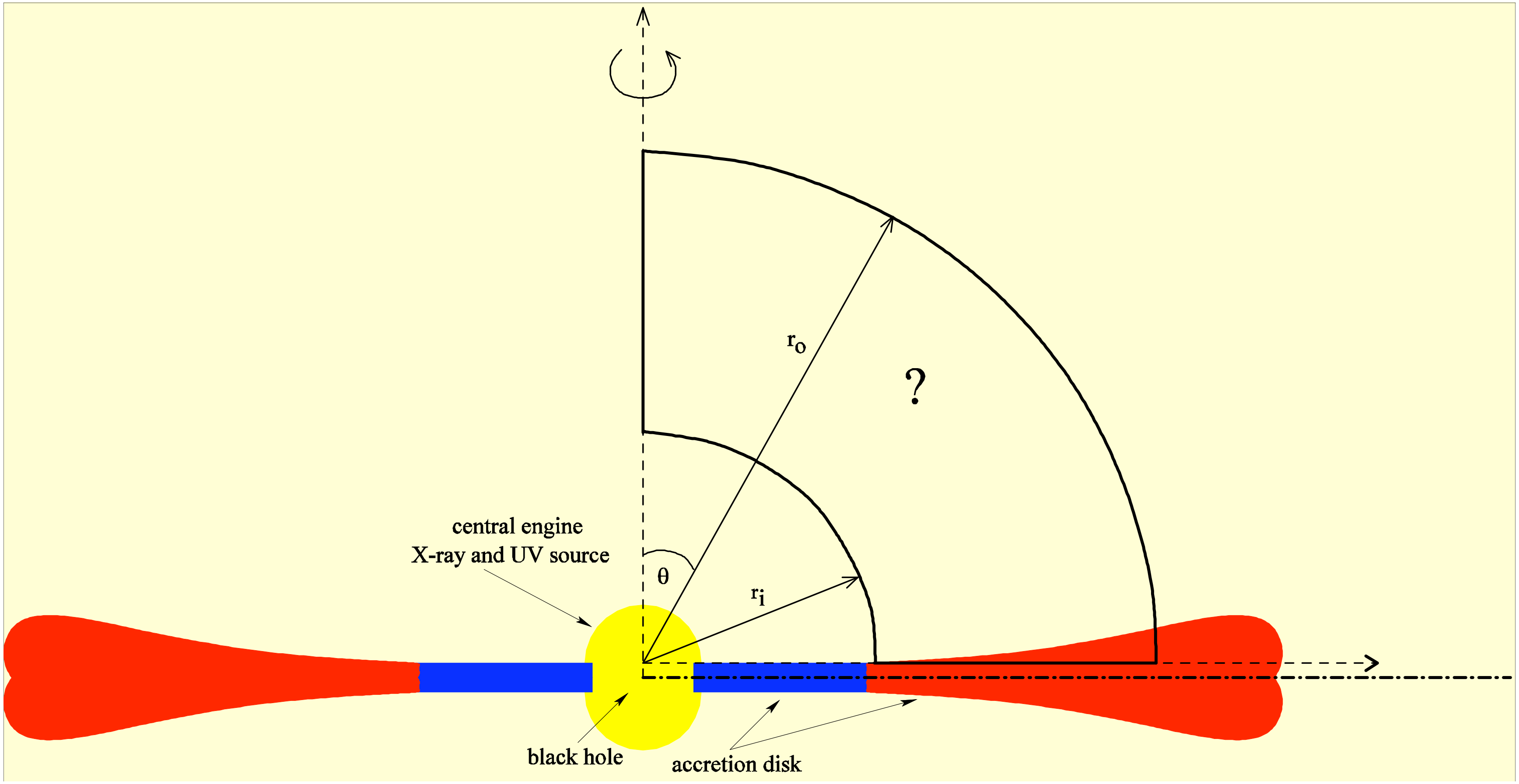
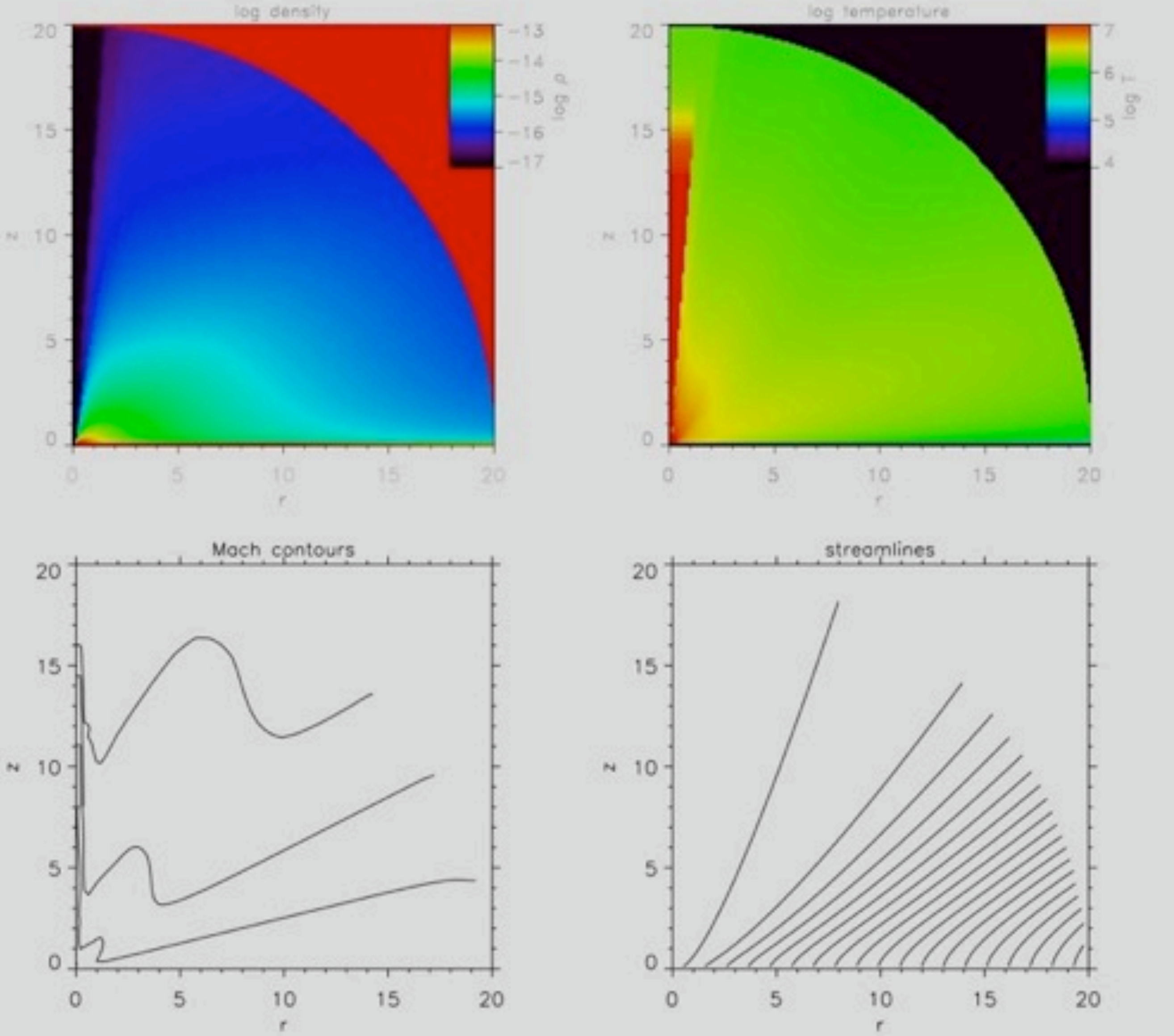
$$\rho\frac{D}{Dt}\left(\frac{e}{\rho}\right) = -P\nabla \cdot v \underline{+ \rho L}$$

$$P = (\gamma - 1)e$$



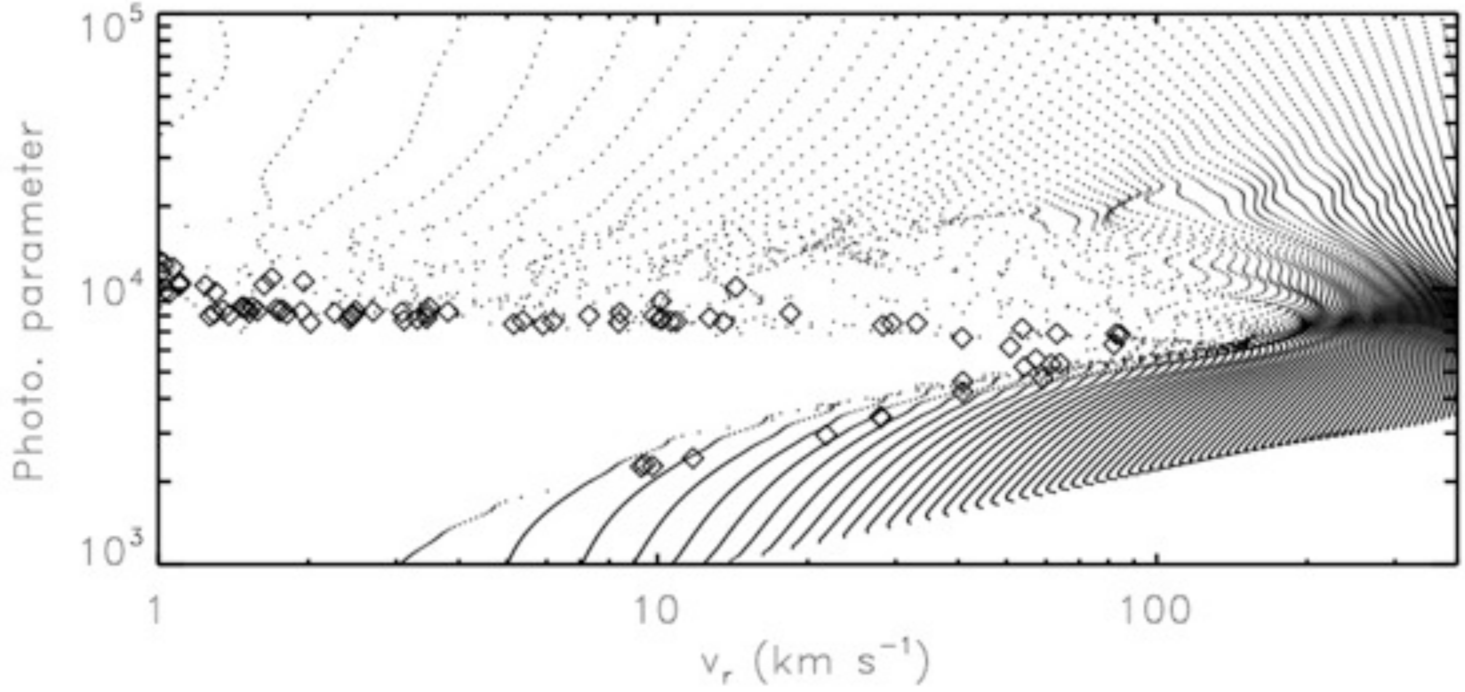
X-ray and UV source

$$R_{\rm IC} = \frac{G M_{\rm BH} m_{\rm p} \mu}{k T_{\rm IC}}$$



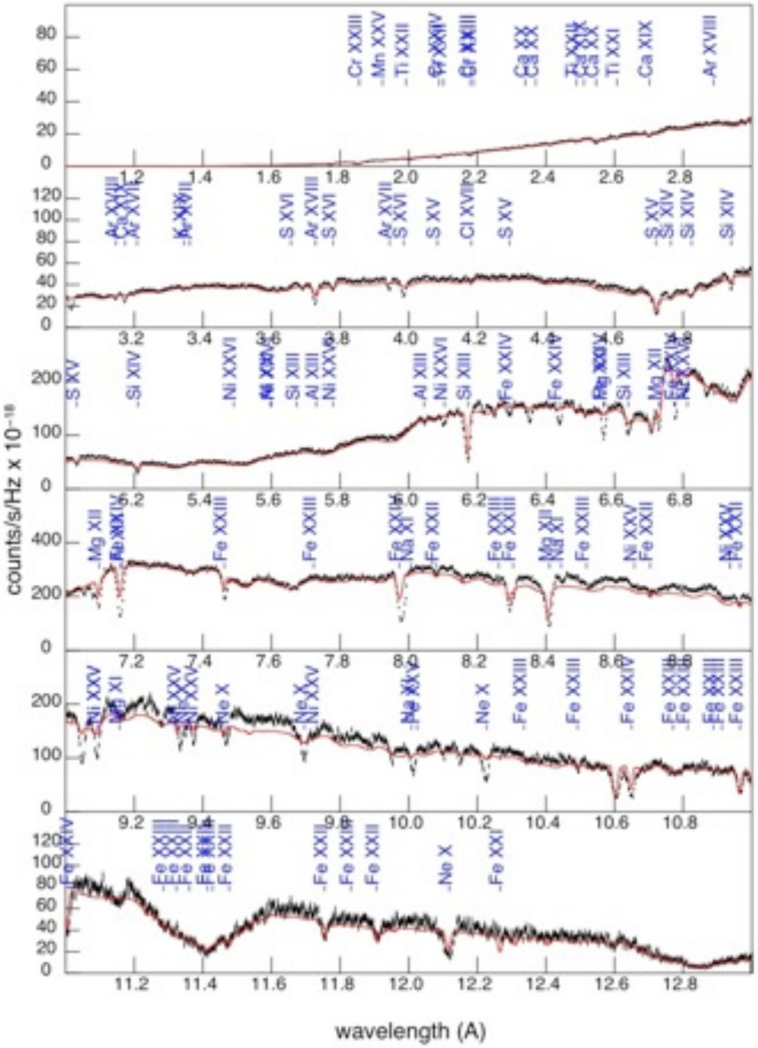
Luketic et al. (2010)

GRO J1655–40

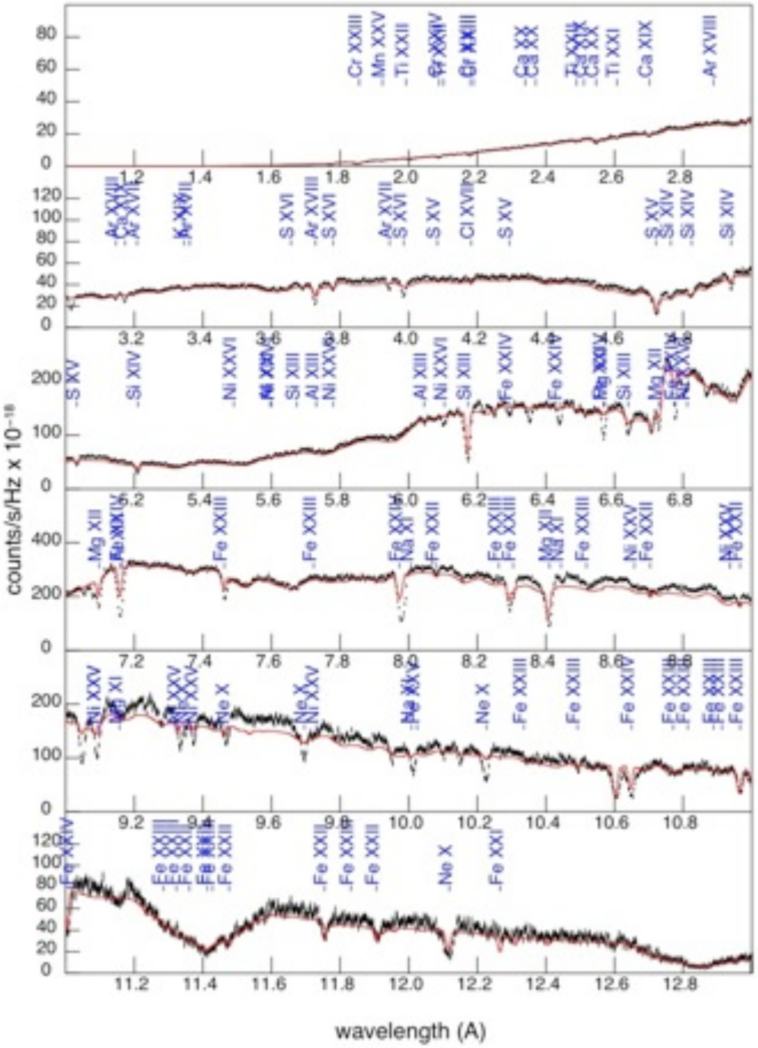


diamonds correspond $n \geq 10^{12}$ cm^{-3}

GRO J1655–40

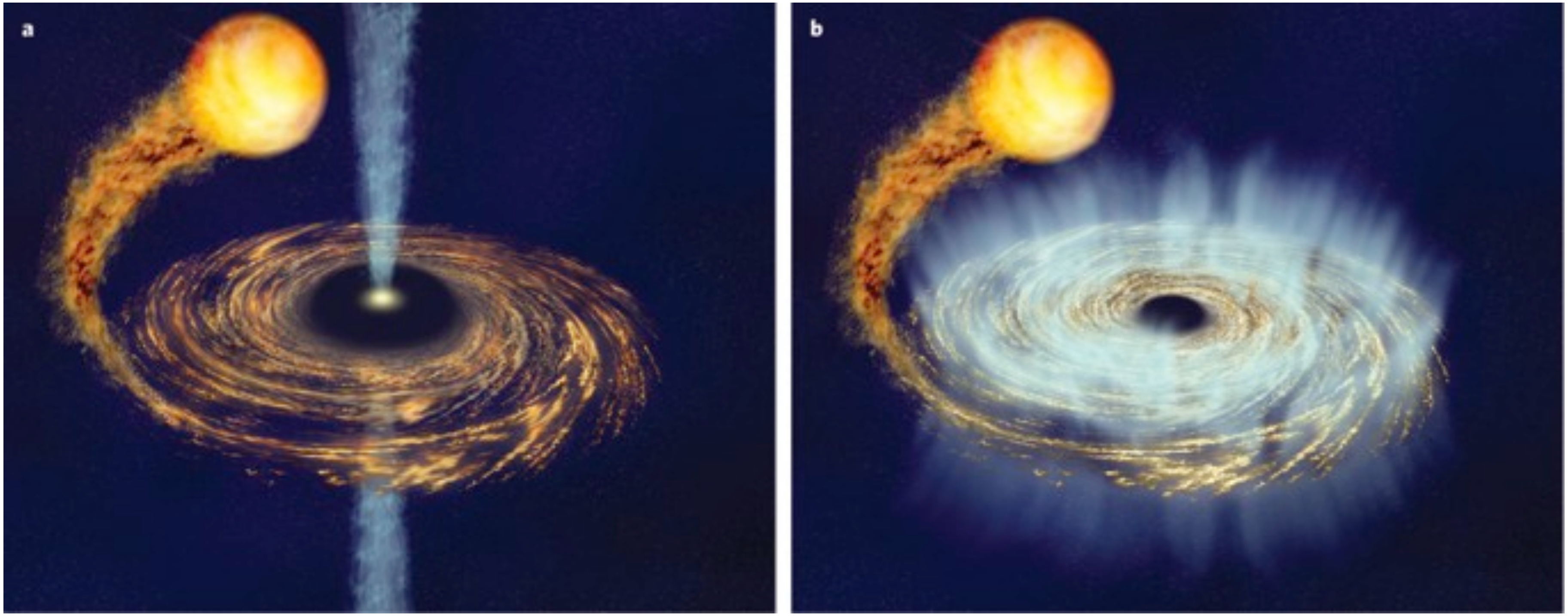

counts/s/Hz x 10⁻¹⁸
wavelength (A)
Cr XXIII
Mn XXV
Ti XXII
Ca XX
Ti XXI
Ca XIX
Ar XVIII
Ar XVII
S XVI
S XV
Cl XVII
Si XIV
Ni XXVI
Si XIII
Al XIII
Fe XXIV
Mg XII
Na XI
Fe XXIII
Fe XXII
Ni XXV
Ne X
Fe XXI
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
11.2
11.4
11.6
11.8
12.0
12.2
12.4
12.6
12.8

GRO J1655–40



- The thermal wind is not dense enough to account for the observed wind.
- But does it mean that the thermal wind is unimportant?
- Maybe not because the wind mass lose rate can be as high as 5 times the disk accretion rate (see Neilsen & Lee 2009)!!!

GRS 1915-105



Neilsen & Lee (2009)

fig. from P’s new&views (2009)

Radiation-Driven Winds

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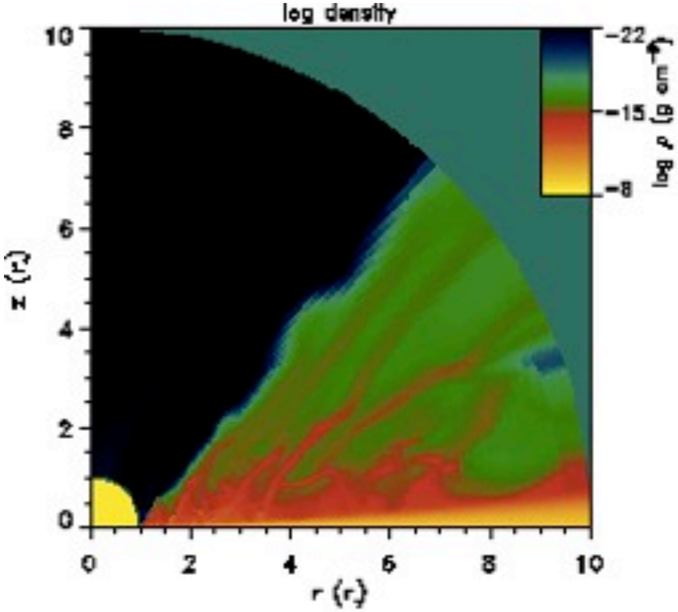
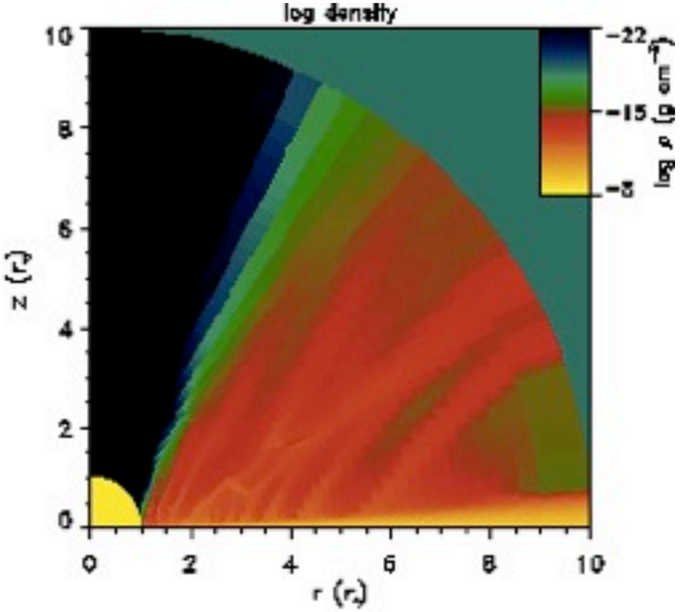
$L_D = 1$
$L_S = 0$



$L_D = 3$
$L_S = 0$



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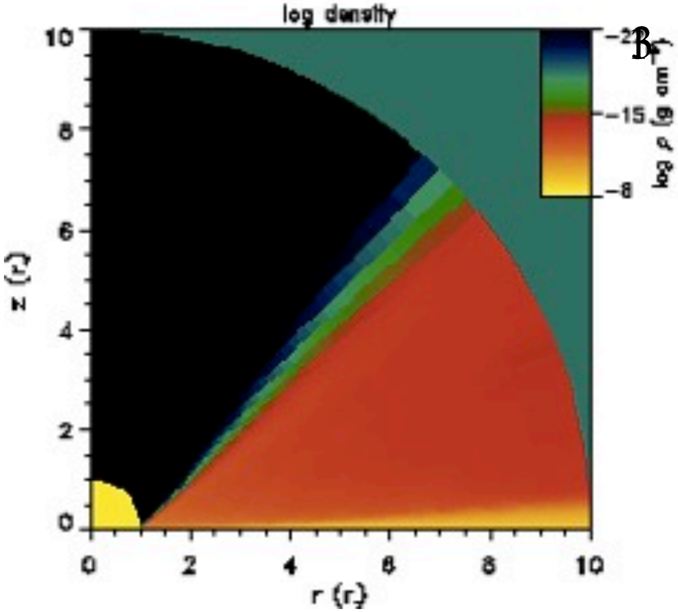
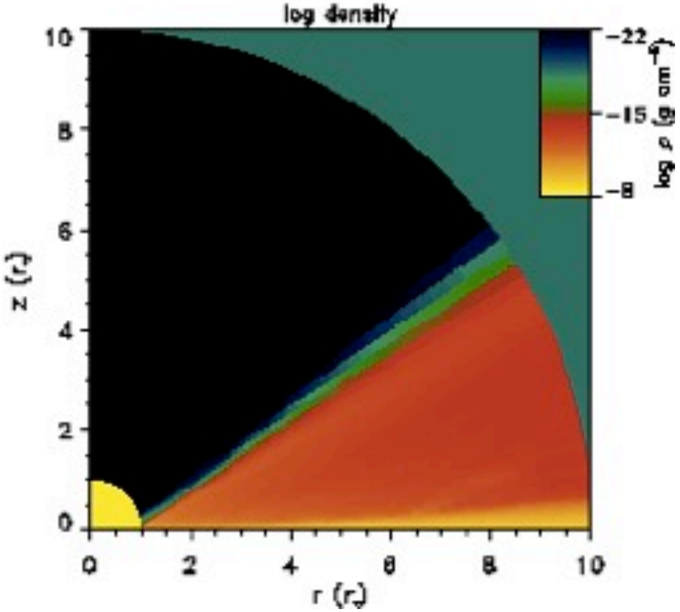
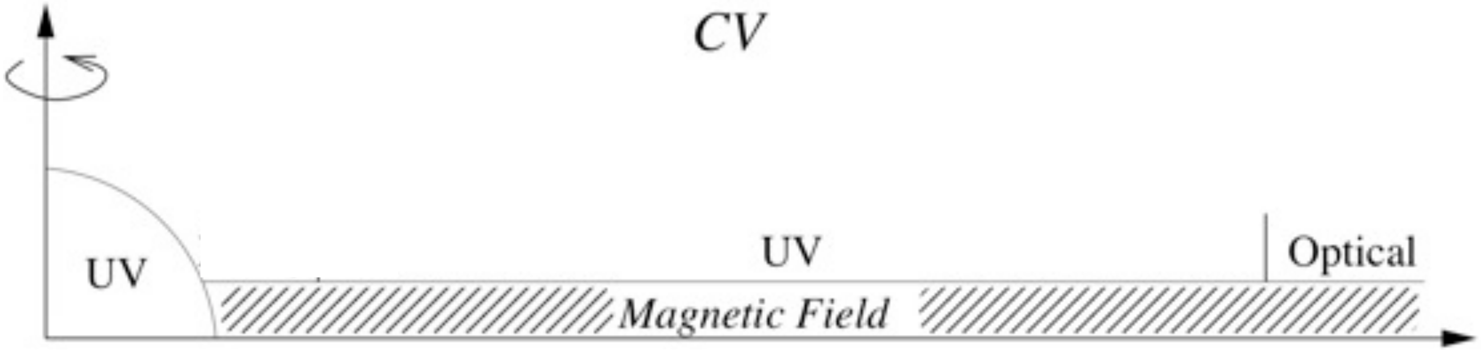


$L_D = 3$
$L_S = 9$



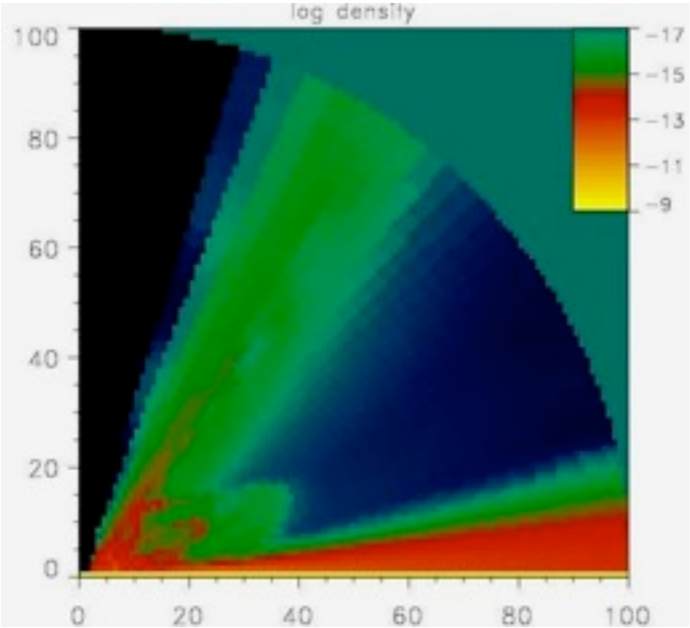
Proga, Stone & Drew (1998)

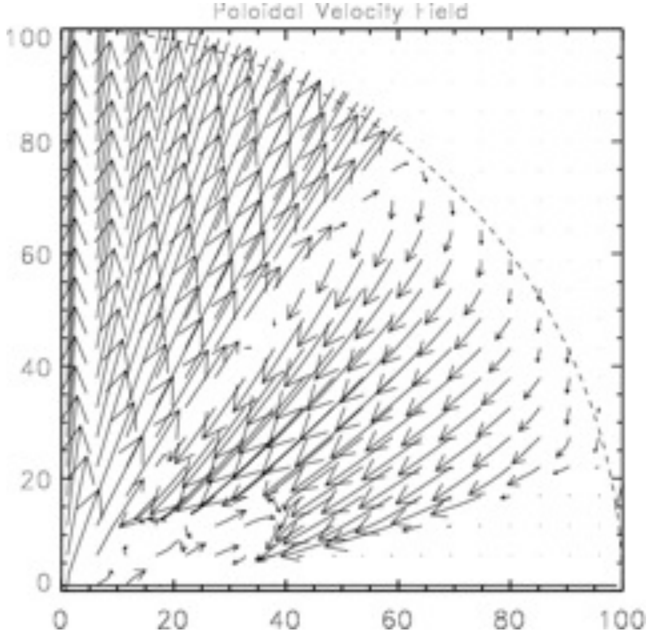
But the disk emits the UV radiation only from a relatively narrow ring.



L(disk)=3

L(star)=0





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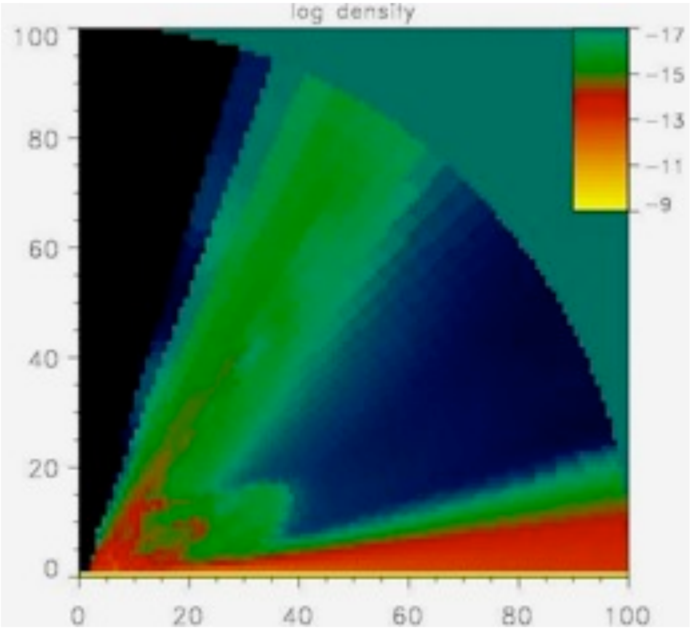
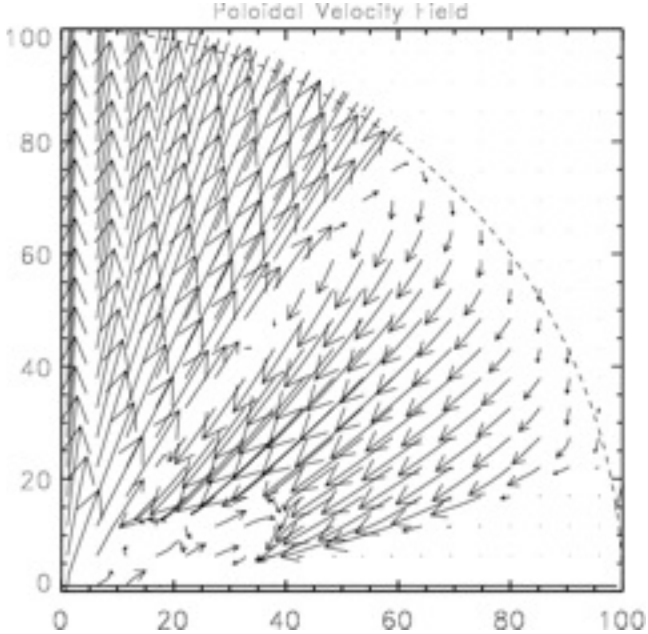
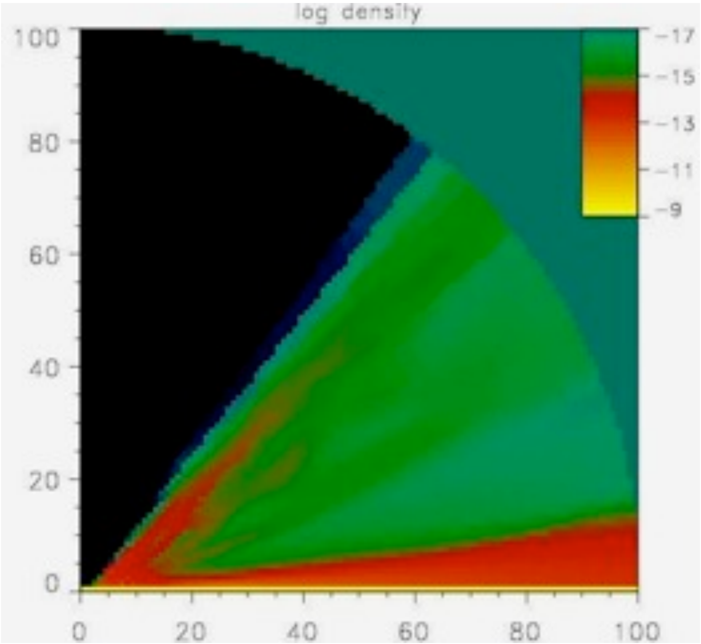
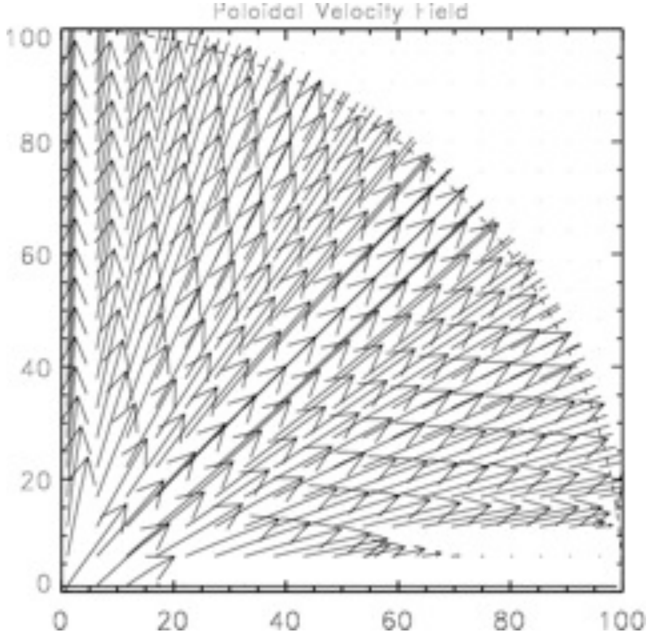

log density


Poloidal Velocity Field

L(disk)=3

L(star)=3


log density


Poloidal Velocity Field

HD simulations and their line profiles

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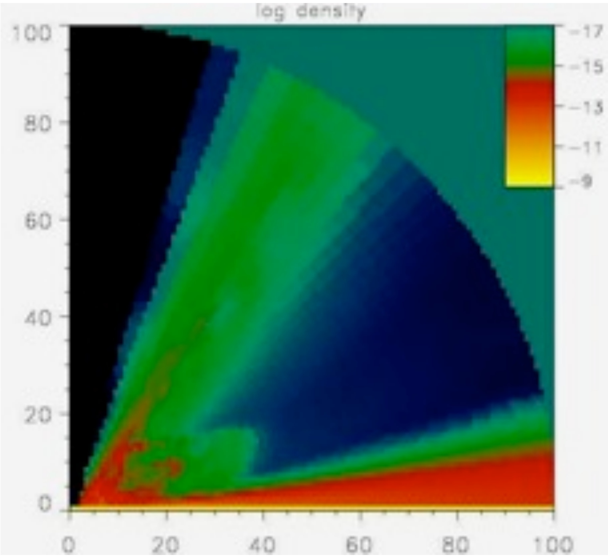

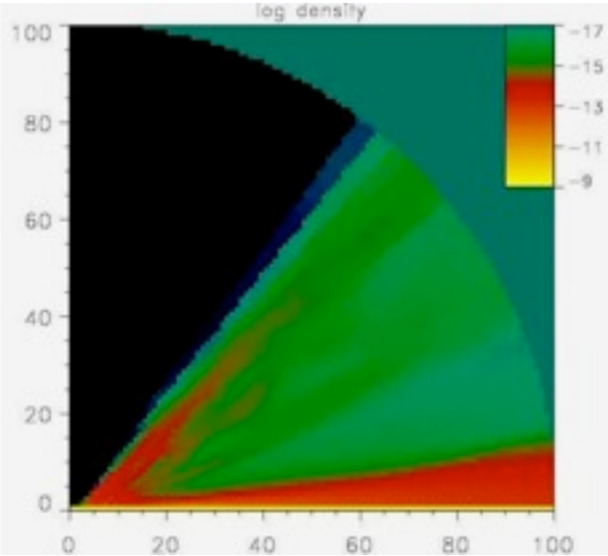

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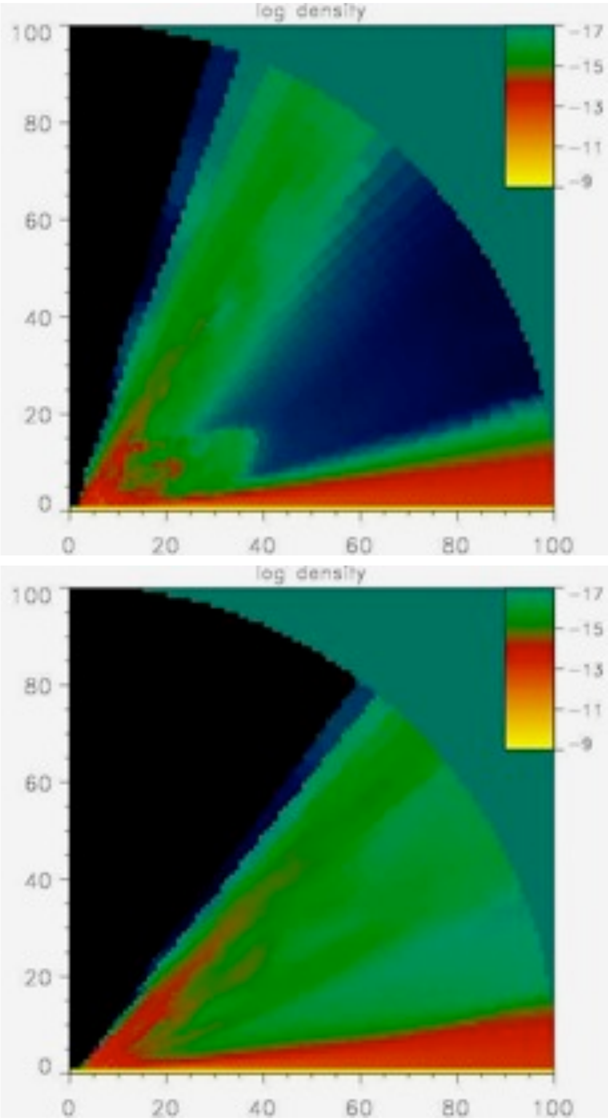

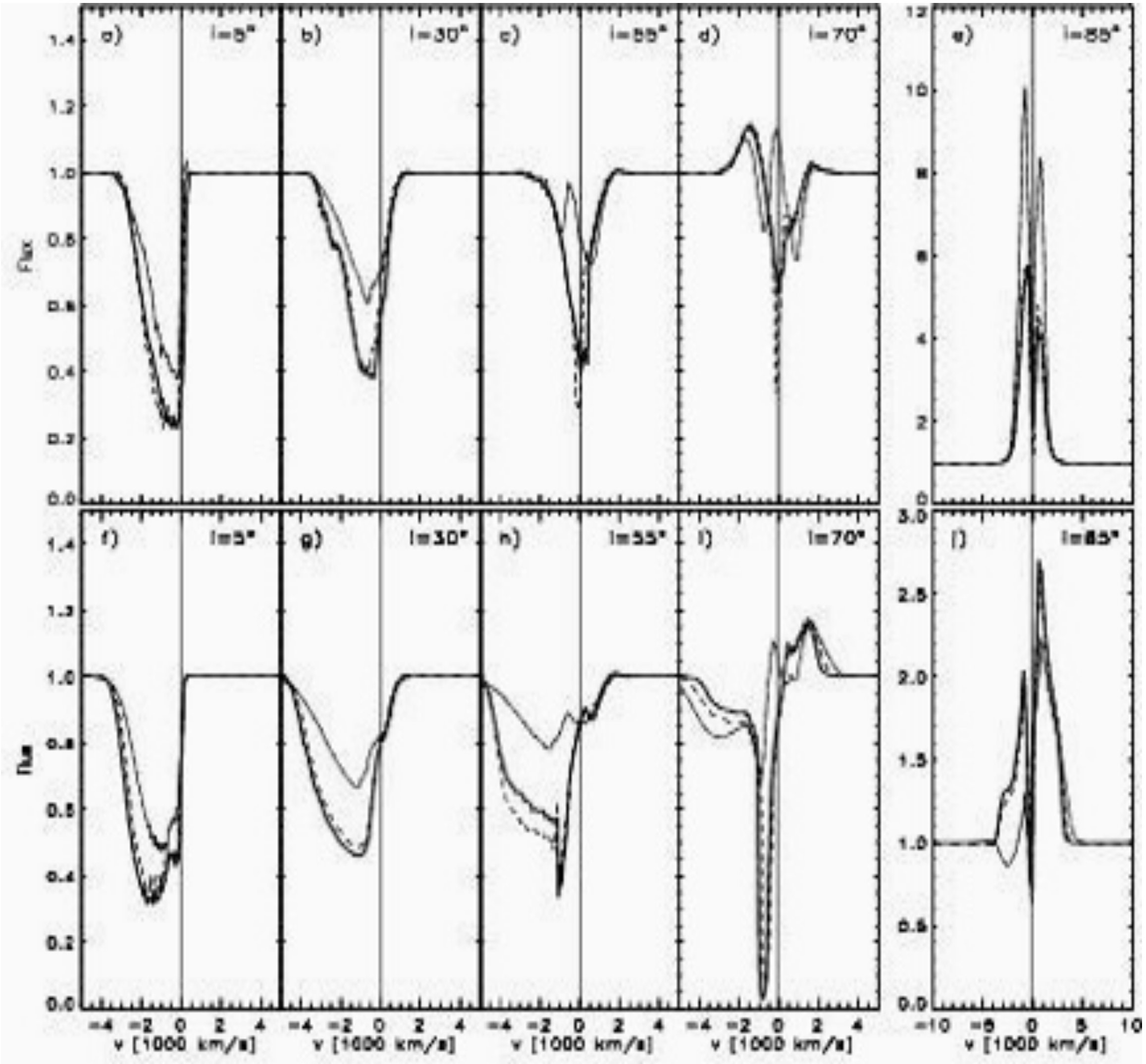

HD simulations and observations

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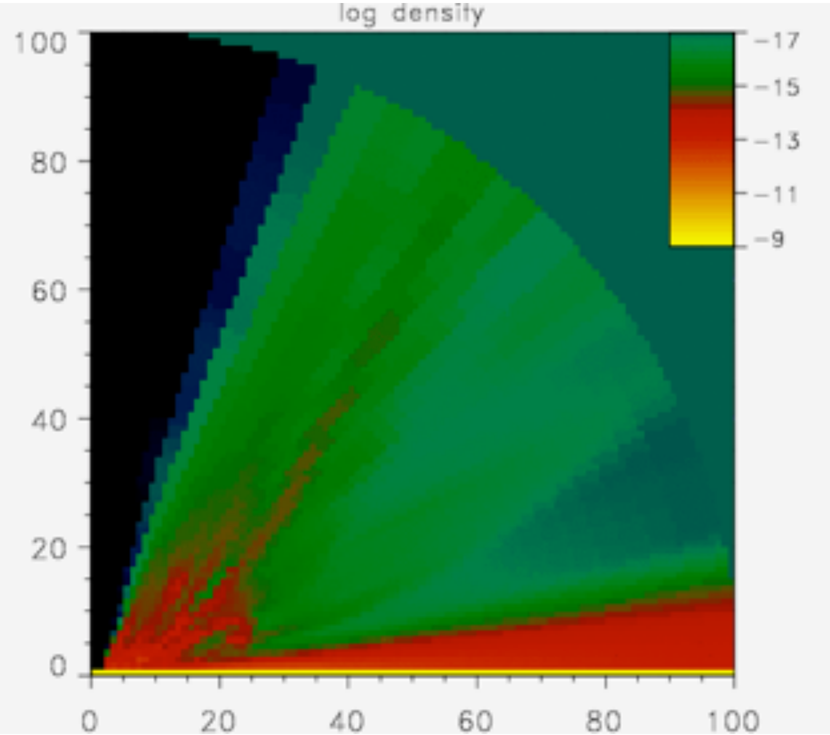

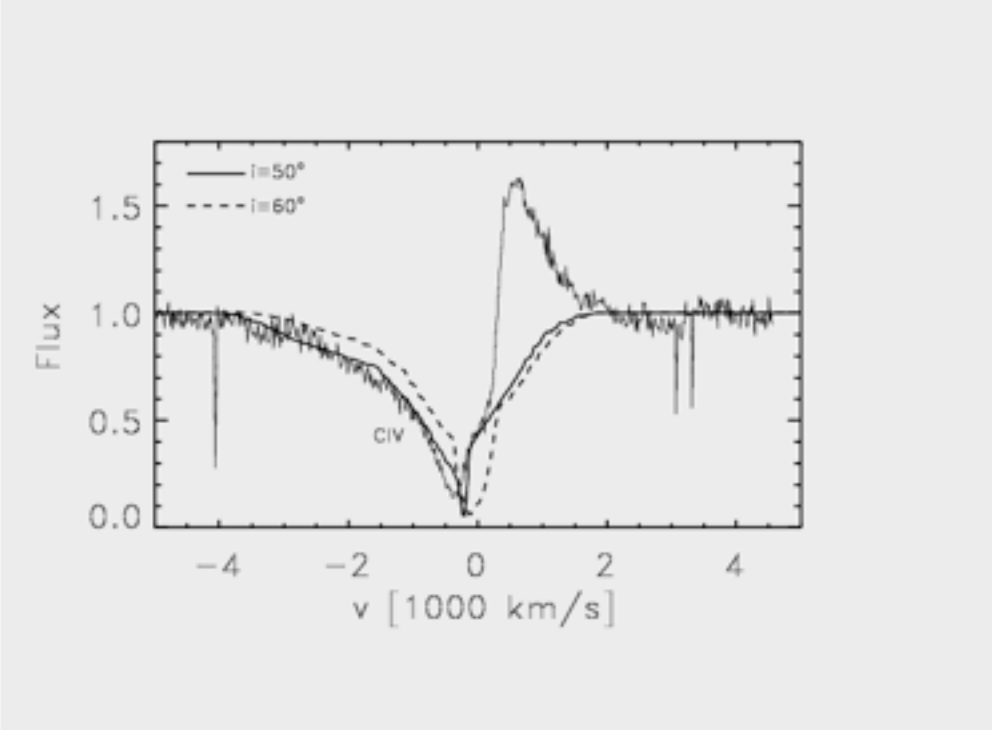

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CIV 1549 for IX Vel (Hartley et al. 2001); models Proga (2003b)

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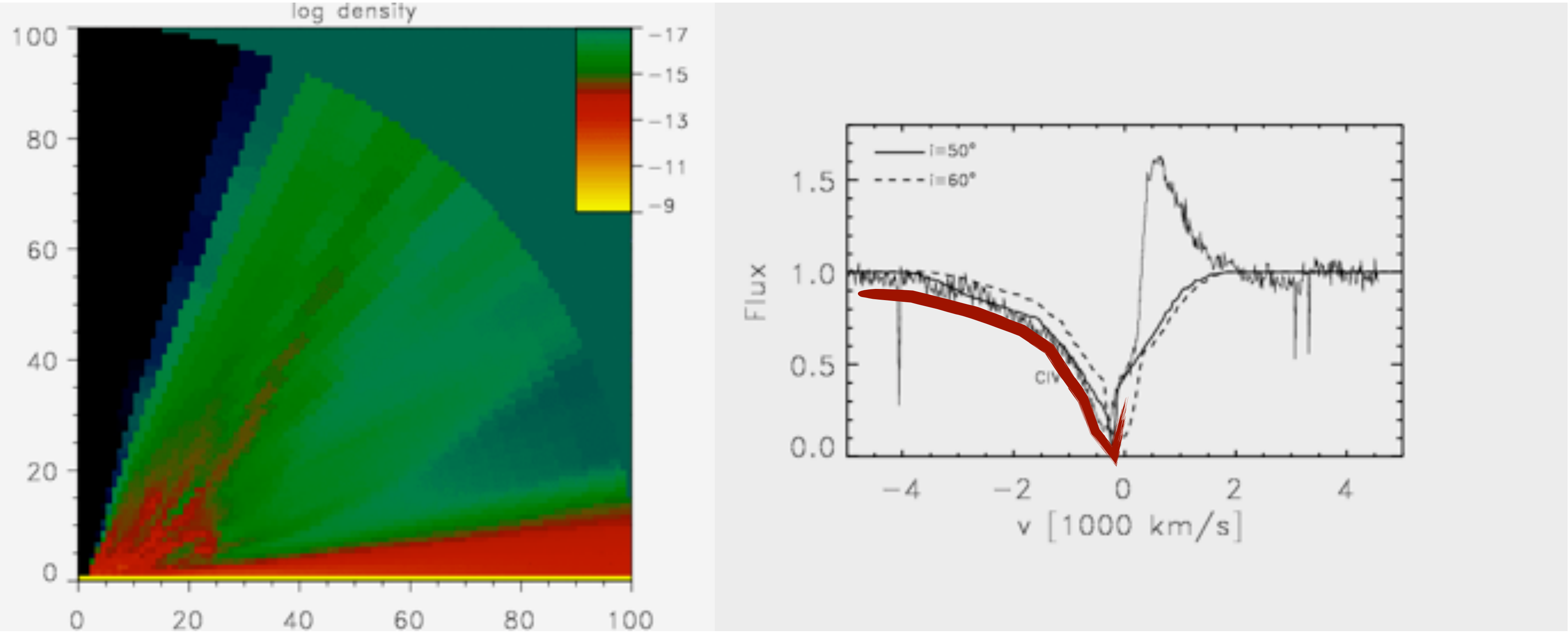

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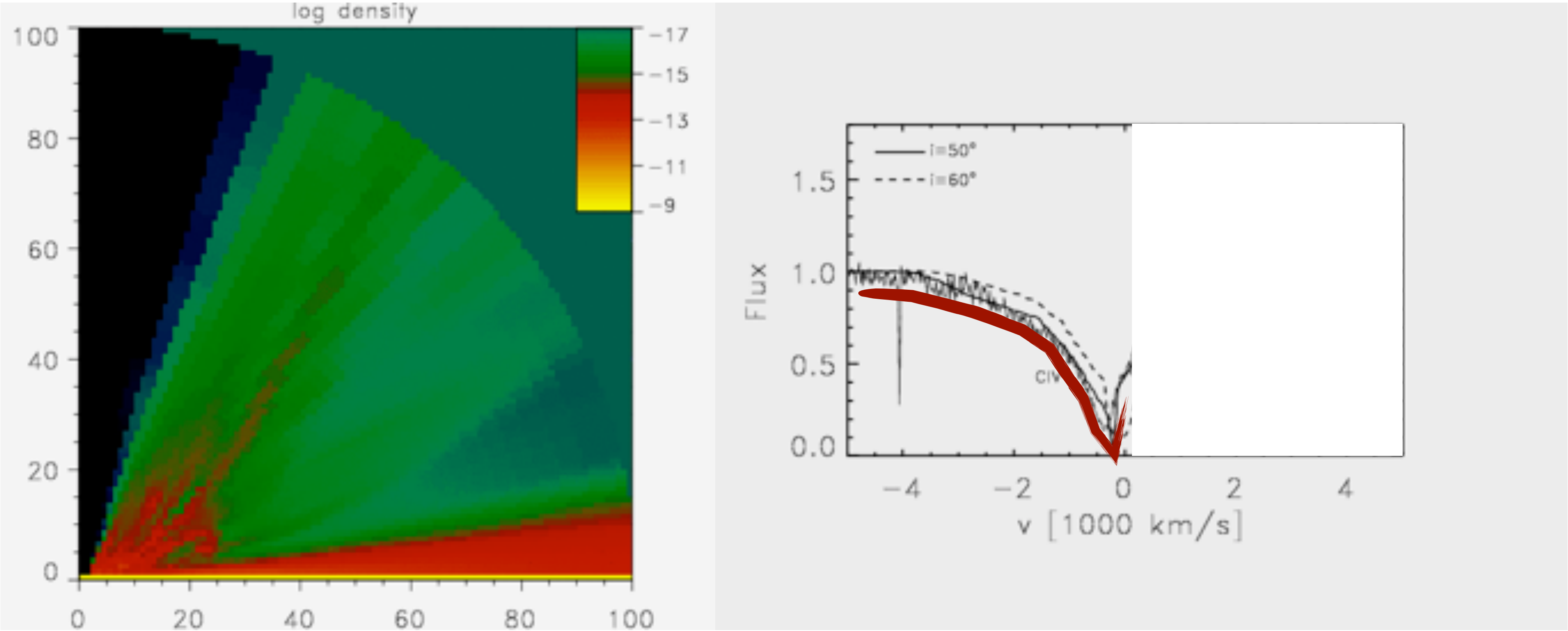

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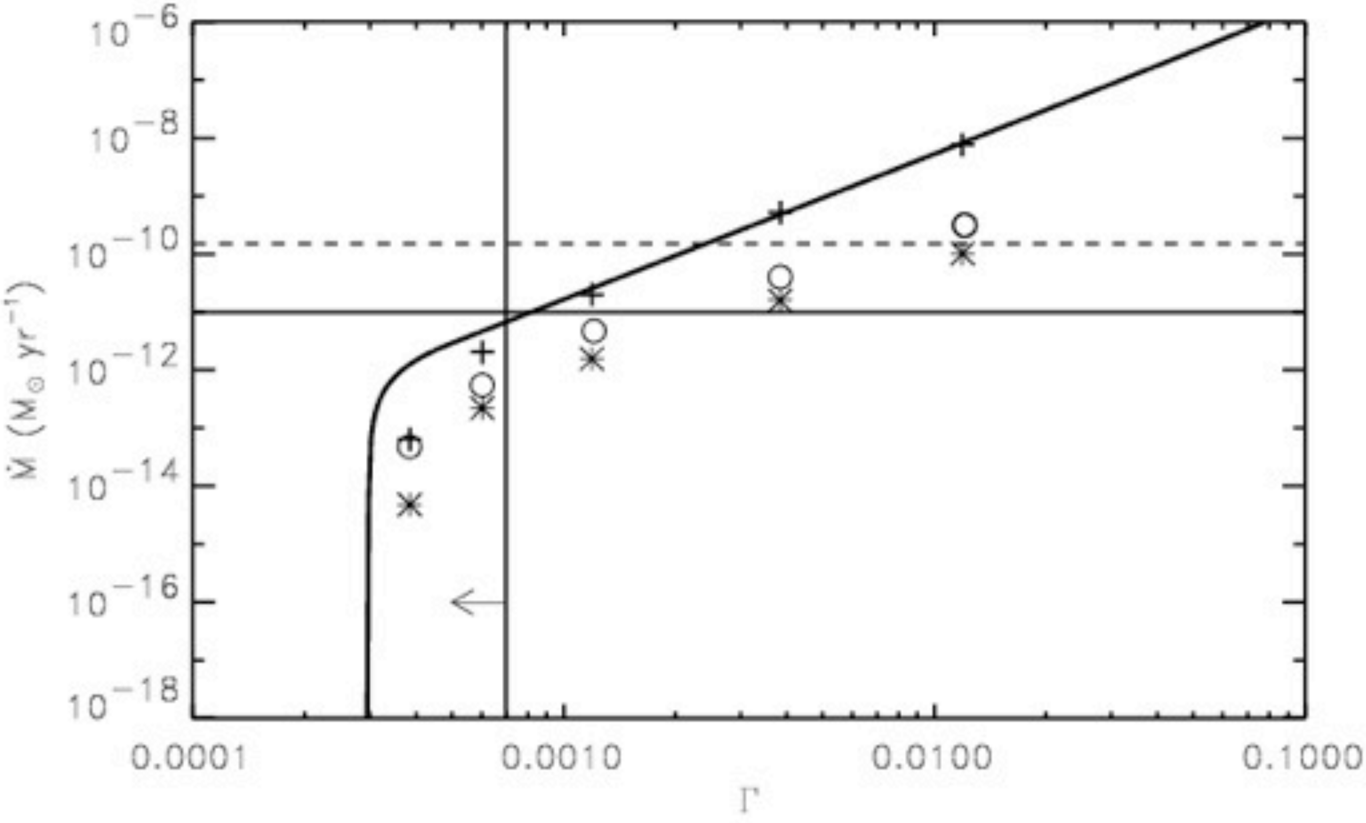
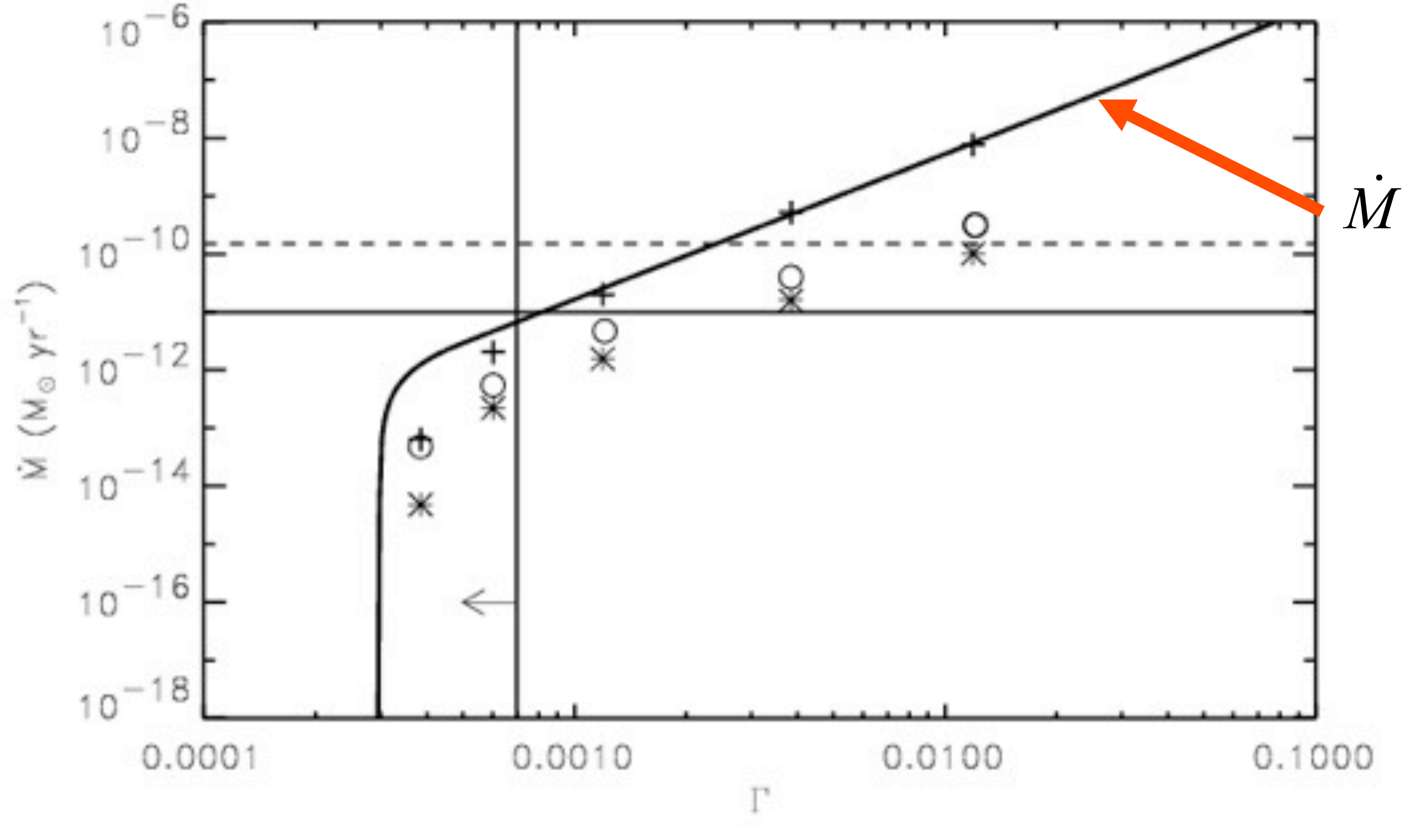


Drew & Proga (1999)

$M_{\max} = 4400, \;\; k = 0.2, \;\; \alpha = 0.6$



$$\dot{M}_a \propto \Gamma^{1/\alpha}$$

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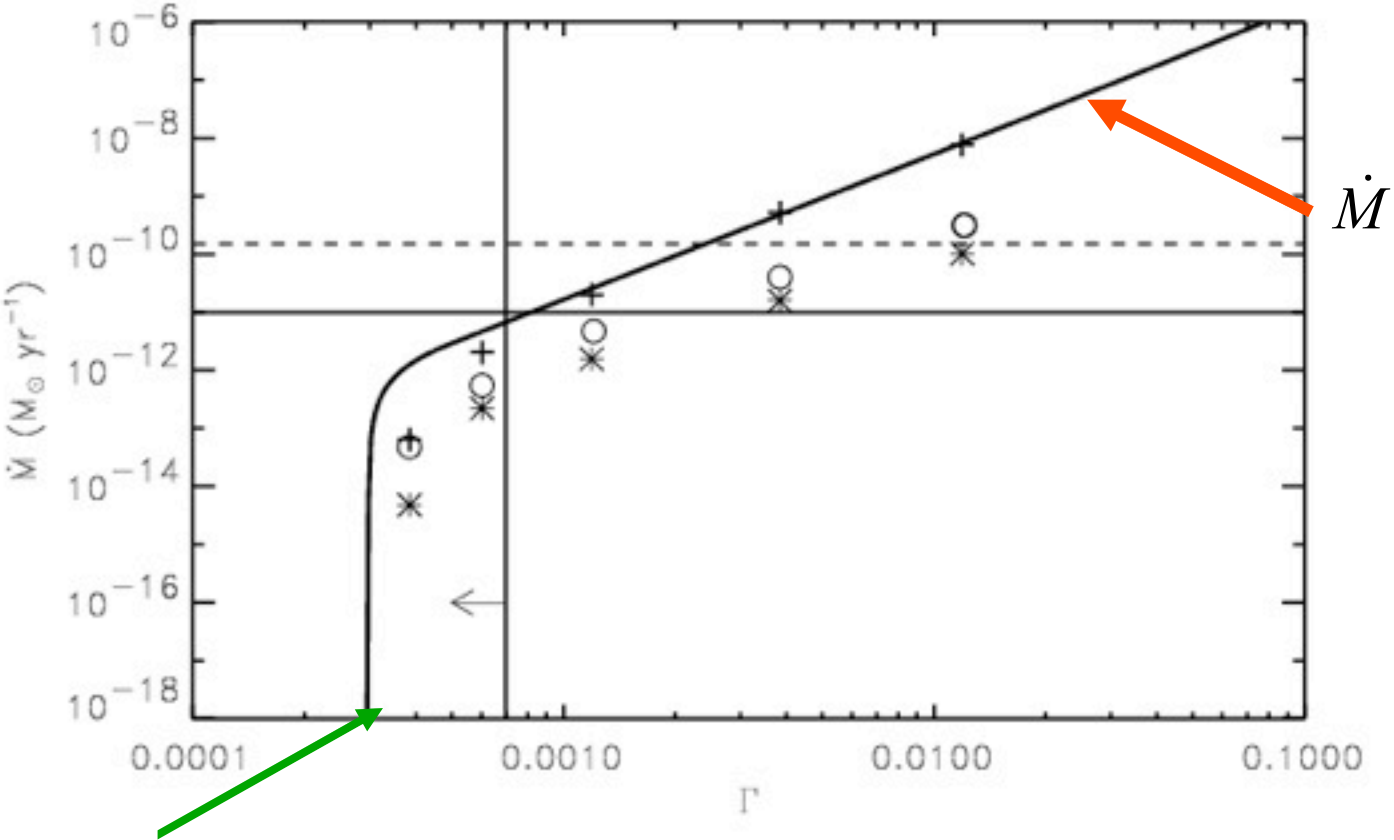

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$\frac{1}{M_{\max}}$

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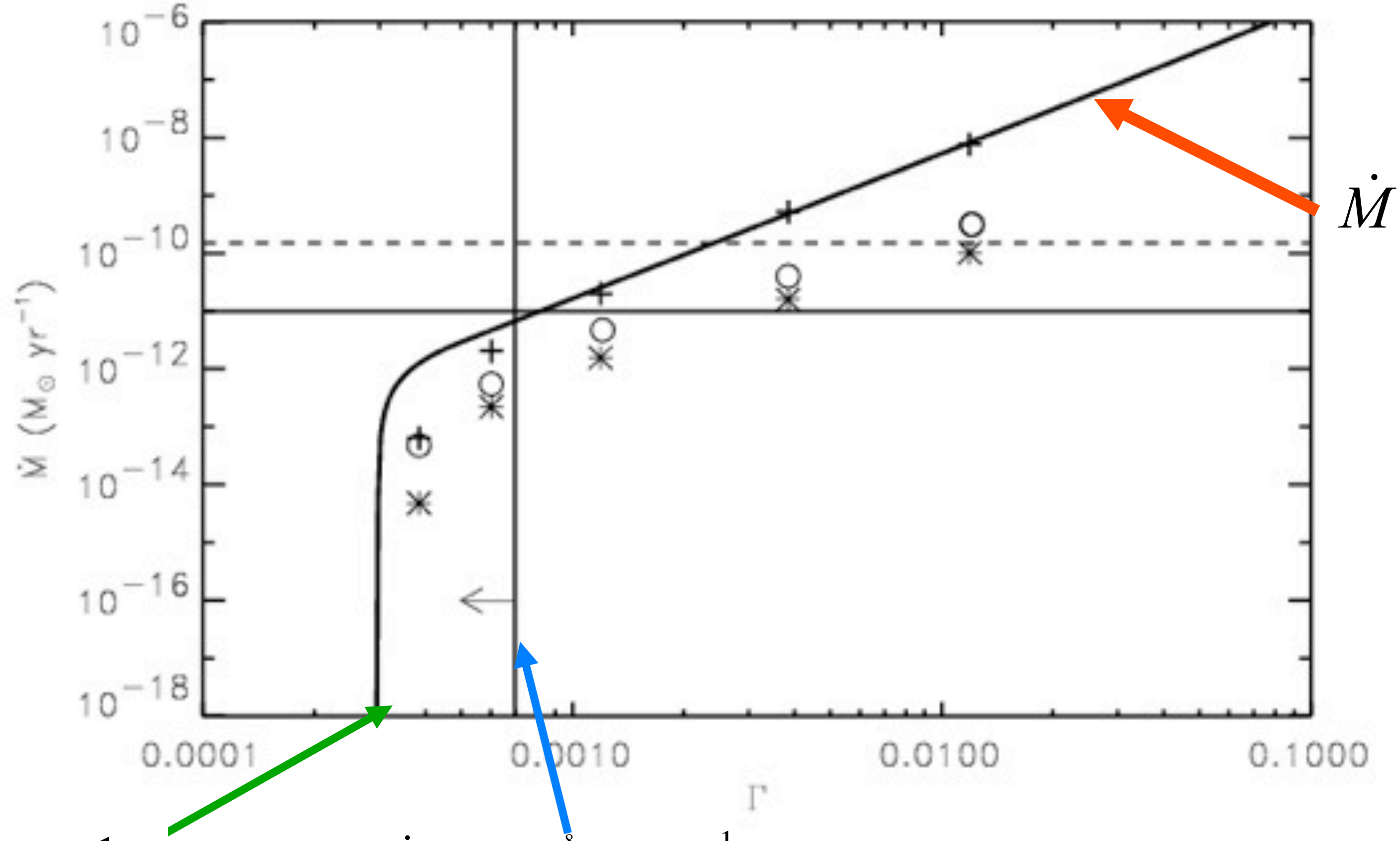

$\dot{M}_a \propto \Gamma^{1/\alpha}$

$\frac{1}{M_{\max}}$

$\dot{M}_a = 1\times10^{-8} M_{Sun}\, yr^{-1}$

$M_{WD} = 1 M_{Sun}$

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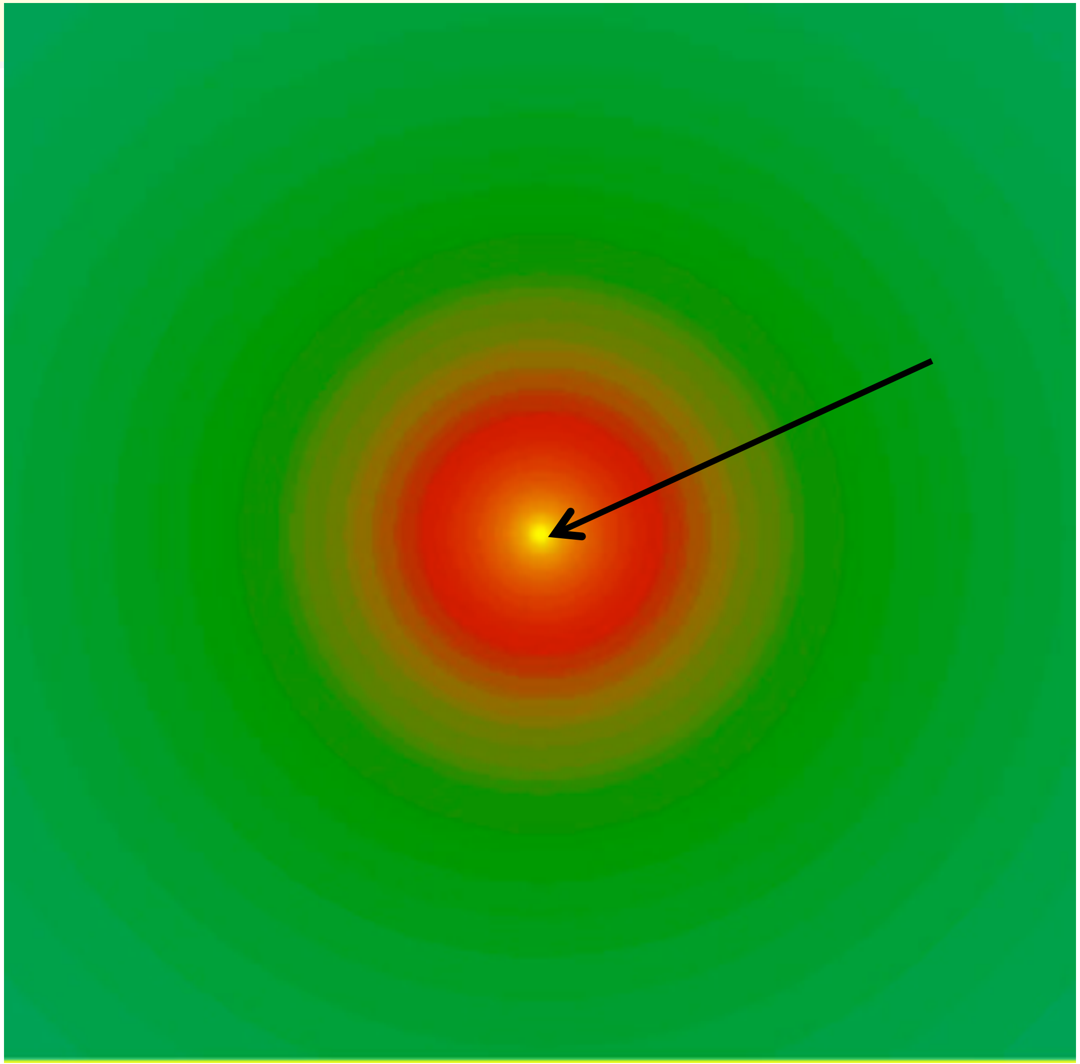
MHD Driven Winds

Black Hole Accretion

Black Hole Accretion



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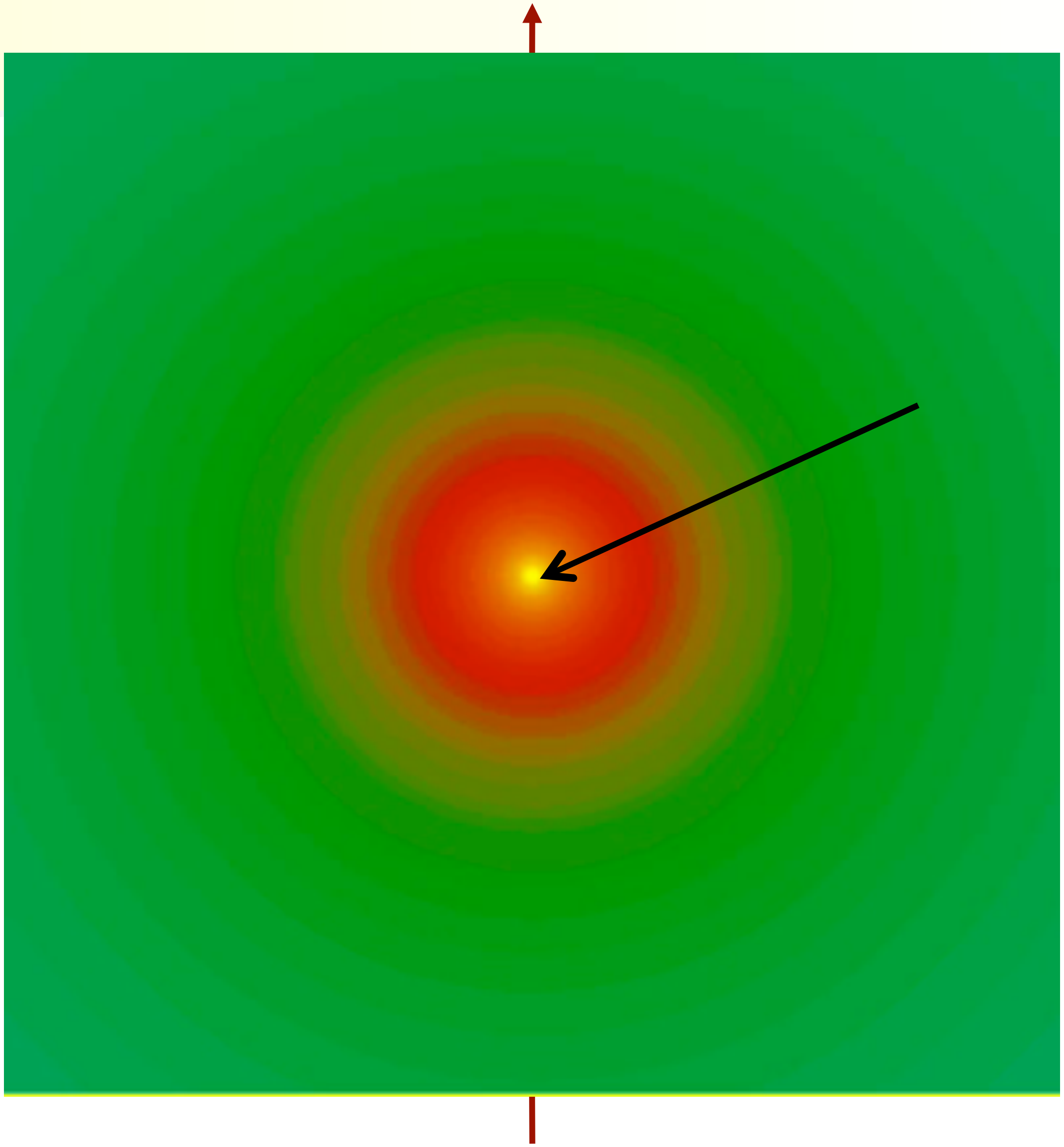
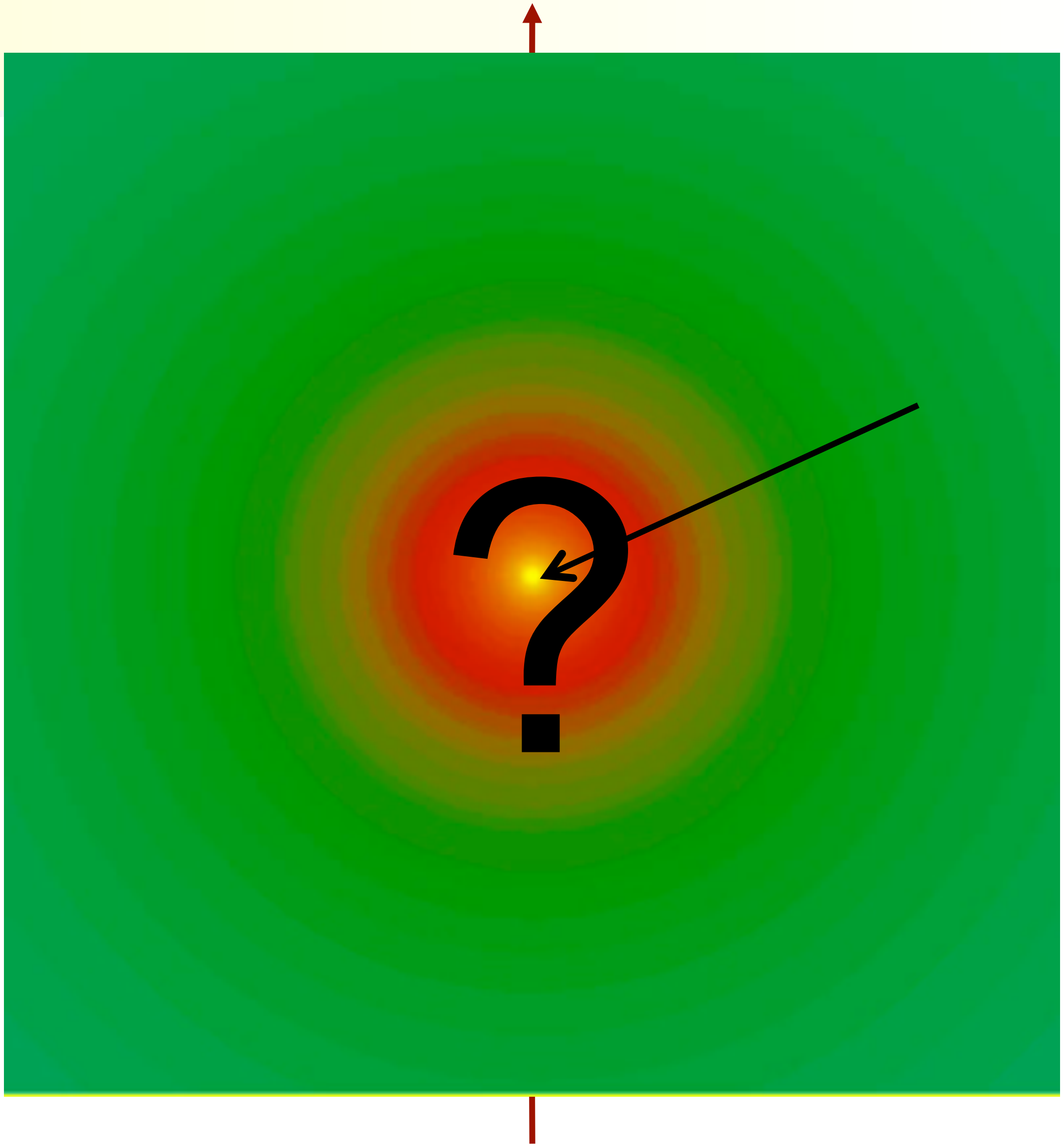


Black Hole Accretion



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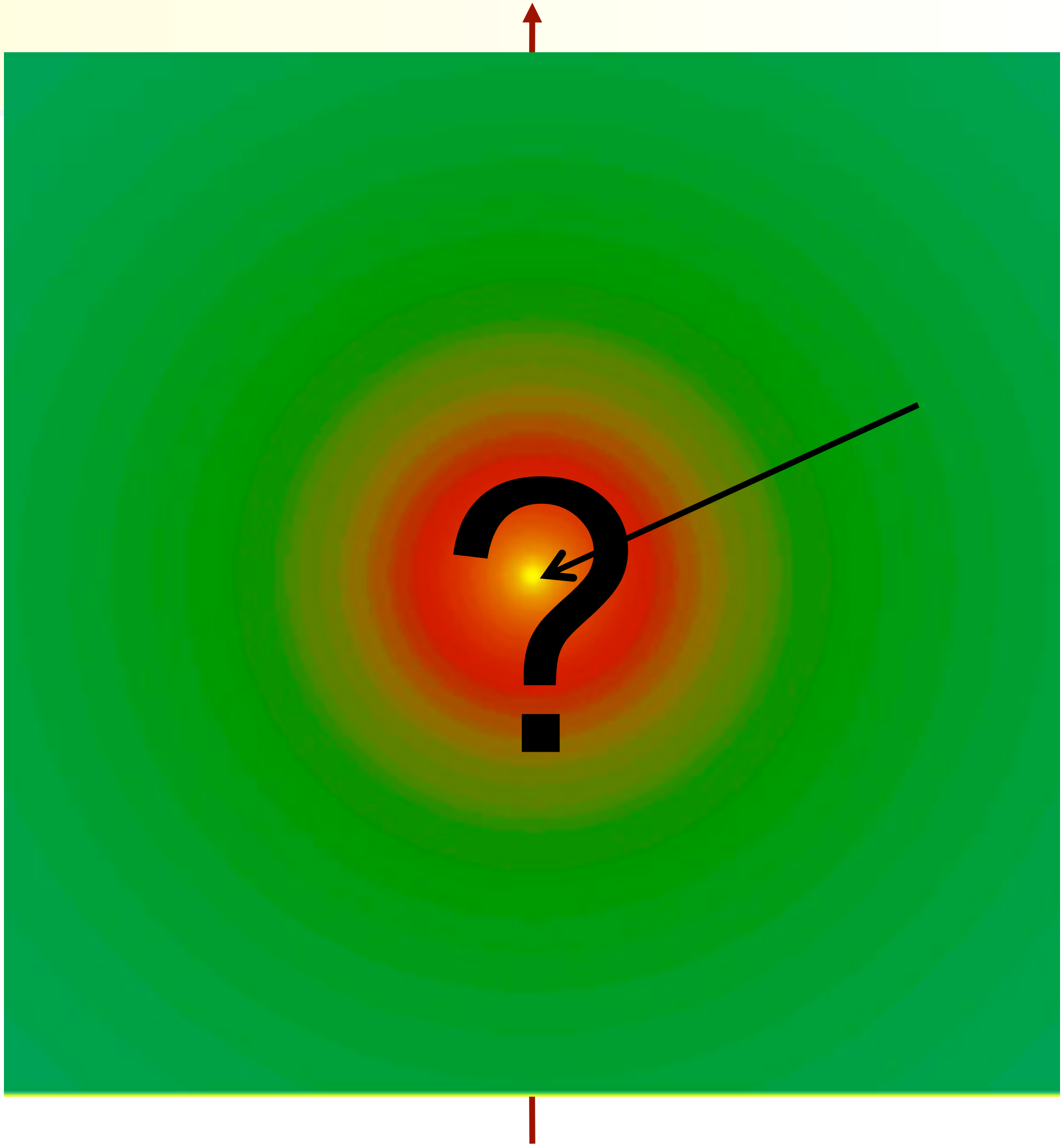

Black Hole Accretion -> Outflow

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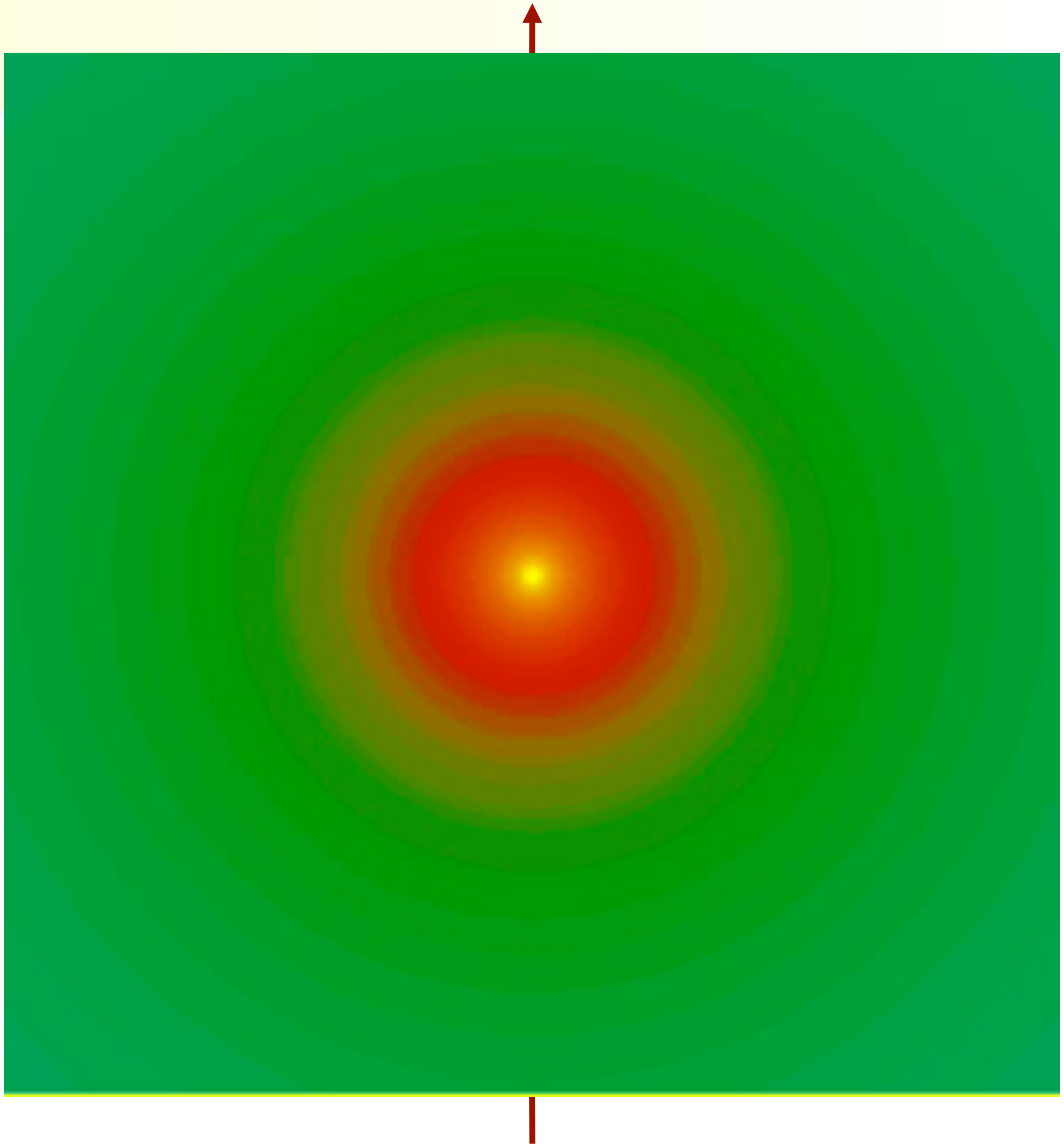
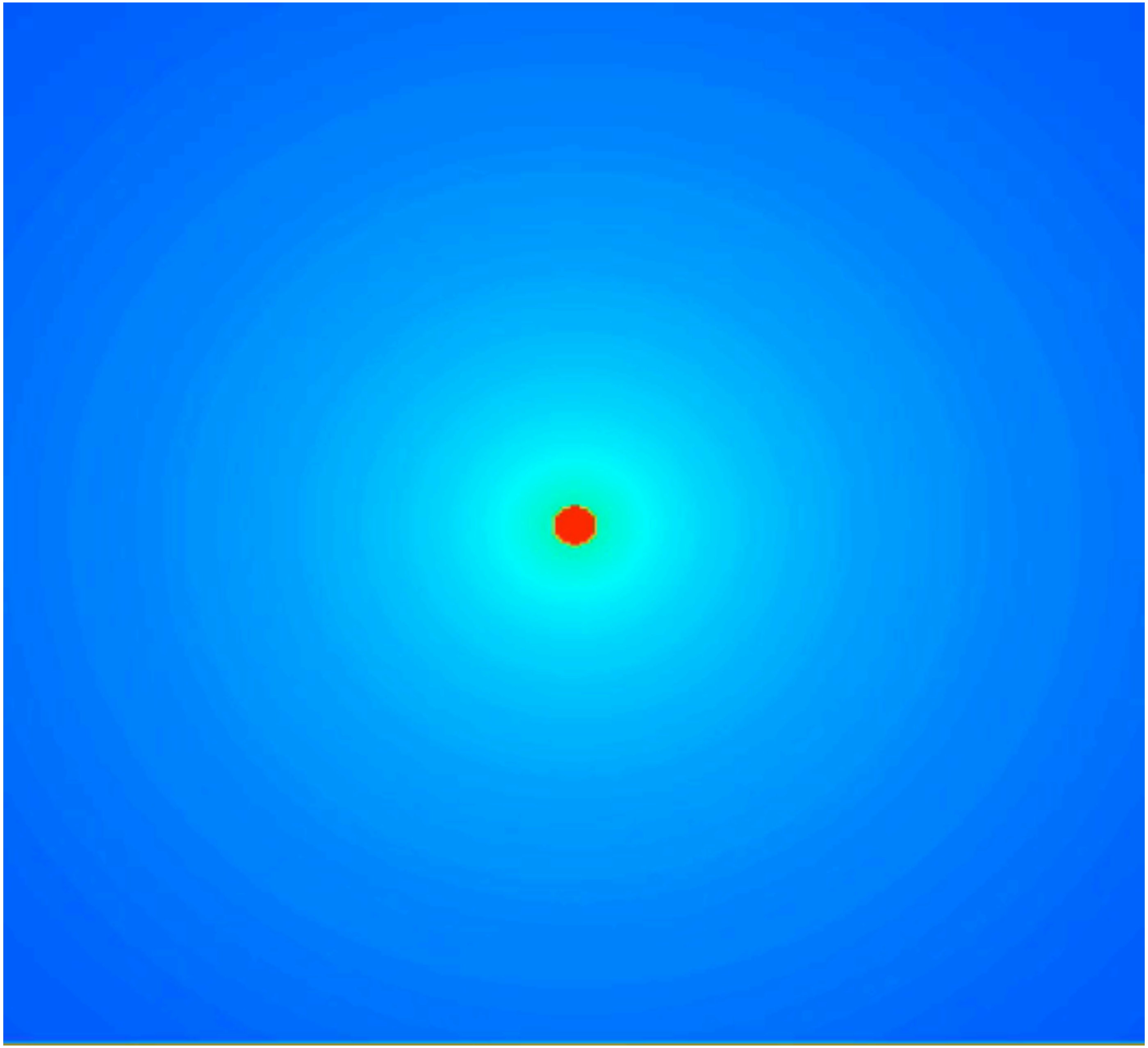
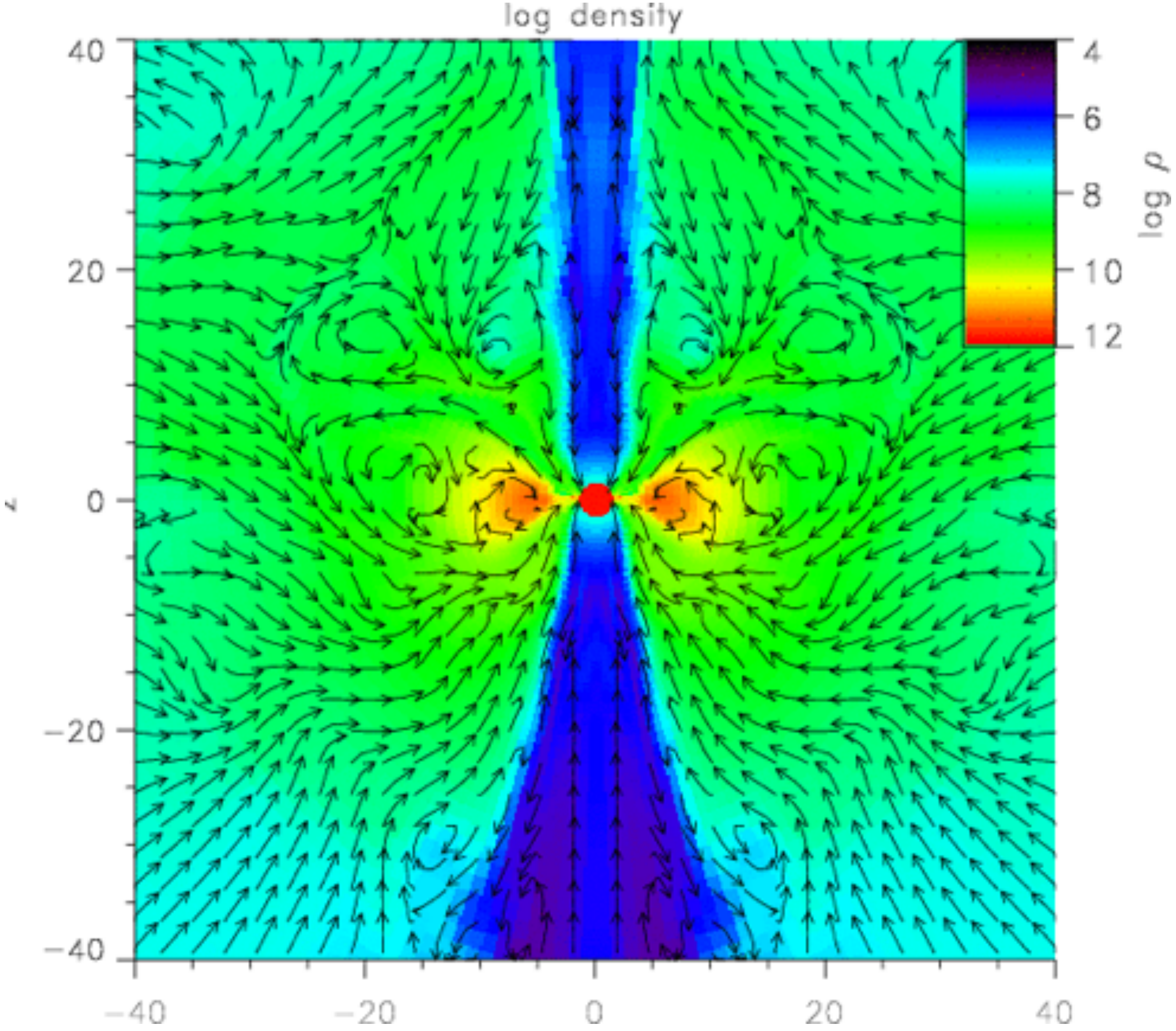




Multi-component flow



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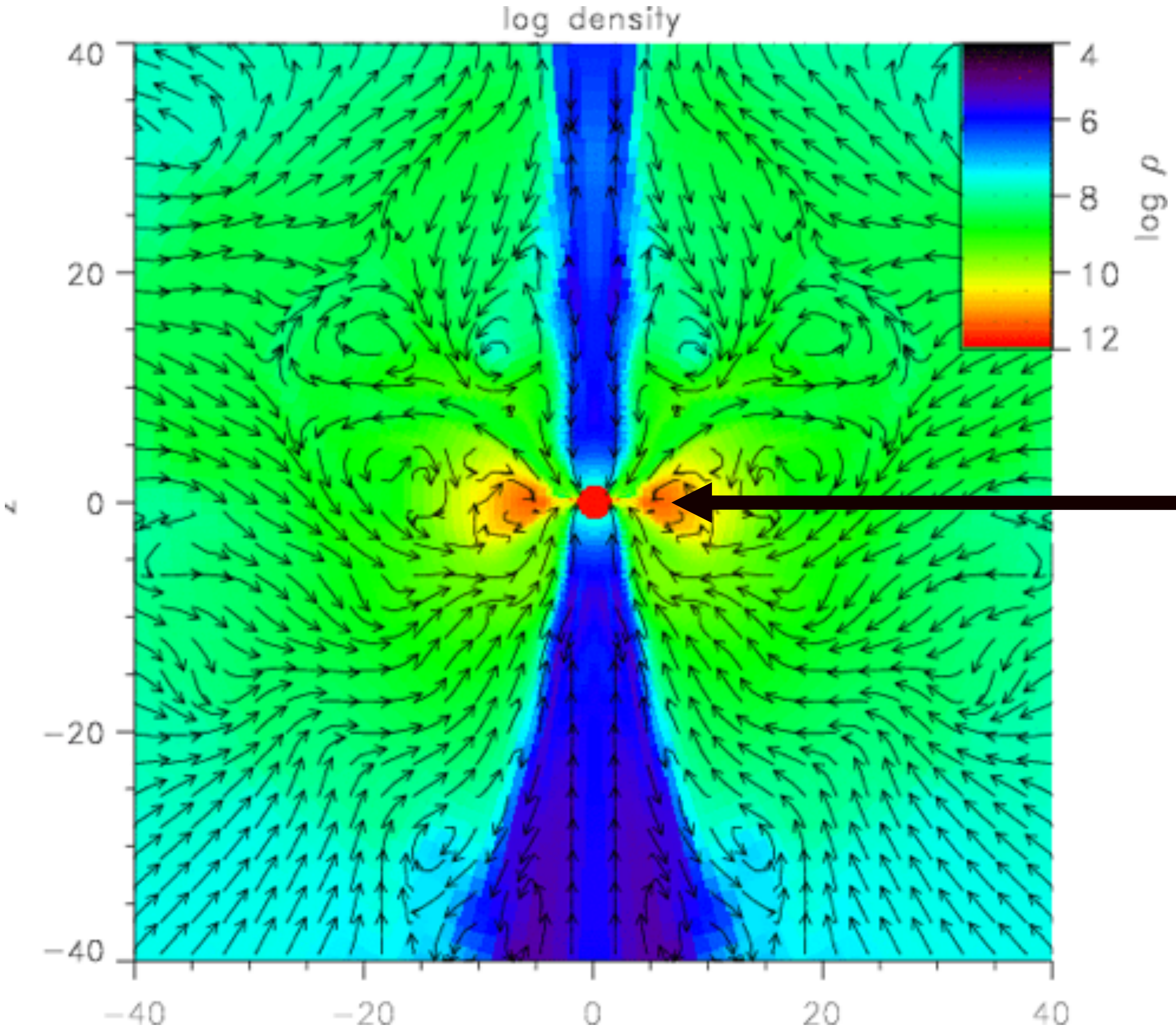
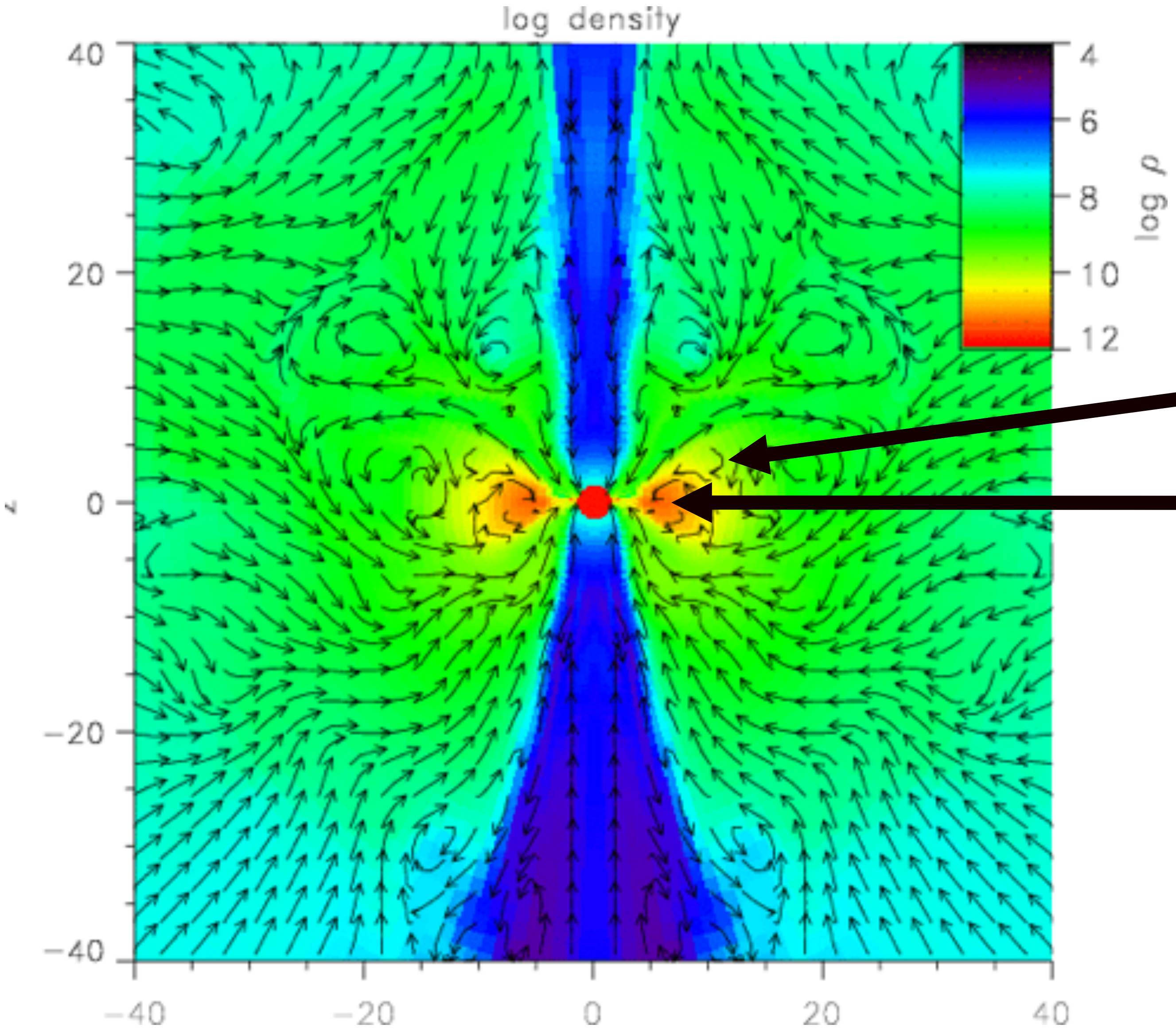


torus

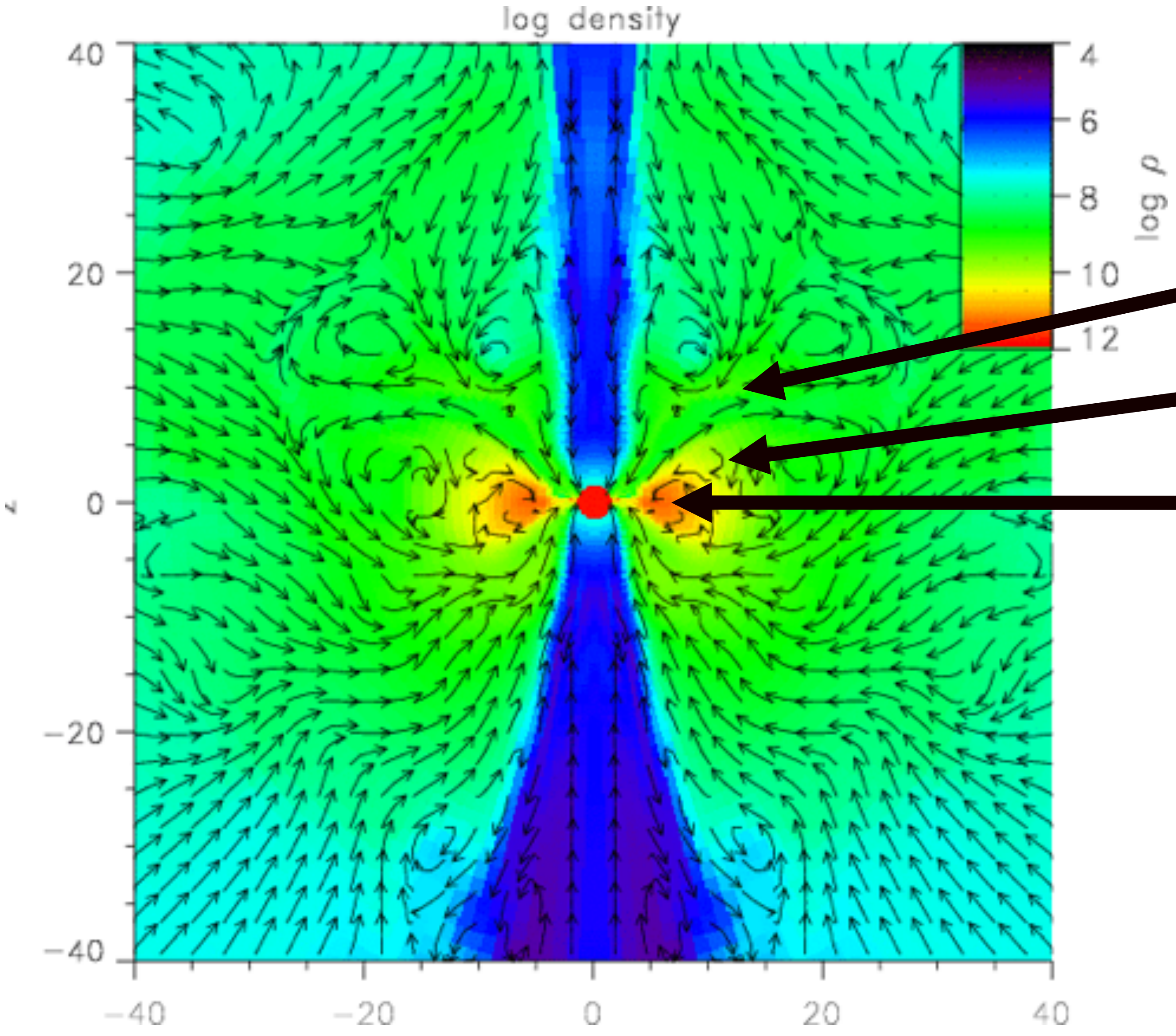
Multi-component flow



torus corona

torus

Multi-component flow

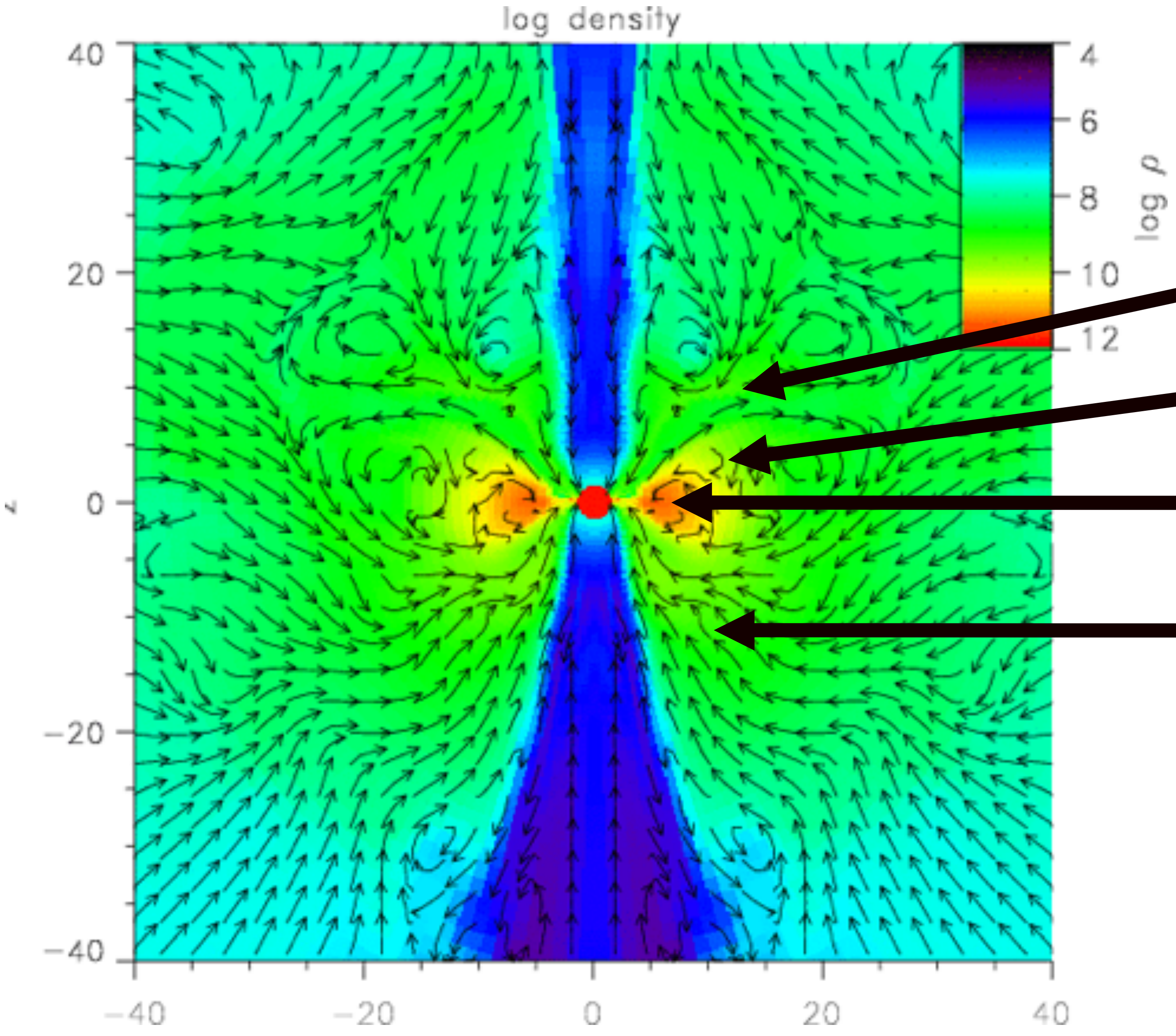


torus wind

torus corona

torus

Multi-component flow



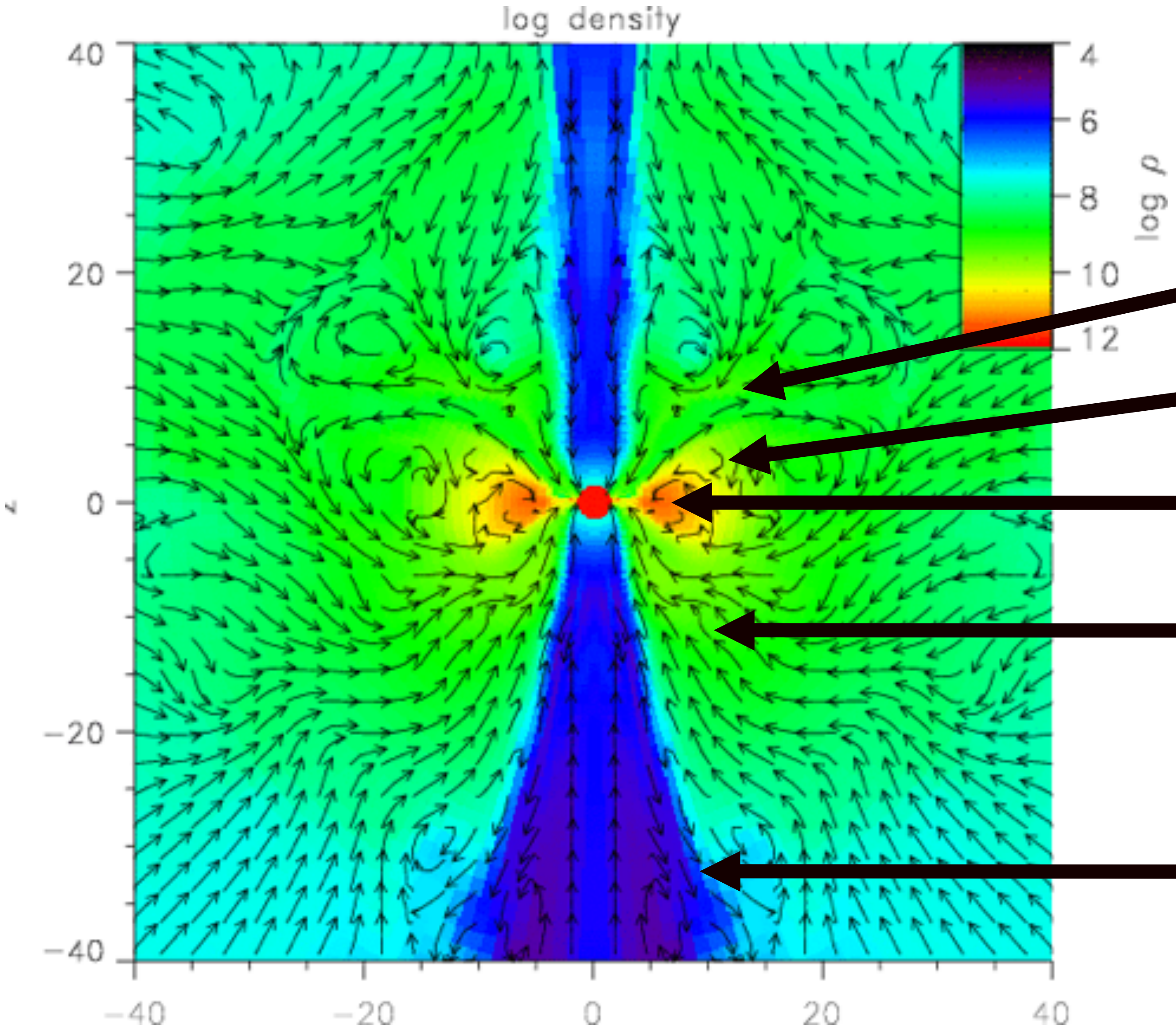
torus wind

torus corona

torus

low l inflow

Multi-component flow



torus wind

torus corona

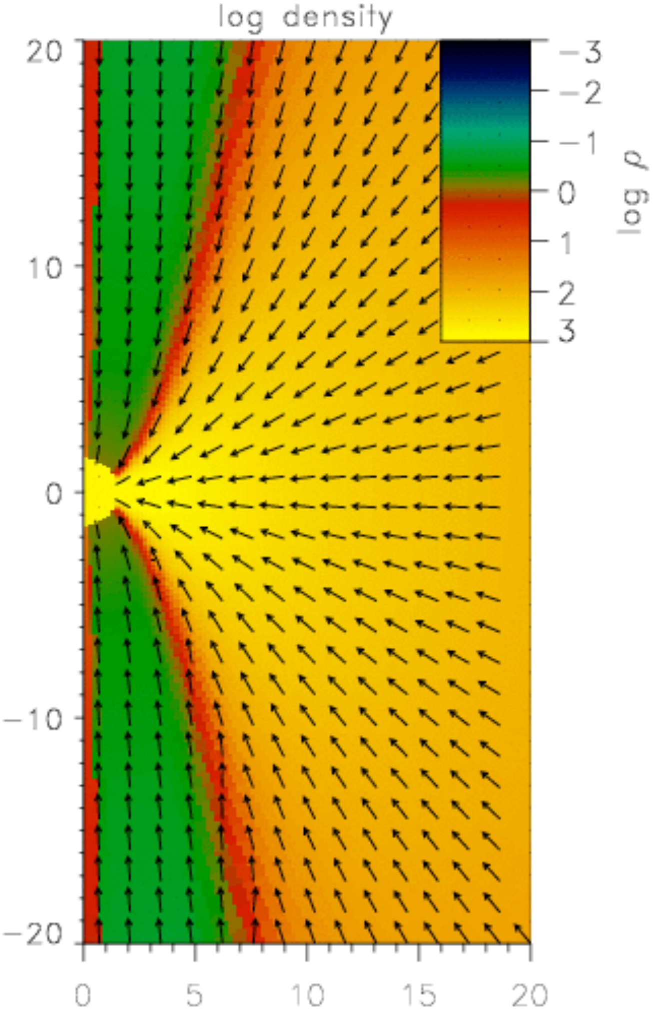
torus

low l inflow

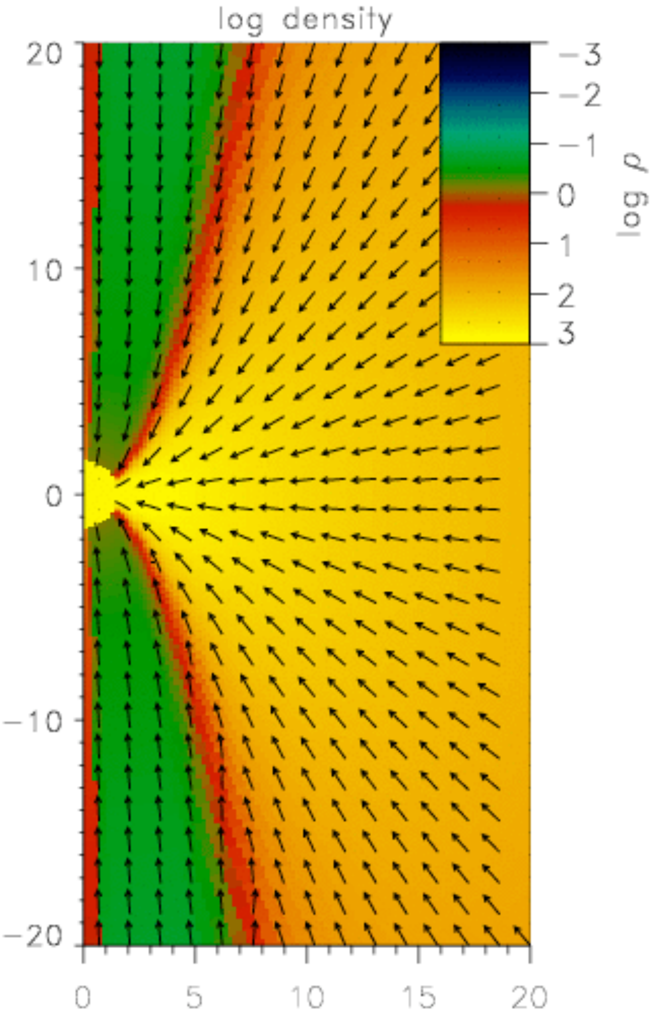
outflow/jet

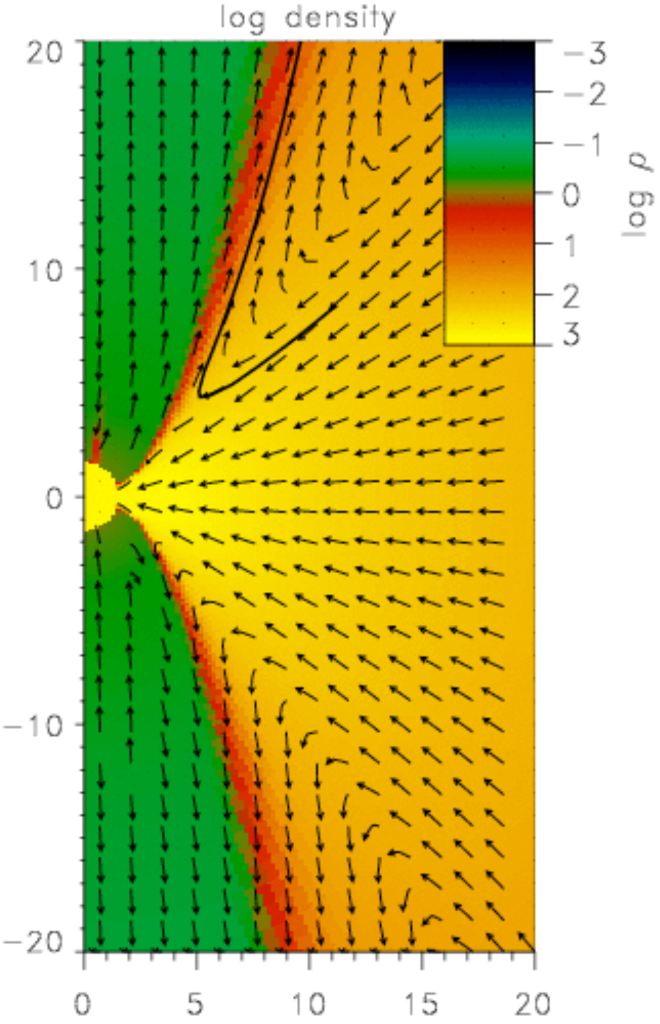
Does it have to be so complex?

Does it have to be so complex?

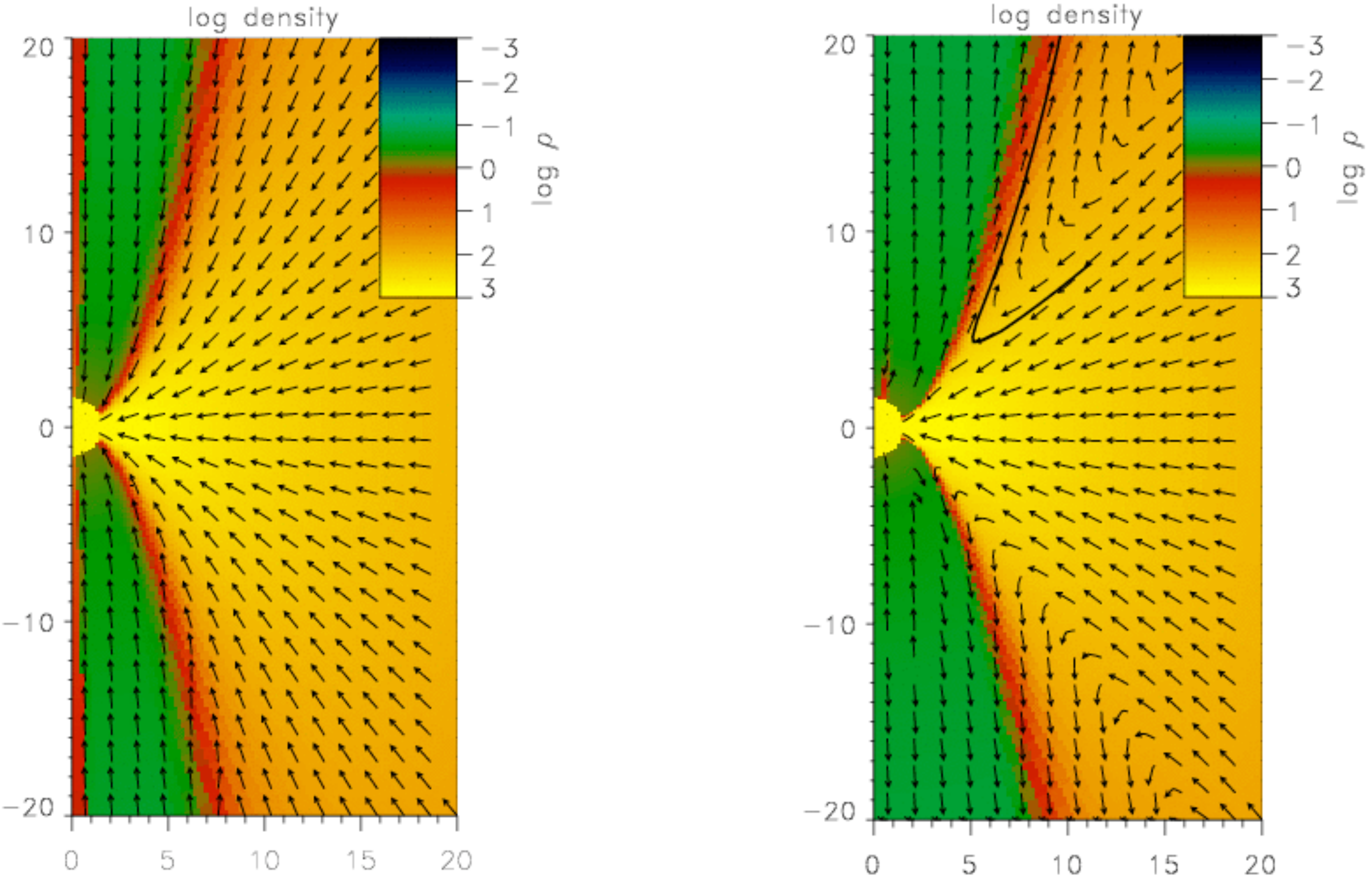


Does it have to be so complex?



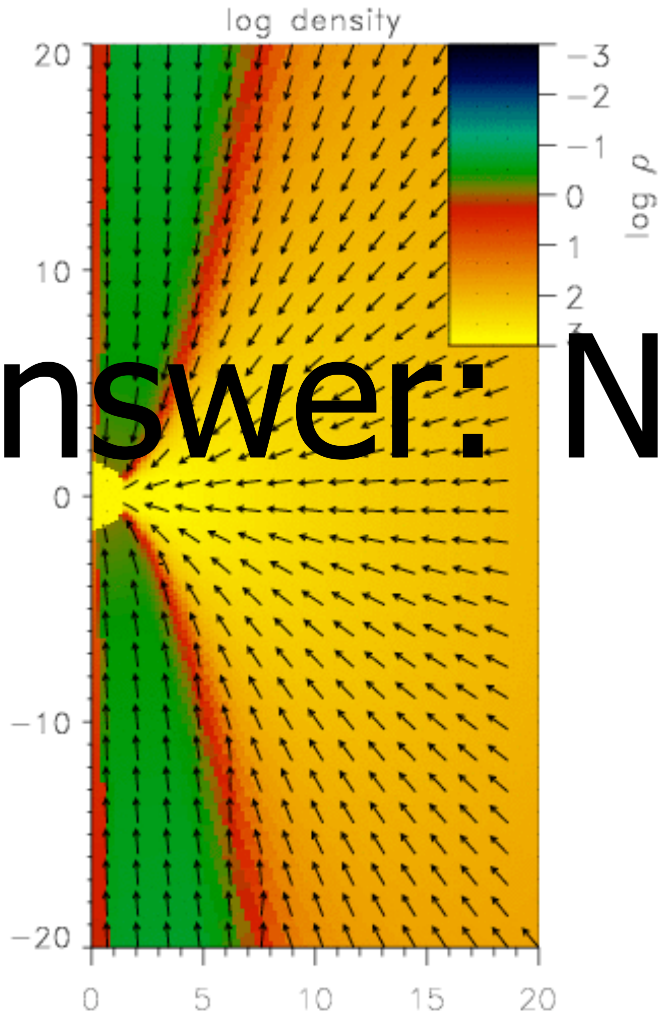


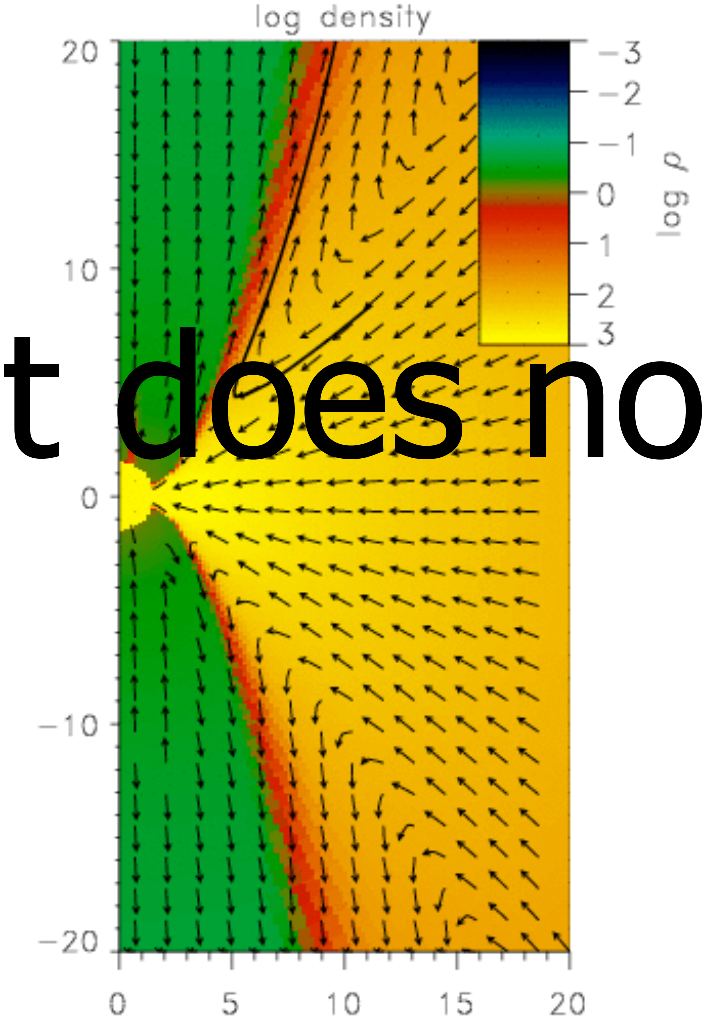
Does it have to be so complex?



Proga (2005)

Does it have to be so complex?





Answer: No, it does not.

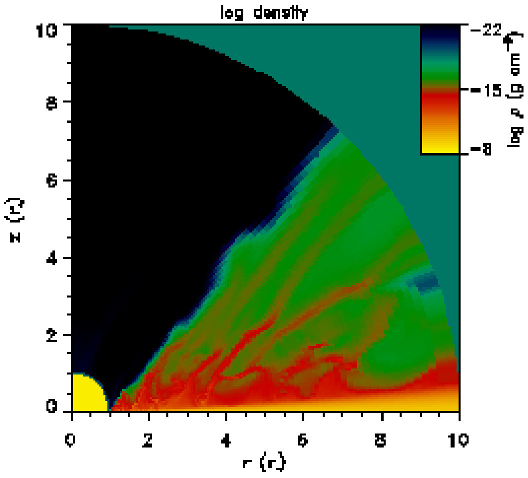
Proga (2005)

MHD and Radiation Driven Winds

MHD-LD Disk Winds

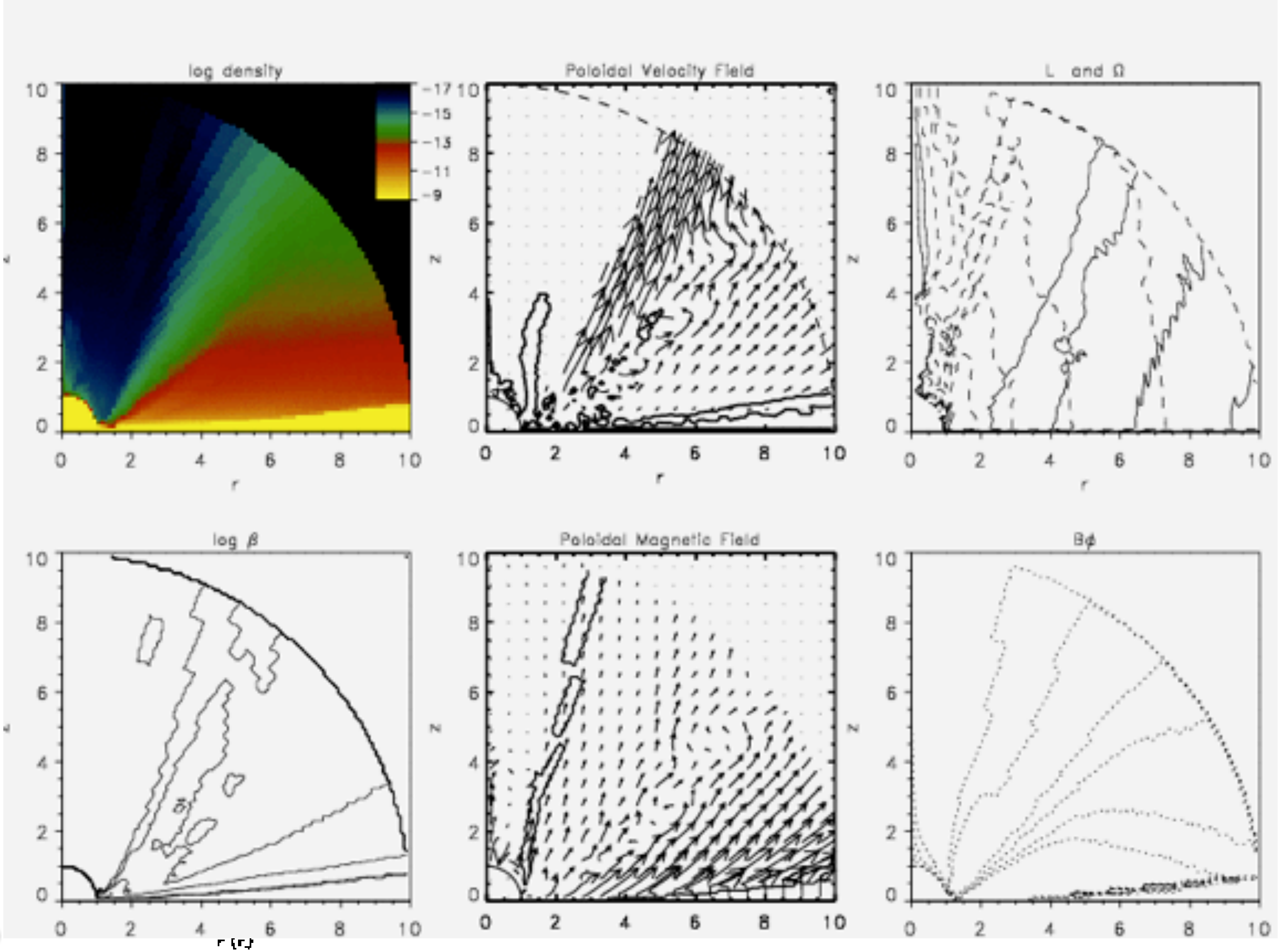
DP (2003a)

MHD-LD Disk Winds



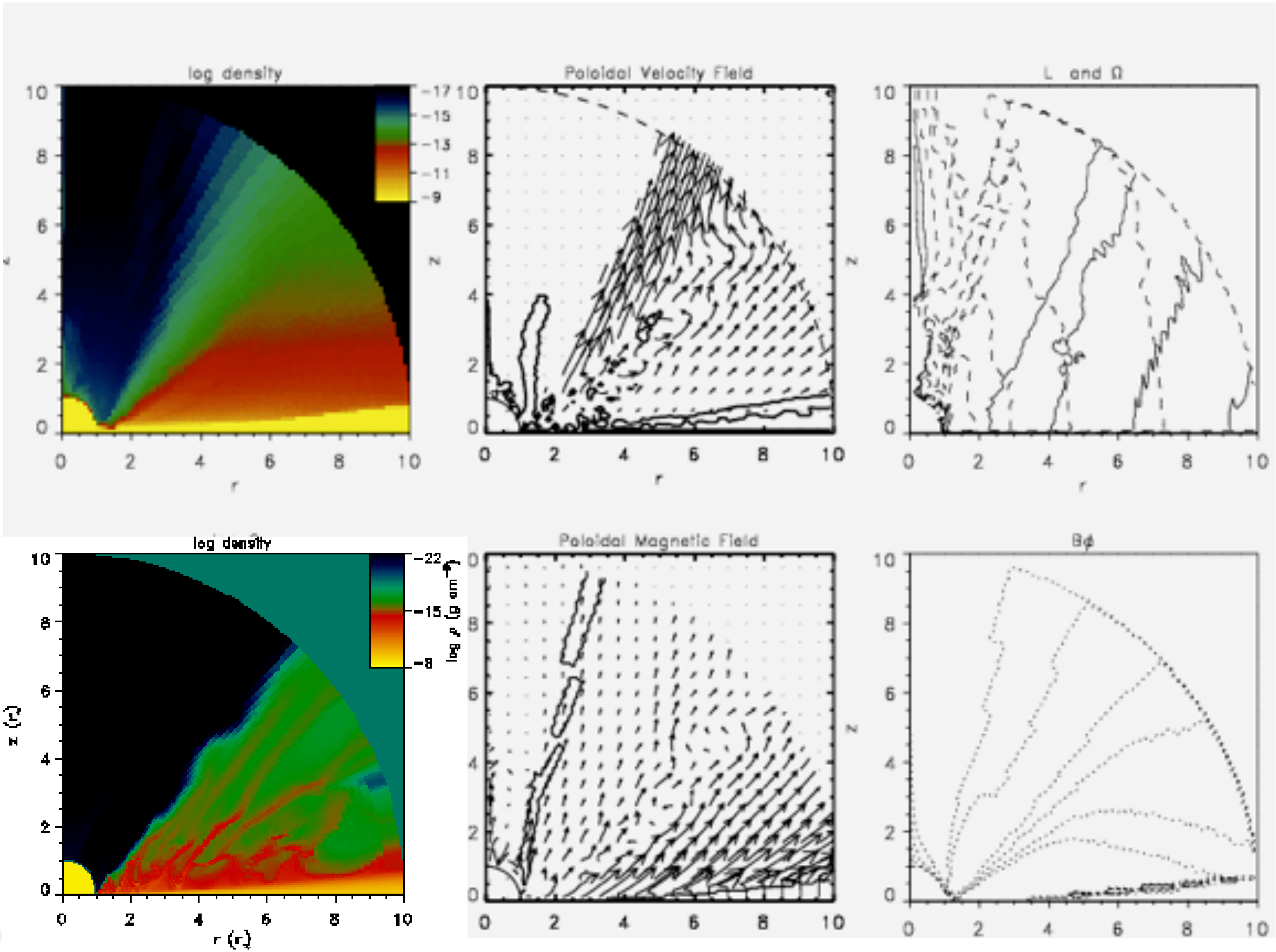
DP (2003a)

MHD-LD Disk Winds



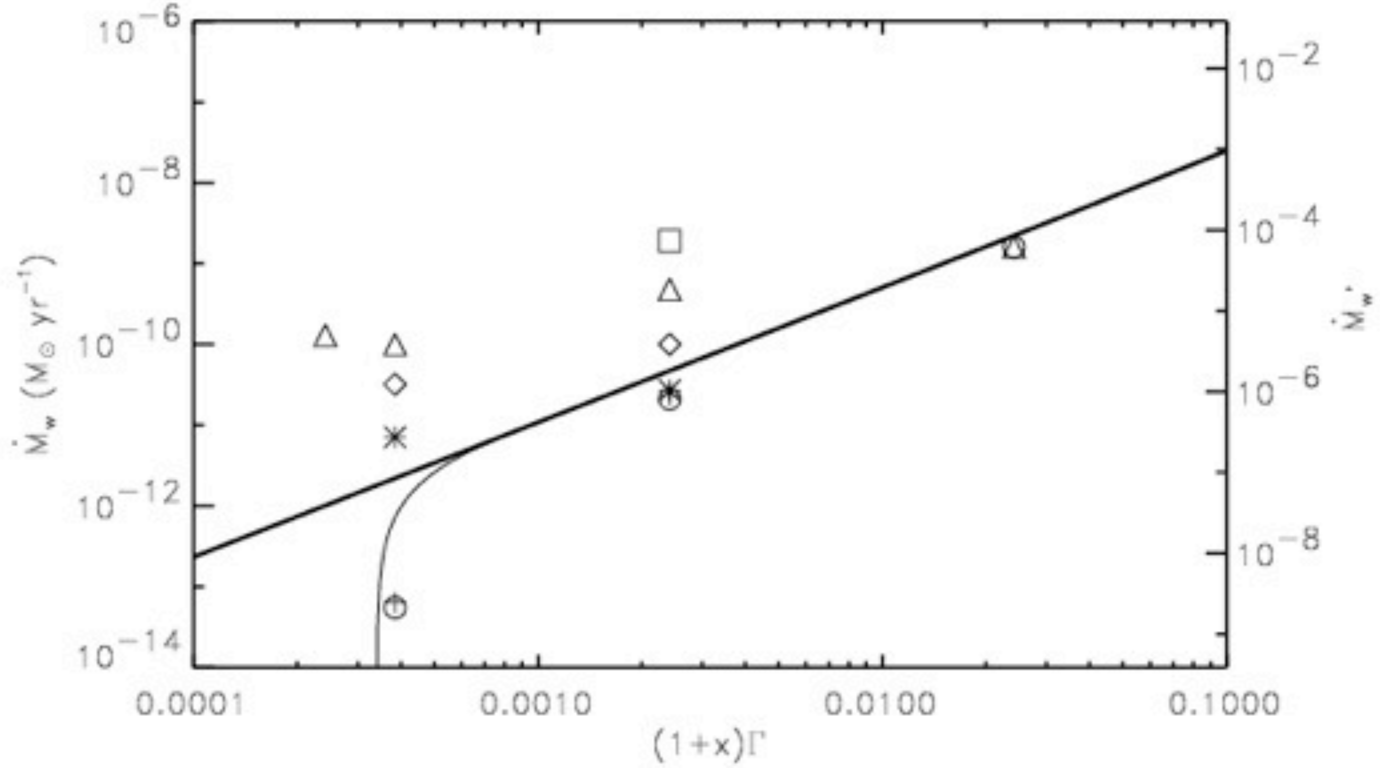
DP (2003a)

MHD-LD Disk Winds

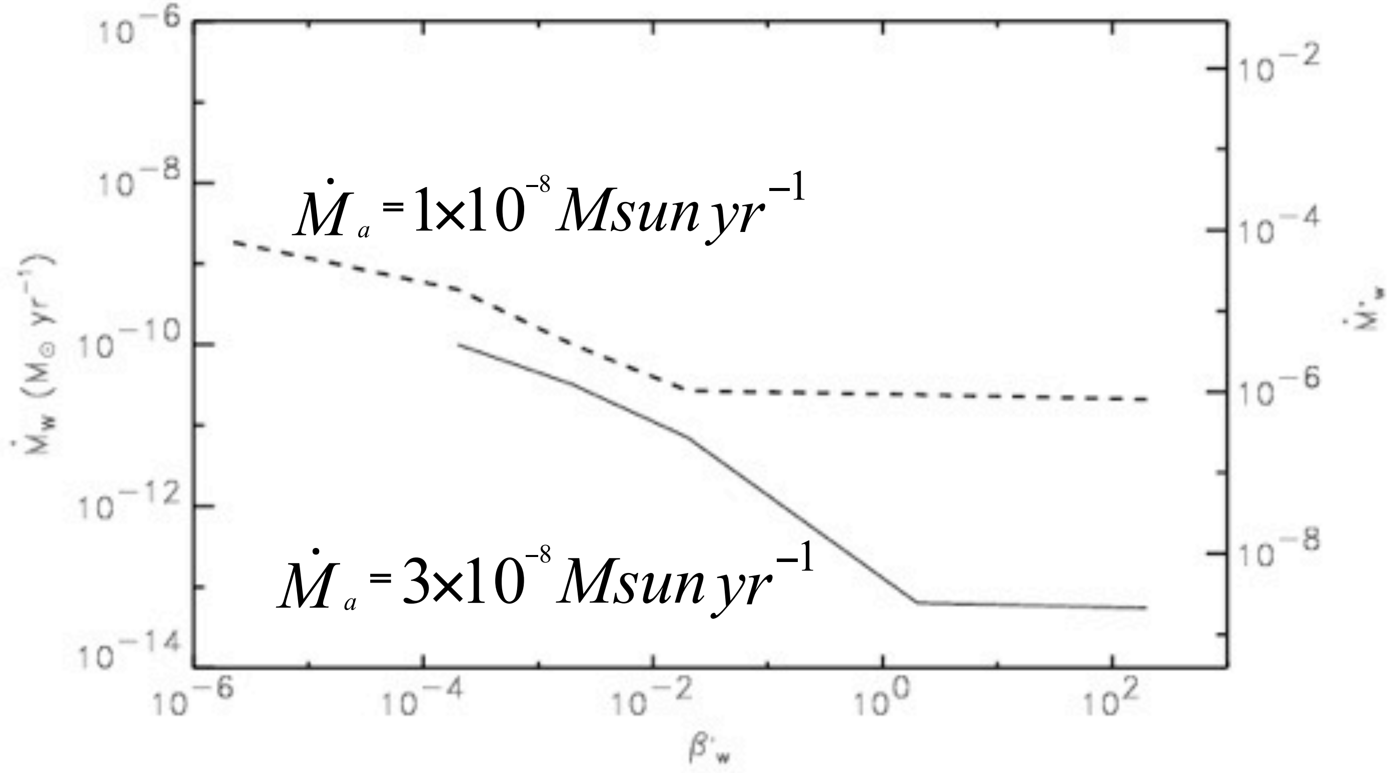


DP (2003a)

The mass loss rate in MHD-LD winds.



The mass loss rate in MHD-LD winds.



$\dot{M}_a = 1\times10^{-8}\,Msun\,yr^{-1}$

$\dot{M}_a = 3\times10^{-8}\,Msun\,yr^{-1}$

Thermal and Radiation-Driven Winds

The equations of hydrodynamics

$$\frac{D\rho}{Dt} + \rho \nabla \cdot v = 0$$

$$\rho \frac{Dv}{Dt} = -\nabla P + \rho g$$

$$\rho \frac{D}{Dt}\left(\frac{e}{\rho}\right) = -P \nabla \cdot v$$

$$P = (\gamma - 1)e$$

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The equations of hydrodynamics

$$\frac{D\rho}{Dt} + \rho \nabla \cdot v = 0$$

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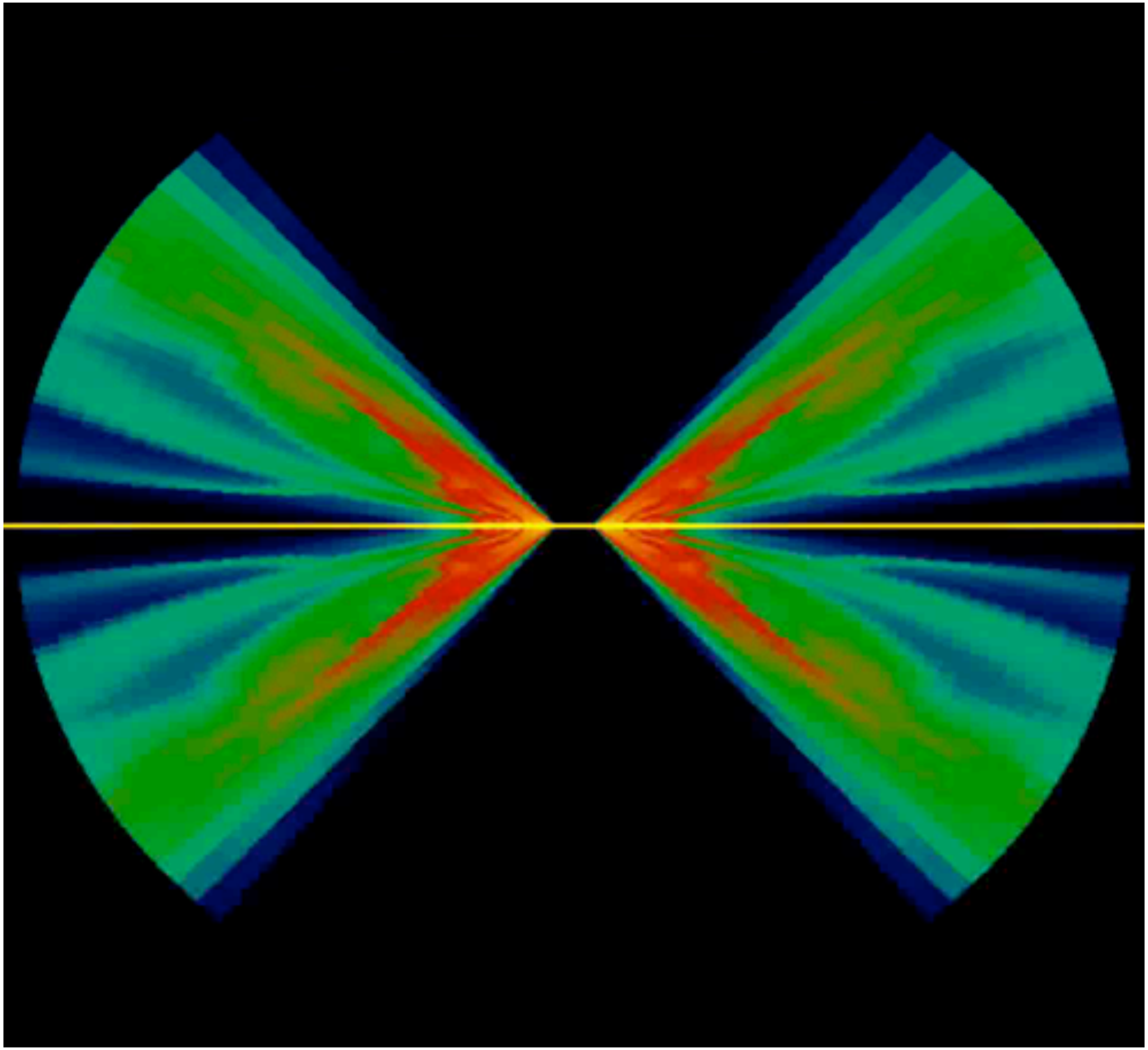
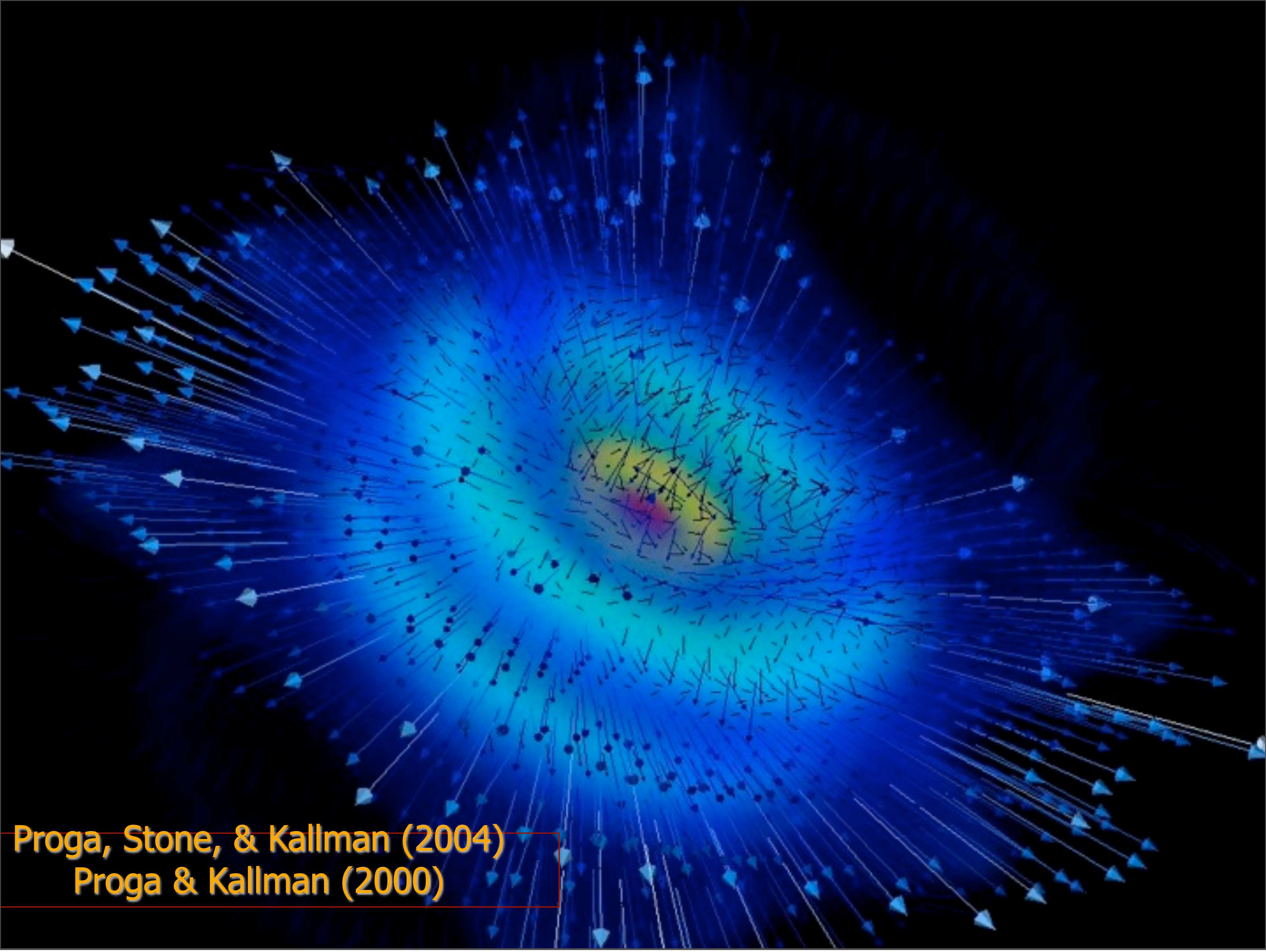
$$\rho \frac{D}{Dt}\left(\frac{e}{\rho}\right) = -P \nabla \cdot v + \underline{\rho L}$$

$$P = (\gamma - 1)e$$

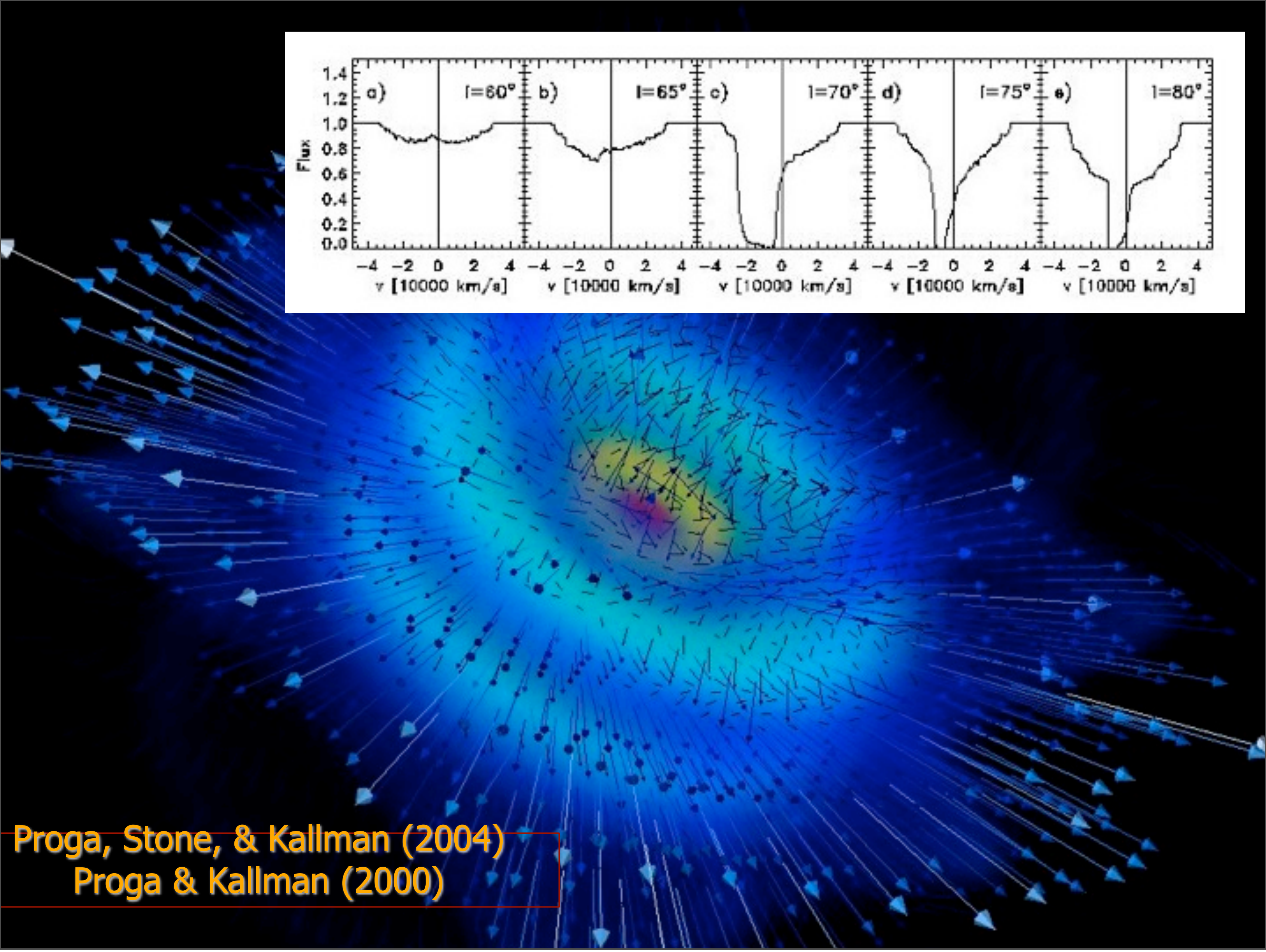


$M_{BH} = 10^8 Msun$

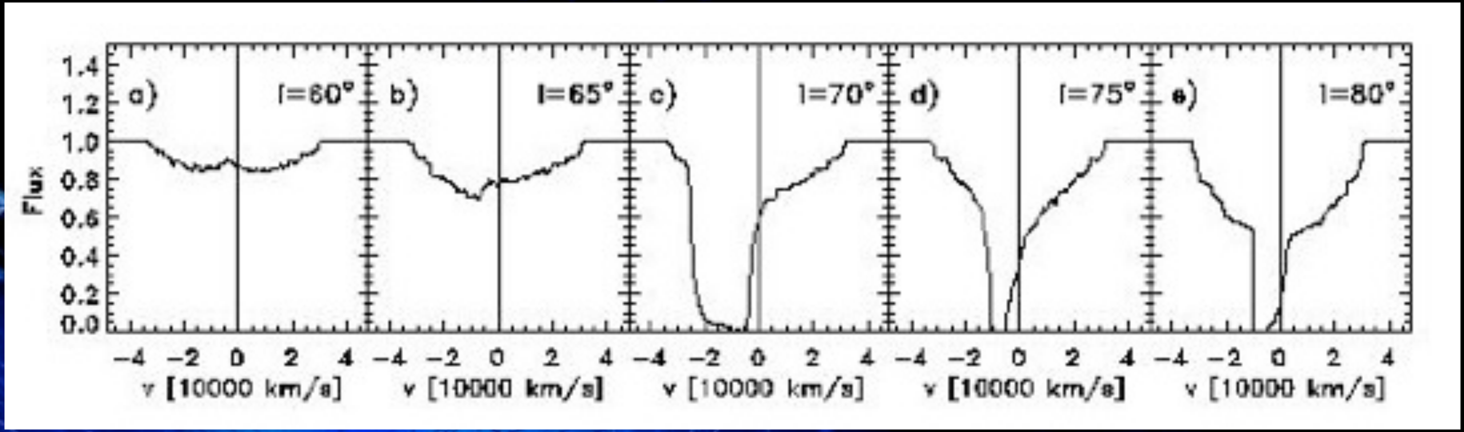
$\Gamma = 0.6$

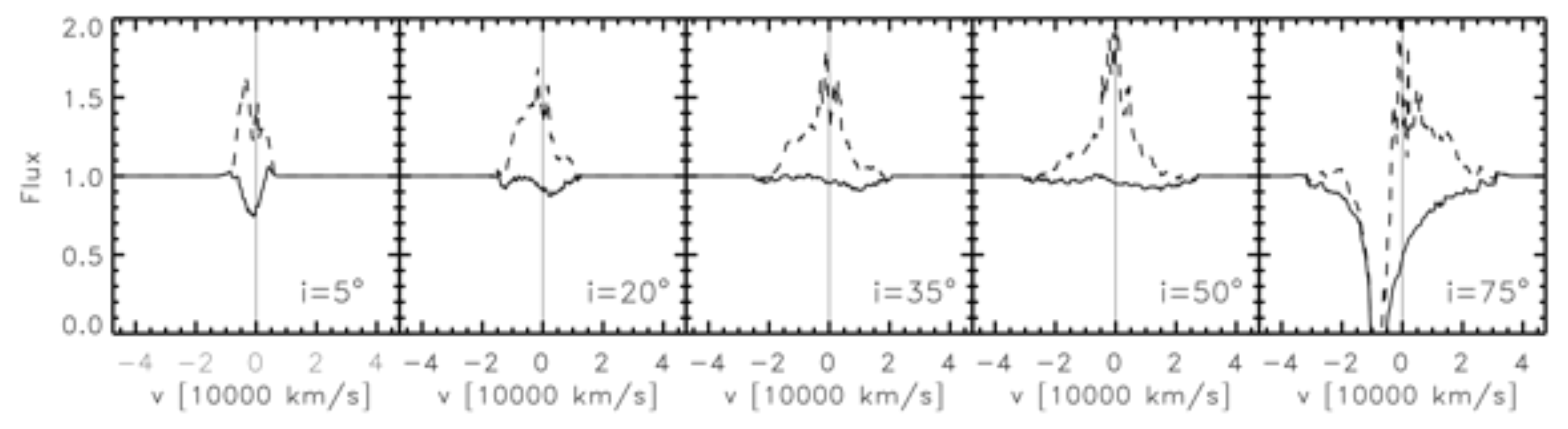


Proga, Stone, & Kallman (2004)
Proga & Kallman (2000)



Proga, Stone, & Kallman (2004)
Proga & Kallman (2000)





Proga, Stone, & Kallman (2004)
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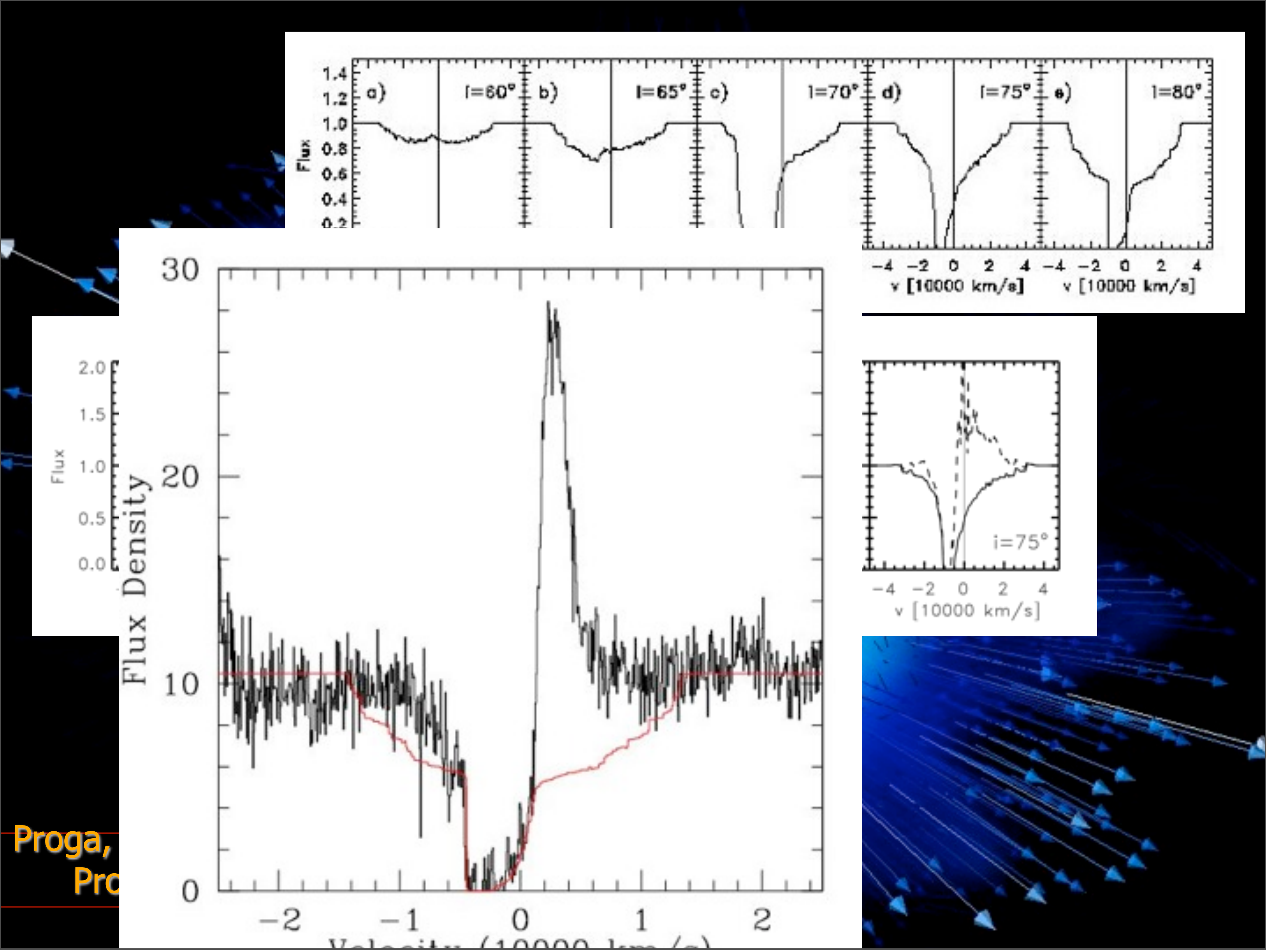

1.4
1.2
1.0
0.8
0.6
0.4
0.2
Flux
a)
i=60°
b)
i=65°
c)
i=70°
d)
i=75°
e)
i=80°
−4 −2 0 2 4
v [10000 km/s]
2.0
1.5
1.0
0.5
0.0
Flux
i=75°
30
20
10
0
Flux Density
−2
−1
0
1
2

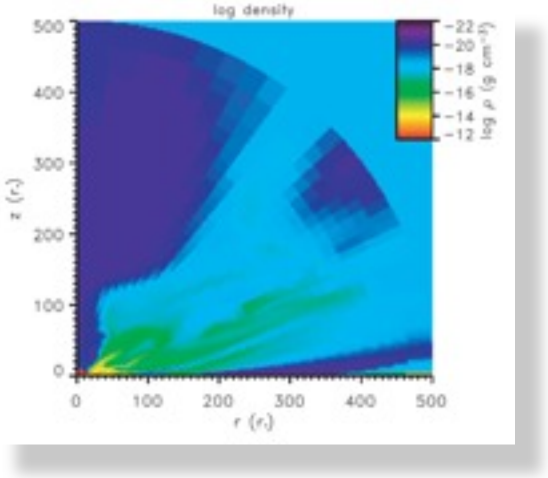
Proga,

Pro

Broad band spectra for various l.o.s.

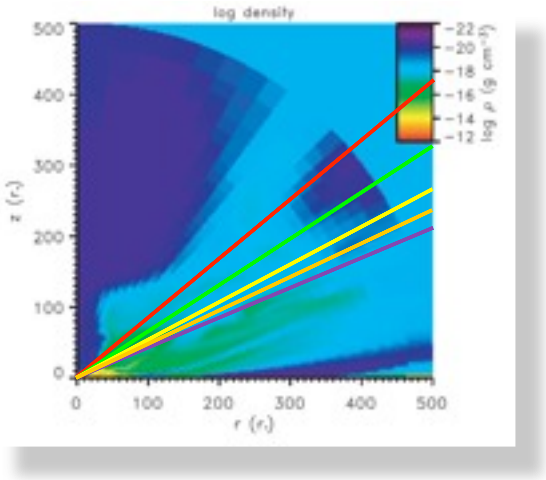
Schurch, Done, & Proga (2009)

Broad band spectra for various l.o.s.



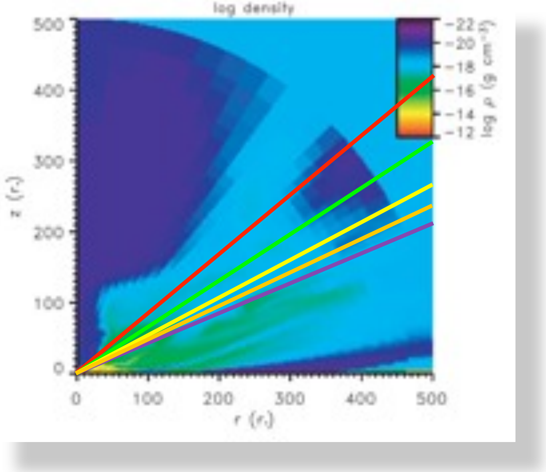
Schurch, Done, & Proga (2009)

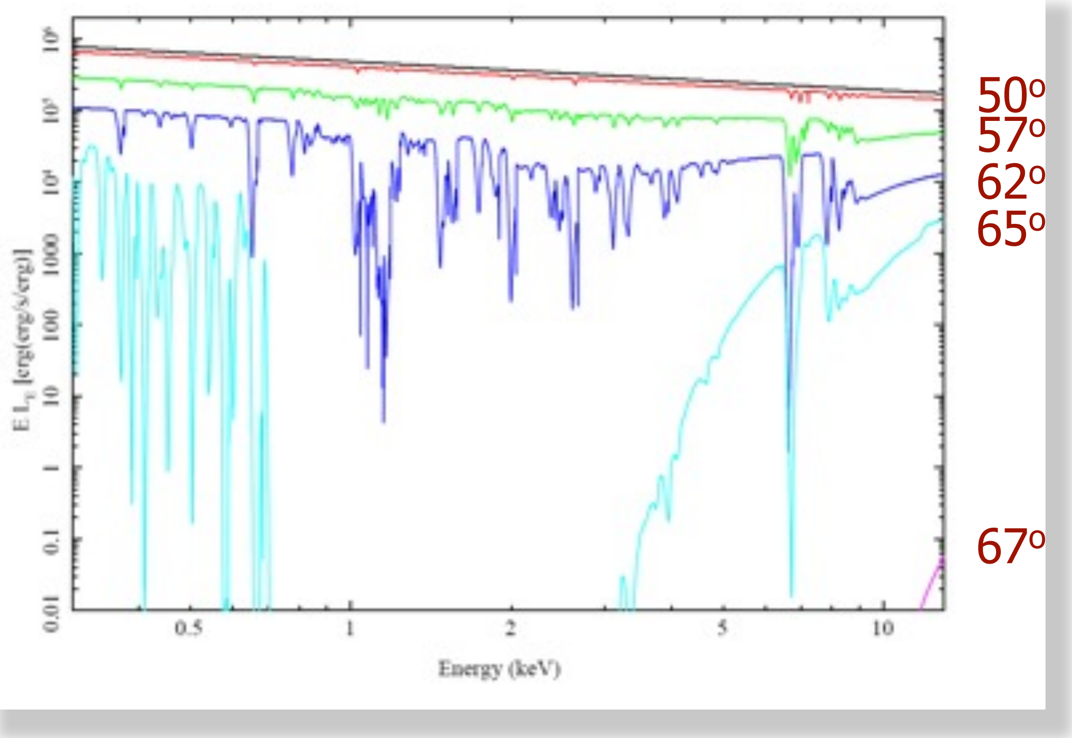
Broad band spectra for various l.o.s.



Schurch, Done, & Proga (2009)

Broad band spectra for various l.o.s.





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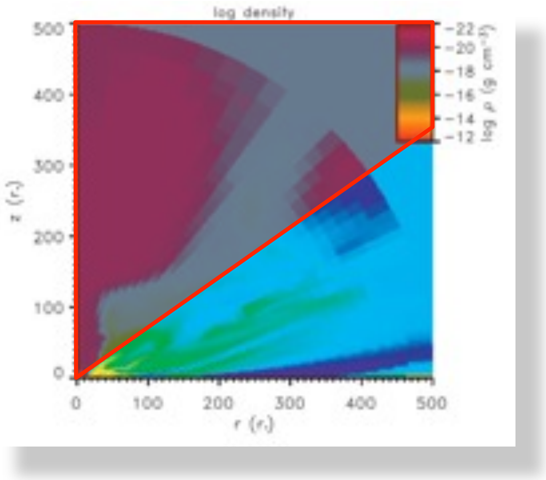
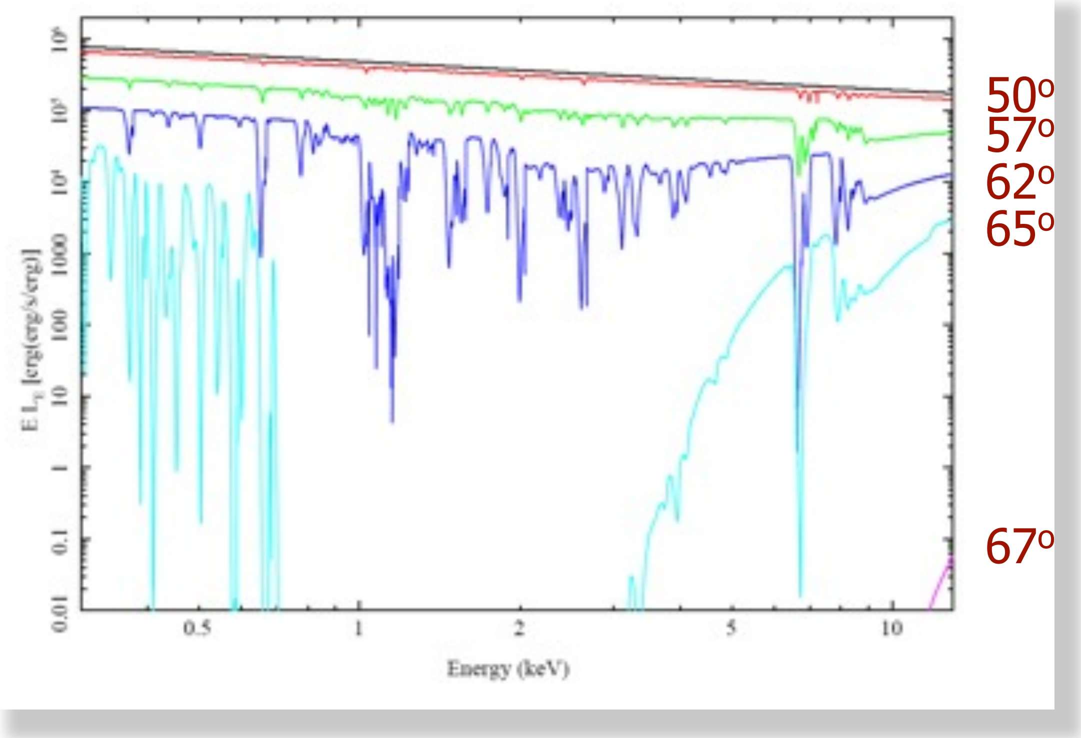
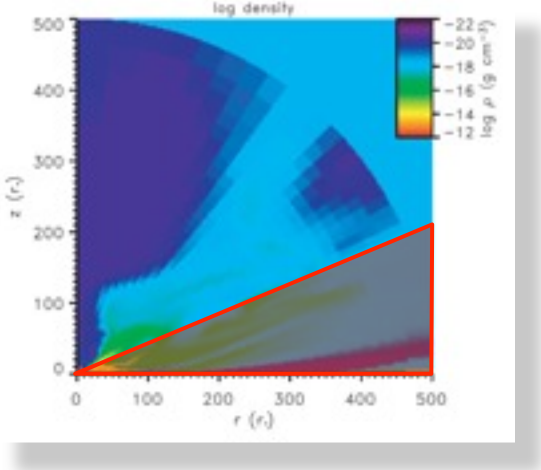
Broad band spectra for various l.o.s.

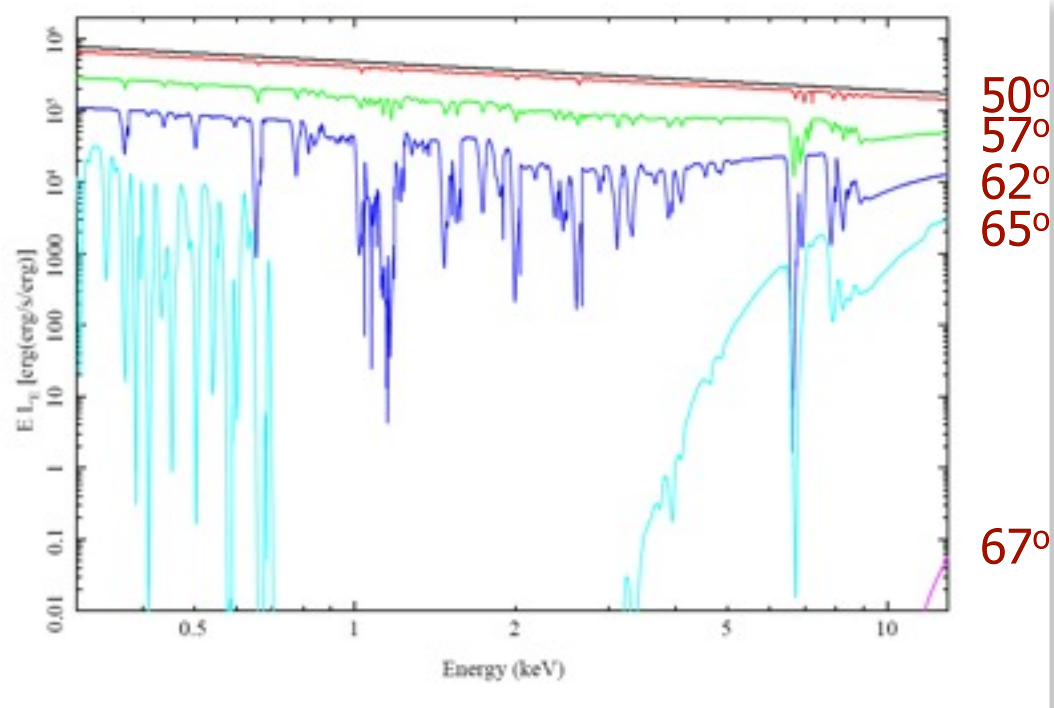




Schurch, Done, & Proga (2009)

Broad band spectra for various l.o.s.





Schurch, Done, & Proga (2009)

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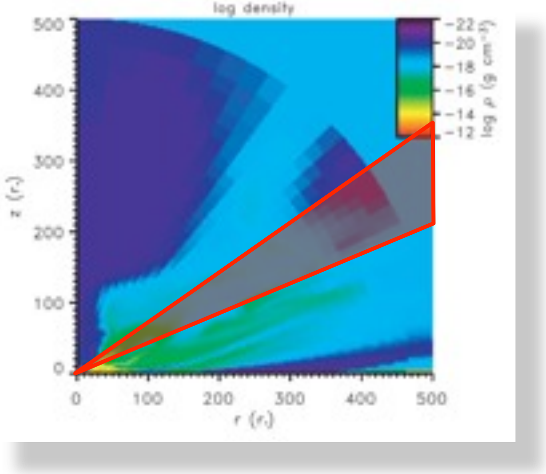

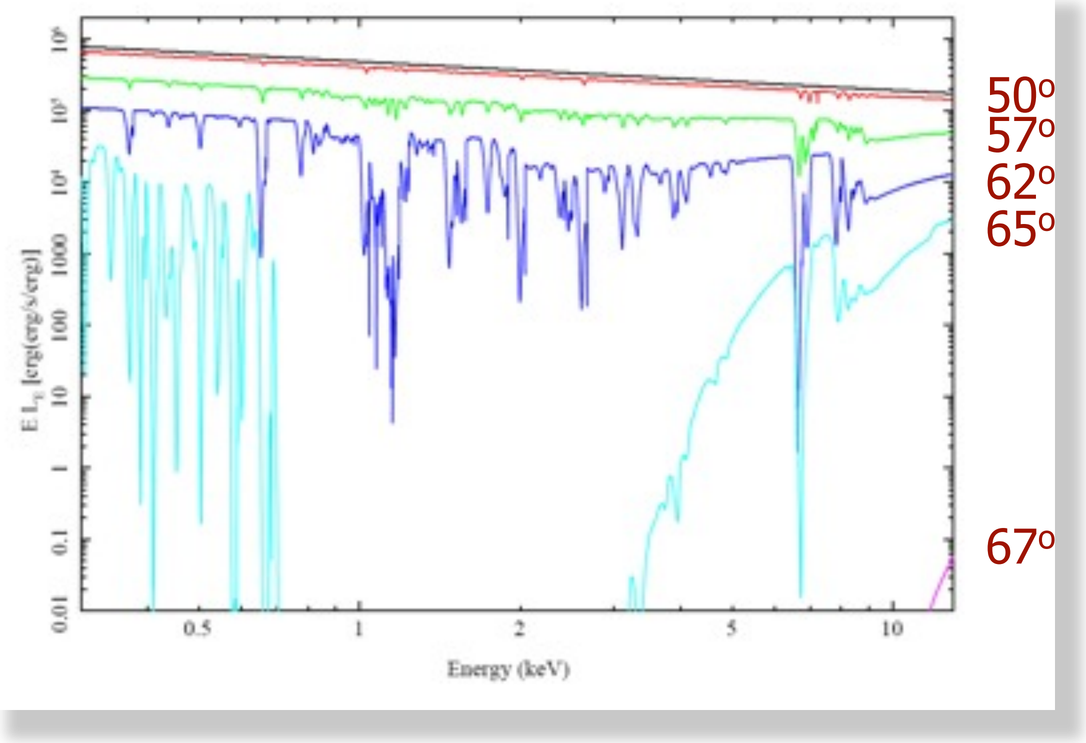

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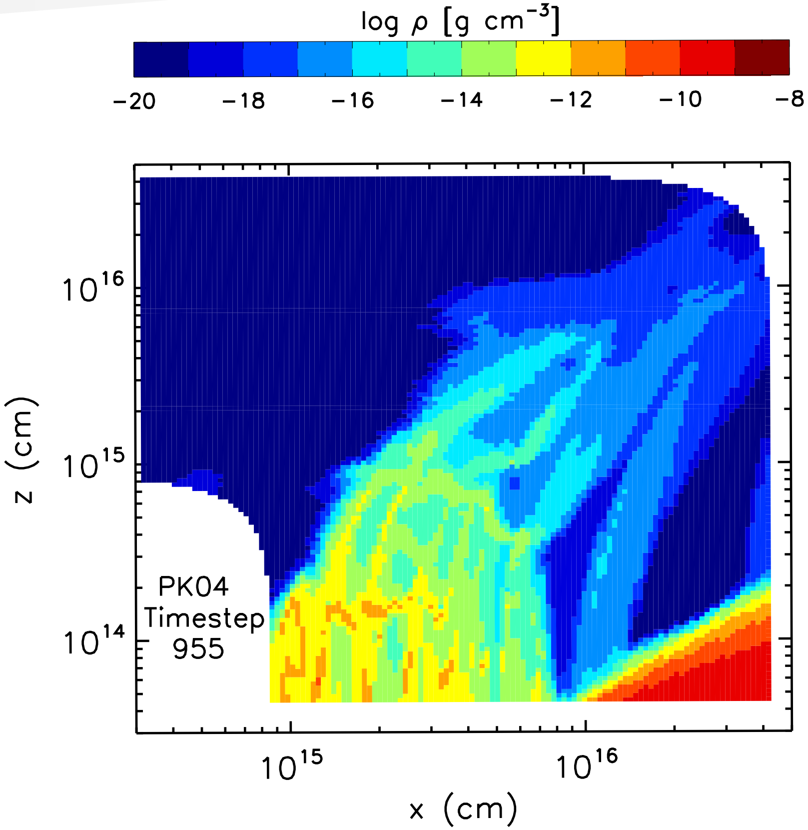
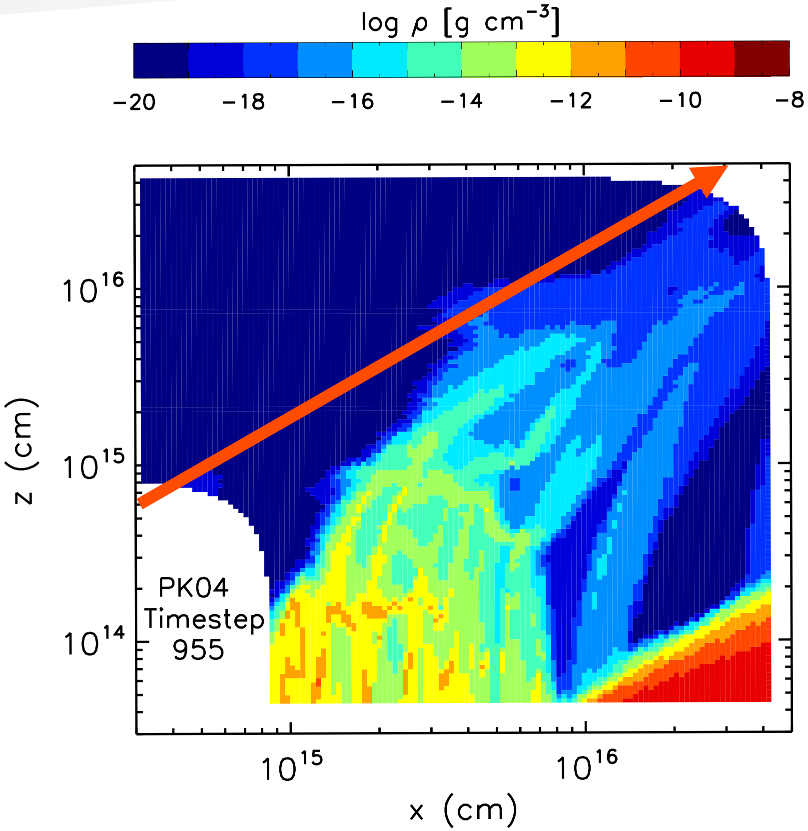
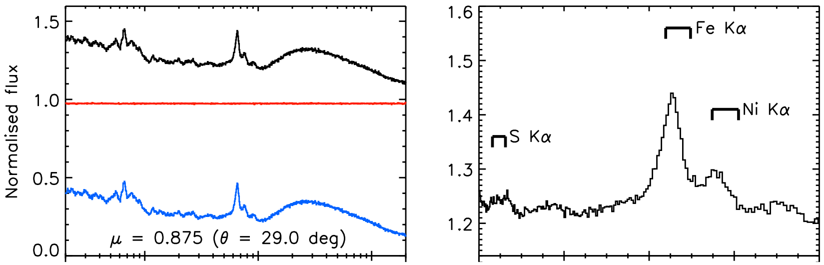


Sim et al. (2010)

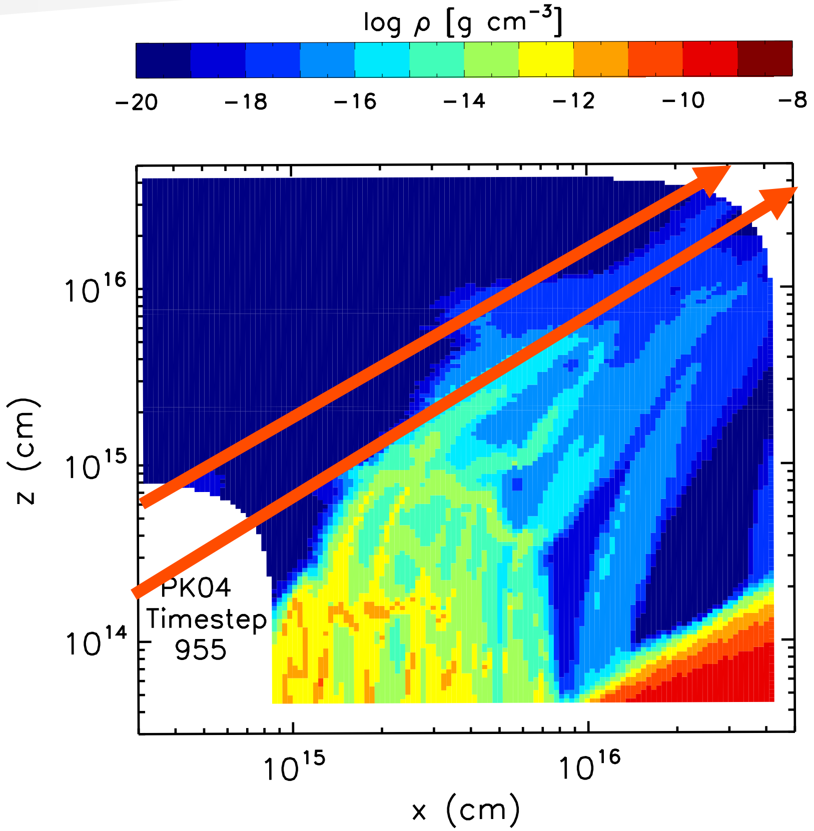
Broad band spectra for various l.o.s.

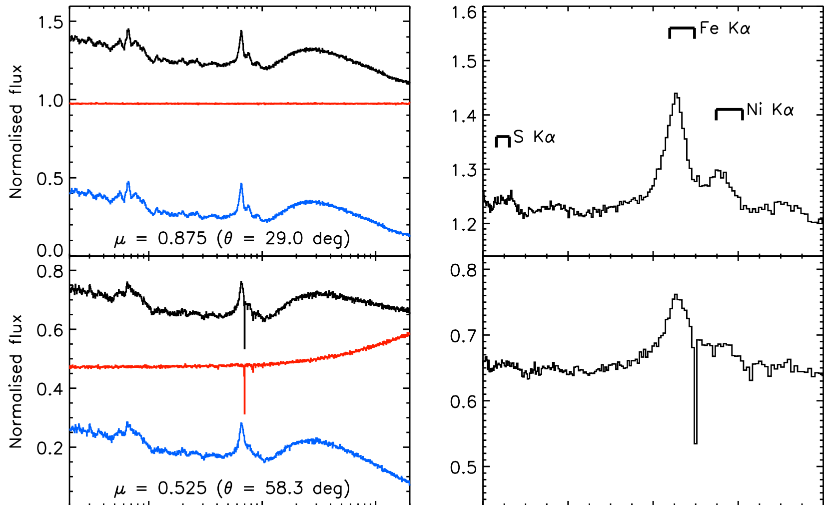




Sim et al. (2010)

Broad band spectra for various l.o.s.





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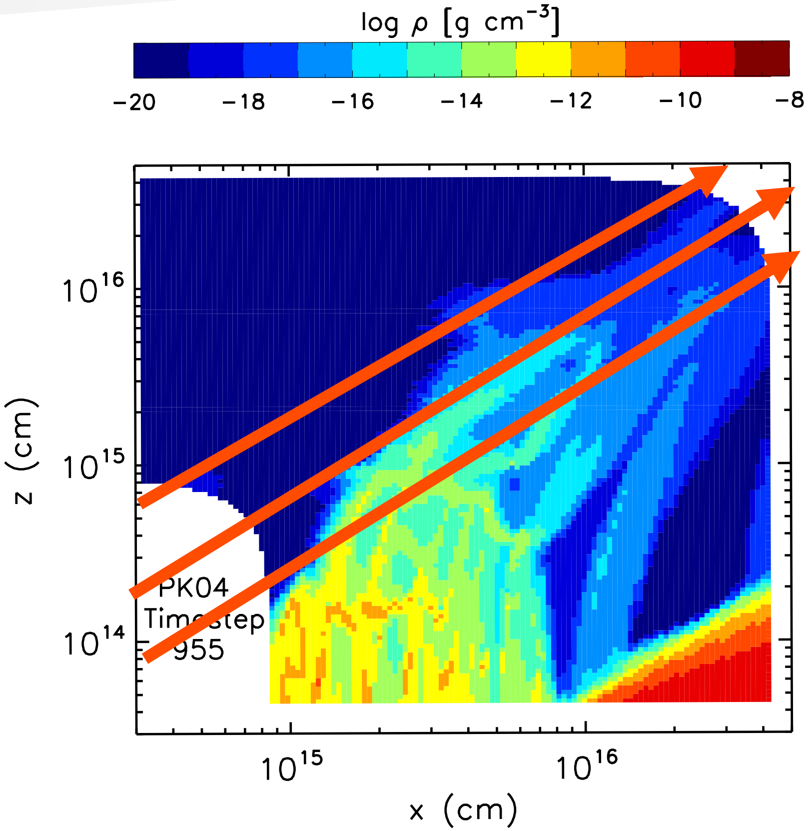
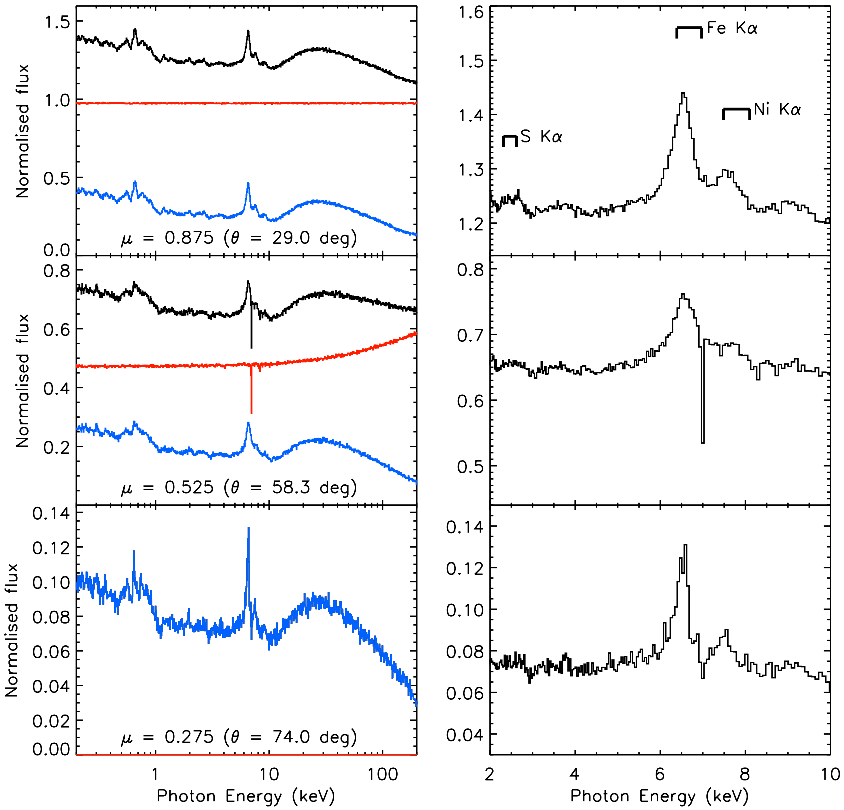
Broad band spectra for various l.o.s.





Sim et al. (2010)

Quasar Irradiation

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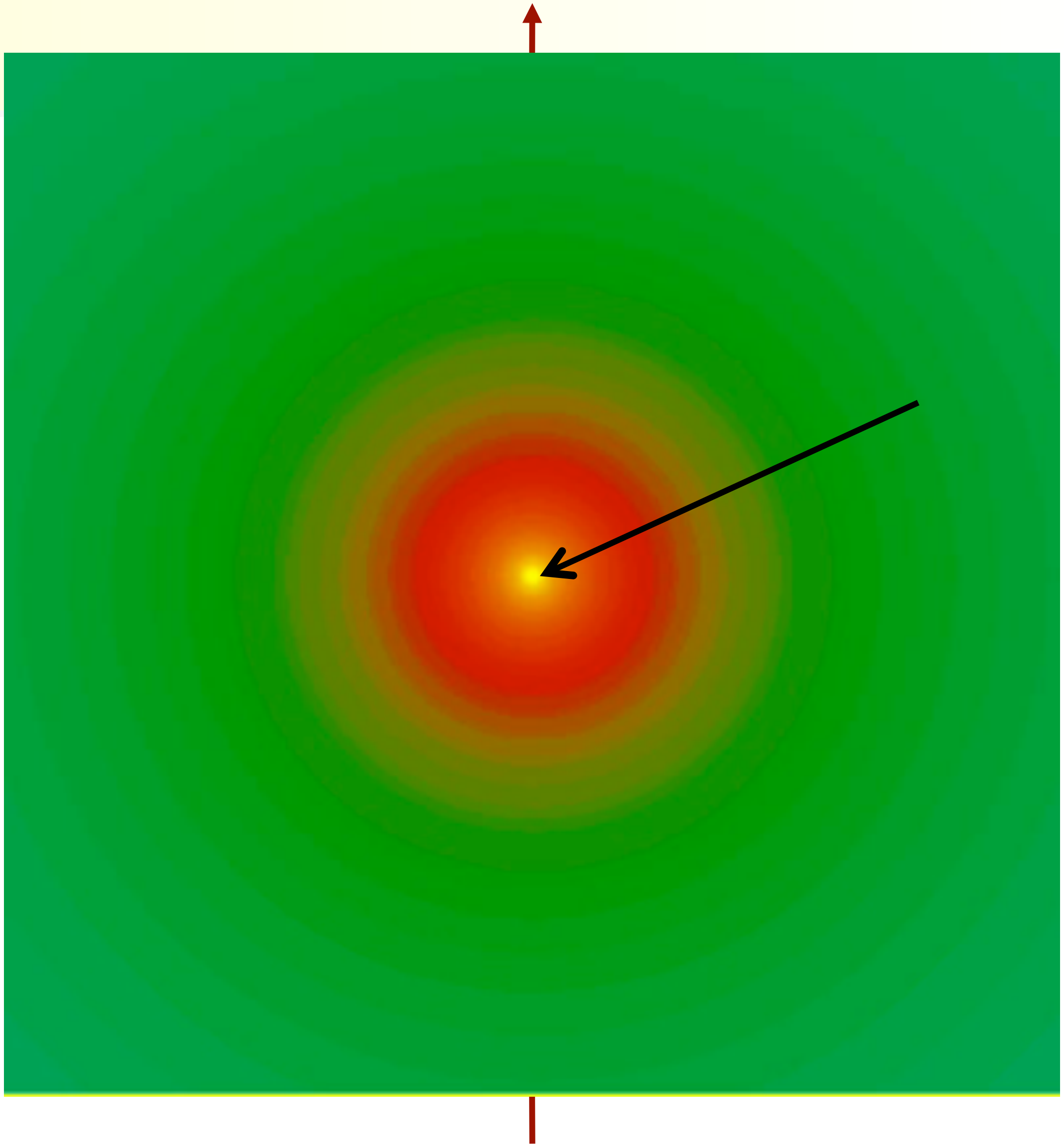
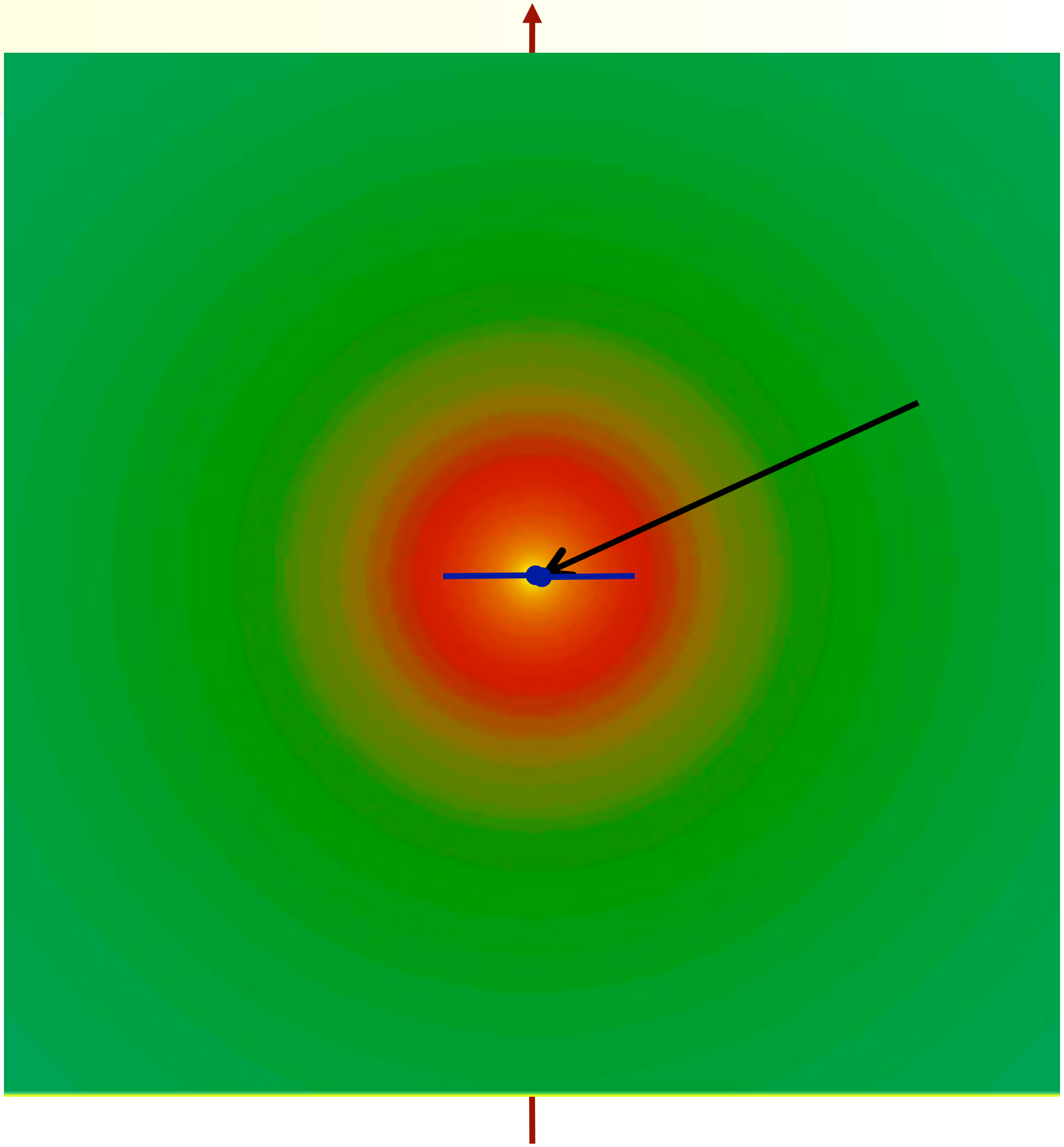
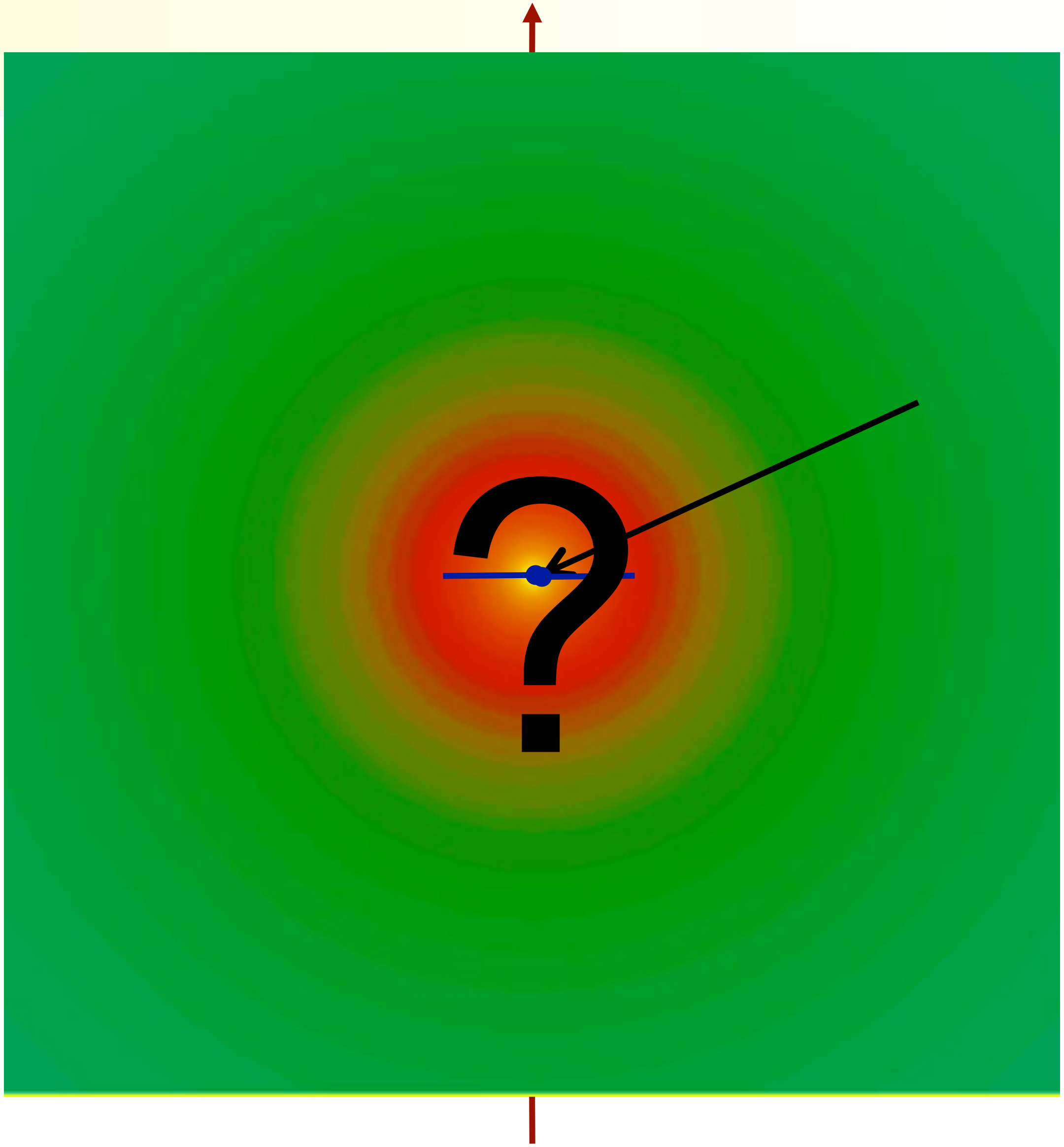


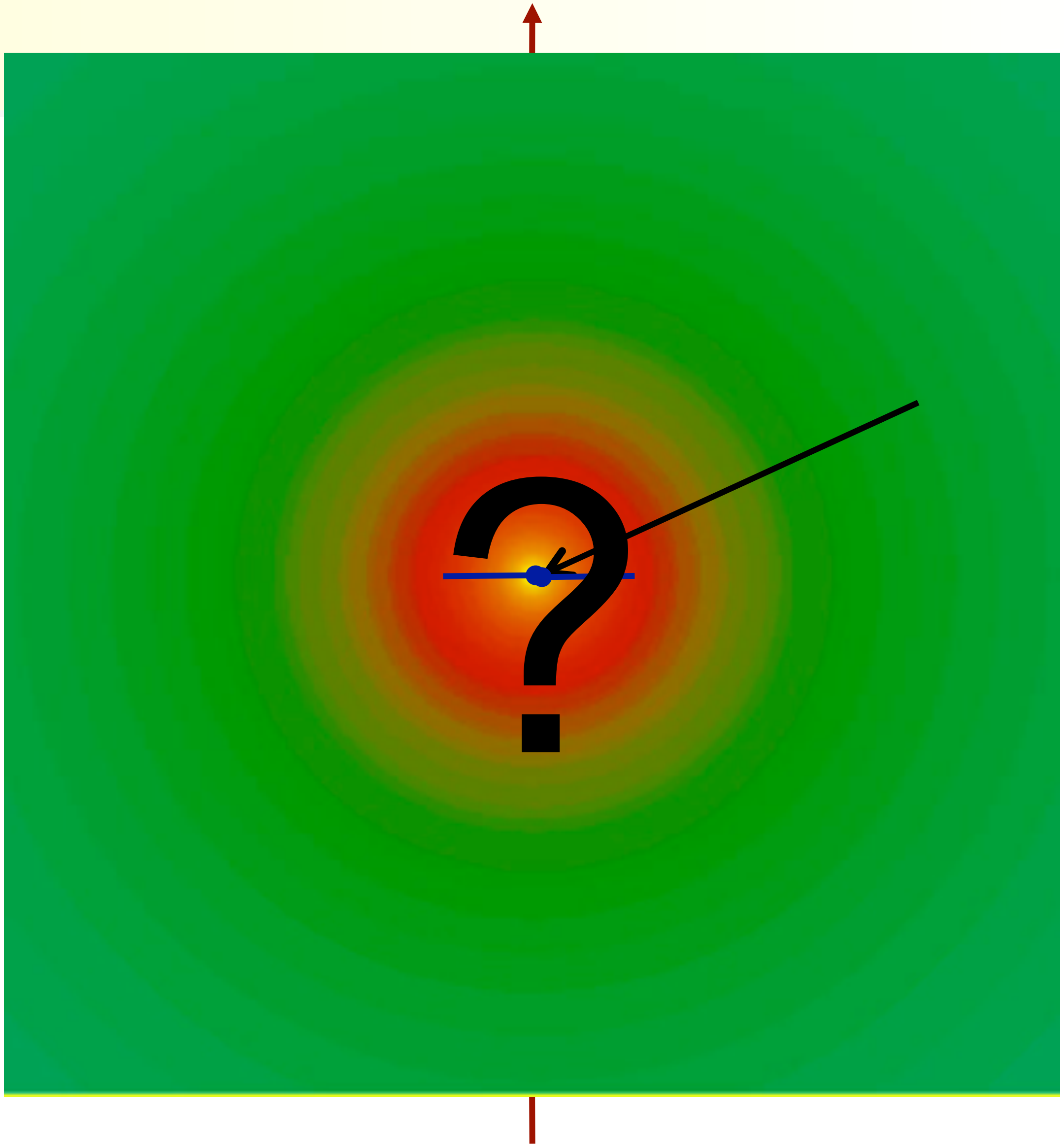
Quasar Irradiation



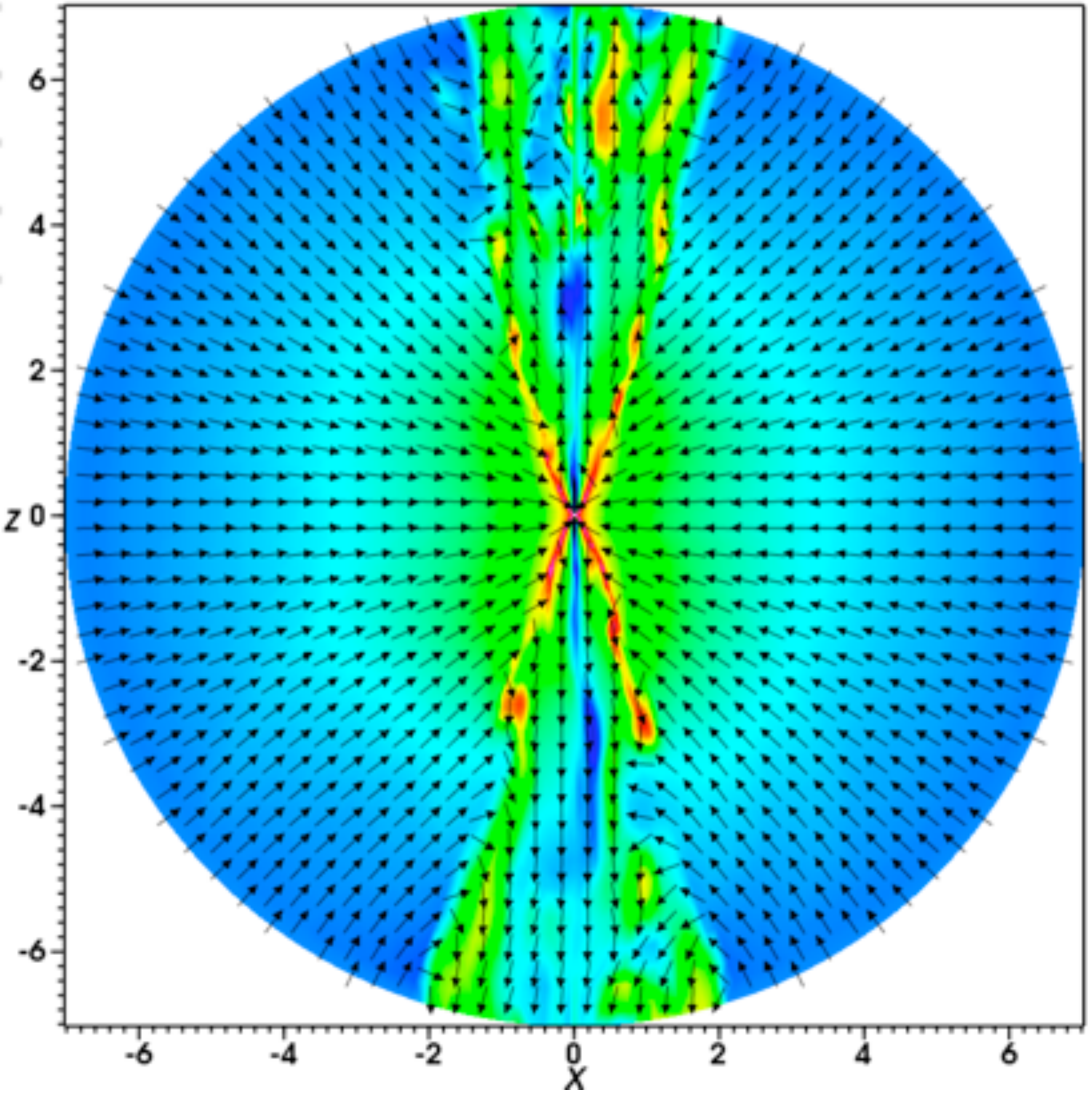
Quasar Irradiation



Quasar Irradiation



An outflow from an inflow



$$M_{BH} = 10^{8} M_{SUN}$$

$$\dot{M}_{D} = 10^{26} g/s = 1.6 M_{SUN}/yr$$

$$T_{X} = 8 \; x 10^{7} K$$

$$\rho(r_{o}) = 10^{-21} g/cm^{3}$$

$$f_{UV} = f_{X} = 0.5$$

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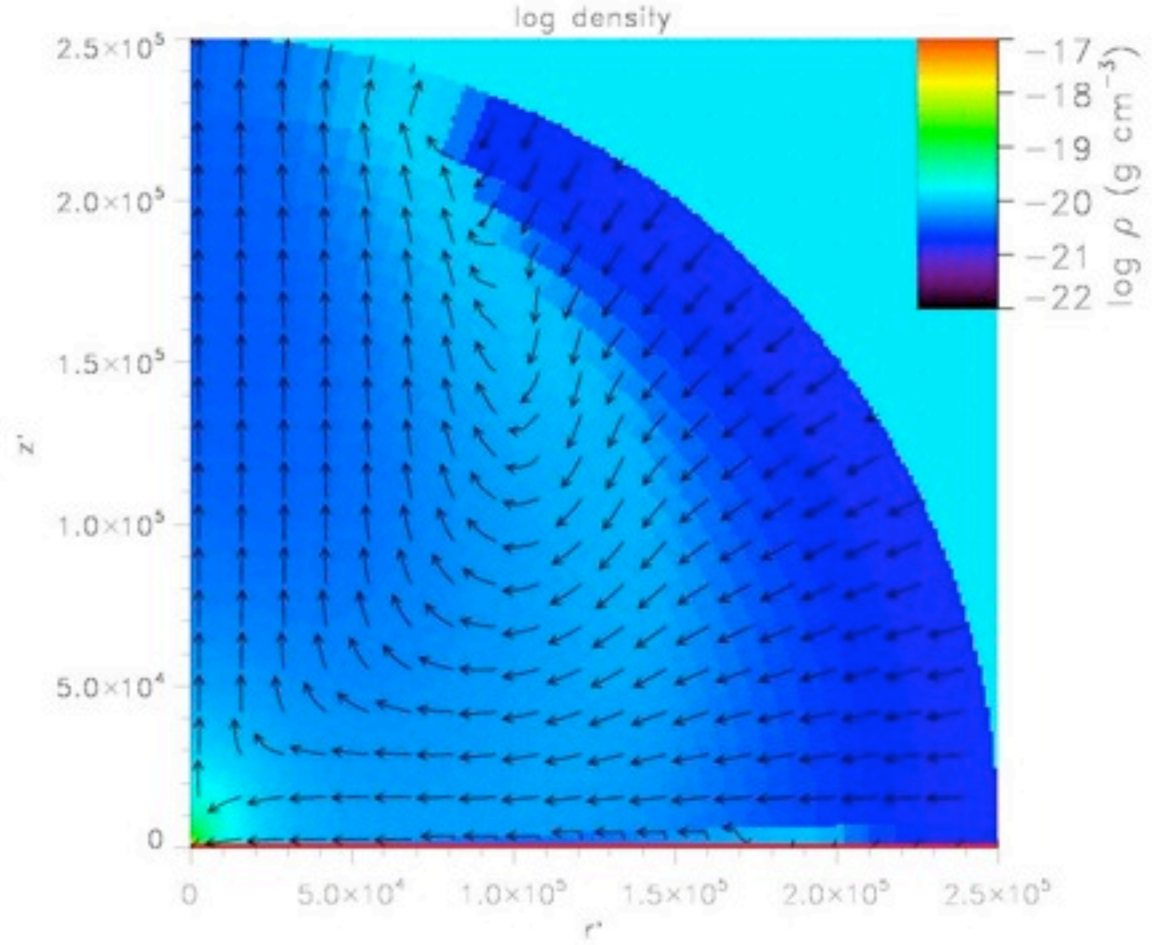

Proga (2007)

$M_{BH} = 10^8 M_{SUN}$

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$T_X = 8 \ x 10^7 K$

$\rho(r_o) = 10^{-21} g/cm^3$

$f_{UV} = 0.95 \quad f_X = 0.05$

$$M_{BH} = 10^{8} M_{SUN}$$

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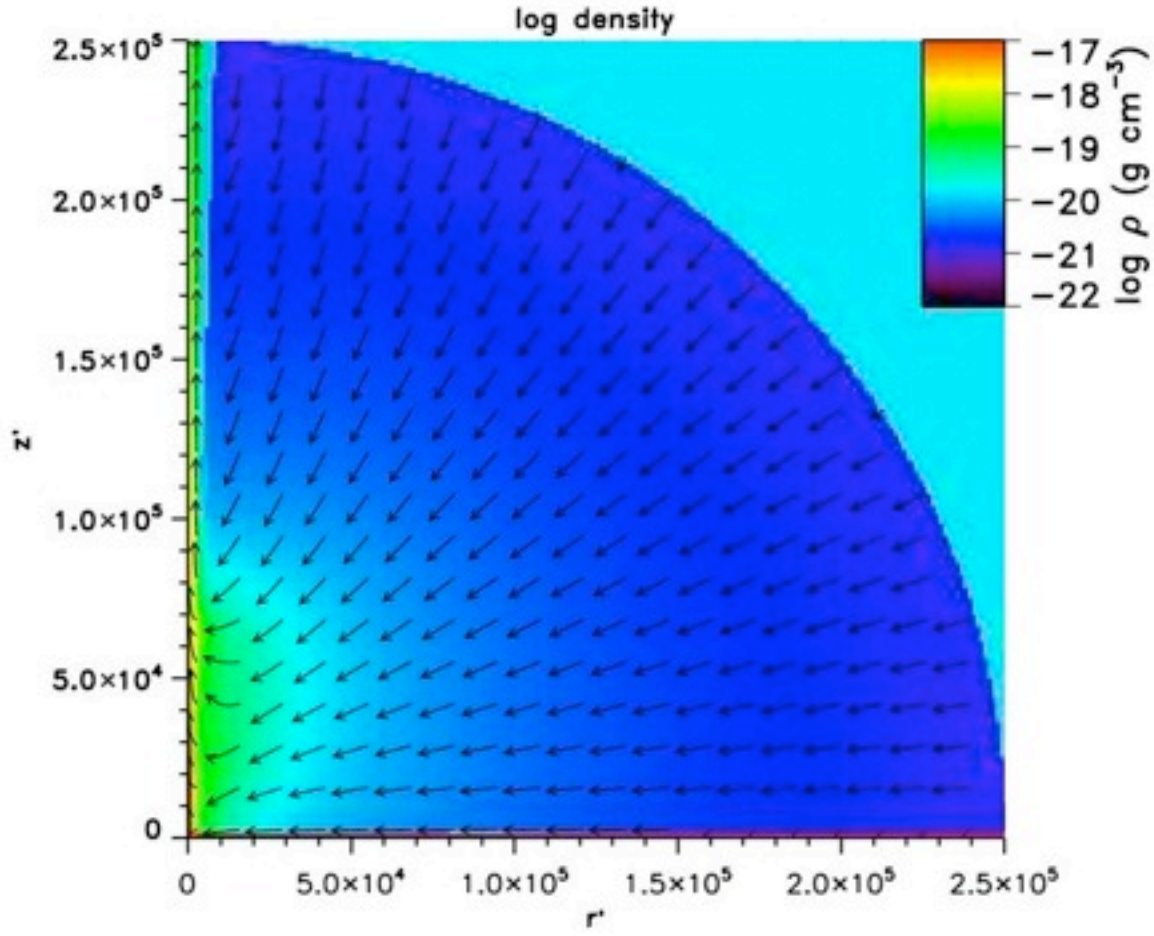
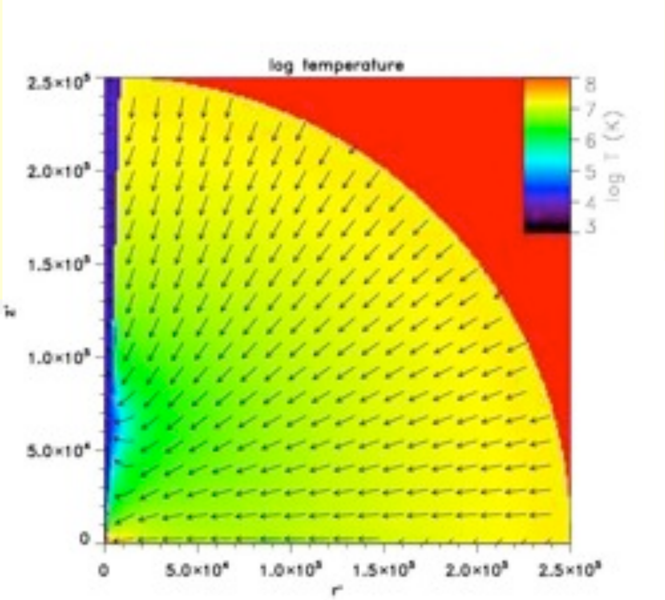
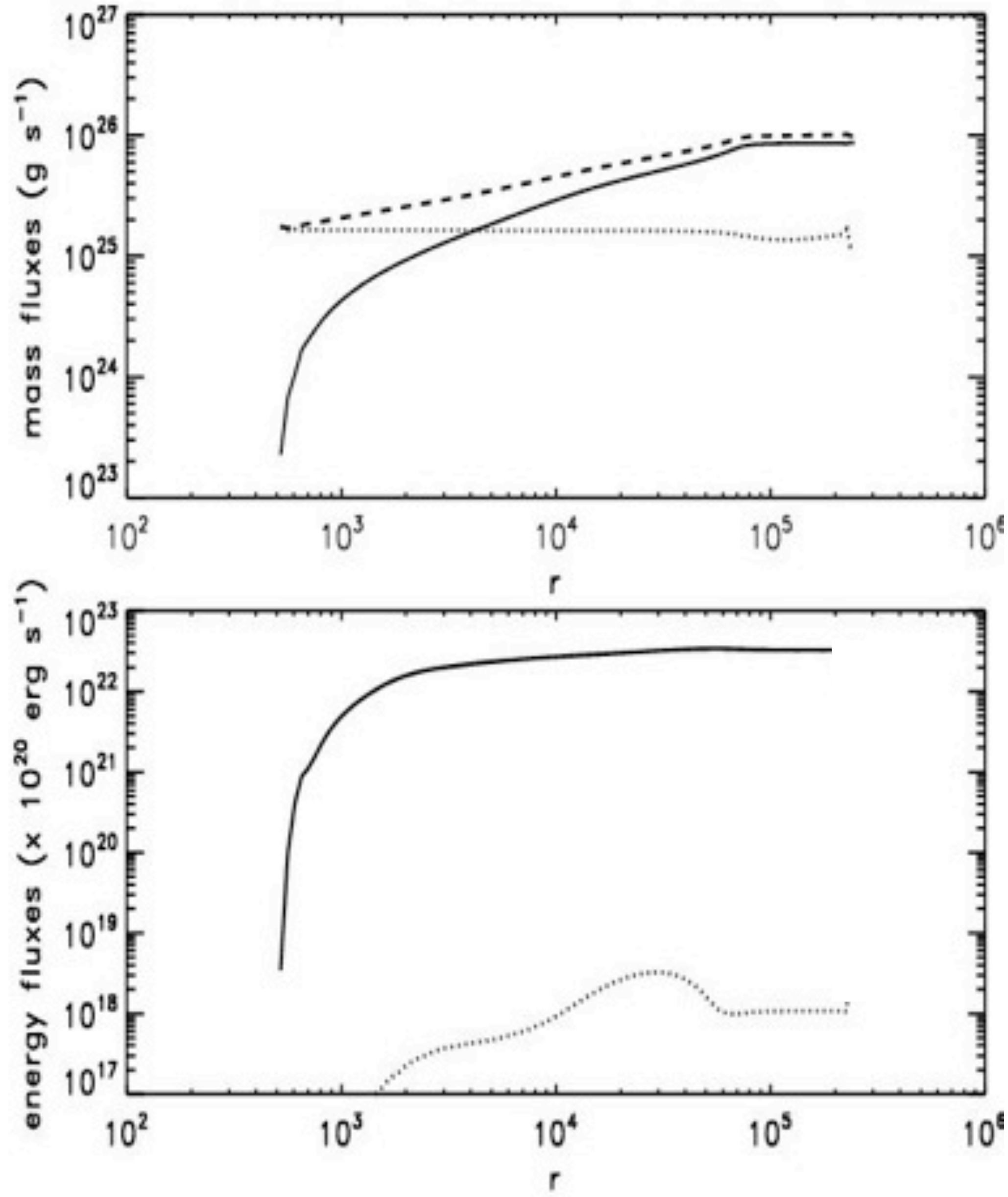


Proga (2007)





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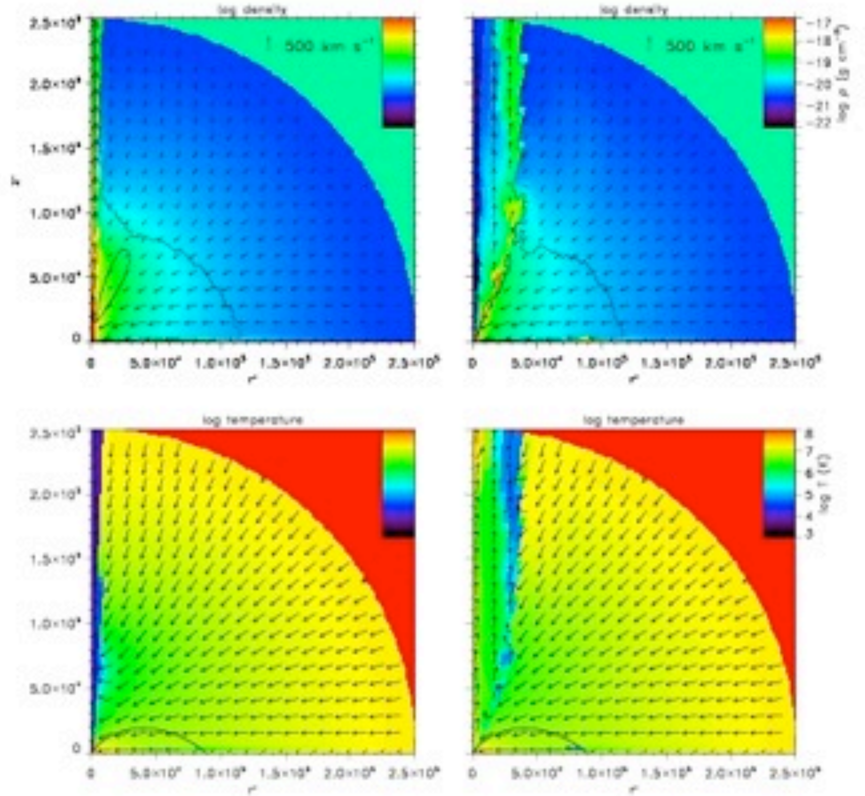
Effects of gas rotation, optical depth and X-ray background radiation

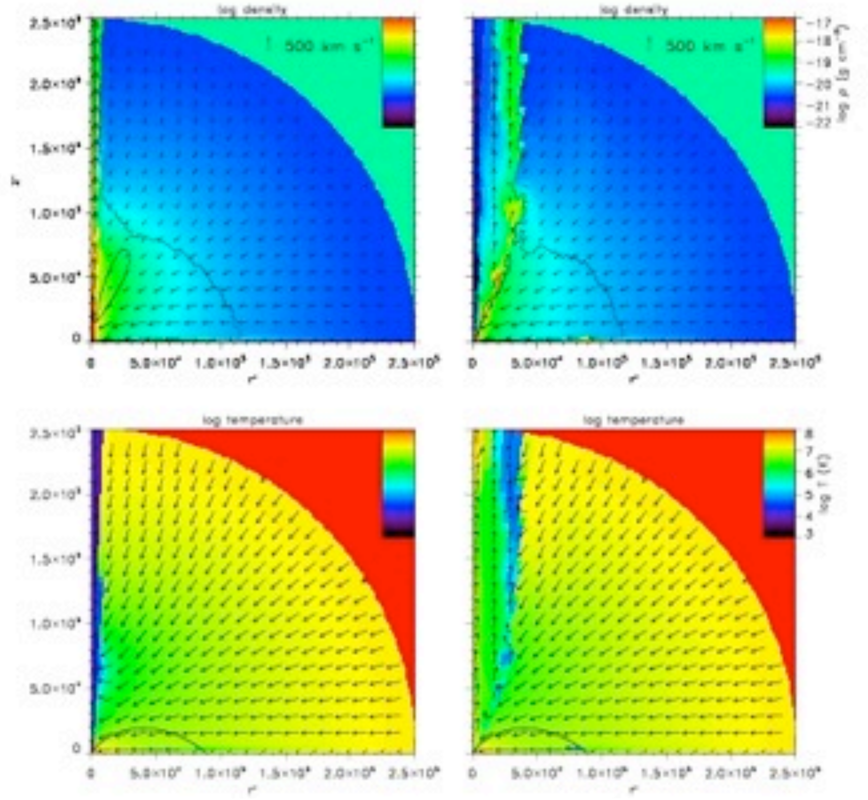
Effects of gas rotation, optical depth and X-ray background radiation



Proga, Ostriker, Kurosawa (2007)

Effects of gas rotation, optical depth and X-ray background radiation

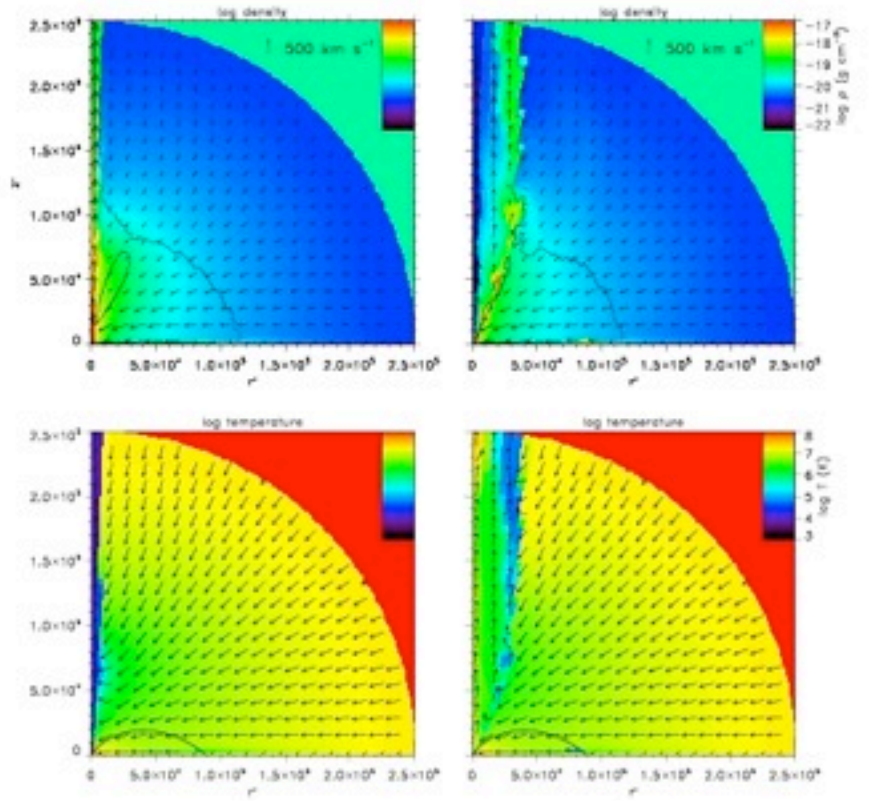
no rotation



Proga, Ostriker, Kurosawa (2007)

Effects of gas rotation, optical depth and X-ray background radiation

no rotation rotation



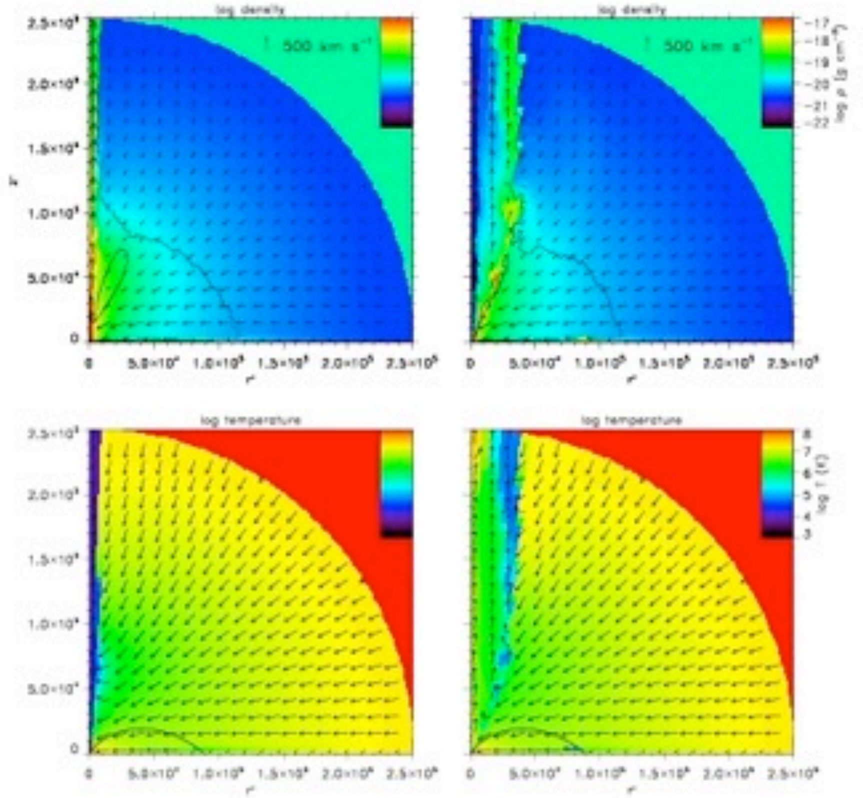
Proga, Ostriker, Kurosawa (2007)

Effects of gas rotation, optical depth and X-ray background radiation

rotation and opt. thick

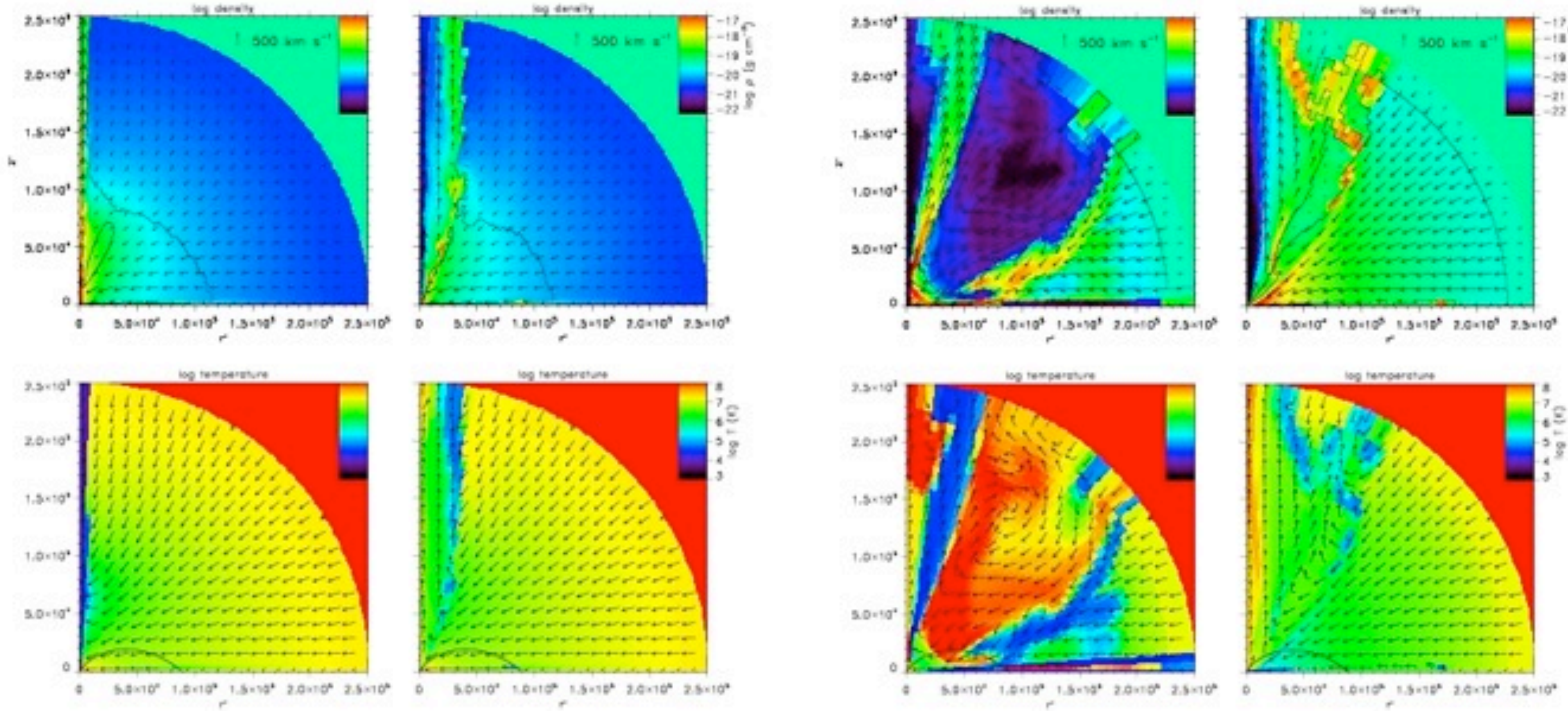
no rotation

rotation



Proga, Ostriker, Kurosawa (2007)

Effects of gas rotation, optical depth and X-ray background radiation



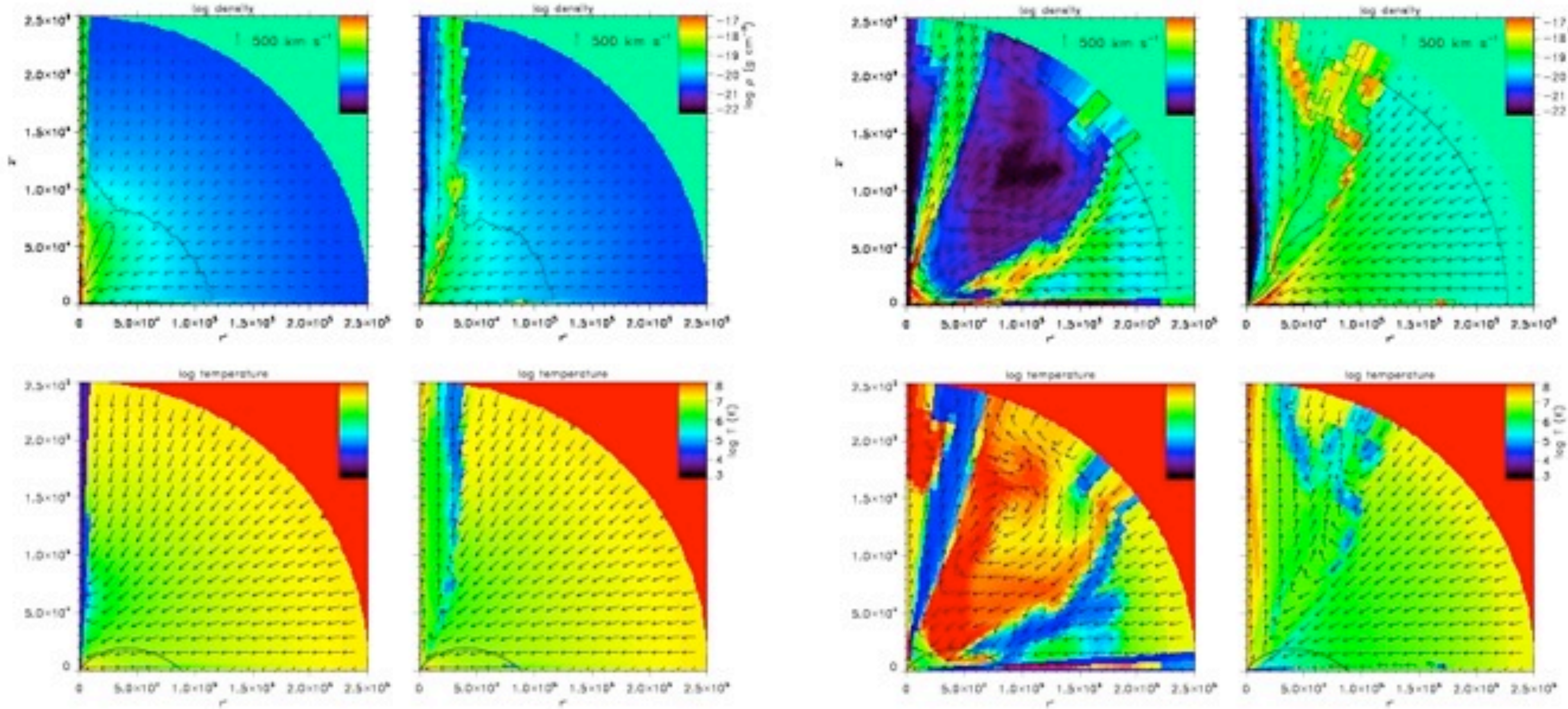
no rotation

rotation

rotation and opt. thick
no X-ray background

Proga, Ostriker, Kurosawa (2007)

Effects of gas rotation, optical depth and X-ray background radiation



rotation and opt. thick

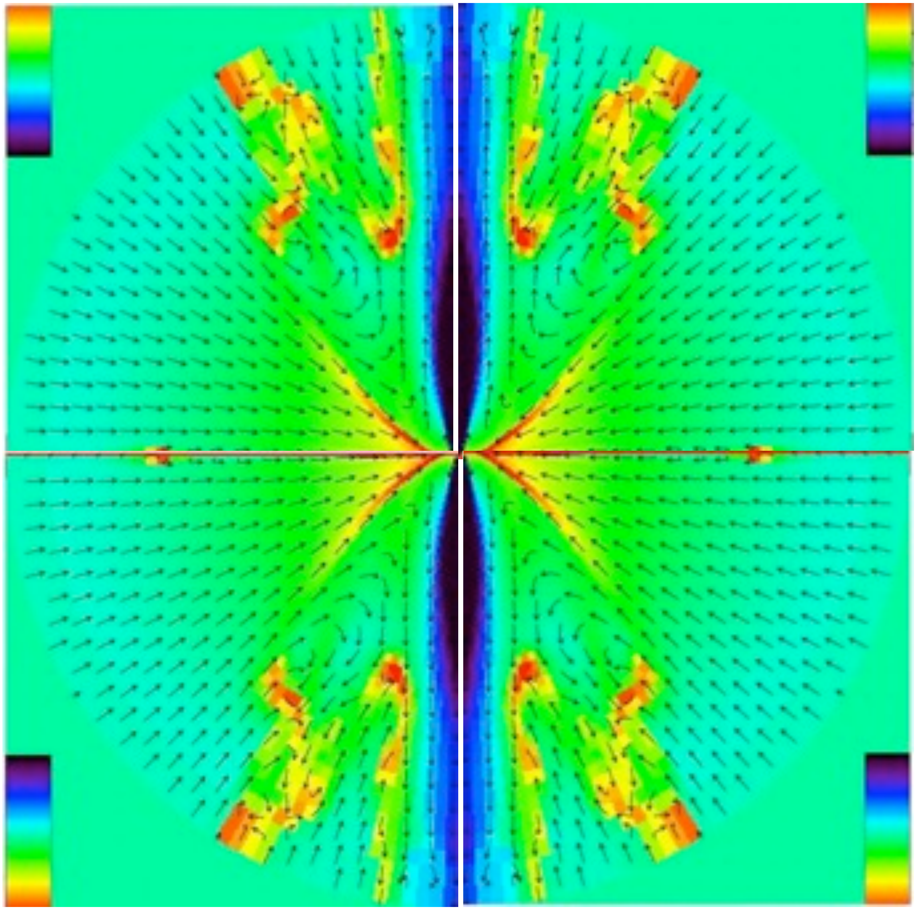
no rotation

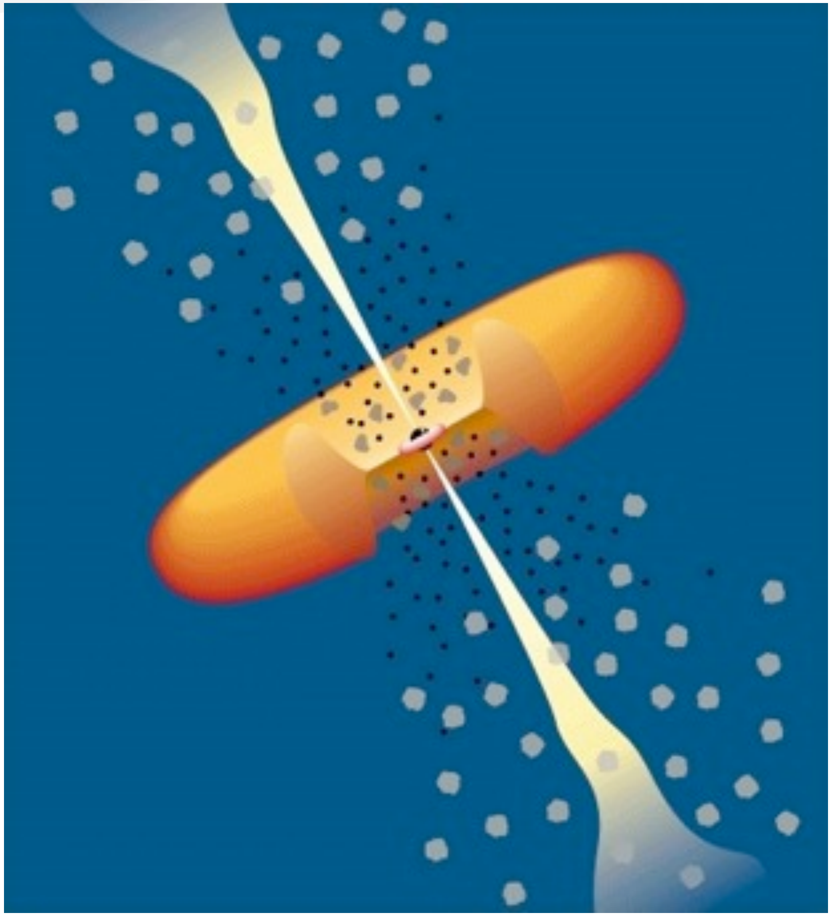
rotation

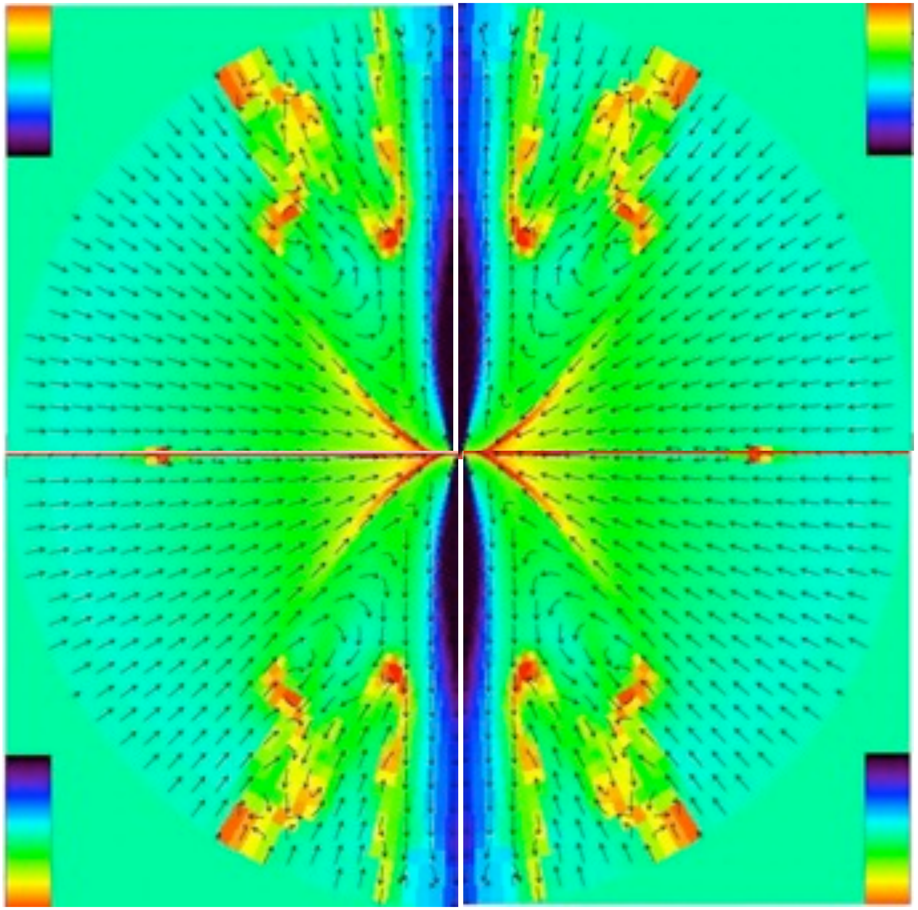
no X-ray background

X-ray background

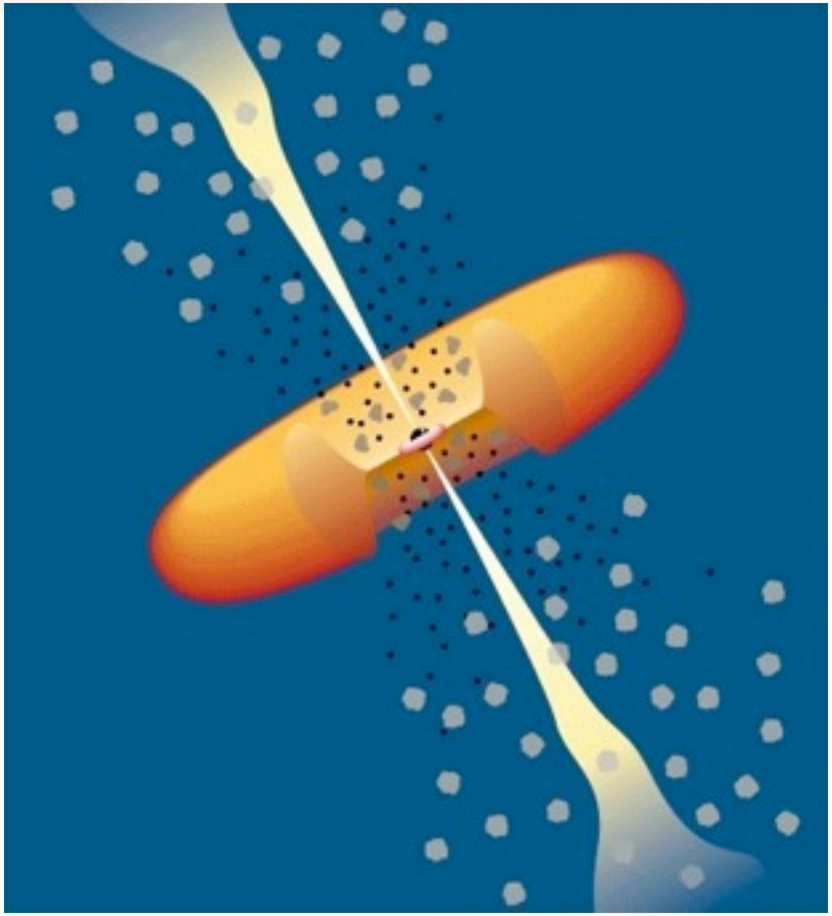
Proga, Ostriker, Kurosawa (2007)

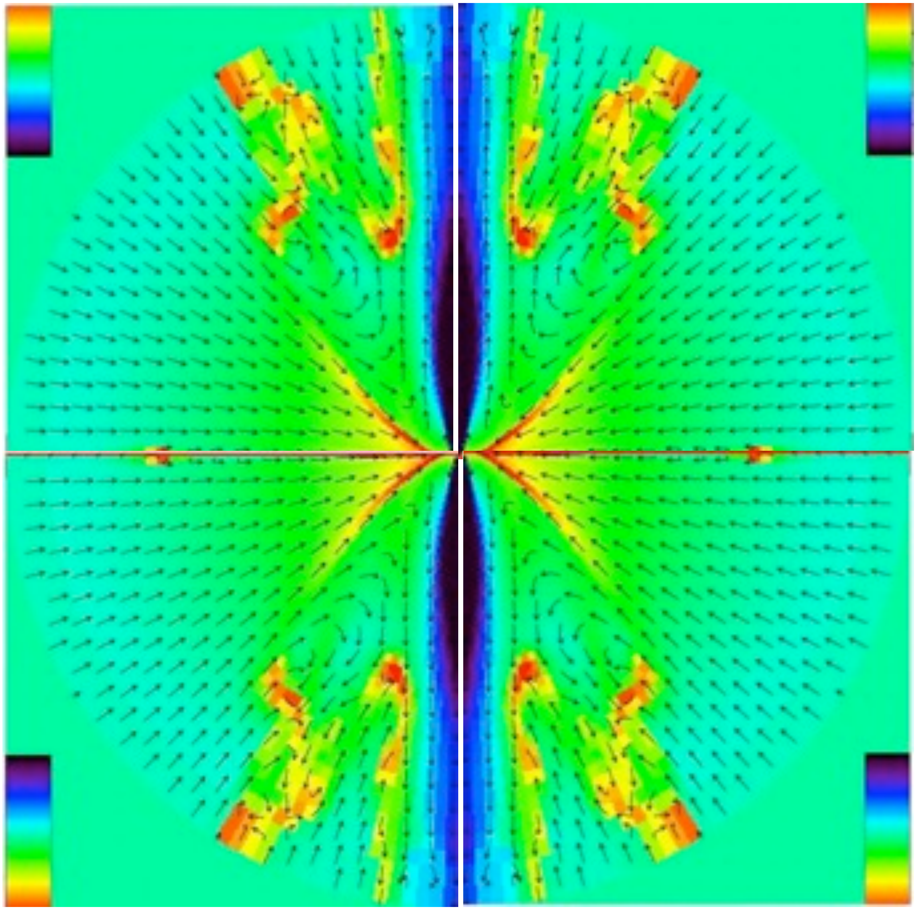






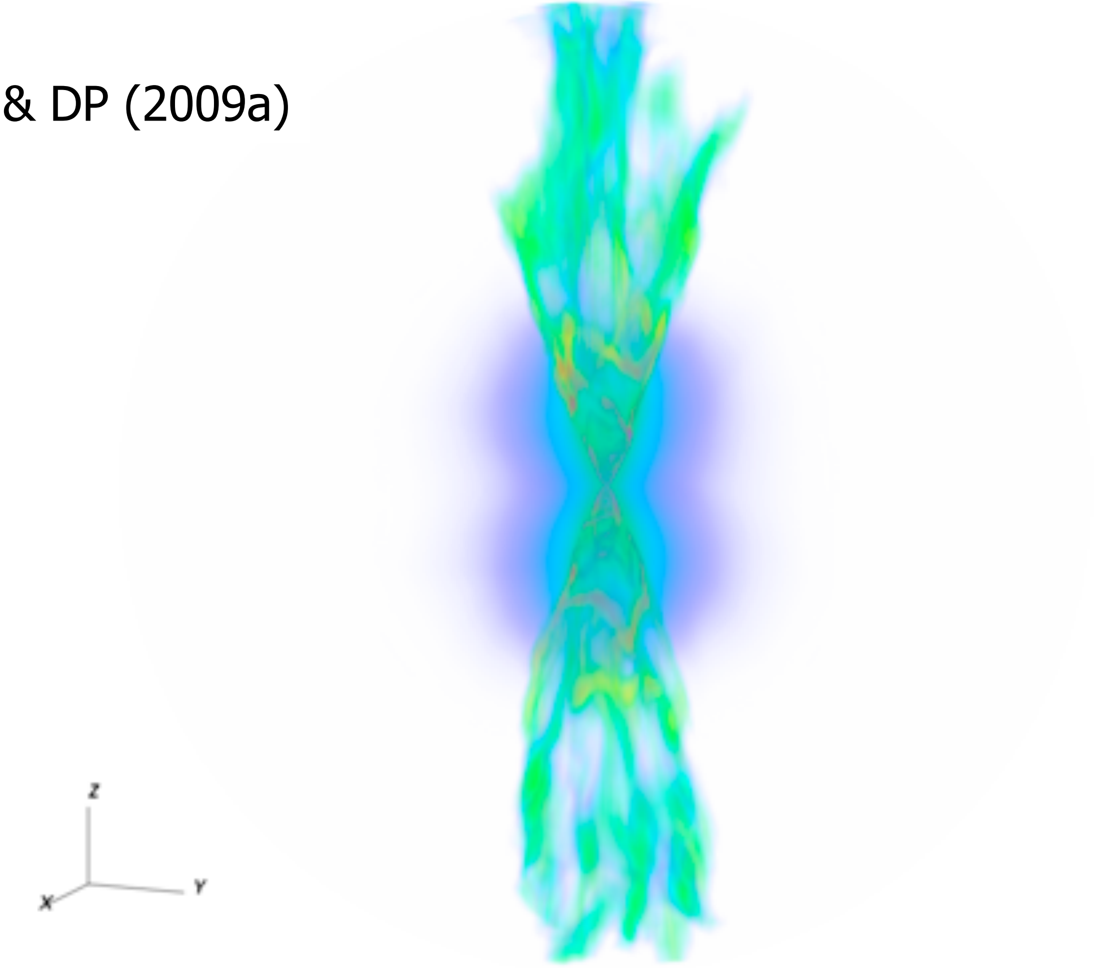
Dynamical model for clouds in NLR!?





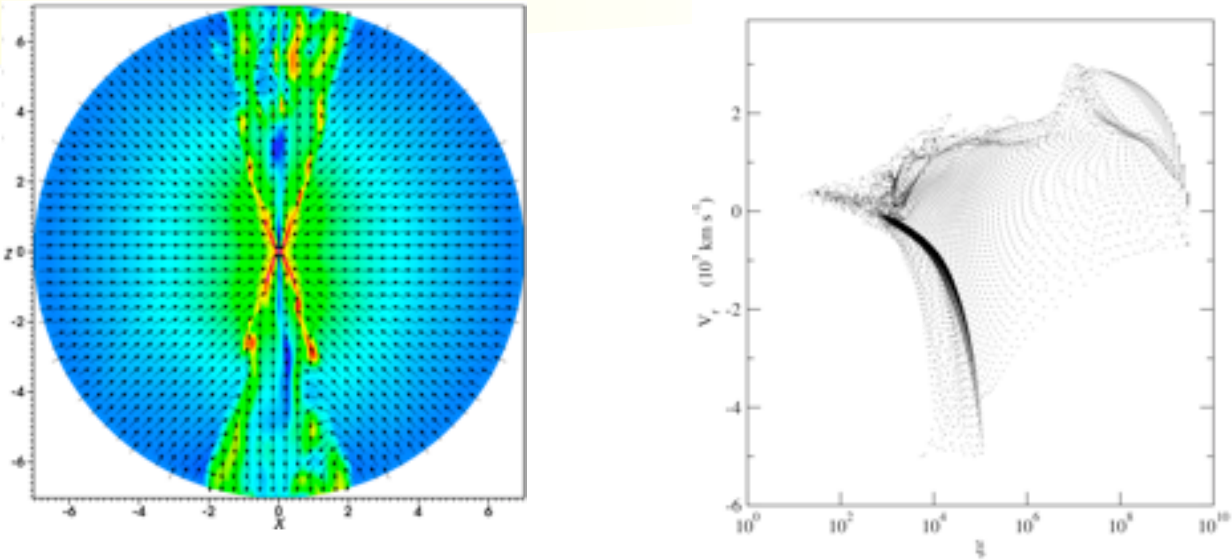
3-diminesional simulations

Kurosawa & DP (2009a)

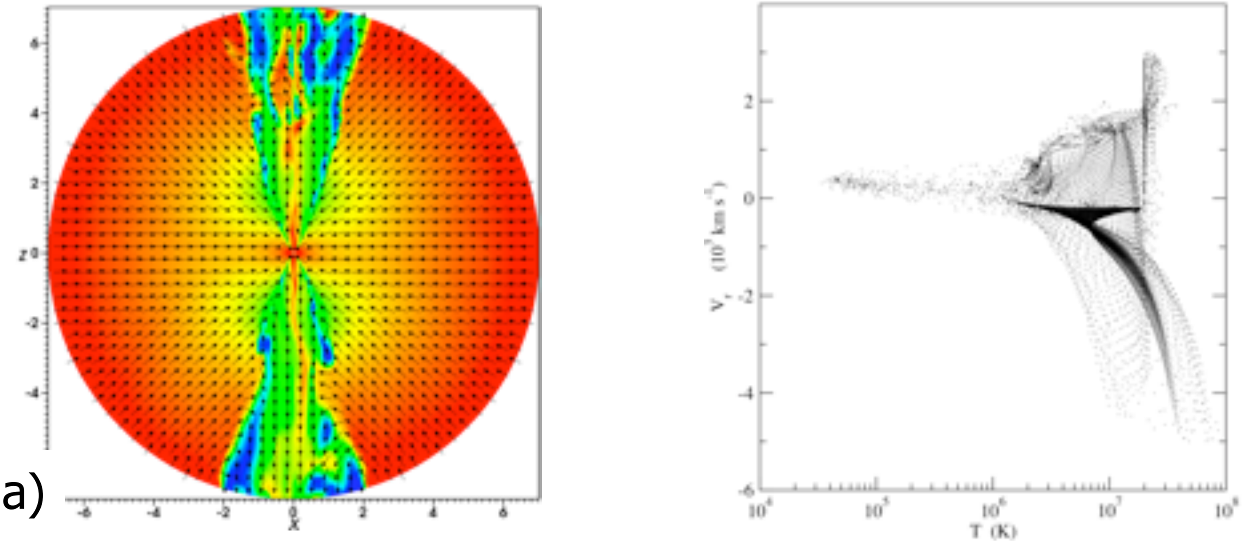


Clouds properties

density map

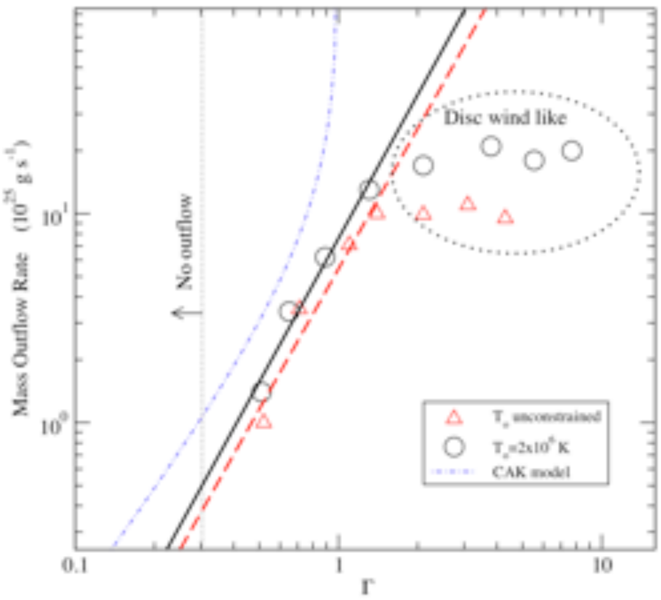


temperature map



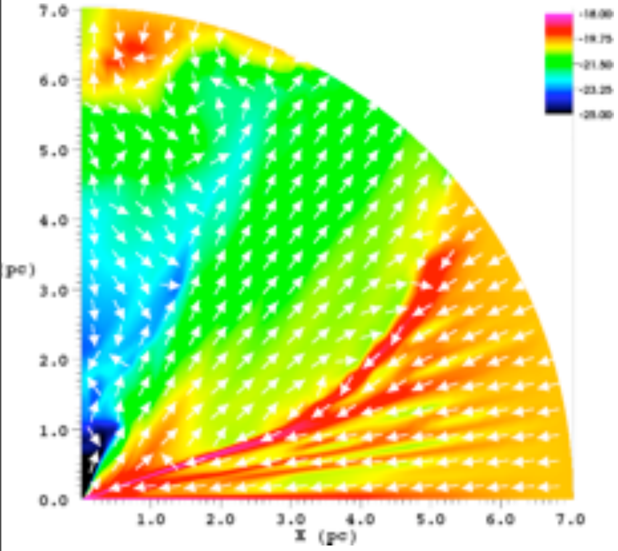
Kurosawa & DP (2009a)

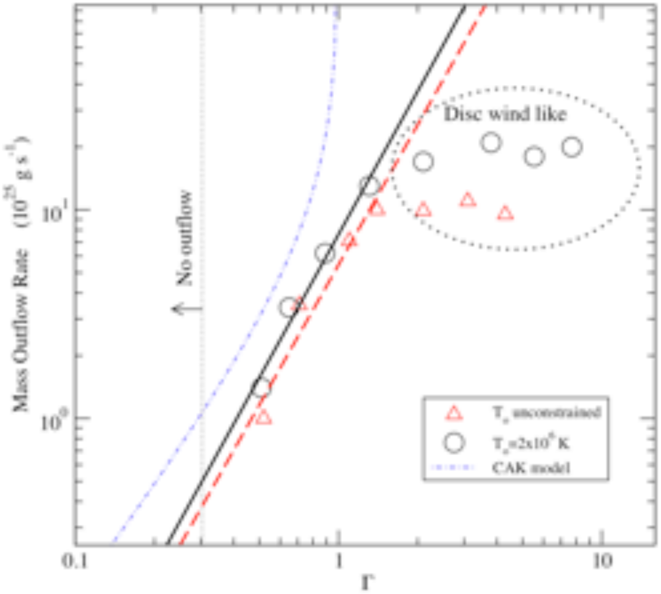
What is the limit for the mass supply rate?



Kurosawa & DP (2009b)

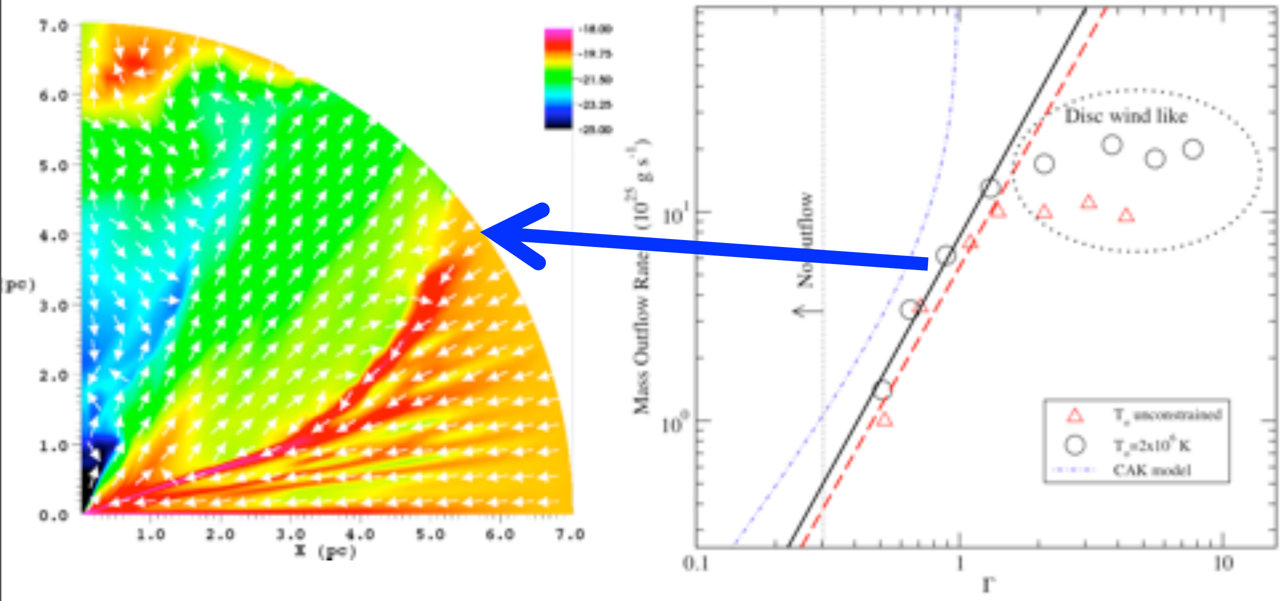
What is the limit for the mass supply rate?





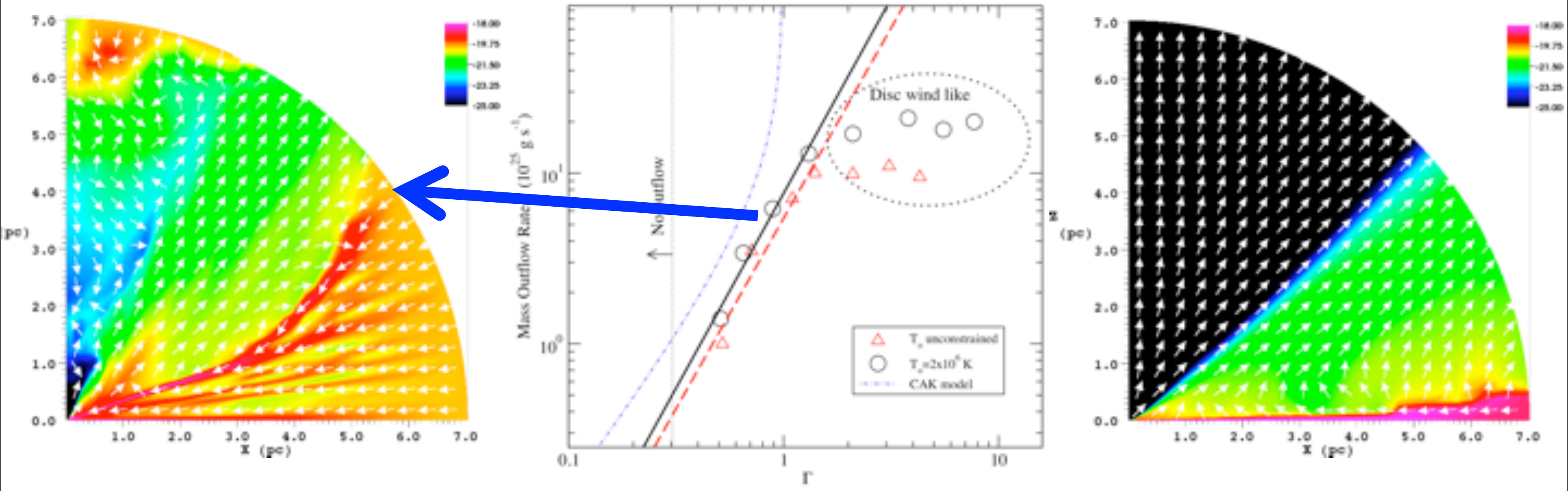
Kurosawa & DP (2009b)

What is the limit for the mass supply rate?



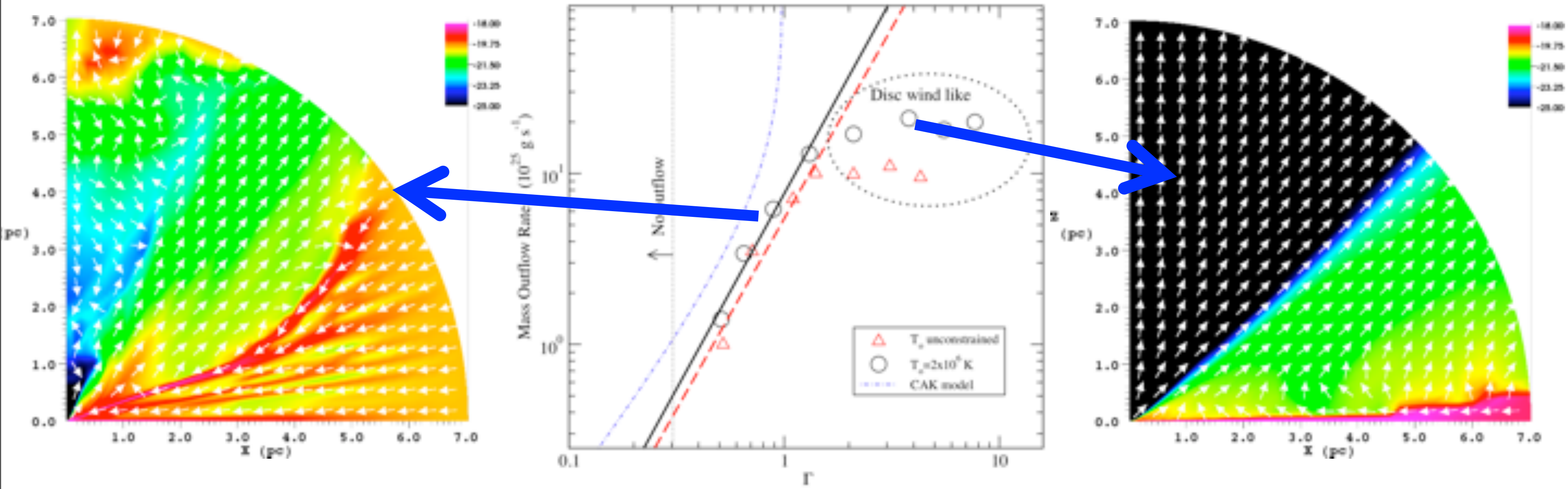
Kurosawa & DP (2009b)

What is the limit for the mass supply rate?



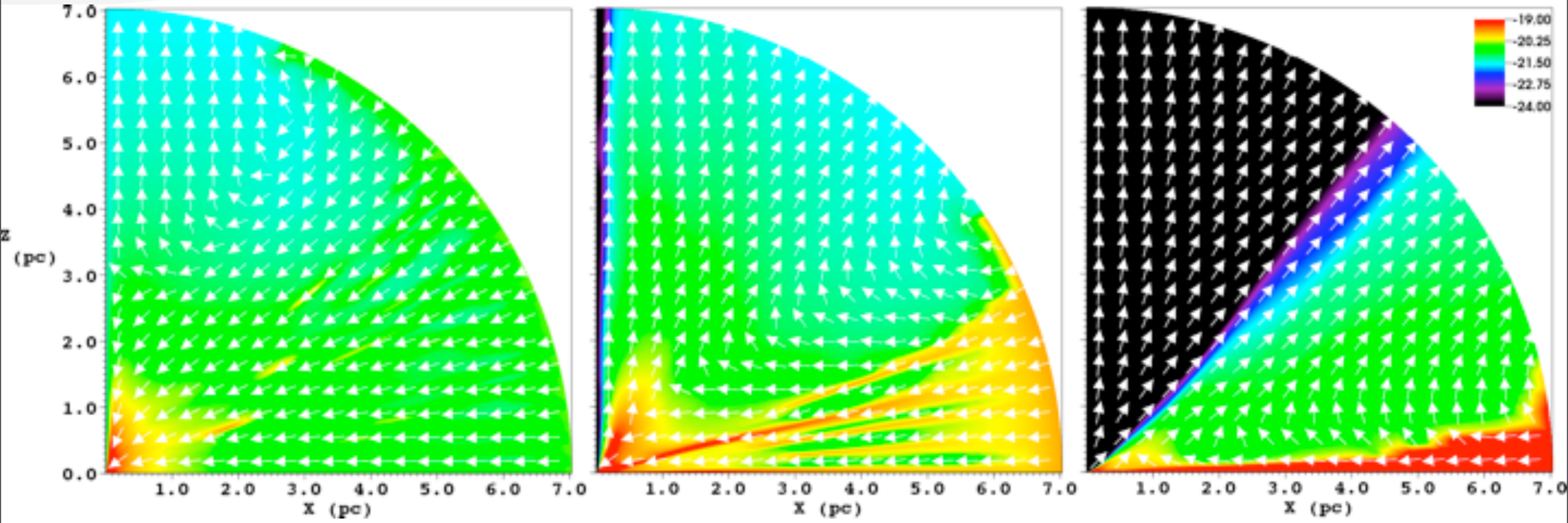
Kurosawa & DP (2009b)

What is the limit for the mass supply rate?

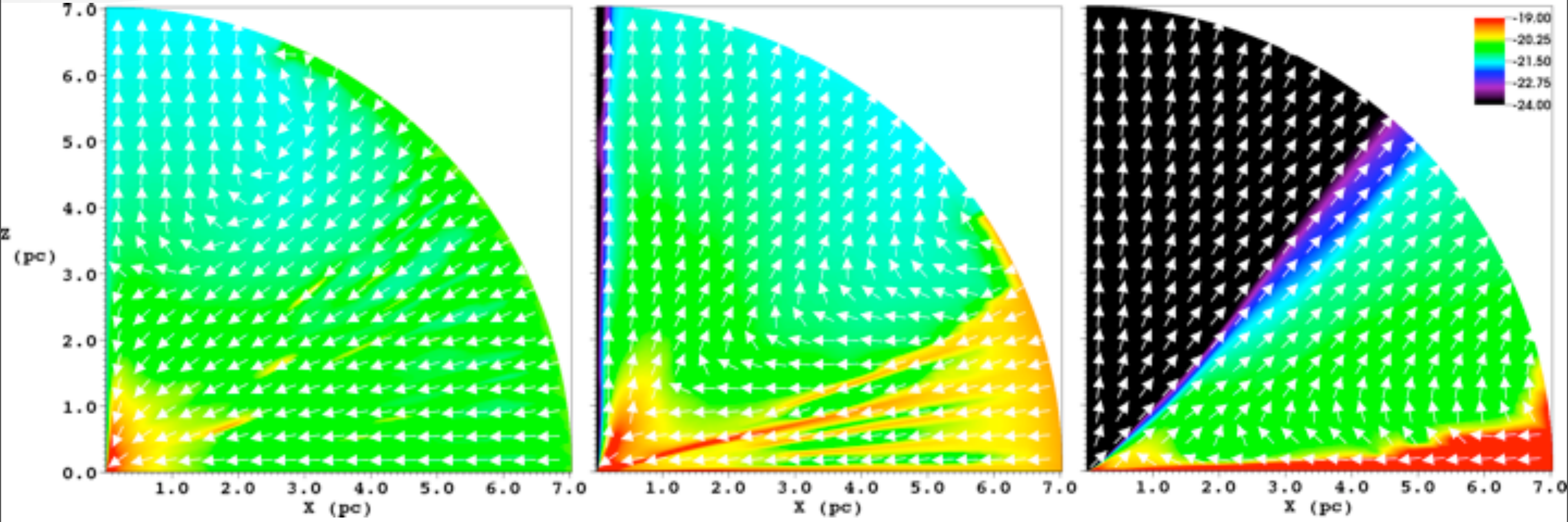


Kurosawa & DP (2009b)

What is the geometry of the

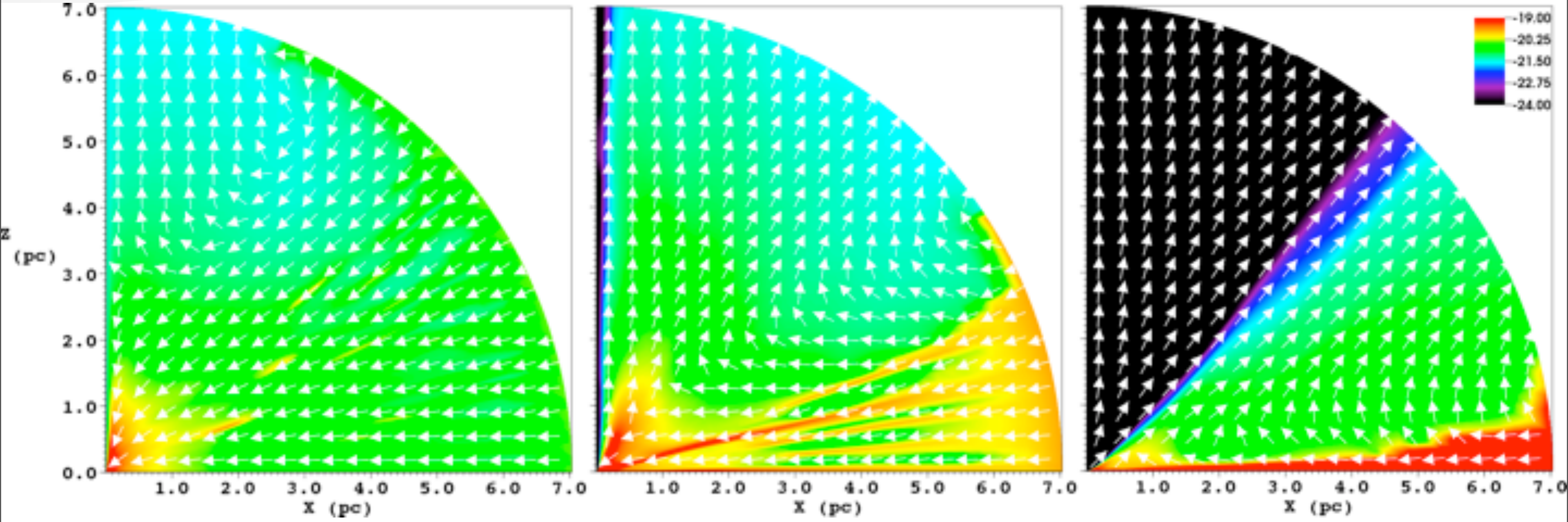


What is the geometry of the



jet like

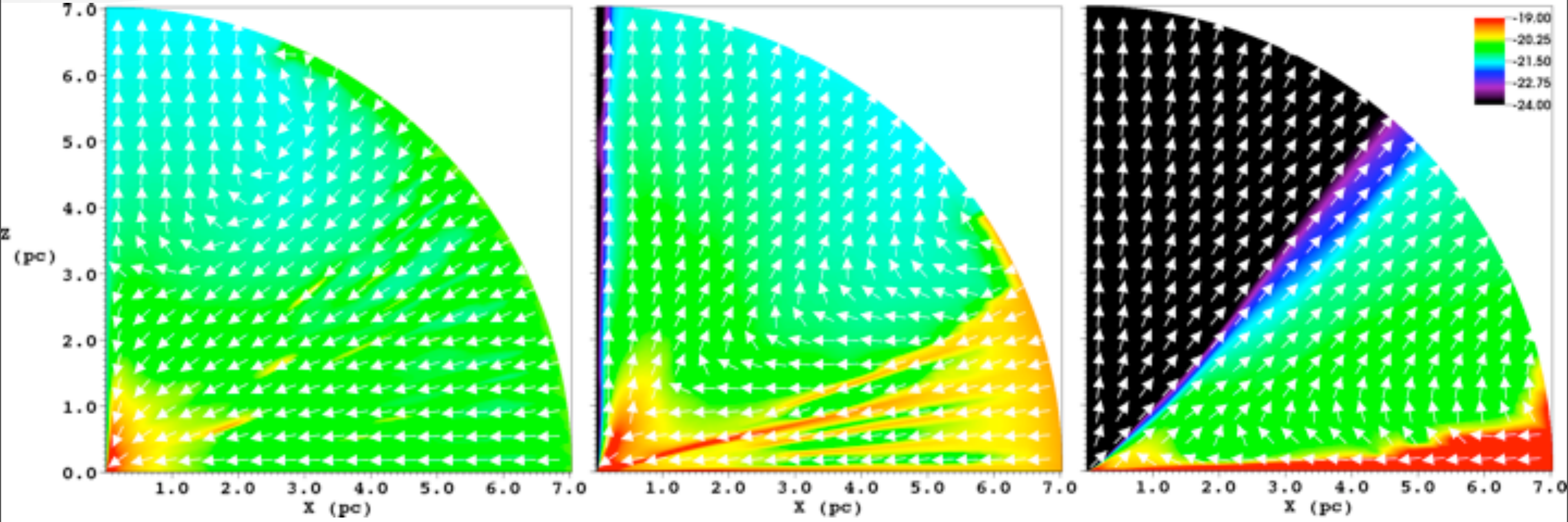
What is the geometry of the



jet like

i/o

What is the geometry of the

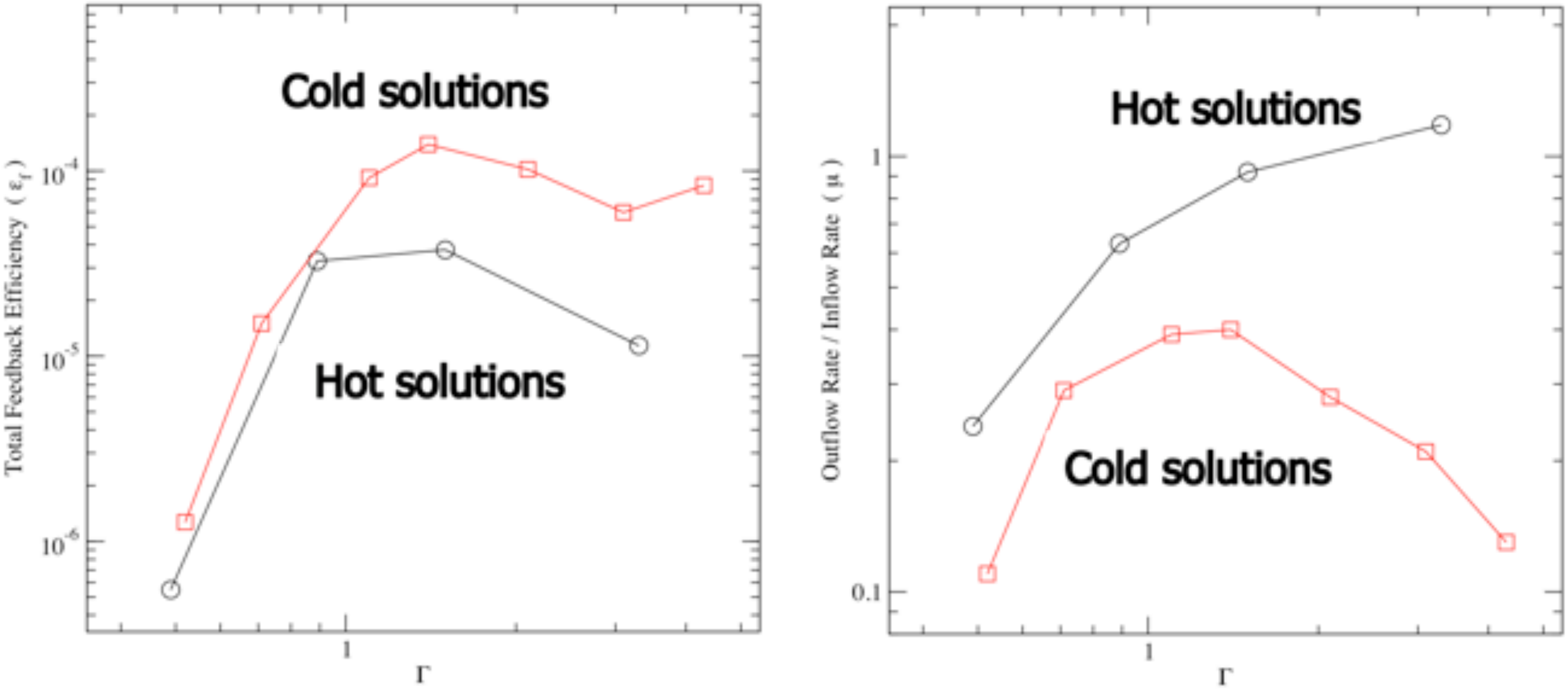


jet like

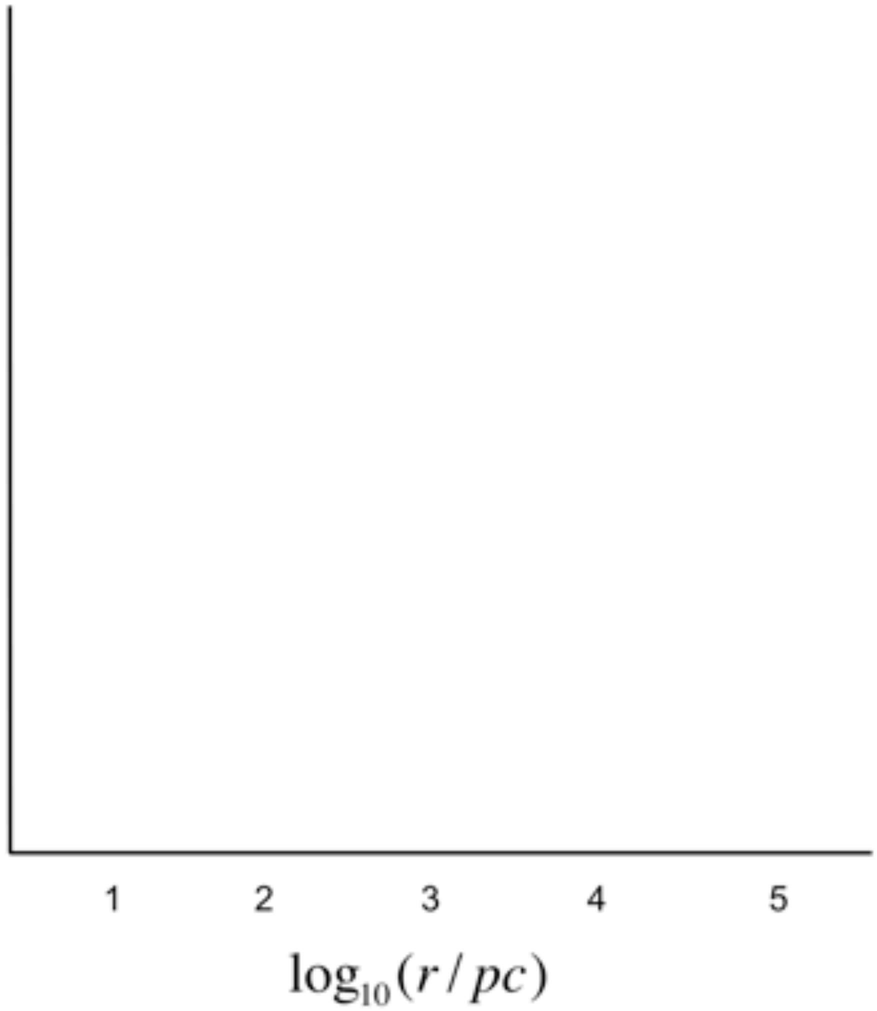
i/o

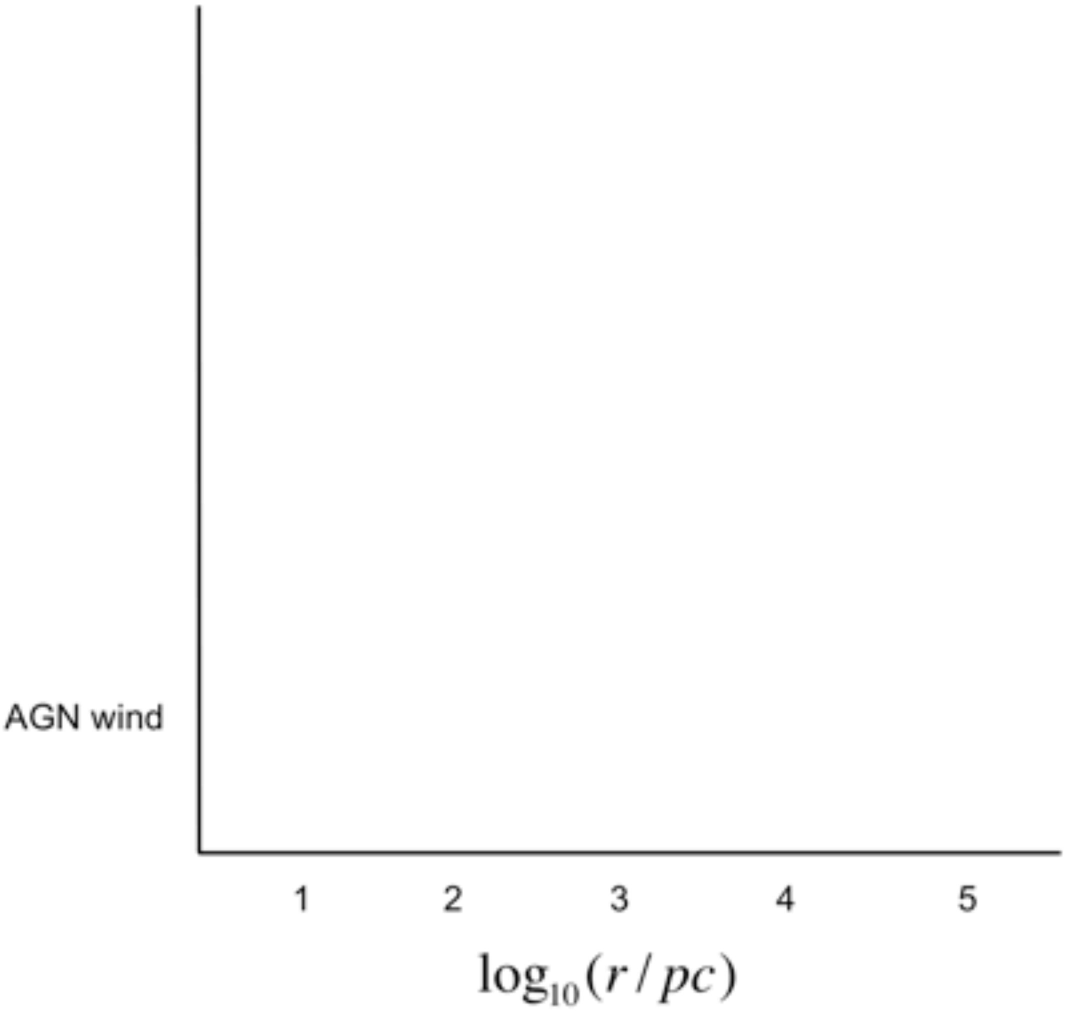
disk-wind like

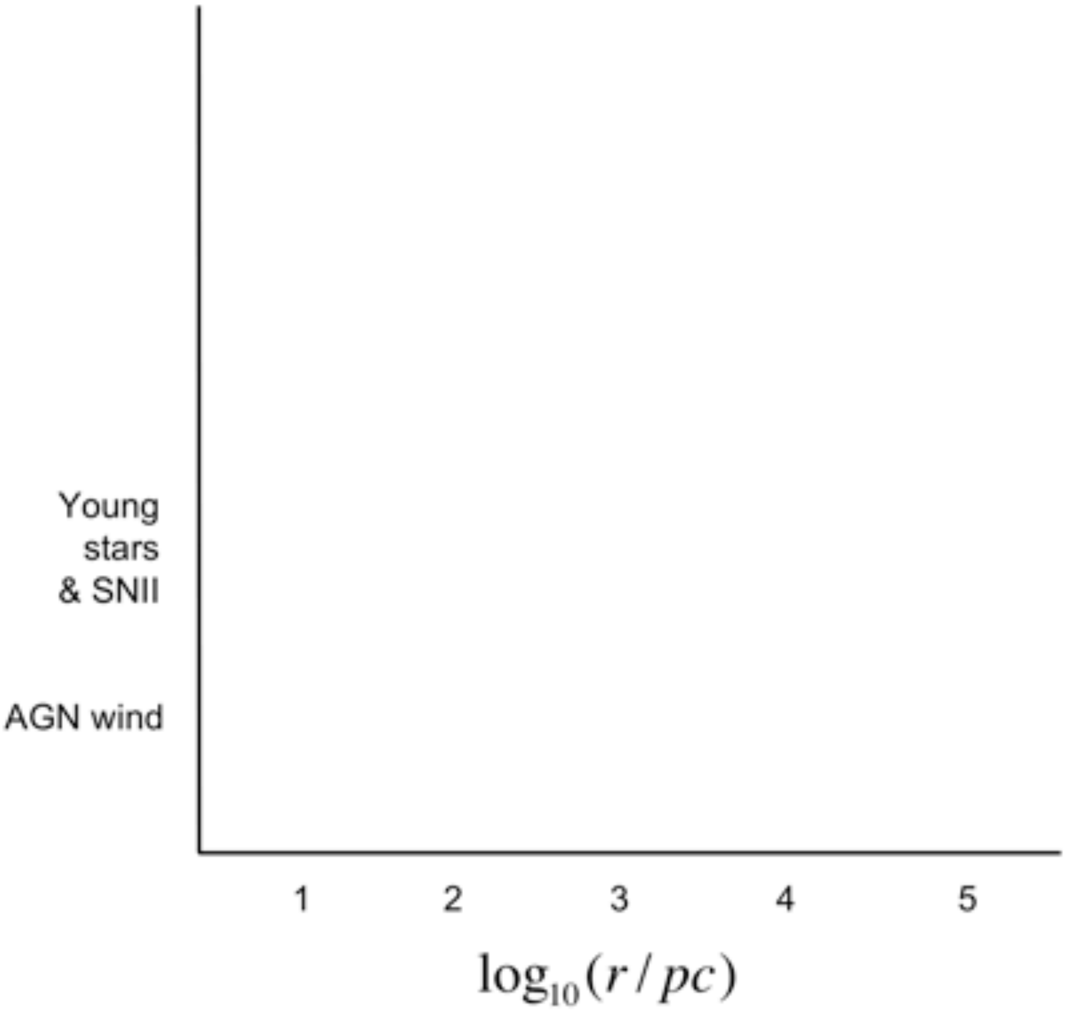
How efficient are the outflows?

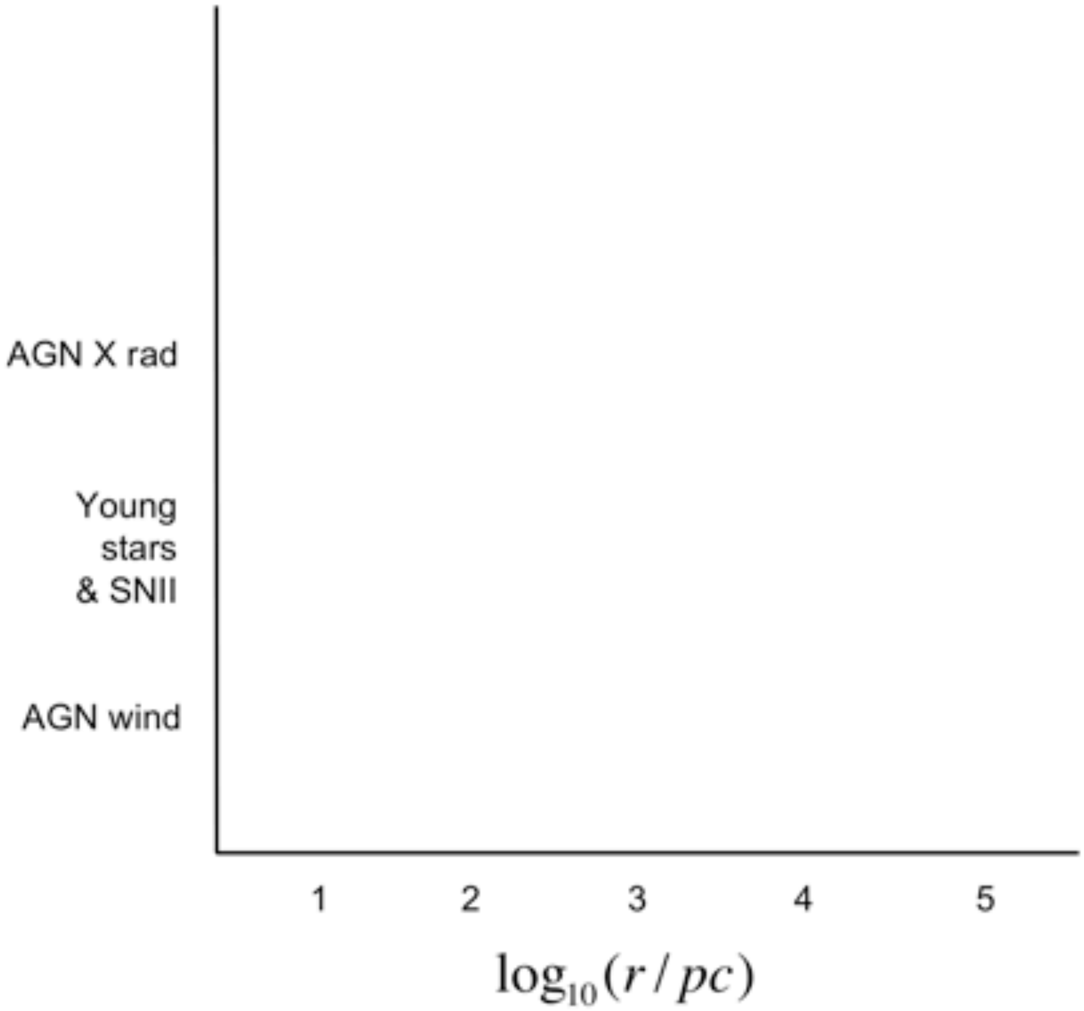


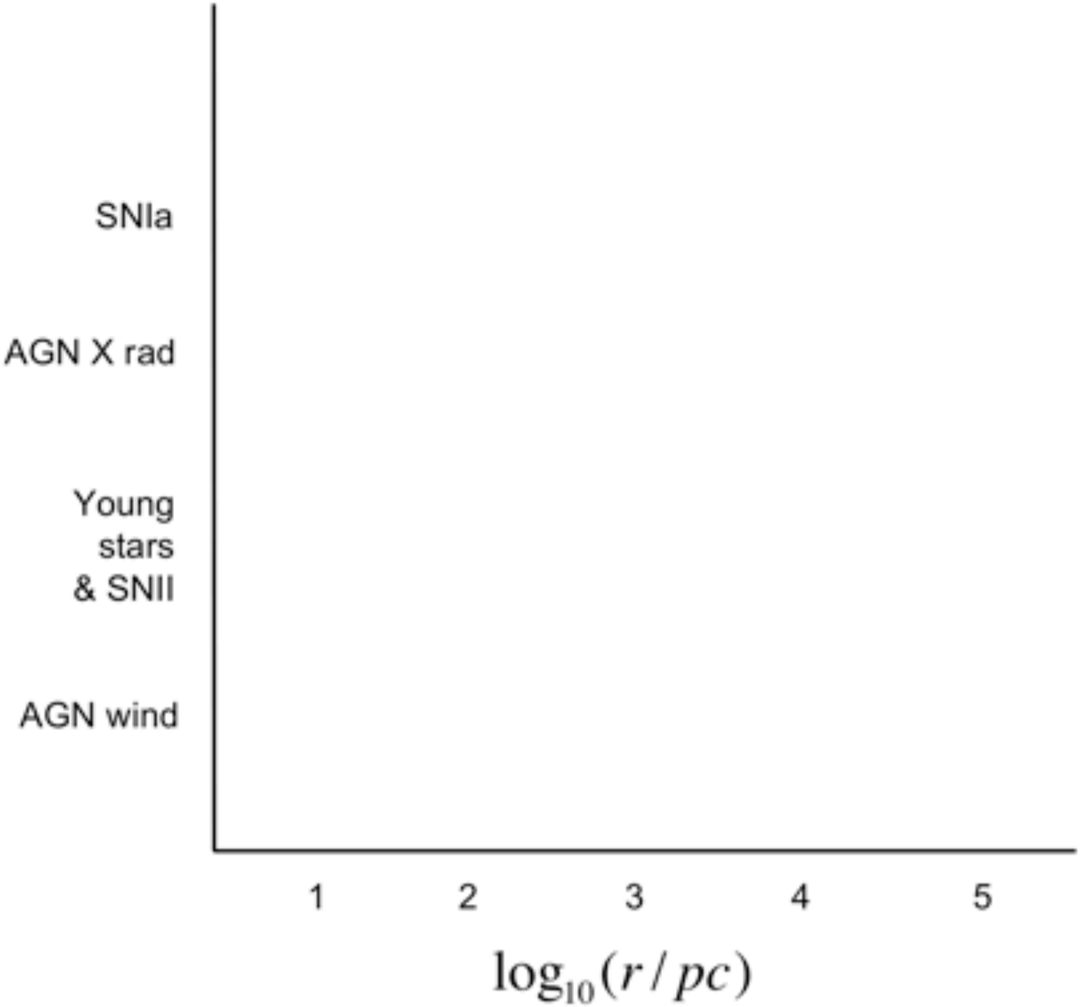
Kurosawa, DP, & Nagamine (2009)

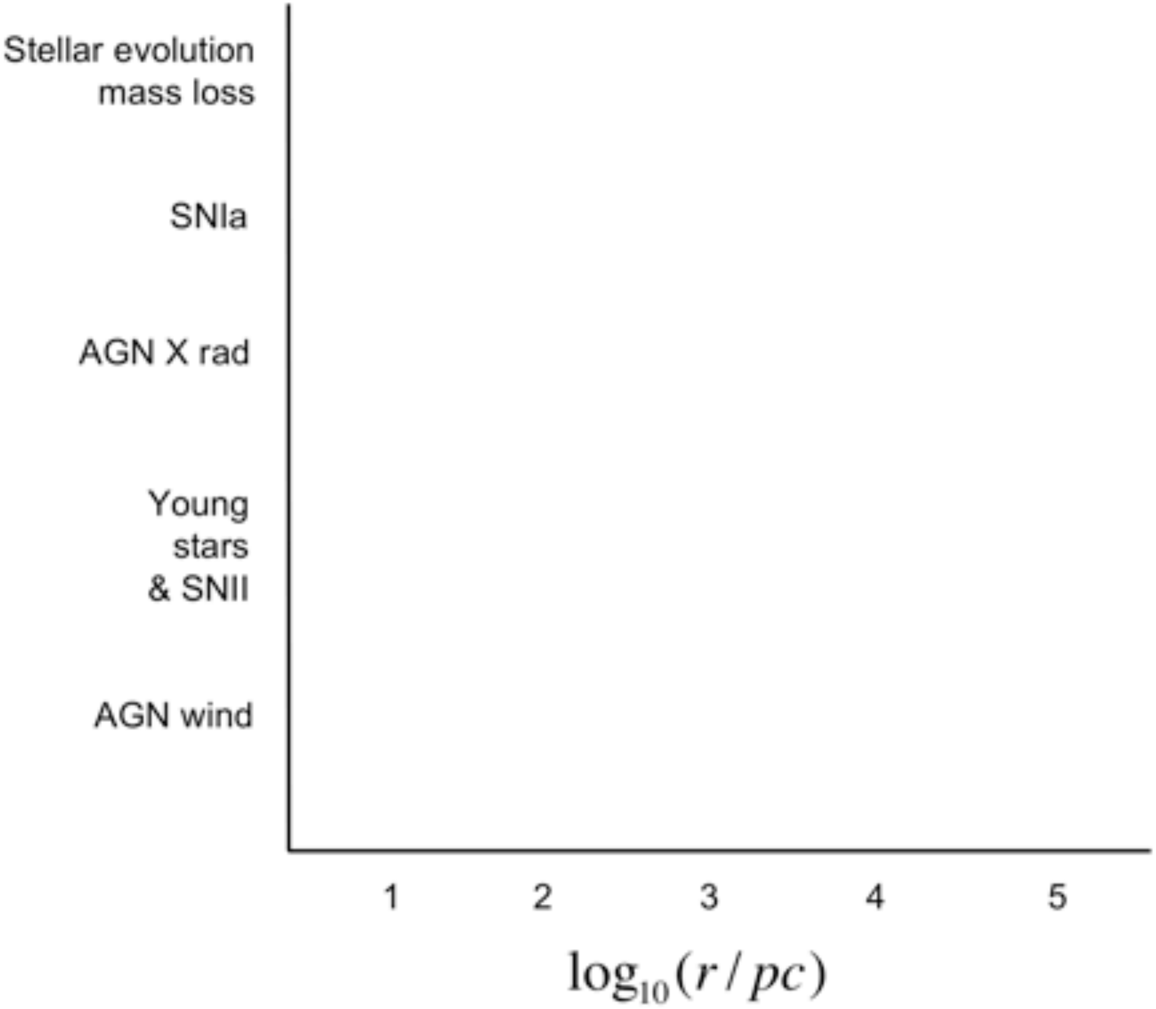

1
2
3
4
5
$\log_{10}(r/pc)$

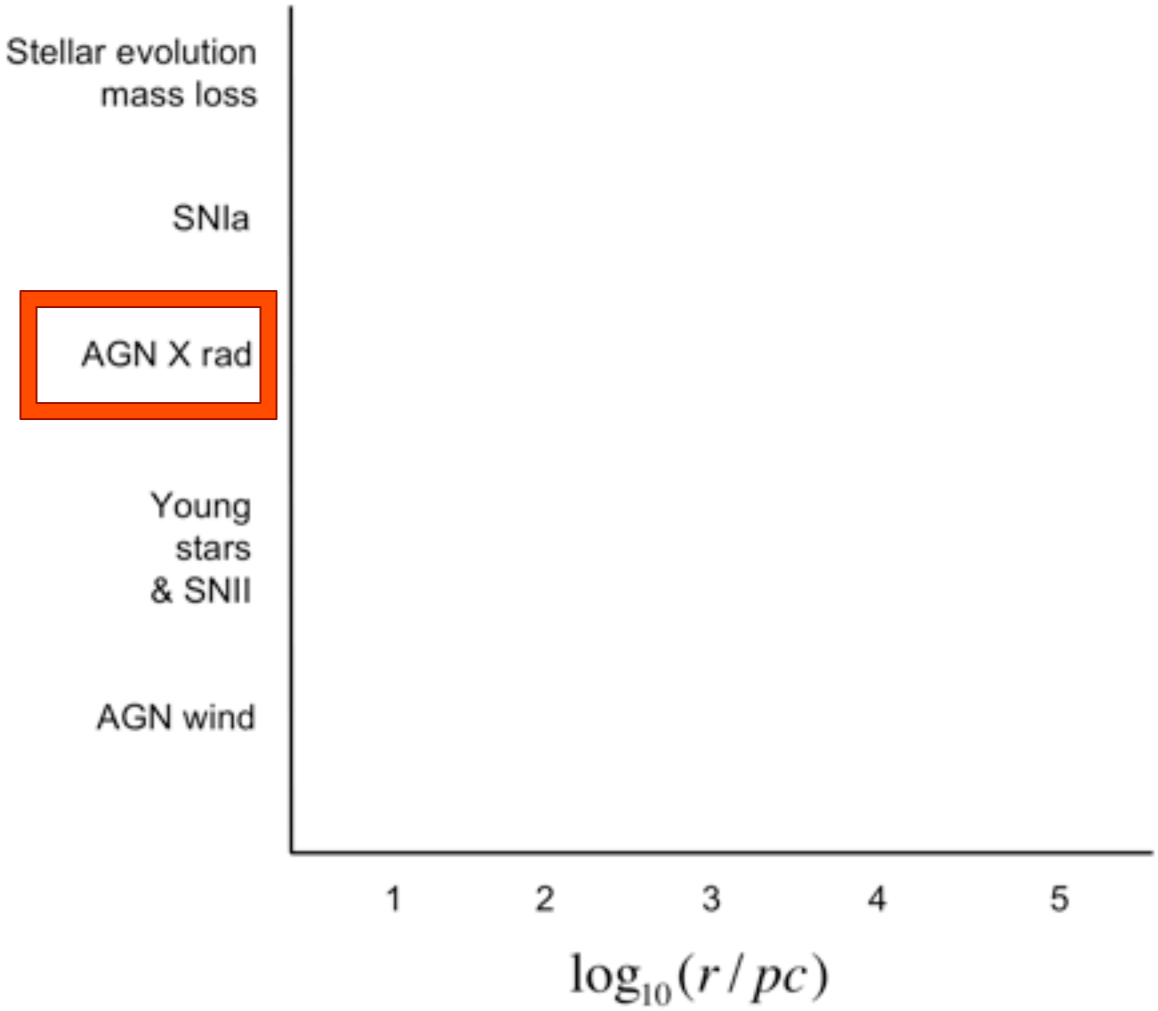

AGN wind
1
2
3
4
5
$\log_{10}(r/pc)$


Young
stars
& SNII
AGN wind
1
2
3
4
5
$\log_{10}(r/pc)$


AGN X rad
Young stars & SNII
AGN wind
1
2
3
4
5
$\log_{10}(r/pc)$


SNIa
AGN X rad
Young stars & SNII
AGN wind
1
2
3
4
5
$\log_{10}(r/pc)$


Stellar evolution mass loss
SNIa
AGN X rad
Young stars & SNII
AGN wind
1
2
3
4
5
$\log_{10}(r/pc)$


Stellar evolution mass loss
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AGN X rad
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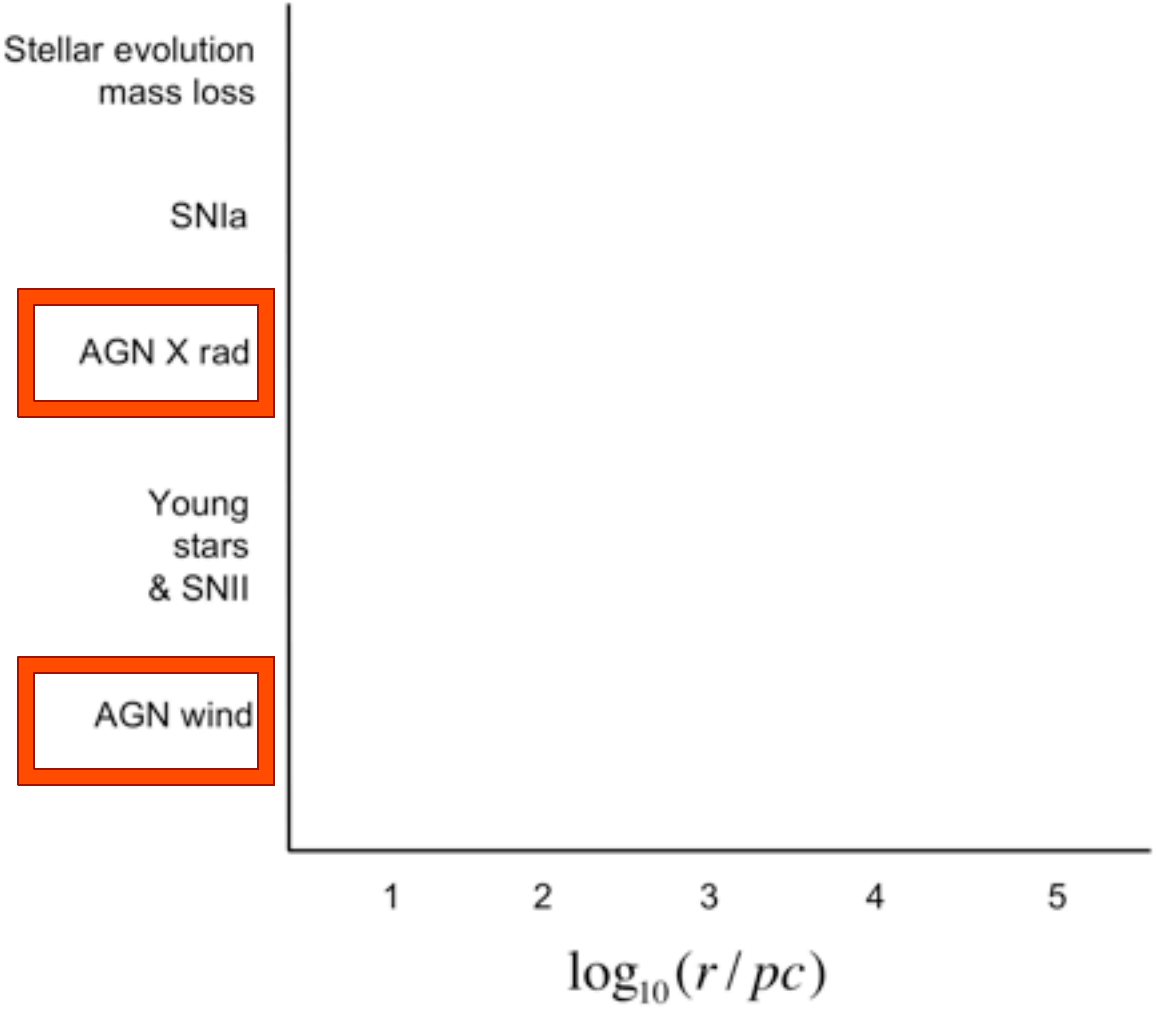


Stellar evolution mass loss

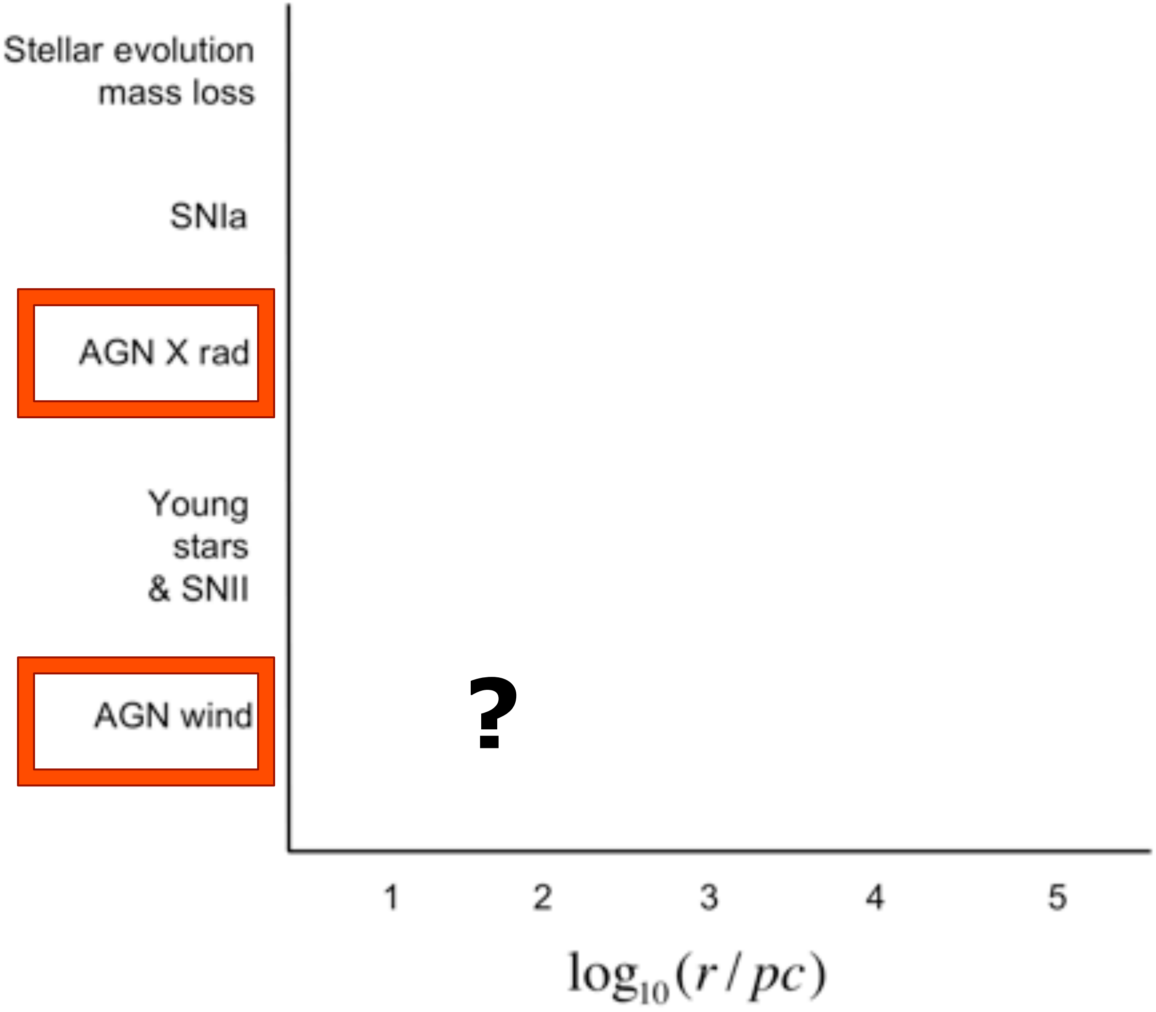
SNIa

AGN X rad

Young stars & SNII

AGN wind

$\log_{10}(r/pc)$


Stellar evolution mass loss
SNIa
AGN X rad
Young stars & SNII
AGN wind
?
1
2
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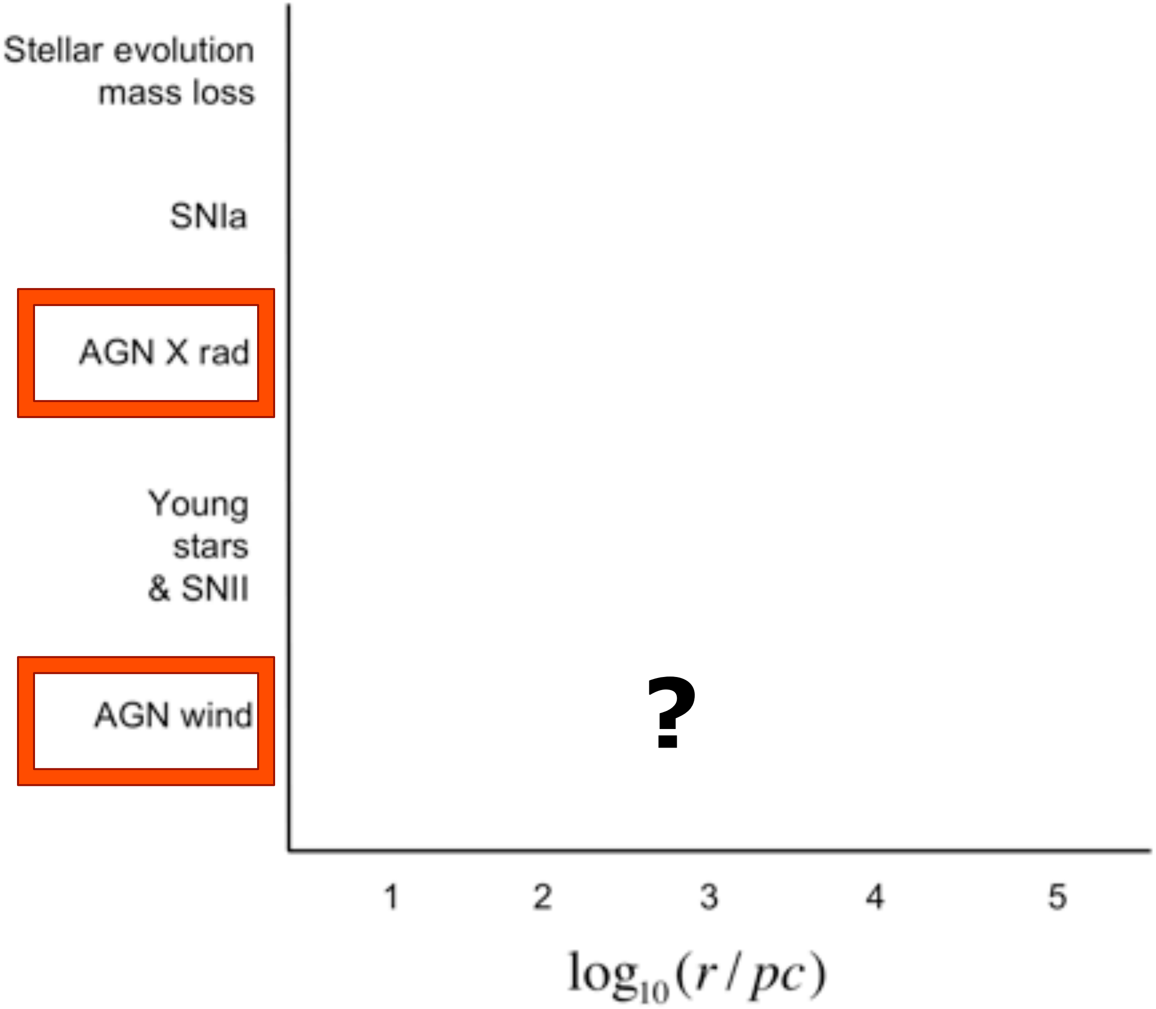
4
5
$\log_{10}(r/pc)$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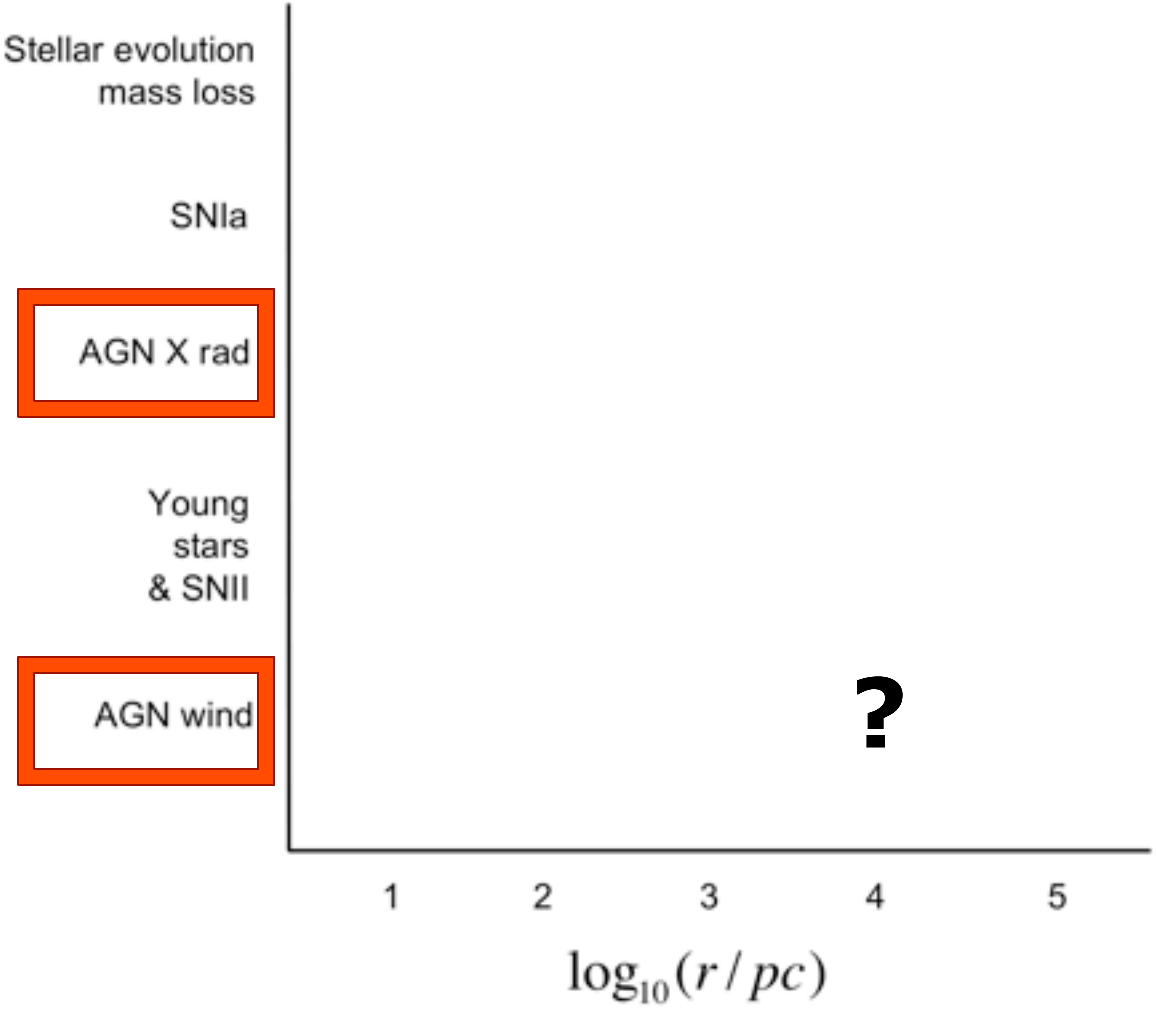
Stellar evolution mass loss
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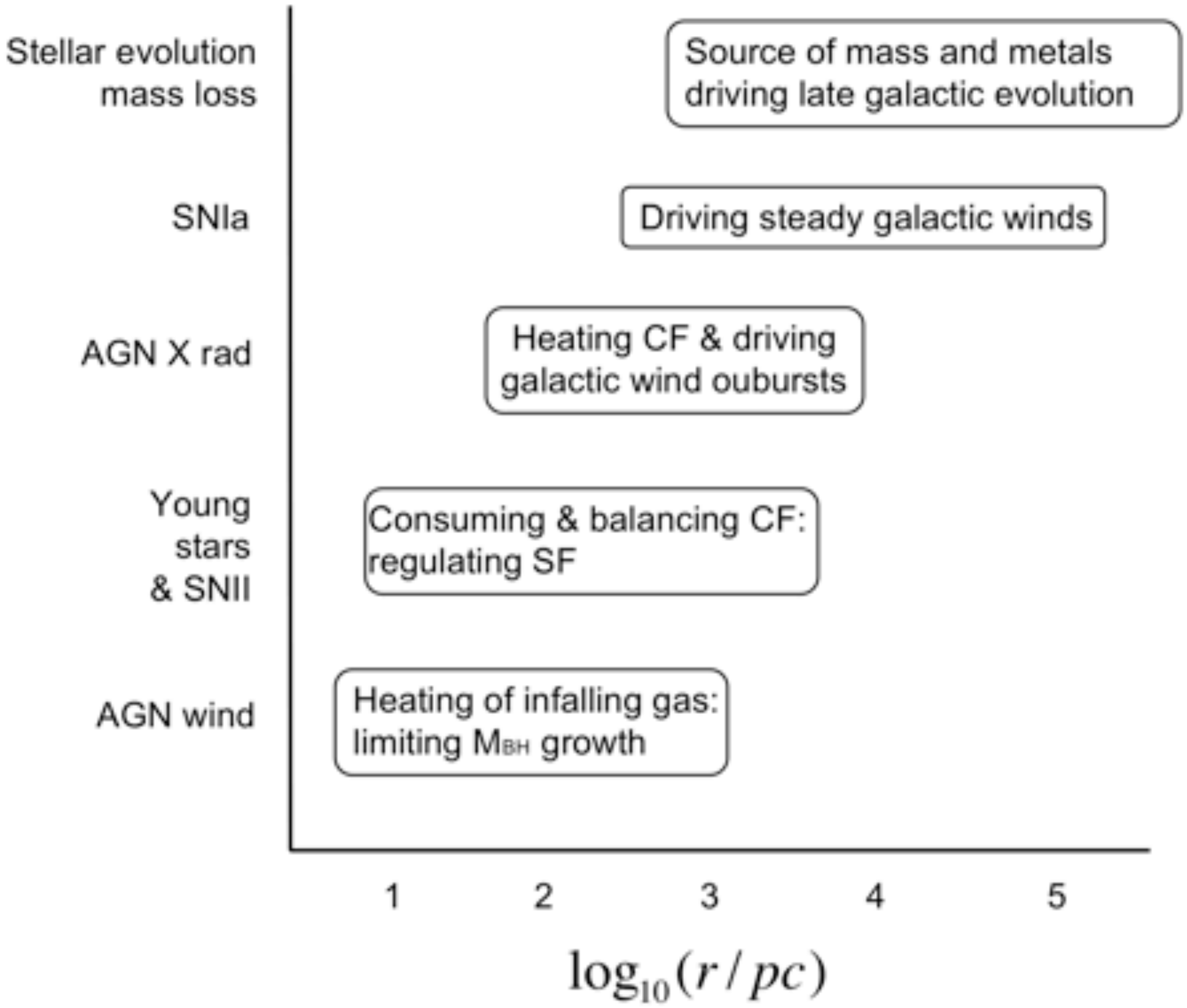

Stellar evolution mass loss

Source of mass and metals driving late galactic evolution

SNIa

Driving steady galactic winds

AGN X rad

Heating CF & driving galactic wind oubursts

Young stars & SNII

Consuming & balancing CF: regulating SF

AGN wind

Heating of infalling gas: limiting M_{BH} growth

Ciotti, Ostriker, & Proga (to be submitted to ApJ)

Conclusions

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- Simulations of accretion flows and their outflows provide important insights into the dynamics and geometry of the material that produces radiation. In particular, we can use the simulations to assess the effects of radiation on the flow properties. We can also explore coupling between accretion flows and they outflows as well as mass supply (e.g., various forms of feedback).

Conclusions

- Simulations of accretion flows and their outflows provide important insights into the dynamics and geometry of the material that produces radiation. In particular, we can use the simulations to assess the effects of radiation on the flow properties. We can also explore coupling between accretion flows and they outflows as well as mass supply (e.g., various forms of feedback).
- The simulations can be and are used to compute synthetic spectra for direct comparison with the observations. As such, the simulations are useful in explaining specific spectral features as well as overall shape of the SED (not just pretty movies with complex equations/physics behind).