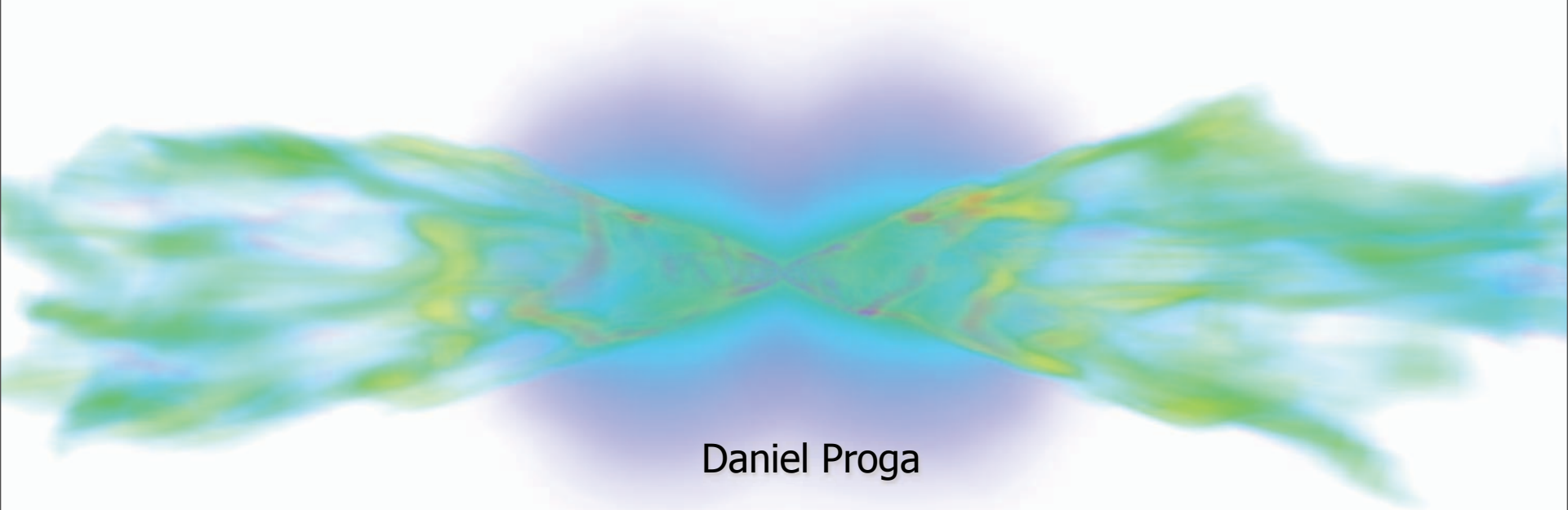
Simulations of Winds



Daniel Proga

University of Nevada, Las Vegas

Princeton University

Collaborators

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

OUTLINE

OUTLINE

1. Introduction

OUTLINE

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

OUTLINE

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

 - thermal expansion

OUTLINE

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

- thermal expansion
- radiation pressure

OUTLINE

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

- thermal expansion
- radiation pressure
- magnetic fields (please see other talks in this session)

OUTLINE

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

- thermal expansion
- radiation pressure
- magnetic fields (please see other talks in this session)
- and in some combinations.

OUTLINE

1. Introduction
2. Multidimensional, time-dependent simulations of disk winds driven by:
   - thermal expansion
   - radiation pressure
   - magnetic fields (please see other talks in this session)
   - and in some combinations.
3. Conclusions

What can drive an outflow?

What can drive an outflow?

- Thermal expansion (evaporation, hydrodynamical escape)

What can drive an outflow?

- Thermal expansion (evaporation, hydrodynamical escape)
- Radiation pressure (gas, dust)

What can drive an outflow?

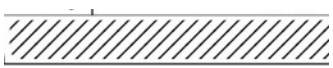
- Thermal expansion (evaporation, hydrodynamical escape)
- Radiation pressure (gas, dust)
- Magnetic fields

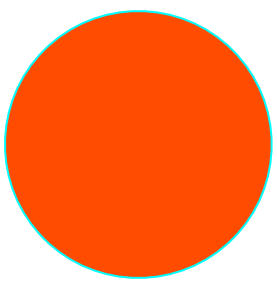
What can drive an outflow?

- Thermal expansion (evaporation, hydrodynamical escape)
- Radiation pressure (gas, dust)
- Magnetic fields

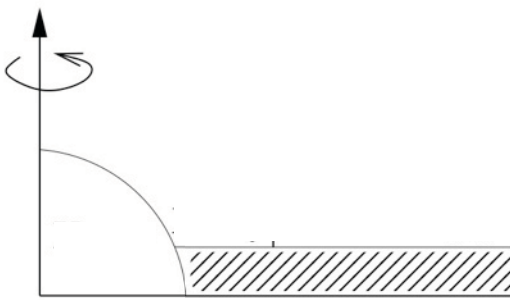
In most cases, rotation plays a key role (directly or indirectly) especially in AD.

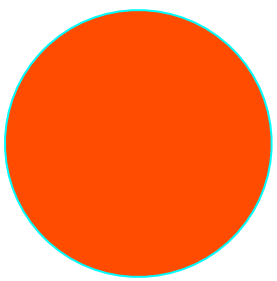
Accretion Disks vs Stars



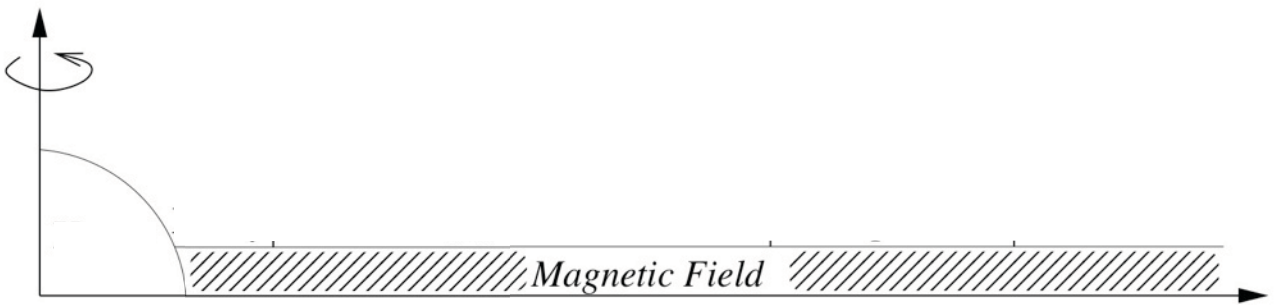


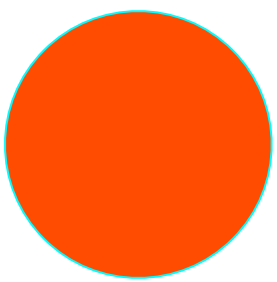
Accretion Disks vs Stars



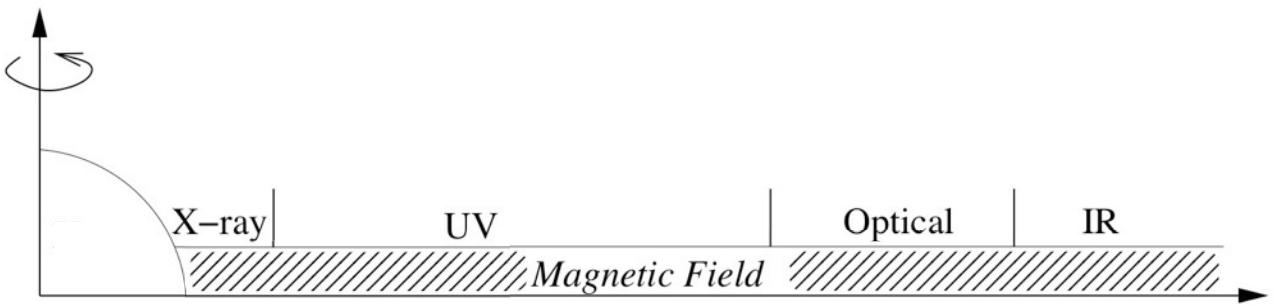


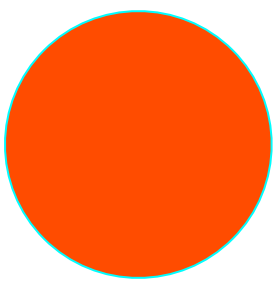
Accretion Disks vs Stars



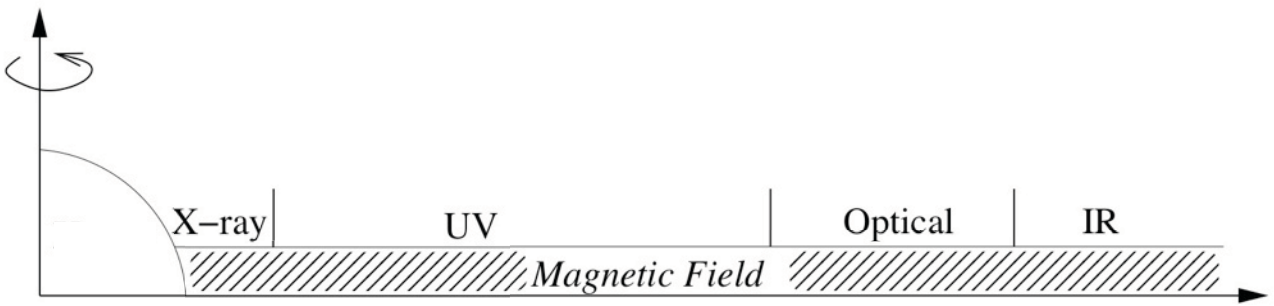


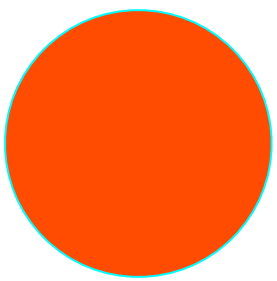
Accretion Disks vs Stars





Accretion Disks vs Stars

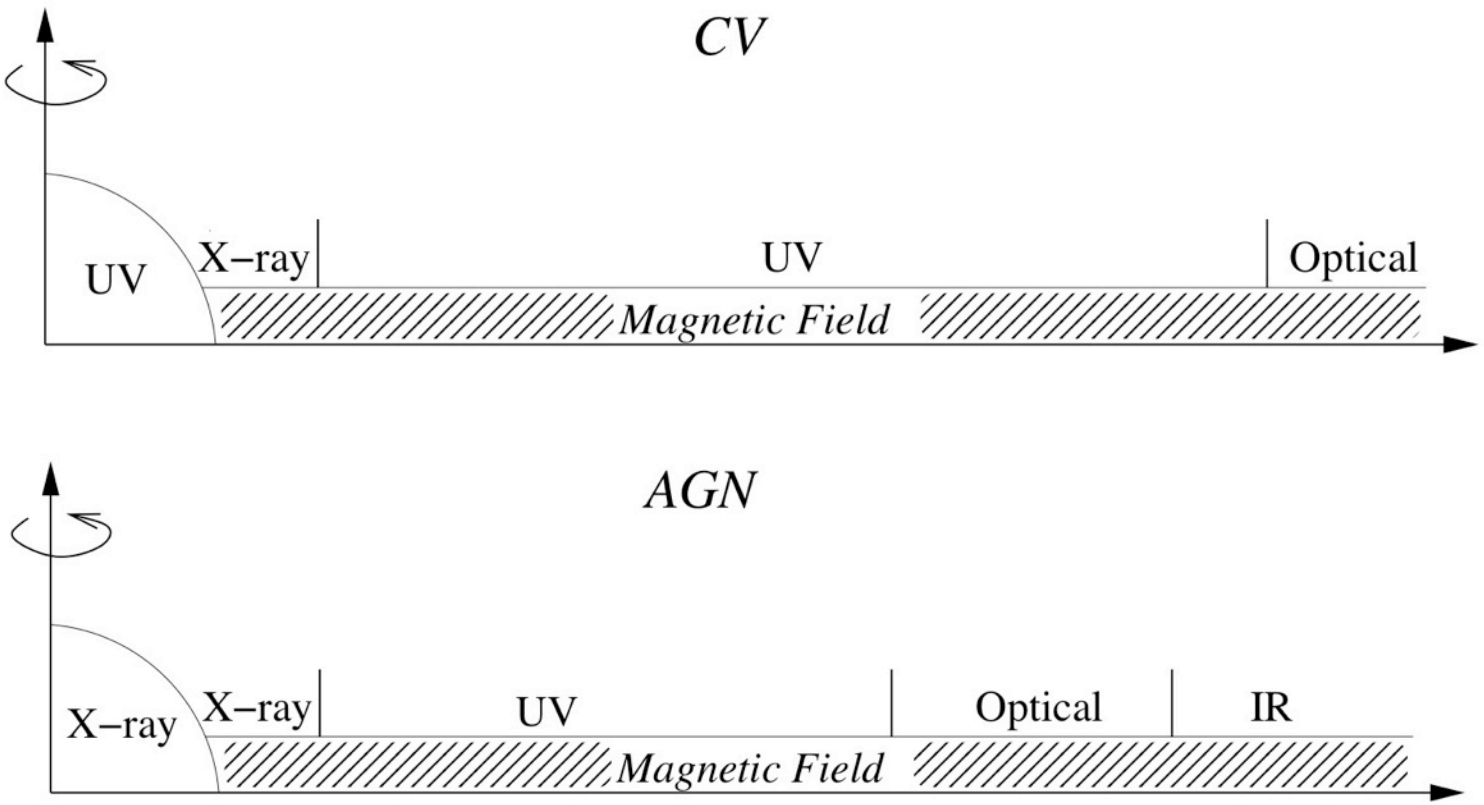




See a poster by Tim Waters

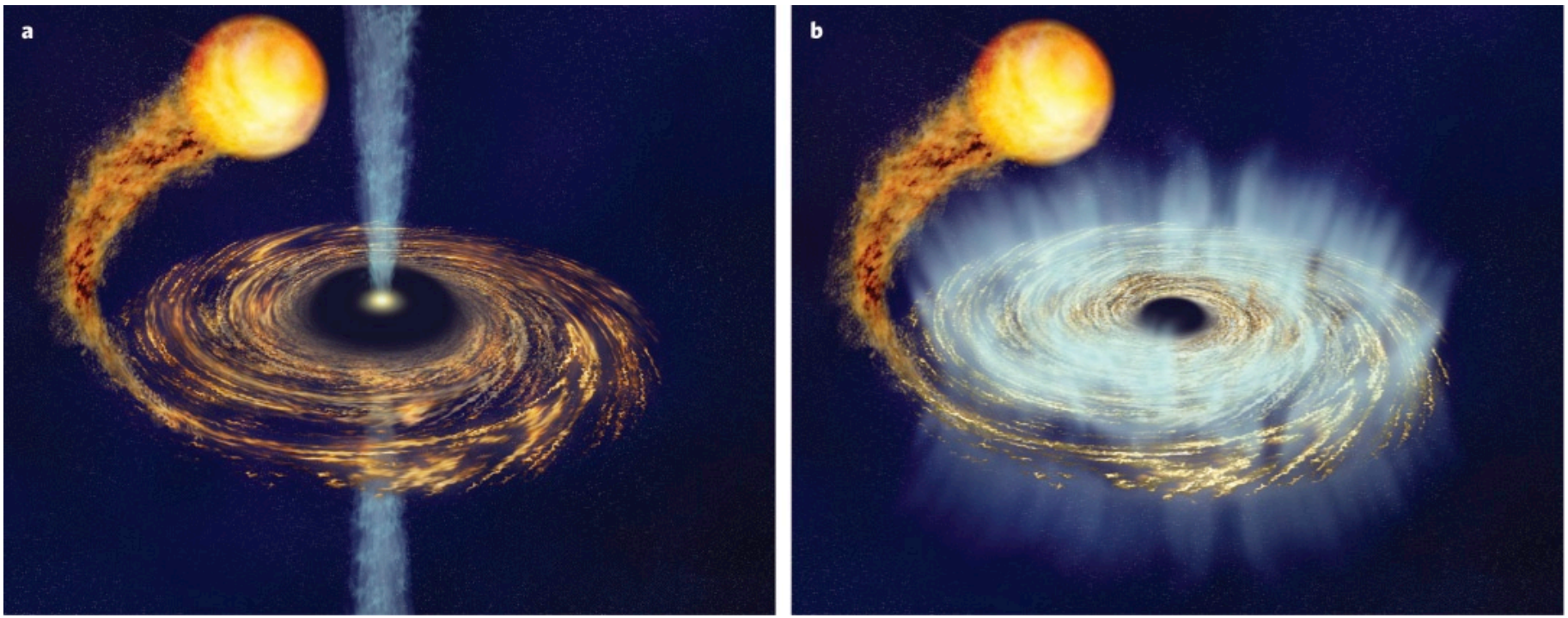
Accretion Disks in Various Objects

Two examples:



Thermal Disk Winds

GRS 1915-105

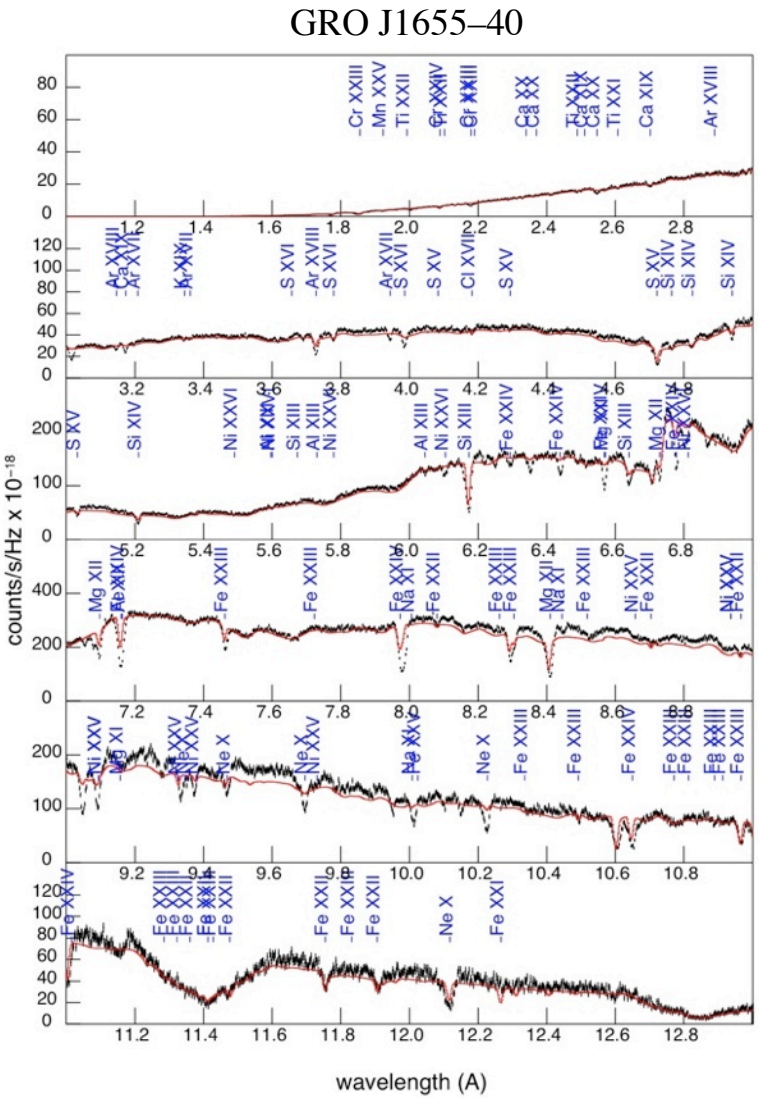


Neilsen & Lee (2009)

fig. from DP'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" ... !!!
- future ... ATHENA?



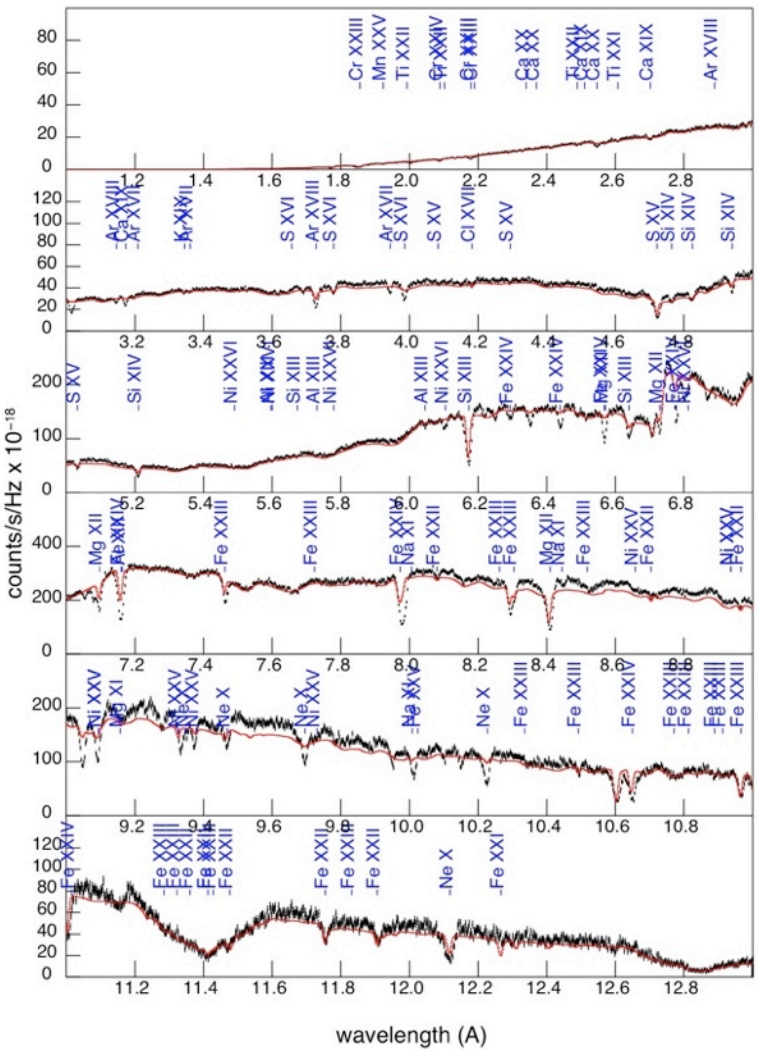
Observations: Miller et al. (2006)

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)

$$R_{\rm IC} = \frac{GM_{\rm BH} m_{\rm p} \mu}{kT_{\rm IC}}$$

GRO J1655–40



Observations: Miller et al. (2006)

The equations of hydrodynamics

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

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

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

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

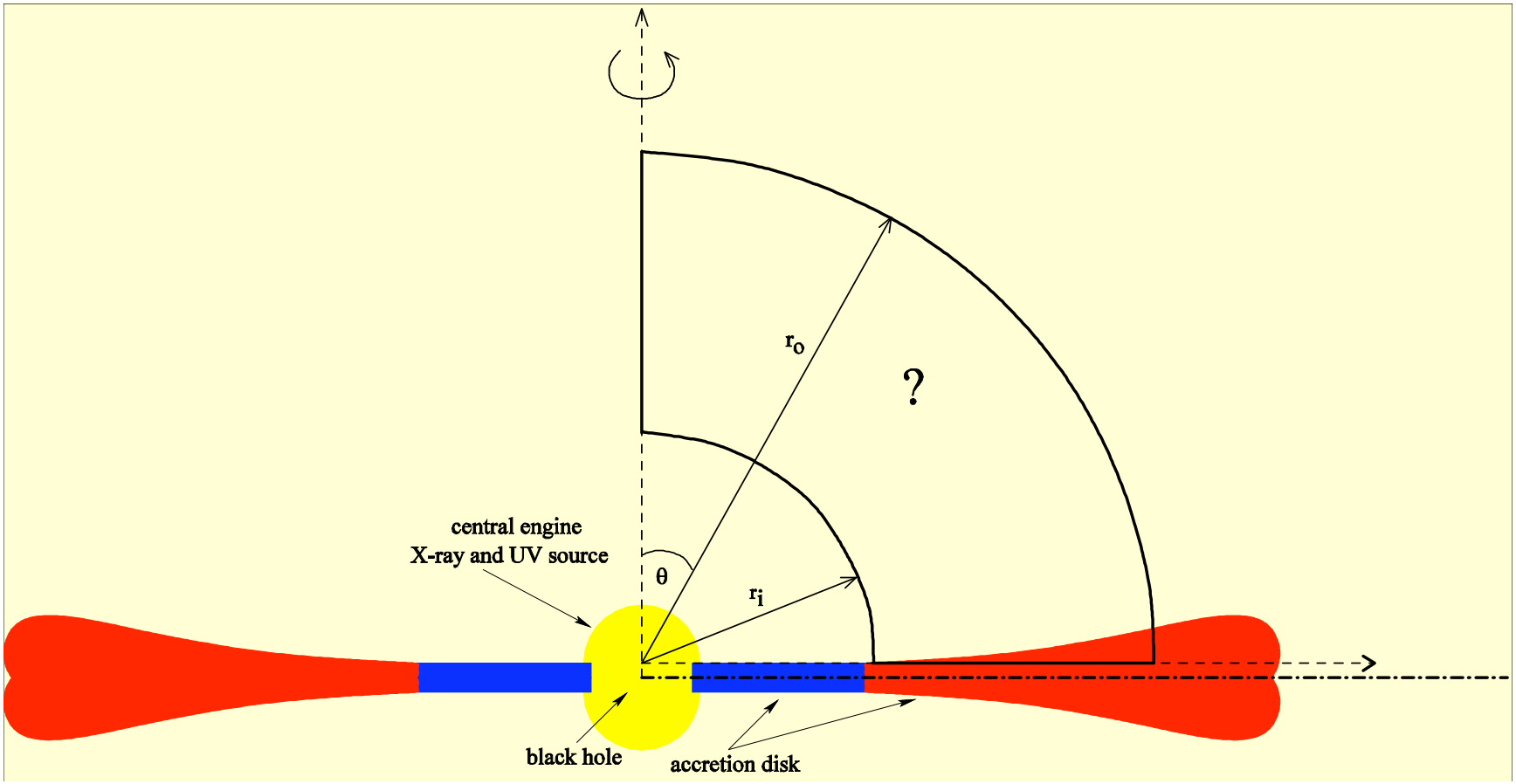
The equations of hydrodynamics

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

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

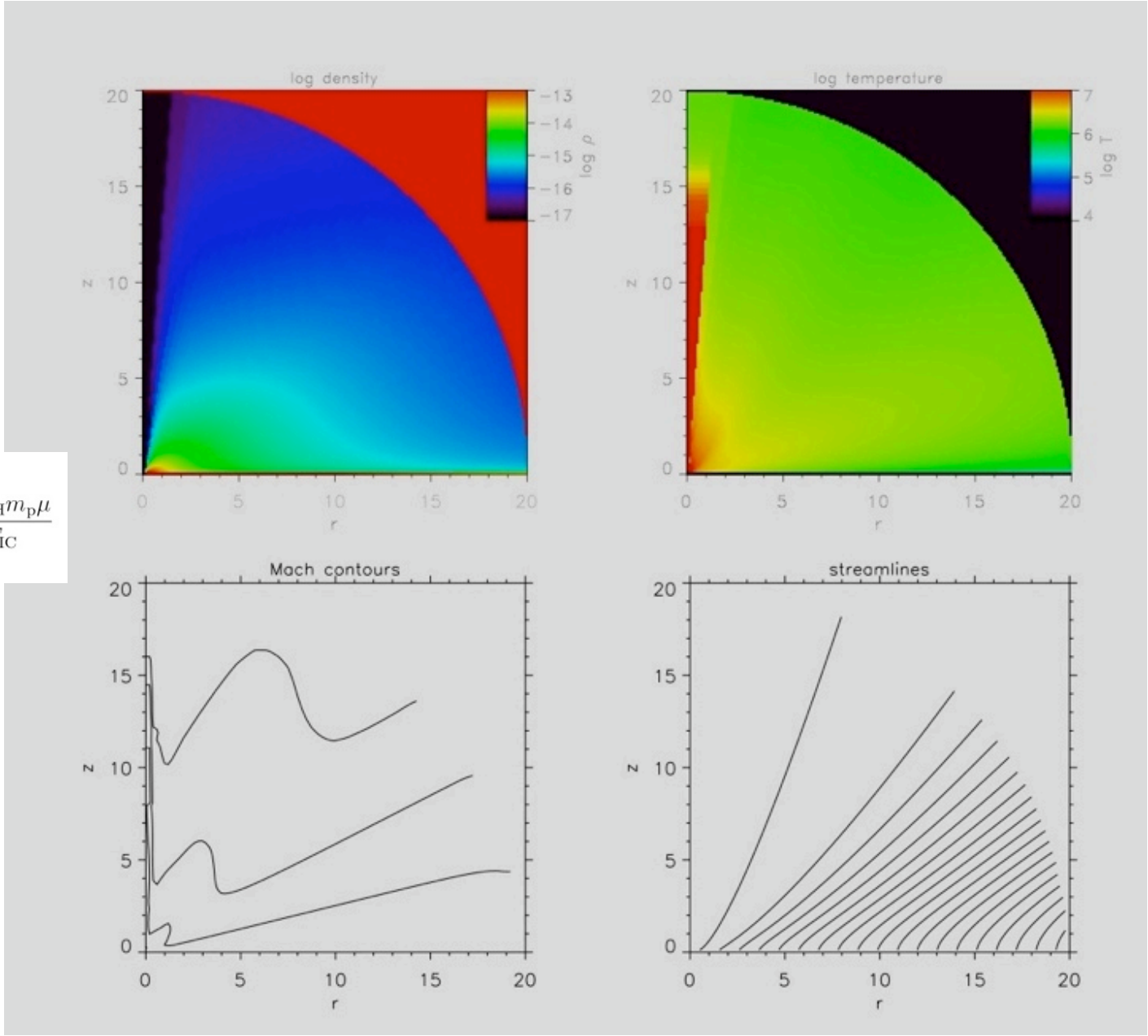
$$\rho\frac{D}{Dt}\left(\frac{e}{\rho}\right) = -P\nabla \cdot v + \rho L$$

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

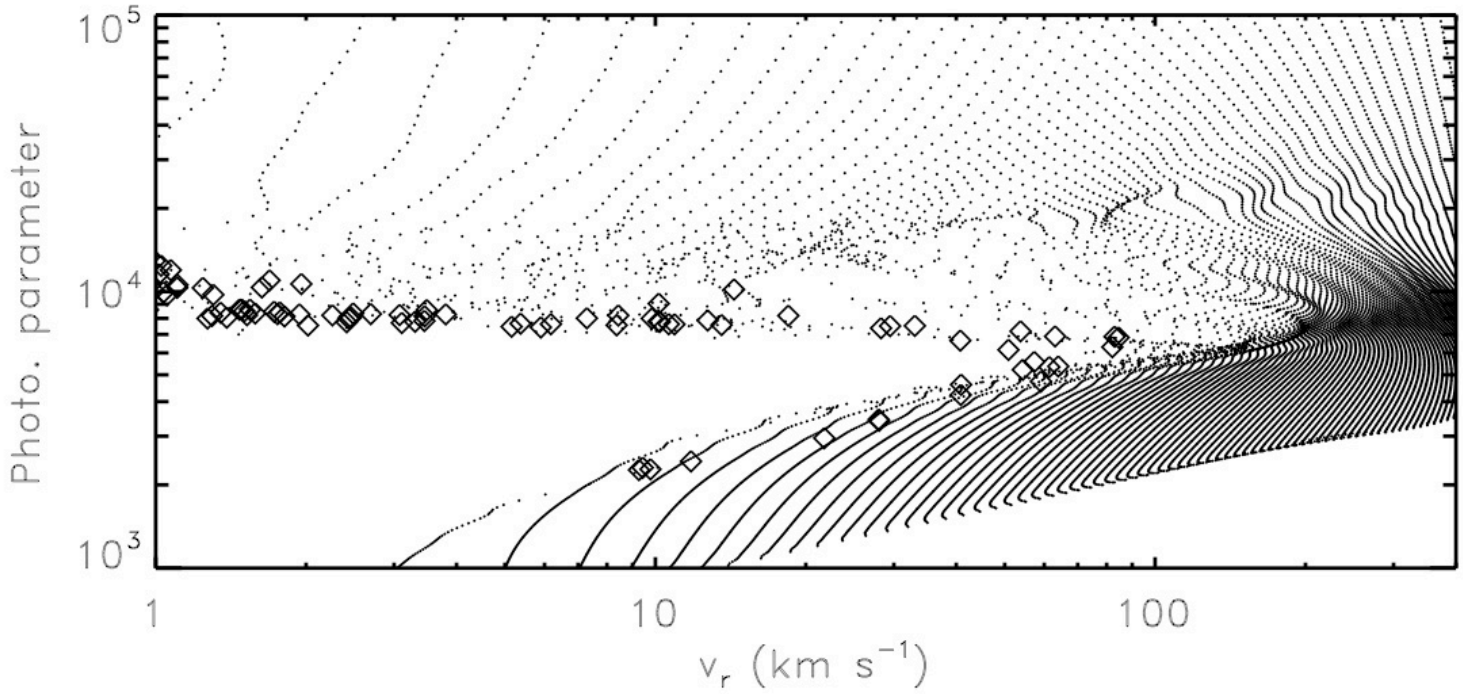


X-ray and UV source

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



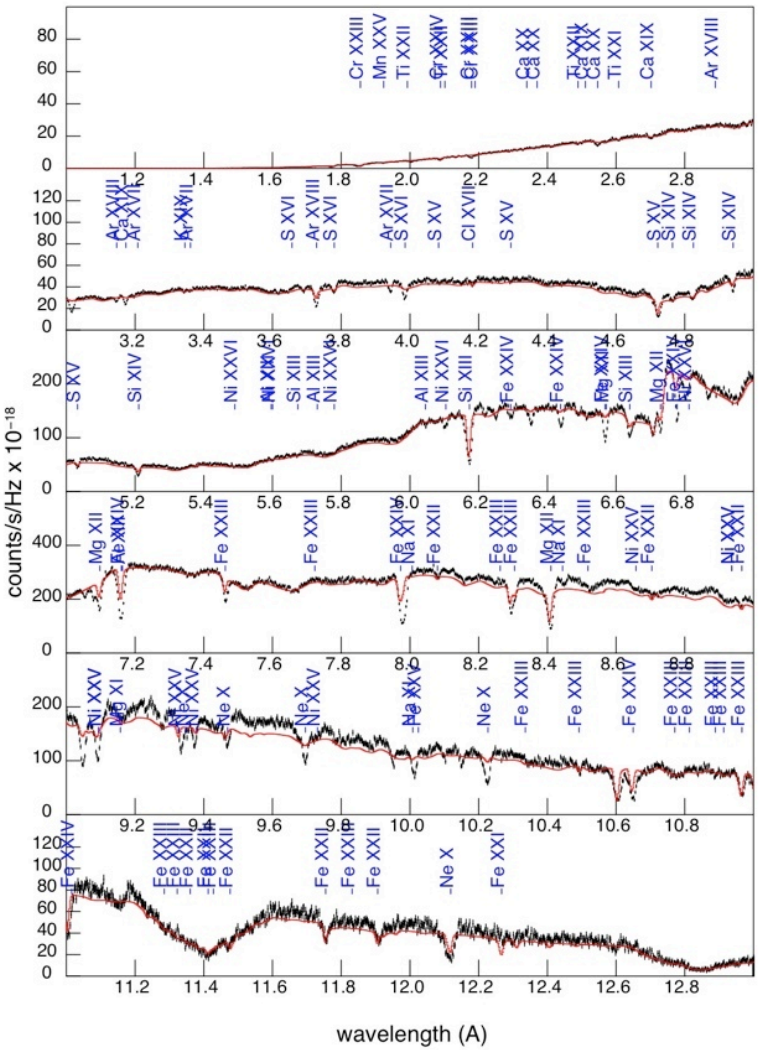
Luketic et al. (2010)



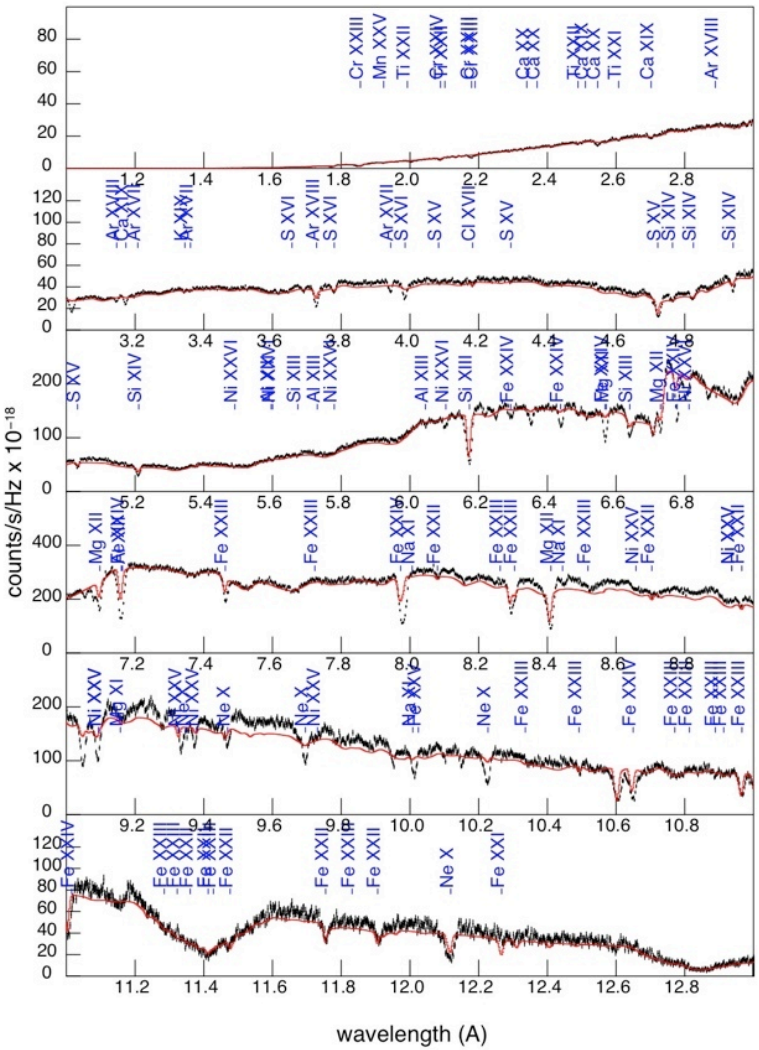
GRO J1655–40

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

GRO J1655–40



- 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 also Neilsen & Lee 2009)!



Radiation-Driven Winds

The equations of hydrodynamics

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

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

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

The equations of hydrodynamics

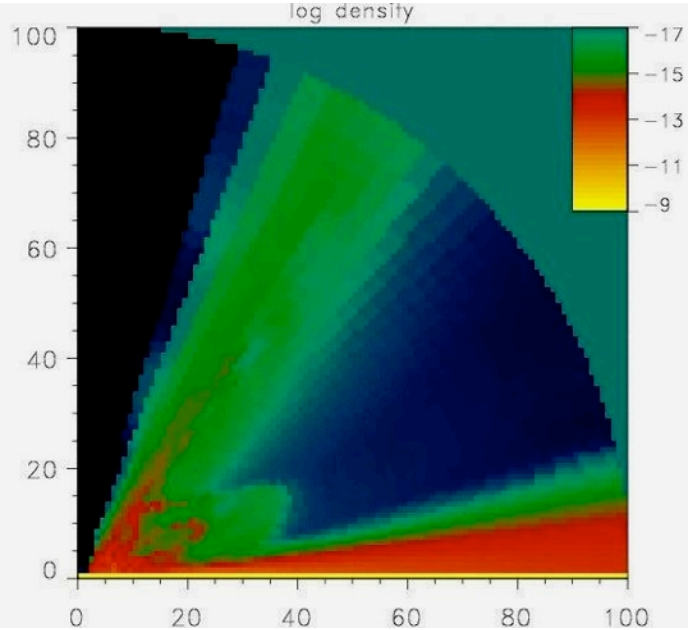
$$\frac{D\rho}{Dt} + \rho \nabla \cdot v = 0$$

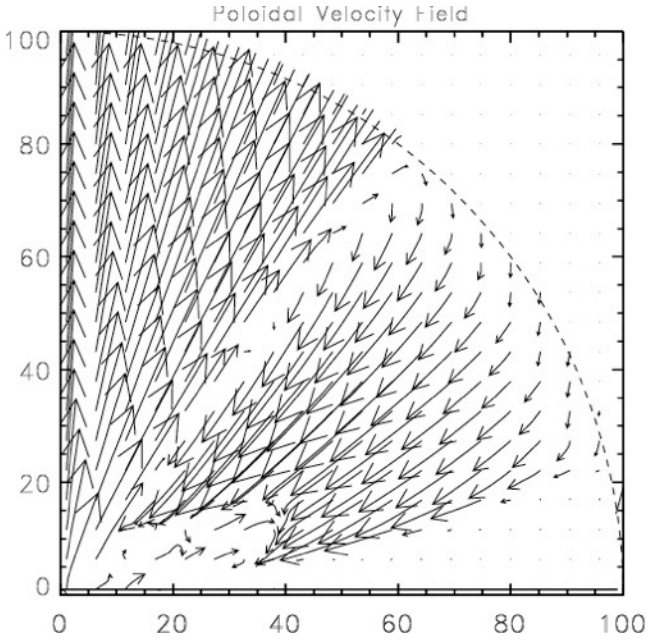
$$\rho \frac{Dv}{Dt} = -\nabla P + \rho g + \rho f^{rad}$$

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

L(disk)=3

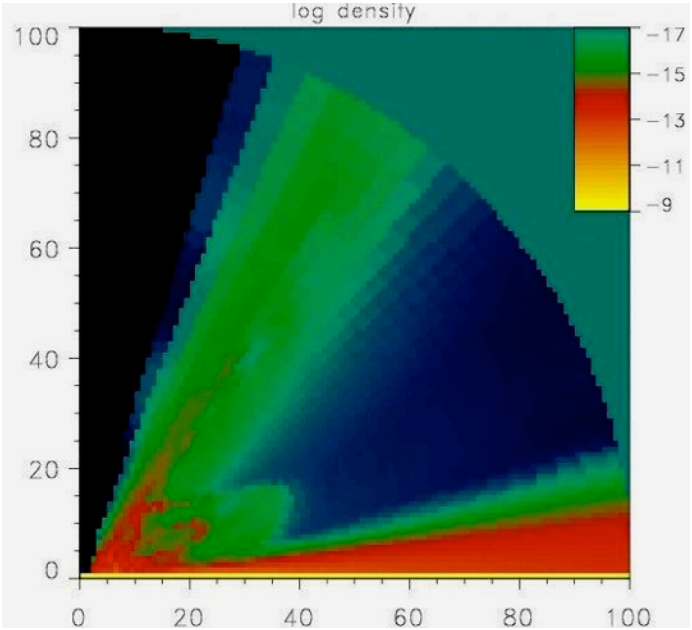
L(star)=0

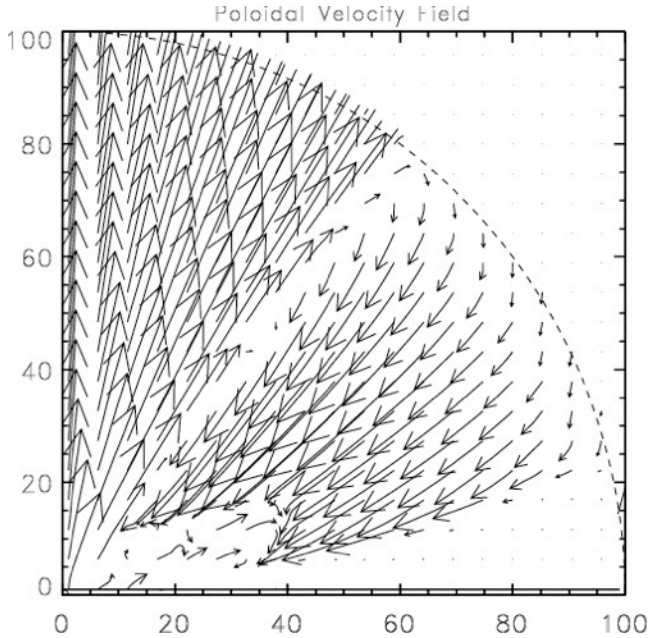




L(disk)=3

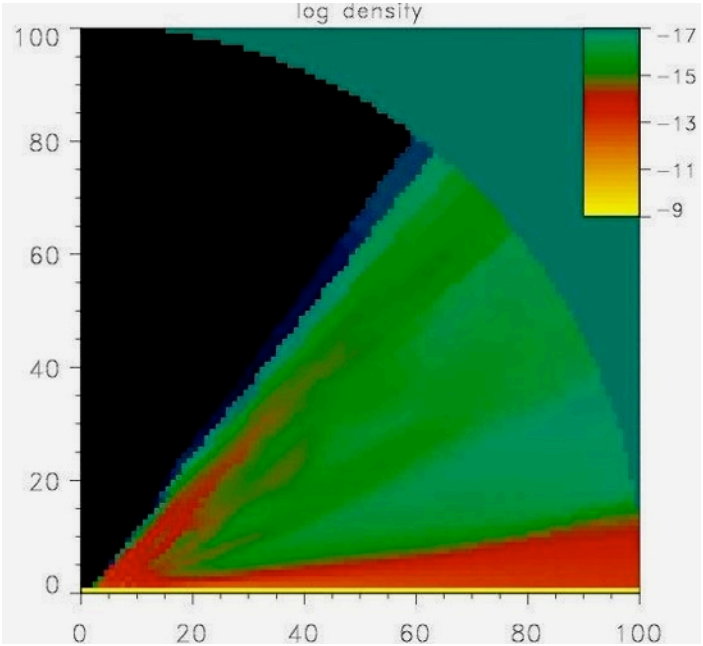
L(star)=0

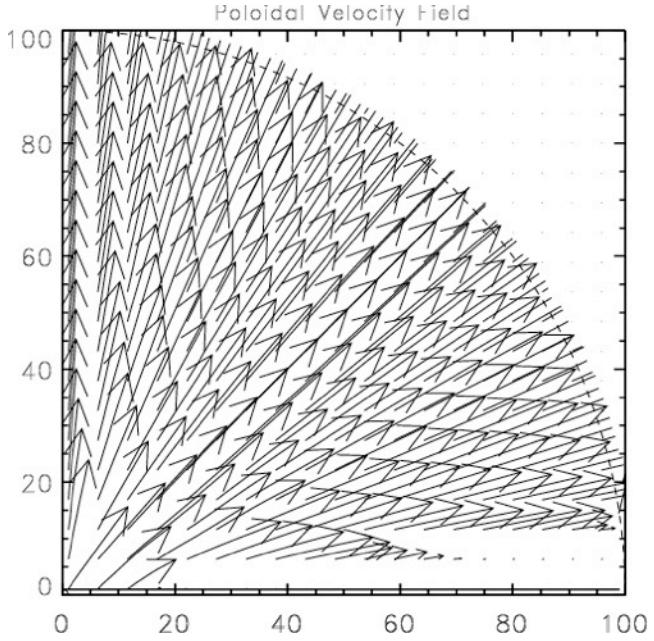




L(disk)=3

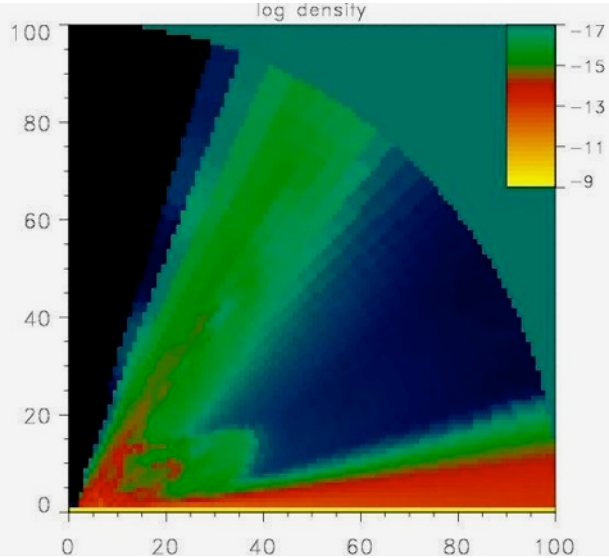
L(star)=3

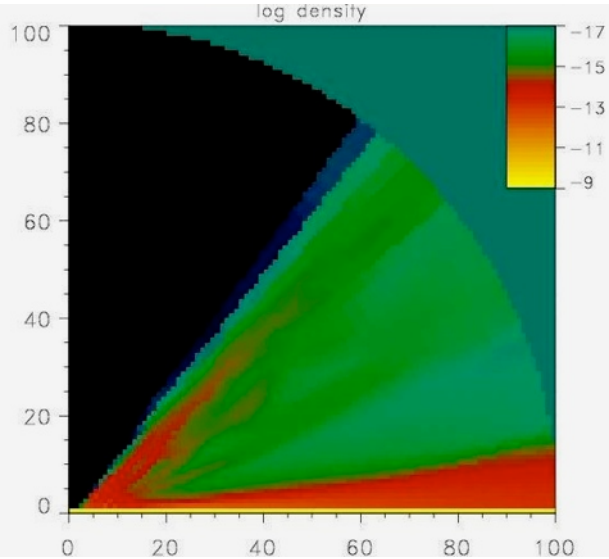




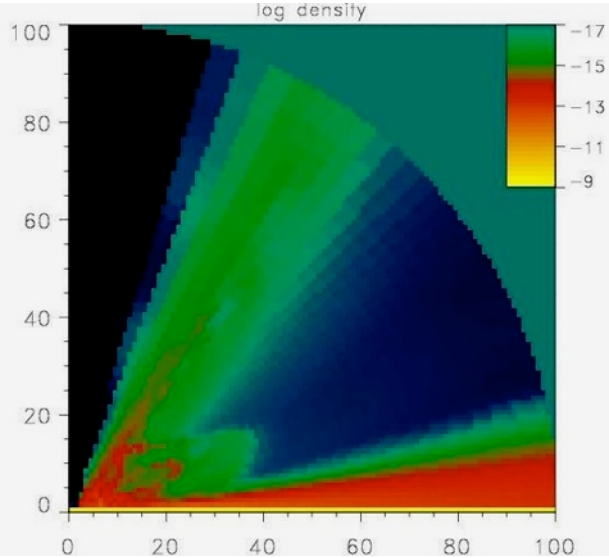
HD simulations and their line profiles

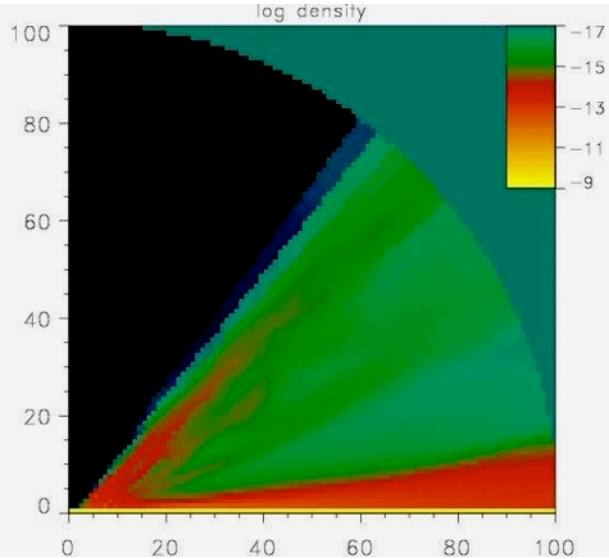
HD simulations and their line profiles

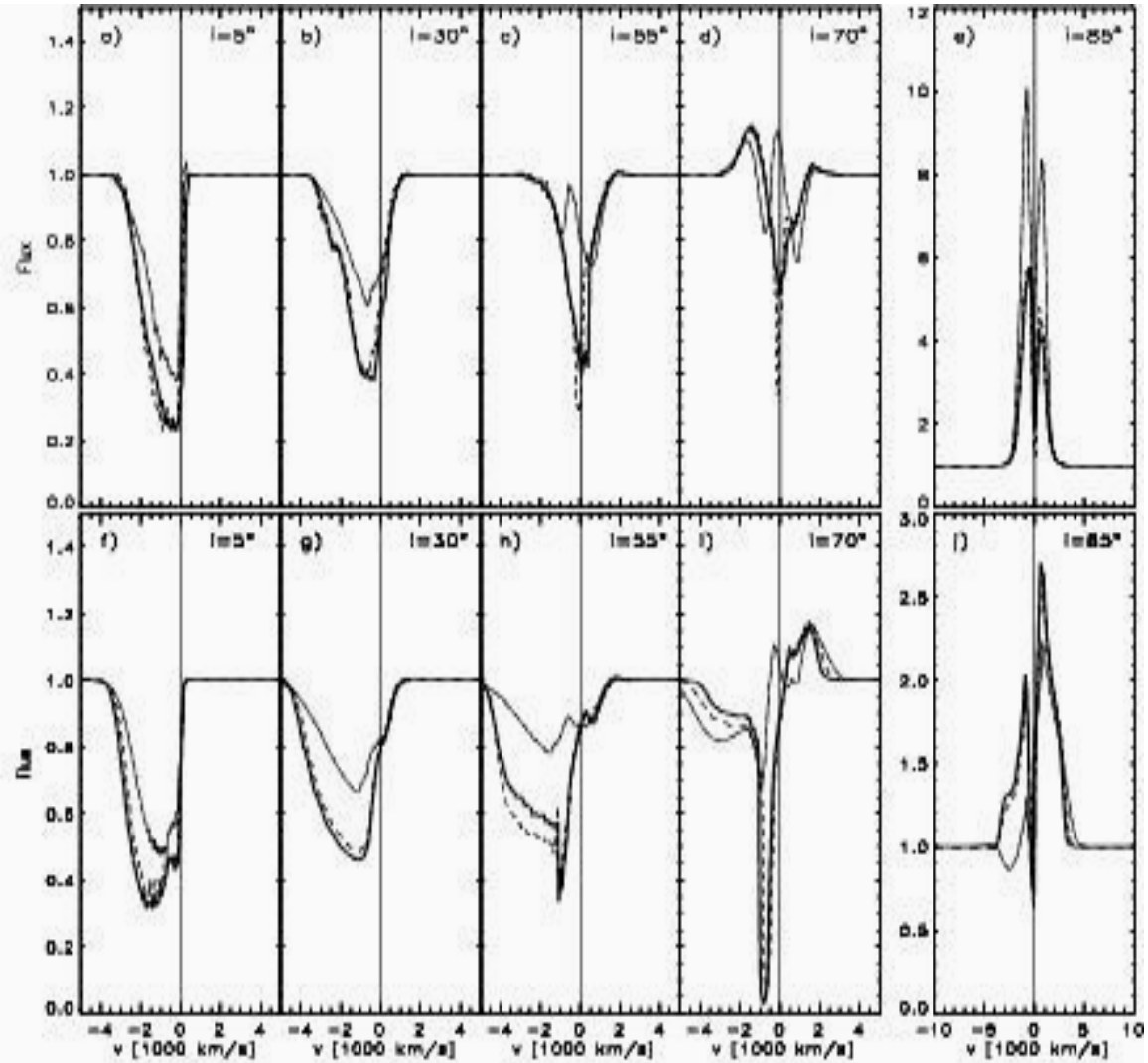




HD simulations and their line profiles







HD simulations and observations

HD simulations and observations

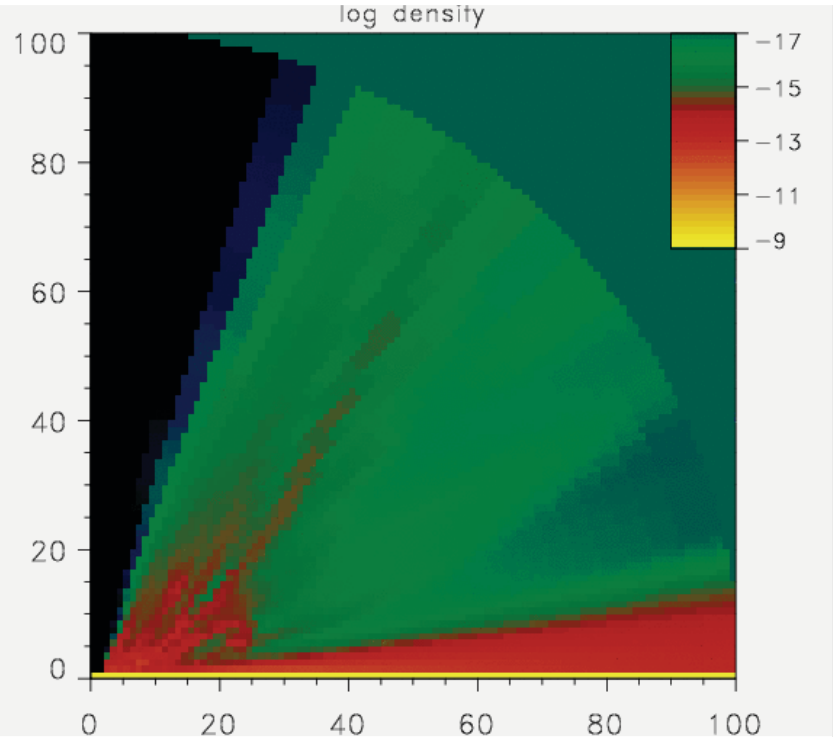
$$L_D = 23.4\,L_{SUN},\quad L_{WD} = 0.25\,L_D,\quad \dot{M}_a = 3\times10^{-8}\,M_{SUN}\,yr^{-1}$$

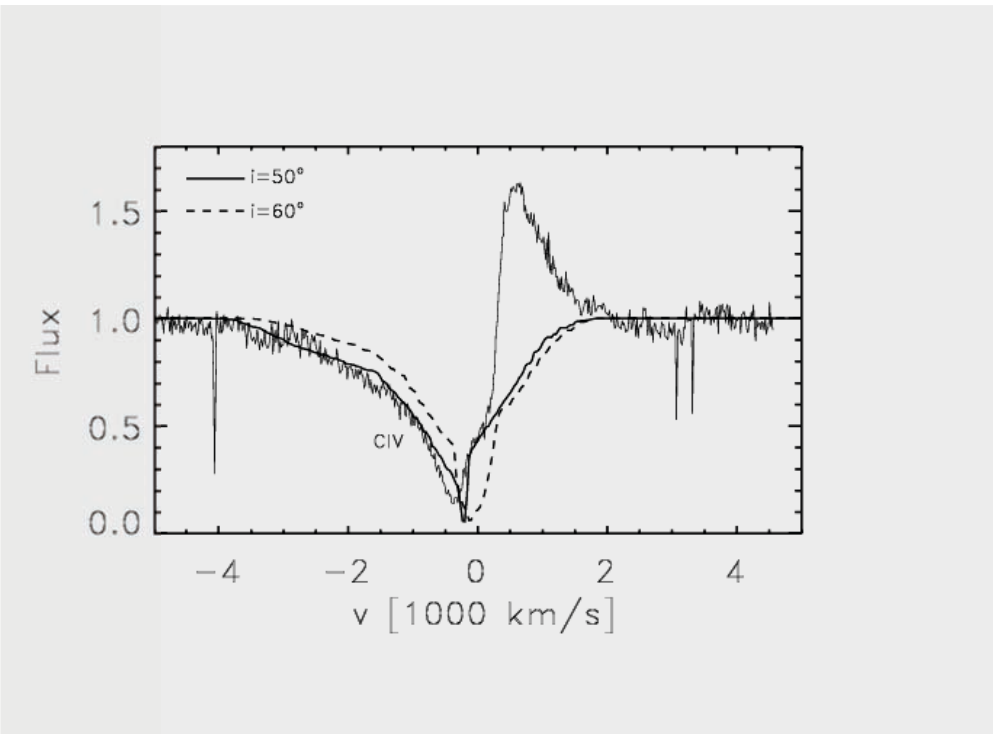
HD simulations and observations

$L_D = 23.4 L_{SUN}$, $L_{WD} = 0.25 L_D$, $\dot{M}_a = 3 \times 10^{-8} M_{SUN}\, yr^{-1}$

$\dot{M}_W = 3 \times 10^{-12} M_{SUN}\, yr^{-1}$

HD simulations and observations



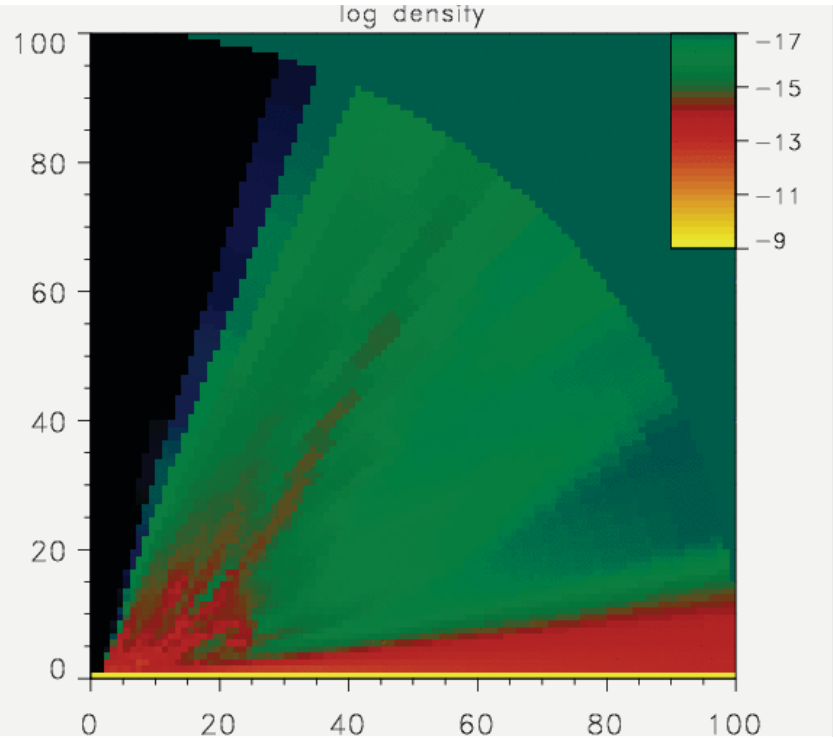


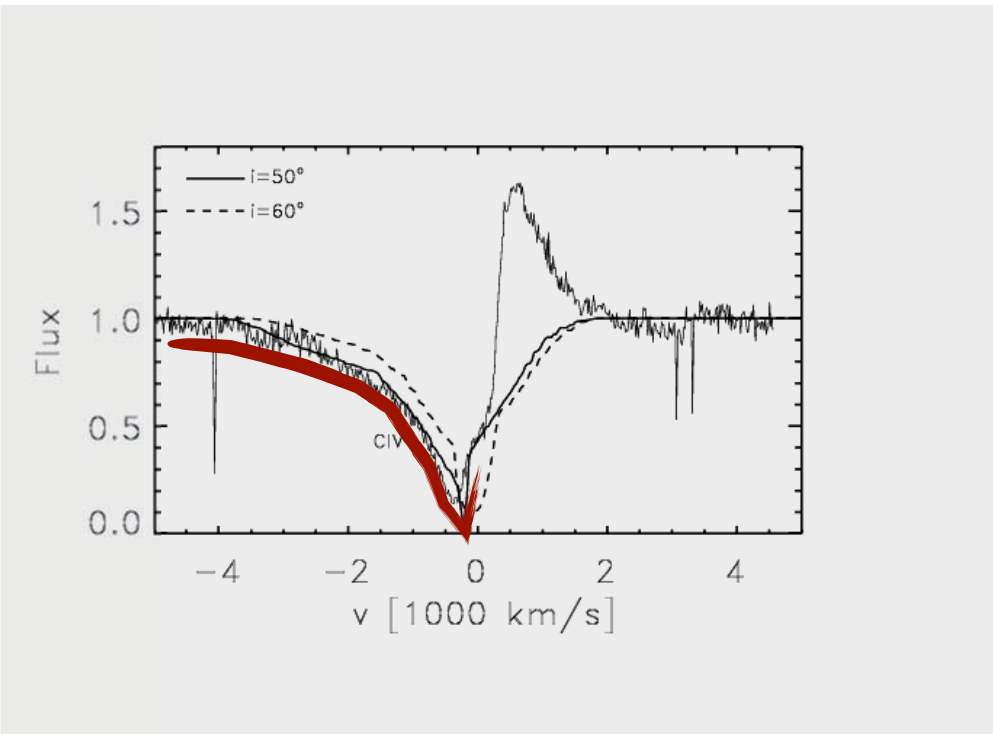
$L_D = 23.4 L_{SUN}$, $L_{WD} = 0.25 L_D$, $\dot{M}_a = 3\times10^{-8} M_{SUN}\, yr^{-1}$

$\dot{M}_W = 3\times10^{-12} M_{SUN}\, yr^{-1}$

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

HD simulations and observations



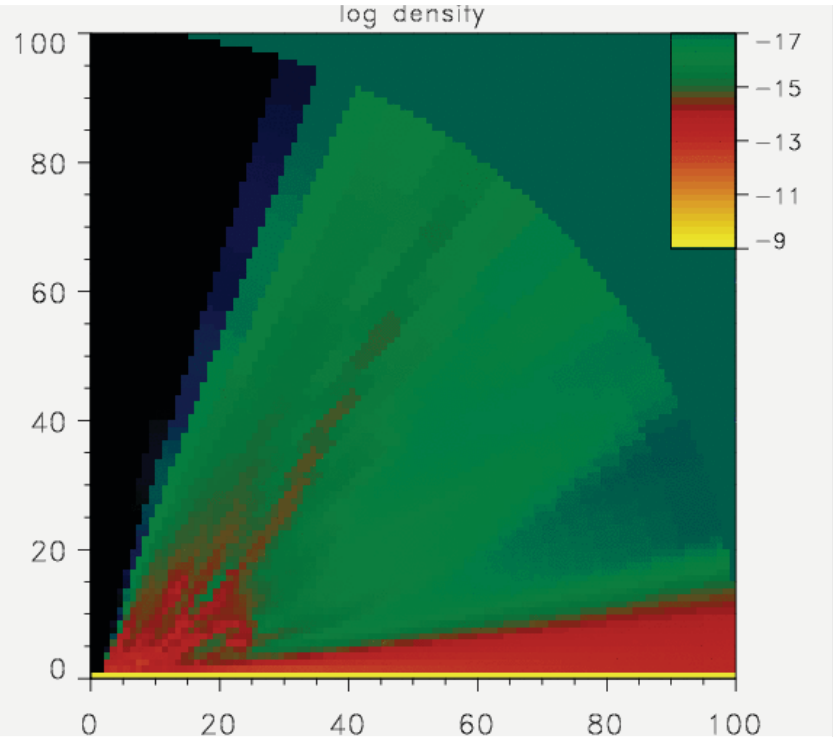


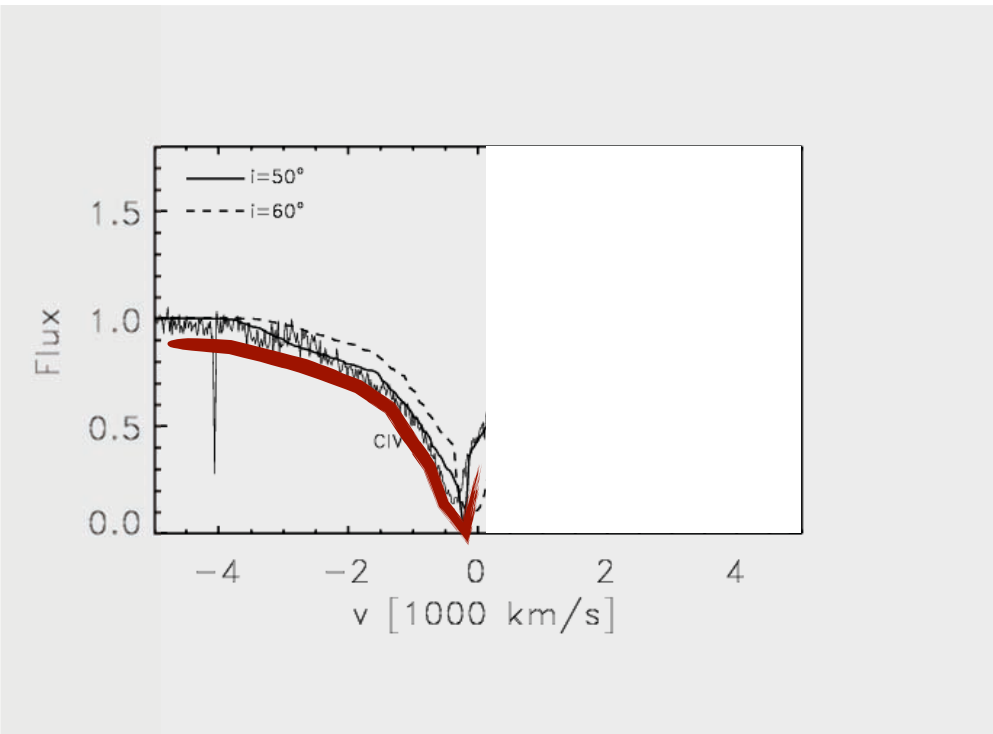
$L_D = 23.4 L_{SUN}$, $L_{WD} = 0.25 L_D$, $\dot{M}_a = 3\times10^{-8} M_{SUN}\, yr^{-1}$

$\dot{M}_W = 3\times10^{-12} M_{SUN}\, yr^{-1}$

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

HD simulations and observations

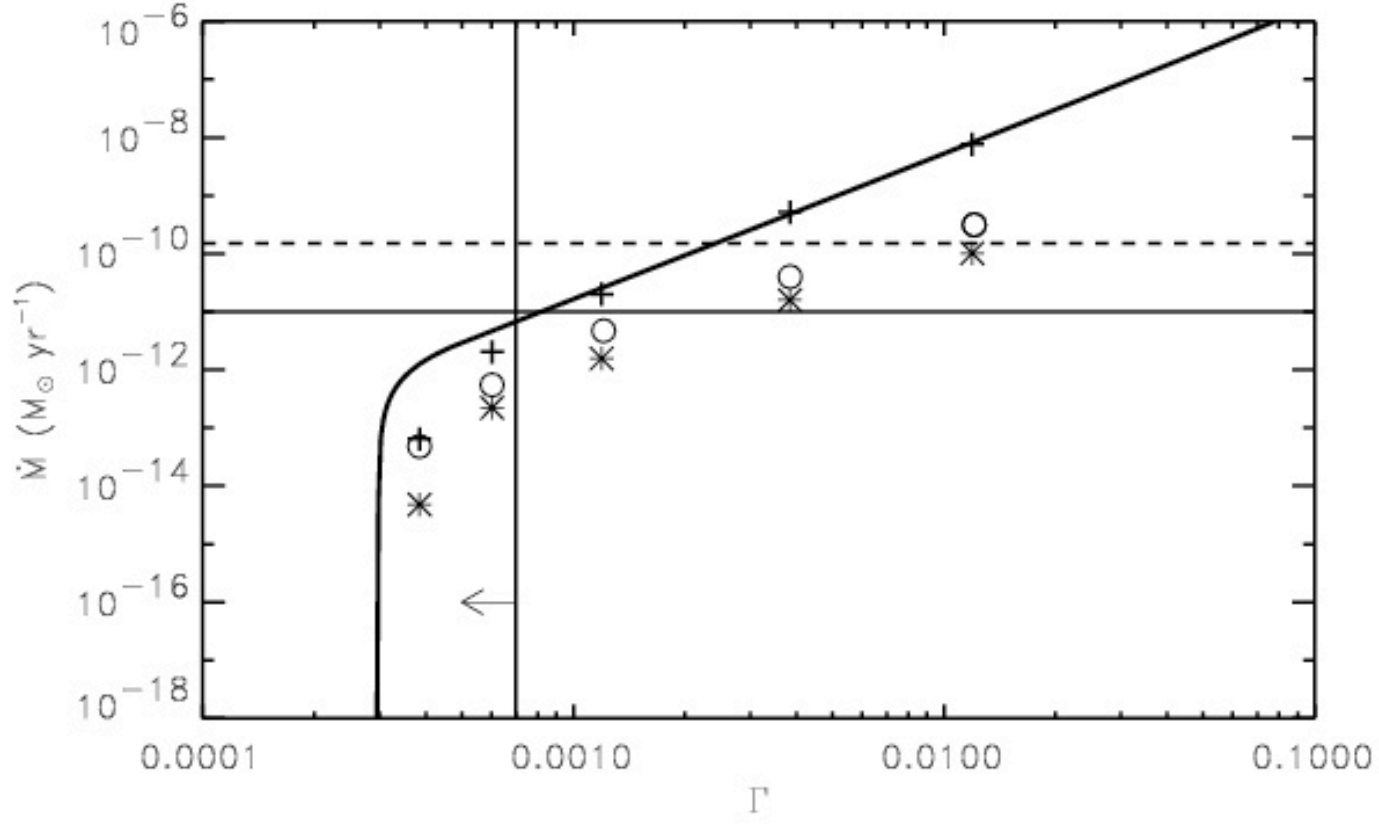




$L_D = 23.4 L_{SUN}$, $L_{WD} = 0.25 L_D$, $\dot{M}_a = 3\times10^{-8} M_{SUN}\, yr^{-1}$

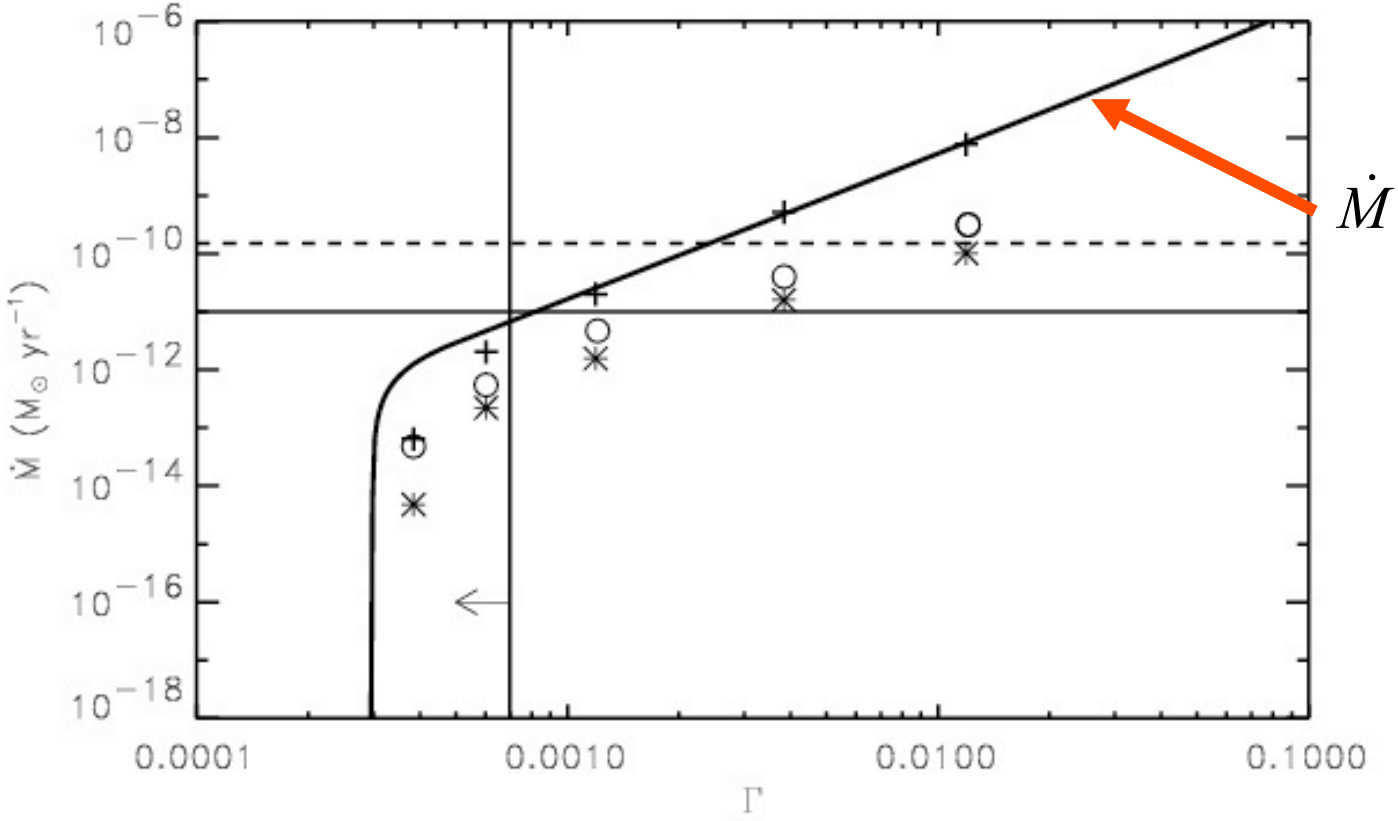
$\dot{M}_W = 3\times10^{-12} M_{SUN}\, yr^{-1}$

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



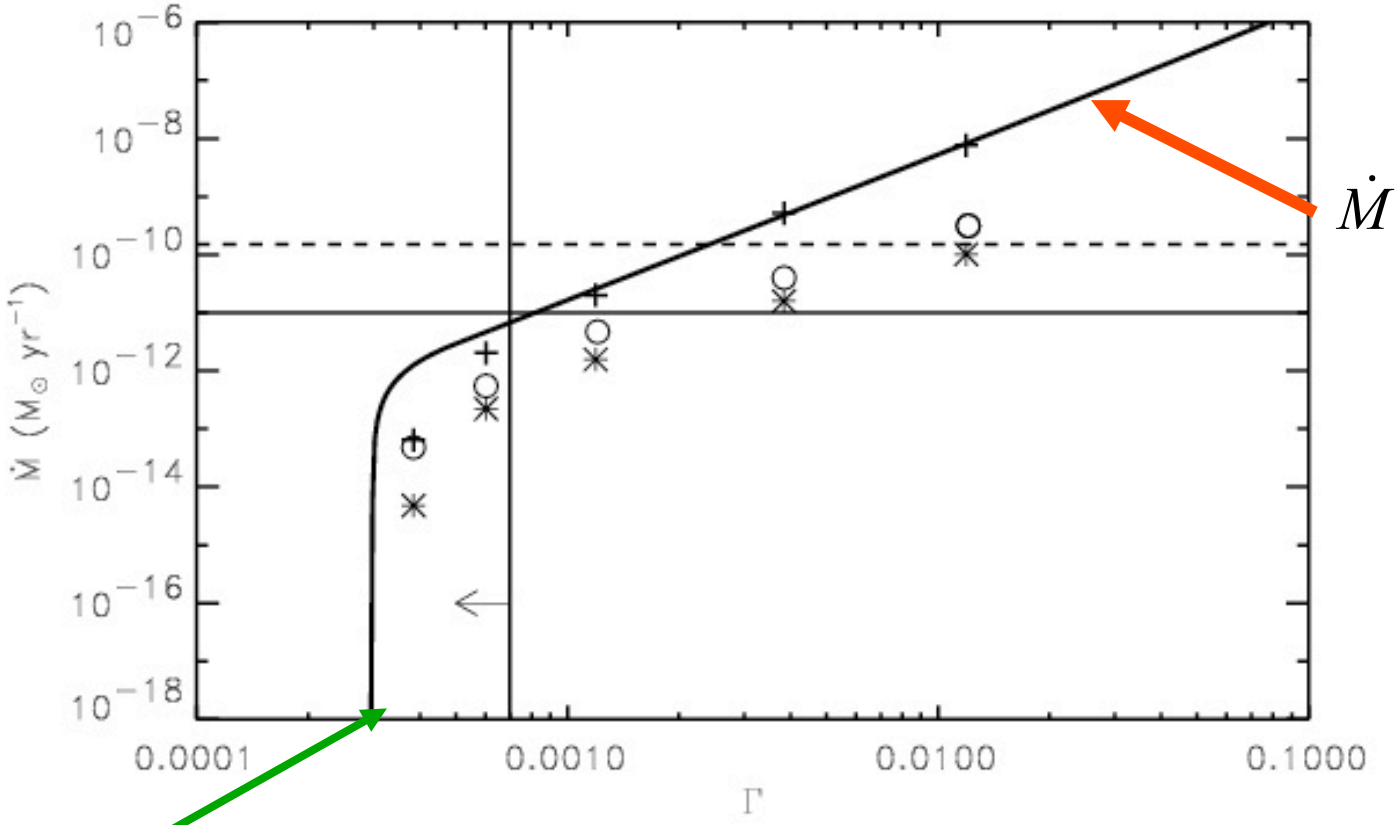
Drew & Proga (1999)

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



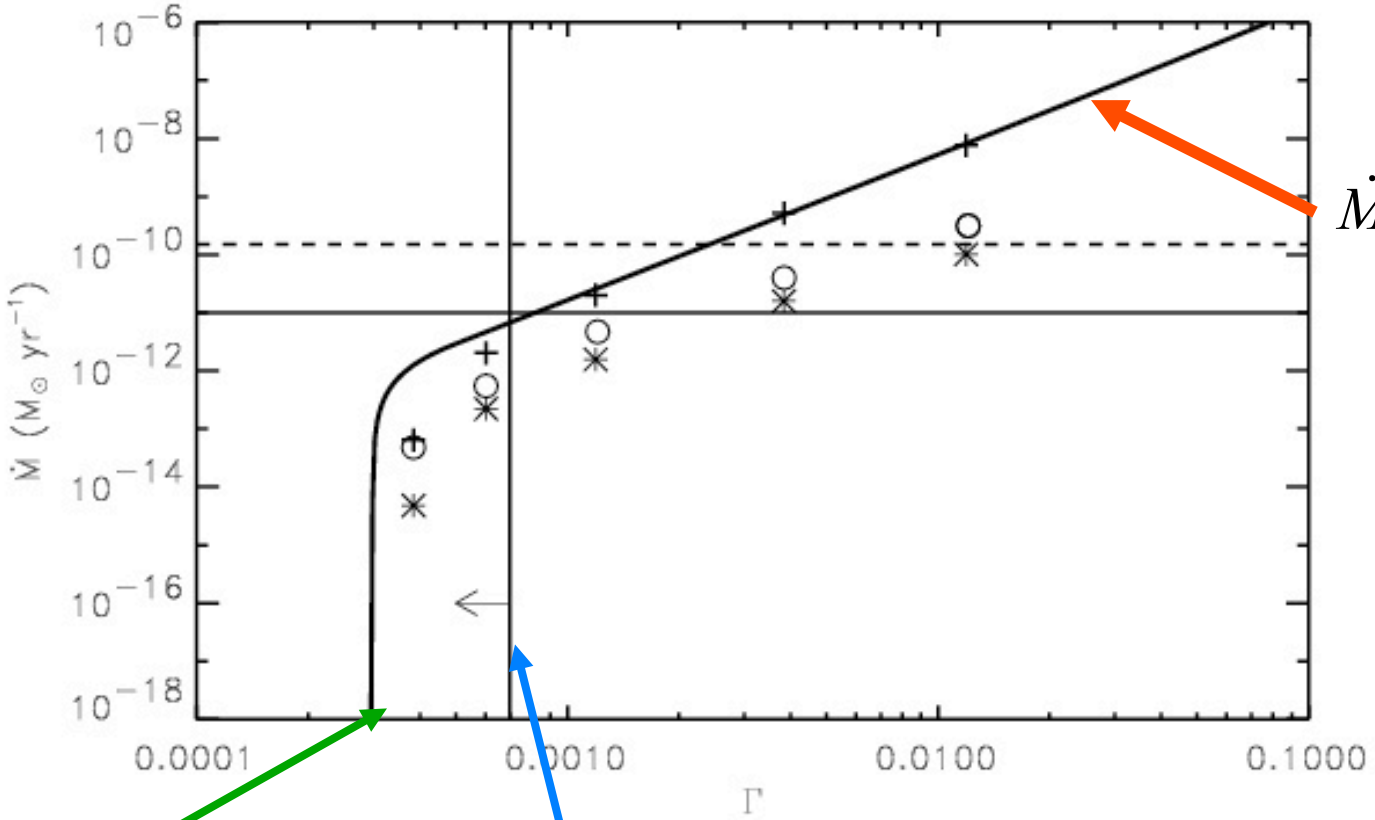
Drew & Proga (1999)

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



Drew & Proga (1999)

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



Drew & Proga (1999)

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

Thermal and Radiation-Driven Winds

The equations of hydrodynamics

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

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

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

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

The equations of hydrodynamics

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

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

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

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

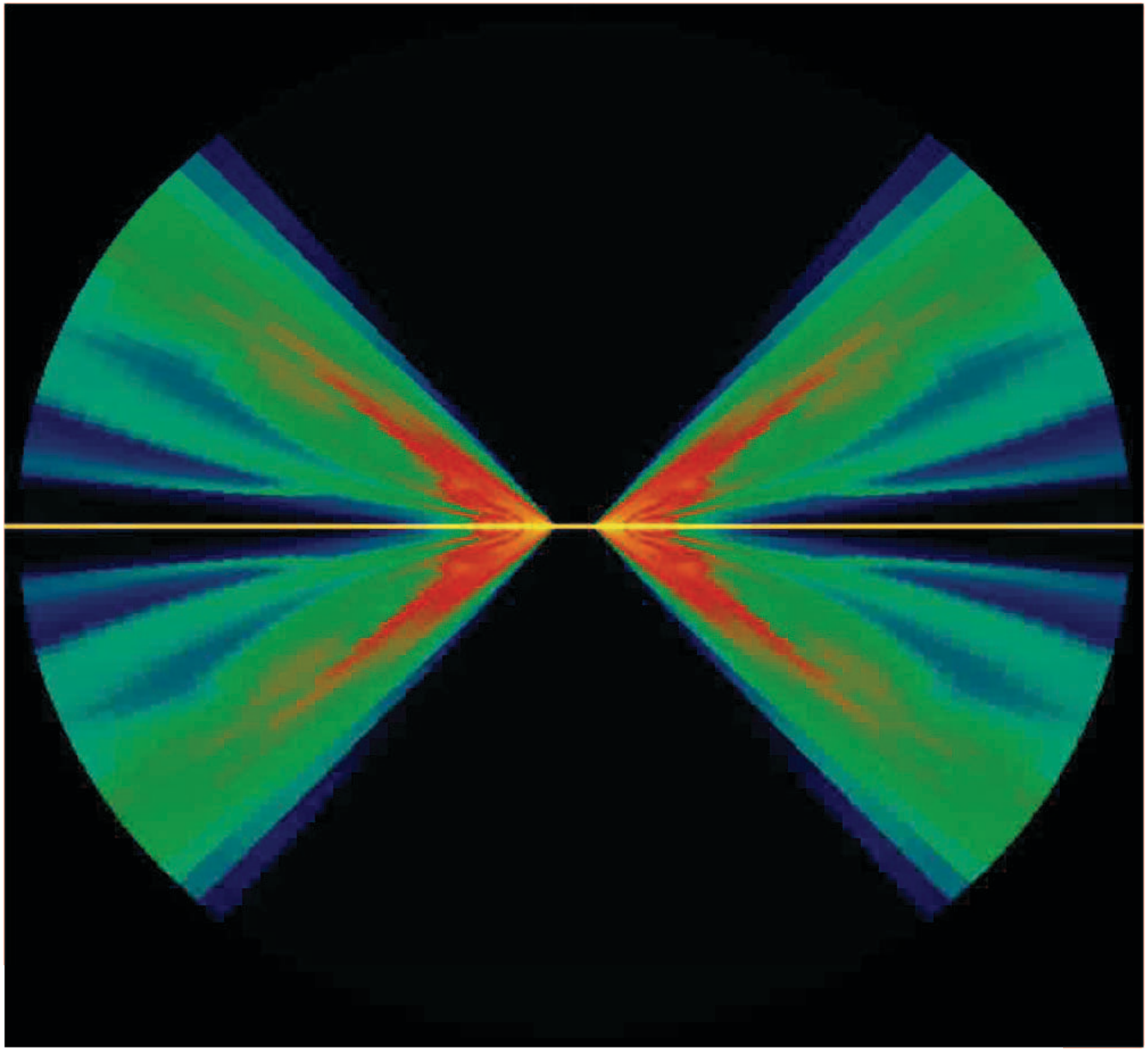
The equations of hydrodynamics

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

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

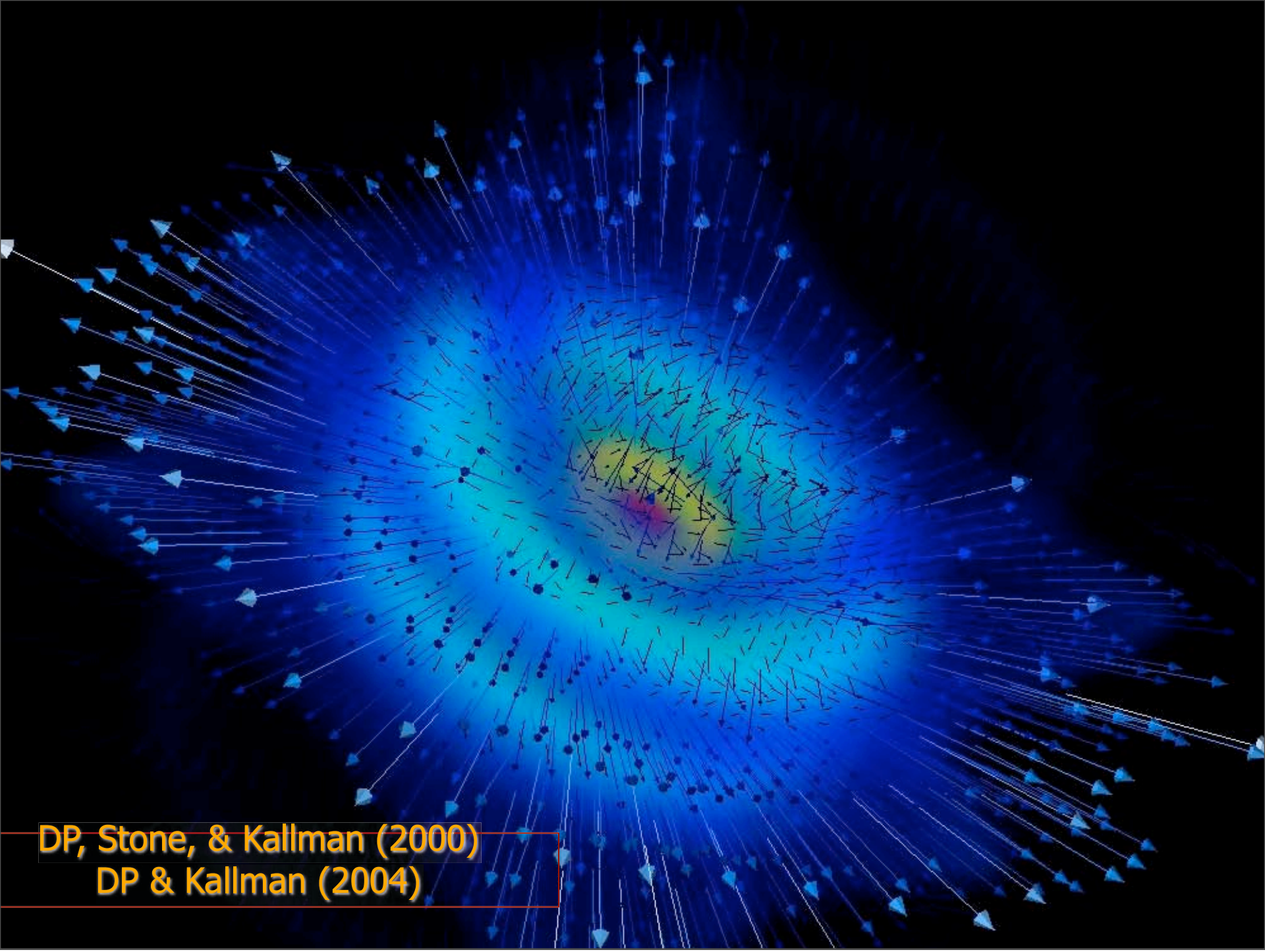
$$\rho \frac{D}{Dt}\left(\frac{e}{\rho}\right) = -P \nabla \cdot v + \rho L$$

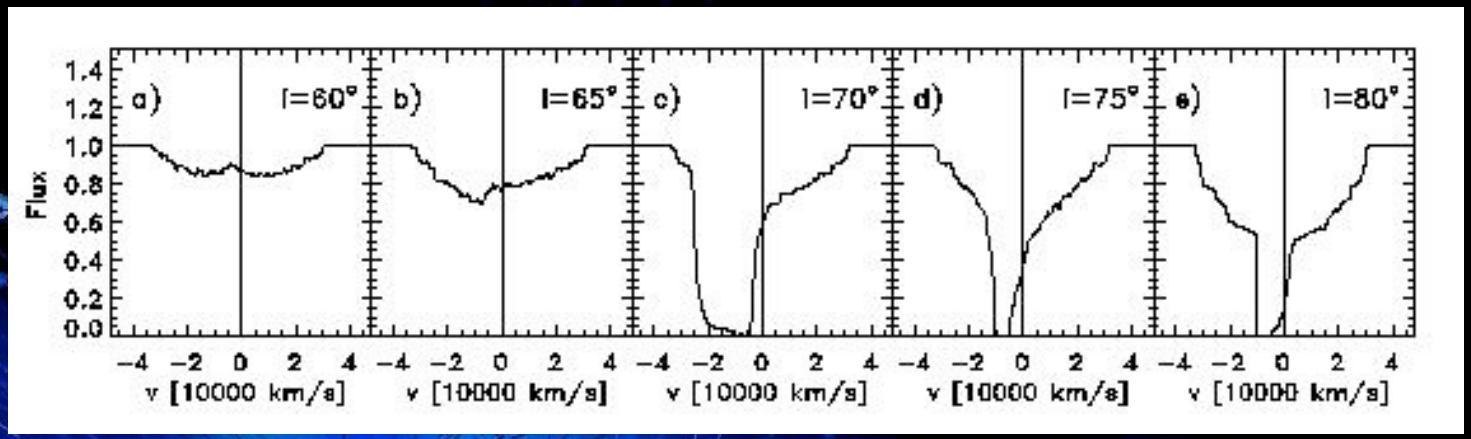
$$P = (\gamma - 1)e$$



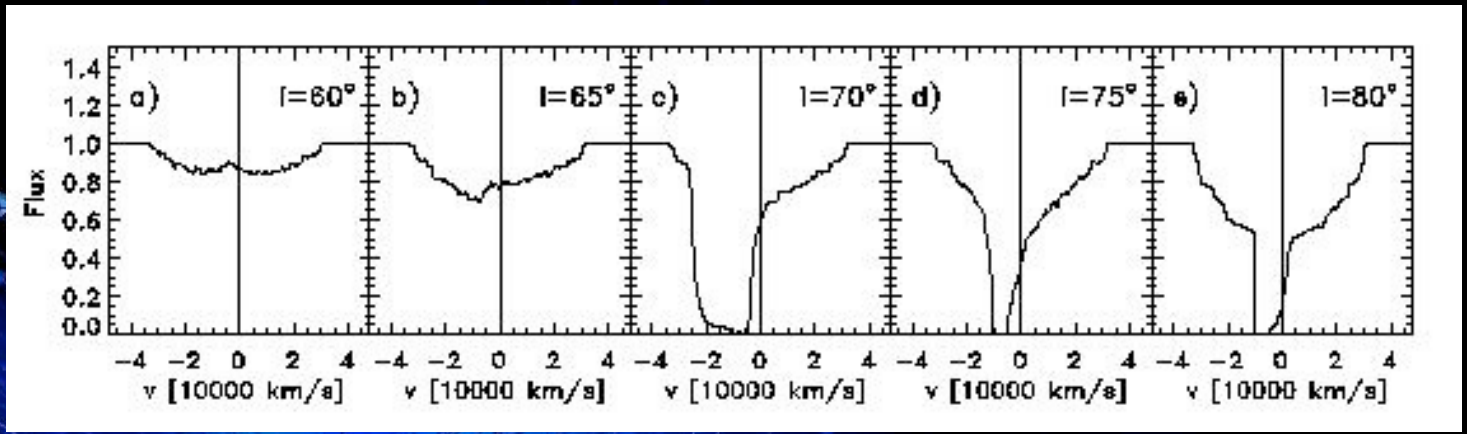
$M_{BH} = 10^8 Msun$

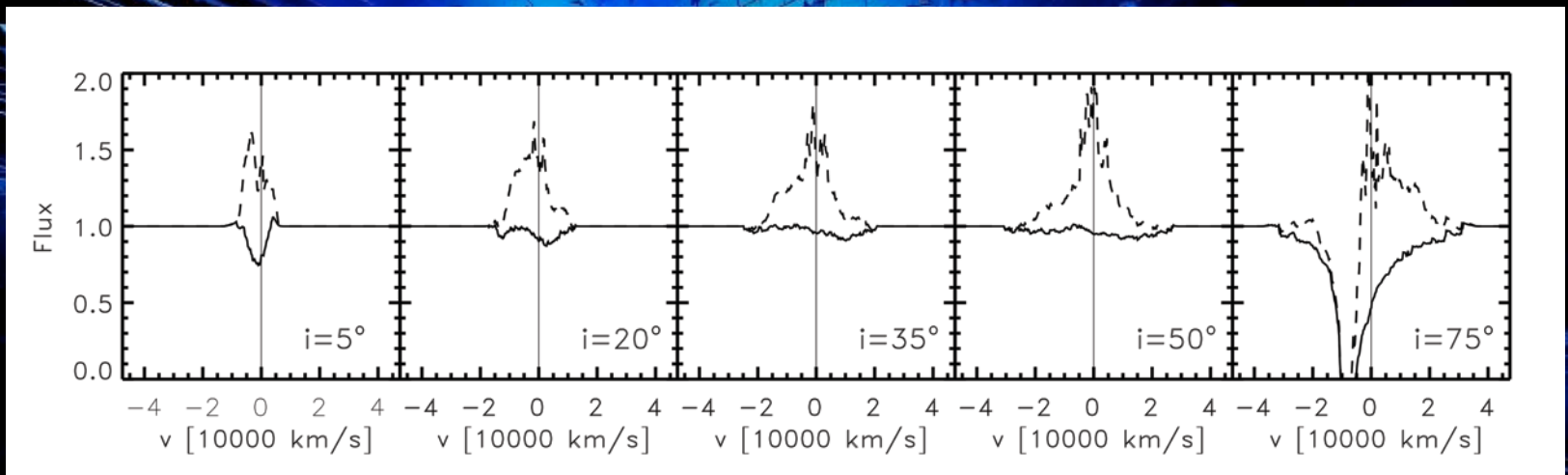
$\Gamma = 0.6$


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

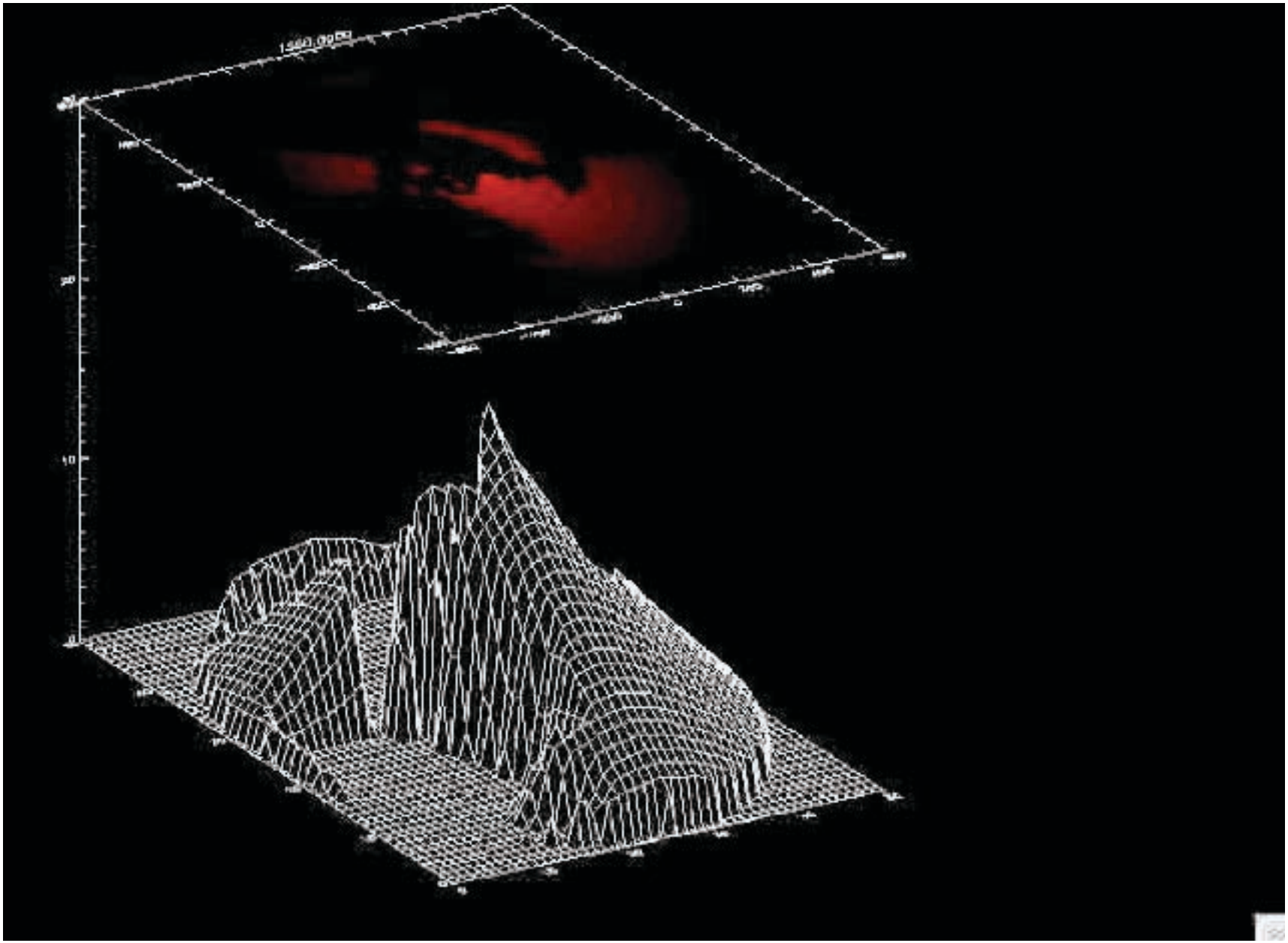


DP, Stone, & Kallman (2000)
DP & Kallman (2004)





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

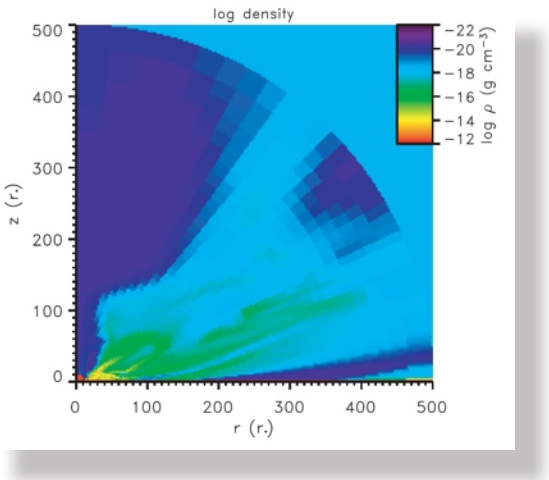


Paola Rodriguez-Hidalgo, DP, F. Hamann

Broad band spectra for various l.o.s.

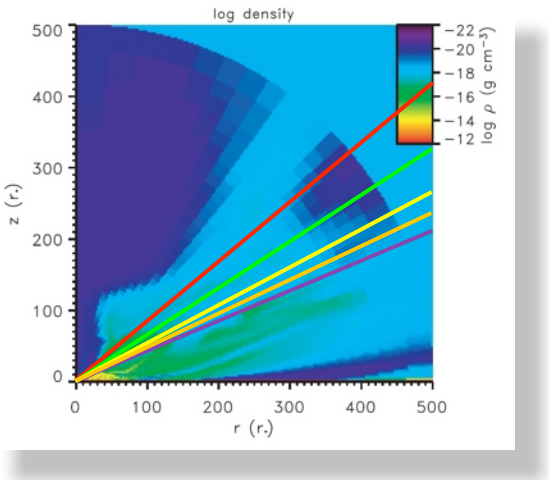
Schurch, Done, & DP (2009)

Broad band spectra for various l.o.s.



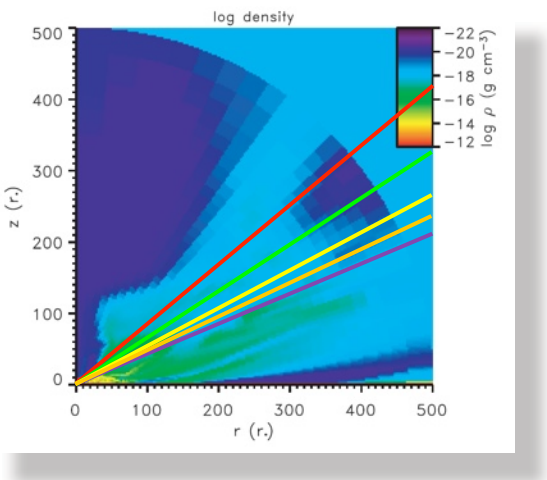
Schurch, Done, & DP (2009)

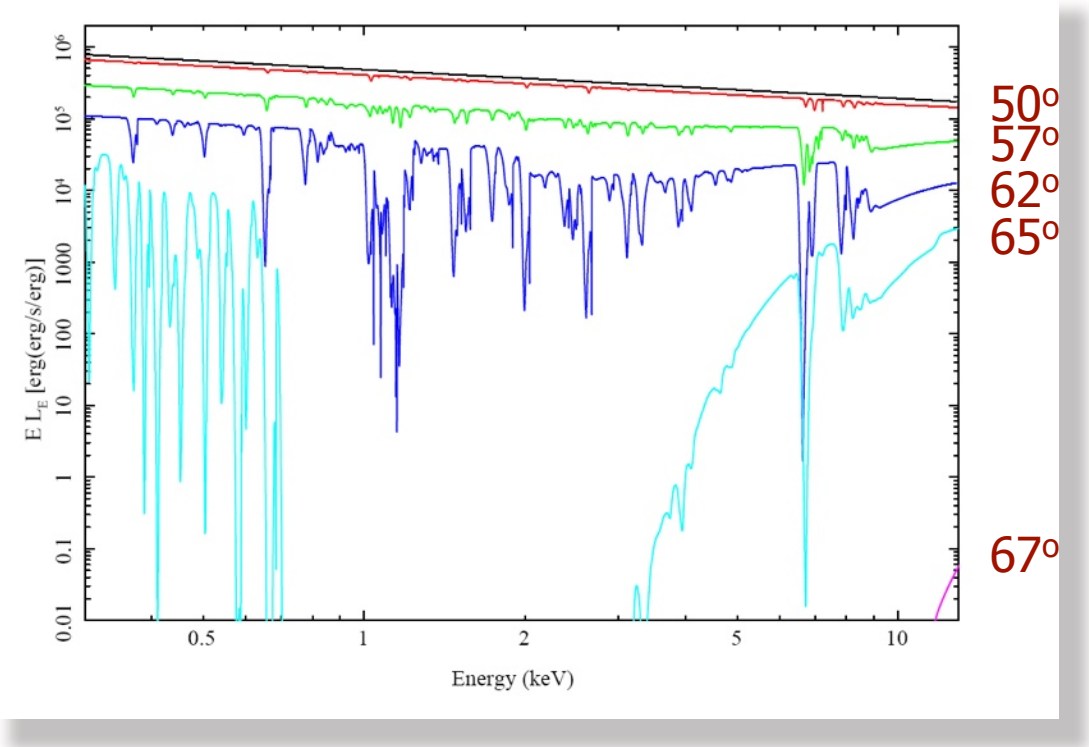
Broad band spectra for various l.o.s.



Schurch, Done, & DP (2009)

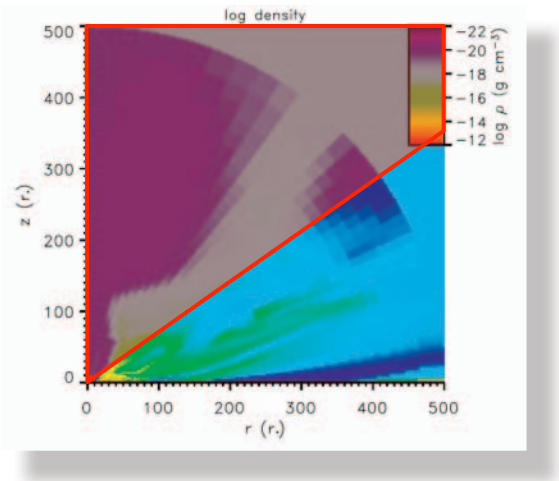
Broad band spectra for various l.o.s.

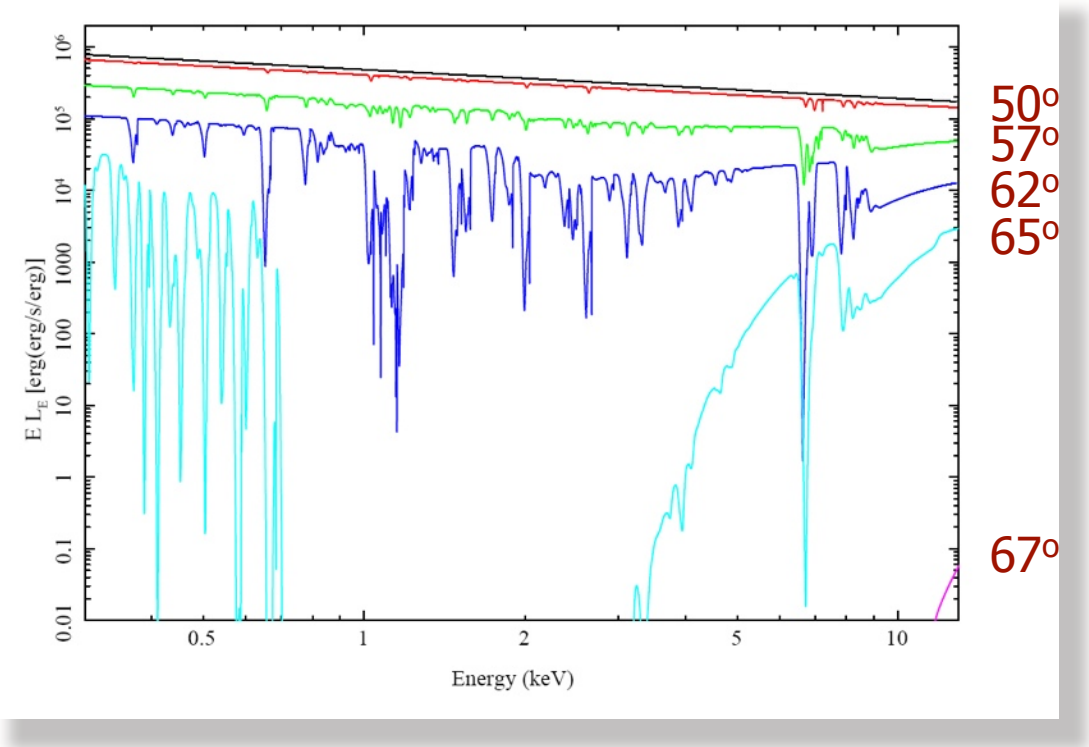




Schurch, Done, & DP (2009)

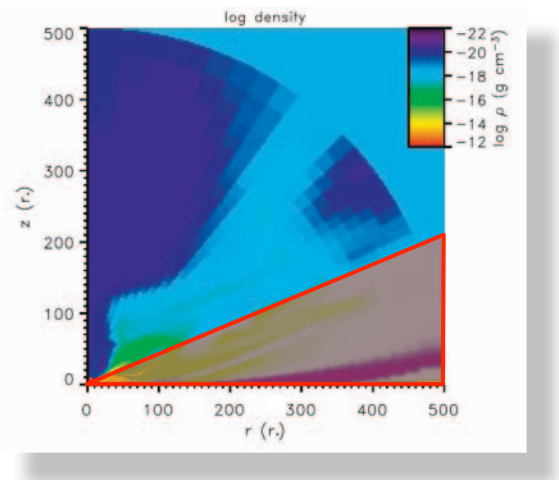
Broad band spectra for various l.o.s.

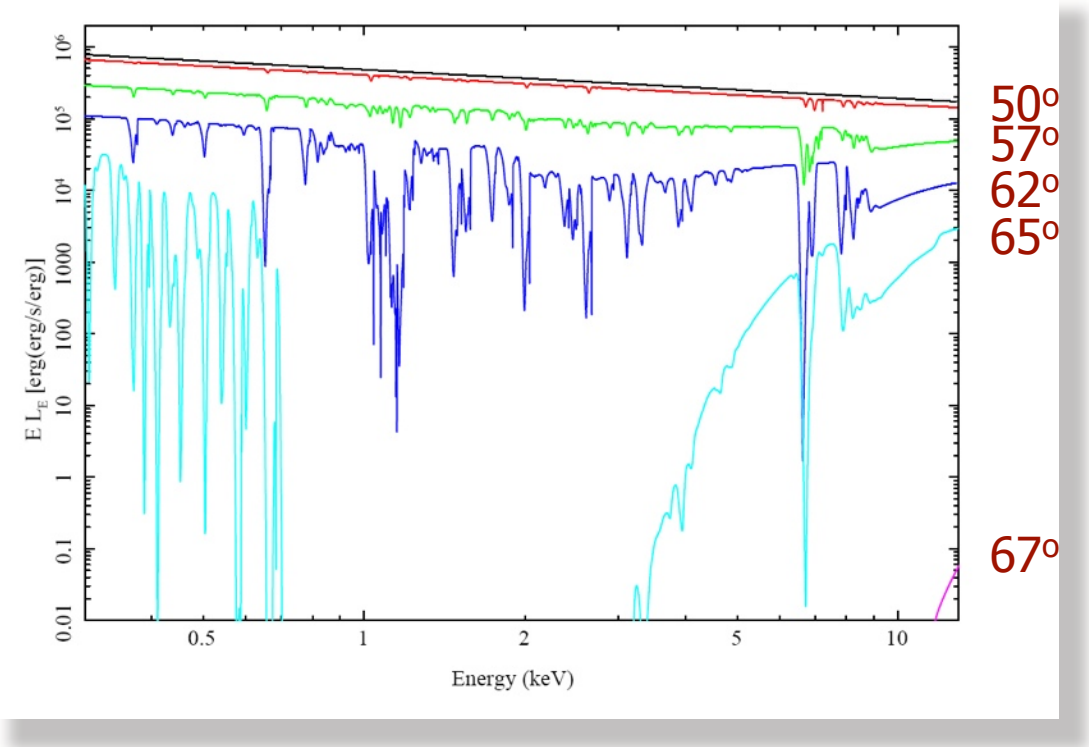




Schurch, Done, & DP (2009)

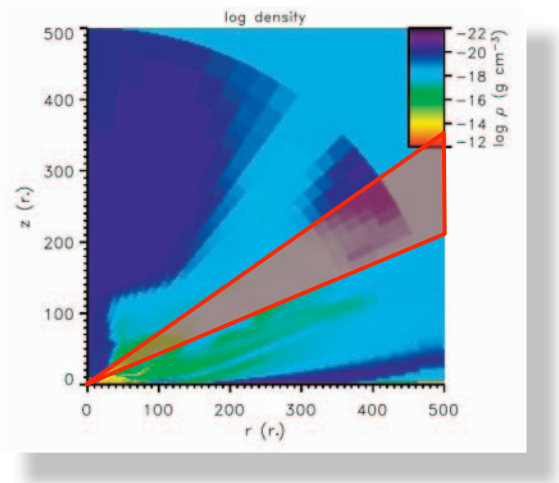
Broad band spectra for various l.o.s.

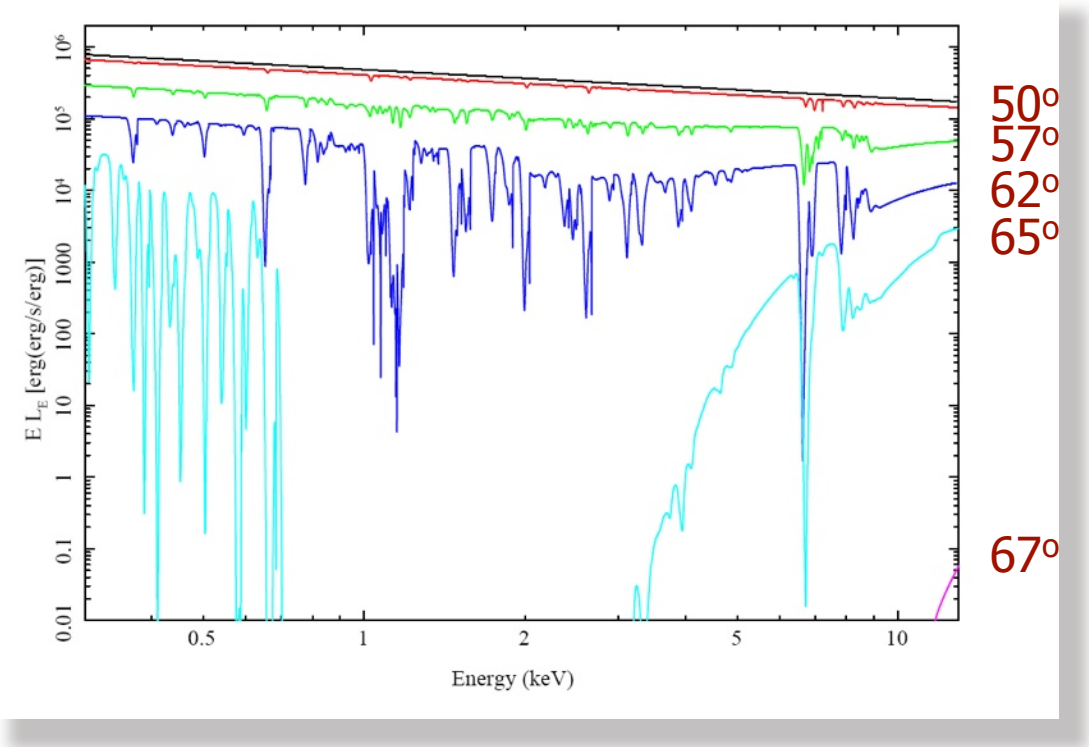




Schurch, Done, & DP (2009)

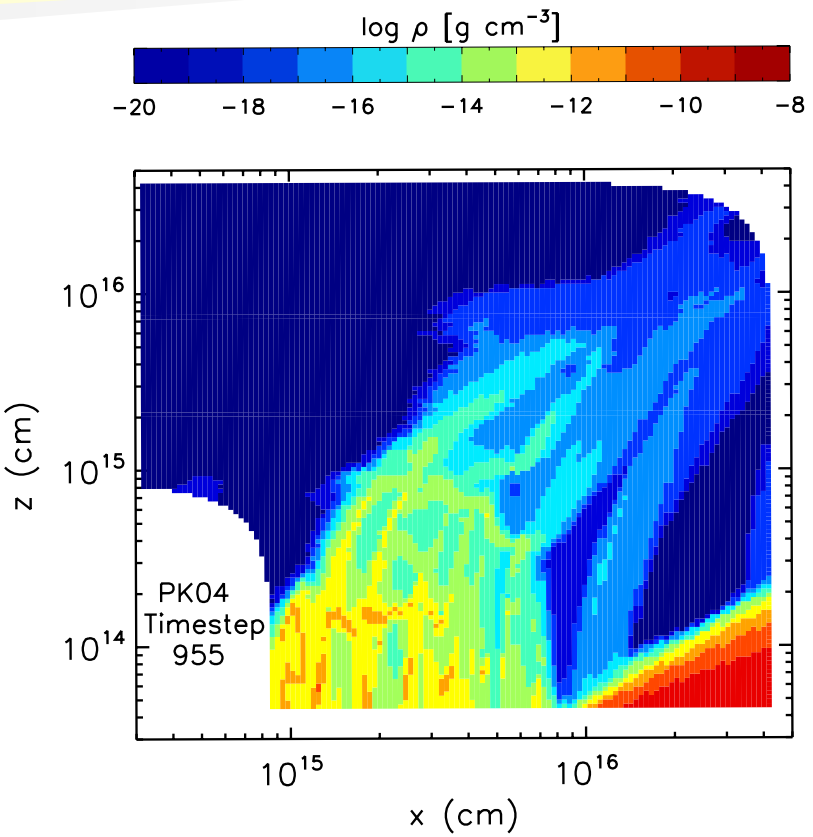
Broad band spectra for various l.o.s.





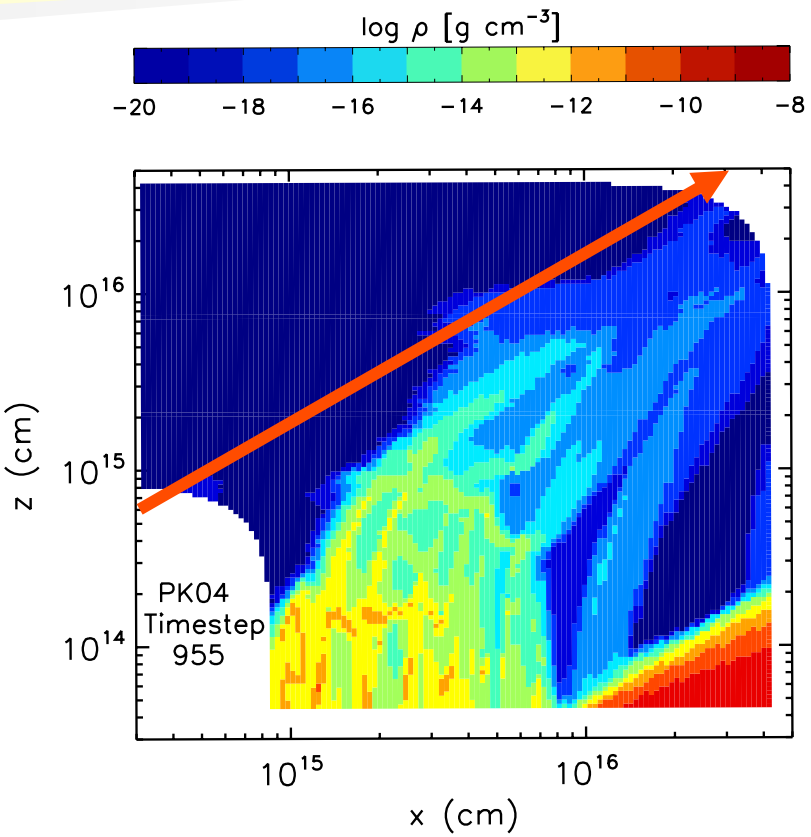
Schurch, Done, & DP (2009)

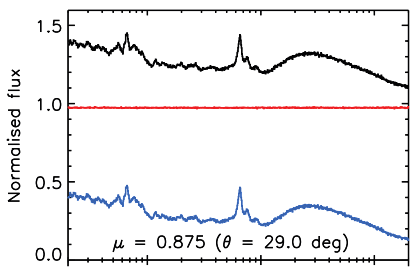
Broad band spectra for various l.o.s.

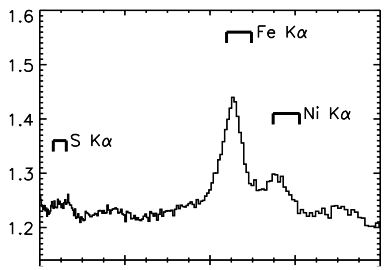


Sim et al. (2010)

Broad band spectra for various l.o.s.

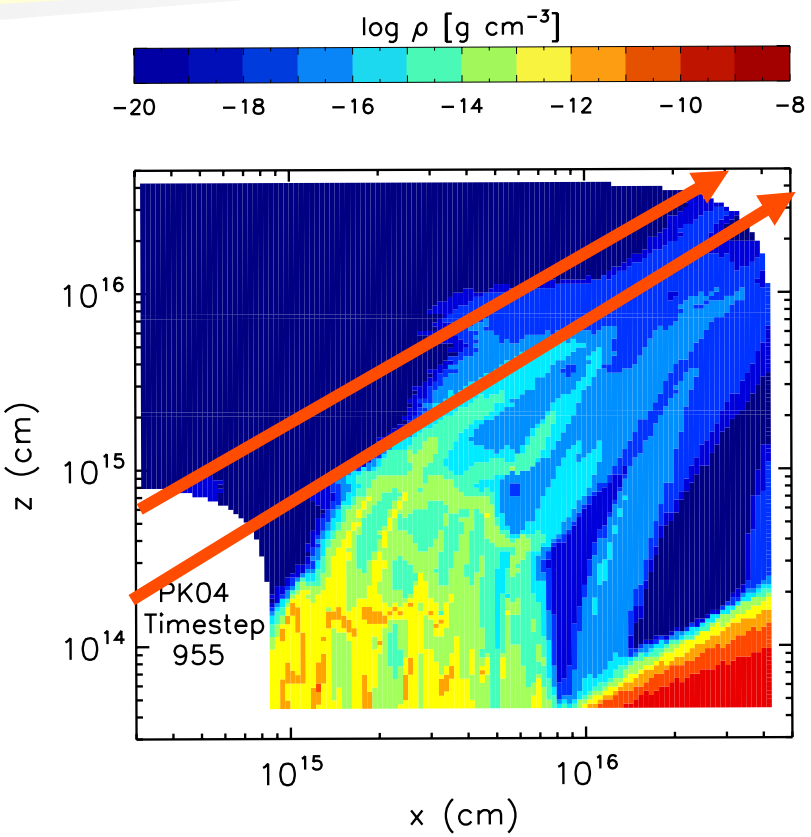


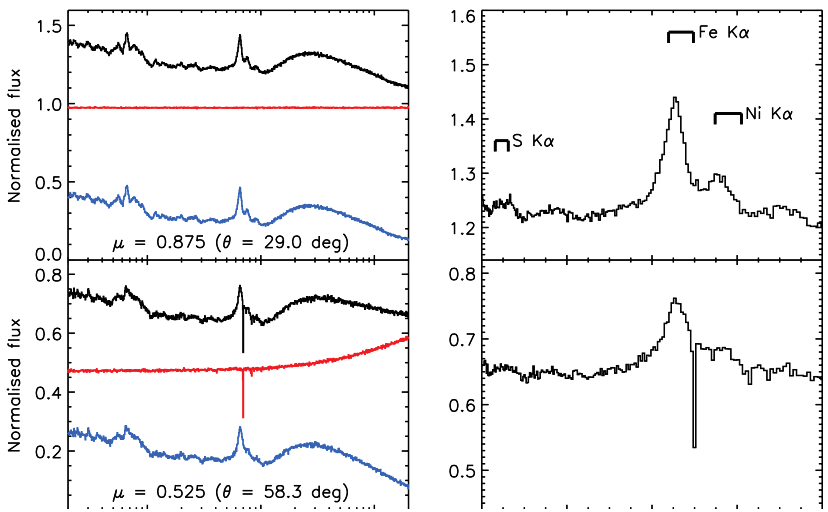




Sim et al. (2010)

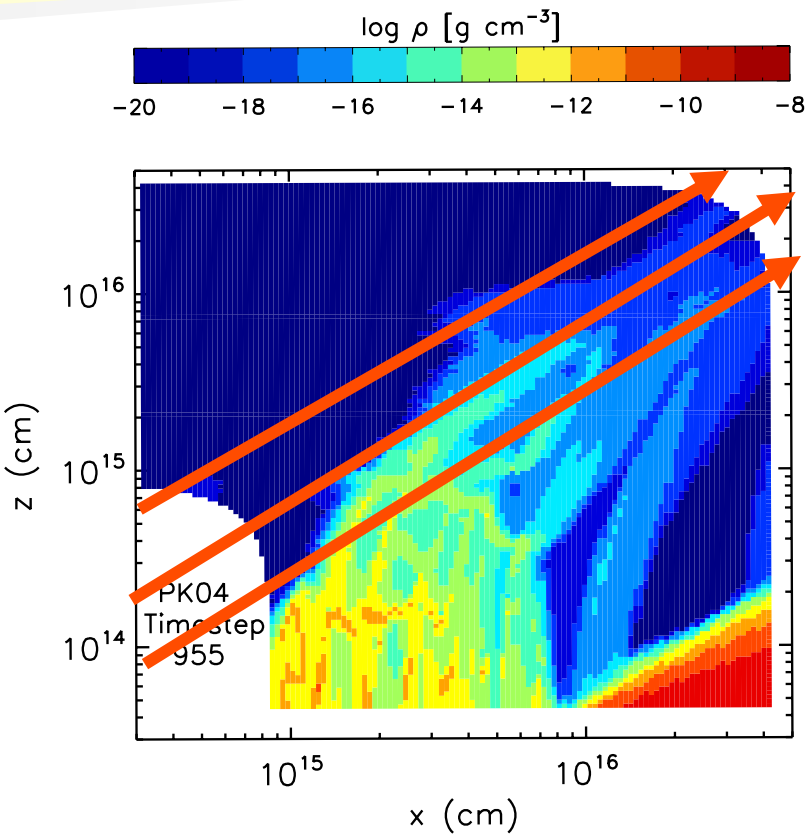
Broad band spectra for various l.o.s.

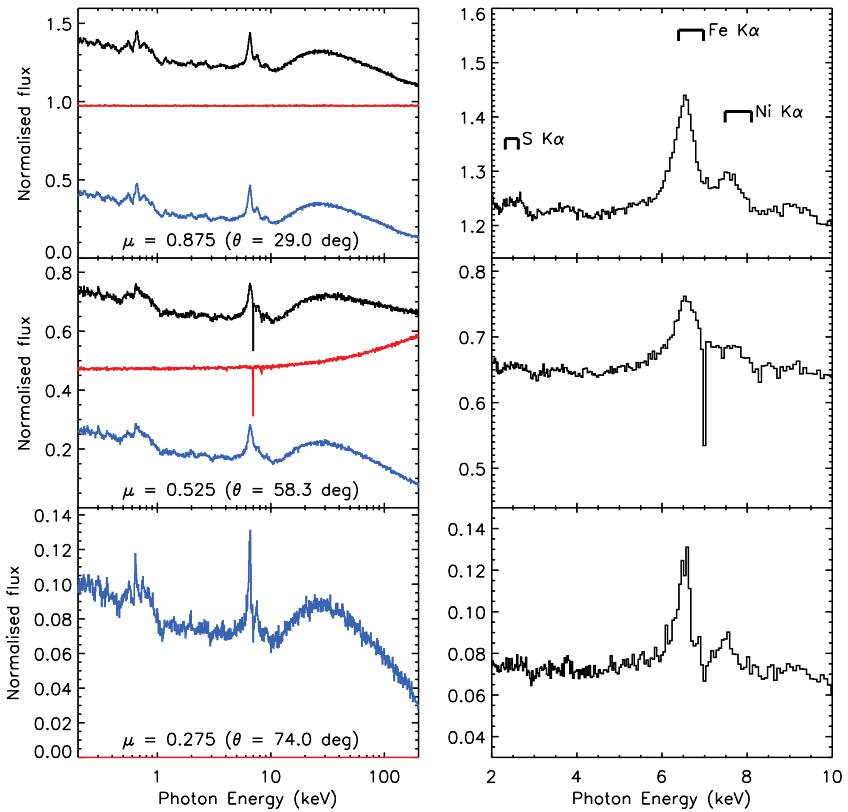




Sim et al. (2010)

Broad band spectra for various l.o.s.

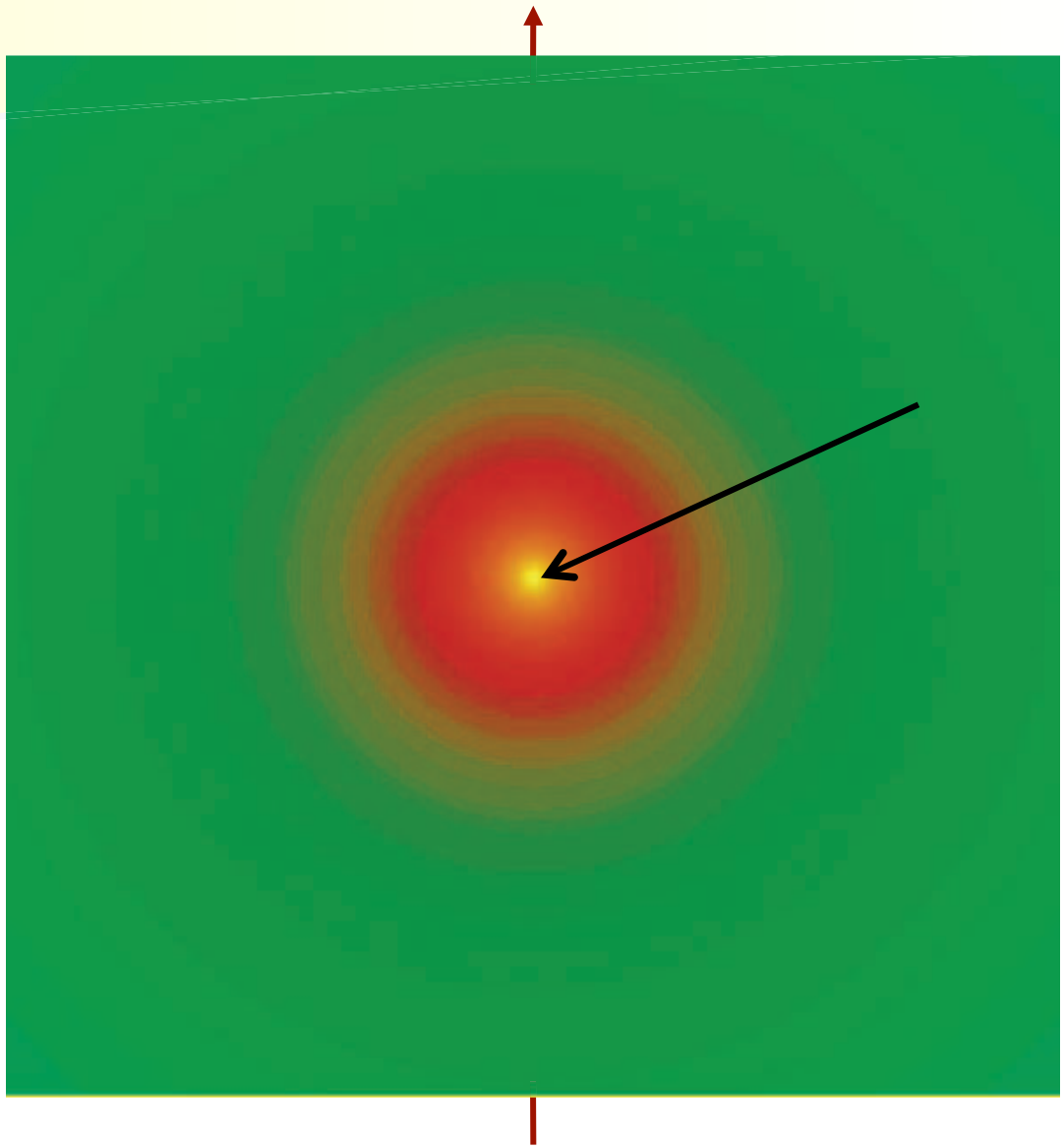




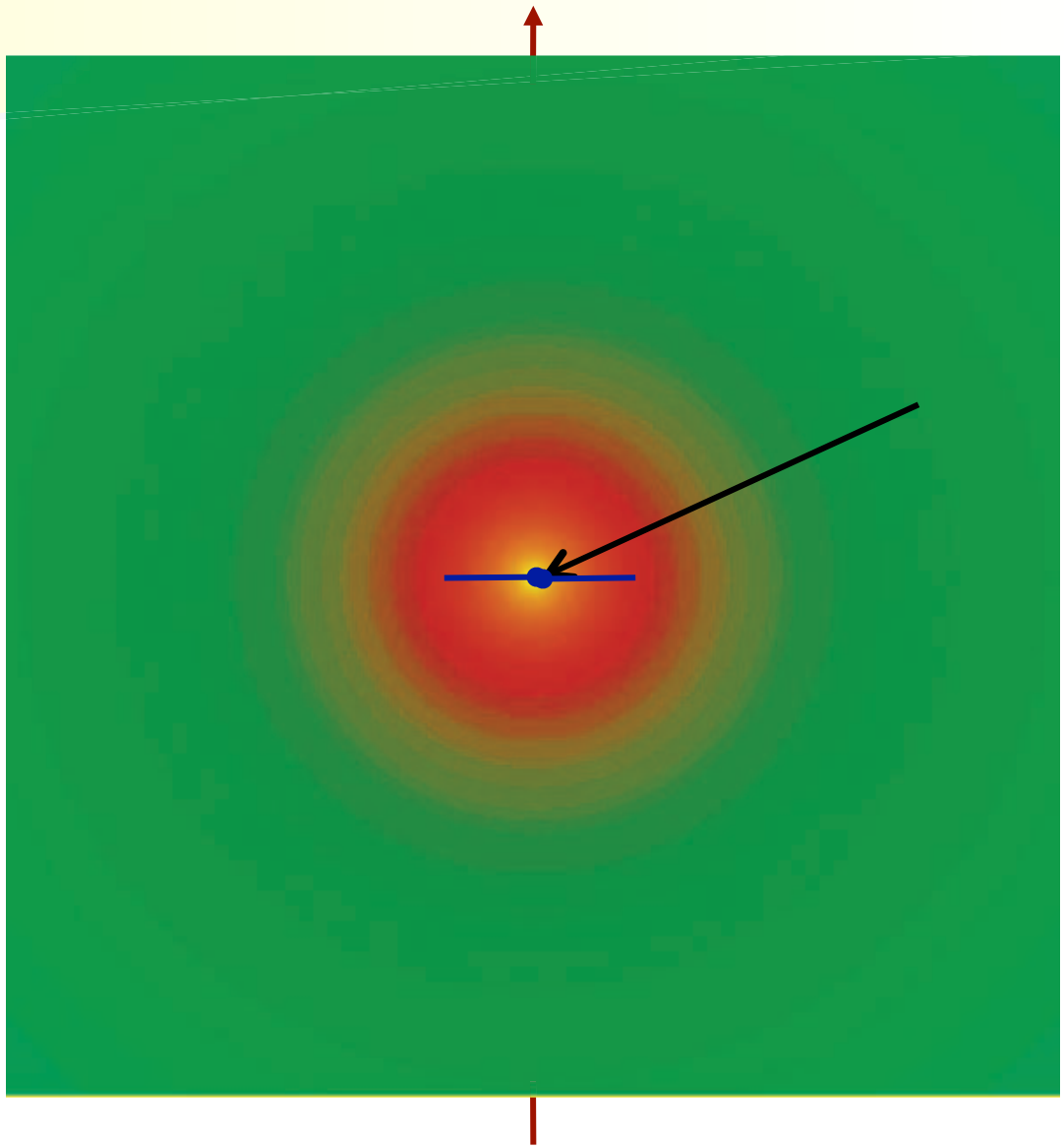
Sim et al. (2010)

Quasar Irradiation

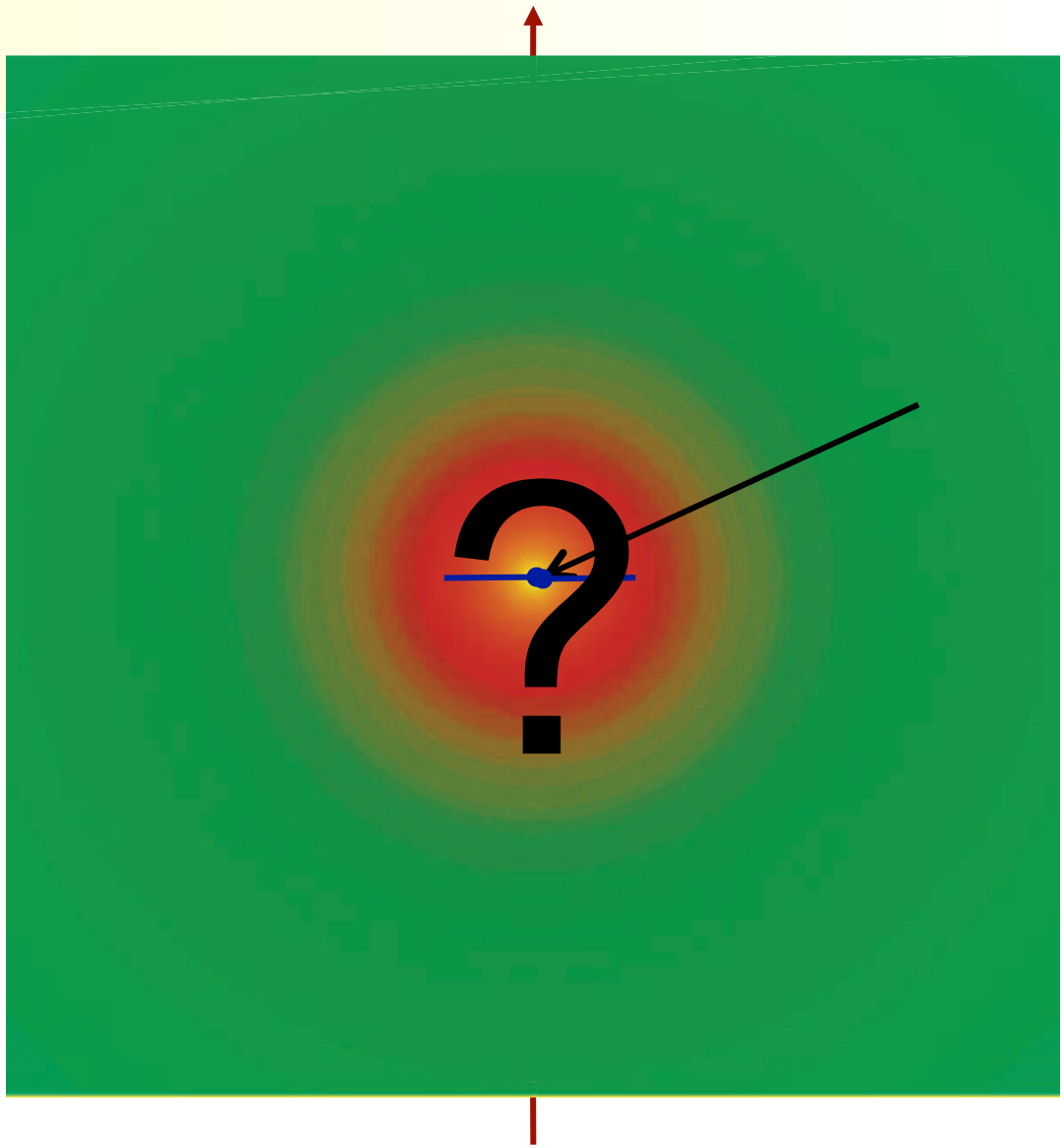
Quasar Irradiation



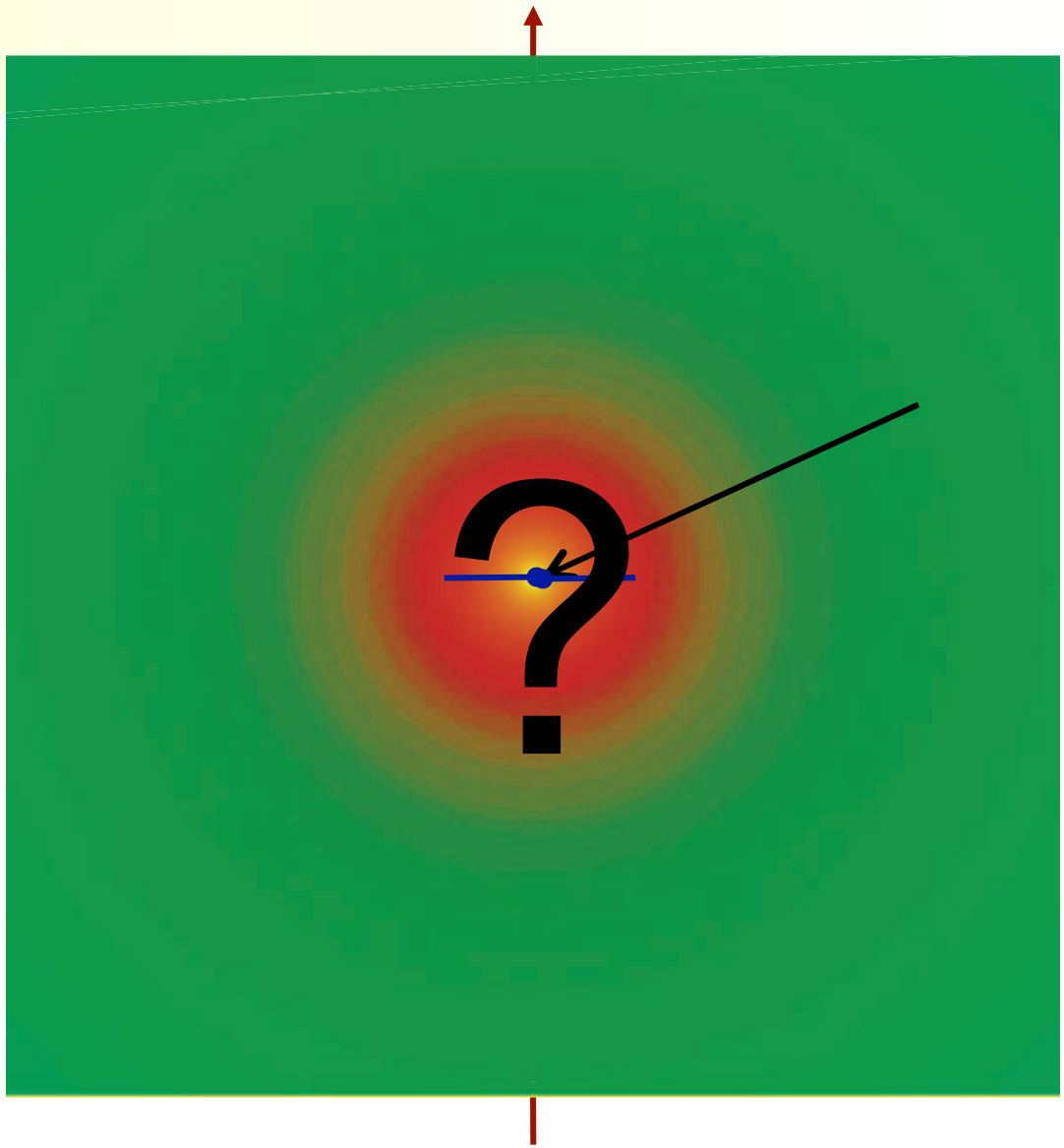
Quasar Irradiation



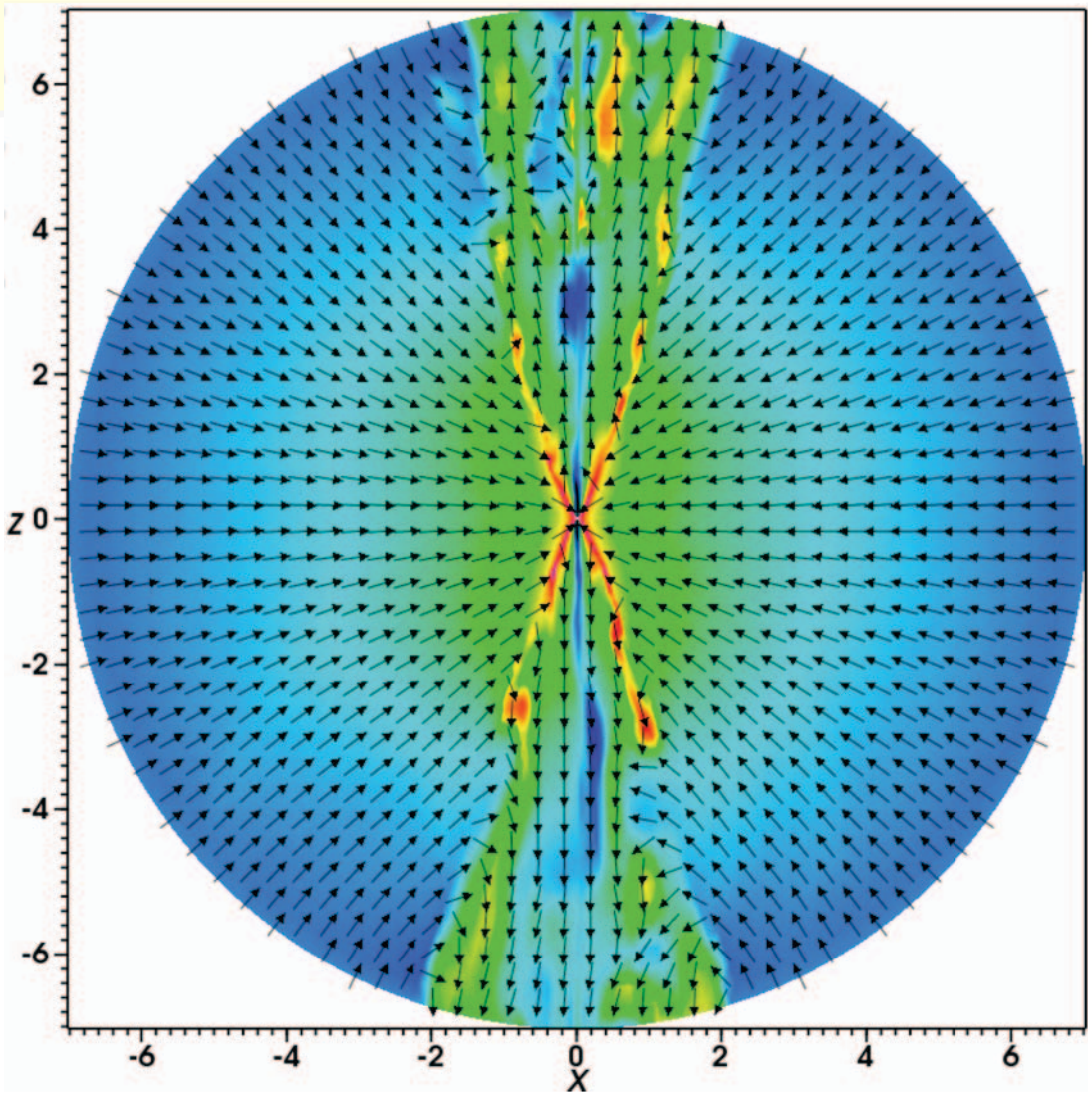
Quasar Irradiation



Quasar Irradiation



An outflow from an inflow



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

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

$$T_{X} = 8\ x10^{7} K$$

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

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

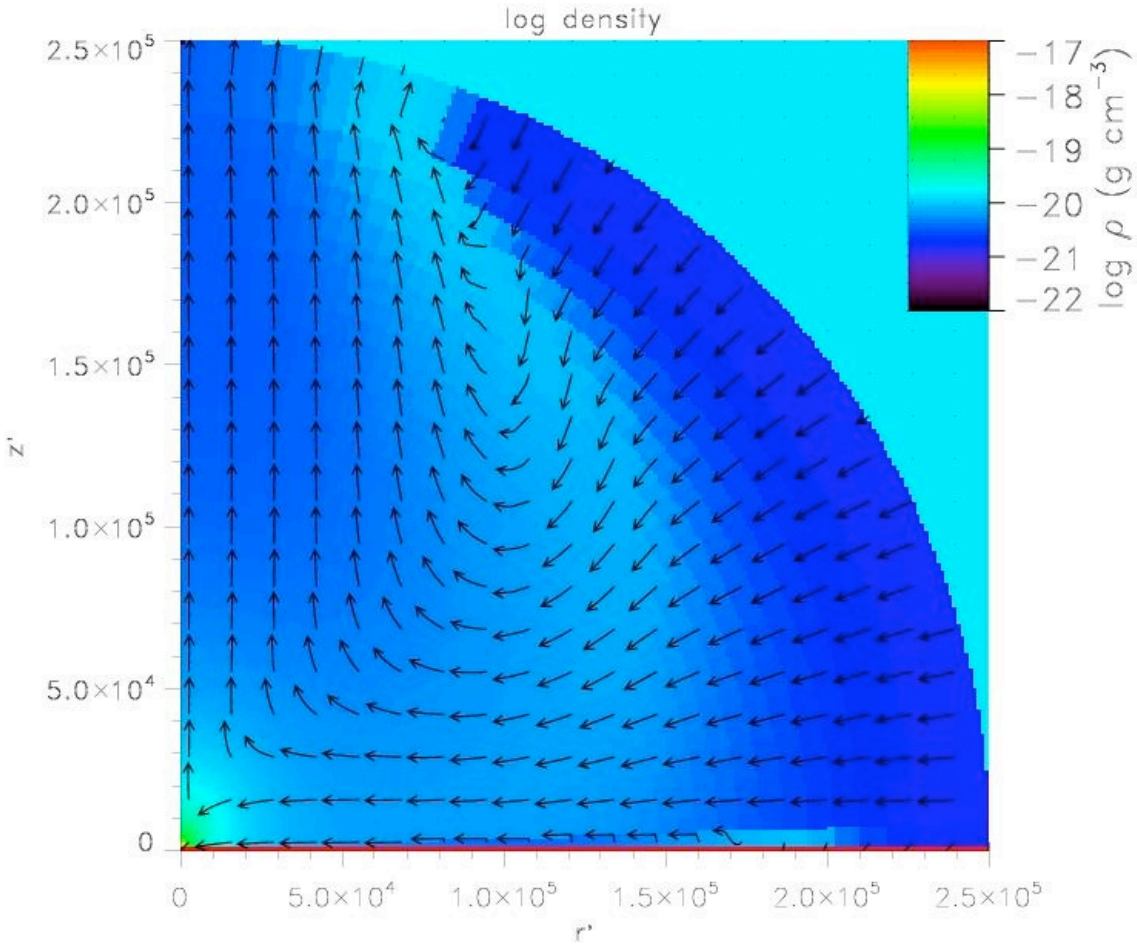
$$M_{BH} = 10^8 M_{SUN}$$

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

$$T_X = 8\ x10^7 K$$

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

$$f_{UV} = f_X = 0.5$$



Proga (2007)

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

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

$$T_{X} = 8 \ x10^{7} K$$

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

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

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

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

$$T_{X} = 8 \ x10^{7} K$$

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

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

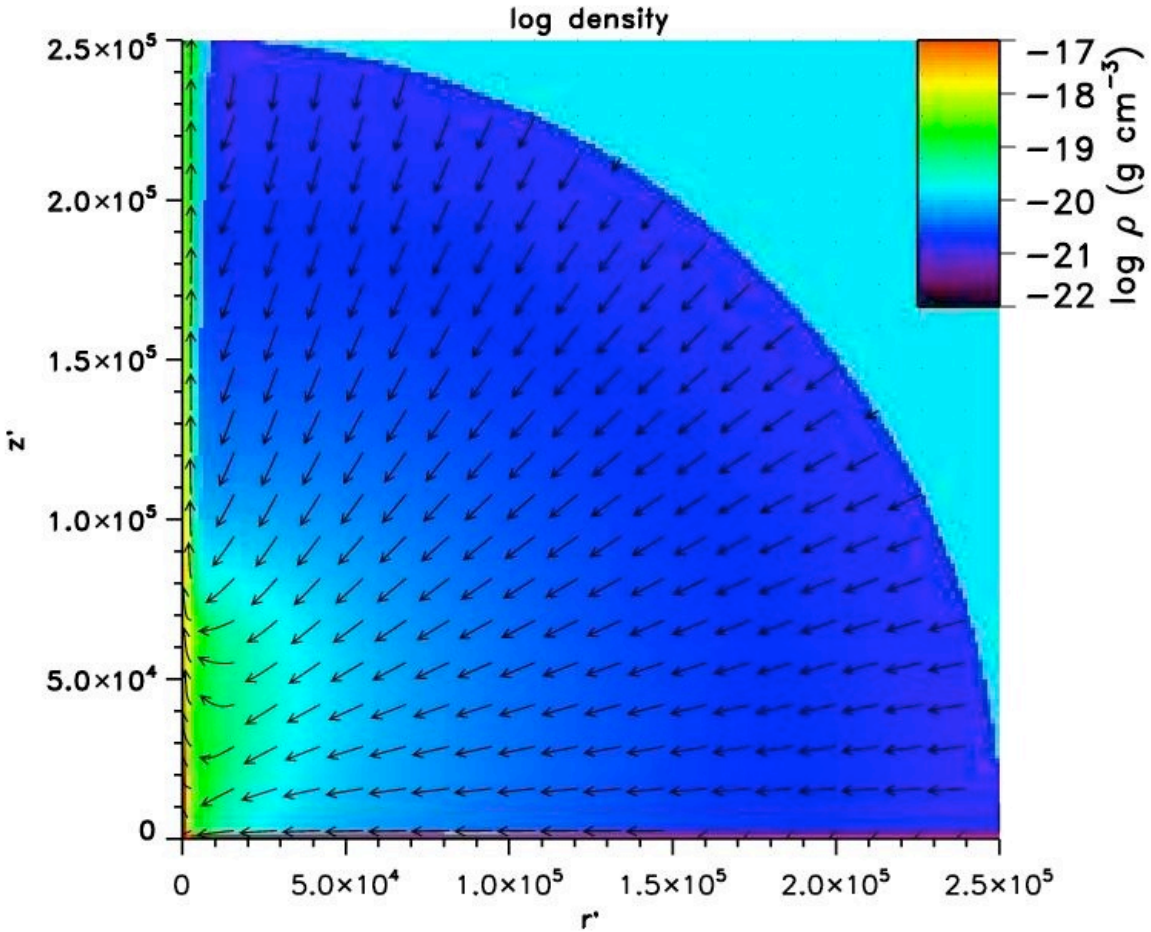
$M_{BH} = 10^8 M_{SUN}$

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

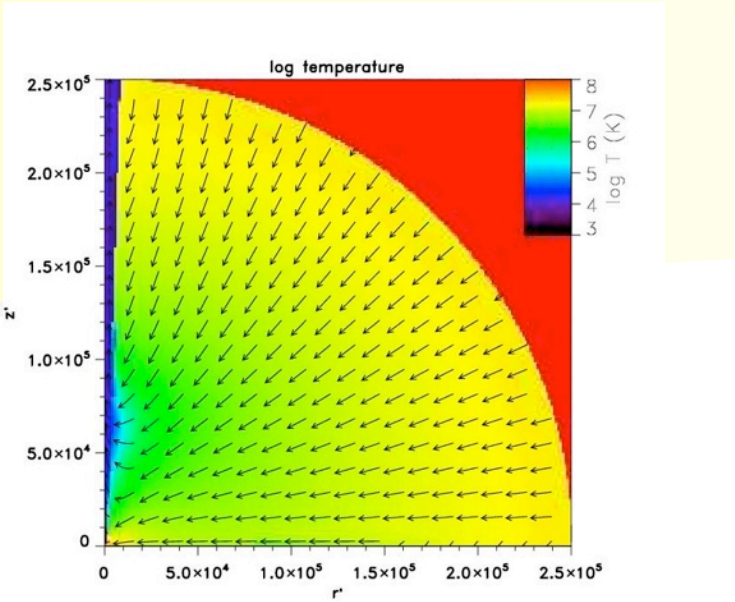
$T_X = 8\ x10^7 K$

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

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



Proga (2007)



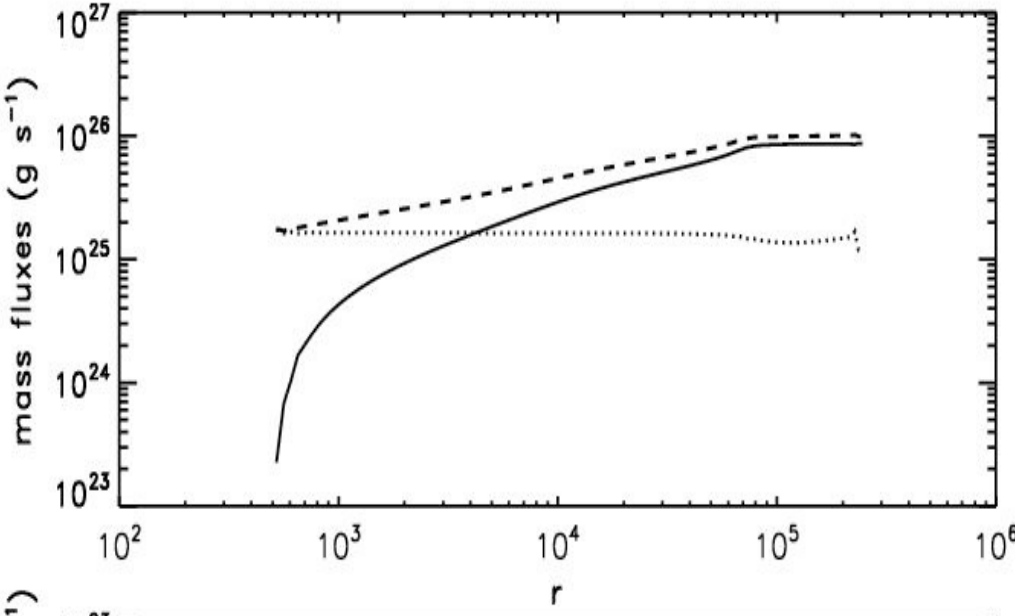
$M_{BH} = 10^8 M_{SUN}$

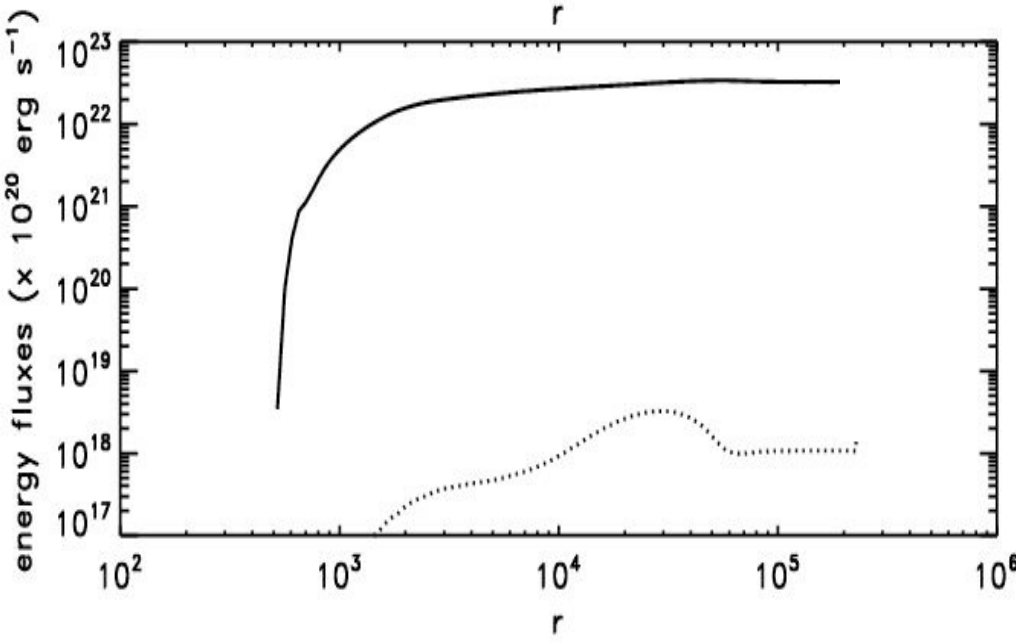
$\dot{M}_D = 10^{26} g/s = 1.6 M_{SUN}/yr$

$T_X = 8\ x10^7 K$

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

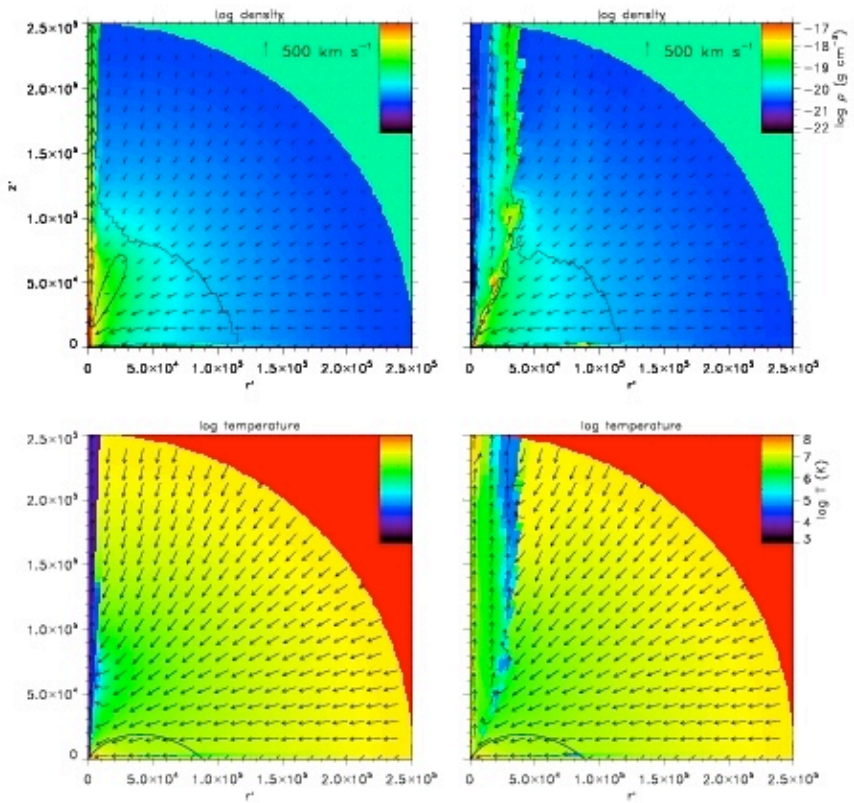
$f_{UV} = 0.95 \quad f_X = 0.05$





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

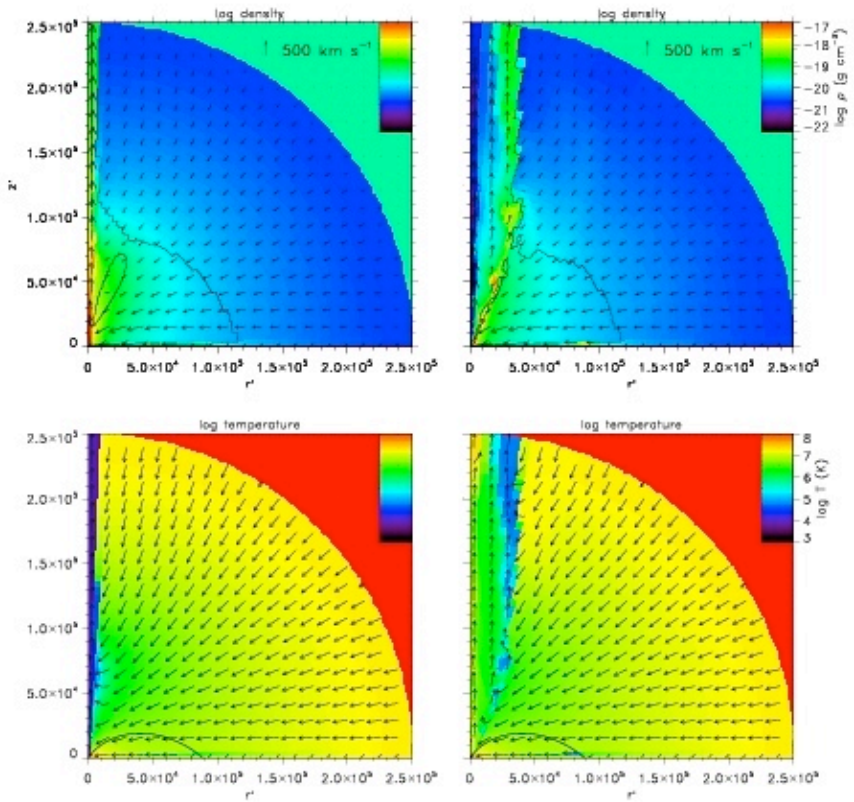
Effects of gas rotation, optical depth and X-ray background radiation



DP, Ostriker, Kurosawa (2007)

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

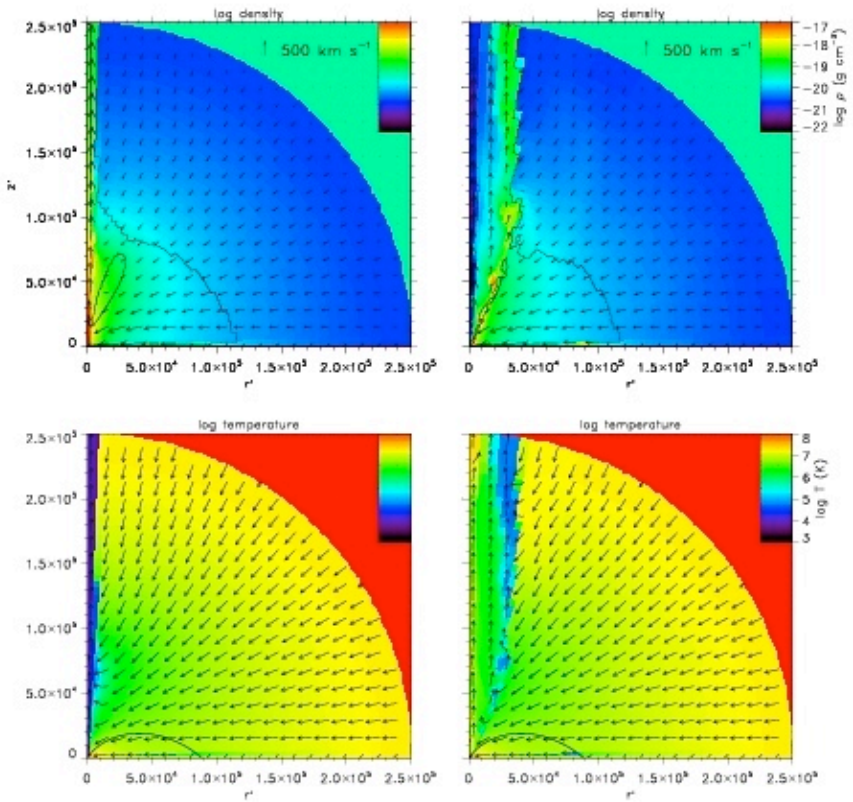
no rotation



DP, Ostriker, Kurosawa (2007)

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

no rotation rotation



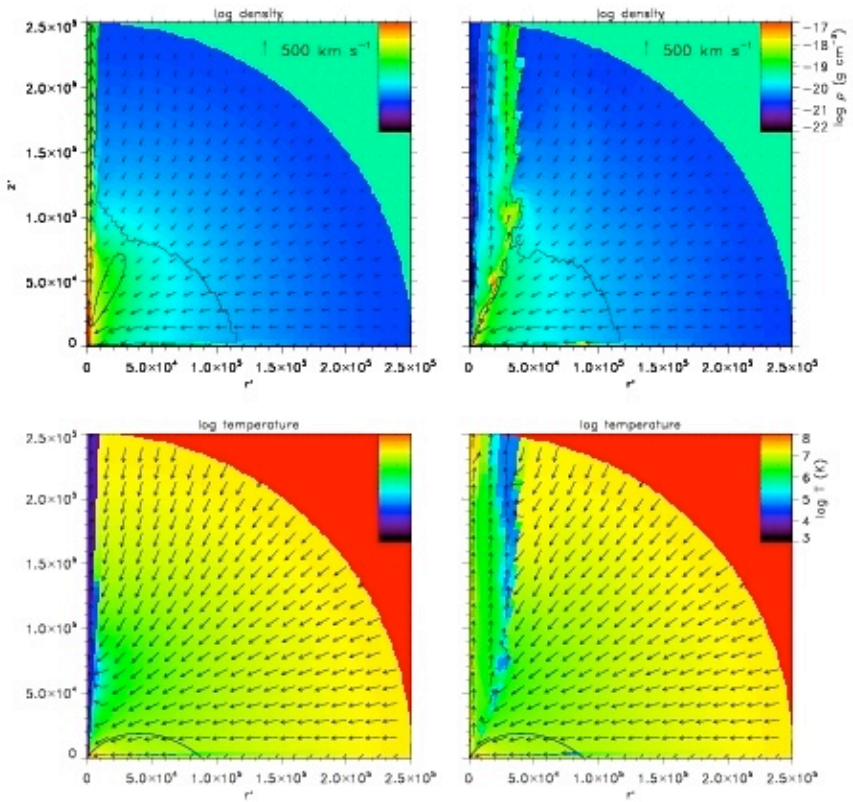
DP, Ostriker, Kurosawa (2007)

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

rotation and opt. thick

no rotation

rotation



DP, Ostriker, Kurosawa (2007)

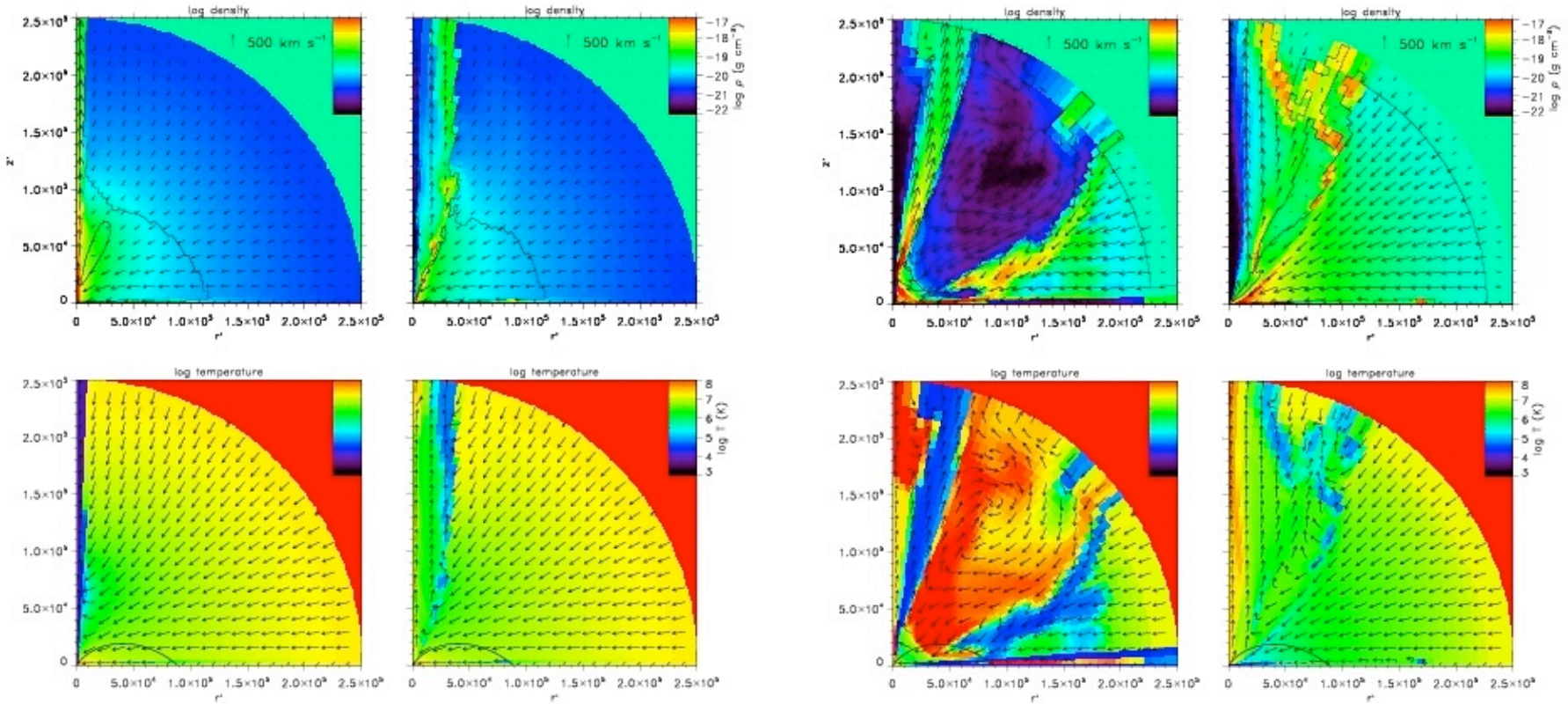
Effects of gas rotation, optical depth and X-ray background radiation

rotation and opt. thick

no rotation

rotation

no X-ray background

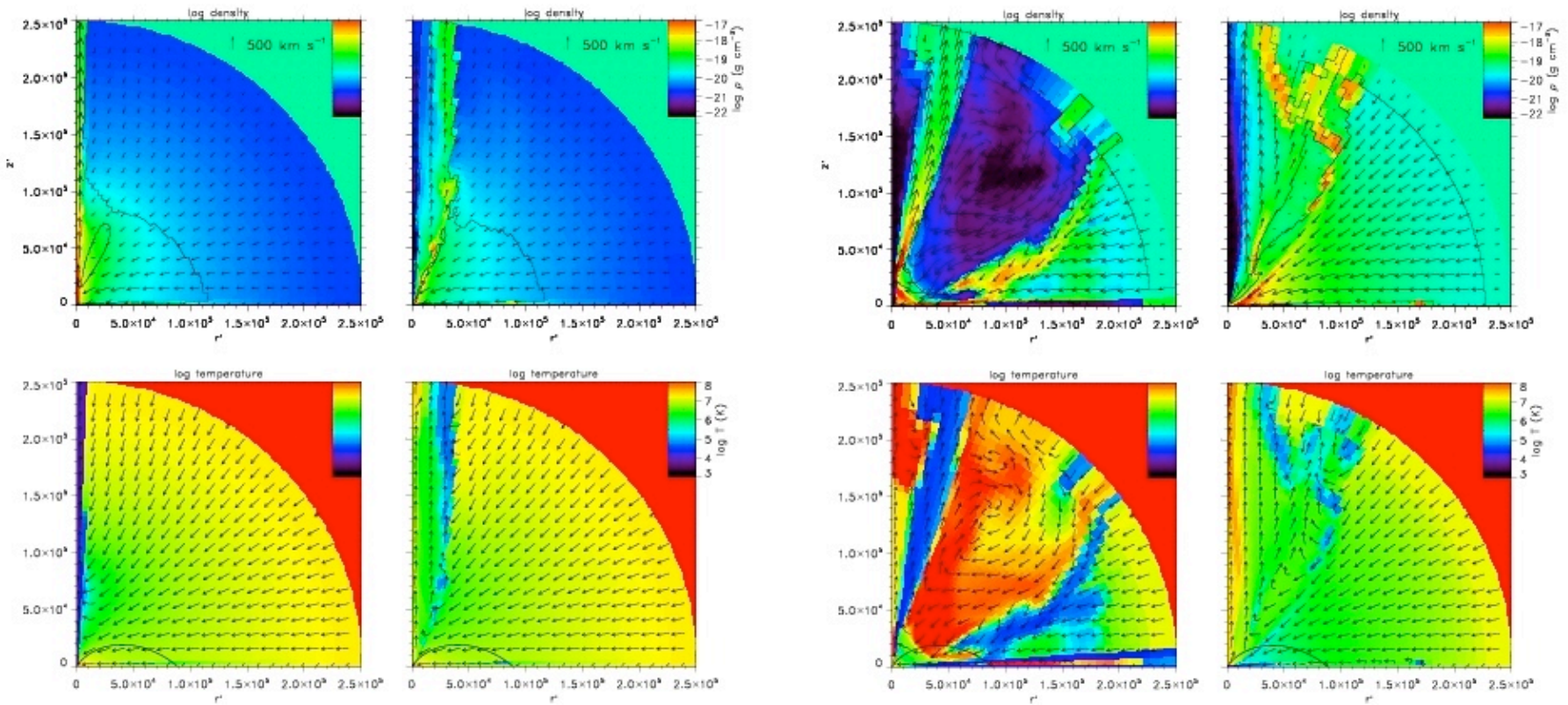


DP, Ostriker, Kurosawa (2007)

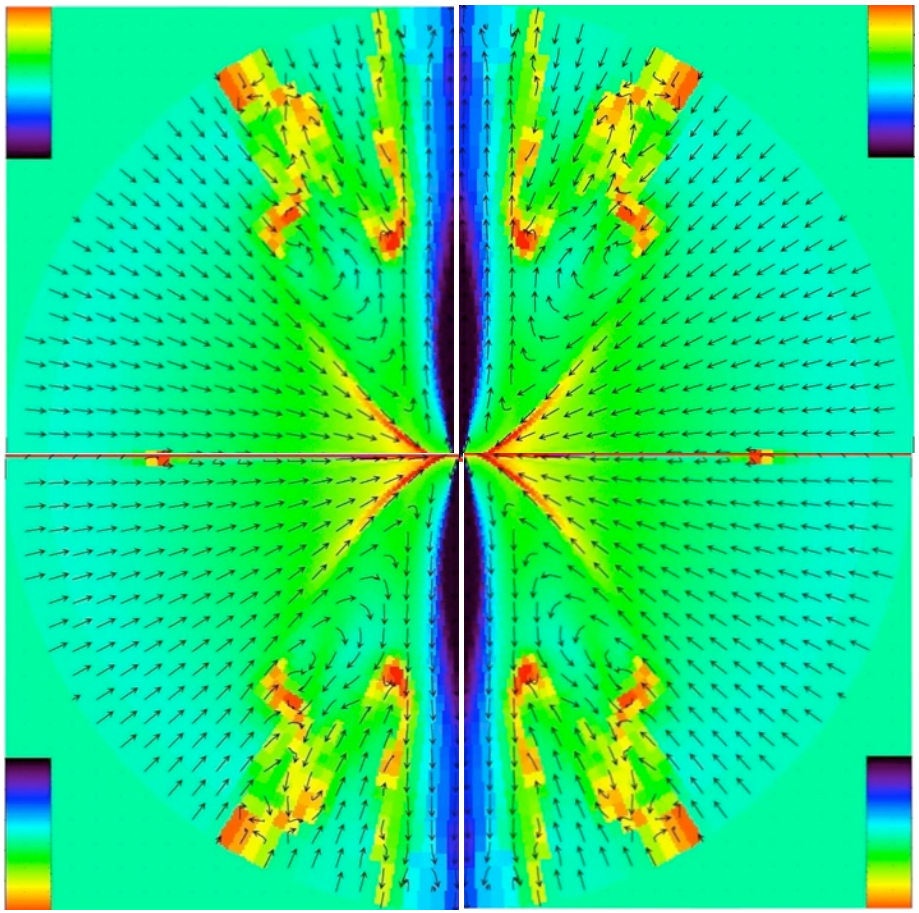
Effects of gas rotation, optical depth and X-ray background radiation

rotation and opt. thick

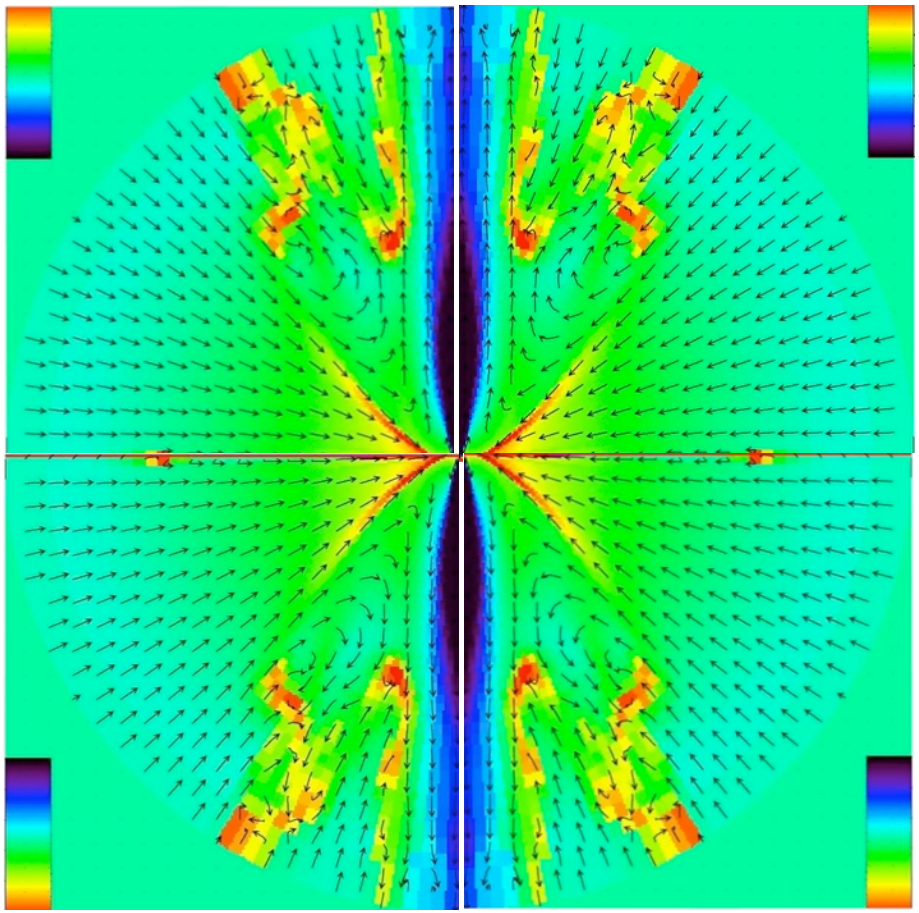
no rotation | rotation | no X-ray background | X-ray background



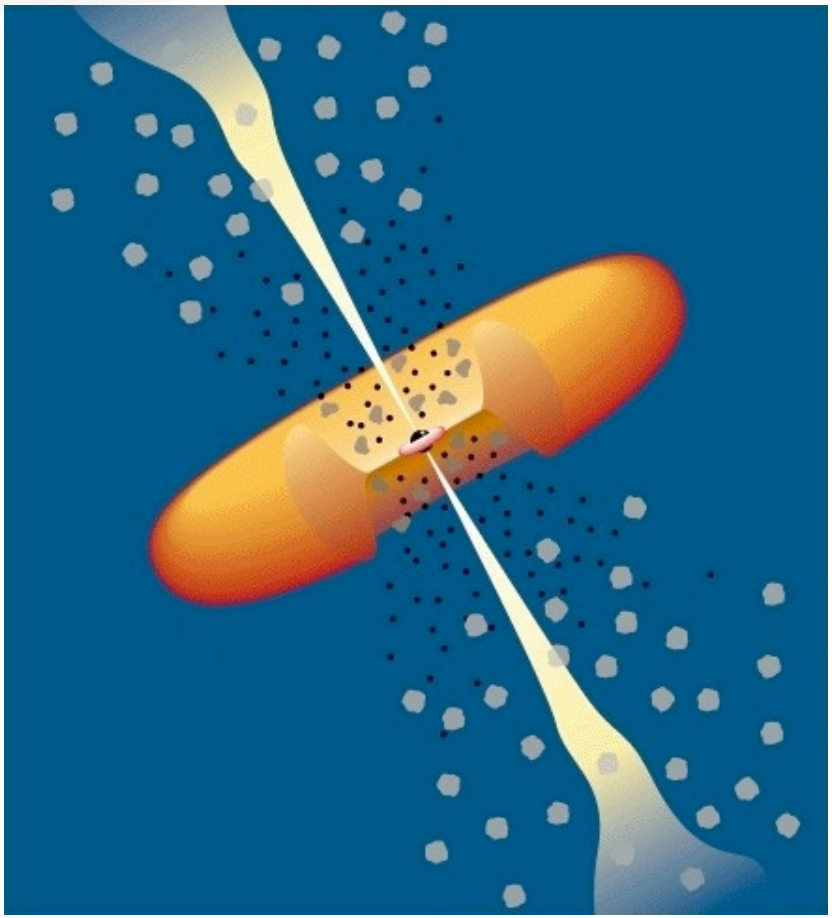
DP, Ostriker, Kurosawa (2007)

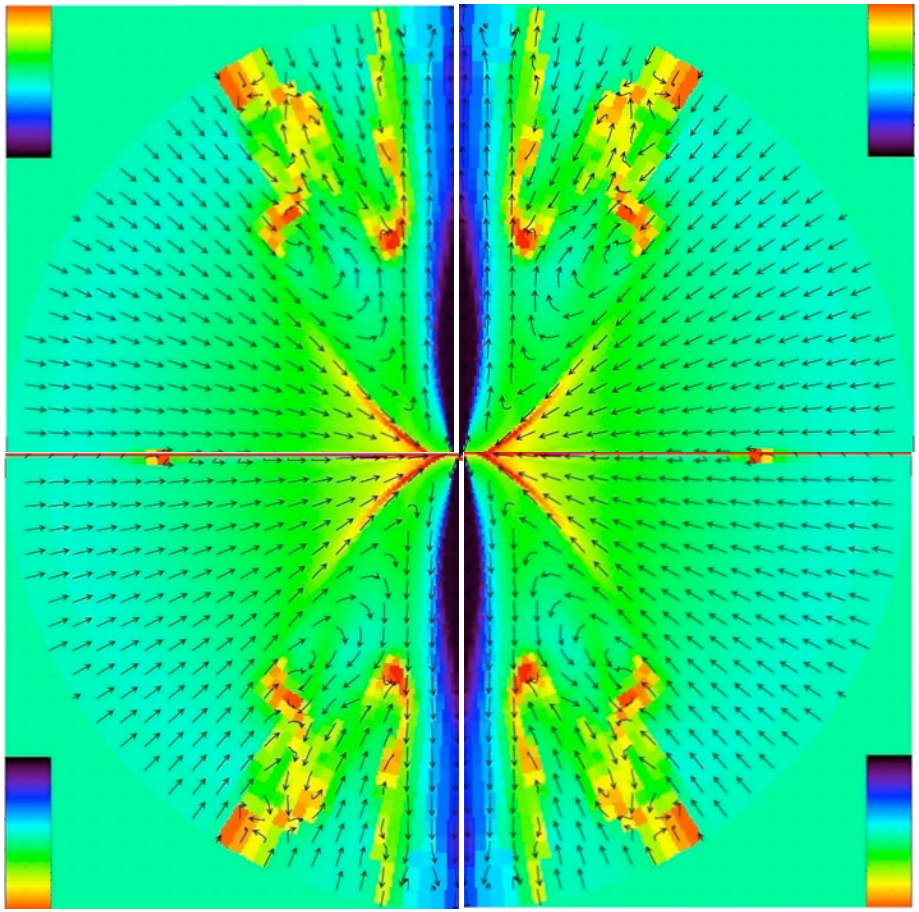


Dynamical model for clouds in NLR!?

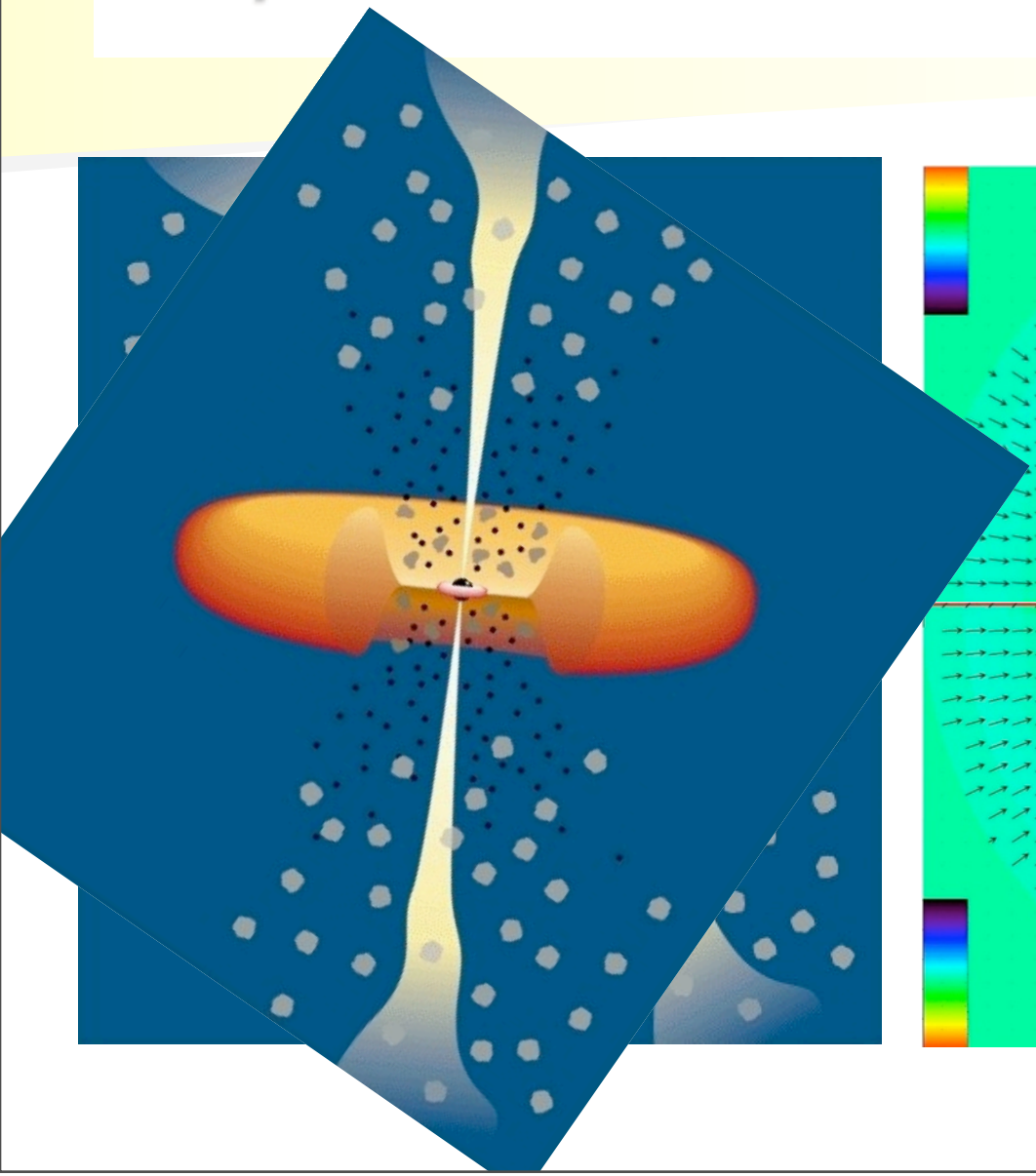


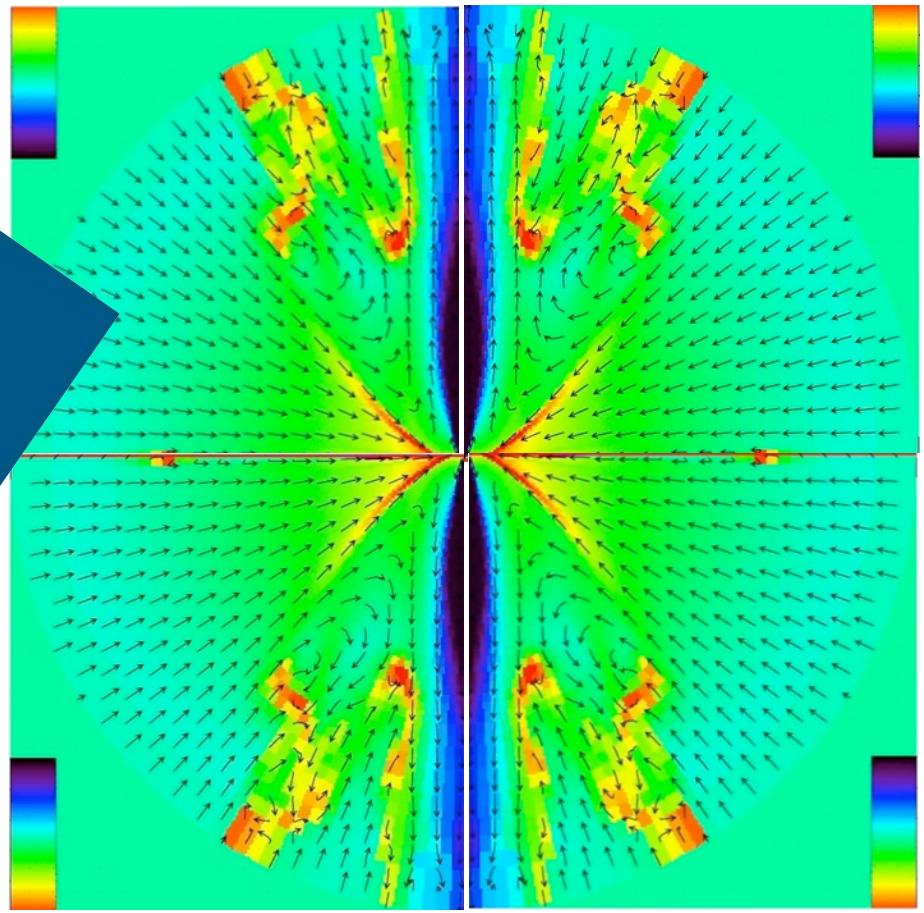
Dynamical model for clouds in NLR!?





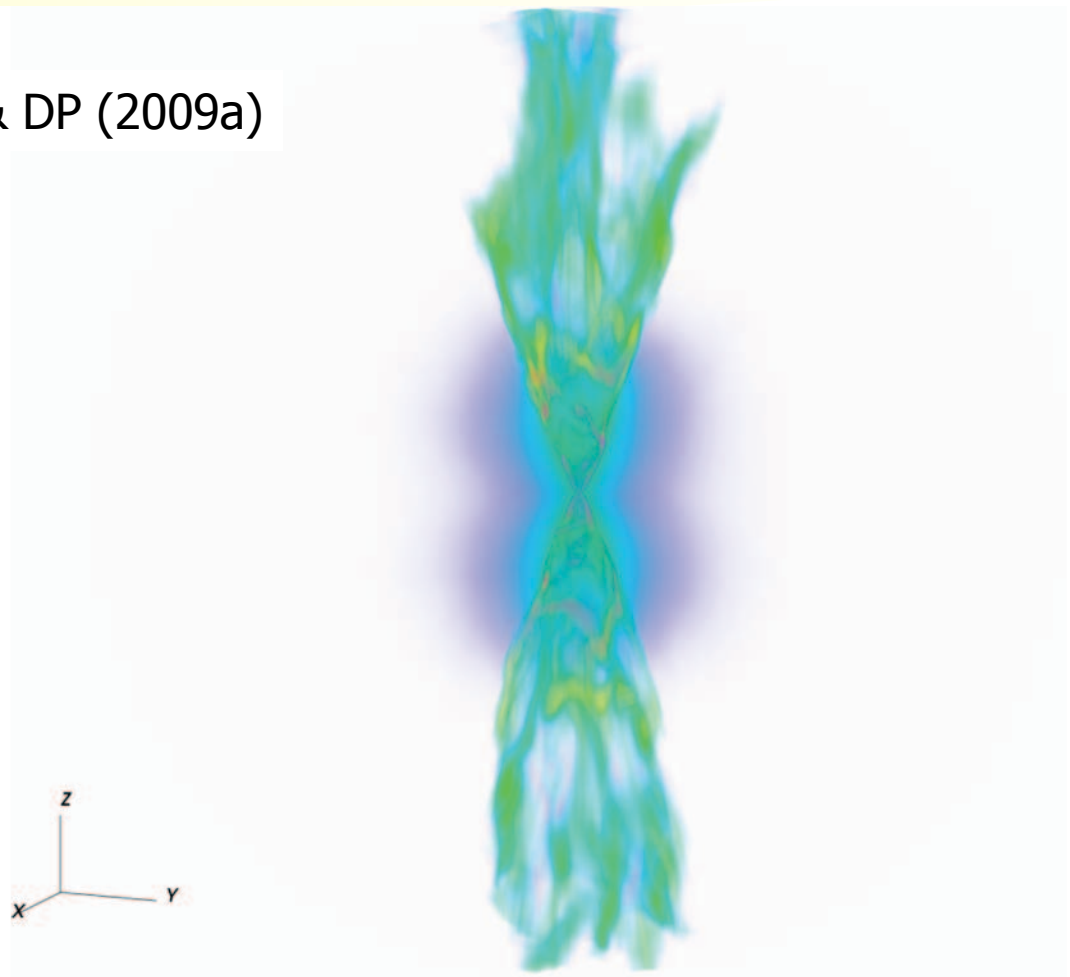
Dynamical model for clouds in NLR!?





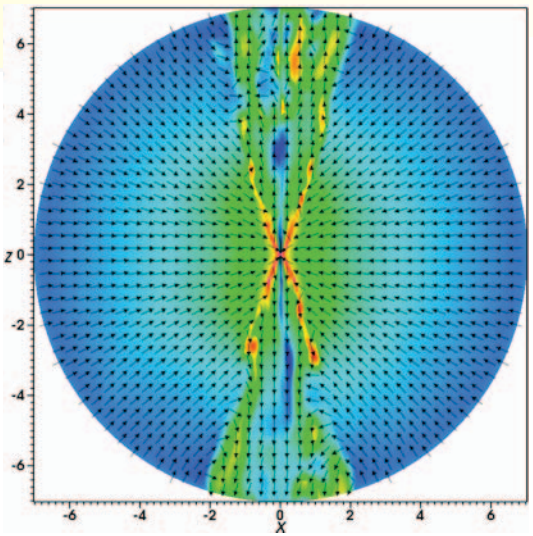
3-diminesional simulations

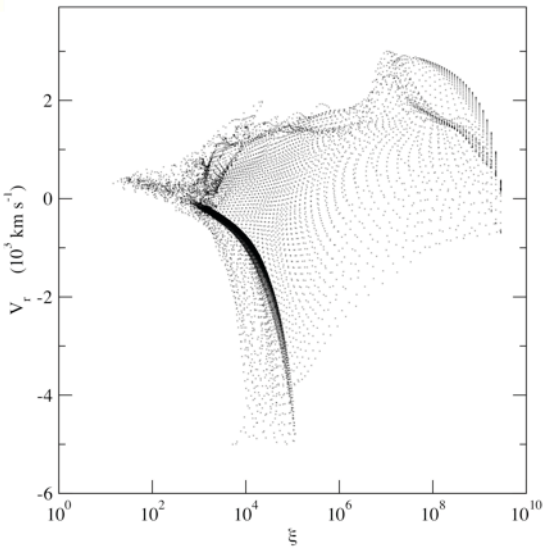
Kurosawa & DP (2009a)



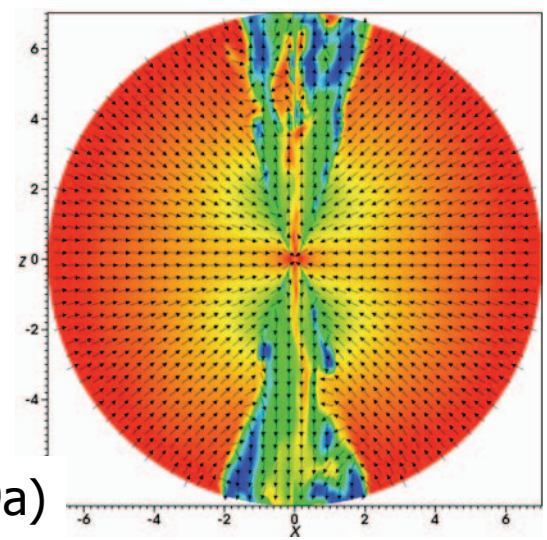
Clouds properties

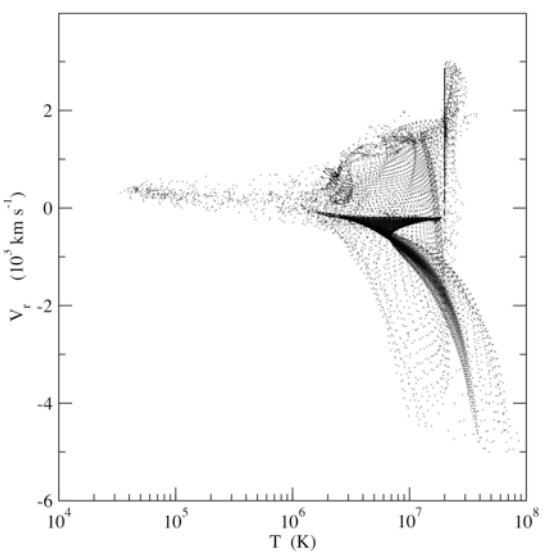
density map





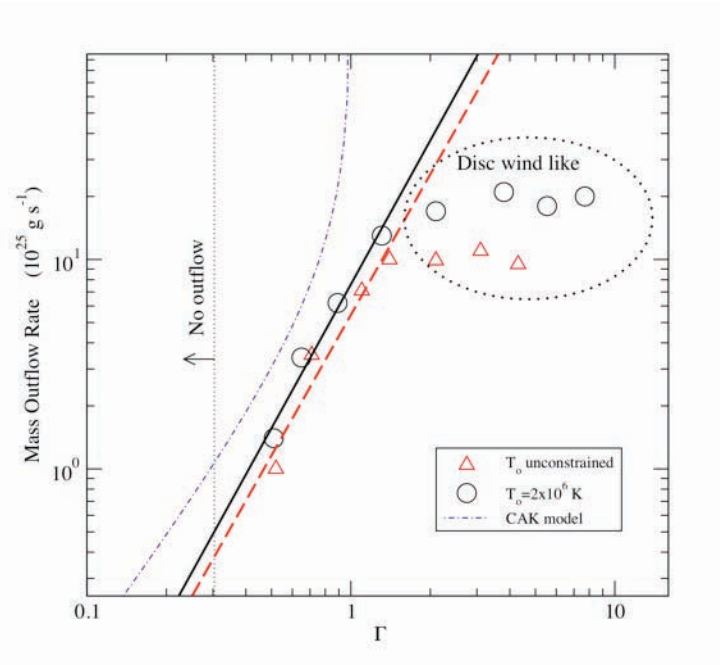
temperature map





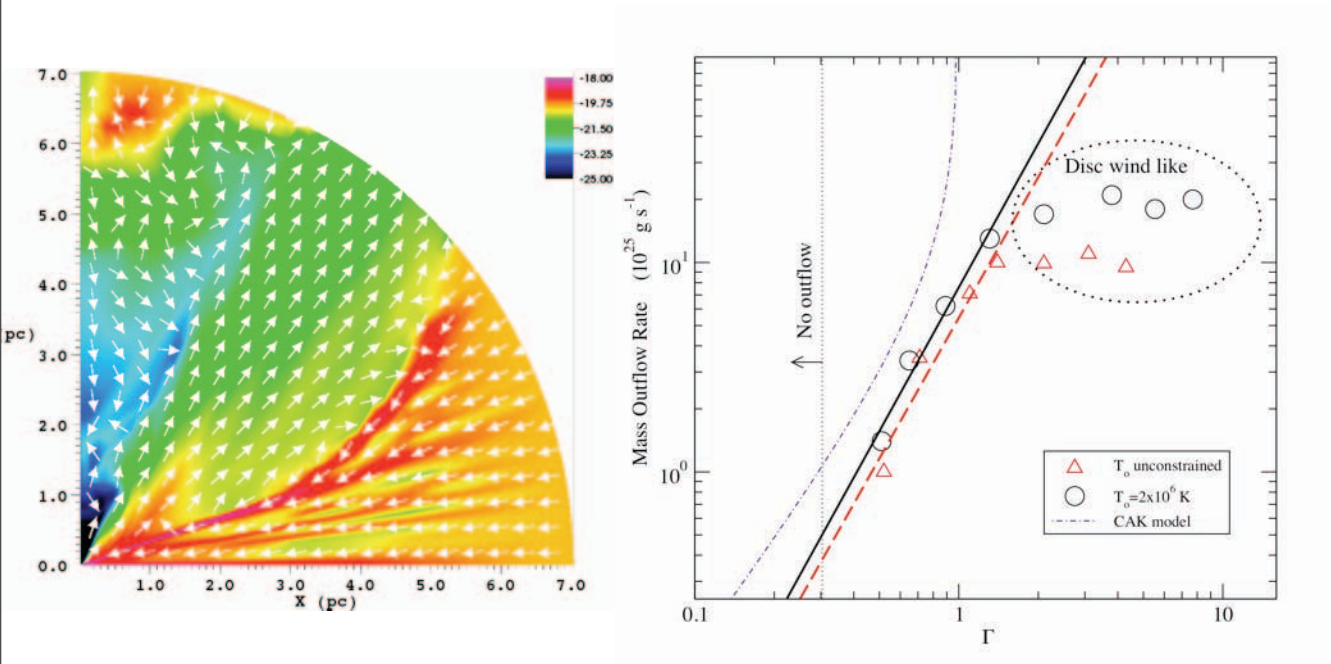
Kurosawa & DP (2009a)

What is the limit for the mass supply rate?



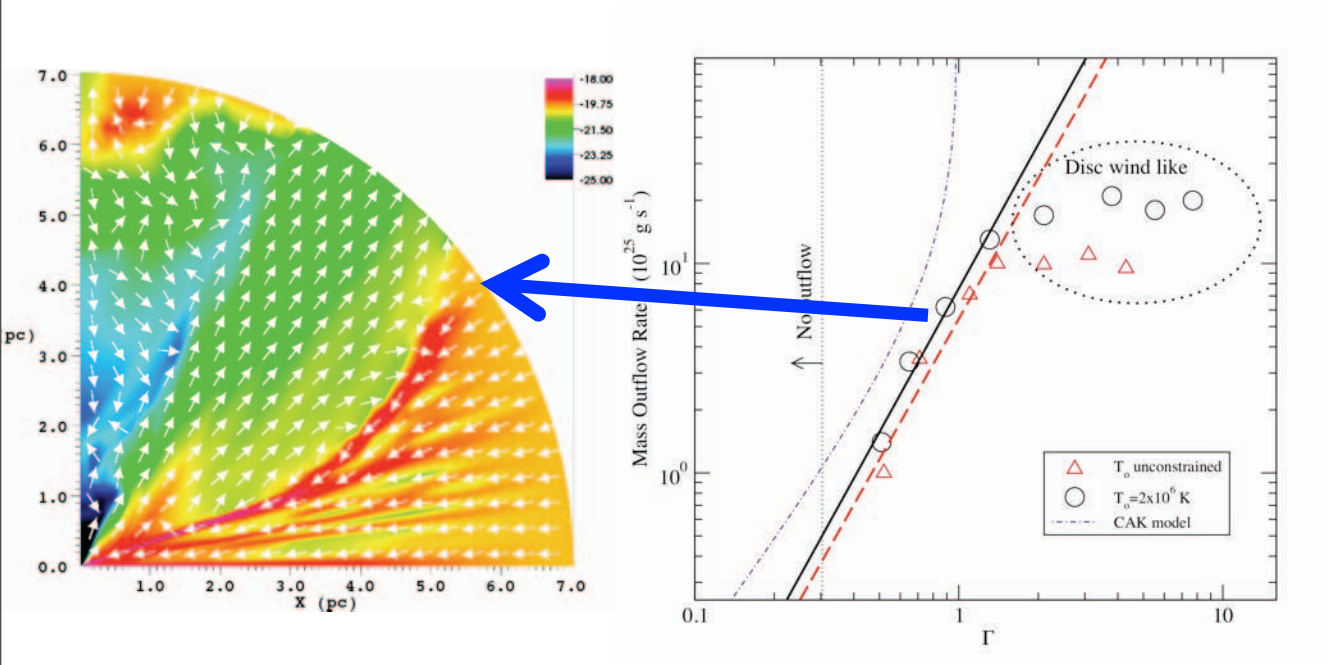
Kurosawa & DP (2009b)

What is the limit for the mass supply rate?



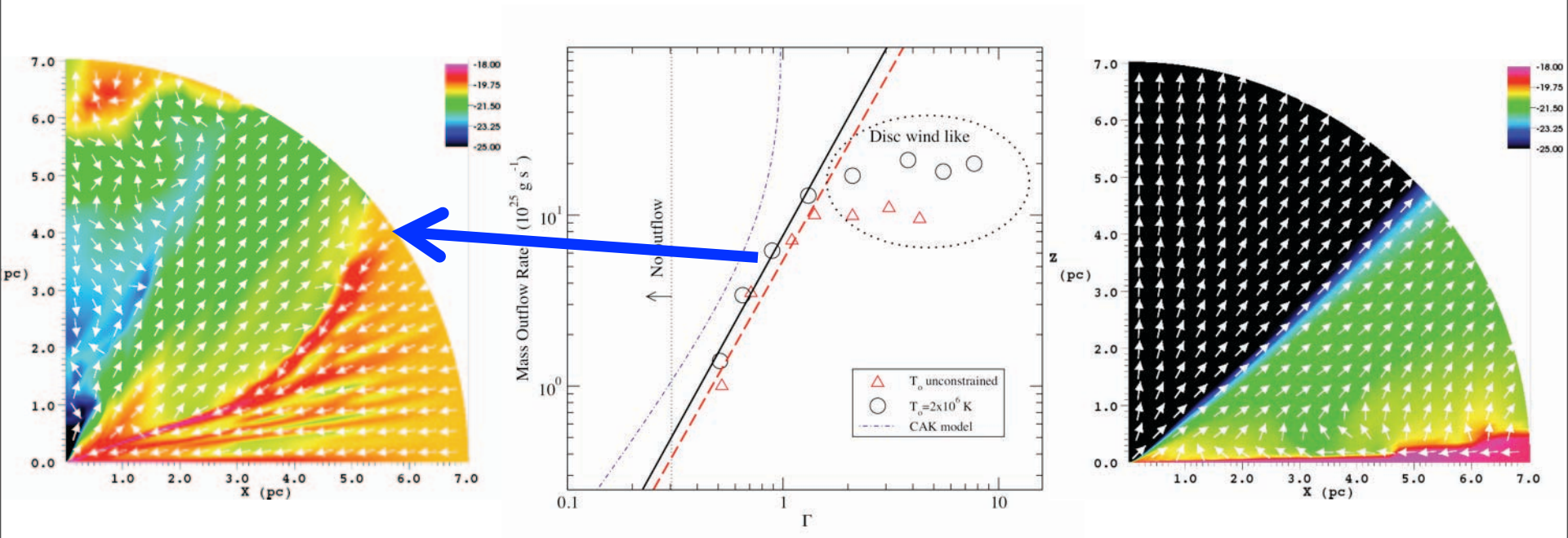
Kurosawa & DP (2009b)

What is the limit for the mass supply rate?



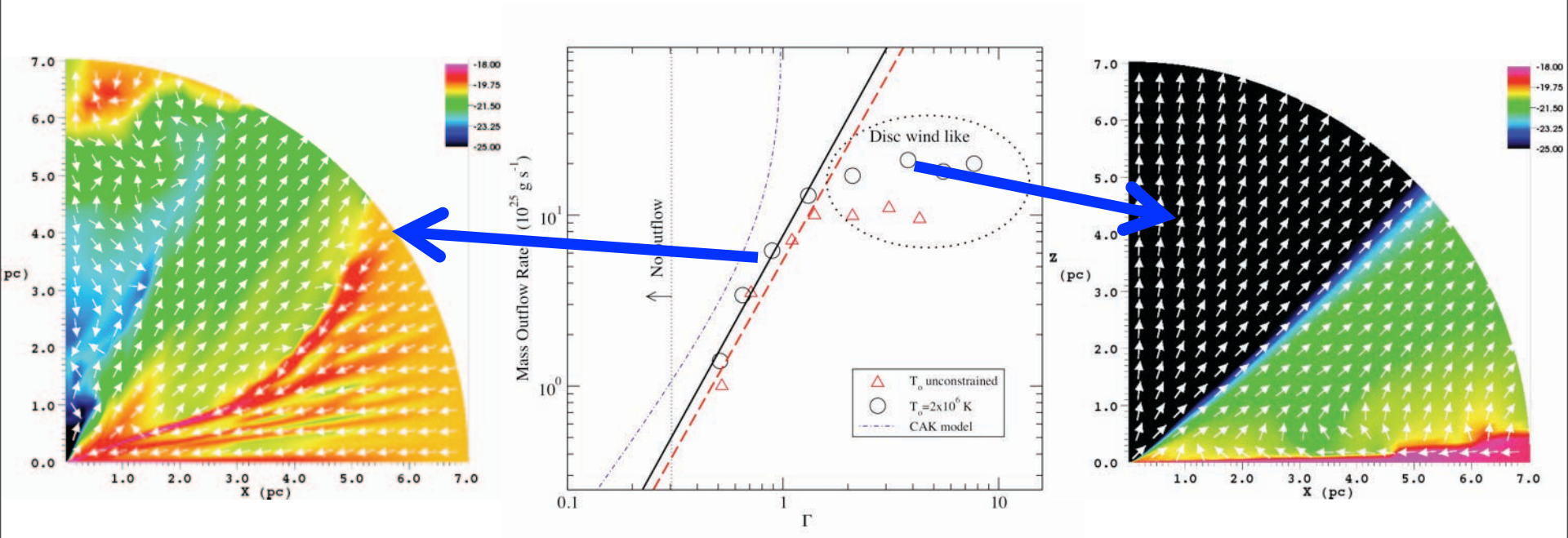
Kurosawa & DP (2009b)

What is the limit for the mass supply rate?



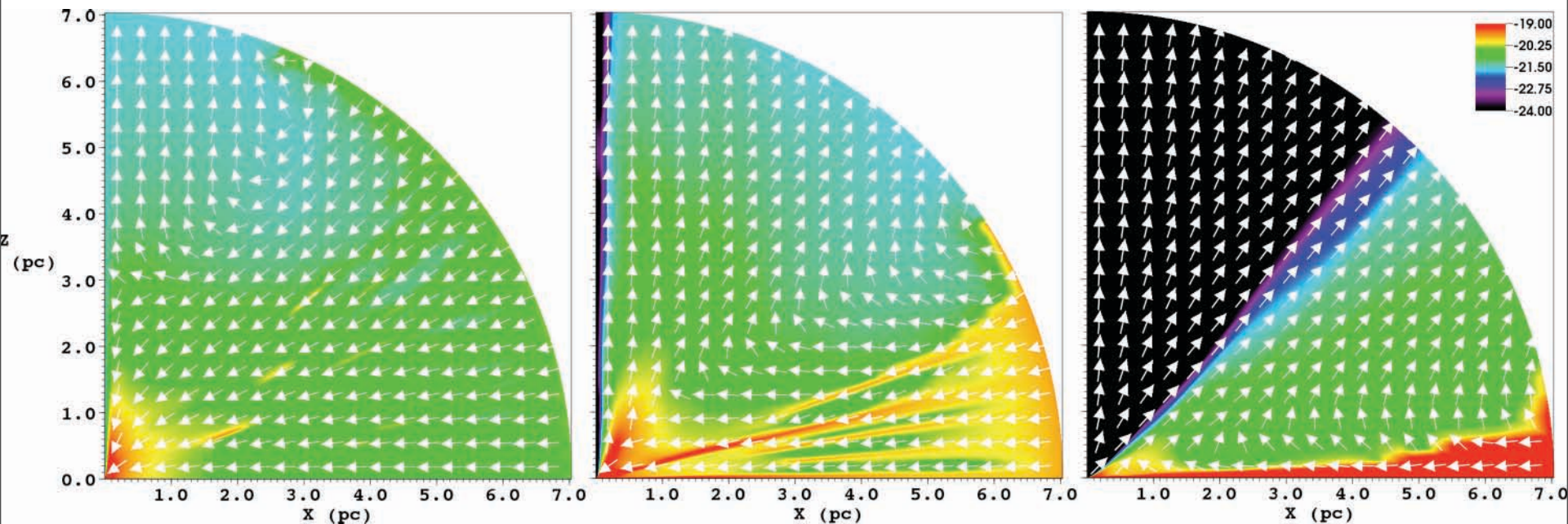
Kurosawa & DP (2009b)

What is the limit for the mass supply rate?

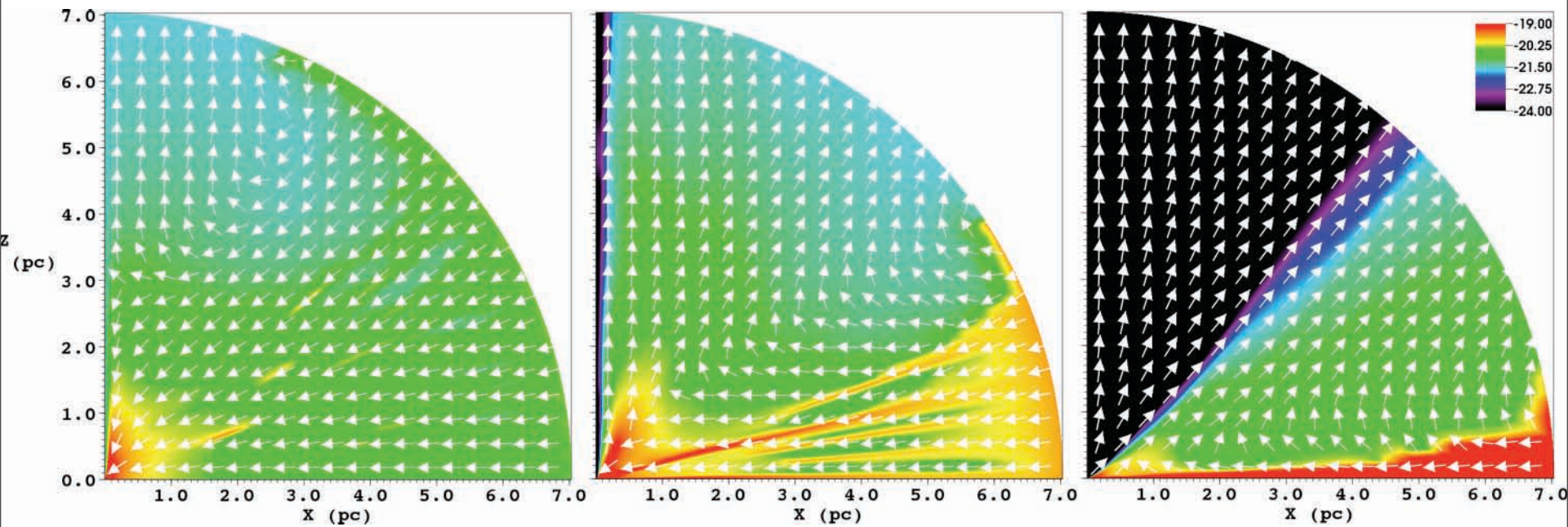


Kurosawa & DP (2009b)

What is the geometry of the outflow?

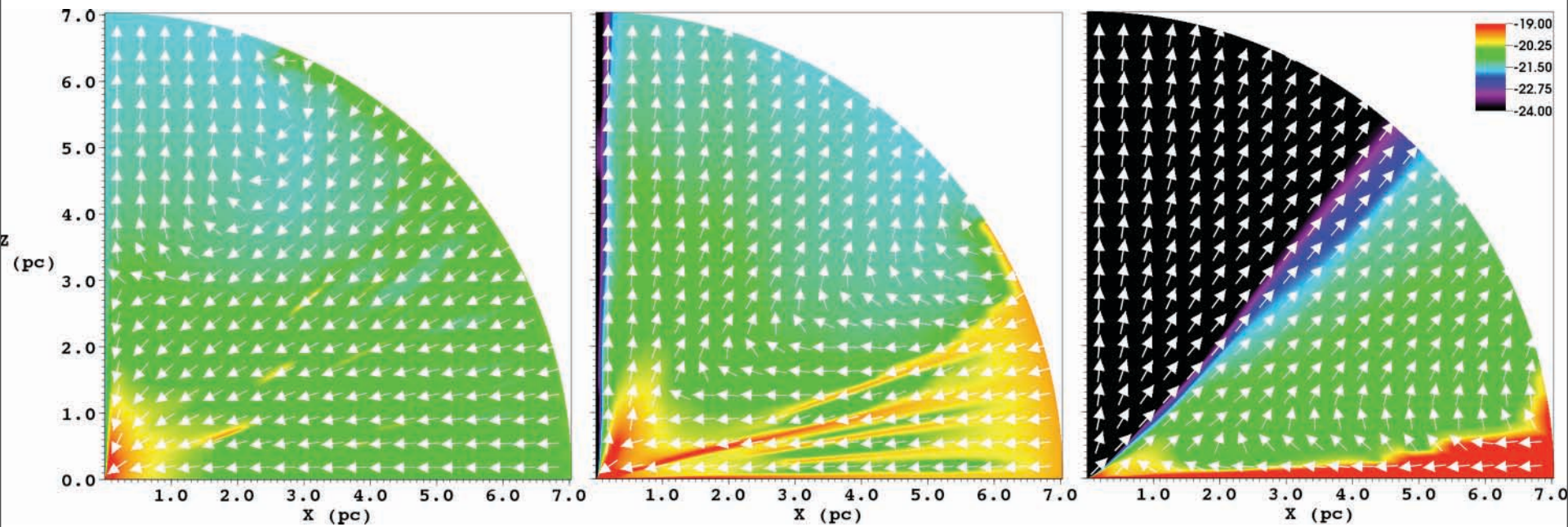


What is the geometry of the outflow?



jet like

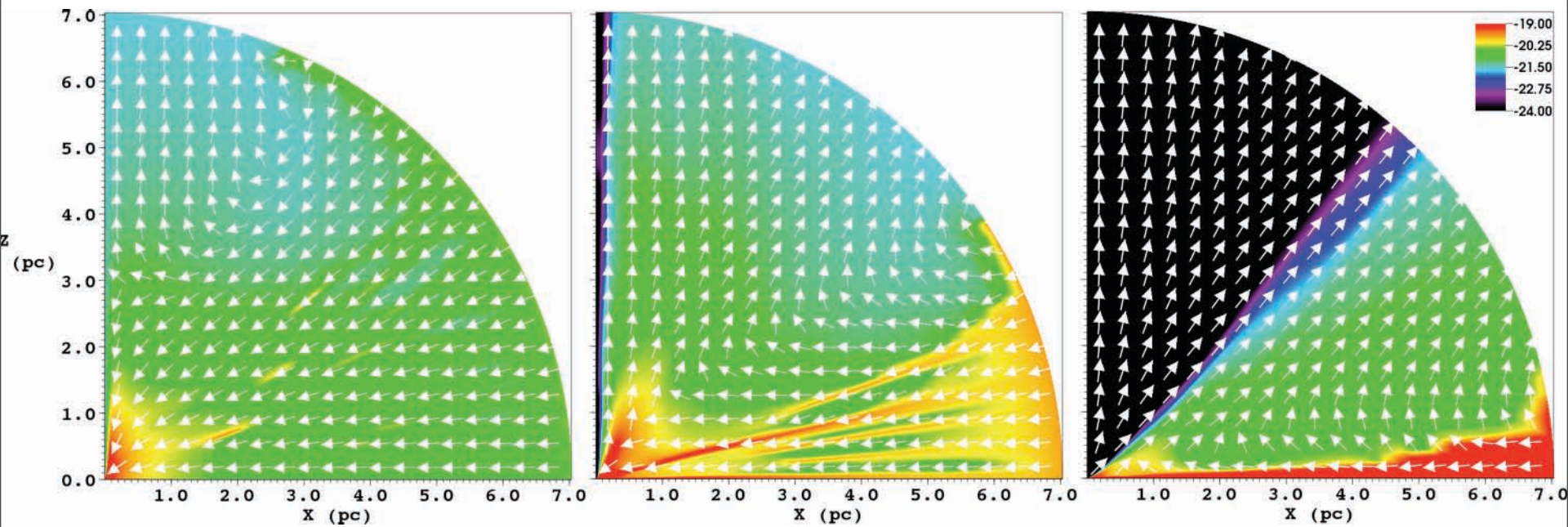
What is the geometry of the outflow?



jet like

i/o

What is the geometry of the outflow?

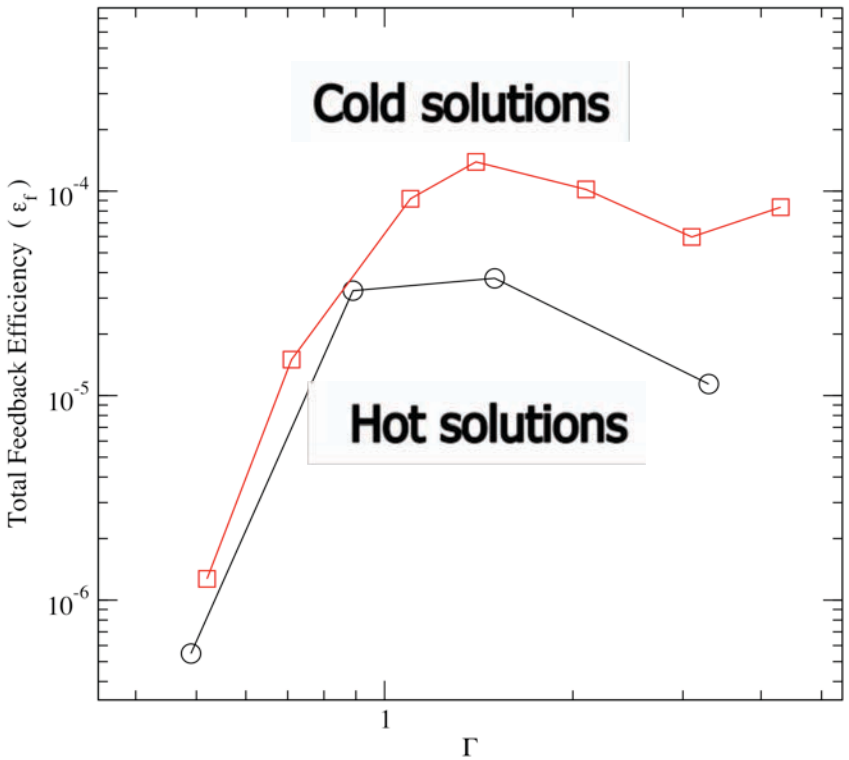


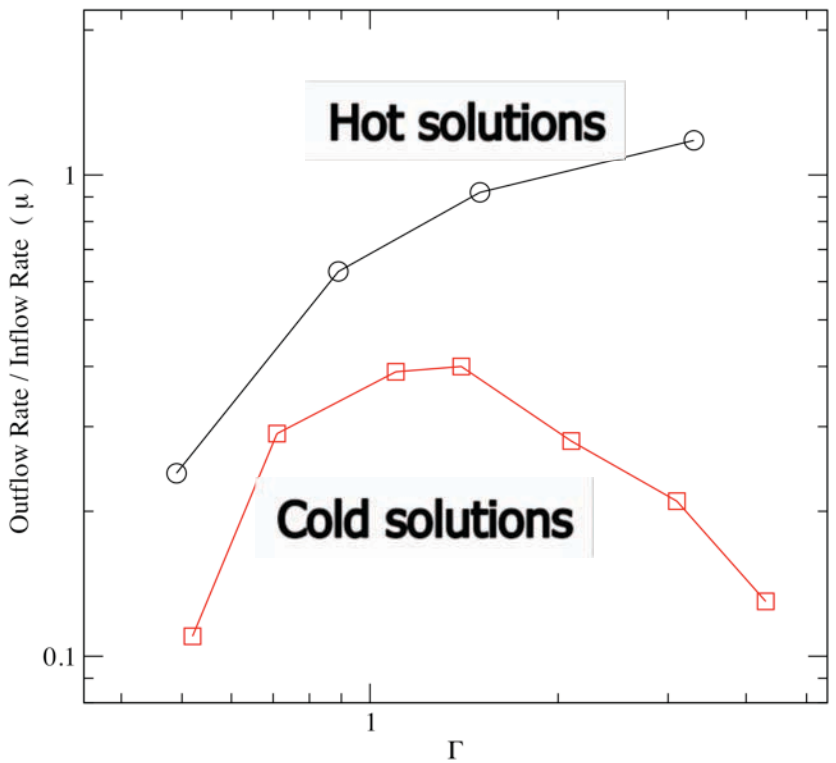
jet like

i/o

disk-wind like

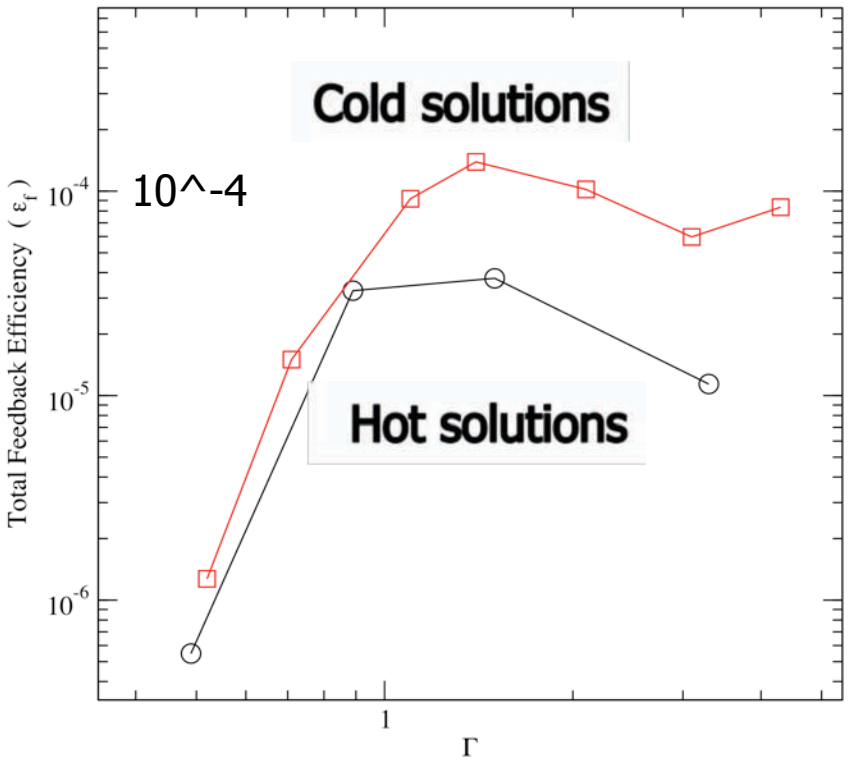
How efficient are the outflows?

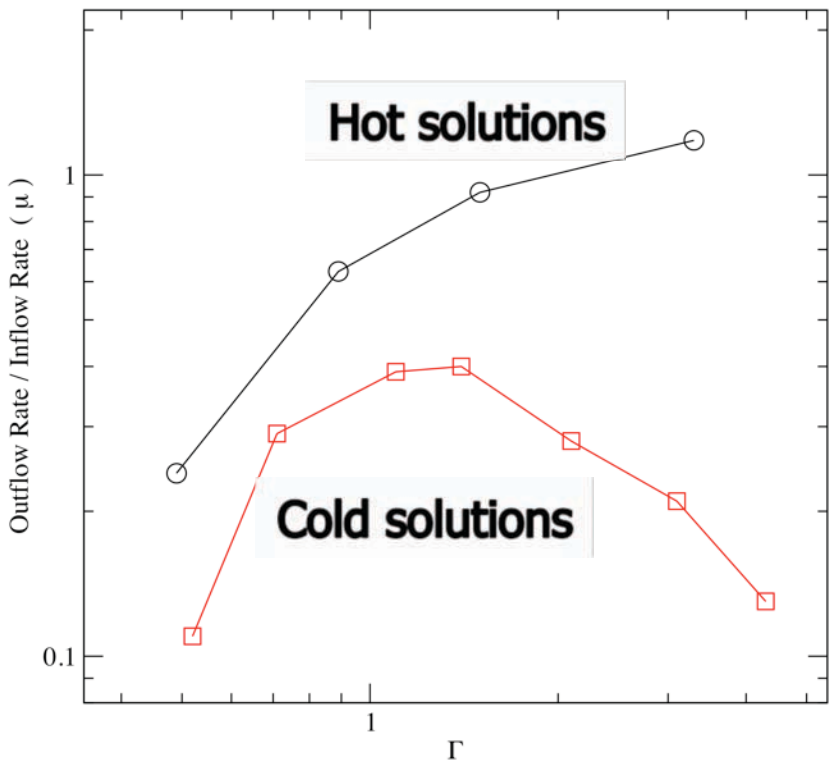




Kurosawa, DP, & Nagamine (2009)

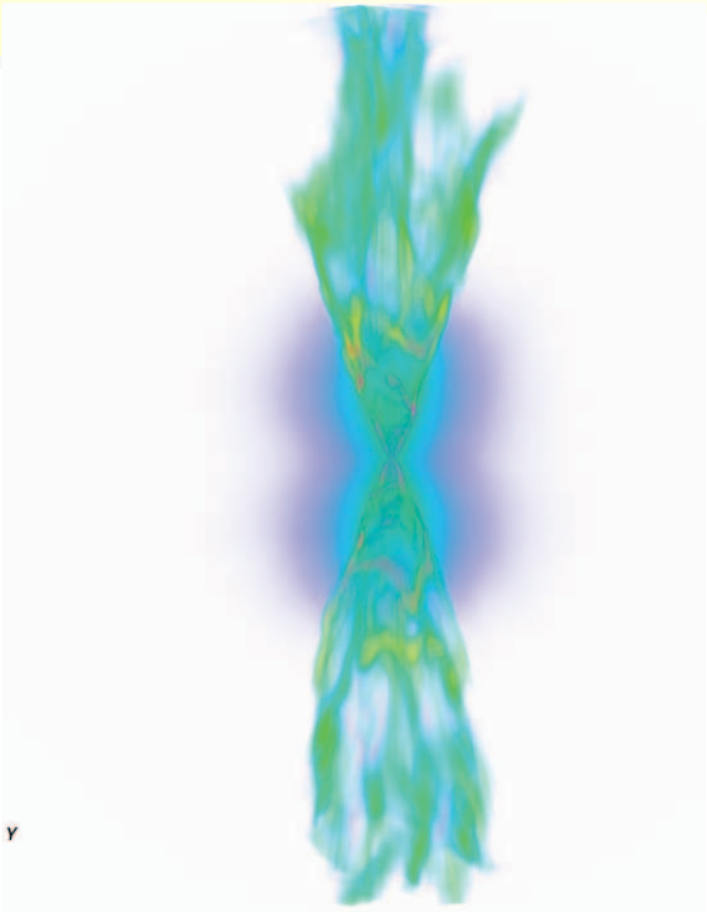
How efficient are the outflows?



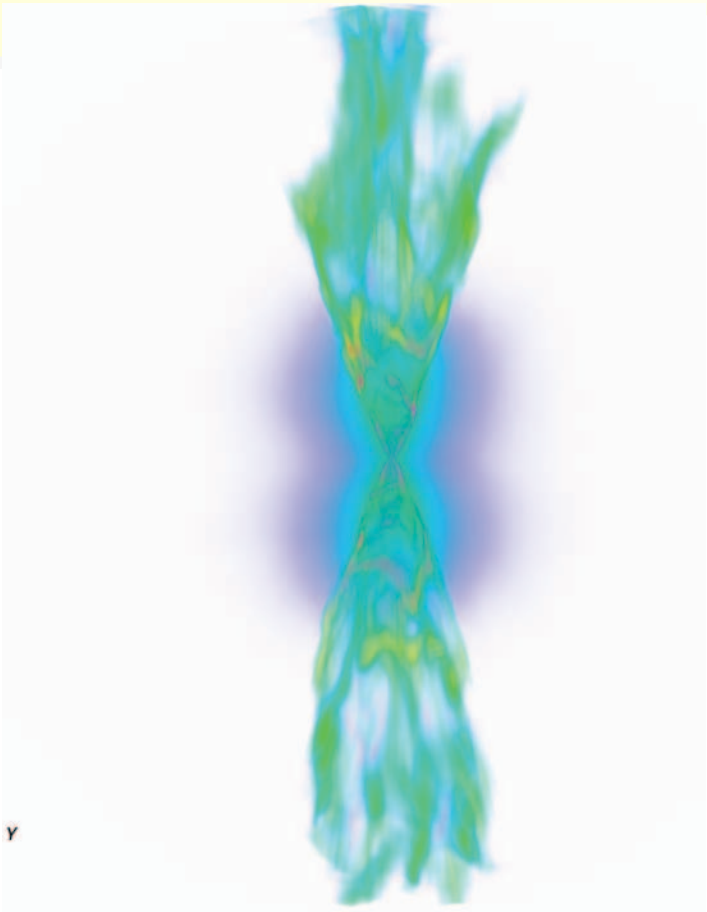


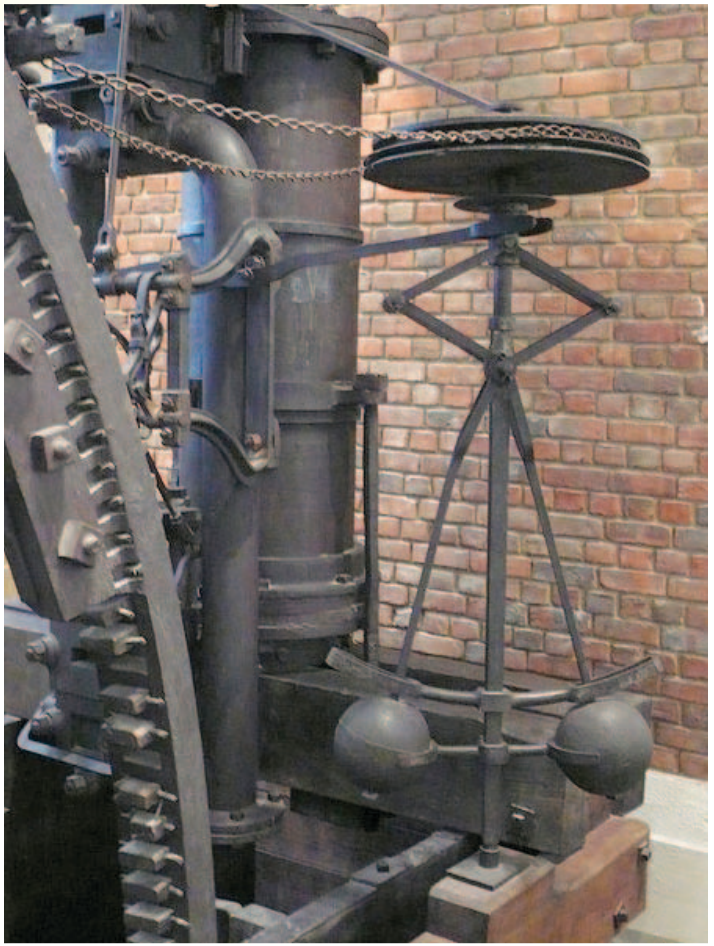
Kurosawa, DP, & Nagamine (2009)

AGN feedback

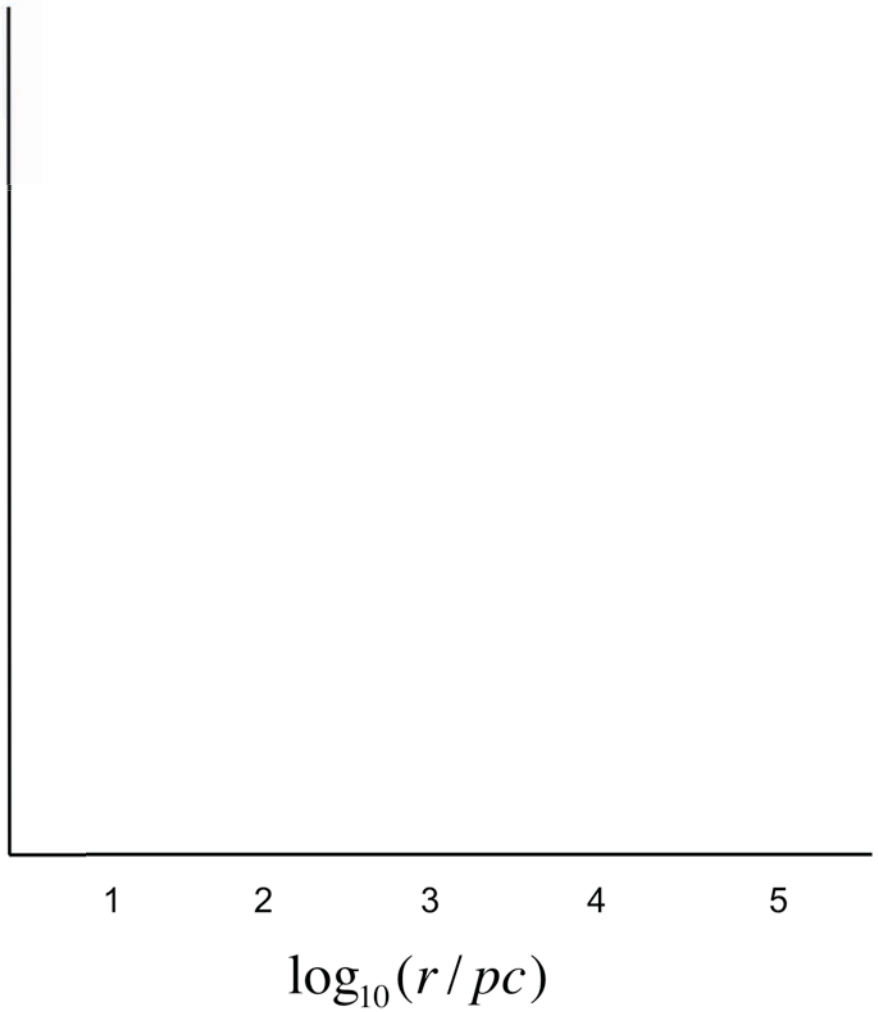


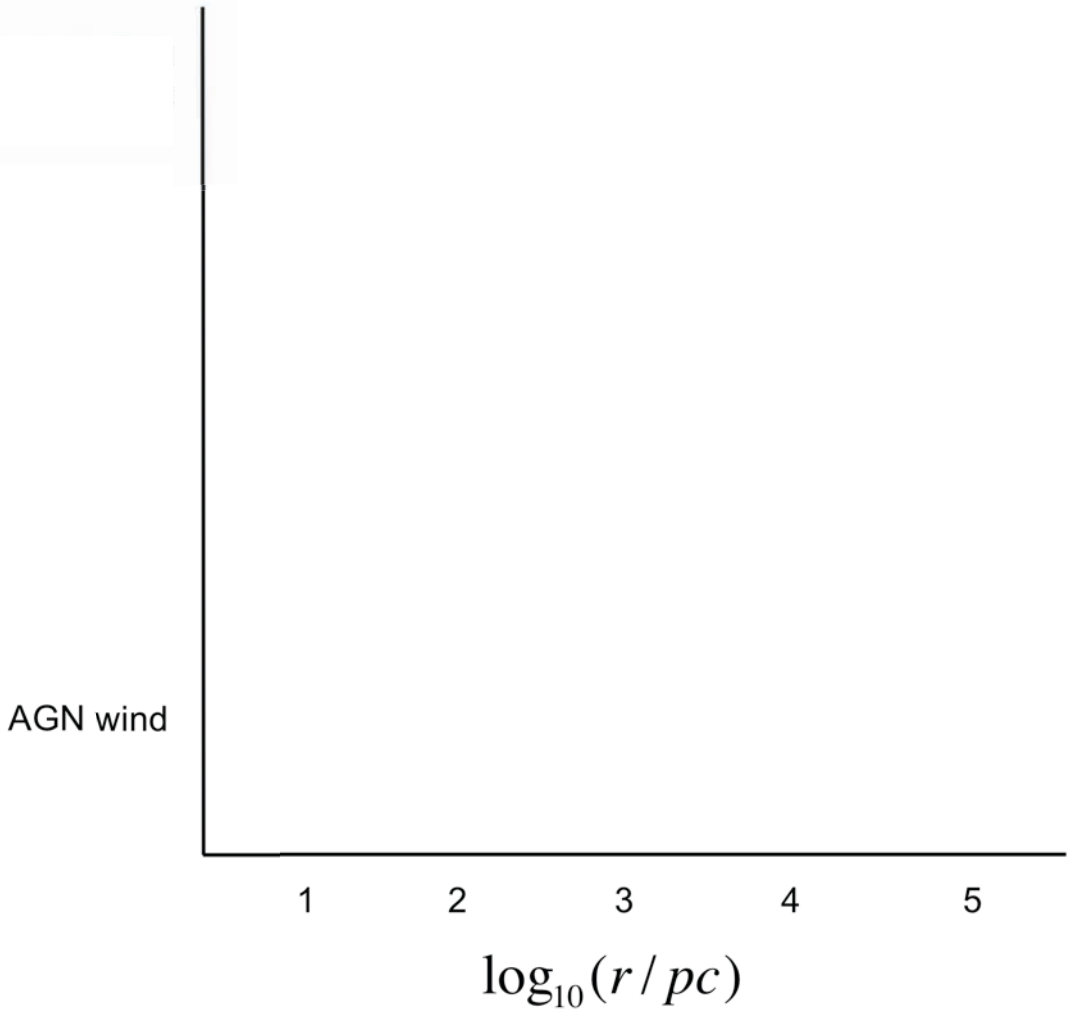
AGN feedback

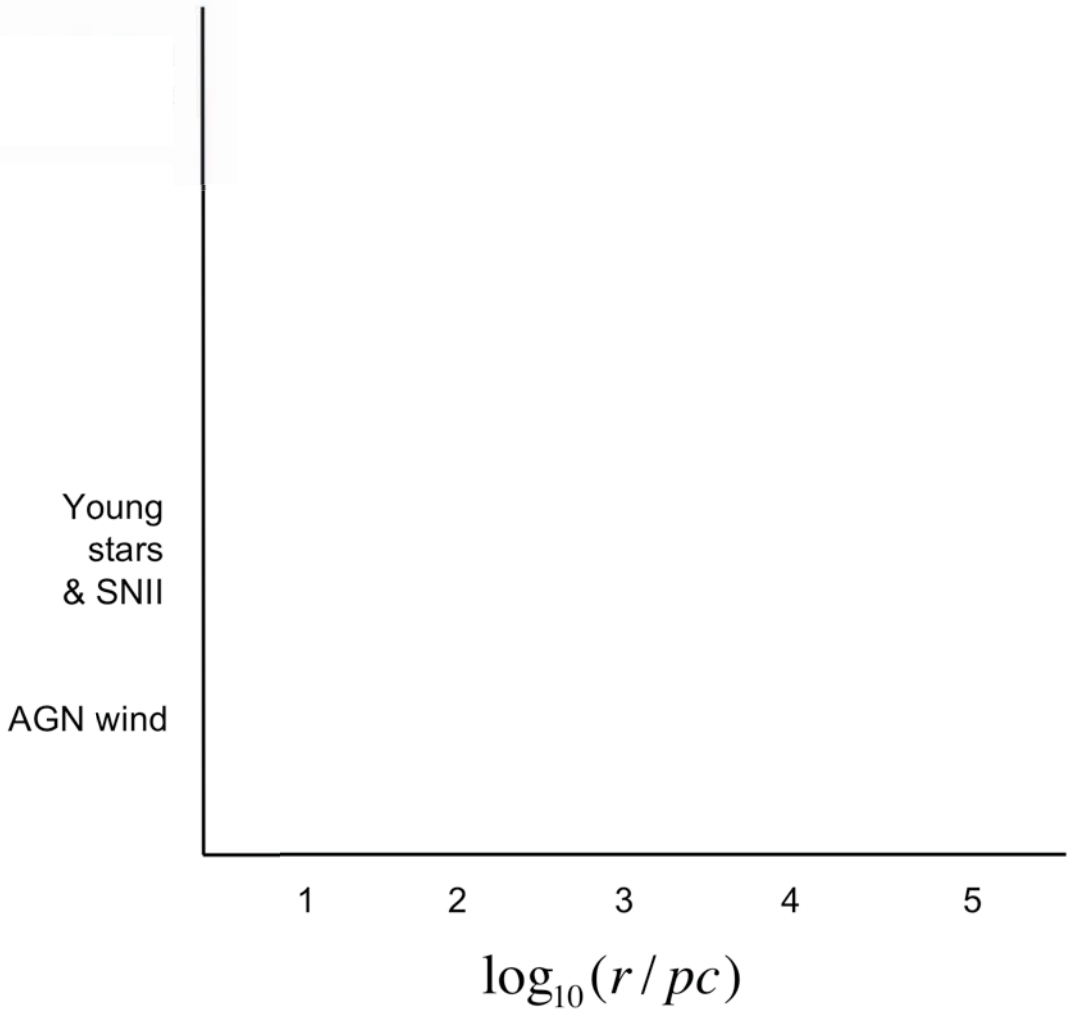


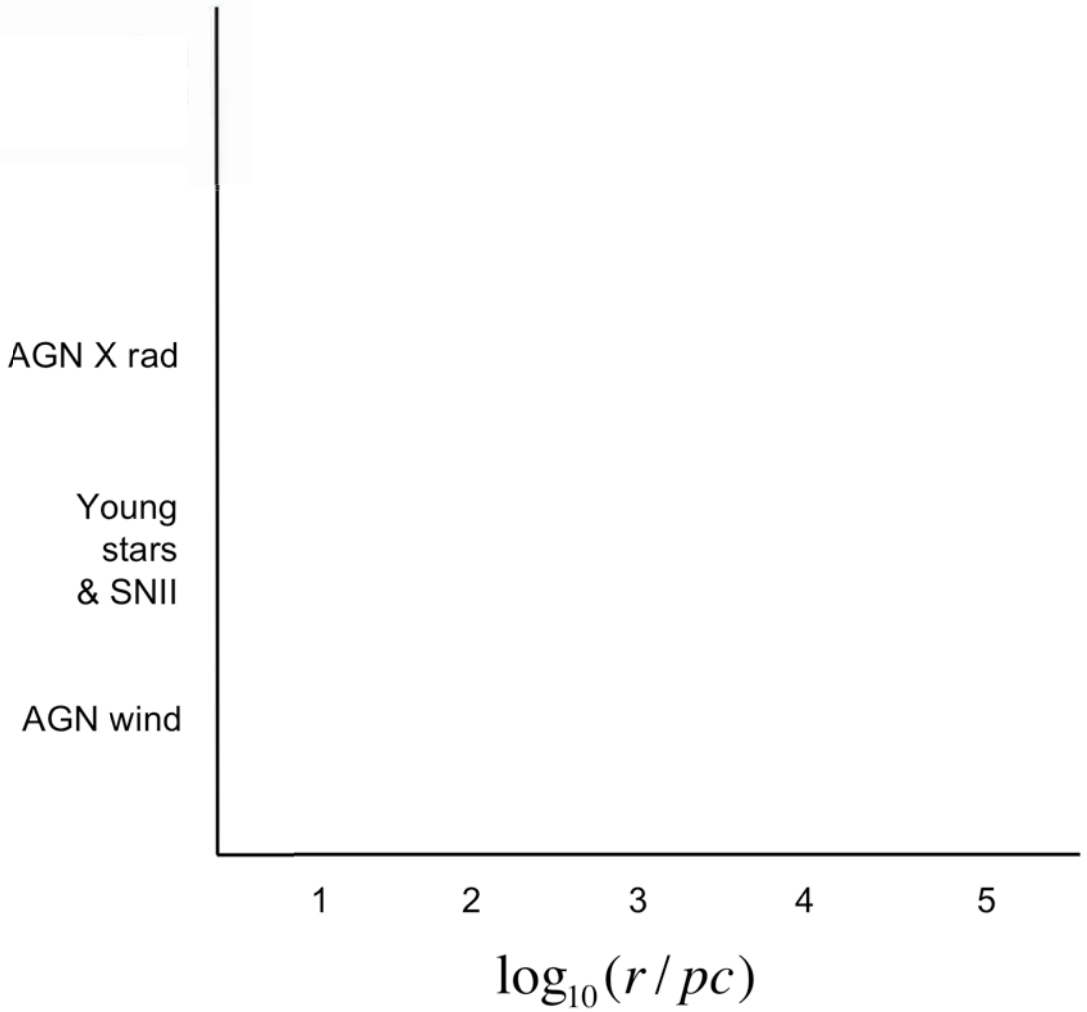


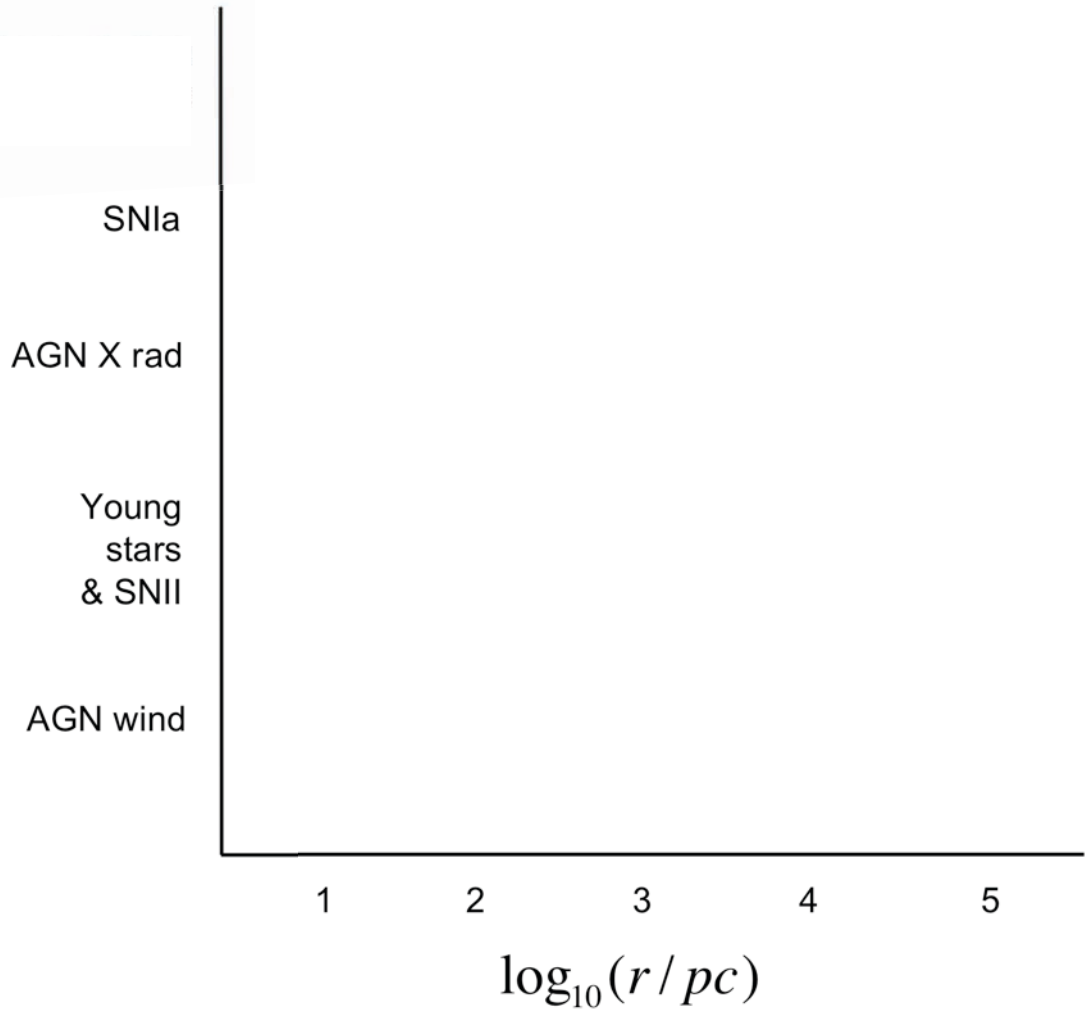
Watt centrifugal governor of 1788

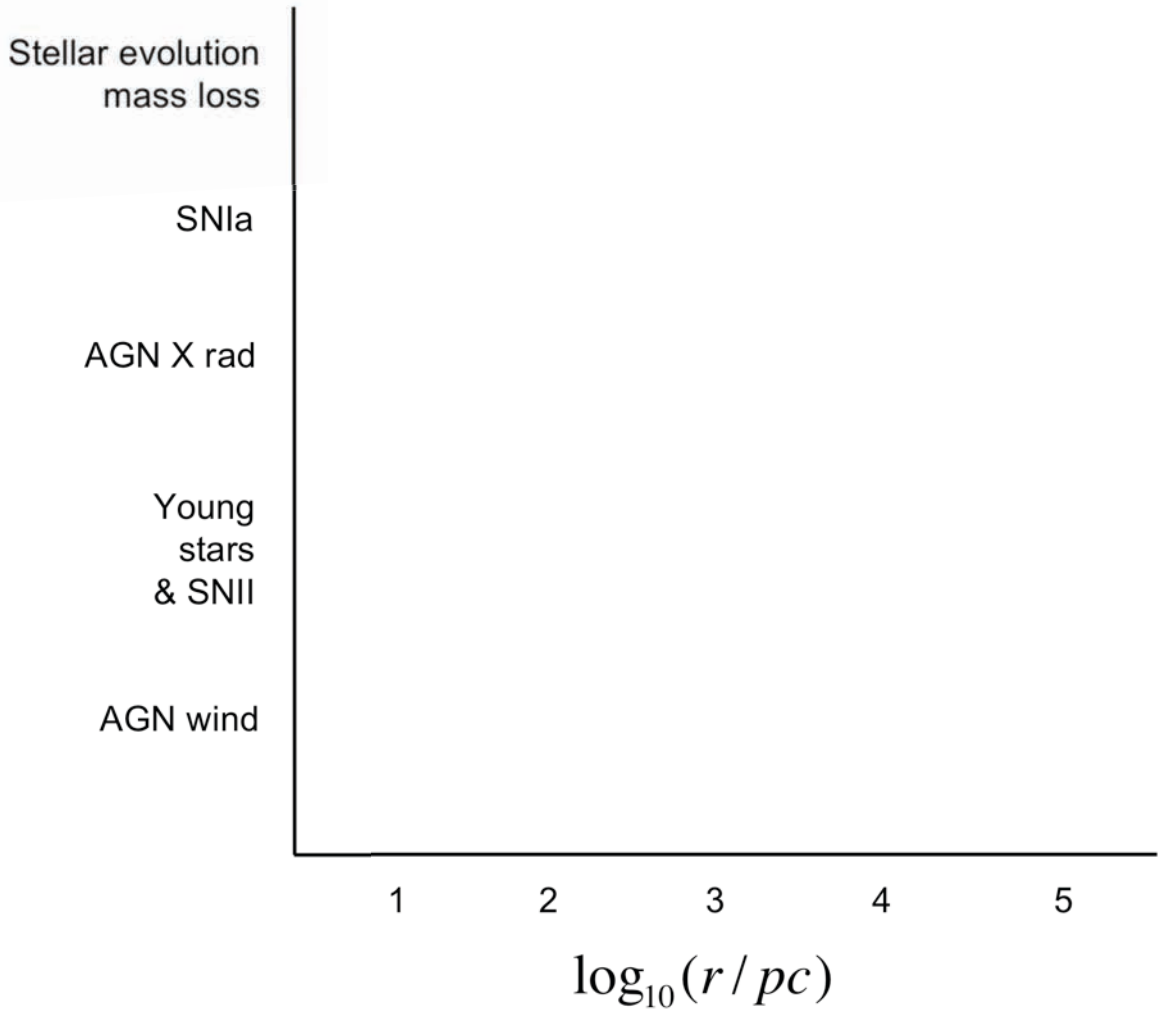

1
2
3
4
5
$\log_{10}(r/pc)$

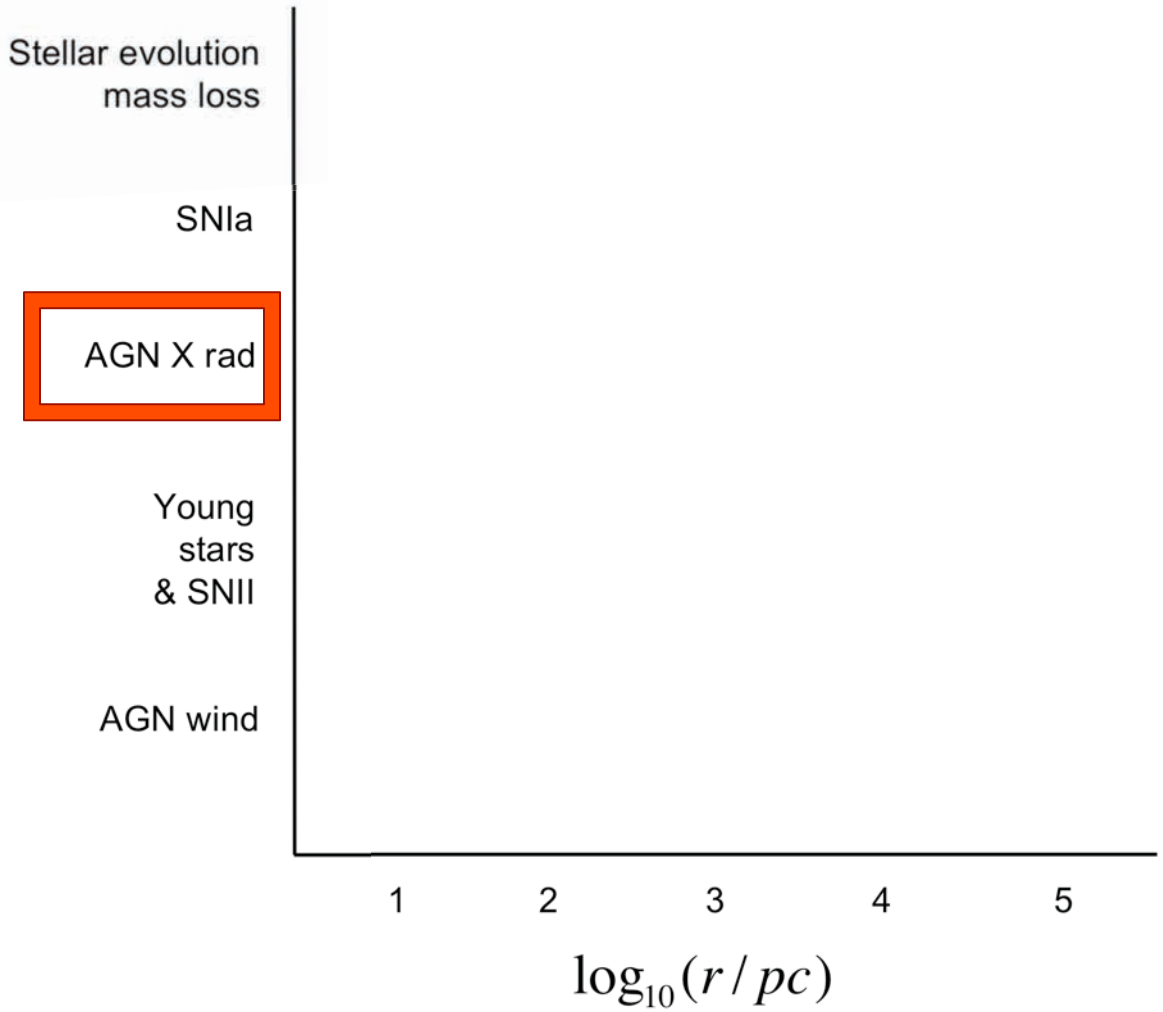

AGN wind
1
2
3
4
5
$\log_{10}(r/pc)$

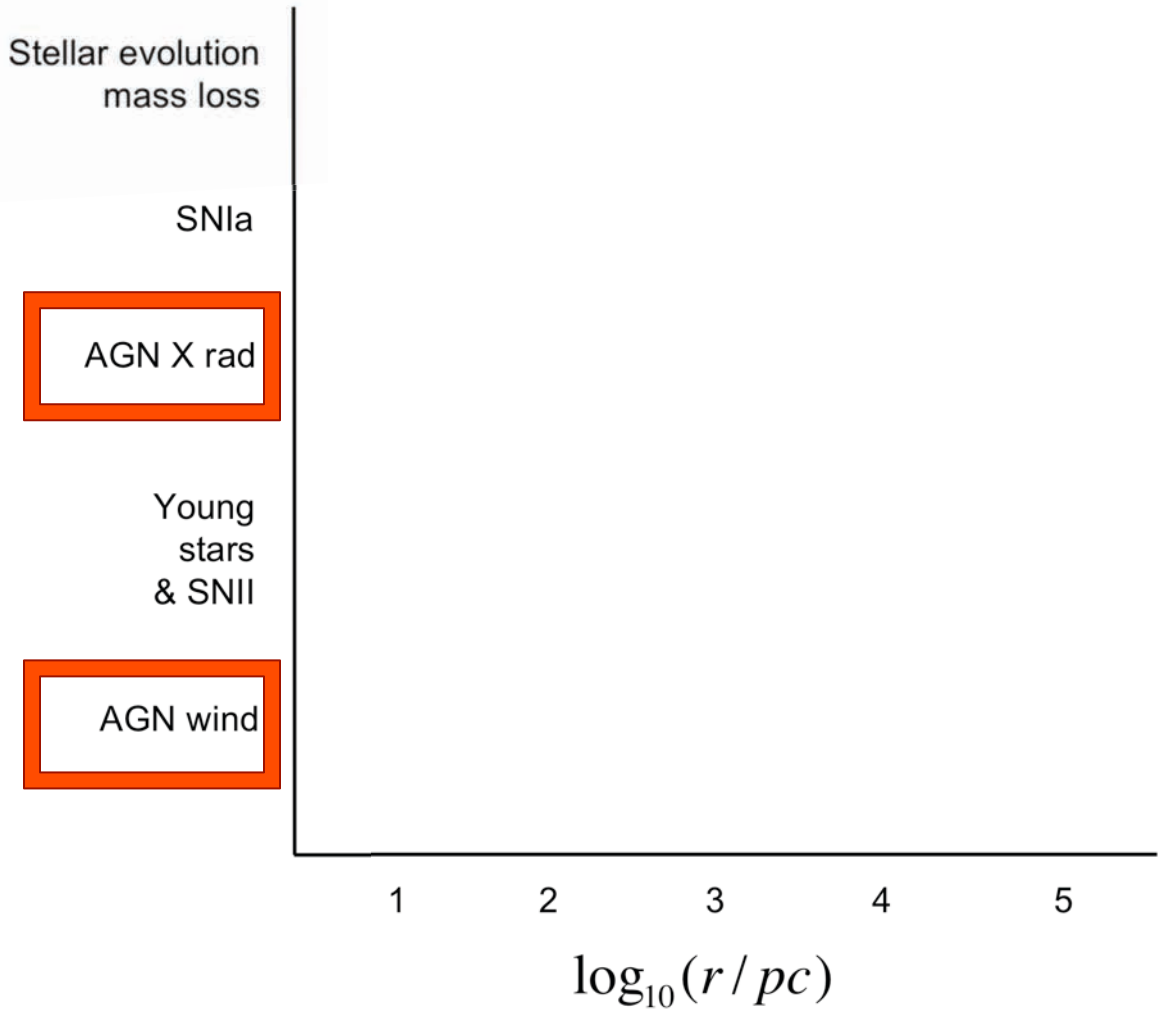

Young
stars
& SNII
AGN wind
1
2
3
4
5
$\log_{10}(r/pc)$

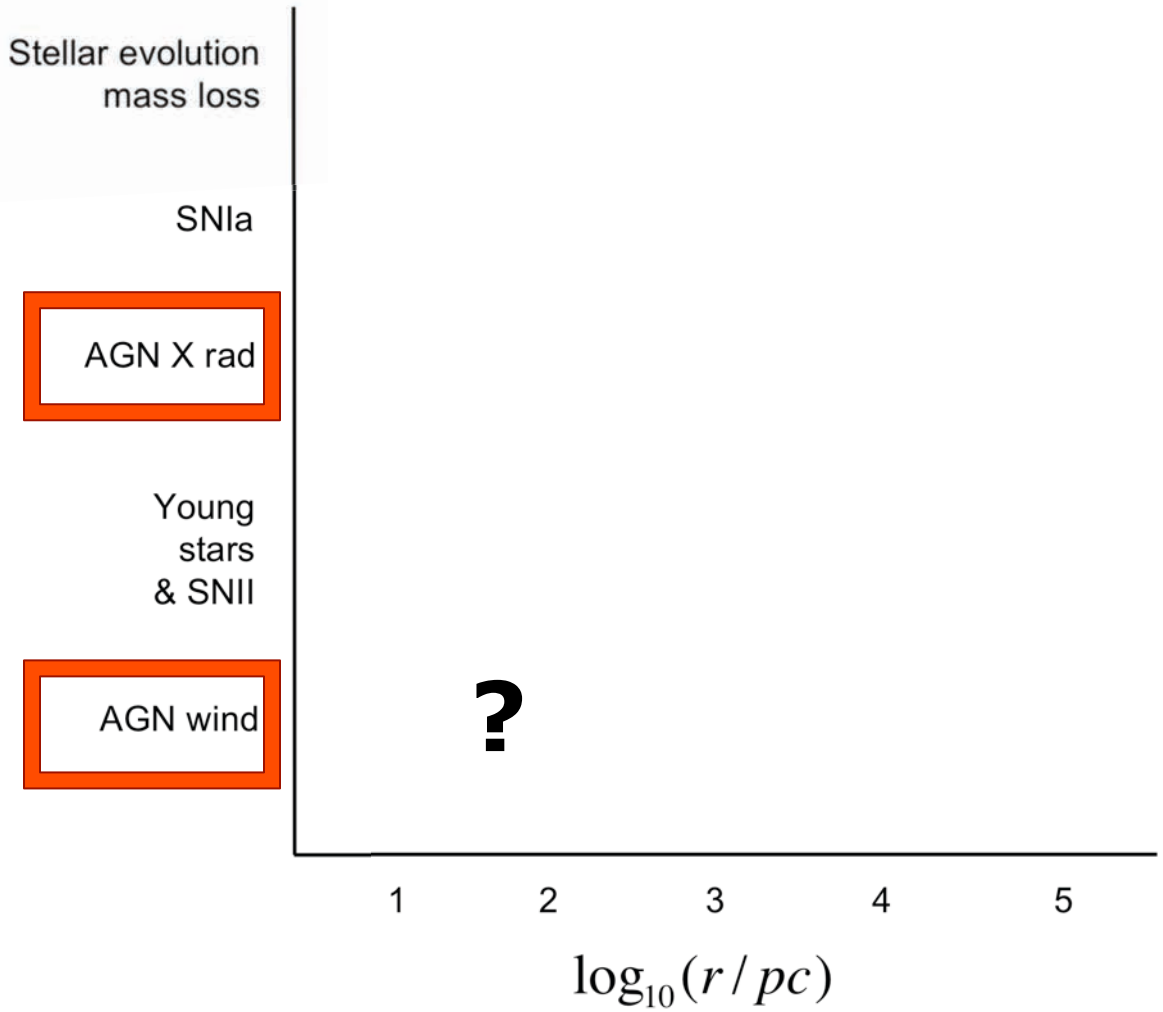

AGN X rad
Young
stars
& SNII
AGN wind
1
2
3
4
5
$\log_{10}(r/pc)$

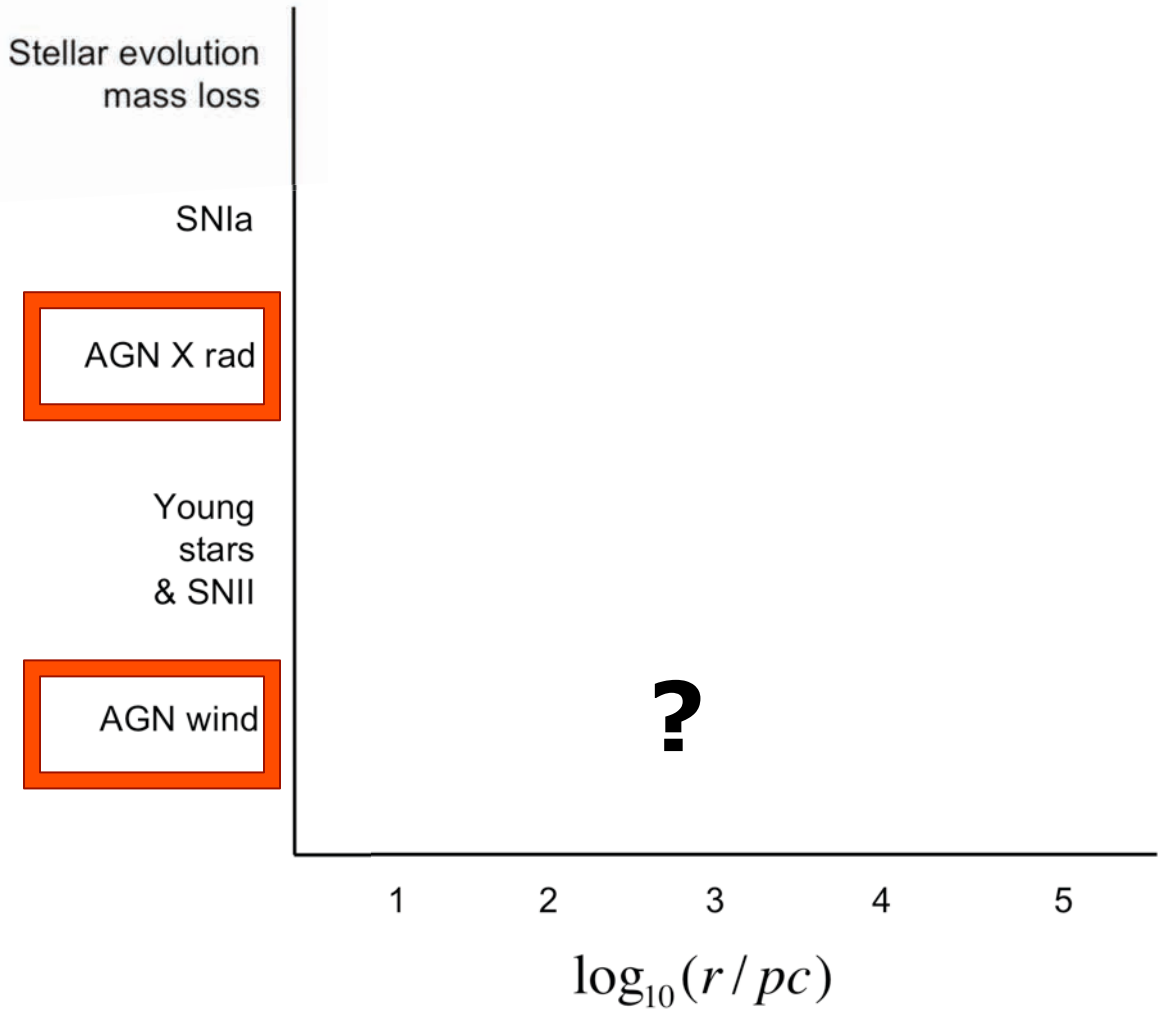

SNIa
AGN X rad
Young
stars
& SNII
AGN wind
1
2
3
4
5
$\log_{10}(r/pc)$

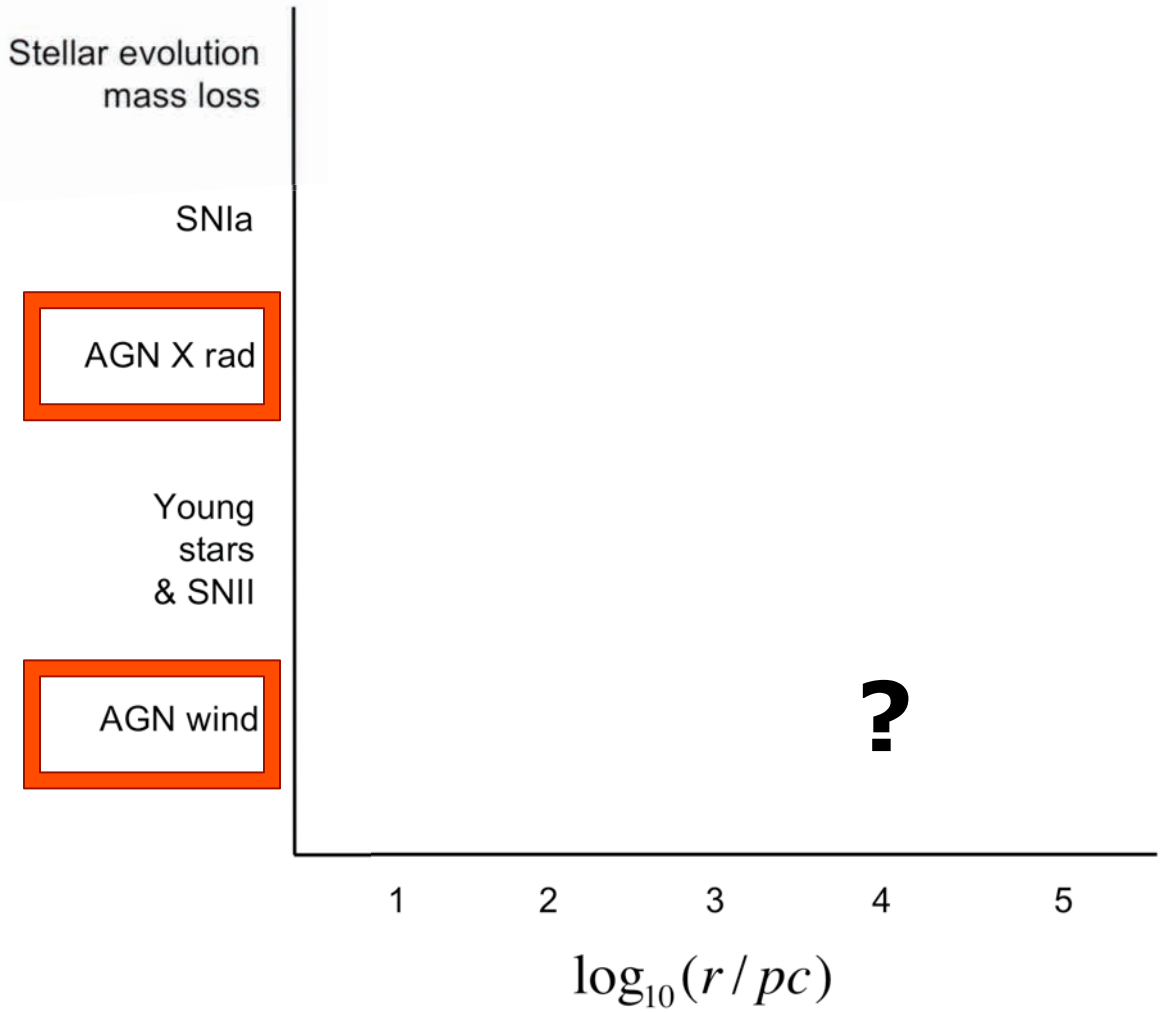

Stellar evolution
mass loss
SNIa
AGN X rad
Young
stars
& SNII
AGN wind
1
2
3
4
5
$\log_{10}(r/pc)$

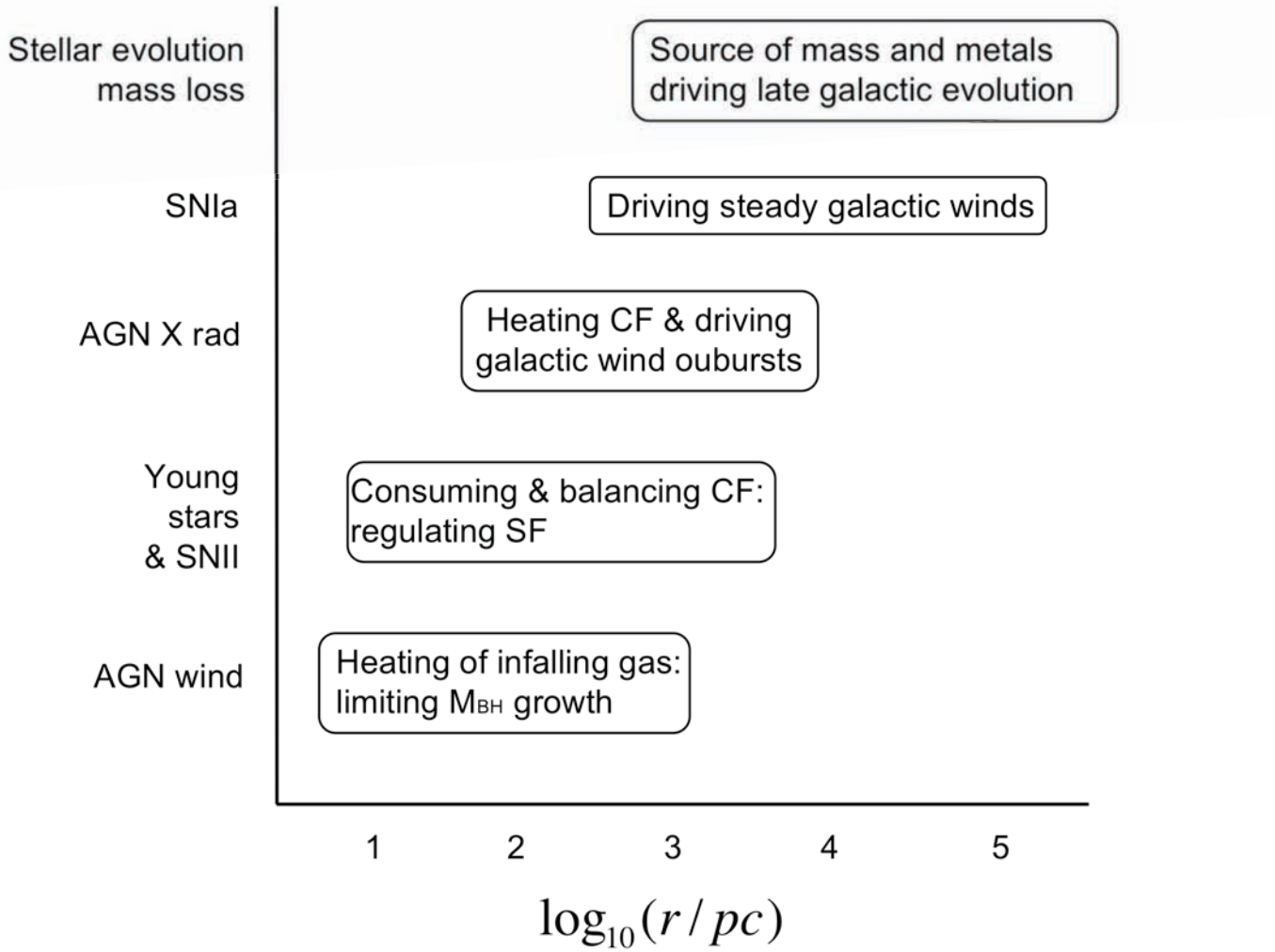

Stellar evolution
mass loss
SNIa
AGN X rad
Young
stars
& SNII
AGN wind
1
2
3
4
5
$\log_{10}(r/pc)$


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



Ciotti, Ostriker, & DP (2010)

Conclusions

Conclusions

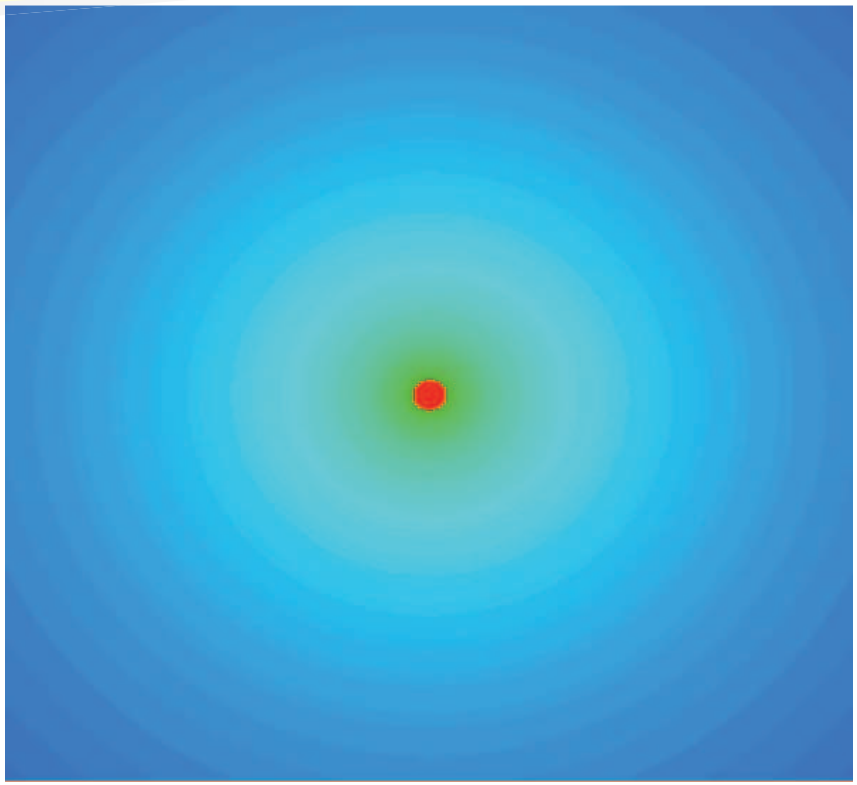
- Simulations of accretion flows and their outflows provide important insights into the dynamics and geometry of the material that produces radiation. In particular, we can use the simulations to assess the effects of radiation on the flow properties. We can also explore coupling between accretion flows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

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).

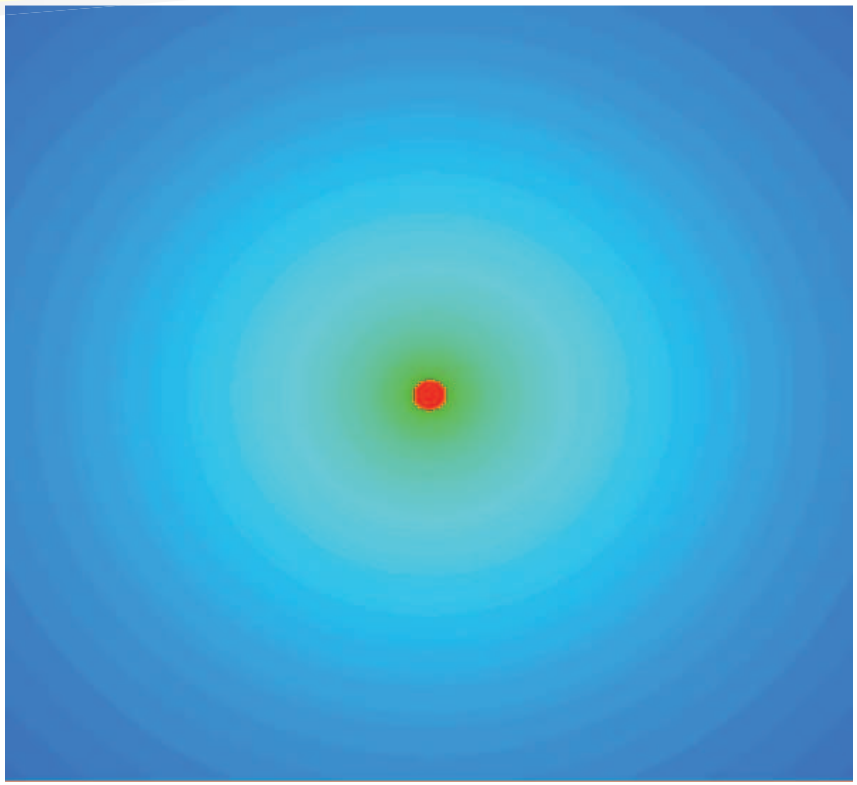
Future Works

Future Works



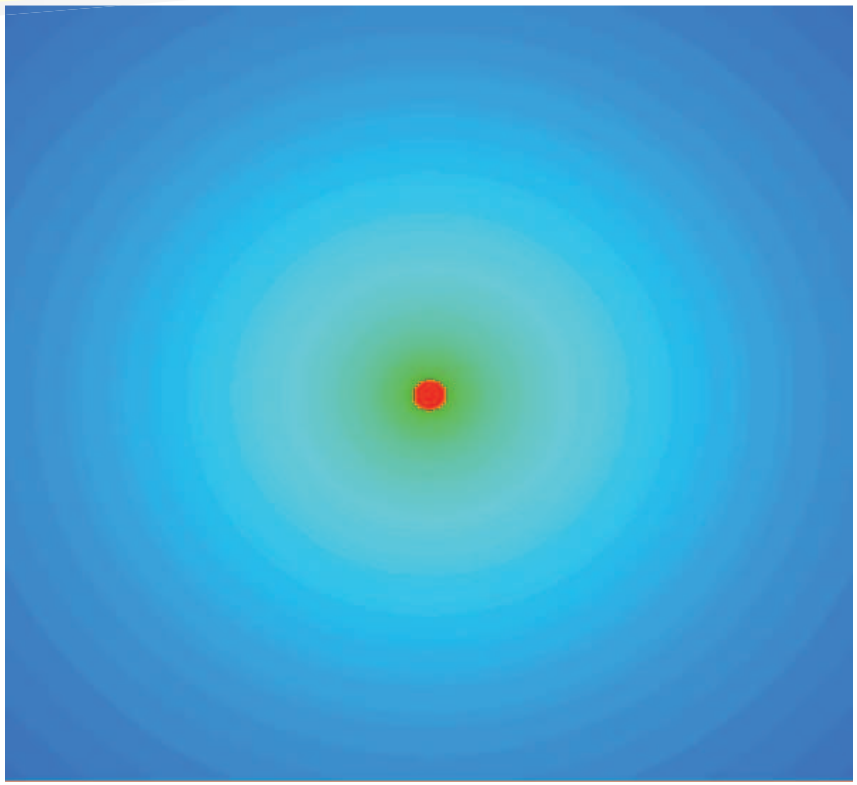
- Add effects of dust.

Future Works



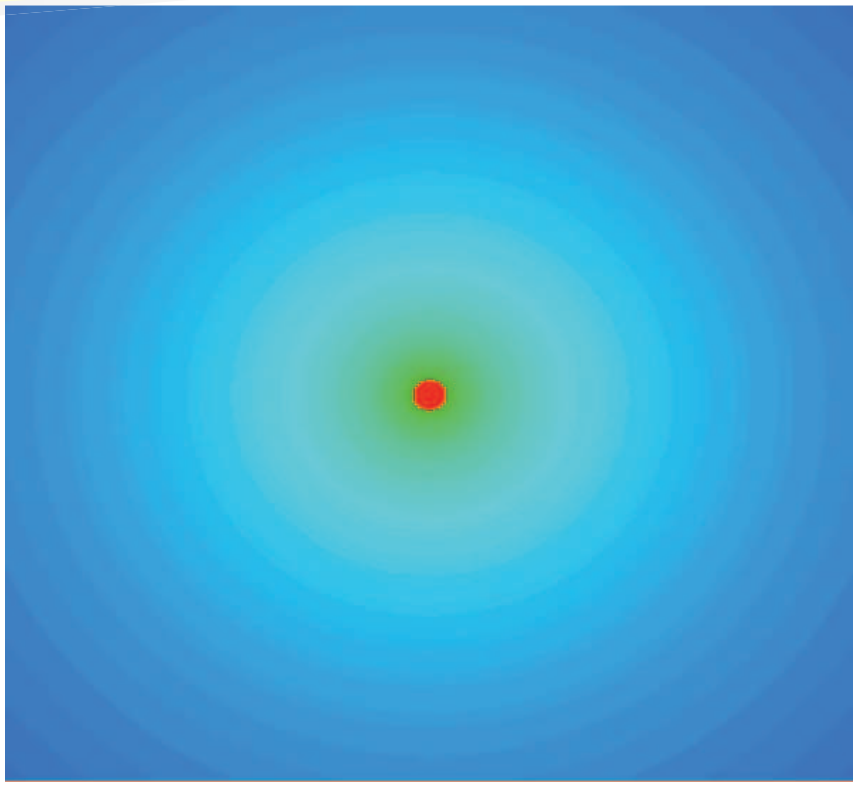
- Add effects of dust.
- Add other modes of operation (e.g., radiatively inefficient accretion, magnetic).

Future Works



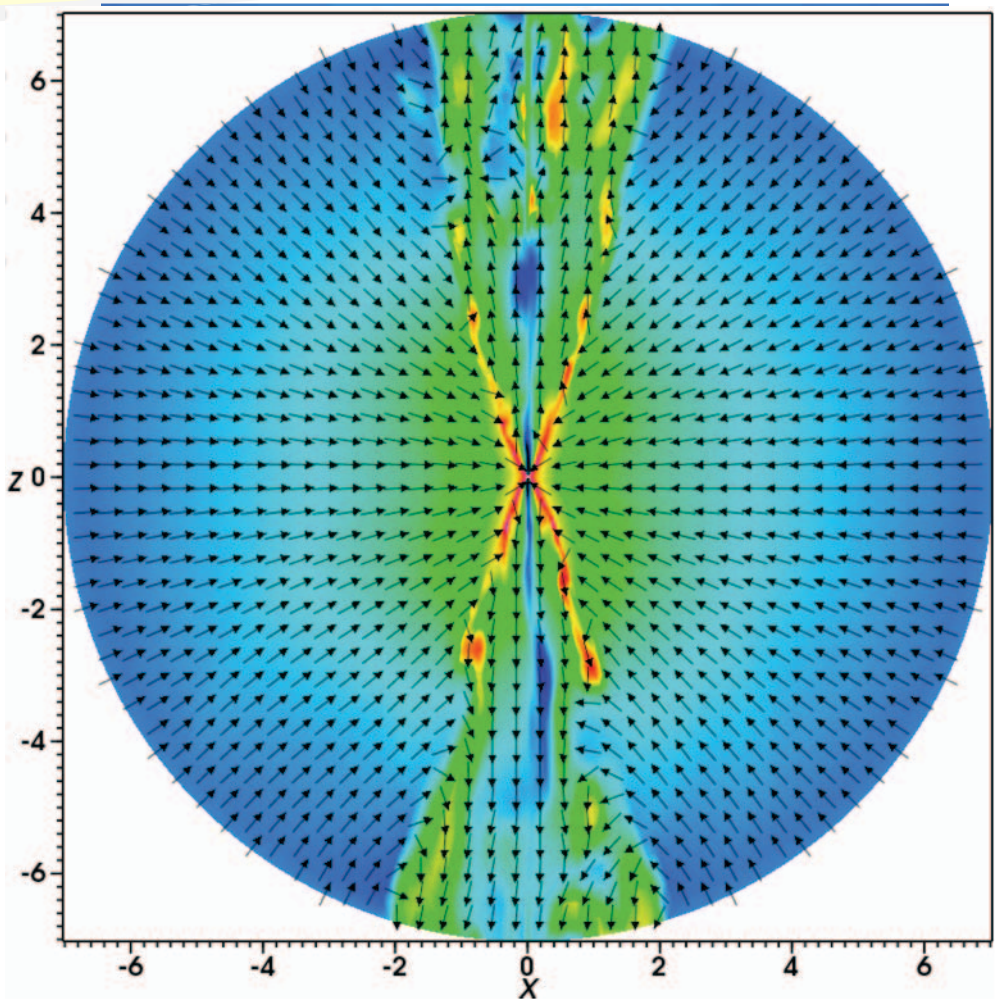
- Add effects of dust.
- Add other modes of operation (e.g., radiatively inefficient accretion, magnetic).

Future Works



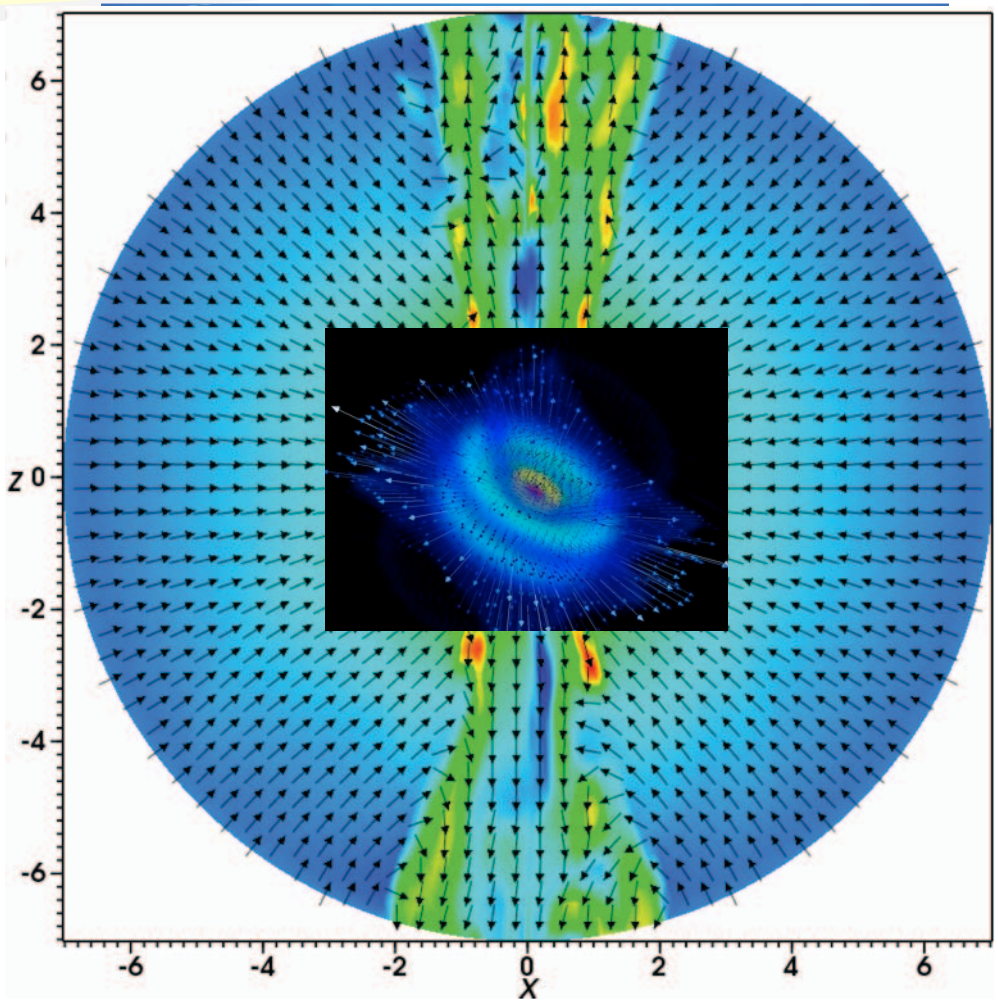
- Add effects of dust.
- Add other modes of operation (e.g., radiatively inefficient accretion, magnetic).
- Follow interaction of disk winds with outer inflows/outflows and incorporate these type of simulations into cosmological simulations

Future Works



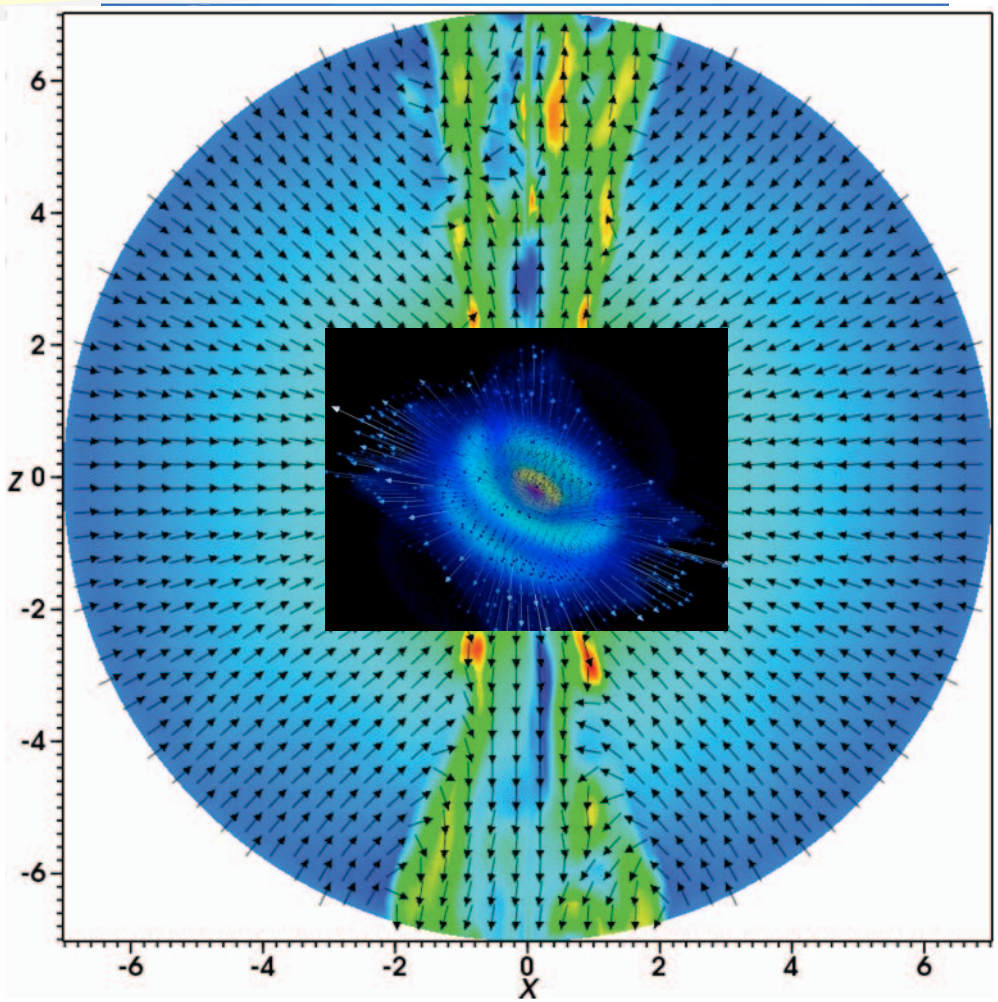
- Add effects of dust.
- Add other modes of operation (e.g., radiatively inefficient accretion, magnetic).
- Follow interaction of disk winds with outer inflows/outflows and incorporate these type of simulations into cosmological simulations

Future Works



- Add effects of dust.
- Add other modes of operation (e.g., radiatively inefficient accretion, magnetic).
- Follow interaction of disk winds with outer inflows/outflows and incorporate these type of simulations into cosmological simulations

Future Works



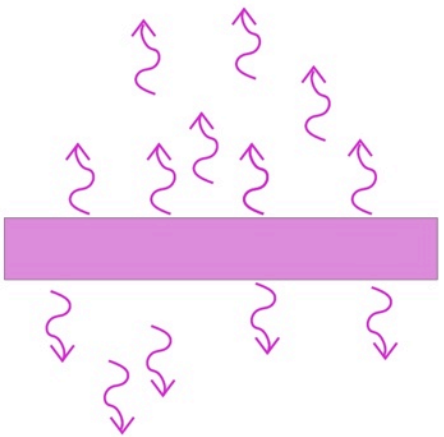
- Add effects of dust.
- Add other modes of operation (e.g., radiatively inefficient accretion, magnetic).
- Follow interaction of disk winds with outer inflows/outflows and incorporate these type of simulations into cosmological simulations
- Most importantly, keep comparing the model predictions with observations of AGN.

Quenching Disk Corona

DP (2005)

Quenching Disk Corona

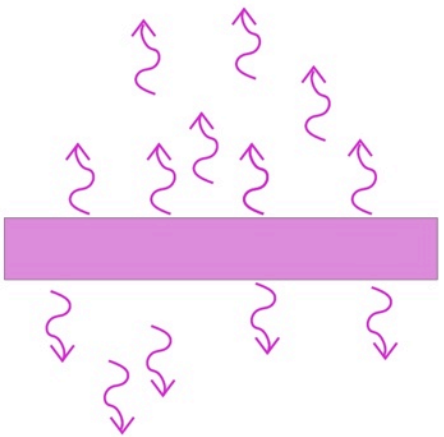
Disk



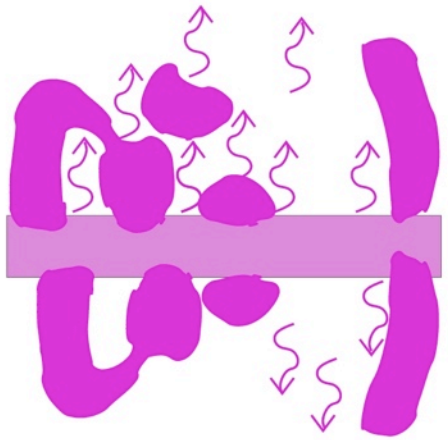
DP (2005)

Quenching Disk Corona

Disk



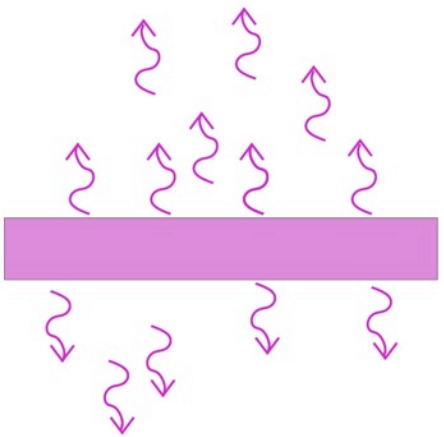
Disk and inflow/outflow



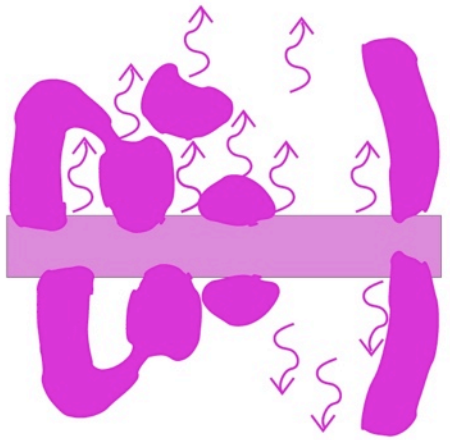
DP (2005)

Quenching Disk Corona

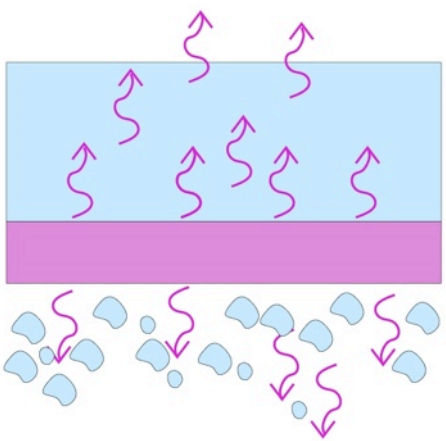
Disk



Disk and inflow/outflow



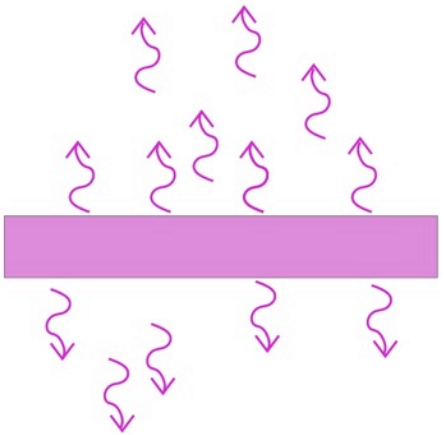
Disk and corona



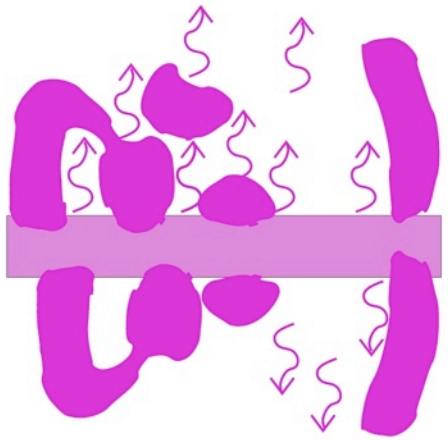
DP (2005)

Quenching Disk Corona

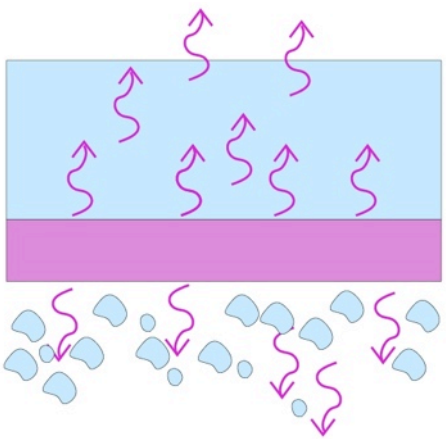
Disk



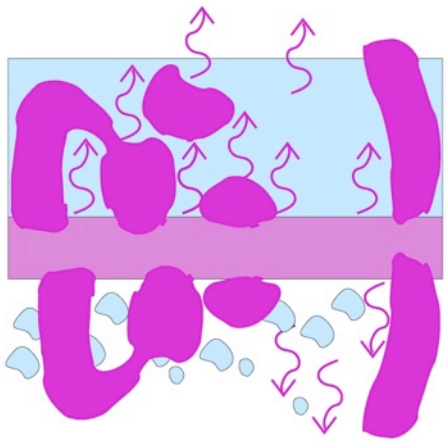
Disk and inflow/outflow



Disk and corona



Disk and ???

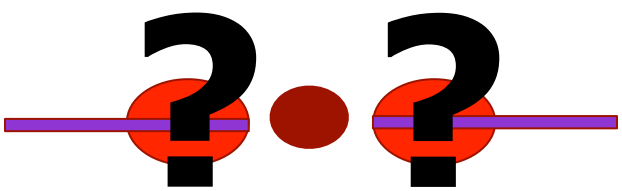


DP (2005)

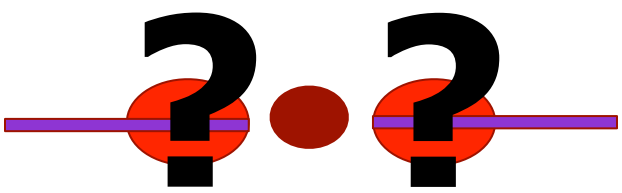
Where is the X-ray corona?

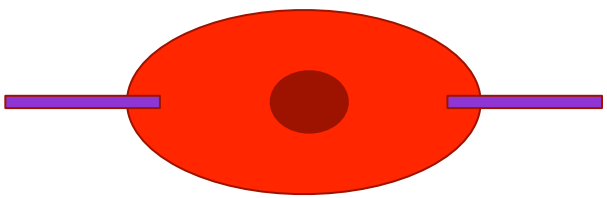
Where is the X-ray corona?

Where is the X-ray corona?

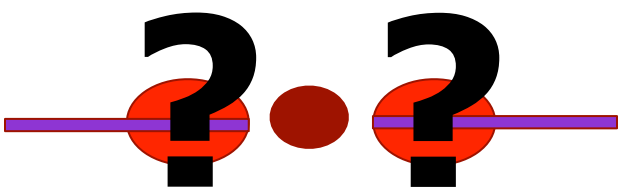


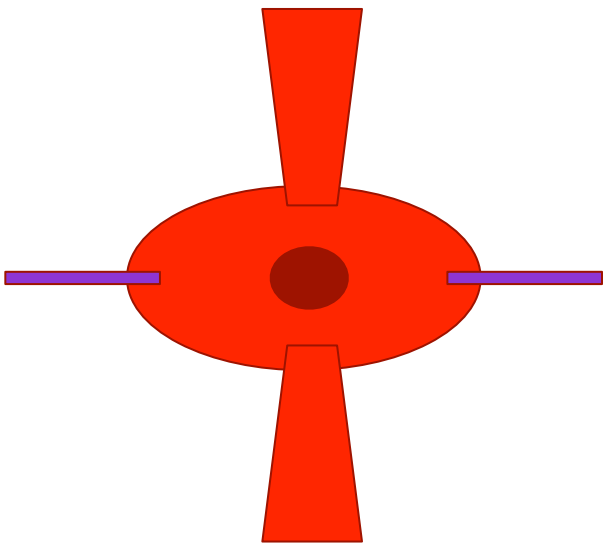
Where is the X-ray corona?

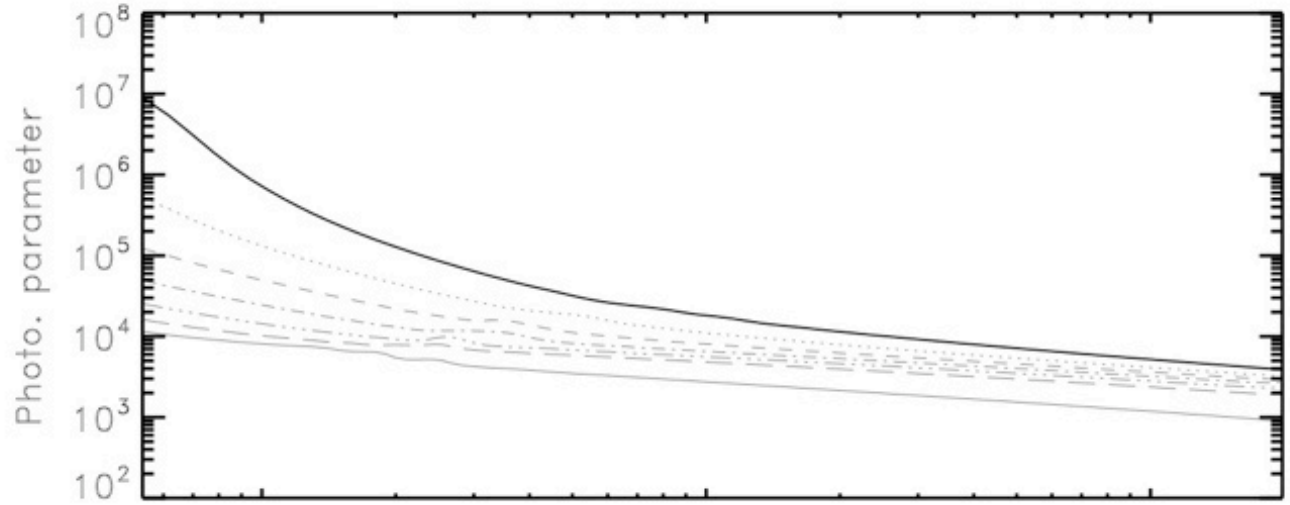


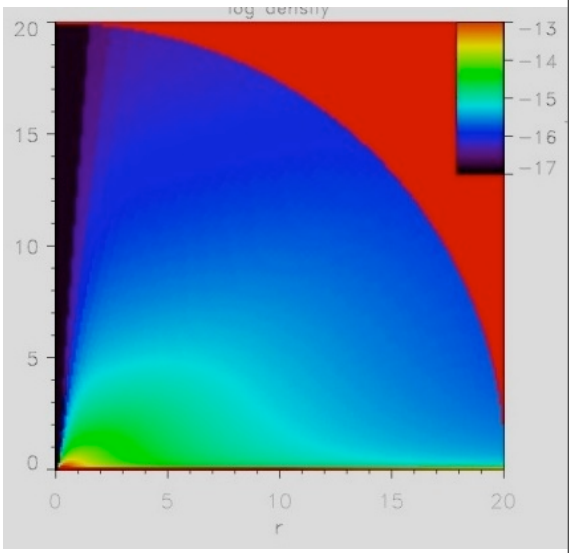


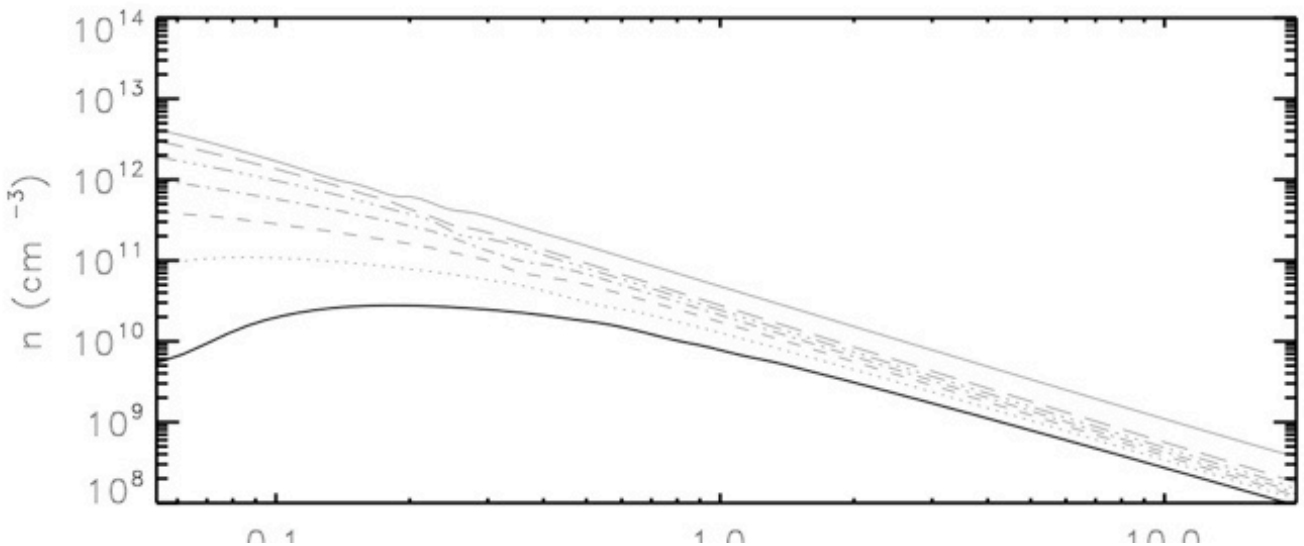
Where is the X-ray corona?





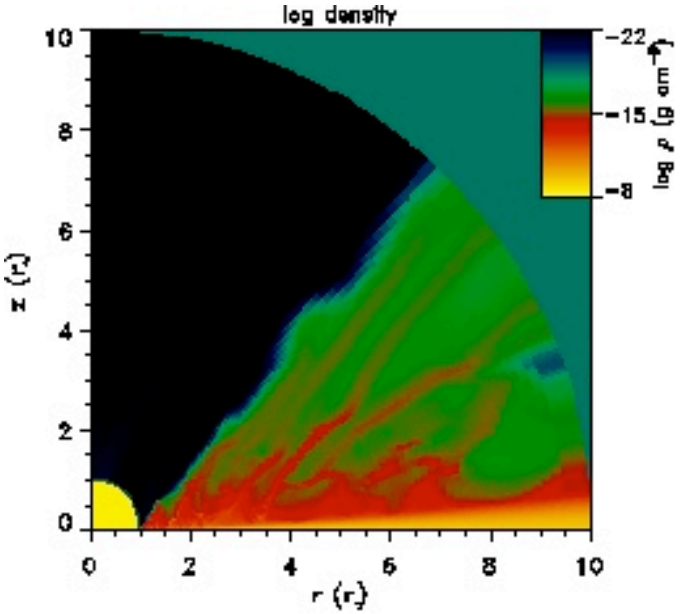


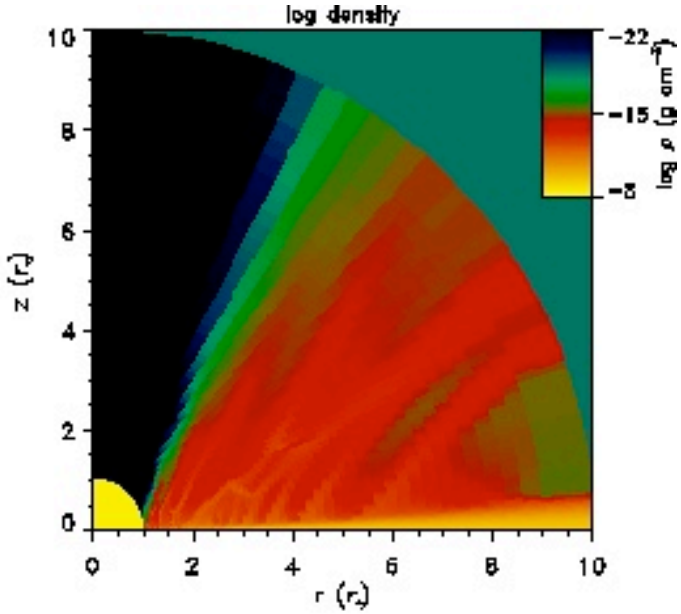




$\theta = 48.3°$ (thick solid), $\theta = 60.5°$ (dotted), $\theta = 69.4°$ (dashed), $\theta = 76.0°$ (dot-dashed), $\theta = 80.9°$ (triple dot-dashed), $\theta = 84.5°$ (long dashed) and $\theta = 89.1°$ (thin solid).

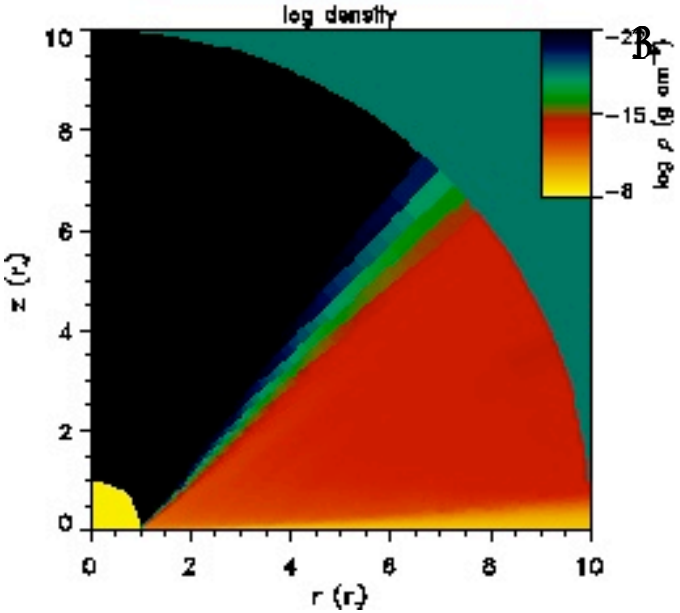
$L_D = 1$
$L_S = 0$

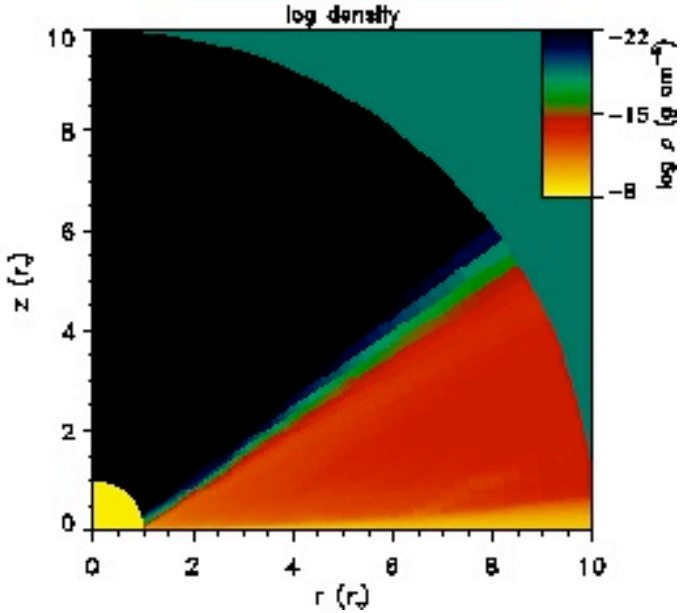




$L_D = 3$
$L_S = 0$

$L_D = 3$
$L_S = 3$



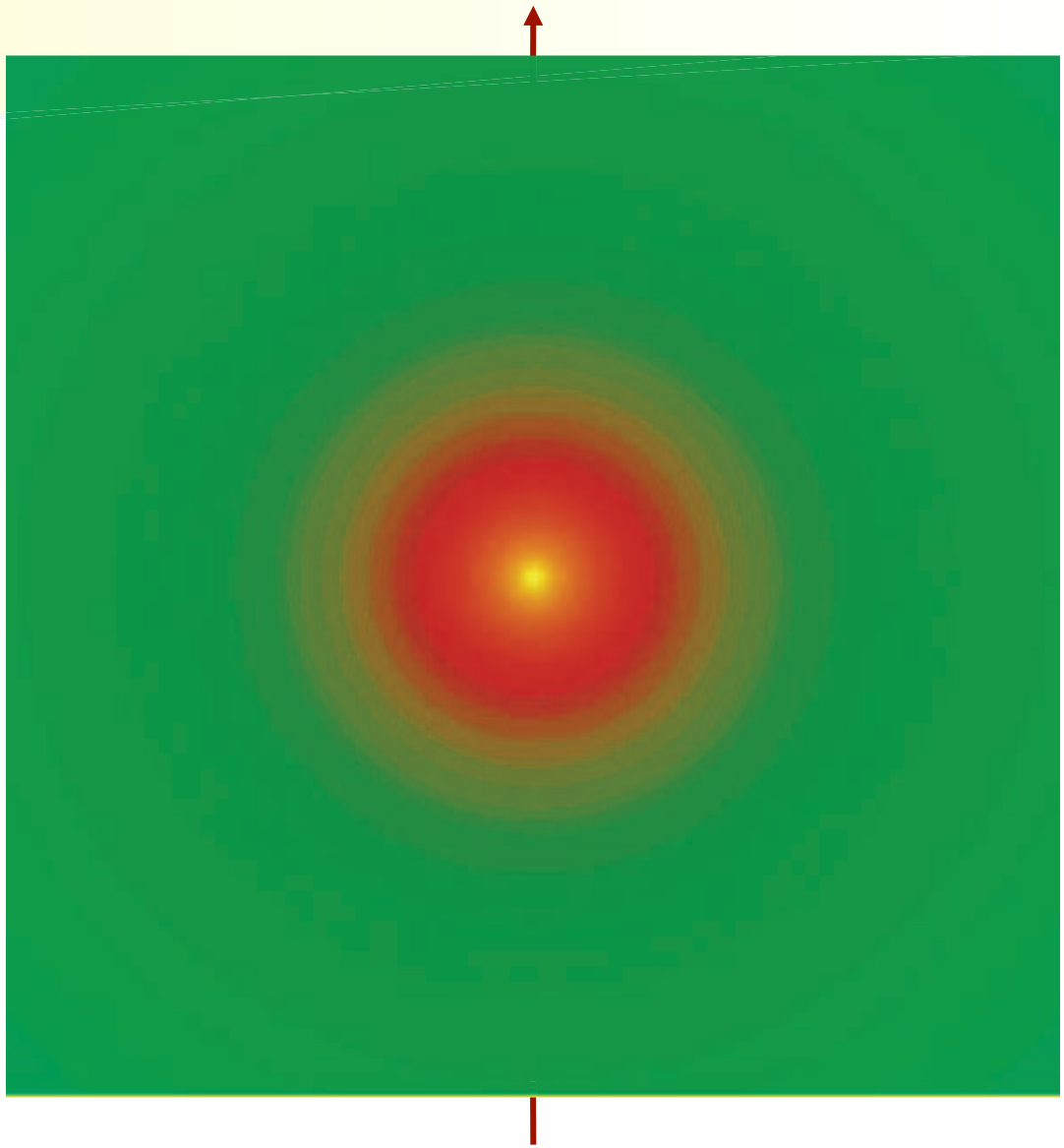


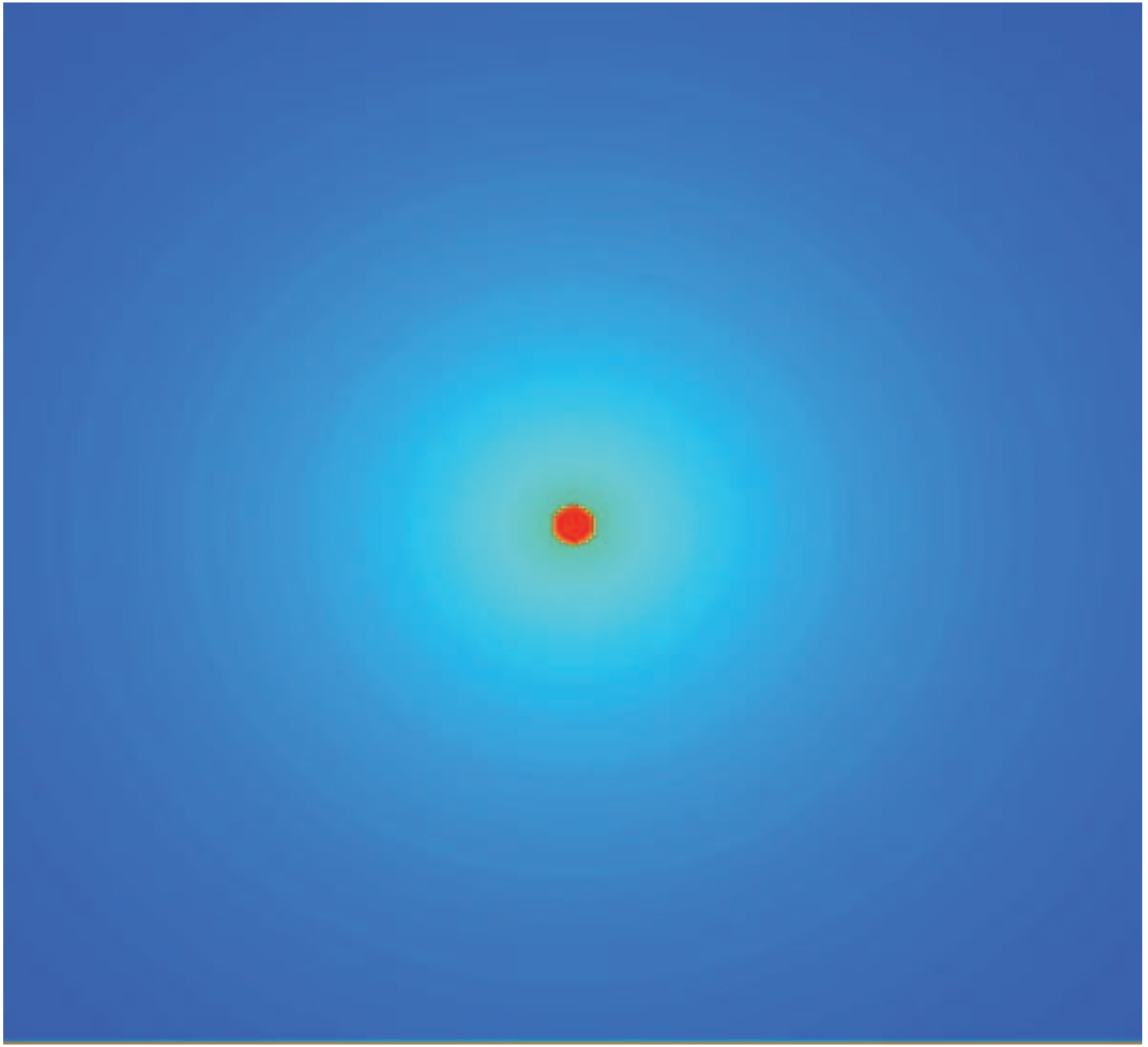
$L_D = 3$
$L_S = 9$

Proga, Stone & Drew (1998)

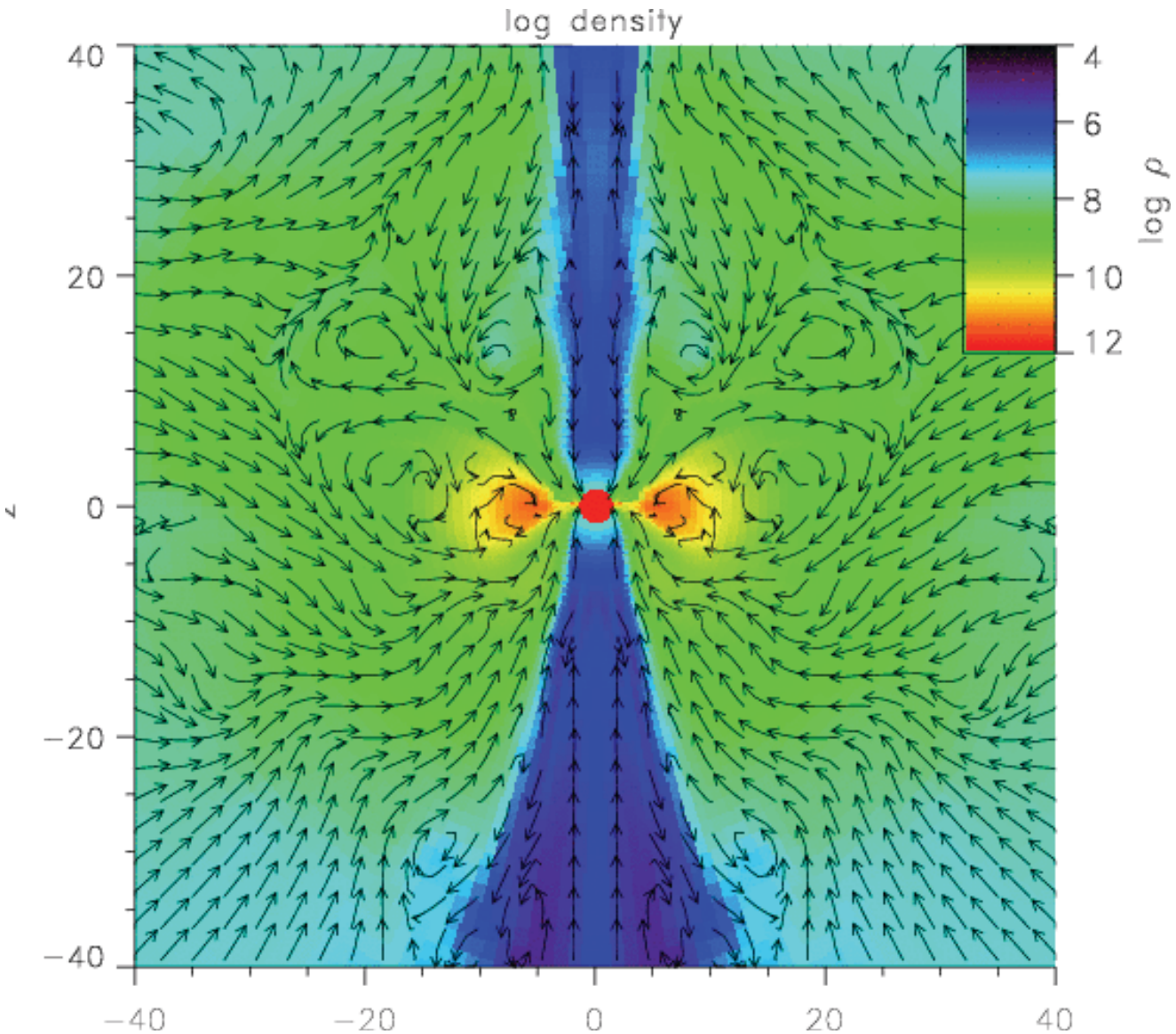
Black Hole Accretion -> Outflow

Black Hole Accretion -> Outflow

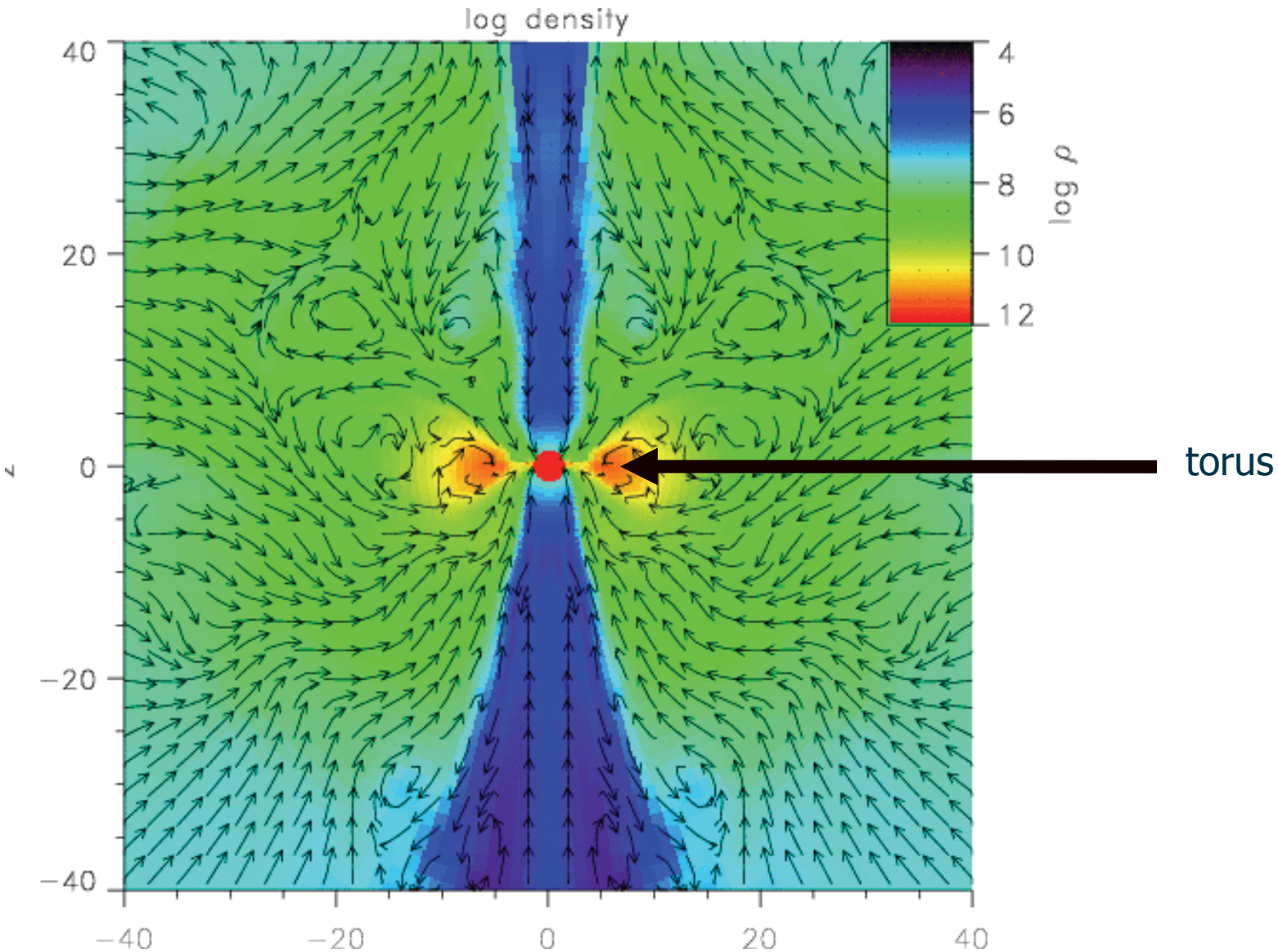




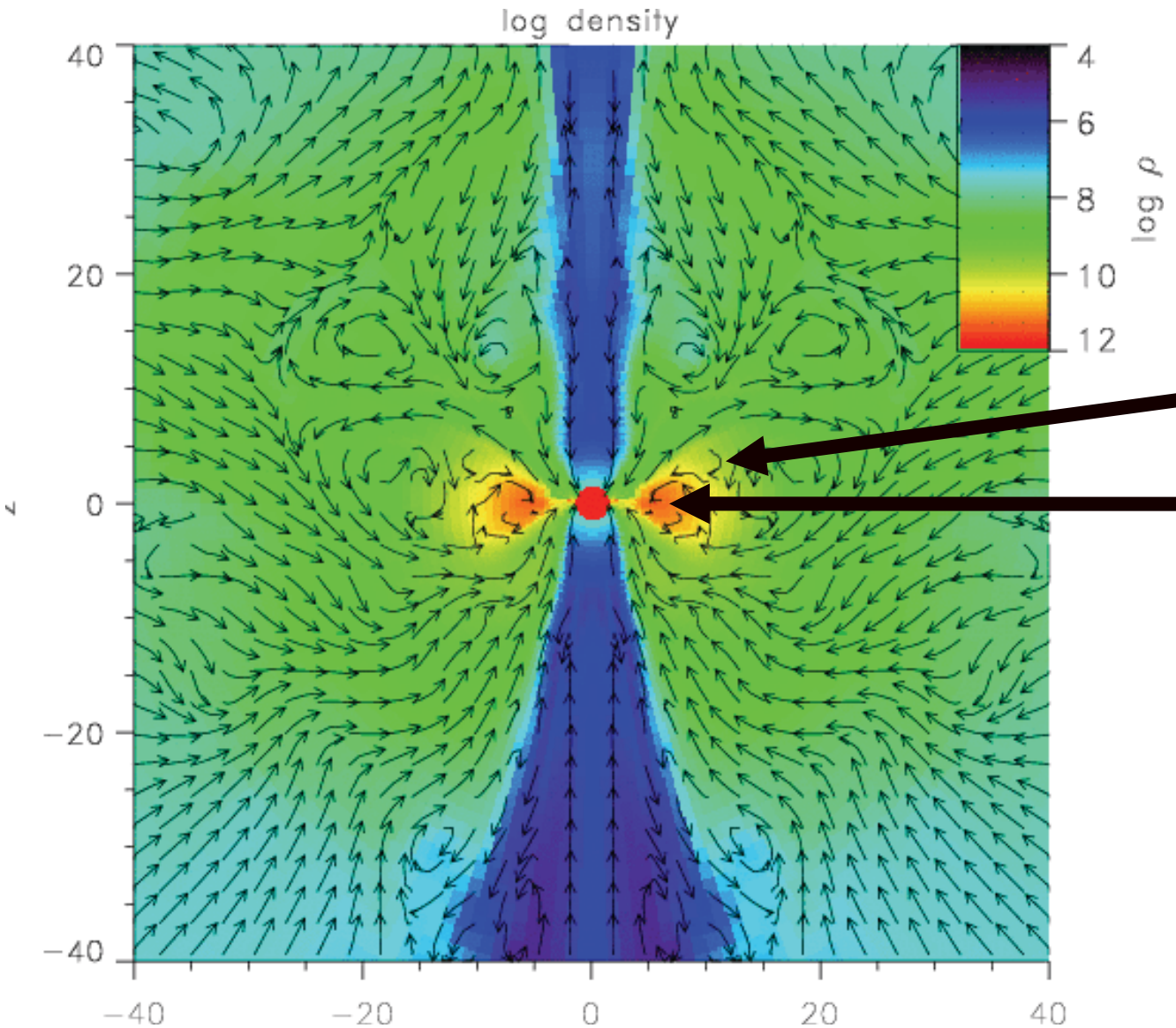
Multi-component flow



Multi-component flow



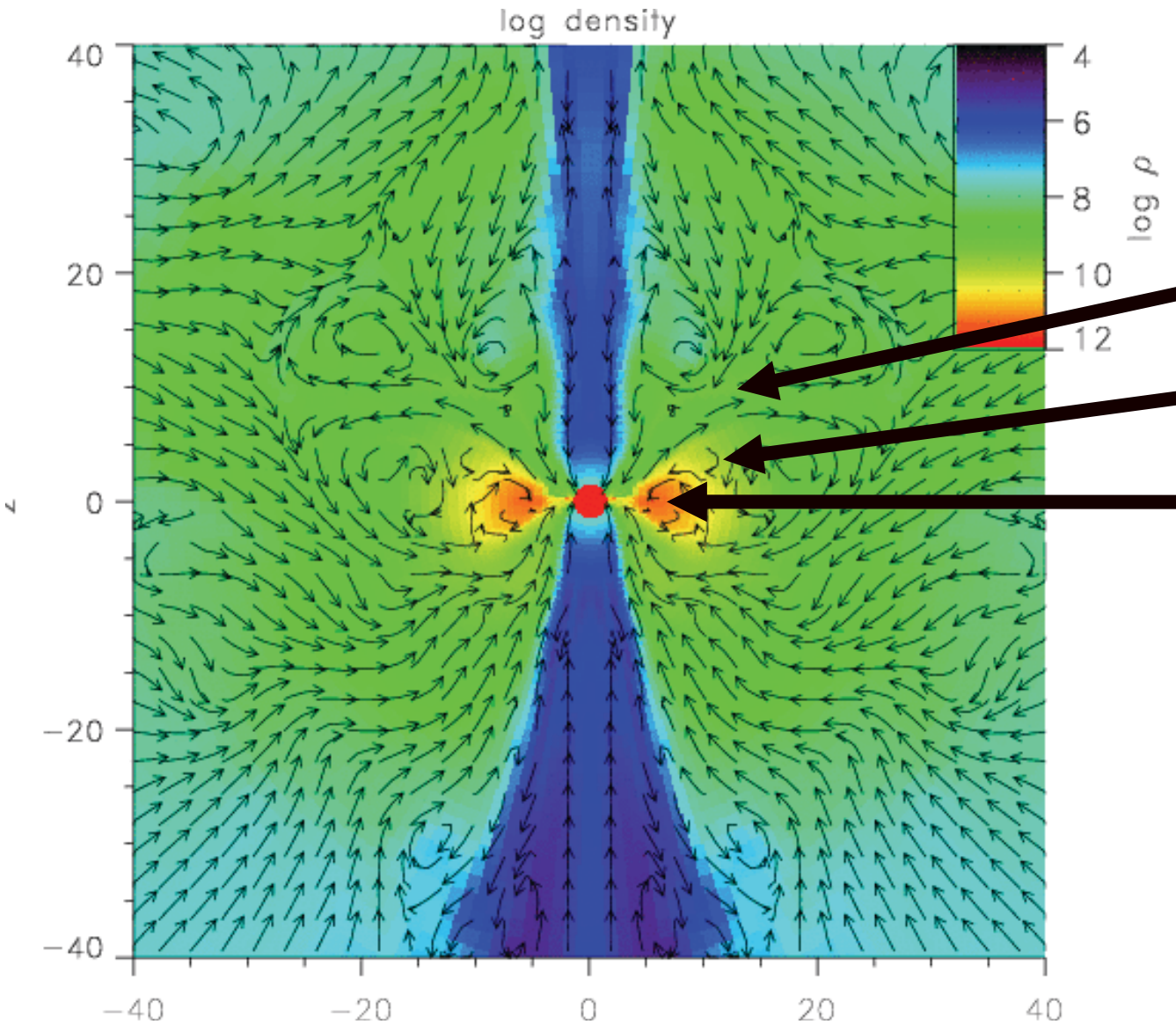
Multi-component flow



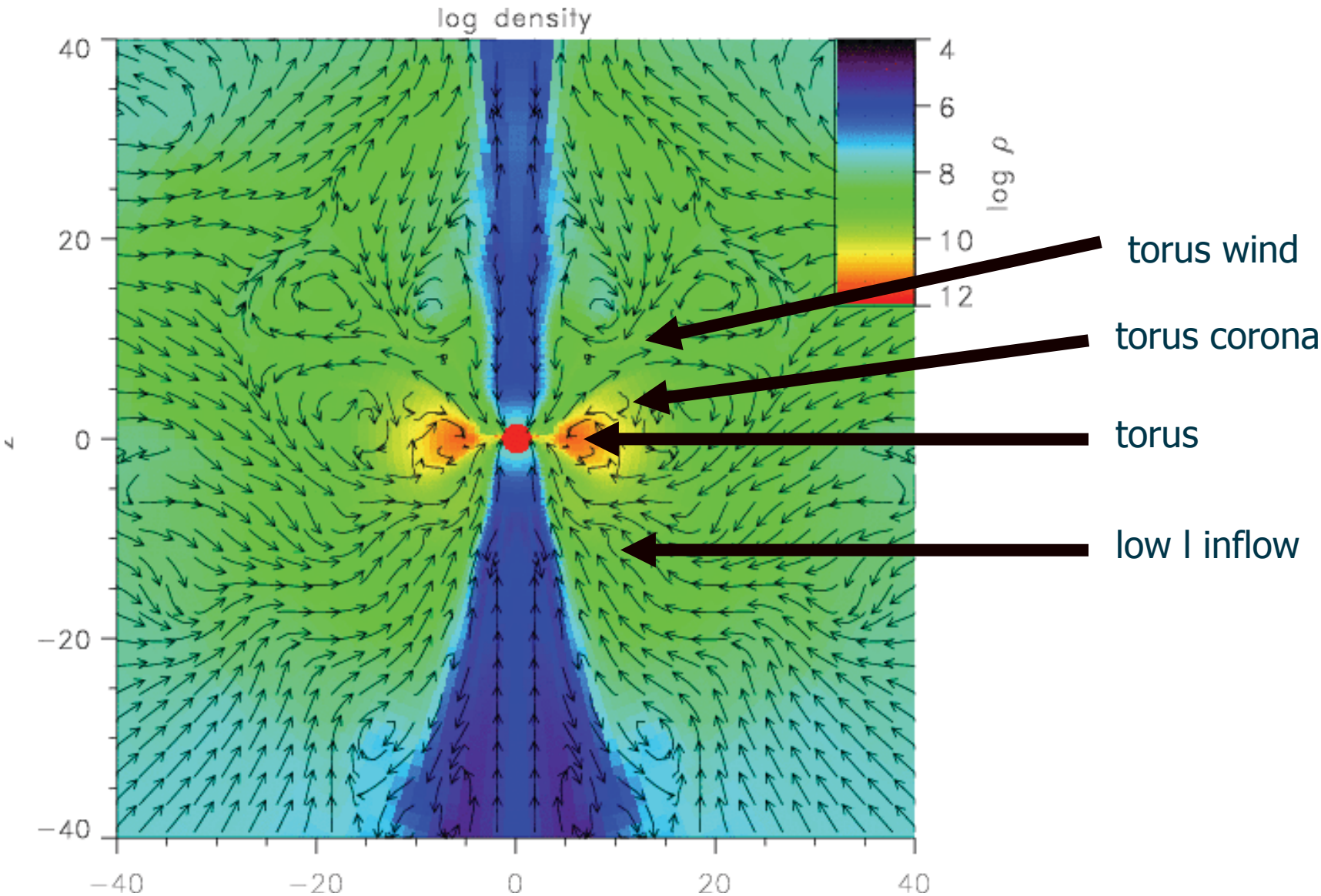
torus corona

torus

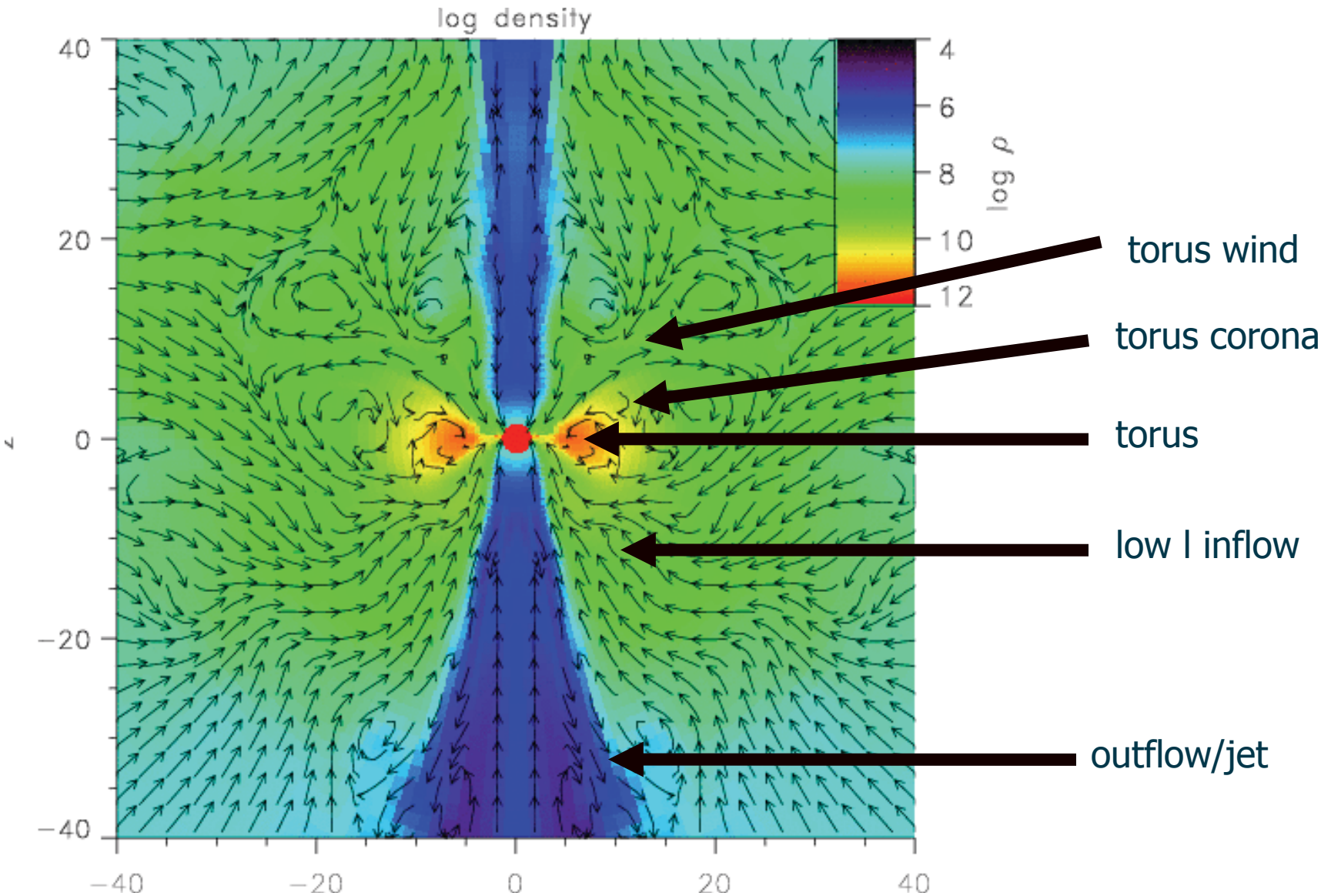
Multi-component flow



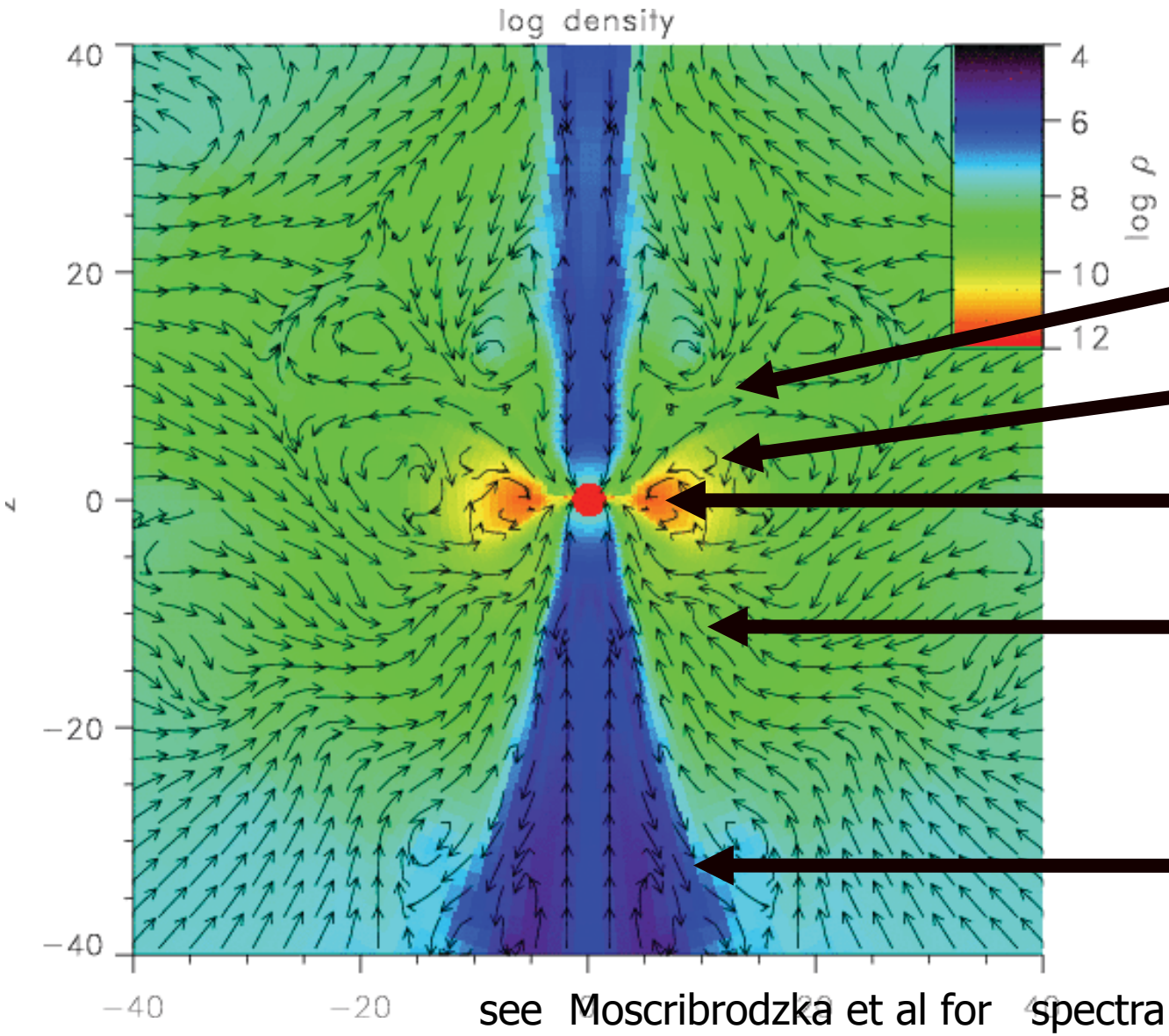
Multi-component flow



Multi-component flow



Multi-component flow



torus wind

torus corona

torus

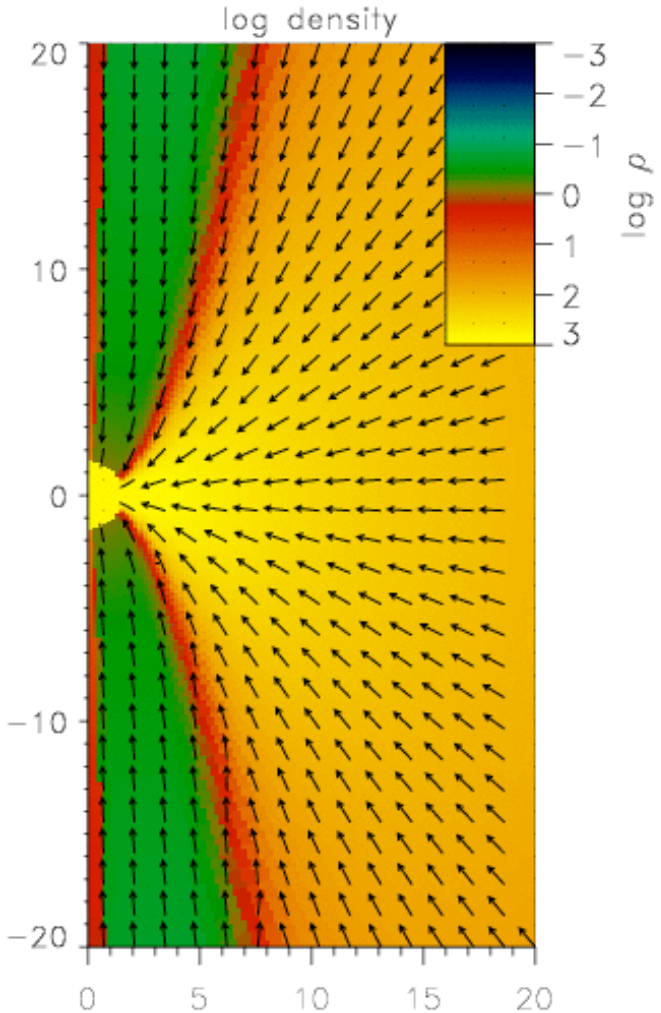
low l inflow

outflow/jet

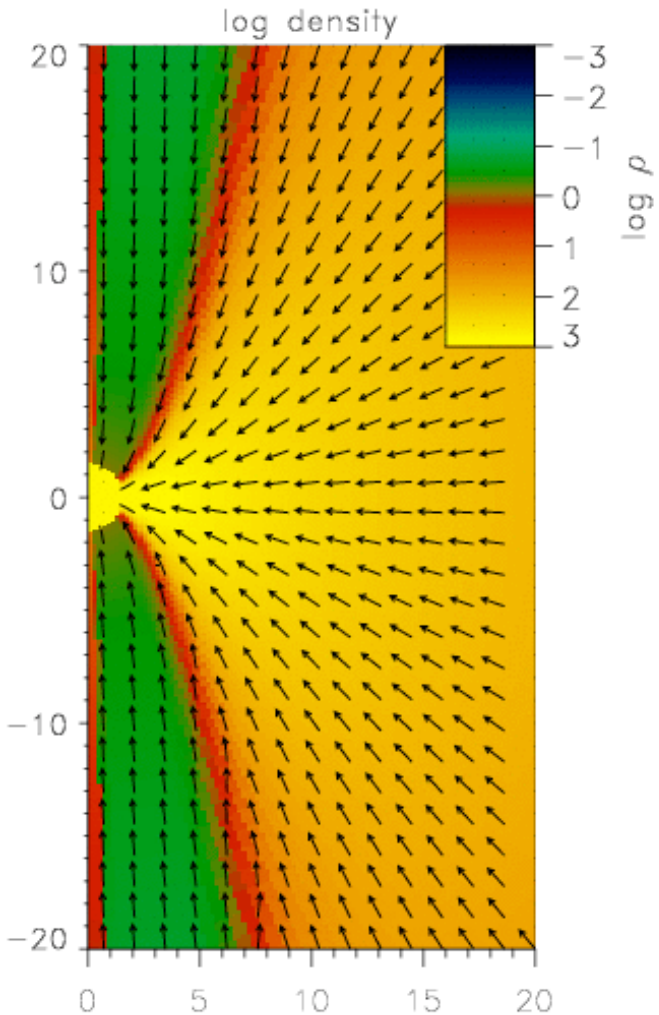
see Moscribrodzka et al for spectra predicted by such flows

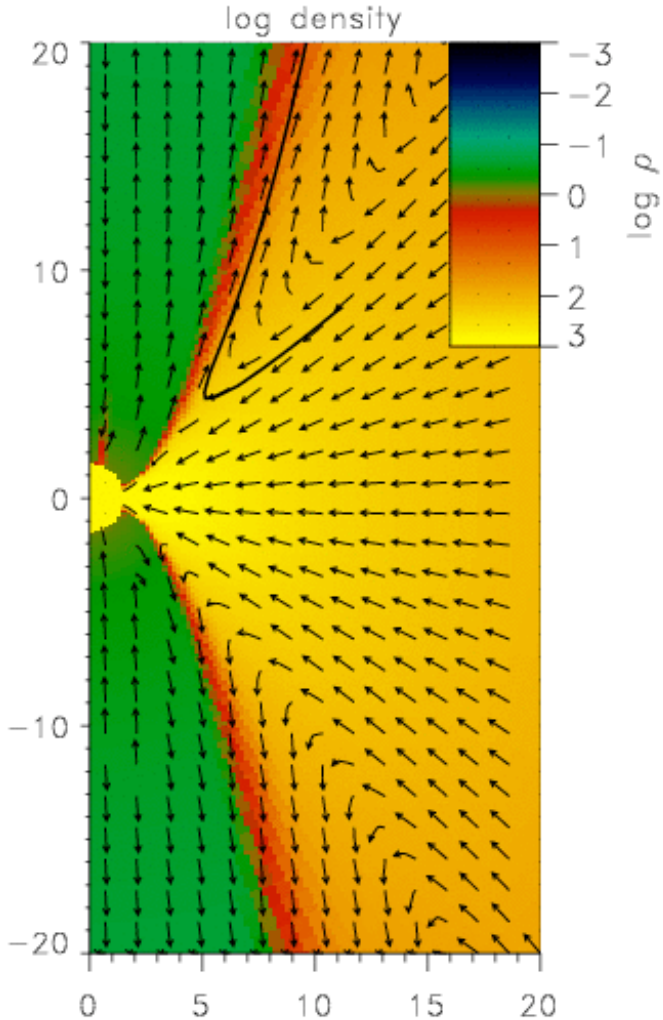
Does it have to be so complex?

Does it have to be so complex?

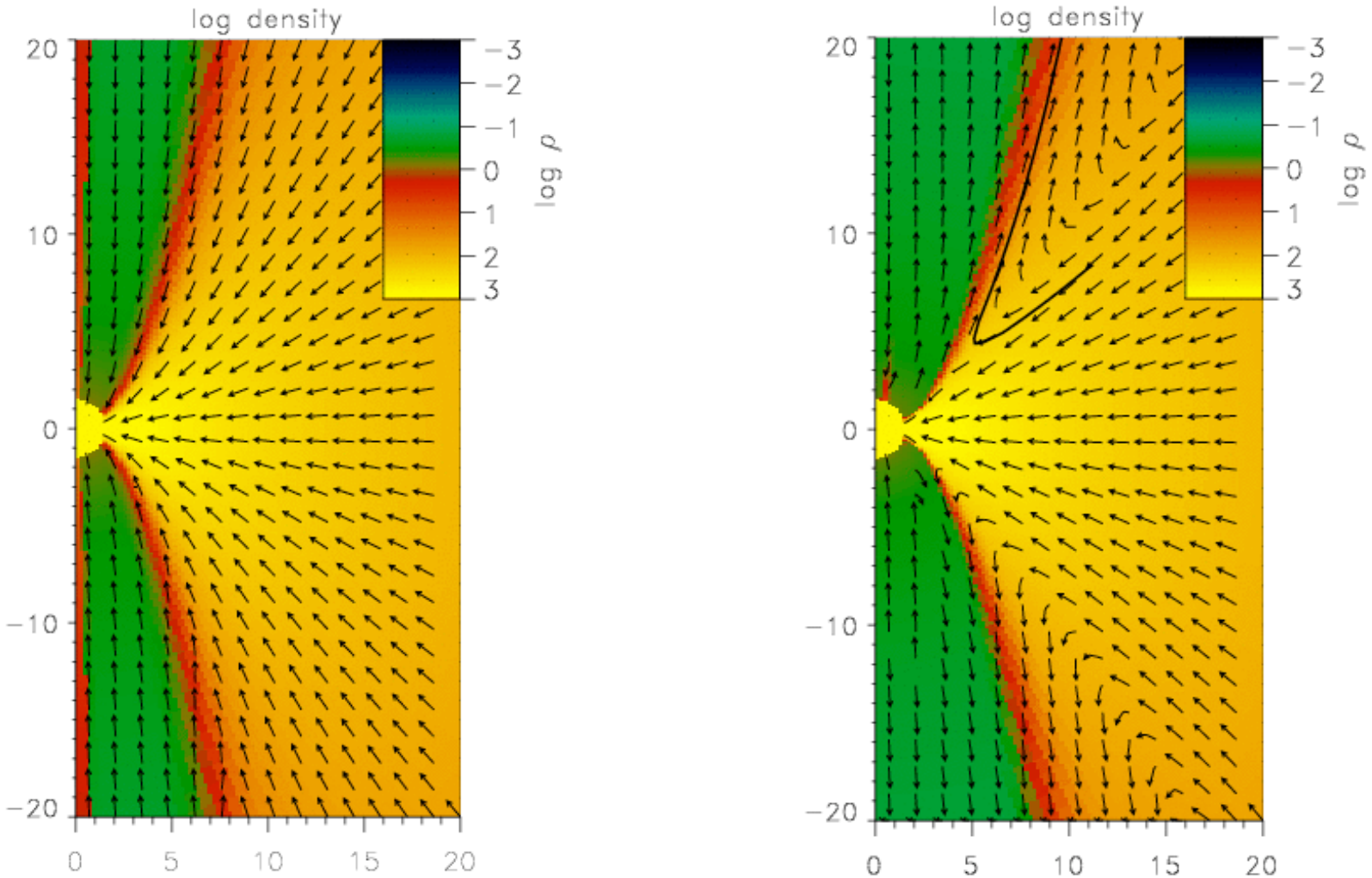


Does it have to be so complex?



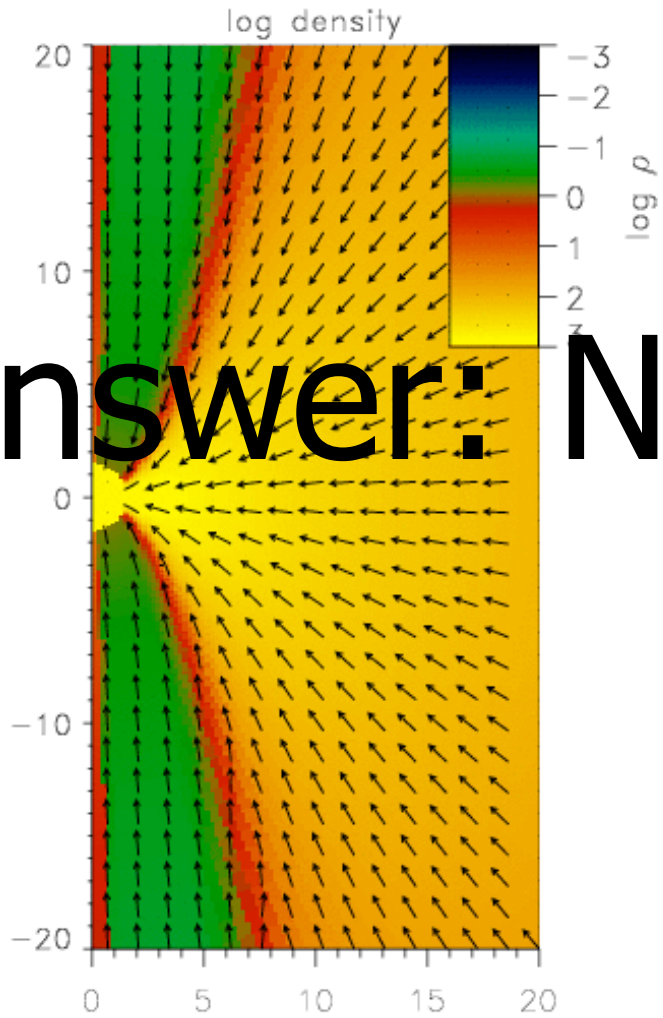


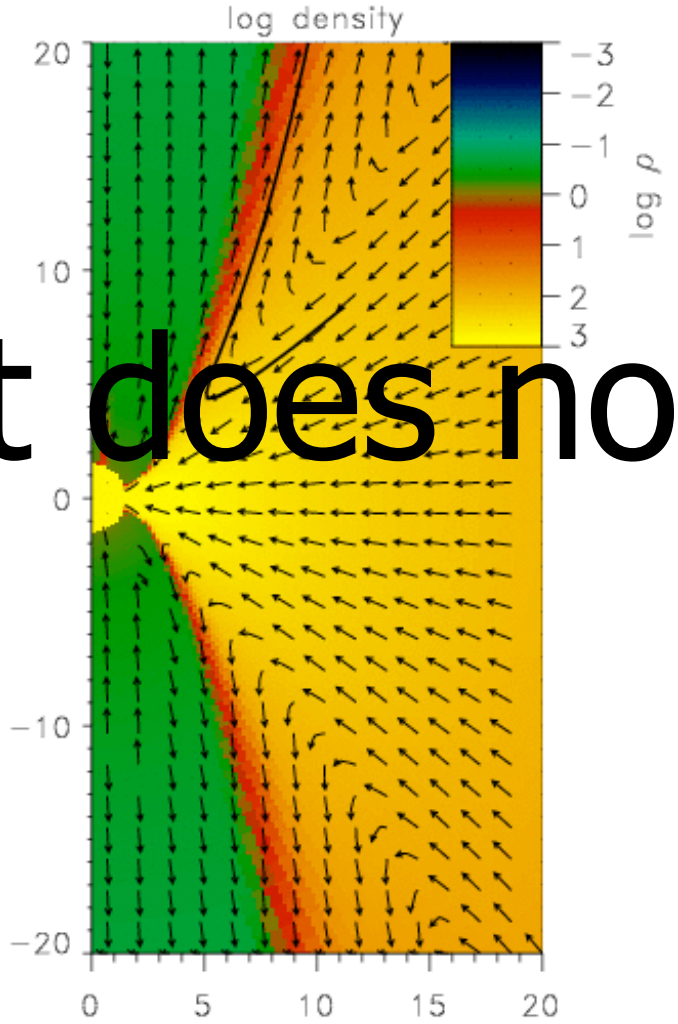
Does it have to be so complex?



Proga (2005)

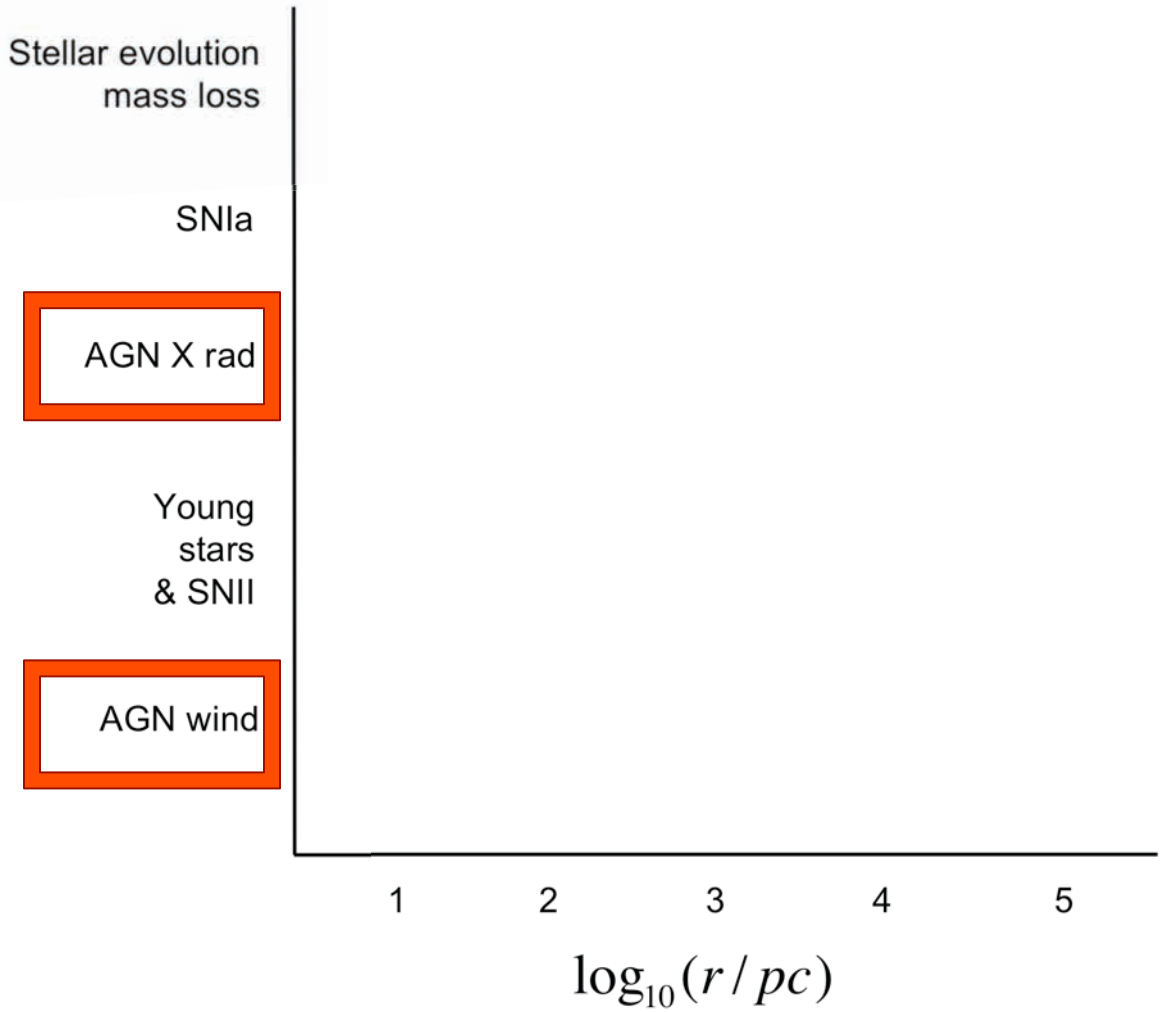
Does it have to be so complex?



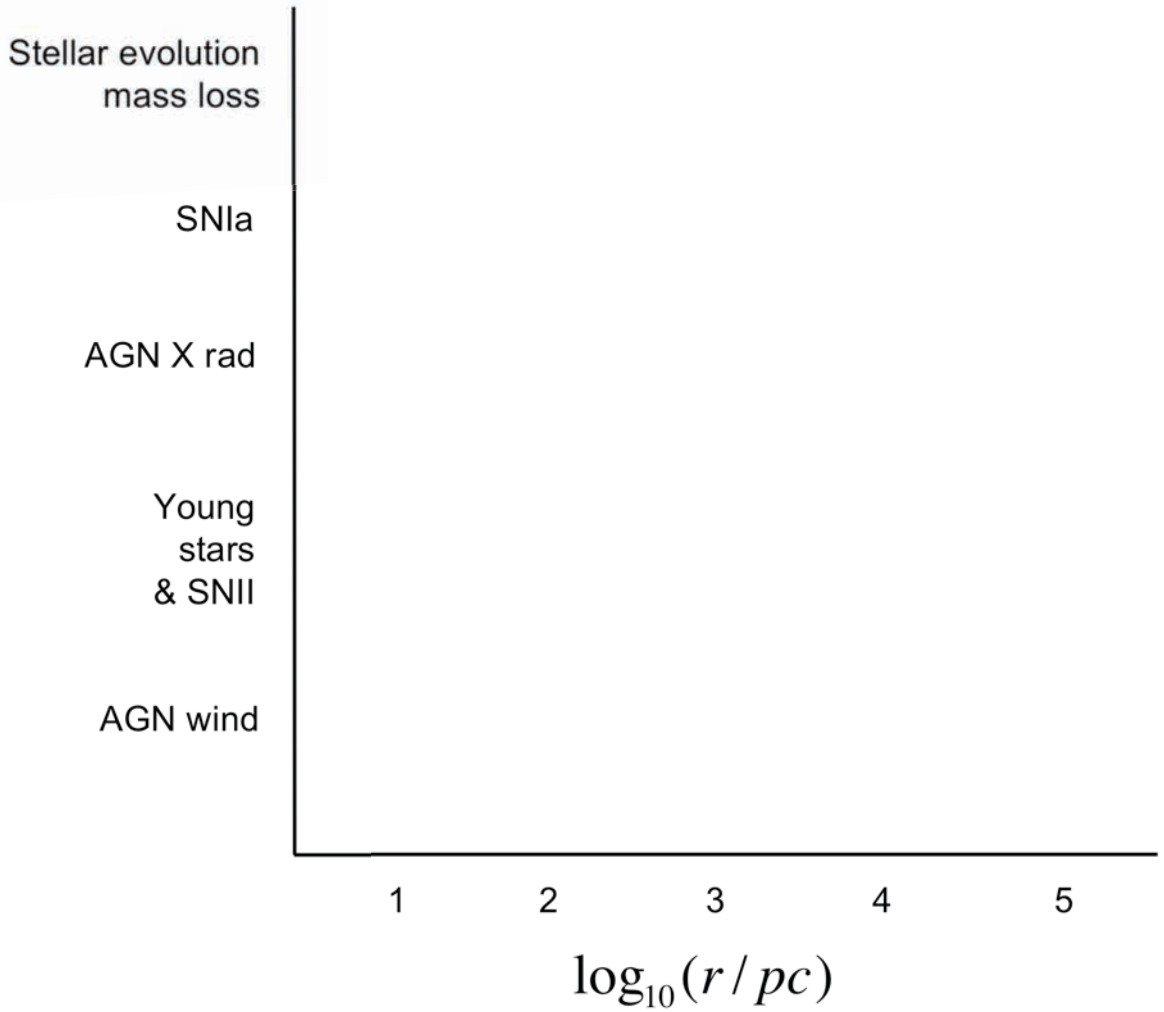


Answer: No, it does not.

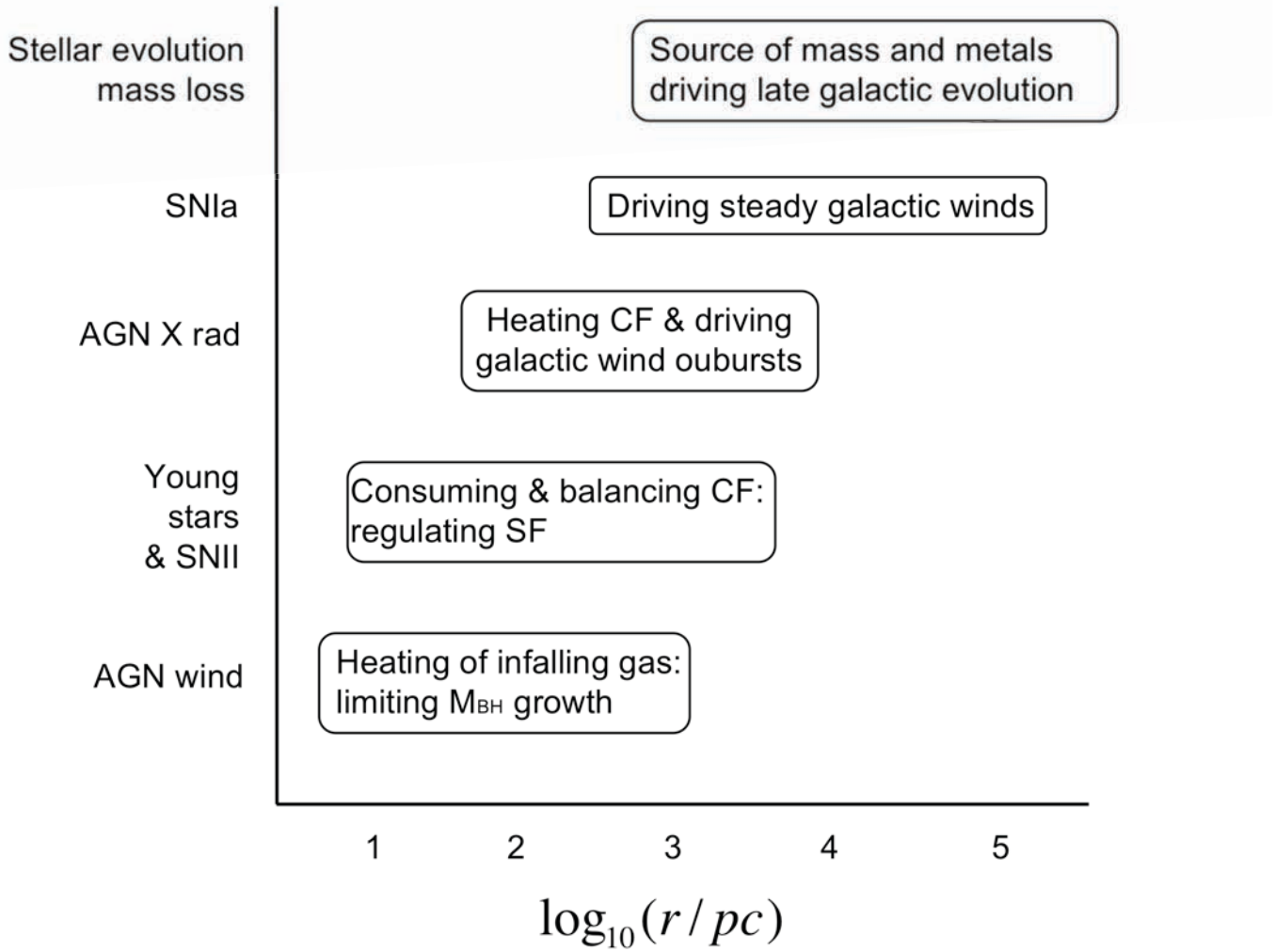
Proga (2005)



Ciotti, Ostriker, & Proga (2010)



Ciotti, Ostriker, & Proga (2010)



Ciotti, Ostriker, & Proga (2010)

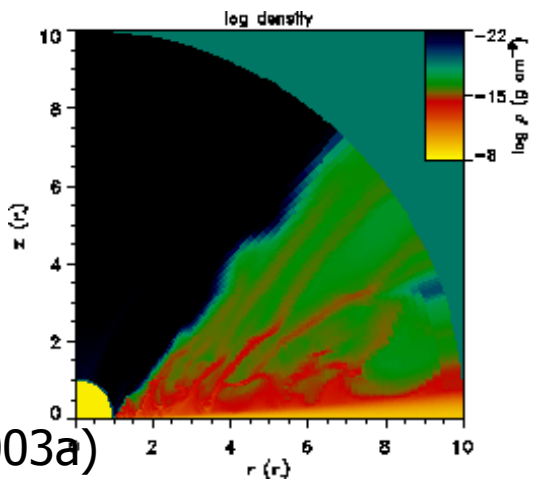
MHD Driven Winds

MHD and Radiation Driven Winds

MHD-LD Disk Winds

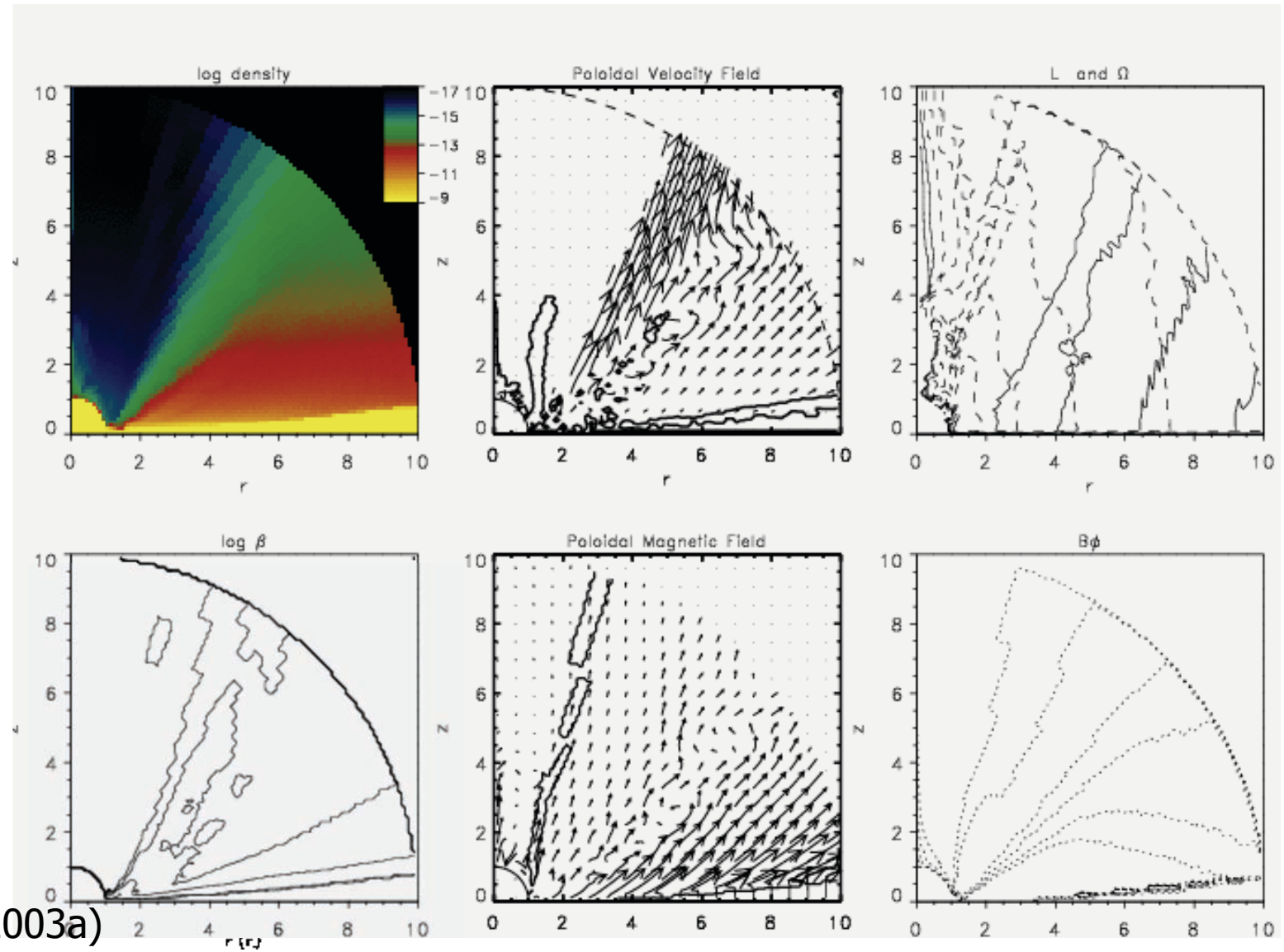
DP (2003a)

MHD-LD Disk Winds



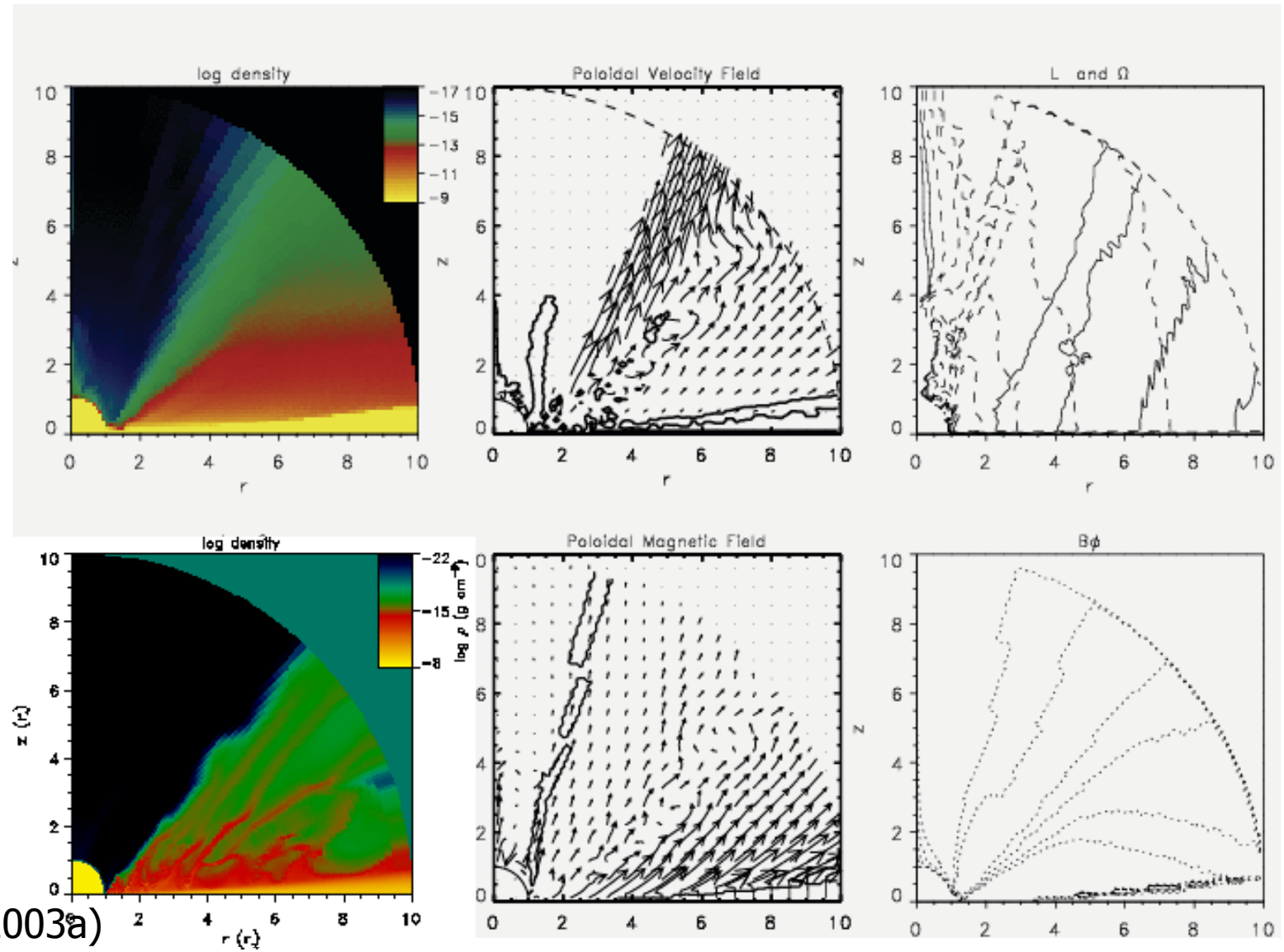
DP (2003a)

MHD-LD Disk Winds



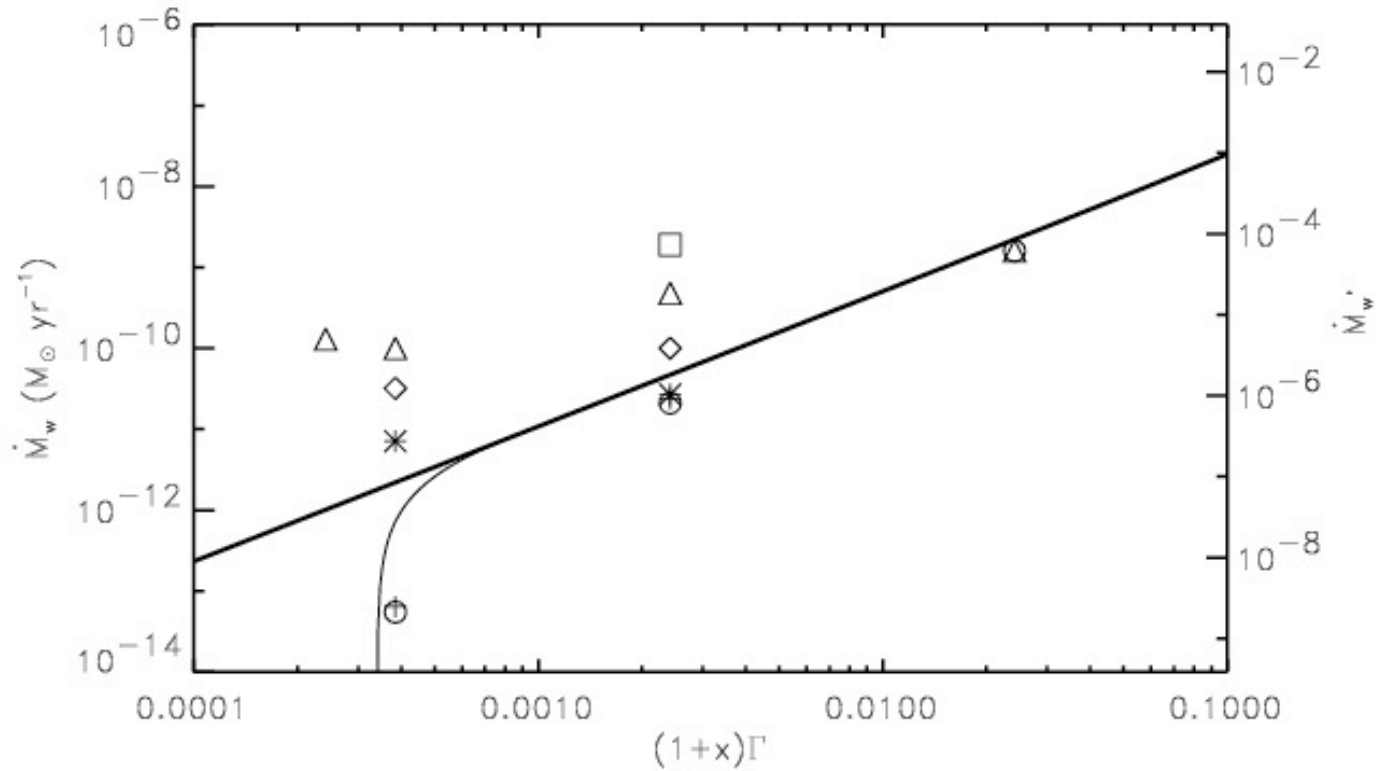
DP (2003a)

MHD-LD Disk Winds

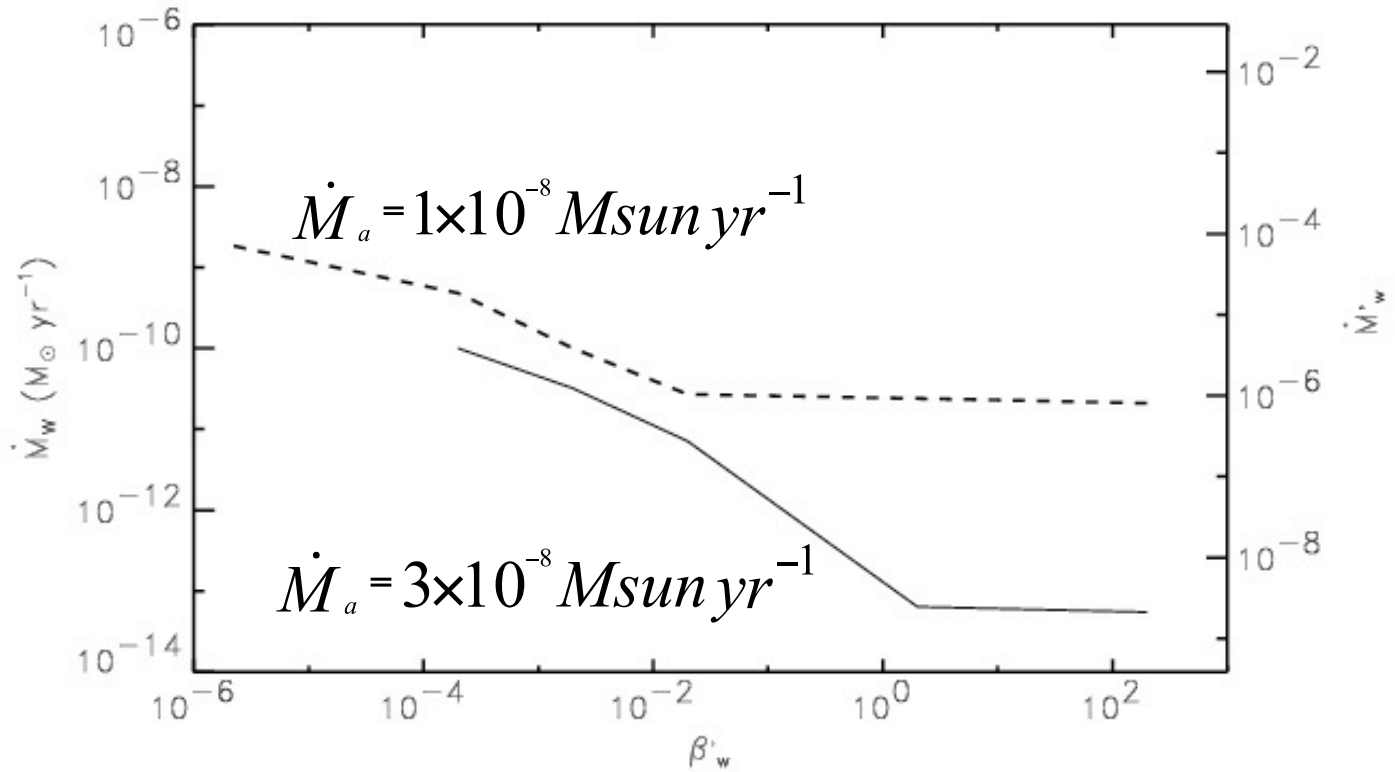


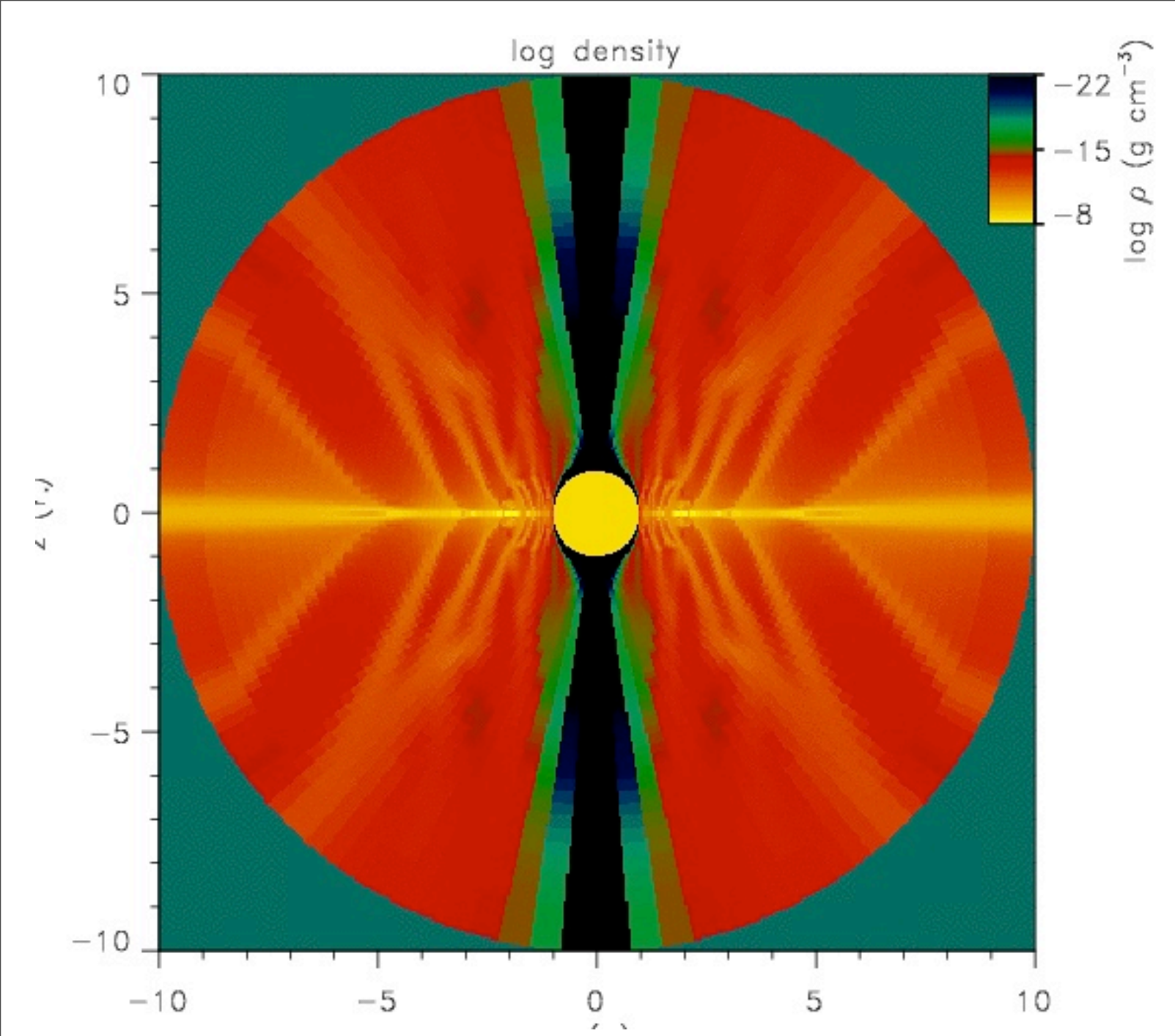
DP (2003a)

The mass loss rate in MHD-LD winds.



The mass loss rate in MHD-LD winds.




log density
10
5
0
−5
−10
−10
−5
0
5
10
−22
−15
−8
log ρ (g cm⁻³)

A big picture

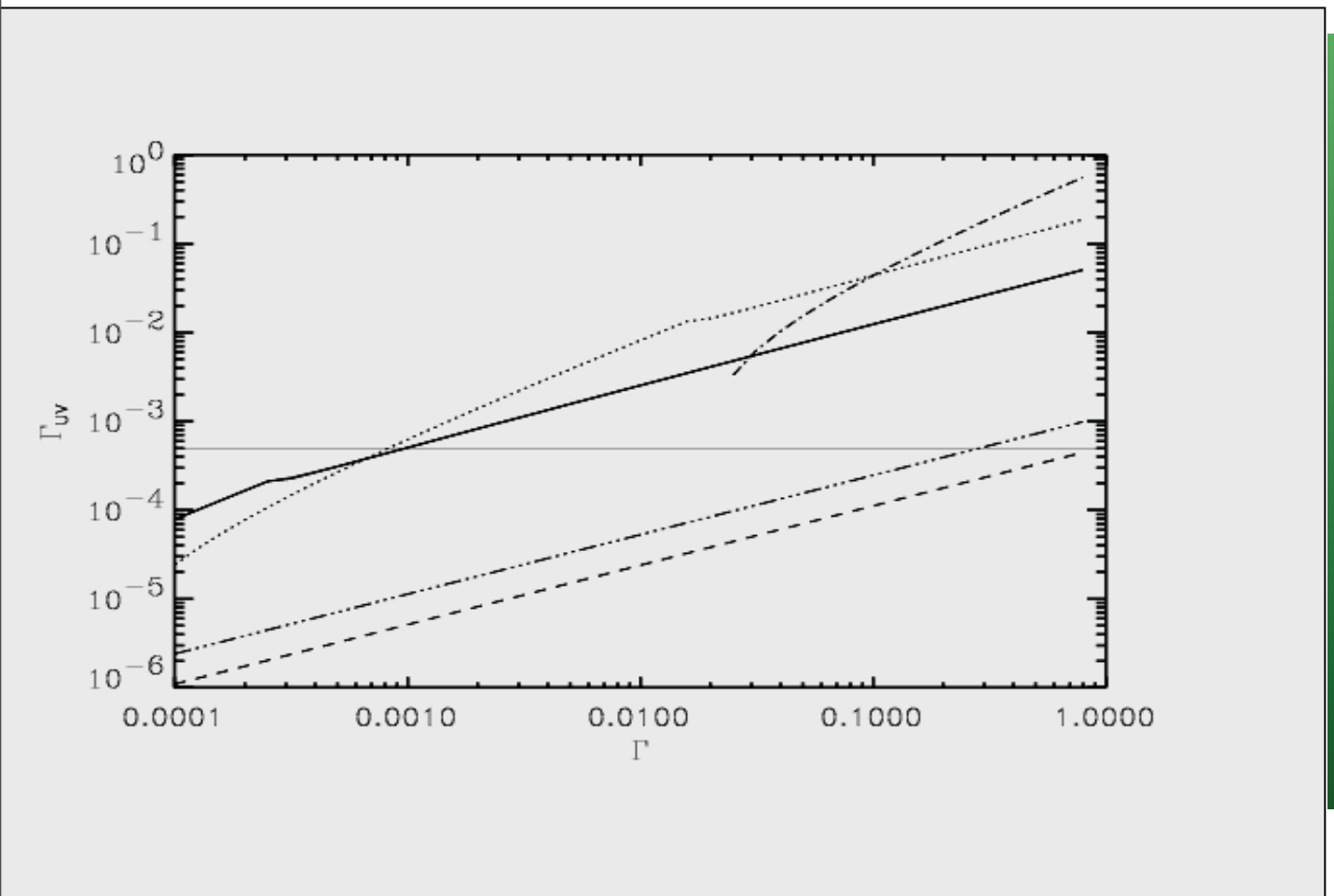
$$L_{Edd} = \frac{4\pi c G M_a}{\sigma}$$

$$L = \frac{M \dot{M}_a G}{2 r_a}$$

$$\Gamma = \frac{L}{L_{Edd}} = \frac{\dot{M}_a \sigma}{8\pi c r_a}$$

$$\Gamma_{UV} = \frac{L_{UV}}{L_{Edd}}$$

A big picture



$$L_{Edd} = \frac{4\pi c G M_a}{\sigma}$$

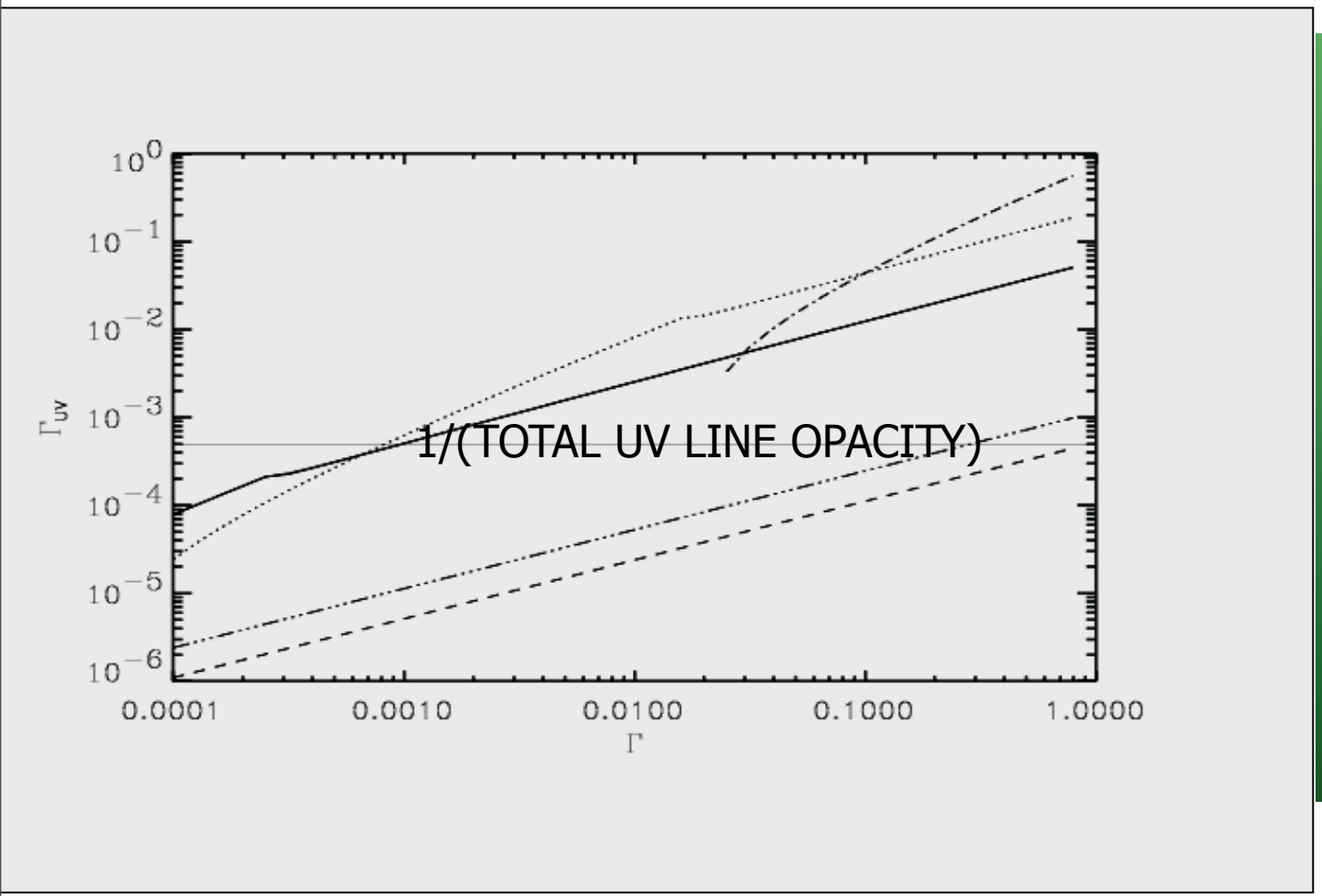
$$L = \frac{M \dot{M}_a G}{2 r_a}$$

$$\Gamma = \frac{L}{L_{Edd}} = \frac{\dot{M}_a \sigma}{8\pi c r_a}$$

$$\Gamma_{UV} = \frac{L_{UV}}{L_{Edd}}$$

Proga (2002)

A big picture



$$L_{Edd} = \frac{4\pi c G M_a}{\sigma}$$

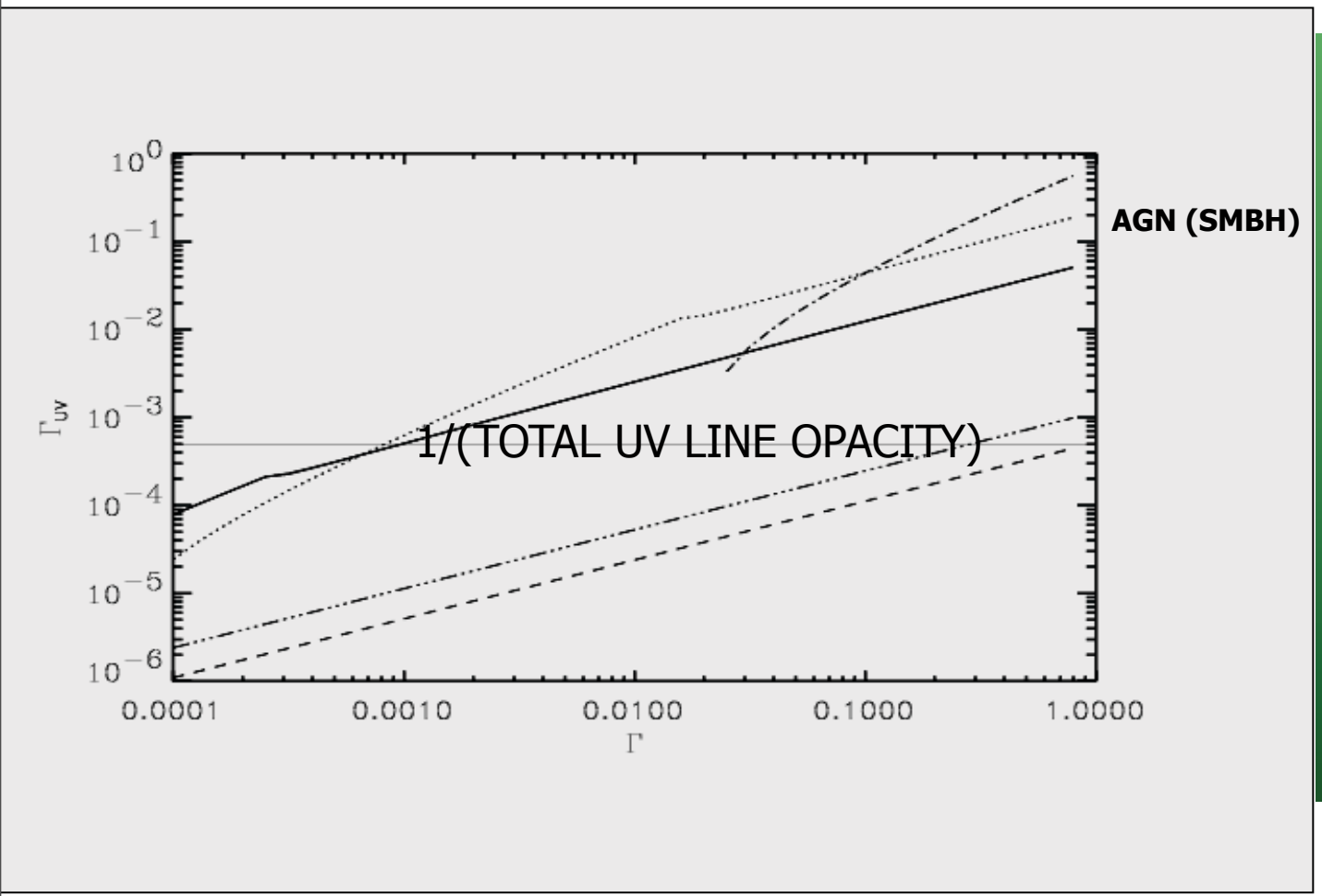
$$L = \frac{M \dot{M}_a G}{2 r_a}$$

$$\Gamma = \frac{L}{L_{Edd}} = \frac{\dot{M}_a \sigma}{8\pi c r_a}$$

$$\Gamma_{UV} = \frac{L_{UV}}{L_{Edd}}$$

Proga (2002)

A big picture



$$L_{Edd} = \frac{4\pi c G M_a}{\sigma}$$

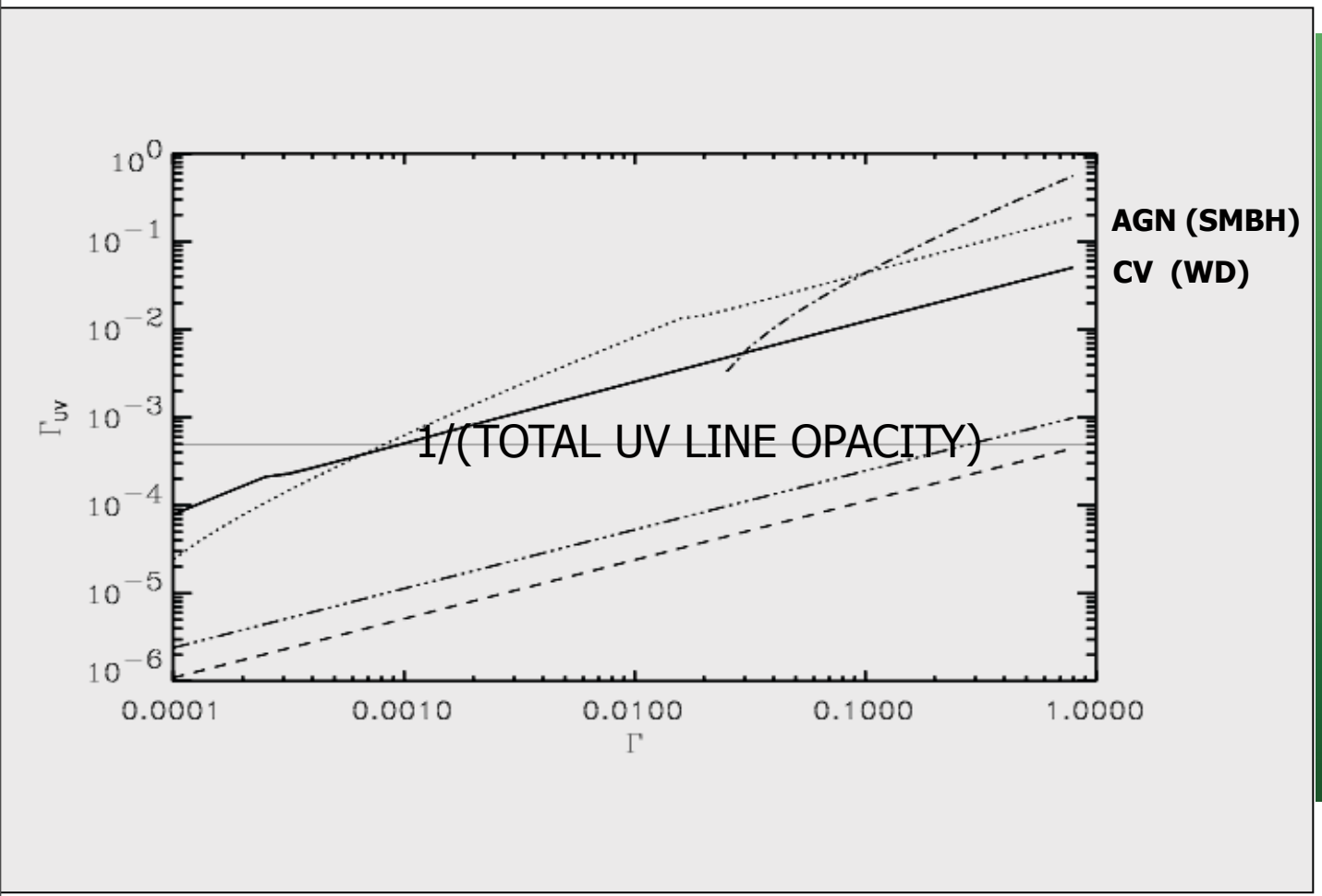
$$L = \frac{M\dot{M}_a G}{2r_a}$$

$$\Gamma = \frac{L}{L_{Edd}} = \frac{\dot{M}_a \sigma}{8\pi c r_a}$$

$$\Gamma_{UV} = \frac{L_{UV}}{L_{Edd}}$$

Proga (2002)

A big picture



$$L_{Edd} = \frac{4\pi c G M_a}{\sigma}$$

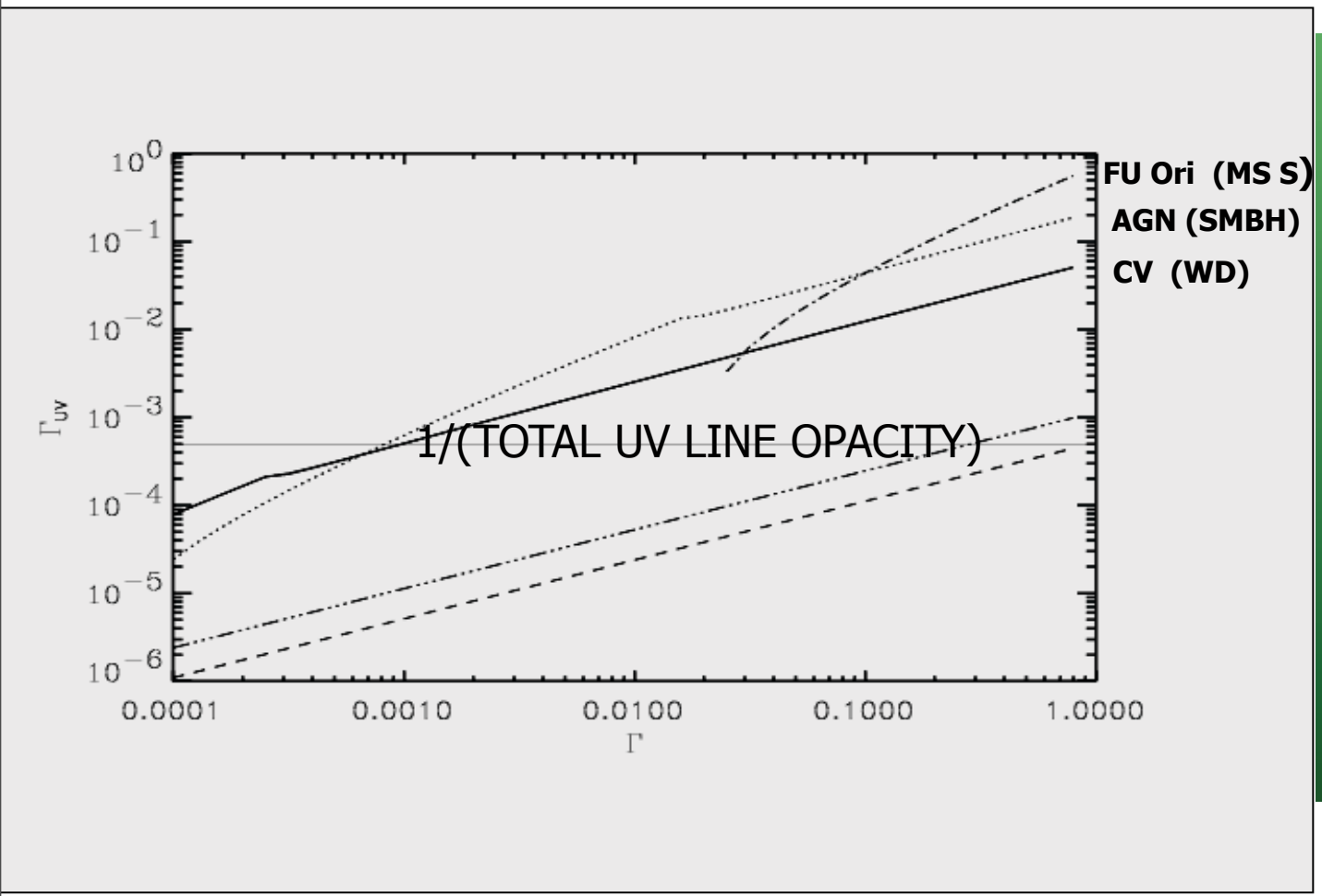
$$L = \frac{M \dot{M}_a G}{2 r_a}$$

$$\Gamma = \frac{L}{L_{Edd}} = \frac{\dot{M}_a \sigma}{8\pi c r_a}$$

$$\Gamma_{UV} = \frac{L_{UV}}{L_{Edd}}$$

Proga (2002)

A big picture



$$L_{Edd} = \frac{4\pi c G M_a}{\sigma}$$

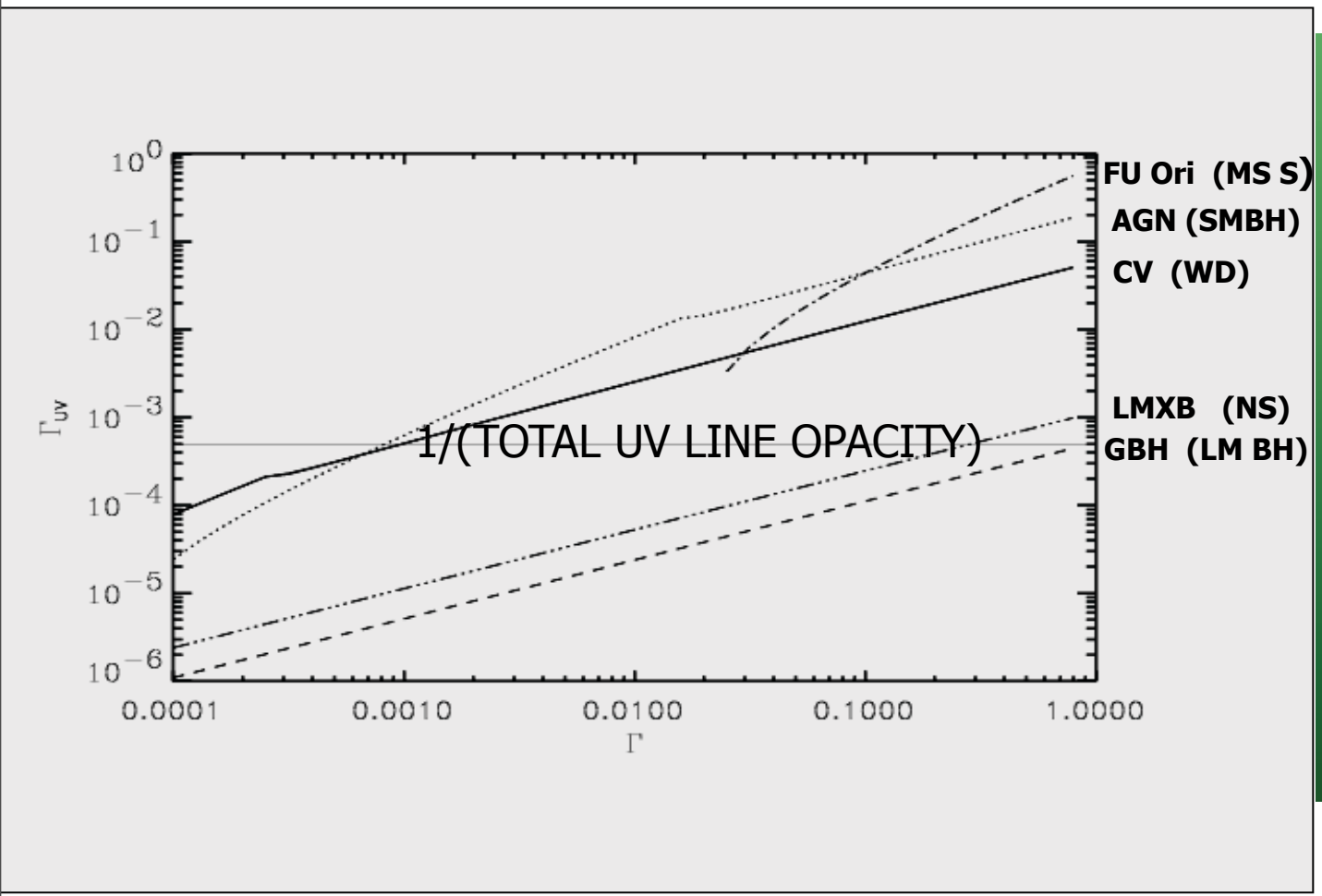
$$L = \frac{M\dot{M}_a G}{2r_a}$$

$$\Gamma = \frac{L}{L_{Edd}} = \frac{\dot{M}_a \sigma}{8\pi c r_a}$$

$$\Gamma_{UV} = \frac{L_{UV}}{L_{Edd}}$$

Proga (2002)

A big picture



$$L_{Edd} = \frac{4\pi c G M_a}{\sigma}$$

$$L = \frac{M\dot{M}_a G}{2r_a}$$

$$\Gamma = \frac{L}{L_{Edd}} = \frac{\dot{M}_a \sigma}{8\pi c r_a}$$

$$\Gamma_{UV} = \frac{L_{UV}}{L_{Edd}}$$

Proga (2002)

Conclusions

Conclusions

- A significant fraction of the inflowing matter can be expelled by radiation pressure and heating.

Conclusions

- A significant fraction of the inflowing matter can be expelled by radiation pressure and heating.
- The non-rotating flow settles into a steady inflow/outflow solution. Gas rotation and large optical depth can lead to time variability.

Conclusions

- A significant fraction of the inflowing matter can be expelled by radiation pressure and heating.
- The non-rotating flow settles into a steady inflow/outflow solution. Gas rotation and large optical depth can lead to time variability.
- In time variable flows, dense clouds form (as in NRL of AGN?).

Conclusions

- A significant fraction of the inflowing matter can be expelled by radiation pressure and heating.
- The non-rotating flow settles into a steady inflow/outflow solution. Gas rotation and large optical depth can lead to time variability.
- In time variable flows, dense clouds form (as in NRL of AGN?).
- The outflows are multi-temperature/phases (as in WA?).

Conclusions

- A significant fraction of the inflowing matter can be expelled by radiation pressure and heating.
- The non-rotating flow settles into a steady inflow/outflow solution. Gas rotation and large optical depth can lead to time variability.
- In time variable flows, dense clouds form (as in NRL of AGN?).
- The outflows are multi-temperature/phases (as in WA?).
- The I/O solution is quite robust but its characteristics are sensitive to the geometry and SED of the central object radiation.

Conclusions

- A significant fraction of the inflowing matter can be expelled by radiation pressure and heating.
- The non-rotating flow settles into a steady inflow/outflow solution. Gas rotation and large optical depth can lead to time variability.
- In time variable flows, dense clouds form (as in NRL of AGN?).
- The outflows are multi-temperature/phases (as in WA?).
- The I/O solution is quite robust but its characteristics are sensitive to the geometry and SED of the central object radiation.
- The mass supplied rate does not appear to be limited by the luminosity of AGN.

Conclusions

- A significant fraction of the inflowing matter can be expelled by radiation pressure and heating.
- The non-rotating flow settles into a steady inflow/outflow solution. Gas rotation and large optical depth can lead to time variability.
- In time variable flows, dense clouds form (as in NRL of AGN?).
- The outflows are multi-temperature/phases (as in WA?).
- The I/O solution is quite robust but its characteristics are sensitive to the geometry and SED of the central object radiation.
- The mass supplied rate does not appear to be limited by the luminosity of AGN.
- The outflow is inefficient in removing energy.

Conclusions

- A significant fraction of the inflowing matter can be expelled by radiation pressure and heating.
- The non-rotating flow settles into a steady inflow/outflow solution. Gas rotation and large optical depth can lead to time variability.
- In time variable flows, dense clouds form (as in NRL of AGN?).
- The outflows are multi-temperature/phases (as in WA?).
- The I/O solution is quite robust but its characteristics are sensitive to the geometry and SED of the central object radiation.
- The mass supplied rate does not appear to be limited by the luminosity of AGN.
- The outflow is inefficient in removing energy.
- Disk winds are much more efficient than the large scale outflows …