Warm Absorbers: Are They Disk Outflows?

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Collaborators

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OUTLINE

- Introduction
- Multidimensional Time-Dependent Simulations
- Conclusions
- Future Work

AGN are powered by gas accretion onto a supermassive black hole.

$$L = \eta c^2 \dot{M}_a$$

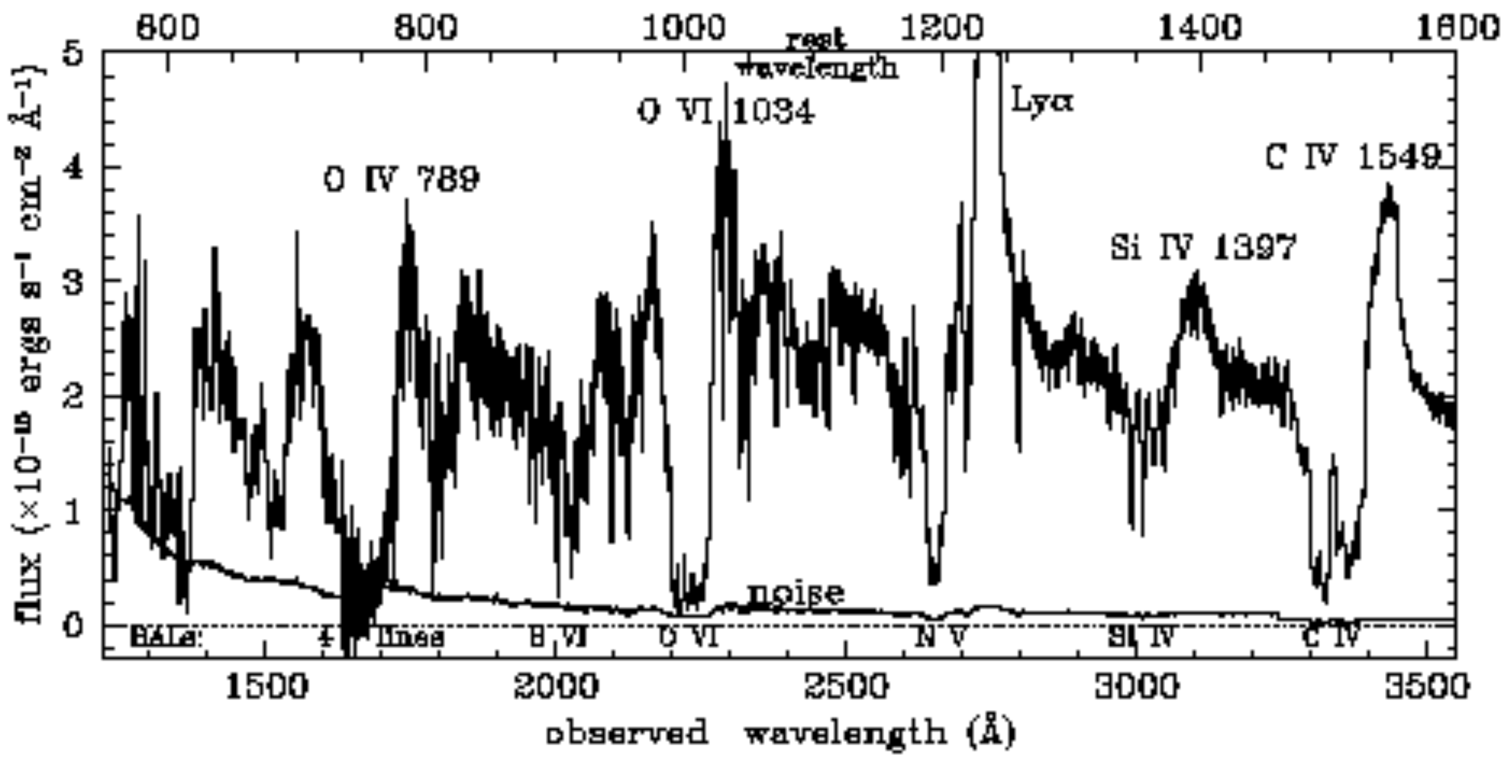
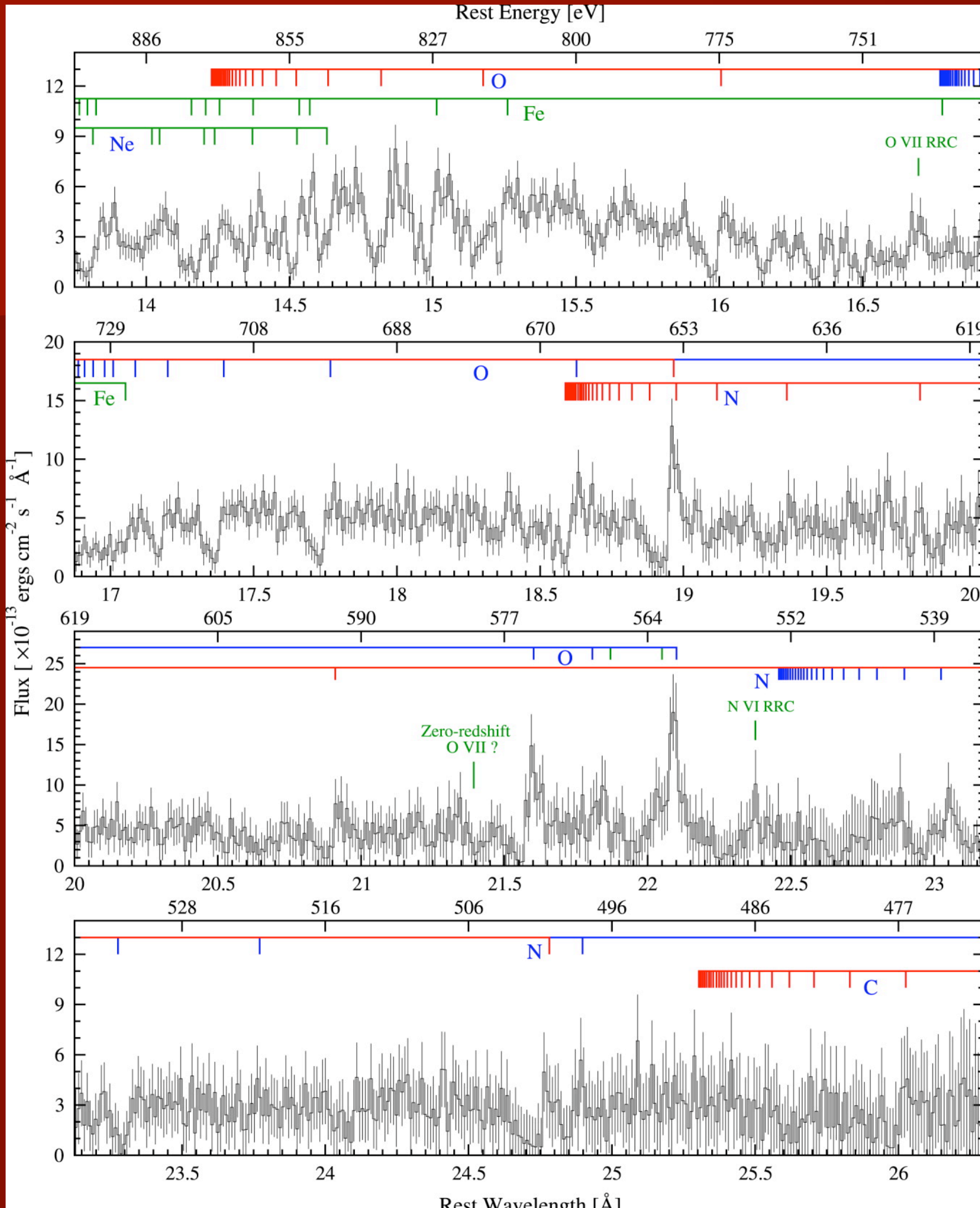


FIG. 1.—Composite spectrum of PG 0946+301; flux is measured in the observed frame

Arav et a. (1999) -- HST and ground-based obs. of PG 0946+301



NGC 3785:
Warm Absorbers

Chandra spectrum (Kaspi et al. 2002). The H-like and He-like lines of the identified ions are marked in red and blue, respectively. Lines from other ions (lower ionization metals and Fe XVII Fe XXIV) are marked in green.

Outflows: another aspect of activity

- Mass outflows are very common in AGN
- Outflows are important because they can change

  - the rate of accretion onto a black hole;
  - the AGN radiation;
  - environment of the AGN, its host galaxy, and IGM

  …

There are many questions:

- Where do the outflows come from?
- How do the outflows avoid full ionization?
- What is the geometry and structure of the outflows (e.g., wind or moving clouds)?
- What force accelerates the outflows?
- What is the mass loss rate, momentum, and energy of the outflows?

…

An accretion disk is the most plausible origin of AGN outflows.

What can drive an outflow?

- Thermal expansion (the Sun, X-ray binaries)
- Magnetic fields (stars, accretion disks)
- Radiation pressure (OB stars, accretion disks)

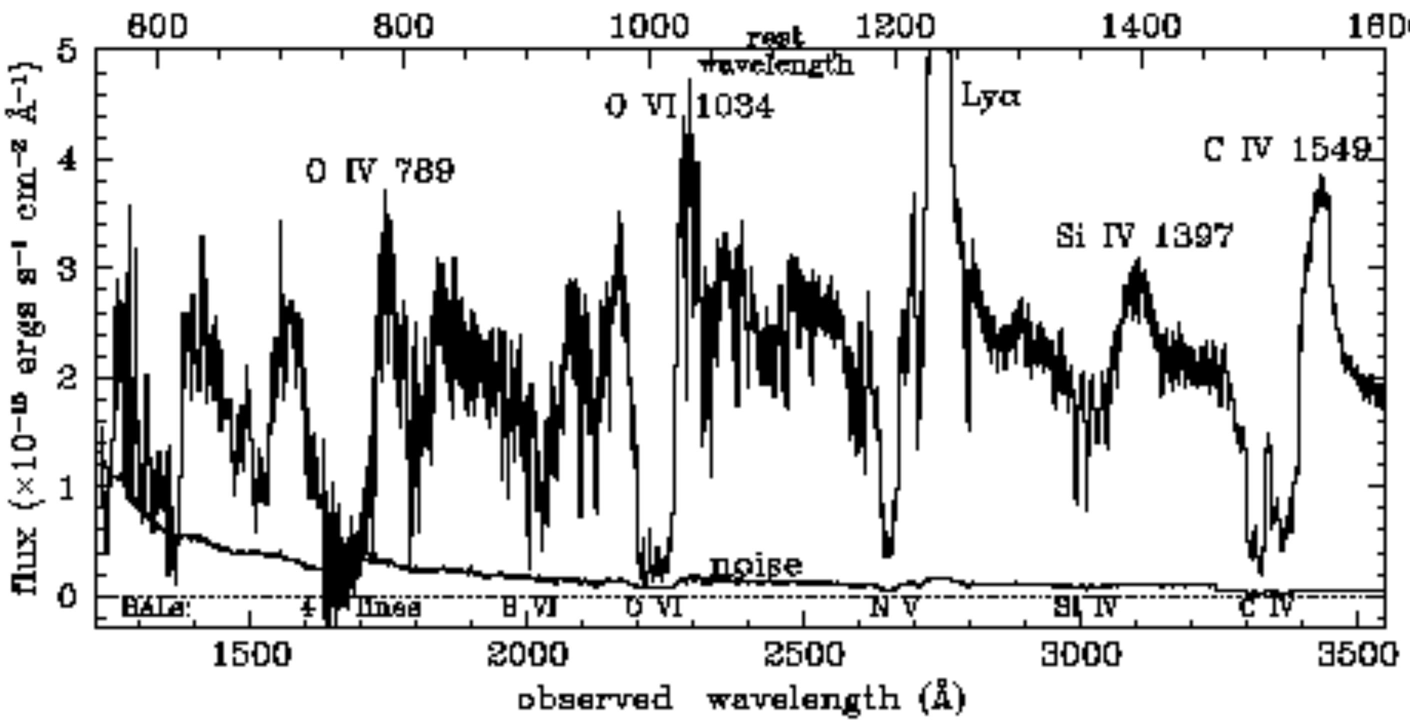
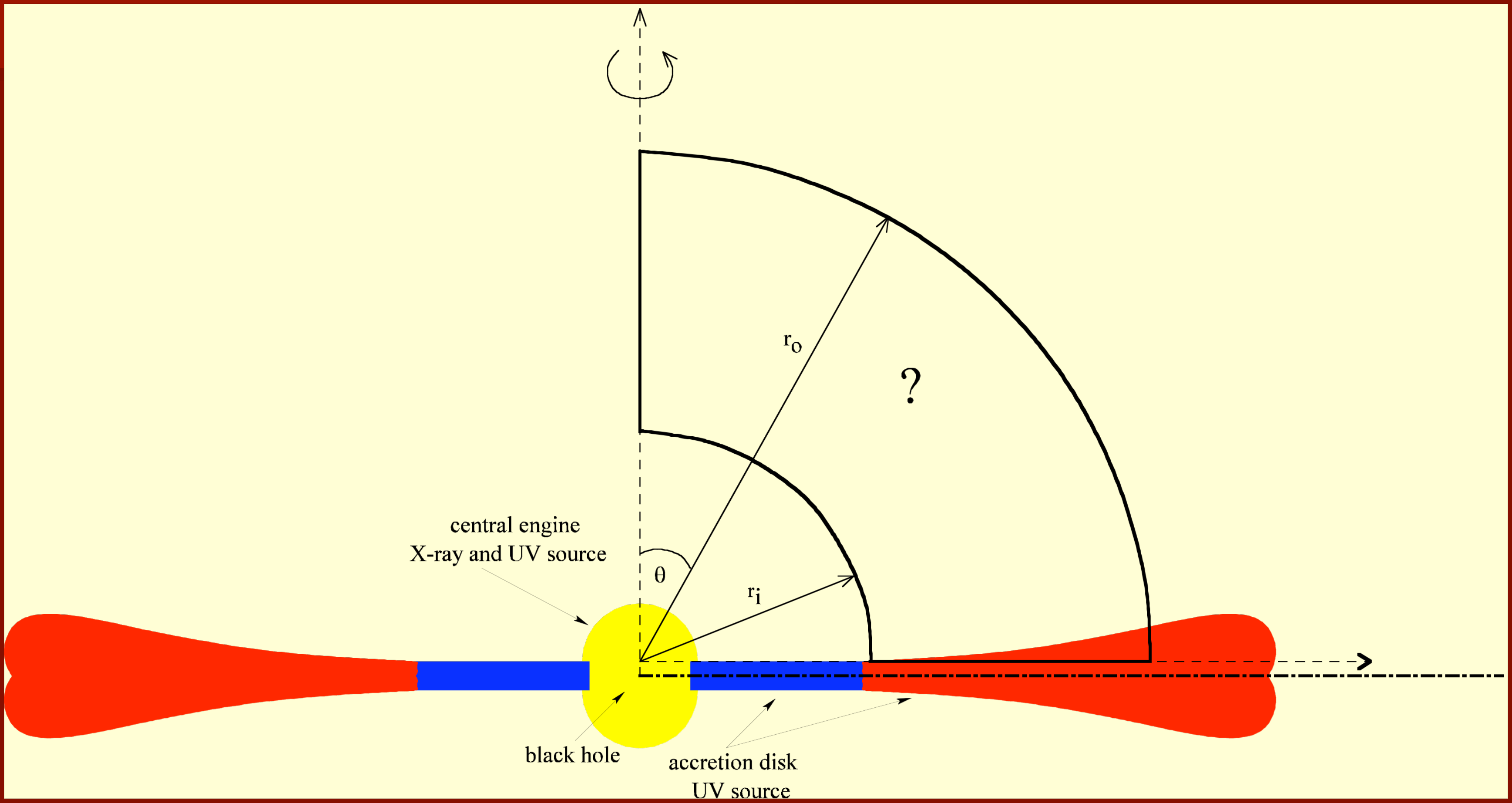


FIG. 1.—Composite spectrum of PG 0946+301; flux is measured in the observed frame

Numerical HD simulations.



Proga, Stone & Kallman (2000)

Calculations

- Geometry:
  axial symmetry – 2D spatial domain but 3D velocity (i.e., so-called 2.5D)
- Assumptions:
  disk - flat, Keplerian and optically thick;
  radiation field (?)
  (the Shakura Sunyaev model);
  central engine - sphere;
  radiation field (?)
  (the black body radiation, comptonization)

gas - an ideal gas with adiabatic EOS

- Forces:

  gravity, rotation, gas and radiation

  pressure effects

- The structure and evolution of a wind:

the ZEUS code is used to solve

the equations of HD that describe

the conservation of mass,

momentum, and

energy.

We allow for radiative heating and cooling.

The equations of hydrodynamics

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

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

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

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

$$f^{rad,e} = \frac{\sigma_e}{c}\frac{L}{4\pi r^2} = \frac{\sigma_e}{c}F$$

the radiation force due to electron scattering

$$f^{rad,e} = g \quad \Rightarrow \quad L_{Edd} = \frac{4\pi cGM}{\sigma_e}$$

the Eddington luminosity

$$\Gamma = L / L_{Edd}$$

the Eddington factor

The accretion disk

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

$$L_{Edd,D} = \frac{4\pi c G M_a}{\sigma_e}$$

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

$$f^{rad,\ l} = \sum_{lines} \frac{\kappa_L F_c \Delta \nu_D}{c} \min(1,\ 1/\tau_L)$$

the radiation force due to lines

$$f^{rad,\ total} = f^{rad,\ e} + f^{rad,\ l} = f^{rad,\ e}\left(1 + M\right)$$

the total radiation force

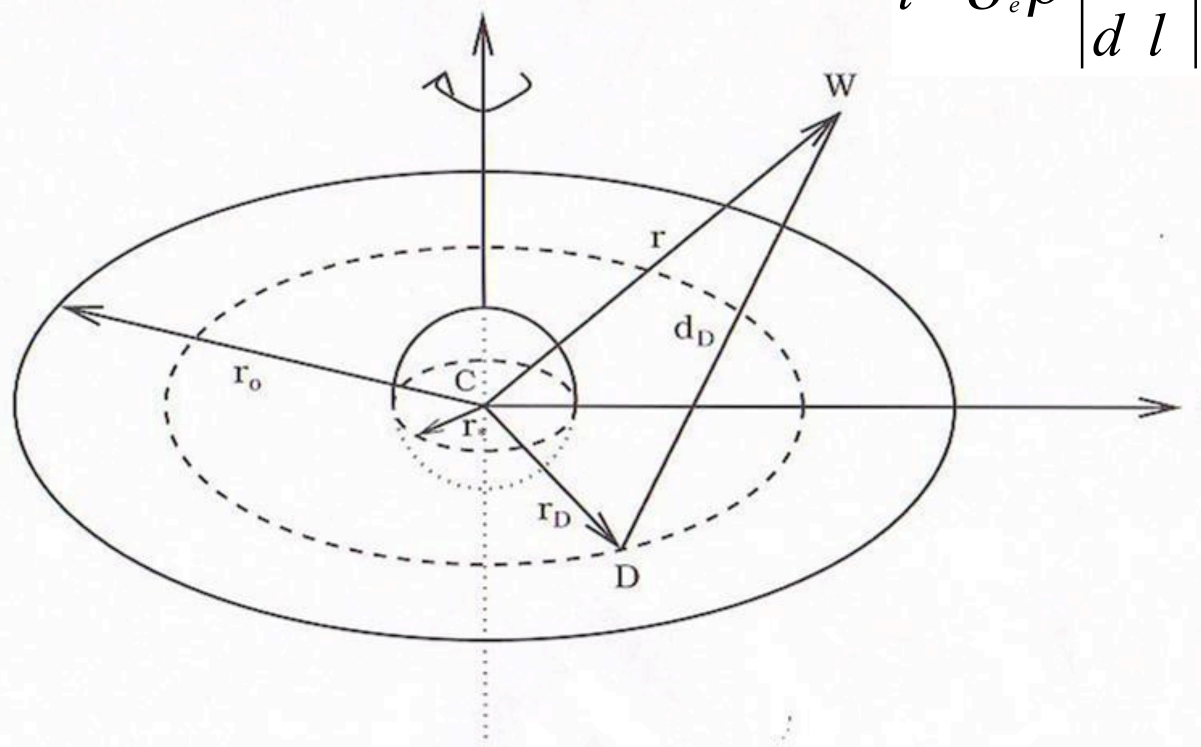
Radiation force

The Sobolev approximation (a generalized version) and the force multiplier due to Castor, Abbott, & Klein (1975)

$$t = \frac{\sigma_e}{\kappa_L}\tau_L = \sigma_e \rho \left| \frac{d\ v_l}{d\ l} \right|^{-1} \qquad M(t) = k t^{-\alpha} \left[\frac{\left(1 + \tau_{max}\right)^{(1-\alpha)} - 1}{\tau_{max}^{(1-\alpha)}} \right]$$

$$\lim_{\tau_{max} \to 0} M(t) = k t^{-\alpha}$$

$$\lim_{\tau_{max} \to \infty} M(t) = (\text{TOTAL LINE OPACITY}) = k(1-\alpha)\eta_{max}^{\alpha}$$



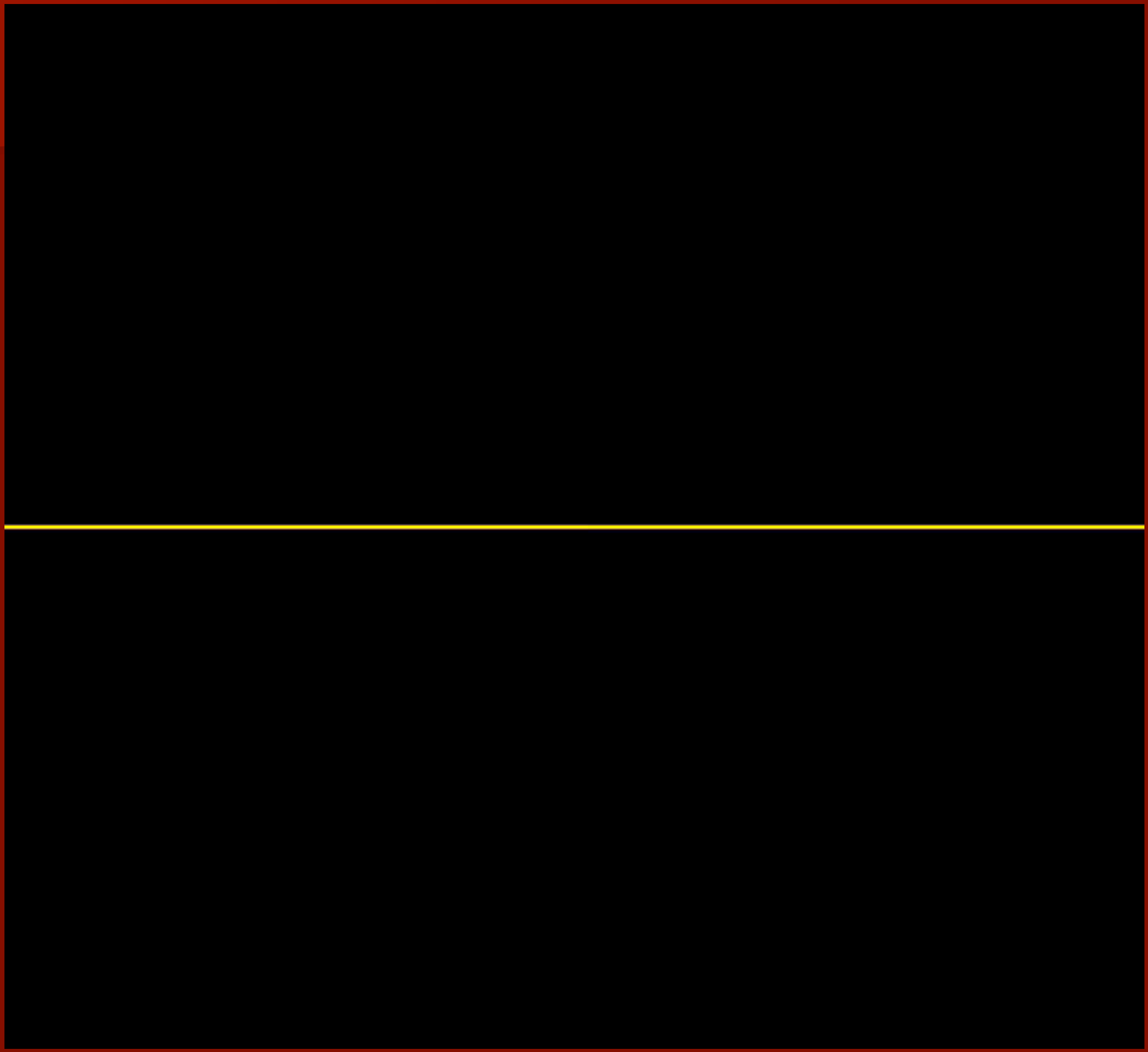
$$t = \sigma_e \rho \left| \frac{d\, v_l}{d\, l} \right|^{-1}$$

An angle-adaptive quadrature to evaluate the flux integral

What do we need to specify?

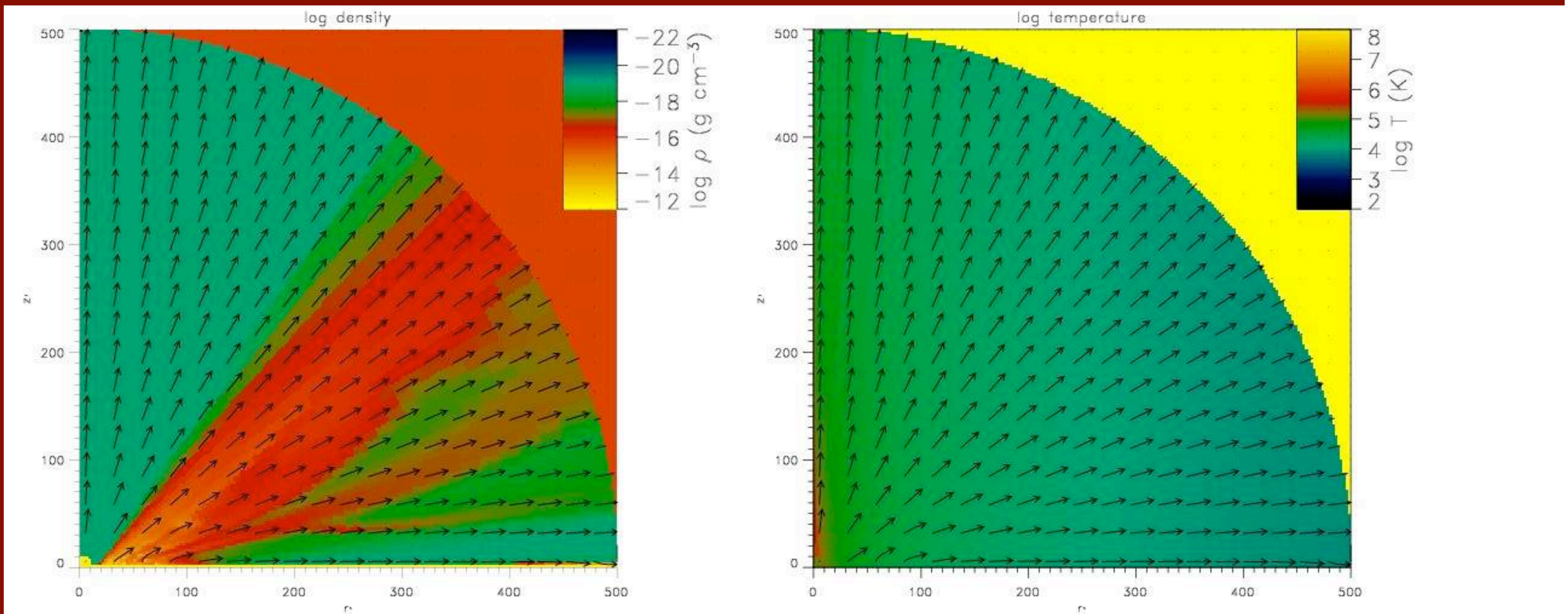
- the mass of the central object;
- the mass accretion rate;
- the luminosity of the central object; and the SED of the central object radiation

CASE ONE: no X-rays



$M_{BH} = 10^8 Msun$

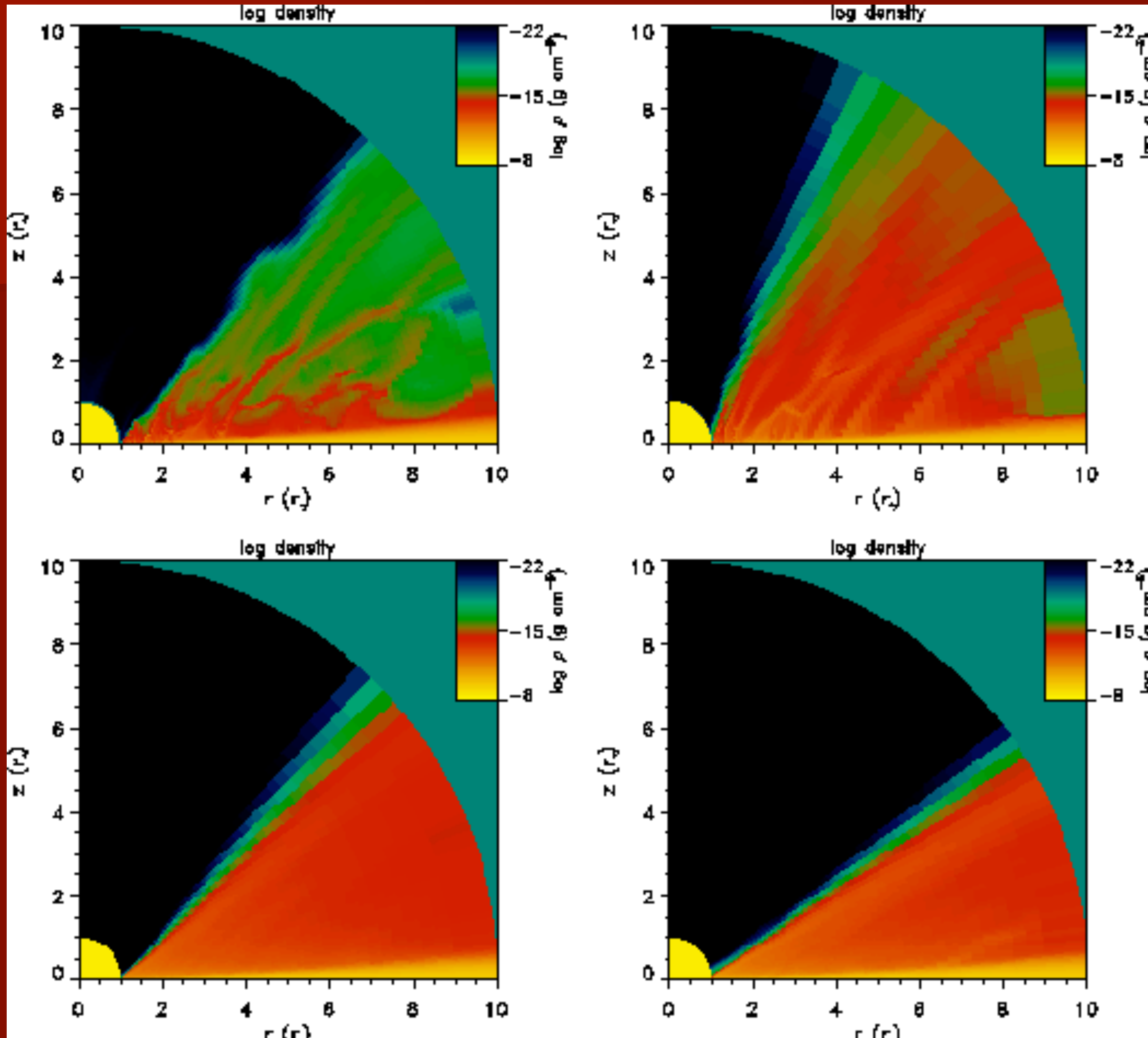
$\Gamma = 0.5$



log density
log ρ (g cm⁻³)
−22
−20
−18
−16
−14
−12
log temperature
log T (K)
8
7
6
5
4
3
2
0
100
200
300
400
500

$L_D = 1$
$L_{CE} = 0$

$L_D = 3$
$L_{CE} = 0$

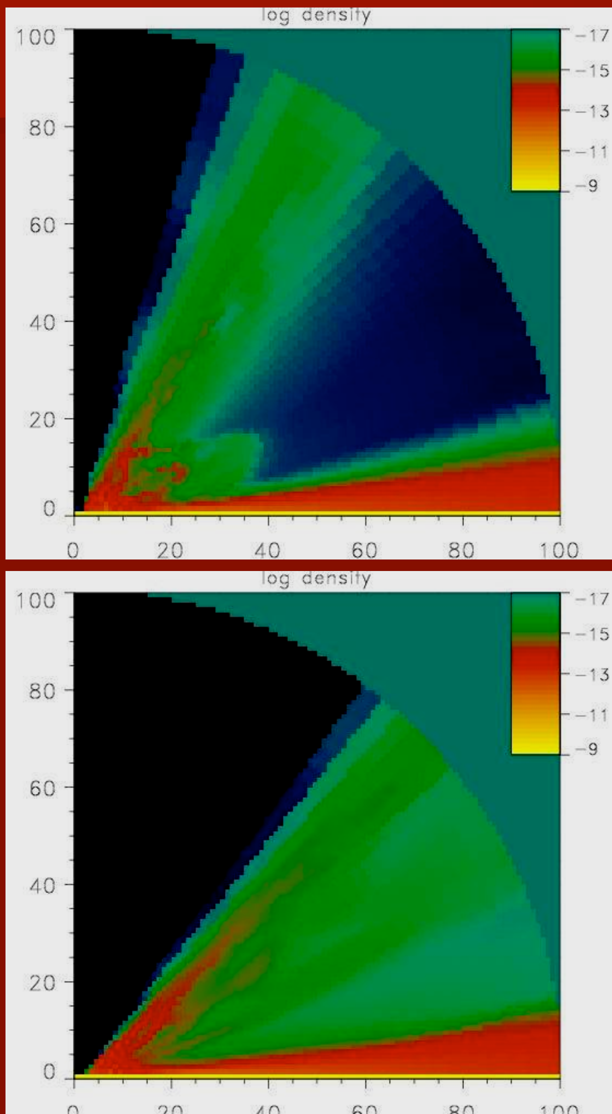


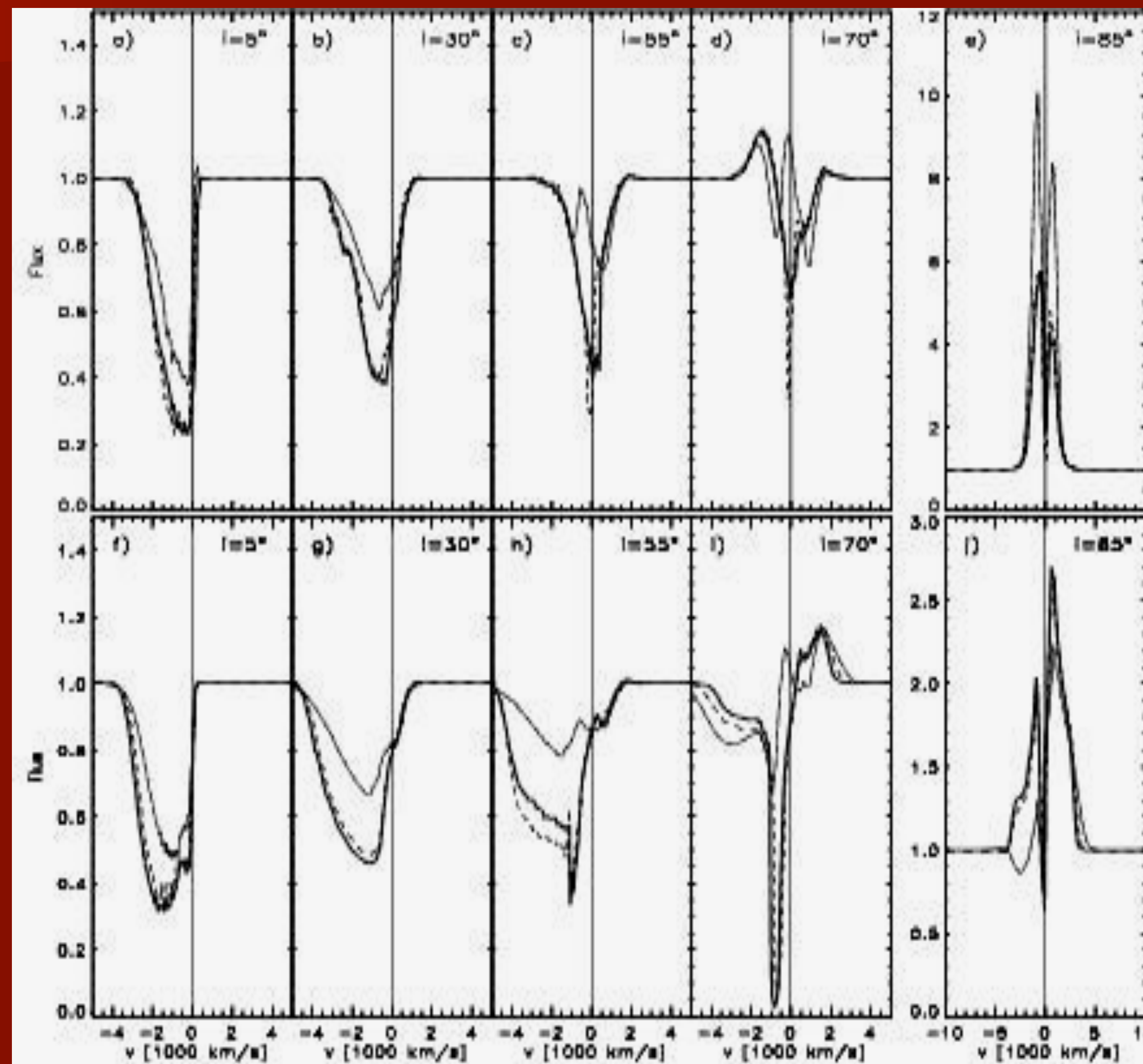
$L_D = 3$
$L_{CE} = 3$

$L_D = 3$
$L_{CE} = 9$

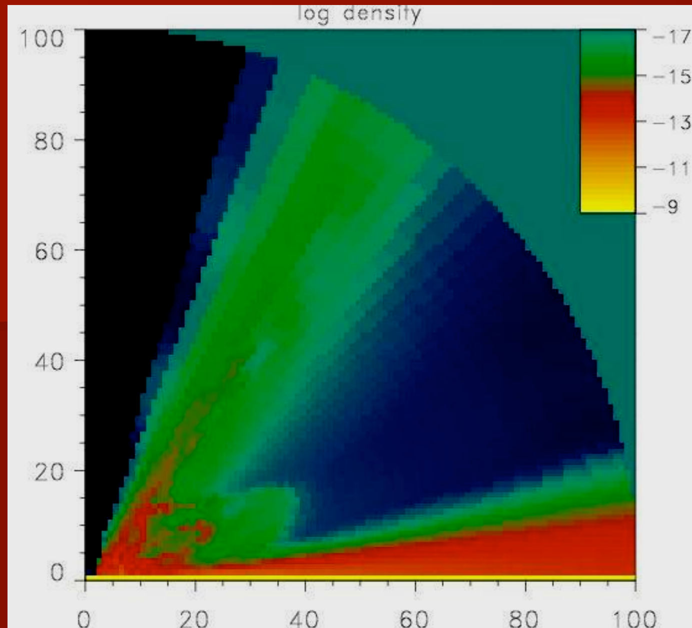
Proga, Stone & Drew (1998)

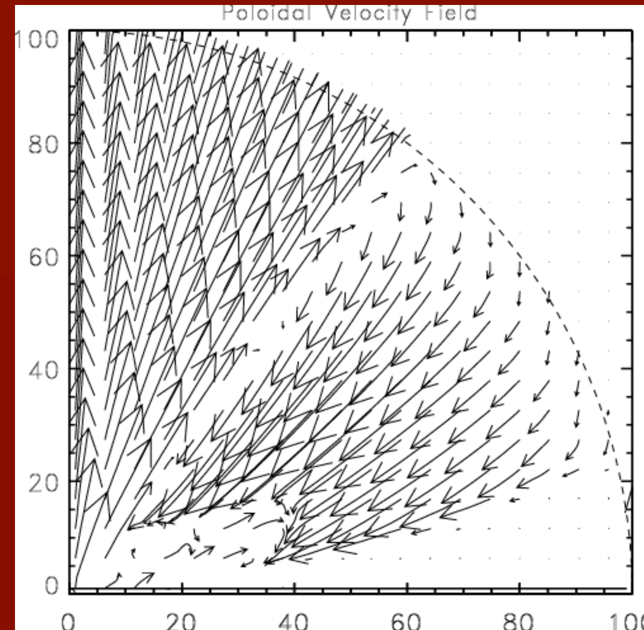
HD simulations and their line profiles



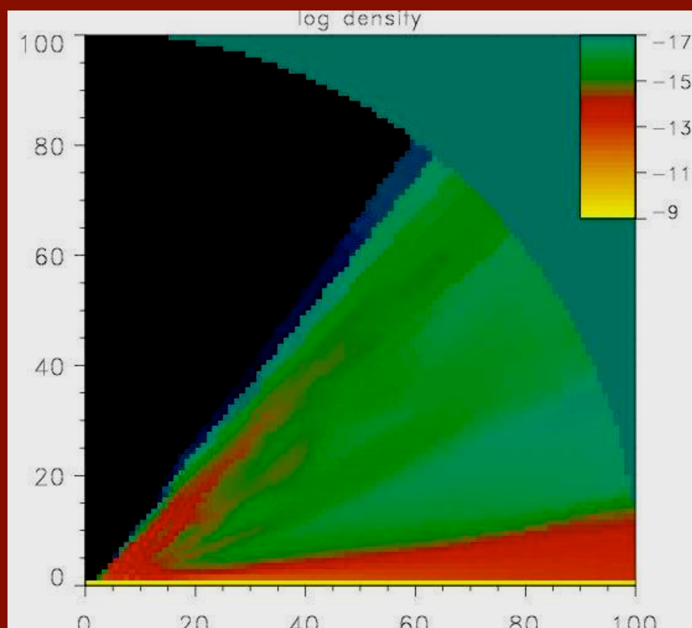


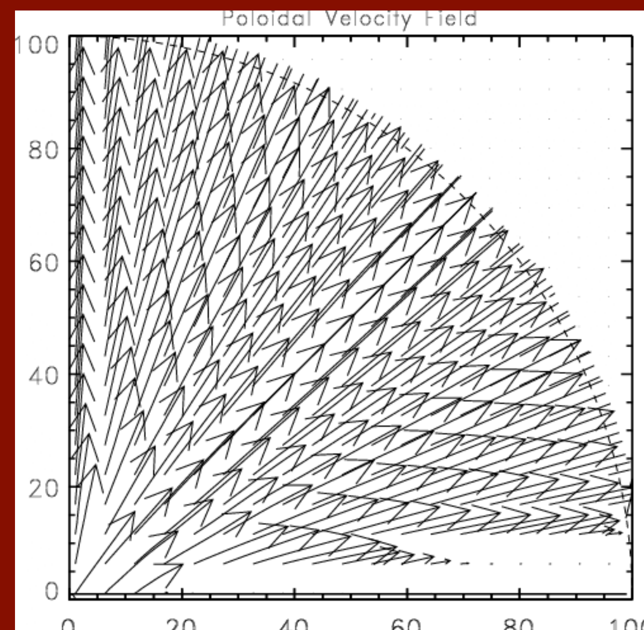
$L_D = 3$
$L = 0$


log density
100
80
60
40
20
0
0
20
40
60
80
100
-17
-15
-13
-11
-9


Poloidal Velocity Field
100
80
60
40
20
0
0
20
40
60
80
100

$L_D = 3$
$L = 3$


log density
100
80
60
40
20
0
0
20
40
60
80
100
-17
-15
-13
-11
-9

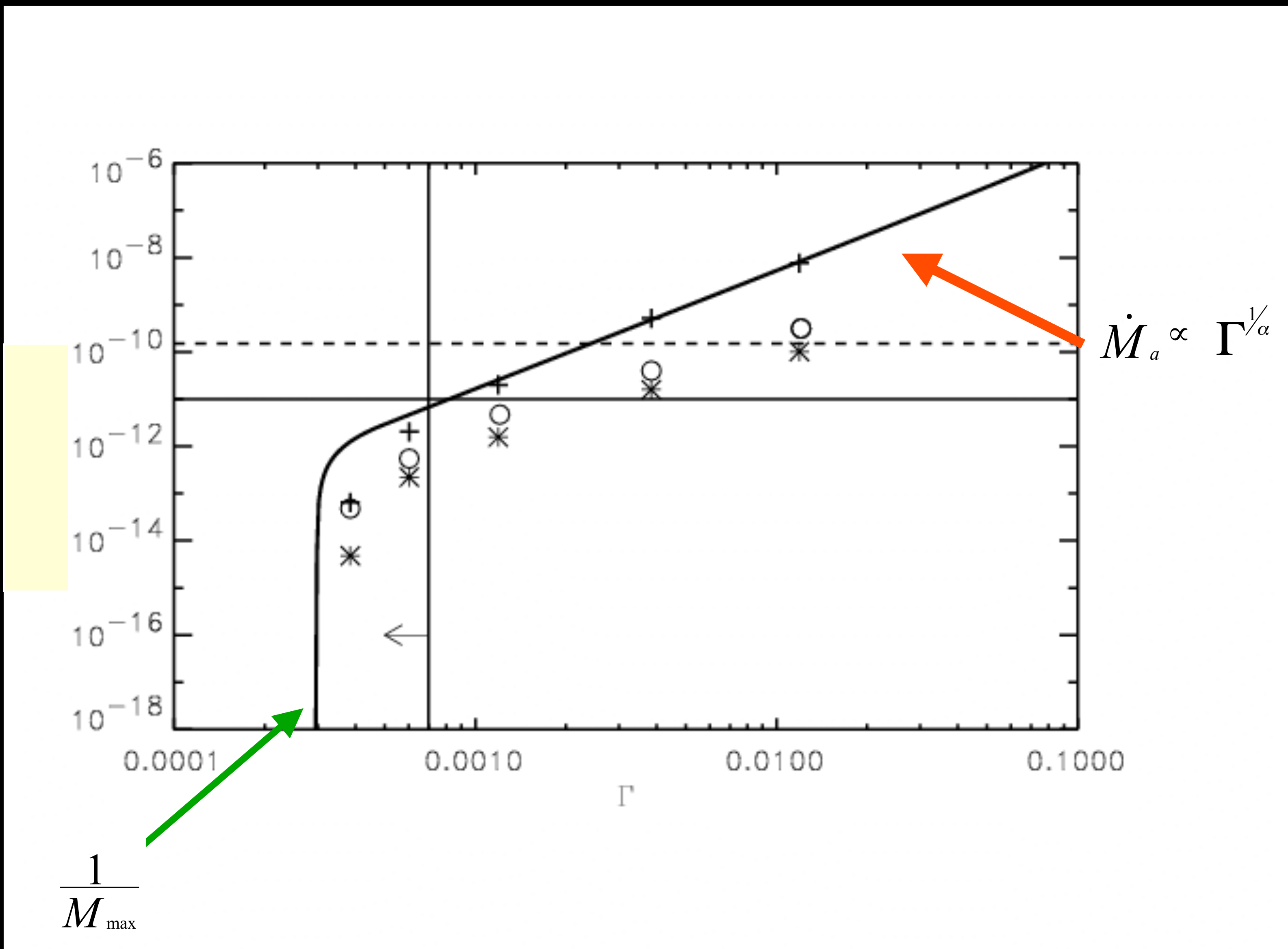

Poloidal Velocity Field
100
80
60
40
20
0
0
20
40
60
80
100

Applications:

- Cataclysmic Variables

  (Proga, Drew, Stone 1998, 1999 …
  Proga 2003 added magnetic fields,
  Proga et al. 2002 computed synthetic line profiles)
- Young Stellar Objects

  (Drew et al. 1999 and Oudmaijer et al. 1999)



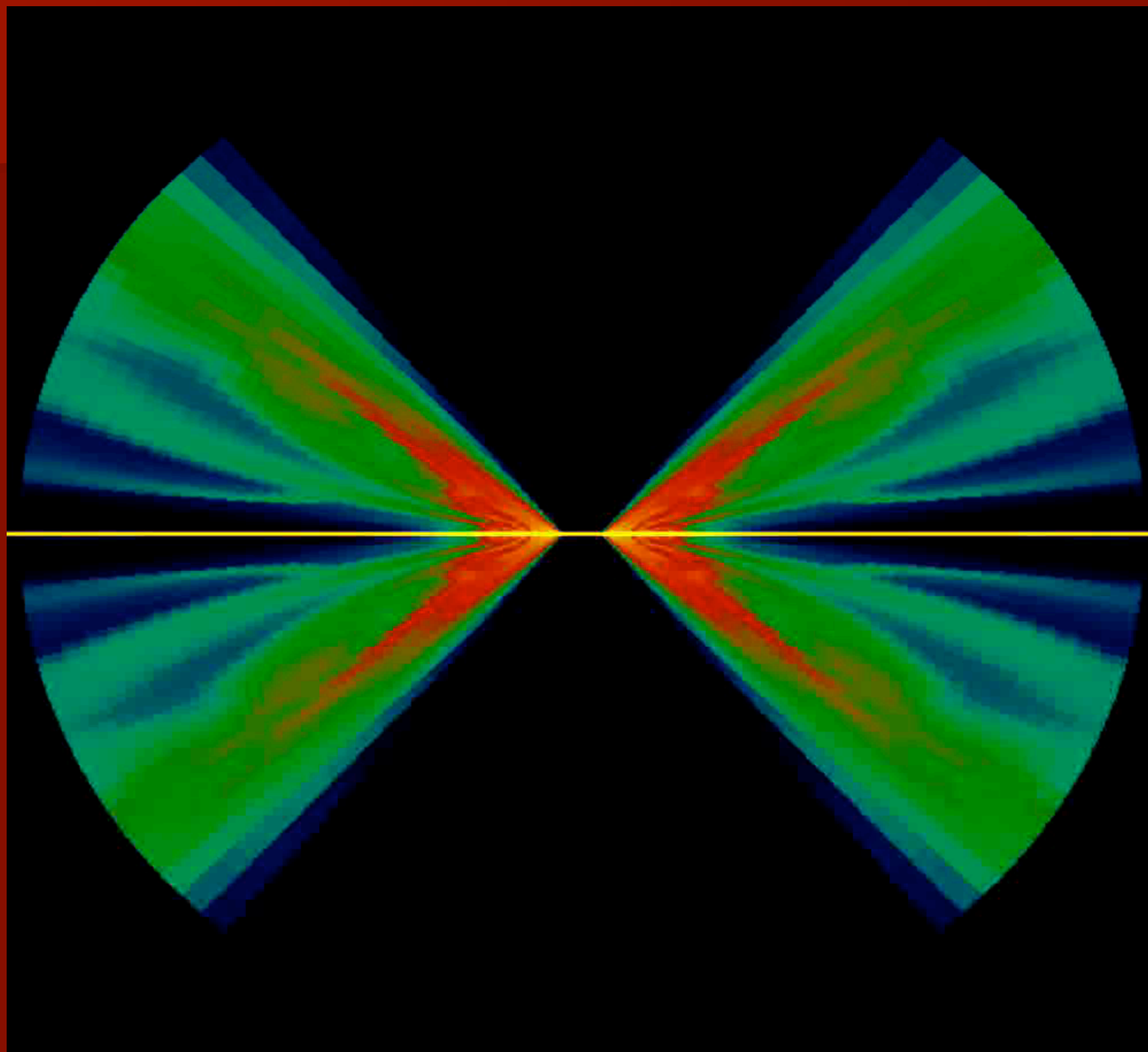
Proga (1999) and Drew & Proga (2000)

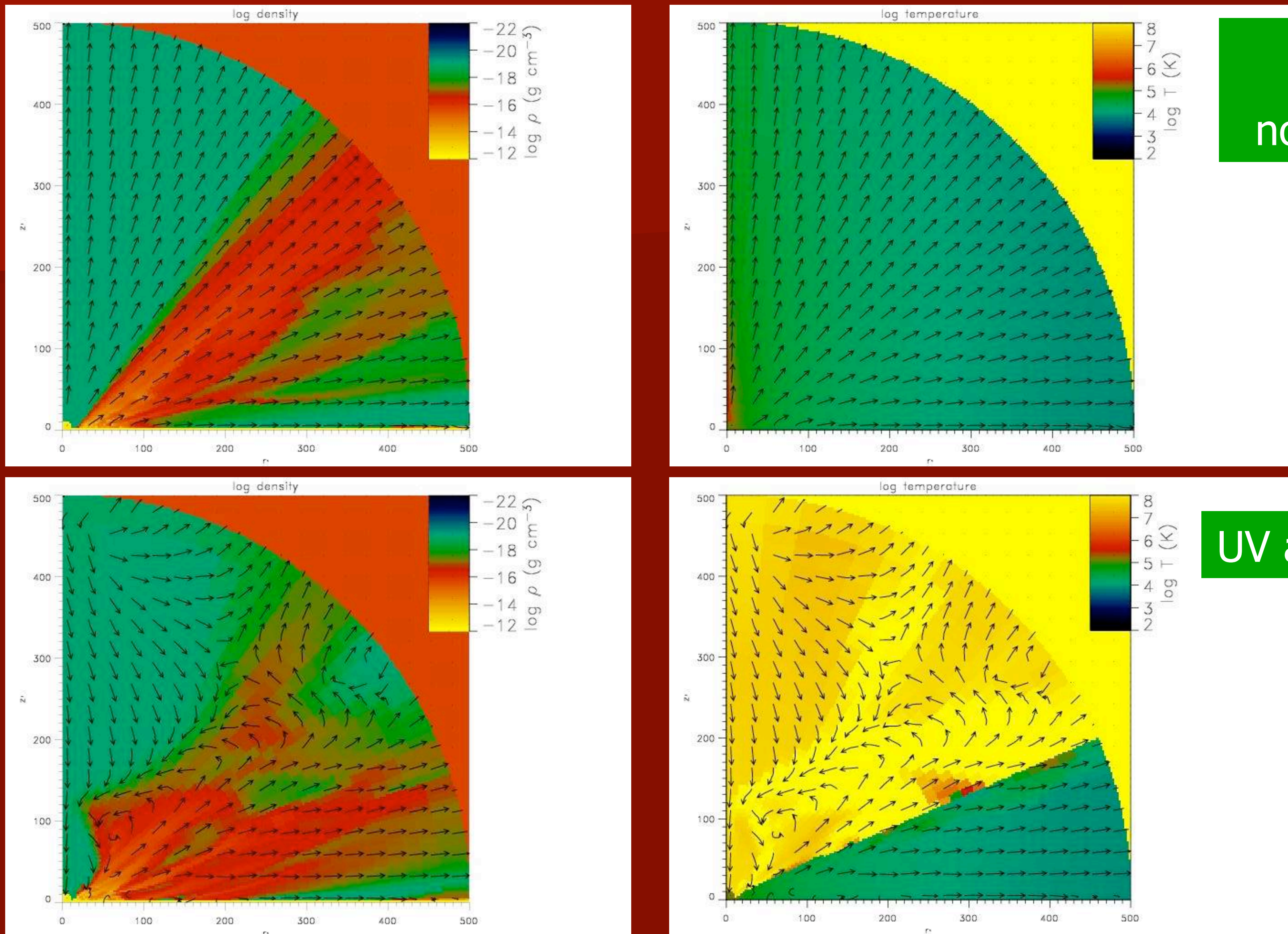
$$M_{\max} = 4400, \quad k = 0.2, \quad \alpha = 0.6$$

CASE TWO: X-rays & UV

$M_{BH} = 10^8 Msun$

$\Gamma = 0.5$





UV and no X-rays

UV and X-rays

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

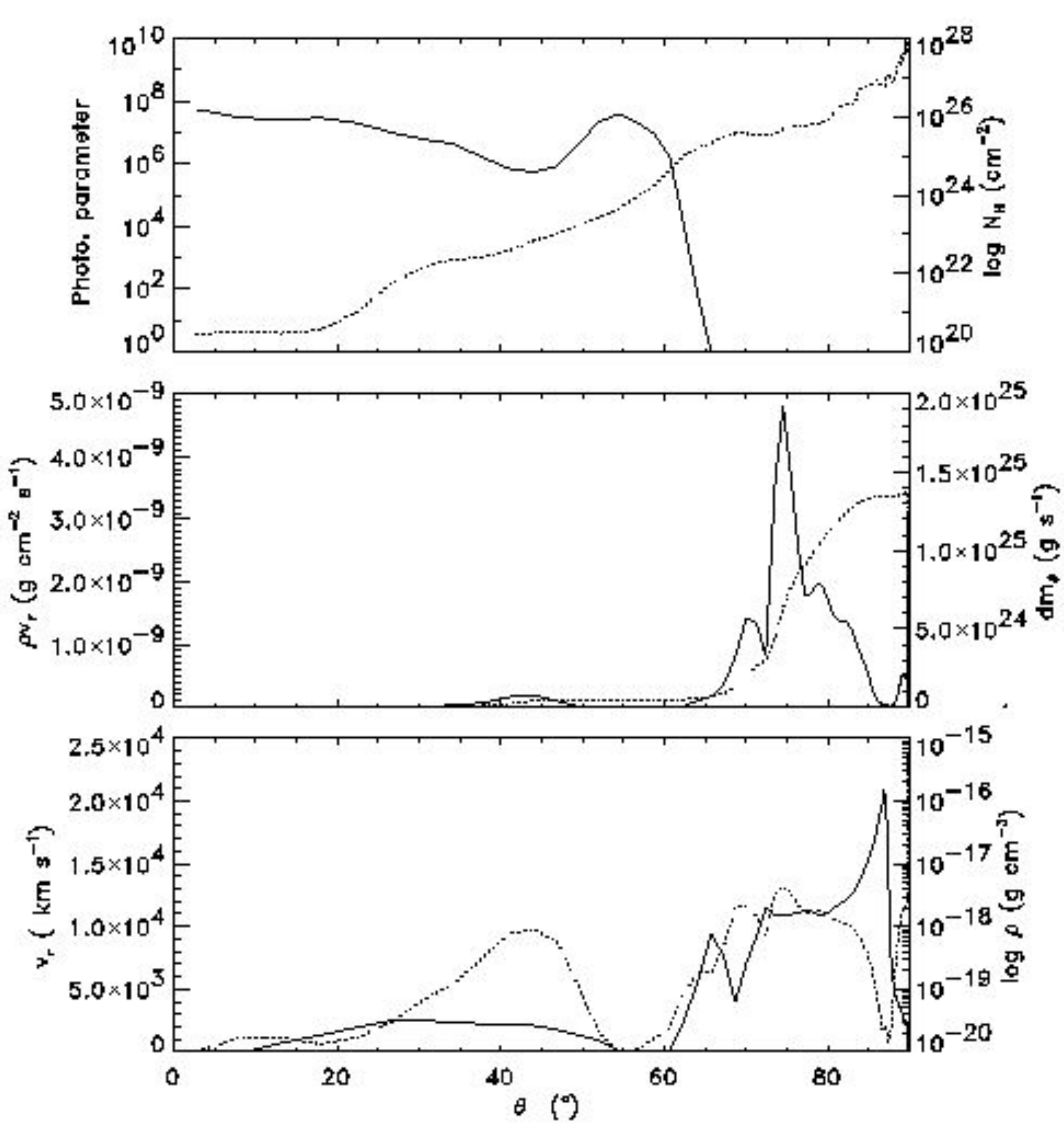
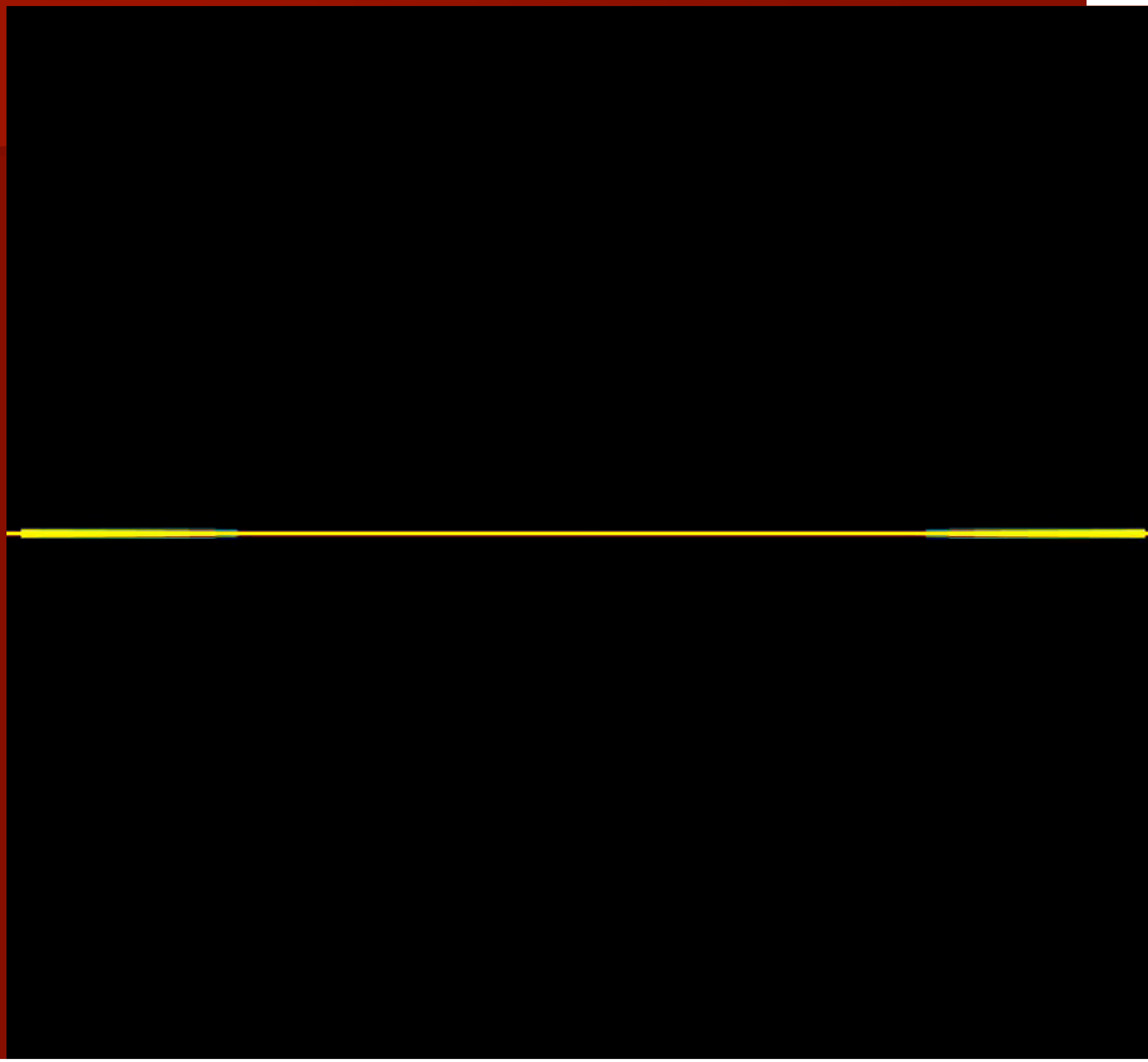


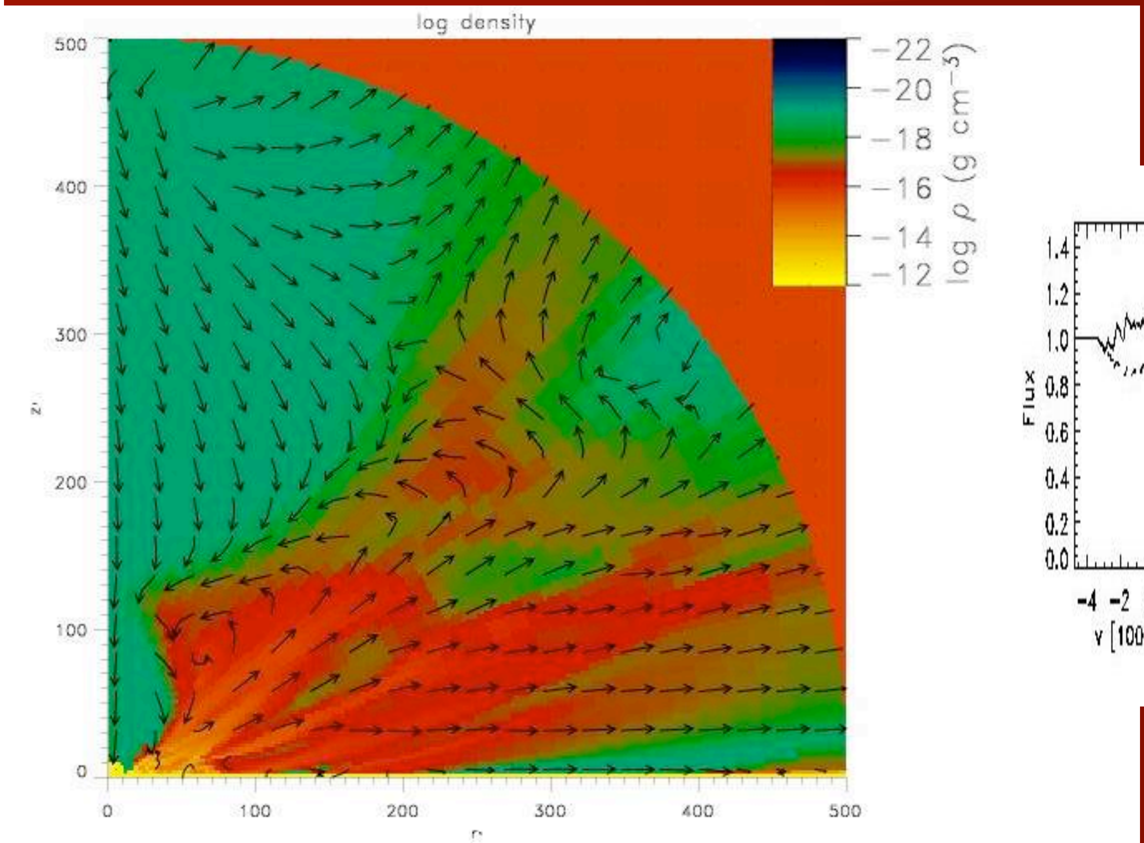
Photo. parameter
log N_H (cm^{-2})
ρv_r ($g\ cm^{-2}\ s^{-1}$)
dm_a ($g\ s^{-1}$)
v_r ($km\ s^{-1}$)
log ρ ($g\ cm^{-3}$)
θ (°)

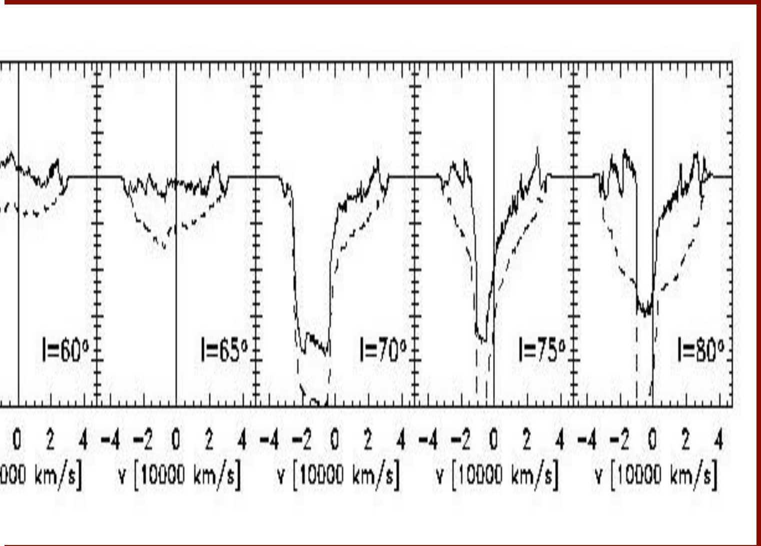
The wind solution is sensitive to the BH mass and accretion rate.

$M_{BH} = 10^6 Msun$

$\Gamma = 0.9$




log density
log ρ (g cm⁻³)
-22
-20
-18
-16
-14
-12
z'
r'
0
100
200
300
400
500


Flux
I=60°
I=65°
I=70°
I=75°
I=80°
v [10000 km/s]

Summary

ASSUMED

- What is the origin of the outflows?

- What force accelerates the outflows?
- How do the outflows avoid full ionization?
- What is the geometry and structure of the outflows (e.g., wind or moving clouds)?
- What is the mass loss rate, momentum, and energy of the outflows?

...

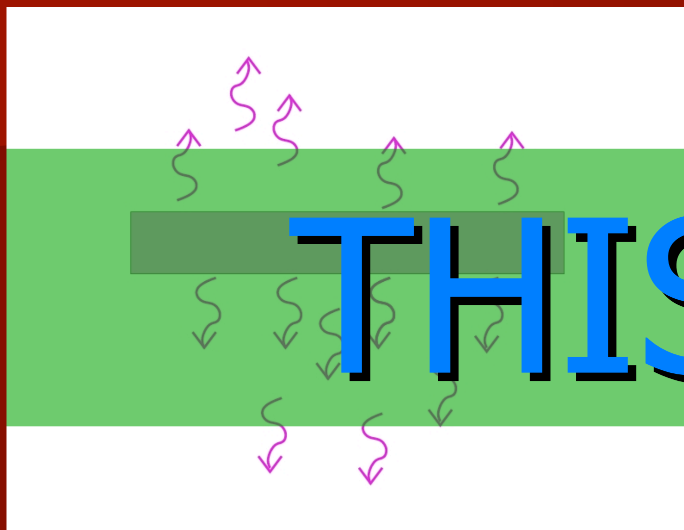
Conclusions

- LD winds can withstand external X-rays.
- LD disk winds can be powerful but only for high BH masses and accretion rates.
- They change the radiation of the source

  (i.e., the spectrum and total flux depend on orientation).
- LD disk wind models can explain observed UV line absorption (and likely capable of reproducing observed absorption lines).
- The models predict a warm absorbing outflow but its velocity appears too high to account for warm absorbers observed in AGN.

Quenching Disk Corona

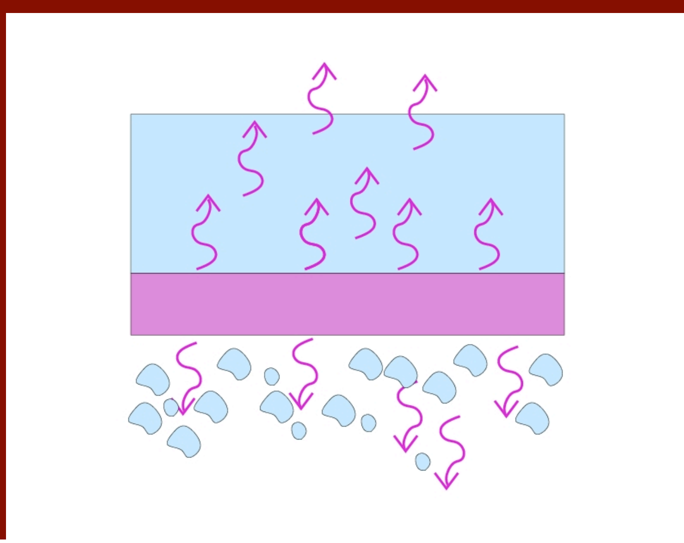
Disk



Disk and inflow/outflow

THIS TALK

Disk and corona



Disk and ????