Dynamics of Winds from Luminous Accretion Disks

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OUTLINE

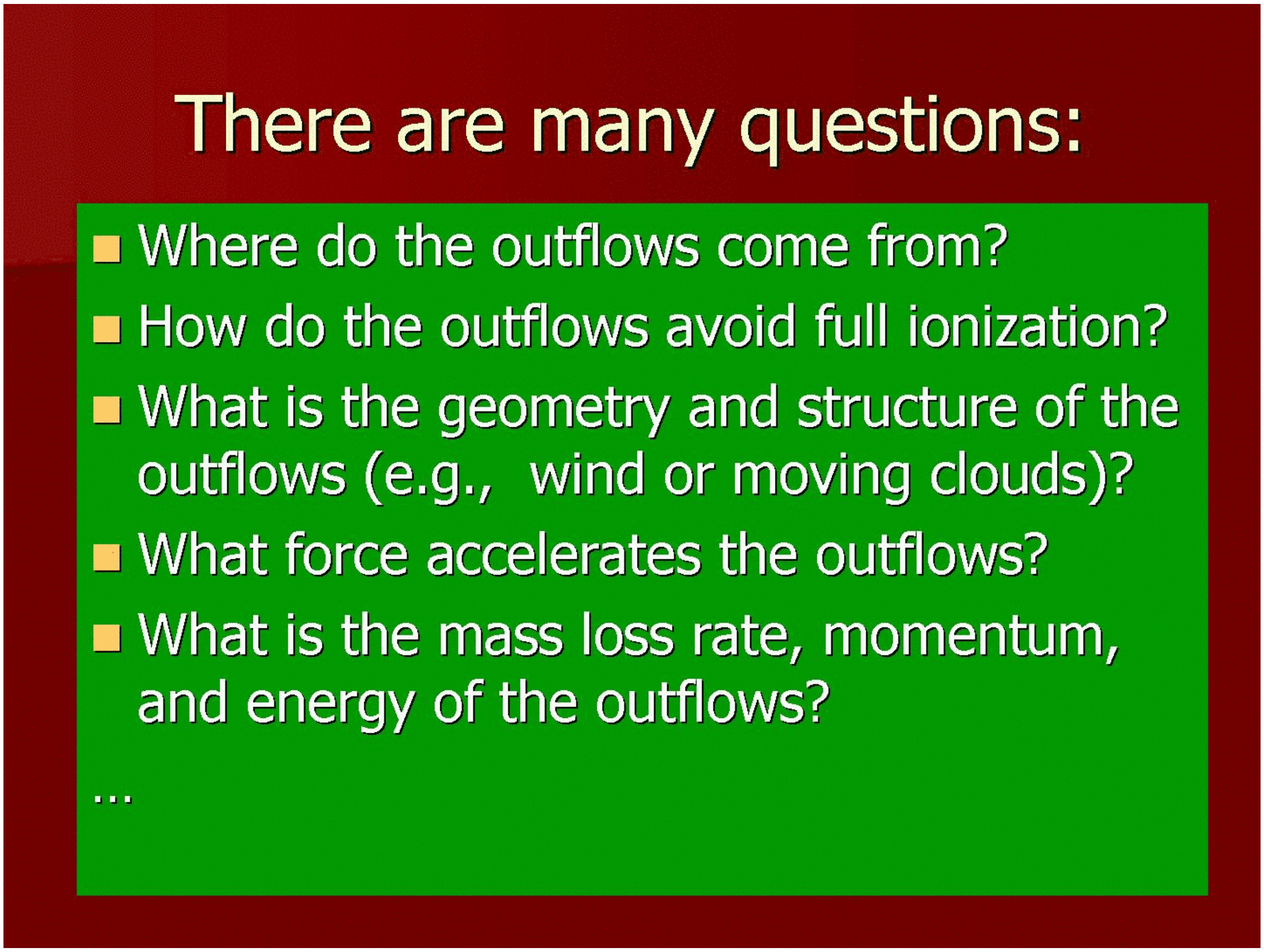
- Introduction
- Time-Dependent Simulations
- Conclusions
- Future Work

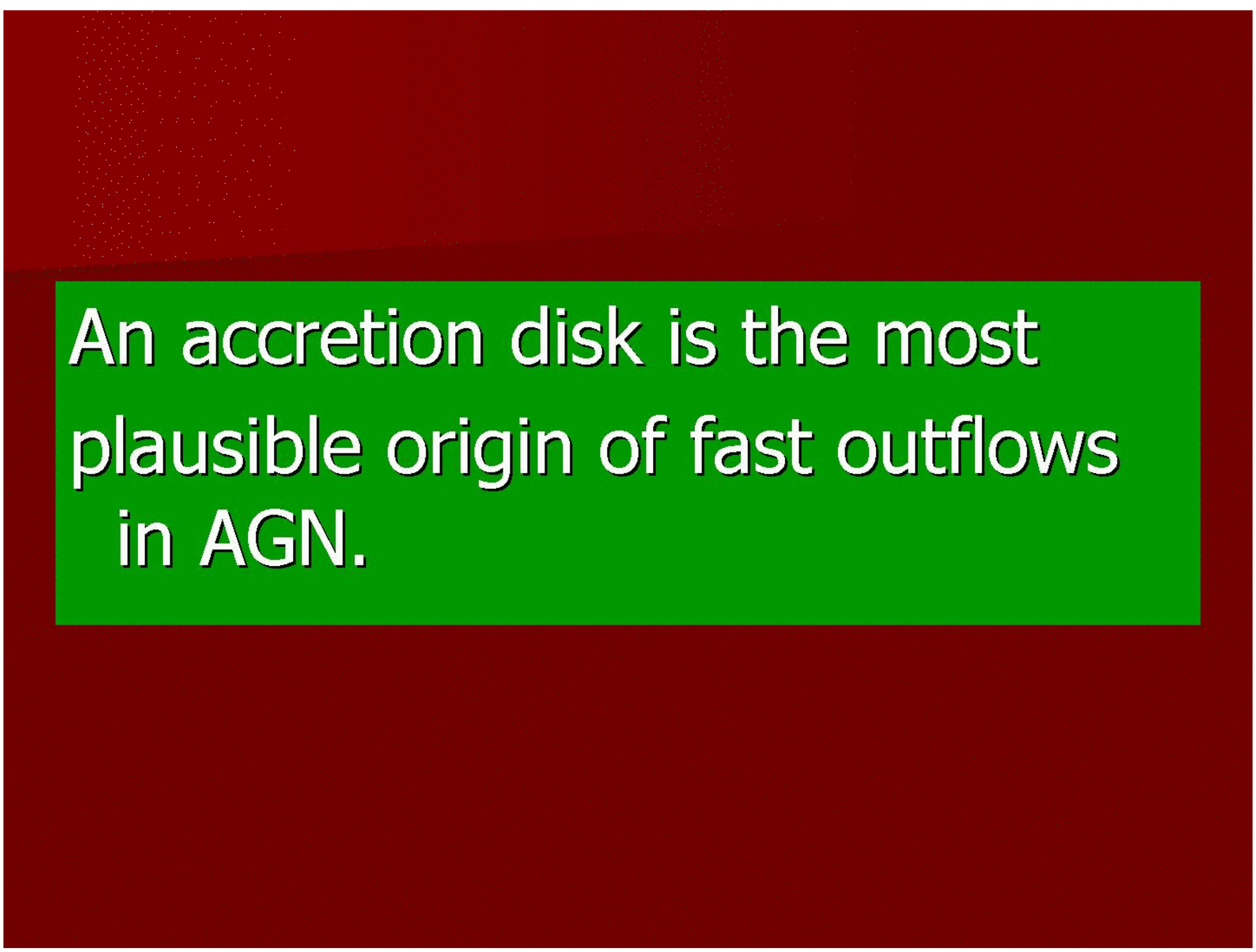
AGN are powered by gas accretion onto a supermassive black hole.

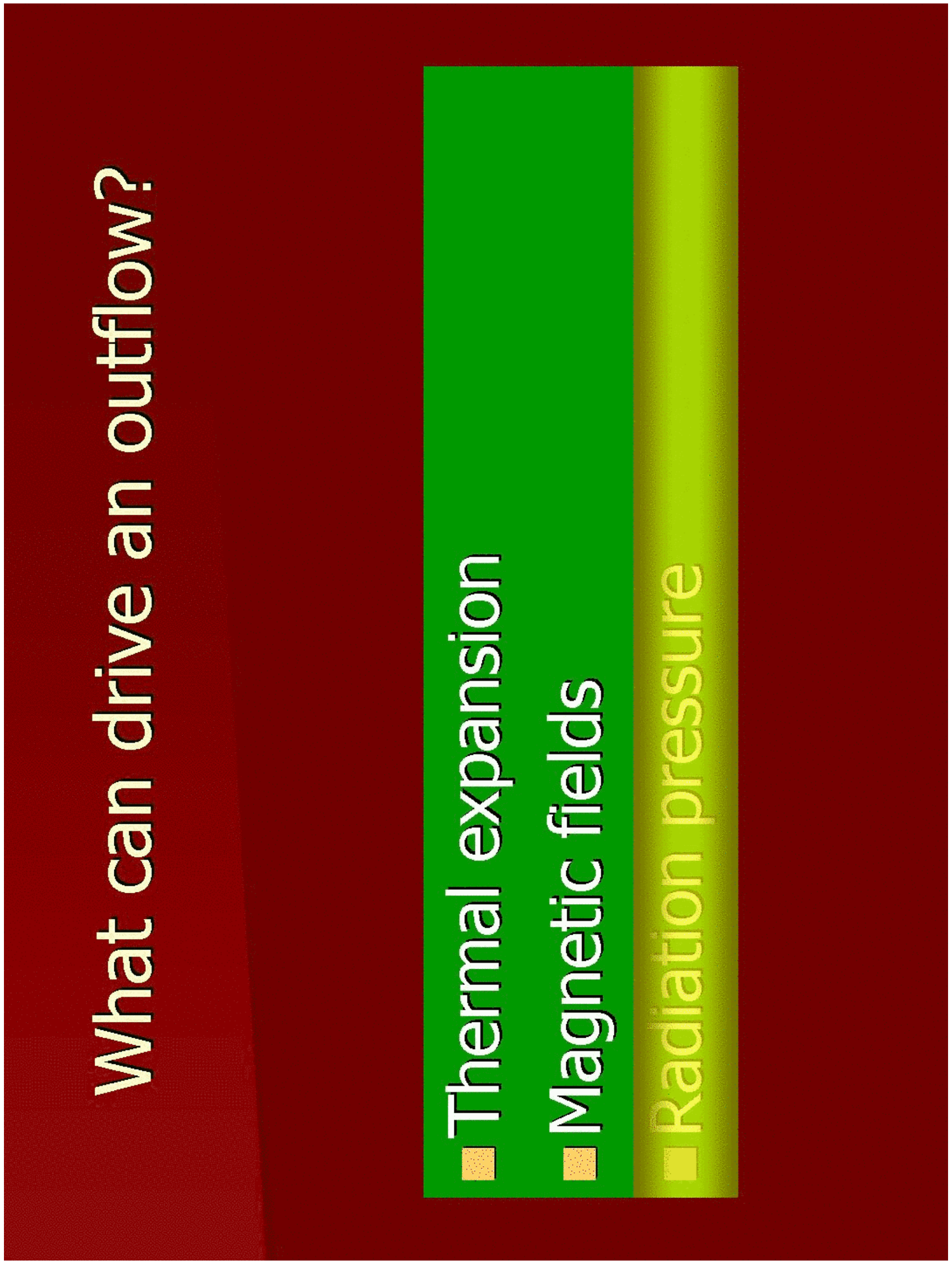
$$L = \eta c^2 \dot{M}_a$$

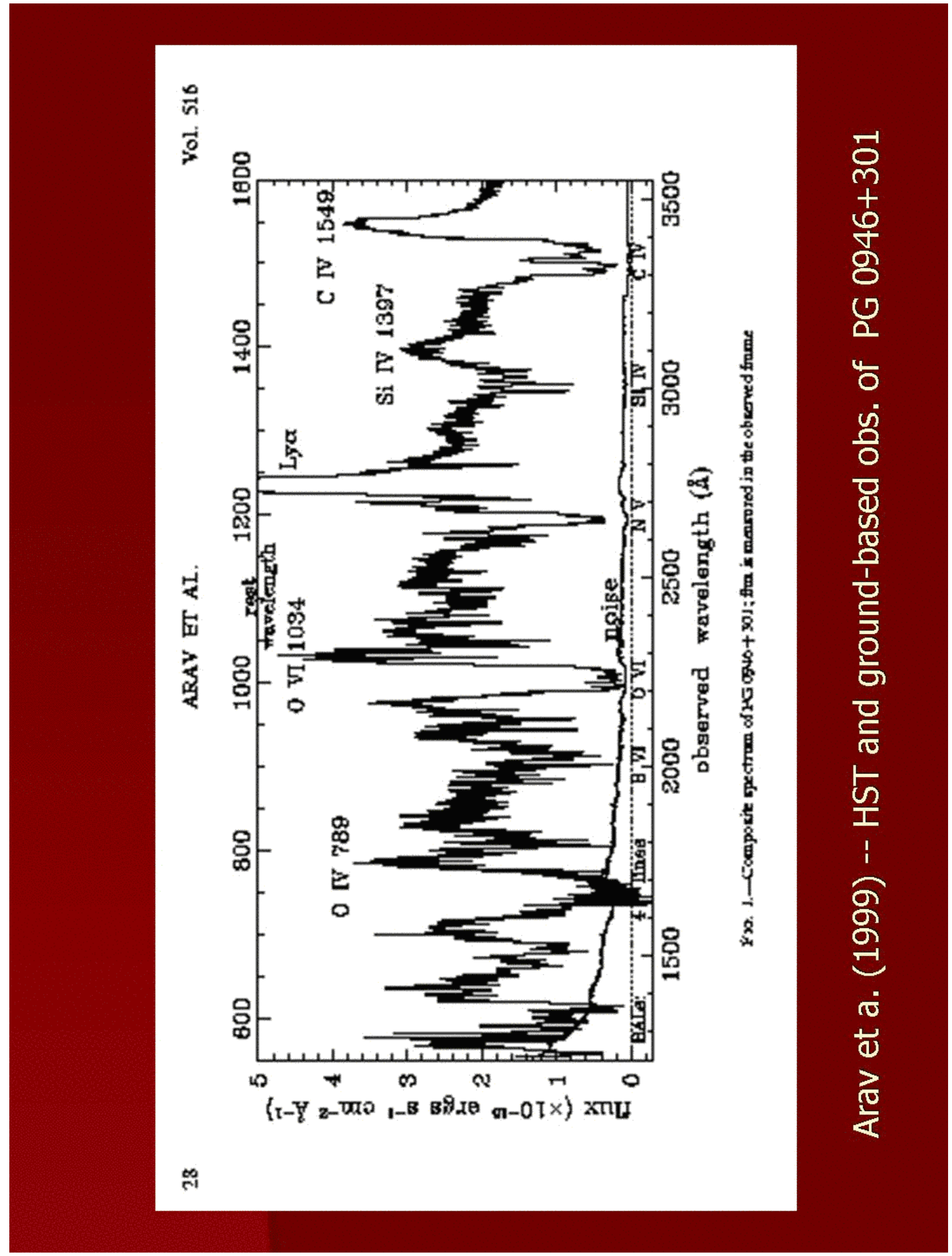
Outflows: another aspect of activity

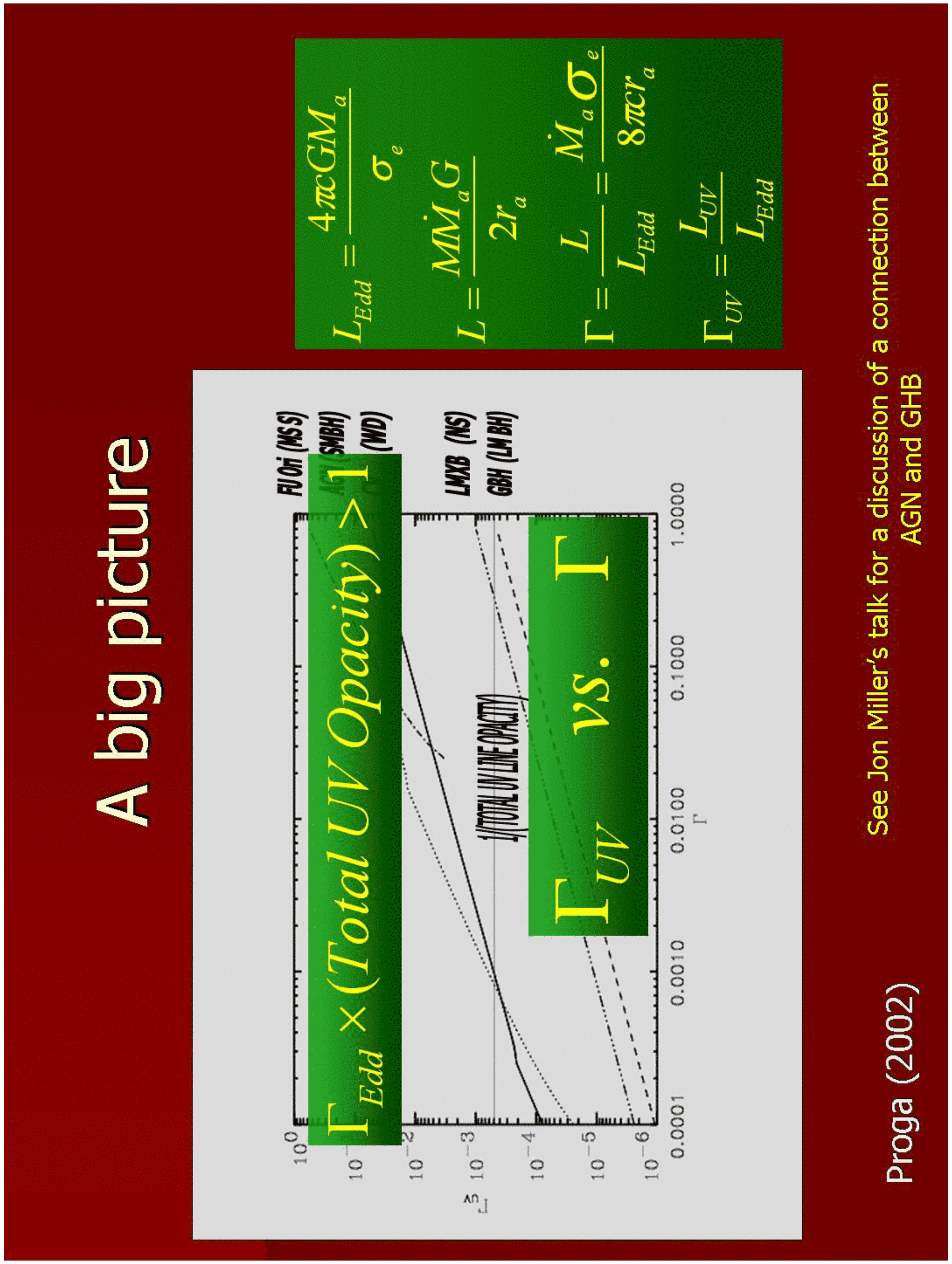
- Mass outflows are very common
- Outflows are important because they can change
  - the rate of accretion onto a black hole
  - the radiation properties
  - environment of the AGN, its host galaxy, and IGM
  - ...

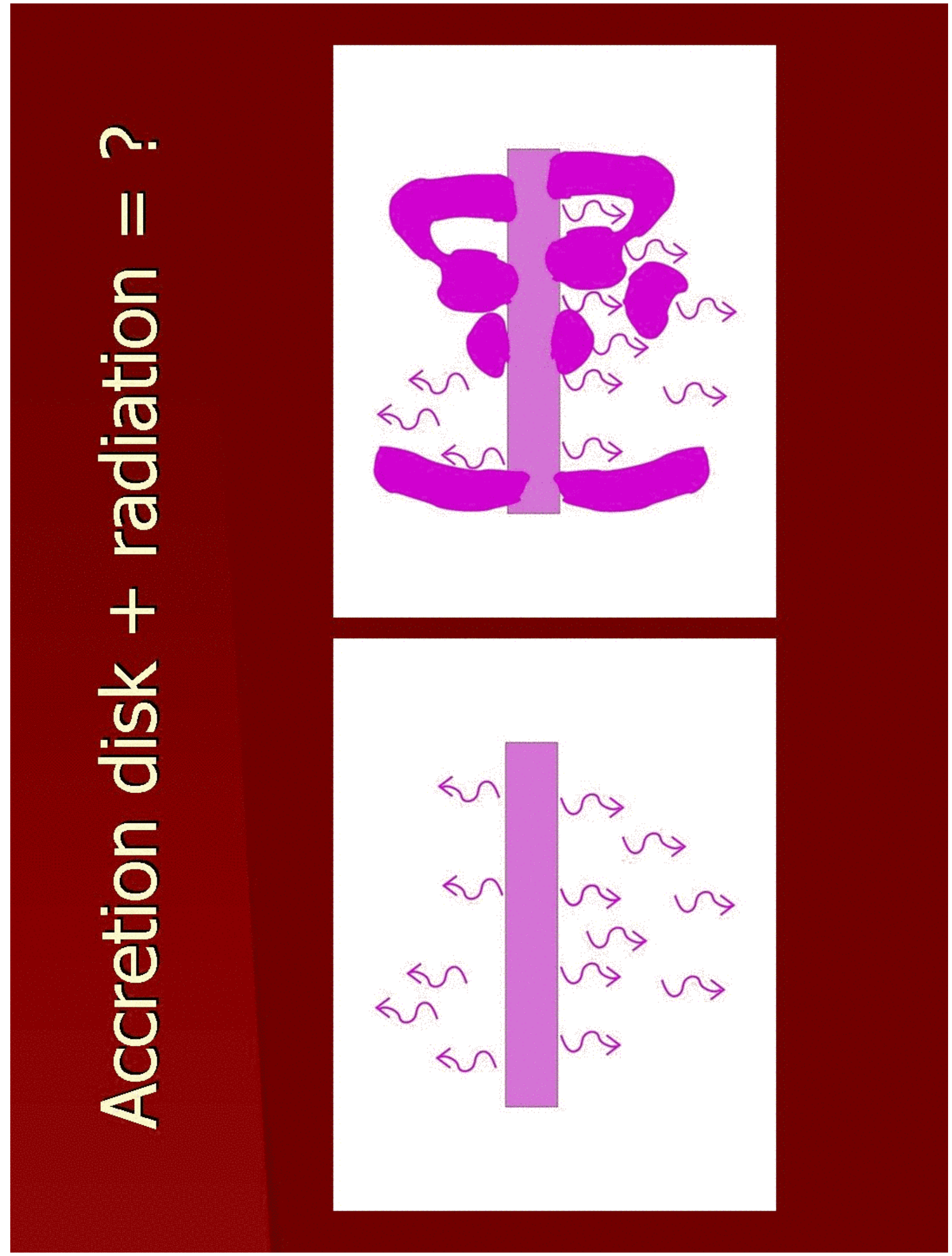

There are many questions:
Where do the outflows come from?
How do the outflows avoid full ionization?
What is the geometry and structure of the outflows (e.g., wind or moving clouds)?
What force accelerates the outflows?
What is the mass loss rate, momentum, and energy of the outflows?
…

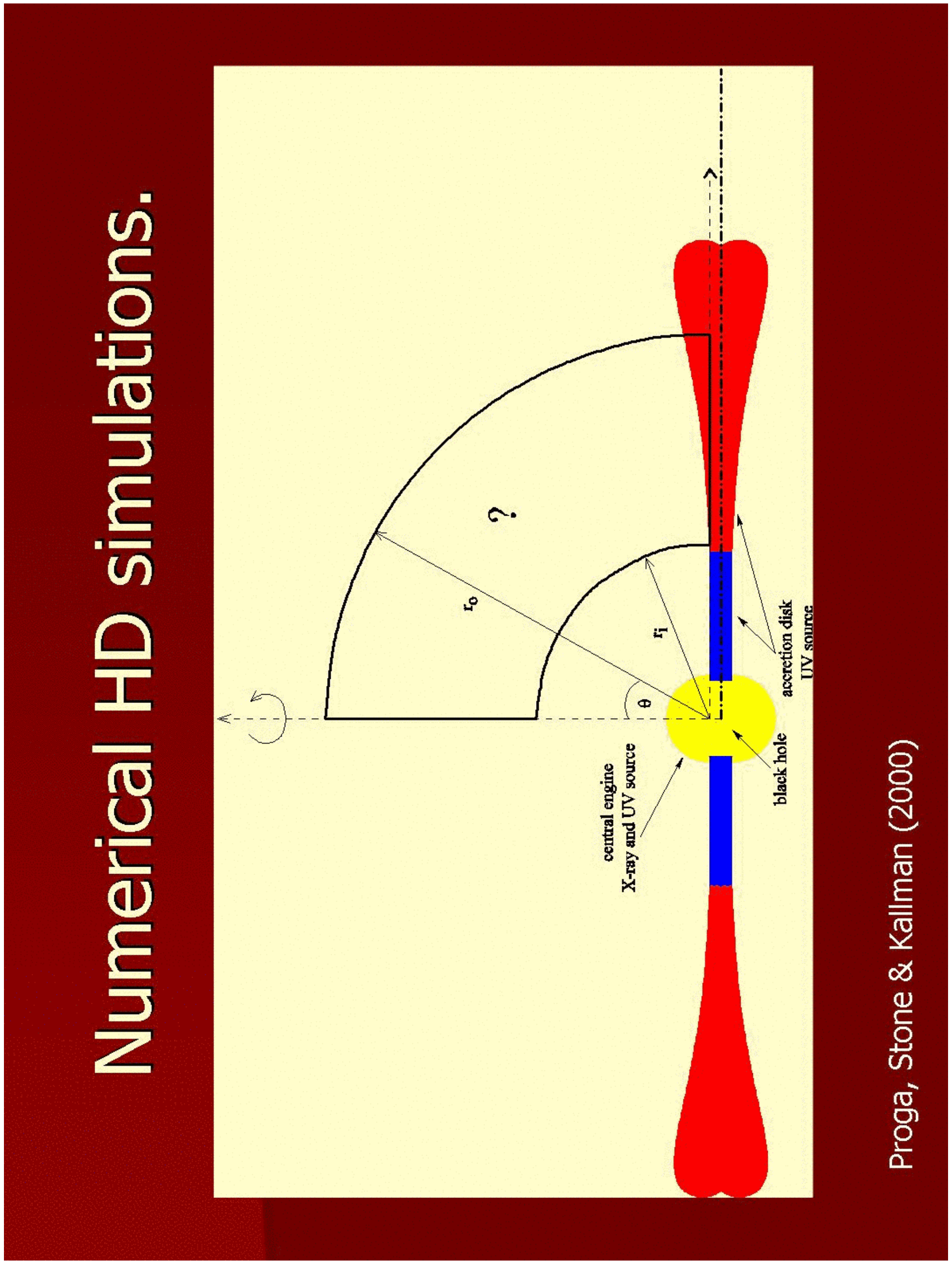

An accretion disk is the most plausible origin of fast outflows in AGN.

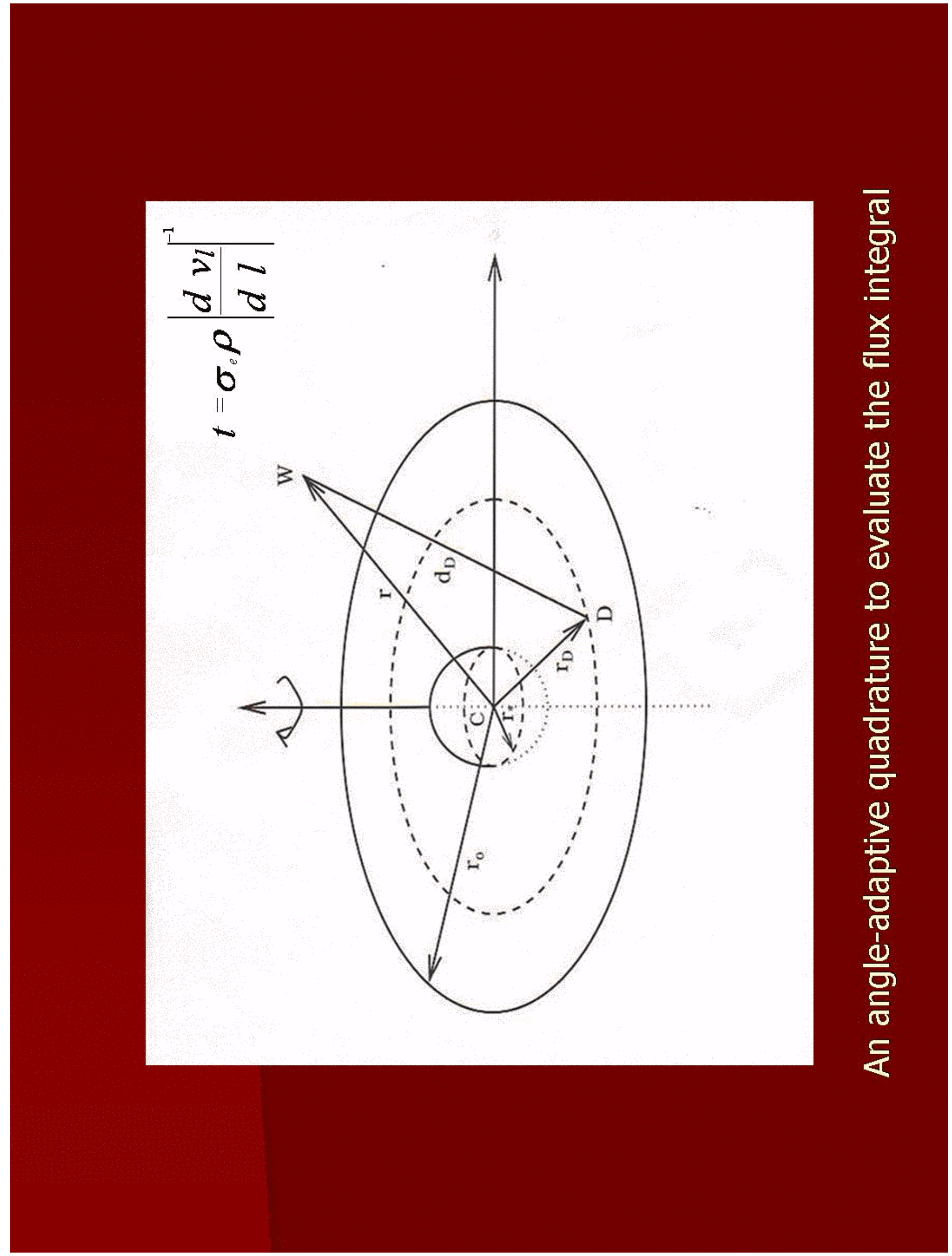

What can drive an outflow?
Thermal expansion
Magnetic fields
Radiation pressure

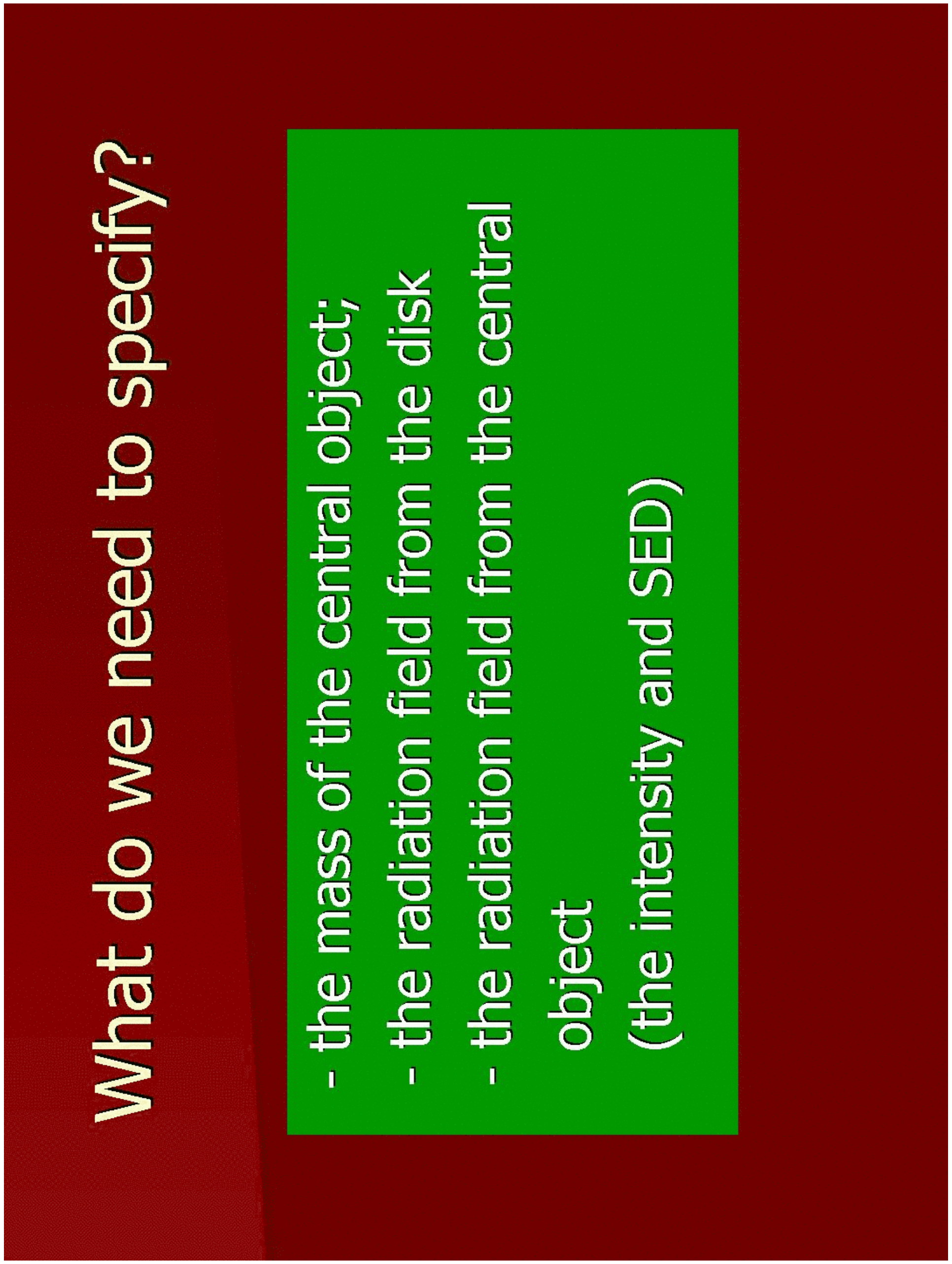

23
ARAV ET AL.
Vol. 516
O IV 789
O VI 1034
rest wavelength
Lyα
Si IV 1397
C IV 1549
noise
BALs:
lines
O VI
N V
Si IV
C IV
observed wavelength (Å)
Flux (×10^-15 ergs s^-1 cm^-2 Å^-1)
FIG. 1.—Composite spectrum of PG 0946+301; flux is measured in the observed frame
Arav et a. (1999) -- HST and ground-based obs. of PG 0946+301

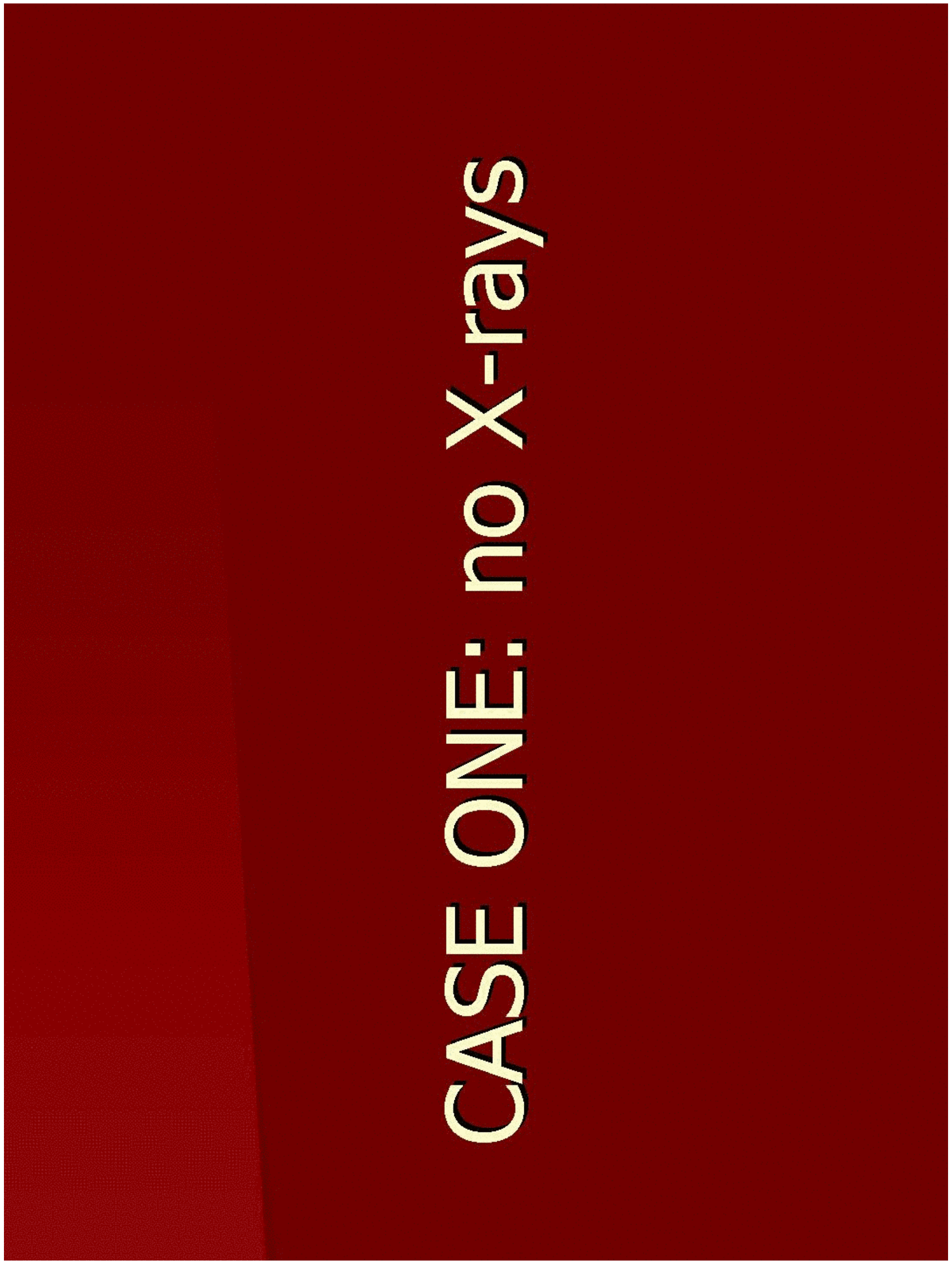

A big picture
$L_{Edd} = \frac{4\pi c G M_a}{\sigma_e}$
$L = \frac{\dot{M} M_a G}{2 r_a}$
$\Gamma = \frac{L}{L_{Edd}} = \frac{\dot{M}_a \sigma_e}{8 \pi c r_a}$
$\Gamma_{UV} = \frac{L_{UV}}{L_{Edd}}$
FU Ori (MS S)
(WD)
LMXB (NS)
GBH (LM BH)
1/(TOTAL UV LINE OPACITY)
$\Gamma_{Edd} \times (Total\ UV\ Opacity) > 1$
Γ_{UV} vs. Γ
See Jon Miller's talk for a discussion of a connection between AGN and GHB
Proga (2002)

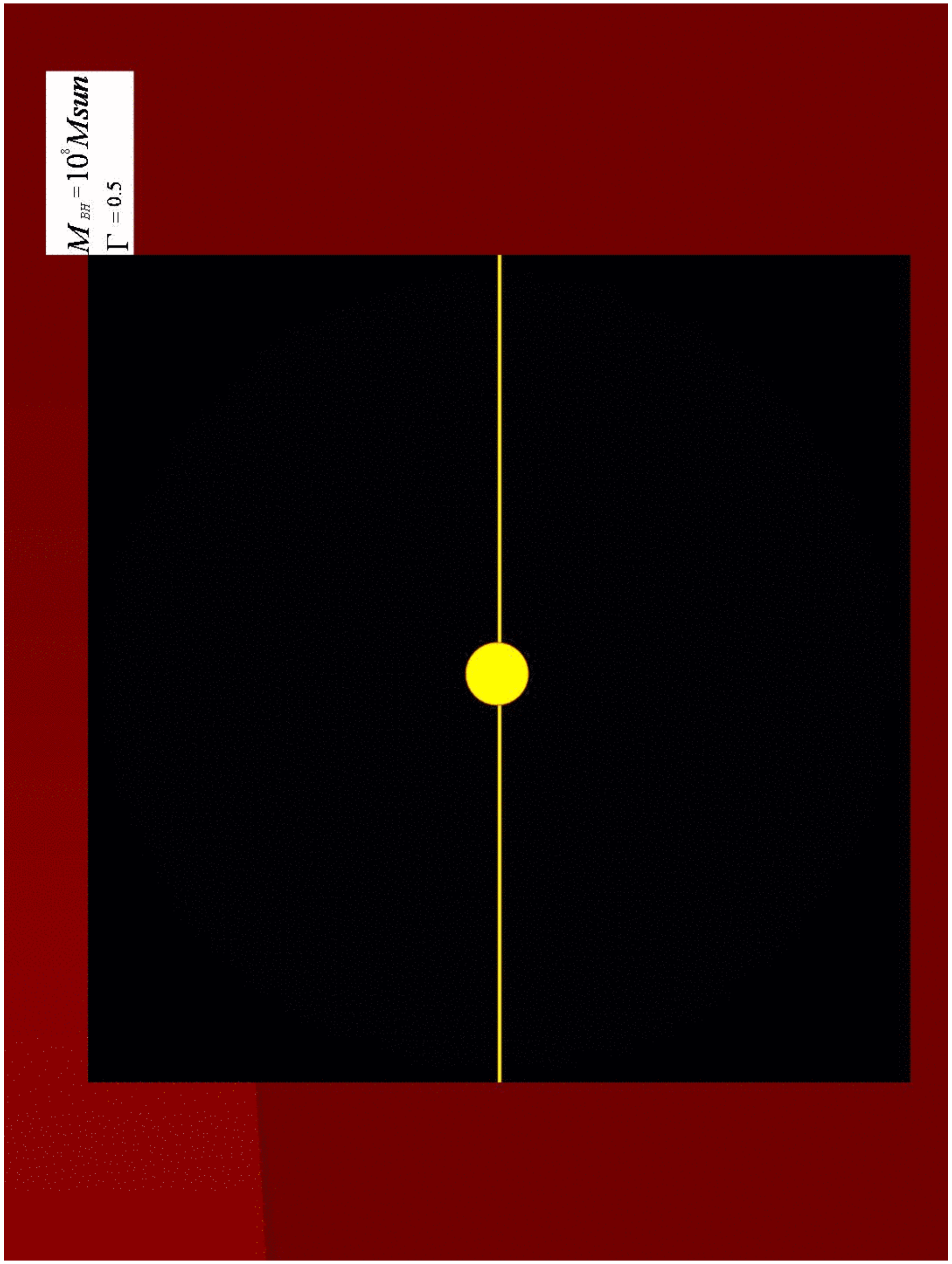

Accretion disk + radiation = ?

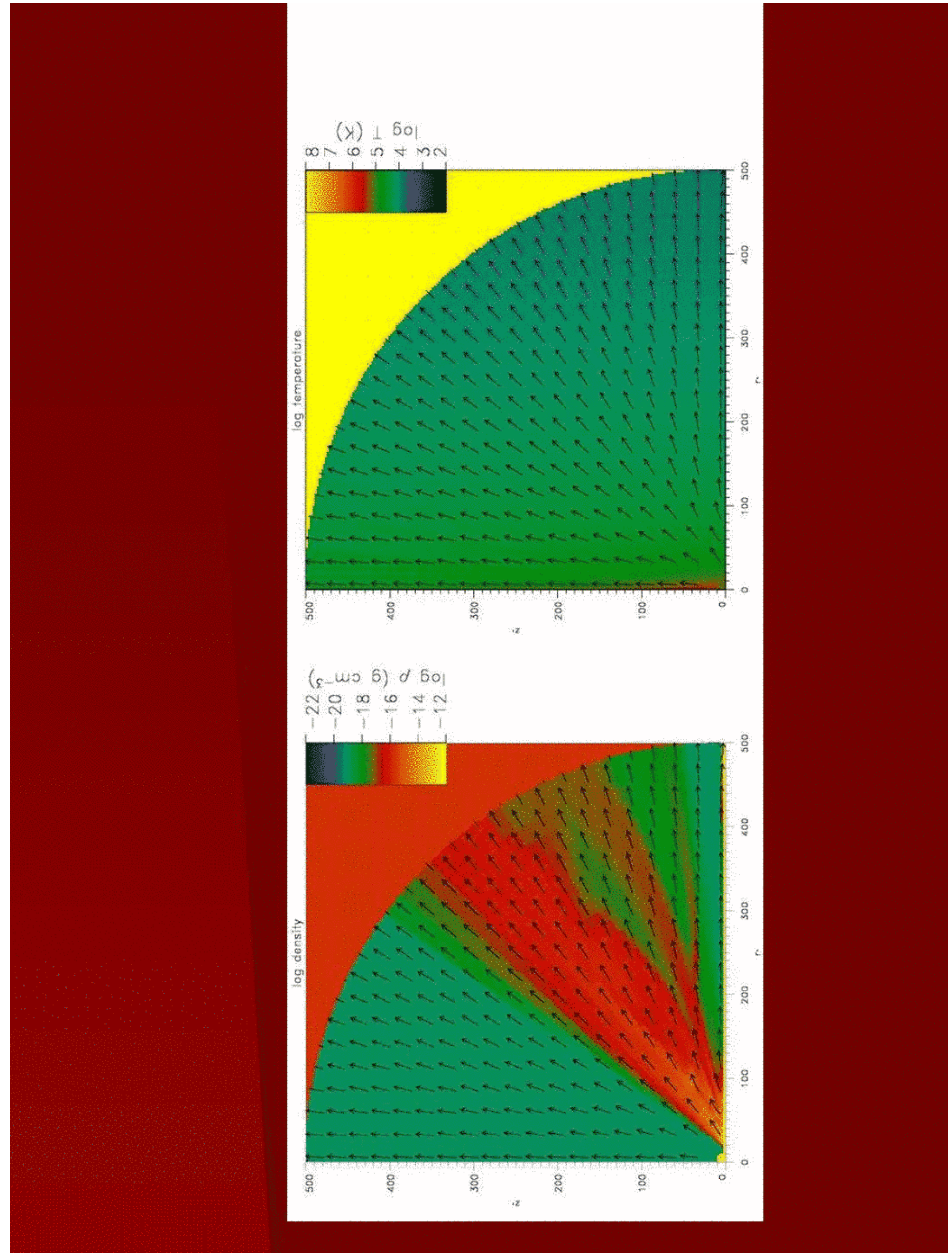

Numerical HD simulations.
?
r_o
r_i
θ
accretion disk
UV source
black hole
central engine
X-ray and UV source
Proga, Stone & Kallman (2000)

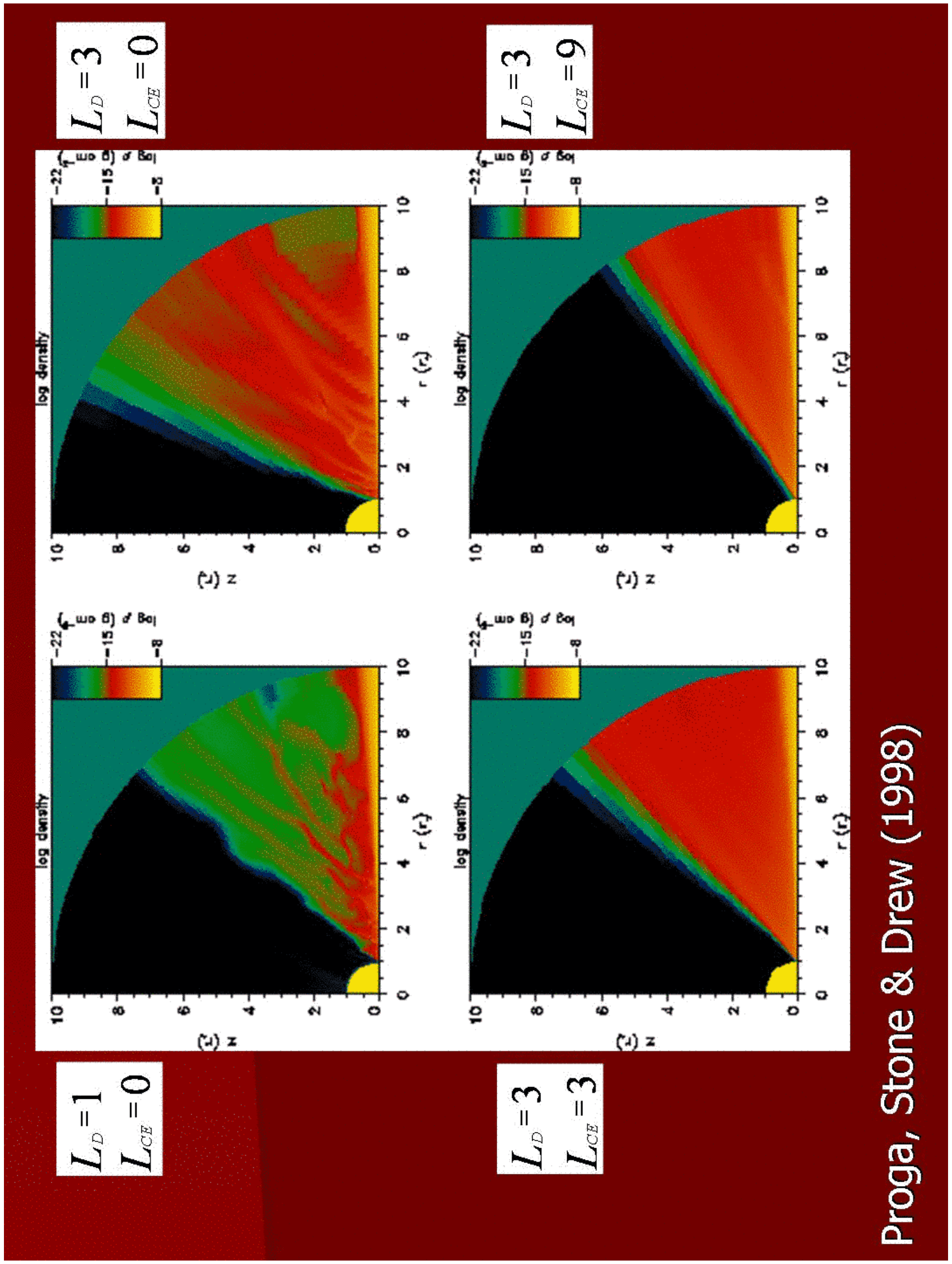

$t = \sigma_e \rho \left| \frac{d\, v_l}{d\, l} \right|^{-1}$
W
d_D
r
D
r_D
C
r_o
An angle-adaptive quadrature to evaluate the flux integral


What do we need to specify?
- the mass of the central object;
- the radiation field from the disk
- the radiation field from the central object
(the intensity and SED)

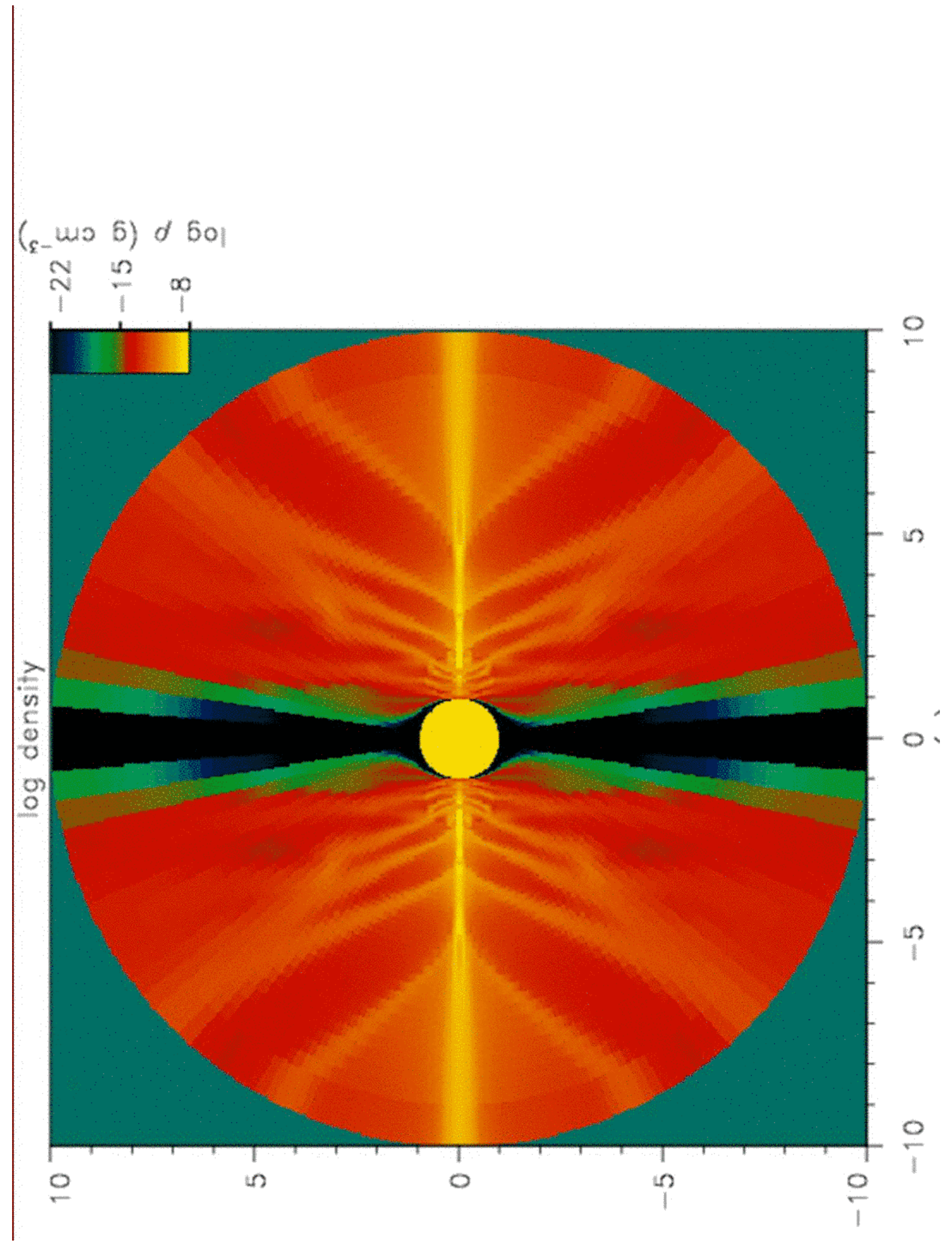

CASE ONE: no X-rays


$M_{BH} = 10^8 Msun$
$\Gamma = 0.5$

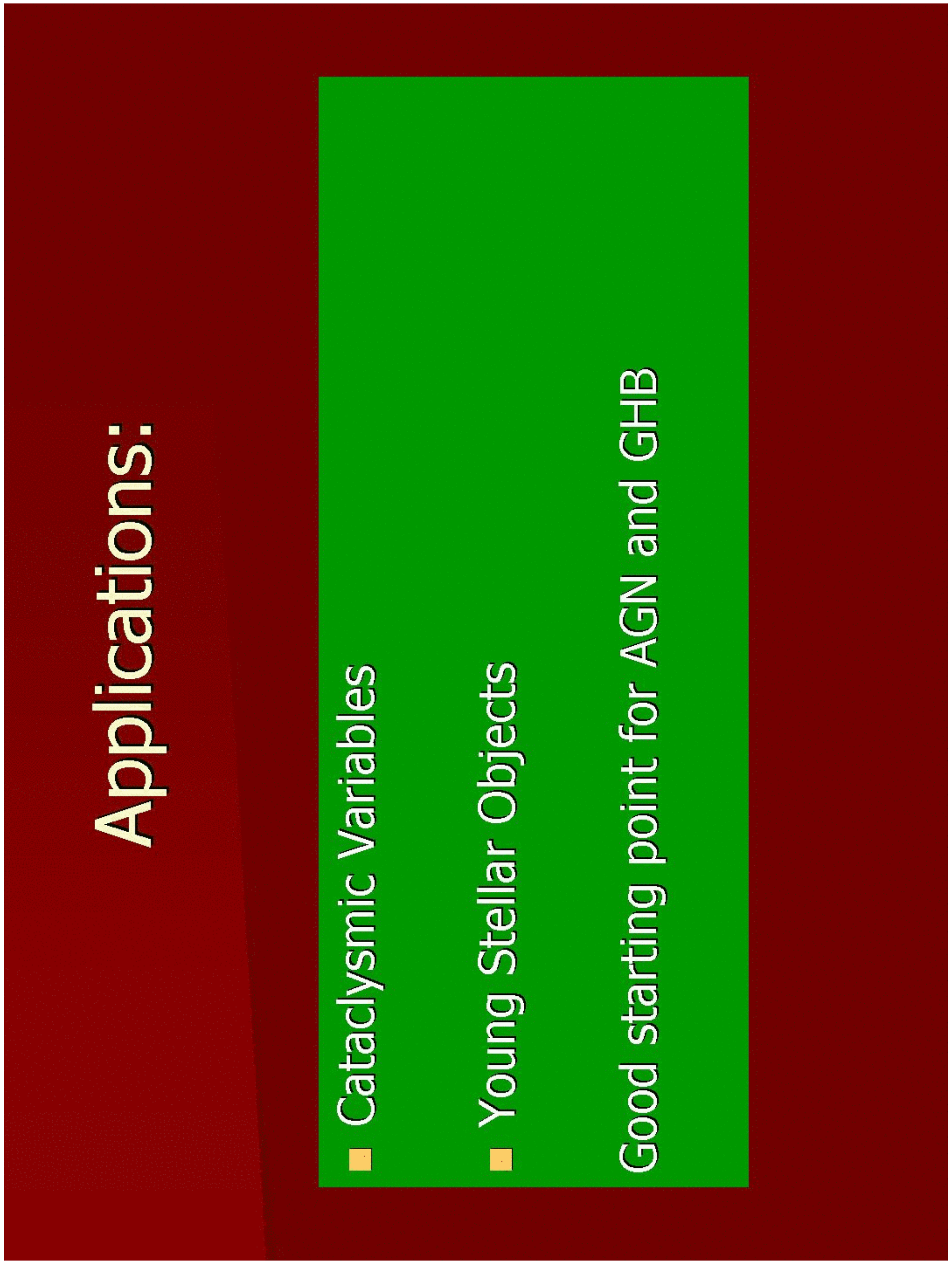

log temperature
log T (K)
log density
log ρ (g cm⁻³)

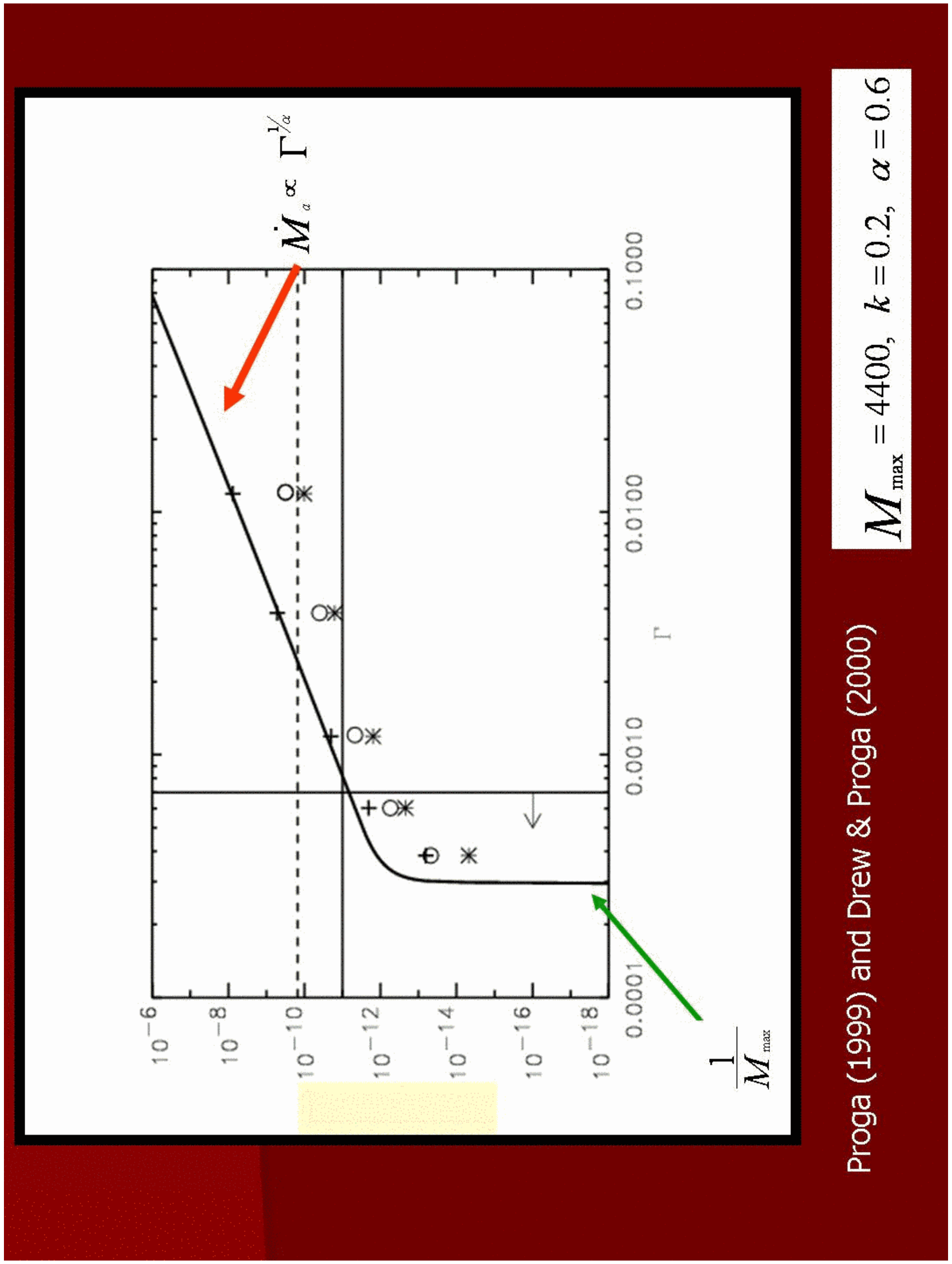


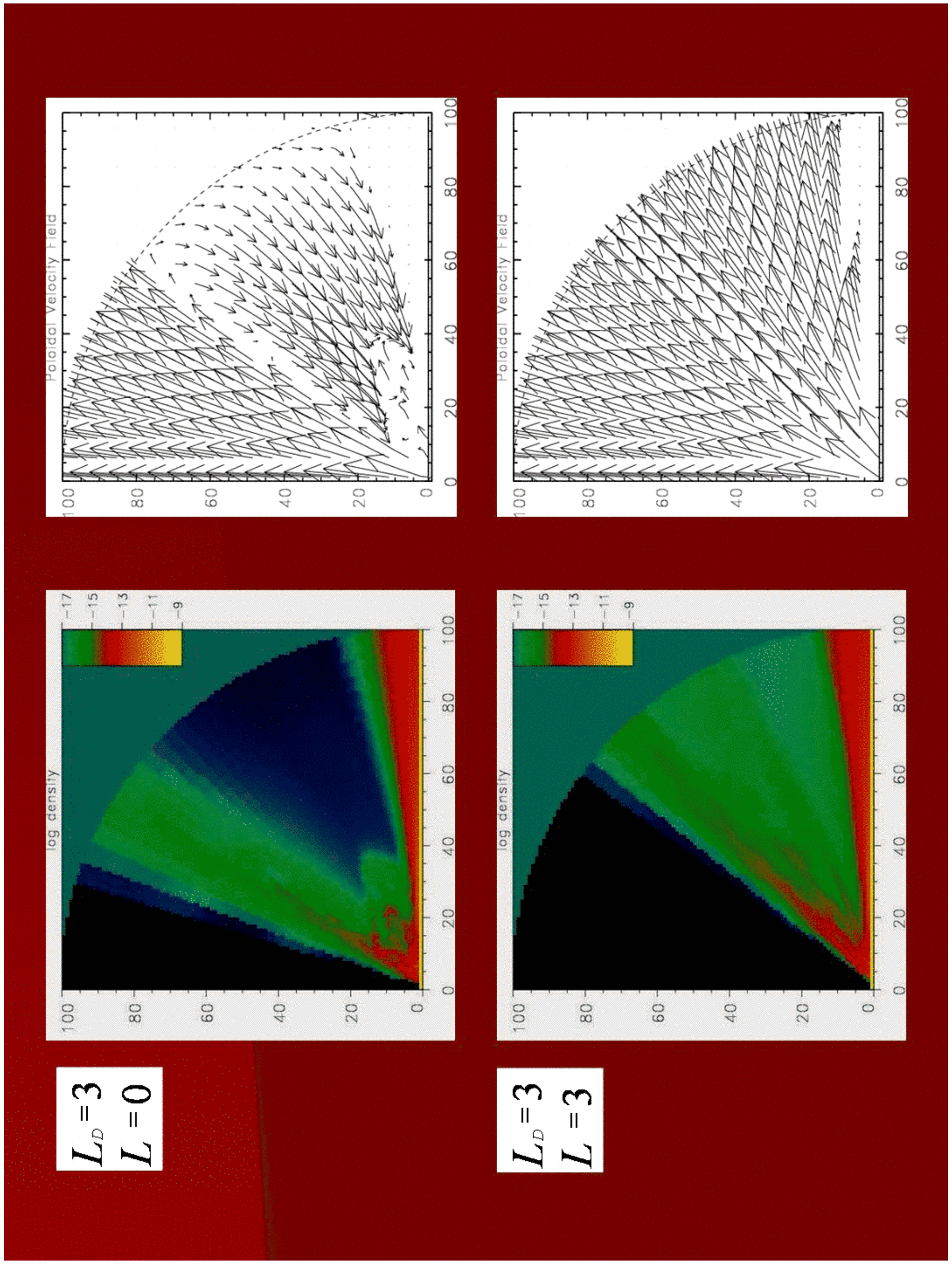
L_D = 3 L_CE = 0
L_D = 3 L_CE = 9
L_D = 1 L_CE = 0
L_D = 3 L_CE = 3
log density
log ρ (g cm⁻³)
z (r*)
r (r*)
Proga, Stone & Drew (1998)

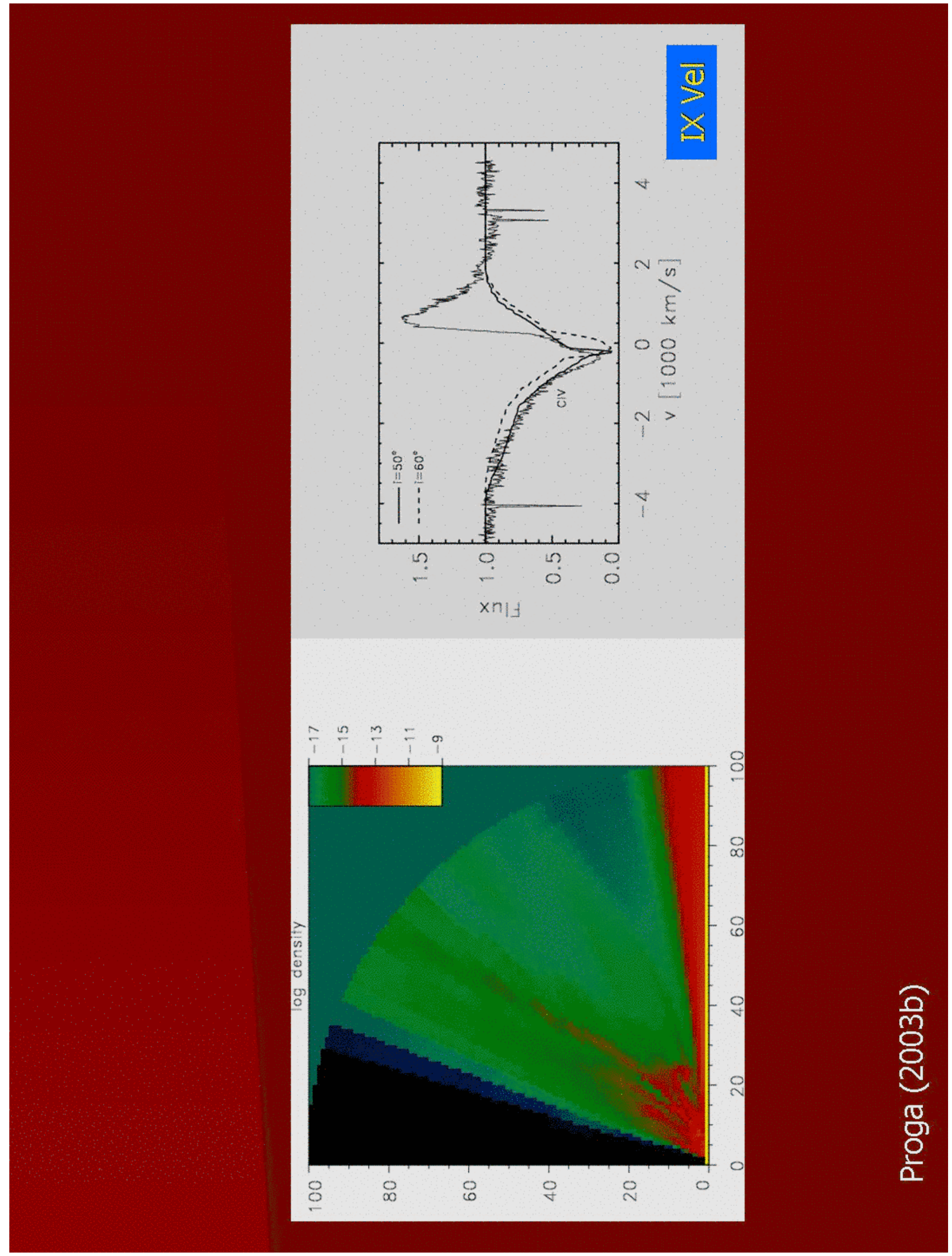


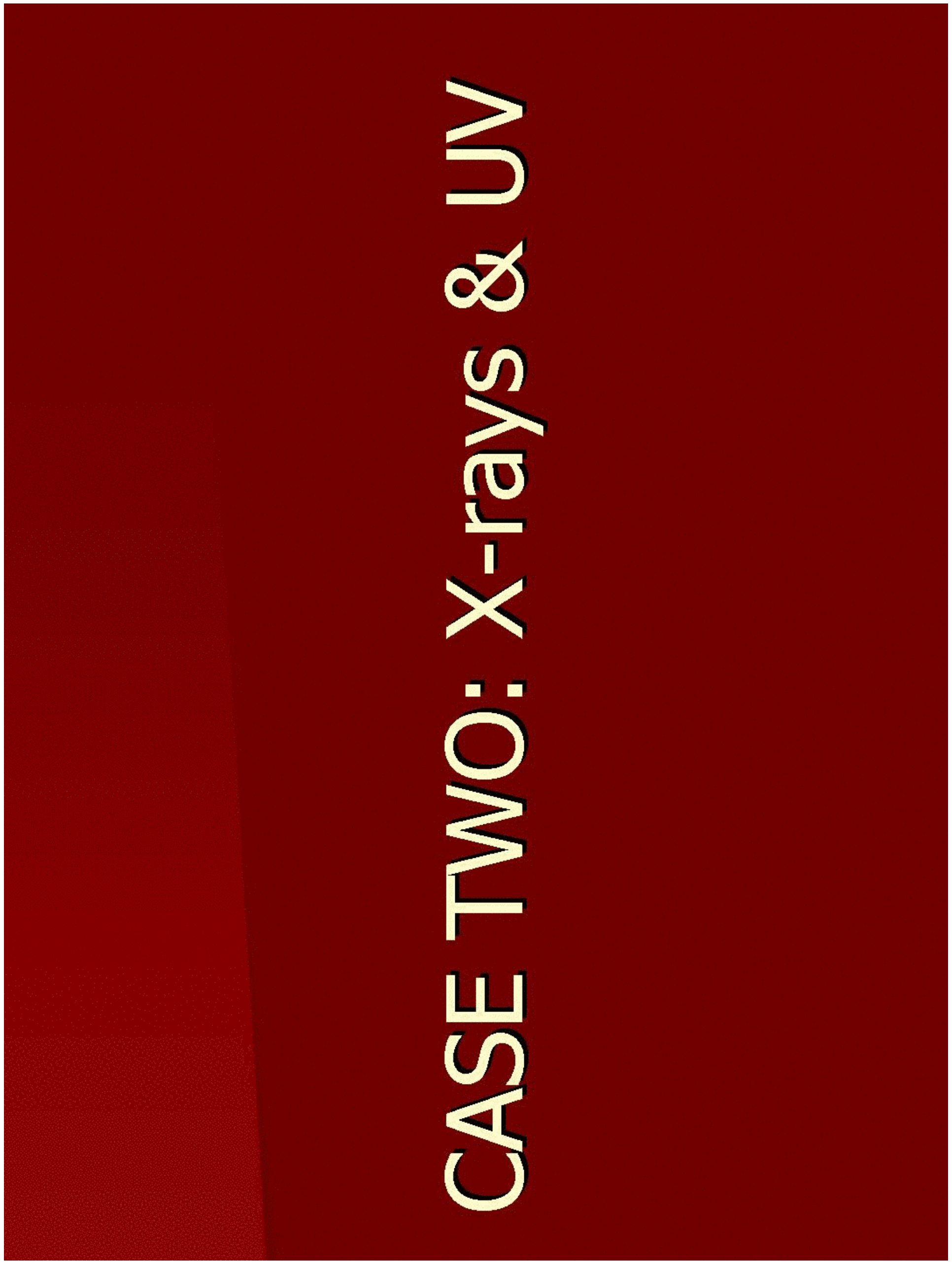
log density
log ρ (g cm⁻³)
−22
−15
−8

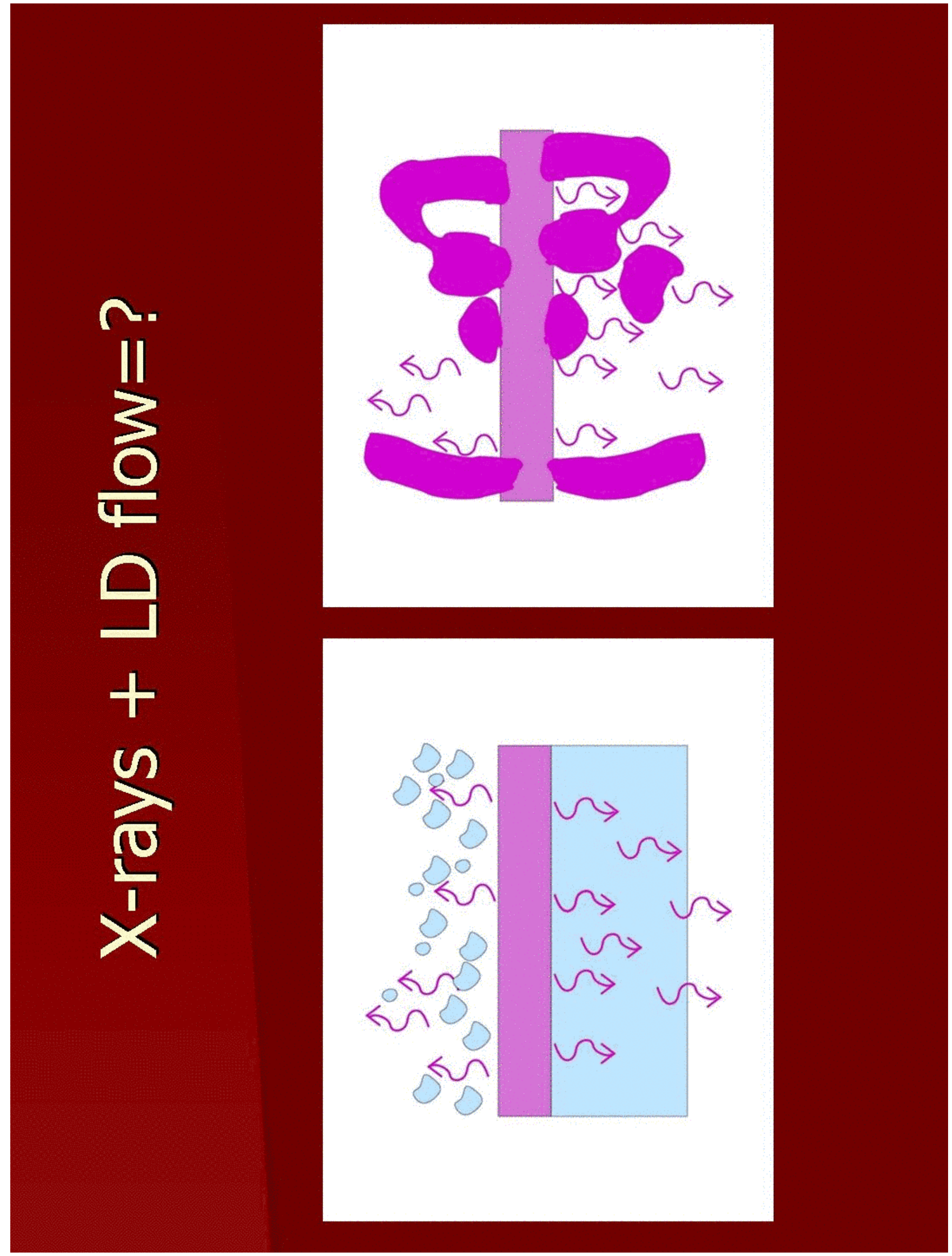

Applications:
Cataclysmic Variables
Young Stellar Objects
Good starting point for AGN and GHB

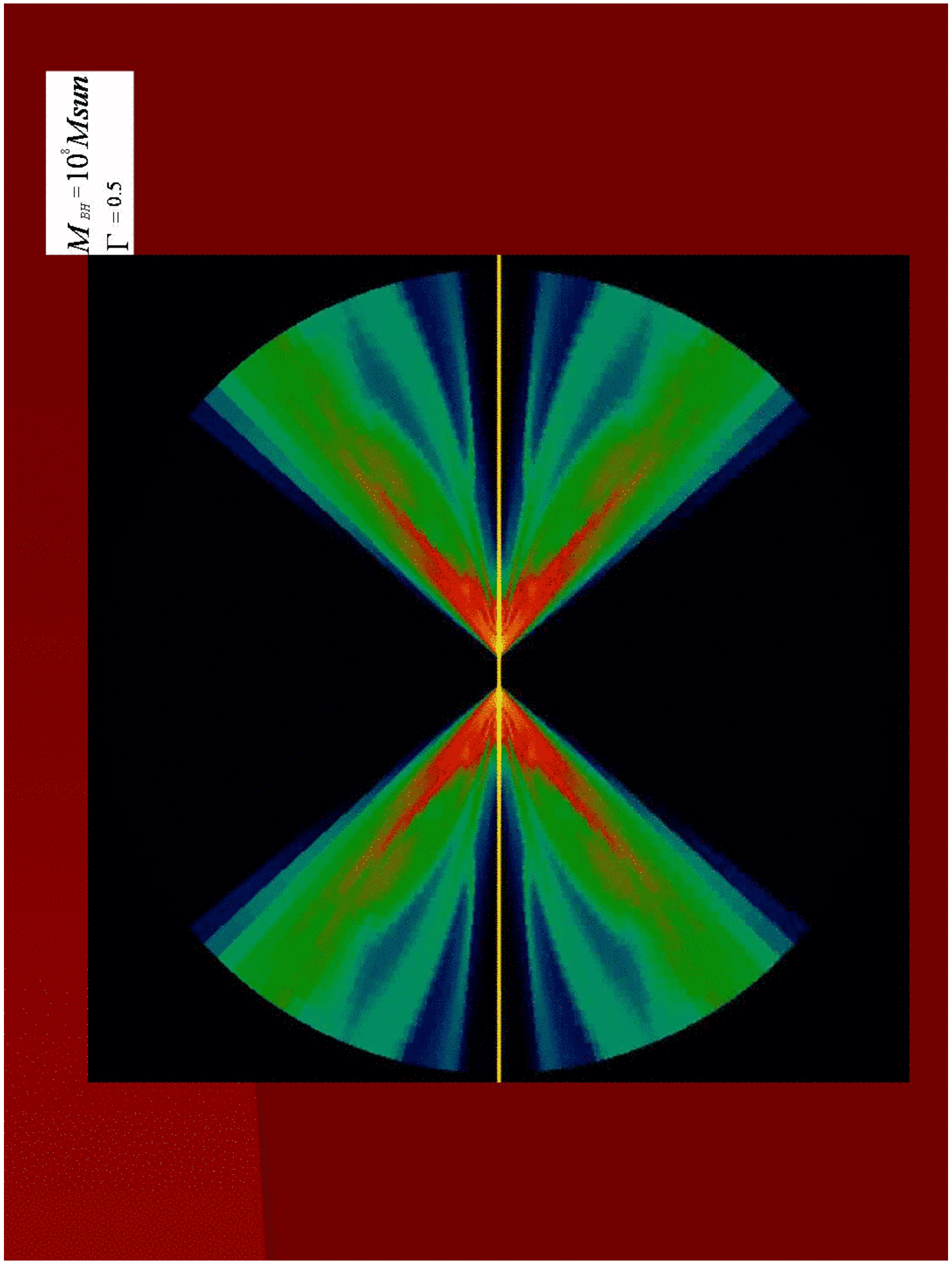

$\dot{M}_a \propto \Gamma^{1/\alpha}$
$\frac{1}{M_{max}}$
$M_{max} = 4400, \; k = 0.2, \; \alpha = 0.6$
Γ
0.0001
0.0010
0.0100
0.1000
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-18}
Proga (1999) and Drew & Proga (2000)


$L_D = 3$
$L = 0$
$L_D = 3$
$L = 3$
log density
Poloidal Velocity Field


log density
IX Vel
Flux
v [1000 km/s]
CIV
i=50°
i=60°
Proga (2003b)


CASE TWO: X-rays & UV


X-rays + LD flow=?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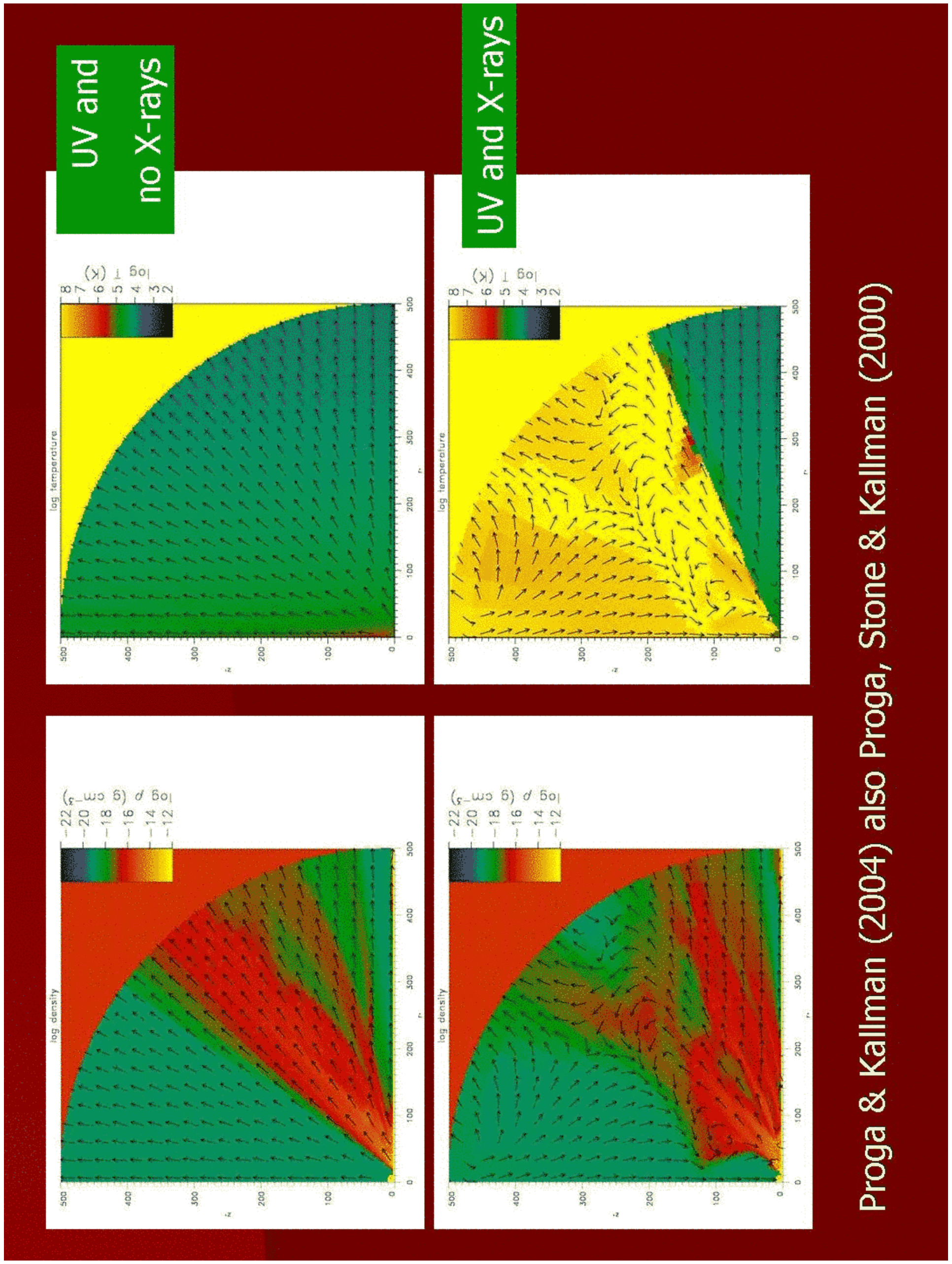
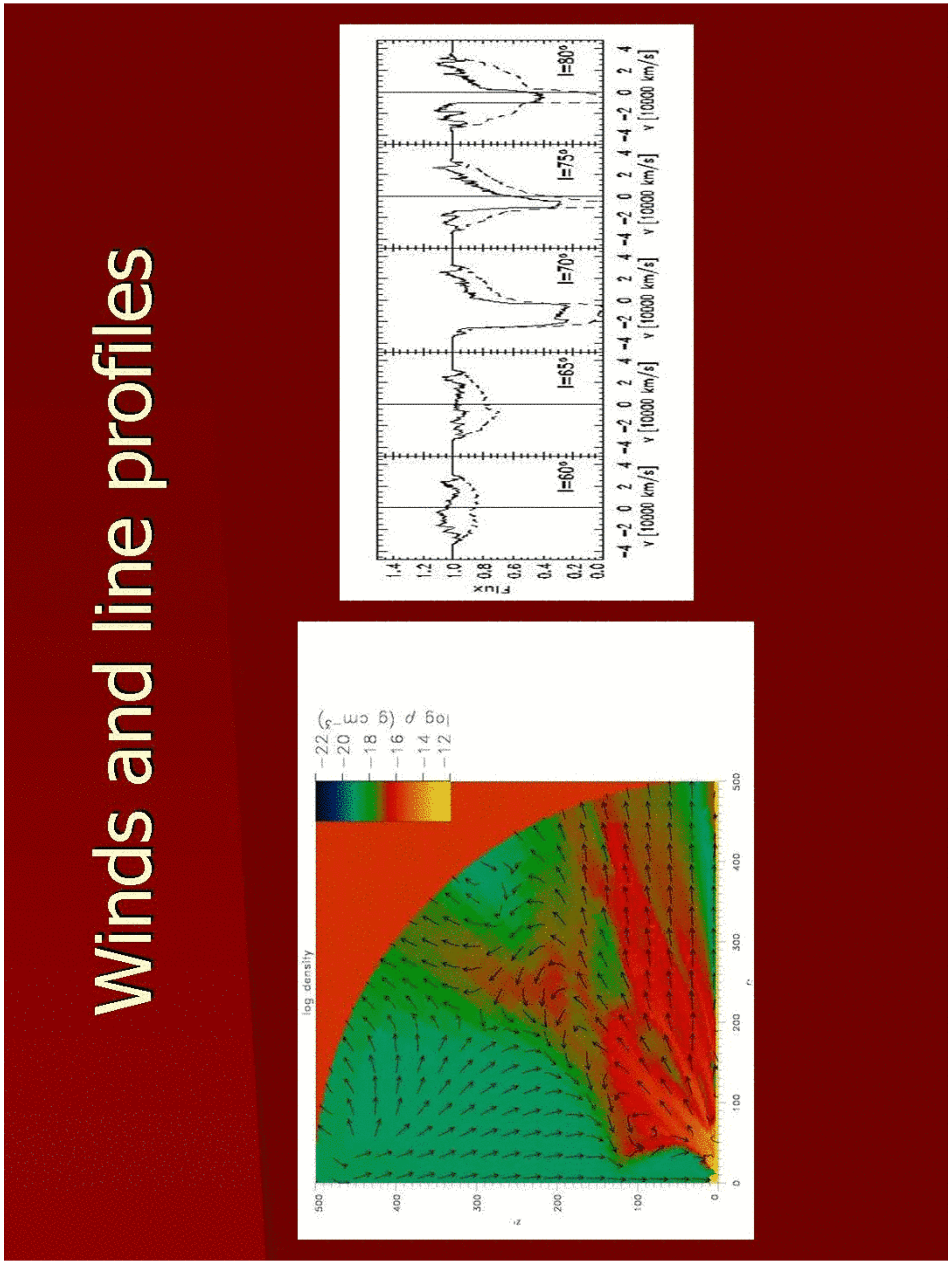
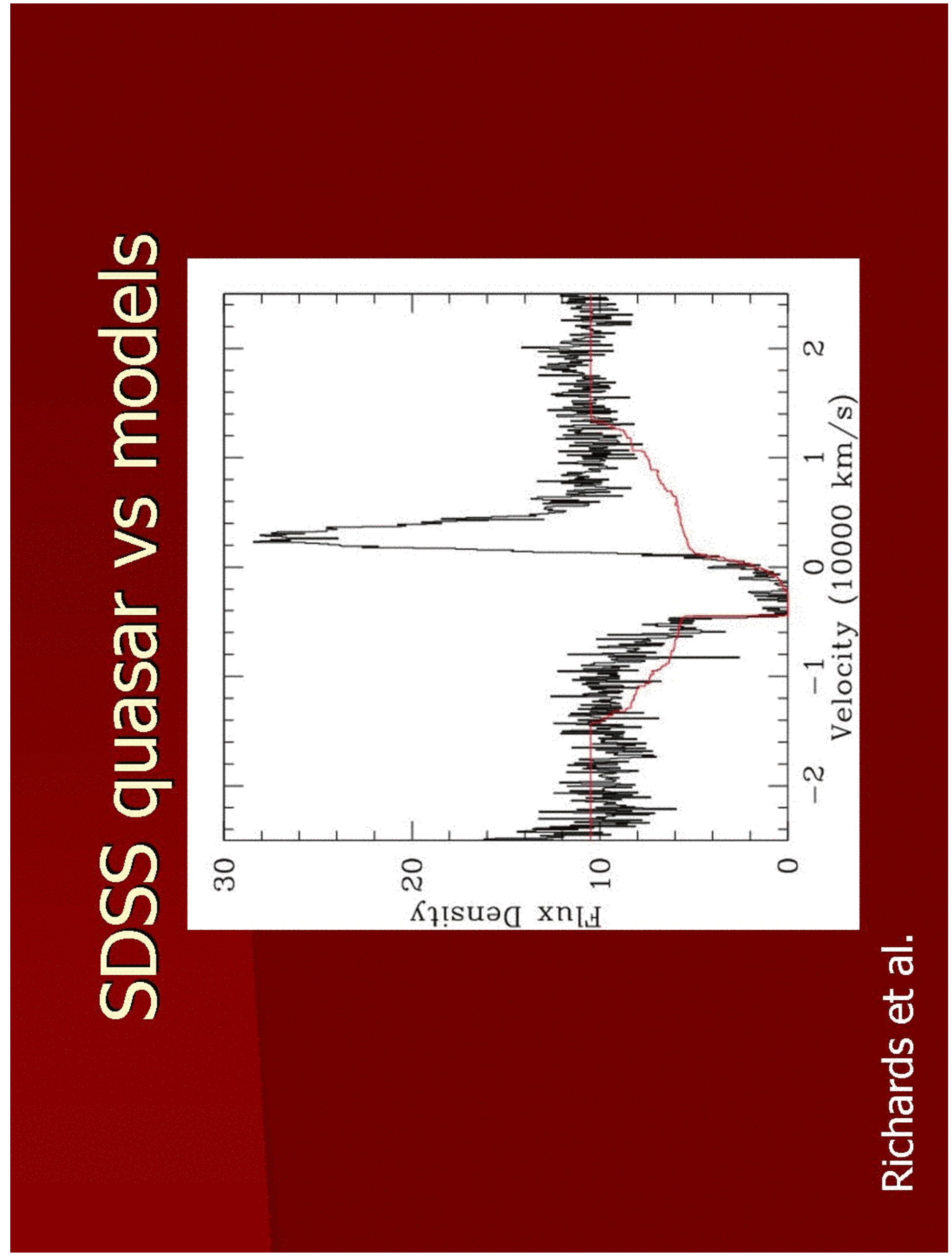
$\Gamma = 0.5$


UV and no X-rays
UV and X-rays
log temperature
log T (K)
log density
log ρ (g cm⁻³)
Proga & Kallman (2004) also Proga, Stone & Kallman (2000)

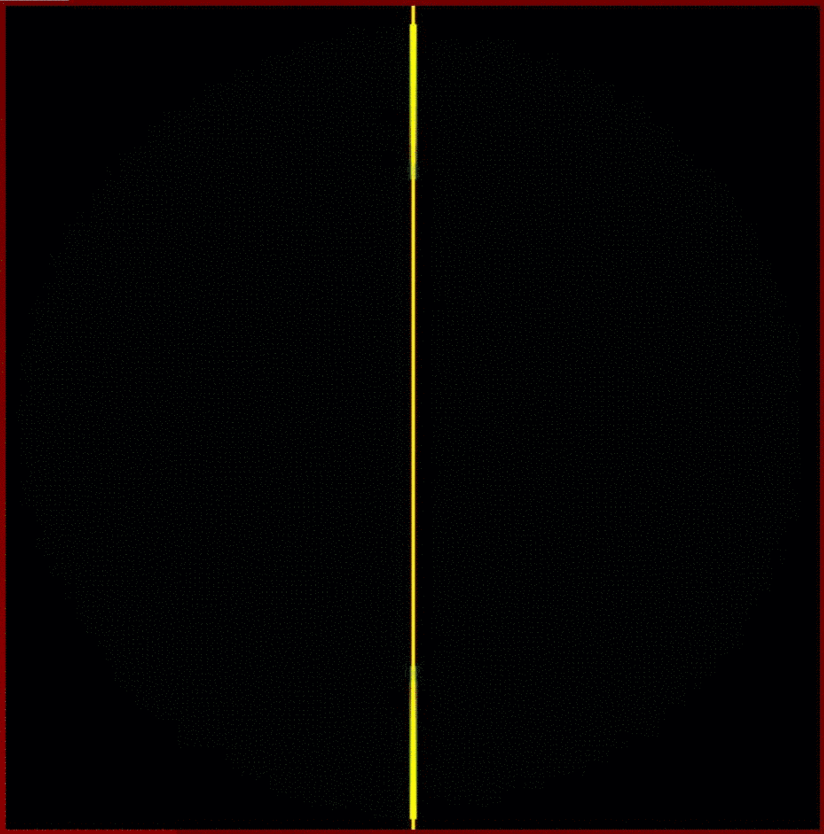

Winds and line profiles

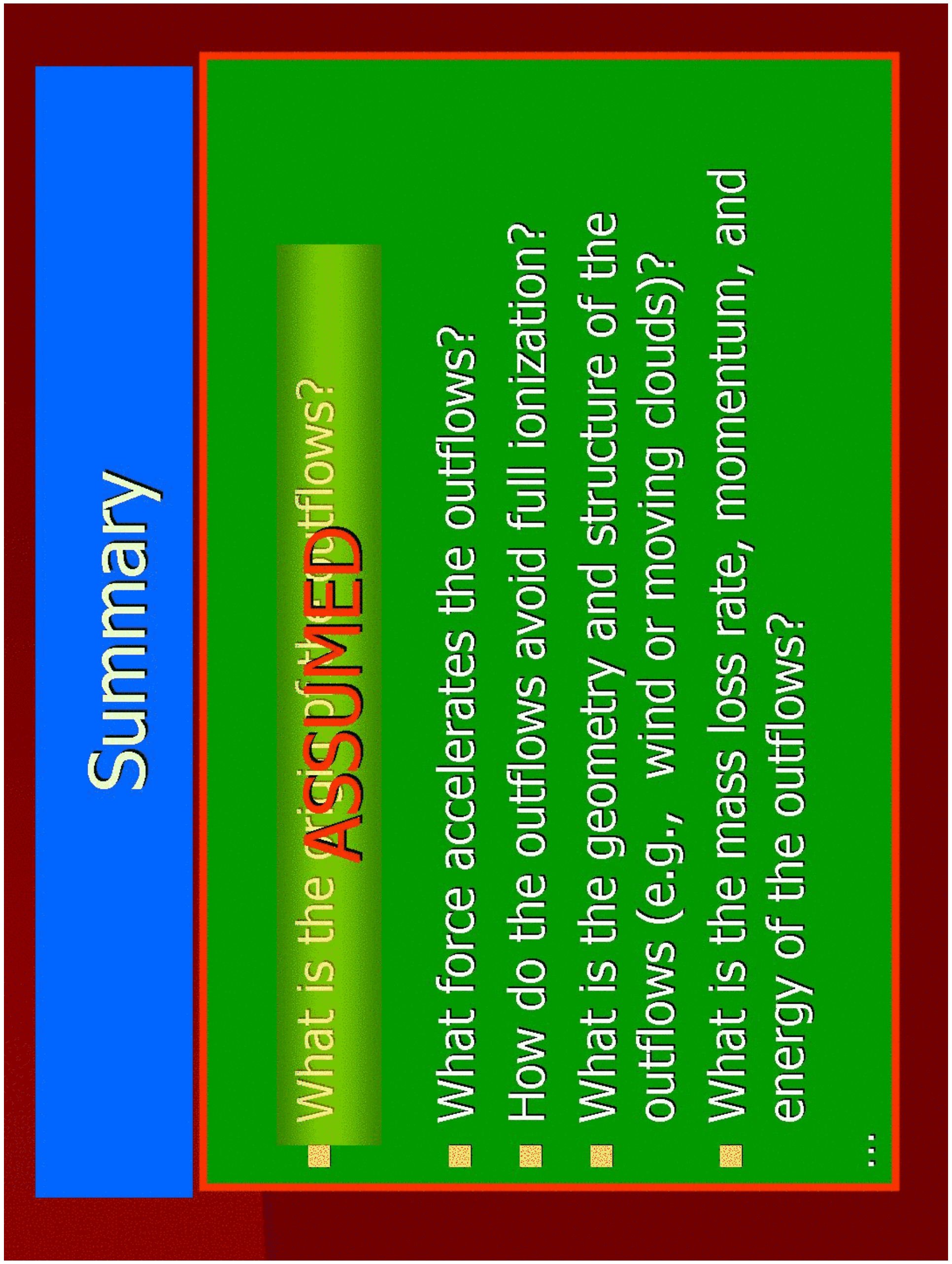

SDSS quasar vs models
Flux Density
Velocity (10000 km/s)
Richards et al.

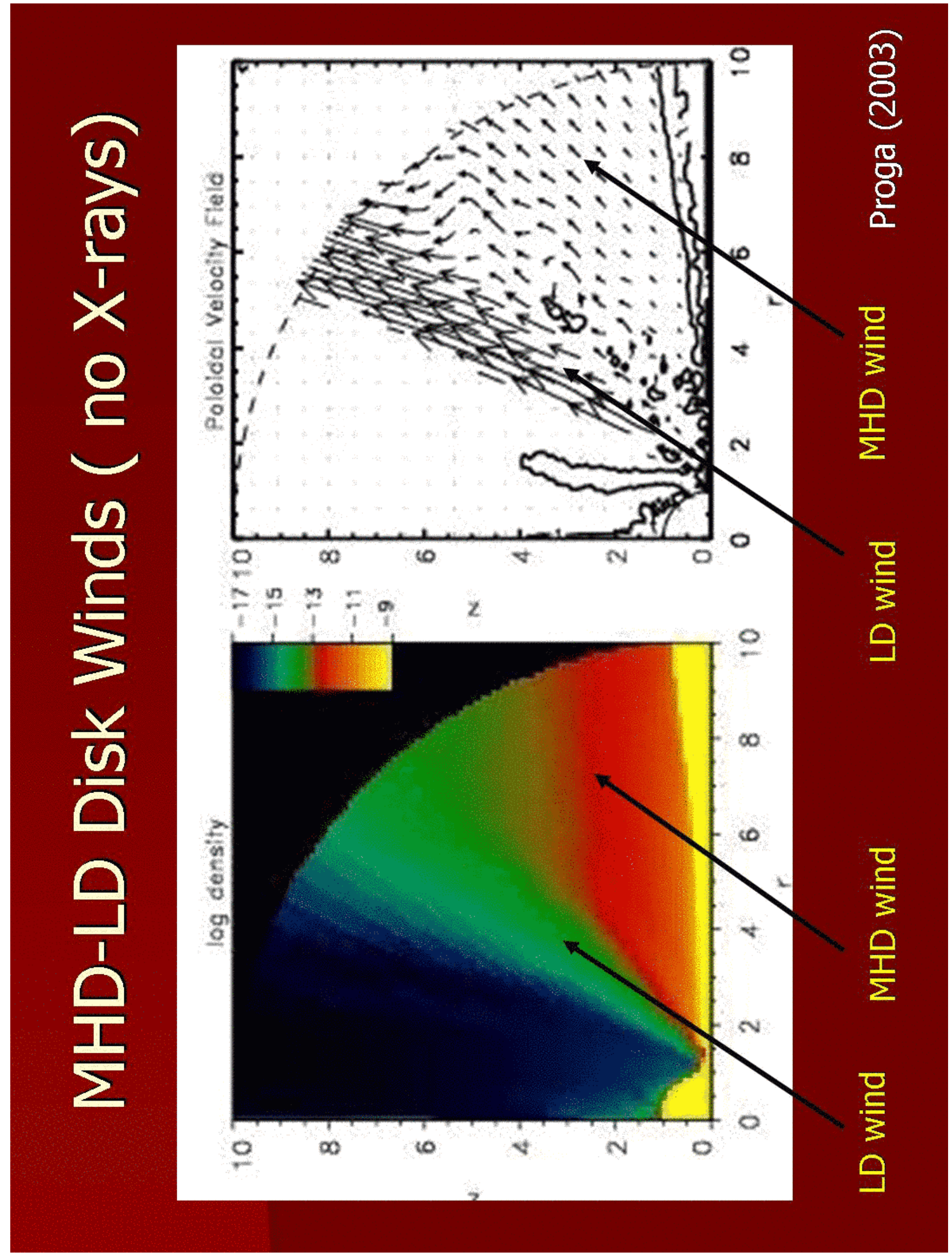
The wind solution is sensitive to the mass of the accretor.

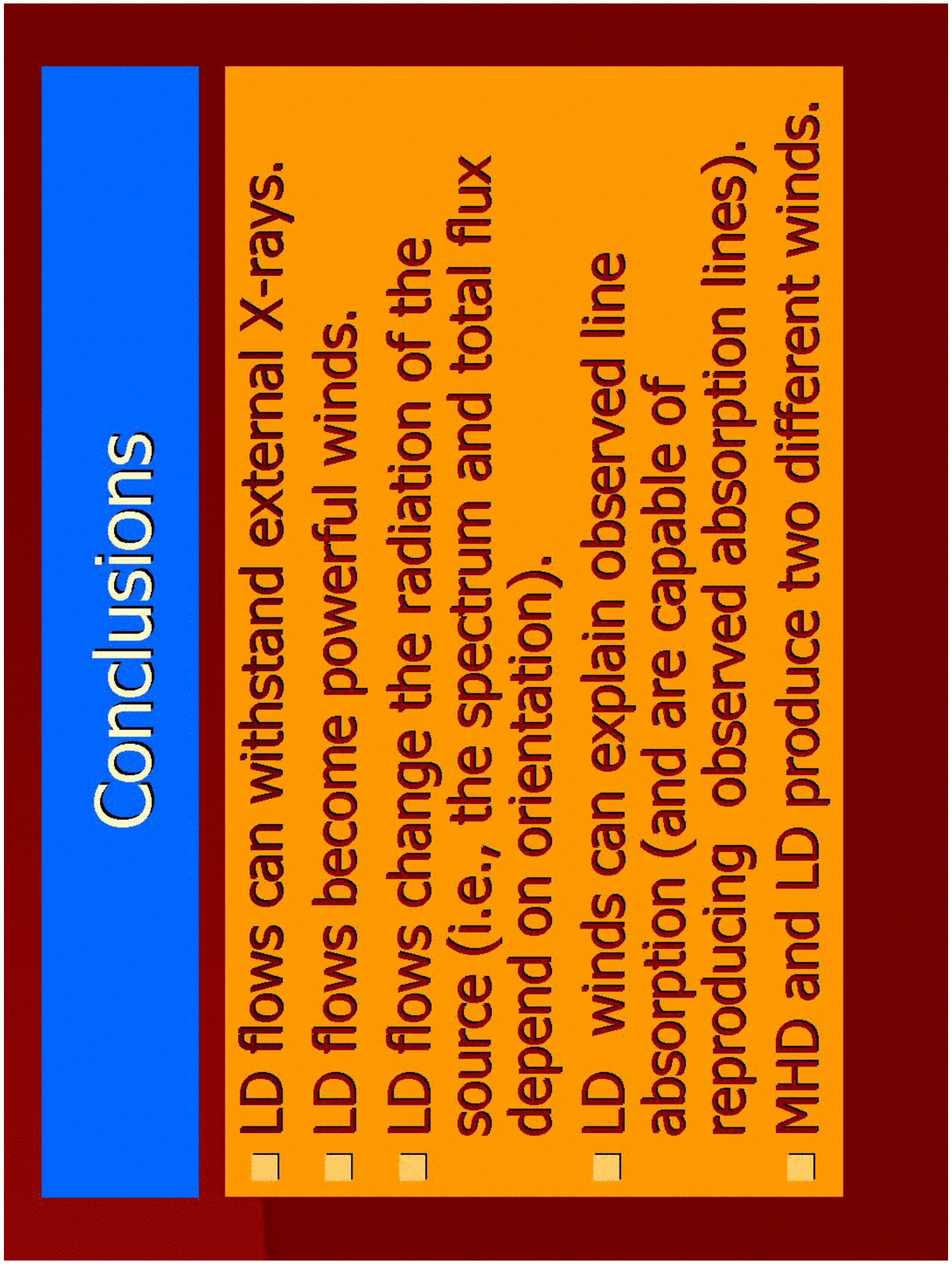
$M_{BH} = 10^6 Msun$

$\Gamma = 0.9$




Summary
What is the origin of the outflows?
ASSUMED
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?
…


MHD-LD Disk Winds (no X-rays)
log density
Poloidal Velocity Field
LD wind
MHD wind
LD wind
MHD wind
Proga (2003)


Conclusions
LD flows can withstand external X-rays.
LD flows become powerful winds.
LD flows change the radiation of the source (i.e., the spectrum and total flux depend on orientation).
LD winds can explain observed line absorption (and are capable of reproducing observed absorption lines).
MHD and LD produce two different winds.