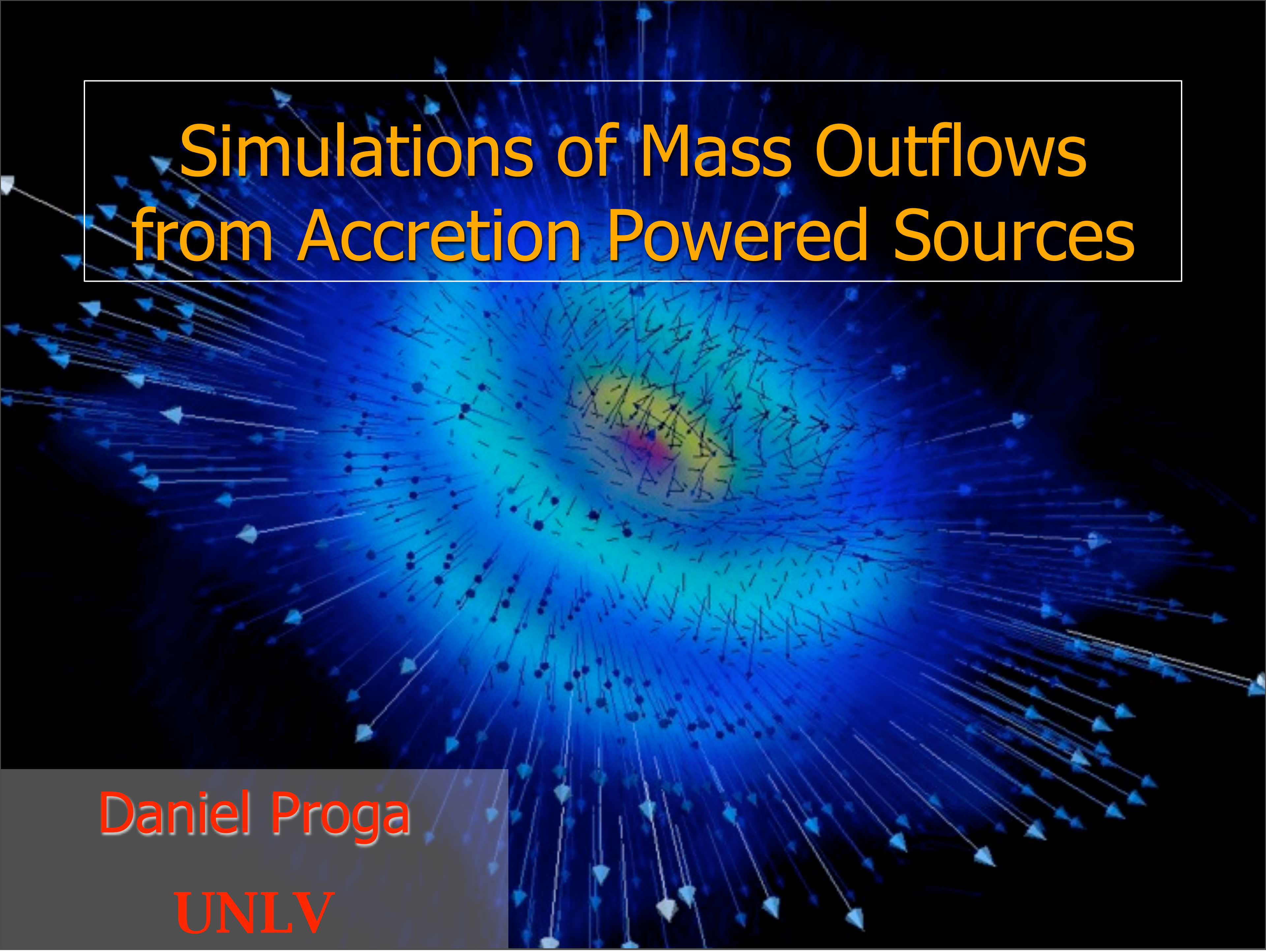
Simulations of Mass Outflows from Accretion Powered Sources

Daniel Proga

UNLV



Collaborators

- J. Drew
- J. Stone
- T. Kallman
- J. Raymond
- M. Begelman
- J. Ostriker
- R. Kurosawa
- 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

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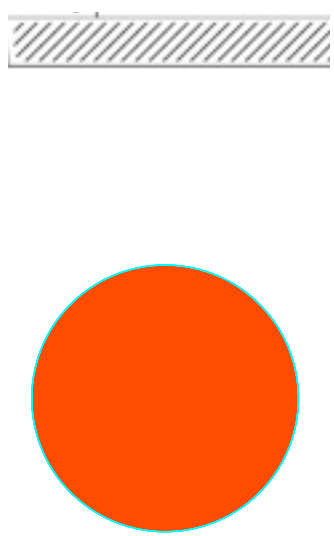
In most cases, rotation plays a key role (directly or indirectly) especially in AD.

Accretion Disks vs Stars



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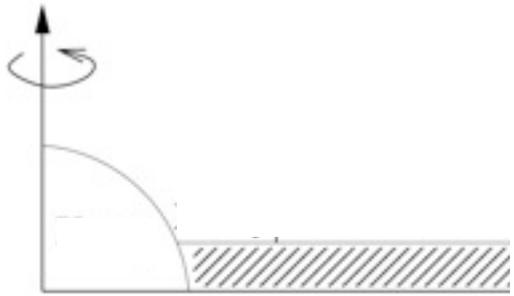

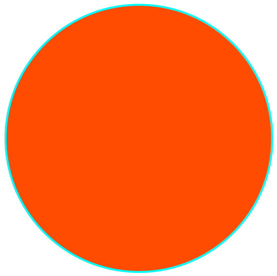

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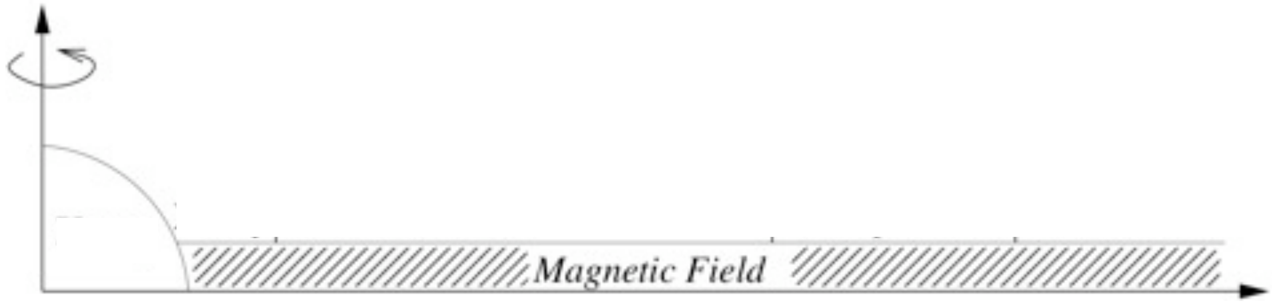

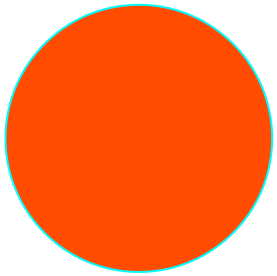

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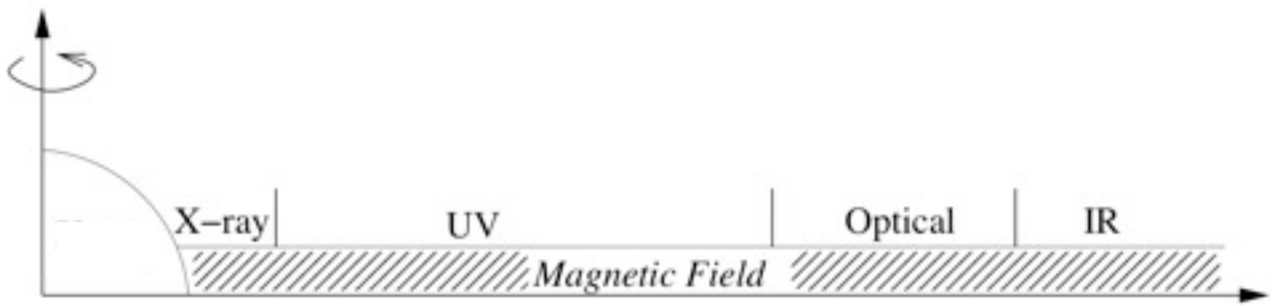

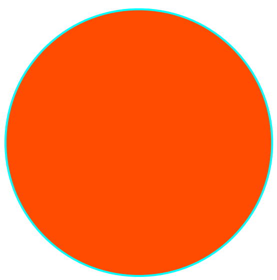

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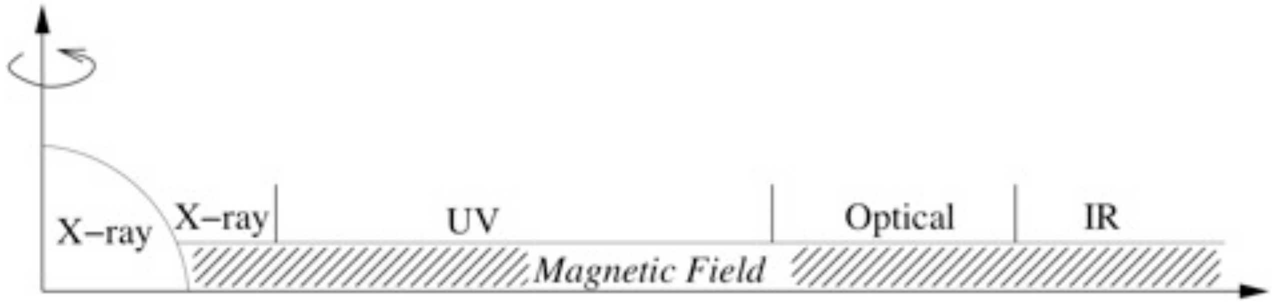
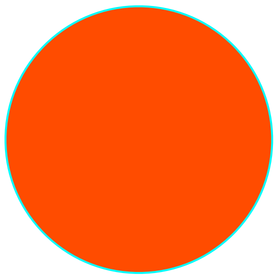
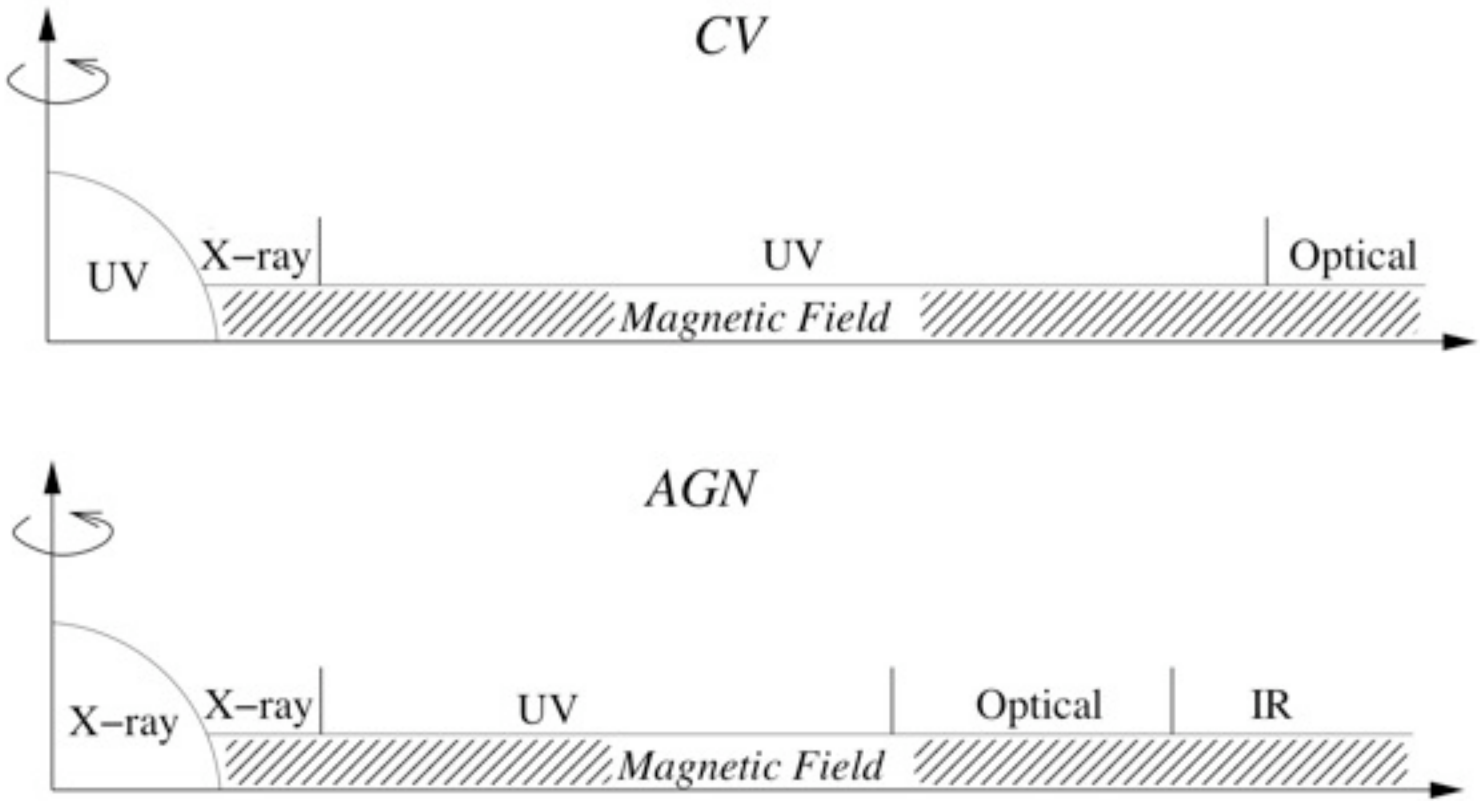




Accretion Disks in Various Objects

Two examples:

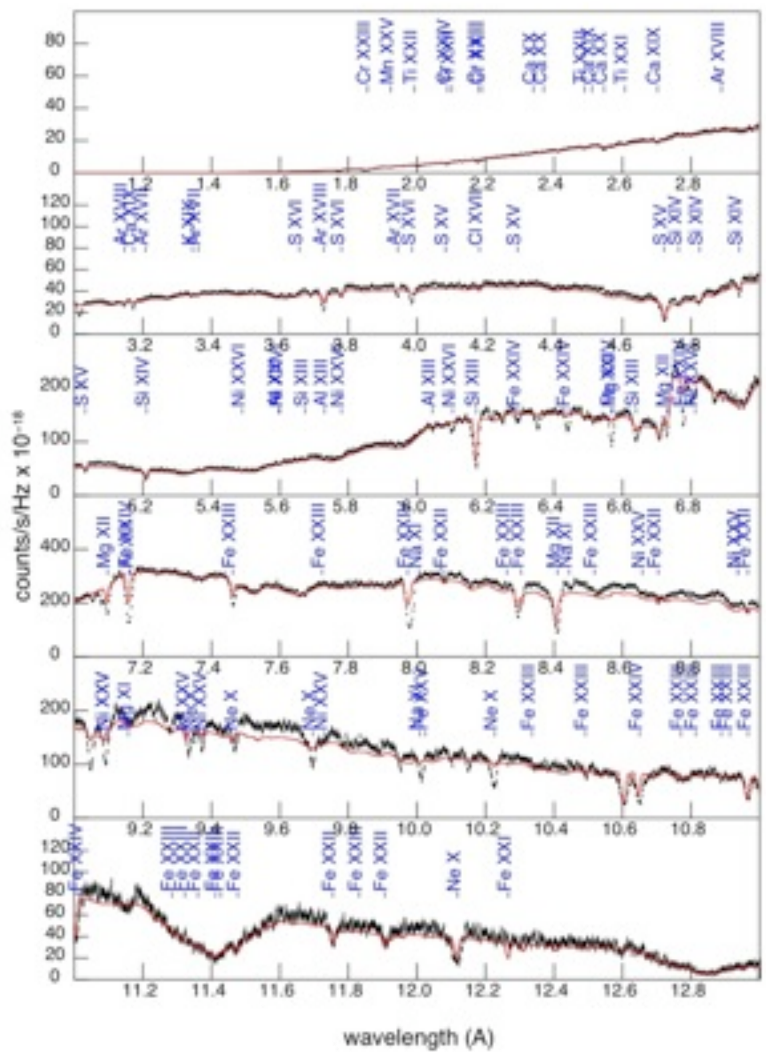


Thermal Disk Winds

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



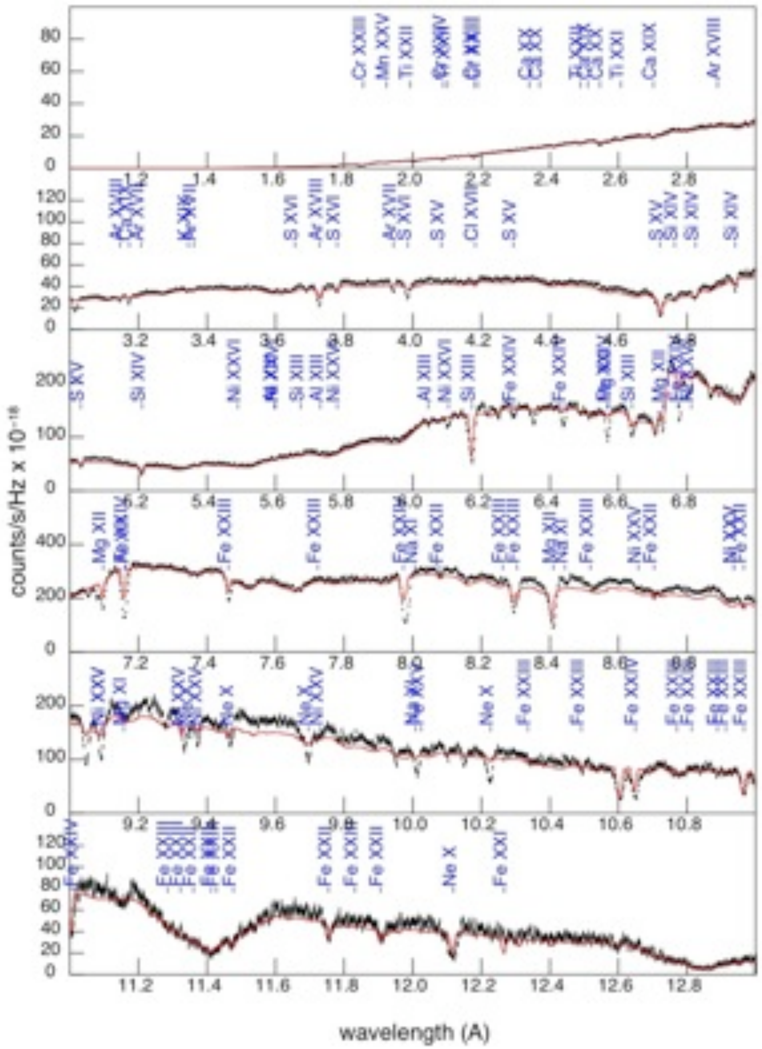
Observations: Miller et al. (2006)

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

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

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

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

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

The equations are solved using the ZEUS code (Stone & Norman 1992) extended by Proga, Stone, & Kallman (2000; see also Proga, Stone & Drew 1998, 1999; Proga & Kallman 2002, PD 2007, Kursowa & Proga 2008, 2009a, b)

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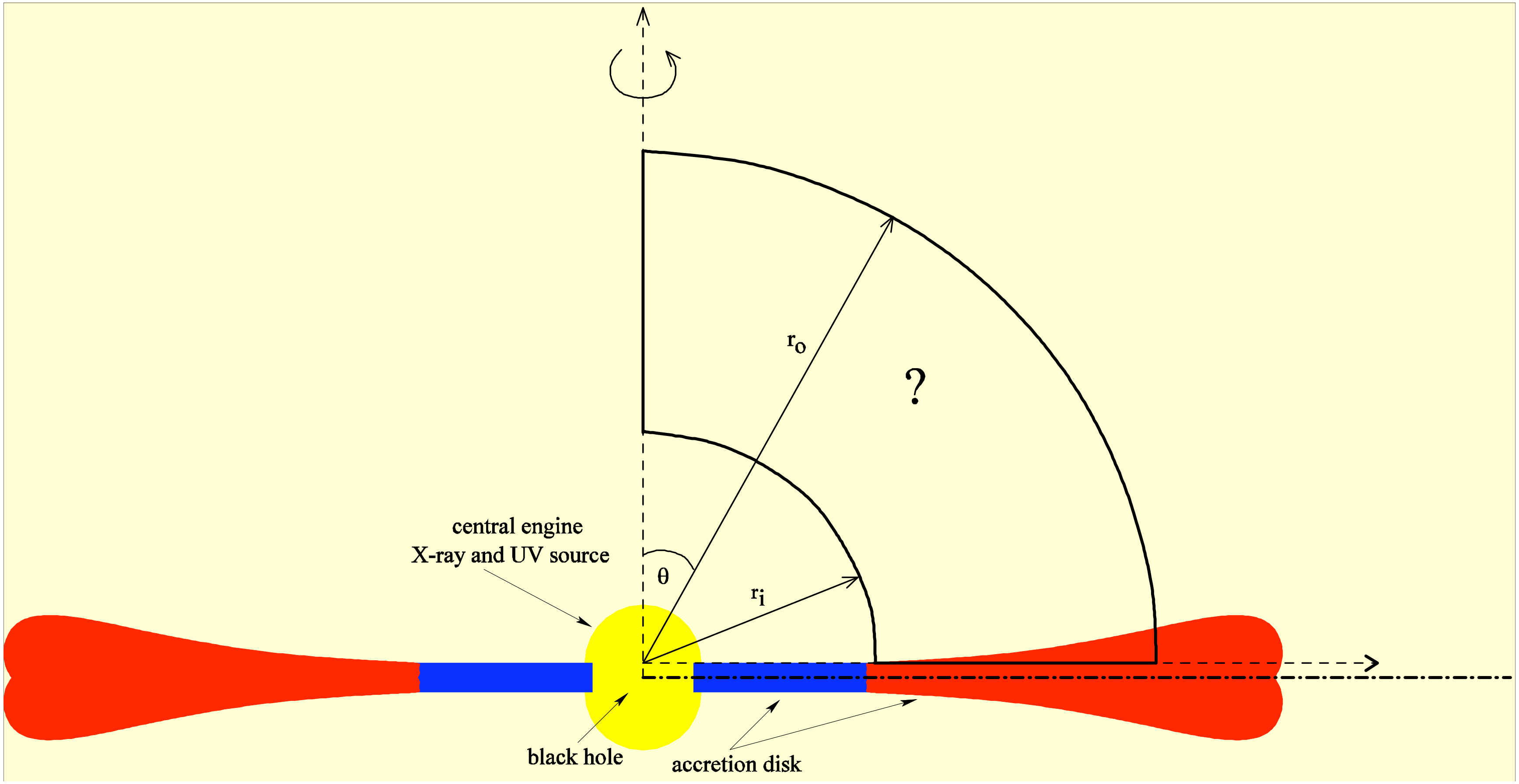
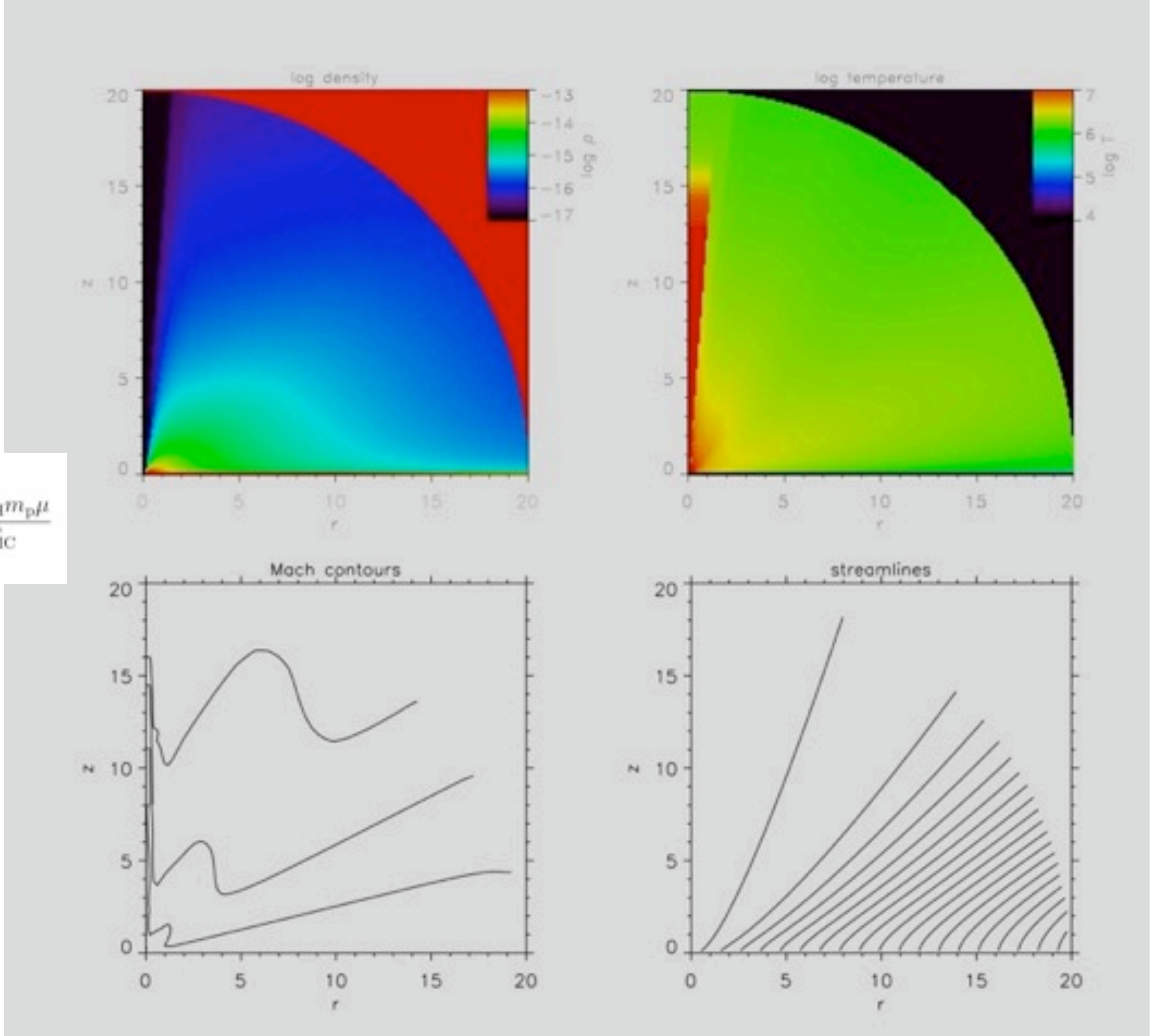


X-ray and UV source



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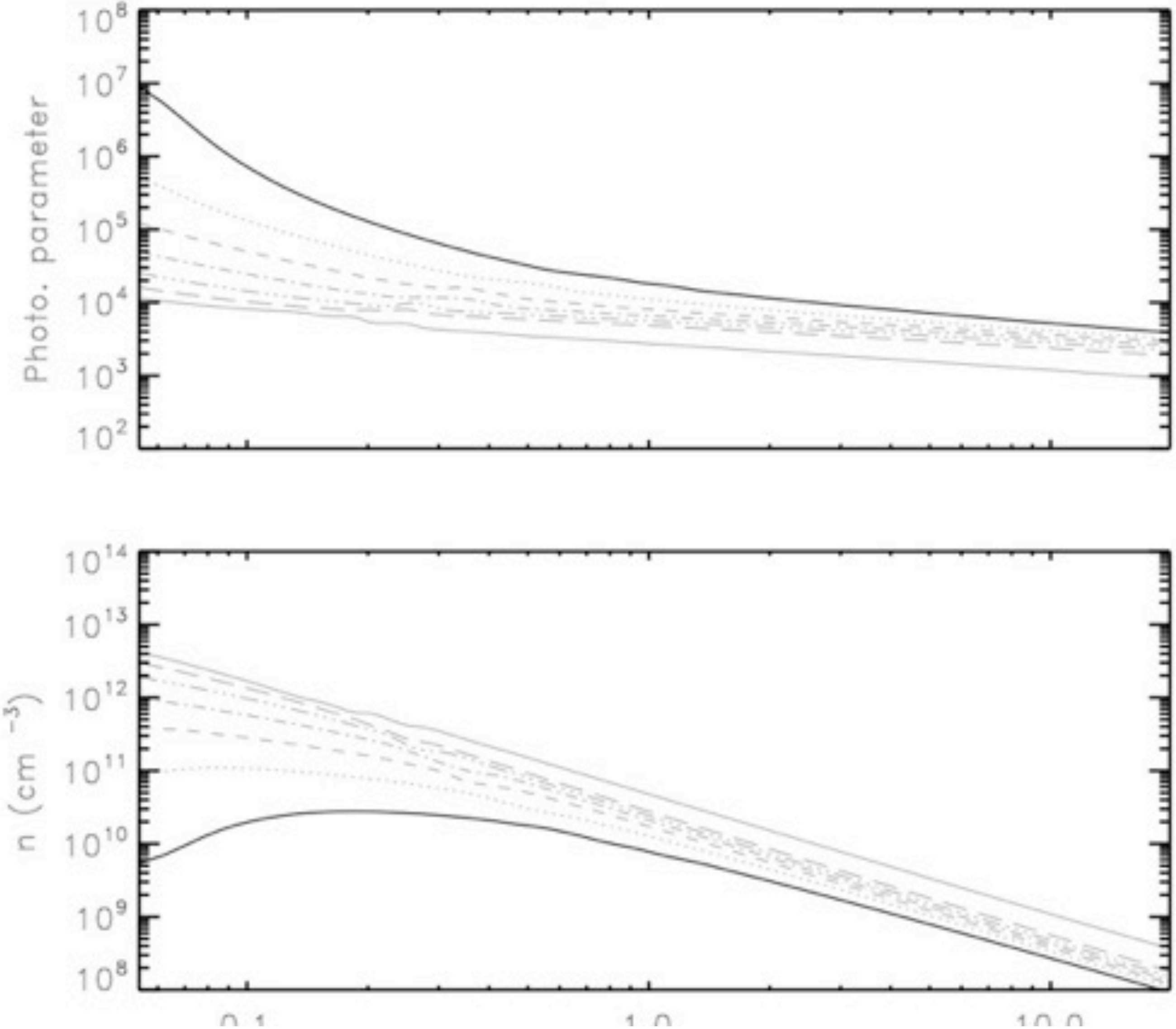
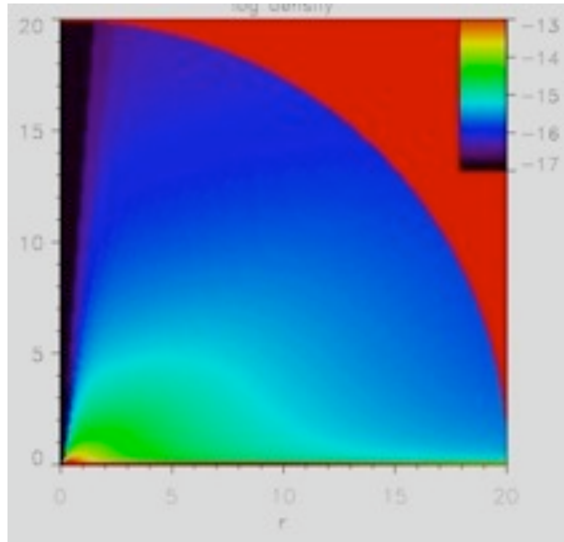
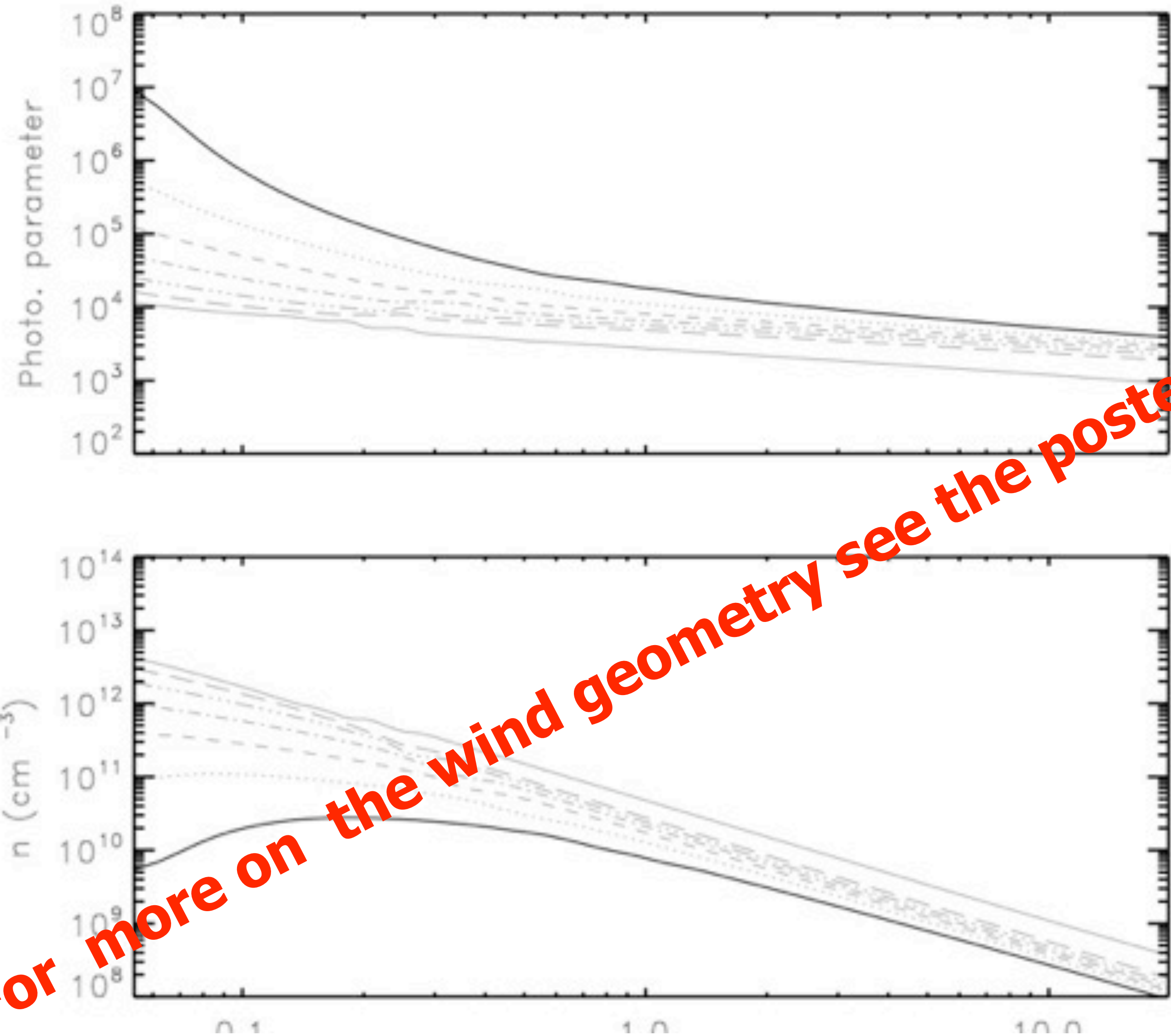
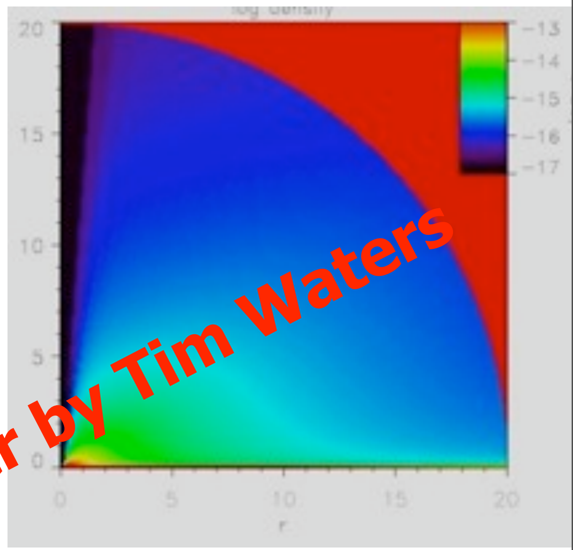
Luketic et al. (2010)





$\theta = 48.3°$ (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).





For more on the wind geometry see the poster by Tim Waters

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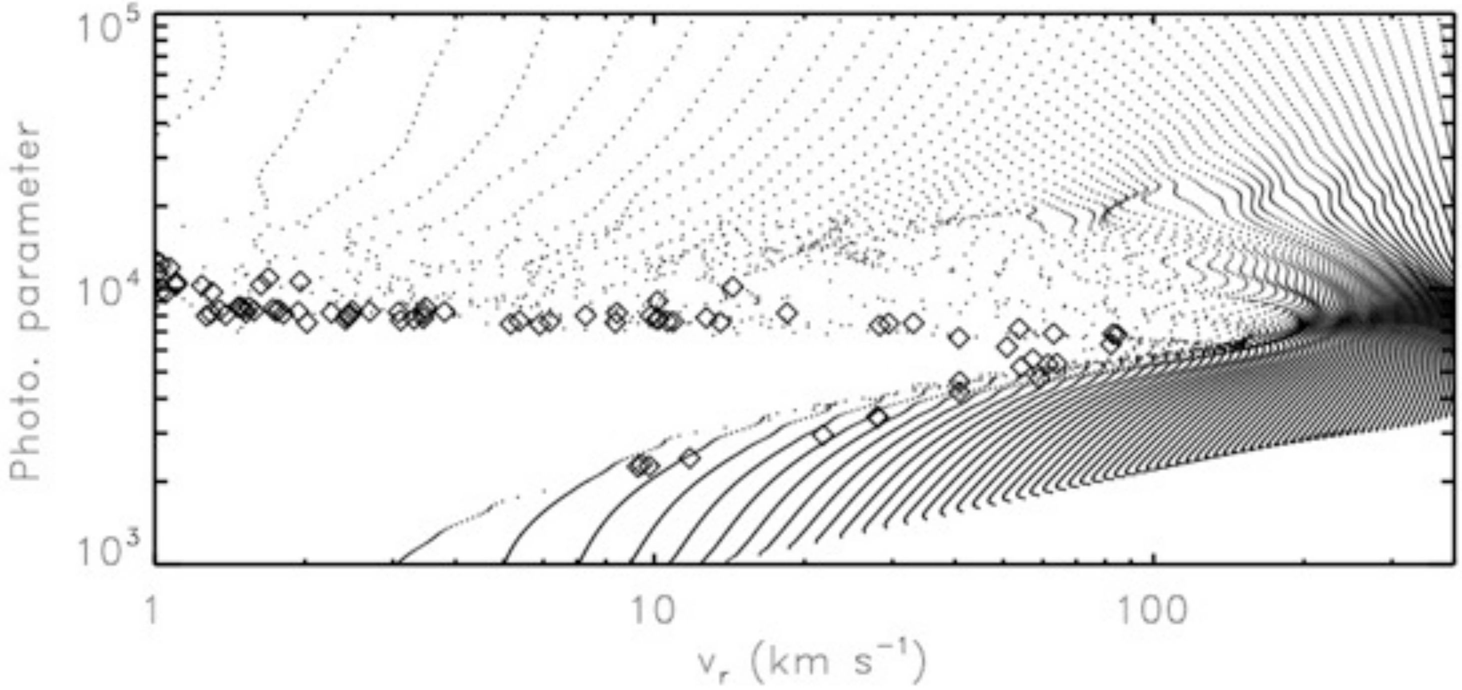
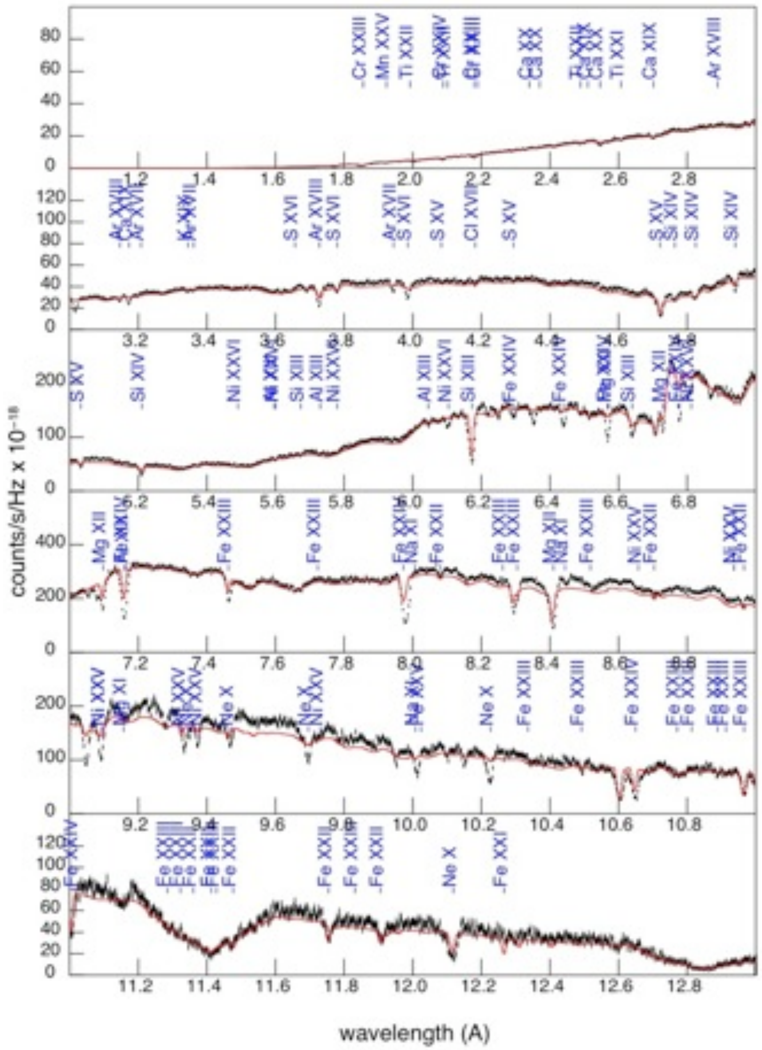


GRO J1655–40

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

GRO J1655–40



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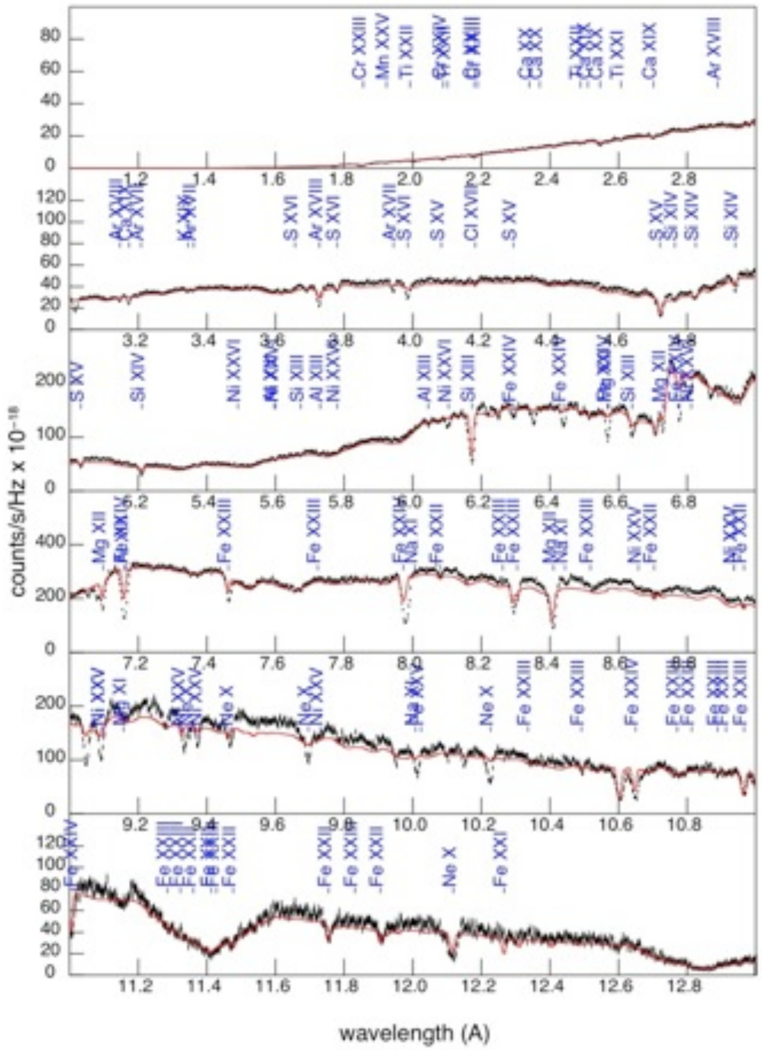

- The thermal wind is not dense enough to account for the observed wind.
- But does it mean that the thermal wind is unimportant?
- Maybe not because the wind mass lose rate can be as high as 5 times the disk accretion rate (see Neilsen & Lee 2009)!!!

Radiation-Driven Winds

The equations of hydrodynamics

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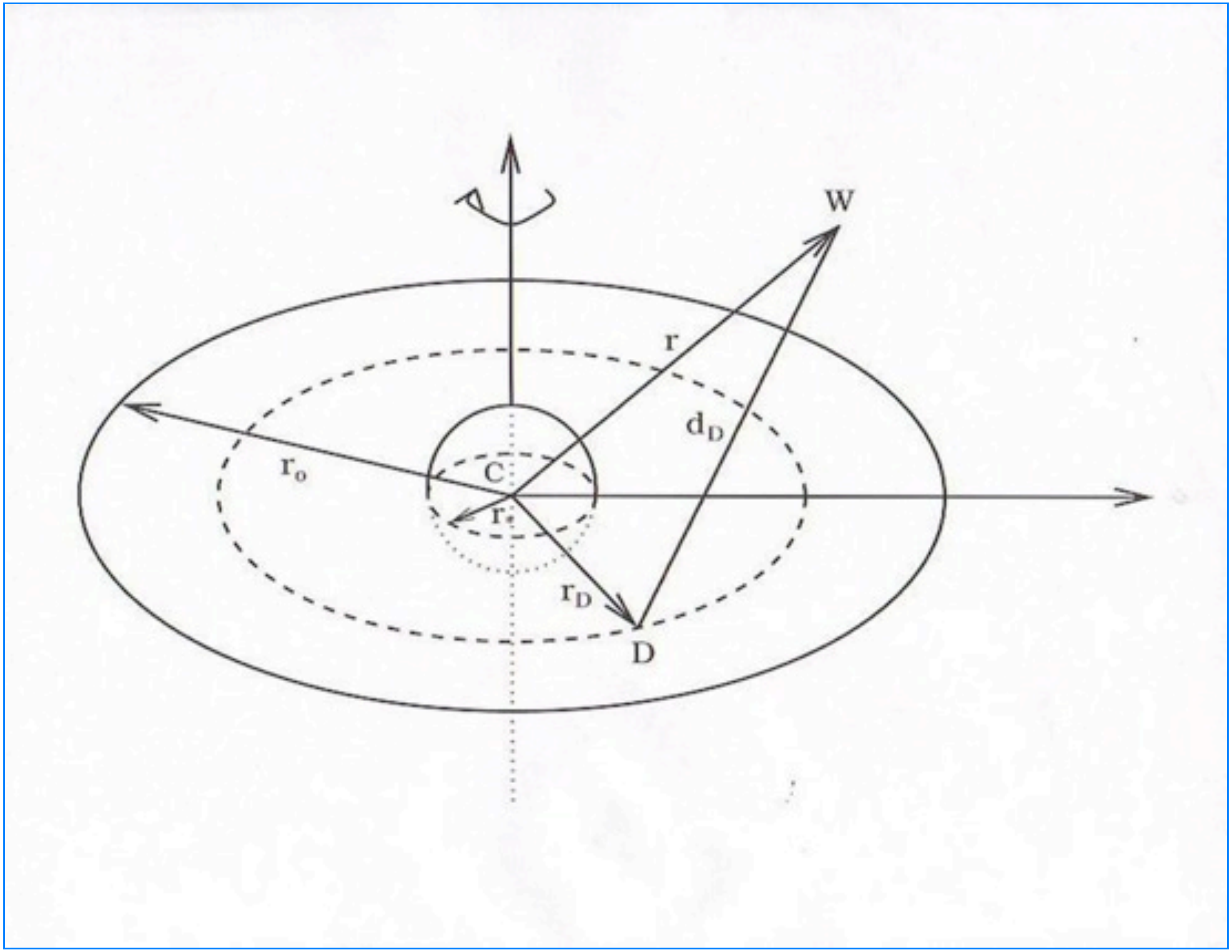
Geometry



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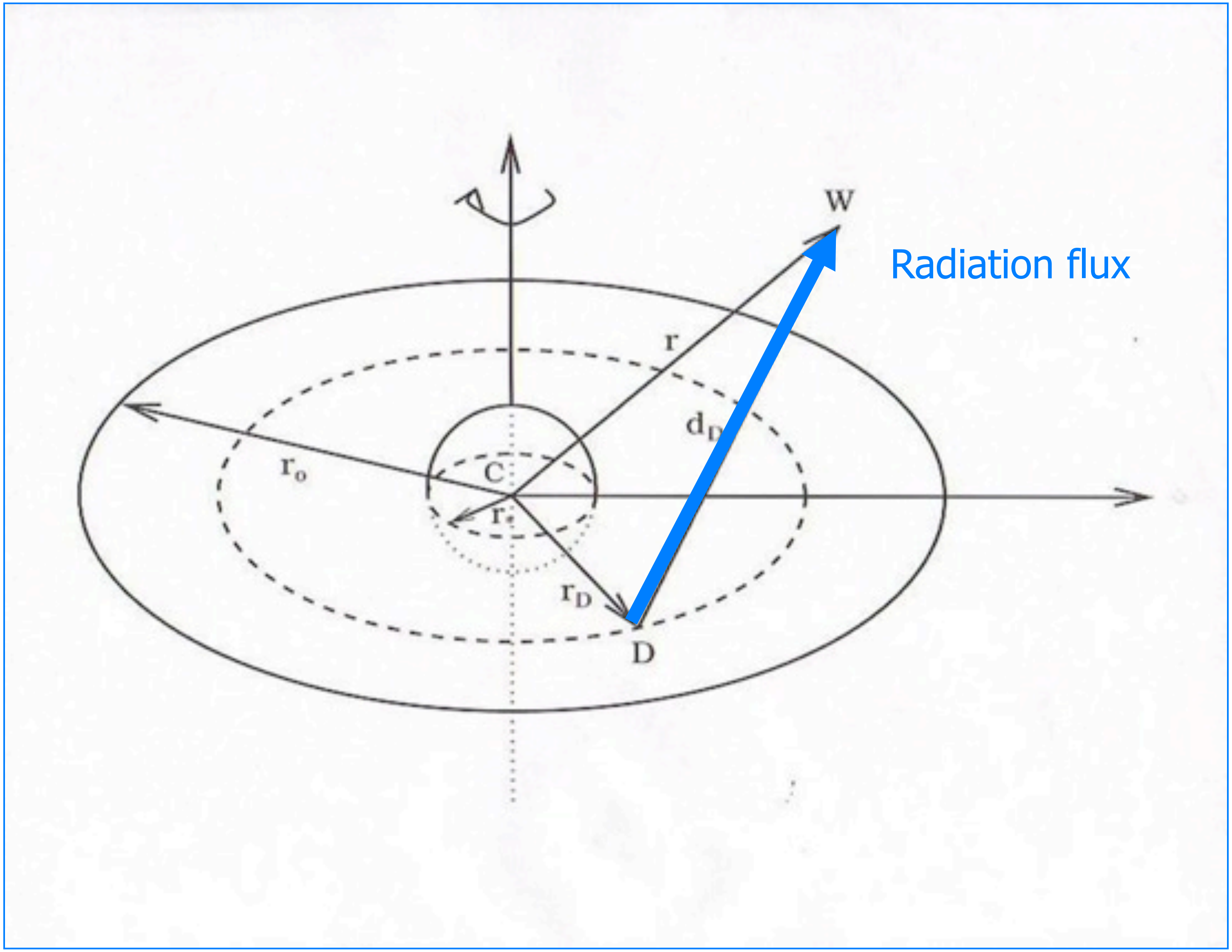

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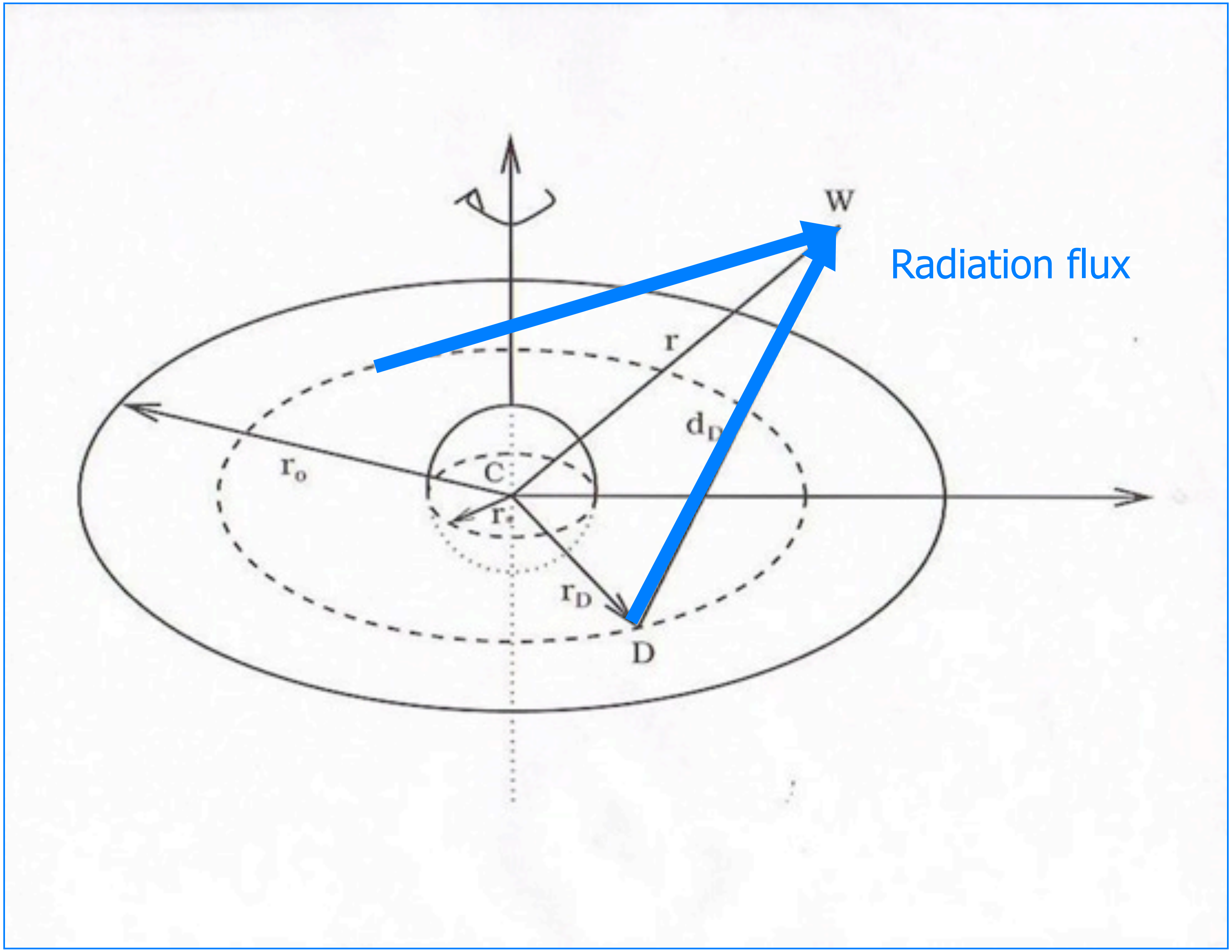

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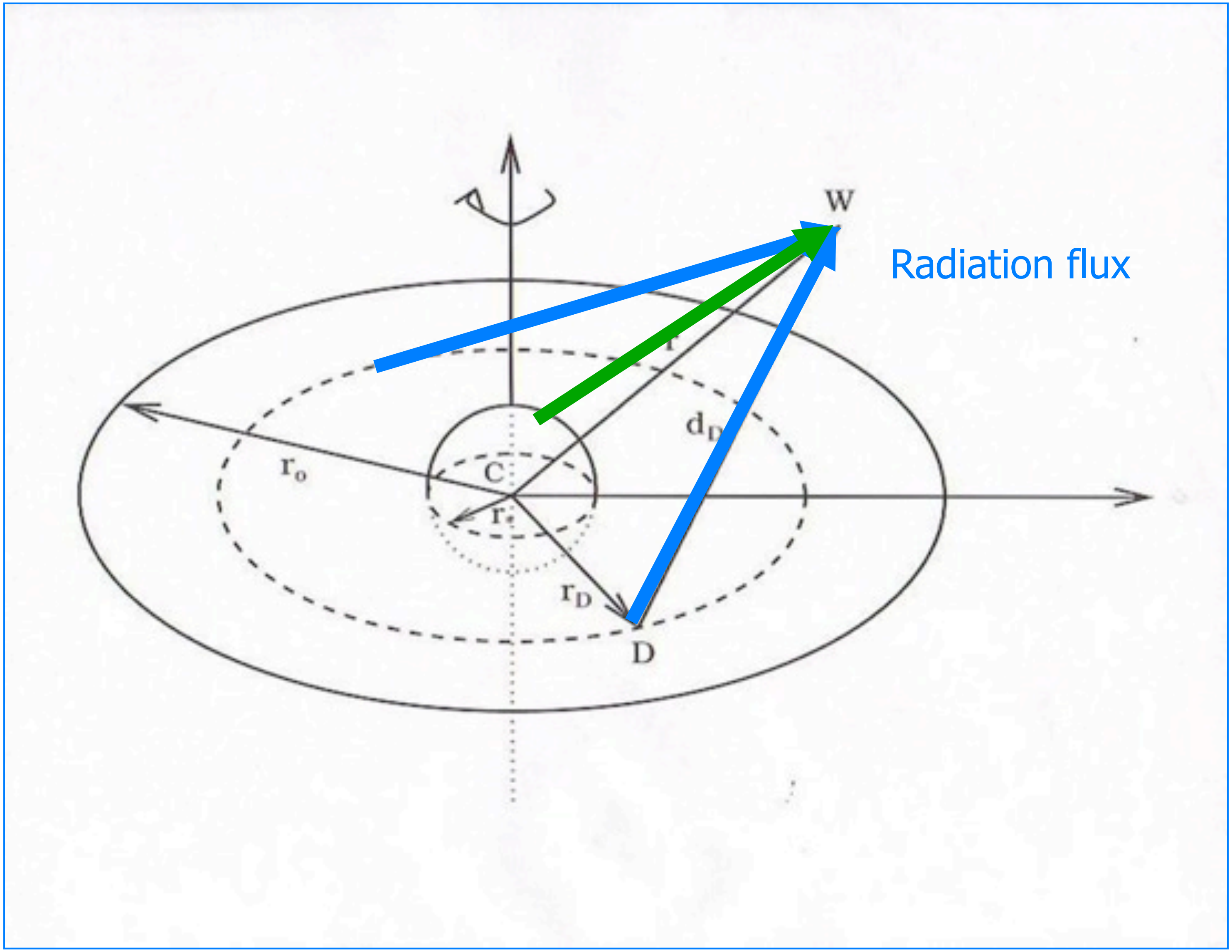
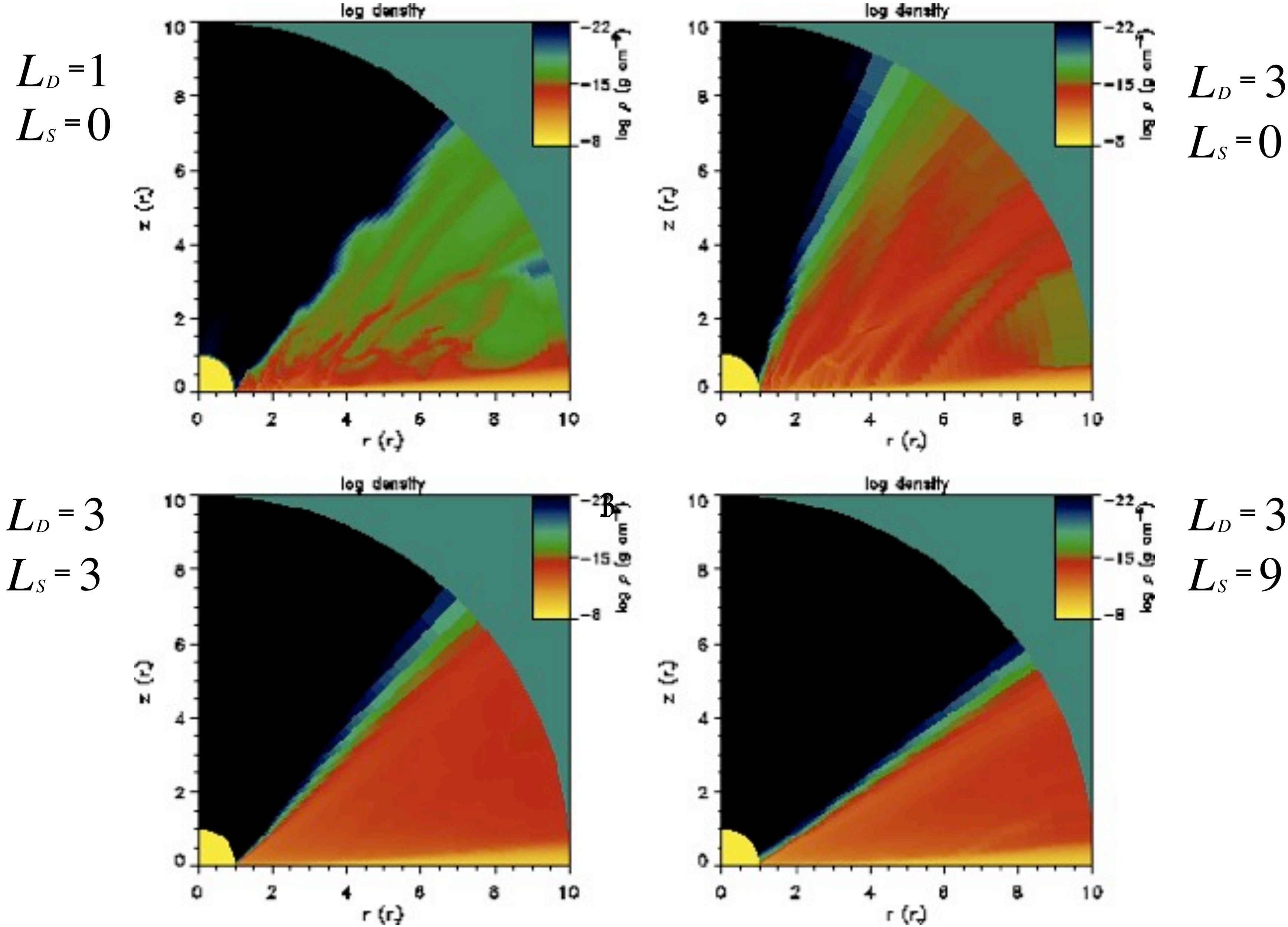
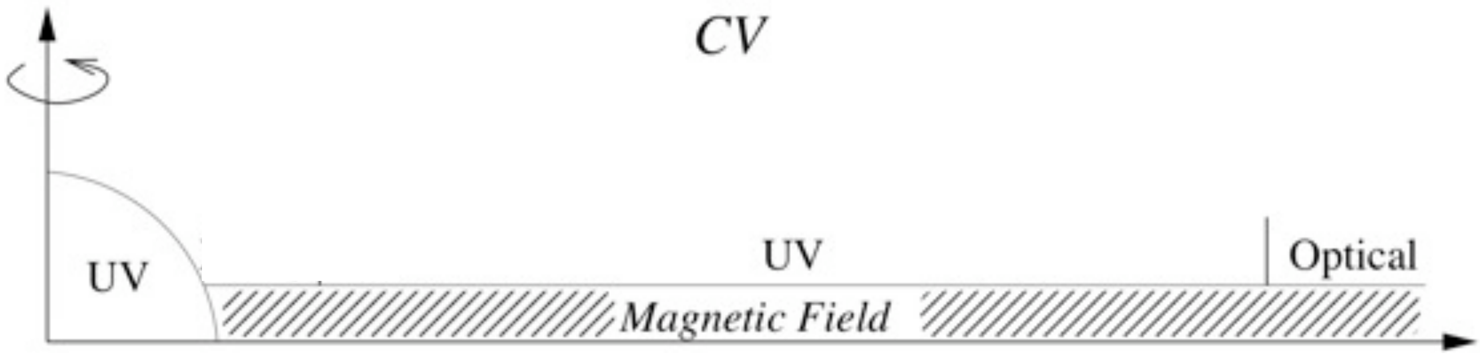




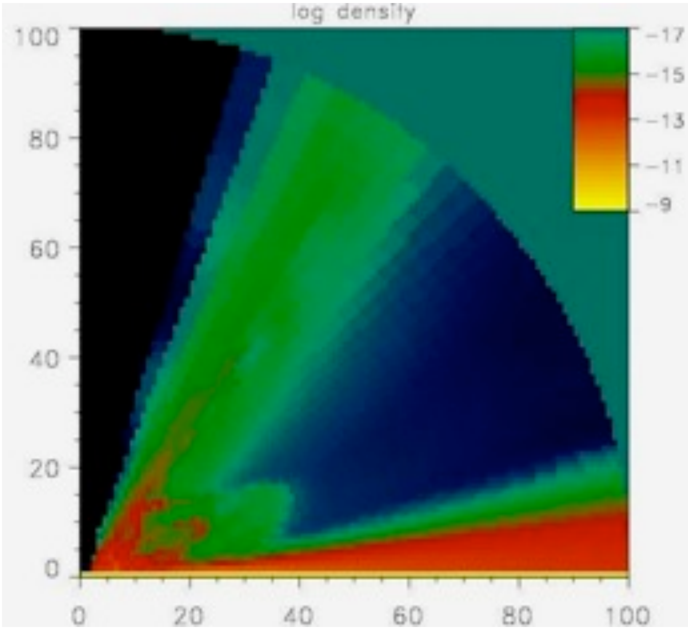
Proga, Stone & Drew (1998)

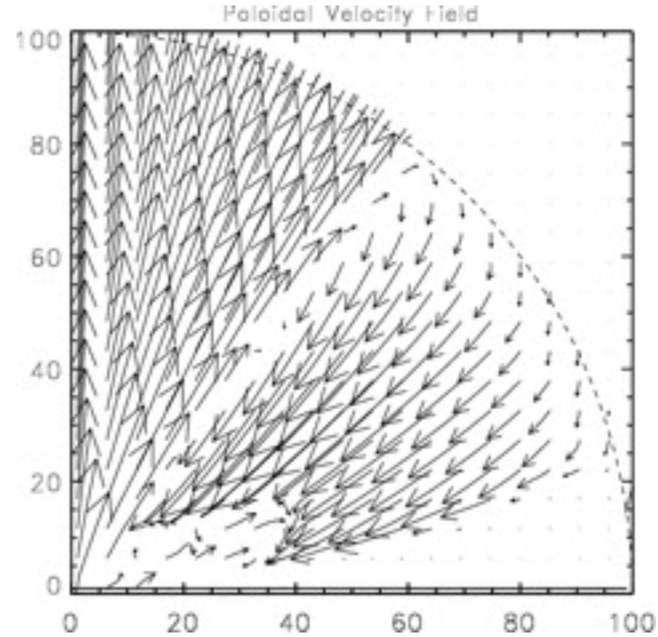
But the disk emits the UV radiation only from a relatively narrow ring.



L(disk)=3

L(star)=0





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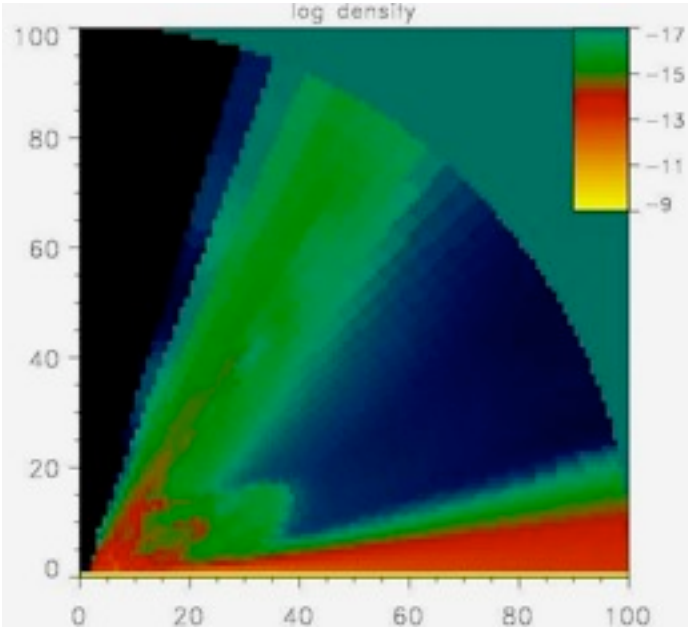

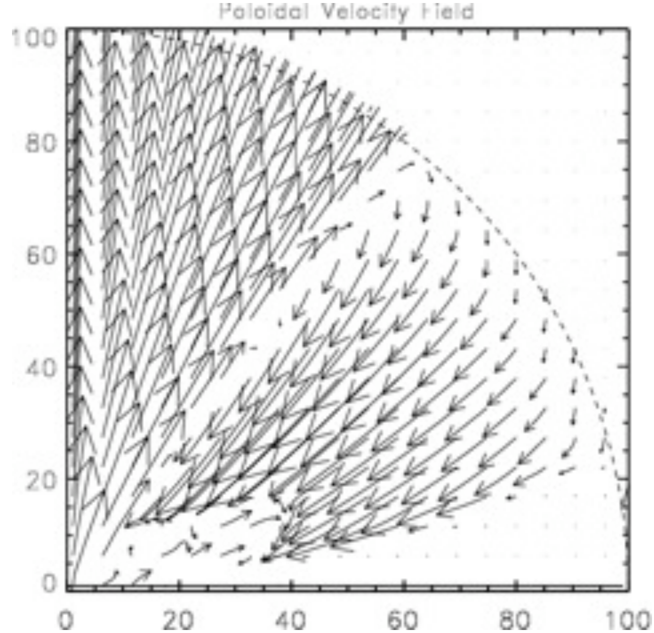

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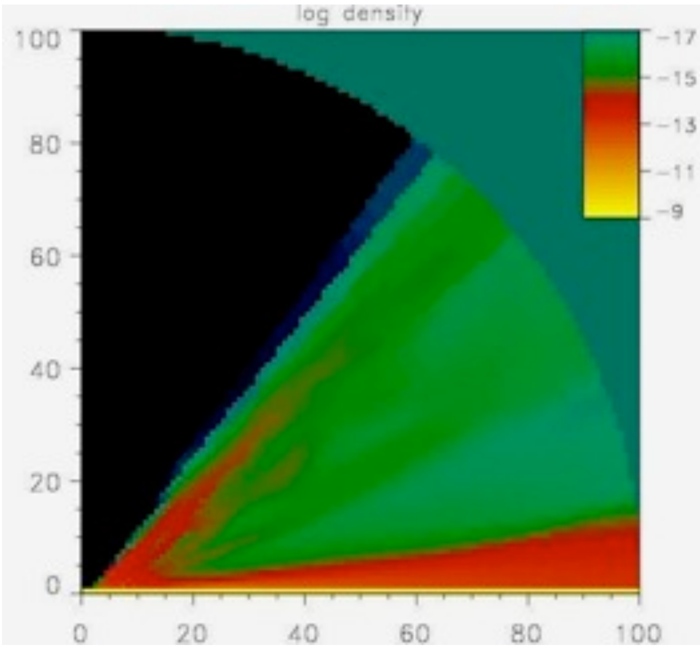

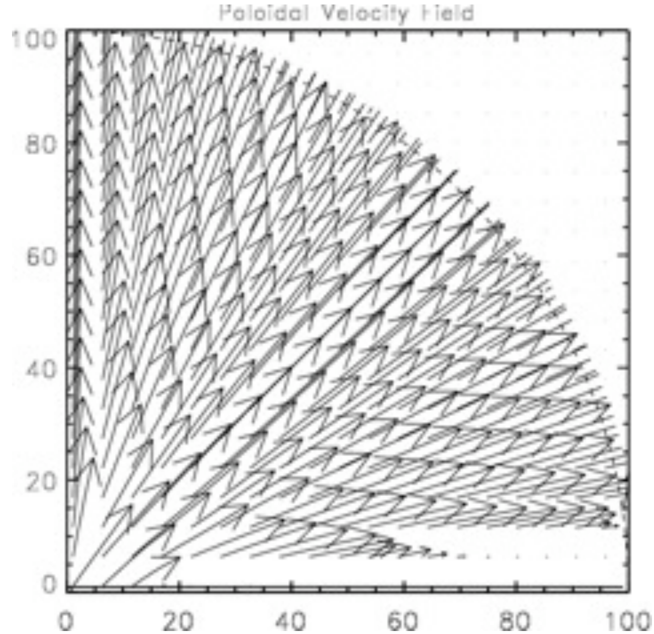

HD simulations and their line profiles

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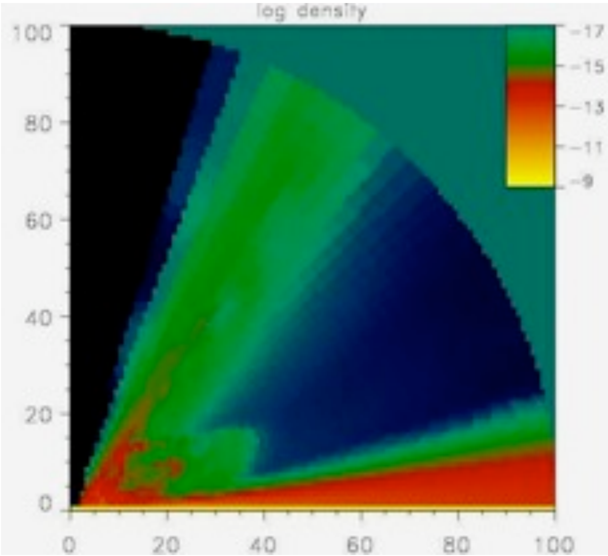

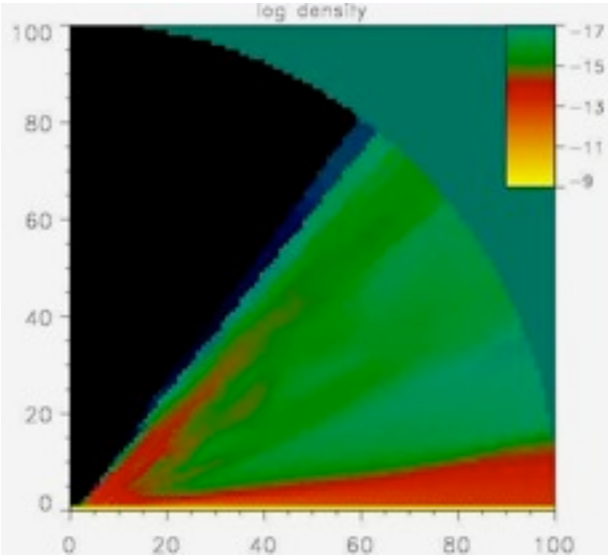

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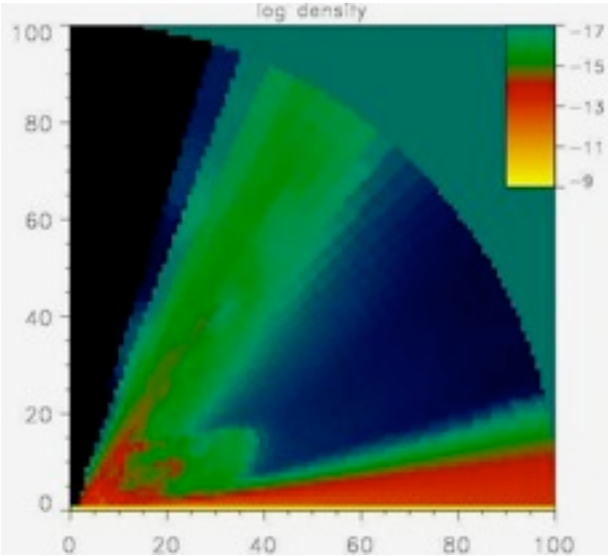

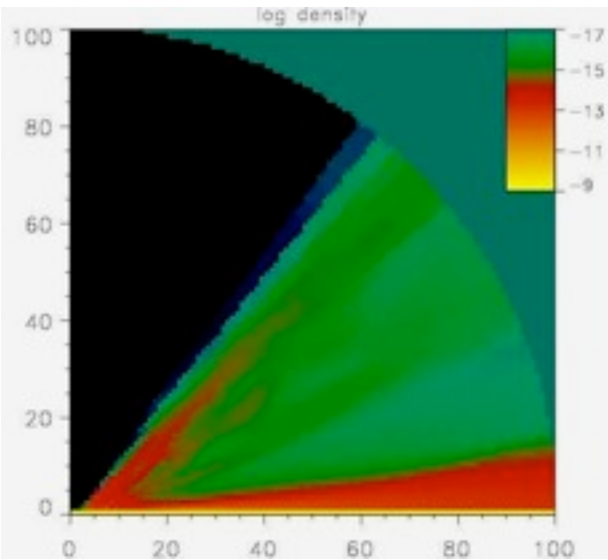

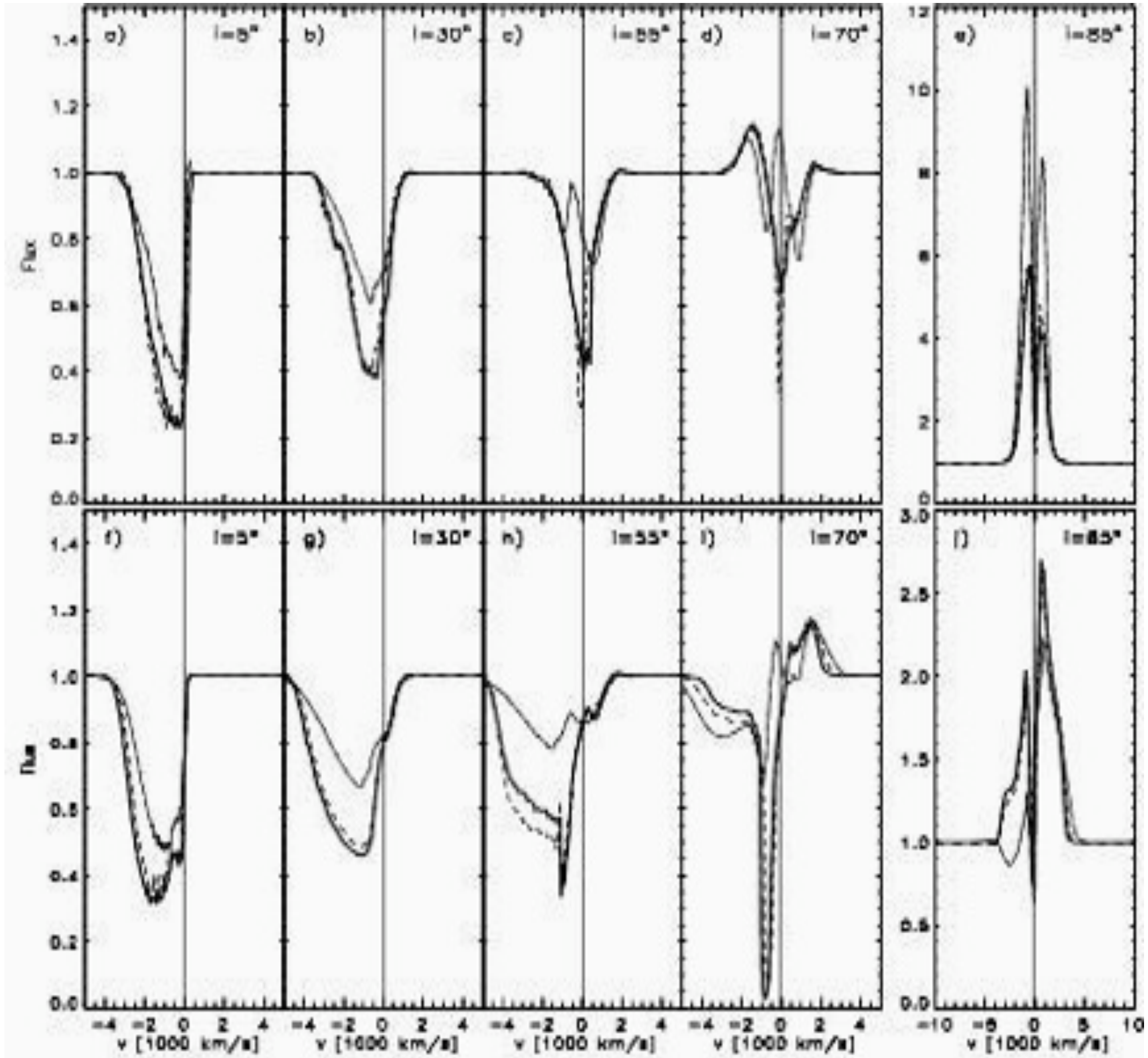

HD simulations and observations

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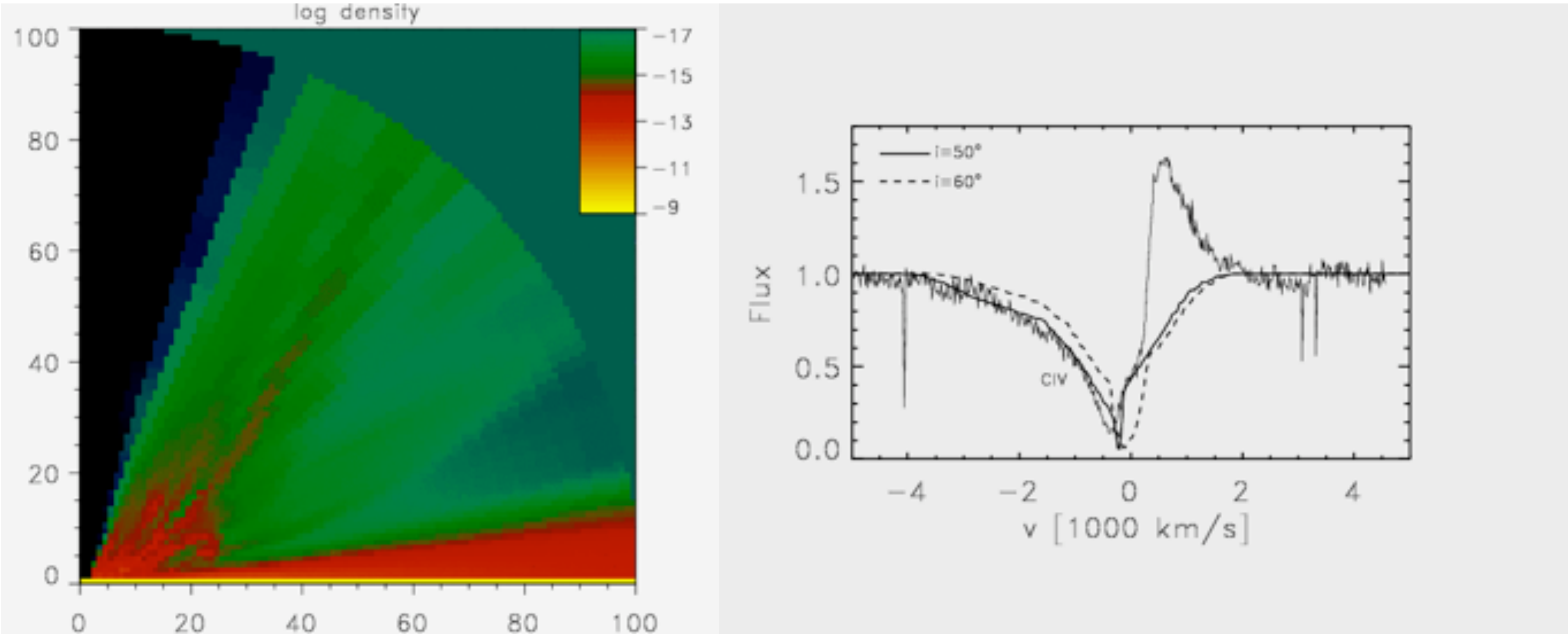

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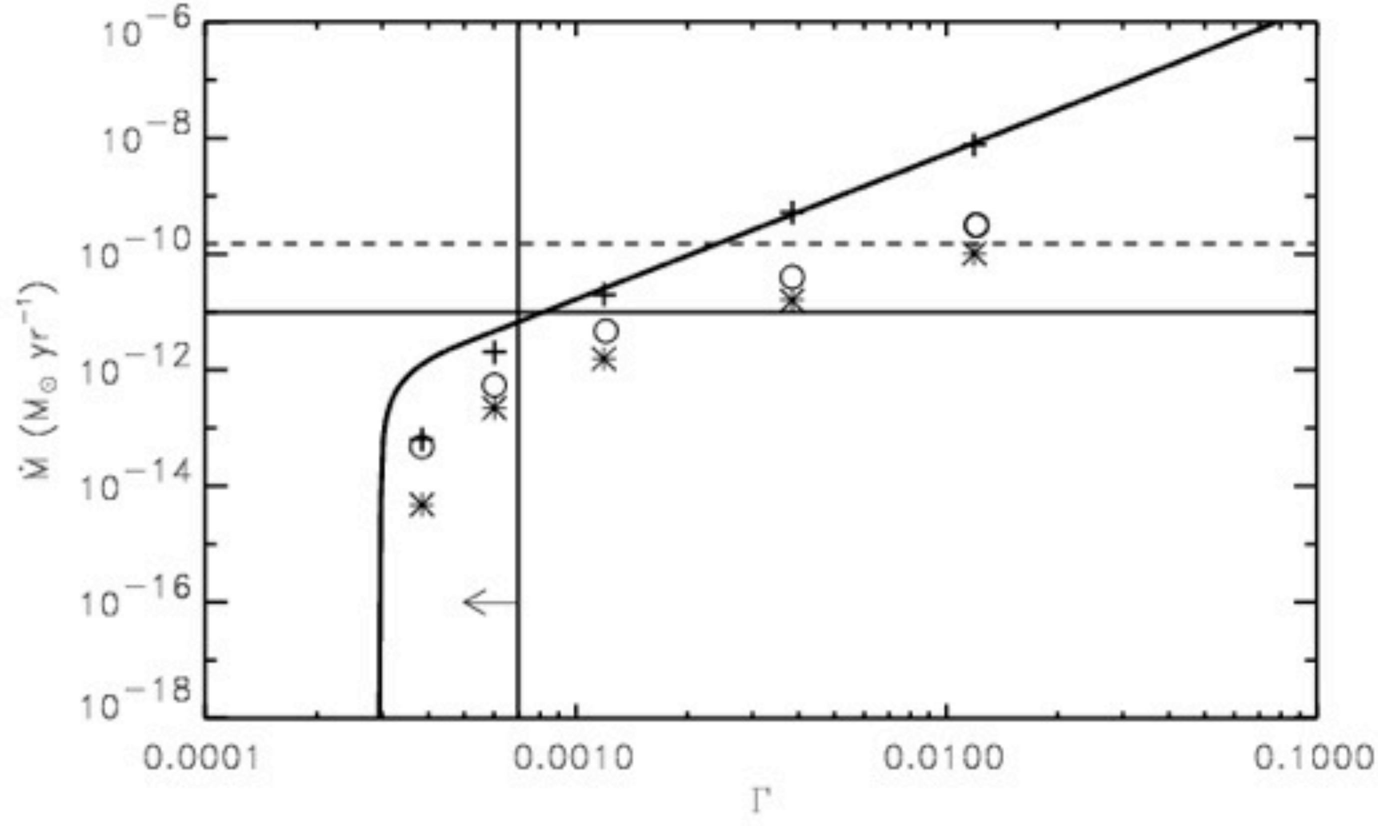
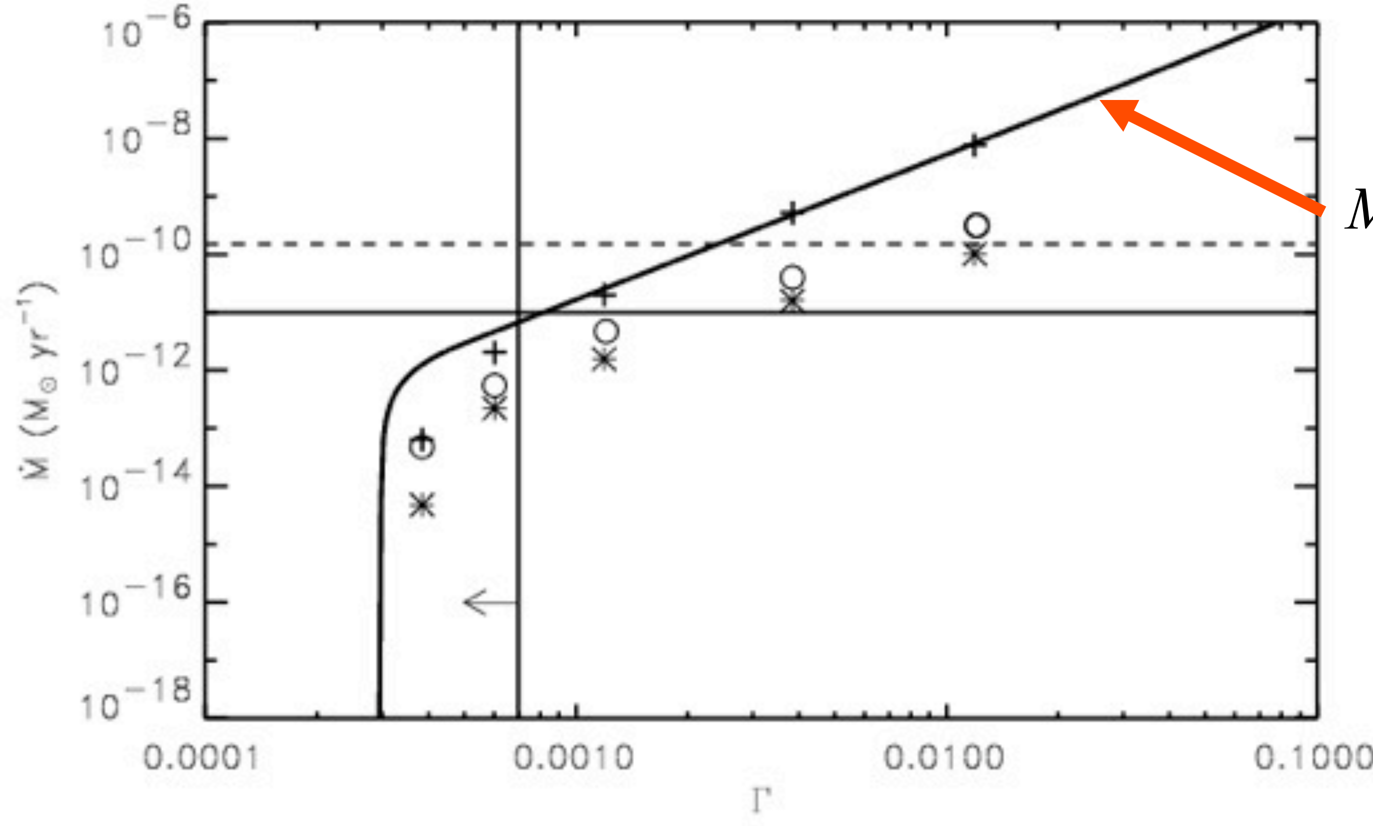
CIV 1549 for IX Vel (Hartley et al. 2001); models Proga (2003b)



Drew & Proga (1999)

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



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

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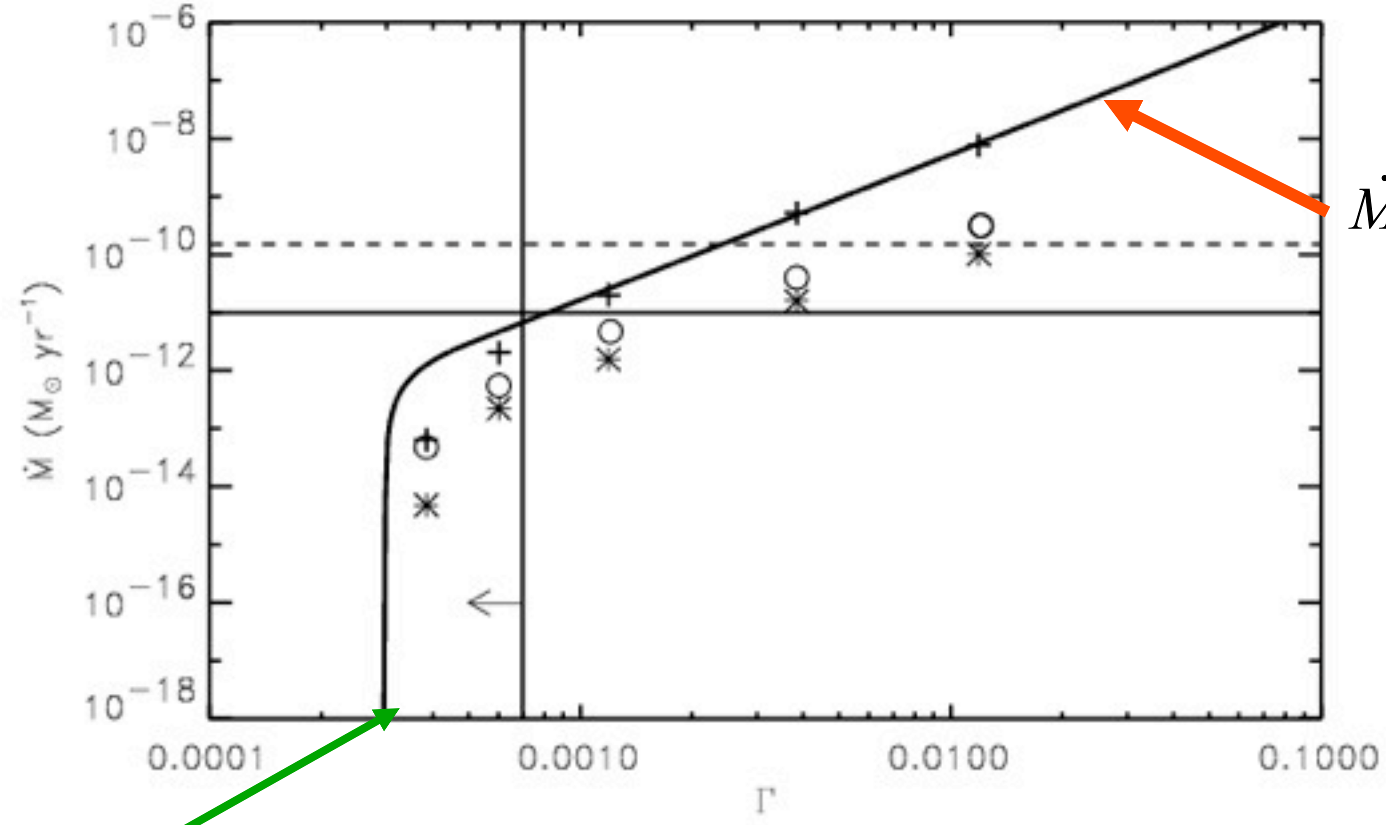

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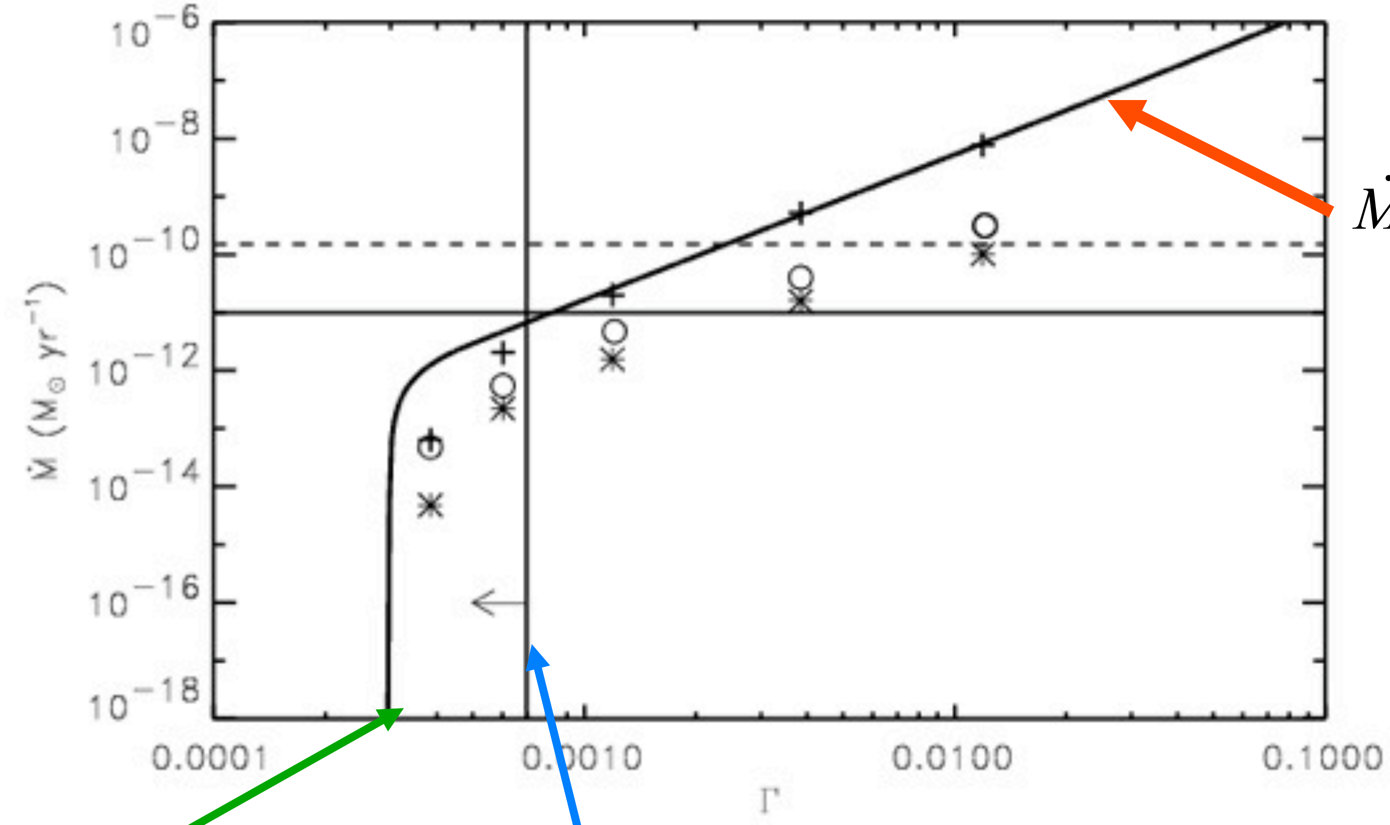

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$M_{WD} = 1 M_{Sun}$

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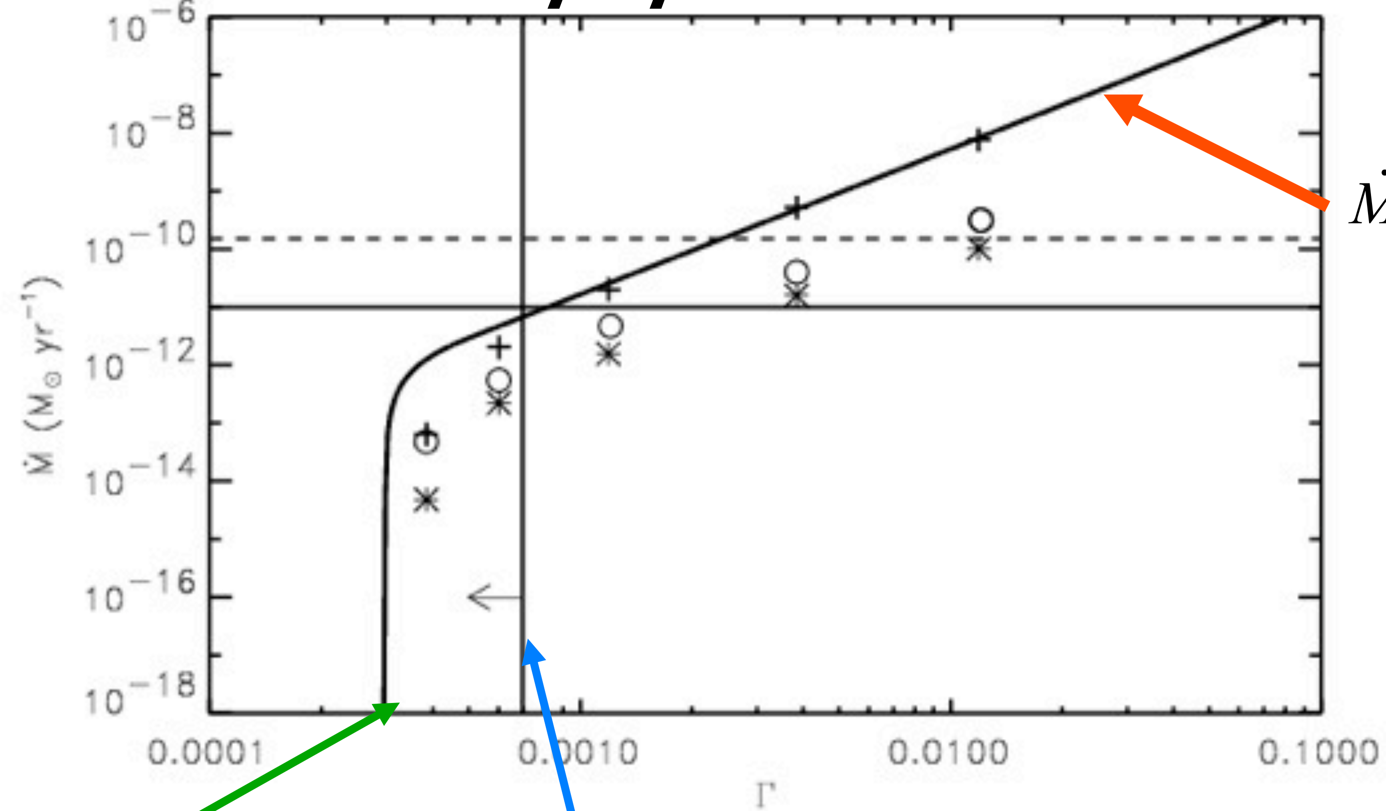
For more on the radiation driven outflows see talk by Ryuichi Kurosawa



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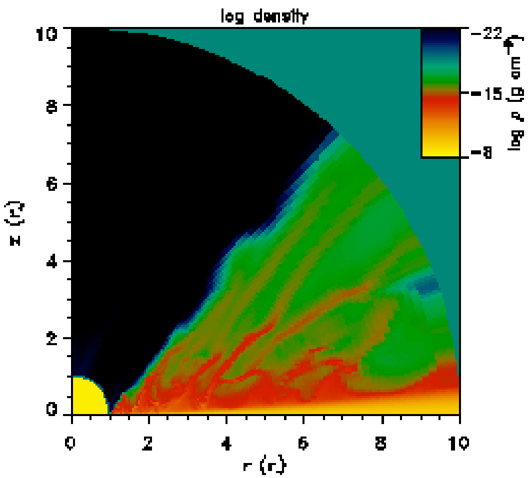
MHD and Radiation Driven Winds

MHD-LD Disk Winds

DP (2003a)

MHD-LD Disk Winds



DP (2003a)

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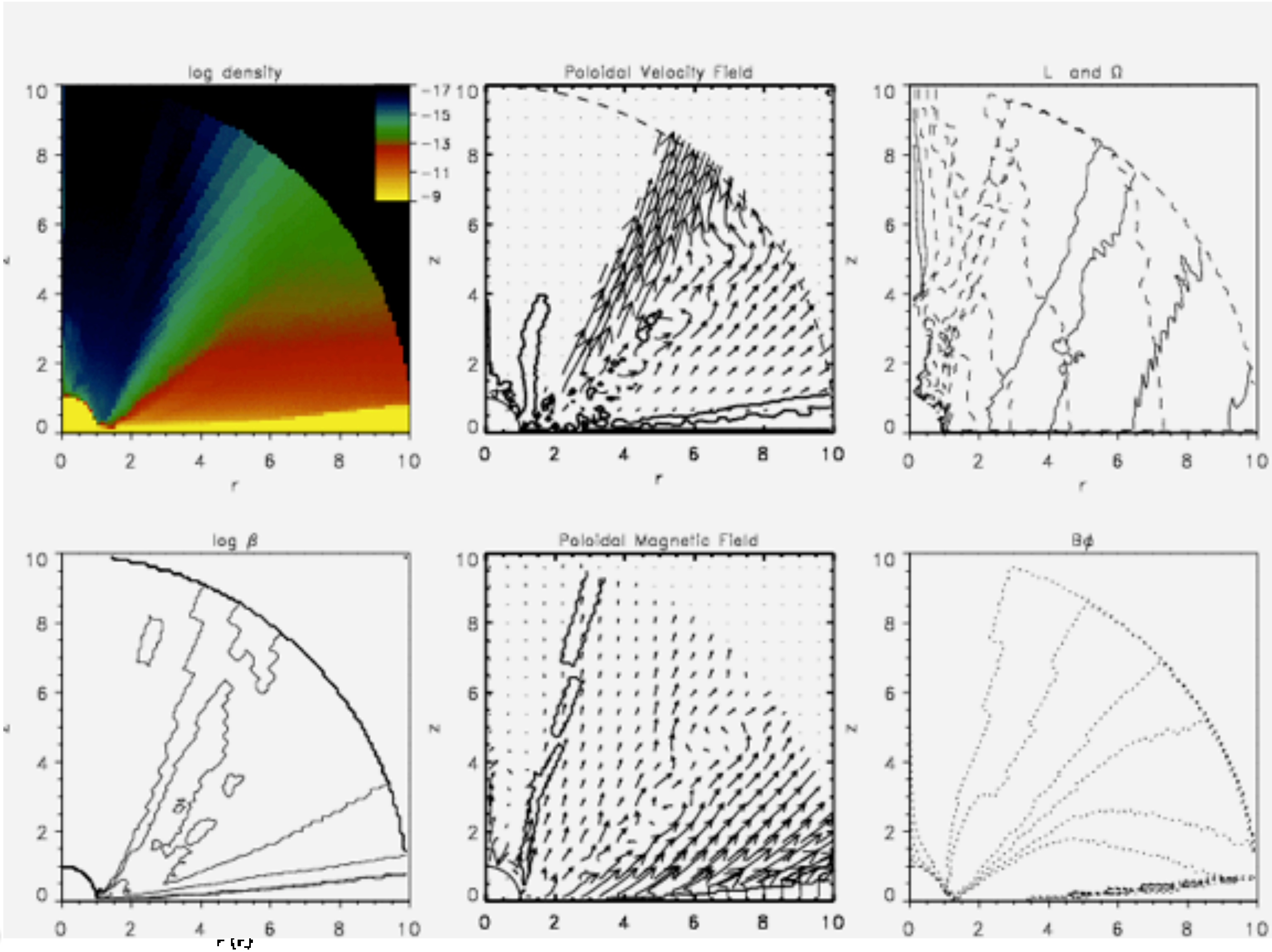

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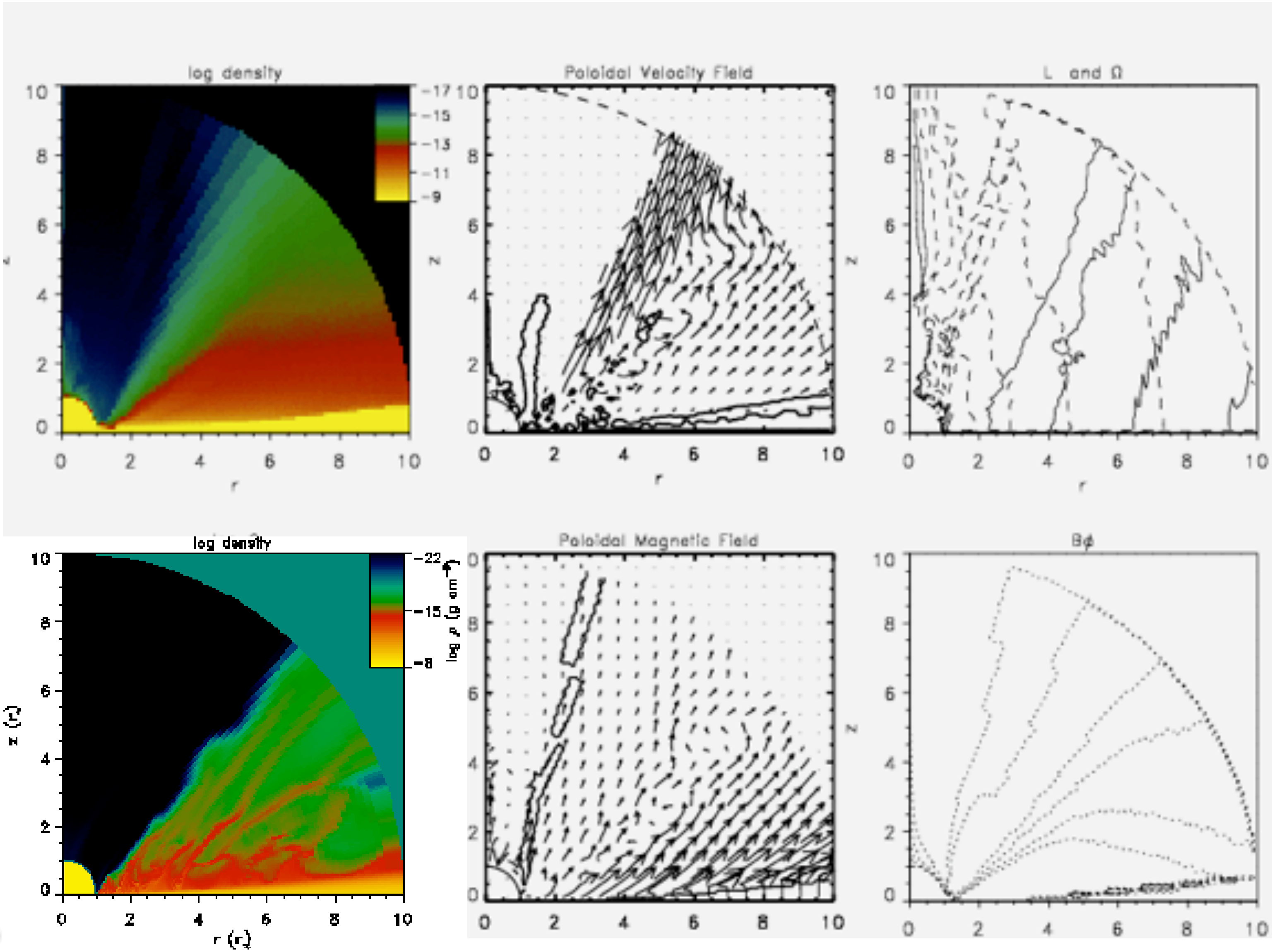
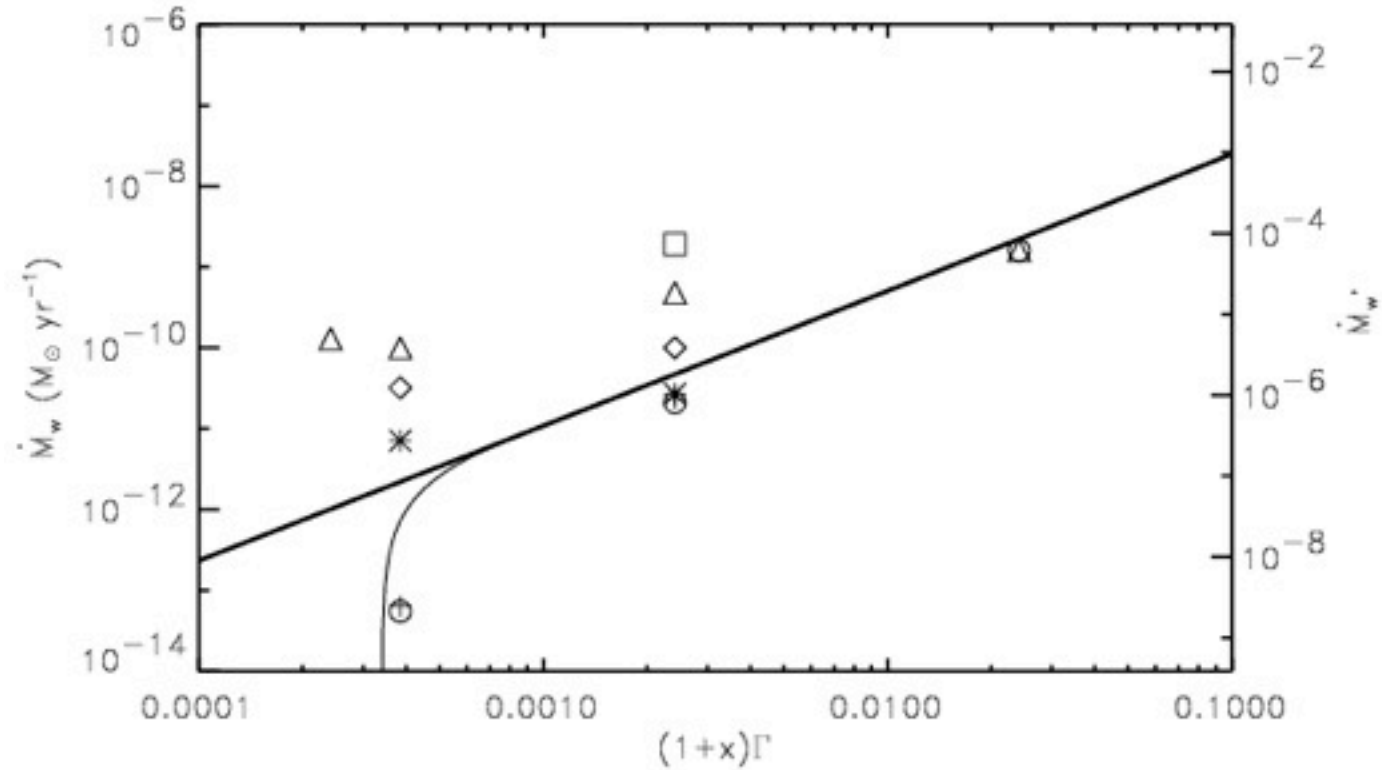


DP (2003a)

The mass loss rate in MHD-LD winds.



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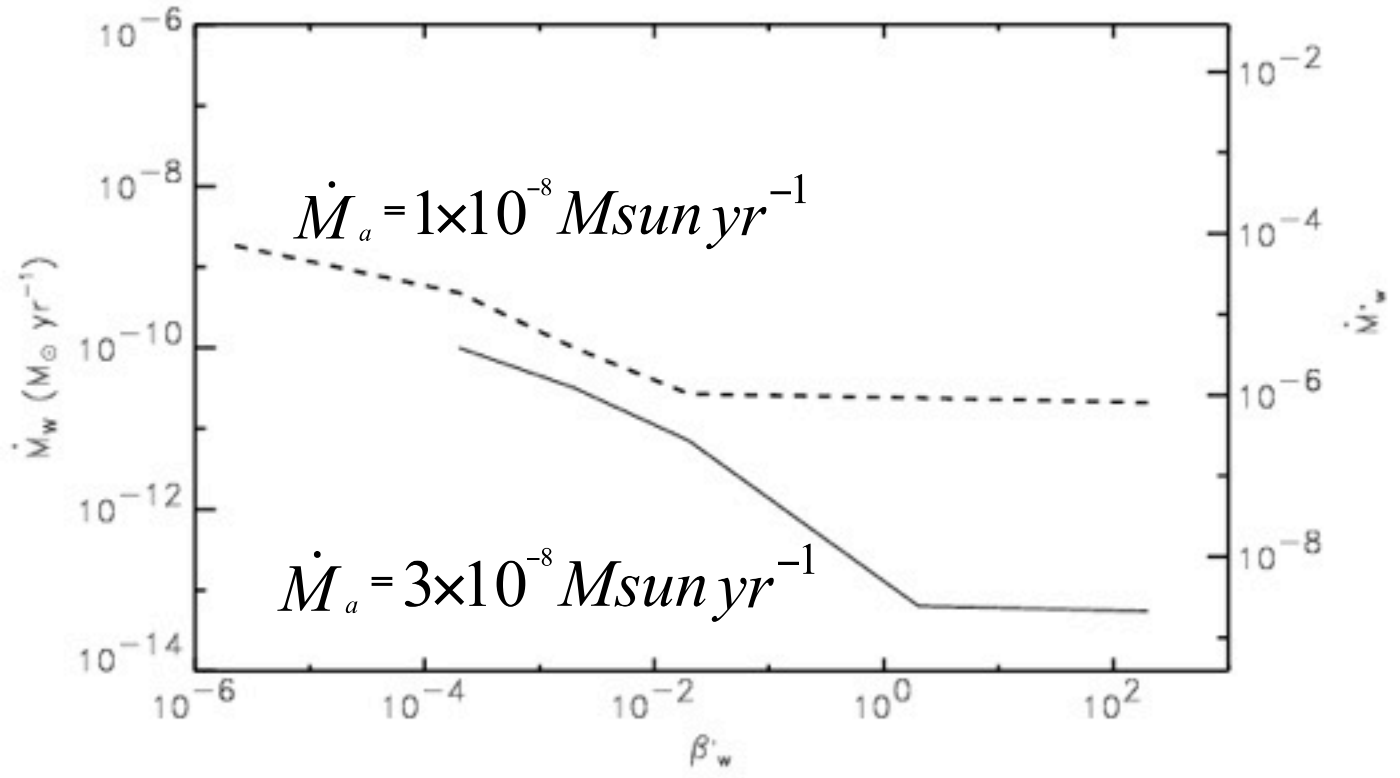

Thermal and Radiation-Driven Winds

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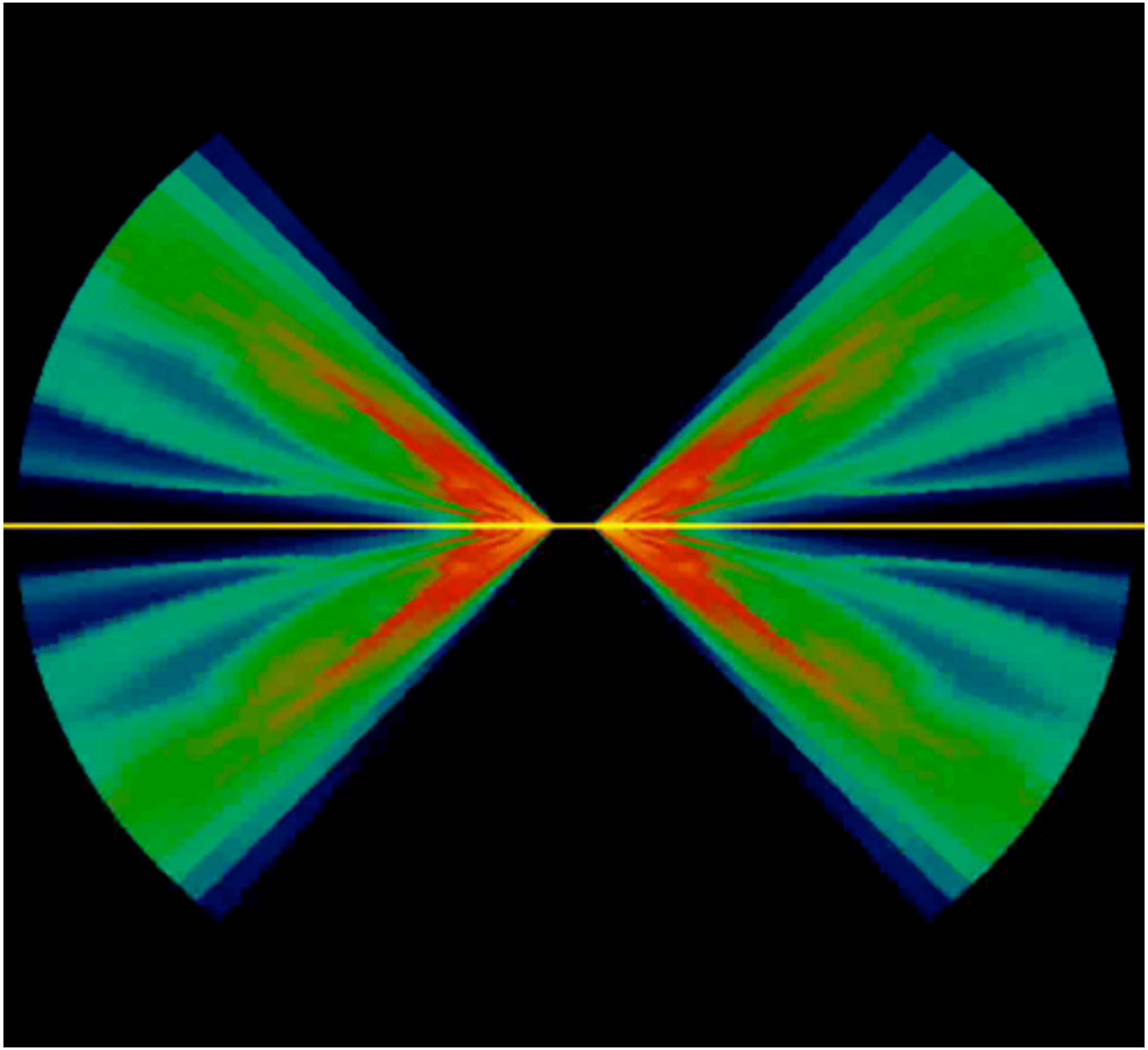
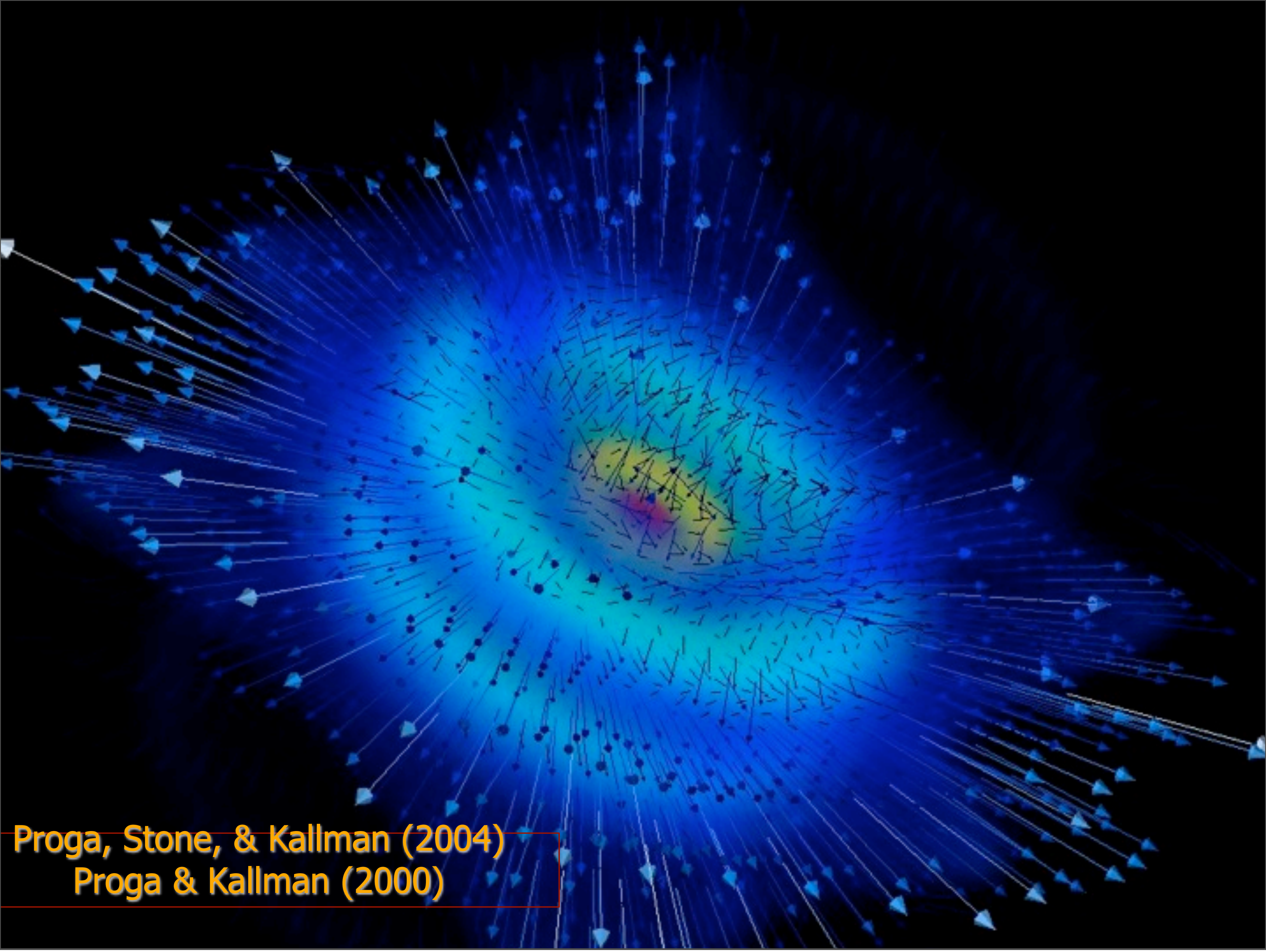
$$\rho \frac{D}{Dt}\left(\frac{e}{\rho}\right) = -P\nabla \cdot v + \rho L$$

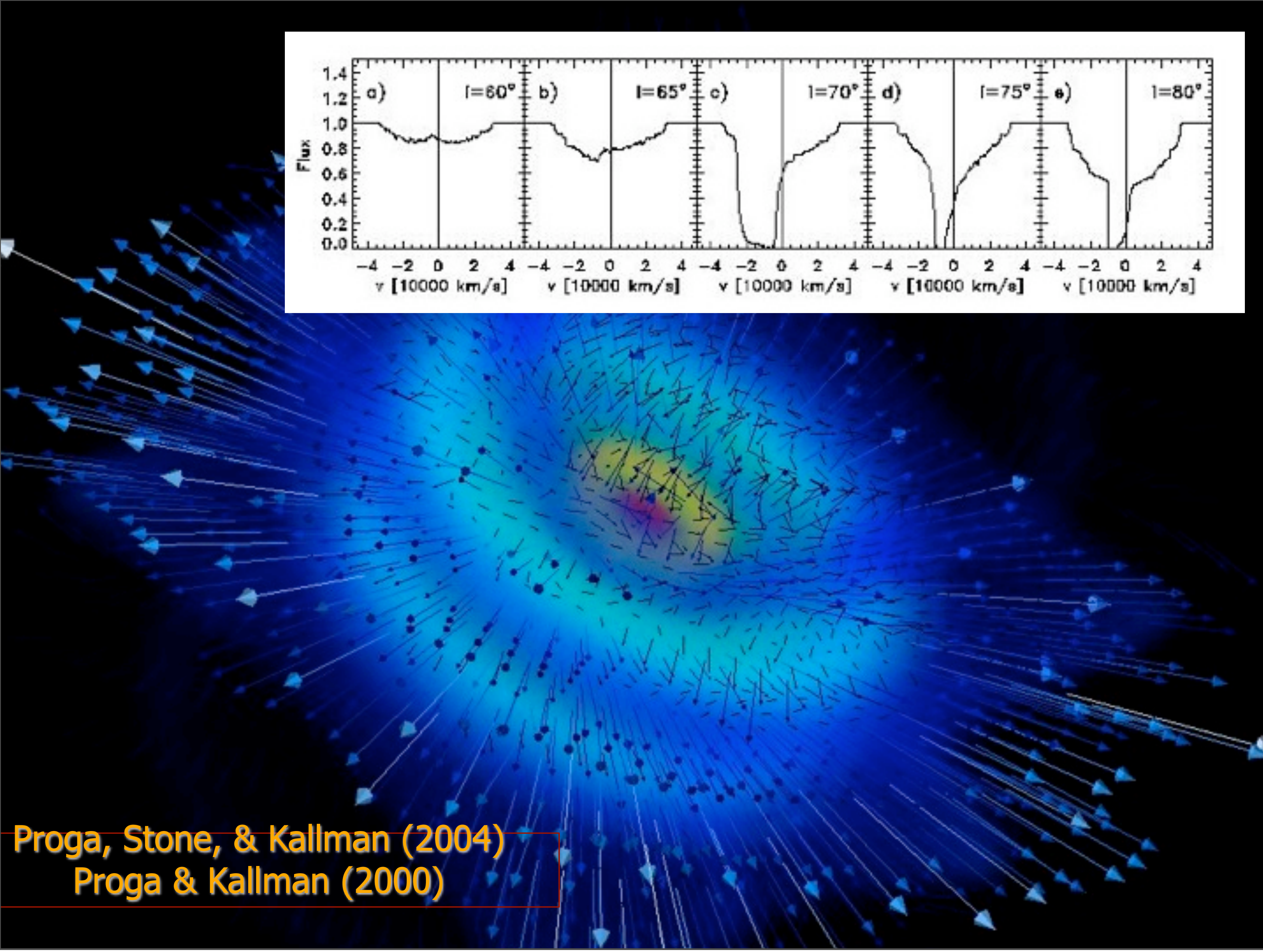
$$P = (\gamma - 1)e$$



$M_{BH} = 10^8 Msun$

$\Gamma = 0.6$


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



Proga, Stone, & Kallman (2004)

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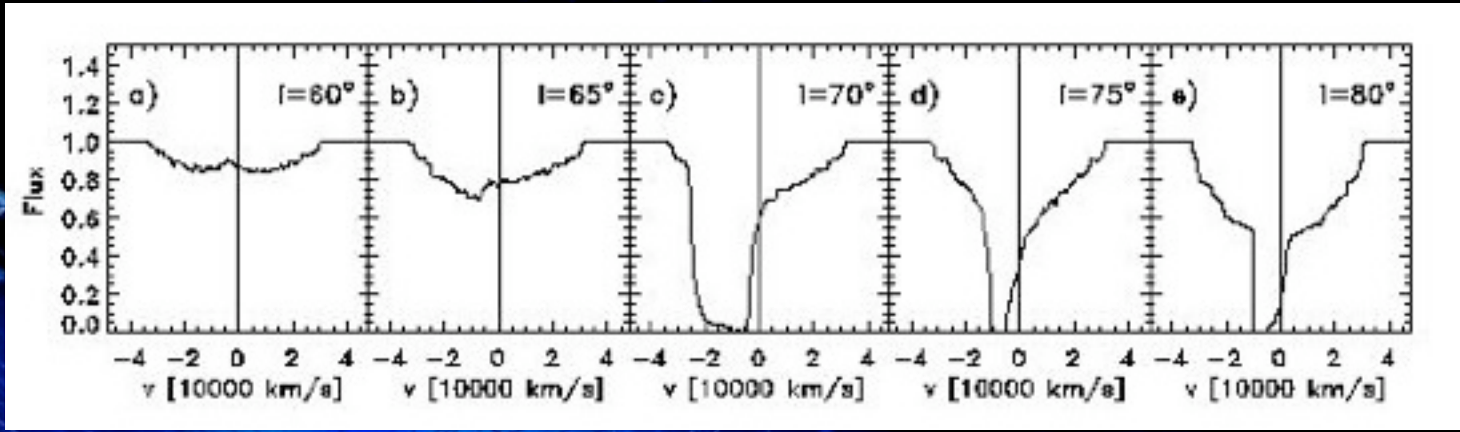

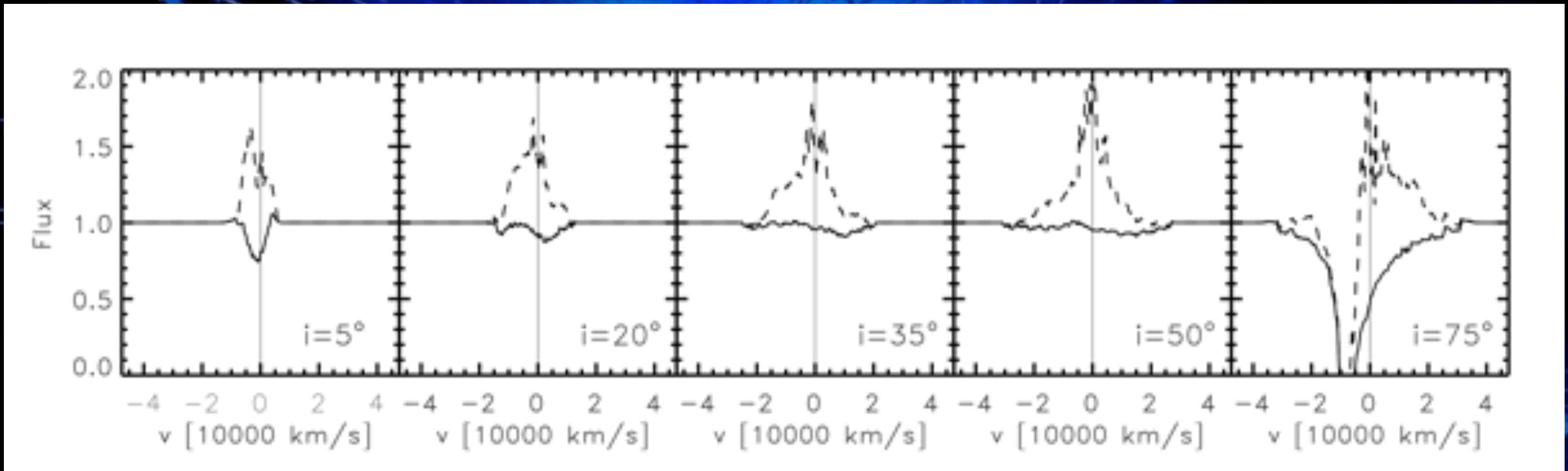

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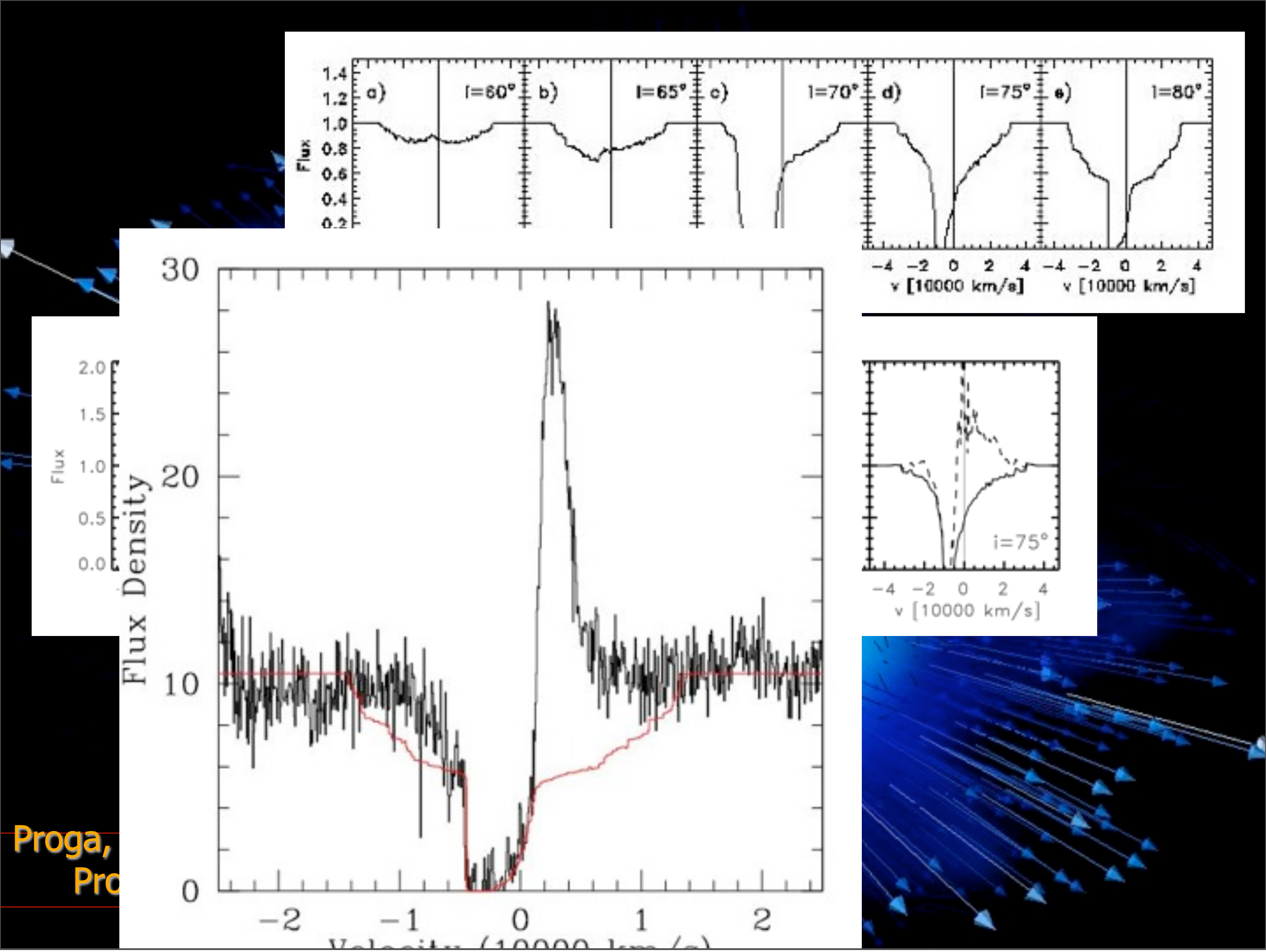
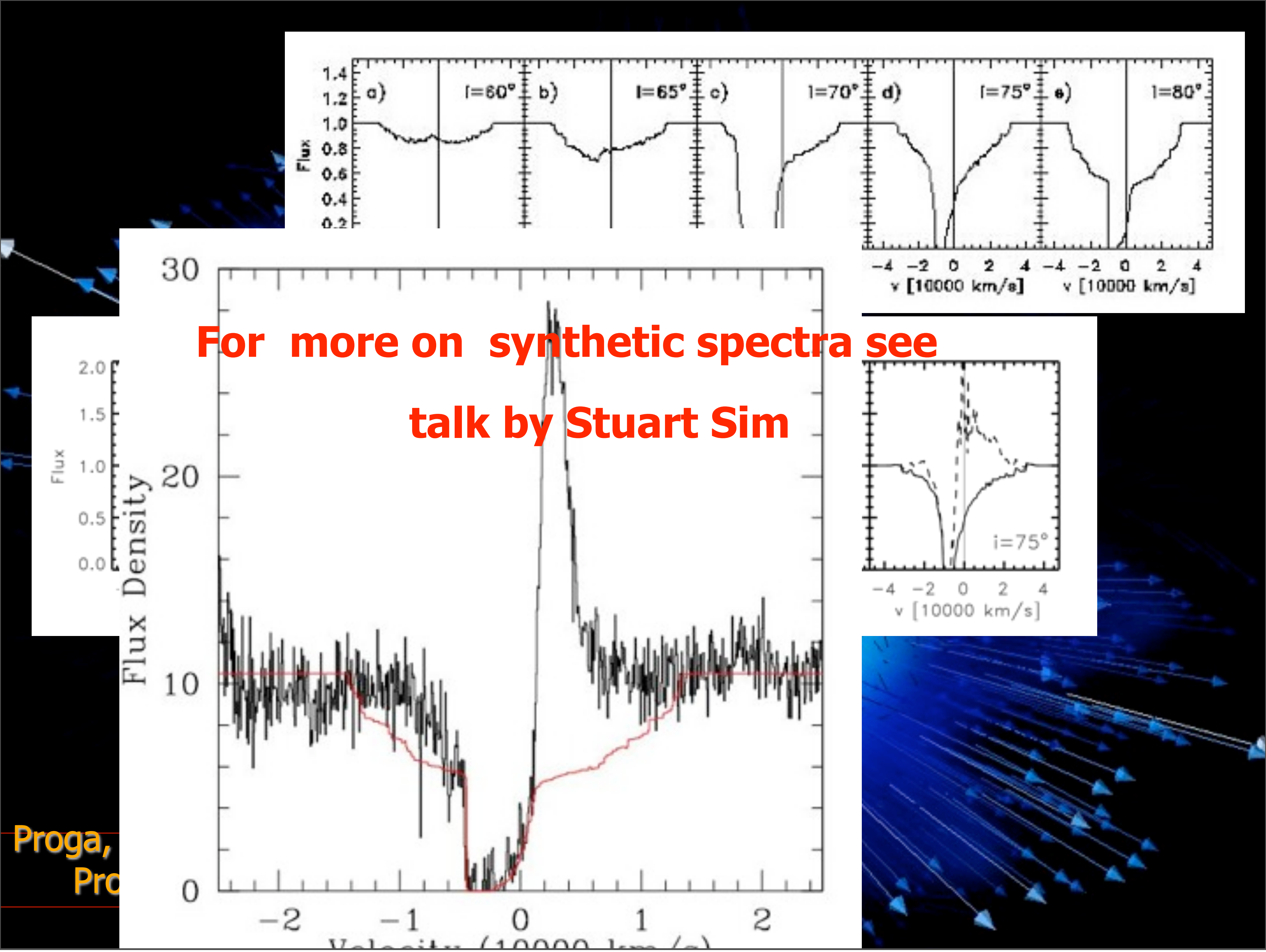


a) i=60°
b) i=65°
c) i=70°
d) i=75°
e) i=80°
Flux
v [10000 km/s]
Flux Density
Velocity (10000 km/s)
i=75°
Proga,
Pro



For more on synthetic spectra see
talk by Stuart Sim
a)
i=60°
b)
i=65°
c)
i=70°
d)
i=75°
e)
i=80°
Flux
v [10000 km/s]
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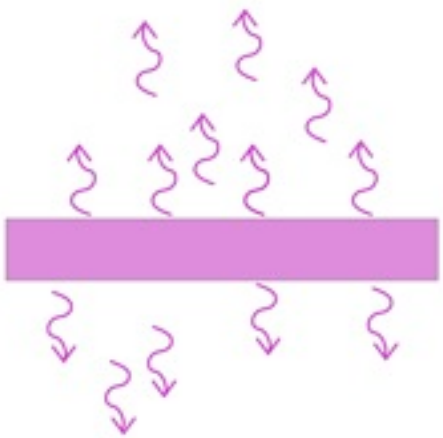
Pro

Quenching Disk Corona

DP (2005)

Quenching Disk Corona

Disk



DP (2005)

Quenching Disk Corona

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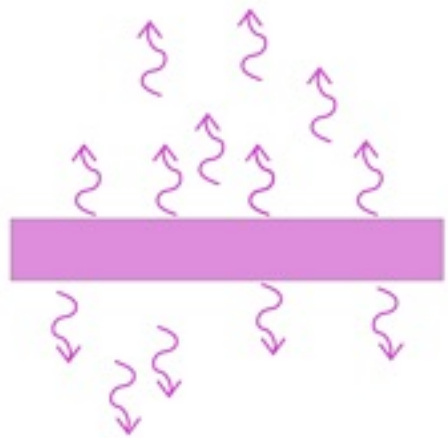
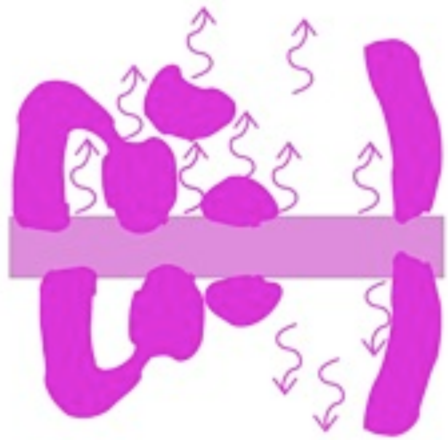


Disk and inflow/outflow



DP (2005)

Quenching Disk Corona

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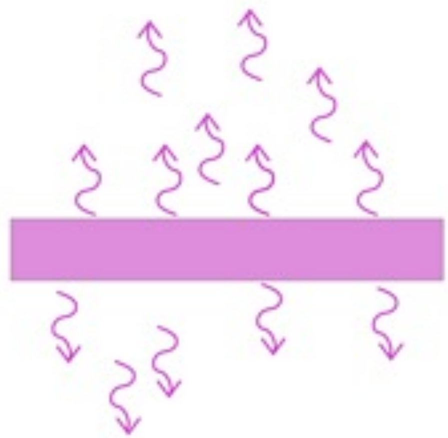

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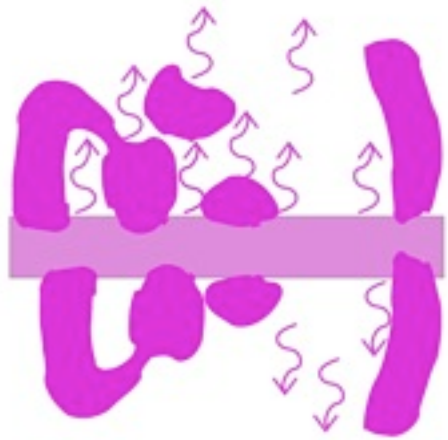

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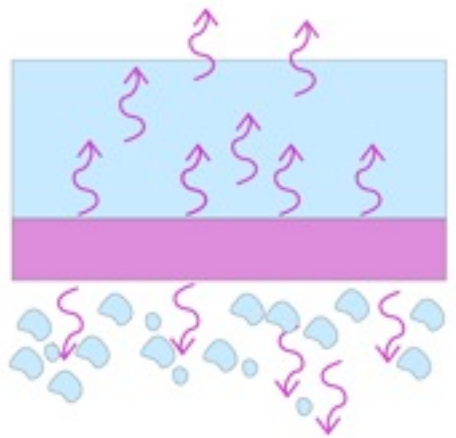

DP (2005)

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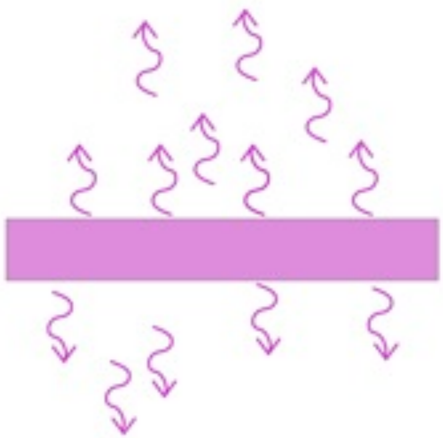

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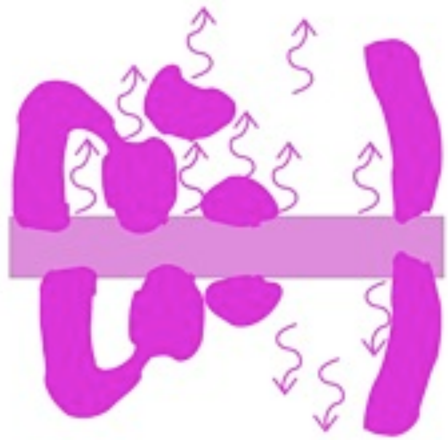

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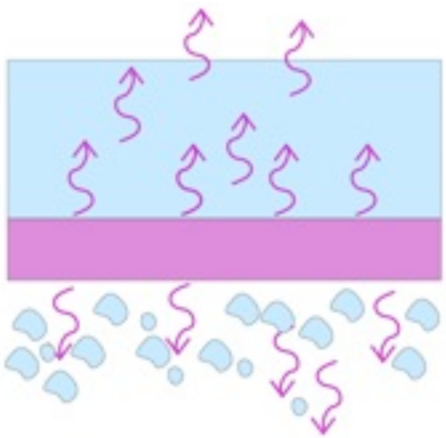

Disk and ???

DP (2005)

Where is the X-ray corona?

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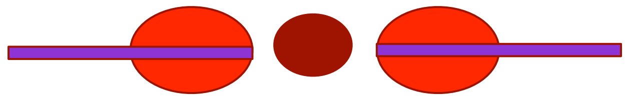

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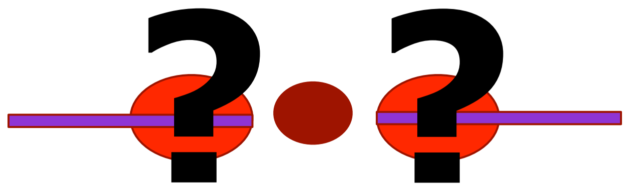

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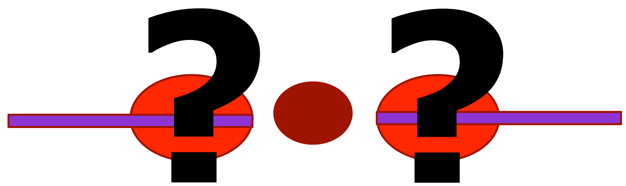

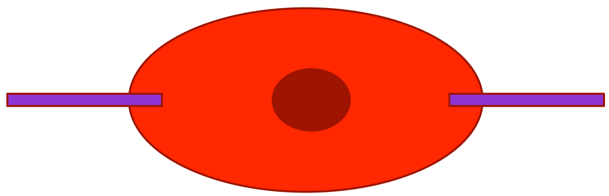

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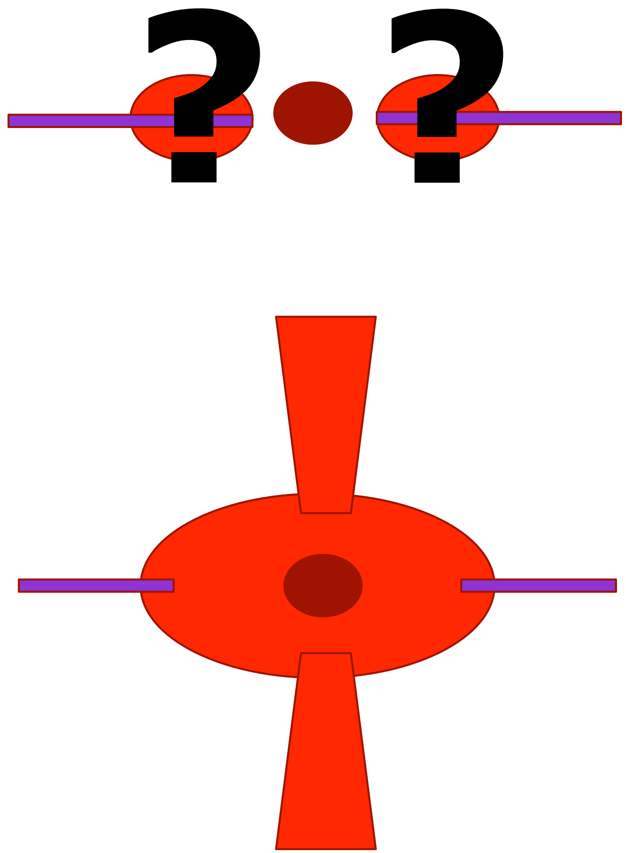

Conclusions

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- 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).
- In general, we have moved beyond spectra modeling: we can predict spectra based on a physical model, some properties of which can be determined from first principles.