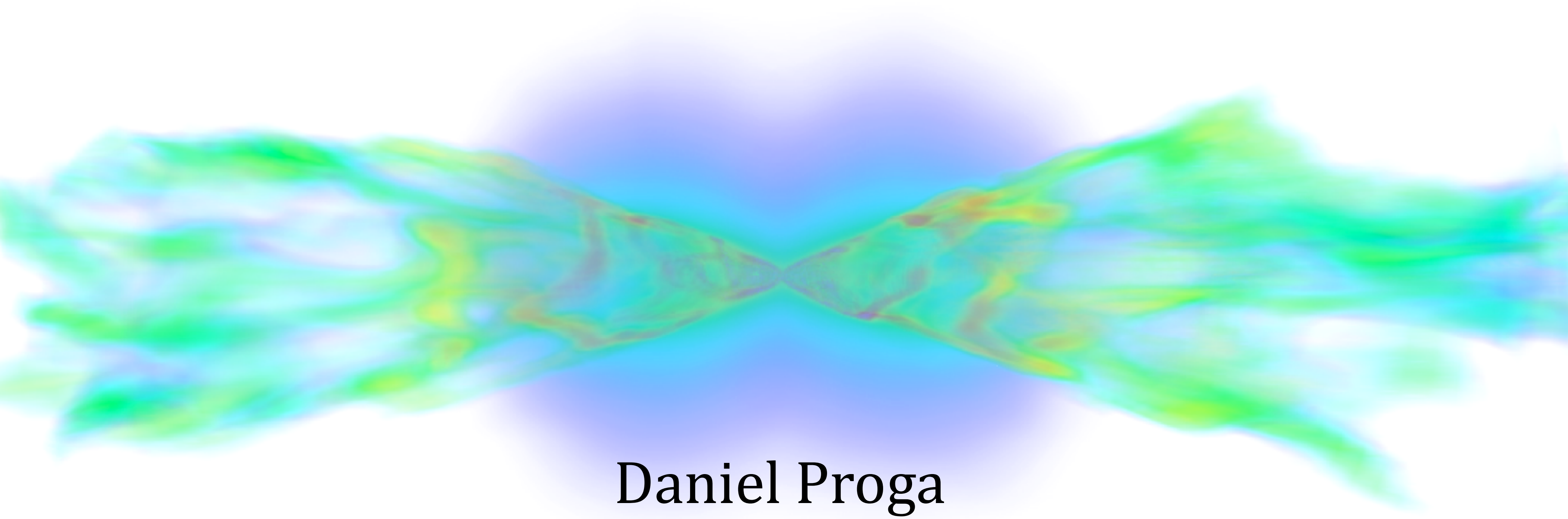
Over-ionization and screening of AGN outflows



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Collaborators: J. Stone, T. Kallman, M. Begelman, J. Ostriker, S. Sim, Y-F. Jiang, S. Davis, **A. Janiuk, R. Kurosawa, M. Moscibrodzka**, **P. Barai, A. Kashi, N. Higginbottom, S. Dyda, and T. Waters,** and many more

OUTLINE

1) Introduction

2) Toward a More Fundamental Model of Quasars/AGNs

a) large scale inflows and outflows

- AGN: Are they the NLRs?
- AGN FB: Can we model the AGN FB directly?

b) radiation driven disk winds

- AGN: Are they the BLRs?
- AGN FB: What is the physics of a 'subgrid'?

3) Future Work

Questions:

1) Why over-ionization is a problem in AGN outflows?

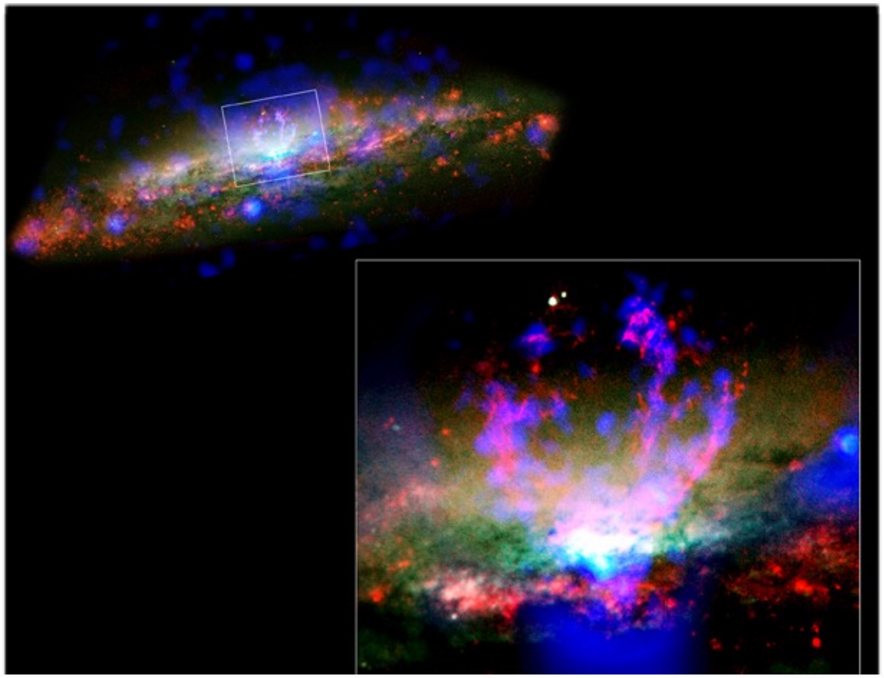
2) Is the problem unique to AGN or do other astrophysical outflows have a similar problem?

3) What are the consequences of the over-ionizaton in magnetically driven outflows and in radiative driven outflows?

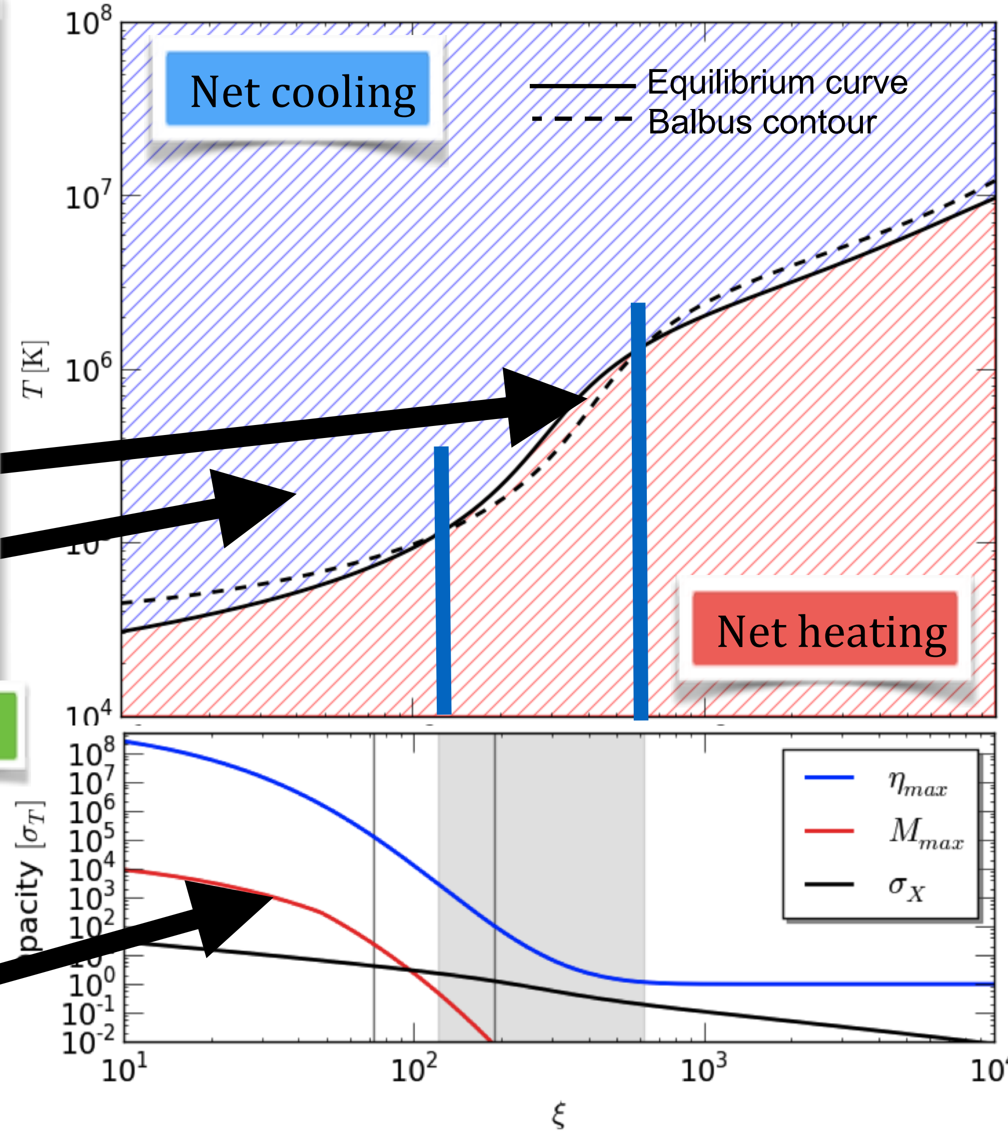
4) Can screening help to solve the over-ionization problem?

5) Do we know the geometry and SED of the AGN radiation well enough to assess the severity of the problem?

Photoionized Gas & Thermal Instability



Credit: NASA/CXC/STScI/U.North Carolina/G.Cecil

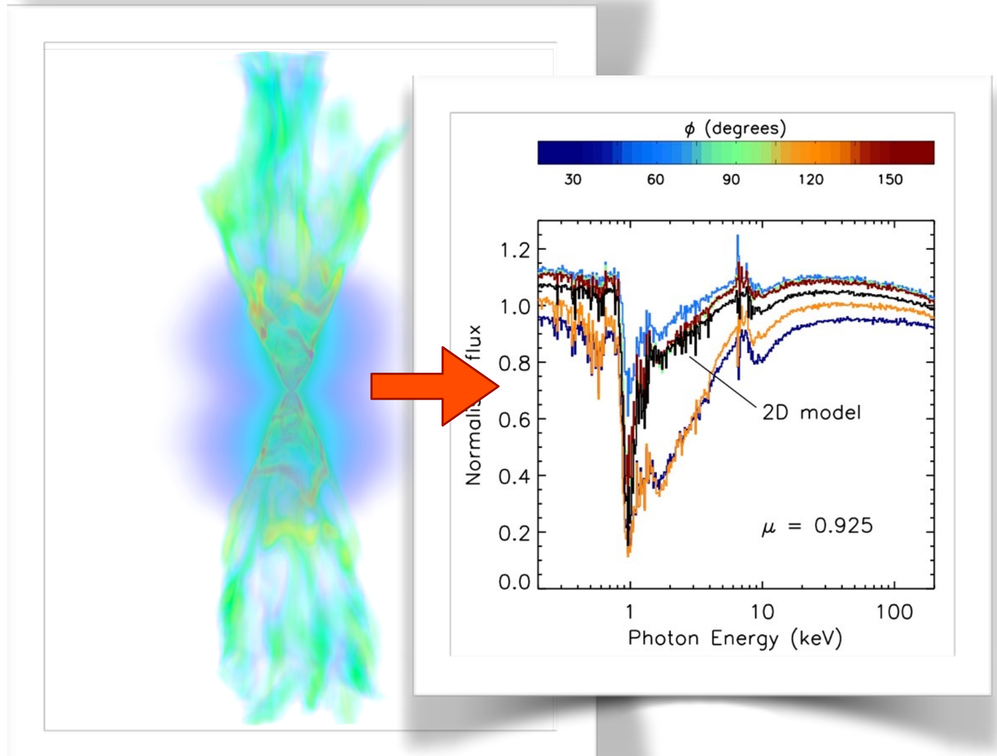


Opacity due to lines is large especially at low photoionization parameter

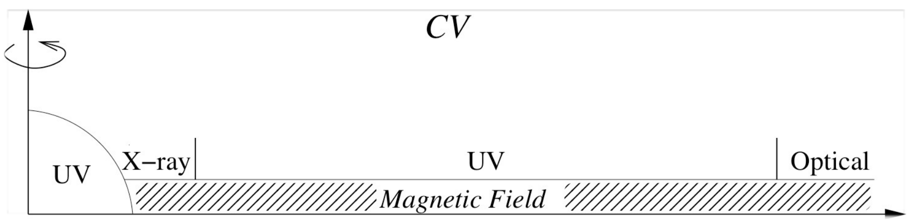
Essentials:

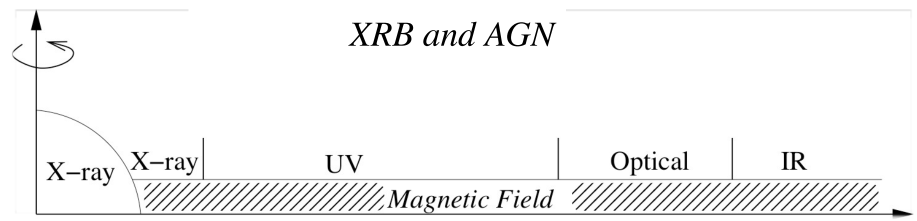
1) Calculations of the physical conditions and emission/ transmitted spectra of photo-ionized gases.
2) Simulations of fluid dynamics.

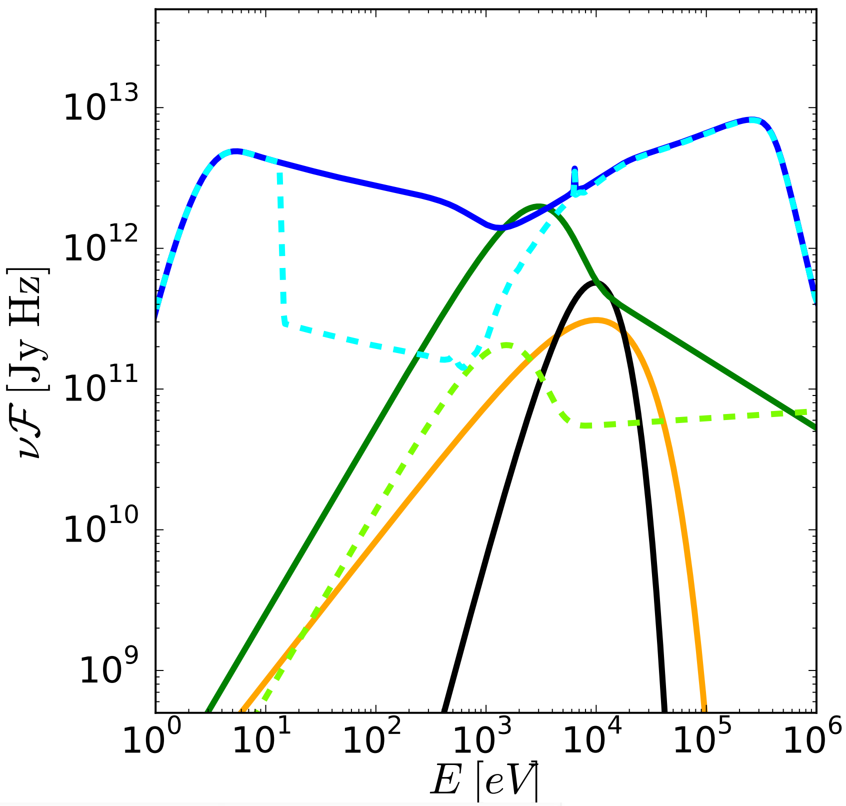
- Compute structure and dynamics of accretion flows and related outflows.
- Study thermal, MRI and other instabilities.
- Determine strength of outflows/ feedback (e.g., mass accretion & supply rates), growth rate of BHs.
- Compute emergent spectra and variability to compare to observations.



Accretion Disks in Various Objects



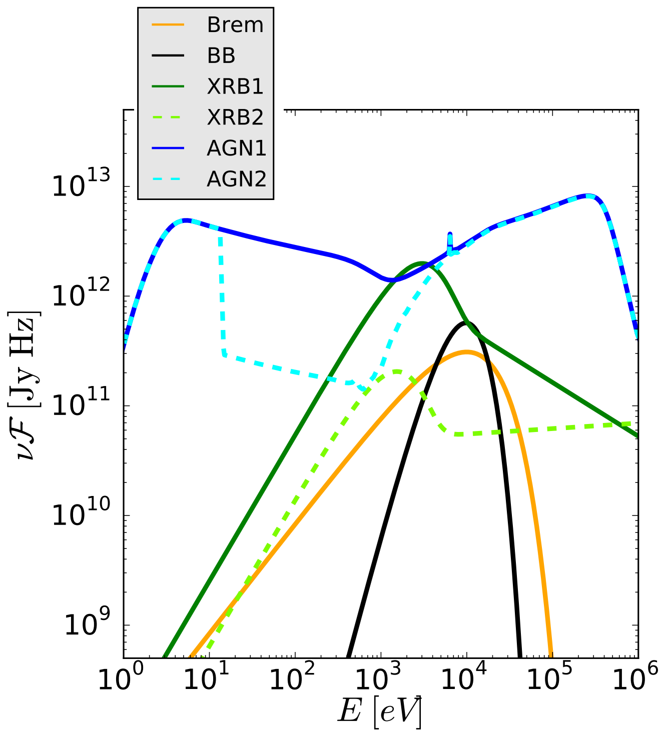


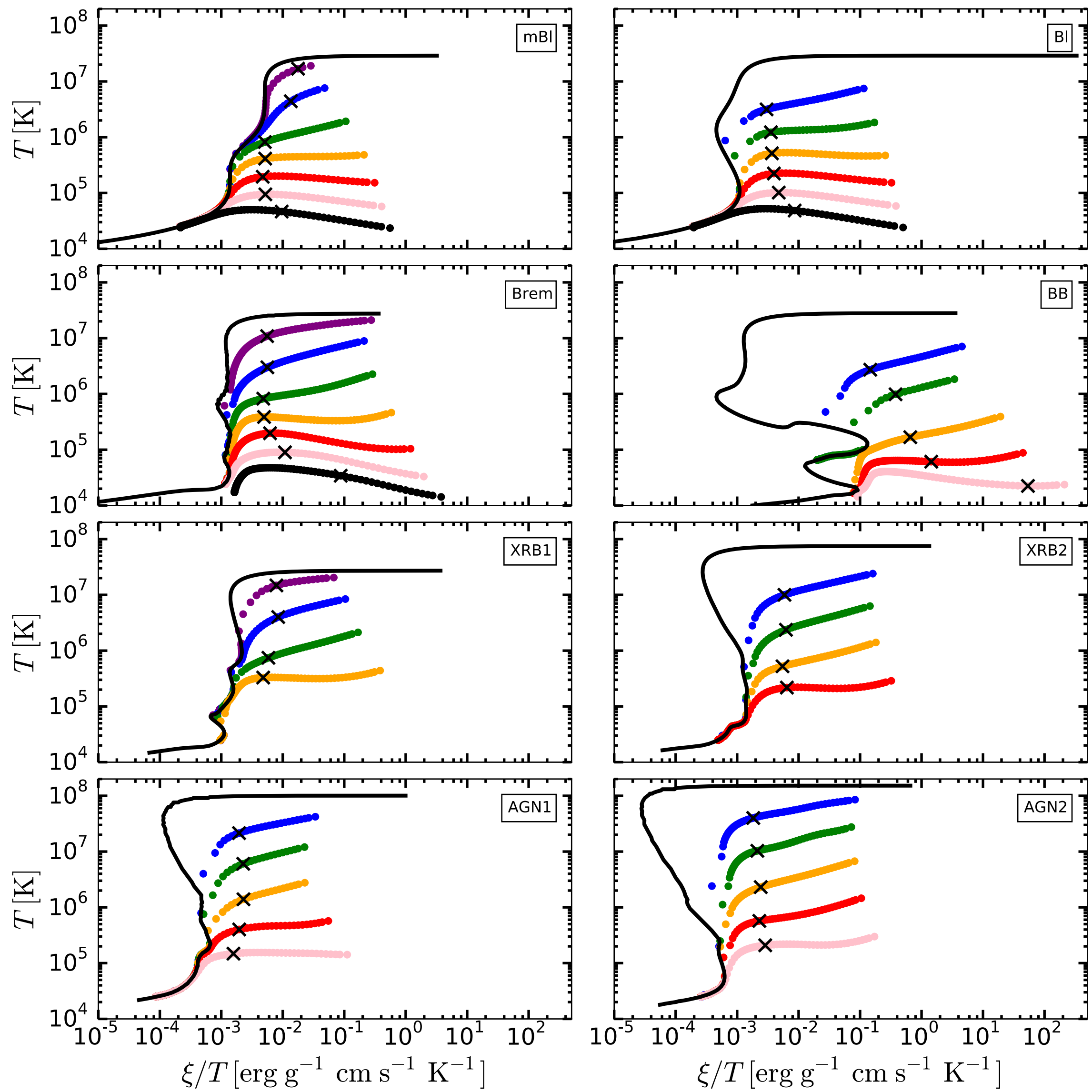


Dyda, Dannen, Waters, DP (2017)

photoionization calculations using XSTAR

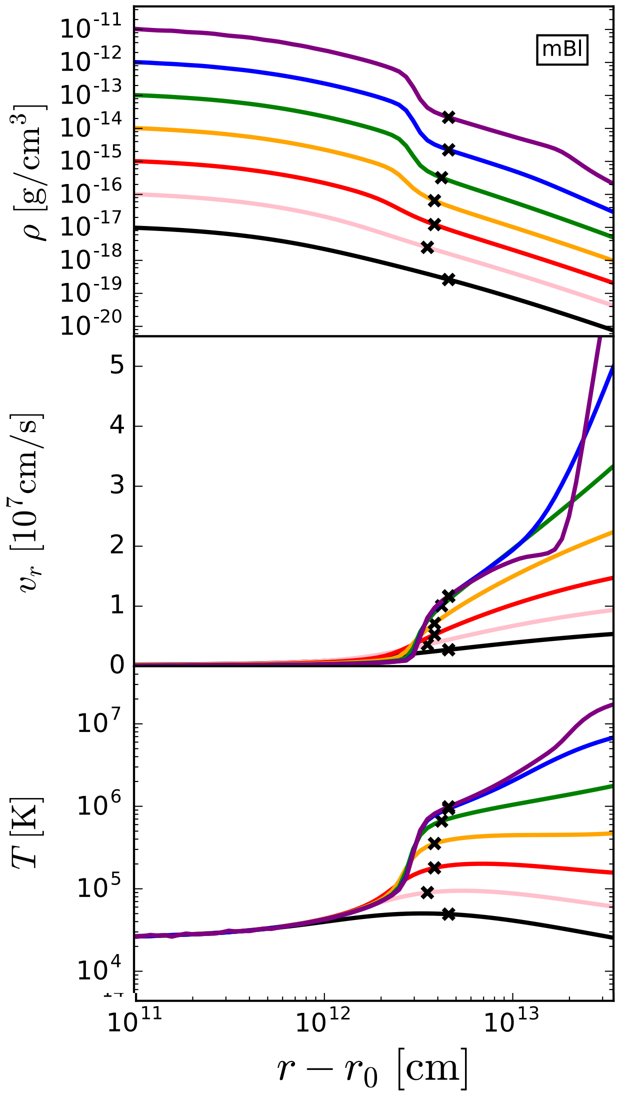
Thermal winds: effects of SED and flux

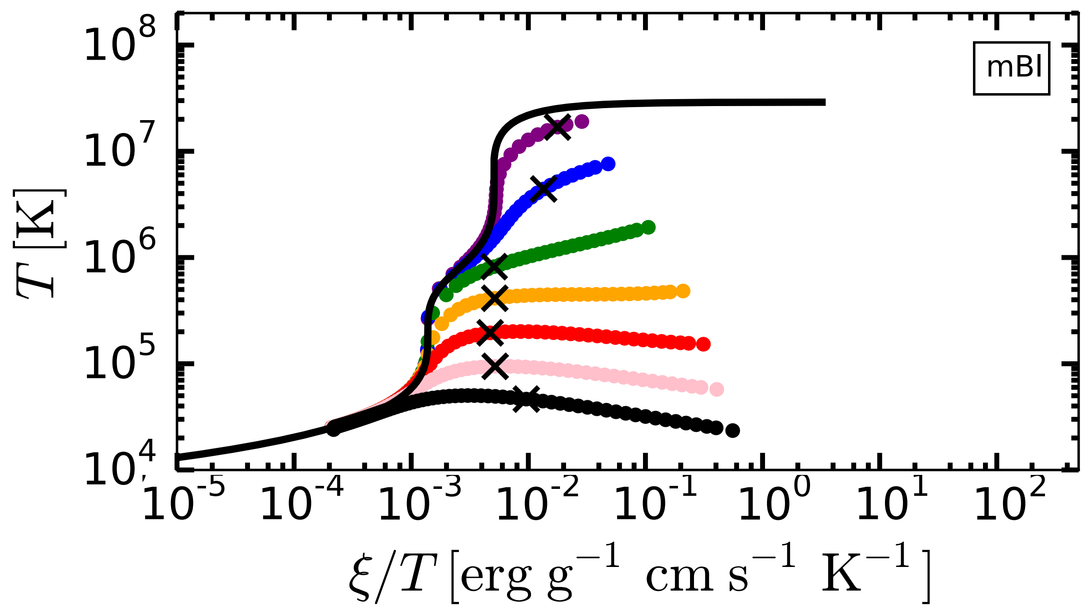




Dyda, Dannen, Waters, DP (2017)

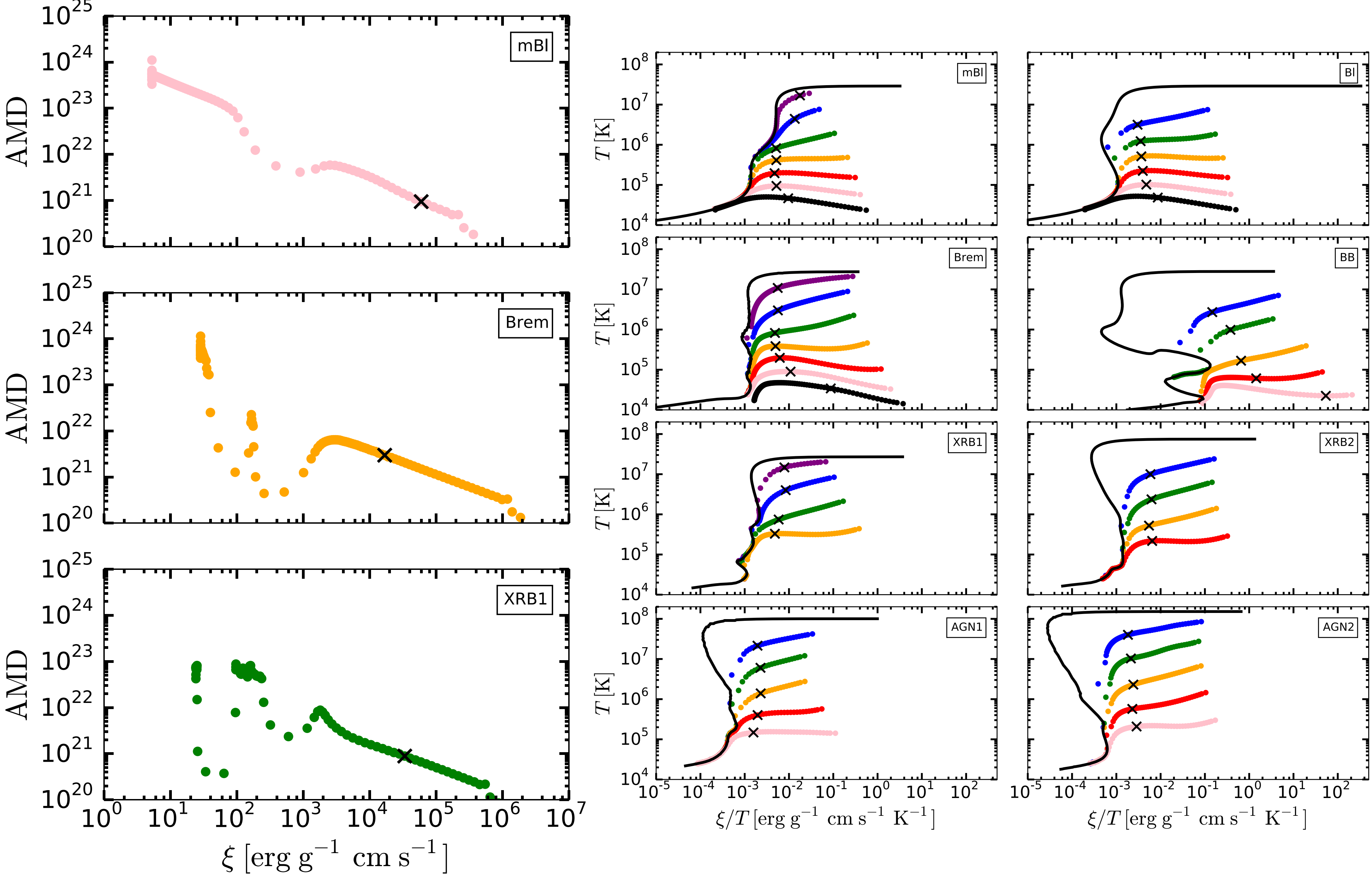
Thermal winds: effects of flux





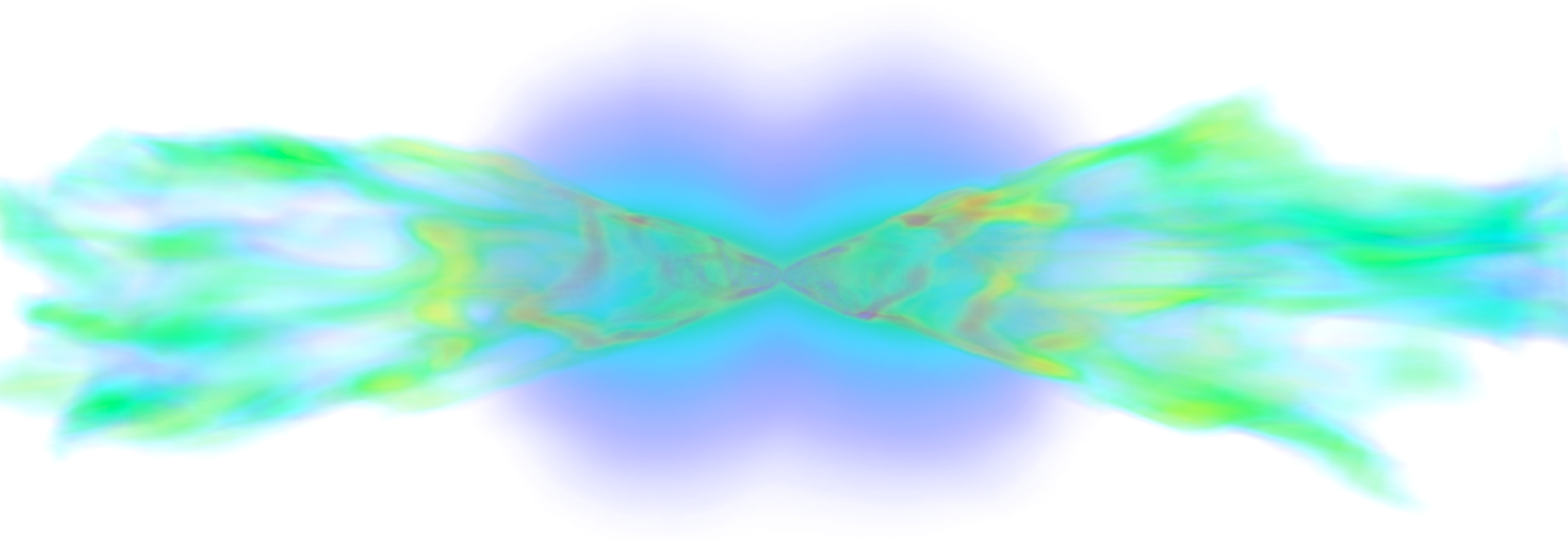
Dyda, Dannen, Waters, DP (2017)

Thermal winds: effects of SED and flux



Large Scale Inflows and Outflows

(Are they the NLRs? Can we model the AGN FB directly?)



Irradiation of an Inflow

(effects of radiative heating/cooling and radiation pressure)

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

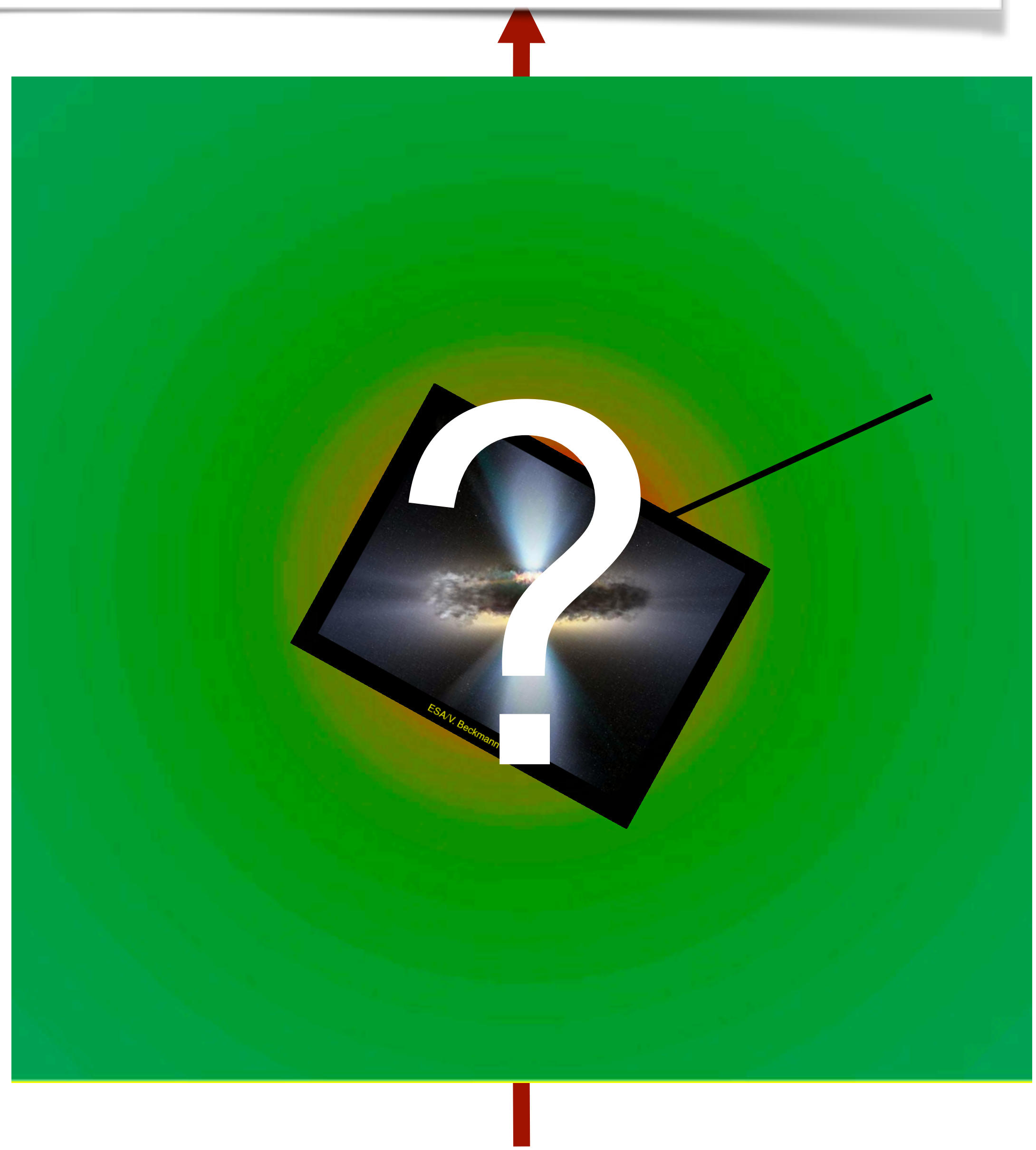
$$\rho \frac{Dv}{Dt} = -\nabla P + \rho g + \rho f^{rad}$$

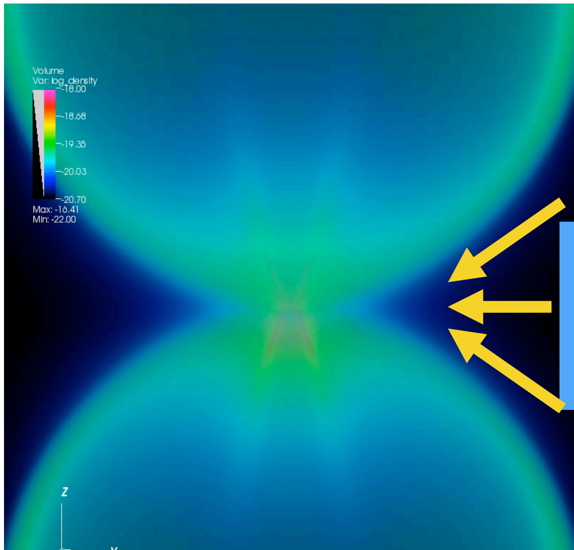
$$\rho \frac{D}{Dt}\left(\frac{e}{\rho}\right) = -P \nabla \cdot v + \rho L$$

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

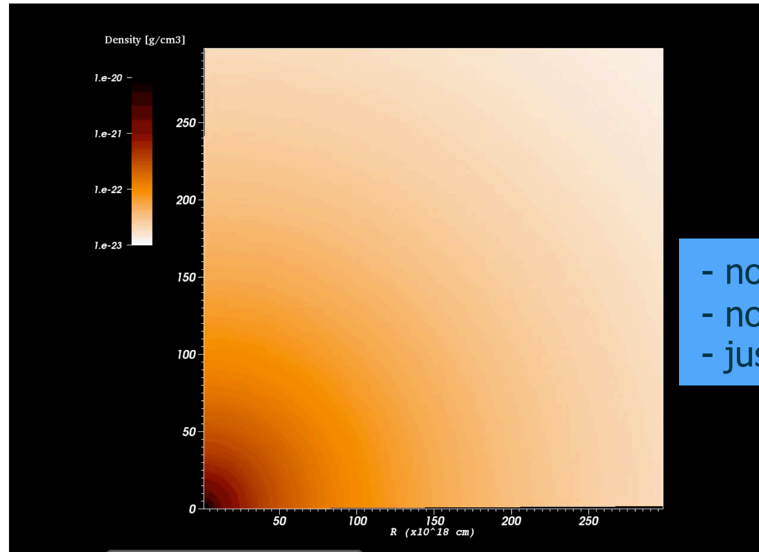
$$\dot{M}_{\mathrm{BH}} = \min(\dot{M}_{\mathrm{Edd}}, \dot{M}_{\mathrm{B}})$$

$$\dot{E}_{\mathrm{feed}} = \epsilon_{\mathrm{f}} L_{\mathrm{r}} = \epsilon_{\mathrm{f}} \epsilon_{\mathrm{r}} \dot{M}_{\mathrm{BH}} c^2$$





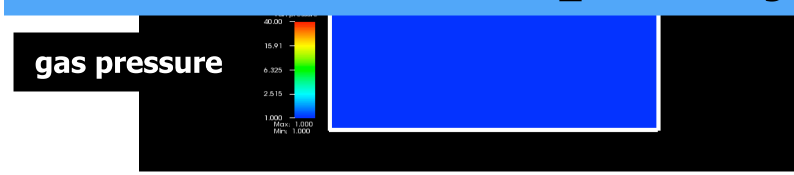
- slowly rotating inflow
- rad. force
- rad. H&C

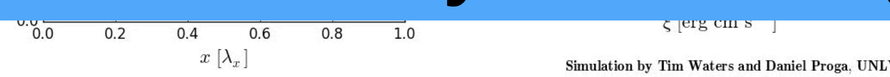


- no rotation
- no rad. force
- just rad. H&C

Dos and Don'ts: Take gas and radiation and let clouds to be accelerated while they form (TI+ line driving+lifting by a hot gas; gas rotation and variable radiation help).

Do not try to accelerate pre-existing clouds unless the opacity is dominated by scattering!

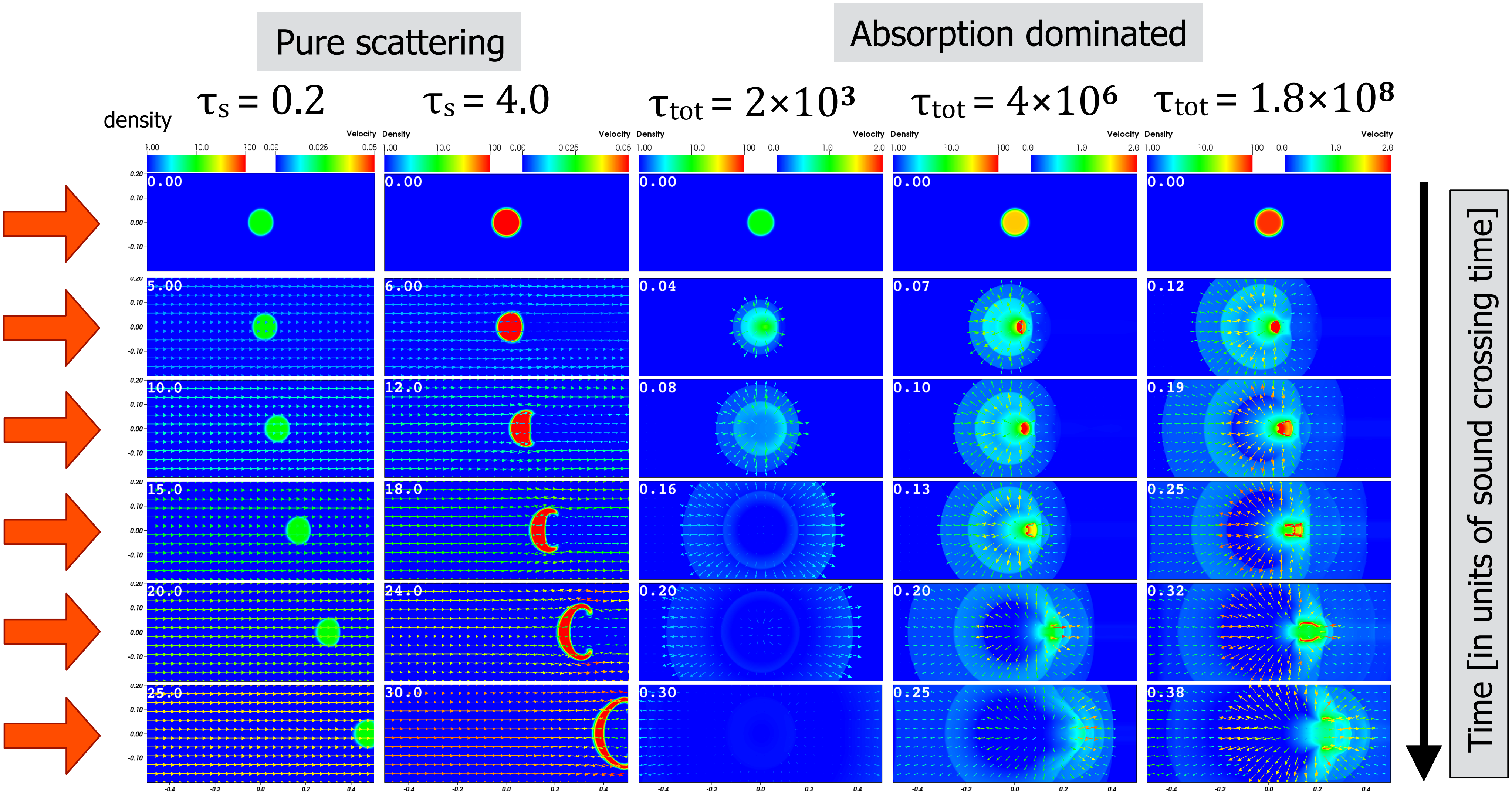




Proga, Jiang, Davis, Stone, & Smith (2014)

Proga & Waters (2015)
Waters & Proga (2016)

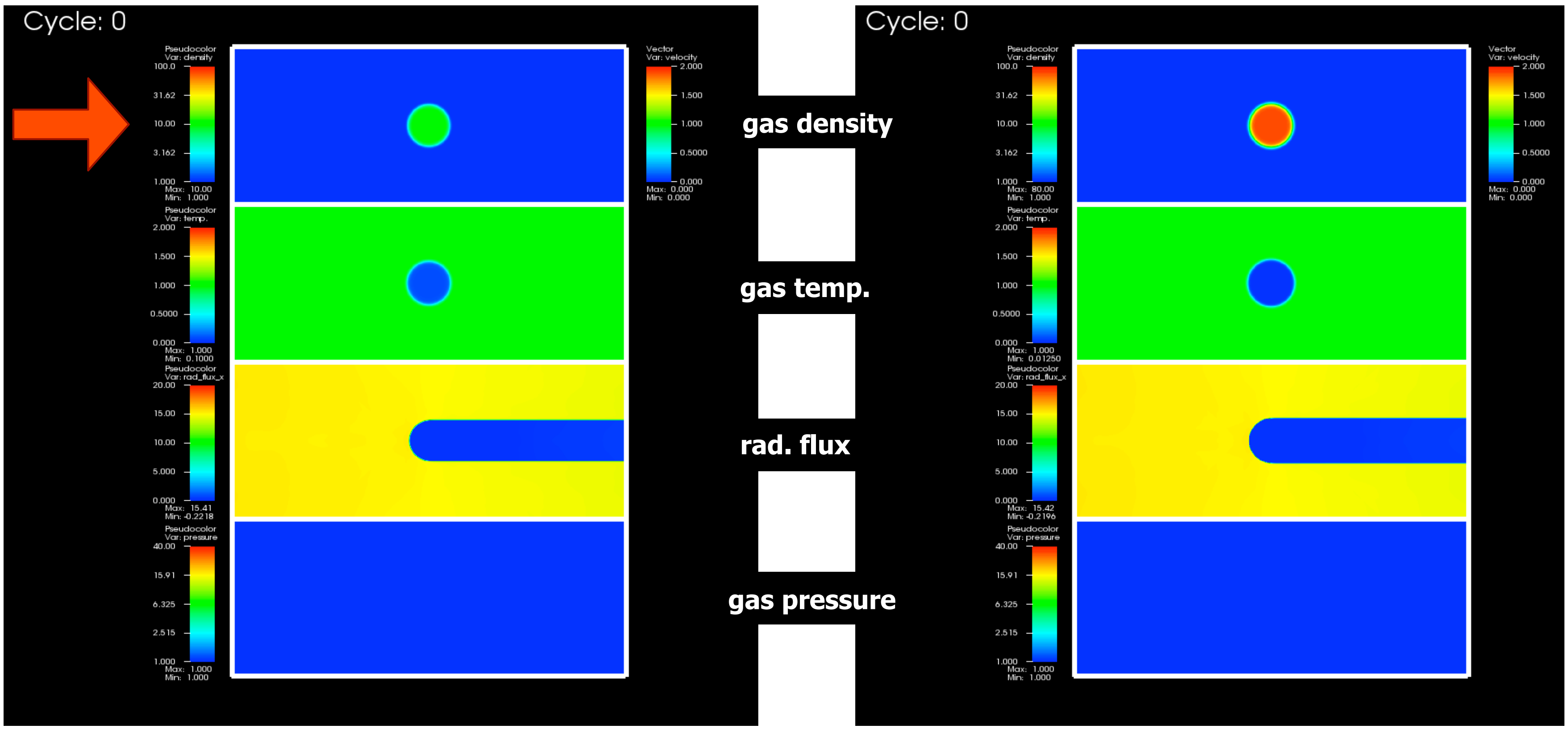
Five cases:



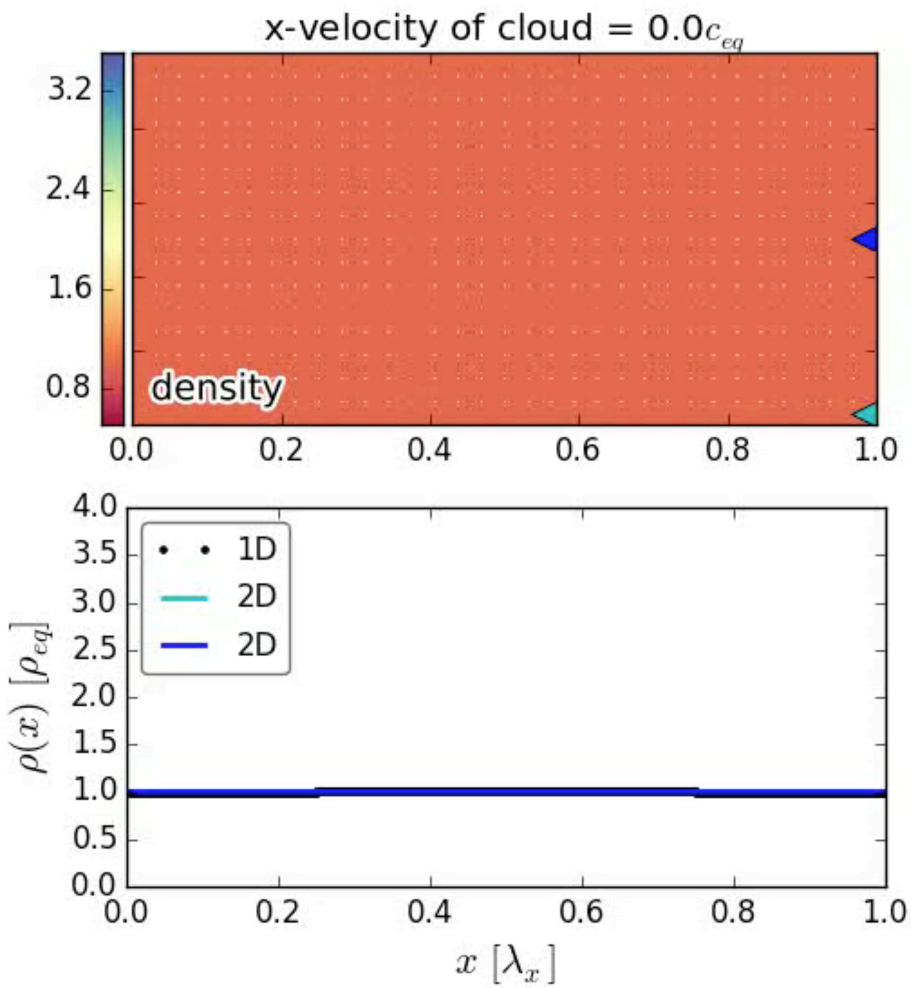
DP et al. (2014)

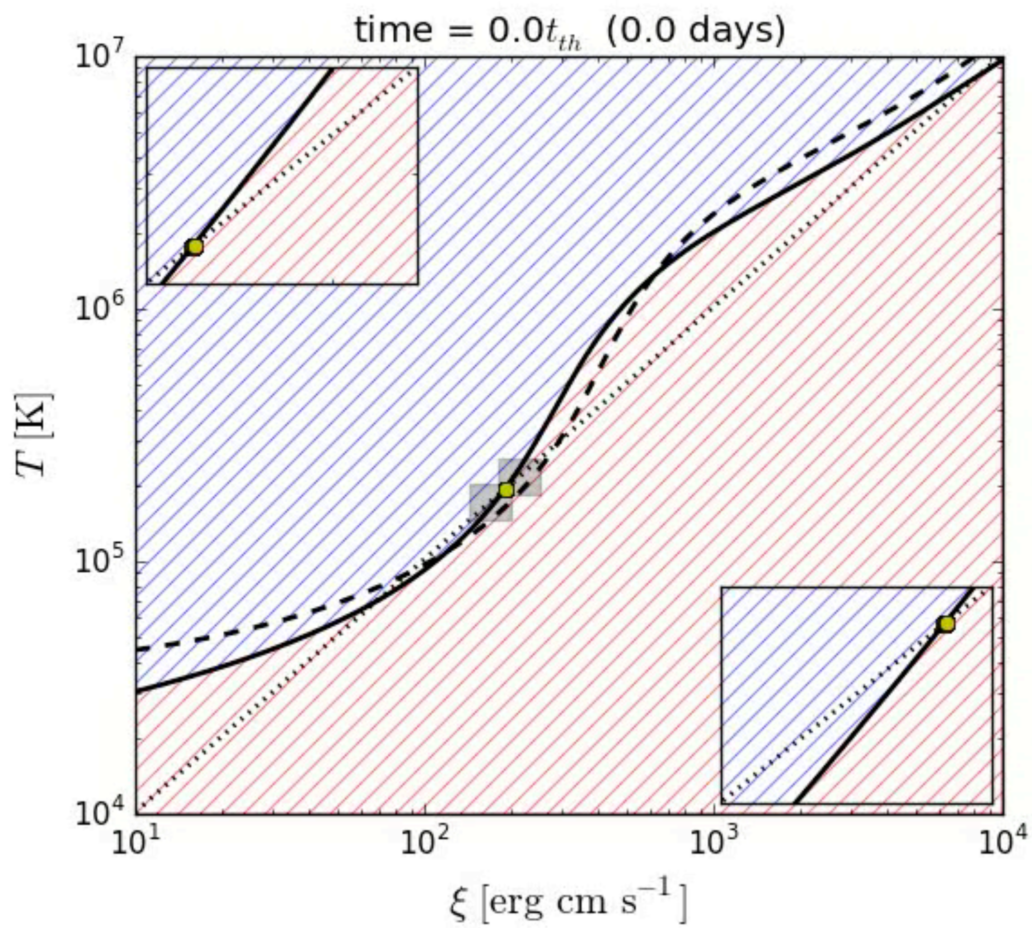
Absorption dominated cases

$\tau_{tot} = 2\times10^3$ $\tau_{tot} = 1.8\times10^8$

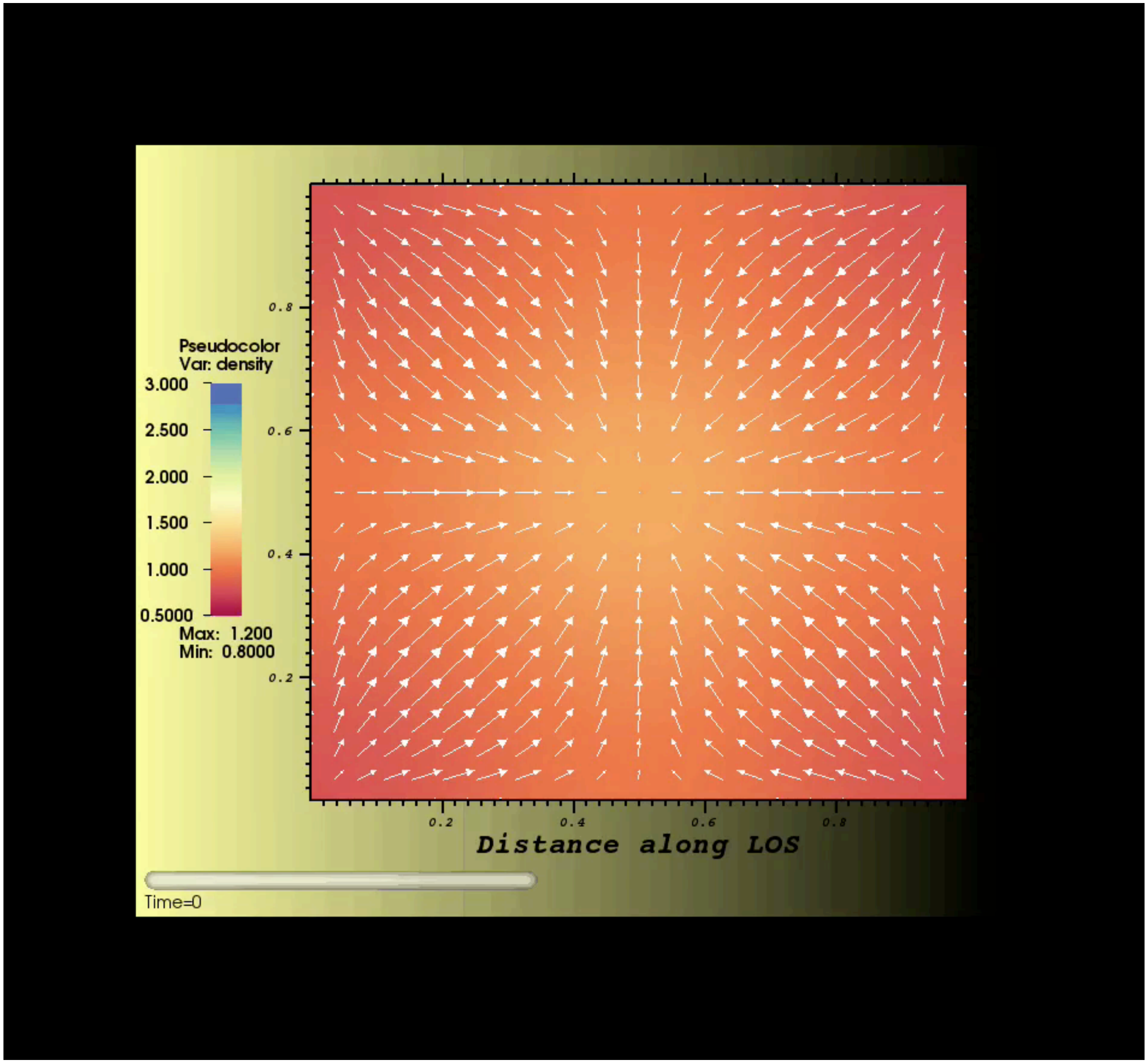


DP et al. (2014)

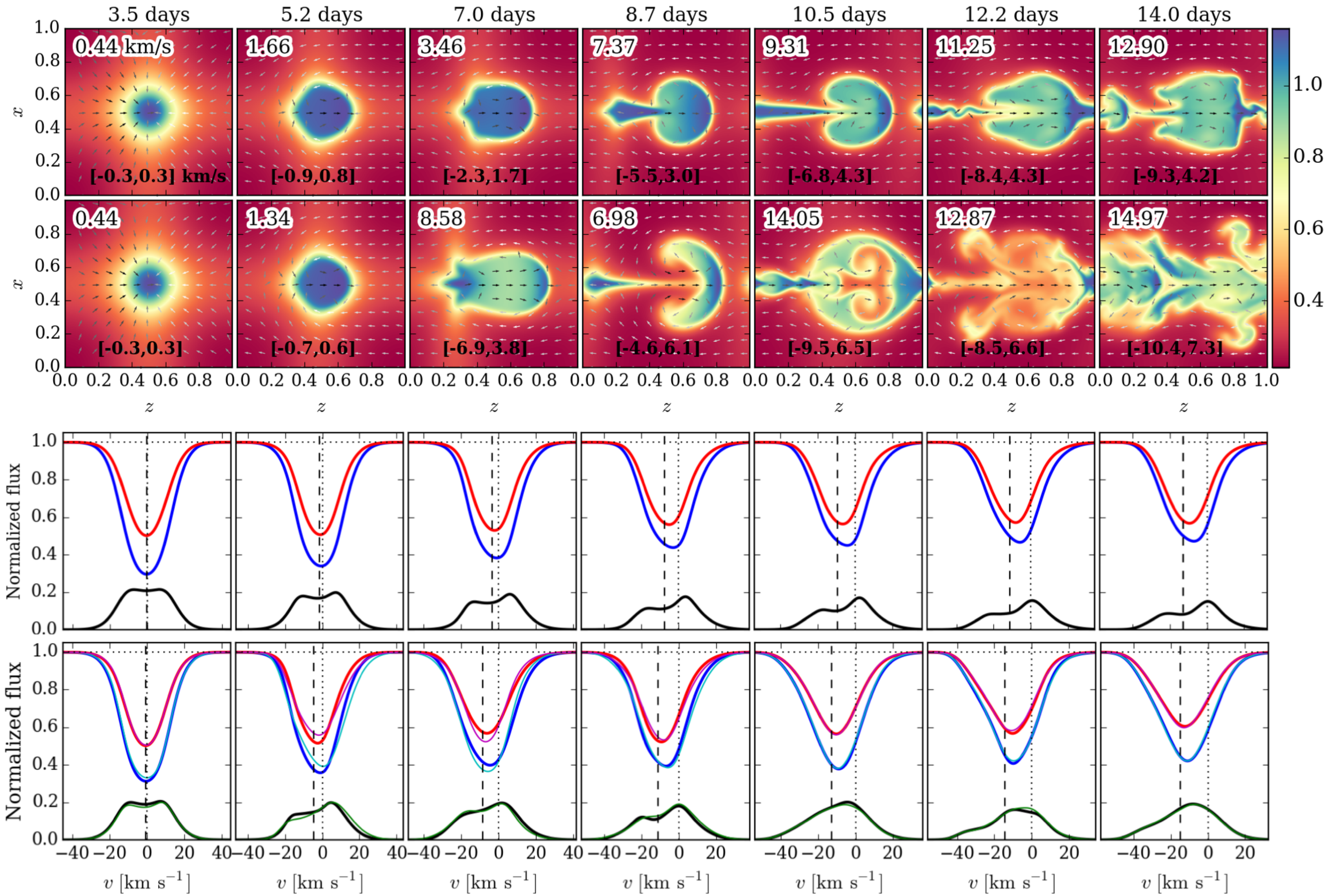




Proga & Waters (2015)



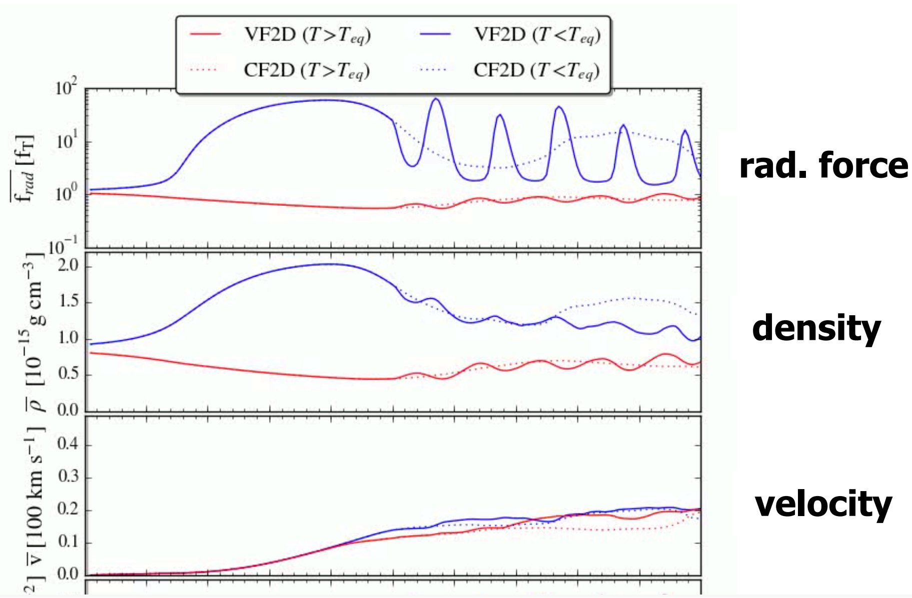
Waters, DP + (2017)

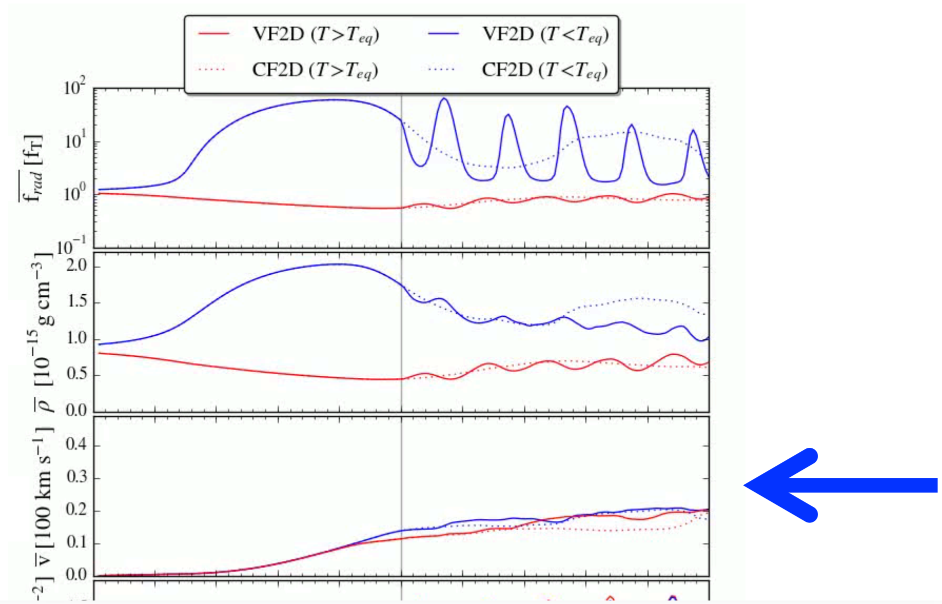


O VIII Ly alpha (18.9 A)

Waters, DP + (2017)

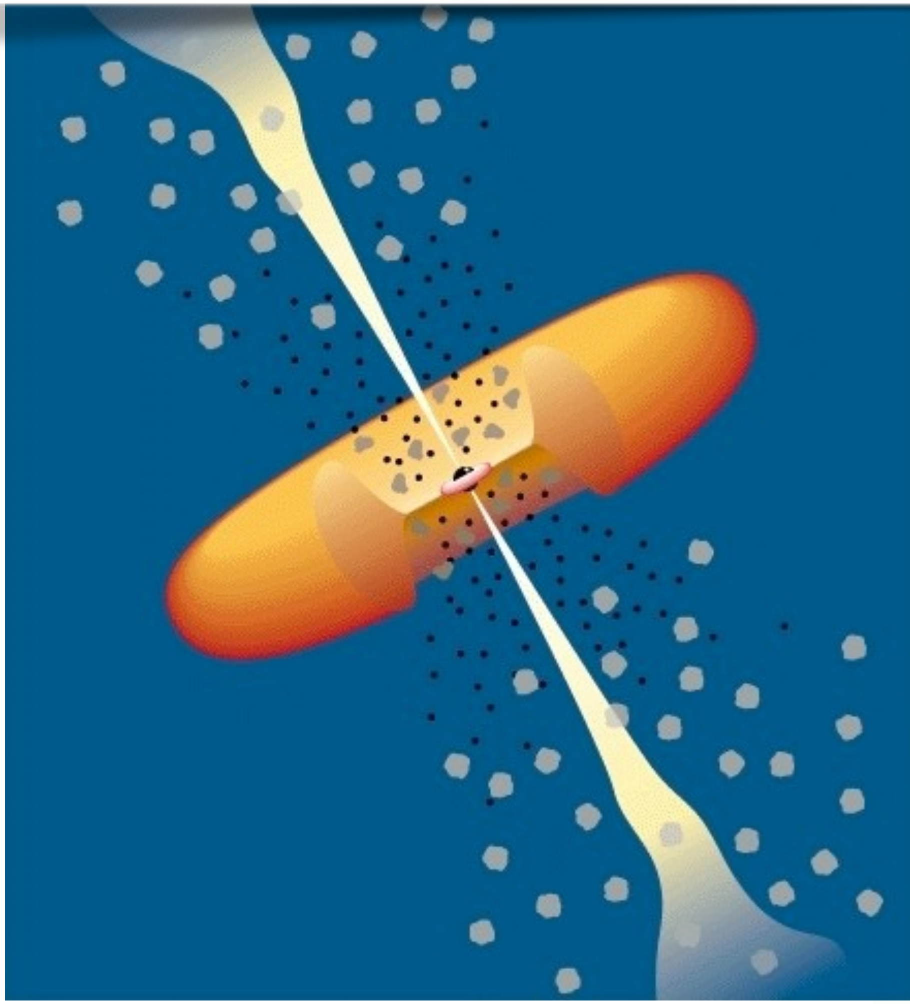
How to accelerate a cloud most efficiently?

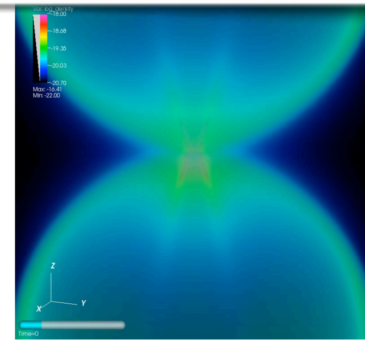


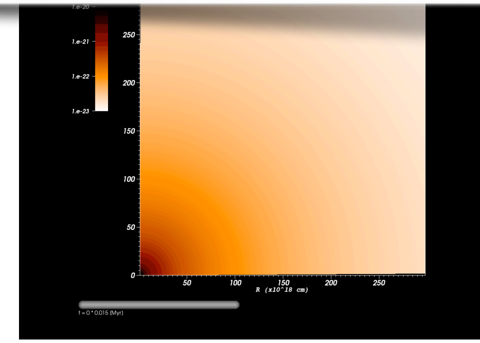


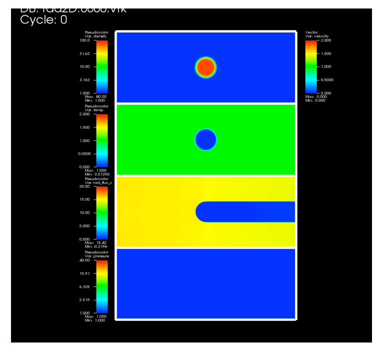
Most efficient acceleration is when the driving flux varies on a timescale comparable to the cooling time scale
[relevant to AGN variability, including reverberation mapping, e.g., see Waters et al. (2016)]

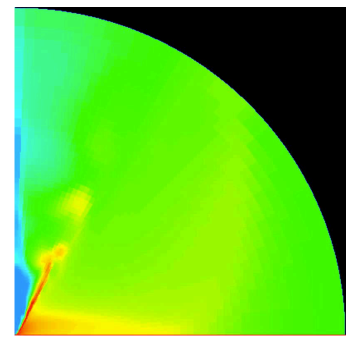
We have been building a physical model of NLRs: clouds are formed and accelerated (result of TI and radiation force). Although they are destroyed, they can be formed again.

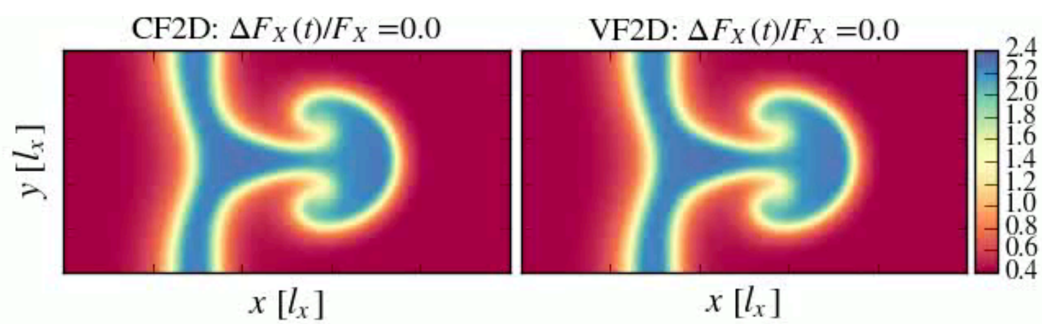




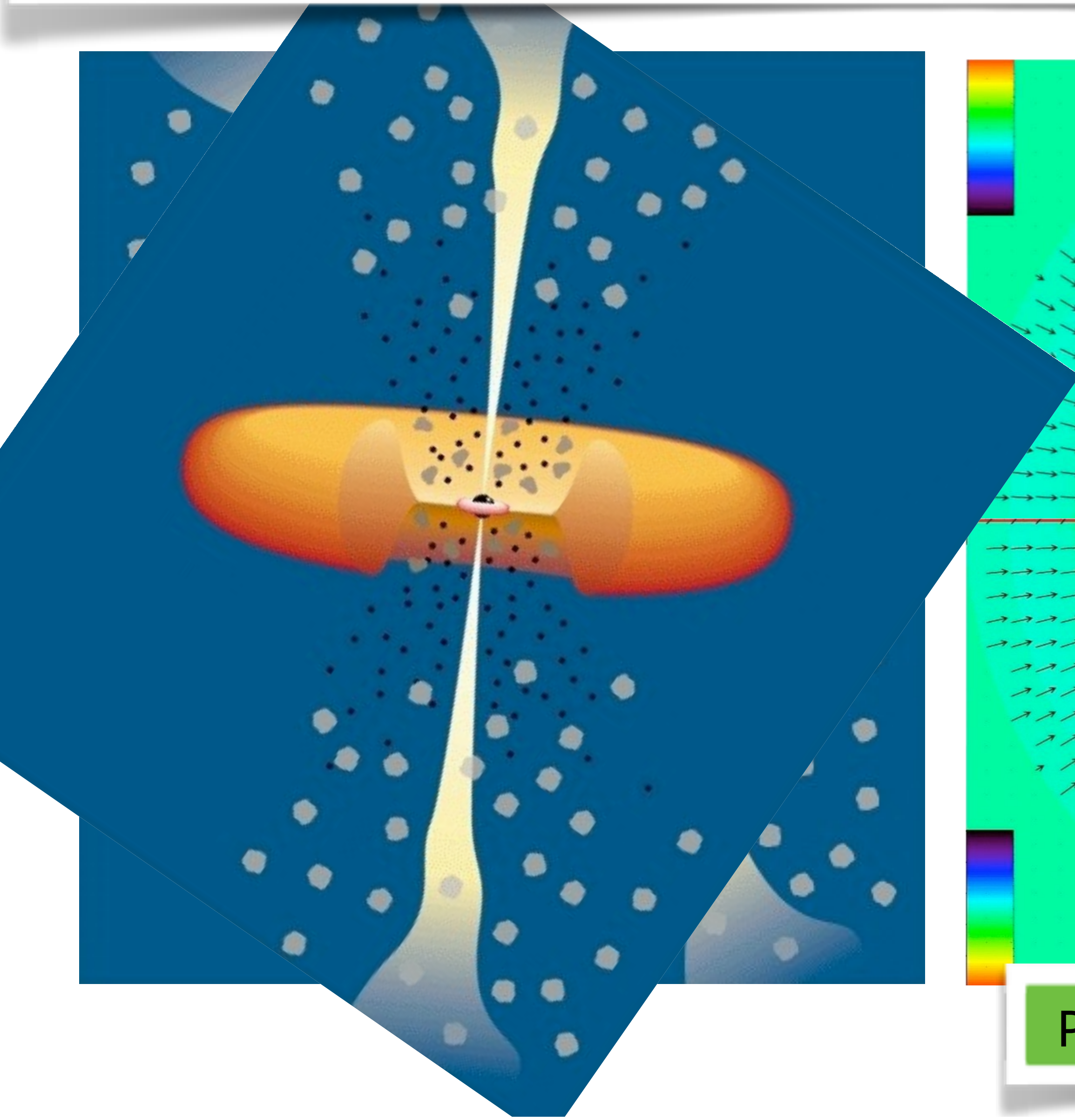


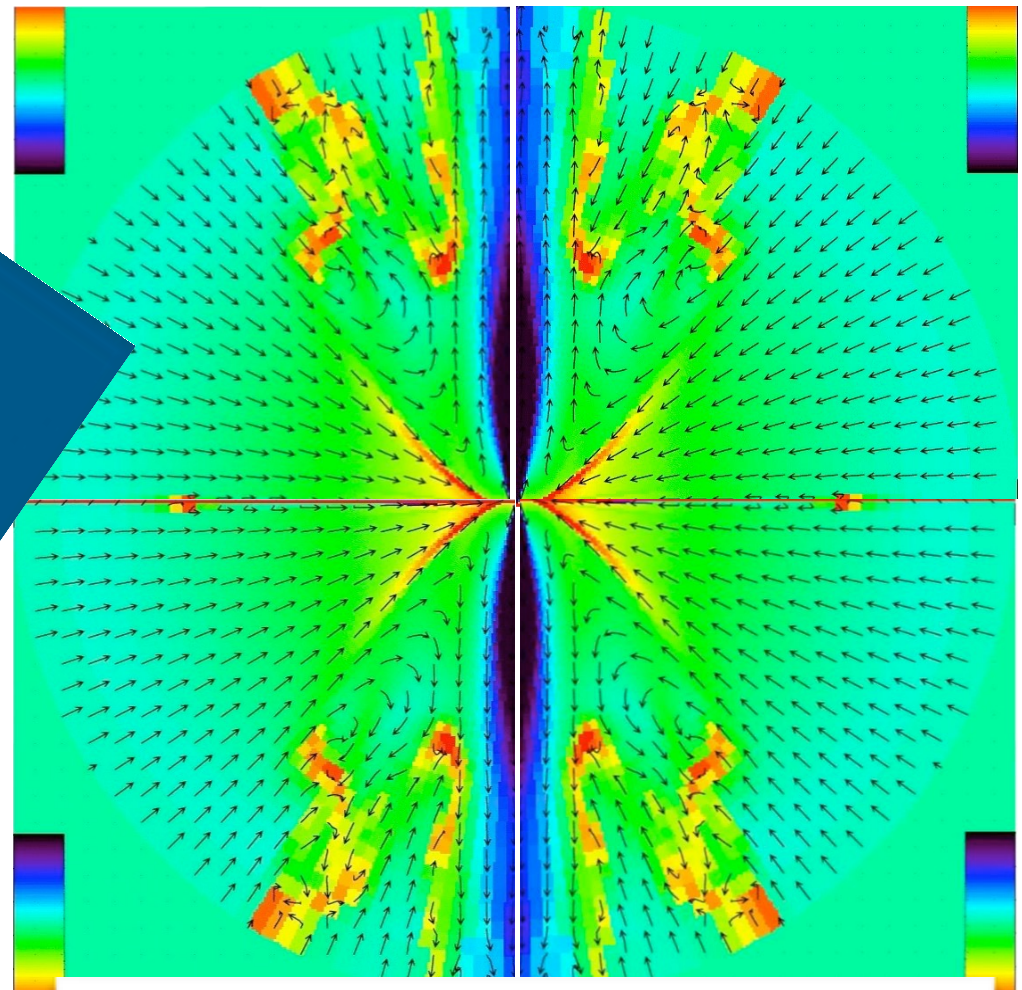






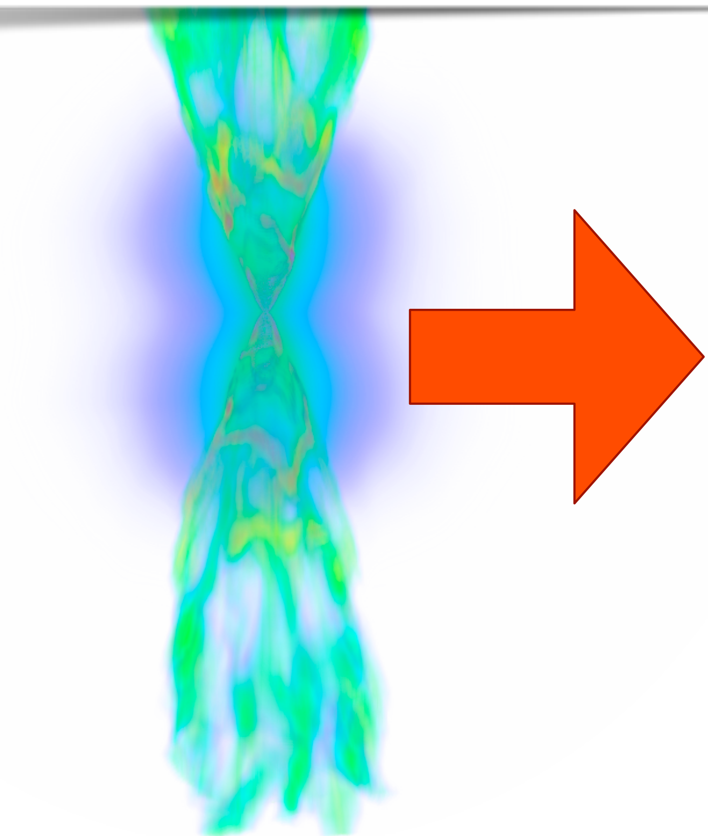
The model is promising not only because it predicts the dynamics and morphology that resemble our old picture but it also makes several more specific predictions.





Proga, Ostriker, & Kurosawa (2010)

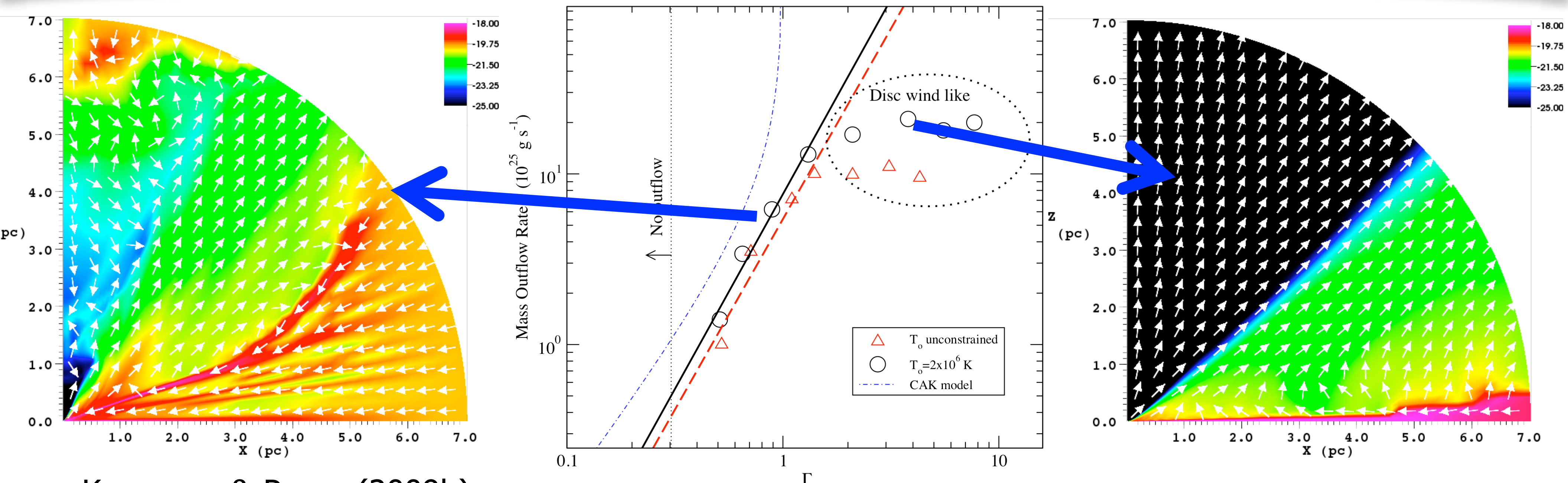
Broad band spectra for various lines of sight (Monte Carlo calculations).



Kurosawa & Proga (2009a)

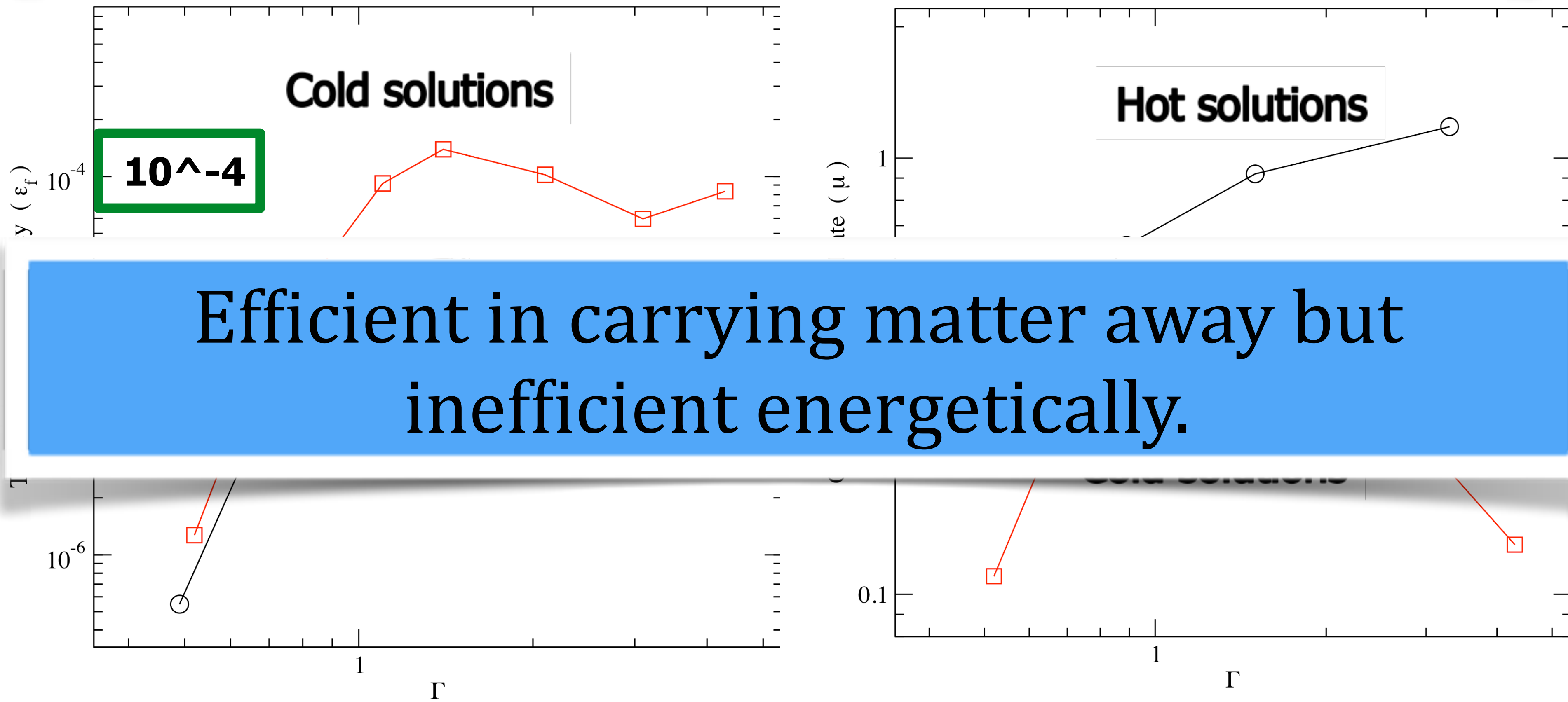
What controls the mass supply rate?

The geometry of the radiation field and optical depth effects
(the total luminosity is important but only for low luminosity cases).
Mass supply can be super-Eddington!



Kurosawa & Proga (2009b)

How efficient are the large scale outflows?

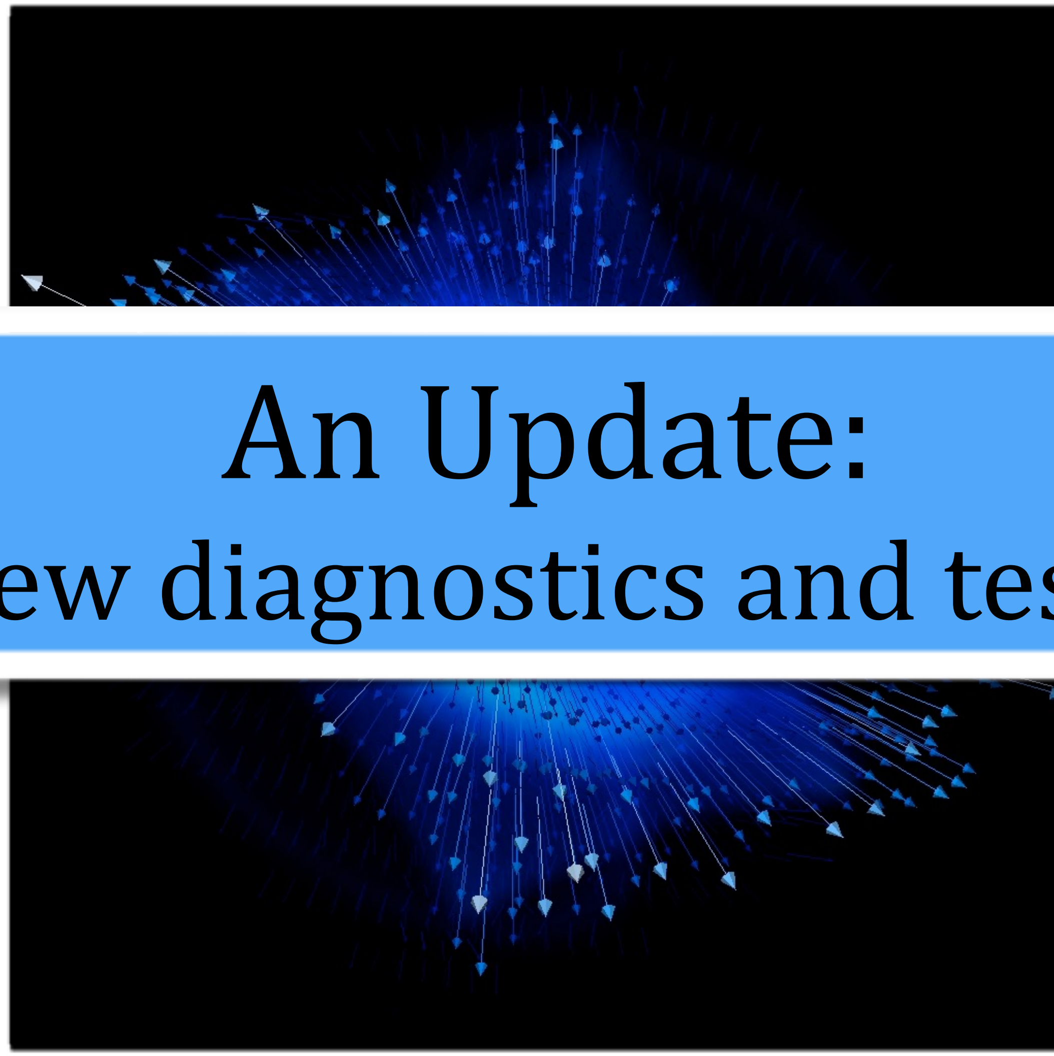


Efficient in carrying matter away but inefficient energetically.

Kurosawa, Proga, & Nagamine (2009)

Radiation Driven Disk Winds

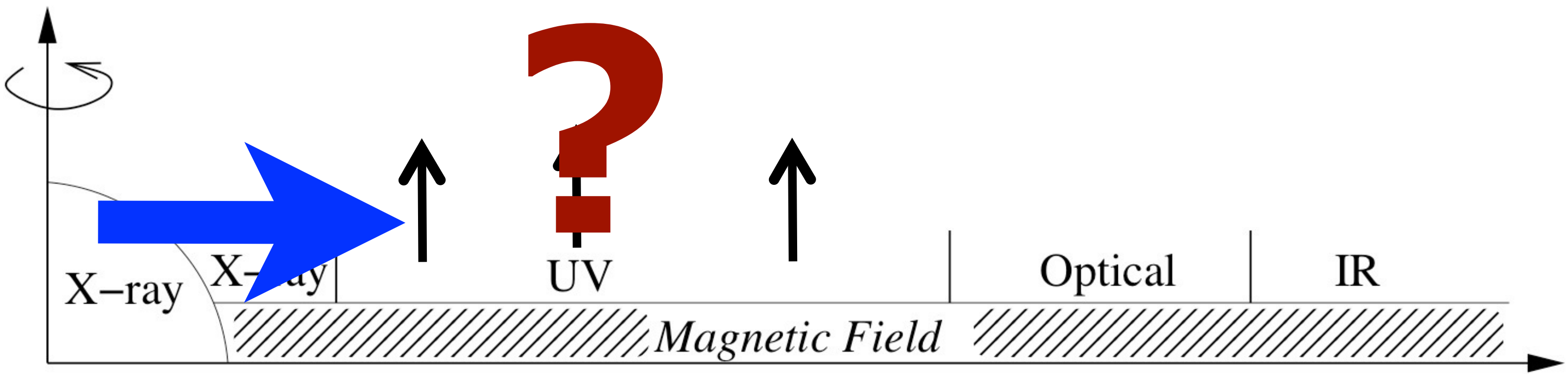
(Are they the BLRs? What is the physics of a 'subgrid'?)



An Update:

new diagnostics and tests

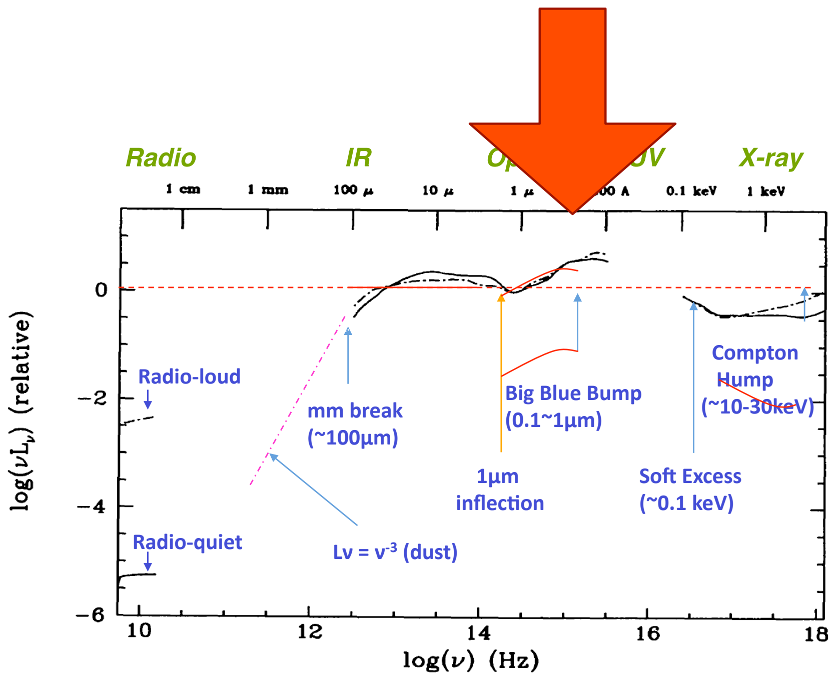
Irradiation of a Disk Wind



A wind driven by UV photons, similar to winds from OB stars or CVs

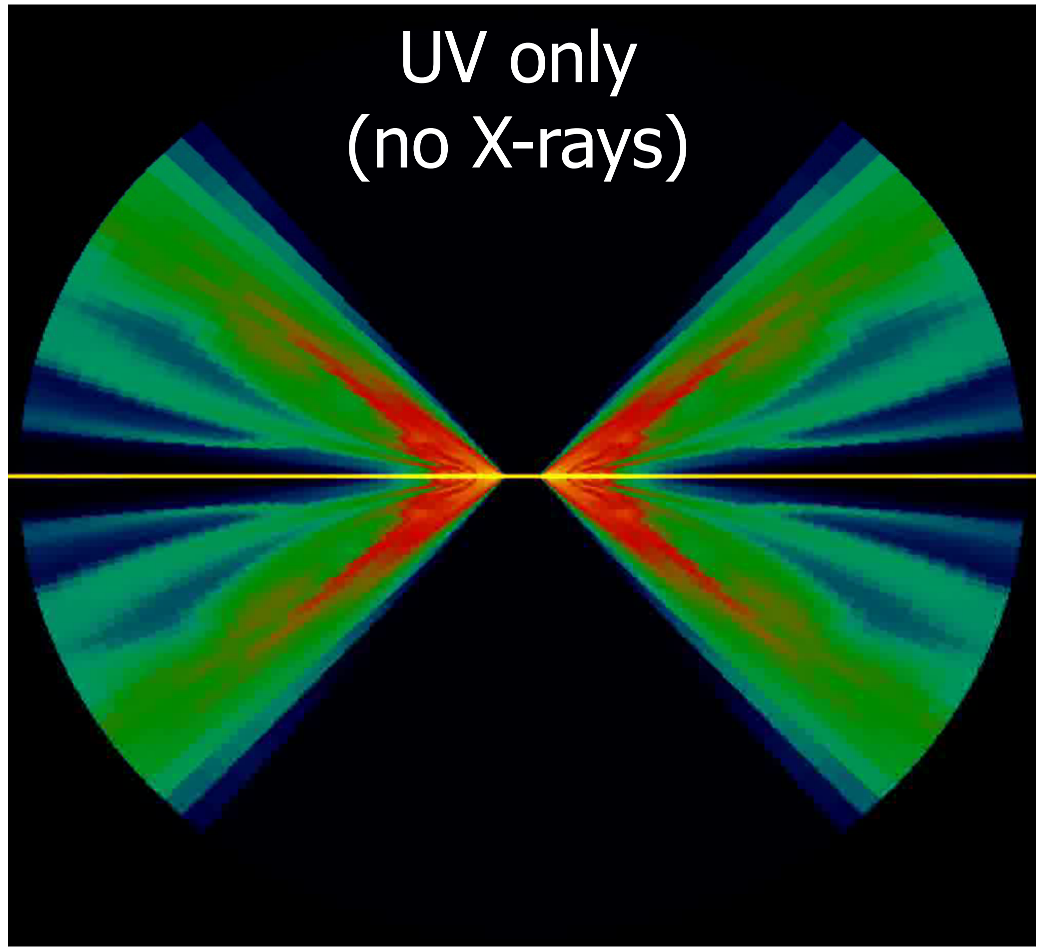
(main differences: the geometry and energy distribution of radiation field).

Line-Driven Disk winds (application to quasars)



Elvis et al., 1994, ApJS, 95, 1

The equations were solved using the ZEUS code (Stone & Norman 1992) extended by PD, Stone, & Kallman (2000; see also PD, Stone & Drew 1998, 1999)



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

$M_{BH} = 10^8 Msun$

$\Gamma = 0.6$

Line-Driven Disk winds (application to quasars)

Radiation pressure on UV lines can drive a powerful wind from a disk even when the wind is irradiated by a strong central source of X-rays.

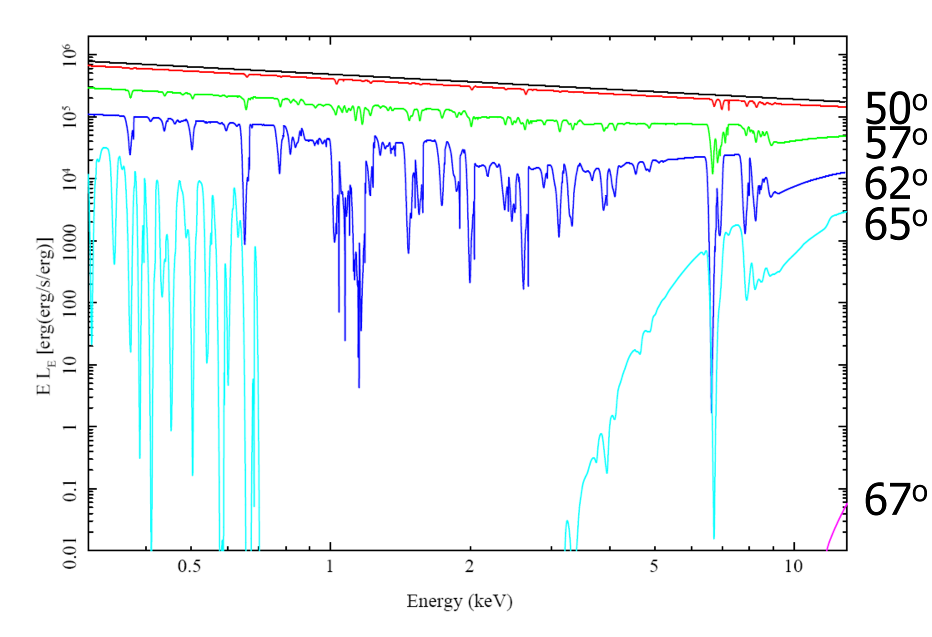
The wind can be very fast (~20,000 km/s) and its mass loss rate is high (~1 solar mass per year)

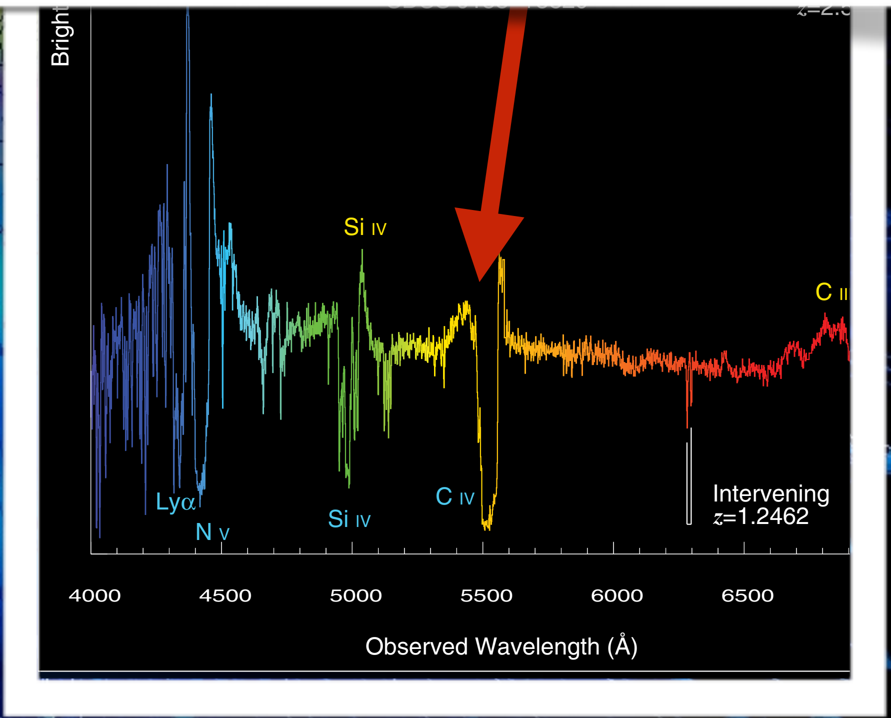
Results from the line-driven disk wind simulations have been applied in models of AGN momentum-driven feedback, e.g., Ostriker et al. (2010), Choi et al. (2012), Ciotti et al. (2016)

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

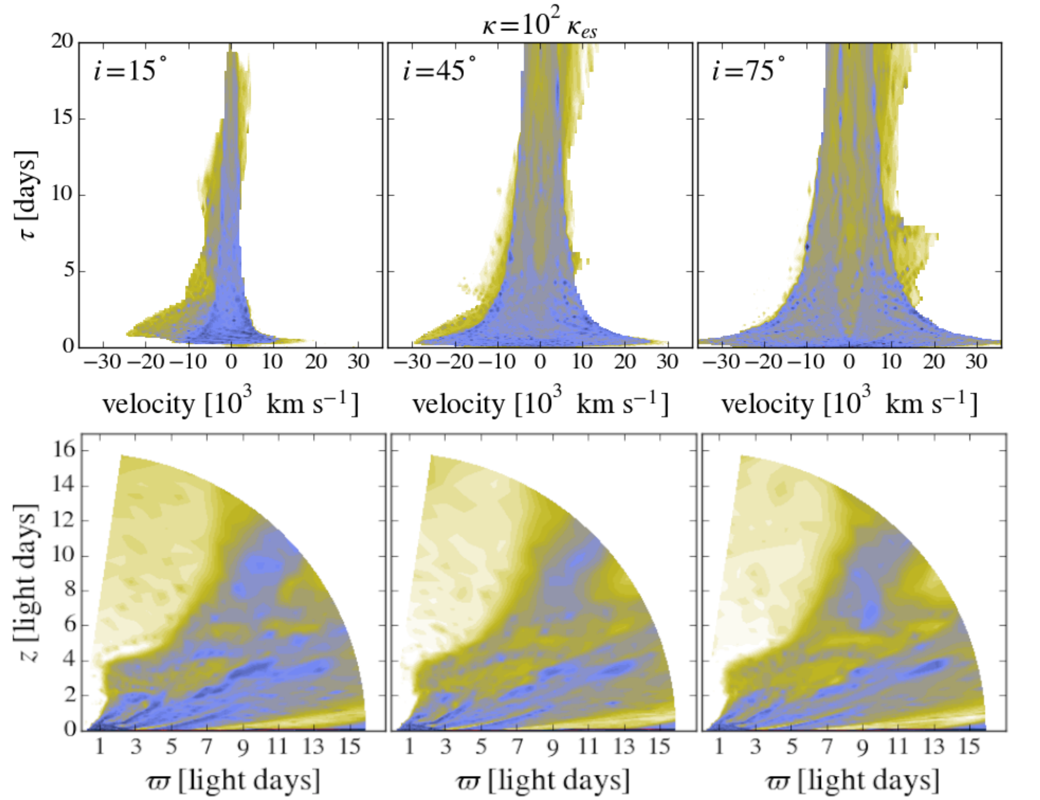
Γ = 0.6

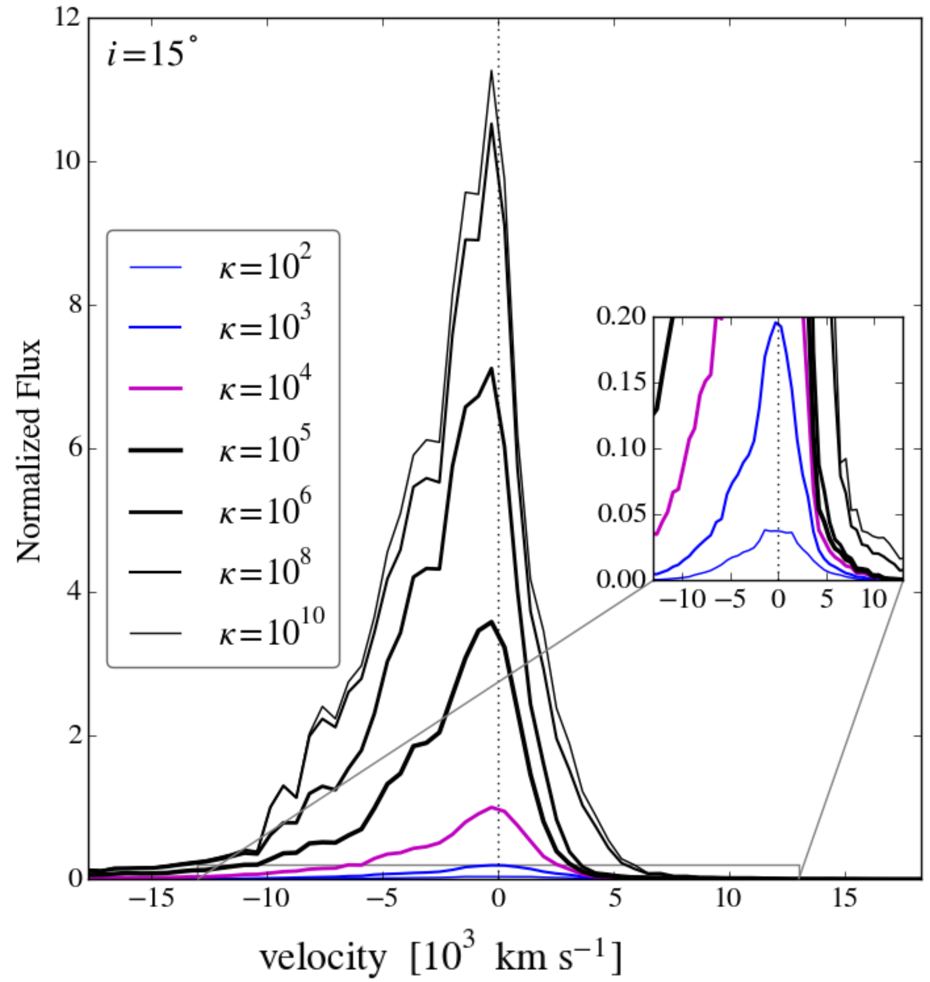
Computed profiles of UV resonant lines resemble the observed profiles (strong single-peaked emission lines for low and intermediate inclinations; P-Cygni like lines for high inclinations). BAL quasars should be X-ray weak because of the shielding.





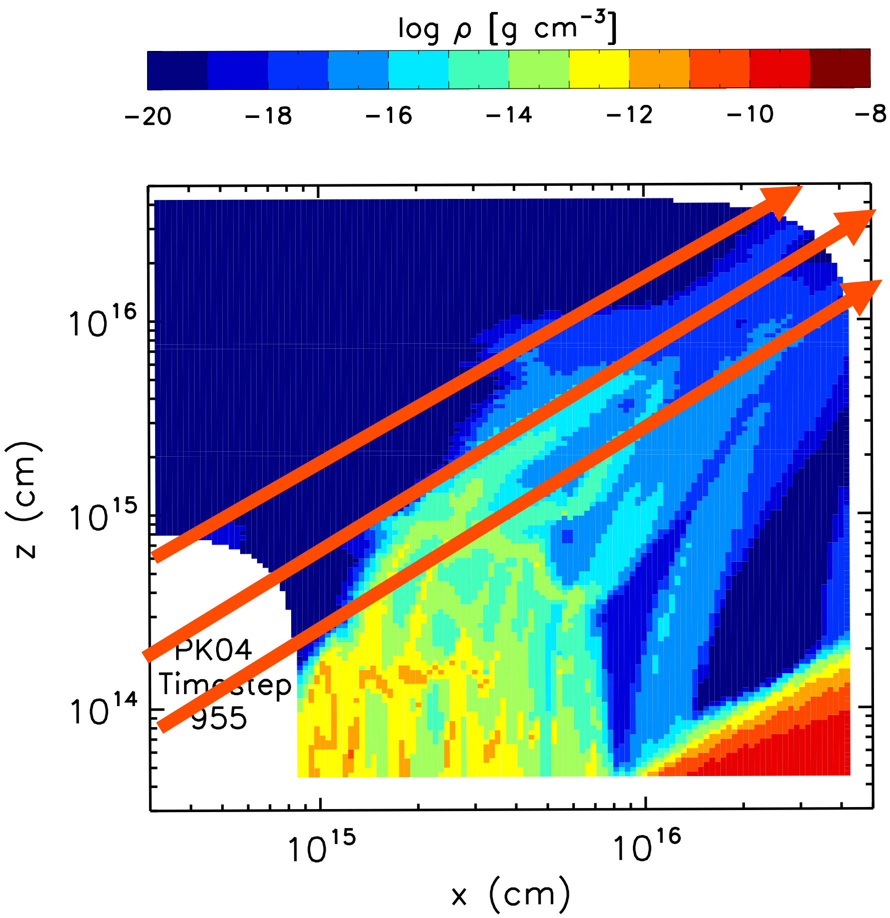
Reverberation Mapping





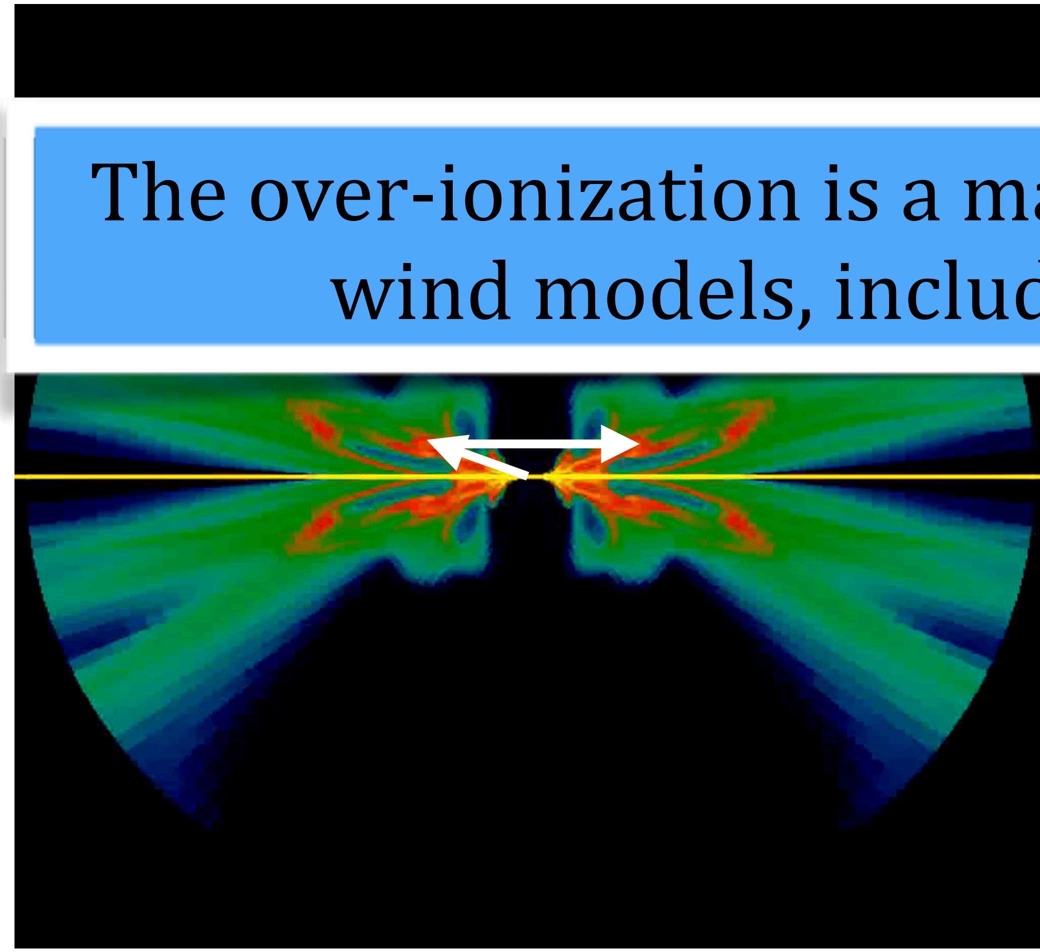
Waters, Kashi, DP et al. (2016)

Monte Carlo photoionization and radiative transfer calculations.



Sim, DP et al. (2010) and Higginbottom, DP et al. (2014)

Monte Carlo photoionization and radiative transfer calculations.

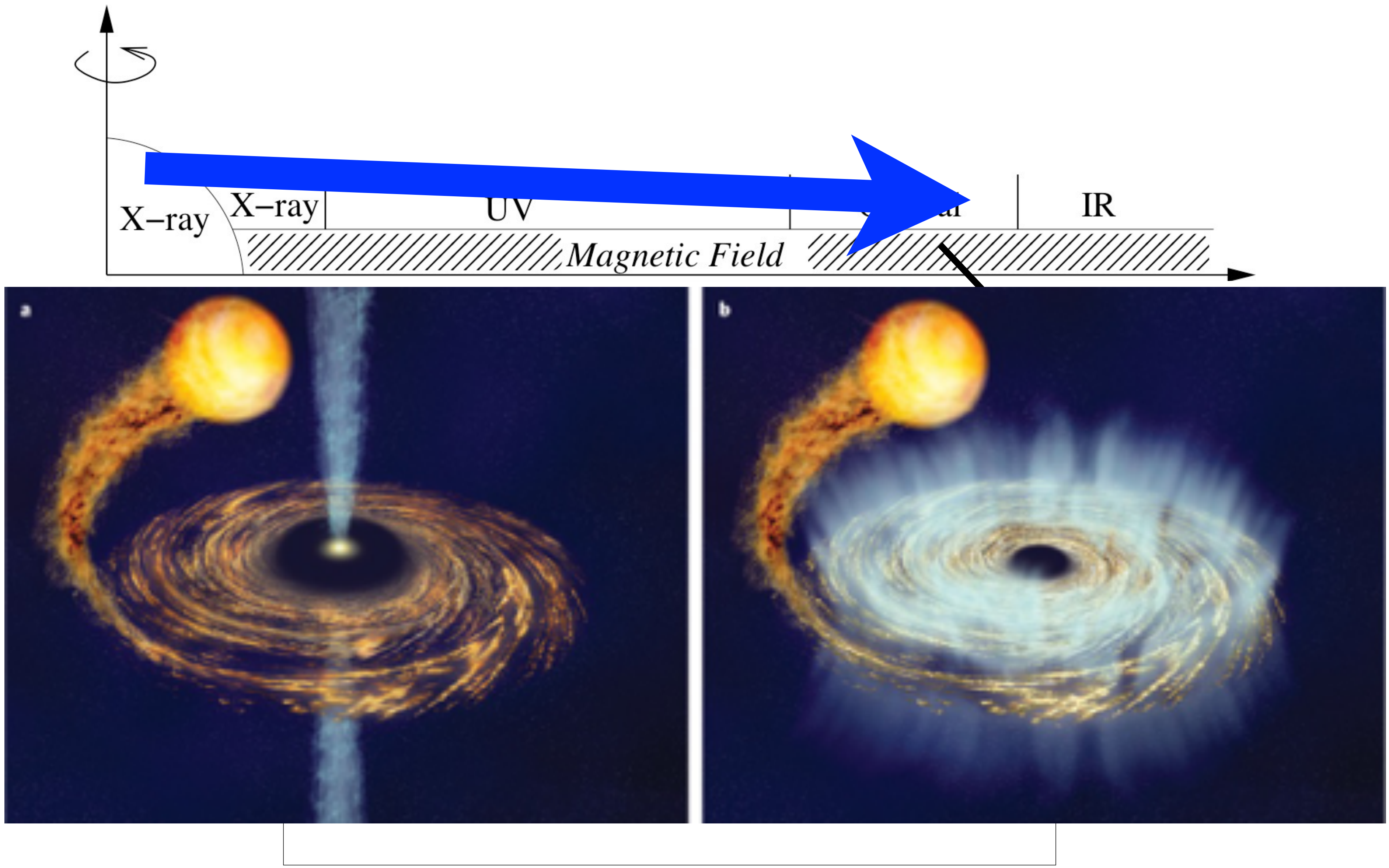


The over-ionization is a major problem for all AGN wind models, including MHD models.

can affect the dynamics of a line driven disk wind, e.g., multiple scattering as well as the EUV photons from the inner most disk can significantly increase the wind ionization. So the problem is not just the direct irradiation.

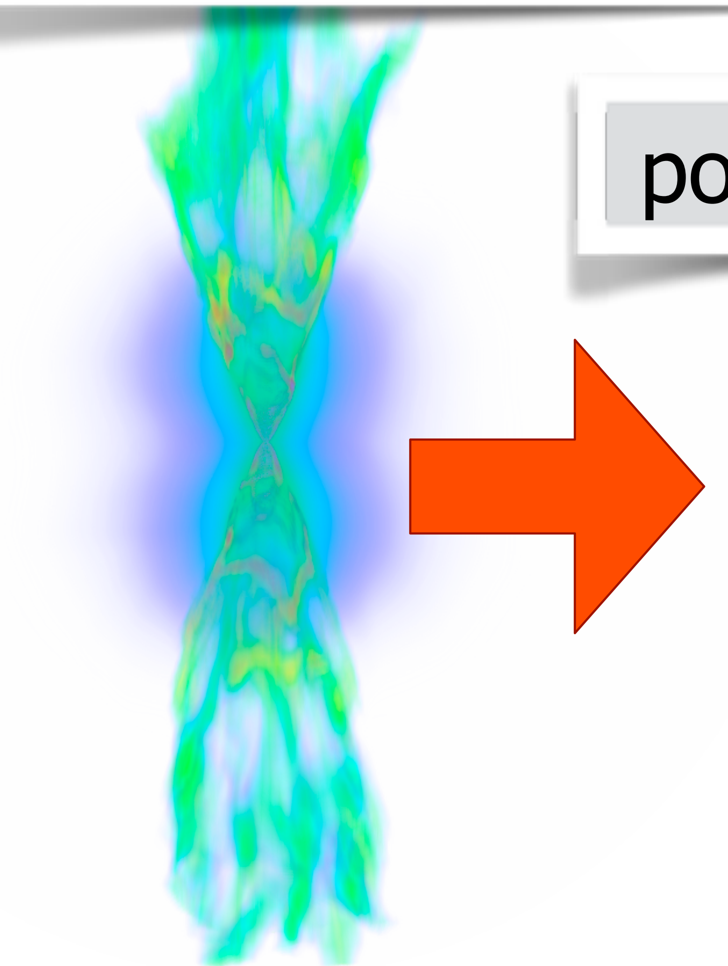
Sim, DP et al. (2010) and Higginbottom, DP et al. (2014)

Irradiation of a Disk



Connecting simulations with observations has been done mostly through

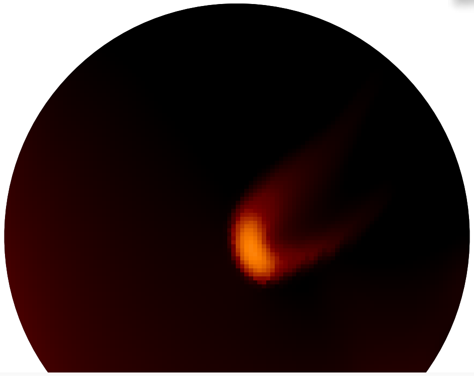
post-processing

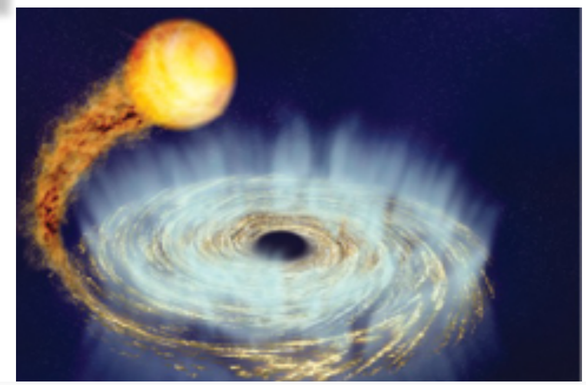


Kurosawa & Proga (2009a)

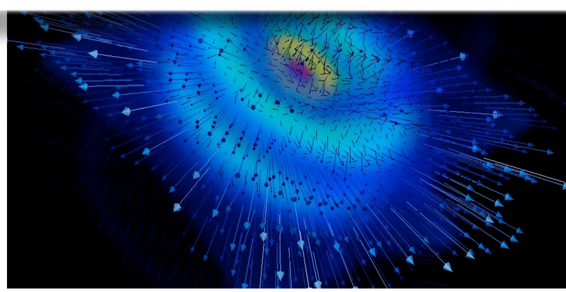
Sim, DP et al. (2012)
MC photoionization/RT calculations

Future

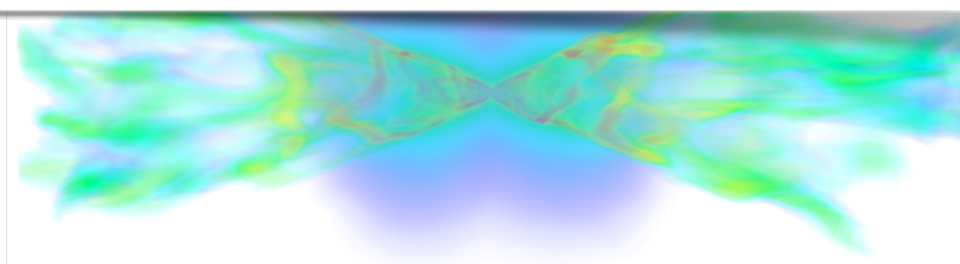




Multi-frequency Radiation-Magnetohydrodynamics.



Winds in AGNs and PPDs



Inflows and Outflows in GRBs and AGNs