Radiative Transfer and Acceleration in Magnetocentrifugal Winds

John Everett

Canadian Institute for Theoretical Astrophysics

University of Toronto

Thanks to my collaborators:

D. Ballantyne, A. Königl, N. Murray

Introduction

Introduction & Conclusions

Outline/Conclusions

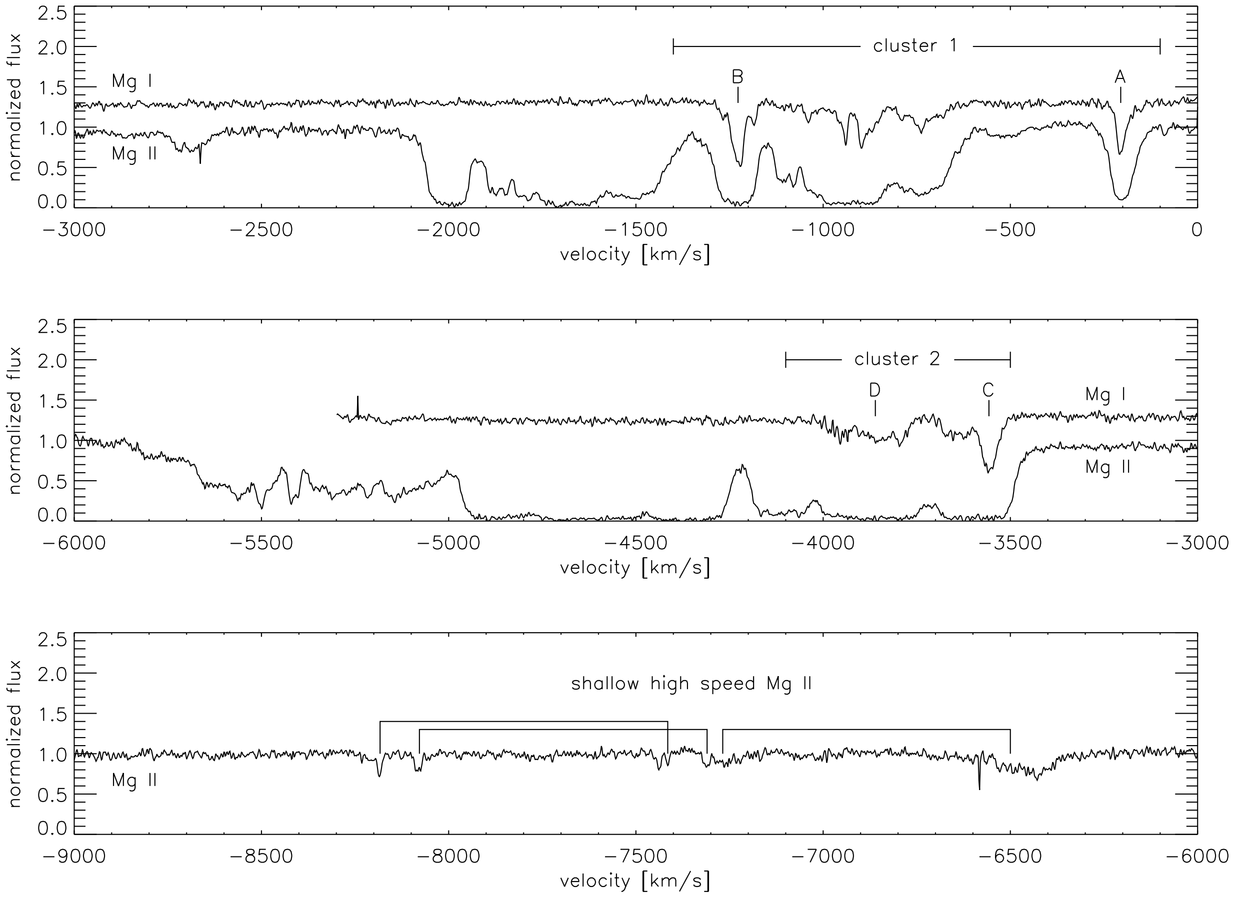
- Radiative acceleration can happen under certain circumstances, but is not always dominant.
- Magnetocentrifugal winds can launch the wind from the disk, and then allow efficient radiative acceleration.
- Evidence is mounting in observations and models that magnetocentrifugal acceleration is important in AGN.

CITA–ICAT

Radiative Acceleration Models

Radiative Acceleration Does Happen

$\sim$15% of Quasars show high velocity absorption (Reichard et al. 2003)



de Kool et al. (2001)

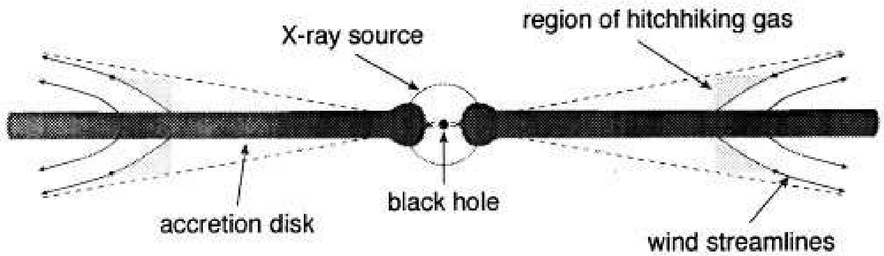
Radiative Acceleration is Not Easy: Theory

Radiative acceleration is not easy to compute, theoretically.

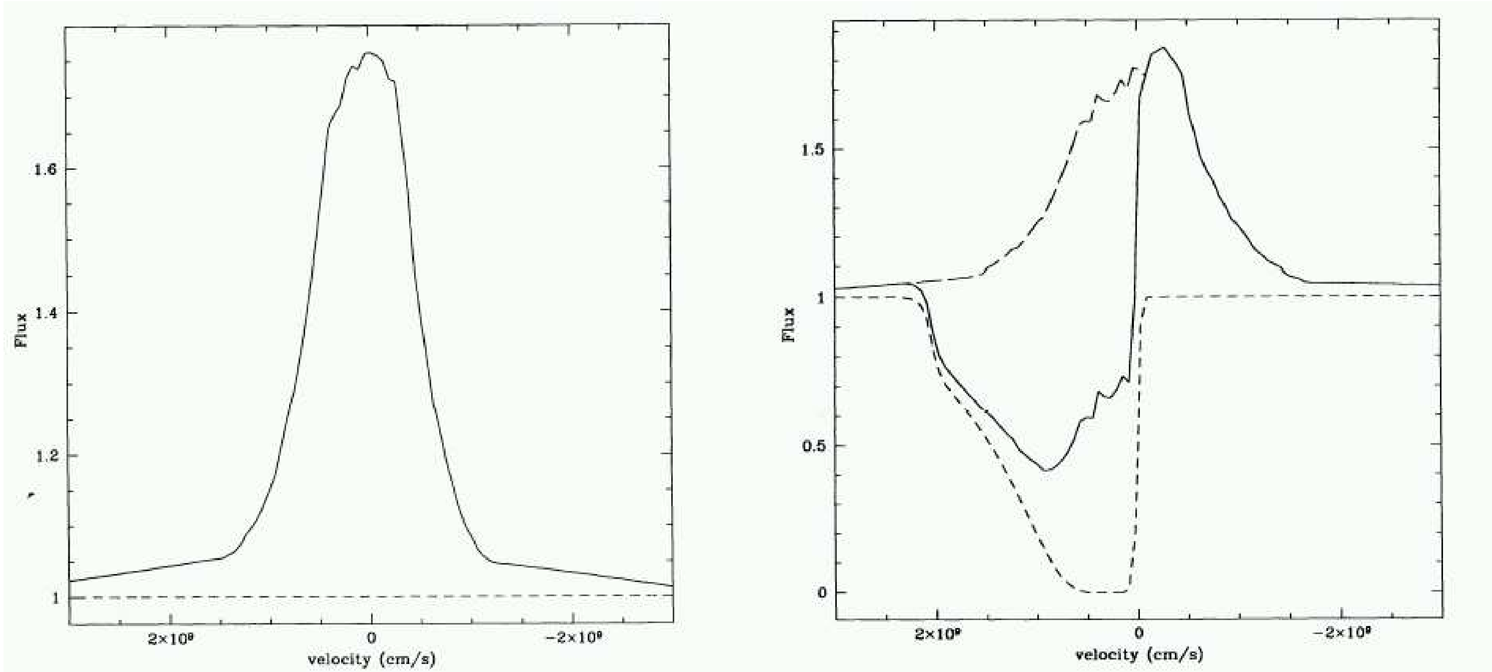
One needs to consider:

- Detailed photoionization simulations of the accelerating gas (see also Chelouche & Netzer 2003a,b)
- Intrinsic Spectral Energy Distribution
- Shielding against X-ray ionizing photons

Radiatively-driven Winds Need Shielding



Murray et al. (1995)



Nota Bene: The single-peaked line is (itself) evidence of a wind!

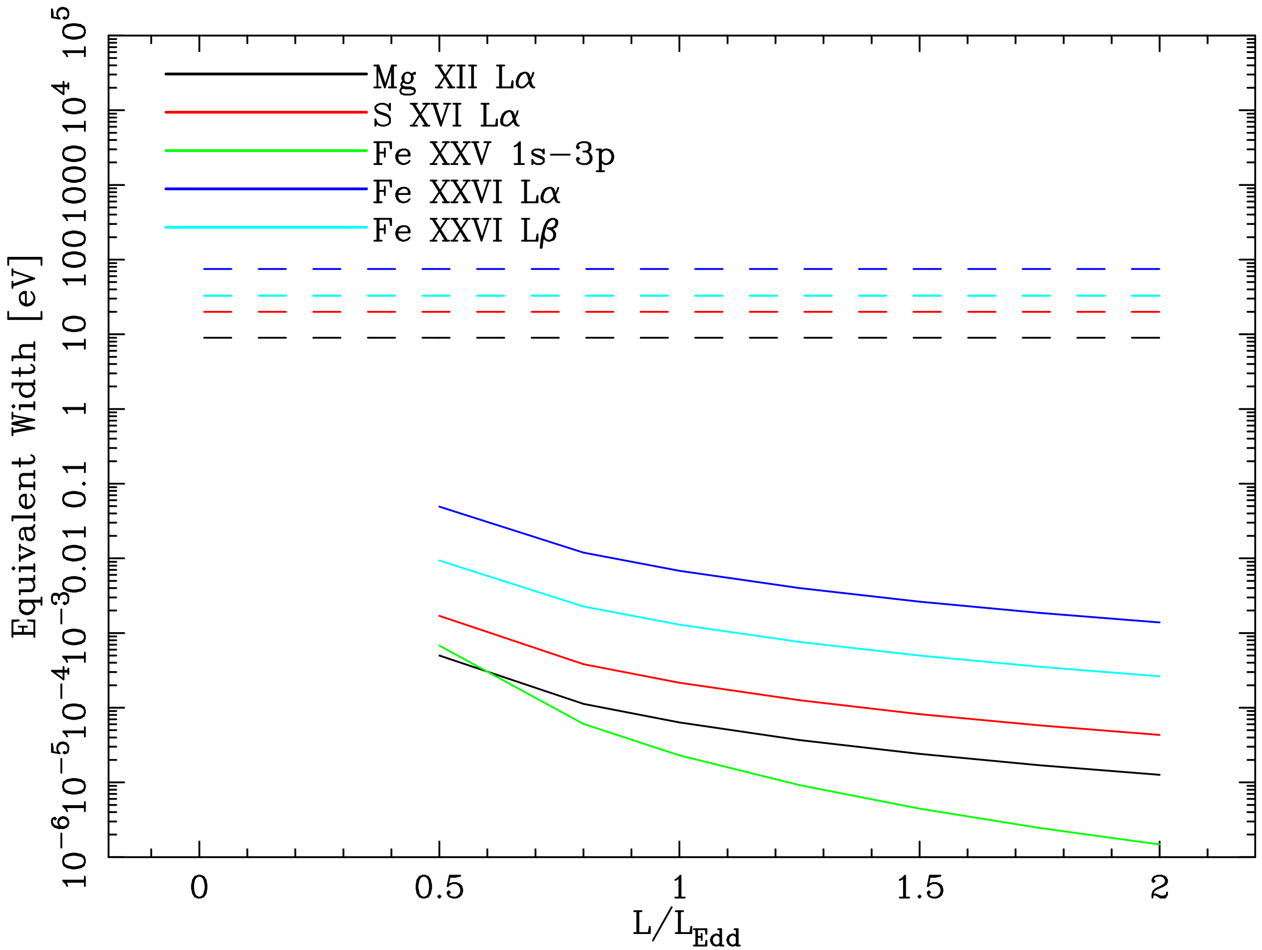
Radiative Acceleration is Not Easy: Obs.

Radiative acceleration is not easily seen to be dominant, observationally.

- [O III] NLR gas is not radiatively or thermally driven (J.E. & Murray 2006)
- UV Absorption lines are not radiatively or thermally driven, and *absorbers seem to show transverse motion* (Kraemer et al. 2005)
- Relativistic X-ray winds cannot be radiatively driven (J.E. & Ballantyne 2004)

Radiative Driving Doesn't Work for PG 1211

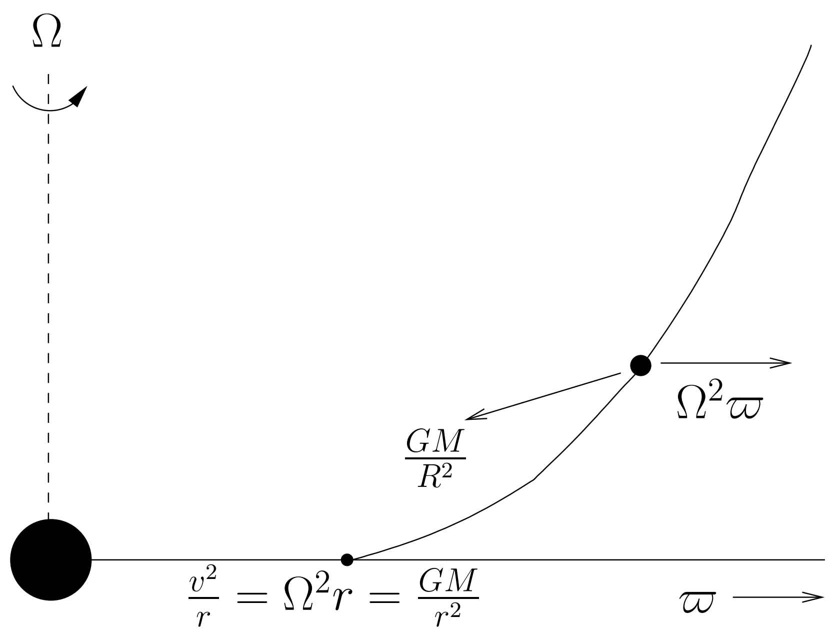
$N_{\rm H,0} = 5 \times 10^{23}\ {\rm cm}^{-2}$ at the base of the wind; $N_{\rm H}$ required to decrease as the wind accelerates and n decreases.



J.E. & Ballantyne (2004)

MHD Winds Allow Radiative Acceleration

Intro to Magnetocentrifugal Winds

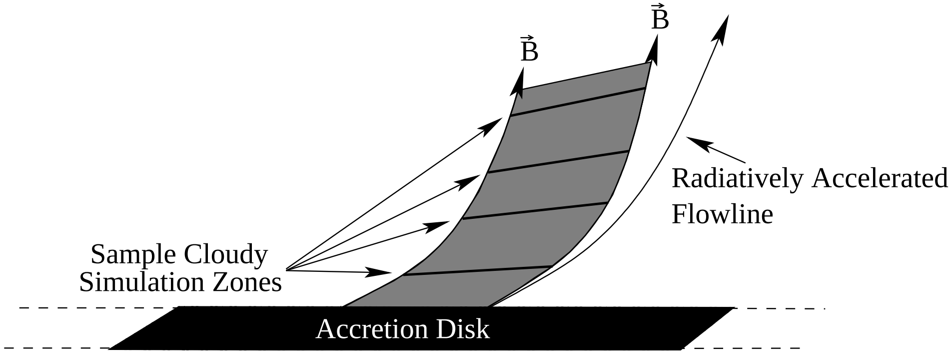


- Gas is centrifugally flung outwards, like “beads on a wire” (Blandford & Payne 1982).
- Field line must be at $< 60^\circ$ to the disk for centrifugal force to overcome gravity.
- Assumes that large-scale poloidal magnetic field exists.
- “Mass loading” is only parameterized.

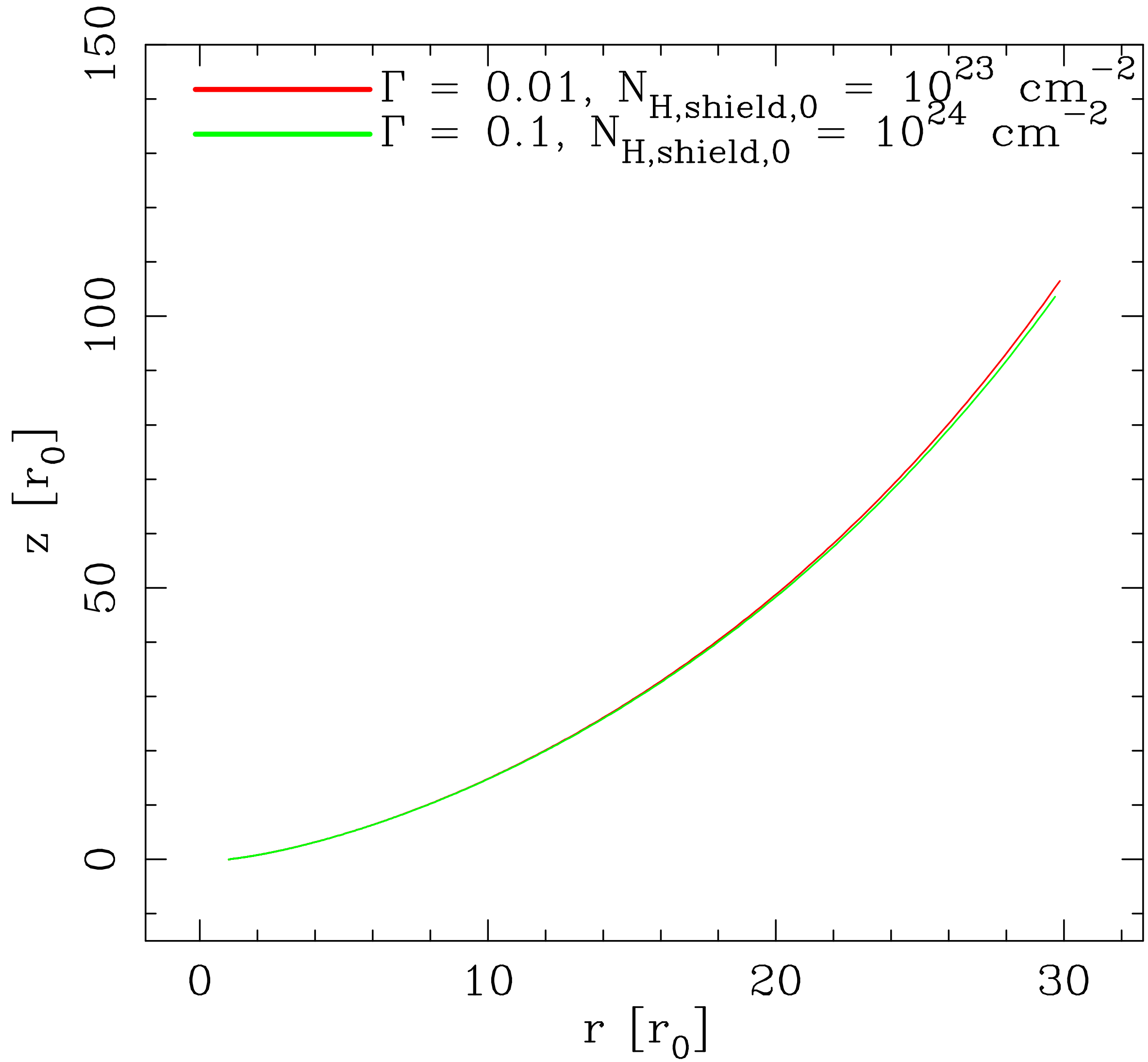
Magnetocentrifugal + Line-Driven Winds

Illuminated Magnetocentrifugal winds:

- Self-Similar Magnetocentrifugal Wind Model
- Wind is launched magnetically, and *can be* radiatively accelerated if conditions permit.
- $r_0 = 3 \times 10^{16}$ cm
- $n_0 = 10^7 - 10^{11}$ cm^{-3}
- Magnetocentrifugal Shield Column: $N_{\mathrm{H},0} = 10^{21} - 10^{24}$ cm^{-3}
- $L/L_{\mathrm{Edd}} = 10^{-3} - 0.1$
- Risaliti & Elvis (2004) spectrum



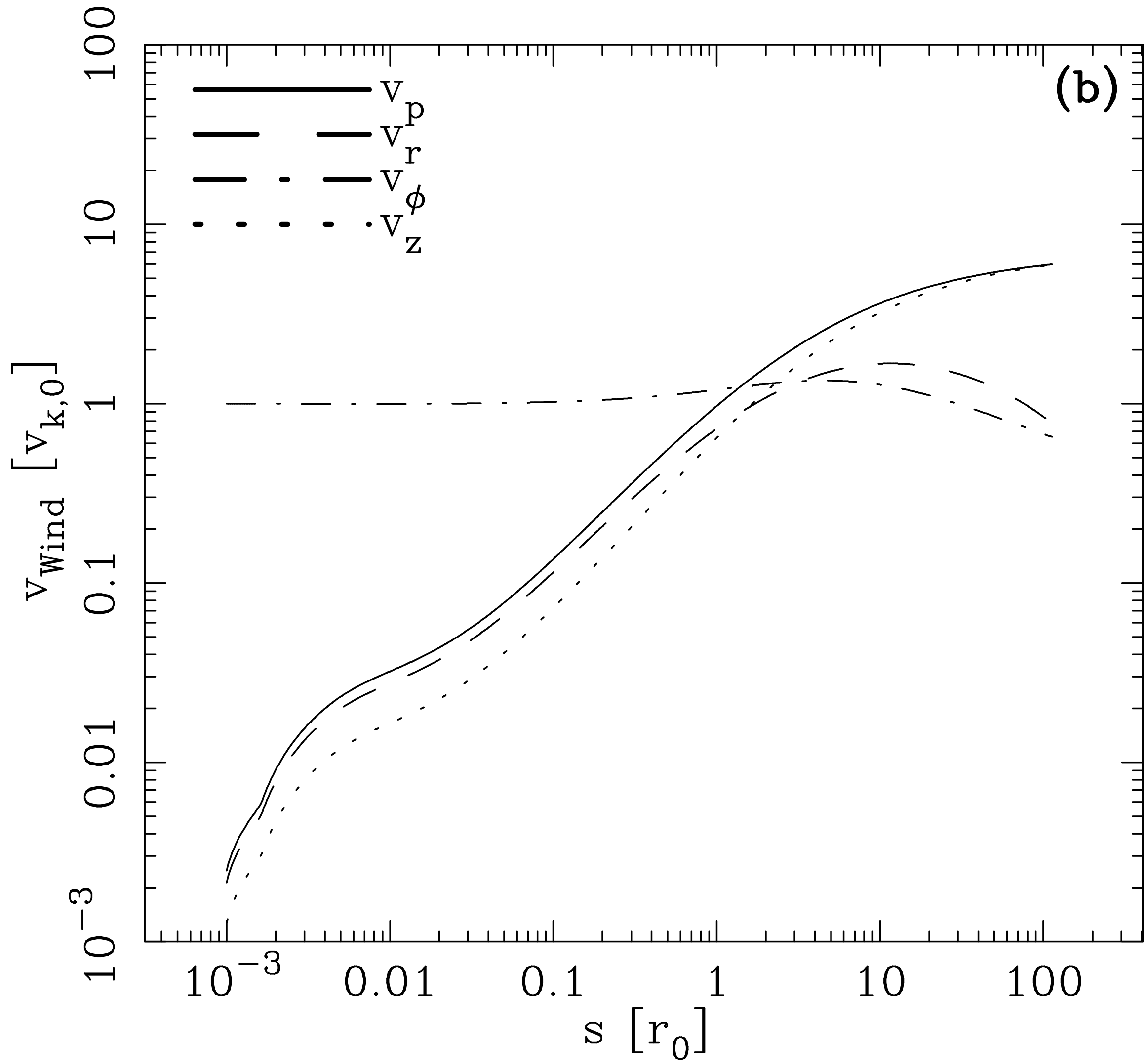
Brief Tour of a Magnetocentrifugal Wind



Winds still largely collimated: not an equatorial outflow.

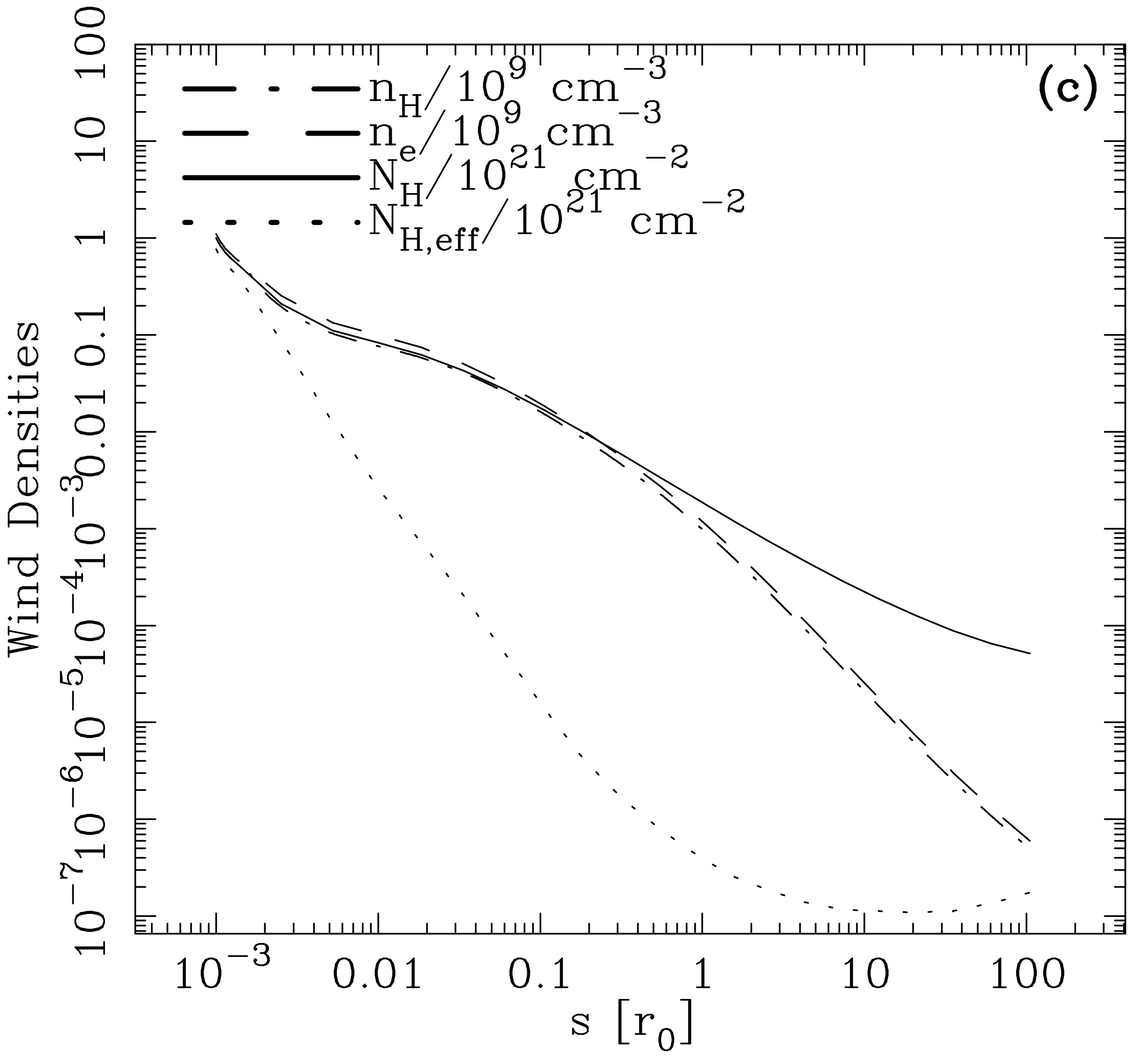
Brief Tour of a Magnetocentrifugal Wind

CITA–ICAT



J.E. (2005)

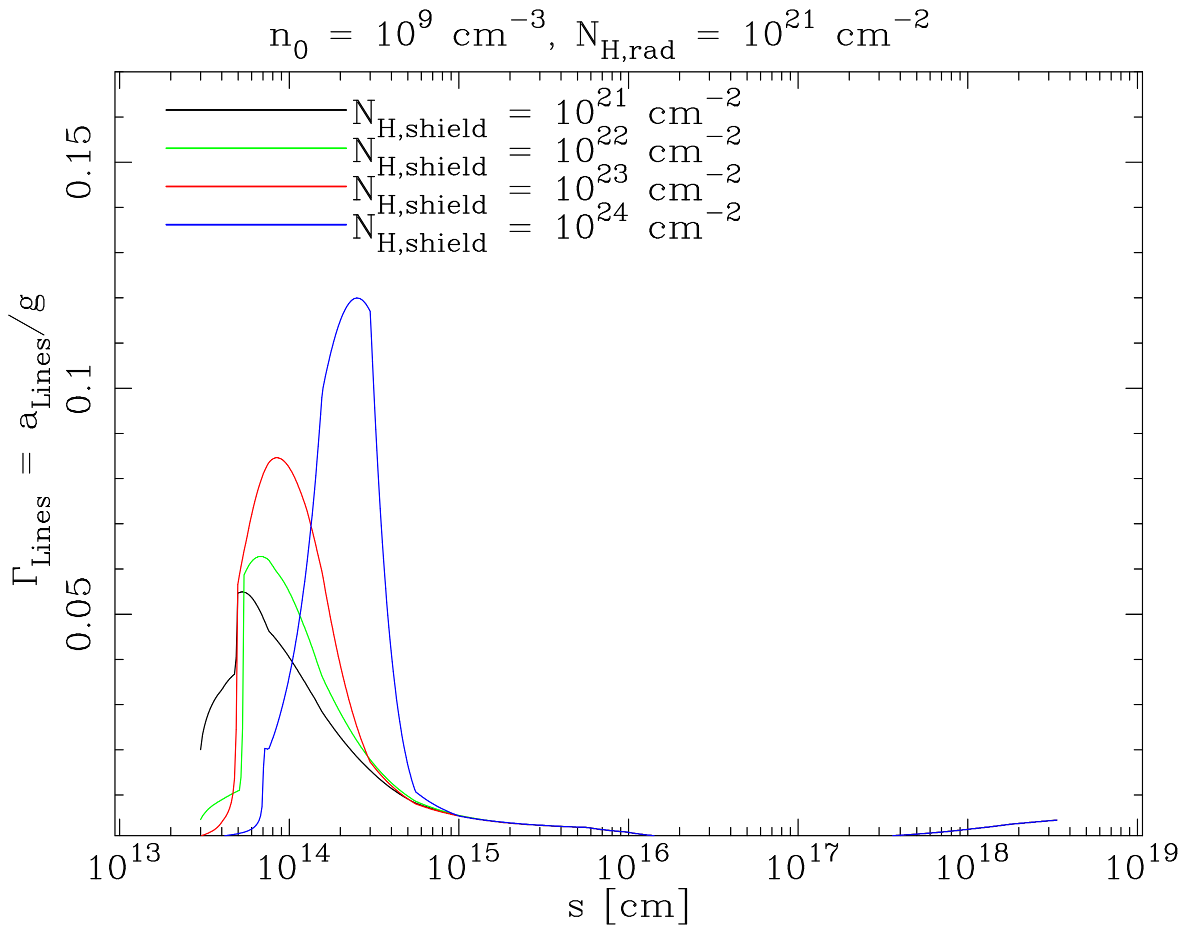
Brief Tour of a Magnetocentrifugal Wind



J.E. (2005)

MHD Winds Make Line Driving Efficient

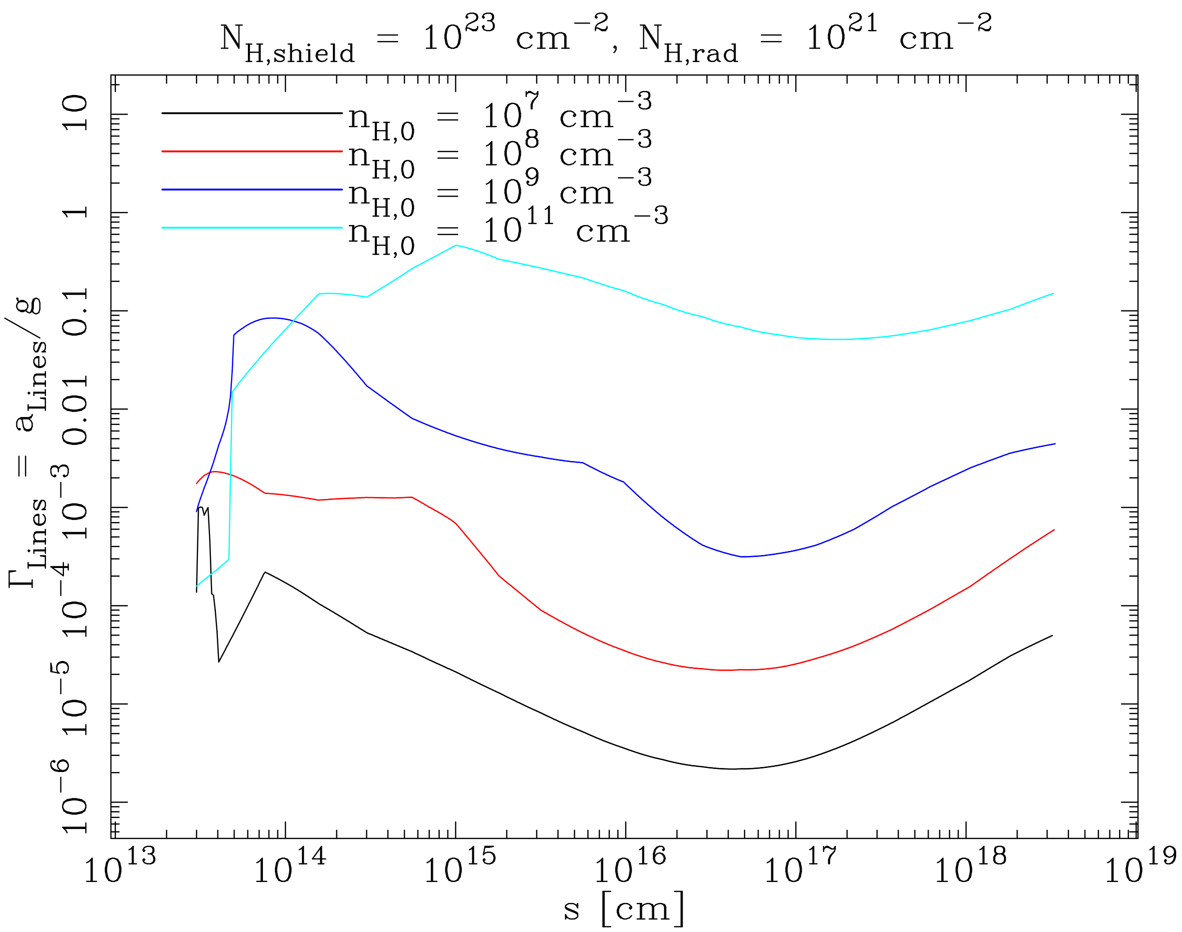
Adding a greater column (more shielding) in the magnetocentrifugal wind helps make line driving more efficient.



J.E. (2005)

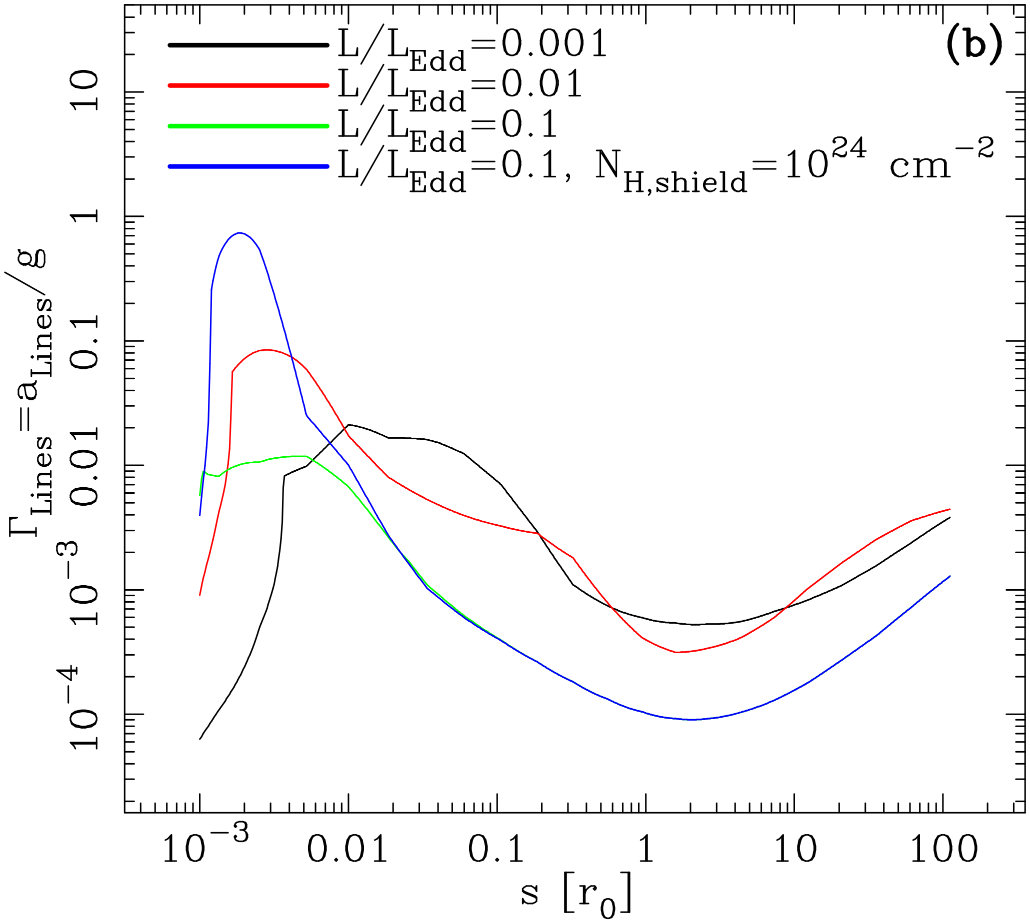
Density is very important

The wind models are very dependent on the initial density, though, which sets the ionization state at the base of the wind.



J.E. (2005)

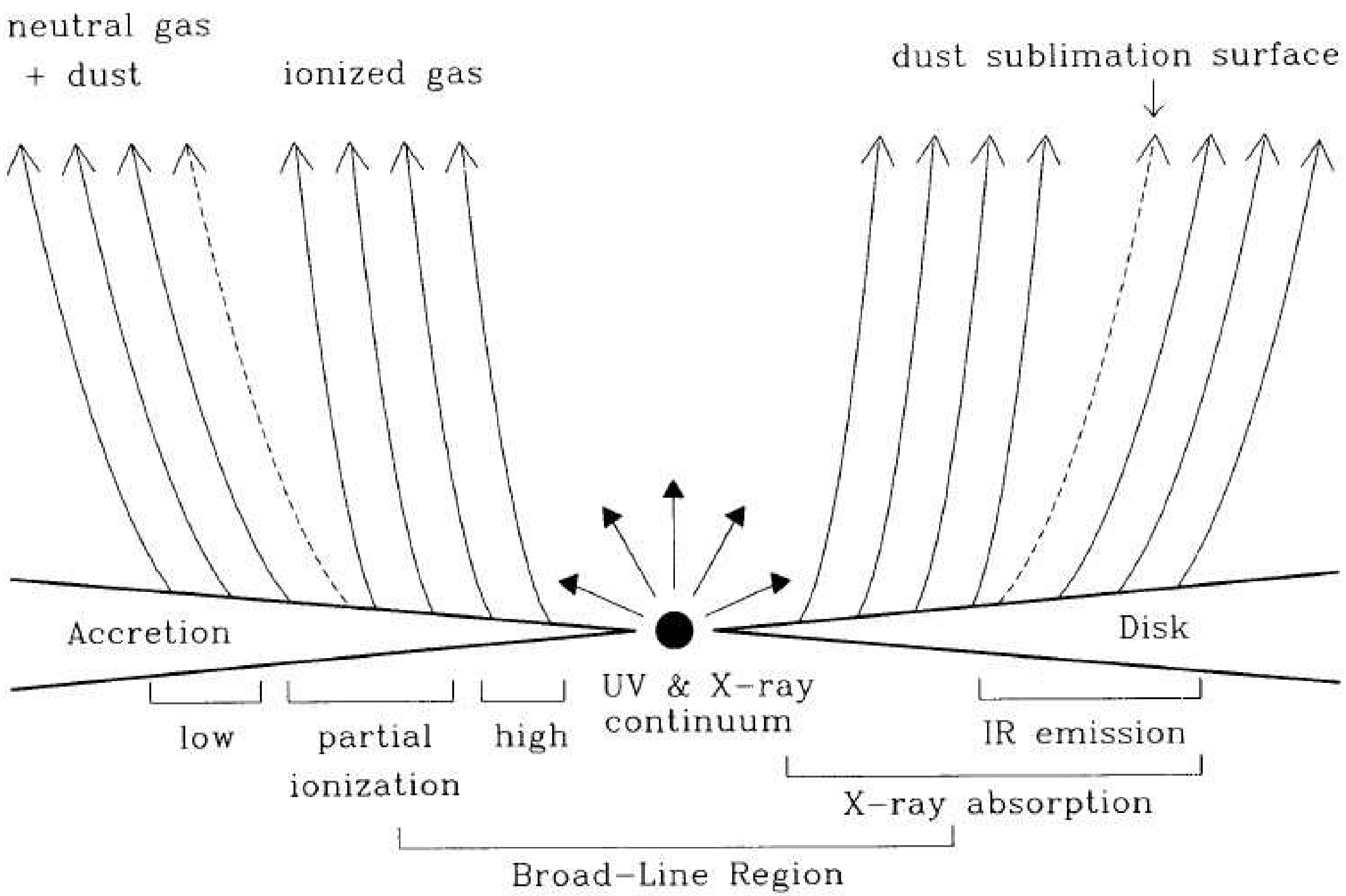
High Eddington Number Required



J.E. (2005)

Evidence for Magnetocentrifugal Winds

MHD Winds Explain Unification Model

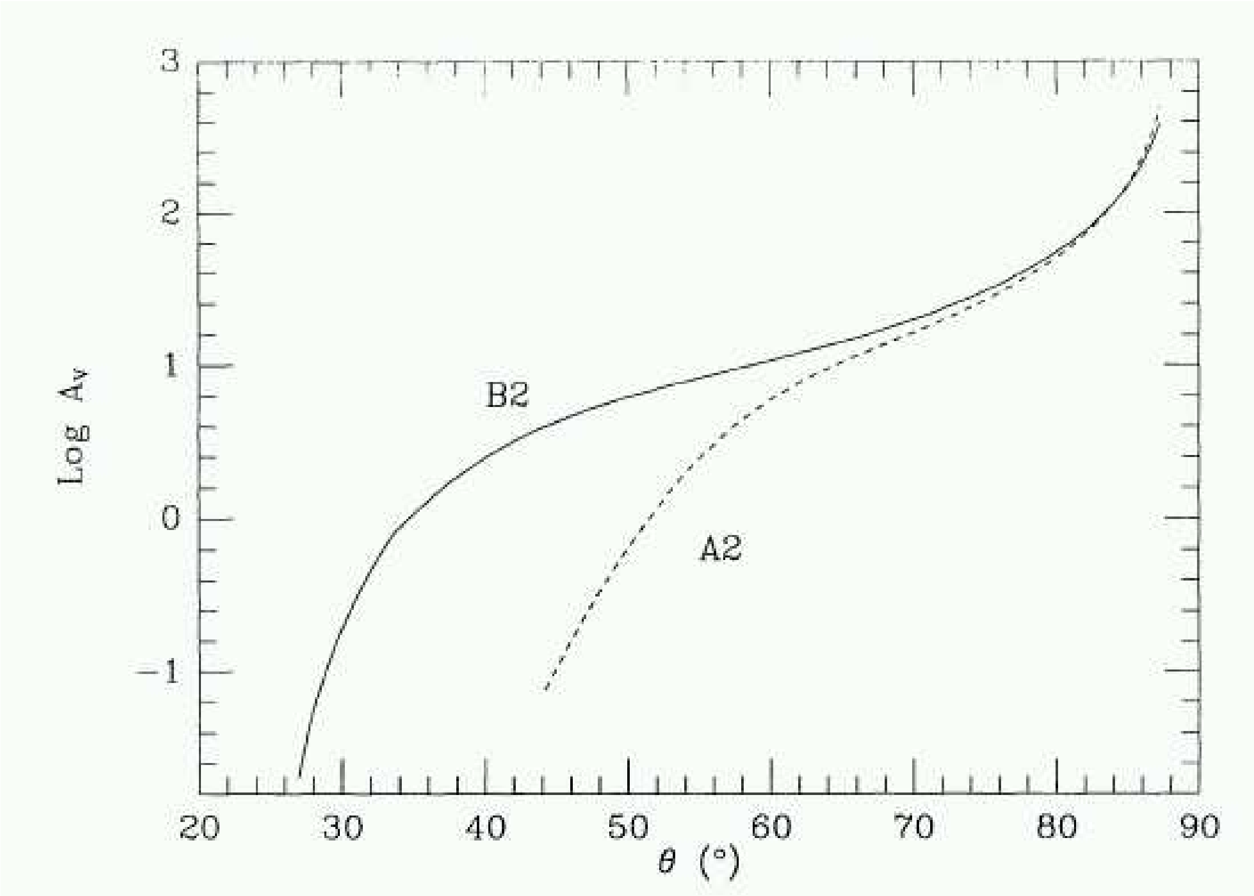


Königl & Kartje (1994)

A dusty, continuous magnetocentrifugal wind explains AGN obscuration.

CITA–ICAT

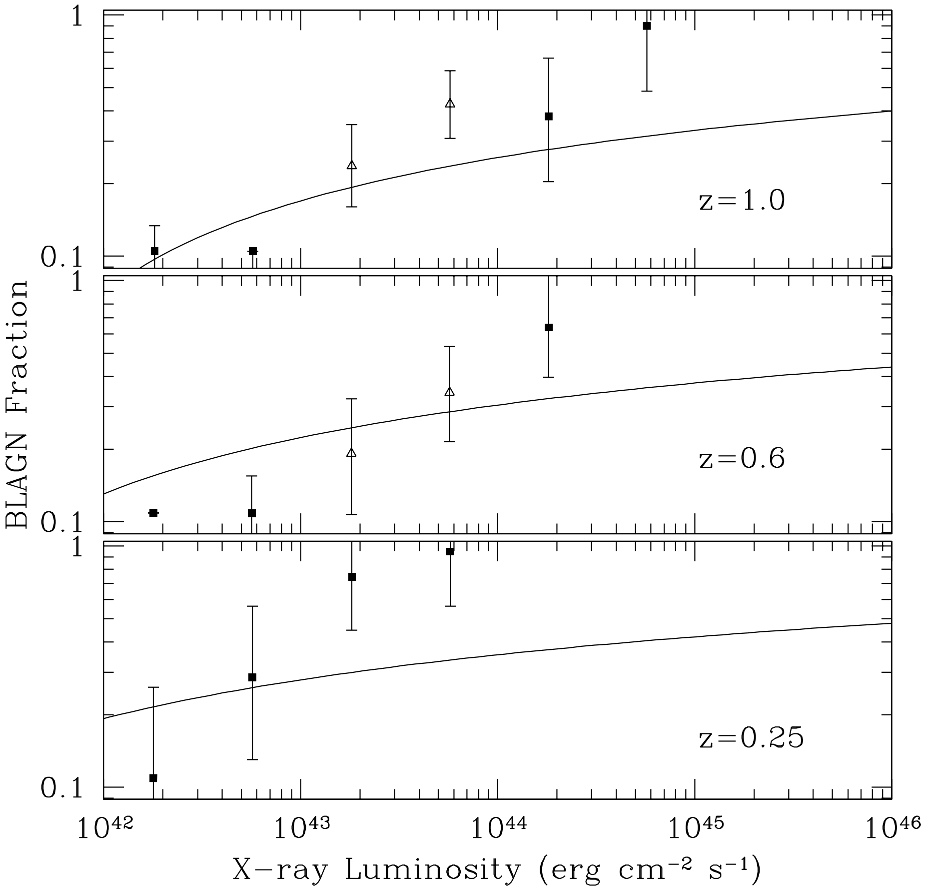
MHD Winds Explain Unification Model



Königl & Kartje (1994)

The increased extinction near the disk in a dusty wind may explain AGN Unification. The Sy 1/Sy 2 dichotomy is due to a dusty disk wind.

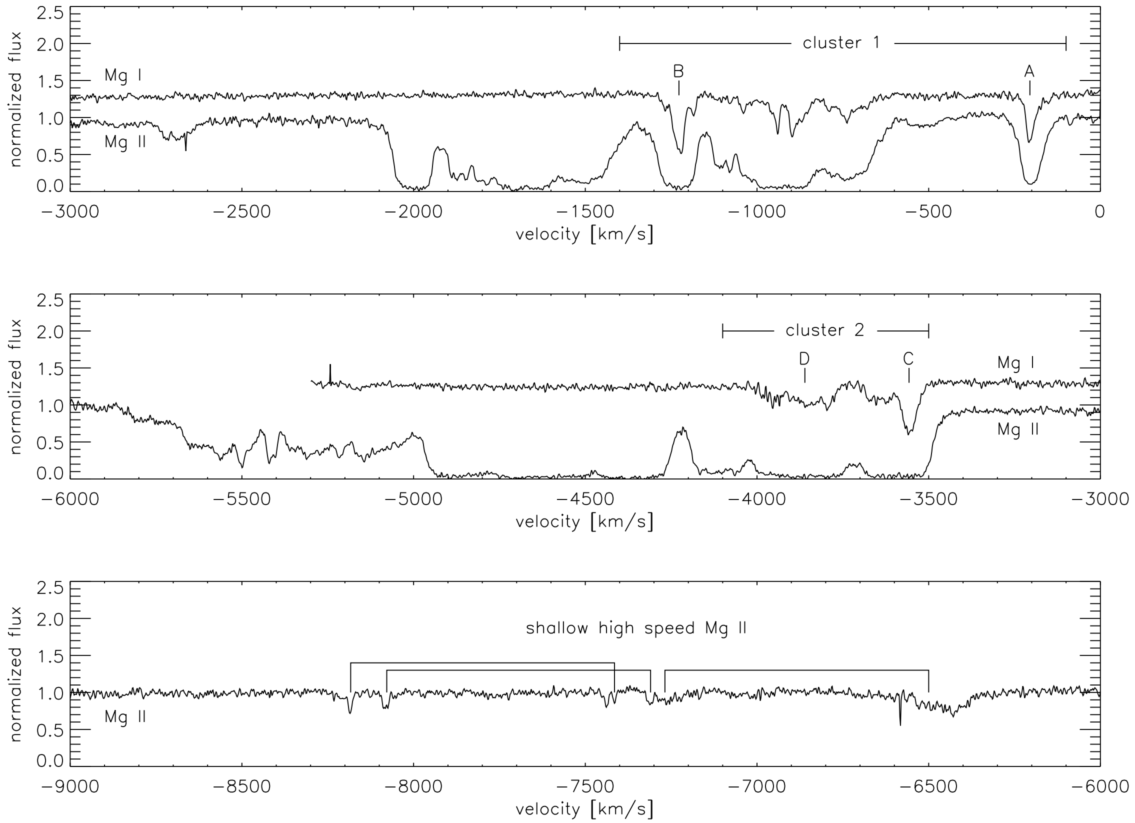
MHD Winds Explain Unification Model



Barger et al. 2005, Ballantyne, J.E., & Murray (2006)

Dusty MHD winds also give a natural explanation to variation in Broad Line Fraction as a function of luminosity.

MHD Wind Models of BALQSOs



de Kool et al. (2001):

- Low Ionization Lines of Mg II, Mg I, Fe II, Fe I
- Outflow velocities of $\sim$ 200 km s^{-1} to 6000 km s^{-1}

MHD Wind Fits to FBQS 1044

J.E., Königl, Arav (2002):
What if the outflow is shielded, as in our magnetocentrifugal model?

Using a shielded, multiphase magnetocentrifugal wind model, we found:

- $r_{\mathrm{absorber}} \approx 4$ pc
- $n_{\mathrm{H},0} \approx 10^{8.75}$ cm^{-3}
- $n_{\mathrm{H,cloud,obs}} \approx 10^{8.5}$ cm^{-3}
- Fe II, Fe I, Mg I, Mg II/Mg I, A_{2500} all in agreement with observations.
- This model, however, **requires** a large shielding column to absorb ionizing X-ray photons!

MHD Wind Fits to FBQS 1044

J.E., Königl, Arav (2002):
What if the outflow is shielded, as in our magnetocentrifugal model?

Using a shielded, multiphase magnetocentrifugal wind model, we found:

- $r_{\rm absorber} \approx 4$ pc
- $n_{\rm H,0} \approx 10^{8.75}$ cm^{-3}
- $n_{\rm H,cloud,obs} \approx 10^{8.5}$ cm^{-3}
- Fe II, Fe I, Mg I, Mg II/Mg I, A_{2500} all in agreement with observations.
- This model, however, **requires** a large shielding column to absorb ionizing X-ray photons!
- *That shielding column has now been observationally verified*: Brotherton et al. (2005) find X-ray absorption by a column with $N_{\rm H} \approx 10^{23}$ cm^{-2}.

CITA–ICAT

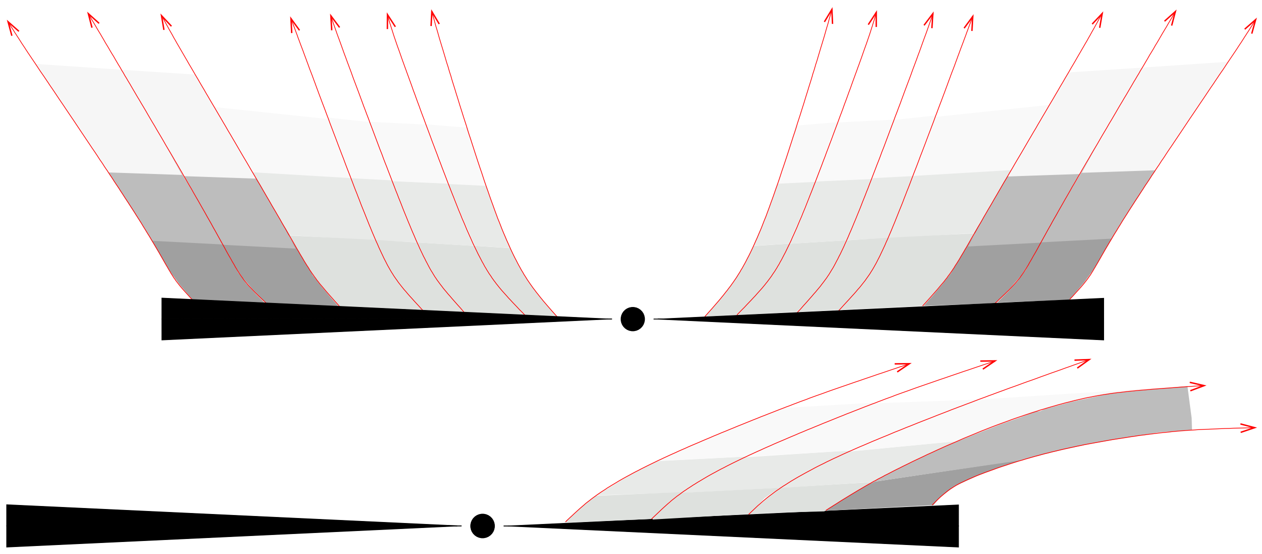
Conclusions

Conclusions

Conclusions

- Radiative acceleration can occur under certain circumstances, but is not always dominant.
- Magnetocentrifugal winds can launch the wind from the disk, and then allow efficient radiative acceleration.
- Evidence is mounting in observations and models that MHD mechanisms are important.
  - [O III] gas is not radiatively or thermally driven
  - Relativistic X-ray winds in PG 1211 cannot be radiatively driven
  - UV Absorption lines in NGC 4151 are not radiatively driven (Kraemer et al. 2005)
  - AGN obscuration and outflows explained simultaneously
  - MHD winds can produce observed BALQSO columns and the observed shielding columns in FBQS 1044

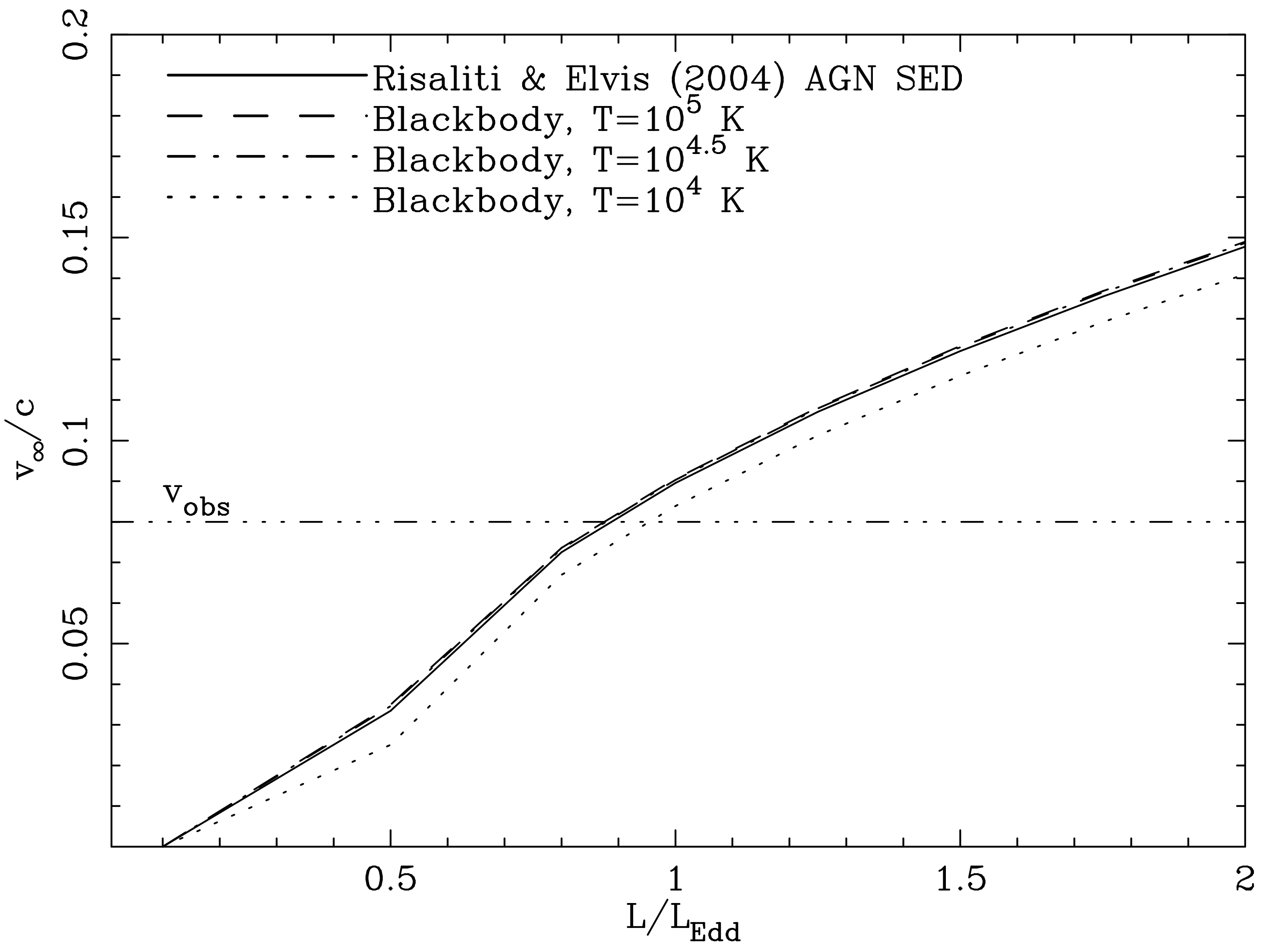
MHD Winds in AGN



Radiative Driving Doesn't Work for PG 1211

These winds are almost purely electron scattering-driven.

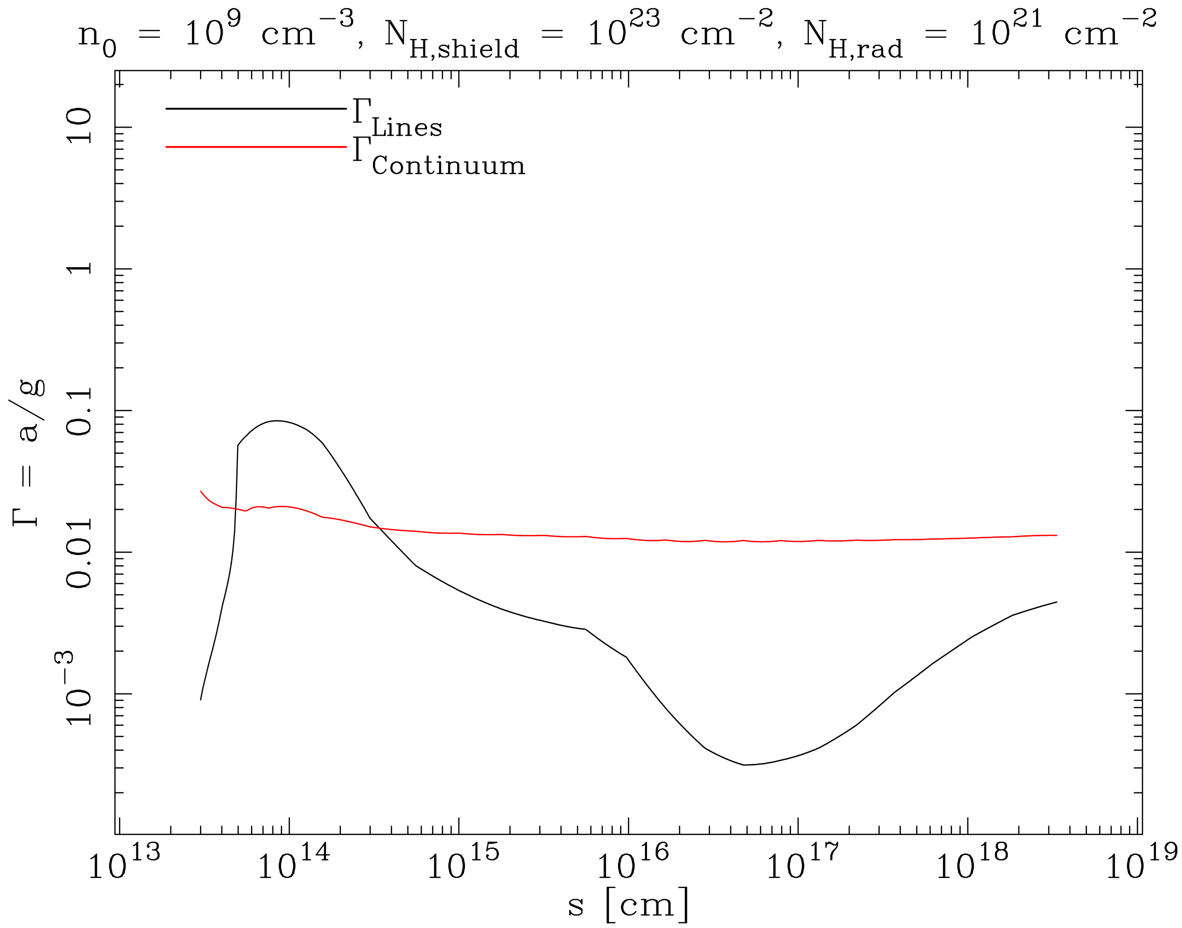
Achieving $v_{\rm obs}$ requires $L/L_{\rm Edd} \gtrsim 1$.



J.E. & Ballantyne (2004)

Line Driving > Continuum Driving

Line driving can be more important than continuum driving in magnetocentrifugal winds:



J.E. (2005)