Magneto-centrifugal winds from accretion discs around black hole binaries

by

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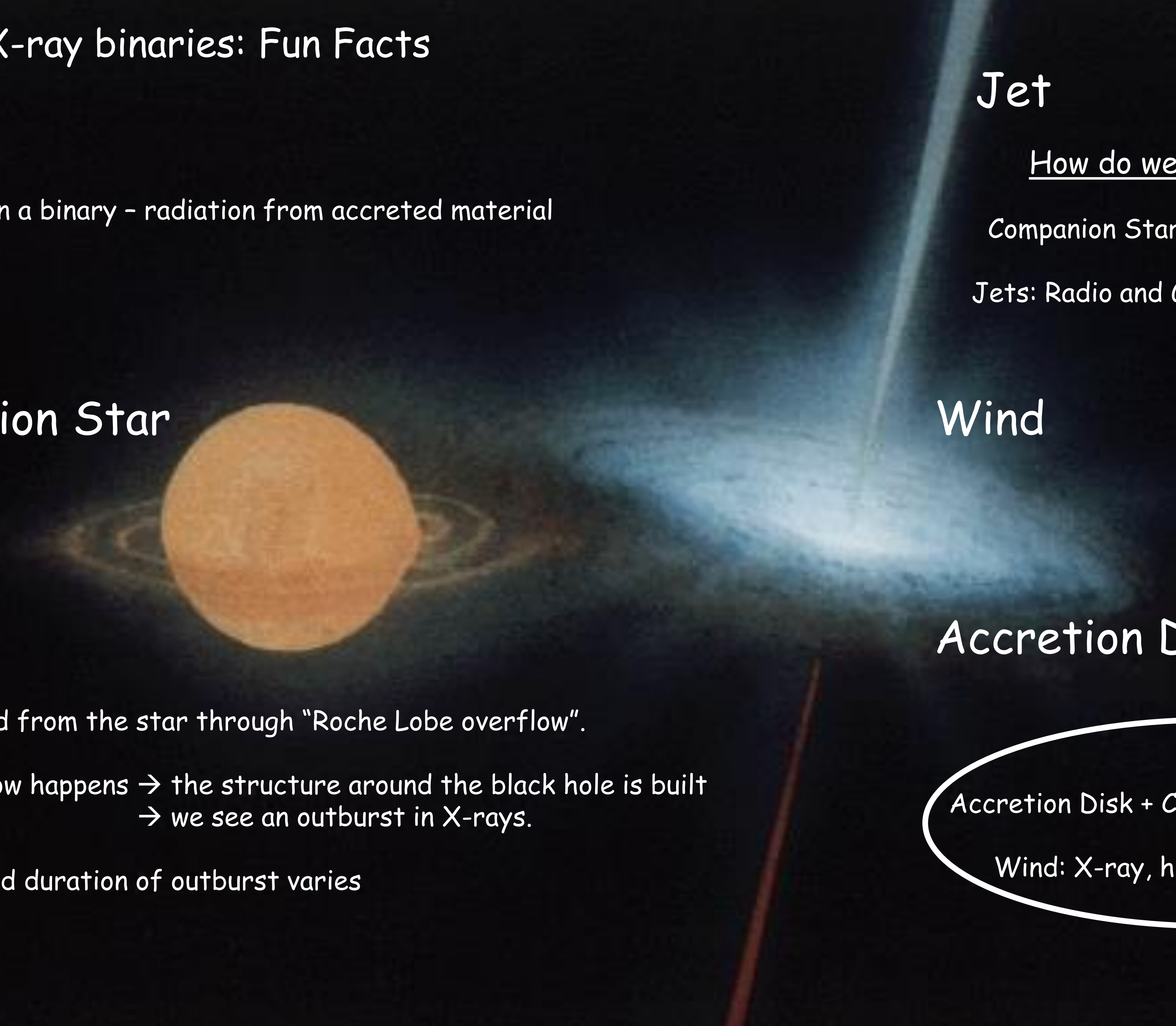
Shining from the heart of darkness: black hole accretion and jets

18th October, 2016

Black Hole X-ray binaries: Fun Facts

We “see” a BHB in a binary – radiation from accreted material



How do we study the BHB?

Companion Star: UV, optical, infrared

Jets: Radio and Gamma Ray wavelengths

Accretion Disk + Corona: X-ray wavelengths

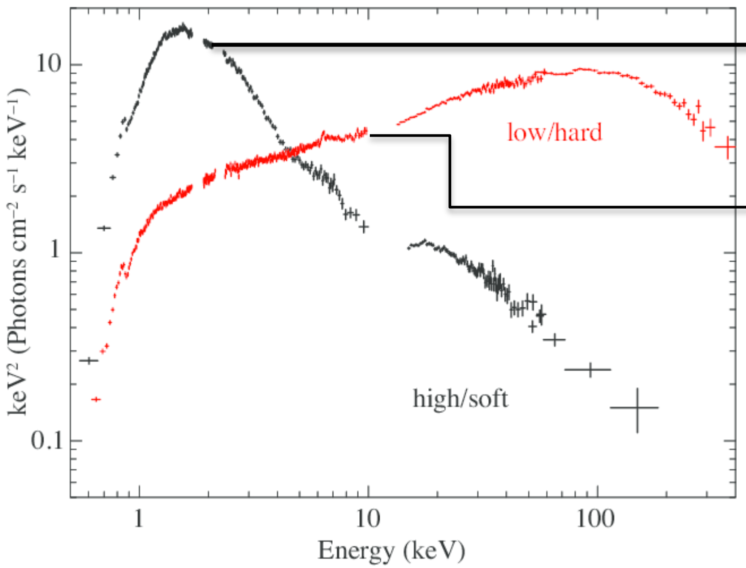
Wind: X-ray, high resolution spectra

Material accreted from the star through “Roche Lobe overflow”.

When the overflow happens → the structure around the black hole is built
→ we see an outburst in X-rays.

The frequency and duration of outburst varies

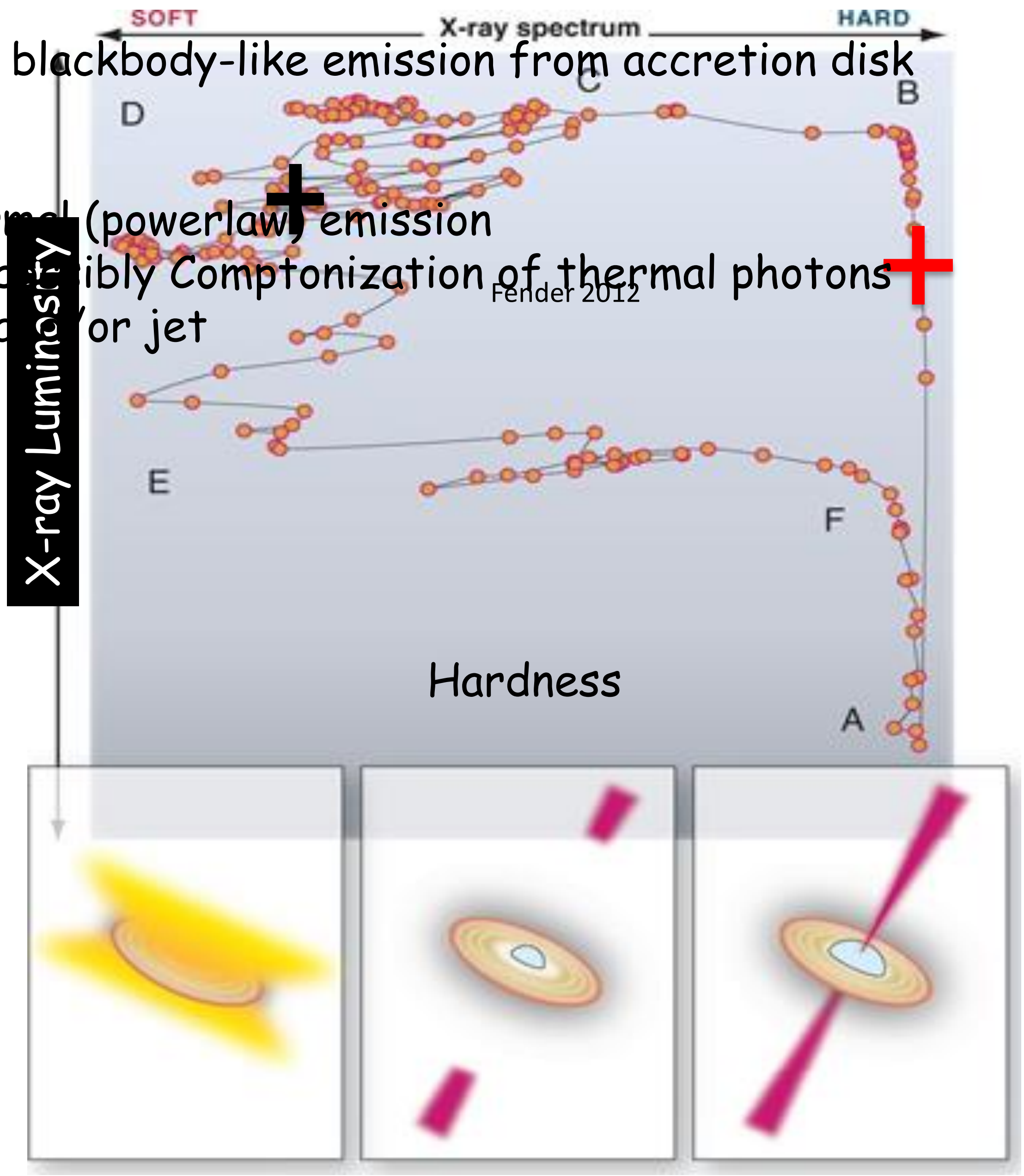
What do we see using X-ray spectra?



CygX1 using Suzaku, Yamada, Shin'ya et al. PASJ 45 (2012)

Thermal, blackbody-like emission from accretion disk

Non thermal (powerlaw) emission
possibly Comptonization of thermal photons
and/or jet



Using a broad band telescope

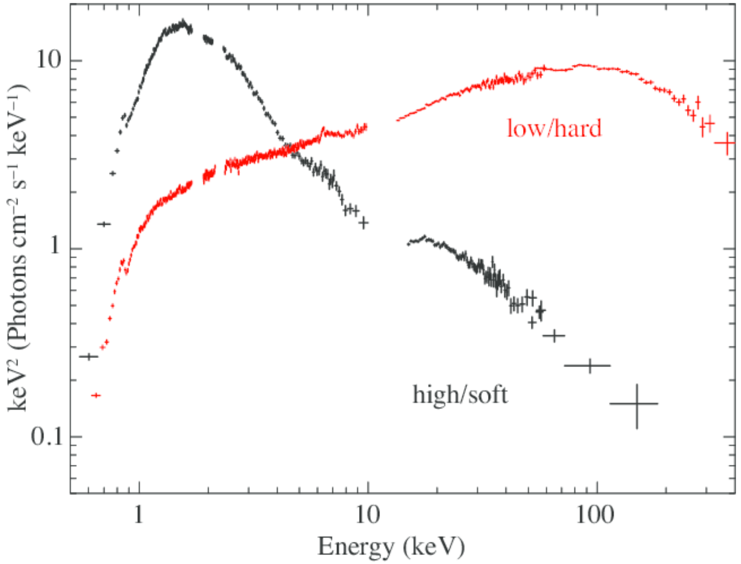
Observing in ~ 1 – 100 keV
(e.g. Astrosat, RXTE, Suzaku)

If we monitor the source for a long time

We see a "hysteresis"

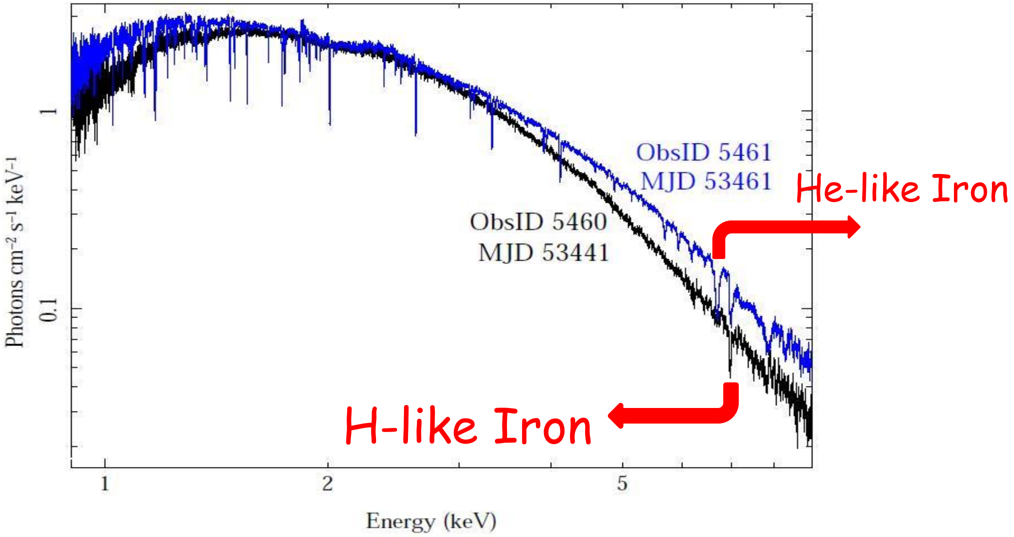
How long? Days – Months

What do we see using X-ray spectra?



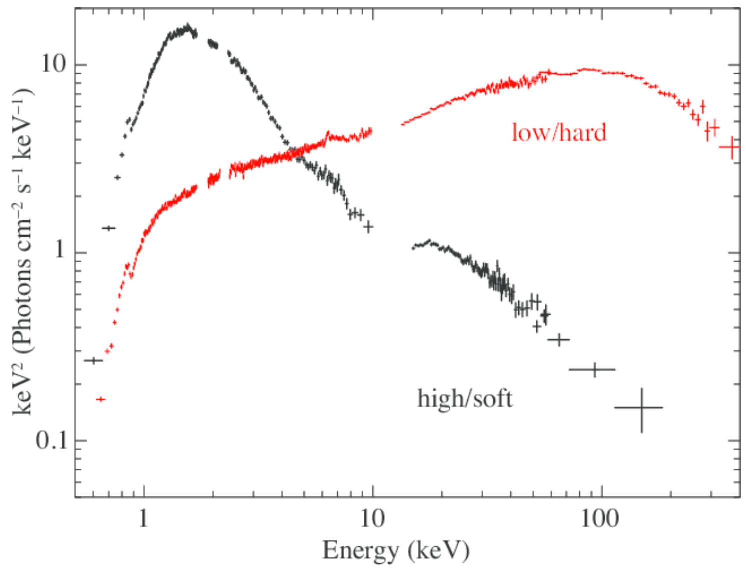
Using a high resolution telescope

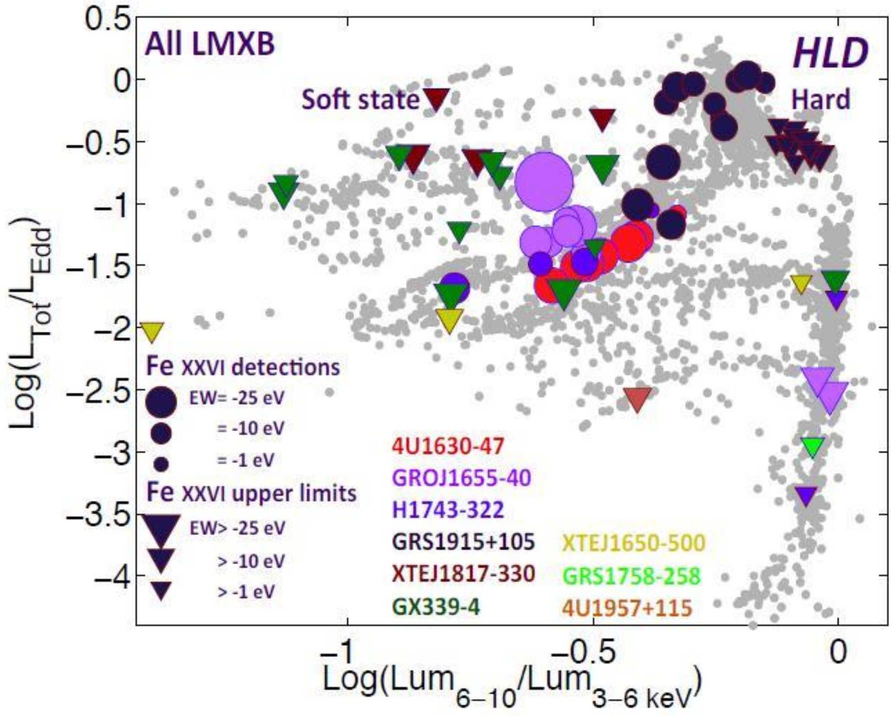
Observing in ~ 1 – 10 keV
(e.g. Chandra, XMM-Newton)



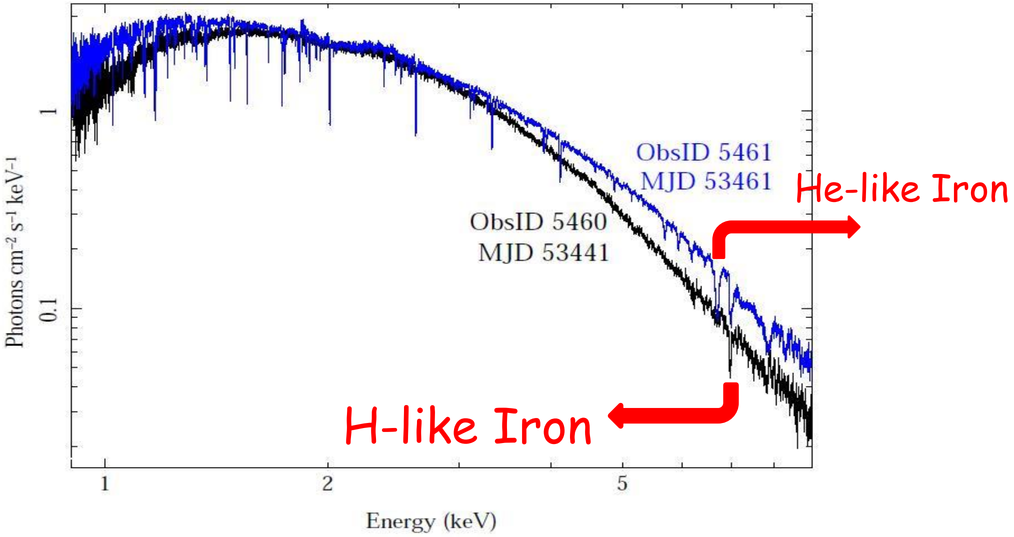
GROJ 1655, using Chandra, Neilsen & Homann, 2012

What do we see using X-ray spectra?





Ponti et.al 2012



Winds are observed only in the Soft state

Winds are equatorial – i.e. close to the surface of the accretion disk

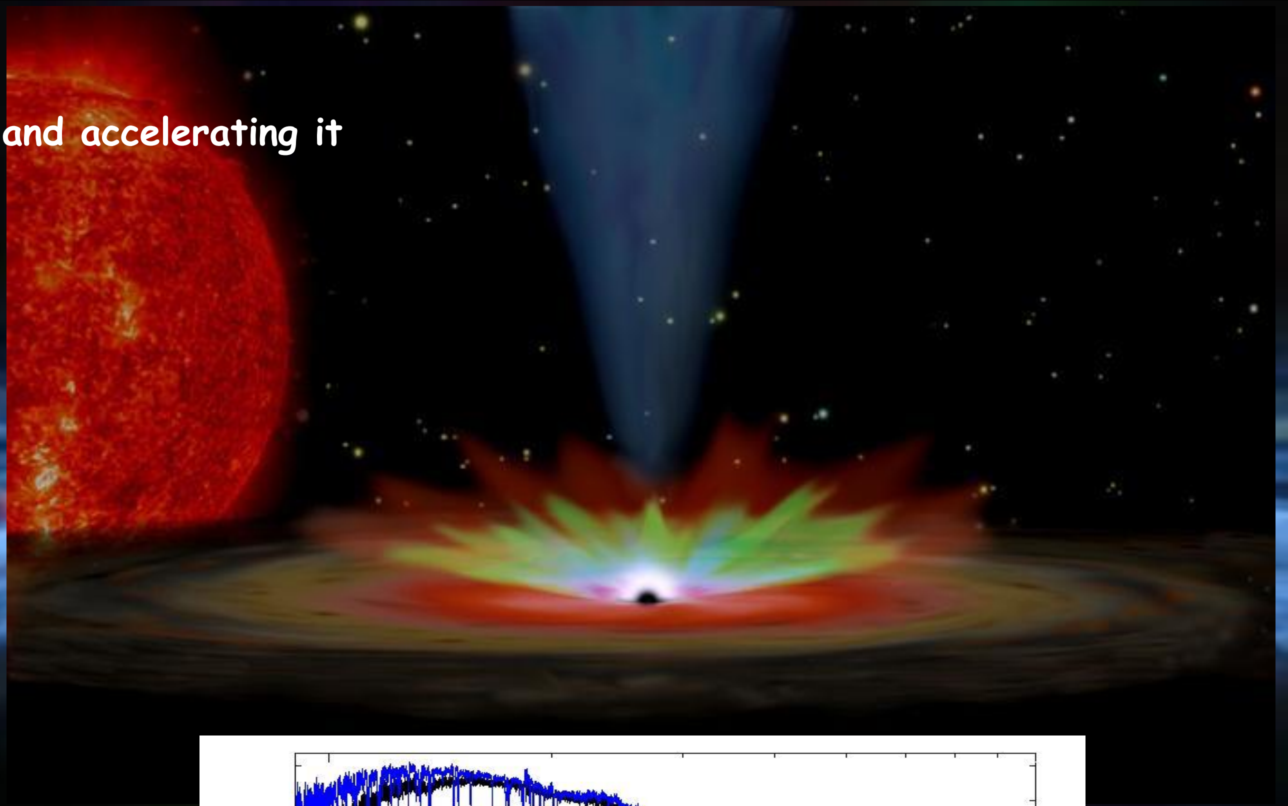
How are the winds accelerated?

We see the absorption lines when we see through the outflow

Some physical mechanism is lifting material off the accretion disk and accelerating it

Search for the accelerating physical mechanism is on

Magnetic fields:
Our group has MHD (magnetohydrodynamic) models of outflows
We show how well (or not) we explain BHB winds with them

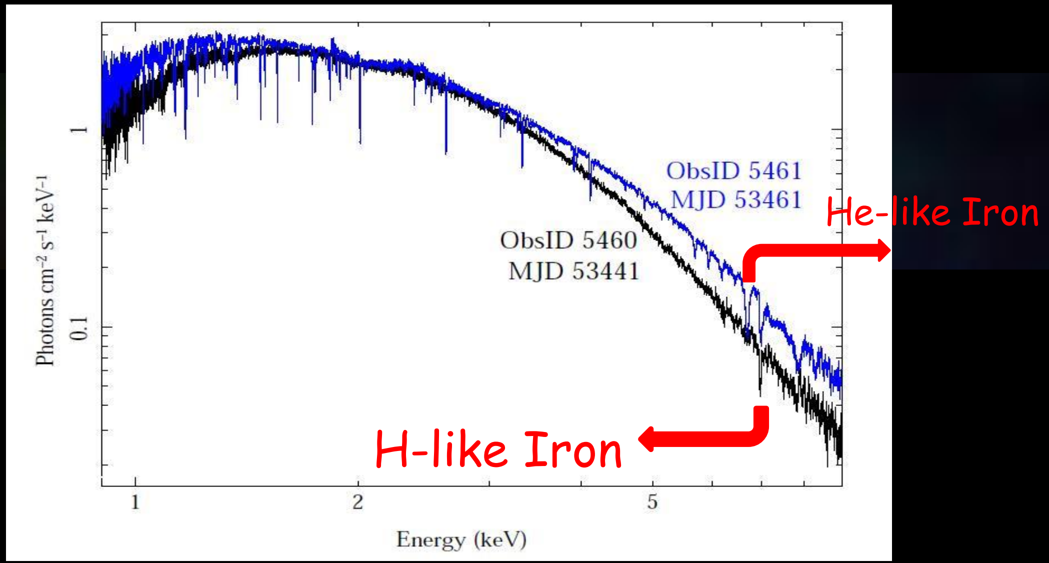


Why magnetic fields?

Mhd is the popular model for Jets

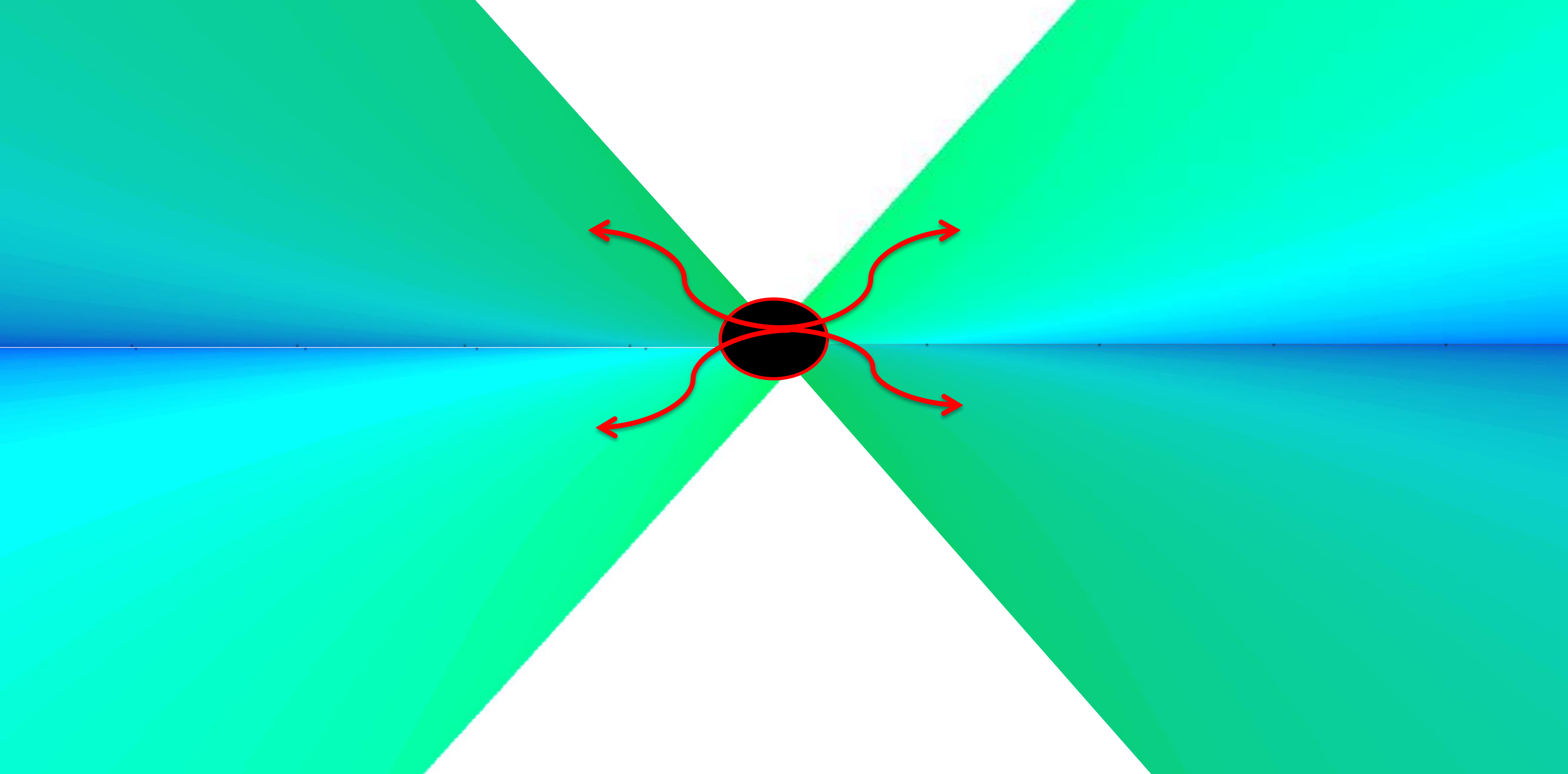
Can they also explain winds?
Successful attempts in case of AGN (super-massive black holes)
[see Fukumura+ 2010-2015]
No attempts for BHBs.yet.

Miller et.al. (2008) suggest MHD winds from spectra of GROJ 1655
~ they found very high densities
~ implying wind launched from close to the black hole



MHD winds from the accretion disk: the ANR-Chaos project

Chakravorty+ 2016, A&A, 589A, 119



MHD winds from the accretion disk: the ANR-Chaos project

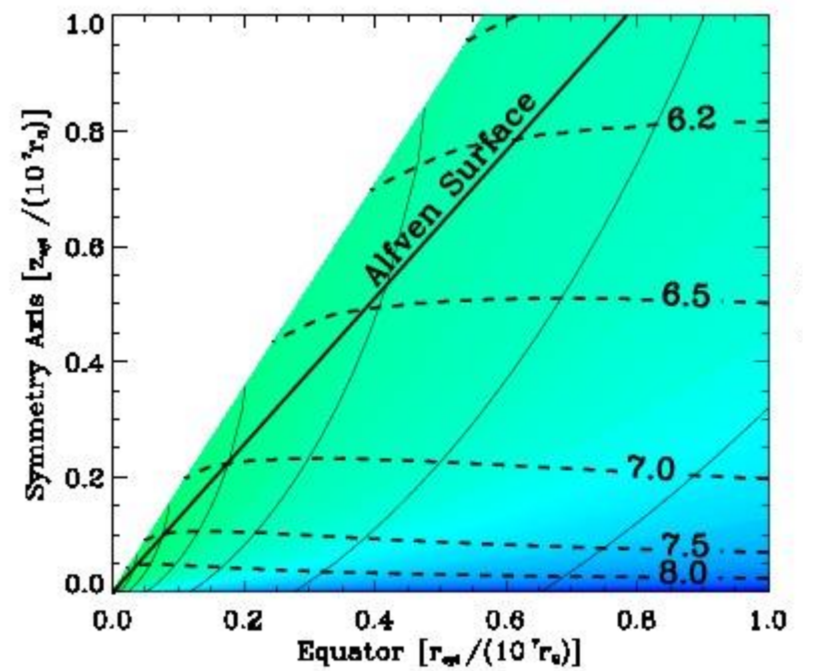
Pre computed
MHD model of outflow from the disk
(Ferreira 1997, Casse & Ferreira, 2000)

Predicts many physical quantities as a function of distance (r, z) from black hole

Gas density, Magnetic field, Gas velocity etc.

The solutions are self similar.
Hence can spread out to large distances.

ε = h/r = 0.001
p = 0.04 ($\dot{M}_{acc}$ = r^p)



$$n(r) = \frac{\dot{m}}{\sigma_T r_g}\left(\frac{r}{r_g}\right)^{(p-3/2)}$$ f(n)

$$v(r) = c\left(\frac{r}{r_g}\right)^{-1/2}$$ f(v)

$$B(r) = \left(\frac{\mu_o m_p c^2}{\sigma_T r_g}\right)^{1/2}\left(\frac{r}{r_g}\right)^{(-5/4+p/2)}$$ f(B)

$$\tau_{dyn}(r) = \frac{2\pi r_g}{c}\left(\frac{r}{r_g}\right)^{3/2}$$ f(dyn)

Disk aspect ratio ε (= h/r)
Ejection efficiency p (where $\dot{M}_{acc}$ = r^p)

The ejection or outflow of material is related to the accretion
Mechanism - **not a free parameter (unlike ADIOS scenarios)**

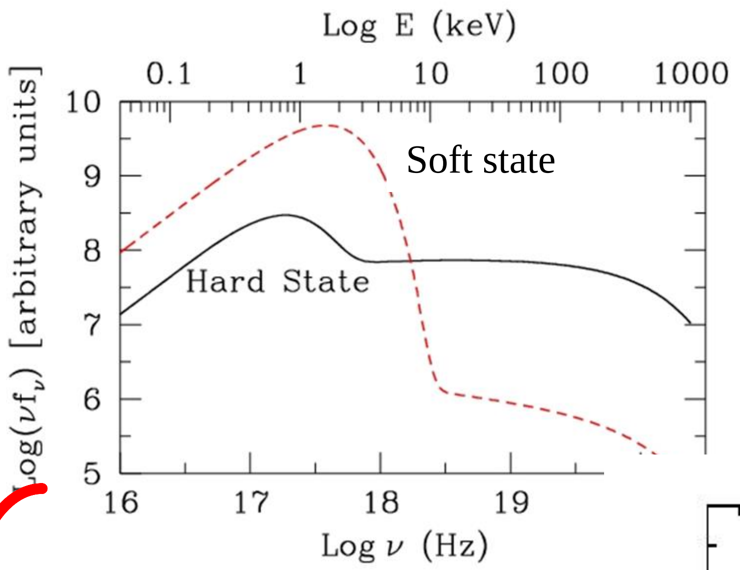
$$n^+ m_p = \rho^+ \simeq \frac{p}{\varepsilon}\frac{\dot{M}_{acc}}{4\pi\Omega_K r^3}$$

$\sigma \sim 1/p$, , $V_{max} \sim p^{-1/2}$

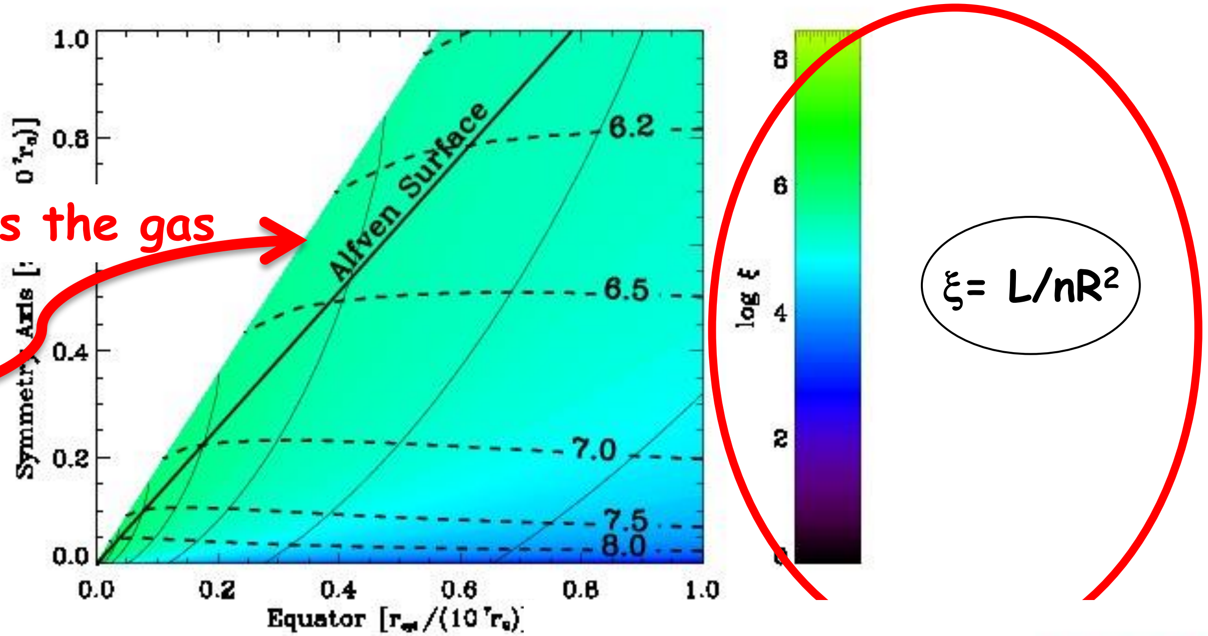
Find the wind region within the MHD model

SED

Description of the light from the innermost part of the disk

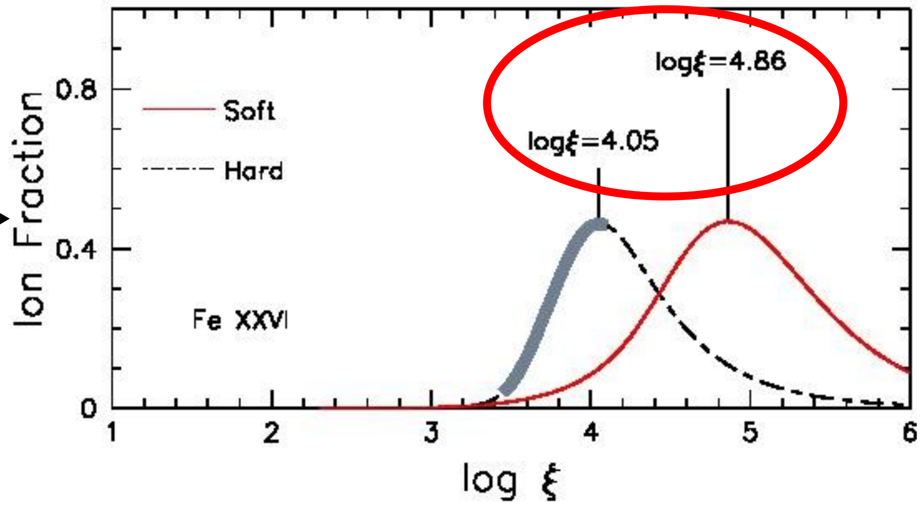


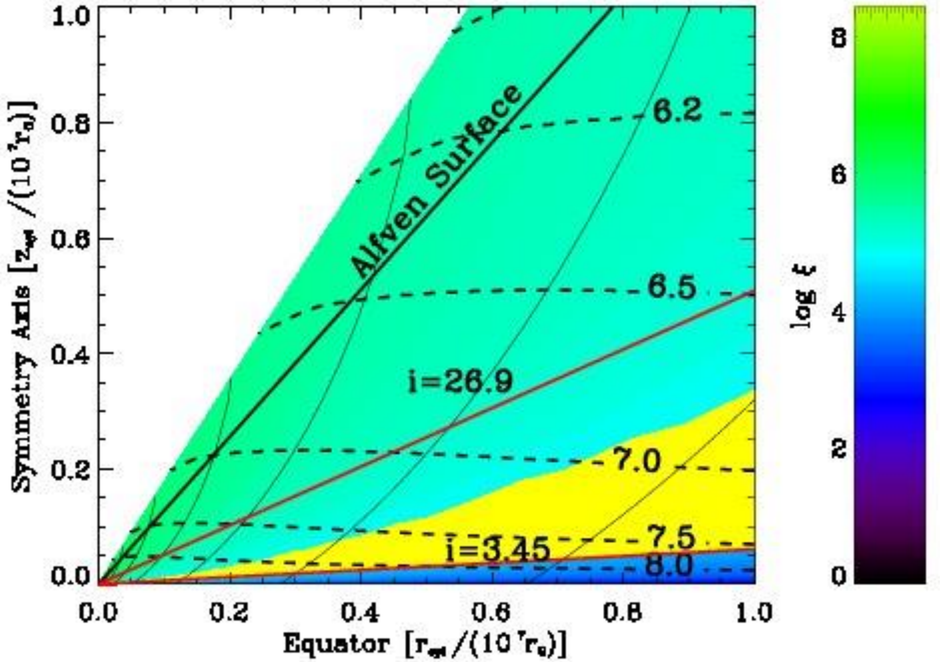
Illuminates the gas



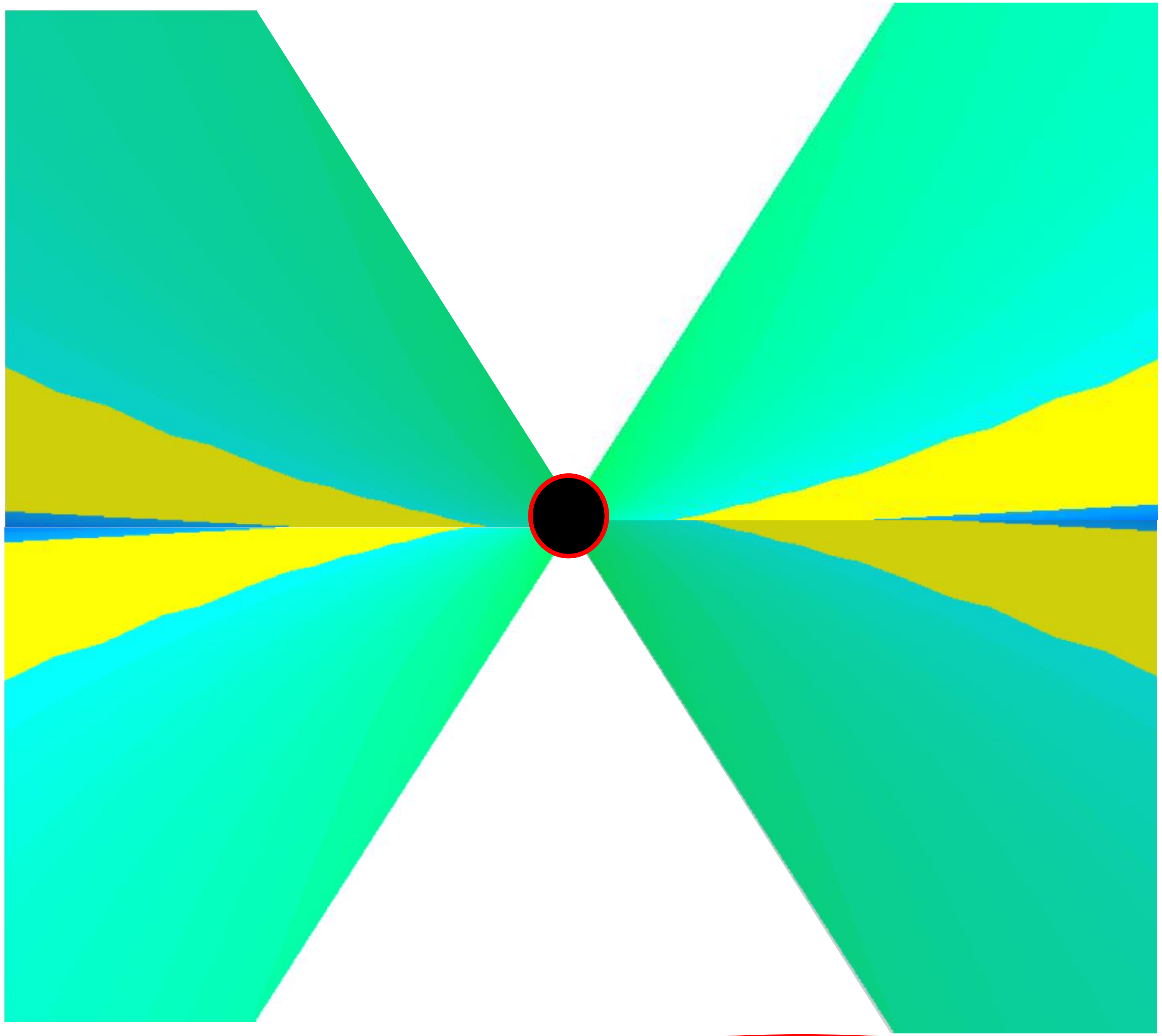
Work out the Atomic Physics of the gas

CLOUDY



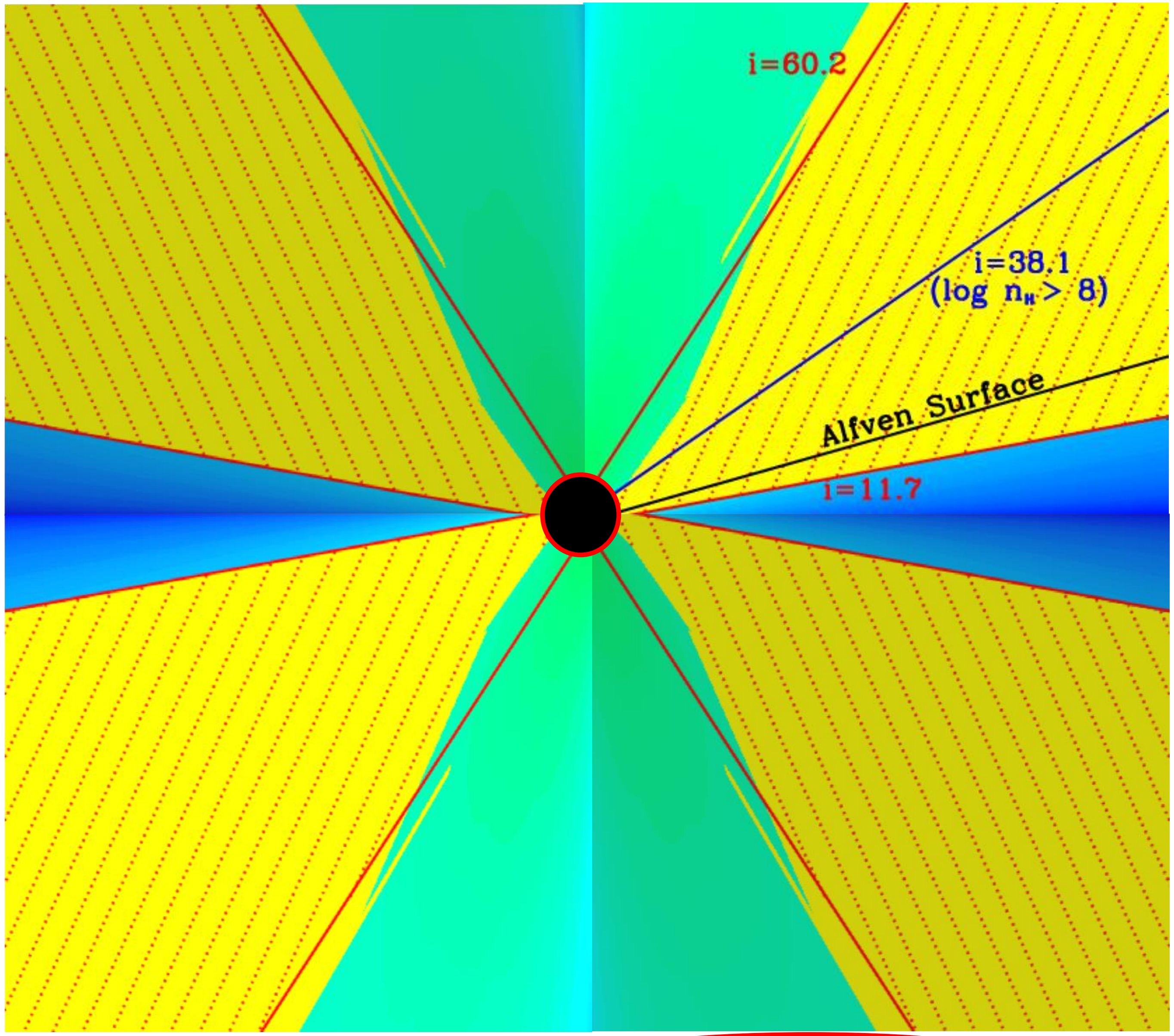


Only a small fraction of the outflow is observable wind



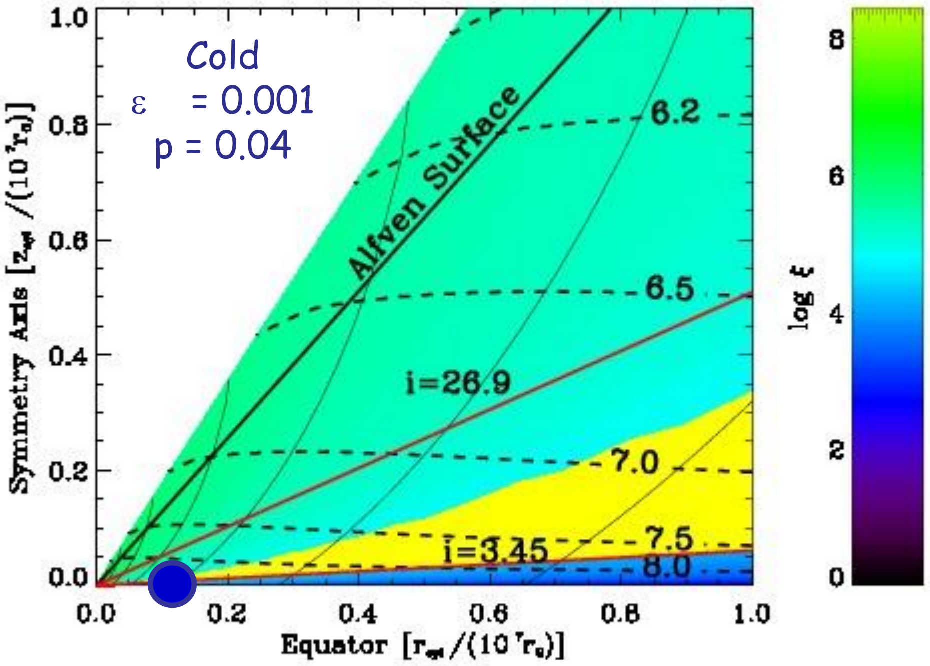
A Cold model with ε = h/r = 0.001 and p = 0.04

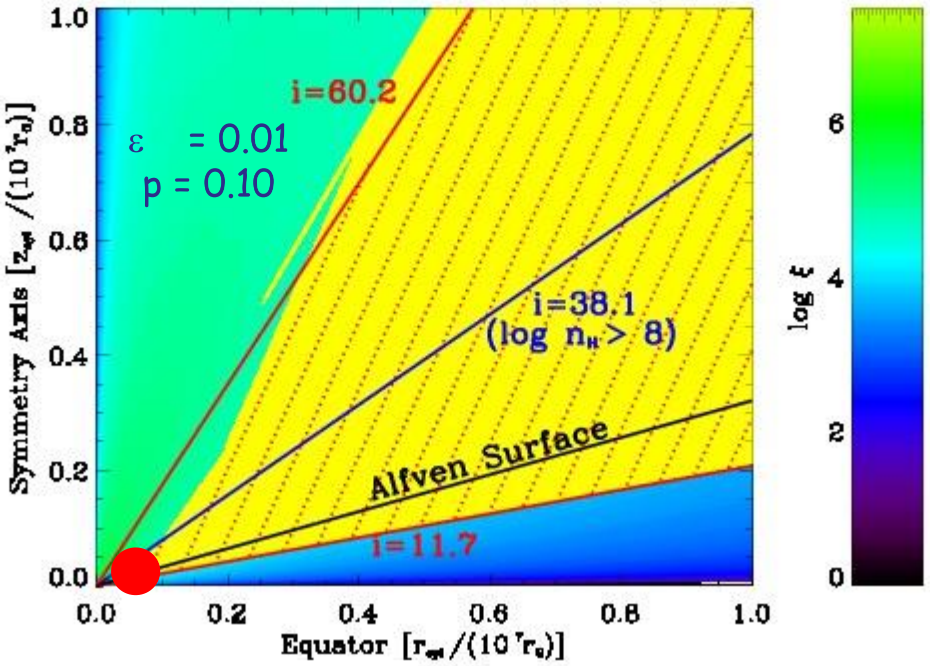
The “wind fraction” will depend on the MHD model



A **<u>denser</u>** Warm model with ε = h/r = 0.01 and p = 0.1

Cold vs warm magnetic solutions





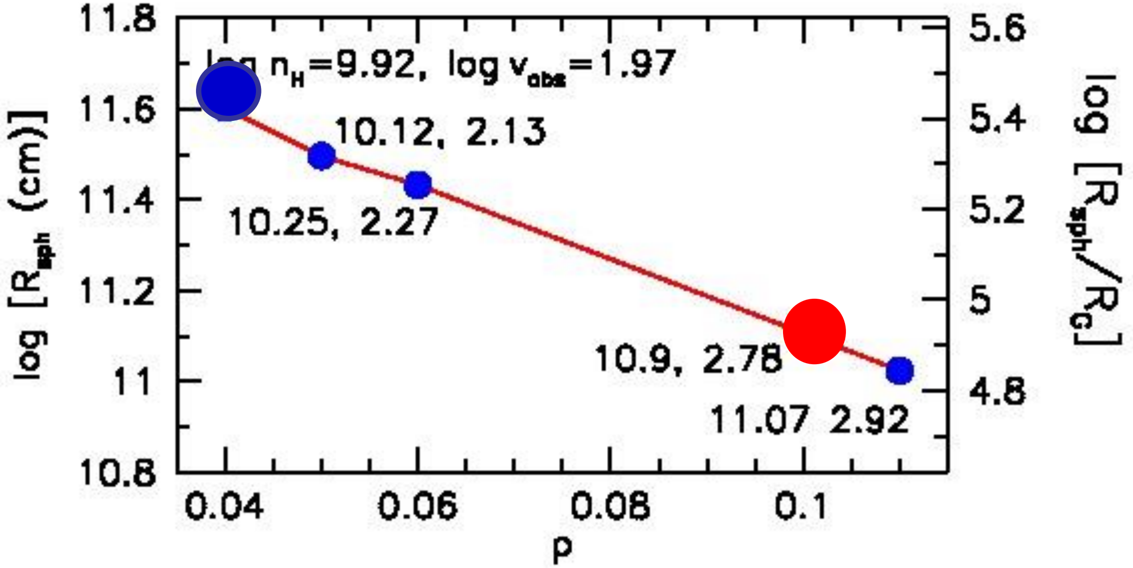
Cold

Purely magnetic acceleration

Does not work

The wind is too far away

Density too low



Warm

Disk surface is heated

Hence more material is lifted off the disk

Magnetic acceleration follows

Works for "average" winds

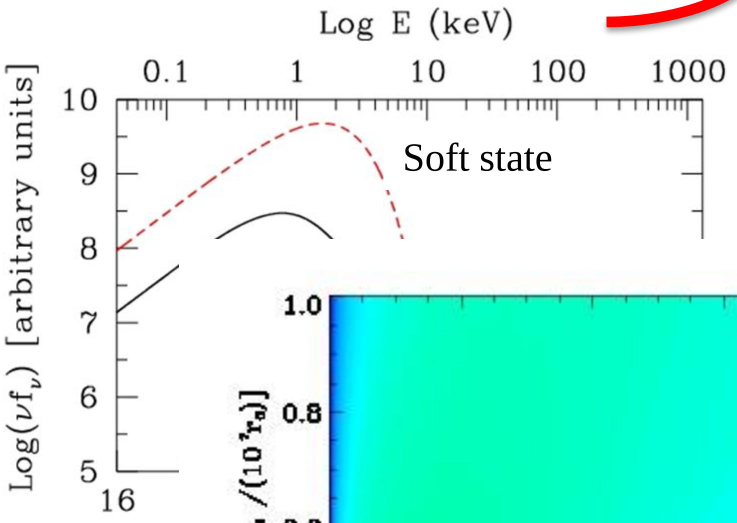
Density < 10^{12} cm^{-3},

Velocity $\leq 10^3$ Km/s

Why no winds in the hard state?

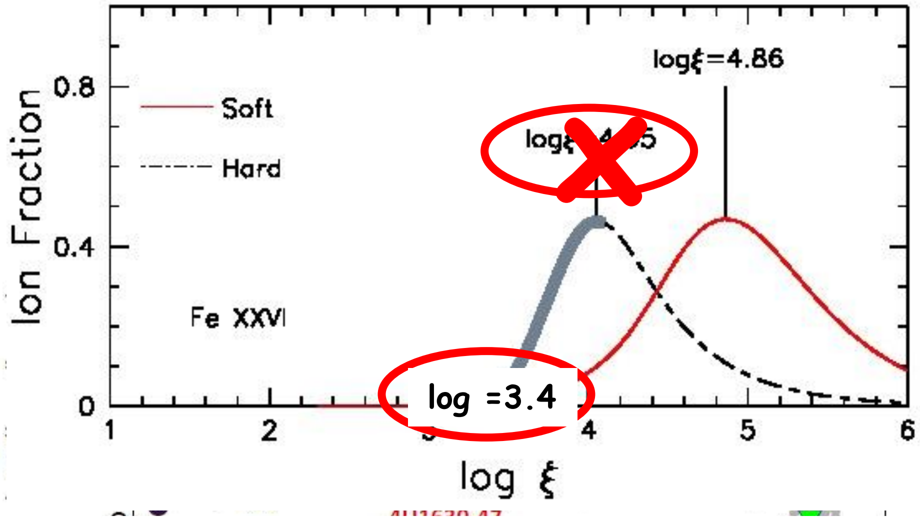
SED

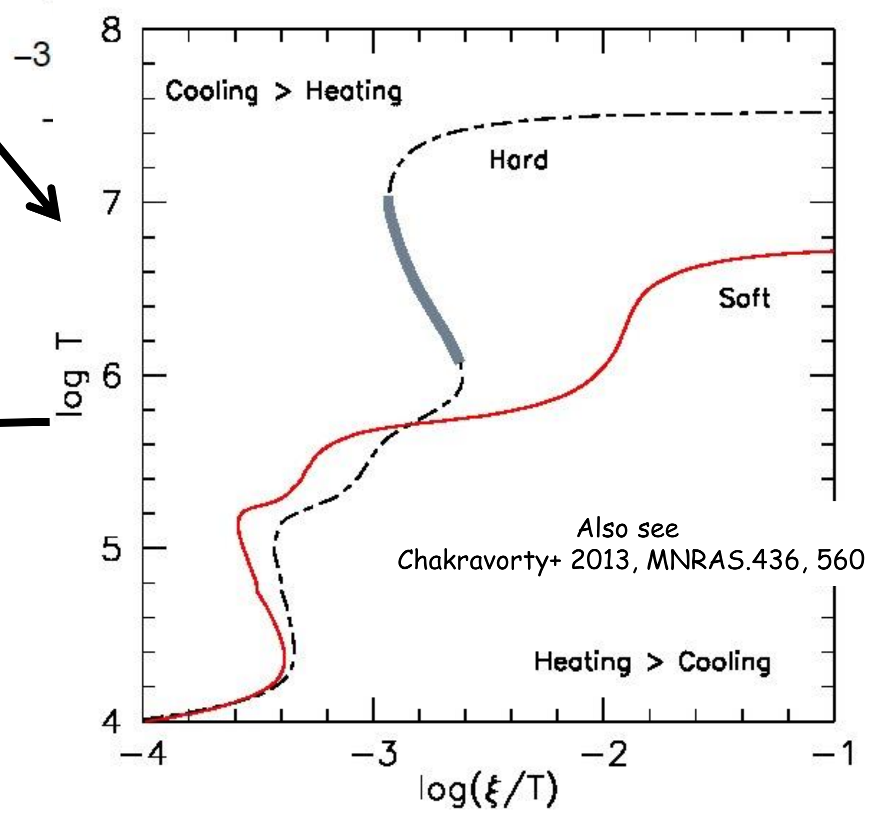
Description of the light from the innermost part of the disk



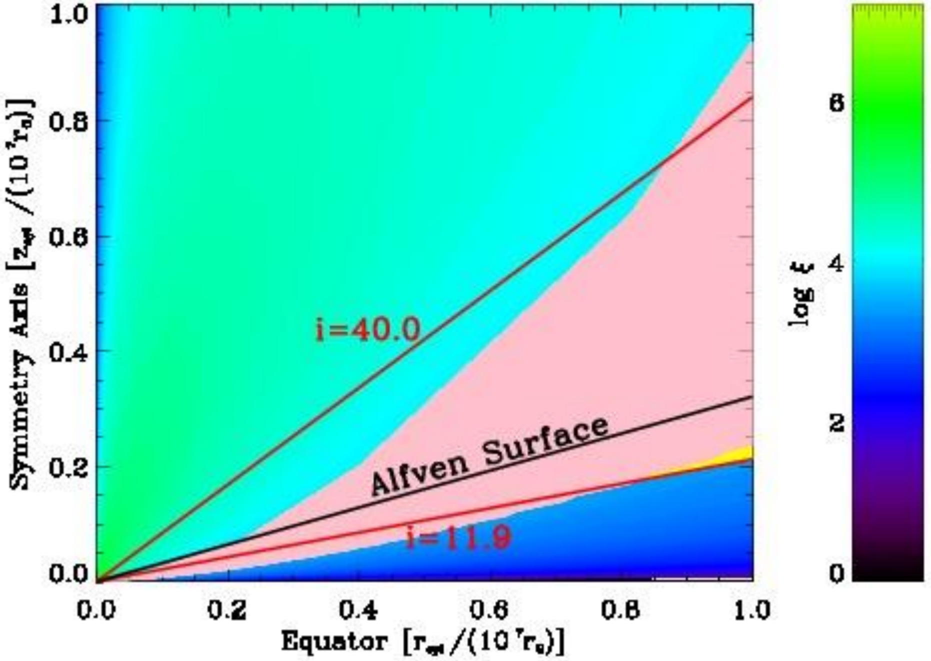
Work out Atomic Physics of the gas

CLOUDY





Also see
Chakravorty+ 2013, MNRAS.436, 560

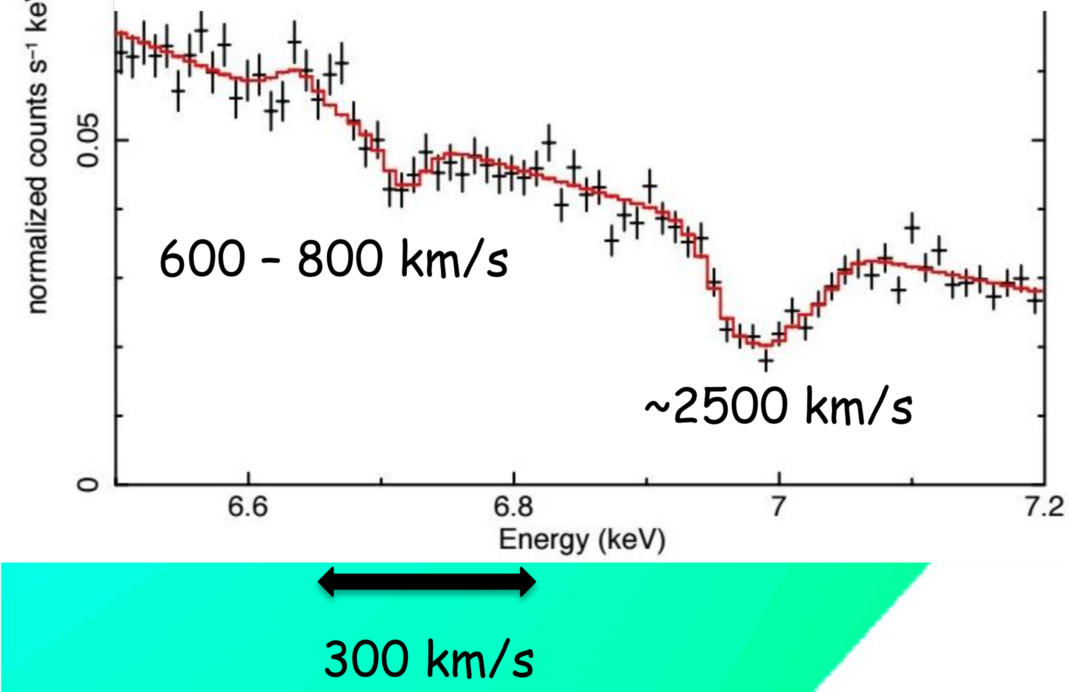


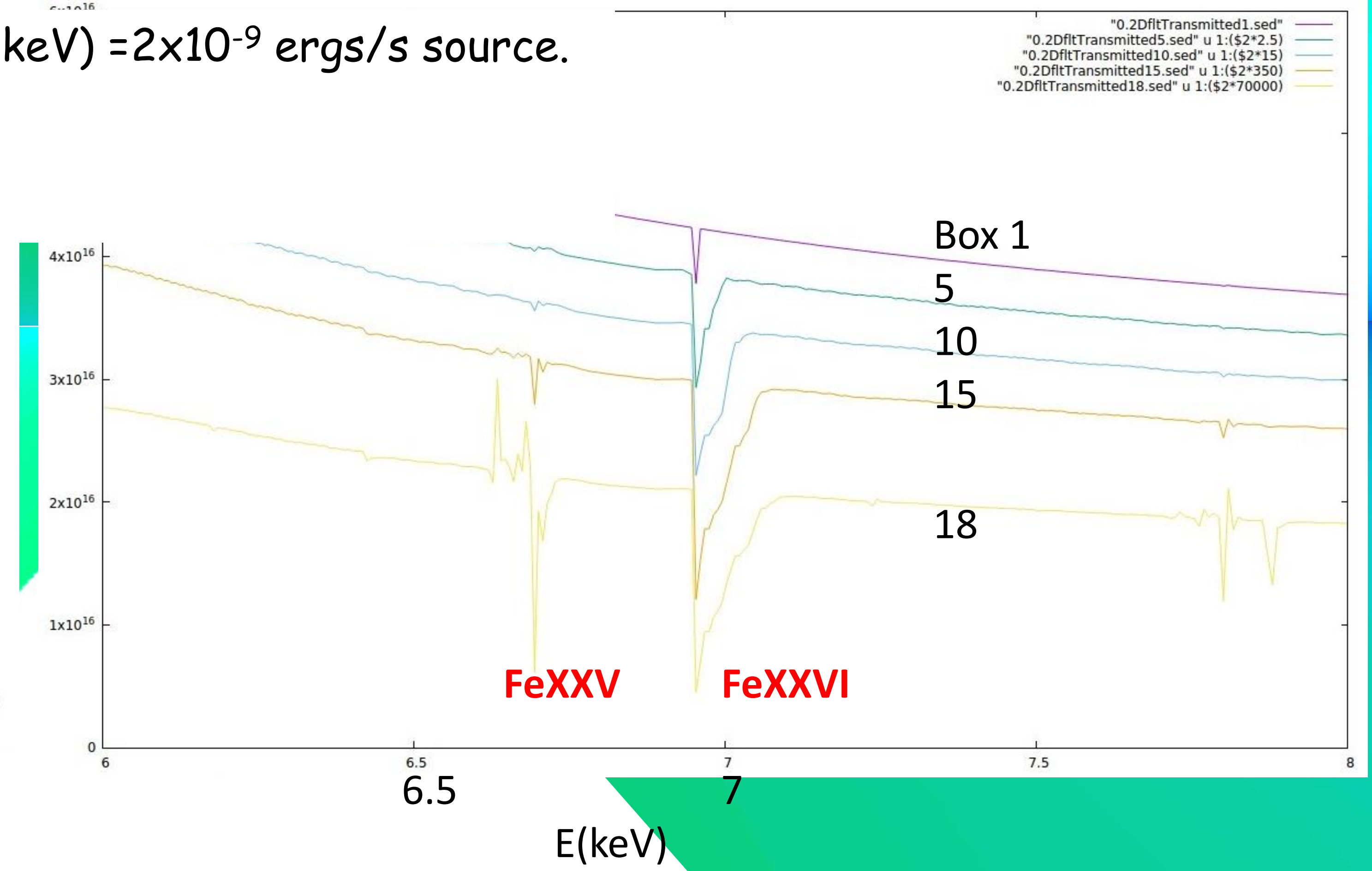
MHD winds from the accretion disk: Simulate spectra to fit to observations

Work in progress

Absorption spectra in terms of MHD parameters (p and ε) and i (inclination angle)

Fake Chandra data for 800ks of a F(3-10 keV) =2×10^{-9} ergs/s source.
Disk black body + Powerlaw
1 Gaussian for FeXXV line
2-3 Gaussian lines for the FeXXVI line





MHD winds from the accretion disk: the ANR-Chaos project

Aim of the project

Can MHD models represent observed BHB winds
- correct ionization state of the gas
- with correct values of density, column density and velocity of the gas

Will the models explain
- the average winds (density < 10^{12} cm^{-3}, velocity $\leq 10^3$ Km/s)
- the extreme winds (density > 10^{12} cm^{-3}, velocity ~ 5×10^3 Km/s)

~ will be a success over "thermal pressure" models

Can we explain that
winds are observed only in Soft state
winds seem to hug the accretion disk surface

We have satisfied the observed trend

- winds are observed only in Soft state
- winds seem to hug the accretion disk surface

Warm MHD models works

Disk surface is heated
Hence more material is lifted off the disk
Magnetic acceleration follows

Works for "average" winds
Density < 10^{12} cm^{-3},
Velocity $\leq 10^3$ Km/s

Work in progress

We are trying to generate absorption spectra in terms of MHD parameters (p and ε) and i (inclination angle)

Warm MHD models with high p will explain extreme winds

We need MHD models with high ejection index p
Only Warm solutions can provide them
We do not yet have those models
- we are building them

Reasonable extrapolations show
- we can easily reproduce the extreme winds
- This would be a success over the thermal pressure models

Thank you

Questions?

MHD winds from the accretion disk: Conclusions and Future work

Future work

Absorption spectra in terms of MHD parameters

To match with observations

This technique will enable to fit for MHD parameters

Apply the same methods to AGN winds.

The current MHD models working for AGN do not have link with accretion disk

Our models are physically better, because of this link

We can predict nature of the accretion disk, if we can match results

(as we did for the BHBs)

The same outflow models can also be used to predict emission line profiles.

Compare the predictions of MHD driven with those from thermally driven models

Can we find ways to distinguish from observations?

Will be important for new X-ray telescopes with better capabilities

Conclusions

We have satisfied the observed trend

- winds are observed only in Soft state
- winds seem to hug the accretion disk surface

Warm MHD models works

Works for "average" winds

Density < 10^{12} cm^{-3},

Velocity $\leq 10^{3}$ Km/s

Warm MHD models with high p will explain extreme winds

Density > 10^{12} cm^{-3},

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