Magneto centrifugal winds from accretion discs around black hole binaries

by

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from

Indian Institute of Science

with

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as part of the

ANR-CHAOS collaboration

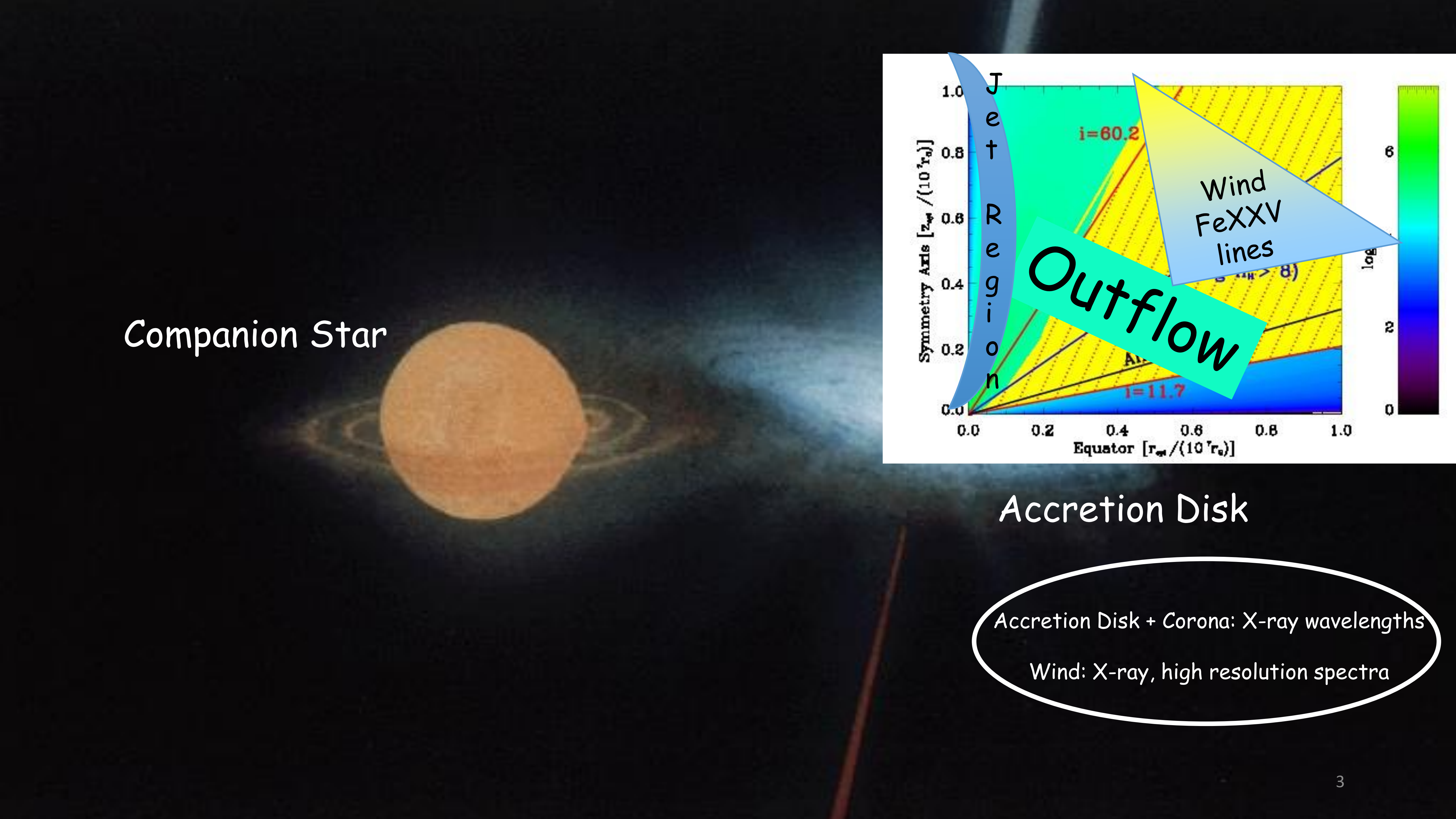
Institut de Planétologie et d'Astrophysique de Grenoble (IPAG)

Thanks: Julia Lee and Joey Neilsen

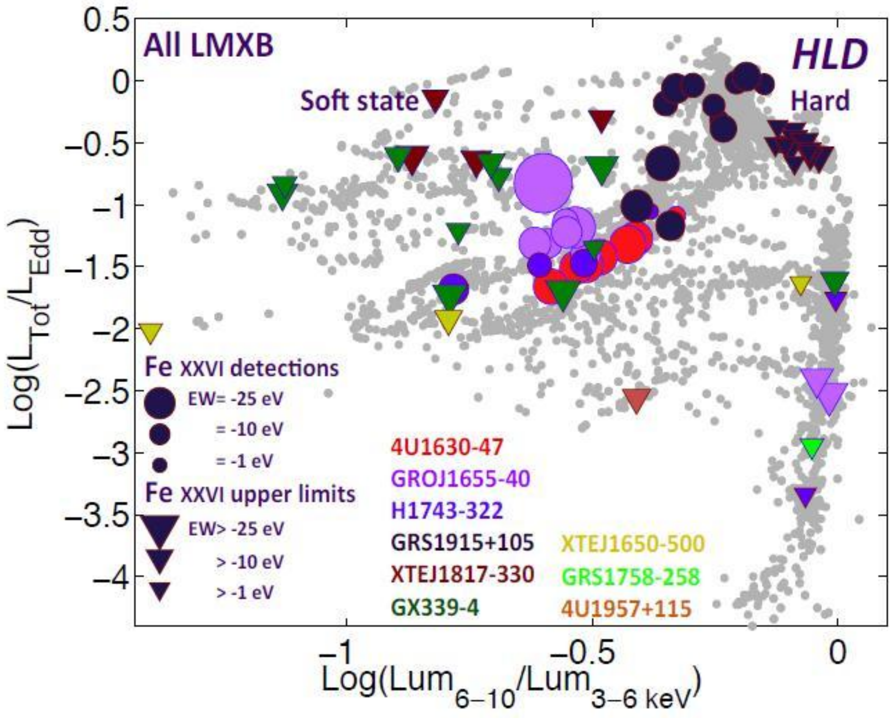
From quiescence to outburst: when microquasars go wild

26th September, 2017


Jet
Companion Star
Wind
Accretion Disk
Accretion Disk + Corona: X-ray wavelengths
Wind: X-ray, high resolution spectra


Companion Star
Accretion Disk
Jet Region
Outflow
Wind
FeXXV
lines
i=60.2
i=11.7
Symmetry Axis
Equator
0.0
0.2
0.4
0.6
0.8
1.0
6
2
0
Accretion Disk + Corona: X-ray wavelengths
Wind: X-ray, high resolution spectra

What do we see using X-ray spectra?



Ponti et.al 2012

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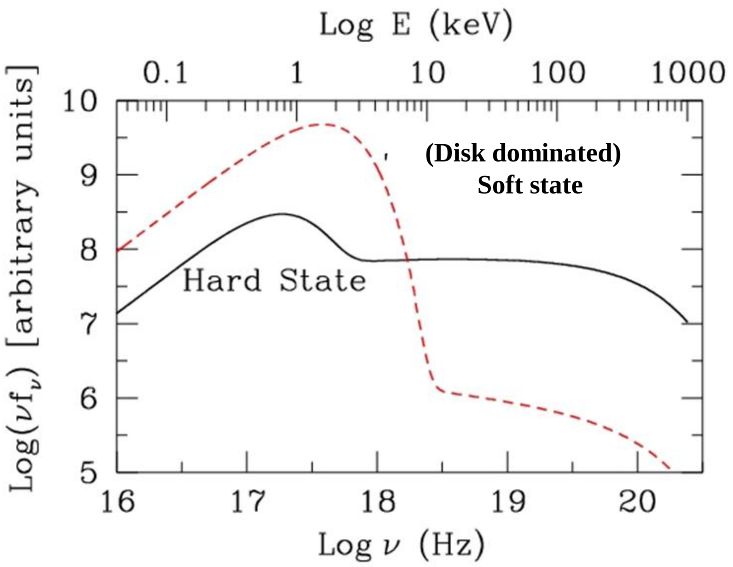
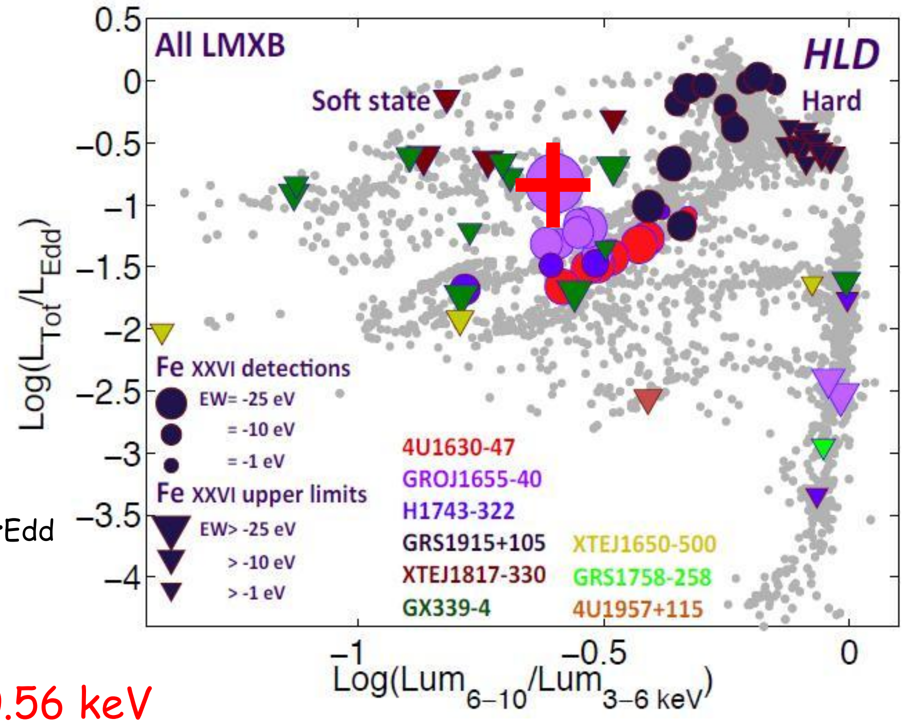


Thermal, blackbody-like emission from accretion disk

$10M_{\odot}$ black hole accreting at ~ 0.1 L_{Edd}
Remillard & Mclintock, 2006



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Thermal –

Diskbb; $r_{in} = 6\ r_g \rightarrow T_{in} = 0.56$ keV
Powerlaw - $\Gamma = 2.5$
$L_{disk}/L_{PL} = 0.8$ in 2 – 20 keV

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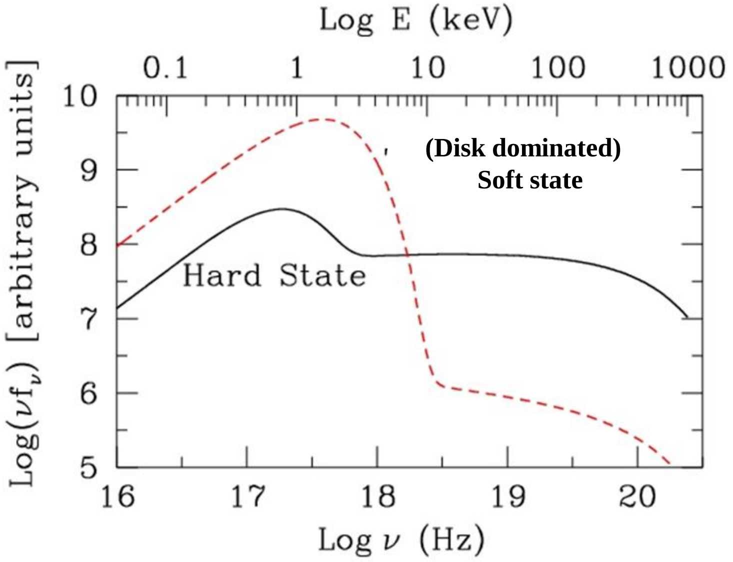

Thermal, blackbody-like emission from accretion disk

Non thermal (powerlaw) emission

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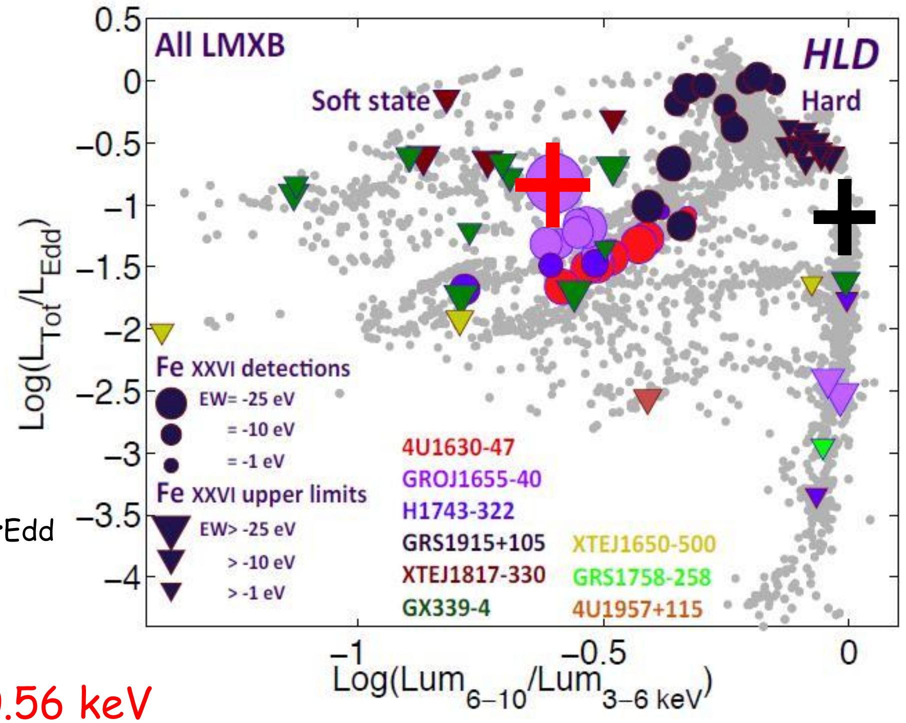

Ponti et.al 2012

Thermal –

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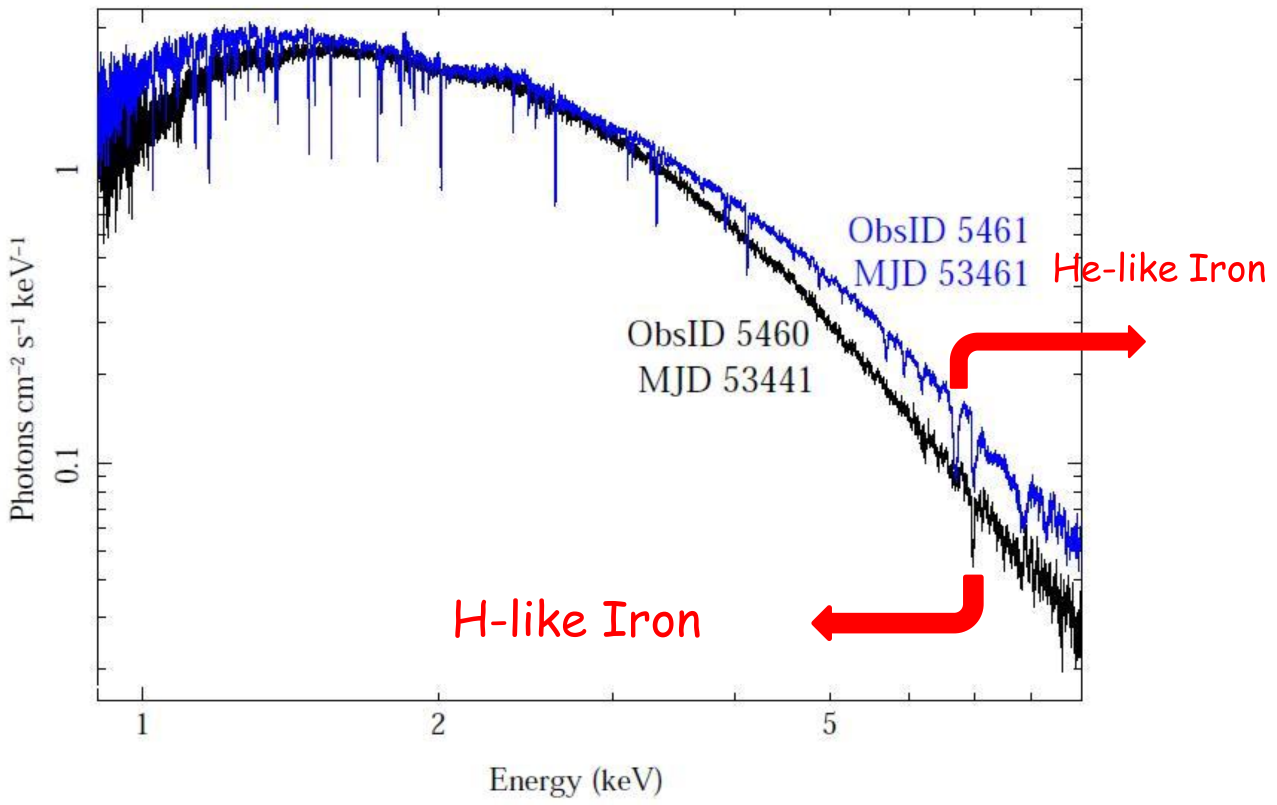
Powerlaw - Γ = 2.5
L_{disk}/L_{PL} = 0.8 in 2 – 20 keV

Hard –

Diskbb; r_{in} = 12 r_g $\rightarrow$ T_{in} = 0.33 keV
Powerlaw - Γ = 1.8
L_{disk}/L_{PL} = 0.2 in 2 – 20 keV

What do we see using X-ray spectra?



GROJ 1655, using Chandra, Neilsen & Homann, 2012

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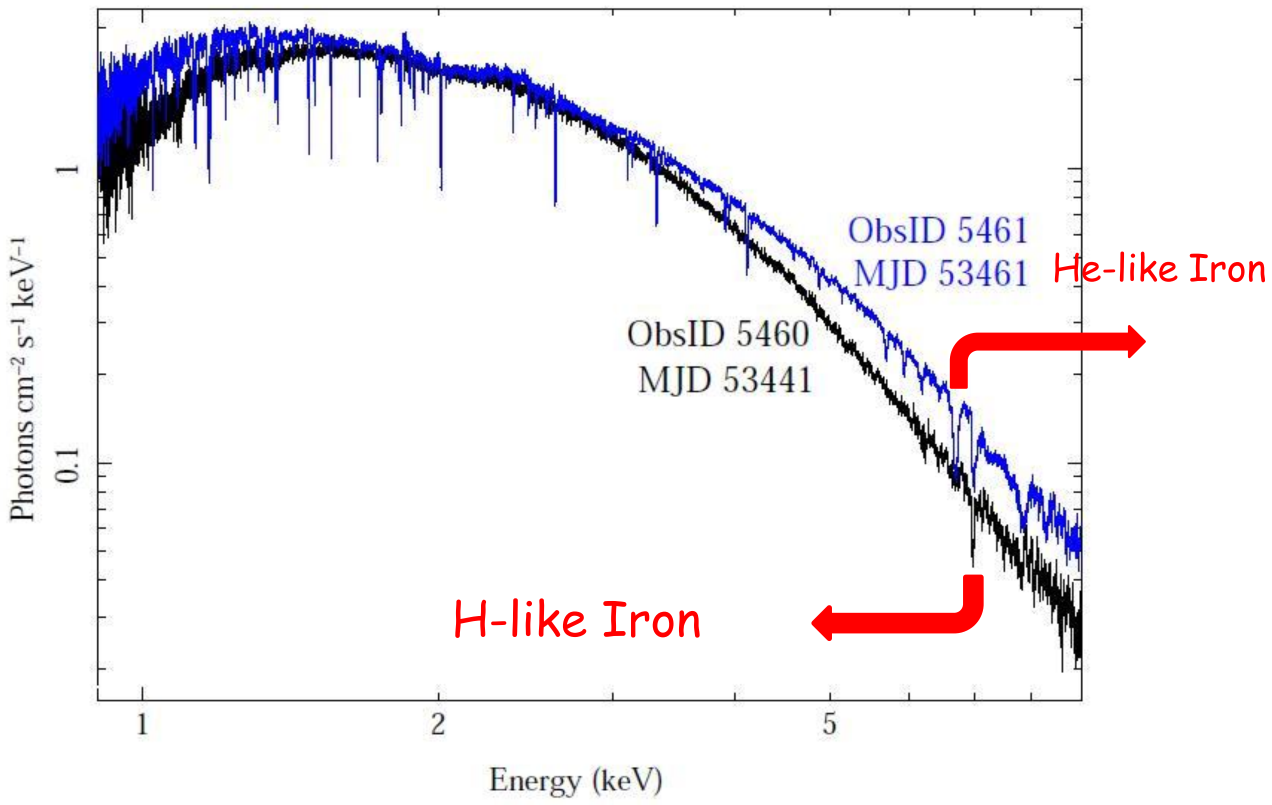

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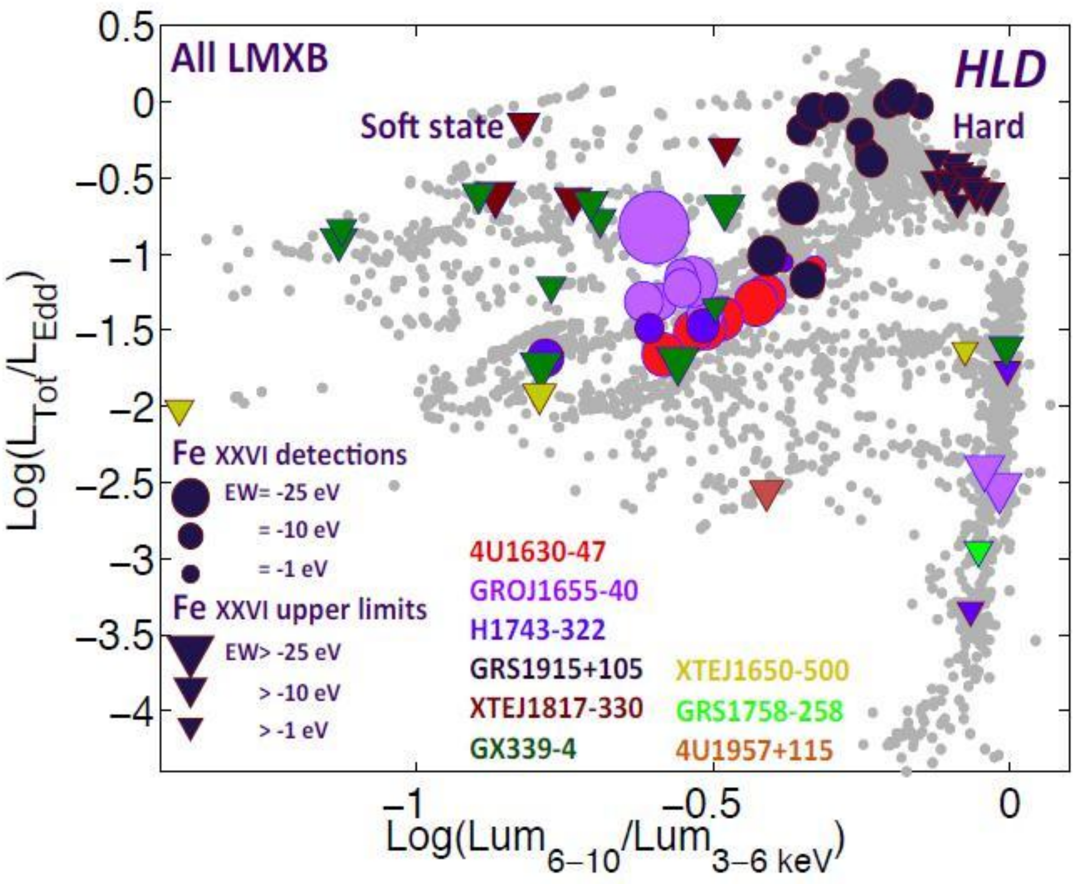


Ponti et.al 2012

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

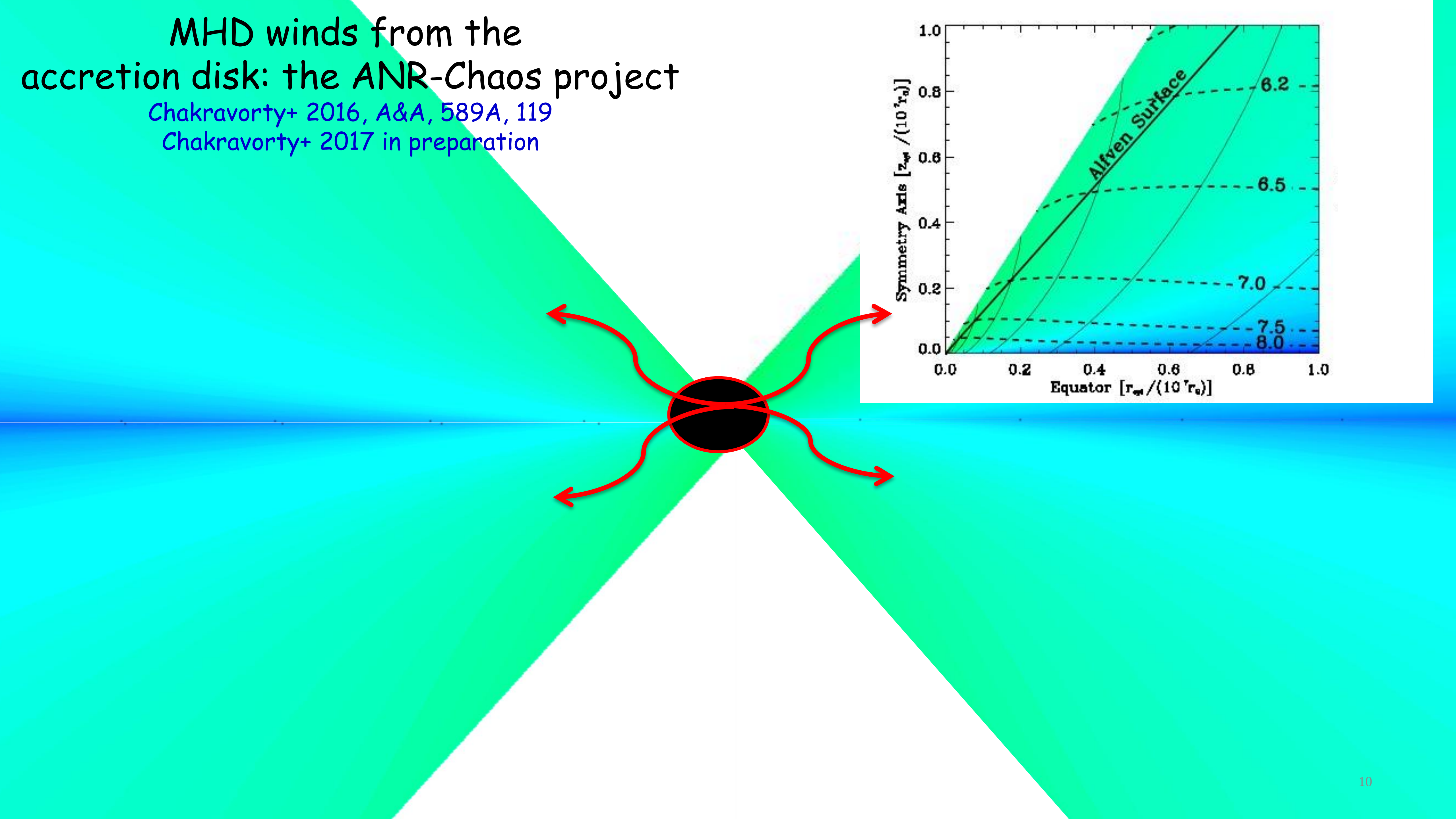
Some physical mechanism is lifting material off the accretion disk and accelerating it

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

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

Chakravorty+ 2016, A&A, 589A, 119
Chakravorty+ 2017 in preparation



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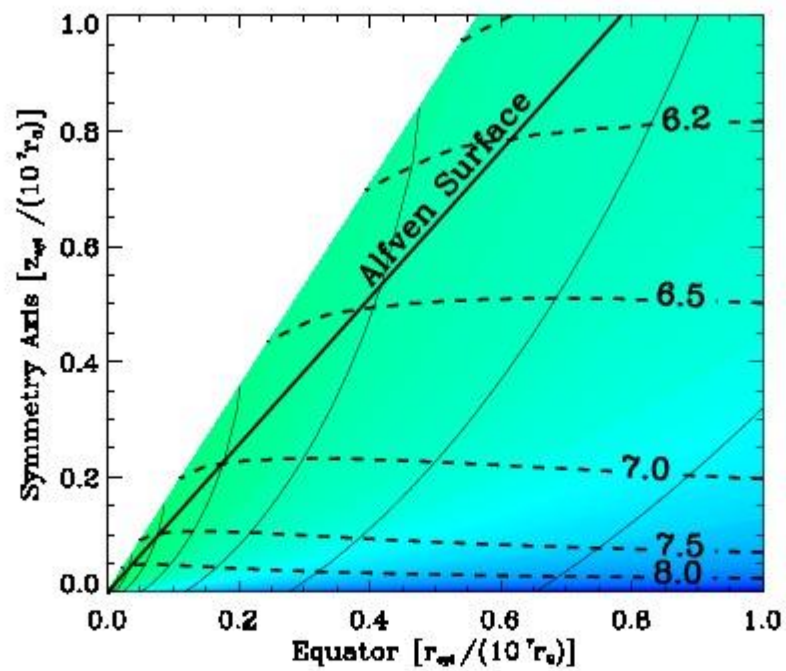
Pre computed
MHD model of outflow from the disk
(Ferreira 1997, Casse & Ferreira, 2000)

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

Gas density, Gas velocity, Magnetic Field etc.

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



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

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

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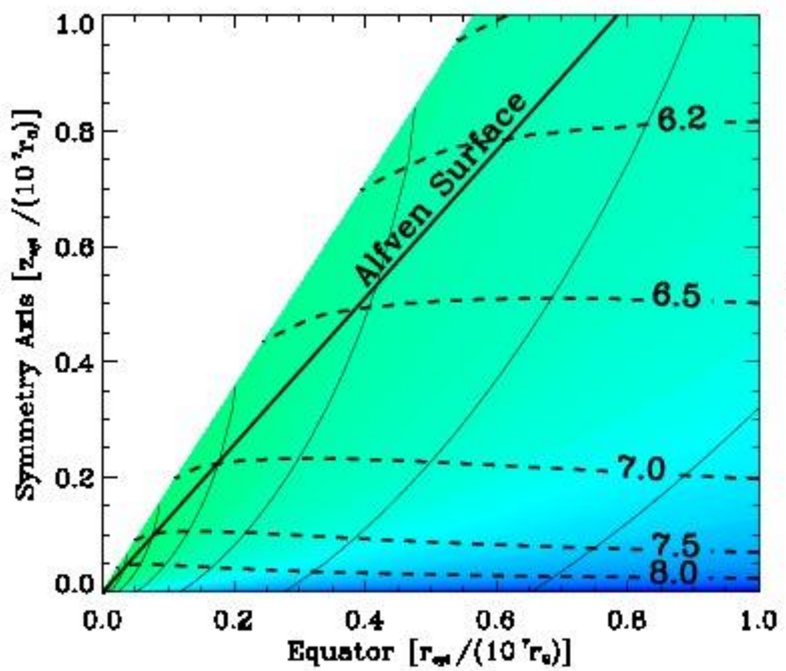

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The ejection or outflow of material is related to the accretion
Ejection Mechanism - **not a free parameter (unlike ADIOS scenarios)**

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

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

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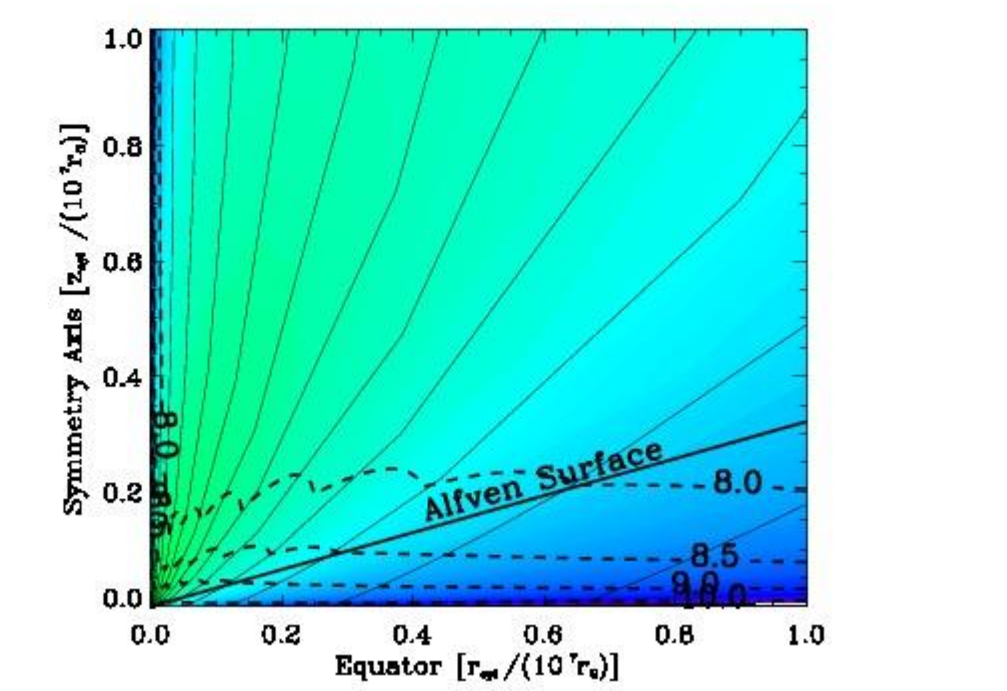
ε = h/r = 0.01
p = 0.1 ($\dot{M}_{acc}$ = r^p)



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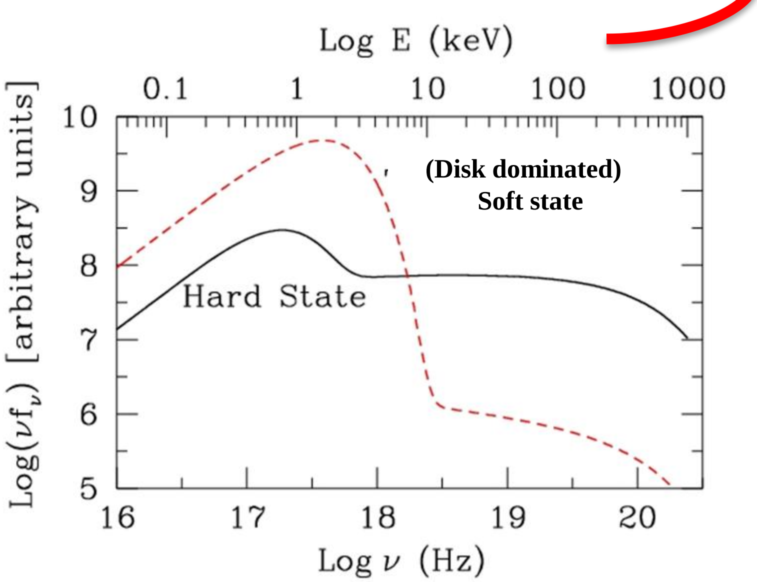
Deriving Atomic Physics Constraints

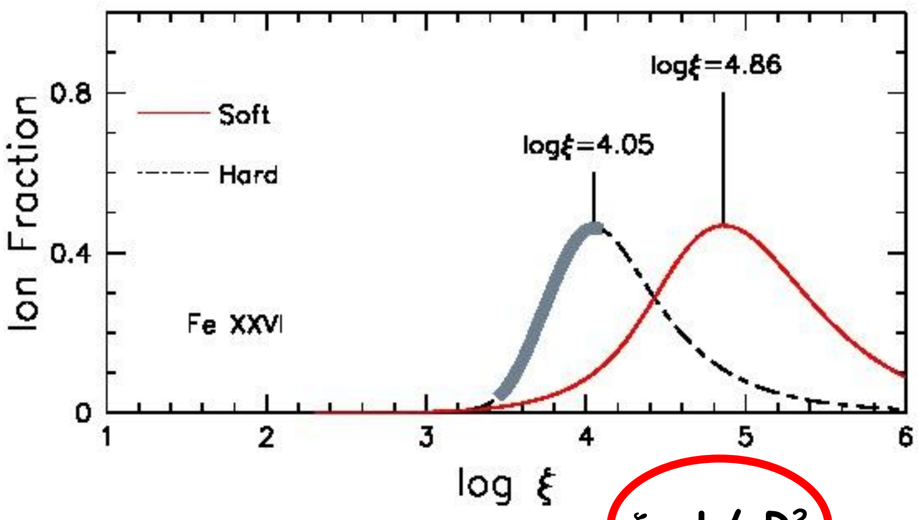
SED

Description of the light from the innermost part of the disk



Work out Atomic Physics of the gas

CLOUDY



$\xi = L/nR^2$

Also see
Chakravorty+ 2013, MNRAS.436, 560

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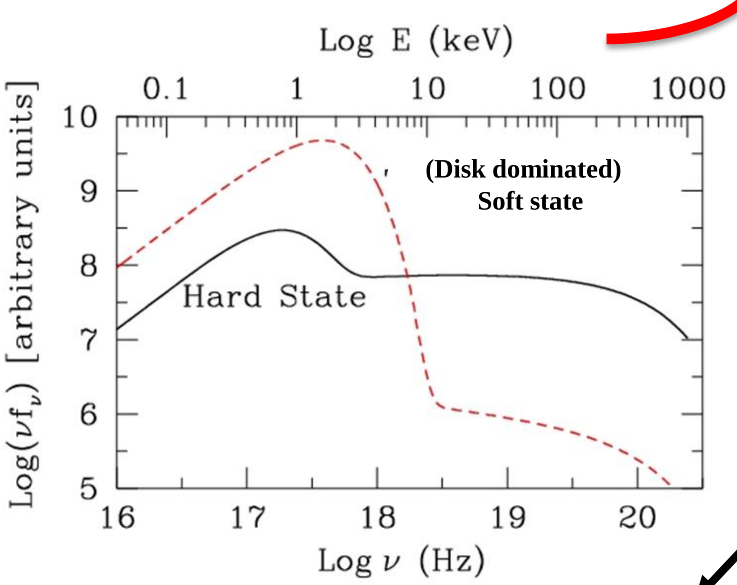

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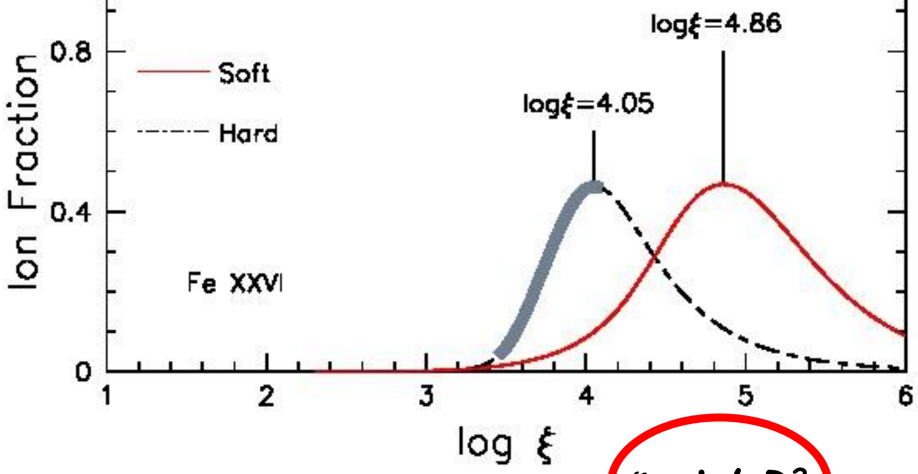

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Limits to be put on

MHD models

log $\xi \leq$ 4.86 for Soft SED

log $\xi \leq$ 3.4 for Hard SED
because 3.4 – 4.1 is
thermodynamically unstable

Find the wind region within the MHD model

SED

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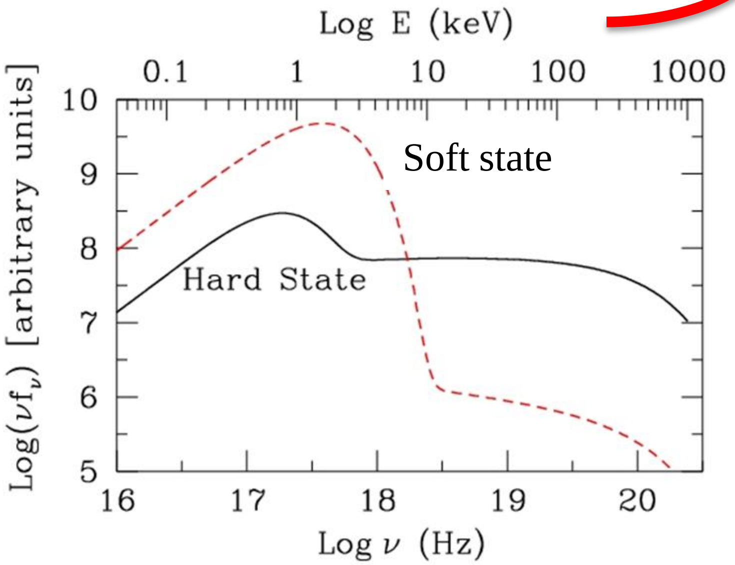
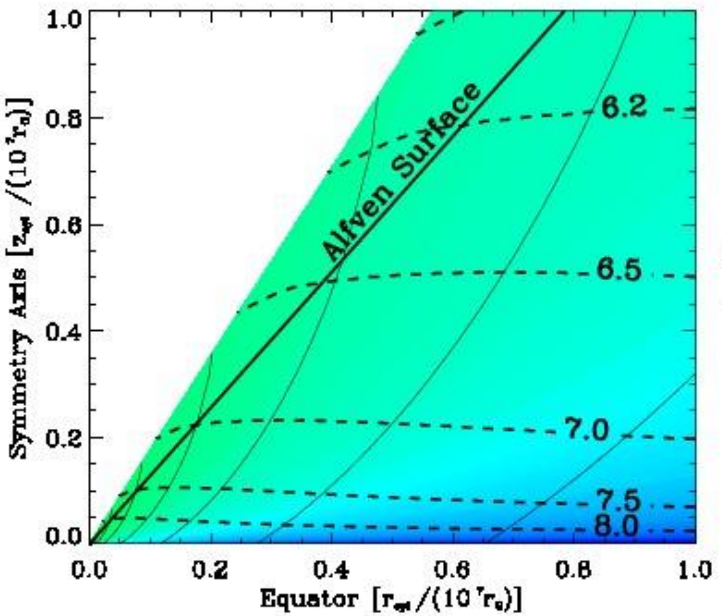


Illuminates the gas



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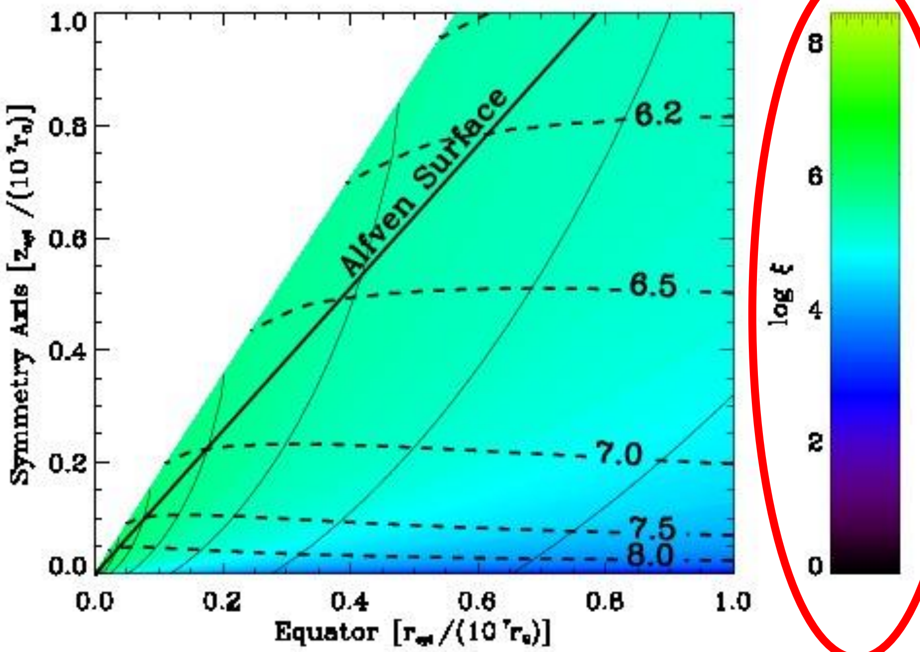

Find the wind region within the MHD model

Some reasonable physical limits on

Column density of the gas
$N_H < 10^{24}$ cm^{-2}

Velocity of the gas in z direction
$v_z > 0$

Remember the <u>Atomic Physics limits</u>

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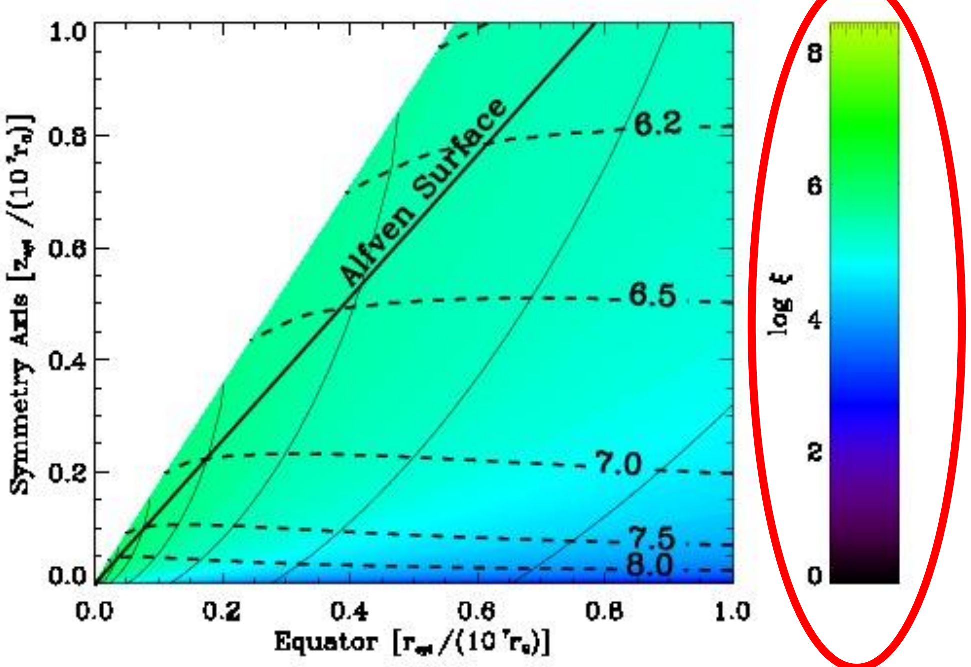

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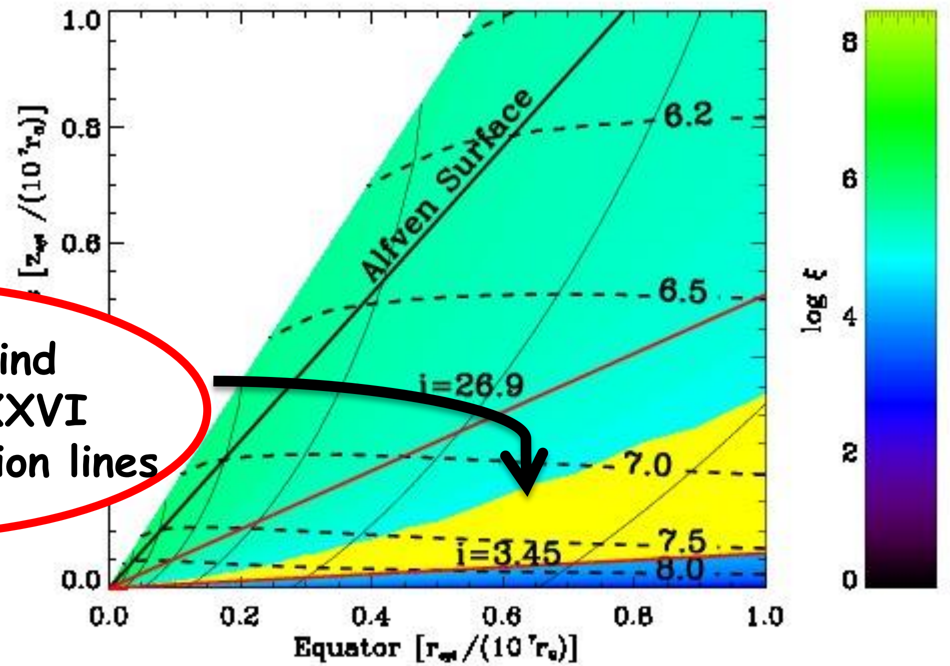
Observable wind via FeXXV, FeXXVI and other absorption lines



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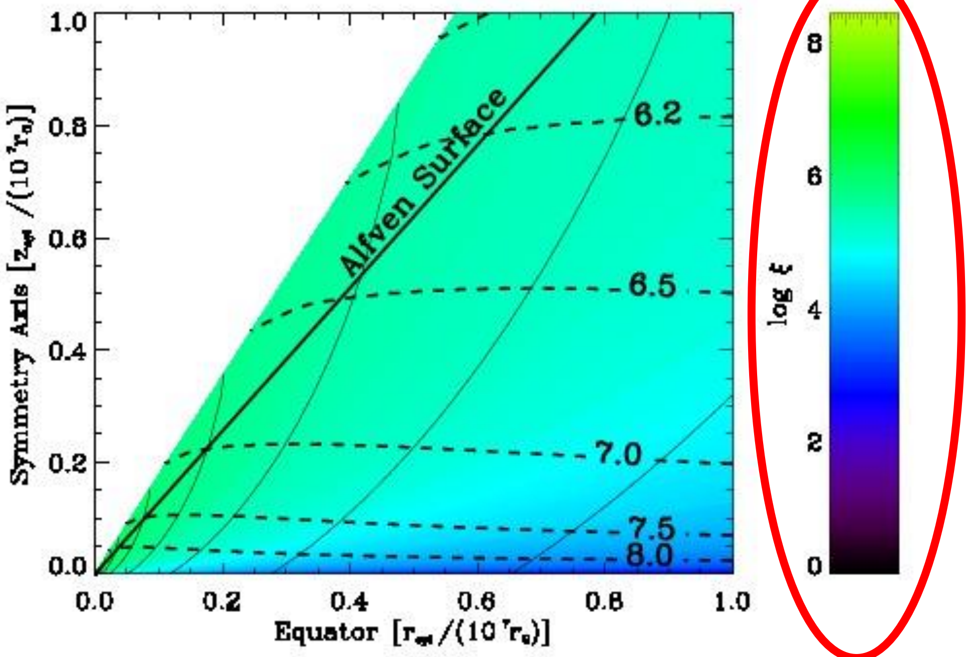
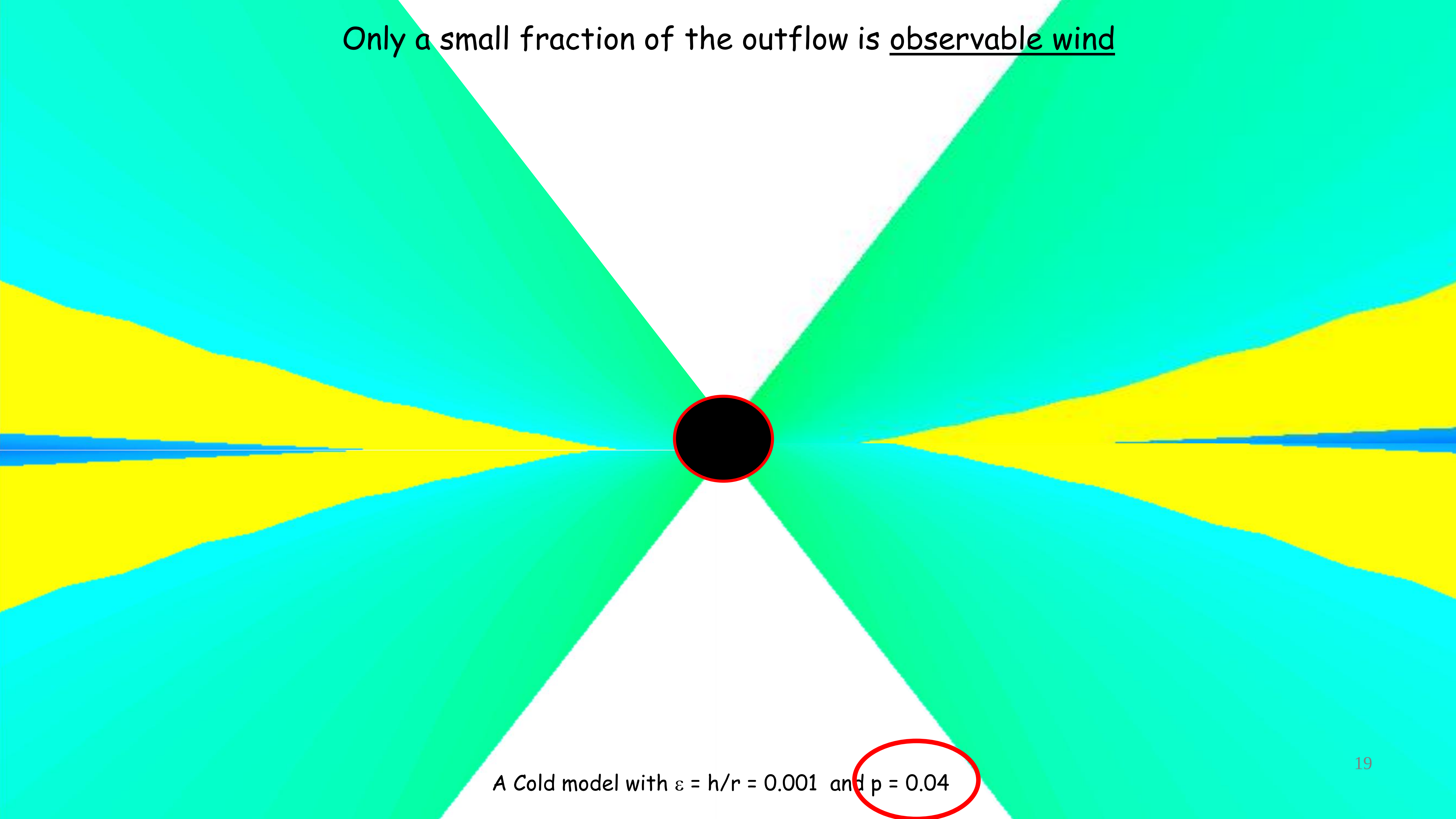
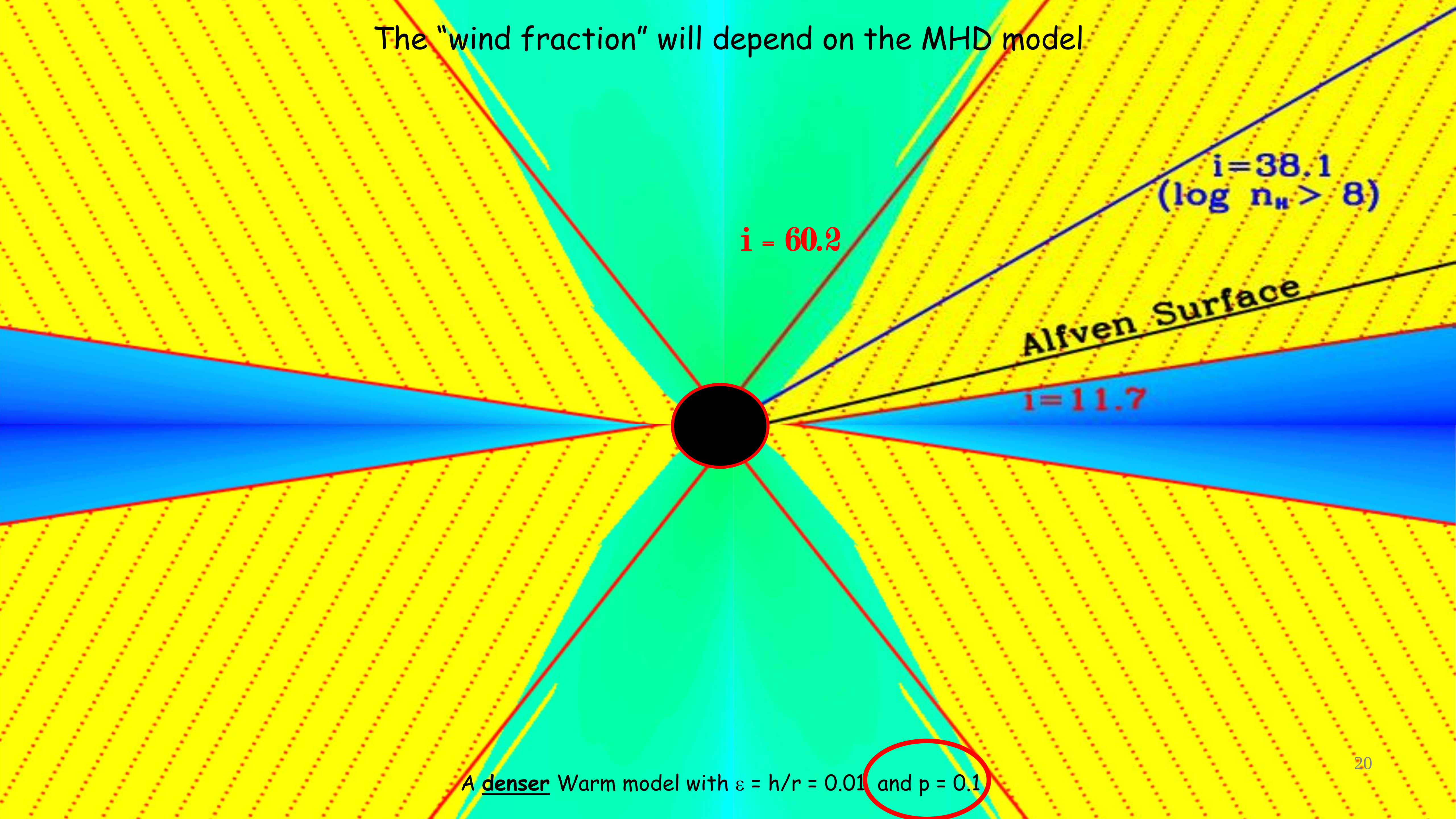


Only a small fraction of the outflow is observable wind



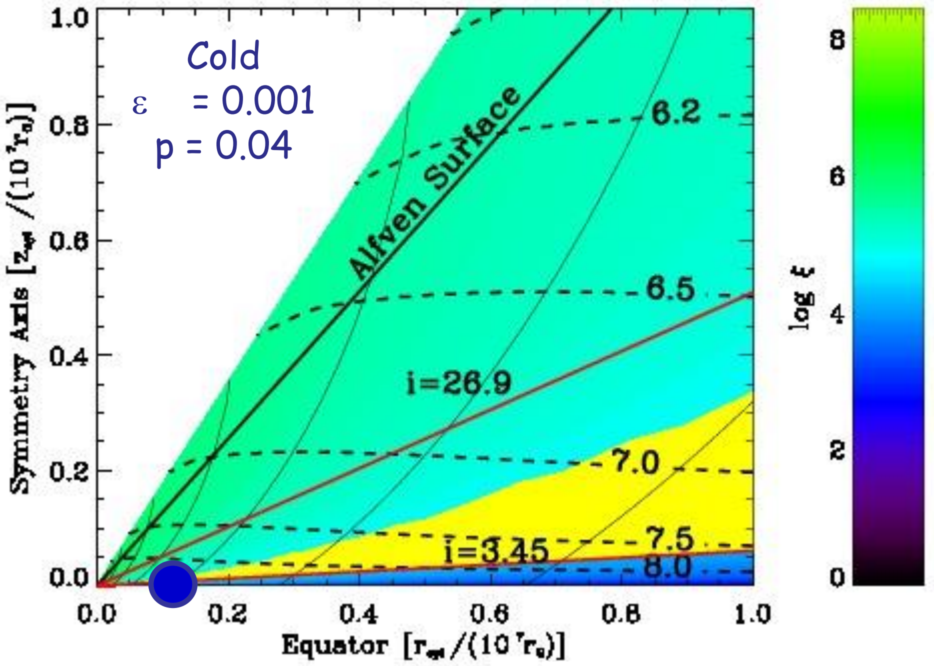
A Cold model with $\varepsilon = h/r = 0.001$ and $p = 0.04$

The “wind fraction” will depend on the MHD model



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

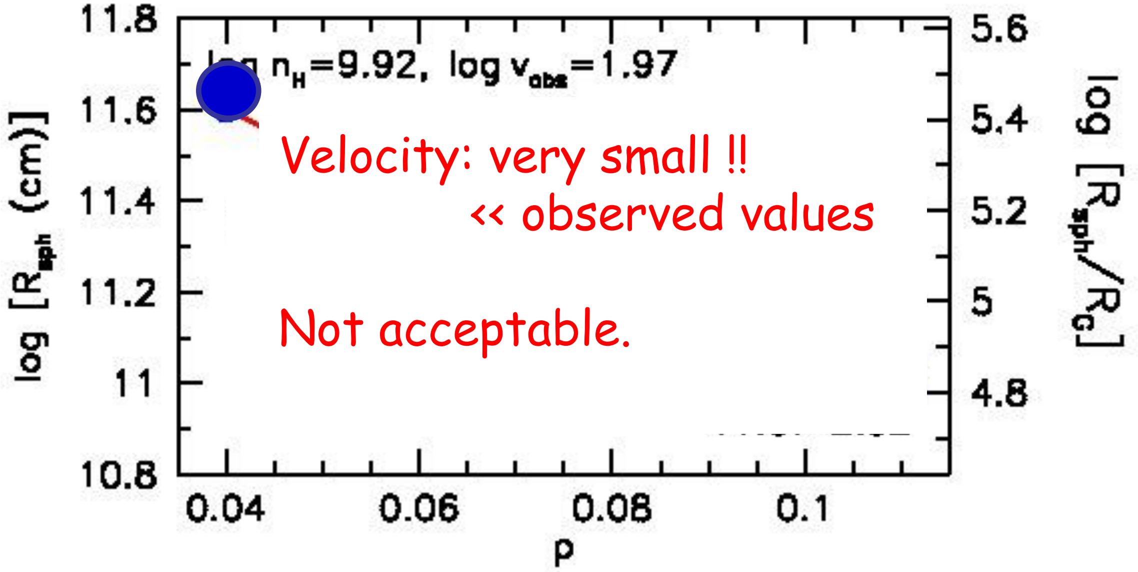
Cold vs warm magnetic solutions



Cold

Purely magnetic acceleration

<u>**Does not work**</u>
The wind is too far away
Density too low
Velocity too low



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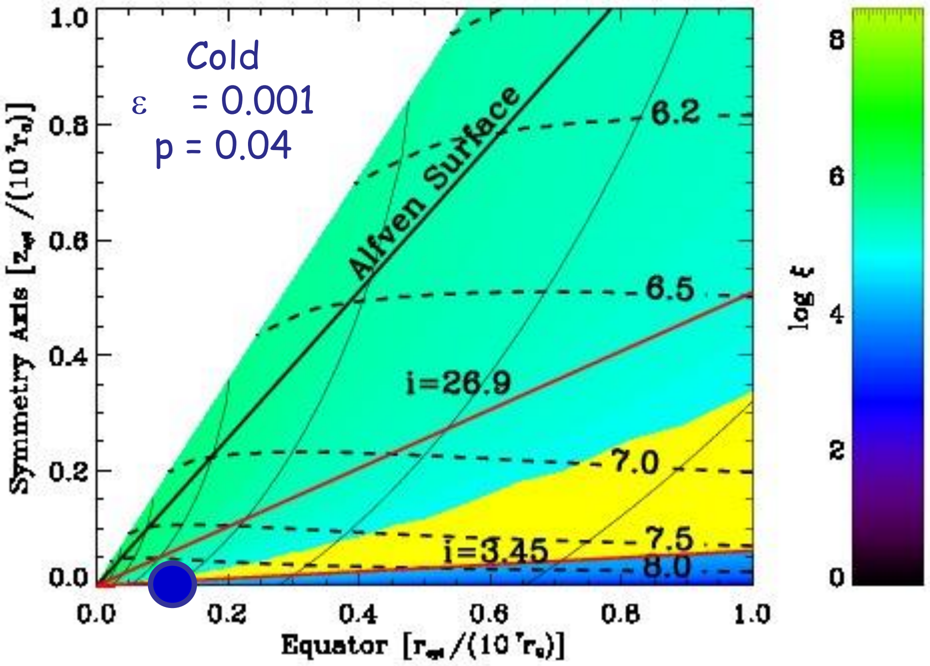

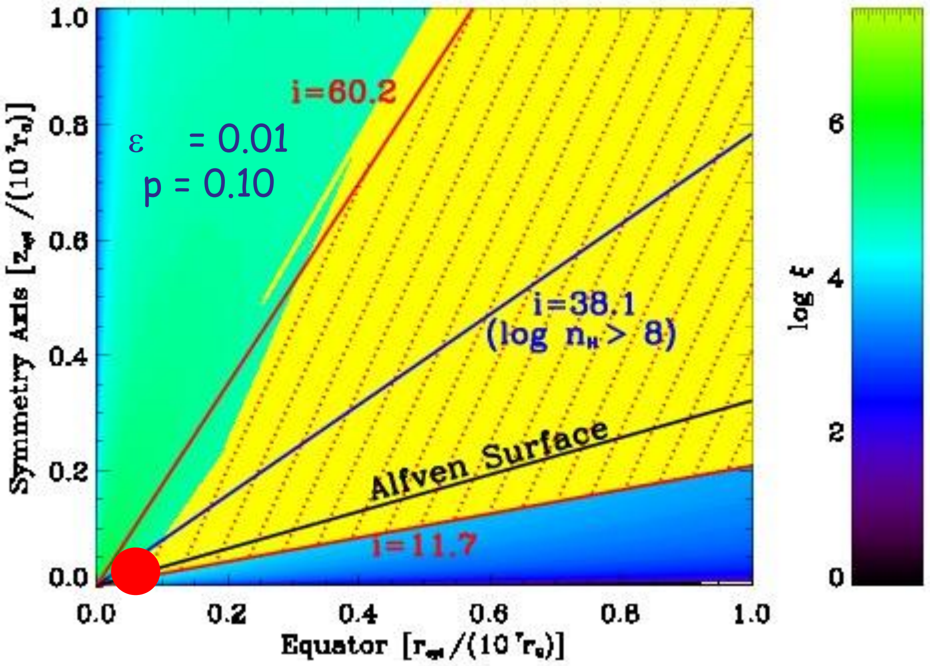

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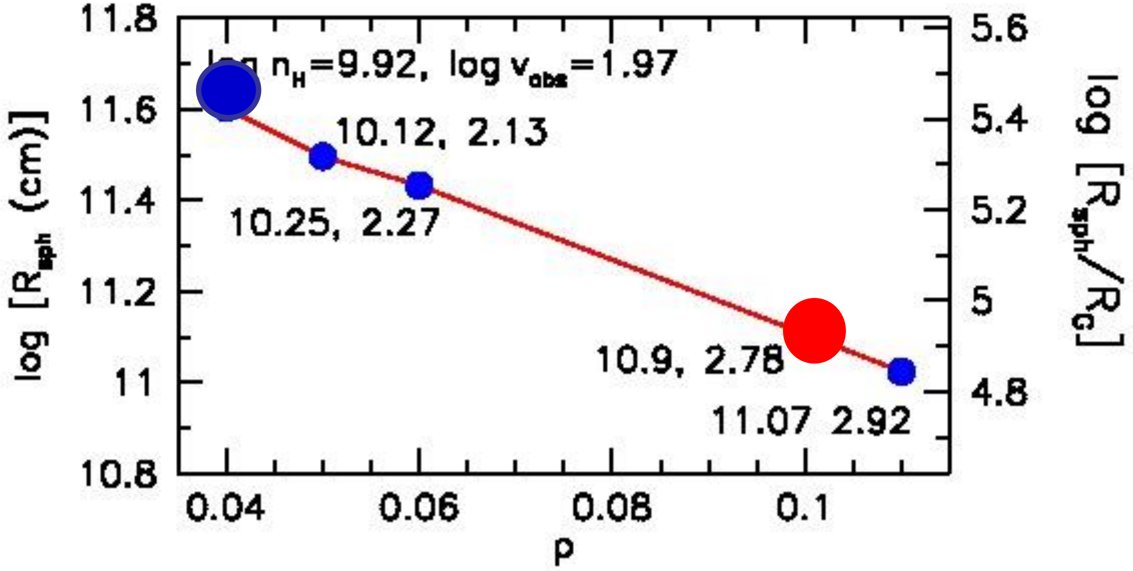

Warm

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?

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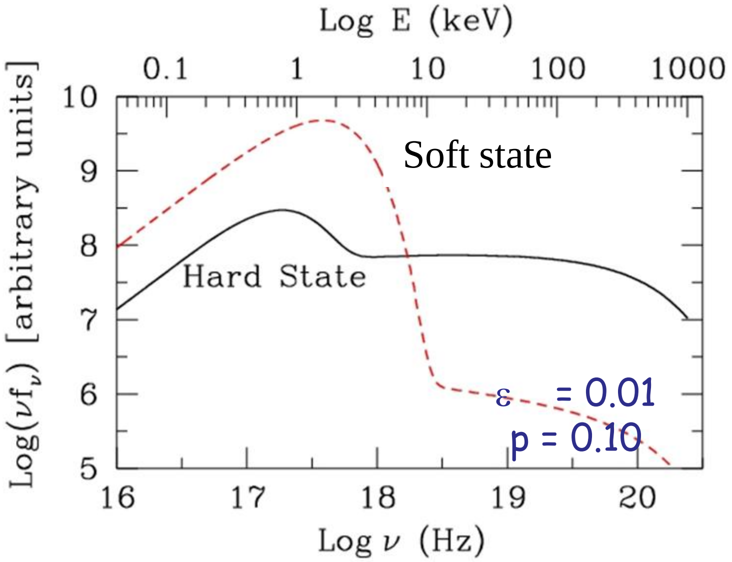

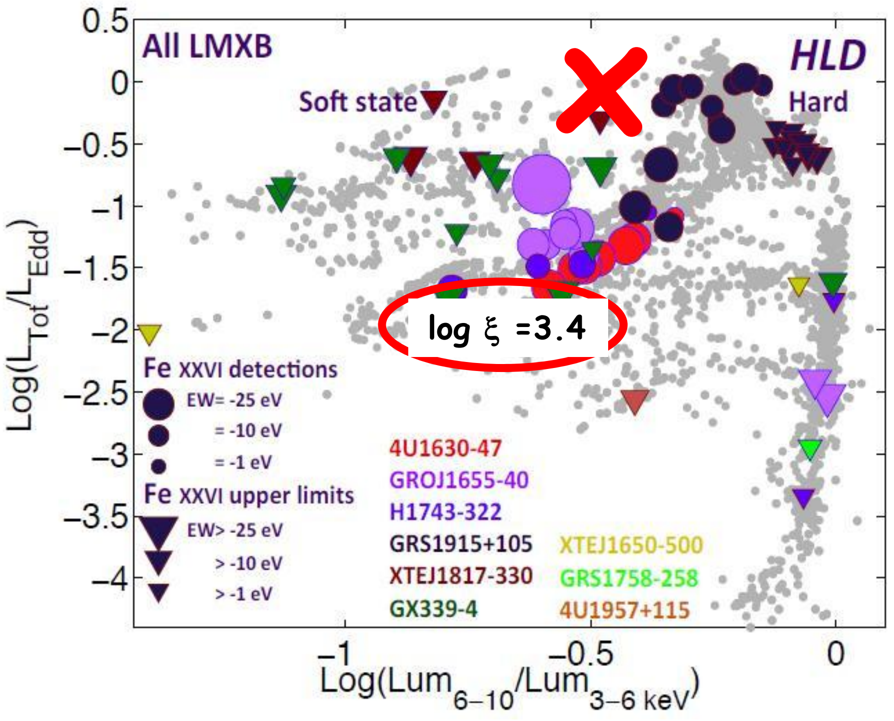

Ponti et.al 2012

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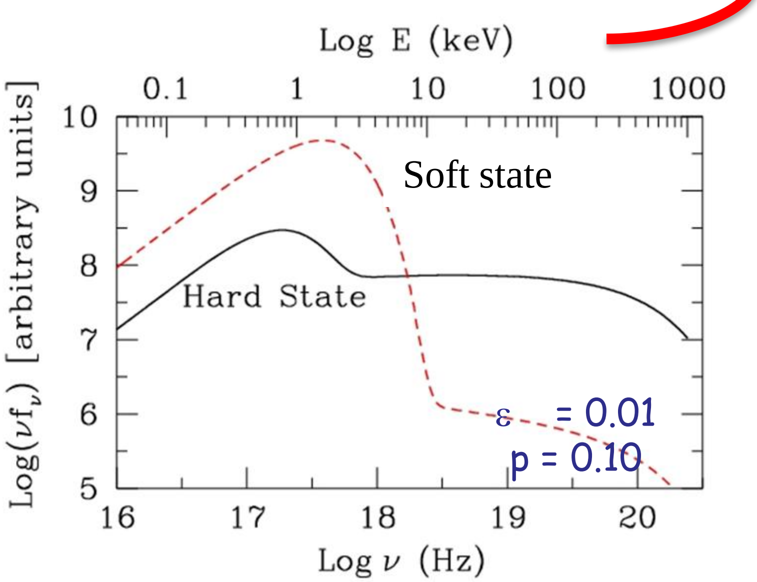

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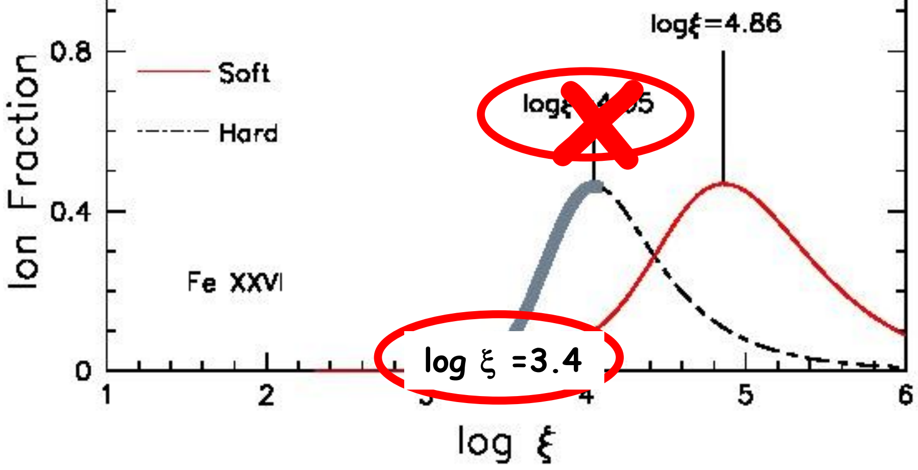

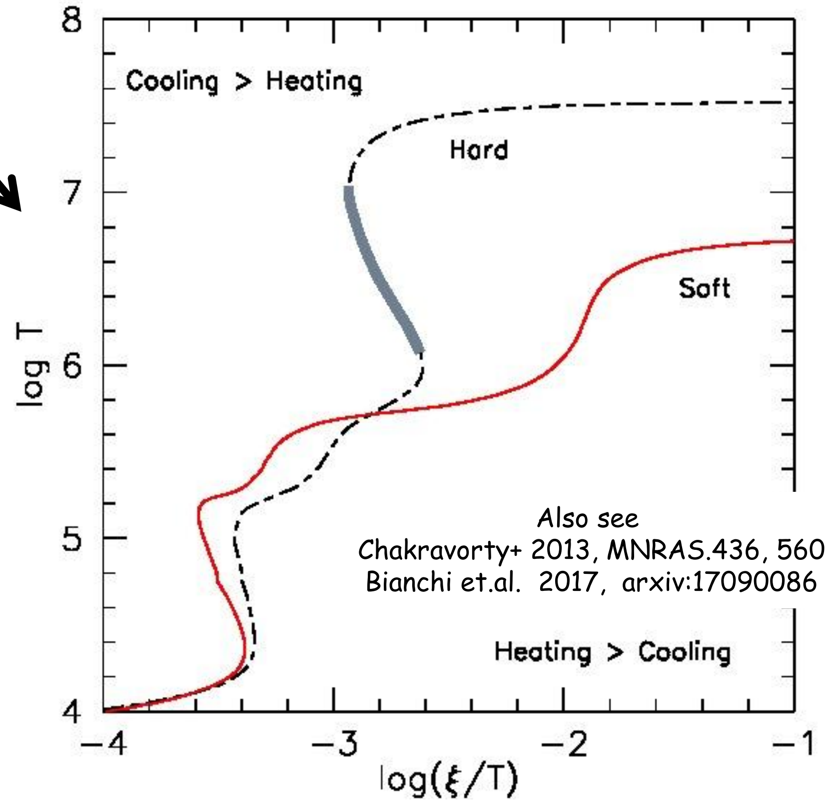

Also see
Chakravorty+ 2013, MNRAS.436, 560
Bianchi et.al. 2017, arxiv:17090086

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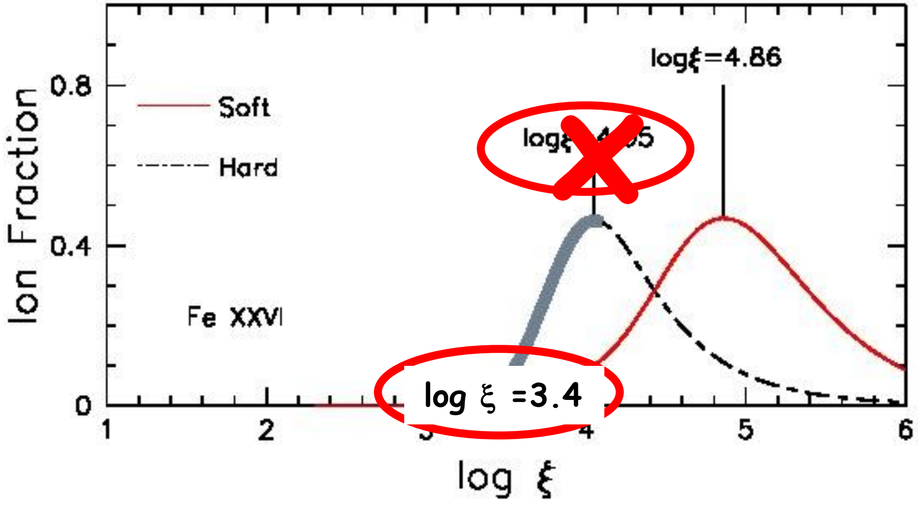

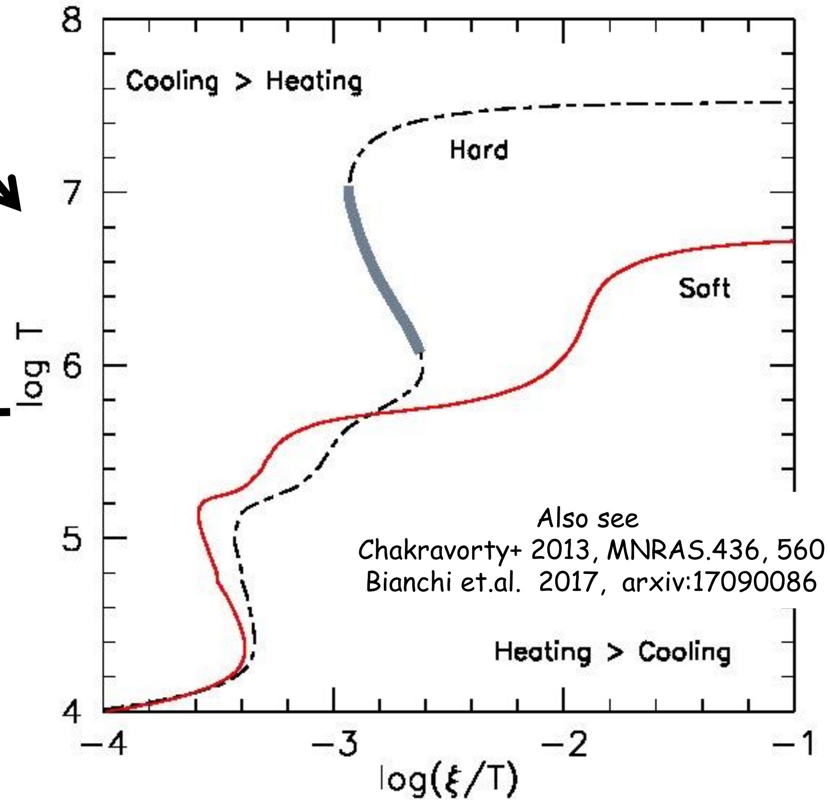

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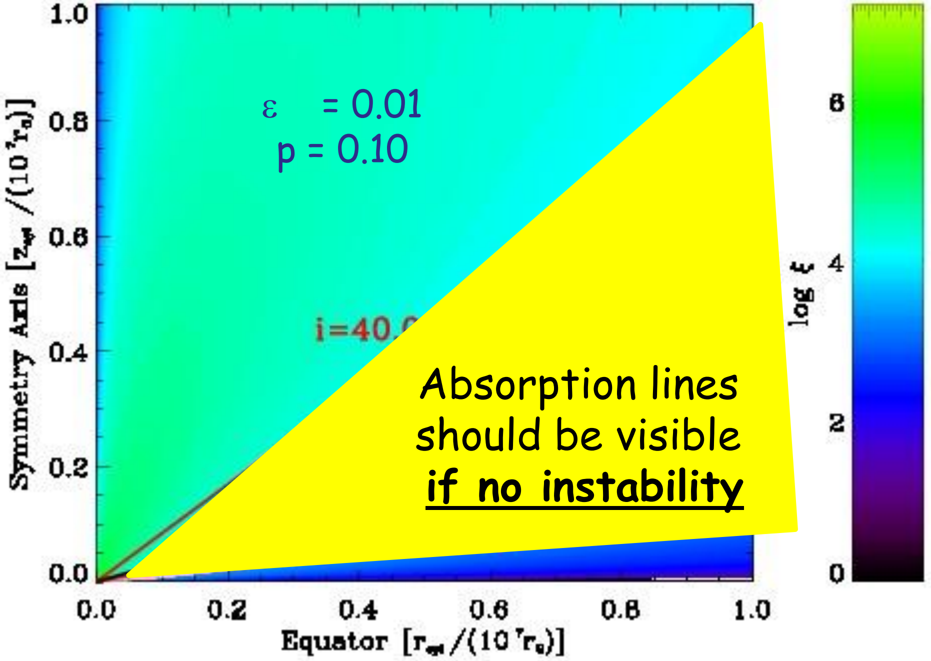

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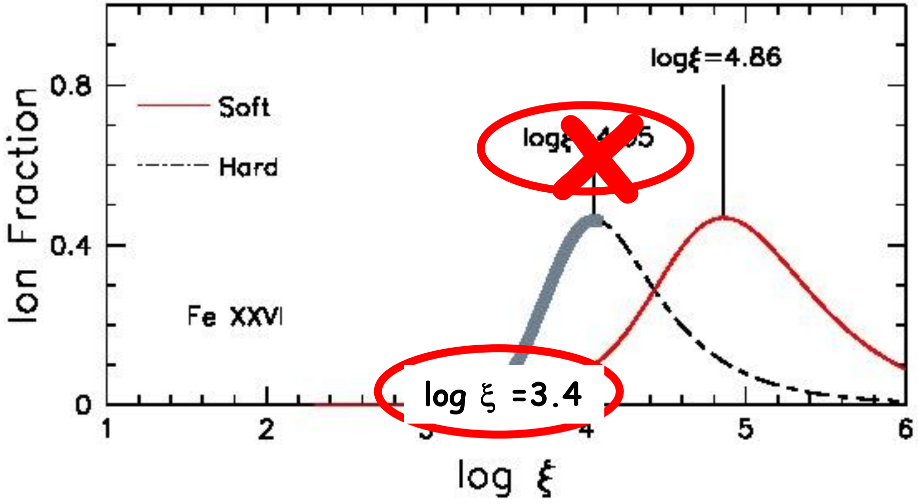

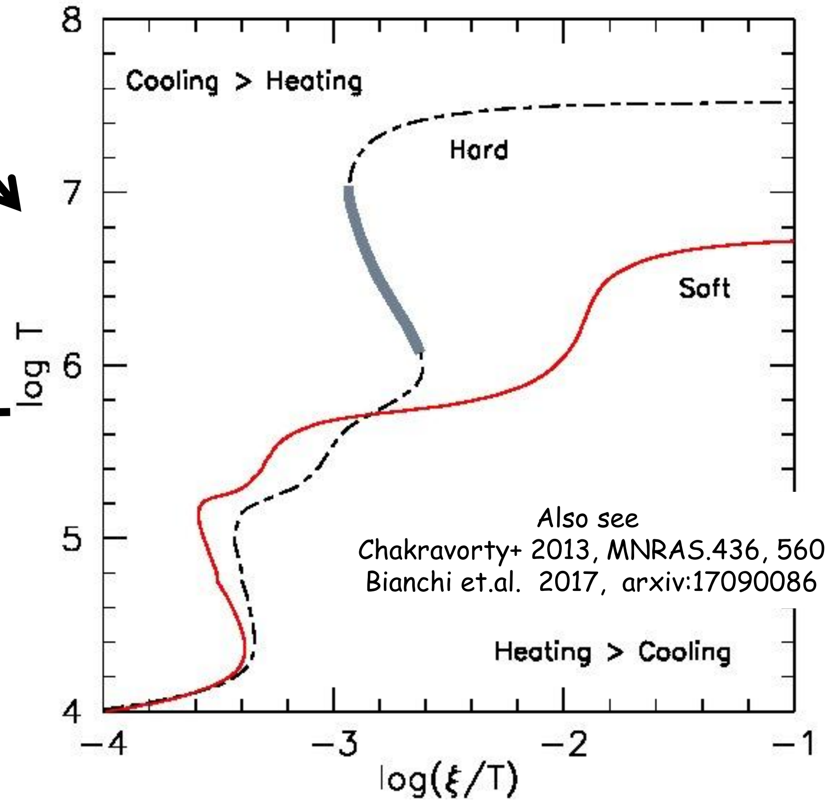

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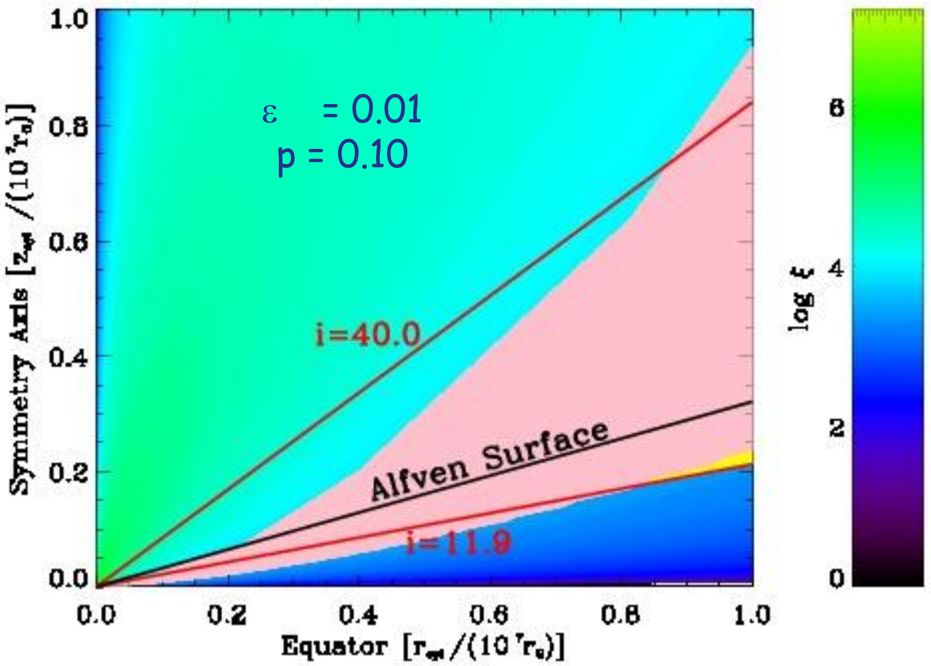
<u>With instability</u>
the "visible" region is wiped out



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

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

We have devised ways to implement
~ correct ionization state
~ correct column density

We have ruled out Cold MHD solutions

Warm MHD solutions work
Disk surface heating lifts of gas
Magnetic acceleration follows

Works for "average" winds
Density < 10^{12} cm^{-3},
Velocity $\leq 10^{3}$ Km/s
We are at par with thermal pressure models

But what about "extreme" winds?

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There is hope and we are working on it

Warm MHD model with high p will explain extreme winds
(ejection index)

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

Reasonable extrapolations show
- we can reproduce the extreme winds if p = 0.5

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Work in progress

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

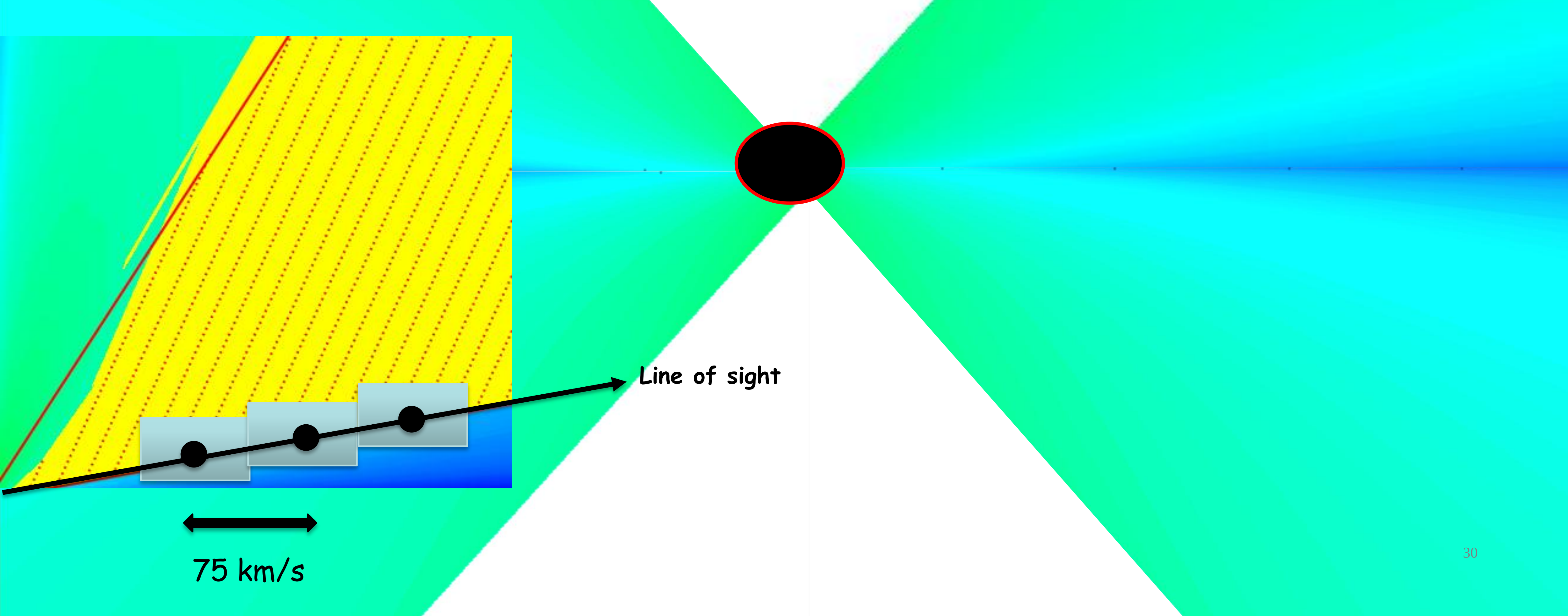
What do they predict?

Lets check it out

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)



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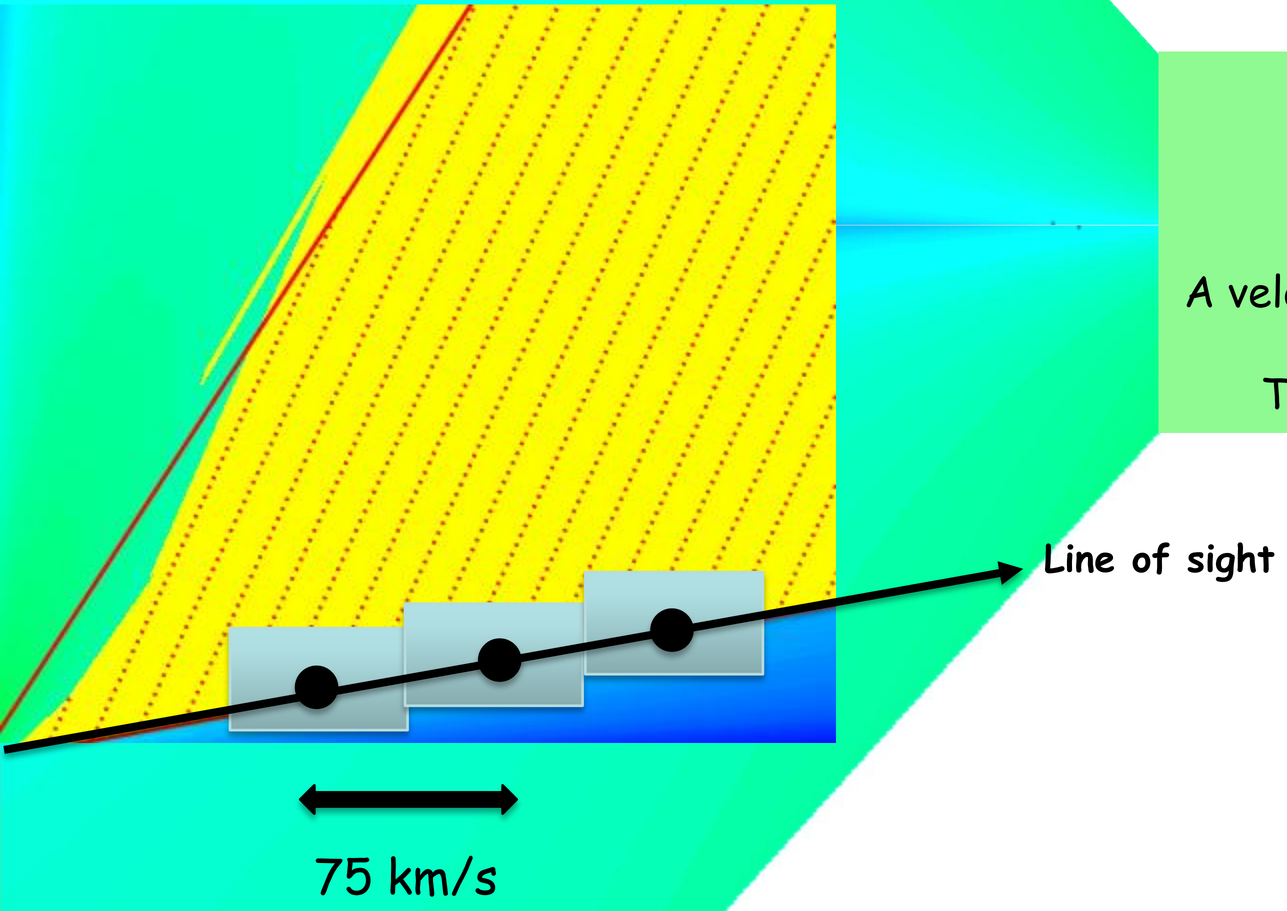


Note: We are keeping our methods generic

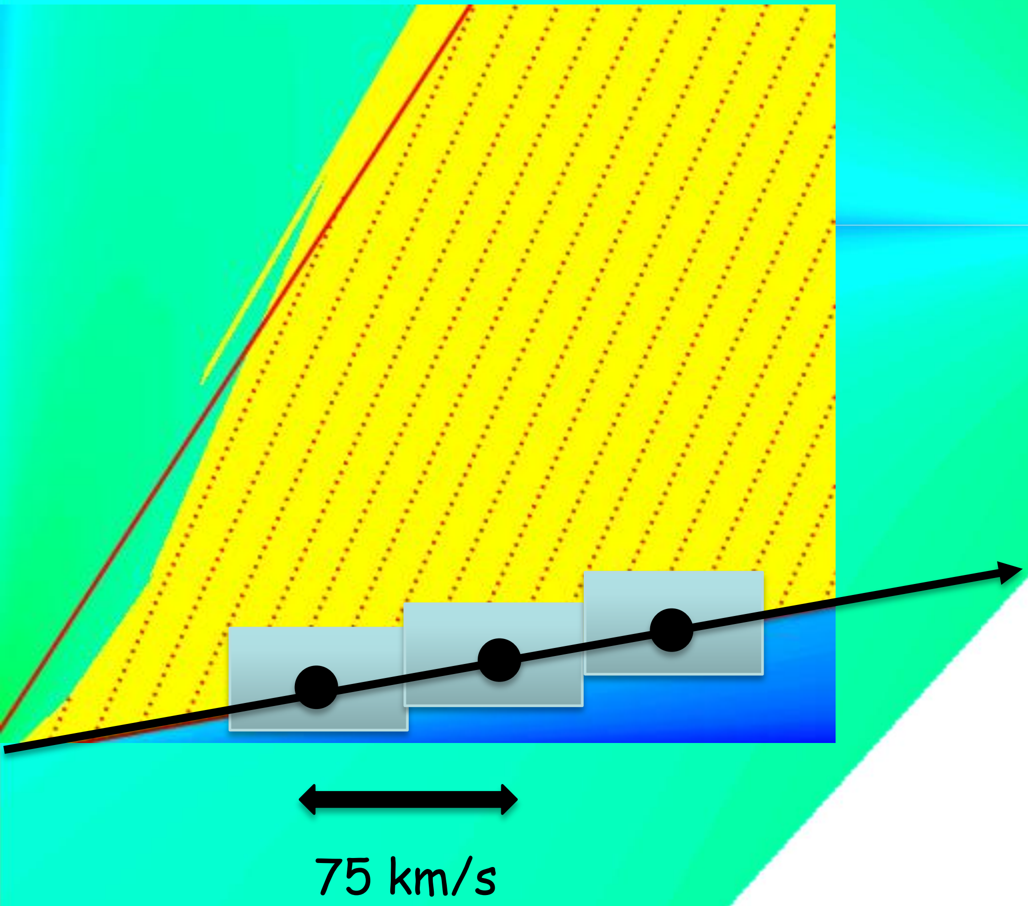
A code that can work for any outflow solution

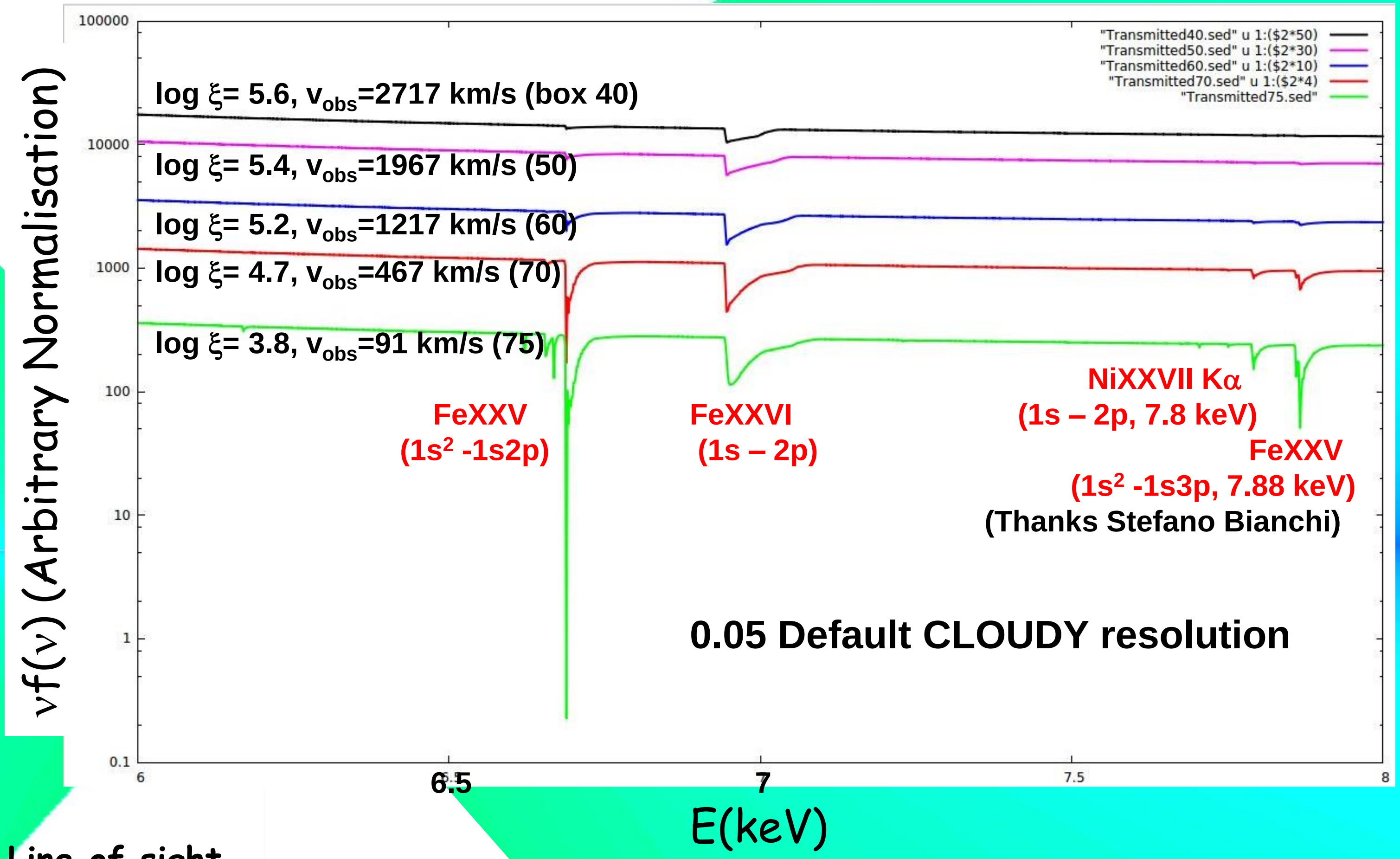
A velocity resolution that can take care of future missions – Athena at 6.5 keV ~ 300 km/s
The limit 75 km/s comes from the limits of CLOUDY

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)

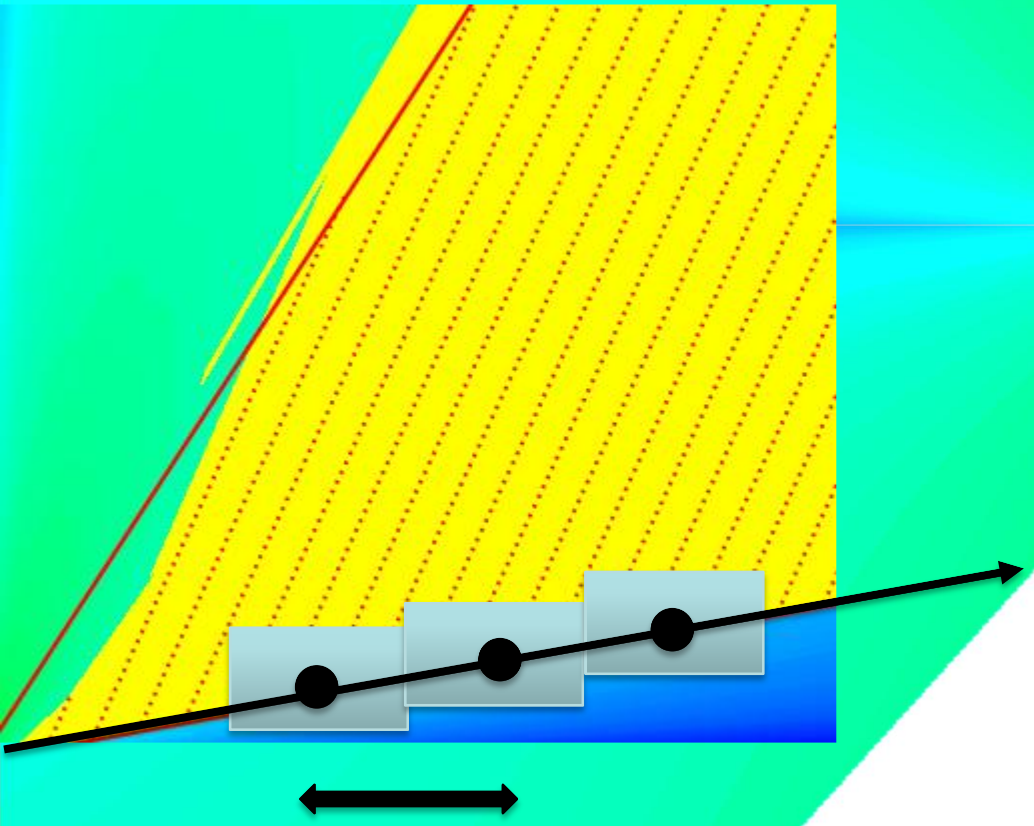


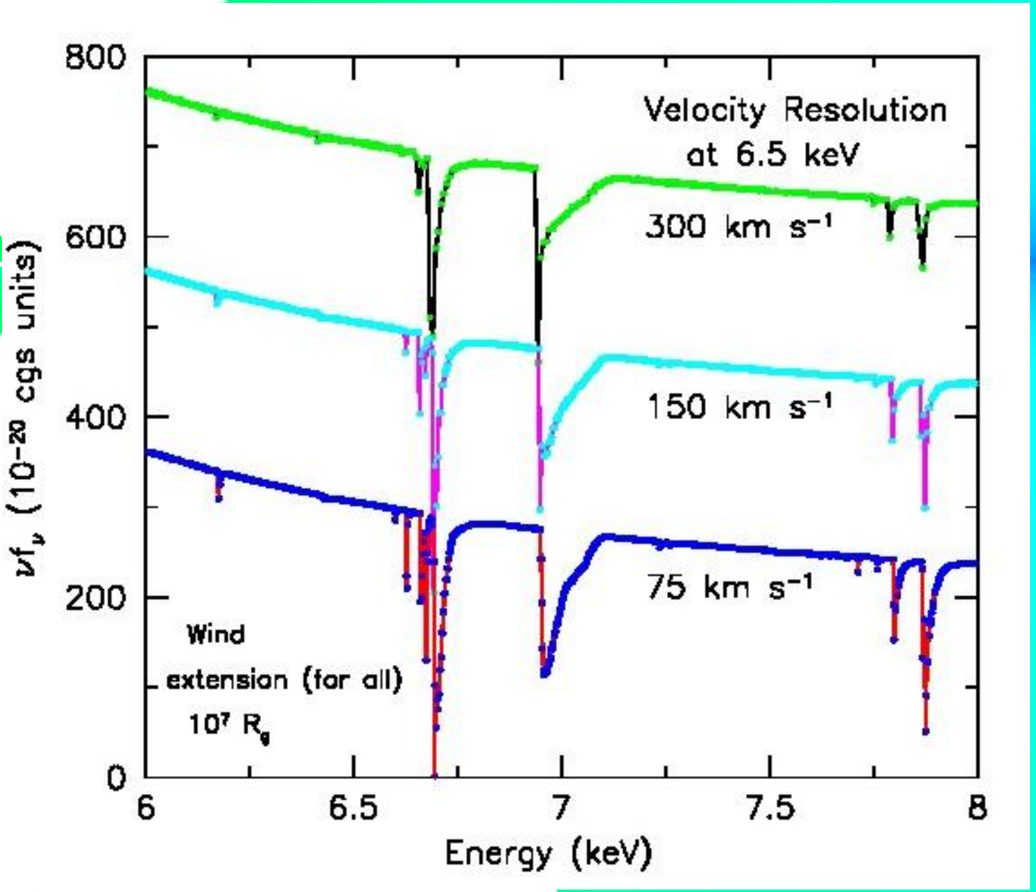


Please see also, Fukumura et.al. 2017, NatAs, 1E, 62

MHD winds from the accretion disk:

The effect of high resolution



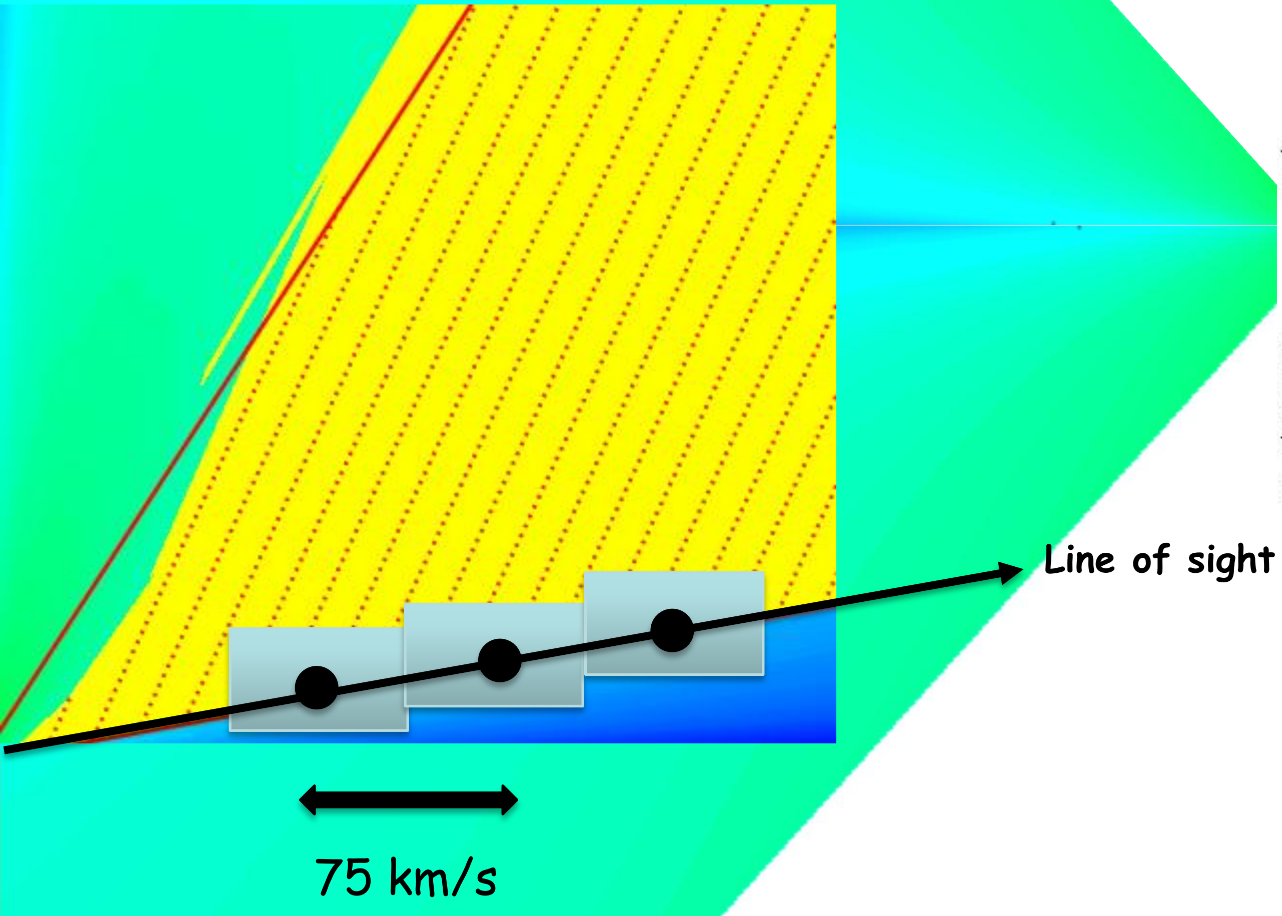


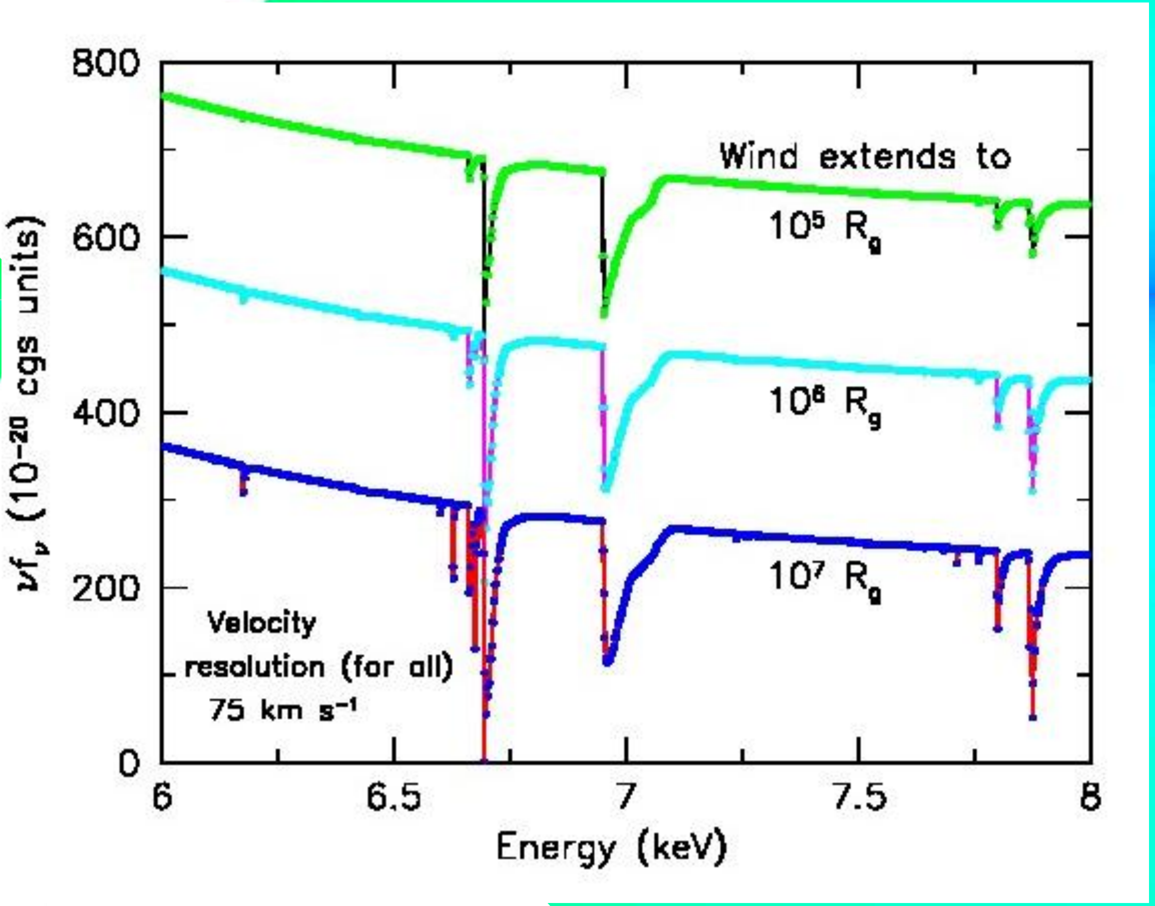
MHD winds from the accretion disk:

Disk Extension

For more extended disks,
we see low ionisation lines

The **6-8 keV** range is **not enough** to identify this effect.



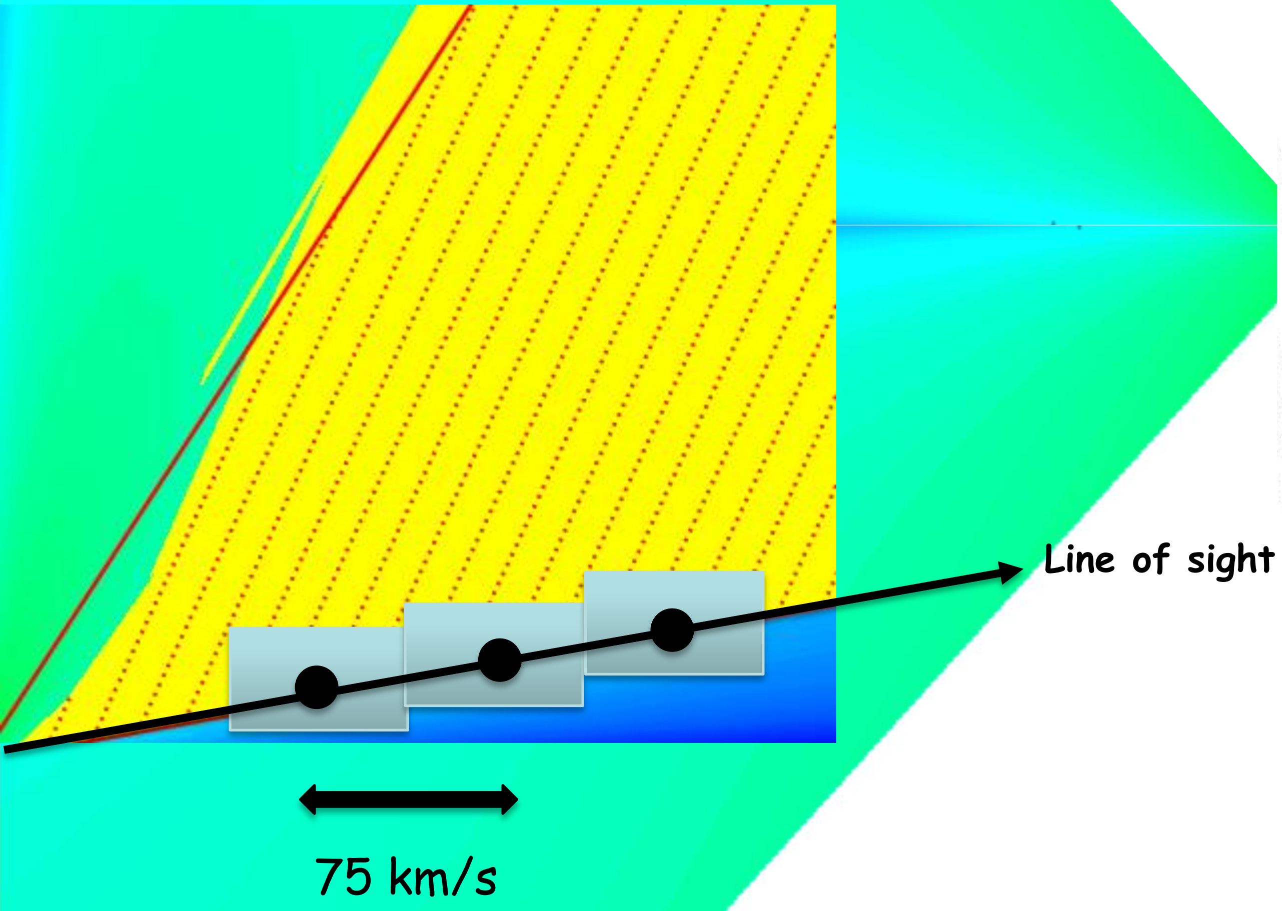


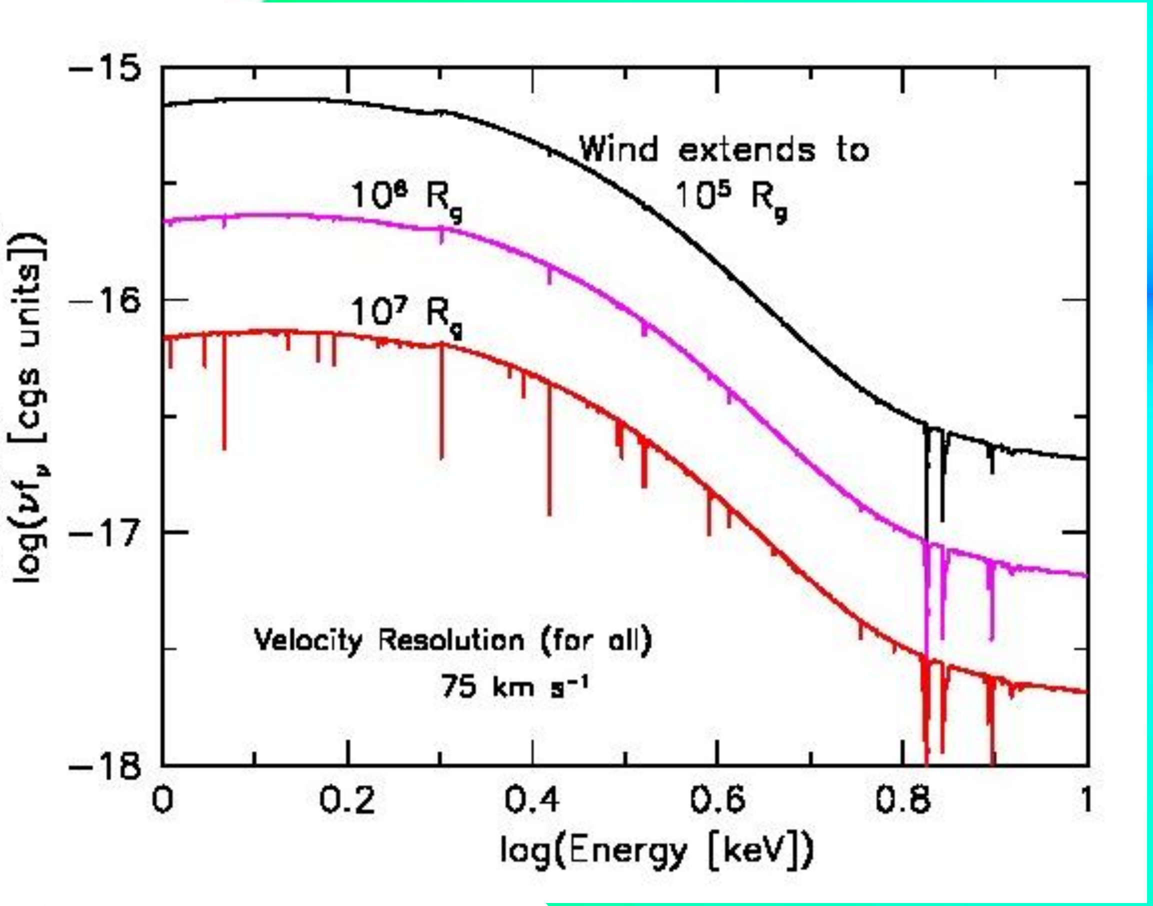
MHD winds from the accretion disk:

Disk Extension

For more extended disks,
we see low ionisation lines

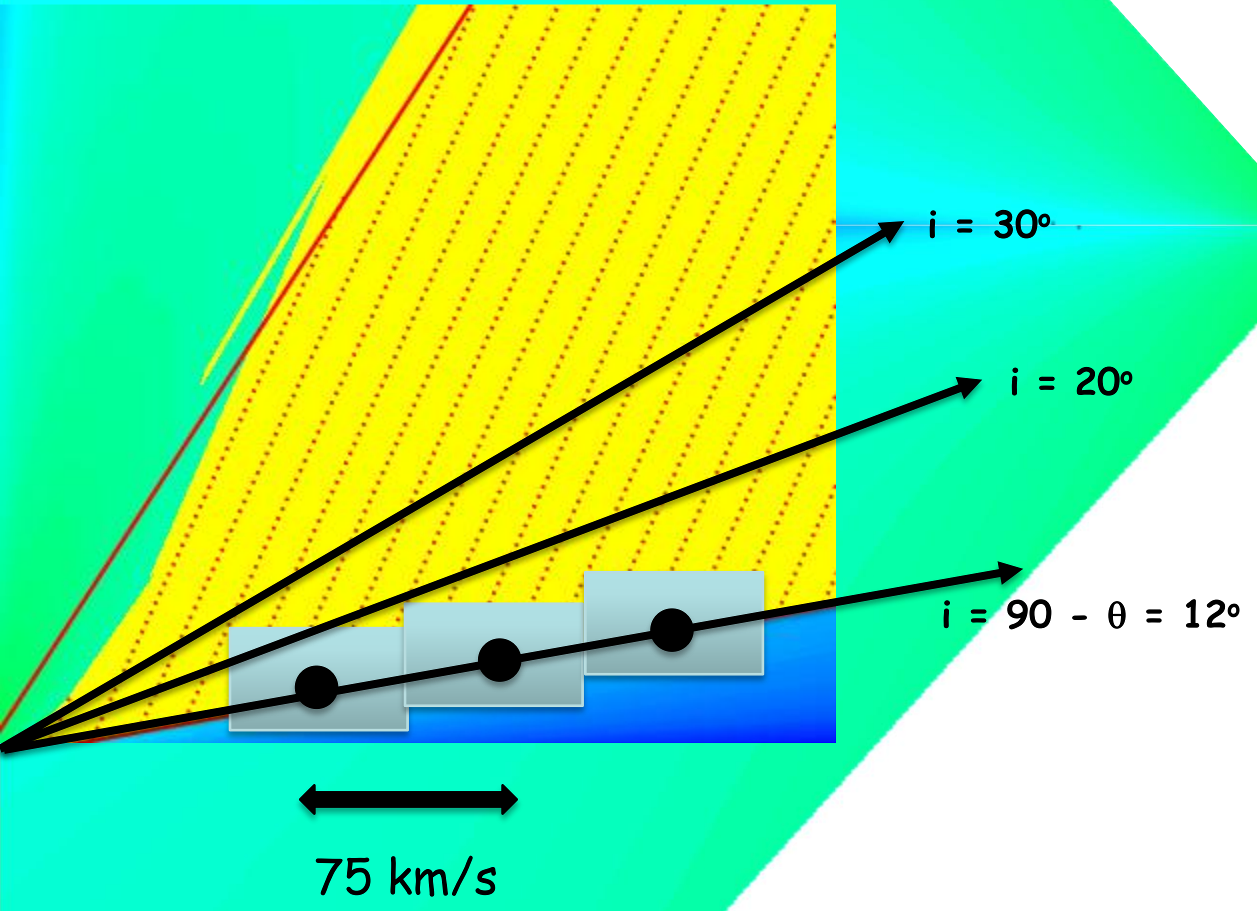
This effect is clearly identified
in the **1-10 keV range**

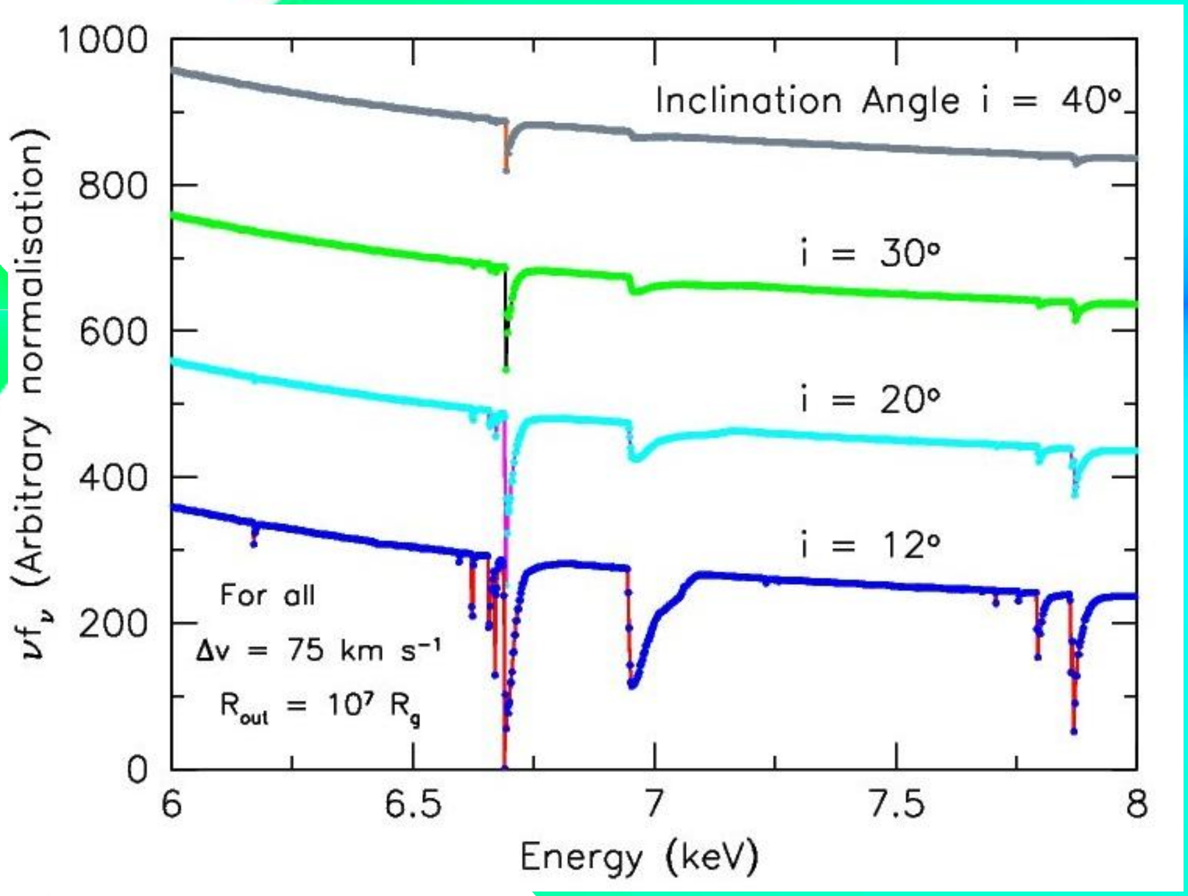




MHD winds from the accretion disk:

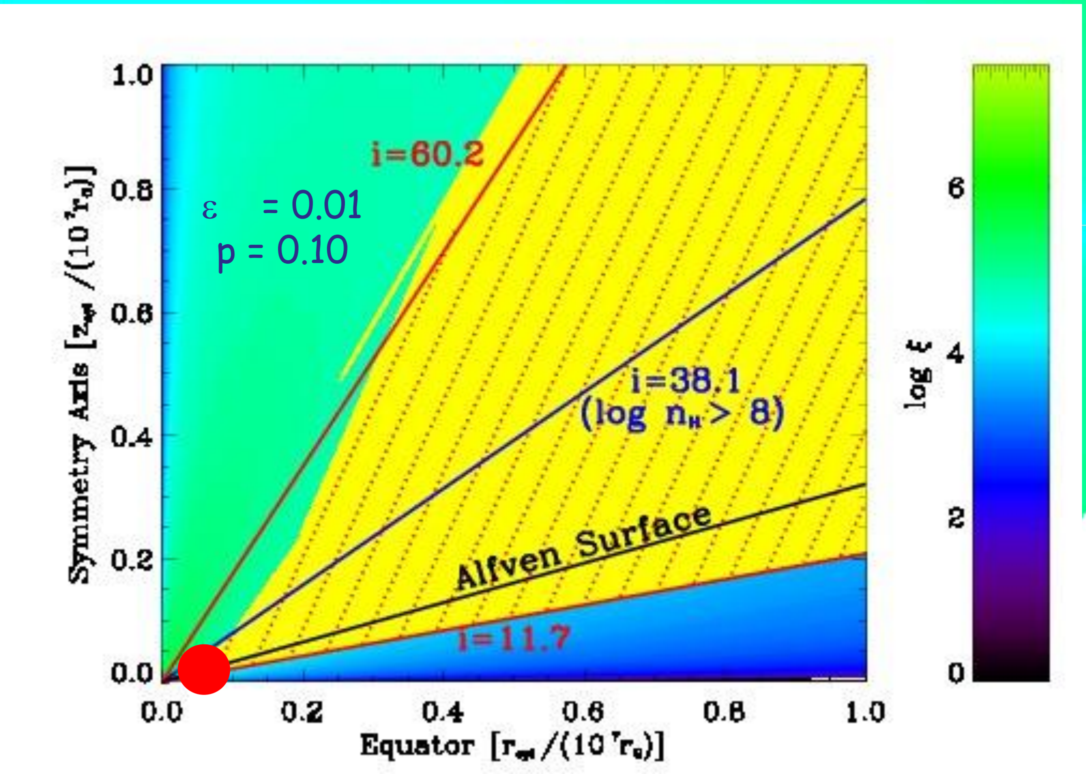
The effect of angle of line of sight





MHD winds from the accretion disk:

What remains to be done?

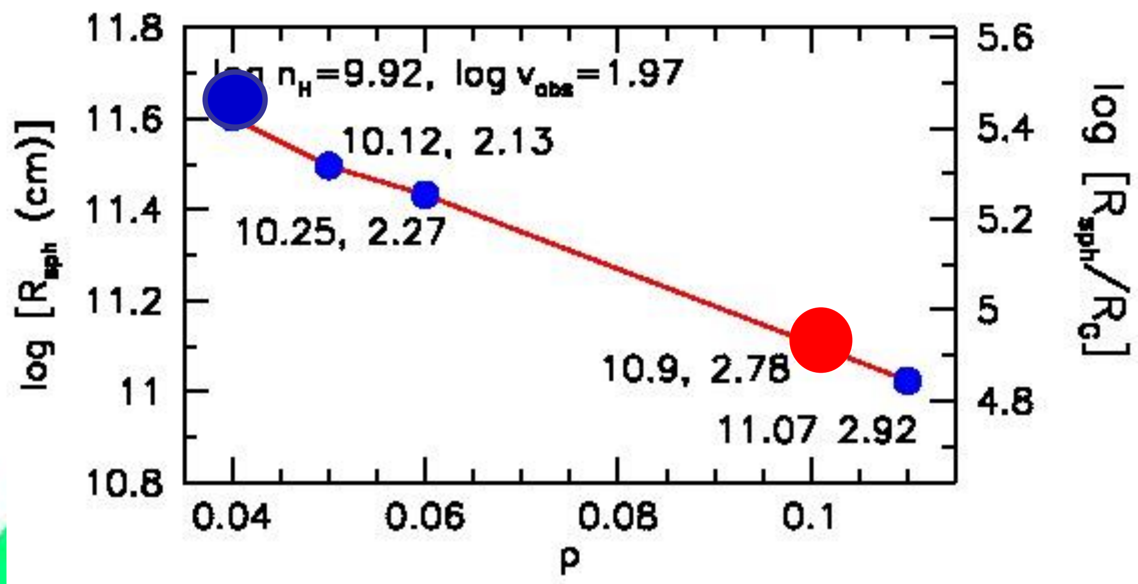


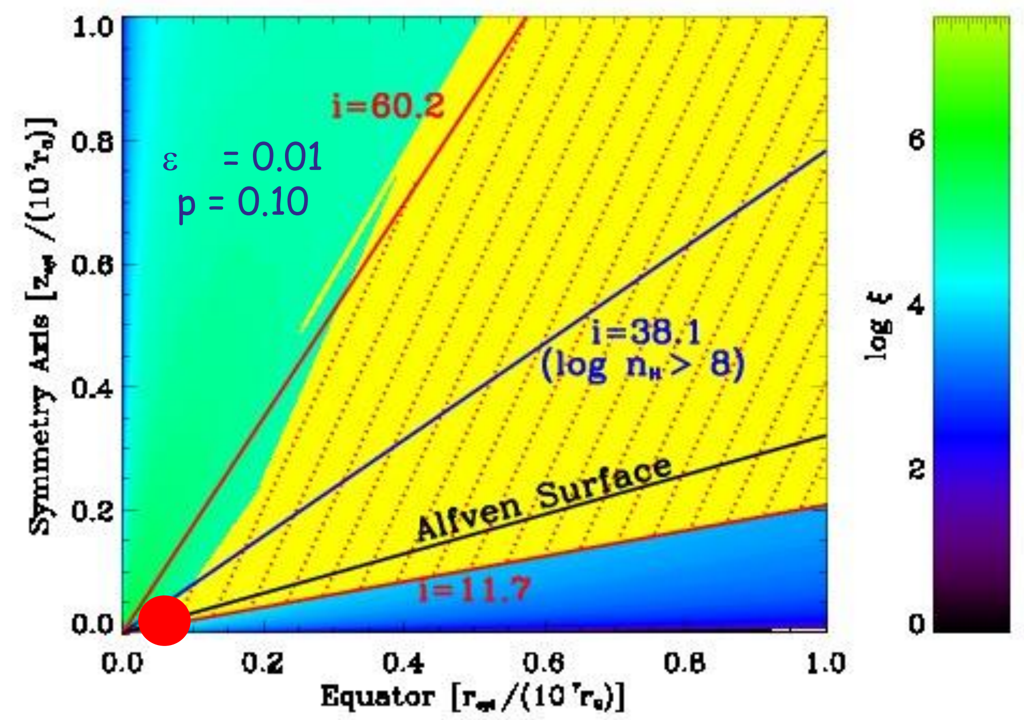
"Best Warm Solution" ionised by a Soft state SED

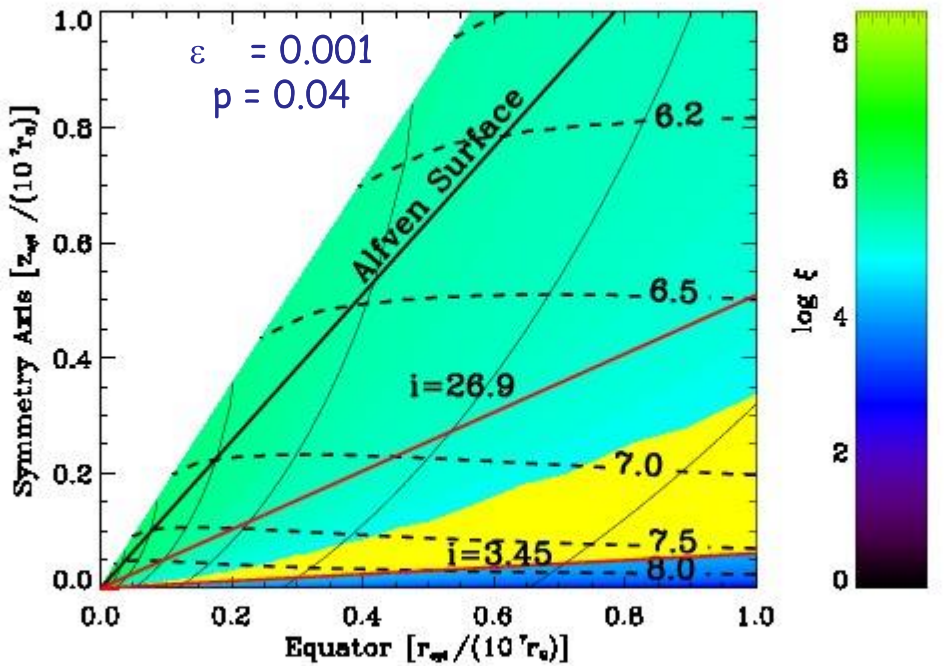
MHD winds from the accretion disk:

What remains to be done?

We have other MHD solutions.
Look at spectra from the other MHD JED solutions







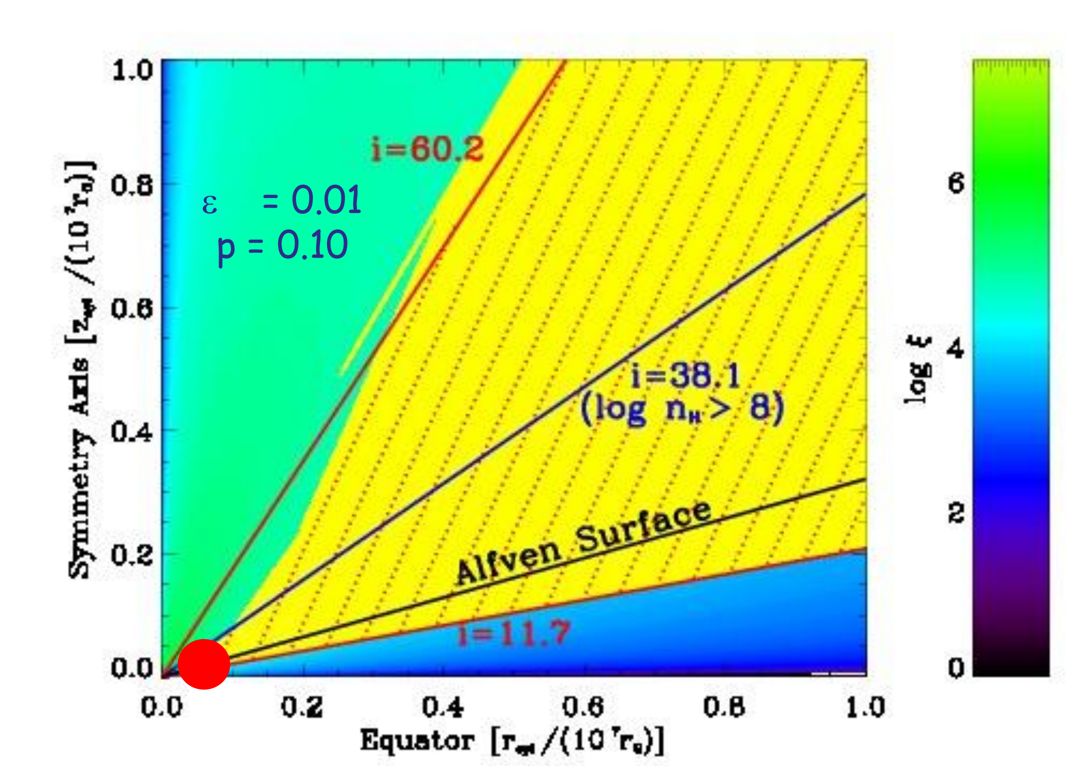
"Best Warm Solution" ionised by a Soft state SED

MHD winds from the accretion disk:

What remains to be done?

How would the spectra in Hard State compare?

Still the "Best Warm Solution"
but now, ionised by a Hard state SED



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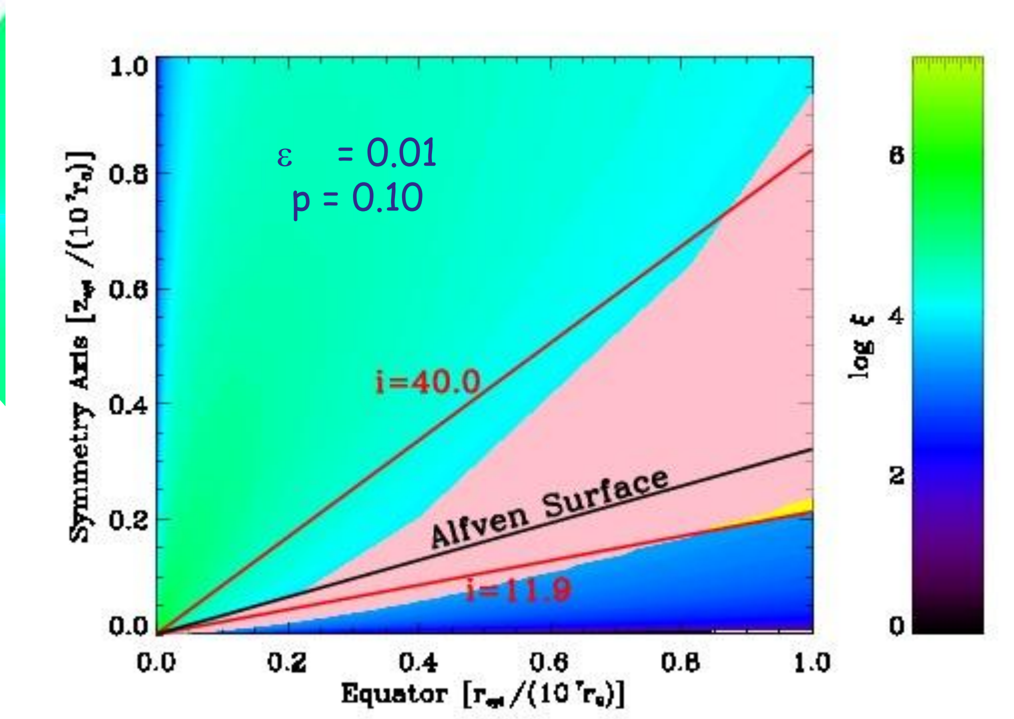
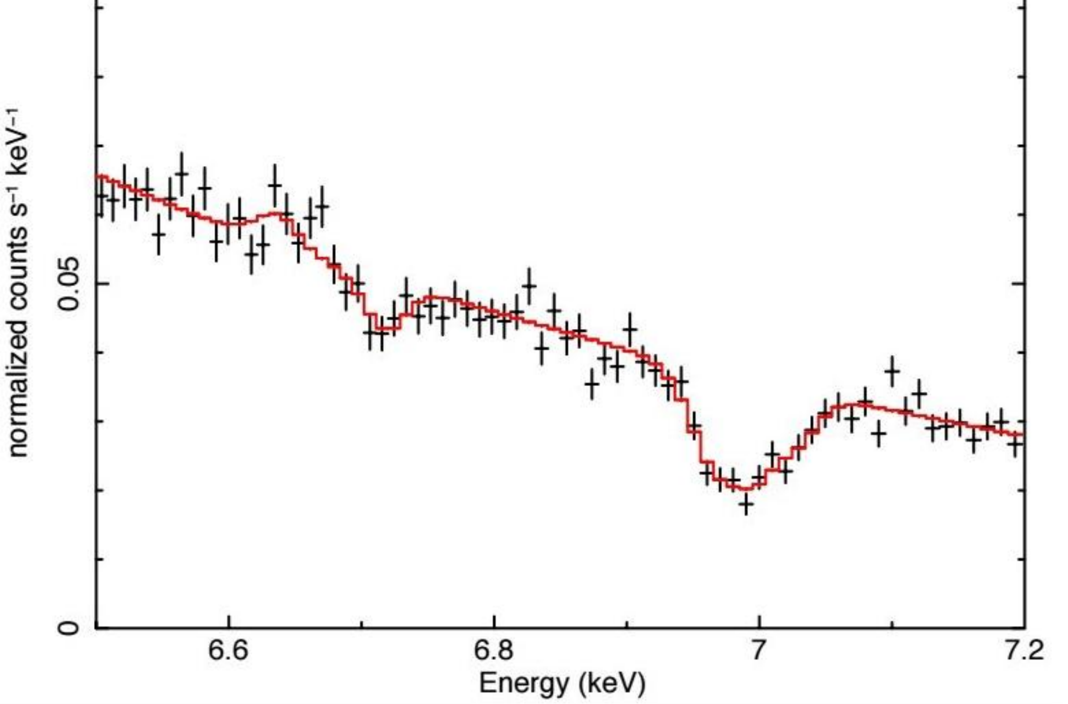


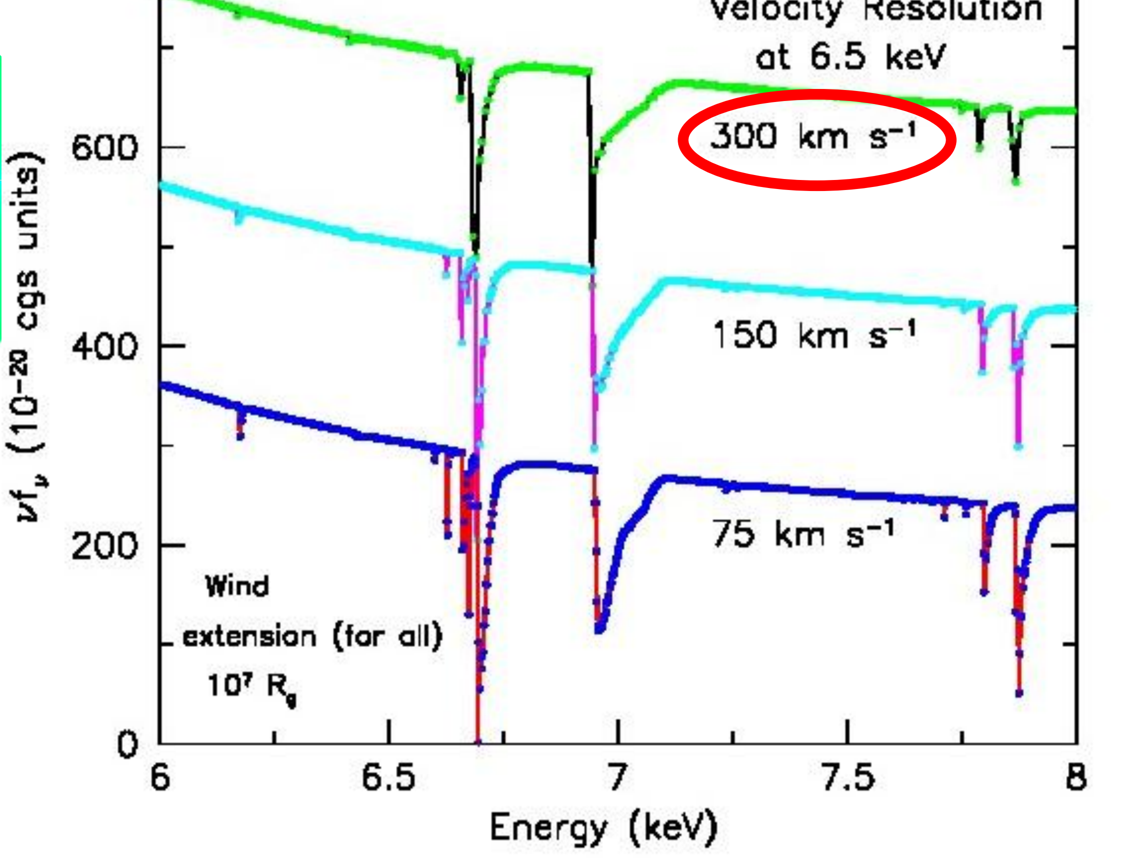
MHD winds from the accretion disk:

What remains to be done?

Simulate spectra to fit to observations

Fake Chandra data for 800ks of a F(3-10 keV) =2×10^{-9} ergs/s source.



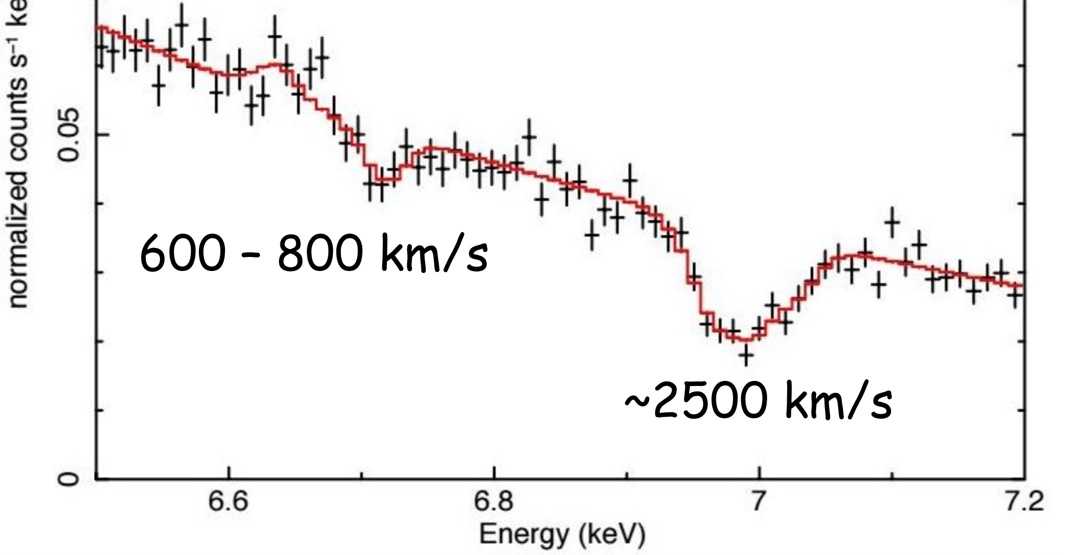


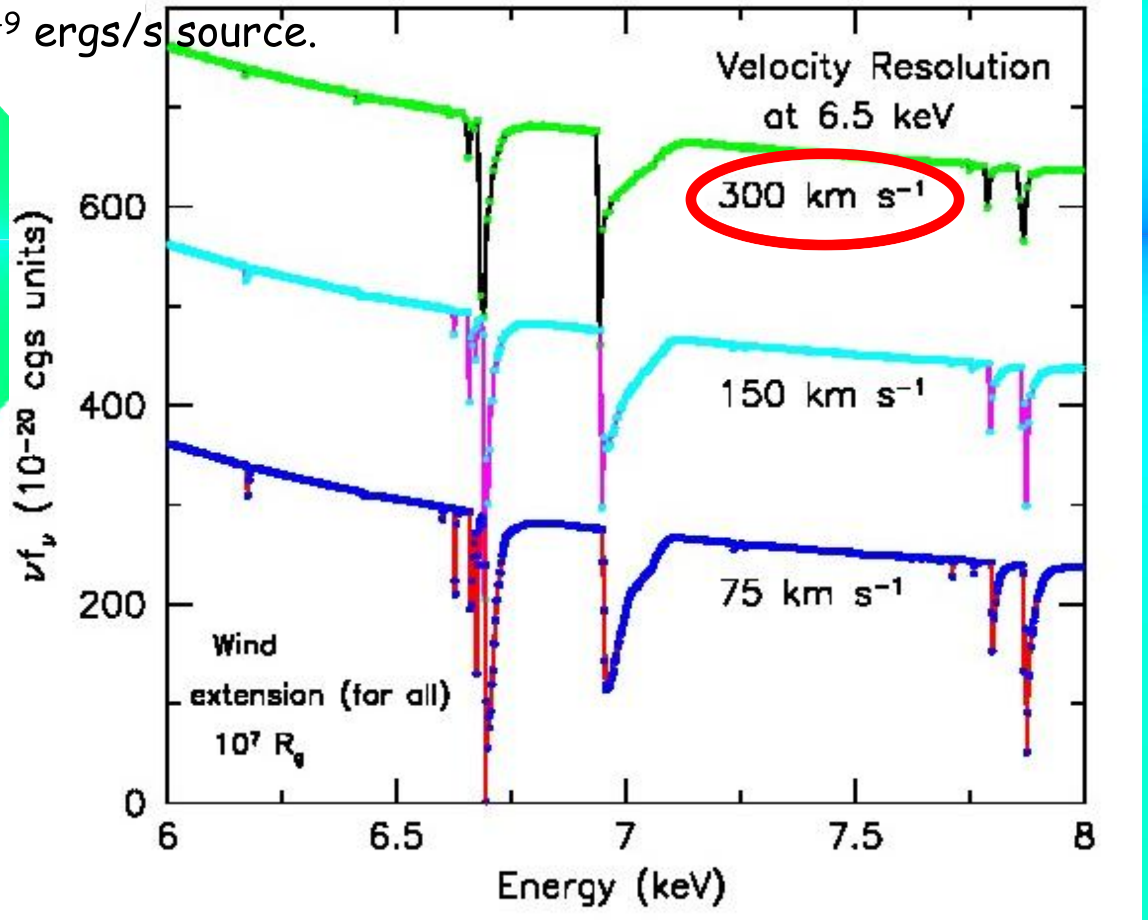
MHD winds from the accretion disk:

What remains to be done?

Simulate spectra to fit to observations

Fake Chandra data for 800ks of a F(3-10 keV) =2x10^{-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

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

We have devised ways to implement
~ correct ionization state
~ correct column density

We have ruled out Cold MHD solutions

Warm MHD solutions work
Disk surface heating lifts of gas
Magnetic acceleration follows

Works for "average" winds
Density < 10^{12} cm^{-3},
Velocity $\leq 10^3$ Km/s
We are at par with thermal pressure models

But what about "extreme" winds?
There is hope and we are working on it

Thank You

Questions

Work in progress

Chakravorty+ 17 (to be submitted soon!)

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

We have checked what they predict

We have **not** dealt with emission lines!

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Future

For our MHD solutions
Table models for xspec?

Our methods are generic – applicable to any solutions.
Please use our methods

Hyperlinks

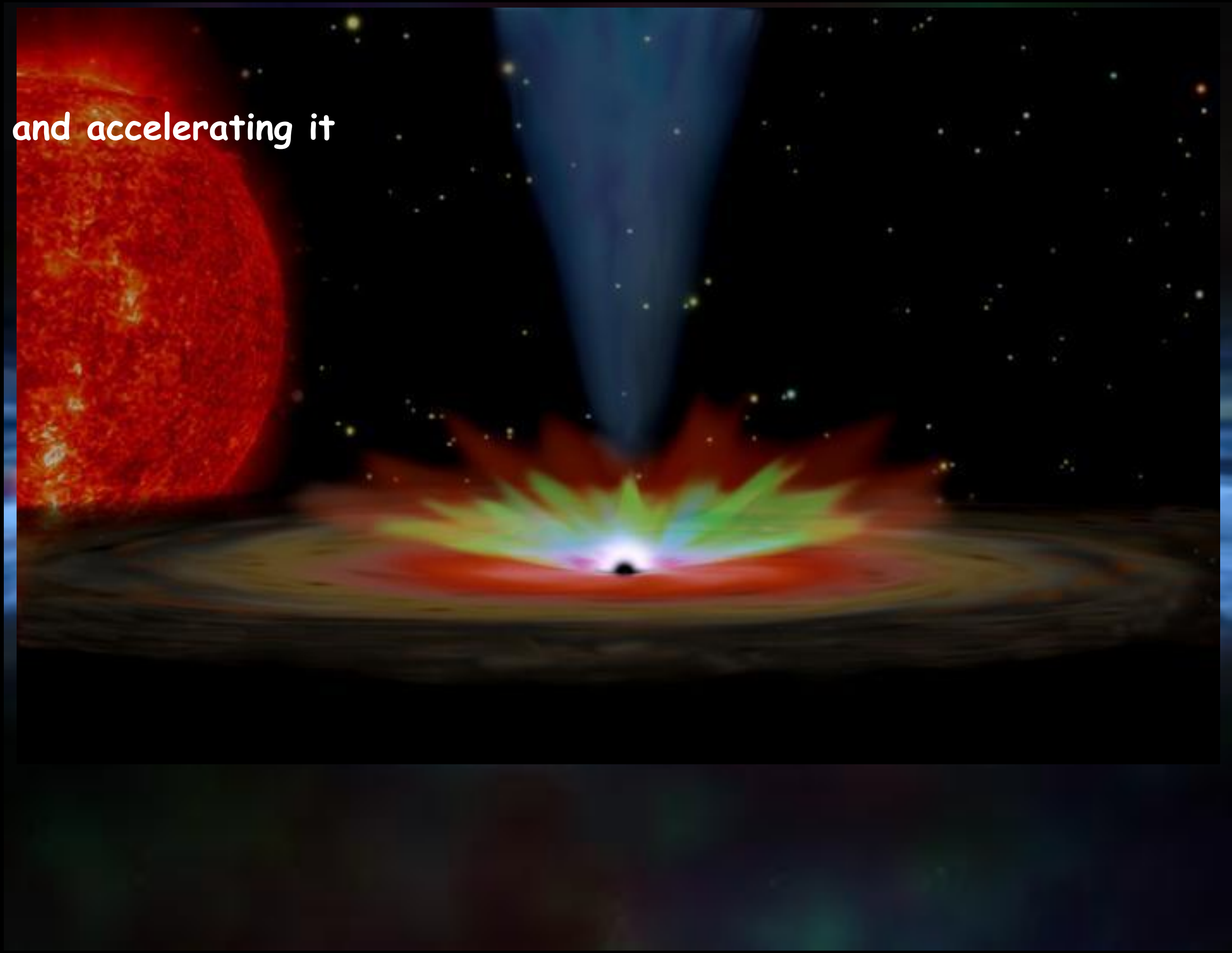
How are the winds accelerated?

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 before us

How are the winds accelerated?

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<u>Some physical mechanism</u> is lifting material off the accretion disk

Search for the <u>accelerating physical mechanism</u> is on

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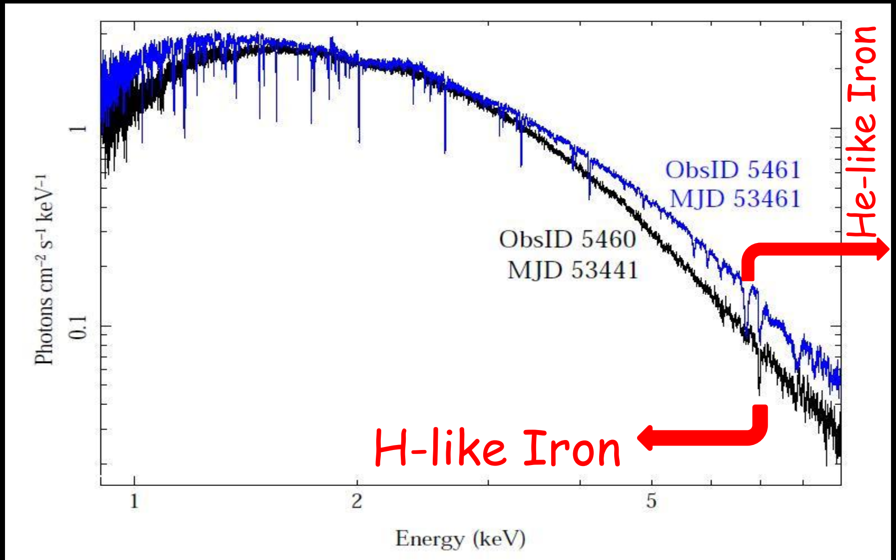

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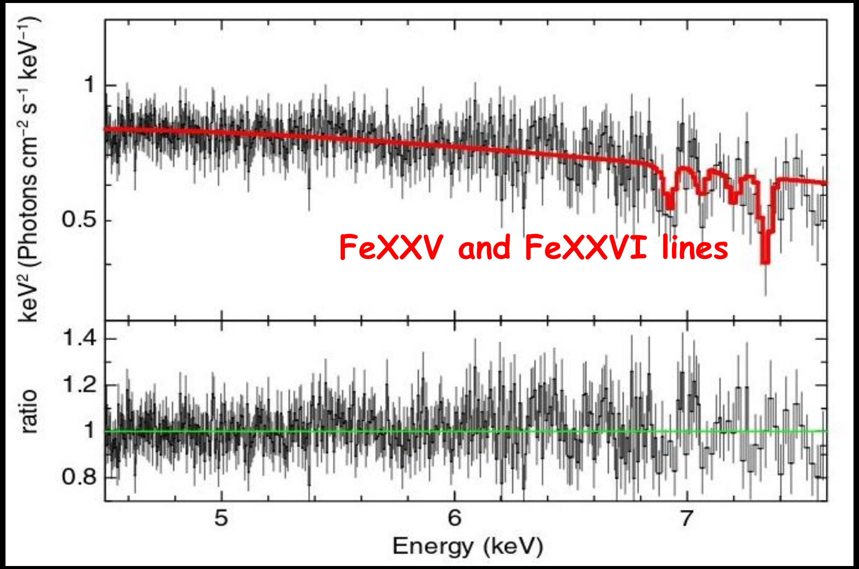
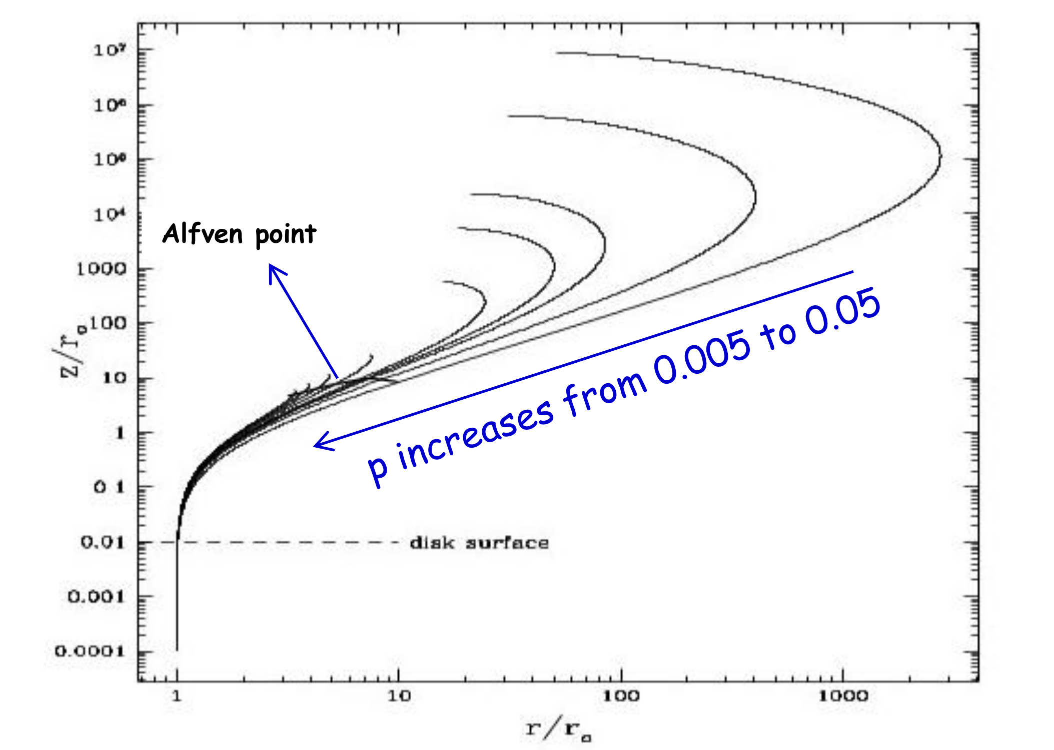


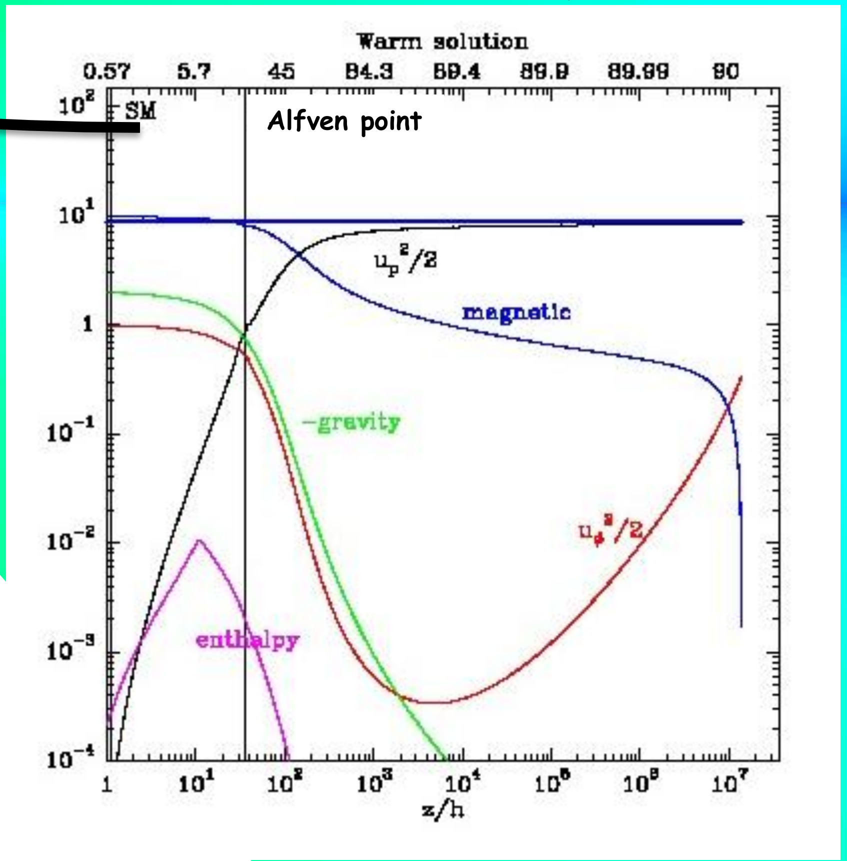
Miller et.al. (2008) suggest MHD winds from spectra of GROJ 1655
~ they found very high densities
~ implying wind launched from close to the black hole

King et.al. (2012) suggest very high velocity winds for IGR J17091-3624
~ FeXXV lines suggest ~ 9000 km/s
~ FeXXVI lines suggest ~ 15000 km/s

Some generic properties of the MHD outflow models

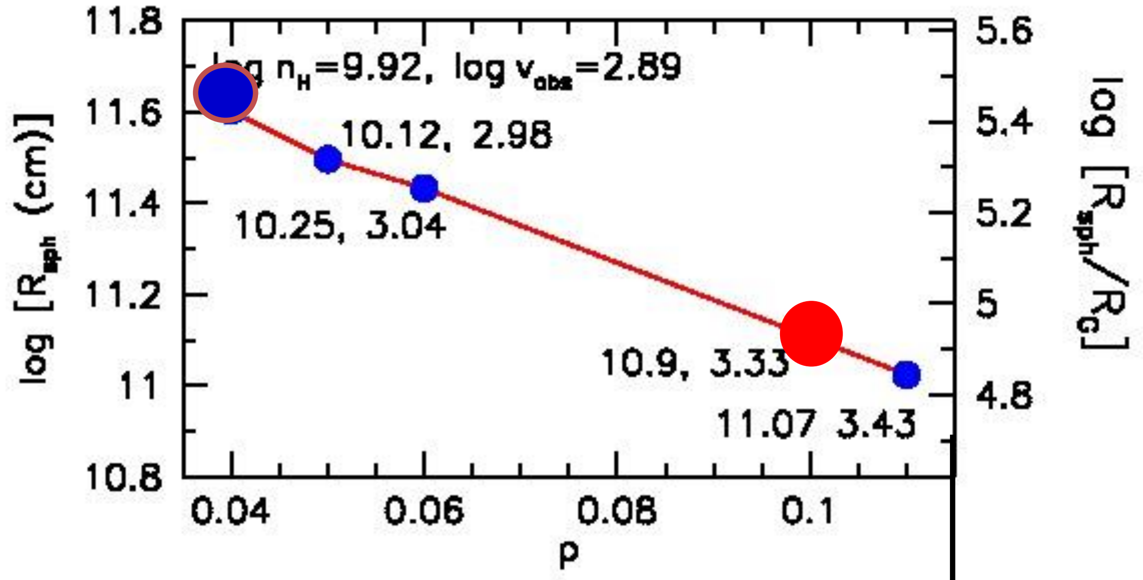


Slow magnetosonic point



The magnetic field lines for different MHD models as a function of ejection index "p"

Extreme winds



For extreme winds we need to increase p

- p cannot be arbitrarily increased
- it is linked to accretion
- we still do not have a model with p > 0.11

In literature:
p ~ 0.5 required to explain AGN winds
p ~ 0.45 to explain YSO winds

We try a rough linear extrapolation for p=0.5
Puts the wind at 5×10^3 R_G

at ~ 5×10^3 R_G
If p = 0.5

Choice of ξ upperlimit decides the results we get.
We had chosen a rather stringent upperlimit, log ξ < 4.86
Relaxing to log ξ < 6 brings the wind closer by ~ 90 times
Wind at < 10^3 R_G

at < 10^3 R_G
If log ξ limit ~ 6
log n_H ~ 13, log v_{obs} ~ 4

Rough linea… d on
the MHD s…
Extrapolati… ers of
magnitude.