MHD disk winds around compact objects: Can next generation X-ray satellites uniquely identify them?

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IPAG
Institut de Planétologie et d'Astrophysique de Grenoble

CHAOS

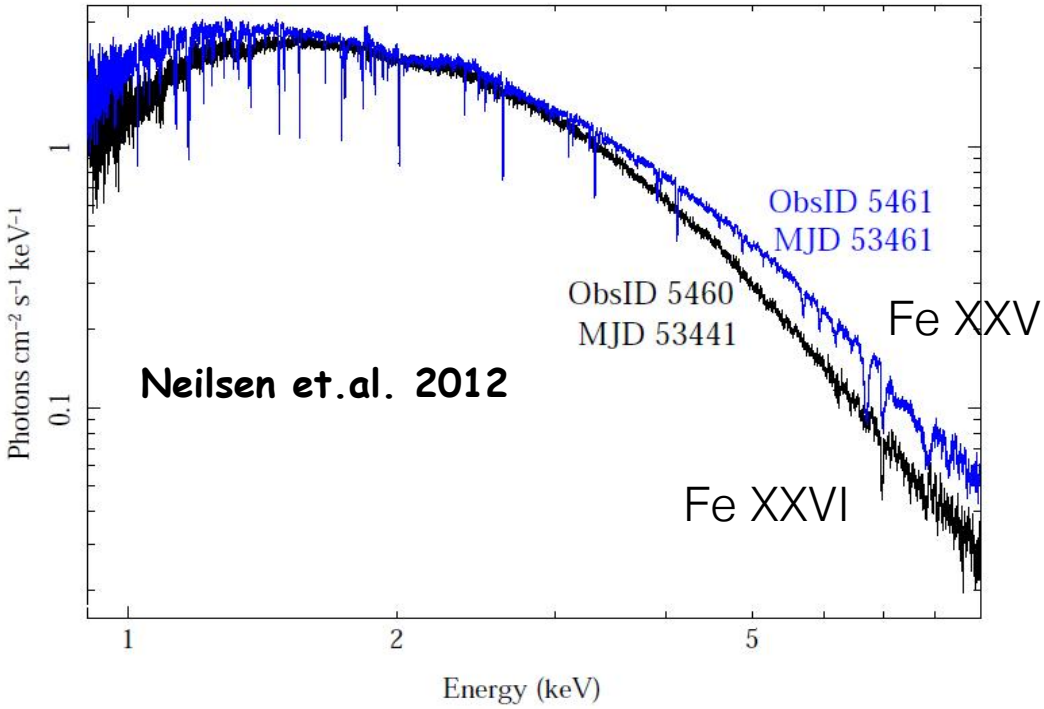
http://ipag.osug.fr/ANR-CHAOS/index.html

XrB Wind Signatures

★There are about 20 confirmed black hole binaries (Remillar & Mclintock 2006)

★A few BHBs show absorption lines (RXTE + Chandra or XMM-Newton)

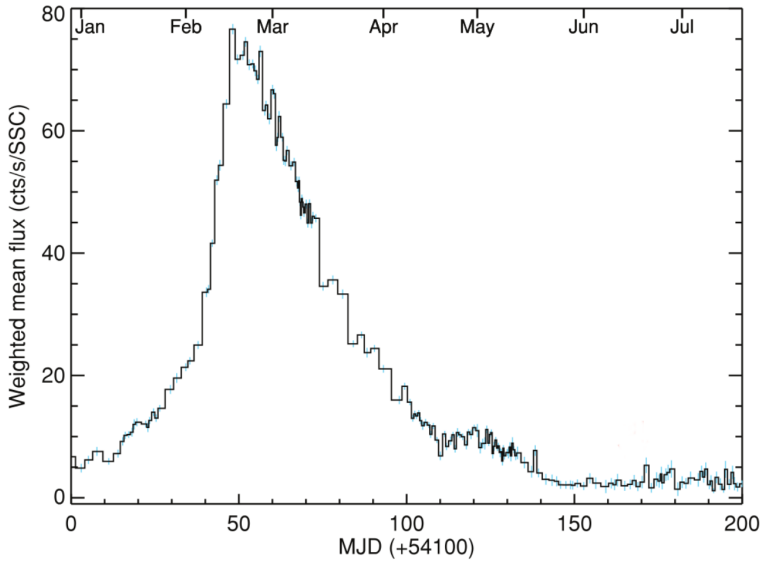
★Most observations show absorption lines from ‘only’ FeXXV and FeXXVI (black spectra)



★Exceptions (?)

- GROJ1655, 2006 observation (Miller et.al. 2008) has numerous lines (blue spectra)
- GRS1915, 2000 observation (Lee at.al. 2002, Ueda et,al. 2010)

Jet/Wind and Spectral States



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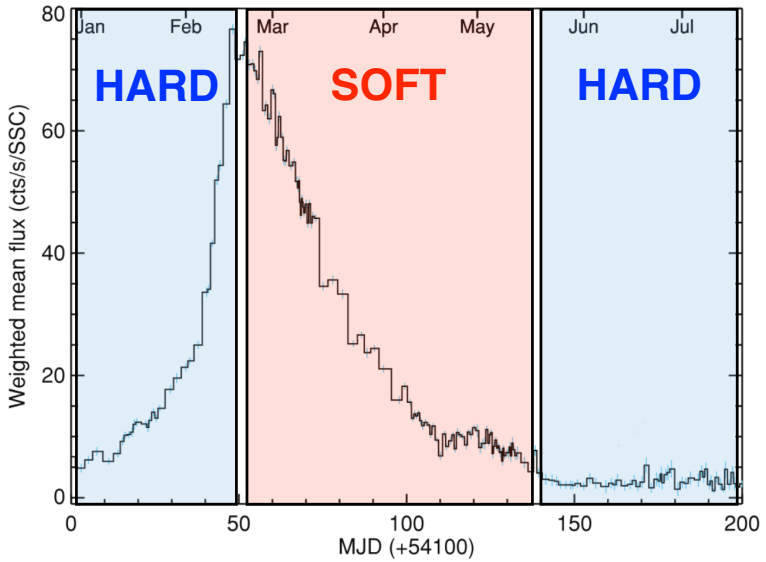

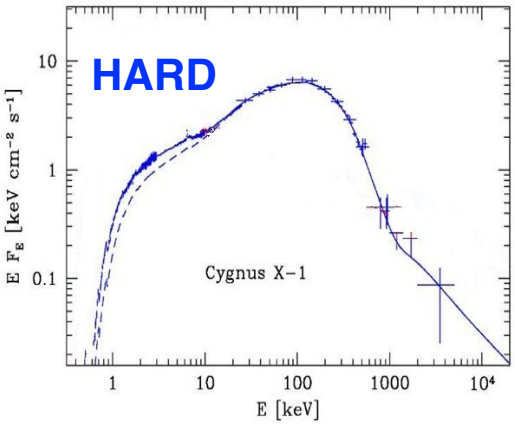

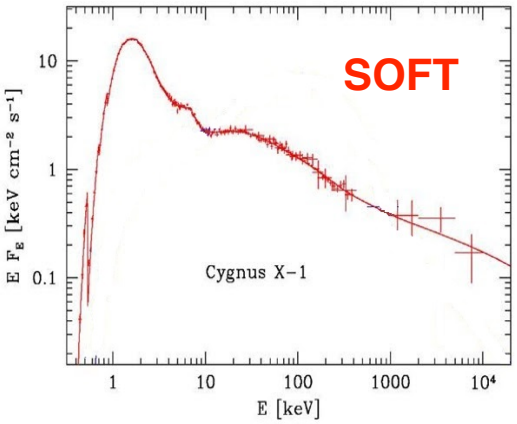

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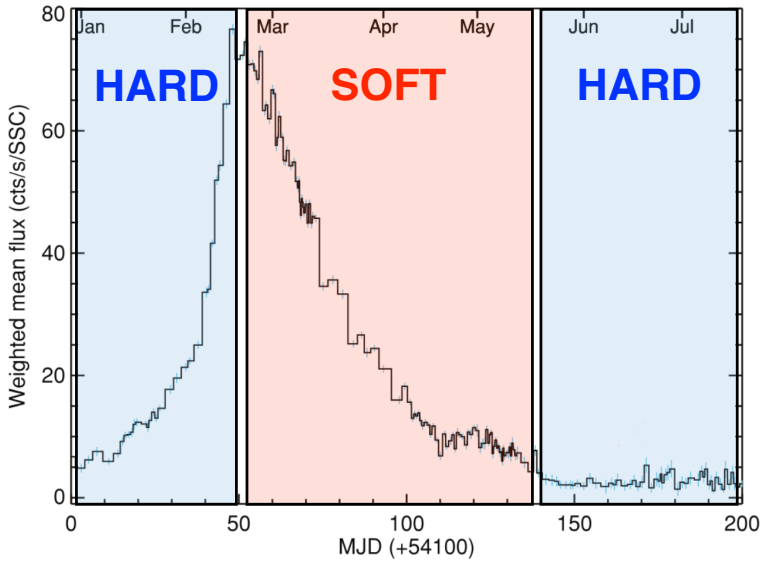
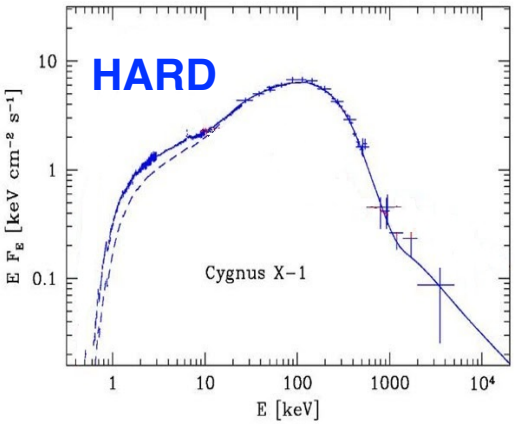
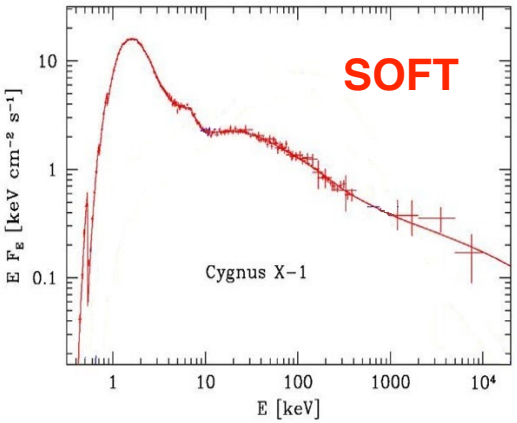
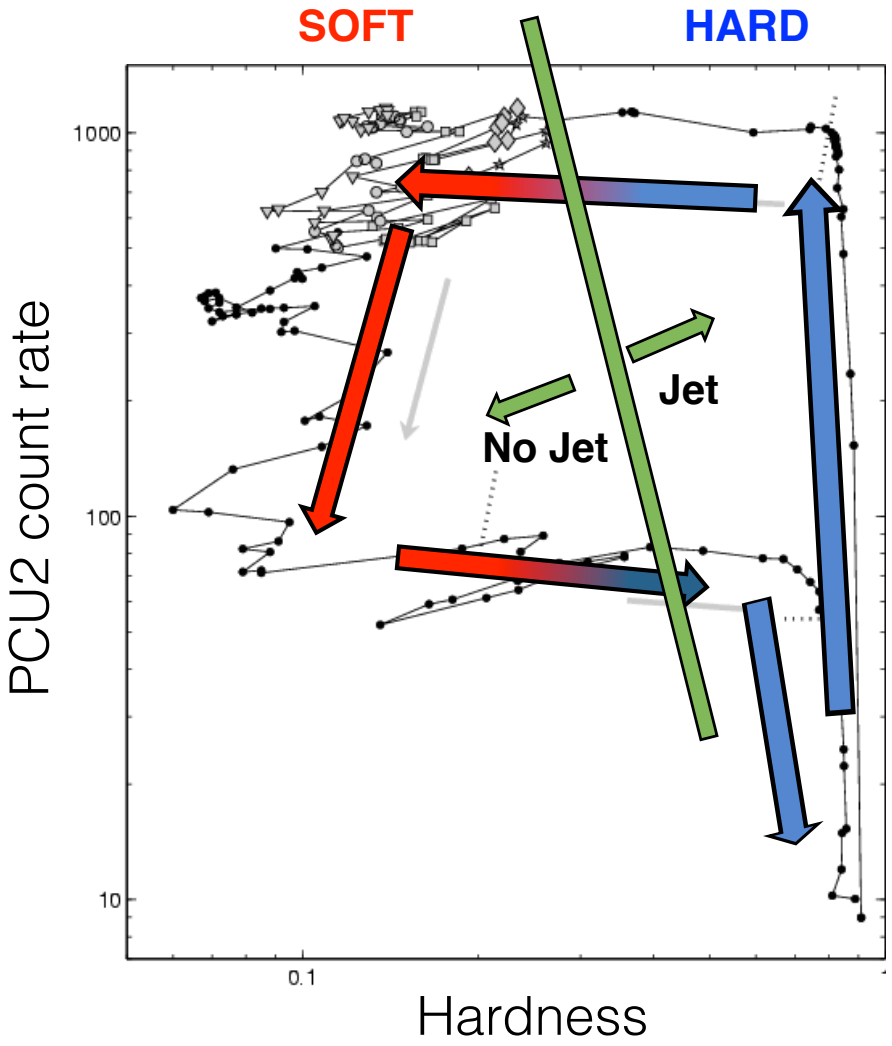


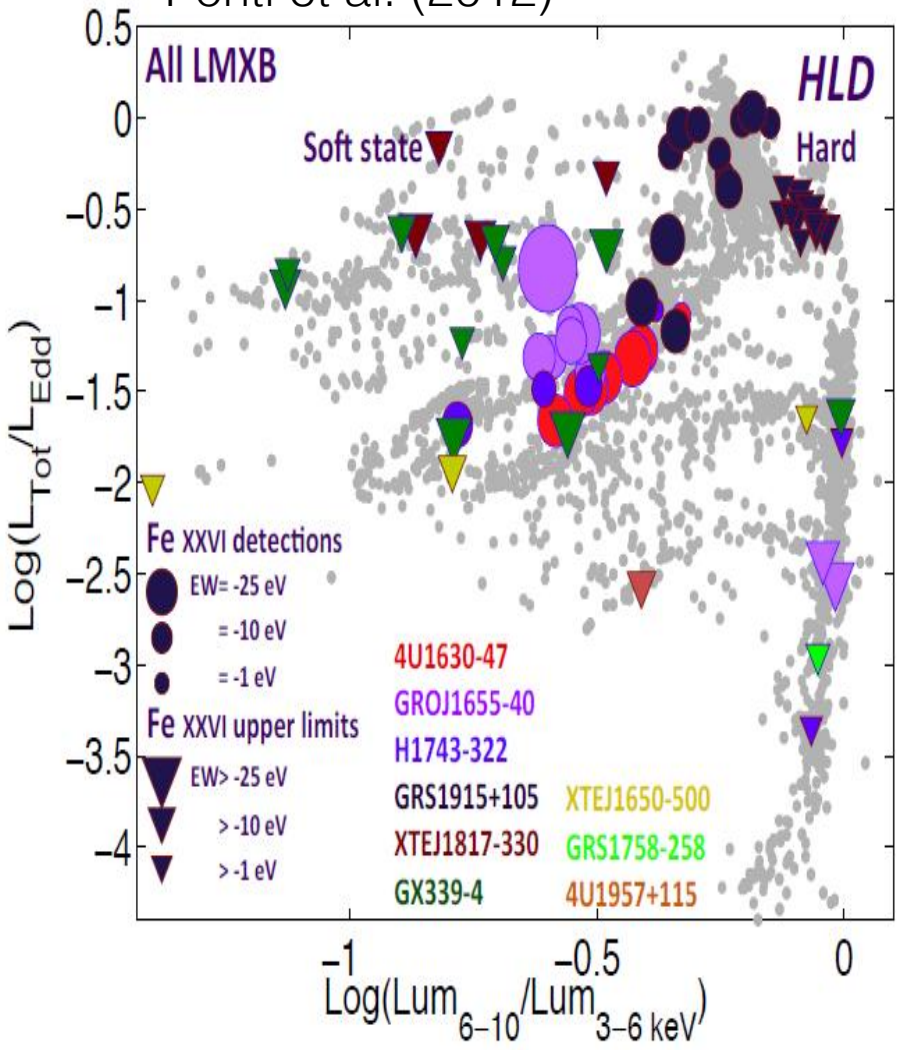






Jet/Wind and Spectral States

Ponti et al. (2012)



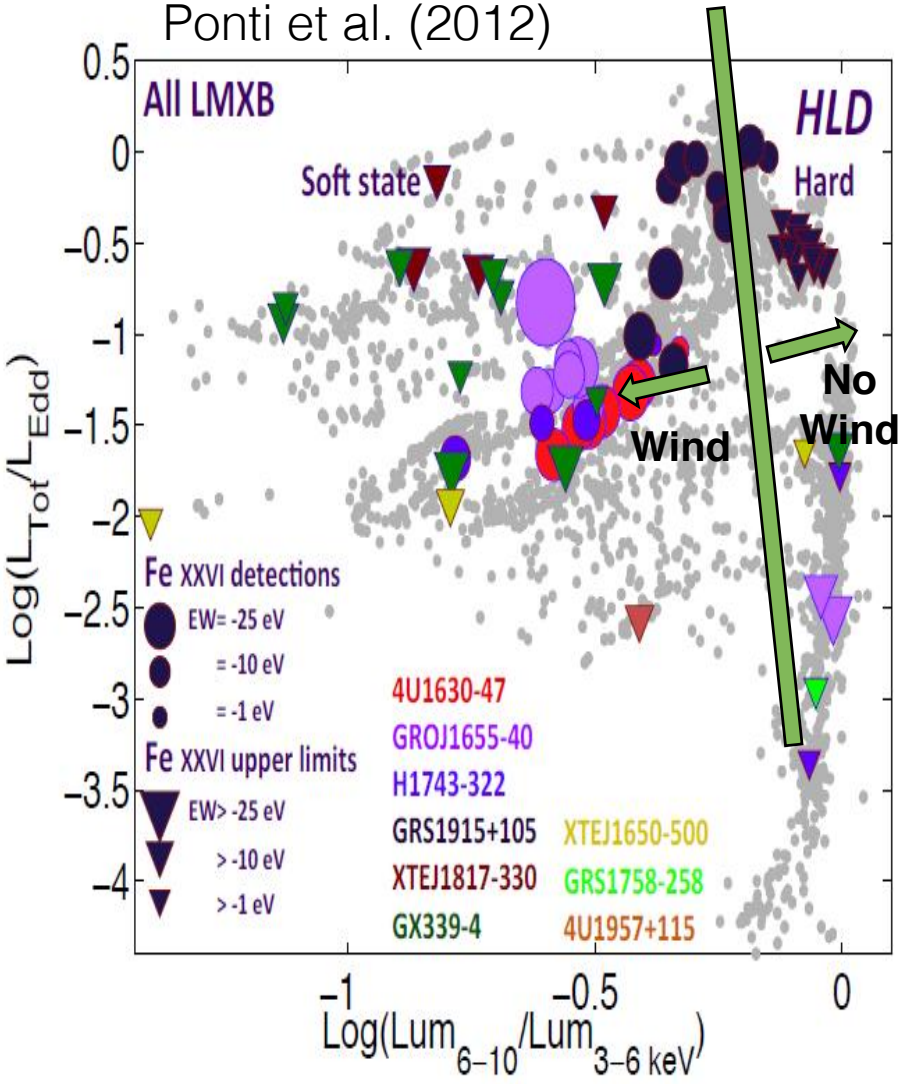
Jet/Wind and Spectral States

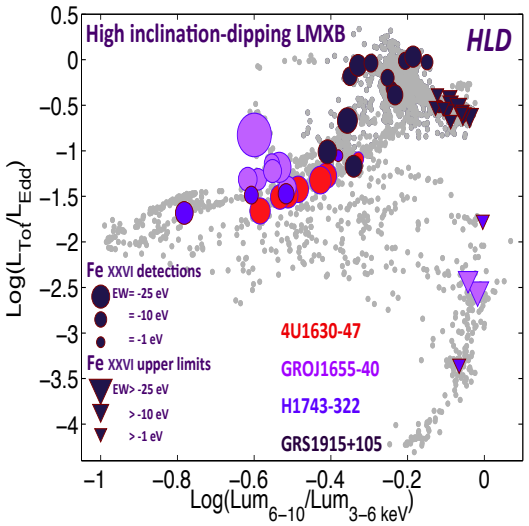
★The presence of winds seems to be a "state dependent" effect

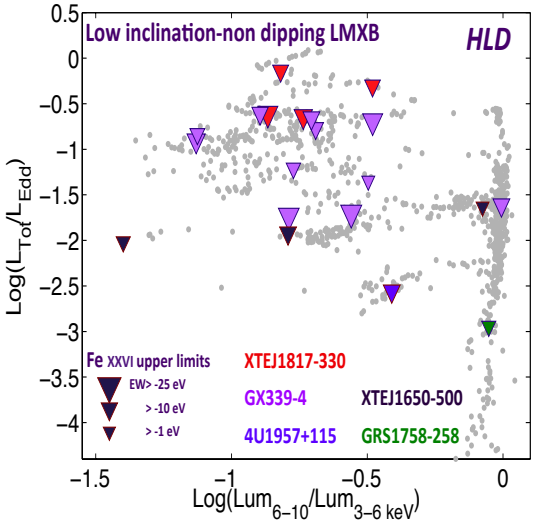
★Winds are observed in the Soft state

★Further, winds are observed in objects of high inclination (i.e. low equatorial angle)

Ponti et al. (2012)







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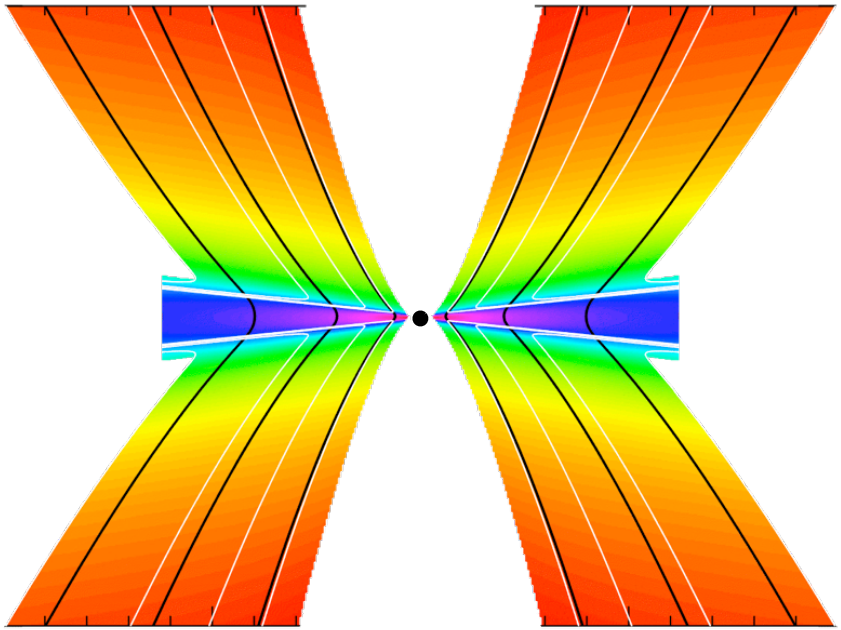
➡ JET: powerful radio emission, strong collimation, high speed, no absorption features

➡ WIND: weak radio emission, low speed, absorption features

The key parameter: the magnetization $\sigma = \dfrac{\text{MHD Poynting flux}}{\text{Thermal + kinetic energy flux}}$

MHD Outflow Solutions

Baryonic jet emitted by the accretion disk through MHD mechanism (Blandford & Payne, 1982)



✓ Assume a large-scale magnetic field

✓ First self-similar solution of the complete set of equations of an accretion-ejection structure (Ferreira & Pelletier 1995; Ferreira 1997)

✓ Analytical computations and heavy numerical simulations (Casse & Ferreira 2000a, 2000b; Ferreira & Casse 2004; Pesenti et al. 2004; Casse & Keppens 2004; Ferreira et al. 2006;)

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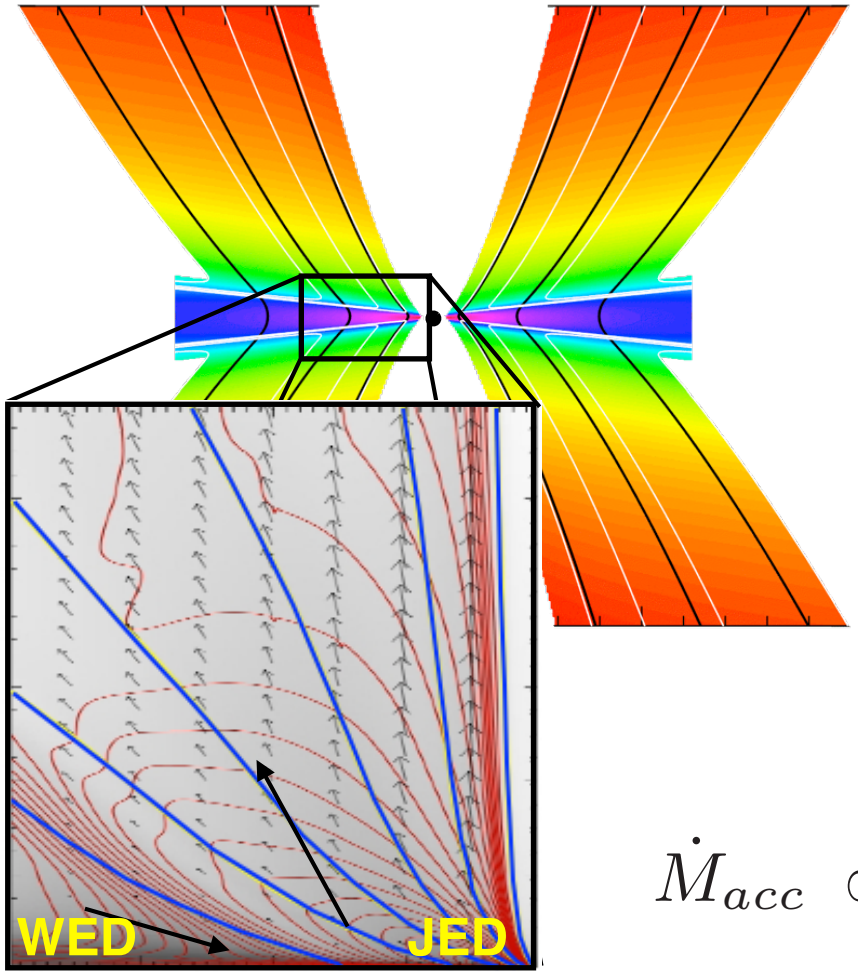

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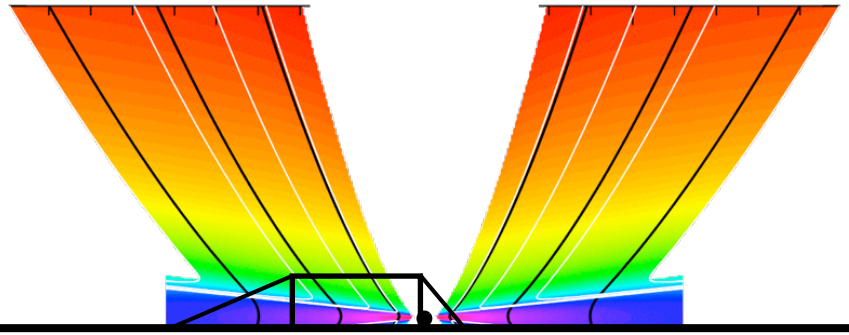

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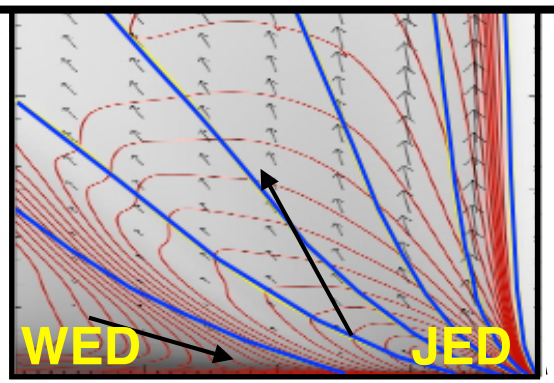
Can these solutions represent observable winds (in terms of , N_H, n and v_{obs})?
Can we recover the (i) state dependent and (ii) angle dependent observability?



Ferreira et al. 2006;)

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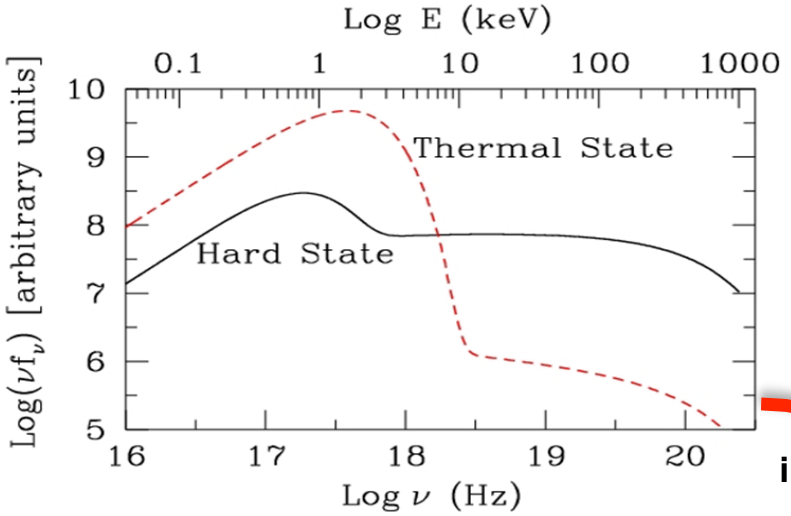
An Example of Solution



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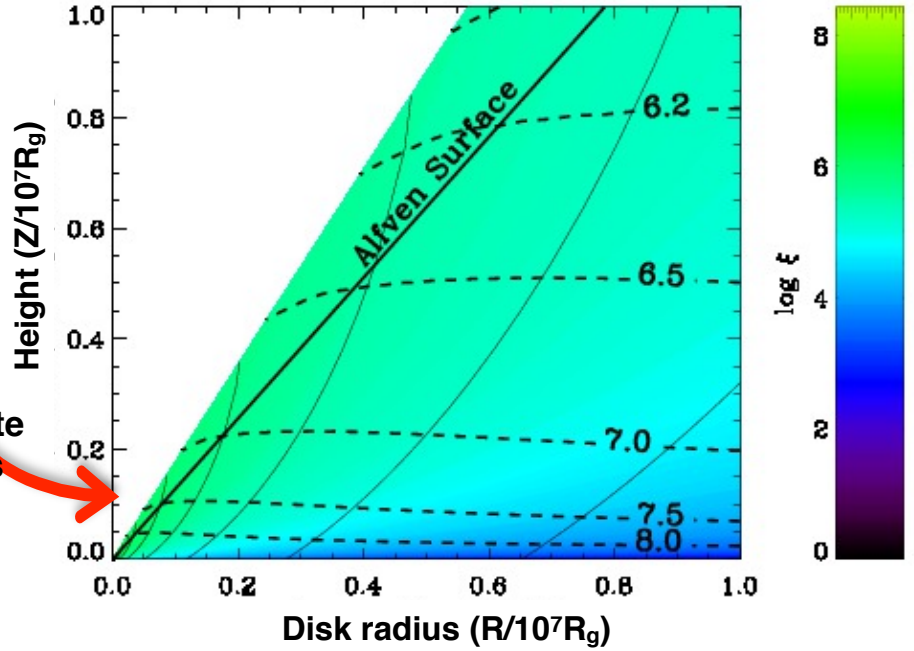
illuminate the gas



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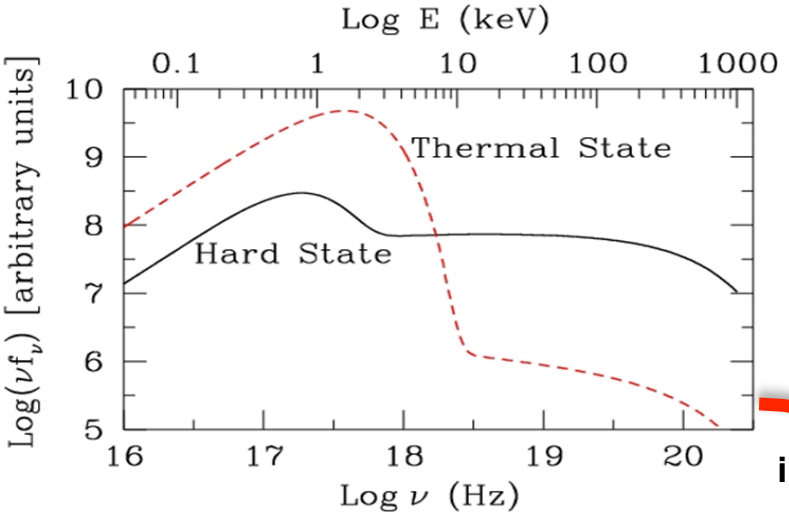

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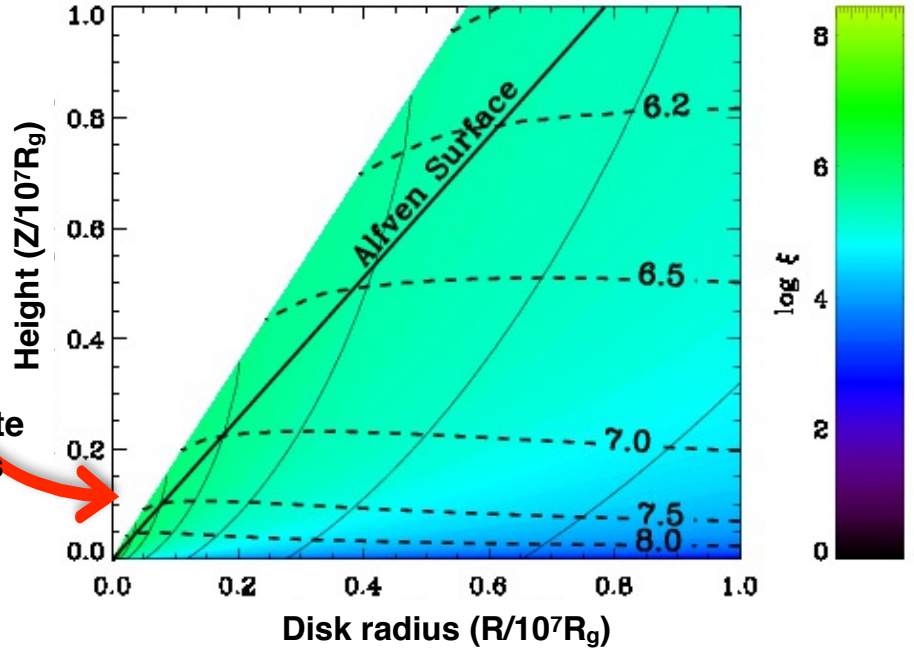

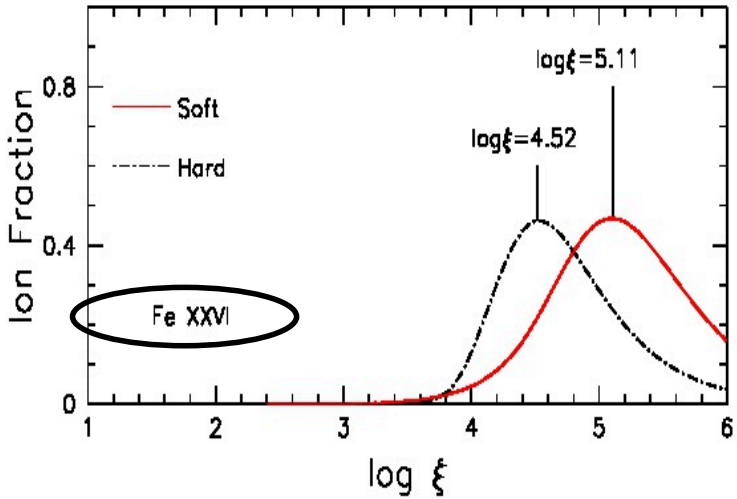

Chakravorty et al. (2013)

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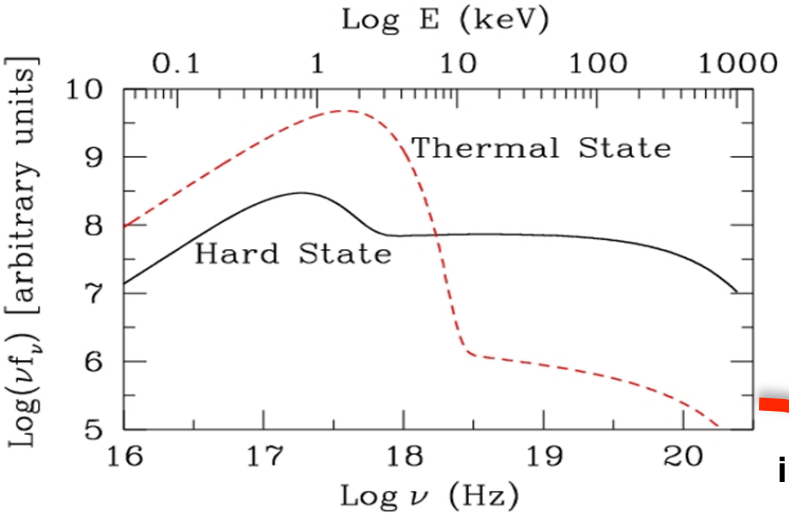

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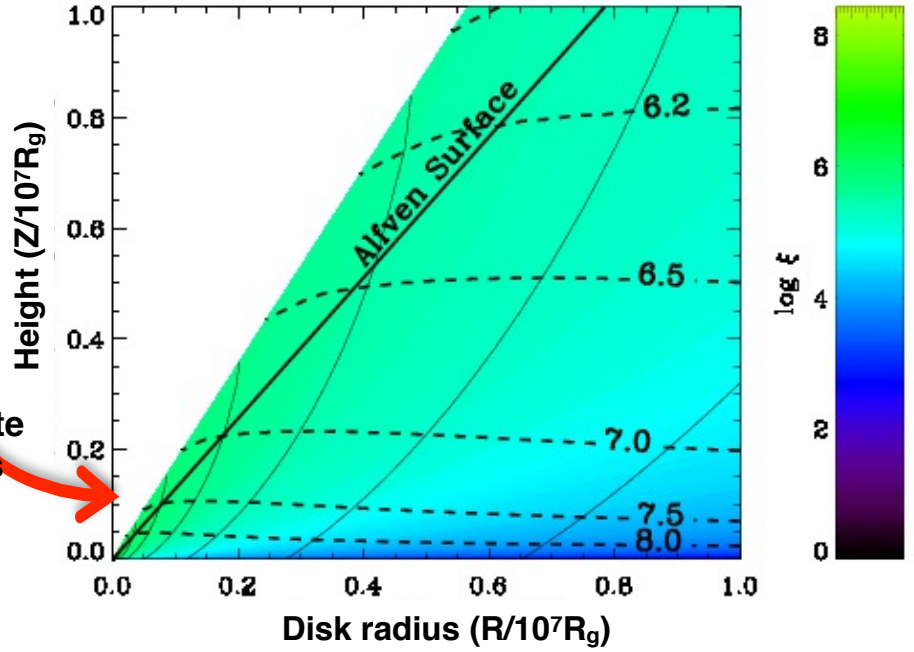

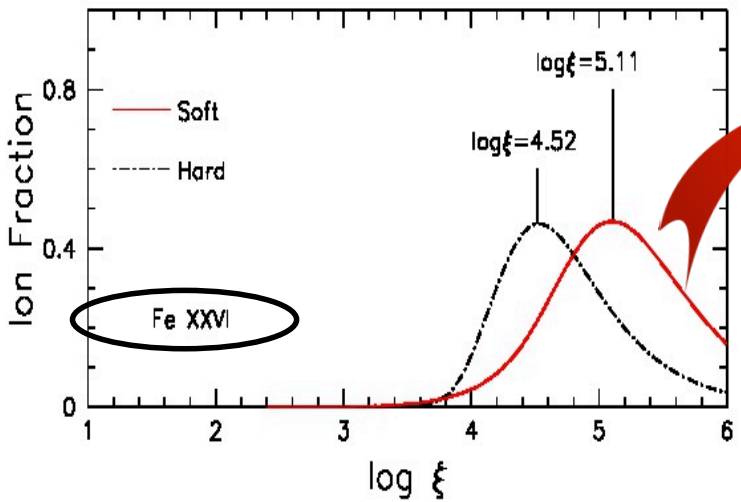

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Limits to put on the MHD model

- $N_H < 10^{24}$ cm^{-2}
- log ξ <$10^{5.11}$ for soft SED
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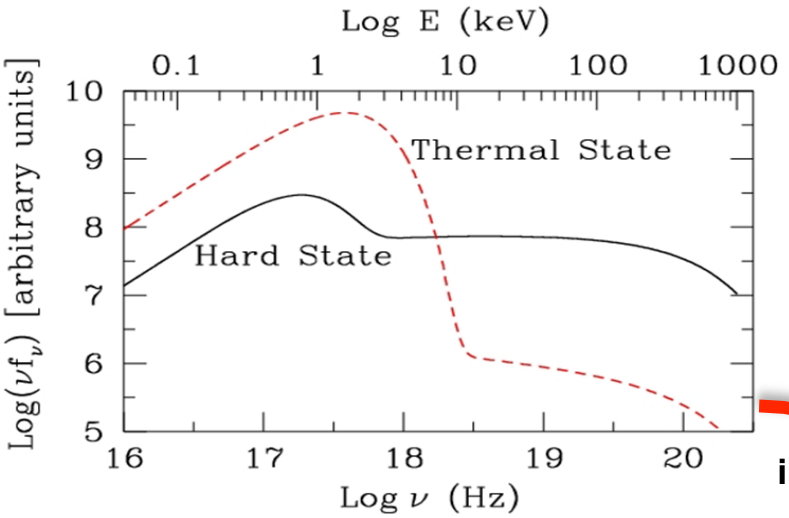

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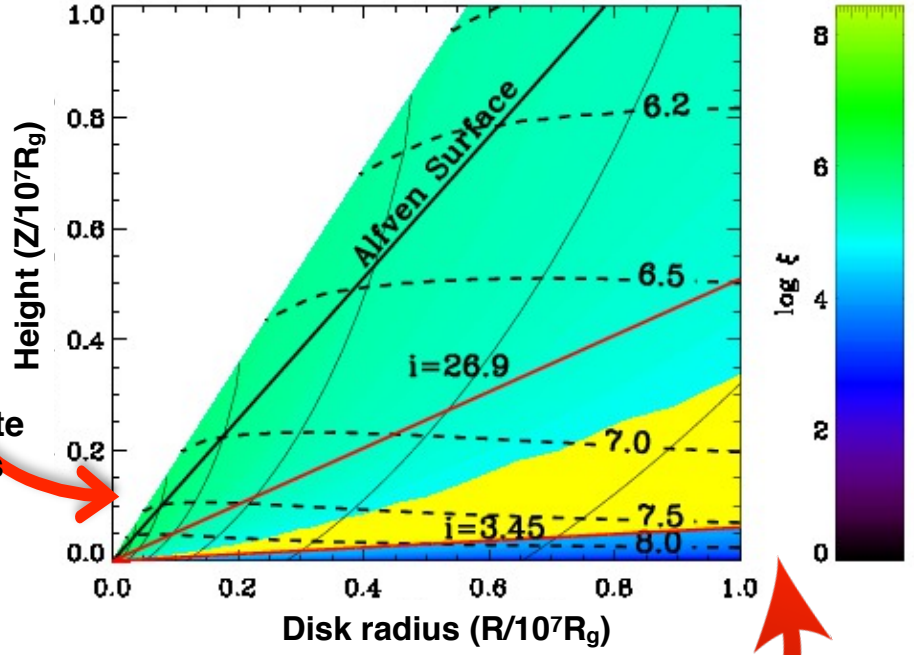

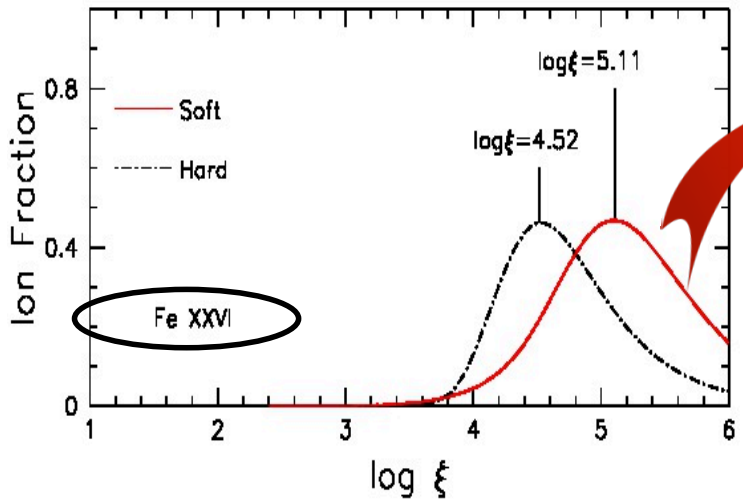

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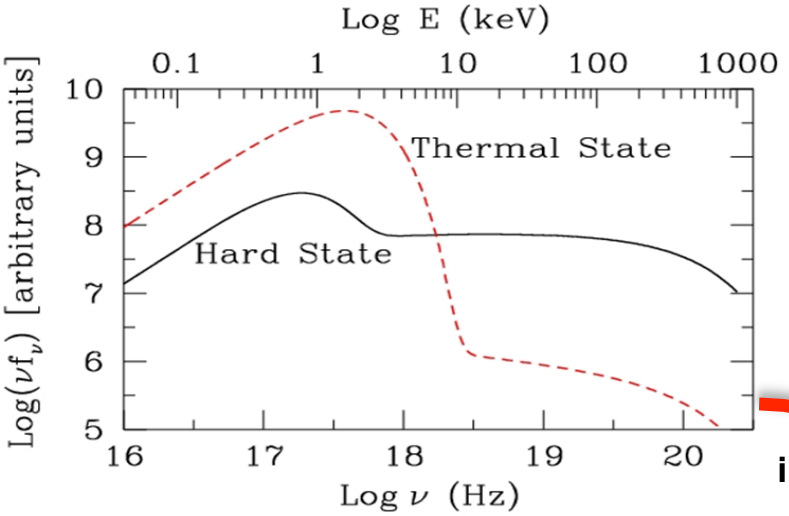

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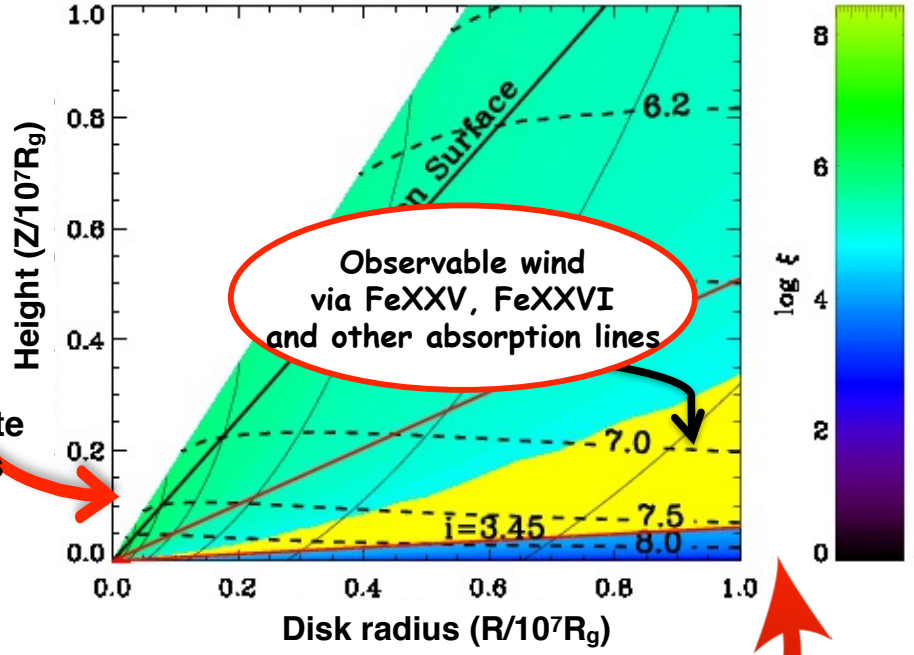

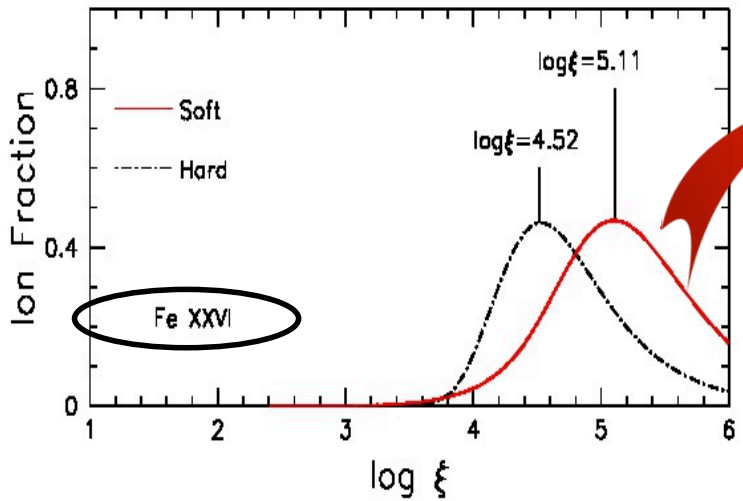

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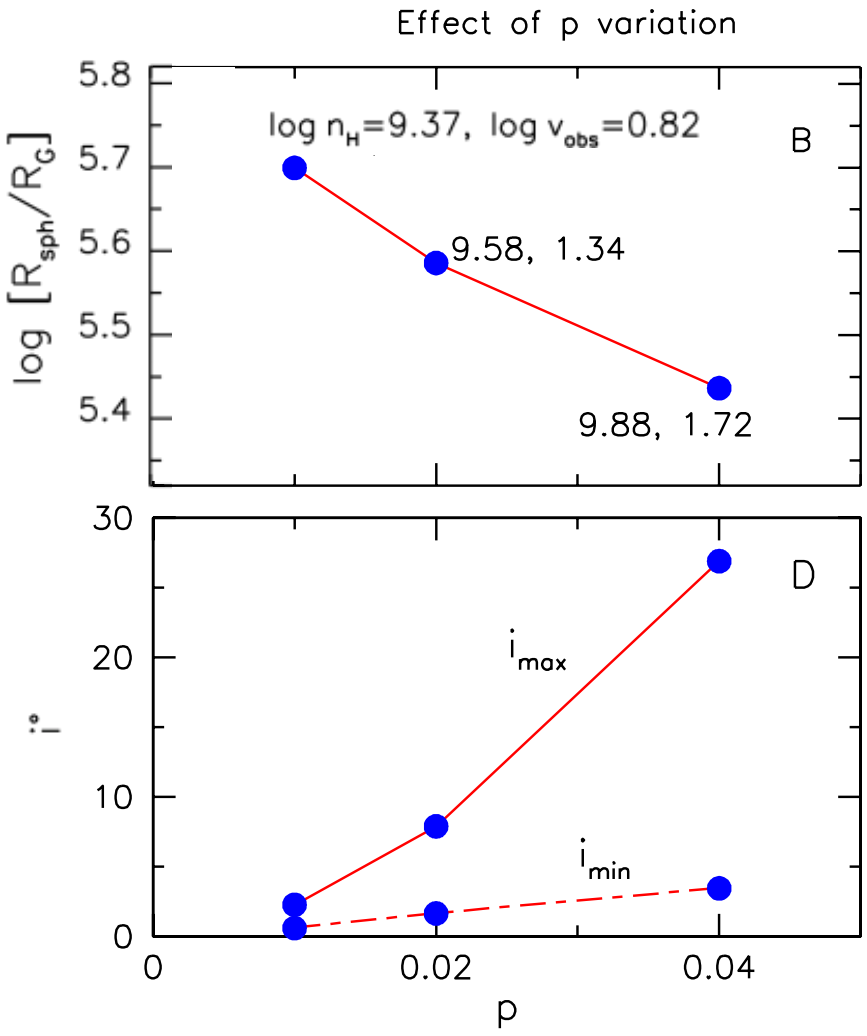
« Cold » Solutions (small p) Do Not Work..



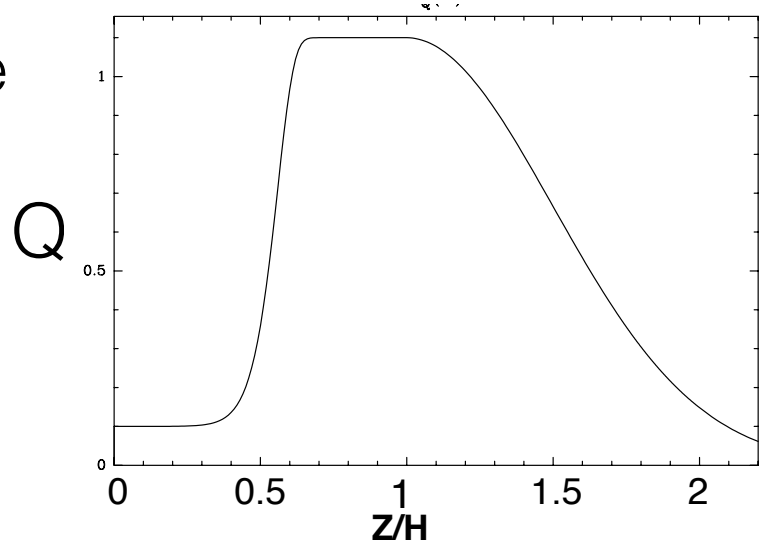
- In « cold » solutions the wind is just too far away, the density and velocity are too low.
- The angles of Line of Sight agree with Ponti et.al. (2012). Winds can be detected for low equatorial angles (high inclination angles.)
- The Hard SED, itself, does not make any significant difference from Soft SED!
  ➡ **the intrinsic flow has to be different to explain "winds in Soft state"**

Chakravorty et al. (2016)

« Warm » Solutions

A sort of thermal-magnetical solution

- Heating source at the disk surface (Casse & Ferreira 2000)



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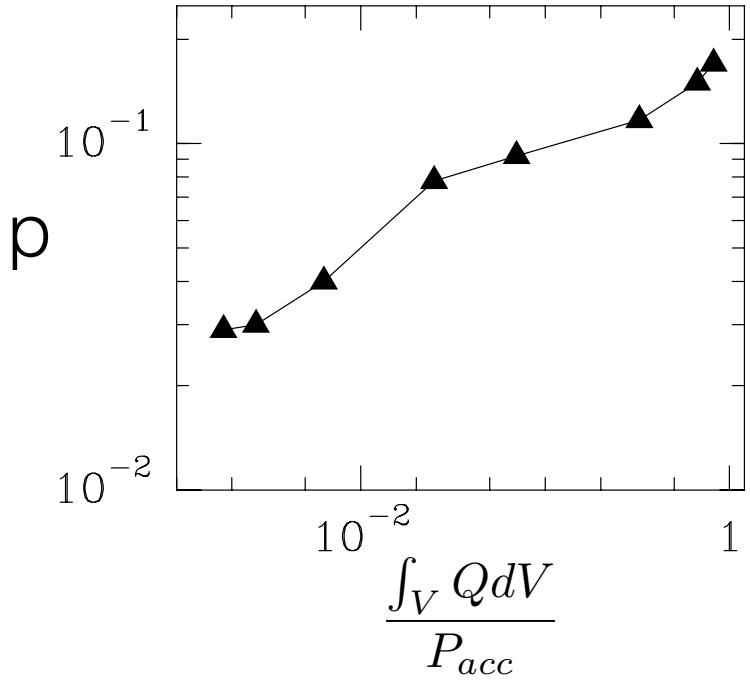
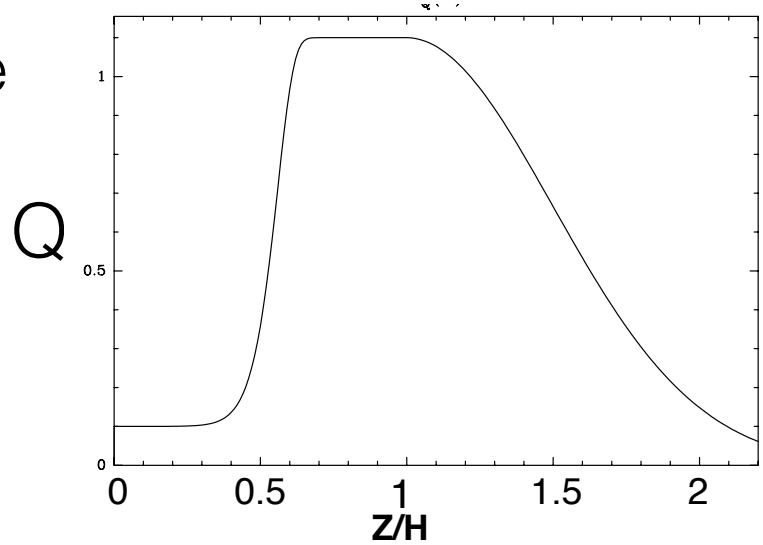
A sort of thermal-magnetical solution

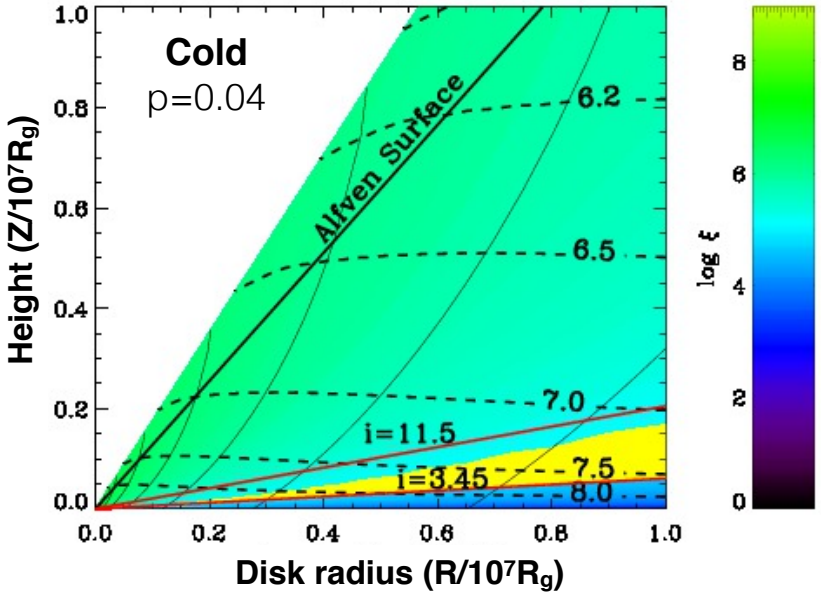
- Heating source at the disk surface (Casse & Ferreira 2000)

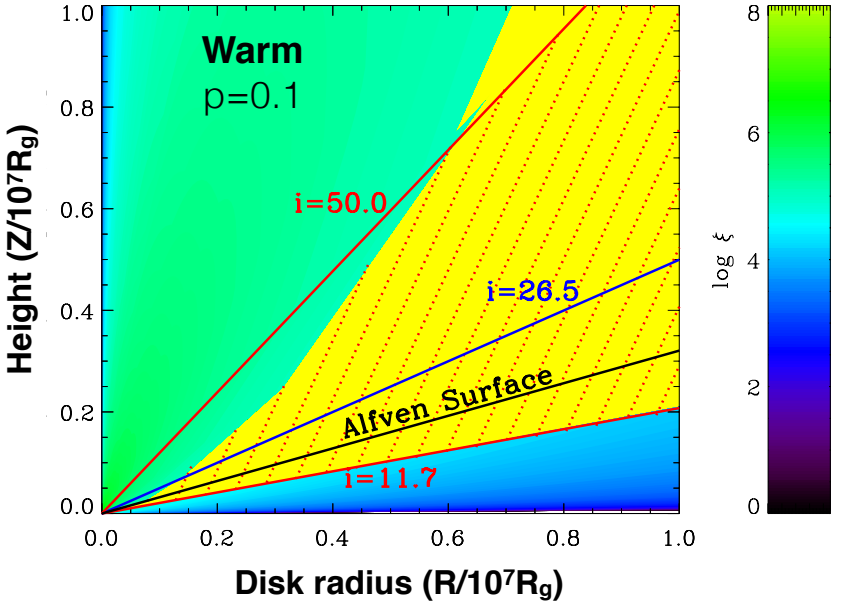
- Increase of the ejection efficiency

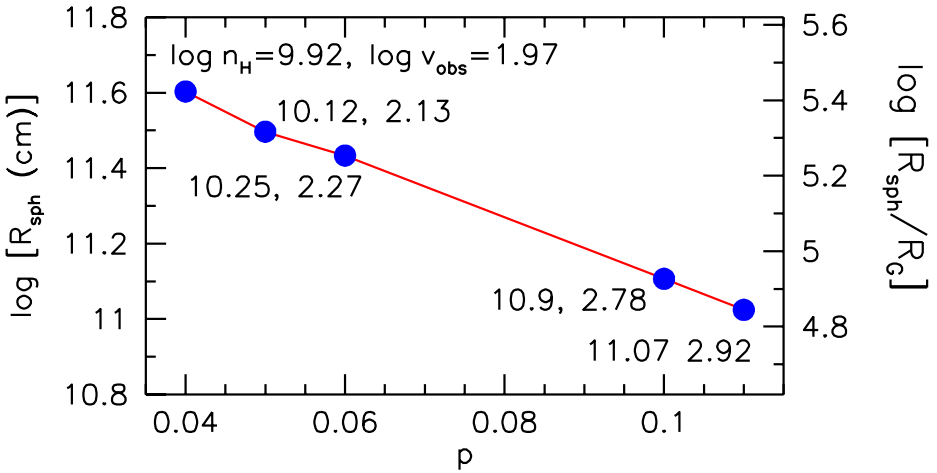




« Warm » Solutions Do the Job







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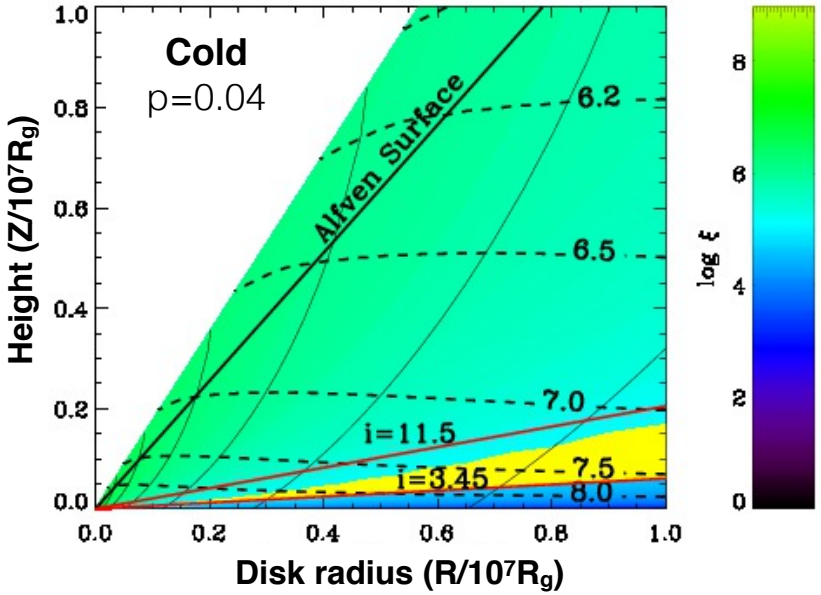
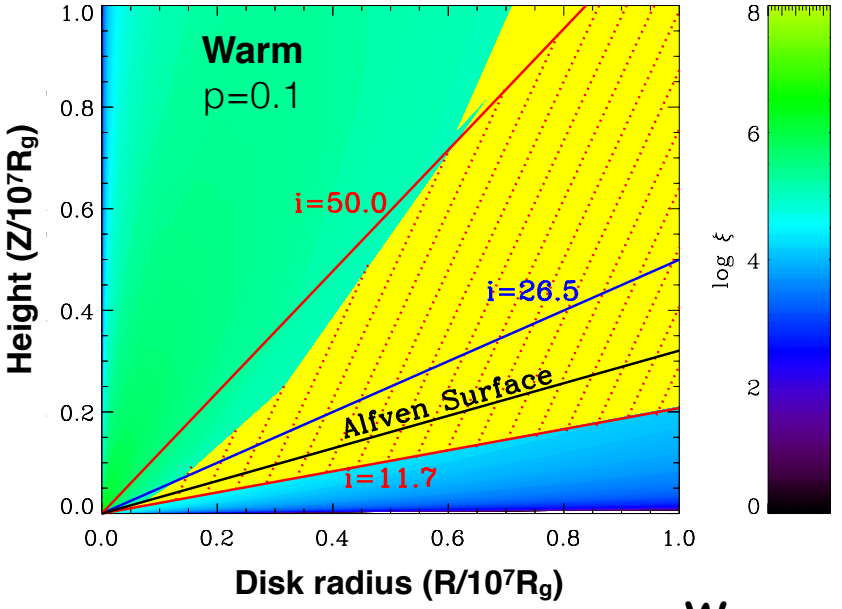


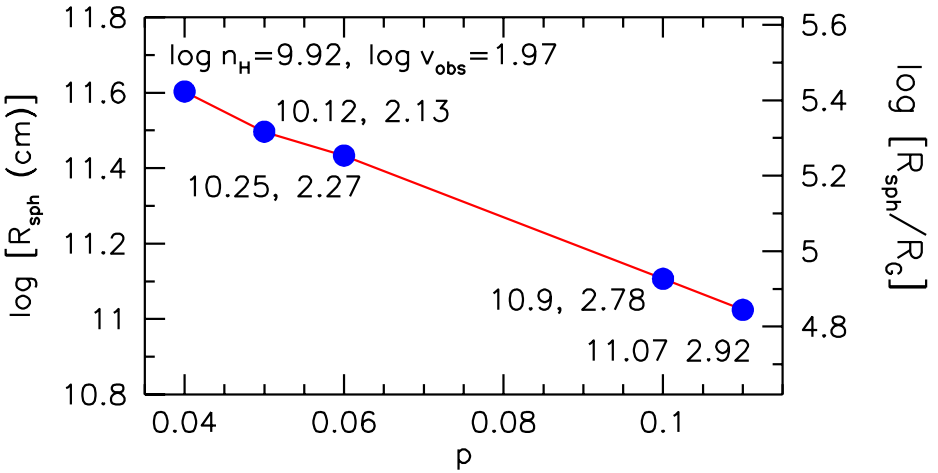


Cold

Purely magnetic acceleration

Does not work

The wind is too far away
Density too low
Velocity too low



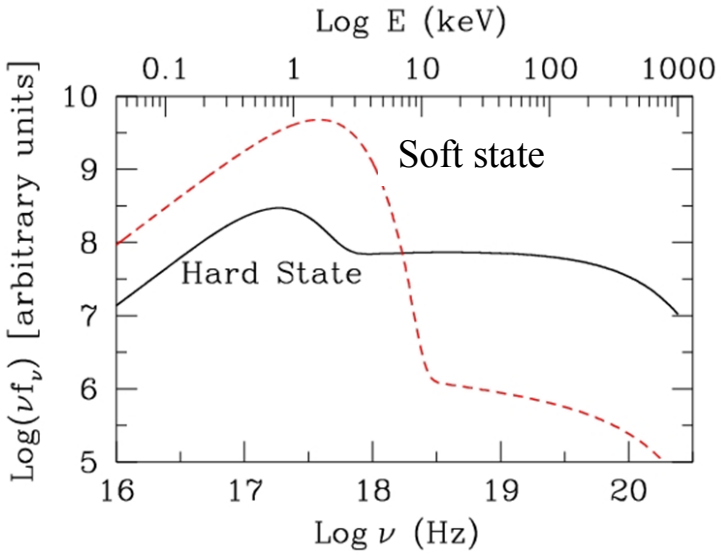
Warm

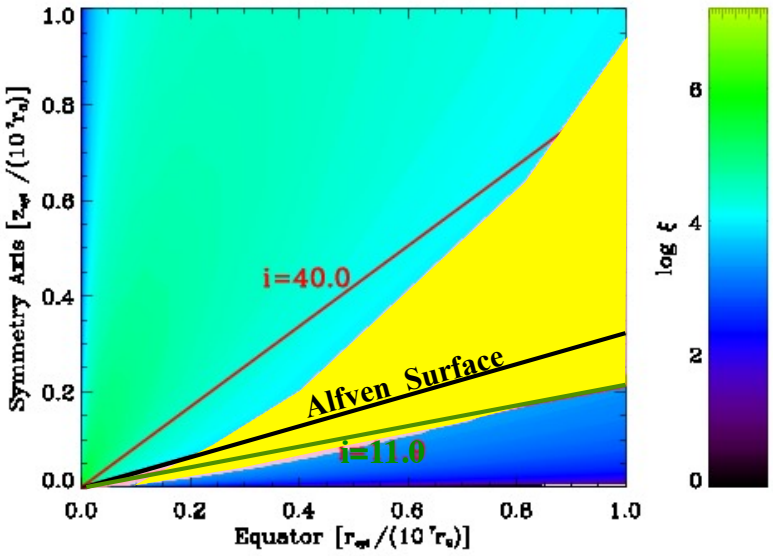
Disk surface is heated. Hence more material is lifted off the disk
Magnetic acceleration follows

Works for "average" winds

Density < 10^{12} cm^{-3},
Velocity 10^3 Km/s

Unstable Solutions in Hard States





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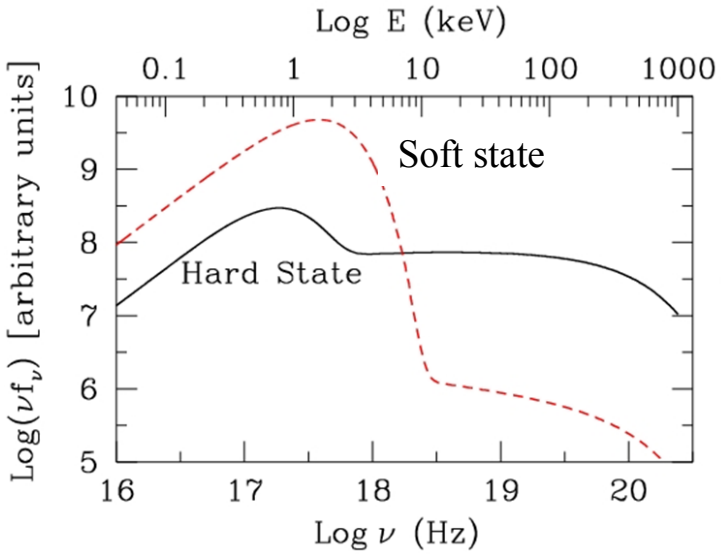
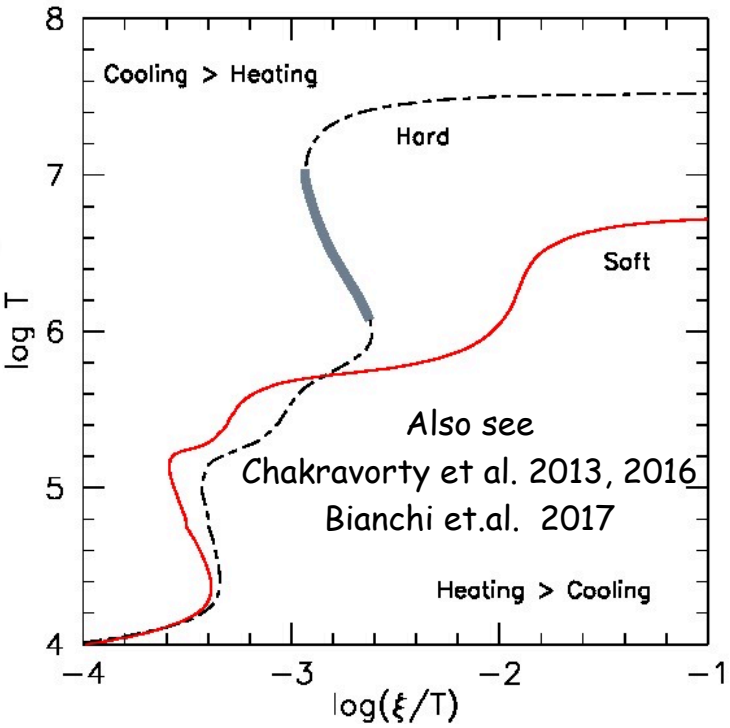
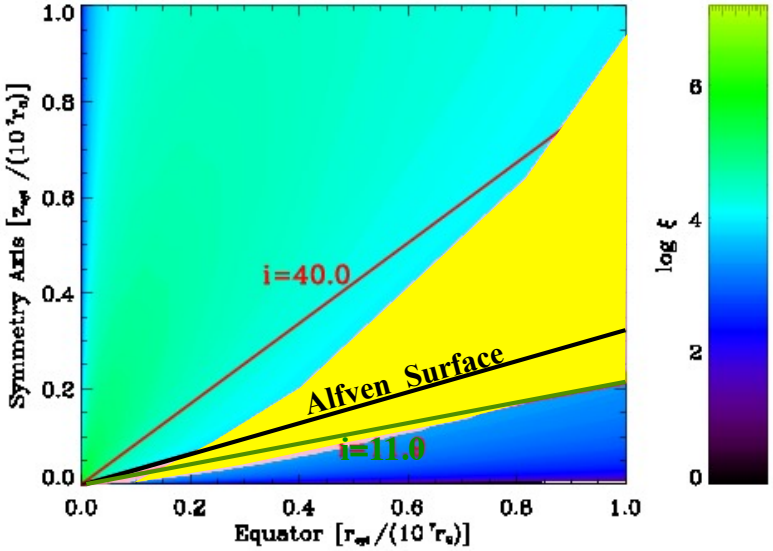


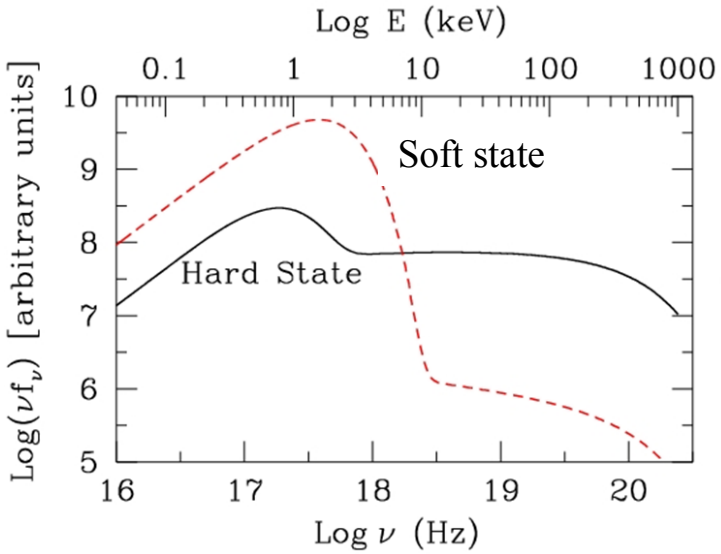
Work out Atomic Physics of the gas

CLOUDY



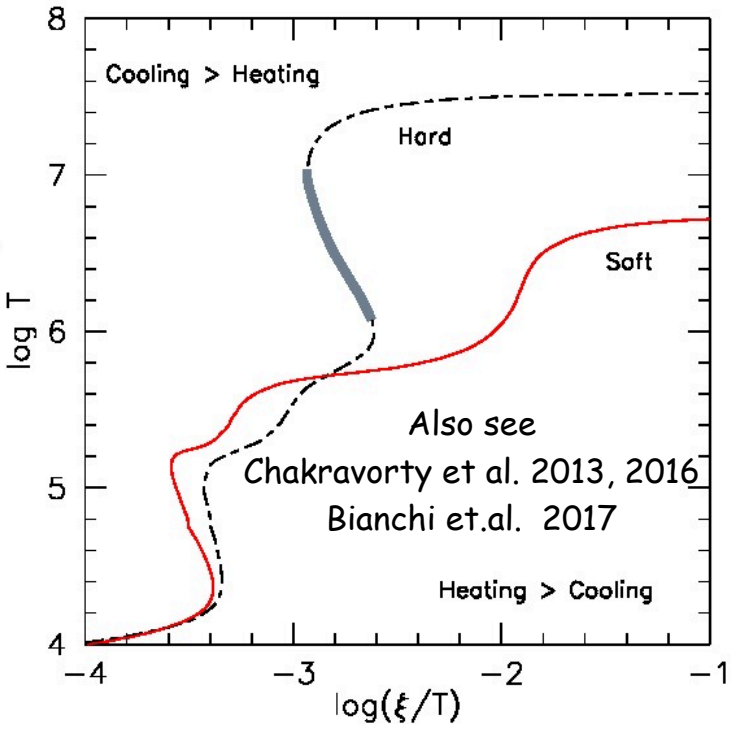


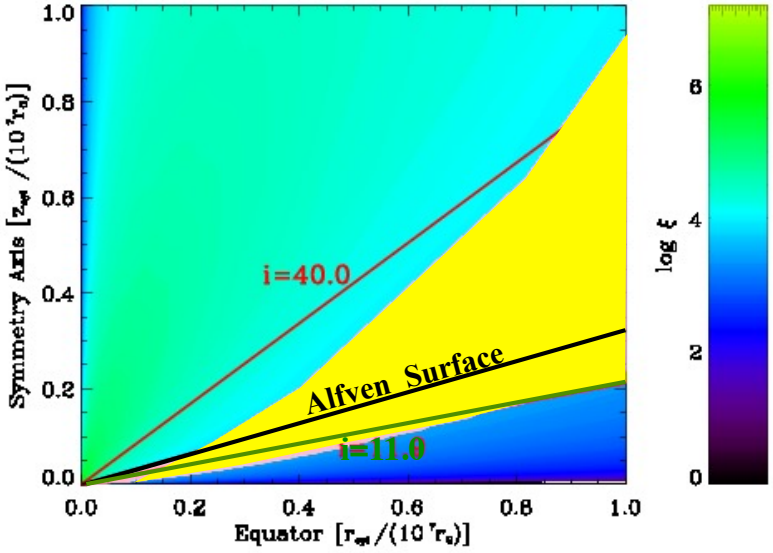
Unstable Solutions in Hard States

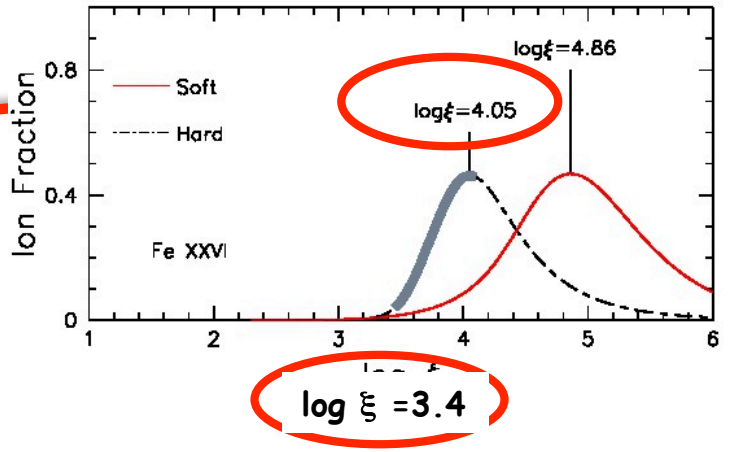


Work out Atomic Physics of the gas

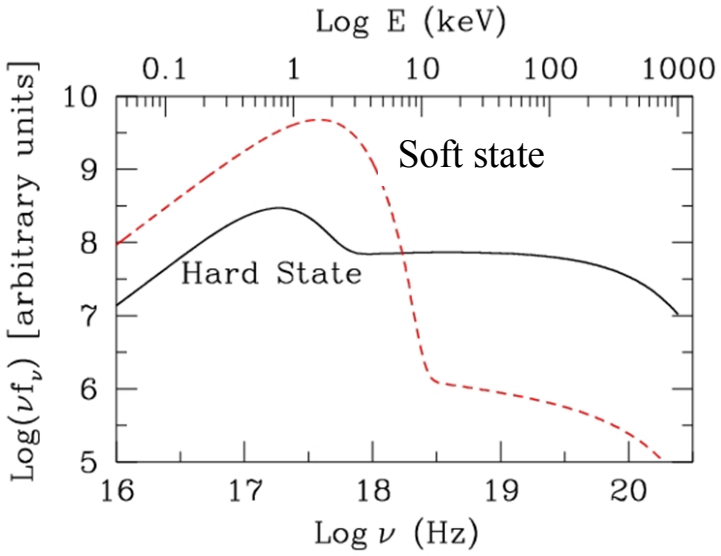
CLOUDY







Unstable Solutions in Hard States



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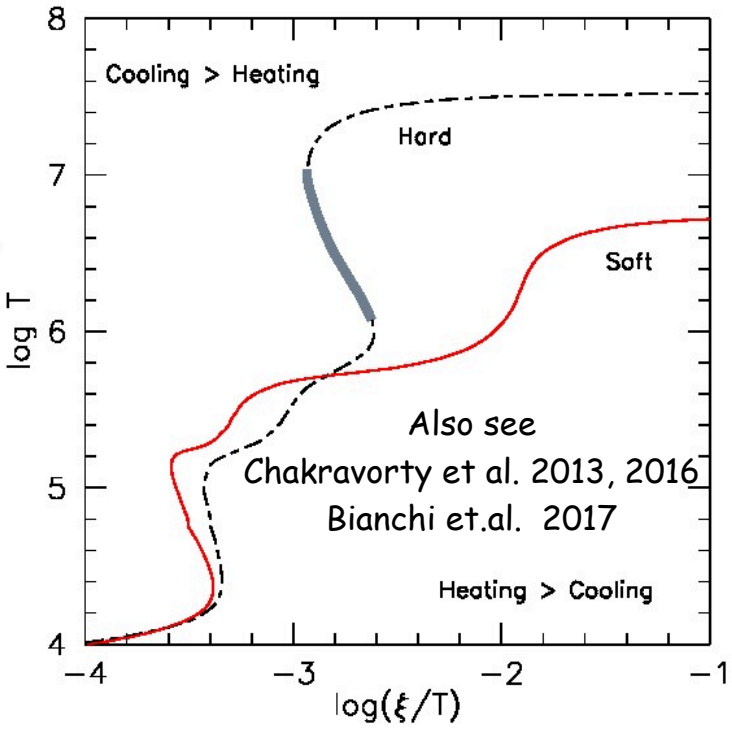
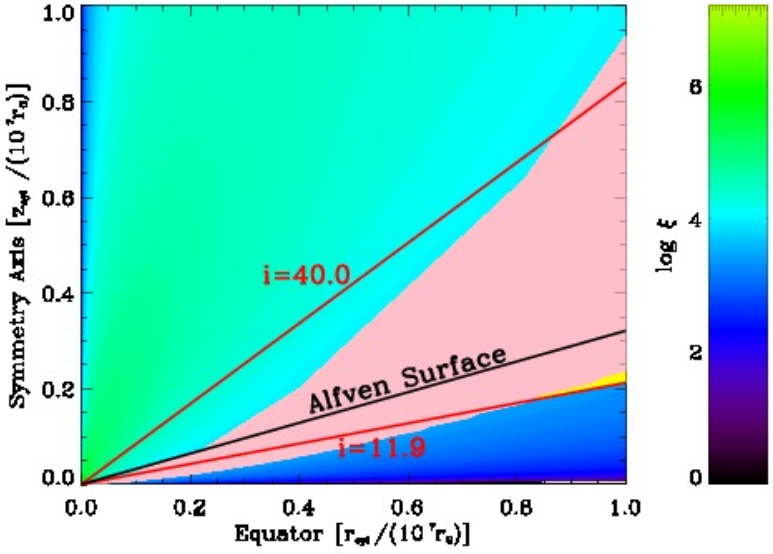
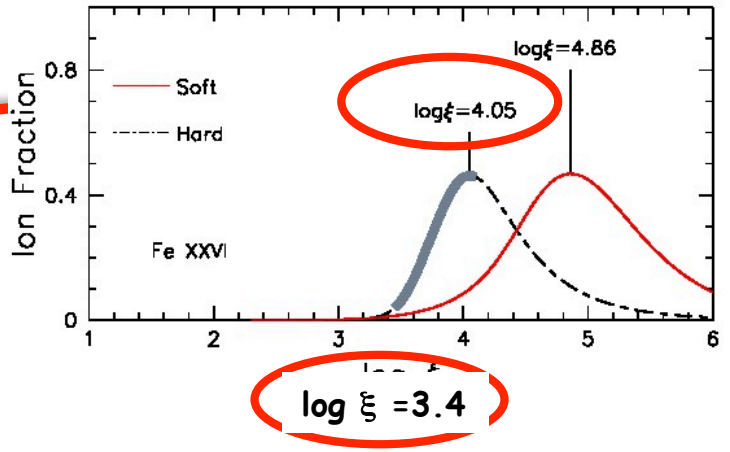


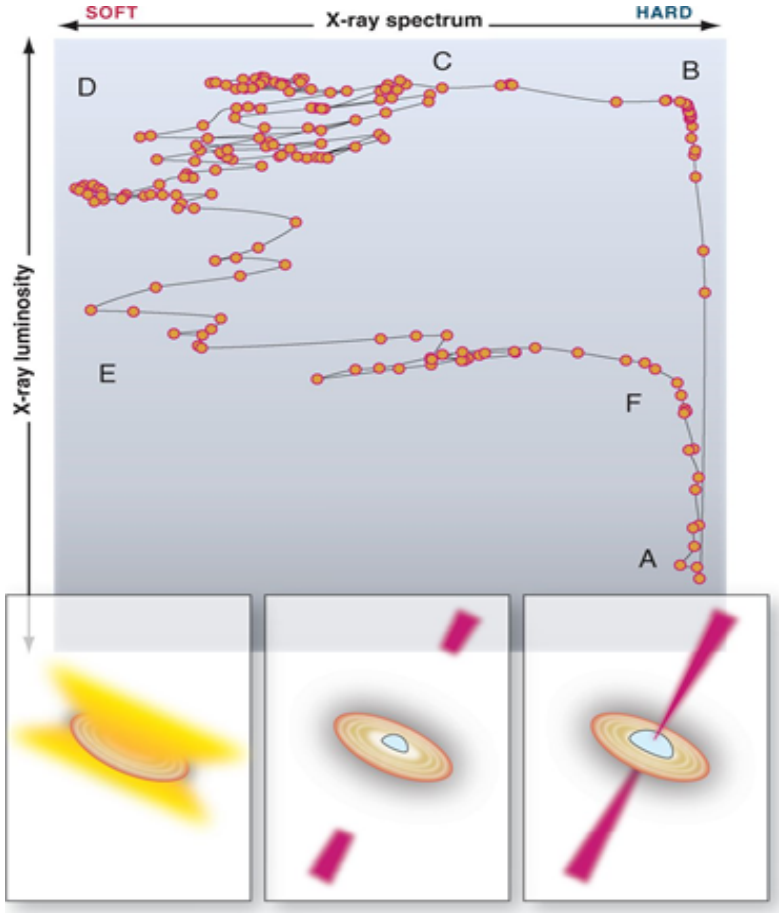




log ξ =3.4

Unstable Solutions in Hard States

Winds could be always present…



… but only observable in the Soft States

Unstable Solutions in Hard States

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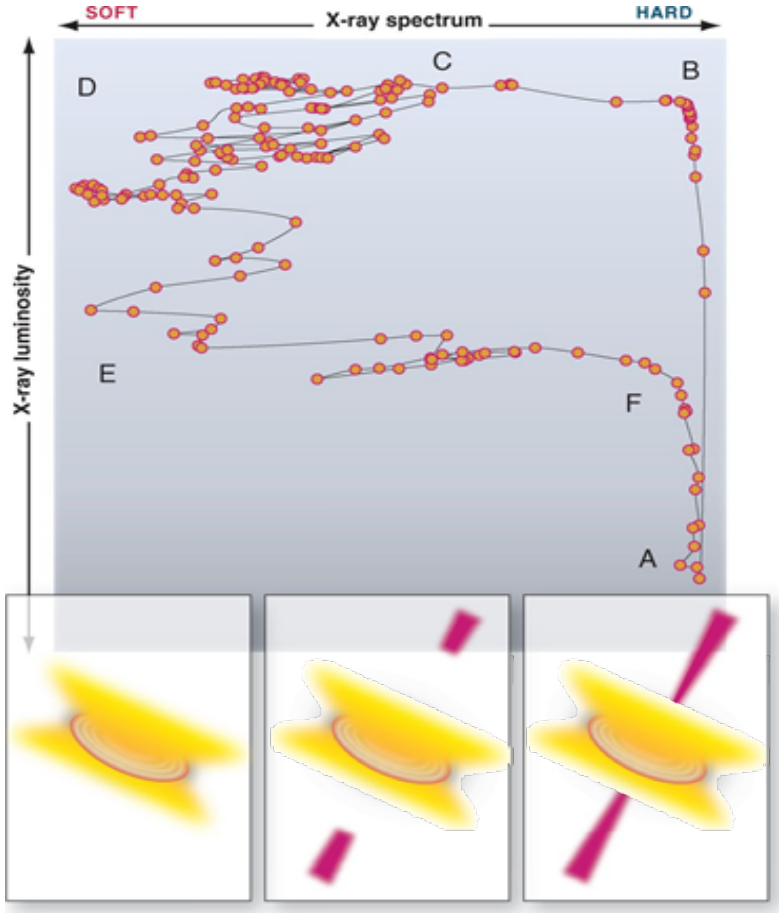
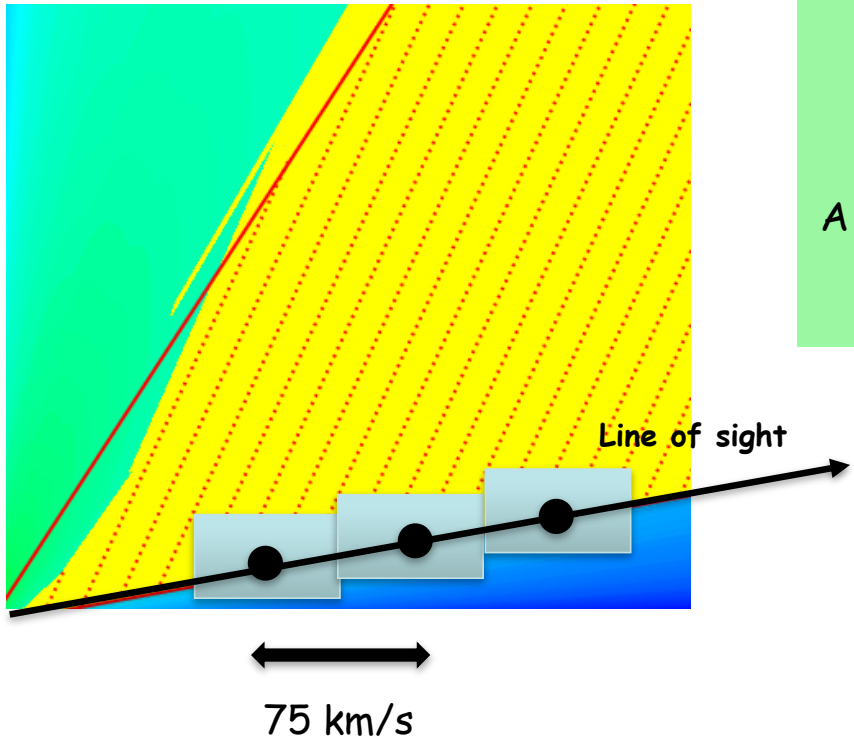


… but only observable in the Soft States

Simulated Spectra

Work in progress (Chakravorty et al. 2018 in prep.)

Absorption spectra in terms of MHD parameters (e.g. p) and i (inclination angle)



Note: We are keeping our methods generic

A code that can work for any outflow solution

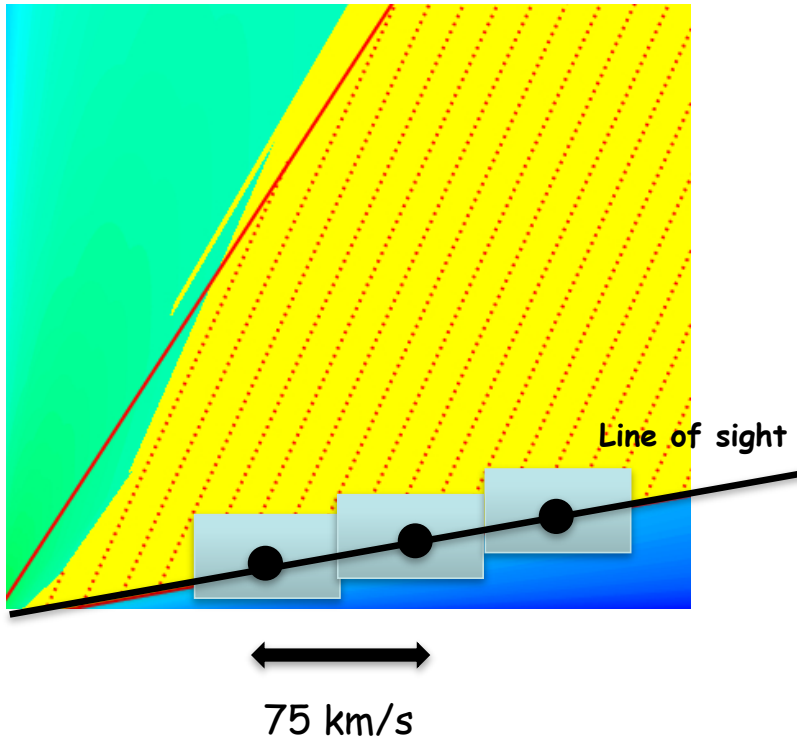
A velocity resolution that can take care of future missions – XARM, Athena at 6.5 keV ~ 300 km/s
The limit 75 km/s comes from the limits of CLOUDY

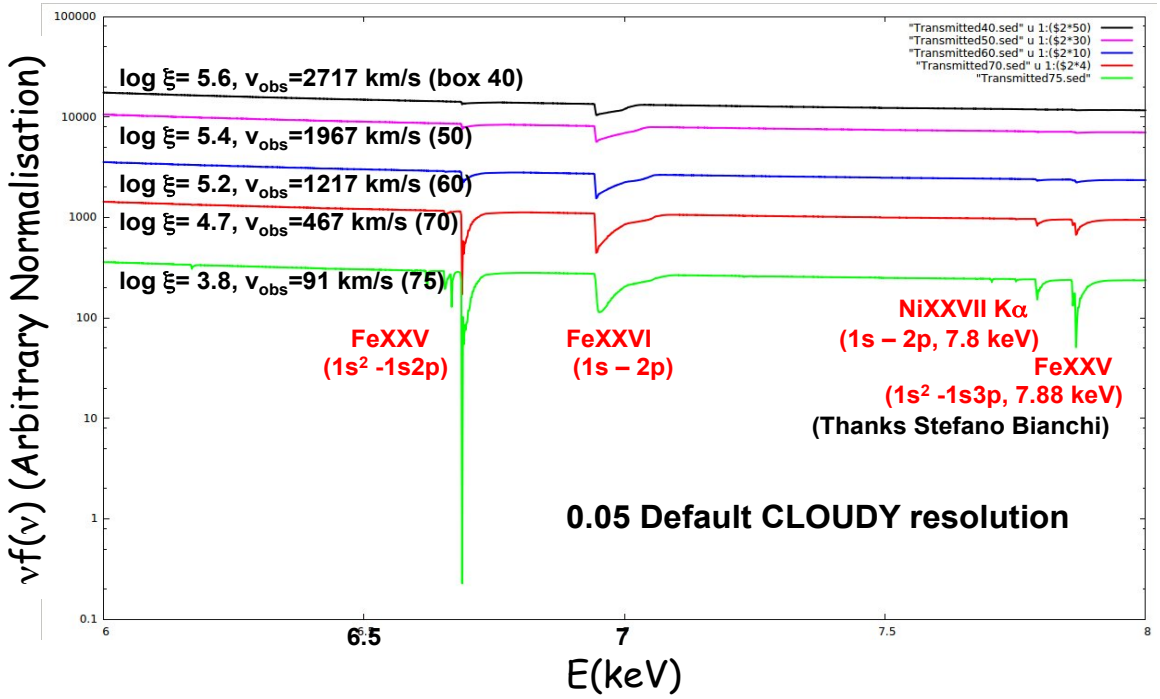
Simulated Spectra

Work in progress (Chakravorty et al. 2018 in prep.)

Absorption spectra in terms of MHD parameters (e.g. p) and i (inclination angle)

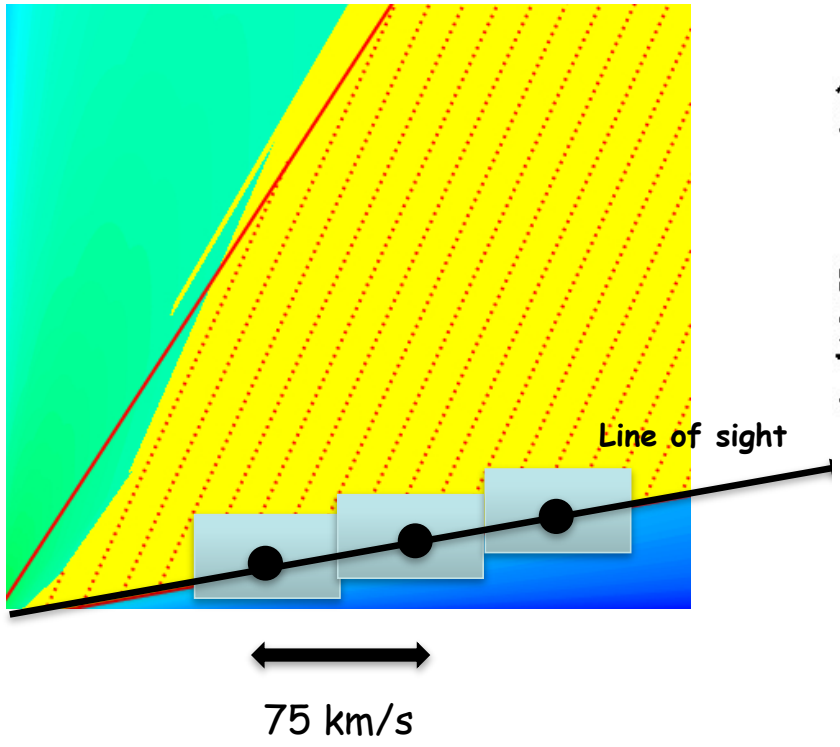
- p = 0.1 solution.
- 10 M_{sol} Black hole mass
- 0.1 Eddington accretion rate.

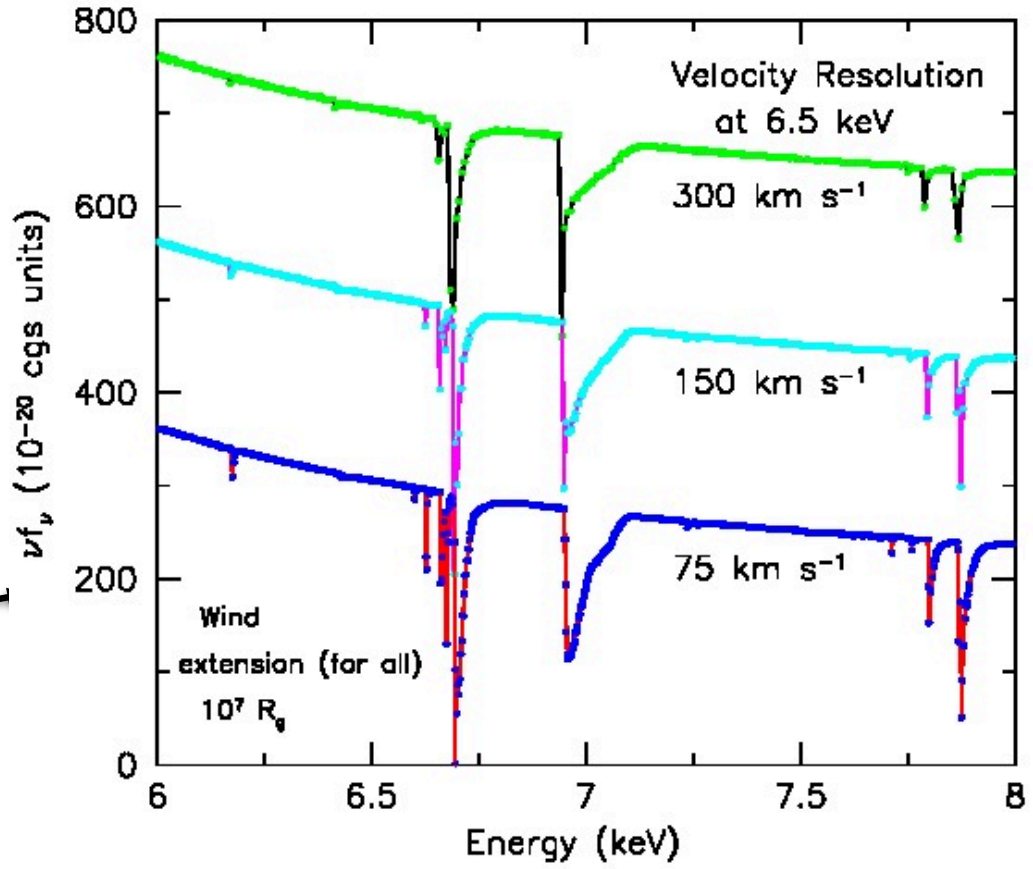




Simulated Spectra

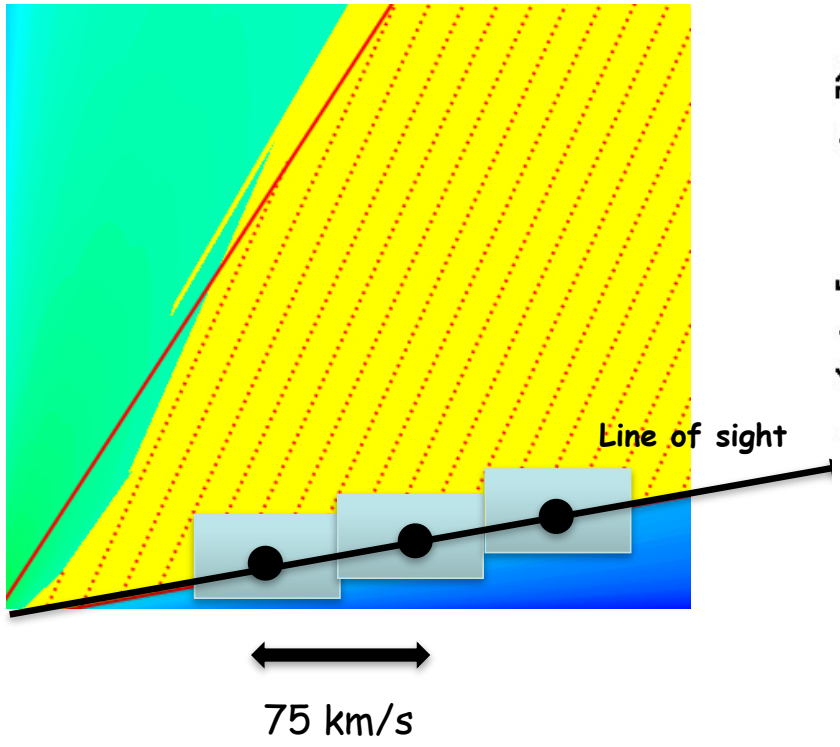
Effect of High Resolution

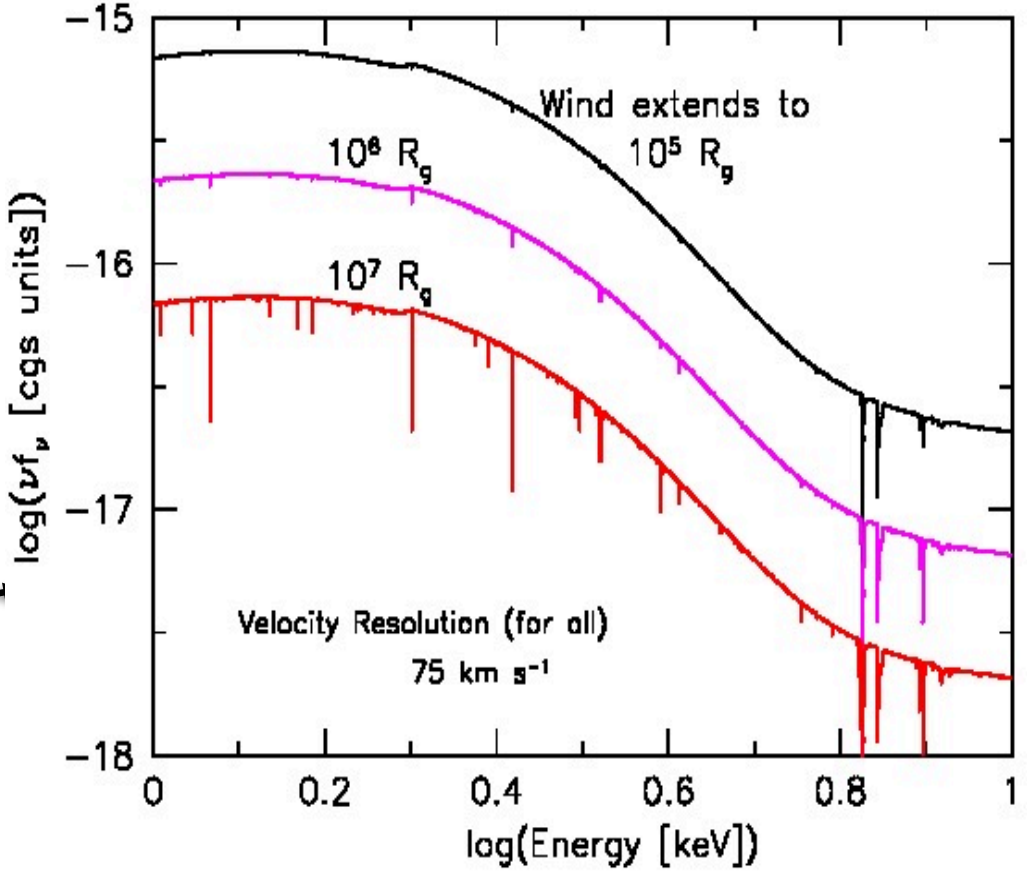




Simulated Spectra

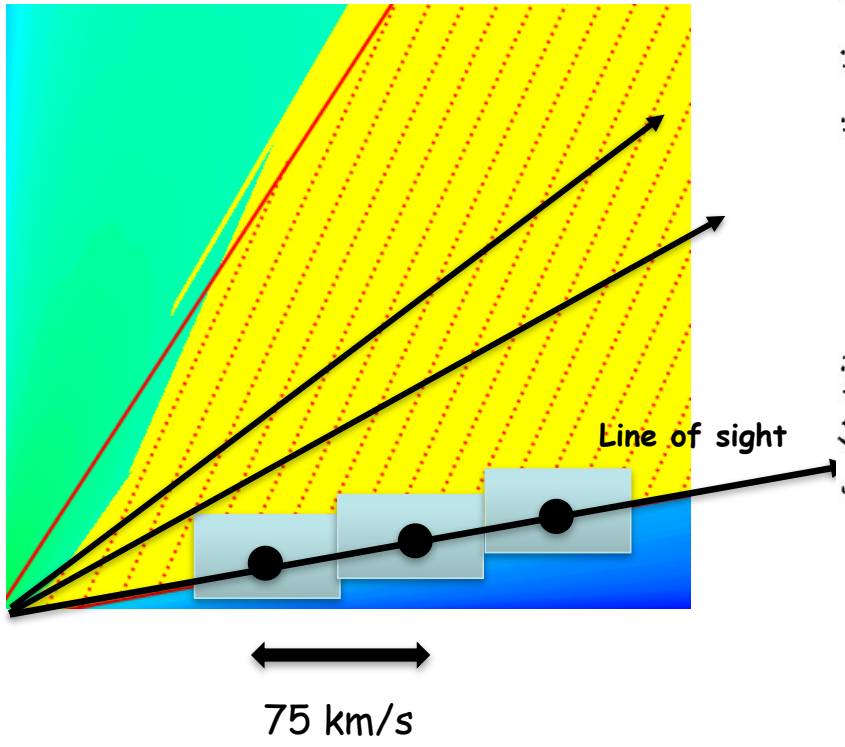
Effect of Disk Extension

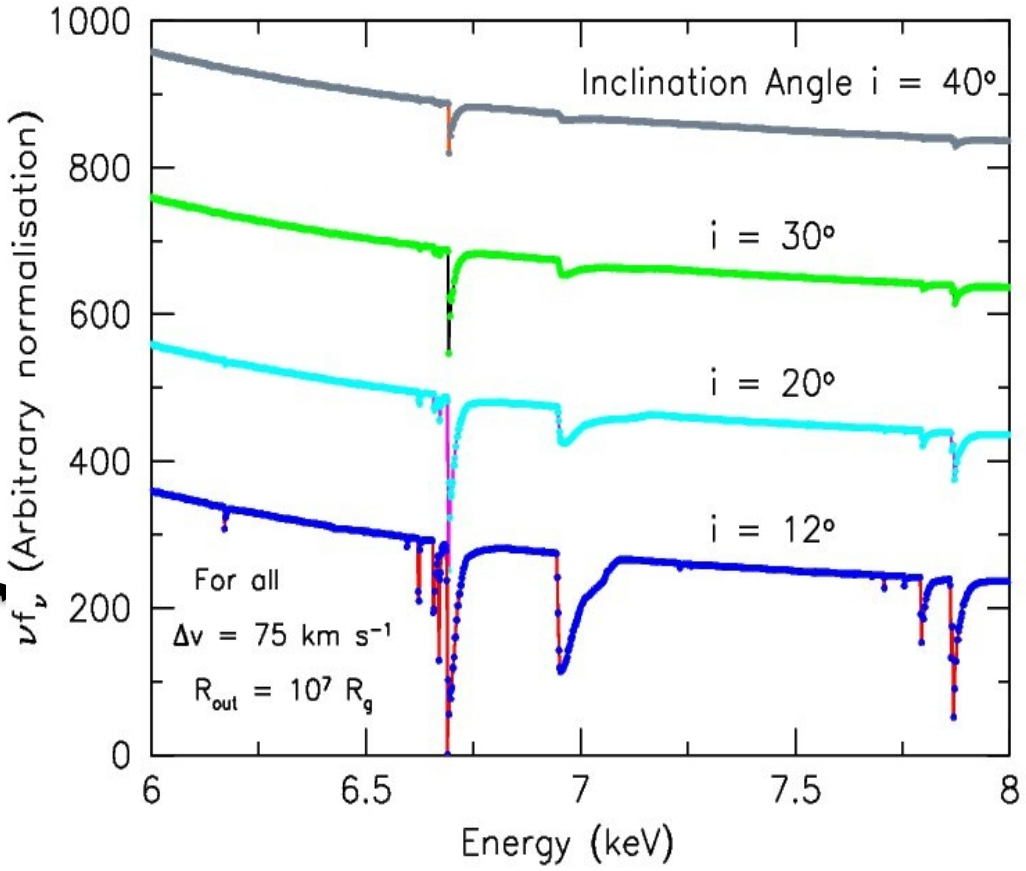




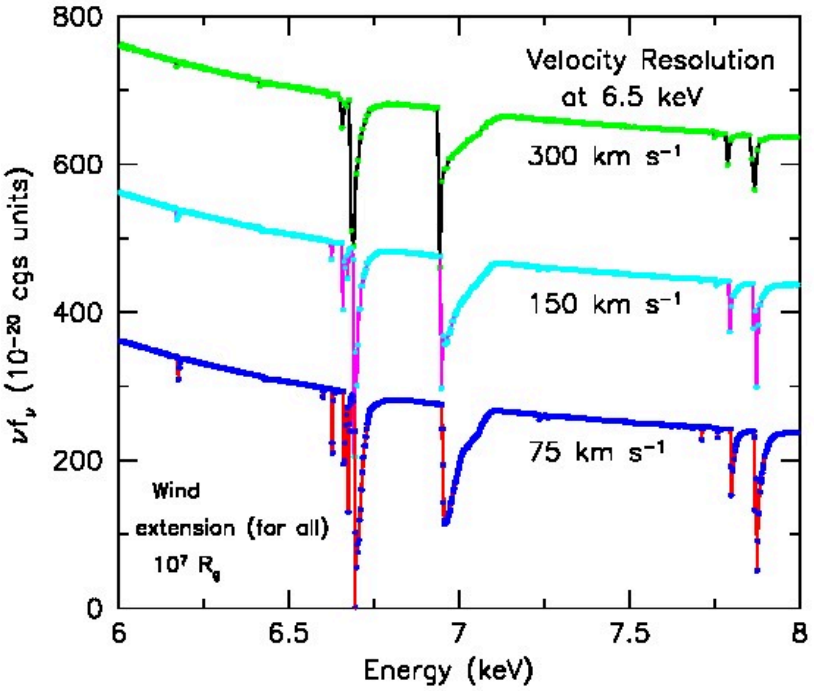
Simulated Spectra

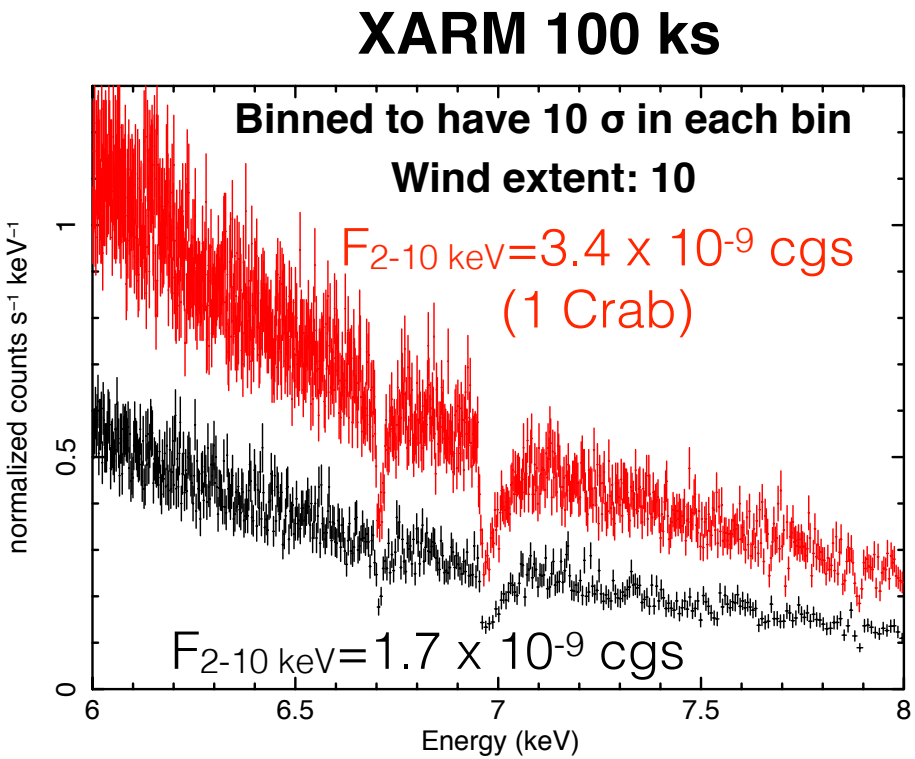
Effect of LOS angle





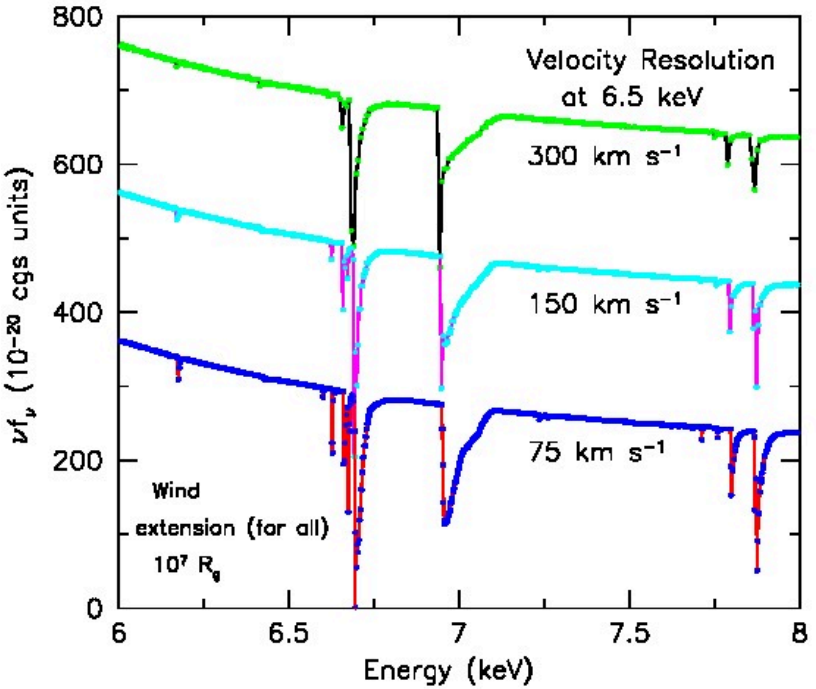
Simulated Observations



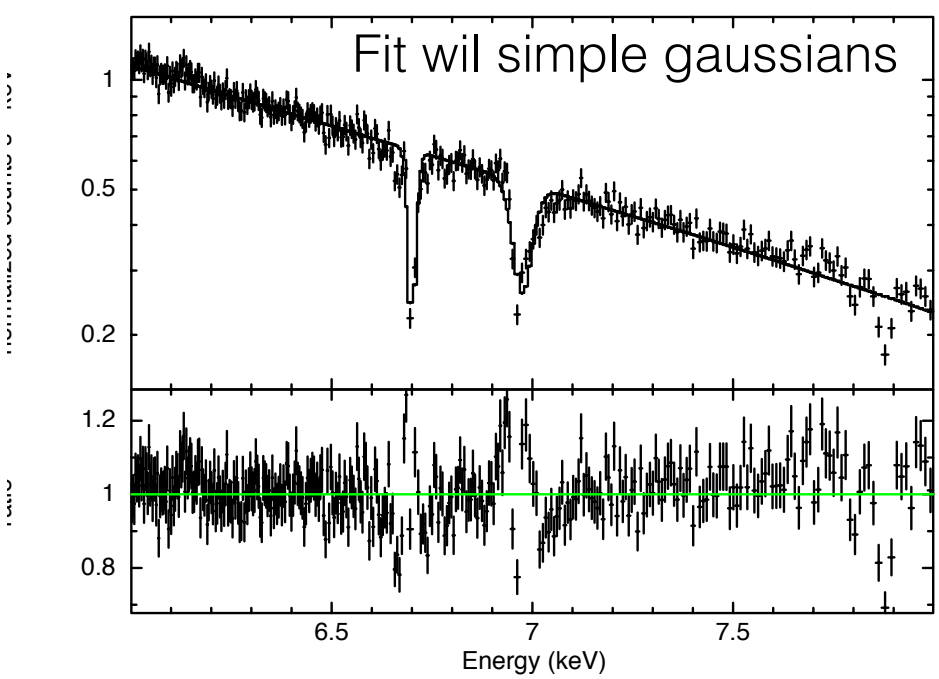


- Chandra will need at least 1000 ks to detect these lines
- Athena will have a resolution twice better and effective area 7 times larger

Simulated Observations



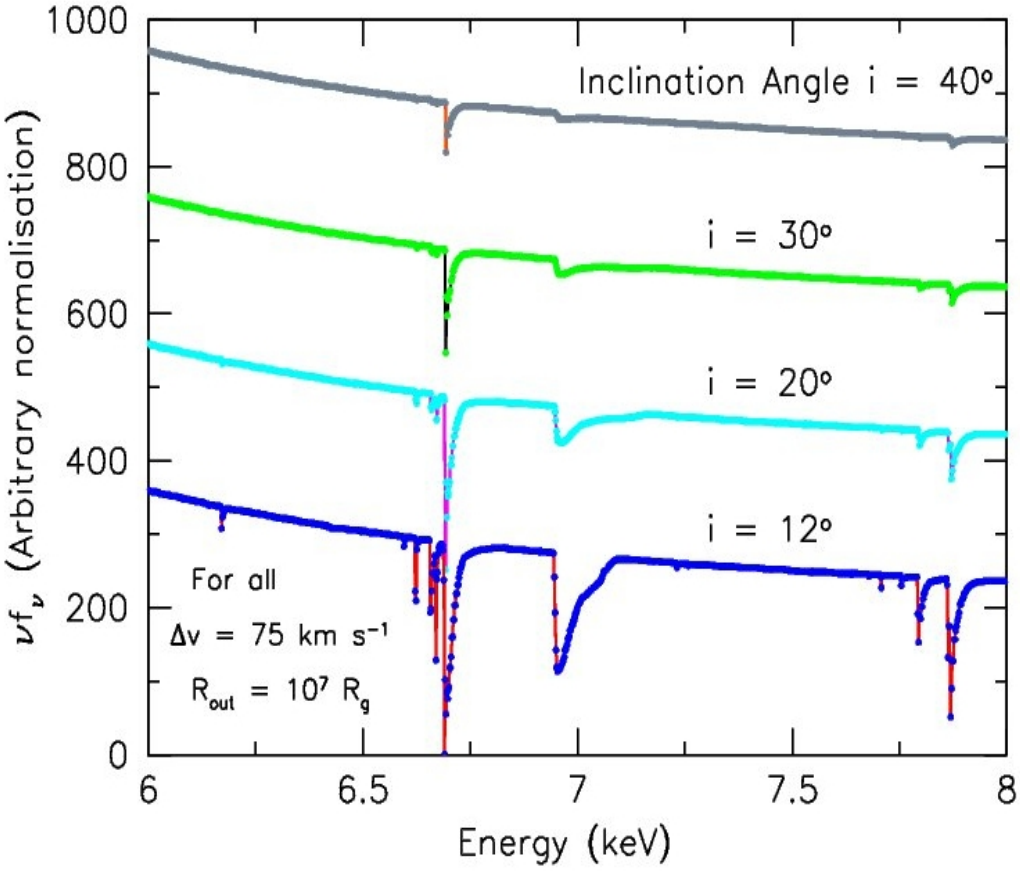
XARM 100 ks

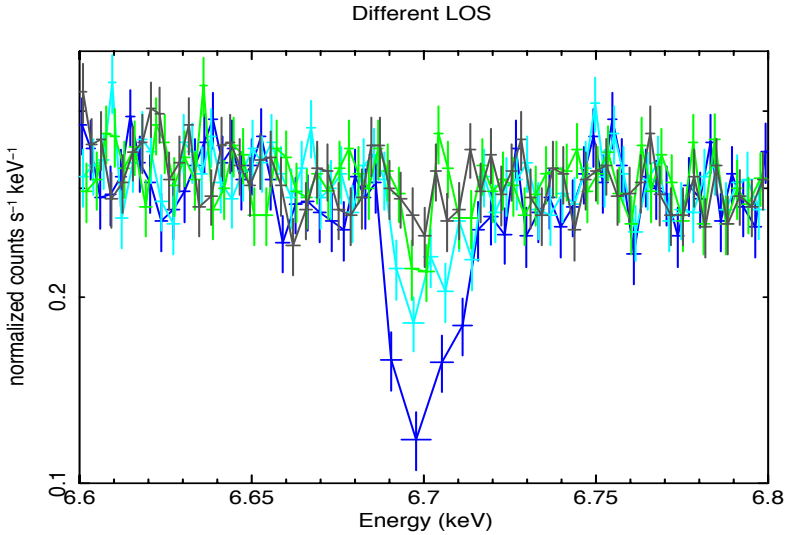


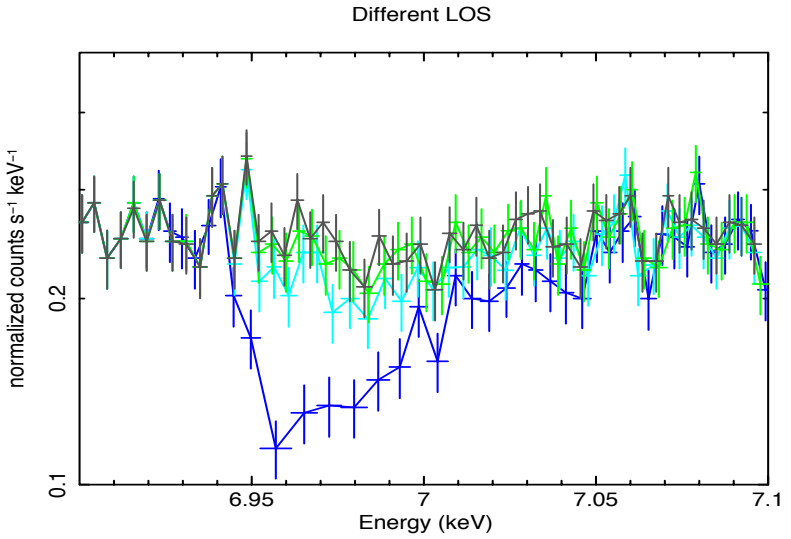
- Line asymmetries are clearly detectable
- NiXXVII Kα, FeXXV ($1s^2$-1s3p, 7.88keV) detectable

Simulated Observations

Sensitivity on LOS

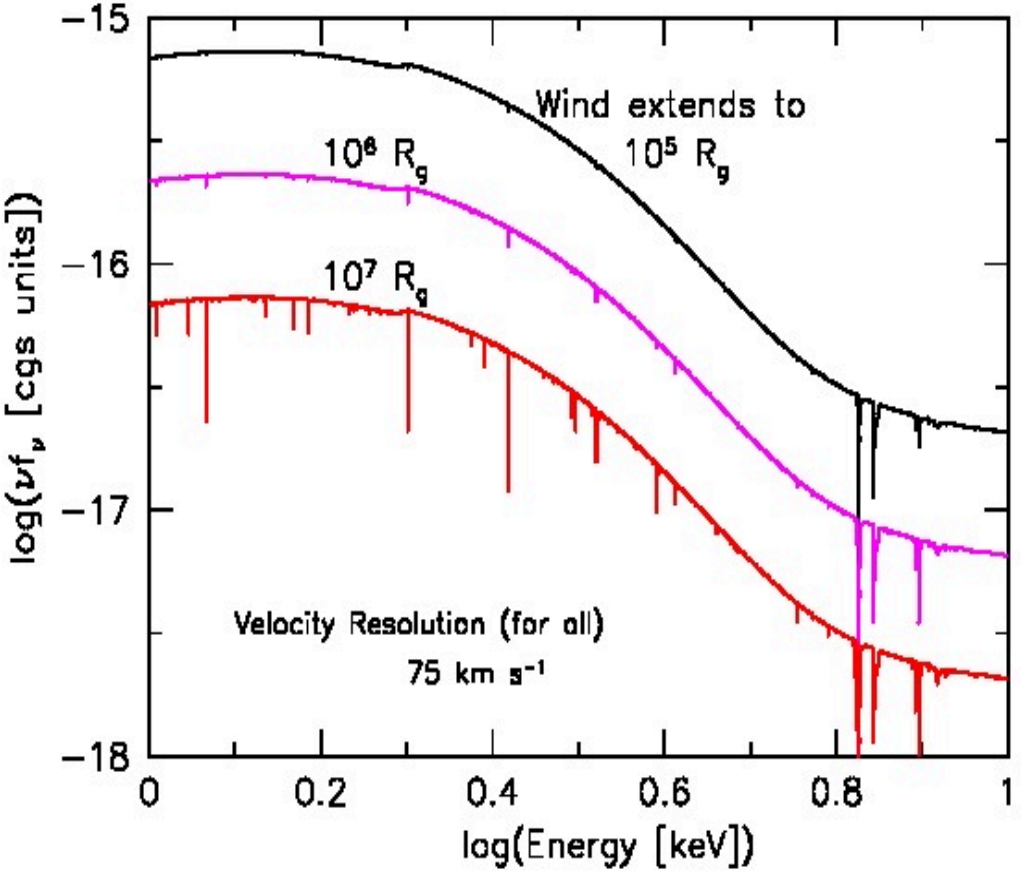


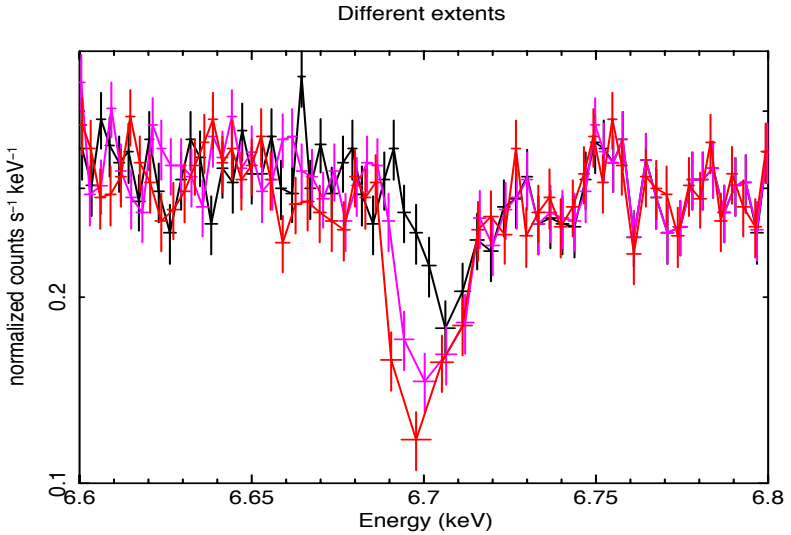


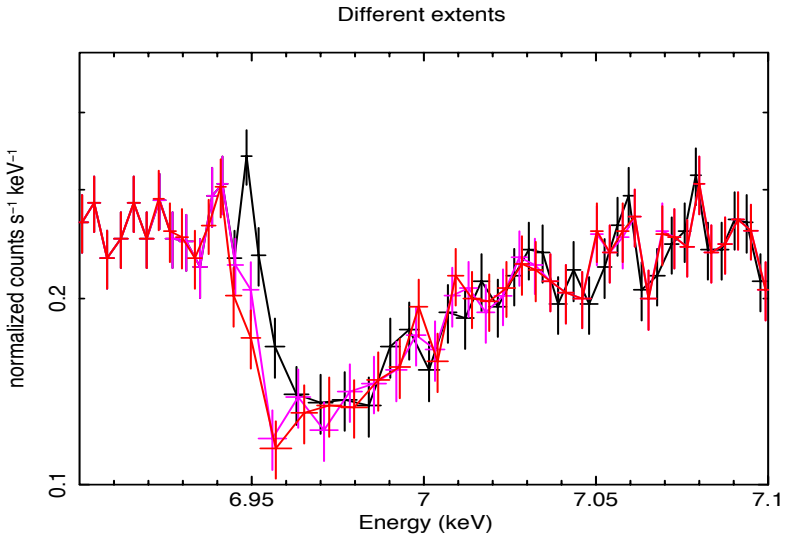


Simulated Observations

Sensitivity on Wind Extent







Conclusions

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 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

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Work in progress
Chakravorty+ 18 (to be submitted soon!)

Absorption spectra in terms of MHD parameters (e.g. p) and i (inclination angle)

We have checked what they predict
We have **not** dealt with emission lines!

Future
For our MHD solutions, table models for xspec?

Our methods are generic – applicable to any solutions.