IPAG
Institut de Planétologie et d'Astrophysique de Grenoble

# Suzaku Observations of GX 339-4 during its soft-to-hard state transition

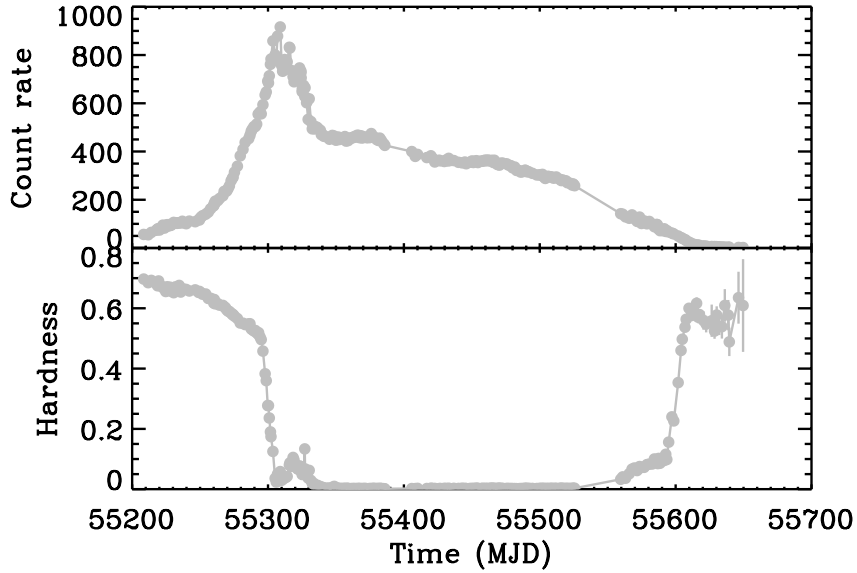
P.O. Petrucci

Coll.: C. Cabanac, S. Corbel, E. Koerding, R. Fender

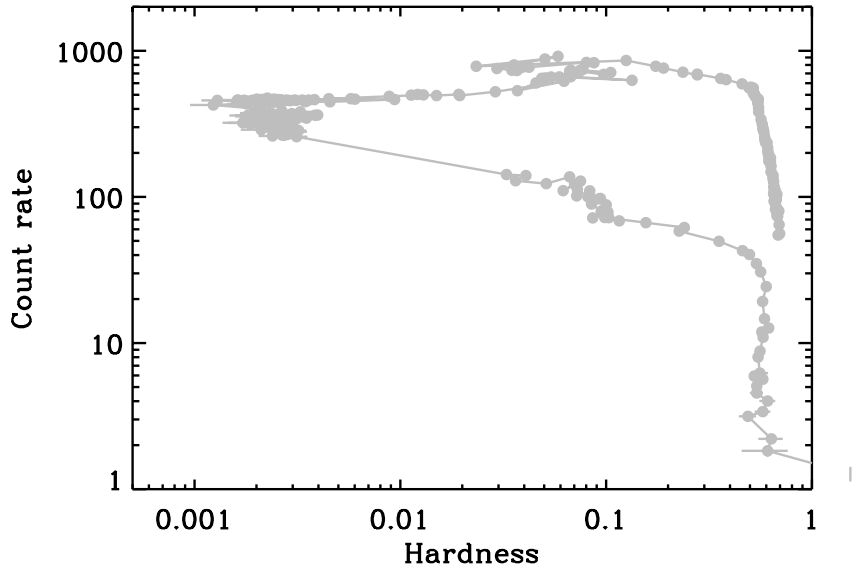
# GX 339-4 2010-2011 Outburst

IPAG
Institut de Planétologie et d'Astrophysique de Grenoble

## Light curve & Hardness

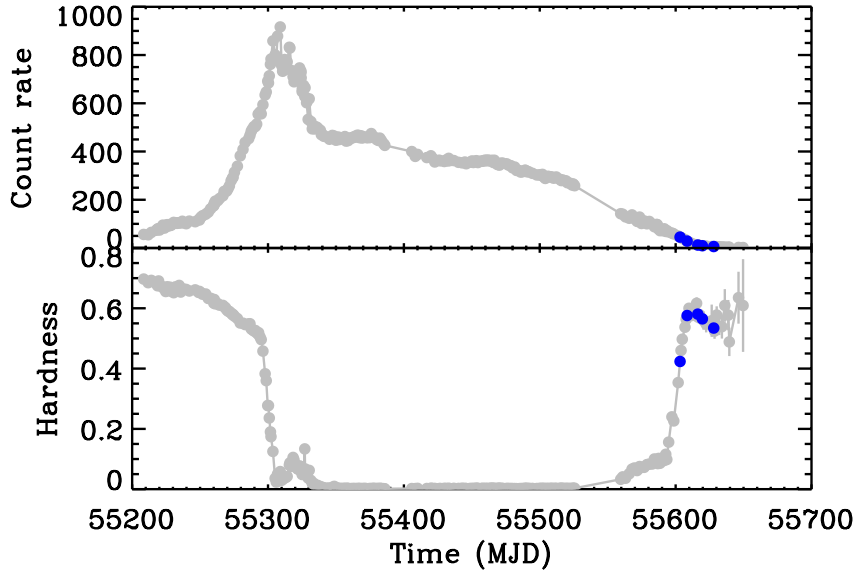



## Hardness-Intensity Diagram

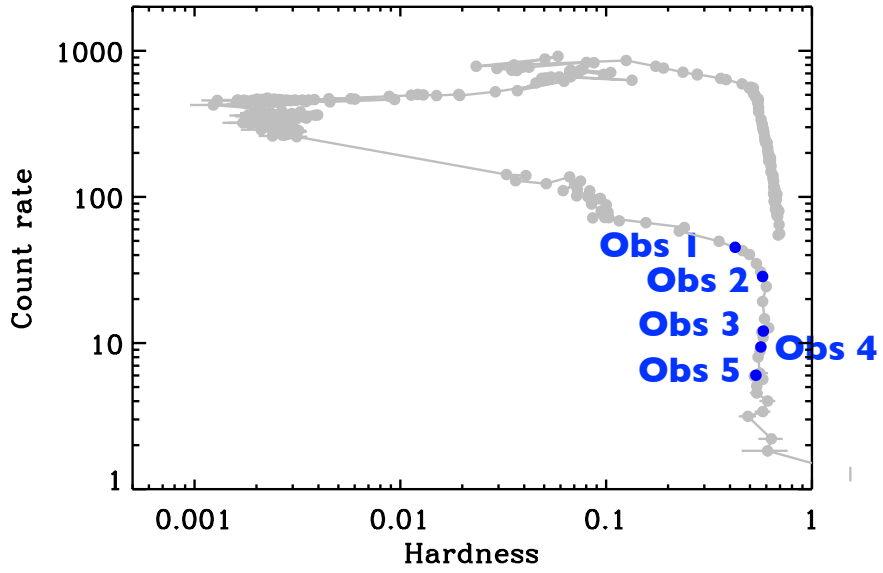


# The Suzaku Observations

## Light curve & Hardness



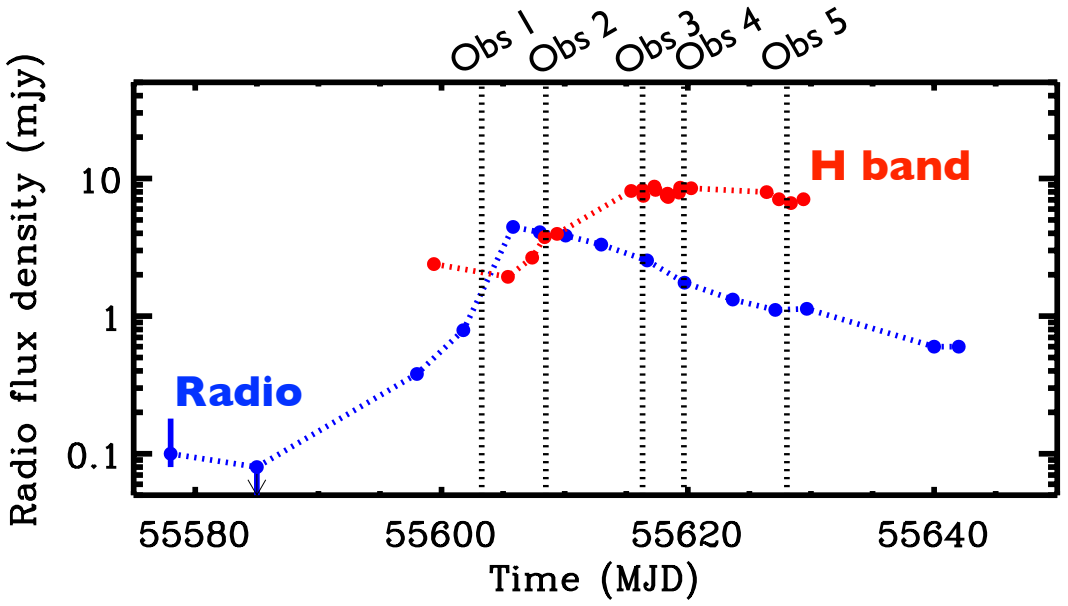

## Hardness-Intensity Diagram

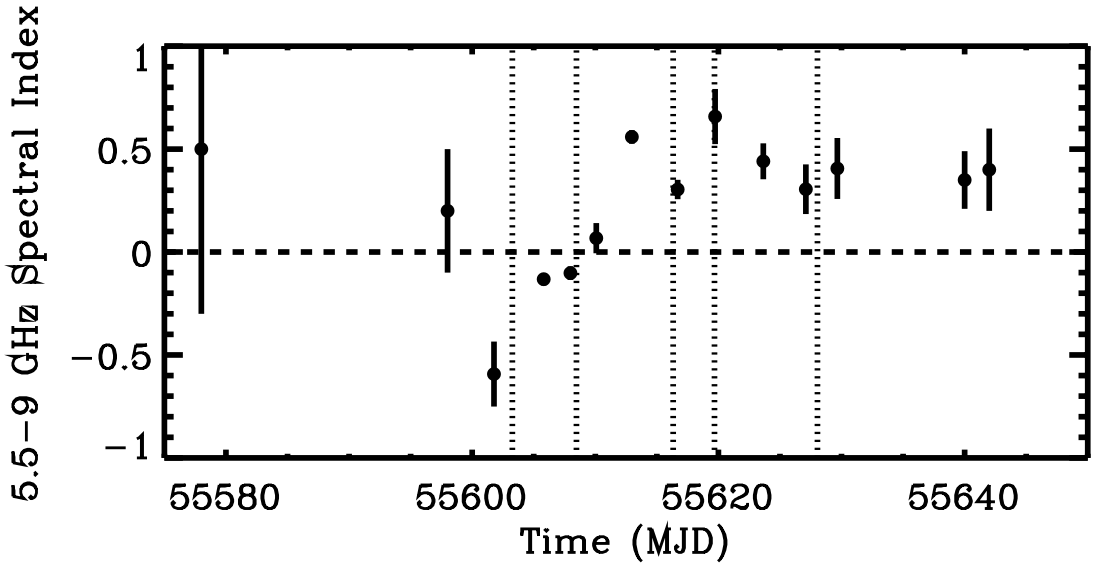



- **ToO** to catch an XrB during its path back to the hard state
- **Five** observations of 20 ks spaced by a few days to follow the disk recession
- Triggered as soon as GX 339-4 became observable by Suzaku (i.e. February-March 2011)

# Simultaneous Radio/IR Emission

- Radio observations (ATCA, Corbel et al. 2012).
- OIR observations (SMARTS, Buxton et al. 2012, Dincer et al. 2012)



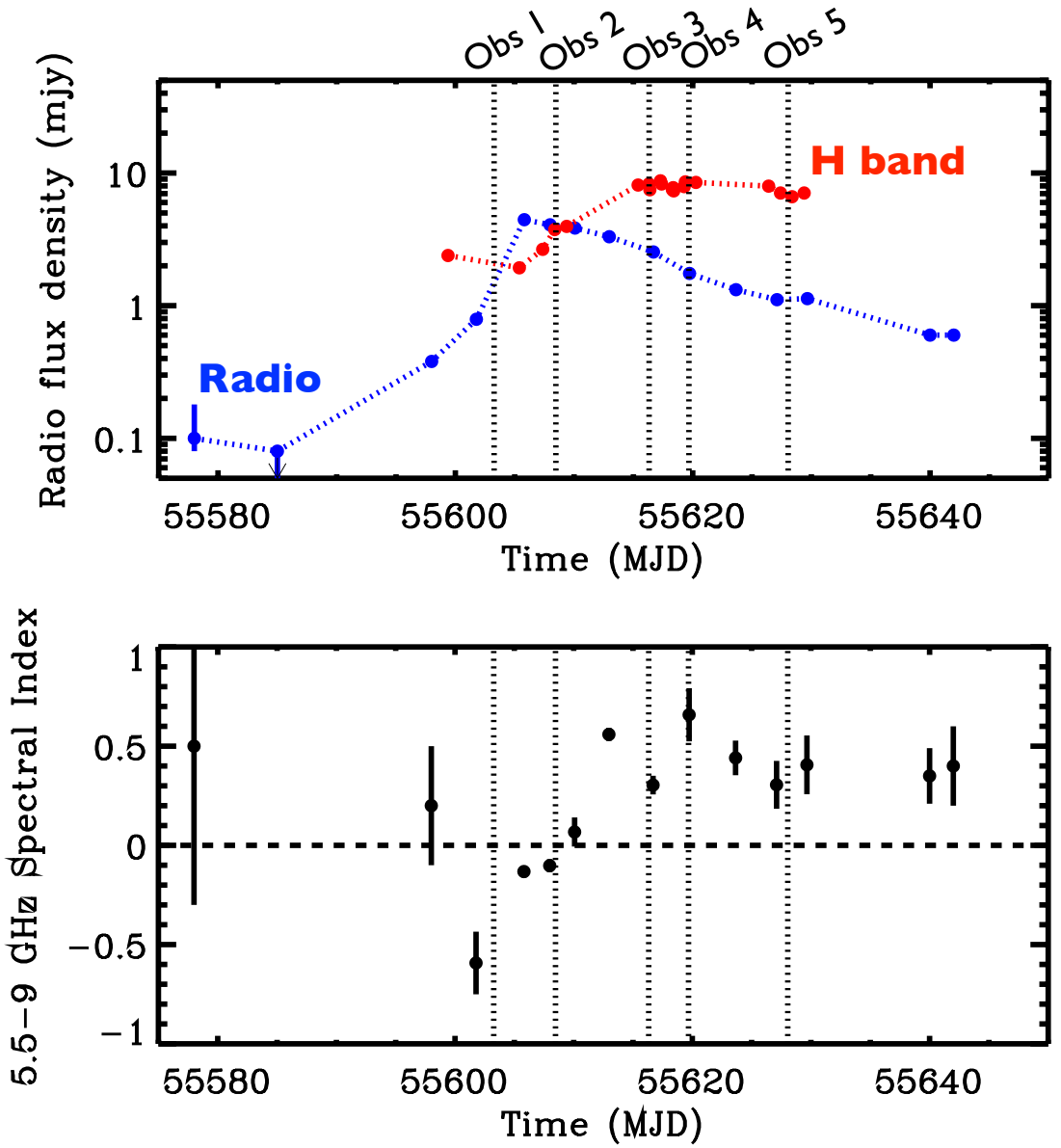



# Simultaneous Radio/IR Emission

- Radio observations (ATCA, Corbel et al. 2012).
- OIR observations (SMARTS, Buxton et al. 2012, Dincer et al. 2012)

- The radio switches on just before Obs 1 and peaks between Obs 1 and Obs 2 and the radio spectrum (5-9 GHz) becomes inverted (>0) signature of jet

➡"jet line" between Obs 1 and Obs 2 or Obs 3



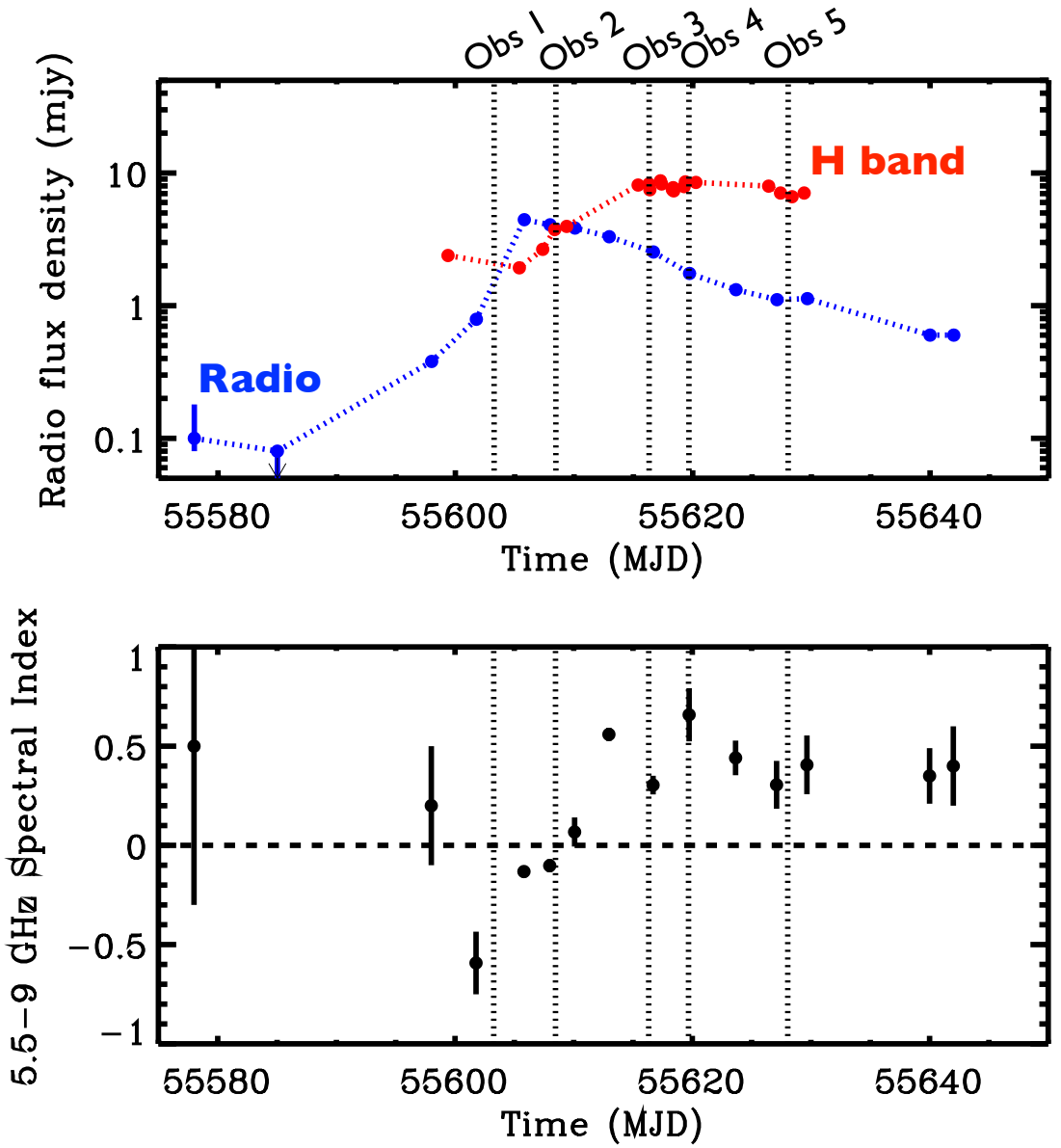
# Simultaneous Radio/IR Emission

- Radio observations (ATCA, Corbel et al. 2012).
- OIR observations (SMARTS, Buxton et al. 2012, Dincer et al. 2012)

- The radio switches on just before Obs 1 and peaks between Obs 1 and Obs 2 and the radio spectrum (5-9 GHz) becomes inverted (>0) signature of jet

➡"jet line" between Obs 1 and Obs 2 or Obs 3

- H flux reaches max close to Obs 3



# Suzaku Data: Treatment and Analysis

The data treatment follows step-by-step the "*ABC Guide*" v4.0. Version 2 processed data. Last calibration files (May 2012). HeaSoft v6.11, xspec v12.7

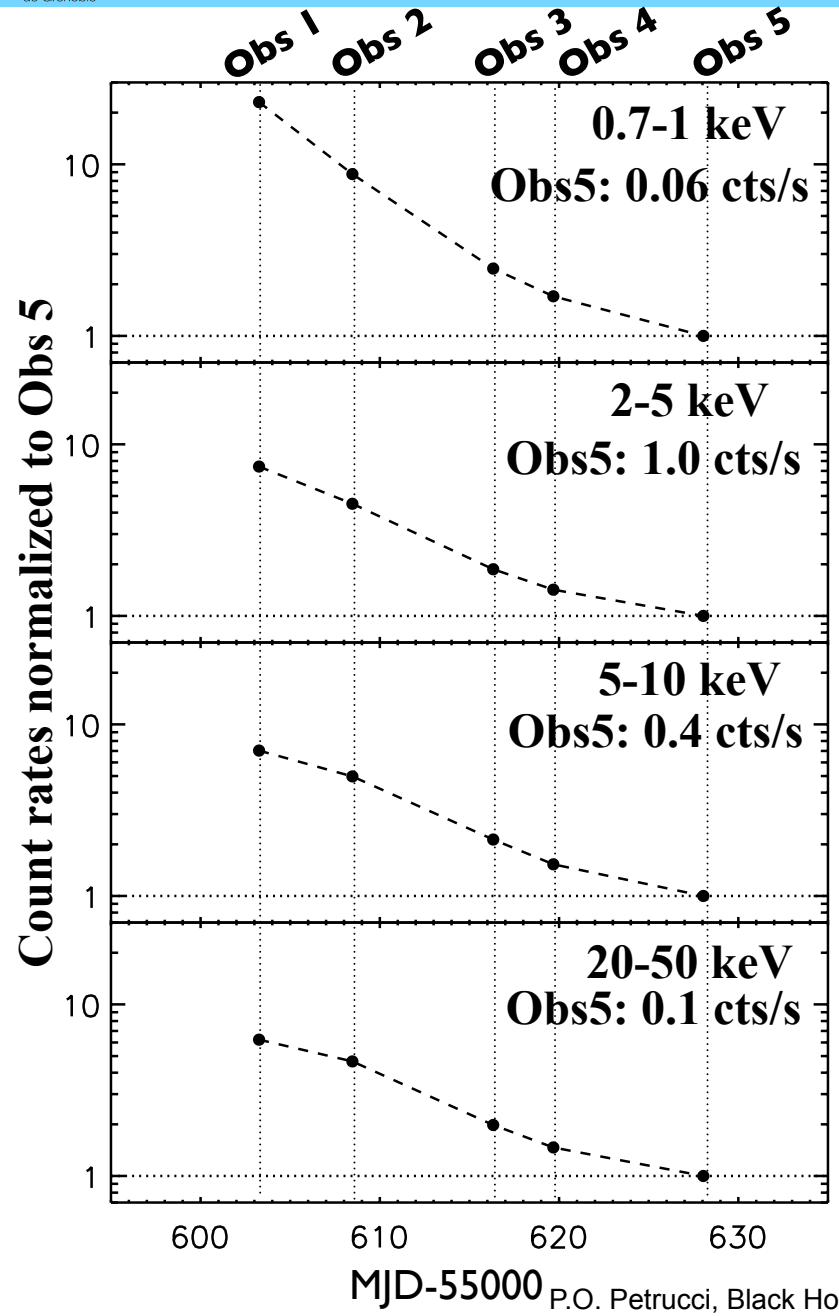
## XIS (0,1 and 3):

- ✓Recalibration and rescreening (*aepipeline*)
- ✓**pile-up** correction (*pileest*)
- ✓Night Sky **Background** (*xisnxbgen*) and Cosmic X-ray Background
- ✓xis0 and xis3 have been combined

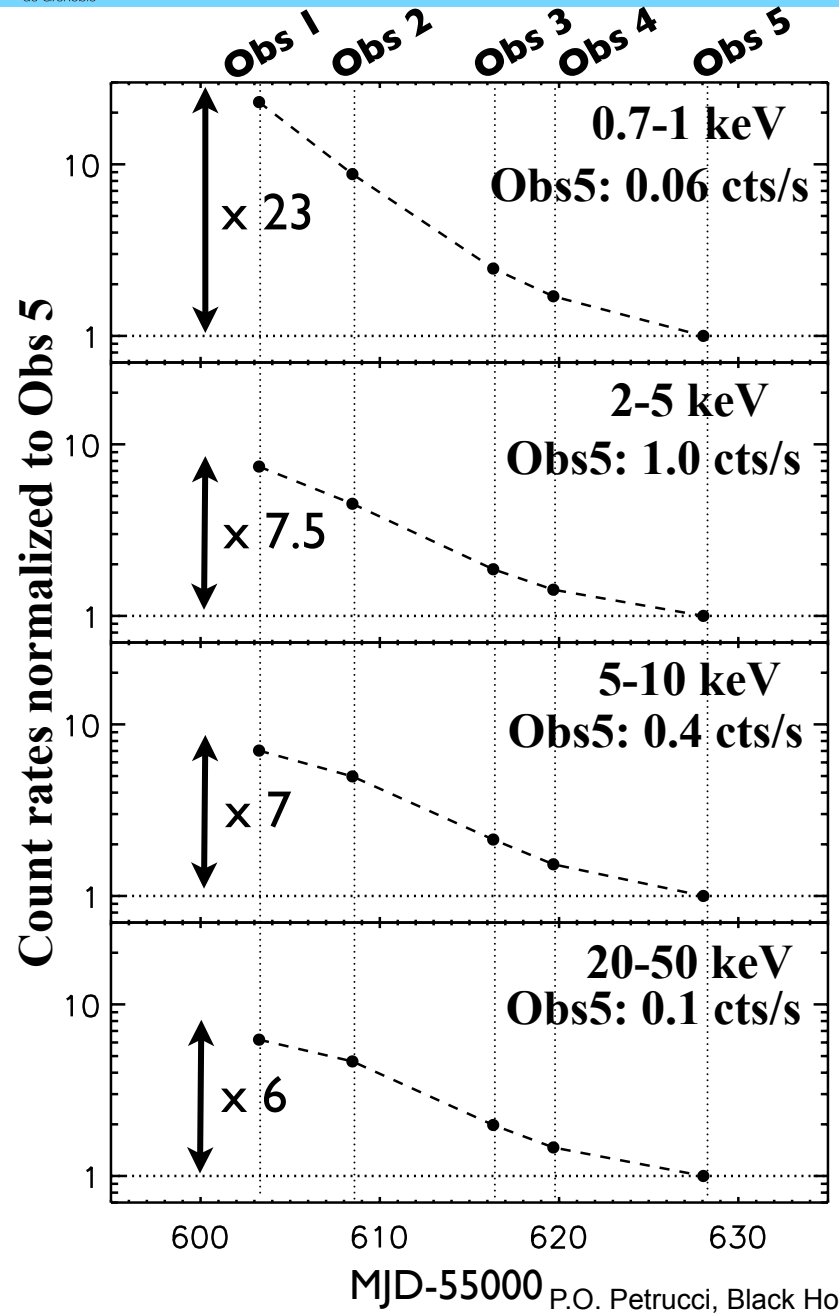
## HXD (PIN and GSO):

- ✓Recalibration and rescreening (*aepipeline*)
- ✓No known X-ray source in the FoV
- ✓Night Sky **Background** files and fake Cosmic X-ray Background (*hxdpinxbpi* and *hxdgsoxbpi*). GSO of poor quality.

# Suzaku Light Curves



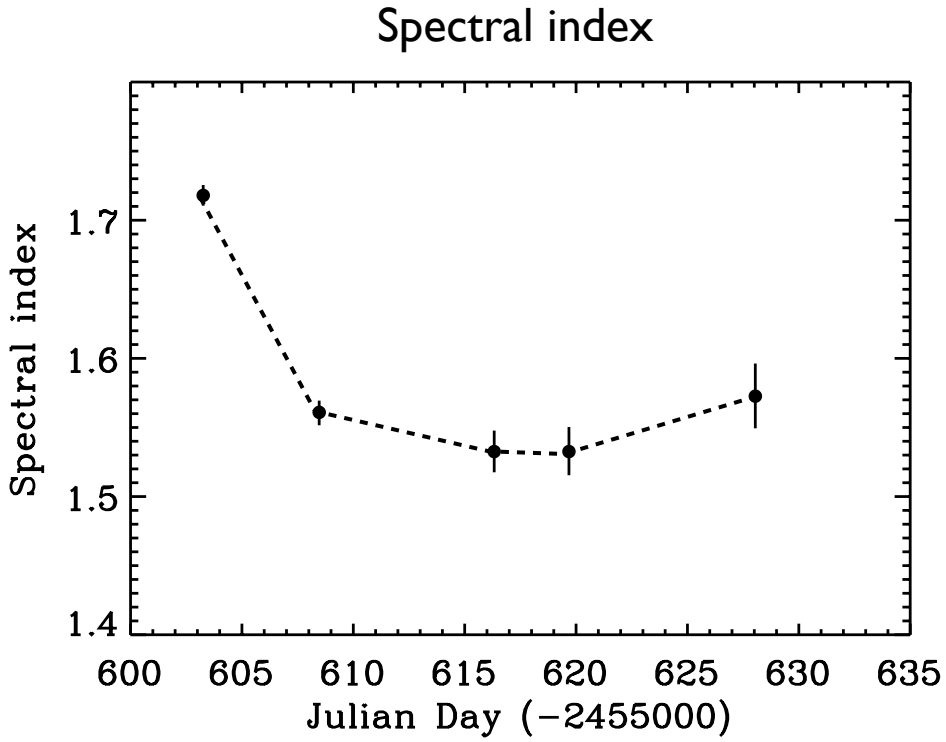
# Suzaku Light Curves




- Larger decrease in the soft X-rays (< 1 keV)
- ~ Energy-independent decrease above 2 keV

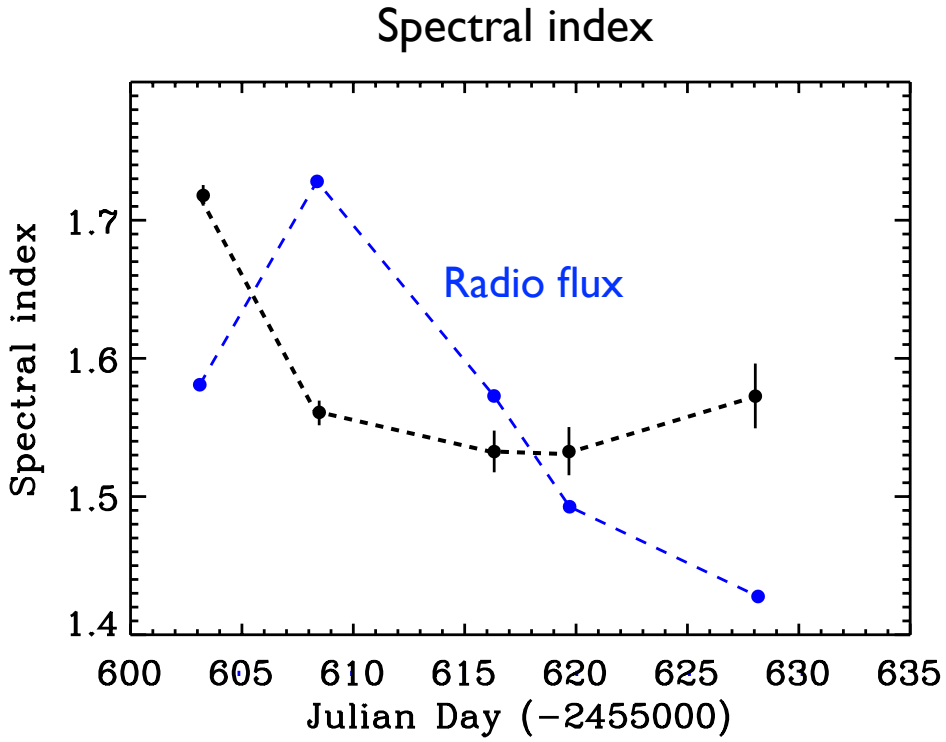
# Primary continuum

Fits XIS-PIN data simultaneously above 3 keV with a cut-off power law (but poor data above 50 keV



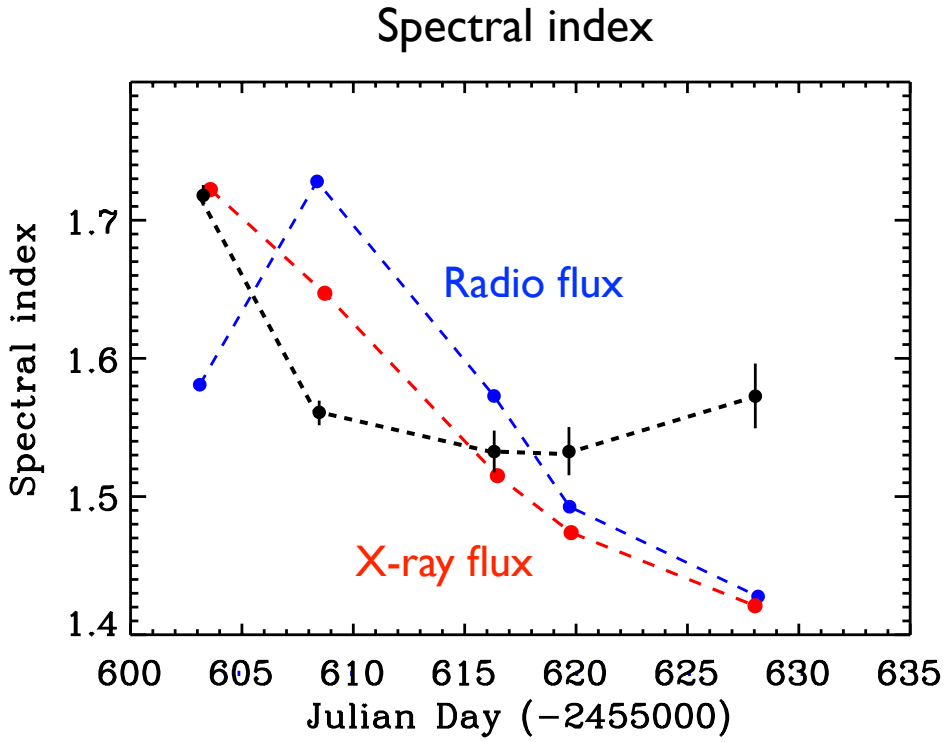
# Primary continuum

Fits XIS-PIN data simultaneously above 3 keV with a cut-off power law (but poor data above 50 keV



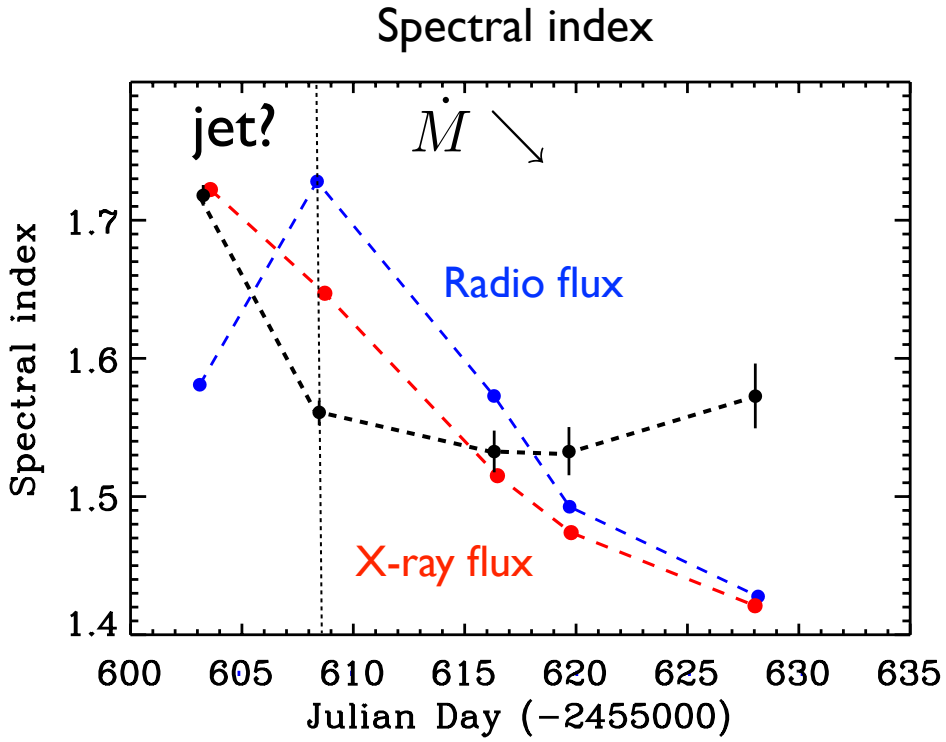
# Primary continuum

Fits XIS-PIN data simultaneously above 3 keV with a cut-off power law (but poor data above 50 keV



# Primary continuum

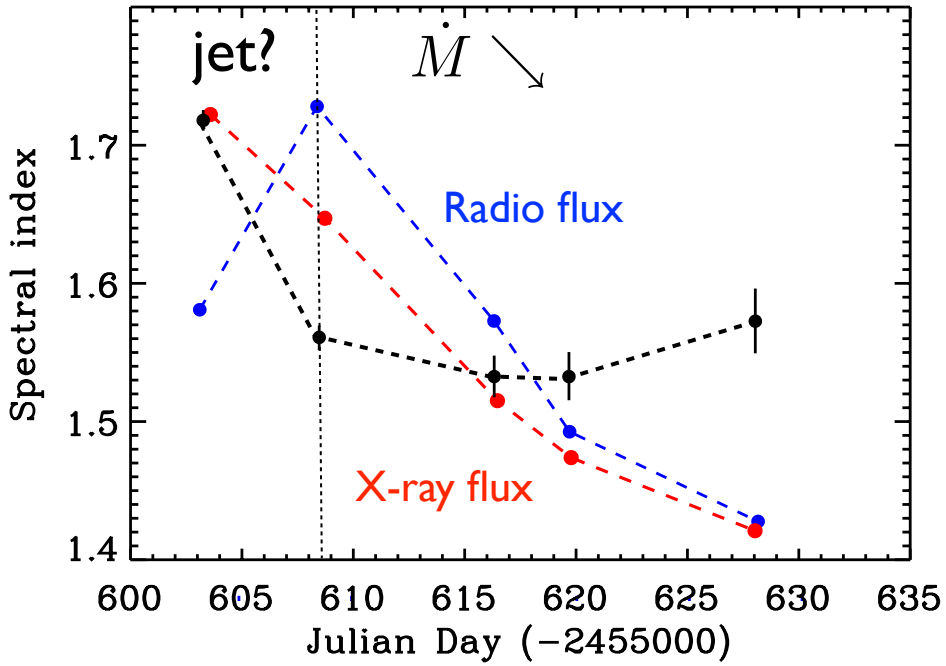
Fits XIS-PIN data simultaneously above 3 keV with a cut-off power law (but poor data above 50 keV



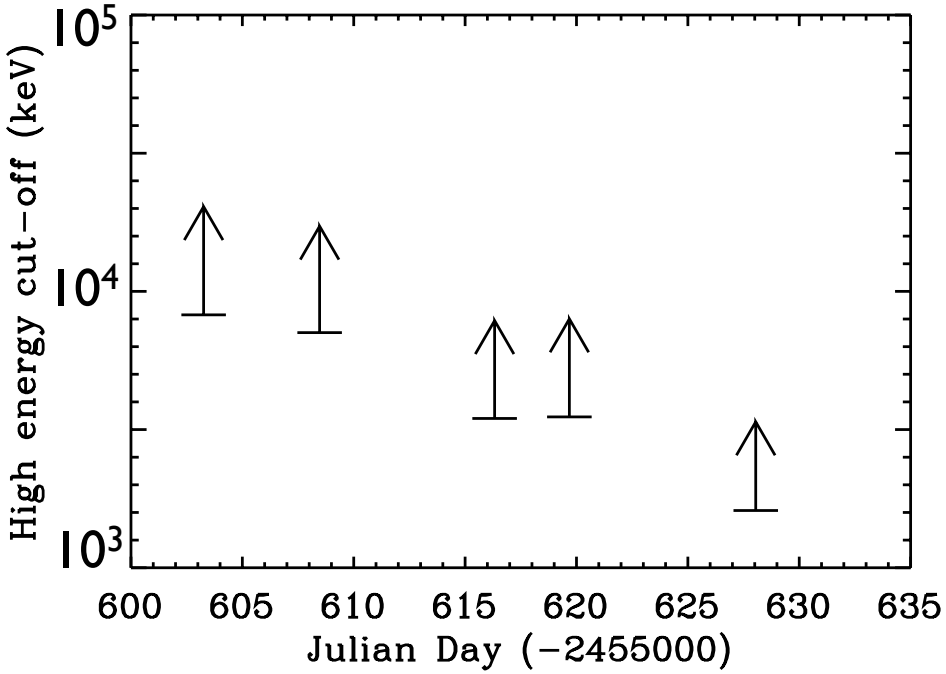
# Primary continuum

Fits XIS-PIN data simultaneously above 3 keV with a cut-off power law (but poor data above 50 keV

Spectral index

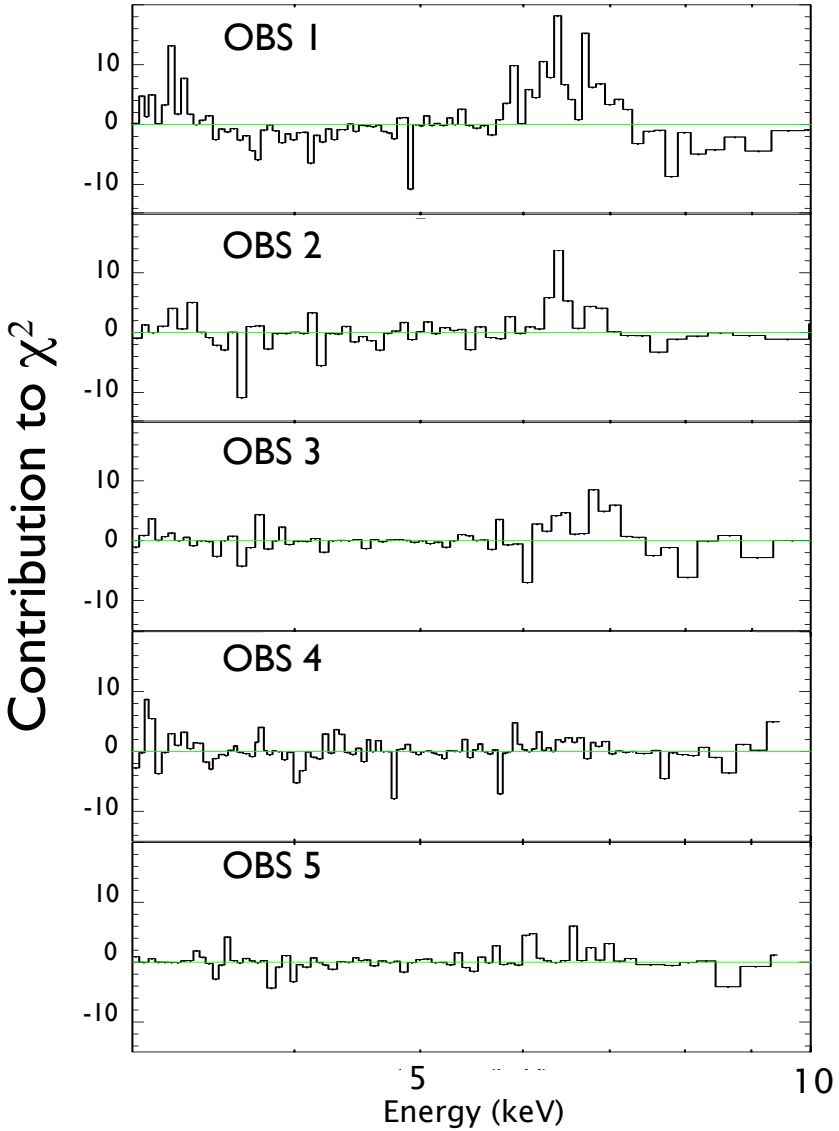



High energy cut-off



# Iron Line: gaussian

## Fit between 3 and 10 keV

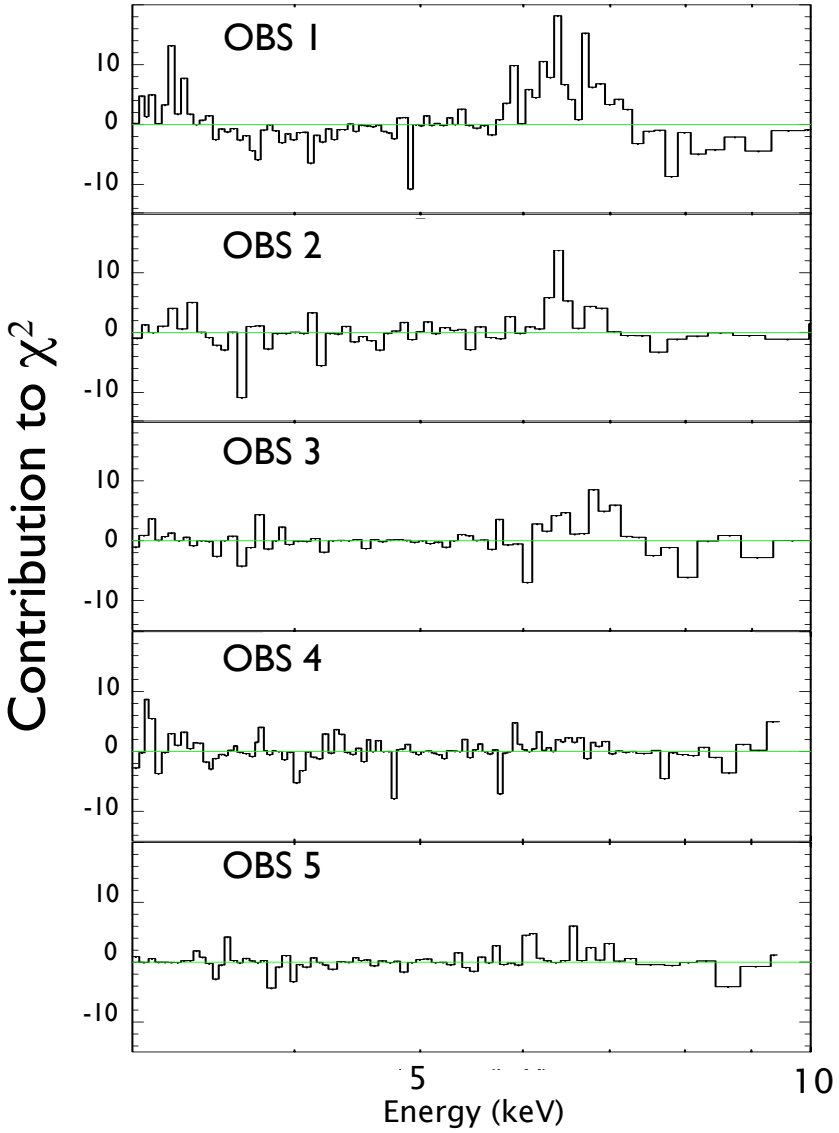



Addition of a gaussian

| | Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 5 |
|---|---|---|---|---|---|
| $\Delta\chi^2$ | 143 | 29 | 30 | 14 | 14 |

# Iron Line: gaussian

## Fit between 3 and 10 keV

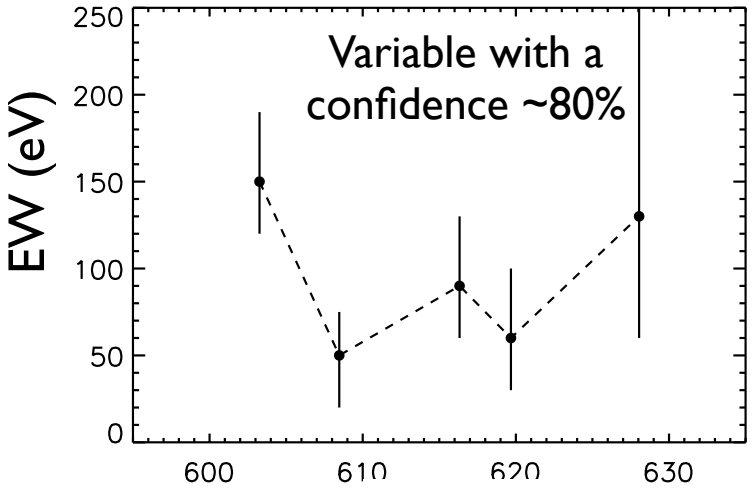



### Addition of a gaussian

| | Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 5 |
|---|---|---|---|---|---|
| $\Delta\chi^2$ | 143 | 29 | 30 | 14 | 14 |

### Equivalent width

| Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 5 |
|---|---|---|---|---|
| $150^{+40}_{-30}$ | $50^{+25}_{-30}$ | $90^{+40}_{-30}$ | $60^{+40}_{-30}$ | $130^{+230}_{-70}$ |

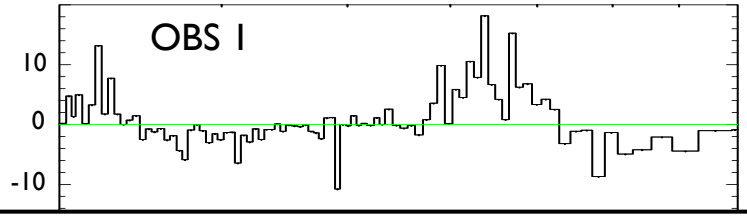


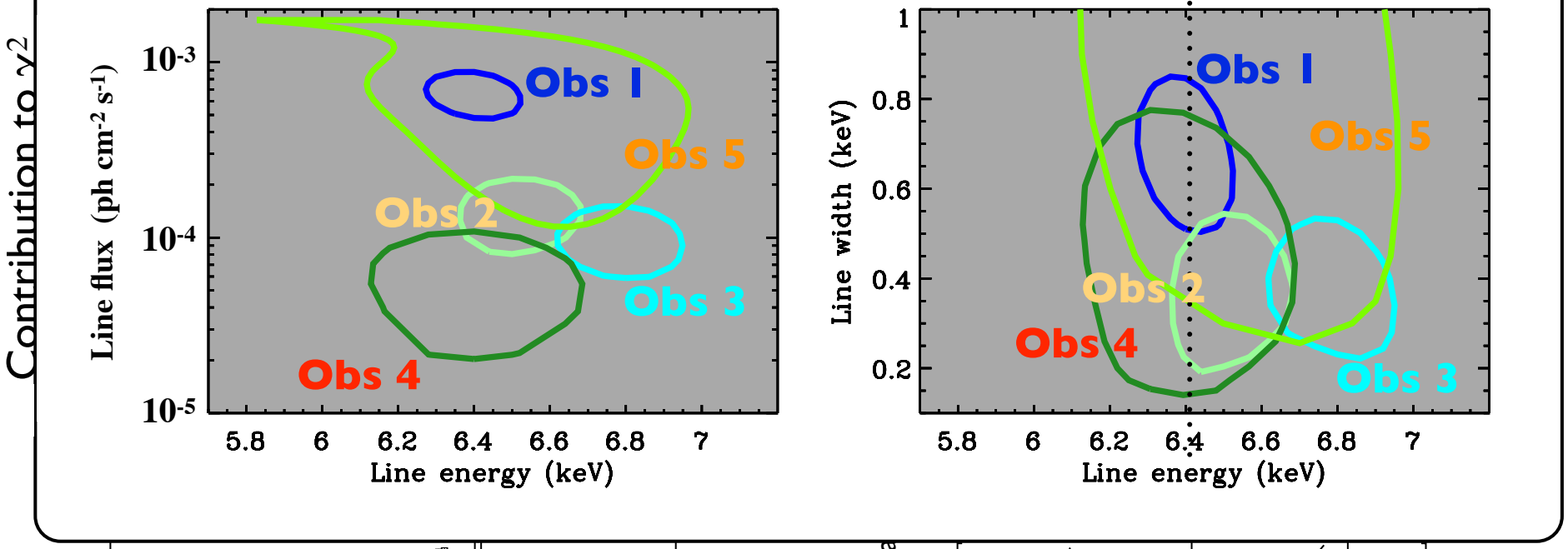
# Iron Line: gaussian

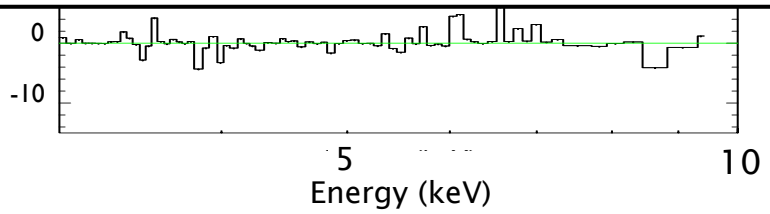
## Fit between 3 and 10 keV

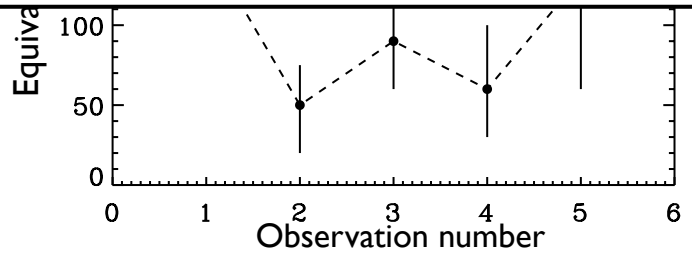
Addition of a gaussian

| Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 5 |
|---|---|---|---|---|



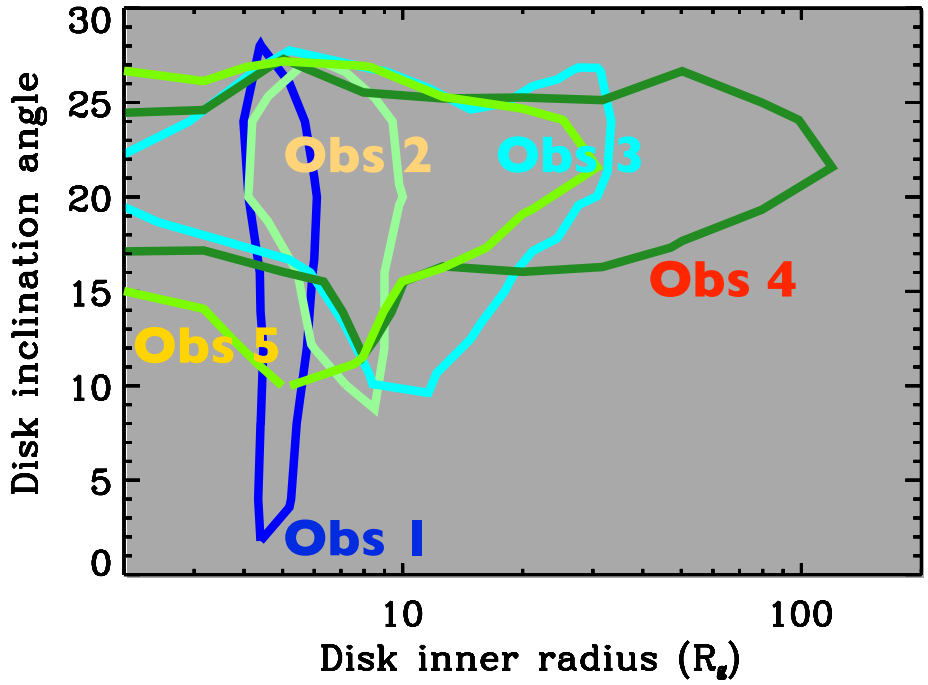



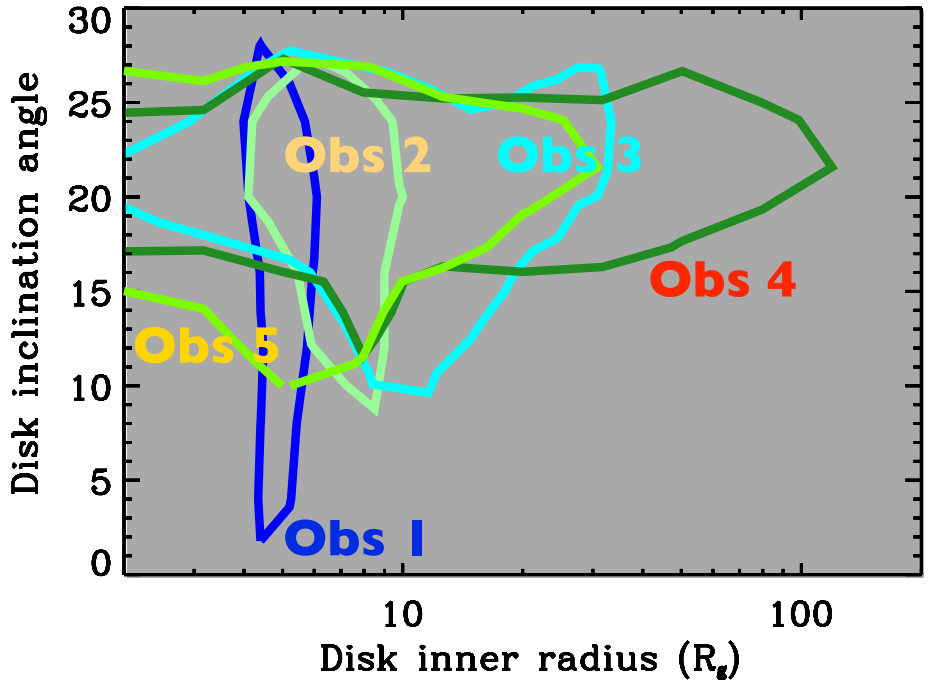
# Iron Line: laor

The 5 observations fitted simultaneously (3-10 keV) assuming the same inclination angle (with $q=3$, $R_{out}=400\ R_g$)



# Iron Line: laor

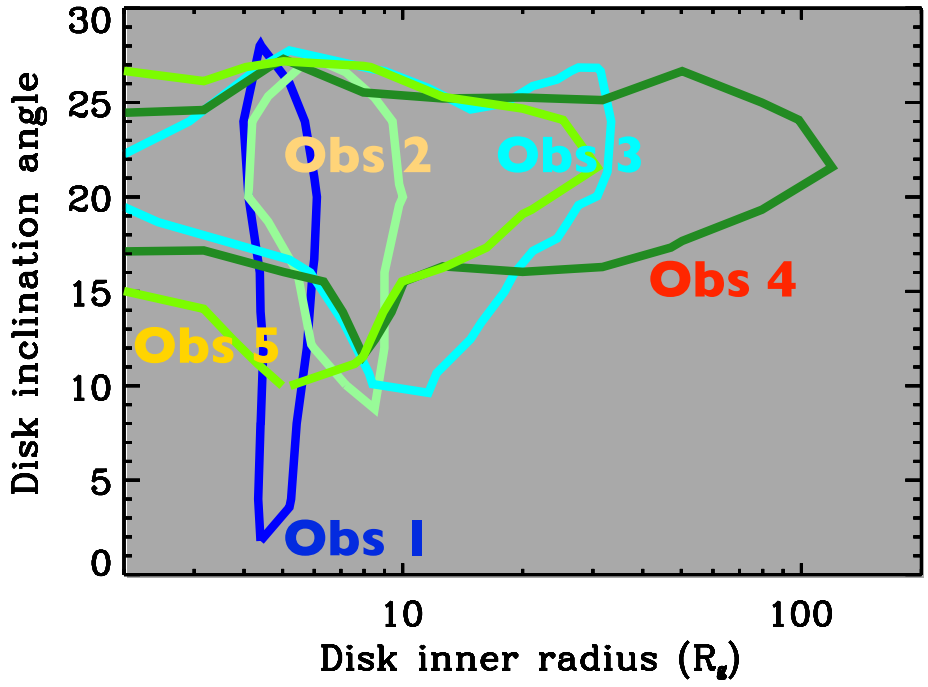
The 5 observations fitted simultaneously (3-10 keV) assuming the same inclination angle (with $q=3$, $R_{out}=400\ R_g$)




| Addition of a laor | | | | $\Delta\chi^2$ |
|---|---|---|---|---|
| Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 5 |
| 150 | 35 | 34 | 14 | 14 |
| Comparison with a Gaussian | | | | |
| +7 | +6 | +4 | 0 | 0 |

# Iron Line: laor

The 5 observations fitted simultaneously (3-10 keV) assuming the same inclination angle (with $q=3$, $R_{out}=400\ R_g$)

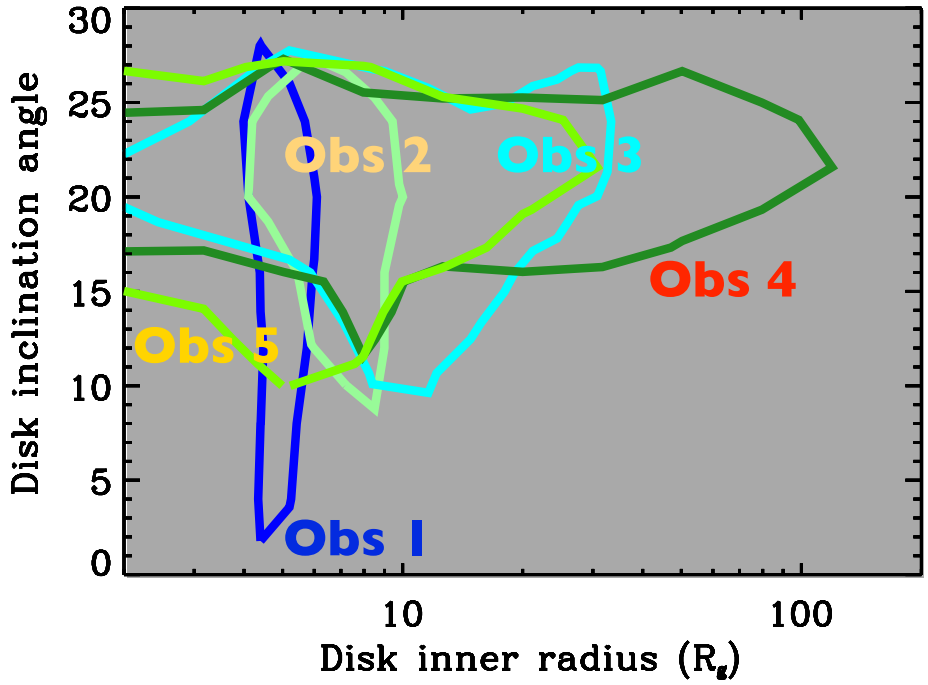



| Addition of a laor | | | | $\Delta\chi^2$ |
|---|---|---|---|---|
| Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 5 |
| 150 | 35 | 34 | 14 | 14 |
| Comparison with a Gaussian | | | | |
| +7 | +6 | +4 | 0 | 0 |

- Inclination angle ~20 deg. (e.g. Miller et al. 2004; Reis et al. 2008)

# Iron Line: laor

The 5 observations fitted simultaneously (3-10 keV) assuming the same inclination angle (with $q=3$, $R_{out}=400\ R_g$)

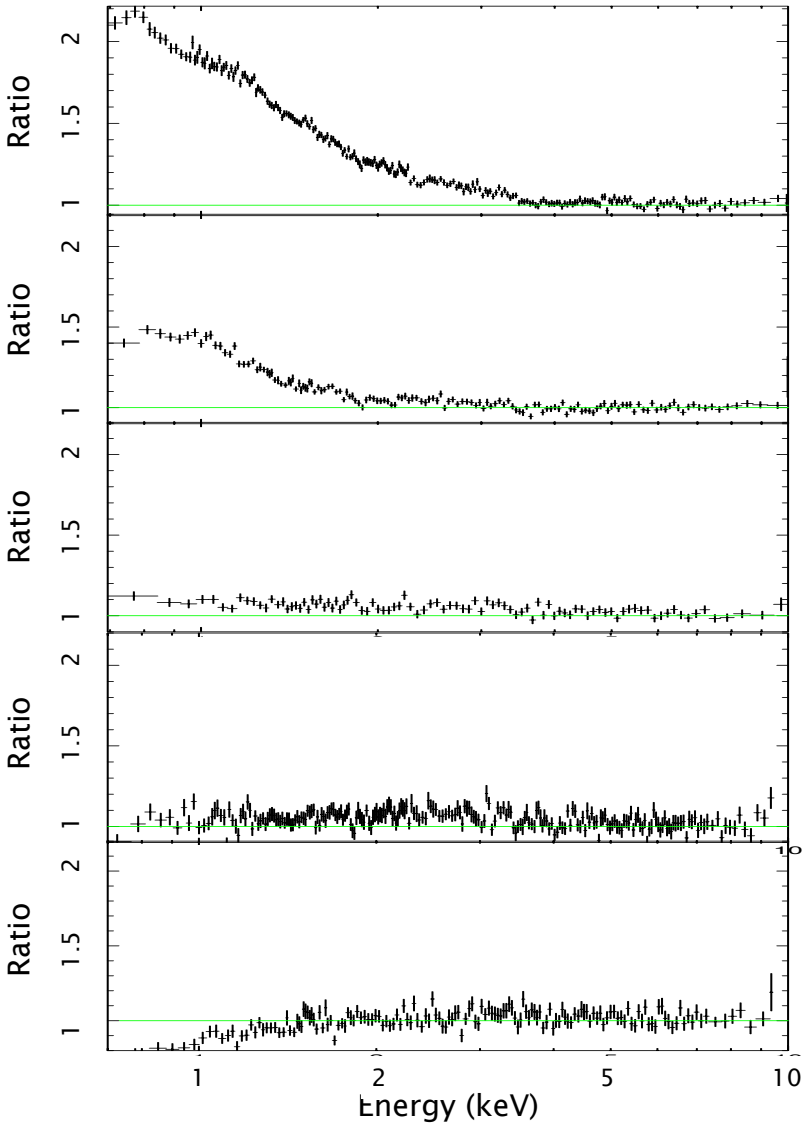



| Addition of a laor | | | | $\Delta\chi^2$ |
|---|---|---|---|---|
| Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 5 |
| 150 | 35 | 34 | 14 | 14 |
| Comparison with a Gaussian | | | | |
| +7 | +6 | +4 | 0 | 0 |

- Inclination angle ~20 deg. (e.g. Miller et al. 2004; Reis et al. 2008)
- Disk recession?

# Soft-X-ray Excess

Extrapolation down to 0.7 keV,
$N_h$=4 $10^{21}$cm$^2$

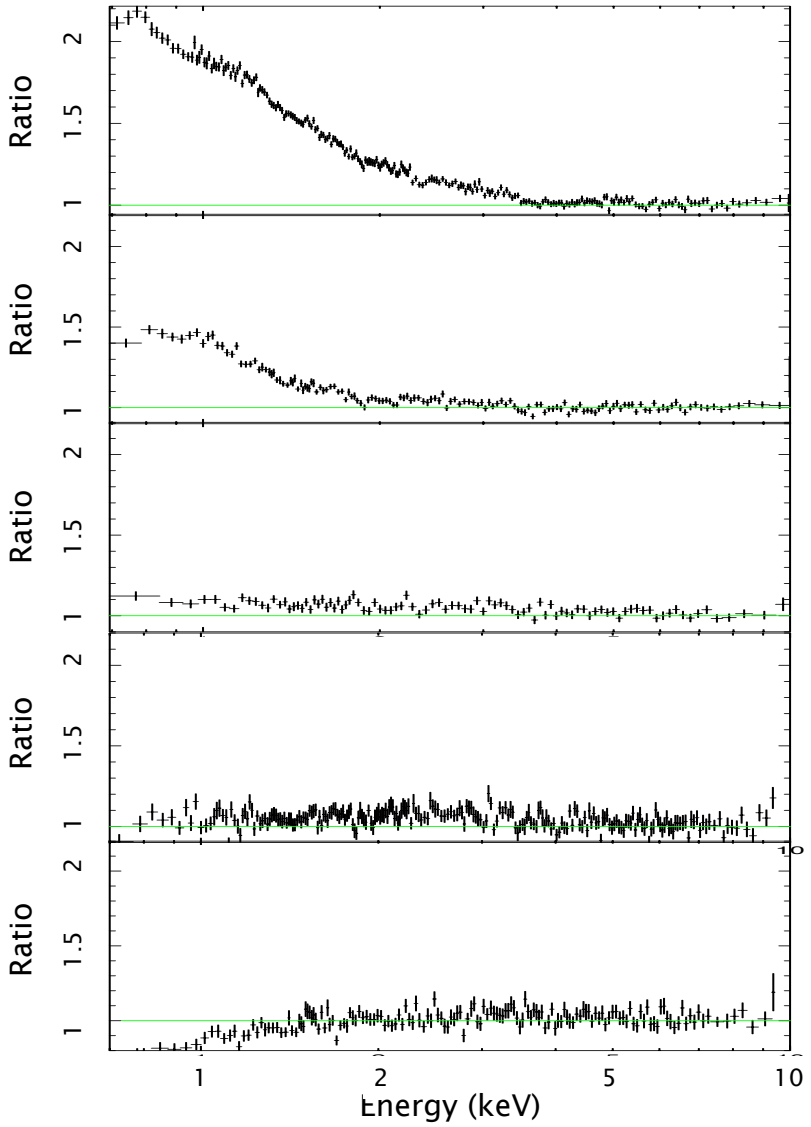



wabs+po+gau $\chi^2/dof$

| Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 5 |
|---|---|---|---|---|
| 1948/448 | 753/432 | 449/433 | 479/422 | 407/390 |

# Soft-X-ray Excess

Extrapolation down to 0.7 keV,
$N_h$=4 $10^{21}$cm$^2$

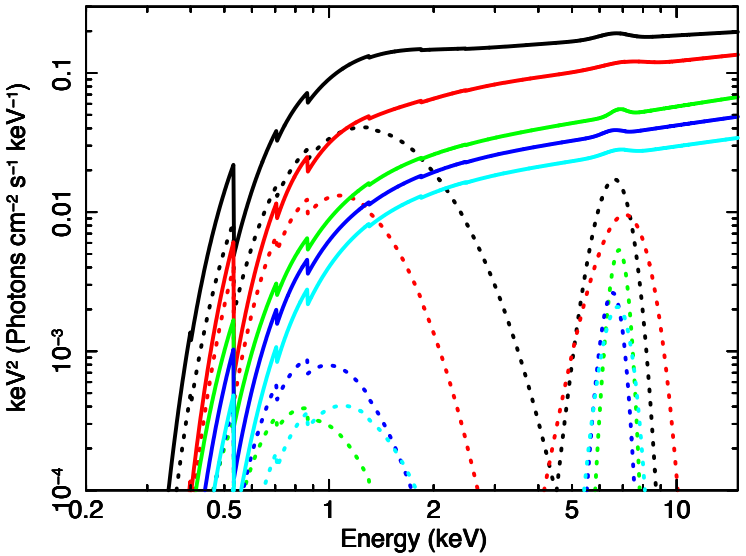



wabs+po+gau $\chi^2/dof$

| Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 5 |
|---|---|---|---|---|
| 1948/448 | 753/432 | 449/433 | 479/422 | 407/390 |

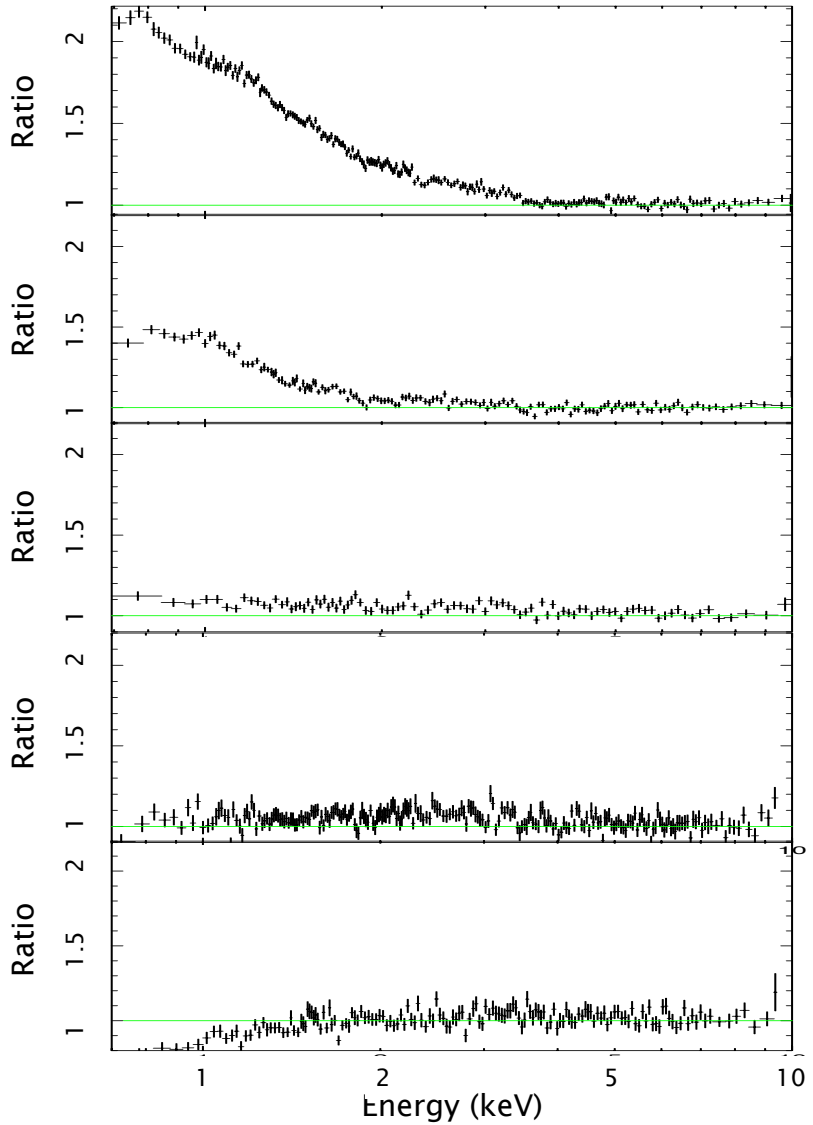
Addition of a multicolor disk

| | Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 5 |
|---|---|---|---|---|---|
| $\Delta\chi^2$ | 1317 | 220 | 2 | 5 | 1 |



# Soft-X-ray Excess

Extrapolation down to 0.7 keV,
$N_h$=4 $10^{21}$cm$^2$




wabs+po+gau

| Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 5 |
|---|---|---|---|---|
| 1948/448 | 753/432 | 449/433 | 479/422 | 407/390 |

Addition of a multicolor disk

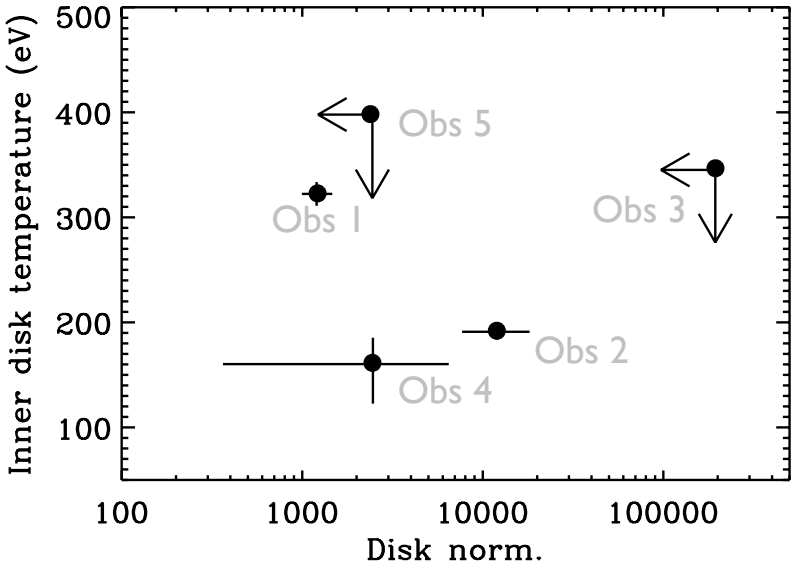
| | Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 5 |
|---|---|---|---|---|---|
| $\Delta\chi^2$ | 1317 | 220 | 2 | 5 | 1 |

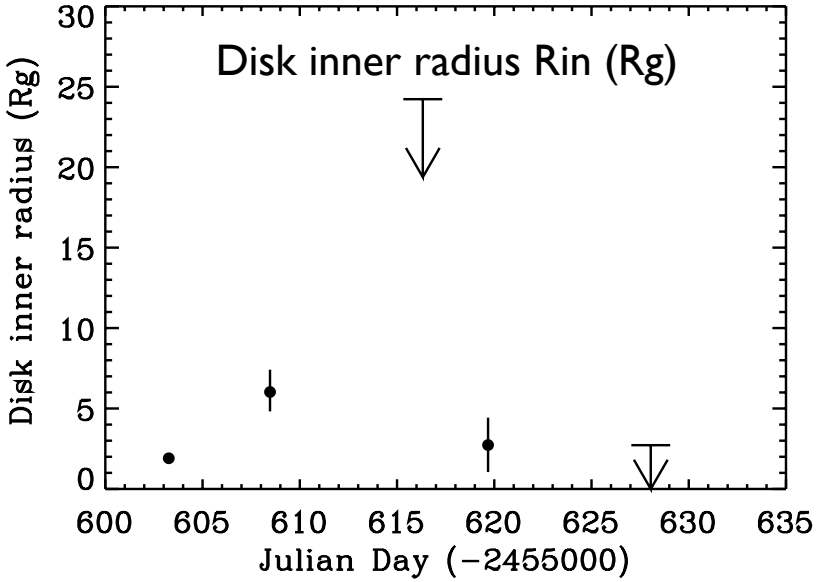
Still some excess...

Addition of a power law

| | Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 5 |
|---|---|---|---|---|---|
| $\Delta\chi^2$ | 121 | 21 | 2 | 5 | 1 |

# Disk parameters




- Very extreme values of $R_{in}$
- Is the variability real?

# Broad Band Analysis

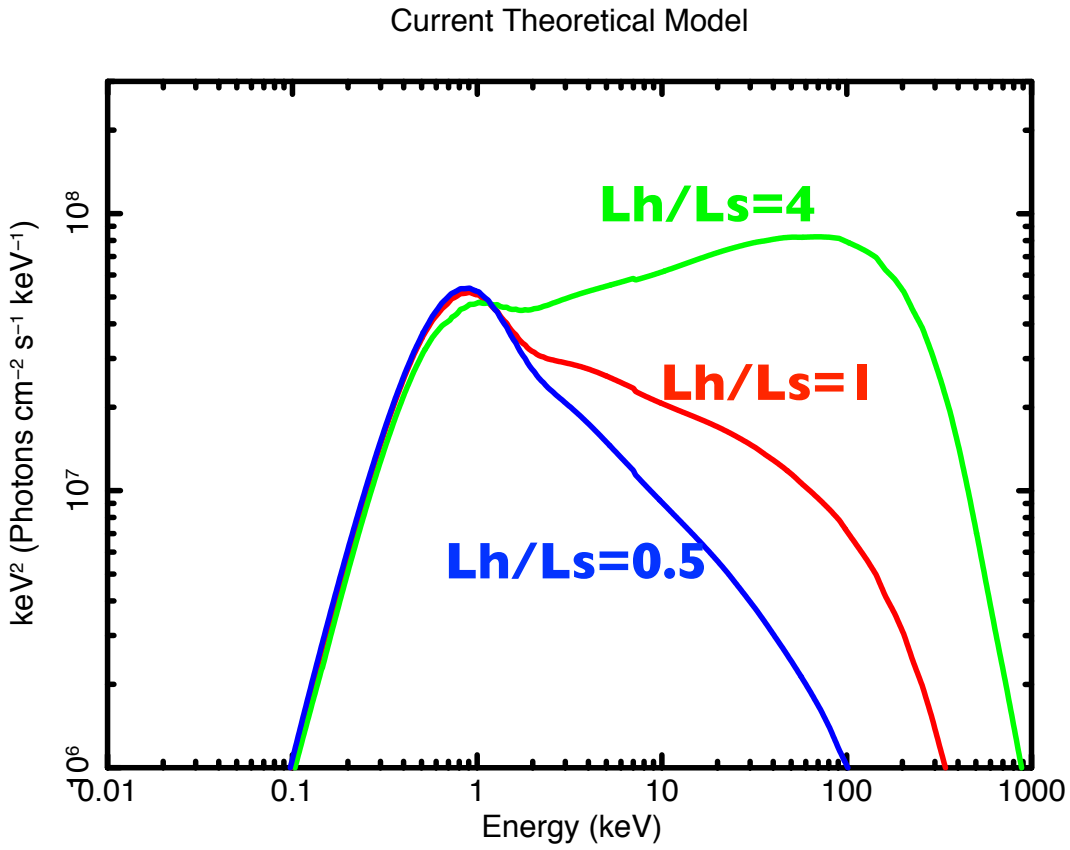
## The data

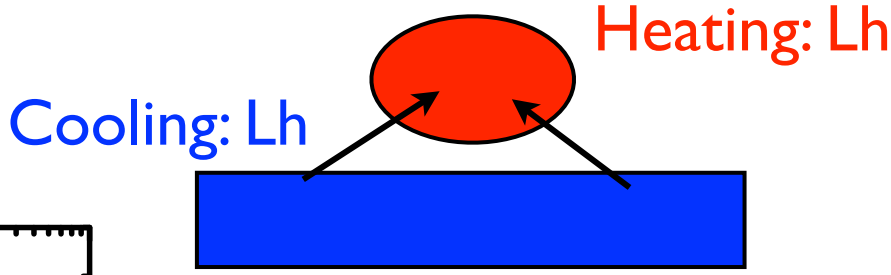
- XIS (0,3) between 0.7 and 10 keV
- PIN between 20 and 70 keV
- PIN/XIS = 1.16

## The model components

- Primary continuum: *EQPAIR* (Coppi 1999)
- Reflection component: *REFBHLO* (Ross & Fabian 2007)
- Blurring (if requested by the data): *KDBLUR*
- Soft X-ray excess (if requested by the data): *DISKBB, power law*

# Comptonisation model



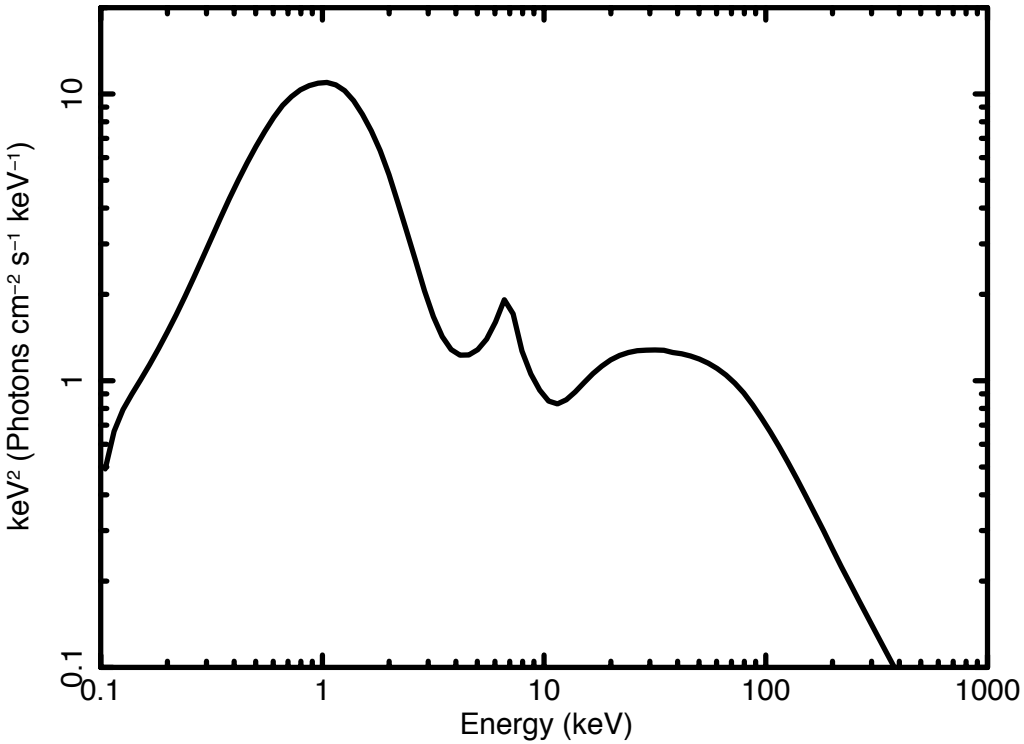



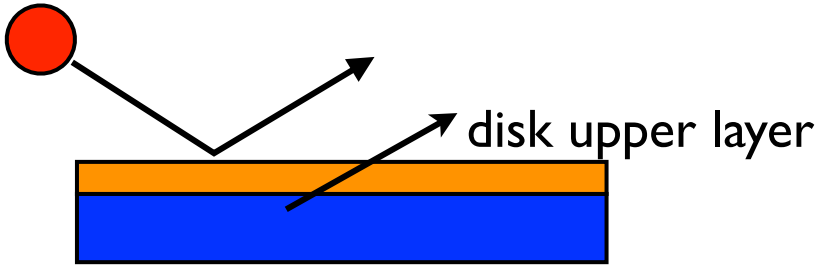

- Lh/Ls=1, slab corona above a passive disk
- Lh/Ls>1, photon starved geometry
- Lh/Ls>1, photon-fed geometry

# Reflection model

## REFBHB

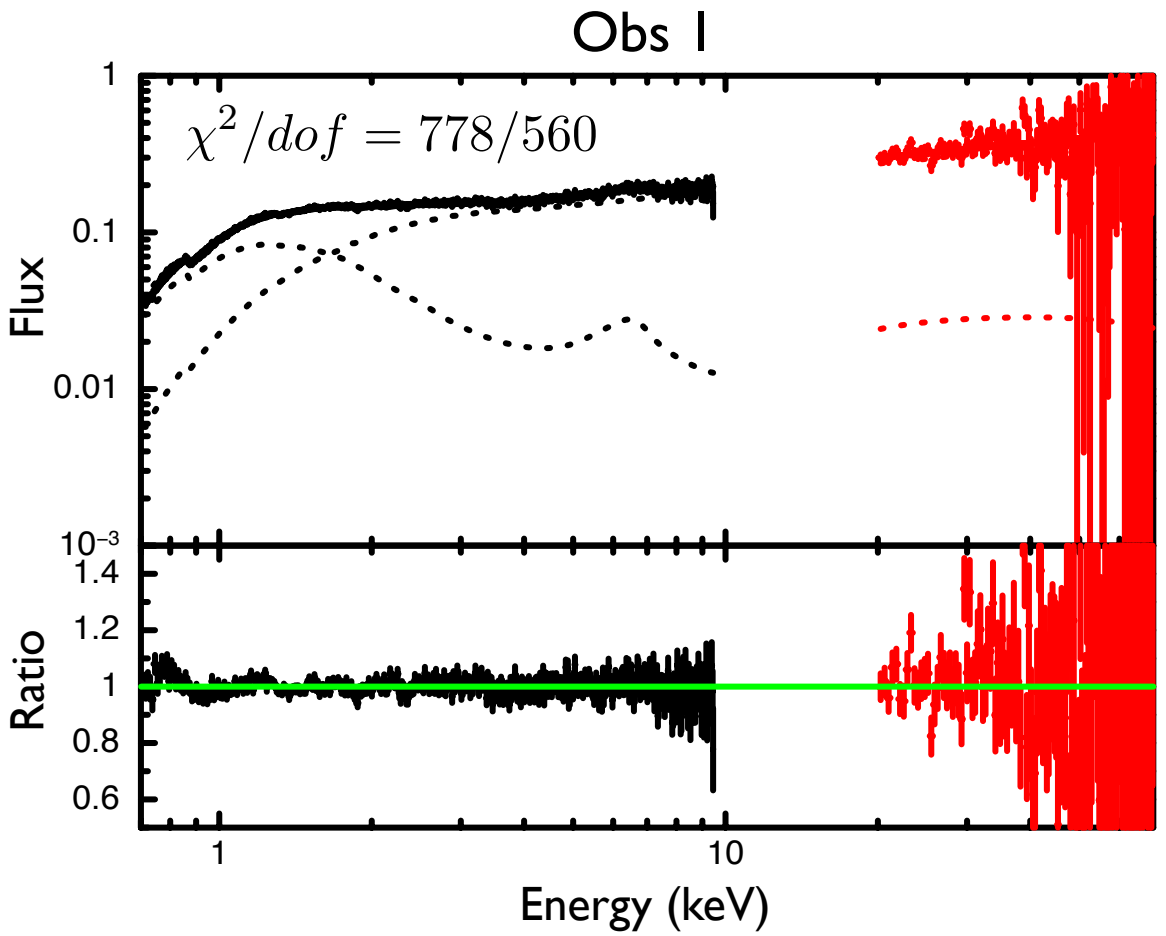
Emergent spectrum: transmitted + reflected

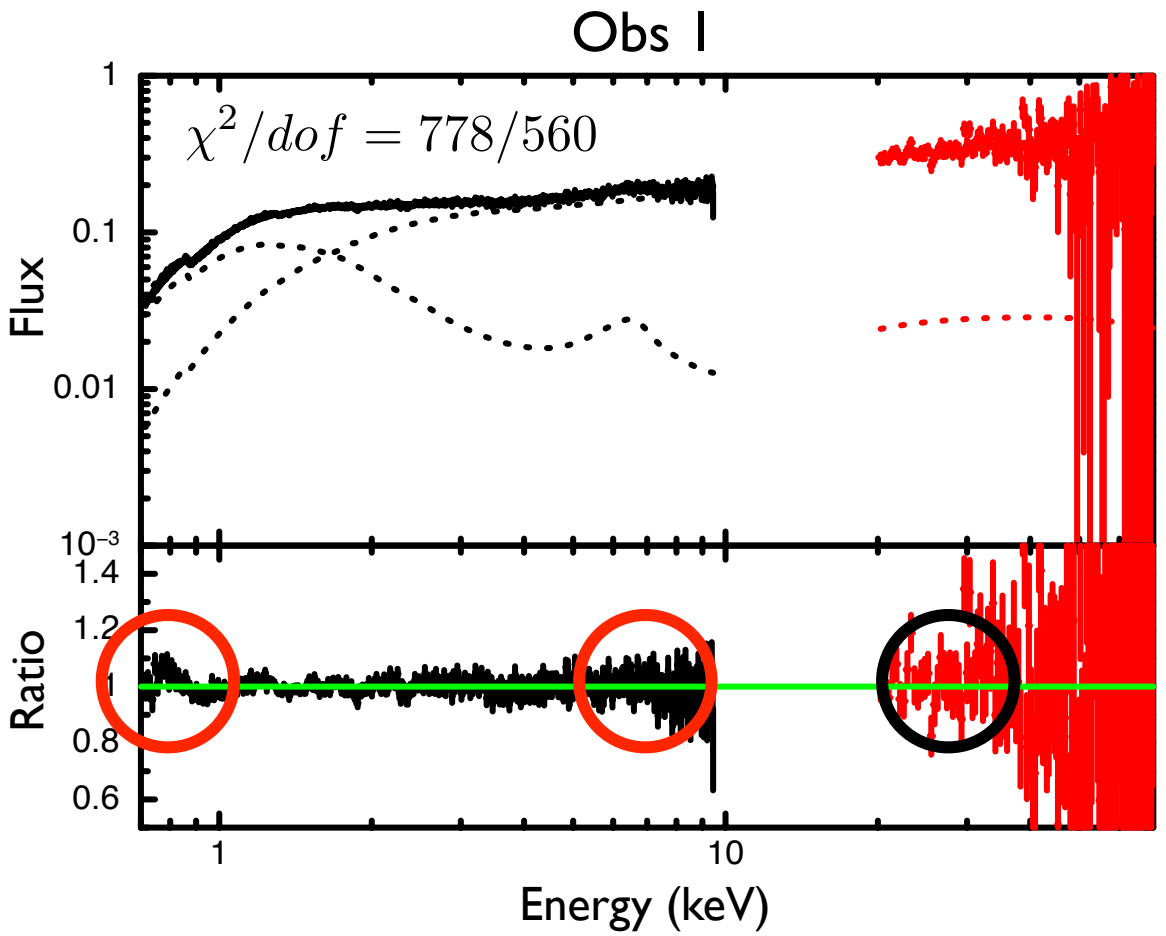


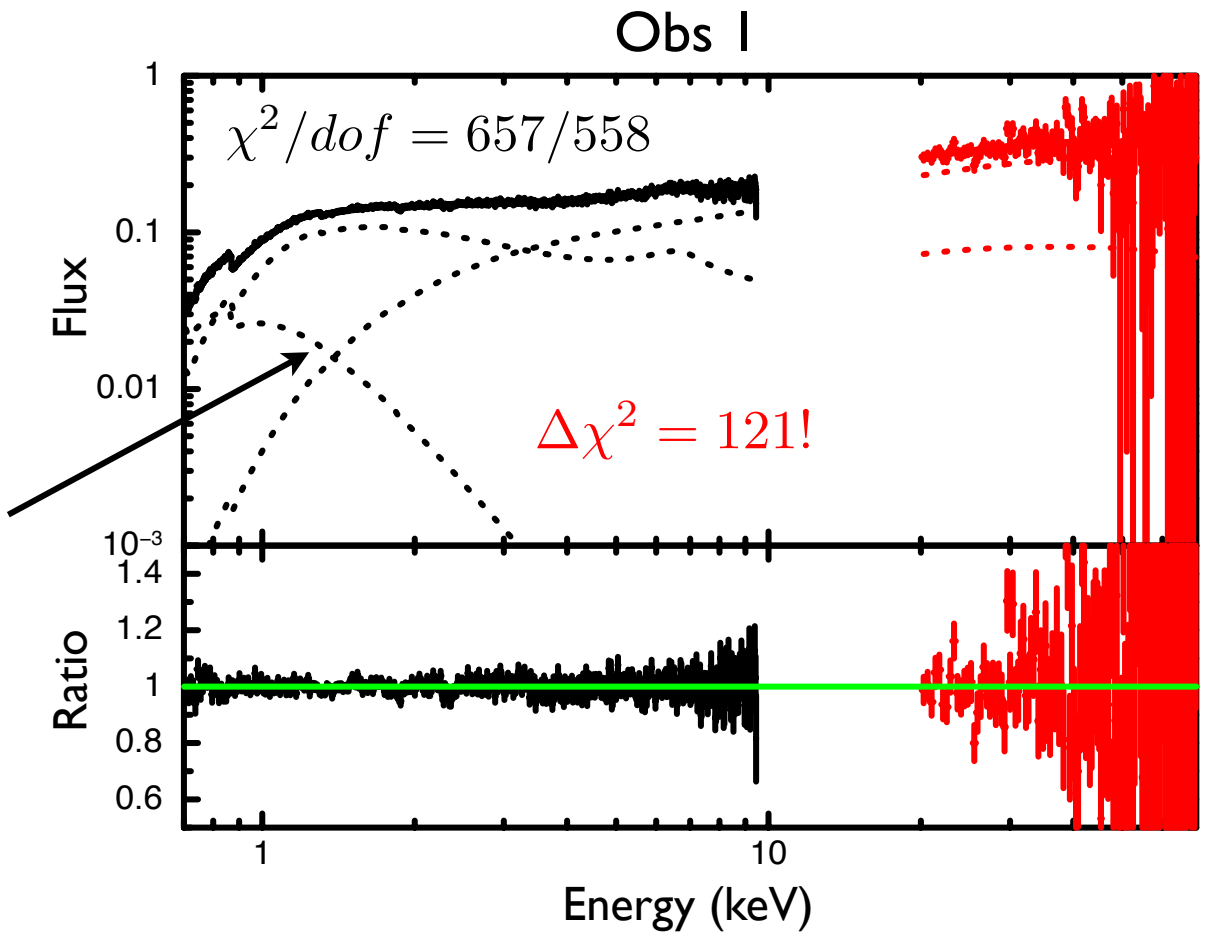

## Parameter:

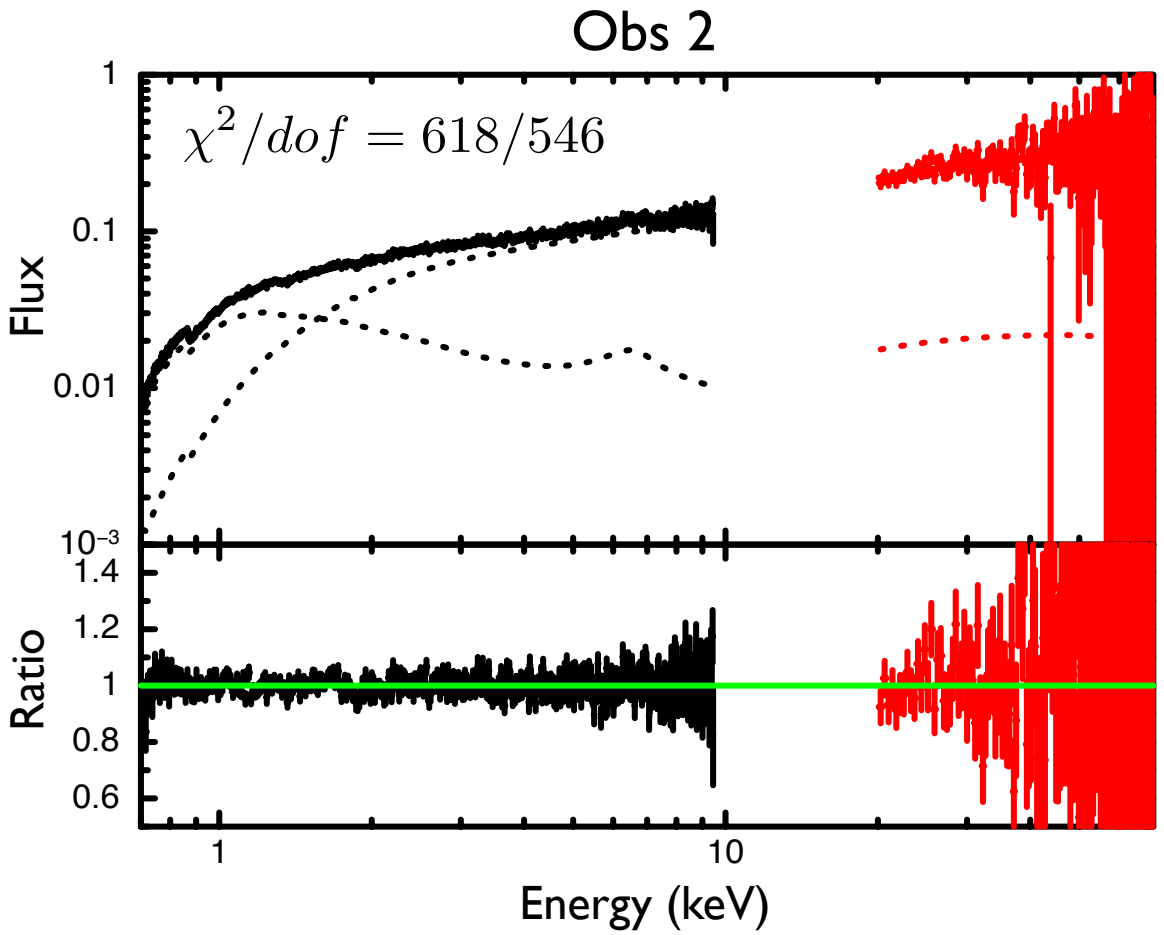
- Disk temperature
- Density of the illuminating surface
- Photon index X-ray emission
- Ratio Illuminating flux/Disk flux


Obs 1
$\chi^2/dof = 778/560$
Flux
1
0.1
0.01
$10^{-3}$
Ratio
1.4
1.2
1
0.8
0.6
1
10
Energy (keV)

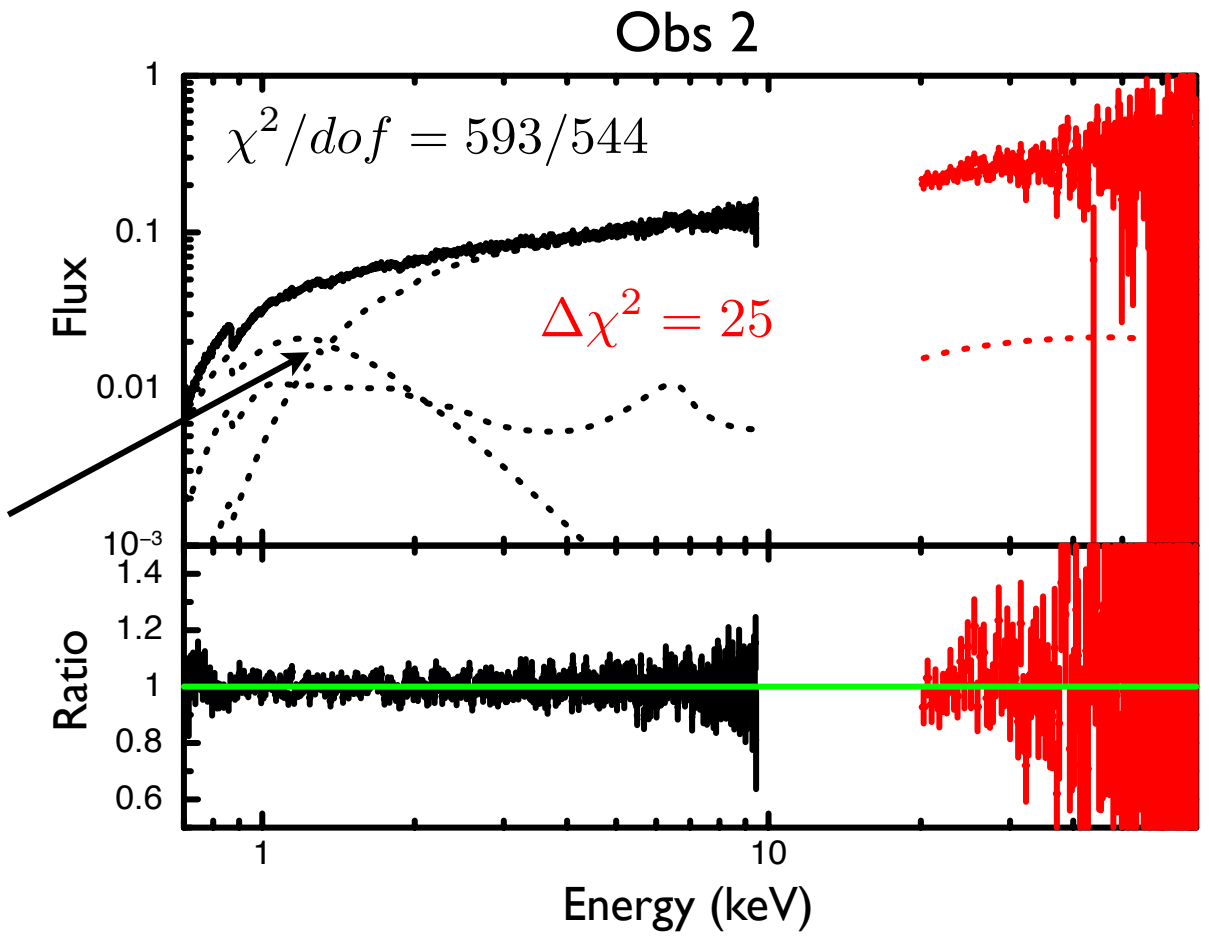

Obs 1
$\chi^2/dof = 778/560$
Flux
1
0.1
0.01
$10^{-3}$
Ratio
1.4
1.2
1
0.8
0.6
1
10
Energy (keV)

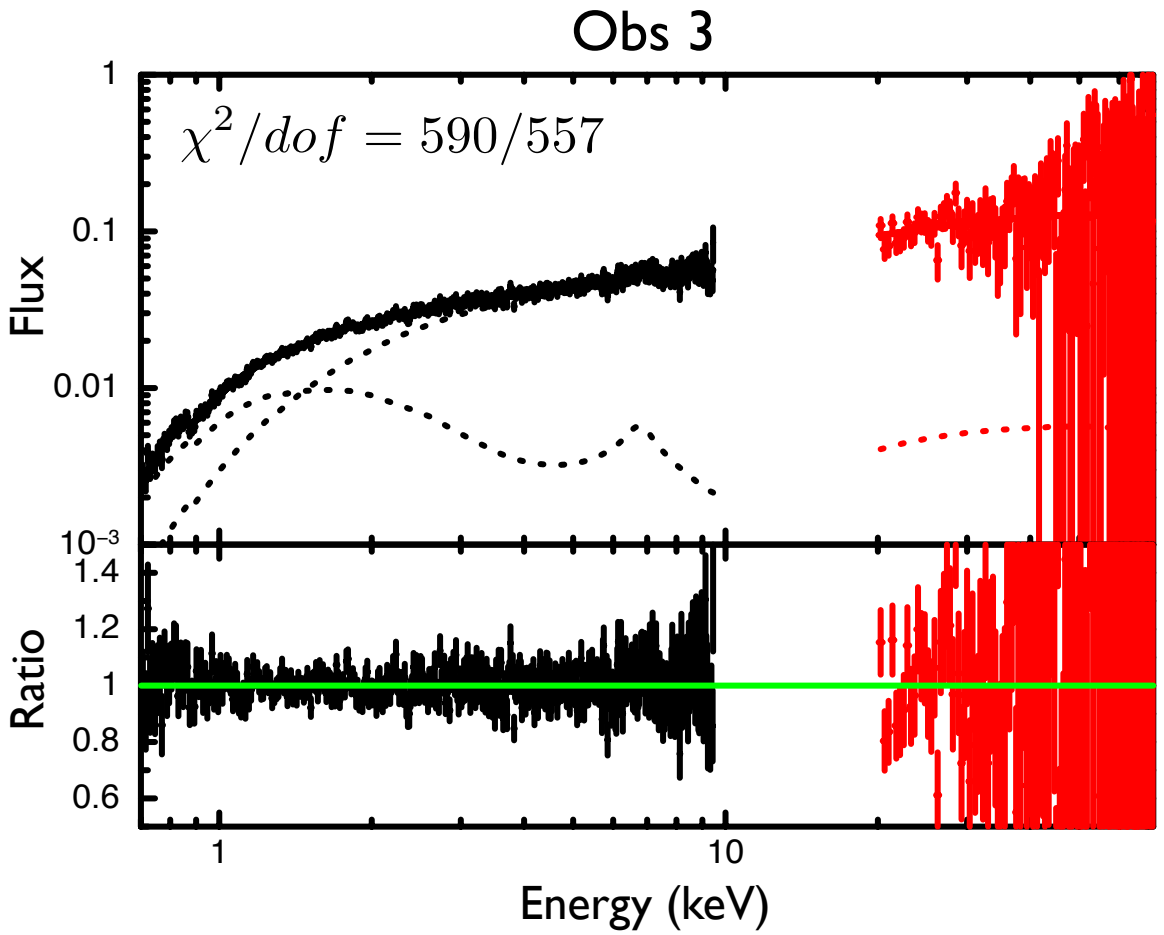
Addition of a component (power-law) at low energy

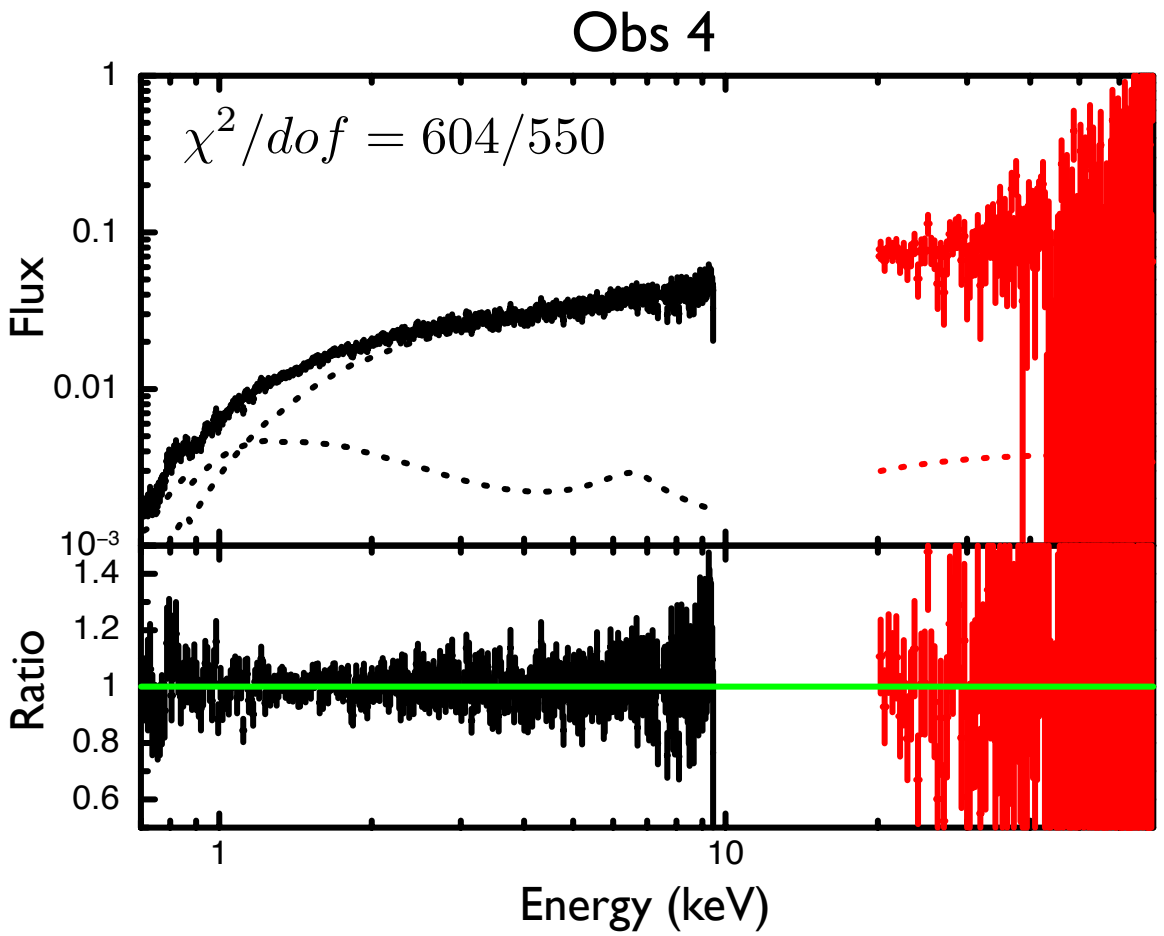


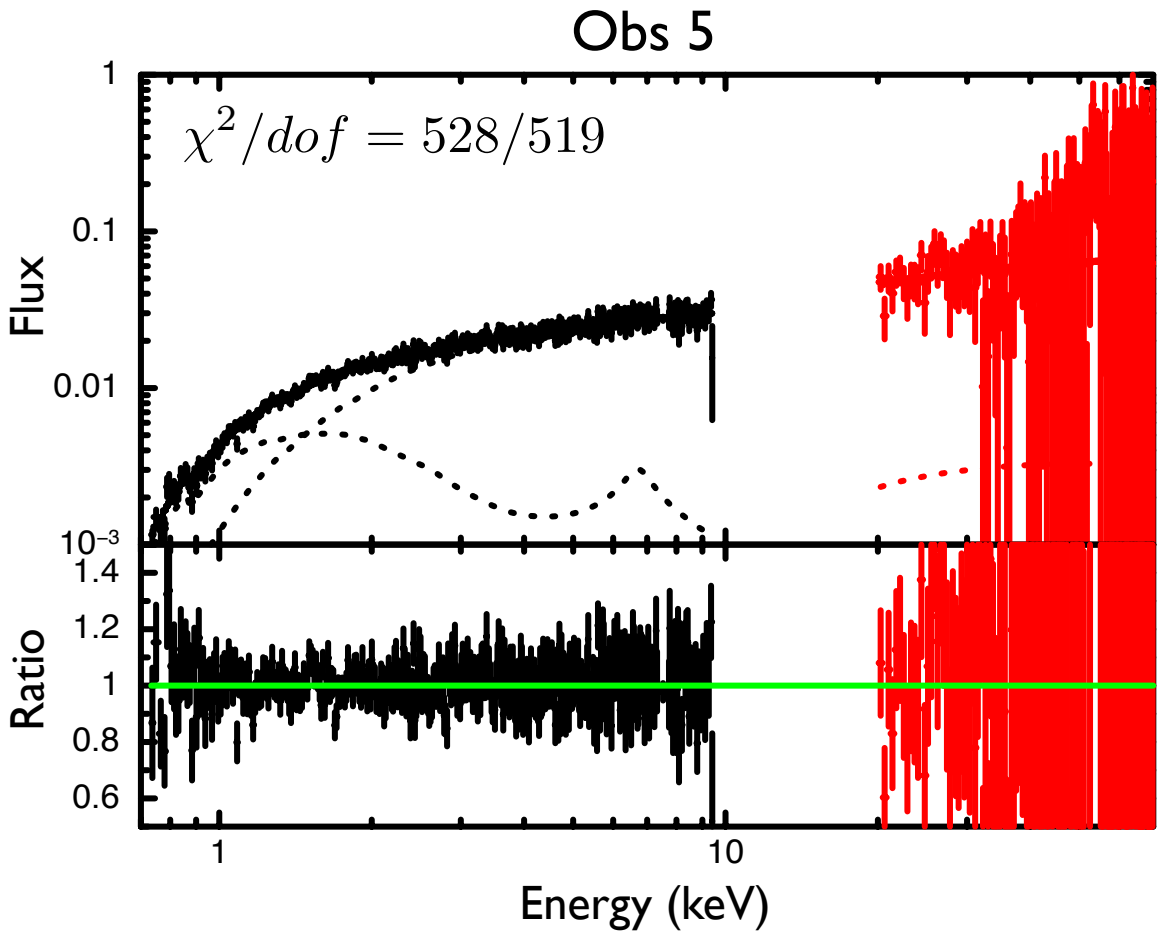

Obs 2
$\chi^2/dof = 618/546$
Flux
1
0.1
0.01
$10^{-3}$
Ratio
1.4
1.2
1
0.8
0.6
1
10
Energy (keV)

Addition of a component (power-law) at low energy



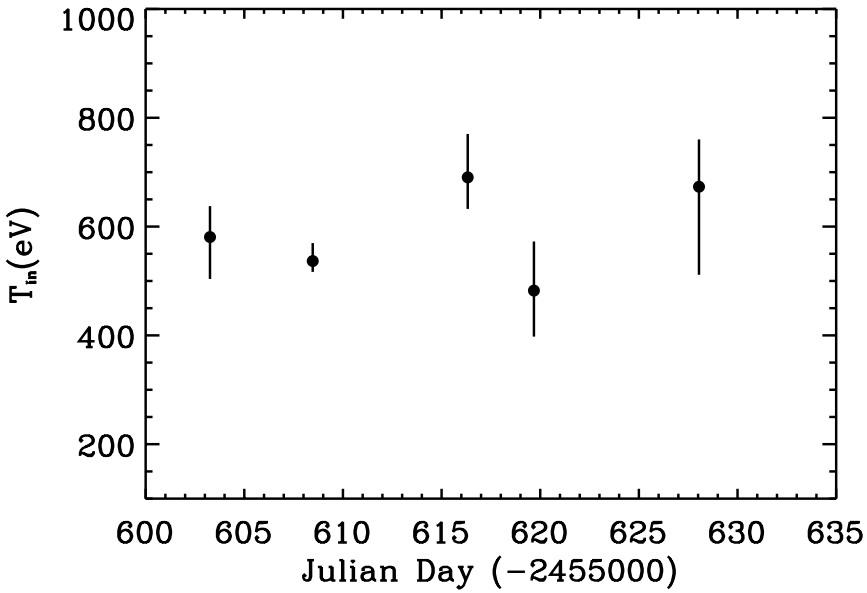

Obs 3
$\chi^2/dof = 590/557$
Flux
1
0.1
0.01
$10^{-3}$
Ratio
1.4
1.2
1
0.8
0.6
1
10
Energy (keV)


Obs 4
$\chi^2/dof = 604/550$
Flux
1
0.1
0.01
$10^{-3}$
Ratio
1.4
1.2
1
0.8
0.6
1
10
Energy (keV)

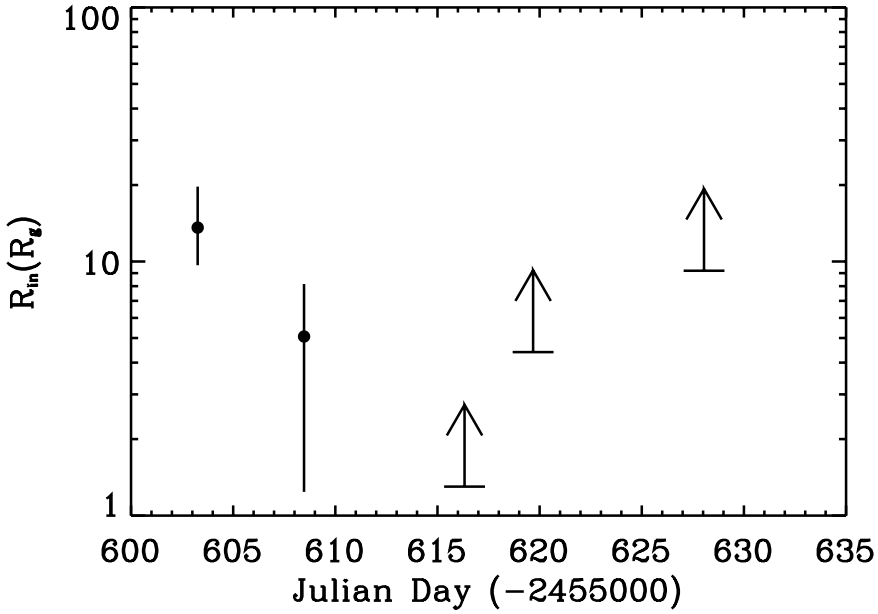

Obs 5
$\chi^2/dof = 528/519$
Flux
1
0.1
0.01
$10^{-3}$
Ratio
1.4
1.2
1
0.8
0.6
1
10
Energy (keV)

# Disk parameters

## Disk temperature (from REFBHB)

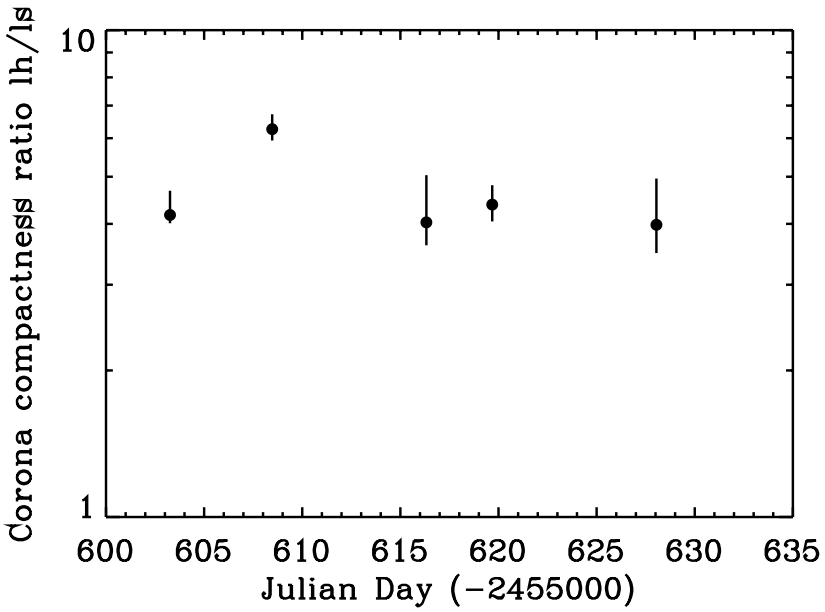



## Disk inner radius (from blurring)



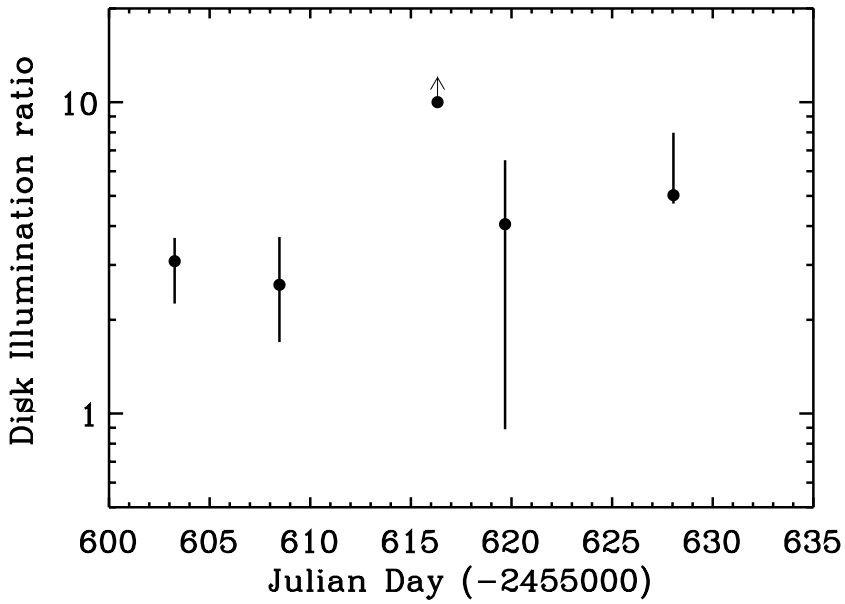
# “Geometrical” parameters

## Heating/cooling Hot corona




- Photon starved geometry
- weak change of the geometry

## Disk Illumination ratio




- The disk surface dominated by X-ray illumination

# Conclusions

- Data agrees with comptonization+reflection models
- Need of an additional component in the soft X: bad model or jet signature?
- No conclusive results on disk recession. The disk can still be present down to a few Rg but becomes less luminous
- Next step: Broad band Radio-OIR-X