Probing multi-phase AGN outflows with high-resolution spectroscopy

Using variability as a tool

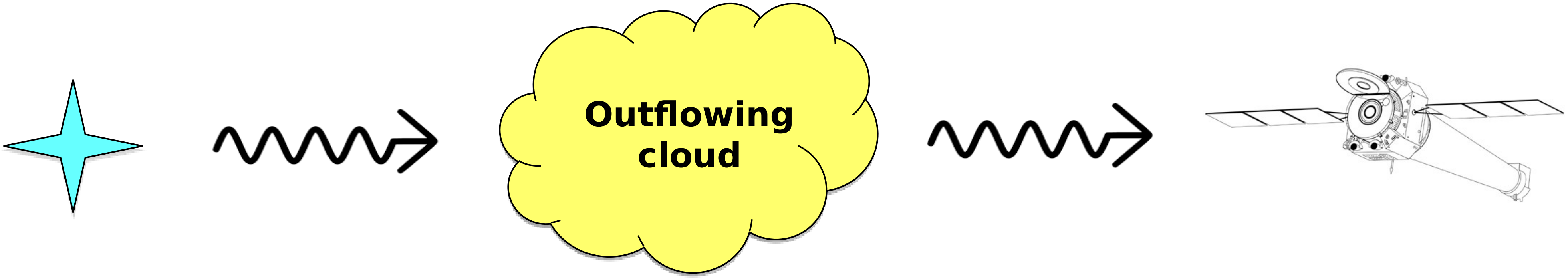
Missagh Mehdipour

Collaborators:
Jerry Kriss, Jelle Kaastra, Elisa Costantini, Daniele Rogantini, Junjie Mao, and many others

STScI | SPACE TELESCOPE SCIENCE INSTITUTE

Chandra Workshop, 2023-08-02

Photoionization in AGN



SED modeling

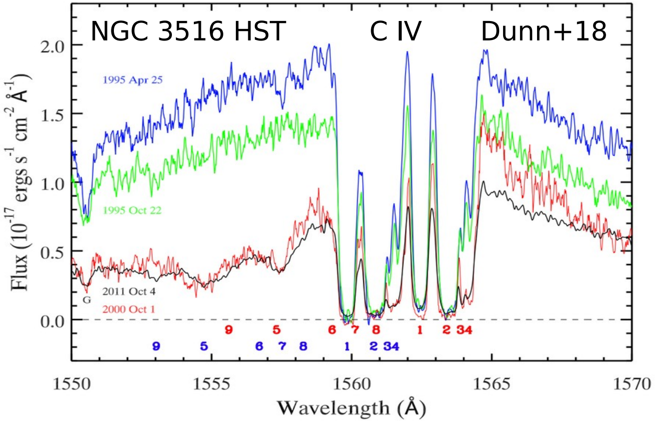
Photoionization modeling

High-resolution spectroscopy

Multi-wavelength spectral view of outflows

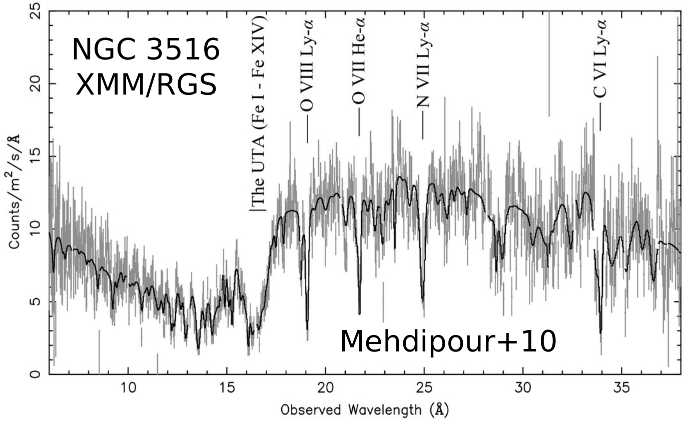
UV

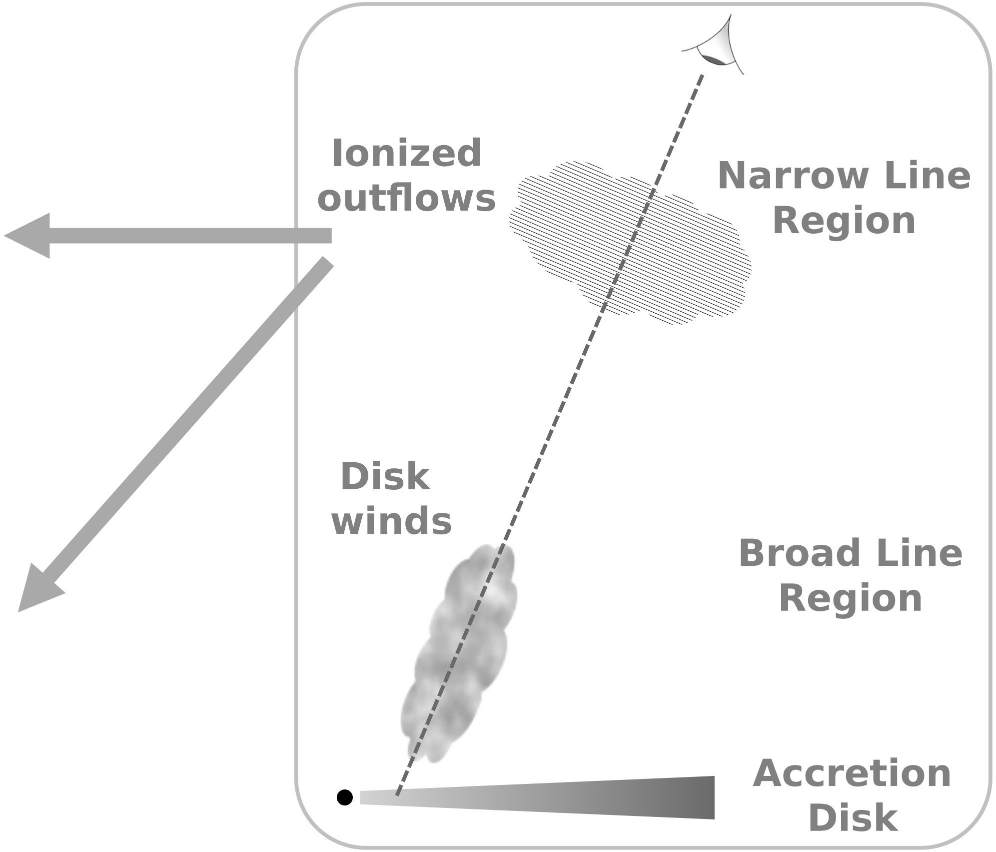
Narrow multi-component UV lines



X-ray

Multi-component "warm-absorbers"

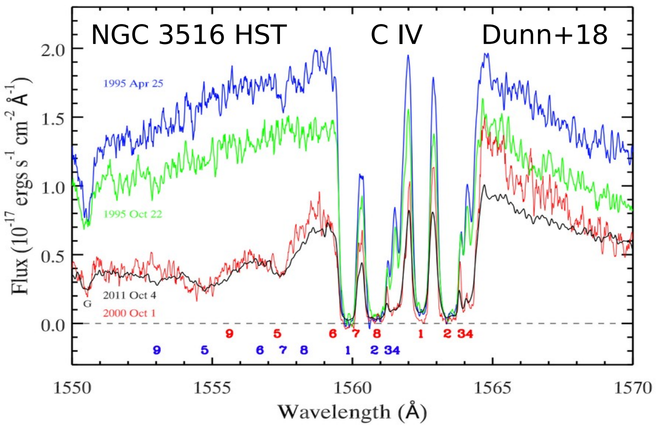




Multi-wavelength spectral view of outflows

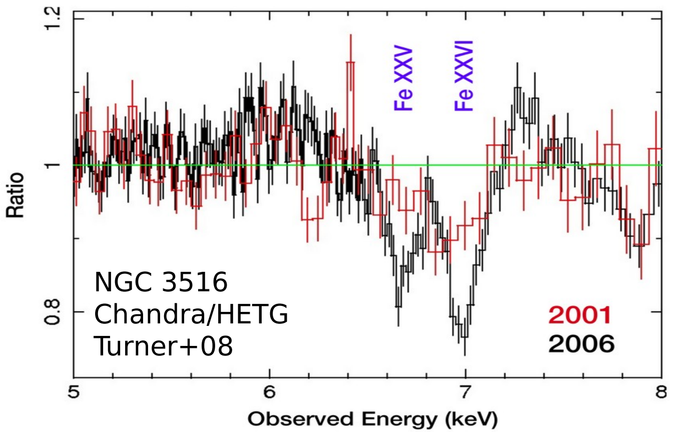
Narrow multi-component UV lines

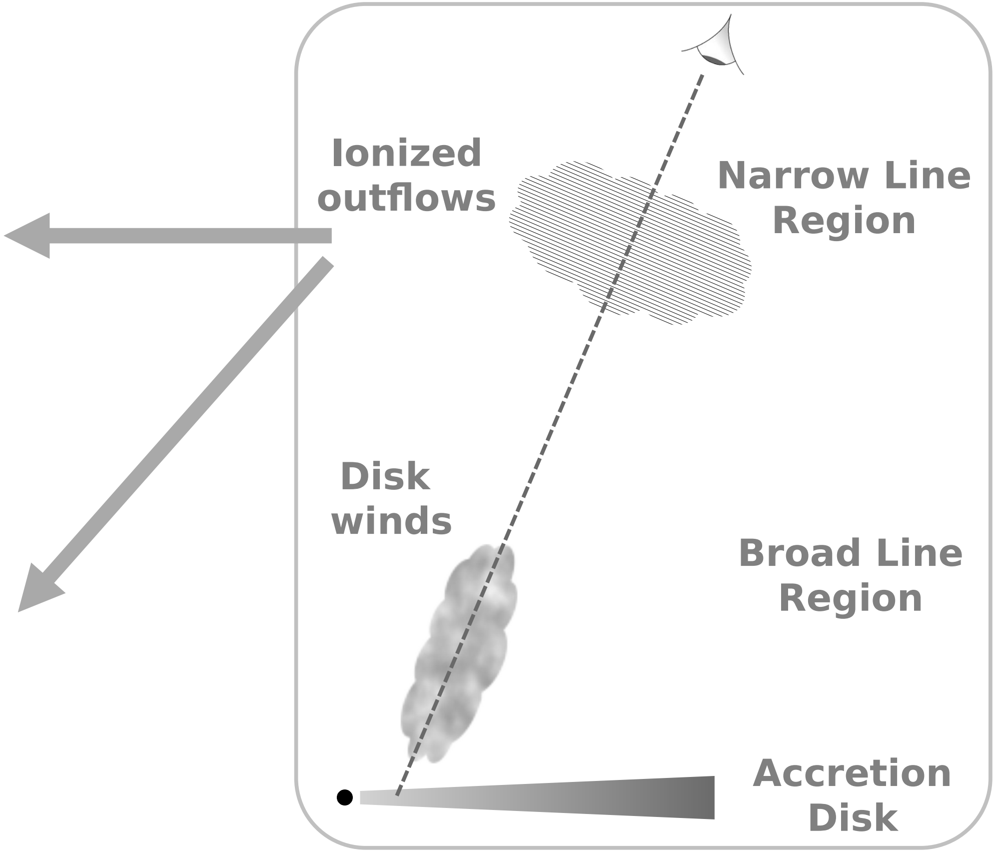
UV



Highly-ionized outflows with moderate v_{out}

X-ray

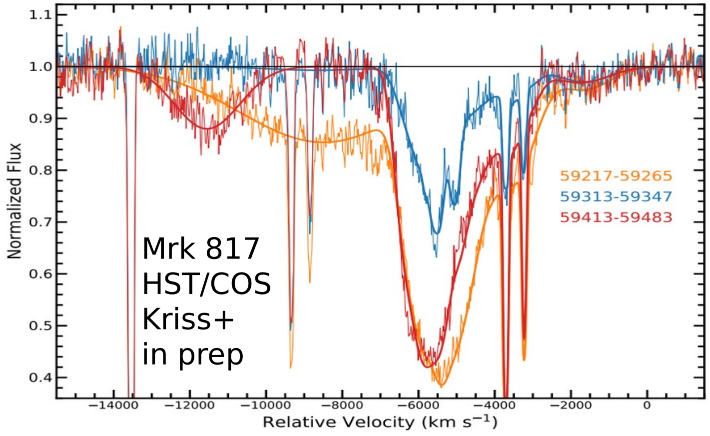




Multi-wavelength spectral view of outflows

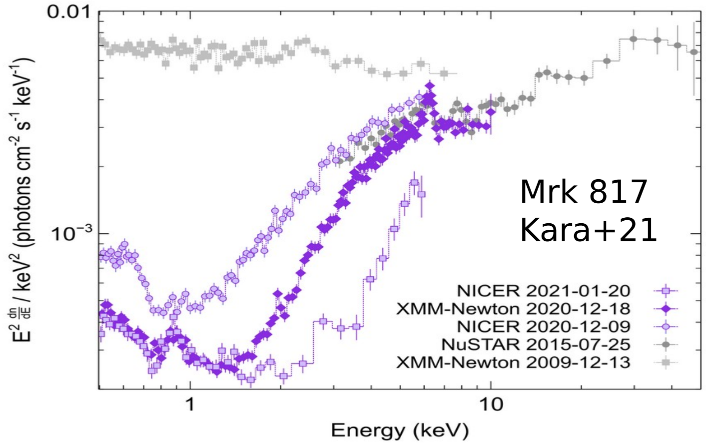
UV

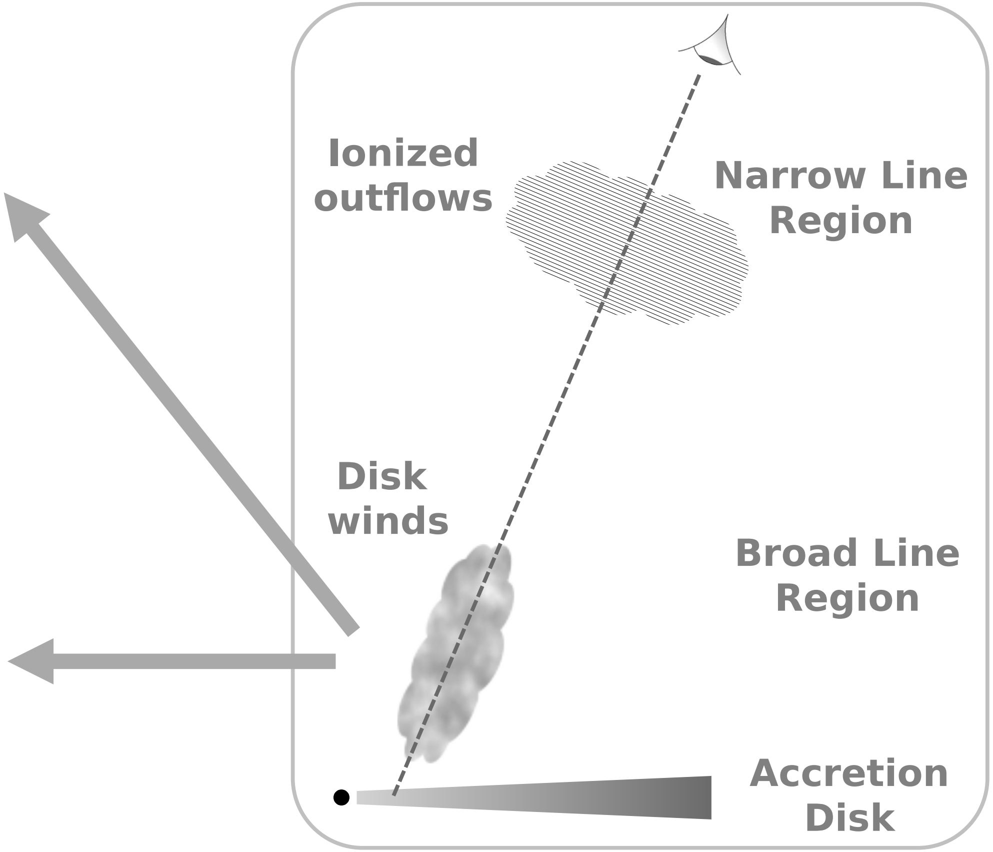
Broad blueshifted UV lines



X-ray

Transient X-ray obscuration

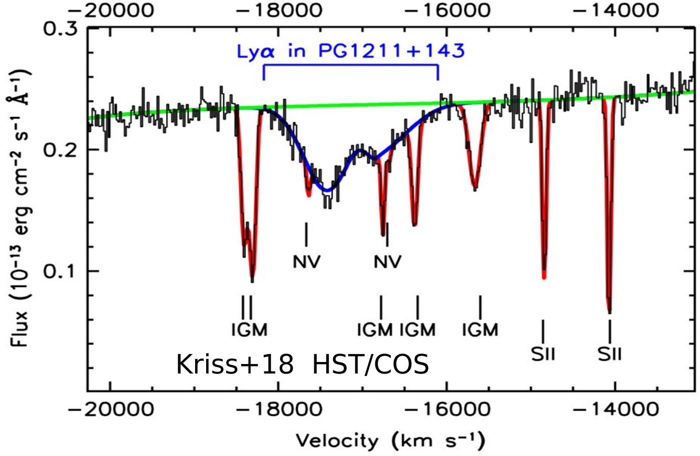




Multi-wavelength spectral view of outflows

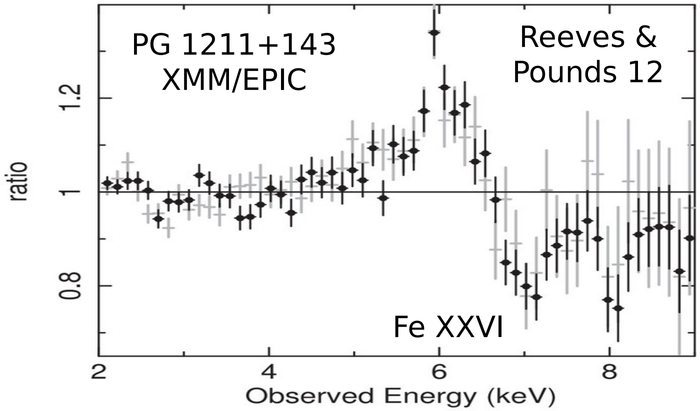
UV

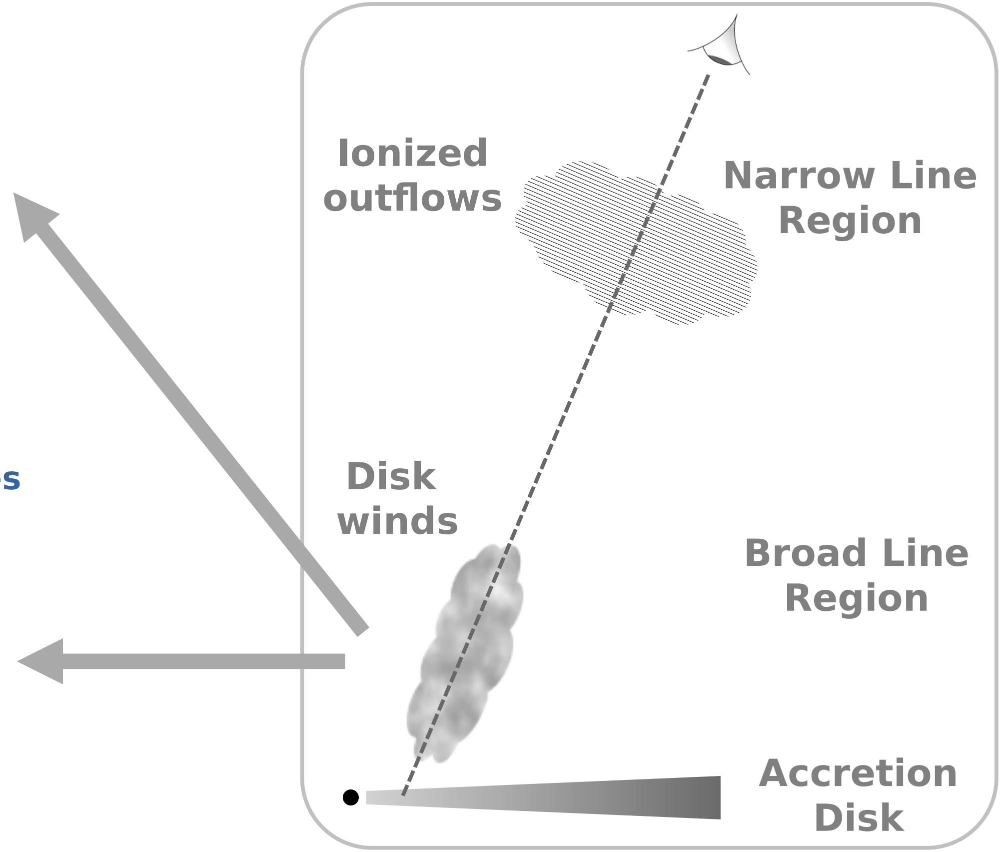
UV counterpart of X-ray ultrafast outflows (UFOs)



X-ray

X-ray UFOs with relativistic outflow velocities

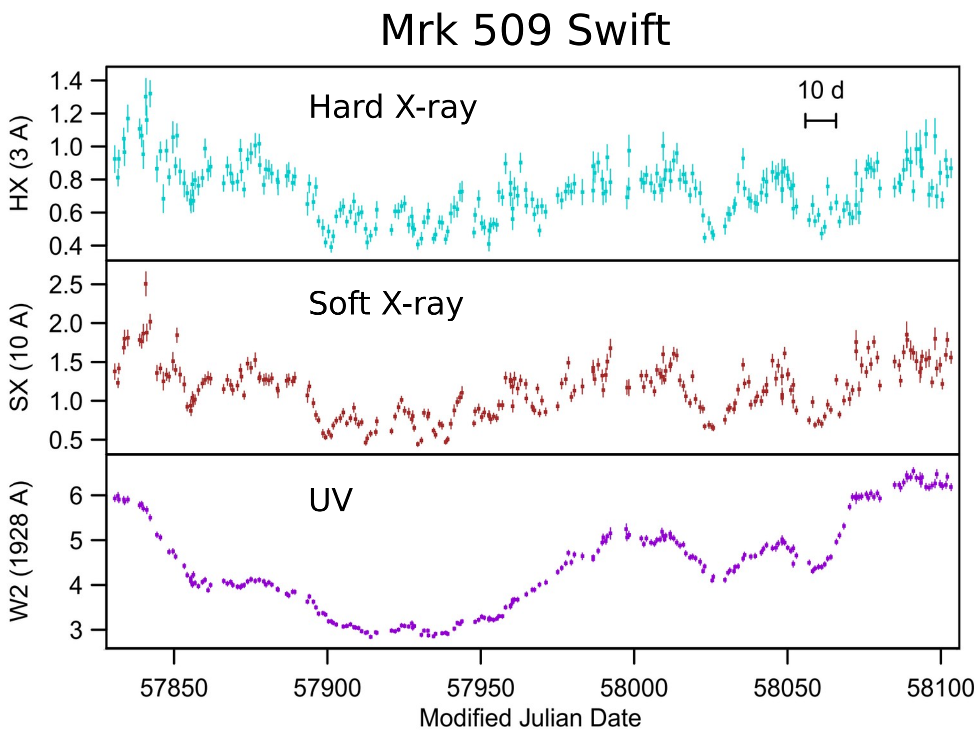


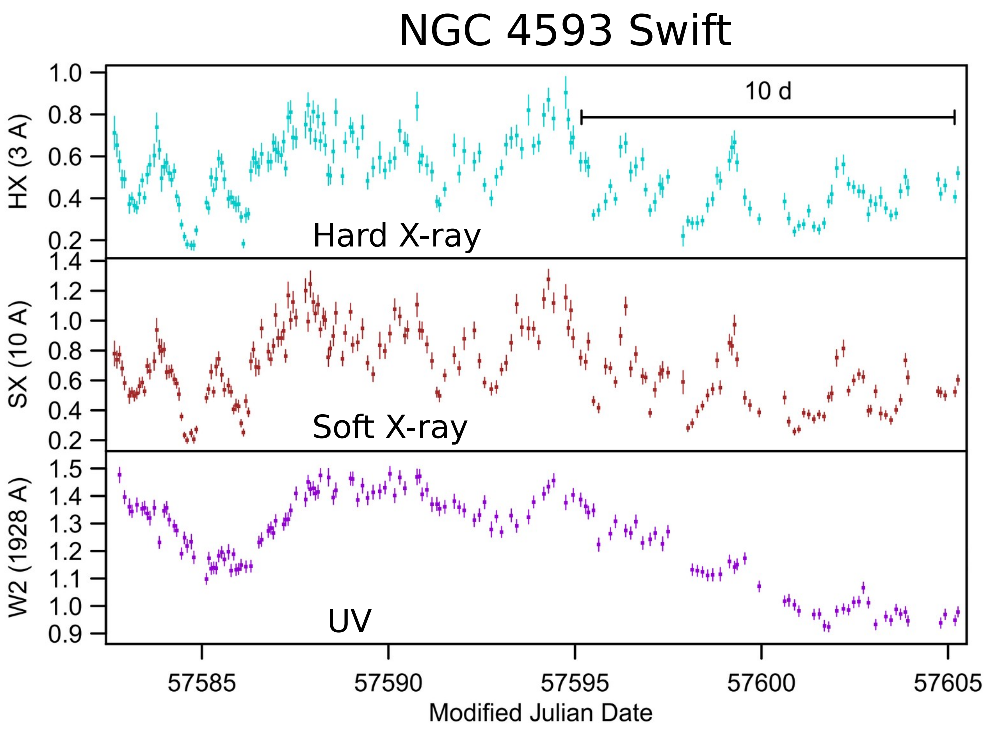


Questions

- **Kinematical & dynamical structure of outflows?**
  How the multiple ionization & velocity components are formed?
- **Are different forms/types of outflows related to each other?**
  What is the connection between outflows in the BLR & NLR?
- **Do they have common or different origin & driving mechanism?**
- **Which wind parameters vary over time and produce the observed spectral variability?**
- **How wind parameters scale with redshift and the AGN properties such as luminosity?**
- **How the energy & momentum of outflows propagate into the galaxy and what are their impact?**

Variability is a useful characteristic of AGN



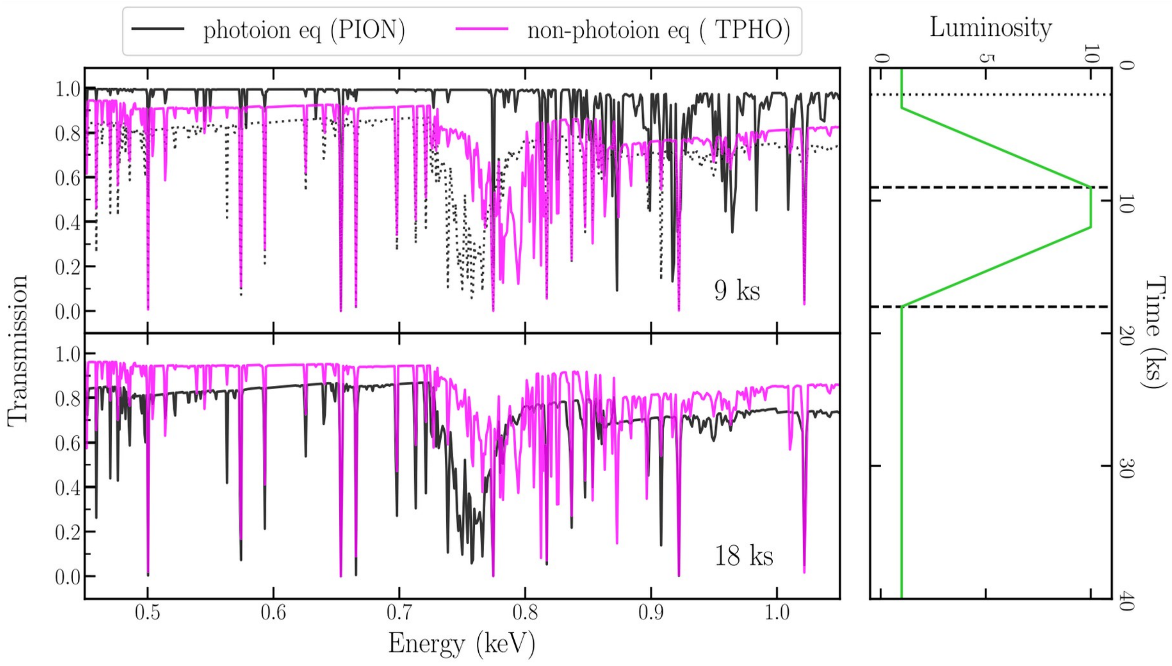


Edelson+19

Joint X-ray/UV/optical monitoring with Swift is helpful for <u>disk</u>, <u>corona</u>, and <u>wind</u> studies

Making use of variability to probe winds in AGN

Timing response of outflows via time-dependent photoionization modeling



Rogantini+22
SPEX code

Important for measuring density & location of outflows, and thus their energetics

Kinetic luminosity

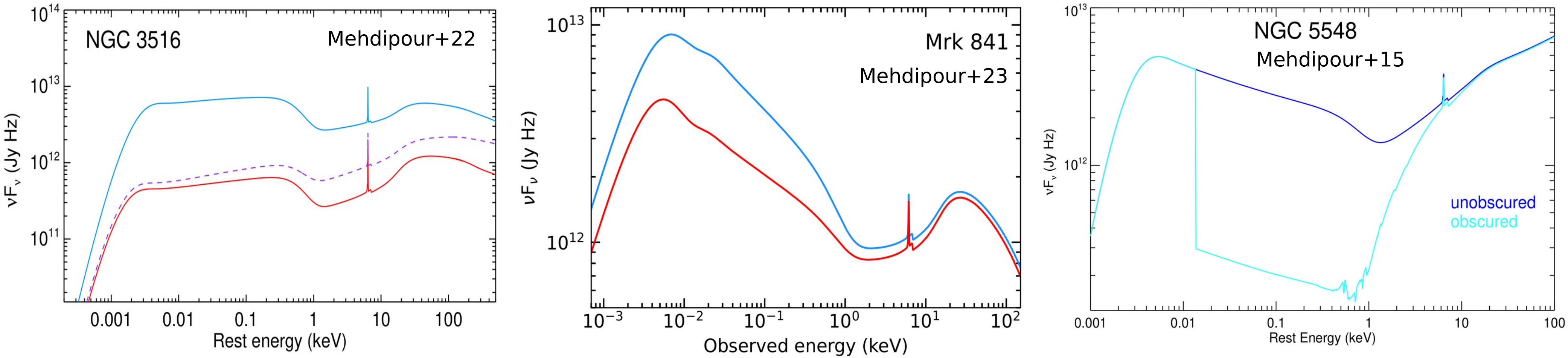
$$L_k = 1/2\ \dot{M}_{out}\ v_{out}^2$$

$$\dot{M}_{out} = \Omega R N_H \mu m_p v_{out}$$

See also Sadaula+23, Luminari+22

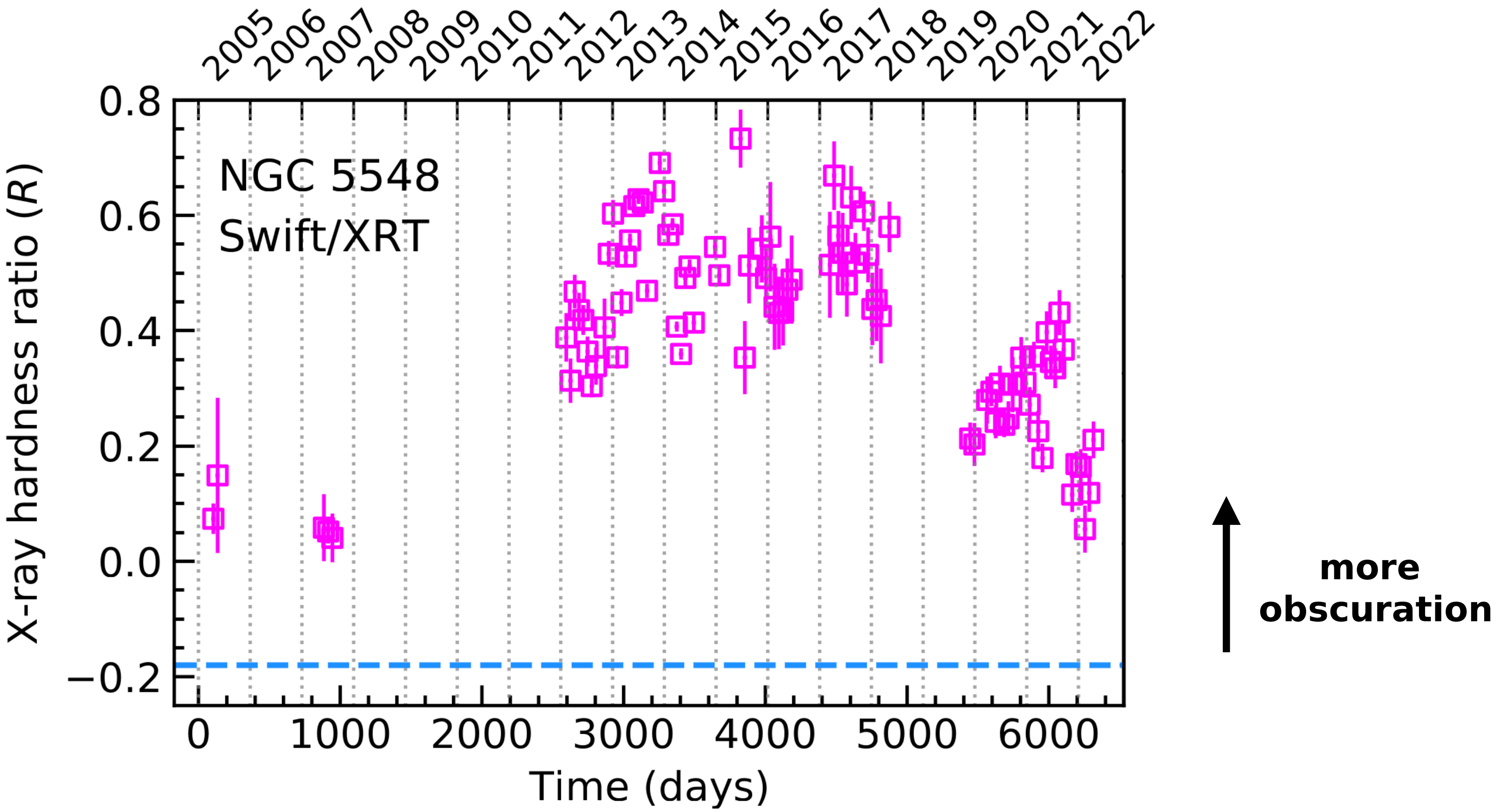
Knowledge of the SED and how it varies is essential

Different SED variations have different impacts



Multi-wavelength spectral coverage is needed for modeling of the <u>continuum</u> and <u>outflows</u> (their studies are intertwined)

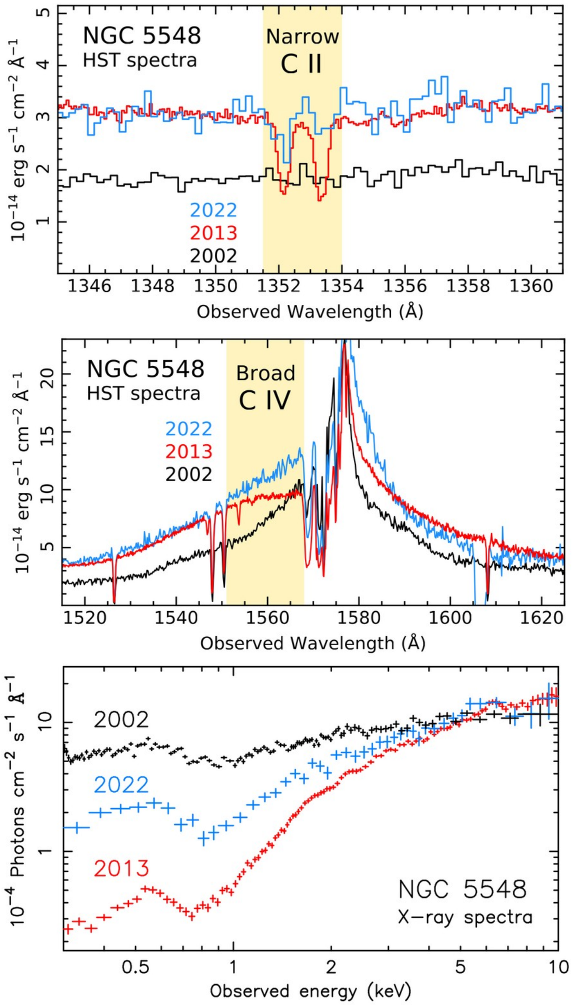
Long-term X-ray spectral hardness variability

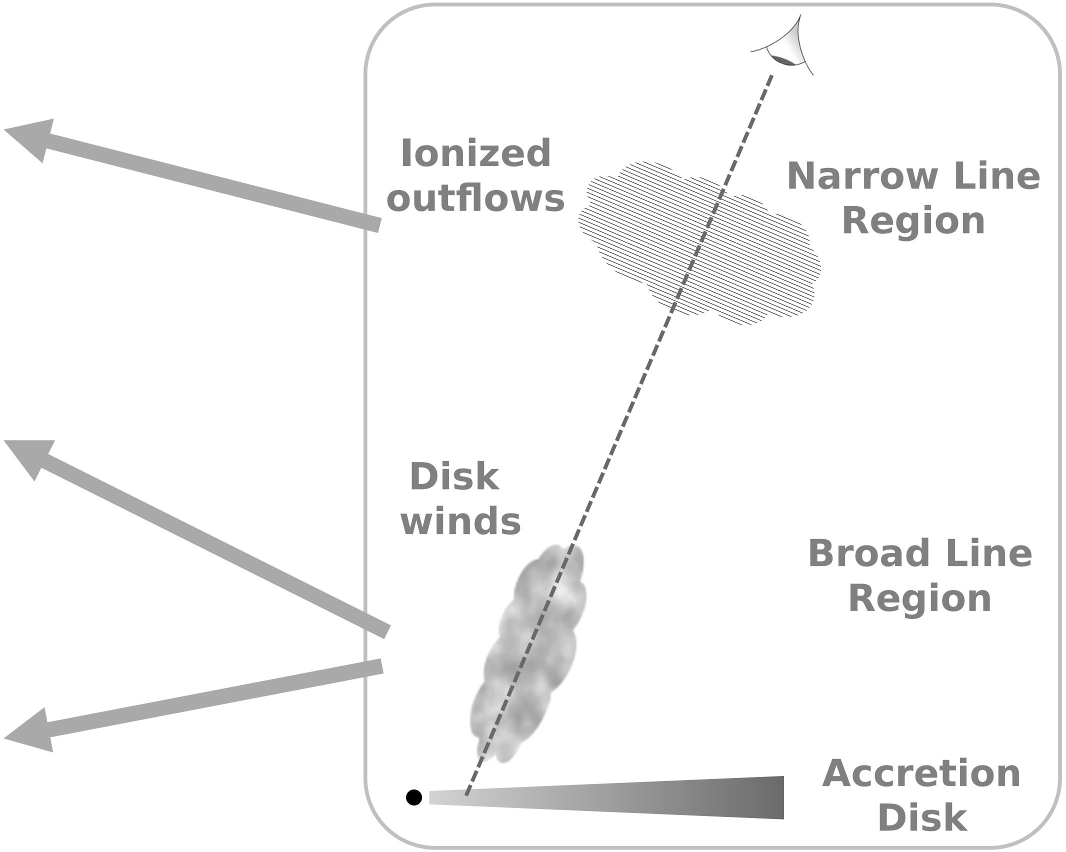


Mehdipour+22

Rise and decline in X-ray obscuration, evolution of a disk wind

Link between X-ray obscuration and BLR winds

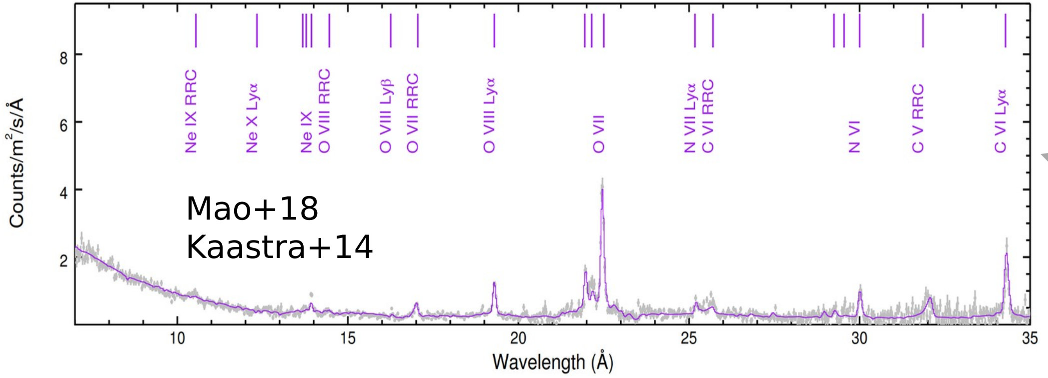




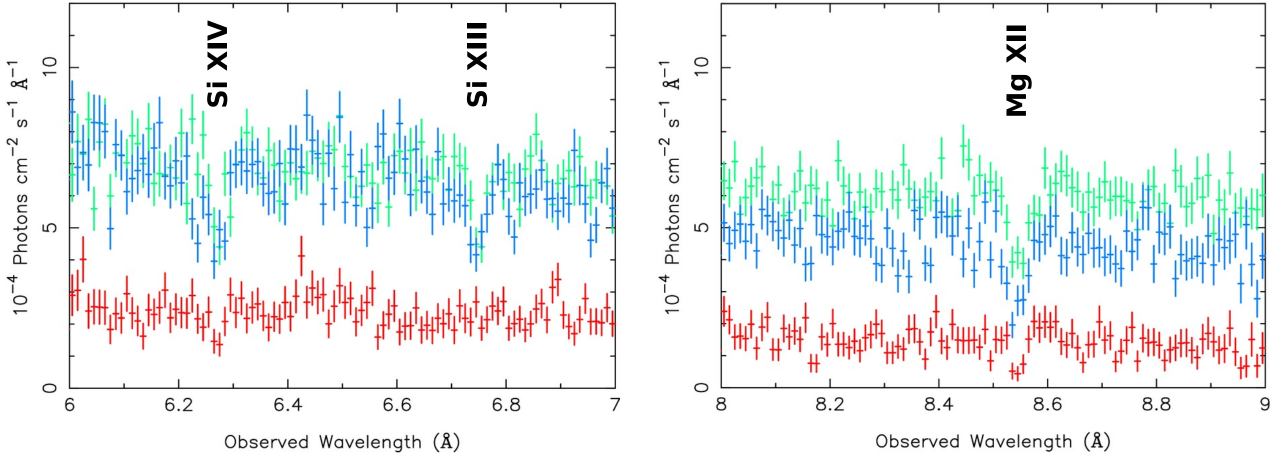
Mehdipour+22

High-resolution X-ray spectral view of obscuration

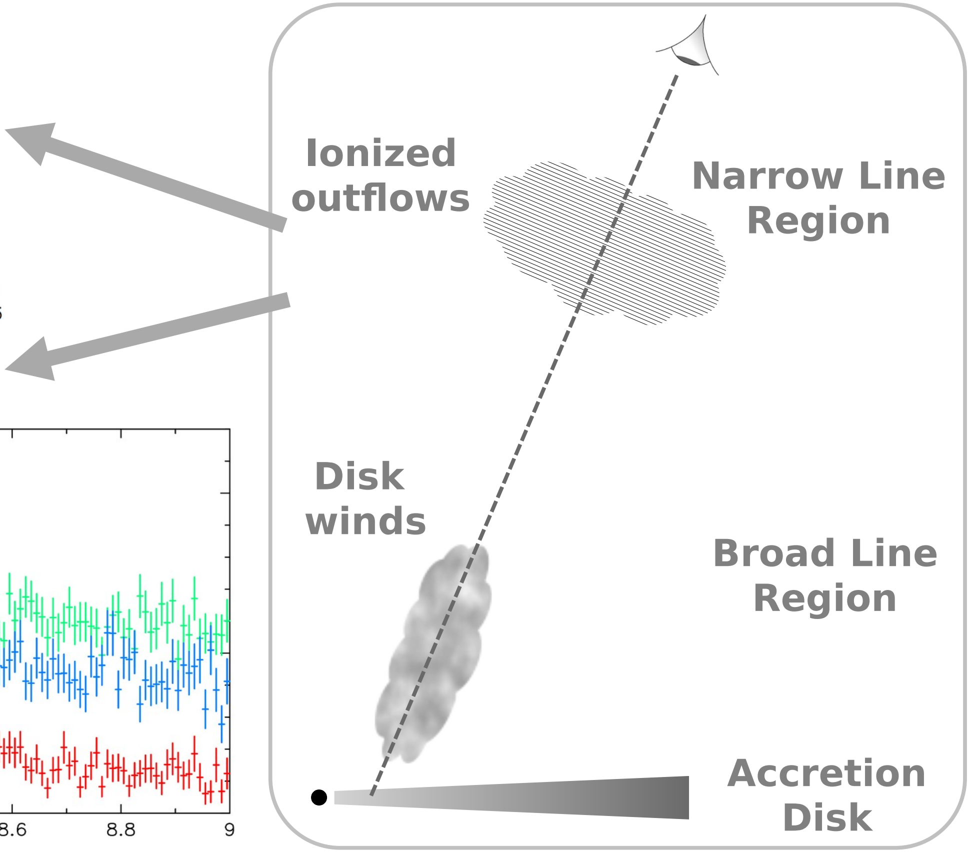
NGC 5548 XMM/RGS



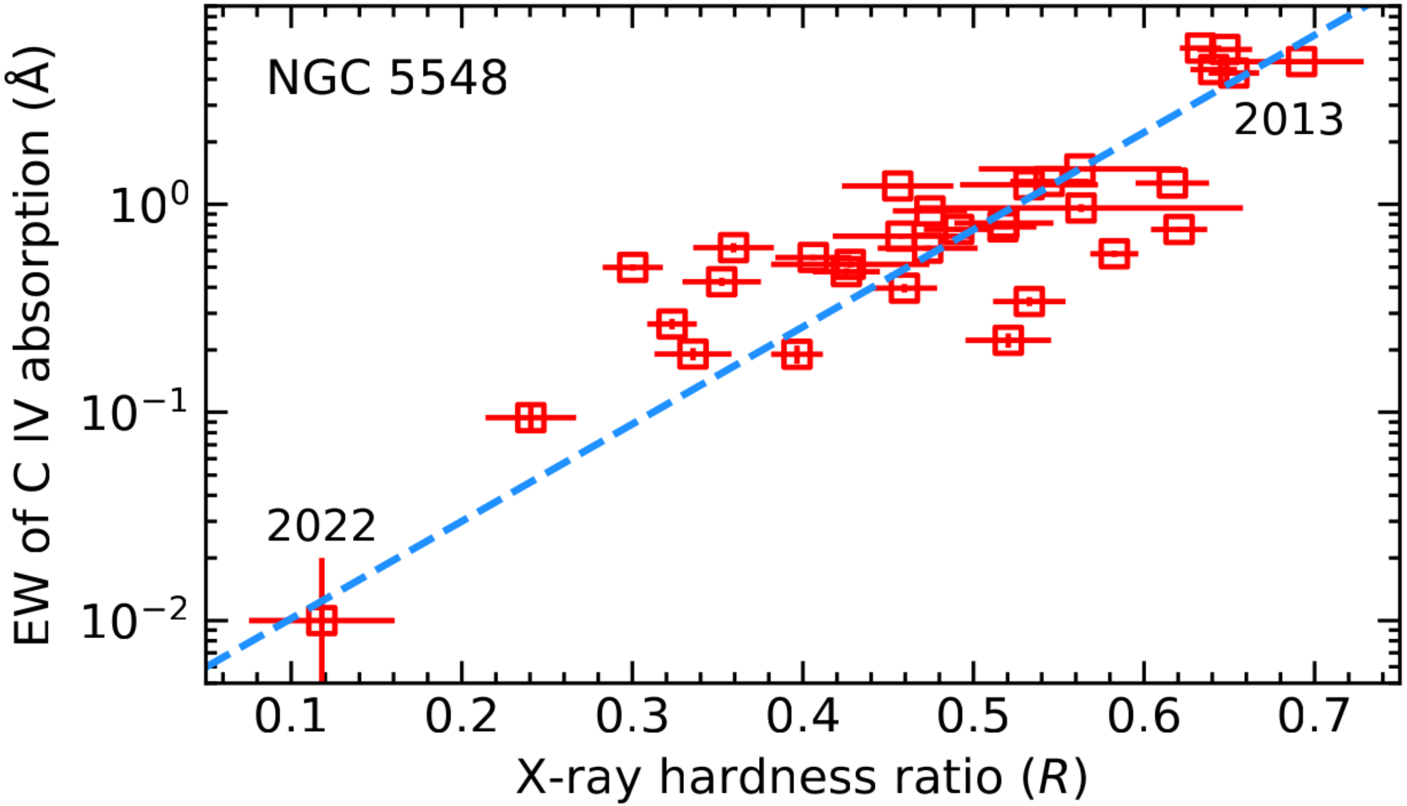
NGC 5548 Chandra/HETG



Mehdipour+in prep

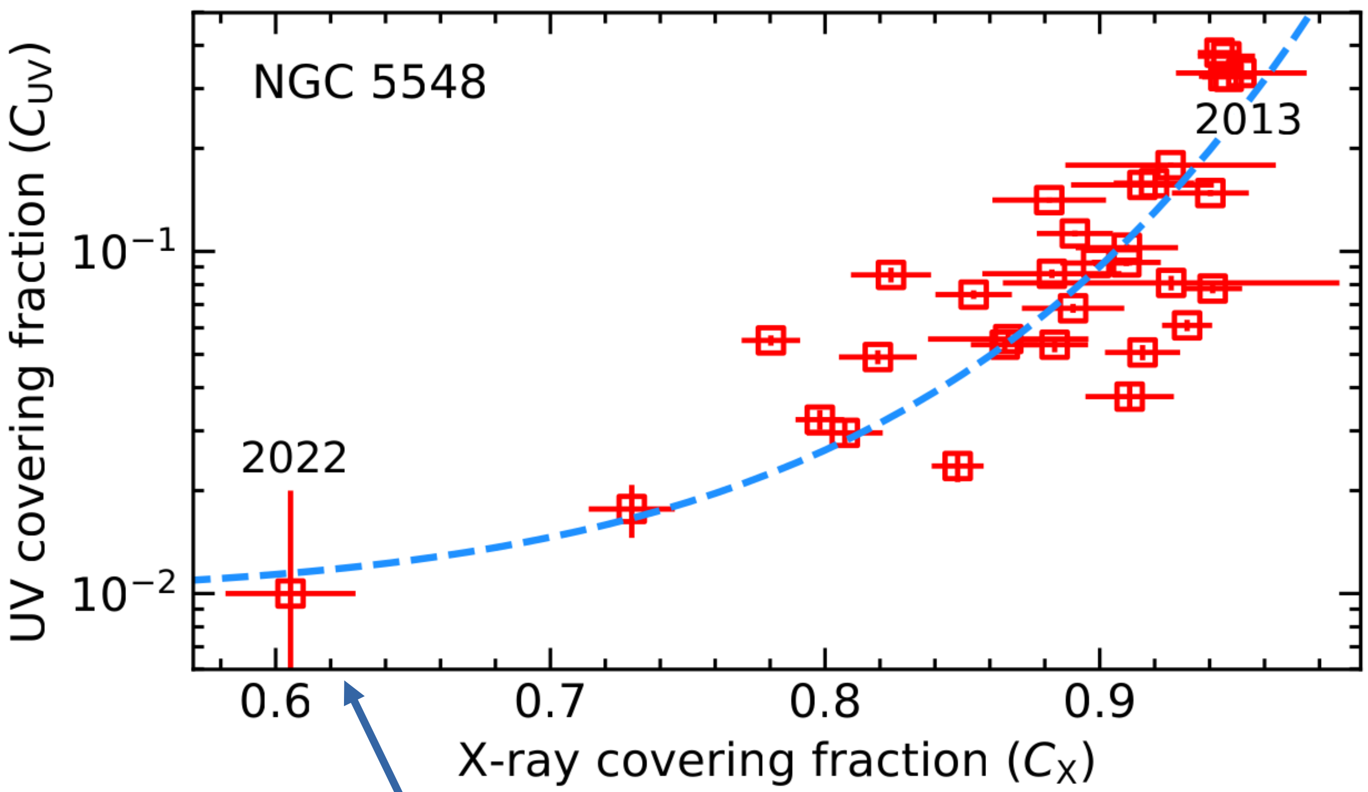


Link between X-ray obscuration and BLR winds



Mehdipour+22

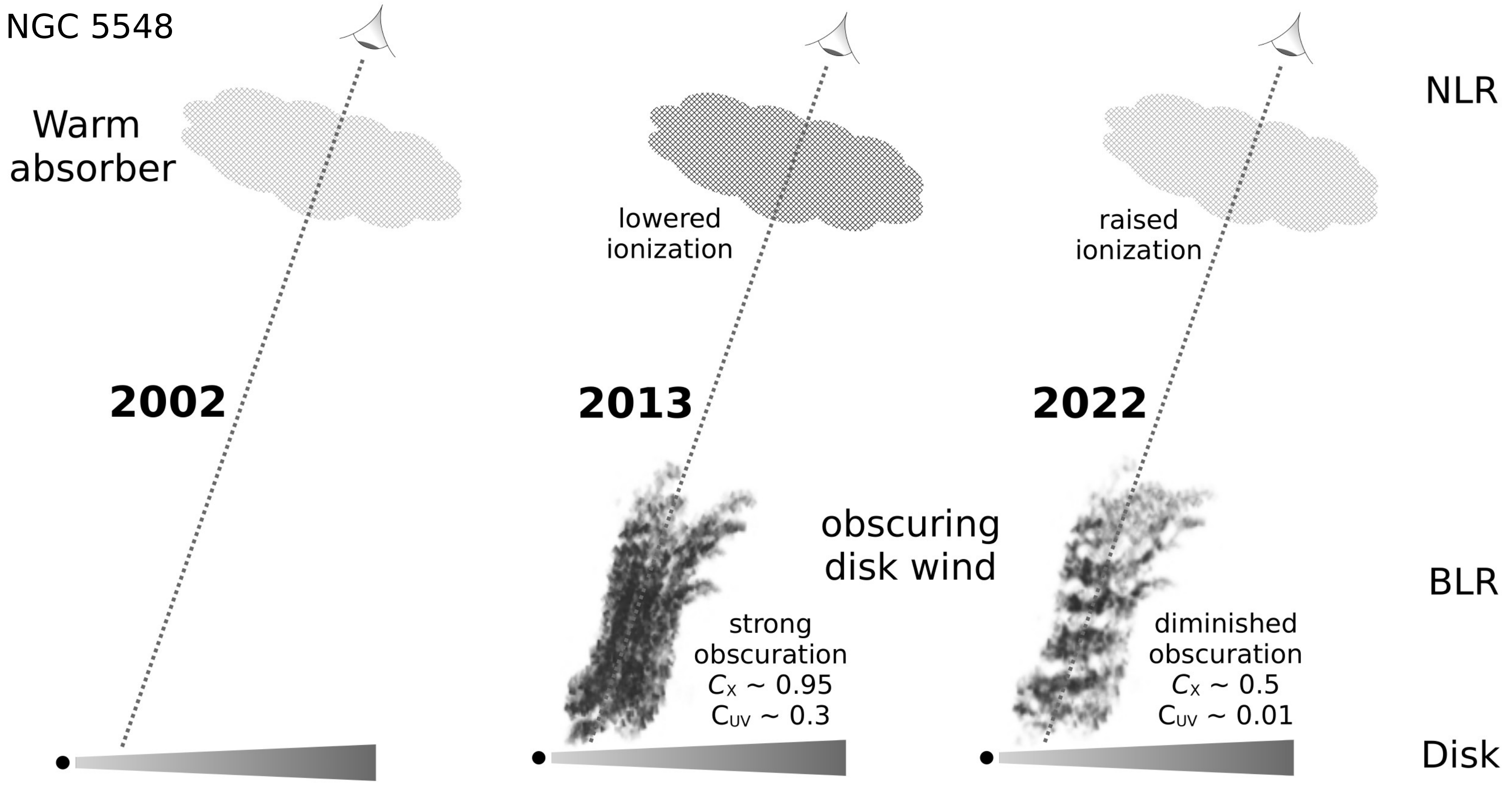
Relation between the UV and X-ray covering fractions of the wind



Mehdipour+22

Broad UV absorber nearly vanishes while still significantly X-ray obscured, this could explain why in some obscuration events (like in NGC 3227) the broad UV absorber is not detected

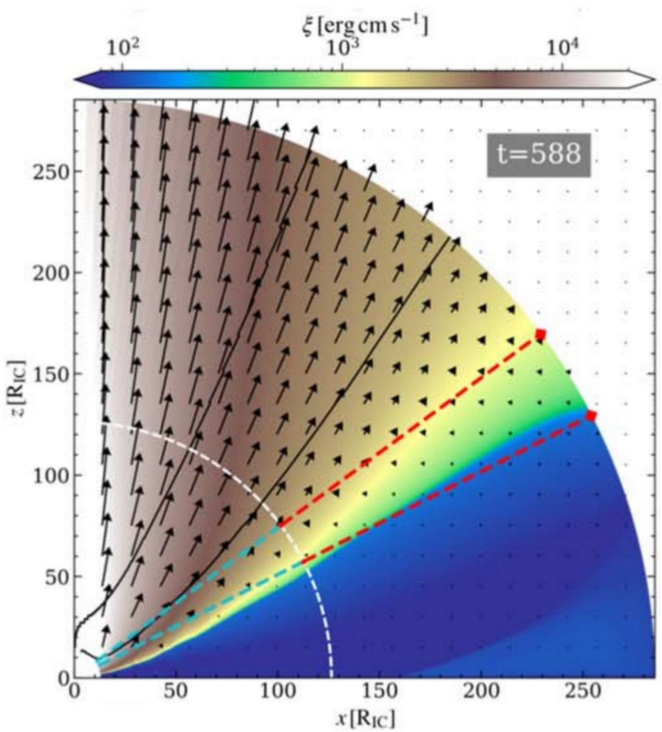
Evolution of an obscuring disk wind: an episodic ejection?

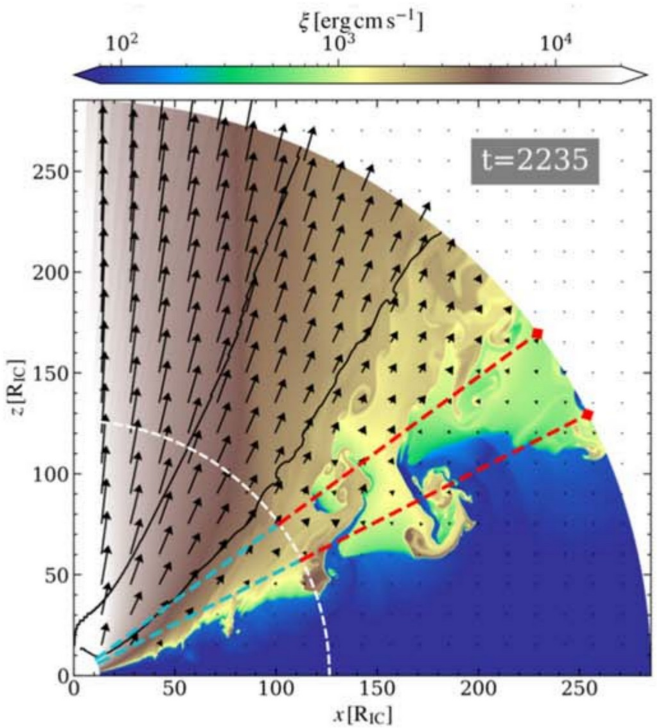


Mehdipour+22

Intrinsic SED shape and luminosity remain unchanged at all epochs

A clumpy multi-phase outflow is needed





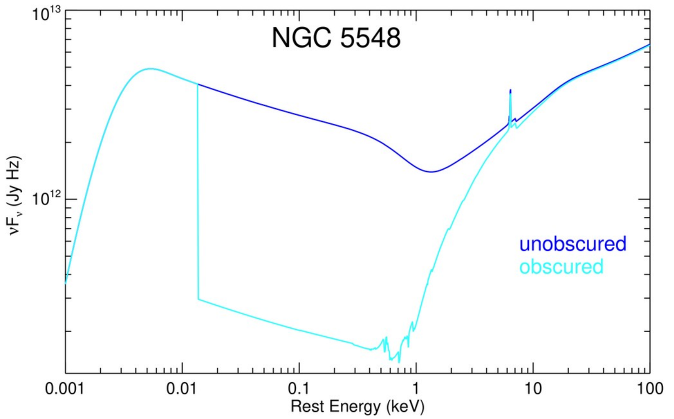
Waters+21

Thermal instabilities lead to a clumpy multi-phase outflow

But what triggered the ejection (obscuration) in the archetypal unobscured NGC 5548 is still uncertain

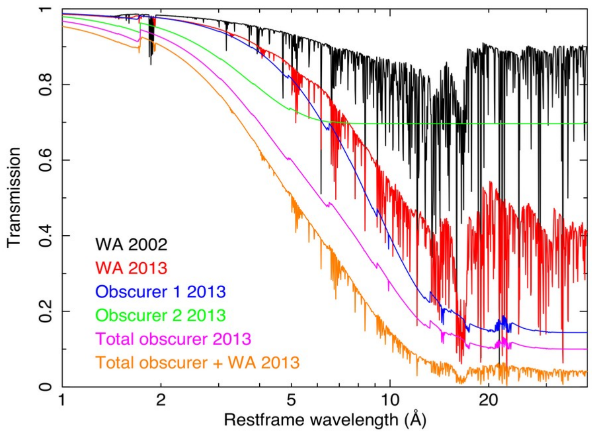
Consequences of inner obscuration shielding outer outflows

The obscured SED would irradiate the surrounding gas



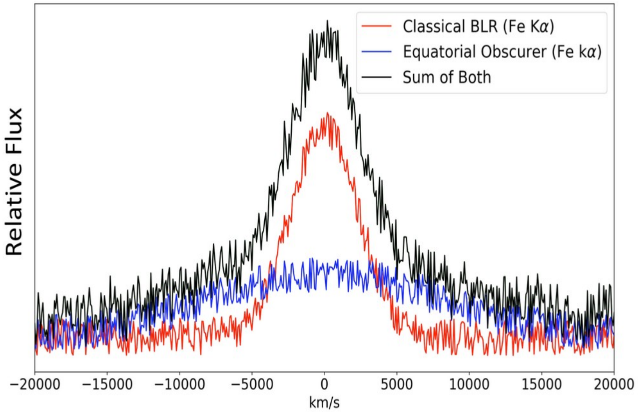
Mehdipour+15

Enhanced X-ray absorption by less-ionized warm-absorber outflows



Kaastra+14

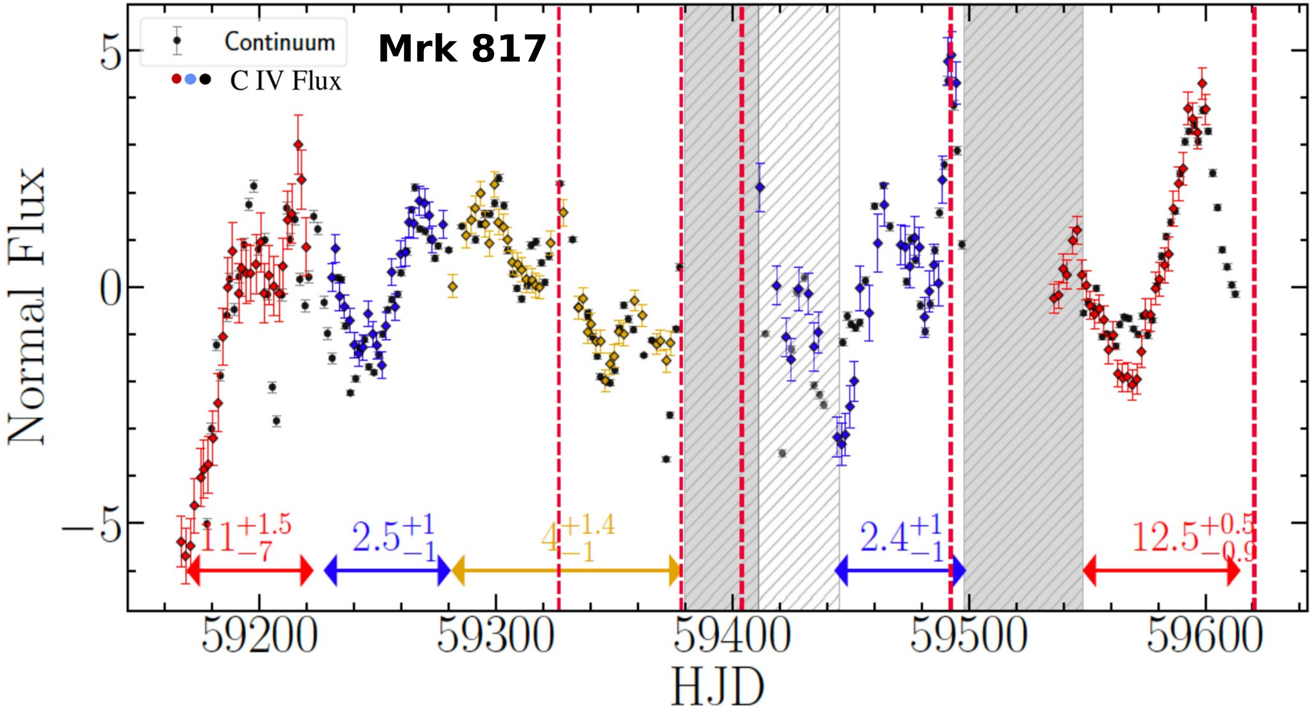
The obscurer contributes to the emission lines



Dehghanian+20

Consequences of inner obscuration shielding outer outflows

Homayouni+23



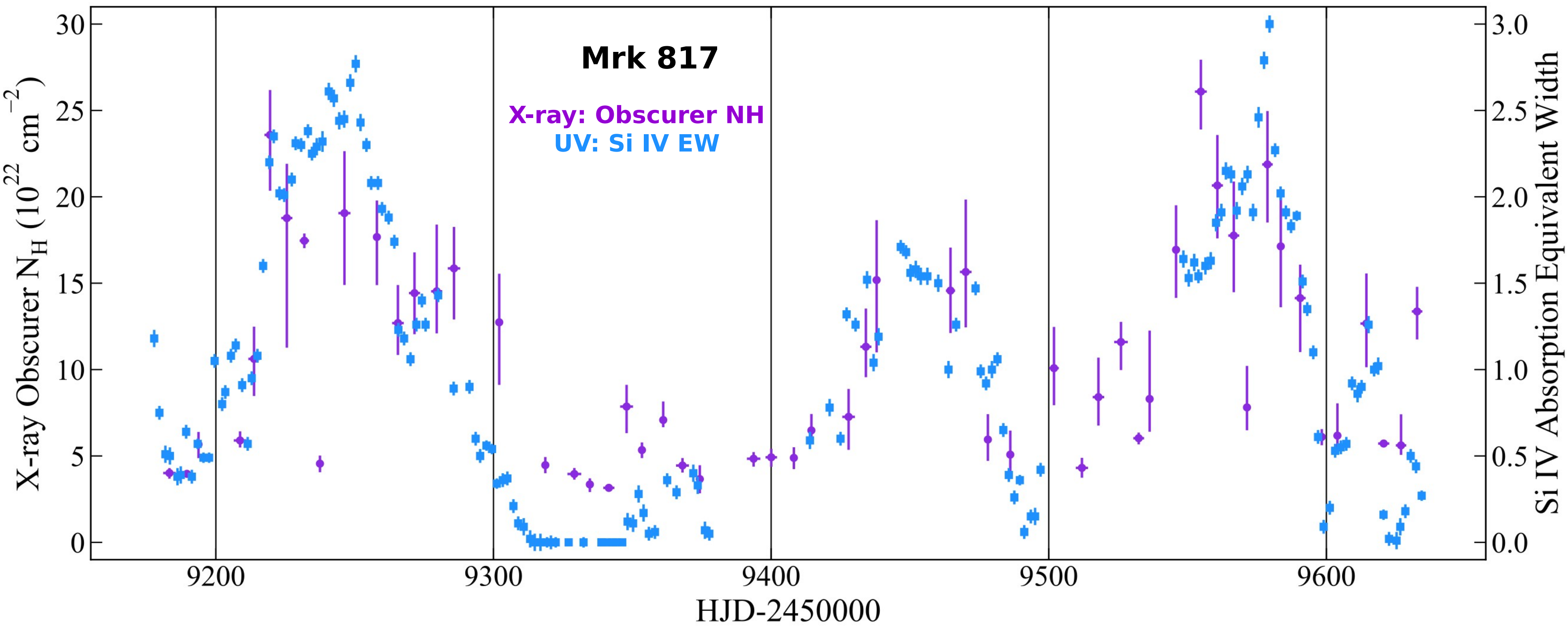
X-ray obscuration impacts the lags of the UV emission

Longer lags (lower responsivity) correspond to time intervals of stronger X-ray obscuration

Implications for reverberation mapping & BH mass measurement

X-ray obscuration in NGC 5548 was also responsible for anomalous variability behavior of UV emission lines, the so-called "BLR holiday" (Dehghanian+19,20,21)

Joint evolution of the X-ray obscurer and broad UV absorber

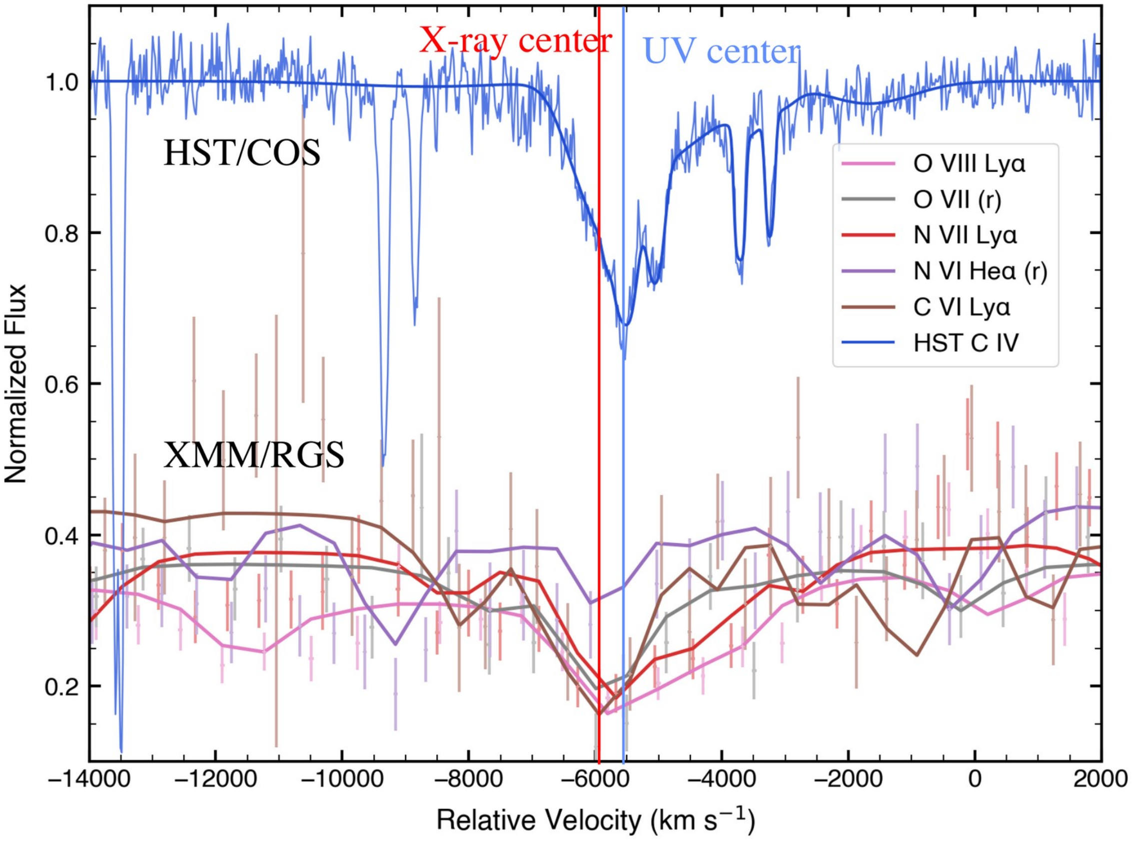


Column density changes in the obscurer drive the X-ray/UV variability

Partington+23

Kinematic correspondence between the X-ray obscurer and UV absorber

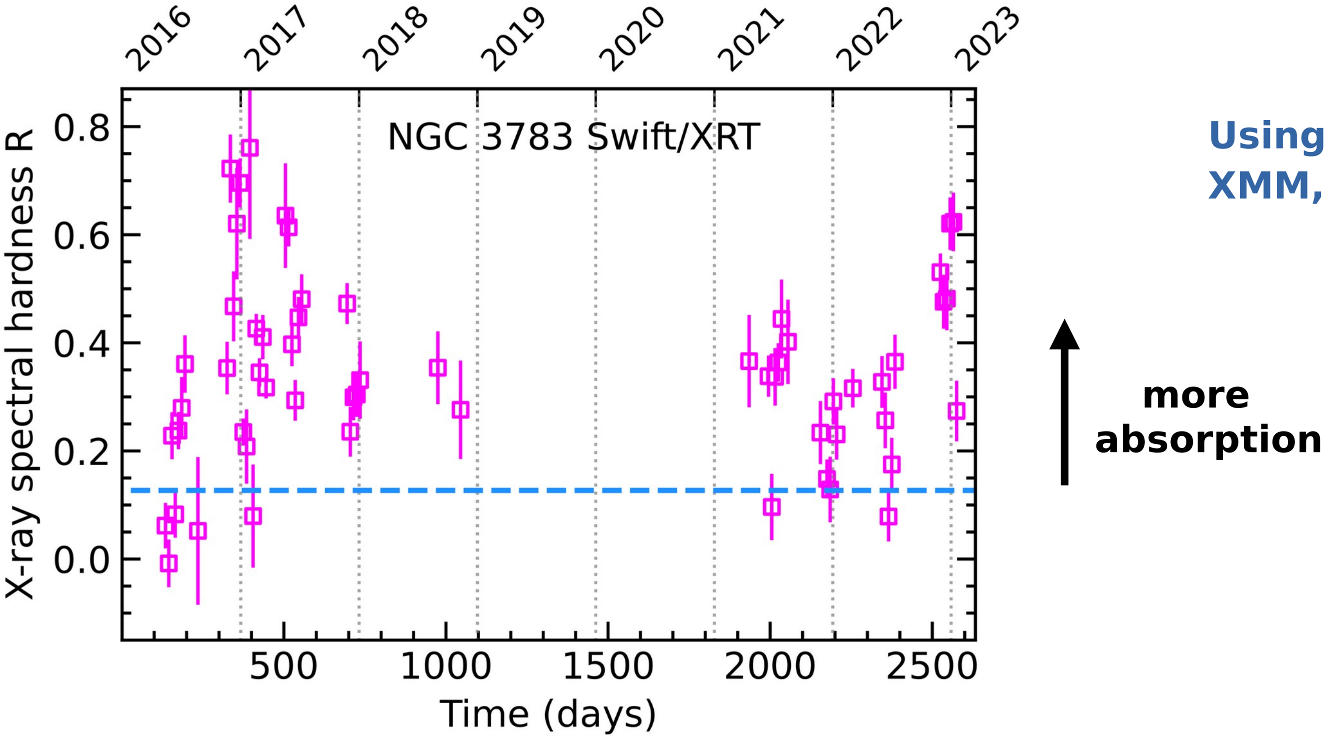
Mrk 817



Zaidouni+
in prep

See her talk

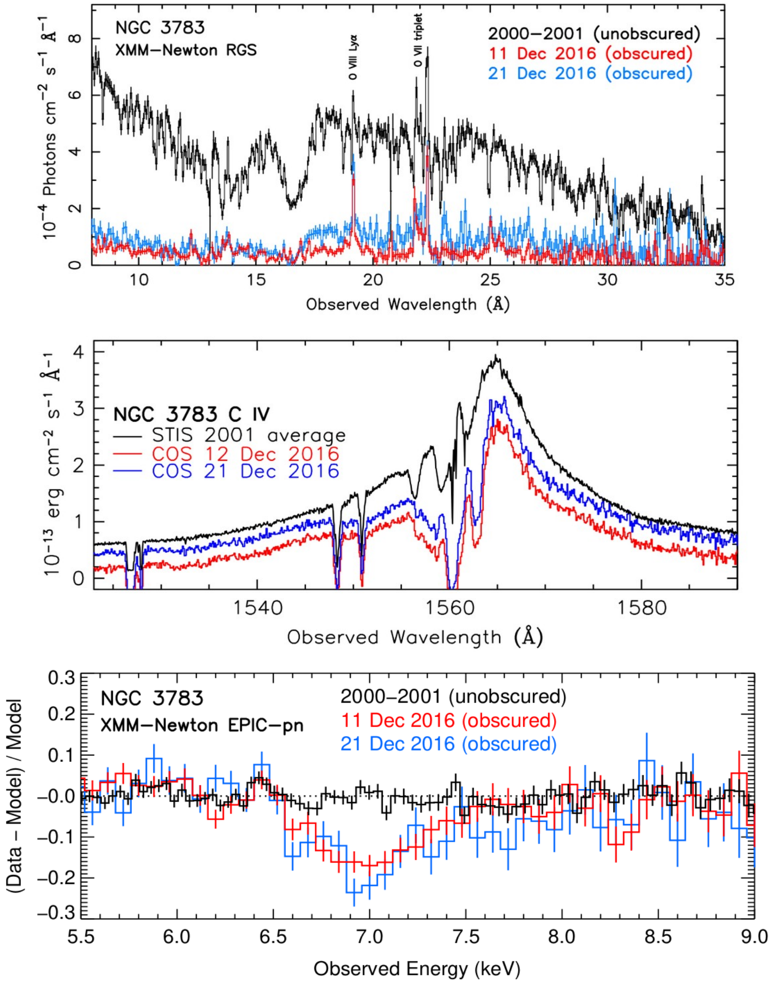
Catching transient obscuration events with Swift



Using Swift to trigger XMM, NuSTAR, and HST

See obscuration events in Mrk 335 (Longinotti+13), NGC 985 (Ebrero+16), NGC 3783 (Mehdipour+17), Mrk 817 (Kara+21), NGC 3227 (Mehdipour+21), NGC 5548 (Mehdipour+22), MR 2251-178 (Mao+22), and Markowitz+14 RXTE sample

Link between UV and high-ionized X-ray absorbers



Mehdipour+17

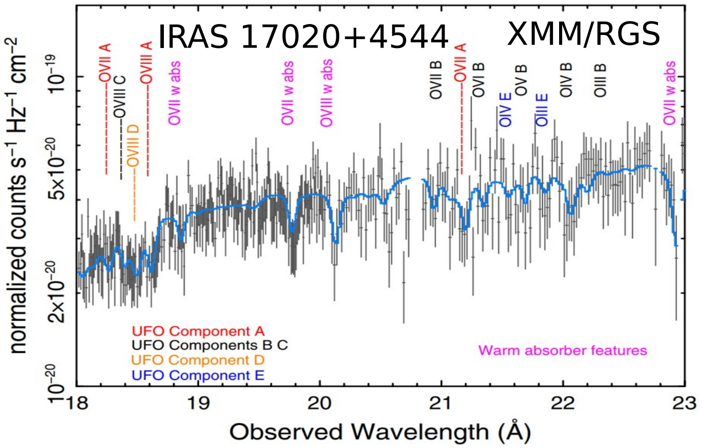
Broad C IV and Fe XXVI absorption features appear together when X-ray obscured

Consistent UV and X-ray velocities

Disk wind composed of multiple ionization components

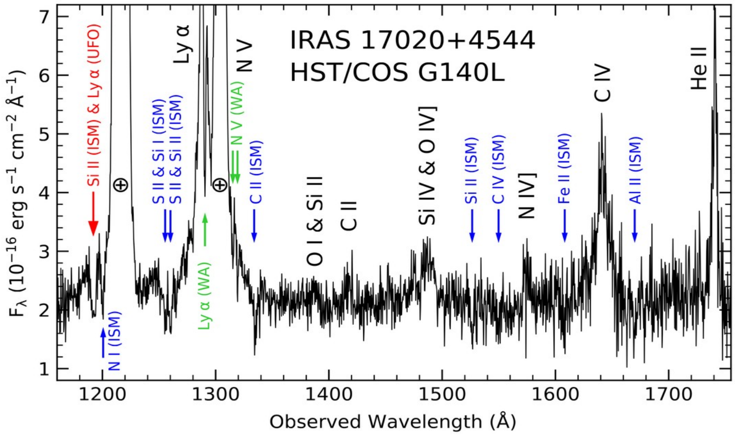
UFOs like obscurers are multi-phase

X-ray



Longinotti+15

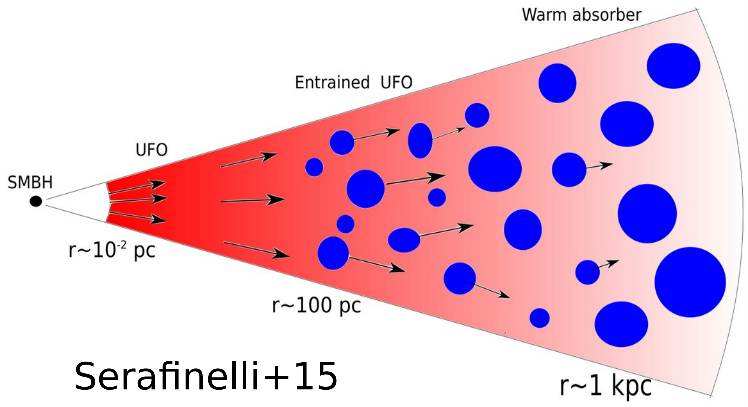
UV



Mehdipour+22

UFOs with multiple velocity and ionization components, alongside the warm absorber and molecular outflows (Longinotti+23)

Primary UFO entraining and shocking the ambient medium, resulting in formation of weaker outflow components

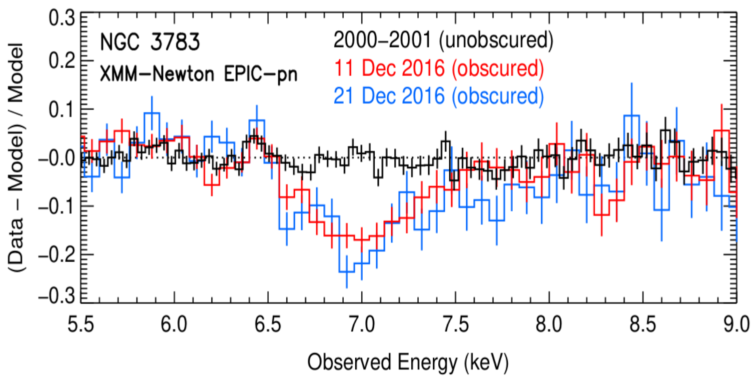


Serafinelli+15

See also Fukumura+22 for MHD-driven UFOs

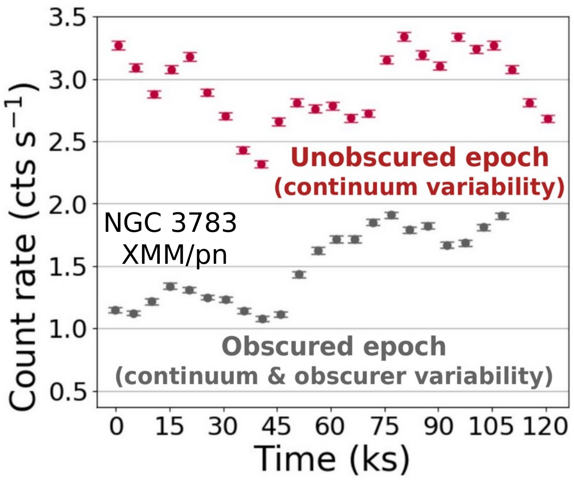
Need for Fe K high-resolution spectroscopy

New Fe K absorption appears when obscured



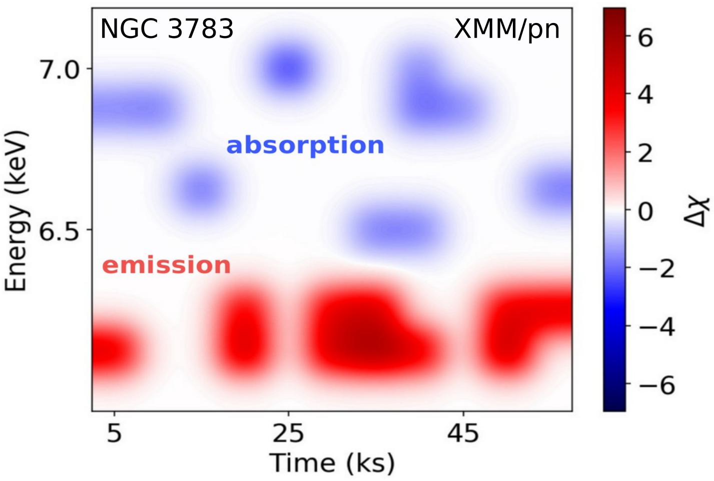
Mehdipour+17

Variability by both the continuum and obscuration



Costanzo+22

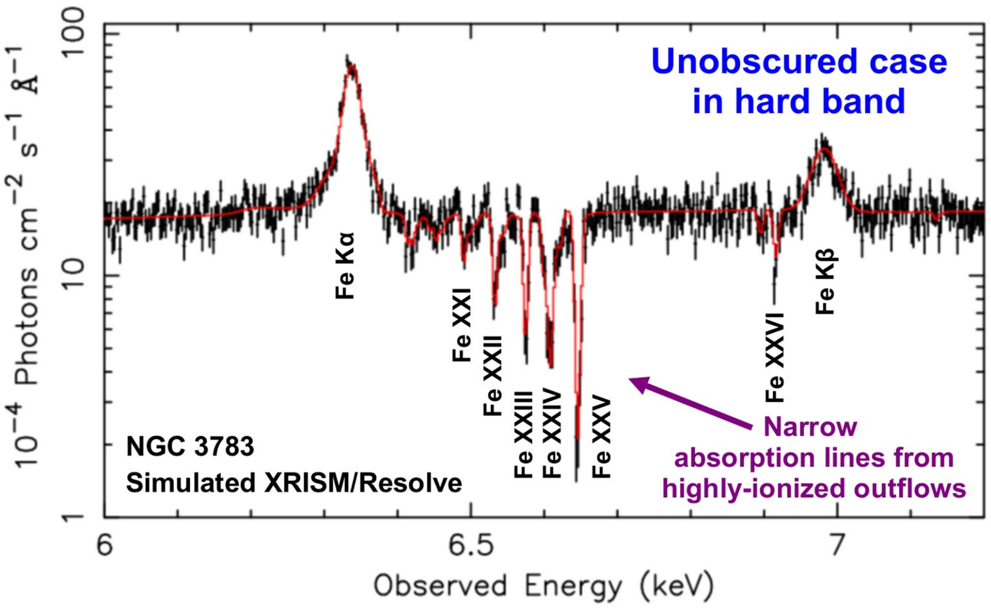
Short-timescale Fe-K features variability

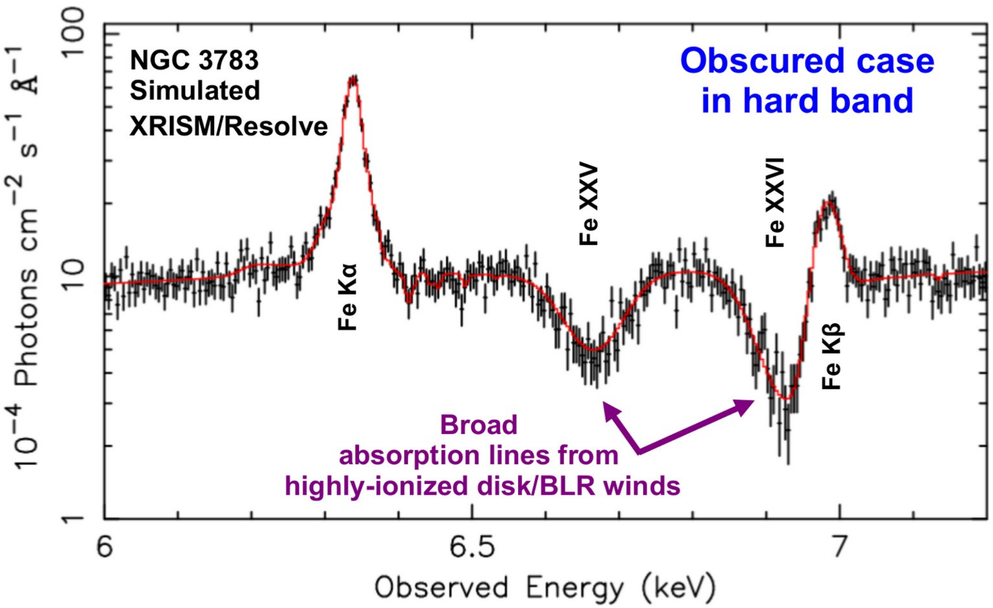


Costanzo+22

Upcoming *XRISM* spectroscopy of outflows

XRISM will facilitate <u>high-resolution spectroscopy of highly-ionized outflows</u>

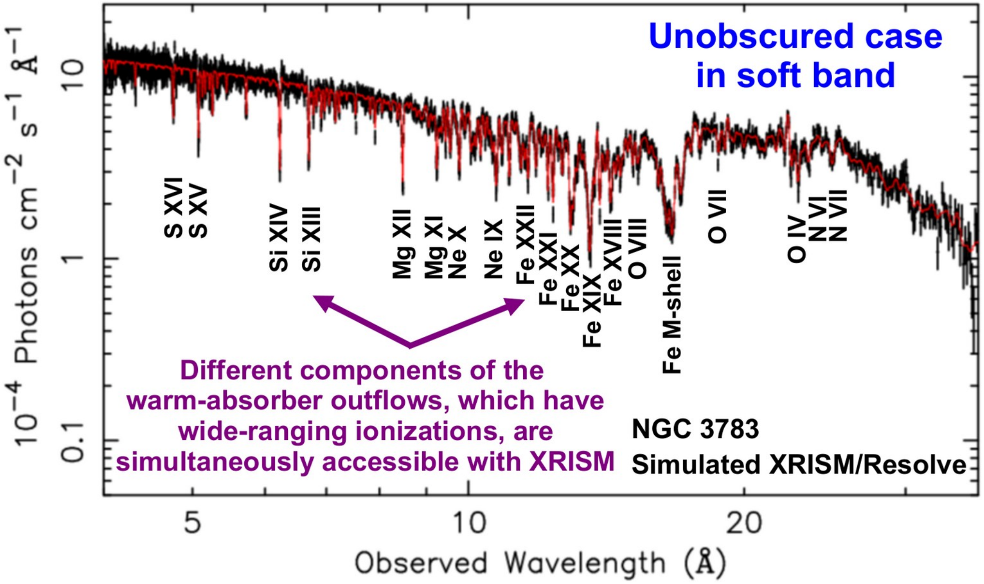


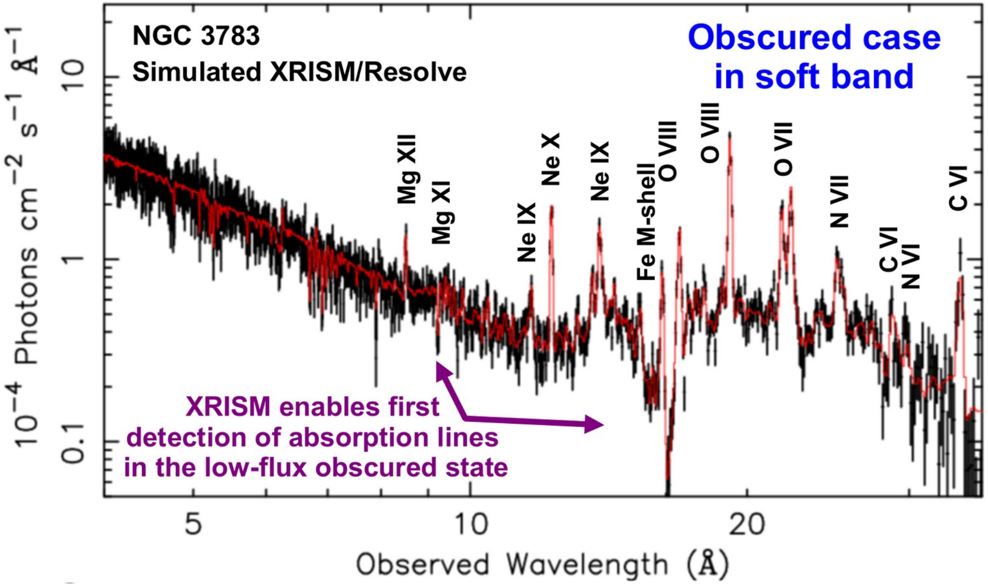


SPEX/pion simulations

Upcoming *XRISM* spectroscopy of outflows

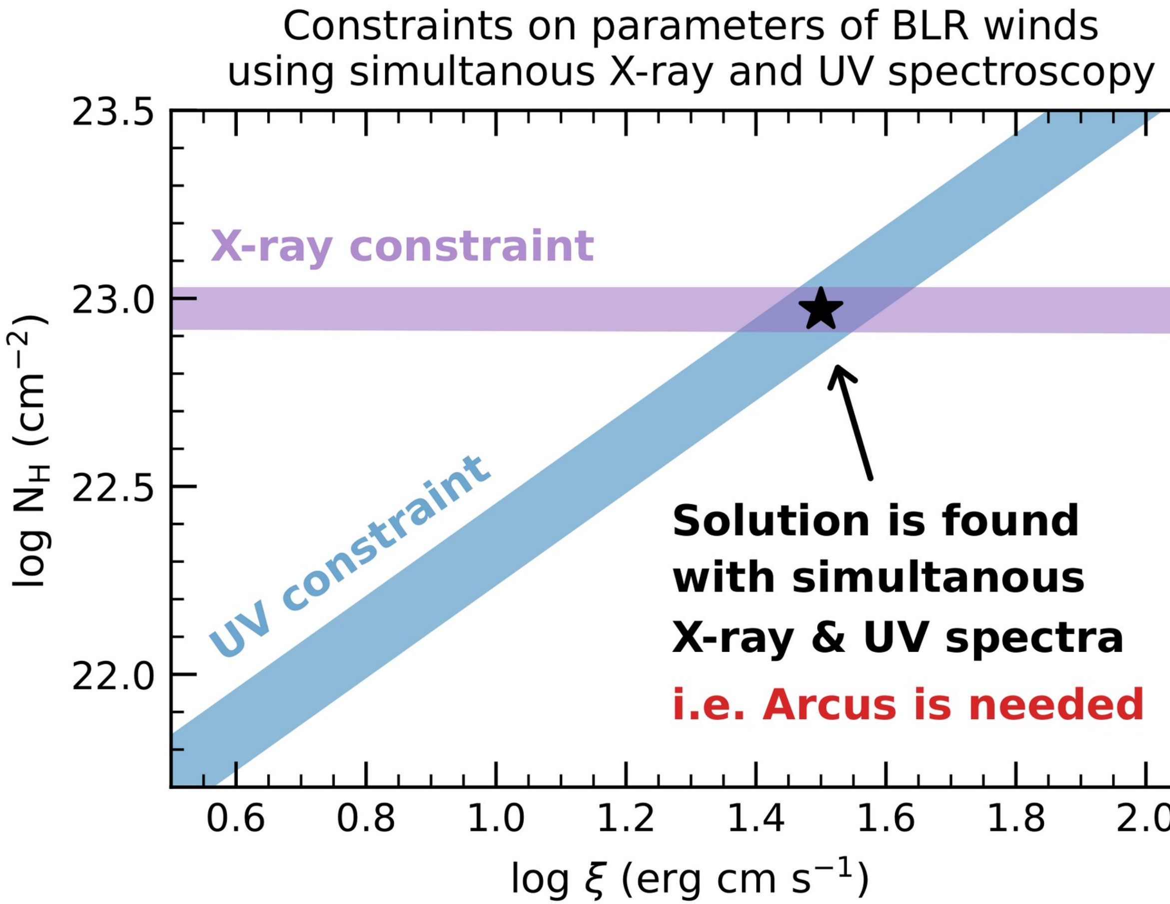
XRISM will facilitate measurement of different X-ray components of outflows





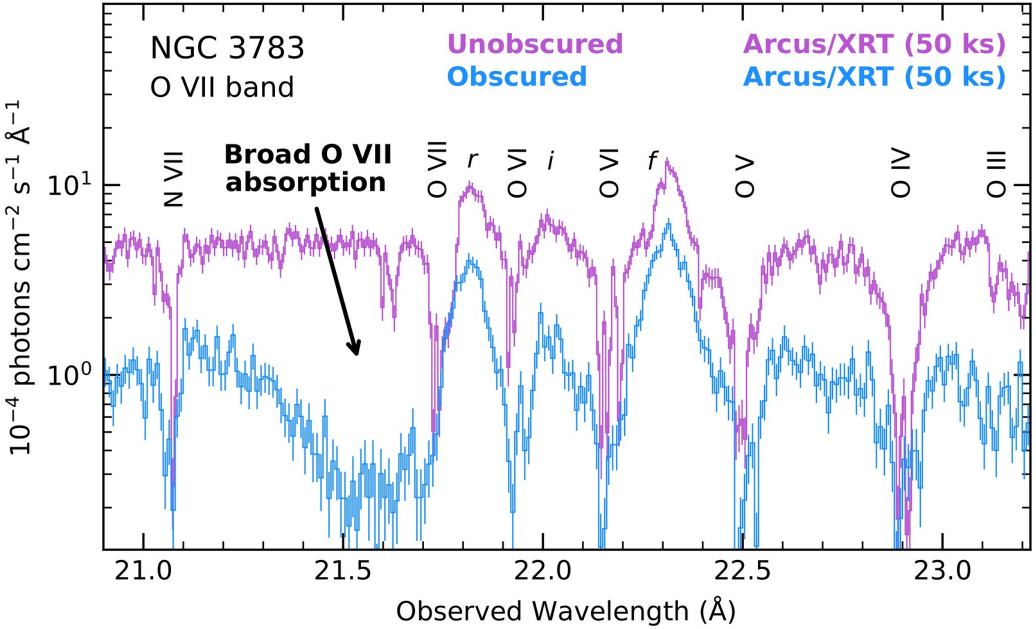
SPEX/pion simulations

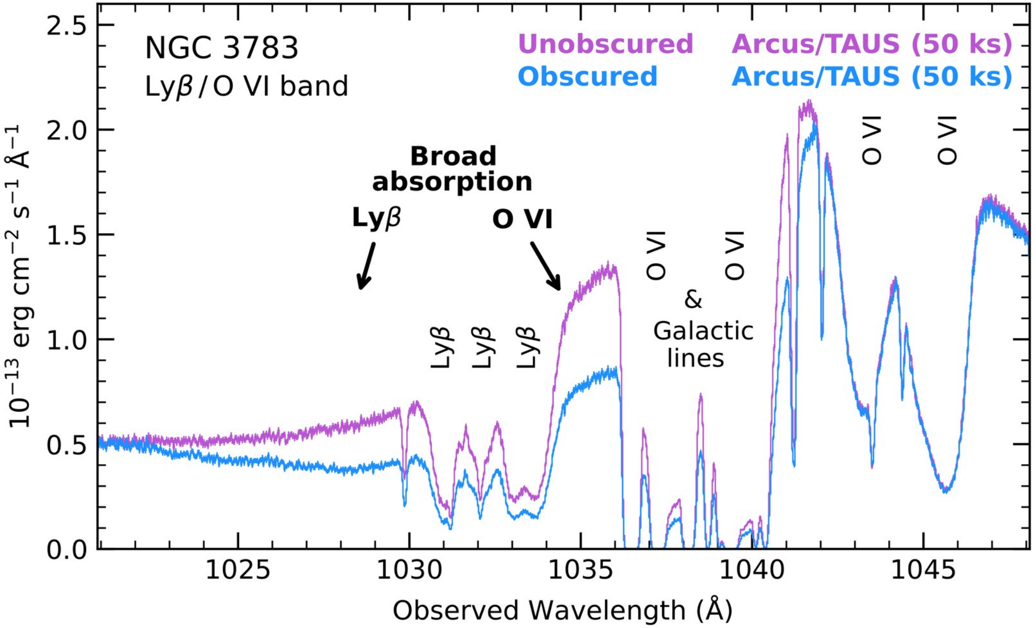
Need for simultaneous X-ray & UV spectroscopy of obscuring winds



Proposed *Arcus* probe of outflows

Arcus would facilitate simultaneous high-resolution X-ray and UV spectroscopy





SPEX/pion simulations

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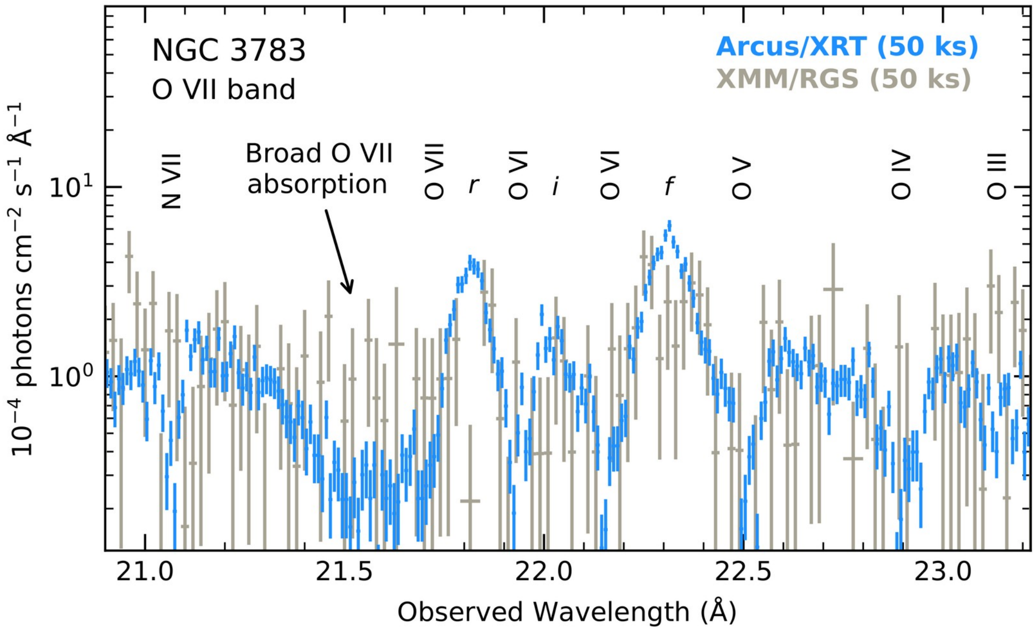

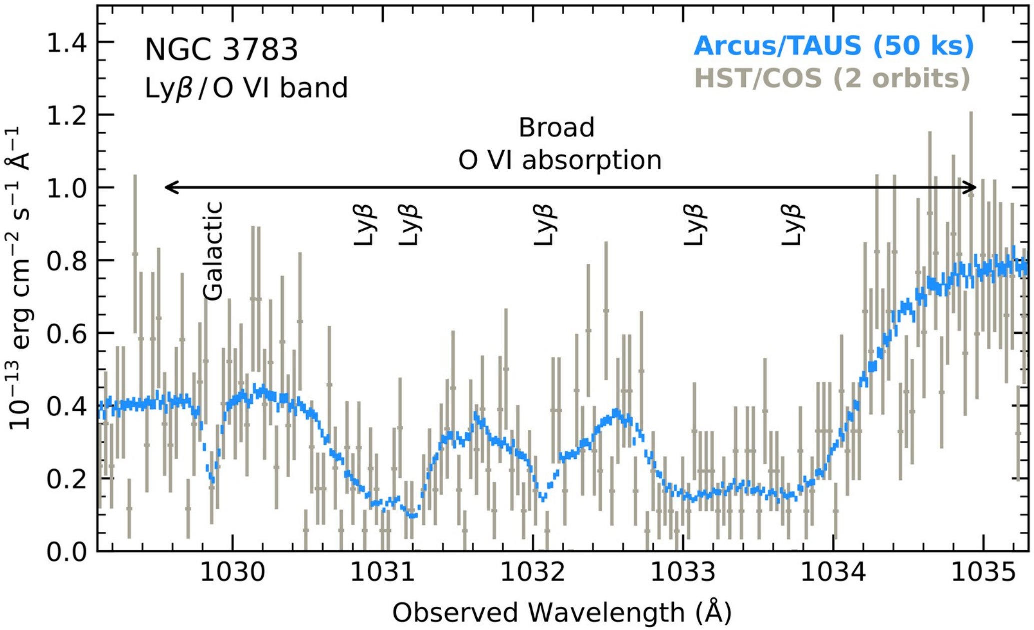

SPEX/pion simulations

Summary

- **Simultaneous X-ray/UV spectroscopy & monitoring of variability are useful for probing the uncertain properties of AGN outflows**
- **Broad UV absorption and highly-ionized X-ray absorption belong to the same obscuring disk wind in the BLR, which shields outflows in the NLR**
- **AGN winds, regardless of their form/type, are multi-component and complex with inhomogeneities in their velocity and ionization/density**
- **Detection of the UV counterpart of X-ray obscuring winds and UFOs is dependent on the covering fraction of the wind**
- **Powerful disk winds likely entrain and shock their surrounding medium, resulting in the formation of weaker outflow components**
- **Need XRISM and Arcus to overcome current limitations in probing winds and need theoretical models to explain the observed complex properties**