HST view of a multifarious landscape of winds in AGN

Variability as a probe of winds

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Collaborators:
Jerry Kriss, Elisa Costantini, Jelle Kaastra,
and many others

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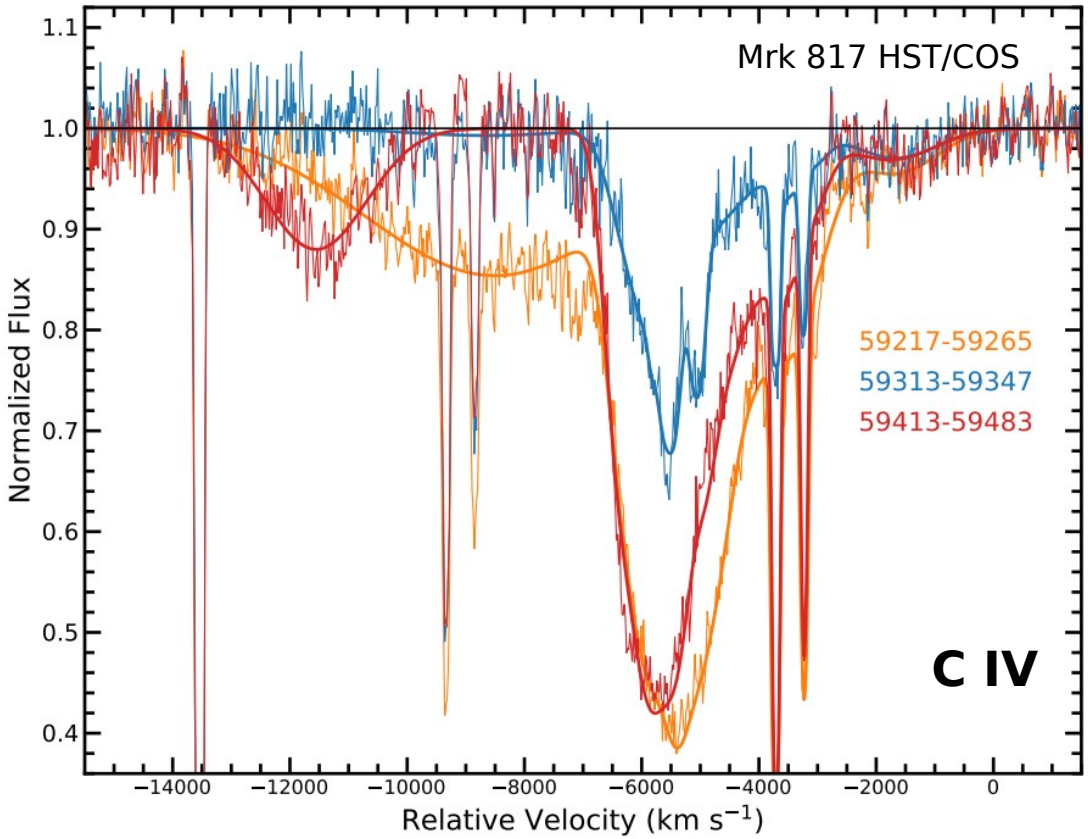
The Restless Nature of AGN: 10 years later, 2023-06-30

“Restless nature” of absorption by outflows



STORM II campaign

Kara+21

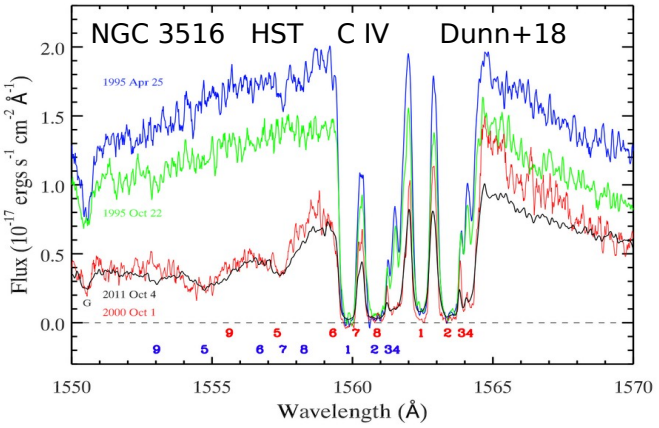
Kriss+in prep

How to decipher this UV variability? X-ray information is essential

Multi-wavelength spectral view of outflows

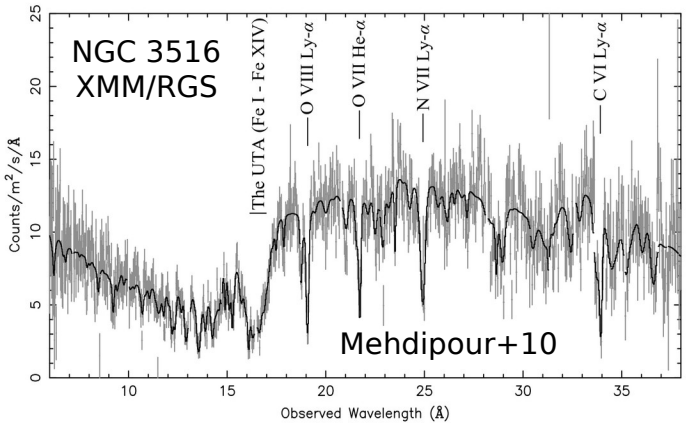
UV

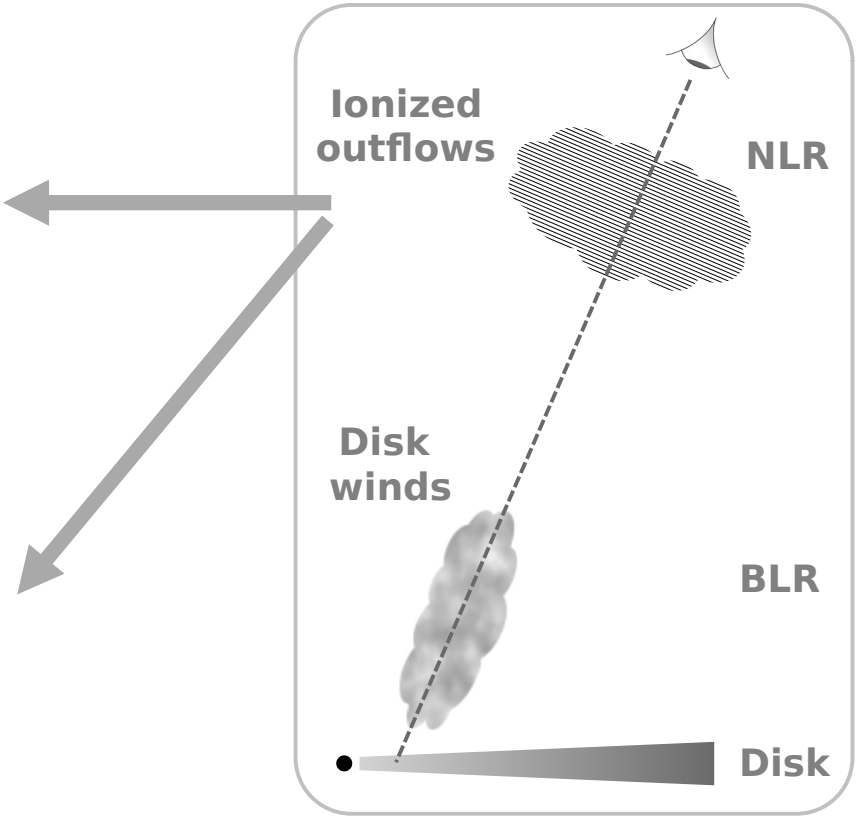
Narrow multi-component UV lines



X-ray

Multi-component "warm-absorbers"



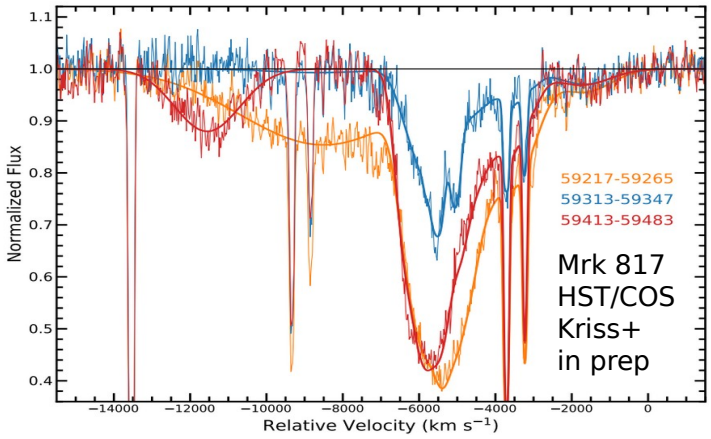


Multi-wavelength spectral view of outflows

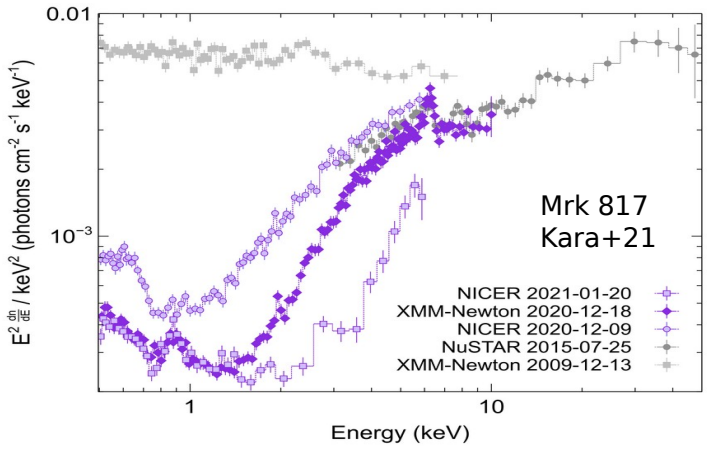
UV

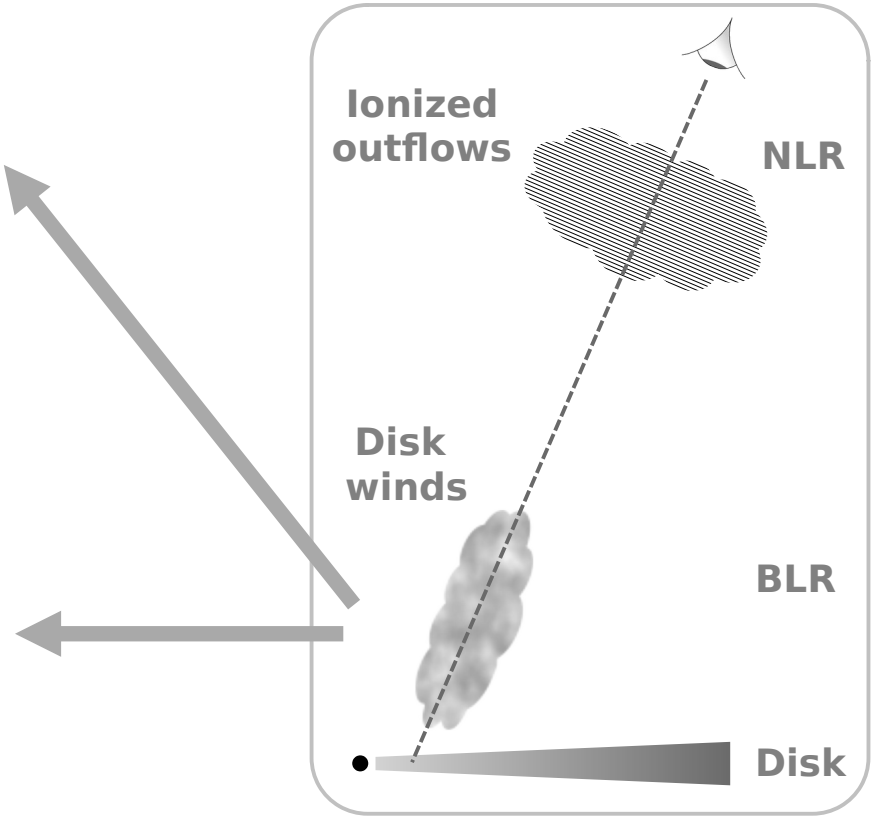
X-ray

Broad blueshifted UV lines



Transient X-ray obscuration

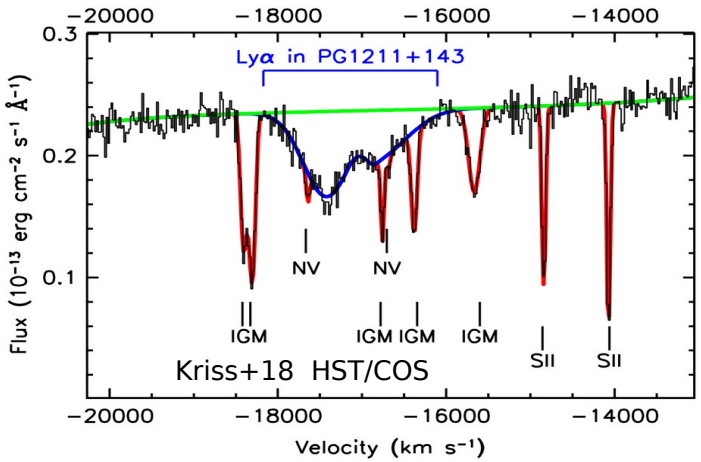




Multi-wavelength spectral view of outflows

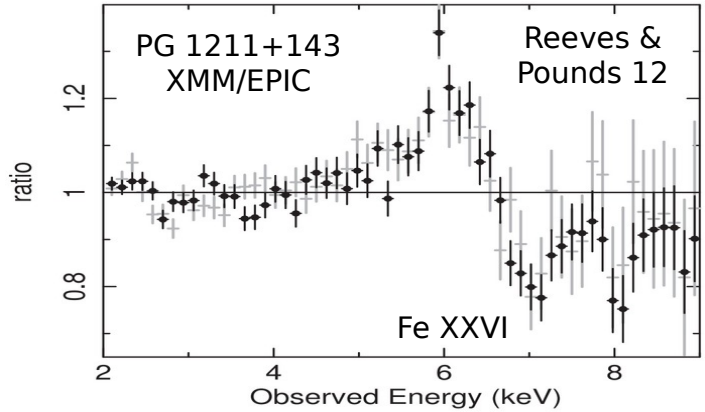
UV counterpart of X-ray ultrafast outflows (UFOs)

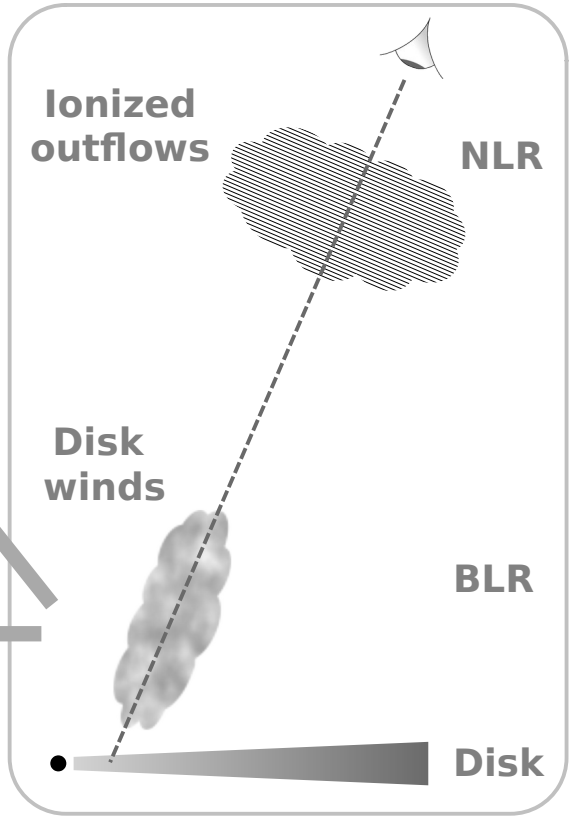
UV



X-ray UFOs with relativistic outflow velocities

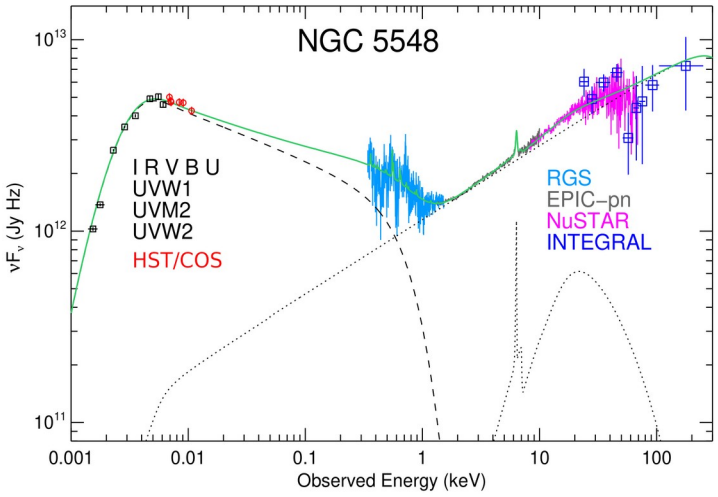
X-ray





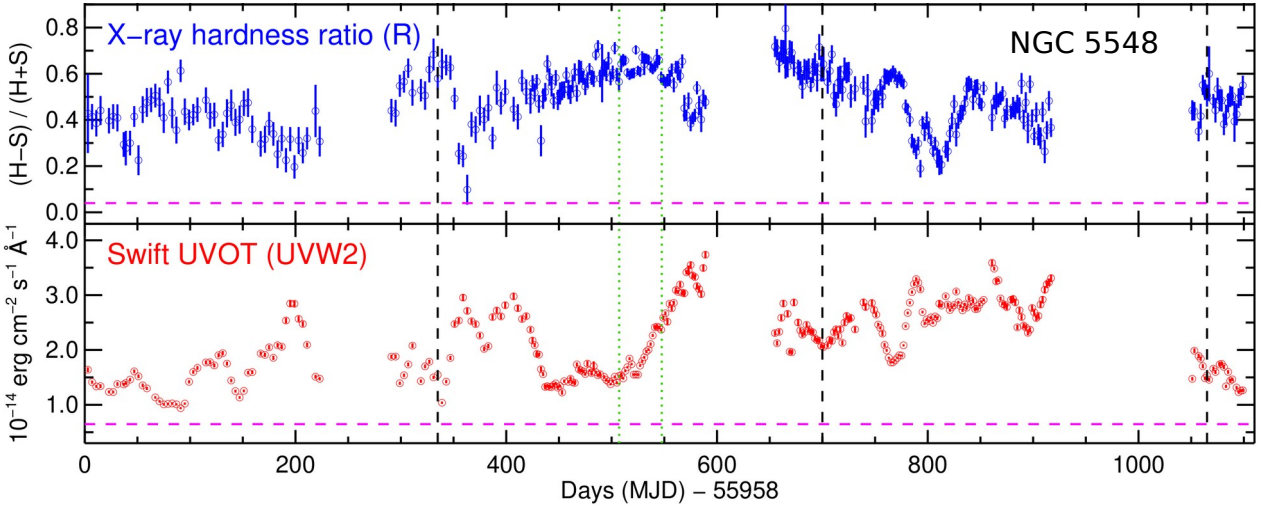
Variability as a diagnostic tool to probe winds

Spectral energy distribution



Mehdipour+15

Light curves



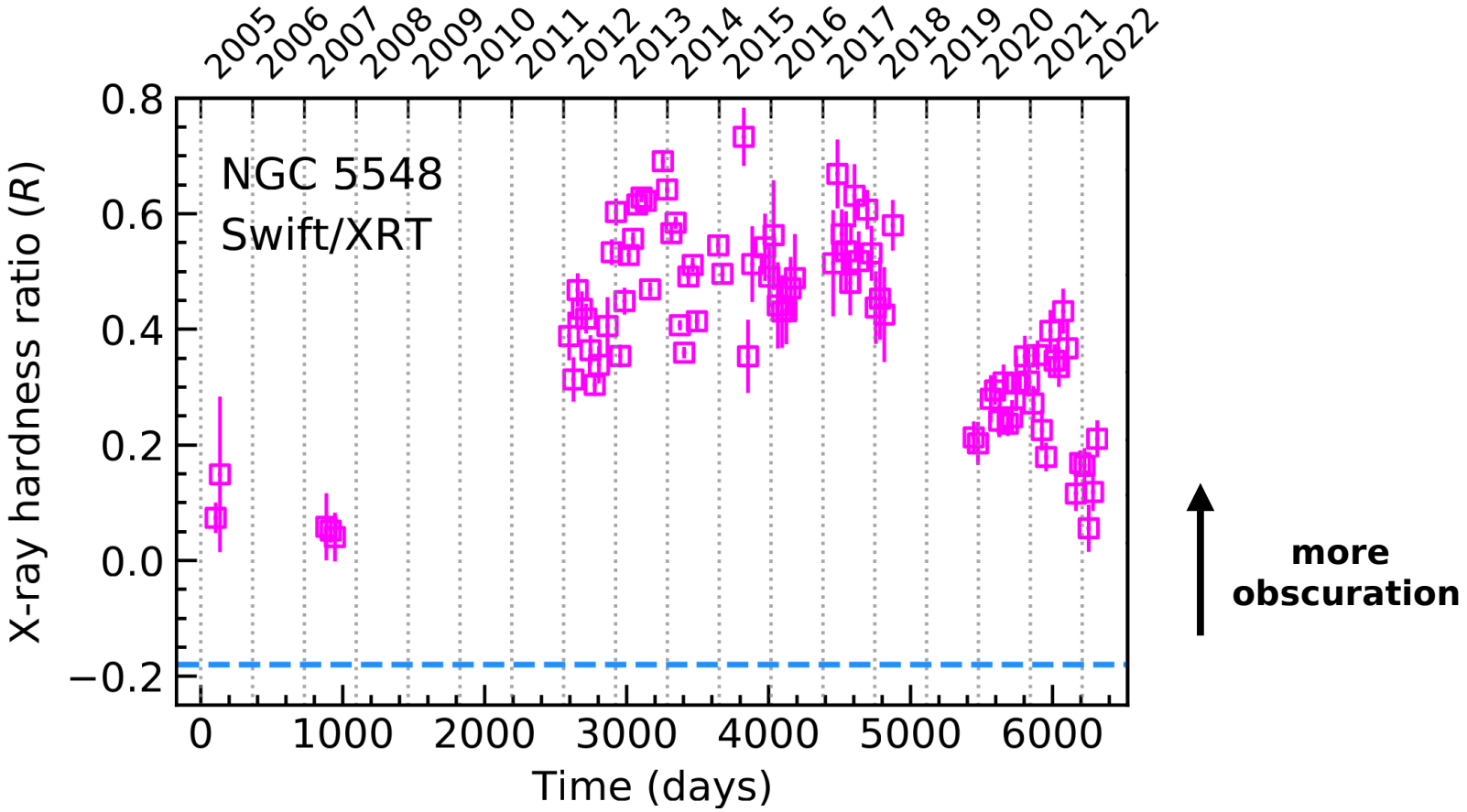
Mehdipour+16

Need <u>multi-wavelength spectral coverage</u> to probe winds

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?**

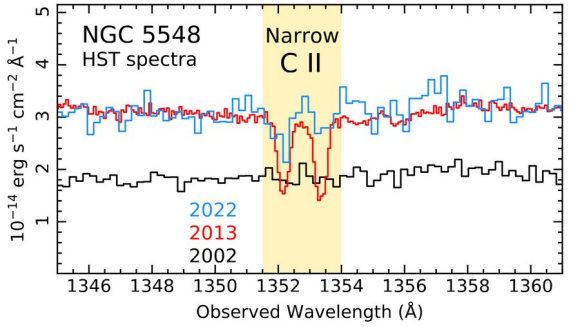
Long-term evolution of an obscuring disk wind

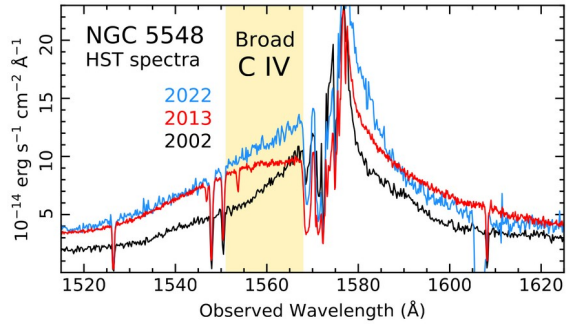


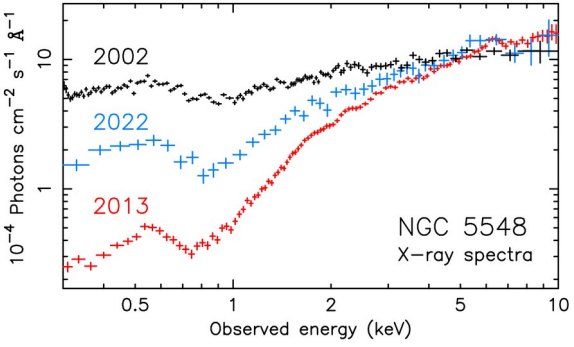
Mehdipour+22

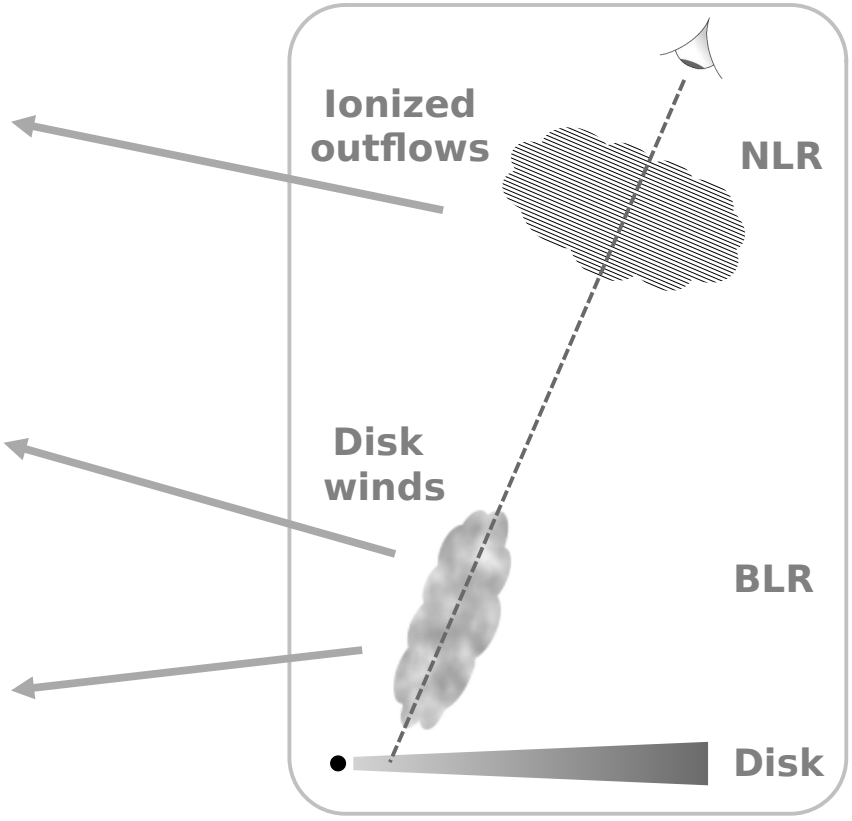
Rise and decline in X-ray obscuration

Link between X-ray obscuration and BLR winds



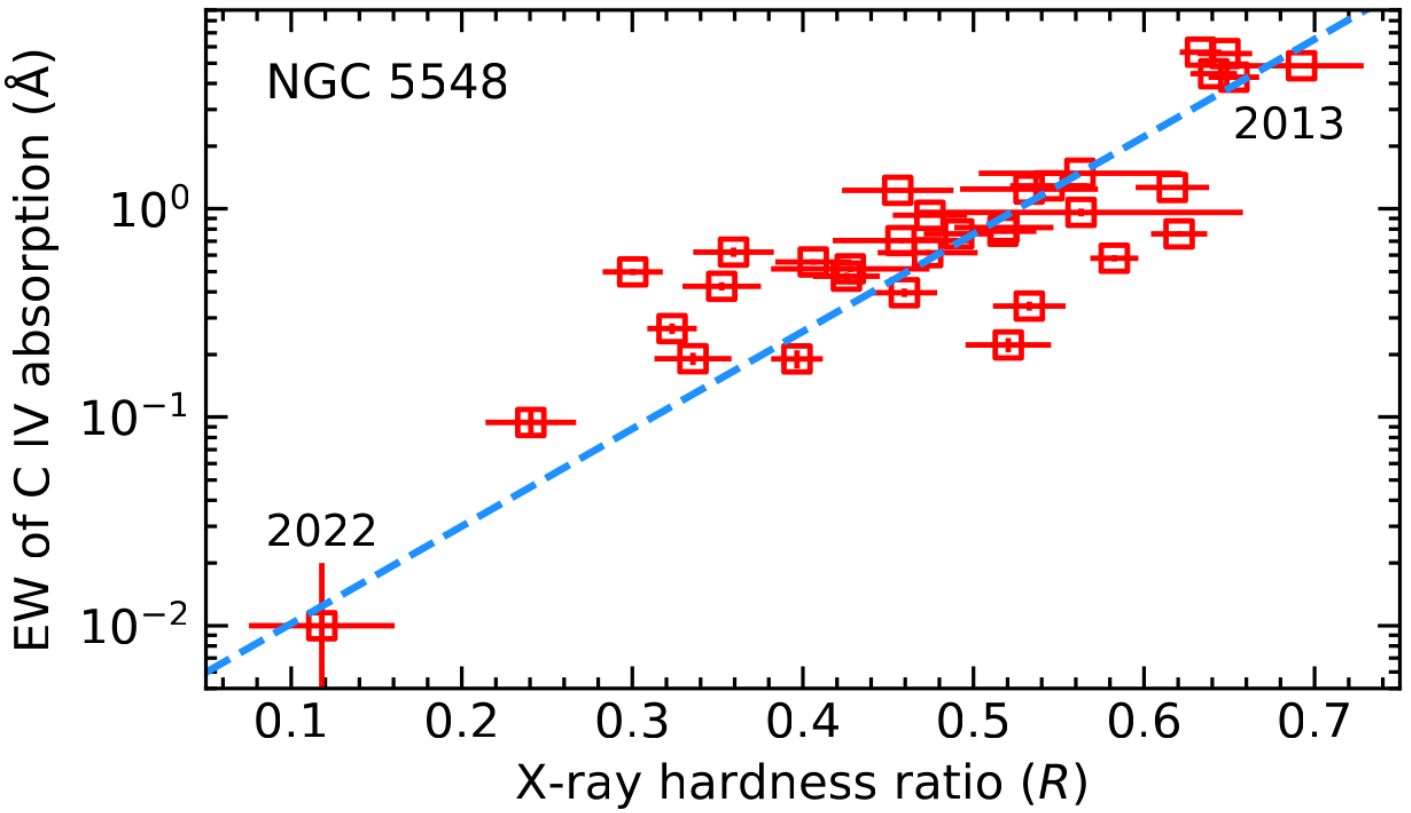






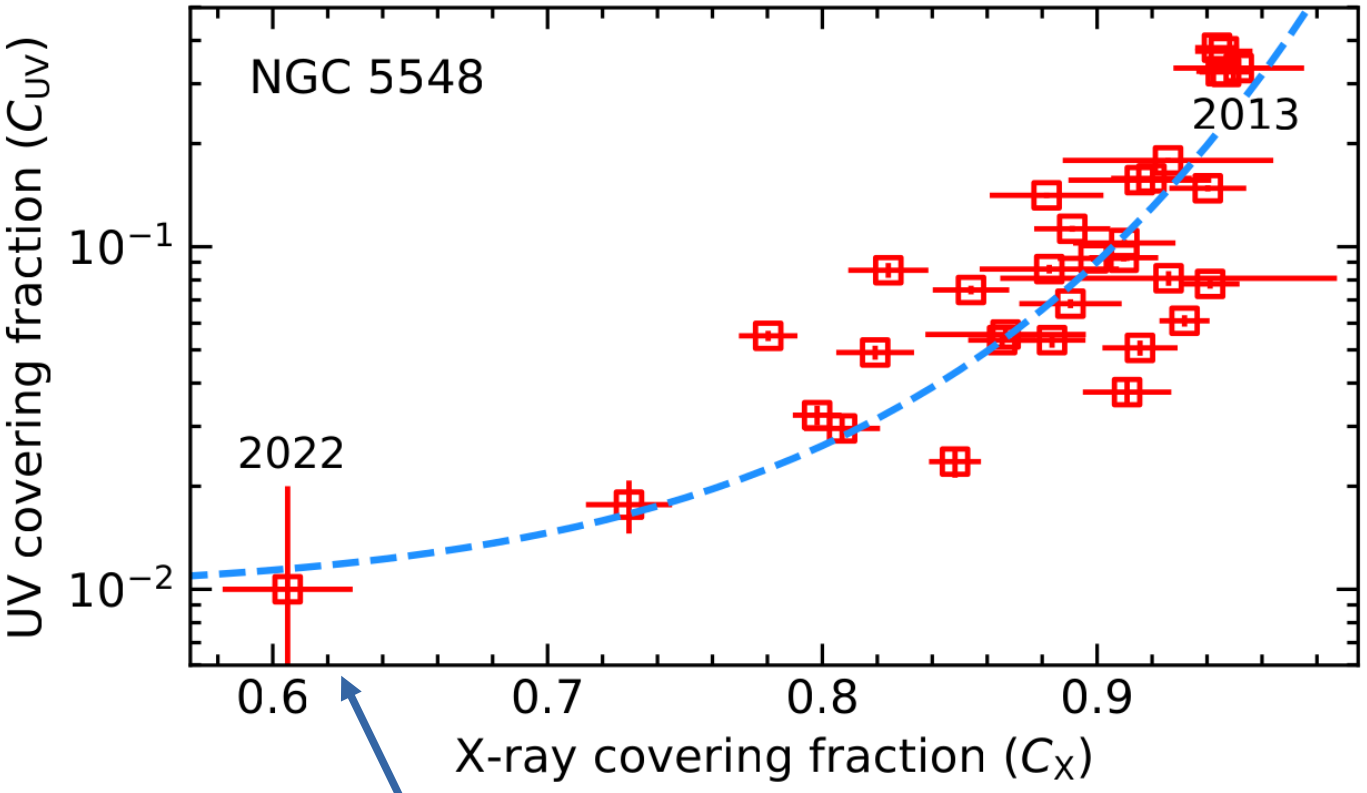
Mehdipour+22

Link between X-ray obscuration and BLR winds



Mehdipour+22

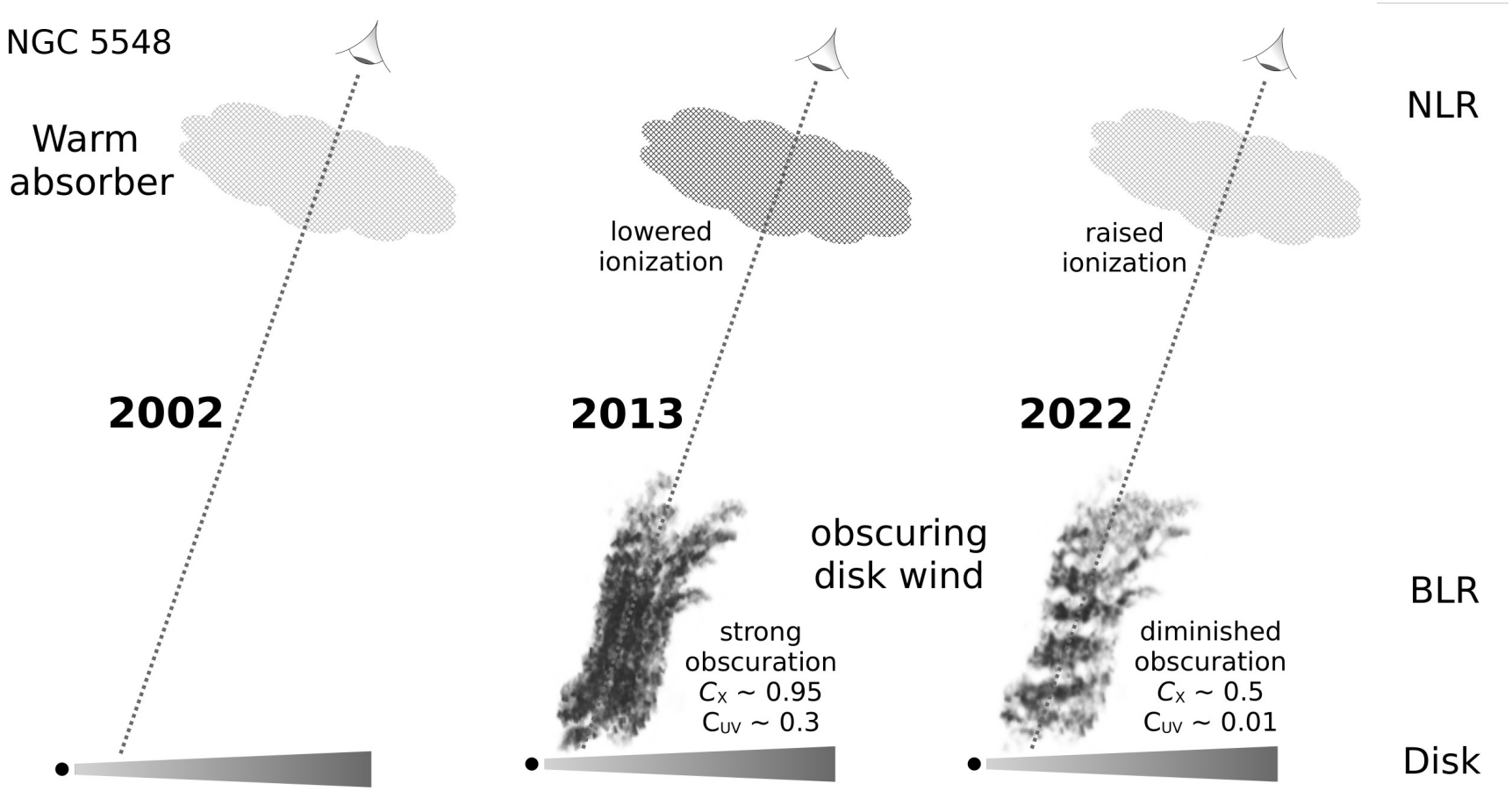
Relation between the UV and X-ray covering fractions of the wind



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

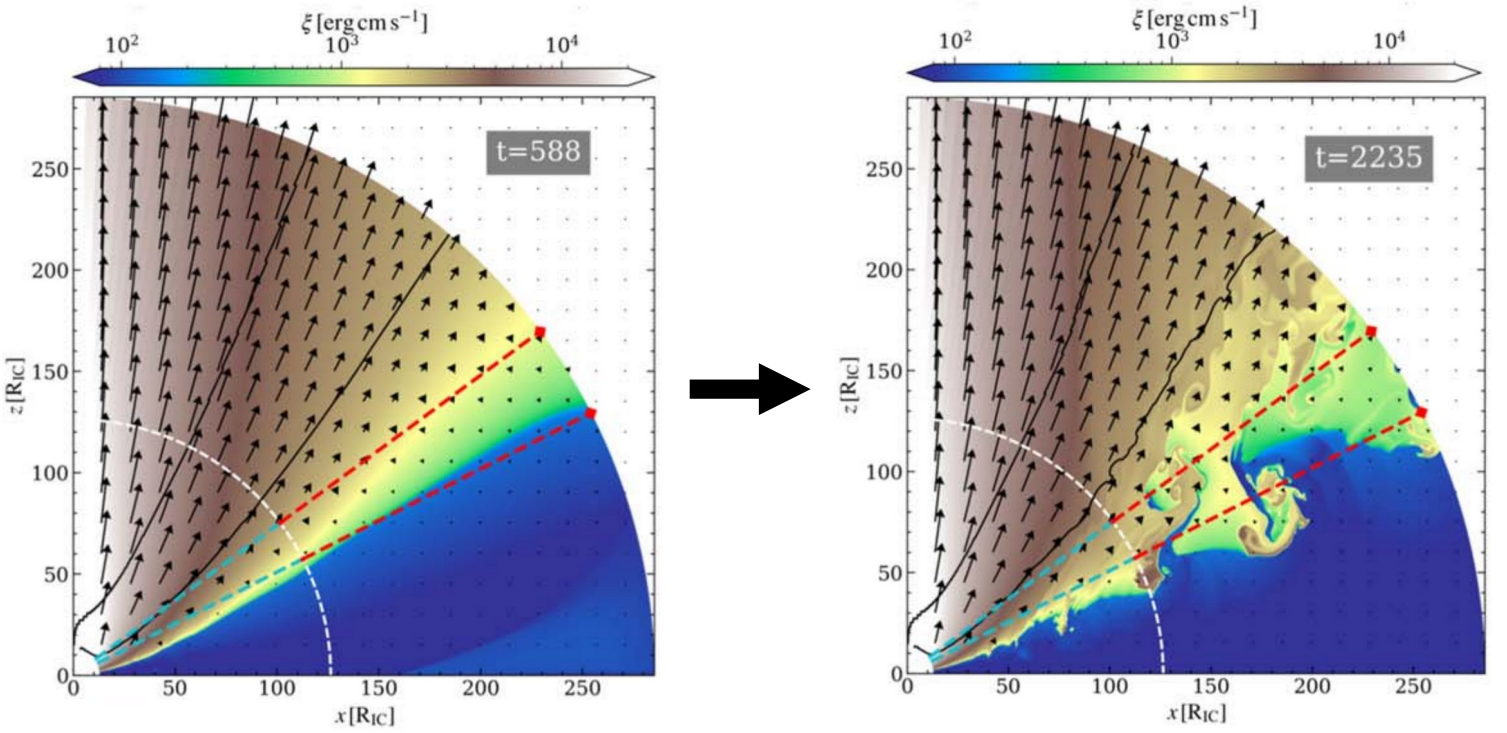
Evolution of an obscuring disk wind: an episodic ejection?



Mehdipour+22

Intrinsic SED shape and luminosity remain the same at all epochs

A clumpy multi-phase outflow is needed



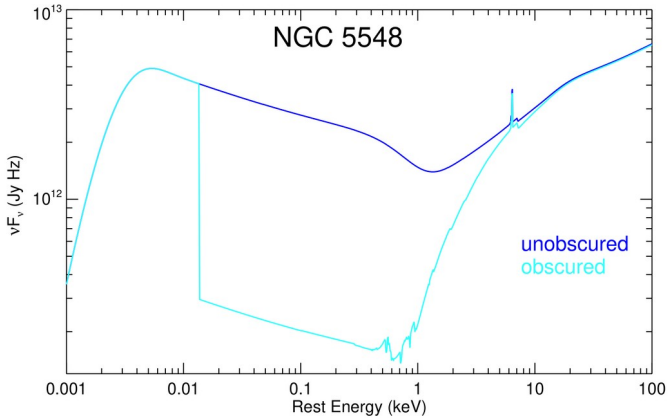
Waters+21

Thermal instabilities lead to a clumpy multi-phase outflow

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

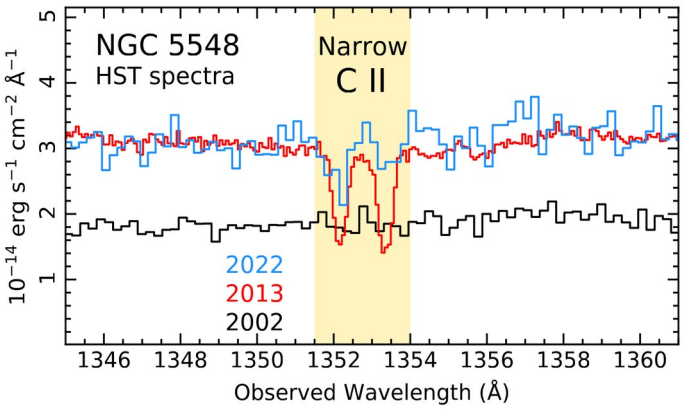
Consequences of inner obscuration shielding outer outflows

The obscured SED would irradiate the surrounding gas



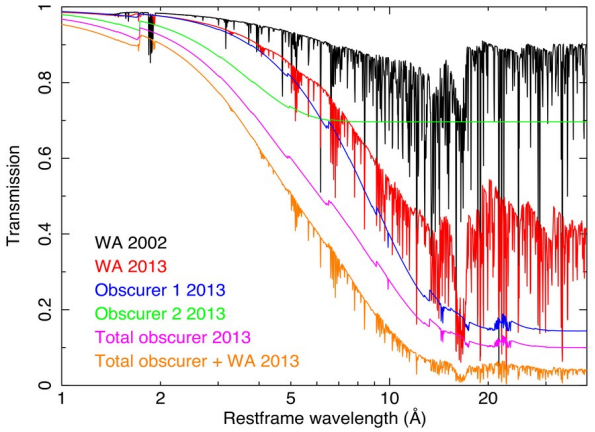
Mehdipour+15

Ionization parameter of warm-absorber outflows is lowered



Mehdipour+22

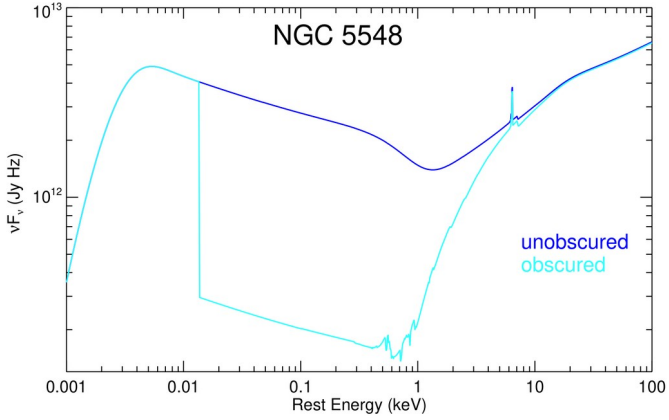
Enhanced X-ray absorption by warm-absorber outflows



Kaastra+14

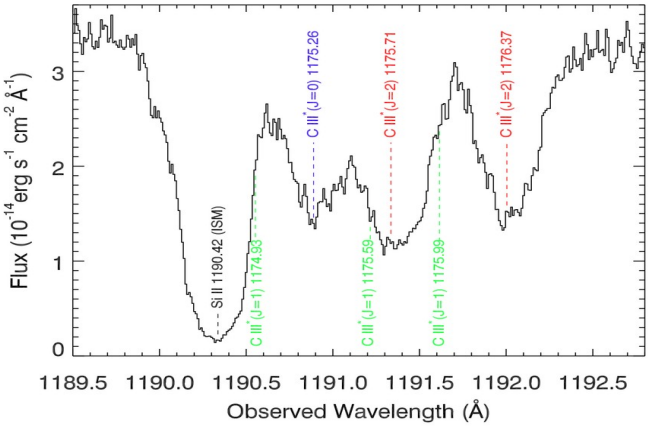
Consequences of inner obscuration shielding outer outflows

The obscured SED would irradiate the surrounding gas



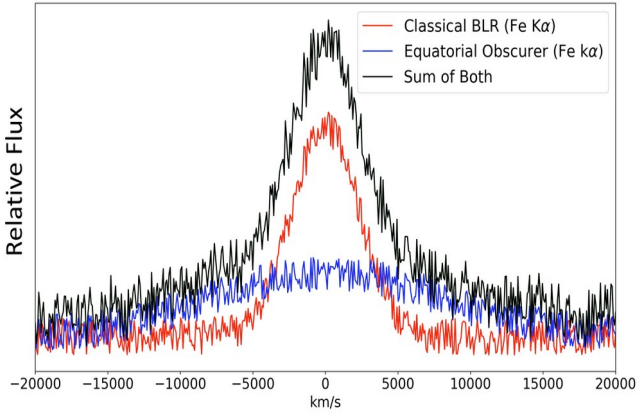
Mehdipour+15

Density & location of warm absorber outflows become measurable using density-sensitive lines



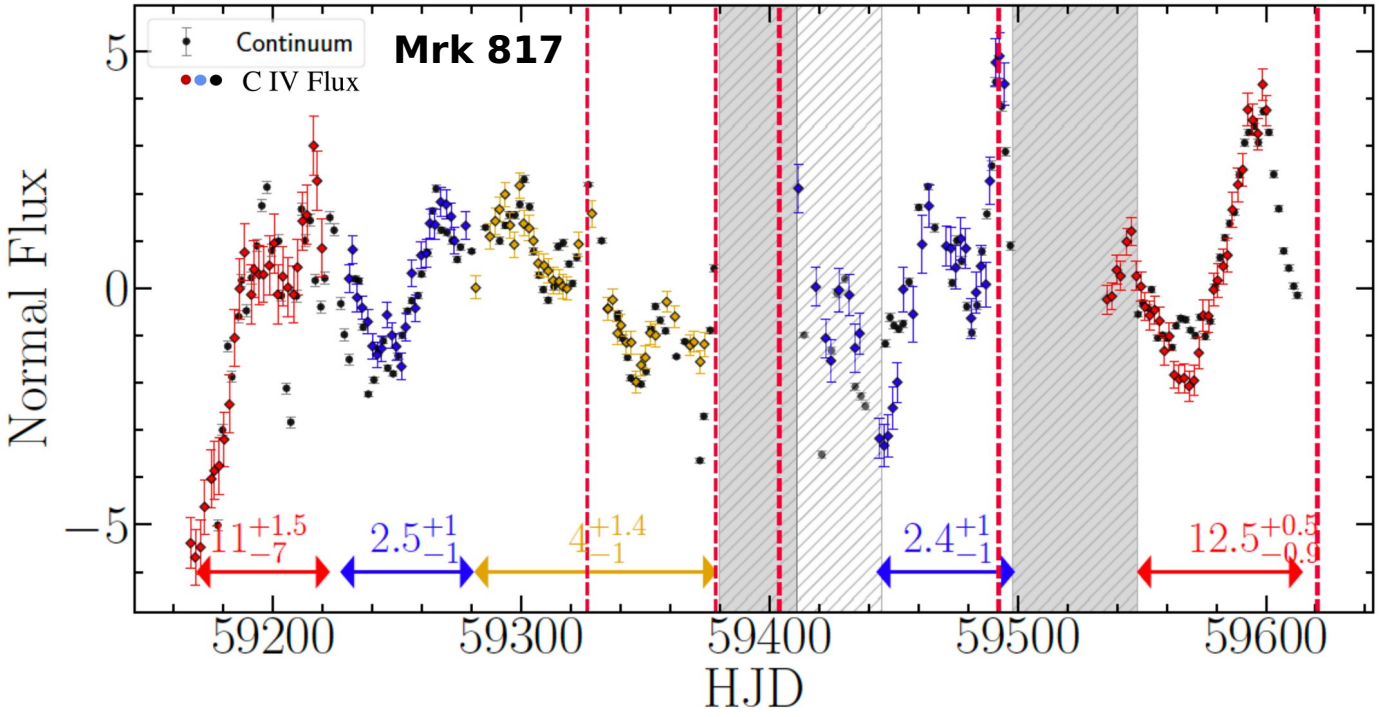
Arav+14

The obscurer contributes to the AGN emission lines



Dehghanian+20

Consequences of inner obscuration shielding outer outflows



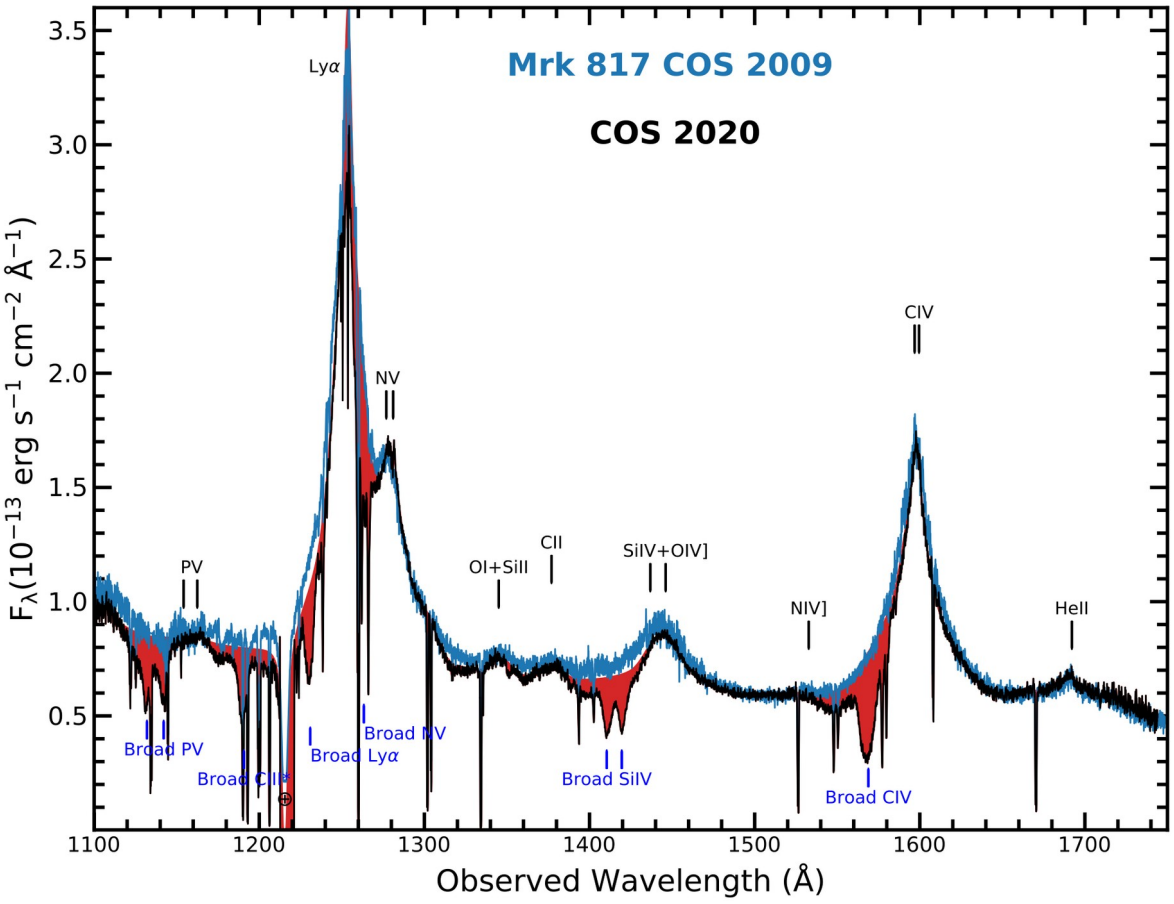
X-ray obscuration impacts the UV emission line lags

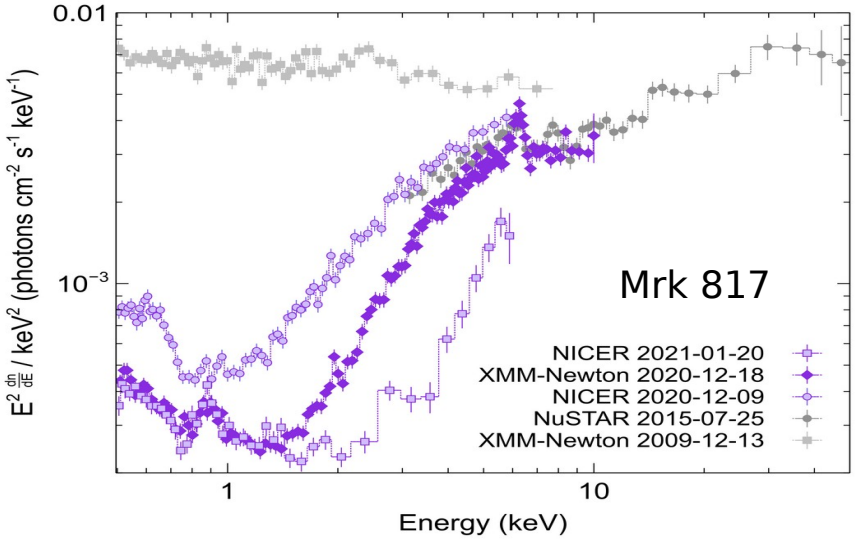
Longer lags (lower responsivity) correspond to time intervals of stronger X-ray obscuration

Homayouni+23

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

Broad & blueshifted UV absorption lines appear when X-ray obscured

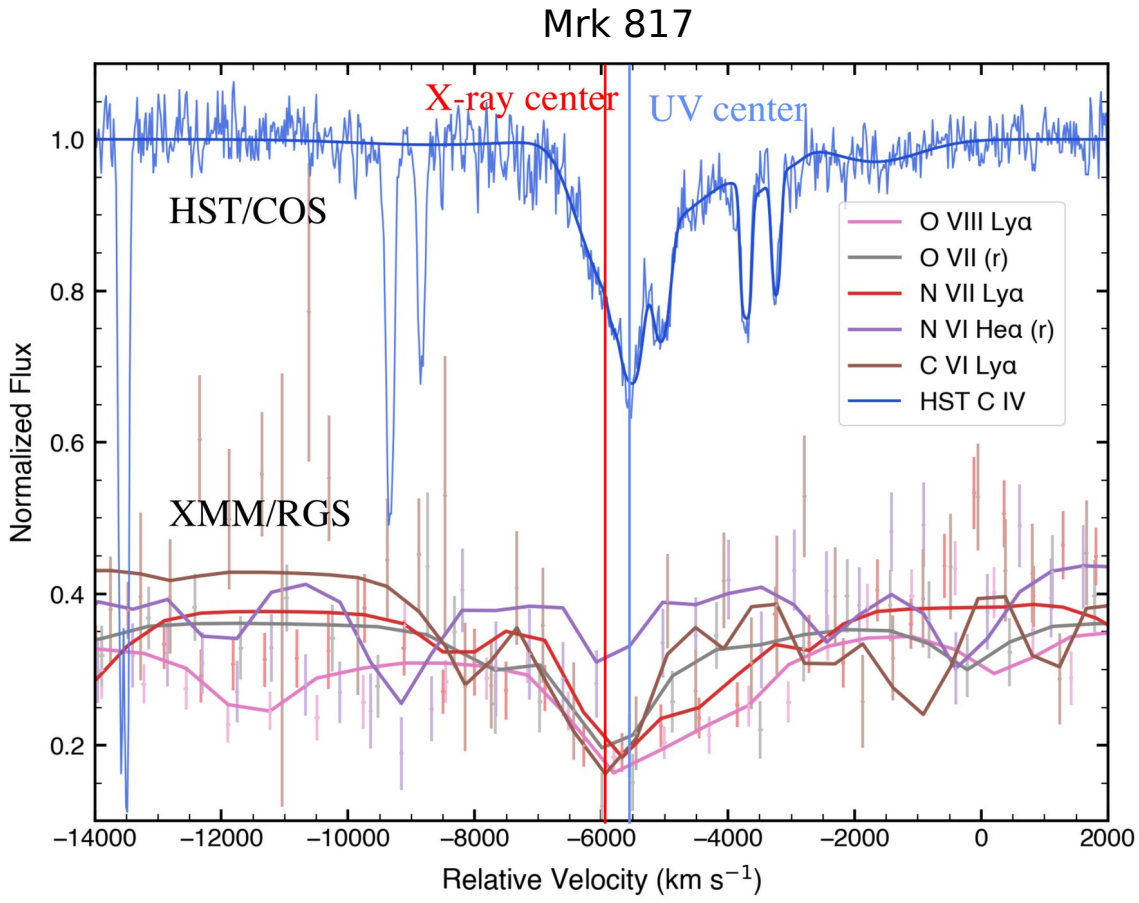




STORM II campaign

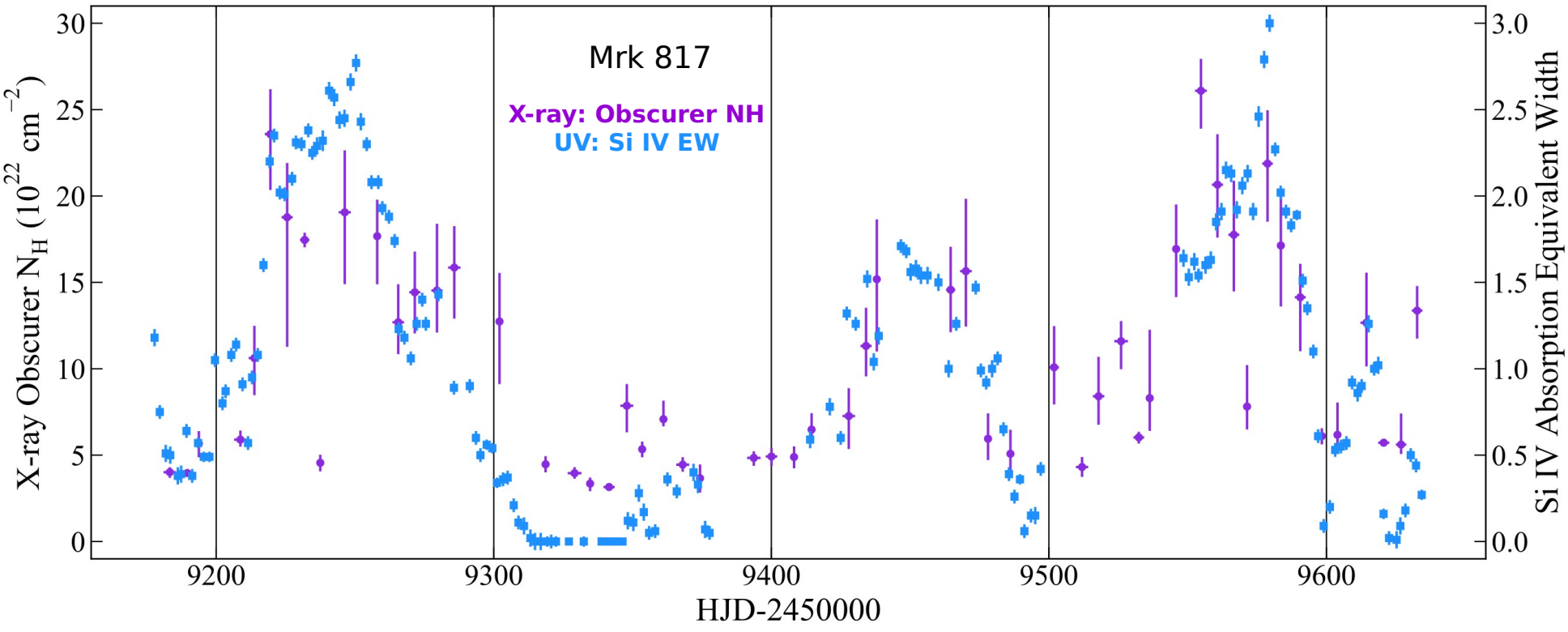
Kara+21
Kriss+in prep

Kinematic correspondence between the X-ray obscurer and UV absorber



Zaidouni+
in prep

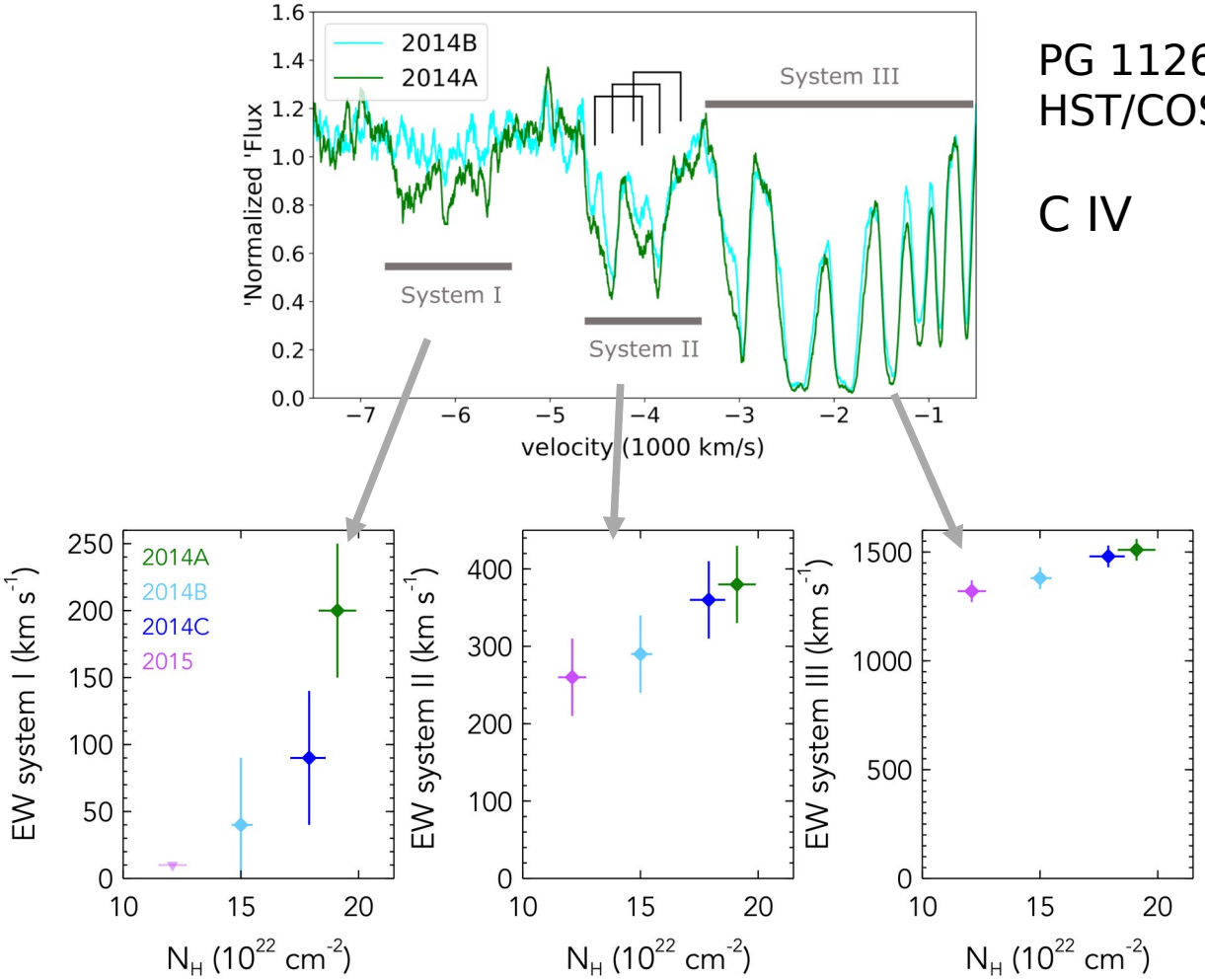
Joint evolution of the X-ray obscurer and broad UV absorber



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

Partington+23

UV absorption varies with the X-ray column density of the wind

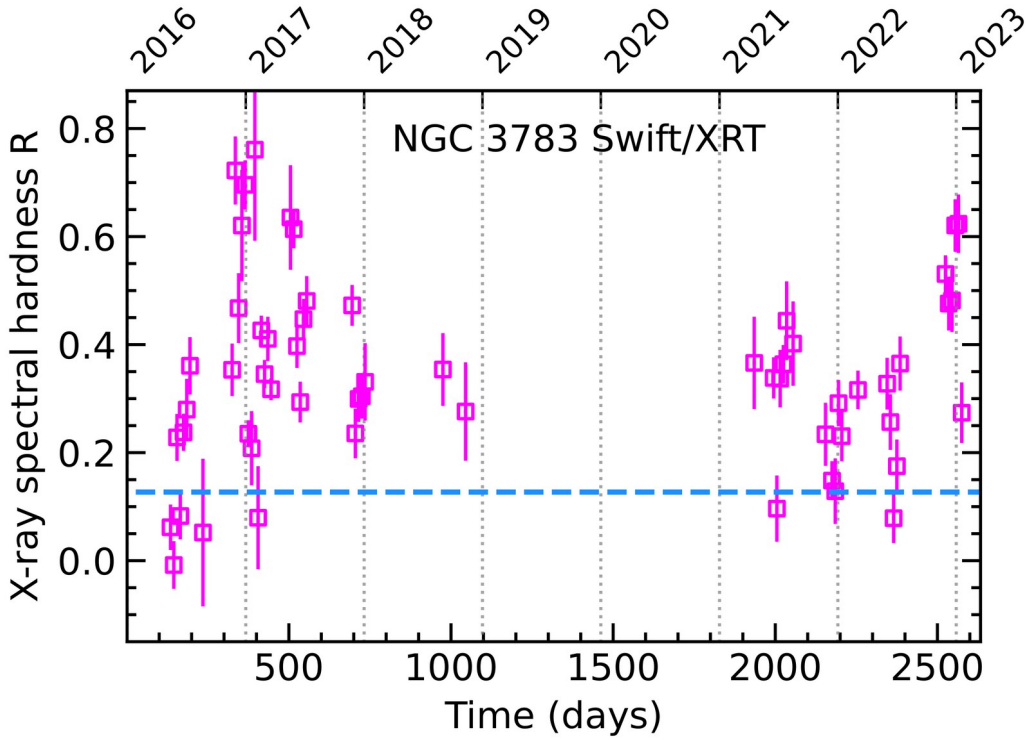


PG 1126-041
HST/COS

C IV

Giustini+23

Catching transient obscuration events with Swift

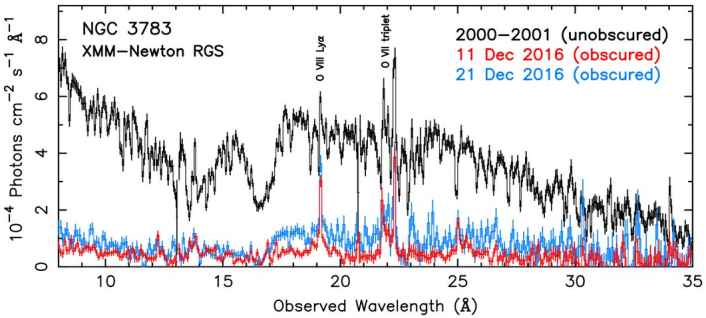


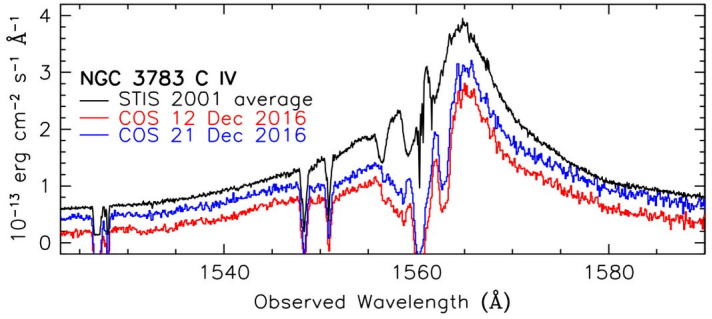
Using Swift to trigger HST, XMM, NuSTAR

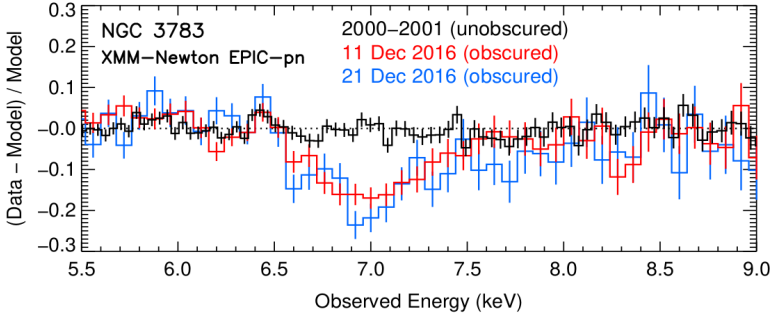
more absorption

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

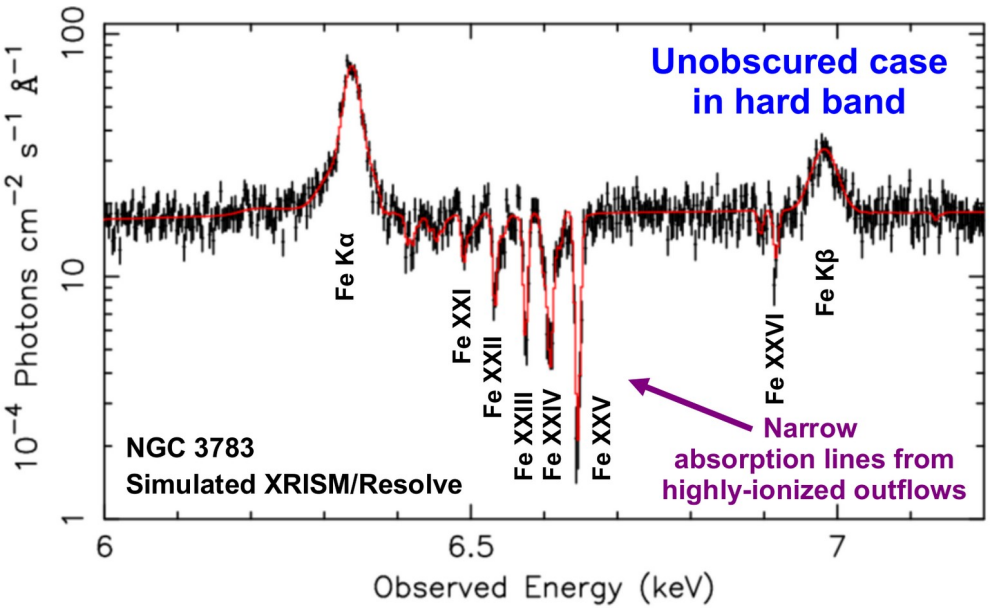
Broad C IV and Fe XXVI absorption features appear together when X-ray obscured

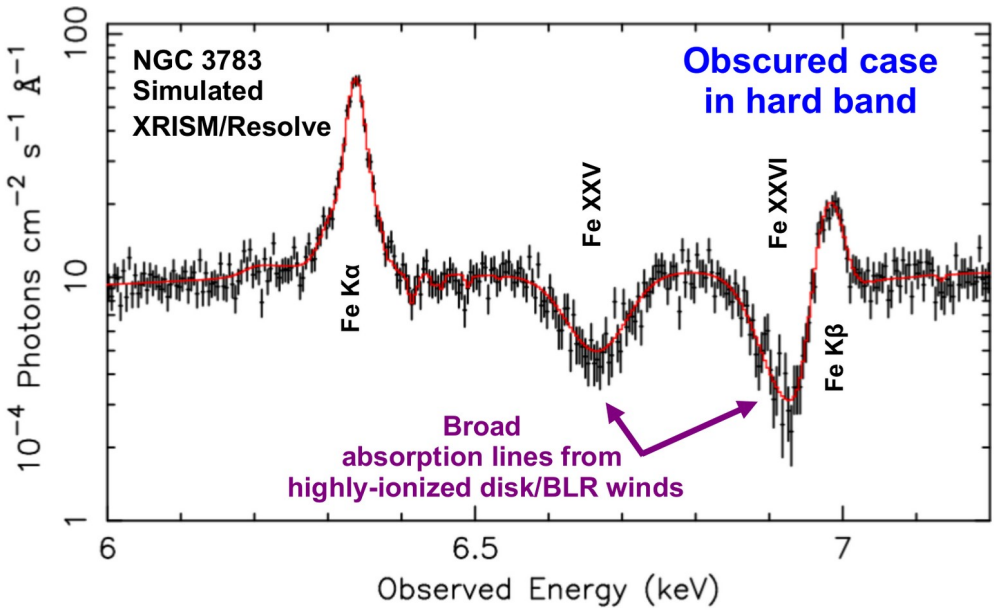
Consistent UV and X-ray velocities

Disk wind composed of multiple ionization components

Upcoming *XRISM* spectroscopy of outflows

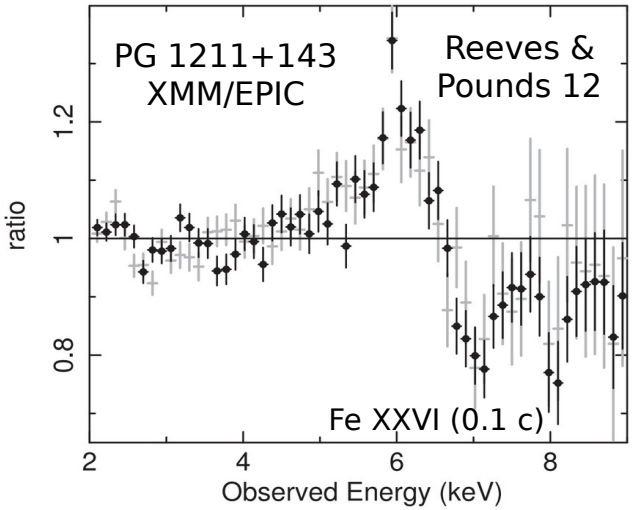
XRISM will facilitate high-resolution spectroscopy of highly-ionized outflows



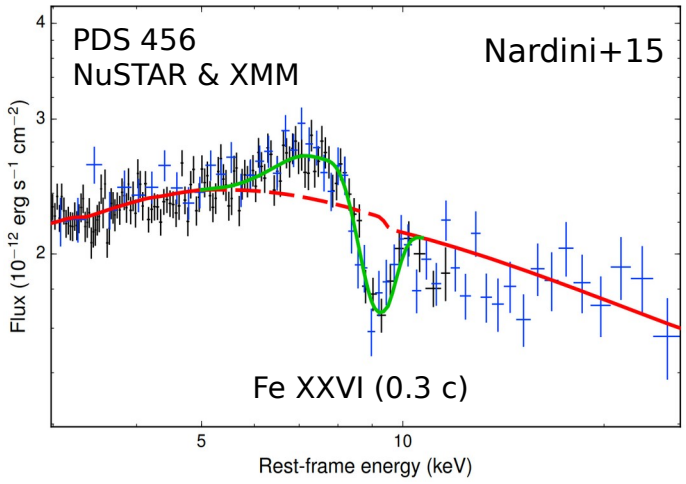


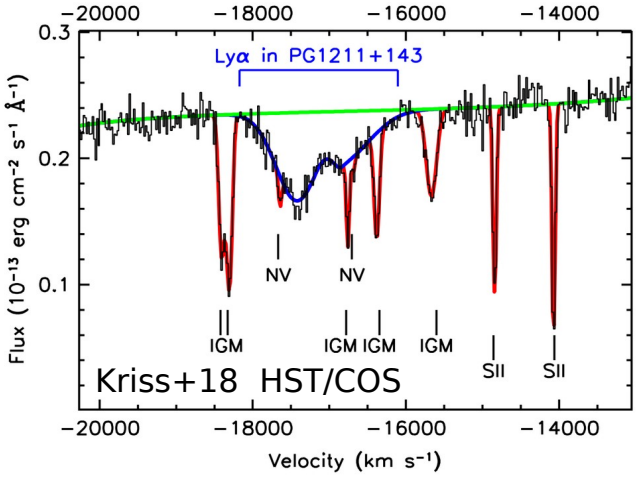
SPEX/pion simulations

UV footprint of X-ray UFOs

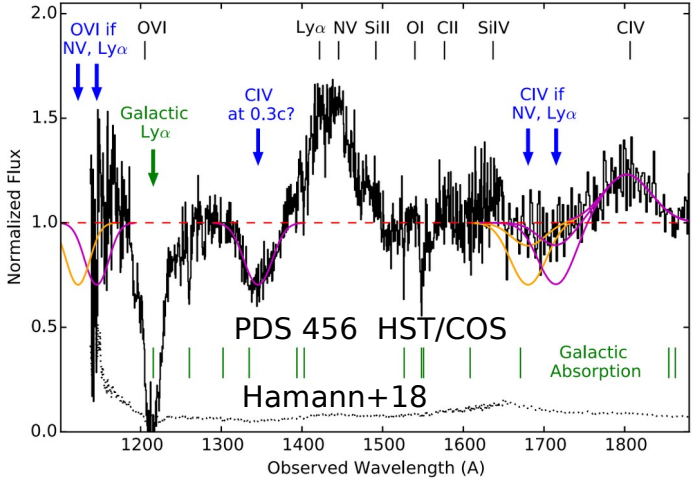


X-ray



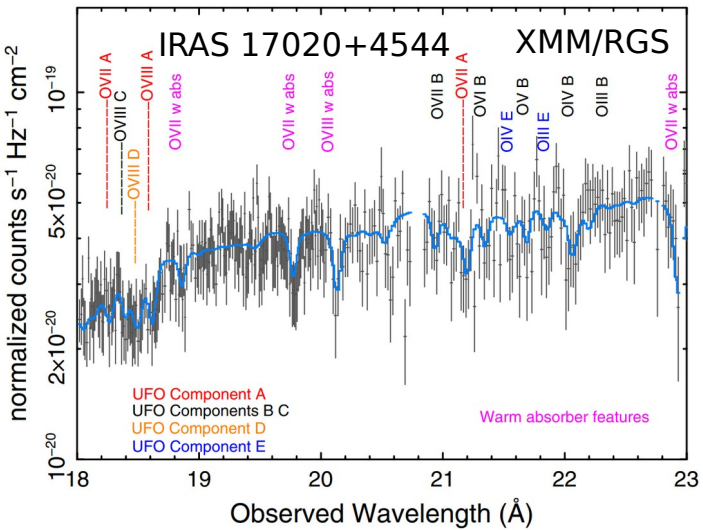


UV



Multi-phase UFOs in action

Soft X-ray

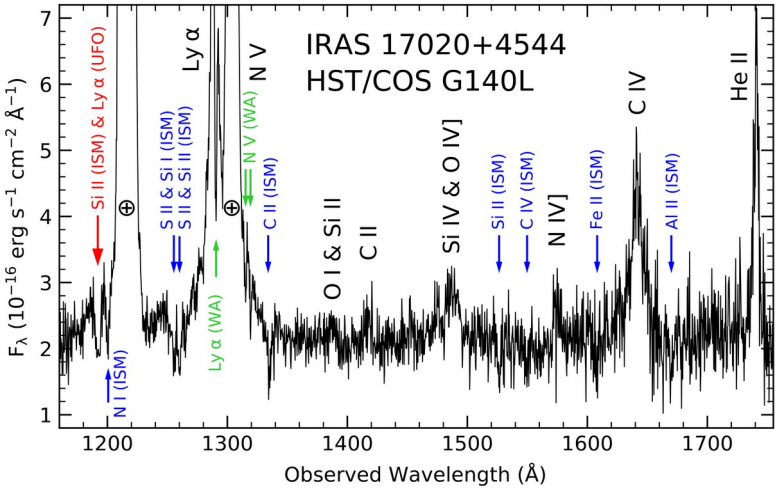


Longinotti+15

X-ray UFO with multiple velocity and ionization components alongside the warm absorber (Sanfrutos+18)

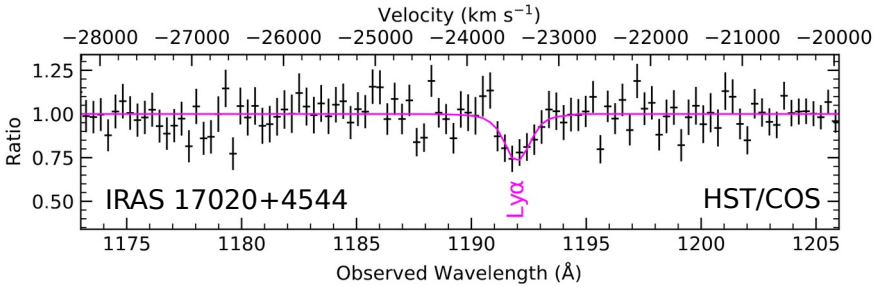
Molecular outflows are also detected (Longinotti+18,23)

UV



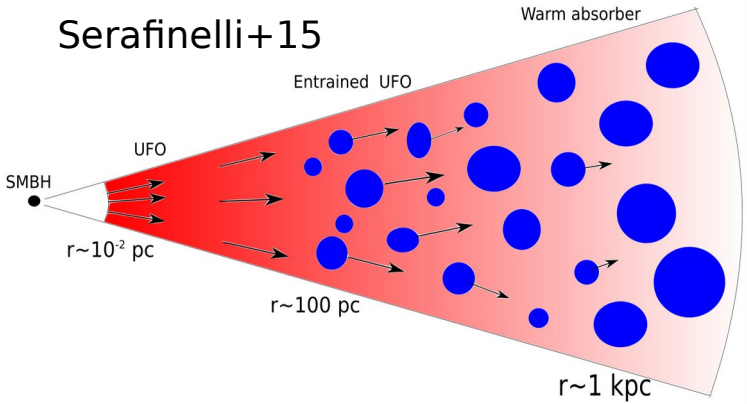
Mehdipour+22

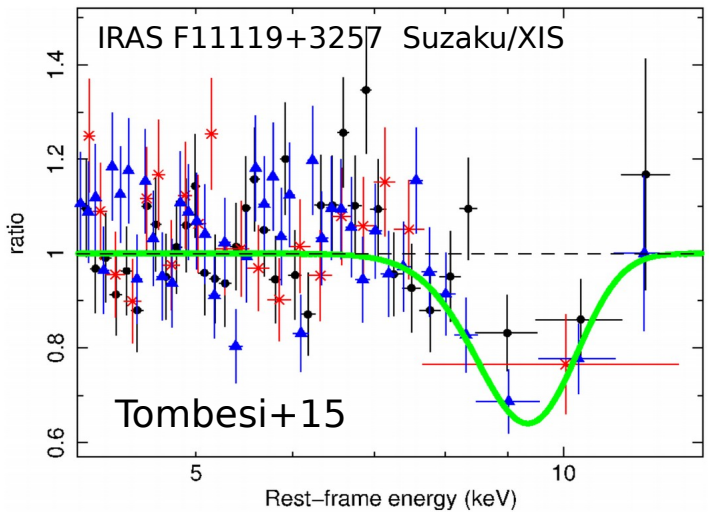
Narrow Lyα counterpart of the lower-velocity component of the X-ray UFO (Comp. A)



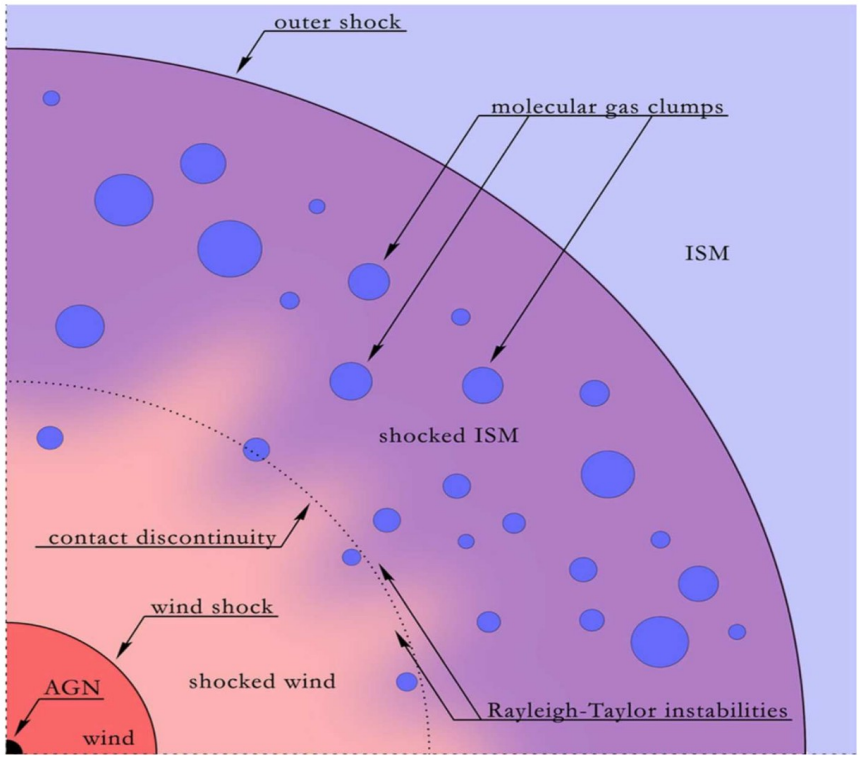
N_H ~ 1e20, log U ~ -0.4, v_{out} ~ 0.08 c

Primary UFO entraining surrounding medium?





UFO driving molecular outflows

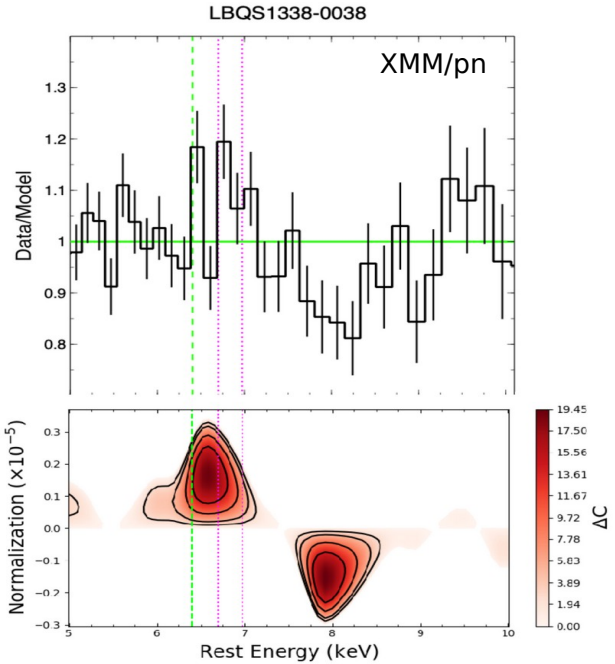


Zubovas & King 2014

Joint X-ray/UV search of outflows at intermediate redshifts

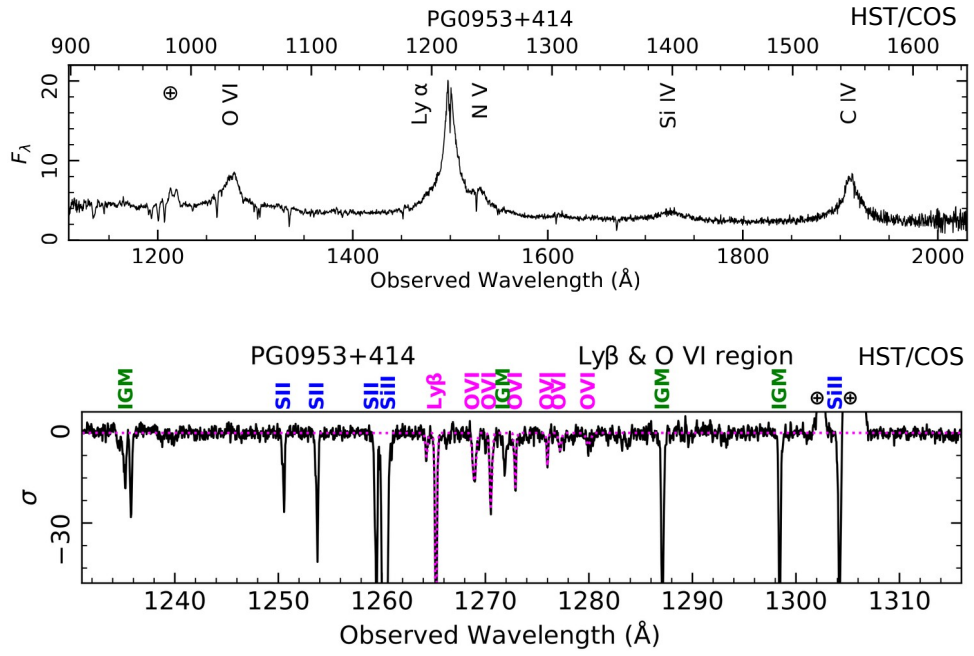
SUBWAYS program (sample of 22 QSOs) with XMM (PI: Brusa) & HST/COS (PI: Kriss), probing the redshift/luminosity parameter space between Seyferts and powerful quasars

Evidence of X-ray UFOs (Fe K absorption with v_{out}>0.1 c) found in 30% of the targets



Matzeu+23

70% of targets have intrinsic Lyα absorption 50% show either C IV, N V, or O VI outflows



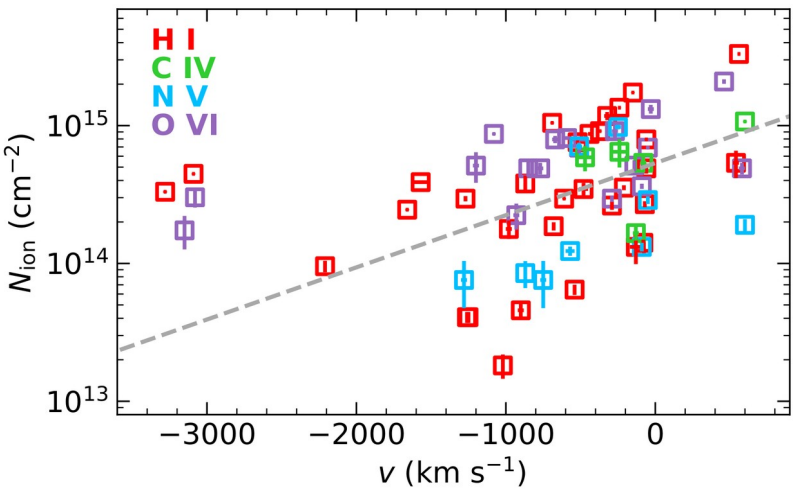
Mehdipour+23

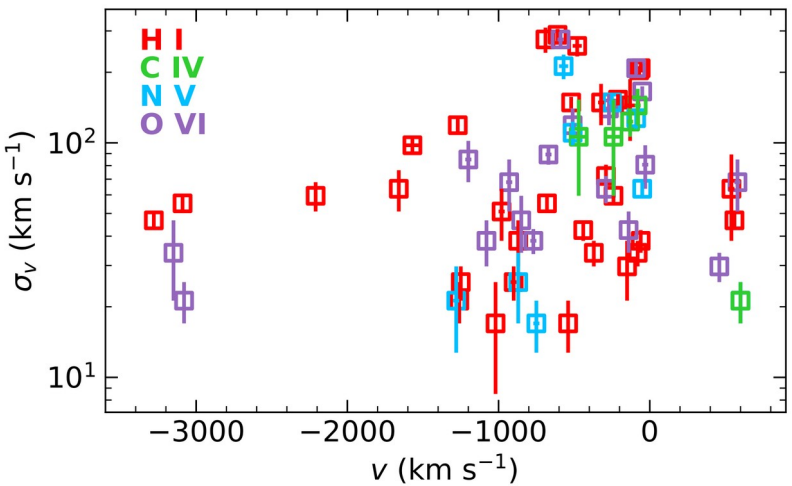
Joint X-ray/UV search of outflows at intermediate redshifts

Parameters of the outflows in the SUBWAYS QSO sample are generally comparable to those seen in the local Seyfert-1 galaxies

Two third of the intrinsic UV absorbers show multiple outflow velocity components in the HST spectra

Only narrow UV absorption lines with moderate outflow velocities are found, and their column density tends to decrease with outflow velocity





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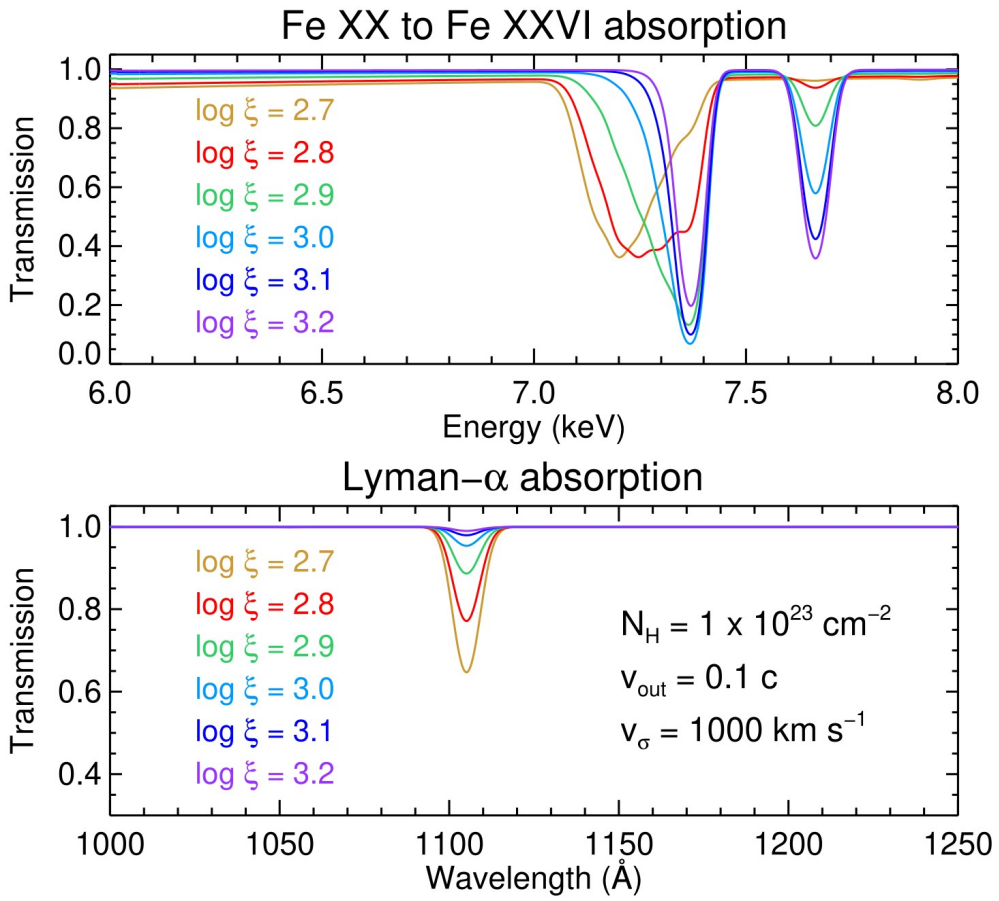
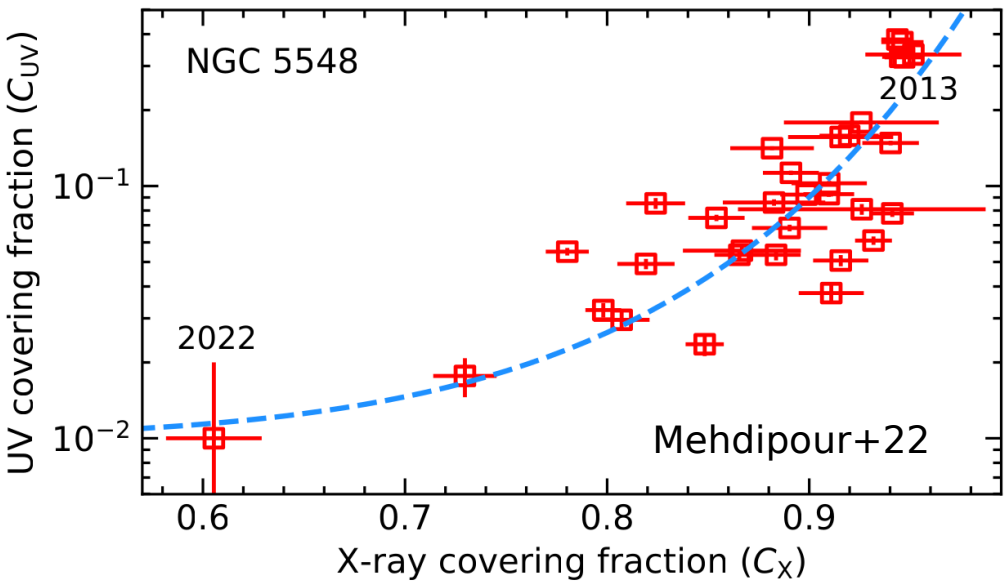
UV UFO detection: dependence on ionization parameter?



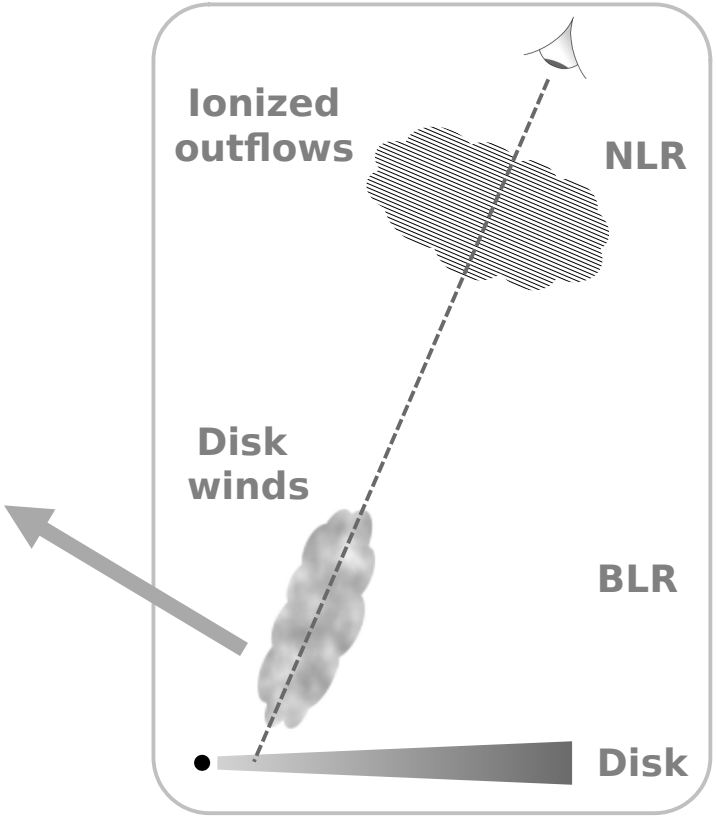
SPEX/pion calculations

UV UFO detection: dependence on wind's covering fraction?

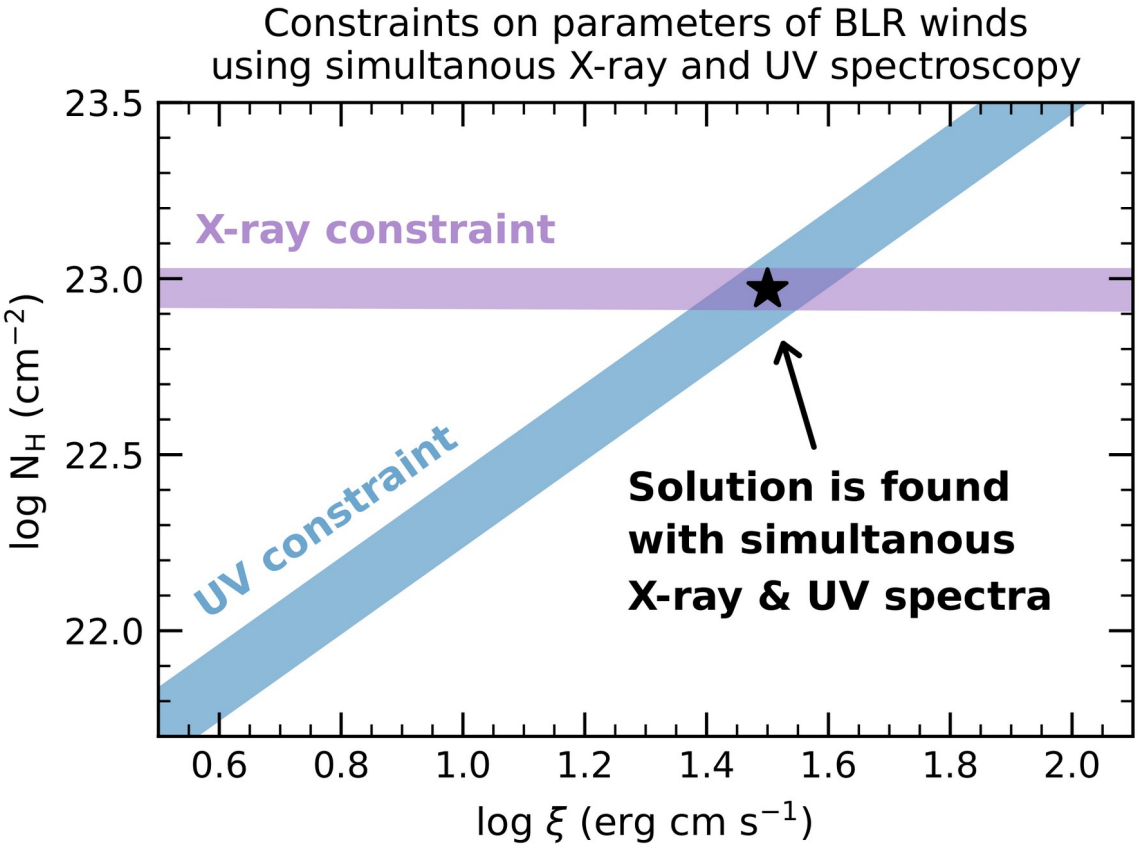
UV vs. X-ray covering fractions of the disk wind in NGC 5548



At C_X~0.6 the C_{UV} is too low for a significant UV absorption detection

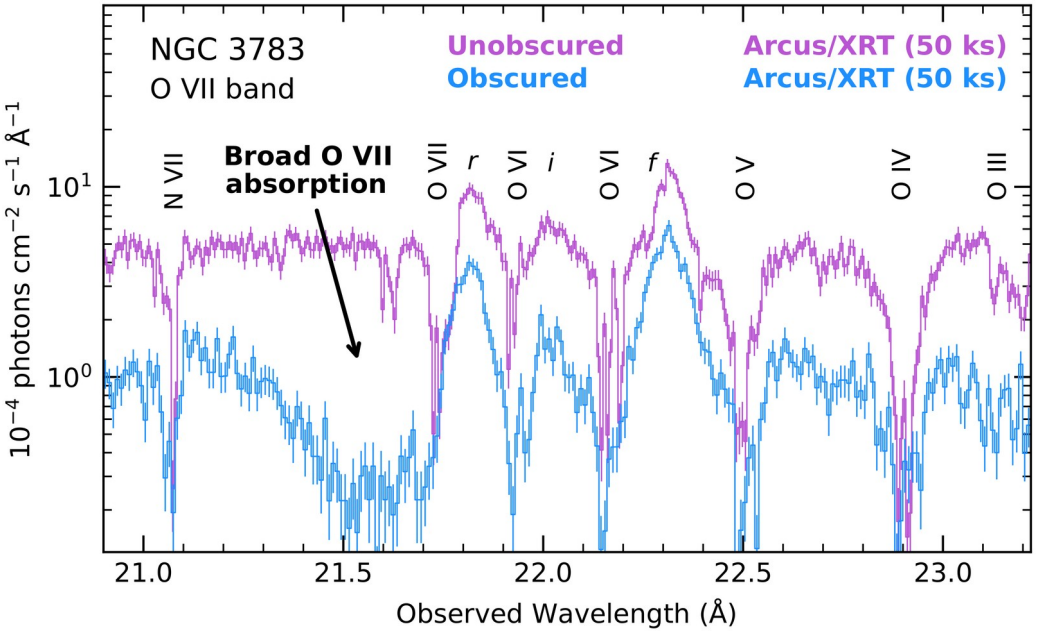


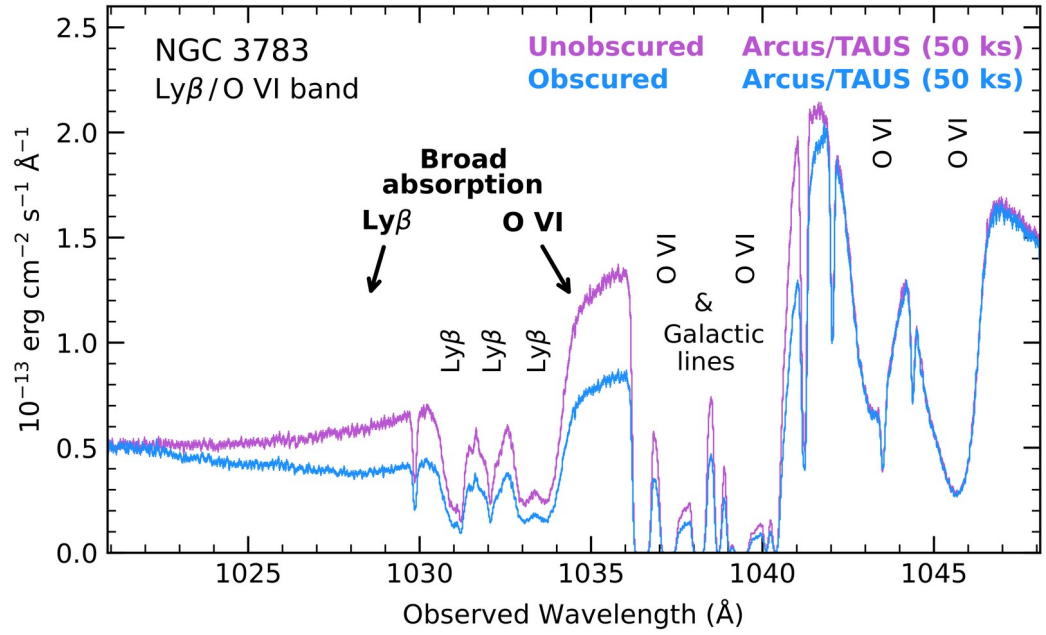
Need for simultaneous X-ray and UV spectroscopy



Proposed *Arcus* probe of outflows

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

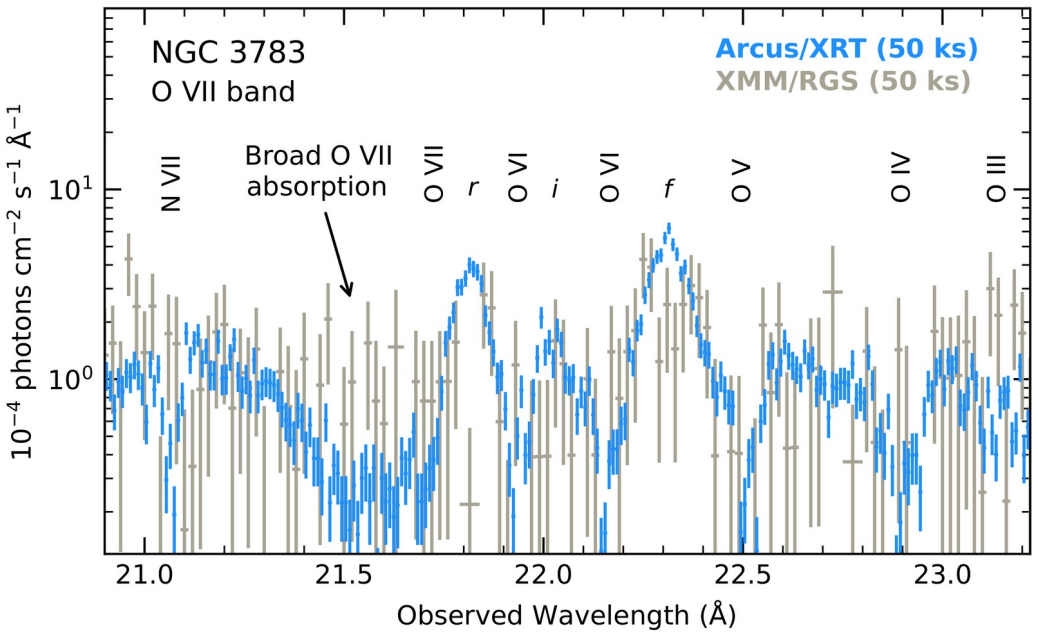


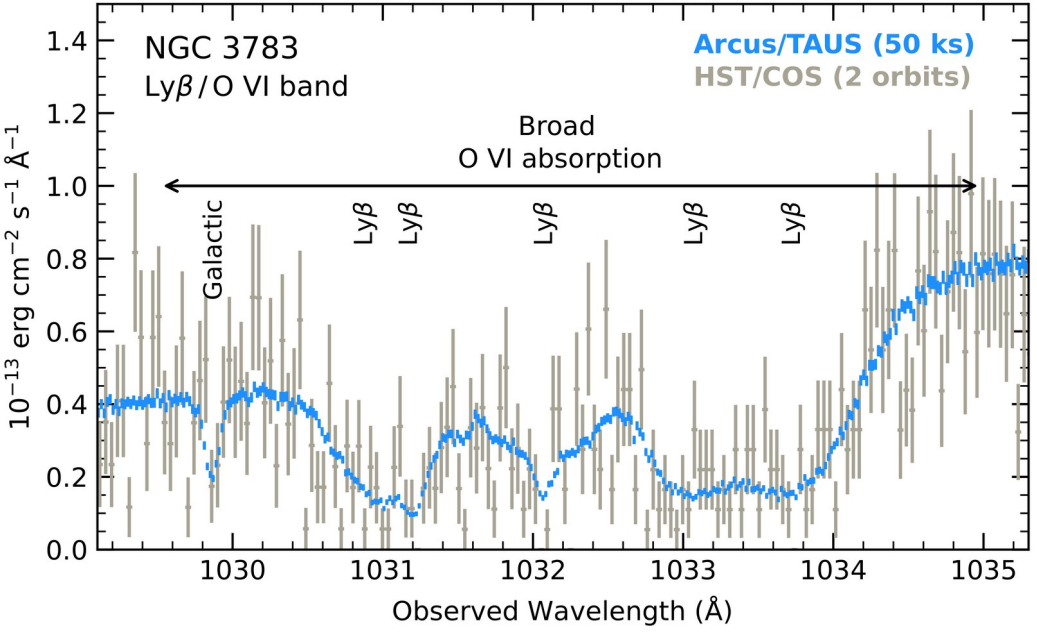


SPEX/pion simulations

Proposed *Arcus* probe of outflows

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





SPEX/pion simulations

Summary

- **Simultaneous UV/X-ray 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 and ionization of the wind**
- **Powerful disk winds likely entrain and shock their surrounding medium, resulting in the formation of weaker outflow components**
- **Need future missions to overcome current limitations in probing winds and need theoretical models to explain the observed complex properties**