Multi-wavelength campaign on NGC 7469: deciphering variability of the ionised outflows

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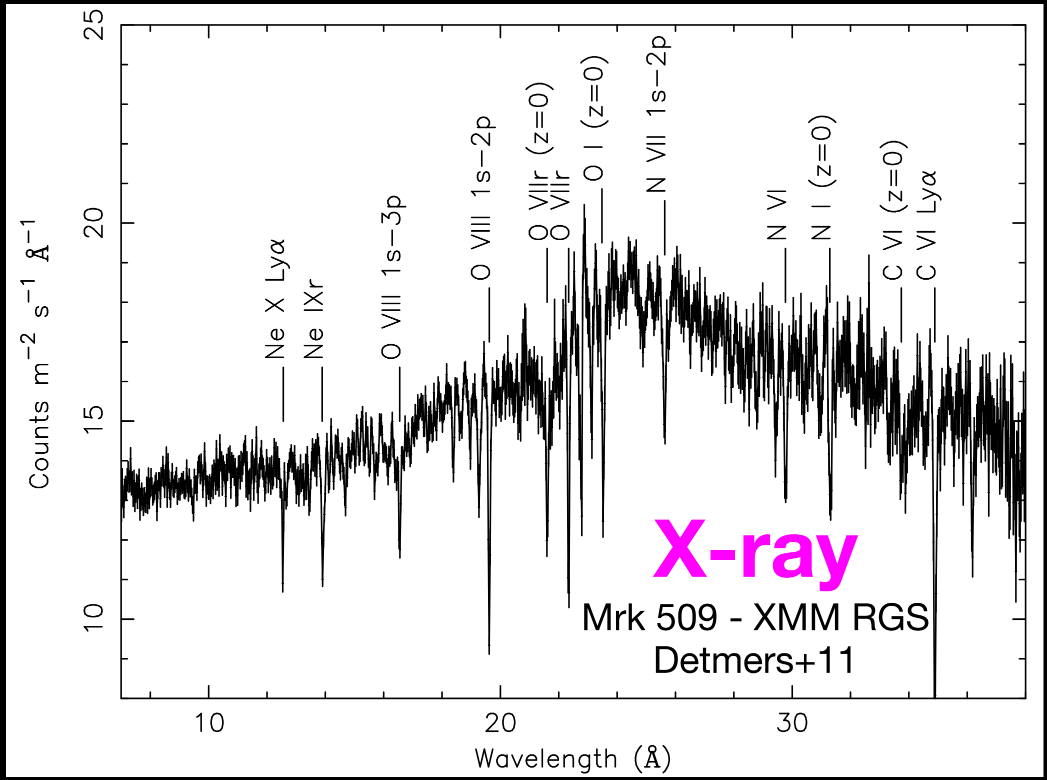
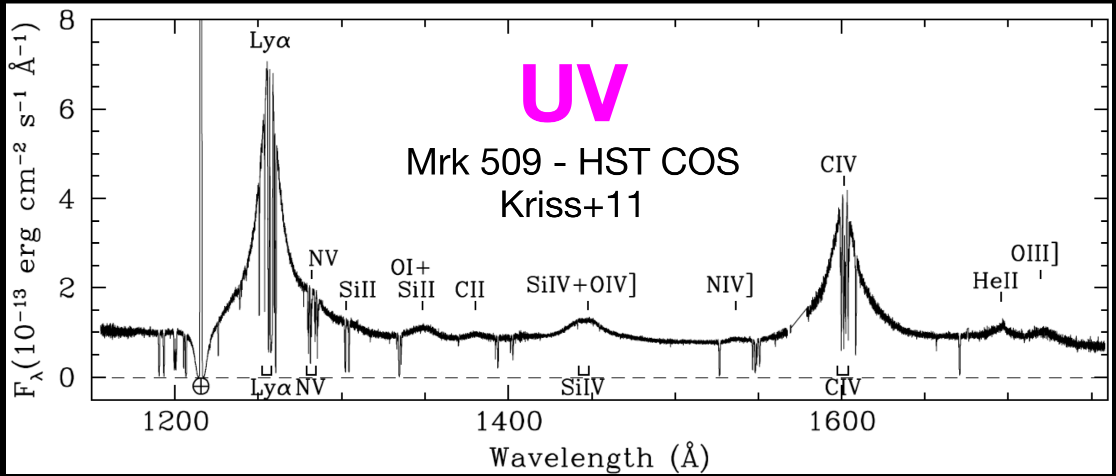
Chandra Workshop 2016

Ionised outflows in AGN





Driving mechanisms of AGN outflows

Equation of motion (Proga 2007):

$$\rho \frac{D\mathbf{v}}{Dt} + \rho \nabla \Phi = -\nabla \mathbf{P} + \frac{1}{4\pi}(\nabla \times \mathbf{B}) \times \mathbf{B} + \rho \mathbf{F}^{rad}$$

Possible driving mechanisms:

- Thermal driving (Krolik & Kriss 2001)
- Magnetic driving (Königl & Kartje 1994)
- Radiation pressure driving (Proga & Kallman 2004)

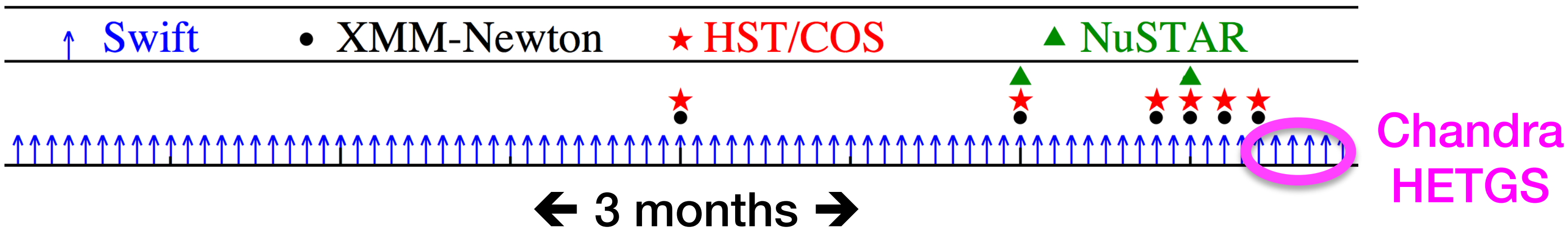
Different kinds of outflows found in AGN:

- warm-absorber outflows
- highly-ionised outflows
- ultra-fast outflows
- obscuring outflows

Origin: accretion disk or the AGN torus?

Multi-wavelength campaign on NGC 7469

Observing program in 2015-2016 (PI: Ehud Behar)
XMM-Newton (7 × 80 ks), Chandra HETGS (250 ks), HST/COS (14 orbits), NuSTAR (7 × 20 ks), Swift (50 × 1.5 ks)



Objectives

- **AGN outflows**
  - mapping the ionisation, chemical and dynamical structure
  - density and location
  - origin and driving mechanism
  - kinetic luminosity and impact on their environment

- **Intrinsic accretion-powered emission**
  - spectral decomposition of the optical/UV/X-ray continuum
  - structure of the reprocessing/reflecting regions
  - origin of the soft X-ray excess emission

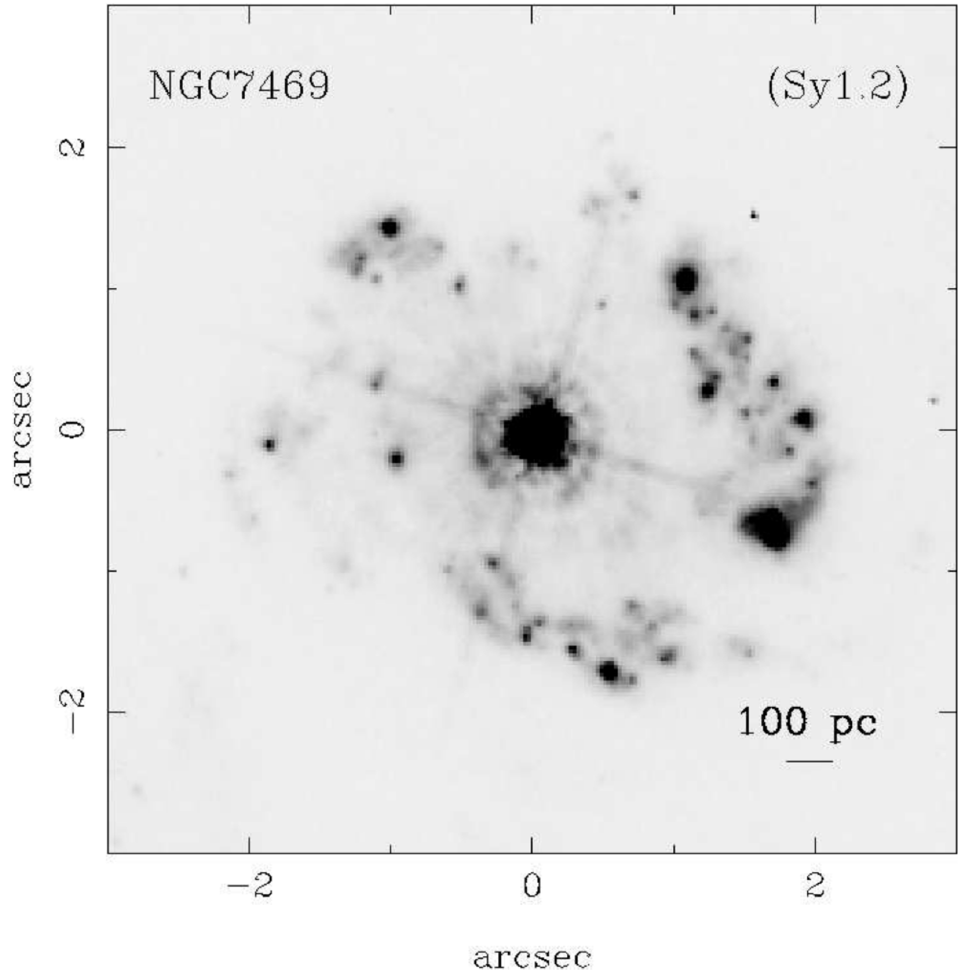
NGC 7469

- Bright Seyfert 1 galaxy $F_{0.3\text{-}10\ \mathrm{keV}} = 5\text{-}6 \times 10^{-11}$ erg s^{-1} cm^{-2}
- Redshift z= 0.016268
- Foreground MW N_H = 4.34×10^{20} cm^{-2}
- $M_{BH} = (1.0\pm0.1) \times 10^{7}\ M_{\odot}$ (Peterson+15)
- Nucleus surrounded by a starburst ring

Image from HubbleSite

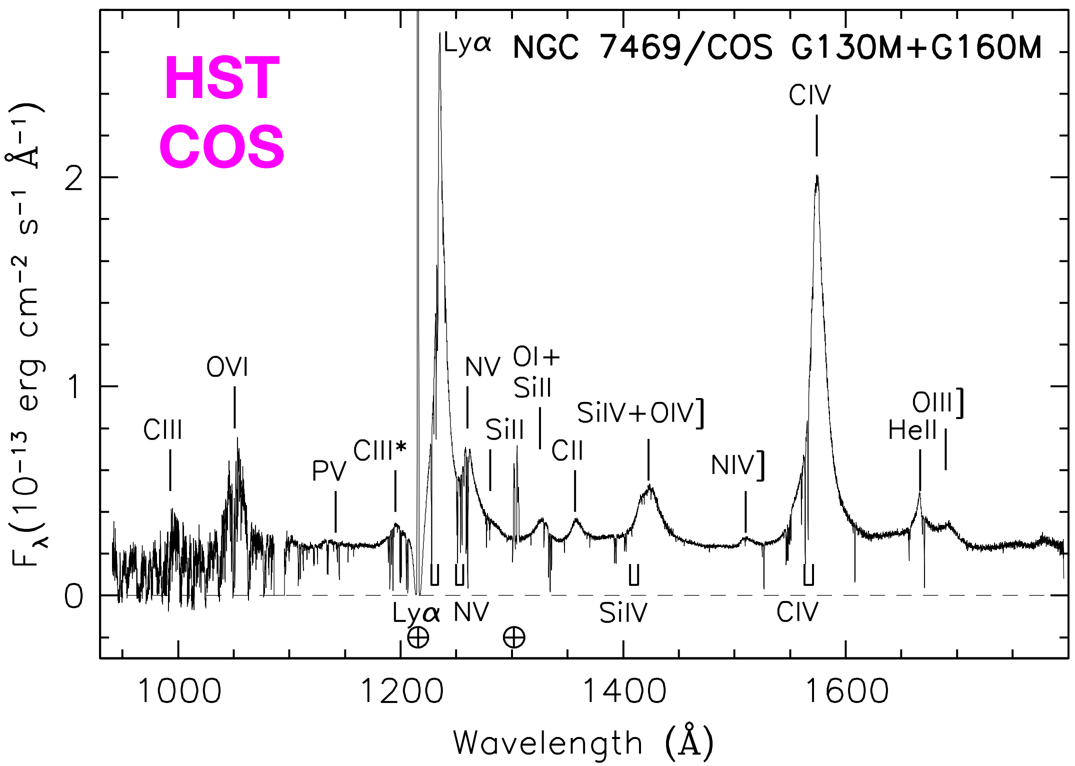
NGC 7469

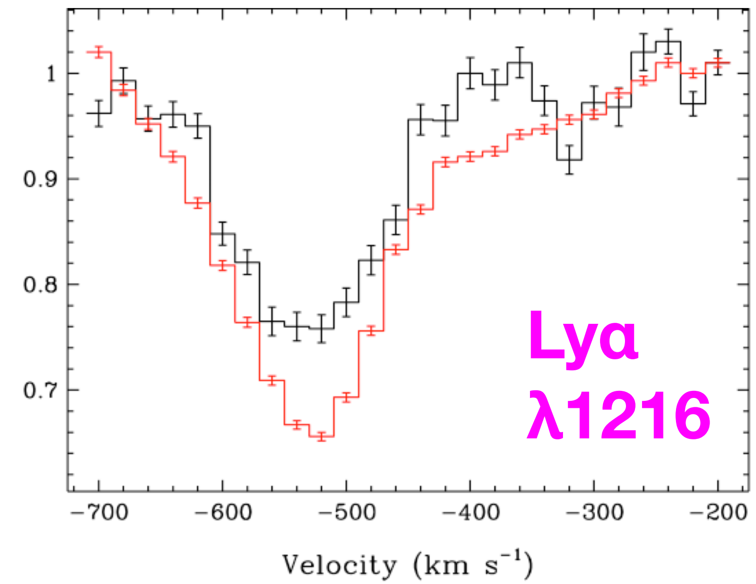
- Ionised outflows seen in the UV and X-rays (Kriss+03; Scott+05; Blustin+07)
- Multiple ionisation and velocity components
- Ambiguity in the radial distances from the central black hole (R < 100 pc or R < 600 pc)
- Link between the UV and X-ray absorption components, and their origin, unclear.

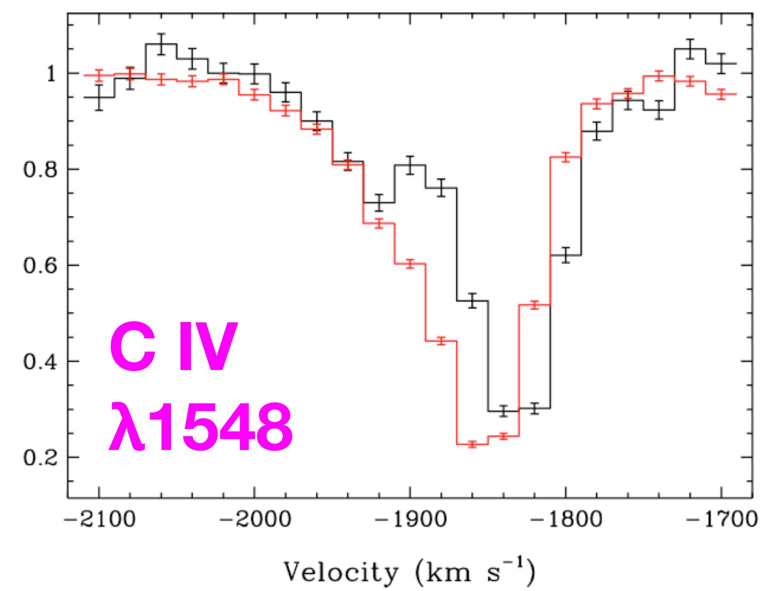


HST ACS/HRC (F330W)
González Delgado+07

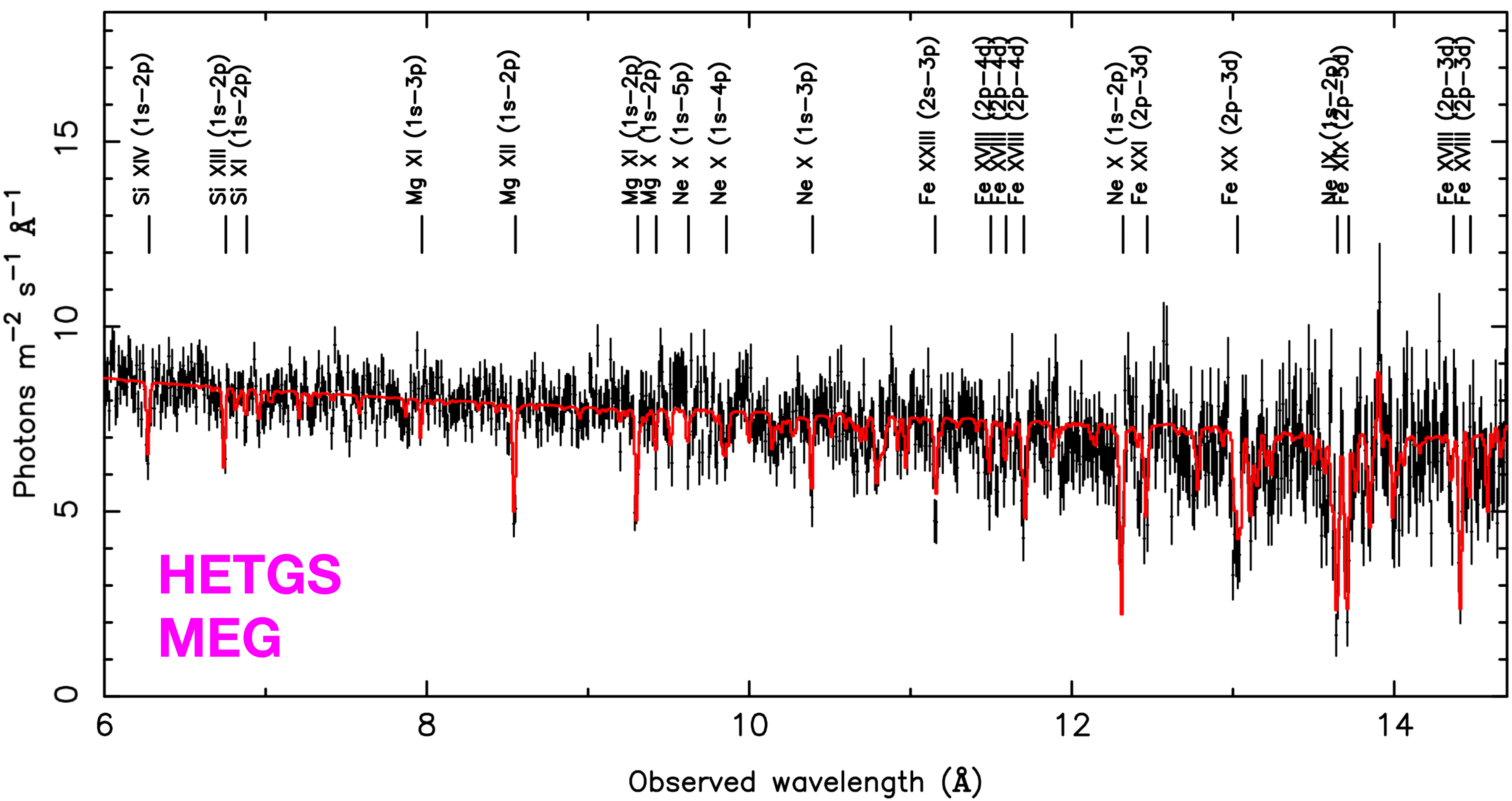
HST COS spectrum of NGC 7469



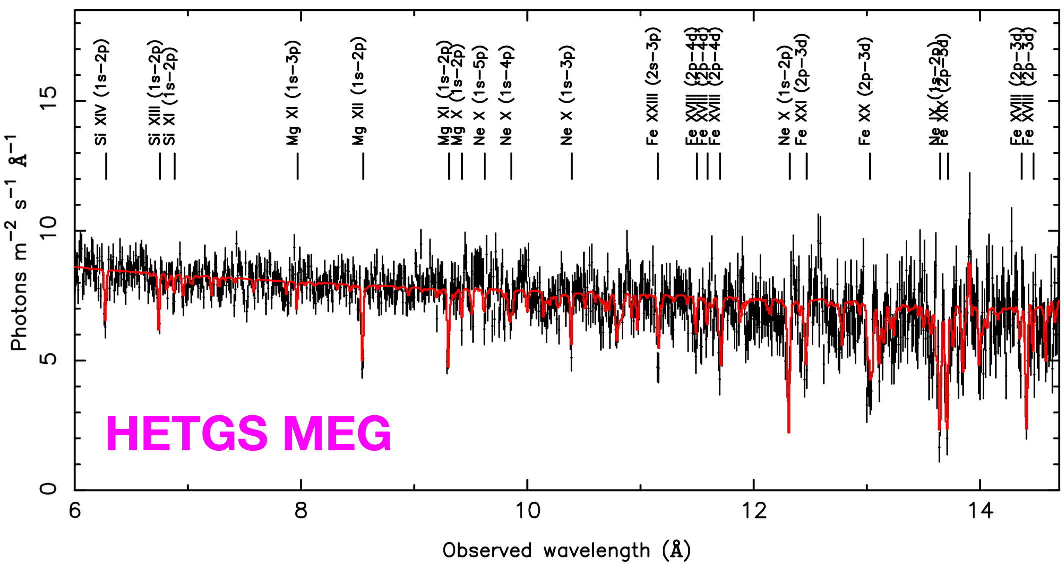


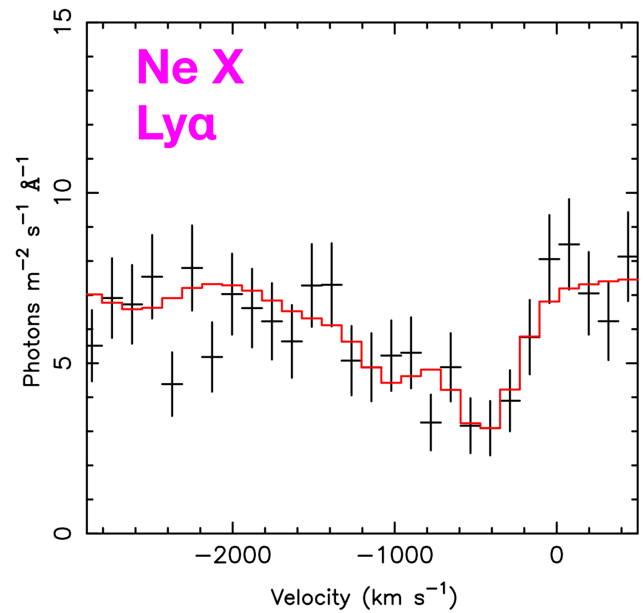


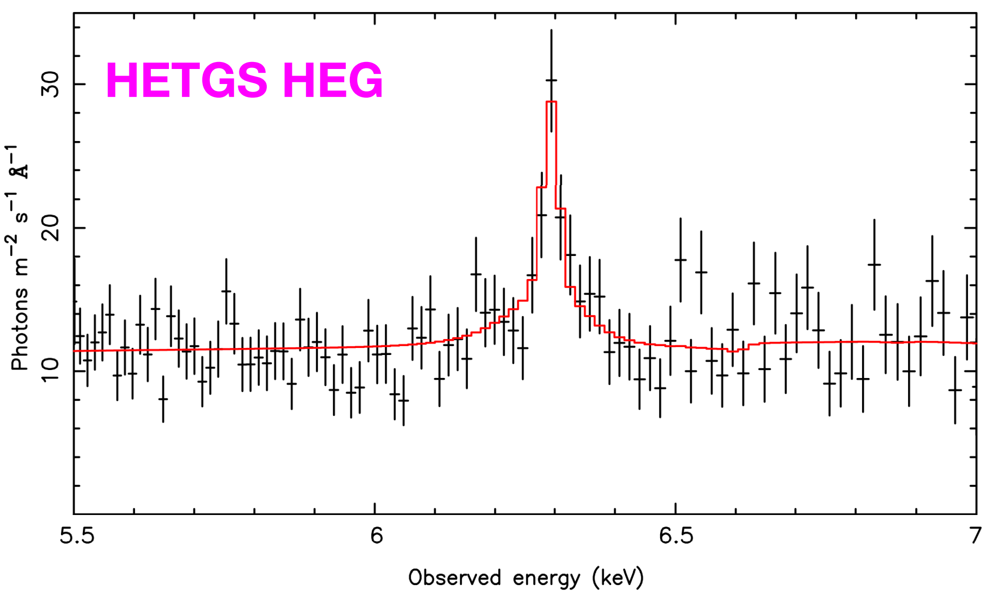
Chandra HETGS spectrum of NGC 7469

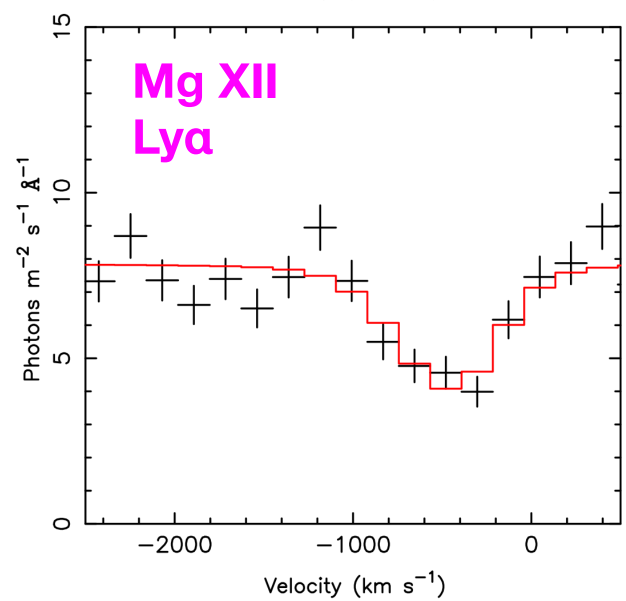


Chandra HETGS spectrum of NGC 7469

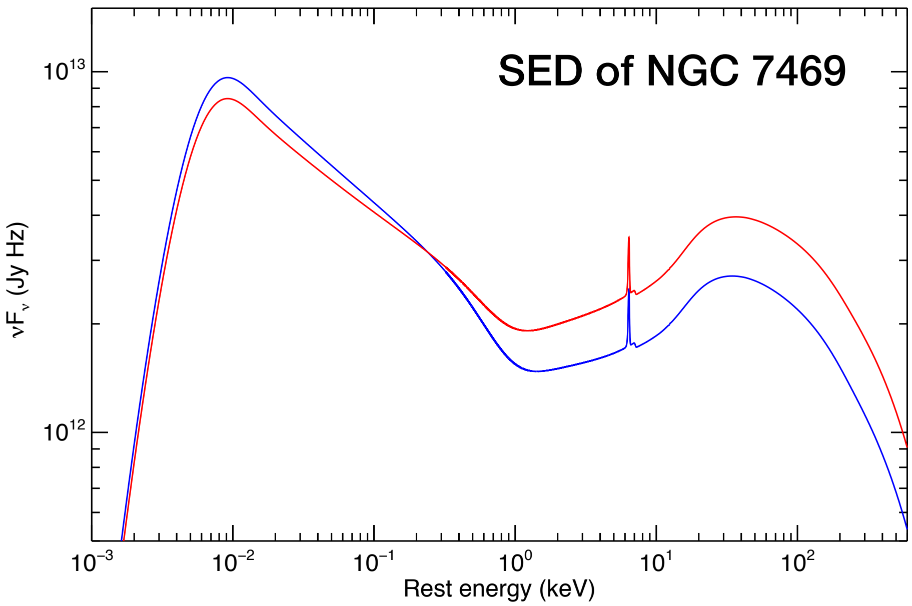


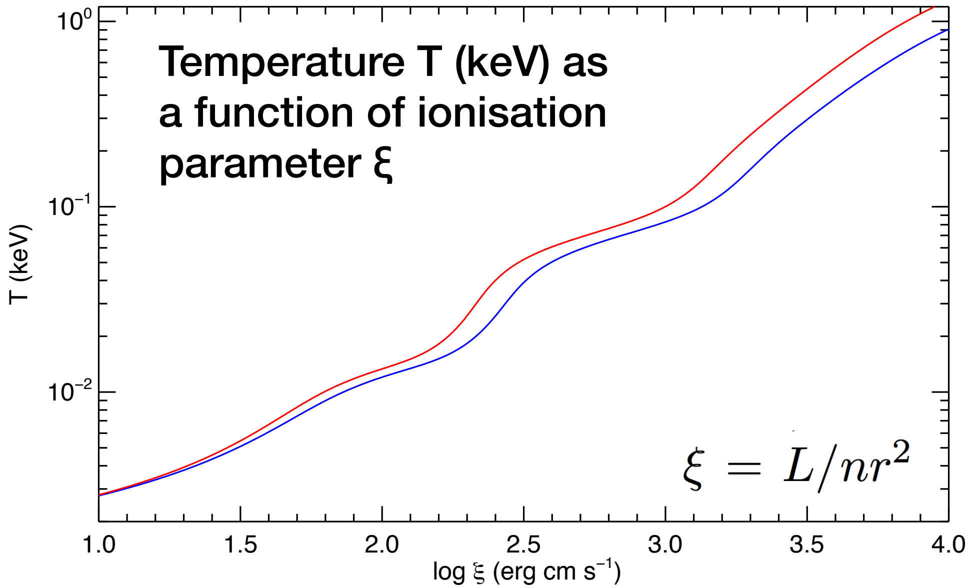






Time-dependent photoionisation modelling

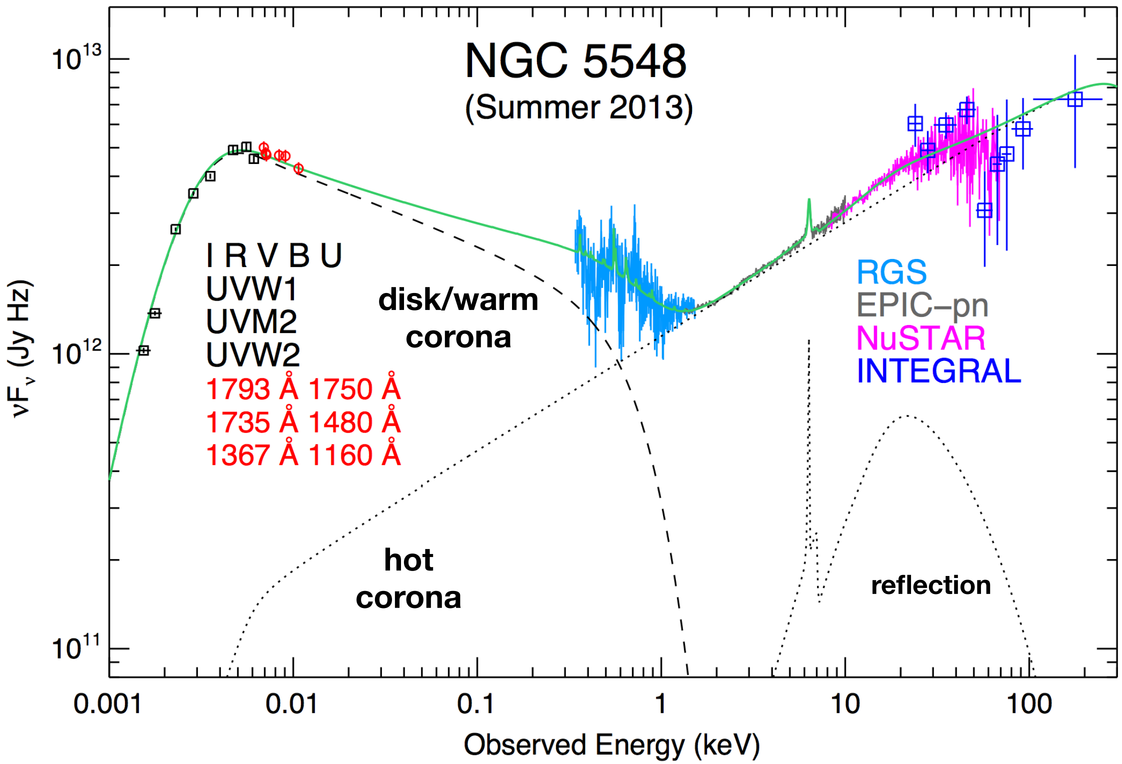


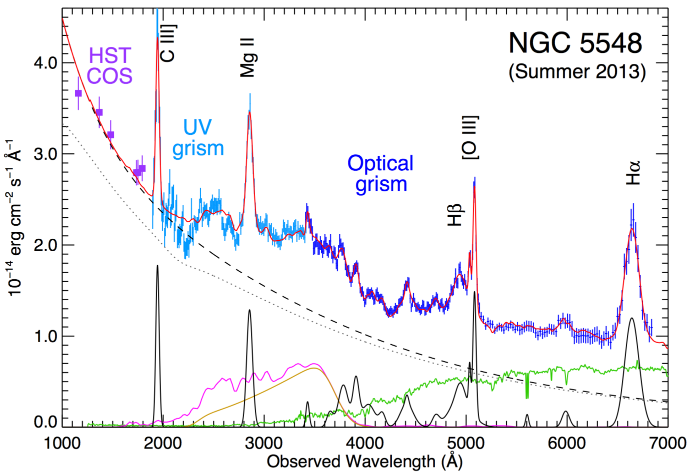


The optical-UV-X-ray SED is determined from continuum modelling of the Swift, HST, XMM-Newton, Chandra and NuSTAR data (using broadband continuum model from Mehdipour+15)

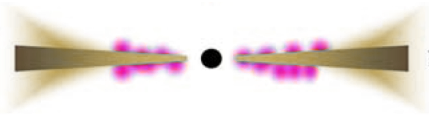
Photoionisation computation and spectral modelling performed using the *pion* code in SPEX.

Model for the AGN broadband continuum





Mehdipour+15



- The NIR/optical/UV continuum is a Comptonised disk component, which also produces the 'soft X-ray excess' (warm Comptonisation).
- A hot Comptonising corona produces the primary hard X-ray continuum.
- A reflection component from cold and distant material.

Components of the AGN outflow in NGC 7469

log ξ = 3.0

- N_H = 2.4e+21 cm^{-2}, v_{out} = –500 km s^{-1}

log ξ = 2.5

- N_H = 1.2e+21 cm^{-2}, v_{out} = –650 km s^{-1}
- N_H = 7.0e+20 cm^{-2}, v_{out} = –900 km s^{-1}

log ξ = 2.1

- N_H = 1.1e+21 cm^{-2}, v_{out} = –500 km s^{-1}
- N_H = 1.8e+20 cm^{-2}, v_{out} = –1900 km s^{-1}

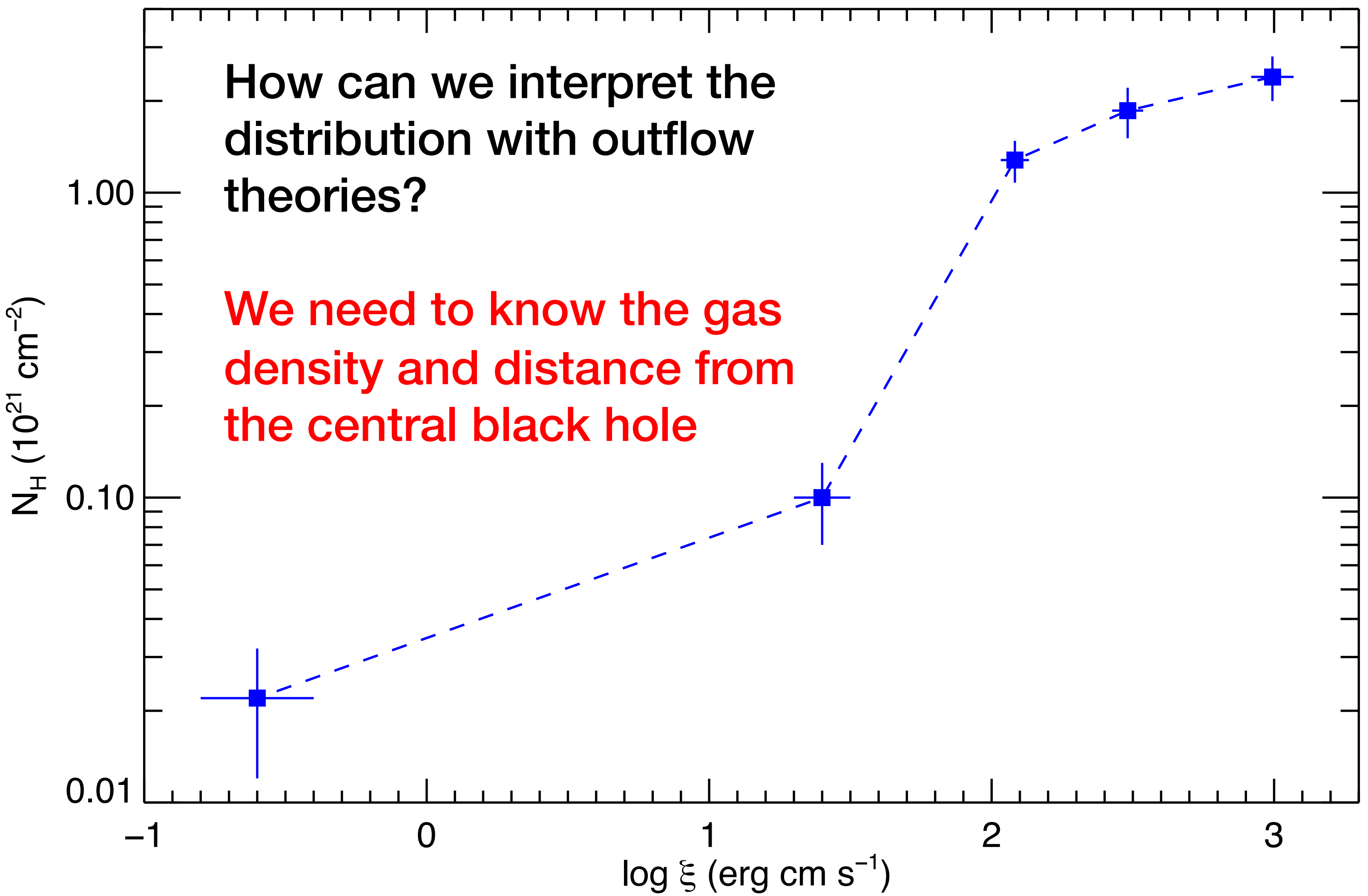
log ξ = 1.4

- N_H = 1.0e+20 cm^{-2}, v_{out} = –600 km s^{-1}

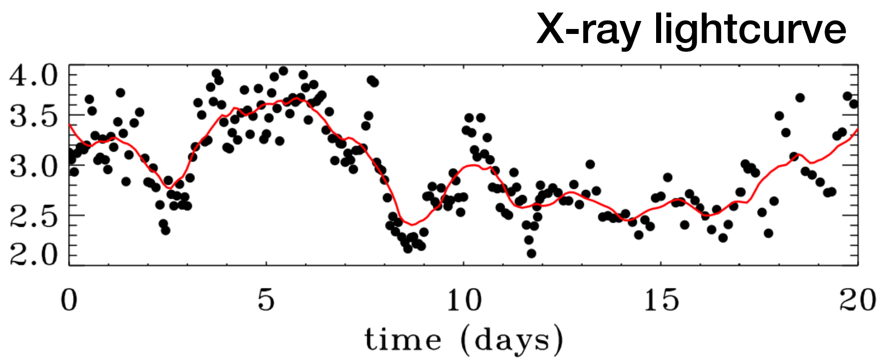
log ξ = –0.6

- N_H = 2.2e+19 cm^{-2}, v_{out} = –600 km s^{-1}

Components of the AGN outflow in NGC 7469



Measuring response of a photoionised plasma to the ionising SED changes: density and distance limits



Change in the ionising SED over time ➔ change in ionisation balance ➔ change in ionic densities

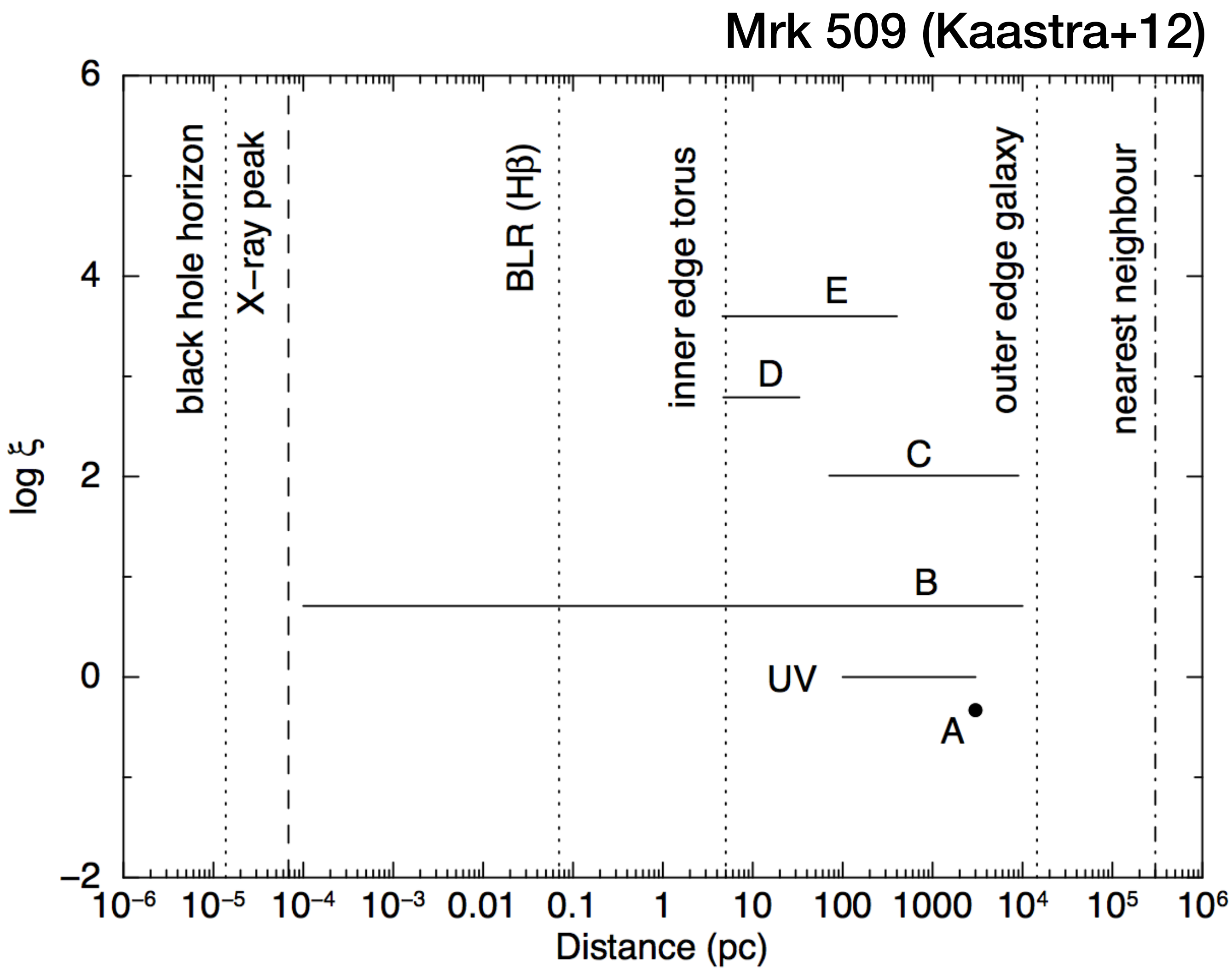
$$\frac{\mathrm{d}n_i}{\mathrm{d}t} = -n_i n_\mathrm{e} \alpha_{i-1} + n_{i+1} n_\mathrm{e} \alpha_i - n_i I_i + n_{i-1} I_{i-1}$$

Photoionisation modelling ➔ ionisation and recombination rates for each ion ➔ ionisation/recombination timescale as a function of density n_e

Observing a timescale of change ➔ constraint on density n_e

Then using the ionisation parameter $\xi = L / n_e R^2$, limits on the distance R from the central ionising source is obtained.

Location of the AGN outflow components



Density and distance limits for the outflows in NGC 7469

Preliminary results:

$100 < n_e < 480\ \mathrm{cm}^{-3}$ ➔ $5 < R < 11$ pc

$340 < n_e < 2900\ \mathrm{cm}^{-3}$ ➔ $2 < R < 6$ pc

$2900 < n_e < 17000\ \mathrm{cm}^{-3}$ ➔ $1 < R < 2$ pc

Size of the BLR: ~ 2-10 light days (Peterson+15)

Inner radius of the torus: ~0.1 pc (Suganuma+06)

Size of the NLR: < 170 pc

Location of the starburst ring: 250-1000 pc

outflows are located between the torus and the NLR

➔ thermal wind produced by irradiation of the torus

Mass outflow rate:

$$\dot{M}_{\mathrm{out}} = \Delta\Omega\ R\ N_{\mathrm{H}}\ \mu m_{\mathrm{p}}\ v_{out}$$

Kinetic luminosity:

$$L_{\mathrm{k}} = 1/2\ \dot{M}_{\mathrm{out}}\ v^2_{\mathrm{out}}$$

Kinetic luminosity in NGC 7469: < 0.1% of bolometric luminosity

Conclusions

Combined high-resolution UV and X-ray spectroscopy is key for mapping the ionisation, chemical and dynamical structure of AGN outflows ➔ origin and launching mechanism

Time-dependent photoionisation modelling and variability study of the outflows ➔ density and location

In bright nearby Seyfert-type AGN (like NGC 7469), warm-absorber outflows are likely thermally-driven torus winds.

Kinetic luminosity of warm absorbers in Seyferts is a small fraction of the bolometric luminosity.

To carry out such investigations in fainter AGN (but with stronger outflows), large observing programs with Chandra and XMM-Newton are needed.