AGN Outflows: Seyfert Galaxy "Winds"

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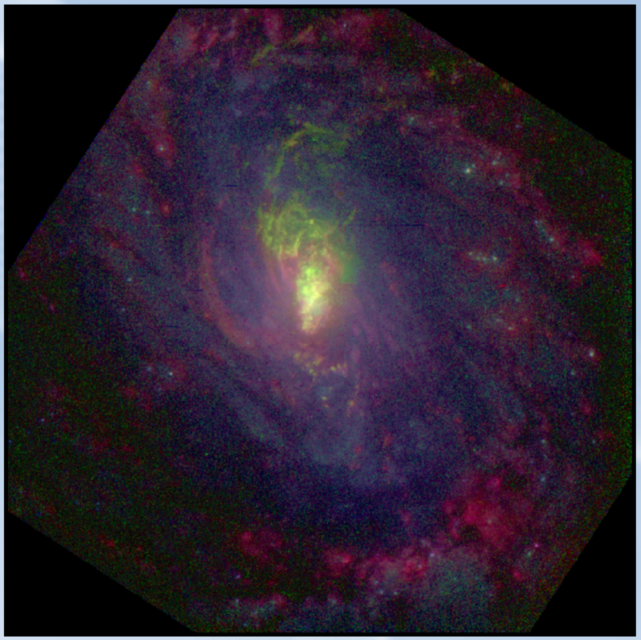
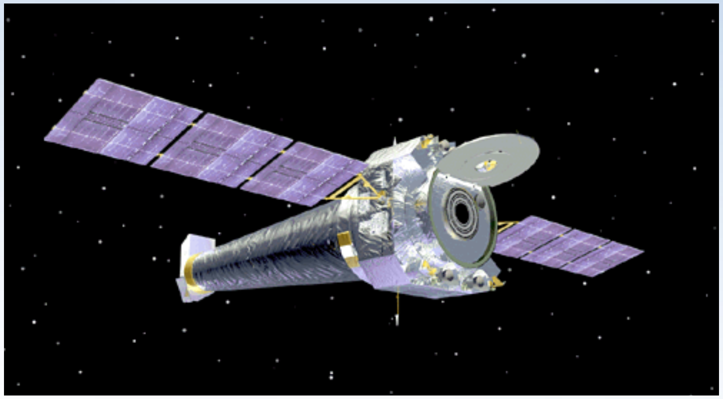
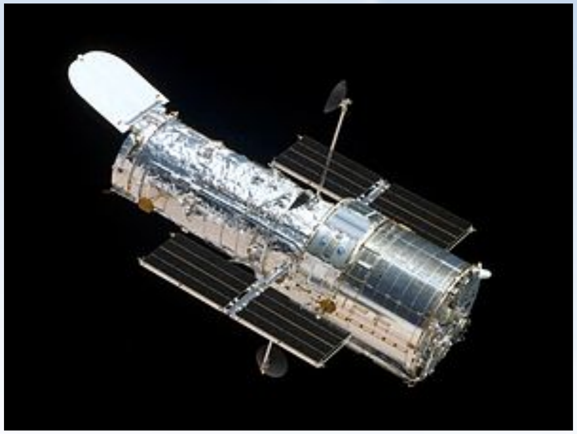
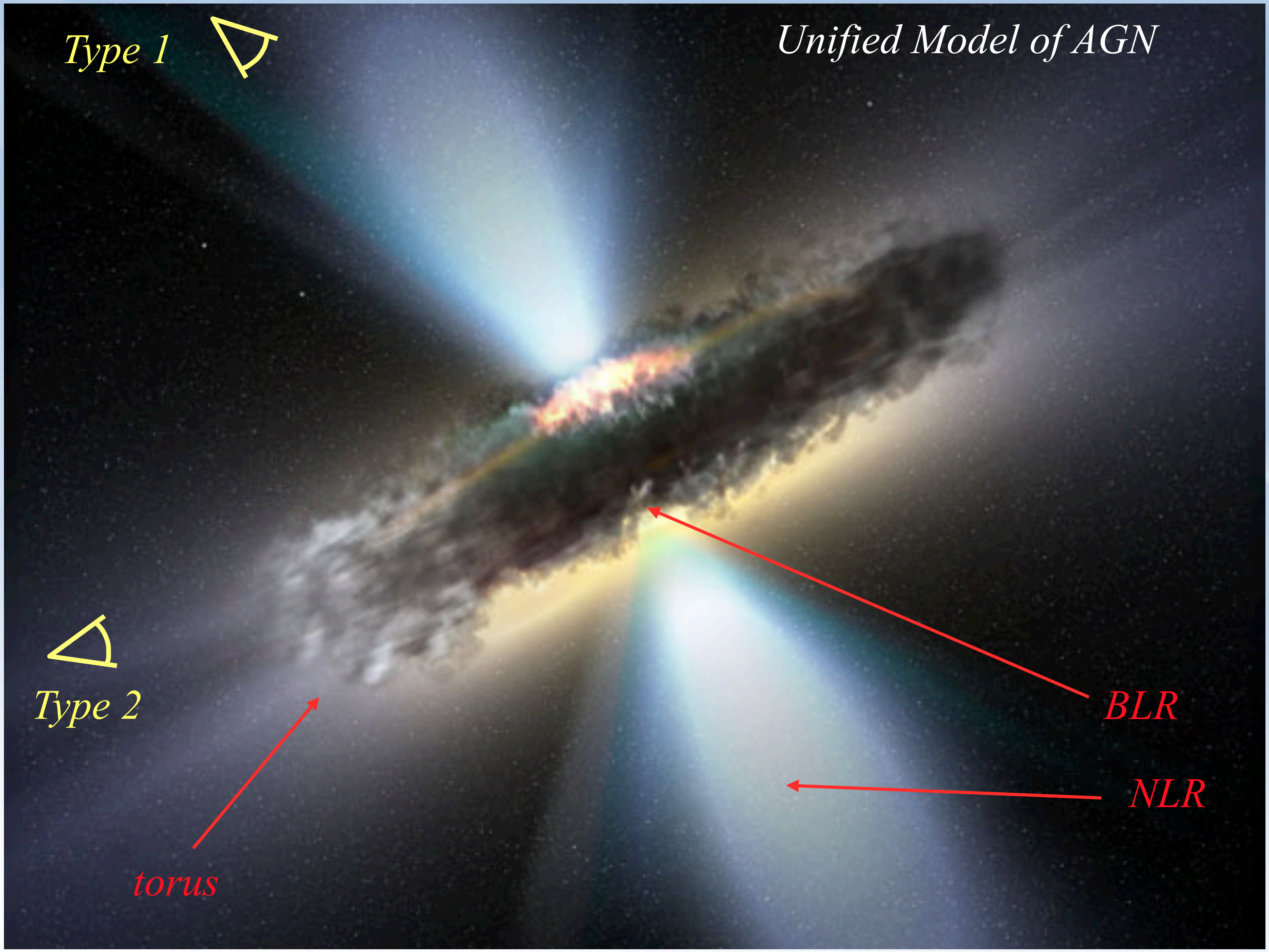






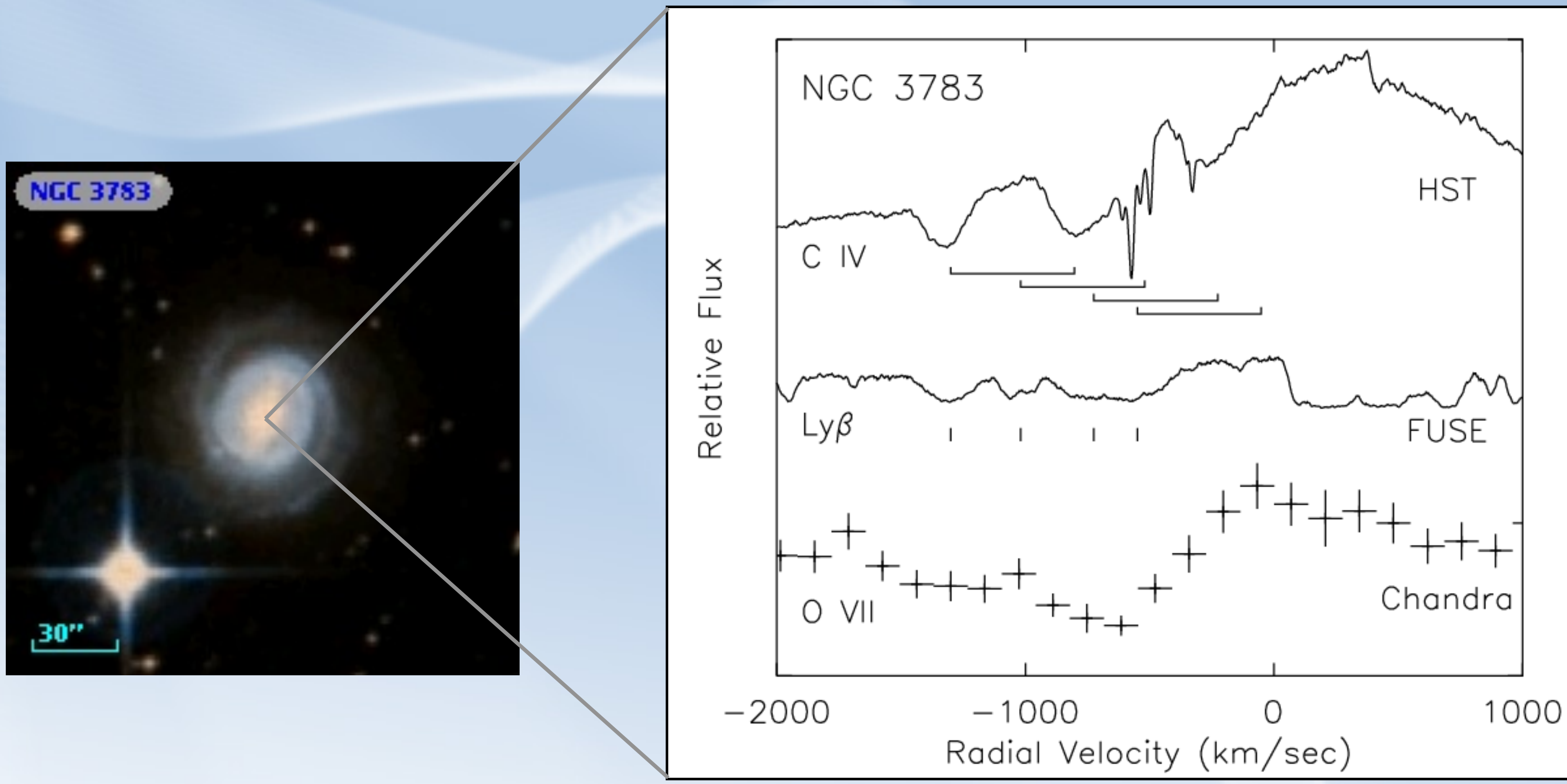

Type 1
Unified Model of AGN
Type 2
BLR
NLR
torus

AGN Outflows of Ionized Gas

- Jets in radio-loud galaxies and quasars
  - Collimated low-density plasma at relativistic speeds, ~5% of quasars
- Broad absorption line (BAL) quasars
  - Blueshifted absorption troughs up to ~0.2c, ~10% of quasars
- Quasars with narrow absorption lines (NALs)
  - Absorbers within 5000 km s^{-1} of quasar redshift, FWHM < 500 km s^{-1}
  - High-velocity NALS with outflow velocities up to 50,000 km s^{-1}
- "Winds" in moderate-luminosity (10^{43} – 10^{45} erg s^{-1}) Seyfert galaxies
  - Blueshifted UV and X-ray absorbers
  - Outflows in the narrow-line region (NLR)

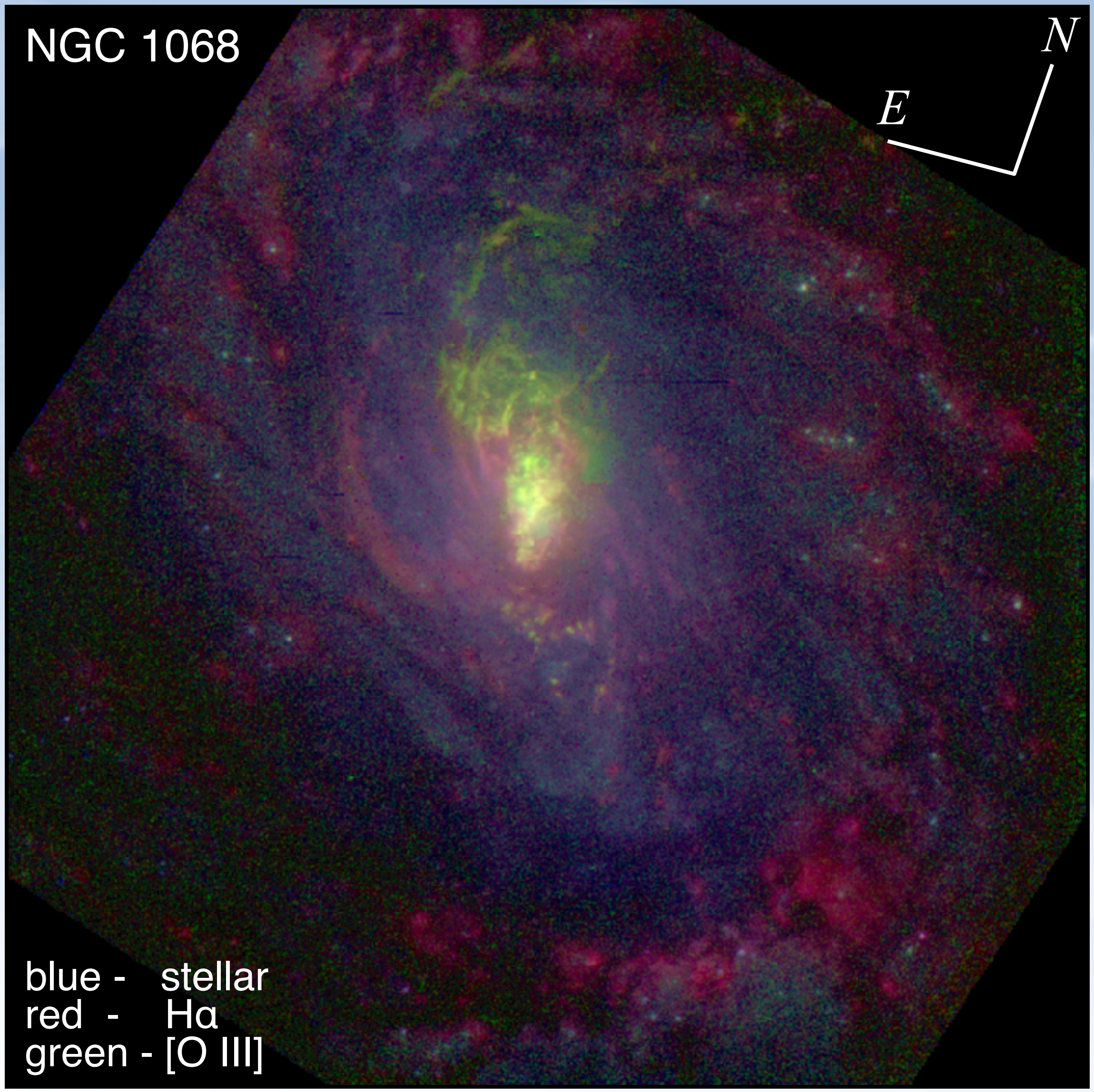
Seyferts are nearby ($z < 0.1$) and bright → best opportunity for detailed physical studies of AGN winds.

UV and X-ray Absorbers



- Blueshifted UV (C IV, N V) absorption components detected in ~60% of Seyfert 1 galaxies at outflow velocities up to 4000 km s^{-1}.
- The same AGN typically show X-ray “warm absorbers” with higher ionization lines (O VII, O VIII).

Outflows in the NLR



2 kpc

Why Study AGN Winds in Seyfert Galaxies?

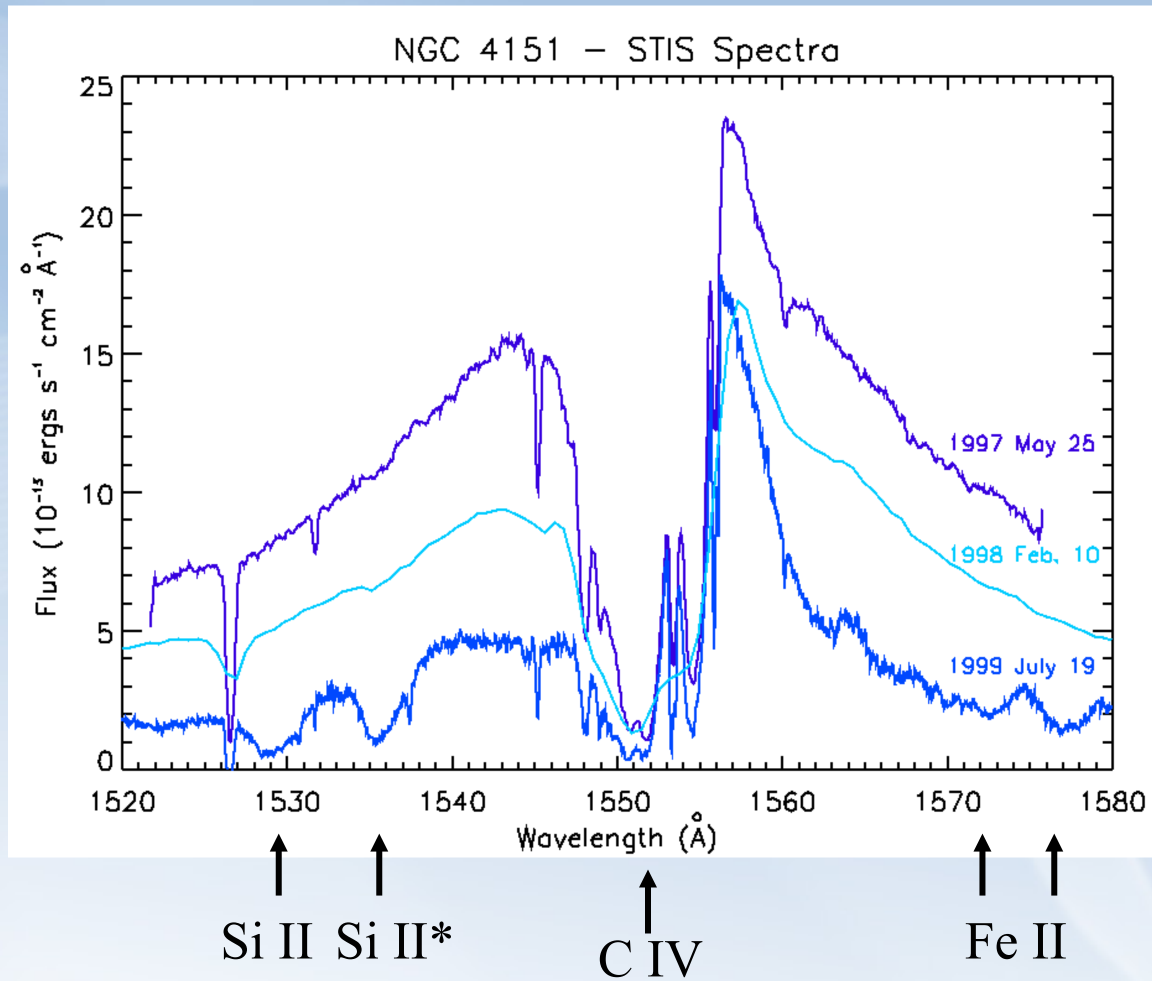
- Winds likely provide feedback in radio-quiet AGN, which are ~95% of the population.
- AGN feedback likely controls the growth and co-evolution of supermassive black holes (SMBHs) and their host galaxies.

What do we want to learn?

- What is the structure (location, geometry, kinematics, physical conditions) of AGN winds?
- What is the contribution of winds to feedback (mass outflow rates, kinetic luminosities) in moderate luminosity AGN?

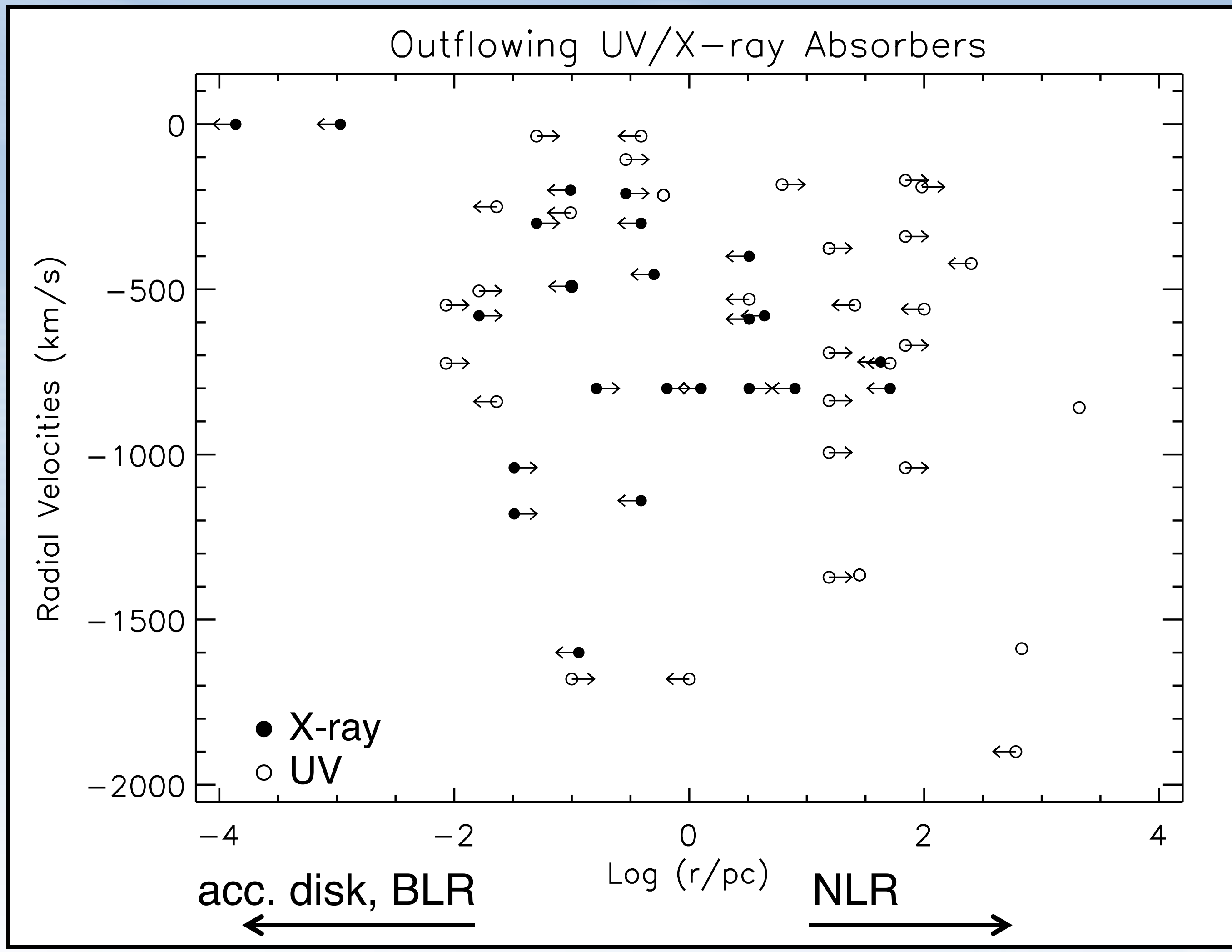
→ *HST, FUSE, CXO, and XMM* observations of outflowing UV and X-ray absorbers and NLR optical outflows in Seyferts

UV absorbers show variable ionization *(U).*



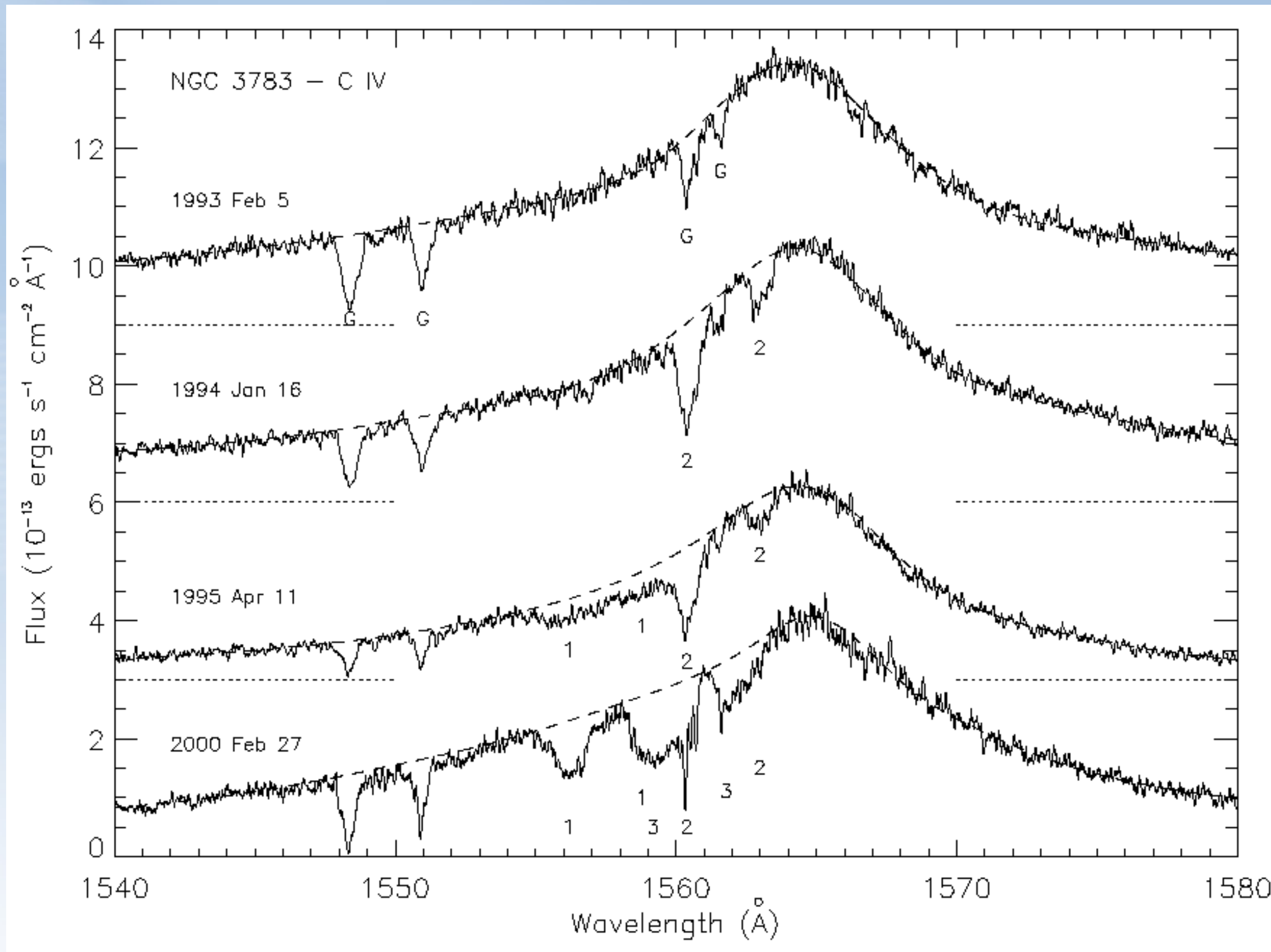
- Space Telescope Imaging Spectrograph (STIS) UV spectra
- Measure ionic columns, photoionization models to get U, N_H
- Variable ionization → recombination time → density → location

Locations: Most absorbers are between the BLR and NLR



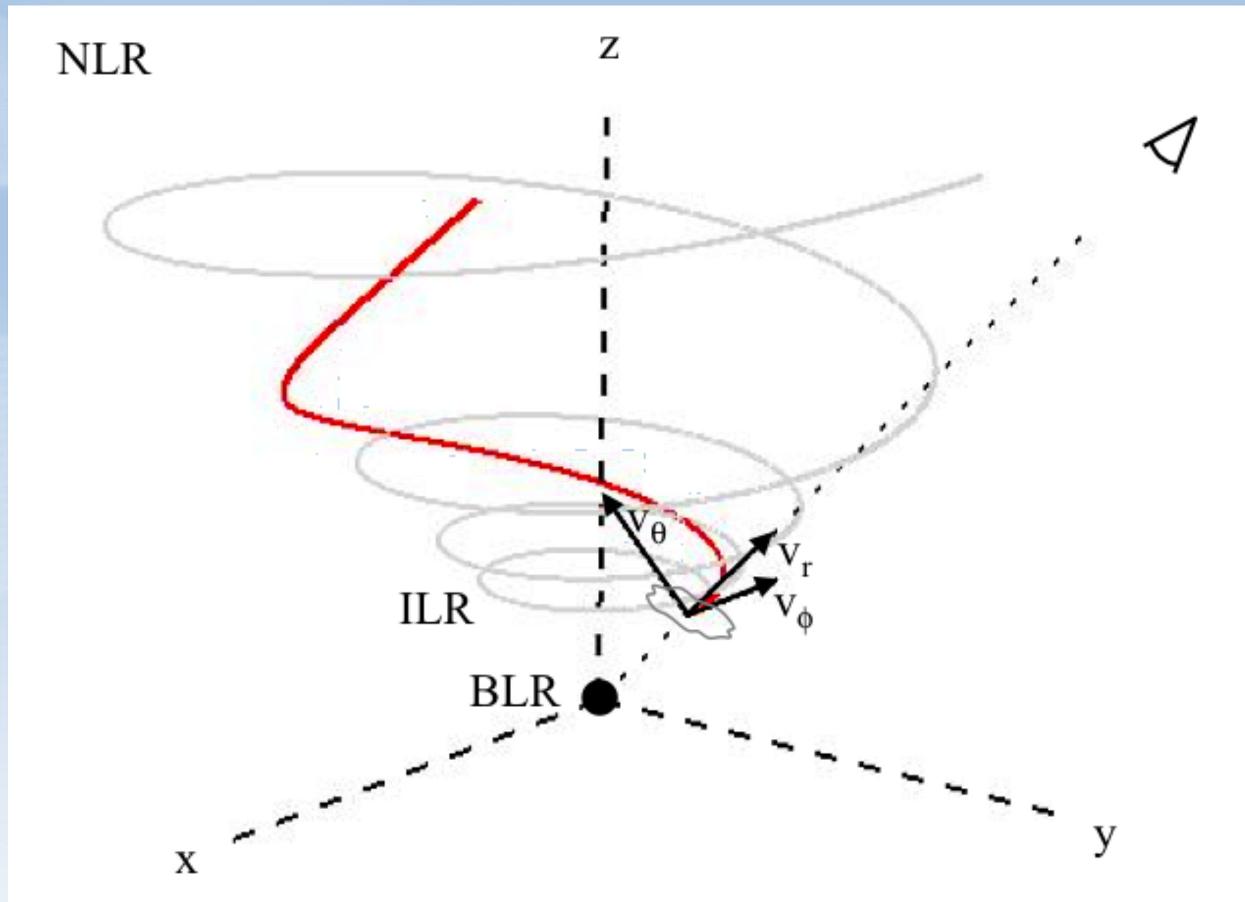
Most Seyfert absorbers are not likely due to an "accretion disk wind".

UV Absorbers show variable column densities *(N_H)*



Some absorbers show bulk motion across the BLR with transverse velocities up to several thousand km s^{-1}.

Simple Picture for Broad Absorber in NGC 4151



- r = 0.1 pc, θ= 45°, $v_r = v_{los}$ = – 490 km s^{-1},
- Assume $v_\theta = 0$, then $v_\Phi = v_T$ = 2100 km s^{-1} (v_T = 10,000 km s^{-1} also shown)
- More on the geometry of outflowing absorbers later.

Dynamical Considerations
(see Crenshaw, Kraemer, & George, 2003, ARA&A, 41, 117)

- Consider the high-column absorber in NGC 4151.
- **Radiation pressure** – calculate the force multiplier (FM):
  - To be efficient FM > $(L_{bol}/L_{edd})^{-1}$ = 70 for NGC 4151
  - From Cloudy models: FM ≈ 40
  - The absorber is marginally susceptible to radiation driving
  - However, many UV absorbers have FM ≈ 1000, so radiative driving is probably very important.
- **Thermal wind**
  - Radial distance at which gas can escape: $r_{esc} \geq GMm_H / T_g k$
  - $r_{esc} \geq$ 400 pc (NGC 4151 absorber) → not thermally driven
- **Magnetocentrifugal acceleration**
  - May be important in this case, relative to alternatives.
  - Can explain large transverse velocities and large line widths (Bottorff et al. 2000)

What are the contributions of the outflowing absorbers to AGN feedback?

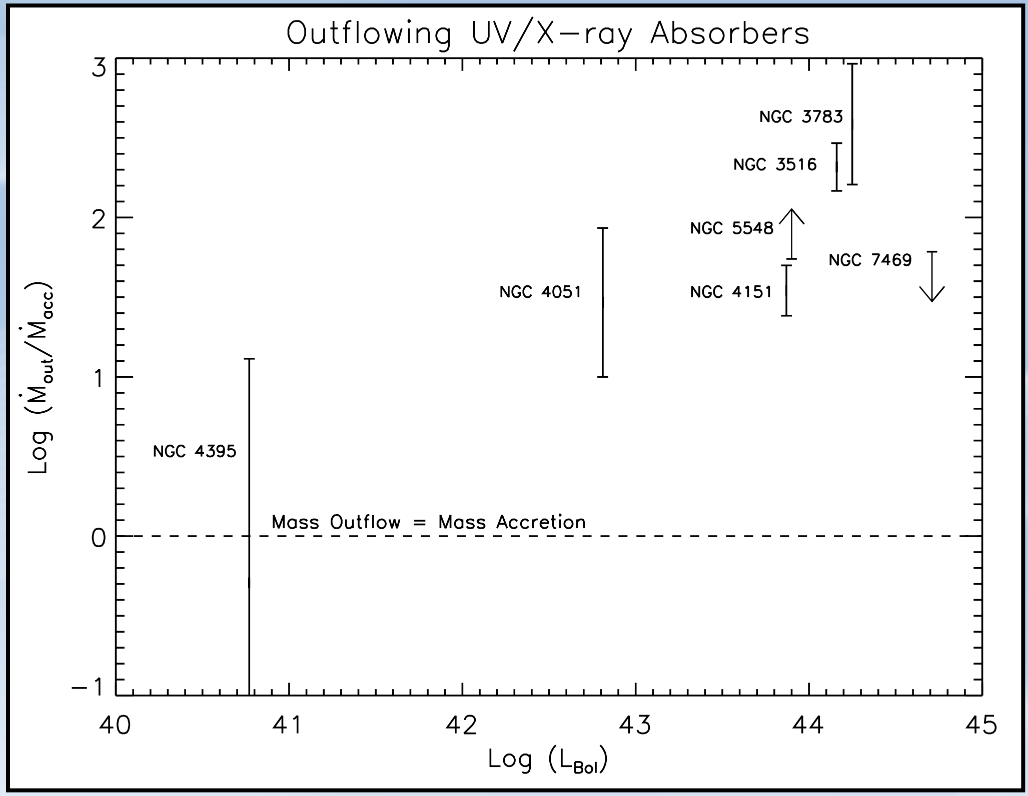
- Compute detailed photoionization models for each absorption component.
- Determine radial locations (or limits) for components from variability and/or excited-state absorption.
- Determine mass outflow rates and kinetic luminosities for each component, then add them up.

$$\dot{M}_{out} = 4\pi r N_H \mu m_p C_g \mathrm{v}_r \quad (C_g = 0.5,\ \mu = 1.4)$$

$$L_K = 1/2\, \dot{M}_{out}\, \mathrm{v}_r^2$$

$$\dot{M}_{acc} = \frac{L_{bol}}{\eta c^2} \quad (\eta = 0.1)$$

Mass Outflow Rates >> Mass Accretion Rates

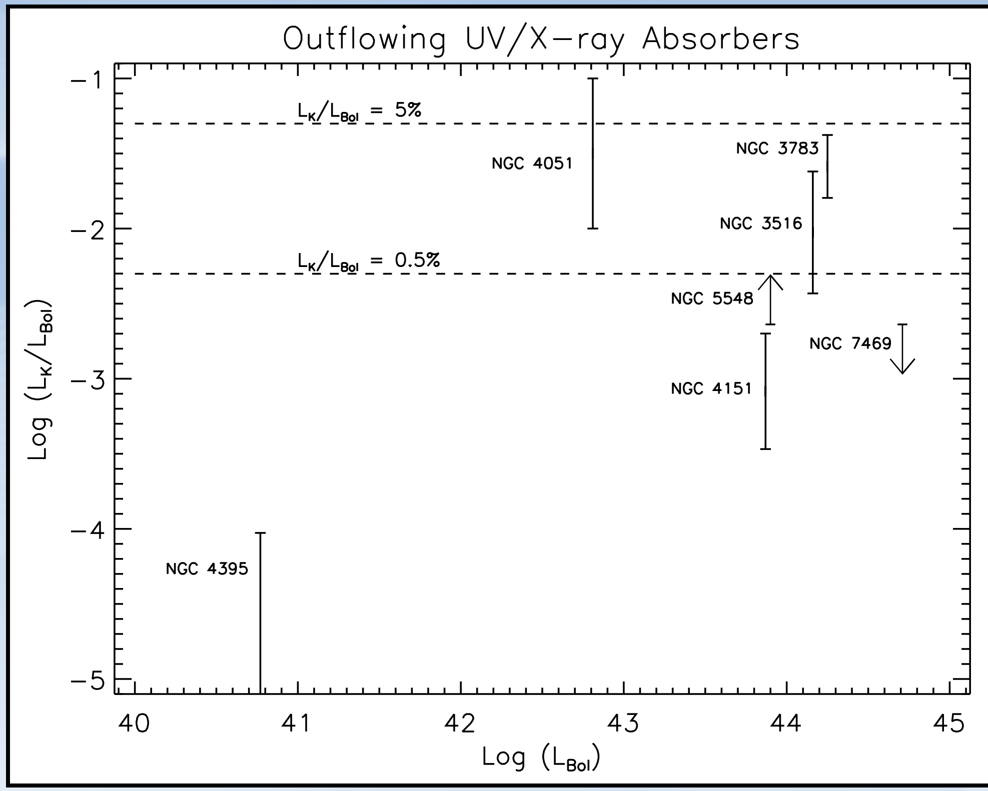


(Crenshaw & Kraemer, 2012, ApJ, submitted)

→ Most of the outflowing gas must originate outside of the inner accretion disk (or it would likely dissipate quickly.)

→ These outflows are not accretion disk winds (although we have not included ultrafast outflows [UFOs], Tombesi et al. 2011, ApJ, 742, 44).

Kinetic Luminosity as large as ~5% Bolometric Luminosity.



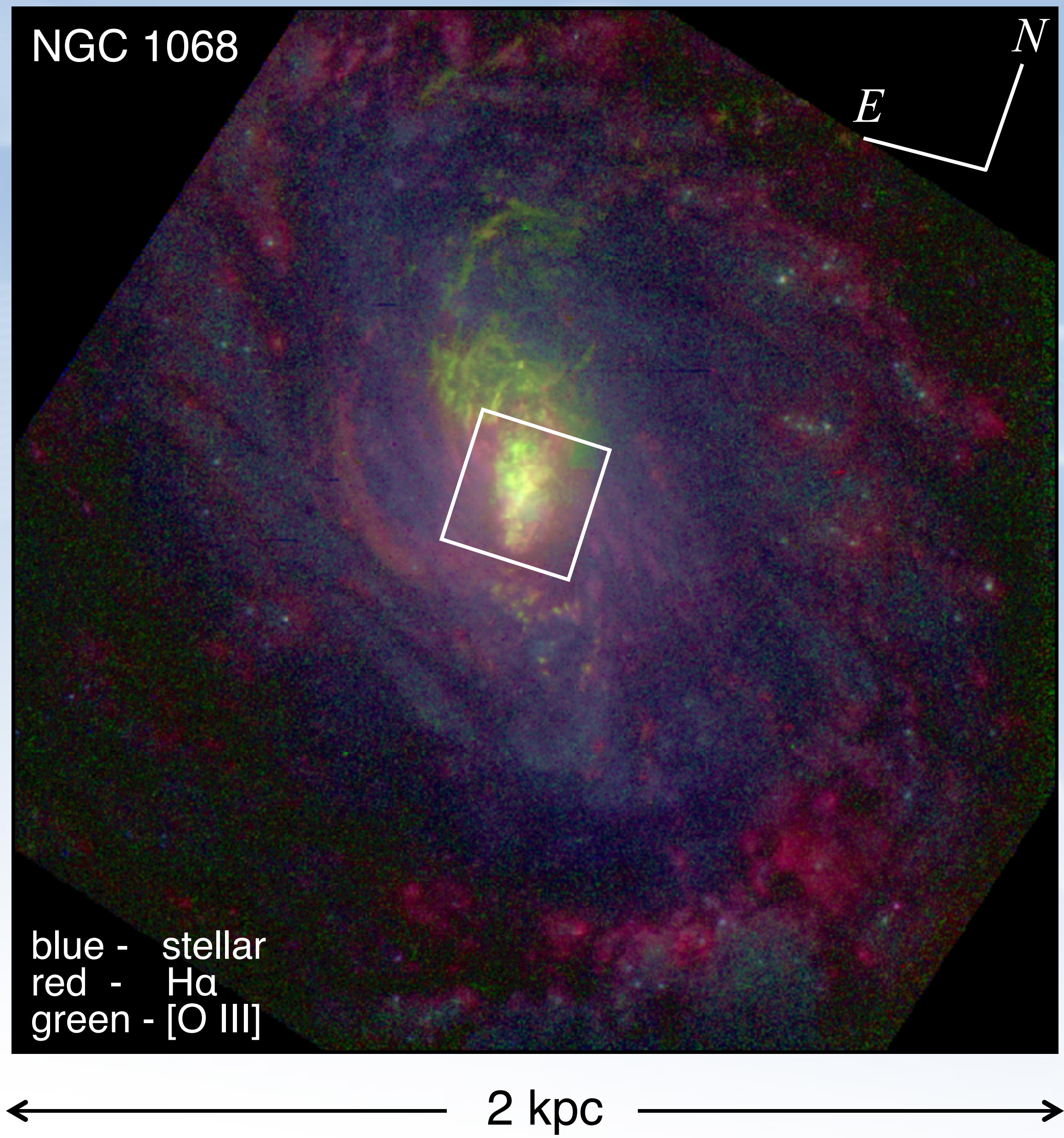
(Crenshaw & Kraemer, 2012, ApJ, submitted)

Most are close to L_{KE} = 0.5% to 5% L_{bol} , which is required by AGN feedback models(Hopkins & Elvis 2010).

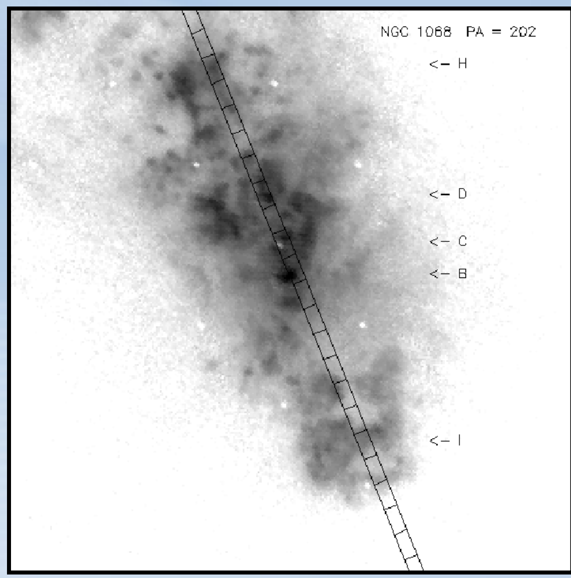
→ Winds likely provide significant feedback in moderate luminosity AGN.

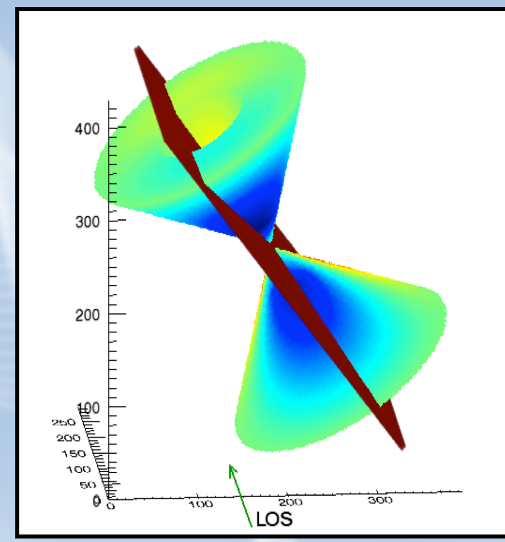
→ They may not be effective at low luminosities (< 10^{43} ergs s^{-1}).

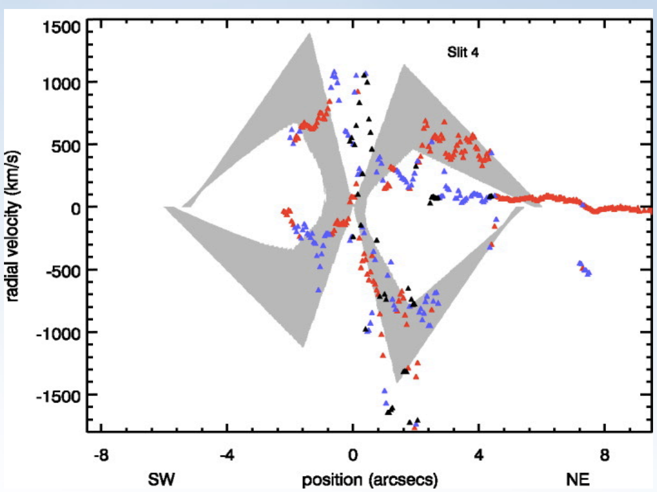
NLR Outflows

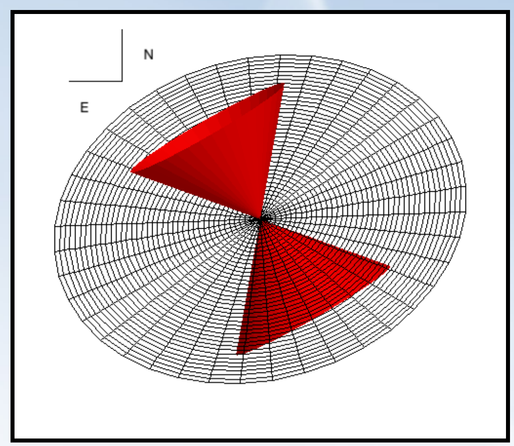


Kinematics of the Narrow-Line Region in NGC 1068



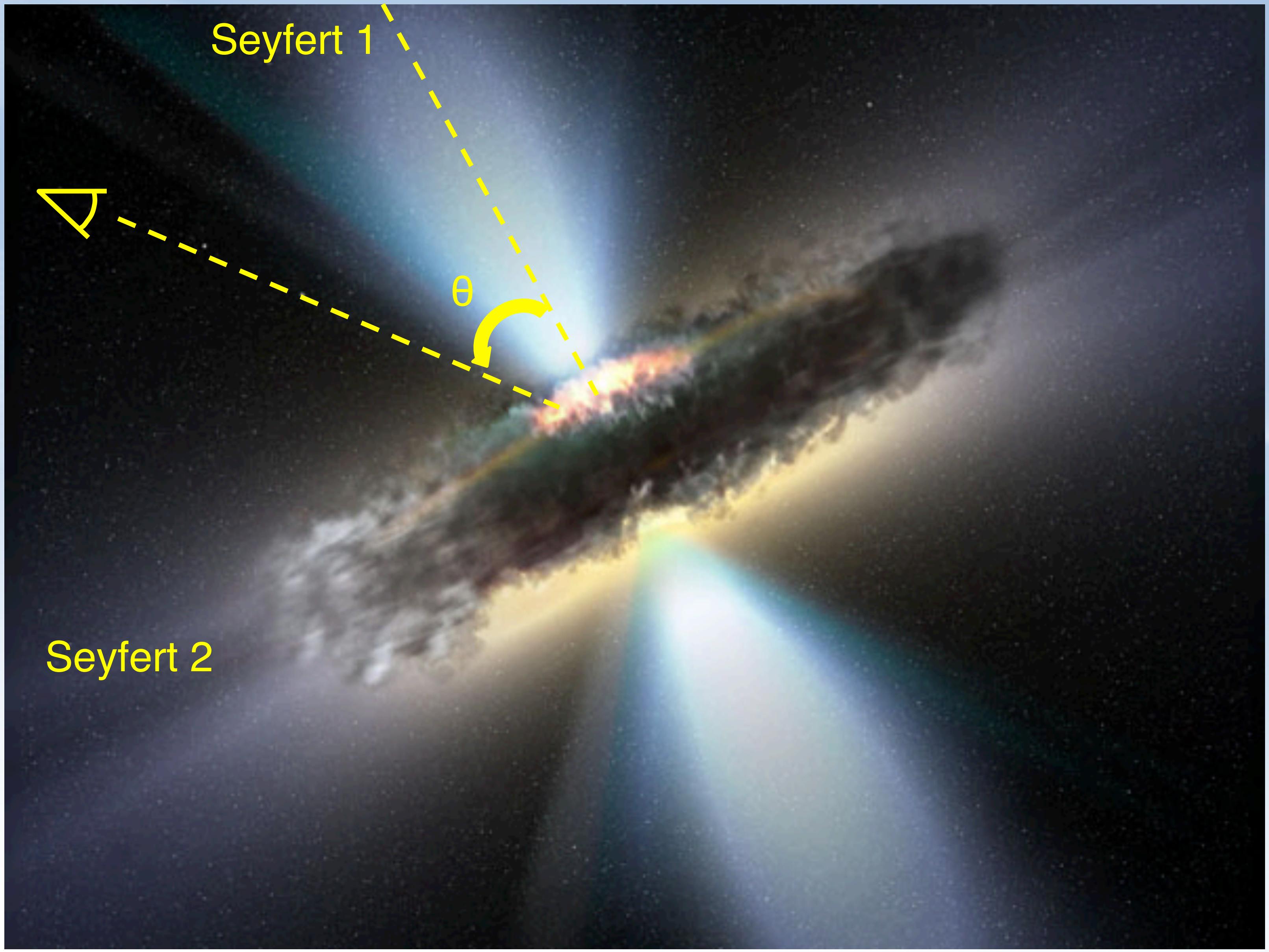




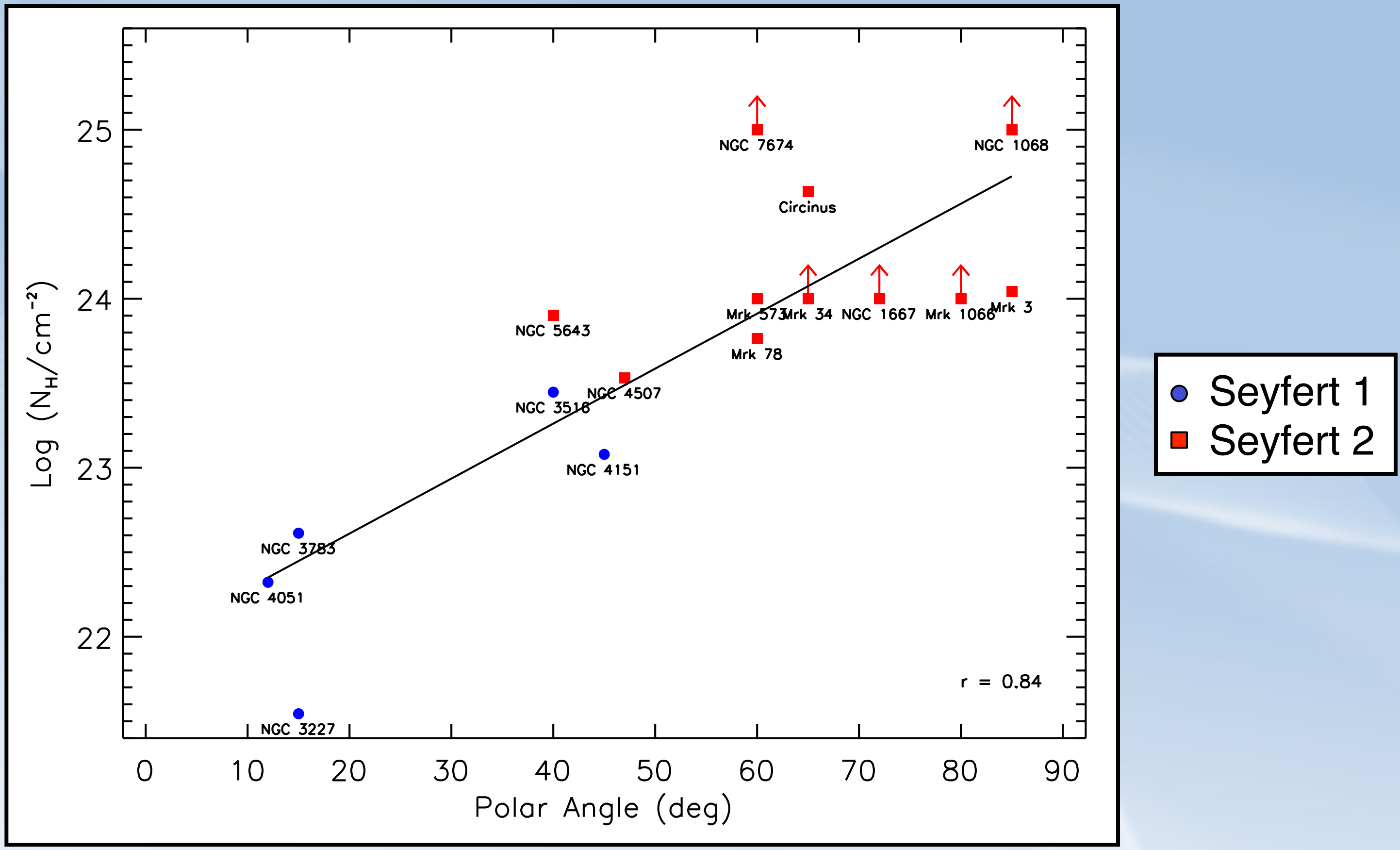


(Das, et al. 2006; Fischer et al. 2010, 2011)

We can use NLR kinematics to determine AGN inclinations!



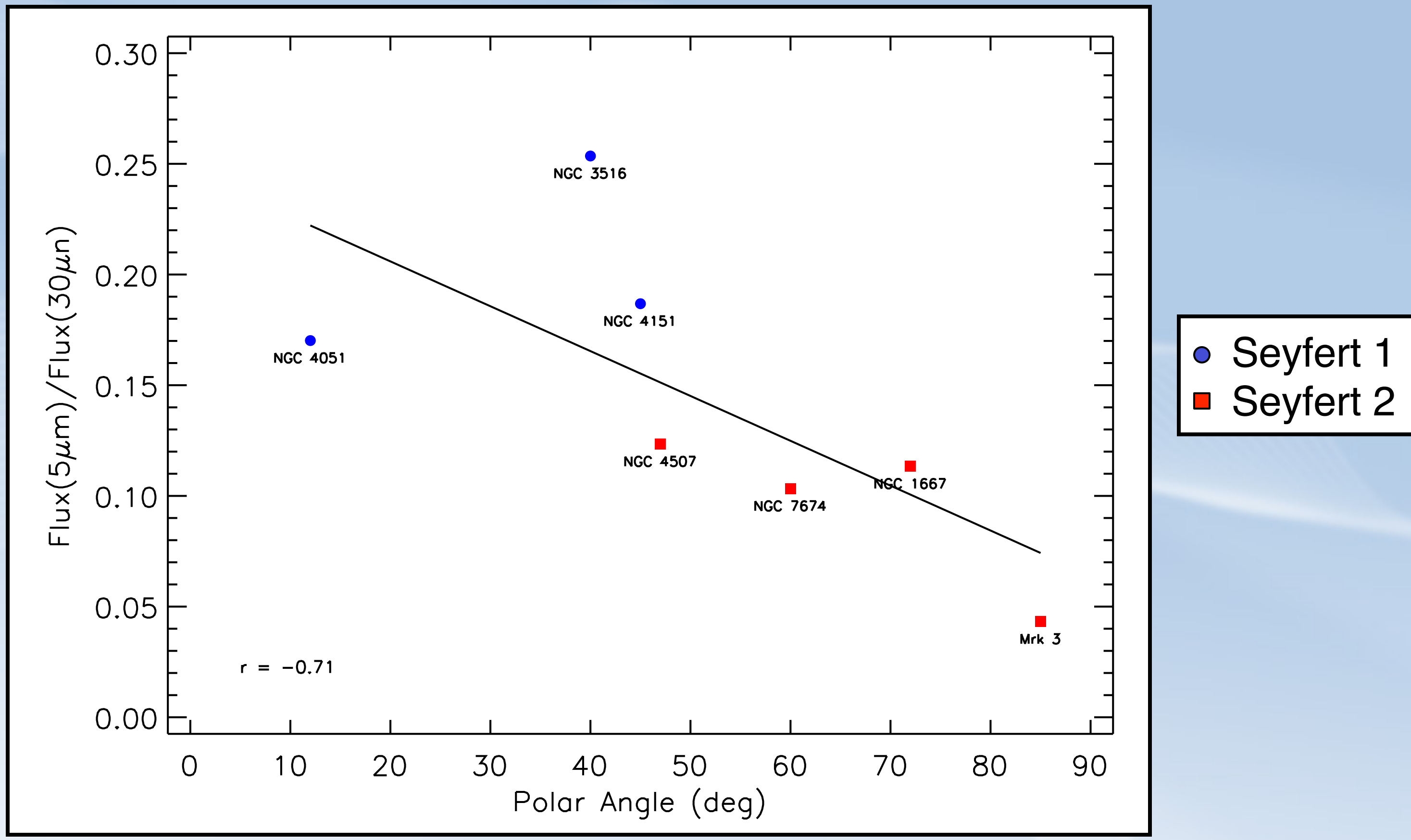
Column density increases with polar angle.



(Fischer, et al. in preparation)

- Ionized column increases with θ up to ~45°.
- Smooth transition to neutral column from "torus".
- Resembles biconical outflow in NLR.

Mid-IR color changes with polar angle.



- Spitzer IRS F(5μm)/F(30μm) (Deo et al. 2009) increases with decreasing θ, as hot throat of torus becomes more visible.

Conclusions (so far):

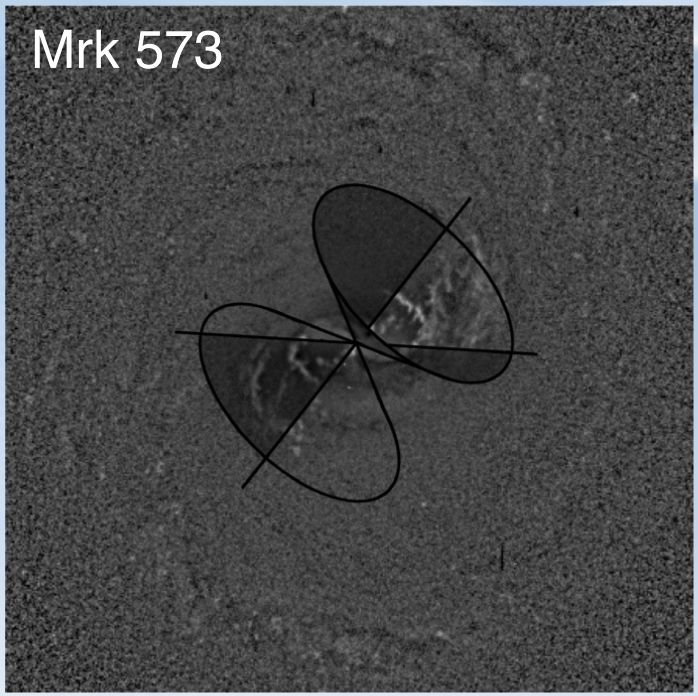
- UV/X-ray absorbers and NLR clouds are outflowing in a biconical geometry (with fuzzy edges) on scales of 0.1 – 1000 pc.

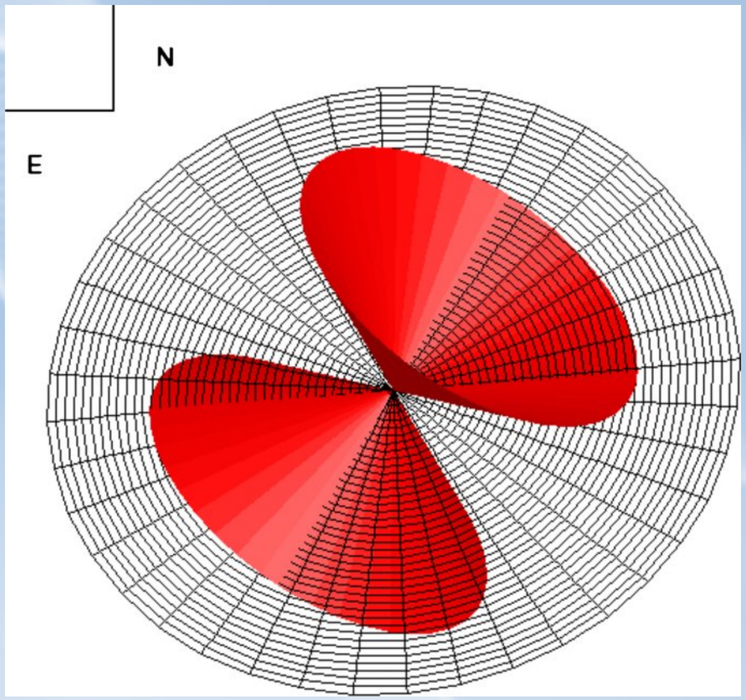
  → Increasing column density with polar angle.
- Radiation driving likely dominates on large scales (100s pc), but magnetocentrifugal acceleration could be important close in.
- Mass outflow rates can be 10 – 1000 times the accretion rates.

  → Most of the infalling gas gets blown out, or a large reservoir is built up before outflows begin.
- Kinetic luminosities of the absorbers can be 0.5% to 5% of the bolometric luminosities (TBD: NLR outflows).

  → Winds can provide significant feedback in moderate luminosity AGN.

What is the connection between feeding and feedback?





(Fischer et al. 2010, AJ, 140, 577)

- Dust spirals (fueling flow) cross into the NLR ionizing bicone.
- Large velocity gradients near ionized spirals indicate *in situ* acceleration.
  → Are AGN winds blowing away the original fueling flows?