AGN Structure from Multi-wavelength Polarization

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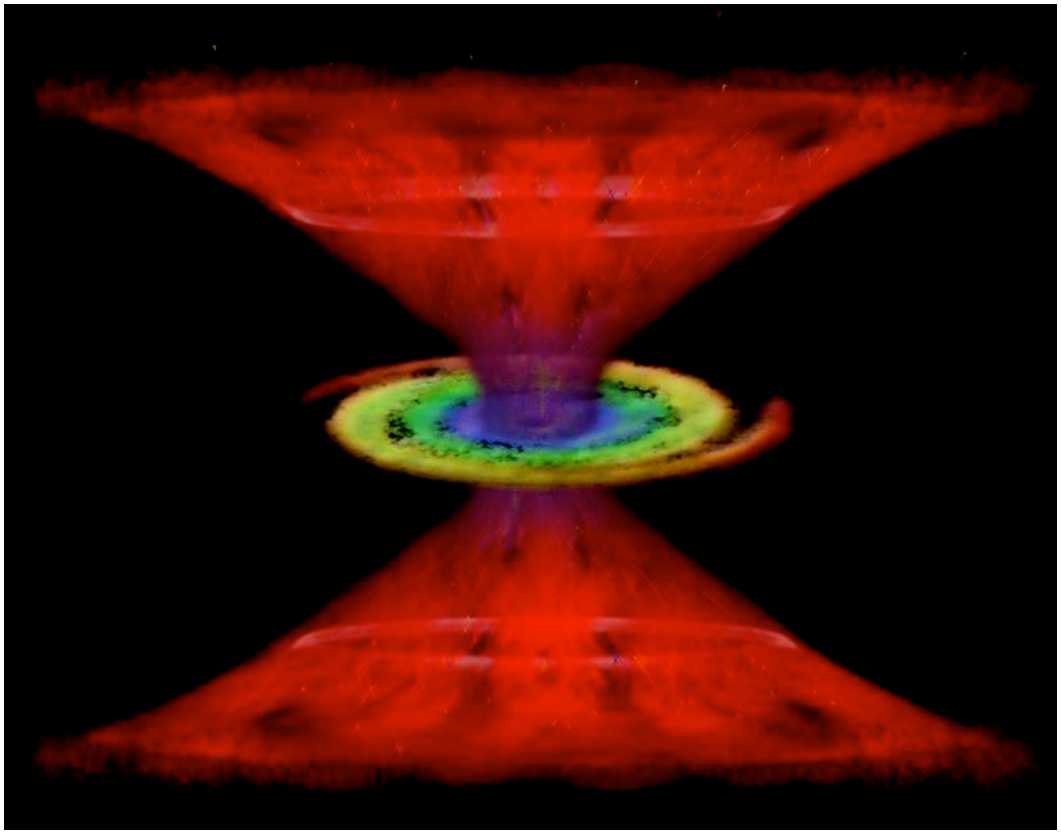
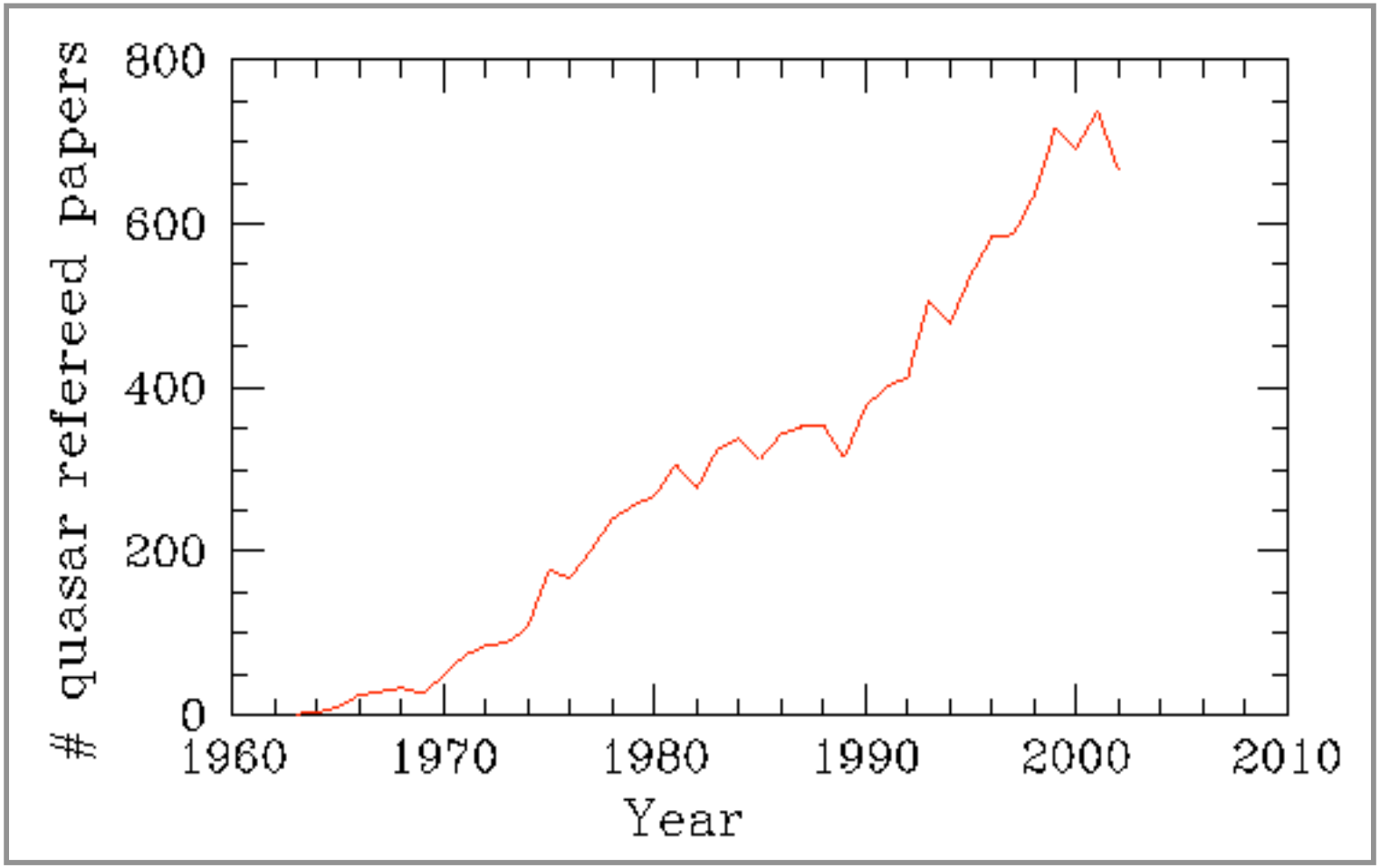


12,277 Papers on Quasars since 1963*

***ADS to 4/18/03, refereed only , search on abstract containing 'quasar' | 'AGN'**

~1% mention polarimetry, yet these gave us the Unified Scheme.

Uniquely diagnostic: a non-spherical geometry is required



Polarimetry is Photon Hungry

- To measure a flux to 10% needs 100 photons
- Typical polarization ~1%
- So to measure a typical polarization at 10σ requires 1,000,000 photons
  - need to measure PA *and* %p (or 4 Stokes parameters: QUVI)
  - 10^4 photons even for 10% polarization
- For a bright AGN: 10 ct/s/m^2 (1mCrab 2-10 keV ~NGC1068)
  - Brightest z > 1 quasars count 1 ct/s/m^2
- Takes 10^5 sq.m^2-s to measure polarization
- Moral: *don't propose <1m^2 with AGN as a goal*
  - even in a broad band

Reflection Phenomena are Common in Type 1 AGN

- ❑ X-ray Compton Hump: Disk? *e⁻ scattering*
- ❑ Fe-K narrow lines: Disk? Torus? NELR *fluorescence*
- ❑ Fe-K broad lines: Disk? *fluorescence*
- ❑ Optical continuum in Warm Absorber AGN ???
  - *Dust transmission? Dust scattering? e⁻ scattering?*
- ❑ BAL polarized trough flux: Wind? *e⁻ scattering*
- ❑ Polarized VBELR Rotating disk? *e⁻ scattering*
  - VBELR = Very Broad Emission Line Region
- ❑ UV polarized continuum, λ<Lyα: Wind? *e⁻ scattering*
- ❑ Hidden BELRs in type 2 AGN

"The people grow tired of a confusion whose end is not in sight"

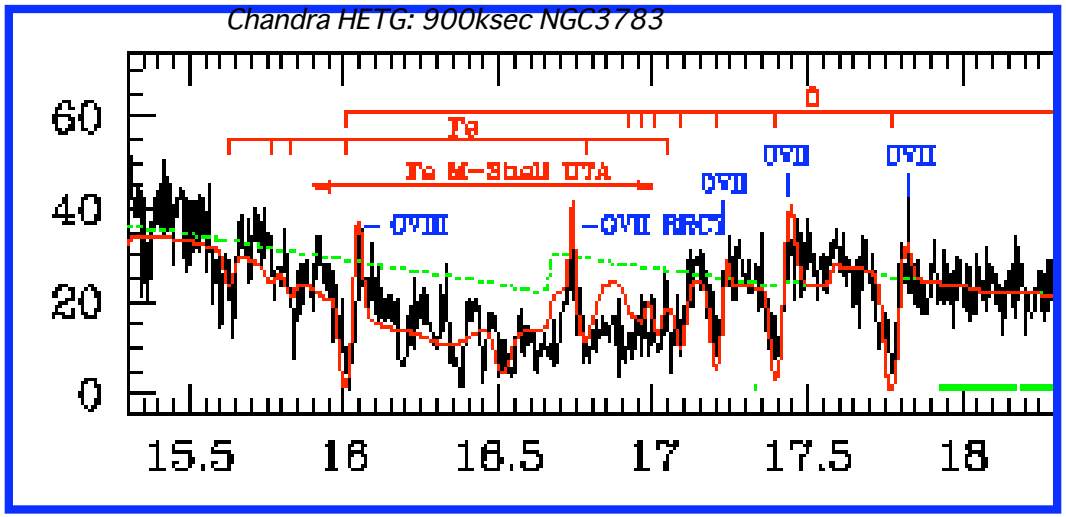
Alexis de Toqueville *'Democracy in America'* *New York Times 9.30.2001 sec.4,p.3*

- 5-6 *different* Compton thick scattering regions?
  - Each dominating in a different
  - Seems unlikely. Occam would not be pleased
  - Several candidates: Disk/Torus/NELR/**Wind**
  - How *few* might there be?
- My argument:

  A Wind explains most of the reflection phenomena

Winds are Common in Quasars

'Warm Absorber' Narrow X-ray lines



Narrow UV lines: NAL

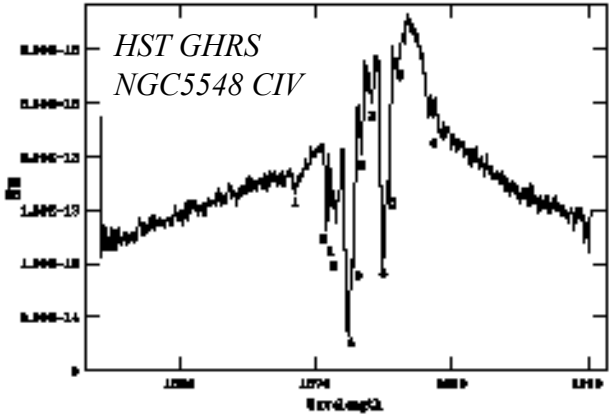
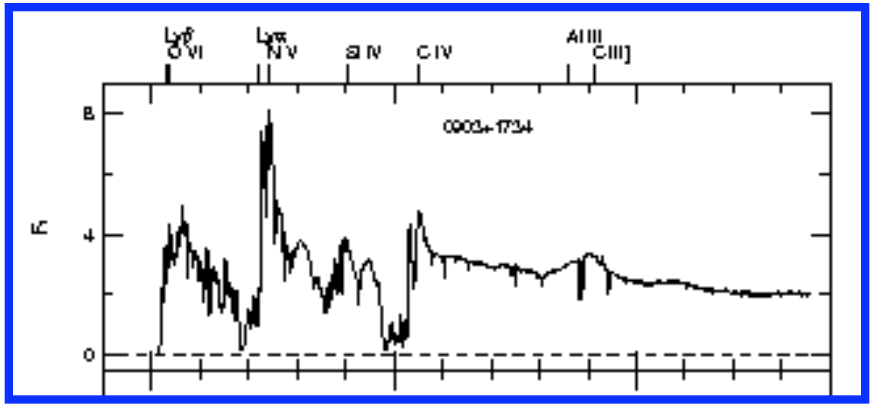


FIG. 1.—GHRS G160M spectrum of C IV line in NGC 5548. It is smoothed to display the multiple absorption components clearly (marked 1–6).

Broad Absorption Lines: BAL



~50% of AGN, quasars

Outflow ~1000 km s^{-1}

~15% of quasars

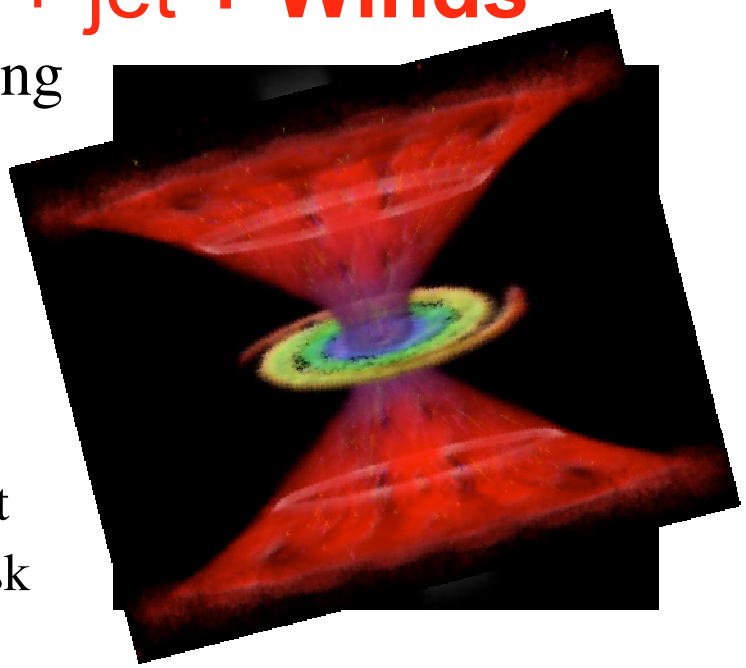
Outflow ~10,000 km s^{-1}
~2xFWHM(BEL)

All are High Ionization

e$^-$ scattering is likely mechanism

AGN = black hole + Disk + jet **+ Winds**

- Winds are the newly recognized 'missing link' in AGN
  - Black hole, disk, jet = 'naked' AGN
  - Winds let us understand the veiling gas
- Winds are dynamically important
  - Kinetic luminosity and mass loss in AGN winds comparable, or greater, than L, mdot
  - May carry off angular momentum from disk
- Affects host galaxy ISM and IGM
- Imposes conditions on torus, accretion disk
- *Polarization tells us about the non-spherical geometry of the AGN wind.*

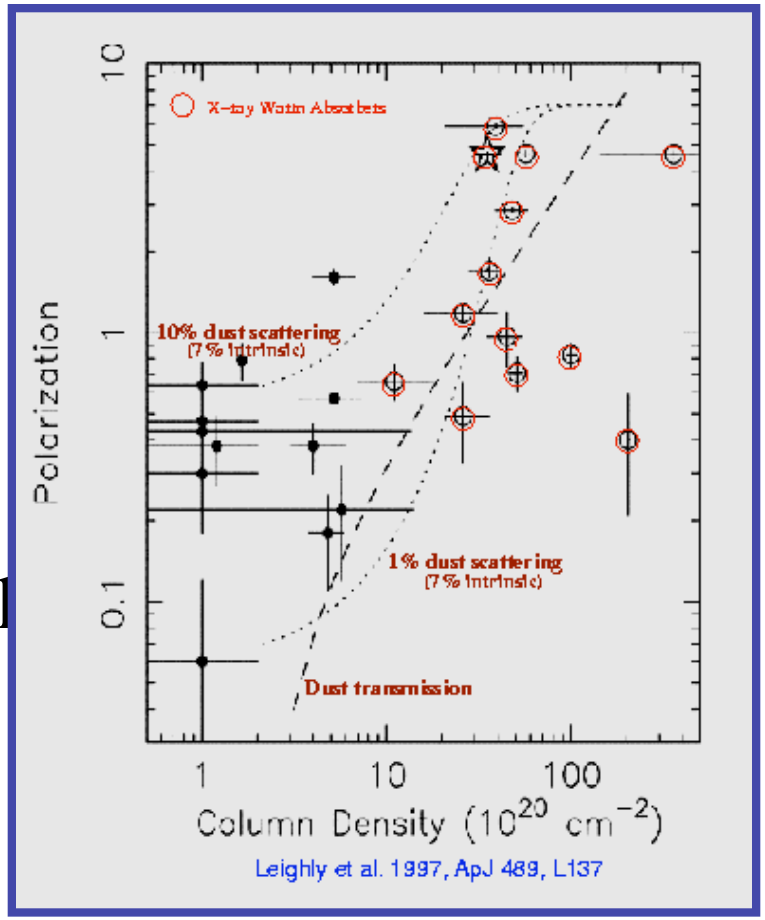


Winds and Polarization are closely connected

Leighly et al. 1997 ApJ 489, L137

- **Warm Absorber AGN more polarized in optical ~1% - ~5%**
- Scattering off non-spherical distribution, *if* scattering
- ➔Edge-on scattering structure
- No polarized unabsorbed AGN
- ➔Absorber and scatterer co-axial

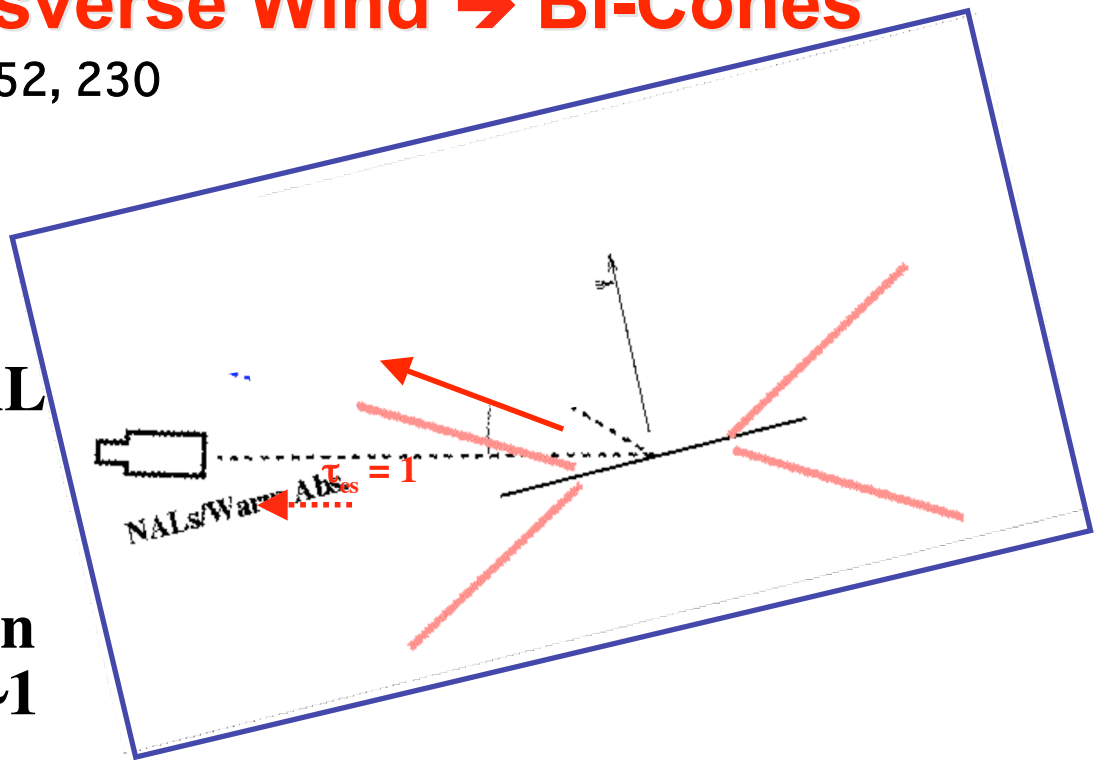
Warm Absorber is the scatterer



Flattened, Transverse Wind → Bi-Cones

Mathur, Elvis & Wilkes 1995 ApJ, 452, 230
Arav et al. 2000, ApJ,
Elvis 2000, ApJ,

- **Wind does not hug disk**
- ***edge-on*** **we see WA, NAL $N_H \sim 10^{22}$ cm^{-2}**
- ***pole-on*****: no absorbers**
- **along cone surface N_H can be large $\sim 10^{24}$ cm^{-2}, $\tau_{es} > \sim 1$**

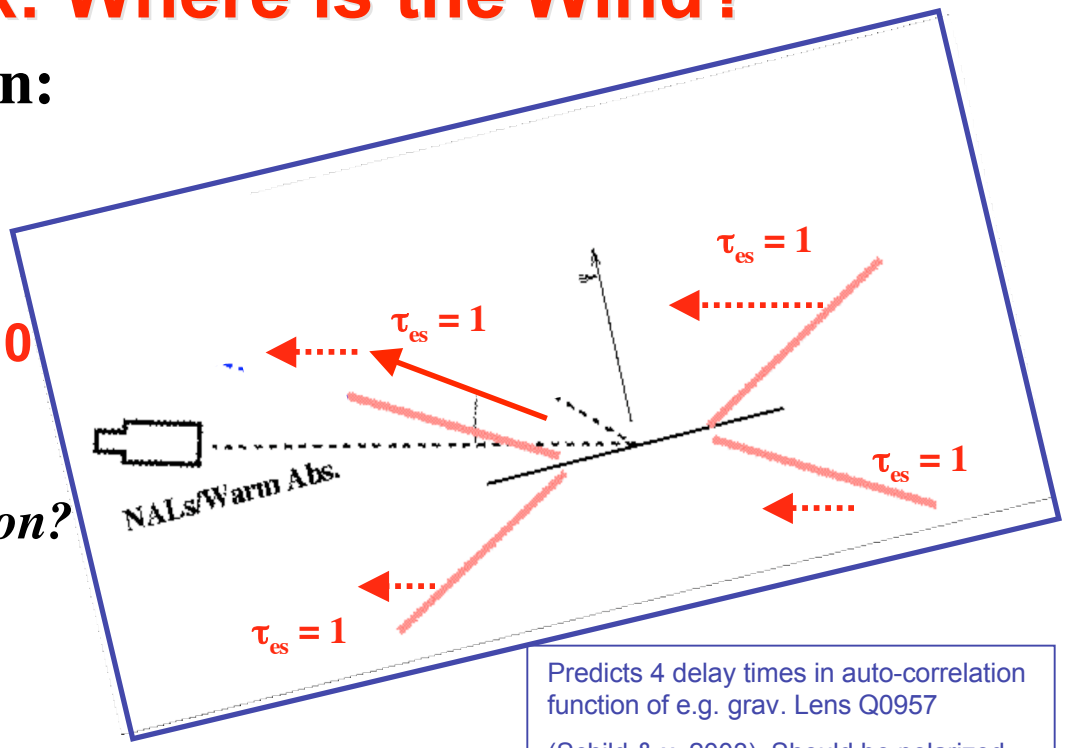


Wind can be Compton Thick to continuum

Torus or Disk: Where is the Wind?

- **Radius of wind is unknown:**
  - **Torus?** ~few light-years
  - **Disk Wind?** **e.g. BELR** ~few light-weeks
  - **Changes L(kinetic) by ~10**
- **Polarization mechanism unknown**
  - ***Thomson? Dust? transmission?***
- **Dusty torus wind**
  - **Soft X-rays absorbed**
- **No dust in disk wind**

➔**Soft X-ray polarization**



Predicts 4 delay times in auto-correlation function of e.g. grav. Lens Q0957

(Schild & x, 2003). Should be polarized

X-ray polarization is diagnostic

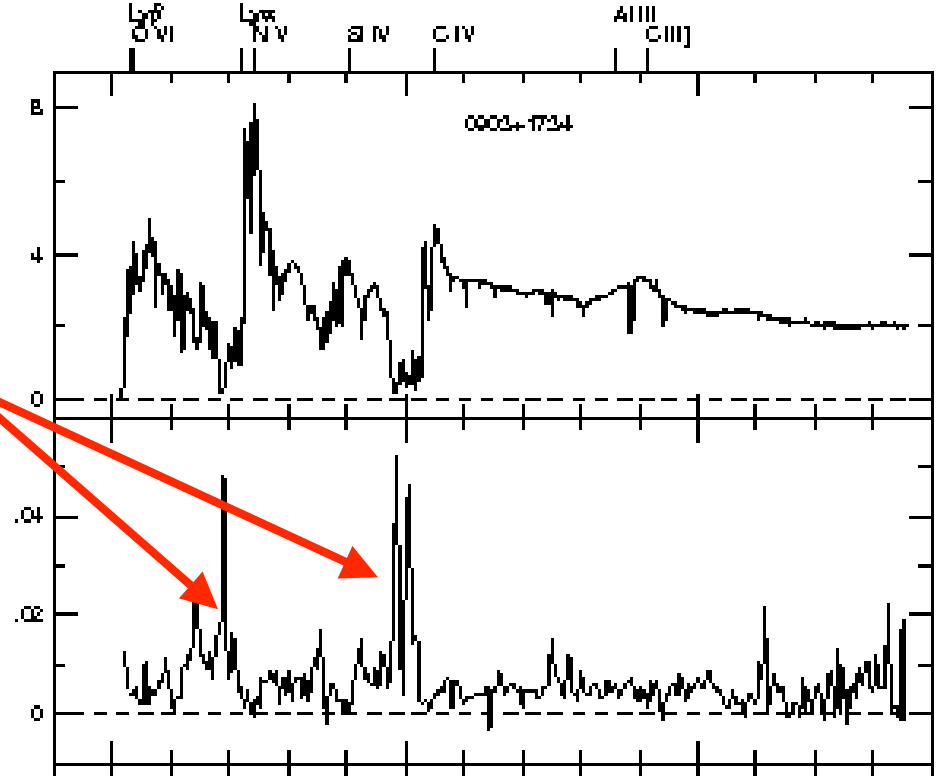
Broad Absorption Line Trough Polarization

Ogle et al. 1999 ApJS, 125, 1; Ogle 1998 PhD thesis, CalTech

~15% of quasars show BALs
Old question: Peculiar subset?
***or* Normal, seen from special angle?**
I.e. *Are fast winds a feature of quasars?*

BAL troughs are highly polarized –
scattered light off flattened structure
⇒ BALs are common, likely Universal

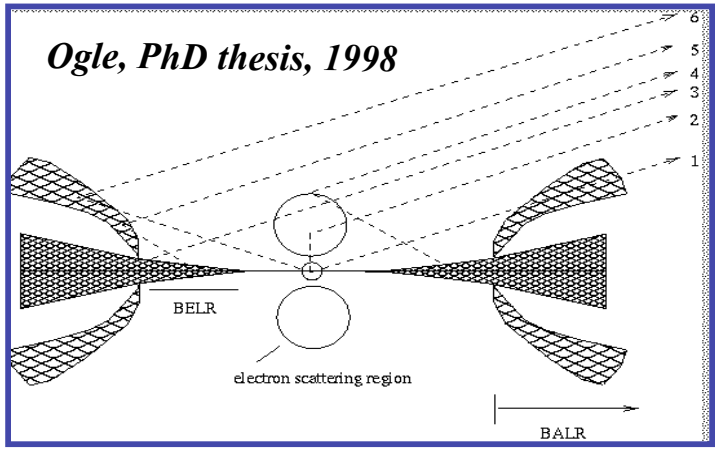
Thomson thick scatterer in All Quasars



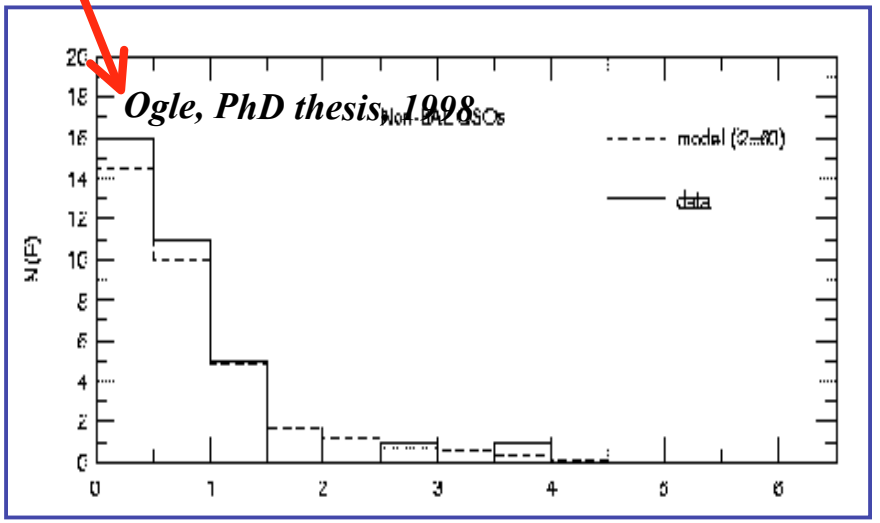
Bi-conical Wind in all Quasars

- ❑ **Is the BAL wind itself the scatterer?**
- ❑ **Bi-cone model p*redicts* distribution of non-BAL quasar polarization**

Bi-Conical geometry fits BAL Winds



- ❑ **How about the lower luminosity AGN ?**



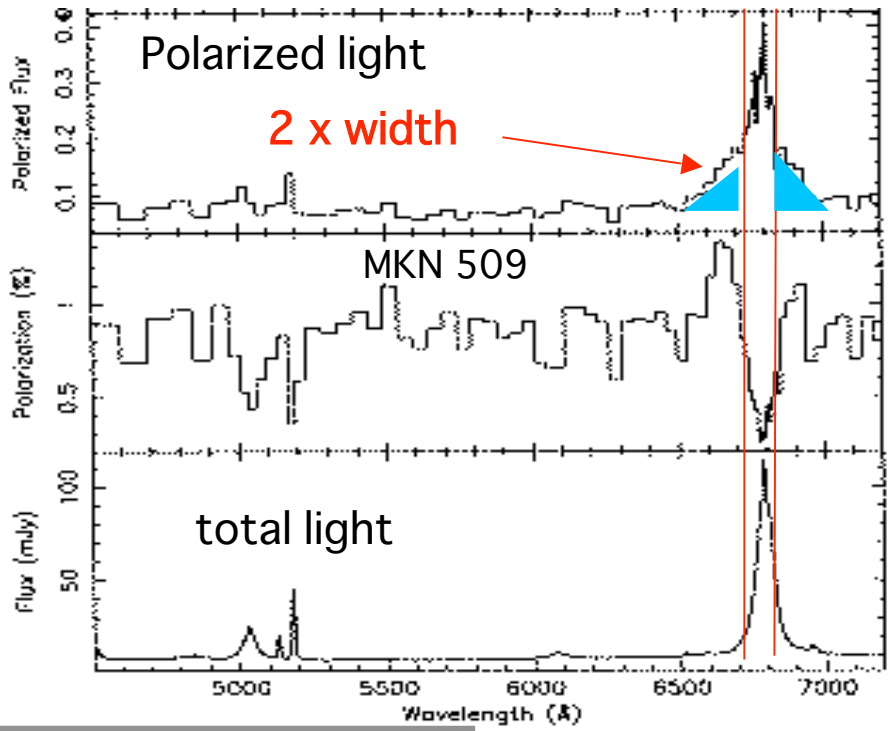
Do all AGN have fast Thomson thick winds?

Goodrich & Miller 1994, ApJ, 434, 92; Young et al. 1999 MNRAS 303, 227

- ❑ Emission lines twice as wide in polarized light
- ➔ **Non-BAL AGN have Thomson thick gas at BAL velocities**
- ❑ Out of our line of sight
  - ➔ No absorption
- ❑ Slowly variable (~<1year)
- ➔**Large scattering region**

Smith et al. 2003 MNRAS

- Not accretion disk, NELR
- Torus or Wind ?



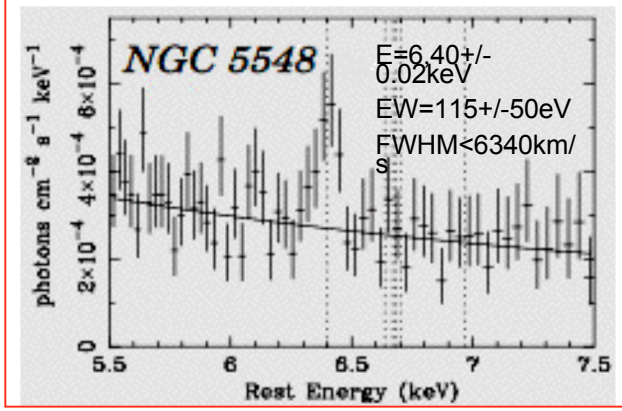
BAL velocity winds exist in normal AGN

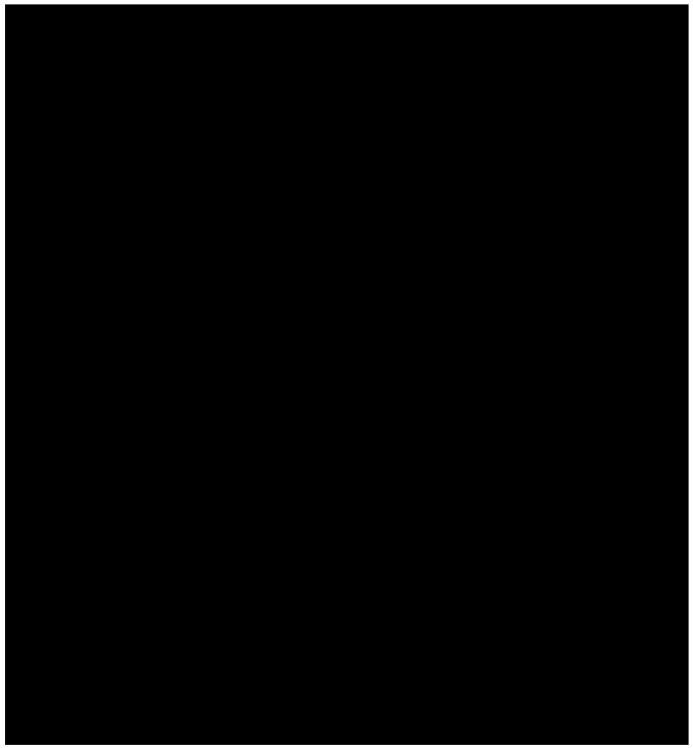
The Scattering Wind in X-rays

- **Thomson scattering is wavelength independent**
  - **Where are the signs of X-ray scattering?**
- **Narrow Fe-K**
  - ~Universal in AGN
  - Does not vary with continuum
    Weaver, Gelbord & Yaqoob 2001 ApJ550,261
  - Large scattering region, *R* > *few light-days*
  - Not accretion disk
  - Line widths similar to BELs?
  - Compton thick
- **Sounds like the scattering wind**
  - Universal in AGN
- **Are Fe-K & Compton Hump polarized?**
  - Do PA, %polarized agree with optical?
  - If yes: use narrow Fe-K monitoring to measure size
  - Disk contribution adds complexity

X-ray polarization diagnoses reflection regions

Yaqoob & Padmanabhan 2003 astro-ph/0311551





Winds & AGN Reflection Phenomena

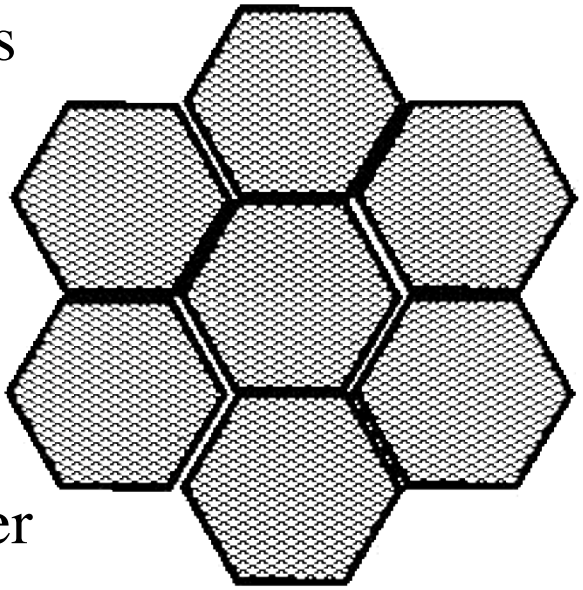
- X-ray Compton Hump: Disk? **+ Wind** *e⁻ scattering*
- Fe-K narrow lines: Disk? Torus? **Wind** *fluorescence*
- Fe-K broad lines: Disk? *fluorescence*
- BAL polarized trough flux: **Wind** *e⁻ scattering*
- Polarized VBELR **rotating disk Wind** *e⁻ scattering*
  - VBELR = Very Broad Emission Line Region
- UV polarized continuum, λ<Lyα: Wind? *e⁻ scattering*
- Optical continuum in Warm Absorber AGN **Wind**
  - *Dust transmission? Dust scattering?* ***e⁻ scattering****?*
  - Test: soft X-ray polarization
- Hidden BELRs in type 2 AGN

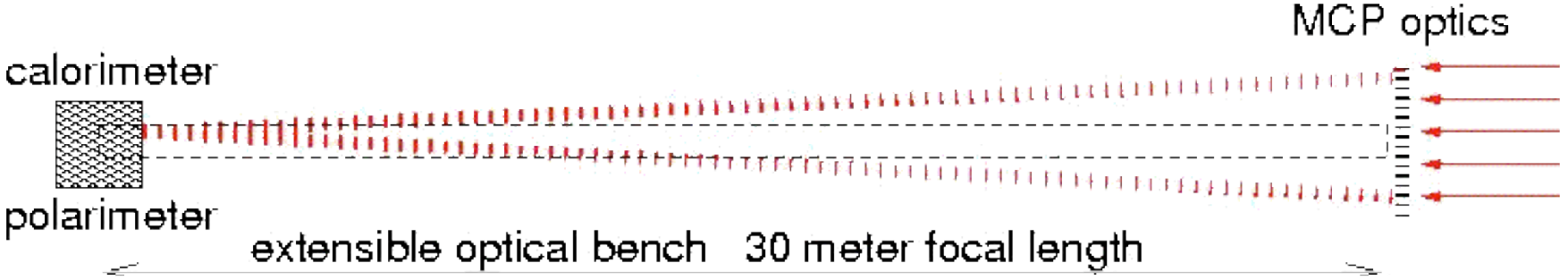
How can we measure AGN X-ray polarization?
Microchannel Plate Optics

- MCP optics have 100 x area:mass ratio of foil optics
  - $10m^2$ weighs 37kg (x2 for structure): MIDEX class
  - $1m^2$ is SMEX class
- Developed at ESTEC, Leicester for XEUS
- Arcminute imaging demonstrated at 8keV Bavdaz et al 2003
- Plate-like rigid structures: deploy easily
- $10m^2$ requires 30-50m focal length (for single focus)
  - Lightweight booms of similar lengths have been flown: UARS, GGC WIND, GGS POLAR, Cassini, Lunar Prospector, IMAGE
  - Or have 10-25 foci @ 10m focal length

Extreme Physics & MCP Optics

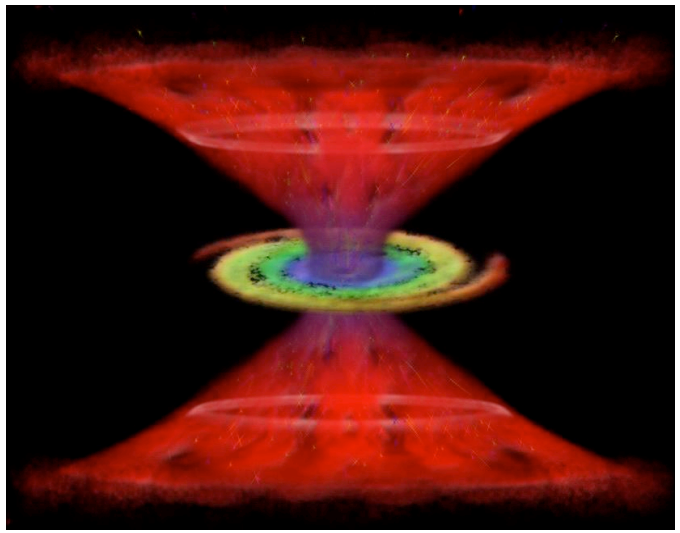
- MCP optics enable study of Extreme Physics
  - Gravity
  - Density
  - Magnetic field
- Test GR, QED, Lorentz invariance
- X-ray binaries as physics labs for conditions near black holes and 'neutron' stars
- 'Beyond Rossi XTE' with a microcalorimeter and a **polarimeter**
  - In a MIDEX-sized mission?





X-ray Polarimetry

- Diagnostic power for AGN & Quasar structure
  - Where is the wind? And so what is L(kinetic), mass loss rate
  - What is the scattering mechanism?
  - What is the geometry of AGN?

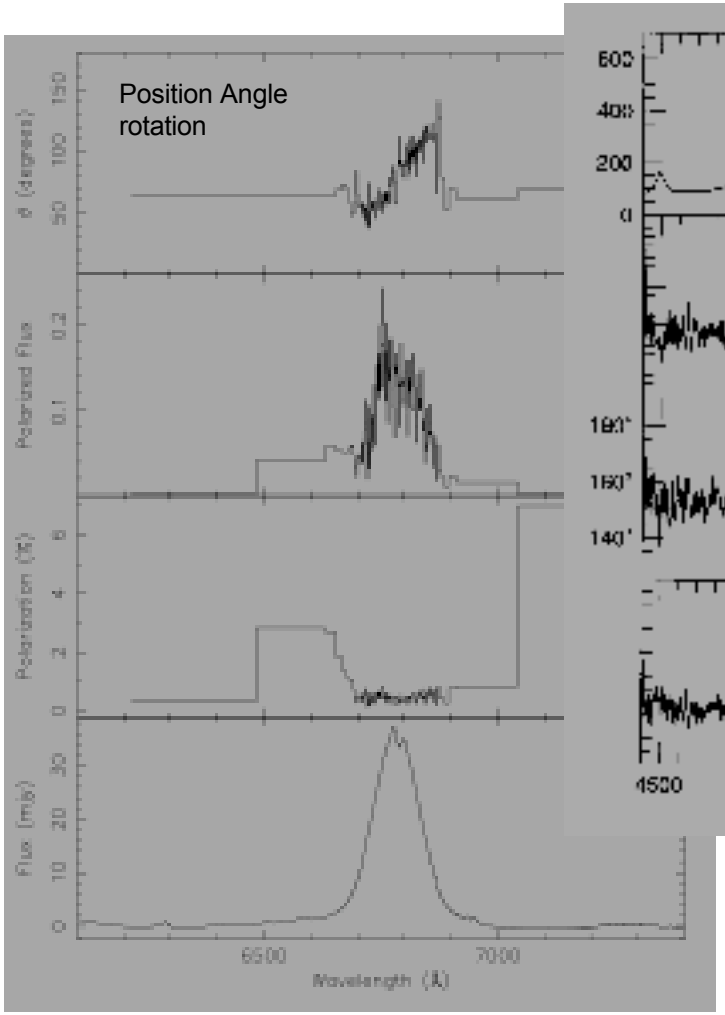


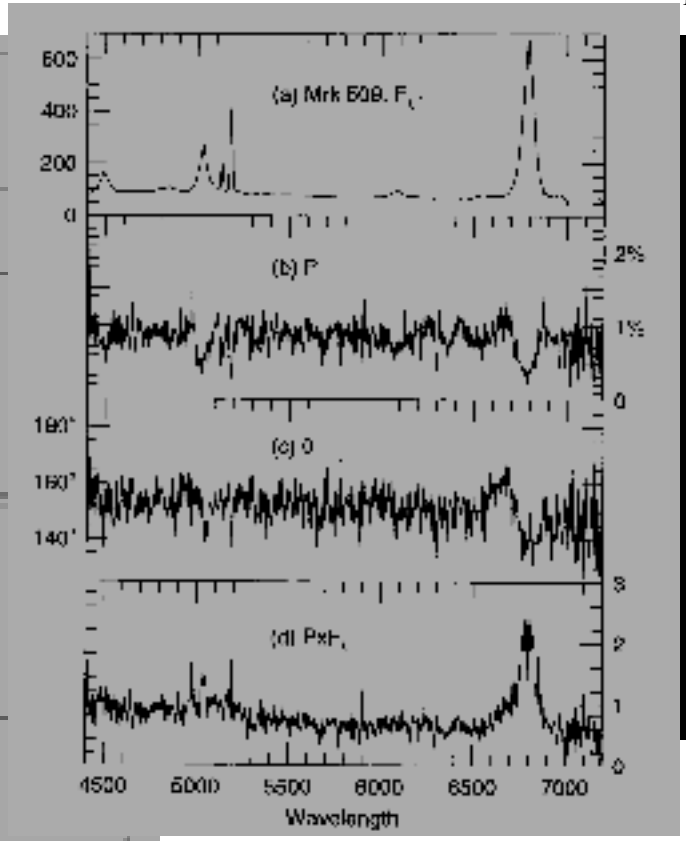
- Polarimetry is photon hungry
  - THINK BIG
- MCP optics offer a solution
  - square meters, yet MIDEX scale
  - Link with fundamental physics
- This is the time: astrophysics and technology are ready

Hα AGN Polarization

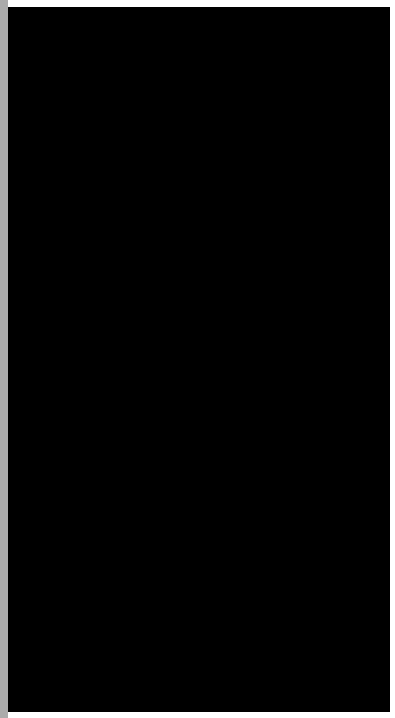
- Position angle rotation: resolved scatterer r~few x BELR
- Hα broader in polarized light: high velocity scatterer

AKN 120





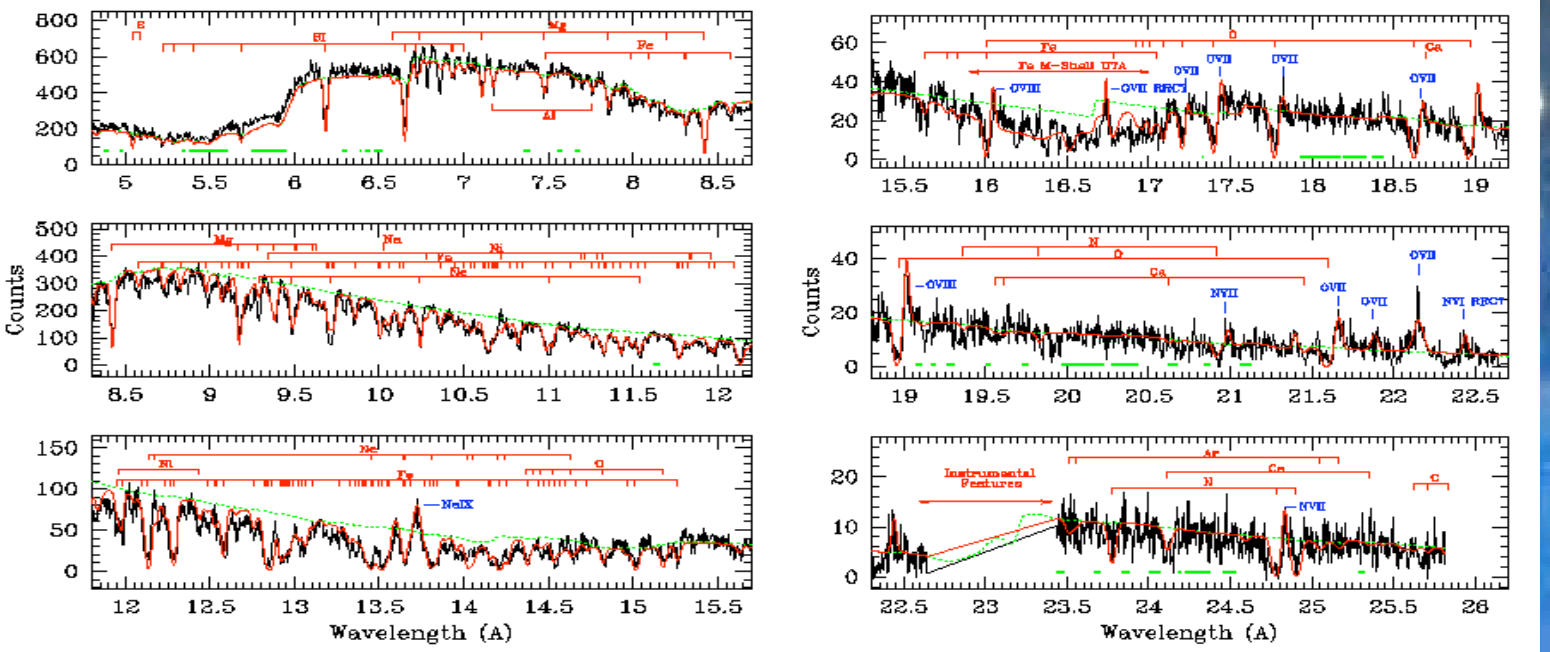
NGC 3783



2. Absorption: 2-phase gas in pressure equilibrium

Krongold, Nicastro, Brickhouse, Elvis, Liedahl & Mathur, 2003 ApJ 597, 832. *astro-ph/0306460*

Chandra HETGS 850ksec spectrum of NGC 3783



Over 100 absorption features fitted by a 6 parameter model

➔ **One T~10^6 K and one T~10^4 K, in *pressure balance* to 5%**

2-phase gas in pressure equilibrium

Need Filters

1. ***Physical*** **measurements**

   Mass, length, density. *Not* ratios, column densities

2. **Favor *absorption*:**

   1-D spatial integral, not 3-D;

   blueshift = outflow

3. **Use *Polarization***

   Non-spherical geometry

Ignore continuum, downplay emission lines

SEDs have little information. After 10 years of SEDs I know!

BELs have lots of information, mostly ambiguous