Probing Seyfert 2 Galaxies with Spectropolarimery

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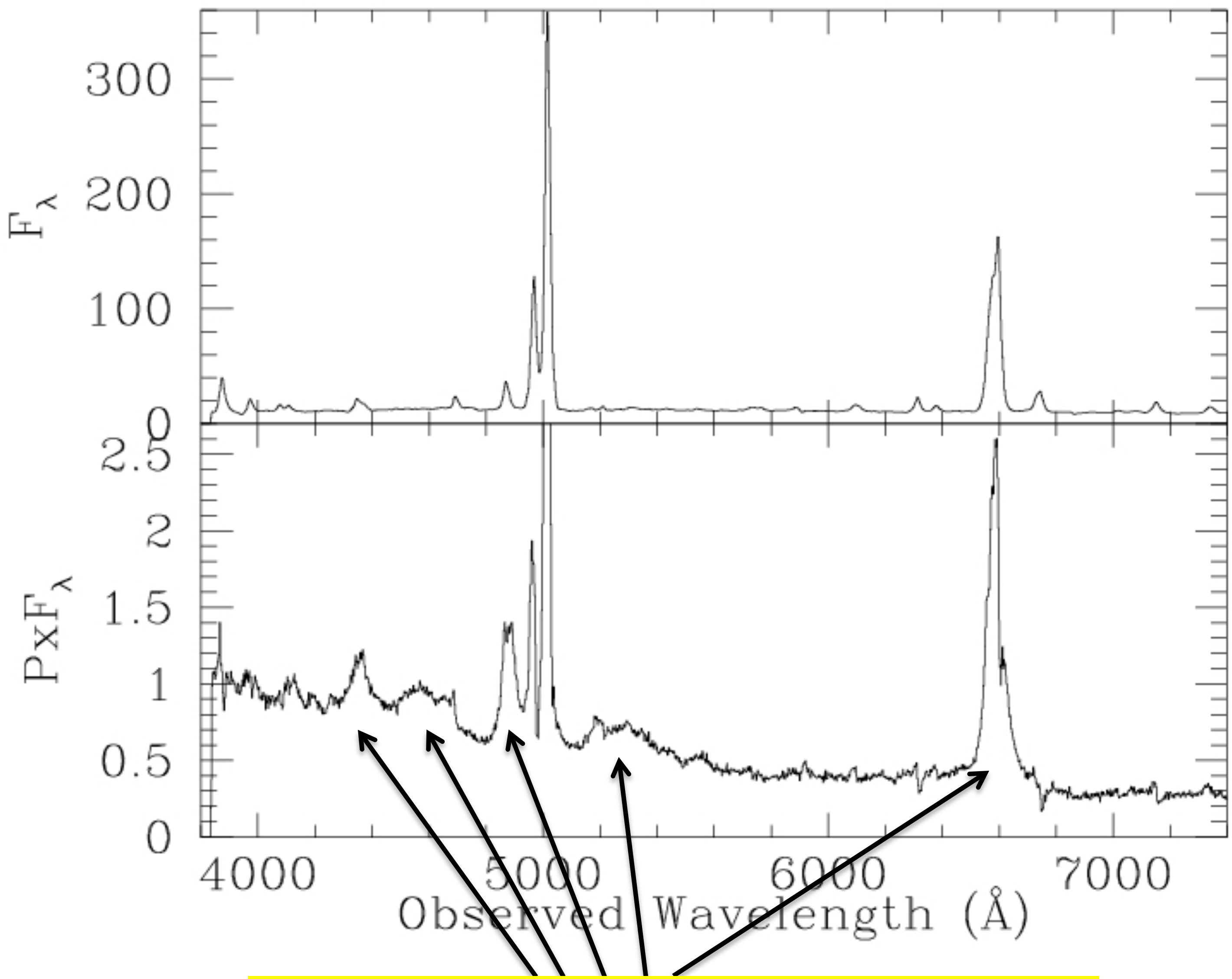
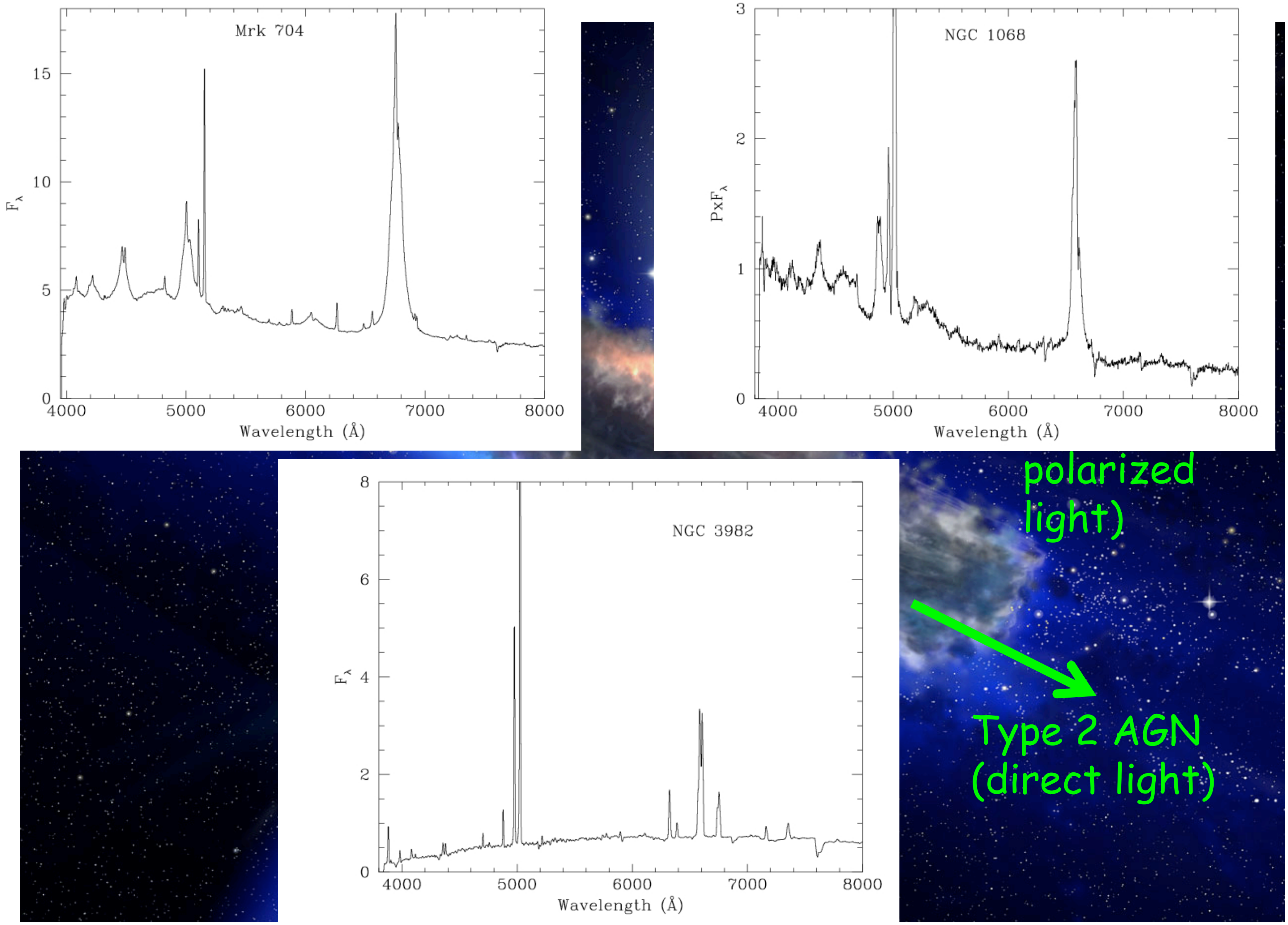
NGC 1068

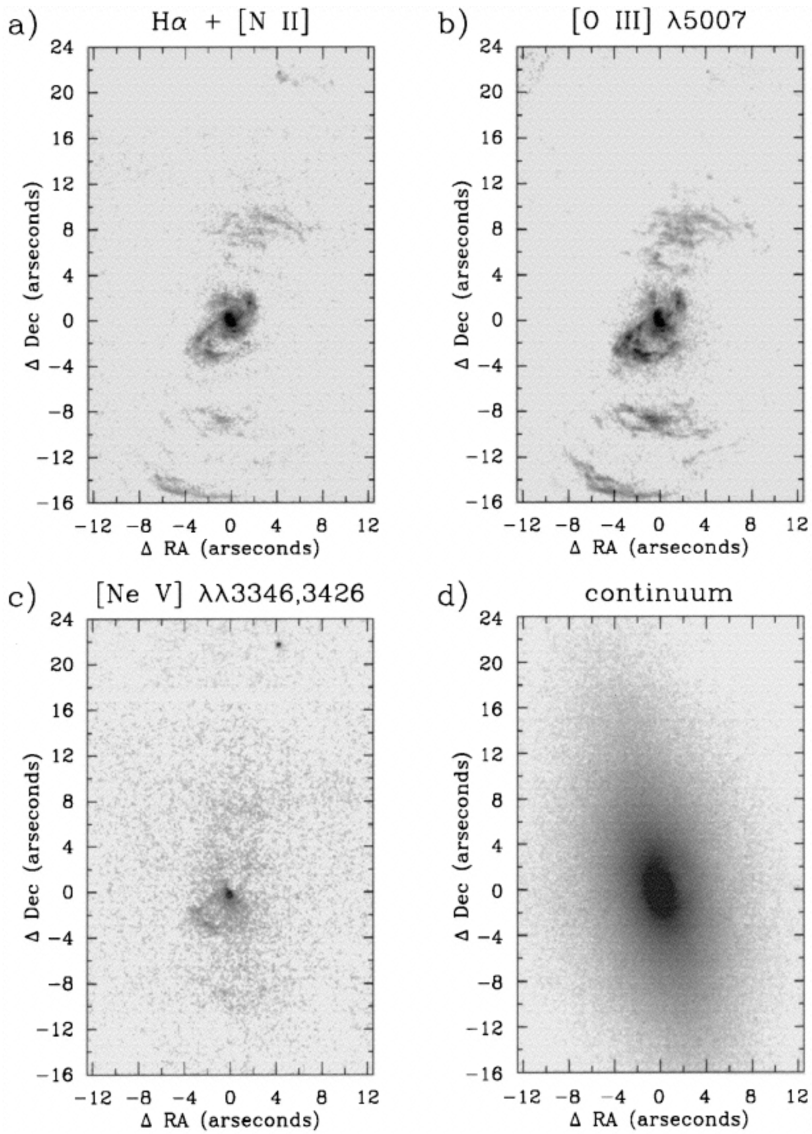


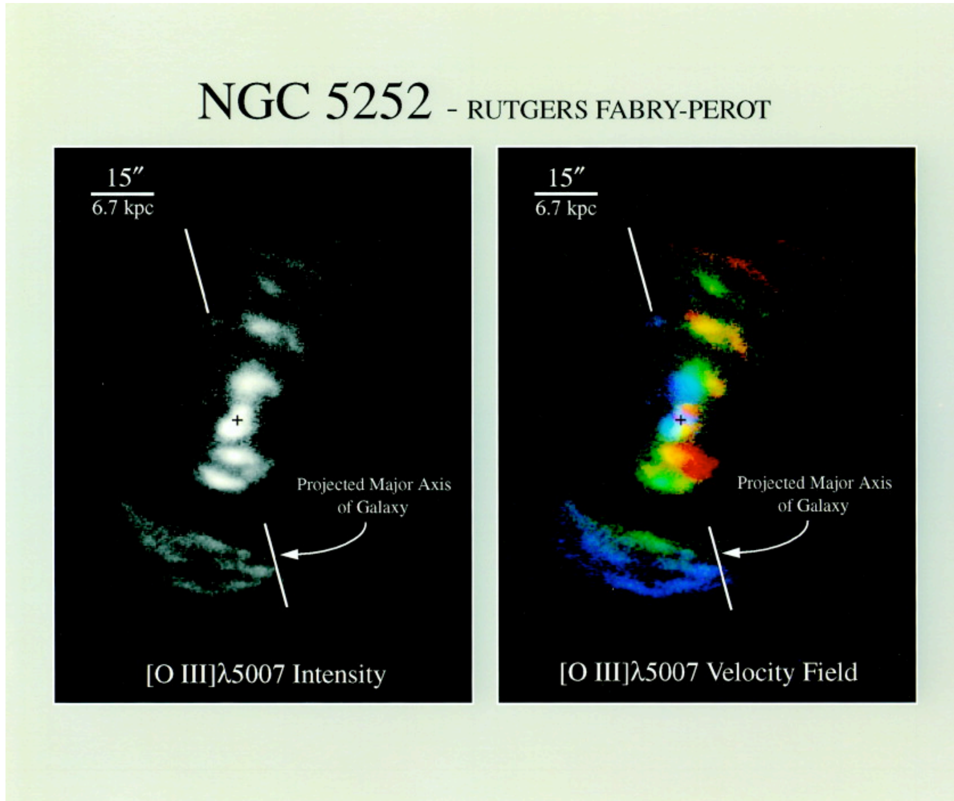
Hidden Broad-Line Region (HBLR)

AGN Unification Model



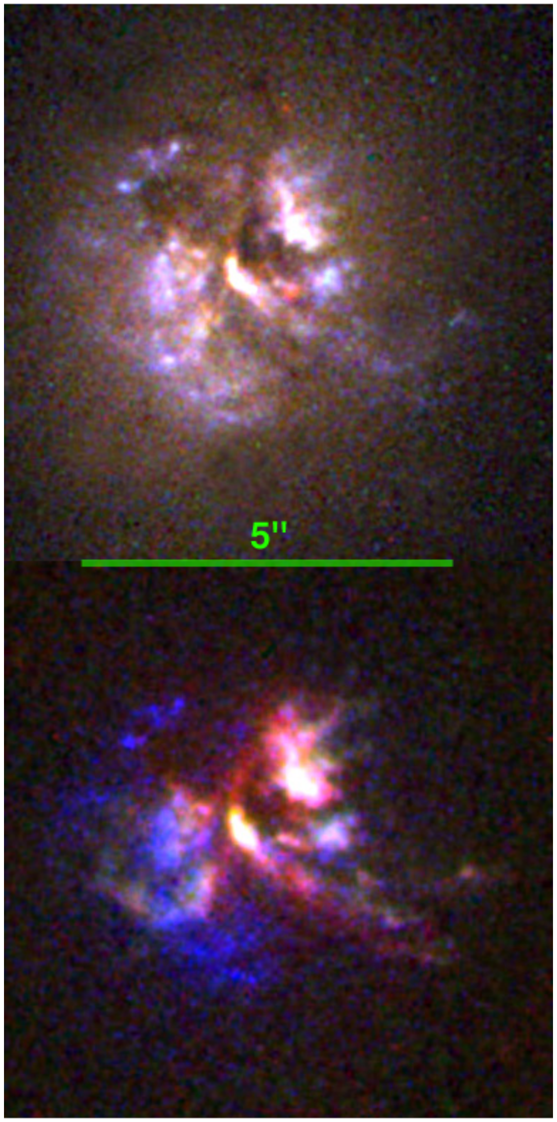
NGC 5252 Ionization Cones

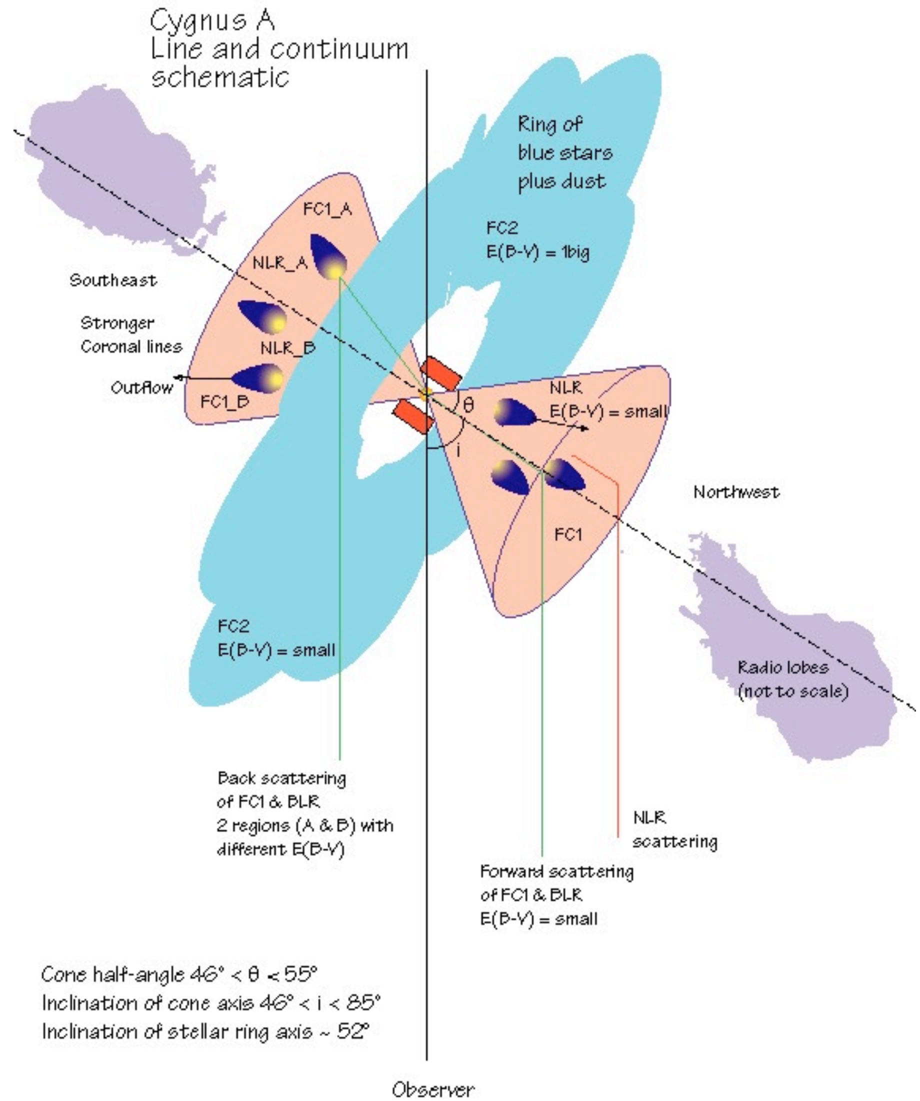




Morse et al. 1998

CygA Ionization Cones





Fosbury et al. 1999

Summary of Previous Surveys

- HBLRs detected in ≈ 1/2 of Seyfert 2 population
- HBLRs are more luminous and warmer than non-HBLRs
- What does it mean?
  - Only HBLR S2s are true counterparts to Seyfert 1s
  - Non-HBLR S2s are too weak to possess or sustain any BLRs
  - Obscuration / torus inclination
  - Broad-line variability
  - Non-HBLRs are narrow-line Seyfert 1s
  - Evolution
  - Scattering material

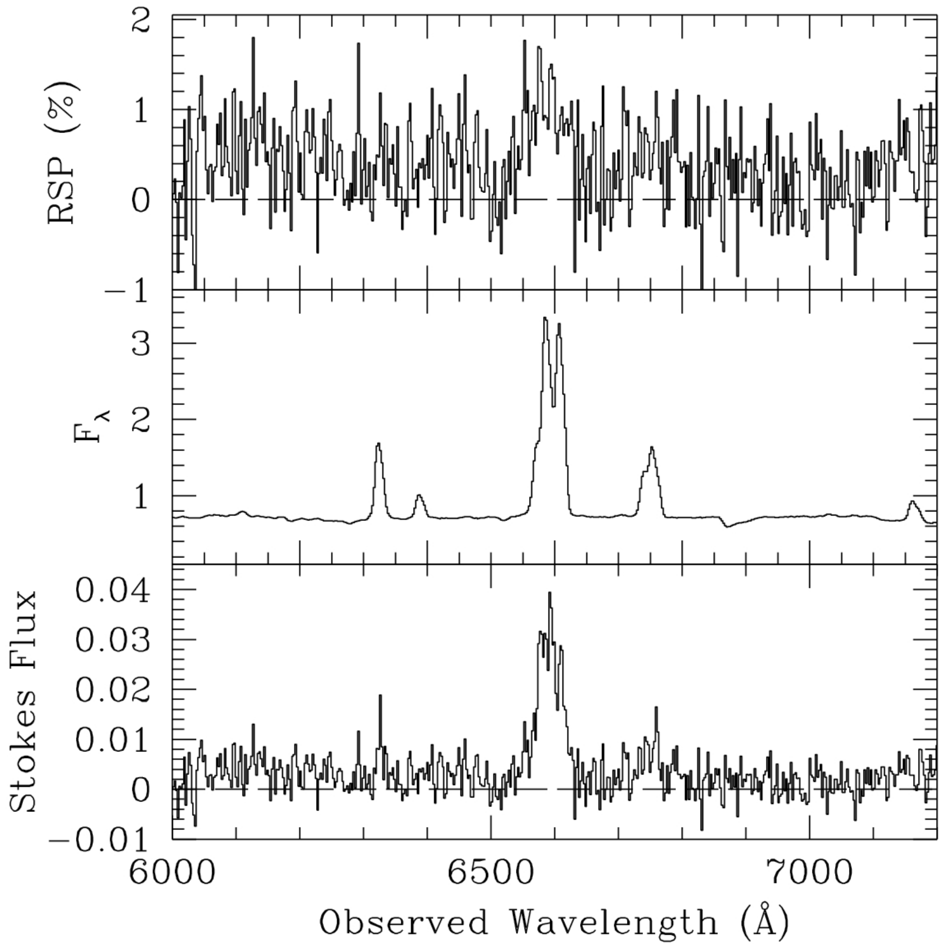
Non-detections real or due to limited depth of surveys?

Deep Keck Spectropolarimetric Survey

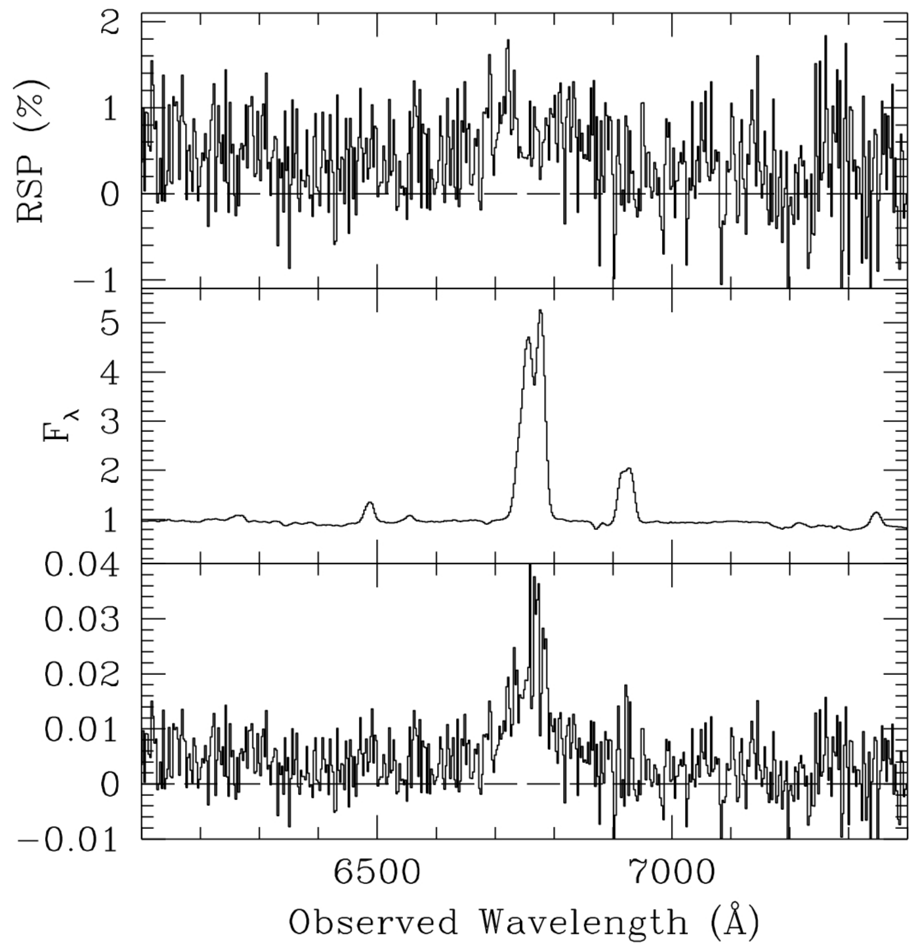
- Same sample as Tran (2003)
  - CfA and 12μm samples
- Target mainly non-HBLR Seyfert 2s
  - ~ 25 objects
- LRIS + polarimeter
  - Typical exposure times: 80-160 min per object
  - Multiple epochs
  - **4 - 15 X deeper than previous surveys**
- Six new southern objects observed at CTIO

New HBLRs: NGC 3982 & UGC 6100

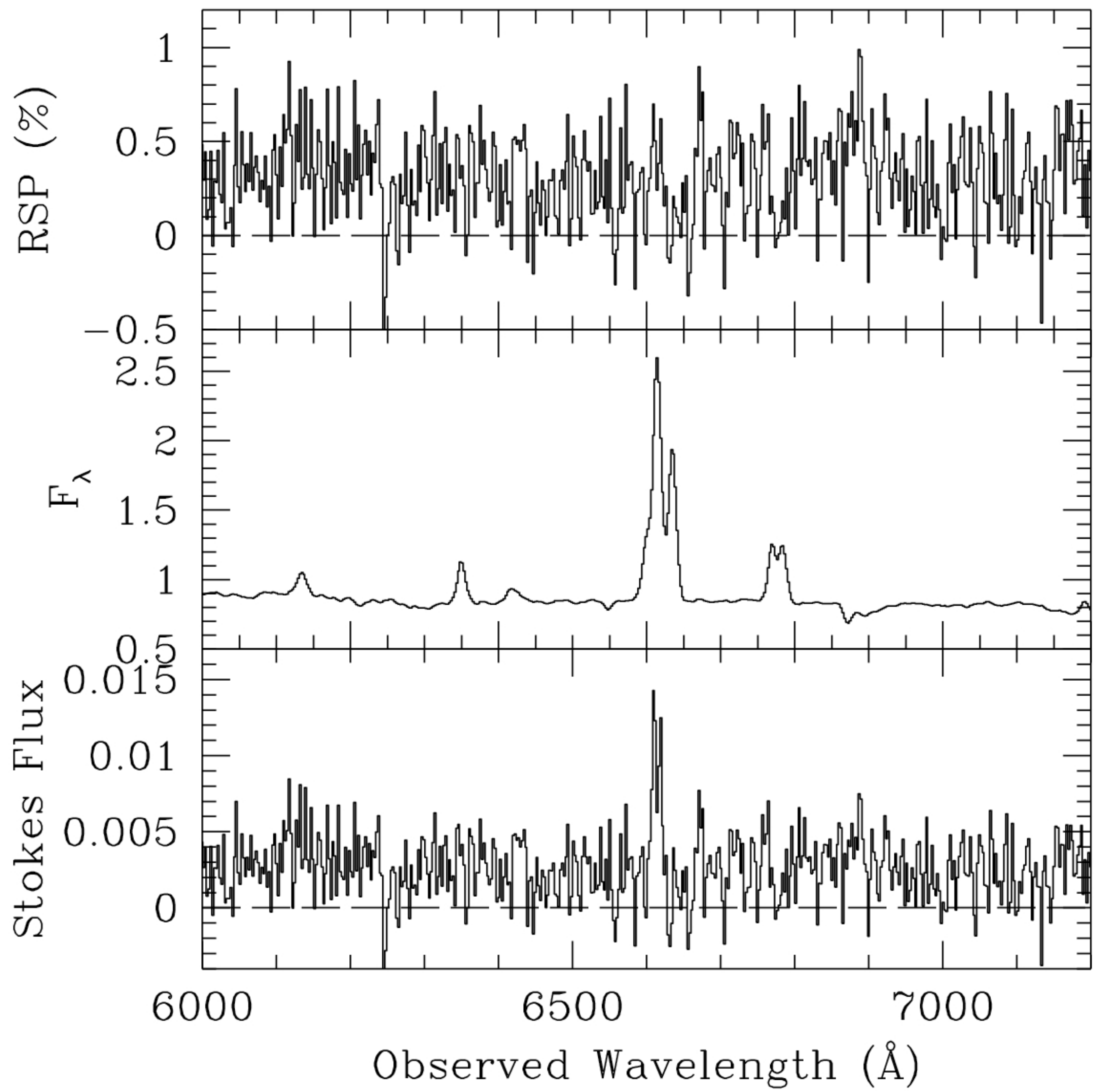
NGC 3982



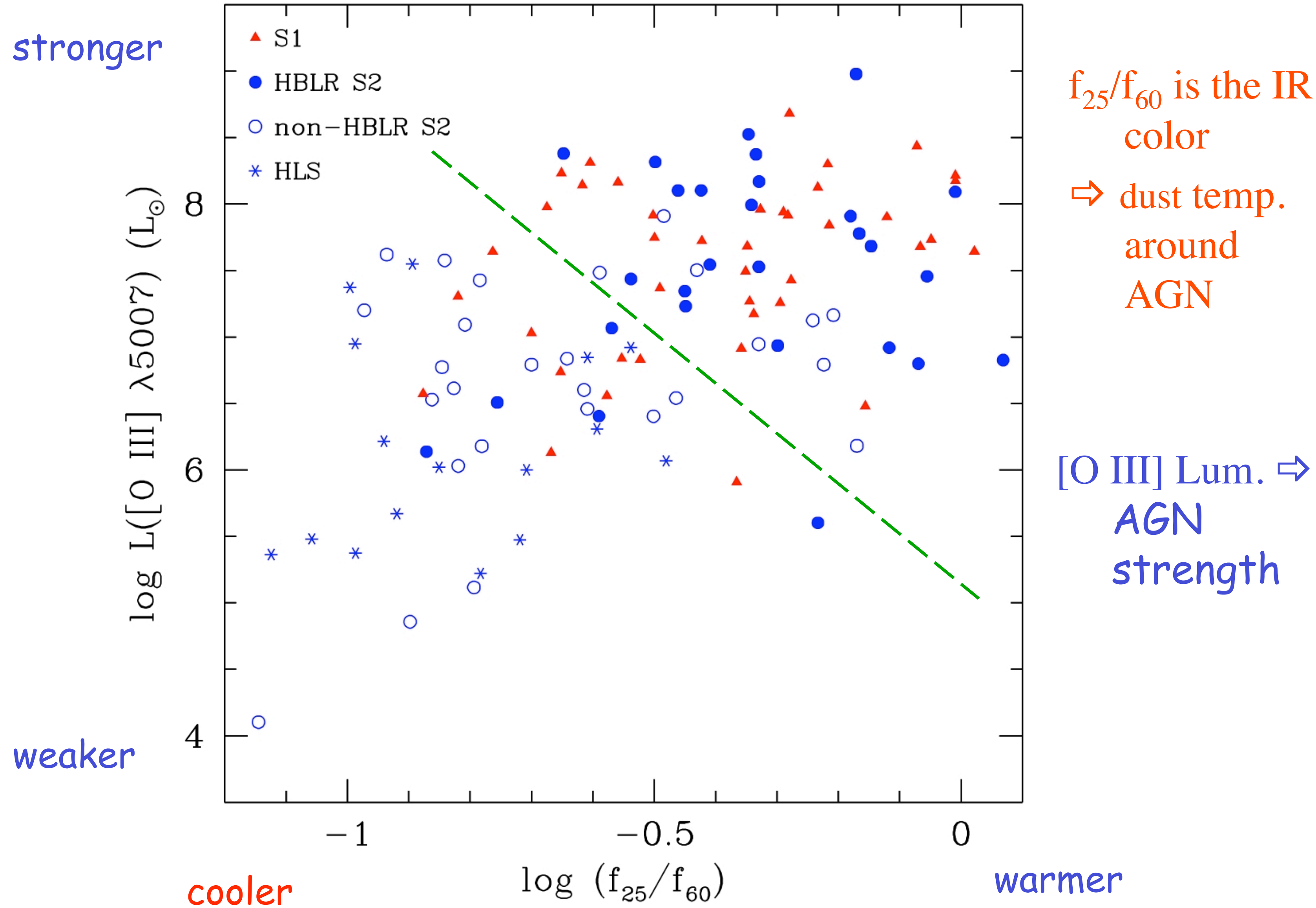
UGC 6100



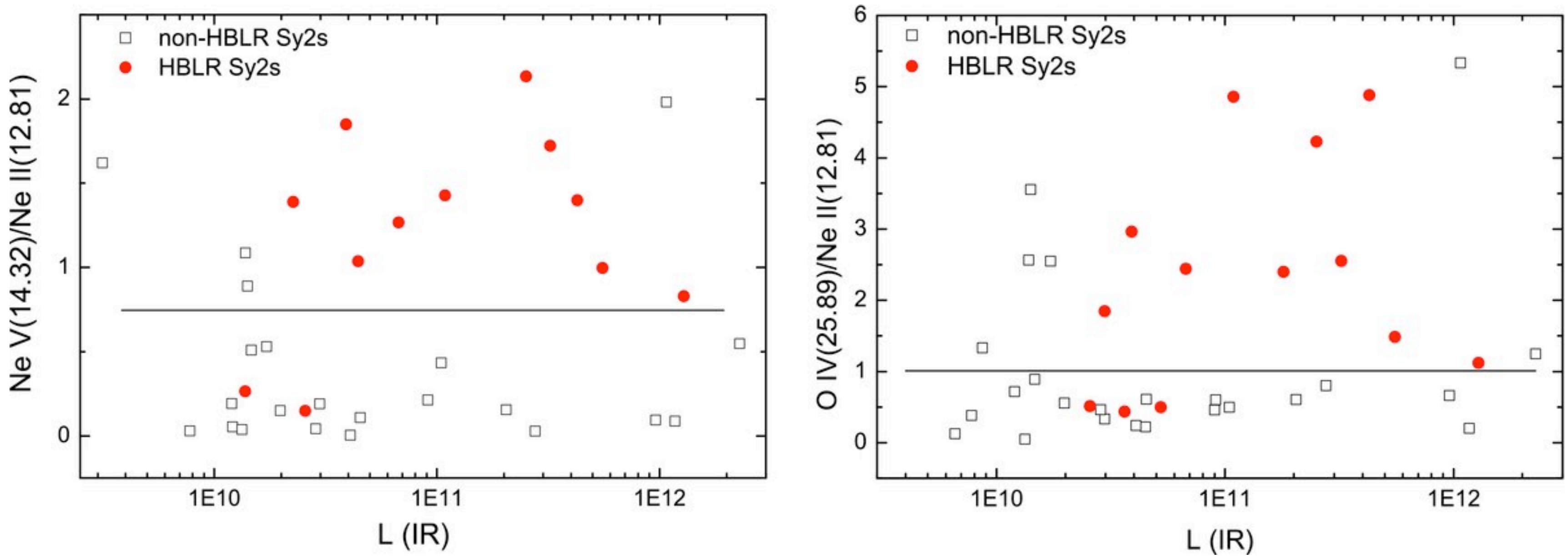
A non-HBLR: NGC 5347



[O III] Luminosity – IR Color Diagram

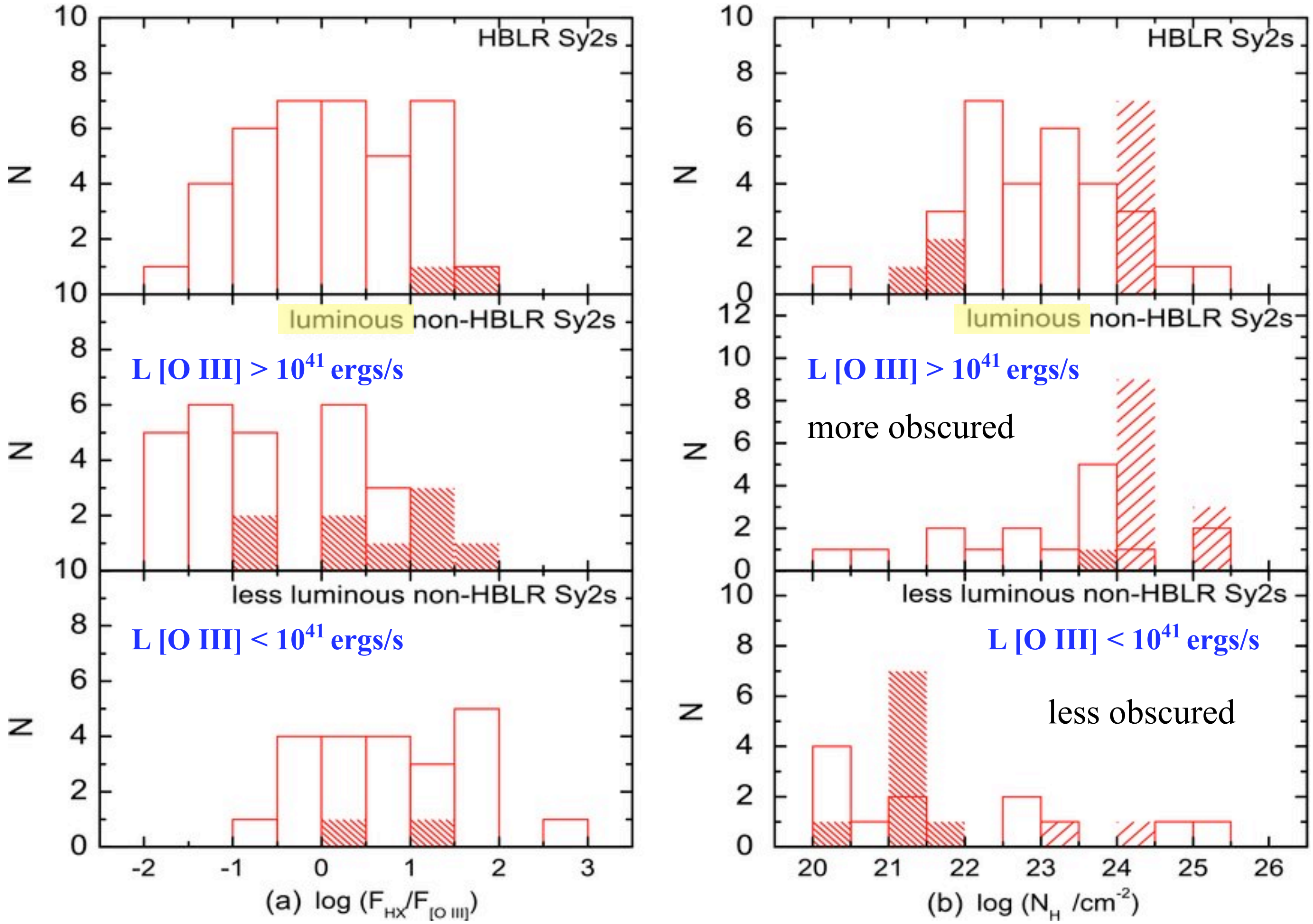


Mid-Infrared line ratios



Wu et al. (2011)

Obscuration



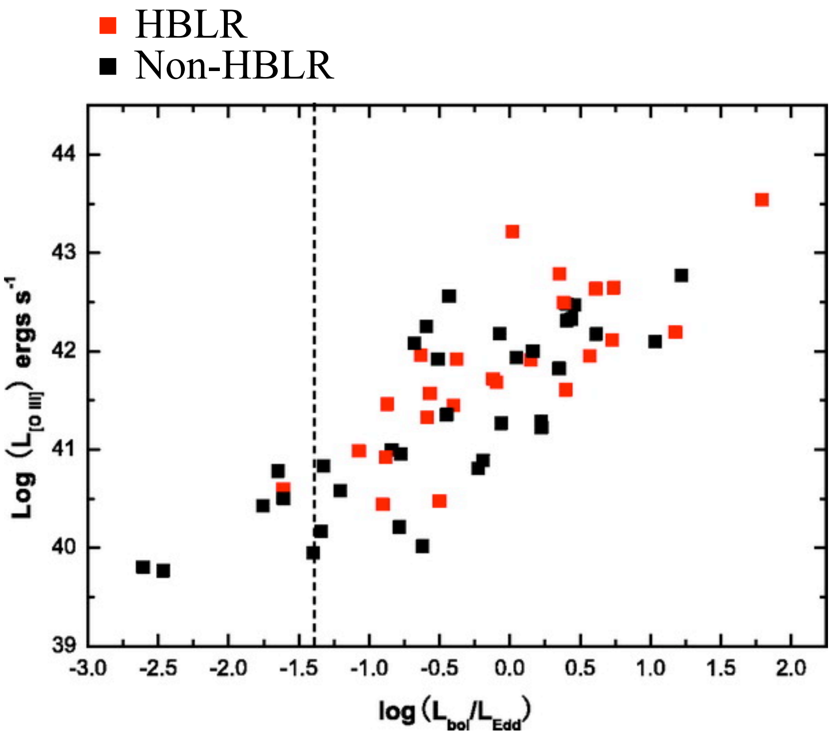
Luminous S2s: More likely to find HBLRs in less obscured objects

Wu et al. (2011)

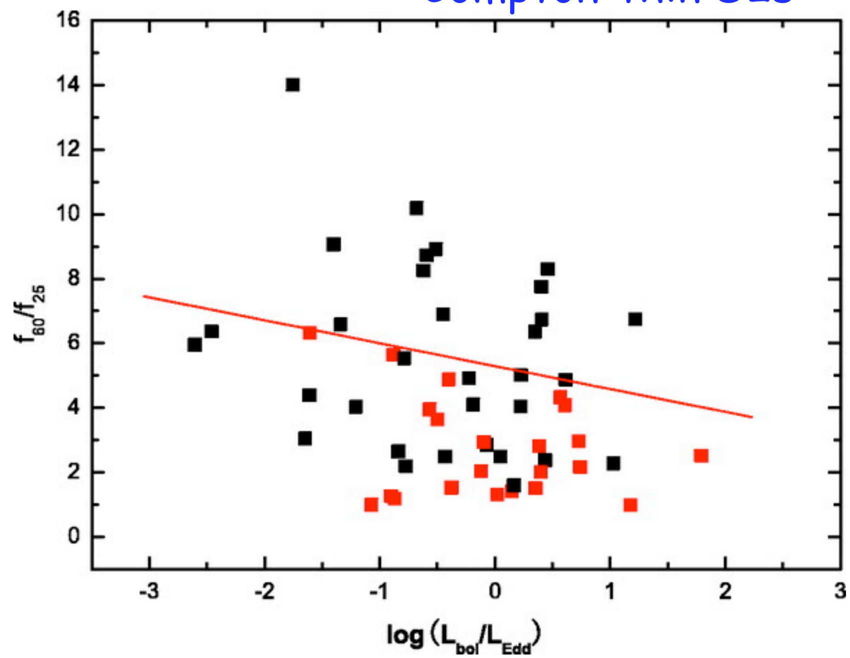
Obscuration plays a role for high-luminosity AGNs

For less luminous AGNs, accretion rates play a role…

Eddington ratios



Compton-thin S2s



Bian & Gu (2007)

Lack of HBLRs below some accretion threshold

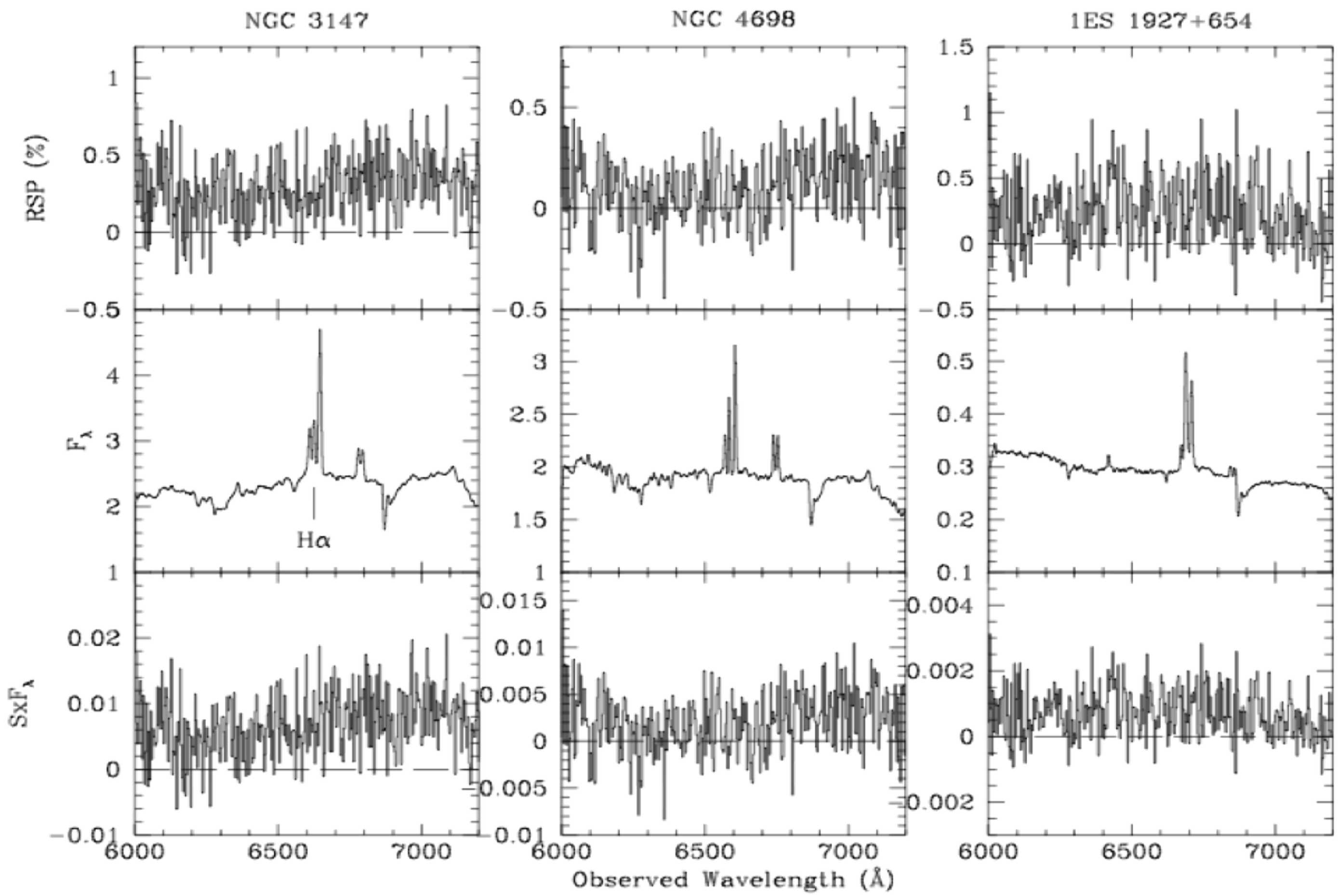
- Theoretical models: BLR unable to form when AGN luminosities or accretion rates are too low to support outflows from accretion disks (Nicastro 2000; Elitzur & Shlosman 2006; Cao 2010)

"Naked" View of three Seyfert Nuclei

- NGC 3147, NGC 4698, 1ES 1927+654
- All are Compton-thin, consistent with little or no intrinsic X-ray absorption above Galactic column density (~ 10^{20} - 10^{21} cm^{-2})
- Rapid, persistent, and strong **X-ray variability** observed over 12 year time scale in 1ES 1927+654
- X-ray variability also observed in NGC 3147
- High hard X-ray to [O III] ratios (1-100) indicate **little** obscuration
- Inferred nuclear optical extinction is less than ~ 1 mag.
- All classified as Seyfert 2 galaxies

➔ **contrary to expectation from the AGN unification model**

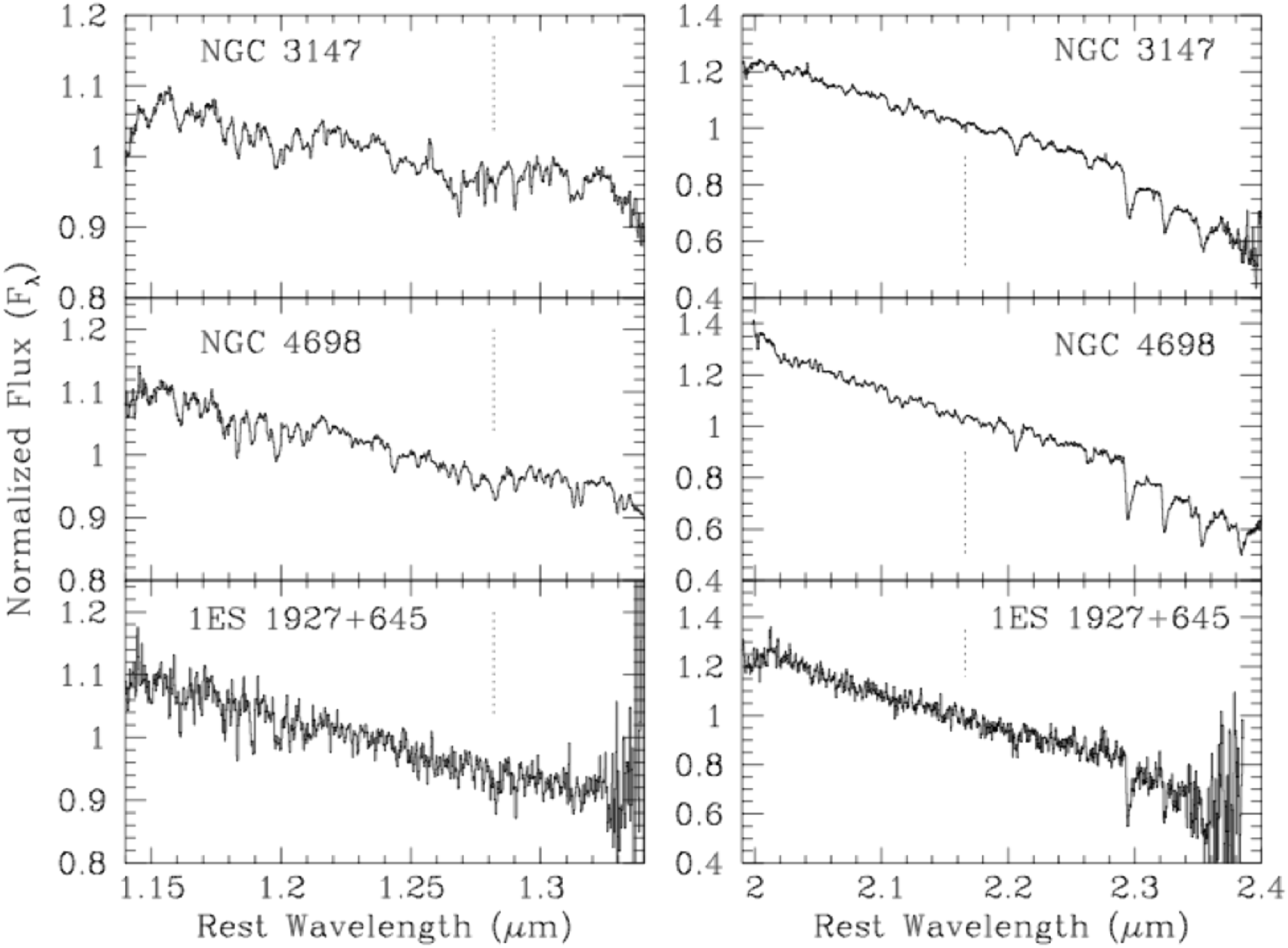
Spectropolarimetric Results



Deep, repeated observations to probe weak lines.

In each case, a small amount of polarization is detected but *no polarized broad lines indicative of a hidden broad-line region are seen in the polarized flux spectra.*

Near-Infrared Spectroscopy Results



The spectra are dominated by galactic starlight, and we do not detect any emission in Paβ or Brγ. No direct broad emission lines are present.

◆ *If typical broad lines were present, their non-detections would indicate an extinction of A_V ~ 11-26*

Why don't we see any broad lines, given the naked nature of these AGNs?

- *Misclassified Compton-thin AGNs?*
  - High spatial resolution *Chandra* and *XMM-Newton* observations rule out confusion from external sources
  - Temporal variation in X-ray flux implies X-ray is not scattered

  ➔ **ruled out**

- *Variable broad emission lines?*
  - Multi-epoch spectropolarimetric observations designed to search for variability failed to find any
  - Available spectra over timescales of years do not show any evidence of broad-line appearance

  ➔ **ruled out**

- *Hidden narrow-line Seyfert 1 (NLS1) galaxies?*
  - No emission lines of any kind, broad or narrow, are seen in polarized flux spectra
  - No polarized FeII emission

  ➔ **ruled out**

- *X-ray unobscured, but optically highly obscured?*
  - Narrow-line Balmer decrements are fairly normal, giving $A_V < 1.6$ mag
  - Heavy obscuration in BLR itself? High A_V/N_H ratio?

  ➔ **unlikely**

Most Likely Explanation

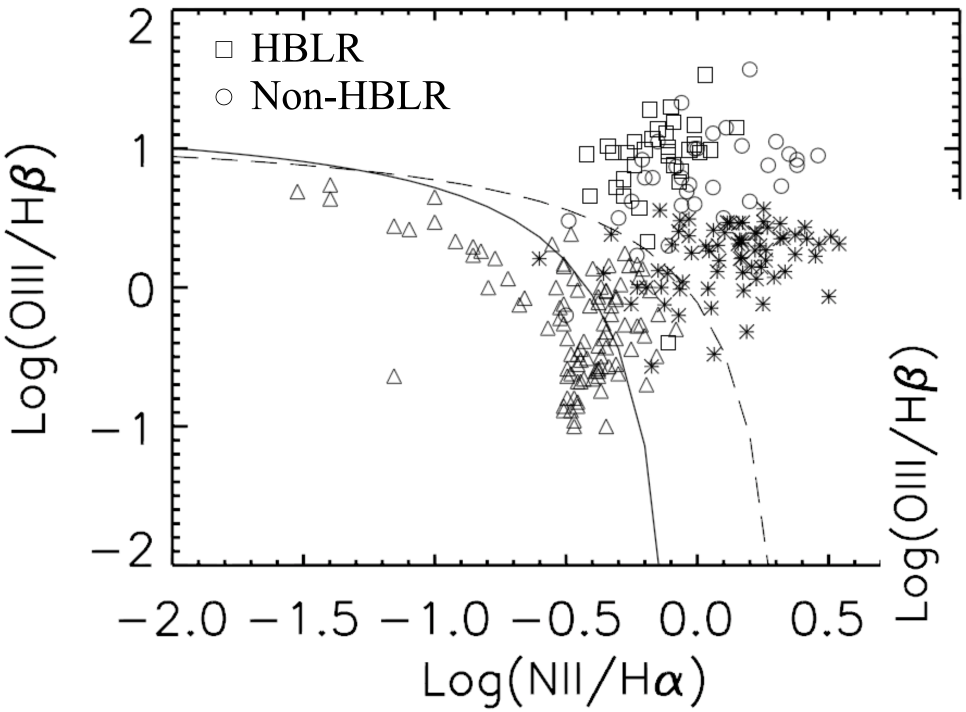
- ***Low-powered AGNs with weak or absence of BLRs***

  - All three objects are low-luminosity AGNs

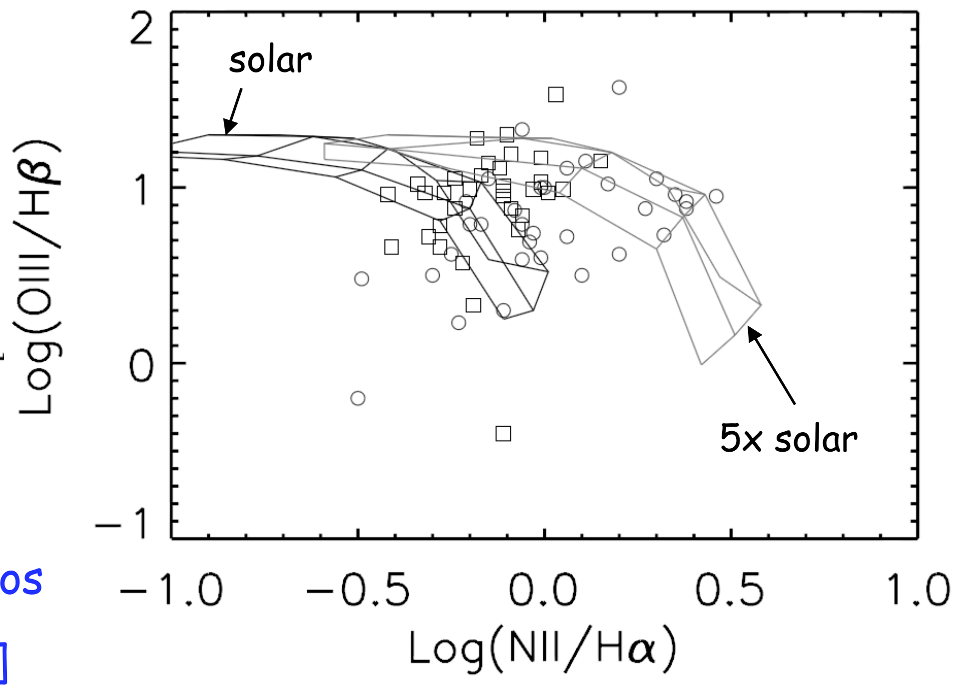
  - Observed Eddington ratios are consistent with being below minimum threshold needed to support BLRs ($L/L_{Edd} \lesssim 10^{-3}$)

➔ Evolutionary connection ?

Evolution?



Yu & Hwang (2011)

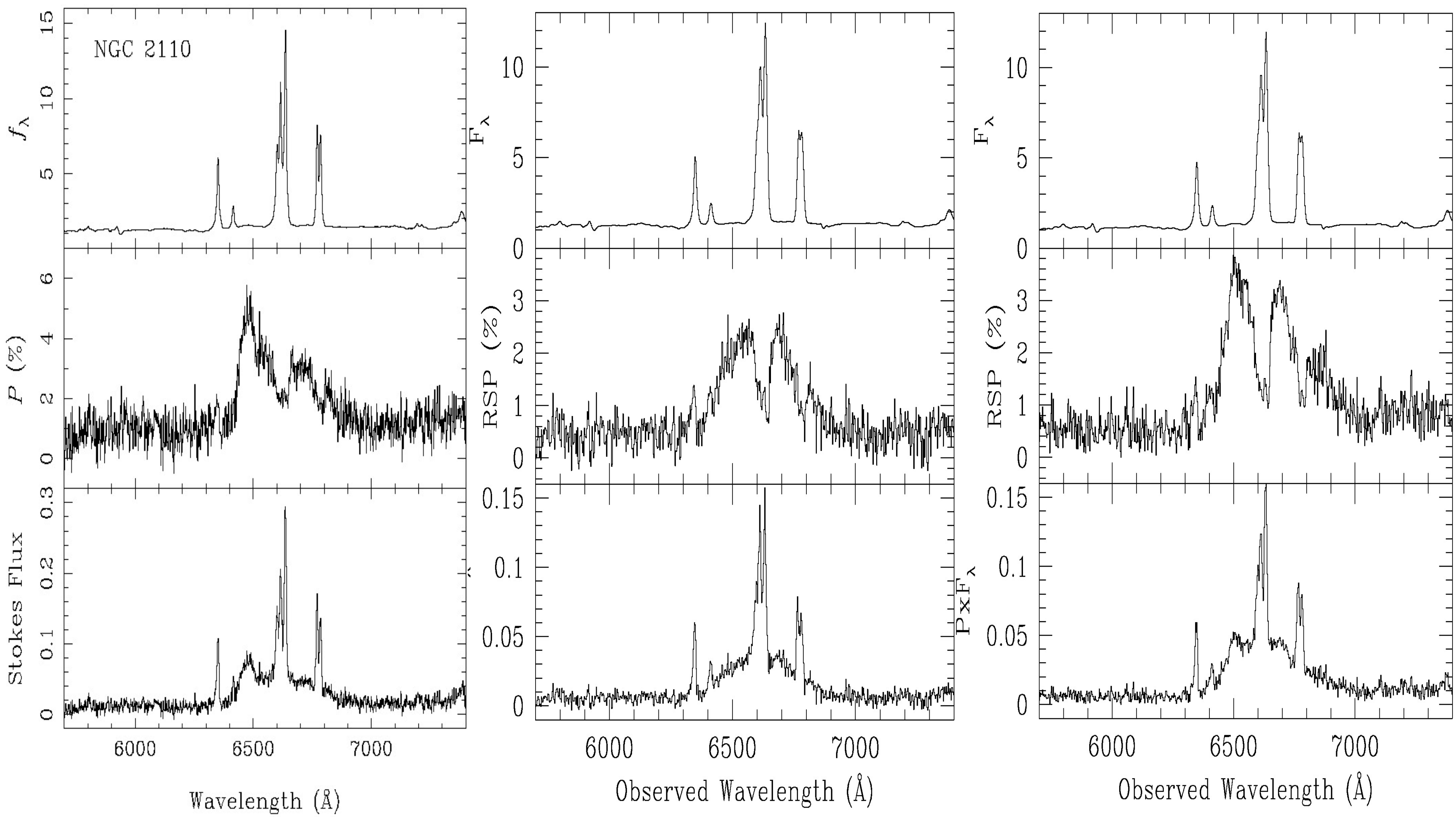


- Significant difference in [N II]/Ha ratios
- Can be explained by an increase in [N II] abundance in non-HBLR S2s
- Stellar evolution ➔ overabundance of N/O ➔ evolutionary connection between HBLR and non-HBLR S2s

Some Surprises

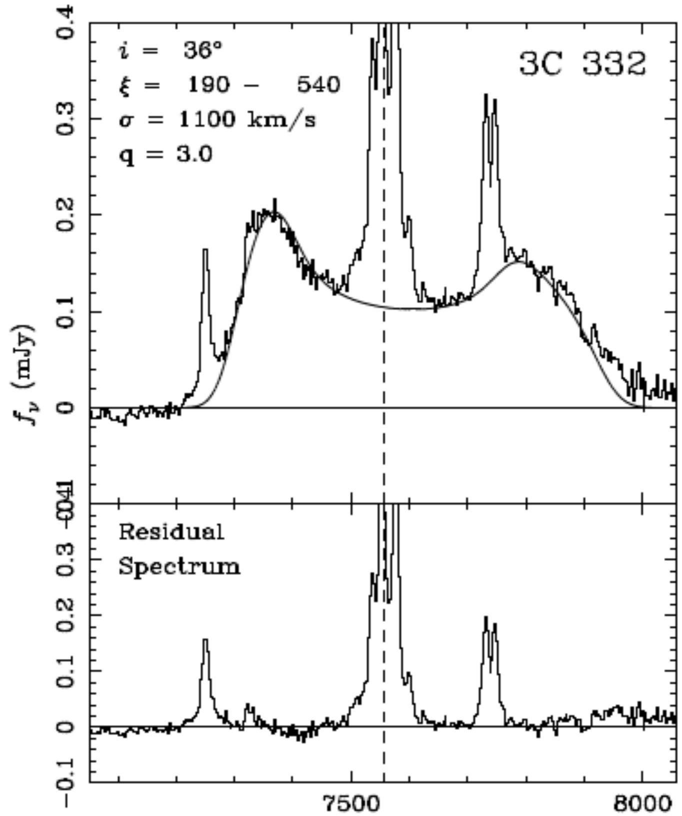
NGC 2110: A Hidden Double-Peaked Emitter

Moran et al, Dec. 2005 | February 2007 | November 2007



FWHM ~ 12,000 km/s FWZI ~ 24,000 km/s

Double-Peaked Emission-Line AGN



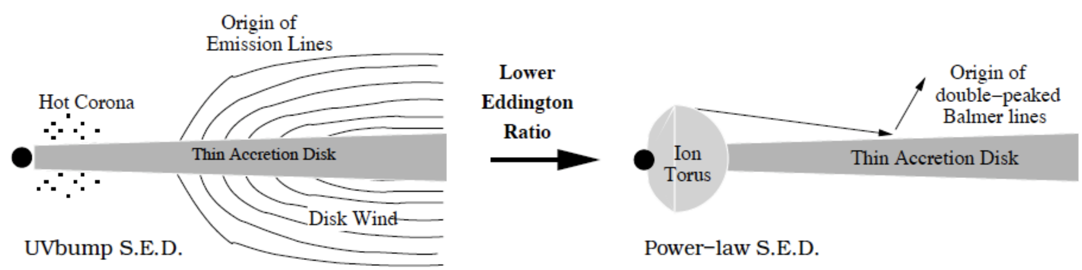
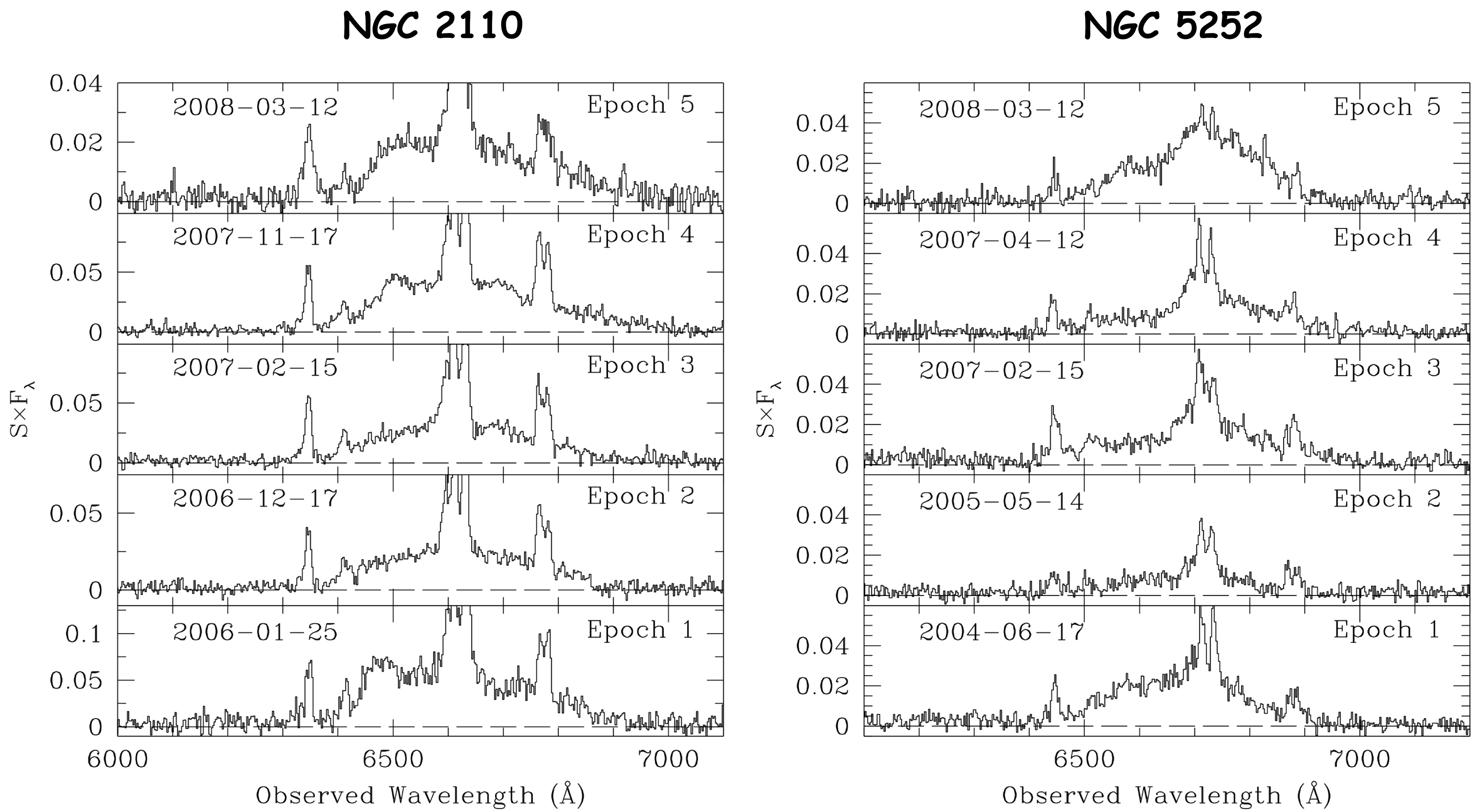


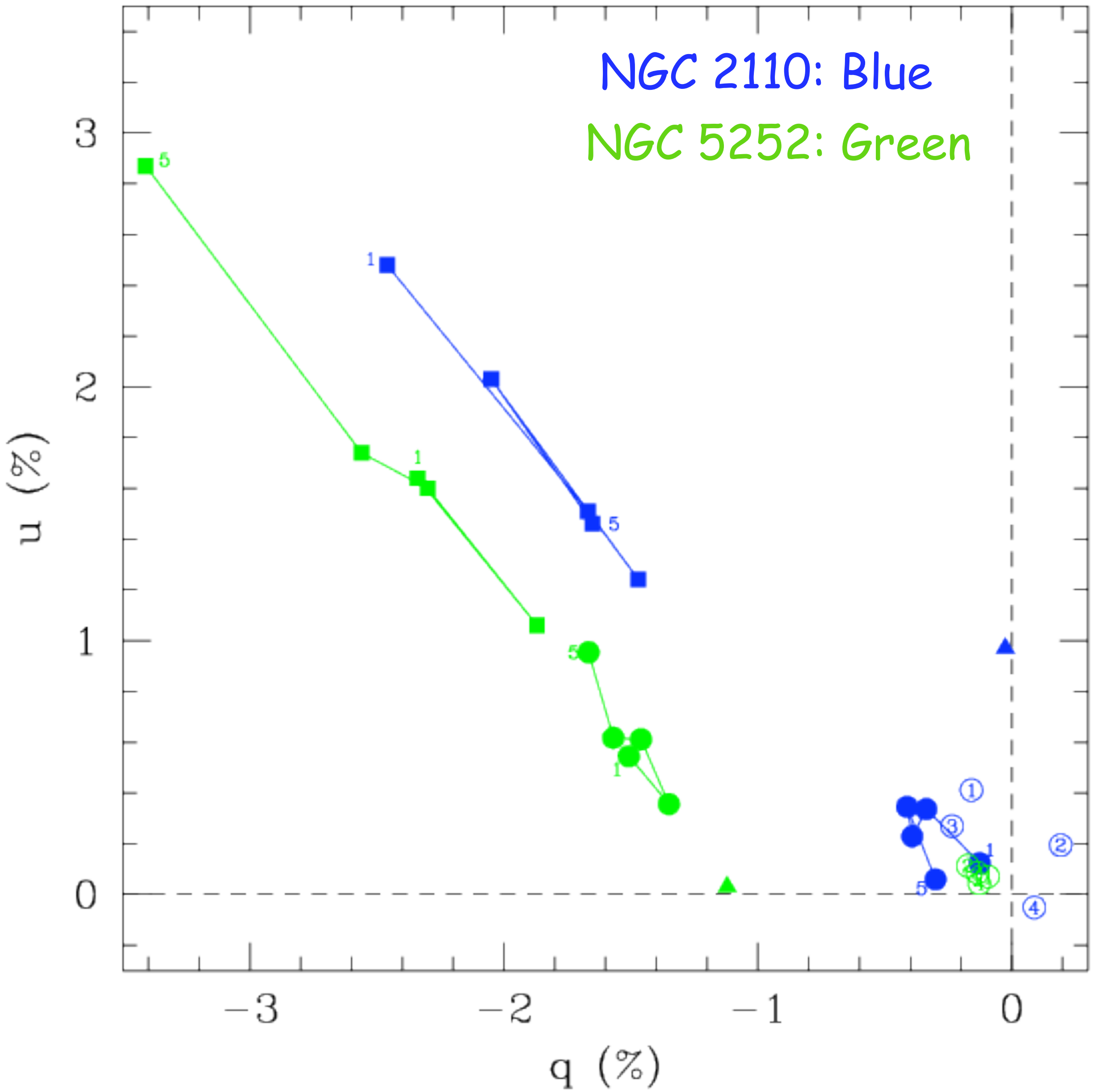
Figure 3. A sketch of how the structure of the accretion disk and its associated wind change as the Eddington ratio goes from high values ($\dot{M}/\dot{M}_{Edd} \gtrsim 0.1$) to low values ($\dot{M}/\dot{M}_{Edd} \lesssim 10^{-3}$).

Hidden (Polarized) Hα Profile Variability



Timescales ≲ 1 yr (similar to dynamical timescales of accretion disks)

HDPE: Observed Polarization Variability



- continuum and broad-line polarization PAs are the same ➔ similar polarization mechanism and geometry
- polarization PA does not change with time
- polarization PA (~70°) perpendicular to ionization cone axes
➔ scattering is the source of polarization

What Causes the Rapid Variations?

- Variability timescales ≲ 1 yr ➔ very compact scatterers
  - Discrete clouds ≲ 1 ly, NOT filled cones with large filling factor
- Dramatic line profile changes in polarized flux
  - NOT due to “light echo” or “search light” effect
- Non-changing polarization PA ➔ changes in line-emitting flux, *not* scattering medium

Constraining the Properties of the Scatterers

- No "smearing" of line profile ➔ $T_e \lesssim 10^6$ K
- Polarization PA ⊥ to cone axis ➔ polar distribution
- Scattering spherical "blob" model:

$f = L_{sc}/L_{in} \approx \sigma_T n_e 2r \Delta\Omega$

assume $\tau_e = \sigma_T n_e 2r \sim 1$ (optically thin)

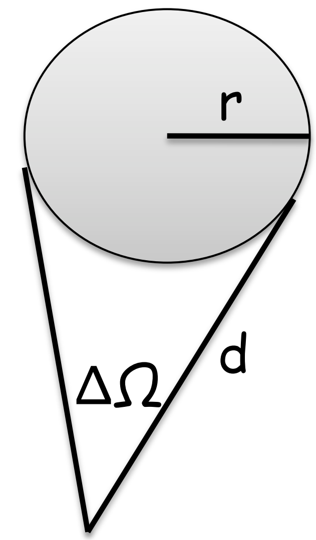
$\Delta\Omega \approx \frac{1}{4} (2r/d)^2 = r^2/d^2$

$2r \sim 1$ ly

$f \sim 1\%$

➔ $n_e \sim 10^7$ cm^{-3}

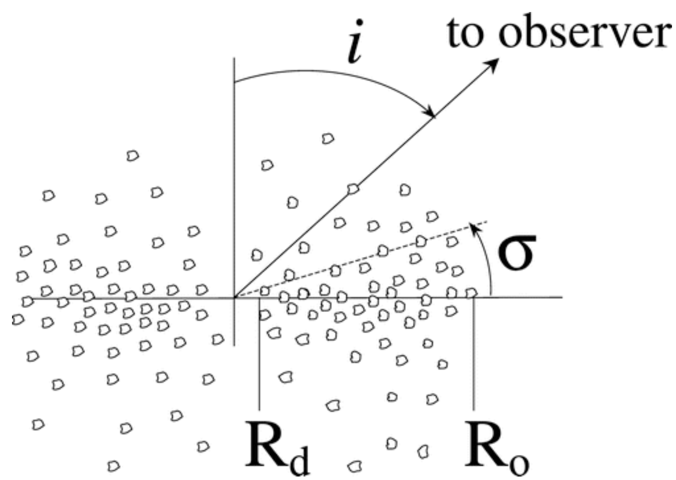
$d \lesssim 10$ pc



- Scatterers lie just outside the obscuring torus between BLR and NLR
- Much more compact and close-in than previously thought

Compact Scattering Region, Close to Nucleus

- Line-emitting "ejectiles" from the nucleus
  - Ejection (bi-polar) outflow model
  - Simple: same material for both scatterer and line-emitting gas
  - Well-defined bi-cones
- Radio hot spots or material entrained in the base of jets
  - Preference of DPEs in radio-loud AGNs
  - Problematic for accretion disk model as scattering angle **must** be small (< 15°)
- Material from outskirts of obscuring torus itself
  - Clumpy obscuring torus model (Elitzur & Schlosman 2006; Nenkova et al 2008)
  - Properties similar to scattering clumps
  - Viewing angle ($i \sim 65°$) more consistent with extended cone morphology



Summary

- Unified Model of AGN is undoubtedly correct
- Orientation, evolution, luminosity, and obscuration all play important roles
- Scatterers can be very compact, (≲ 1 ly), and located close (< 10 pc) to central nucleus, *giving rise to variability of polarized light*