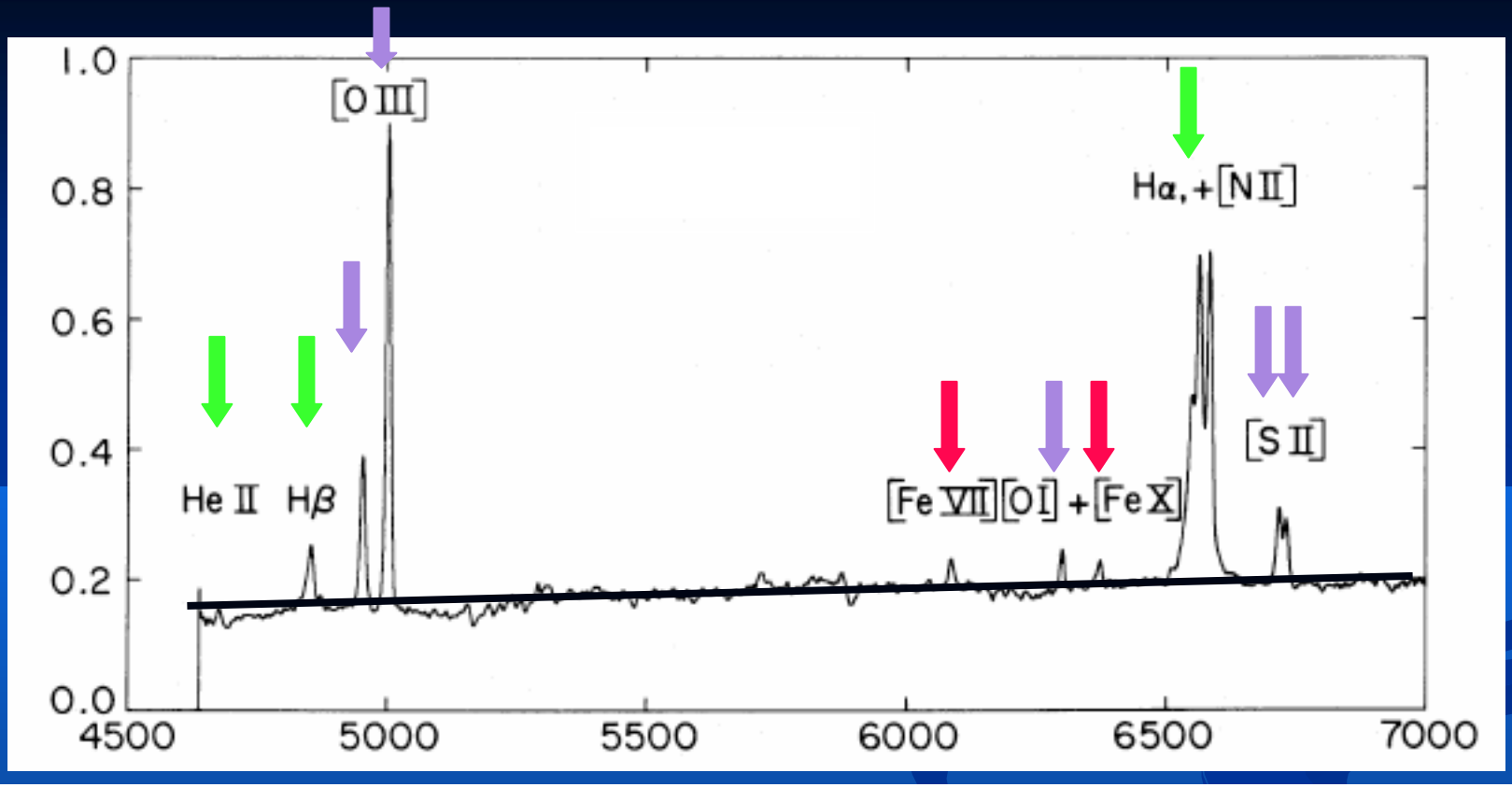
Near Infrared (0.8-2.3 μm) High-ionization Forbidden Lines in Active Galactic Nuclei

José Gregorio Portilla
Observatorio Astronómico Nacional, Universidad Nacional de Colombia

Alberto Rodríguez-Ardila
(Laboratório Nacional de Astrofísica, Itajubá, Brazil)

Juan Manuel Tejeiro
Observatorio Astronómico Nacional, Universidad Nacional de Colombia

The spectrum of a great majority of active galatic nuclei shows



Flat non-thermal continuum

Recombination lines :H I, He I, He II

Collision excited lines from low ionization species [O III], [S II]

Collision excited lines from high ionization species [Fe VII], [Fe X]

Coronal lines

Coronal lines (CLs)

or

Forbidden high ionization lines (FHILs)

Forbidden transitions within low lying levels excited by collisions whose ionization degree of the emitting species are equal or higher than 0.1 kev

They have been detected in:

- Solar Corona
- Corona in others stars
- Supernova remnants
- Agns

CL observed in the optical

SPECIE	χ (eV)	LINE
Fe^{+6}	99	[Fe VII] λ 5721 Å
Fe^{+6}	99	[Fe VII] λ 6087 Å
Fe^{+13}	331	[Fe XIV] λ 5303 Å
Fe^{+9}	234	[Fe X] λ 6374 Å
Fe^{+10}	262	[Fe XI] λ 7892 Å

Observationally, coronal lines show:

- Profiles blueshifted relative to lower excitation species (Grandi 1978, Penston et al. 1984)

- Tend to be broader than low ionization forbidden lines (Phillips & Osterbrock 1975, Cooke et al 1976)

- It is frequent to observe a correlation between ip (χ) neccesary to create the ionized specie and its FWHM (Wilson 1979, Pelat, Aloin & Fosbury 1981)

There have been a lot of controversy about the mechanism of ionization and location of the emitting lines

Which mechanism is causing the high ionization?

- Photoionization due to the central source, which emits hard uv and soft x-rays (Osterbrock 1969, Shields & Oke 1975)

- Shocks between high velocity clouds (osterbrock & parker 1964, Oke & Sargent 1968)

- Photoionization & shocks (Viegas-Aldrovandi & Contini 1989)

CLR Location

Theoretical models indicate:

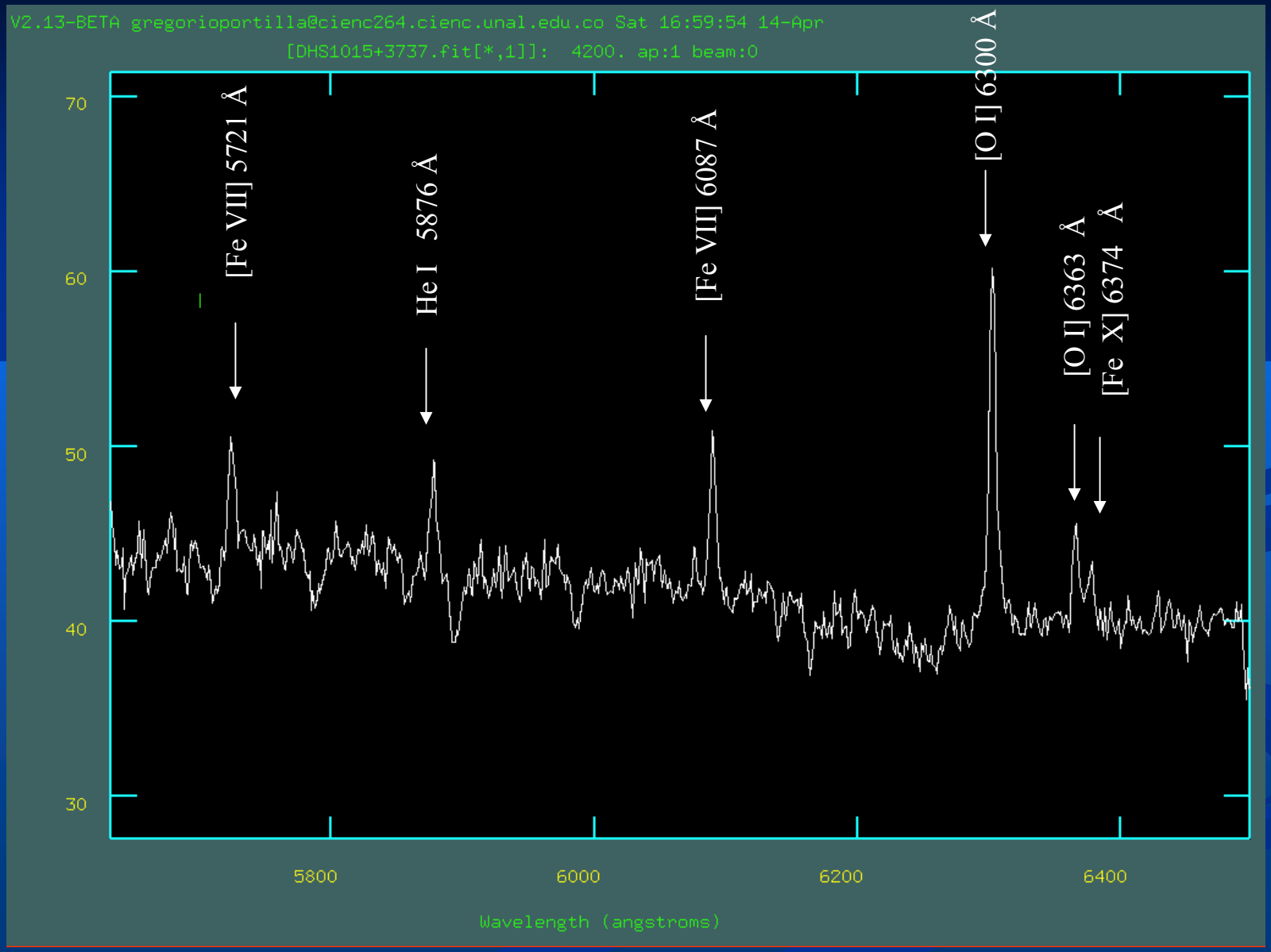
- Inner edge of the torus (~1 pc) Pier & Voit (1995)
- In the NLR and beyond (≥100 pc) Korista & Ferland (1989)
- ~1-400 pc (more efficient ~10 pc) Ferguson et al. (1997)

CLR Location

Direct observation of nearby AGNs indicate:

- ~ 10 pc ([Fe XI]) (Oliva et al. 1994)
- ~ 50 pc ([Fe VII], [Si VI]) (Marconi et al. 1994
- ~ 20-50 pc ([Si VI]) (Maiolino et al. 1998)
- ~ 1100 pc ([Fe X]) (Muruyama et al. 1998)
- ~ 100-200 pc ([Si VI]) (Rodríguez-Ardila et al. 2006)

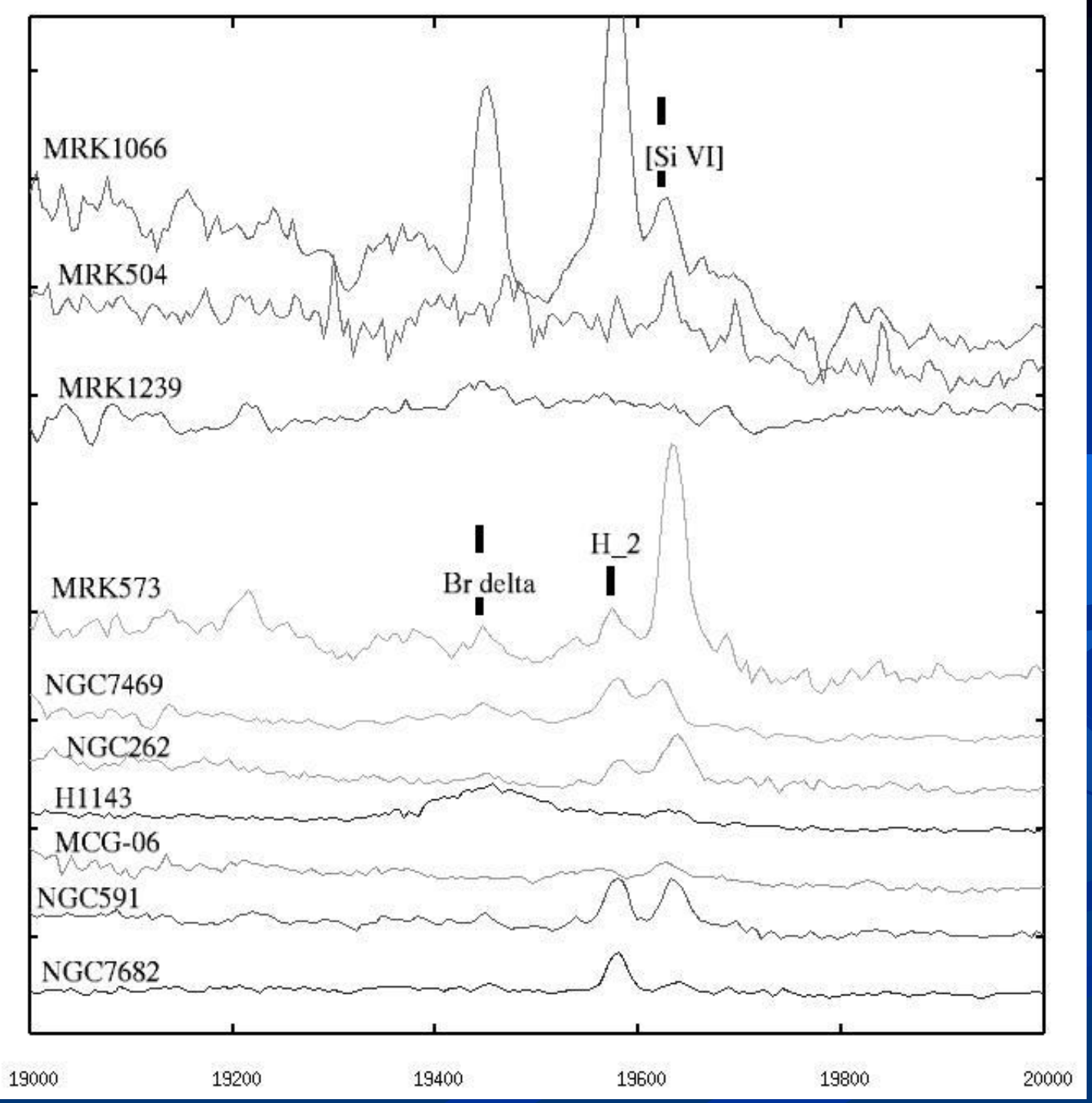
It would be desirable to analyze others CLs but they are few in the optical range



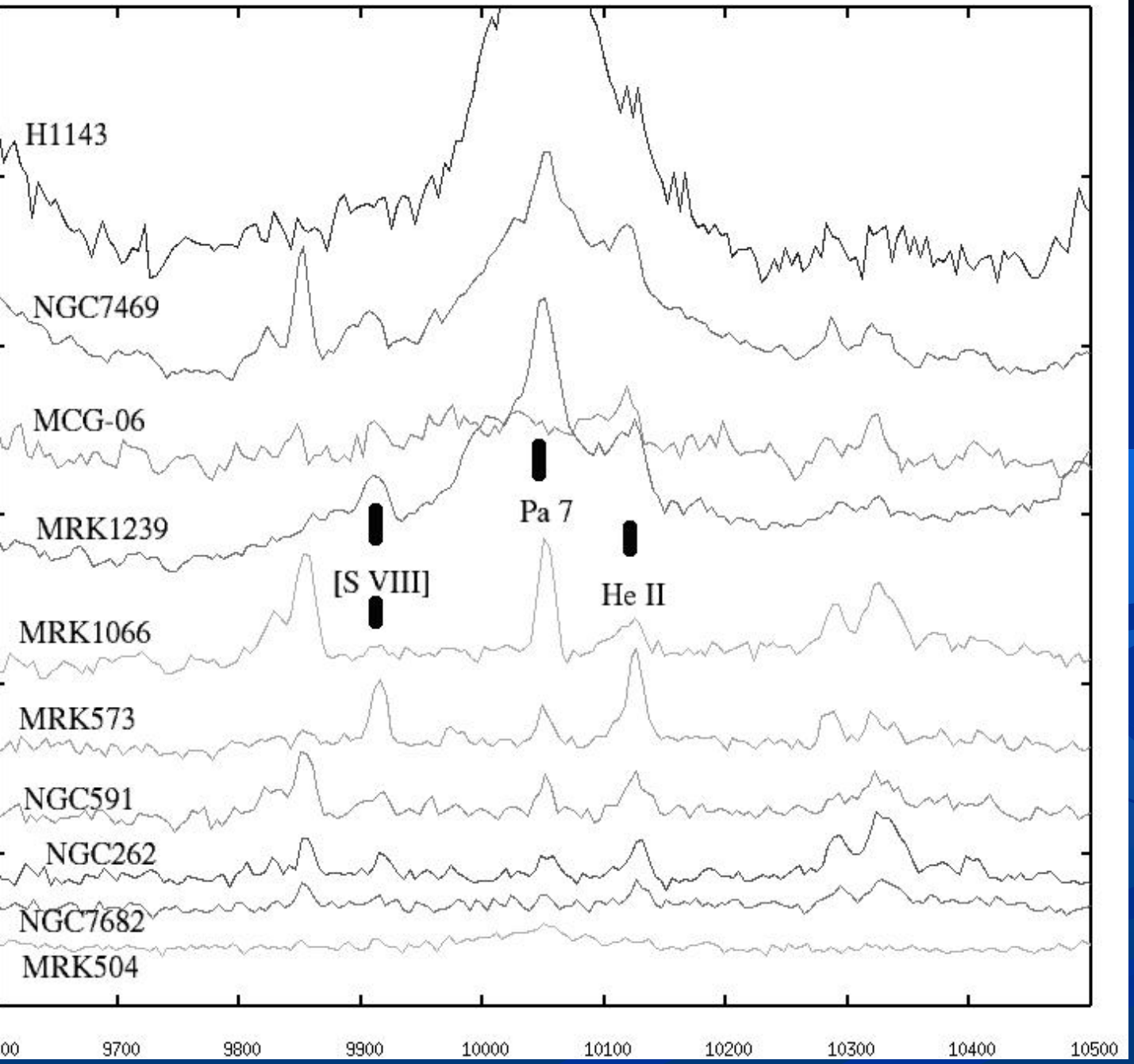
But near infrared offers a fair number of coronal lines

Near -infrared coronal lines
(0.8-2.3 μm)

SPECIE	χ (eV)	LINE
S^{7+}	280.9	[S VIII] λ 9912 Å
S^{+8}	328.8	[S IX] λ 12523 Å
Si^{9+}	351.1	[Si X] λ 14305 Å
Fe^{+12}	330.8	[Fe XIII] λ 10747 Å
Fe^{+12}	330.8	[Fe XIII] λ 10798 Å
S^{10+}	447.5	[S XI] λ 19200 Å
Si^{5+}	167	[Si VI] λ 19630 Å
Ca^{7+}	127.2	[Ca VIII] λ 23213 Å



[Si VI] λ 1.963 μm



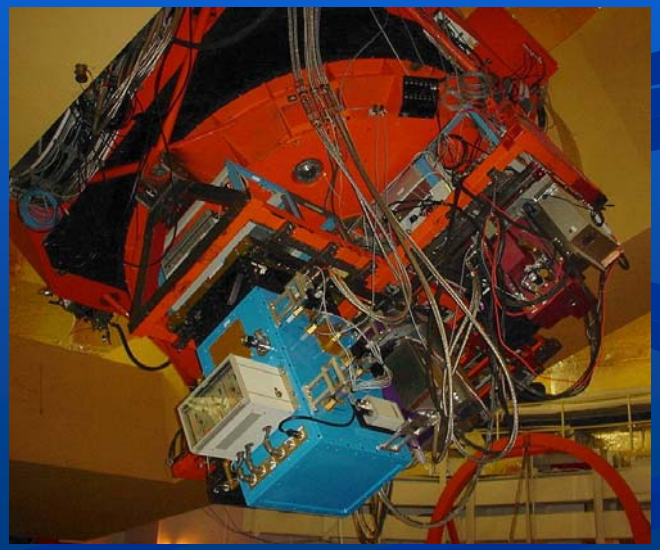
[S VIII] λ 0.991 μm

The increase in the number of coronal lines allows us to study:

- Possible orientation effects (torus?)
- If it is loccated in the inner part of the NLR
- Is there any dependence of CLs with X ray emission?
- If Cls are associated with high ionization winds?

The present work seeks to study for the first time in the NIR region the Cls present in a sample of Ty1 and Ty2 galaxies

Most of our sample spectra were taken in the Infrared Telescope Facility (IRTF, NASA) at Mauna Kea (Hawaii)



SpeX Spectrometer

Detector: 1024 x 1024 Aladdin 3 InSb

Selection of the sample

- All except 4 non-active spectra galaxies of the sample studied by Riffel et al. (2006) + 9 other galaxies with available data in the literature

Main selection criteria: CfA sample for Sy1, Sy2 & NLS1 (Boller et al, 1997), PG quasars

54 Active-galaxies

- 36 Ty1
  - 17 “normal” Ty1
  - 19 NLS1
- 18 Ty2

Questions that I will address in this work:

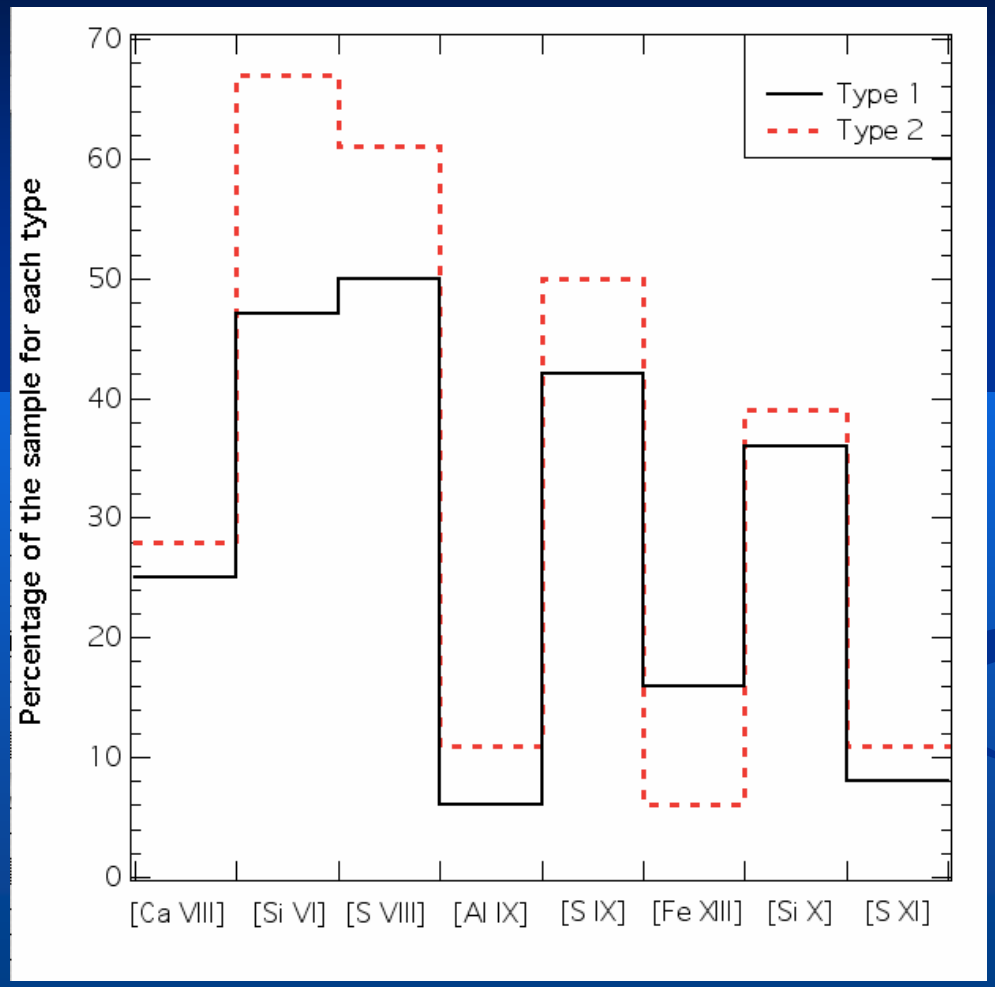
- The distribution of Cls according to AGN type

- How the FWHM of the Cls is related with the IP and AGN type?

The relationship between the Cls and soft X-ray emission

Results

% of each type for CL detected

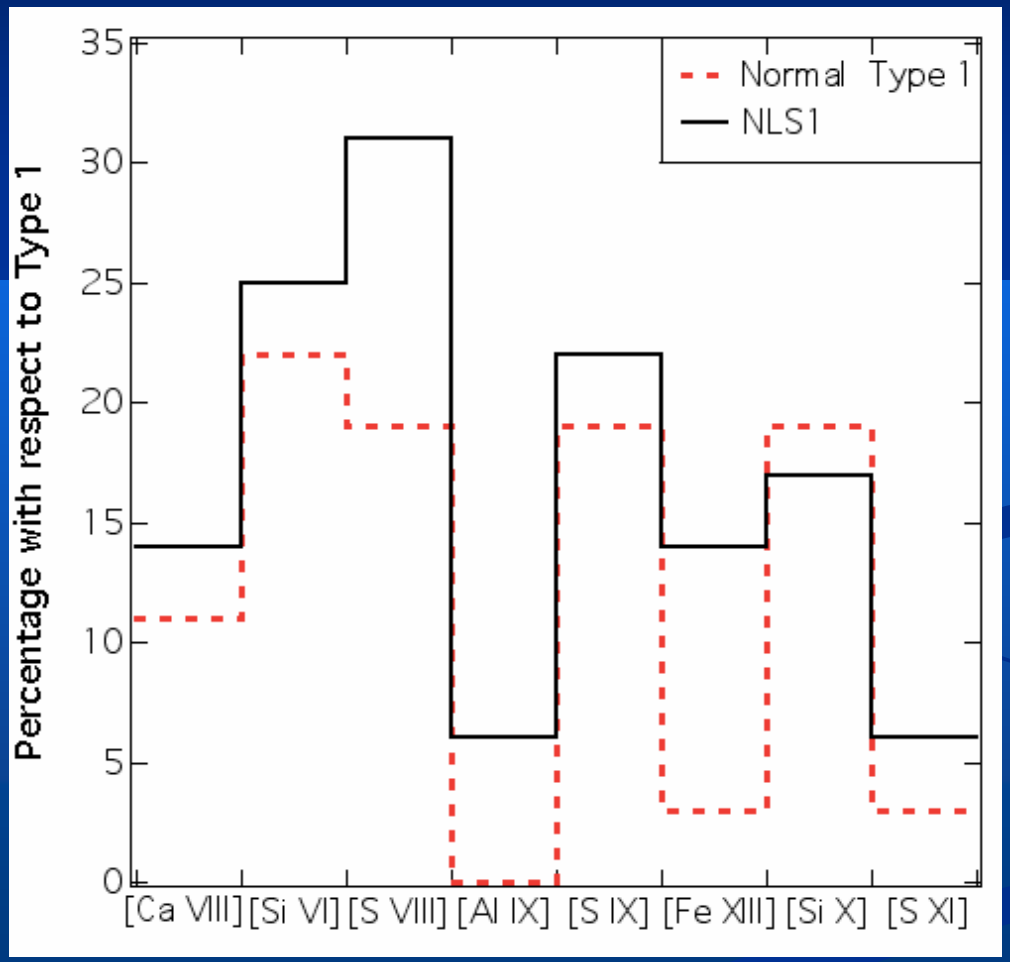


127.7 447.1 eV

- CLs seems to appear equally distributed for Ty2 and Ty1 galaxies except for [Si VI] λ 1.964 μm and [S VIII] λ0.9913 μm which are more frequent in Ty2.

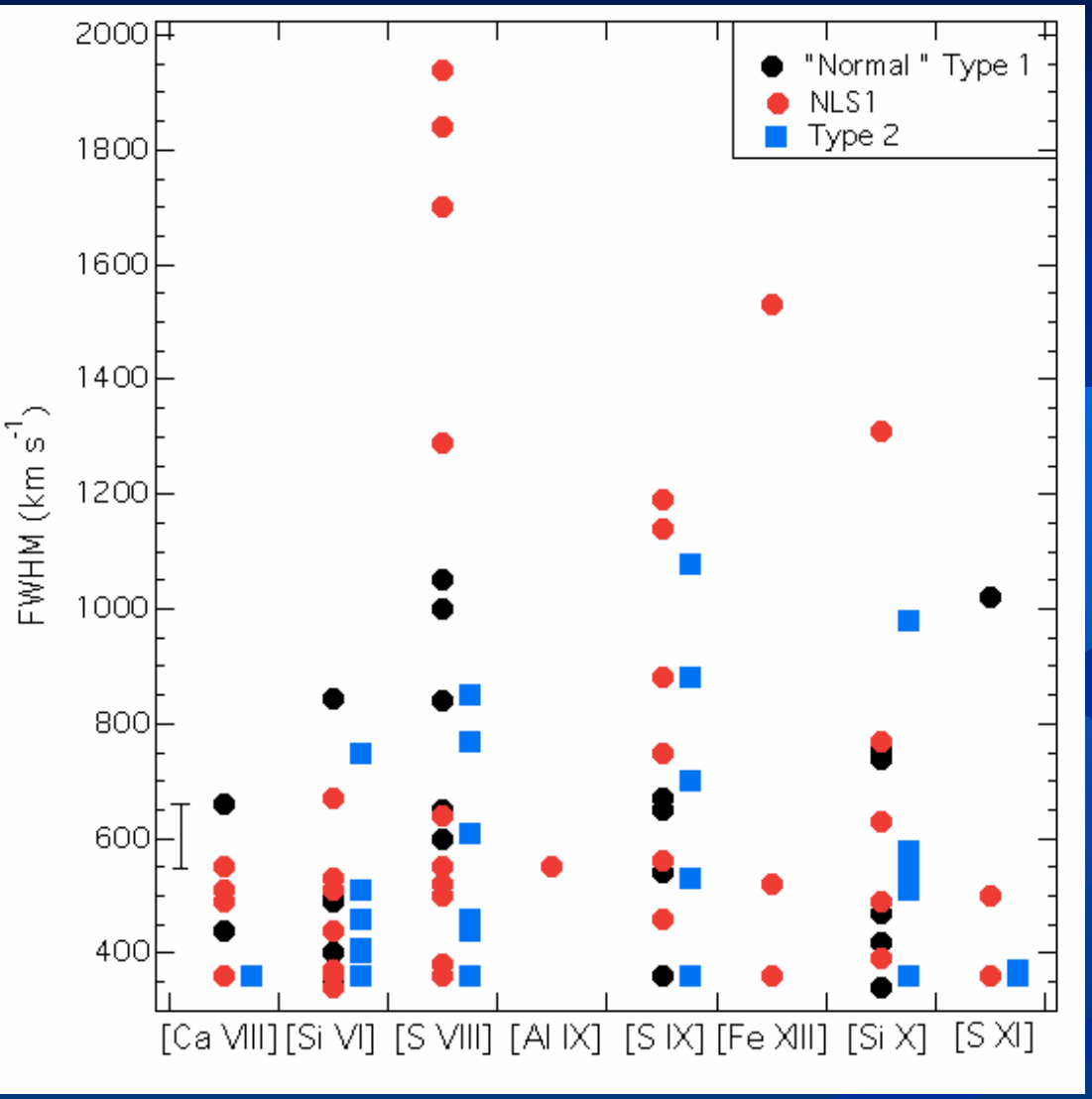
% of "normal" Ty1 and NLS1 for CL detected with respect to the total sample

NLS1 galaxies are prone to show more cls that "normal" Ty1 galaxies



127.7 447.1 eV

FWHM vs. IP (all types included)

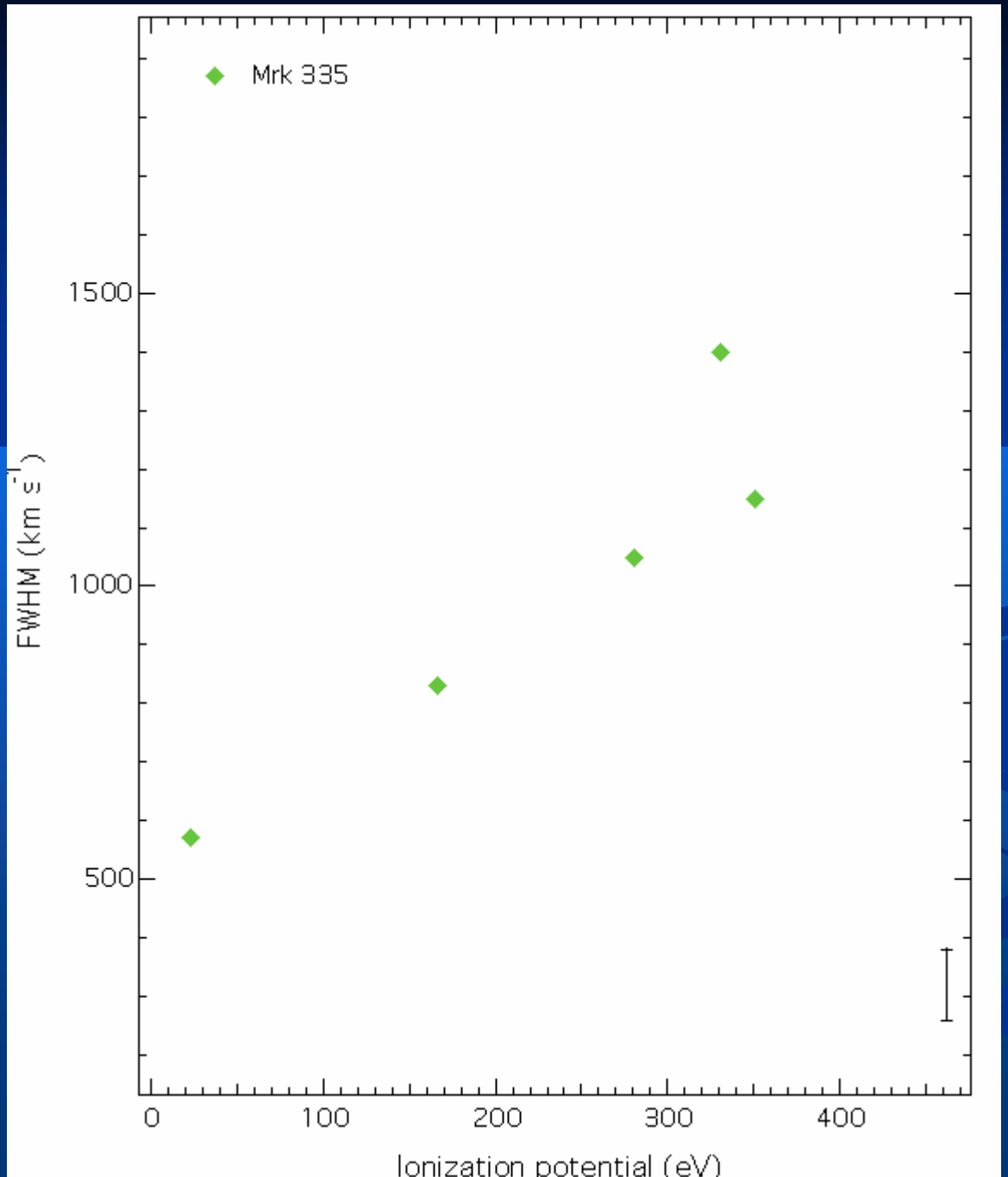


Taken as a whole, a correlation between FWHM and IP it is not clearly seen

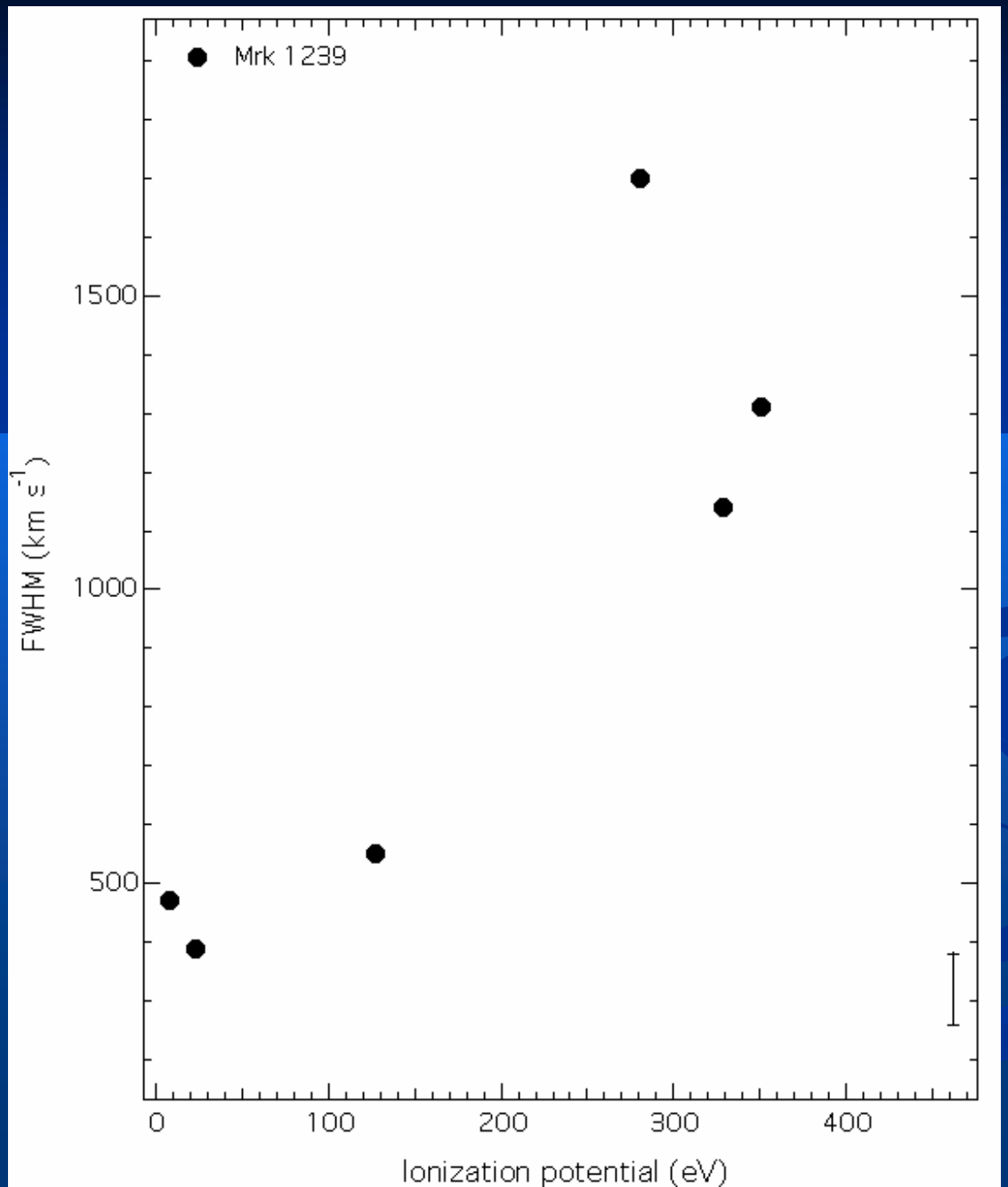
NLS1 tend to show the highest values of FWHM

Ionization potential

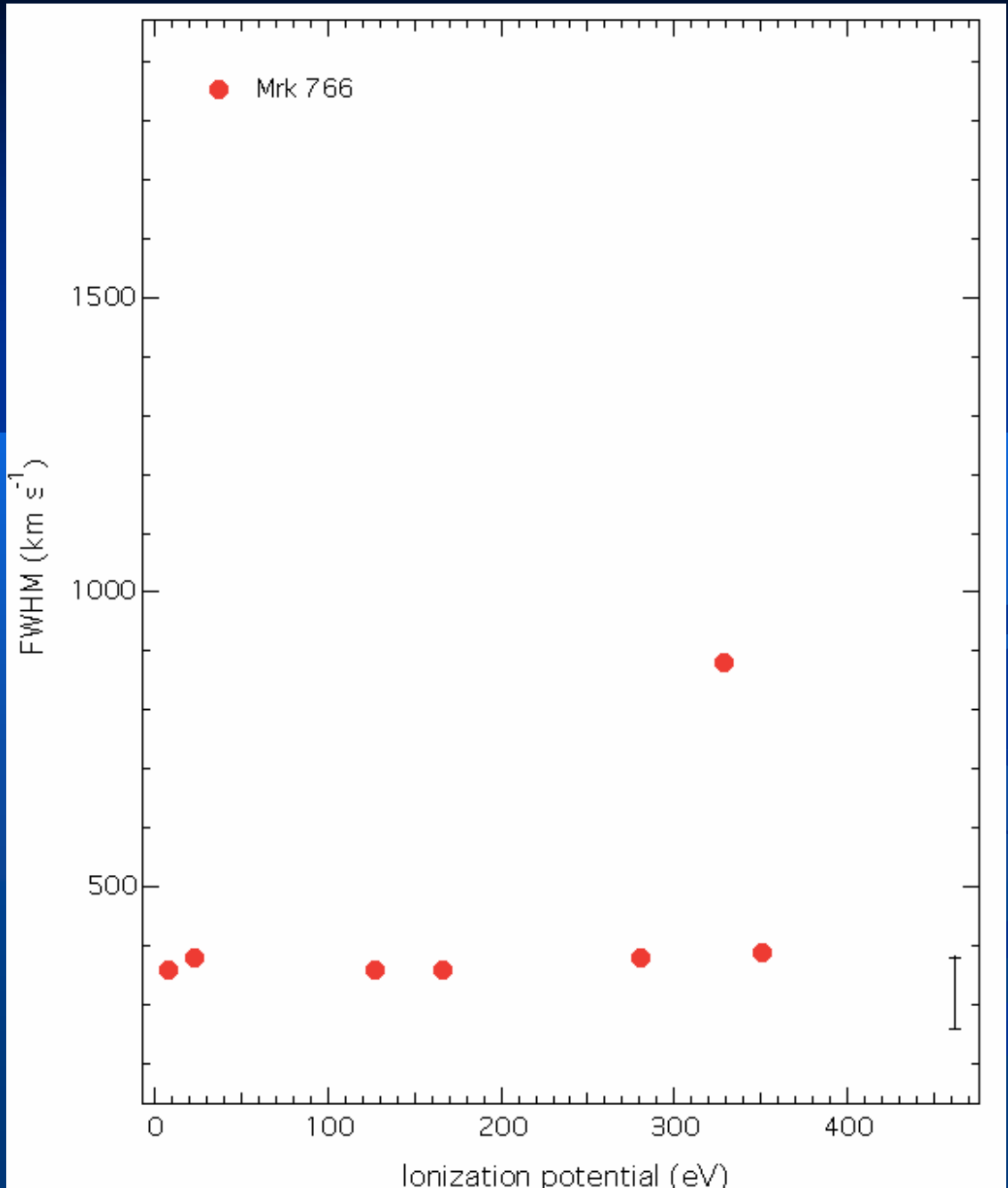
FWHM vs. IP in NLS1



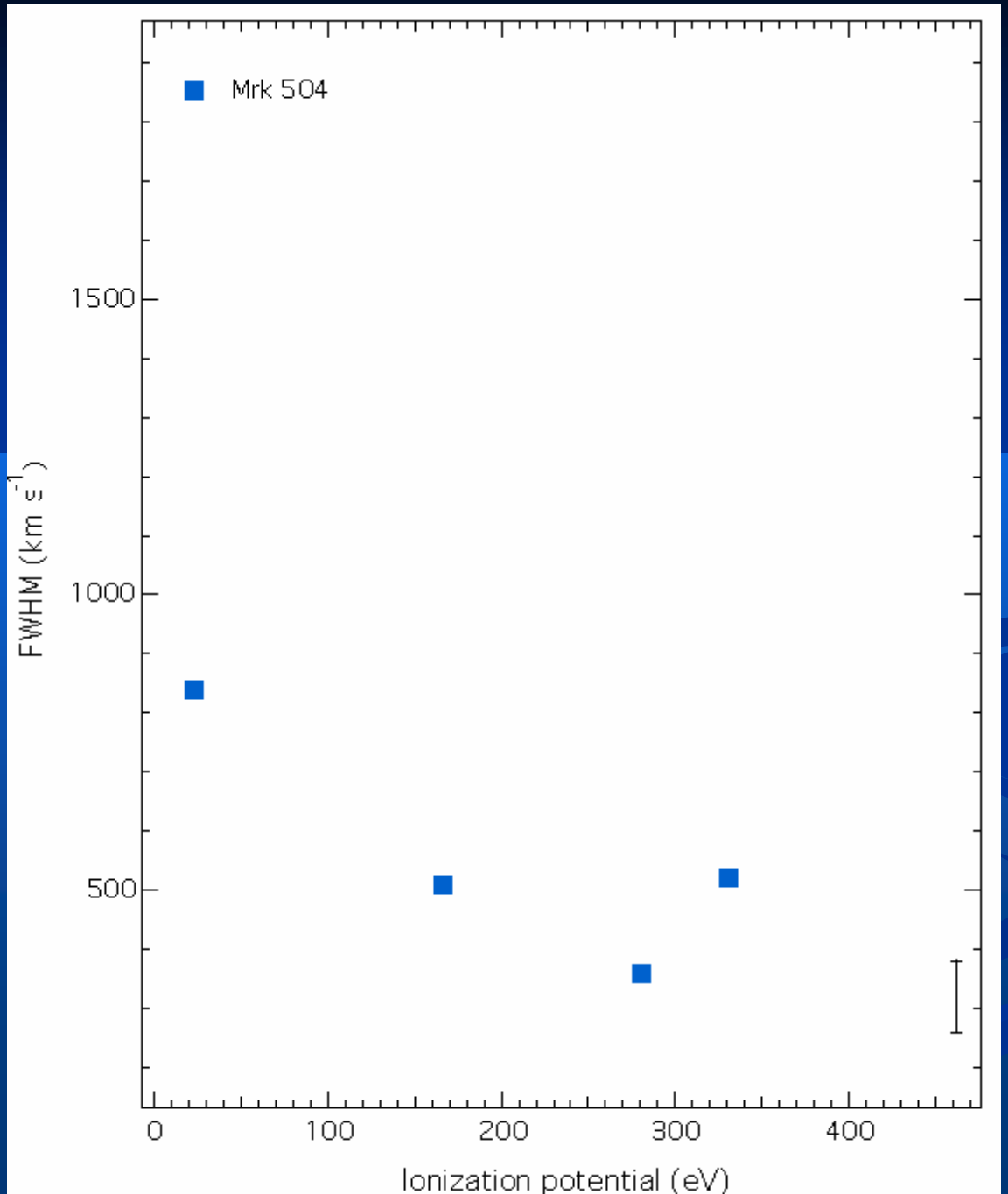
FWHM vs. IP in NLS1



FWHM vs. IP in NLS1



FWHM vs. IP in NLS1



FWHM vs. IP in NLS1

8 NLS1 show clear correlation

1 NLS1 shows anticorrelation

2 NLS1 shows constant tendency

FWHM vs. IP in “normal” Ty1

4 Ty1 show correlation

4 Ty1 do not show correlation

1 Ty1 shows anticorrelation

FWHM vs. IP IN Ty2

3 Ty2 do not show correlation

1 Ty2 shows anticorrelation

1 Ty2 shows weak correlation

The FWHM vs. IP relation tell us:

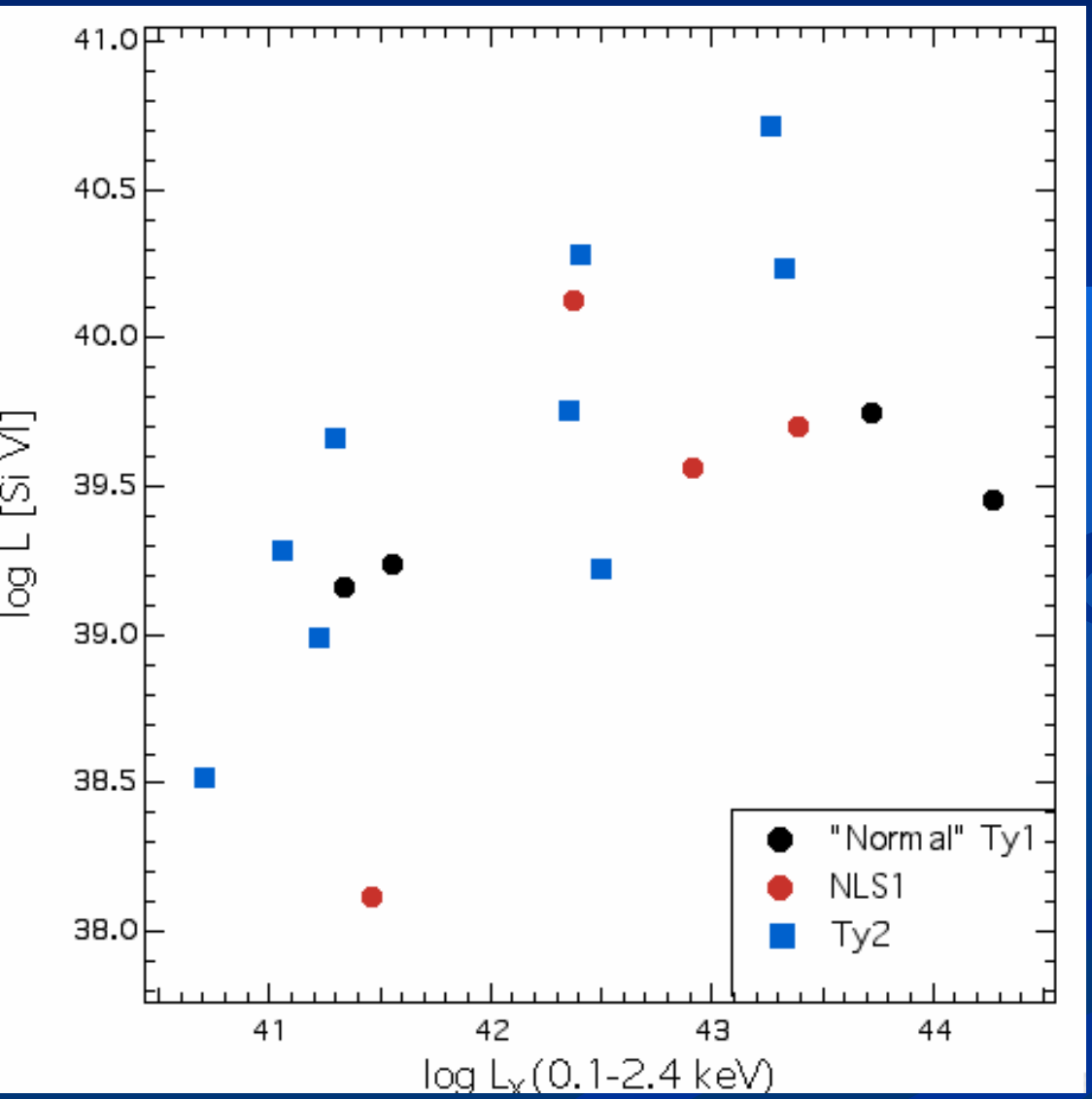
•The majority of "normal" Ty1 and Ty2 galaxies have Cls with FWHM 360-800 km s^{-1}

•Higher values of FWHM appear in NLS1 galaxies: 1000-1800 km s^{-1}

•This could indicate that in NLS1 galaxies the CLR tend to be nearer to the BLR?

•No clear trend for ¨normal¨ Ty1 and Ty2 galaxies is found. This is in contrast with the results found in the optical region

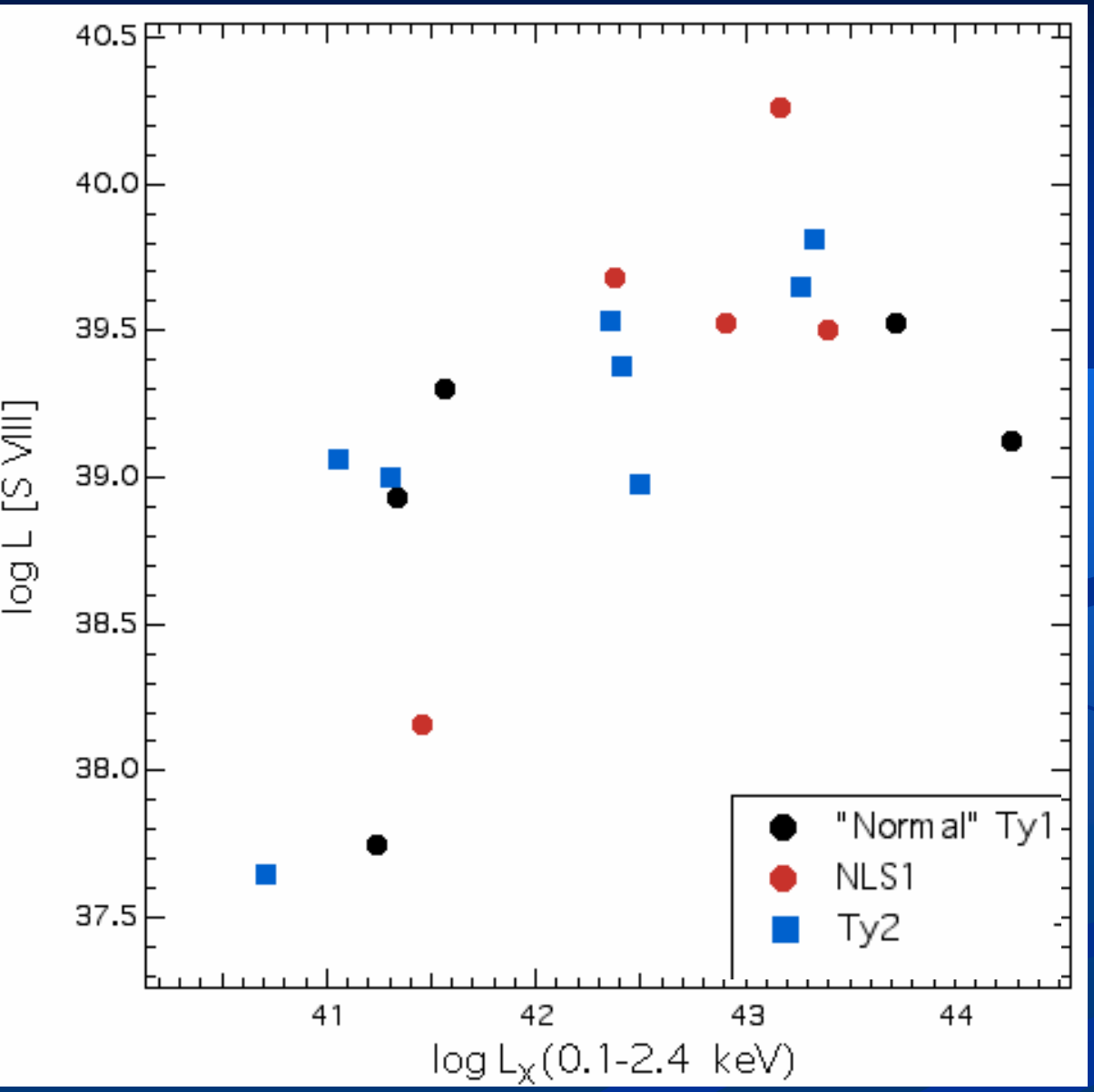
Relation between luminosity of [Si VI] 1.964 μm and soft x-ray (0.1-2.4 keV)



There exists a weak correlation between $L_{[Si\ VI]}$ and $L_{X(0.1\text{-}2.4\ KeV)}$

Ty2 galaxies tend to display a higher $L_{[Si\ VI]}$ than Ty1 for the similar soft x-ray luminosity

Relation between luminosity of [S VIII] 0.991 μm and soft x-ray (0.1-2.4 keV)

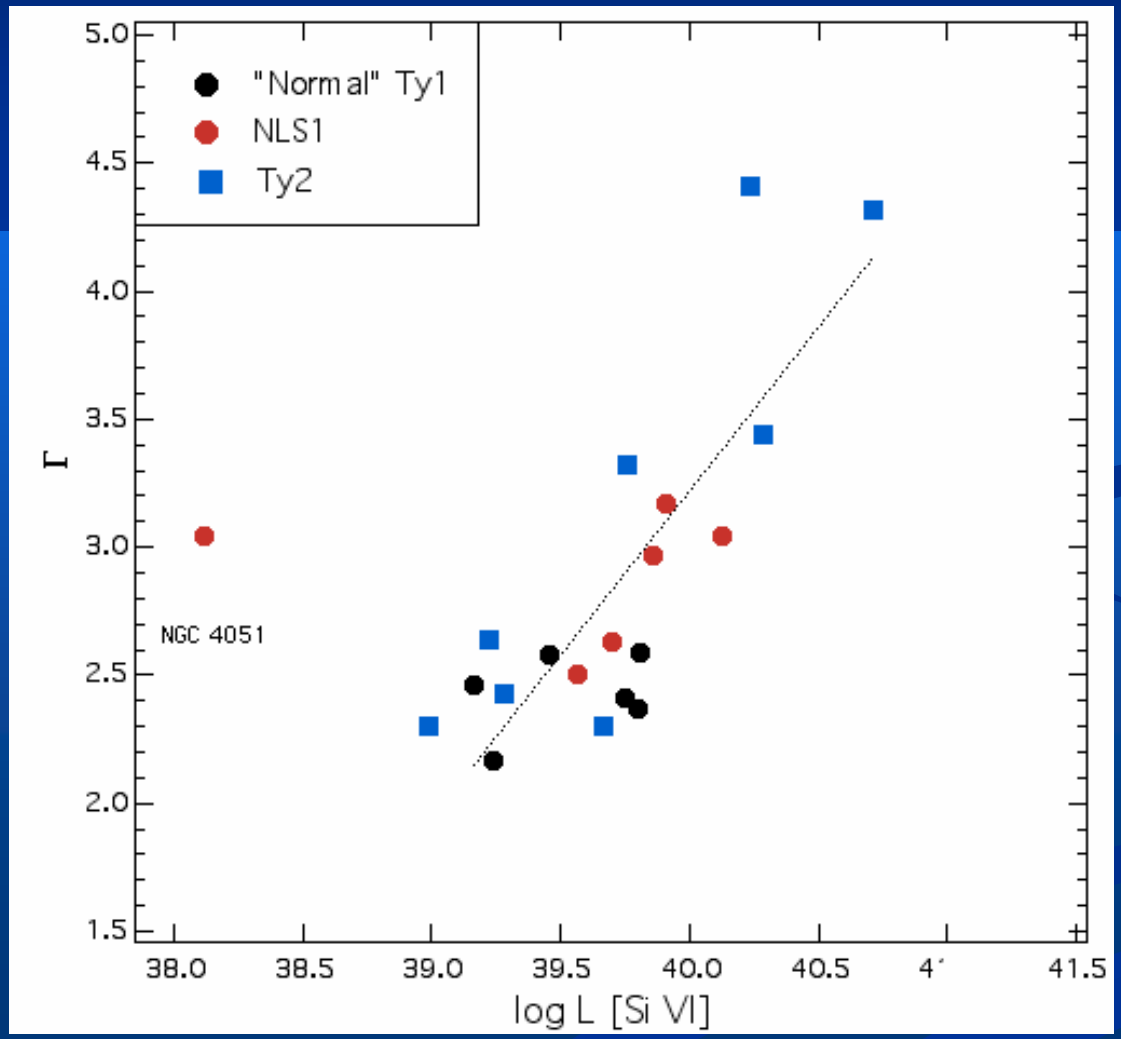


There exists a weak correlation between $L_{[S\ VIII]}$ and $L_{X(0.1\text{-}2.4\ keV)}$ but no differences between the types is detected

Photon index (Γ) soft x-ray vs. luminosity [Si VI]

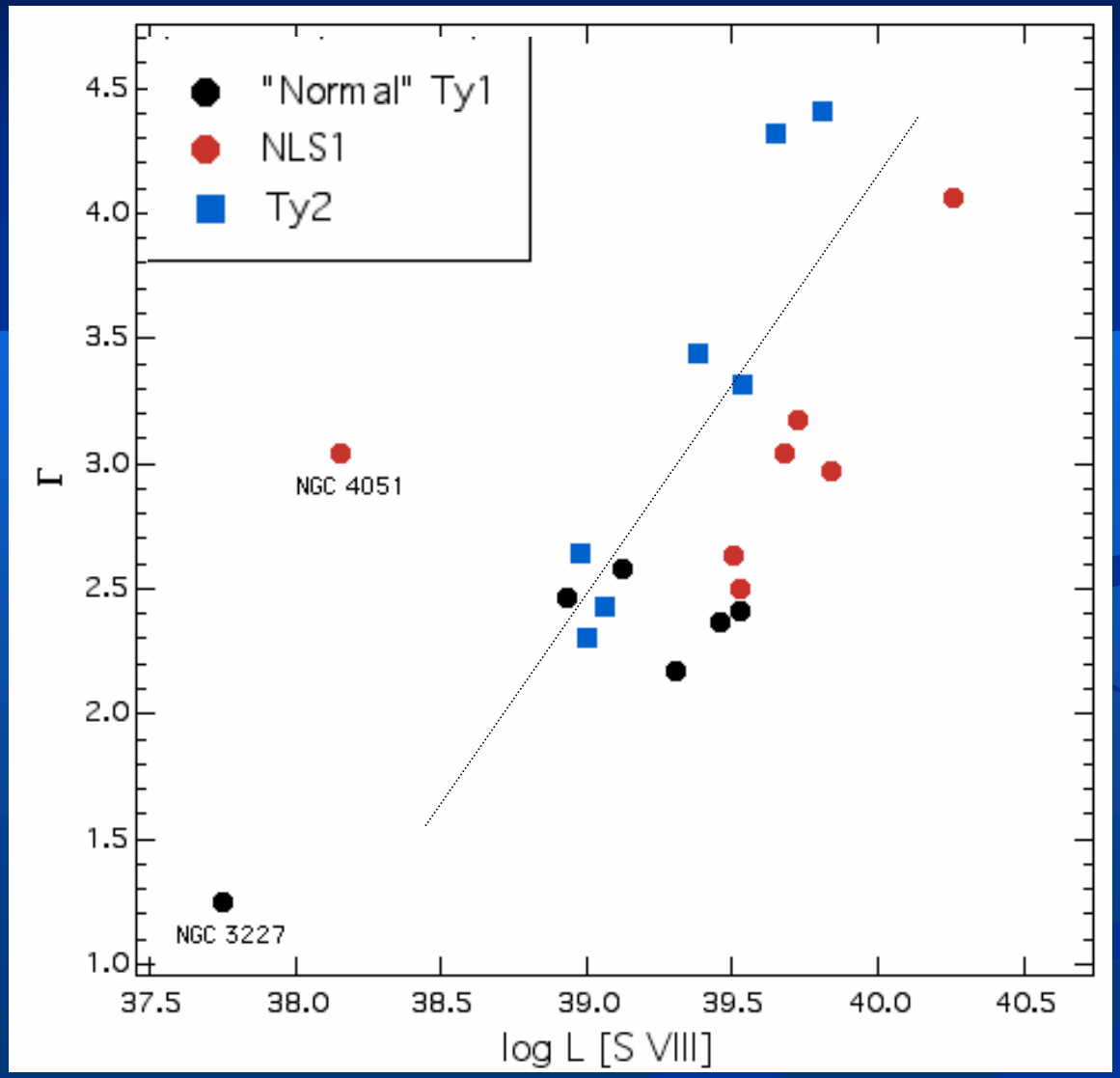
$$P = kE^{\Gamma}$$

P, # photons $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{keV}^{-1}$
k, constant
E energy, (keV)
Γ, photon index



There exists a correlation between Γ and $L_{[Si\ VI]}$

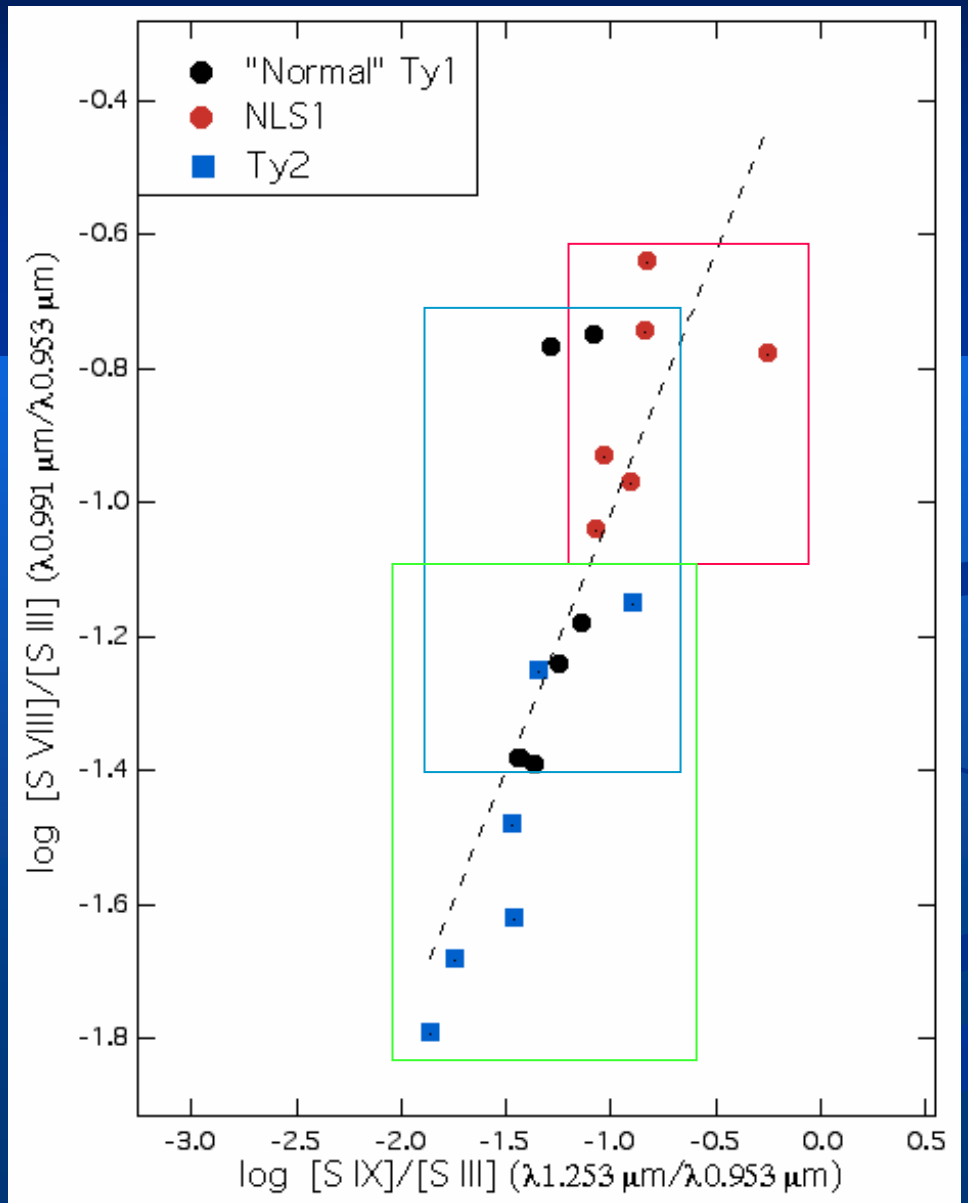
Photon index (Γ) soft x-ray vs. luminosity [S VIII]



There exists a correlation between Γ and $L_{[S\ VIII]}$

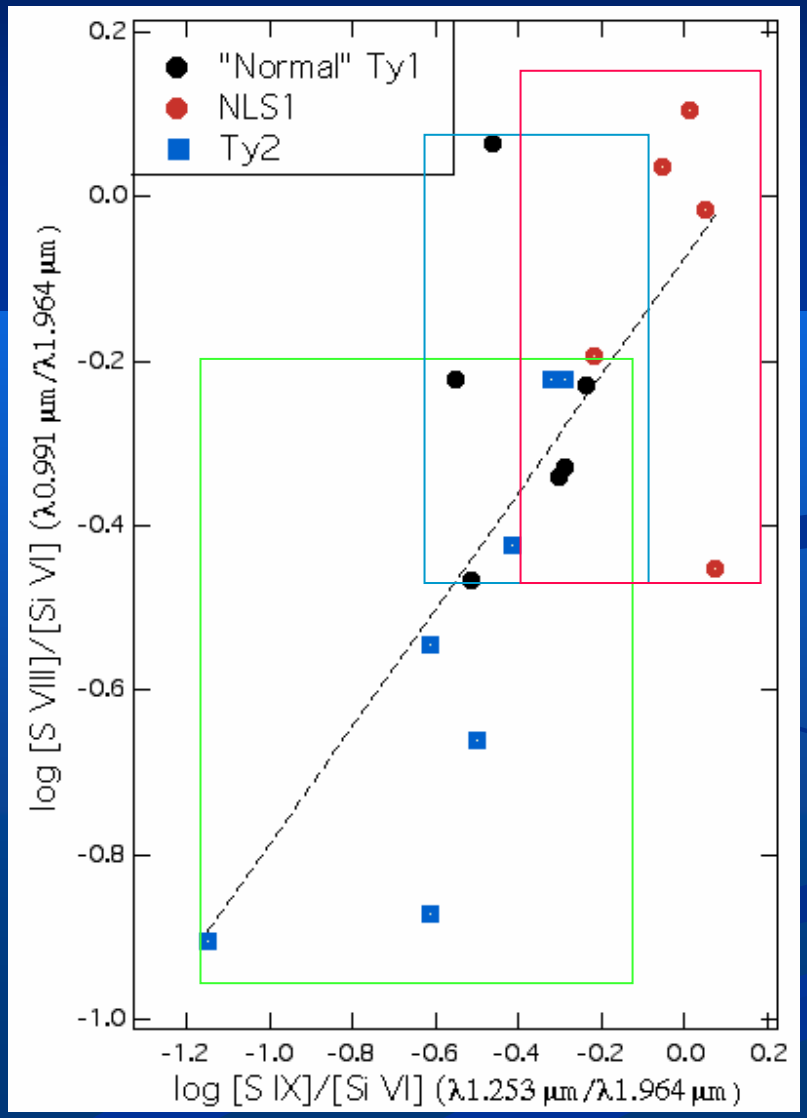
Diagnostic diagram

[S VIII]/[S III] vs. [S IX]/[S III]



Diagnostic diagram

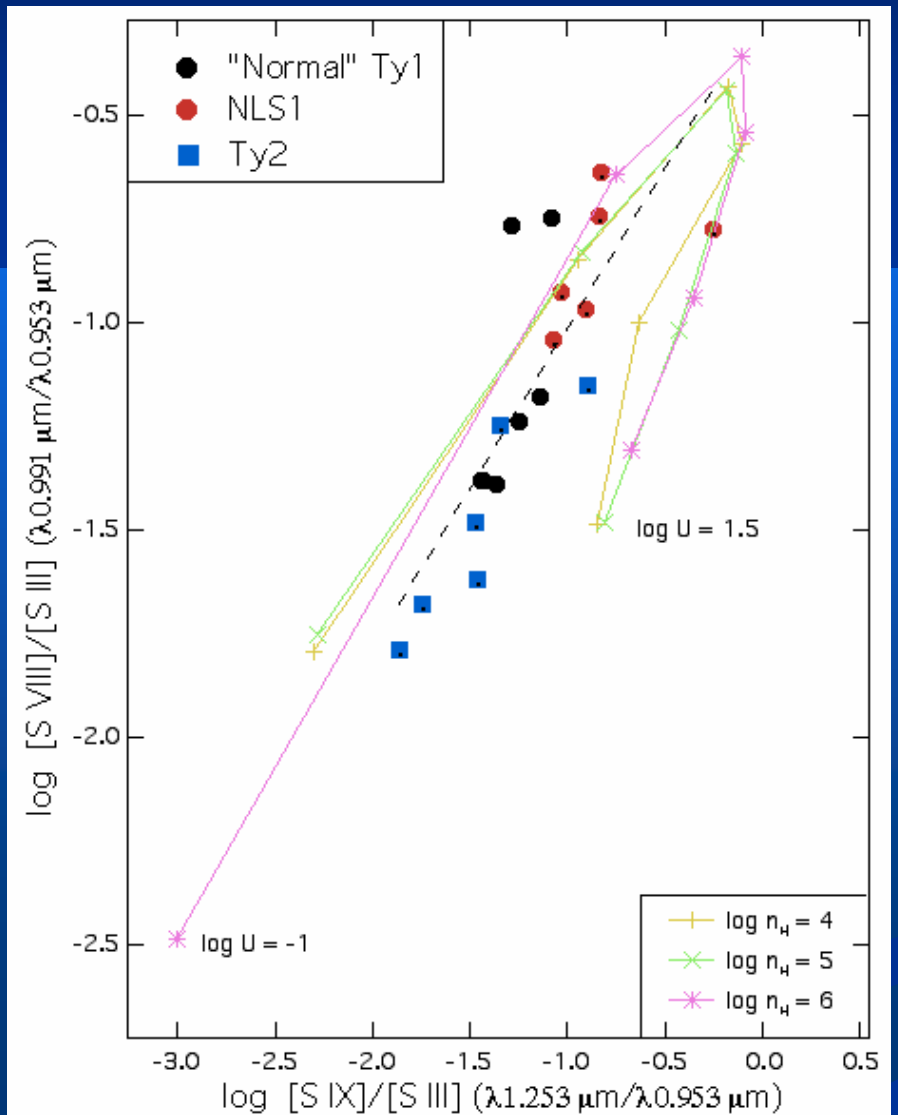
[S VIII]/[Si VI] vs. [S IX]/[Si VI]



Photoionization model

CLOUDY 06.02.09

[S VIII]/[S III] vs. [Si VI]/[S III]



(Ramos-Almeida et al. , 2006) for Mrk 78

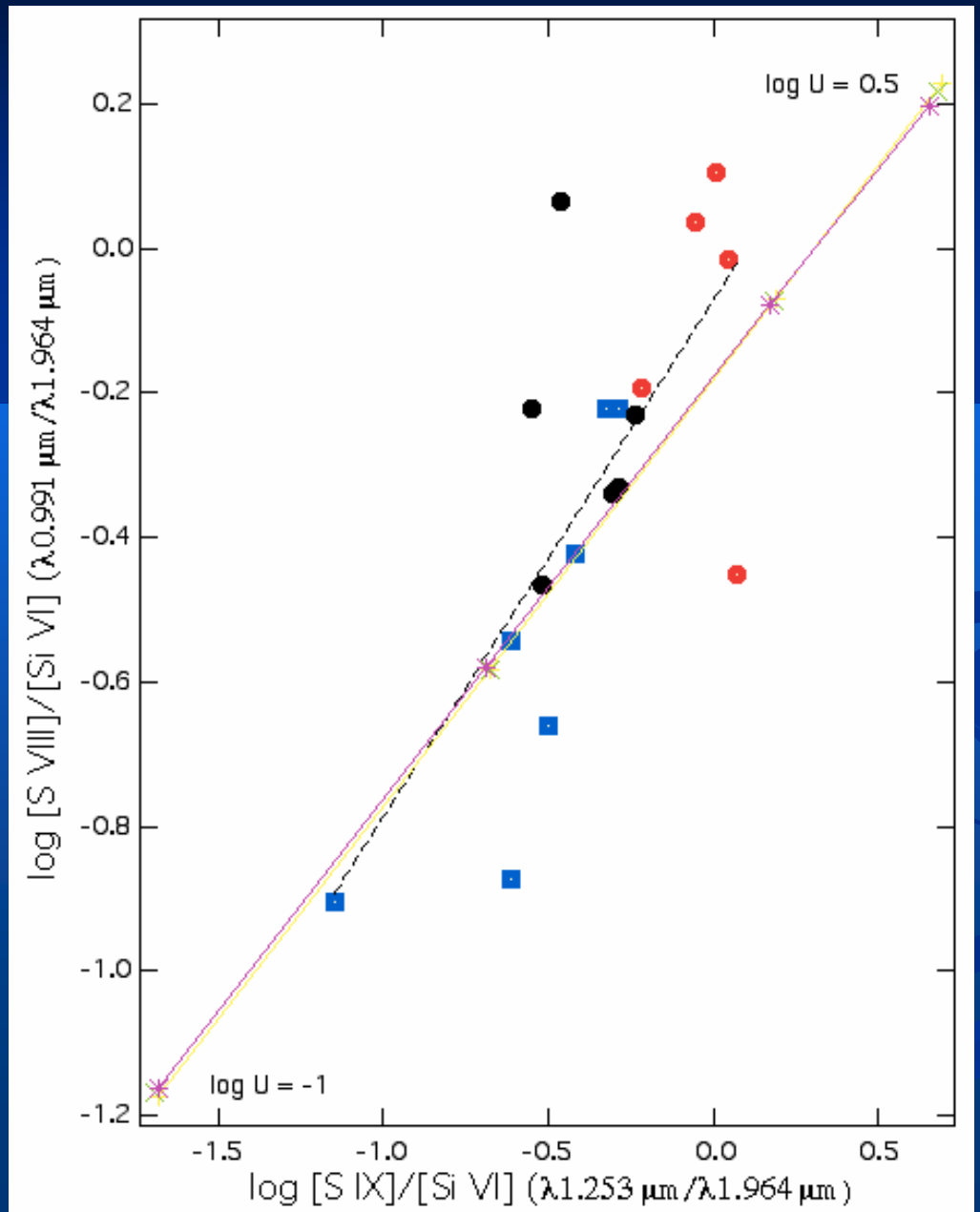
$$f_\nu \propto \nu^\alpha \begin{cases} \alpha = -2 \ (\lambda < 10\ \mu m) \\ \alpha = 2.5 \ (\lambda > 10\ \mu m) \end{cases}$$

- Plane parallel geometry
- 0.3 sollar metallicity
- Grains orion nebula type

log U = -1.0, -0.5, 0.0, 0.5, 1.0 ,1.5

$n_H = 10^4, 10^5, 10^6$

[S VIII]/[Si VI] vs. [S IX]/[Si VI]



Conclusions

- CLs seems to appear equally distributed for Ty2 and Ty1 galaxies except for [Si VI] λ 1.964 μm and [S VIII] λ0.9913 μm which are more frequent in Ty2.

- NLS1 galaxies tend to produce more CLs than normal Ty1 galaxies.

- Overall, the fact the Cls seems to be equally present in Ty1 and Ty2 AGNs supports the idea that the CLR is not orientation dependent

- No clear relationship between FWHM and IP is found for NIR Cls, except for NLS1 galaxies

- There exists a weak correlation between luminosity of [Si VI] λ 1.964 μm and [S VIII] λ 0.9913 μm and soft x-ray luminosity (0.1-2.4 keV).

- The fluxes ratios such as [S VIII]/[S III] and [Si VI]/[S III] tend to be: greatest for NLS1; lowest ones for Ty2.

- A photoionization model applied to Mrk 78 seems to explain well the coronal fluxes for Ty2 and Ty1 galaxies as far as the ionization factor ranges from -1.0 to 0 and density between 10^4 to 10^6

THANKS !

NARROW LINE SEYFERT 1 GALAXIES (NLS1)

BASIC SPECTRAL CHARACTERISTICS OF SEYFERT 1 GALAXIES BUT UNUSUALLY NARROW PERMITTED LINES

FORMAL CLASSIFICATION CRITERIA (POGGE, 2000)

- NARROW PERMITTED LINES ONLY SLIGHTLY BROADER THAN THE FORBIDDEN LINES
- [O III]/[H BETA] < 3, EXCPETIONS MADE IF THERE IS STRONG [Fe VII] AND [Fe X]
- FWHM(H BETA) < 2000 KM/S