ACTIVE GALACTIC NUCLEI: optical spectroscopy

From AGN classification to Black Hole mass estimation

First Lecture

Main optical spectral characteristics,
some taxonomy, classification &
the AGN Unification (pro/con)

Introduction and some caveats

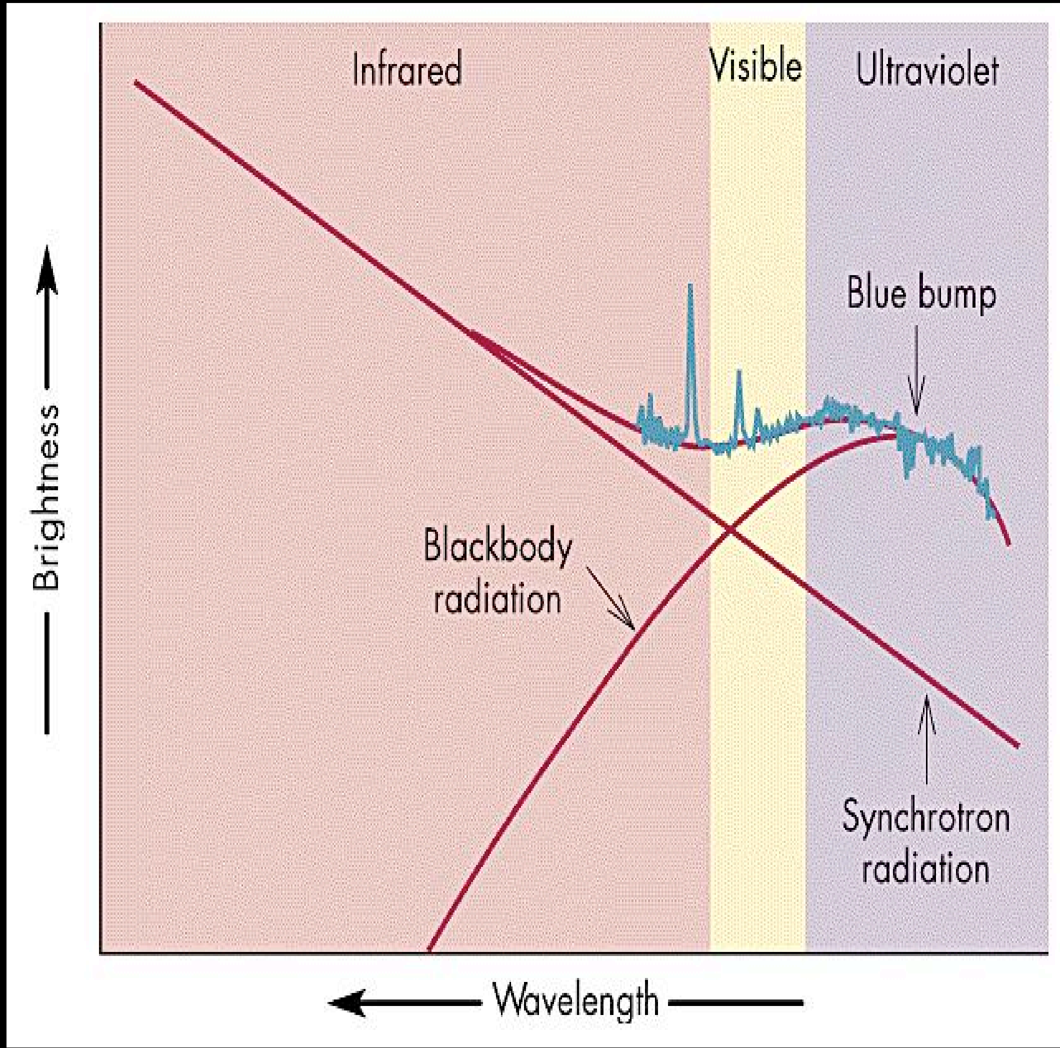
- ~~Sy1/QSO~~
- ~~QSO/quasar~~
- ~~NLRG/QSO2/Sy2~~
- ~~RL QSO/RQ QSO~~
- ~~Point-like/extended~~

Reducing the AGN zoo as much as possible !

"Active galactic nuclei (AGN) are a class of galaxies where a significant fraction of the energy output, emerging from their centers, is not produced by the normal galaxy components : stars, dust and interstellar gas. This energy can be emitted across the whole electromagnetic spectrum, from radio waves to gamma rays"

The UV/optical/NIR spectrum

- Power-law: emitted by an highly compact non-thermal source (power law)
- Big Blue Bump: this component possibly comes from the BH accretion disk (black body)

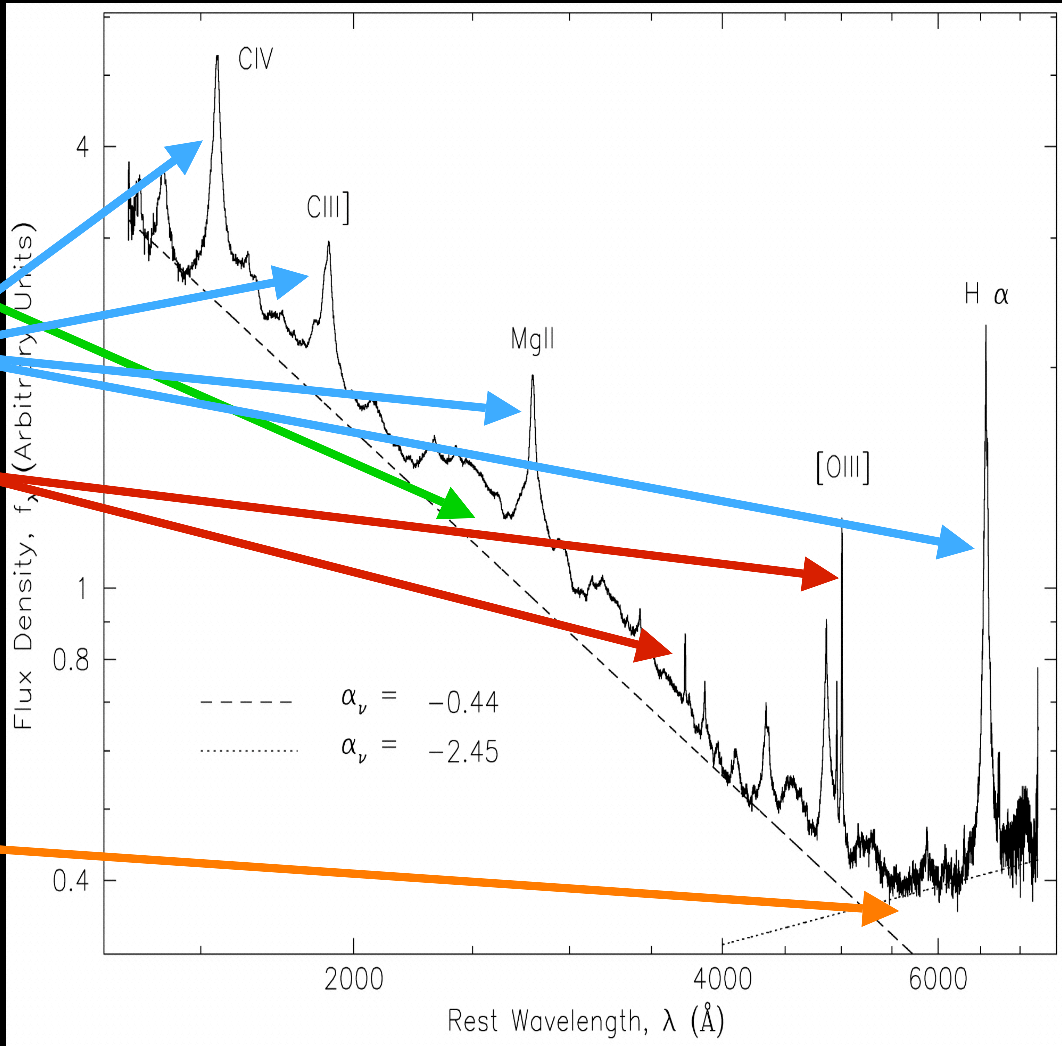


The UV/optical AGN spectrum

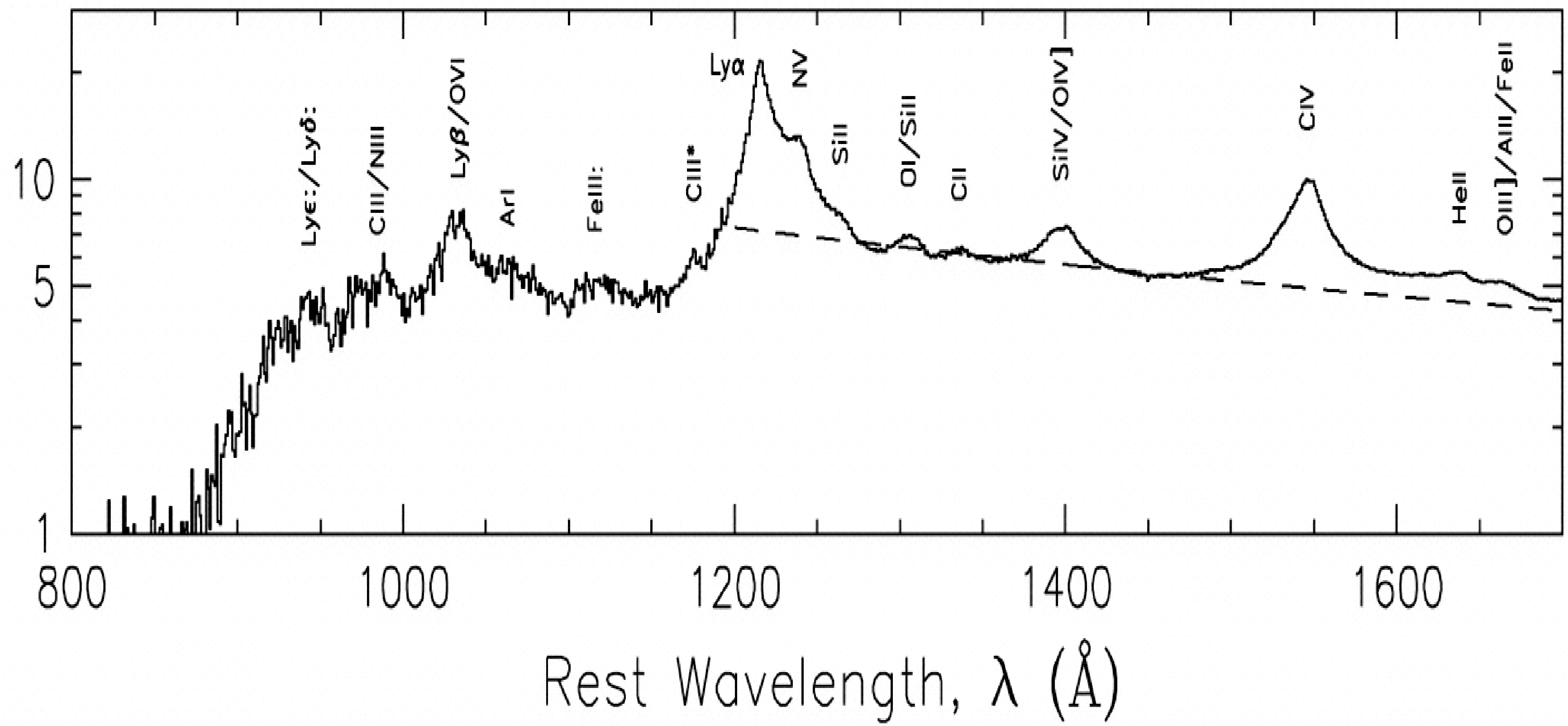
- Power-law
- Big Blue Bump
- Small Blue Bump:
FeII+Balmer Continuum
- Broad emission lines:
FWHM > 1500 Km/s
- Narrow emission lines:
FWHM < 900 Km/s

The emission lines characterize the AGN spectra: they are produced in two separate regions, a subarcsec Broad Line Region (BLR) close to the central engine, and a more extended Narrow Line Region (NLR).

- Galaxy Starlight:
usually overwhelmed by the AGN non-thermal continuum and emerging in the red part of the spectrum



The UV/optical emission line spectrum



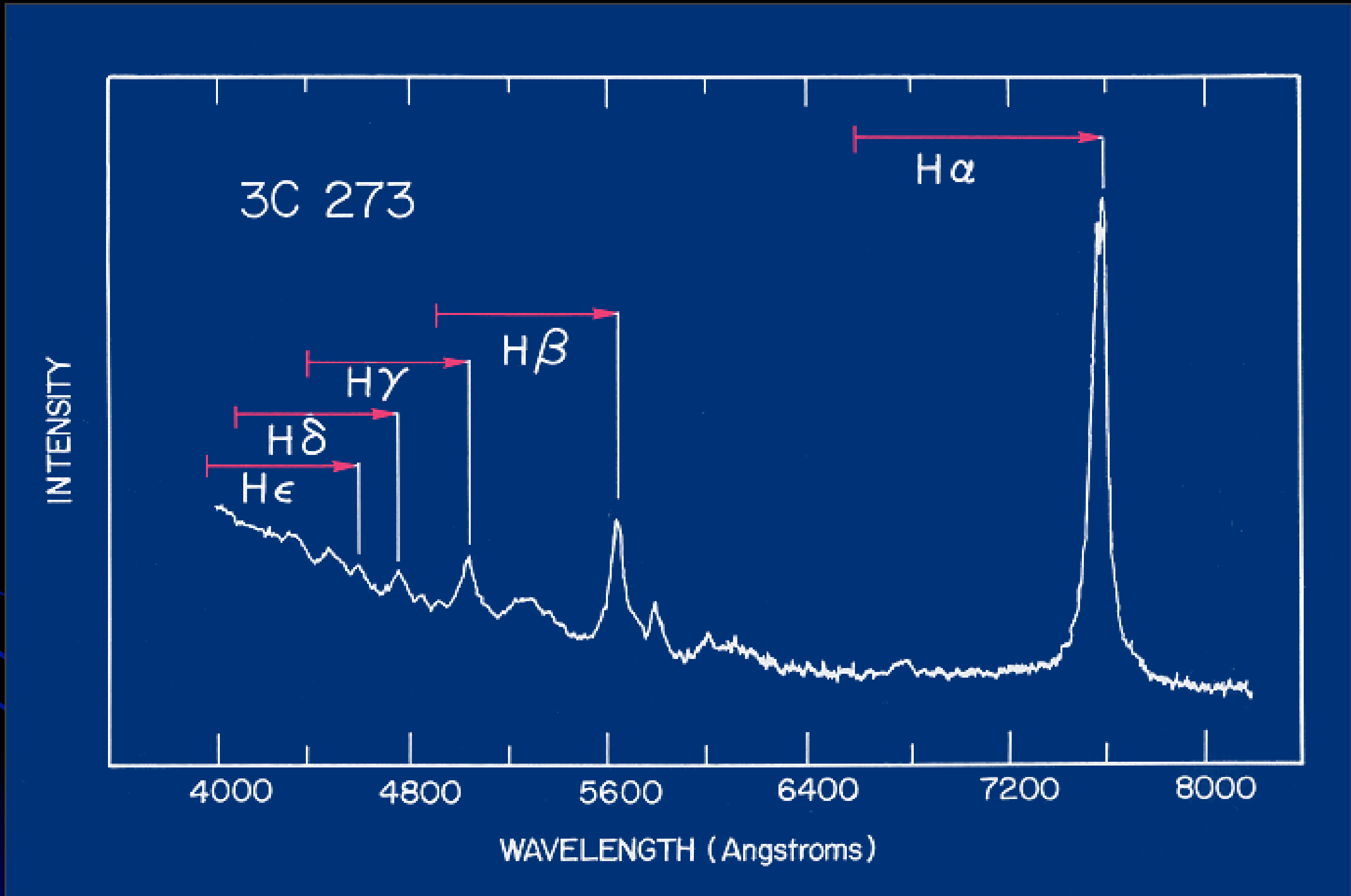
What we *learn* from the AGN UV/optical spectra

- Redshift
- Classification (optical): Type 1/Type 2
- AGN Unification: evidences
- Physical state of the emitting-line gas
- AGN/StB separation: Diagnostic Diagrams
- Unconventional AGNs

Redshift

- Discovery of the true nature of quasar
- Cosmological Distance
- Absolute physical quantities (*L,M,size*)
- Only the optical spectrum (sometimes UV, near-IR) gives *z*
- Easy way to measure *z*

In 1963 Schmidt identifies highly redshifted Balmer lines in 3C273's spectrum

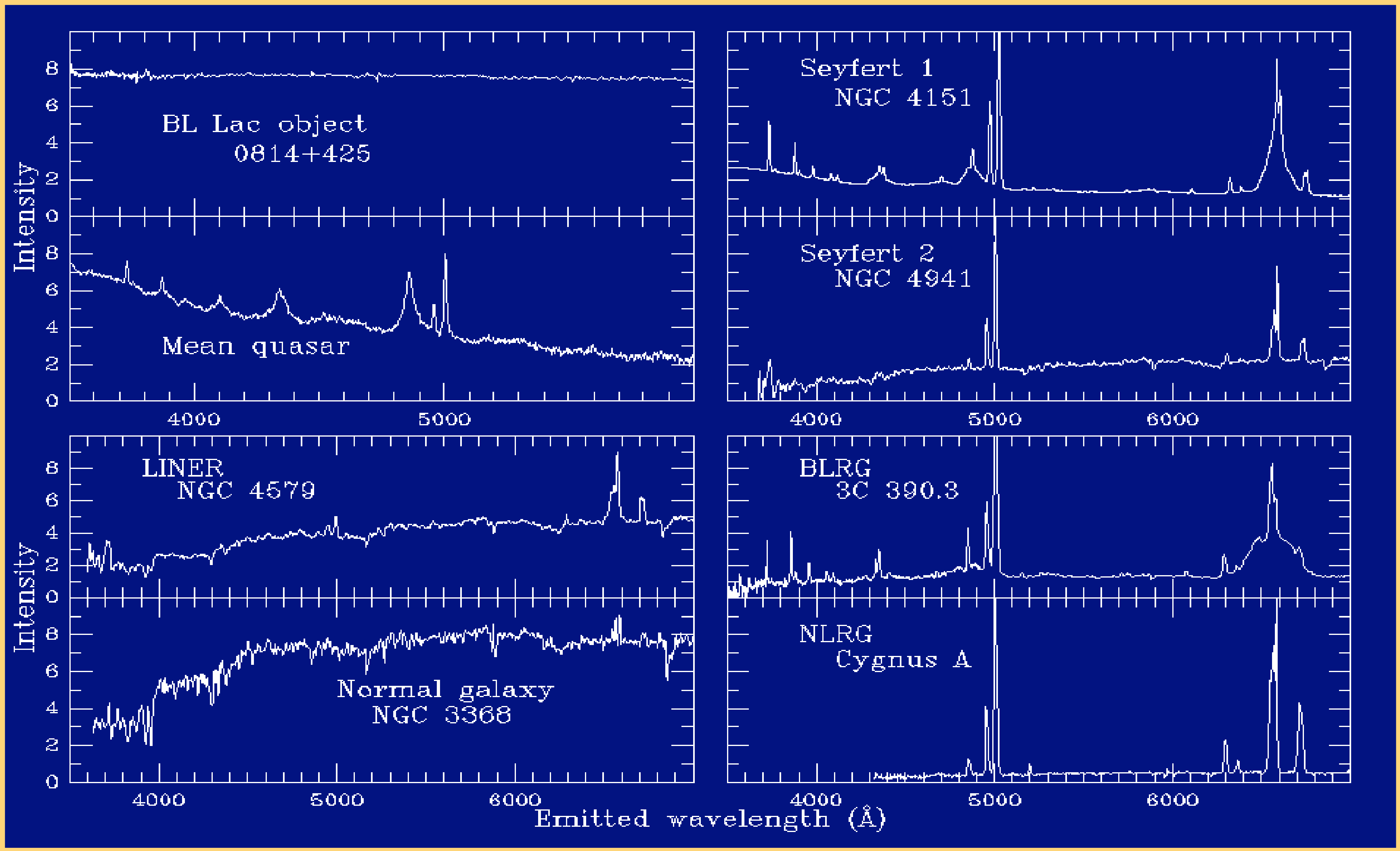


$z = 0.158$ ($v_r = 47500$ km/s)

Redshift

- Discovery of the true nature of quasar
- Cosmological Distance
- Absolute physical quantities (*L,M,size*)
- Only the optical spectrum (sometimes UV, near-IR) gives *z*
- Easy way to measure *z*

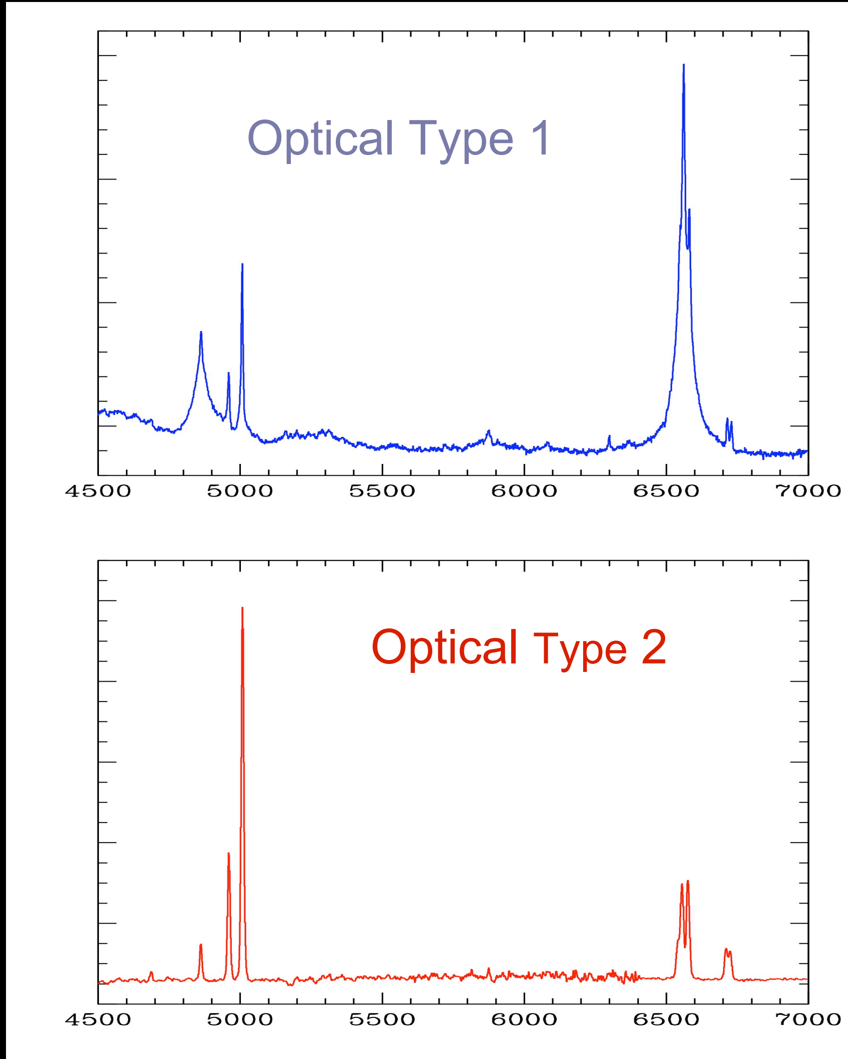
Optical spectra of different AGN types



AGN emission line spectra

- **Type 1 AGN** are those with very broad optical/UV permitted emission lines, with FWHM~1500-15000 km/s, while the forbidden lines, like [OII]3727, [OIII]4959/5007, [NII]6548/6583, typically have FWHMs of order of 500-1000 km/s.

- **Type 2 AGN** have permitted and forbidden lines with approximately the same FWHM, similar to the FWHMs of the forbidden lines in Type 1 objects.
 The forbidden lines, while narrower than the permitted ones, are usually broader than the emission lines in most starburst galaxies.



AGN Unification: the *"standard model"*

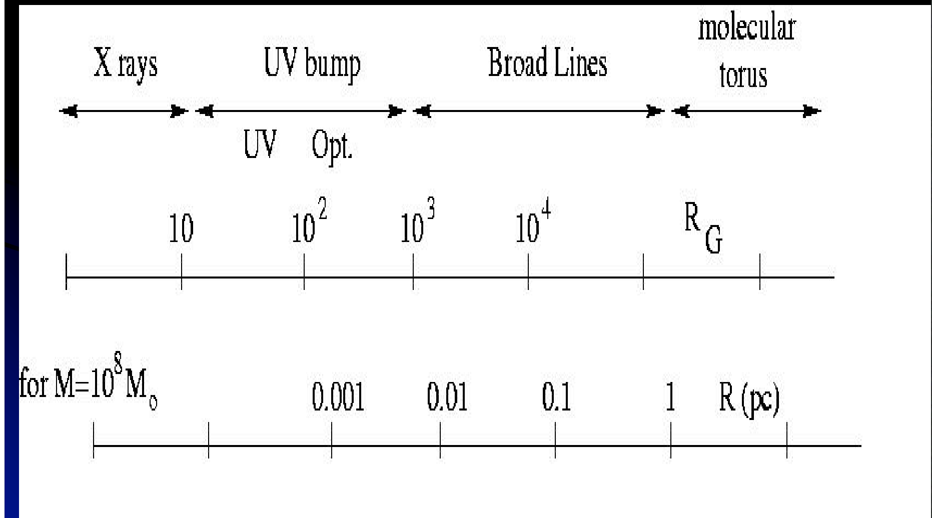
Components:

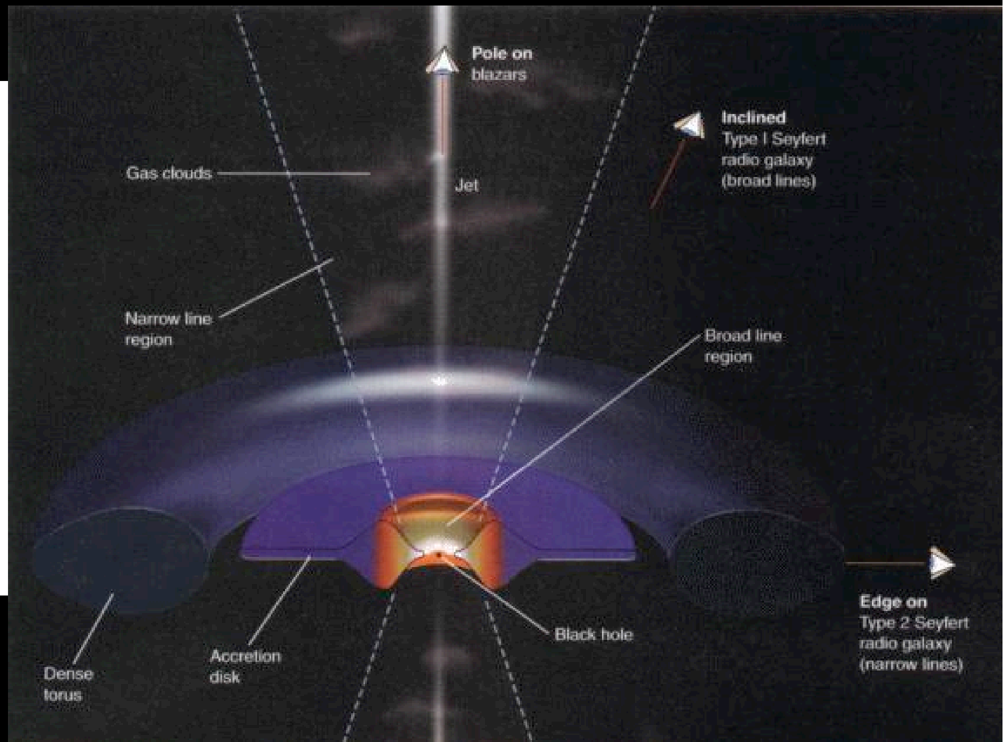
Accretion Disk: $r \sim 10^{-3}$ pc $n \sim 10^{15}$ cm^{-3} $v \sim 0.3c$

Broad Line Region: $r \sim 0.01\_0.1$ pc $n \sim 10^{10}$ cm^{-3} $v \sim$ few x 10^3 km s^{-1}

Dusty Torus: $r \sim 1\_100$ pc $n \sim 10^3\_10^6$ cm^{-3}

Narrow Line Region: $r \sim 100\_1000$ pc $n \sim 10^2\_10^4$ cm^{-3} $v \sim$ few x 10^2 km s^{-1}

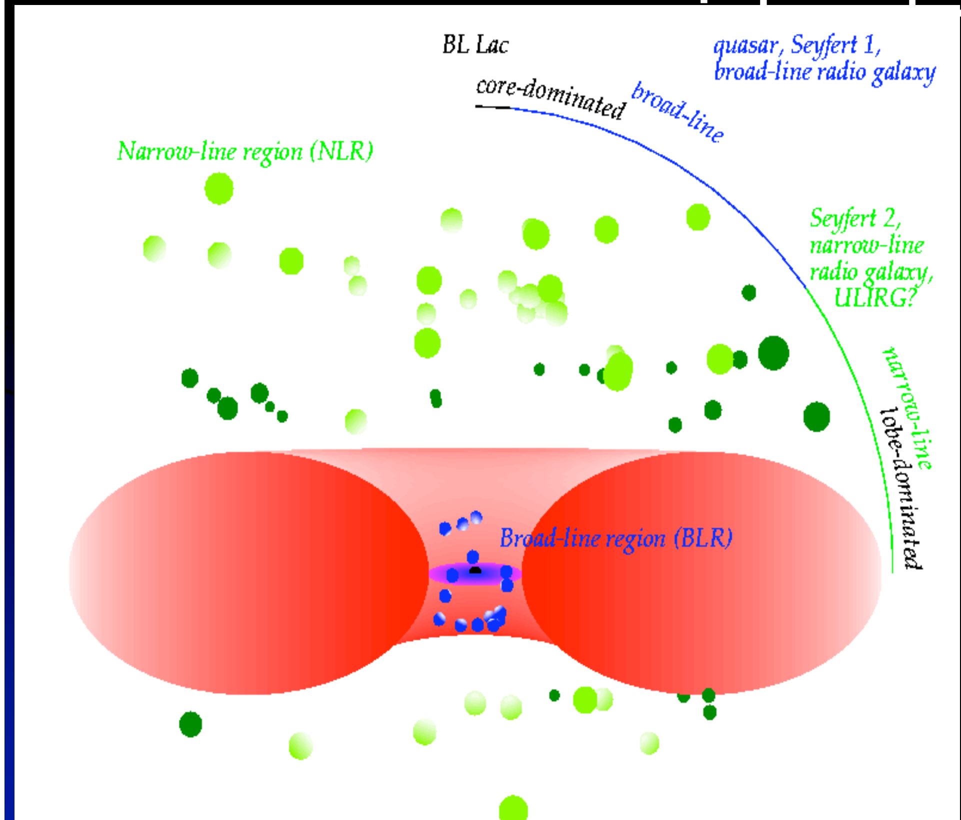


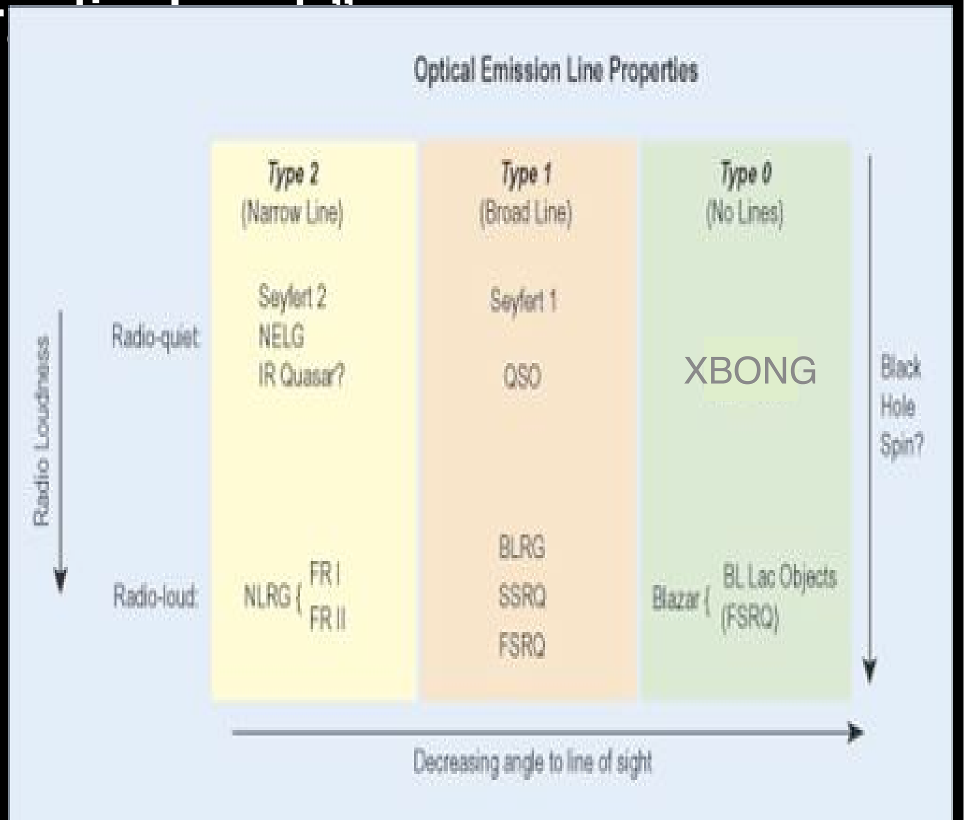


AGN Unification: the paradigm

"... Much of the variety in AGN types is just the result of varying orientation relative to the line of sight. [...]
We can define an extreme hypothesis in which there are only two basic AGN types: the radio

(Antonucci 1993)





AGN Unification: a milestone

A classical Seyfert2 galaxy (NGC1068) observed in polarized light showed a Sy1-like polarized spectrum, a featureless continuum with high polarization and position angle perpendicular to the radio jet. The observed properties could be explained by reflection of an hidden BLR into the line of sight, the scattering source being composed of hot electrons rather than dust grains.

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SPECTROPOLARIMETRY AND THE NATURE OF NGC 1068

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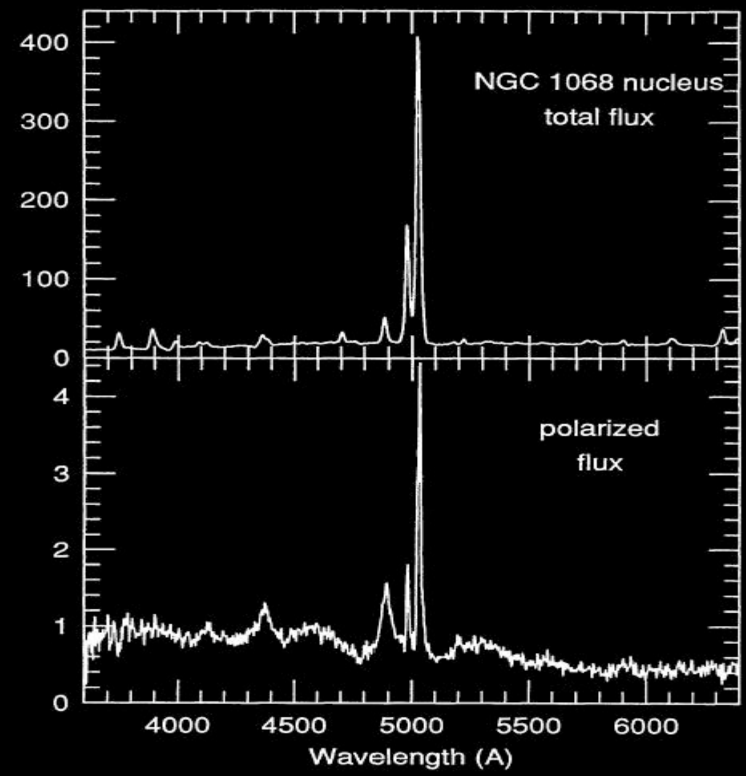
ABSTRACT

Extensive high-resolution, high signal-to-noise ratio polarization spectra of the nucleus of NGC 1068 are presented. The nonstellar continuum is polarized $\sim 16\%$, independent of wavelength. We have discovered broad Balmer lines and Fe II emission, with polarization $\gtrsim 15\%$ at approximately the same position angle as that of the continuum. The polarized flux spectrum closely resembles the flux spectrum of Seyfert type 1 nuclei. We conclude that the continuum and broad-line polarization is due to scattering, probably by free electrons. For NGC 1068, as well as apparently for all other Seyfert 2 galaxies, the optical polarization position angle is perpendicular to the nuclear symmetry axis as determined by the radio morphology. We suggest that the continuum and broad-line emission regions are located inside an optically and geometrically thick disk. Continuum and broad-line photons are scattered into the line of sight by free electrons above and below the disk. The narrow-line region and the thermally emitting nuclear dust clouds have a more direct view of the continuum source, explaining why they seem too strong to be powered by the observed continuum.

The narrow lines seen in the flux spectrum all have similar low polarizations, including the narrow Balmer lines. There is no evidence that the narrow Balmer lines and the [O III] lines come from qualitatively different regions, despite earlier suggestions to the contrary. Both P and θ vary with wavelength within the profile of the [O III] $\lambda 5007$ emission line. Therefore, the velocity field in the spatially unresolved narrow-line region is organized and not chaotic. The polarization variations may mean that the spatially resolved velocity field, reported by Walker in 1968, indicating expansion of narrow-line clouds in the plane of the host galaxy, extends into the unresolved region.

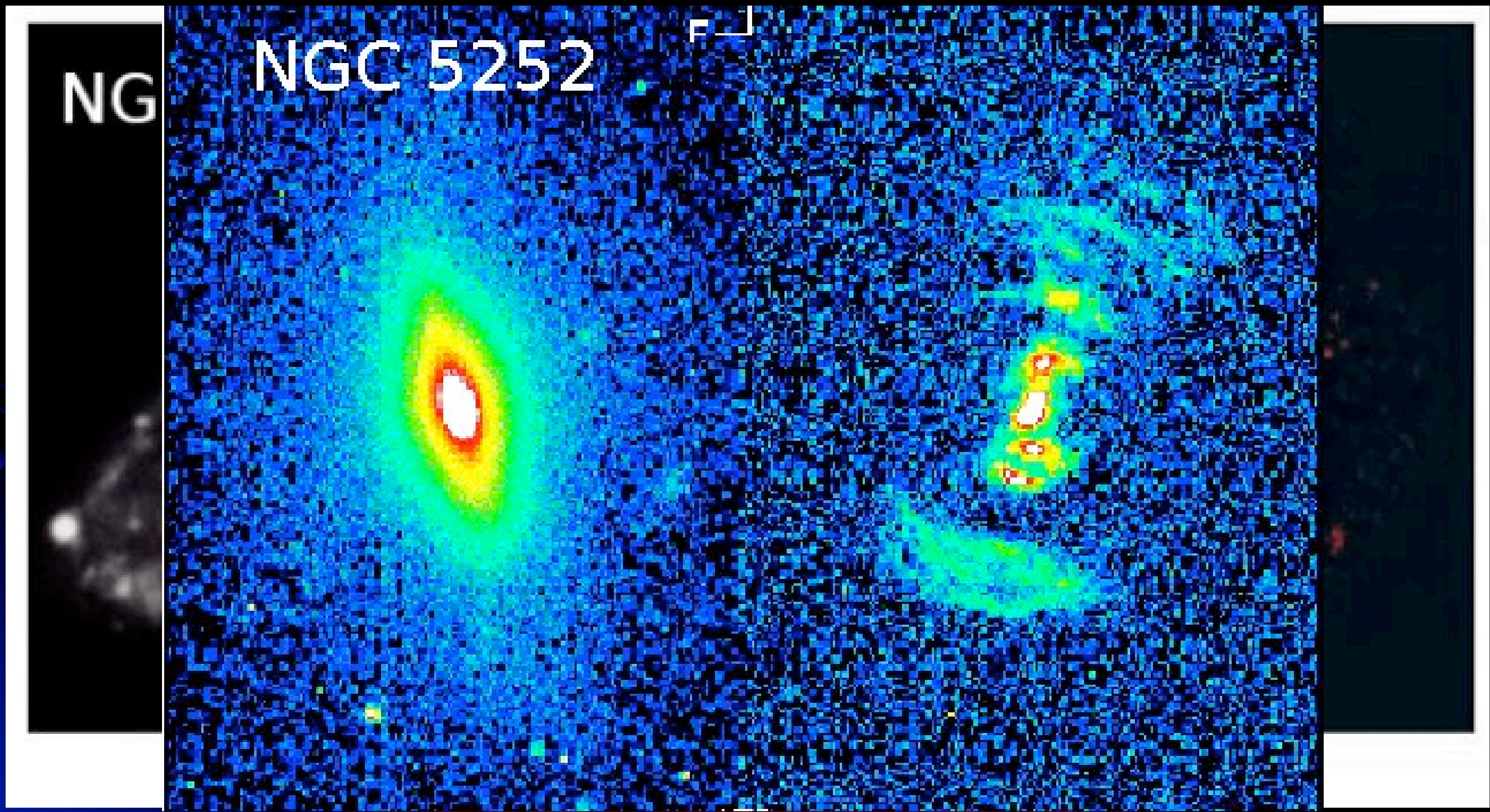
Subject headings: galaxies: individual — galaxies: nuclei — galaxies: Seyfert — polarization



AGN Unification evidence: ionization cones

A number of type2 objects also show clear anisotropy in the highly ionized emission lines (like [O III]) which, often, resemble a cone (Pogge 1988):

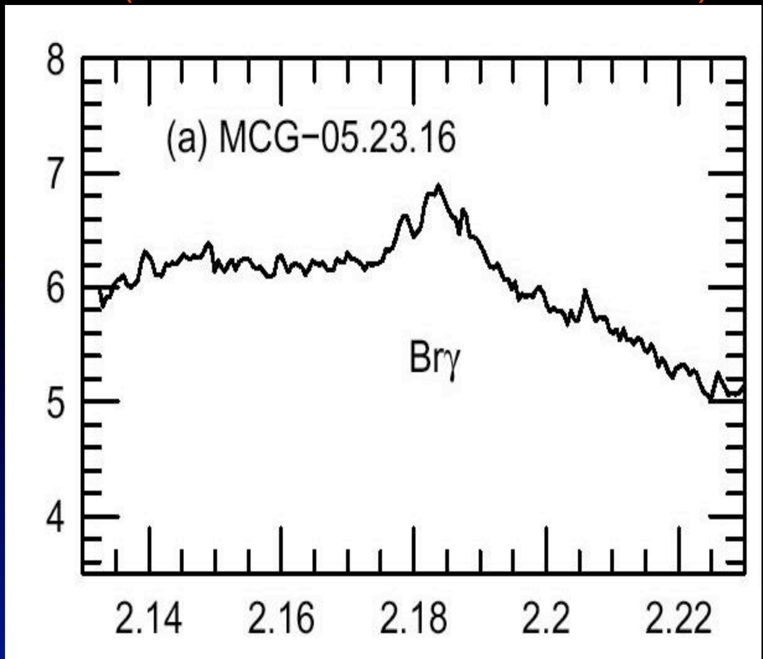
1. The ionization cone is "collimated" by the obscuring torus.
2. Anisotropy of the radiation field



AGN Unification evidence: broad IR lines

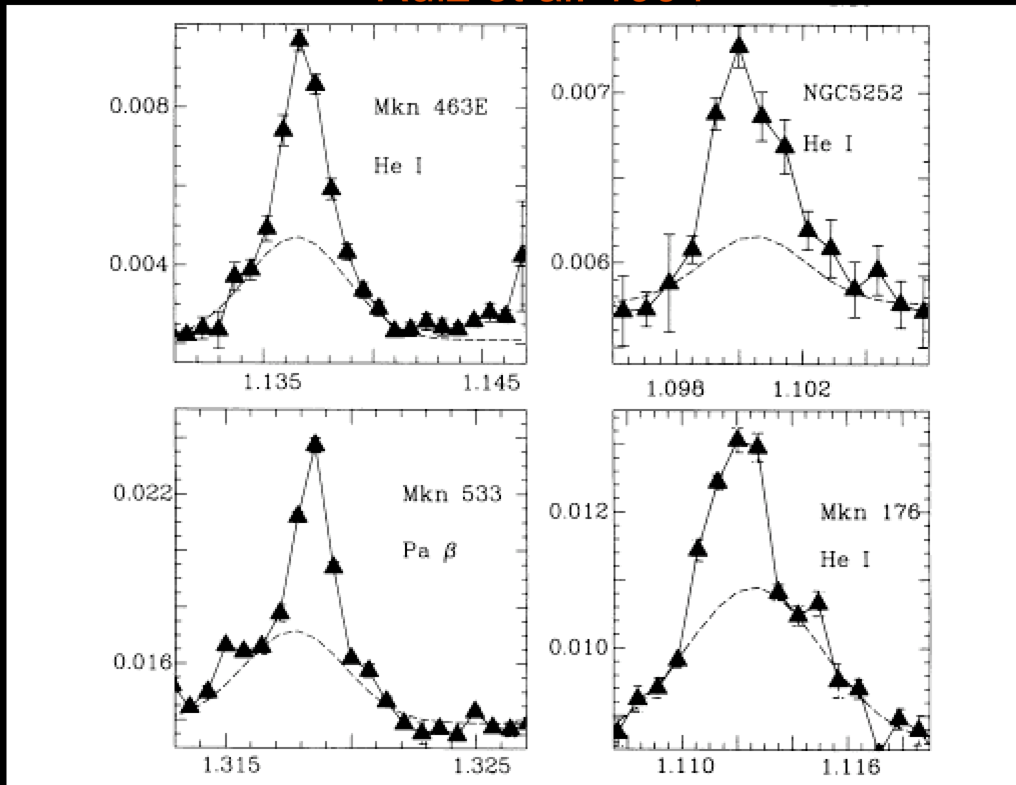
There are searches for broad-recombination lines in the near-IR spectrum of Seyfert 2 galaxies, where the extinction affects the emitted spectrum less. The lines are detectable if $A_V \leq 11^m$ for Pa_, $A_V \leq 26^m$ for Br_ and $A_V \leq 68^m$ for Br_. These searches have had moderate success: ~25% of Sy2s show some broad component in the IR (Goodrich et al. 1994).

(Veilleux, Goodrich & Hill 1997)



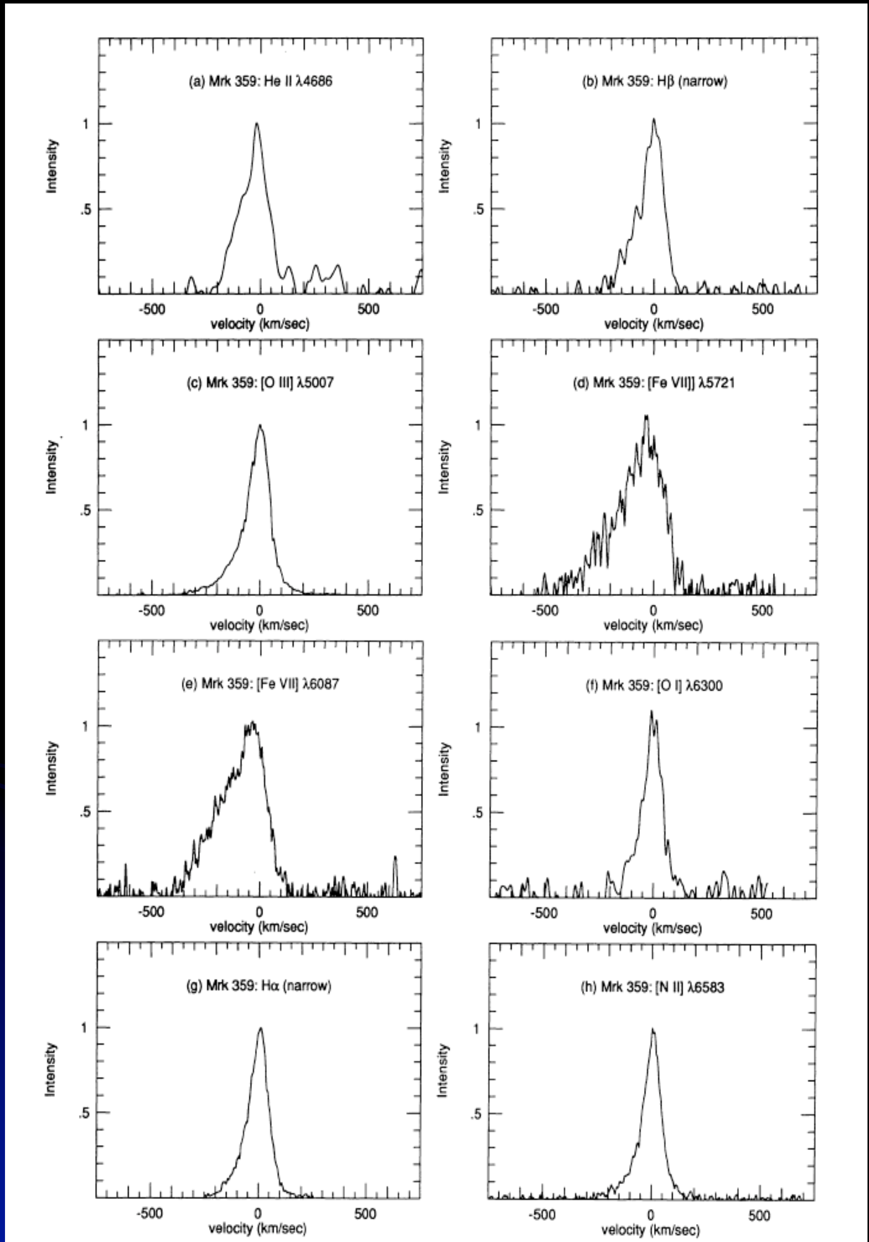
_(_m)

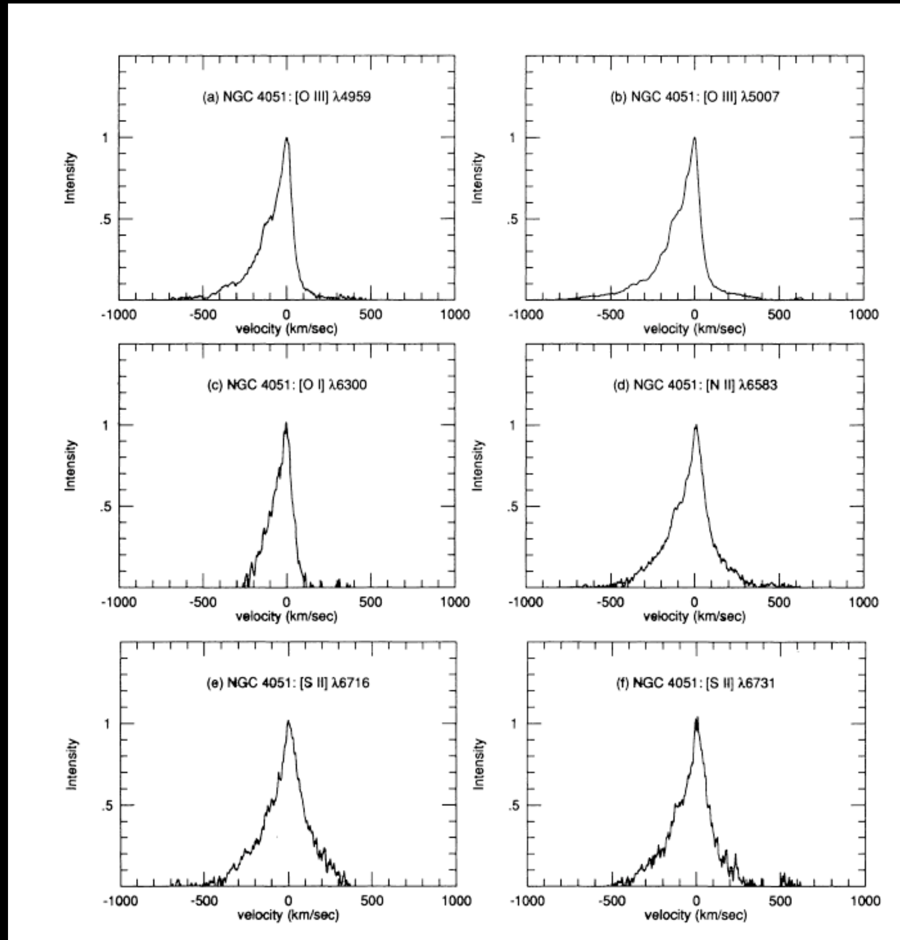
Ruiz et al. 1994



Physical state of the NLR gas:

- Both low ([OI]_6300), high ([OIII]_5007) and very high (FeVII-XIV) ionization lines in NLR
- Forbidden lines in NLR _ $n_e < n_c \sim 10^5$ cm^{-3}
- [SII]_6716/[SII]_6731 _ $n_e \sim 10^{2\text{-}4}$ cm^{-3} ($\langle n_e \rangle \sim 2000$)
- [OIII]_4959+5007/[OIII]_4363 _ $T_e \sim$ 10000-25000 °K
- L(H_)=$1.65\mathrm{x}10^{-25}\pi$_$n_e^2 r^3$ _ r ~ 100-1000 pc with _$<10^{-2}$
- NL FWHM correlate with *L*(bulge) _ virial NL widths
- NL FWHM ~ 500 Km/s, non-Gaussian, blue asymmetry _ radial motions *and/or* large scale opacity source (dusty)





Veilleux 1991

Physical state of the BLR gas:

- NO [OIII]__4363,4959/5007 in BLR _ $n_e > n_c \sim 10^8$ cm^{-3}
- CIII]_1909 observed in BLR $n_e < n_c \sim 10^{10}$ cm^{-3}
- RM _ BLR stratification: Ly_/CIV zone with $n_e \sim 10^{11}$
- No direct information on the BLR temperature, but...

  FeII emission _ $T_e < 35000$ °K.

  Line ratios suggest $T_e \sim 4000$ °K _ $v_{kT} \sim 10$ Km/s
- BL FWHM ~ 5000 Km/s _ bulk motion of BLR clouds
- continuum vs. BEL fluxes _ low filling factor (~10%)
- BL profiles smoothness _ $N_{clouds} > 10^7$
- $T_e + n_e + L$(CIV) _ compact BLR (d $\underset{\sim}{<}$ 0.1 pc)

Physical state of the emitting gas: extinction from line ratios

- Balmer line flux ratios _ dust reddening (NLR/BLR)

  F(H_)/F(H_)=I(H_)/I(H_)x$10^{-c(_(H_)-_(H_))}$

  Observed flux ratio — intrinsic flux ratio — E(*B-V*)=0.77c — _=interstellar extinction curve

  $$E(B-V) = 2.3 \times \log_{10}(R_{obs}/R_{int})$$

  with R_{int}=2.8 (HII region,Case B), but R_{int}=3.1-3.4 for AGN

- Same also for H_/H_ and H_/H_ ratios (but fainter ...)
- Absorption component correction
- $E(B-V)/N_H$(X-rays) = 1.7 _ 10^{-22} mag cm^2 (galactic standard value, Bohlin et al. 1978).

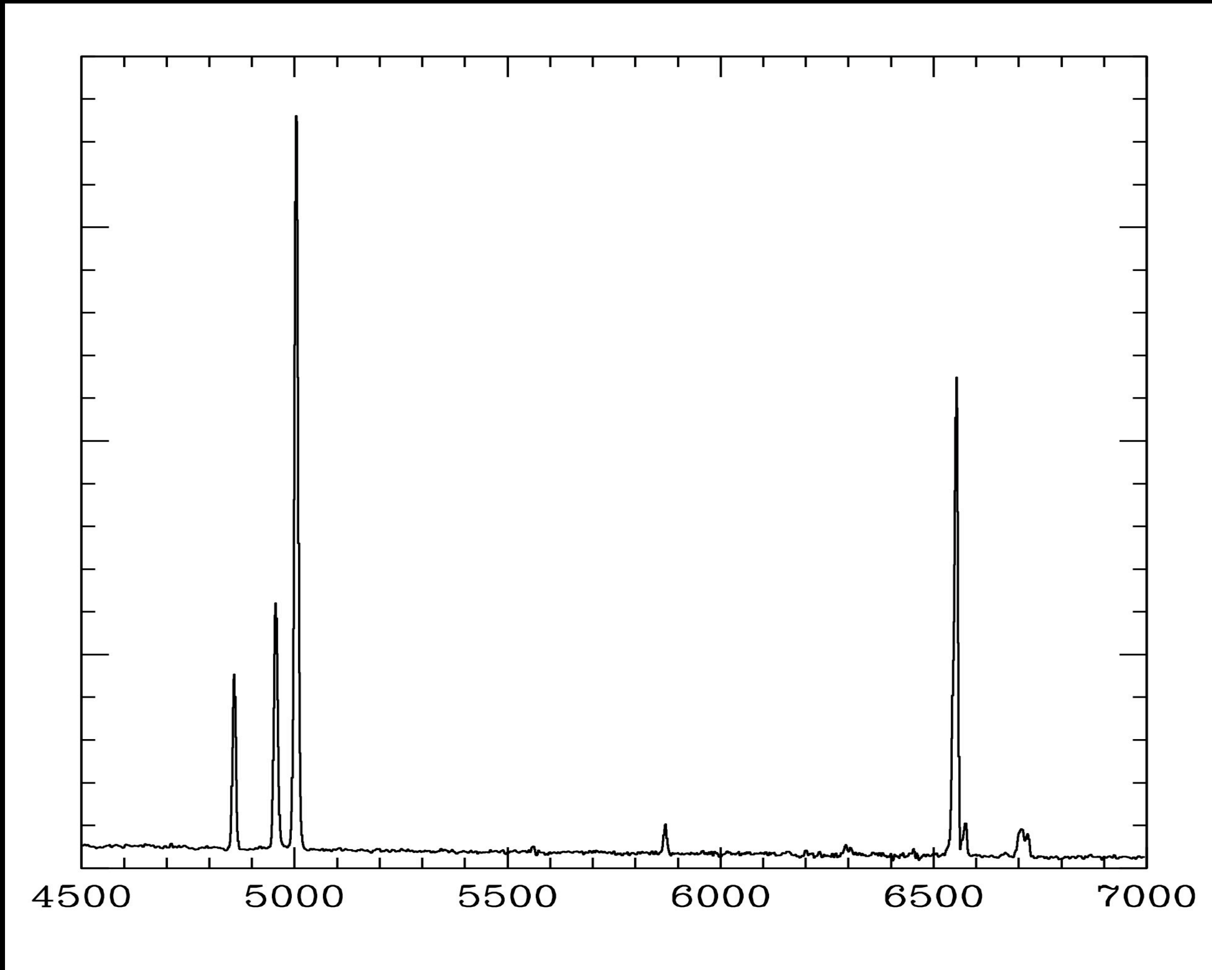
BLR vs. NLR

- Photo-ionized by nuclear continuum radiation
- $n_e \sim 10^{10}$ cm^{-3}
- $T_e \sim$ few x 10^3 °K
- $r_{BLR} < 0.1$ pc (*but RM*)
- $m_{BLR} \sim$ few x $M_\odot$
- _ ~ 10^{-2}
- Complex/dissimilar line prof.
- Doppler line widths _ _ central object gravity

- Photo-ionized by nuclear continuum radiation
- $n_e \sim 10^{3}$ cm^{-3}
- $T_e \sim$ 1-3 x 10^4 °K
- $r_{NLR} > 10^2$ pc (*measured*)
- $m_{NLR} \sim$ few x $10^4 M_\odot$
- _ ~ 10^{-3}-10^{-4}
- Simple/similar line profiles
- Doppler line widths _ _ stellar bulge gravity

Spectral classification (em.lines)

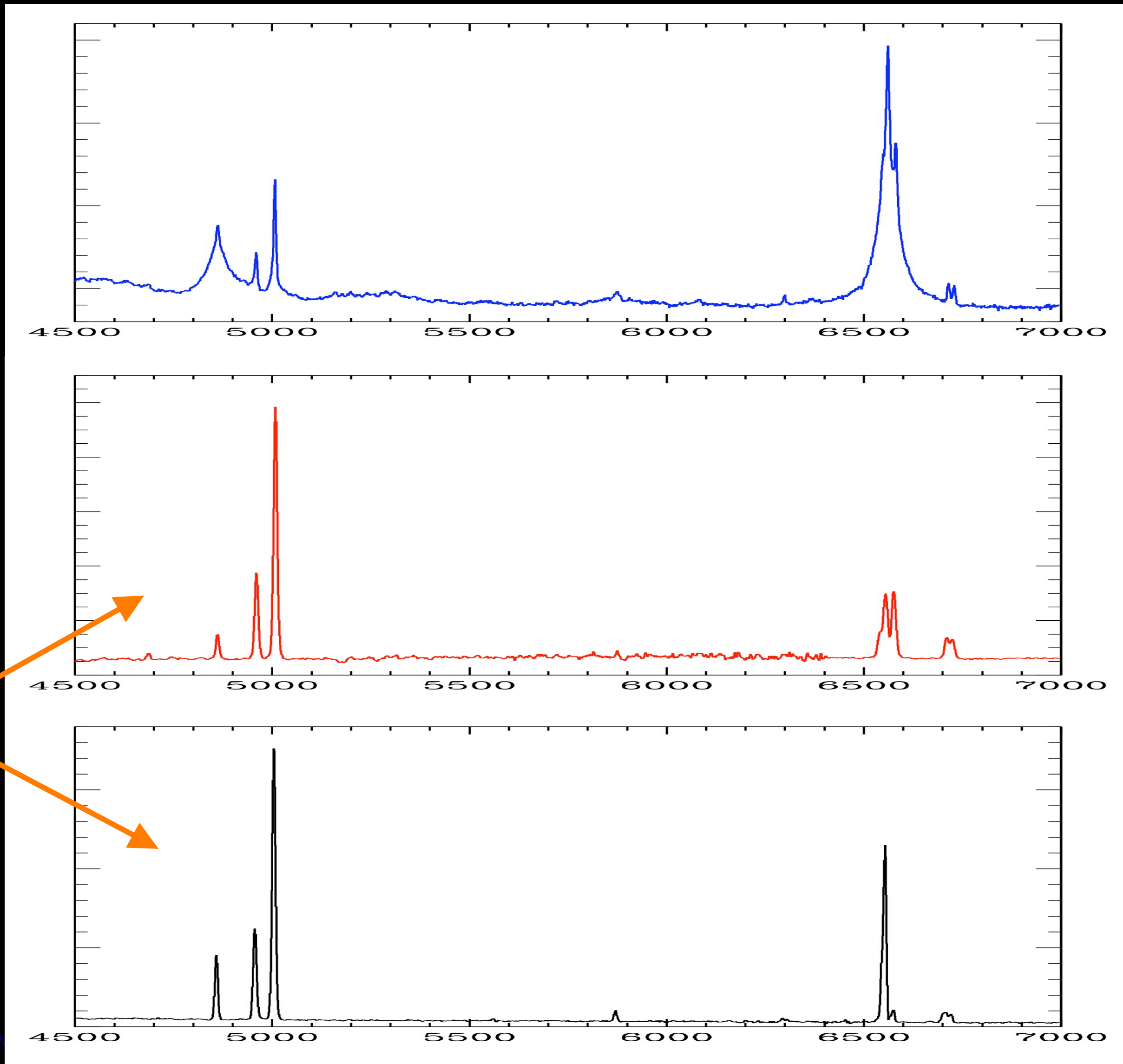
- Type 1
- Type 2
- Starforming galaxies



Spectral classification (em.lines)

- Type 1
- Type 2
- Starforming galaxies

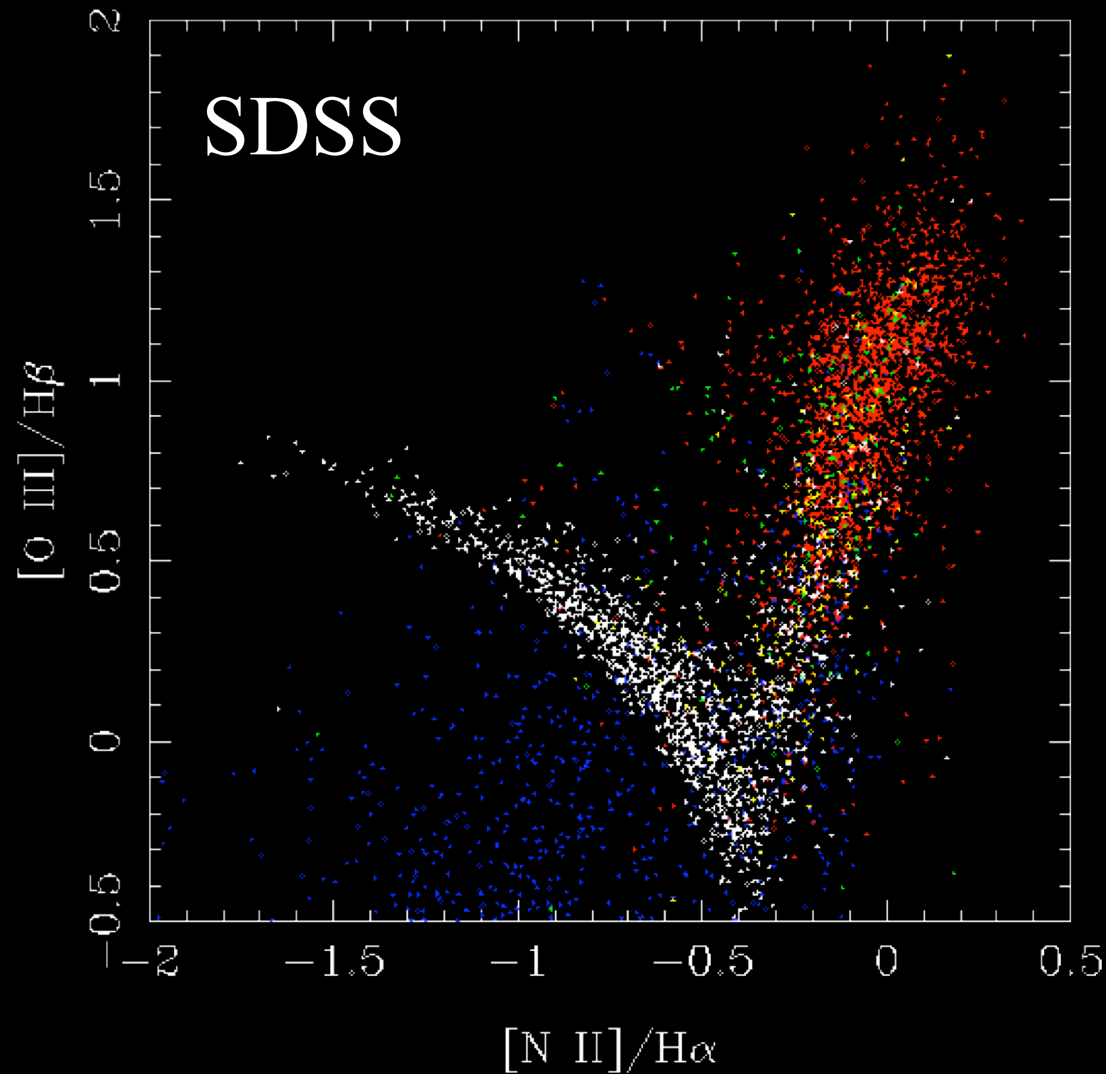
How we can discriminate the narrow line objects?



Spectral classification (em.lines)

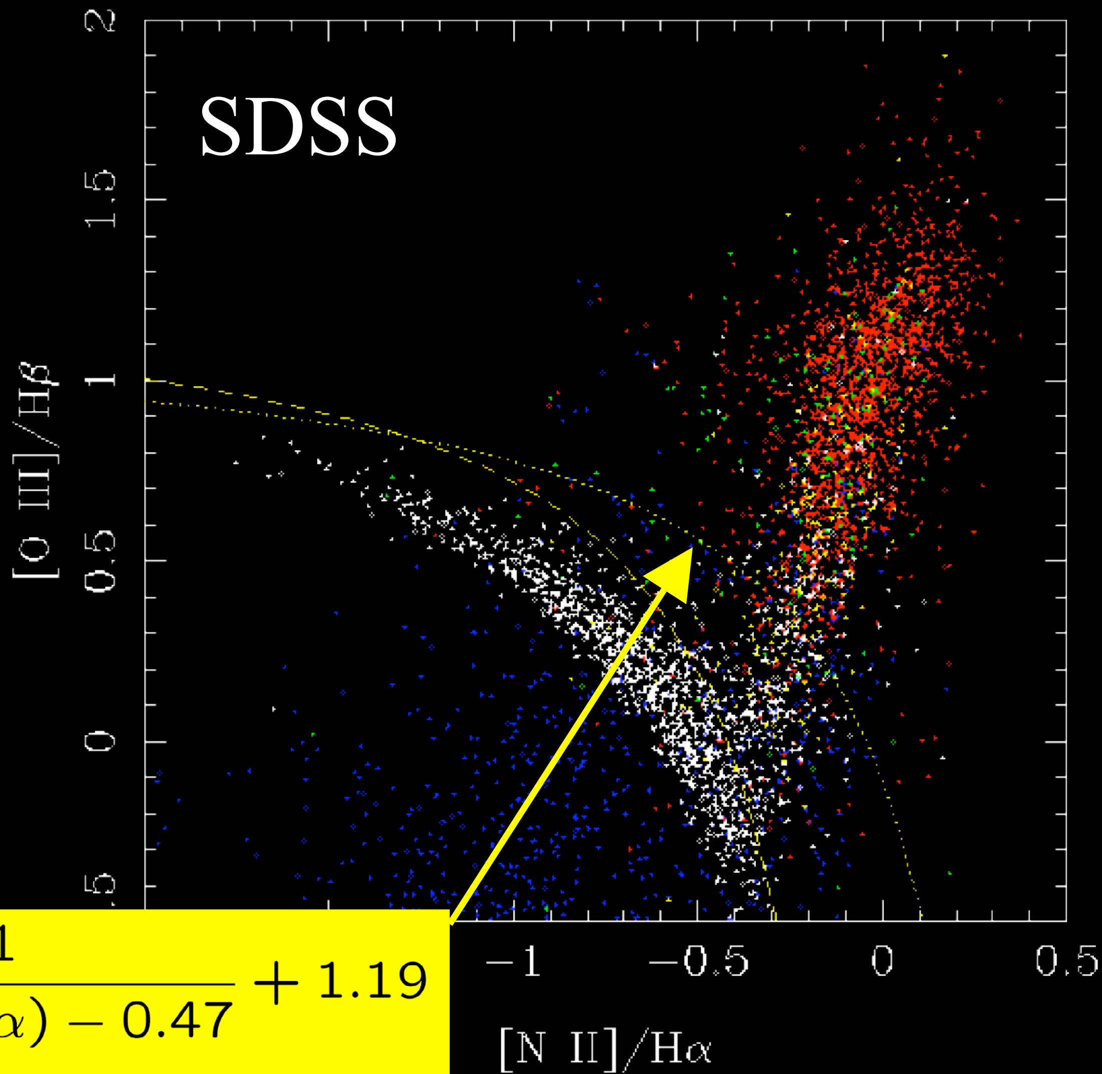
DIAGNOSTIC DIAGRAM

- Sy 1 galaxies
- Sy 2 galaxies
- Starforming galaxies
- Composite galaxies



Diagnostic Diagrams

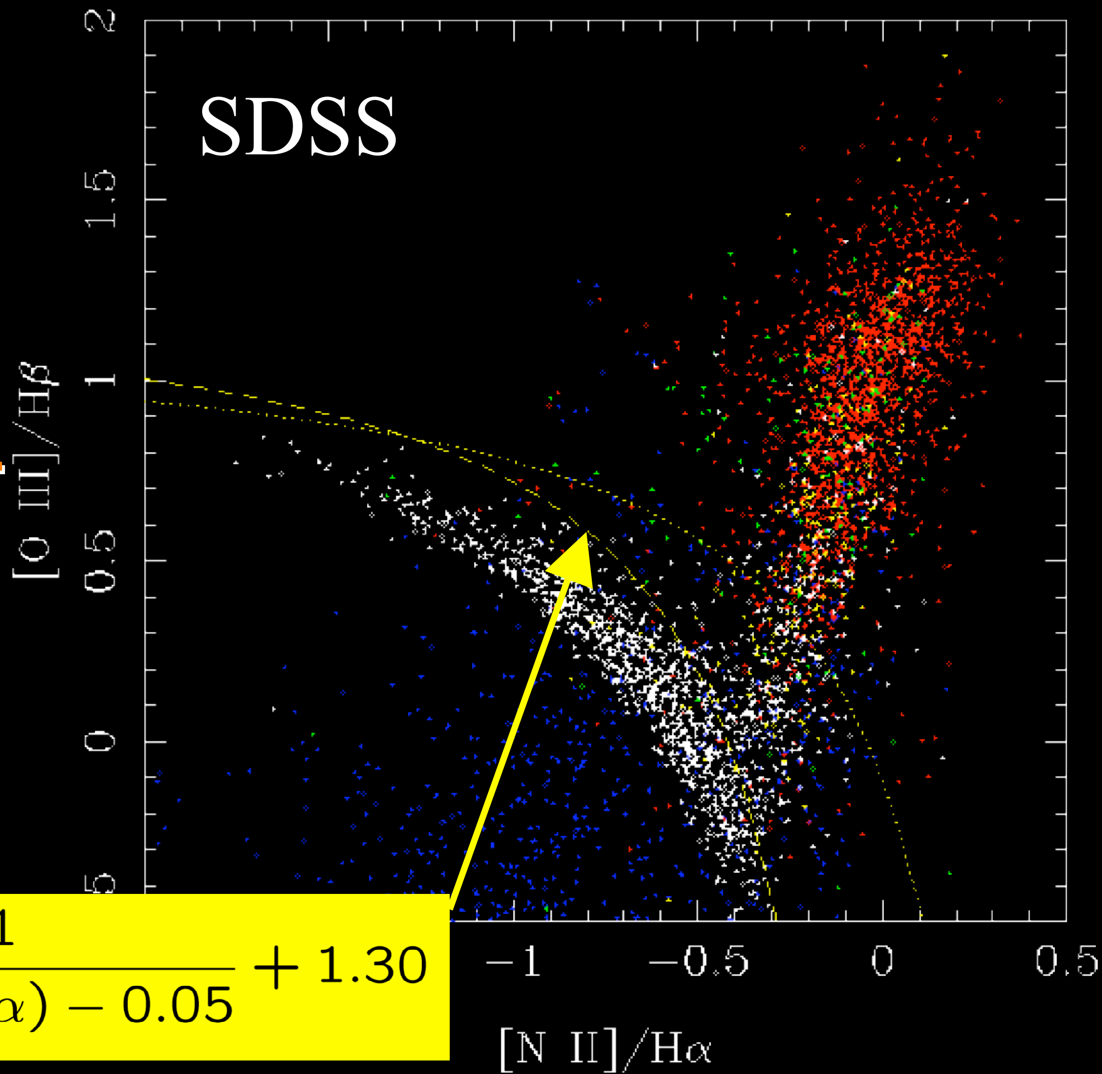
- Sy2/StB *theoretical* separation Kewley et al. (1991)



$$\log([\mathrm{O\,III}]/\mathrm{H}\beta) = \frac{0.61}{\log([\mathrm{N\,II}]/\mathrm{H}\alpha) - 0.47} + 1.19$$

Diagnostic Diagrams

- Sy2/StB *empirical* separation Kauffmann et al. (1994).

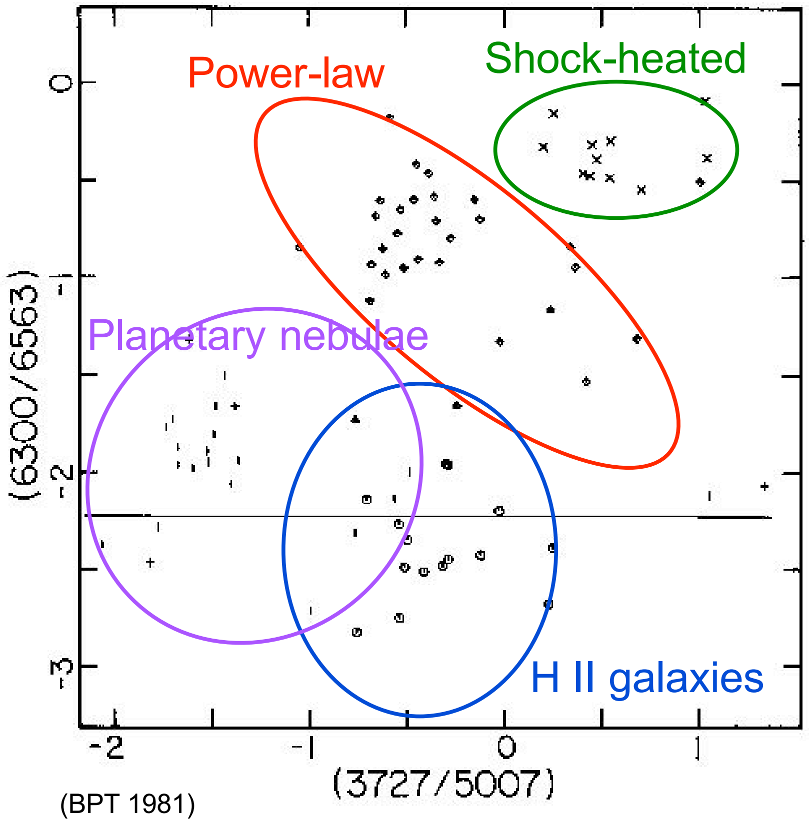


$$\log([\mathrm{O\,III}]/\mathrm{H}\beta) = \frac{0.61}{\log([\mathrm{N\,II}]/\mathrm{H}\alpha) - 0.05} + 1.30$$

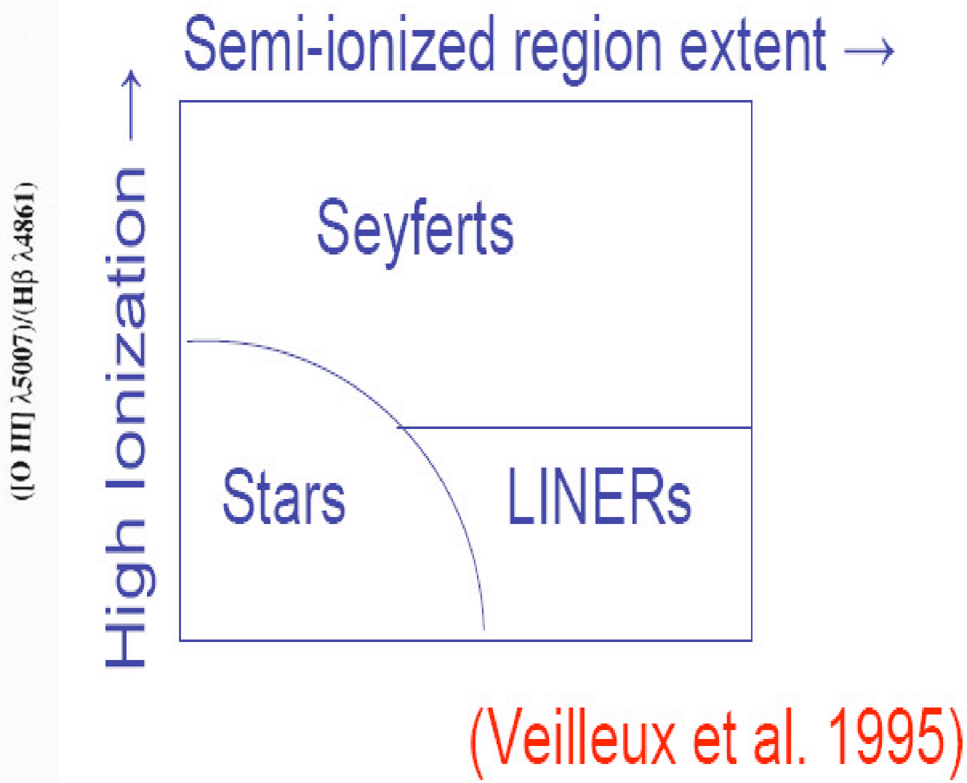
Diagnostic Diagrams

The BPT diagrams (Balwin, Phillips & Terlevich 1981, Veilleux & Ostrebrock 1987), are used in narrow-line emission systems, to distinguish between the origins of the photo-ionization, hard and soft radiation, which is usually ascribed to non-stellar and stellar activity, respectively.

The general criterium [O III] / H_ > 3 could be wrong !



(BPT 1981)



(Veilleux et al. 1995)

Diagnostic Diagrams

The ten commandments of emission-line diagnosis (Veilleux'01):

1. Thou shalt use lines which emphasize the differences between H II regions and AGN; i.e., use high-ionization lines or low-ionization lines produced in the partially ionized zone.
2. Thou shalt use strong lines which are easy to measure in typical spectra.
3. Thou shalt avoid lines which are badly blended with other emission or absorption line features.
4. Thou shalt use lines with small wavelength separation to minimize sensitivity to reddening.
5. Thou shalt use lines from the same elements or involving hydrogen recombination lines to eliminate or reduce abundance dependence.
6. Thou shalt avoid lines from Mg, Si, Ca, Fe – depleted onto dust grains.
7. Thou shalt use lines easily accessible to current UV/optical/IR detectors.
8. Thou shalt avoid lines affected by strong stellar absorption features.
9. Thou shalt avoid lines affected by strong atmospheric features.
10. Thou shalt use lines at long wavelengths to reduce the effects of dust extinction.

Diagnostic Diagrams

DIAGNOSTIC DIAGRAMS

Em.lines in the red range

- [NII]6584/H_ vs. [OIII]5007/H_
- [SII]6717-31/H_ vs. [OIII]5007/H_
- [OI]6300/H_ vs. [OIII]5007/H_

Em.lines in the blue range

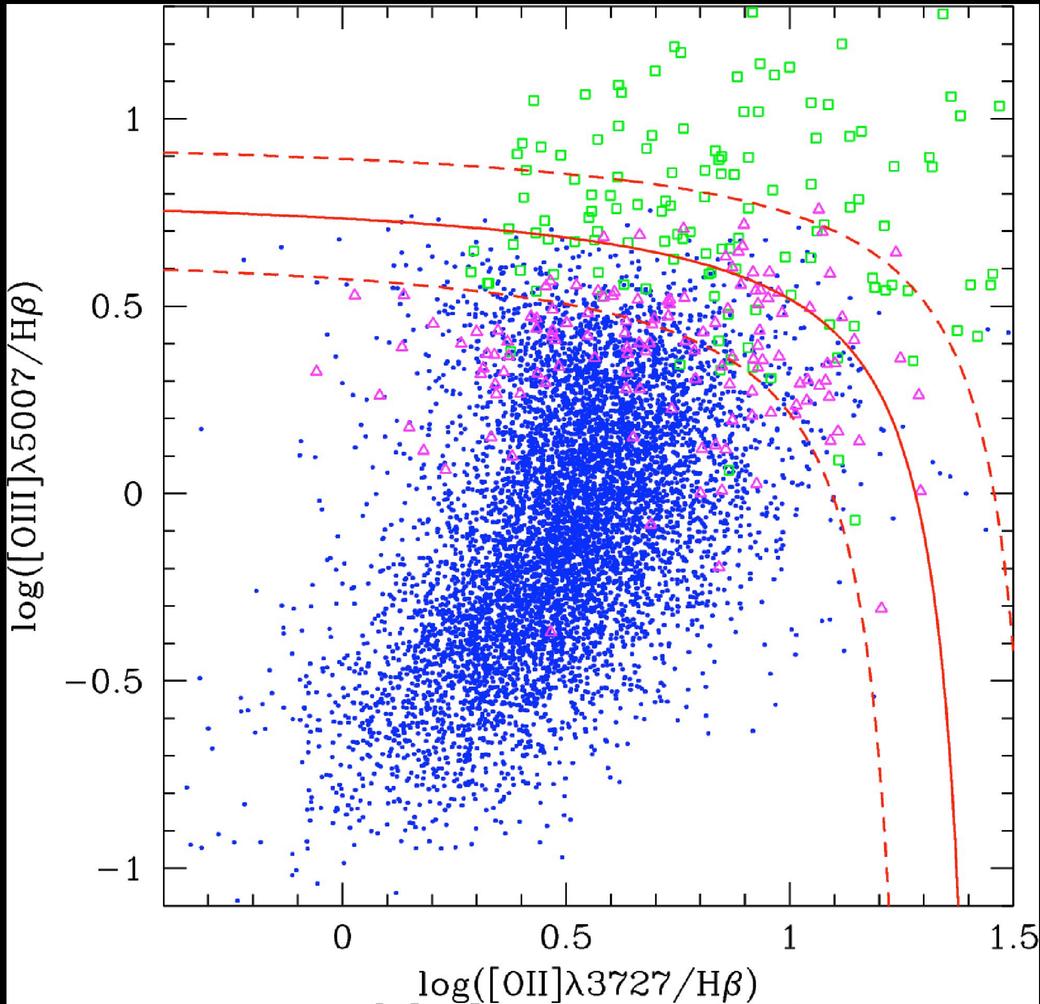
- [OII]3727/H_ vs. [OIII]5007/H_
- [OII]3727/H_ vs. continuum index

Other line ratios in UV, NIR and FIR spectral ranges

NV1240/Ly_, NV1240/HeII1640, CIV /Ly_

[Si VI] 1.962_m/Pa_

[NeV]14_m/[NeII]12.8_m,
[OIV]26_m/[NeII]12.8_m,
EW(PAH 7.7_m)



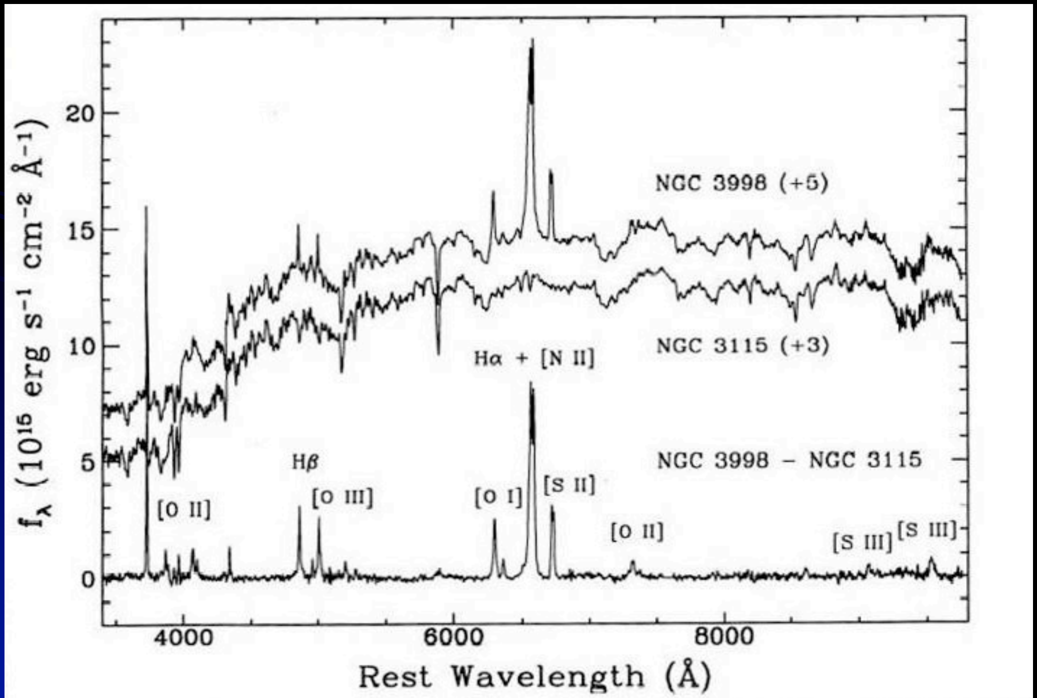
AGN taxonomy: LINERs

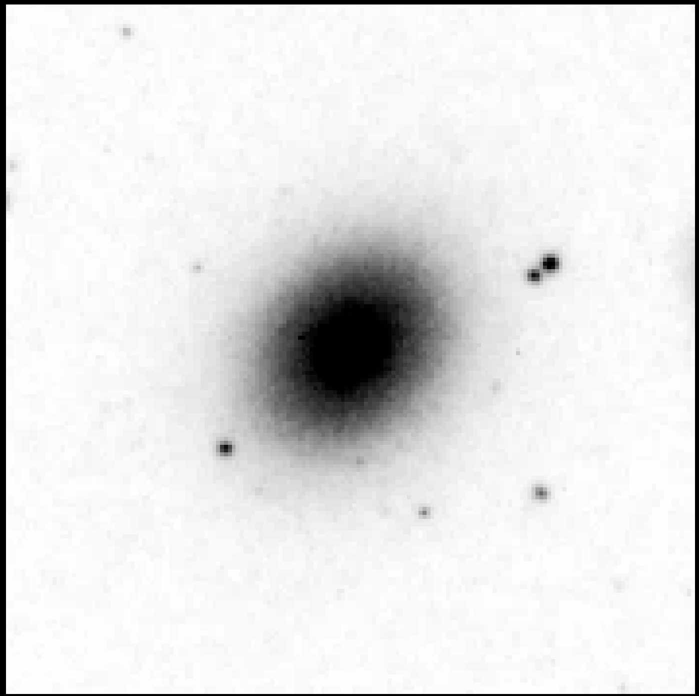
LINER = Low-Ionization Narrow-Line Region

They are characterized by [O II] _3727Å / [O III] _5007Å ≥ 1
[O I] _6300Å / [O III] _5007Å ≥ 1/3 (Heckman 1980)

Most of the nuclei of nearby galaxies are LINERs. A census of the brightest 250 galaxies in the nearby Universe shows that 50–75% of giant galaxies have some weak LINER activity (Phillips et al. 1986, Ho, Filippenko & Sargent 1993, …).

They are the weakest form of activity in the AGN zoo.

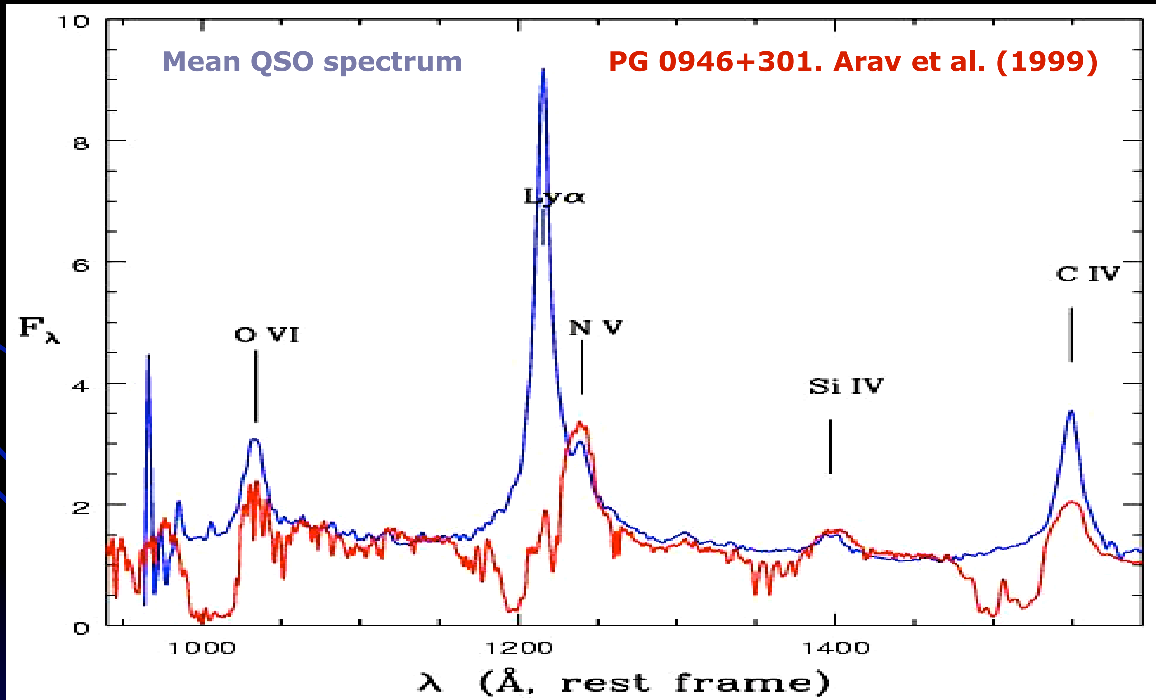




AGN taxonomy: BAL QSOs

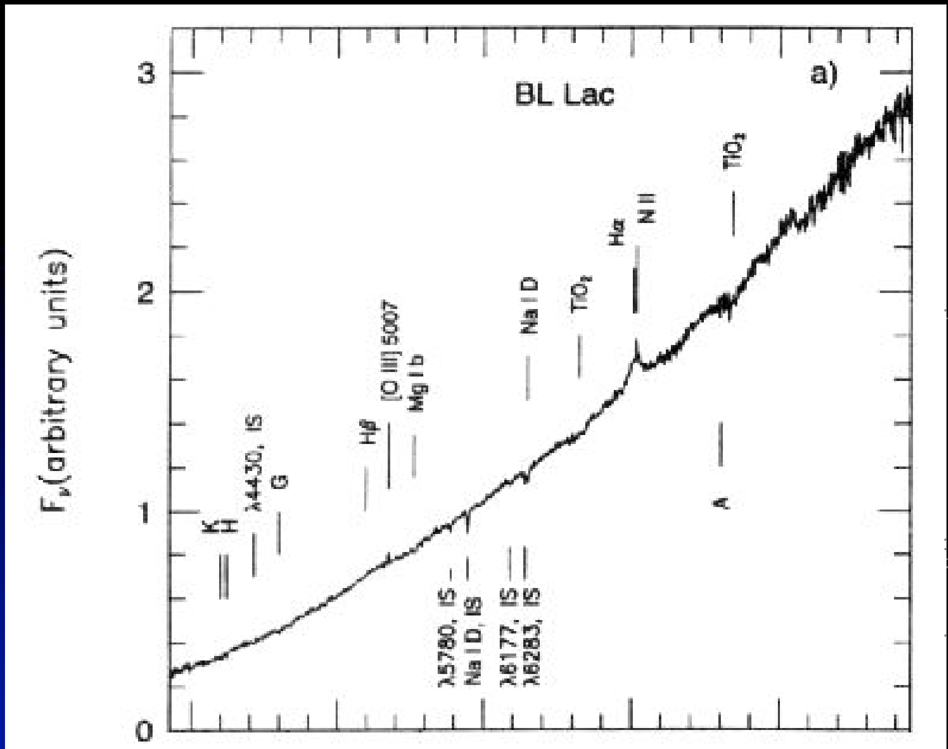
BAL QSOs = Broad Absorption Line QSOs

Otherwise normal QSOs that show deep broad absorption lines, blueward of the corresponding emission resonance lines of CIV, SiIV, NV. The interpretation is that they are *intrinsic* and arise from clouds outflowing the nucleus. They mainly are at $z \geq 1.5$ because the phenomenon is observed in the rest-frame UV. At these redshifts, they are ~10% of the *observed* population.



AGN taxonomy: BL Lacs & Blazars

➢ BL Lacertae is the prototype of this class: an object, stellar in appearance, with very weak emission lines and variable, intense and highly polarized continuum. The weak lines often just appear in the most quiescent stages. BL Lacs, along with optically violent-variable (OVV) QSOs, constitute the class of Blazars: these are believed to be objects with a strong relativistically beamed jet in the line of sight.



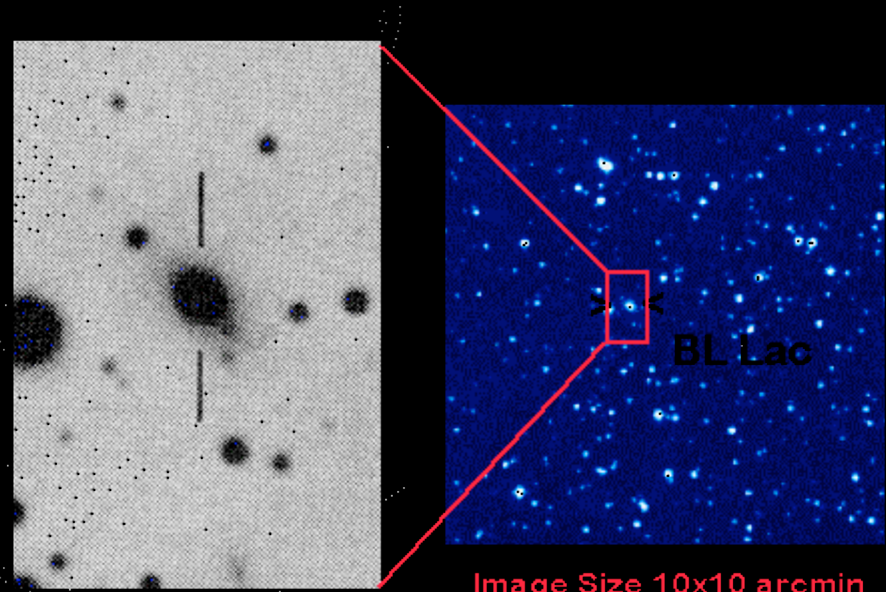


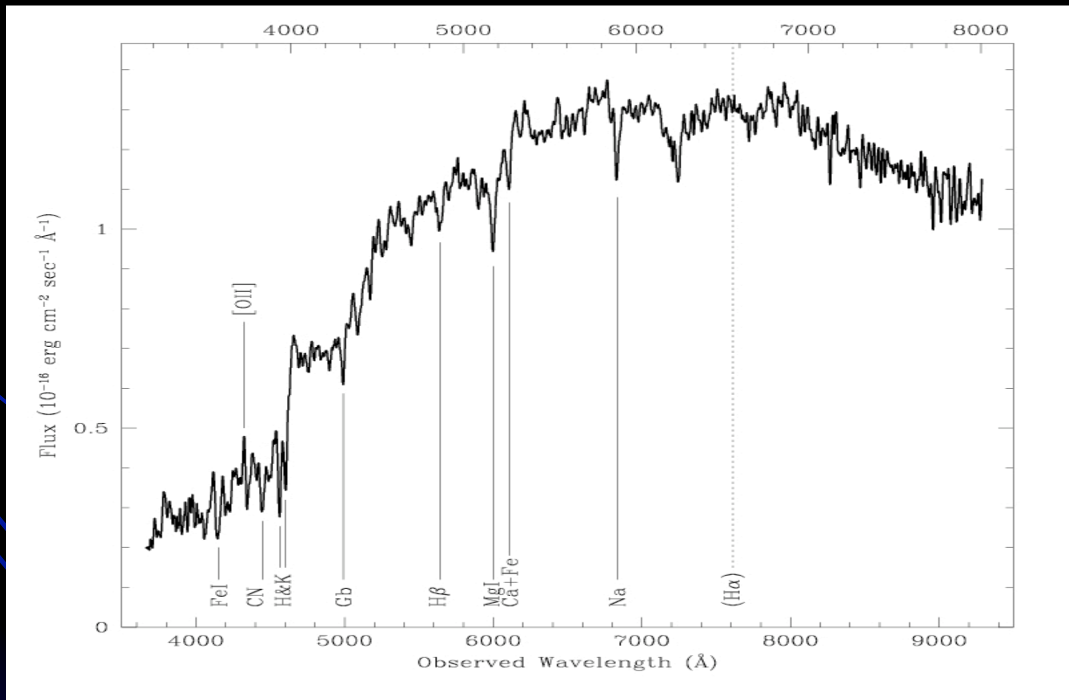
Image Size 55x80 asec

Image Size 10x10 arcmin

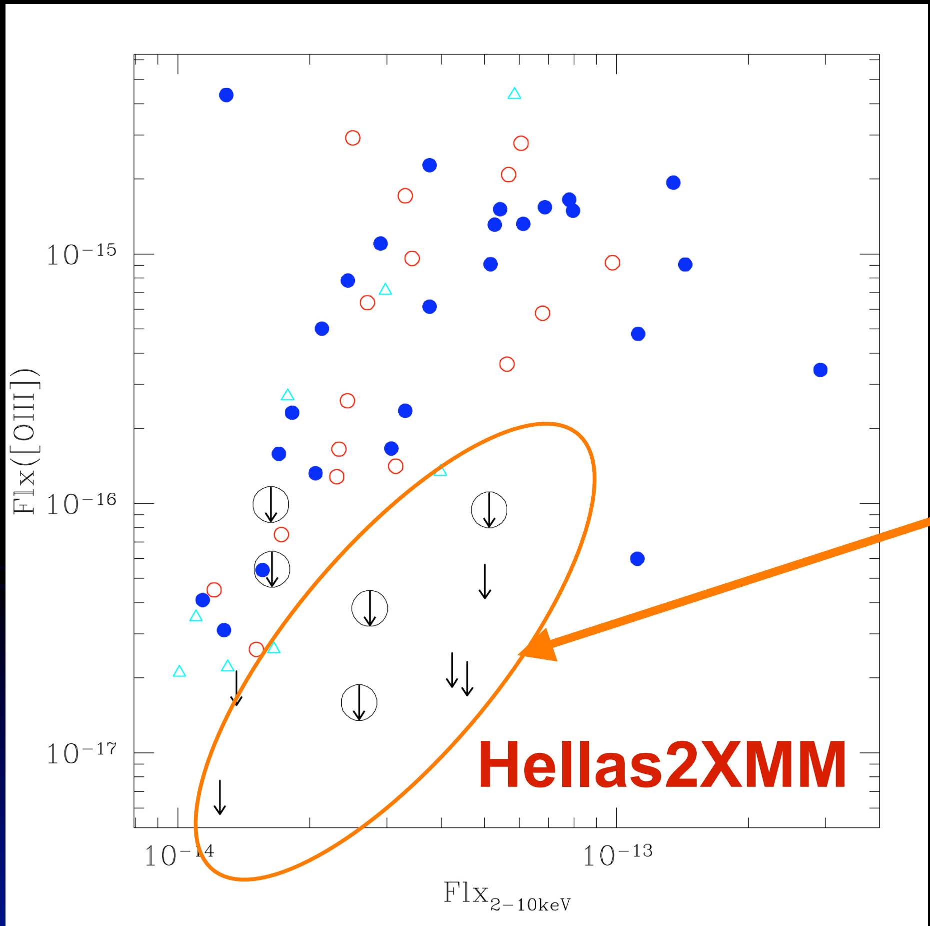
AGN taxonomy: XBONGs

XBONGs = X-ray Bright Optically Normal Galaxies

This AGN class consists of luminous hard X-ray sources hosted by "normal" galaxies with optical spectra typical of early-type systems (Comastri et al. 2002). Why the relatively bright X-ray emission, typical of moderately luminous (10^{42-43} erg s^{-1}) Active Galactic Nuclei , does not leave any optical signature of the presence of a nuclear source is still matter of debate.



AGN taxonomy: XBONGs



- The upper limits on the optical emission lines ([OIII], H_), expected from the nuclear activity, in some XBONGs are tight enough to place these sources outside the typical AGN properties.
- Possible interpretations:

1. ~~Dilution from the host galaxy light~~
2. Radiatively inefficient accretion flow
3. Heavy obscuration by Compton-thick nuclear gas
4. NLR obscured on galaxy scale (i.e., Kpc dust lanes, see Malkan et al. 1998)
5. Extreme BL Lacs objects

AGN taxonomy: the type-2 QSOs

Definition:

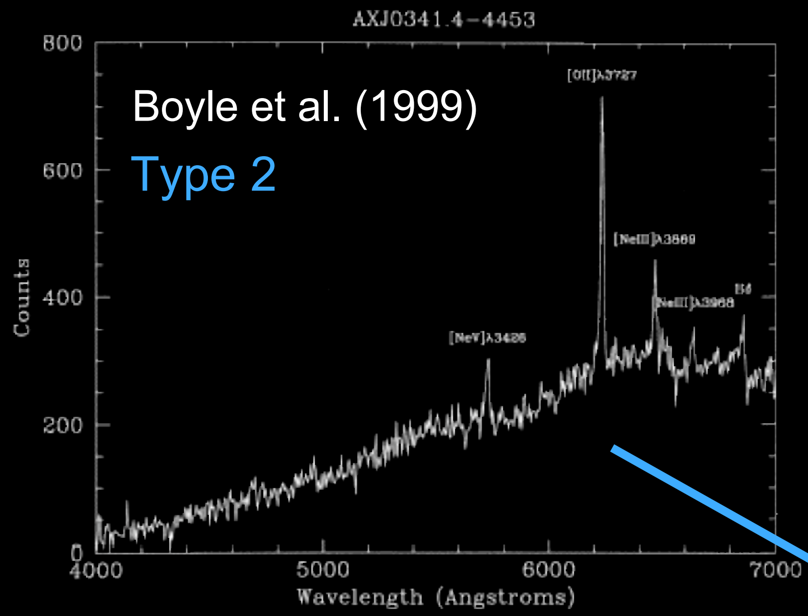
"Quasar (high L) analogue of Sy2 galaxies"

OPTICAL: high *bolometric* luminosity (_ high z) objects with high ionization, narrow (FWHM<1500 km/s) emission lines, no broad lines. (expected according to the Unification models of AGN)

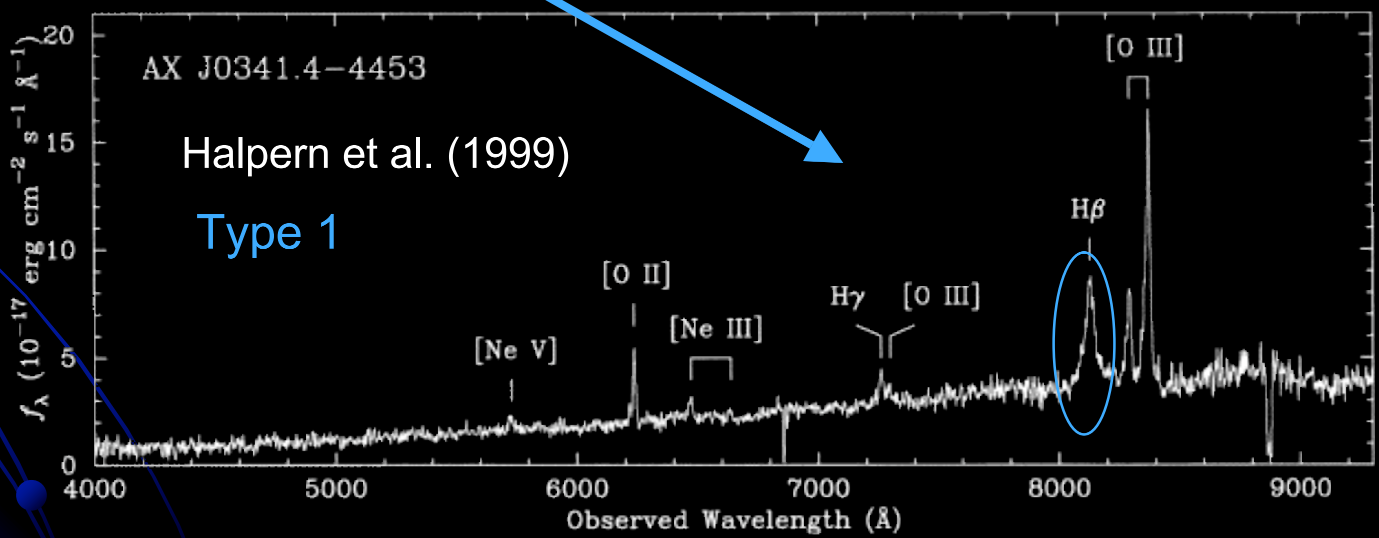
X-RAYS: high-luminosity ($L_x > 10^{44}$ erg/cm/s^2) and obscured ($N_H > 10^{22}$ cm^{-2}) AGN (*required by XRB synthesis models*).

Do obscured (type II) quasars exist? To date, only a small number of candidates have been found (but NLRG). First examples did not confirm their classification after follow-up observations (high S/N and/or redward).

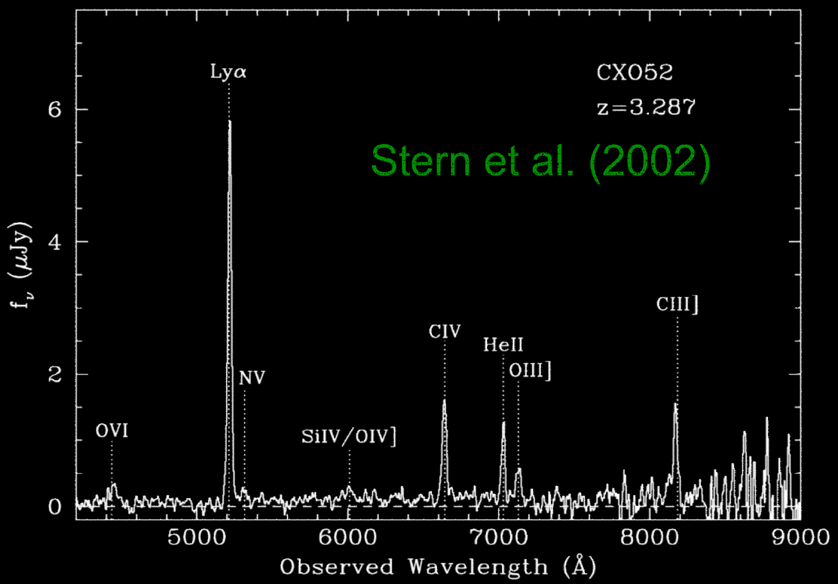
AGN taxonomy: the type-2 QSOs

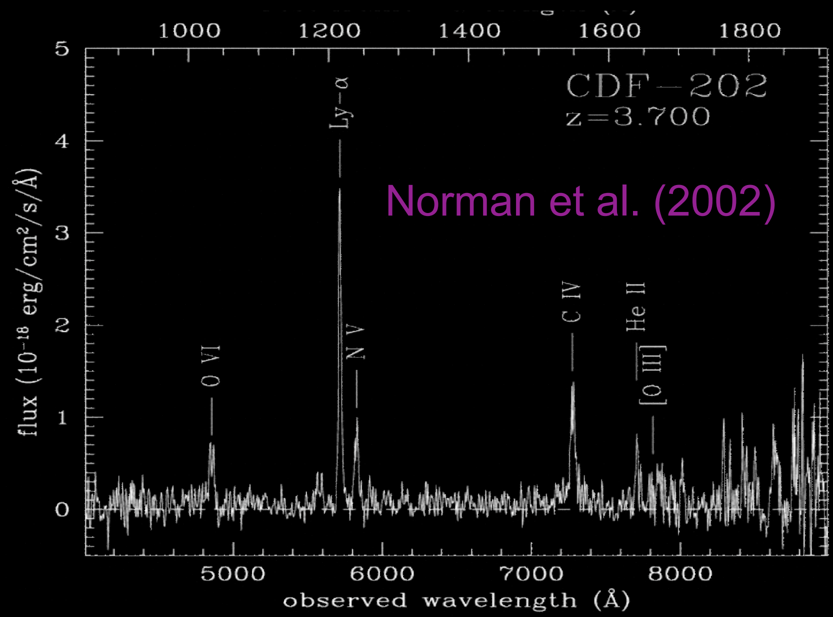


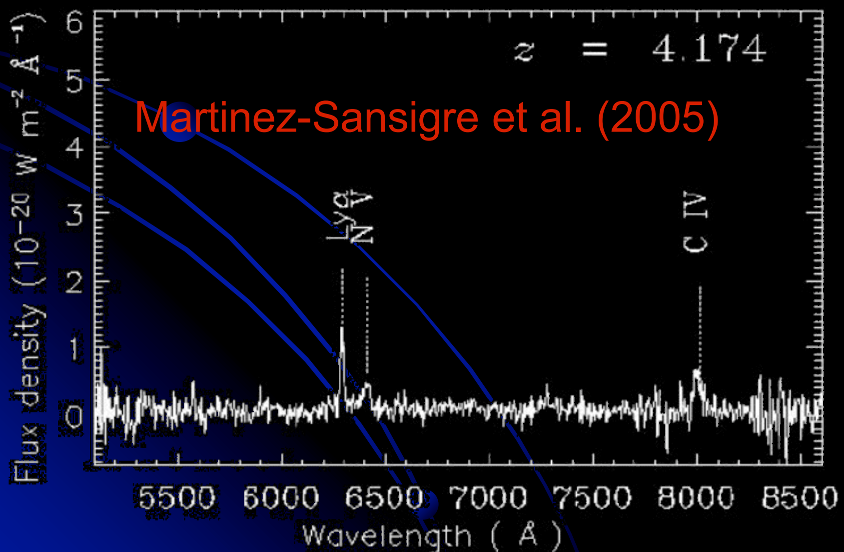
Without the low order Balmer lines, a *secure* type2 classification is a moot point.



AGN taxonomy: the type-2 QSOs

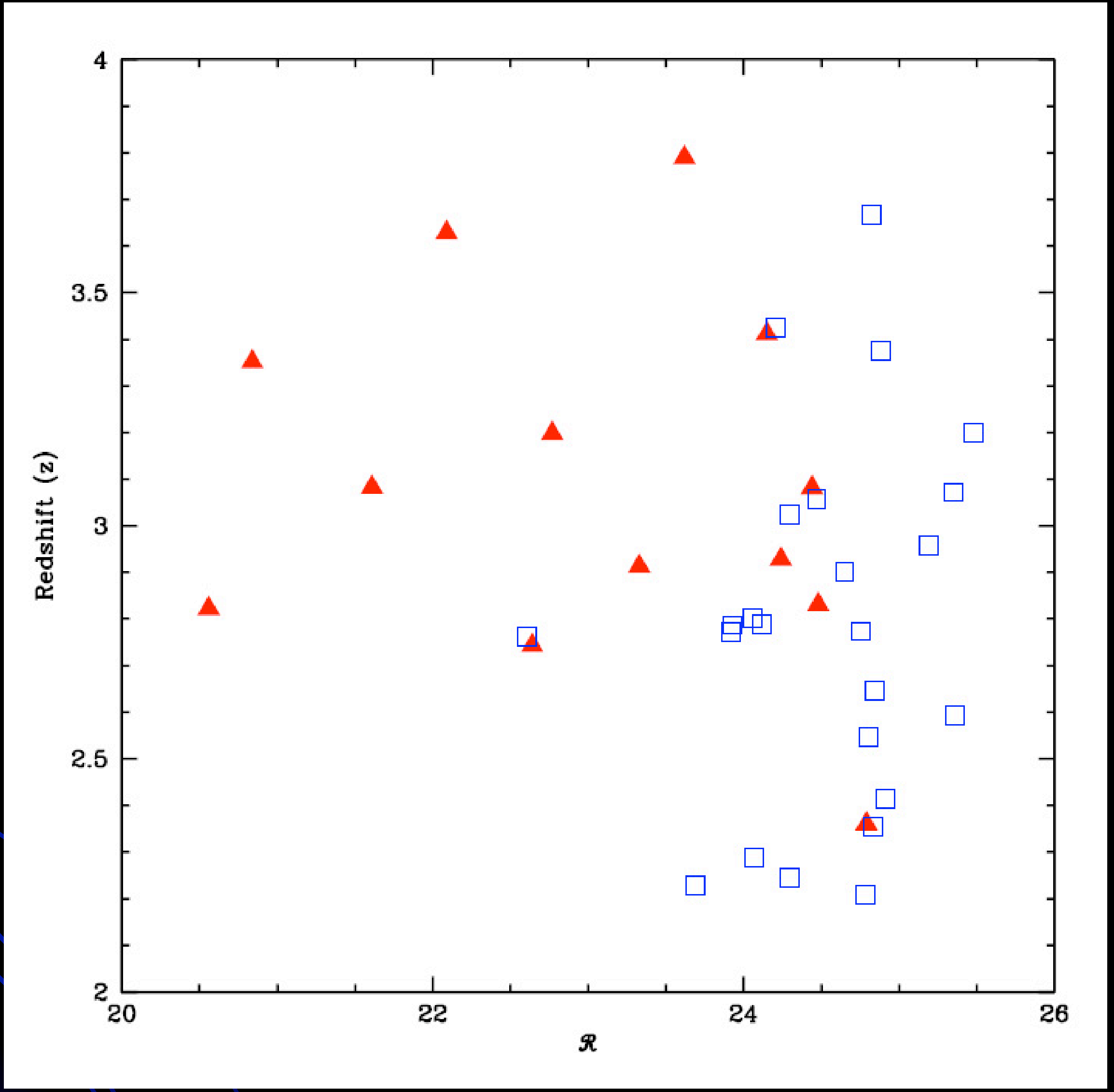






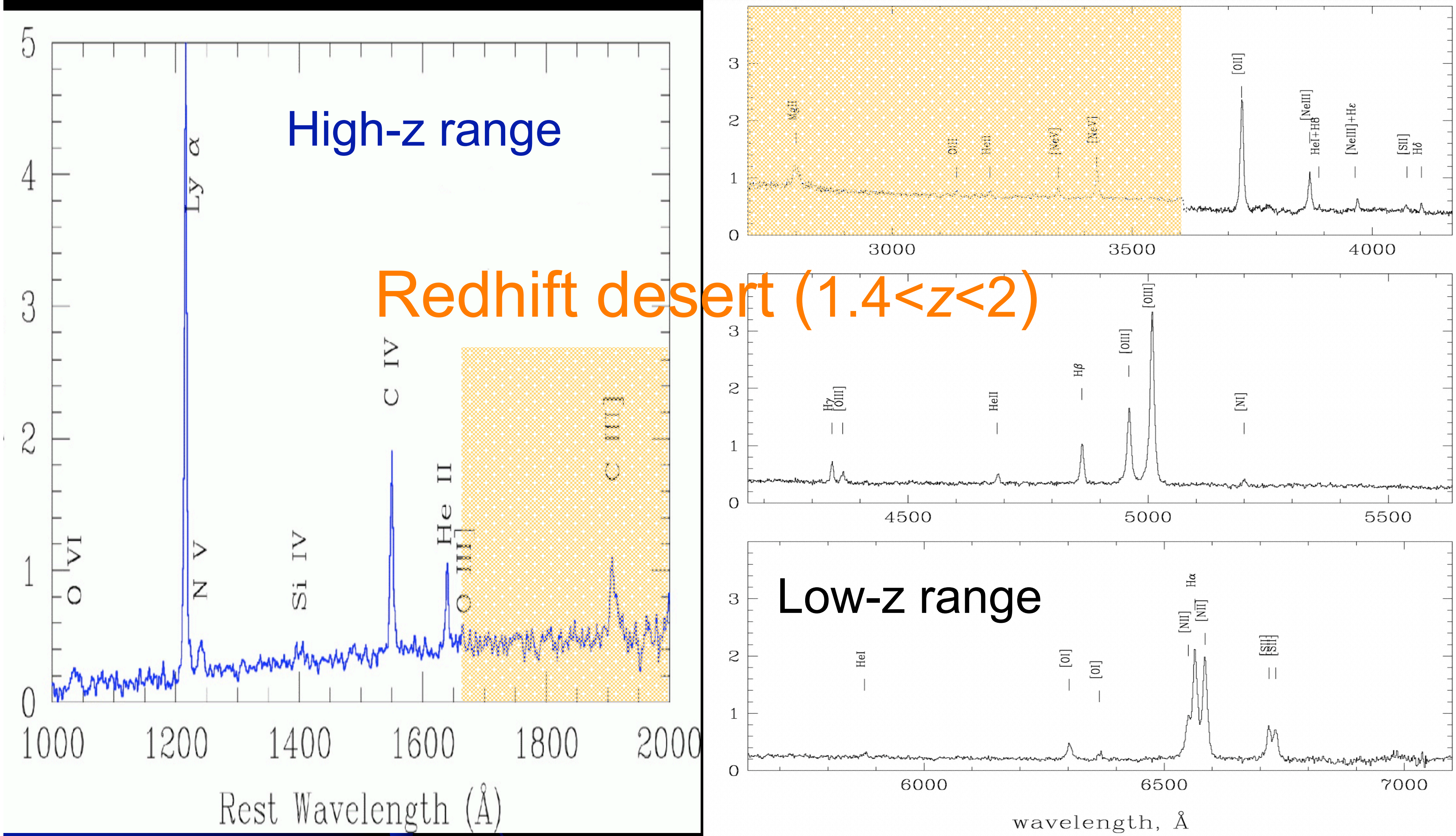
The high-z type-2 QSOs do exist! Selected both in optical, X-rays and FIR. But they are demanding targets for optical spectroscopy. (but see SDSS…)

Type 1 Lyman Break Objects   Type 2 Lyman Break Objects



Steidel et al. 2003 “*The Population of Faint Optically Selected Active Galactic Nuclei at z ~ 3*”

The “*redshift desert*” for type-2 QSOs



Points to Take Away

- The optical spectrum offers a wealth of information about BLR/NLR and the AGN structure, but it is mainly composed by “secondary” radiations.
- The unification scheme is a clear and simple way to classify AGN, but don’t tell us all the truth.

ty1/ty2 _ f*(L)*,f*(z)*,f*(_)*,f*(env)*,f*(host-type)*,f*(t)*

- Multi-wavelength approach to AGN study