AGNs

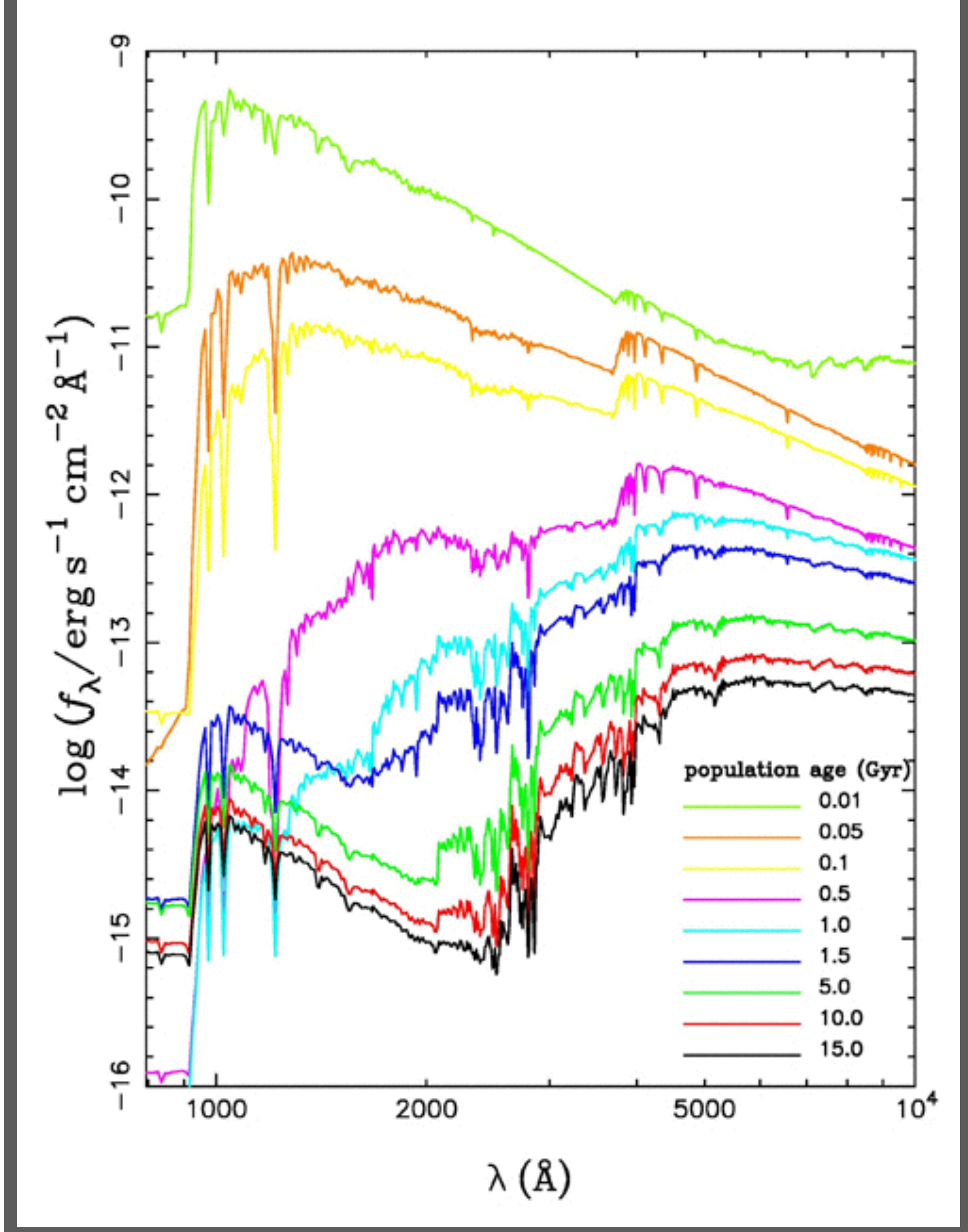
aulas 26/junho e 01/julho

Mo, van den Bosch & White "Galaxy Formation and Evolution", cap. 14
L. Sparke, "Galaxies in the Universe, an Introduction", cap. 9

SED de galáxias normais

- Galáxias "normais": galáxias onde a emissão é dominada por estrelas => predominantemente radiação térmica, somatória dos corpos negros de temperatura entre ~3000 e 40.000K
- A maior parte da emissão está confinada entre 4000A e 20μm.
- Emissão estende para o UV e IV se há starburst e poeira

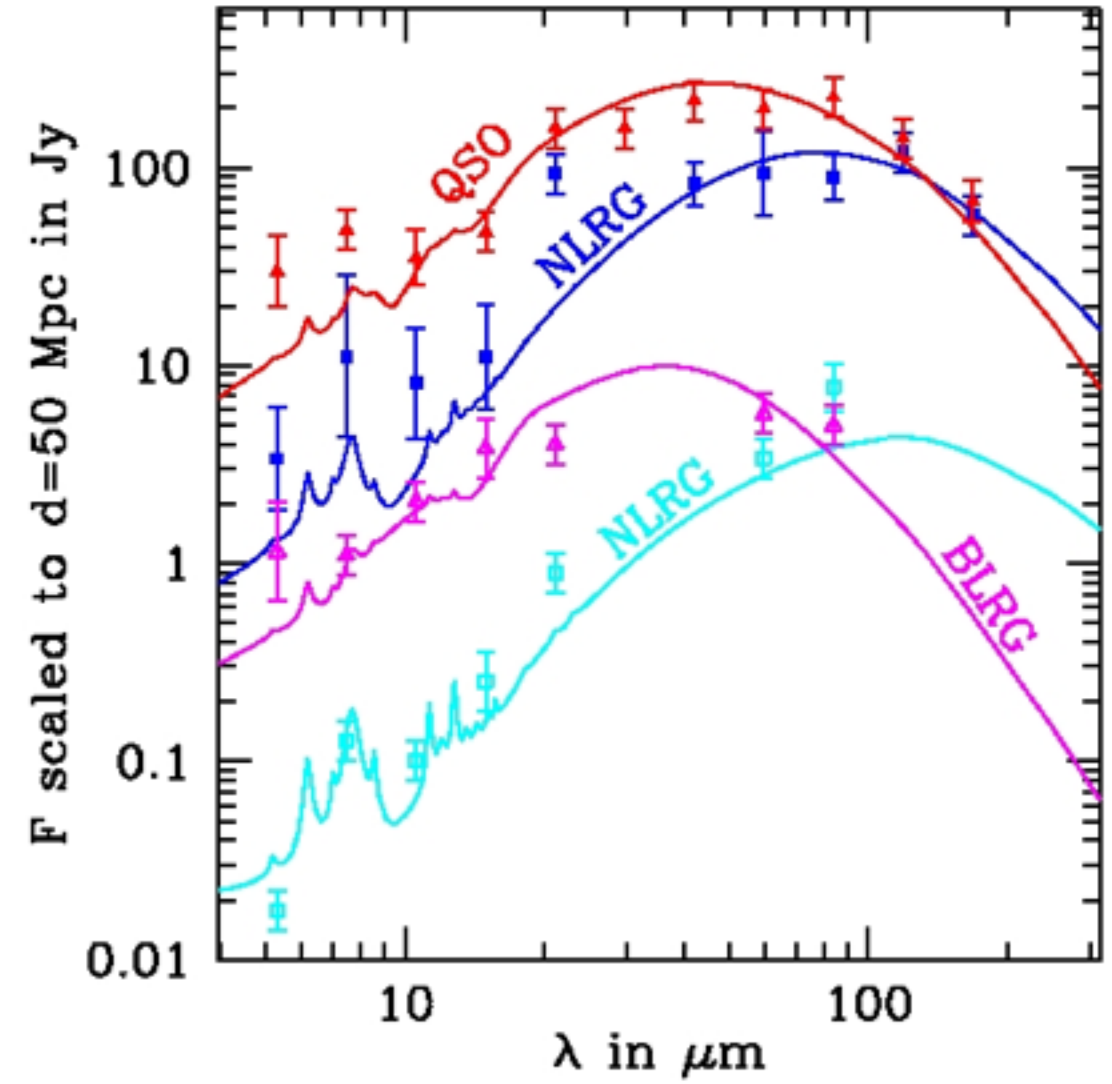
http://www1.ynao.ac.cn/~zhanwenhan/bps.html



The evolution of spectral energy distribution (SED) of elliptical galaxies. The far-UV part is dominated by hot subdwarf stars from binary interactions when the age is larger than 1 Gyr (Han et al., 2007, MNRAS, 380, 1098).

SED de AGNs

- Uma pequena fração das galáxias tem um SED (spectral energy distribution) que é muito mais larga, cobrindo de raio X ao rádio.
- E a parte óptica revela numerosas linhas de emissão intensas.
- A luminosidade não-termal está confinada a uma região extremamente pequena da galáxia mas pode ser até 10^4x mais intensa do que a luminosidade do restante da galáxia



http://www.eso.org/~rsiebenm/agn_models/

AGNs

- Understanding the properties and formation of active galaxies is an important part of galaxy formation
  - active galaxies form an important population of galaxies, and so any theory of galaxy formation should also address the formation of AGN.
  - it is believed that AGN are powered by matter accreting onto a supermassive black hole (SMBH). The observed correlation between the masses of SMBHs and the masses of their host galaxies strongly suggests that the formation of SMBHs is closely connected to galaxy formation.
  - the fact that virtually all spheroids are found to harbor a SMBH suggests that many, if not all, normal galaxies may have experienced an active phase in their past.
  - AGN are powerful energy sources, and their energy feedback may have important impact on the intergalactic medium as well as on the formation and evolution of galaxies. The effects of such feedback must be taken into account in any theory of galaxy formation and evolution.

Características observacionais

(I) a compact nuclear region much brighter than a region of the same size in a normal galaxy;

(II) non-stellar (non-thermal) continuum emission;

(III) strong emission lines;

(IV) variability in continuum emission and/or in emission lines on relatively short time scales.

Table 14.1. Local number densities.

Type of object	Number density [Mpc^{-3}]
Field galaxies	10^{-1}
Luminous spirals	10^{-2}
Seyfert galaxies	10^{-4}
Radio galaxies	10^{-6}
QSOs	10^{-7}
Radio-loud quasars	10^{-9}

Grupos de AGNs

- Classificação essencialmente histórica:

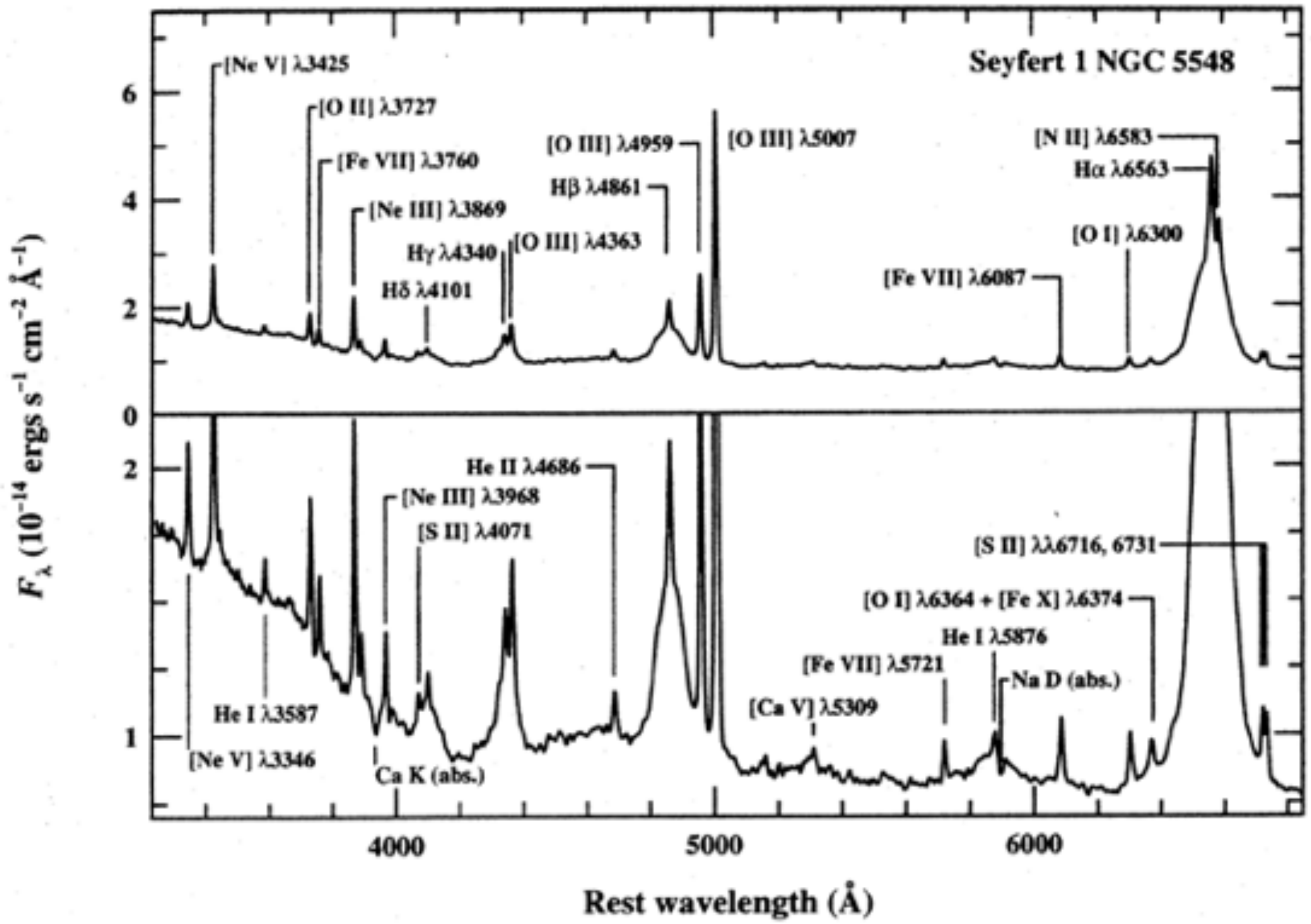
    - Seyfert 1 e 2
    - Liners (?)
    - Radio galáxias
    - Quasares e QSOs
    - Blazars (BL Lac e OVVs)

Seyfert Galaxies

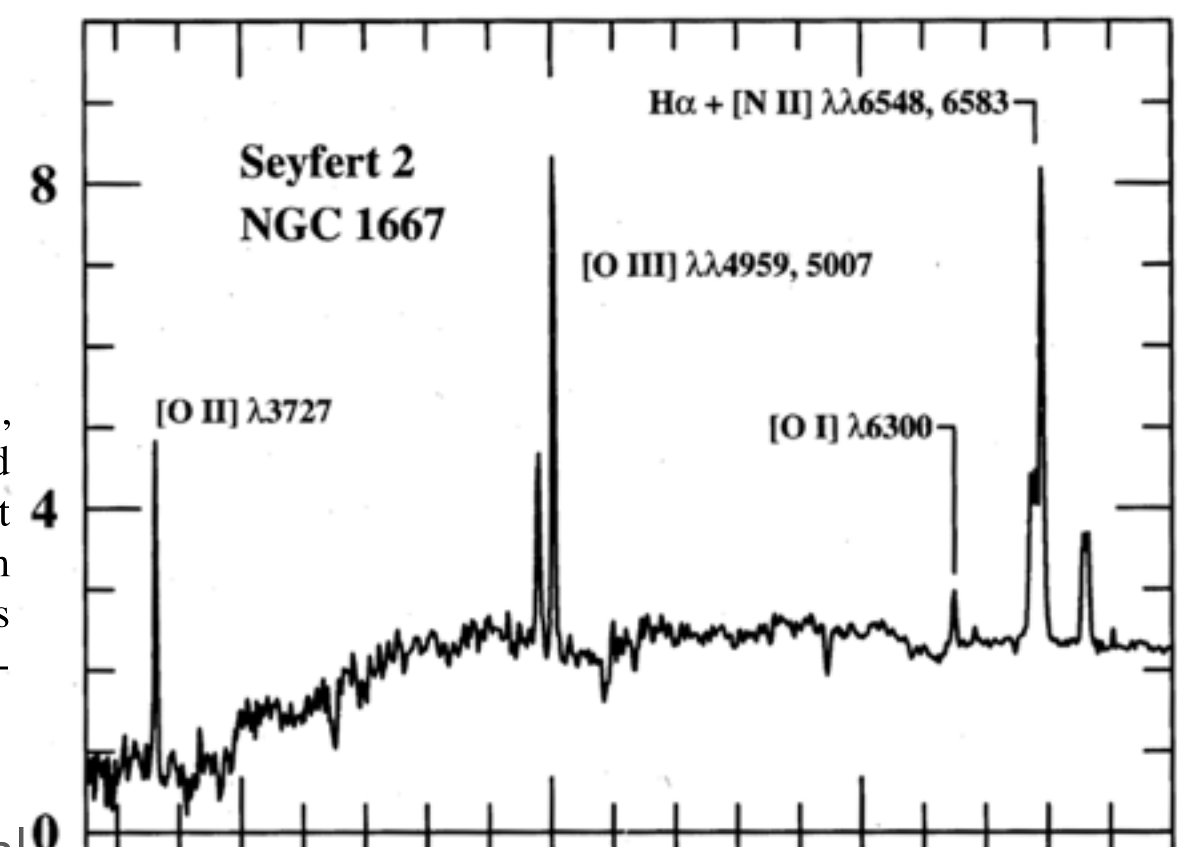
- Galáxias espirais com núcleos brilhantes
- SED: contínuo não-térmico e linhas de emissão intensas e alargadas, de níveis de alta excitação
- É comum apresentar variabilidade
- Tipo 1: linhas alargadas de transições permitidas de H, indicando velocidades de 1000 a 5000 km/s. Linhas proibidas (como [OIII]) estreitas (~10^2km/s)
- Tipo 2: todas as linhas são estreitas

NGC 7742

http://apod.nasa.gov/apod/ap981023.html



The optical spectrum of the Seyfert 1 galaxy [NGC 1275](). The prominent broad and narrow emission lines are labeled, as are strong absorption features of the host galaxy spectrum. The vertical scale is expanded in the lower panel to show the weaker features. The full width at half maximum (FWHM) of the broad components is about 5900 km s^{-1}, and the width of the narrow components is about 400 km s^{-1}. The strong rise shortward of 4000 Å is the long-wavelength end of the ``small blue bump'' feature which is a blend of Balmer continuum and FeII line emission. This spectrum is the mean of several observations made during 1993 with the 3-m Shane Telescope and Kast spectrograph at the Lick Observatory. Data courtesy of A. V. Filippenko.



The optical spectrum of the Seyfert 2 galaxy [NGC 1667]() is shown, with important emission lines identified (Ho, Filippenko, and Sargent 1993). Some strong absorption lines that arise in the host galaxy rather than the AGN itself are also identified. This spectrum can be compared with the spectrum shown in Figure 1. The units are: Wavelength (Å) for the x-axis and *F* (ergs s^{-1} cm^{-2} Å^{-1}) for the y-axis. Data courtesy of A. V. Filippenko.

http://ned.ipac.caltech.edu/level5/Glossary/Essay_seyfert.html

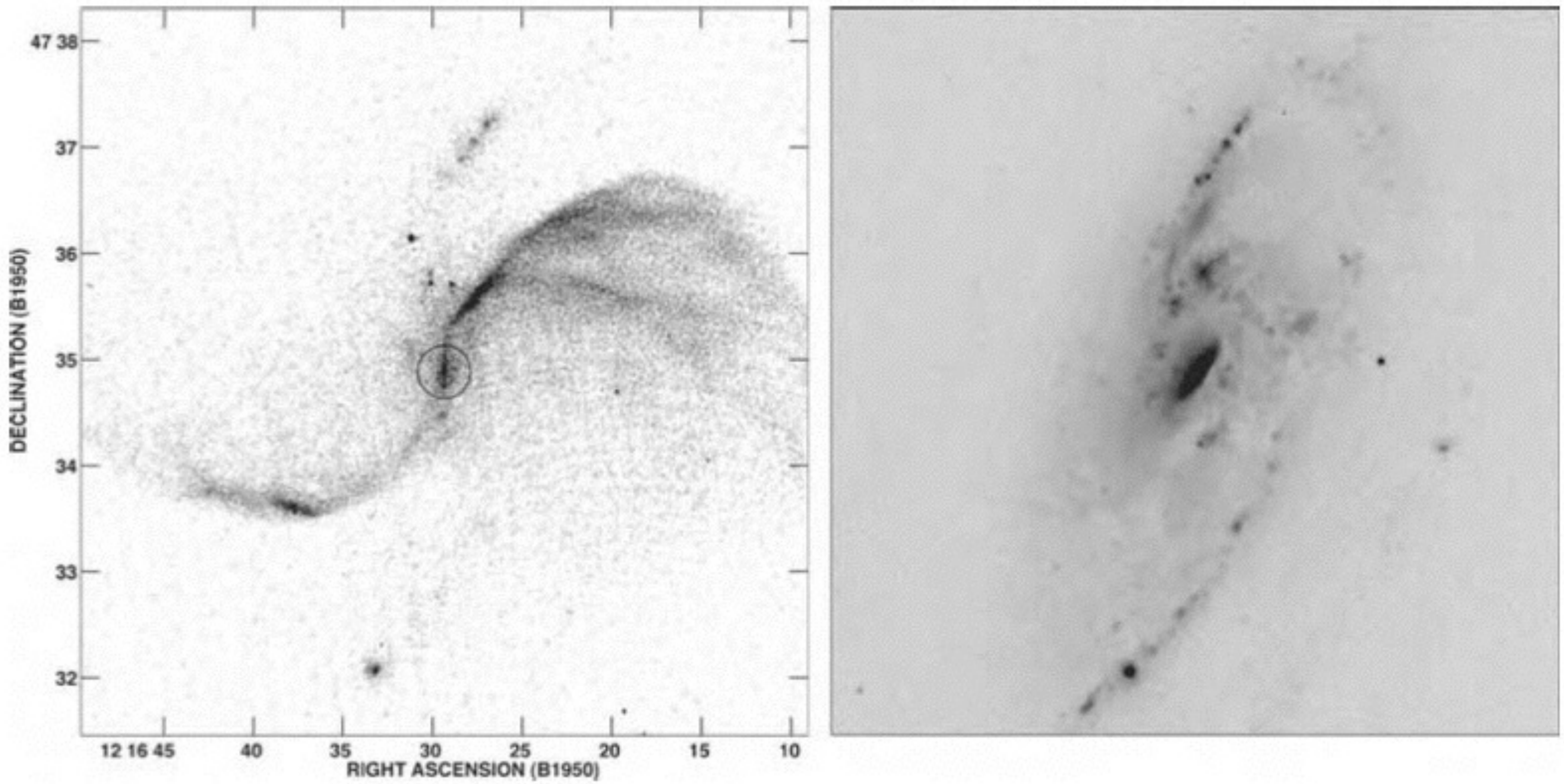


Fig. 9.2. Seyfert 2 galaxy NGC 4258 (Sbc). Left, a radio map at 20 cm shows oppositely directed twin jets (within the circle), channelling radio-bright plasma from the nucleus to lobes at east and west, and HII regions in the spiral arms. Right, an image in the U band at 3700 Å shows the bright center, and brilliant knots of young stars in the spiral arms. At distance $d \approx 7\,\mathrm{Mpc}$, $1' = 2\,\mathrm{kpc}$ – G. Cecil.

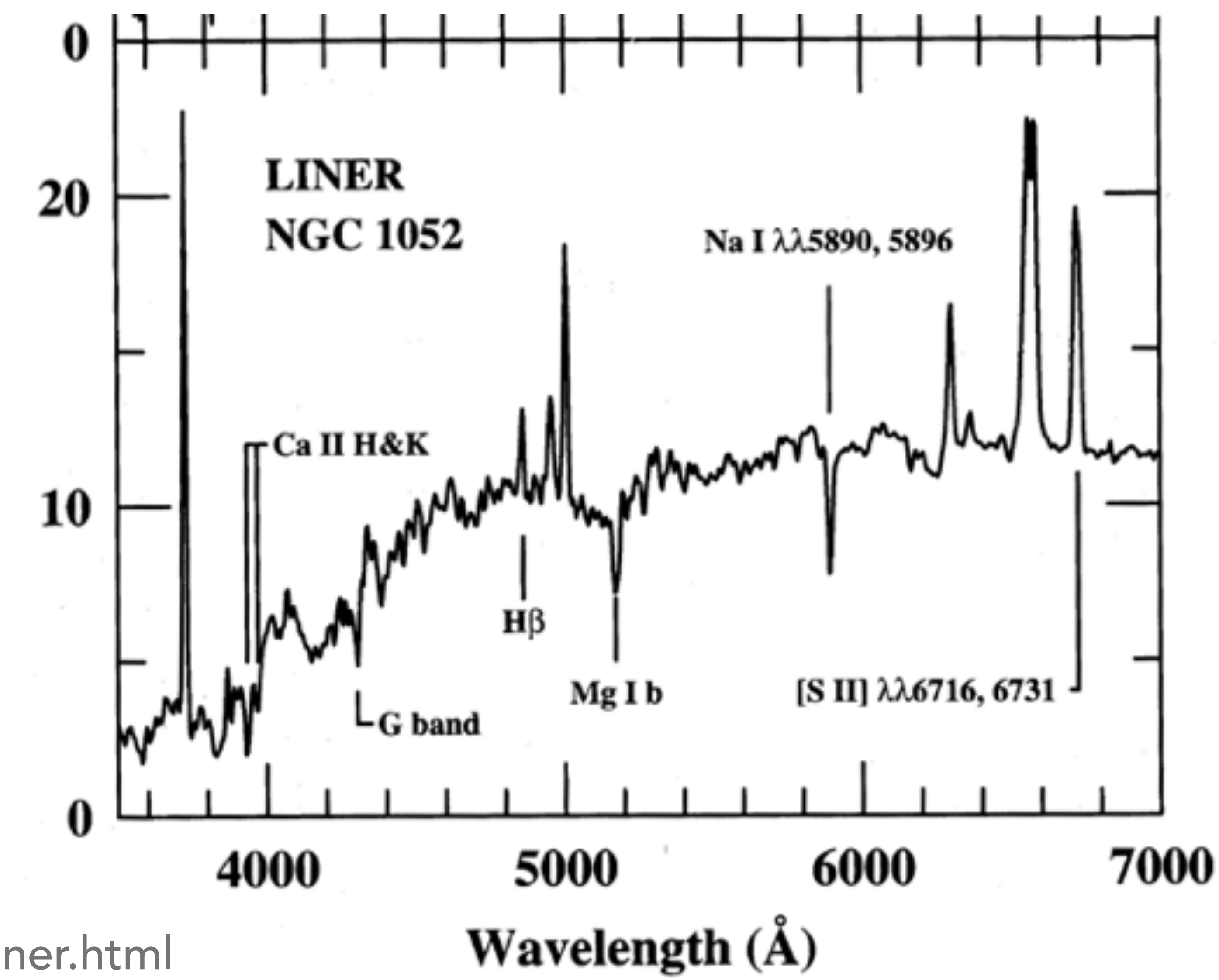
LINERs

- low-ionization nuclear emission line regions
- características semelhantes a Seyferts, mas as linhas proibidas se originam de átomos pouco ionizados ou neutros
- são bastante comuns (cerca de 1/3 das galáxias próximas, até 40Mpc)
- 75% as LINERs são elípticas, S0/a-Sab e são comuns em LIRGs
- Há um debate se a fonte de energia é AGN de fato, ou regiões de formação estelar intensas

Sombrero (M104)
http://www.spacetelescope.org/images/opo0328a/

LINERs

The optical spectrum of NGC 1052 is shown, with important emission lines identified (Ho, Filippenko, and Sargent 1993). Important differences between Seyfert 2s and LINERs are apparent: the [O III] 5007 / H flux ratio is much larger in Seyfert 2s than in LINERs, and low-ionization lines ([N II] 6716, 6731, [S II] 6548, 6853, [O II] 3727, and [O I] 6300) are all relatively prominent in LINER spectra. The y-axis units are F (ergs s^{-1} cm^{-2} $Å^{-1}$).



http://ned.ipac.caltech.edu/level5/Glossary/Essay_liner.html

Radio galáxias

- Galáxias com potência em 1.4GHz maiores do que $2 \times 10^{23} \mathrm{W\,Hz^{-1}}$
- Quase todas as rádio galáxias são elípticas
- Também são divididas entre broad-line (BLRGs) e narrow-line (NLRGs)
- Quase todas as rádio galáxias são elípticas
- É comum a existência de radio lobes que se estendem várias centenas de kpc a megaparsecs do núcleo e jatos

Fig. 14.2. Radio image of 3C175 (a prototypical FR II radio galaxy) at 4.9 GHz (see Bridle et al., 1994). The source has a redshift $z = 0.768$, and the overall linear size of the image is $212\,h^{-1}$kpc. The source shows double lobes with prominent hot spots, a narrow jet, but no counterjet. [NASA/courtesy of nasaimages.org]

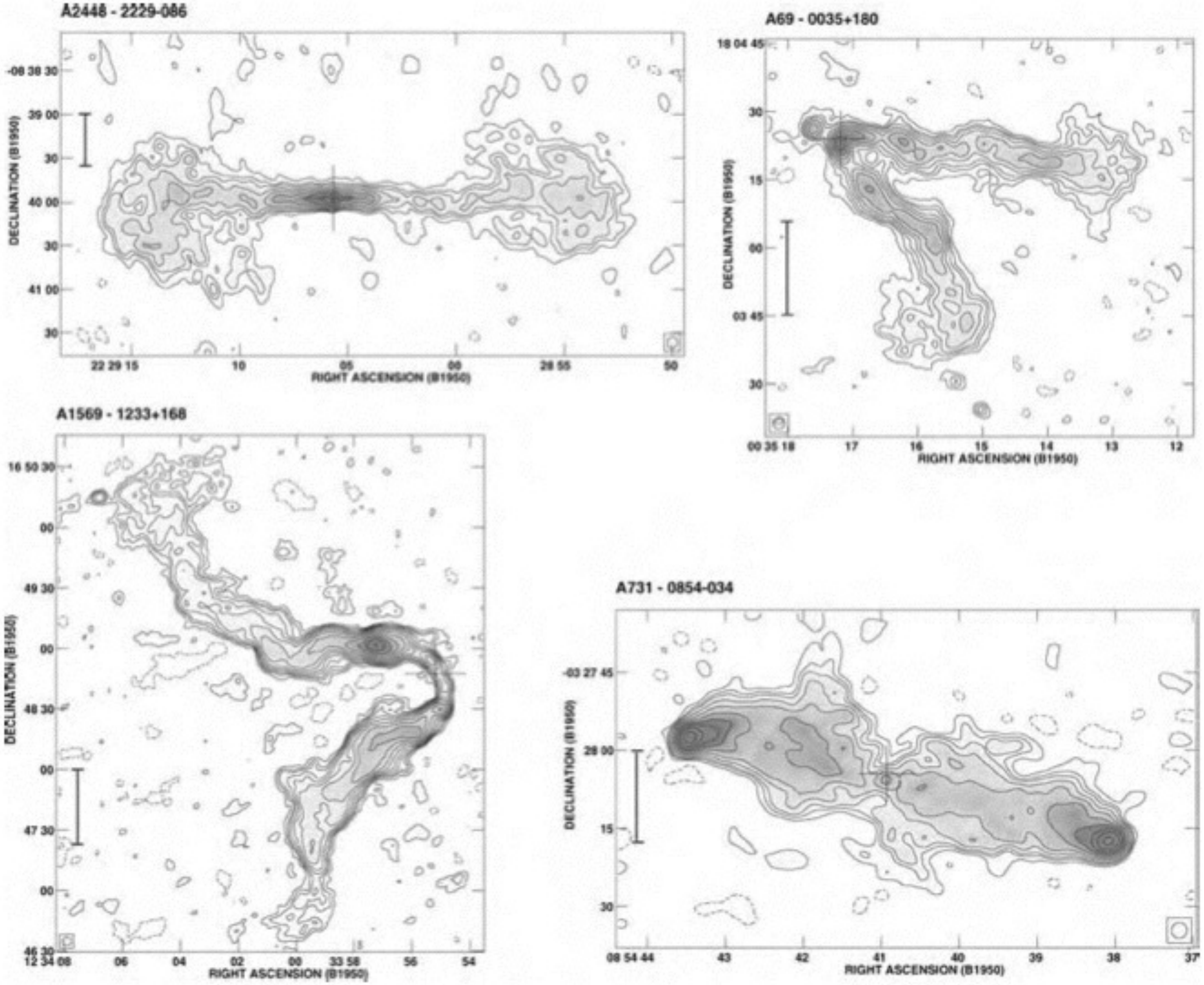


Fig. 9.4. Four radio galaxies, observed at 20 cm: galaxy luminosity L is measured in the R band, radio power P in units of $10^{25}\,\mathrm{W\,Hz^{-1}}$ at 20 cm. Clockwise from top left: a twin jet with $L \approx 6L_{\star}$, $P \approx 1$; a narrow-angle tail source ($L \approx 3L_{\star}$, $P \approx 1$); an edge-brightened classical double ($L \approx 1.4L_{\star}$, $P \approx 7$); and a wide-angle tail ($L \approx 2L_{\star}$, $P \approx 1.7$). The scale bar shows 50 kpc, assuming $H_0 = 75\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ and $\Omega_0 = 1$ – M. Ledlow.

Quasares e QSO

- Quasi-Stellar Radio Source: originalmente usado para as identificações ópticas de fontes de rádio compactas com espectro similar a Seyferts.

- As características em rádio são similares a fontes intensas de rádio, mas as imagens ópticas não são resolvidas, com núcleo luminoso e com frequência variável.

- Observações de rádio de alta resolução espacial mostram que os núcleos são bem compactos (~ 10^{-3} arcsec) e alguns revelam estruturas que parecem ser jatos, alguns super-luminais.

- As cores são unusualmente azuis, o que permitiu detectar a existência em óptico de diversos objetos similares mas que, surpreendentemente, não emitem em rádio => quasi-stellar object (QSO), que são quase 100 mais numerosos do que quasares.

- Em alguns livros coloca-se como distinção que quasar são radio-loud, e QSO são radio-quiet (mas há controvérsias sobre esta nomenclatura!)

Quasar e QSO

- Espectro óptico similar a Seyfert 1
- Luminosidades tão altas quanto ~1000L* (dificultando a detecção da galáxia hospedeira)

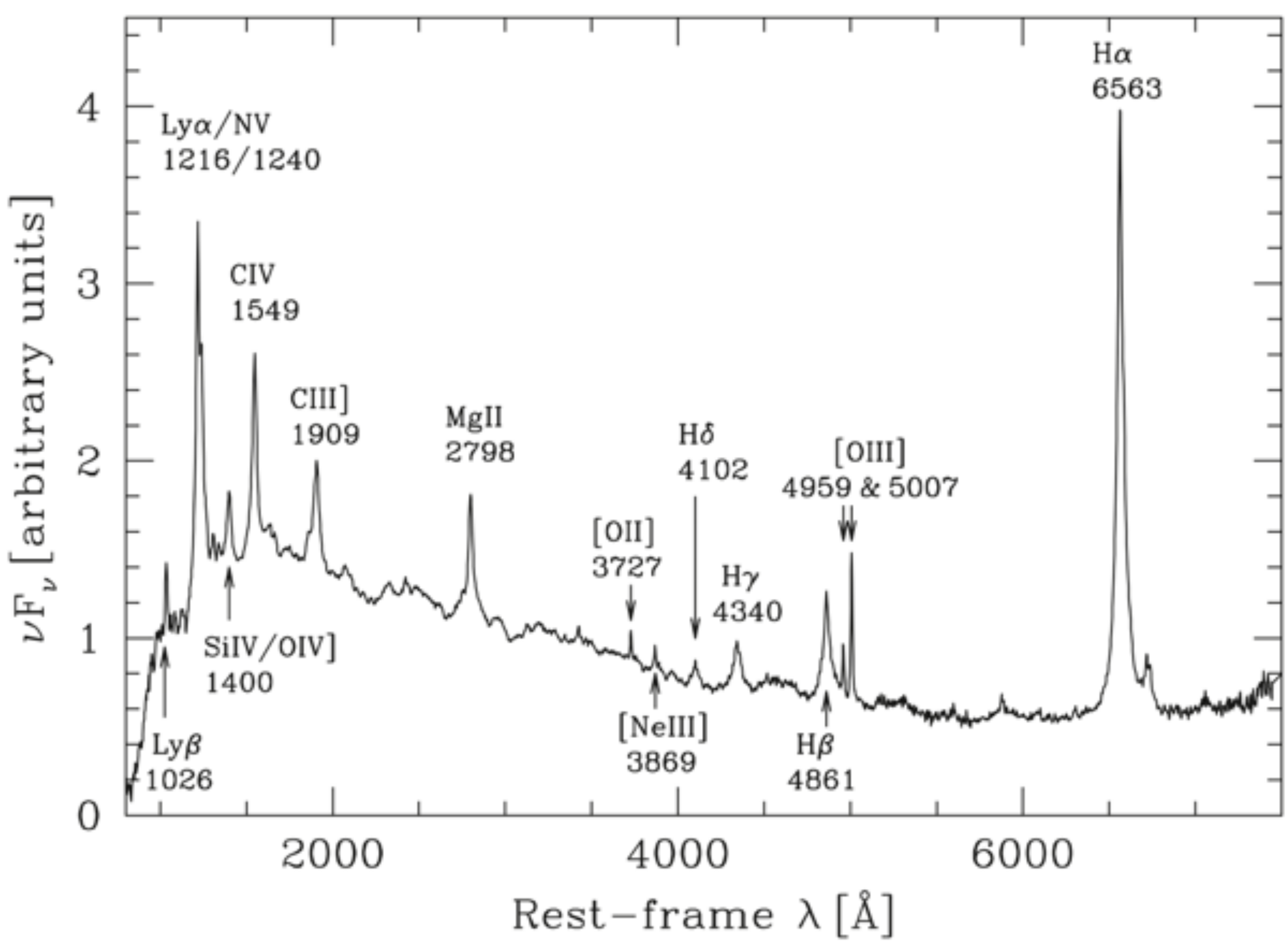
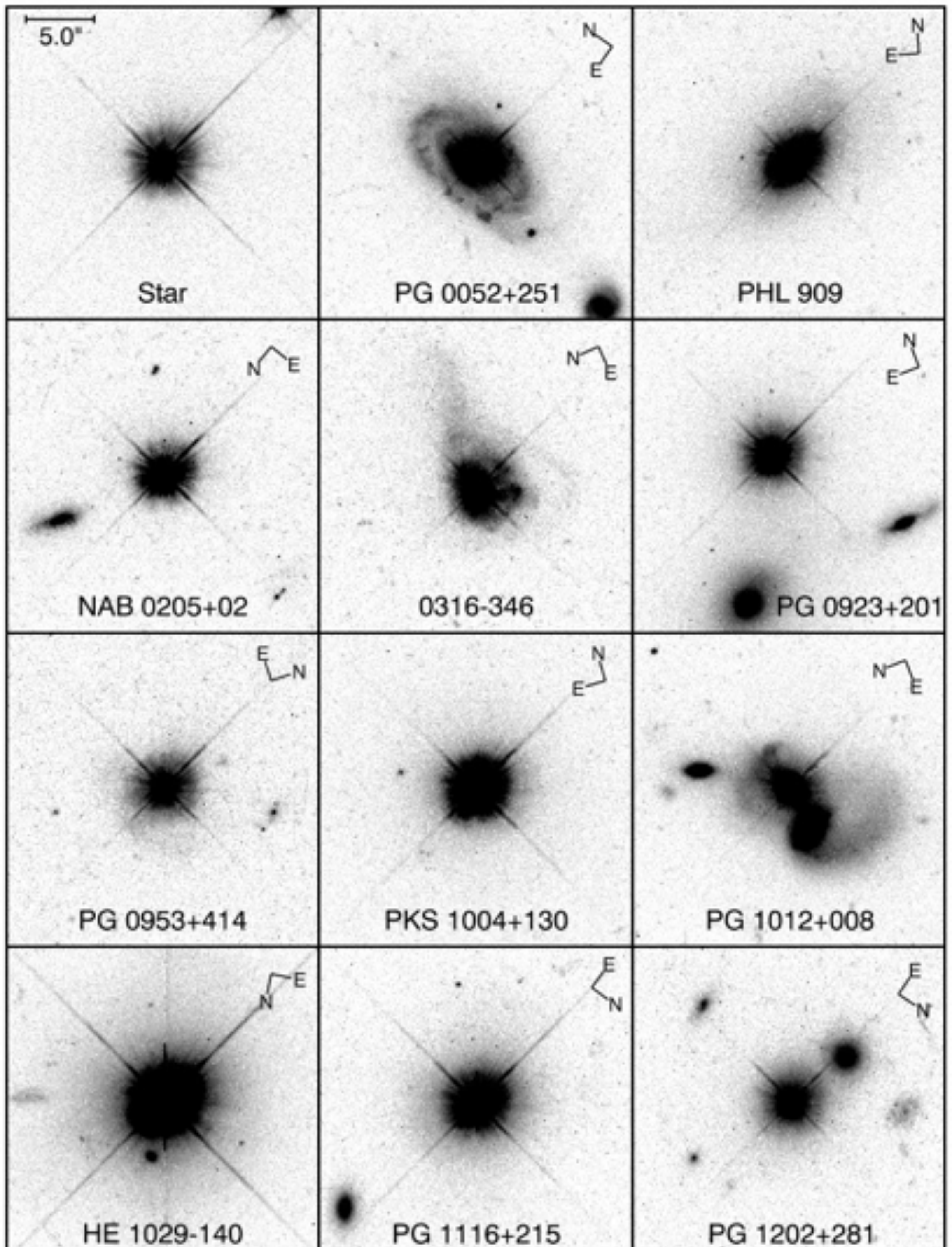
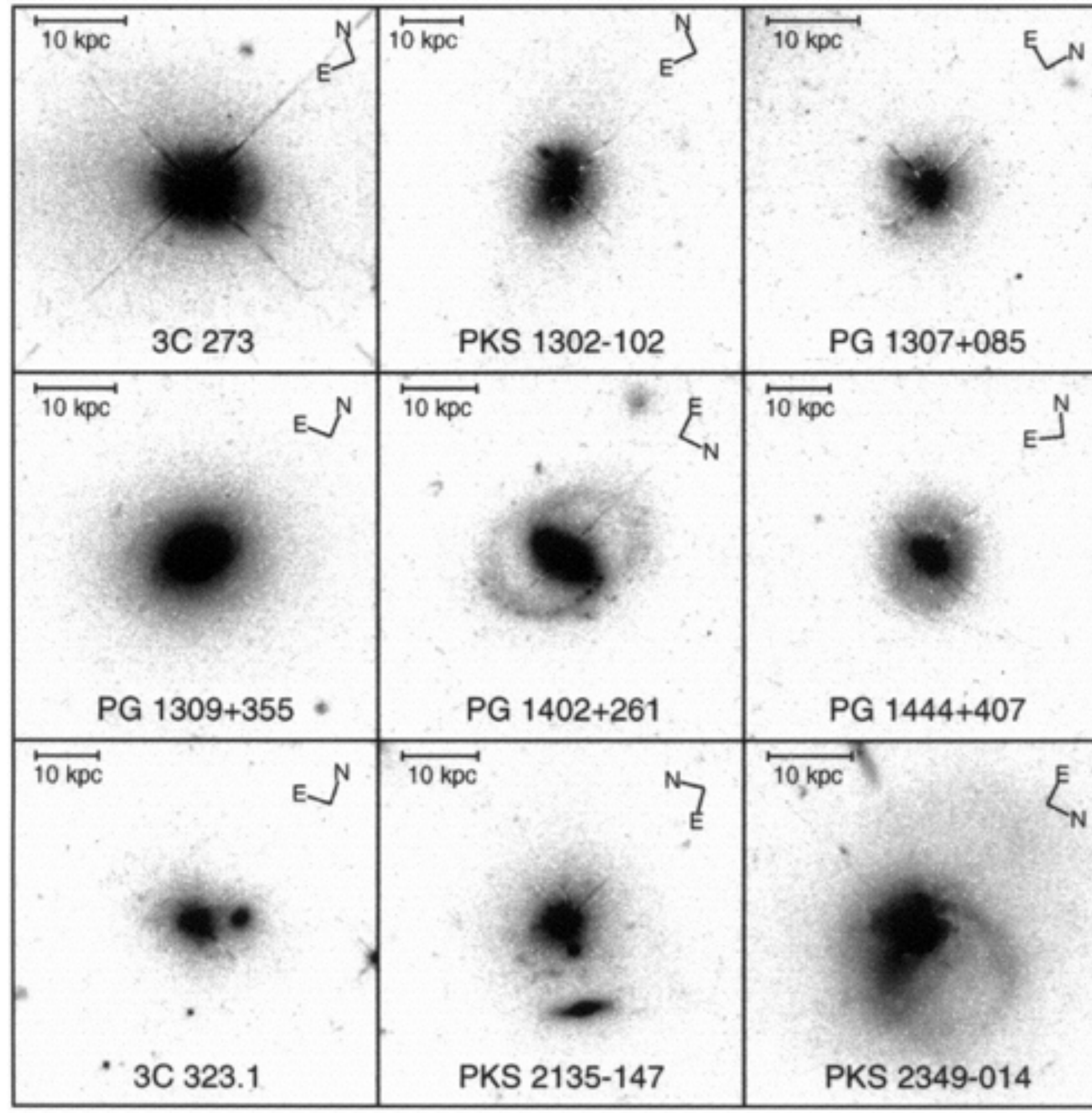


Fig. 14.1. A composite spectrum of QSOs revealing the typical non-thermal continuum and various emis- sion lines. Lines in brackets are forbidden lines, those in semibrackets are semiforbidden lines, and lines without brackets are permitted lines. Note that the permitted lines are much broader than the forbidden lines, as is typical for QSOs and Seyfert 1 galaxies. [Courtesy of C. Foltz and P. Hewett, based on an extension of the data published in Francis et al. (1991)]

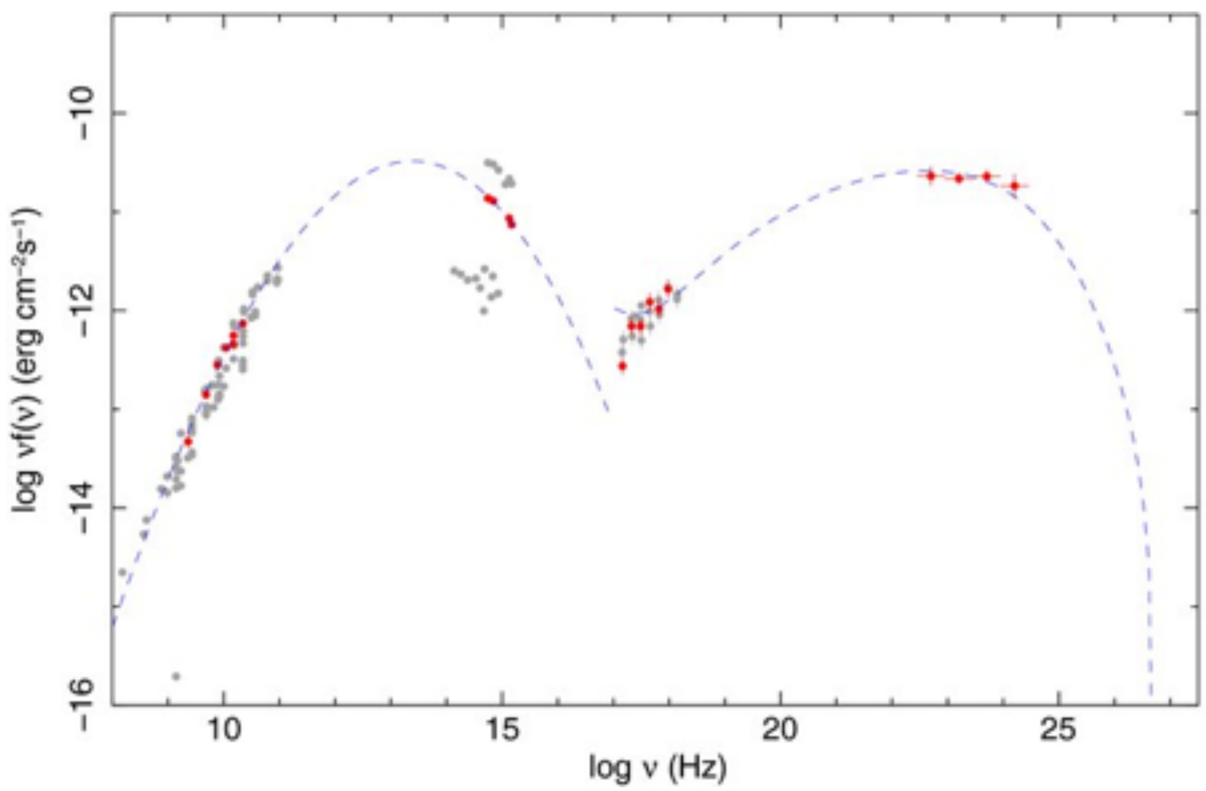


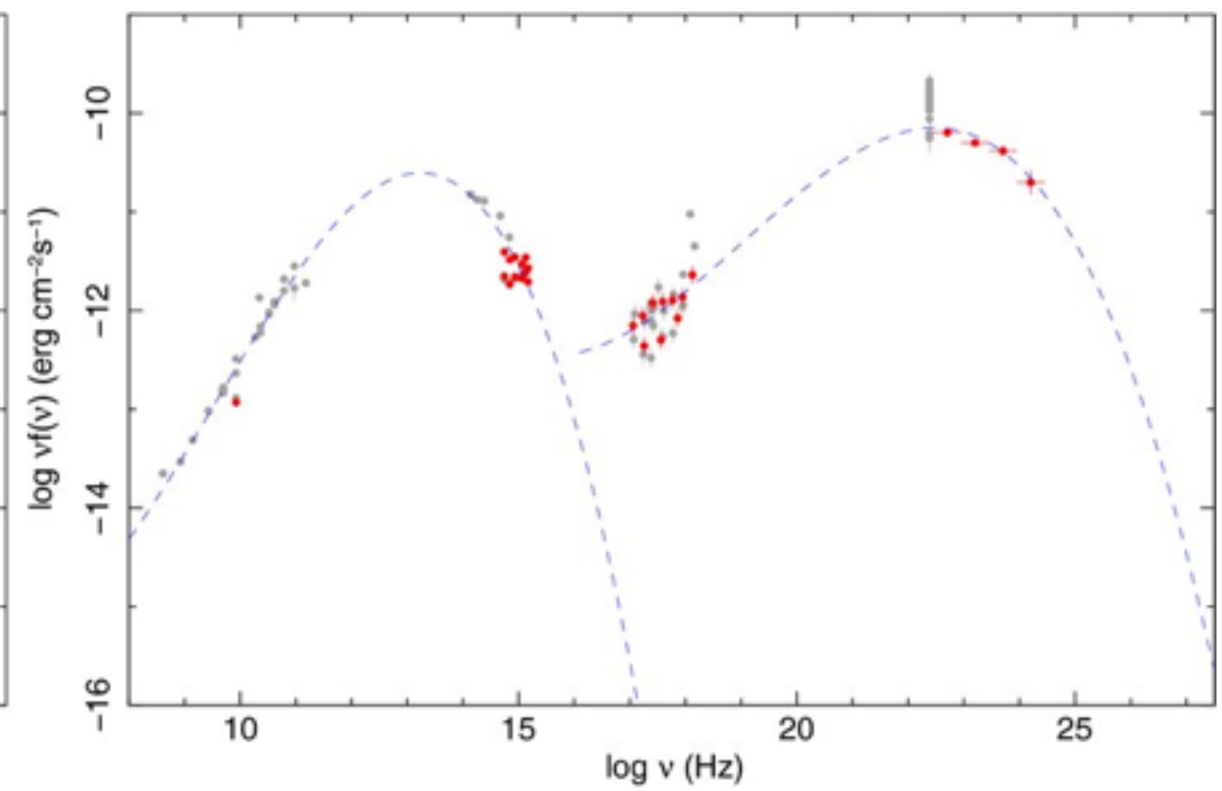


http://adsabs.harvard.edu/abs/1997ApJ...479..642B

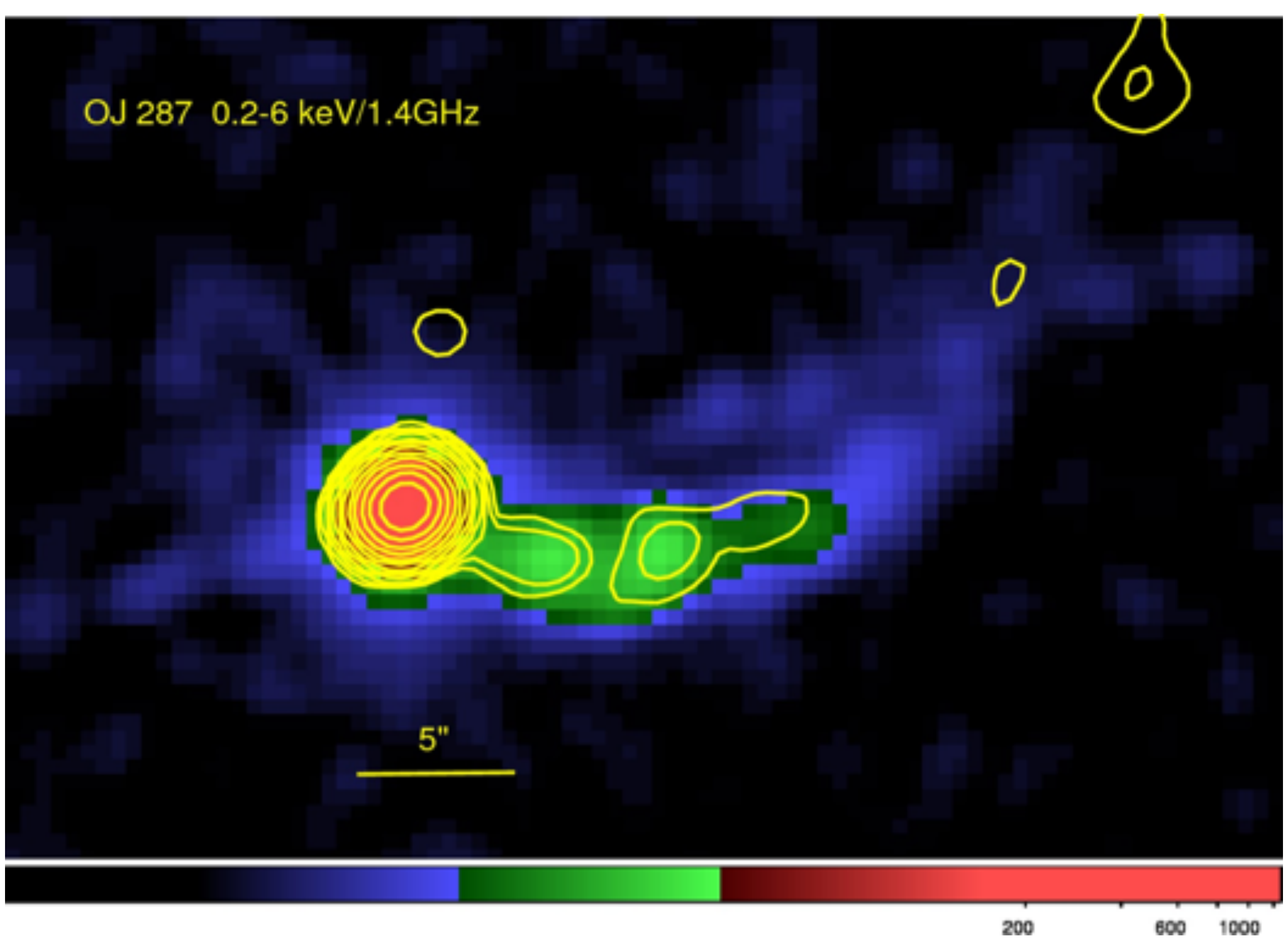
Blazares

- OVV
  - subclasse especial de quasares “optically violent variables” (fluxo óptico varia significativamente em menos de um dia)
  - alta polarização da luz (alguns % em comparação com <= 1% de quasares normais)
- BL Lac
  - mesmas propriedades dos OVV mas não apresenta linhas de emissão
  - mais frequentemente associados a elípticas



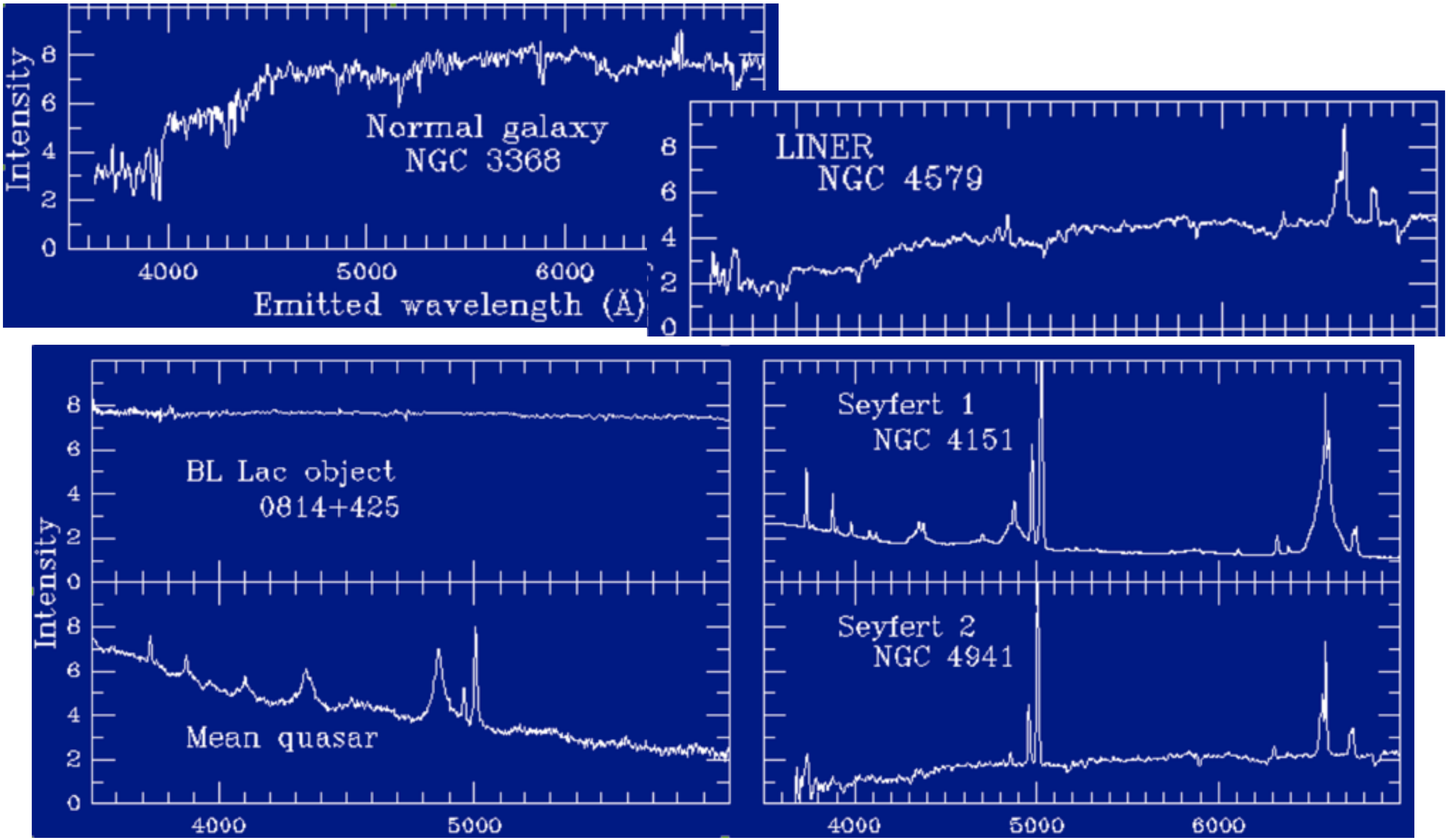


SED of 0FGL J0137.1+4751 = S40133+47 (left) and of 0FGL J0210.8 − 5100 = PKS0208-512 (right).
Abdo et al. (2010)



X-ray image from the Chandra X-ray Observatory; contours: 1.4 GHz radio image from the Very Large Array.
http://www.bu.edu/blazars/

Resumindo



Normal galaxy
NGC 3368
Intensity
Emitted wavelength (Å)
LINER
NGC 4579
BL Lac object
0814+425
Mean quasar
Seyfert 1
NGC 4151
Seyfert 2
NGC 4941
4000
5000
6000
0
2
4
6
8

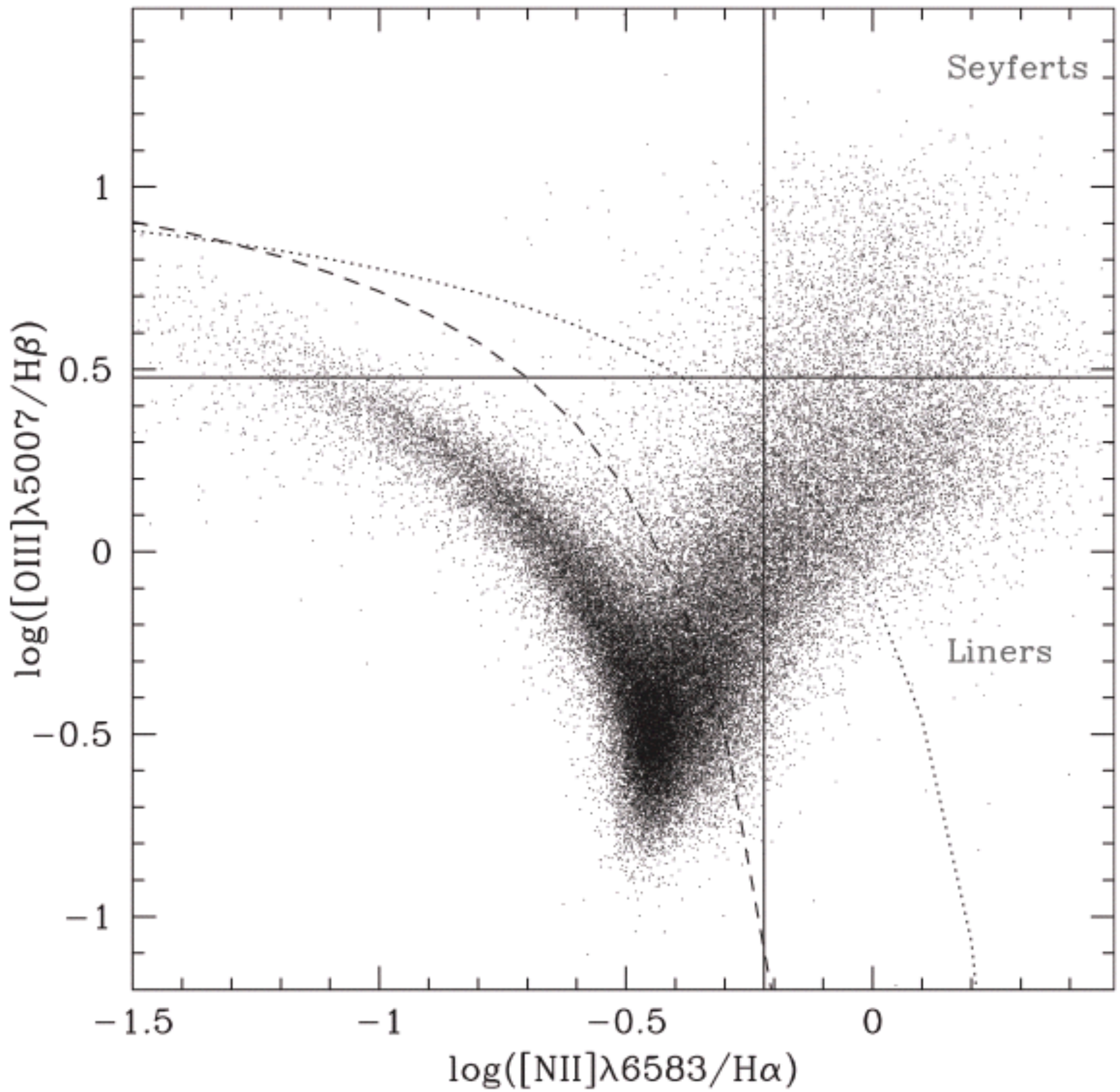


Fig. 14.6. The emission-line flux ratio [OIII]$\lambda 5007/\mathrm{H}\beta$ versus the ratio [NII]$\lambda 6583/\mathrm{H}\alpha$ for a galaxy sample constructed from the SDSS. A diagram of emission-line ratios like this is often called a BPT diagram, after Baldwin et al. (1981) who demonstrated its usefulness for separating AGN from normal star-forming galaxies. The dashed curve represents the demarcation line of pure star formation defined by Kauffmann et al. (2003a) and the dotted line is the extreme starburst demarcation line of Kewley et al. (2001). Seyfert galaxies are often defined to have [OIII]/H$\beta > 3$ and [NII]/H$\alpha > 0.6$, and LINERs to have [OIII]/H$\beta < 3$ and [NII]/H$\alpha > 0.6$. [Adapted from Kauffmann et al. (2003a)]

Modelo unificado de AGNs

The Supermassive Black Hole Paradigm

- In terms of energetics, an AGN is extraordinary in that it emits a large amount of energy from a very small region.
- An obvious question is how this energy is generated.
- It is now generally believed that this central engine is a supermassive black hole (SMBH), an idea originally proposed by Salpeter (1964), Zel'dovich & Novikov (1964) and Lynden-Bell (1969).
- In the SMBH paradigm, an AGN is assumed to be powered by a SMBH accreting gas, and the energy source is the gravitational potential of the central black hole.

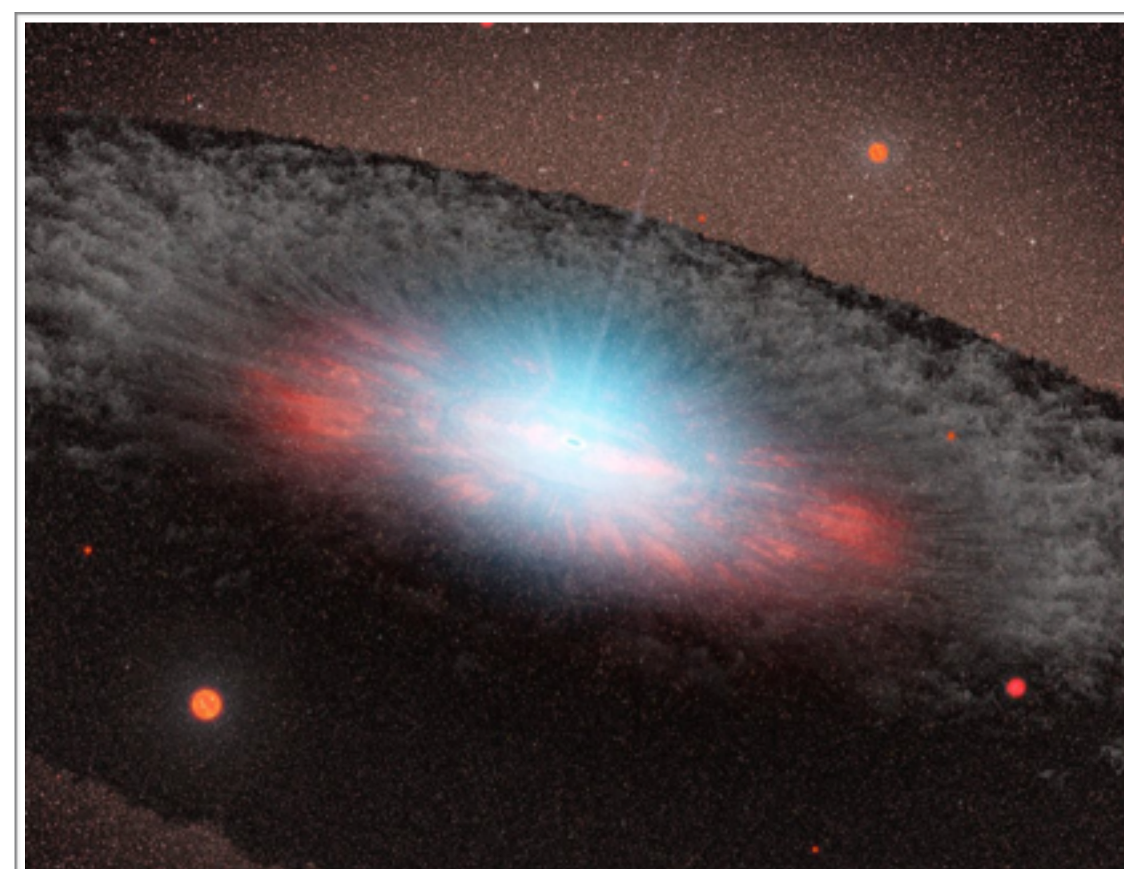
$$L = \frac{GM_{\rm BH}}{r}\dot{M}_{\rm BH}$$

$$L_{\rm Edd} \equiv \frac{4\pi G c m_{\rm p}}{\sigma_{\rm T}} M_{\rm BH} \approx 1.28 \times 10^{46} M_8 \,{\rm erg\,s^{-1}}$$

$$(M_8 \equiv M_{\rm BH}/10^8\,{\rm M_\odot})$$

Standard model

- Cold material close to a black hole forms an accretion disc.
- Dissipative processes in the accretion disc transport matter inwards and angular momentum outwards, while causing the accretion disc to heat up.
- A corona of hot material forms above the accretion disc and can inverse-Compton scatter photons up to X-ray energies.
- A large fraction of the AGN's radiation may be obscured by interstellar gas and dust close to the accretion disc, but (in a steady-state situation) this will be re-radiated at some other waveband, most likely the infrared.



An artist's conception of a supermassive black hole and accretion disk.
NASA JPL/Public Domain

SED

- Continua: relativistic electrons
  - Synchrotron radiation (charged particles being accelerated radially emit photons)
  - inverse-Compton (photons are scattered by electrons, gaining energy)
- Emission lines from atoms in excited states
  - Permitted lines
  - Forbidden lines (“improbable" lines; only in low density environments)

How can we explain the variety of AGN observed?

- All AGN are intrinsically the same and we are just viewing them differently?
- Each type of AGN is a distinct phenomenon?
- Some combination of 1 and 2

"Unified" Model consists of 2 schemes: radio-quiet & radio-loud

Unified Model

Radio-quiet

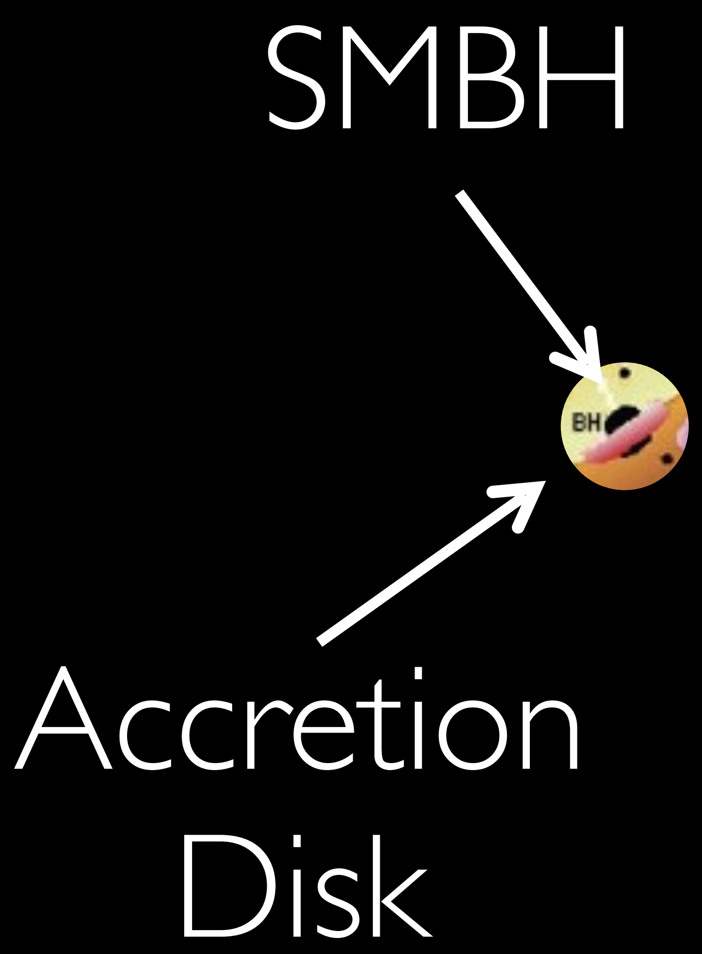
- Seyfert 1
- Seyfert 2
- QSO
- LINERs?

Radio-loud

- Quasars
- Blazars

All radio-quiet AGN have the same central engine

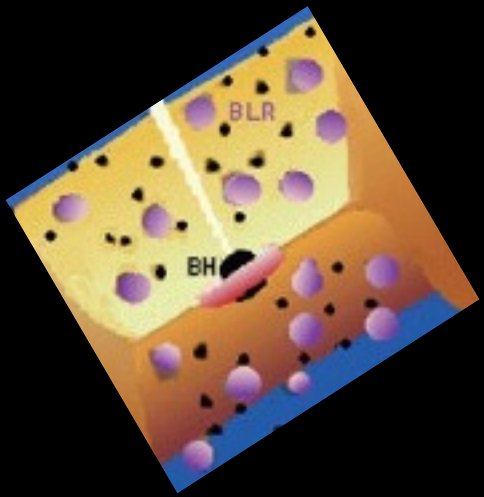
- Supermassive black hole + hot accretion disk at center



Credit: C. M. Urry and P. Padovani and slides by T. Esposito

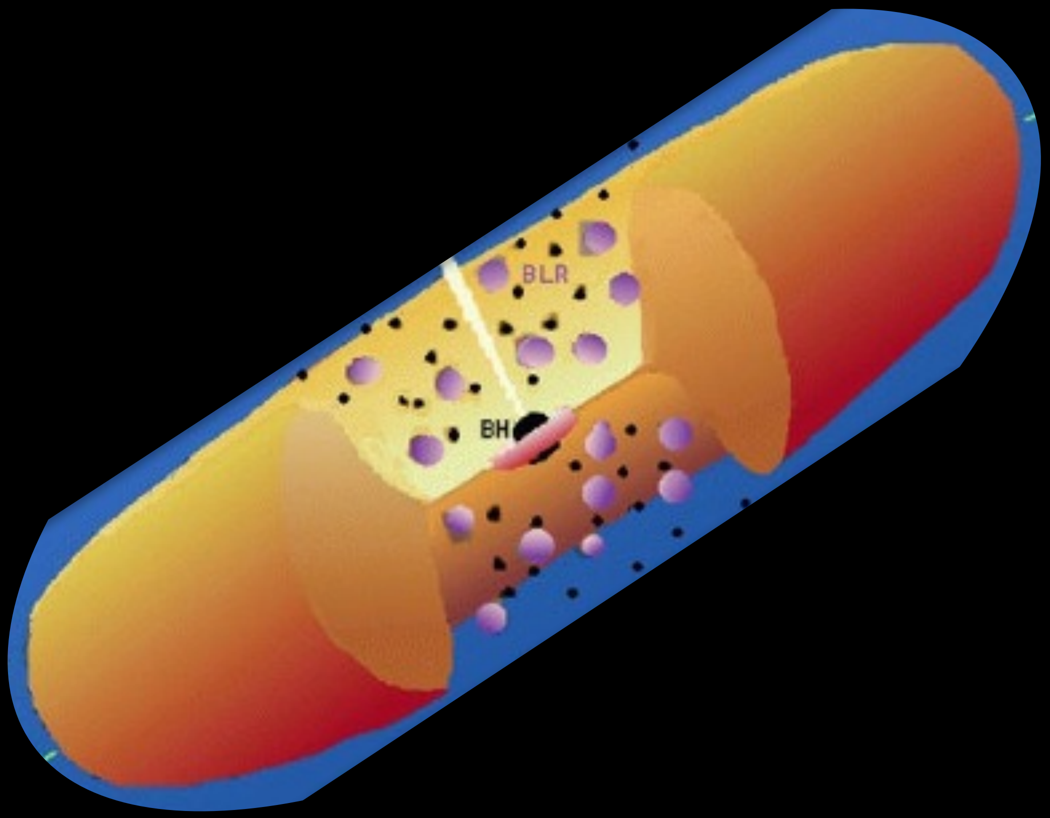
BLR gas excited by UV photons emits broad optical lines

- Supermassive black hole + hot accretion disk at center
- Hot, high velocity, dense gas clouds near BH form broad-line region



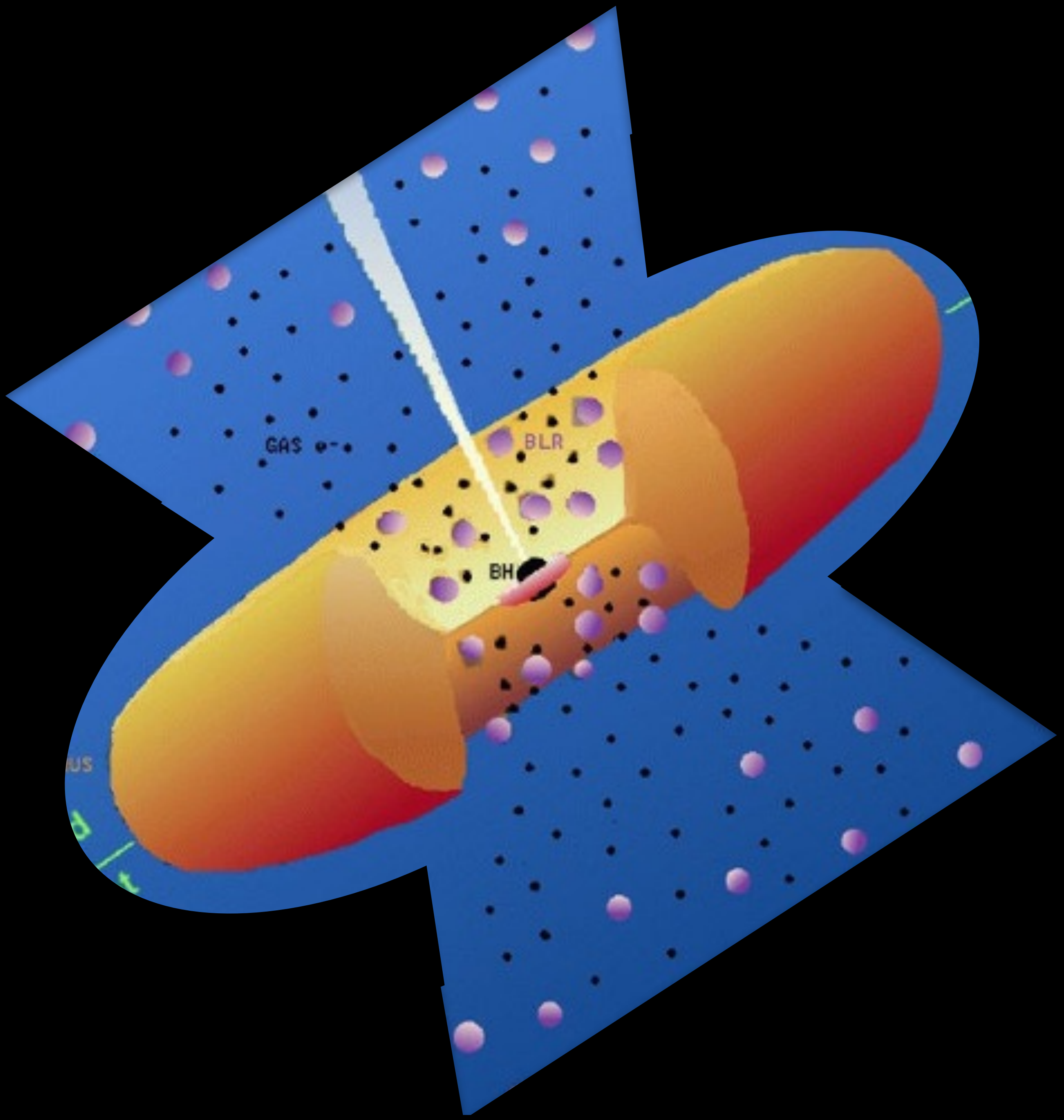
Dust & gas torus may obscure central regions of AGN

- Supermassive black hole + hot accretion disk at center
- Hot, high velocity, dense gas clouds near BH form broad-line region
- Dusty torus surrounds engine and broad-line region



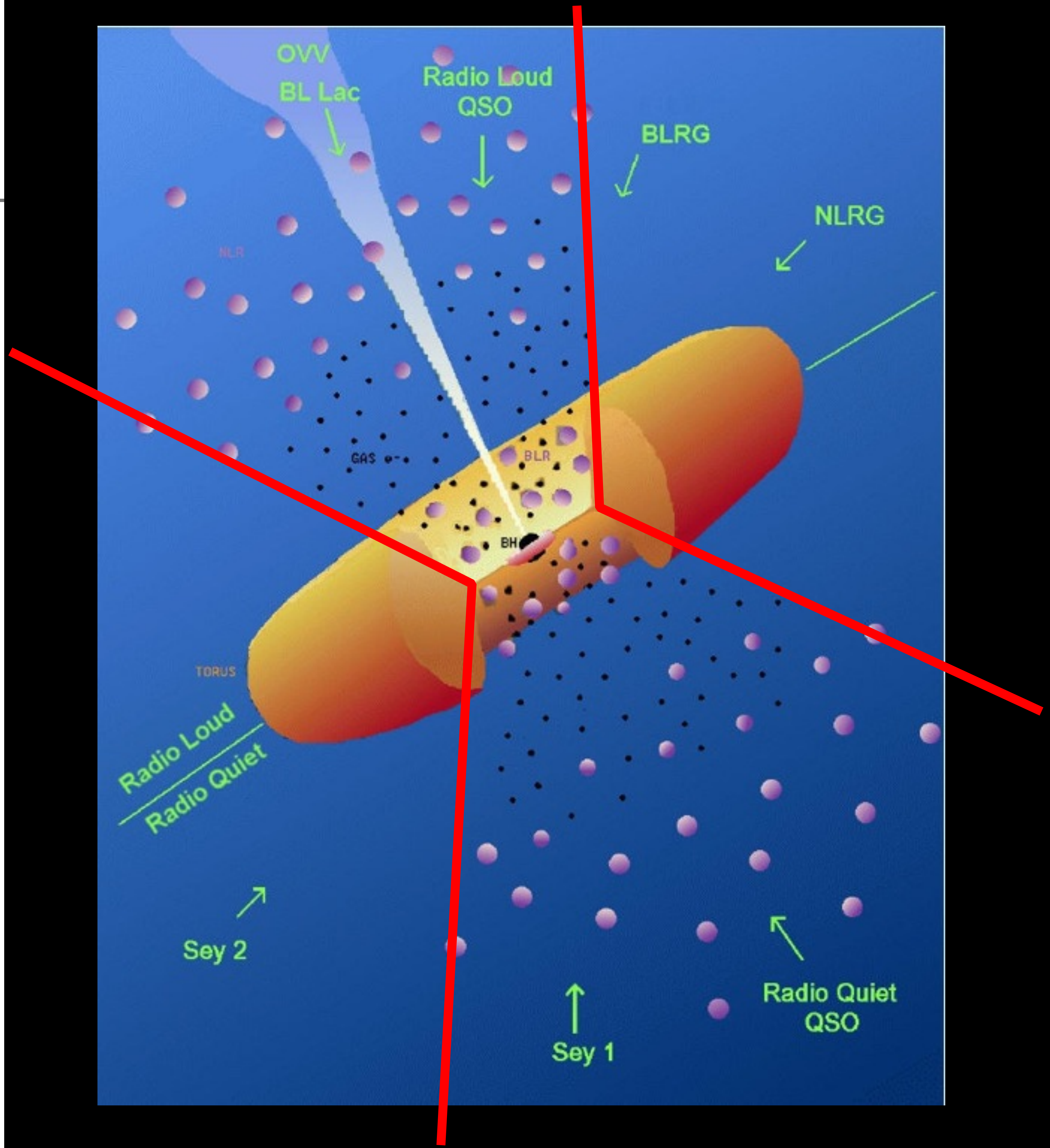
Hot electrons outside torus and BLR scatter nuclear emission

- Supermassive black hole + hot accretion disk at center
- Hot, high velocity, dense gas clouds near BH form broad-line region
- Dusty torus surrounds engine and broad-line region
- Hot electrons scatter polarized continuum + broad-line emission



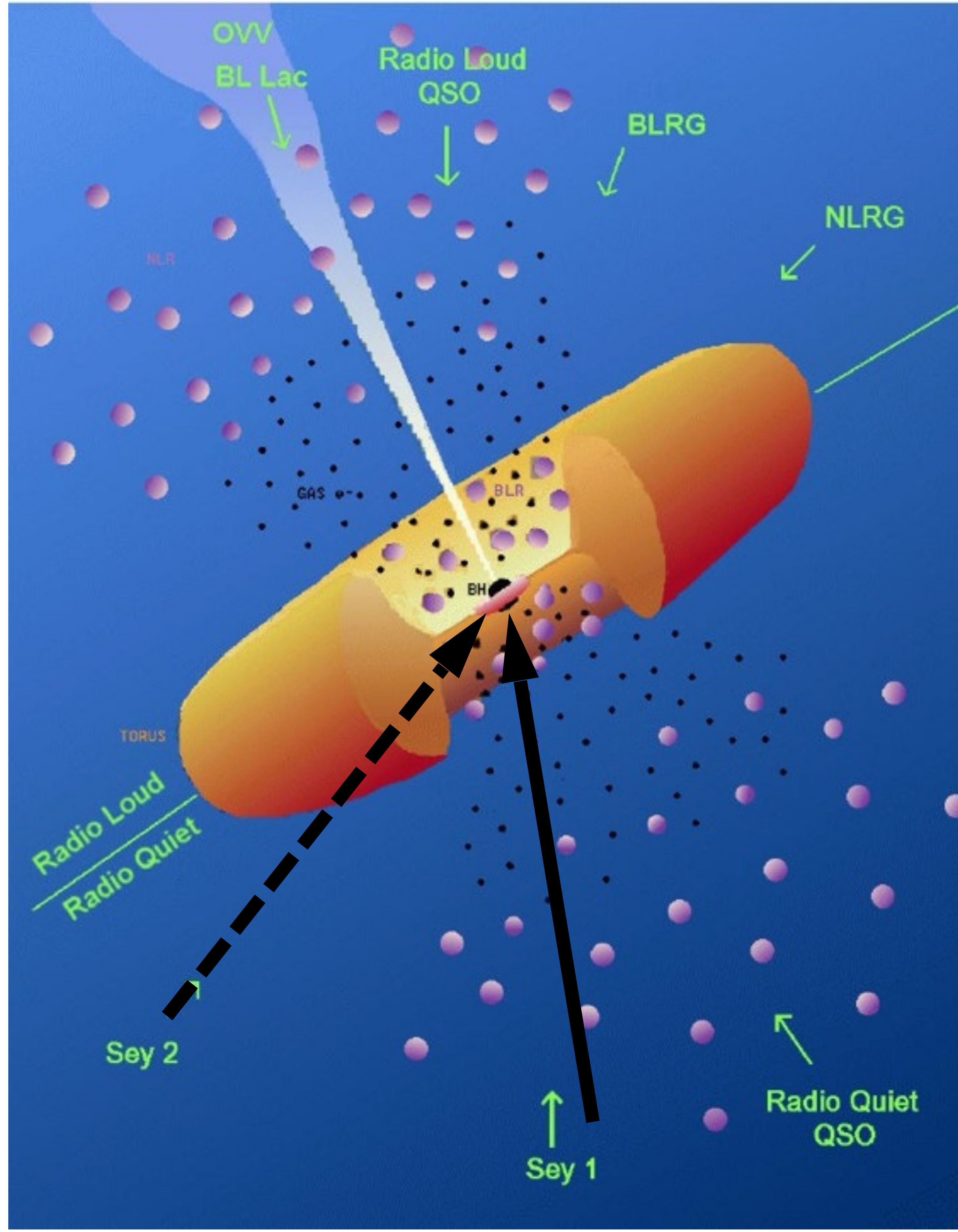
Narrow emission lines from gas within ionization cones

- Supermassive black hole + hot accretion disk at center
- Hot, high velocity, dense gas clouds near BH form broad-line region
- Dusty torus surrounds engine and broad-line region
- Hot electrons scatter polarized continuum + broad-line emission
- Cool, low velocity, low density gas clouds beyond torus edge form narrow-line region

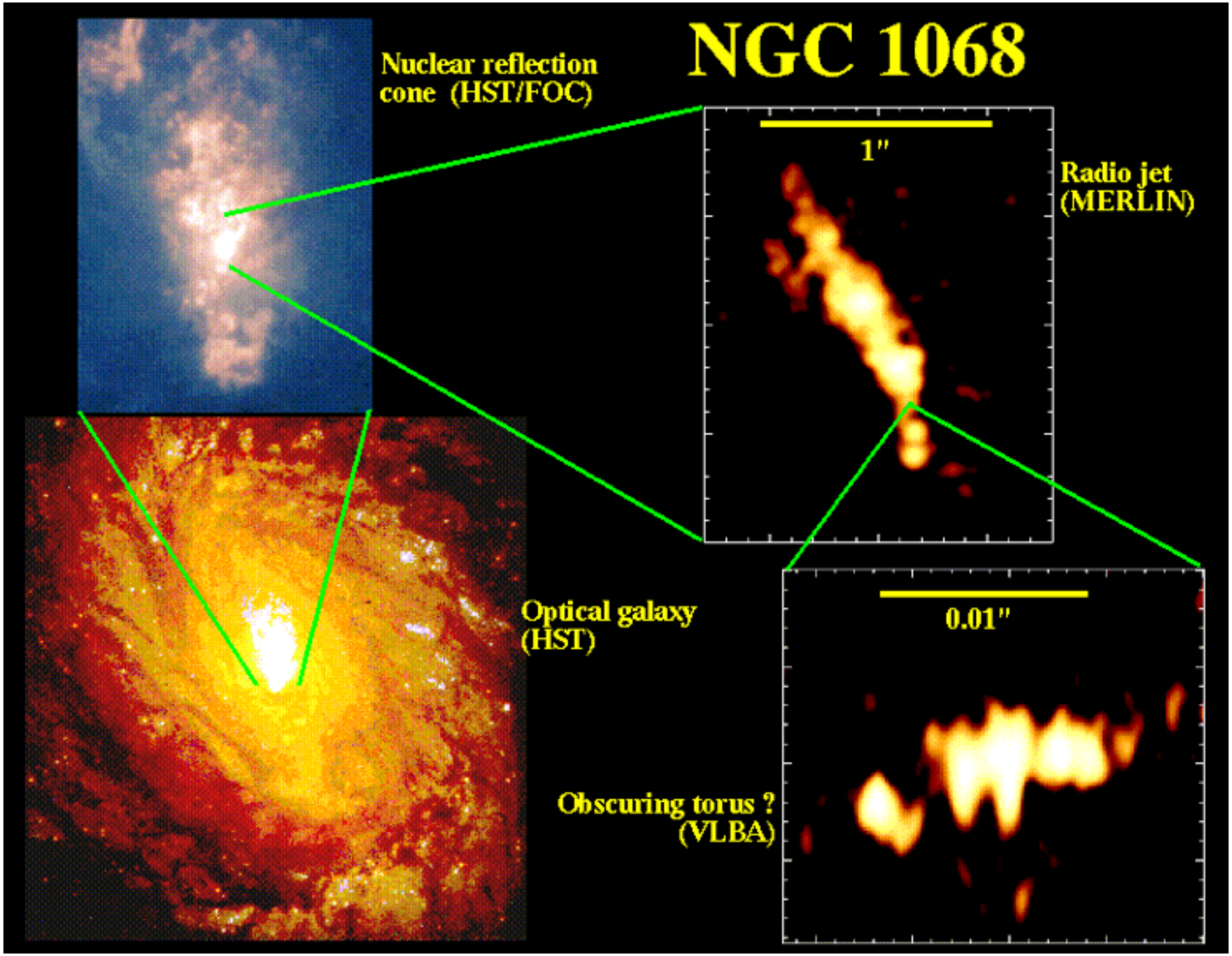


Orientation is the only factor that determines if we see a Type 1 or Type 2 AGN!

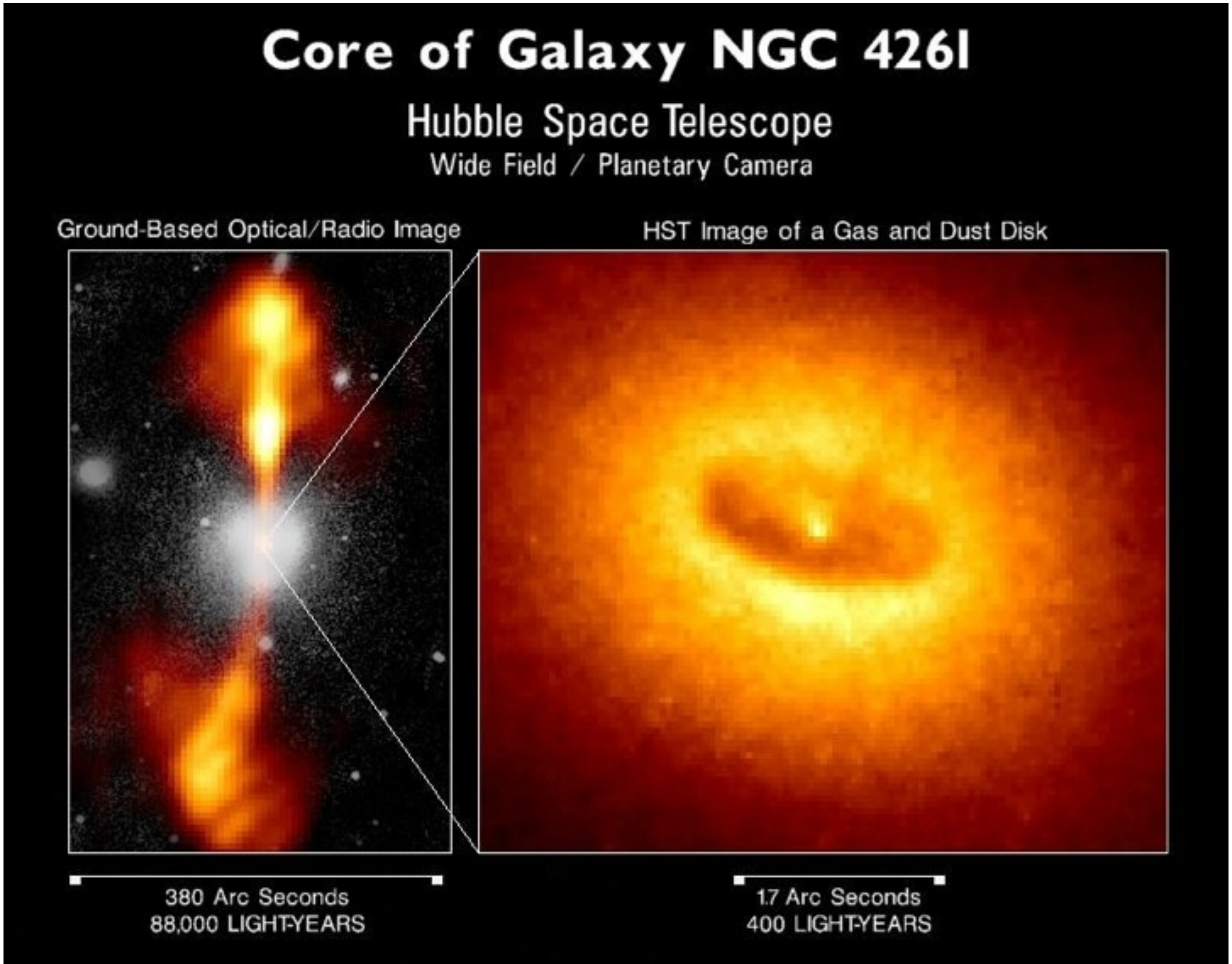
Radio-loud unification similar to radio-quiet but with radio emission



Direct imaging of disk-shaped dust around SMBH



Direct imaging of disk-shaped dust around SMBH



[Right]: A giant disk of cold gas and dust fuels a possible black hole at the core of the galaxy. Estimated to be 300 light-years across, the disk is tipped enough (about 60 degrees) to provide astronomers with a clear view of the bright hub, which presumably harbors the black hole. The dark, dusty disk represents a cold outer region which extends inwards to an ultra-hot accretion disk with a few hundred million miles from the suspected black hole. This disk feeds matter into the black hole, where gravity compresses and heats the material. Hot gas rushes from the vicinity of the black hole's creating the radio jets. The jets are aligned perpendicular to the disk.

Quasar versus radio-mode?

- In large ellipticals, there isn't large amounts of cold gas to form a torus and accretion disk
- SMBH still accrete hot gas through Bondi accretion:
    - spherical accretion onto an object, and occurs within a region where the gravitational potential of the black hole overcomes the specific thermal energy of the gas.
    - low accretion rate, but which may be sufficient to power many of the radio galaxies in the local Universe (e.g. Allen et al., 2006).
    - the standard geometrically thin, optically thick disk model described may not be valid. Instead, the disk may be geometrically thick and optically thin, as in the advection dominated accretion flow (ADAF) and advection dominated inflow–outflow solution (ADIOS) models (Narayan & Yi, 1994; Blandford & Begelman, 1999).

Evidence against the Unified Model or not?

- Recent efforts to reproduce mid-IR observations of Type-1 and Type-2 Seyferts by Almeida et al. 2011 used clumpy torus models
- They found more dependence on torus morphology than inclination
  - Type-2's have broader, clumpier, more opaque tori
- Does this matter *much* to the Unified Model?

Finally…

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Review

Galaxy formation theory

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A R T I C L E   I N F O

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Galaxy evolution
Galaxy formation

A B S T R A C T

We review the current theory of how galaxies form within the cosmological framework provided by the cold dark matter paradigm for structure formation. Beginning with the pre-galactic evolution of baryonic material we describe the analytical and numerical understanding of how baryons condense into galaxies, what determines the structure of those galaxies and how internal and external processes (including star formation, merging, active galactic nuclei, etc.) determine their gross properties and evolution. Throughout, we highlight successes and failures of current galaxy formation theory. We include a review of computational implementations of galaxy formation theory and assess their ability to provide reliable modeling of this complex phenomenon. We finish with a discussion of several "hot topics" in contemporary galaxy formation theory and assess future directions for this field.

Finally…

Contents

Topics of current interest

- The first galaxies
- The formation and sizes of galaxy disks
- The overcooling problem
- Local group dwarf satellites
- The origins of the hubble sequence

9. Future directions

The fundamental goal of galaxy formation studies is to comprehend how the laws of nature turned a Gaussian random distribution of density fluctuations laid down by inflation into a complex population of galaxies seen at the present day. At this time, this author does not see any convincing evidence that any new physics is needed to explain the phenomena of galaxies.[35] The problem is more one of complexity: can we tease out the underlying mechanisms that drive different aspects of galaxy formation and evolution. The key here then is "understanding". One can easily comprehend how a $1/r^2$ force works and can, by extrapolation, understand how this force applies to the billions of particles of dark matter in an

[35] By "new physics" here I mean modifications to established physical laws, new forces or fields etc. Of course, dark matter and dark energy probably require "new physics" of one type or another, but I will leave those as a problem for cosmology....

distinguishable, incorporating aspects of each other into each other (once again, yin yang).

Galaxy formation benefits from a wealth of observational data, often to the degree that it is an observationally lead field in which theory plays the role of trying to explain observed phenomena. This deluge of data is unlikely to cease any time soon—we can expect more and higher quality data on local galaxies and also the arrival of usefully sized datasets of galaxies at the highest redshifts. Galaxy formation theory should continue to attempt to develop our comprehension of these observed phenomena but should also strive to move into the regime of making true predictions for as-yet-unobserved regions of parameter space (e.g. the high redshift, $z \gtrsim 6$, Universe; e.g. Finlator et al., 2010; Lacey et al., 2010). Only in this way can we grow our confidence that we have truly understood the physics of galaxy formation.

10. Summary

Our theory of galaxy formation is gradually becoming more and more complete, but it is clear that large gaps in our understanding remain. This is, perhaps, not surprising—galaxy formation incorporates a wide array of physical processes, many of which we can currently observe the consequences of only indirectly. Most of the physics of galaxy formation is inherently nonlinear, making it difficult to obtain accurate solutions. Finally, what we observe from galaxies is usually several steps removed from the underlying physical properties (mass, density etc.) that we would ideally like to know about. Despite all of these difficulties, rapid progress is being made. The next decade should see this trend continuing via a combination of ever better observational datasets (both low and high redshift) and the continued development of novel theoretical tools.