Overview of Active Galactic Nuclei

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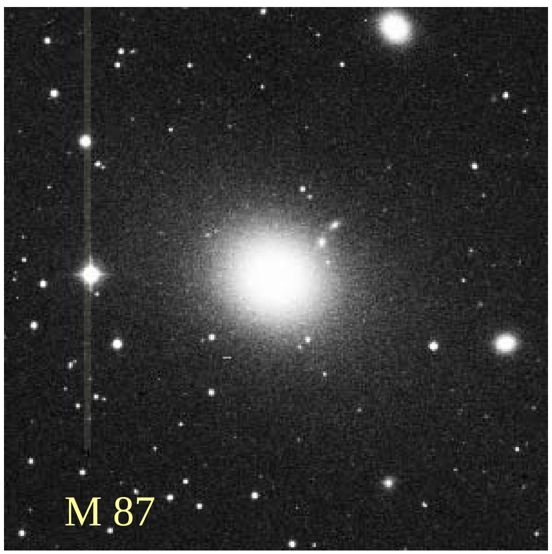
Outline

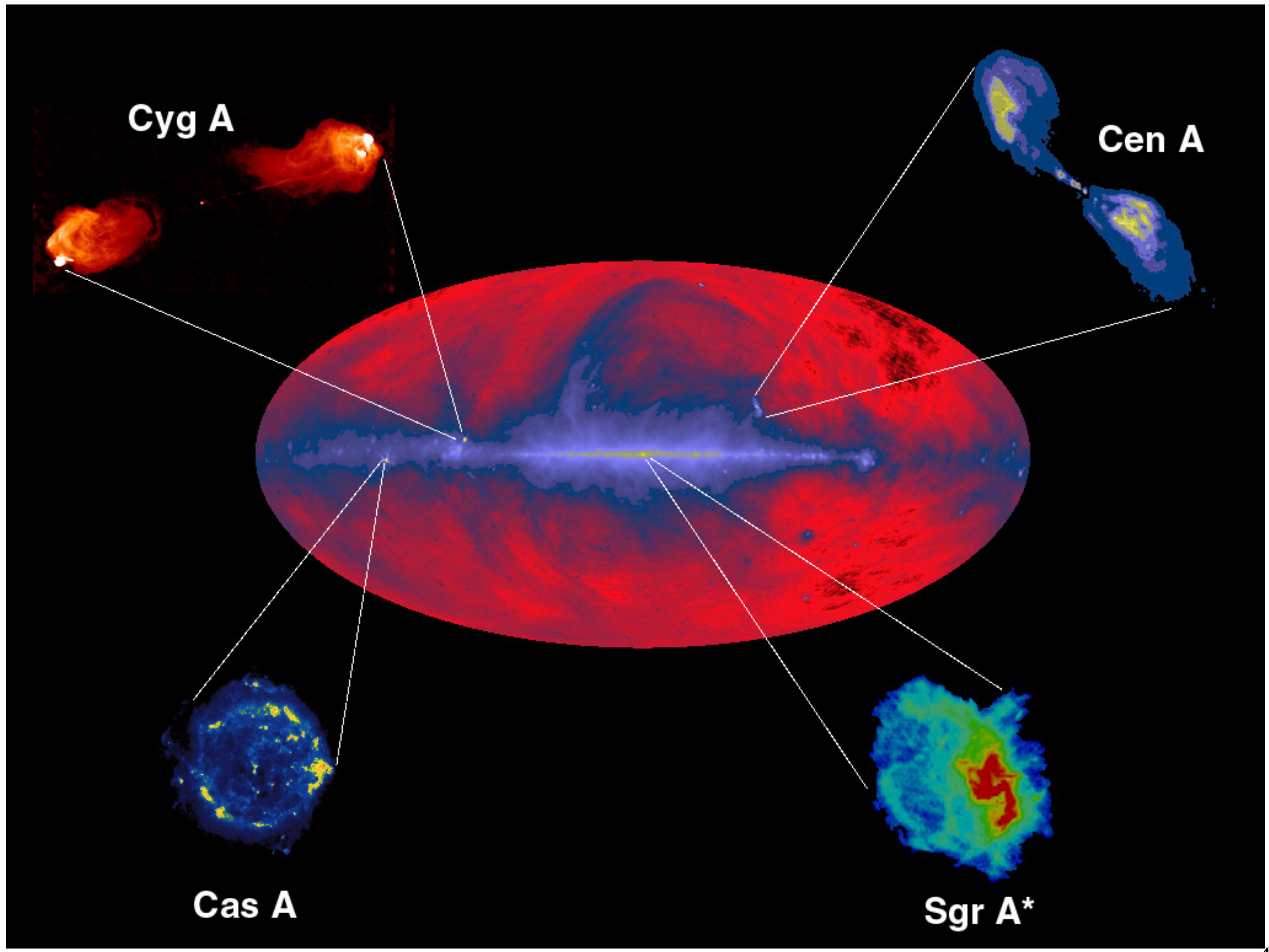
- Brief account of AGN studies
- Specific properties of AGN
- Major constituents of AGN
- AGN „gallery“
- AGN nomenclature and unification
- Astrophysical relevance of AGN

Discoveries and Properties

The Discovery I

- Curtis (1917): a „curious straight ray" in M87
- Radio surveys: extragalactic objects, often compact.





The Discovery II

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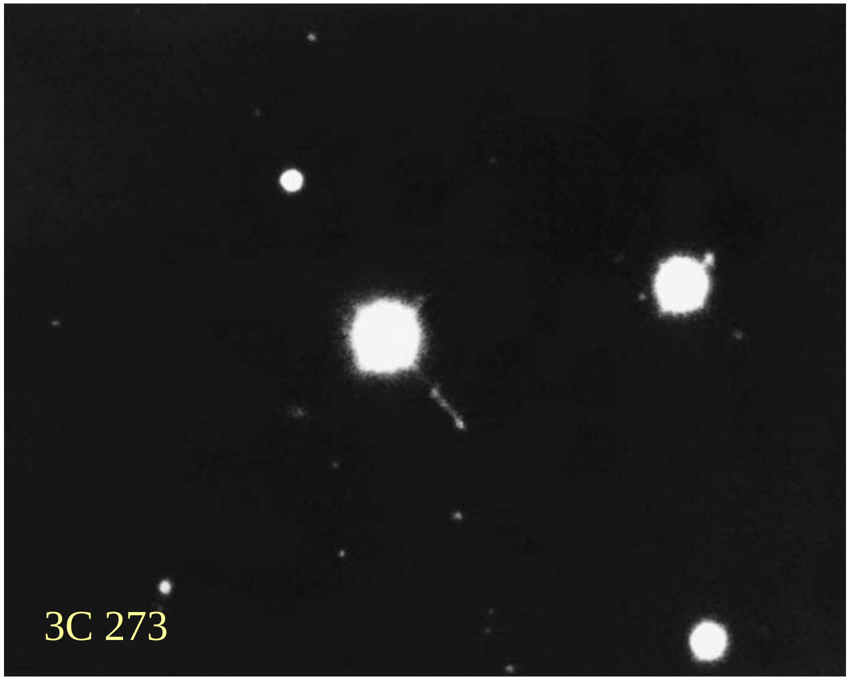
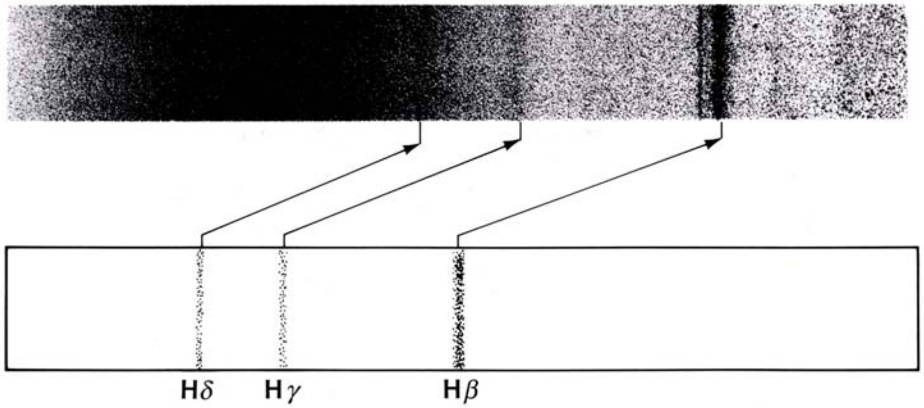
- ❑ Seyfert (1943): broadened line profiles in some galaxies.
- ❑ Maarten Schmidt: identification of 3C273 as an object at a redshift of 0.158 – the first quasar is „unveiled".



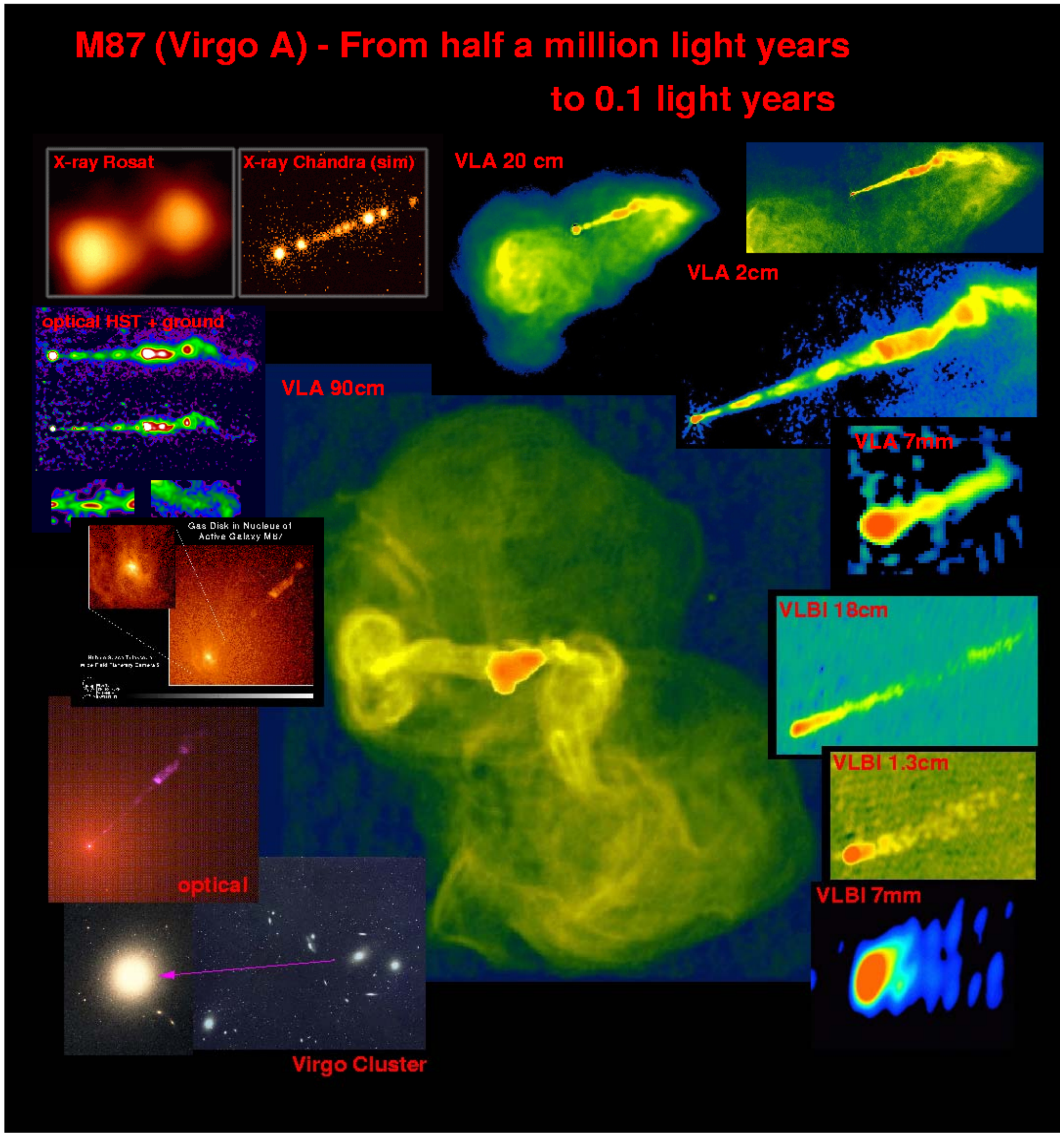
3C273 and its optical spectrum



Nuclear Activity: A Summary

Nuclear activity in galaxies

- is ubiquitous: a large fraction of galaxies exhibit some level of activity
- comes in many faces: quasars, BL Lac, RG, Sy 1,2, LINERs…
- covers the entire range of the electromagnetic spectrum
- spans over 12 orders of magnitude in spatial and temporal domain
- reflects processes and physical conditions in the immediate vicinity of a BH
- can be observed throughout much of the Universe: from the Galactic Center to z>10
- affects processes in galaxies and in the Universe at large



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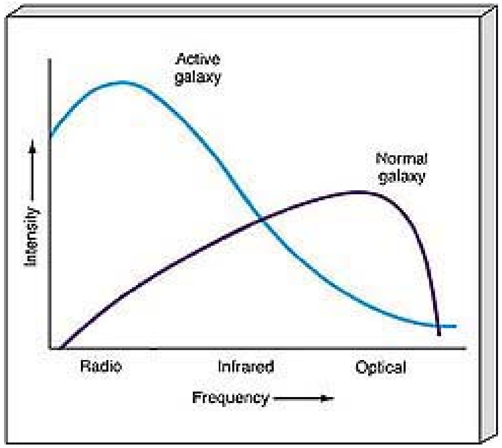
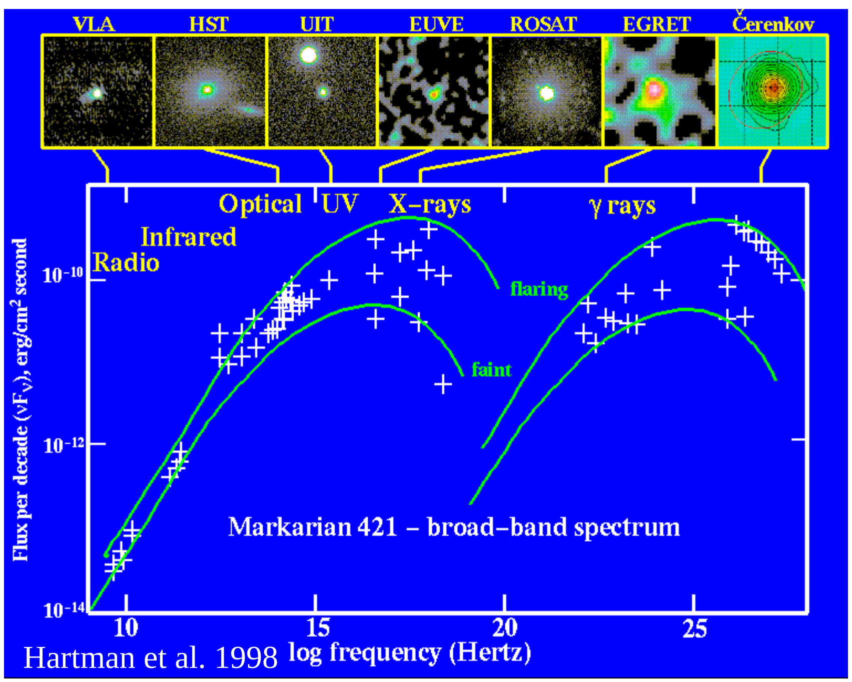
AGN and Their Studies



Properties	Popularity
Small angular size	Many
Galactic (or greater) luminosity	Many
Broad-band continuum	Most
Strong emission lines	Most
Variability	Most
Weakly polarized	Most
Radio emission	Many
Collimated outflows	Many
Supermassive black holes	Most

Source of energy in AGN

1. colliding galaxies
2. starburst
3. gravitational collapse
4. SN chain explosions
5. annihilation
6. quark interaction
7. compact stellar cluster
8. accretion on a black hole



AGN: basic studies

1. surveys: correlations between different types of AGN
2. multifrequency campaigns: broad-band spectra
3. spectroscopy: narrow-band spectra
4. variability: long and short term changes of emission
5. morphology: optical, X-ray and radio structures on scales of up to a few Mpc
6. radio interferometry: structure and evolution of parsec-scale emission

Main traits of AGN

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- High luminosity: $L_{AGN} \leq 10^{48}$ erg/s; cf. $\langle L_g \rangle = 10^{44}$ erg/s.
- Large range of luminisoties: $L_{AGN} = 10^{42} - 10^{48}$ erg/s.
- Extremely small size: emitting volume $\ll 1$ pc^3.
- Broad spectrum: ~10 orders of magnitude in frequency.
- Remarkable line spectra (emission & absorption): $f_{line} \sim 0.1\, f_{cont}$; $W_{opt} \sim 10^4$ km/s; $W_{xray} \sim 0.1$–$0.3c$!
- Variable structures: jets with $\beta_{app} \sim 10 - 40c$.
- Strong cosmological evolution, peaking at $z \approx 2.5$ (about 10 billion years ago).
- Strong effect on intergalactic medium and large-scale structures in the Universe.

AGN Constituents

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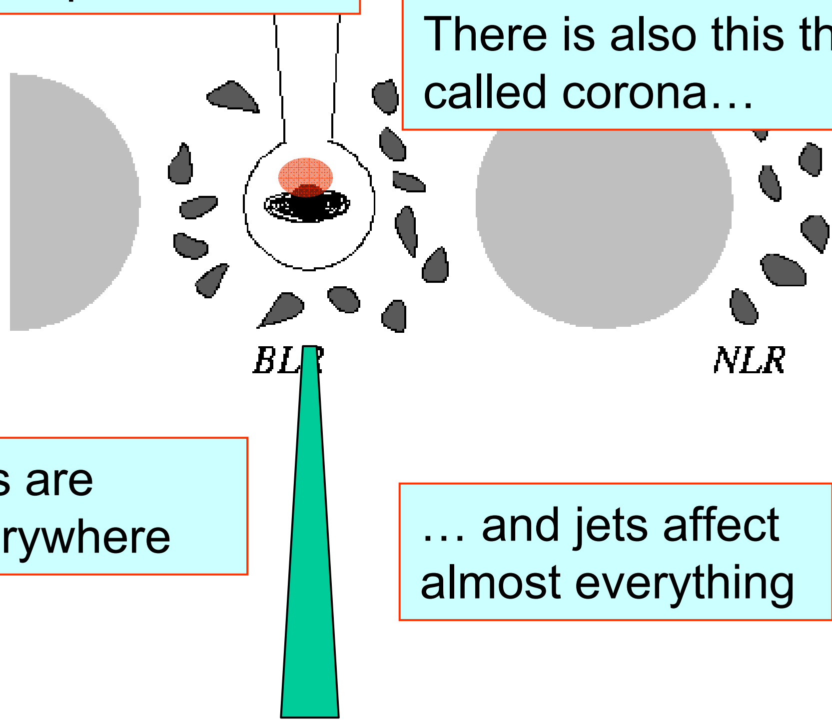
The BLR is a multicomponent complex

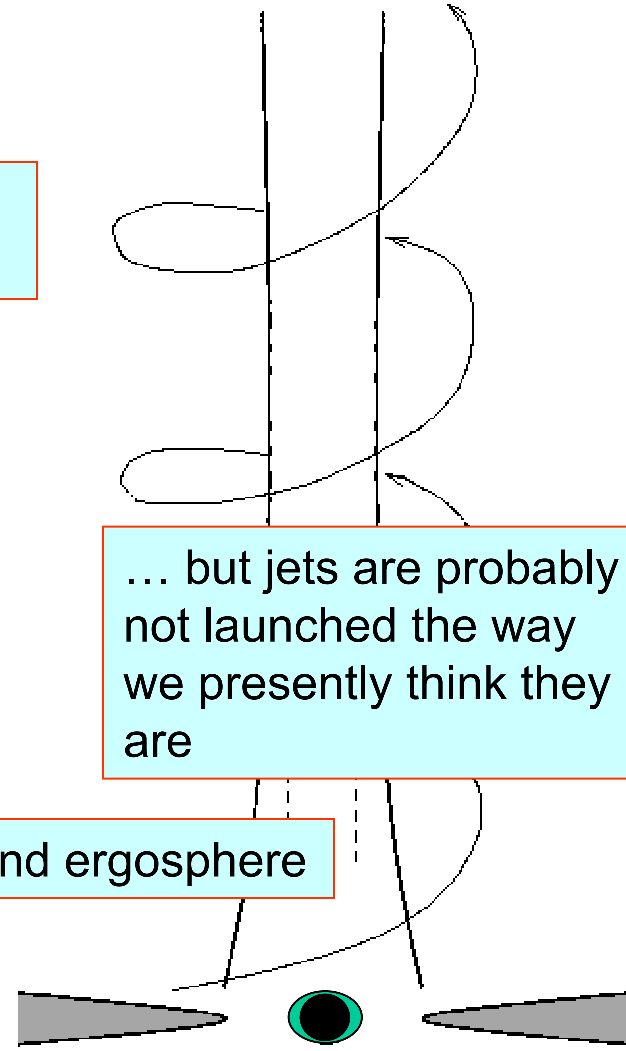
… and so is the NLR

There is also this thing called corona…



Jets are everywhere

… and jets affect almost everything



… but jets are probably not launched the way we presently think they are

… and ergosphere

AGN Scales: 10μpc – 1pc

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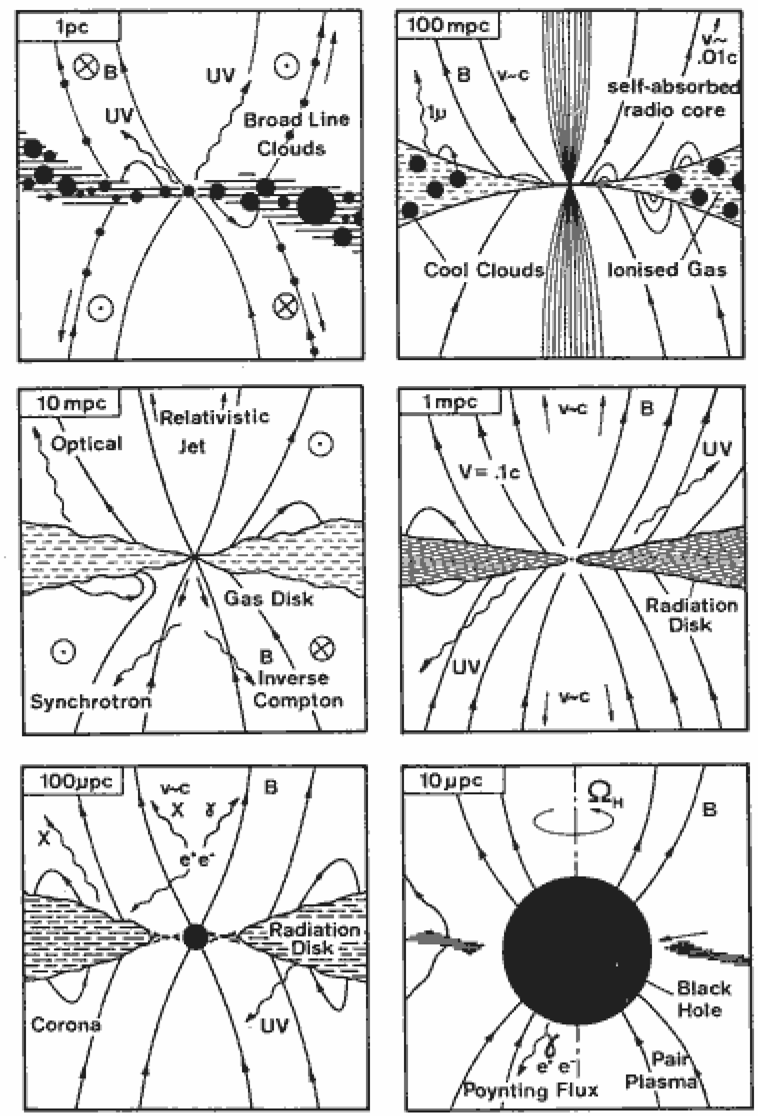
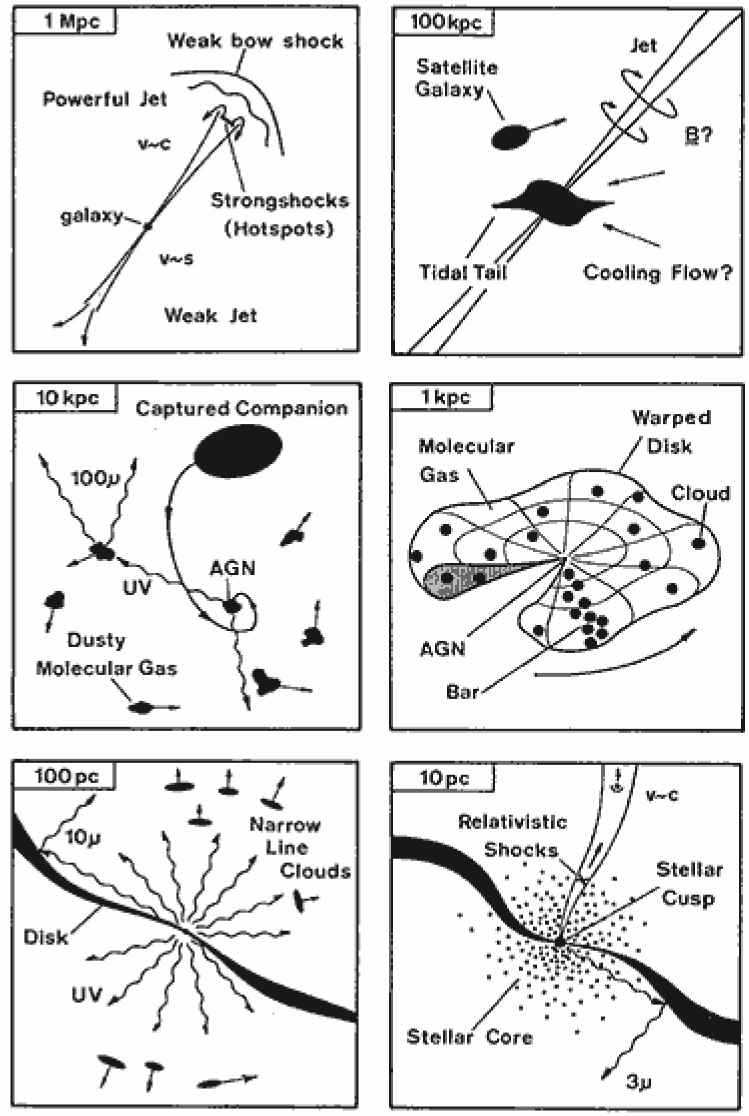
Scale	Properties
10 μpc	R_S = 2 $M_{BH,8}$ AU, last stable orbit is 3R_S ($M_{BH,8}$= M_{BH}/10^8M)
100 μpc	relativistic accretion disk (AD); Fe K line; variable X-ray emission (mins-hours)
1 mpc	UV accretion disk; radiation supported AD
10 mpc	optical AD; Broad Line Region (BLR); V~10^4 km s^{-1}; ~few light days
100 mpc	compact, flat-spectrum radio core; VLBI jet; outer BLR
1 pc	star cusp with velocities affected by BH; dense gas may block some sight lines



Blandford 1996

AGN Scales: 10pc – 1Mpc

Scale	Properties
10 pc	inner Narrow Line Region (NLR); V $\lesssim 10^3$ km s^{-1}; shocks; inner bulge.
100 pc	bulge; NLR; forbidden emission lines; warm dust; instabilities in jet.
1 kpc	inner disk; disk ISM; Extended-NLR; Bar & inflow; VLA jet.
10 kpc	host galaxy; distortions/merger?; ENLR; weak jets blocked.
100 kpc	near neighbors; tidal influences; powerful jets.
1 Mpc	jets terminate in IGM hotspots; may affect ICM in cluster.



Blandford 1996

AGN Gallery

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AGN in The Radio

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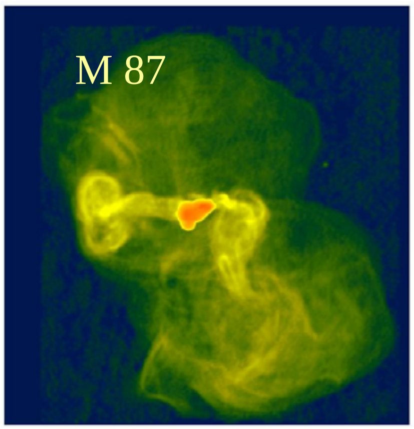
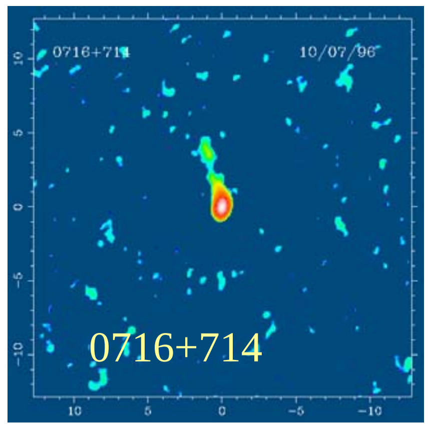
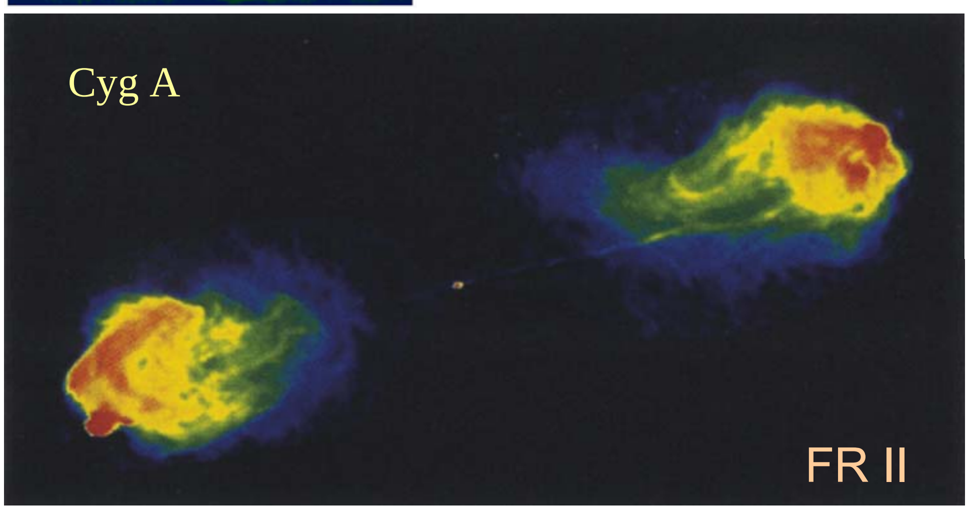
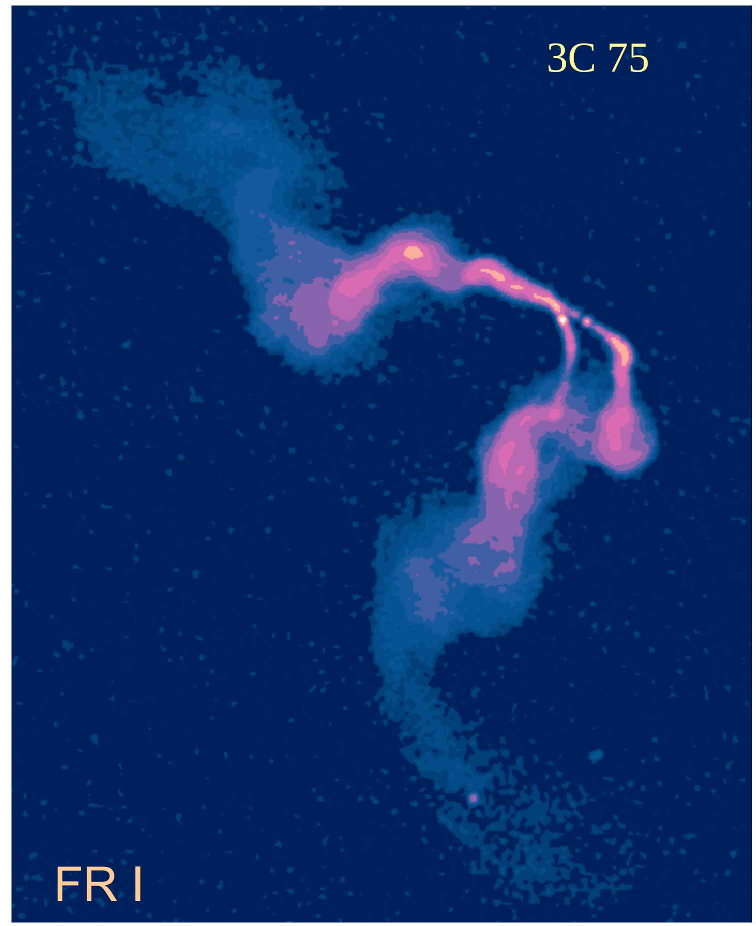
- Variety of morphological types; ubiquity of outflows
- Spectacular dynamics evolution



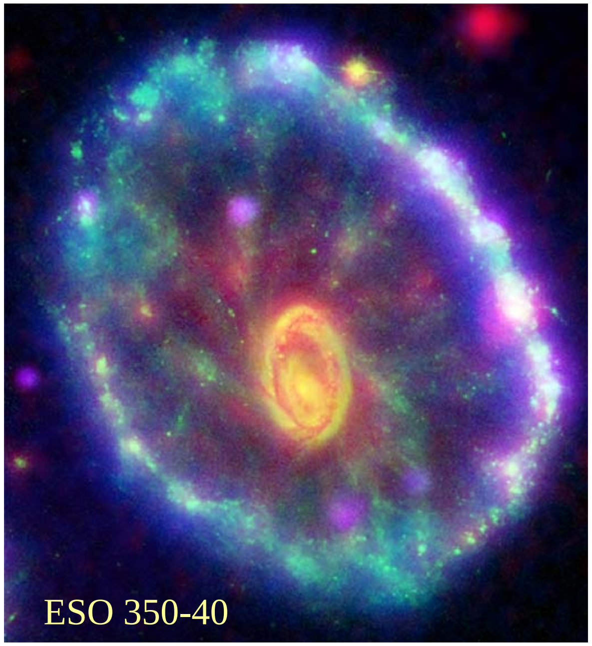


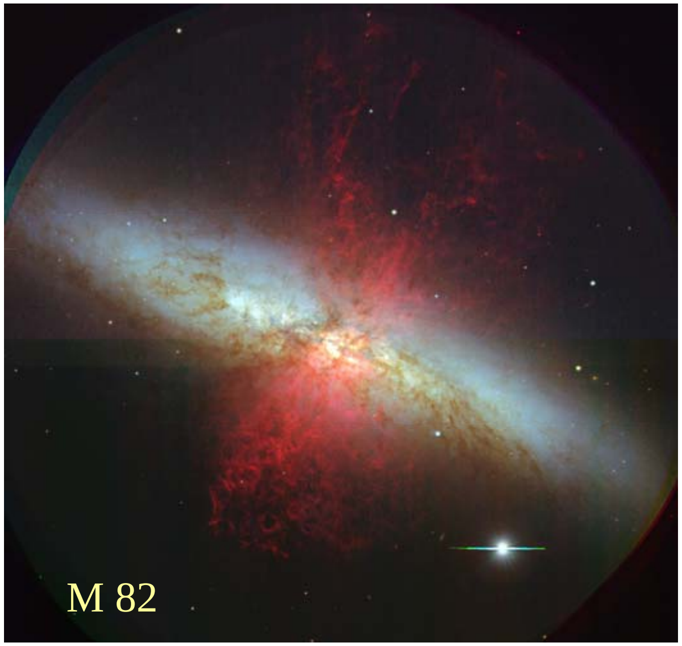


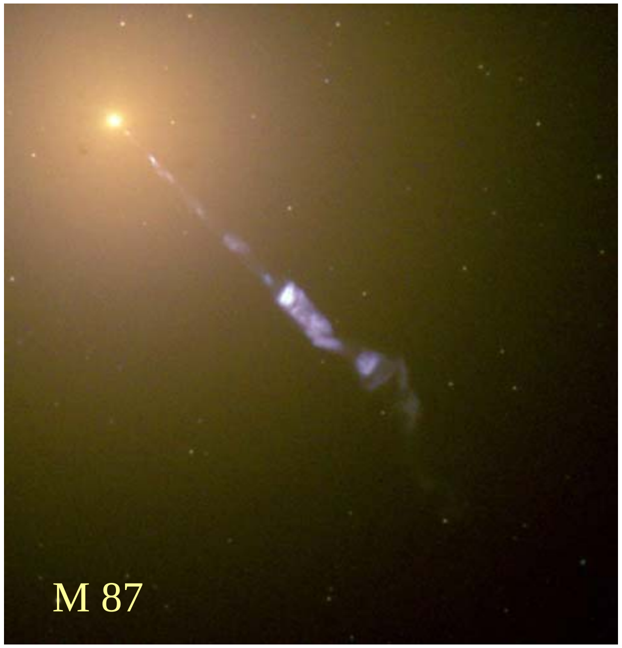


AGN in the Optical

- ❑ Rich emission and absorption spectra
- ❑ Complex morphology; clear signs of galaxy interactions
- ❑ Presence of winds and outflows.







Optical Line Spectra

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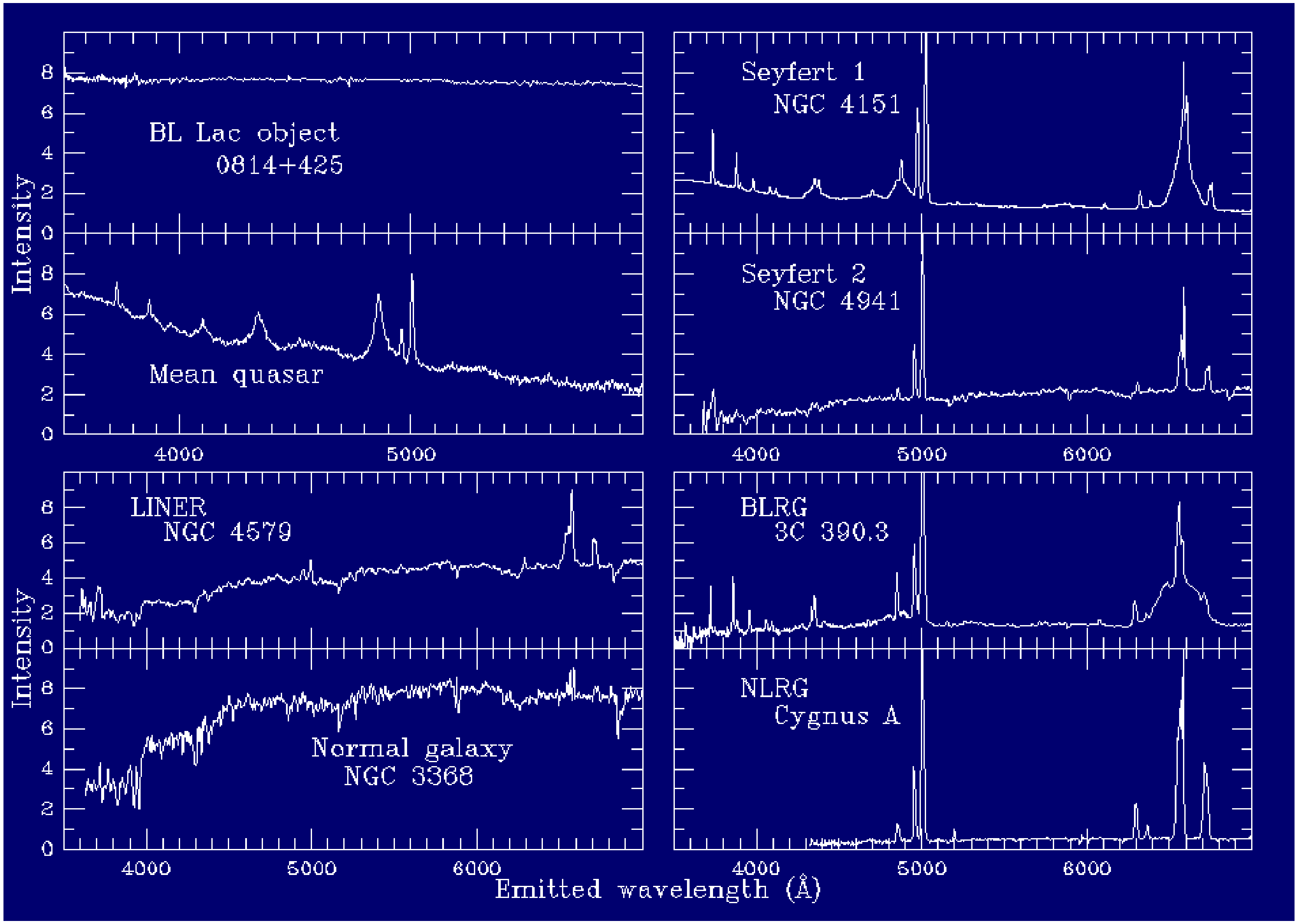
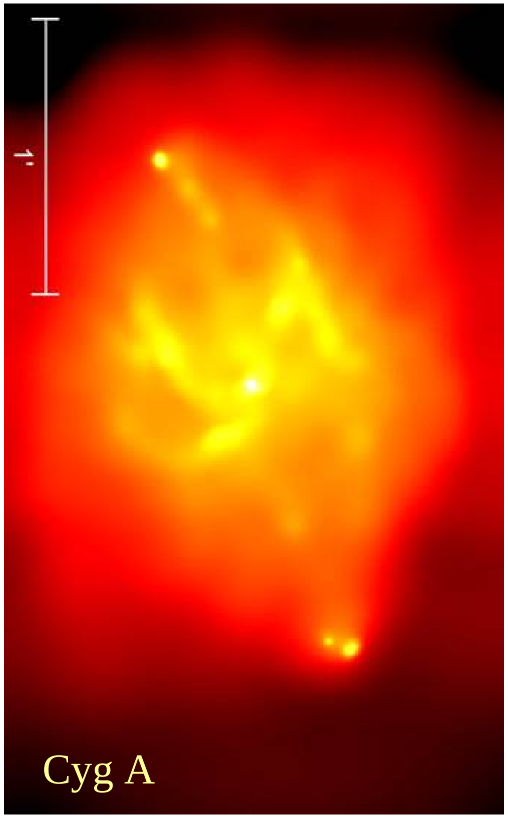
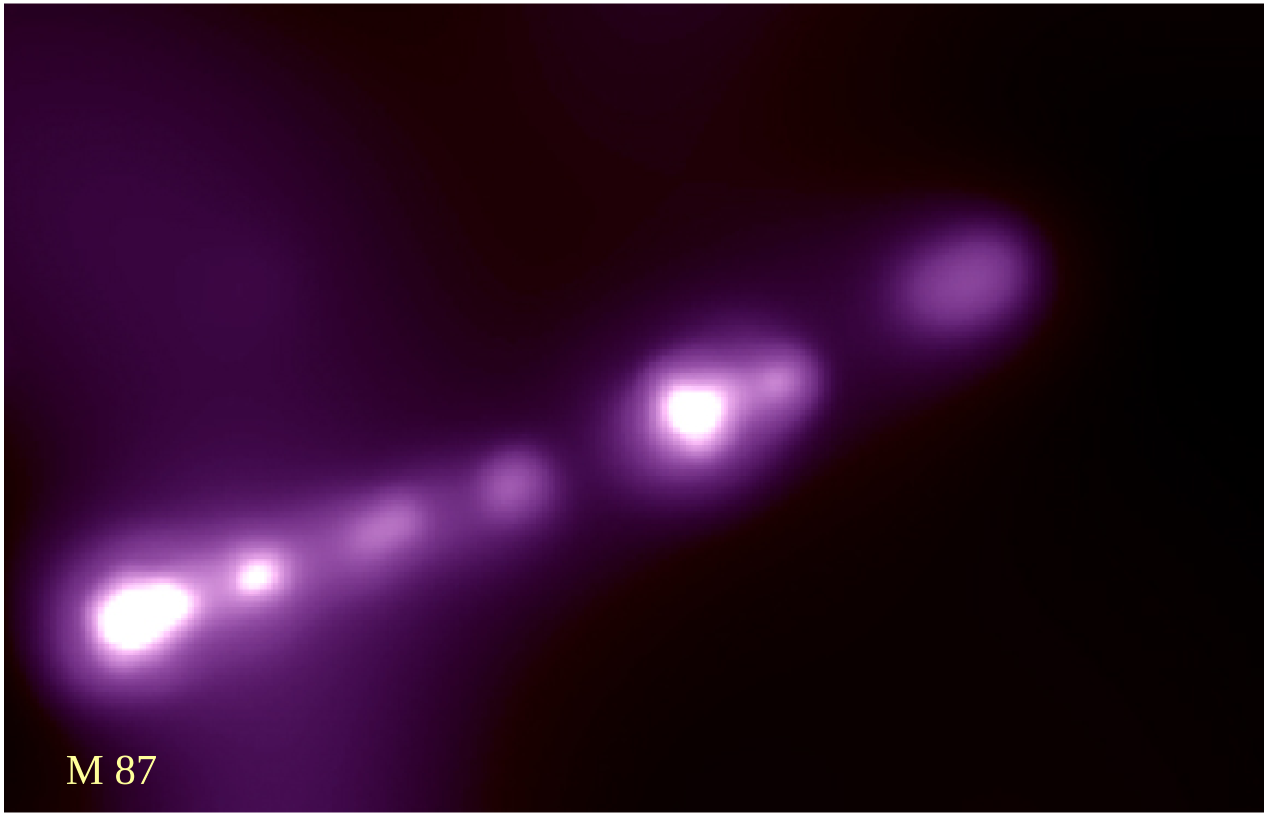
- Optical line spectra show a variety of features.



AGN in the X-ray

- Trace nuclear emission and hot gas blown by AGN
- Show (surprisingly!) large-scale outflows





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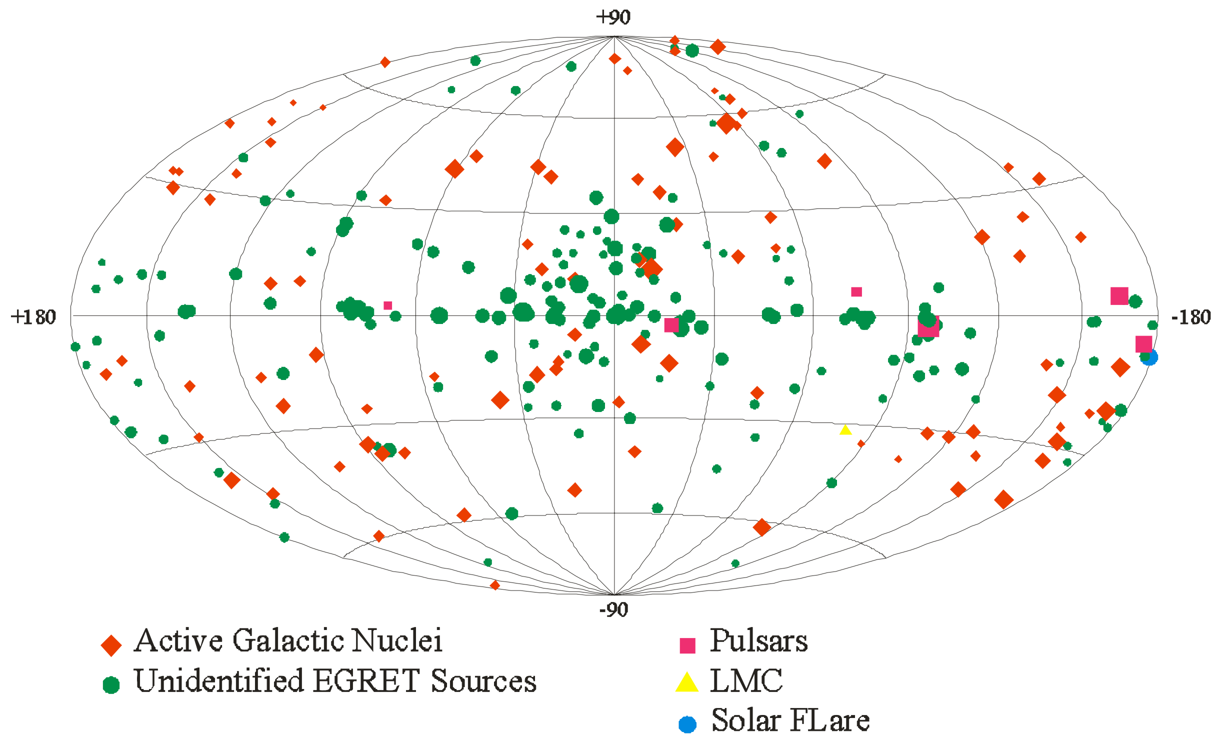
AGN in the Γ-ray Regime

- The first quasar identified as a g-ray source was 3C273, observed with the COS-B Γ-ray satellite that flew between 1975 and 1981. The Energetic Gamma-Ray Experiment Telescope (EGRET), launched as part of the Compton Gamma-Ray Observatory in 1991, increased this number to >60 as shown in the sky map above, indicating that Γ-rays play an important role in the emission of many quasars

Third EGRET Catalog

E > 100 MeV



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AGN at TeV Energies

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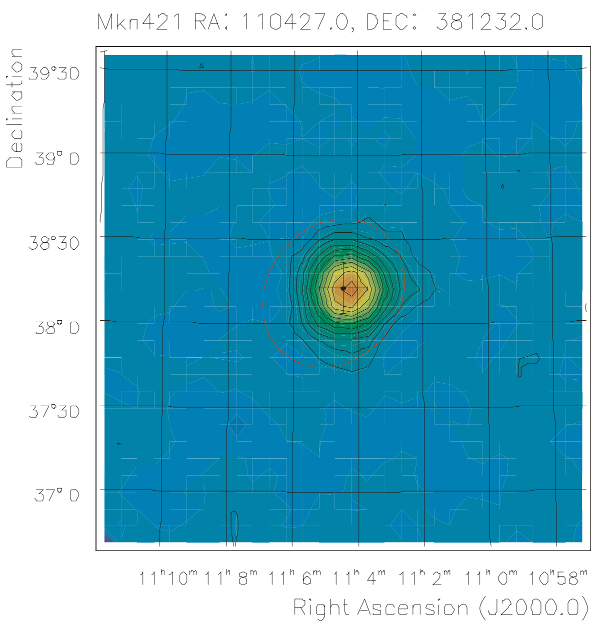
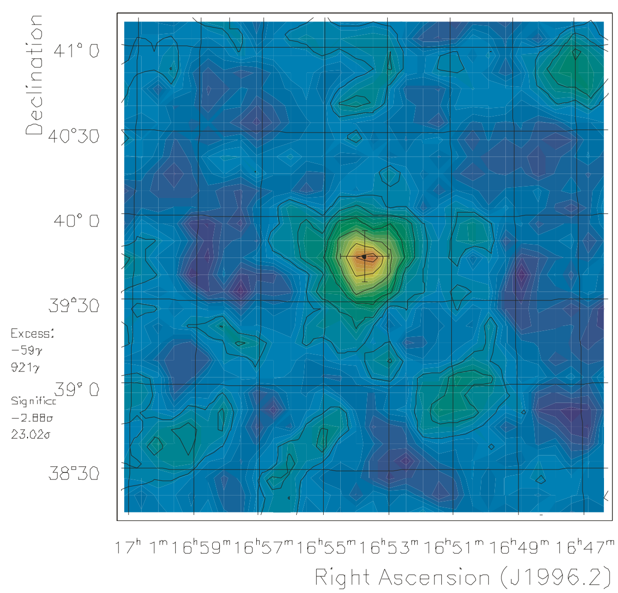
- TeV g-rays were first detected from a quasar, Markarian 421, in 1991 with the ground-based Whipple Observatory Γ-ray telescope. Subsequent observations with various telescopes have detected 3-5 more, some images of which are indicated in the figures above. Though small in number, the TeV detections have had an important impact on our understanding of quasars because of the high energies detected (up to 18 TeV at present).

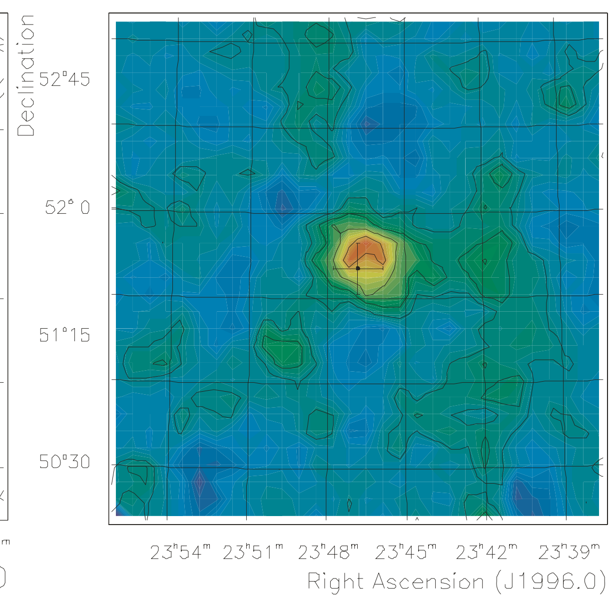
MKN421



MKN501: Localization

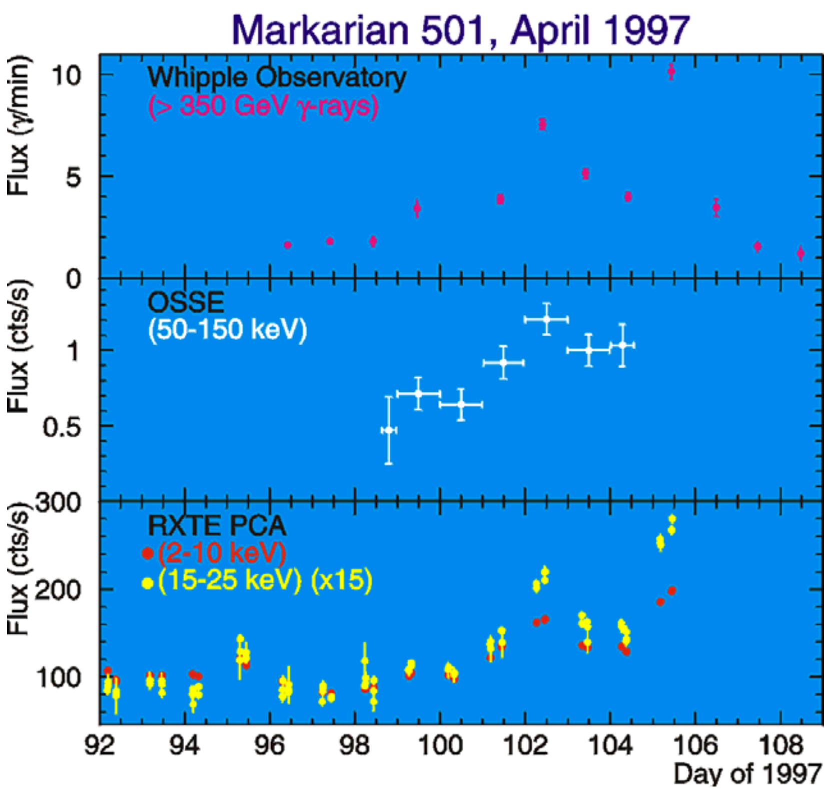


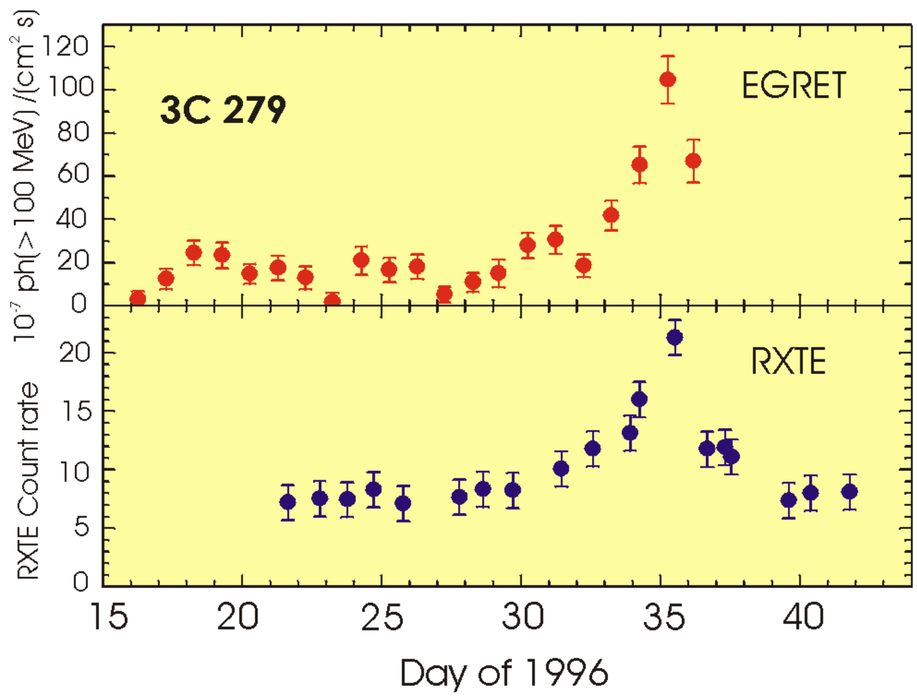
1ES2344+514: Localization



AGN Variability I

- ❑ Short-timescale variability probes the most compact regions in AGN. Size of emitting region: $d_{var} \approx c\, \tau_{var}$





AGN at its Extremes

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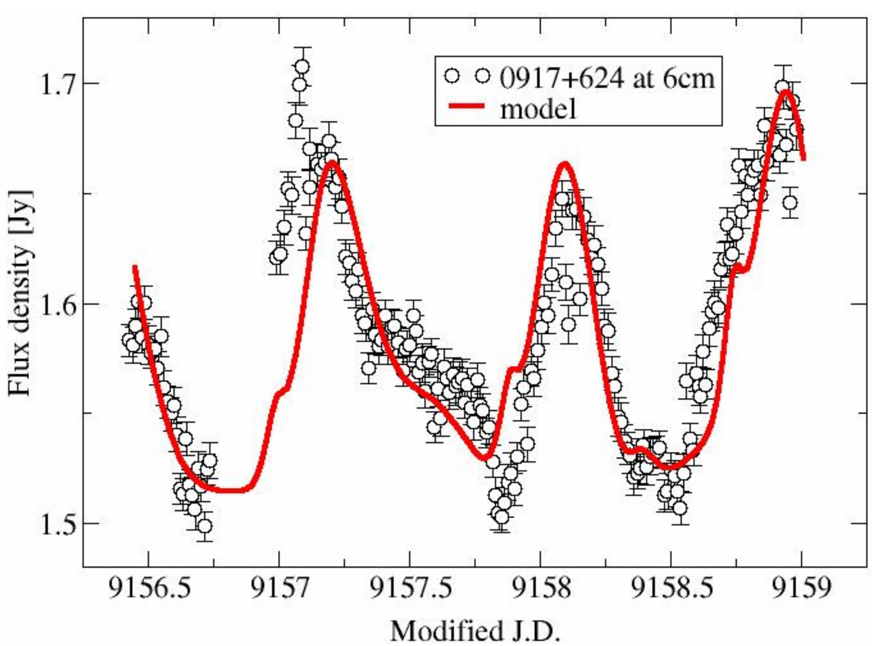
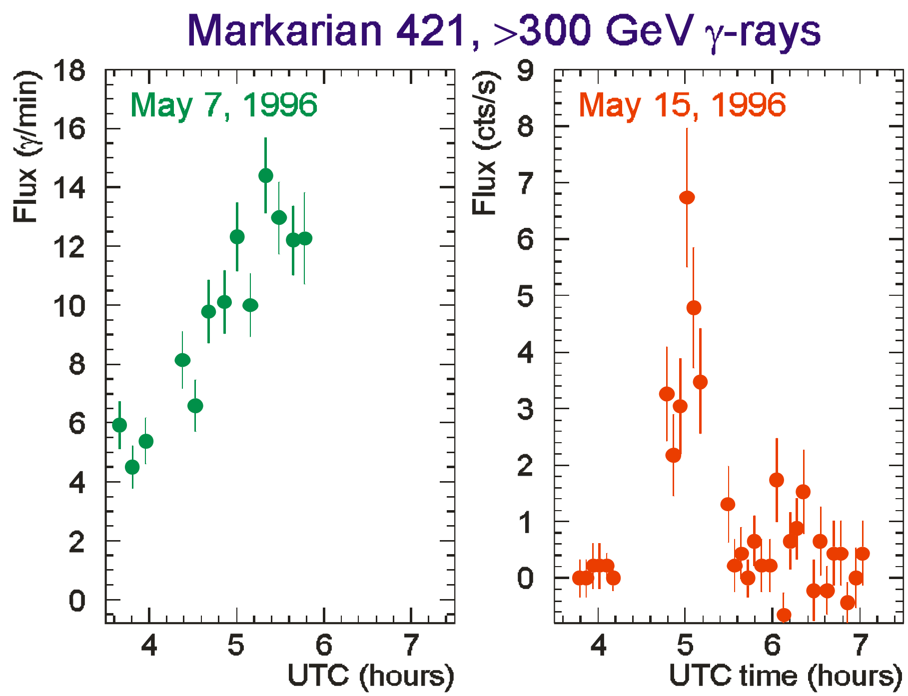
- Extreme variability in AGN. Fast radio variability in 0917+624 implies a brightness temperature of 10^{19}K. The fastest variations ever seen at g-ray energies from a blazar, Markarian 421 indicate a variability doubling time of 1 hour while the entire flare from May 15 lasted only 30 minutes.





Nomenclature and Unification

AGN Census

- AGN have been historically divided into a number of classes, based on their observed properties:

  – morphology (pointlike or extended)

  – optical spectrum: emission and absorption lines (strength and width)

  – broad-band spectrum: shape and location of peaks

  – variability: amplitude and timescale

  – polarization: magnitude

The “Division Lines”

- UV/opt/IR luminosity (the accretion rate and black hole mass)
  – Quasars: $L_{nuc} \geq L_{gal}$
  – Strong AGN: $L_{nuc} \leq L_{gal}$
  – Weak AGN: $L_{nuc} \ll L_{gal}$

- Radio Luminosity (the jet power)
  – Radio-quiet: $L_{rad} \leq 10^{-4} L_{opt}$
  – Radio-loud: $L_{rad} \geq 10^{-2} L_{opt}$

- Emission Line Shapes (broad-line region)
  – broad + narrow lines: no obscuration
  – narrow lines: obscuration
  – weak or no lines: continuum domination

- Variability and polarization (jet orienation)
  – strong variability and polarization: jet at a small viewing angle
  – weak variability and polarization: jet at a large viewing angle

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AGN Taxonomy

AGN Type	Pointlike	Broad-band	Broad lines	Narrow lines	Radio emission	Variable	Polarized
RL quasars	Yes	Yes	Yes	Yes	Yes	Some	Some
RQ quasars	Yes	Yes	Yes	Yes	Weak	Weak	Weak
BLRG	Yes	Yes	Yes	Yes	Yes	Weak	Weak
NLRG	No	No	No	Yes	Yes	No	No
OVV quasars	Yes	Yes	Yes	Yes	Yes	Yes	Yes
BL Lac objects	Yes	Yes	No	No	Yes	Yes	Yes
Seyfert I	Yes	Yes	Yes	Yes	Weak	Some	Weak
Seyfert 2	No	Yes	No	Yes	Weak	No	Some
LINER	No	No	No	Yes	No	No	No

(Krolik 1999)

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AGN Taxonomy II

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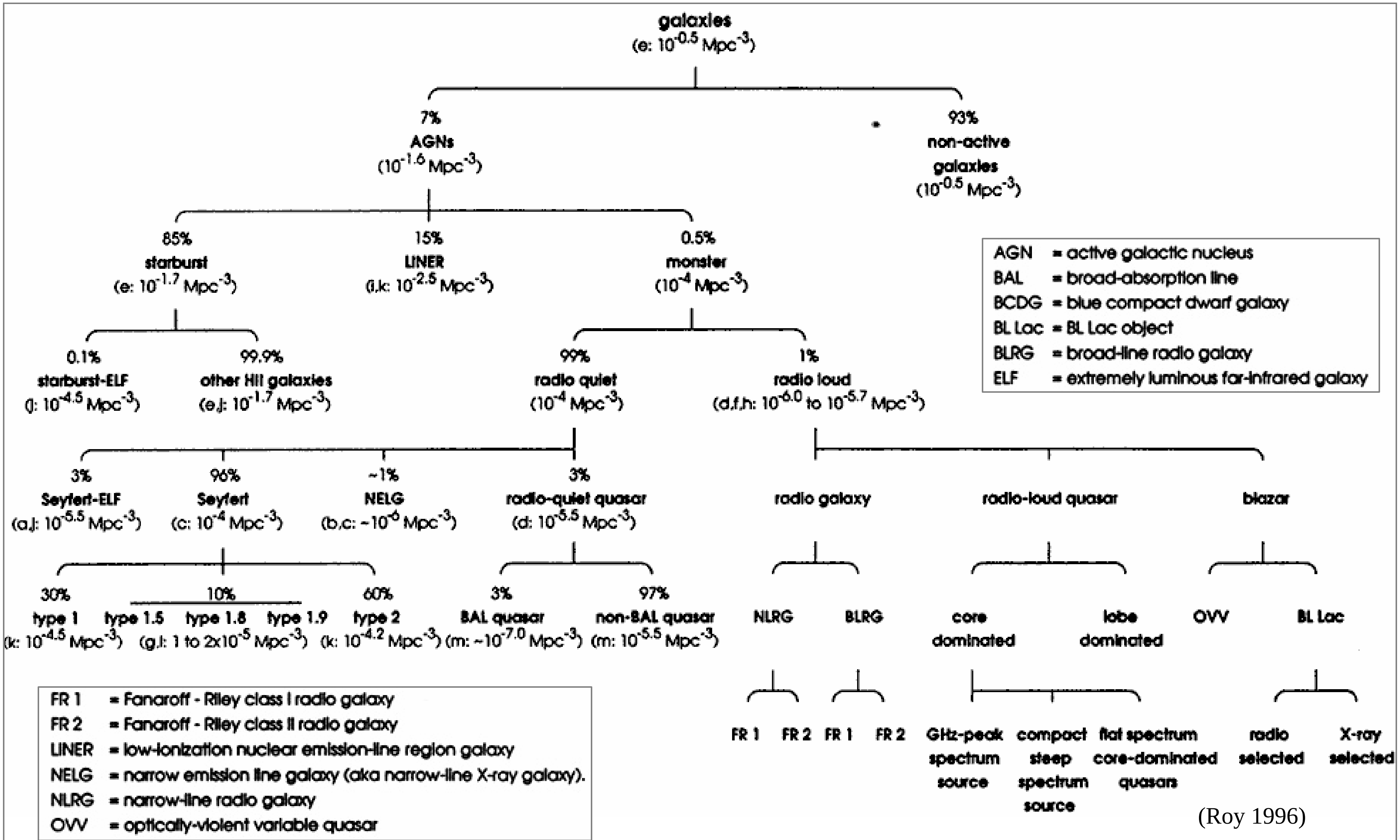


(Roy 1996)

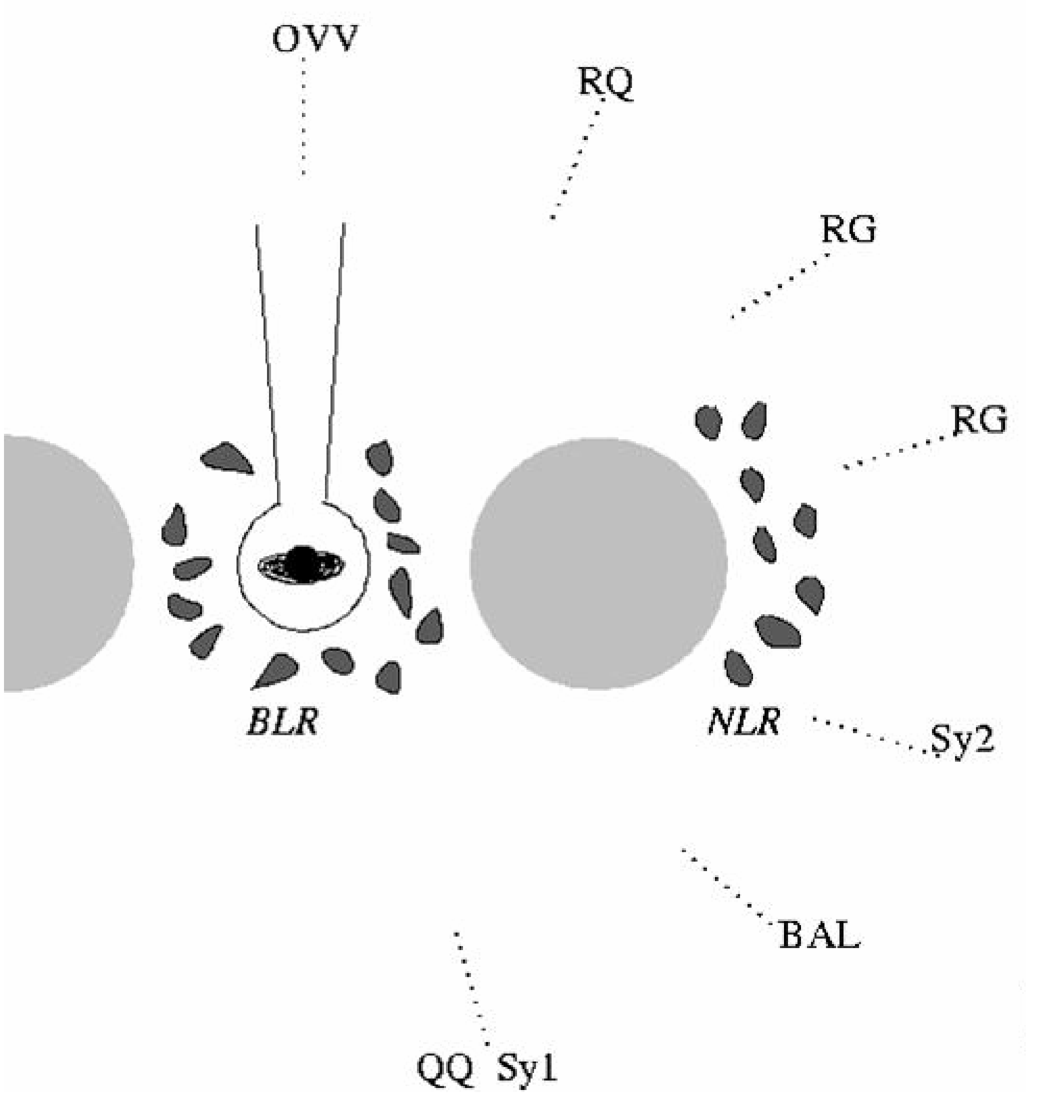
AGN Unification

- The diversity of AGN can be simplified by recognizing two intrinsic differences:

  – a continuous range of luminosity, from very weak to exceedingly powerful

  – a clear division between radio loud ($L_{rad}/L_{opt} \sim 10^{-2}$) and radio quiet ($L_{rad}/L_{opt} \sim 10^{-4}$)

- Further unification: appearance changes with viewing angle
  – unobscured (type 1)
  – obscured (type 2)



Astrophysical Relevance

AGN Relevance

- Originally, nuclear activity was considered to be rare phenomenon
- Recent studies point to a different picture:
  - ~40% of galaxies show HII emission (star formation)
  - ~30% of galaxies are LINERs
  - ~13% are Seyfert 1 and 2
  - ~10% of galaxies have a broad Hα component
- Perhaps every galaxy undergoes an AGN stage during its evolution
- AGNs are important sources of ionizing continuum and kinetic energy deposited into intergalactic medium

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AGN Contributions

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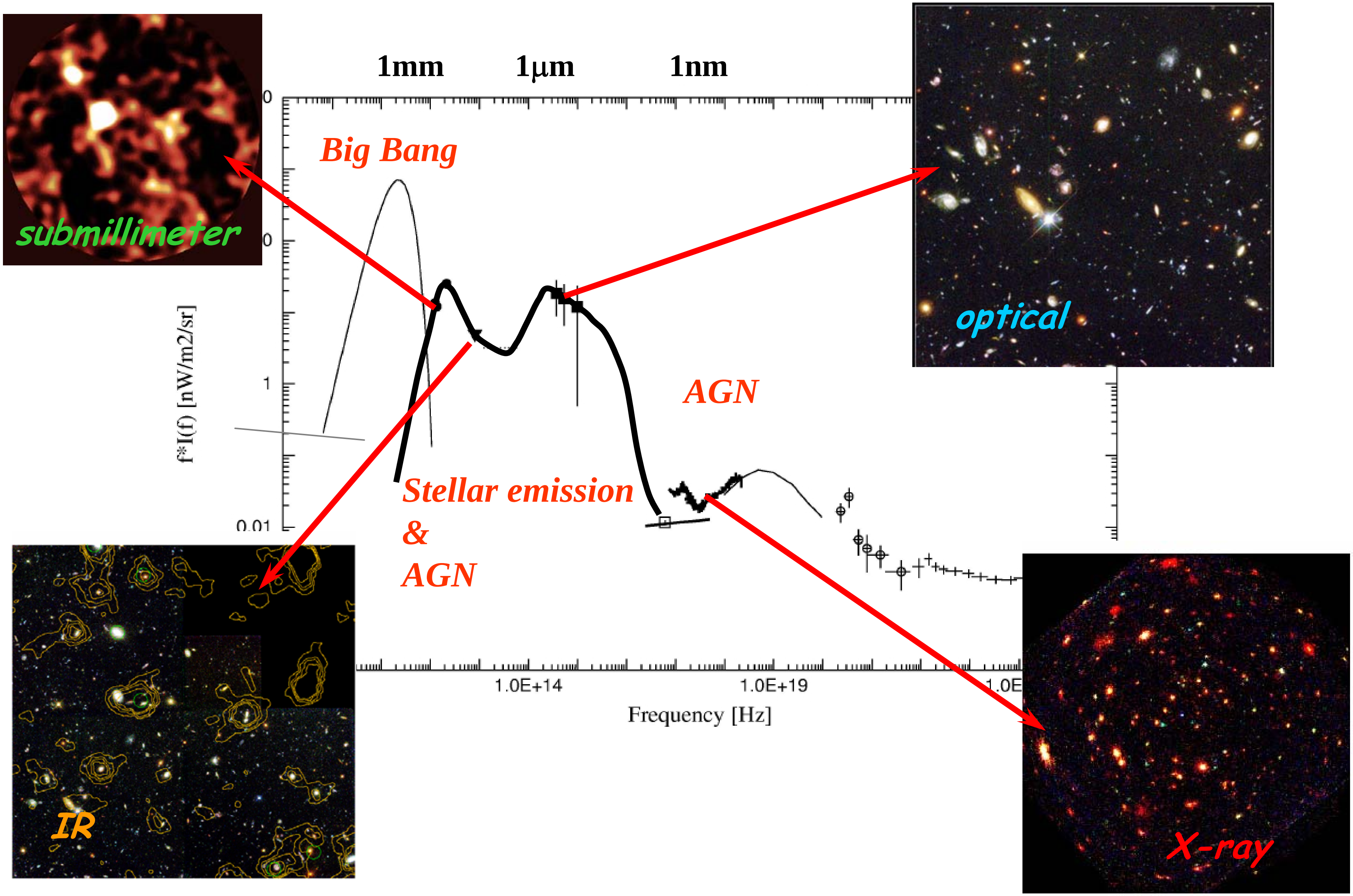

AGN and SMBH Evolution

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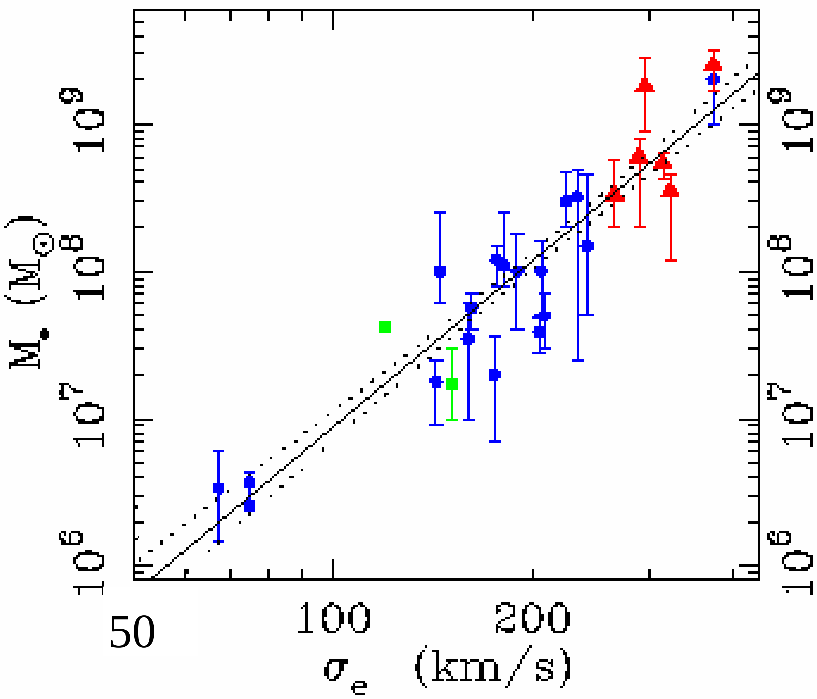
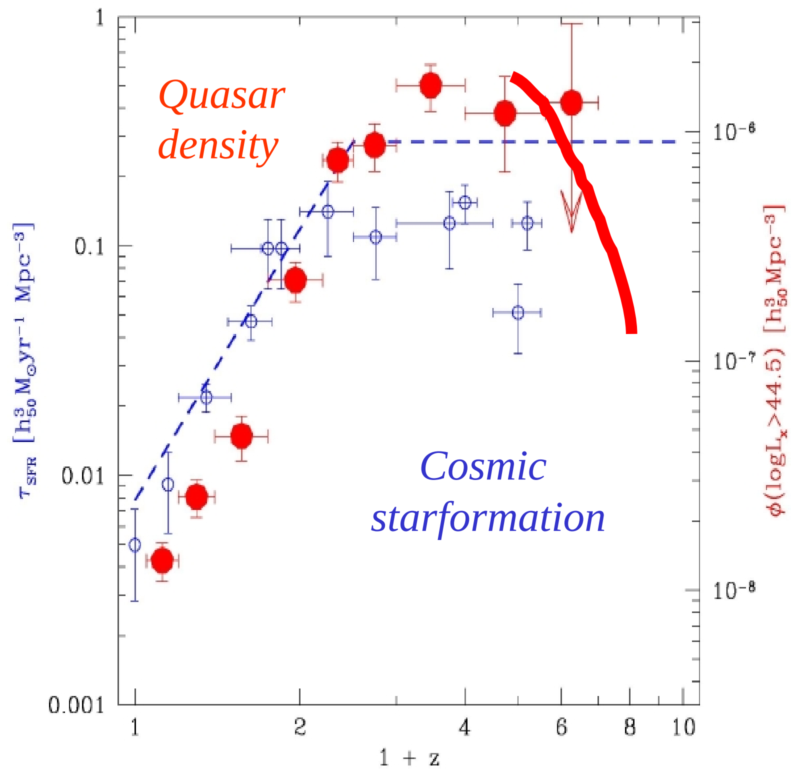
- AGN/SMBH evolution is closely related to galaxy formation and evolution in the Universe.



SMBH masses are correlated with the velocity dispersion in the stellar bulge of their hosts



AGN Feedback

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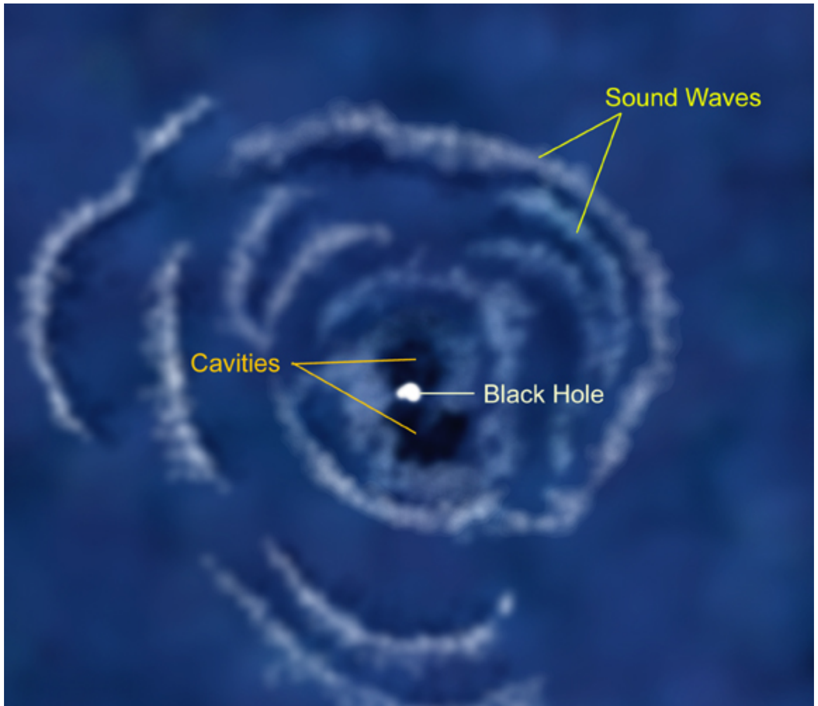
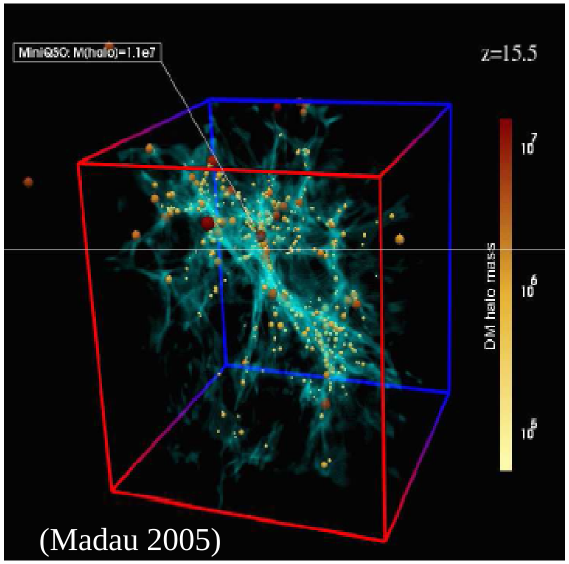
- Kinetic output of AGN $\geq 0.01\, M_{bh}\, c^2$ – jets, BAL outflows (Elvis 2000, Begelman 2004). Collimated outflows may be prime contributors to AGN feedback (Heinz & Sunyaev 2003, Heinz et al. 2005)
- Radiative feedback from AGN influences strongly SMBH growth (Di Matteo et al. 2004, Sazonow et al. 2005)
- Both kinetic and radiative components of the feedback can be highly anisotropic.
- A large fraction of ionizing continuum can be produced in jets (Arshakian et al. 2005)
- Shocks and ripples in the IGM caused by the AGN in Perseus A (Fabian et al. 2003)



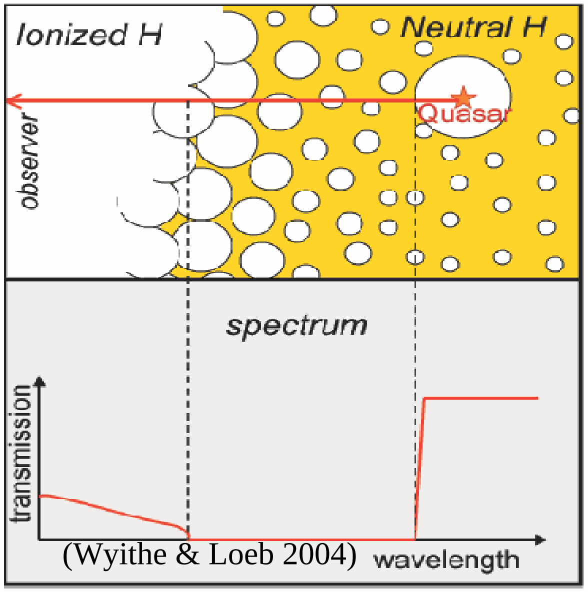
(Fabian et al. 2003)

Cosmological Impact

- MBH assembly begins at z>20 (Madau et al. 2005) and it is closely connected with formation of galaxies (Silk & Rees 1998).
- Nuclear activity sets on at z>10 (Fan 2005), and persists until the present epoch.
- It is likely to contribute to reionization of the Universe (Wyithe & Loeb 2004).
- SMBH and AGN are good tracers of distribution of visible (Miley et al. 2004) and dark matter (Ferrarese 2002) in the Universe.
- “Feedback” from AGN affects their host galaxies and IGM (Silk & Rees 1998, Fabian 1999). Jets are important factors in the feed-back (Rawlings 2003,Rawlings & Jarvis 2005)



(Madau 2005)



(Wyithe & Loeb 2004)

Summary

- AGN phenomenon is spectacular and ubiqitous at the same time – just about every galaxy goes through one or more episodes of nuclear activity.
- Nuclear activity comes in a large variety of observational appearances, yet the underlying mechanisms is likely to be similar in all of those.
- The main „division lines“ in this mechanisms are: range of nuclear luminosities; efficiency of radio emission production and orientation-dependent obsucration of the nuclear region.
- AGN have a substantial impact on galaxy evolution and large-scale structures in the Universe.

Discussion

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- Recalling the basis for the unification and the taxonomy of AGN:

1) How and along which criteria can the AGN types represented in the figure be unified?

2) Which ones would be type 1 and type 2 AGN.

3) Where in this scheme the LINER galaxies could have been placed?