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Selected Chapters on Active Galactic Nuclei as Relativistic Systems

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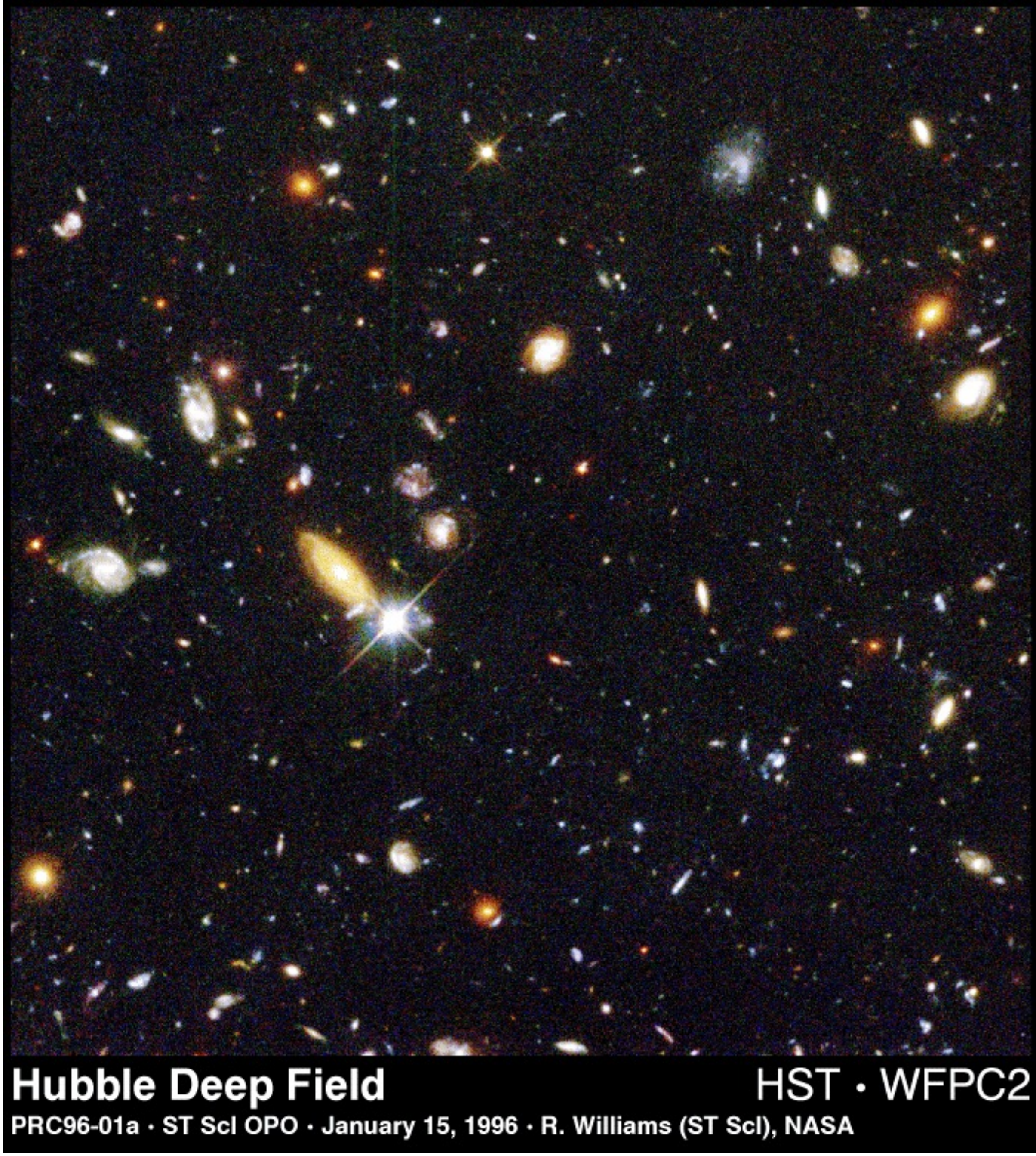
Accretion

Gravitational gathering of gaseous and dusty material onto a central body – namely, a star or a stellar-mass black hole (BH).

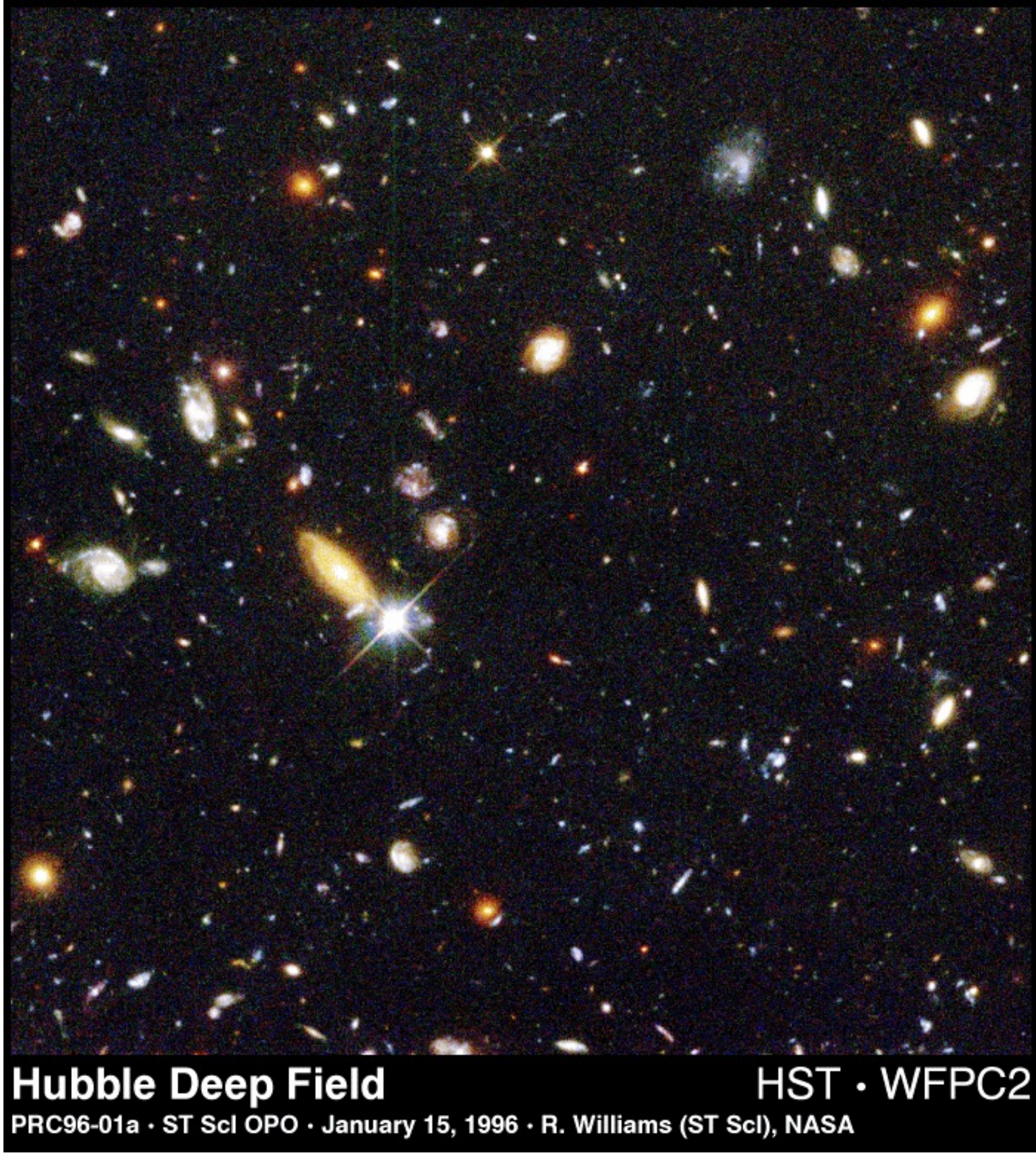
Accretion takes place in stellar systems (binary with overflow onto the primary component from its companion) and in galactic nuclei (onto a supermassive BH).



Accretion

Process of accretion is accompanied by release of binding energy in the form of radiation and particles. The most energetic photons are in X-rays.

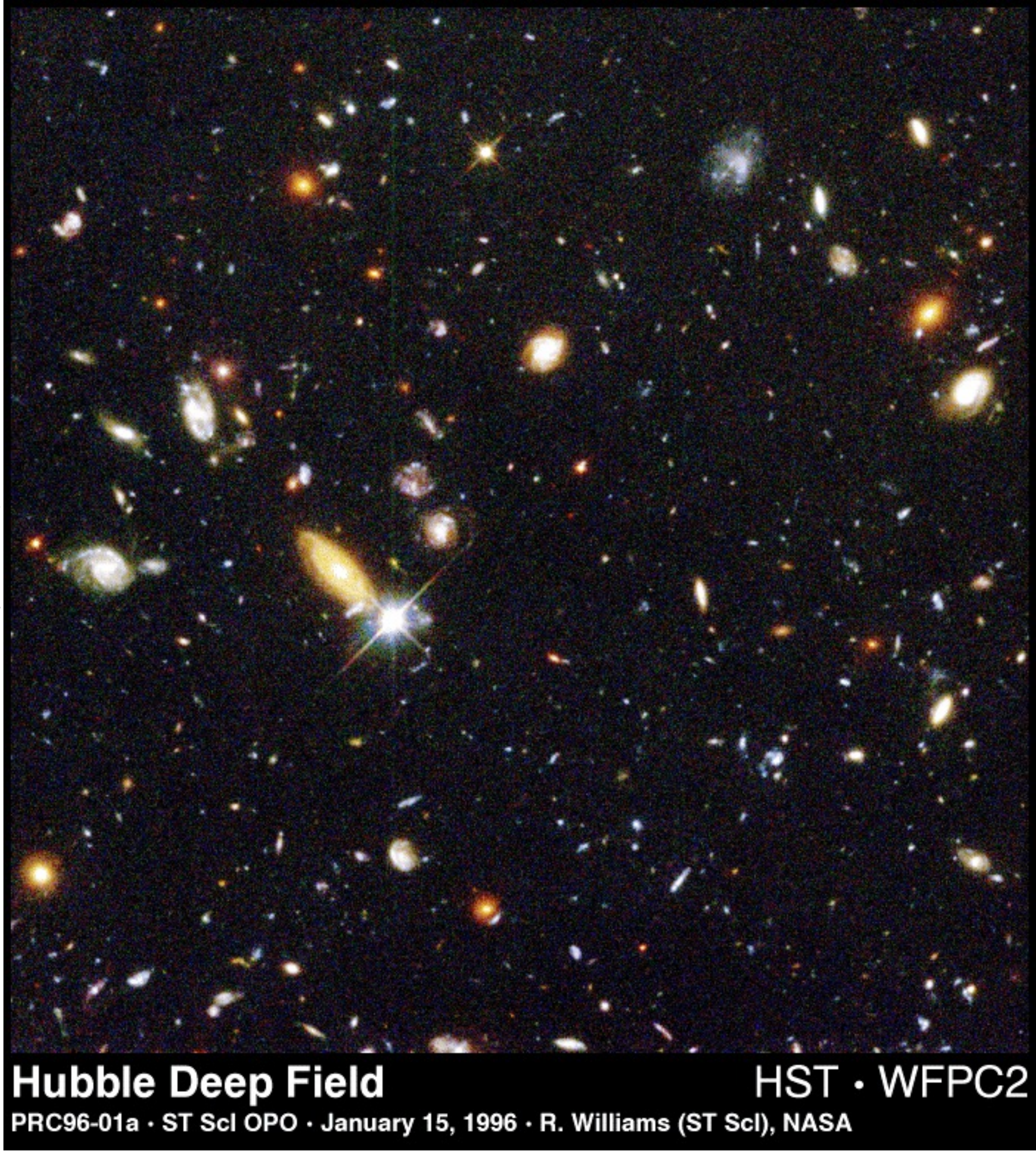
The inward motion of material takes place jointly with the emergence of collimated, magnetized jets. Their radiation spans radio to gamma/ TeV energy.



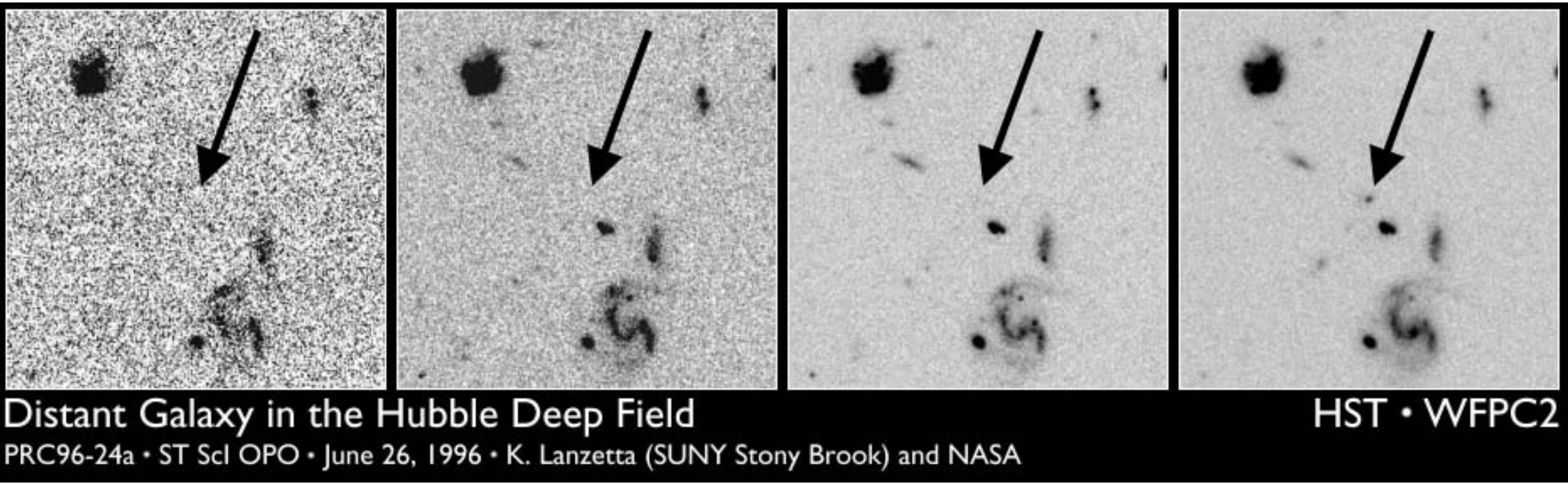
This optical image shows ~1500 galaxies. Some of them exhibit enhanced activity: fast variability and non-thermal spectrum.

A detailed mosaic covers a tiny portion of the sky to the extreme distance.

Quasars are the most luminous form of distant active galactic nuclei (AGN). Seyfert galaxies and radio galaxies are forms of less extreme AGN.



(C) R. Williams & HDF Team (STScI); NASA



Identification of distant galaxies is not an easy task. Here, four images show the same field at different spectral bands (F814W, F606W, F450W, F300W) from near IR to UV.

Early galaxies form stars by gravitational contraction of protostellar material, hence these can be seen predominantly in IR. Distance to the youngest galaxies reaches 13 billion light years.

Morphology of galaxies

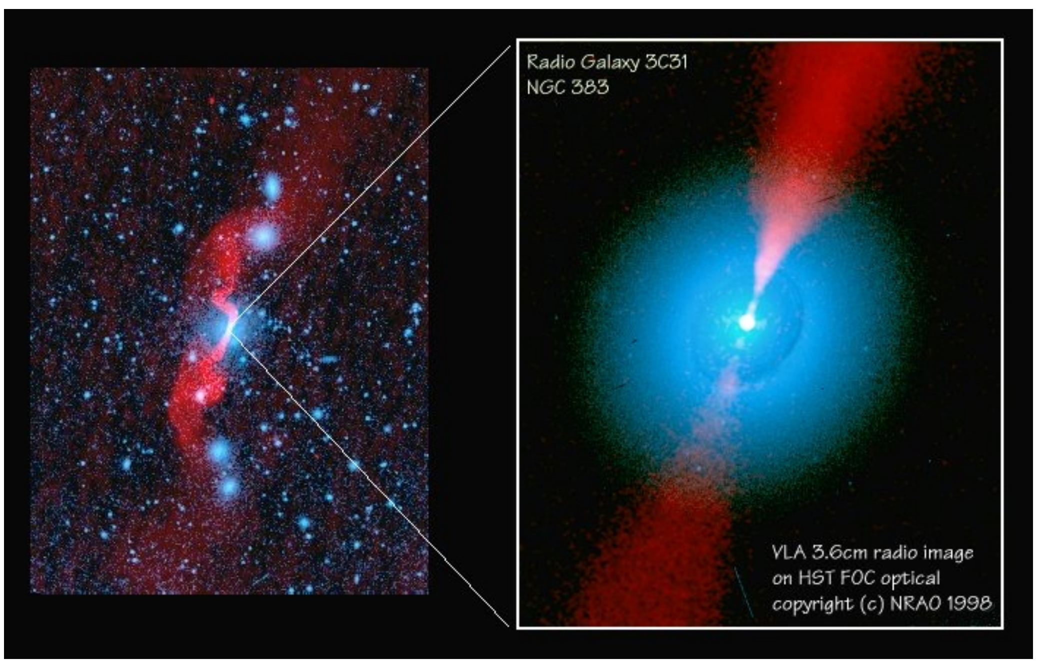
Hubble's classification system of galaxies (*Atlas of galaxies*, Sandage 1961). Despite the original intention, the relation between the morphological type versus the physical nature and evolutionary stage is not straightforward.

(C) K. Lanzetta & A. Yahil (State Univ. New York at.Stony Brook); NASA

Active galaxies

Hubble's system misses some types: *Seyfert galaxies, N-galaxies*, quasars...

FR I radio galaxy NGC383, z = 0.0169 (51/h Mpc, H=100h km/s/Mpc). *Blue*: optical image (*Digitized Palomar Sky Survey*). *Red*: radio band (VLA at 21cm/1.4 GHz).

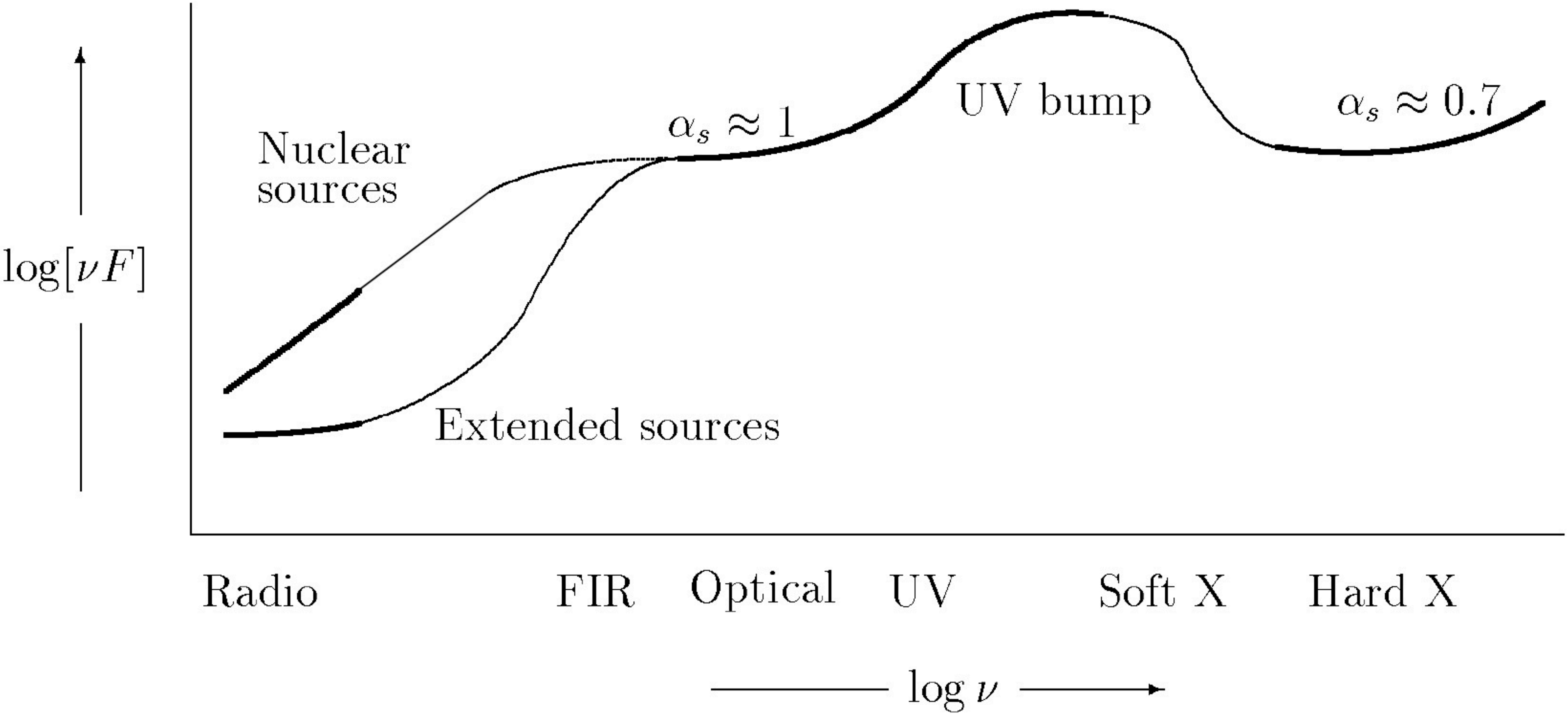


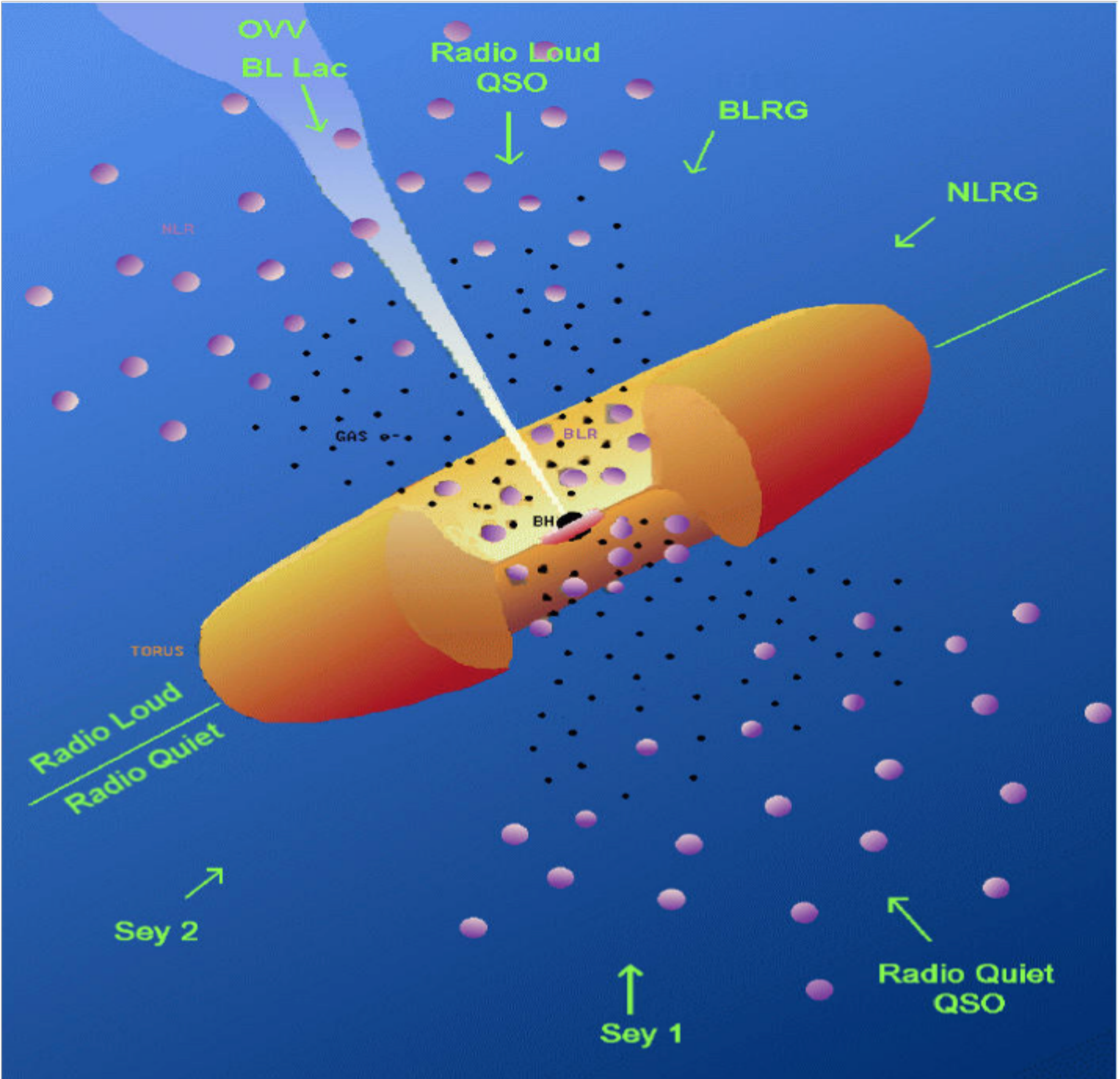
(C) R. Laing (RGO); A. Bridle & R. Perley (NRAO); L. Feretti, G. Giovannini & P. Parma (Bologna); S. Baum (STScI)

Classes of AGN

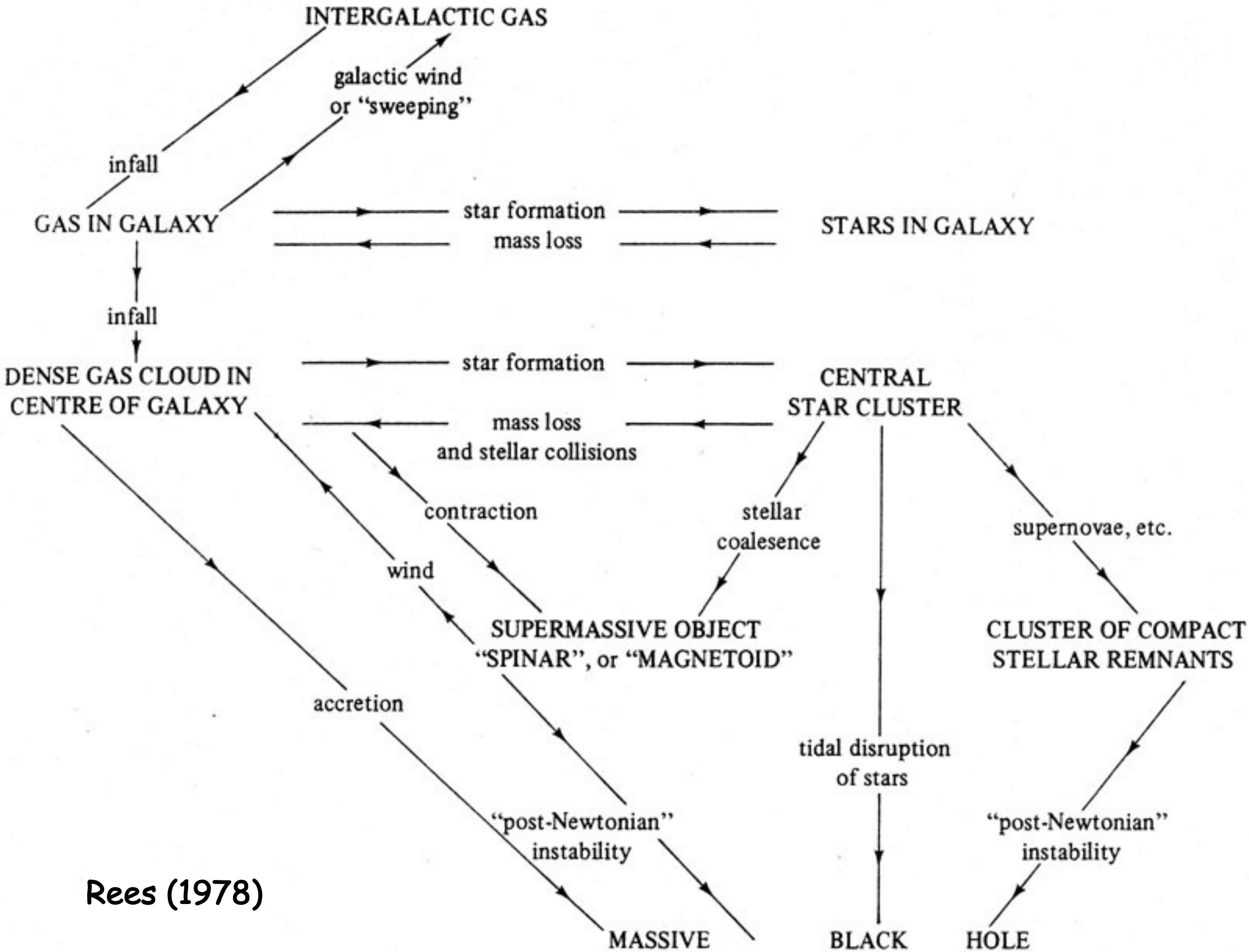
Radio Luminosity	Emission Lines	$L_N \gtrsim L_{gal}$	$L_N \lesssim L_{gal}$	$L_N << L_{gal}$
Radio Quiet	Broad + Narrow	RQ QSO	Seyfert 1 1.5	LINER 1.9 LINER/ Seyfert 2
	Narrow Only	[NLQSO]	Seyfert 2	
$L_R \lesssim 10^{-4} L_{opt}$	None	------	------	
Radio Loud	Broad + Narrow	RL QSO [QSR]	BLRG	PRG Weak lines LINERs
	Narrow Only	------	NLRG	
$L_R \gtrsim 10^{-2} L_{opt}$	None	Blazar [BL Lac] (OVV, HPQ)	------	

Continuum spectrum of an AGN across wavelengths

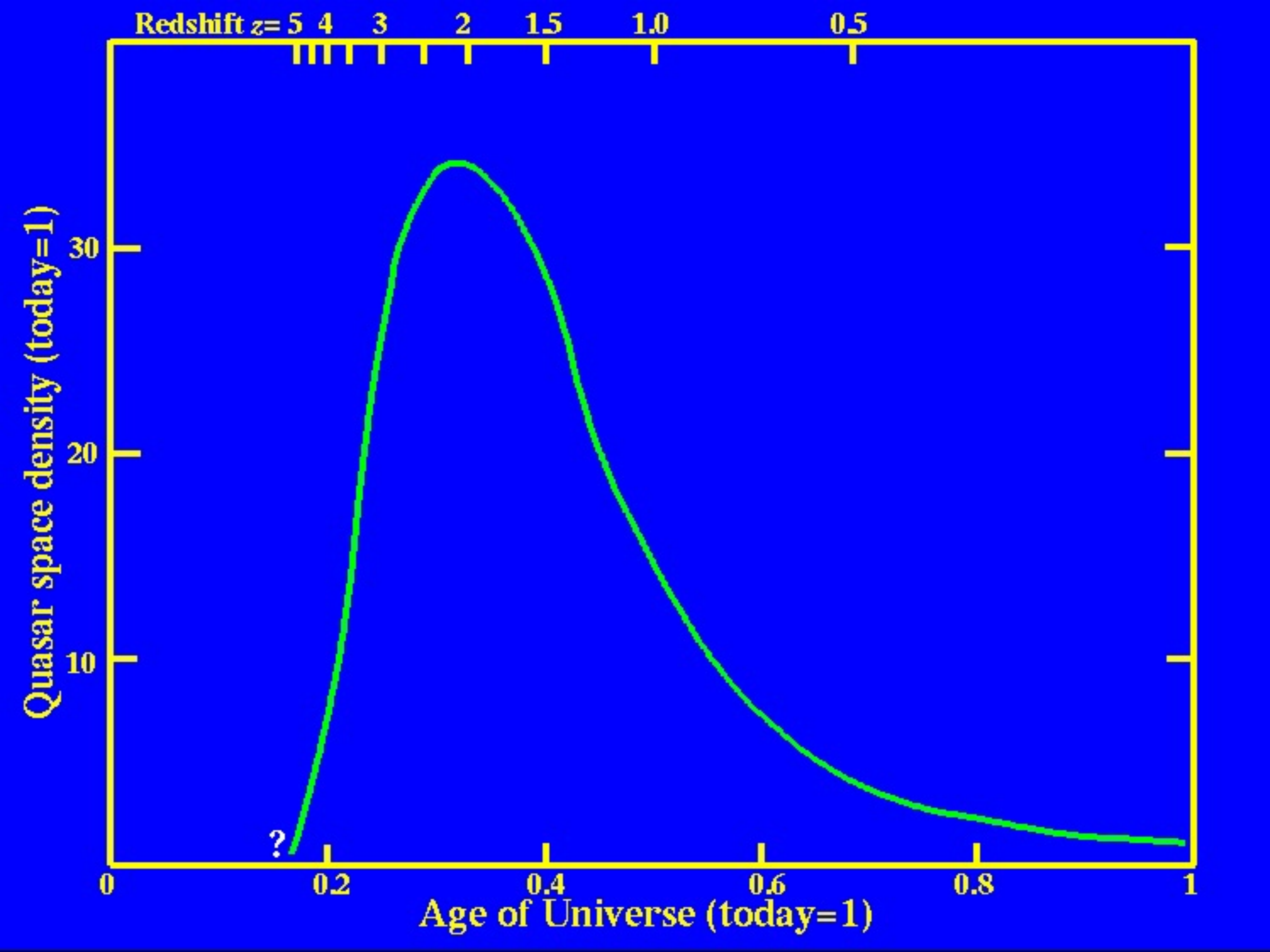




Urry & Padovani: Unified scheme of AGN

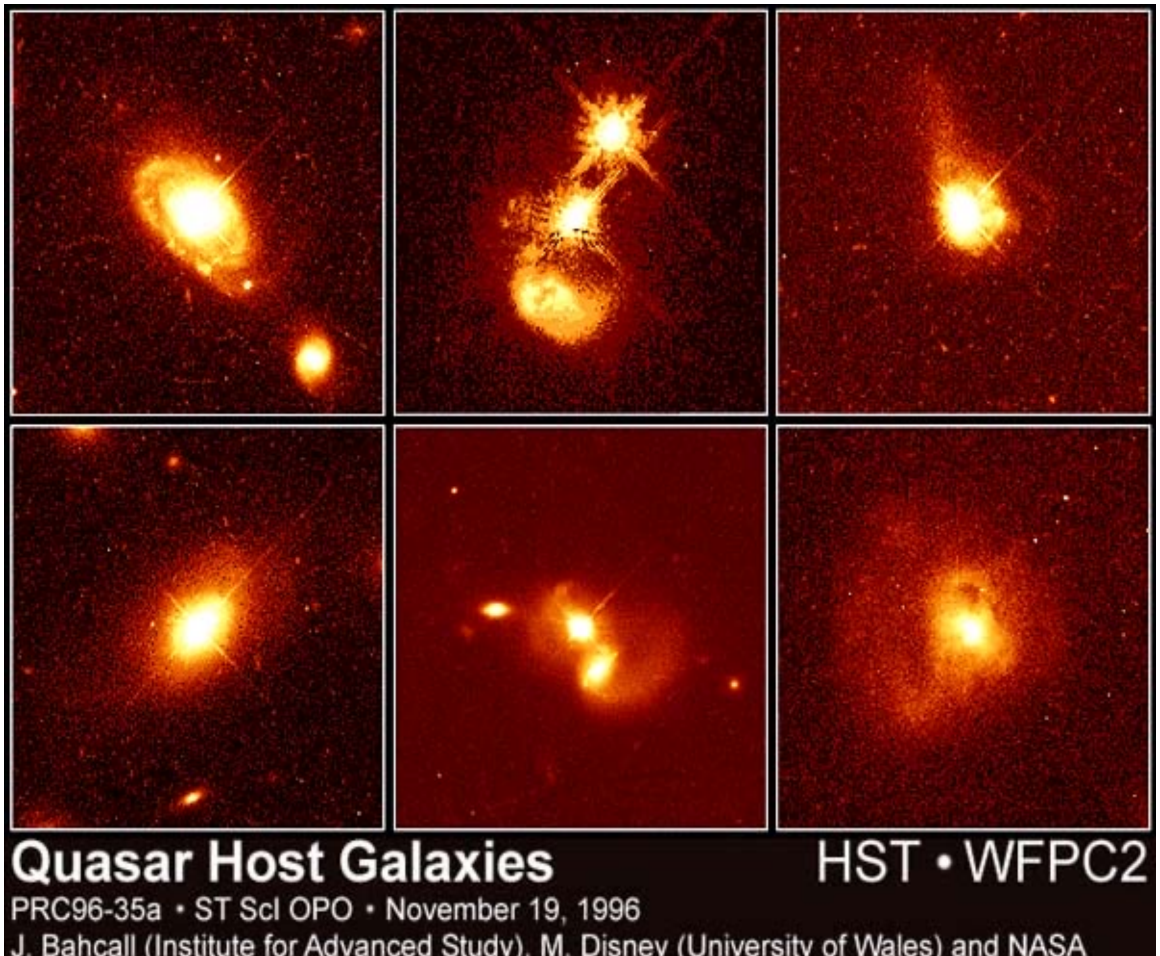

INTERGALACTIC GAS
galactic wind
or "sweeping"
infall
GAS IN GALAXY
star formation
mass loss
STARS IN GALAXY
infall
DENSE GAS CLOUD IN
CENTRE OF GALAXY
star formation
CENTRAL
STAR CLUSTER
mass loss
and stellar collisions
contraction
stellar
coalesence
supernovae, etc.
wind
SUPERMASSIVE OBJECT
"SPINAR", or "MAGNETOID"
CLUSTER OF COMPACT
STELLAR REMNANTS
accretion
tidal disruption
of stars
"post-Newtonian"
instability
"post-Newtonian"
instability
MASSIVE
BLACK
HOLE

Rees (1978)

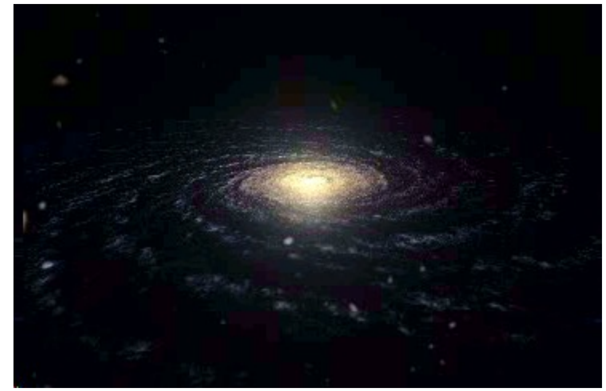


Redshift z= 5 4 3 2 1.5 1.0 0.5
Quasar space density (today=1)
30
20
10
?
0
0.2
0.4
0.6
0.8
1
Age of Universe (today=1)

Quasars are associated with distant galaxies of diverse types, ranging from normal to irregular. Quasars exhibit stellar look but their distances are enormous, and hence also the energy output must exceed standard galaxies.



(C) J. Bahcall (Institut for Advanced Study, Princeton); M. Disney (Cardiff Univ.) et al.; (AURA/STScI)



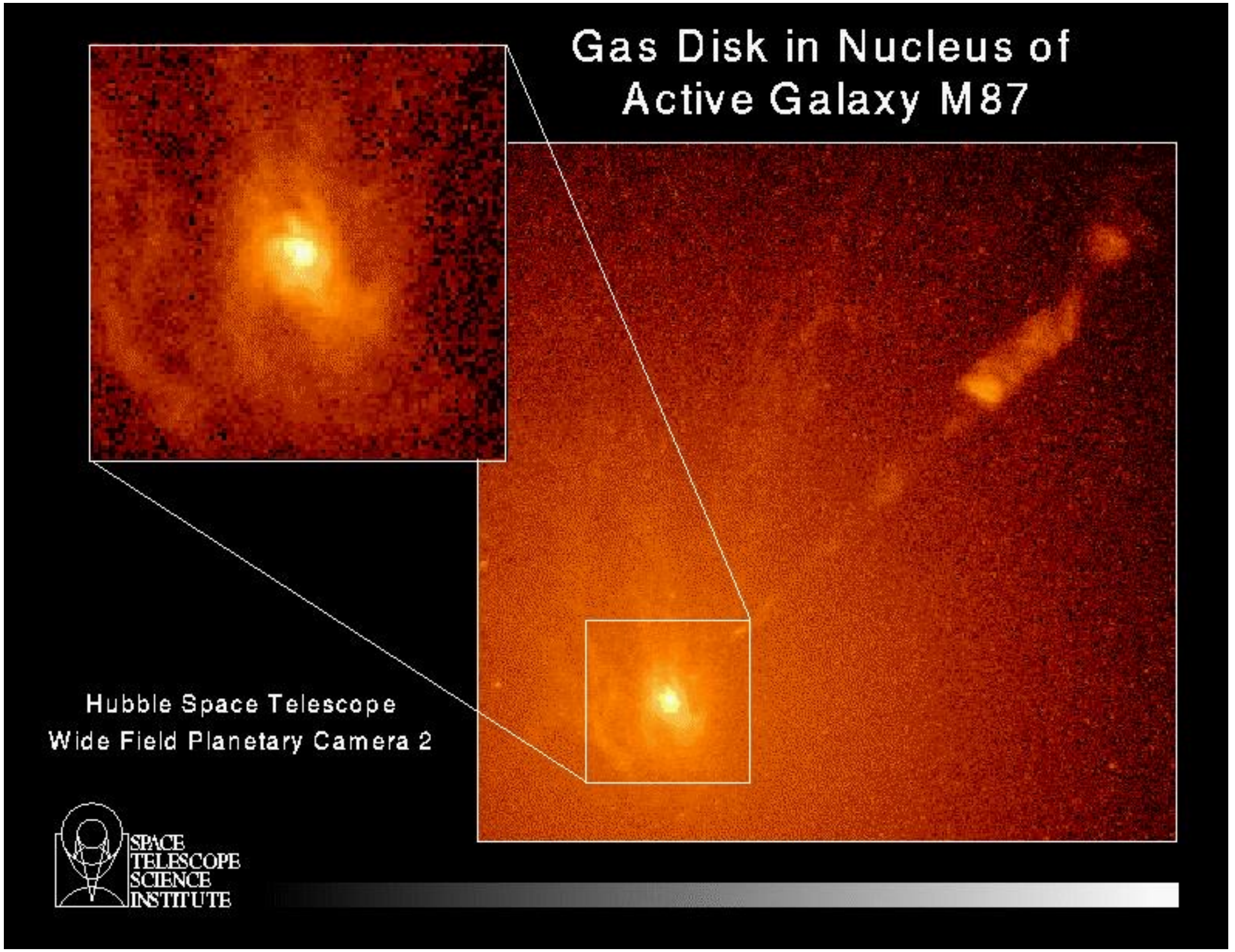
The origin of radiation output of quasars is a compact nucleus. The luminosity is a function of accretion rate → Eddington limit.

Hot gas forms a toroidal structure near the nucleus of a large elliptic galaxy, M87 in Virgo Cluster (dist. 5 x 10^7 l.y.)

Doppler measurements of spectral line energy shifts gives evidence for rotational motion around a dark compact body – a supermassive black hole (SMBH), $M \sim 10^9\ M_{sun}$.

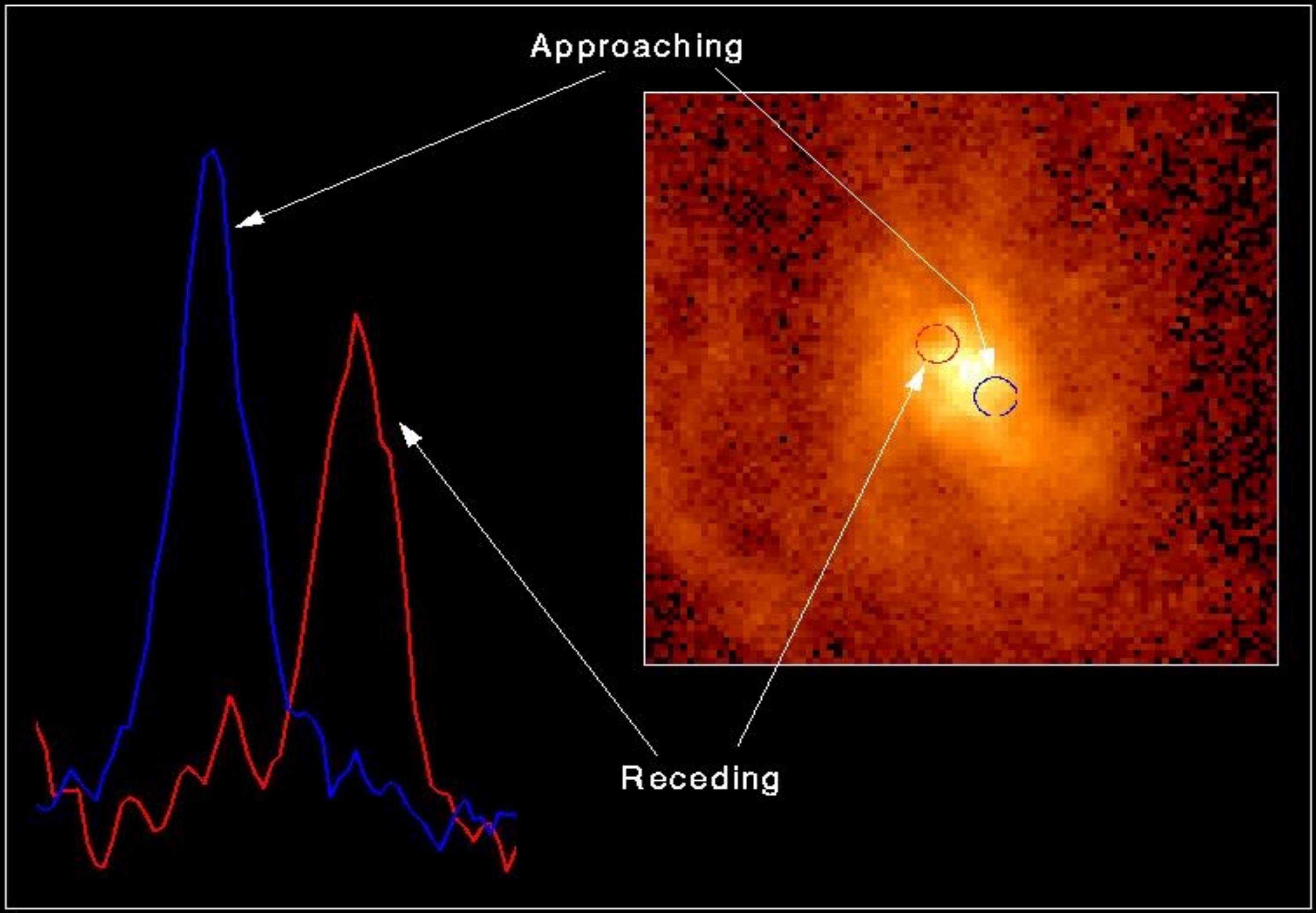
The central NSC cannot explain this large mass.

A long collimated jet emerges from the nucleus.



(C) H. Ford (STScI) et al.

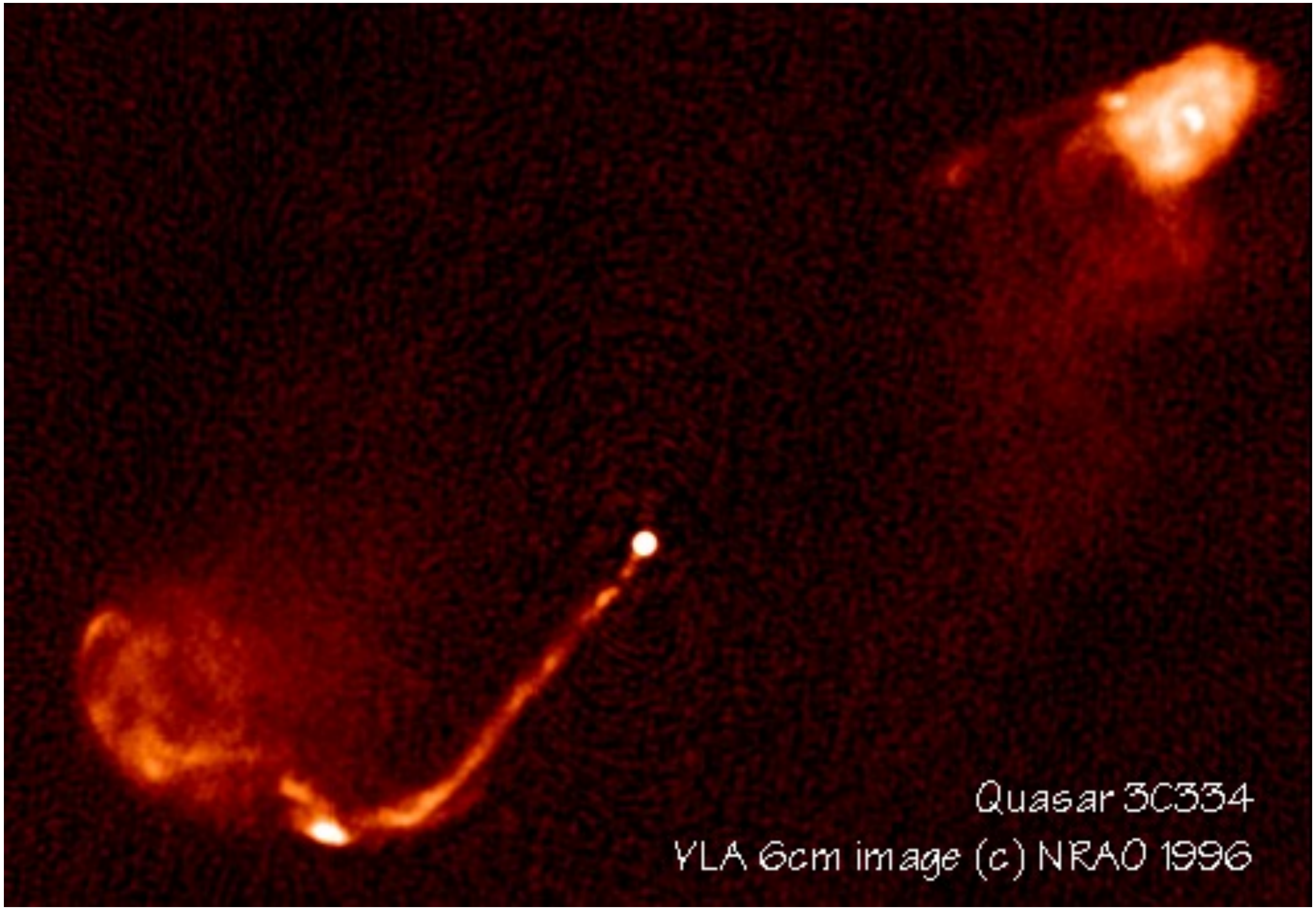
Spectrum of Gas Disk in Active Galaxy M87



Hubble Space Telescope • Faint Object Spectrograph

SPACE TELESCOPE SCIENCE INSTITUTE

3C334 quasar of FR II type, $z = 0.555$. The <u>linear size</u> is $215/h$ kpc (with Hubble constant $H = 100h$ km/s/Mpc);



The structure exhibits <u>double radio lobes</u> with hot spots on both sides and. A bright radio jet and a weaker counter jet.

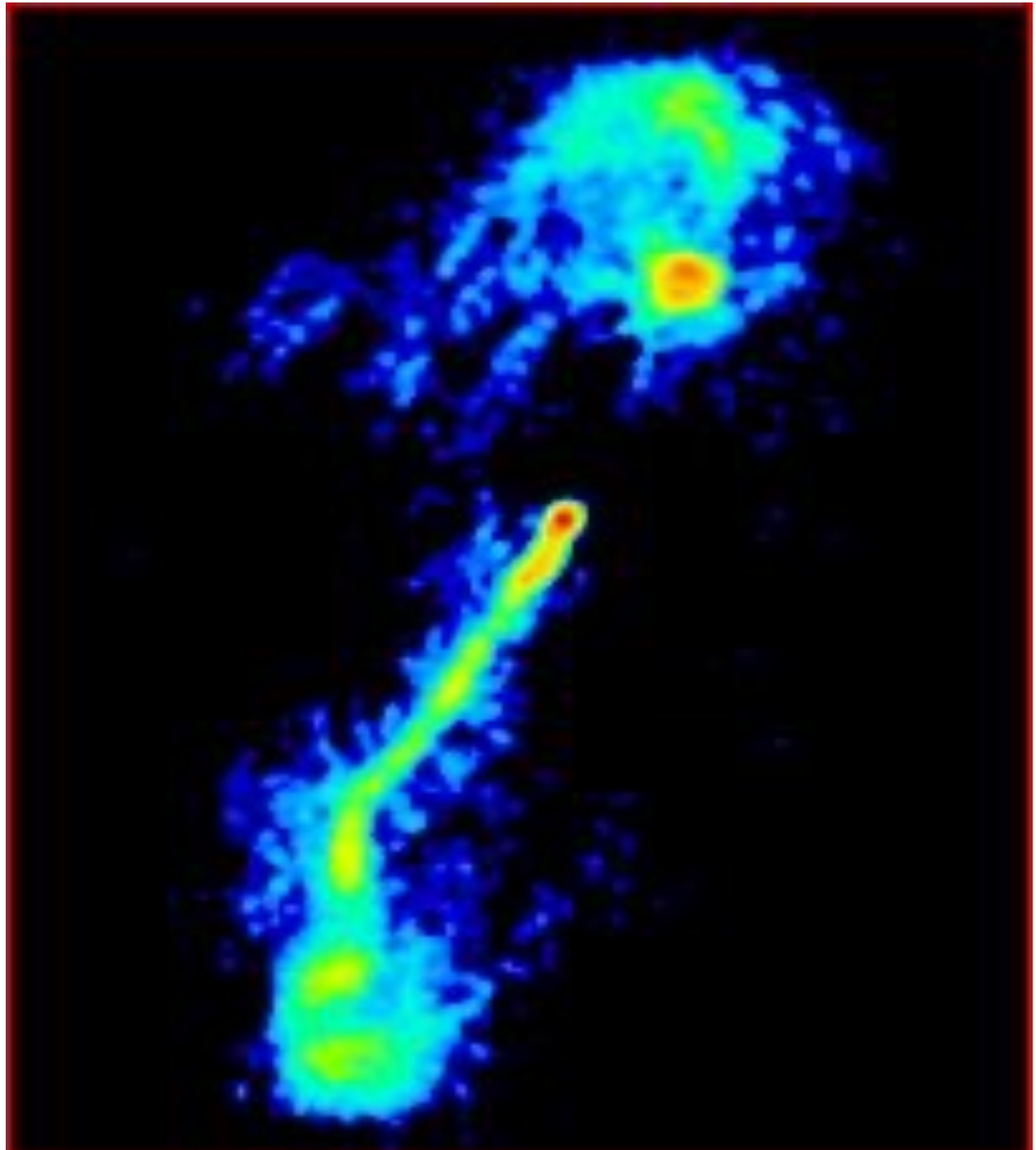
<u>Super-luminal motion</u> occurs in the central region: speed $(1.6/h)c$. The image resolution is 0.35″ at 4.9 GHz.

3C 200 quasar at 4860 MHz, image size ~20''.

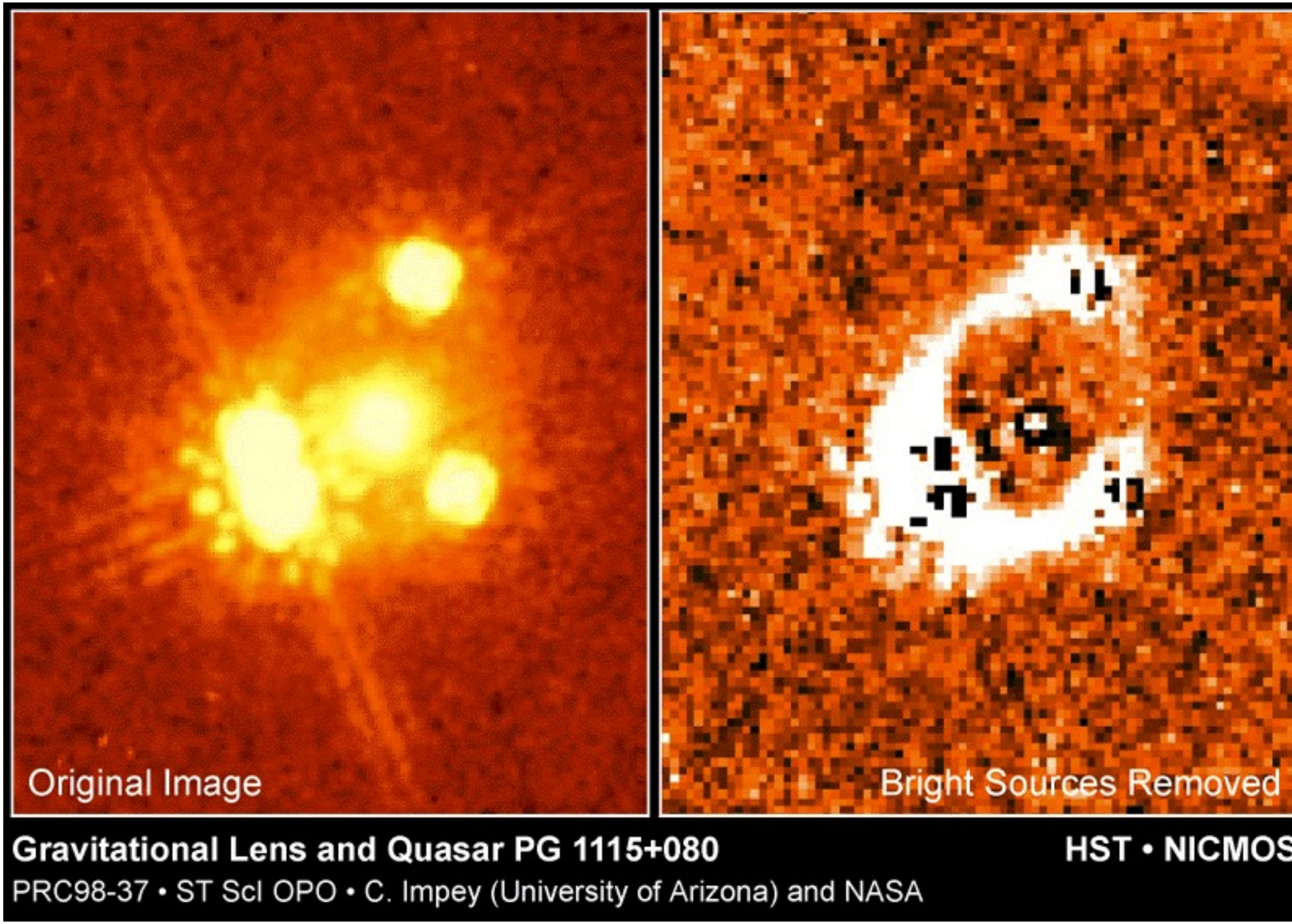
Active galaxies often produce ~100 kpc long jets radiating in radio, as well as shorter wavebands down to X-rays and γ.

Radio images differ significantly from the optical shapes.

(C) D.A. Clarke & J.O. Burns in Leahy et al.

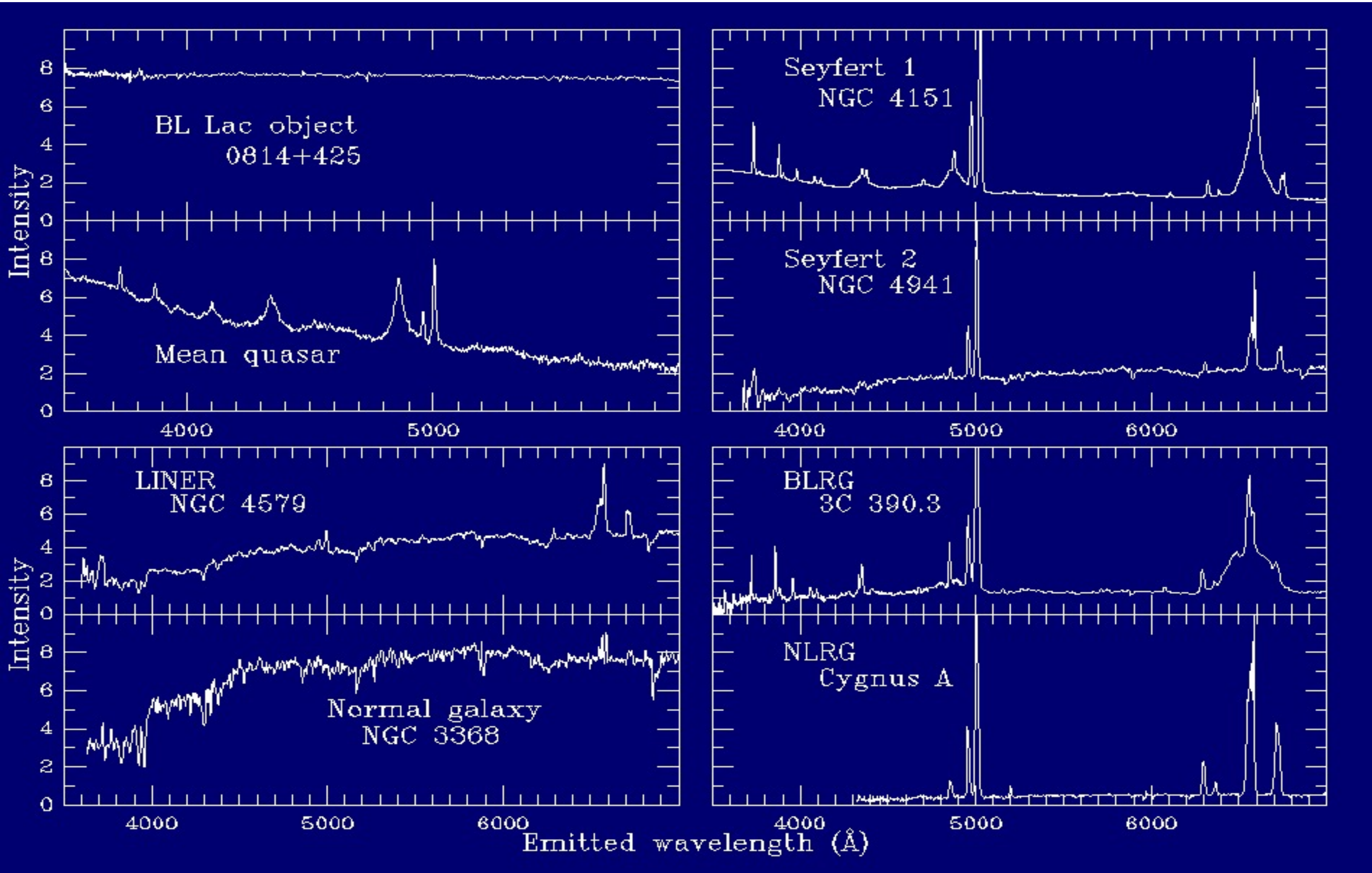


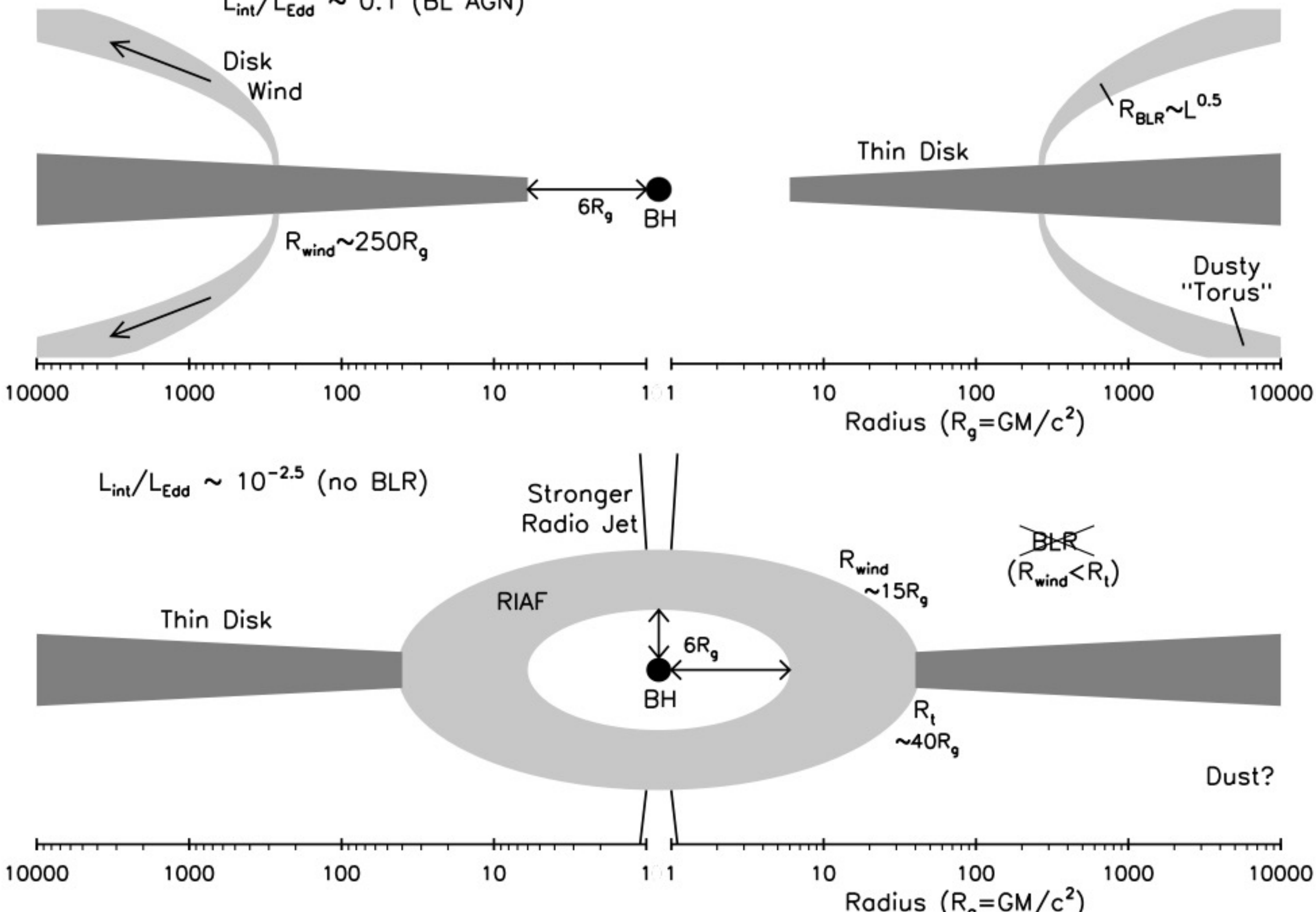
(C) C.D. Impey, Univ.Arizona; STScI

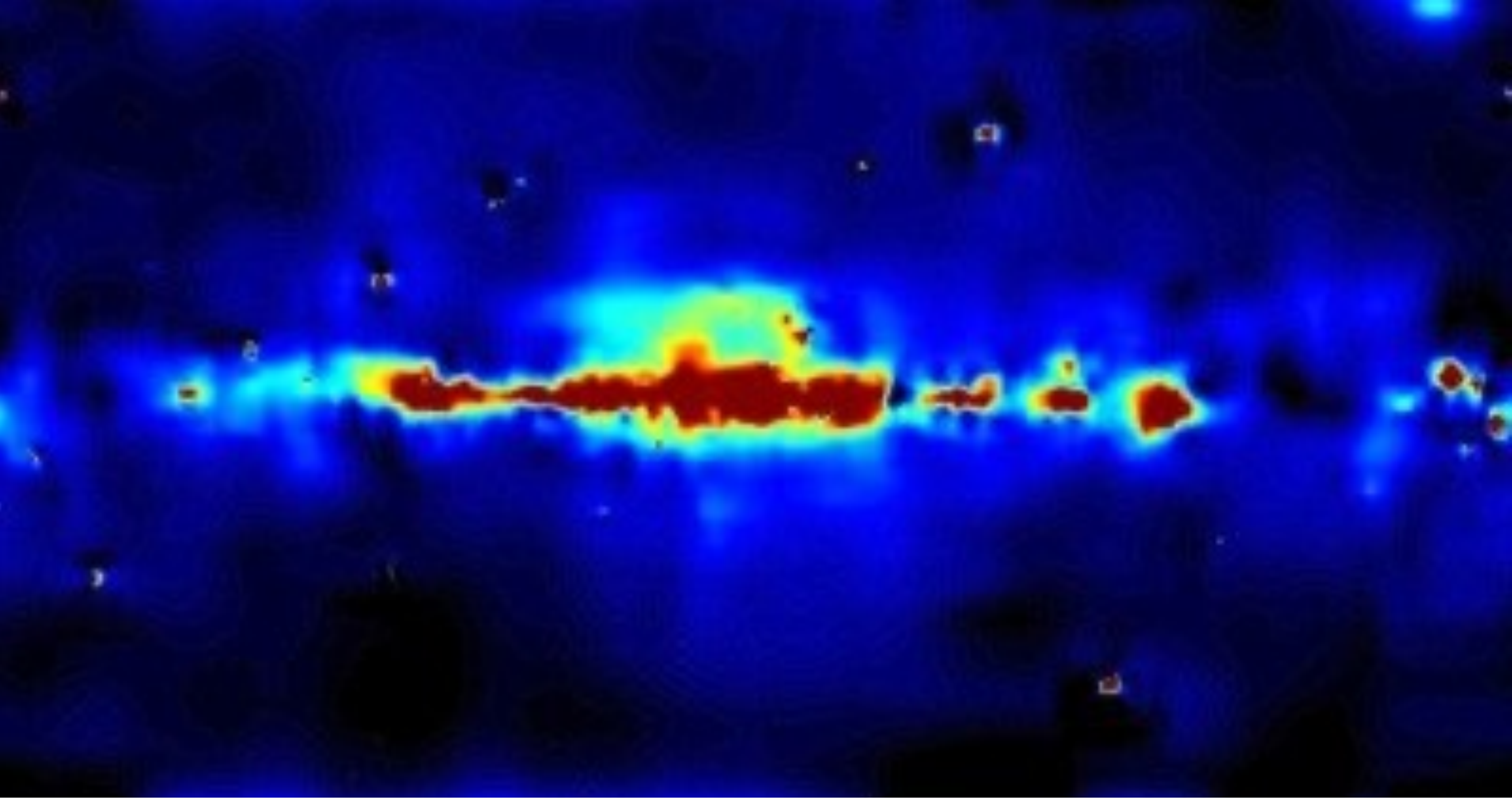


Infrared image of a gravitationally lensed quasar (dist. 8 billion l.y.). The ring (quasar associate galaxy) is visible after subtracting light of the lensing galaxy (dist. 3 billion l.y.) and four images of the quasar.

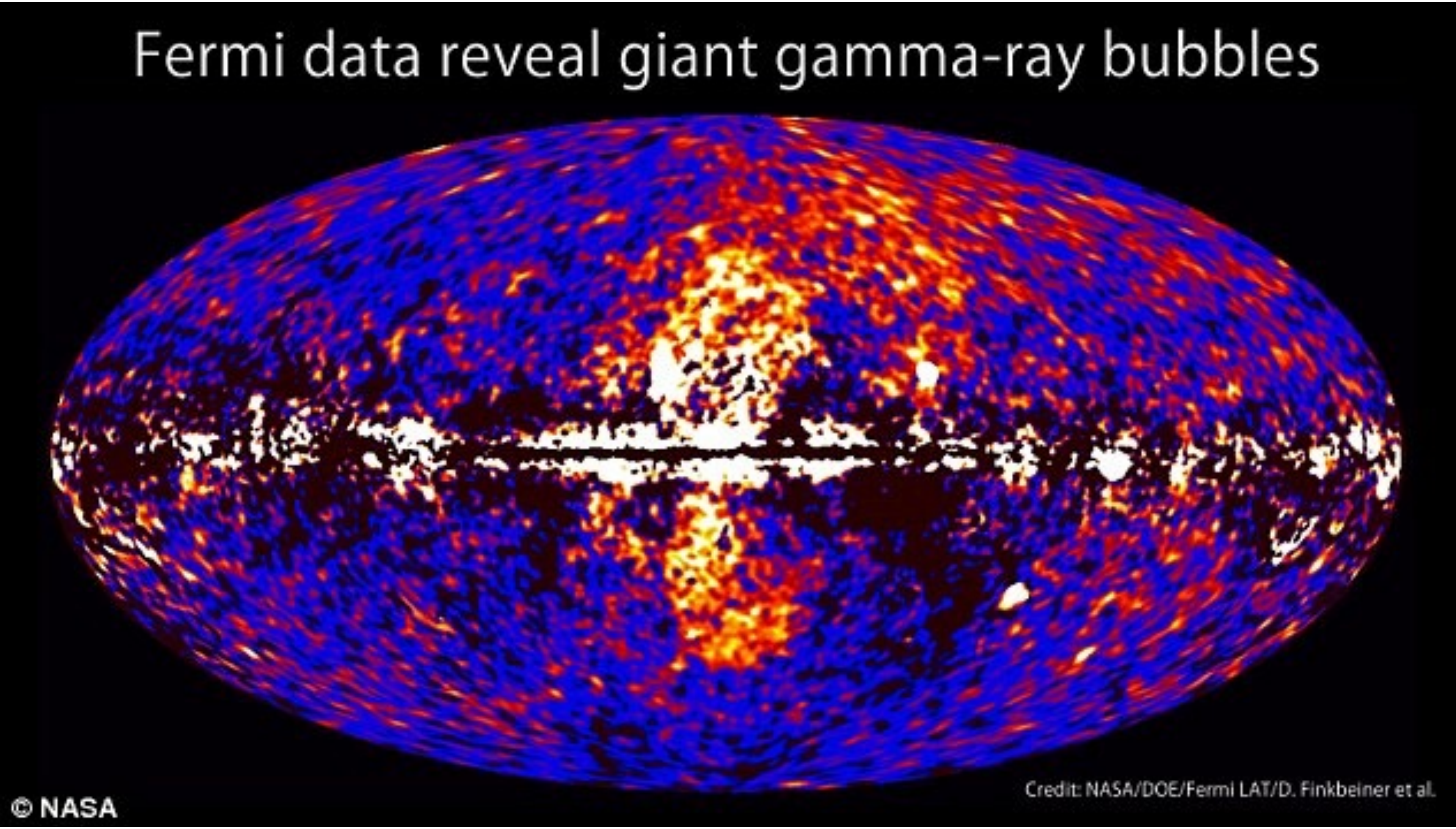
Example: various flavors of AGN spectra

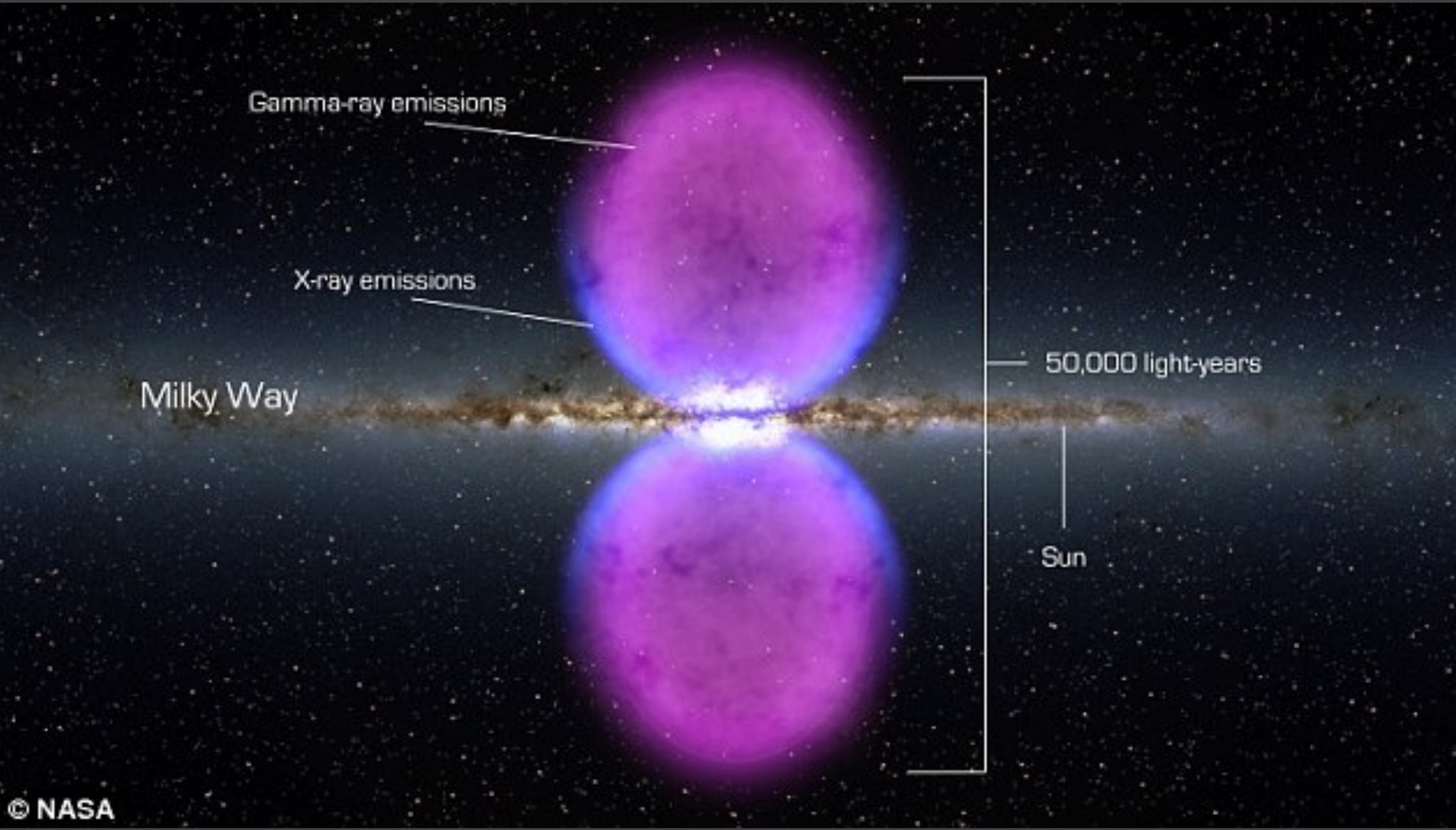



L_int/L_Edd ~ 0.1 (BL AGN)
Disk Wind
R_BLR~L^0.5
Thin Disk
6R_g
BH
R_wind~250R_g
Dusty "Torus"
10000 1000 100 10 1 1 10 100 1000 10000
Radius (R_g=GM/c²)
L_int/L_Edd ~ 10^-2.5 (no BLR)
Stronger Radio Jet
BLR
(R_wind<R_t)
R_wind ~15R_g
RIAF
Thin Disk
6R_g
BH
R_t ~40R_g
Dust?
10000 1000 100 10 1 1 10 100 1000 10000
Radius (R_g=GM/c²)

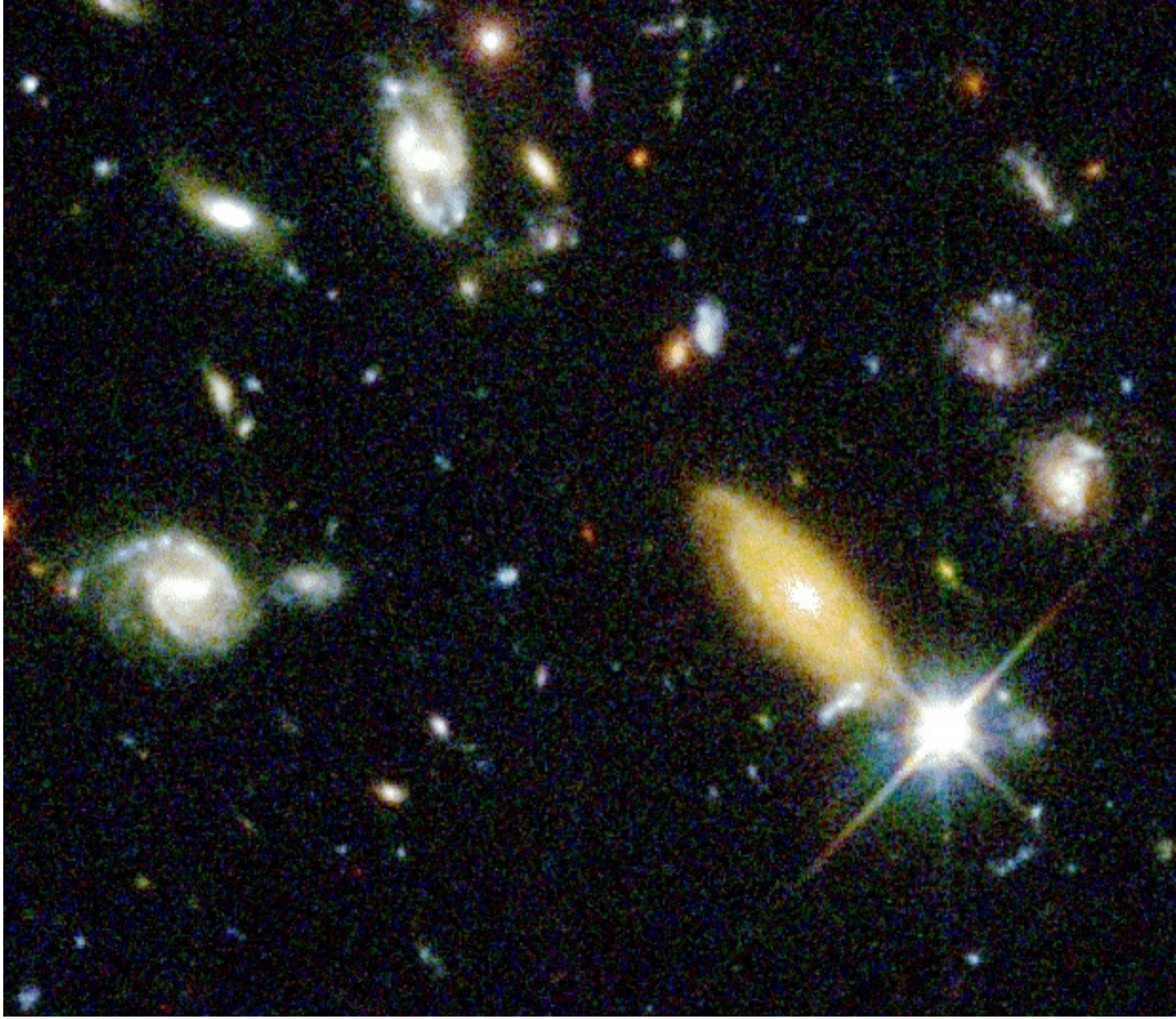


Milky Way: a diffuse halo (blue color) of high-energy γ rays around the Galactic plane (brown, green).
(EGRET/CGRO – Compton Gamma-Ray Observatory)


Fermi data reveal giant gamma-ray bubbles
Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.
© NASA


Gamma-ray emissions
X-ray emissions
Milky Way
50,000 light-years
Sun
© NASA

The mosaic consists of 342 individual images, each one recorded at ~15–40 min exposure by WFPC2 (Wide Field and Planetary Camera 2). It is expected that the distribution



of different type of galaxies is similar in the entire Universes as in this small example.

Baade (1957), based on M 31 galaxy observation:

- Two main morphological components of a galaxy
- Two stellar populations: Population I vs. Population II (different metallicity, age, location)

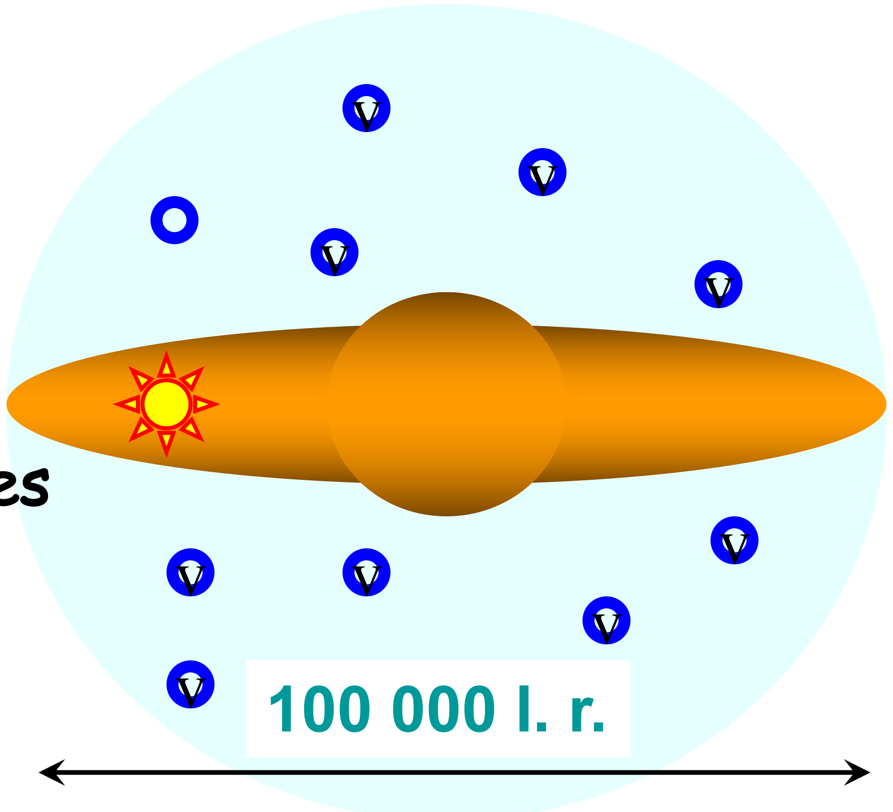
Standard luminosity profiles:

- Spheroids of elliptical galaxies (de Vaucouler 1948)

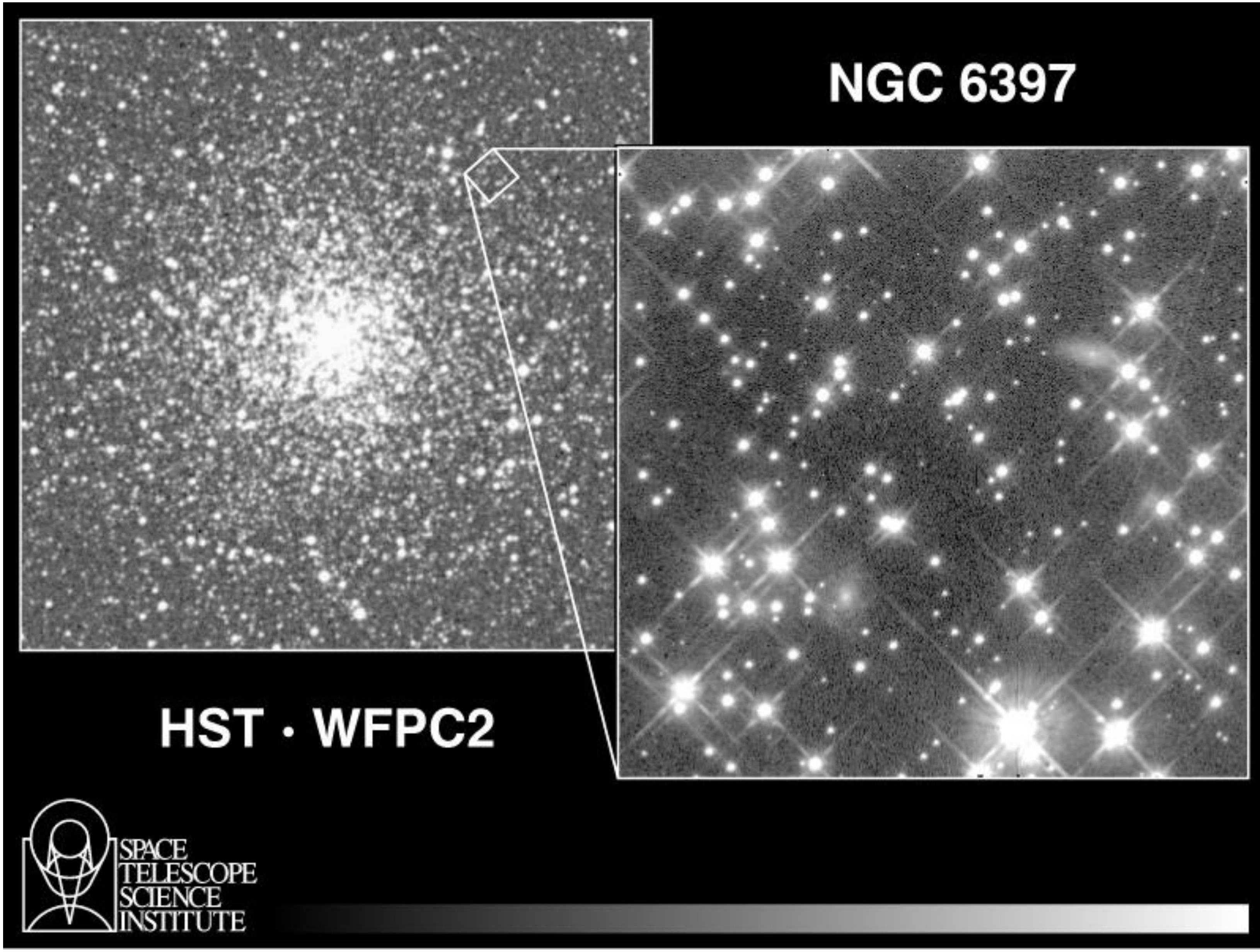
$$I(R) = I_0 \exp(-kR^{\frac{1}{4}}).$$

- Disks of S and S0 spiral galaxies (van der Kruit 1981)

$$I(R) = I_0 \exp(-R/h).$$



Globular star-clusters belong to the spherical component of a galactic „halo“, $n \sim 2 pc^{-3}$.



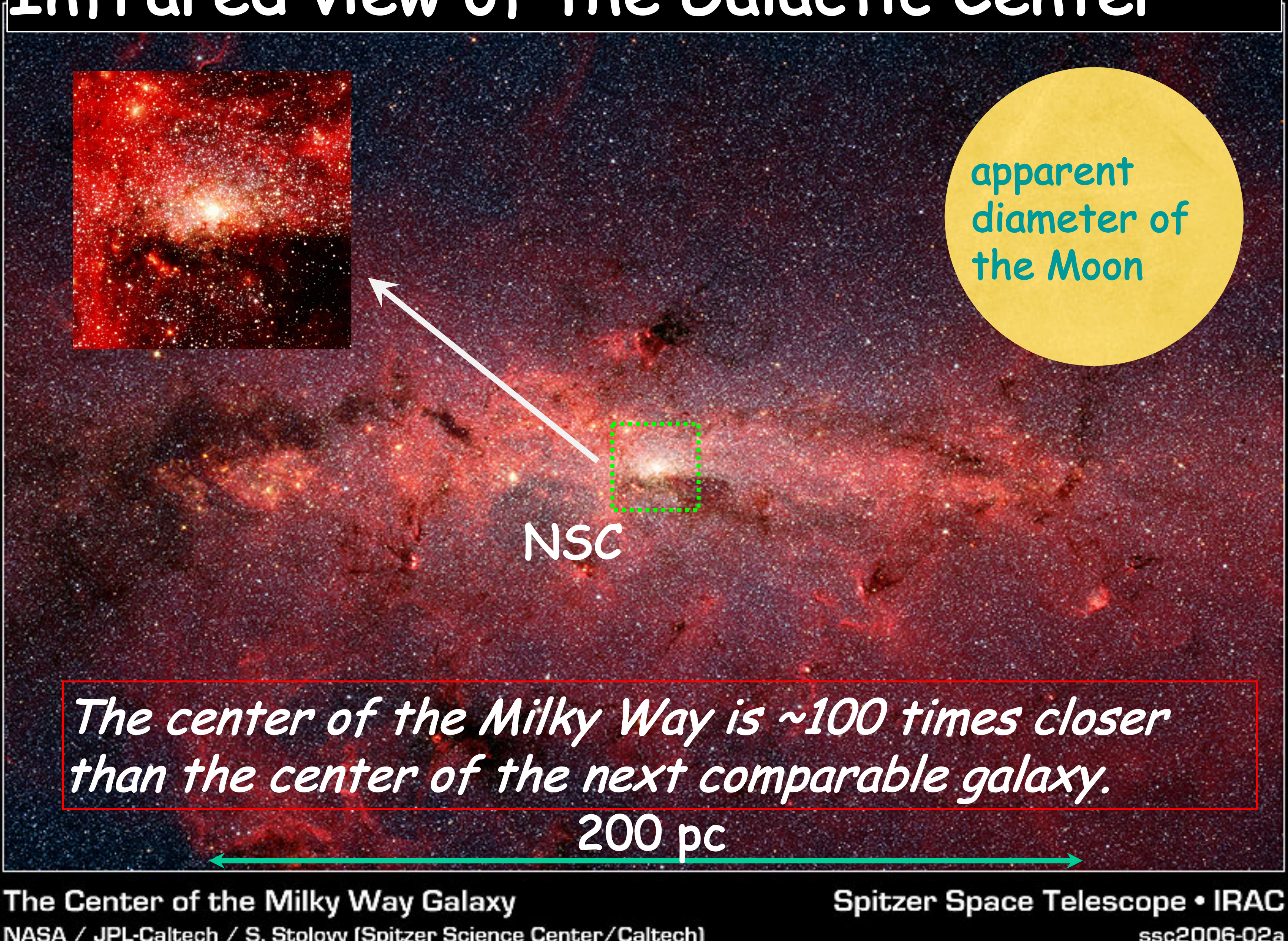
(C) Paresce (STScI)

Nuclear star clusters in centers of galaxies

- **NSCs are detected in ~70% of spiral, spheroid (dwarf elliptical) and S0 galaxies**
- **the actual occurrence in these galaxies may be → 100%**
- **NSCs appear to be absent in elliptical galaxies that are products of major mergers**
- **Half-light radii** 2-5 pc, **Mass** of 10^6 - 10^7 $M_\odot$
- **Complex star formation histories**: frequent and repetitive star formation episodes
- NSCs obey similar **scaling relationships with properties of host galaxies** as do massive black holes

Ferrarese et al. 2006; Kormendy et al. 2009

Infrared view of the Galactic Center



The center of the Milky Way is ~100 times closer than the center of the next comparable galaxy.

The Milky Way disk contains lots of obscuring dust → we probably miss a number of galaxies that may influence dynamics of the Local Group.

Dwingeloo 1 (SBb type) was discovered only more recently.

A member of the group containing also IC342 and Maffei galaxies.

Differential rotation: spiral arms are not permanent objects.

Spiral galaxy M31 Andromeda. Distance 2 milion l.y. (within the local galaxy group). Size ~40 thousand l.y. A double nucleus (resolution ~40 l.y.)