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allenges in Modern Astrophysics

Sofia, Bulgaria Oct. 2009

What Makes a Galaxy ACTIVE ?

What is a Normal Galaxy?

What is an Normal Galaxy?

A literary analogy, adapted quote from “Animal Farm” by George Orwell

ALL PEOPLE ARE EQUAL

BUT…

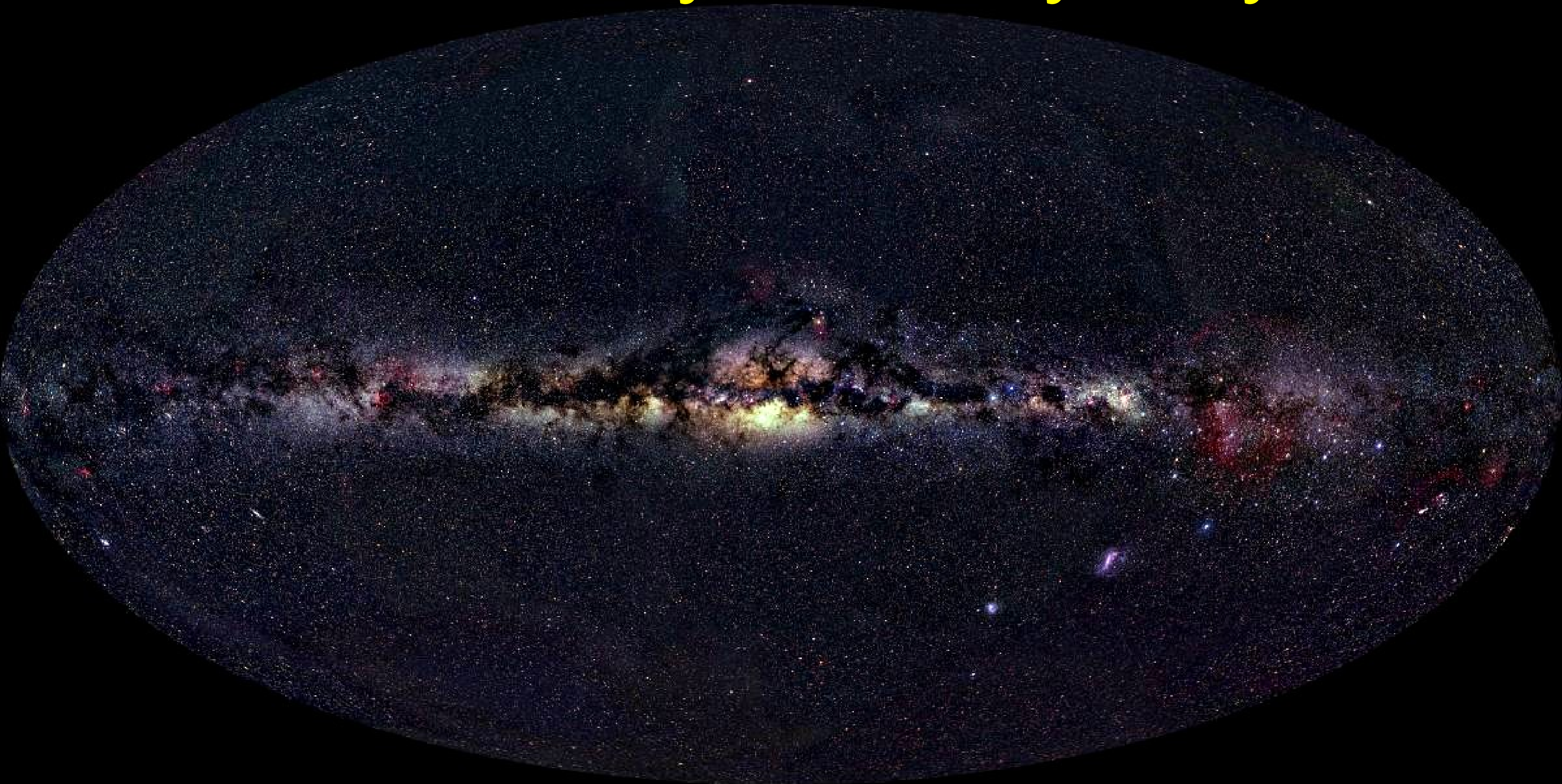
SOME PEOPLE ARE MORE EQUAL THAN OTHERS

**ALL GALAXIES ARE ACTIVE, BUT…
SOME GALAXIES ARE MORE ACTIVE THAN OTHERS**

Multi-frequency observations are crucially important…

A galaxy may appear “normal” at one frequency, yet, it could appear really active at another

First ask: what is a Normal Galaxy ? Our Galaxy the Milky Way



Axel Mellinger, 2000

An Infrared View of Our Galaxy (activity often depends on wavelength !)

BRIEF AGN HISTORY LESSON

- Fath (1907, PhD, Lick) – Spectrum of NGC1068, followed by Slipher, Curtis, Hubble…
- Carl Seyfert (1943) – Postdoc at Mount Wilson
- Radio Stars, extended sources c. 1952
- What are quasars? Maarten Schmidt 1963
- Two basic types Khachikian and Weedman (1973):

Seyfert type 1, broad hydrogen emission lines, narrow forbidden lines

Seyfert type 2, narrow hydrogen emission lines, narrow forbidden lines

AGN HISTORY LESSION

- **Fath (1907, PhD, Lick) – The first AGN spectrum**

Taken using a photographic plate.

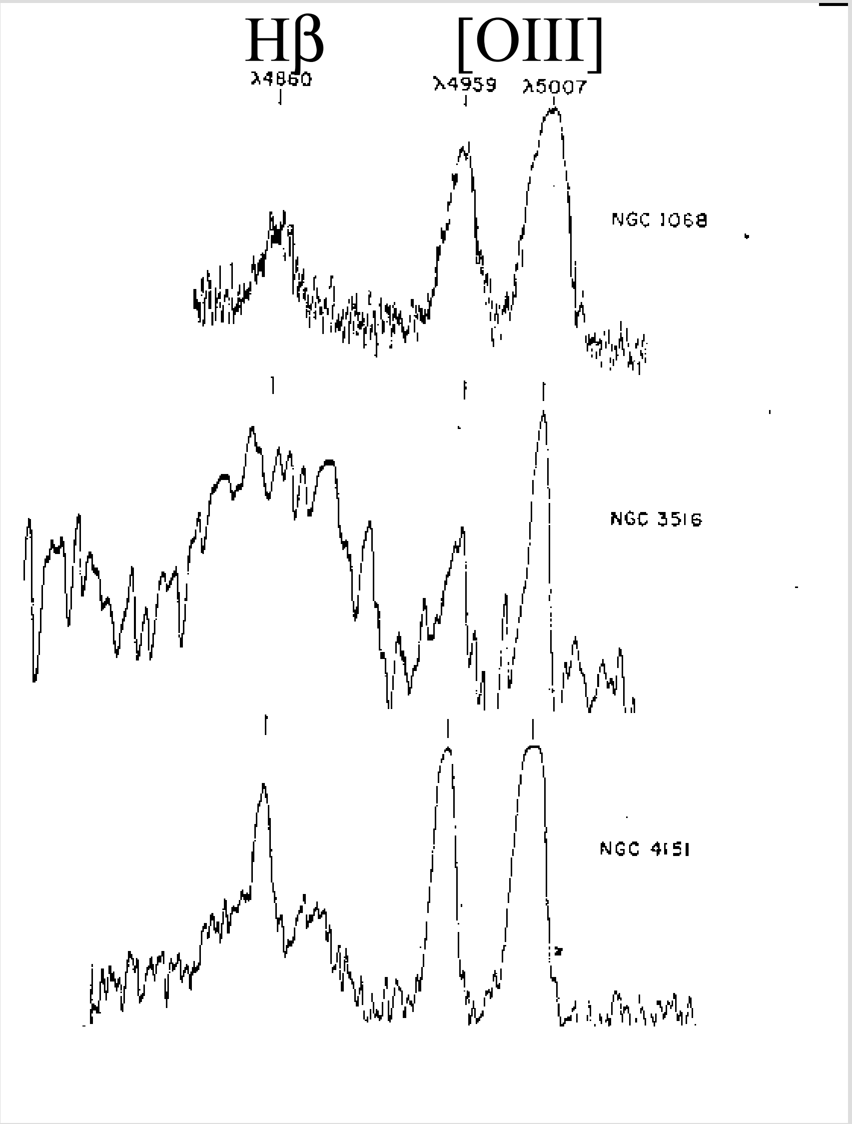
Interestingly he noticed a very slight disagreement between the observed wavelengths of the emission lines, and their laboratory wavelengths

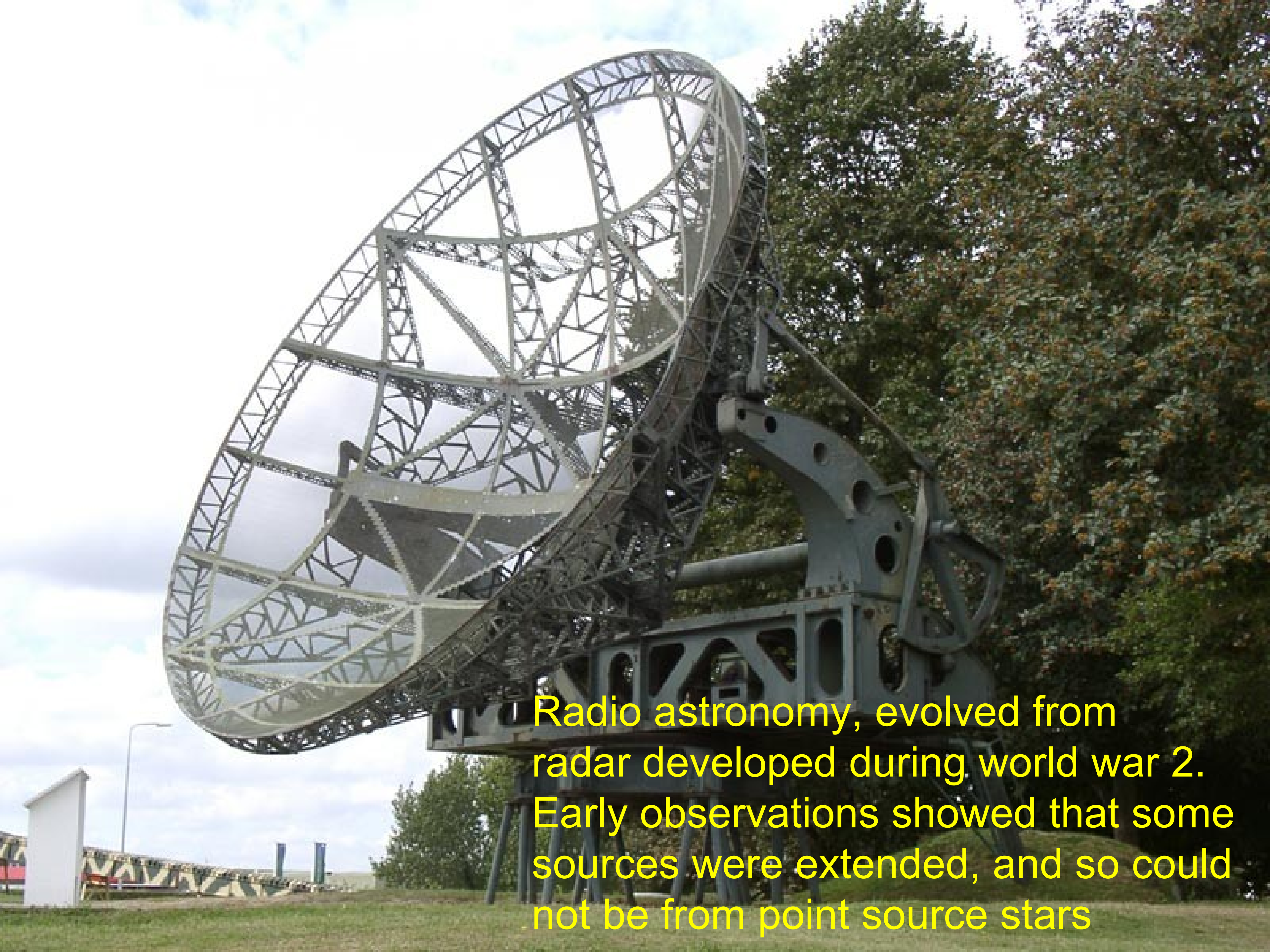
He didn't know it at the time, but he had measured the comological redshift !

20 years before Hubble's famous paper

AGN HISTORY LESSON

- **Carl Seyfert (1943) – Postdoc at Mount Wilson**

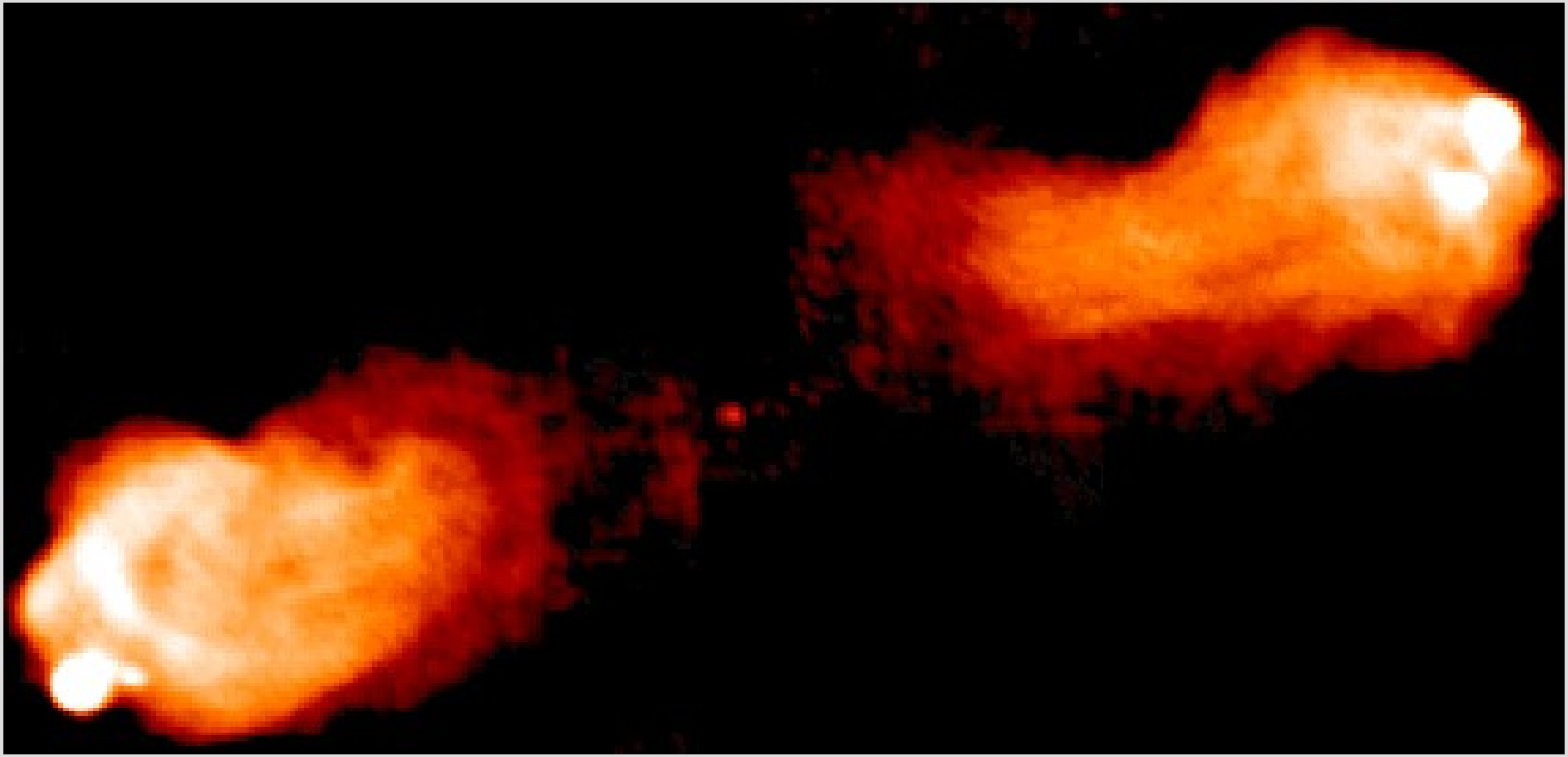




Radio astronomy, evolved from radar developed during world war 2. Early observations showed that some sources were extended, and so could not be from point source stars

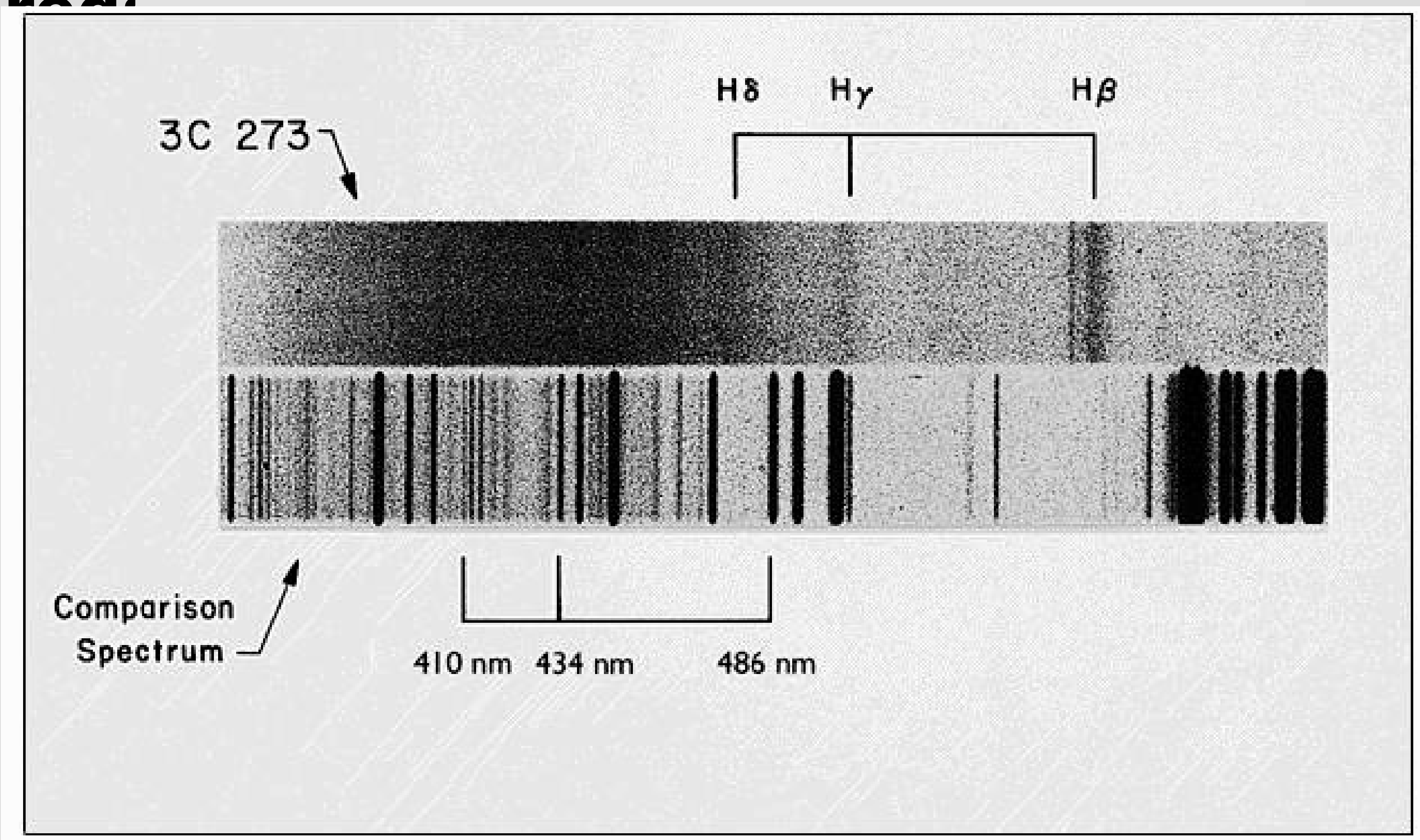
Radio Galaxy with a jet – image in radio

(the jet carries the energy into the bright radio lobes. Energy generated at very centre is transported across millions of light years, HOW?)

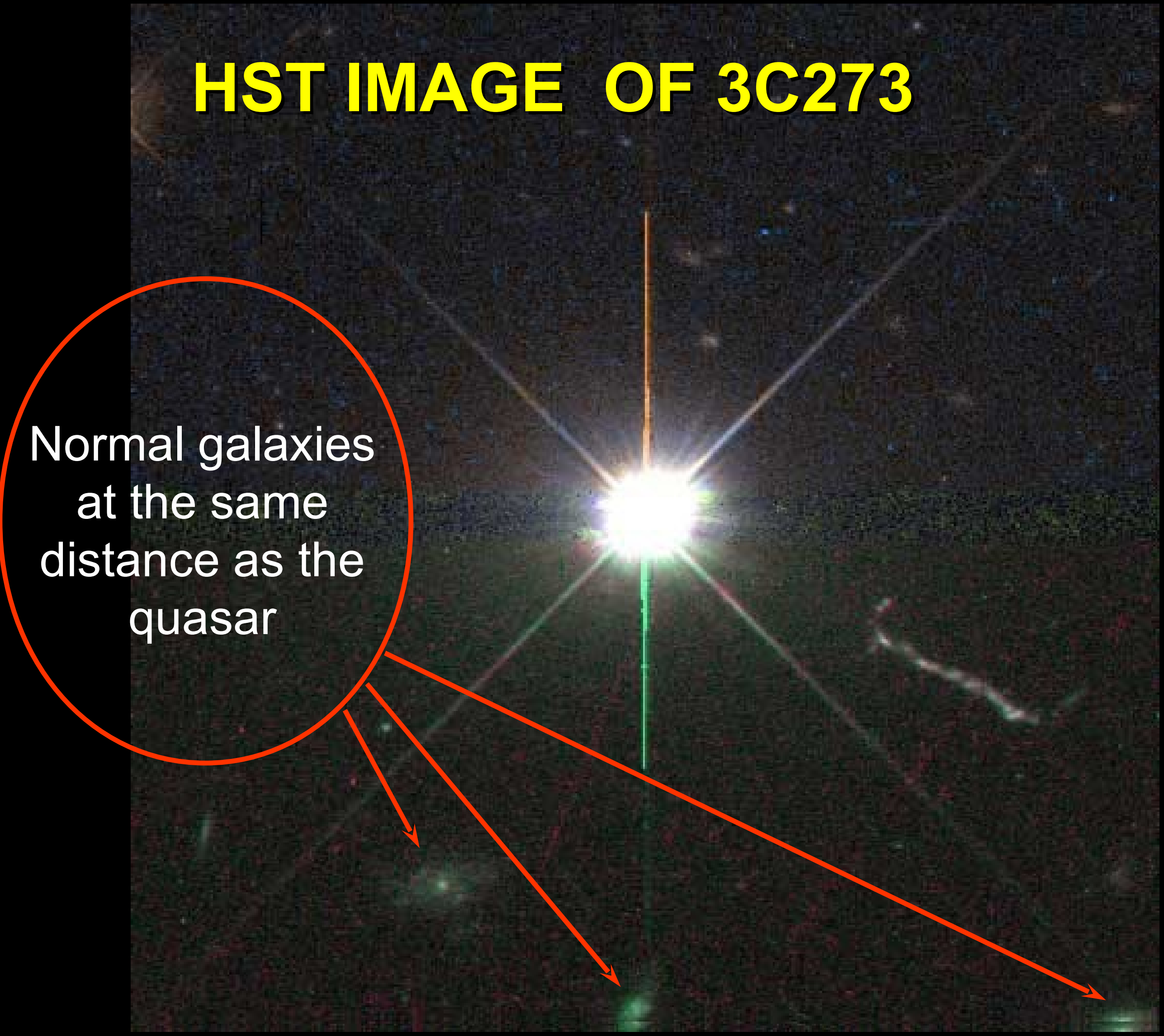


AGN HISTORY LESSON

- **What are quasars? Schmidt 1963 measurement and consequences of redshift**



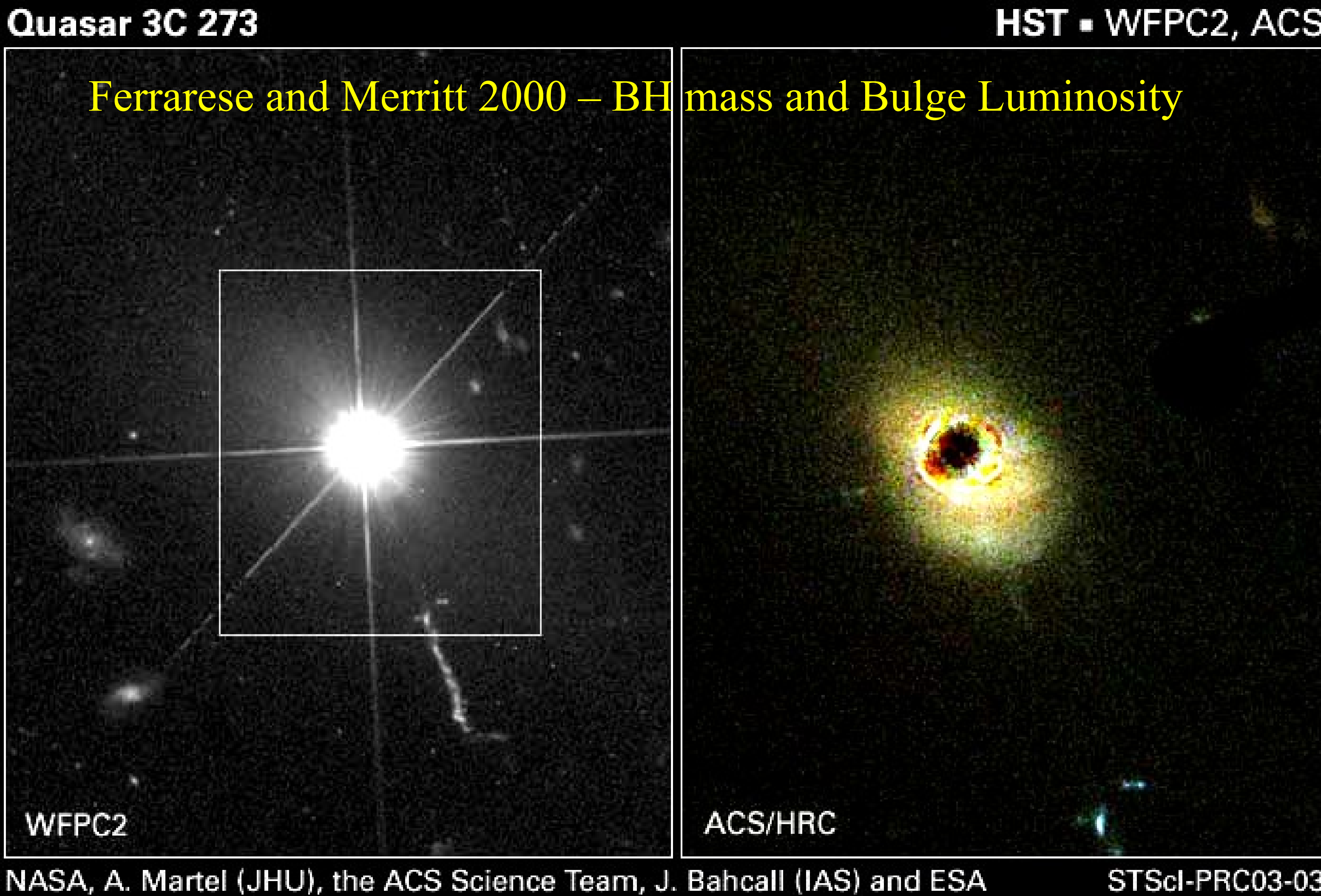
The Quasar 3C 273



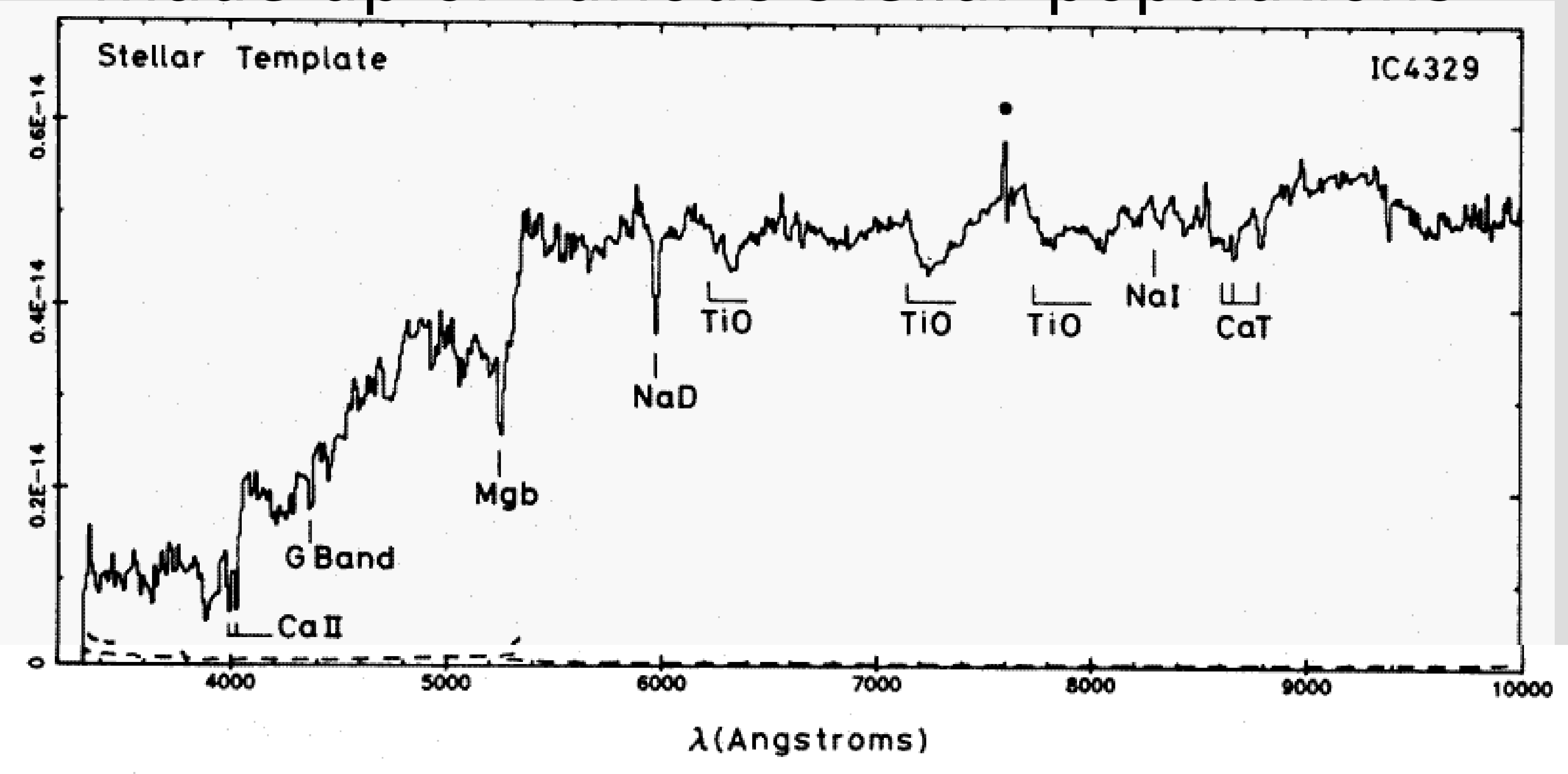
3C 273 was the first quasar which was shown to be the nucleus of an active galaxy. Quasars can be up to 1000 more luminous than massive galaxies.

lationship between the Host Galaxy and the A

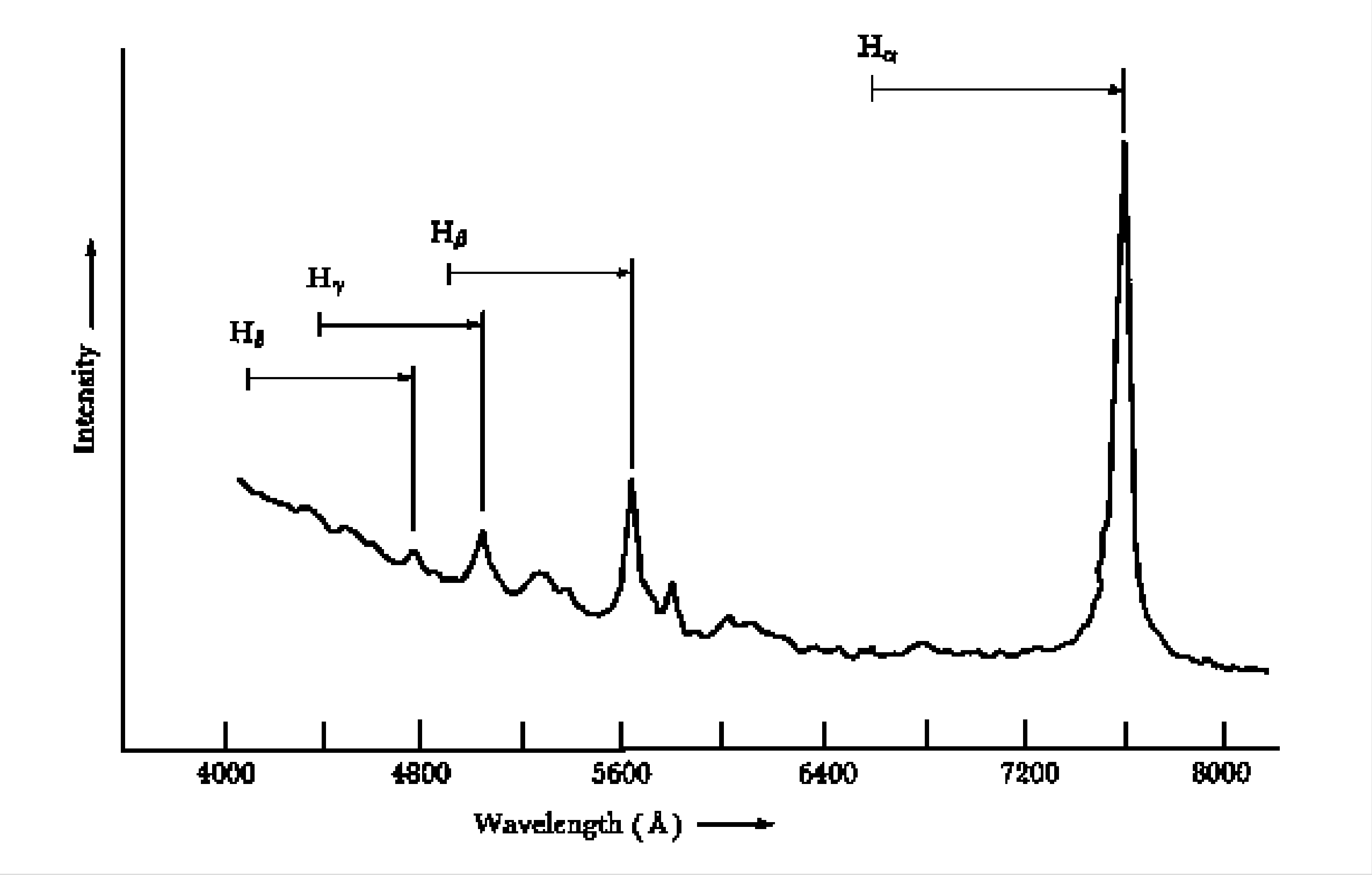
Ferrarese and Merritt 2000 – BH mass and Bulge Luminosity



The Diagnostic Power of Spectroscopy Optical Spectrum of a "Normal Galaxy" made up of various stellar populations



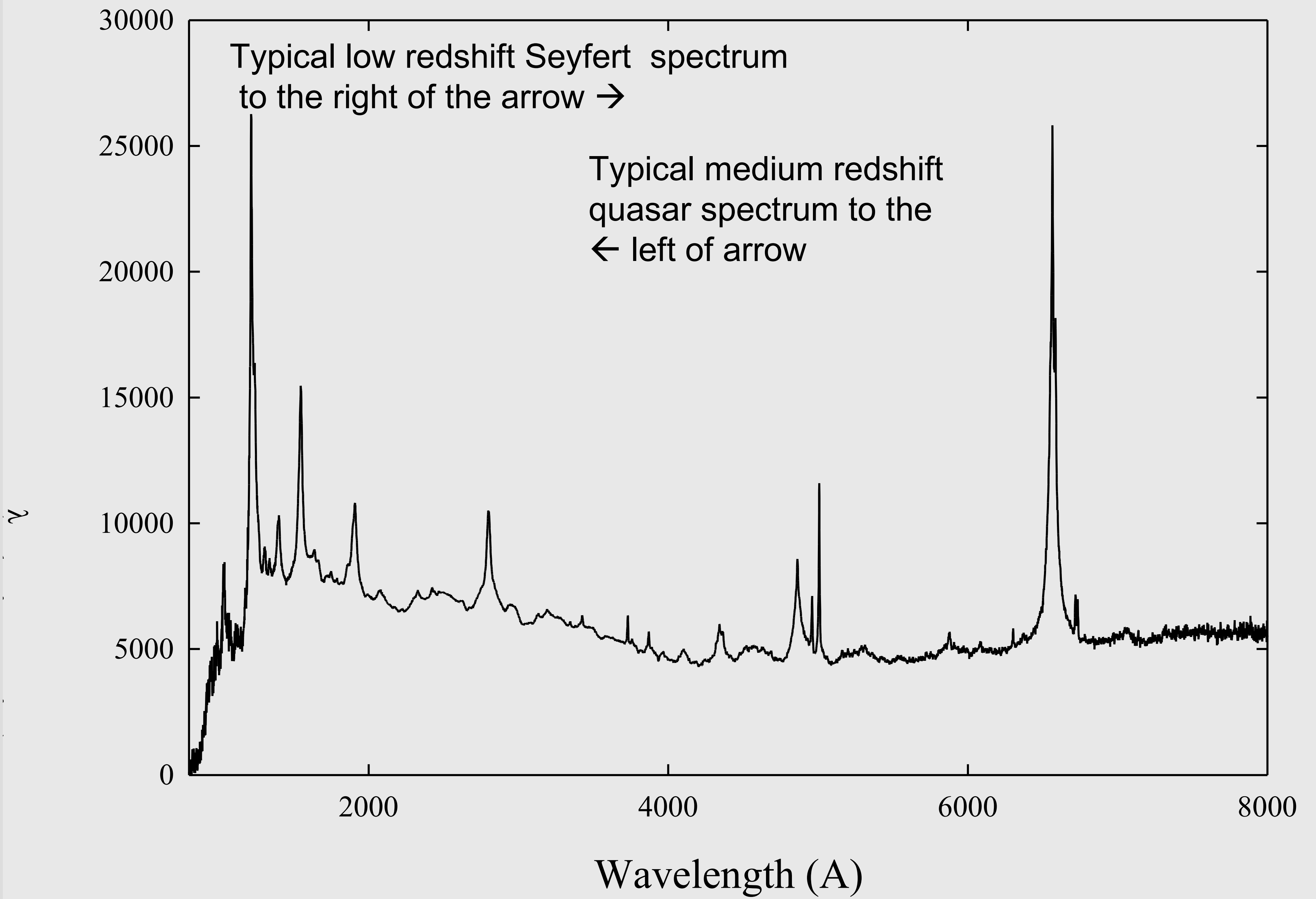
A Quasar Spectrum
(Unlike a normal galaxy this has emission lines which require high energy photons to produce)



End of history lesson – now we consider the **properties** of AGN

- Enormous energy emitted from a very small volume – stars cannot do this
- Energy emitted over vast frequency range, from radio to gamma rays – stars cannot do this
- Influence of the AGN can extend ~1,000,000 light years in case of some radio galaxies
- Their spectra have strong broad emission lines, and highly ionised species

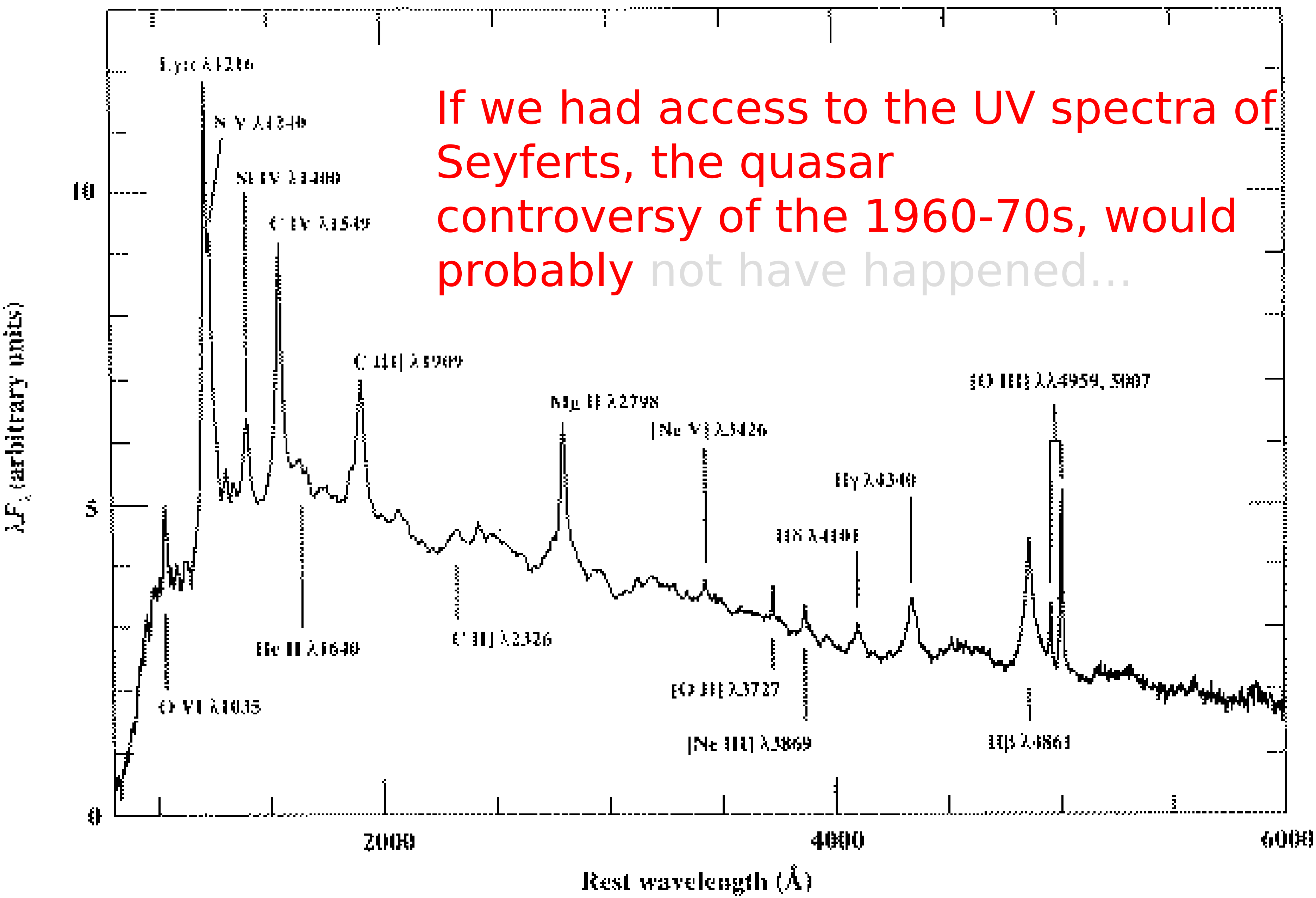
Quasars are like Seyferts, but we see their UV lines



What the emission lines can tell us

- The nucleus is emitting energetic photons able to ionise the gas
- The widths of the emission line, when converted into velocity via the Doppler effect, is equal to many 1000’s km/s
- To keep this gas bound ie. not lost, it must be less than the escape velocity which requires the presence of a high mass at the nucleus (does not **prove** presence of BH)

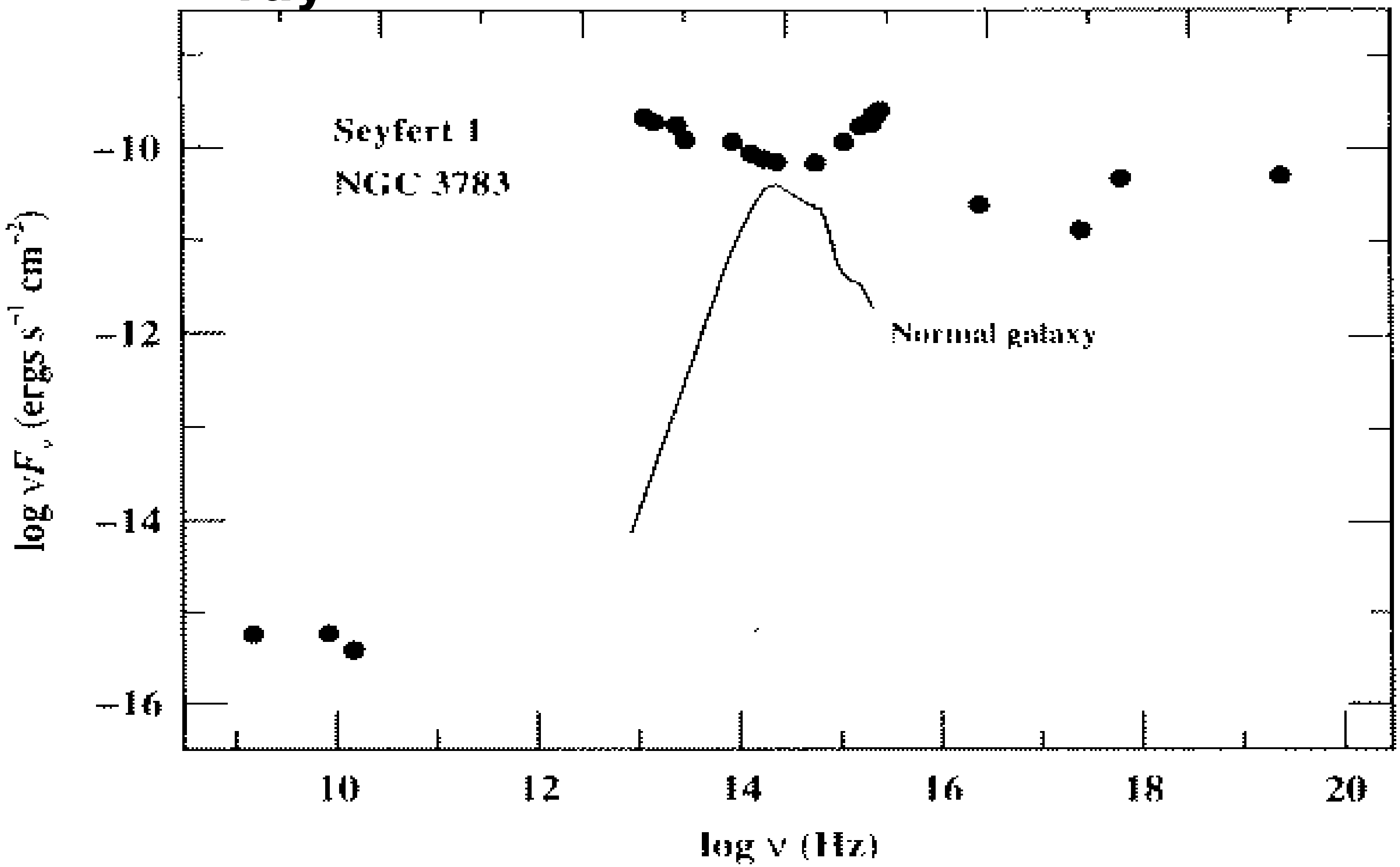
A brief "deadend" in Quasar research, late 60's/early 70's



If we had access to the UV spectra of Seyferts, the quasar controversy of the 1960-70s, would probably not have happened…

AGN emit at all frequencies

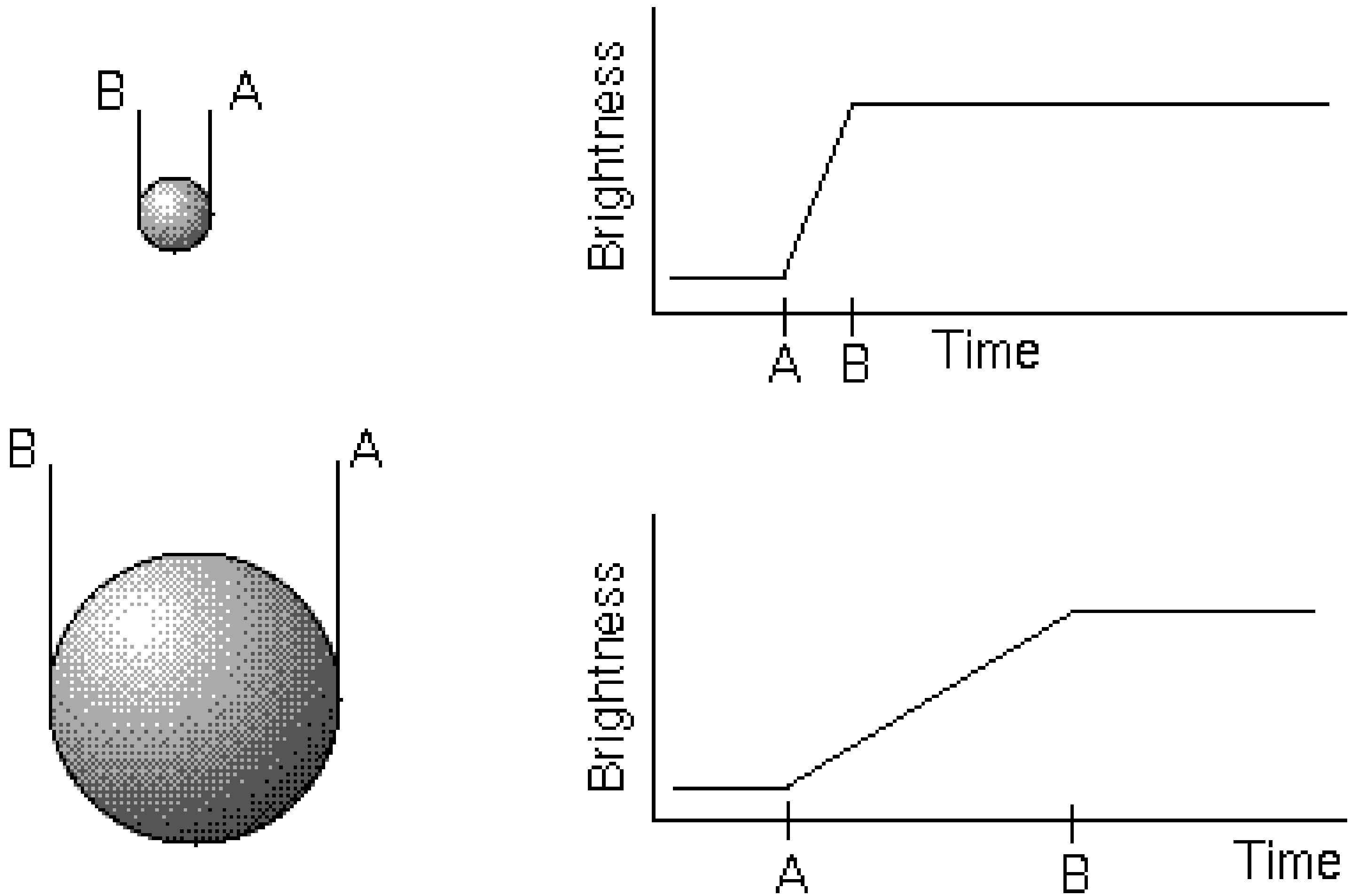
Radio mm IR Opt./UV X-ray



Total Energy Output

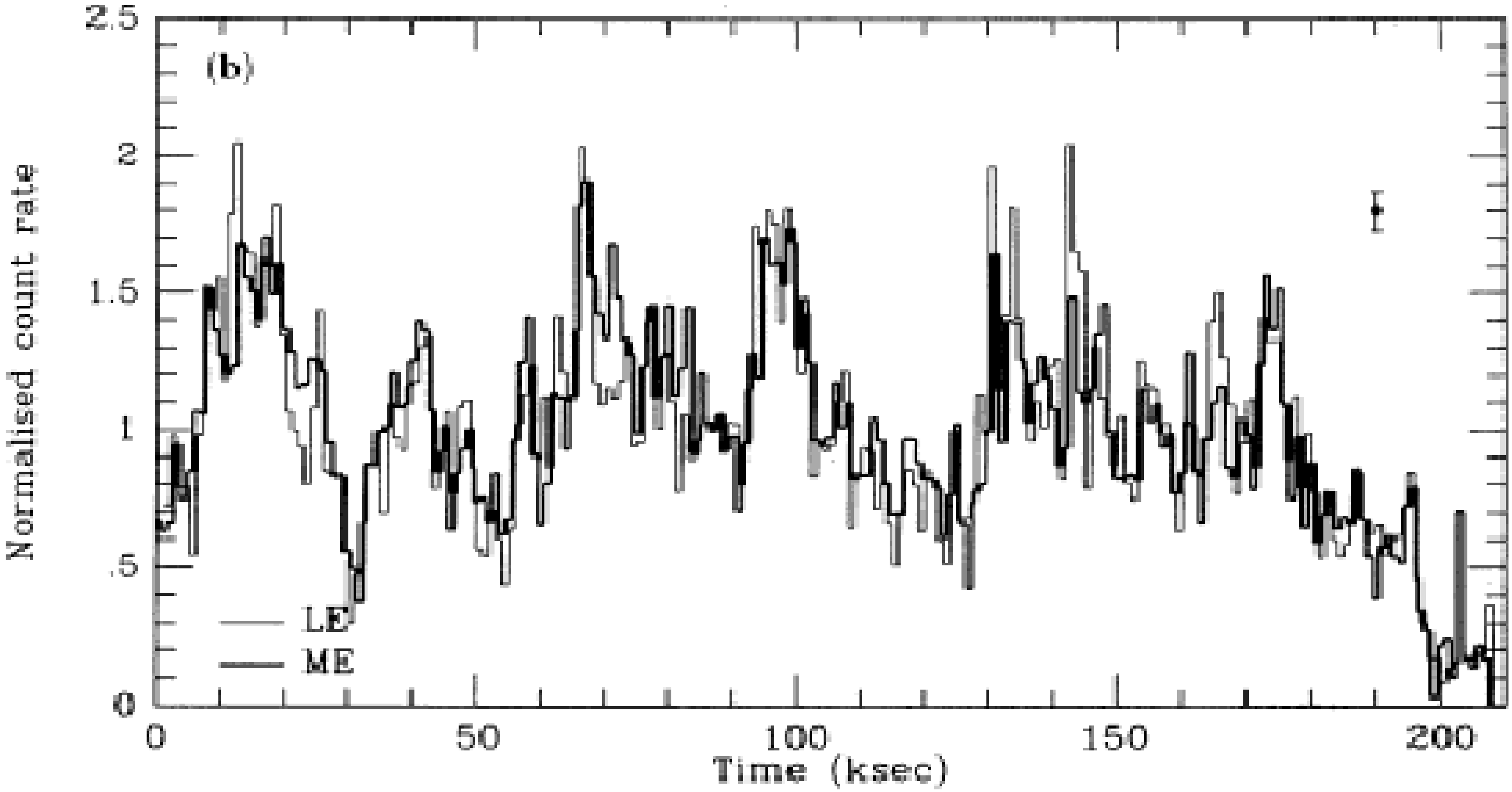
- **Milky Way Galaxy = 10^{44} erg/s**
- **Most energetic normal galaxy = 10^{45} erg/s**
- **Active Galaxies = 10^{43} to 10^{49} erg/s**
  - can be up to 100,00 times more luminosity than the Milky Way!
  - may be similar to a normal galaxies energy but have a different spectrum

Variability and size of the emitting region



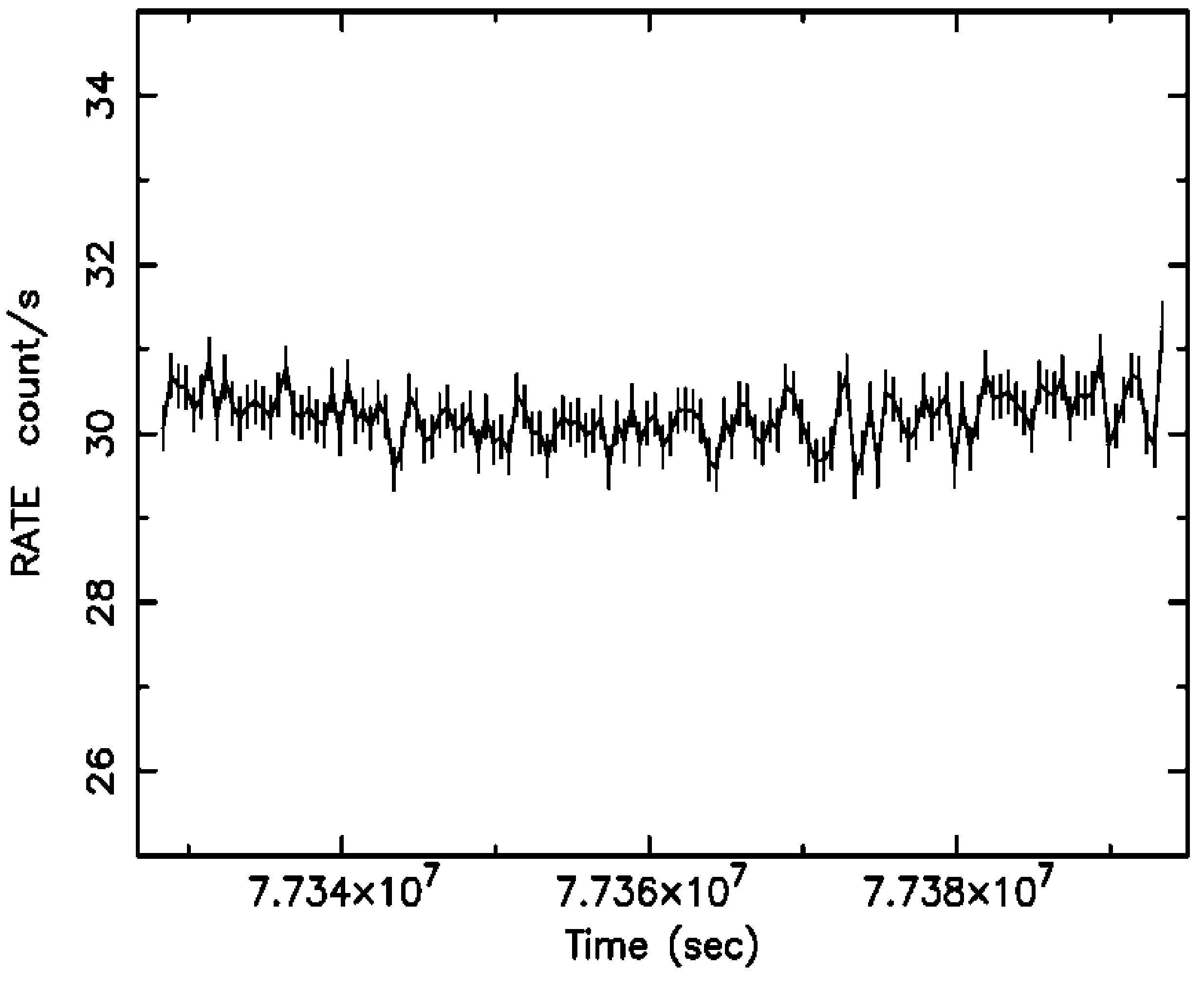
The light from side A reaches us before the light from side B so even if the object could brighten everywhere simultaneously, there is still a delay in brightening observed by us.

X-ray Lightcurve of NGC4051 (low luminosity



X-ray lightcurve of 3C 273 (60 ksec.), high luminosity AGN

So, variability gives us an idea of size (maximum) of the emitting volume



The Quasar Problem

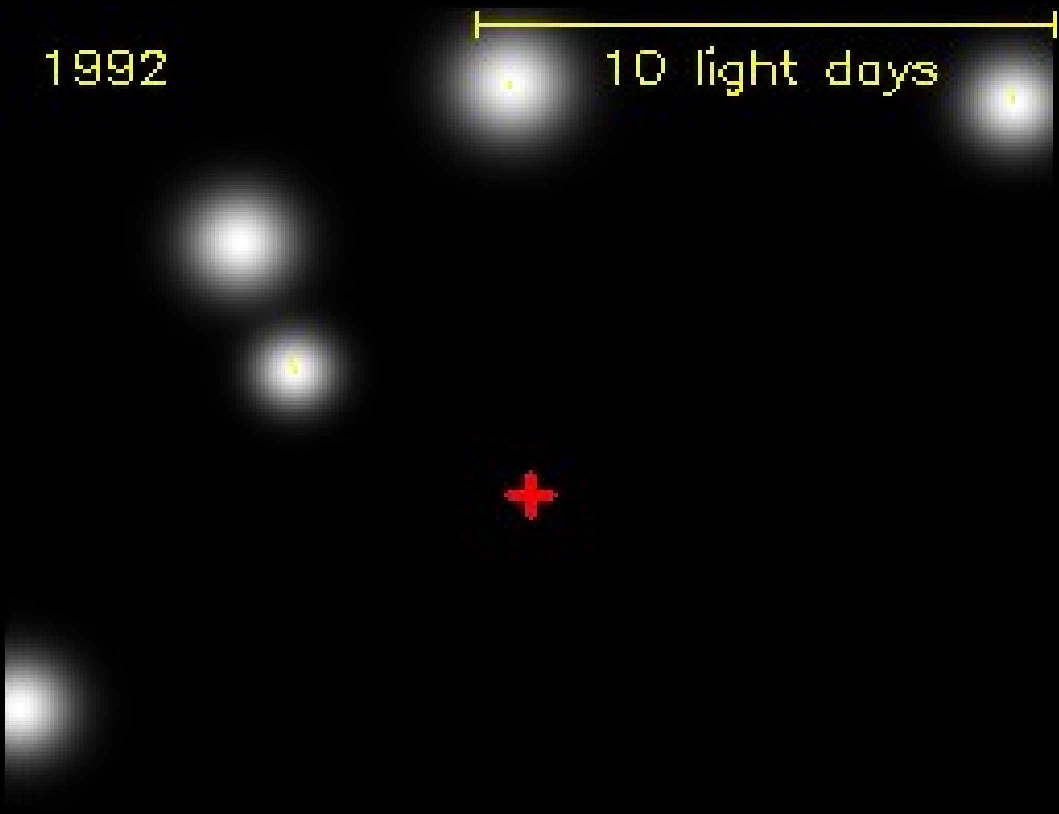
- How can so much energy ie. up to100,000 times the emission from a normal galaxy, be produced in such a small volume?
- Answer: by means of accretion onto a supermassive black hole

Accretion Processes in Quasars

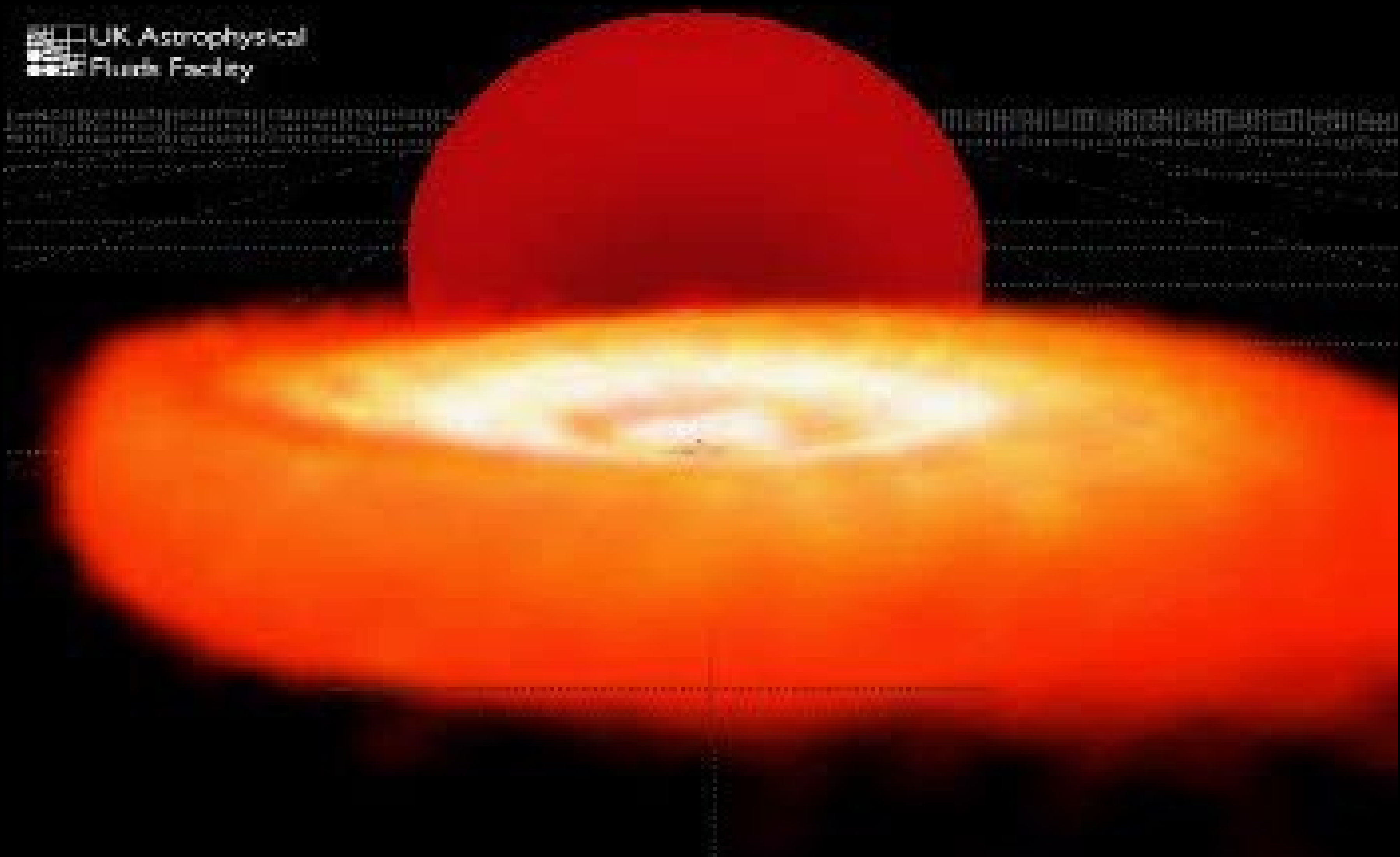
- The efficiency of energy generated via nuclear fusion is far less than that generated by accretion of matter onto a black hole (less than 1%)
- 10% efficiency for non-spinning black hole, up to ~30% for a spinning black hole (because IMSO is closer to BH)
- To power a typical quasar needs about 1 solar mass of material to be converted into energy every year

Motions of Stars in the Galactic Centre

(from their Keplerian orbits implies a black hole with ~4 million solar masses)



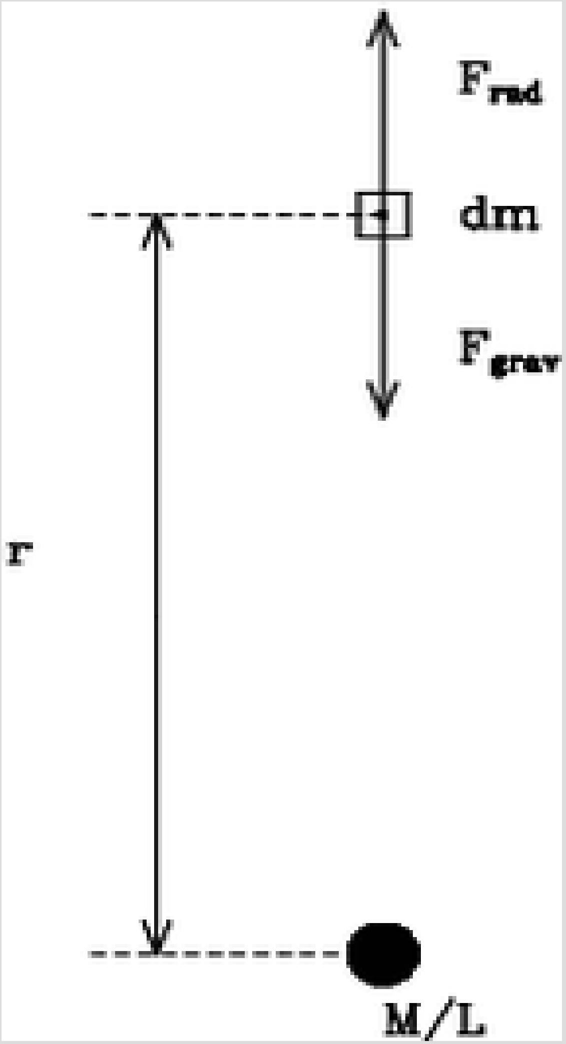
Accretion Power in Astrophysics works for X-ray binaries and AGN



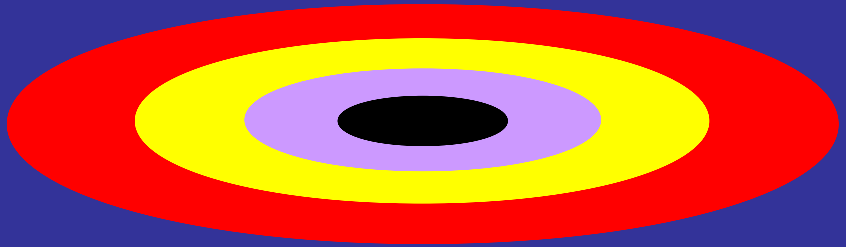
What restricts the accretion power? The Eddington Limit

When the radiation pressure on the material being accreted
= force of gravity.

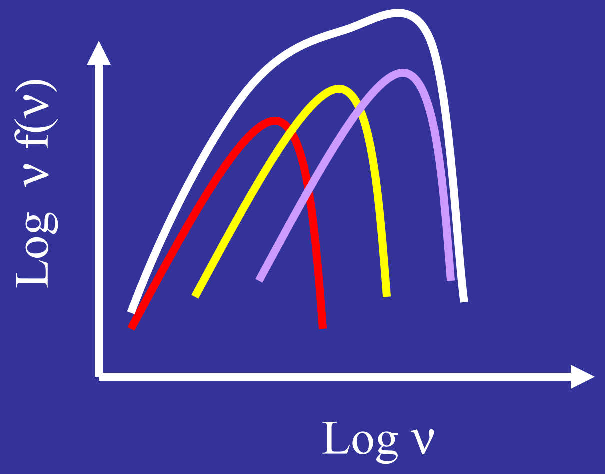
For objects emitting at the Eddington limit, the Black Hole mass can be directly calculated from the **bolometric** luminosity



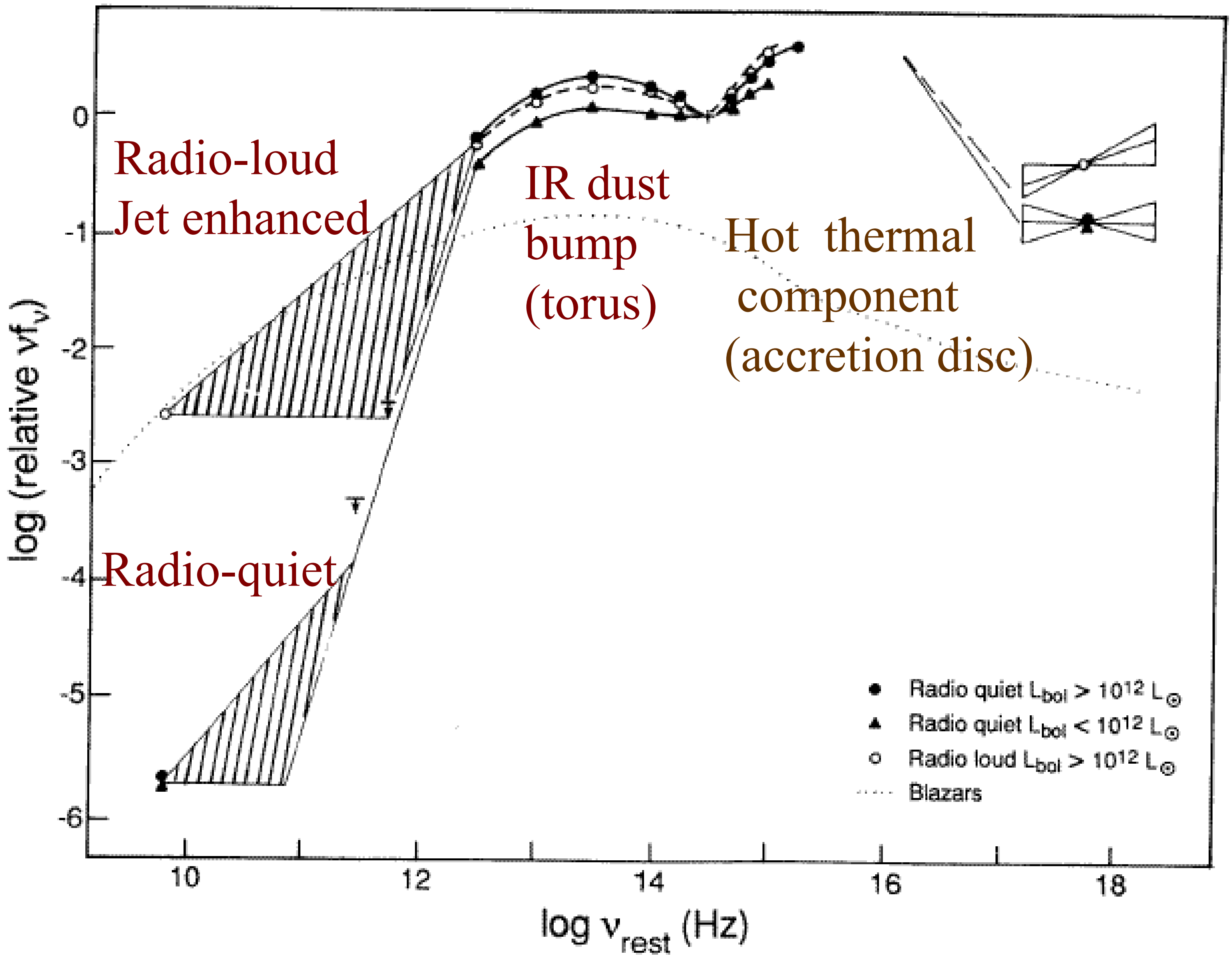
Spectra of accretion flow via a disc



- Differential Keplerian rotation
- Viscosity and gravity → heat
- Thermal emission: $L = A\sigma T^4$
- Temperature increases inwards
- GR last stable orbit gives minimum radius R_{ms}
- For $L \sim L_{Edd}$ the T_{max} is
  - 1 keV (10^7 K) for 10 $M_{\odot}$
  - 10 eV (10^5 K) for 10^8 $M_{\odot}$



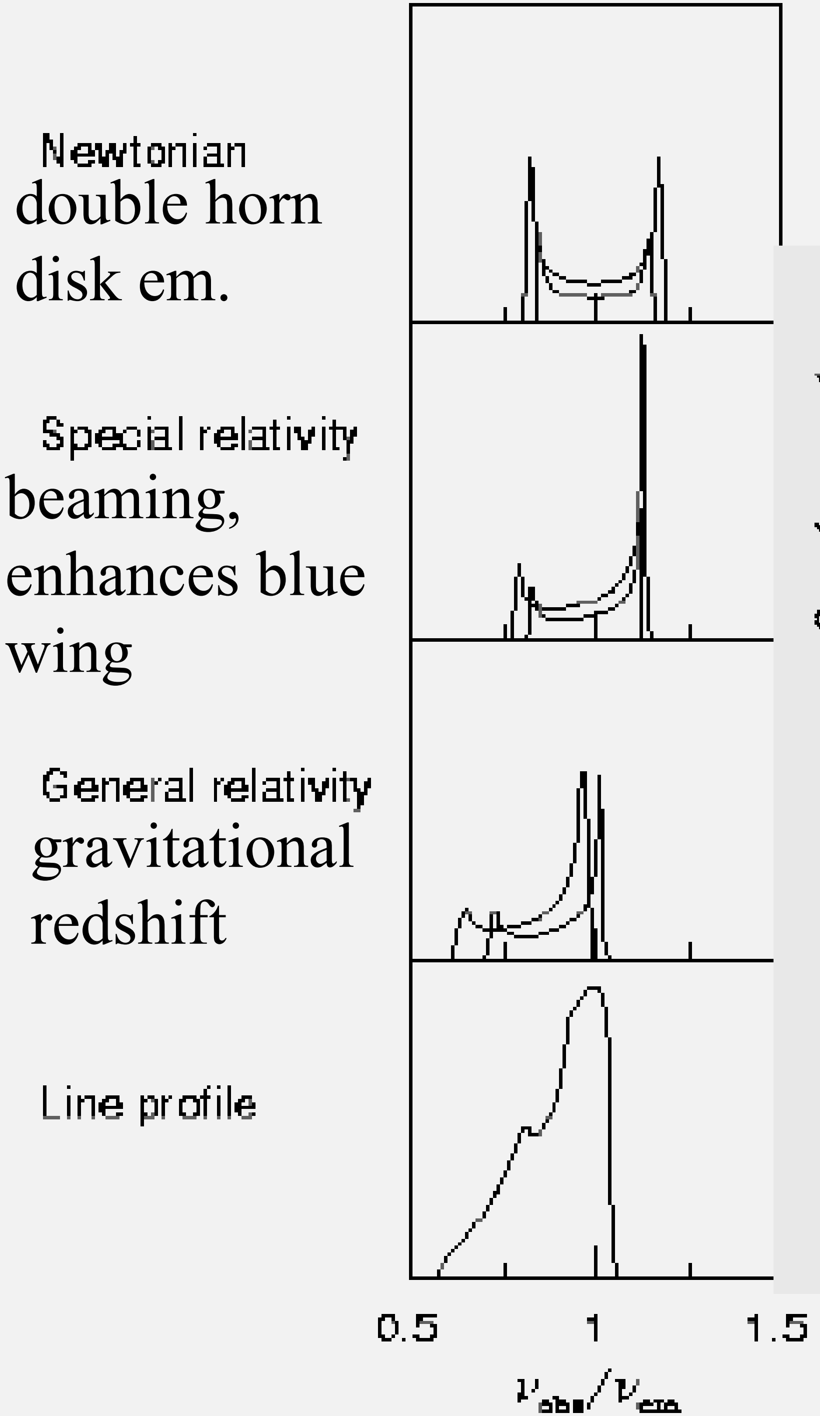
CONTINUUM ENERGY DISTRIBUTIONS OF QUASARS

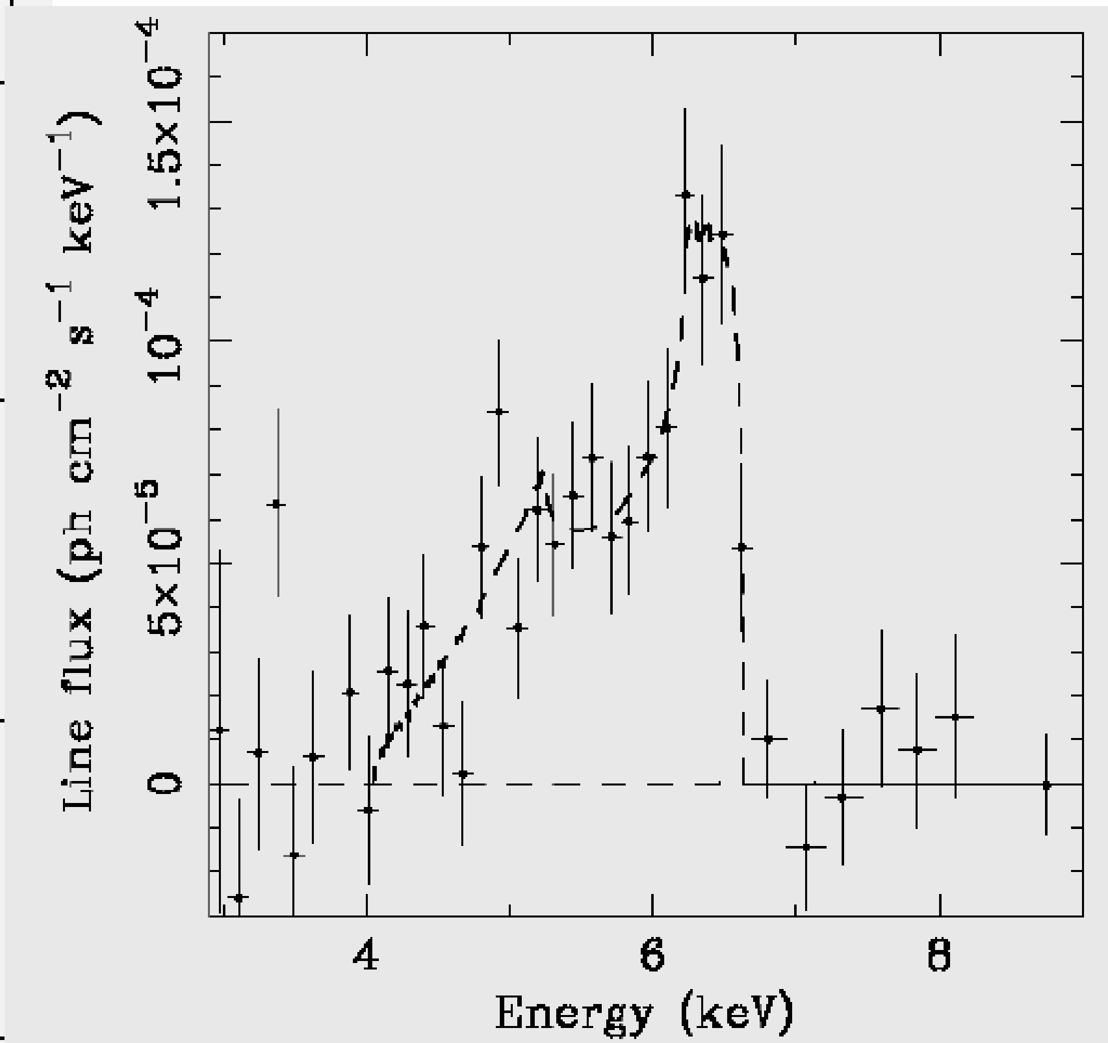


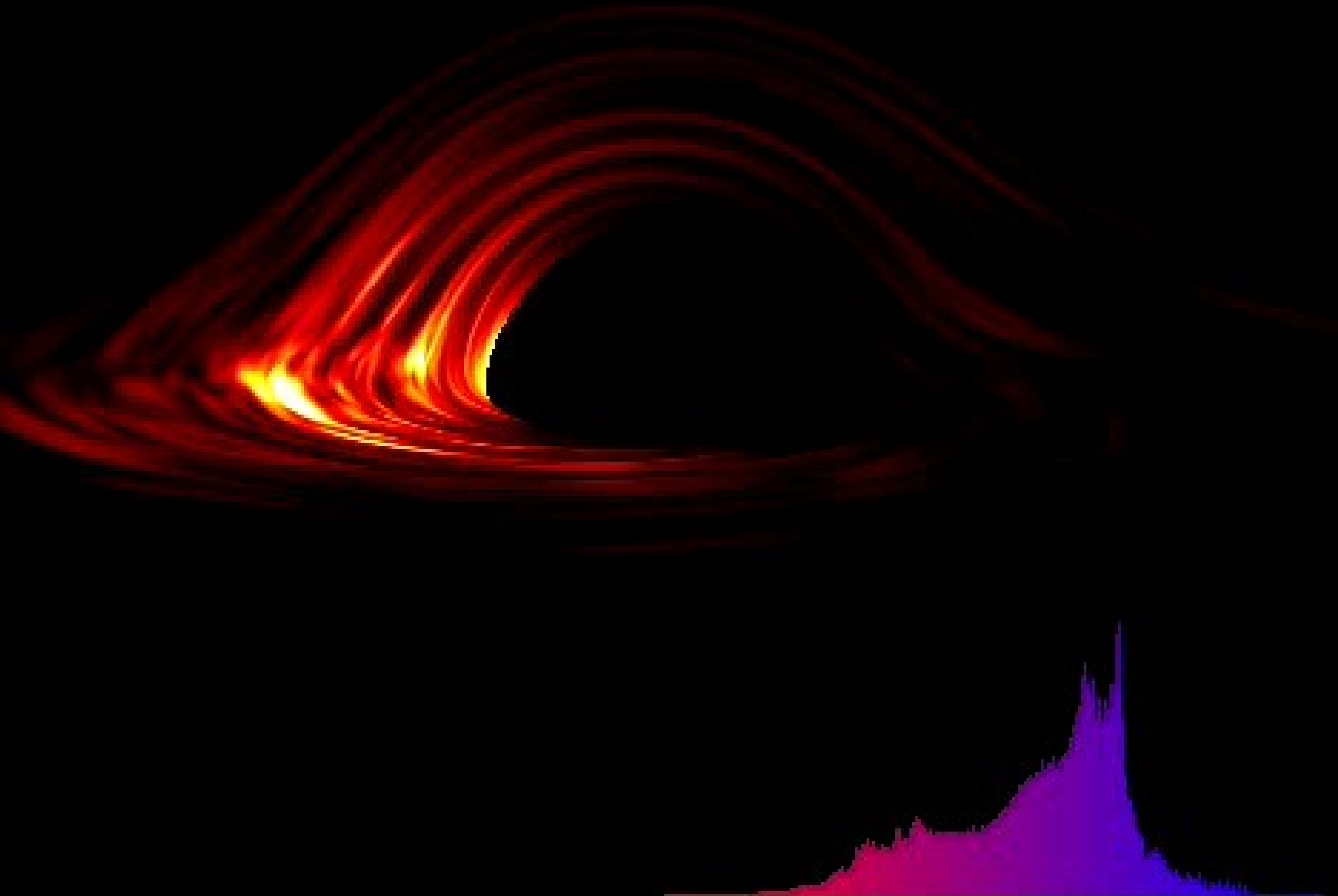
The Accretion Disc in a Quasar

Strong X-ray emission comes from near to the event horizon of the Black Hole

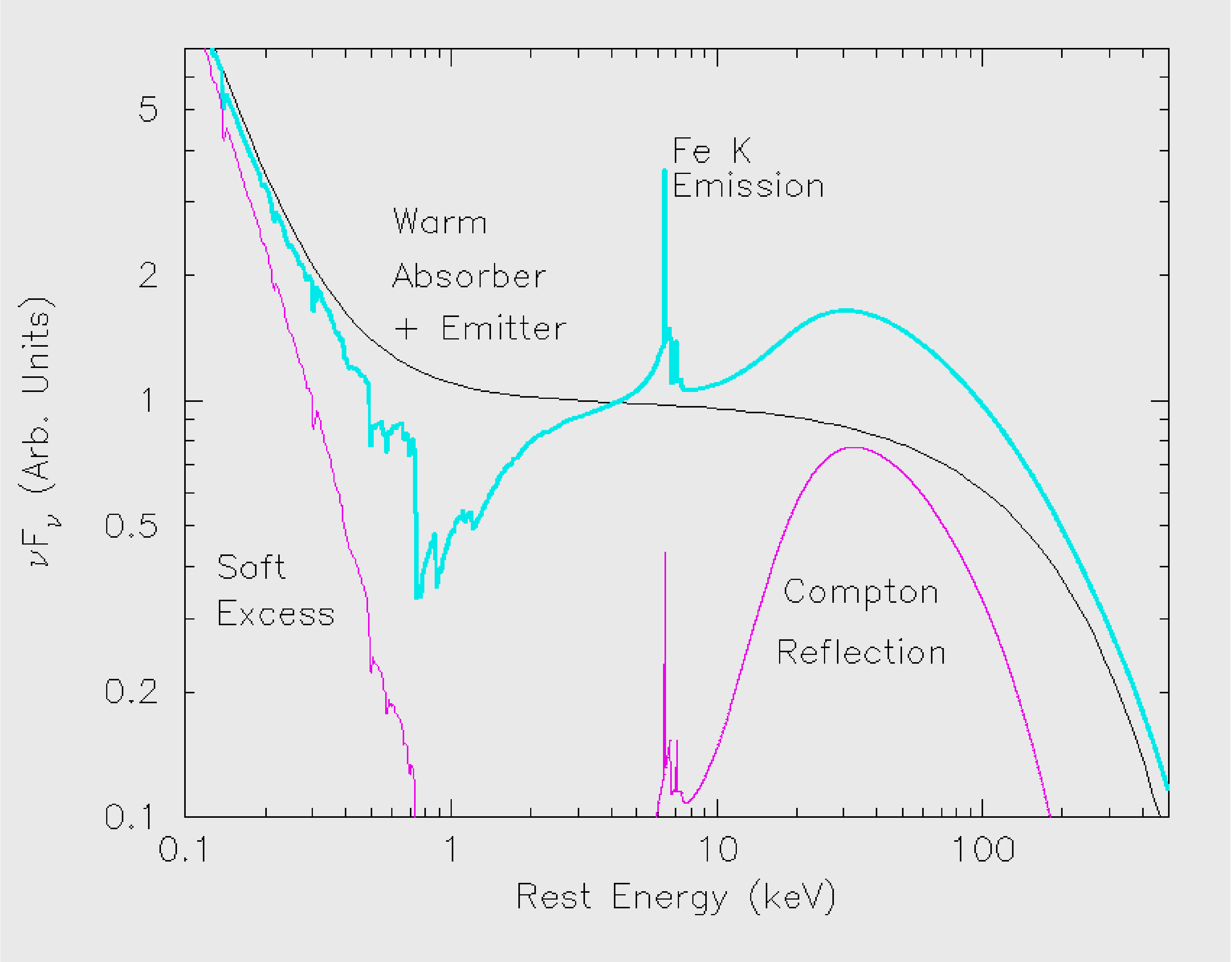
Do we see the effects of General Relativity? YES







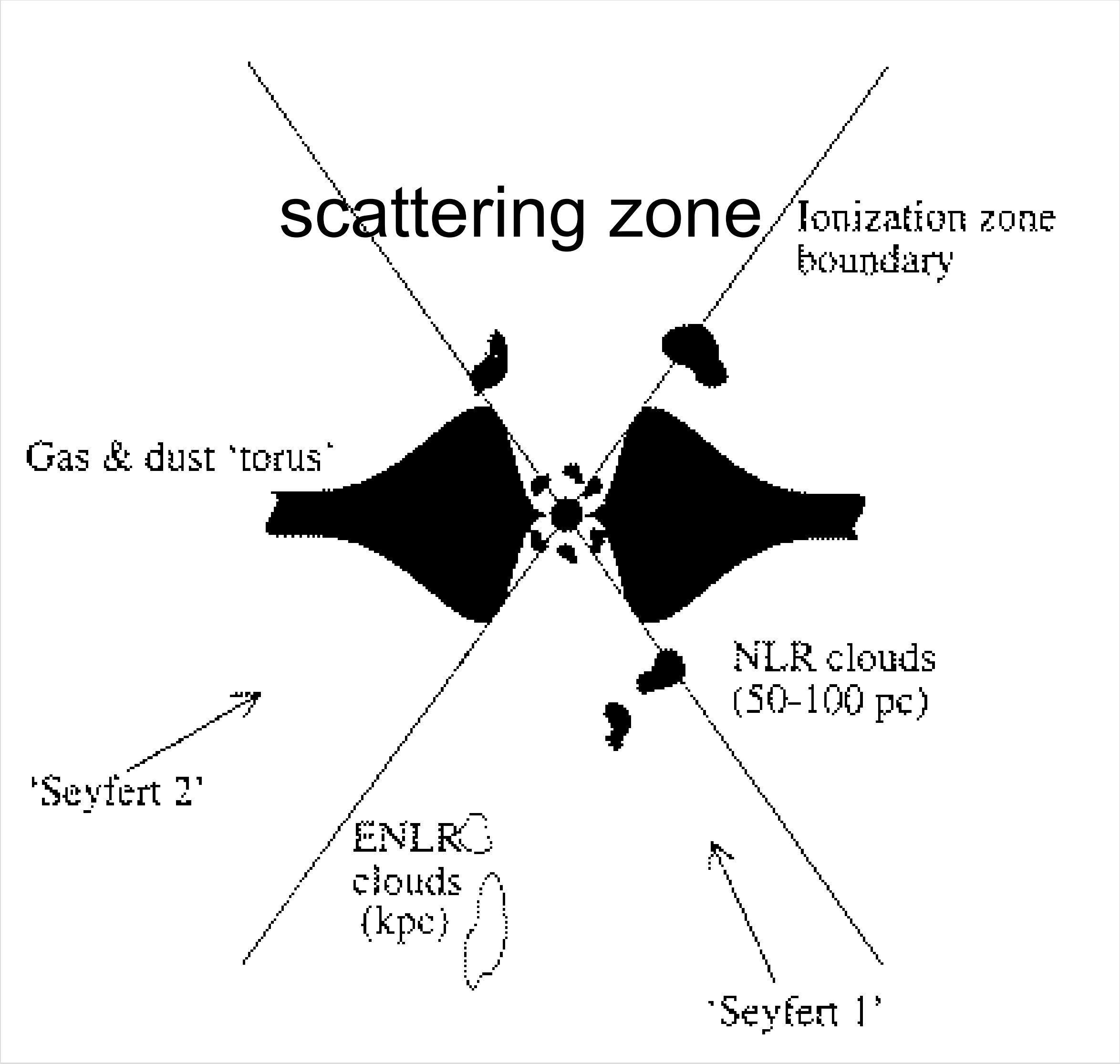
X-ray Properties of AGN



The influence of gas/dust and stars

- The dust absorbs radiation at short wavelengths and then re-emits it at longer wavelengths
- Gas from outside the nucleus finally gets accreted onto the black hole, by means of an accretion disc
- Stars may be “shredded” as they plunge into the black hole, bright UV flares
- Star formation around the nucleus

The Importance of Geometry



Same AGN:
NGC1068
BUT top is direct view, lower spectrum in polarised light.
.
This shows that scatters act like mirrors, showing us the hidden AGN

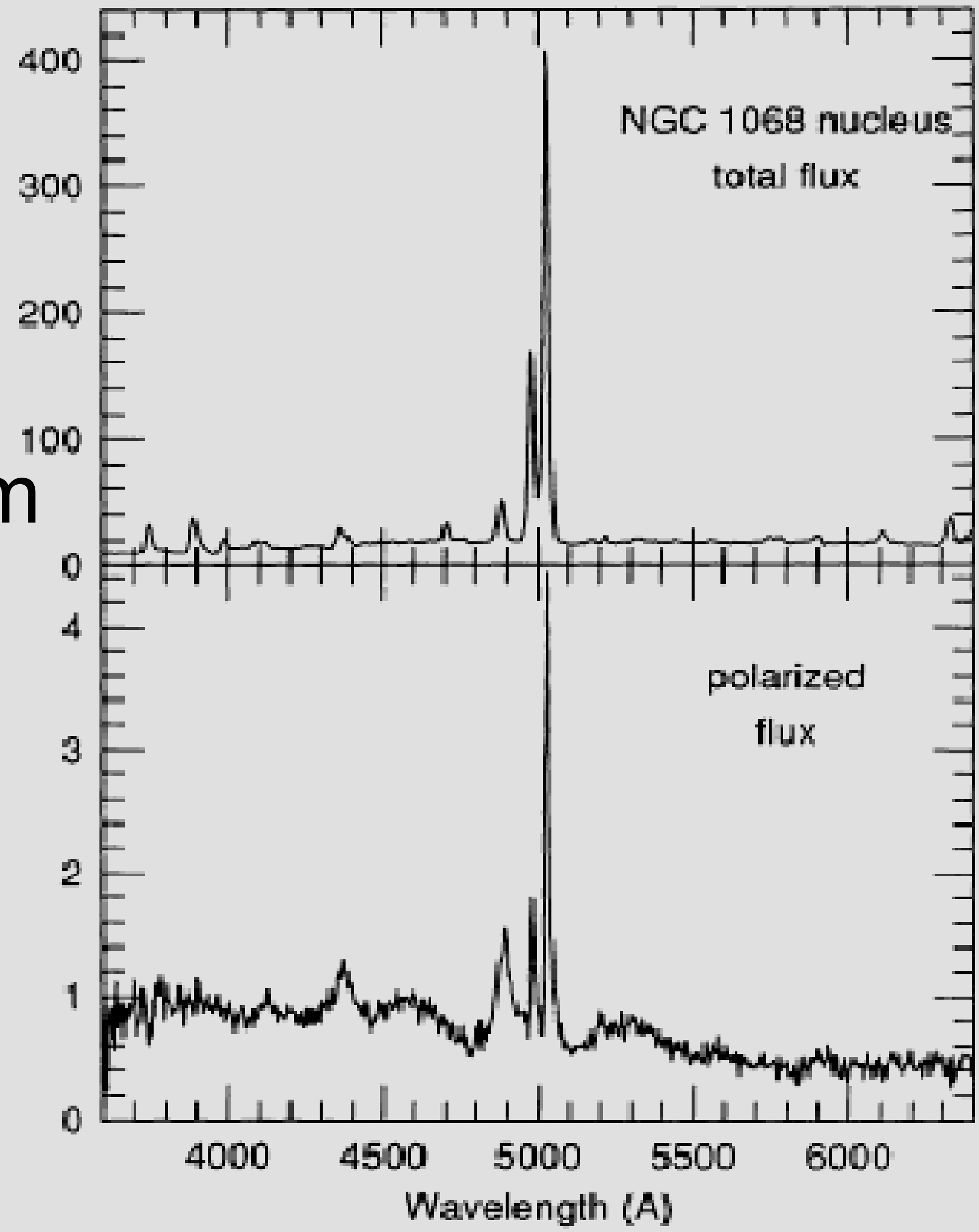
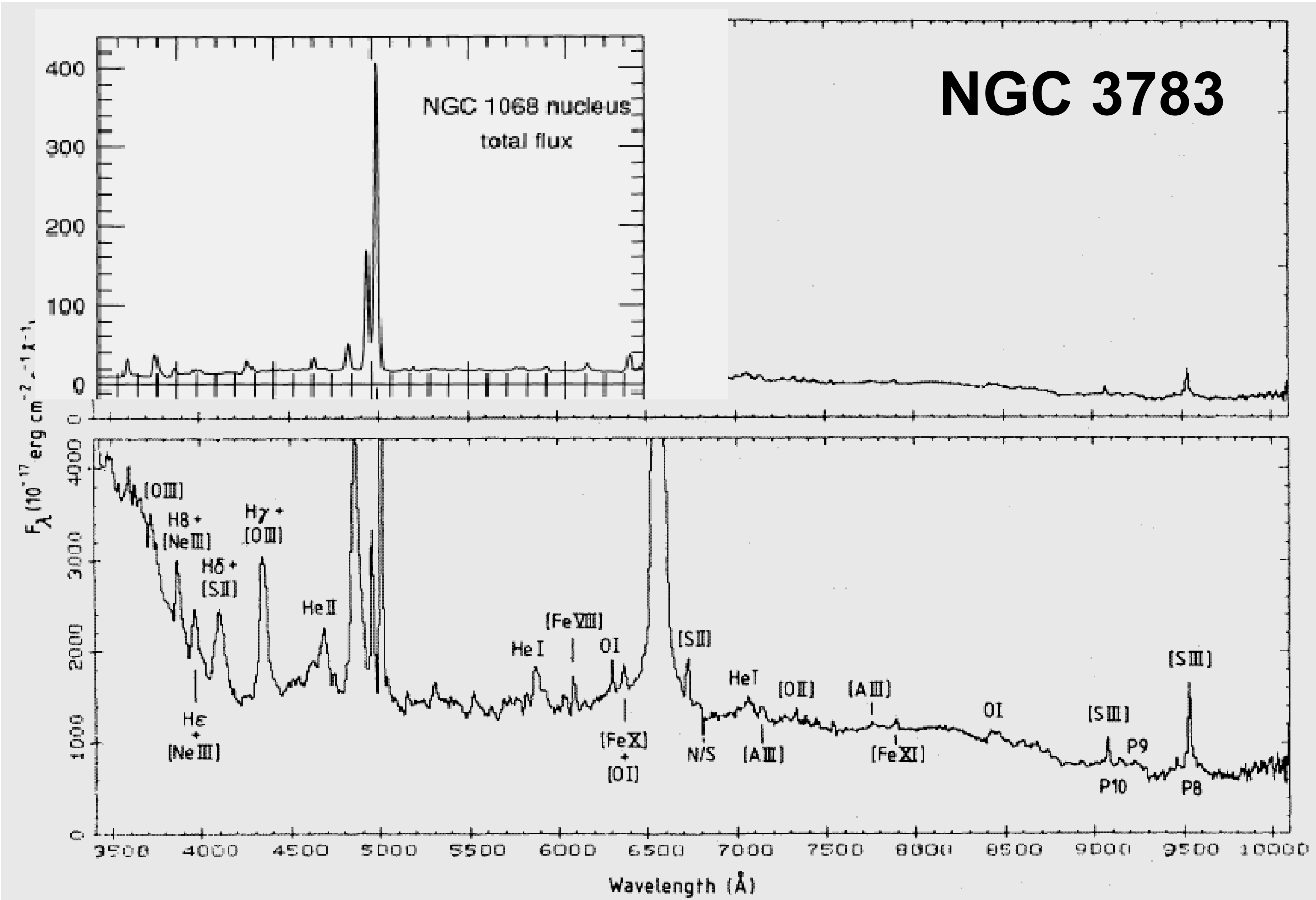


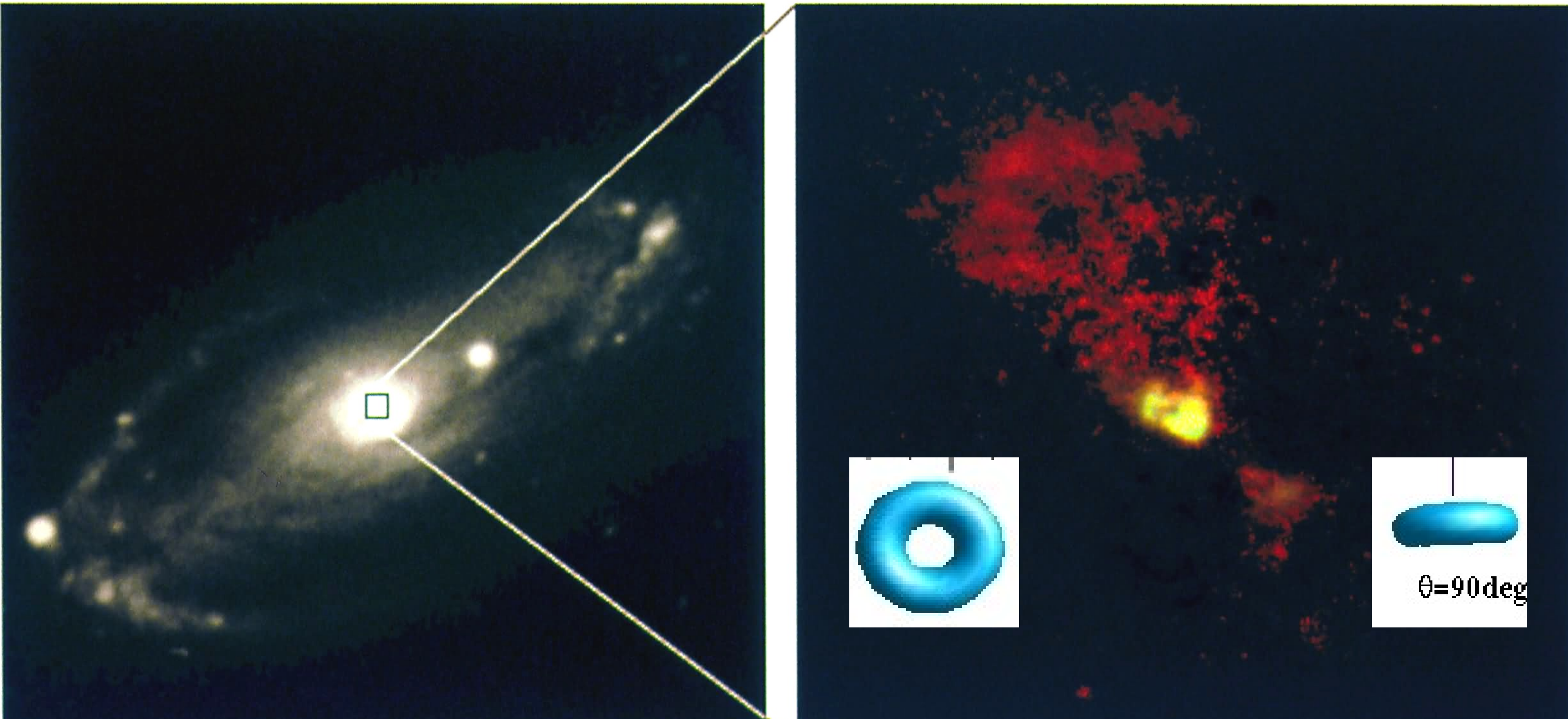
FIG. 6.—Same as Fig. 3, but for the nucleus. This was obtained with an 8" slit to provide reliable photometric calibration with wavelength.



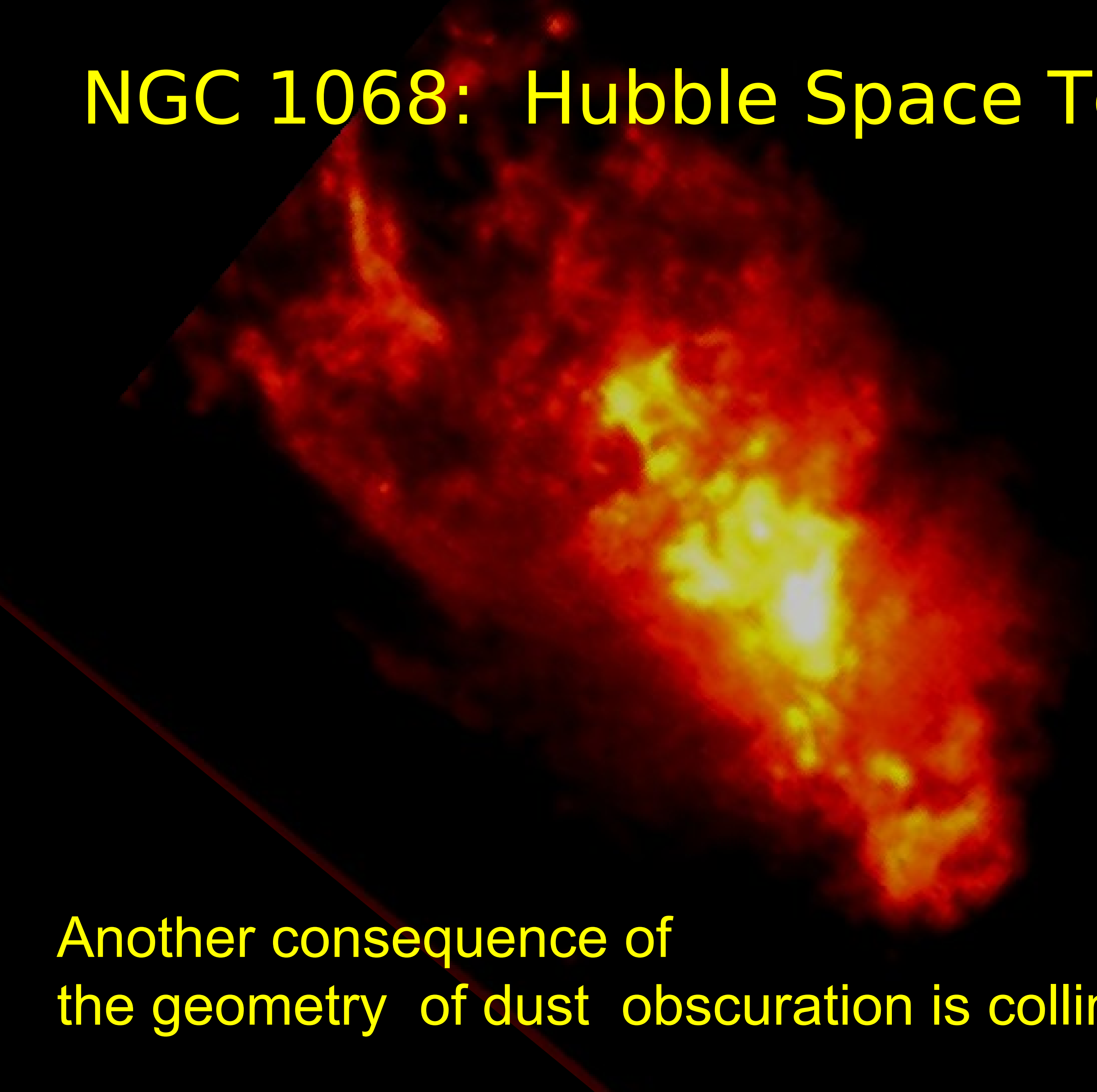
NGC 3783
NGC 1068 nucleus
total flux
[O III]
H8 +
[Ne III]
Hδ +
[S II]
Hγ +
[O III]
He II
He I
[Fe VII]
O I
[S II]
He I
[O II]
[A III]
O I
[S III]
P9
[S III]
He ε
+
[Ne III]
[Fe X]
+
[O I]
N/S
[A III]
[Fe XI]
P10
P8
F_λ (10^{-17} erg cm^{-2} s^{-1} Å^{-1})
Wavelength (Å)

AGN HISTORY LESSON

- **The Unified Scheme, Antonucci and Miller (1985) - A geometric based explanation of the observed differences between different classes of Seyferts**

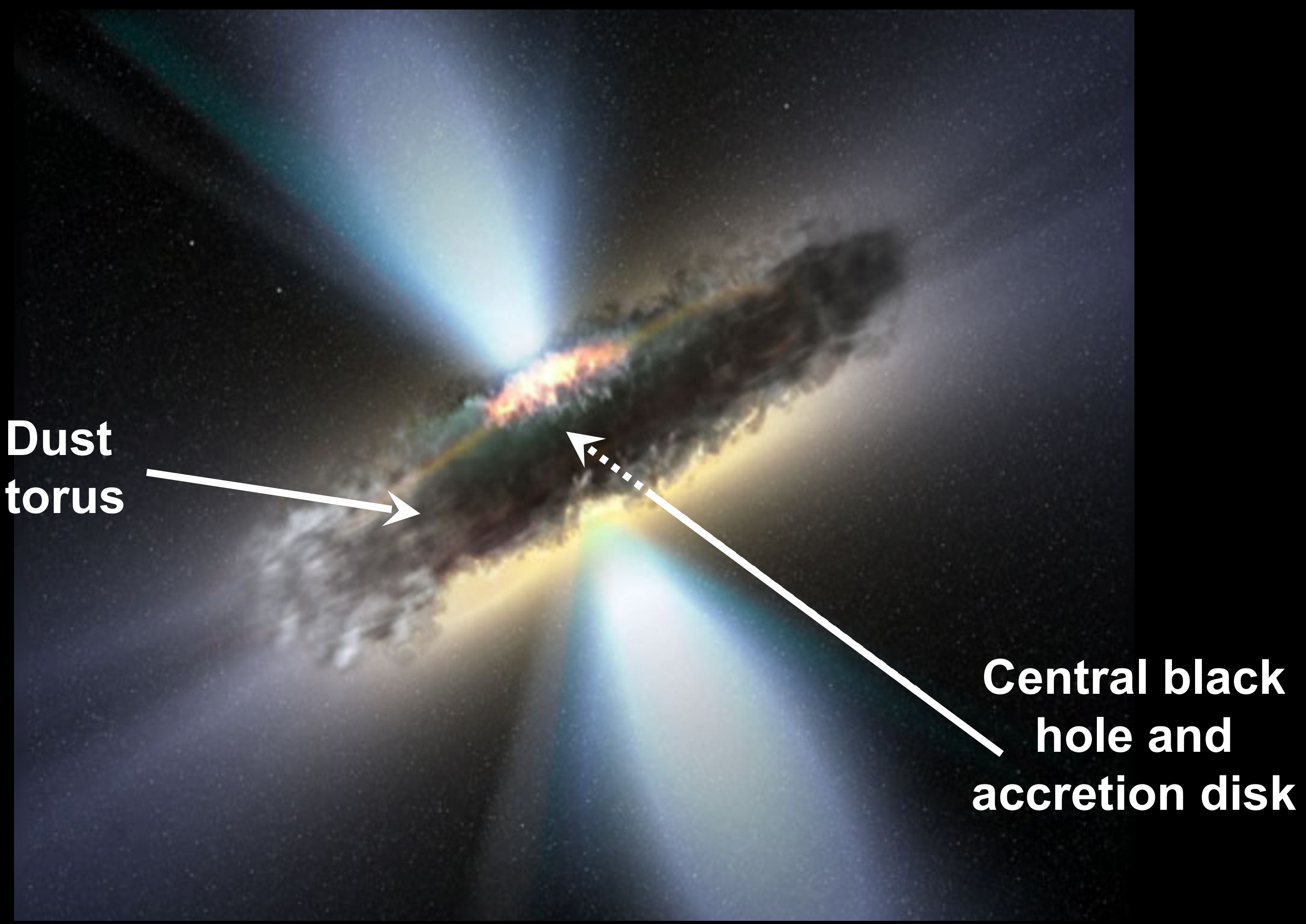


NGC 1068: Hubble Space Telescope



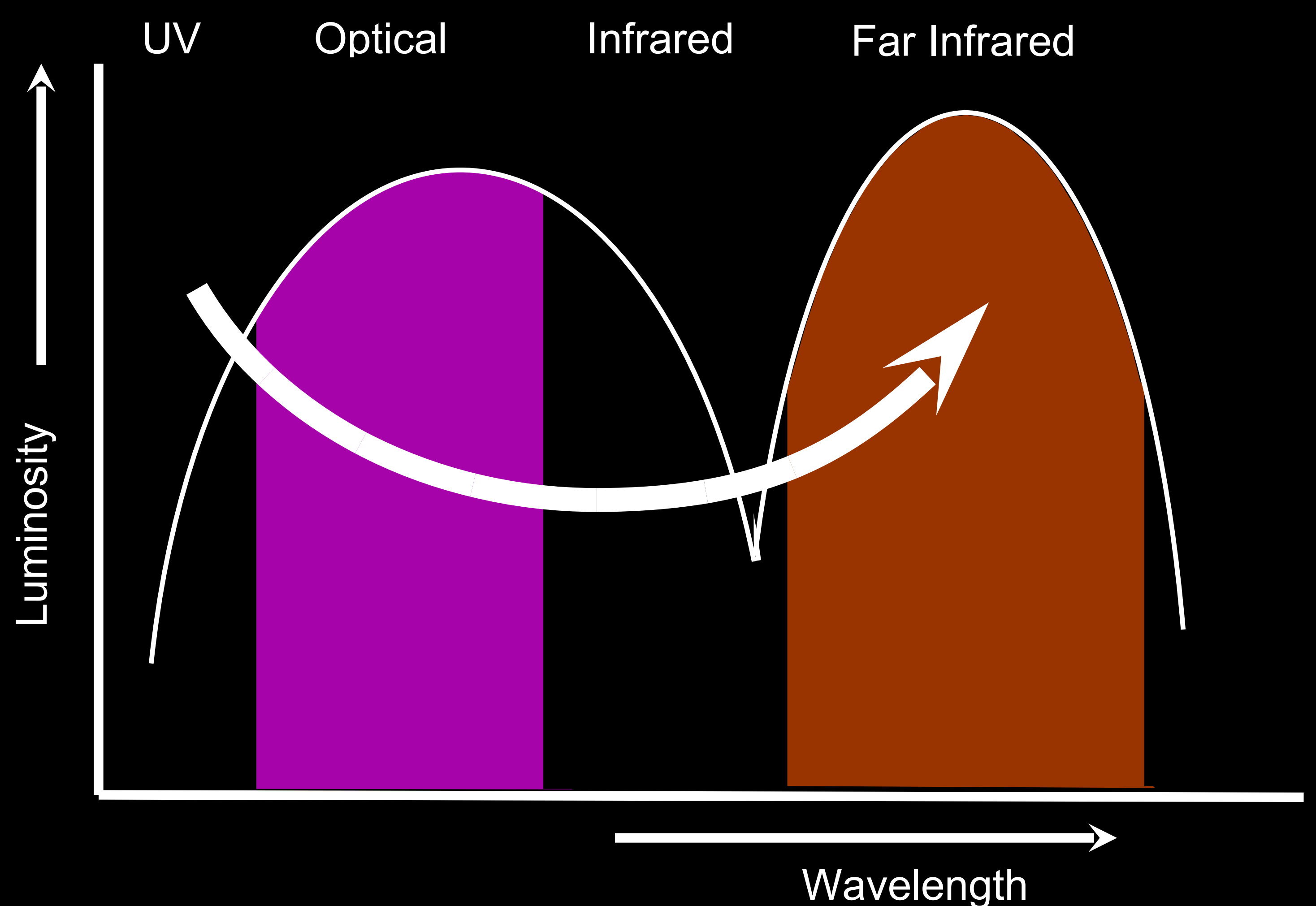
Another consequence of
the geometry of dust obscuration is collimation

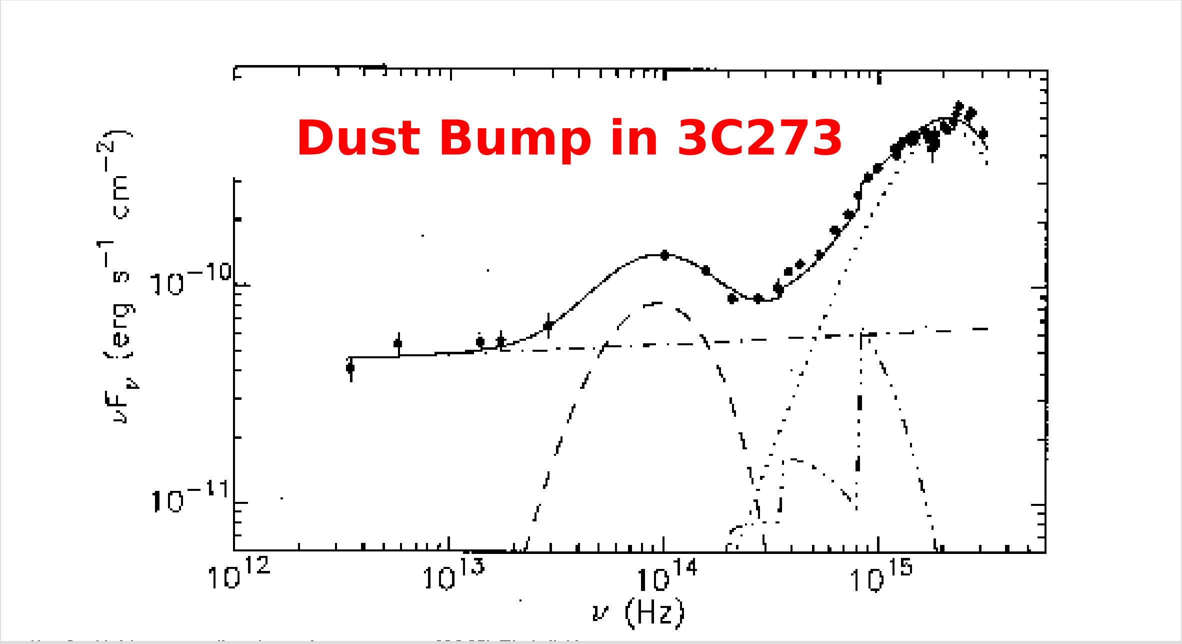
Heavily Obscured Active Galactic Nuclei



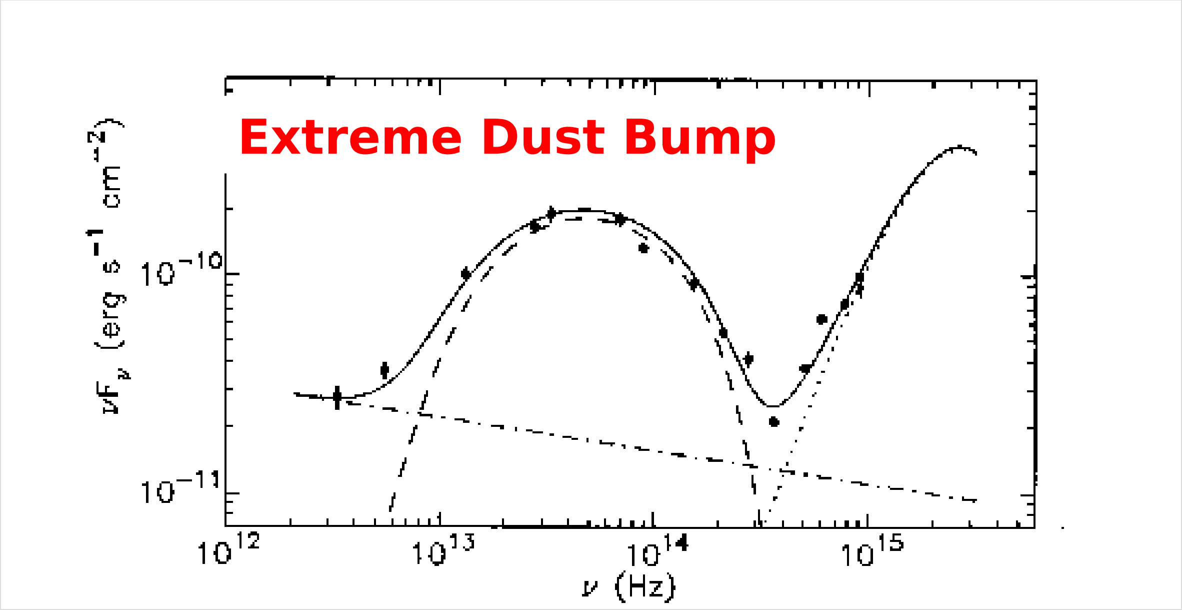
The Important role of dust

Optical and UV emission absorbed by dust and re-radiated at mid-far infrared wavelengths

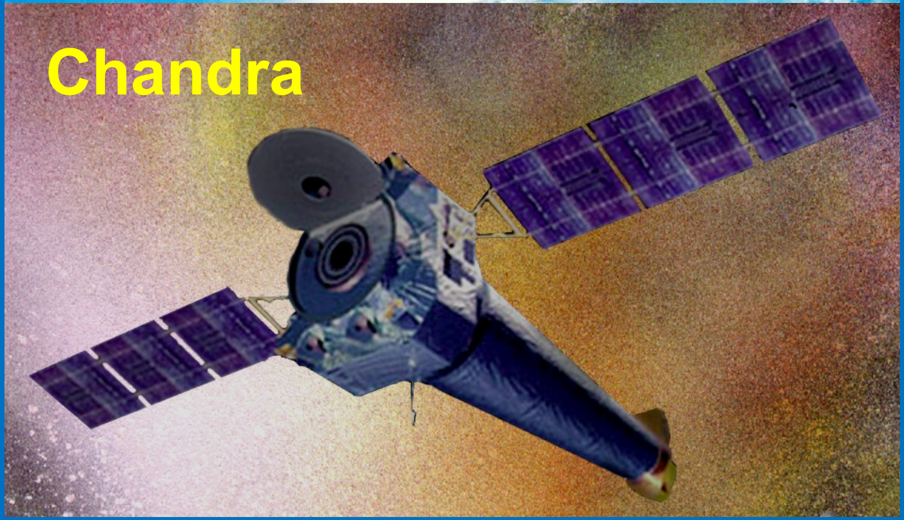




Hot dust bumps are observed in some **quasars**

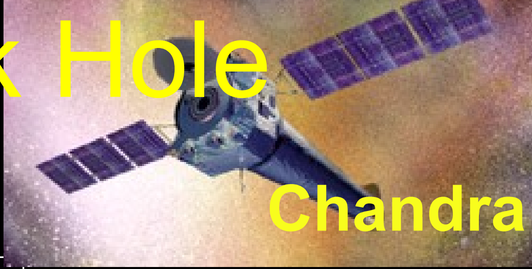


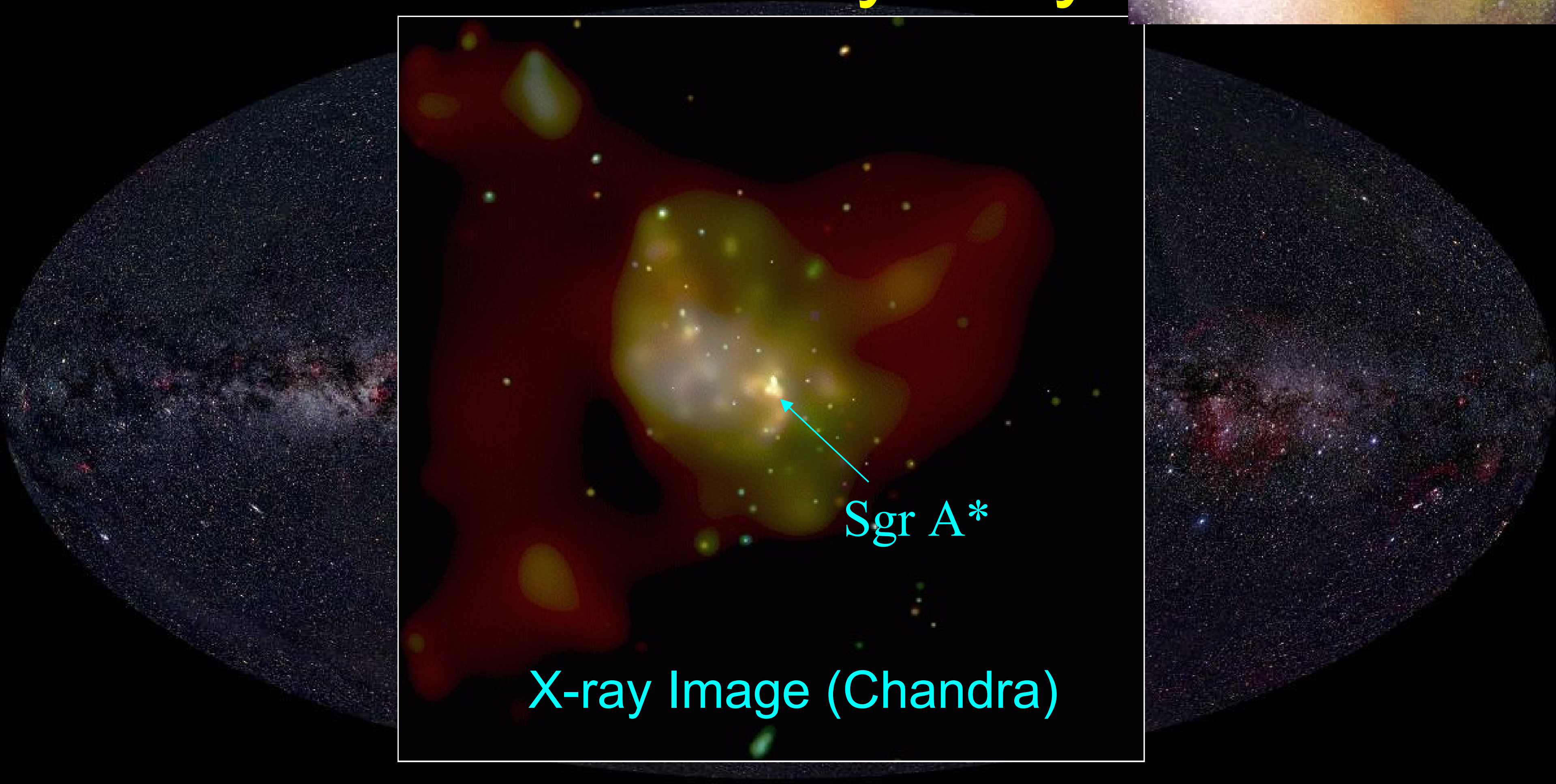
X-rays – the key to obscured AGN



X-rays: (1) apparently a universal property of AGNs which allows AGNs to be identified irrespective of their optical/other properties, and (2) can probe heavily obscured objects

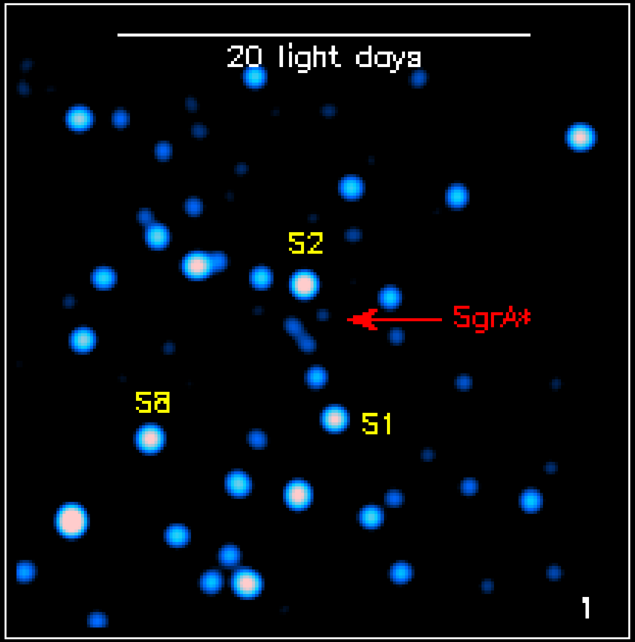
The Supermassive Black Hole in our Milky Way



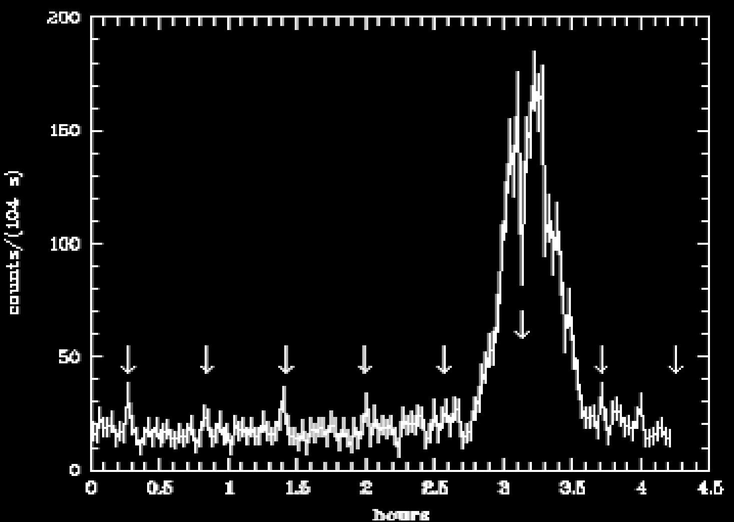


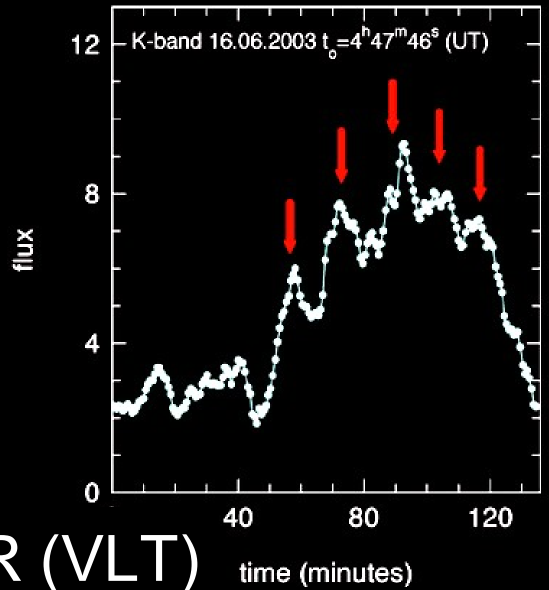
Galactic Centre X-ray Flares

Slide adapted from Hasinger 2006



Sgr A* flares discovered by Chandra (Baganoff et al.), XMM-Newton (Porquet et al. ,2003) and VLT NIR (Schödel et al., 2003)



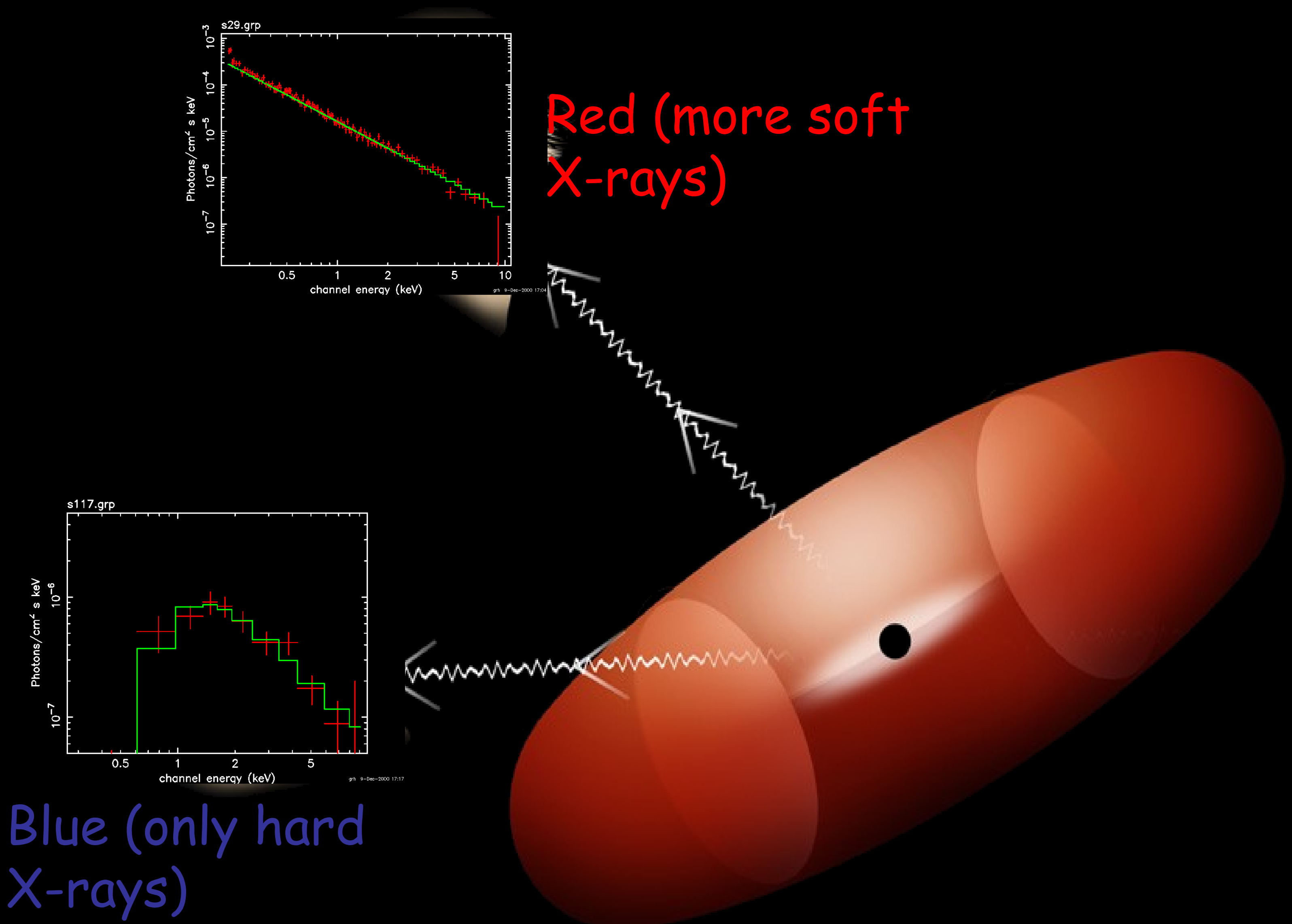


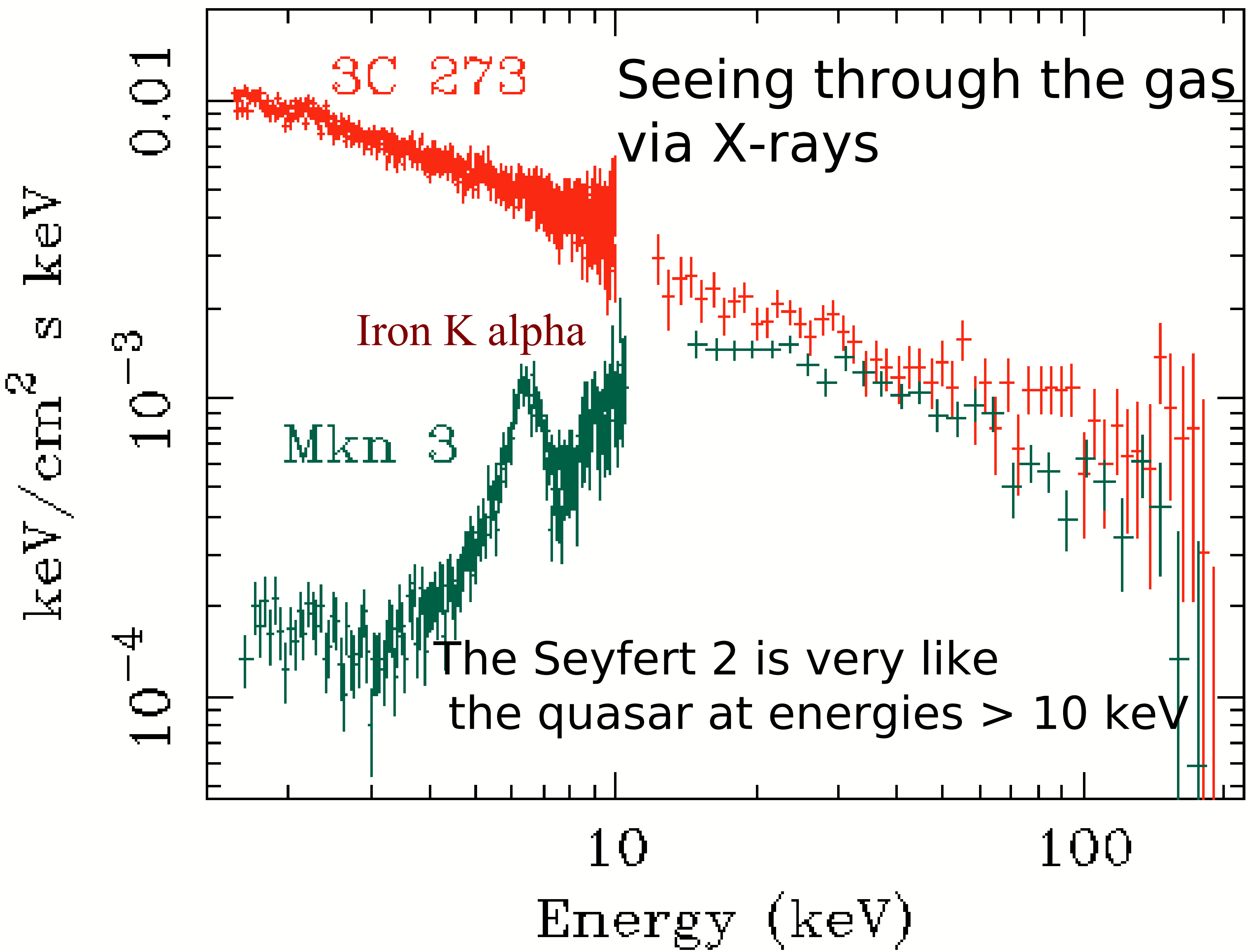
Time Variability indicates spinning Black Hole

Schödel et al., 2003
Aschenbach et al., 2003

X-ray (XMM-Newton) & NIR (VLT)

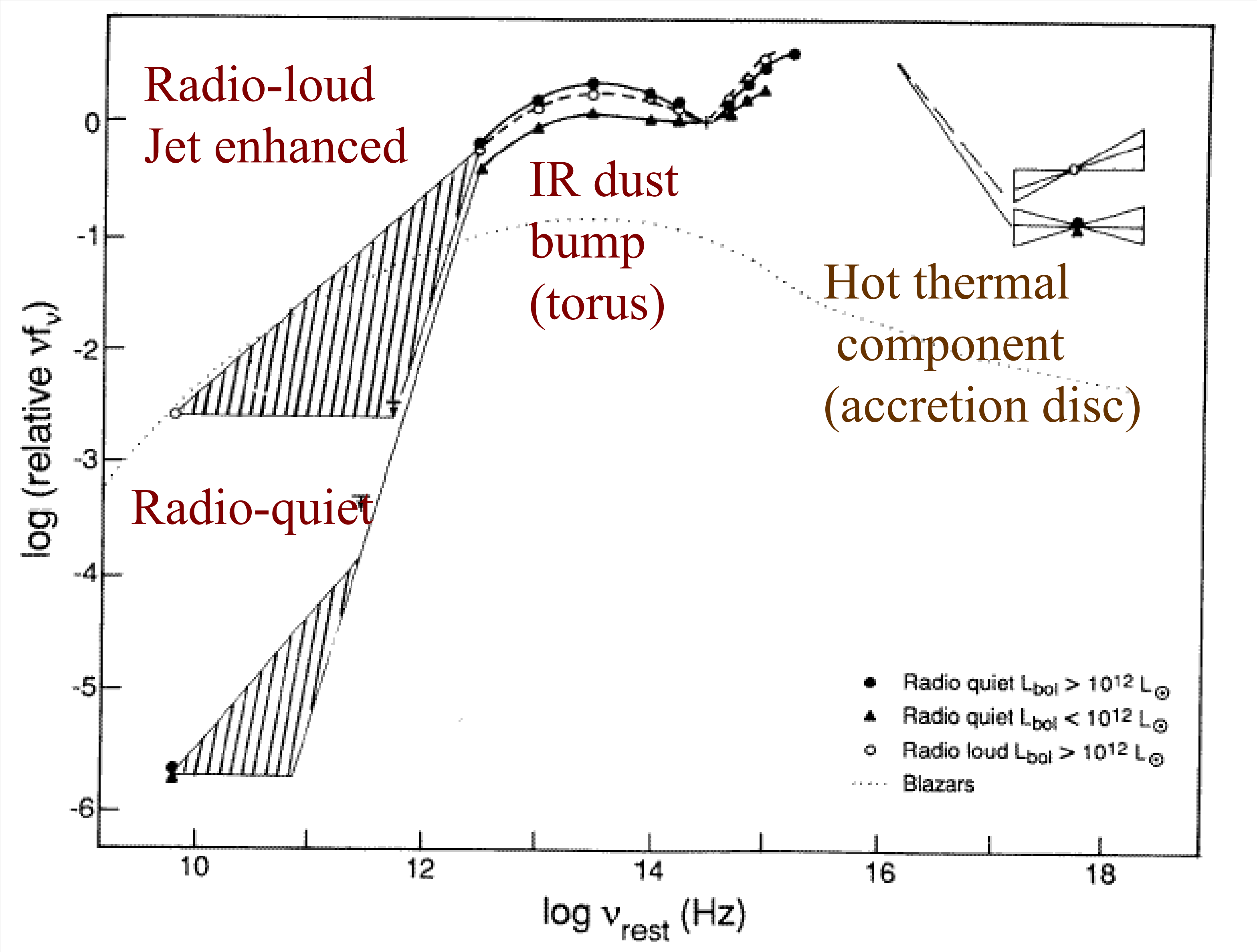
The Torus Viewing Angle and X-rays





3C 273
Seeing through the gas
via X-rays
Iron K alpha
Mkn 3
The Seyfert 2 is very like
the quasar at energies > 10 keV
0.01
10^{-3}
10^{-4}
10
100
Energy (keV)
keV/cm^2 s keV

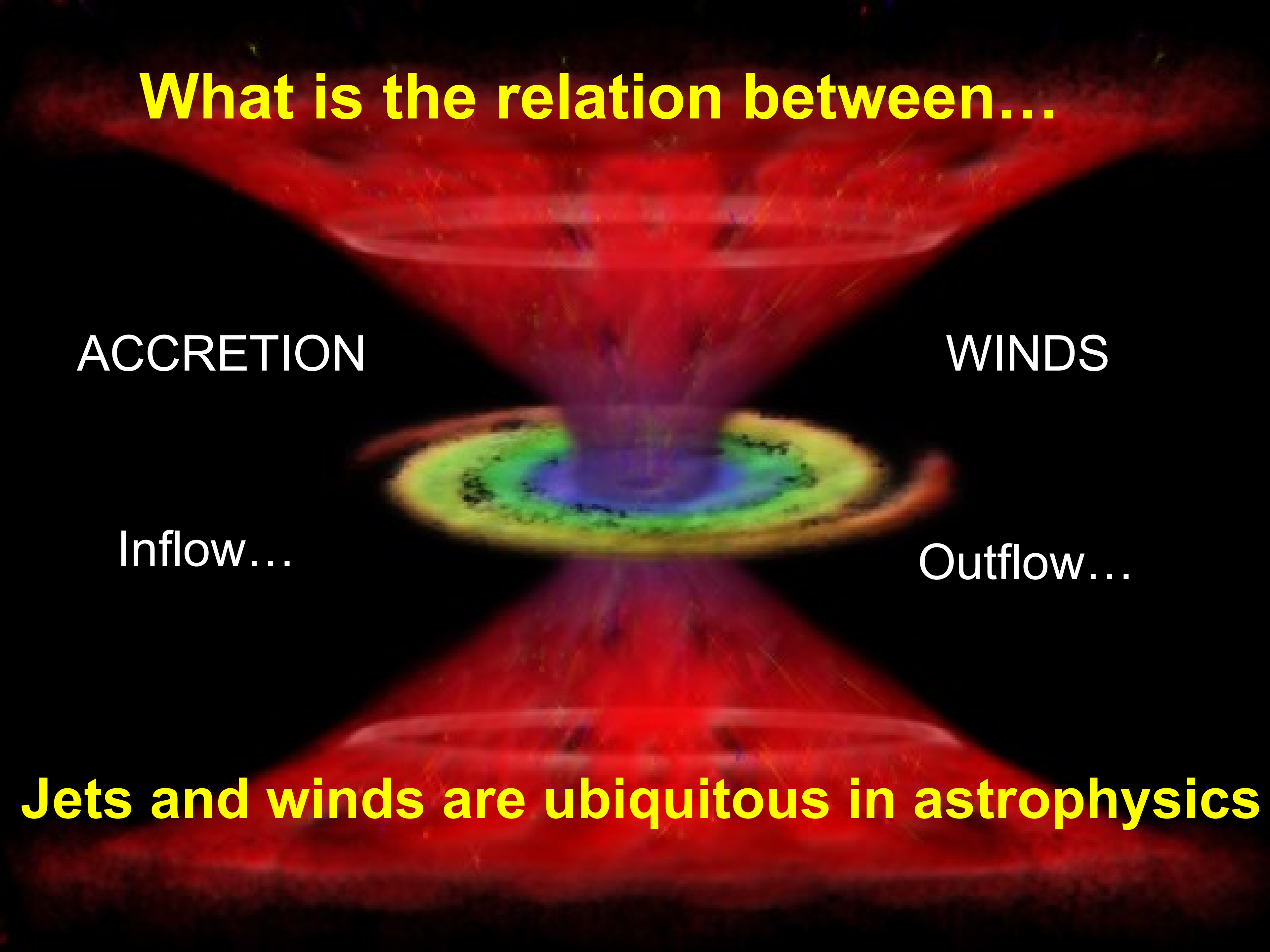
Now we can understand why AGN emit at all frequencies



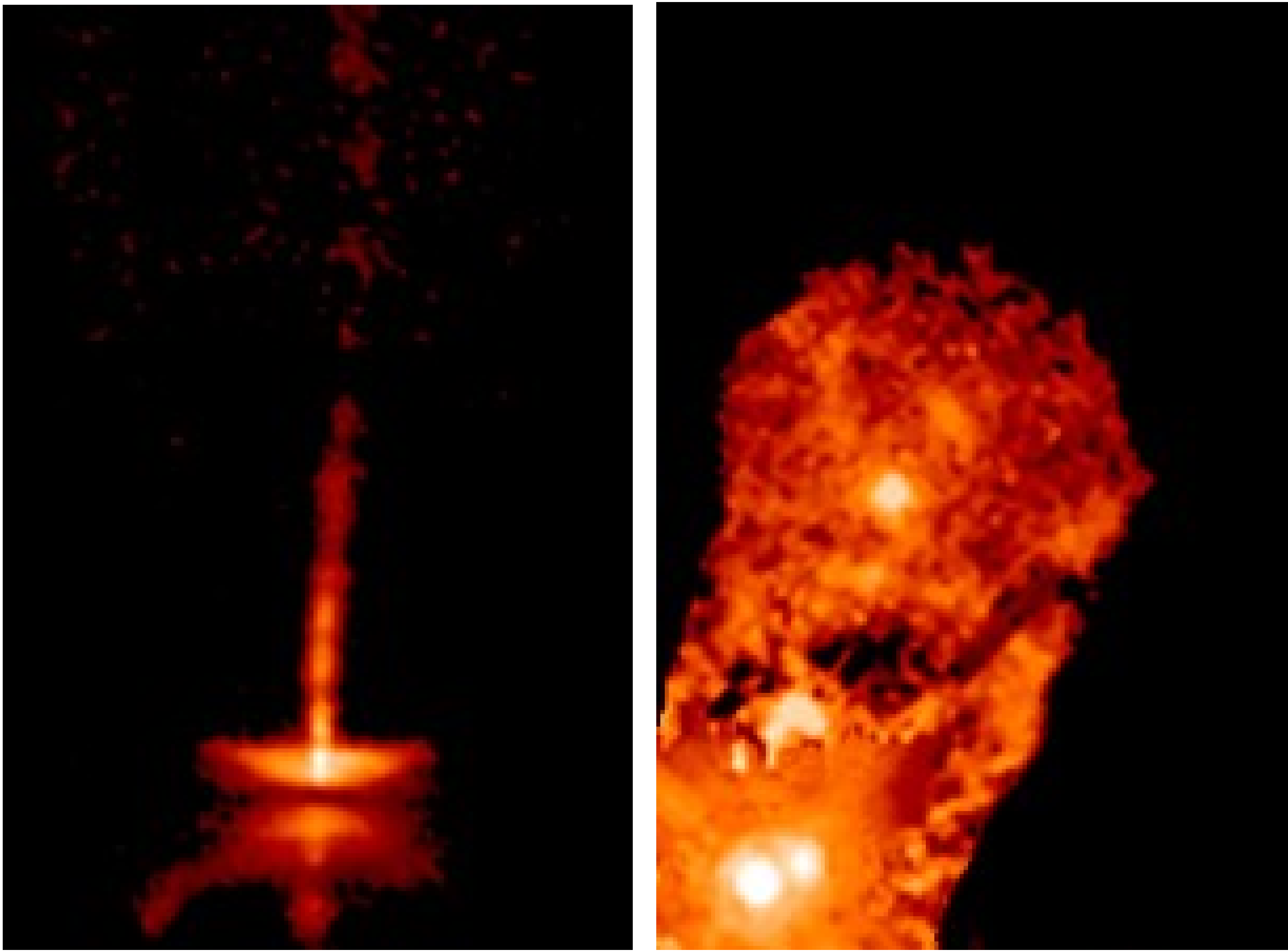
BIG QUESTION
Inflow and Outflow

- We know that accretion powers the central engine of AGNs
- We also know that some galaxies have massive radio jets that extend far beyond the host galaxy
- So, how are these two phenomena related?

What is the relation between…



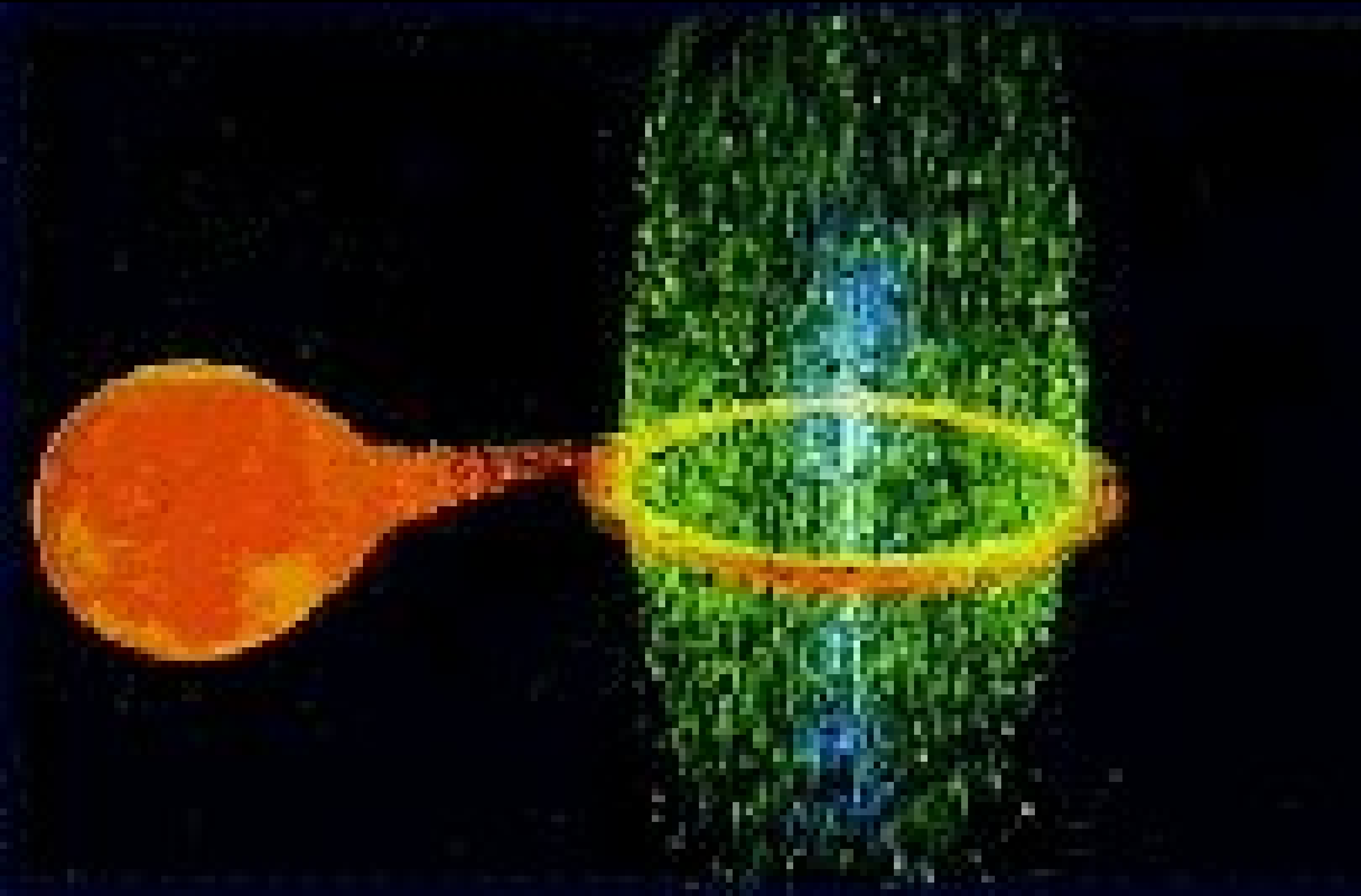
Jets and winds are ubiquitous in astrophysics



Mass Loss via Winds

A Galactic Supernova Outflow: M82

Maybe a wind can disrupt the disc ?



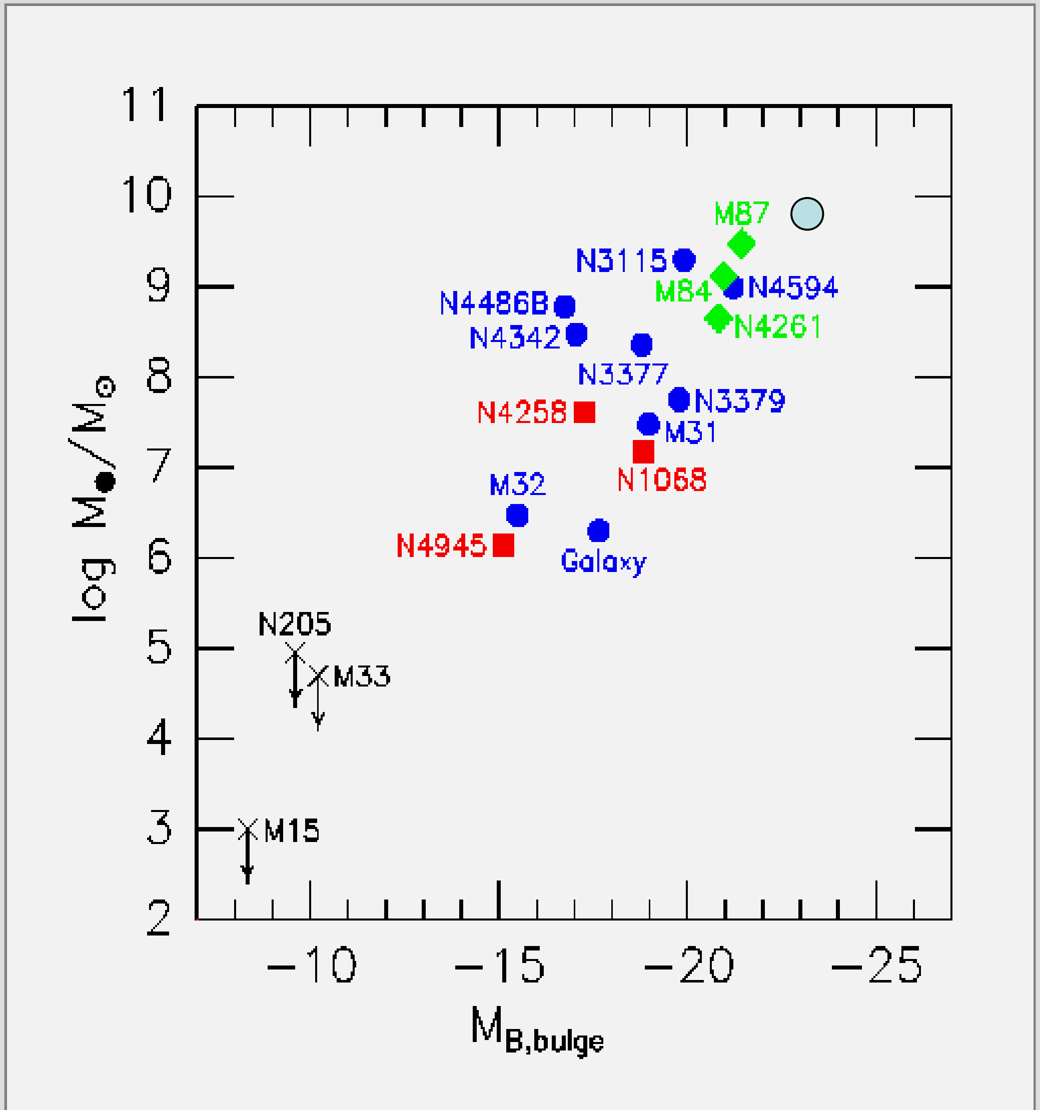
Demographics of Black Holes
(the obscured Universe – X-rays & IR)

Accretion power versus star formation

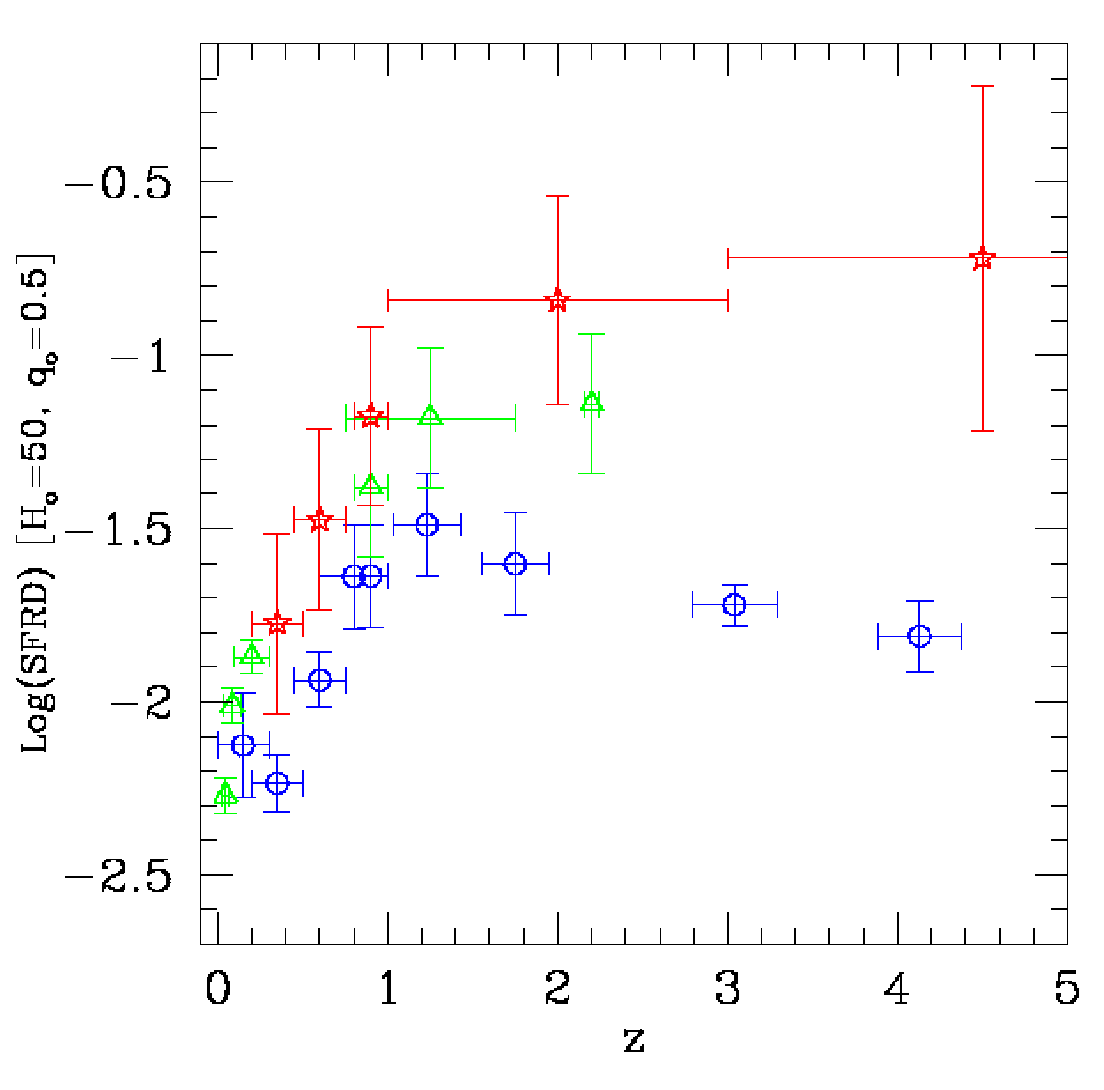
- How many dust obscured AGN? Evolution?
- How many AGN hidden by star formation within the nucleus? Evolution ?
- How many low luminosity AGN? Evolution?
- Related to several of the above questions – are there Intermediate Mass Black Holes?

The Future

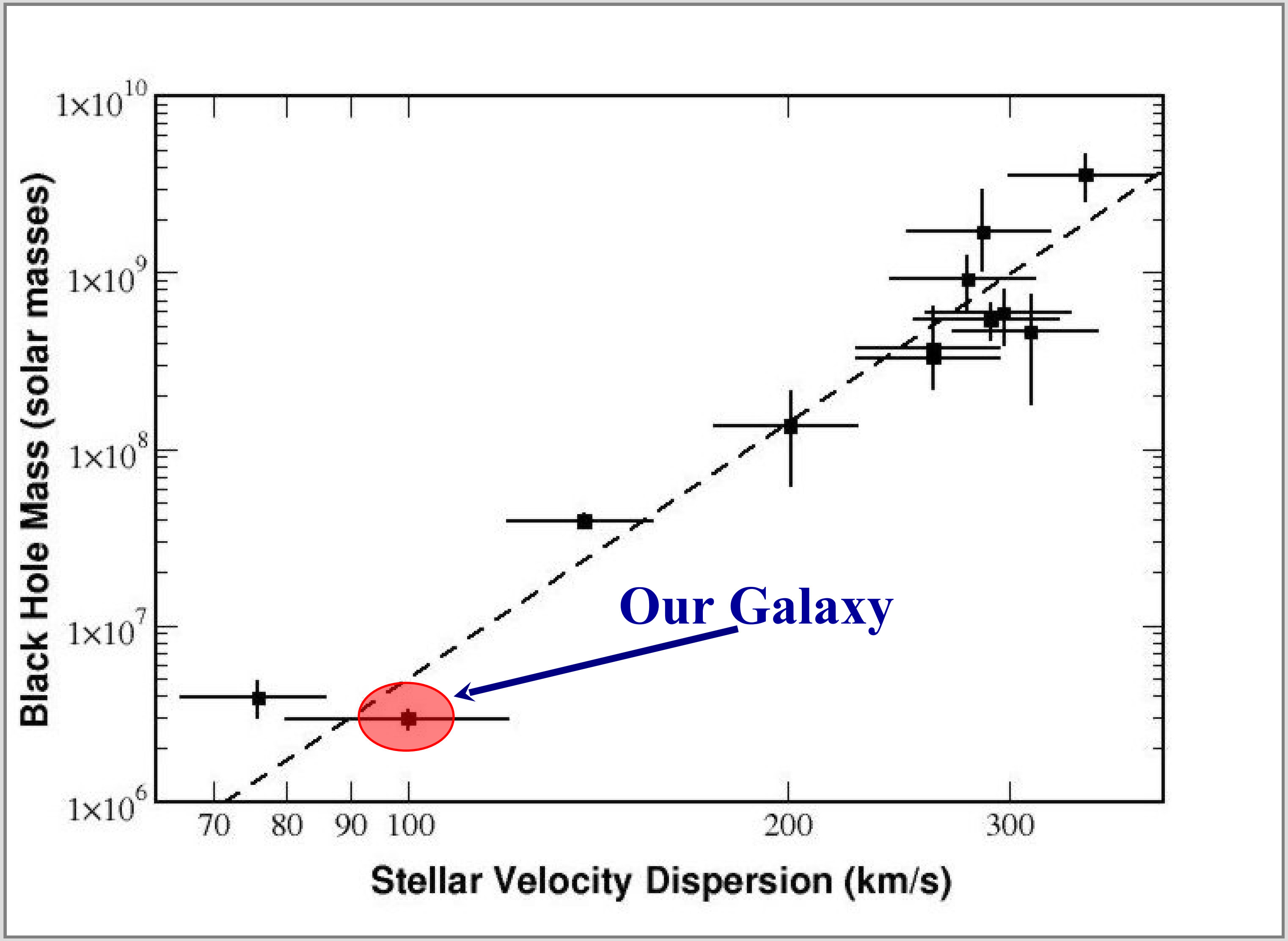
Correlation between black hole mass and galaxy bulge mass/luminosity



Evolution of Star Formation with Redshift (the AGN/starburst connection)



Correlation between black hole mass, and vel. dispersion of stars



Merritt & Ferarese (2000)

James Webb Space Telescope (JWST)

- Successor to HST
- 6.5-m diameter telescope cooled to 30 K
- Wavelength range 0.5 – 30 μm
- Launch 2013 ?

- NIRCAM: 0.7 - 5 μm imaging
- NIRSPEC: 1 - 5 μm multi-object spectroscopy
- MIRI: 5 - 28 μm imaging and integral field spectroscopy

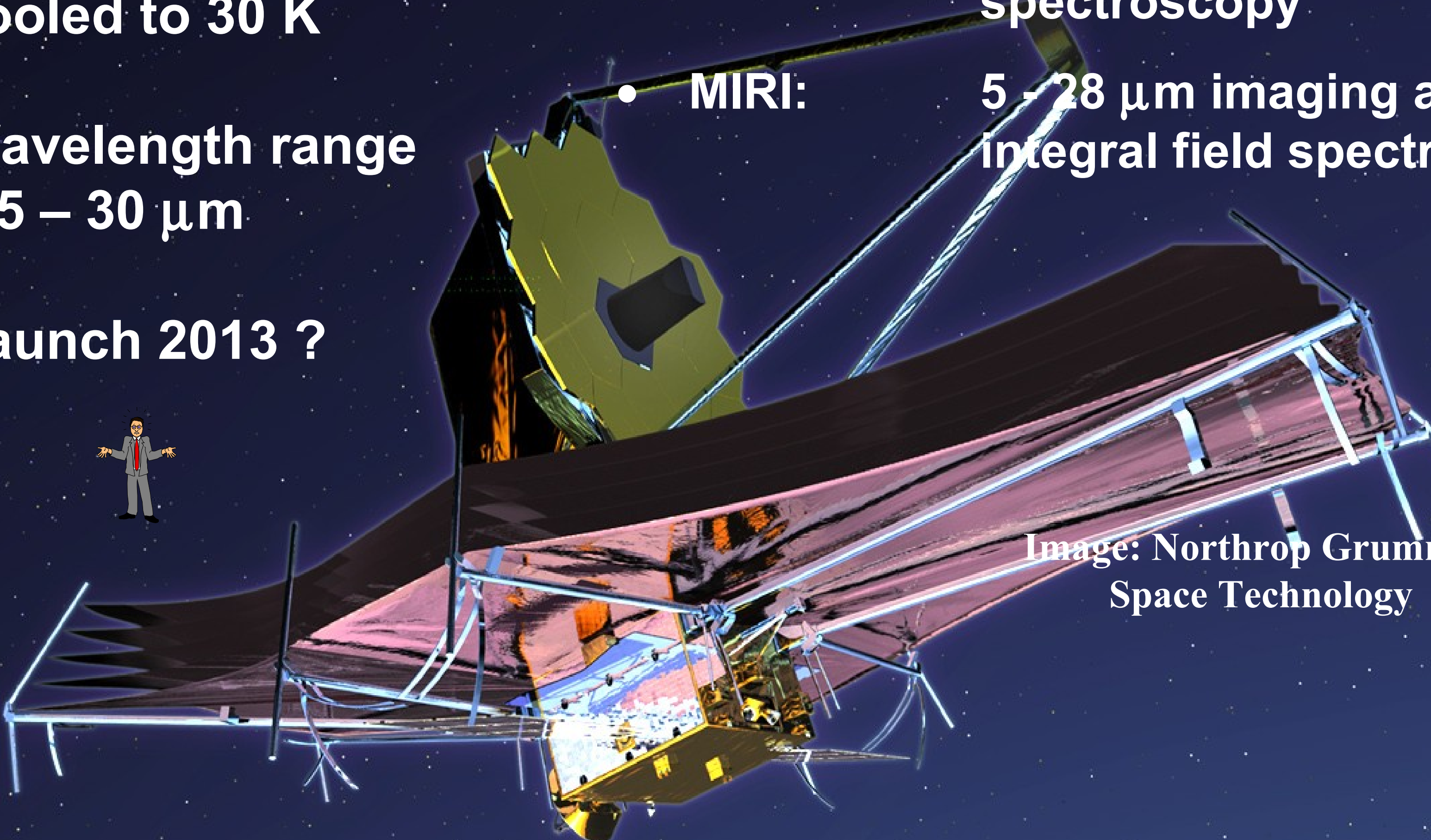
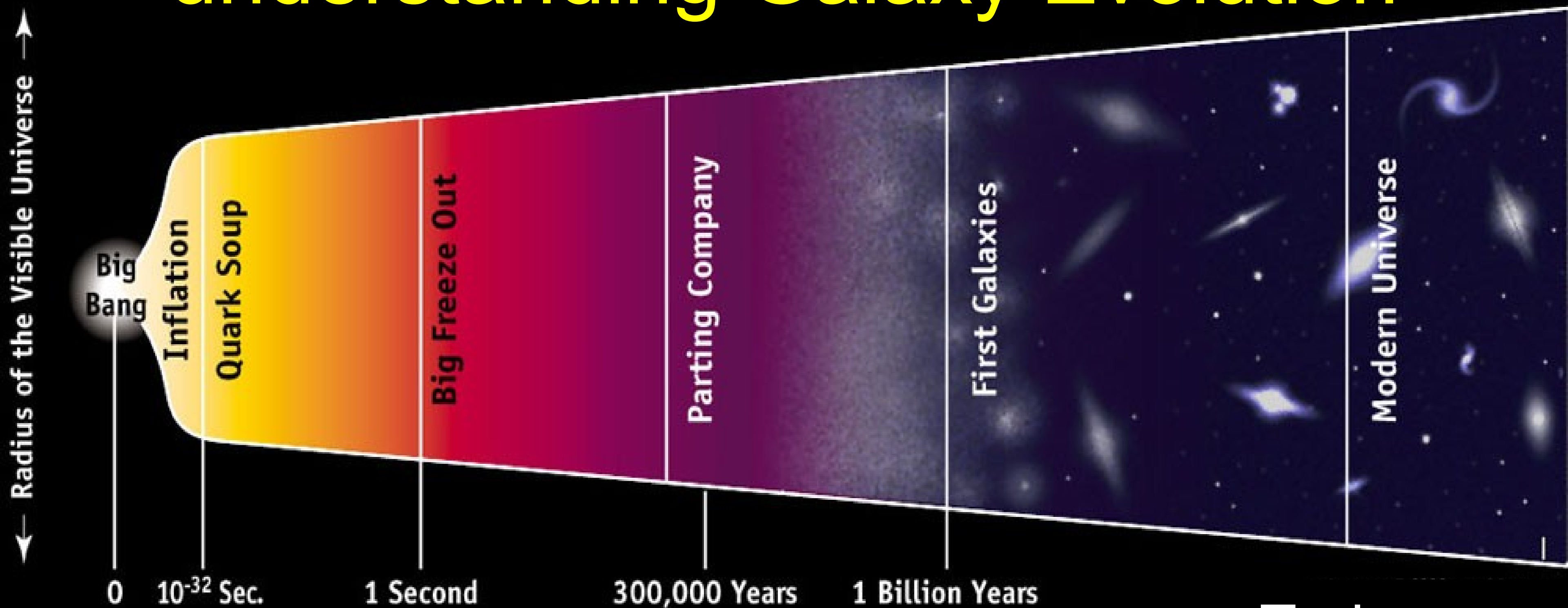


Image: Northrop Grumman Space Technology

Why AGN are Important for understanding Galaxy Evolution



Big Bang

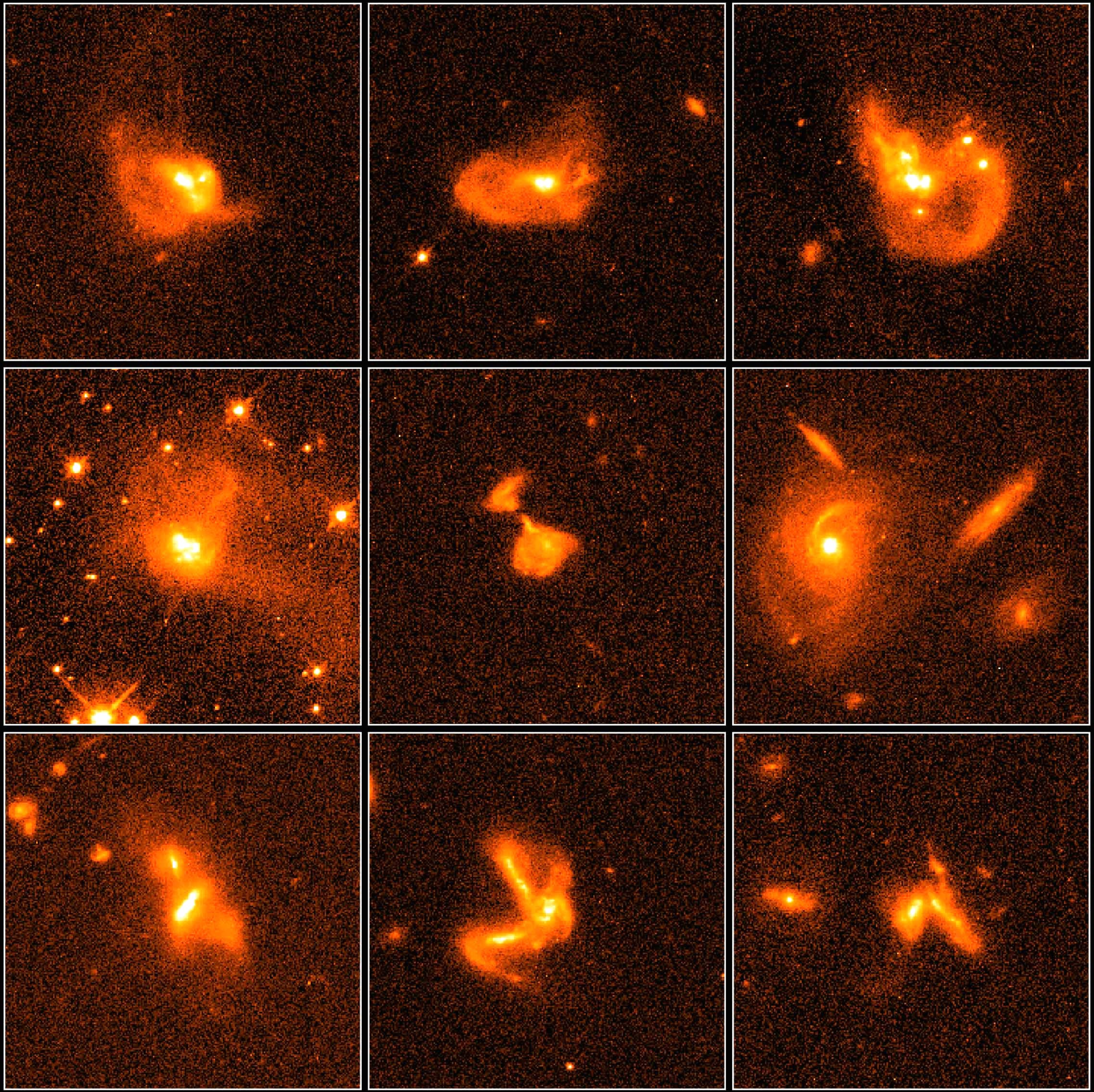
Age of the Universe

Today
13.7 B Years

Redshift z

1000 5 1 0

Galaxy collisions are quite common
More so, in the past…



Ultraluminous Infrared Galaxies

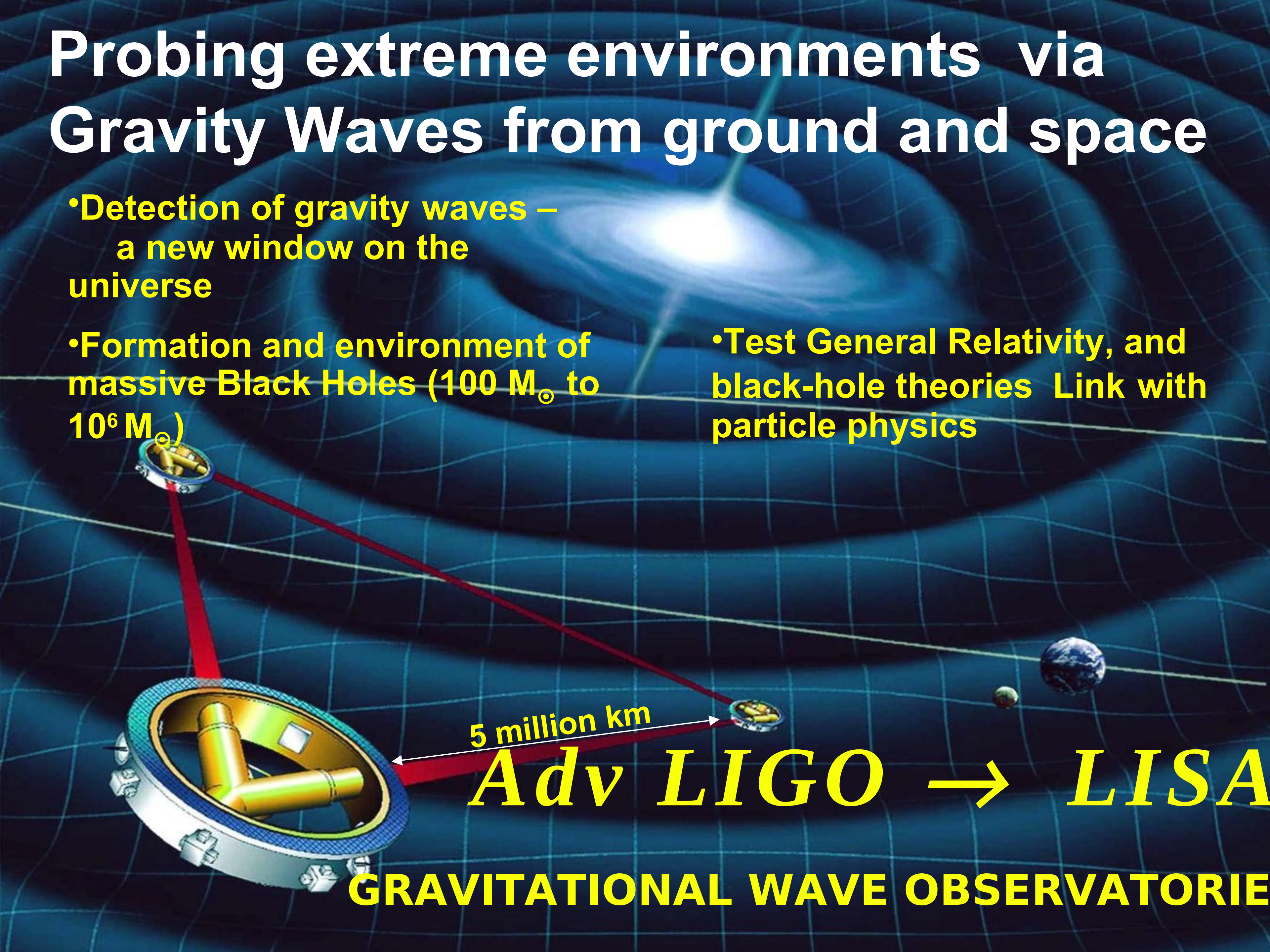
Galaxy Collison

Visualization by
Frank Summers

Simulation by
Chris Mihos &
Lars Hernquist

The *Dance of Death*

Merging Black Holes → Gravitational waves



Probing extreme environments via Gravity Waves from ground and space
•Detection of gravity waves – a new window on the universe
•Formation and environment of massive Black Holes (100 M☉ to 10⁶ M☉)
•Test General Relativity, and black-hole theories Link with particle physics
5 million km
Adv LIGO → LISA
GRAVITATIONAL WAVE OBSERVATORIE

Recall, AGN "Physics" is only ~ 50 years old – there will surely be Some BIG surprises still to come!

Active Galactic Nuclei

What we know

What we don’t know, and…

What we don’t know – we don’t know