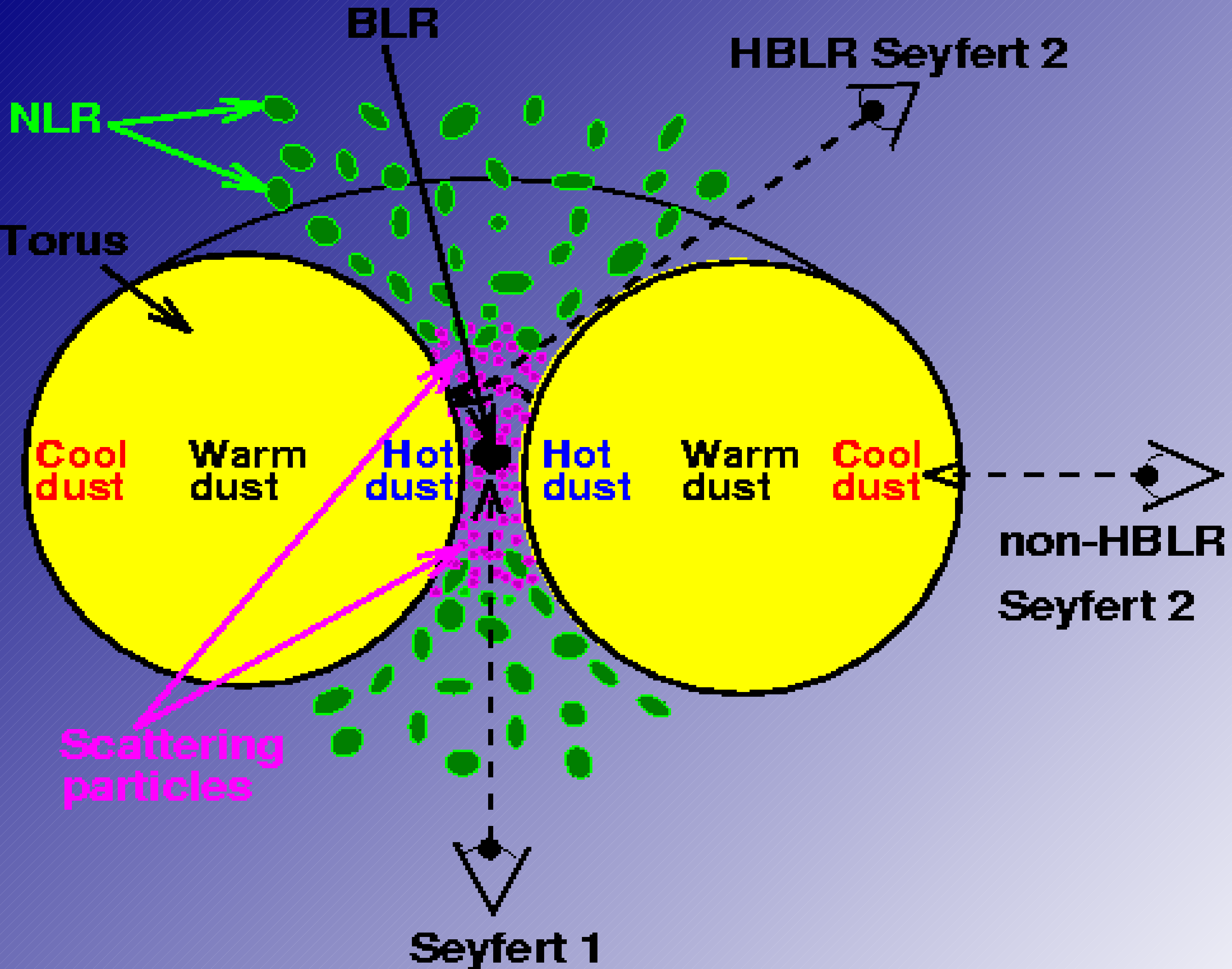
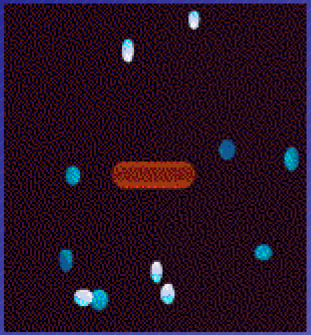
# Unified Model

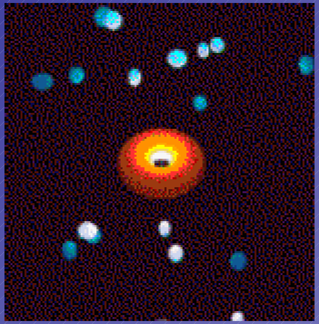
- Black hole with an accretion disk
- Material near the BH is ionized
- Close to the BH the clouds have high velocities (BRL)
  - V > 2000 km/s
- Further away from the BH lower velocity and narrow lines (NLR)
  - 500 km/s < V < 1000 km/s
- Dust torus surrounds the central engine and BLR in the same plane as the accretion disk. The orientation of the dust torus relative to the line of sight affects the classification of the AGN.



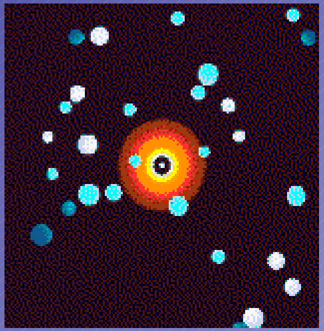

Unified Model



Type 2 objects:
Seyfert 2s, Narrow Line Radio Galaxies
and Type 2 Quasars



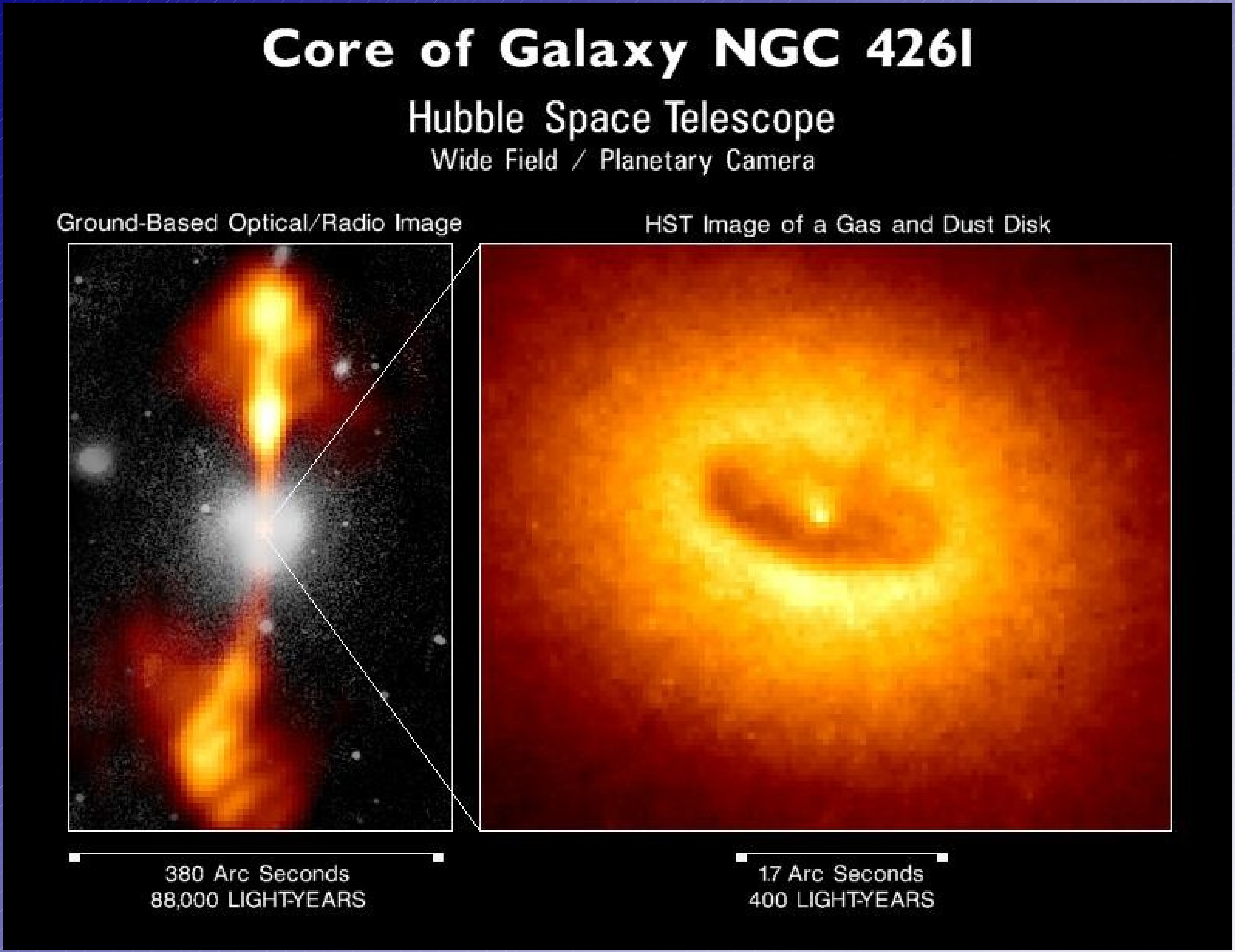
Type 1 objects:
Seyfert 1s, Broad Line Radio Galaxies
and (Type 1) Quasars



Blazars:
BL Lac Objects and
Optically-Violent Variables

# Unified Model cont.

- Different wavelength light comes from different areas of the “central engine”
  - Gamma rays from the very inner accretion disk
  - X-ray and UV from next innermost parts of disk and jet
  - Radio from particles accelerated to relativistic energies in the jet (synchrotron radiation)
  - Visible light (continuum) from farther out in disk or jet
  - Visible light (emission lines) from BLR and NLR clouds
  - Infrared from radiation from surrounding dust grains, either in clouds or from the torus


Core of Galaxy NGC 4261
Hubble Space Telescope
Wide Field / Planetary Camera
Ground-Based Optical/Radio Image
HST Image of a Gas and Dust Disk
380 Arc Seconds
88,000 LIGHT-YEARS
1.7 Arc Seconds
400 LIGHT-YEARS

# What can limit the AGN Luminosity?

$F_{grav} = GMm_p/r^2$

Radiation Pressure = $\sigma_T L/(4\pi r^2 c)$

If the radiation pressure > $F_{grav}$

Then the inflow to the BH will be quenched.

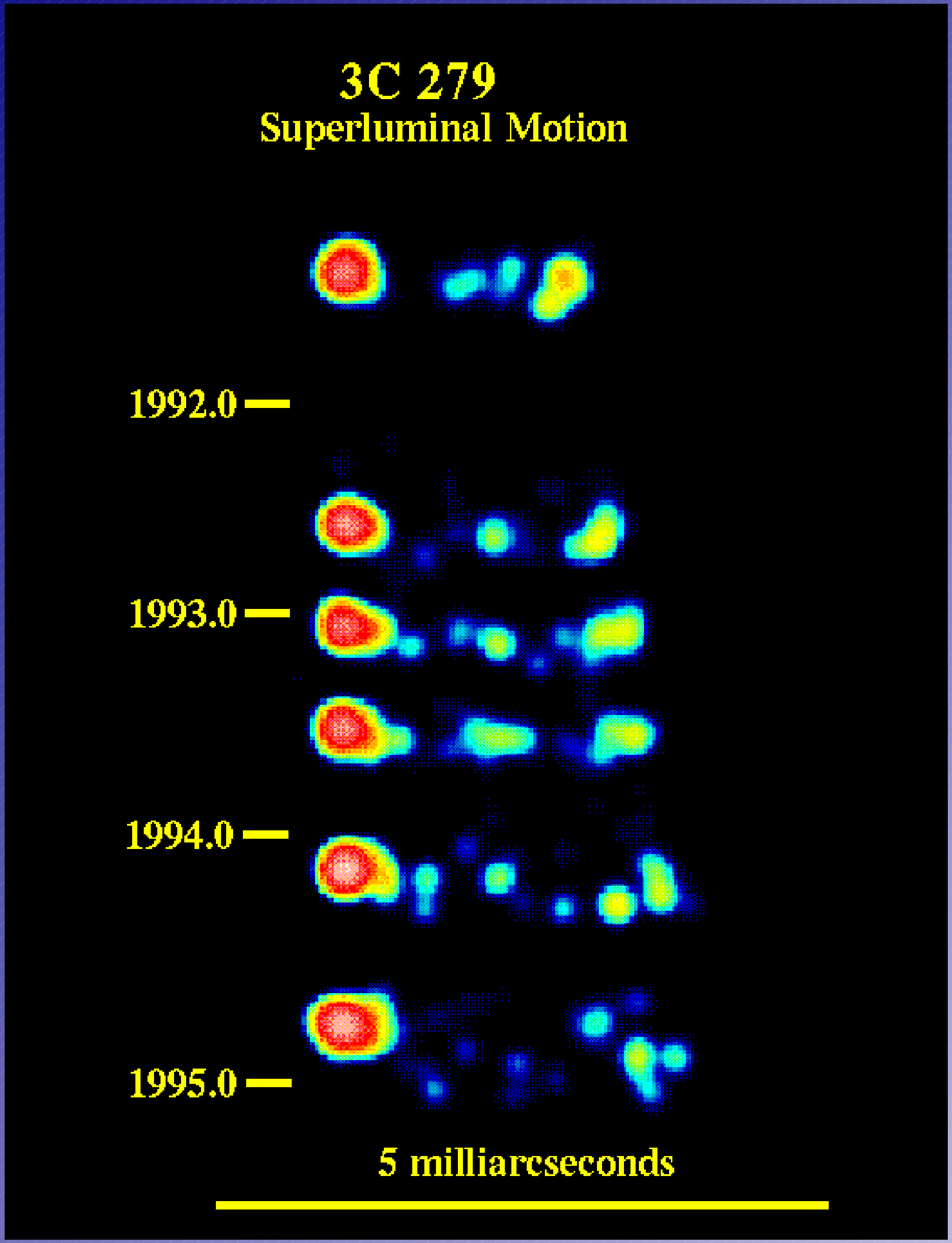
# What can limit the AGN Luminosity? cont.

If $P_{rad} = F_{grav}$ then this is the maximum
luminosity the AGN can have before shutting off the inflow of matter and is

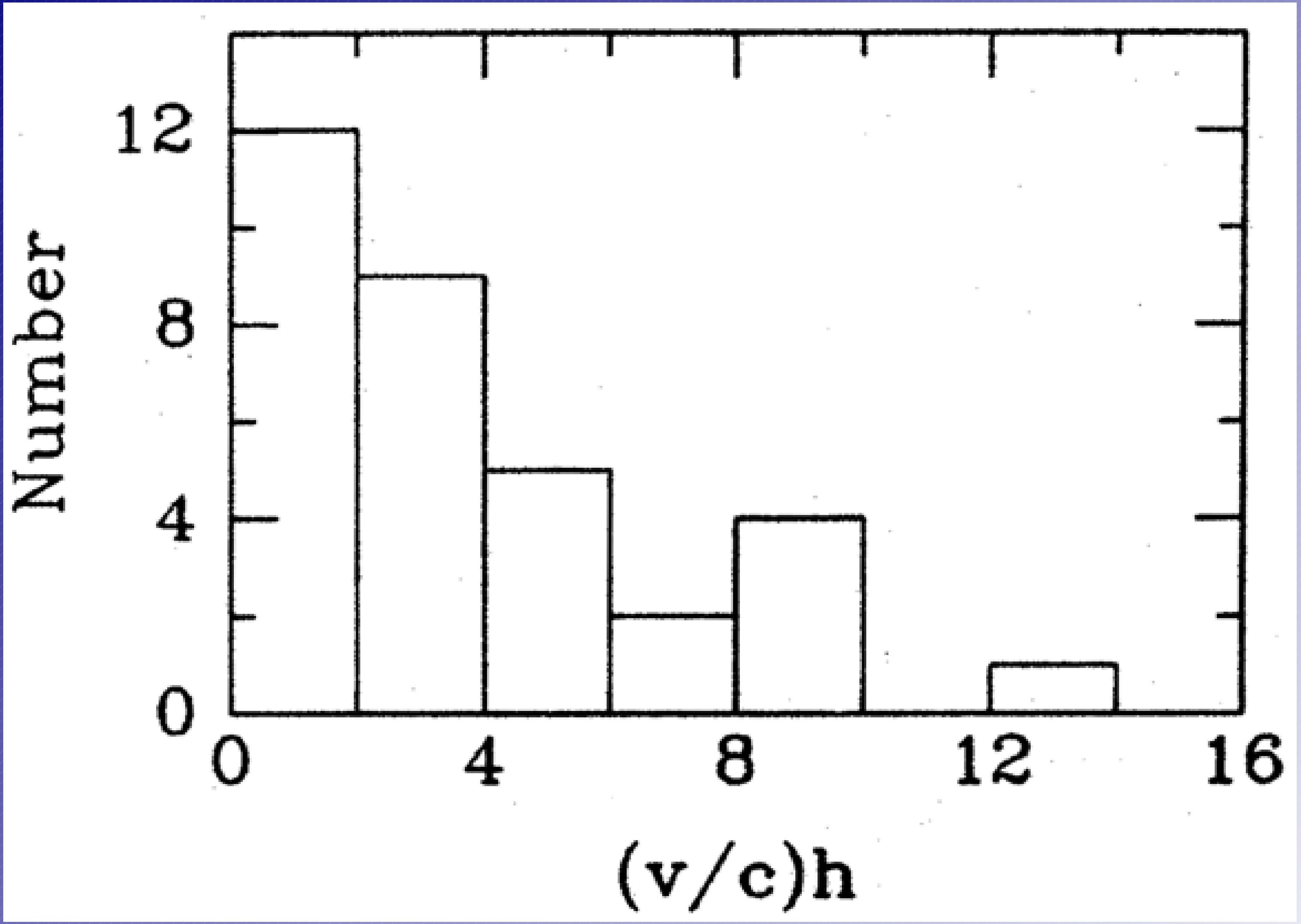
$$L = 4\pi G M m_p c/\sigma_T \simeq 3x10^4 (M/M_\odot) L_\odot$$

This is the Eddington luminosity. This
Is only true for spherical accretion.

# Superluminal Motion

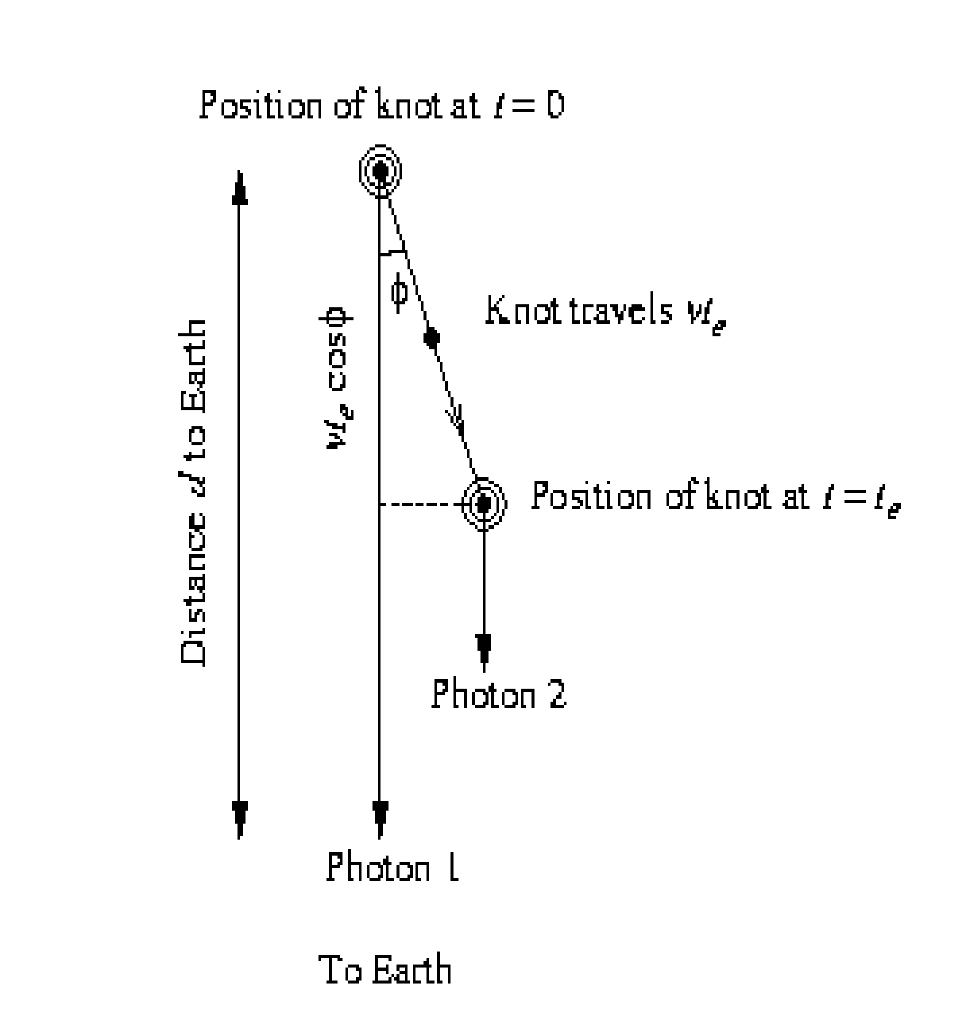



Measuring the apparent motion of the “blobs” gives you v ~ 4c
New Physics??




V/C for a sample of 33 jets

# Superluminal Motion




The knots are moving towards us at an angle $\phi$ measured from the line of sight.

A photon emitted along the line of sight at time t=0, travels a distance d to us, taking a time $t_1$ to arrive:
$t_1 = d/c$

A second photon is emitted at a time t later, when the blob is a distance $d - vt \cos \phi$ away from us. The second photon arrives at $t_2 = t + (d - vt \cos\phi)/c$

The observed difference in the time of arrival from photon 1 & 2 is:
$\Delta t_{obs} = t_2 - t_1 = \Delta t\,(1 - v\cos\phi/c) < \Delta t$

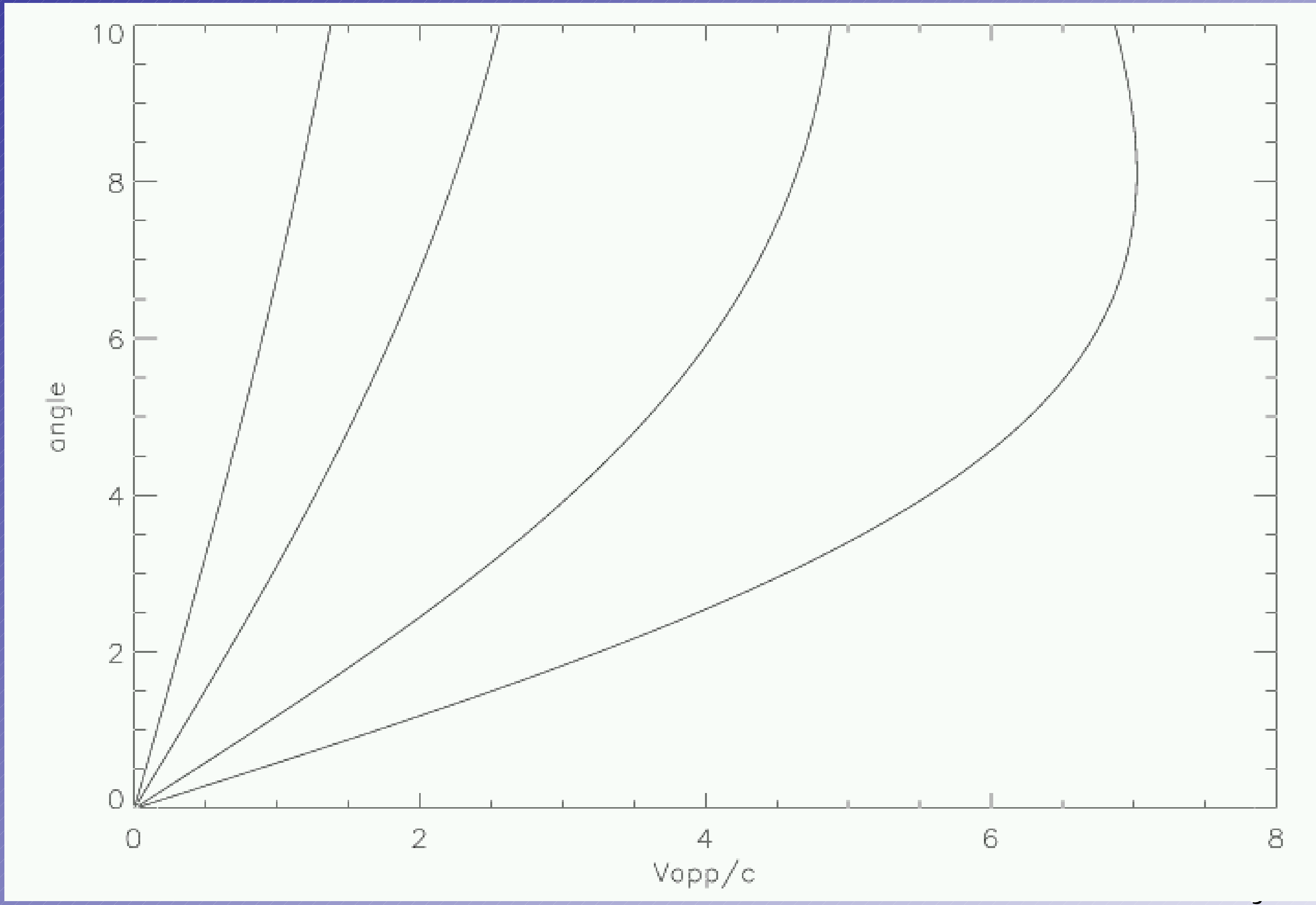
# Superluminal Motion

The apparent transverse velocity is

$V_{app} = vT_e \sin(\phi)/ \Delta t$

$= v \sin(\phi)/(1 - v\cos(\phi)/c)$ let $\beta = v/c$

$= \beta c \sin(\phi)/\{1 - \beta\cos(\phi)\}$



# Superluminal Motion cont.

Let $\gamma = 1/(1- v^2/c^2)^{1/2}$, this is the Lorentz factor. Then: $v_{app} \leq \gamma v$ (the maximum observed velocity) which occurs when $\cos \phi = v/c$. We will only observe superluminal motion when the jets are pointed within an angle of $1/\gamma$ towards the line of sight.

This light will be beamed and brightened.

# Superluminal Motion cont.

To a stationary observer, the "clocks" on the knot appear to run slow by a factor of $\gamma$, from before,

$\Delta t_{obs} = \Delta t\,(1 - v\cos\phi/c)$

$\Delta t_{obs} = \Delta t_e\,\gamma\,(1 - v\cos\phi/c)$

So the observed frequency of the light is

$\nu_{obs} = \nu_e[\gamma\,(1 - v\cos\phi/c)]^{-1}$

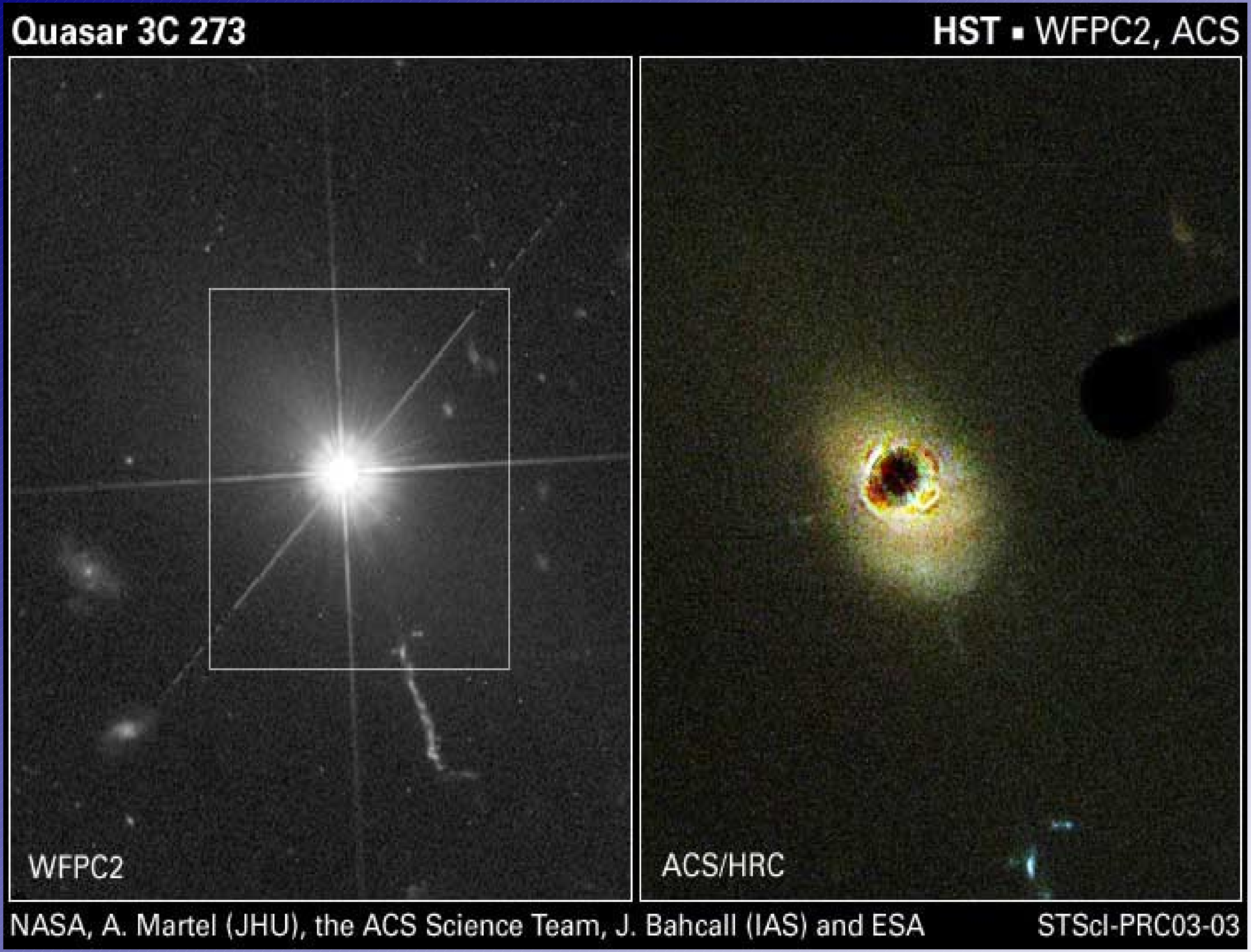
When $\gamma >> 1$, all the light is focused into a narrow cone of $\sin\phi = 1/\gamma \sim \phi$, and compressed in time by $\Delta t_{obs} = \Delta t_e /2\gamma$.

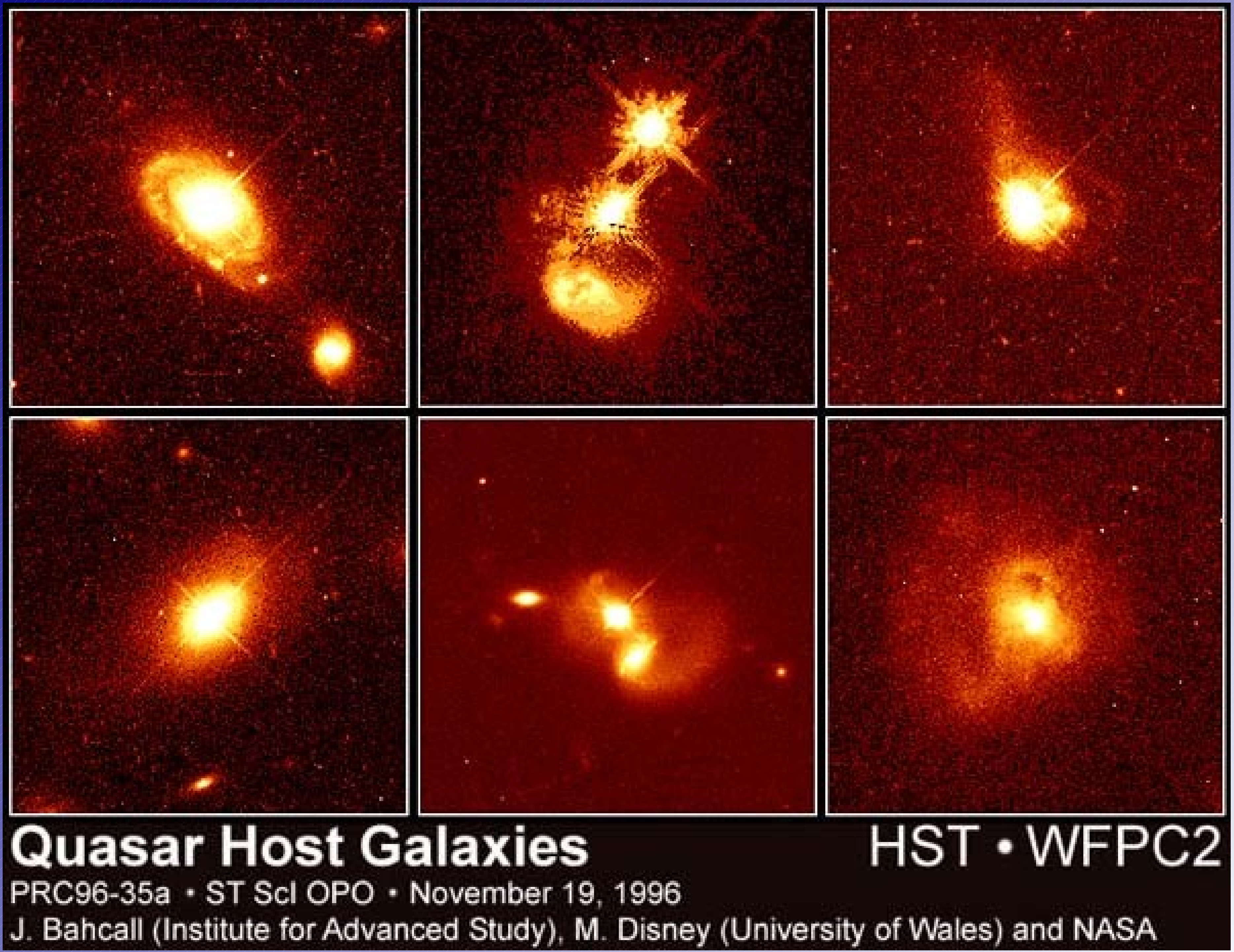
Thus the light will be brightened by a factor of $1/(2\gamma)^2$

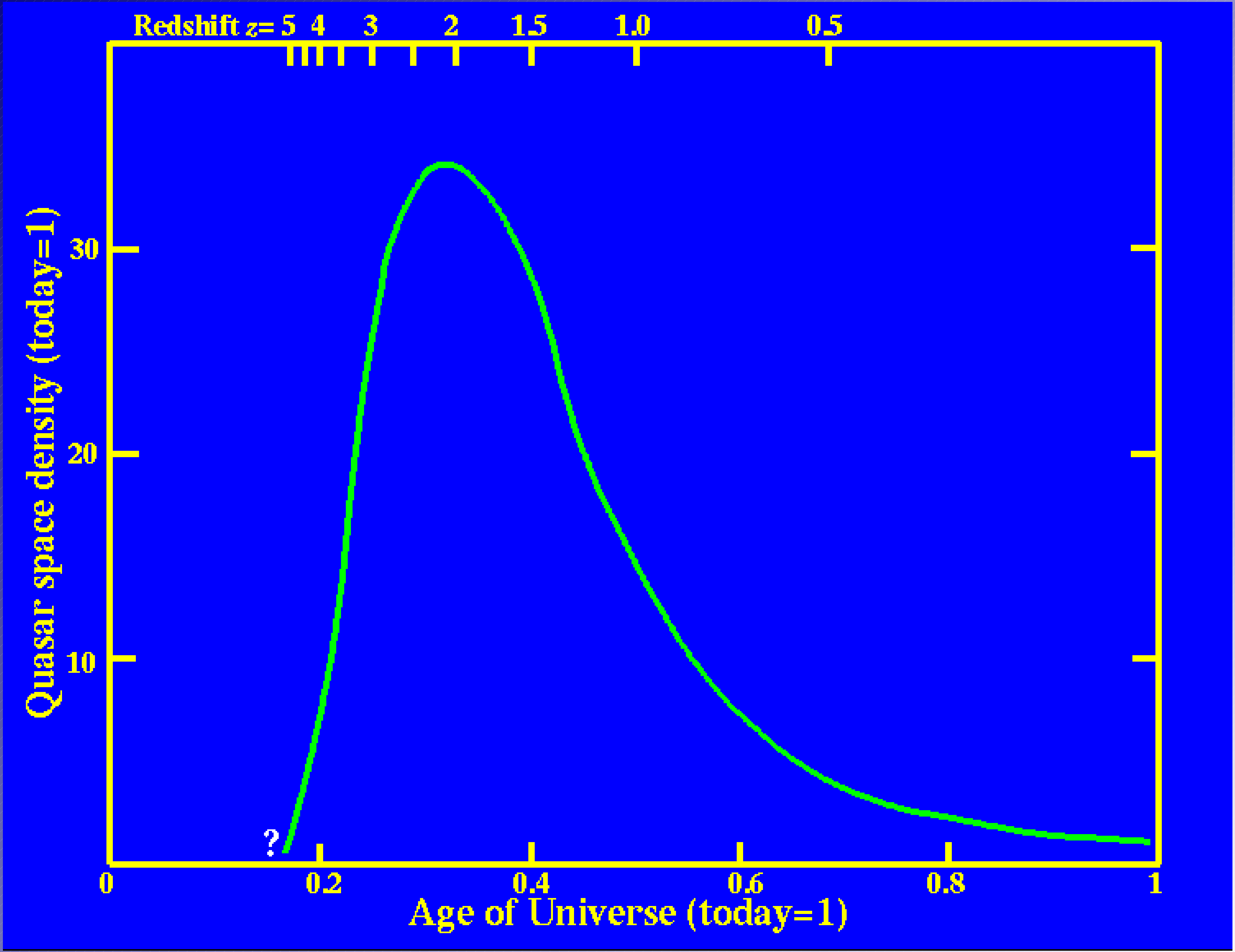
This explains why we usually only see one relativistic jet, the one being beamed towards us.

# Quasar Host Galaxies

- With good telescopes (and some image processing) the quasar light can be subtracted and the host galaxy revealed
  - One can image quasar hosts with HST
  - Many are interacting – does interactions trigger AGN activity?  Promote fueling gas into centers?
- Not all galaxies with SMBH are AGN (even the Milky Way)
- Quasars were much (~1000x) more numerous at z~3 than today
  - Is an AGN a requirement for galaxy formation?  Does every galaxy have a SMBH?
  - More interactions in the past?
- Quasars were also much more luminous in the past
- There is probably some combination of luminosity and density evolution!

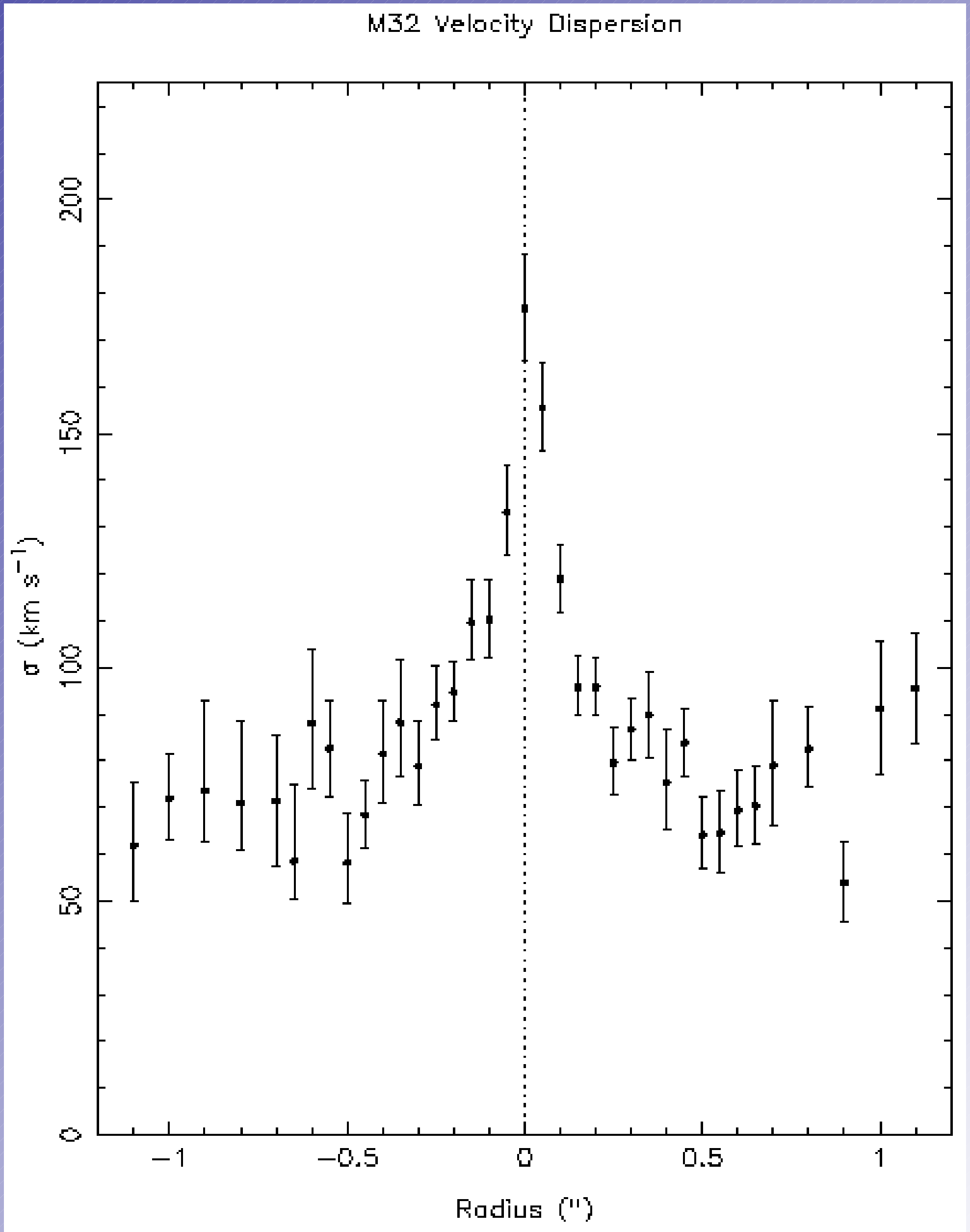

Quasar 3C 273
HST ▪ WFPC2, ACS
WFPC2
ACS/HRC
NASA, A. Martel (JHU), the ACS Science Team, J. Bahcall (IAS) and ESA
STScI-PRC03-03


Quasar Host Galaxies
HST • WFPC2
PRC96-35a • ST ScI OPO • November 19, 1996
J. Bahcall (Institute for Advanced Study), M. Disney (University of Wales) and NASA



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)

# M32




There is evidence that most if not all galaxies have a BH in their center but many of these are quiet! Not being fed(?) so they are hard to detect

# What do they have in common?

- Variability on short time scales implies a small emission region
  - $R = c\Delta t \sim$ 7-10 AU (for variability on the order of hours)
- Highly luminous!
- Most likely powered by a black hole
- Schwarzschild radius is the radius where the "escape velocity" equals the speed of light around a black hole of mass M:
  - $R_{Sch} = 2GM/c^2$
- Continuum emission powered by gas falling onto central black hole, losing potential energy, heating up and radiating
- Since gas has angular momentum it forms an accretion disk

# What Have We Learned?

What is the structure of the Milky Way galaxy?

What are the components of our Galaxy?

Where are stars forming in our Galaxy?

Where are the globular Clusters?

How big is our Galaxy?

Where is the Sun's position in the Milky Way?

Why was the Shapley-Curtis debate important?

Who helped to resolve this debate?

What are proper motions?

What is cluster main sequence fitting?

What is parallax?

What are some of the differences between spiral, elliptical, and irregular galaxies?

What are the different classification schemes? How are they related? How are they different?

What physical characteristics vary among the galaxy types?

How is this related to classification schemes?

What do astronomers mean by the Local Group?

What kind of galaxies make up the local group?

What type of galaxies make up clusters of galaxies?

What are quasars? What are some of their properties?

What are Seyfert Galaxies?

What are Radio Galaxies?

Are Seyfert and Radio Galaxies related? If so how?

Describe the internal dynamics of Spiral galaxies? Of elliptical galaxies. How are they different? How are they similar?

What are spiral arms?

What are the processes that we think may form spiral arms? When are they applicable.

How do we know that the Universe is expanding?

How do we measure this?

What is the Tully-Fischer relation?

Can this be used with elliptical galaxies?

Can this be used with Seyfert galaxies?

What is superluminal motion?

What is gravitational lensing?

What is the origin of large scale structure in the universe?

What are some of the different methods of observing it? Of measuring it?

How is the Hubble parameter related to the expansion of the universe?

What is meant by a radiation dominated universe? A matter dominated universe?

What are peculiar velocities?

Why are quasars important in the study of the early universe?