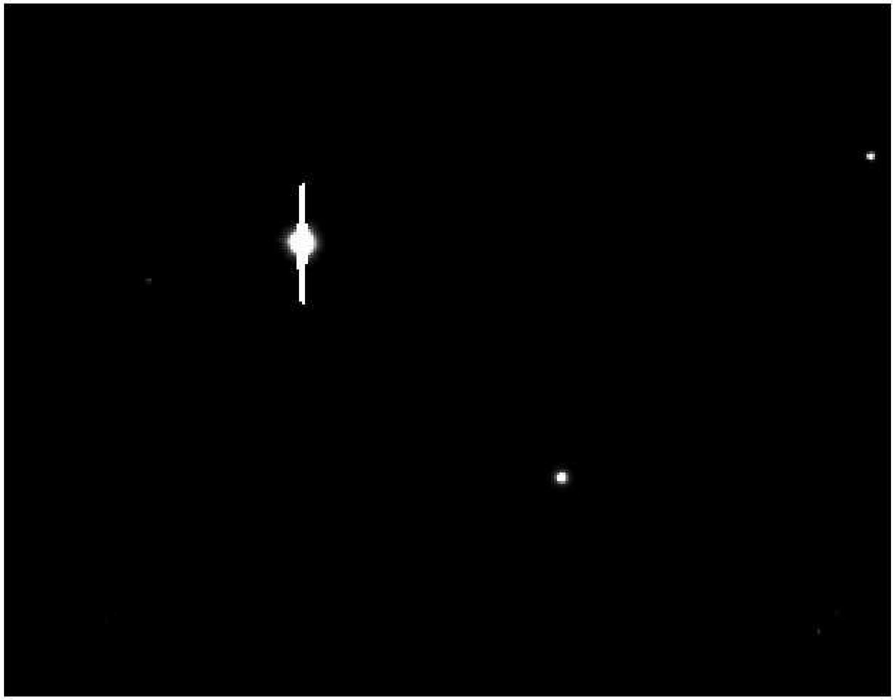
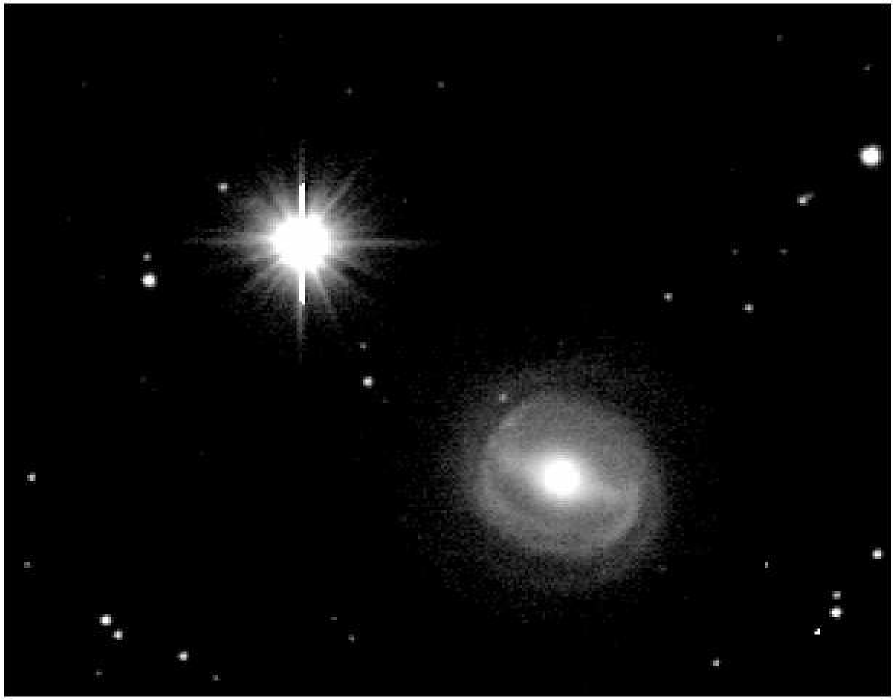
AGN



NGC 3783: *linear* intensity scale



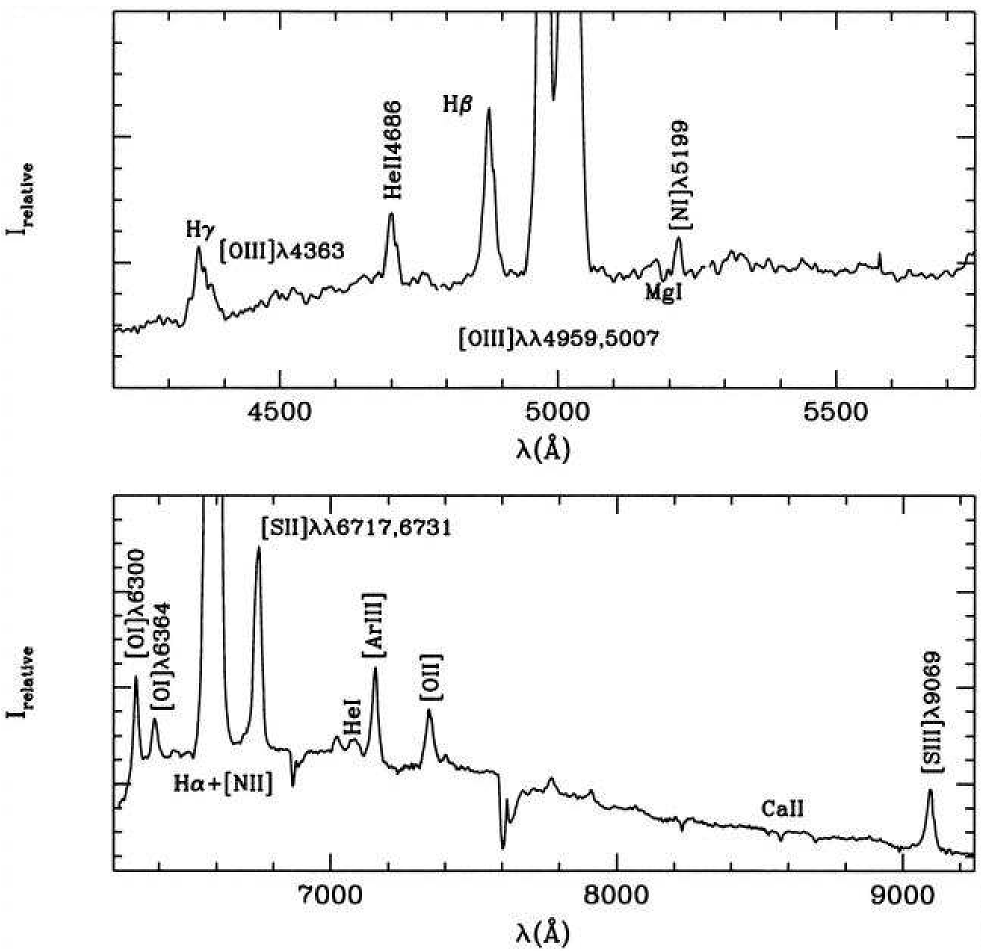
logarithmic intensity scale

Active Galactic Nuclei (AGN): supermassive black holes ($M \sim 10^{6...8}\,M_\odot$), accreting $1 \ldots 2\,M_\odot/\mathrm{year}$

$\Longrightarrow$ Luminosity $\sim 10^{10}\,L_\odot$ (comparable to galaxy luminosity)

NGC 1068 (M77)
courtesy Nordic Optical
Telescope

1908: E. Fath



Optical spectrum of NGC 1068

(García-Lorenzo, Mediavilla & Arribas, 1999, Fig. 4)

1908: Edward A. Fath: There are emission lines in NGC 1068, similar to planetary nebulae.

This was part of Fath's PhD!

Note: High ionization levels, large width of lines

1943: C. Seyfert

NUCLEAR EMISSION IN SPIRAL NEBULAE*

CARL K. SEYFERT†

ABSTRACT

Spectrograms of dispersion 37–200 A/mm have been obtained of six extragalactic nebulae with high-excitation nuclear emission lines superposed on a normal G-type spectrum. All the stronger emission lines from λ 3727 to λ 6731 found in planetaries like NGC 7027 appear in the spectra of the two brightest spirals observed, NGC 1068 and NGC 4151.

Apparent relative intensities of the emission lines in the six spirals were reduced to true relative intensities. Color temperatures of the continua of each spiral were determined for this purpose.

The observed relative intensities of the emission lines exhibit large variations from nebula to nebula. Profiles of the emission lines show that all the lines are broadened, presumably by Doppler motion, by amounts varying up to 8500 km/sec for the total width of the hydrogen lines in NGC 3516 and NGC 7469. The hydrogen lines in NGC 4151 have relatively narrow cores with wide wings, 7500 km/sec in total breadth. Similar wings are found for the Balmer lines in NGC 7469. The lines of the other ions show no evidence of wide wings. Some of the lines exhibit strong asymmetries, usually in the sense that the violet side of the line is stronger than the red.

In NGC 7469 the absorption K line of *Ca* II is shallow and 50 A wide, at least twice as wide as in normal spirals.

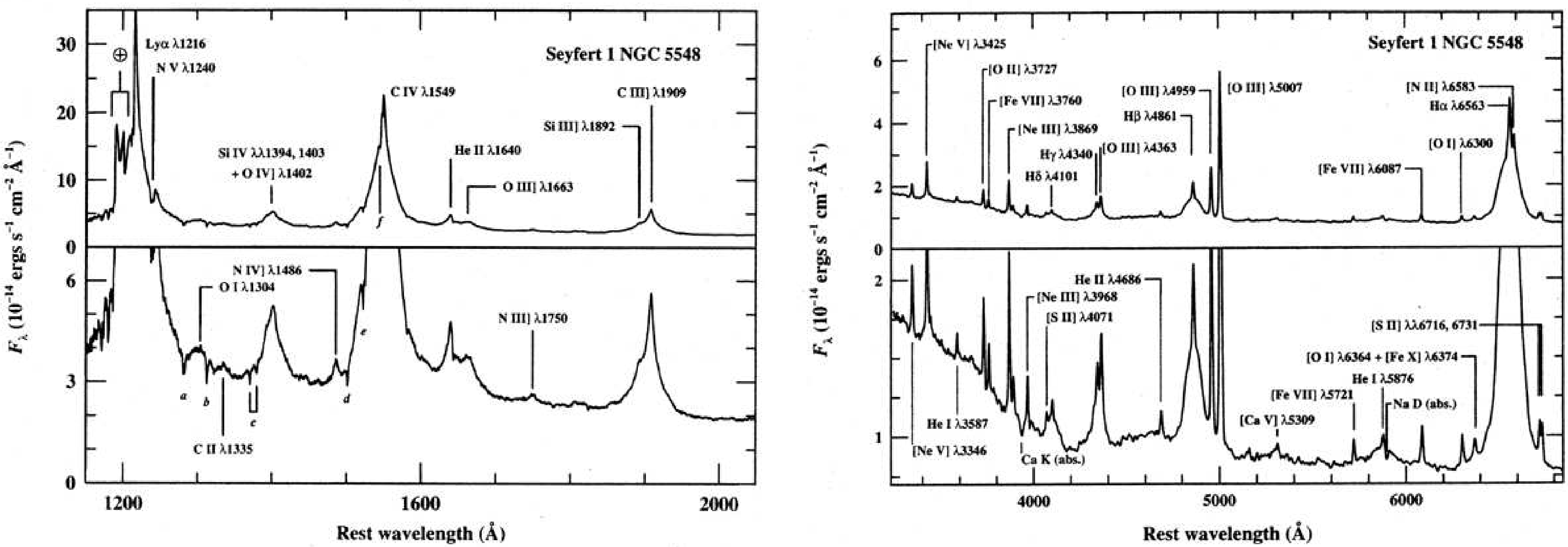
Absorption minima are found in six of the stronger emission lines in NGC 1068, in one line in NGC 4151, and one in NGC 7469. Evidence from measures of wave length and equivalent widths suggests that these absorption minima arise from the G-type spectra on which the emissions are superposed.

The maximum width of the Balmer emission lines seems to increase with the absolute magnitude of the nucleus and with the ratio of the light in the nucleus to the total light of the nebula. The emission lines in the brightest diffuse nebulae in other extragalactic objects do not appear to have wide emission lines similar to those found in the nuclei of emission spirals.

(Seyfert, 1943)

1943: Carl Seyfert: Recognization of spiral galaxies with optical emission lines as a class $\Longrightarrow$ Seyfert galaxies

Seyfert 1

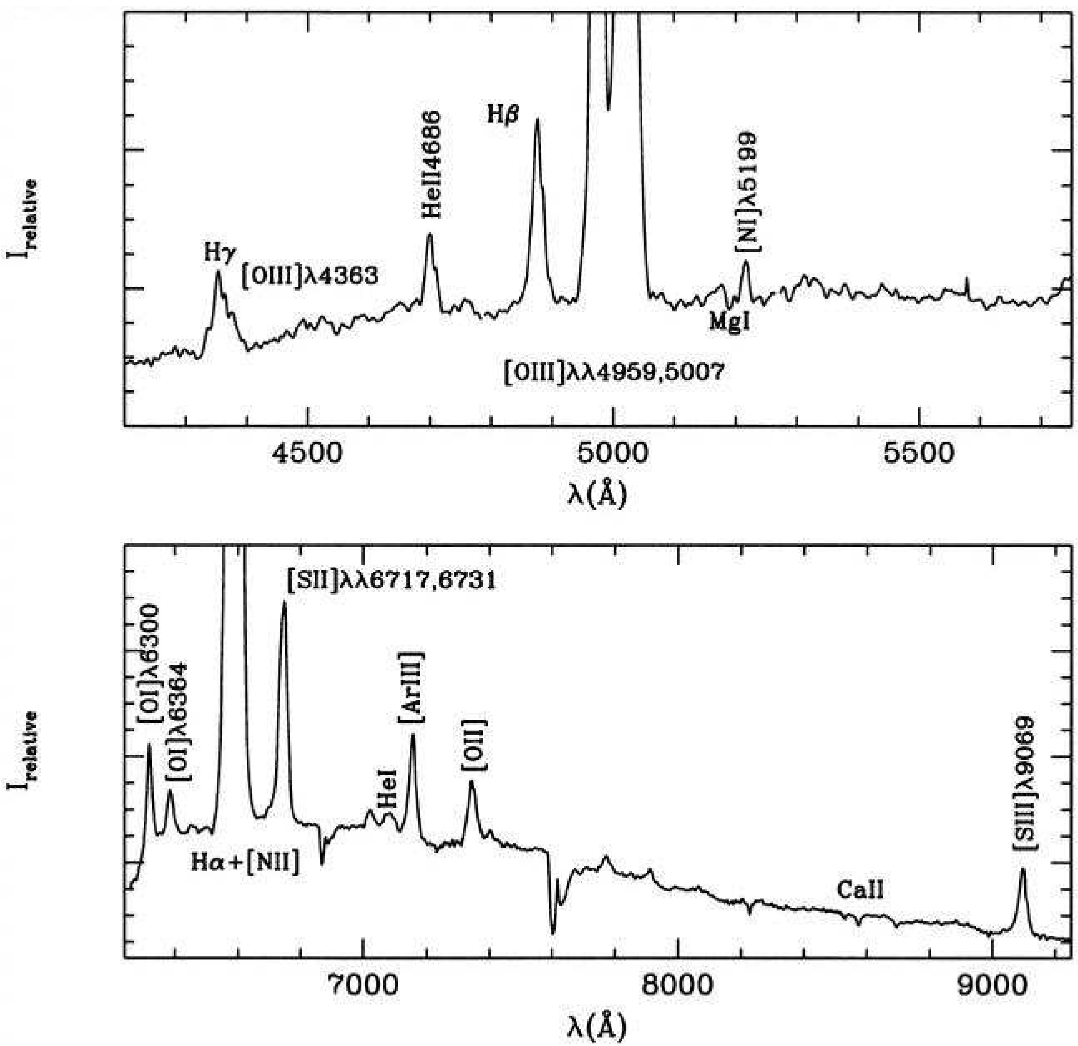


Seyfert 1 galaxies:

- broad dipole allowed lines (e.g., Balmer series), Full width at half maximum (FWHM) up to $10^4\,\mathrm{km\,s^{-1}}$ from high density medium ($n_\mathrm{e} \gtrsim 10^9\,\mathrm{cm^{-3}}$).
- narrow dipole forbidden lines (e.g., [O III5007]), FWHM $\sim$ few $\cdot\, 10^2\,\mathrm{km\,s^{-1}}$ from a low density medium ($n_\mathrm{e} \sim 10^3\,\mathrm{cm^{-3}} \ldots 10^6\,\mathrm{cm^{-3}}$).

Reminder: From the Doppler effect: $\Delta\lambda/\lambda = v/c$.

Seyfert 2

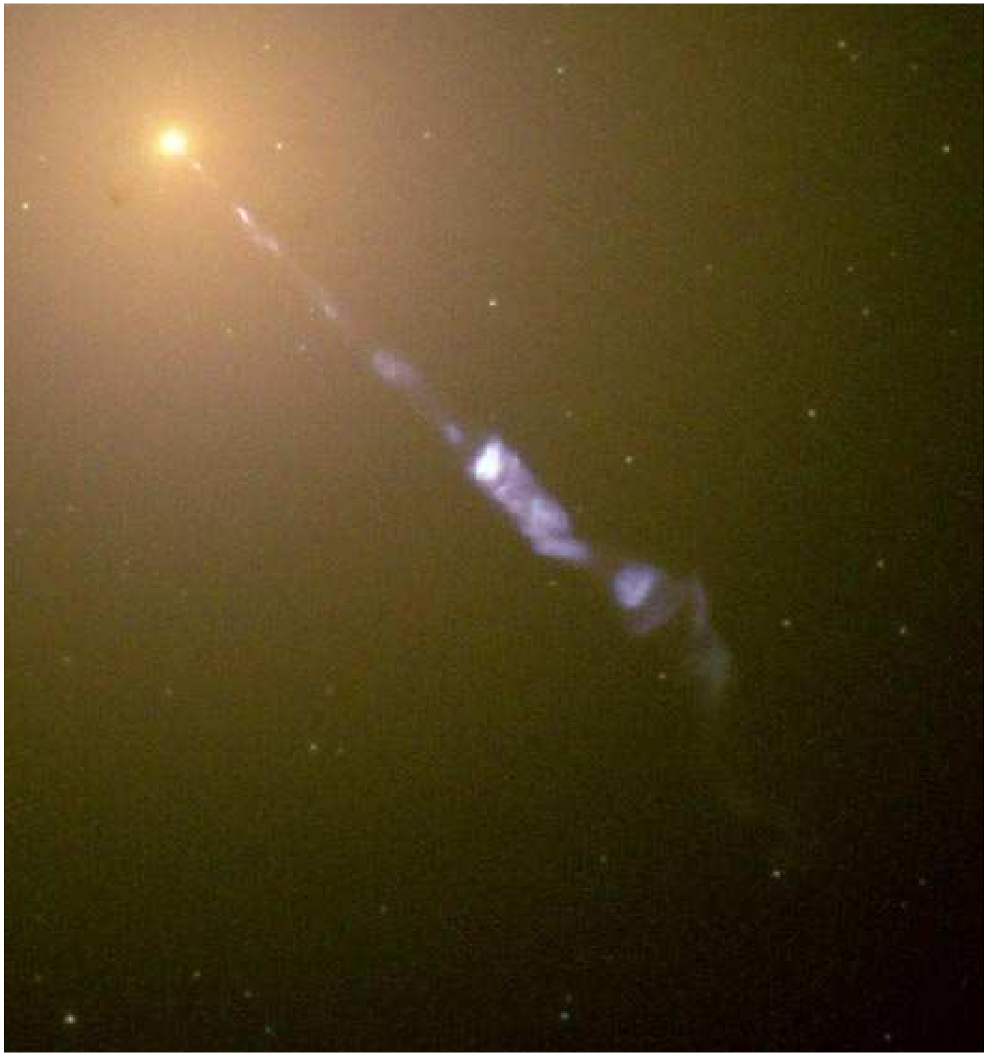


(García-Lorenzo, Mediavilla & Arribas, 1999, Fig. 4)

Optical spectrum of the Seyfert 2 Galaxy NGC 1068:

- Weak continuum (compared to Seyfert 1s).
- Narrow forbidden lines, FWHM $\sim$ few $\cdot\, 10^2\,\mathrm{km\,s^{-1}}$.
- No broad lines
- Absorption lines from underlying galaxy (mainly late-type giants).

1918: H. Curtis



HST

1918: Heber D. Curtis: “[M87 exhibits] a curious straight ray. . . apparently connected with the nucleus by a thin line of matter”.

$\Longrightarrow$ M87 contains an optical jet

1954: W. Baade and R. Minkowski

W. Baade (Mt. Wilson Obs.)

IDENTIFICATION OF THE RADIO SOURCES IN CASSIOPEIA, CYGNUS A, AND PUPPIS A

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MOUNT WILSON AND PALOMAR OBSERVATORIES
CARNEGIE INSTITUTION OF WASHINGTON
CALIFORNIA INSTITUTE OF TECHNOLOGY
Received June 19, 1953

ABSTRACT

The radio sources in Cassiopeia and Puppis A are identified with a new type of galactic emission nebulosity. The outstanding features of these nebulosities are very large internal random velocities. The radio source Cygnus A is an extragalactic object, two galaxies in actual collision.

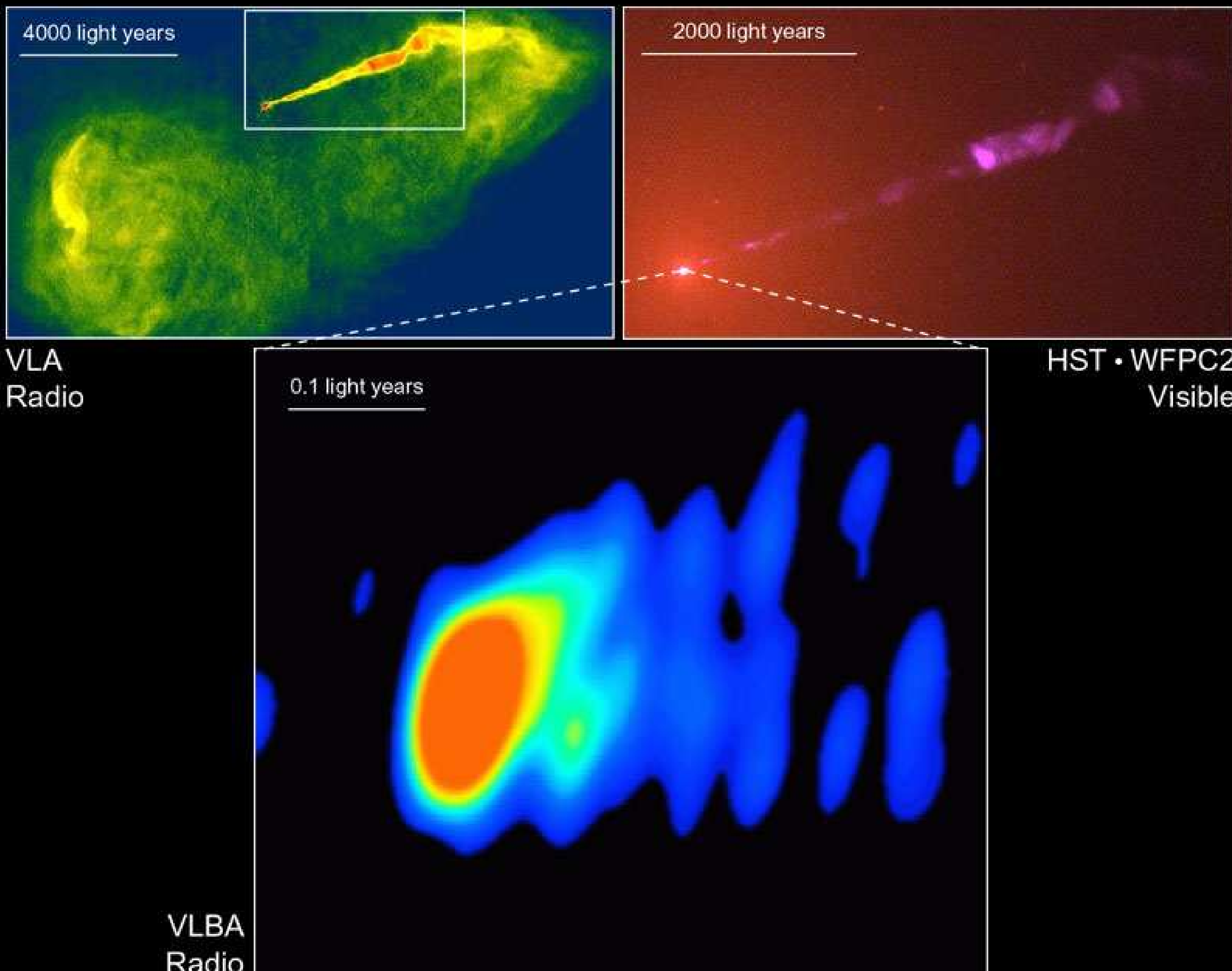
Only very few individual sources of cosmic radio emission have been identified with conspicuous astronomical objects.[1] Although the sources in Cassiopeia[2] and Cygnus A[3]

(Baade & Minkowski, 1954)

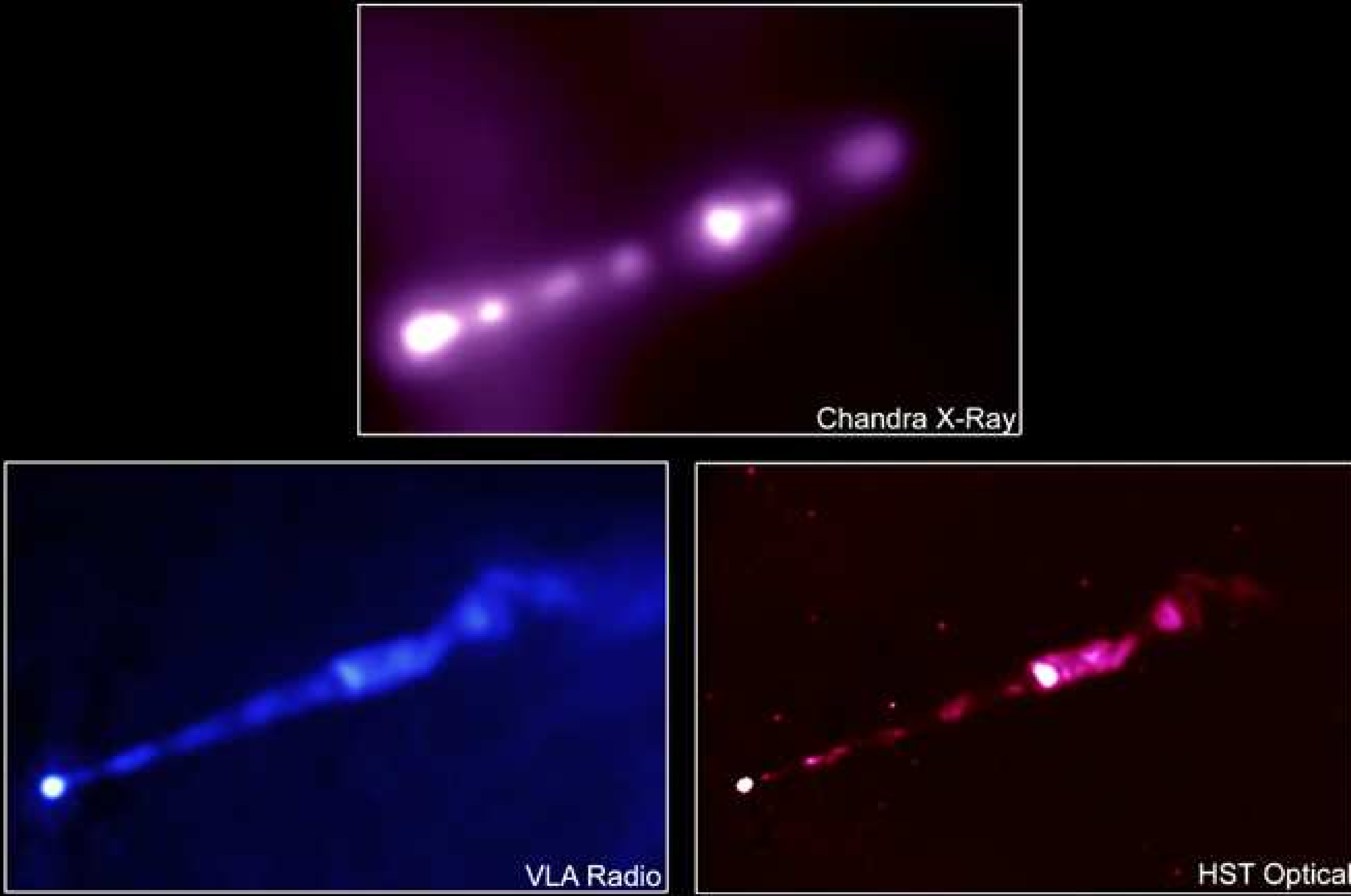
1954: Walter Baade and Rudolph Minkowski: optical counterparts to radio sources Cyg A (NGC 5128), Vir A (M87), Per A (NGC 1275).

Cyg A: First ultra-luminous AGN (2nd brightest radio source in the sky; $L \sim 10^{45}\,\mathrm{erg\,s^{-1}}$).

Galaxy M87

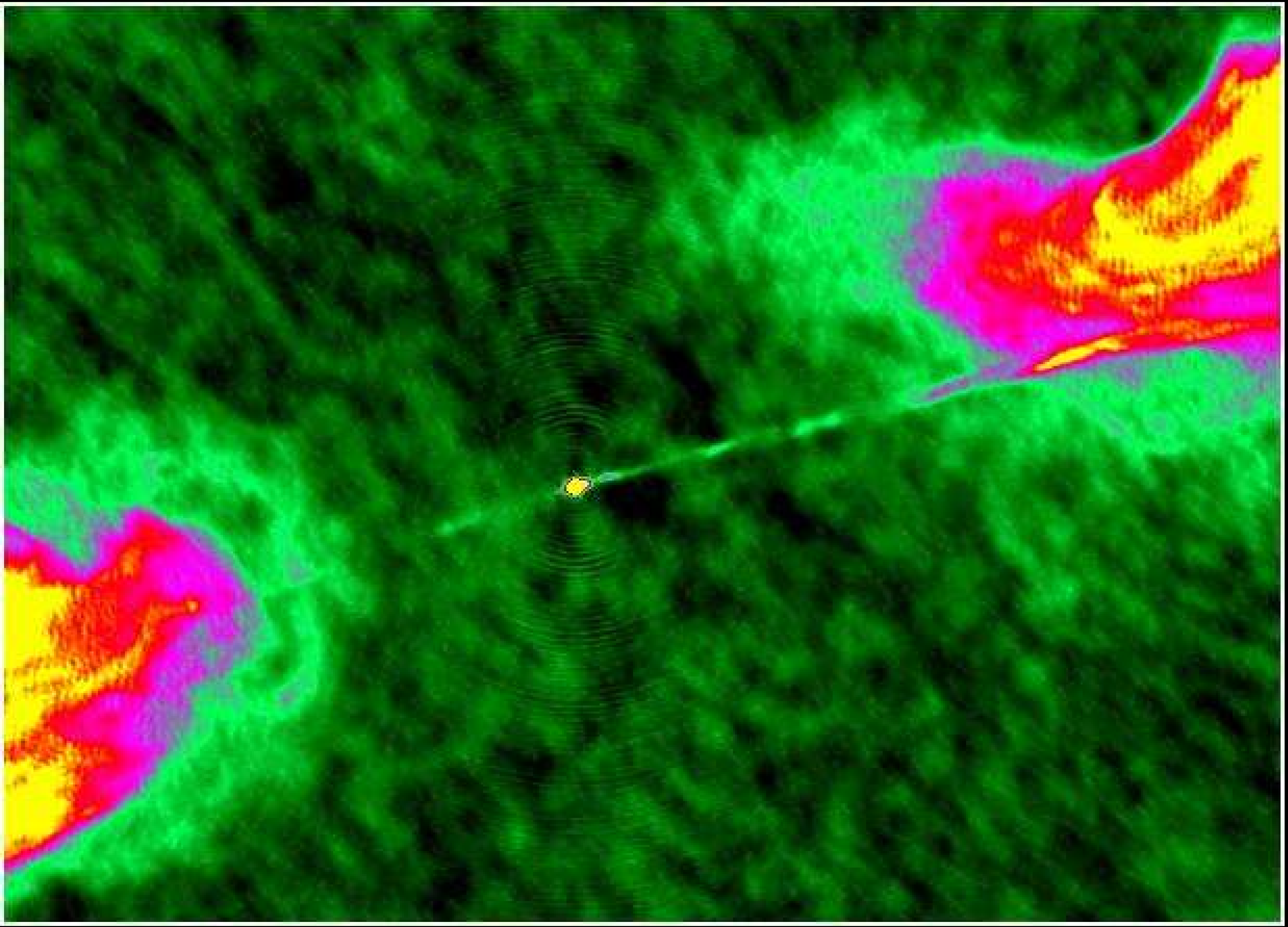


NASA, NRAO and J. Biretta (STScI) • STScI-PRC99-43

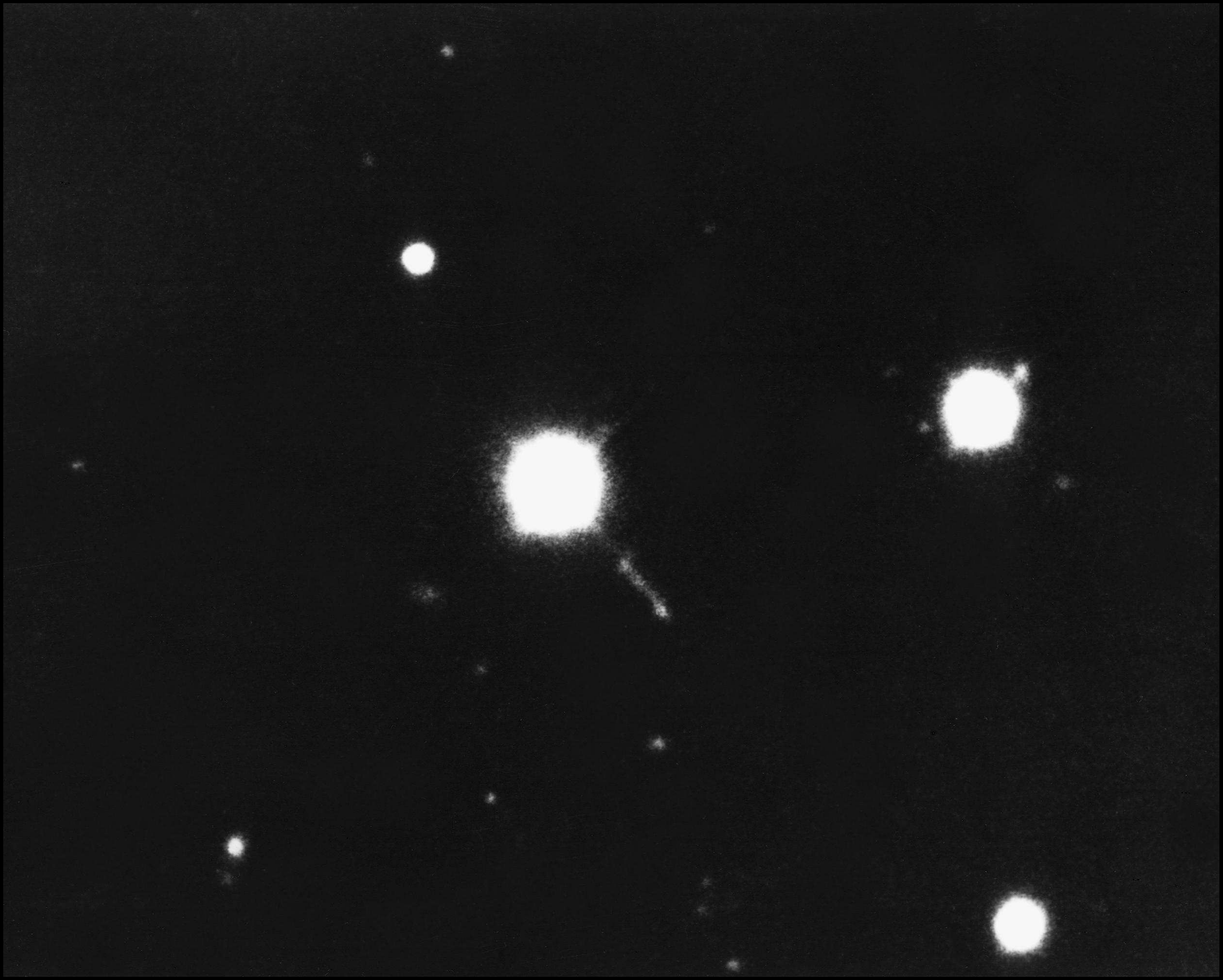


X-ray: NASA/CXC/MIT/H.Marshall et al. Radio: F.Zhou, F.Owen (NRAO), J.Biretta (STScI)
Optical: NASA/STScI/UMBC/E.Perlman et al.

Jets are visible in all wavebands

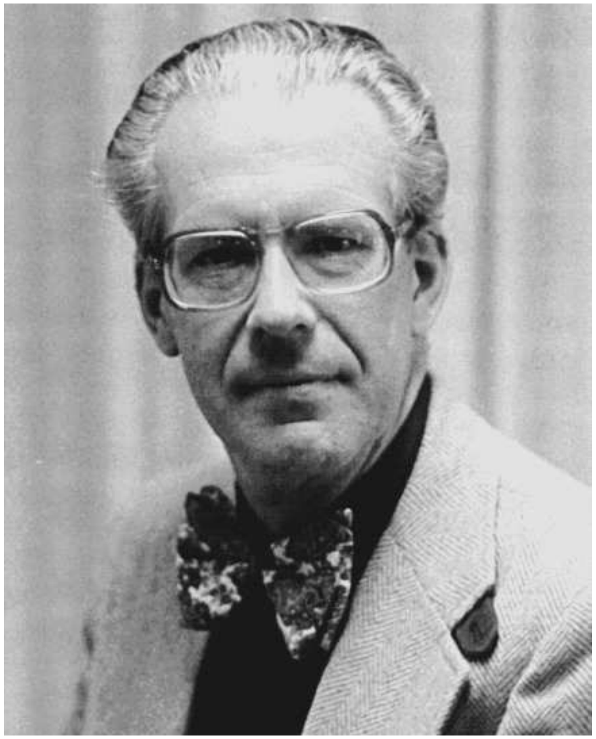


Cyg A in radio ($\lambda = 6\,$cm, VLA, Perley, Dreher & Cowan 1984)

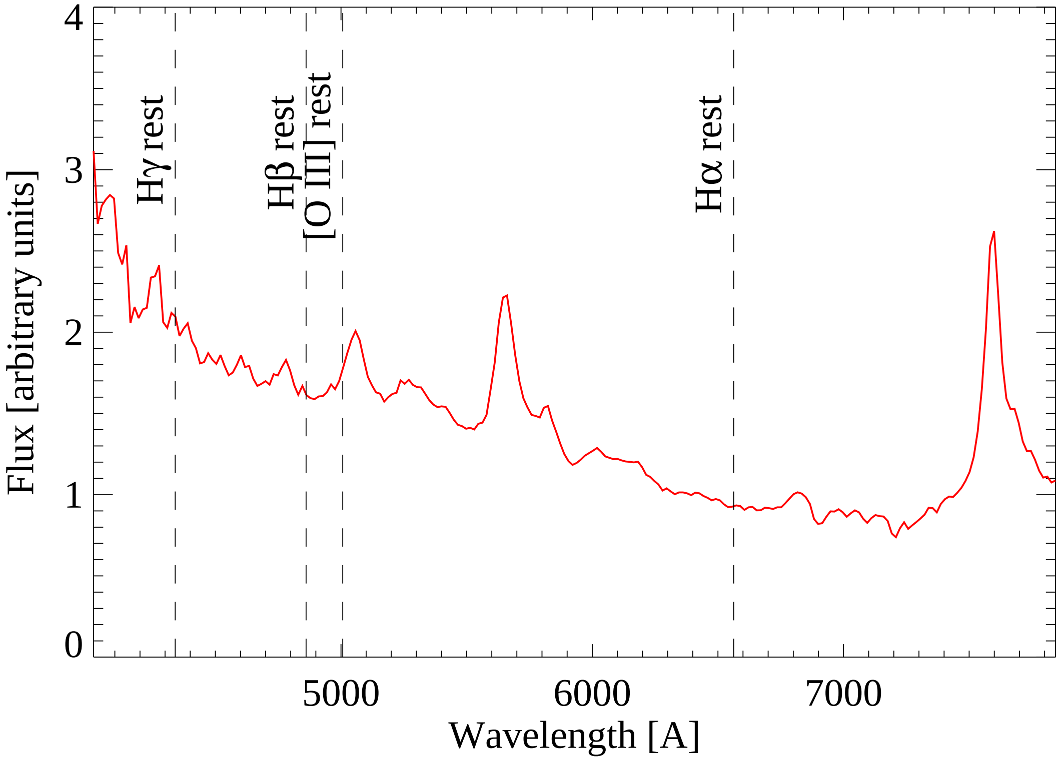


3C273 (4 m Myall telescope, NOAO/AURA/NSF)

Schmidt 1963

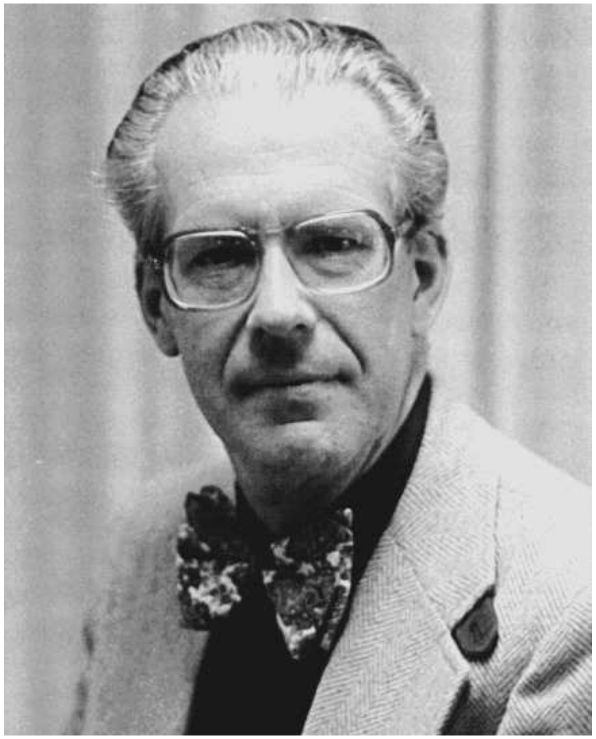


M. Schmidt (Caltech)

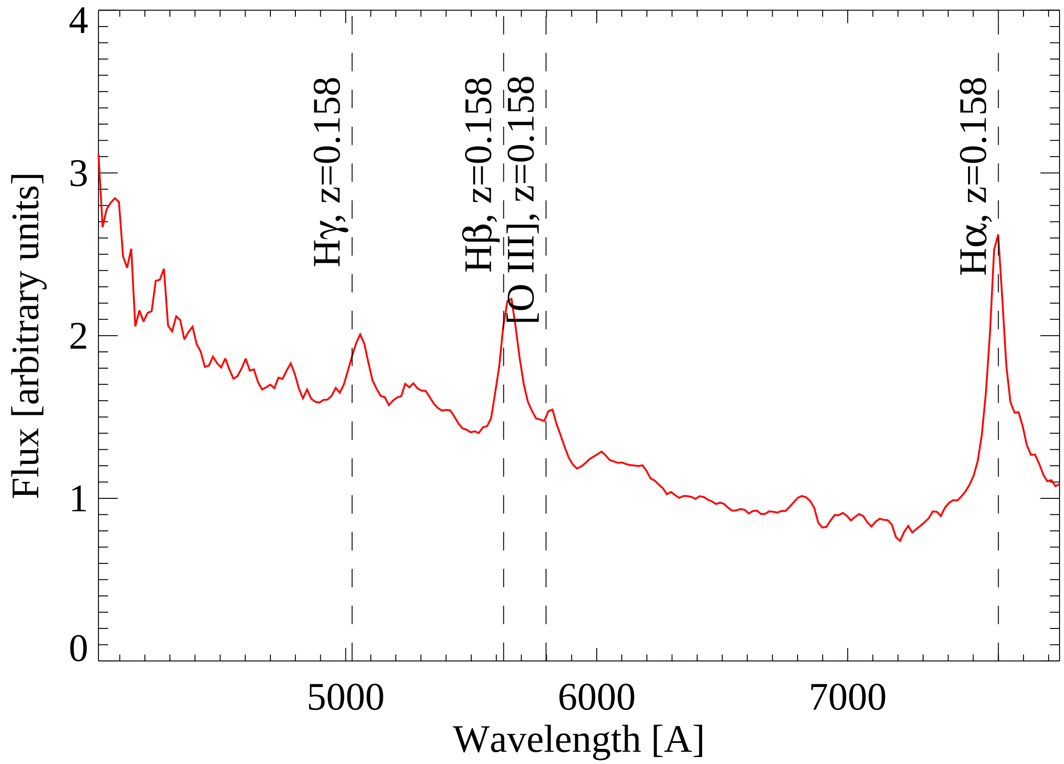


3C273 (Rondi et al., Pic du Midi)

Schmidt 1963



M. Schmidt (Caltech)

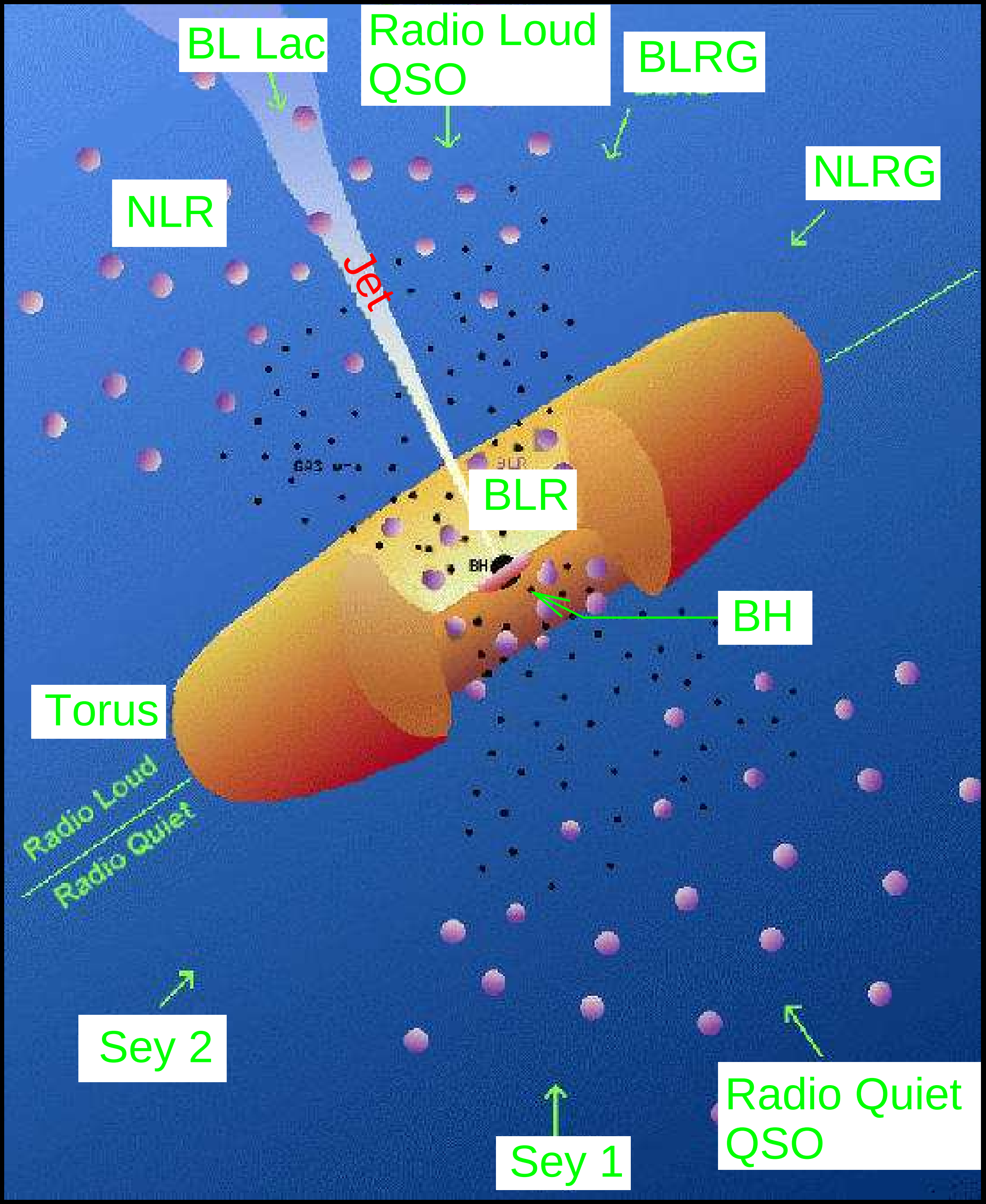


3C273 (Rondi et al., Pic du Midi)

1963: Maarten Schmidt: 3C273 has $z = 0.158 \Longrightarrow$ AGN are far away!

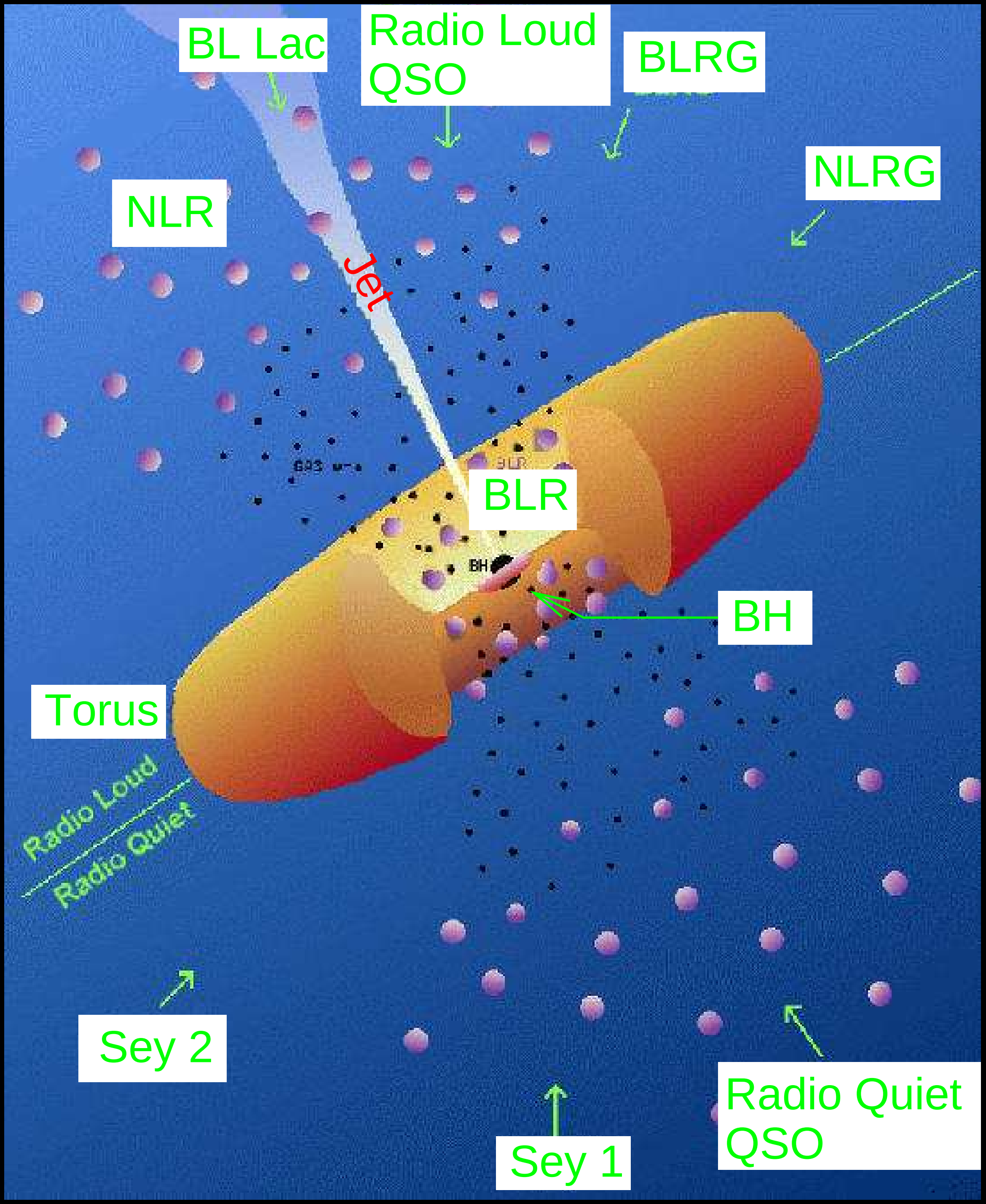
shortly later: 1963: J. Greenstein and Th. Matthews: 3C48 has $z = 0.368$

Nomenclature: Quasar/QSO (from “quasi stellar radio source”: radio emitting AGN)



Unified Model: All AGN types are due to the same physics, different phenomenology just due to different viewing angle.

(Urry & Padovani, 1995, NOTE: logarithmic length scale!)



Physical properties of components:

Accretion disk: $r \sim 10^{-3}$ pc,

$n \sim 10^{15}$ cm^{-3},

$kT \sim 50$ eV $\cdot\, r^{-3/4}$,

$v \sim 0.3c$ at inner edge.

Broad Line Region (BLR):

$r \sim$ 0.01–0.1 pc (=light days),

$n \sim 10^{10}$ cm^{-3},

$v \sim$ 1000–5000 km s^{-1},

$T \sim 10^4$ K

Torus: $r \sim$ 1– few 10 pc,

$n \sim 10^3$–10^6 cm^{-3},

T: cold

Narrow Line Region (NLR):

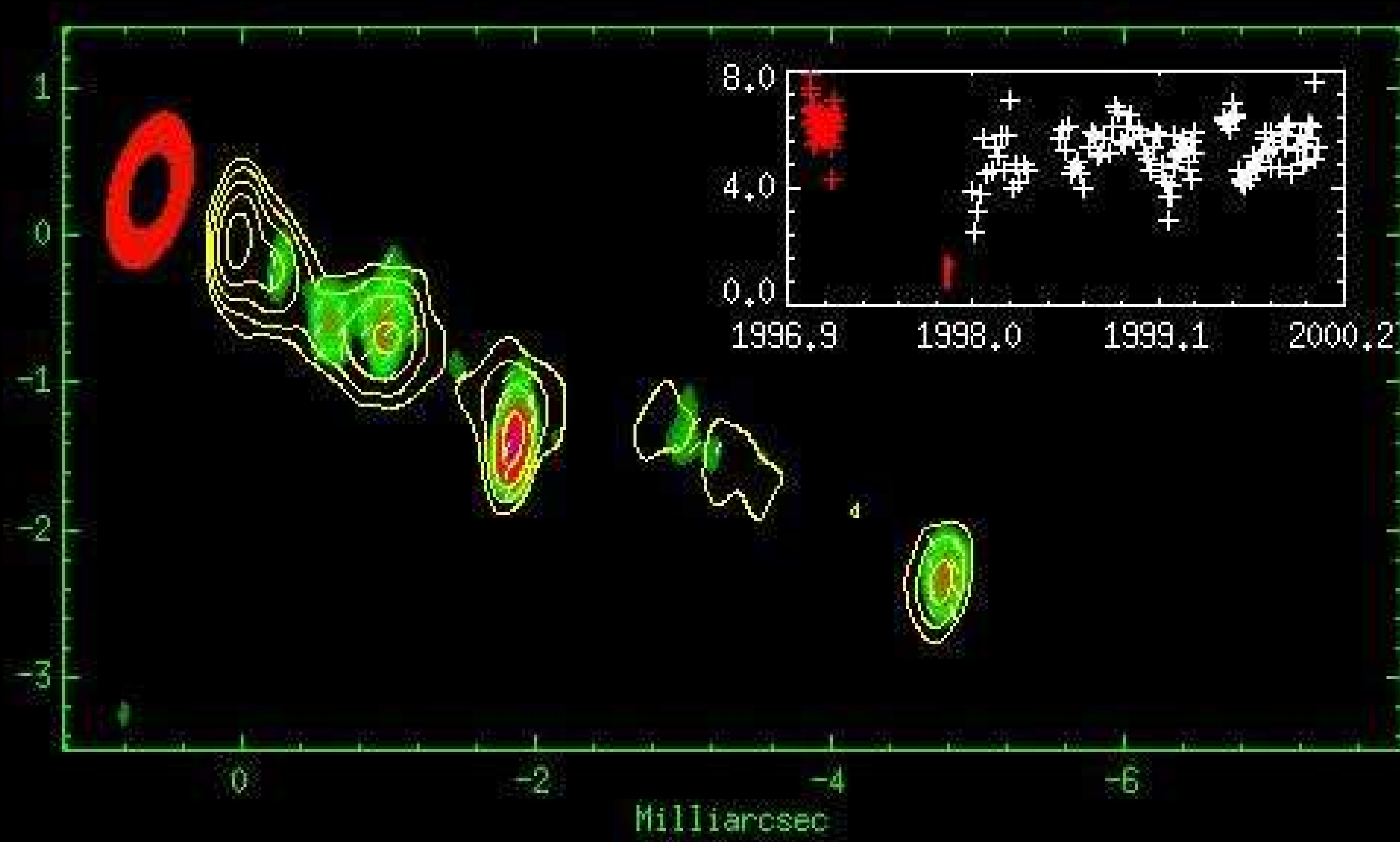
$r \sim$ 100–1000 pc,

$n \sim 10^3$–10^6 cm^{-3},

$v \sim$ few $\cdot$ 100 km s^{-1},

$T \sim 10^4$ K

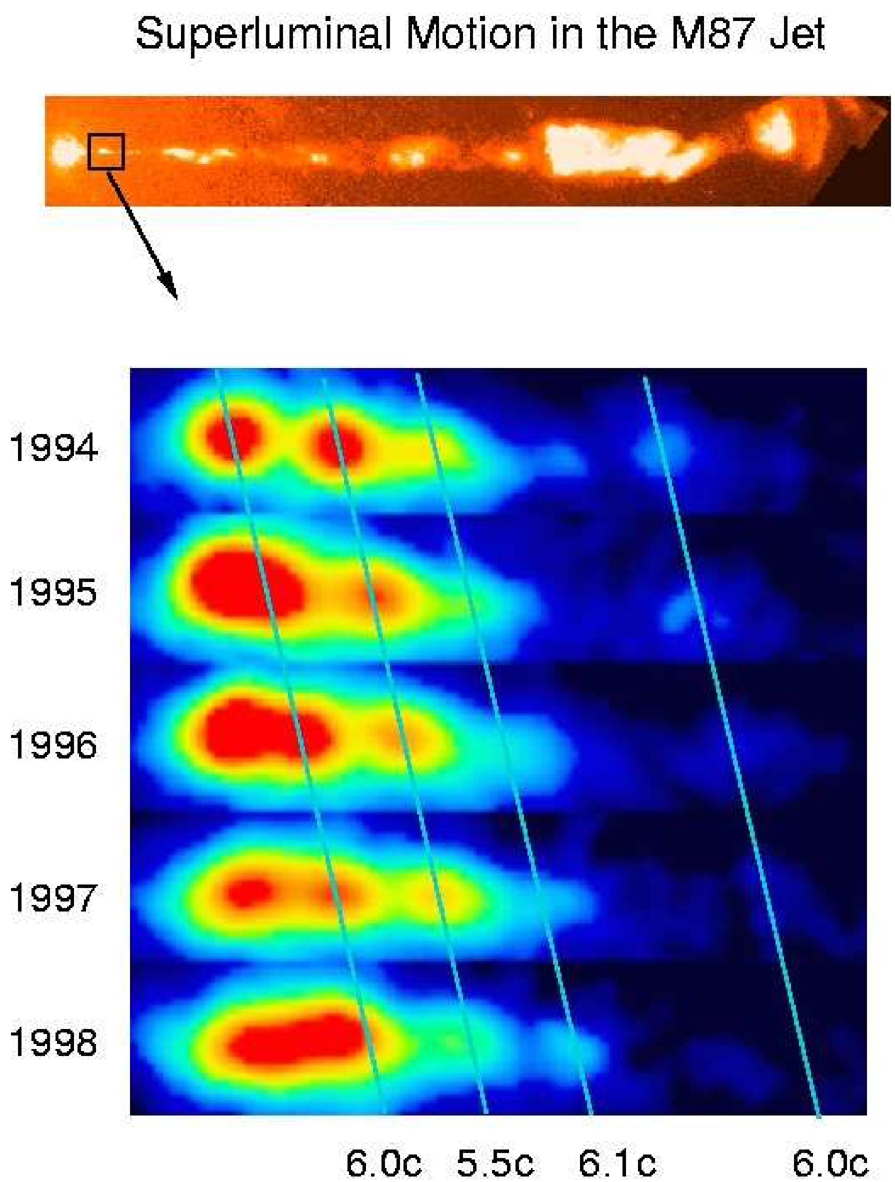
See, e.g., Antonucci (1993) for a review.



Jet motion in 3C120 (Marscher et al., 2002)

3C120: Sy 1, $M_{\rm BH} = 3 \times 10^7\, M_\odot$ from reverberation mapping

Superluminal Motion



3C120: Apparent speed of jet: $\sim 5c$

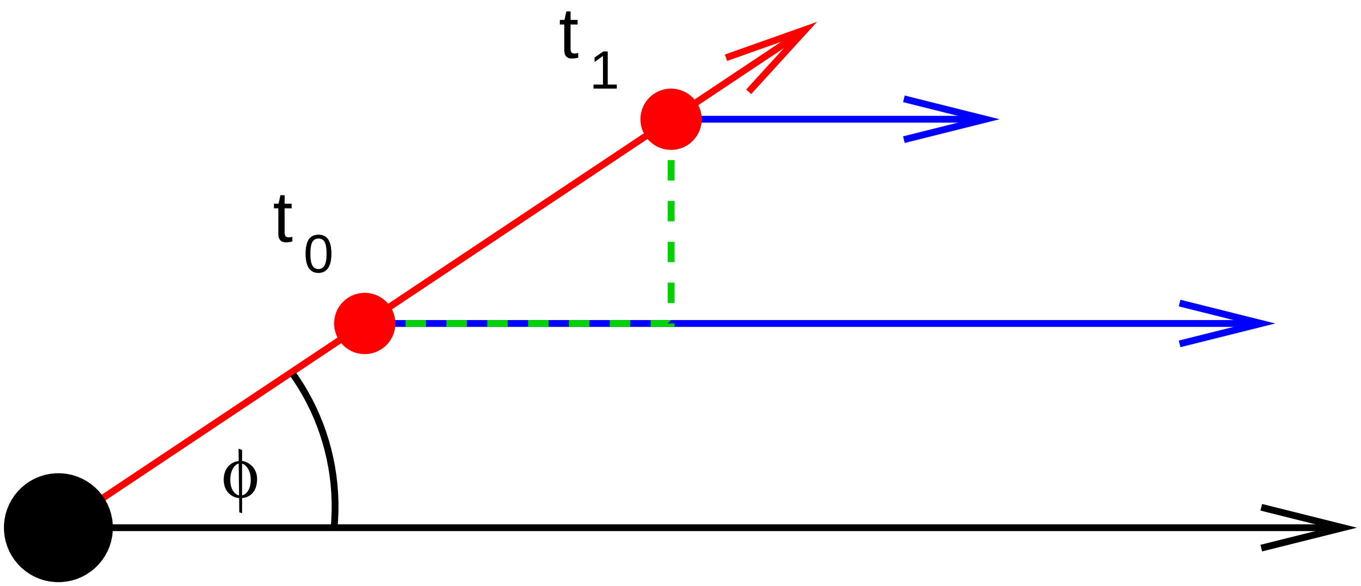
M87: Apparent speed of jet: $\sim 6c$

Superluminal motion: The apparent velocities measured in many AGN jets are $v > c$.

First discovered in 1971 in 3C273.

Biretta/STScI

Superluminal Motion



Consider blob moving towards us with speed v and angle ϕ with respect to line of sight, emitting light signals at t_0 and $t_1 = t_0 + \Delta t_e$

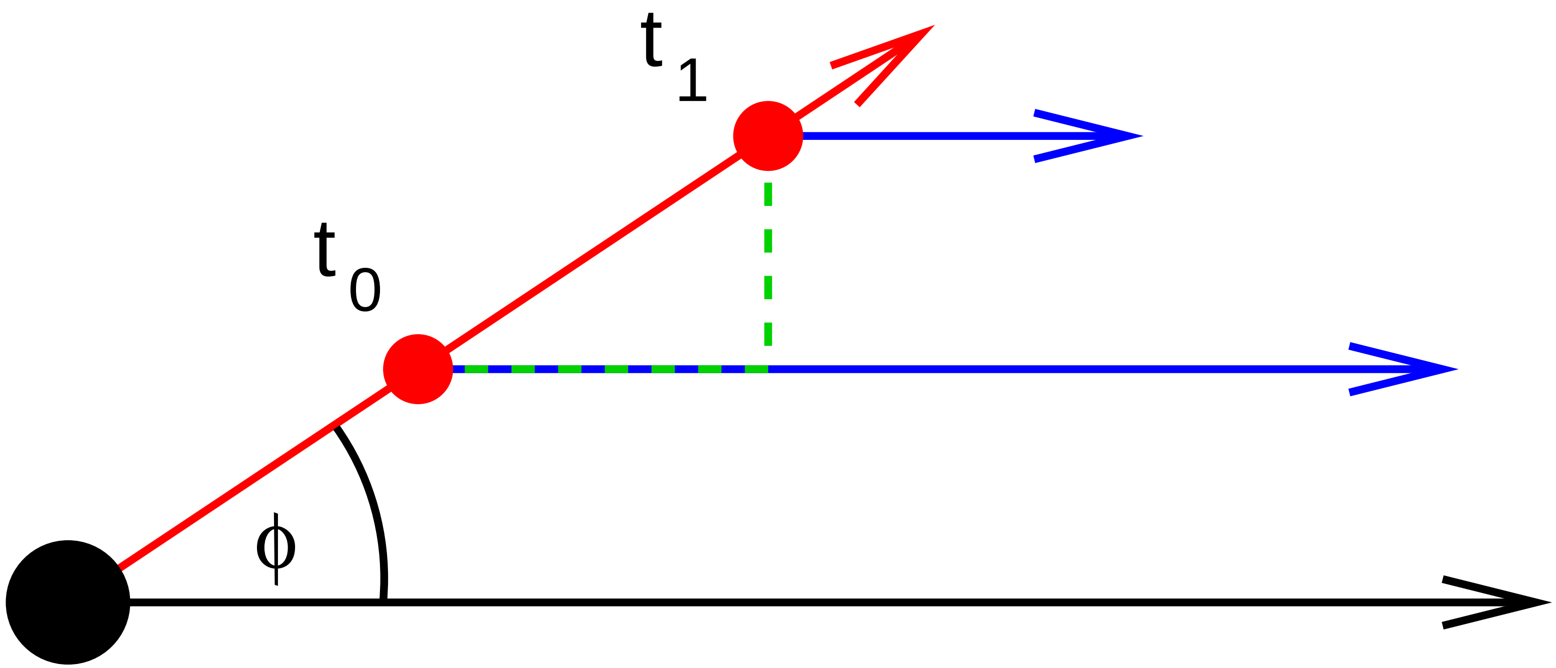
Light travel time: Observer sees signals separated by

$$\Delta t_o = \Delta t_e - \Delta t_e \frac{v}{c}\cos\phi = \left(1 - \frac{v}{c}\cos\phi\right)\Delta t_e \quad (8.1)$$

Observed distance traveled in plane of sky:

$$\Delta\ell_\perp = v\Delta t_e \sin\phi \quad (8.2)$$

Superluminal Motion

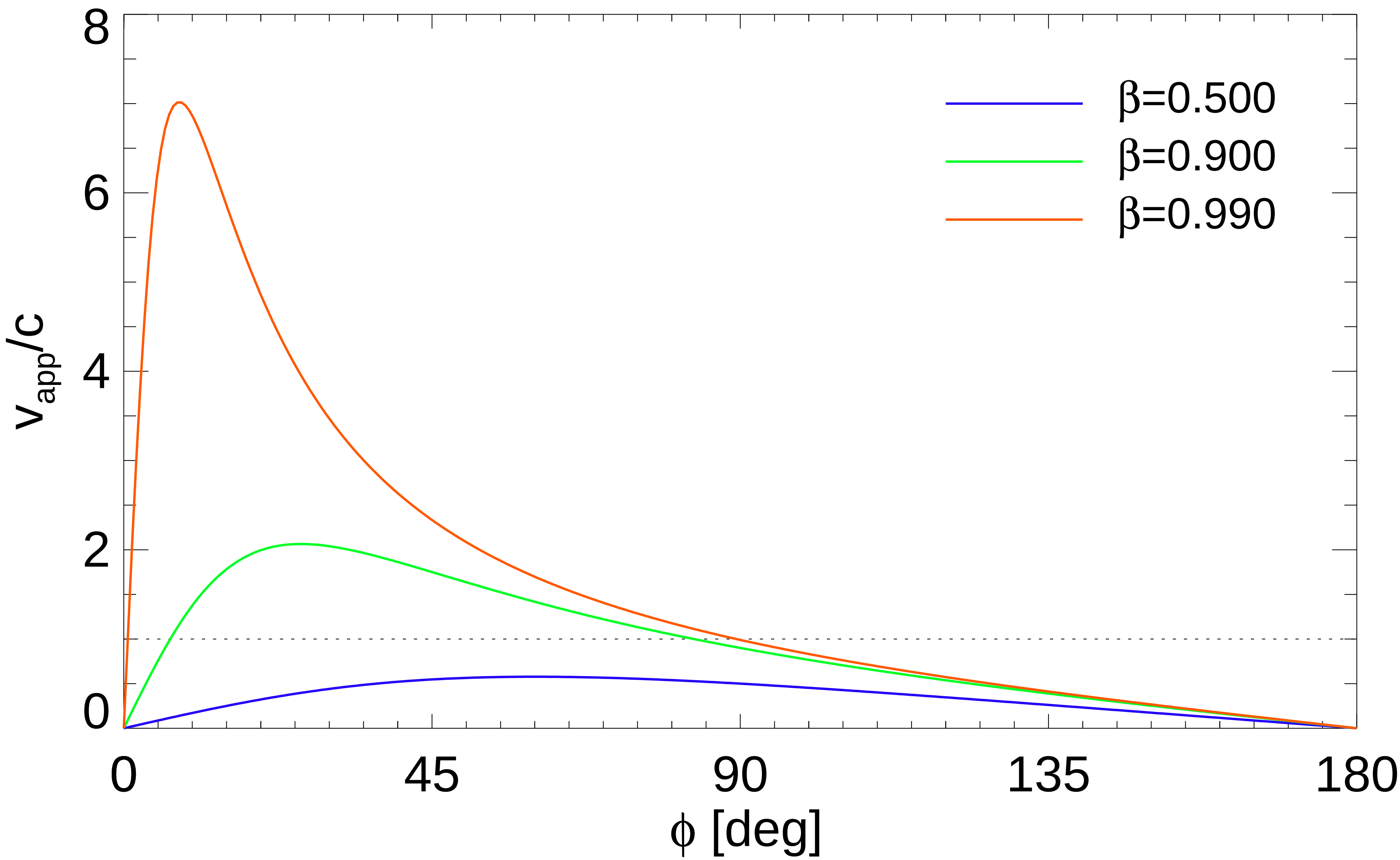


Apparent velocity deduced from observations:

$$v_{\mathrm{app}} = \frac{\Delta \ell_\perp}{\Delta t_{\mathrm{o}}} = \frac{v \Delta t_{\mathrm{e}} \sin\phi}{\left(1 - \frac{v}{c}\cos\phi\right)\Delta t_{\mathrm{e}}} = \frac{v\sin\phi}{\left(1-\frac{v}{c}\cos\phi\right)} \quad (8.3)$$

$\Longrightarrow$ For v/c large and ϕ small: $v_{\mathrm{app}} > c$

Superluminal Motion



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Cosmology