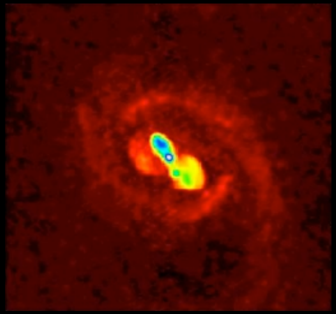
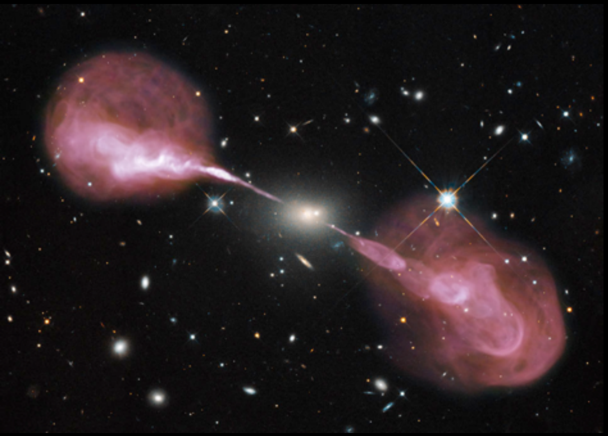
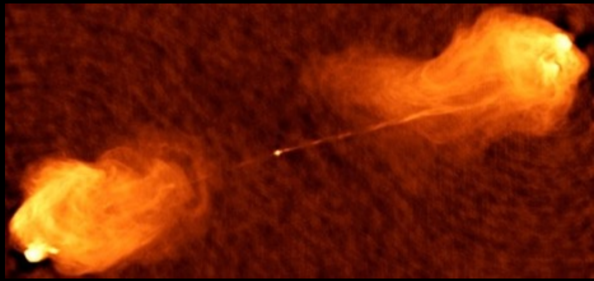
The Fanaroff-Riley Dichotomy in AGN Jets and their Emission-line Regions

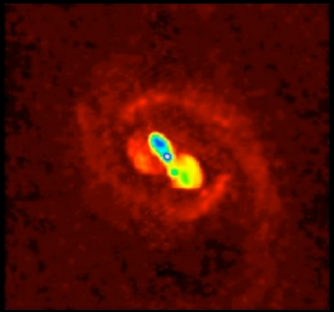


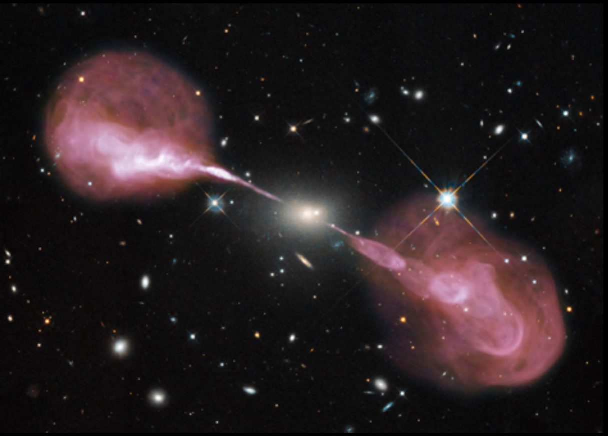
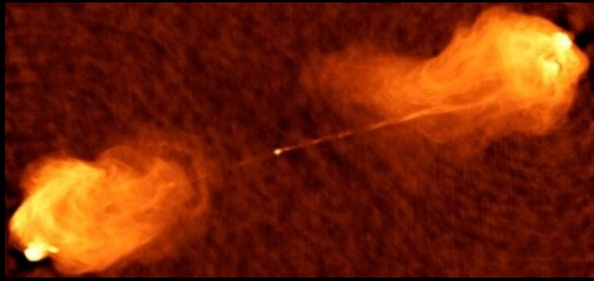


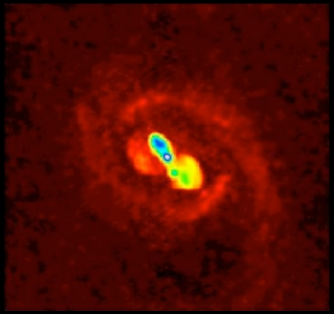
Prajval Shastri

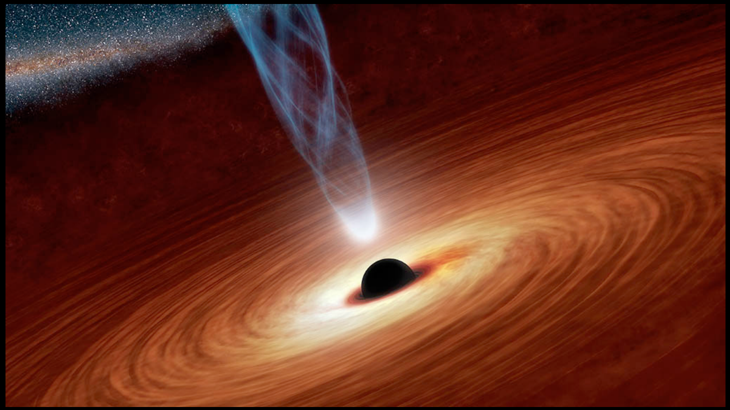
Indian Institute of Astrophysics, Bangalore

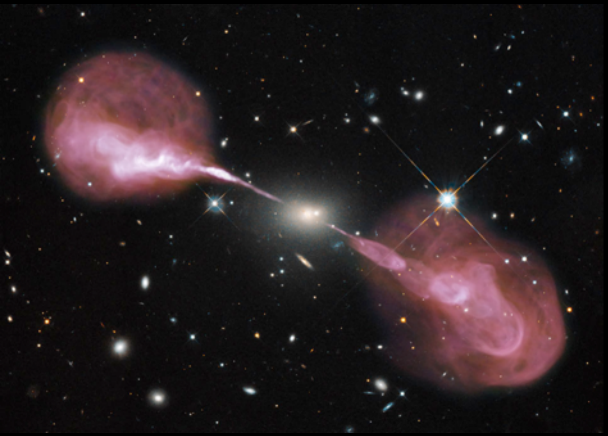


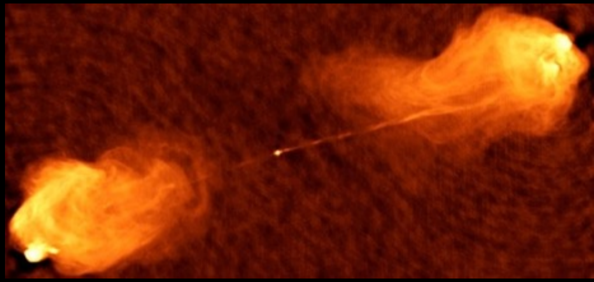




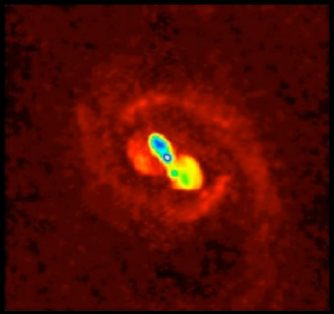


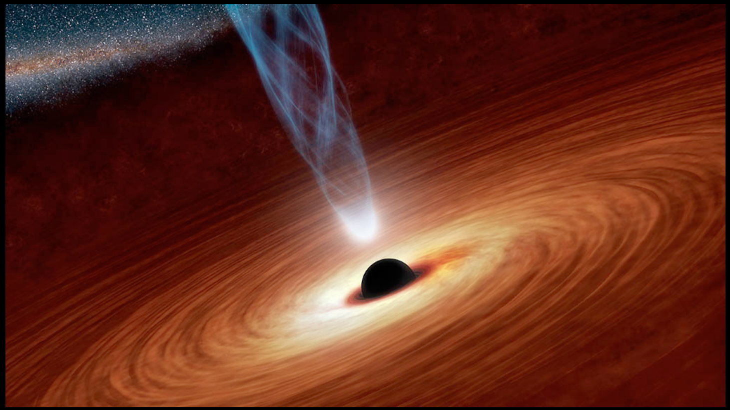


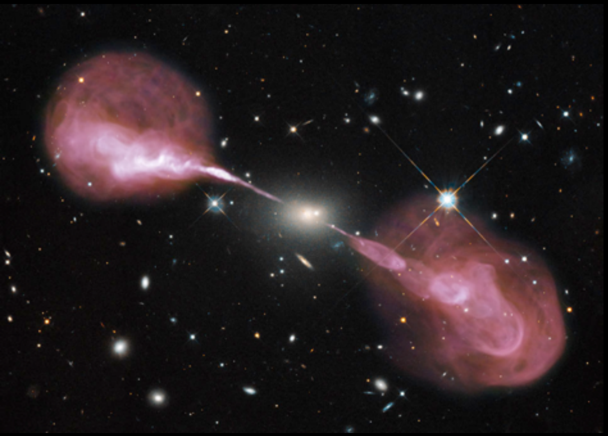


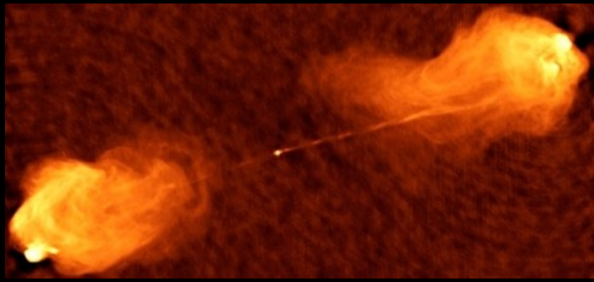
Supermassive ≡ *mass* > 10^6 M_{sun}

Accreting Supermassive black holes = Active Galactic Nuclei









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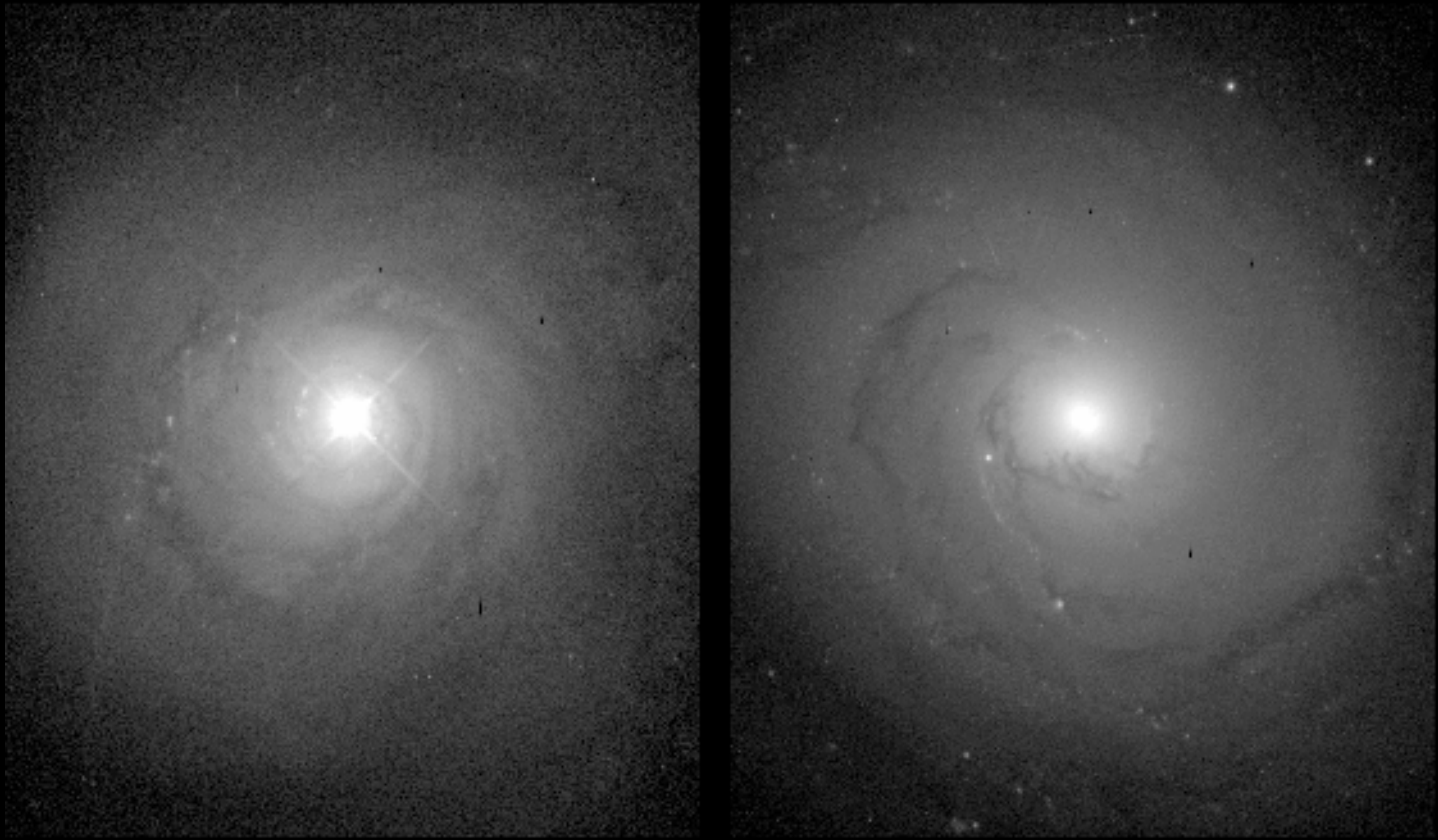
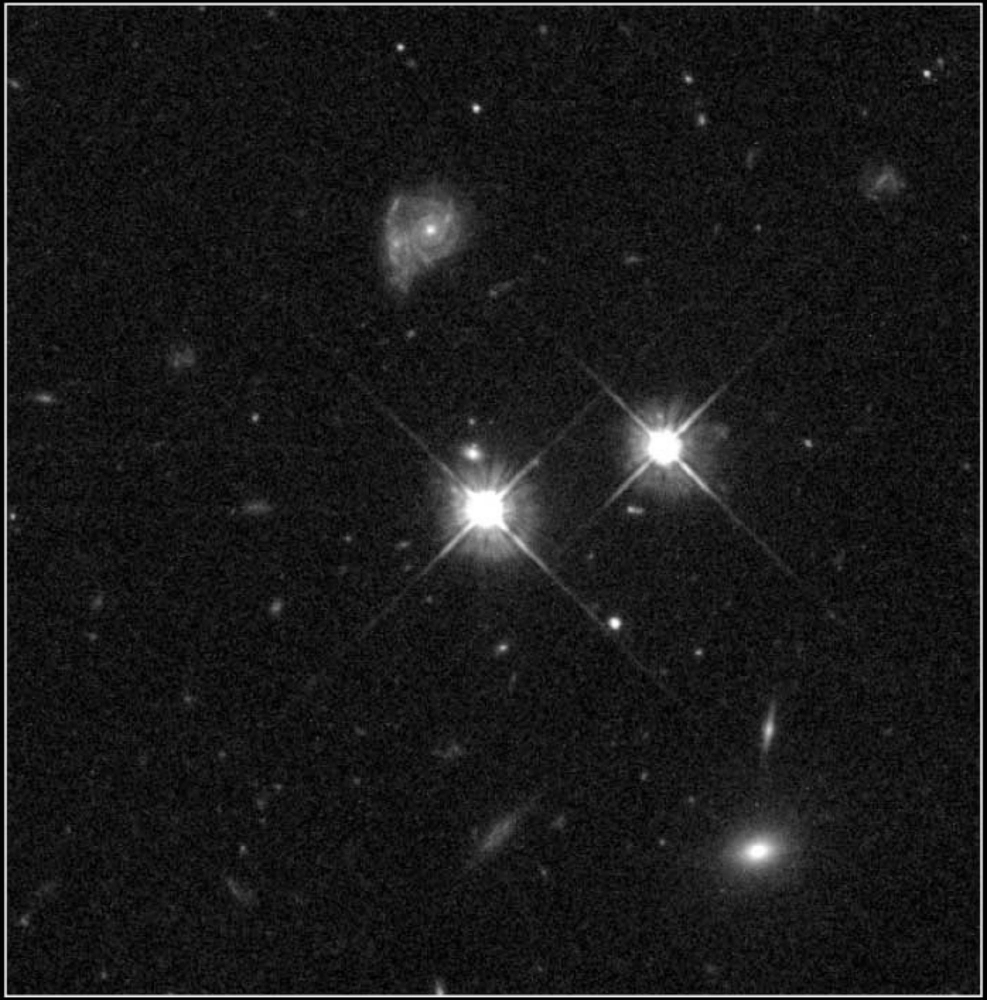


Seyfert Galaxy NGC 5548 versus normal galaxy NGC 3277

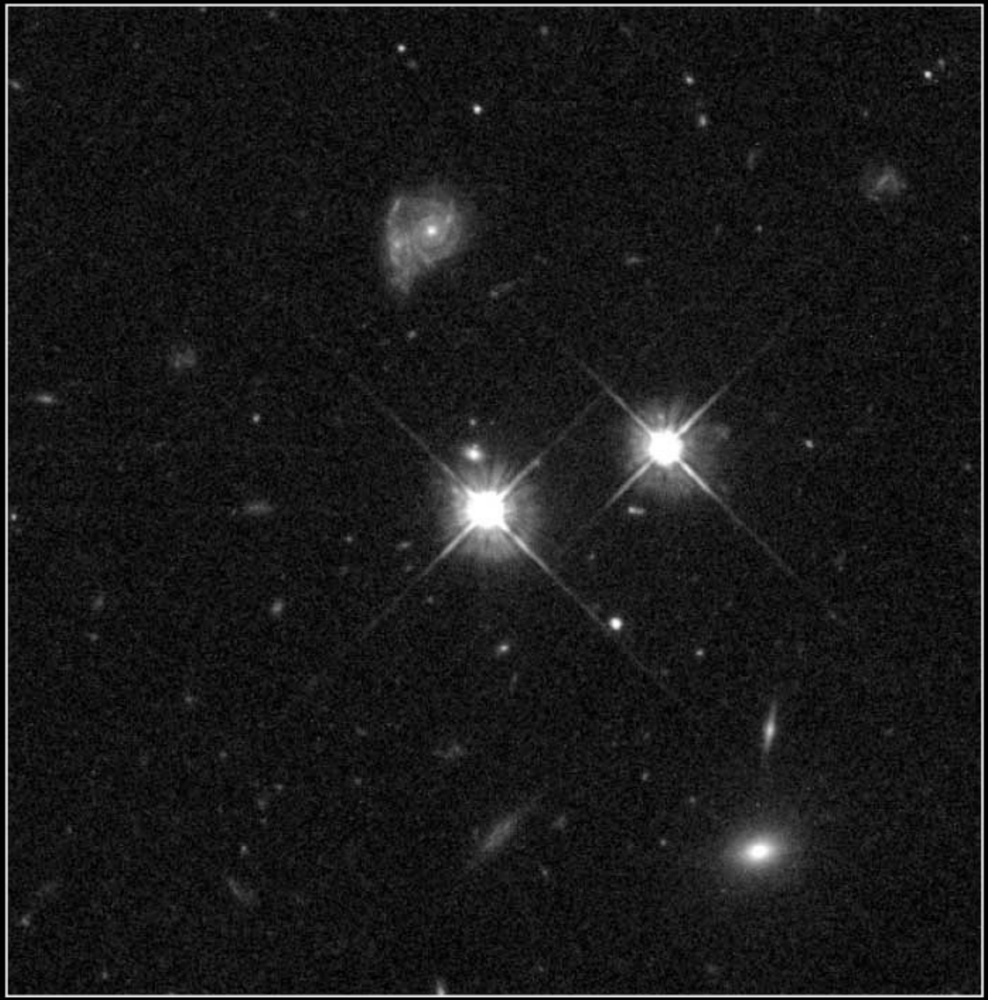
http://www.astr.ua.edu

Seyfert Galaxy NGC 5548 (left) versus normal galaxy NGC 3277 (Right): Notice the diffraction spikes in the NGC5548 image from the brightt point source that is the AGN



HST's 100,000th Observation HST • WFPC2

PRC96-25 · ST ScI OPO · July 10, 1996 · C. Steidel (CalTech), NASA



HST's 100,000th Observation HST • WFPC2

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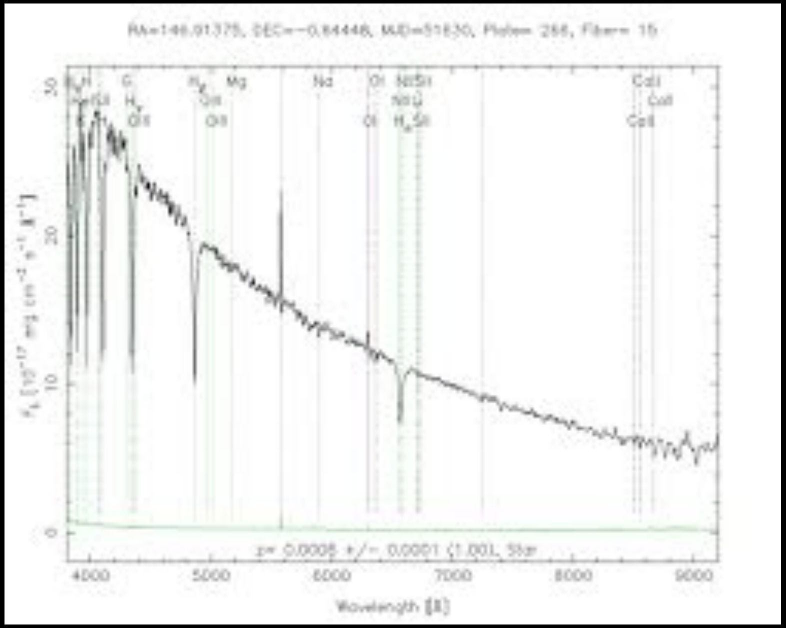

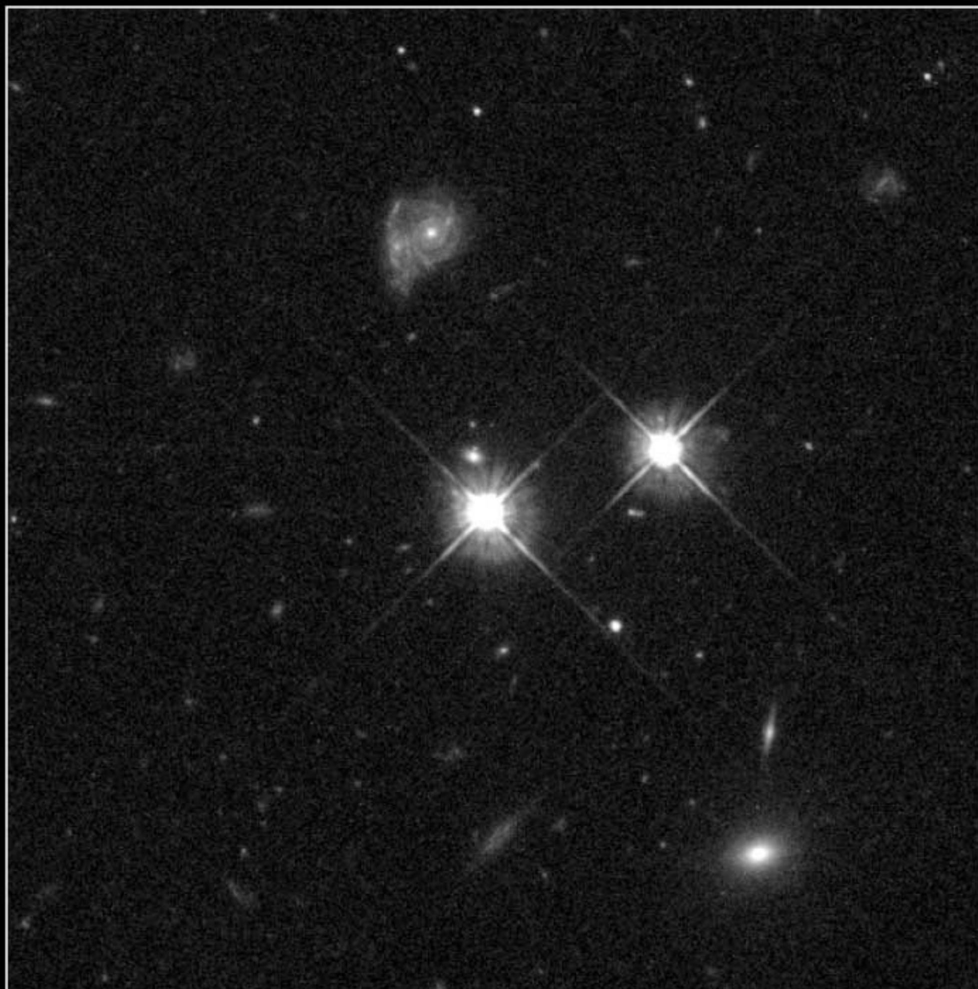

HST's 100,000th Observation HST • WFPC2

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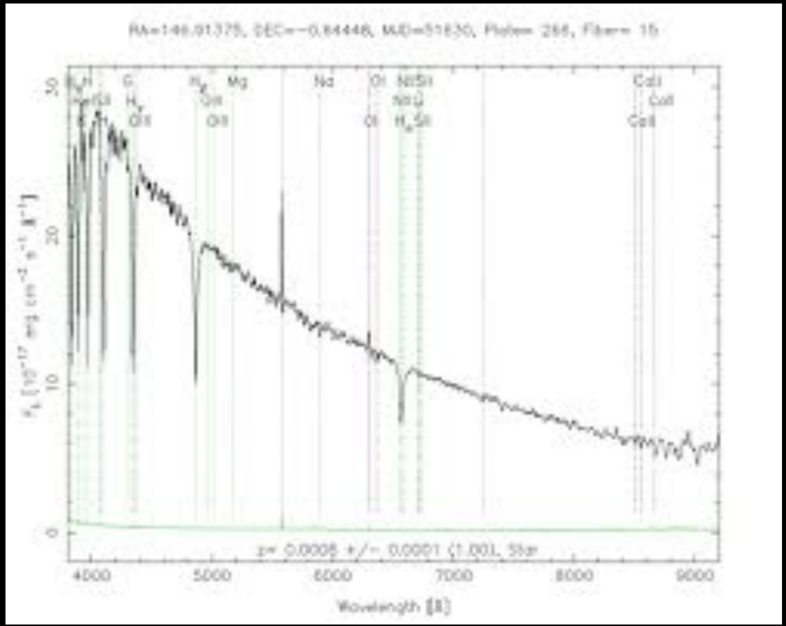


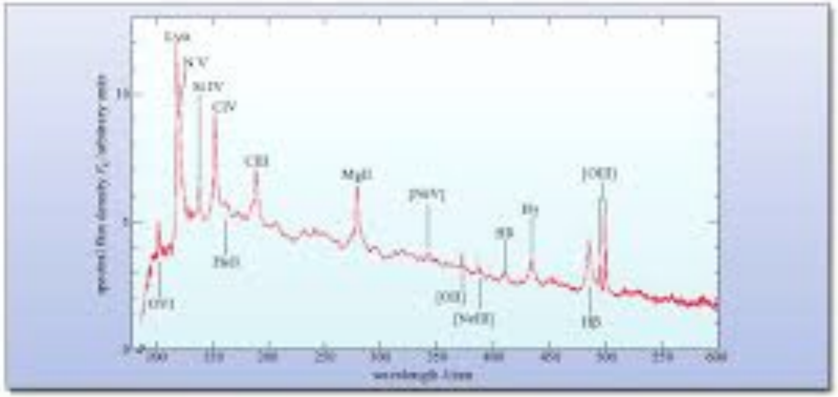
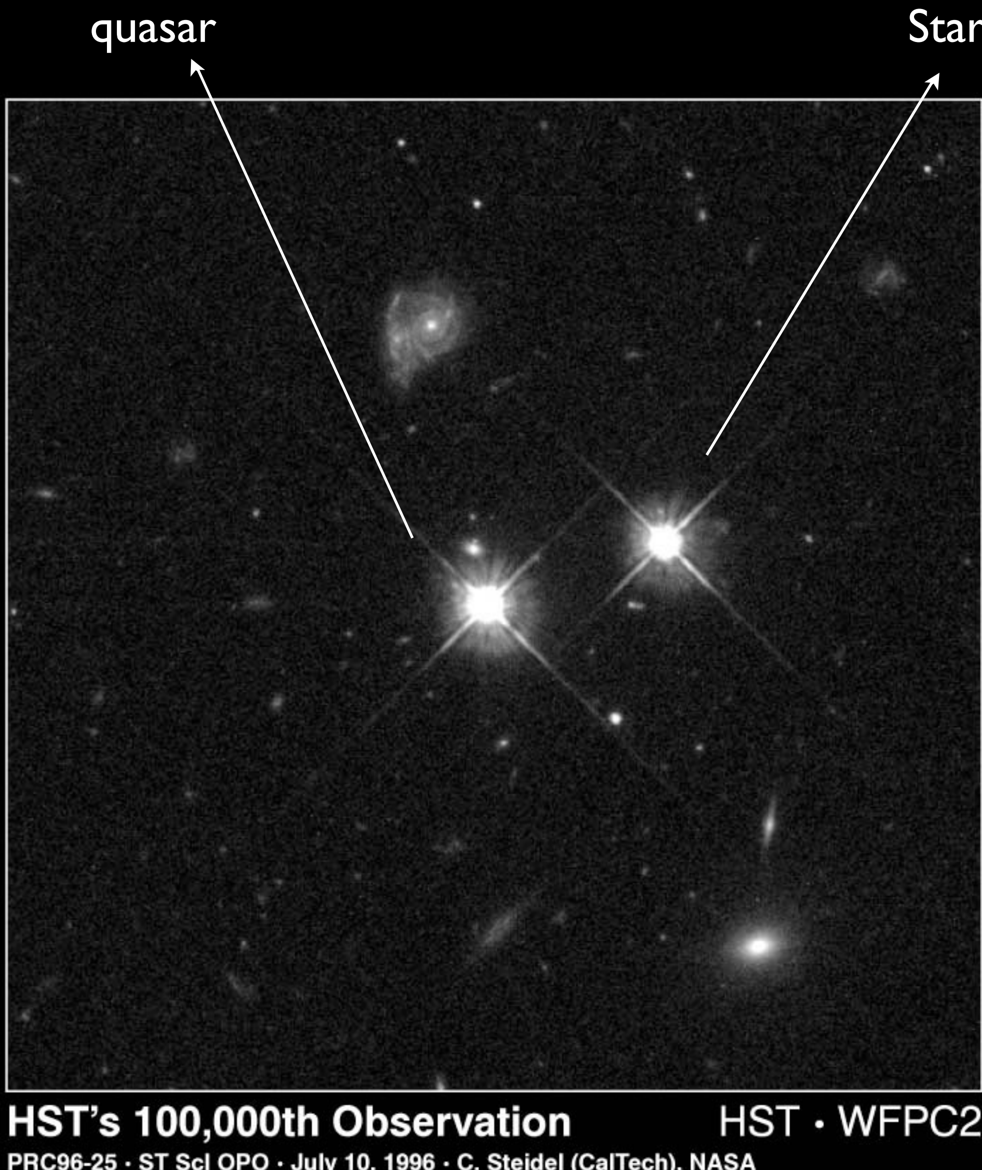
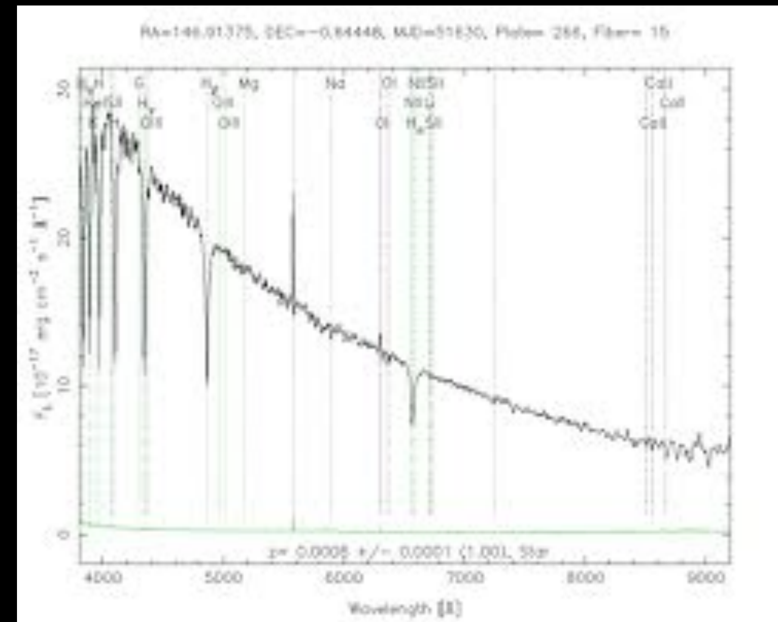


Figure 16: The mean optical spectrum of a sample of more than 700 quasars. The individual spectra were all corrected to remove the effect of red-shift before the spectra were averaged. Note the broad emission lines

An Introduction to Active Galactic Nuclei, Cambridge University Press





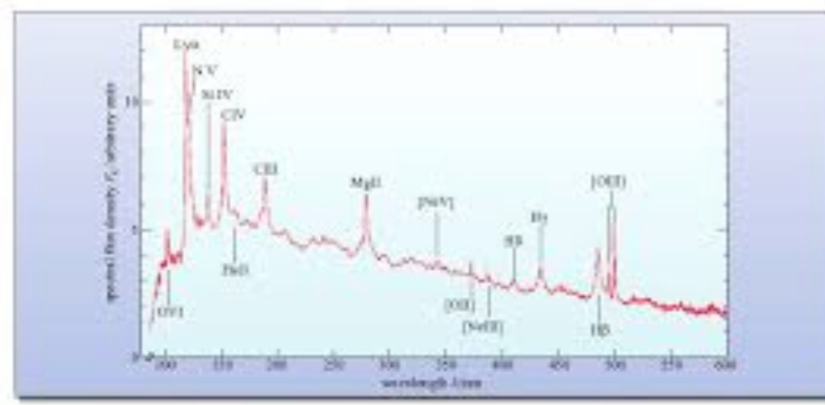


Figure 16: The mean optical spectrum of a sample of more than 700 quasars. The individual spectra were all corrected to remove the effect of red-shift before the spectra were averaged. Note the broad emission lines

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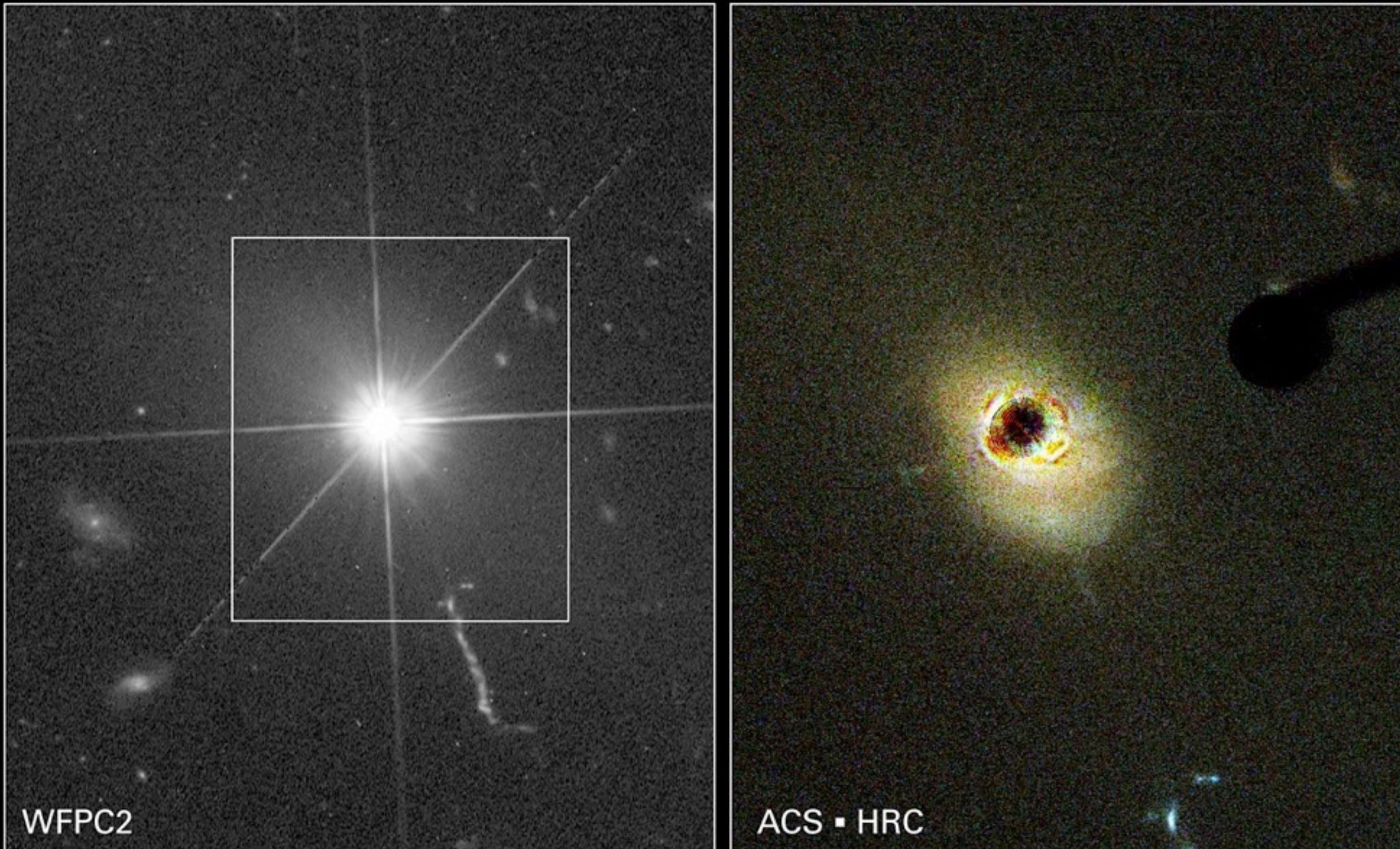


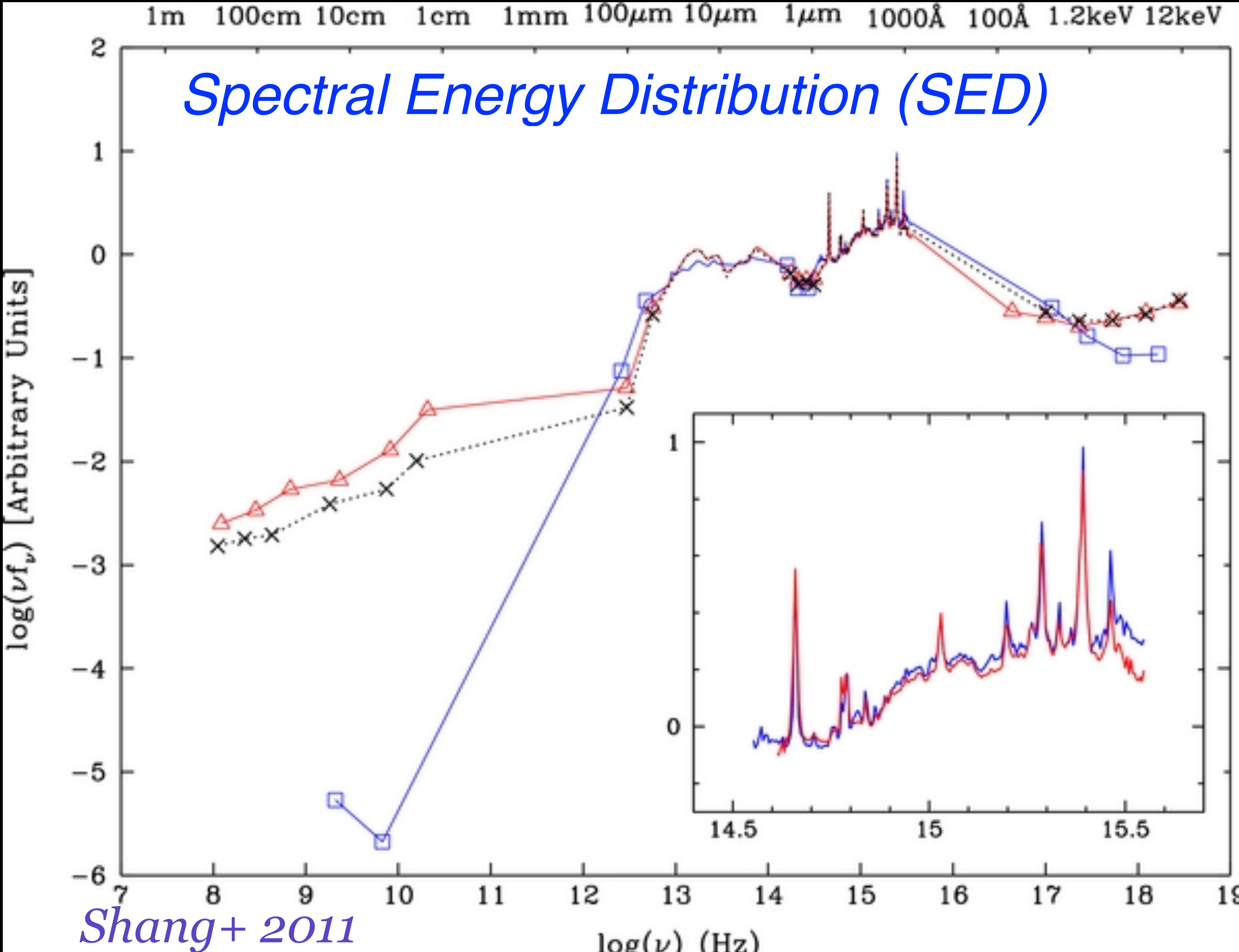
Quasar 3C 273

Hubble Space Telescope ▪ ACS HRC Coronagraph

NASA, A. Martel (JHU), the ACS Science Team, J. Bahcall (IAS) and ESA ▪ STScI-PRC03-03

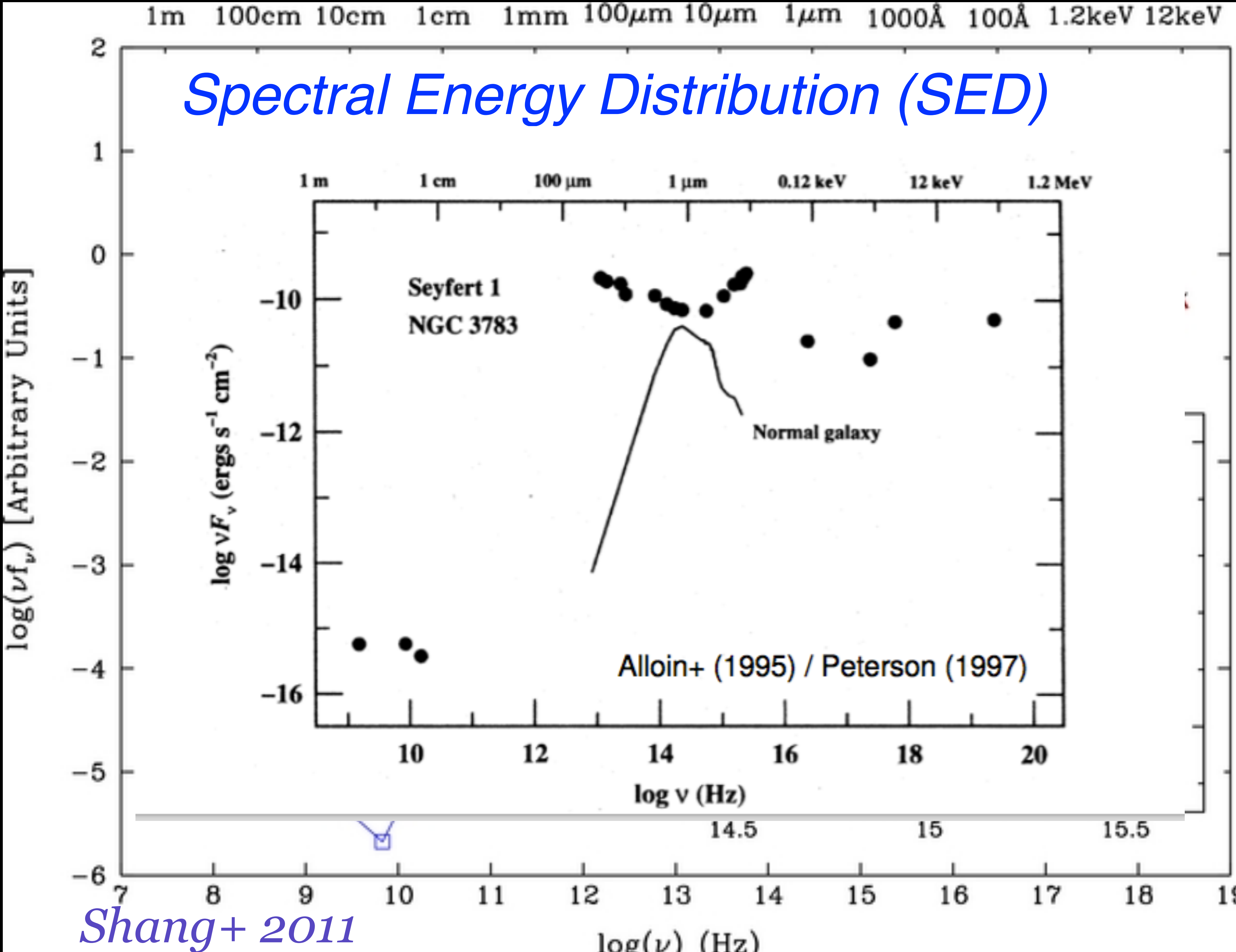
Spectral Energy Distribution (SED)

Spectral Energy Distribution (SED)

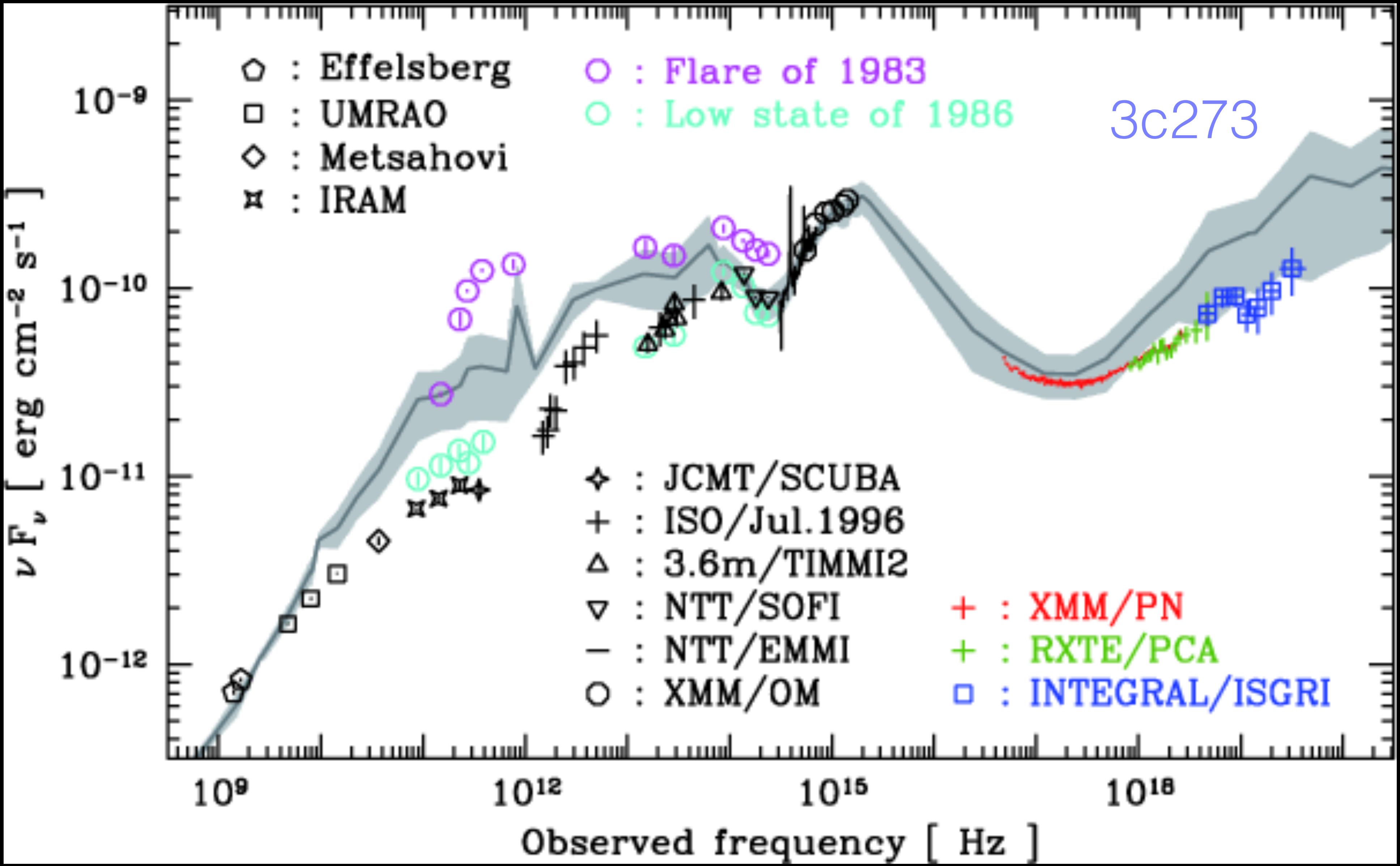


Shang+ 2011

Spectral Energy Distribution (SED)



Shang+ 2011



: Effelsberg
: UMRAO
: Metsahovi
: IRAM
: Flare of 1983
: Low state of 1986
3c273
: JCMT/SCUBA
: ISO/Jul.1996
: 3.6m/TIMMI2
: NTT/SOFI
: NTT/EMMI
: XMM/OM
+ : XMM/PN
+ : RXTE/PCA
: INTEGRAL/ISGRI
νF_ν [erg cm^{-2} s^{-1}]
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{9}
10^{12}
10^{15}
10^{18}
Observed frequency [Hz]

ALMA

October 16, 2013 ·

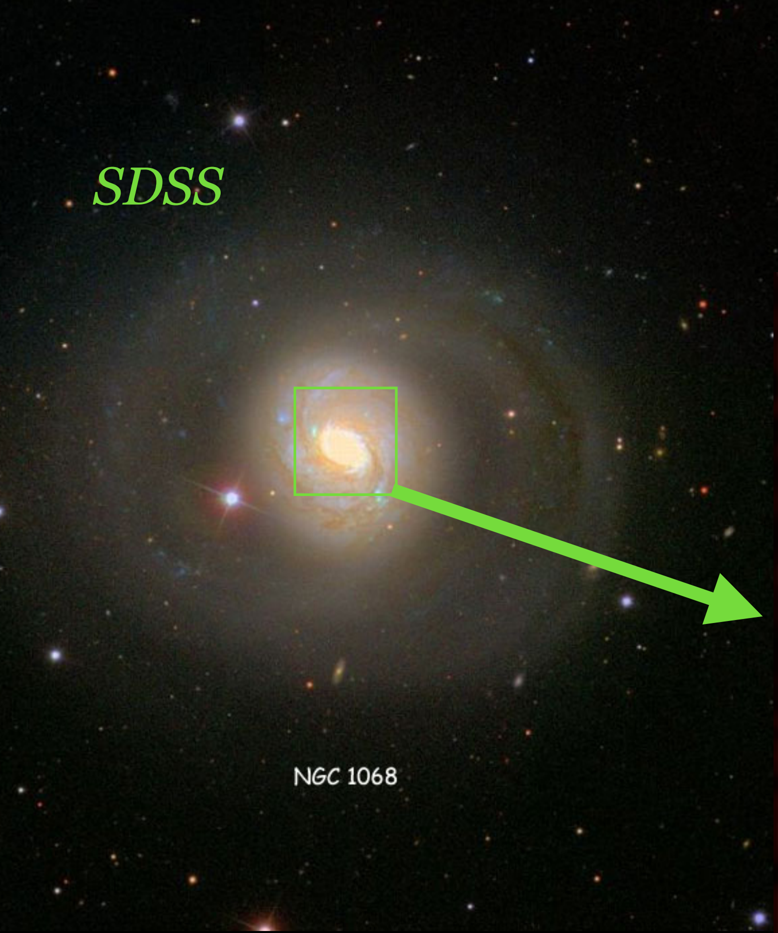
Like Page

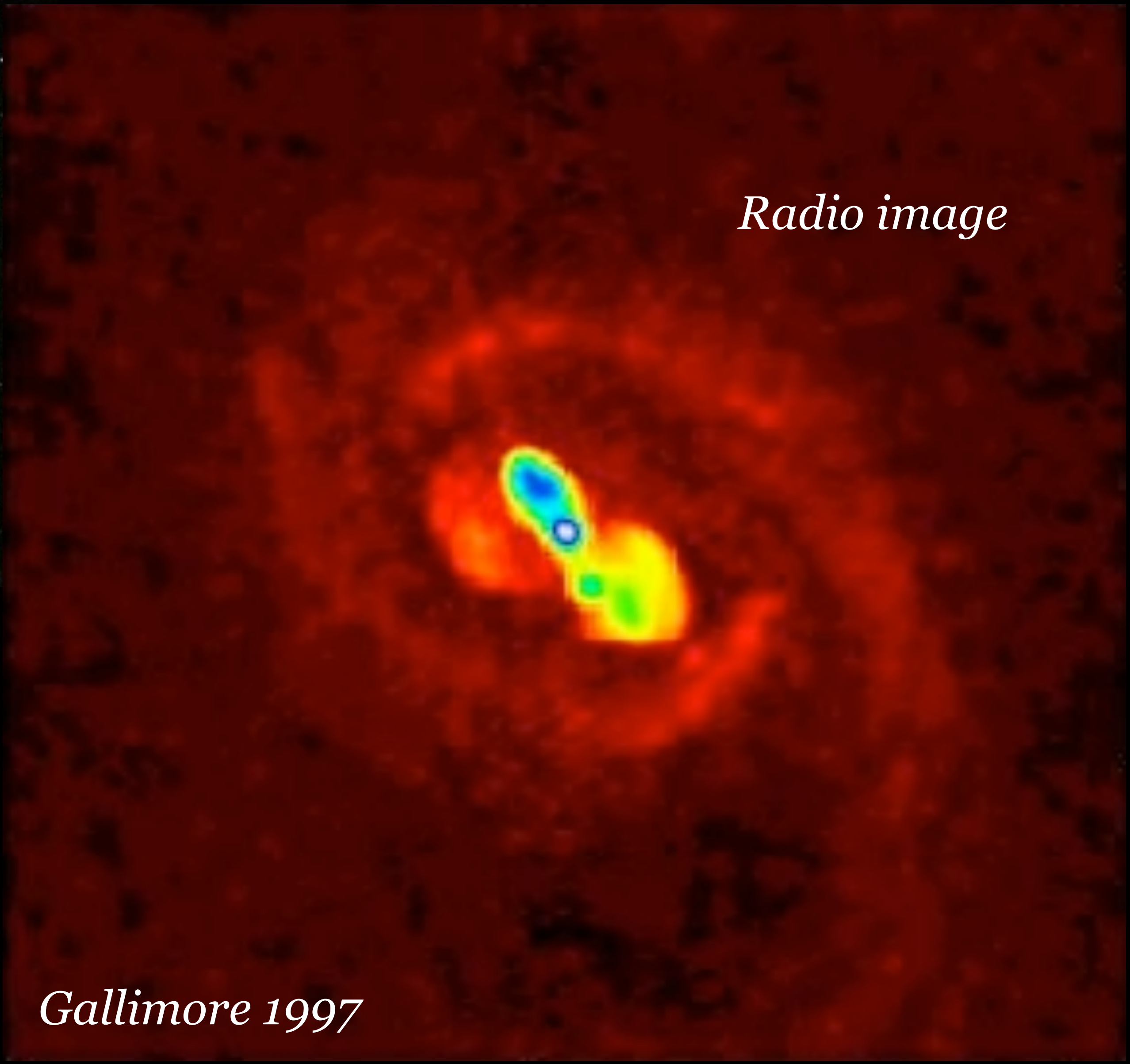
Two international teams of astronomers have used the power of the Atacama Large Millimeter/submillimeter Array (ALMA) to focus on jets from the huge black holes at the centres of galaxies and observe how they affect their surroundings. They have respectively obtained the best view yet of the molecular gas around a nearby, quiet black hole and caught an unexpected glimpse of the base of a powerful jet close to a distant black hole.

There are supermassive black holes — with masses up to several billion solar masses — at the hearts of almost all galaxies in the Universe, including our own galaxy, the Milky Way. In the remote past, these bizarre objects were very active, swallowing enormous quantities of matter from their surroundings, shining with dazzling brilliance, and expelling tiny fractions of this matter through extremely powerful jets. In the current Universe, most supermassive black holes are much less active than they were in their youth, but the interplay between jets and their surroundings is still shaping galaxy evolution.

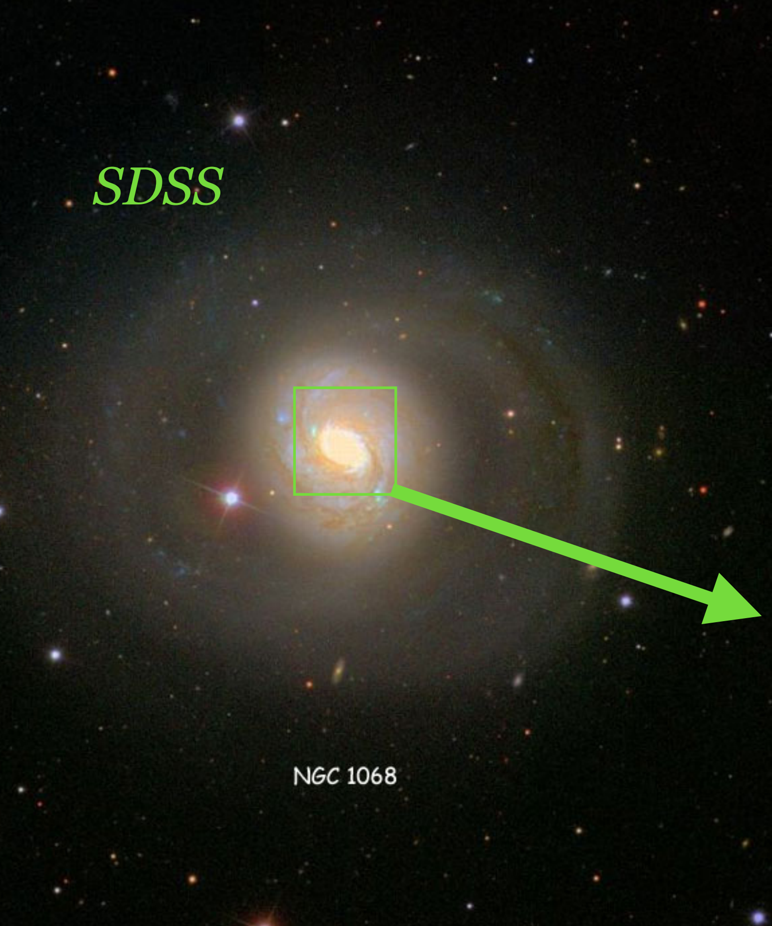
Two new studies, both published today in the journal Astronomy & Astrophysics, used ALMA to probe black hole jets at very different scales: a nearby and relatively quiet black hole in the galaxy NGC 1433 and a very distant and active object called PKS 1830-211.

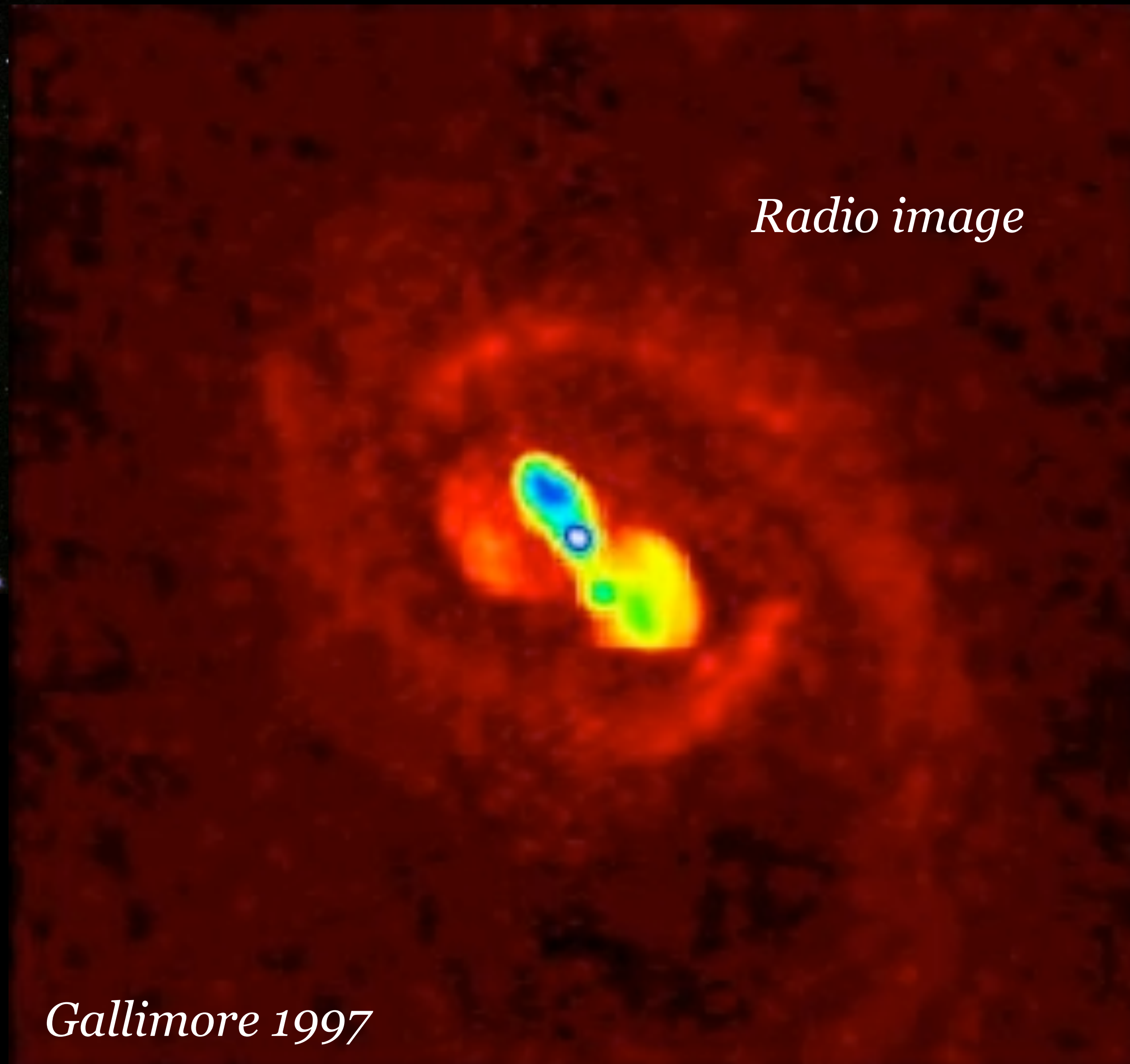
NGC1068





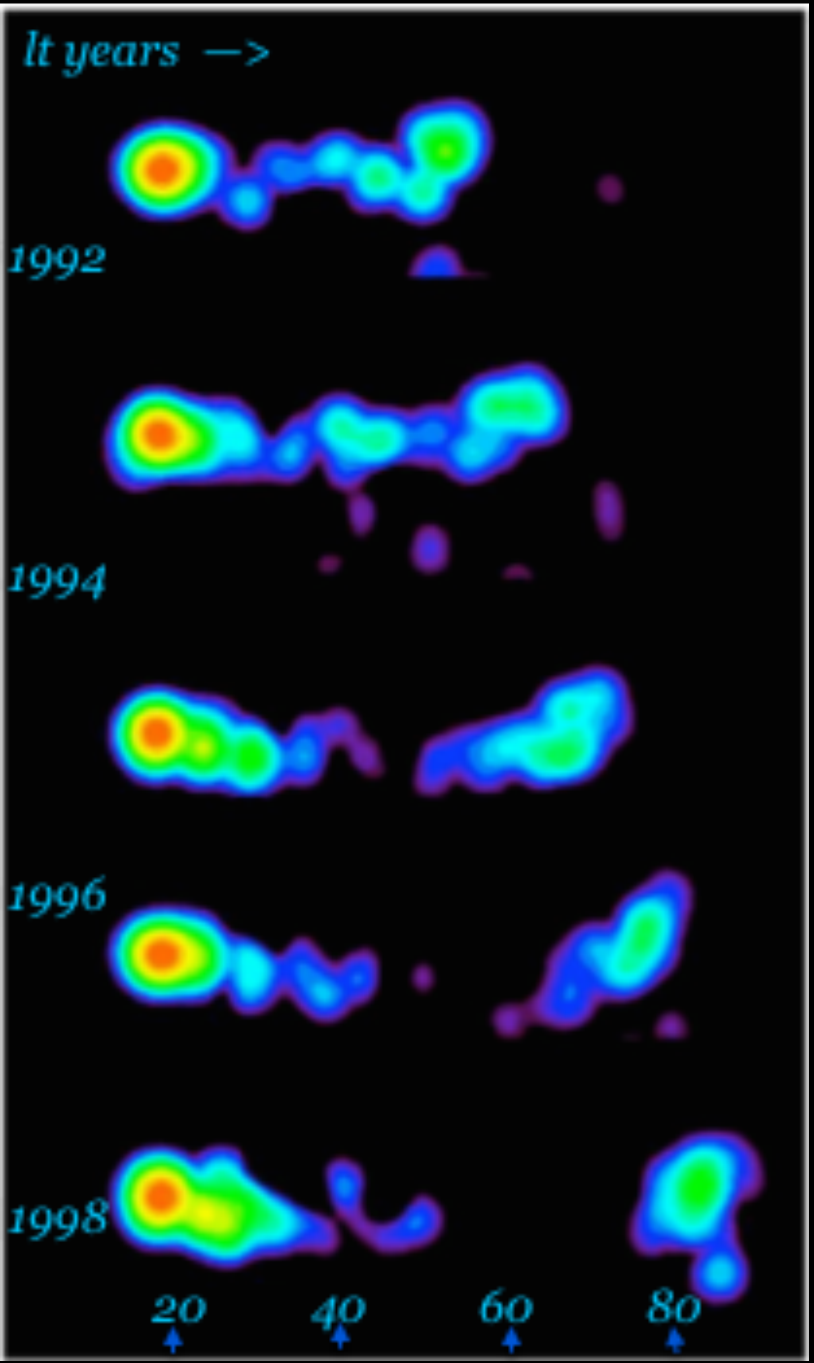
NGC1068

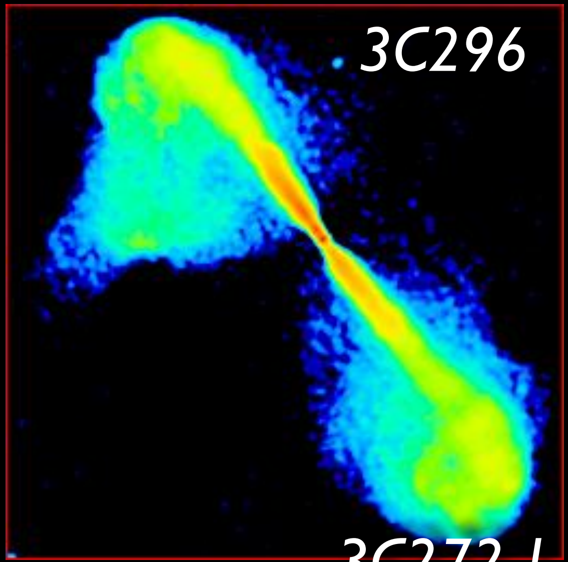


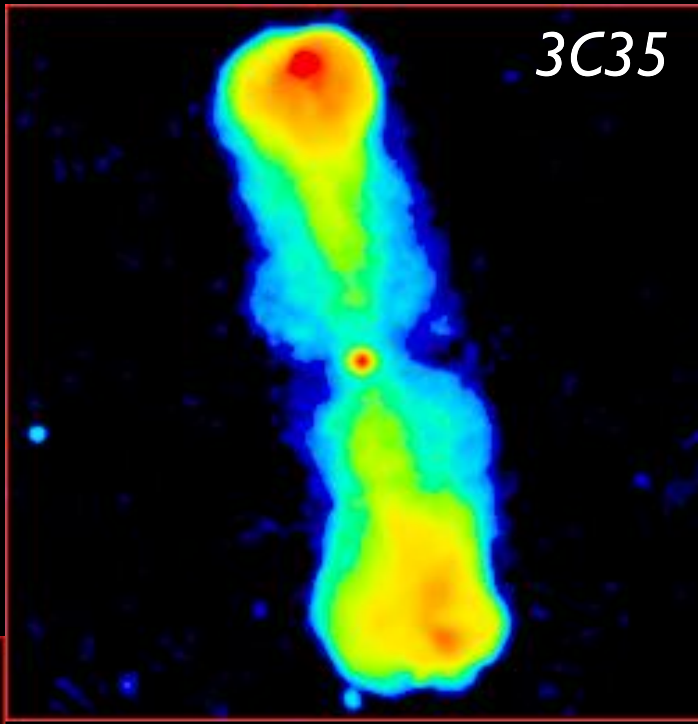


Radio “Loud”: high kinetic power bulk-relativistic jets

WE KNOW there are outflows:







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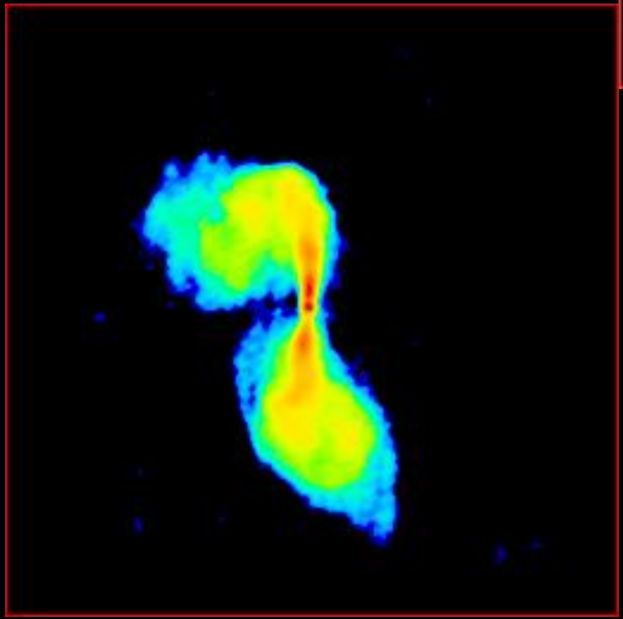
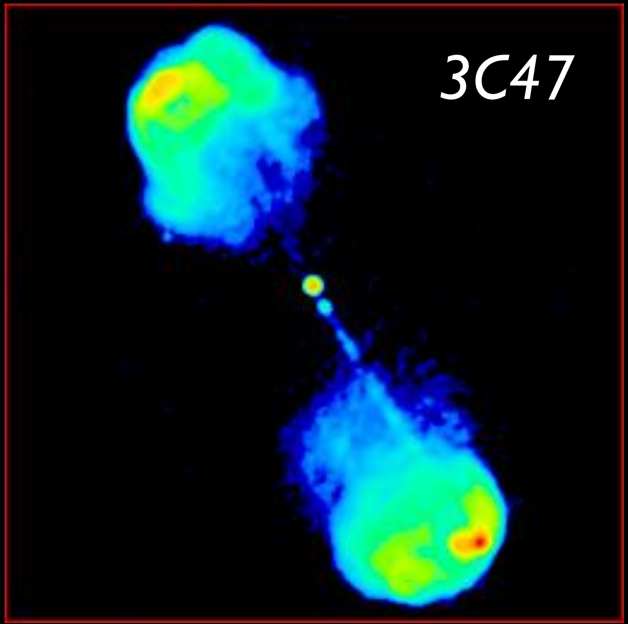
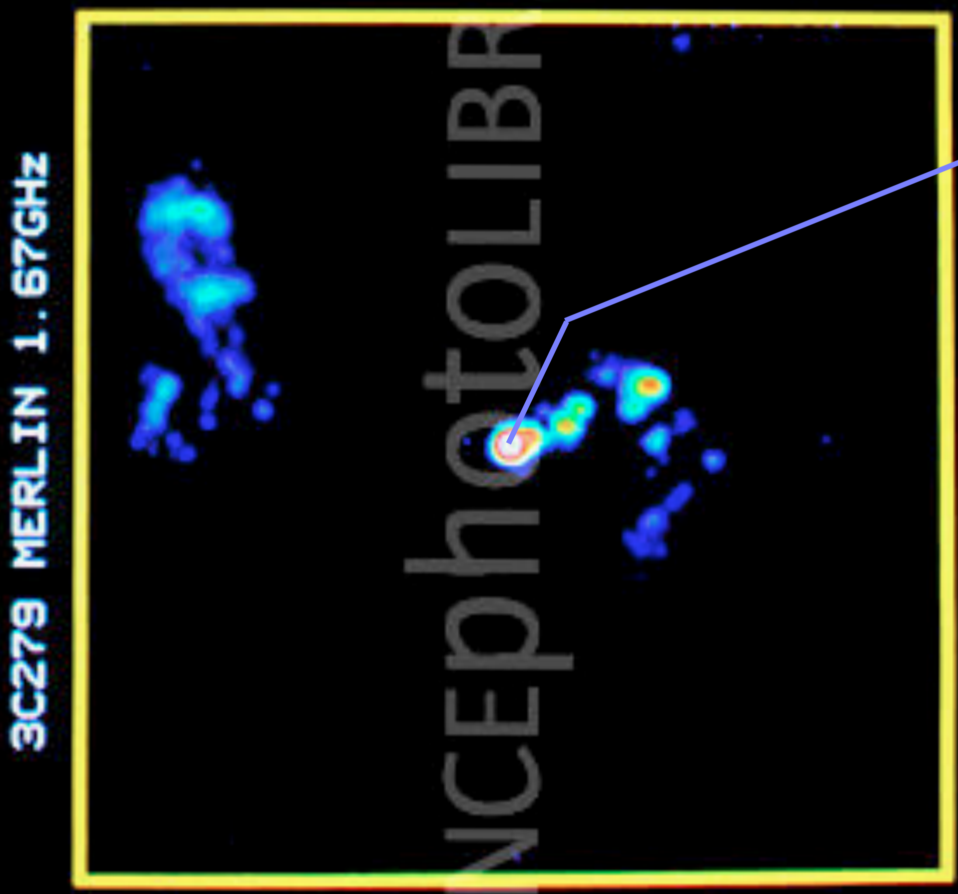
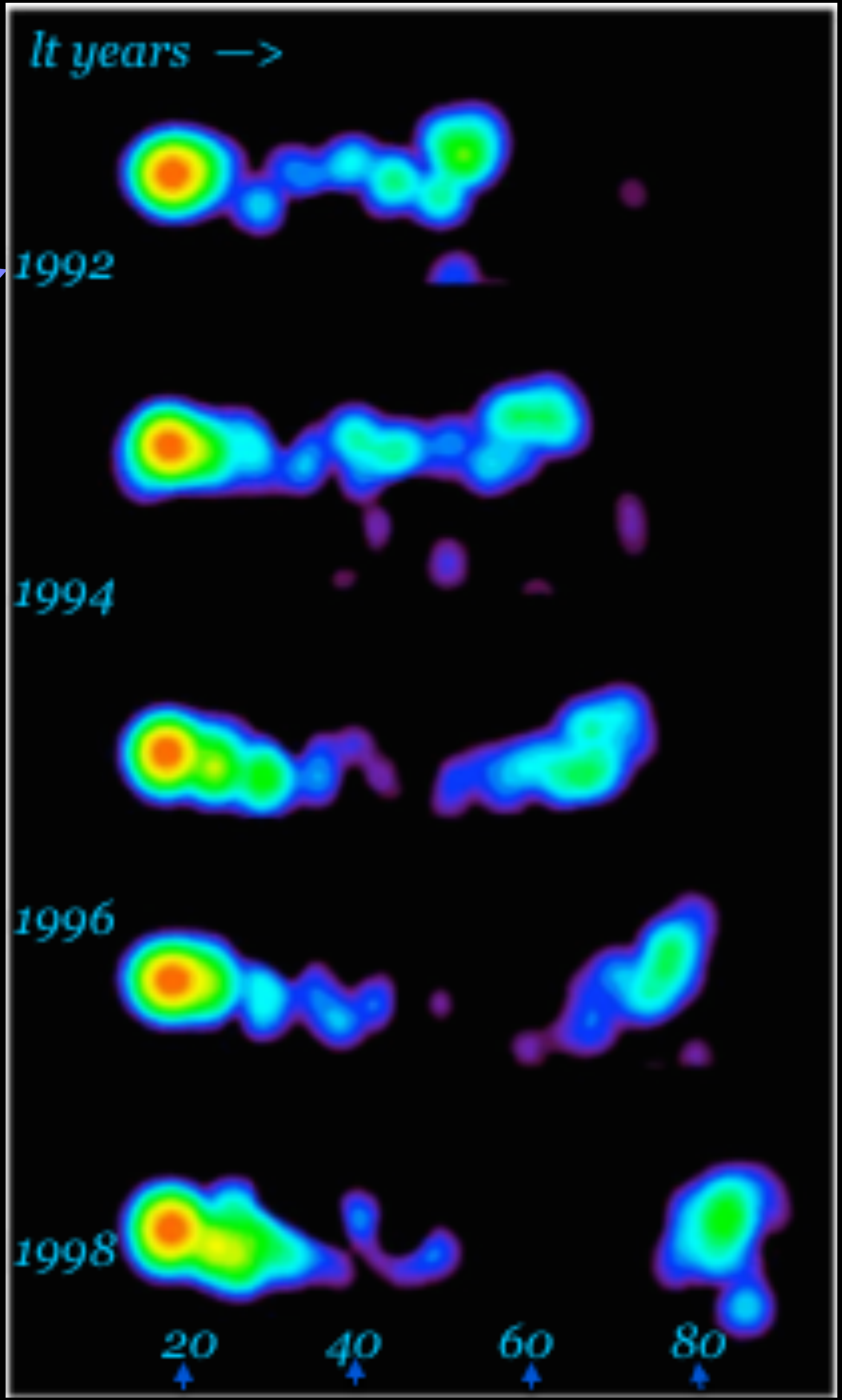
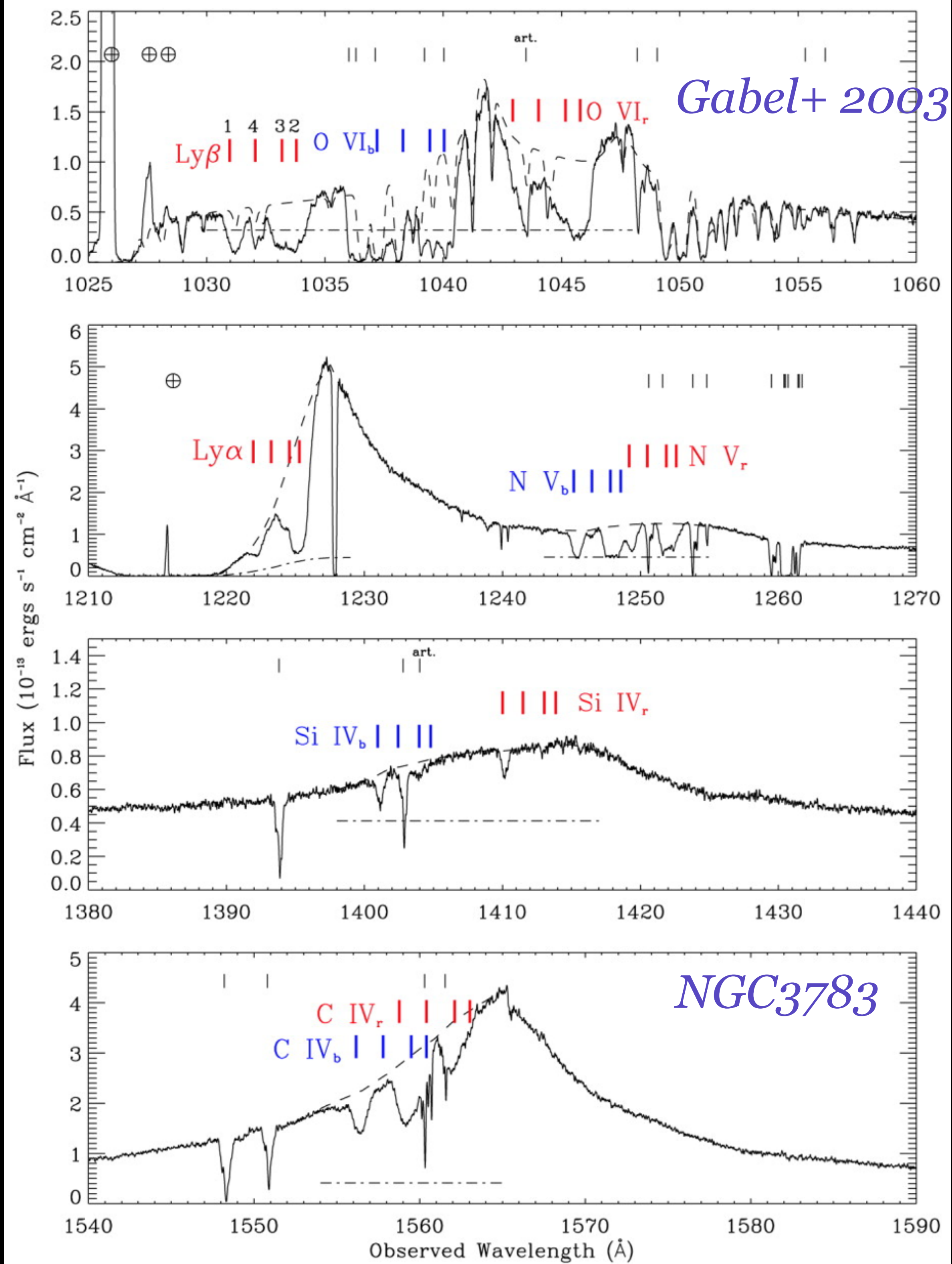








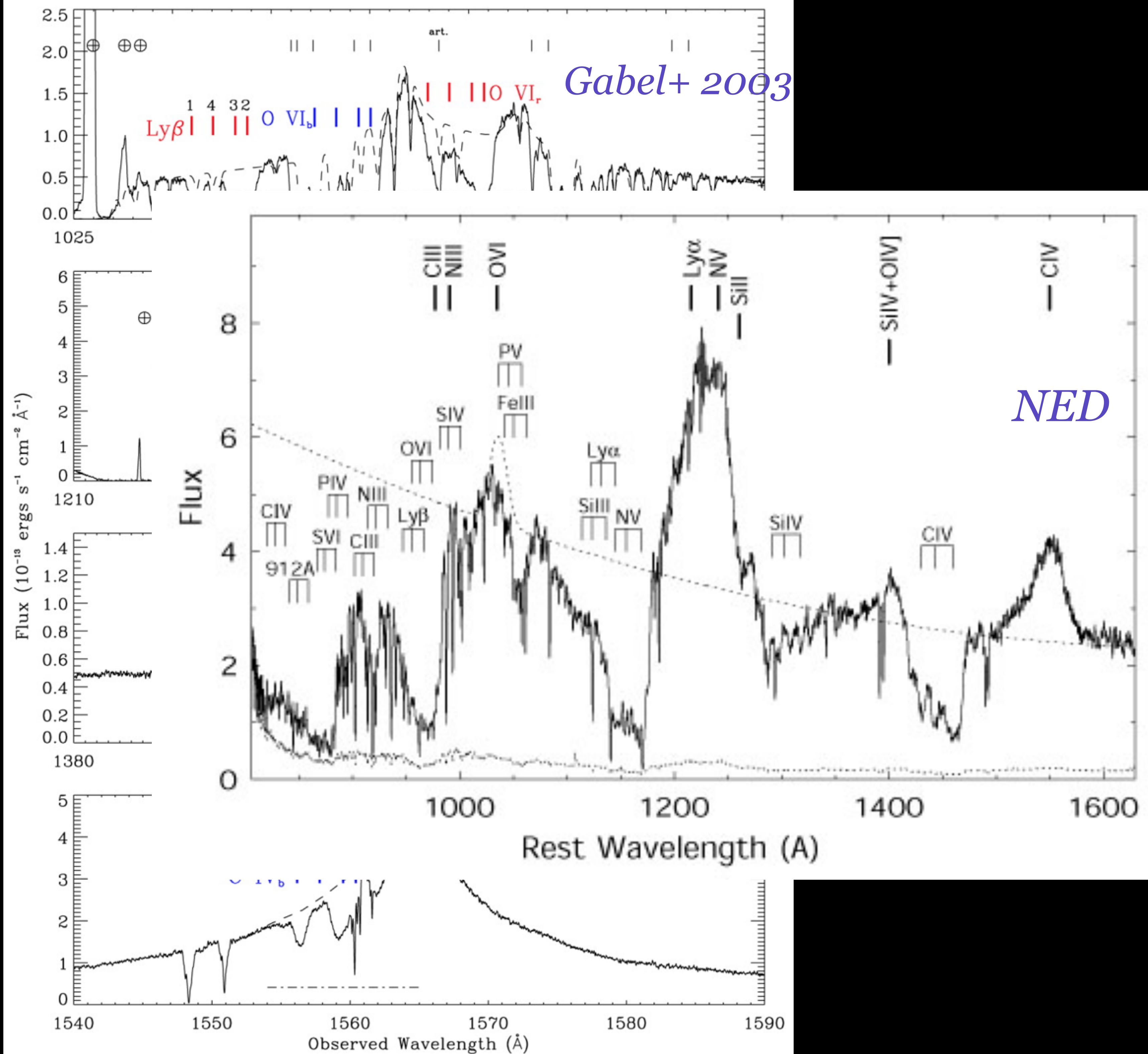
high kinetic power bulk-relativistic jets: Radio "Loud":



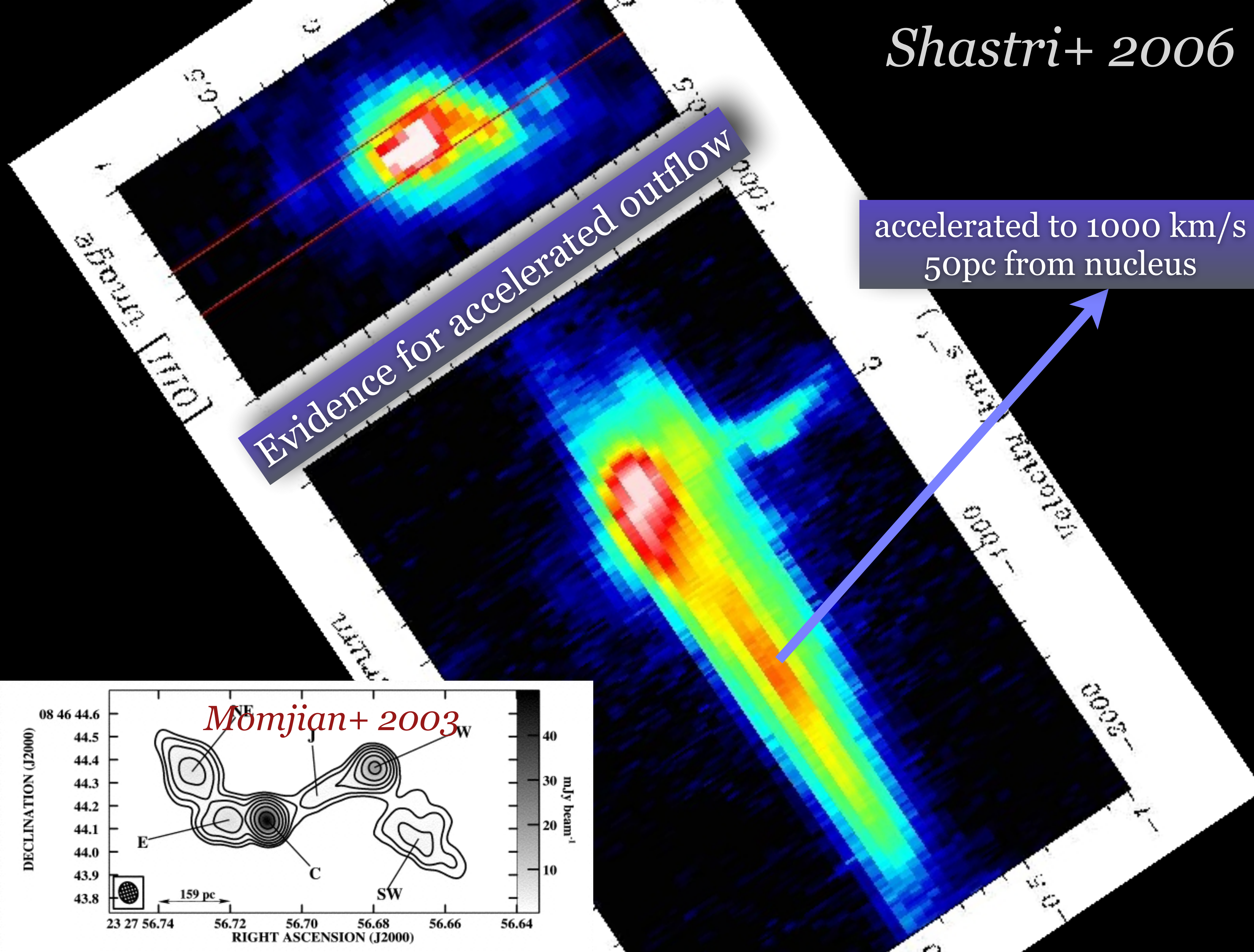
Gabel+ 2003
NGC3783
Lyβ
1 4 32
O VI_b
O VI_r
art.
Lyα
N V_b
N V_r
Si IV_b
Si IV_r
C IV_r
C IV_b
Flux (10^-13 ergs s^-1 cm^-2 Å^-1)
Observed Wavelength (Å)

Gabel+ 2003

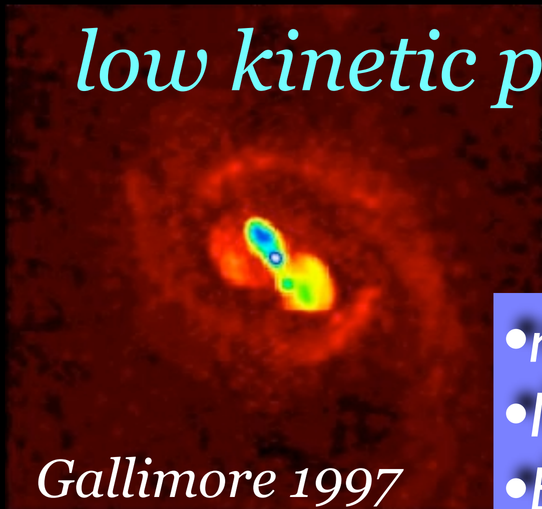
NED



Shastri+ 2006

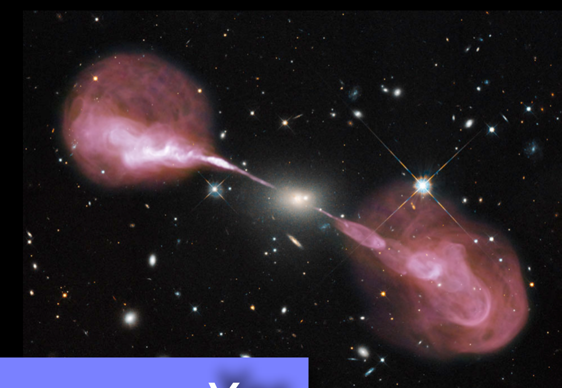


low kinetic power jets: accompanied by winds

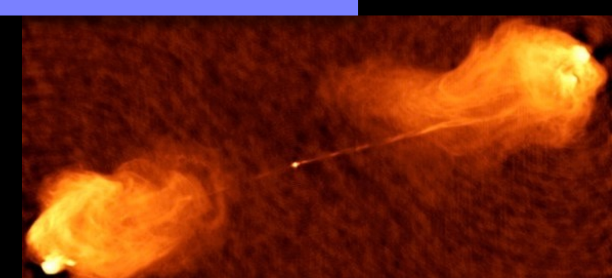


Gallimore 1997

- *mildly relativistic jets?* Yes
- *In spiral galaxy hosts?* maybe
- *Black hole not spinning?* NO



- *Highly relativistic jets?* Yes
- *In elliptical galaxy hosts?* Maybe
- *Black hole spinning?* YES

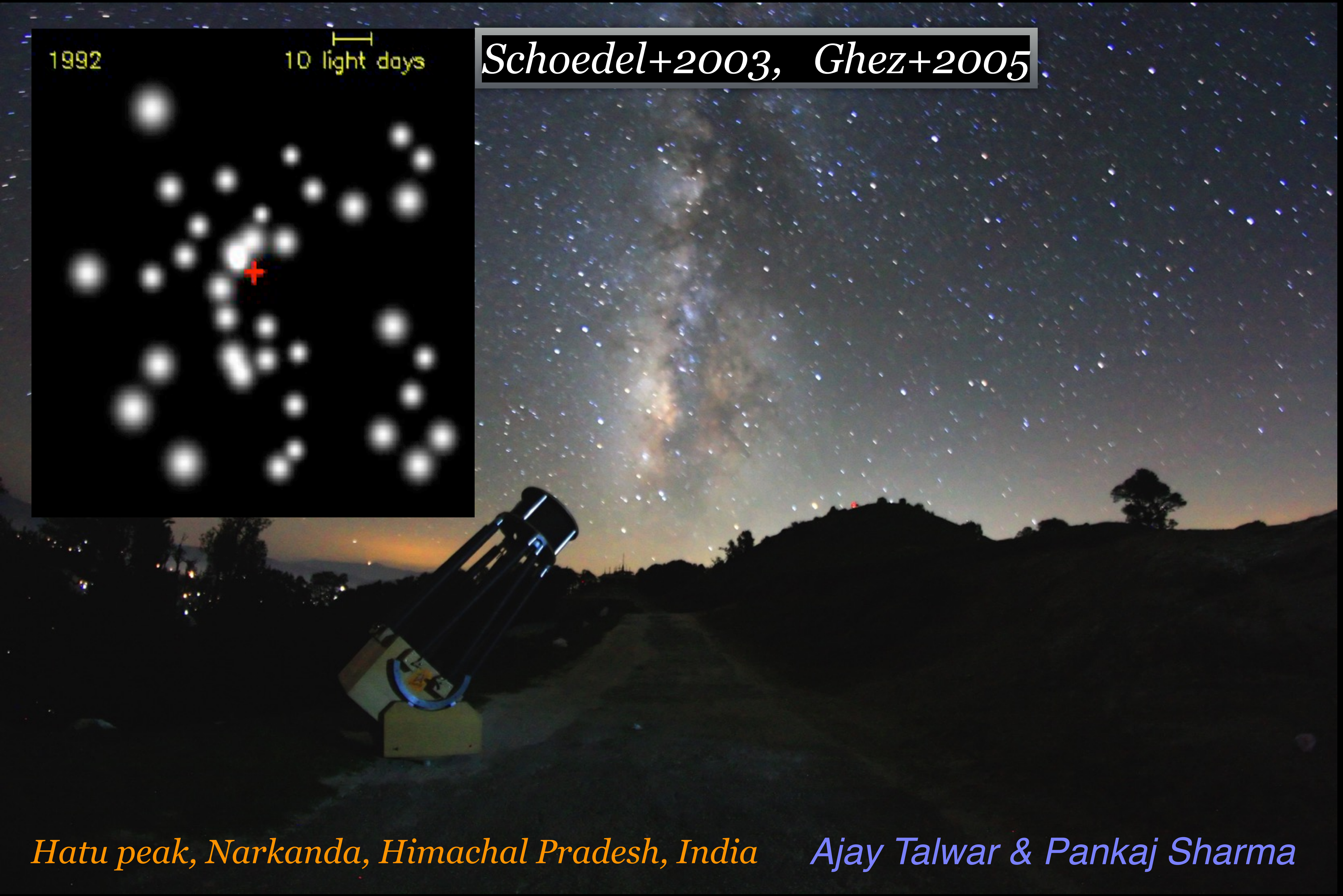


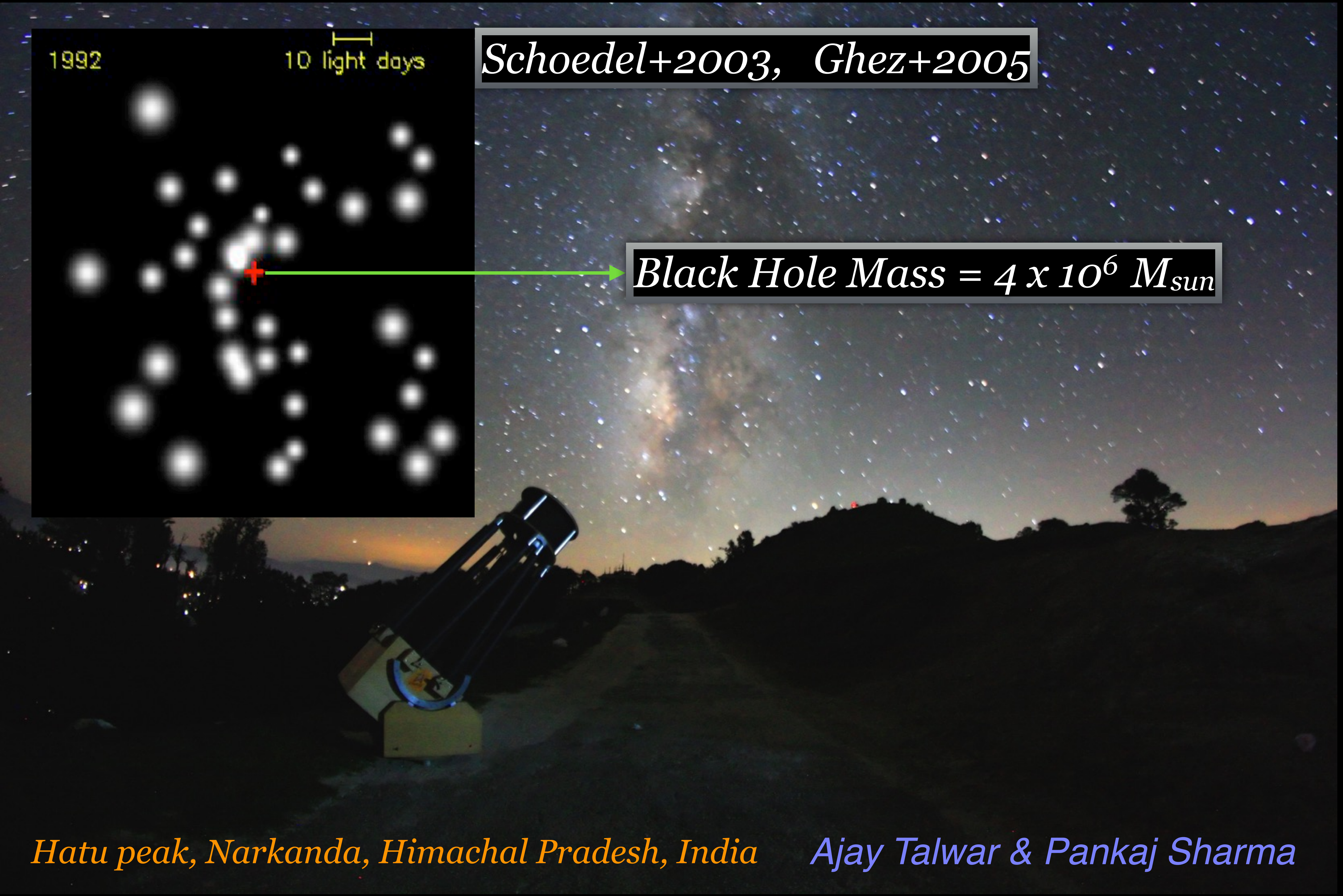
high kinetic power bulk-relativistic jets


The Hubble Ultra Deep Field


Hatu peak, Narkanda, Himachal Pradesh, India
Ajay Talwar & Pankaj Sharma


Schoedel+2003, Ghez+2005
Hatu peak, Narkanda, Himachal Pradesh, India
Ajay Talwar & Pankaj Sharma


1992
10 light days
Schoedel+2003,   Ghez+2005
Hatu peak, Narkanda, Himachal Pradesh, India
Ajay Talwar & Pankaj Sharma


1992
10 light days
Schoedel+2003, Ghez+2005
Black Hole Mass = 4 x 10^6 M$_{sun}$
Hatu peak, Narkanda, Himachal Pradesh, India
Ajay Talwar & Pankaj Sharma

Andromeda

Spiral Galaxy NGC 4622

Hubble Heritage

NASA and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope WFPC2 • STScI-PRC02-03

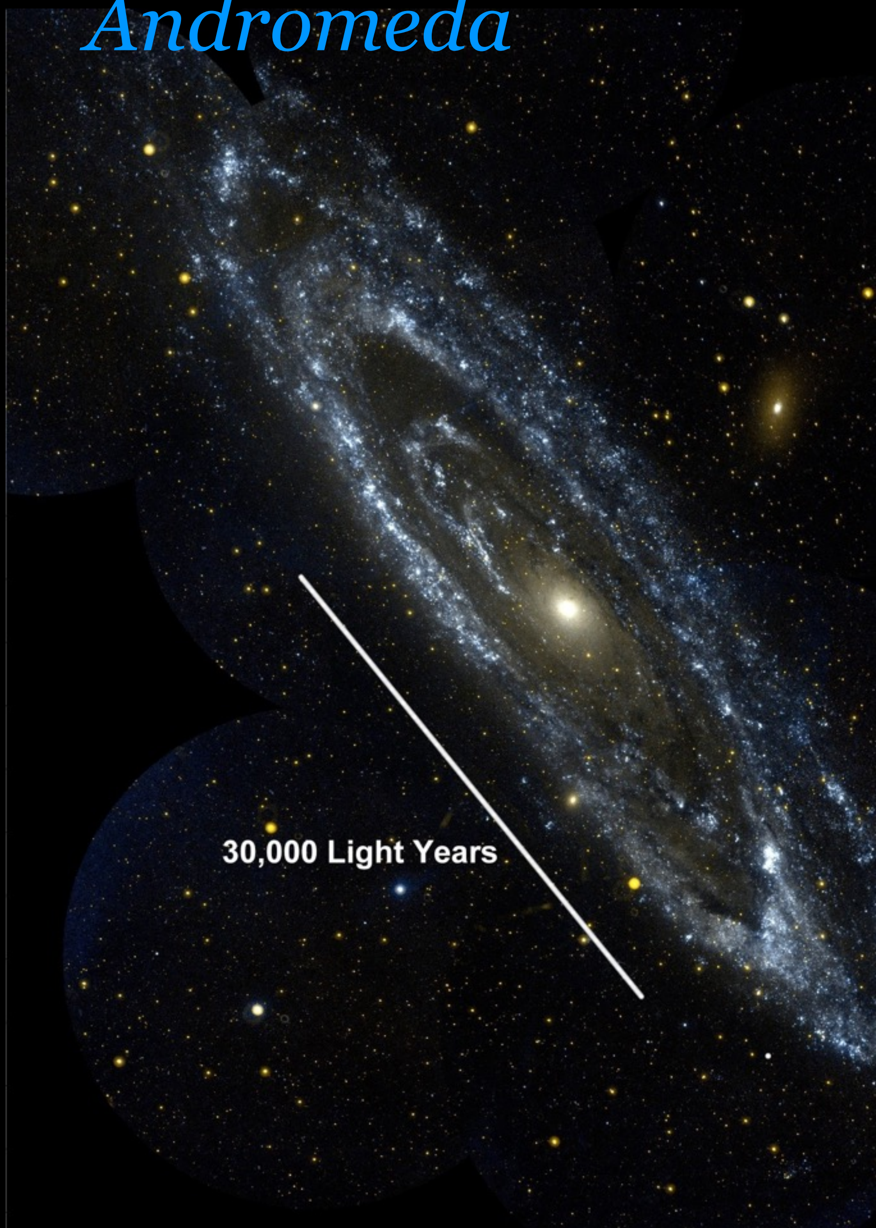
Spiral Galaxy NGC 4414

Starburst Galaxy NGC 3310

Hubble Heritage

NASA and The Hubble Heritage Team (STScI/AURA)
Hubble Space Telescope WFPC2 • STScI-PRC01-26

Andromeda

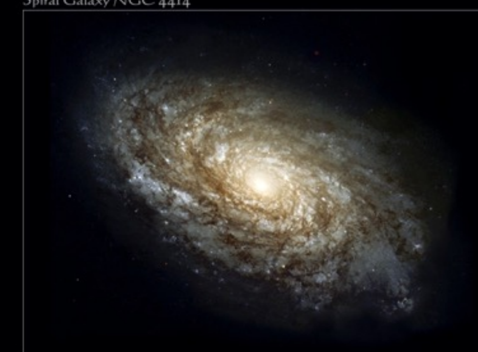


Spiral Galaxy NGC 4622

Hubble Heritage

NASA and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope WFPC2 • STScI-PRC02-03

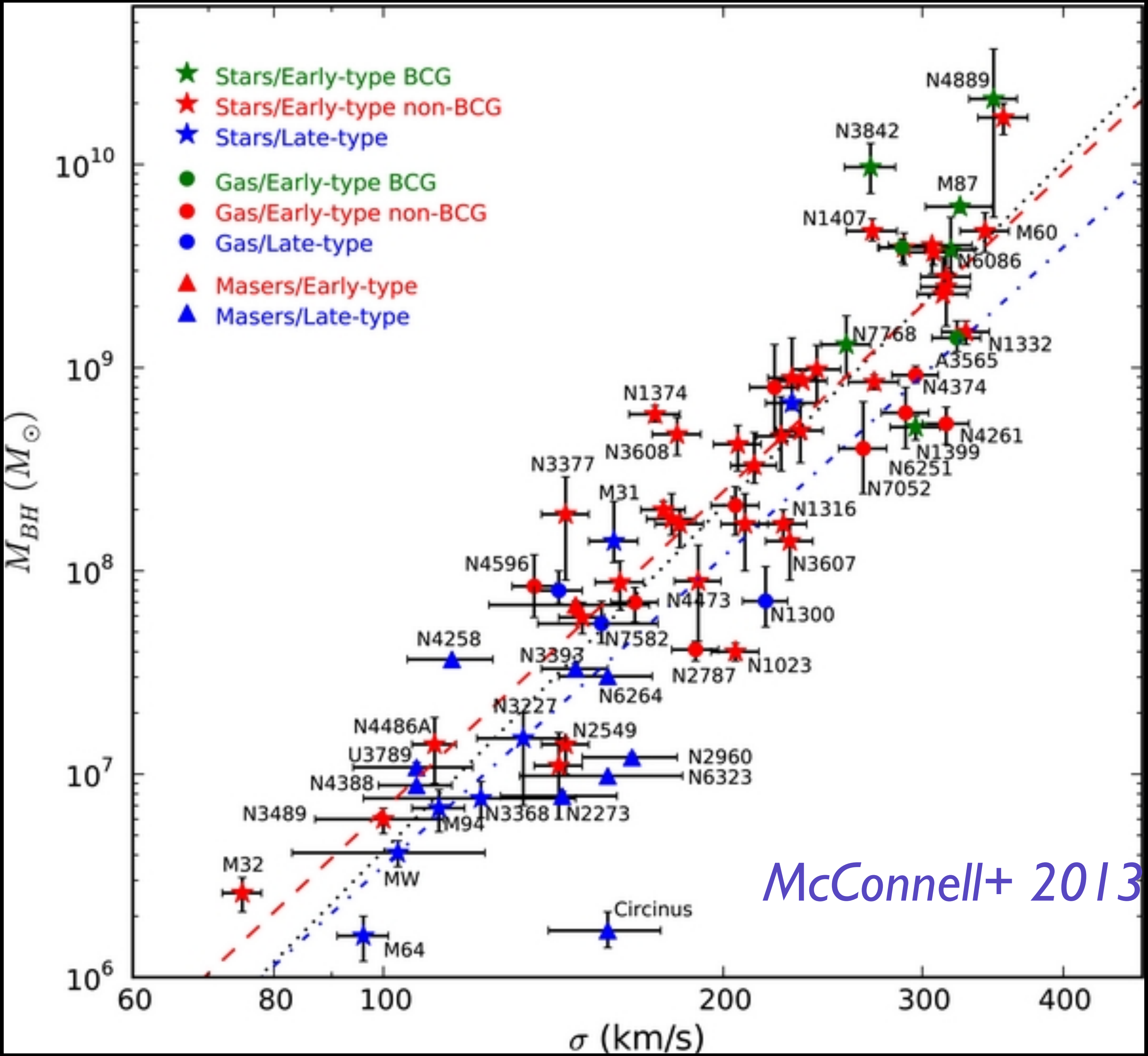
Spiral Galaxy NGC 4414



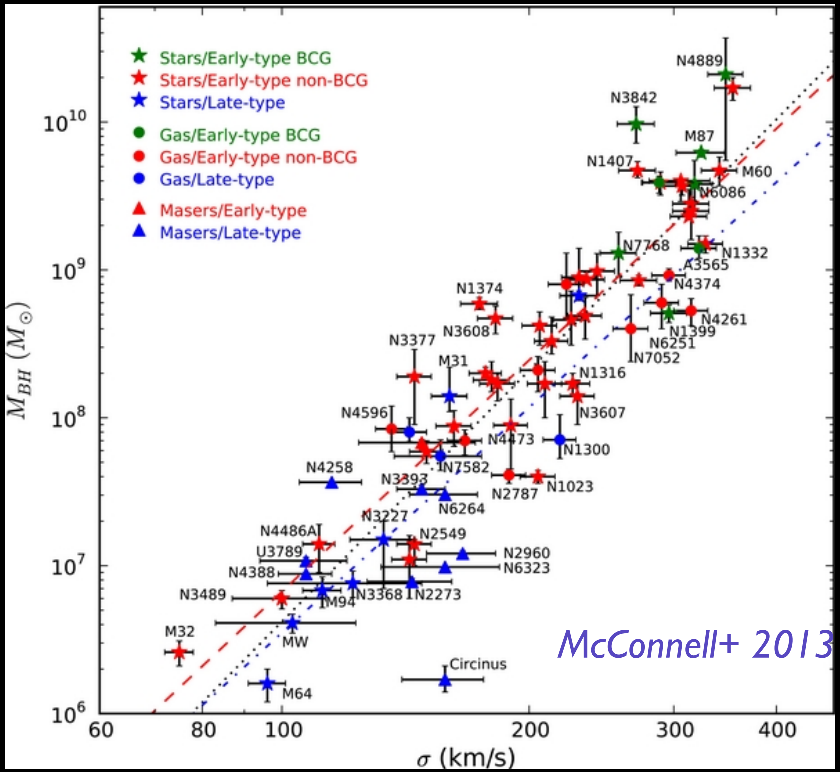
Starburst Galaxy NGC 3310

Hubble Heritage

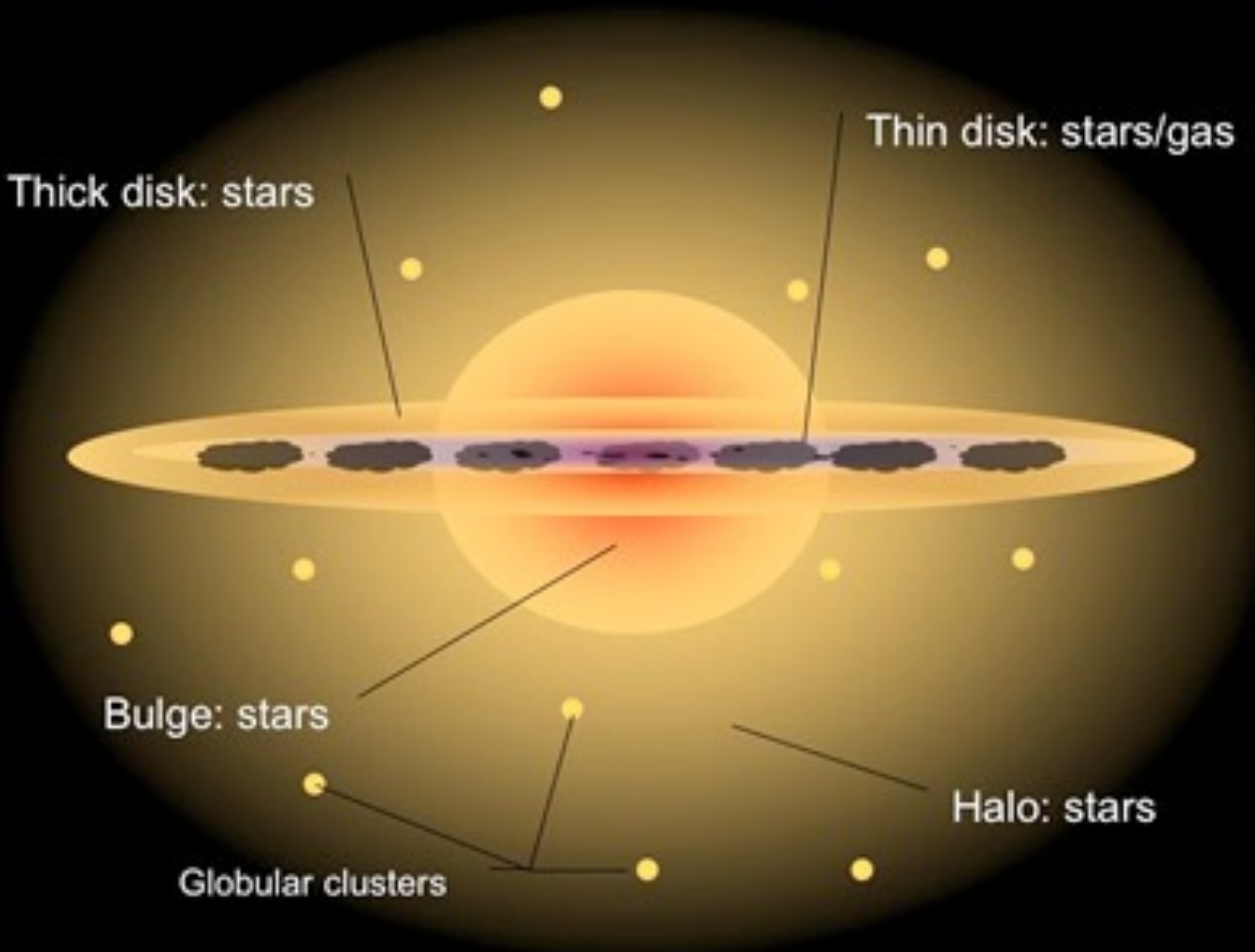
NASA and The Hubble Heritage Team (STScI/AURA)
Hubble Space Telescope WFPC2 • STScI-PRC01-26



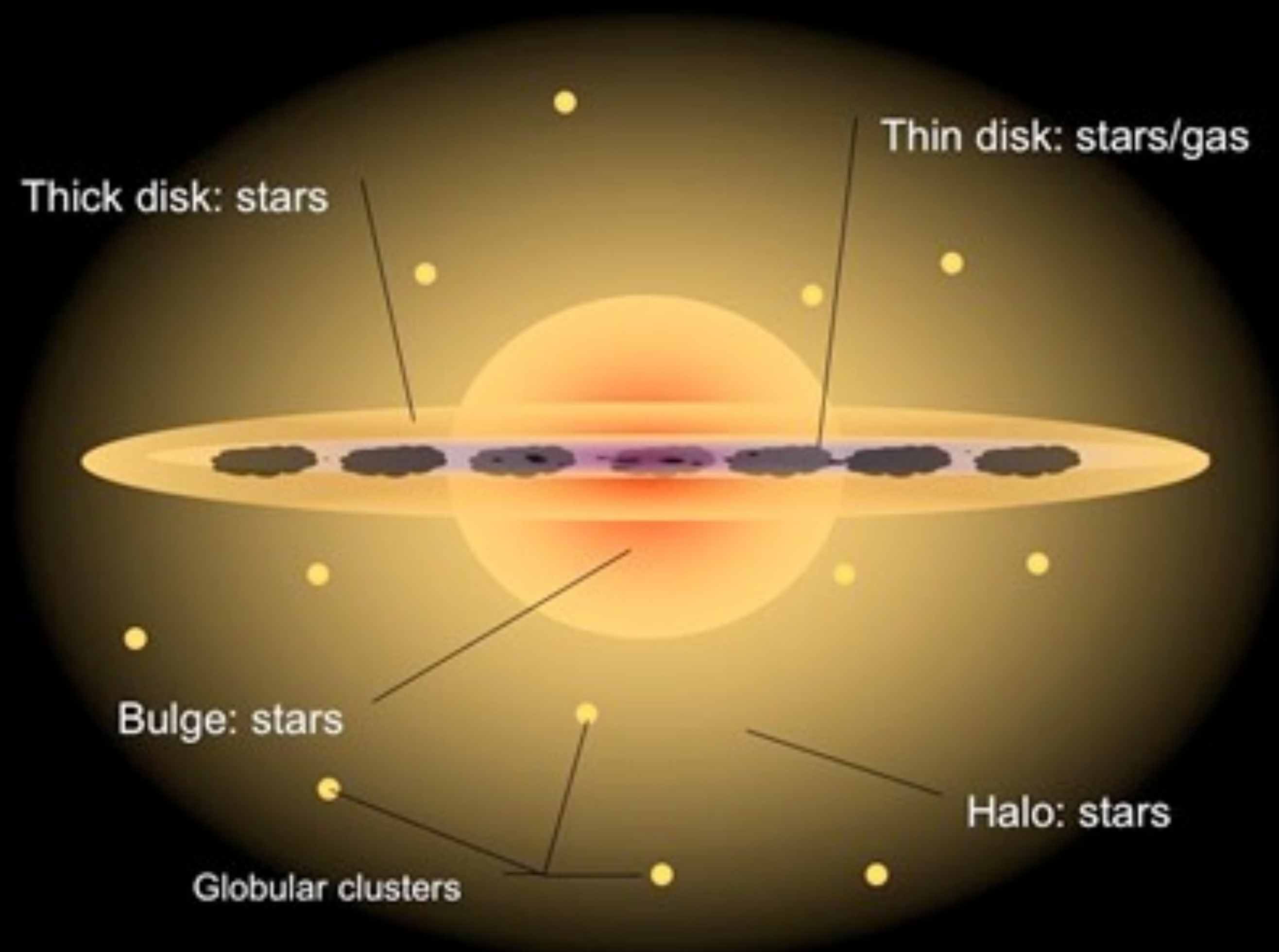
McConnell+ 2013



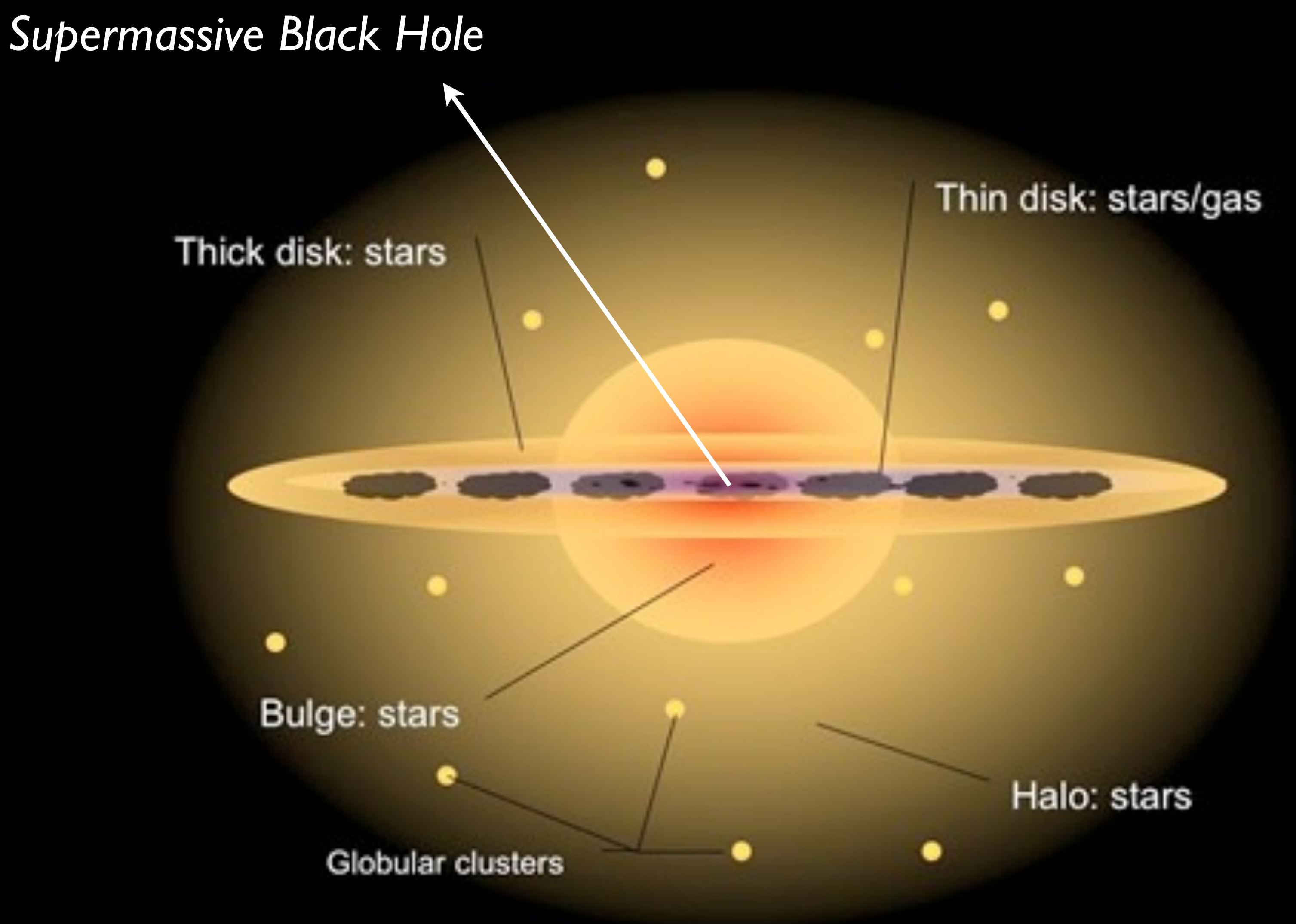
Black Hole & Galaxy must co-evolve

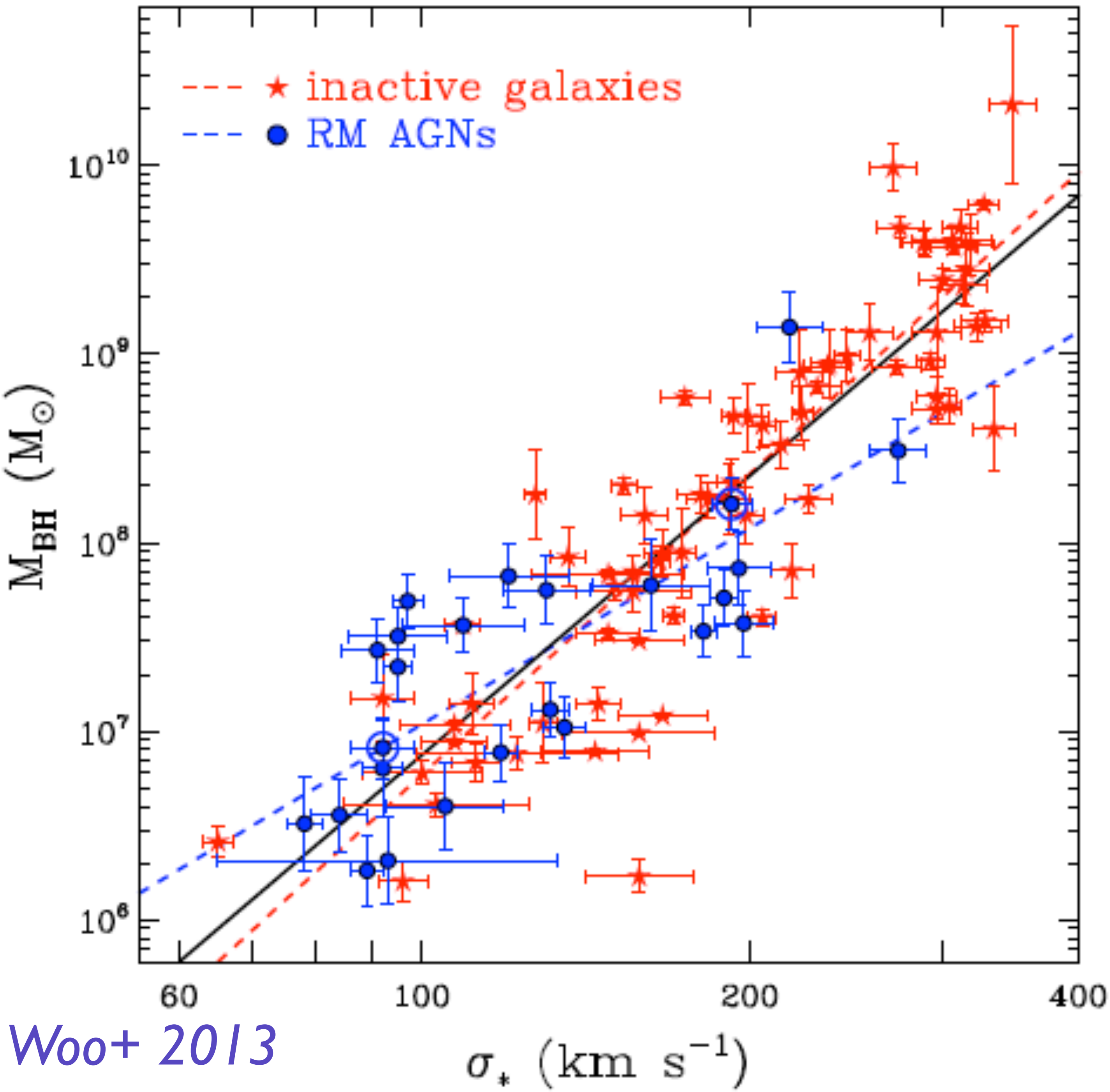

Thin disk: stars/gas
Thick disk: stars
Bulge: stars
Halo: stars
Globular clusters

Black Hole & Galaxy must co-evolve



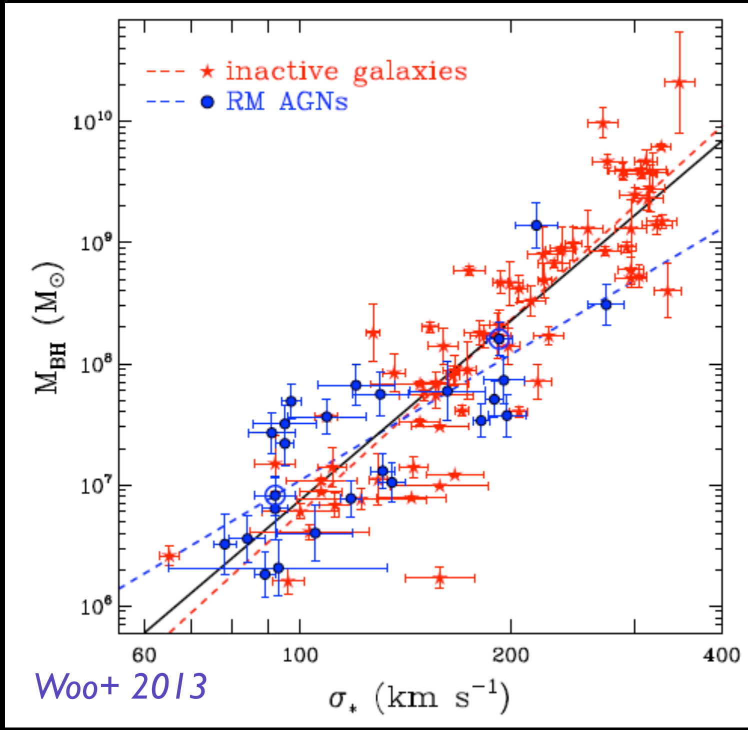
Black Hole & Galaxy must co-evolve





inactive galaxies
RM AGNs
10^{10}
10^9
10^8
10^7
10^6
M_{BH} ($M_\odot$)
60
100
200
400
σ_* (km s^{-1})

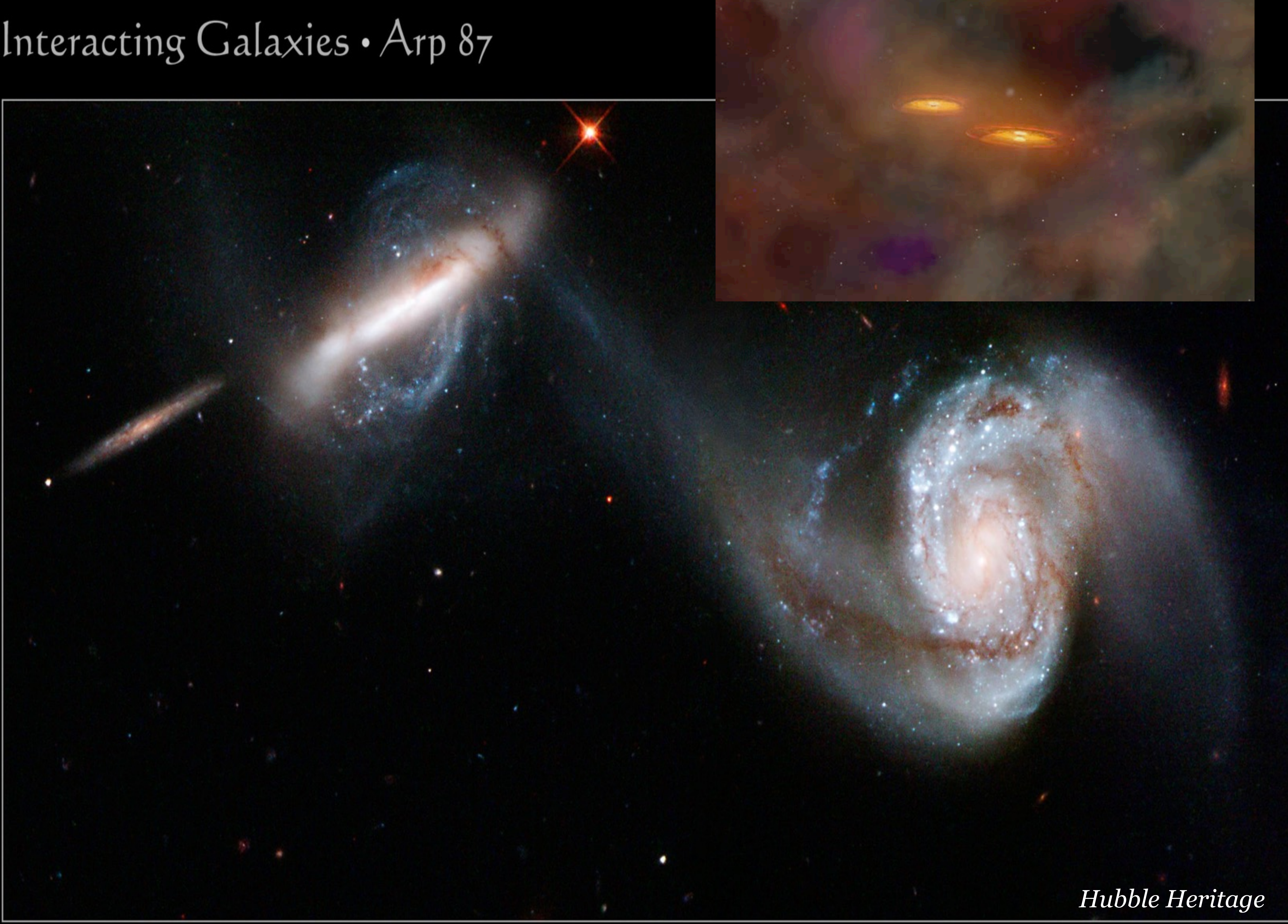
Woo+ 2013



The AGN is a phase (or more) in every? galaxy

Interacting Galaxies • Arp 87

Interacting Galaxies • Arp 87



Hubble Heritage

Hu

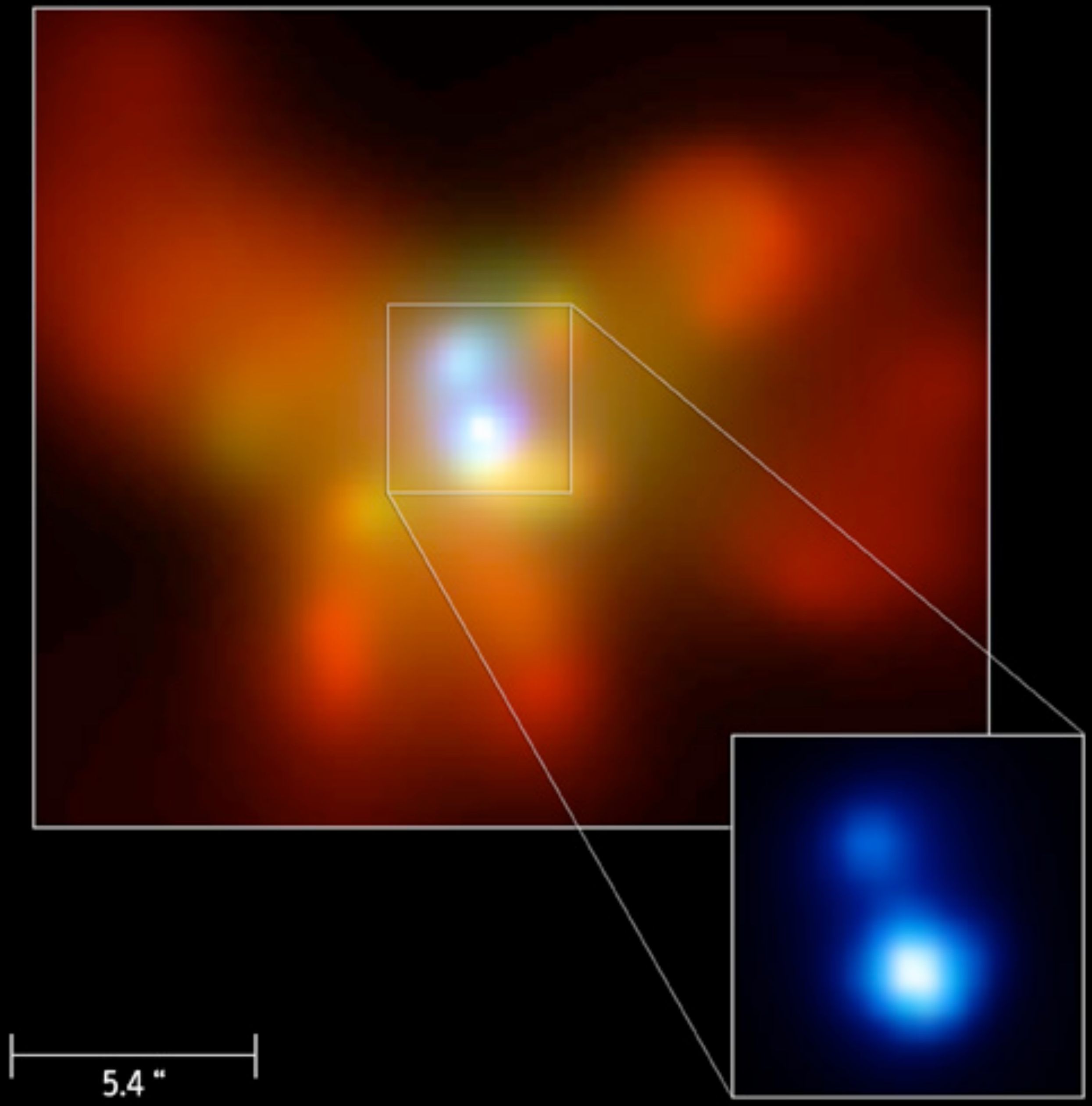
Komossa+ 2003

Credits: Chandra X-ray Observatory (NASA)

Komossa+ 2003

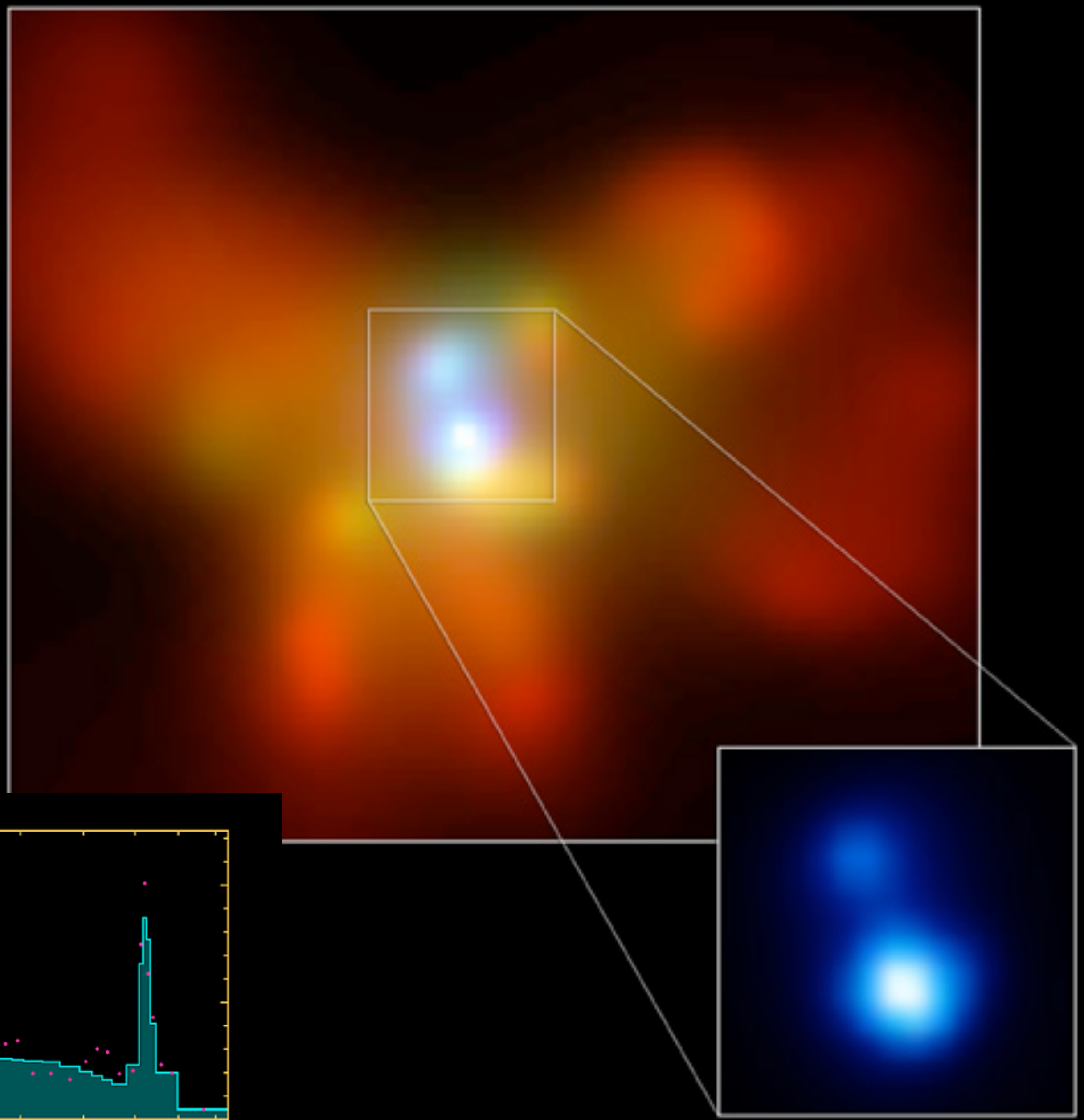
Credits: Chandra X-ray Observatory (NASA)

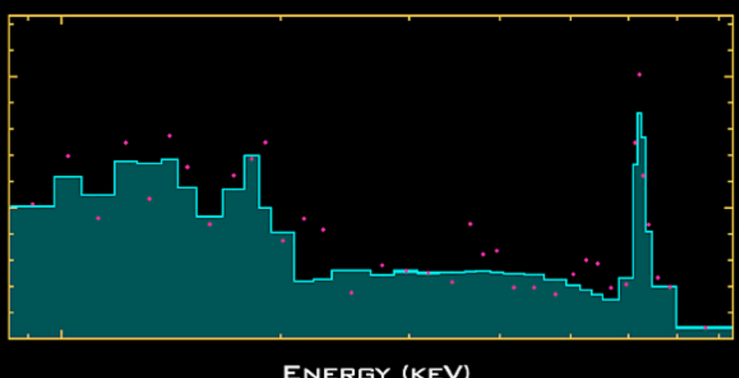
Komossa+ 2003



Credits: Chandra X-ray Observatory (NASA)

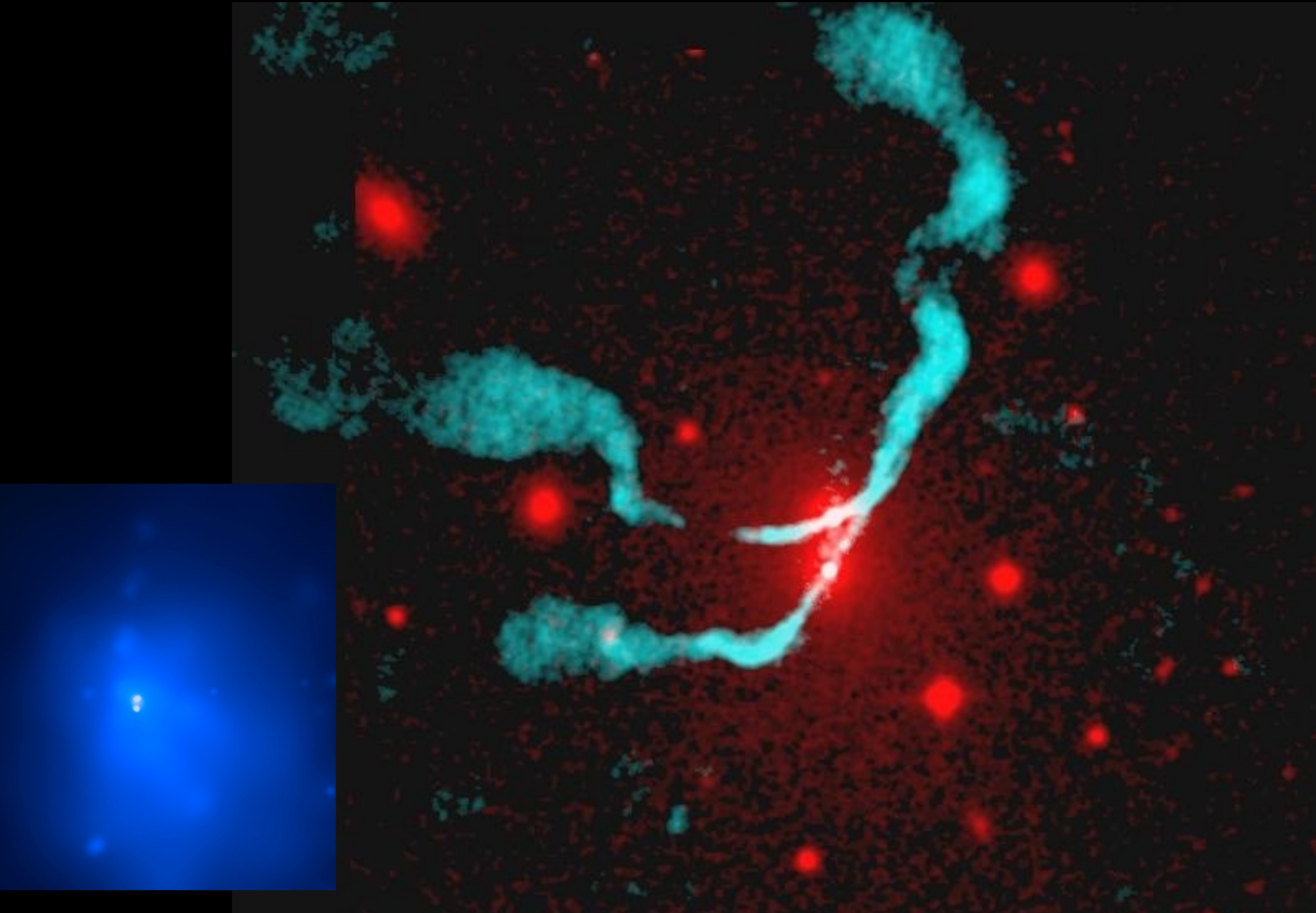
Komossa+ 2003



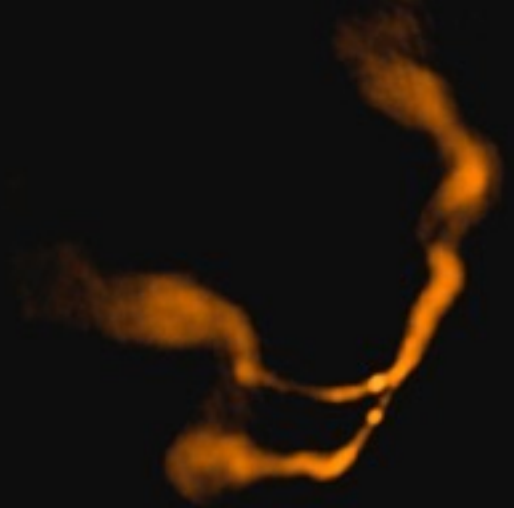


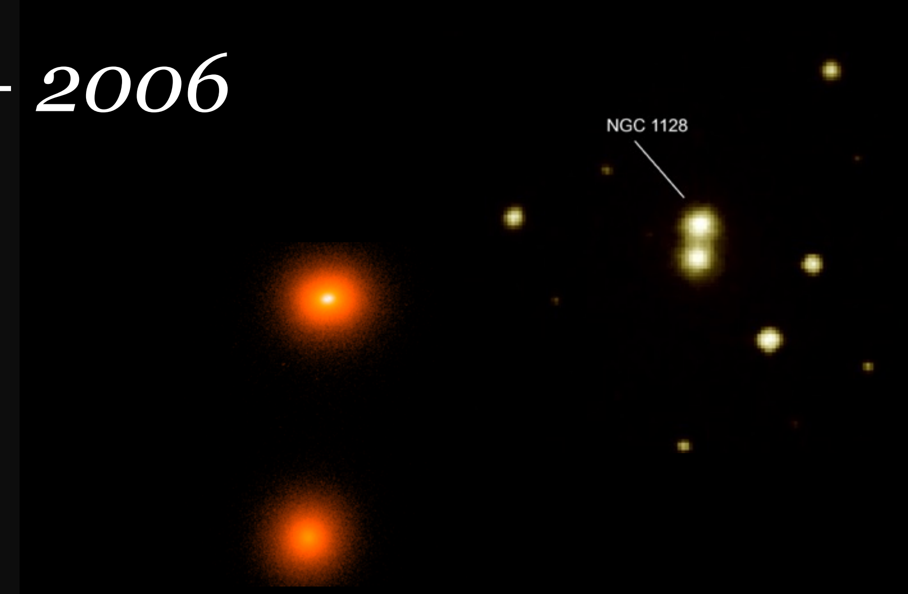
Credits: Chandra X-ray Observatory (NASA)

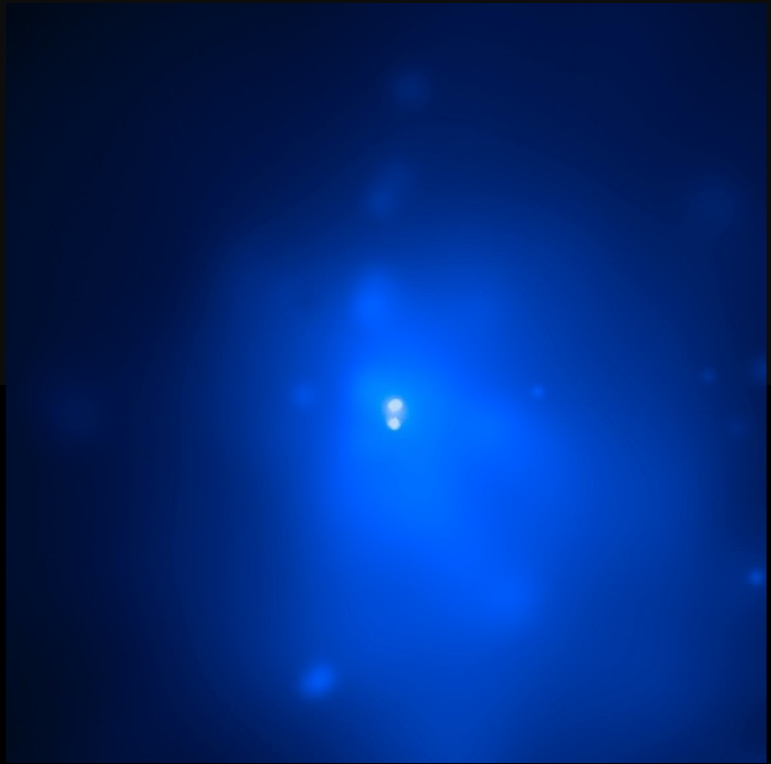
Hudson+ 2006



Hudson+ 2006







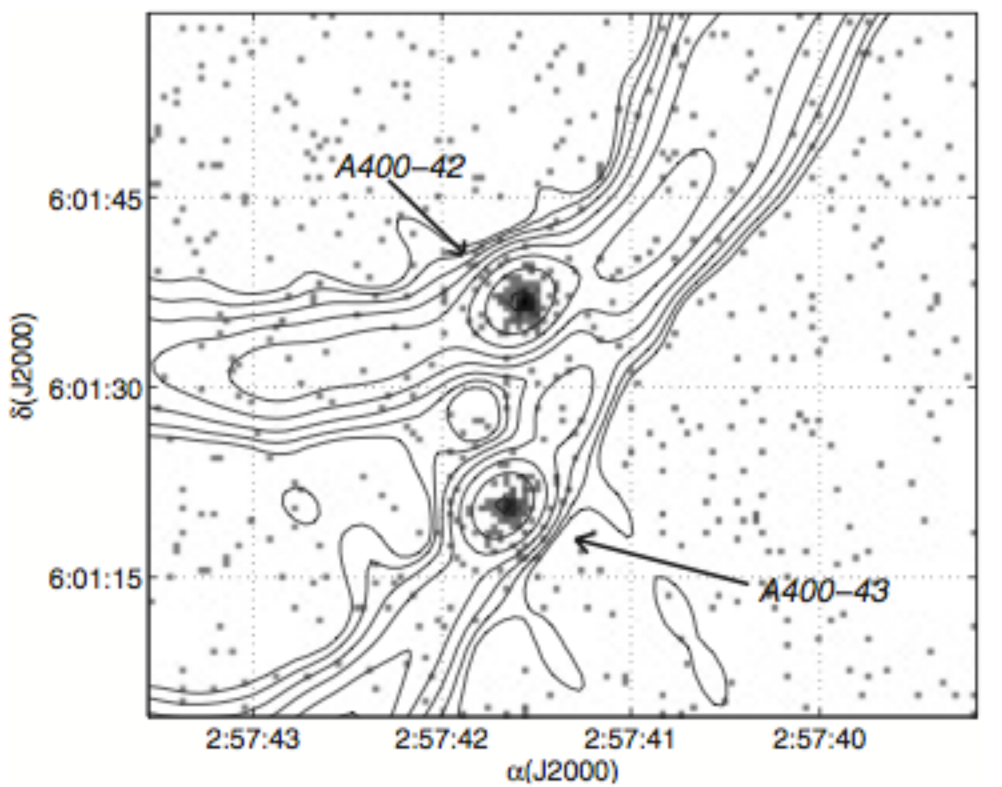
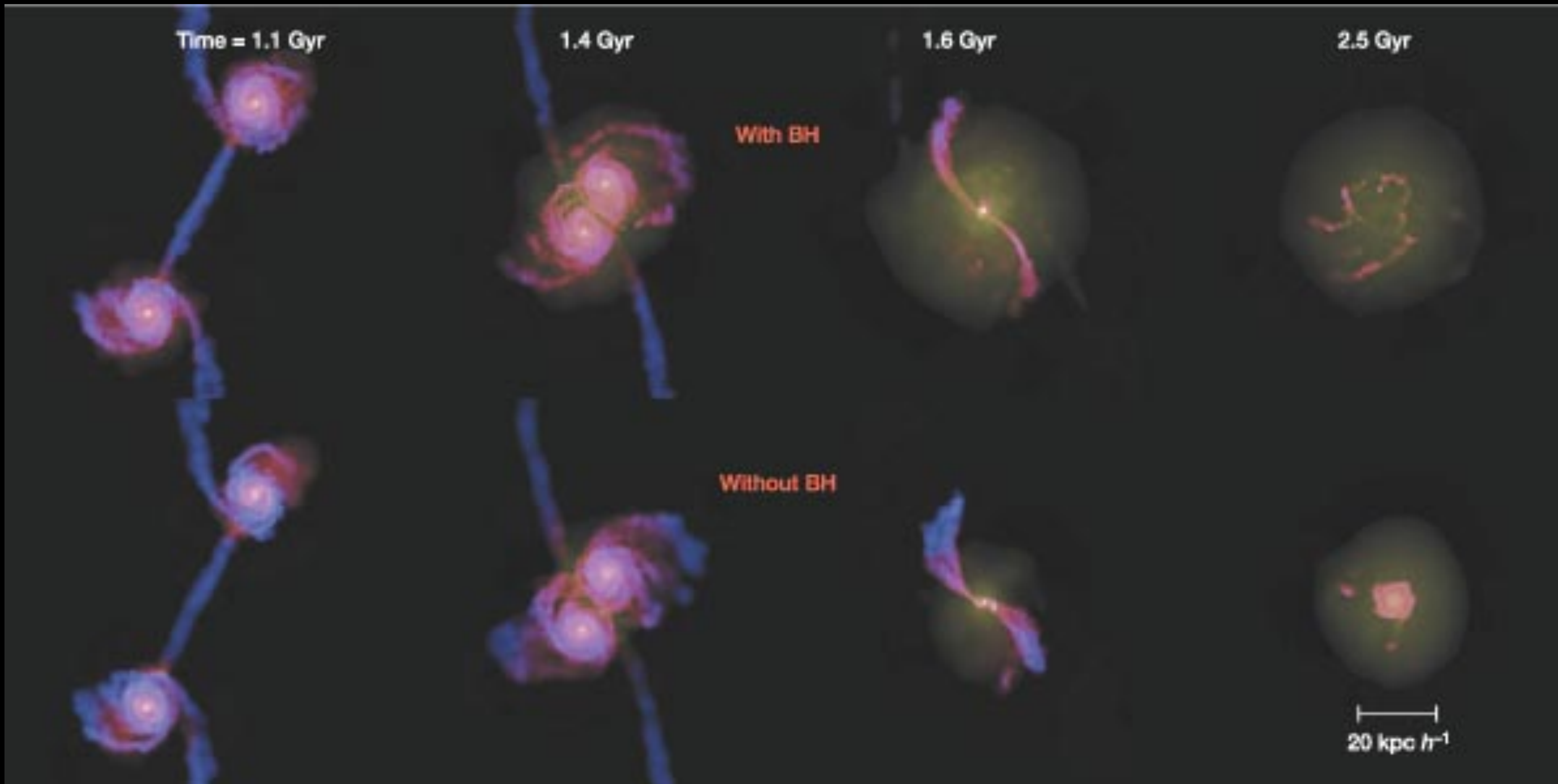


Fig. 4. A zoom-in of the raw *Chandra* image of the central region of A400, with an overlay of VLA 4.5 GHz contours. The double nucleus of 3C 75 is clearly separated. The radio contours are logarithmically

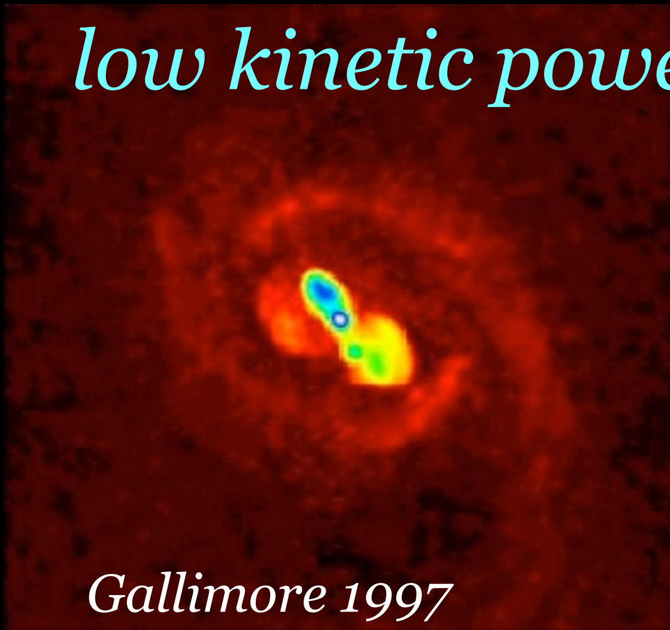
di Matteo+ 2005



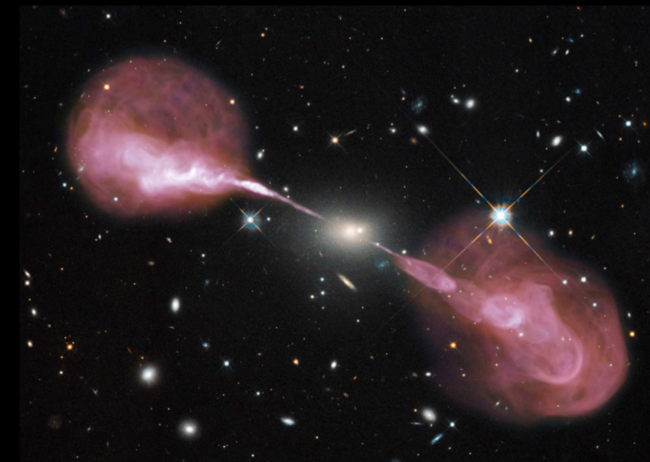
colour=> temperature; brightness => density

Results consistent with correlation between M_{BH} & M_{bulge}

low kinetic power jets: accompanied by winds

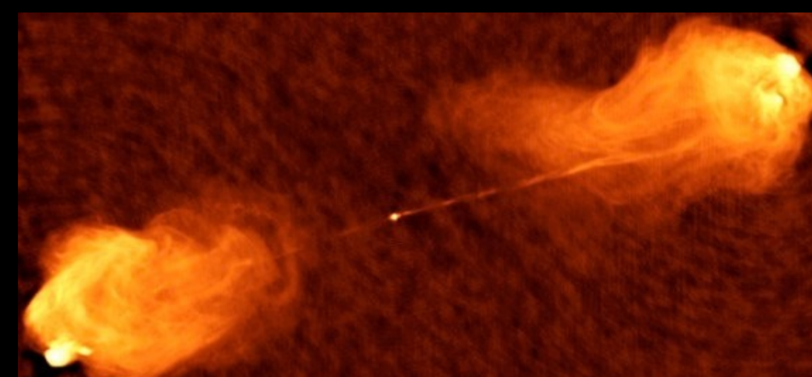


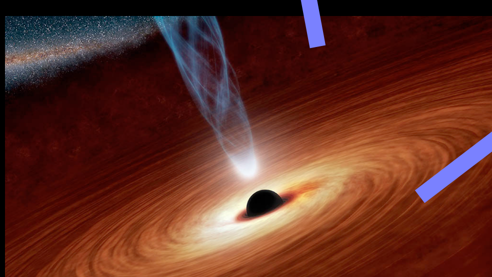
Gallimore 1997



high kinetic power mode of feedback

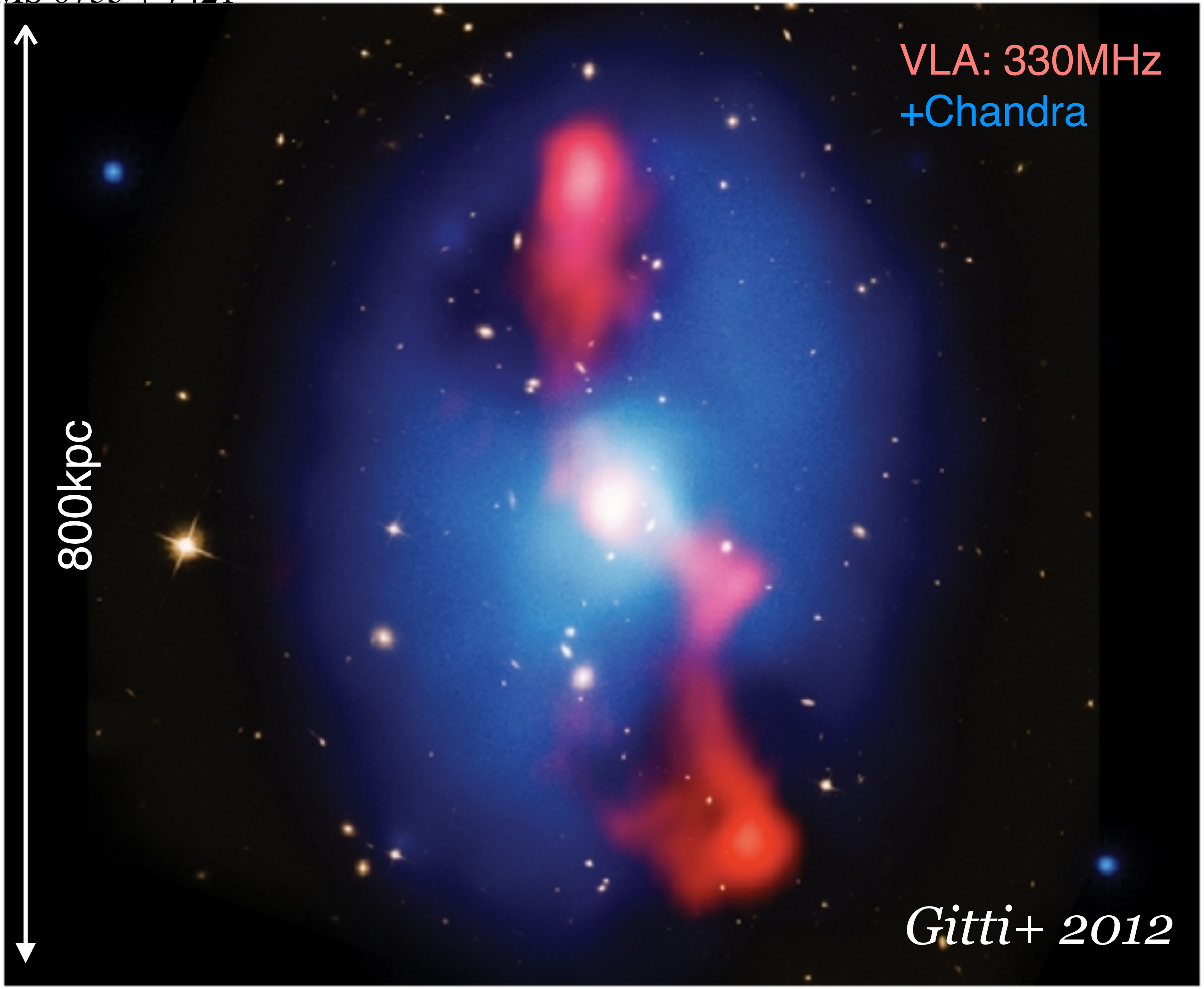
Wind mode of feedback



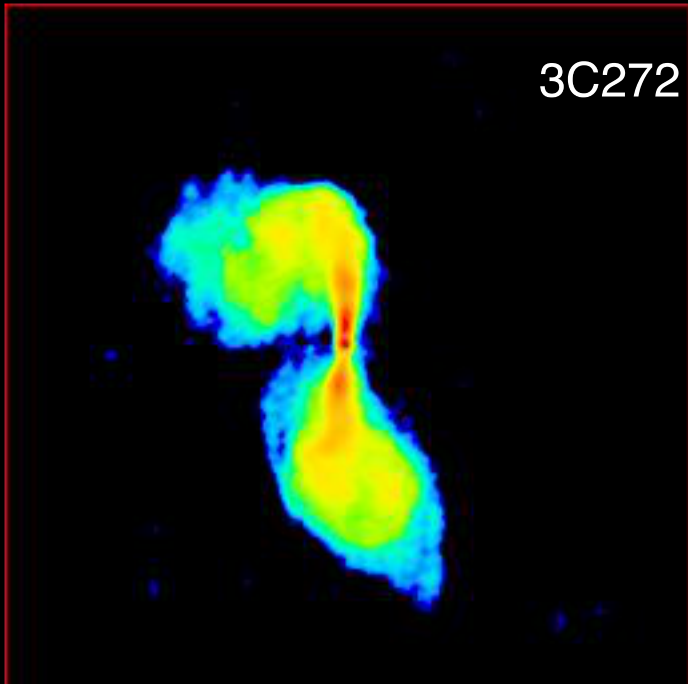


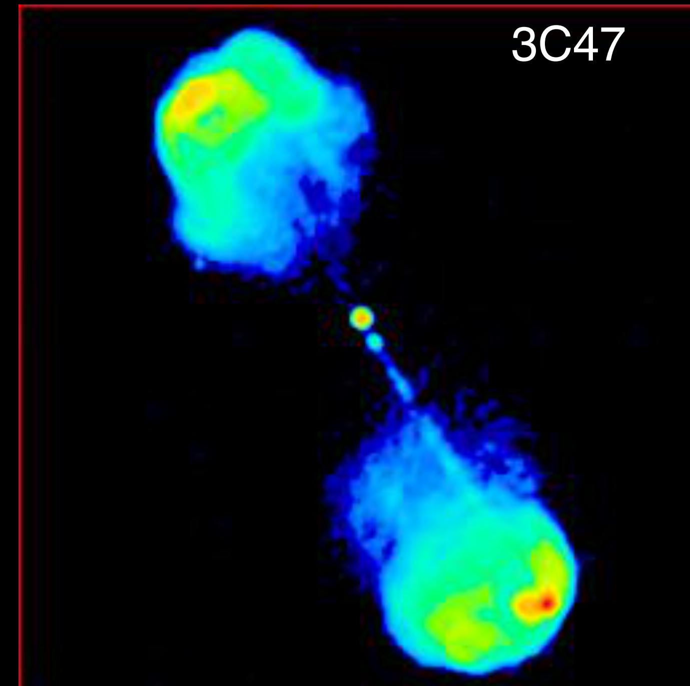
high kinetic power bulk-relativistic jets

MS 0735 + 7421

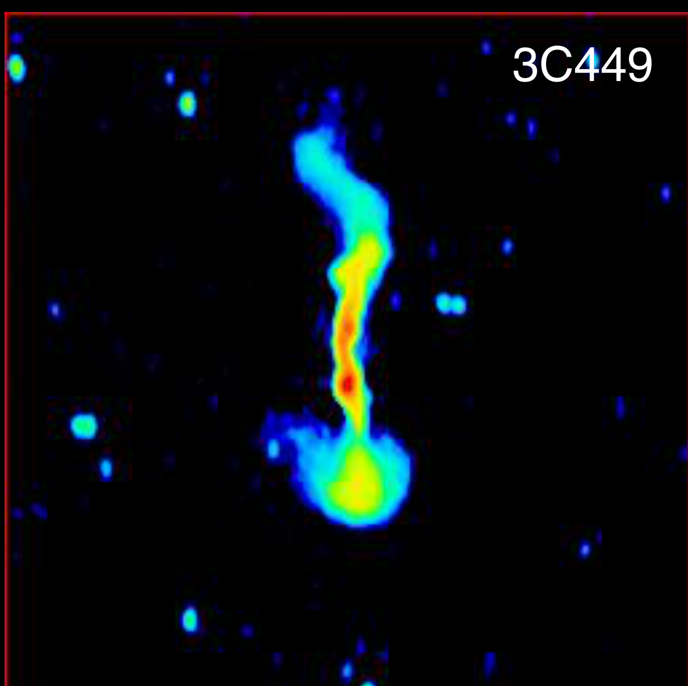


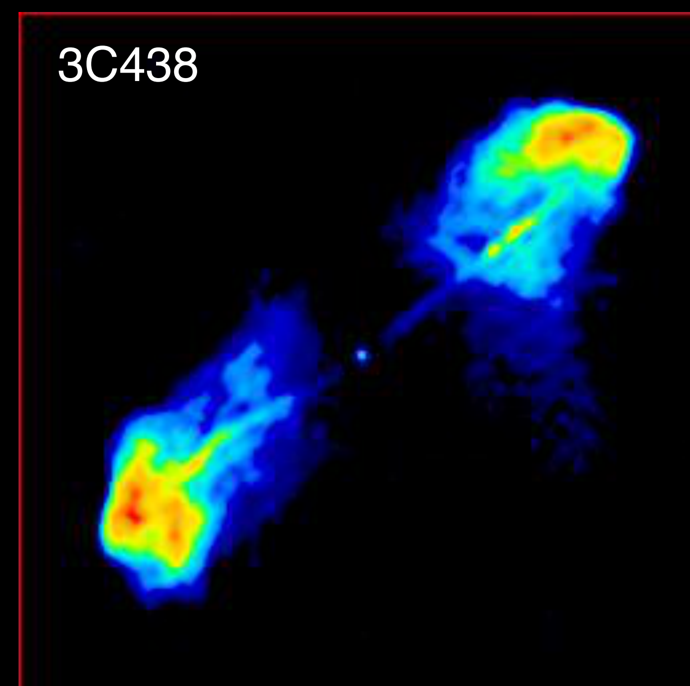
Bernie Fanaroff & Julia Riley's Discovery of 1974





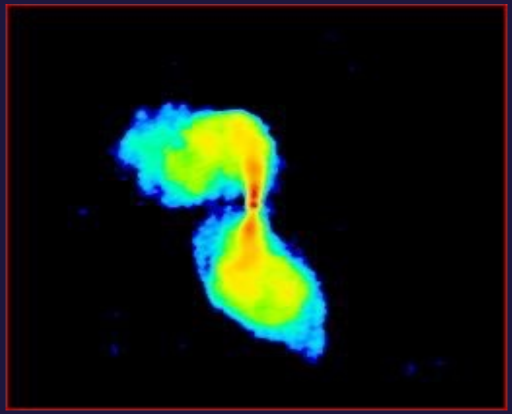
$$L_{178MHz}:$$
$$2 \times 10^{25}\, W\, Hz^{-1}$$

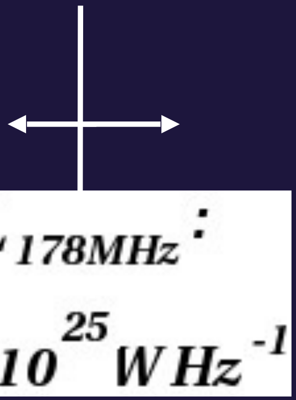




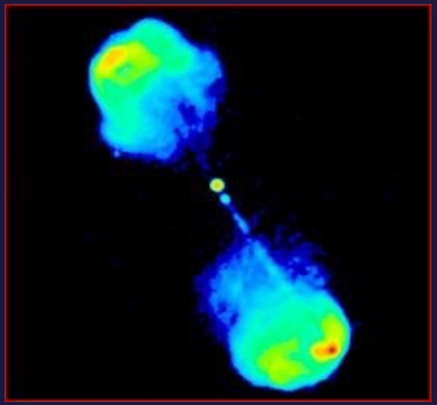
The Systematic differences between the two Fanaroff-Riley types

FR Type 1





FR Type II

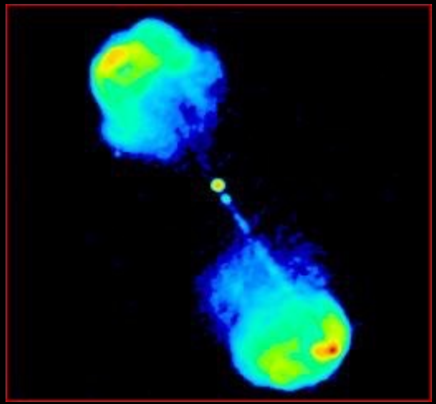


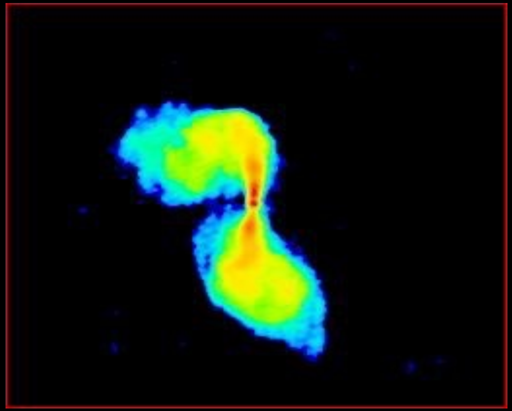
Low radio luminosity
Plume-like jets
Jets fade with distance from core

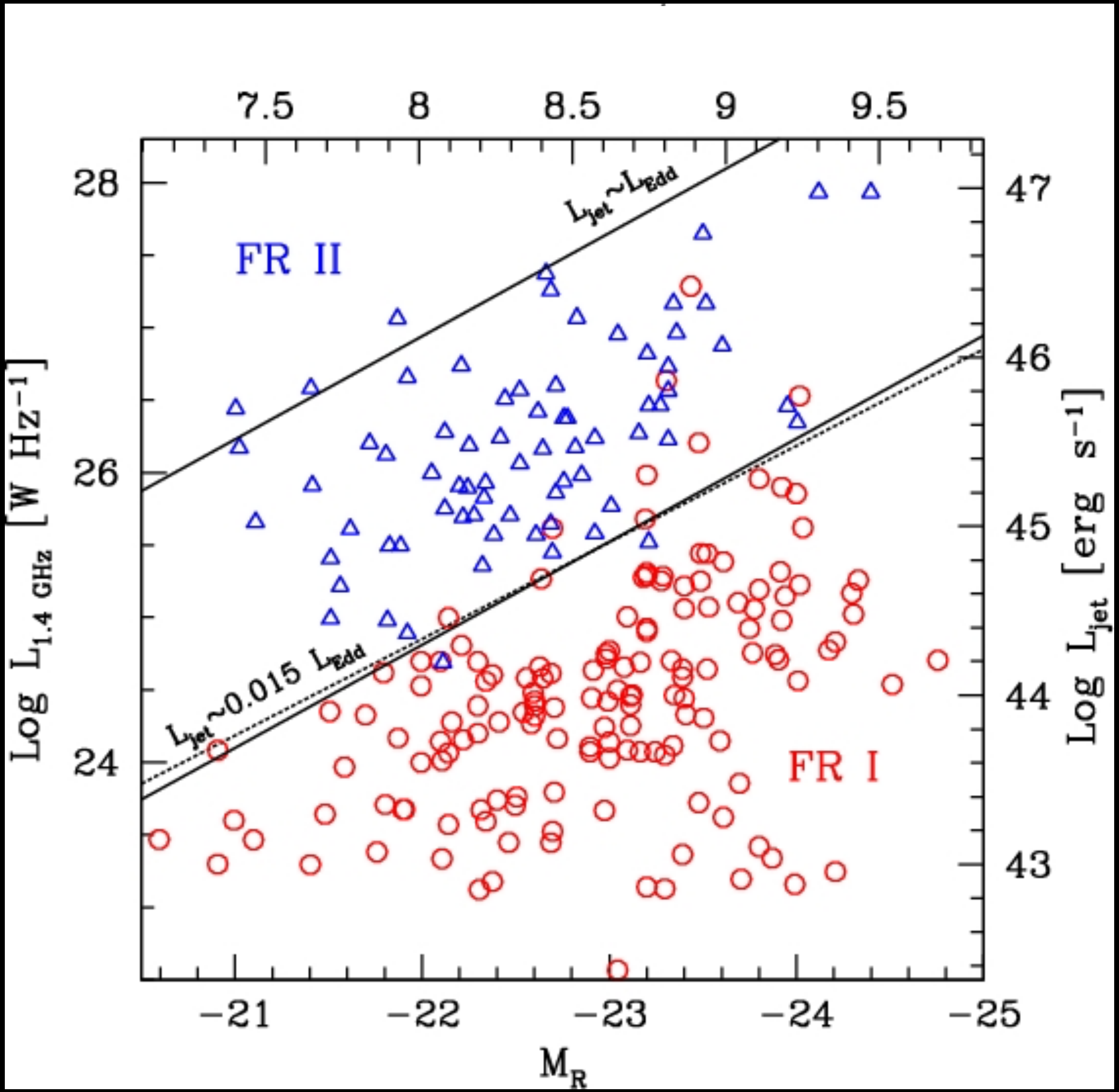
High radio luminosity
Narrow collimated jets
Jets have terminal hotspots

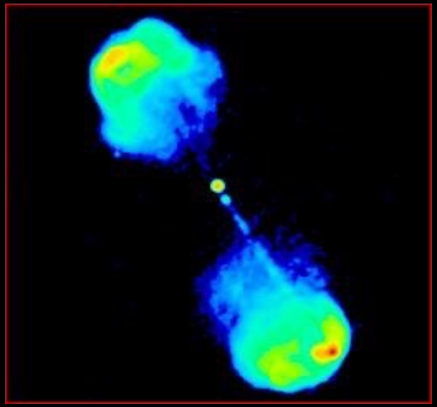
Mass of blackhole? Spin of blackhole?
Environment? Evolution?

Owen Ledlow Plot:

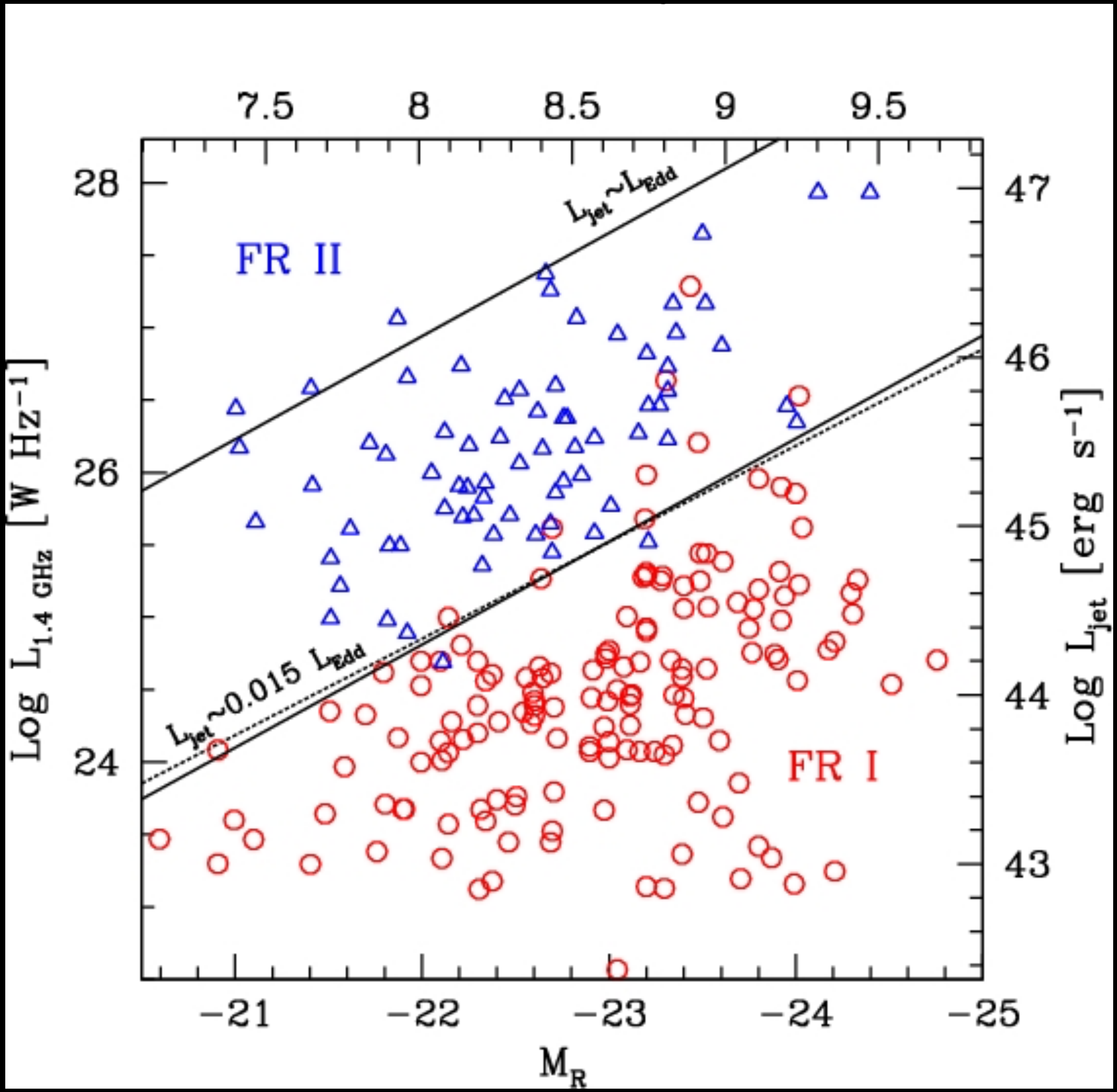








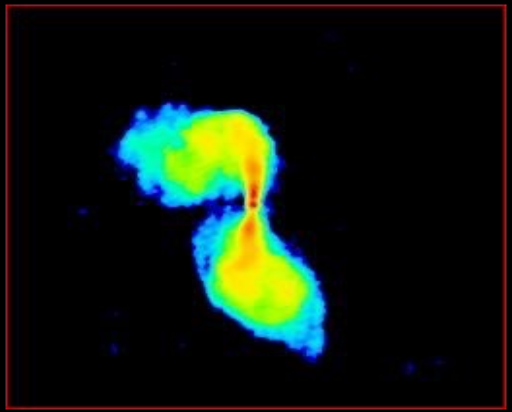
Owen Ledlow Plot:

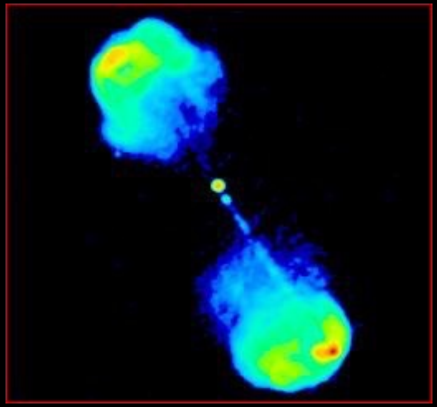


Bicknell 1998:

High galaxy luminosity => High mass

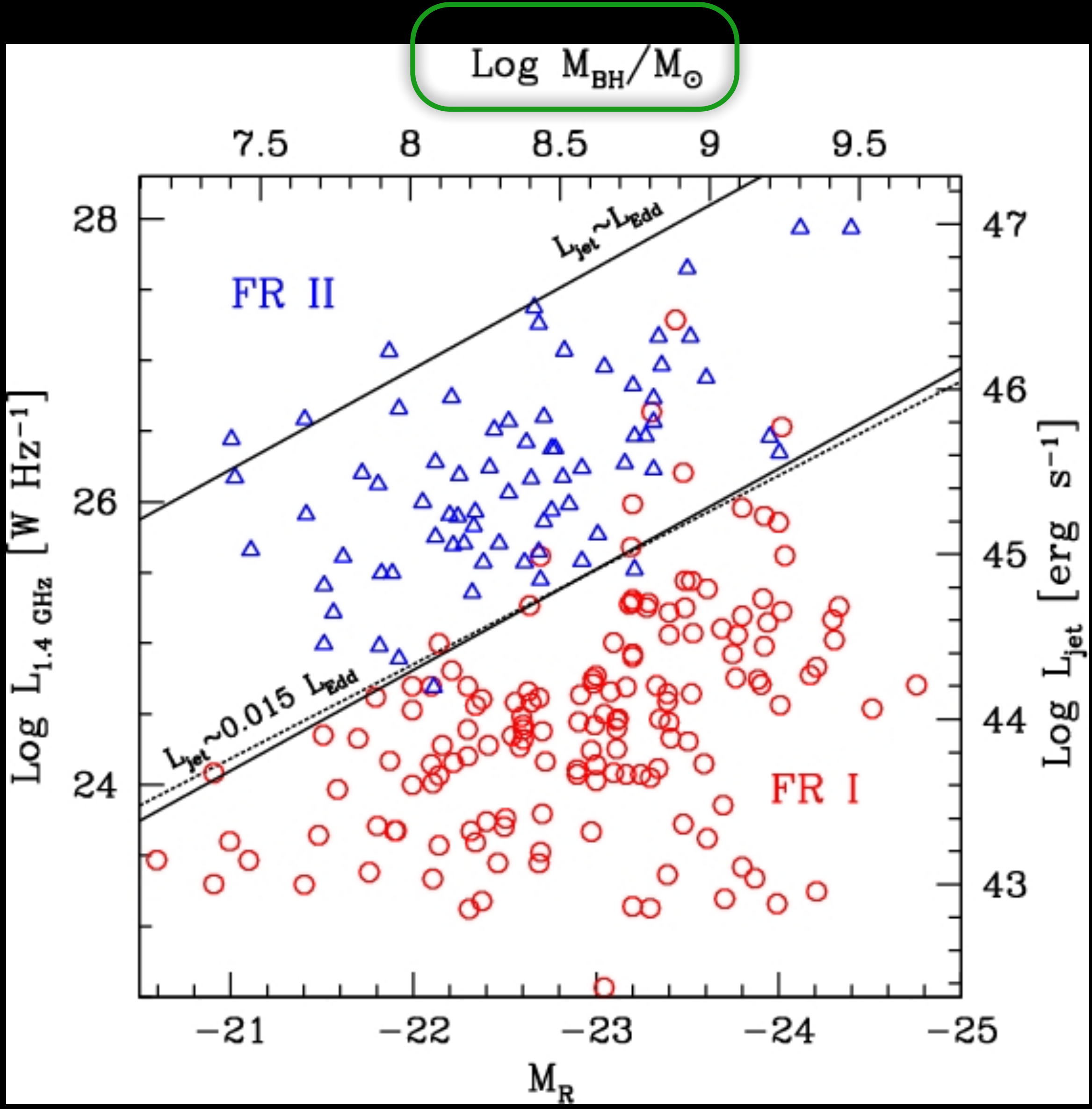
Only powerful jets can retain their thrust through the ISM and remain supersonic

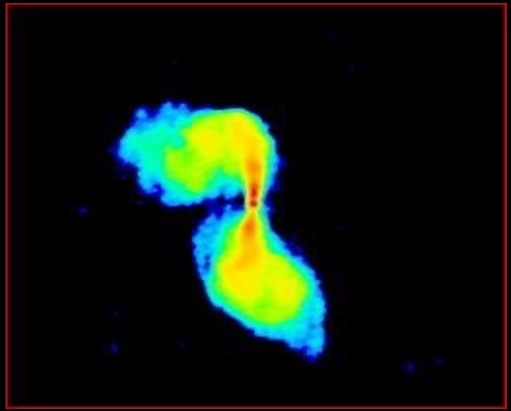




Owen Ledlow Plot:

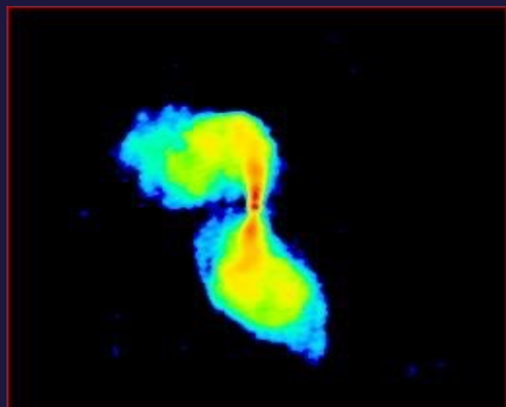
Scaling relations!
mass of the black hole?





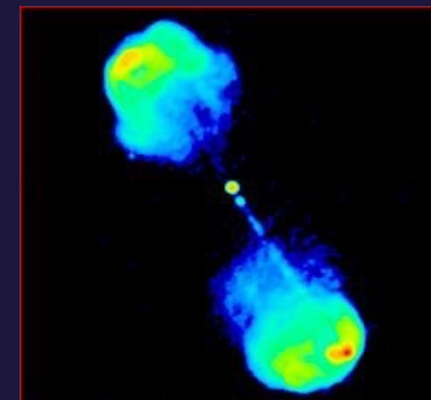
The Systematic differences between the two Fanaroff-Riley types

FR Type 1



L_{178MHz} : $2 \times 10^{25}\ W\,Hz^{-1}$

FR Type II



Low radio luminosity

Plume-like jets

Jets fade with distance from core

tend to occur in clusters of galaxies

Weak emission lines

Dust in extended discs

High radio luminosity

Narrow collimated jets

Jets have terminal hotspots

tend to not be in rich environments

Strong emission lines

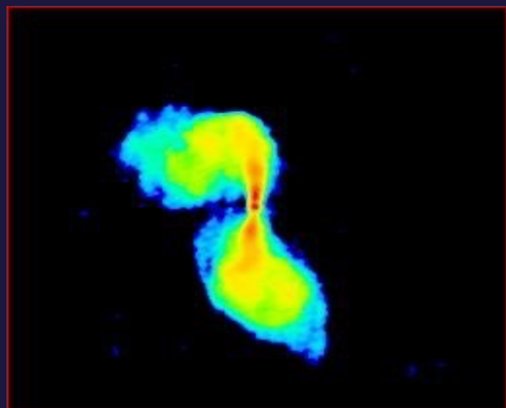
Dust with varied morphology

Mass of blackhole? Spin of blackhole?

Environment? Evolution?

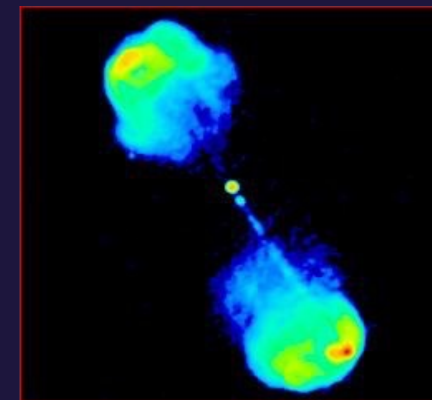
The Systematic differences between the two Fanaroff-Riley types

FR Type 1



$$L_{178MHz}: \quad 2 \times 10^{25}\ W\,Hz^{-1}$$

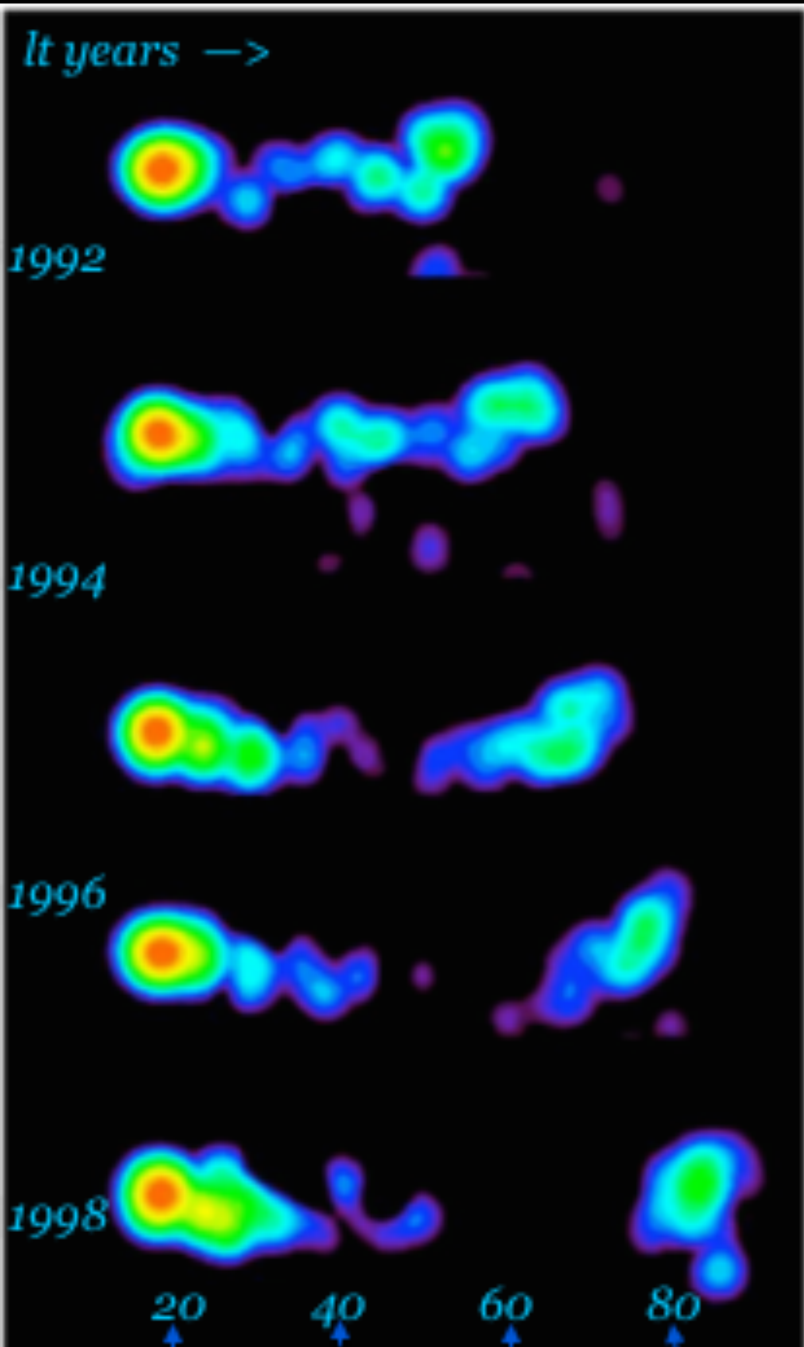
FR Type II

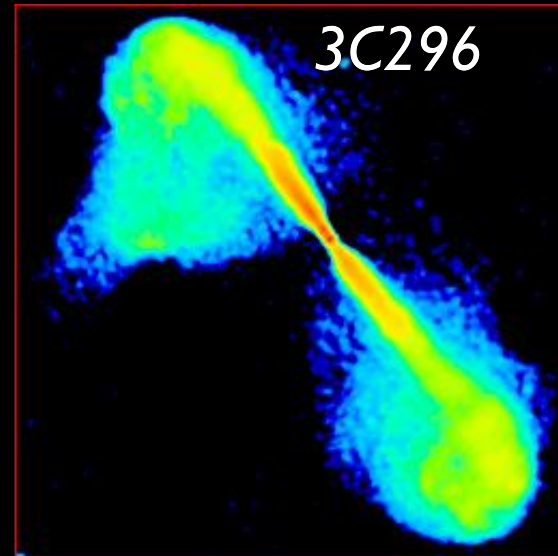


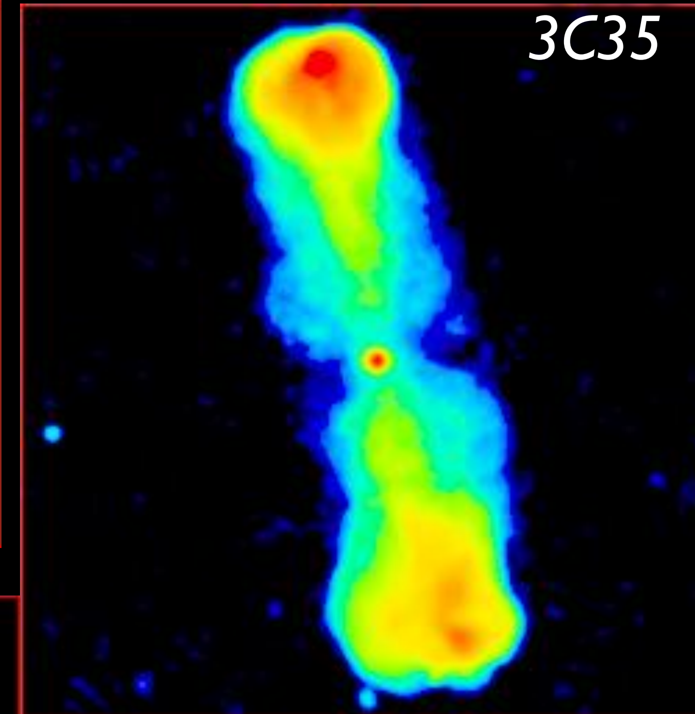
Low radio luminosity
Plume-like jets
Jets fade with distance from core
Weak emission lines
Dust in extended discs

High radio luminosity
Narrow collimated jets
Jets have terminal hotspots
Strong emission lines
Dust with varied morphology

Gopal Krishna & Wiita 2000:
Galaxies with Hybrid Fanaroff-Riley Morphology:
=> Environment!


lt years —>
1992
1994
1996
1998
20
40
60
80


3C296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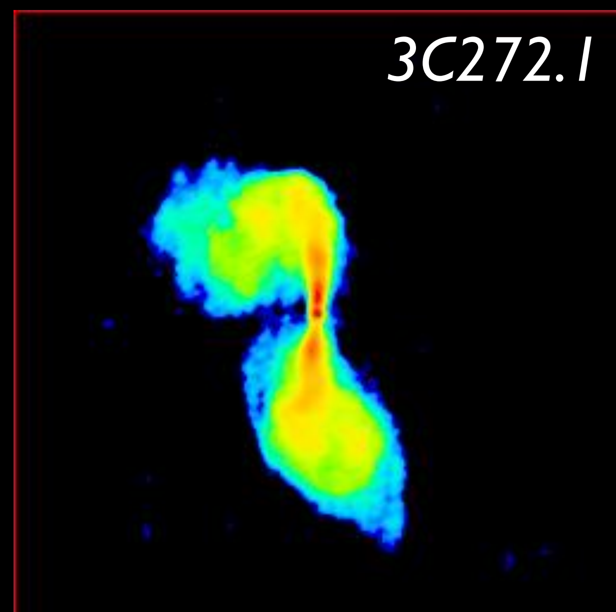
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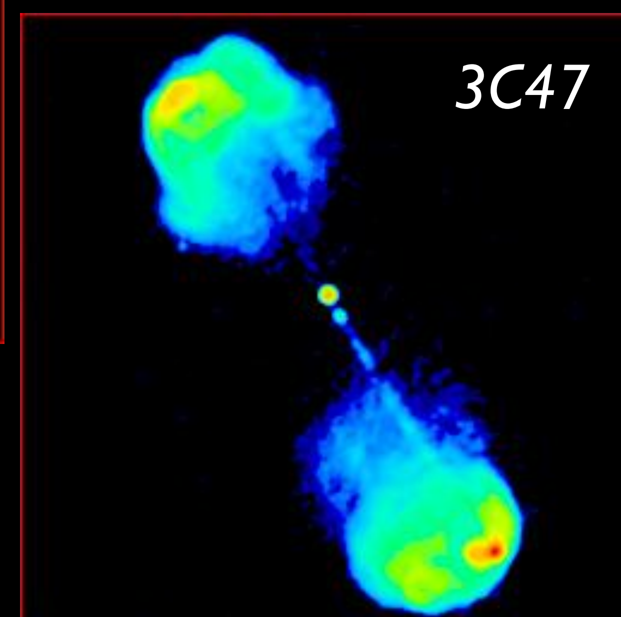
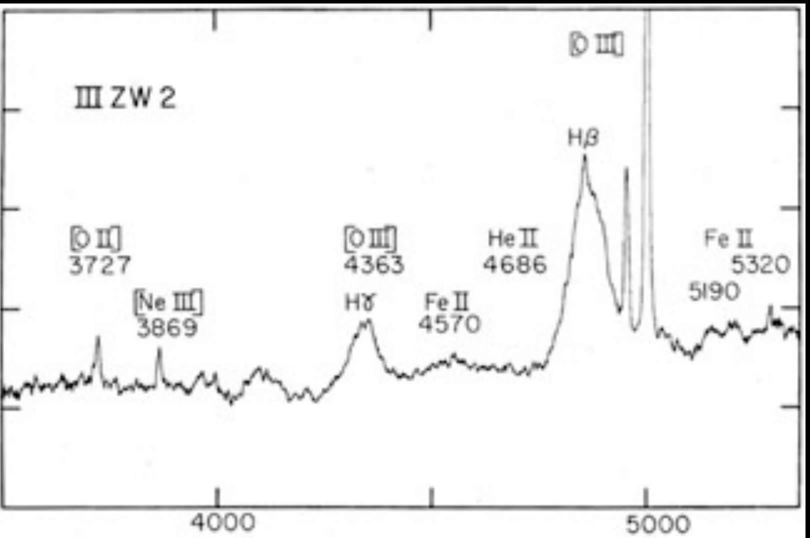
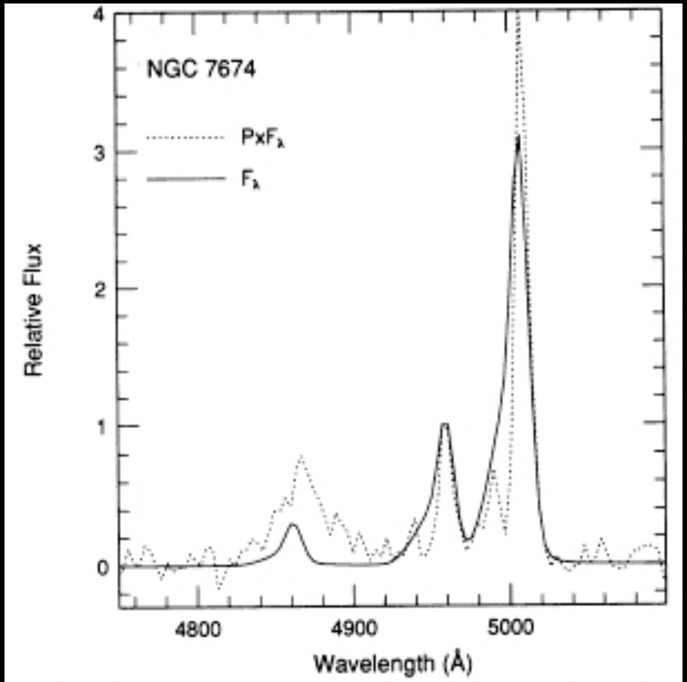

3C47

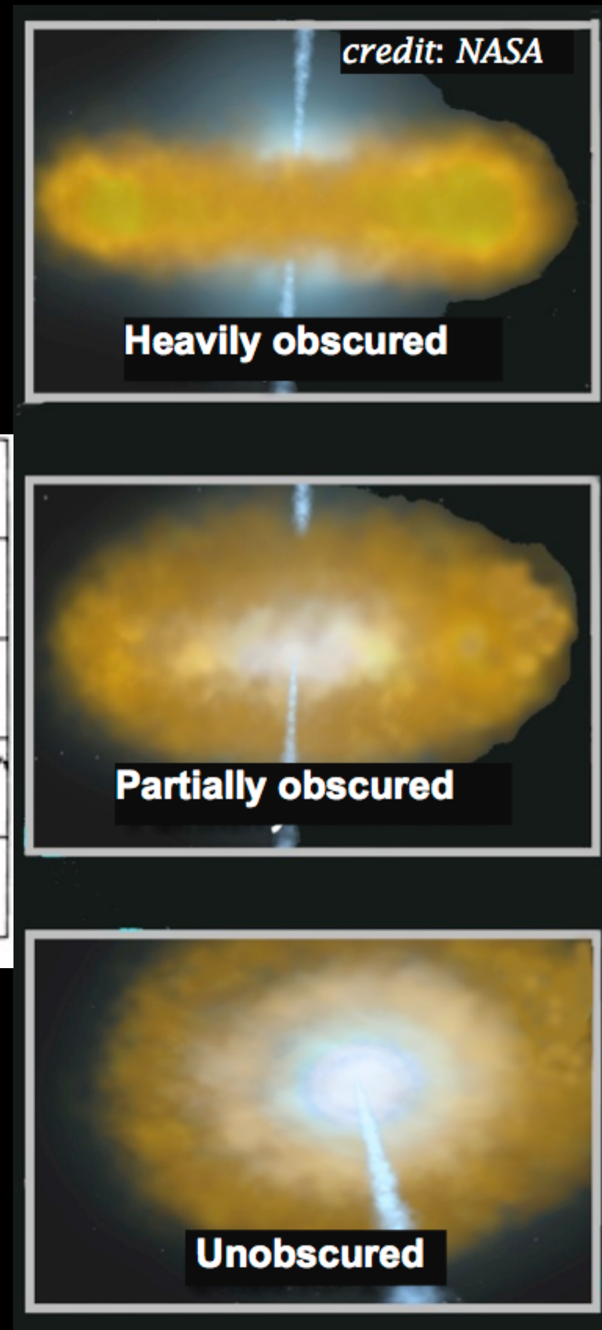
Type 2



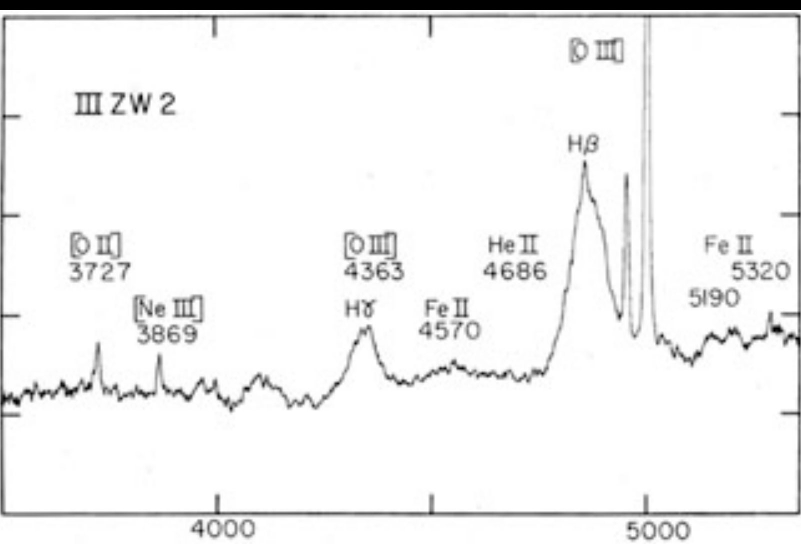
III ZW 2
[O II]
3727
[Ne III]
3869
[O III]
4363
Hγ
Fe II
4570
He II
4686
Hβ
[O III]
Fe II
5320
5190
4000
5000

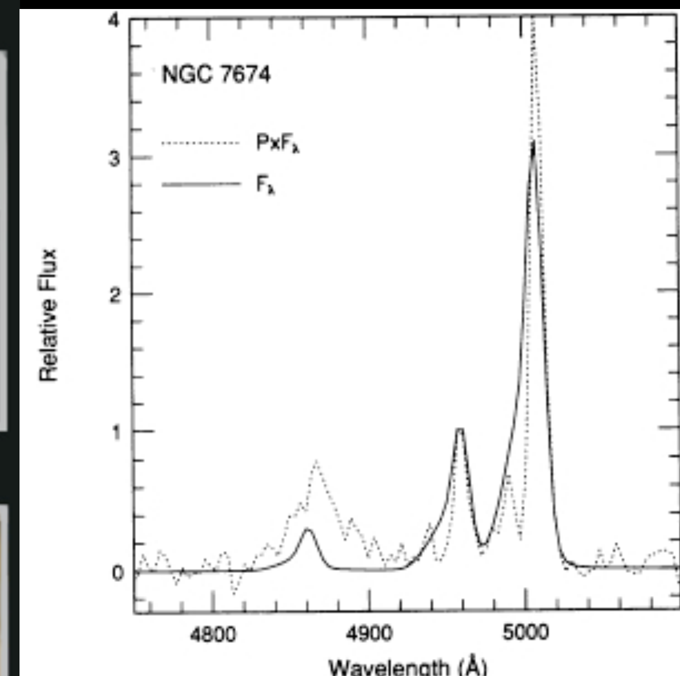


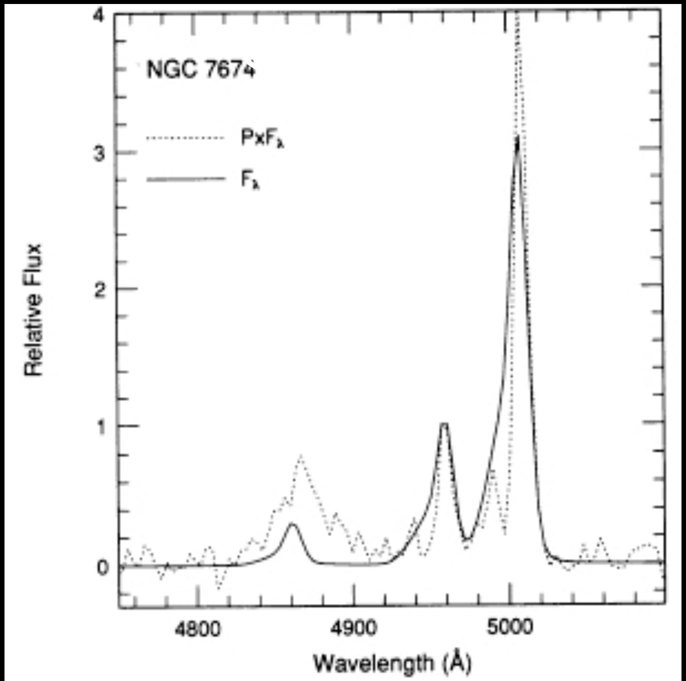
NGC 7674
PxFλ
Fλ
Relative Flux
Wavelength (Å)
4800
4900
5000
0
1
2
3
4


credit: NASA
Heavily obscured
Partially obscured
Unobscured

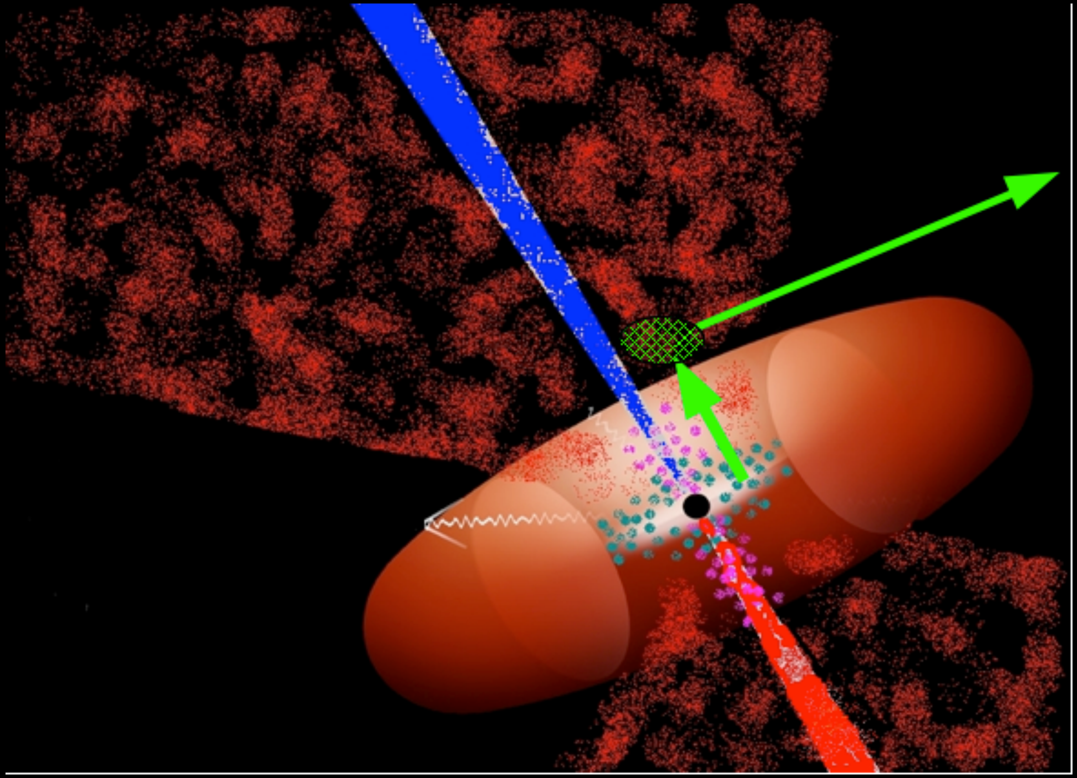
Type 2


III ZW 2
[O II]
3727
[Ne III]
3869
[O III]
4363
Hγ
Fe II
4570
He II
4686
Hβ
[O III]
Fe II
5320
5190
4000
5000

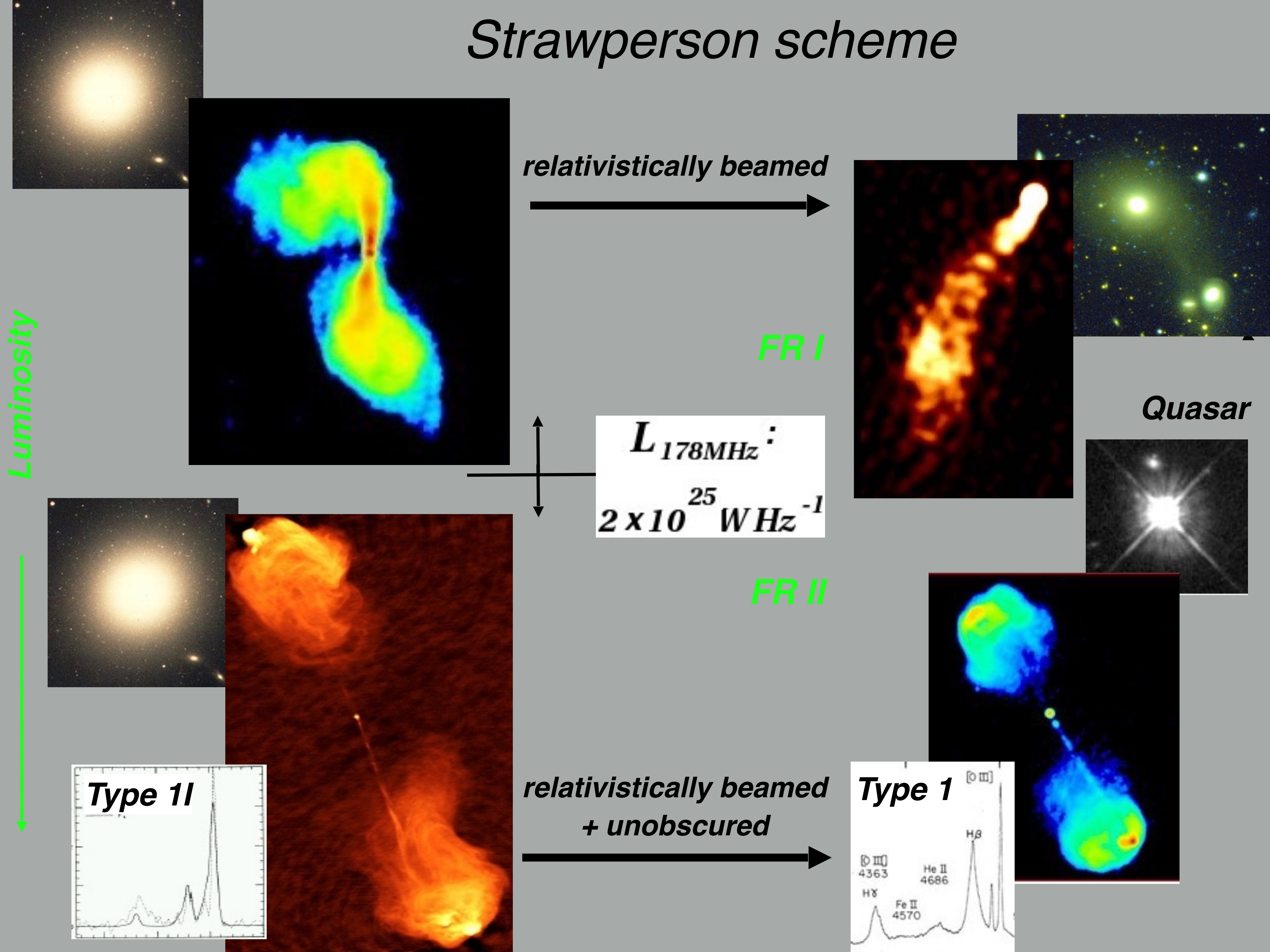

NGC 7674
$P \times F_\lambda$
F_λ
Relative Flux
Wavelength (Å)
0
1
2
3
4
4800
4900
5000



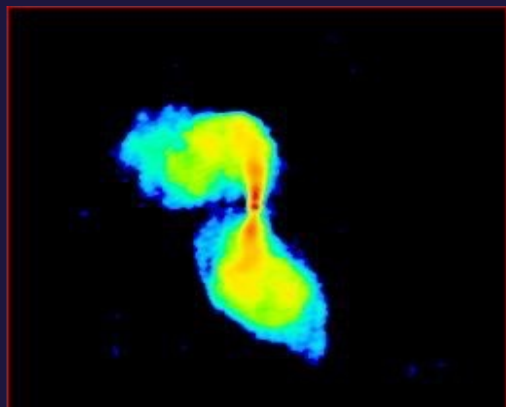
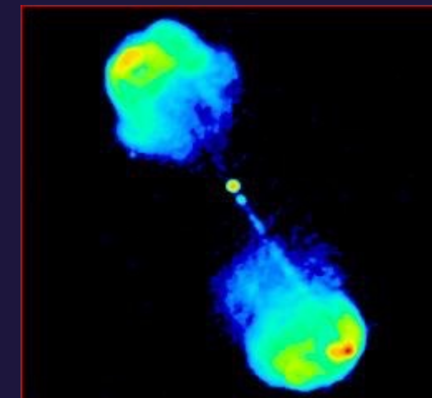
NGC 7674
PxF$_\lambda$
F$_\lambda$
Relative Flux
Wavelength (Å)
4800
4900
5000
0
1
2
3
4



Strawperson scheme



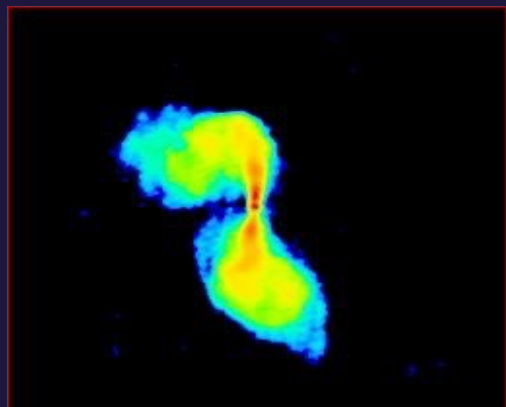
The Systematic differences between the two Fanaroff-Riley types

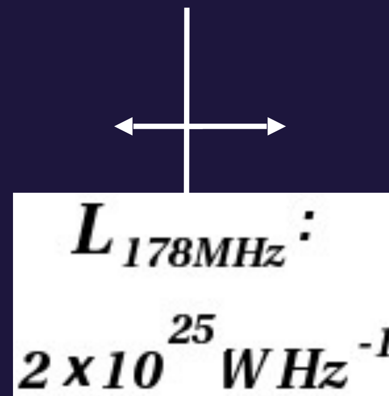
FR Type 1		**FR Type II**
	L_{178MHz}: 2×10^{25} $W Hz^{-1}$	
Low radio luminosity		*High radio luminosity*
Plume-like jets		*Narrow collimated jets*
Jets fade with distance from core		*Jets have terminal hotspots*
Weak emission lines		*Strong emission lines*
Dust in extended discs		*Dust with varied morphology*
Nuclear polarisation detection rate high		*Nuclear polarisation detection rate low*

Kharb, Shastri 2004; Kharb Shastri Gabuzda :
tied in with results of Gabuzda+ and others for the beamed AGN

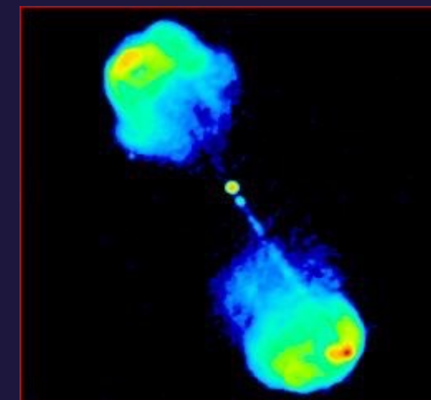
The Systematic differences between the two Fanaroff-Riley types

FR Type 1





FR Type II

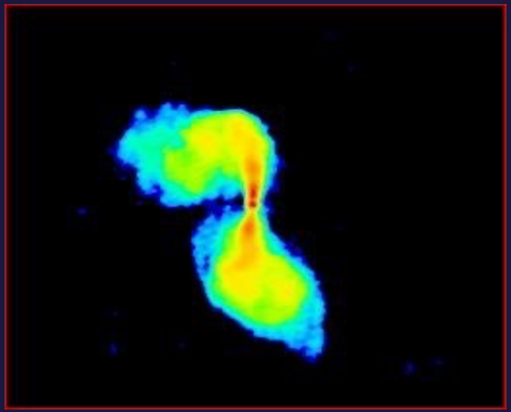


FR Type 1	FR Type II
Low radio luminosity	*High radio luminosity*
Plume-like jets	*Narrow collimated jets*
Jets fade with distance from core	*Jets have terminal hotspots*
Weak emission lines	*Strong emission lines*
Dust in extended discs	*Dust with varied morphology*
Nuclear polarisation detection rate high	*Nuclear polarisation detection rate low*

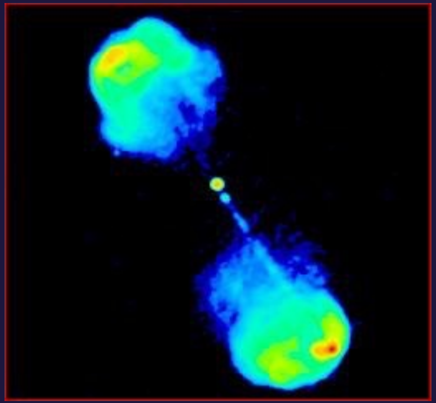
Browne & Battye 2011: parallel minor axis for the weaker FRIs; Saripalli Subrahmanyam 2009: giant radio galaxies: minor axis parallel to radio axis

The Systematic differences between the two Fanaroff-Riley types

FR Type 1



FR Type II



L_{178MHz} :

2×10^{25} W Hz^{-1}

FR Type 1:

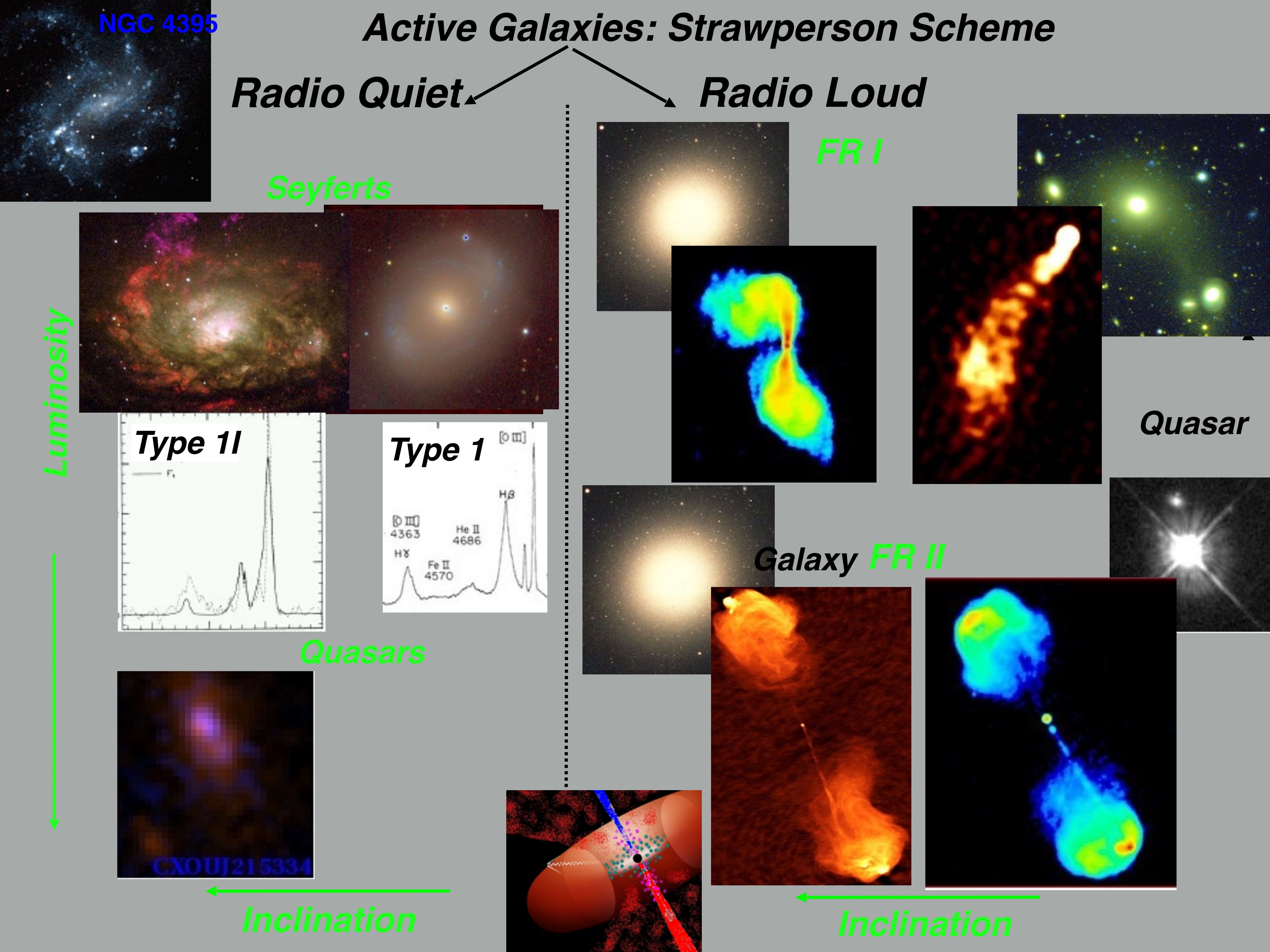
- Low radio luminosity
- Plume-like jets
- Jets fade with distance from core
- Weak emission lines?
- Dust in extended discs
- Nuclear radio polarisation detection rate high
- Dust <250pc, small masses, normal to radio axis

FR Type II:

- High radio luminosity
- Narrow collimated jets
- Jets have terminal hotspots
- Strong emission lines?
- Dust with varied morphology
- detection rate low
- Dust >250pc, large masses, no relatio to radio axis

Difference in feeding? Impulsive feeding vs steady feeding? (e.g. Baum+1992, Saripalli 2012)

Active Galaxies: Strawperson Scheme



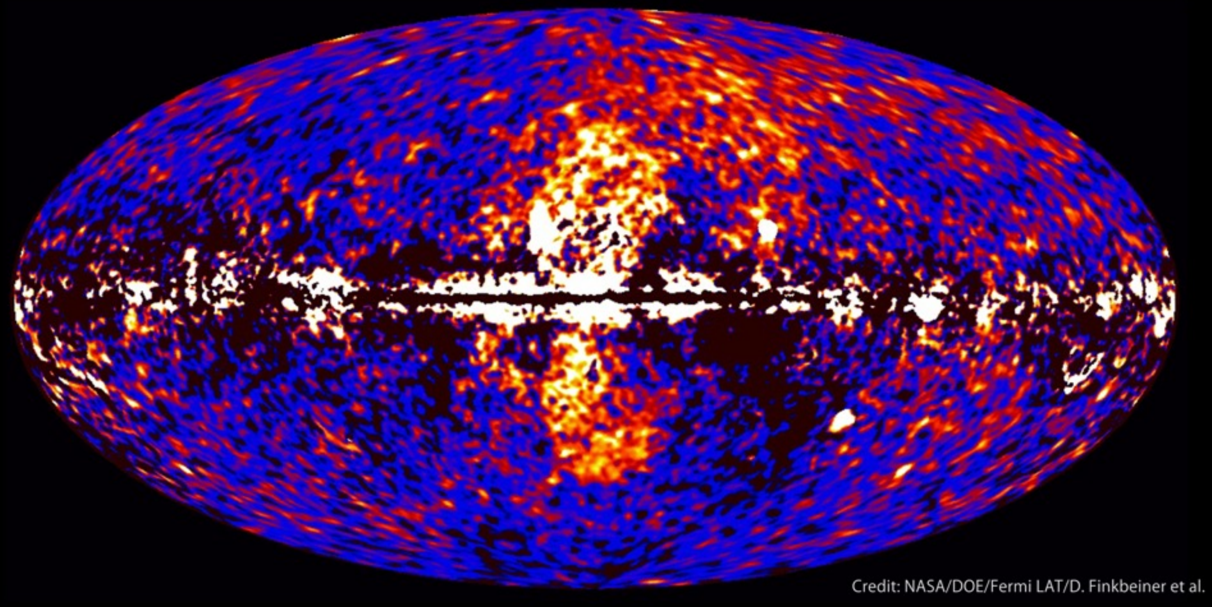
Contrary!

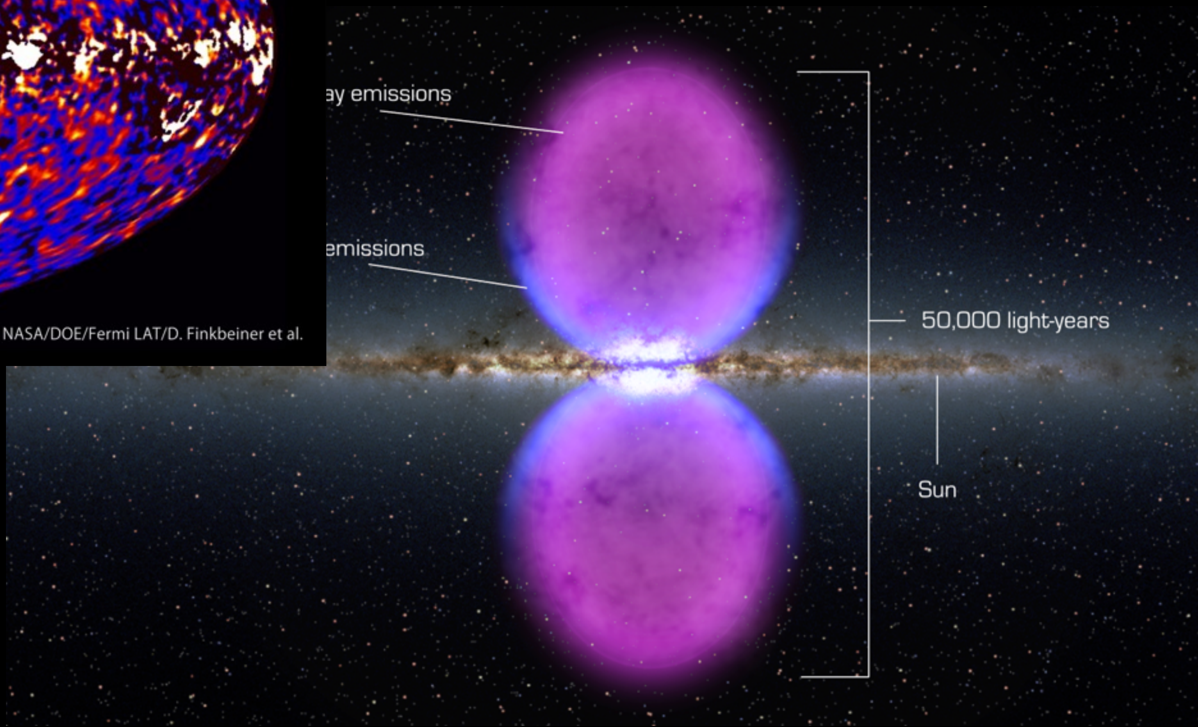
Simonescu:
Serendipitous discovery of an extended X-ray jet without a radio counterpart in a high-redshift quasar

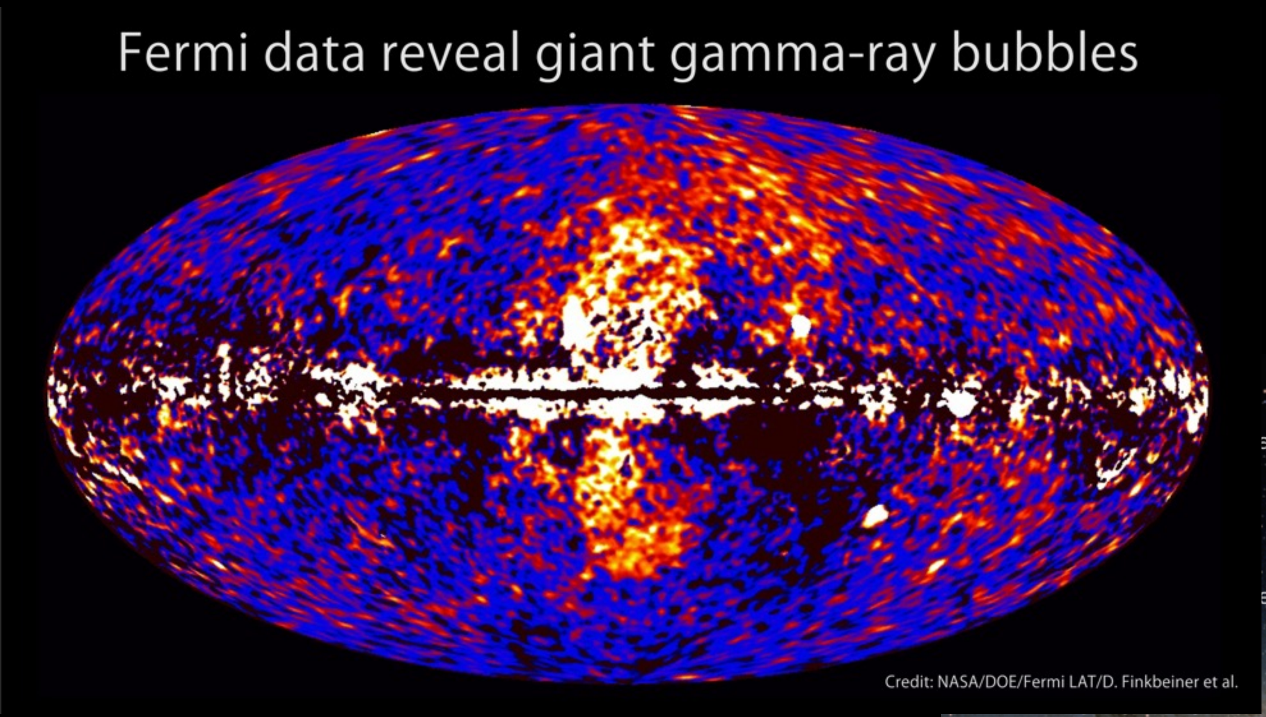
Bagchi:
Megaparsec Relativistic Jets Launched from an Accreting Supermassive Black Hole in an Extreme Spiral Galaxy

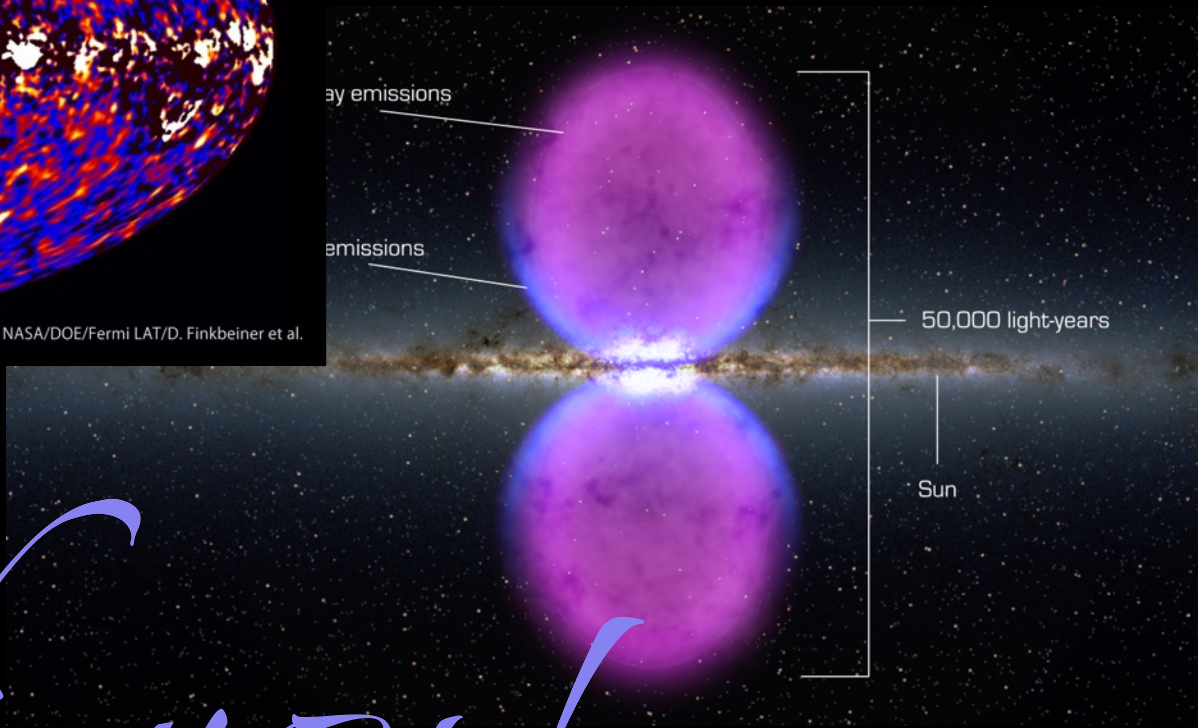
Singh:
Kiloparsec-scale radio emission in Seyfert and LINER galaxies

Fermi data reveal giant gamma-ray bubbles






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


ay emissions
emissions
50,000 light-years
Sun

Thank you!