



Istituto Nazionale di Astrofisica
Osservatorio astronomico di Brera



Universo in fiore

I Nuclei Galattici Attivi

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INAF-Osservatorio Astronomico di Brera

11 marzo 2015



United Nations
Educational, Scientific and
Cultural Organization



INTERNATIONAL
YEAR OF LIGHT
2015

2015 INTERNATIONAL YEAR OF LIGHT
AND LIGHT-BASED TECHNOLOGIES



Sommario

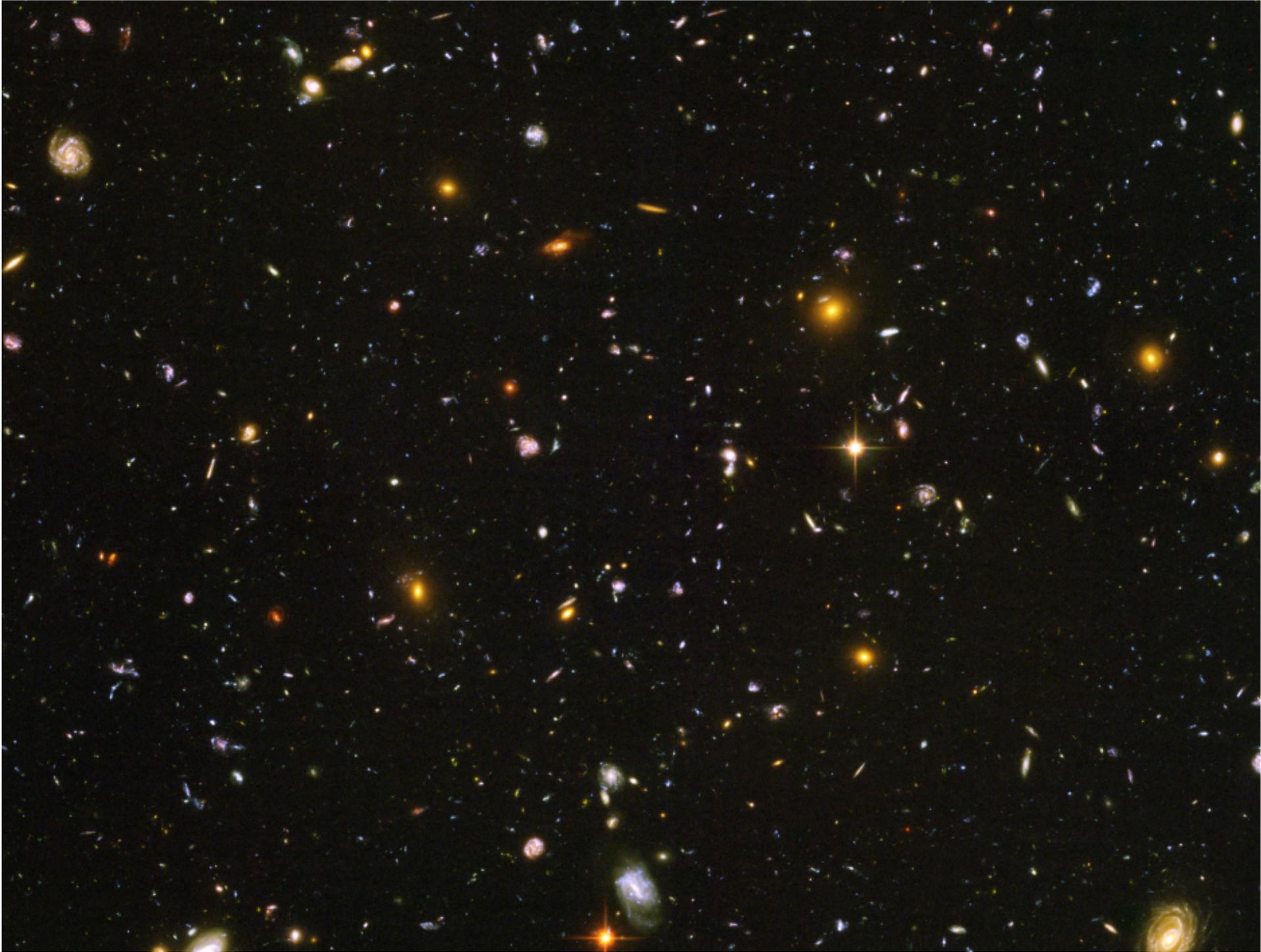
1. Un po' di storia (e ripasso)
2. Strane galassie e tassonomia
3. Proprietà degli AGN
4. Modello unificato
5. [Cosmologia]

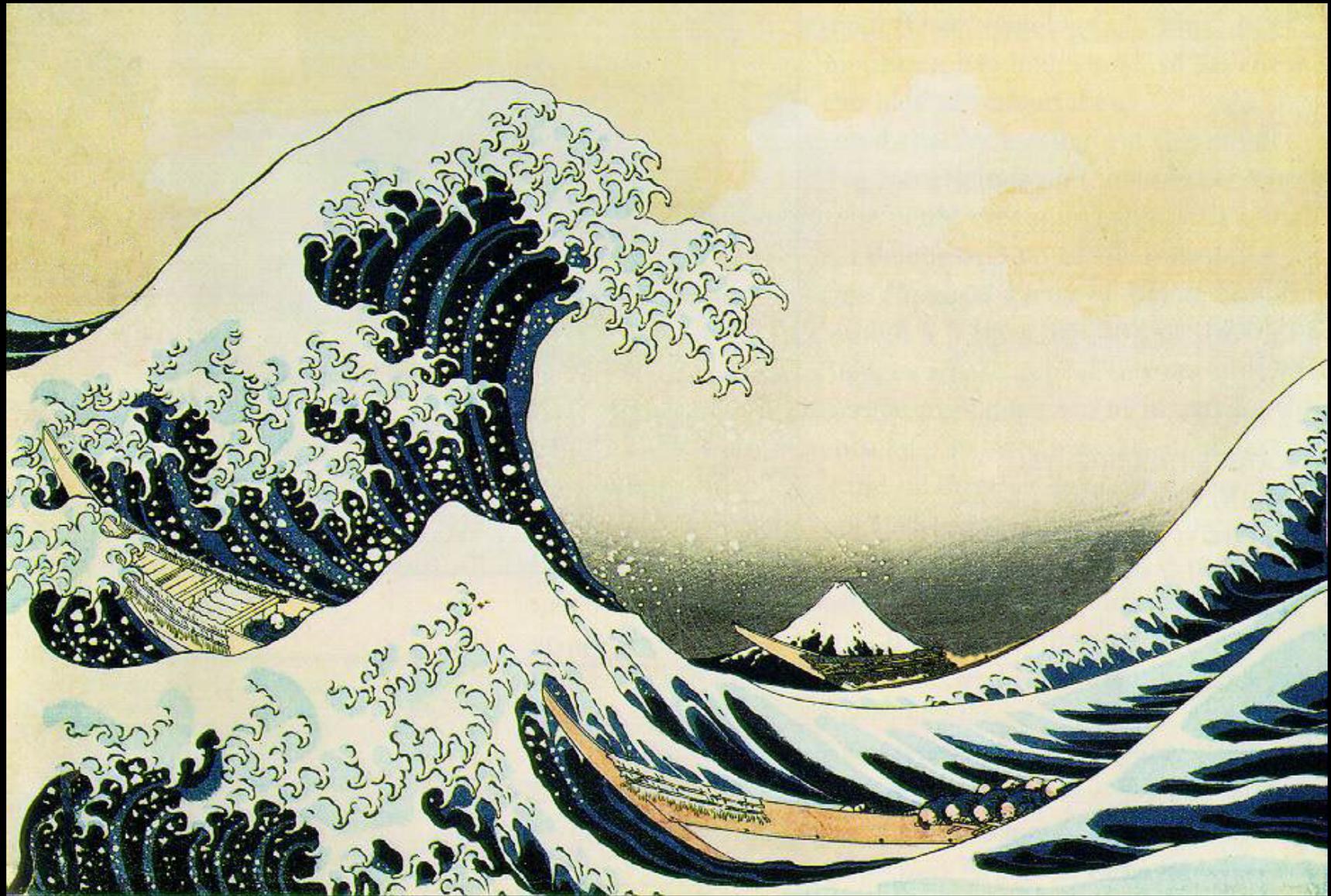
“L’unico vero viaggio verso la scoperta non consiste nella ricerca di nuovi paesaggi, ma nell’averne nuovi occhi”

Marcel Proust, *Alla ricerca del tempo perduto*

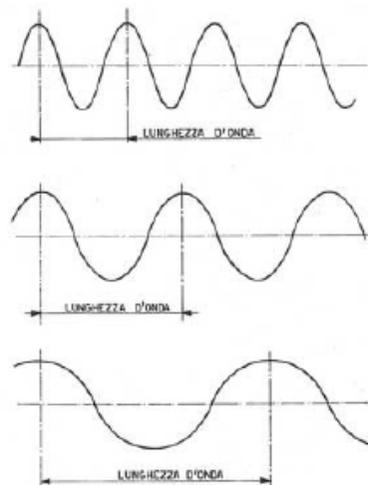
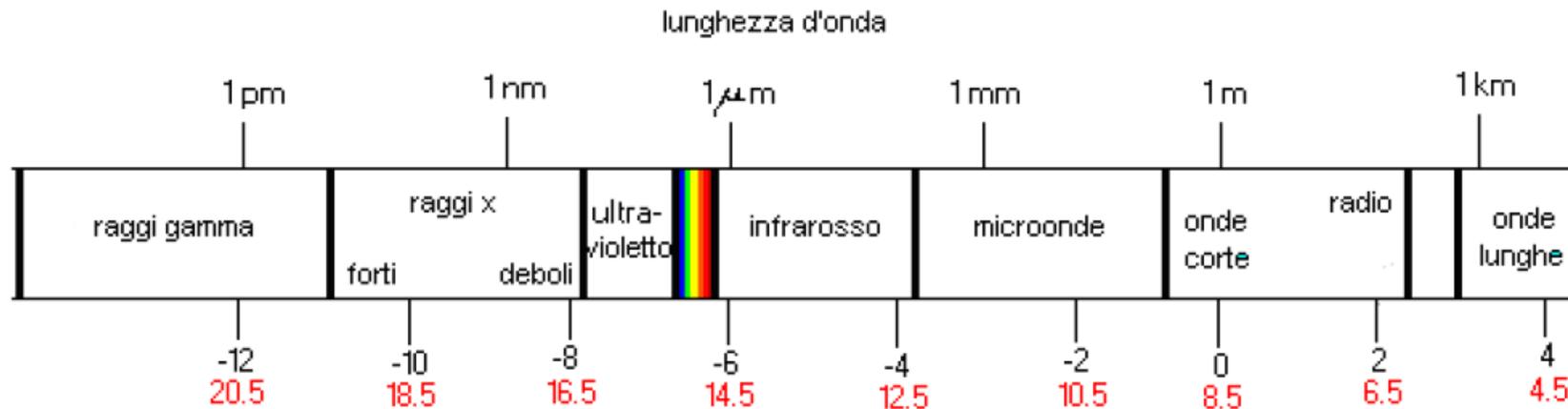
1

Un po' di ripasso



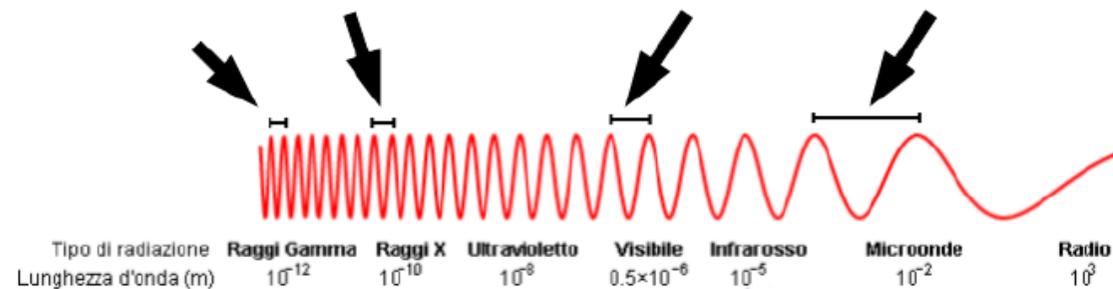


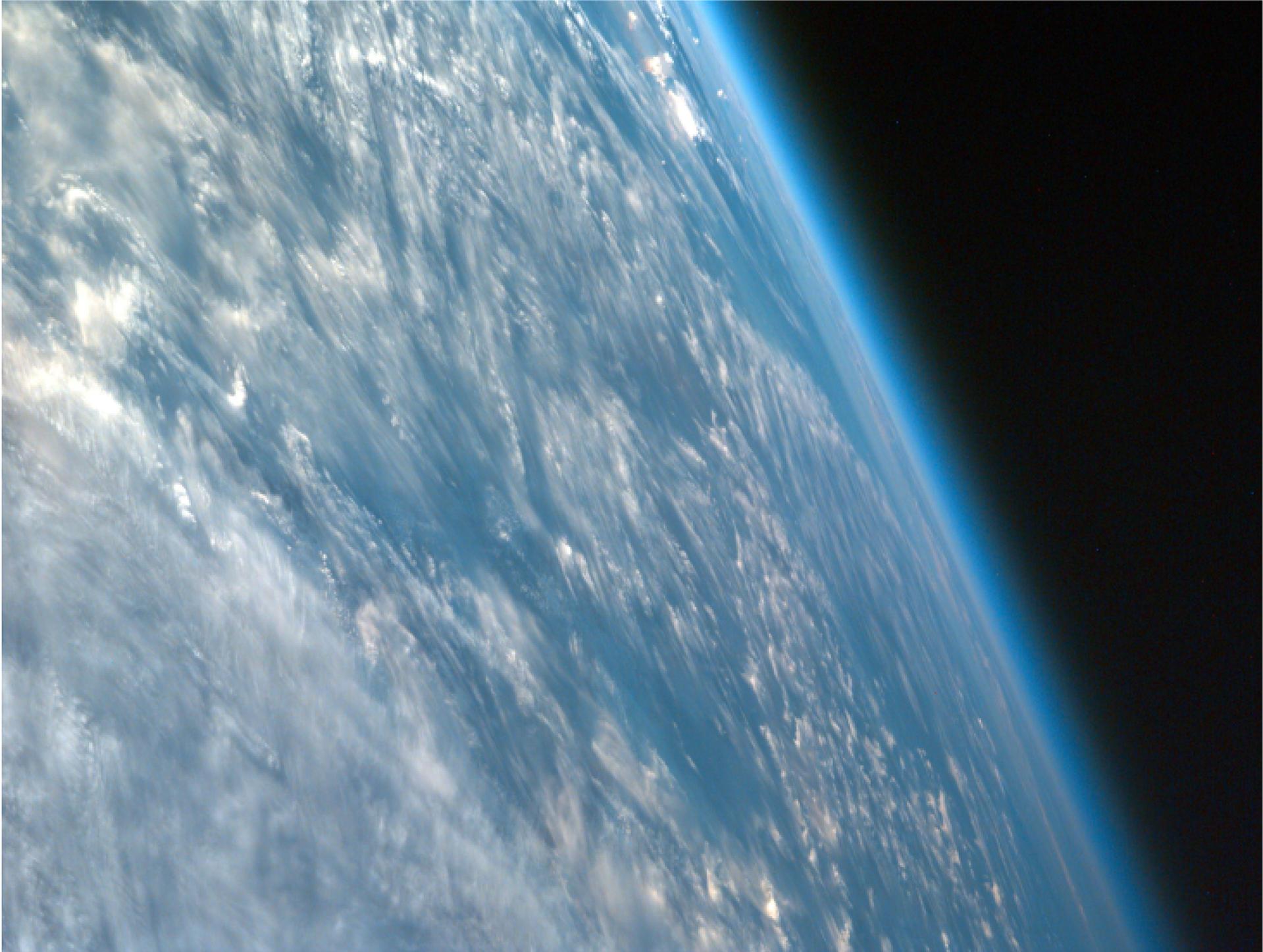
Proprietà della radiazione **luce** ottica



Schema 1
LUNGHEZZA D'ONDA

log lunghezza d'onda (m)
log frequenza (Hz)





$T = 12,000 \text{ K}$

$\lambda_m \approx 250 \text{ nm}$



$T = 6000 \text{ K}$

$\lambda_m \approx 500 \text{ nm}$

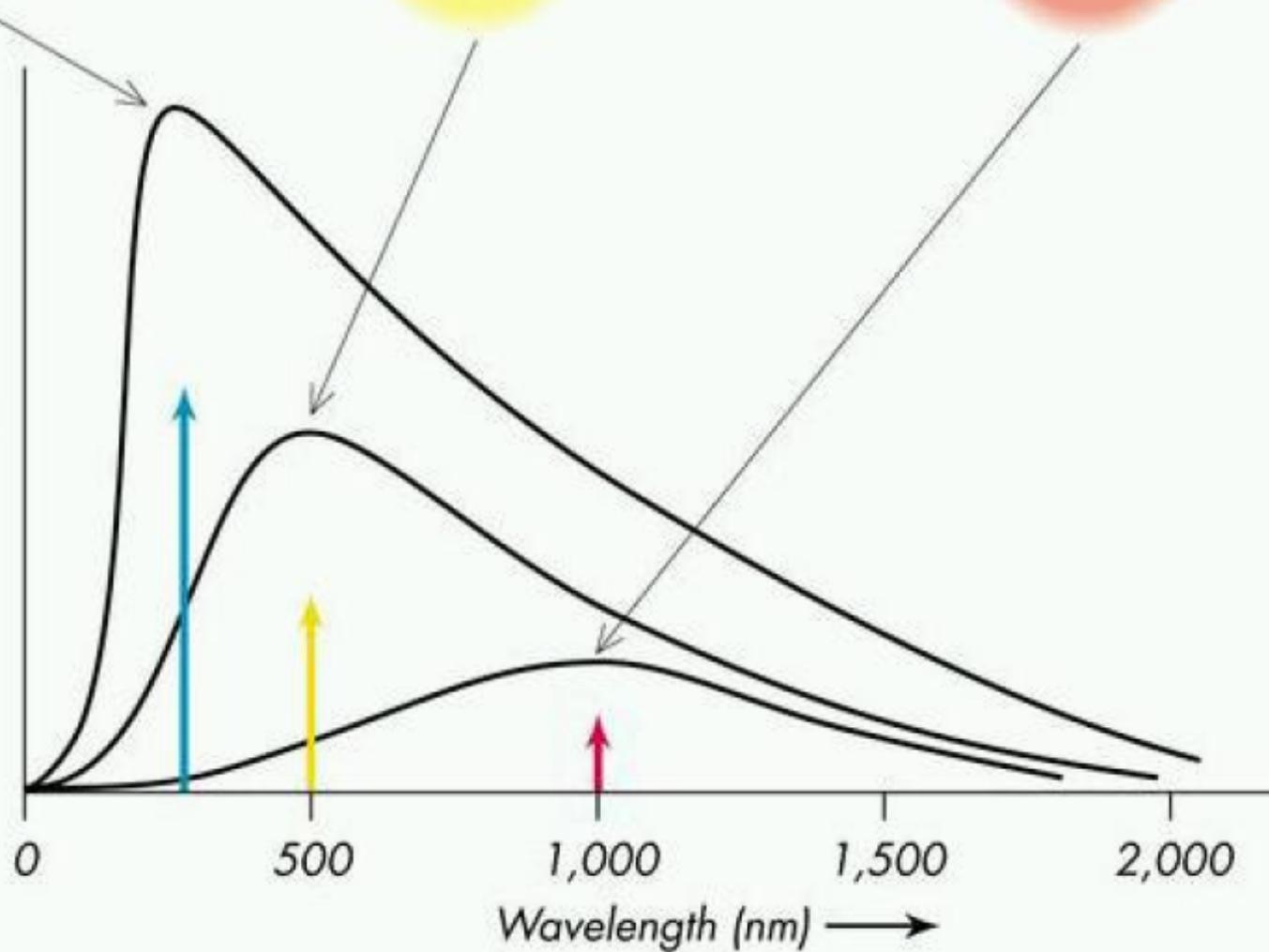


$T = 3000 \text{ K}$

$\lambda_m \approx 1000 \text{ nm}$

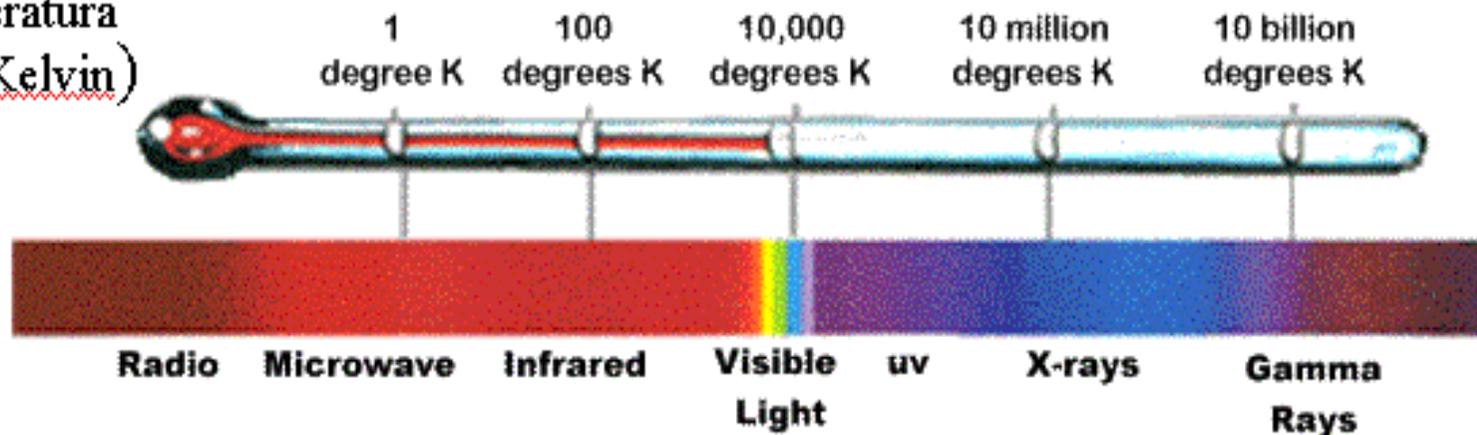


Brightness ↑



Radiazione Termica

Temperatura
(gradi Kelvin)

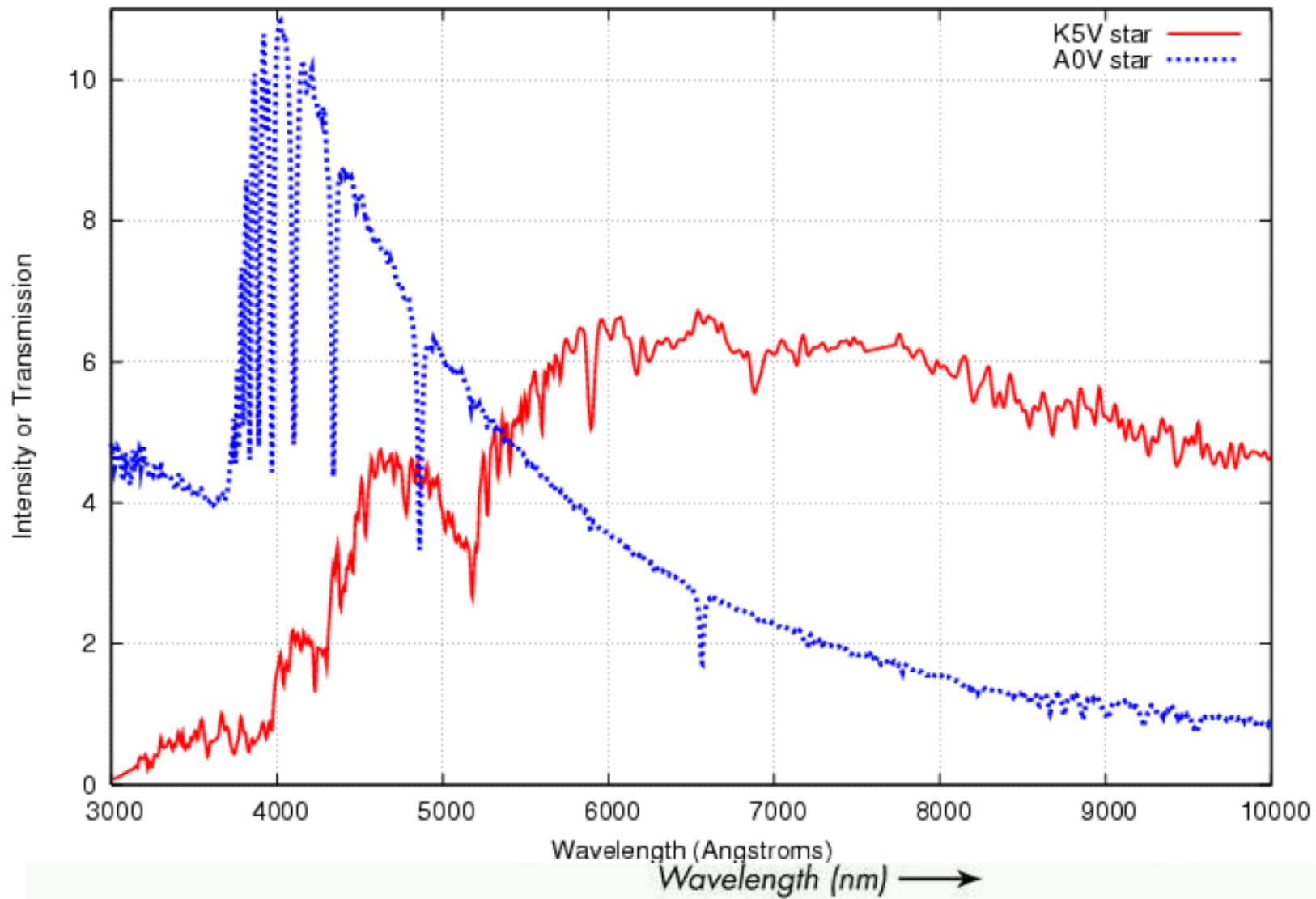


Lunghezza
d'onda

WAVELENGTH

Note: degrees Kelvin (K) = degrees Celsius (C) + 273

Spectra of ordinary stars

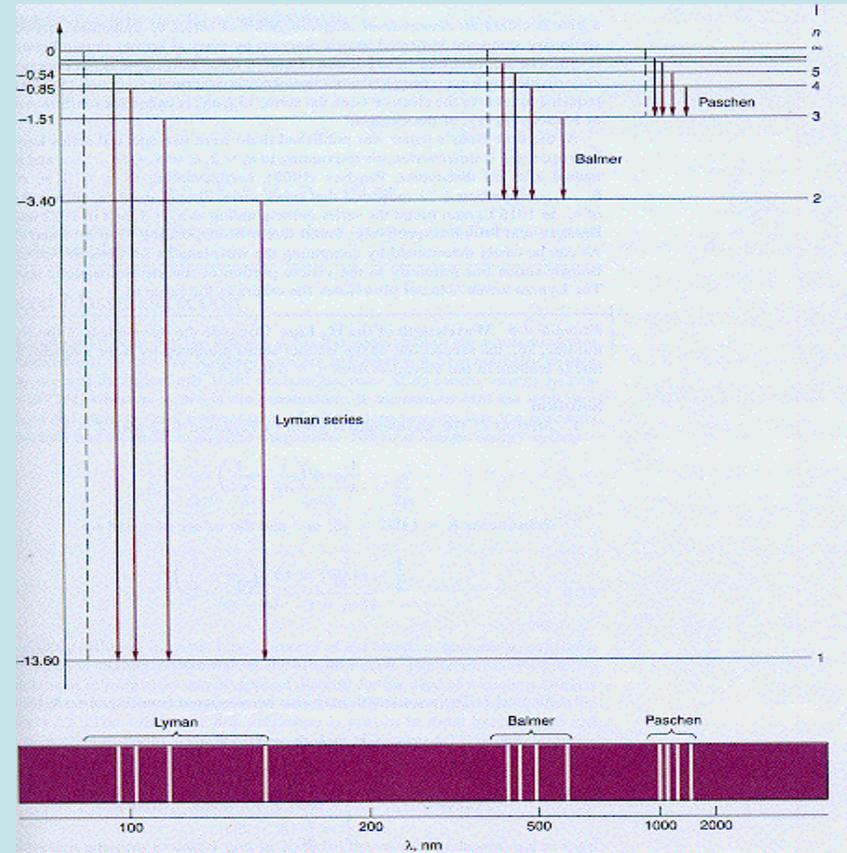


Transizioni quantizzate

Le energie di un atomo di idrogeno seguono la legge

$$E_n = -\frac{Z^2}{n^2} \times 13.6 \text{ eV}$$

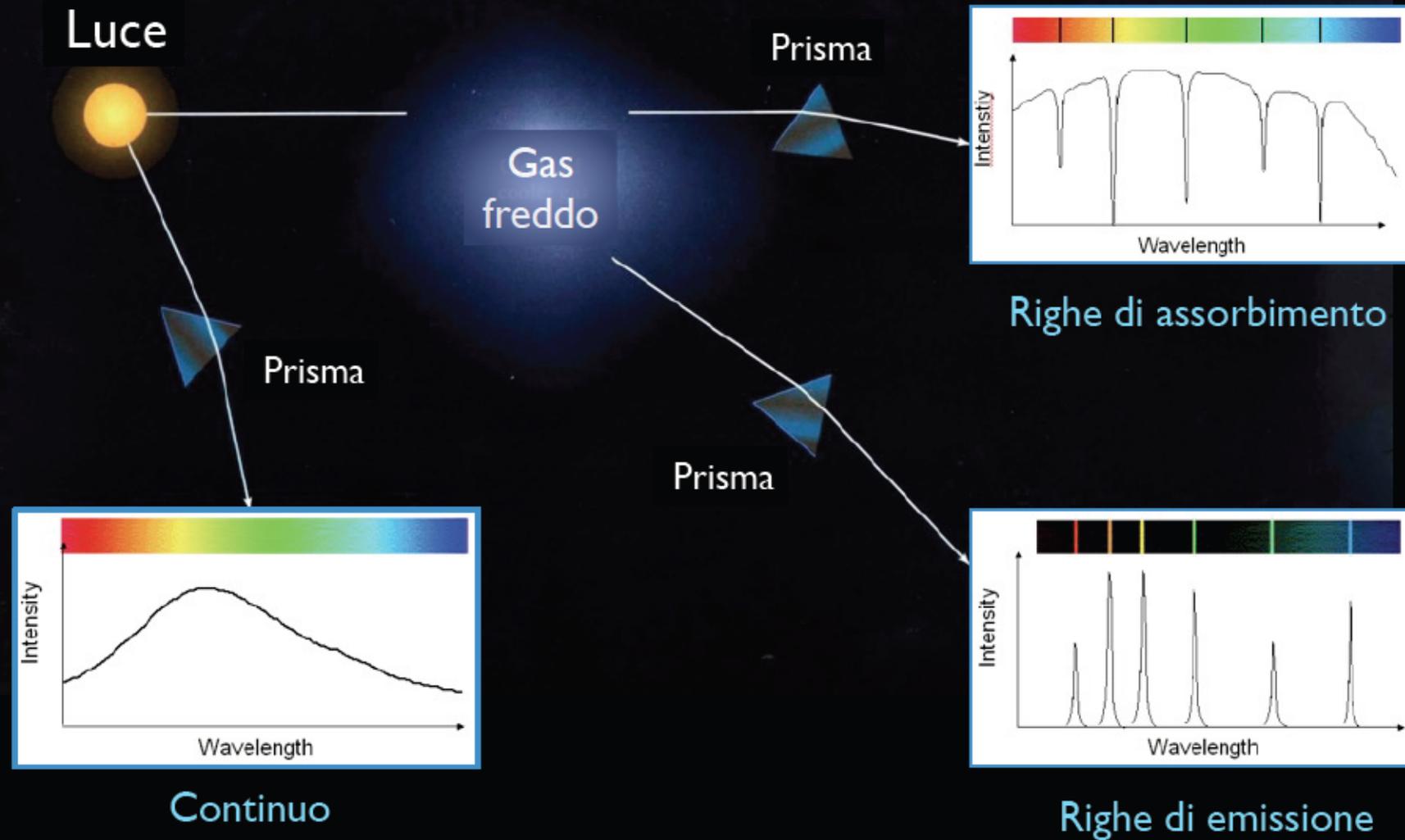
Emissione o assorbimento di fotoni tra livelli quantizzati di un atomo [o di uno ione]



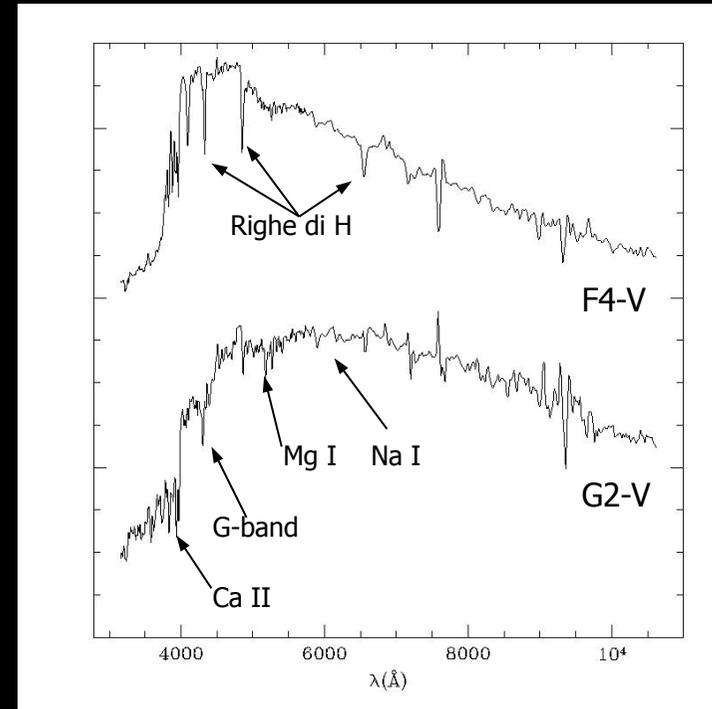
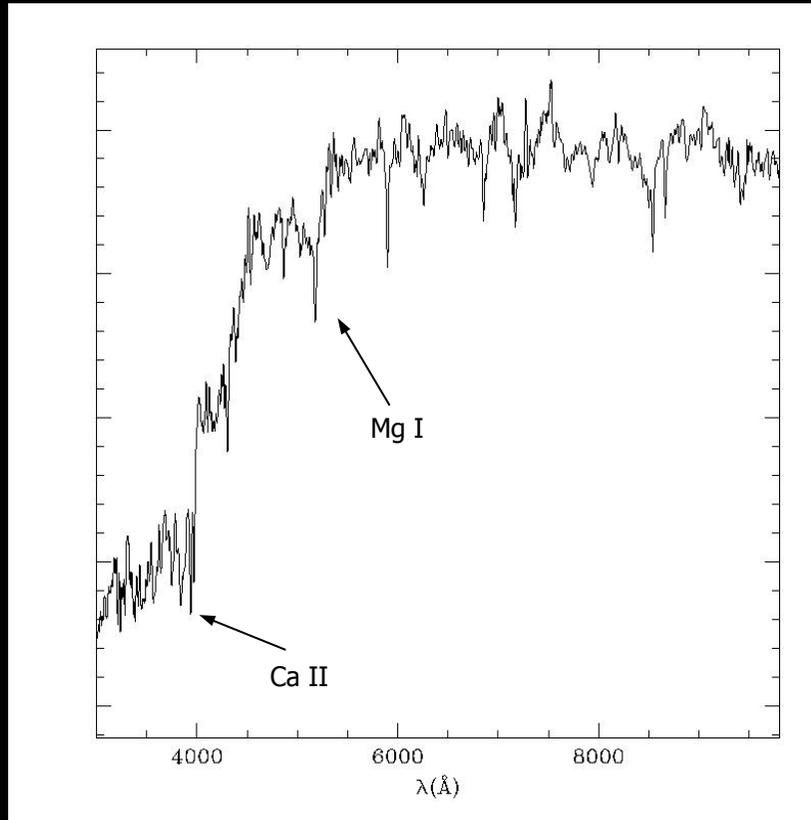
Energie dei fotoni: $hf_{mn} = E_n - E_m$

1 fotone di $f=10^{15}$ Hz $E = 6.62 \cdot 10^{-19}$ Joule lampadina: 100 joule/sec
 $\sim 10^{20}$ fotoni/sec

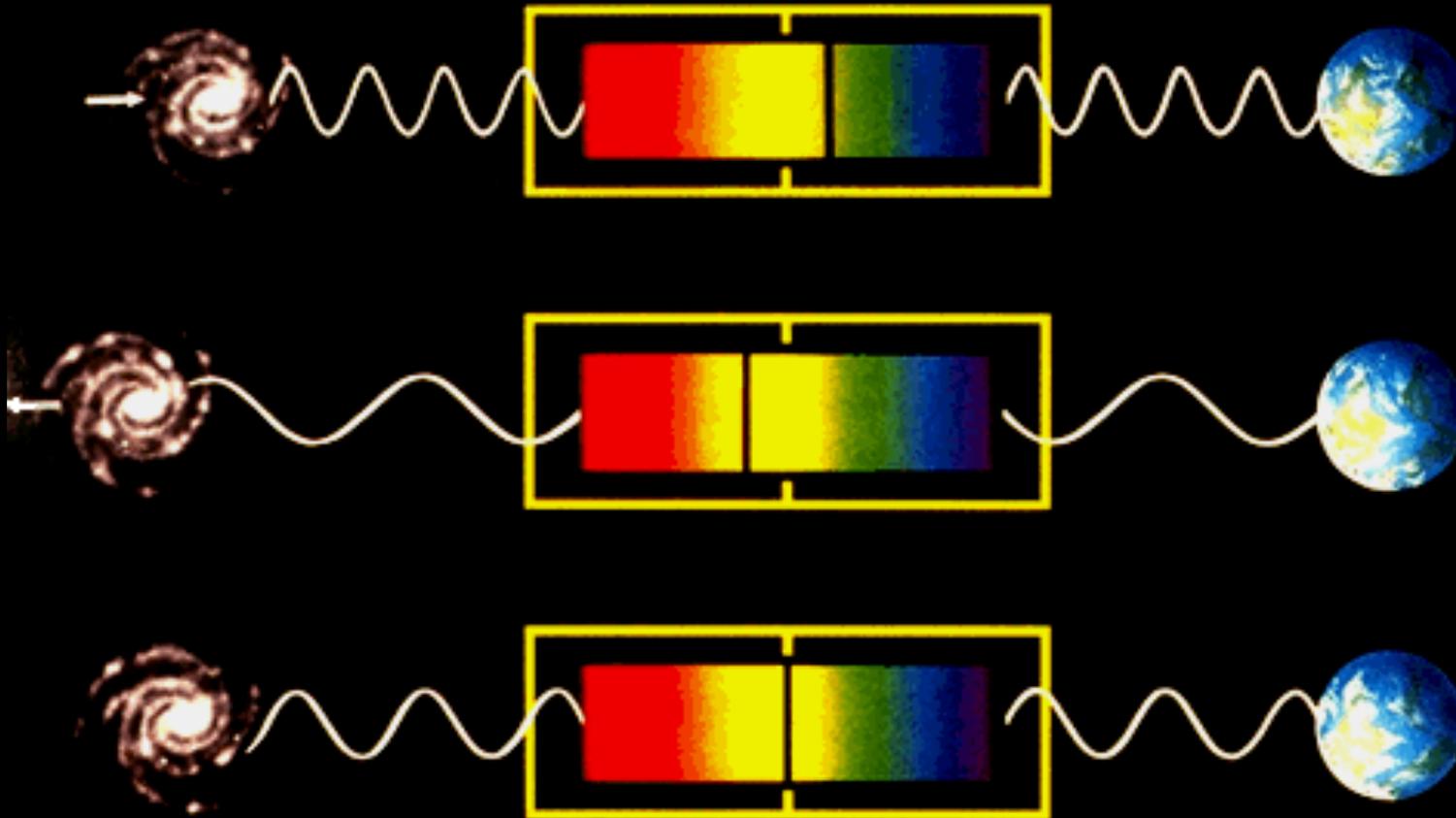
Tipi di spettro



Spettro di una galassia

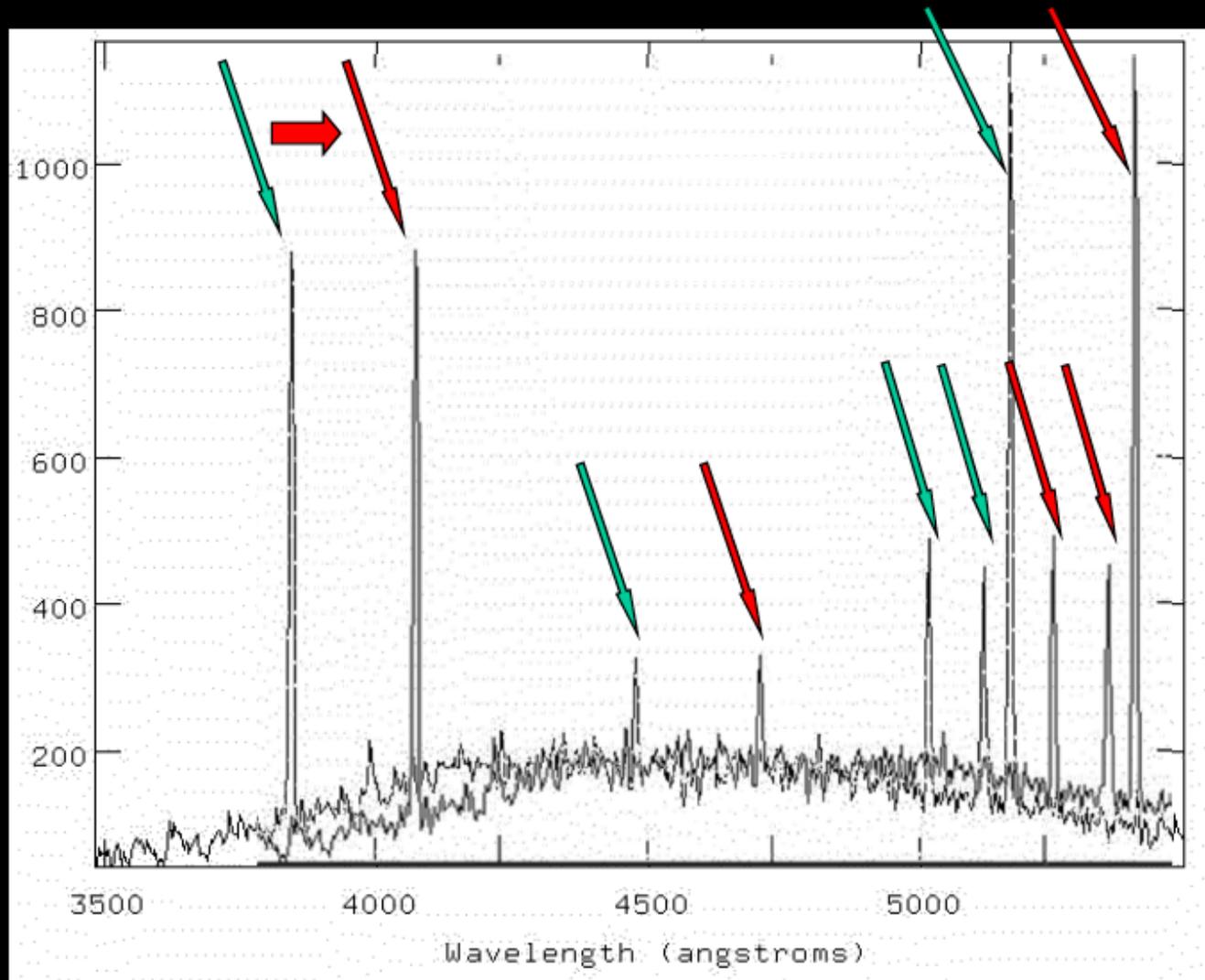


La radiazione di una stella che si avvicina alla terra è più blu



La radiazione di una stella che si allontana dalla terra è più rossa

Effetto Doppler – sorgente in allontanamento



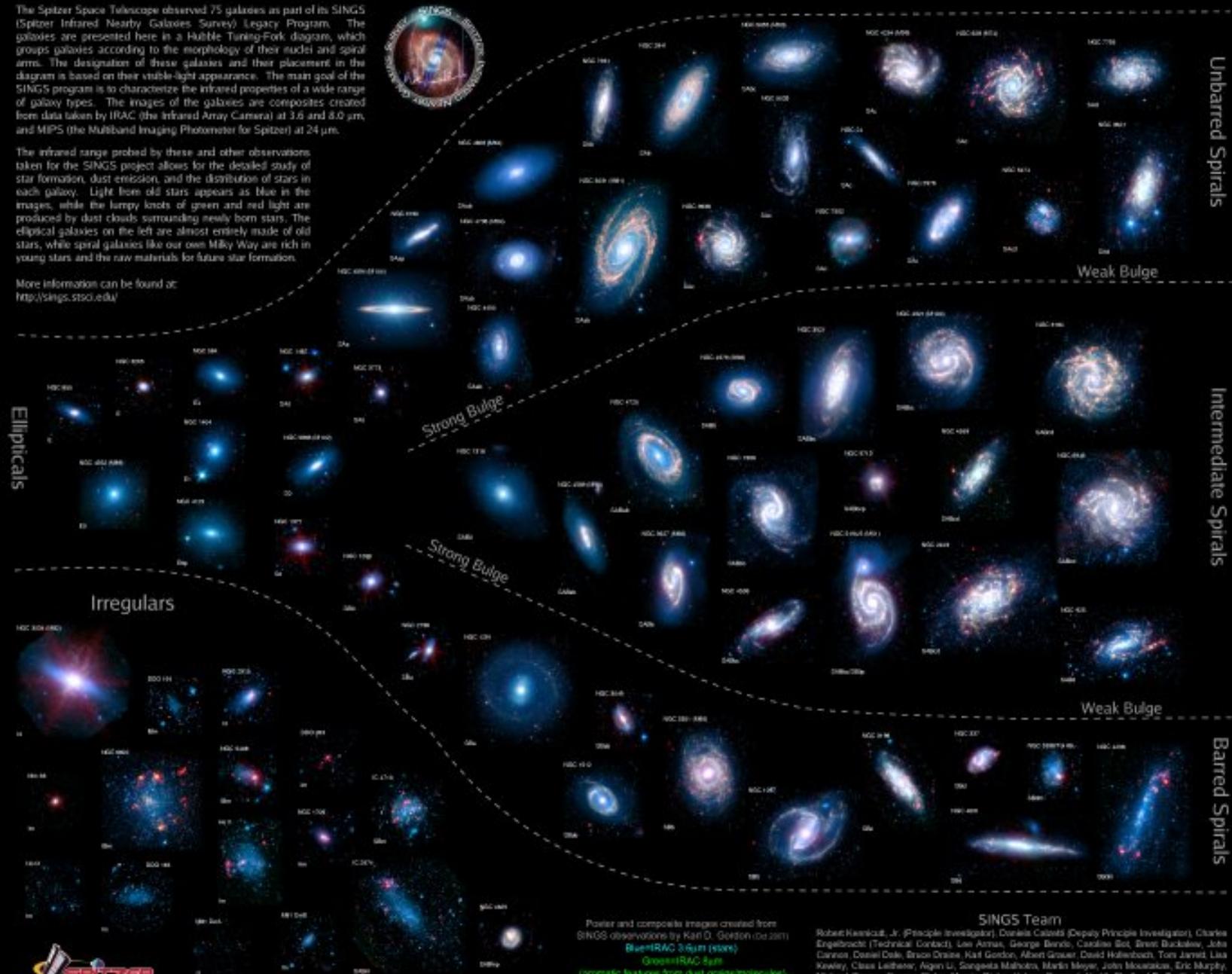
le righe si spostano quindi verso il rosso: **redshift**

The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork

The Spitzer Space Telescope observed 75 galaxies as part of its SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy Program. The galaxies are presented here in a Hubble Tuning-Fork diagram, which groups galaxies according to the morphology of their nuclei and spiral arms. The designation of these galaxies and their placement in the diagram is based on their visible-light appearance. The main goal of the SINGS program is to characterize the infrared properties of a wide range of galaxy types. The images of the galaxies are composites created from data taken by IRAC (the Infrared Array Camera) at 3.6 and 8.0 μm , and MIPS (the Multiband Imaging Photometer for Spitzer) at 24 μm .

The infrared range probed by these and other observations taken for the SINGS project allows for the detailed study of star formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the lumpy knots of green and red light are produced by dust clouds surrounding newly born stars. The elliptical galaxies on the left are almost entirely made of old stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation.

More information can be found at: <http://sings.stsci.edu/>



Ellipticals

Unbarred Spirals

Intermediate Spirals

Barred Spirals

Irregulars

Strong Bulge

Weak Bulge

Strong Bulge

Weak Bulge

Poster and composite images created from SINGS observations by Karl O. Gordon (ed 2007)
 BlueIRAC 3.6um (stars)
 GreenIRAC 8um
 (orange features from dust grains/molecules)
 RedMIPS 24um (warm dust)

SINGS Team

Robert Kennicutt, Jr. (Principal Investigator), Daniela Calzetti (Deputy Principle Investigator), Charles Engelbracht (Technical Contact), Lee Armus, George Bendo, Caroline Bot, Brent Buckalew, John Cannon, David Dale, Bruce Draine, Karl Gordon, Albert Grouer, David Hollenbach, Tom Jarrett, Lisa Kinney, Cassa Leitherer, Agnès U, Sangeeta Mahajan, Marlin Meyer, John Moustakas, Eric Murphy, Michael Regan, George Rieke, Marica Rieke, Heleni Roussos, Karik Sheth, J.D. Smith, Michele Thornley, Fabian Walker & George Helou



Spettri di galassie
in ordine di “tipo di
Hubble”

Sono la SOMMA
degli spettri stellari
Un poco “spostati”
a causa del redshift

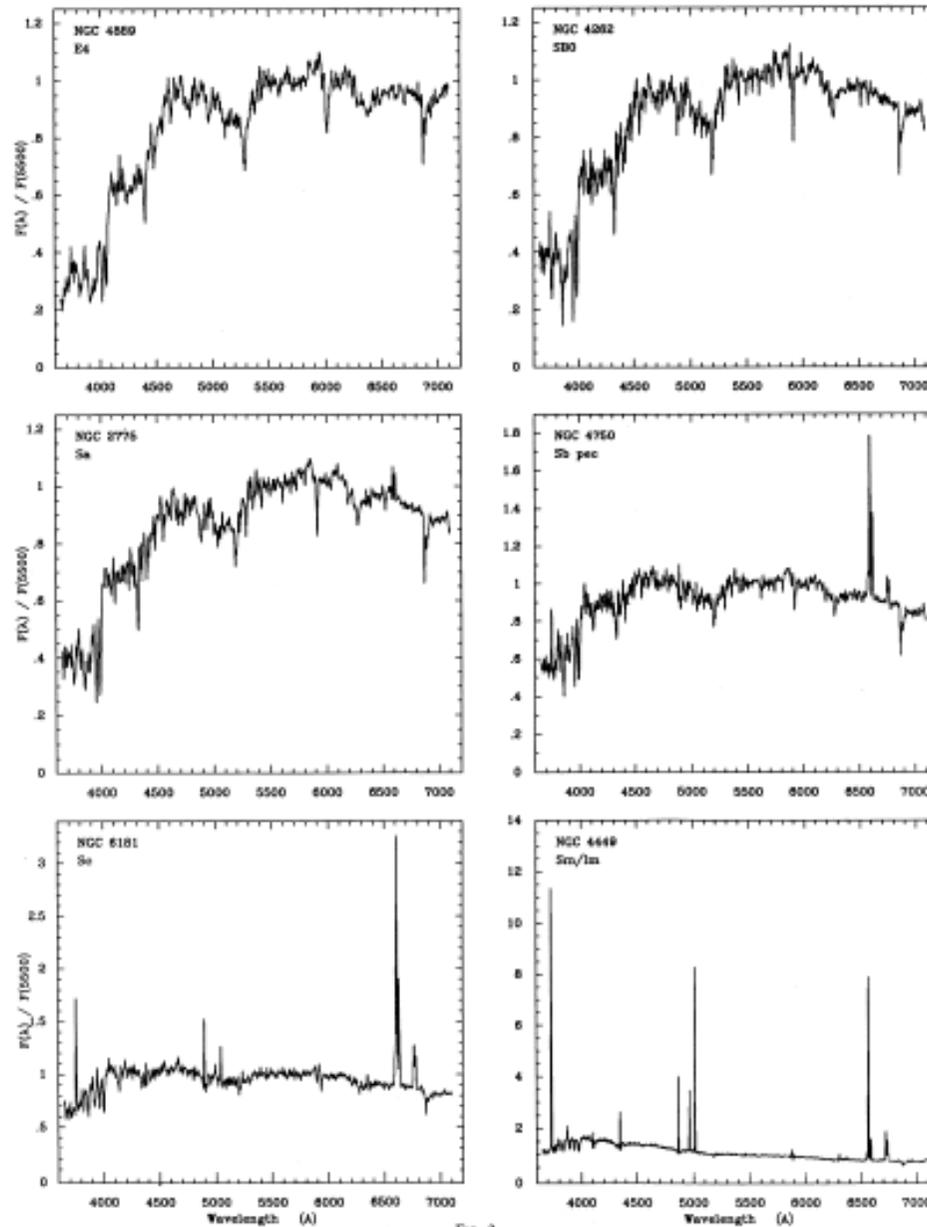
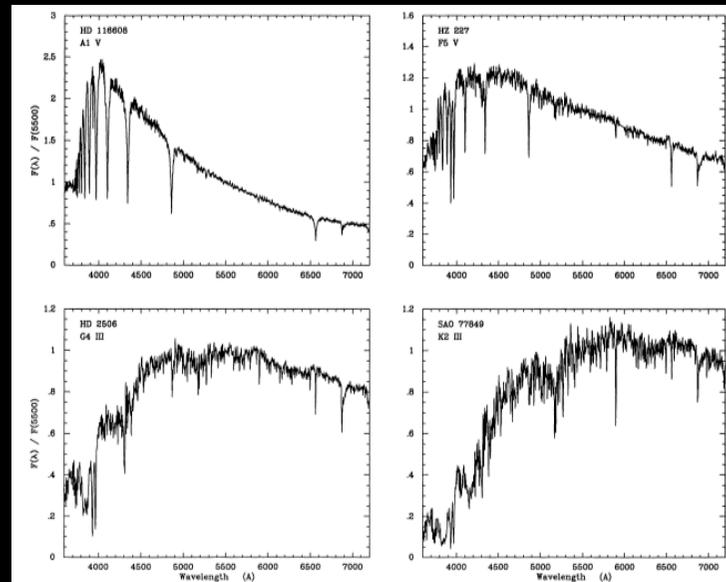
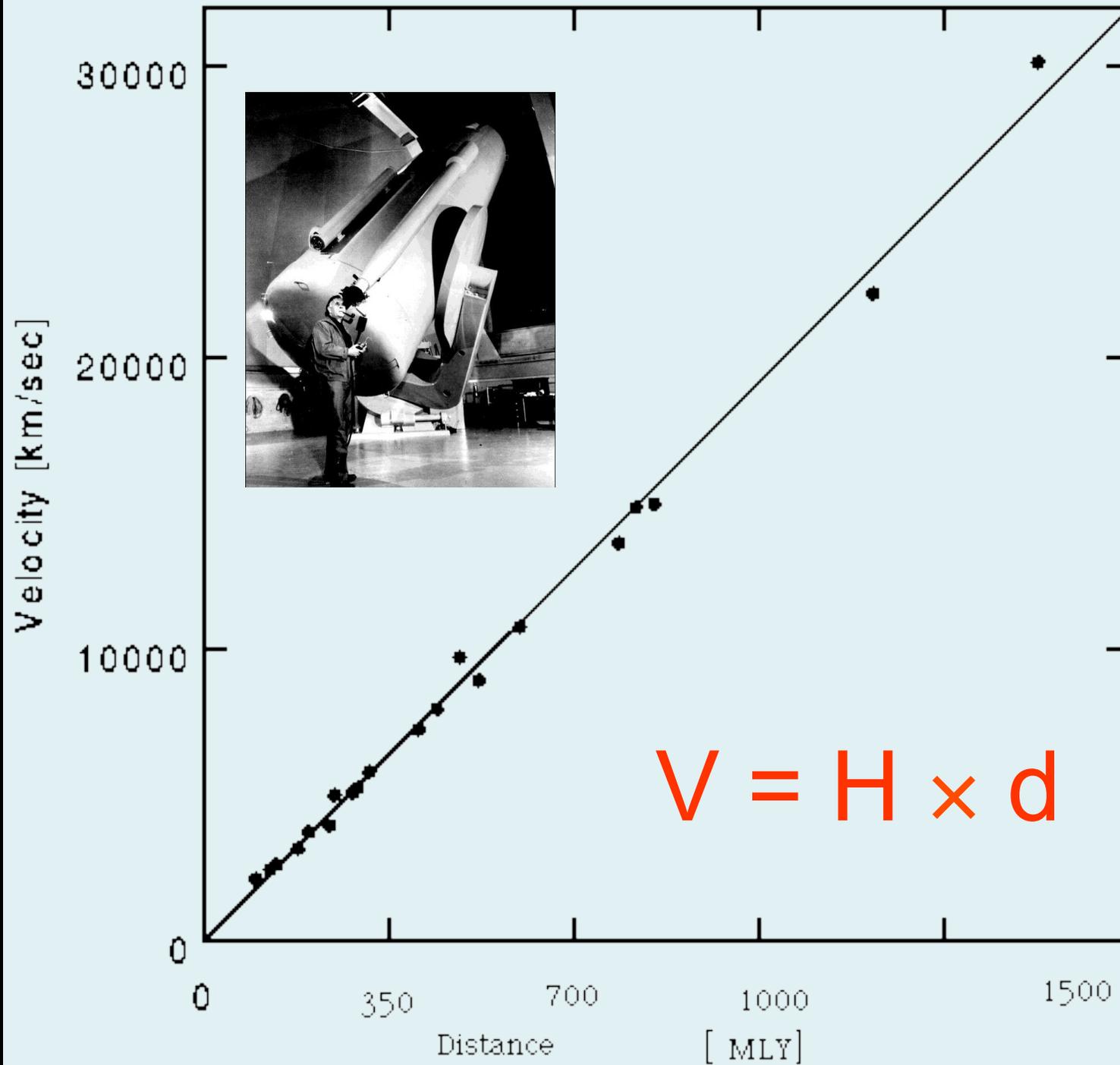


FIG. 2a

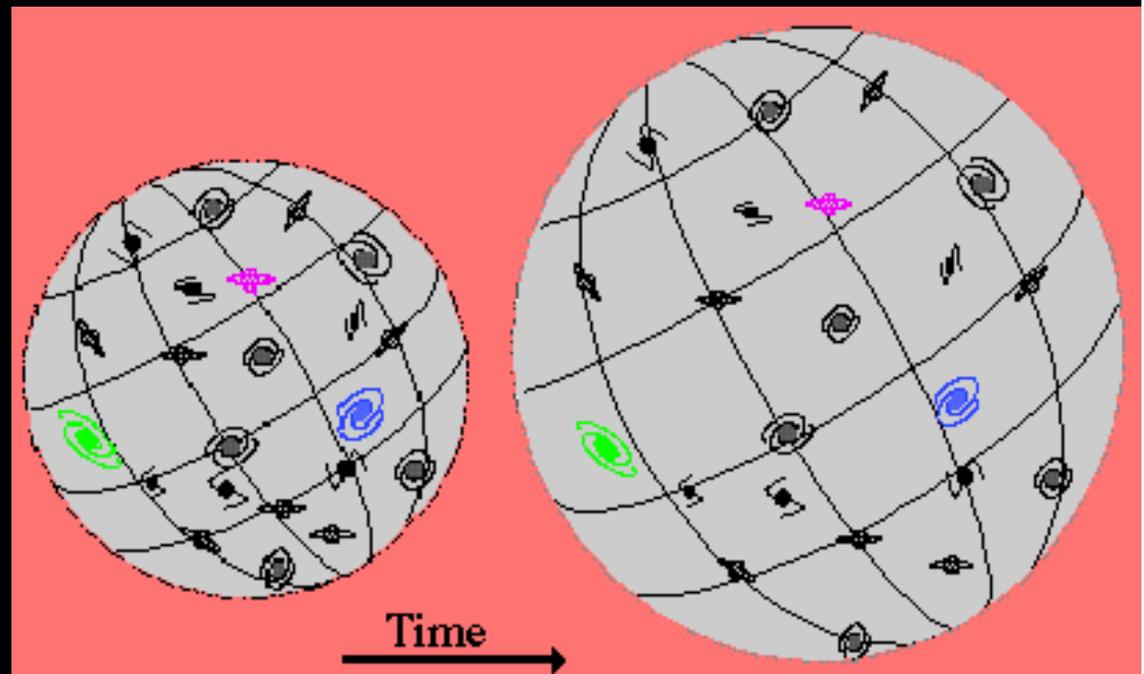
FIG. 2—(a) The spectral Hubble sequence. Galaxies are shown in order of increasing Hubble type from top to bottom. See Table 3 for data on the galaxies. (b) Same spectra as in (a), but expanded in the blue to show the properties of the absorption-line spectra.





Hubble elabora una **relazione tra distanza e velocità** (confermando i risultati teorici del belga Lemaître).

Gli effetti della velocità (redshift) vengono usati come misura della **distanza**.



*A RELATION BETWEEN DISTANCE AND RADIAL VELOCITY
AMONG EXTRA-GALACTIC NEBULAE*

BY EDWIN HUBBLE

MOUNT WILSON OBSERVATORY, CARNEGIE INSTITUTION OF WASHINGTON

Communicated January 17, 1929

Determinations of the motion of the sun with respect to the extra-galactic nebulae have involved a K term of several hundred kilometers which appears to be variable. Explanations of this paradox have been sought in a correlation between apparent radial velocities and distances, but so far the results have not been convincing. The present paper is a re-examination of the question, based on only those nebular distances which are believed to be fairly reliable.

Si tratta della base osservativa che condurrà alla formulazione della teoria del **Big Bang**.

2

Strane galassie e Tassonomia

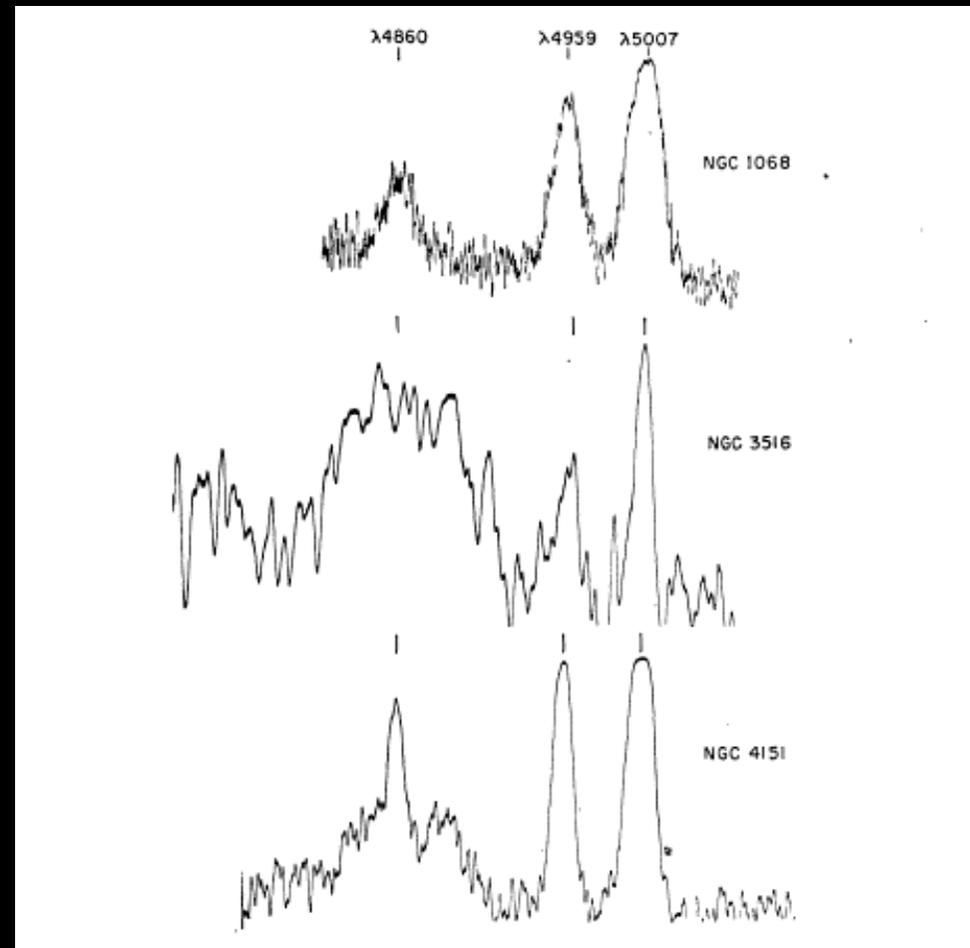
dal [greco](#) τάξις, *taxis*, "ordinamento", e νόμος, *nomos*, "norma" o "regola"
è, nel suo significato più generale, la disciplina della classificazione

Nel 1943 si scoprono delle “strane” galassie: “Nuclear Emission in Spiral Nebulae” by Carl K. Seyfert

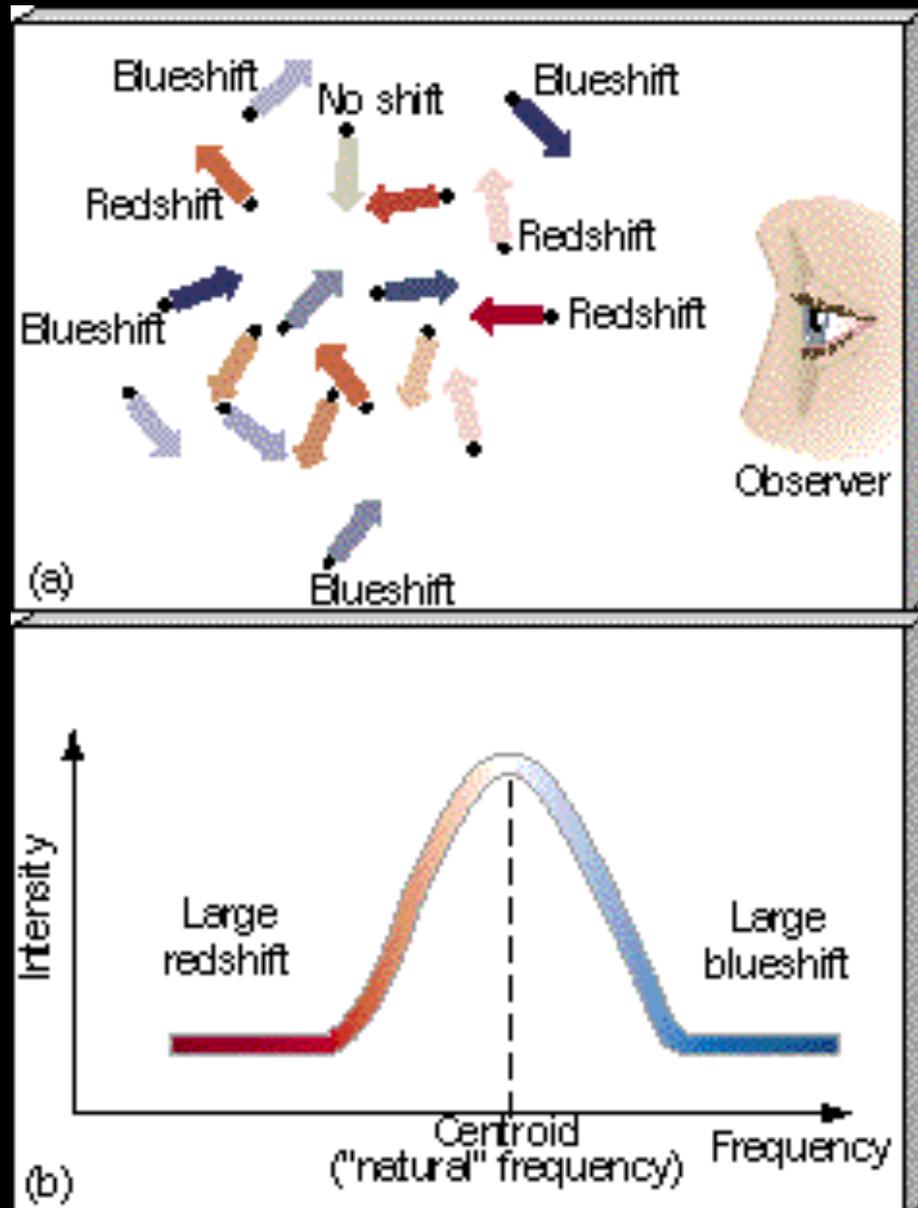
- Nucleo
- Variabilità < 1 anno
- Righe di Emissione



Carl Seyfert al telescopio da 24 pollici della Vanderbilt University.
(Credit: U. Vanderbilt)



Spettri - righe allargate



Un diverso aspetto dell'effetto Doppler

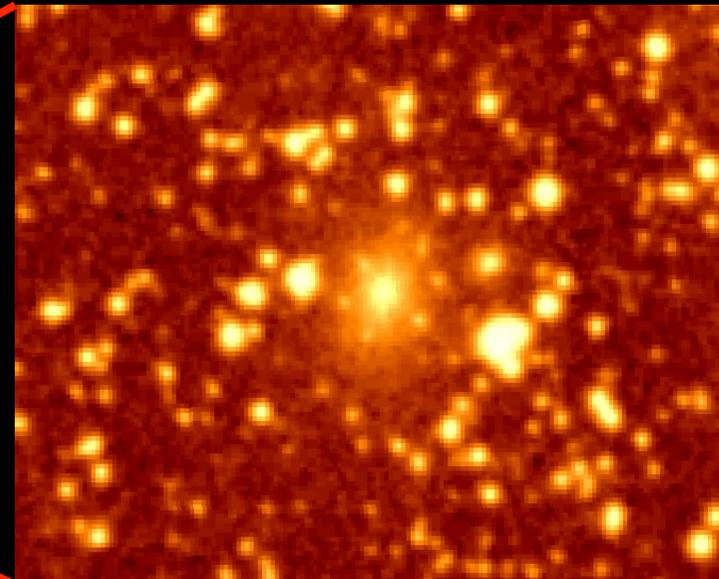
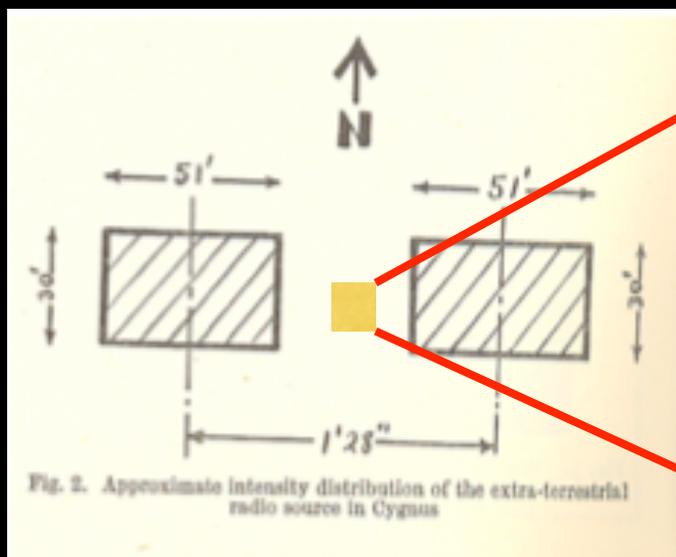
La riga si allarga a causa del moto degli atomi

I primi radiotelescopi



Identificazione delle radio sorgenti

- Se l'identificazione della radio sorgente è corretta, allora non c'è alcuna correlazione tra l'emissione di onde radio e la galassia



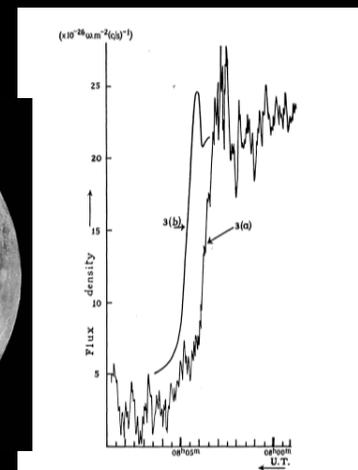
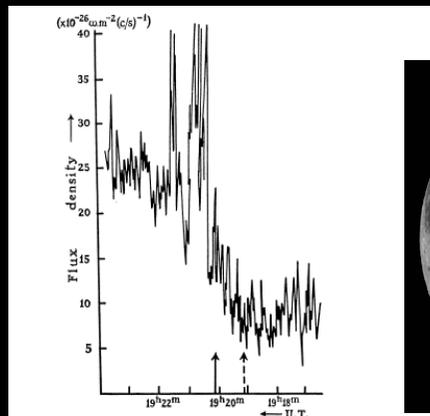
Osservazione di 3C 273

Dal 3° catalogo di Radio Sorgenti di Cambridge (Edge et al 1959)
Che contiene 471 sorgenti di onde radio (159 MHz)

Schmidt 1962: 3C 286 riga a 5170 \AA Non identificato!

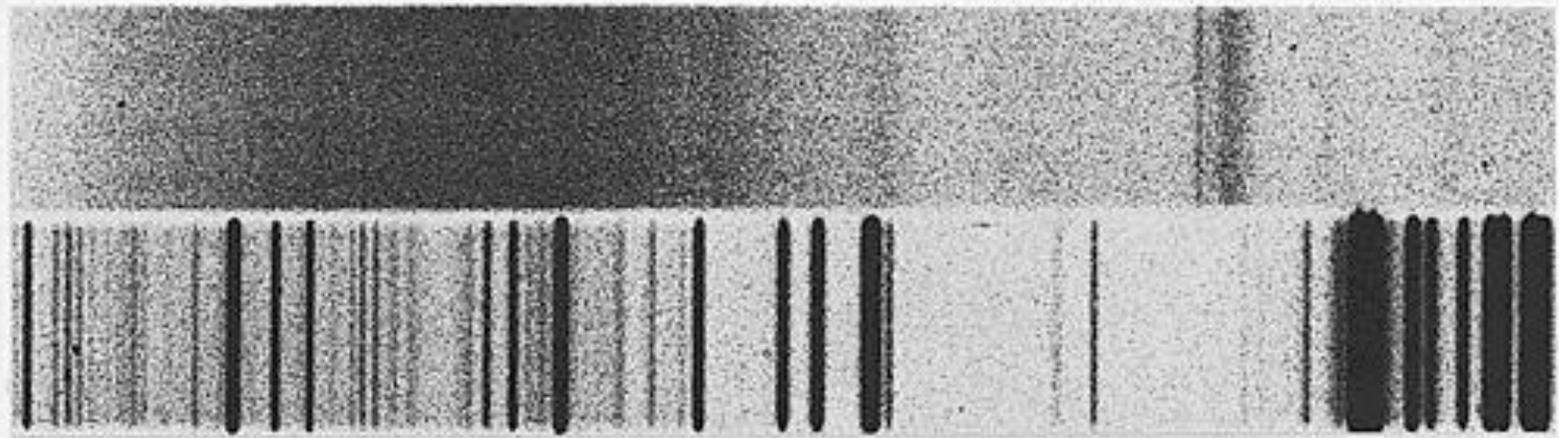
Matthews & Sandage 1963 "Radio stars" 3C 48 3C 169 e 3C 286

Hazard + 1963 occultazione lunare



3C 273

H δ H γ H β

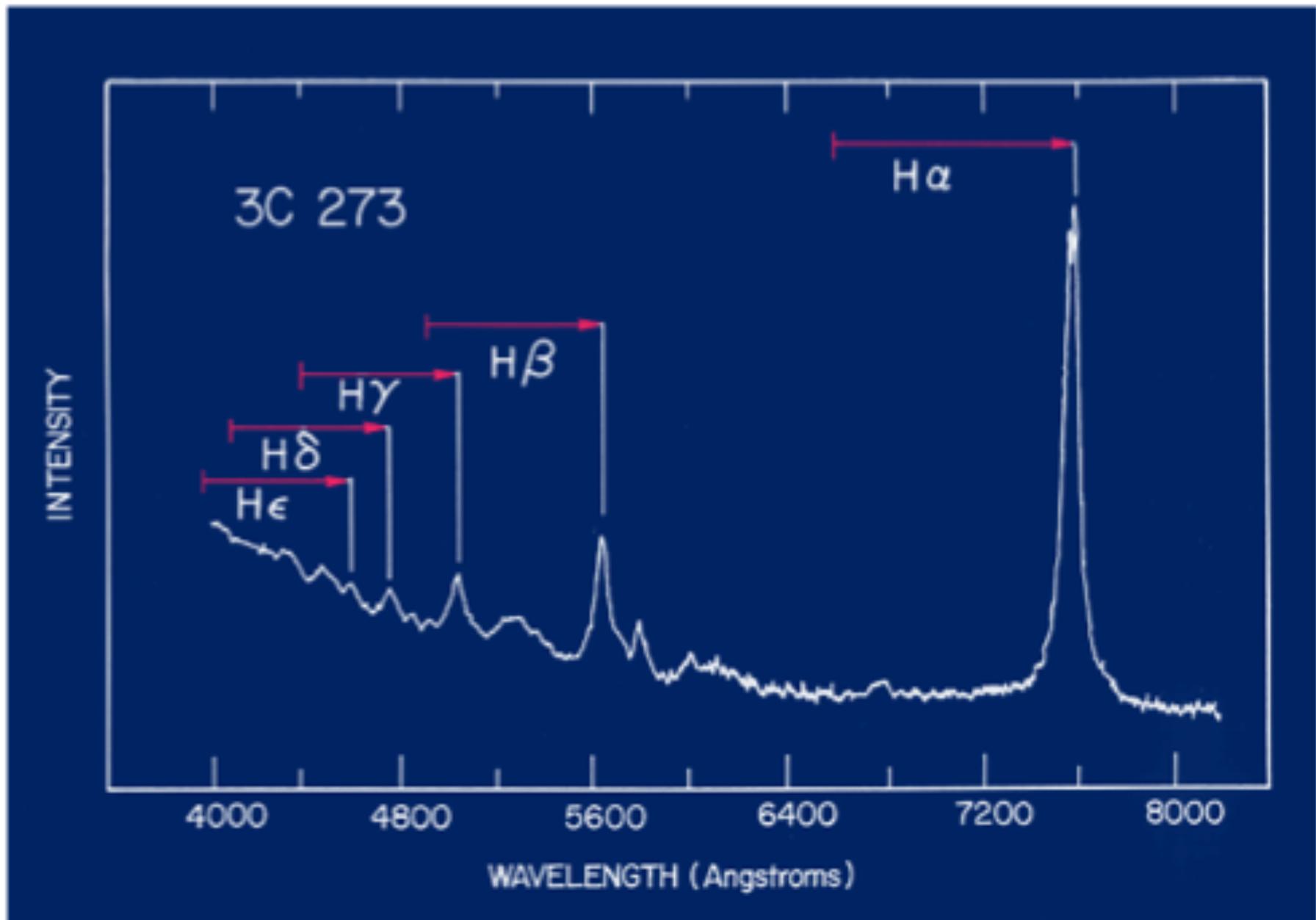


Comparison Spectrum

410 nm 434 nm 486 nm

Table 1. WAVE-LENGTHS AND IDENTIFICATIONS

λ	$\lambda/1-158$	λ_4	
3230	2797	2798	Mg II
4595	3968	3970	H δ
4753	4104	4102	H δ
5032	4345	4340	H γ
5200-5415	4490-4675		
5632	4864	4861	H β
5792	5002	5007	[O III]
6005-6190	5186-5345		
6400-6510	5527-5622		



QUASAR

Secondo la legge di Hubble, questo voleva dire che 3C 273 è distante dalla Terra ben 500 Mpc (~2 miliardi di anni luce) e si allontana alla velocità di 50000 km/s (1/6 di quella della luce!).

“Most direct and least objectionable”
La spiegazione più diretta e meno discutibile



1040 NATURE March 16, 1963 vol. 197

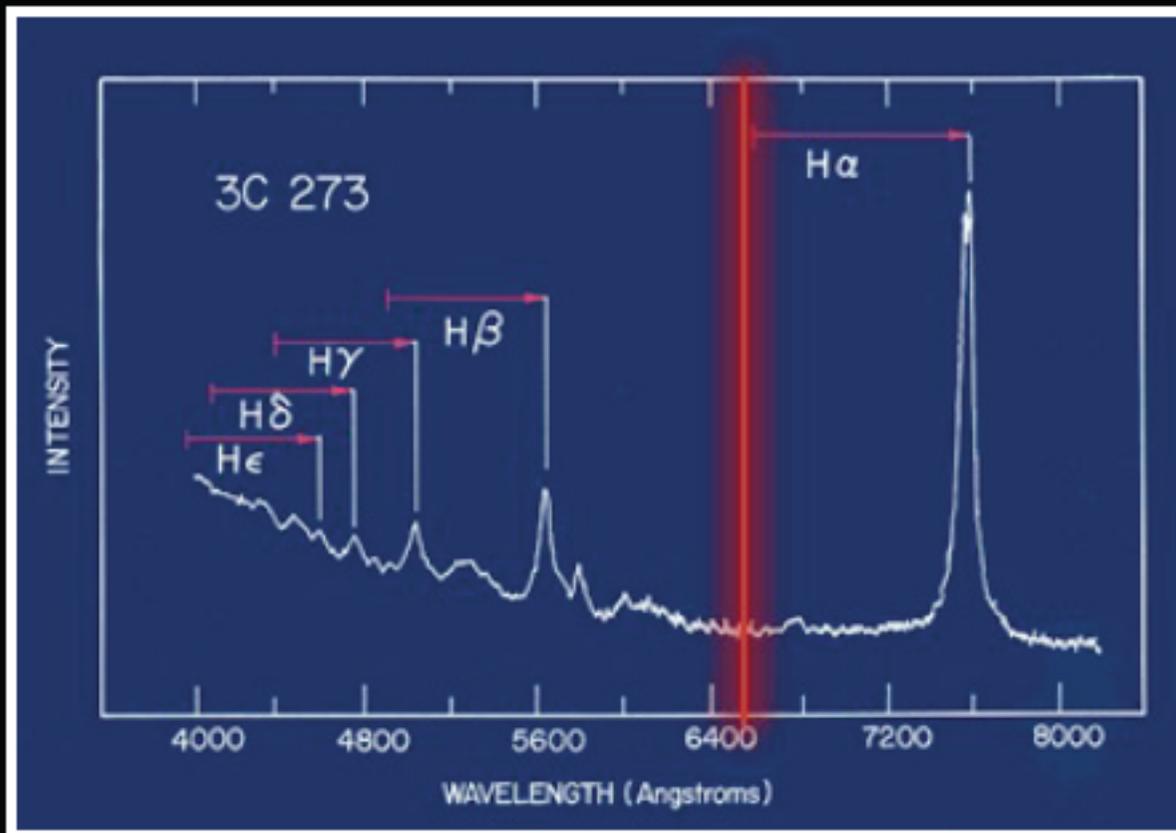
3C 273: A STAR-LIKE OBJECT WITH LARGE RED-SHIFT
By Dr. M. SCHMIDT

Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena

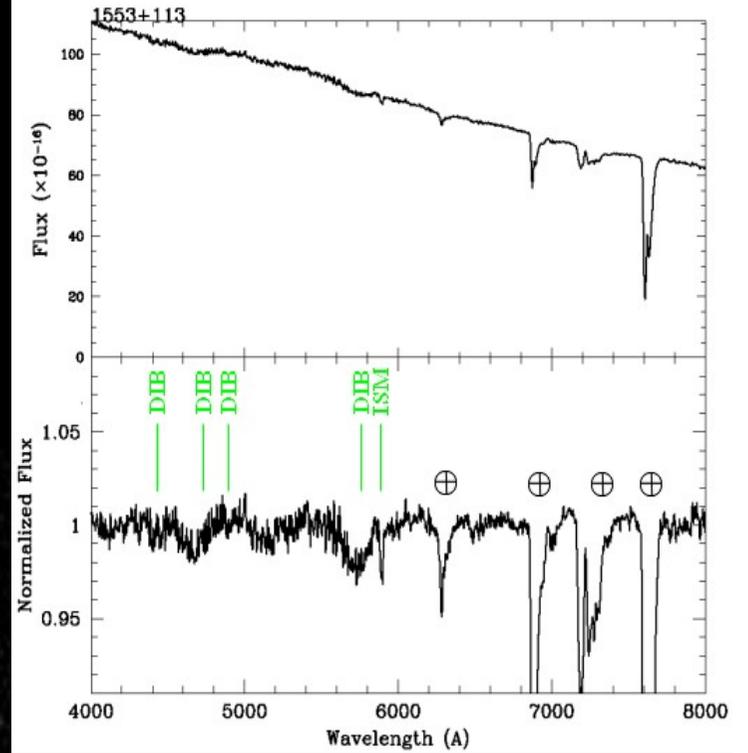
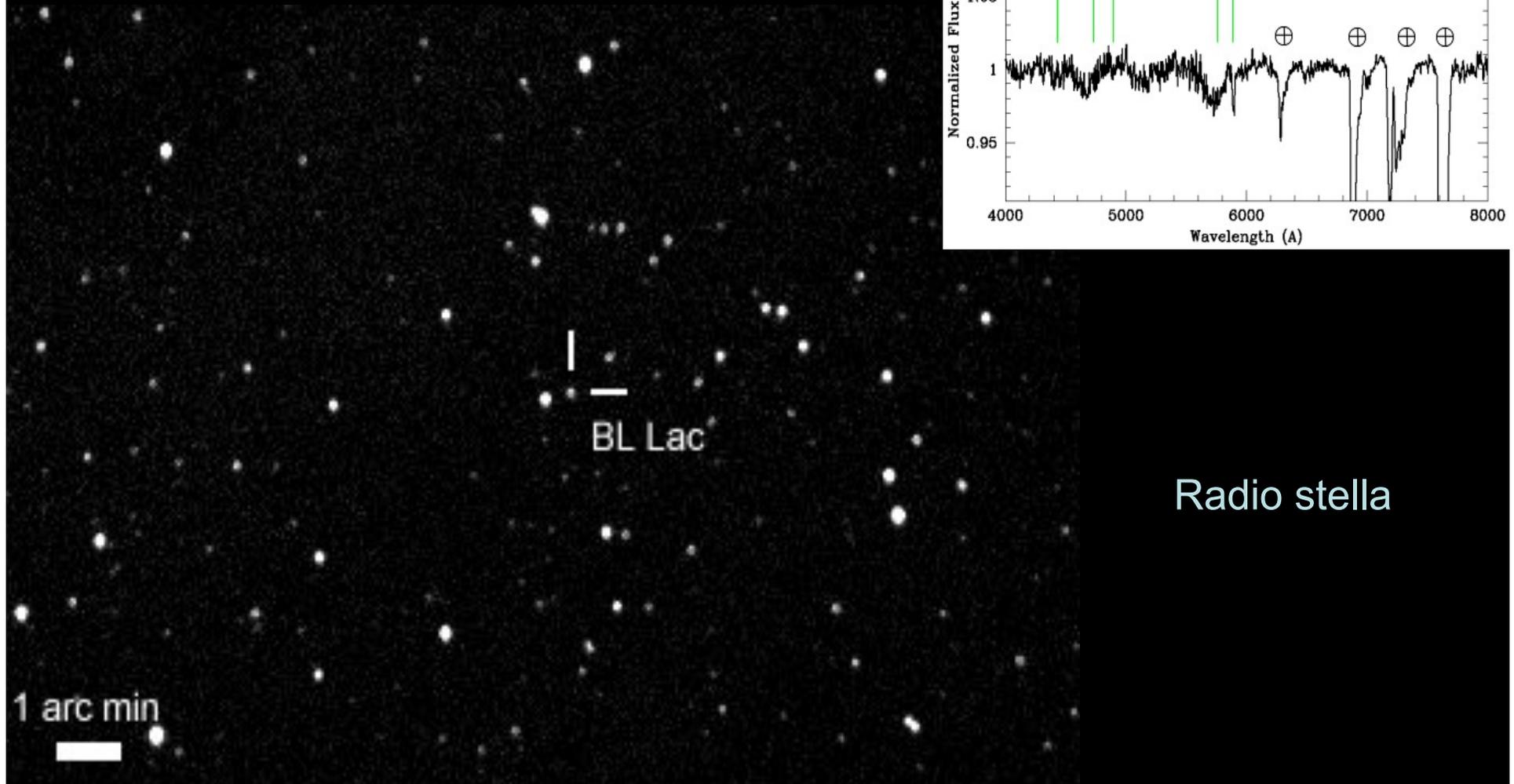
THE only objects seen on a 200-in. plate near the positions of the components of the radio source 3C 273 reported by Hazard, Mackey and Shimozina in the preceding article are a star of about thirteenth magnitude and a faint wispy jet. The jet has a width of 1"-2" and extends away from the star in position angle 43°. It is not visible within 11" from the star and ends abruptly at 20" from the star. The position of the star, kindly furnished by Dr. T. A. Matthews, is B 4

λ	3C 273	λ	Identifications
3230	3747	3796	Mg II
4046	3886	3970	H α
4130	4134	4132	H β
4267	4265	4267	H γ
3200-3425	4480-5075		
3442	4861	4861	H δ
3746	5051	5051	H ϵ
4861-5130	5130-5130		
4861-5130	5130-5130	5130	H ζ

La luminosità di questa sorgente è 100-1000 volte maggiore di qualsiasi oggetto noto in quel momento.



Oggetti di tipo BL Lac



La ricerca continua

1967: >100 quasars identificati, spettri codificati e distanze misurate
(M. Burbidge 1967, Annual Review of Astronomy & Astrophysics)



M. Burbidge

FR I Sey 1.8 NLXG CSS
BLRG LINER
HPQ GPS BLRG
QSO Sey 1 LPO QSR
BALQSO NLS1 Sey 1.9 Sey 2
BLL OVV
FR II

3

Proprietà dei Nuclei Attivi

Proprietà

Spettri con righe di **emissione larghe**

Luminosità elevata

Morfologia peculiare – **getti**

Variabilità

Emissione RADIO

Moti **superluminali**

Proprietà

Spettri con righe di **emissione larghe**

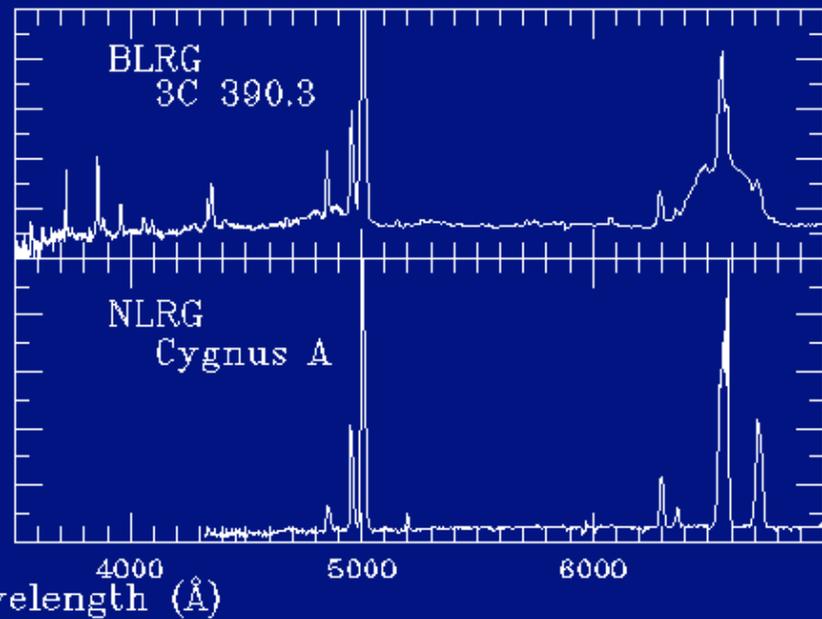
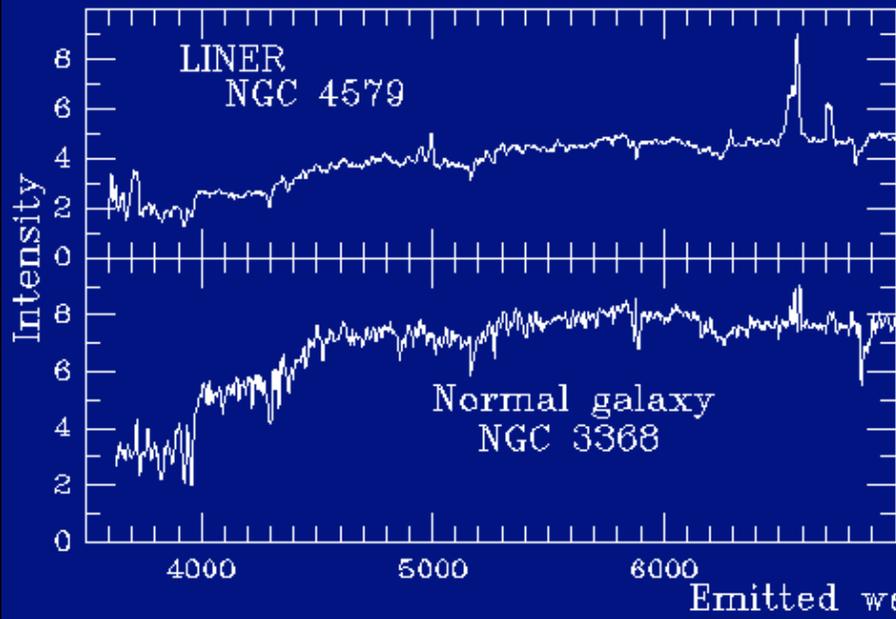
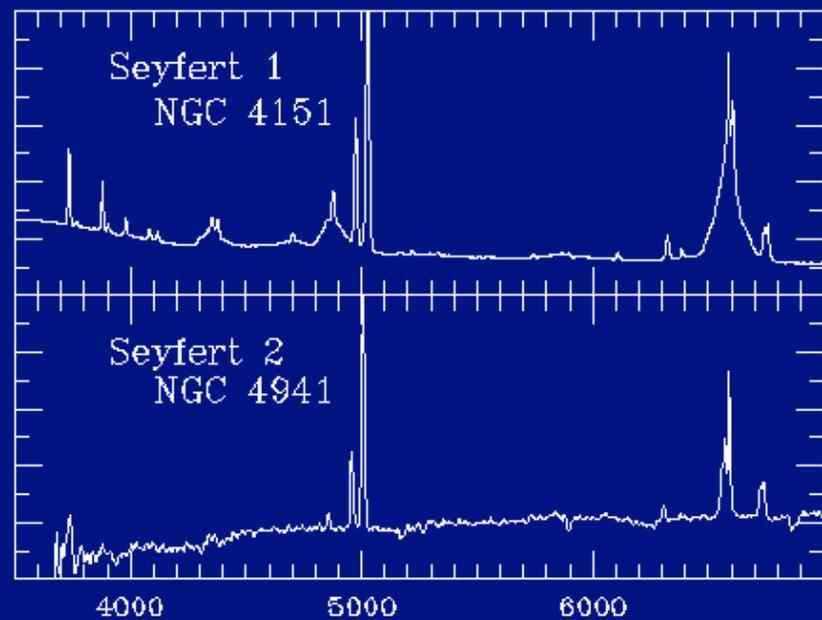
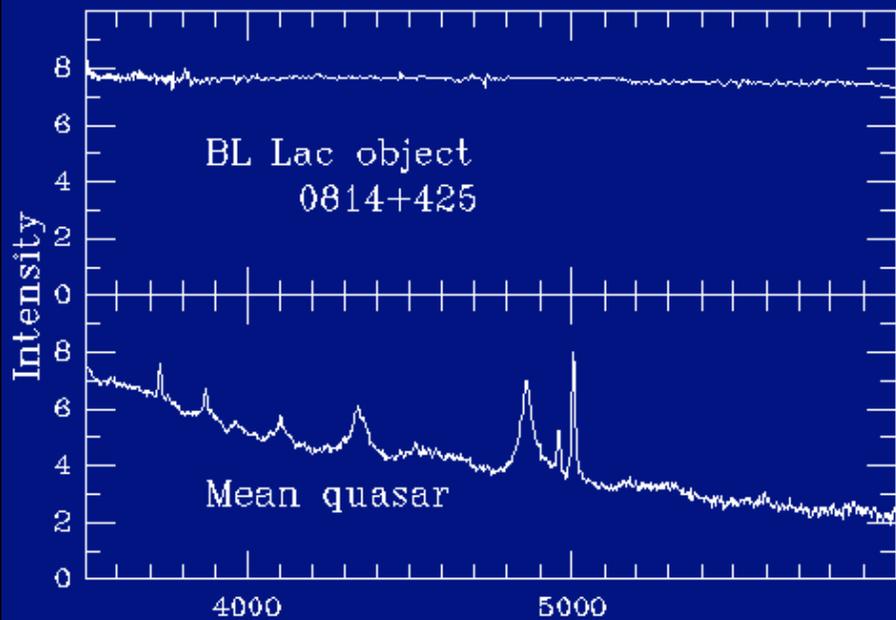
Luminosità elevata

Morfologia peculiare – getti

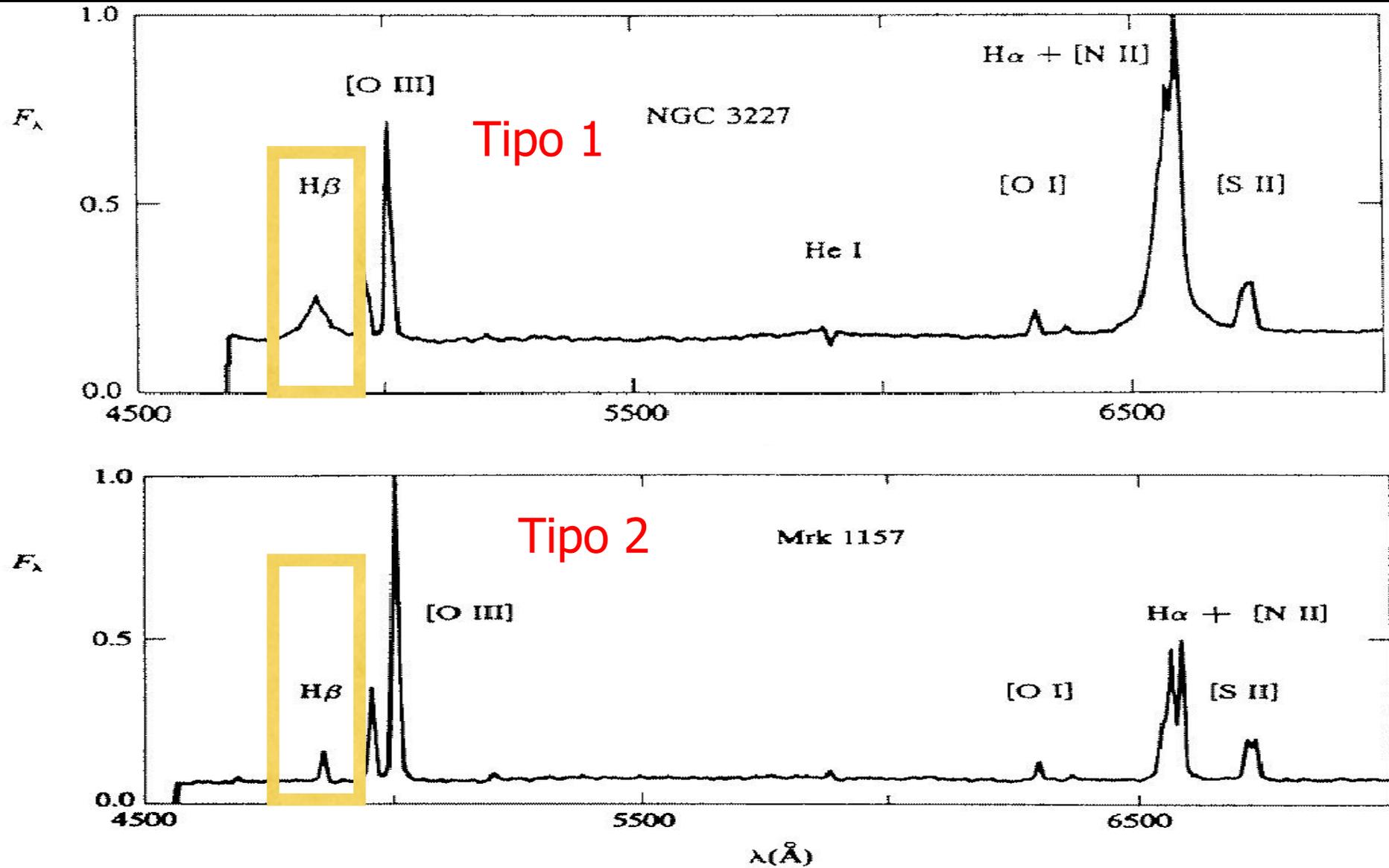
Variabilità

Emissione RADIO

Moti superluminali



Spettro di emissione



Proprietà

Spettri con righe di emissione larghe

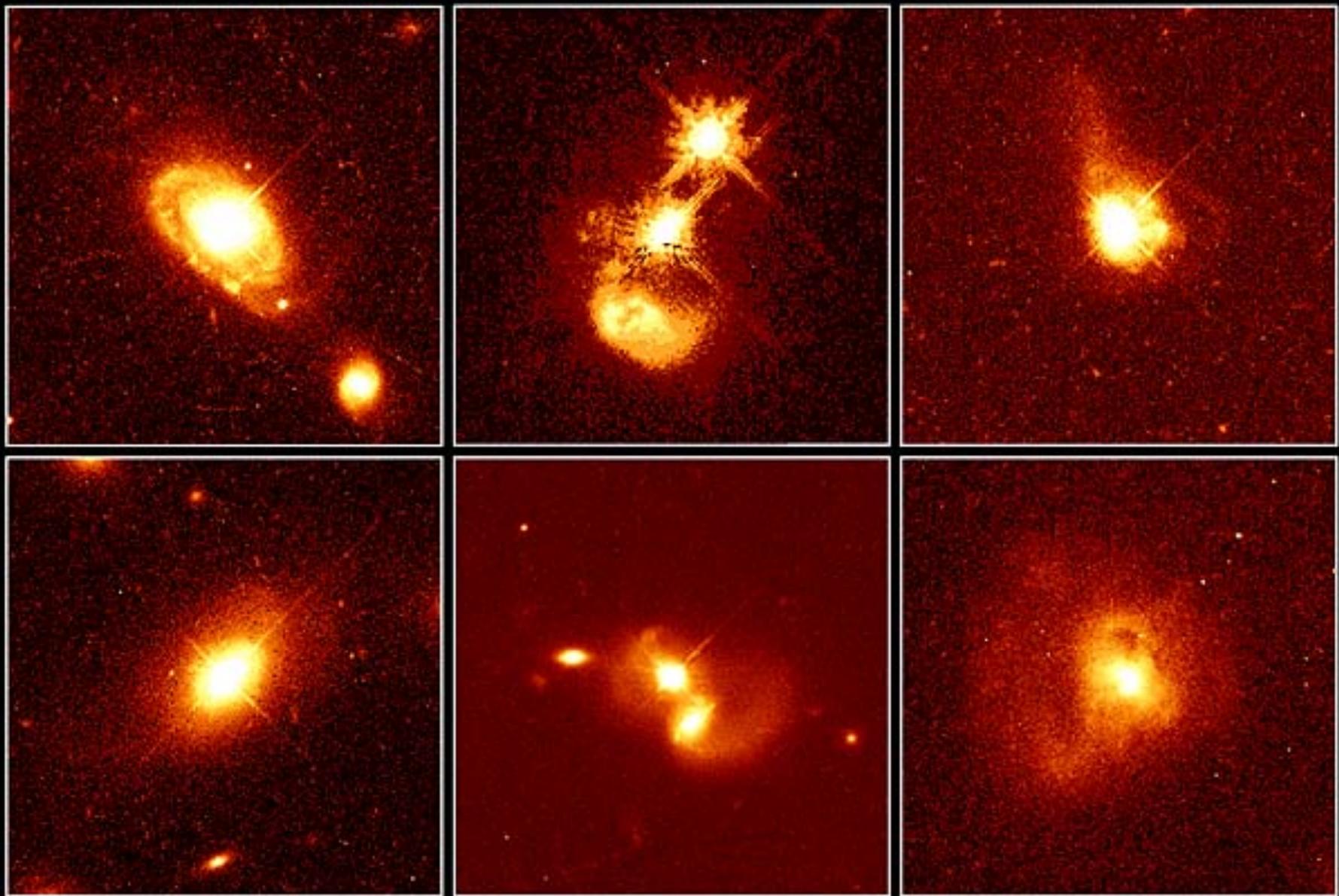
Luminosità elevata

Morfologia peculiare – getti

Variabilità

Emissione RADIO

Moti superluminali



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

Produce molta energia:

Spesso di più di quella prodotta dalla galassia che lo ospita



10^{37} Watt

1'000'000'000'000'000'000'000'000'000 ×

Energia consumata sulla
Terra ogni secondo



Proprietà

Spettri con righe di emissione larghe

Luminosità elevata

Morfologia peculiare – **getti**

Variabilità

Emissione RADIO

Moti superluminali

3C273

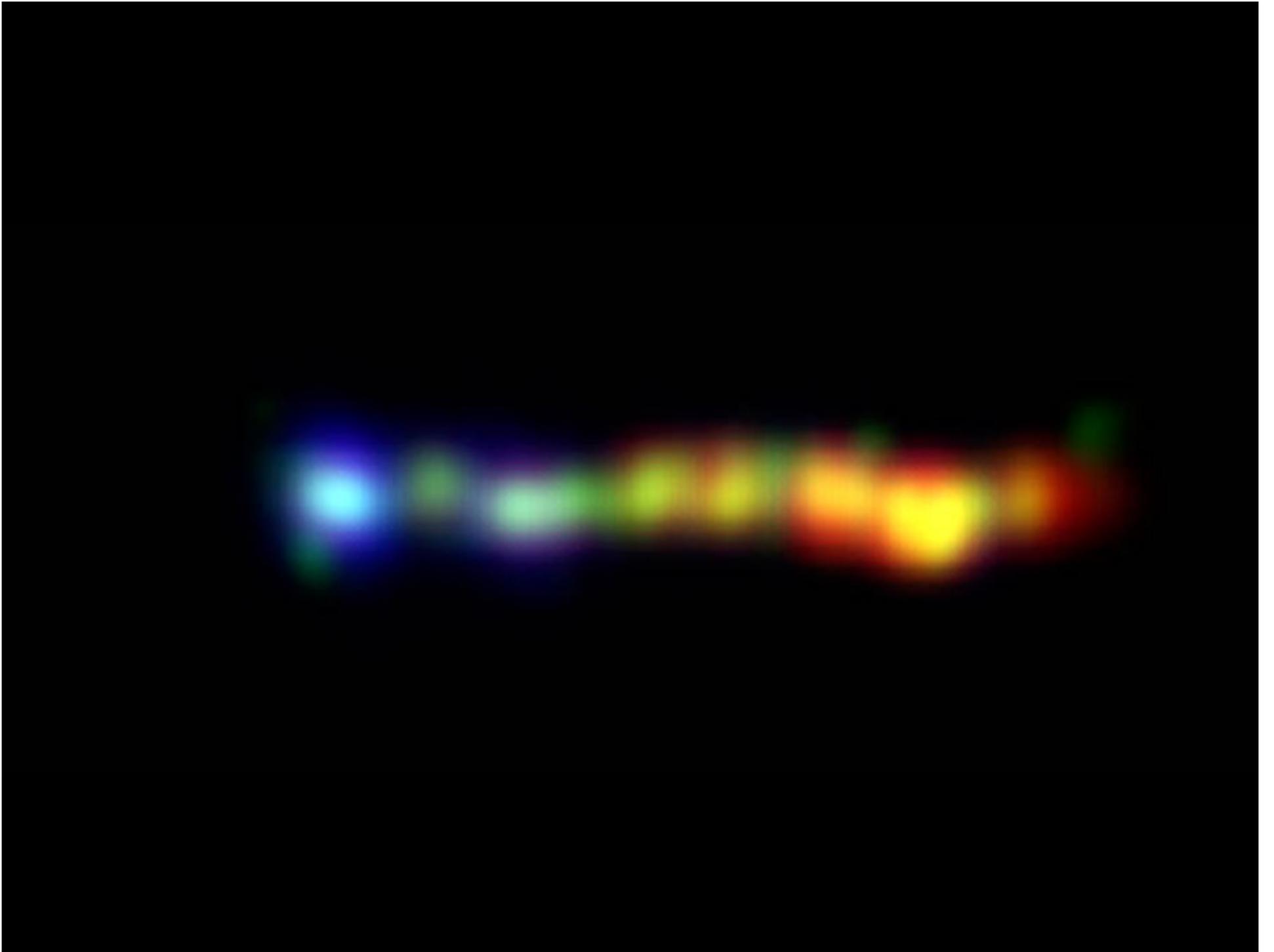
Uno dei più vicini a noi,
3 miliardi di anni luce

Pur essendo il più
brillante è mille volte
troppo debole per
essere visto ad occhio
nudo dalla Terra

La sua luminosità è
12 ordini di grandezza
(10^{12} volte maggiore di
quella del Sole)

Il getto è visibile anche in raggi X

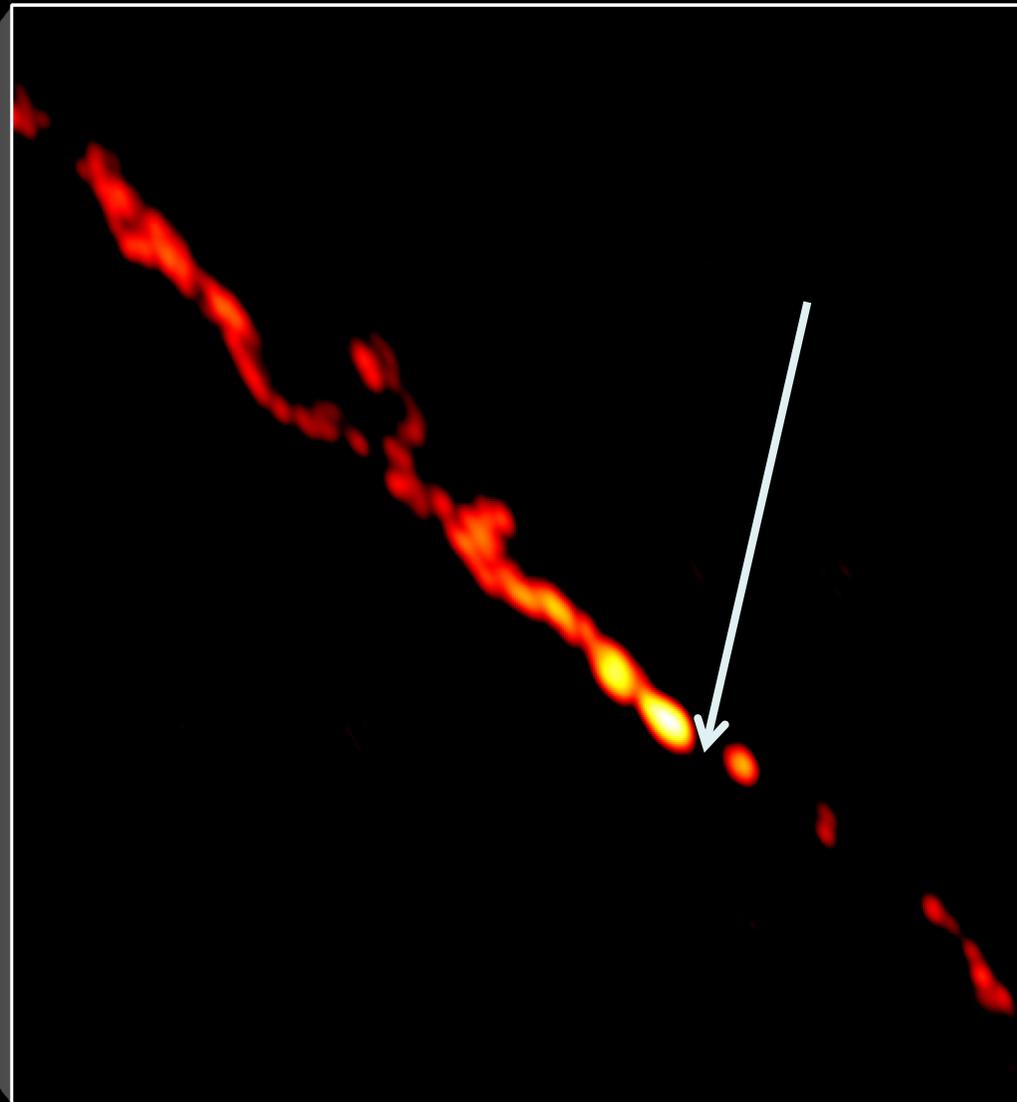




Centauro A: risultato di uno scontro



I getti interni di Centauro A



Proprietà

Spettri con righe di emissione larghe

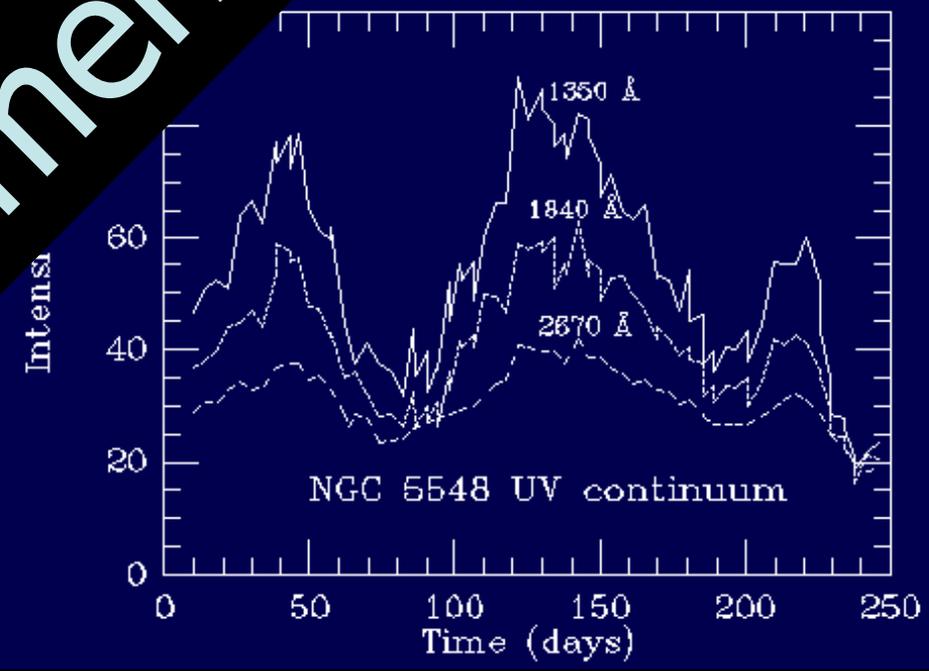
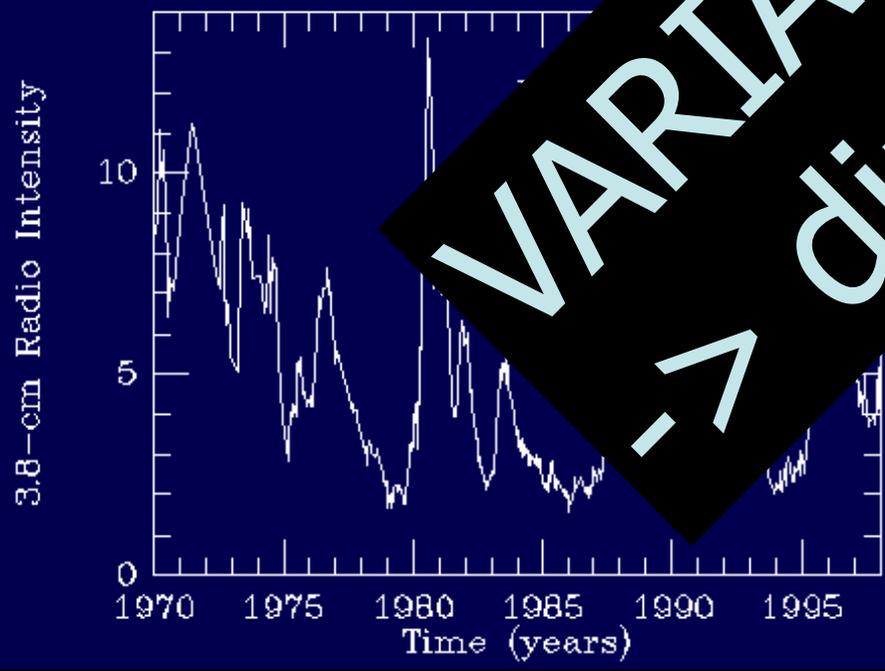
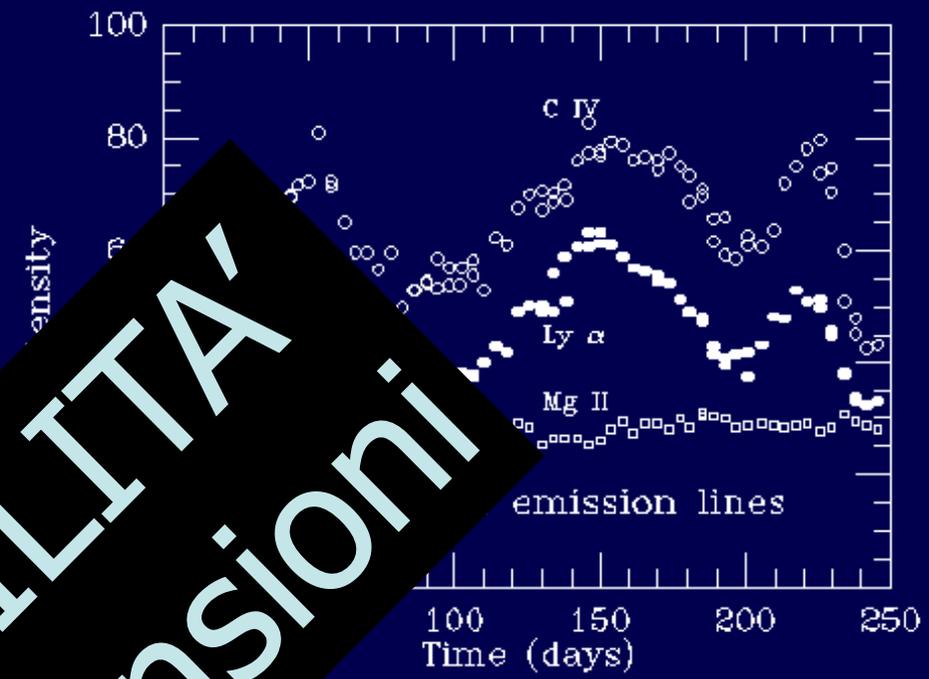
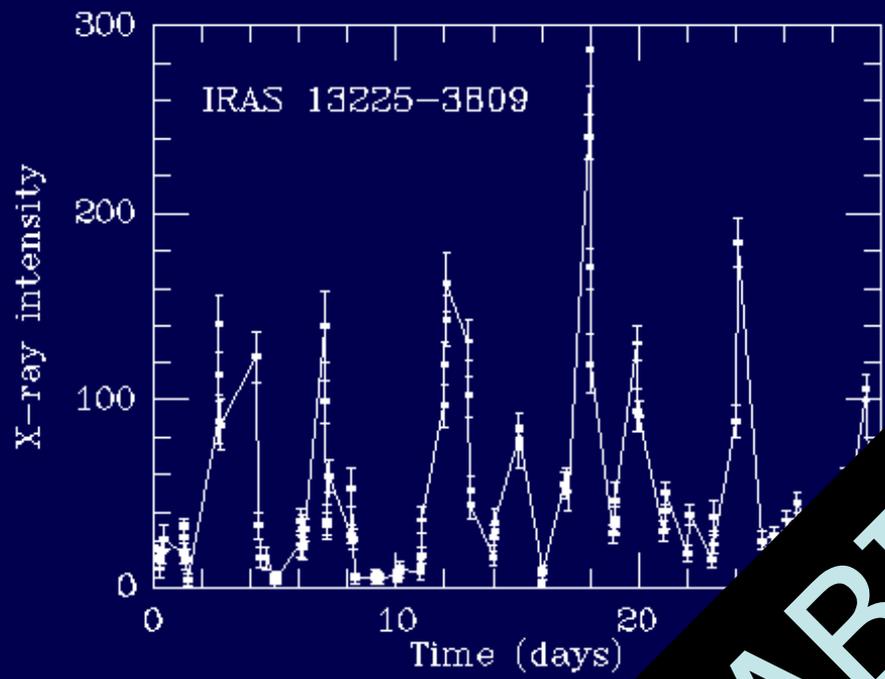
Luminosità elevata

Morfologia peculiare – getti

Variabilità

Emissione RADIO

Moti superluminali

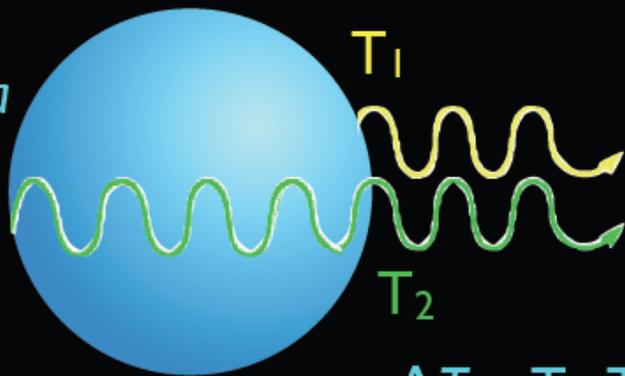


VARIABILITA'
→ dimensioni

La variabilità implica una sorgente di dimensioni piccole

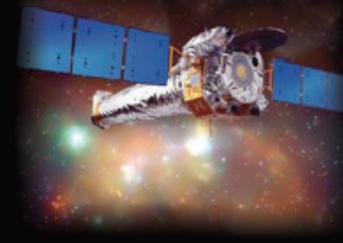
ΔT = tempo sul quale la
luce varia

c = velocità della luce



$$\Delta T = T_2 - T_1$$

$$D = \Delta T \times c$$



Proprietà

Spettri con righe di emissione larghe

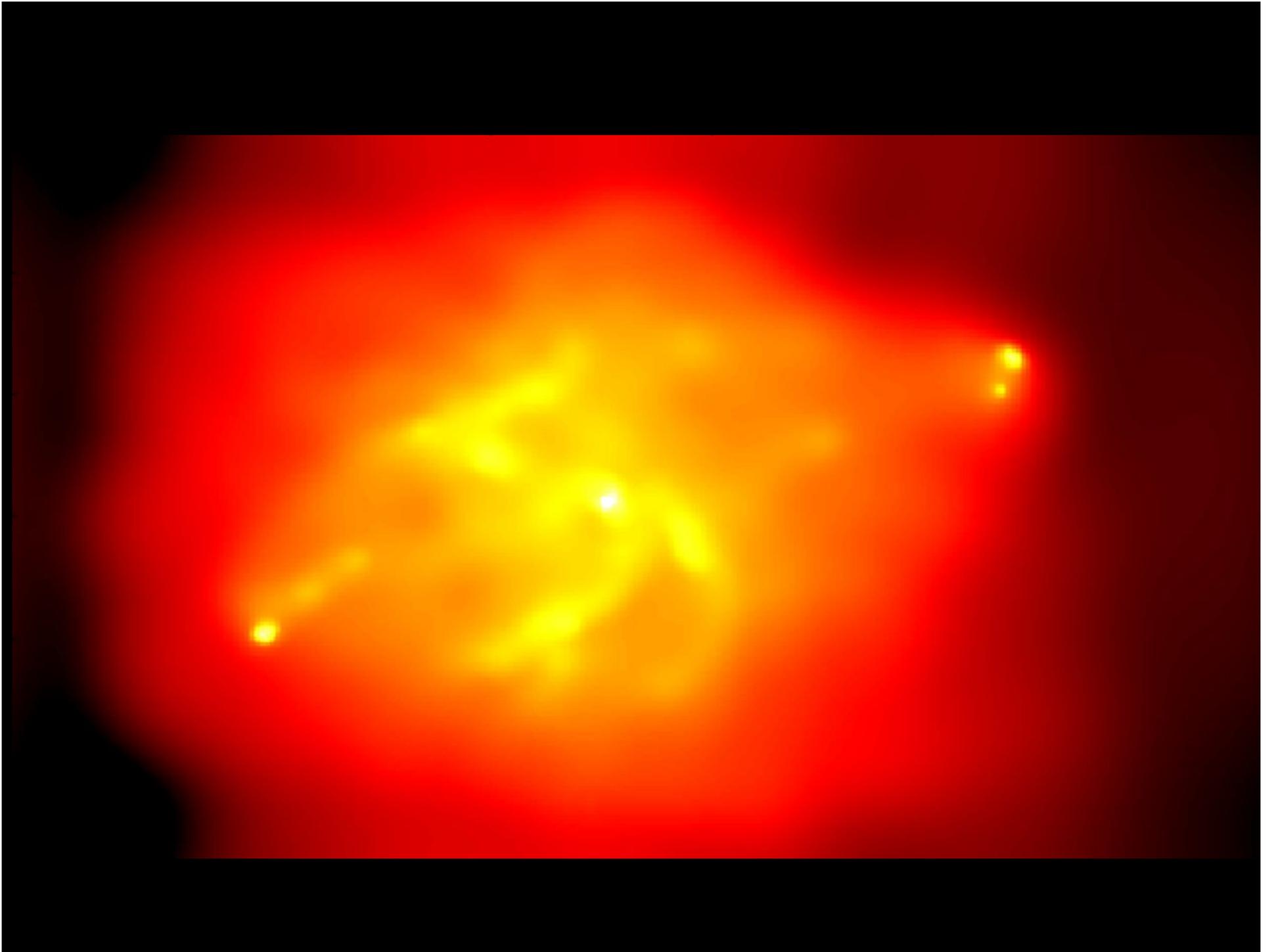
Luminosità elevata

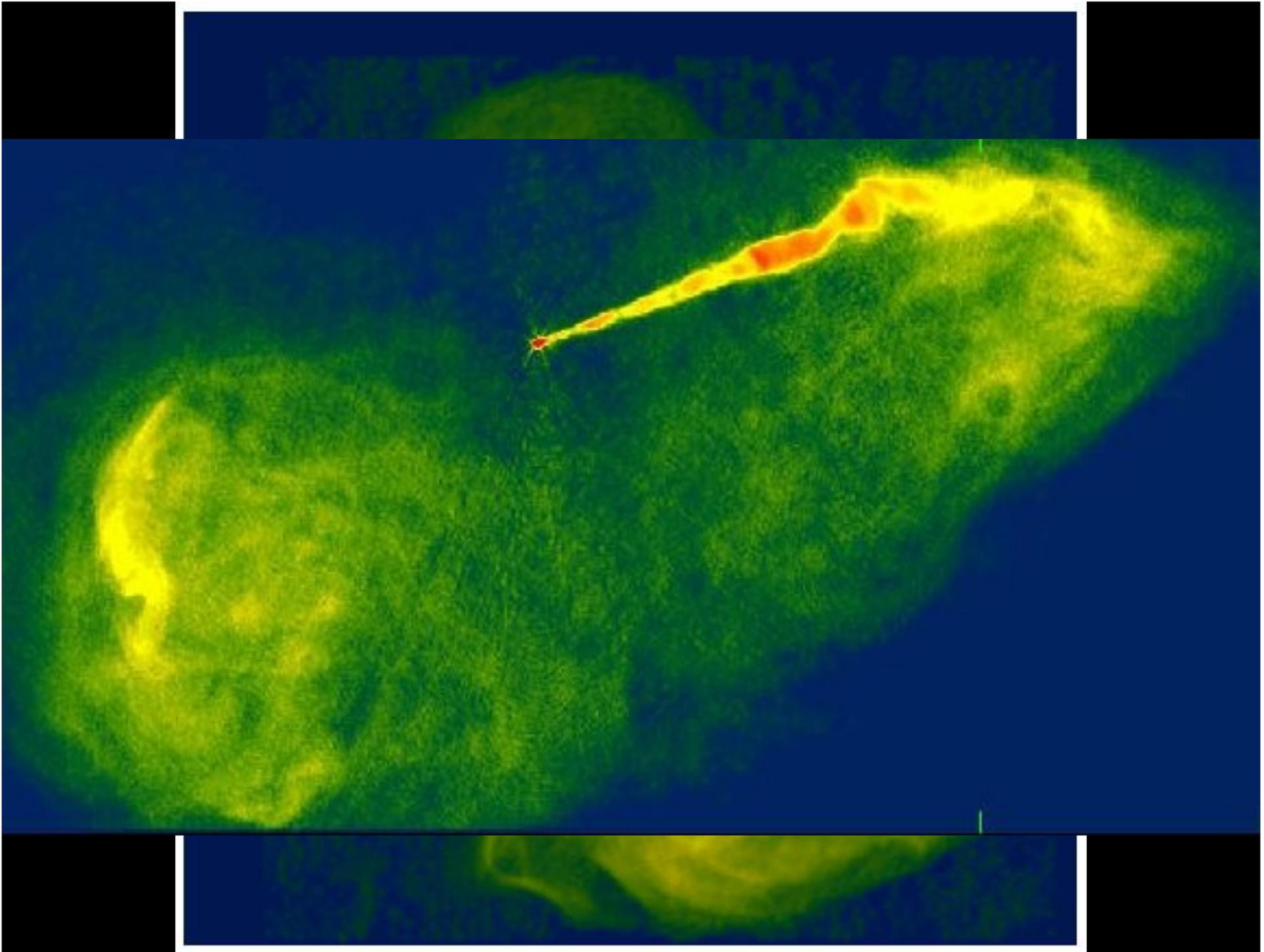
Morfologia peculiare – getti

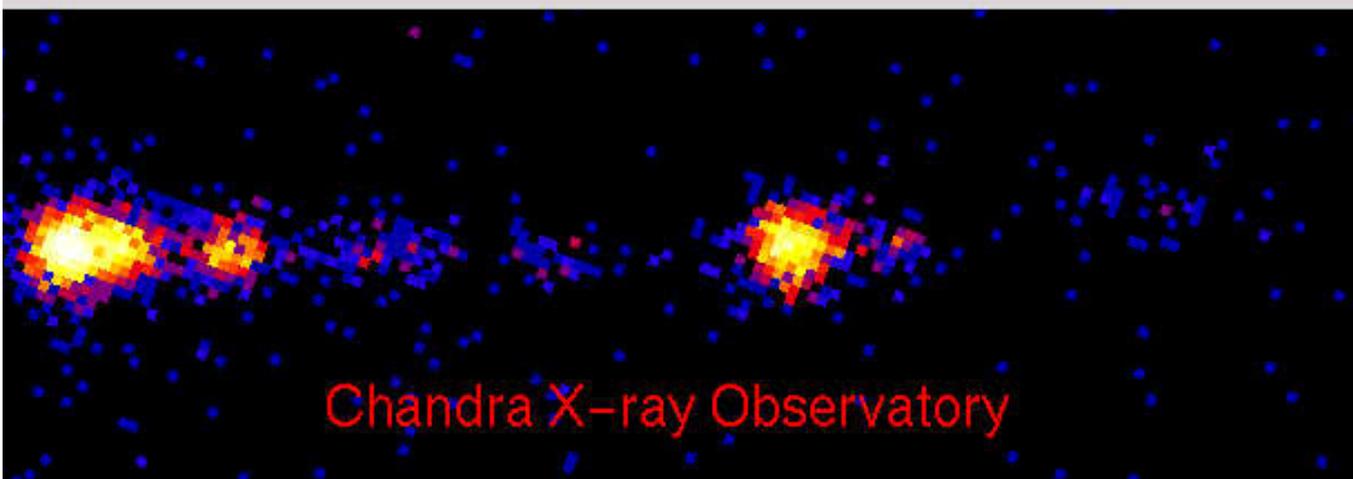
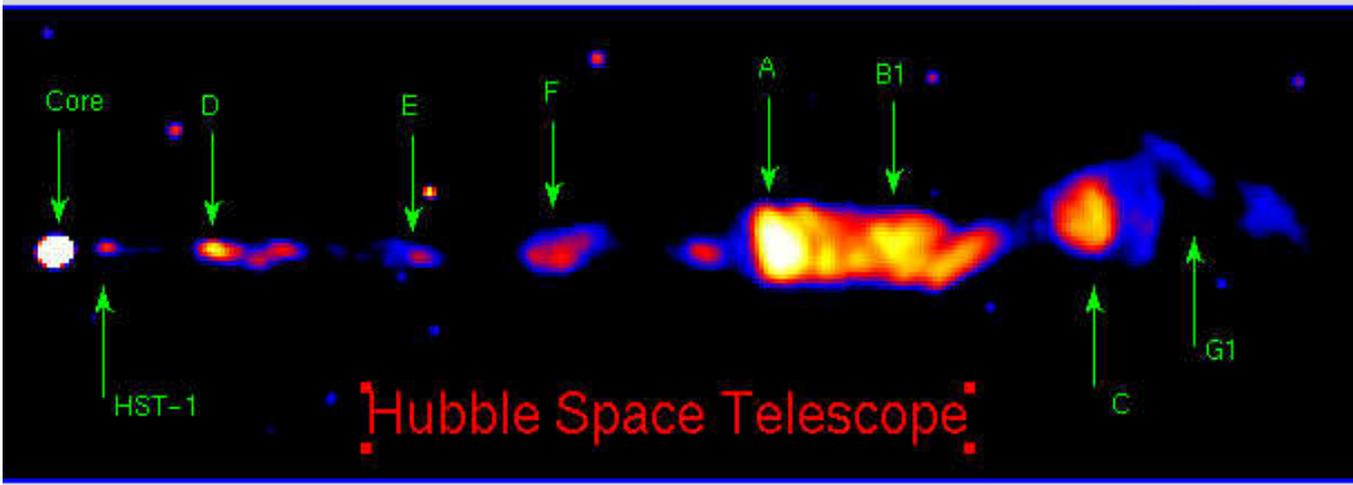
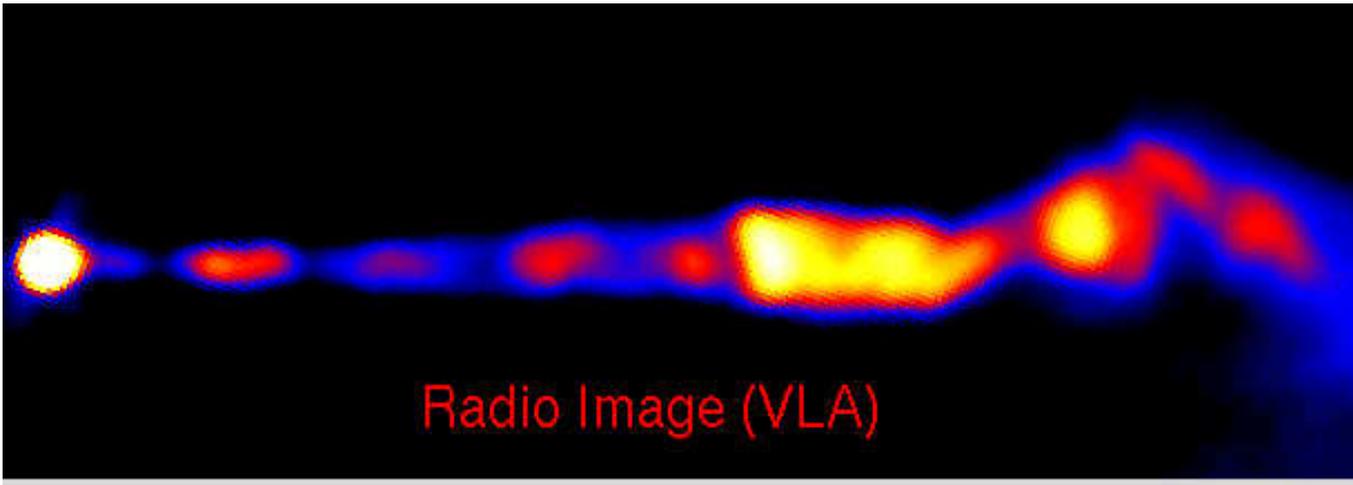
Variabilità

Emissione RADIO

Moti superluminali



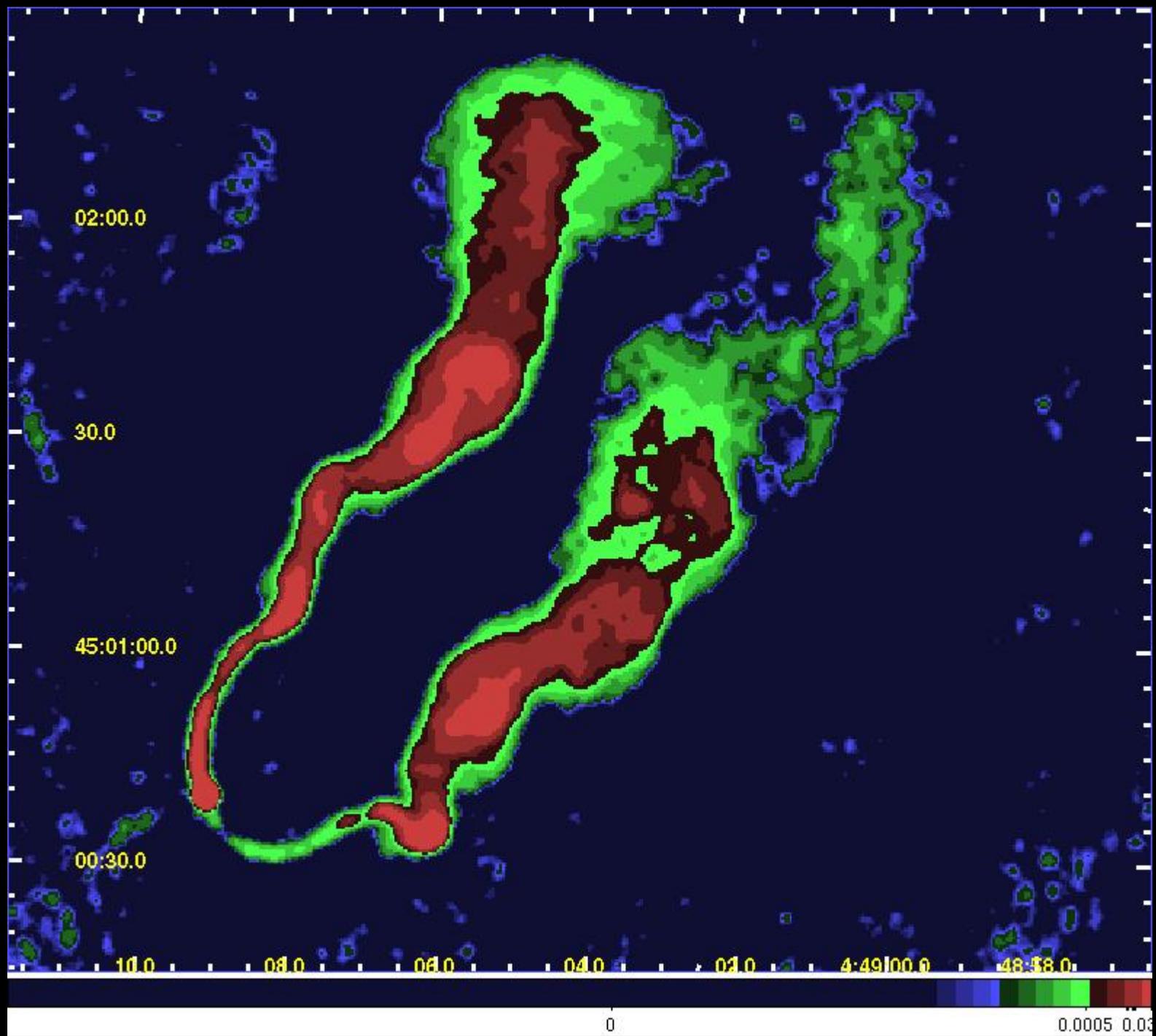




PKS2356-61 ($z = 0.1$)



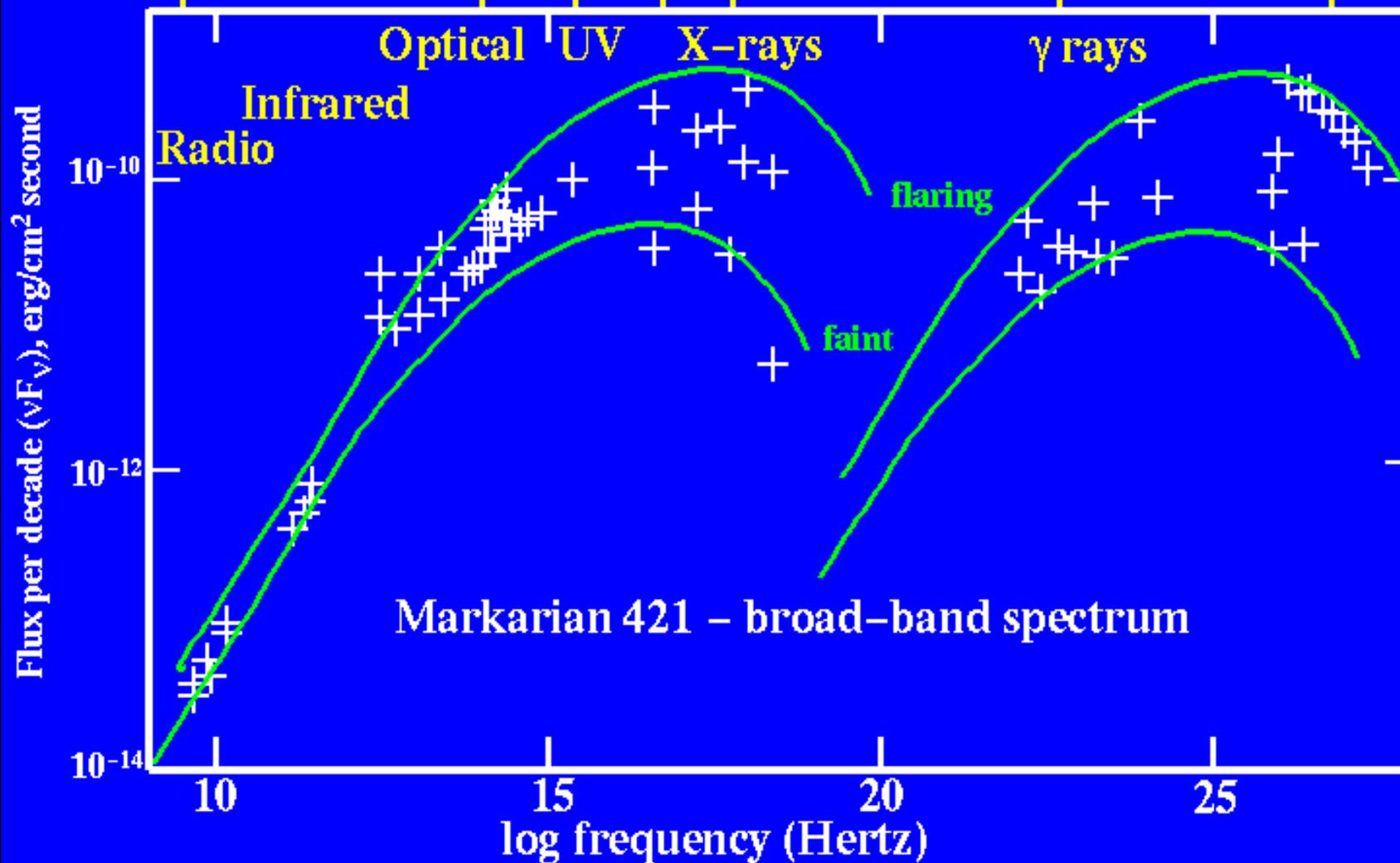
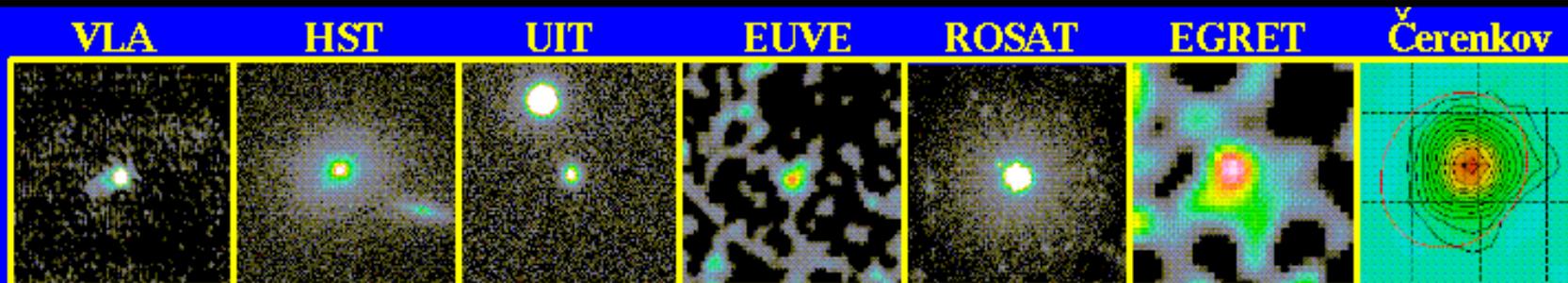
Quasar
in una
galassia
ellittica

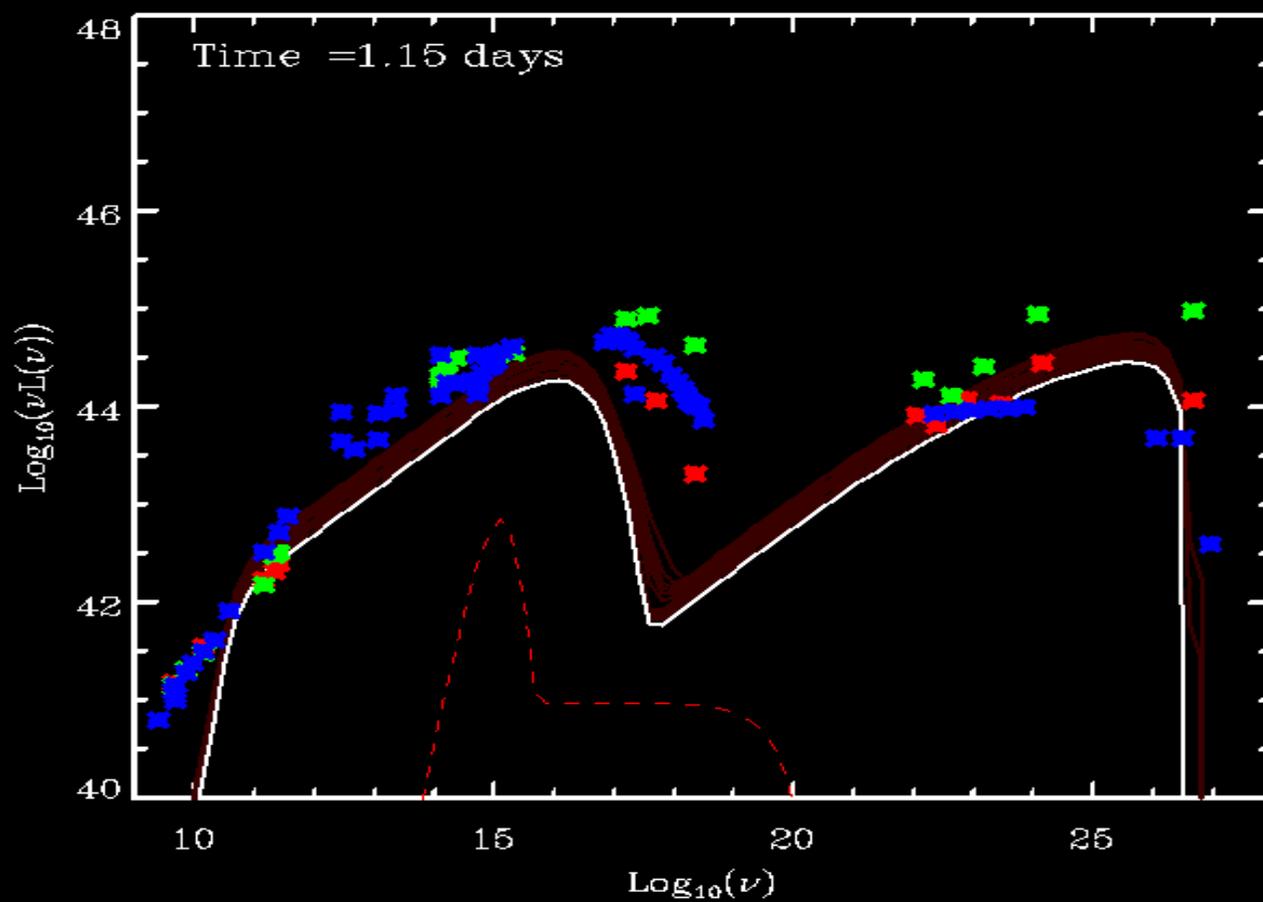
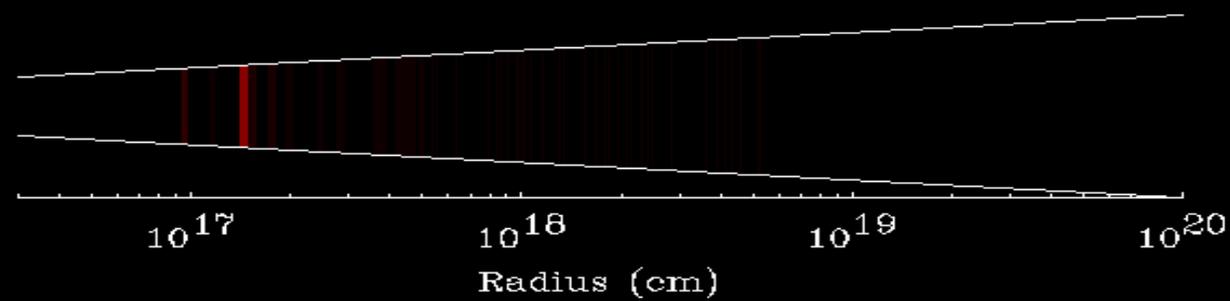


3C 129

$\lambda \sim 90 \text{ cm}$







Proprietà

Spettri con righe di emissione larghe

Luminosità elevata

Morfologia peculiare – getti

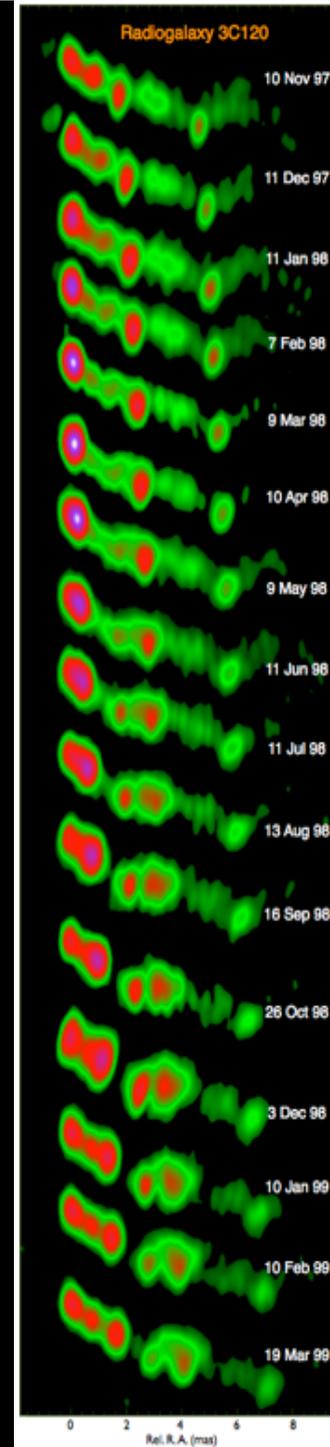
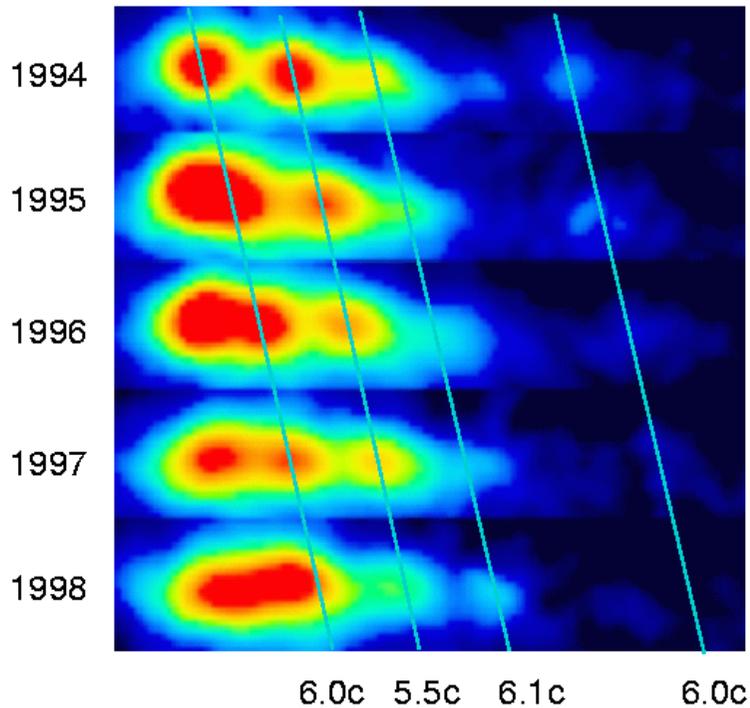
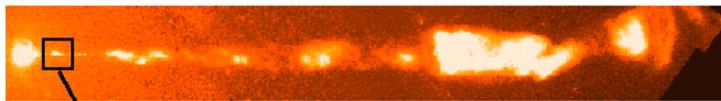
Variabilità

Emissione RADIO

Moti superluminali

Moti superluminali

Superluminal Motion in the M87 Jet



VLBA 22 GHz Observations
of
3C120

José-Luis Gómez

IAA (Spain)

Alan P. Marscher

BU (USA)

Antonio Alberdi

IAA (Spain)

Svetlana Marchenko-Jorstad

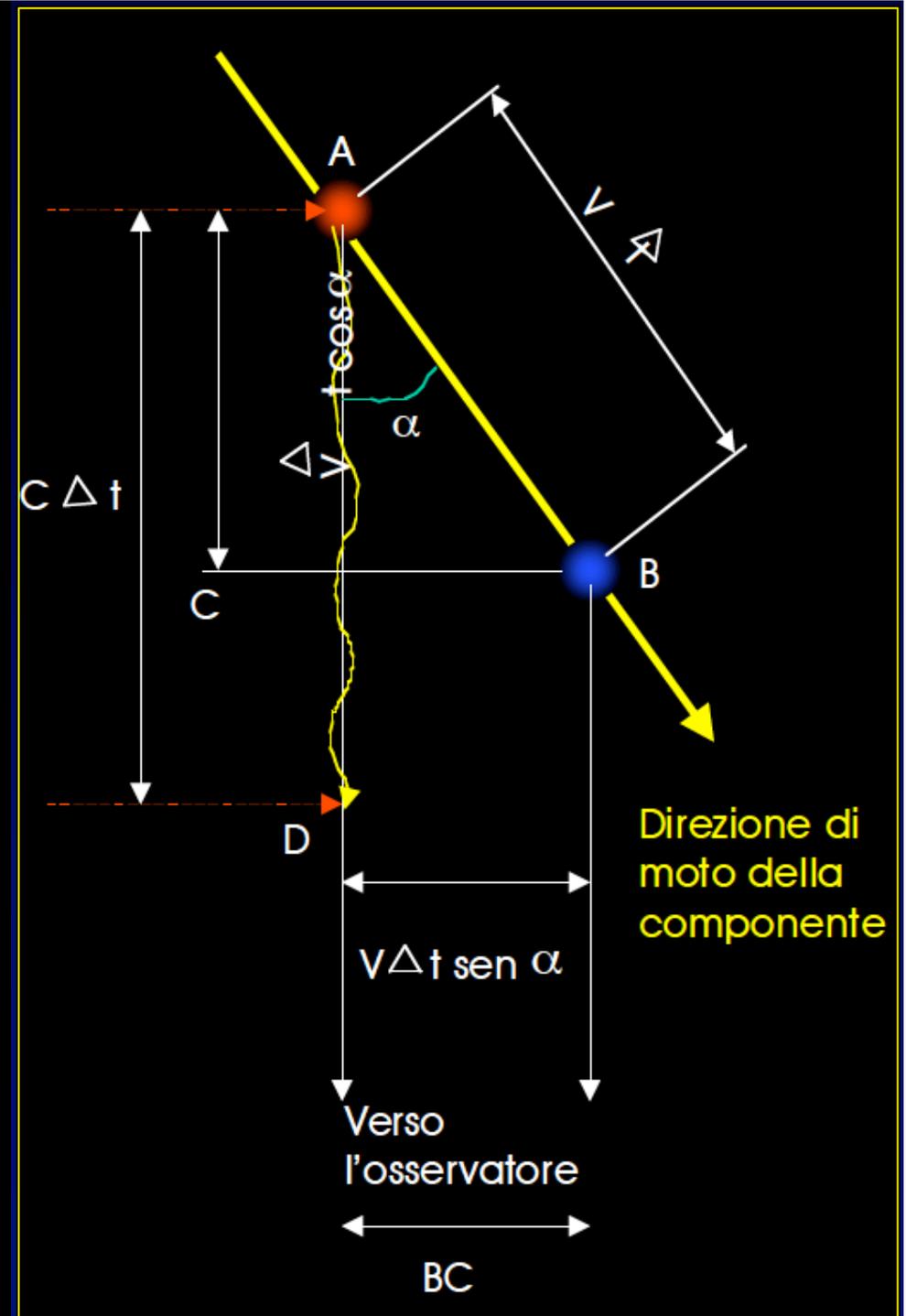
BU (USA)

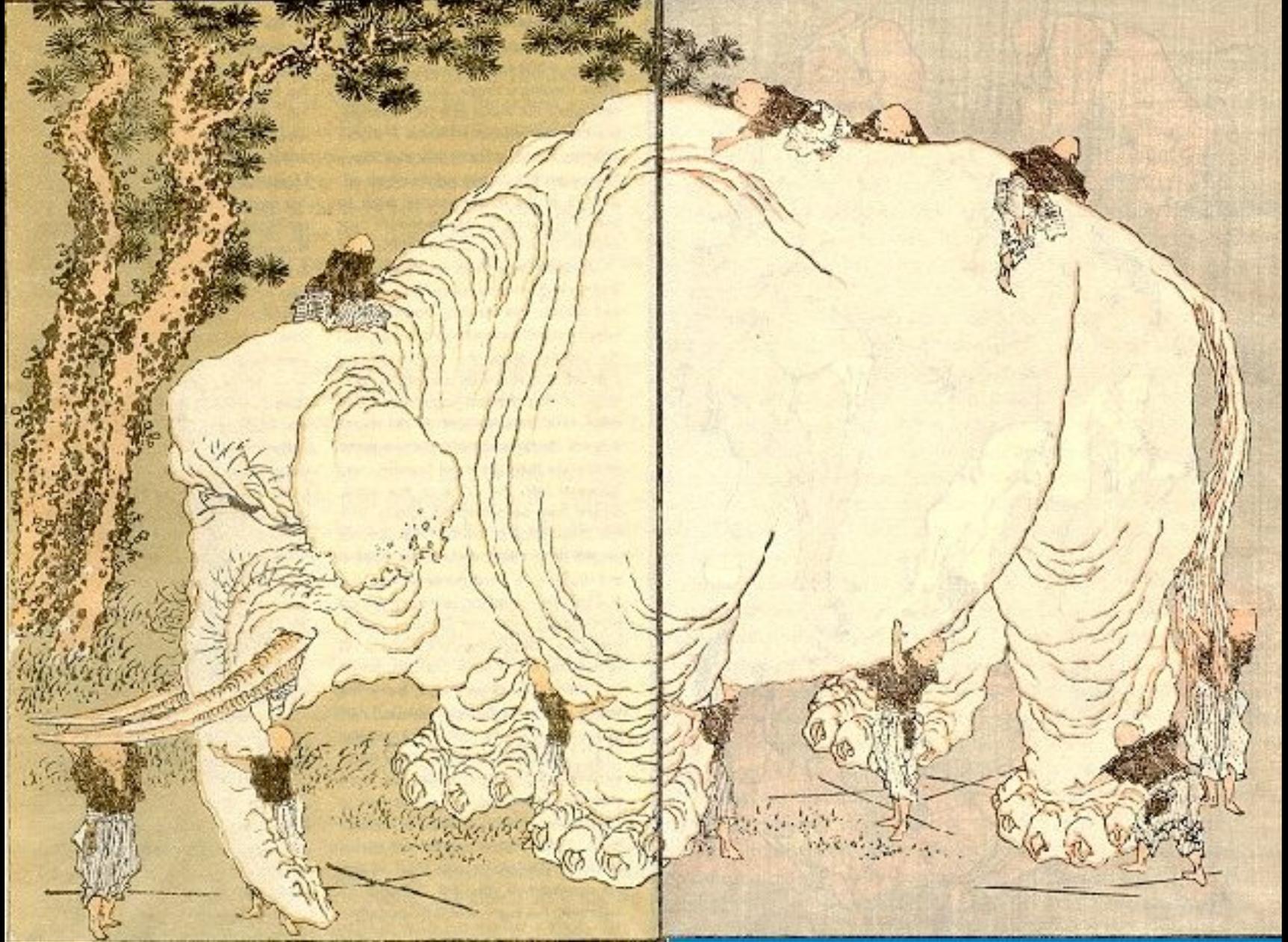
Cristina García-Miró

IAA (Spain)

Più veloce della luce!!!

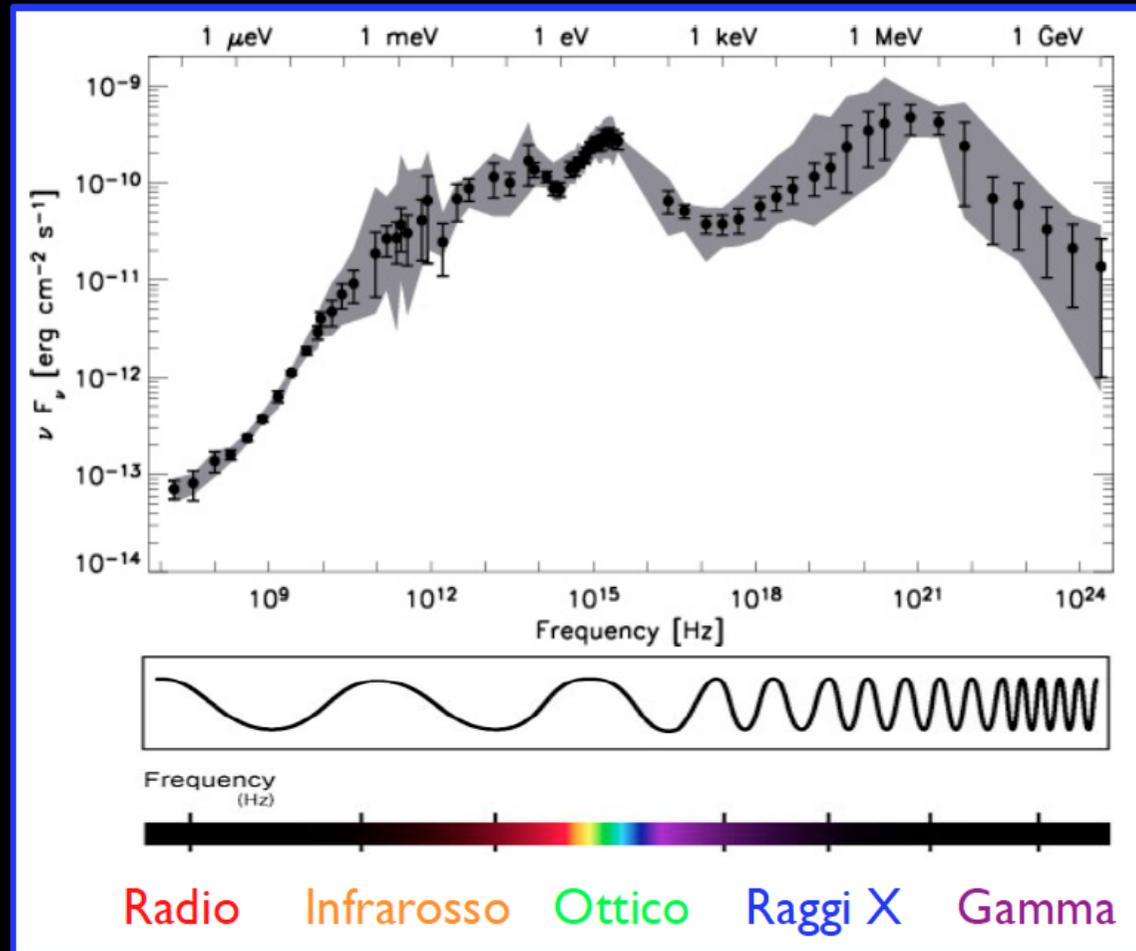
Se l'elemento B si muove a velocità vicina a quella della luce, la distanza percorsa da B nella nostra direzione è vicina a quella percorsa dal raggio di luce in A. La luce da B all'osservatore deve fare meno strada e arriva prima. Sembra che B si sia spostato rispetto ad A (nel piano del cielo) più veloce di c .





Modello Unificato

I Quasars emettono radiazione a tutte le lunghezze d'onda



AGN senza getto
≈90%

Narrow-Line Seyfert 1
Seyfert 1 e 2
LINERS 1 e 2



Galassia ospite: spirale
Raggi gamma: no!

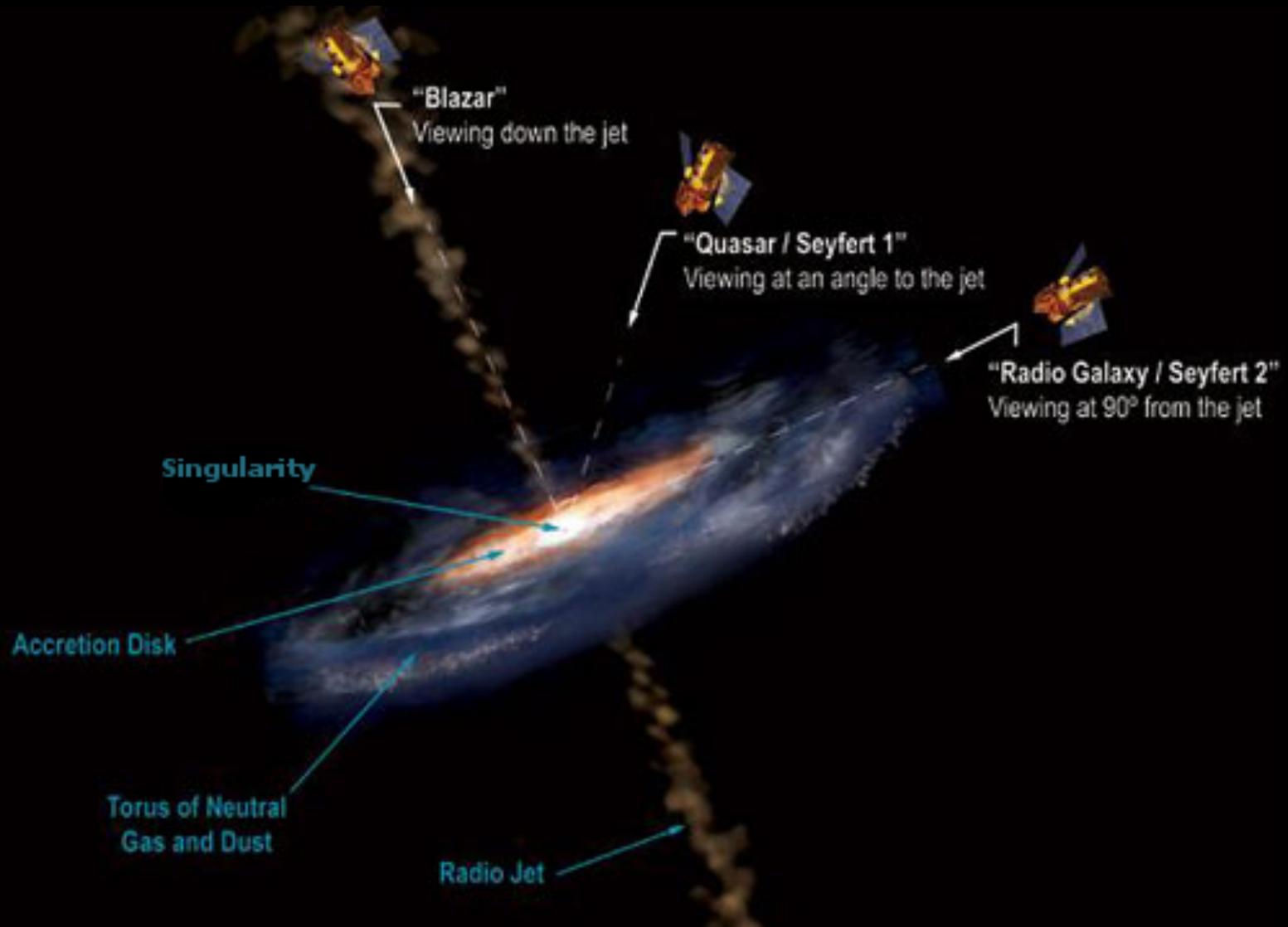
AGN con getto
≈10%

Blazars (BL Lac + Quasar)
Radiogalassie HE
Radiogalassie LE

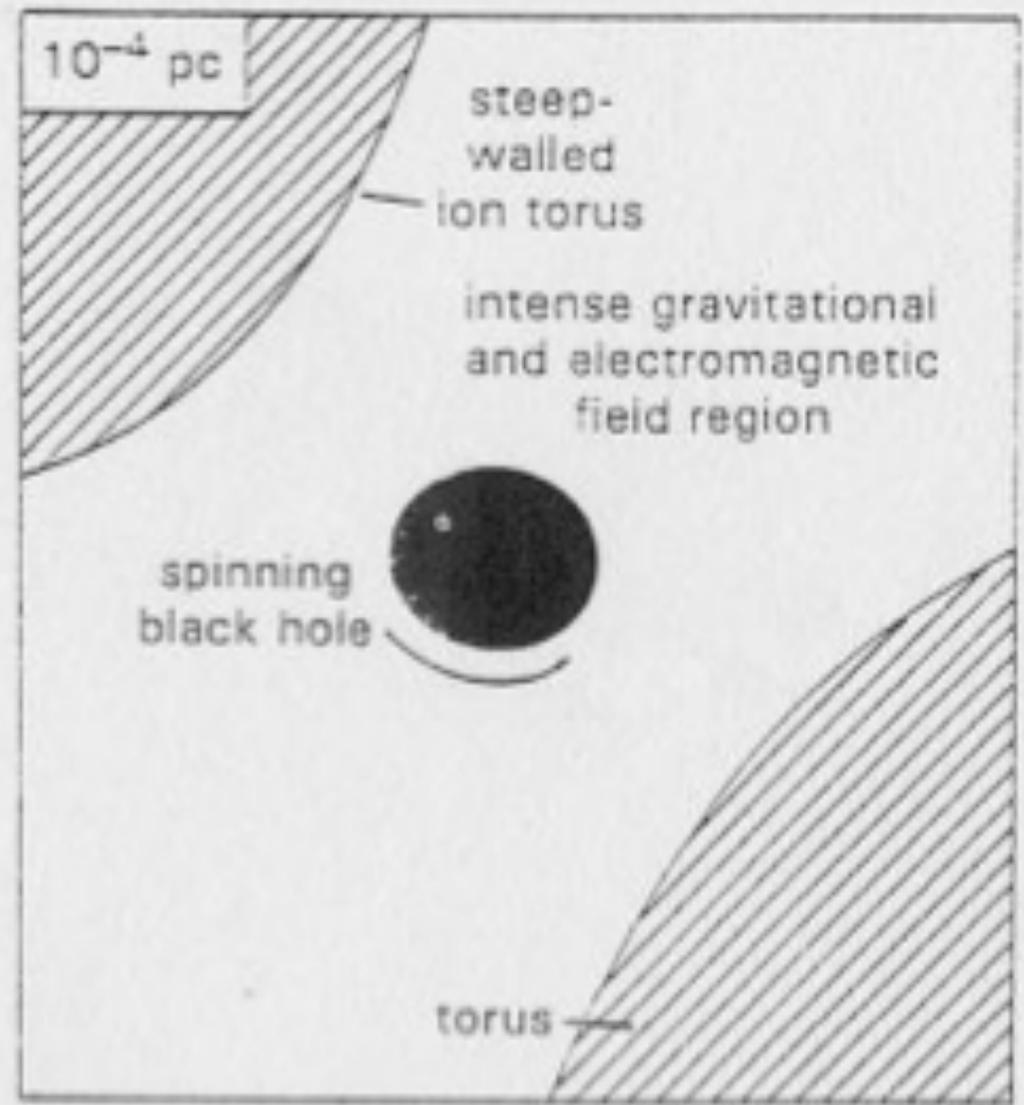


Galassia ospite: ellittica
Raggi gamma: sì!

Anche se in fase di scoperta sono state classificate molti tipi di nuclei galattici attivi, dopo un'attenta analisi (R. Antonucci; C.M. Urry & P. Padovani) si è visto che molte differenze potevano essere spiegate in termini di differenti punti di vista.



Diverse scale



The black hole. The Schwarzschild radius for a $10^6 M_{\odot}$ black hole is 2 AU (10^{-3} pc). The spin will introduce twisted magnetic field lines and particle acceleration.

Blandford 1990

Broad-Line Region (BLR)

Il gas interstellare che si trova oltre il disco, interagisce con la radiazione emessa da quest'ultimo generando delle linee di emissione.

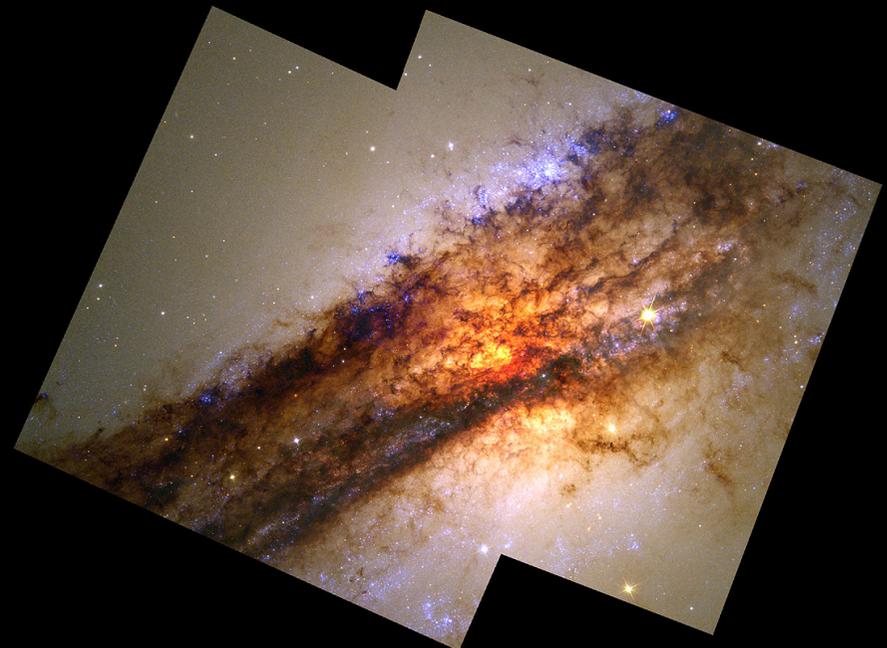
La vicinanza alla singolarità richiede che la velocità orbitale sia elevata (1000-10000 km/s) e si determina un allargamento (broadening) del profilo delle linee.

Narrow-Line Region (NLR)

Più lontano dal disco, ma ancora in grado di interagire con la radiazione emessa da quest'ultimo, c'è un'altra regione che emette delle linee. Questa volta, essendo più lontana dalla singolarità, la velocità orbitale è inferiore (< 1000 km/s) e quindi anche l'allargamento. Le righe sono più strette (narrow).

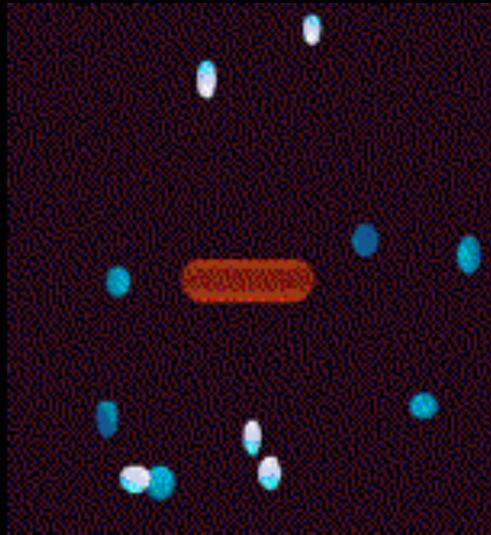
Toro molecolare

Tra le due regioni (BLR e NLR) c'è una ciambella di materiale freddo che oscura la vista diretta del nucleo o della BLR.

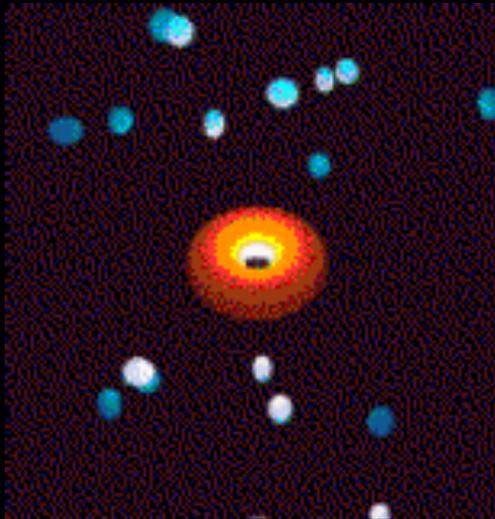


Modello Unificato

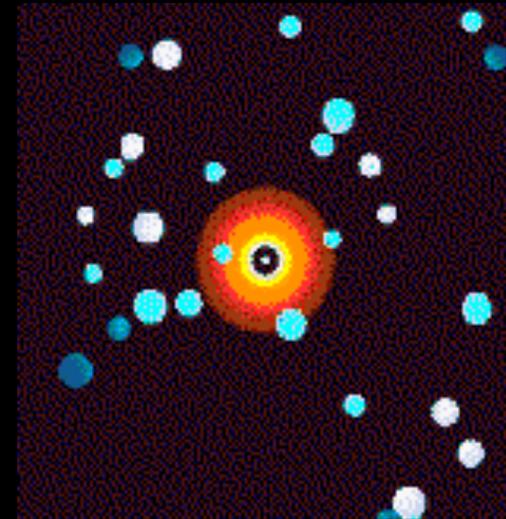
BH + Disco + Toro



SY2
di fianco

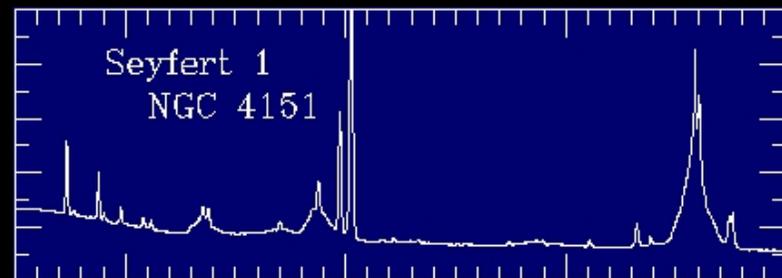
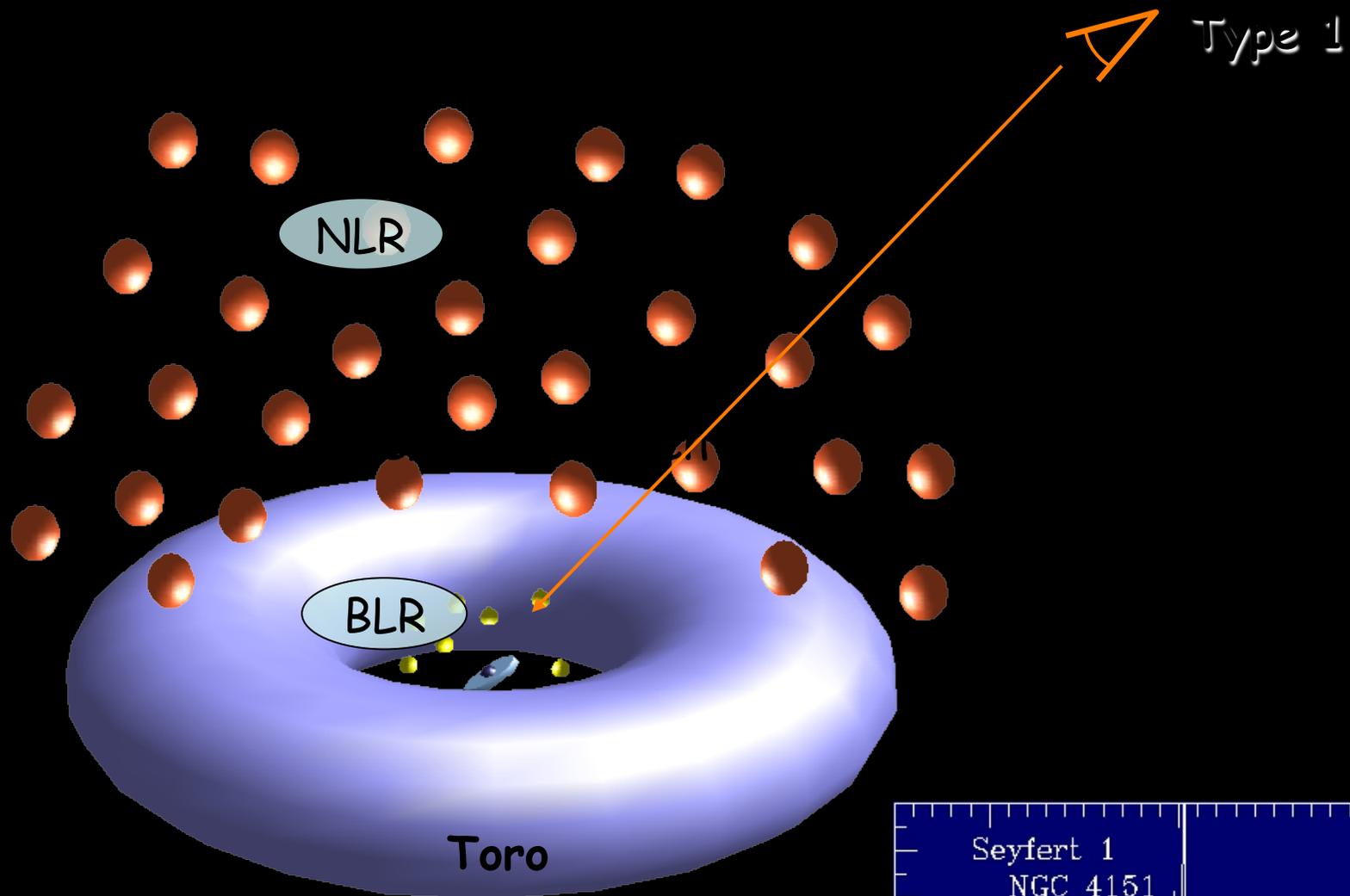


SY1
inclinato

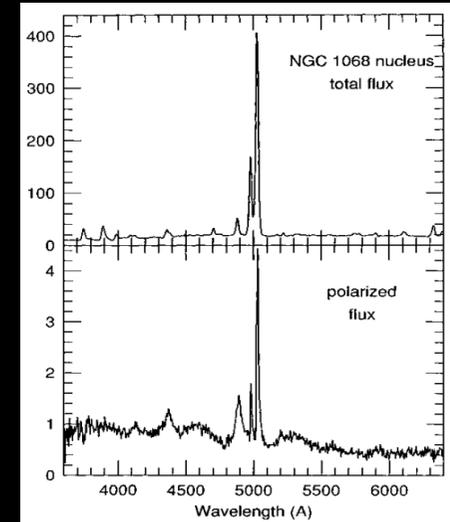
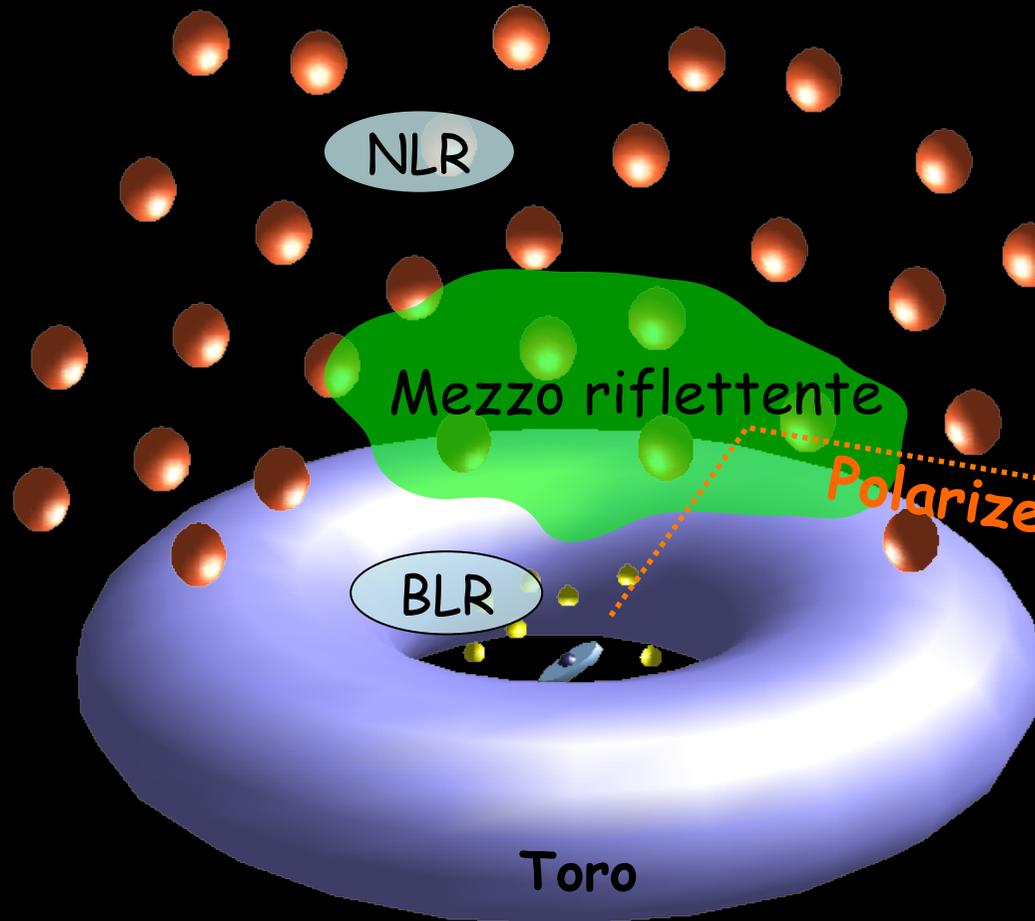


BL Lac
dritto nello scarico!

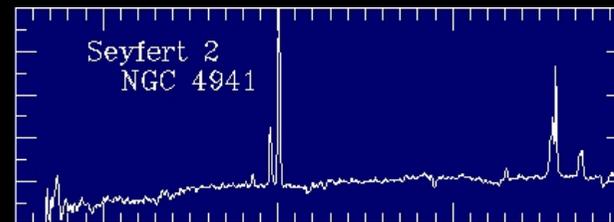
Il Modello Unificato



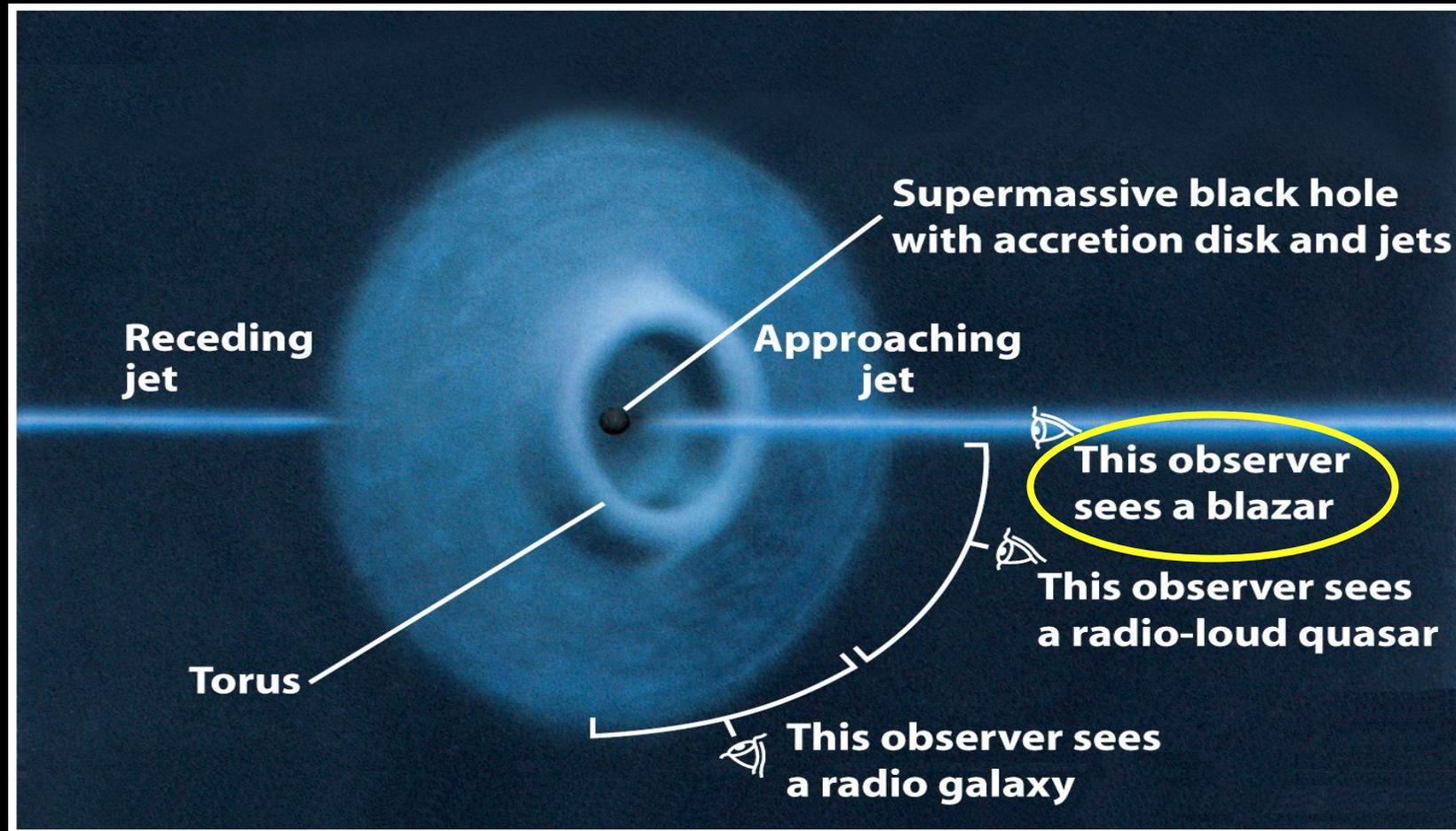
Il Modello Unificato



Narrow Lines
Polarized Broad Lines
No broad lines
Type 2



Getti extragalattici:



Courtesy: Ski Antonucci

Al centro di una grande galassia



Ground



Disk in Galaxy NGC 7052

HST • WFPC2



Active Galaxy
NGC 4438

Hubble Space Telescope
WFPC2



NASA and J. Kenney (Yale University)
STScI-PRC00-21

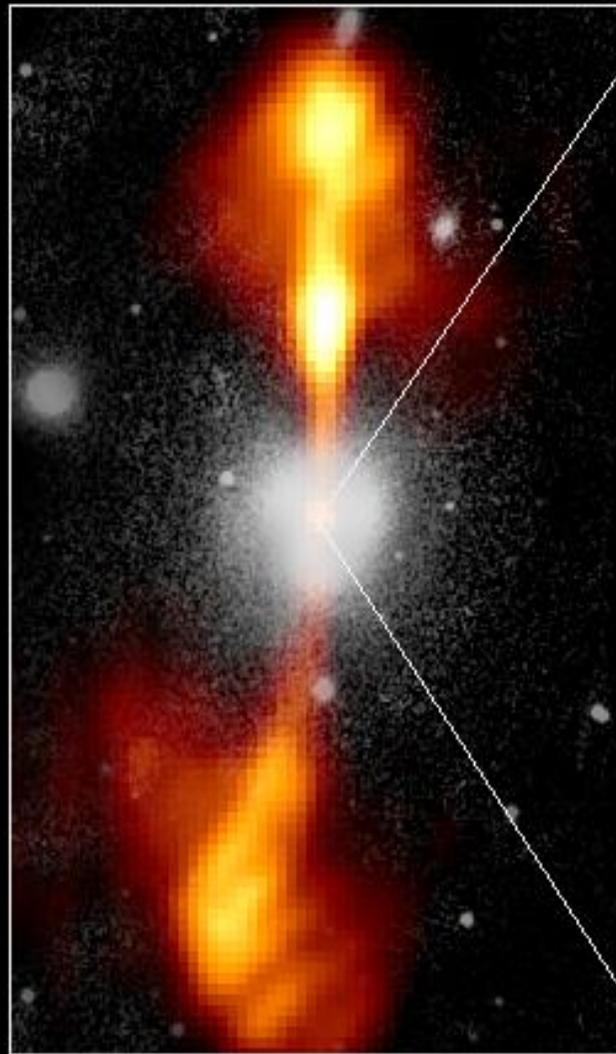
<http://hubblesite.org/newscenter/archive/releases/exotic/black-hole/1998/22/results/20/> and

http://hubblesite.org/newscenter/archive/releases/exotic/black%20hole/2000/21/image/a/format/web_print/results/20/

Hubble Space Telescope

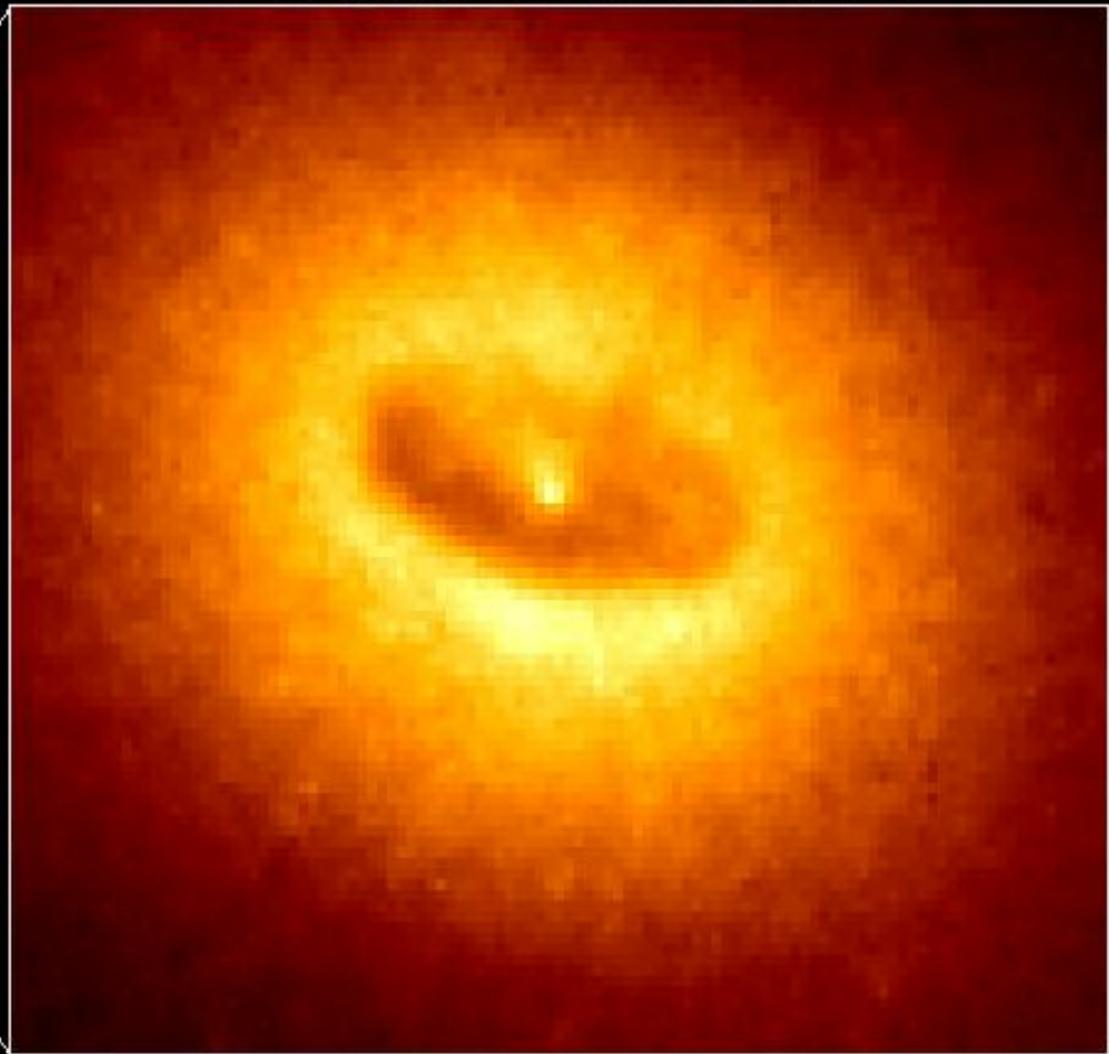
Wide Field / Planetary Camera

Ground-Based Optical/Radio Image



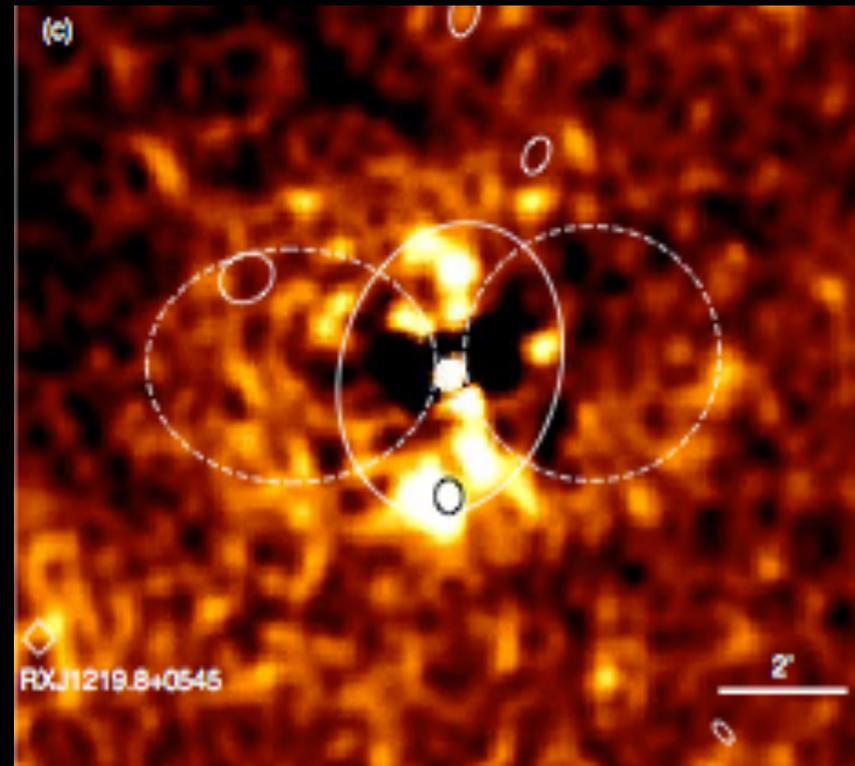
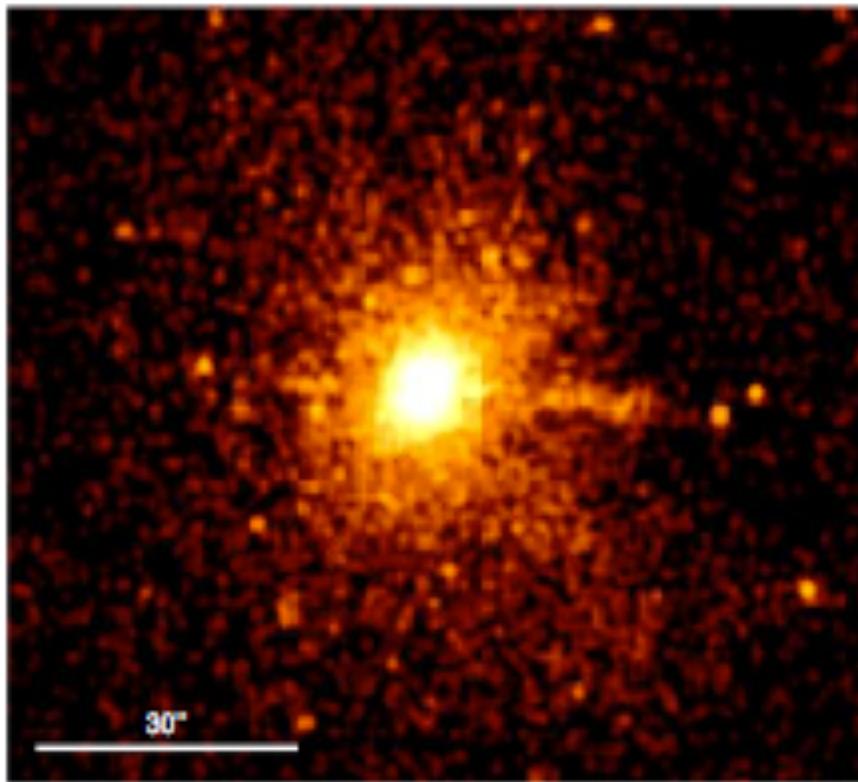
380 Arc Seconds

HST Image of a Gas and Dust Disk



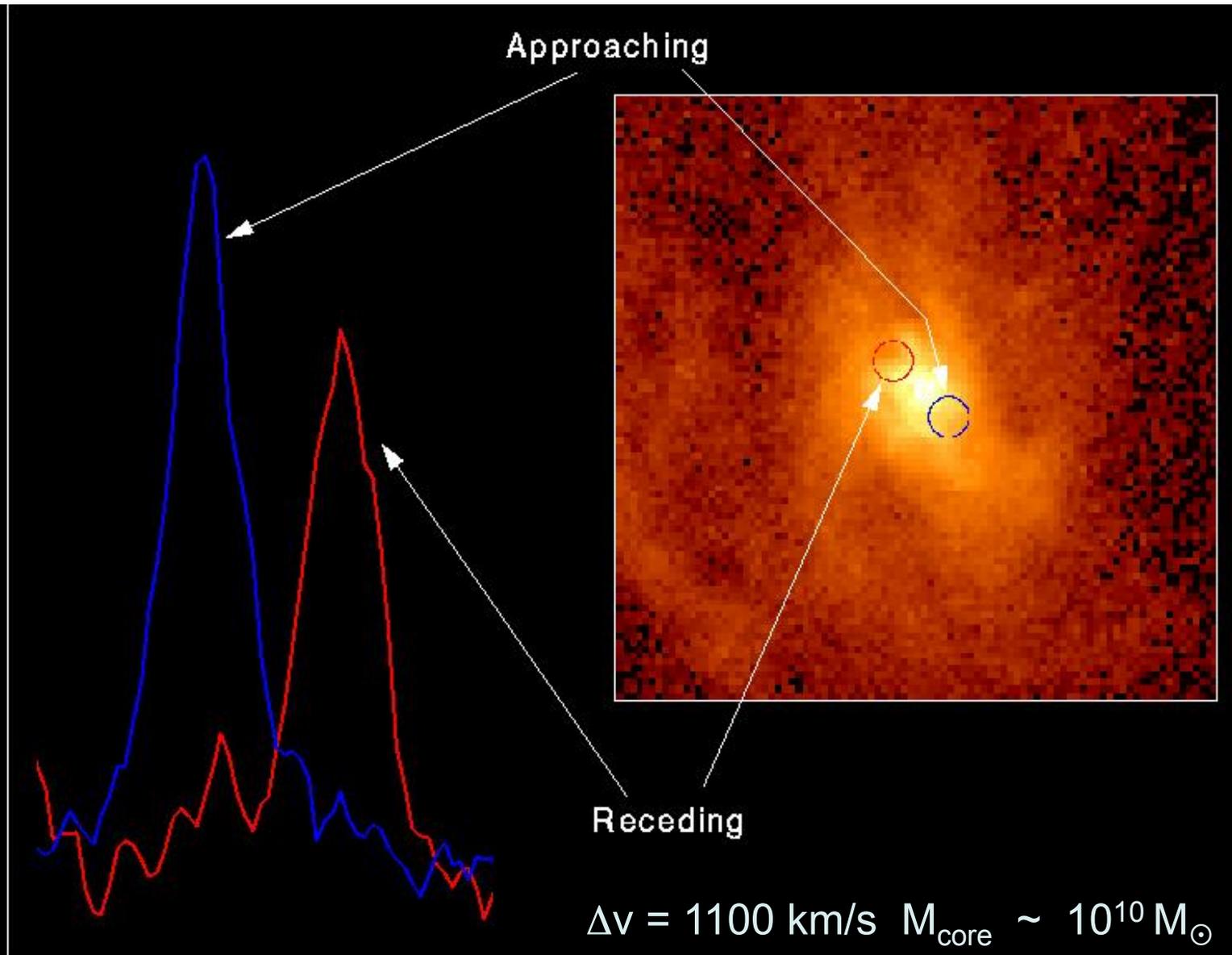
17 Arc Seconds

NGC 4261



- Immagini Chandra O'Sullivan et al

Spettro del disco di gas nella galassia attiva M87



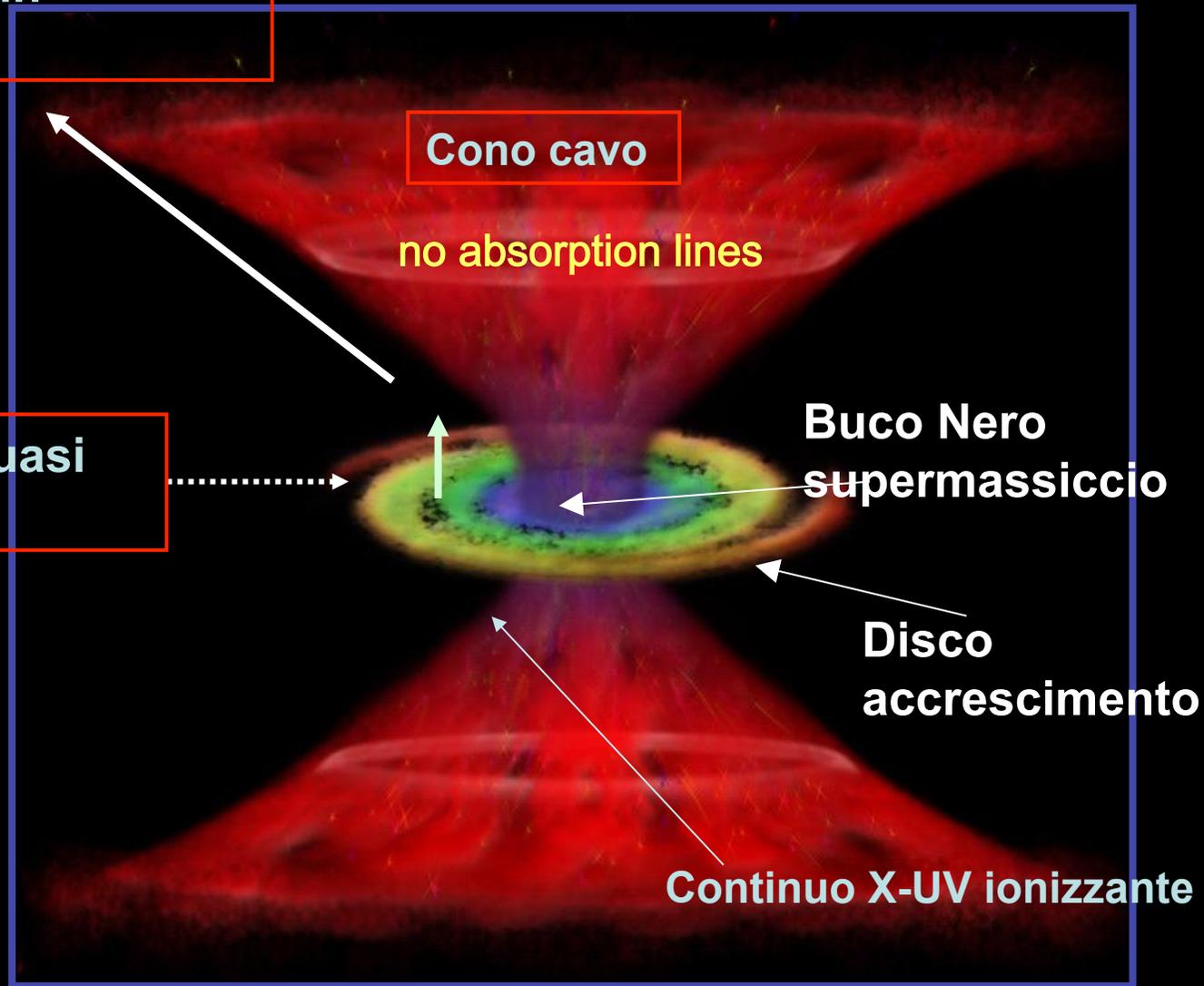
Hubble Space Telescope • Faint Object Spectrograph

Vento bi-conico in accelerazione

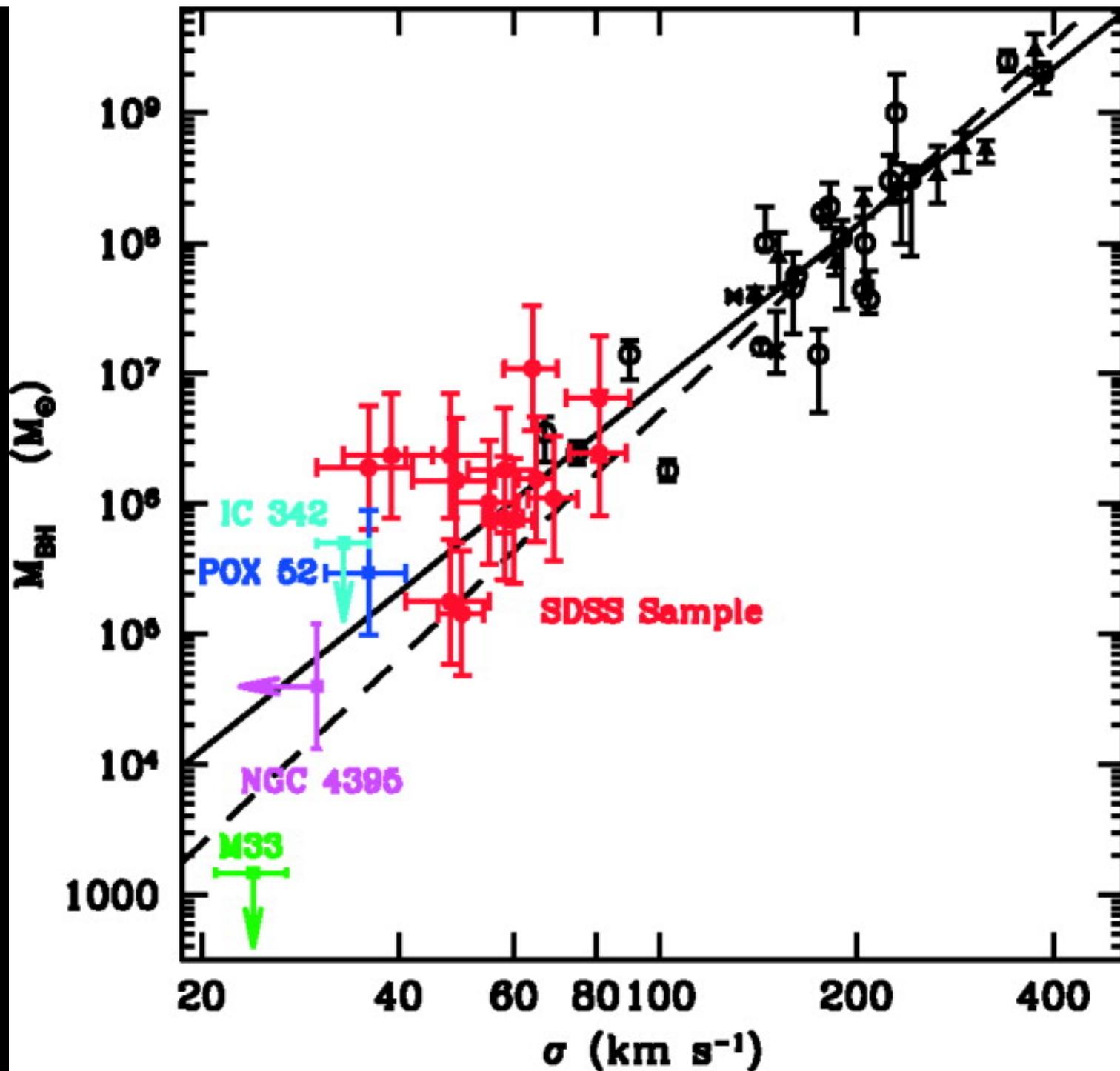
BALs
Polarization

Vento "sottile" quasi verticale

WAs
NALs
BELs



Elvis M., 2000, ApJ, 545, 63





La Via Lattea

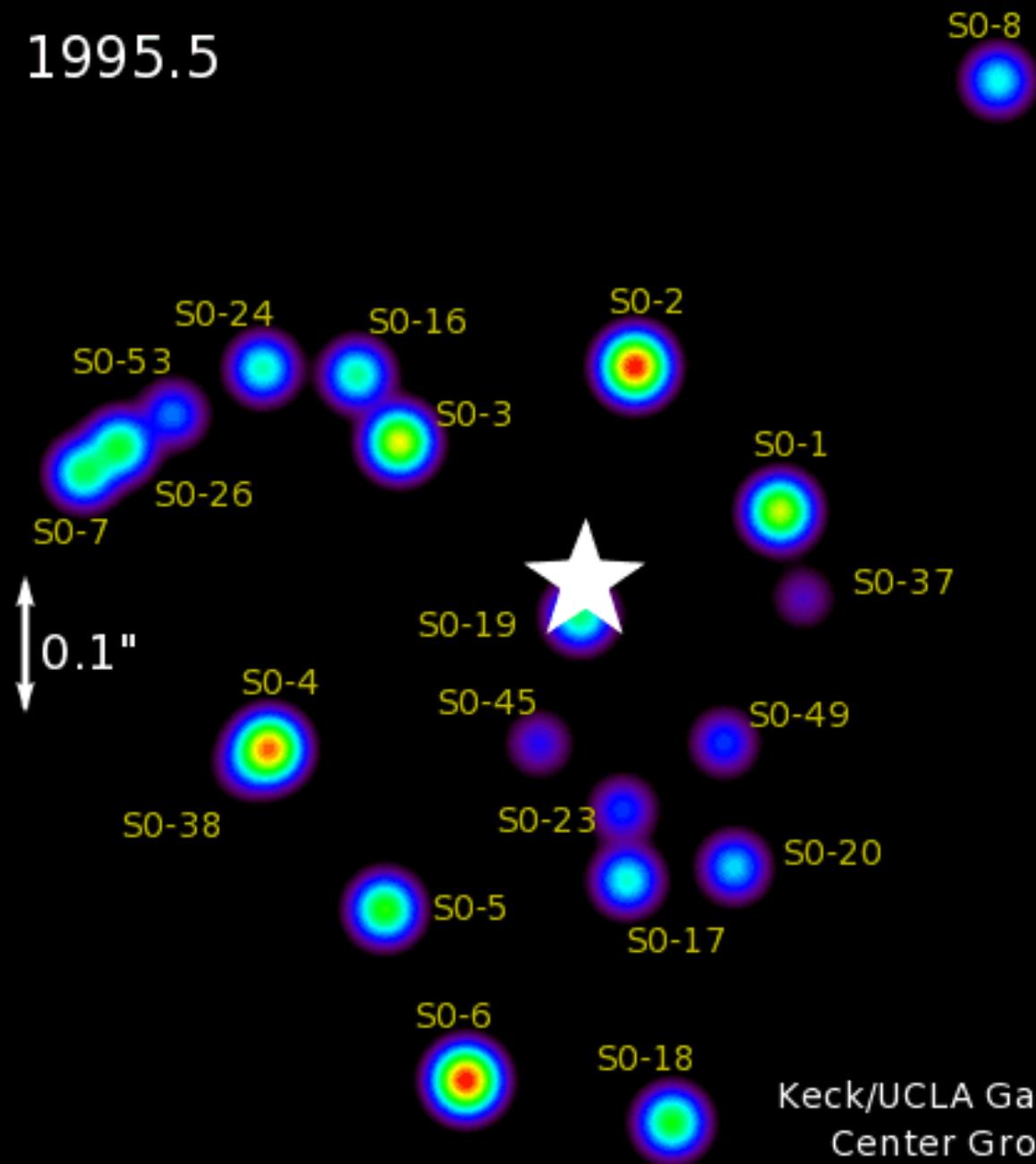


Outer Arm
Perseus Arm
Orion Arm
Carina Arm
Crux Arm

Norma Arm
24Kpc Arm
Sagittarius Arm
Scutum Arm

UNSC Space
Covenant Space

1995.5



Keck/UCLA Galactic
Center Group

Massa del Buco Nero

$$\frac{GMm}{r^2} = \frac{mv^2}{r}$$

$$p^2 = \frac{4\pi^2}{GM} r^3$$

3^a legge di Keplero

$$M =$$

4 milioni di volte la
massa del Sole

Ma cosa sono perciò gli AGN?

Sono galassie ad alto/altissimo z

Hanno distanze cosmologiche ($>10^9$ LYs) che fanno sembrare questi oggetti, che hanno brillanze intrinseche enormi, delle deboli stelle

Dai dati X tale potenza ($\sim 10^{47}$ erg/sec) è confermata, risultando circa 10 trilioni maggiore di quella emessa dal Sole per un oggetto di diametro pari a quello del Sistema Solare.

Si nutrono del materiale circostante, da 1 Sole alla settimana a 1 Sole all'anno

Una piccola frazione presenta getti ed emissione radio collimata

Abbiamo visto che:

- Le galassie sono sede di fenomeni “violenti”
- La causa è la caduta di materia per gravità verso la regione centrale

Resta da capire:

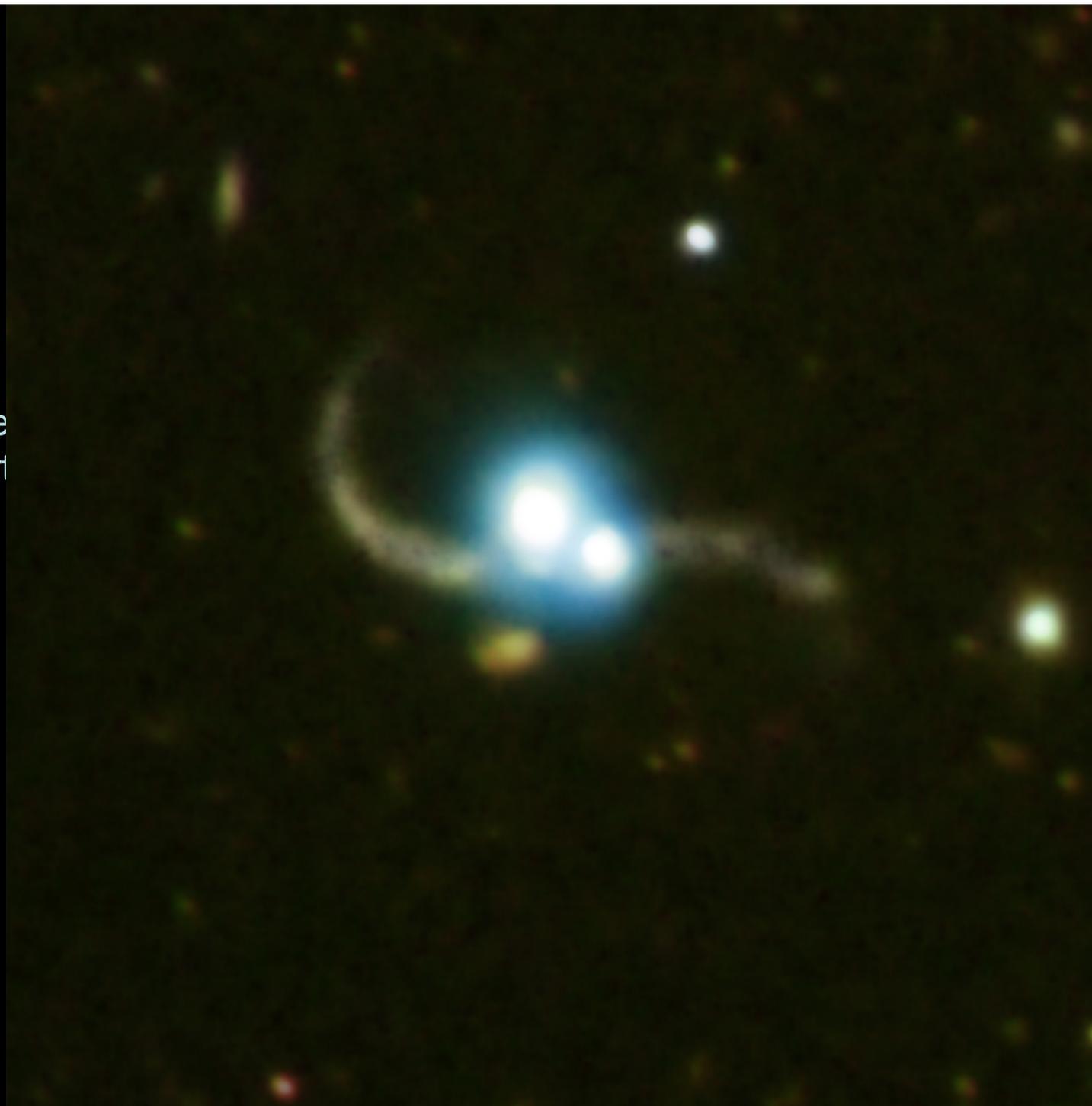
- Come si estrae l'energia dal buco nero per trasmetterla ai getti?
- Se ogni galassia attiva ha un buco nero centrale, perché solo alcune hanno getti radio?
- Perché non ce ne sono vicini a noi?

•...

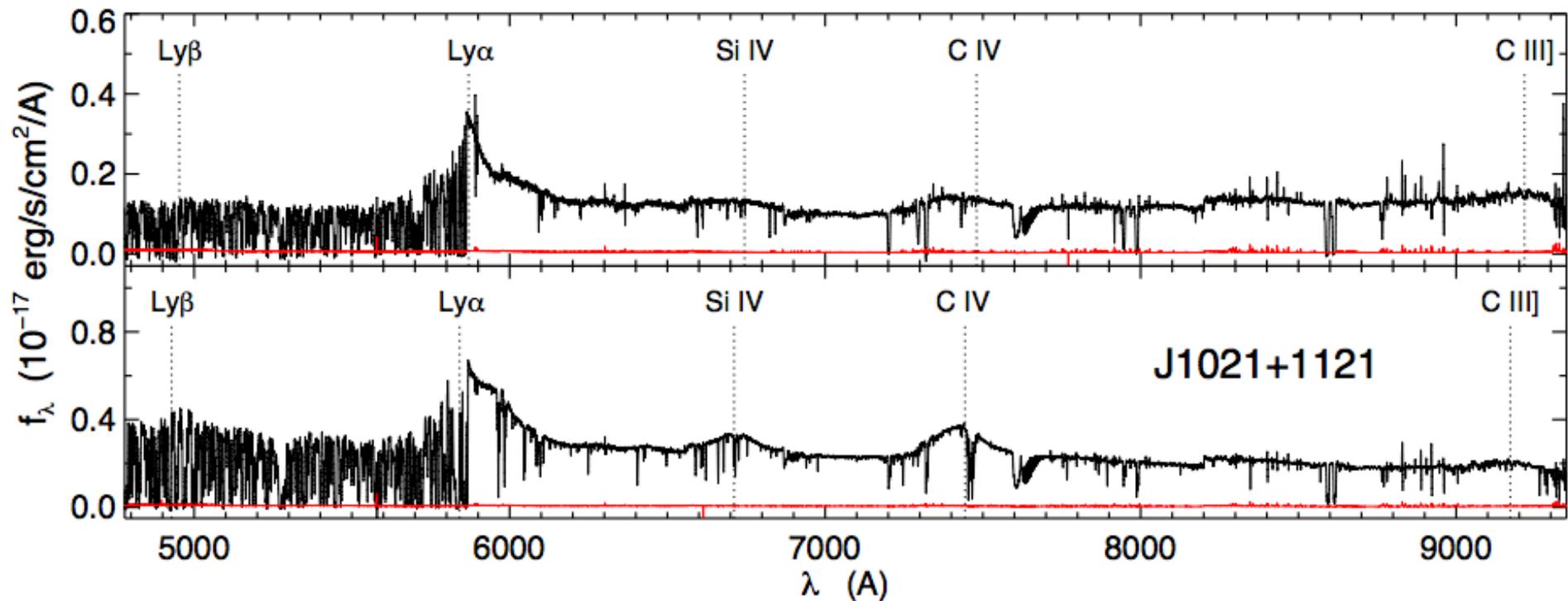
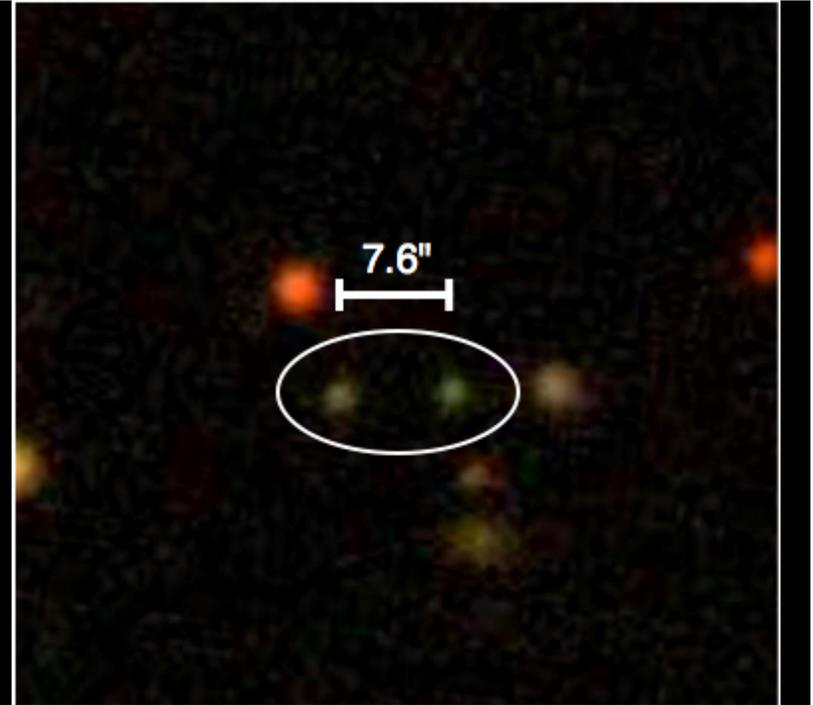
Cosmologia →

Cosmologia

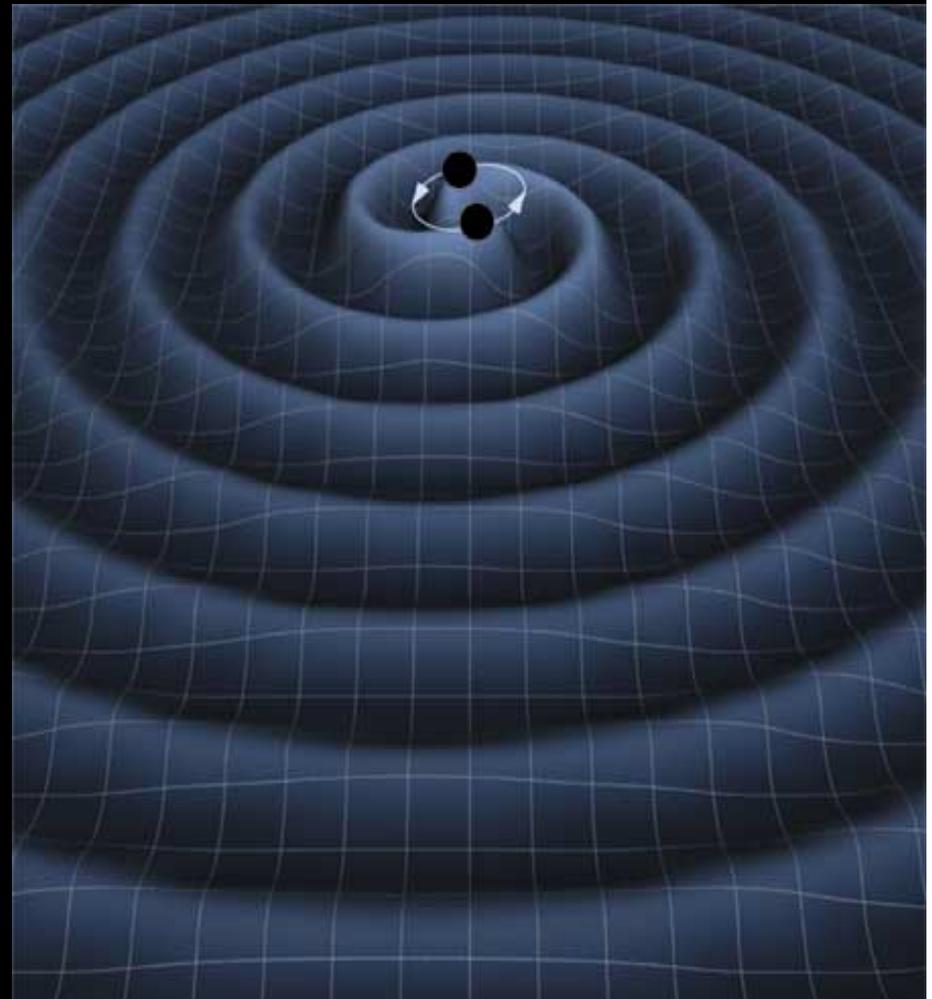
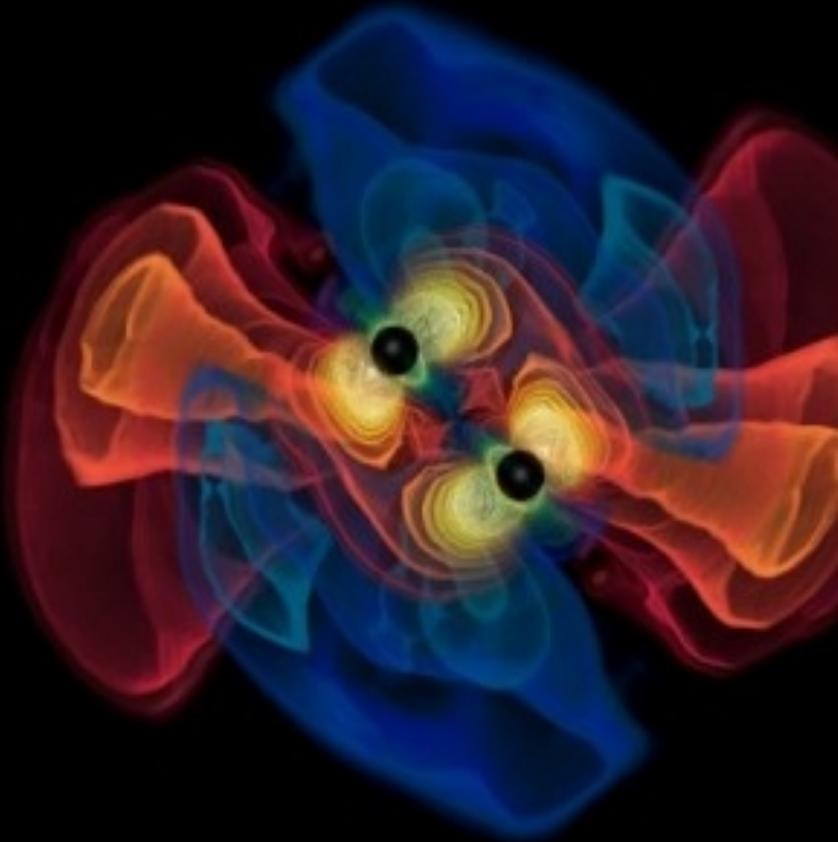
4
galassie
di Sefert
con
Doppio
Nucleo
in IR



Coppia di quasar a $z=3.8$,
40 kpc
27 coppie a $z > 2.9$



Onde Gravitazionali



I Quasars: sonde cosmologiche

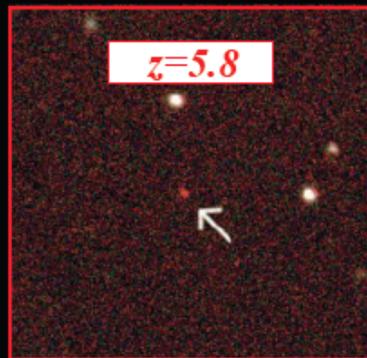
L'elevata luminosità ed apparenza puntiforme offrono la possibilità di usare i quasars come strumenti per sondare l'universo lontano.

I Quasars sono tra gli oggetti più distanti che riusciamo a vedere.

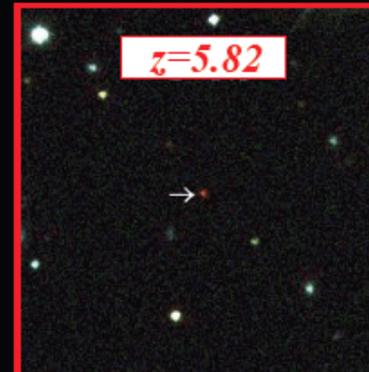
$z \approx 6$



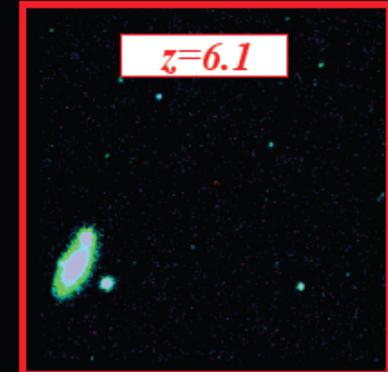
*Età dell'universo \approx
1 miliardo di anni*



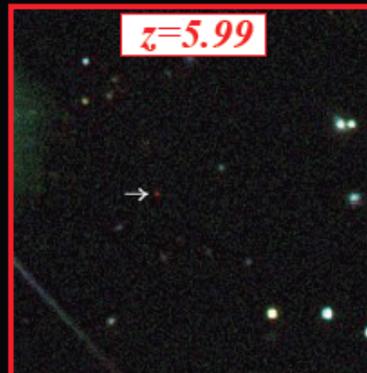
$z=5.8$



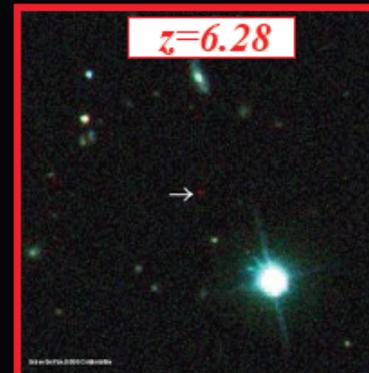
$z=5.82$



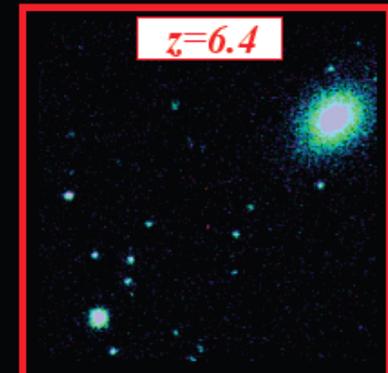
$z=6.1$



$z=5.99$



$z=6.28$



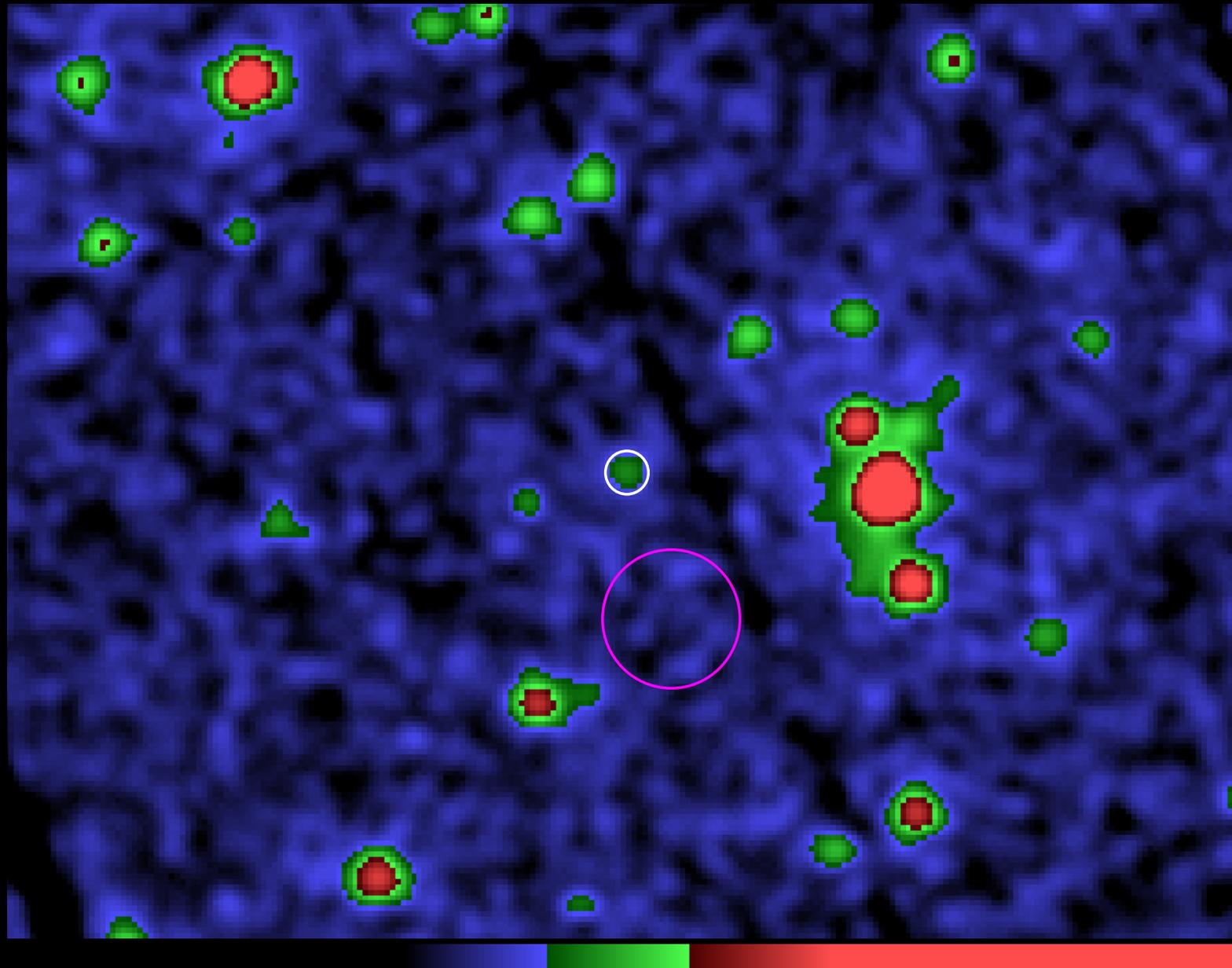
$z=6.4$

Il quasar più distante

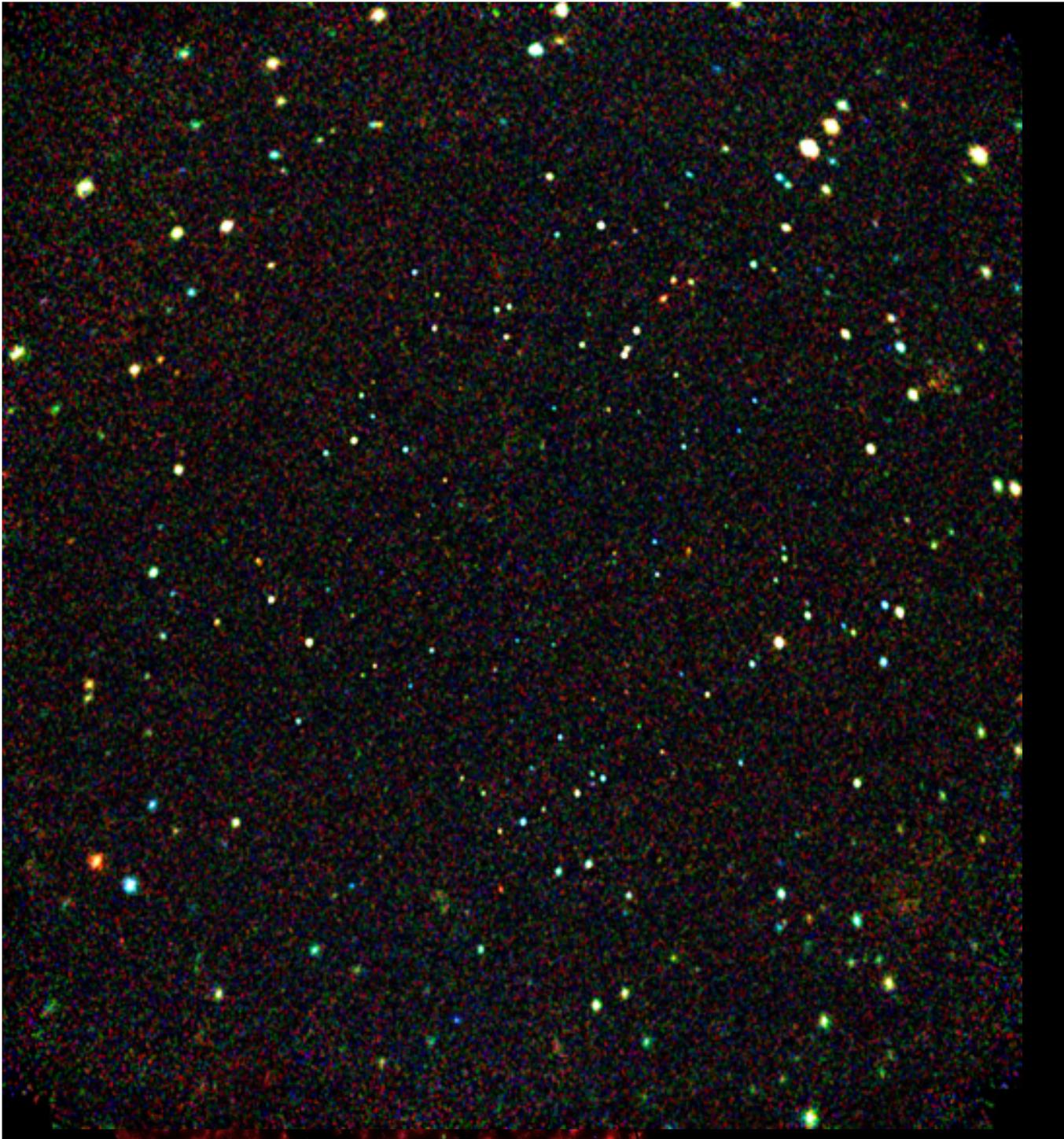
La luce emessa ha impiegato circa
12.9 miliardi di anni per raggiungerci.



$z=7.1$ cioè 770 milioni di anni dopo il Big Bang



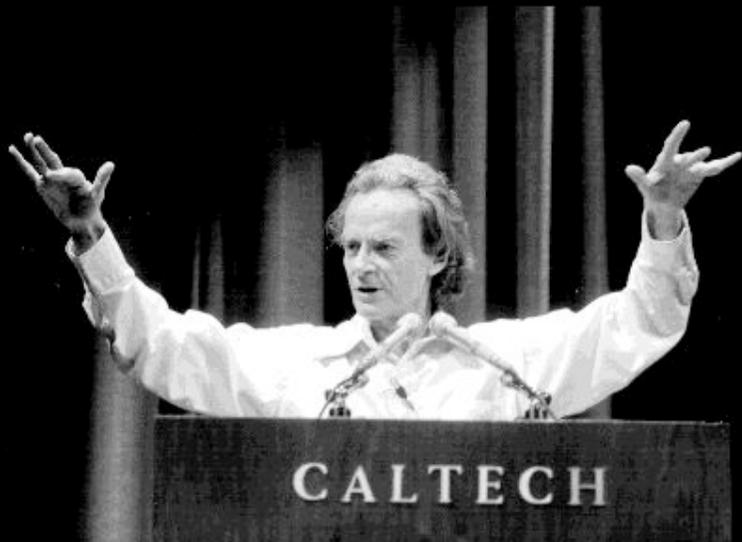
ULAS J1120+0641



Le profondità del
cosmo con XMM-
Newton e Chandra

La maggioranza di
queste sorgenti
sono quasar (AGN)
l'80% circa del
"fondo cosmico" in
raggi X

...on the other hand, when experiments are in hopeless conflict – or when the observations do not make sense according to conventional ideas, or when none of the new models seems to work, in short when the situation is an unholy mess- that is when one is really making hidden progress and a breakthrough is just around the corner!



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R. Feynman, 1973 Hawaii Summer Institute, cited by D. Perkins at the 1995 EPS Conference, Brussels).