active galaxies and quasars

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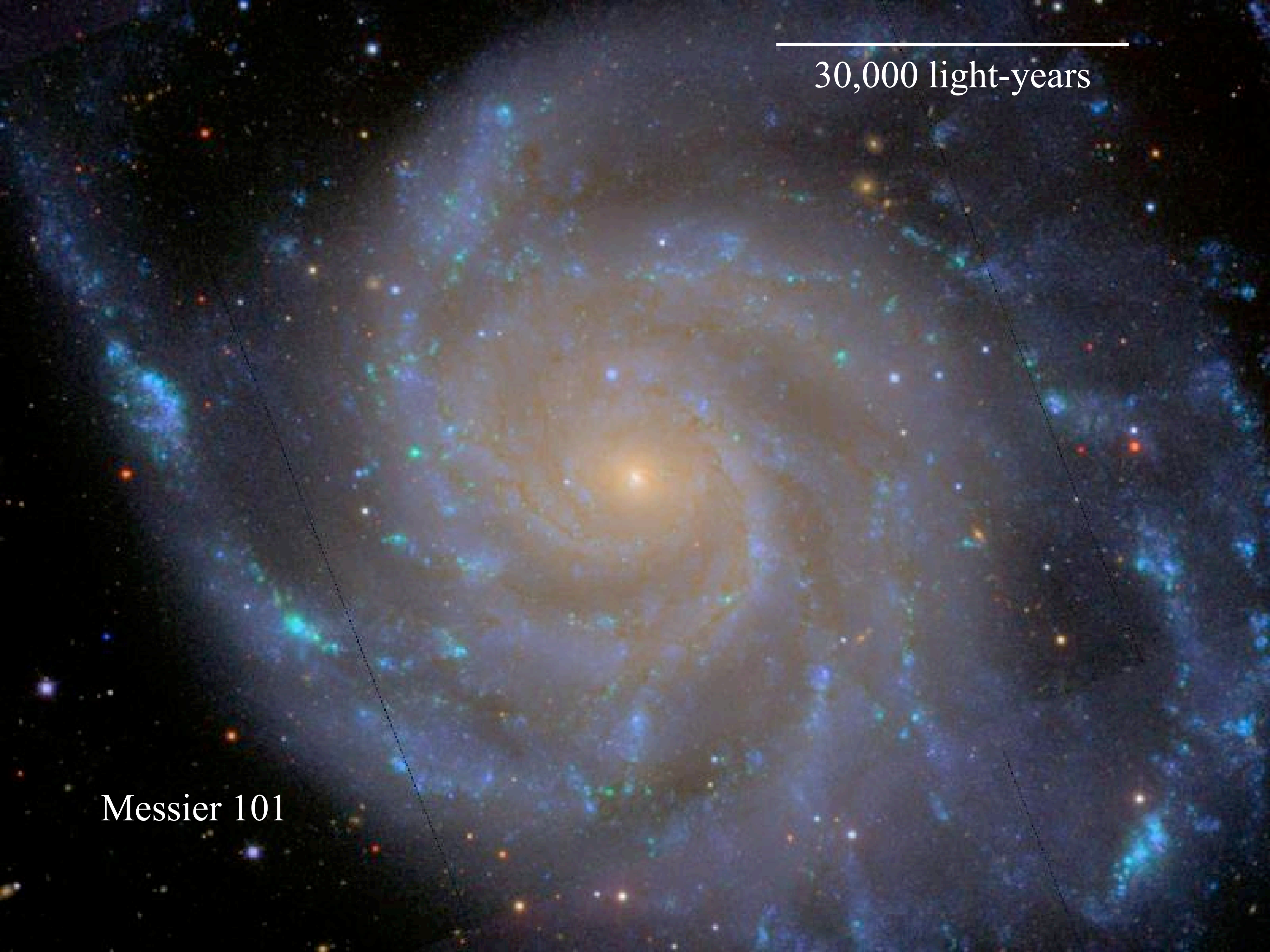
20 July 2011

outline:

centers of galaxies (*nuclei*)
quasars - data
quasars - physical model
Milky Way central black hole
nearby active galaxies

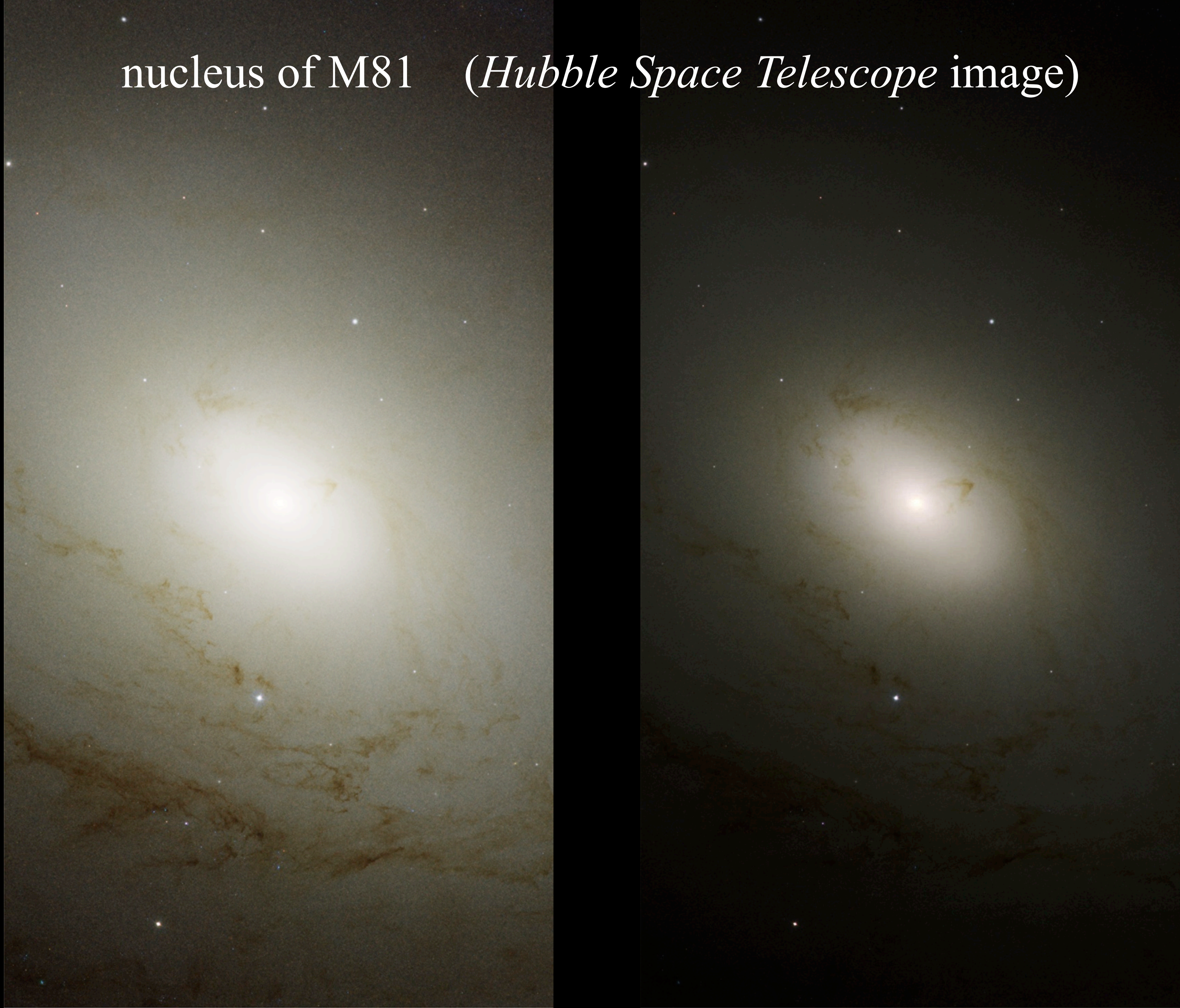

centers of galaxies (*nuclei*)


30,000 light-years
Messier 101


Messier 51 = NGC 5194 & 5195

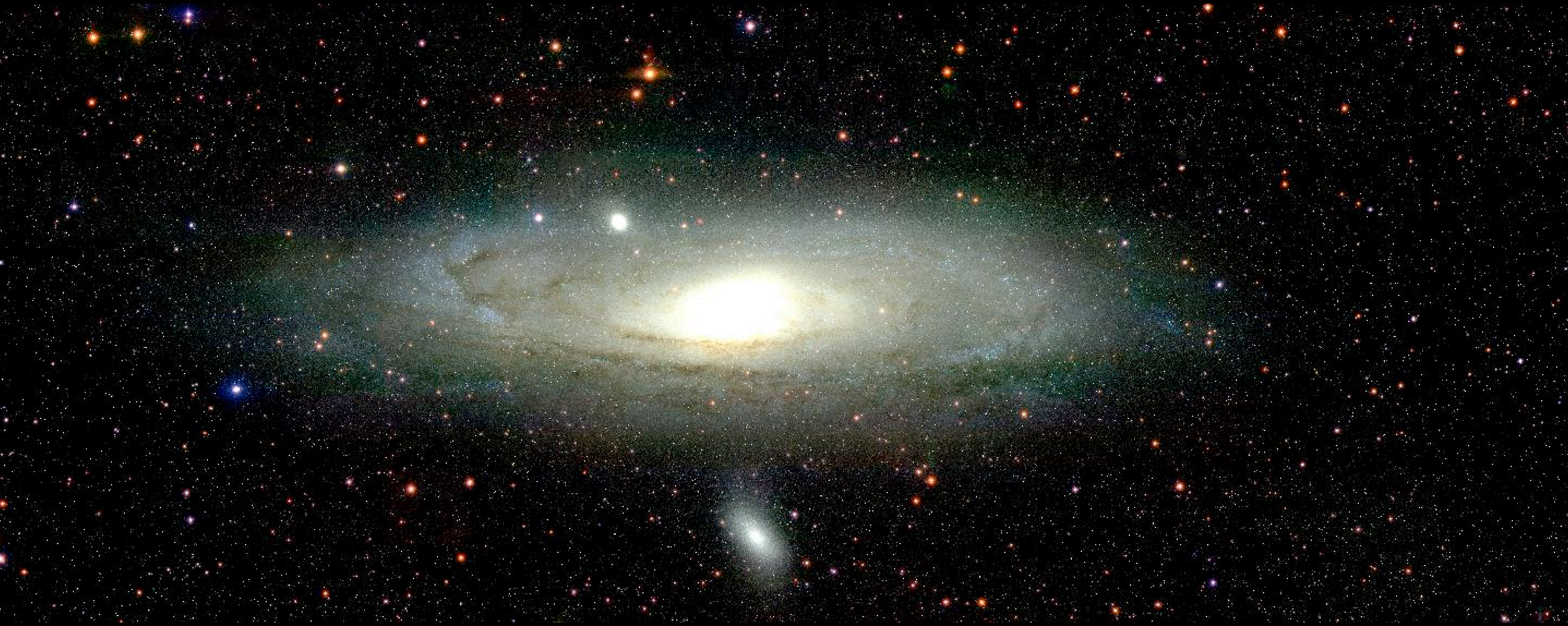
Messier 81 and Messier 82 in Ursa Major

nucleus of M81 (*Hubble Space Telescope* image)



galaxy Messier 31 - the Andromeda Nebula

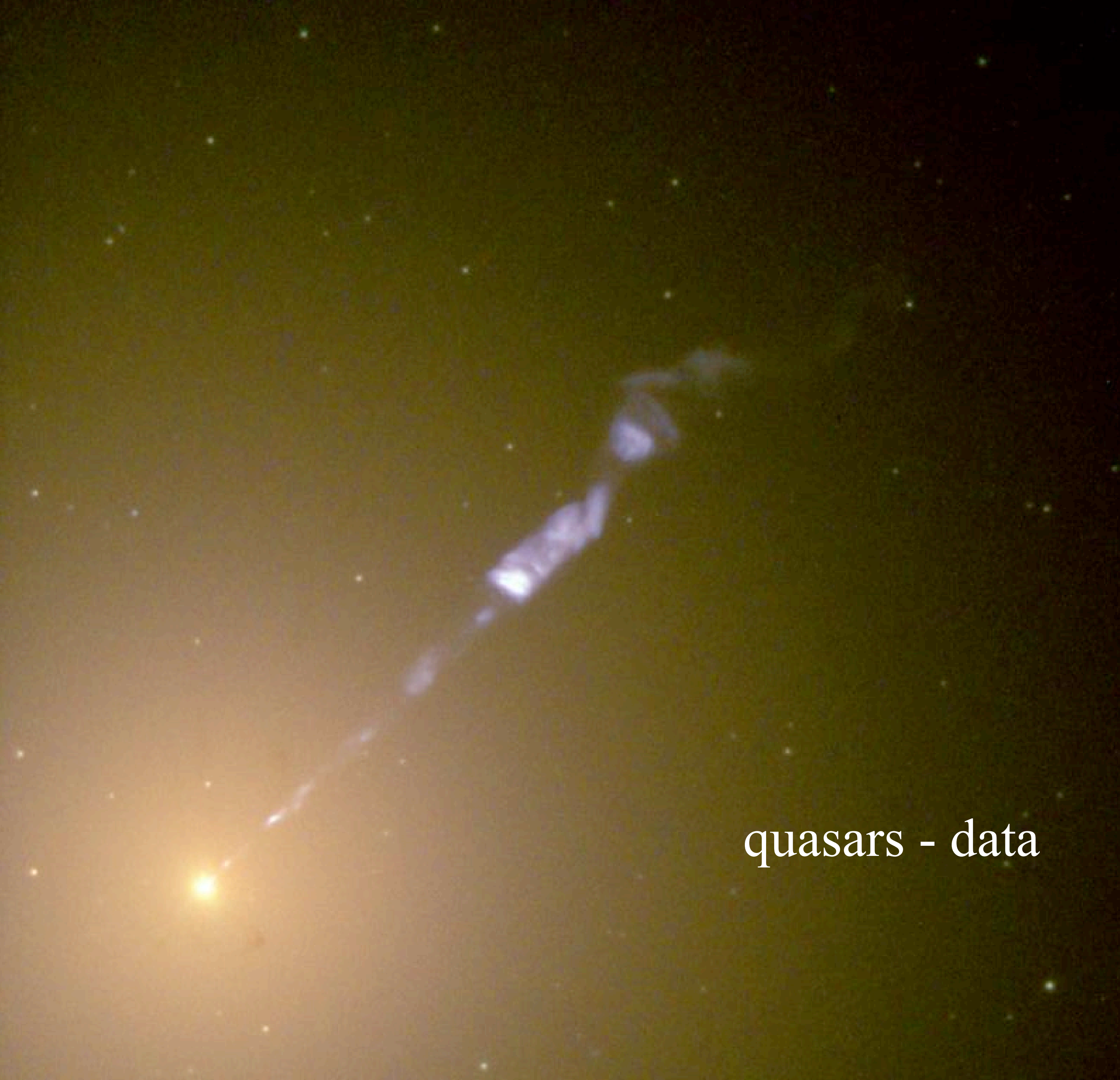
30,000 light-years




galaxy Messier 32 - companion to the Andromeda Nebula
300 light-years

center of the Milky Way in Sagittarius

infrared view of the center of the Milky Way (*Spitzer Space Telescope*)


quasars - data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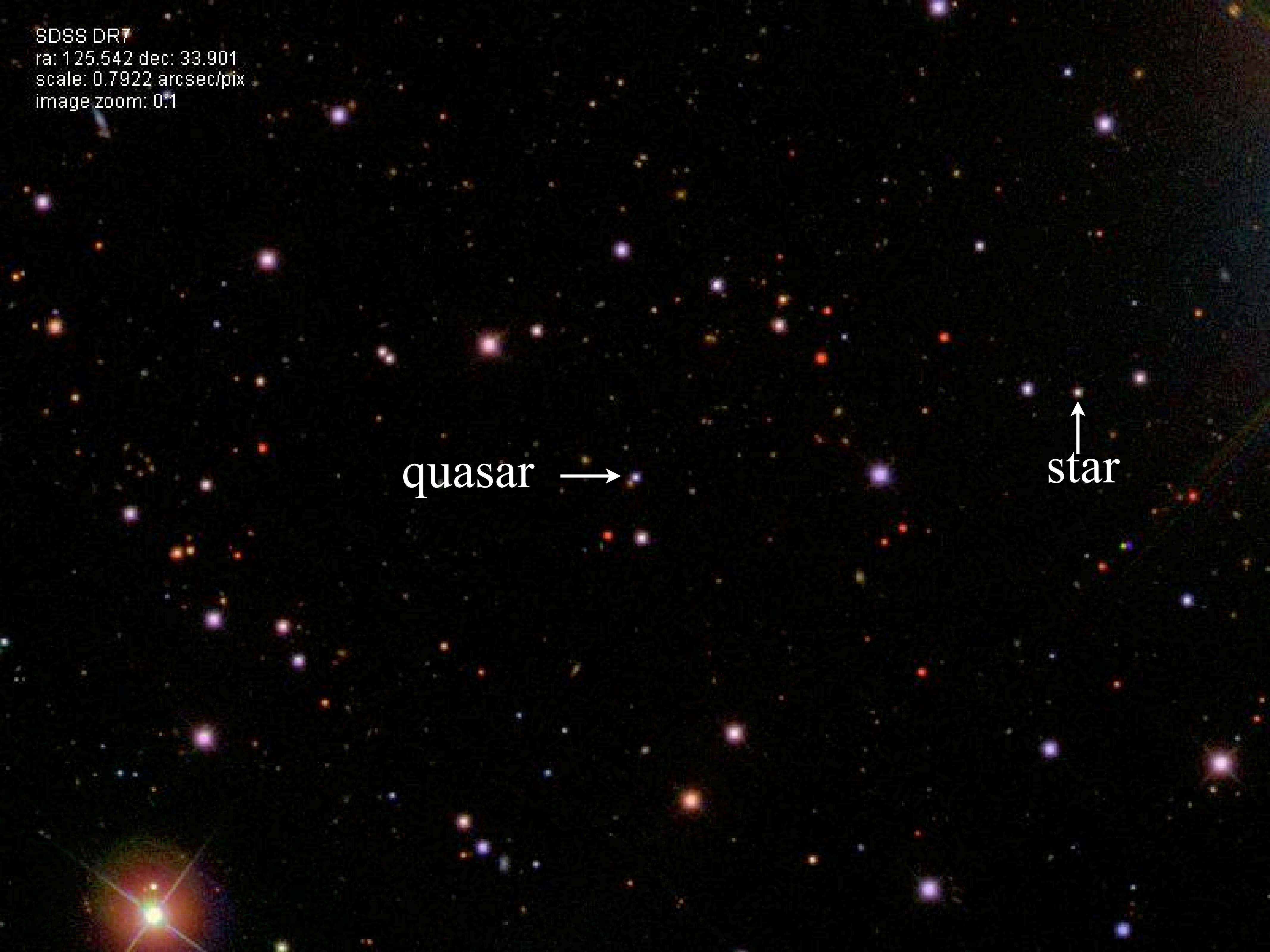
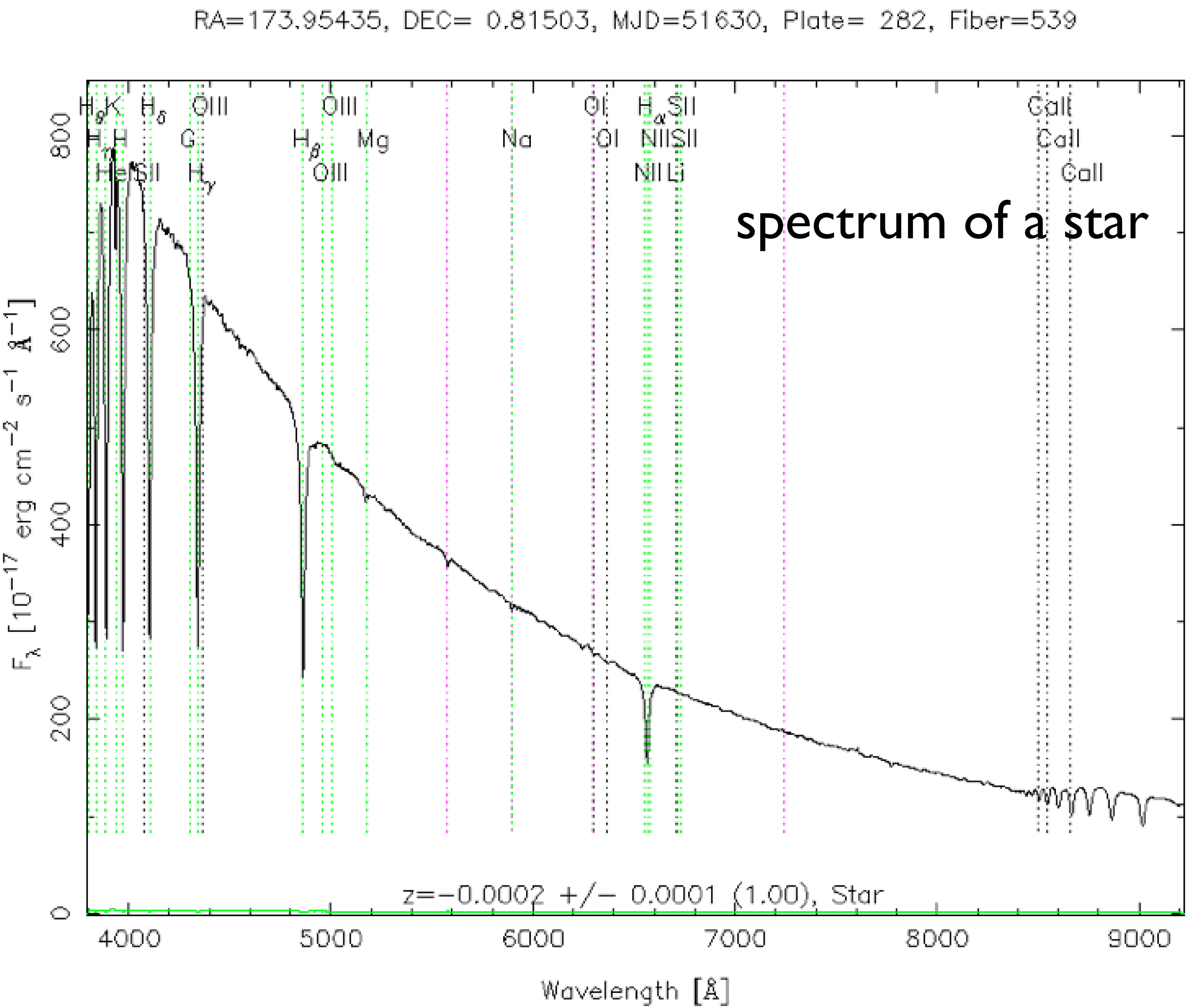
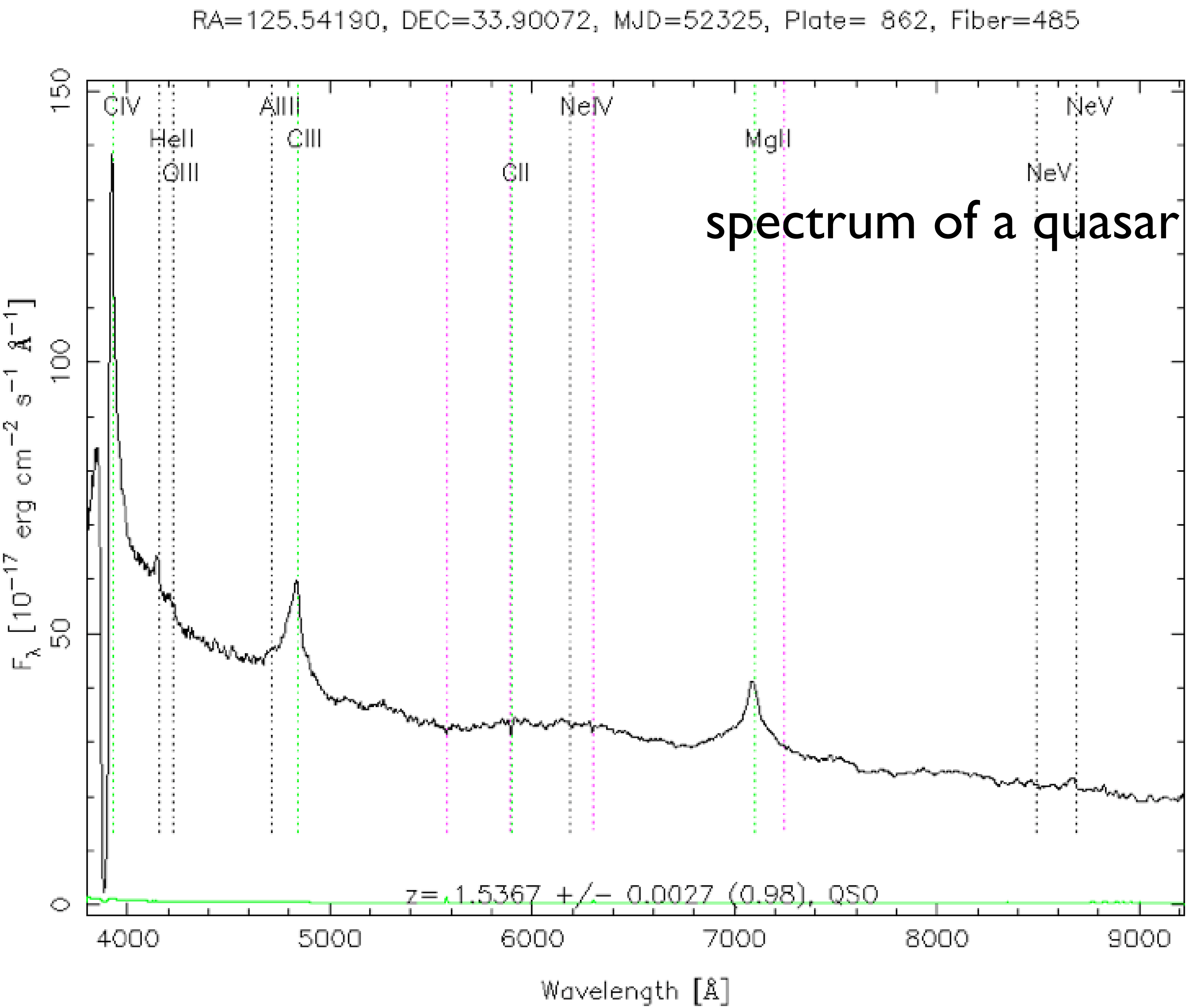
scale: 0.7922 arcsec/pix
image zoom: 0.1


SDSS DR7
ra: 125.542 dec: 33.901
scale: 0.7922 arcsec/pix
image zoom: 0.1
quasar
star

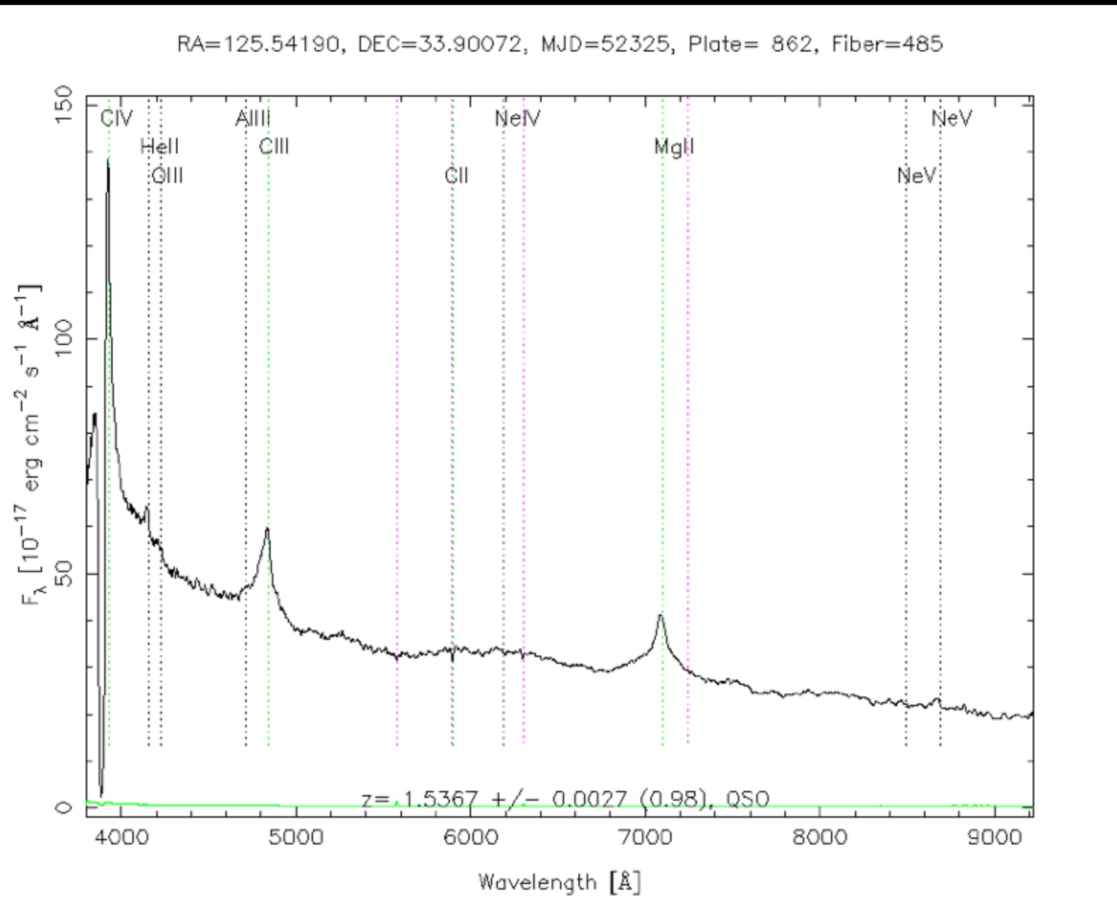

RA=173.95435, DEC= 0.81503, MJD=51630, Plate= 282, Fiber=539
spectrum of a star
z=-0.0002 +/- 0.0001 (1.00), Star
Wavelength [Å]
F_λ [10^-17 erg cm^-2 s^-1 Å^-1]
OIII
OIII
Mg
Na
OI
OI
SII
NIISII
NIILi
CaII
CaII
CaII
0
200
400
600
800
4000
5000
6000
7000
8000
9000


RA=125.54190, DEC=33.90072, MJD=52325, Plate= 862, Fiber=485
CIV
HeII
OIII
AlIII
CIII
CII
NeIV
MgII
NeV
NeV
spectrum of a quasar
z= 1.5367 +/- 0.0027 (0.98), QSO
F_λ [10^{-17} erg cm^{-2} s^{-1} Å^{-1}]
Wavelength [Å]
0
50
100
150
4000
5000
6000
7000
8000
9000

the spectrum tells us several important things:

* redshift = 1.53 ⇒ light travel-time is 9.4 billion years

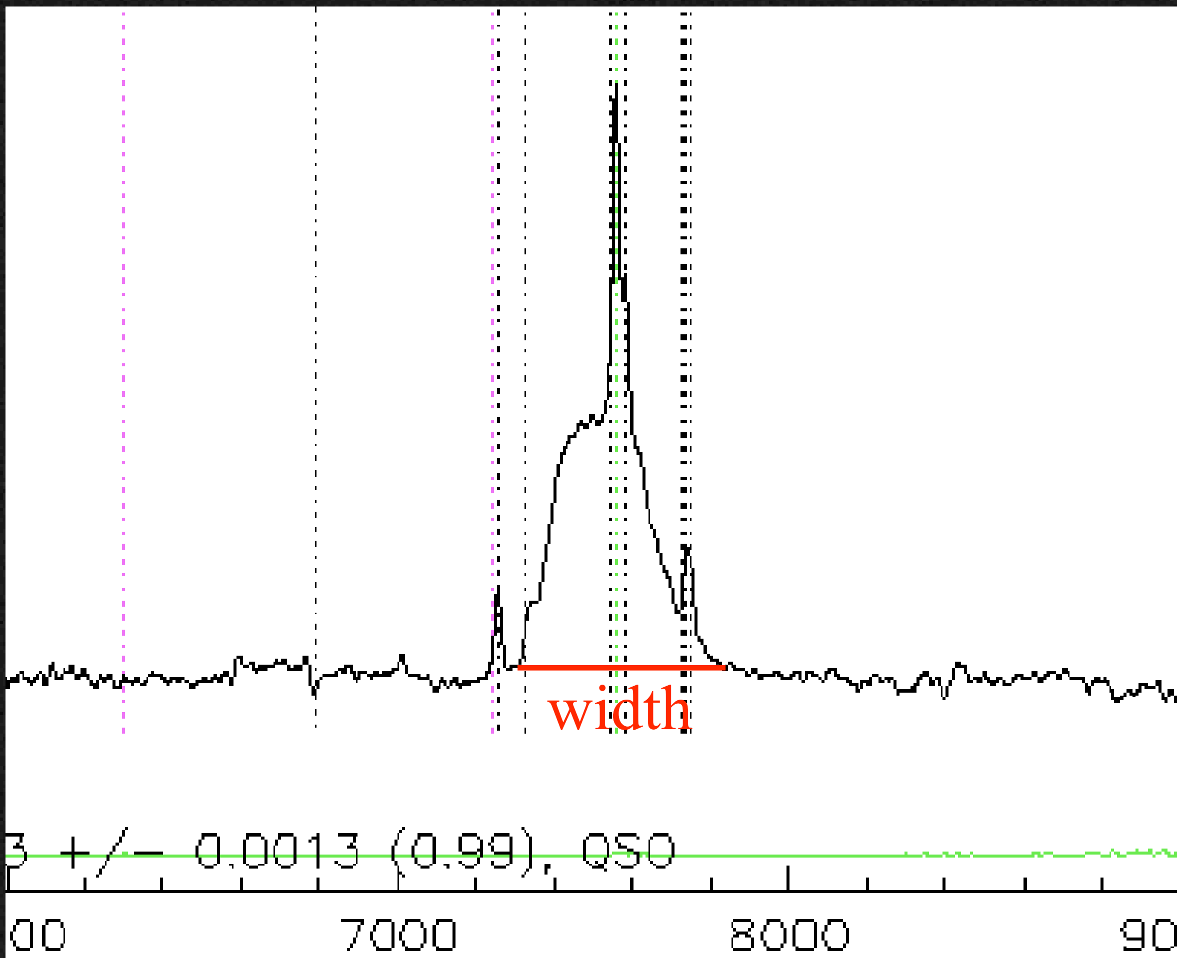
* at this distance, to appear as bright as it does, it must have a luminosity of two trillion Suns (or 100 normal galaxies)



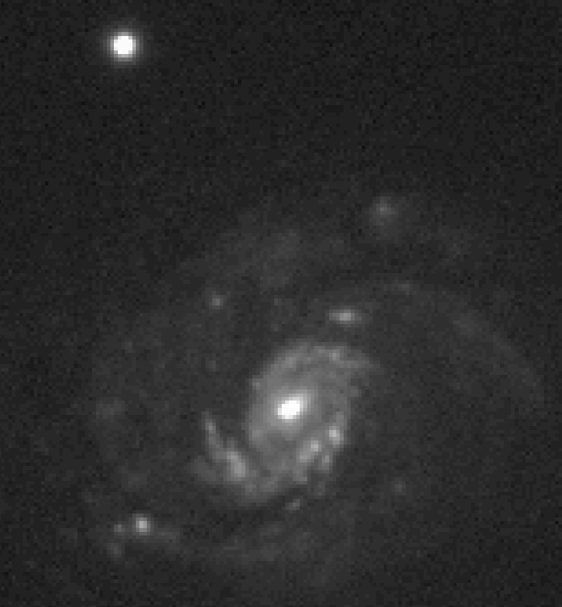
* no evidence for starlight

* the emission lines are *wide* ⇒ glowing gas is moving at very high speed

how fast is the gas moving inside this quasar?



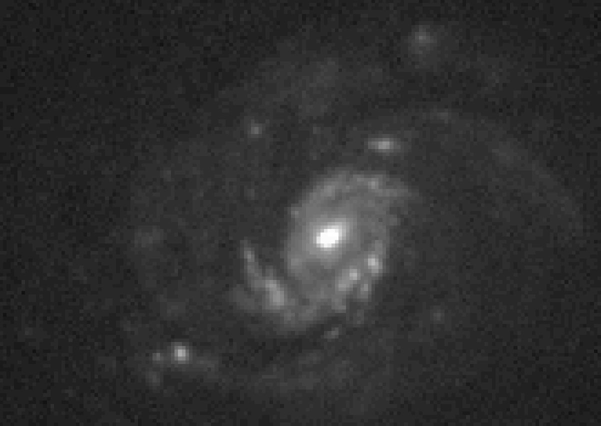
v / c = width / λ

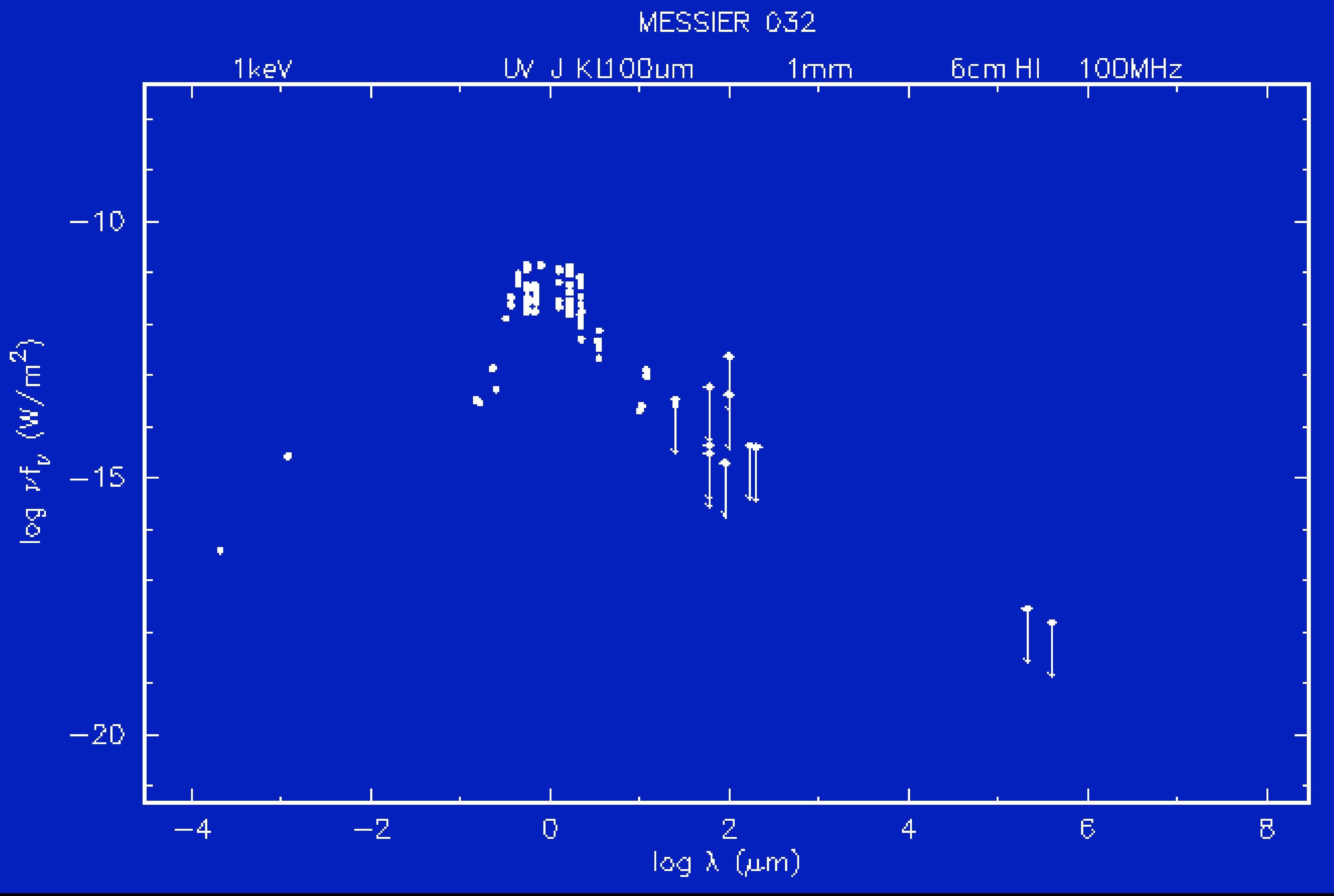


width = 600 Å, λ = 7600 Å
v / c = width / λ = 0.08
v = 24,000 km/sec (!)

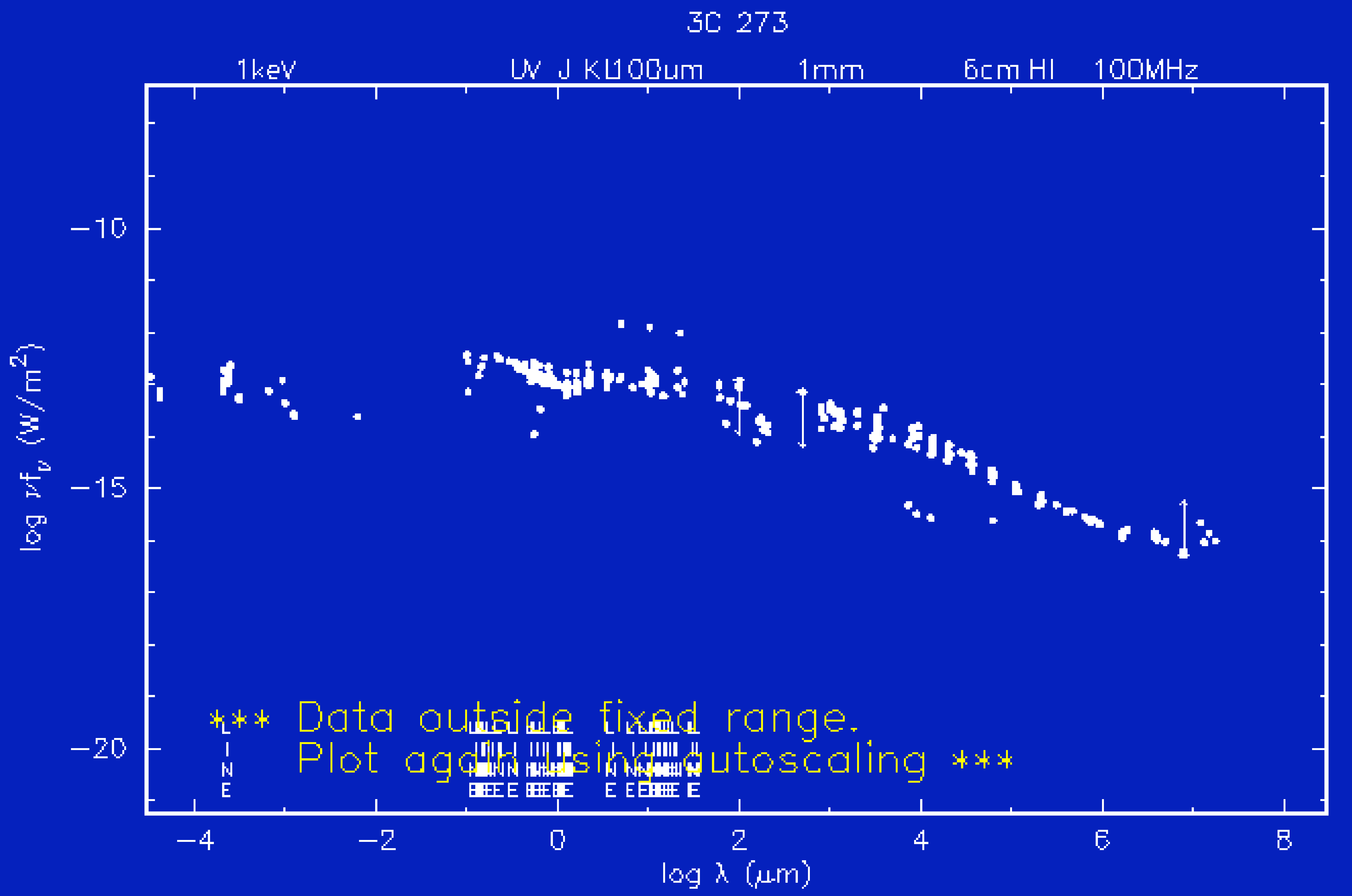
physical properties of quasars (data):

- ✦ high luminosity ✓
- ✦ small emitting volume ✓
- ✦ spectra show broad emission lines ✓
- ✦ visible light + radio + X-rays ✓
- ✦ variable ✓
- ✦ bipolar symmetry ✓

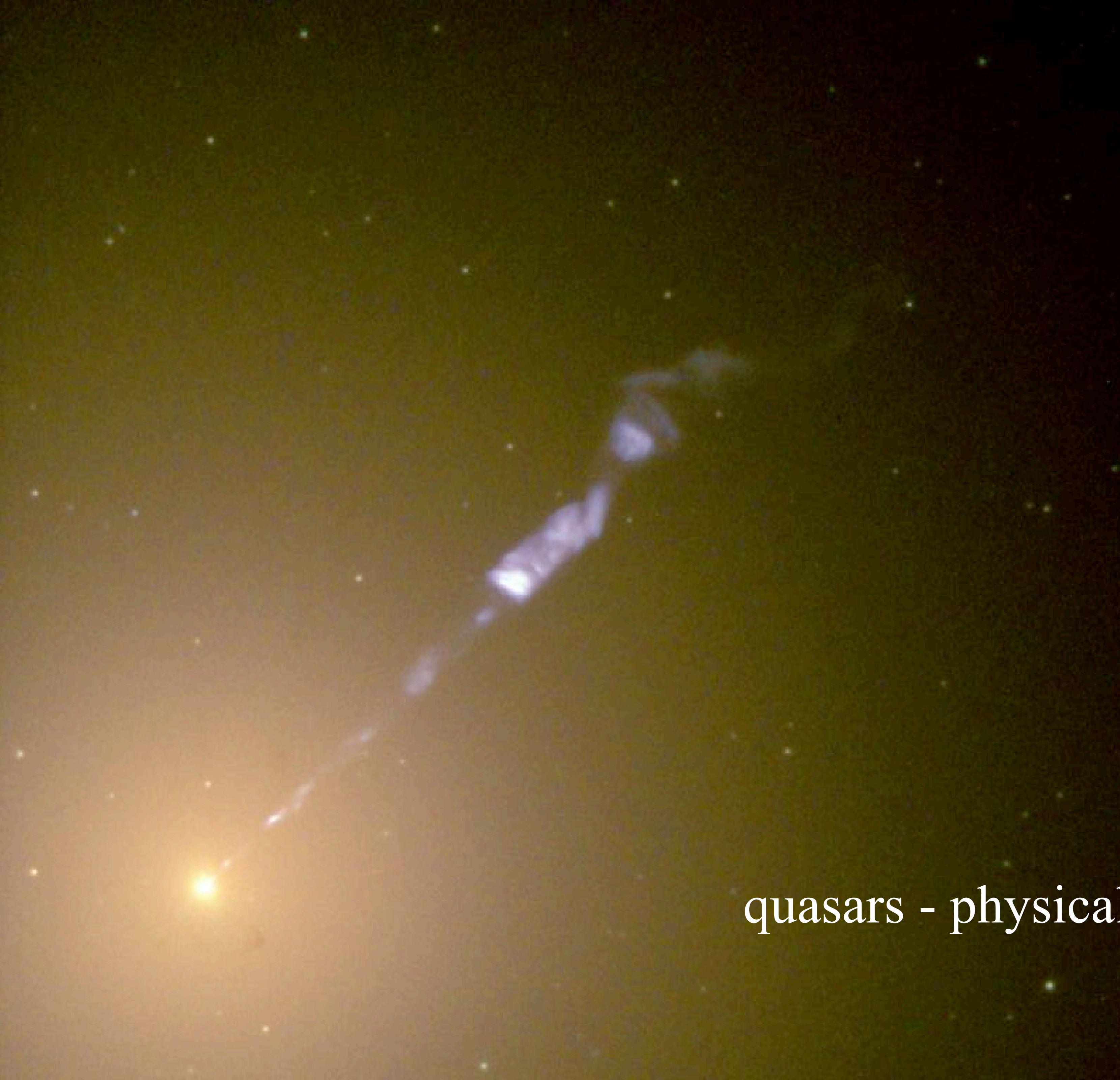




X-ray UV vis IR radio



X-ray UV vis IR radio



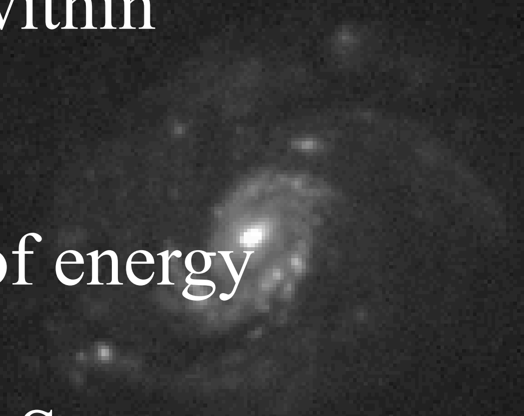
quasars - physical model

the basic problem to understand quasars is:

how can so much energy be emitted from within such a small volume?

⇒ we need an efficient way to make a lot of energy

thermonuclear reactions, such as power the Sun, are not good enough



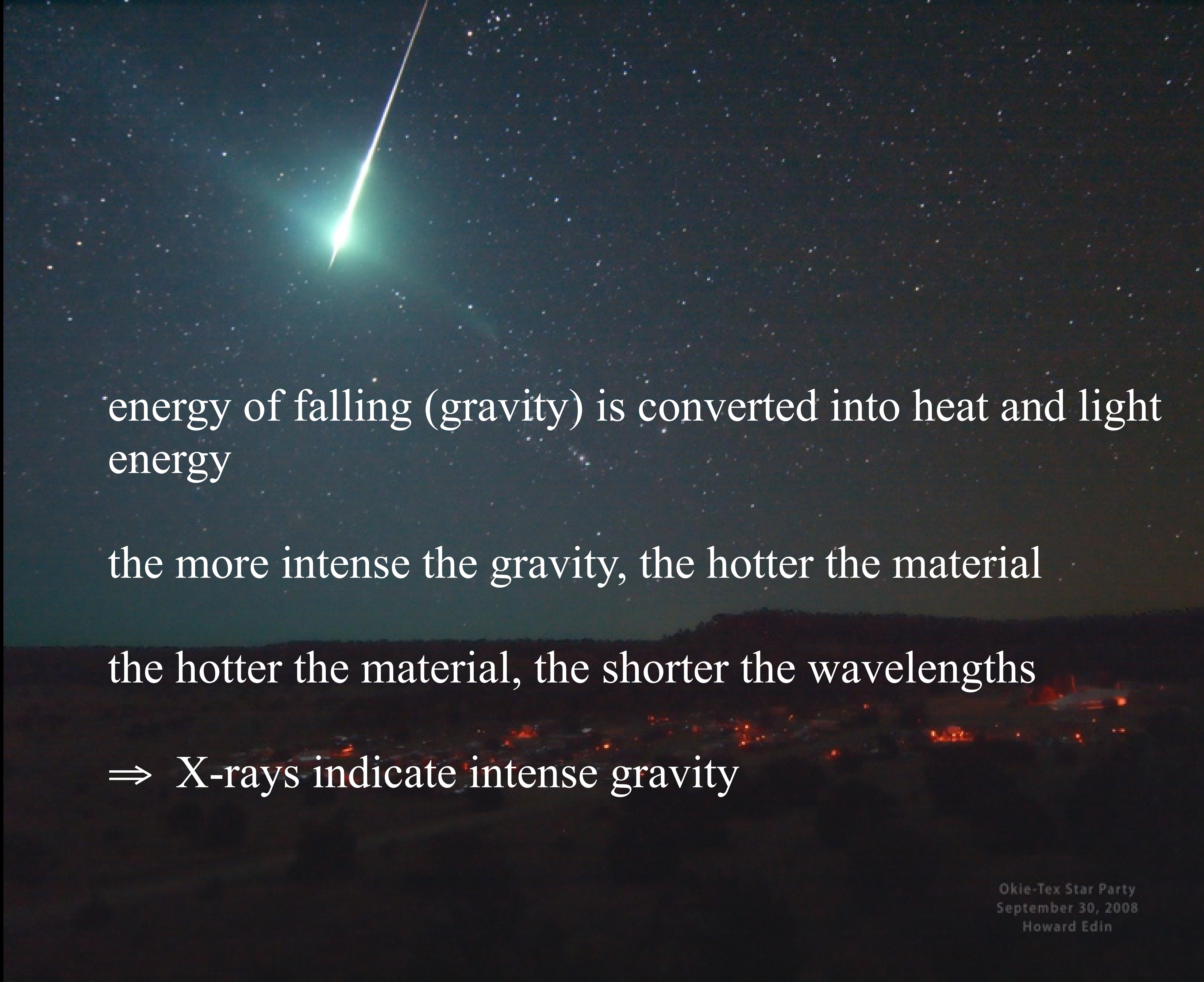
physical model of a quasar:

✧ supermassive black hole at the center of a galaxy

✧ gas from the host galaxy falls into the black hole because of viscosity (drag)

✧ as the gas falls, the gravitational energy of falling is converted by friction into heat and light


Okie-Tex Star Party
September 30, 2008
Howard Edin



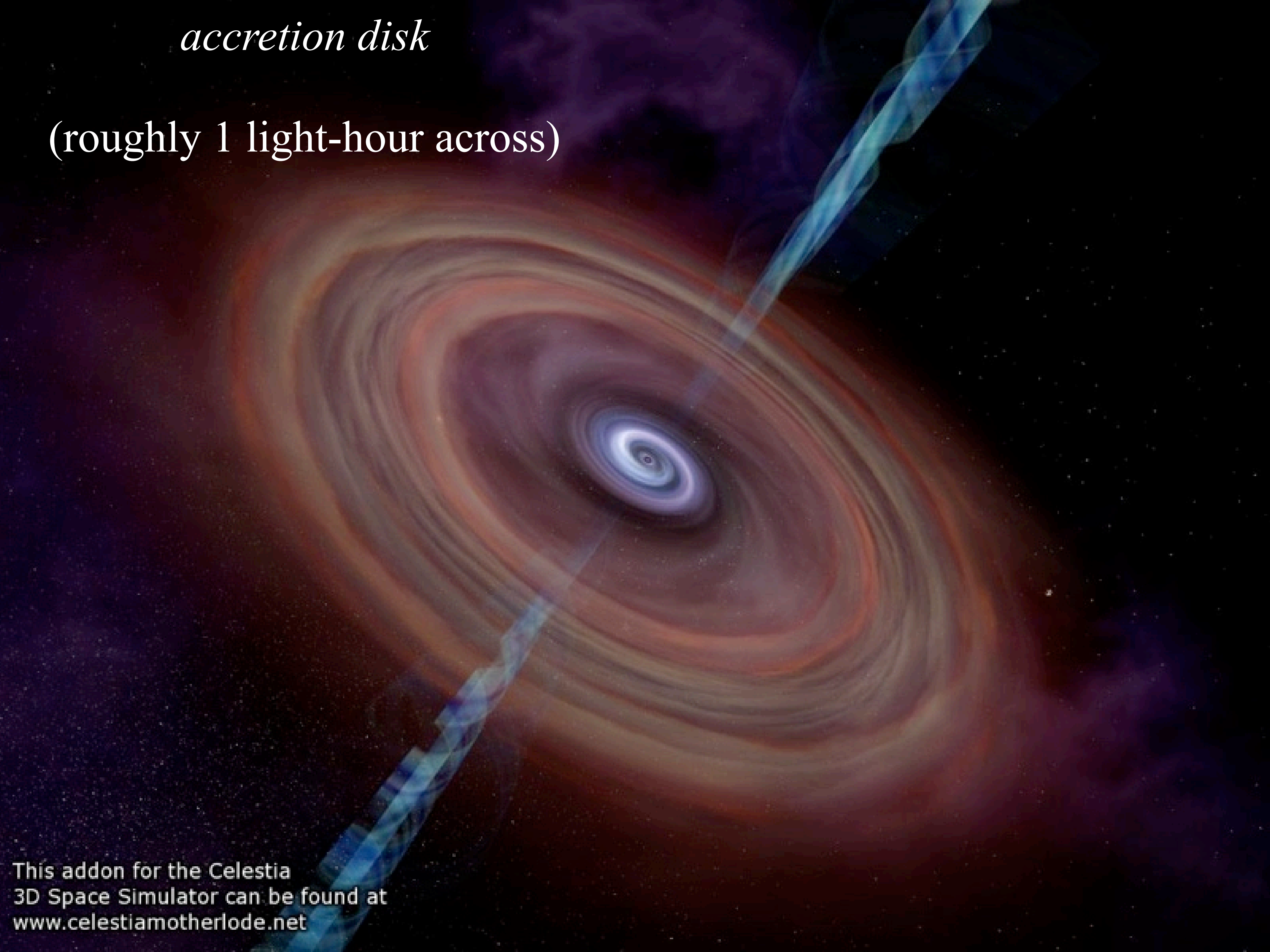
energy of falling (gravity) is converted into heat and light energy

the more intense the gravity, the hotter the material

the hotter the material, the shorter the wavelengths

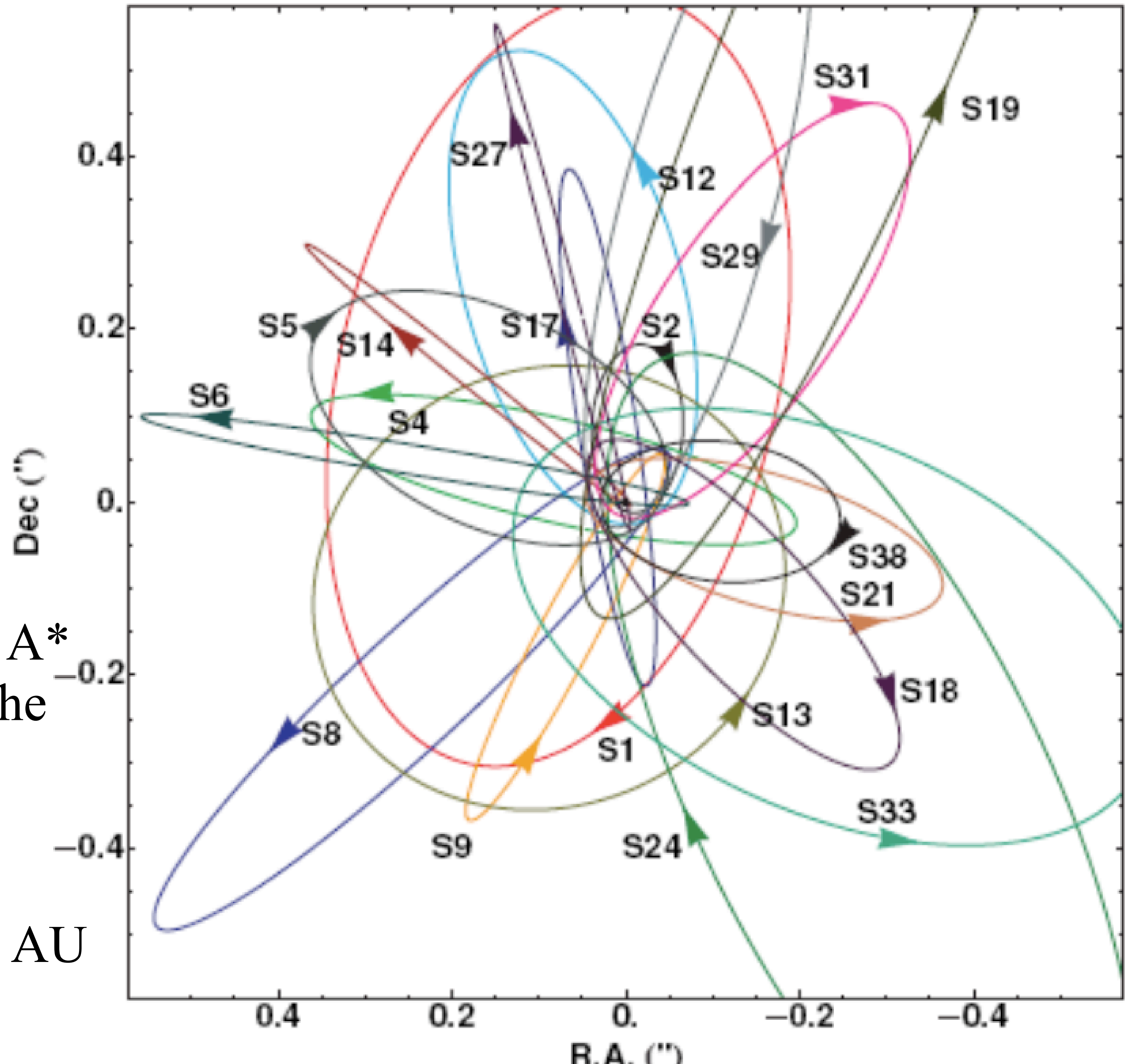
$\Rightarrow$ X-rays indicate intense gravity *accretion disk*

(roughly 1 light-hour across)



Milky Way central black hole

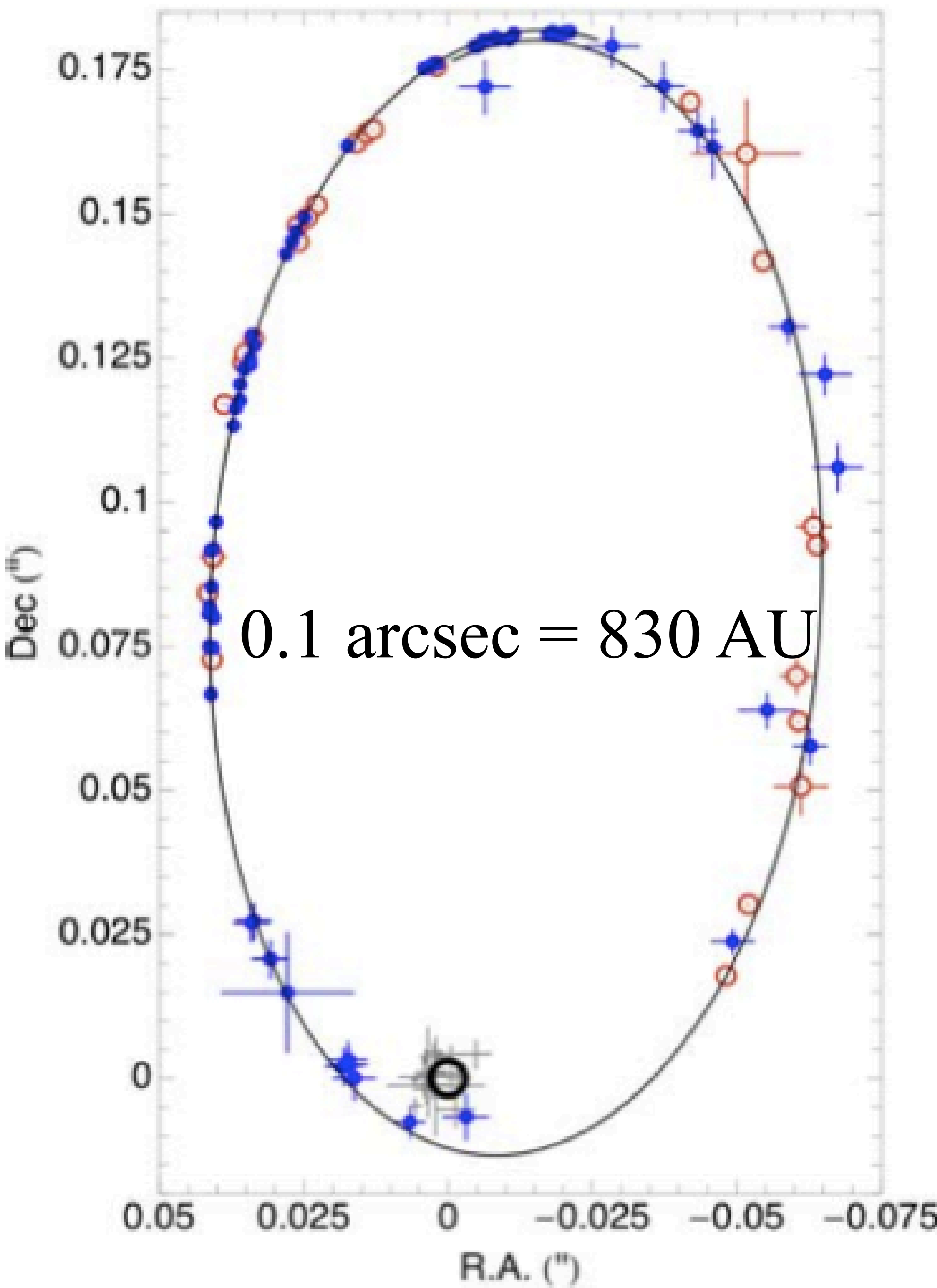

Sgr A*
Keck/UCLA Galactic Center Group

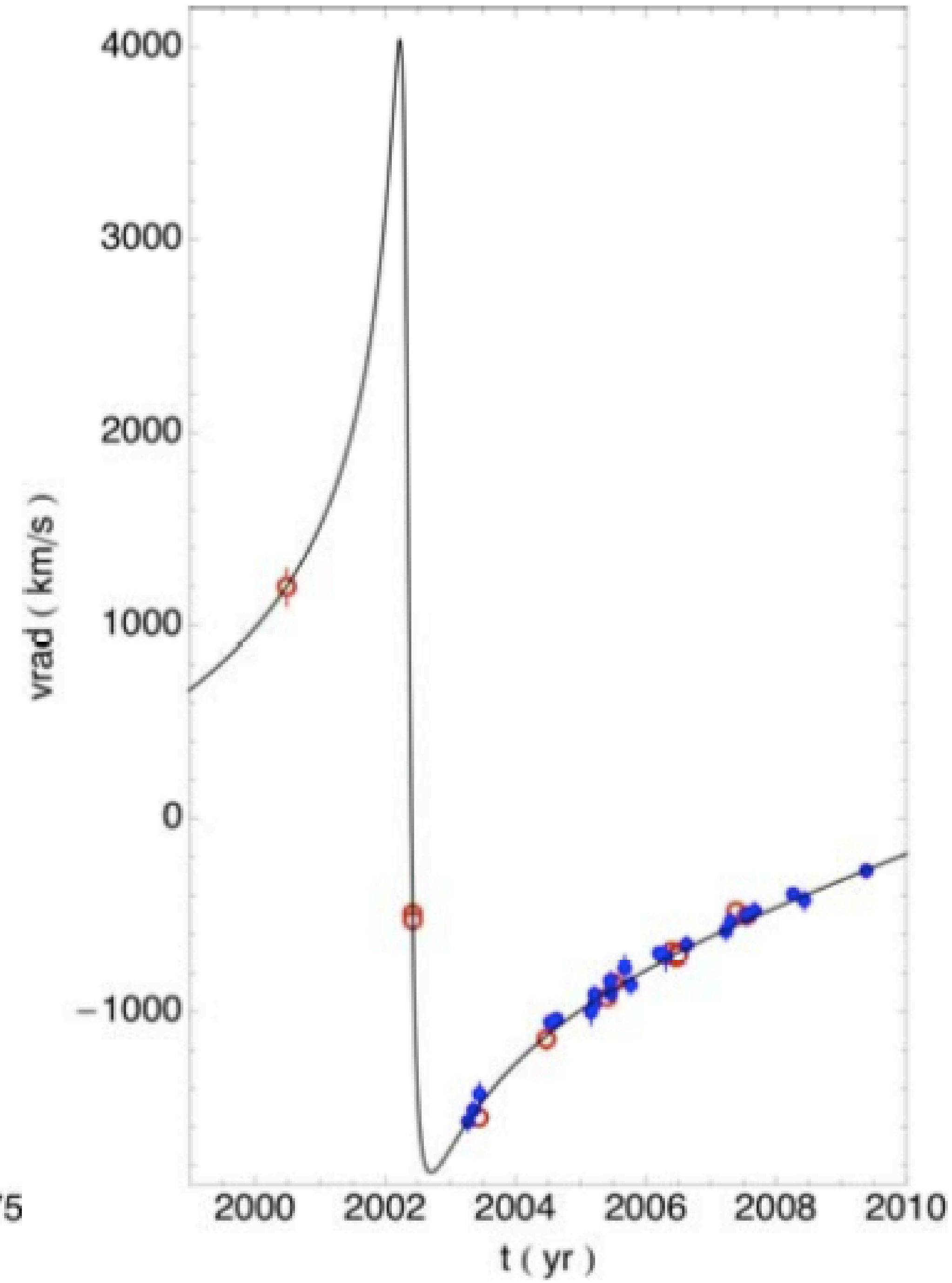


star cluster
surrounding Sgr A*
at the center of the
Milky Way

at this distance,
0.1 arcsec = 830 AU

orbit of star S2 P = 16 years





star S2's orbit around Sgr A*:

a = 1000 AU
P = 16 yr

$a^3 / P^2 = 4 \times 10^6$ mass of Sun

this must be a black hole, since the
orbits pass within 80 AU of the center

r = 20   a = 400 million

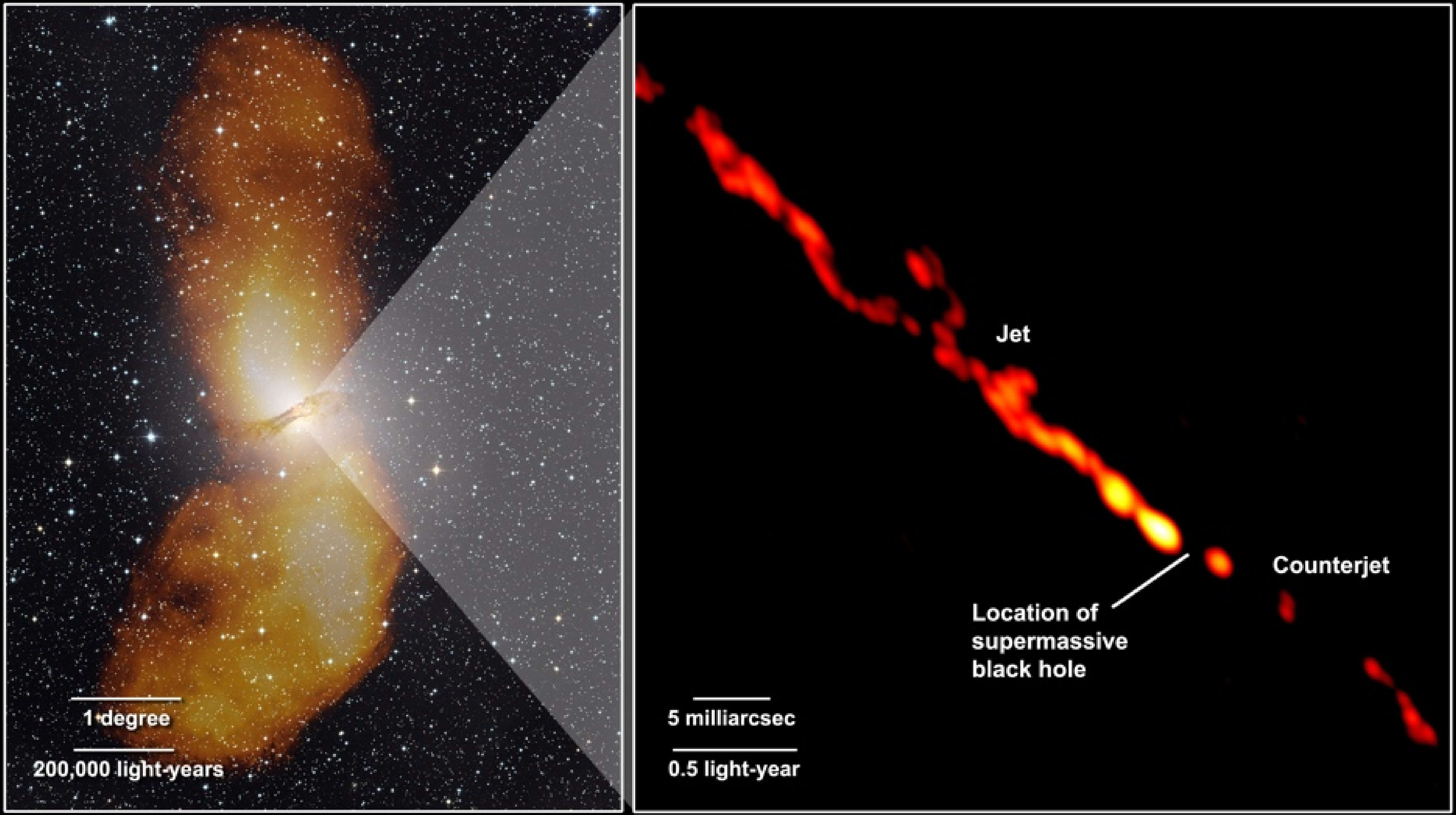
nearby active galaxies

- Centaurus A
- Virgo A
- Cygnus A
- NGC 4051
- MCG 6-30-15

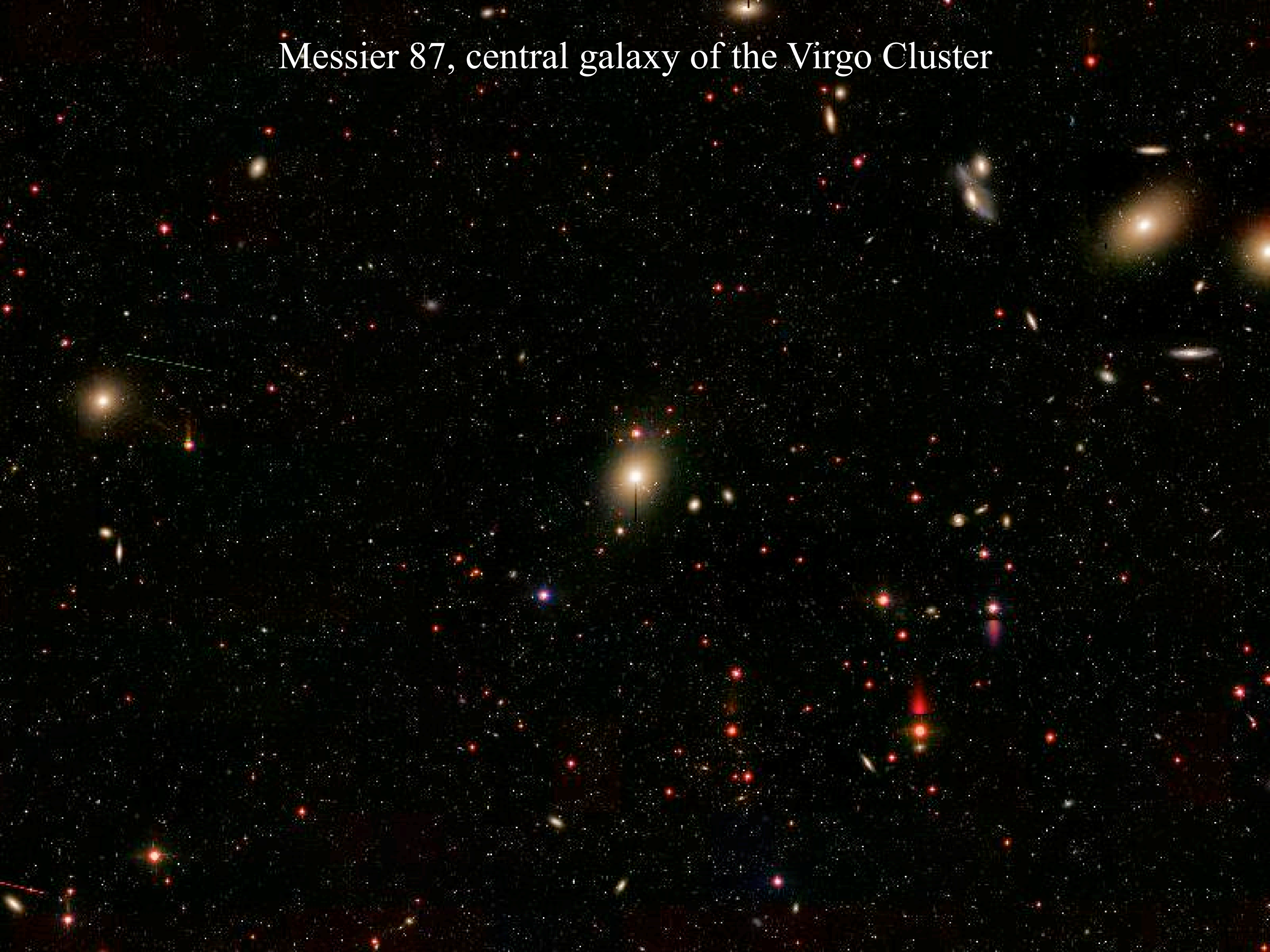
Centaurus A (NGC 5128)

Centaurus A as seen in X-rays (blue) and
millimeter radio waves (orange)
note bipolar symmetry of jets

Centaurus A's Inner Jets

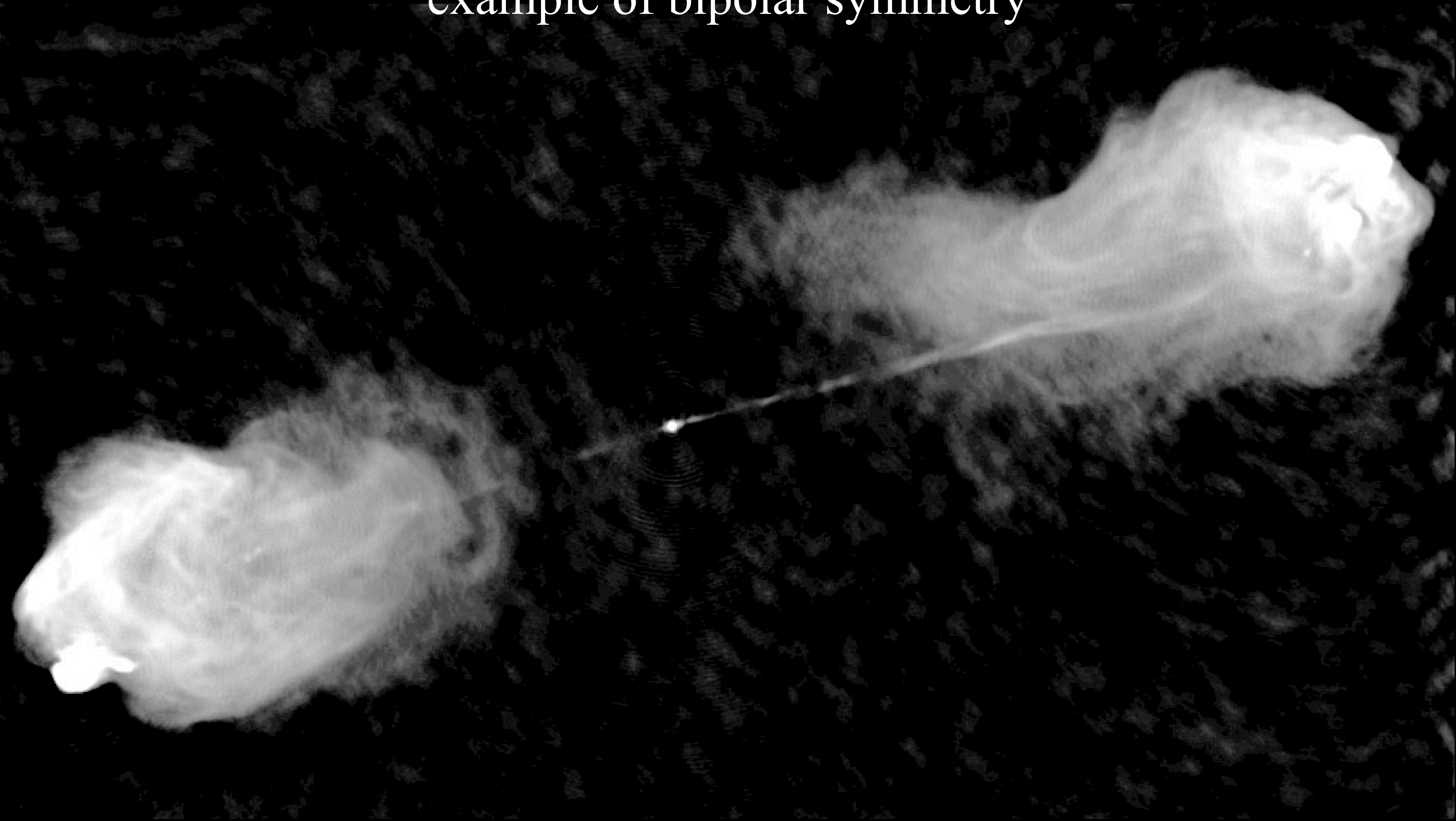


Messier 87, central galaxy of the Virgo Cluster



jet in the center of Messier 87 (visible light)
central supermassive black hole has 3 billion
times the mass of the Sun

radio galaxy Cygnus A
example of bipolar symmetry



1943 Astrophysical Journal, **97**, 285

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.

I. THE OBSERVATIONAL MATERIAL

The present investigation is an intensive study of six of the brightest extragalactic nebulae showing emission bands in their nuclei (Table 1). Of these six, special emphasis was placed on the three having the brightest nuclei, NGC 1068, 3516, and 4151, because

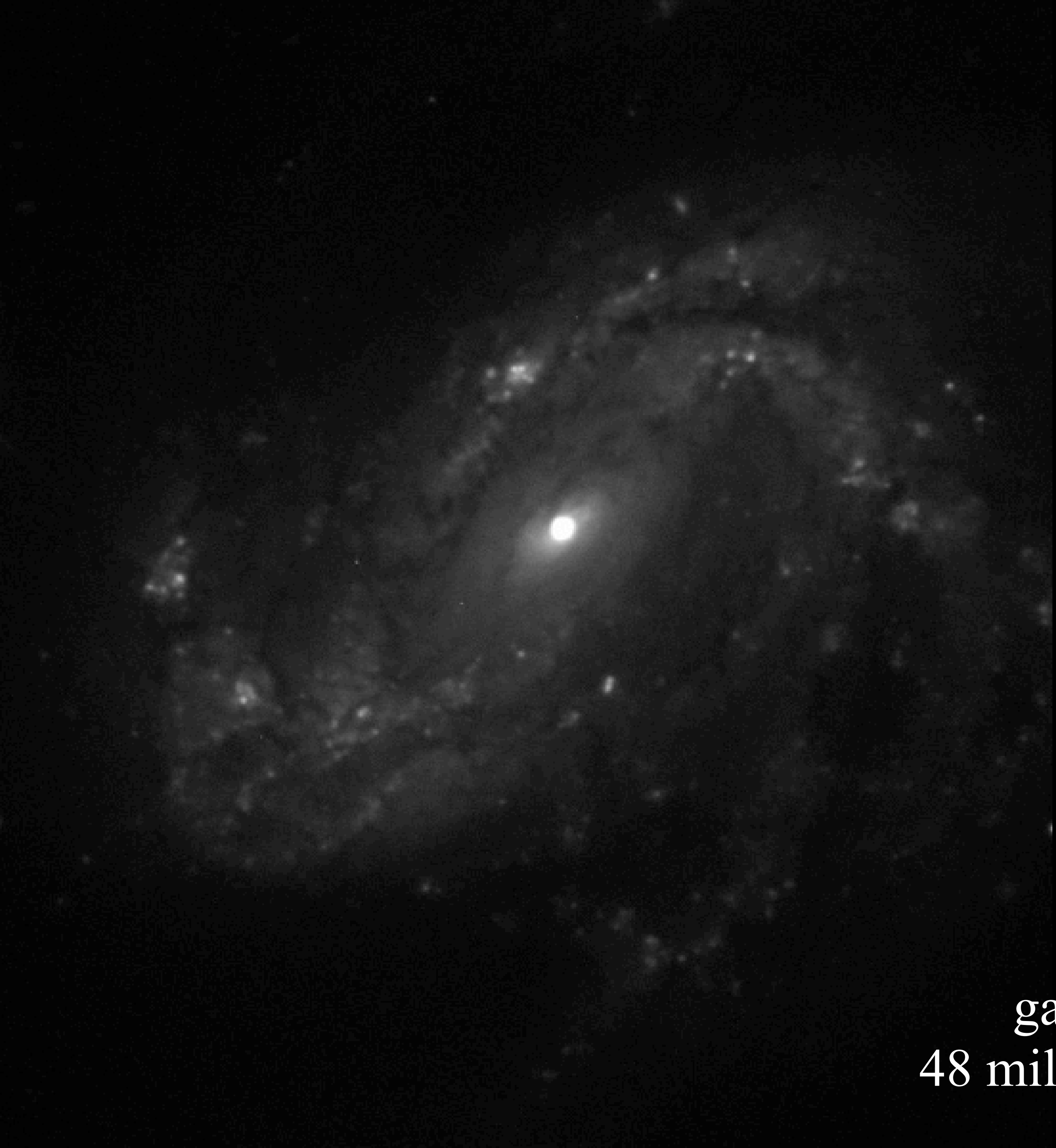
TABLE 1*

EMISSION SPIRALS OBSERVED

NGC	1950		Type	m_{total}	$m_{\text{nucl.}}$	Spect.	Modulus	No. of Plates
	R.A.	Dec.						
1068	$2^h 40.1$	− 0° 14	Sb	10.0	13.0	G3	$26^m.0$	17
1275	3 15.6	+41 18	E:	13.0	15.5	G3	30.0	4
3516	11 3.4	+72 50	Sa	12.2	13.7	G2:	28.5	6
4051	12 0.6	+44 48	Sb	11.7	14.0	G2	26.0	4
4151	12 8.0	+39 41	Sb	11.2	12.0	G2	26.0	12
7469	23 0.7	+ 8 36	Sa	13.0	14.3:	G0:	29.8	2

* The total apparent photographic magnitudes are from the *Shapley-Ames Catalogue of External Galaxies* (*Harv. Ann.*, **88**, 43, 1932). The apparent magnitudes (photographic) of the nuclei were estimated from short-exposure plates, taken in series with selected areas. The distance moduli are new determinations derived from magnitudes of resolved stars in the arms (NGC 1068), radial velocity (NGC 1068, 3516, 7469), or from association with recognized clusters or groups (NGC 1275, 4051, 4151). The plates used for determinations of nuclear magnitudes and most of the data for computing the distance moduli were supplied by E. P. Hubble. The spectral types were determined by M. L. Humason.

it was possible to observe them with higher dispersion than could be used on the fainter objects.



galaxy NGC 4051
48 million light-years away

Hubble Space Telescope image of the nucleus of NGC 4051

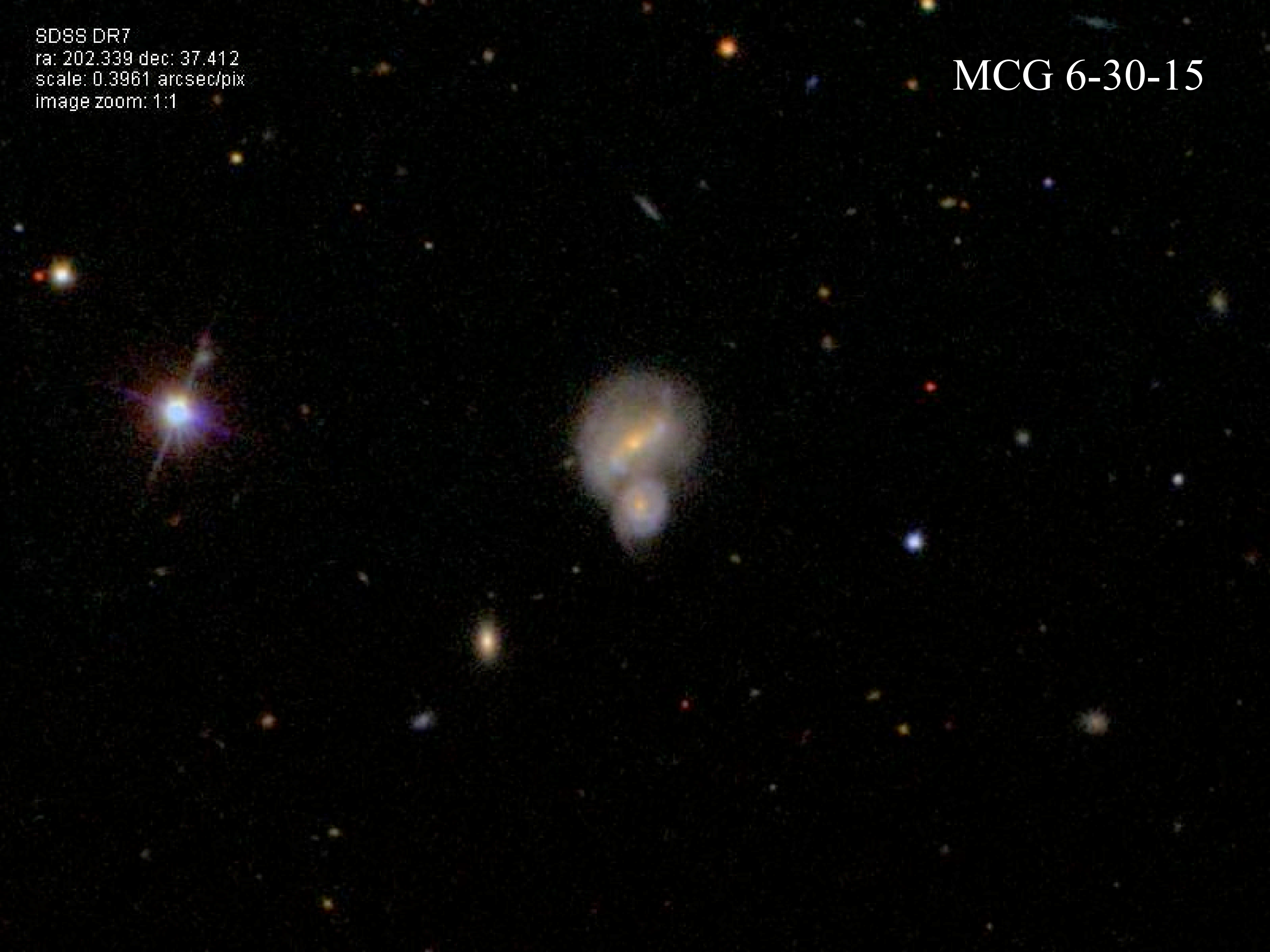

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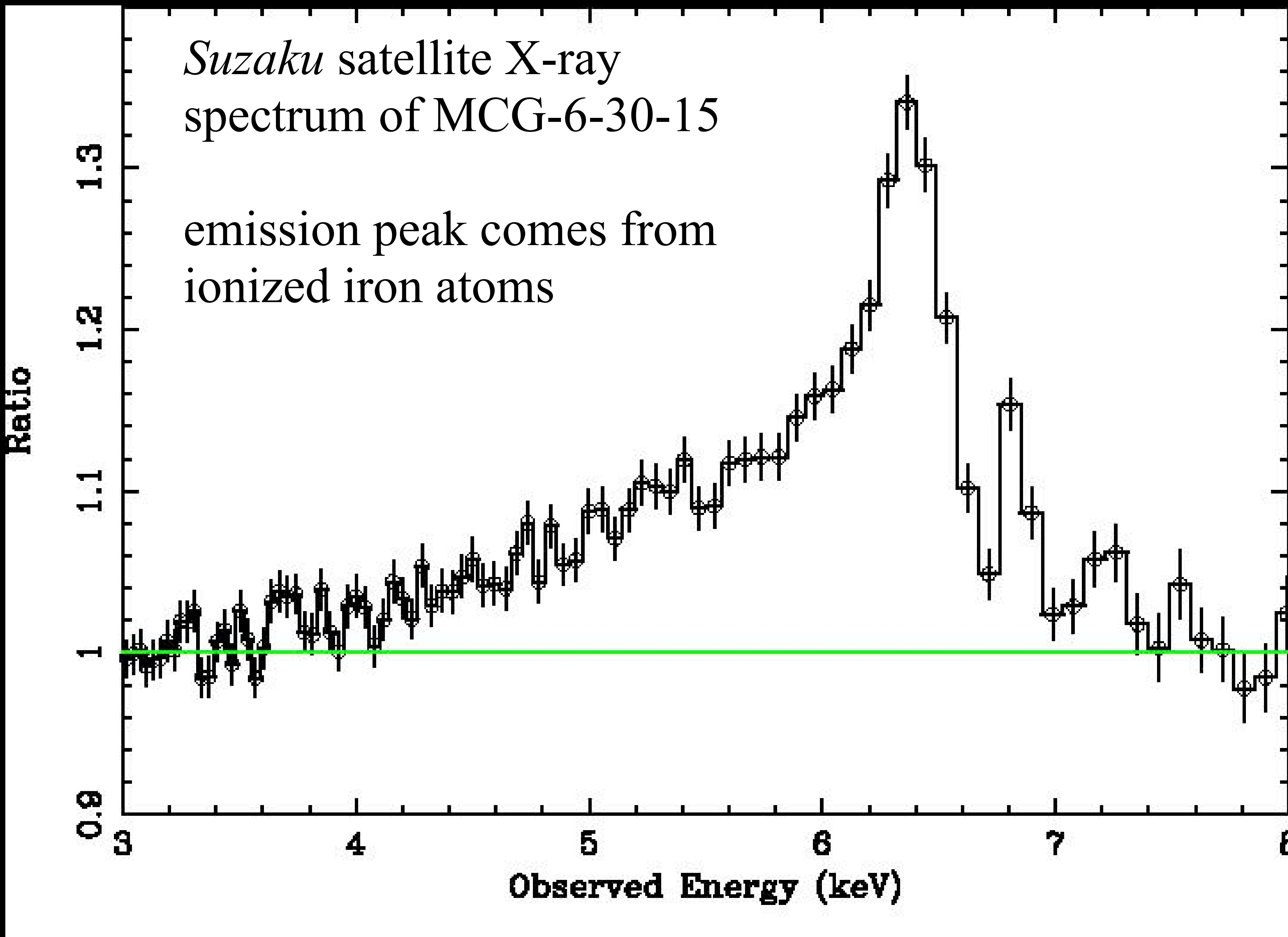
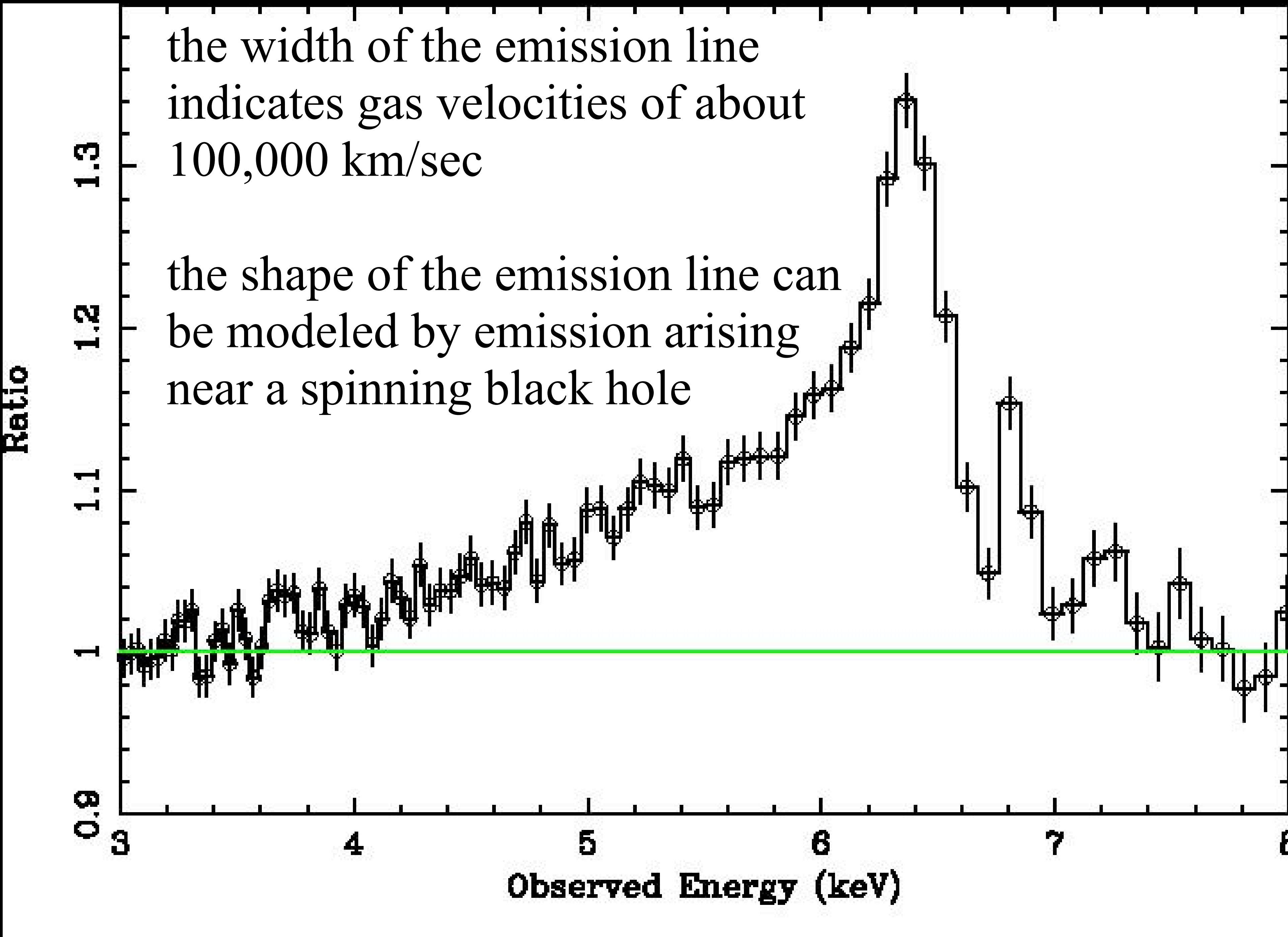
image zoom: 1:1
MCG 6-30-15

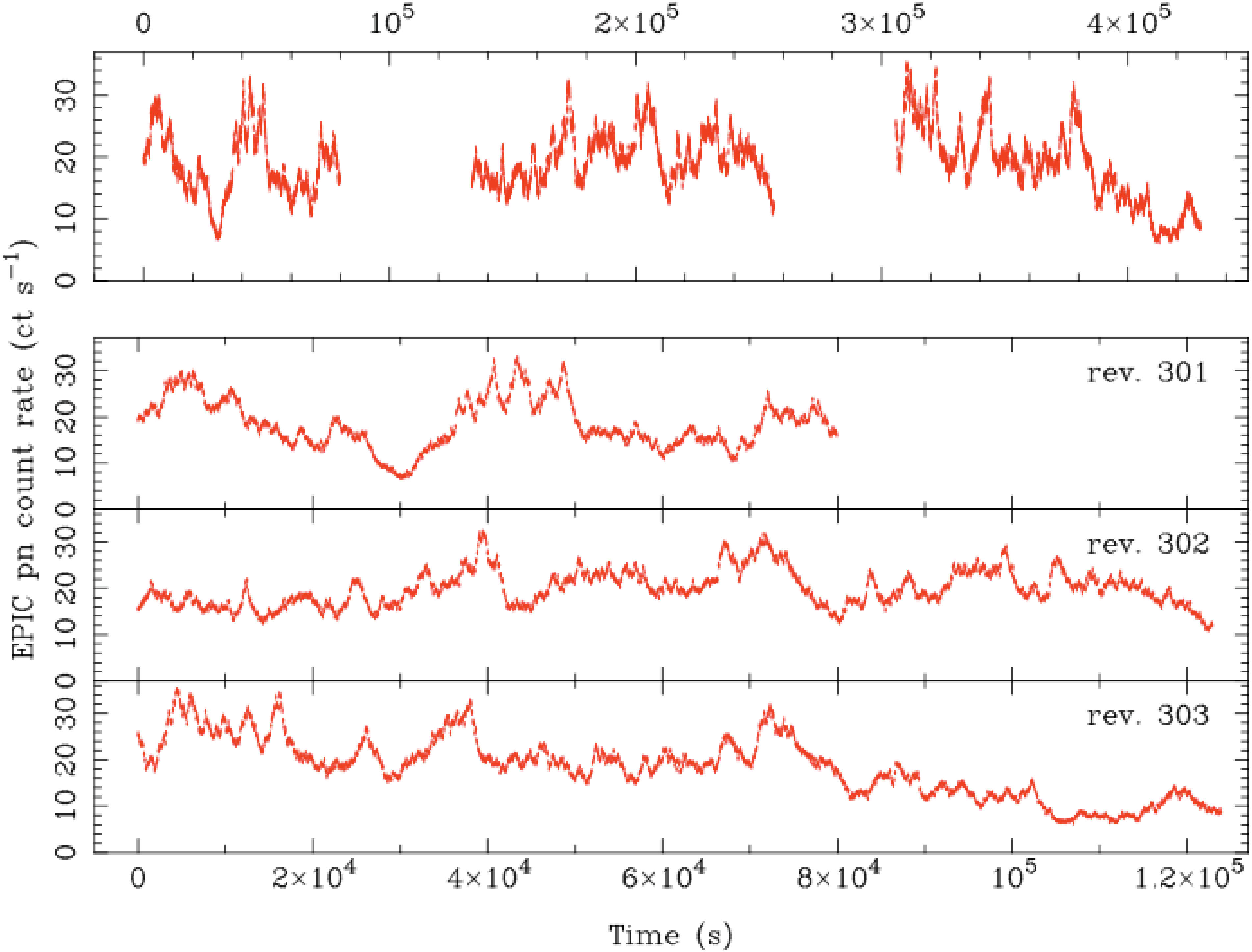


Suzaku satellite X-ray spectrum of MCG-6-30-15
emission peak comes from ionized iron atoms
Ratio
0.9
1
1.1
1.2
1.3
3
4
5
6
7
8
Observed Energy (keV)

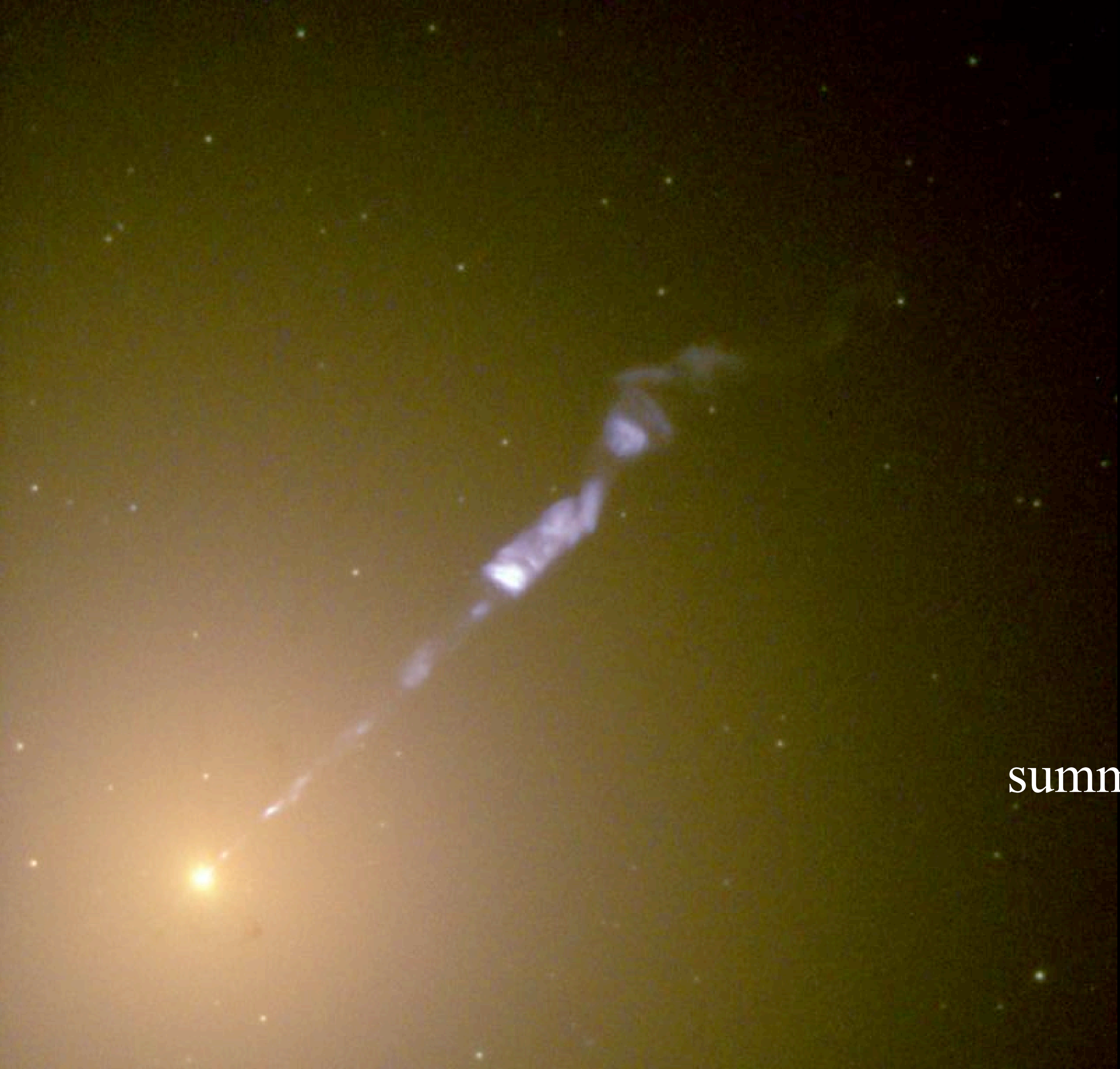


the width of the emission line indicates gas velocities of about 100,000 km/sec

the shape of the emission line can be modeled by emission arising near a spinning black hole
Ratio
0.9
1
1.1
1.2
1.3
3
4
5
6
7
8
Observed Energy (keV)



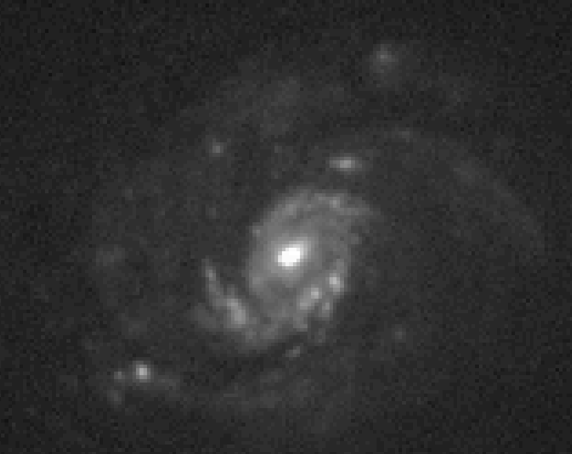
0
10^5
2×10^5
3×10^5
4×10^5
EPIC pn count rate (ct s^-1)
rev. 301
rev. 302
rev. 303
0
2×10^4
4×10^4
6×10^4
8×10^4
10^5
1.2×10^5
Time (s)



summary

physical properties of quasars (data):

- ✦ high luminosity ✓
- ✦ small emitting volume ✓
- ✦ spectra show broad emission lines ✓
- ✦ visible light + radio + X-rays ✓
- ✦ variable ✓
- ✦ bipolar symmetry ✓
- ✦ more quasars at high redshift ✓



Names:

quasi-stellar radio sources (quasars)
quasi-stellar objects (QSO's)
radio galaxies
ultra-luminous infrared galaxies
Type 1 Seyferts
Type 2 Seyferts
BL Lac objects
N galaxies
blazars
etc., etc.

$\Rightarrow$ all are *active galactic nuclei*, or *AGN*

An AGN *is an extragalactic source that emits non-stellar radiation from a small volume*.

If the AGN is sufficiently close, we can see the galaxy surrounding the nucleus (otherwise hard to see the faint fuzz of stars around the intensely bright center).

We call these Seyfert galaxies - they are generally low-redshift (close) and low-luminosity (so contrast is not too high).

Otherwise, if the thing is at high redshift and/or has high luminosity, we call it a quasar or QSO. Even if we cannot see the host galaxy, we assume it is there.

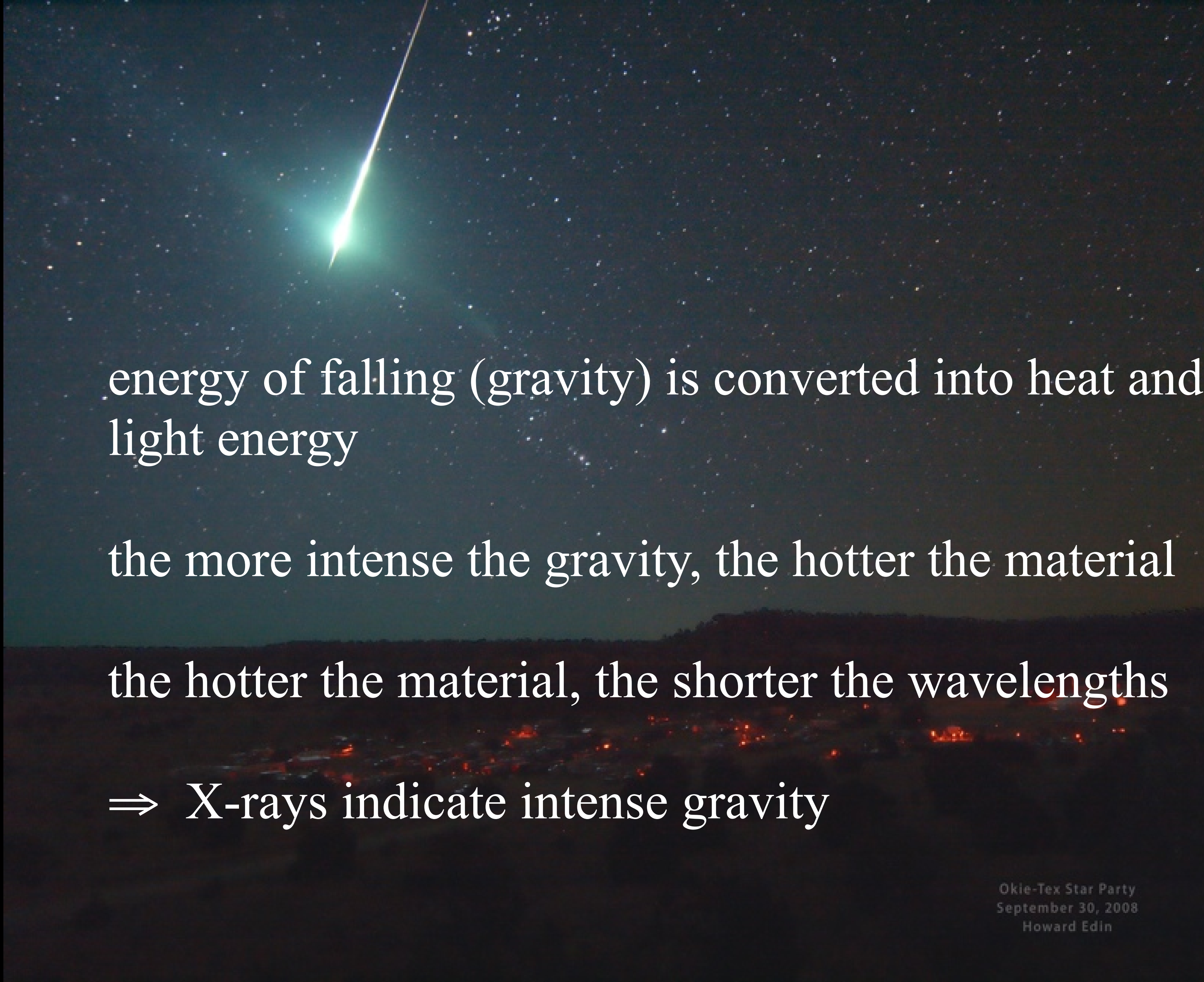
The various flavors of AGN's may be related to each other, differing by how the energy emerges (e.g., some are radio-loud, some are radio-quiet). Dust may surround the galaxy nucleus such that radiation is beamed in special directions (e.g. the rotation axis of the accretion disk). Many things are going on close to the black hole (magnetic fields, jets of particles moving near the speed of light, X-ray reflection), and the geometry is likely to be complex.

energy of falling (gravity) is converted into heat and light energy

the more intense the gravity, the hotter the material

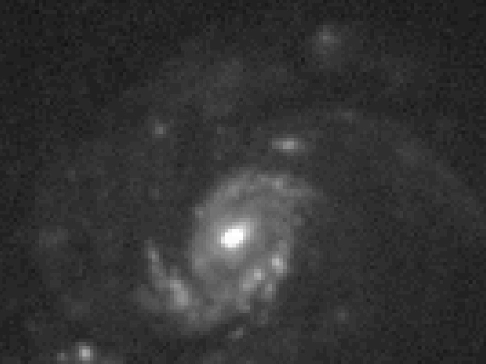
the hotter the material, the shorter the wavelengths

$\Rightarrow$ X-rays indicate intense gravity



physical properties of AGN (interpretation):

- ✦ intense gravity is due to a central supermassive black hole
- ✦ besides X-rays, this conclusion is indicated by:
  - high velocities ⇒ high mass
  - variability ⇒ small size



- ✦ the accretion disk is surrounded by a dusty torus, opaque to visible light. The AGN may then look very different depending on the angle at which we view it.

physical properties of AGN (interpretation):

✦ all giant galaxies have a central supermassive black hole, but not all galaxies are active (requires also gas to flow in)

✦ the gas flow can be triggered by a mergers between two galaxies

✦ the energy flowing out of the nucleus can affect the host galaxy on much larger scales (“feedback”)