

Tenerife, Spain, November 11-22, 2013

COSMIC MAGNETIC FIELDS

THE ELEPHANT IN THE ASTROPHYSICAL ROOM

Interstellar magnetic fields dominate
Solar magnetic fields
Galactic magnetic fields
The role of magnetic fields in star formation
Magnetic fields in galaxies
Magnetic fields in galaxy clusters and at larger scales
Primordial magnetic fields and magnetic fields in the early universe

TOPICS

- 1. Galaxies, IAC
- 2. IAGP, IAC
- 3. Interstellar Turbulence
- 4. Magnetic Fields
- 5. MHA, University
- 6. Solar Coronal
- 7. Solar Wind

www.iac.es/winterschool/2013/

Organizing Committee

- J. Sánchez-Solís
- M. J. Martínez-Gallego
- F. Gómez
- A. Sánchez

EXCELLENCE
EXTERIO
OCHEM

Cosmic Magnetic Fields

“The elephant in the astrophysical room”

Tenerife, Spain, November 11-22, 2013

COSMIC MAGNETIC FIELDS

THE ELEPHANT IN THE ASTROPHYSICAL ROOM

Astrophysical magnetic field structure
 Solar magnetic fields
 Interstellar magnetic fields
 The role of magnetic fields in star formation
 Magnetic fields in galaxies
 Primordial magnetic fields and magnetic fields in the early universe

TOPICS
 1. Galaxies
 2. Stars
 3. Interstellar medium
 4. Solar system
 5. Early universe

SPEAKERS
 1. Galaxies: IGA
 2. Stars: IGA
 3. Interstellar medium: IGA
 4. Solar system: IGA
 5. Early universe: IGA

www.iac.es/winterschool/2013/

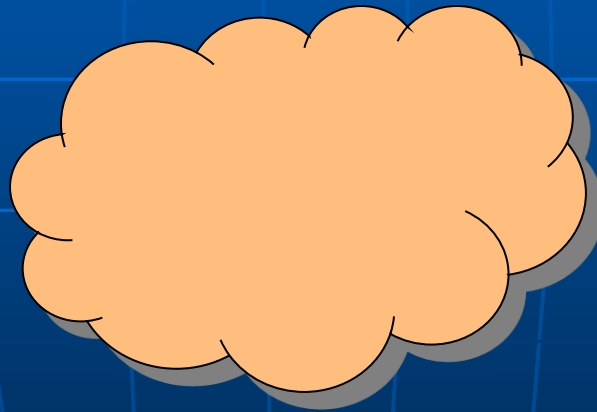
Organizing Committee:
 Sánchez-Alfonso
 M. J. Martínez-González
 J. Gómez
 J. Sánchez

IAC3W13CA
 IAC3W13CB
 IAC3W13CC



“Listen and learn”

7 (almost blind) astronomers
study a magnetized elephant:



R. Beck
(Brazil 2004)

The first does not have a polarimeter
and cannot separate it from the
background forest.

The second measures the elephant's polarized flux, applies the textbook formula and concludes it must be a mosquito.

The third runs an MHD code of an expanding bubble and finds sufficient agreement with the elephant.

The other 4 astronomers know that magnetism is unimportant, so that the elephant cannot exist.

Basic facts about cosmic magnetic fields

- Most baryonic matter is ionized:
Magnetic fields are easy to generate
- No magnetic monopoles:
Magnetic fields are hard to destroy
- But magnetic fields need illumination:
Magnetic fields are difficult to observe



Fundamental questions on cosmic magnetic fields

- When and how were the **first fields** generated ?
- Did significant fields exist **before galaxies formed** ?
- How and how fast were the fields **amplified** ?
- How did fields affect the **evolution** of stars, planets, galaxies and galaxy clusters?
- Is **intergalactic space** magnetic ?



Lecture 1: Galaxies in a Nutshell

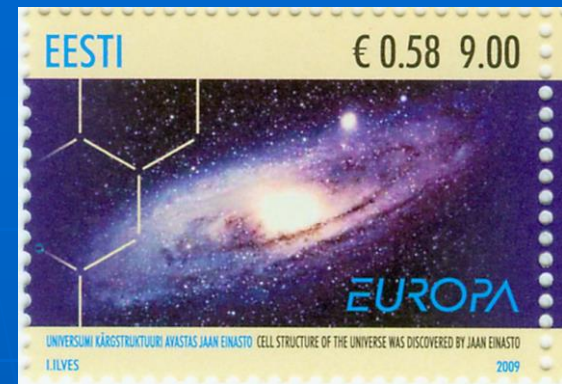
Lecture 2: Basics of Radio Astronomy

Lecture 3: Measuring Cosmic Magnetic Fields

Lecture 4: Origin of Magnetic Fields in Galaxies

Lecture 4: Magnetic Fields in the Milky Way

Lecture 6: Magnetic Fields in External Galaxies



Lecture 1: Galaxies in a Nutshell

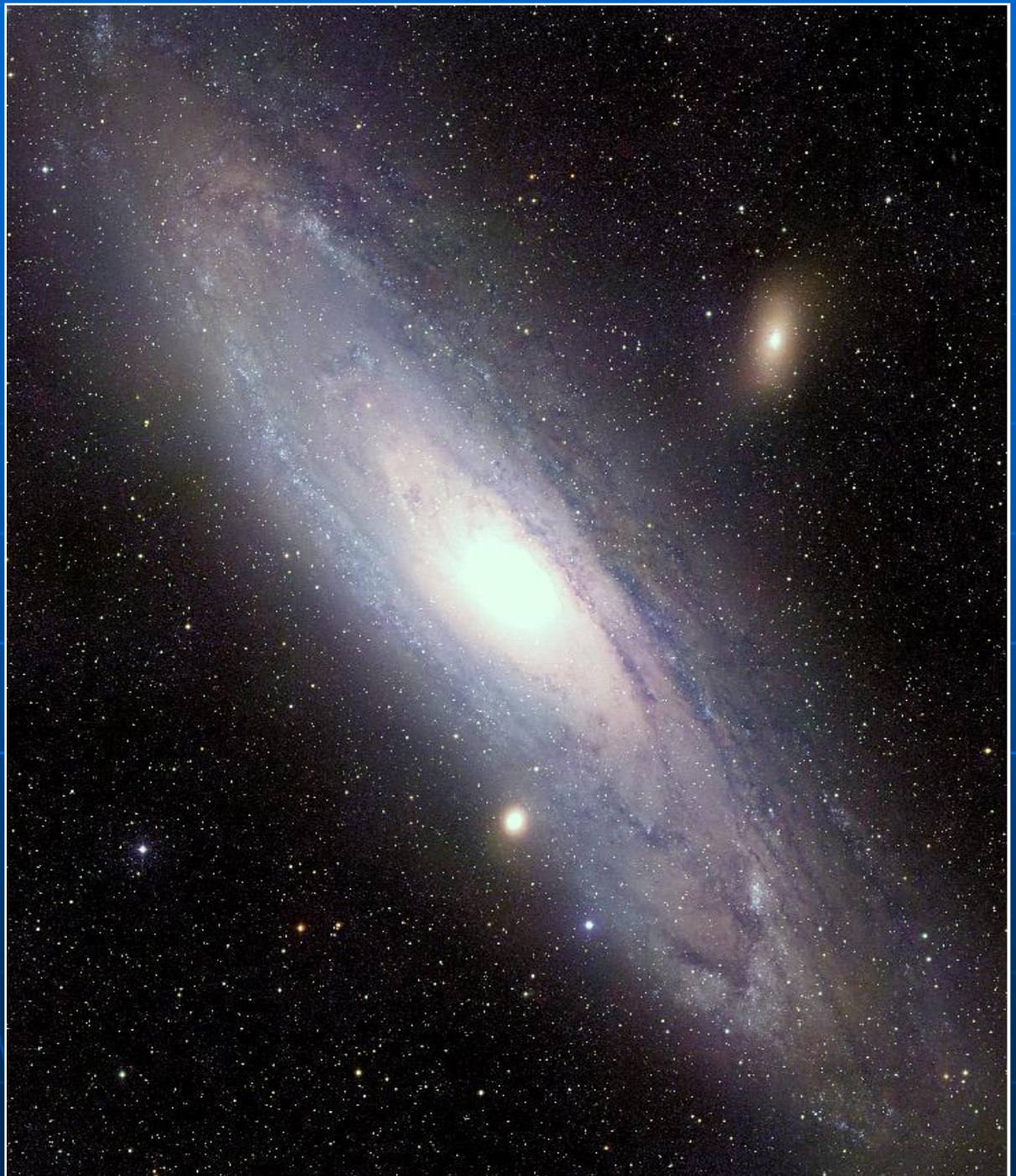
Dr. Rainer Beck, MPIfR Bonn



Spiral galaxies

M 31

(Andromeda
Galaxy)
Tautenburg



M 51

Hubble Space Telescope (HST)



Whirlpool Galaxy • M51

Barred galaxies

M 83

ESO

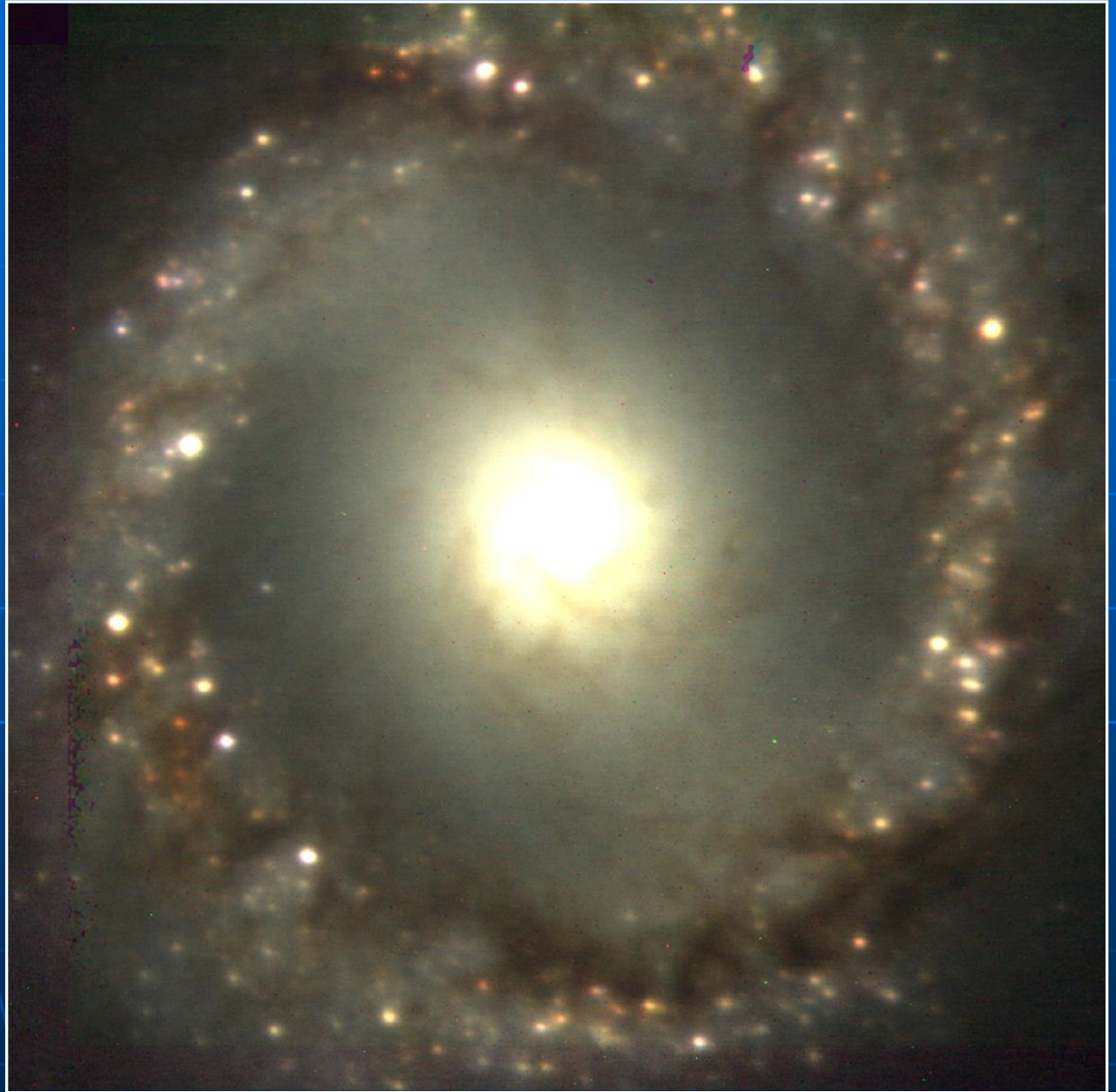


NGC 1097

Gendler/ESO



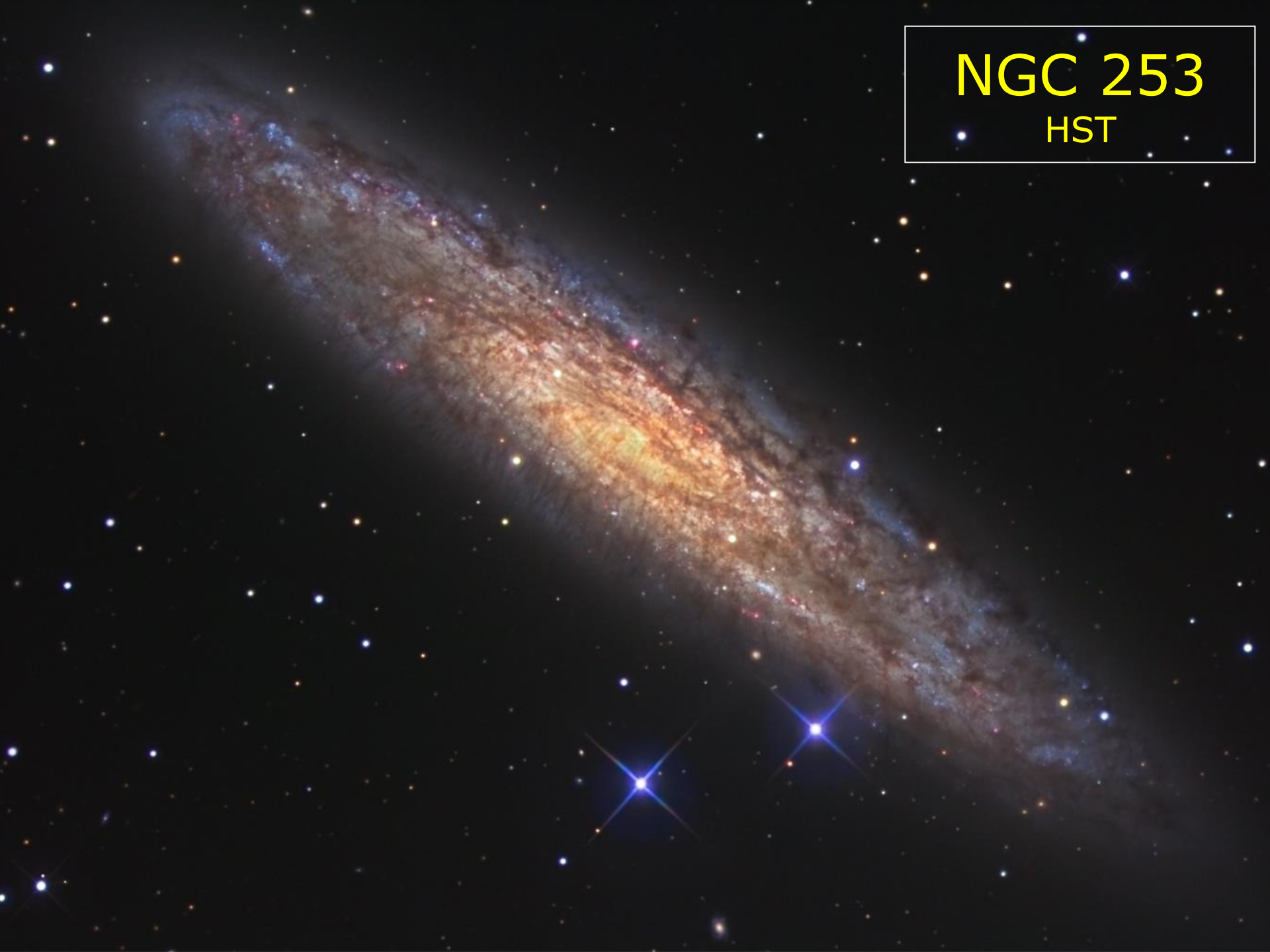
NGC 1097
Central region
HST



Edge-on galaxies

NGC 253

HST

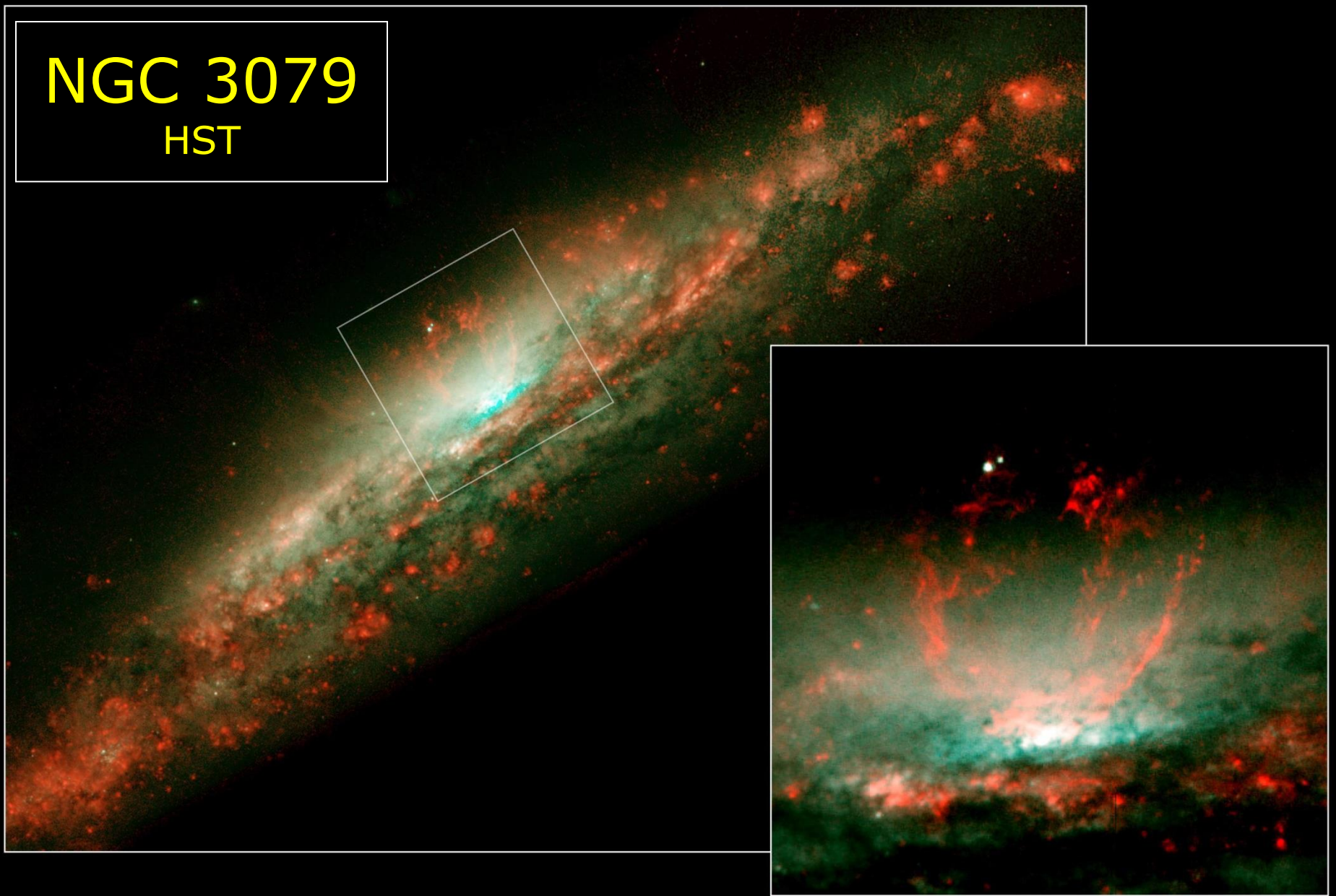


NGC 4631

Misti Mountain



NGC 3079
HST



Galaxy NGC 3079
Hubble Space Telescope • WFPC2

Elliptical galaxies

M 104

Sombrero galaxy

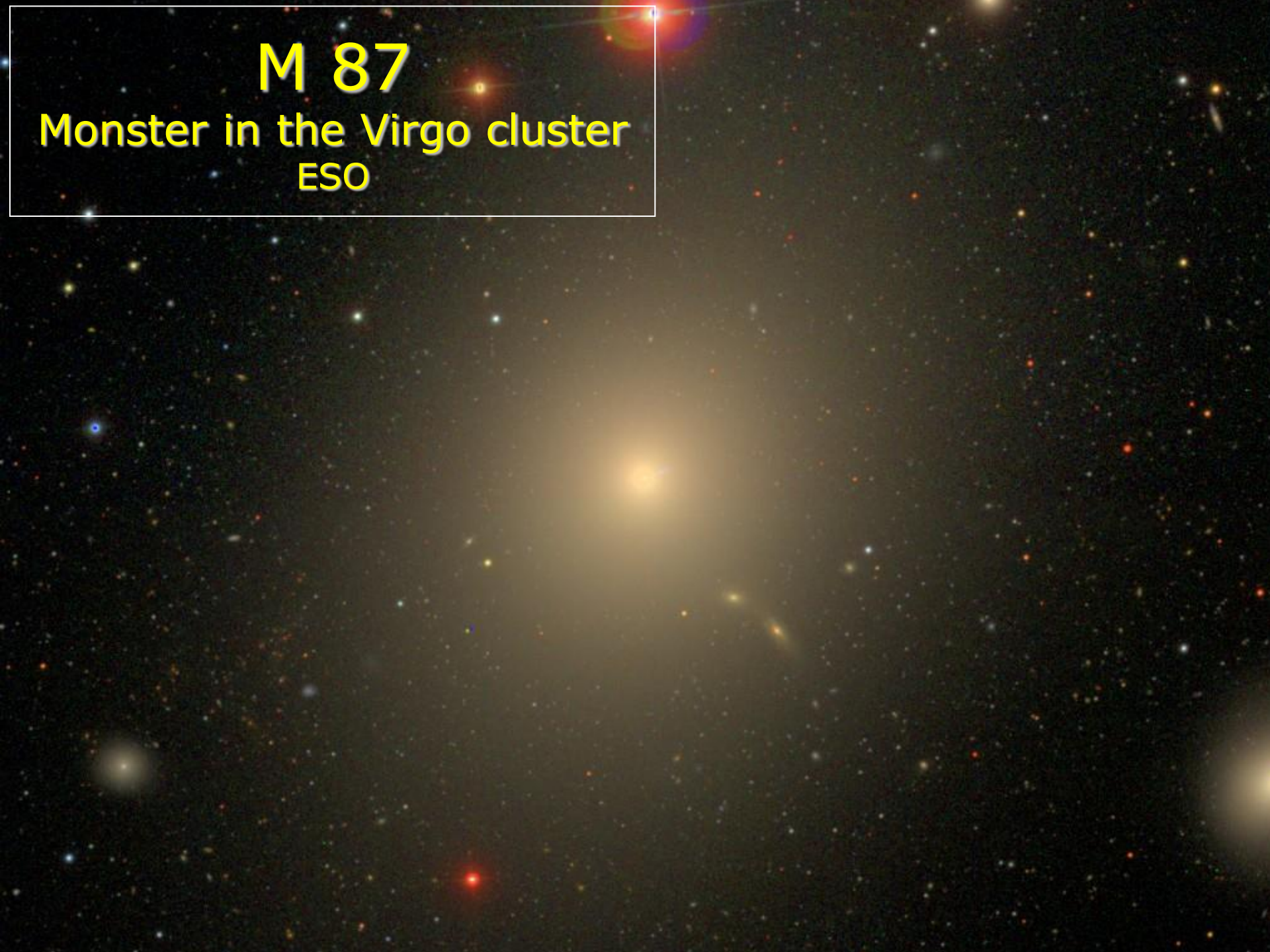
ESO



M 87

Monster in the Virgo cluster

ESO



Jet of M 87



Irregular galaxies

Large Magellanic Cloud





IC 10
HST

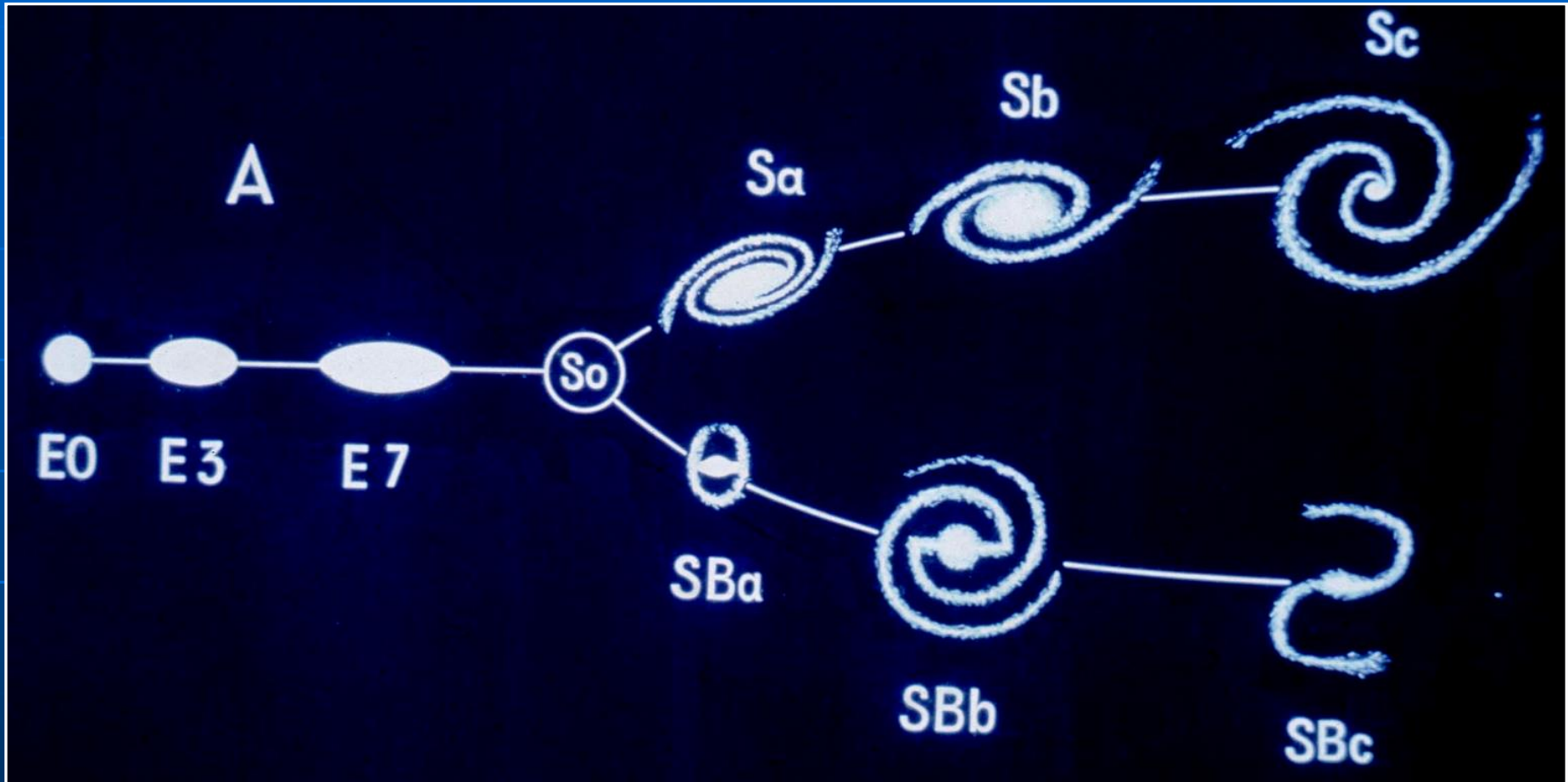
This image shows the IC 10 galaxy, also known as the Bode's Galaxy, captured by the Hubble Space Telescope. The galaxy is characterized by a dense field of stars, with a prominent red emission-line region in the center-right. The red color highlights the presence of ionized hydrogen (H-alpha) and other emission-line elements. The overall appearance is that of a star-forming galaxy with a complex internal structure.

Dwarf galaxies

NGC 6822
(local group)



Hubble classification

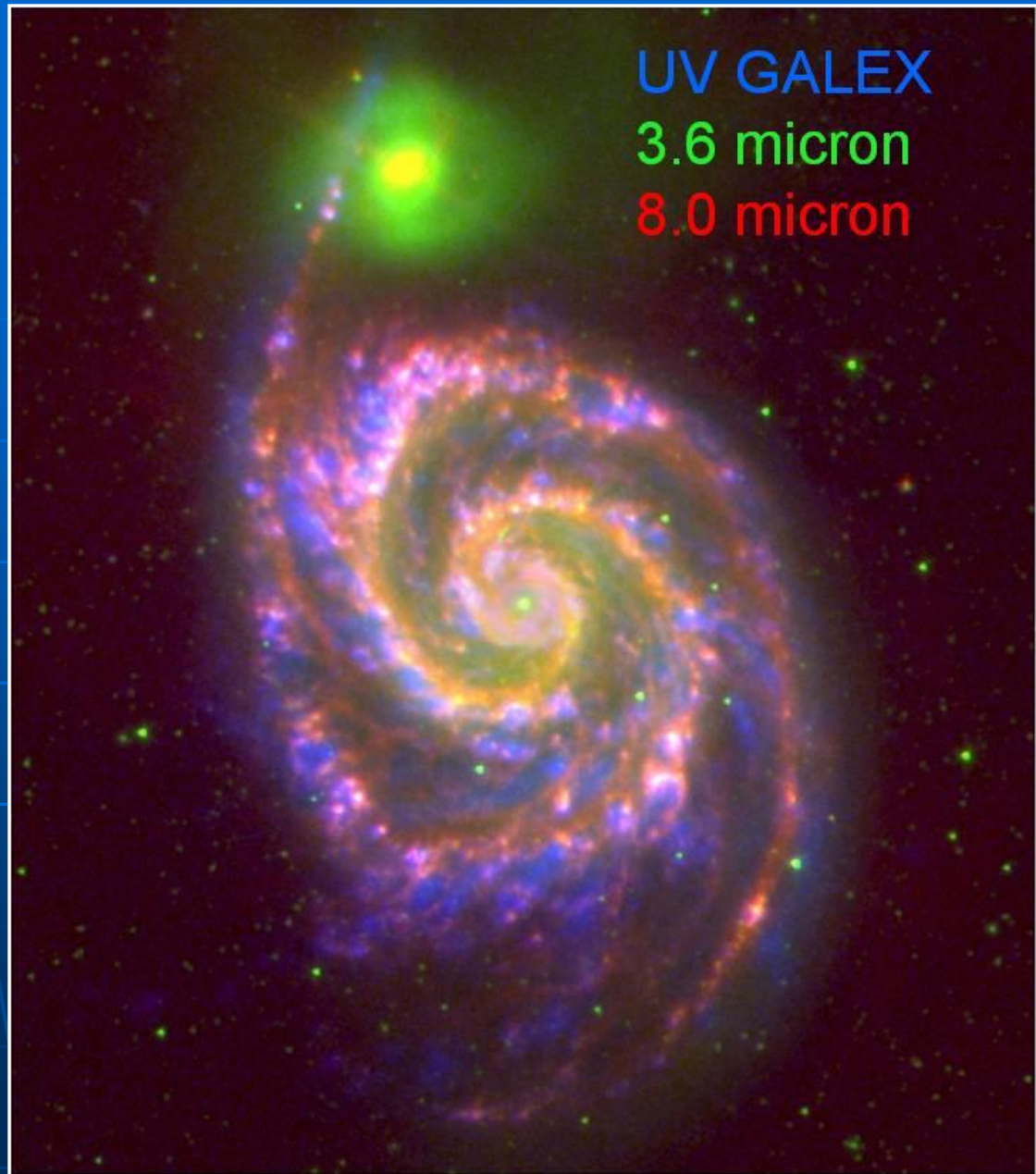


Gas fraction → → →

*The multi-wavelength view:
the full beauty of galaxies*

M 51

UV + infrared
GALEX + SPITZER



UV GALEX
3.6 micron
8.0 micron

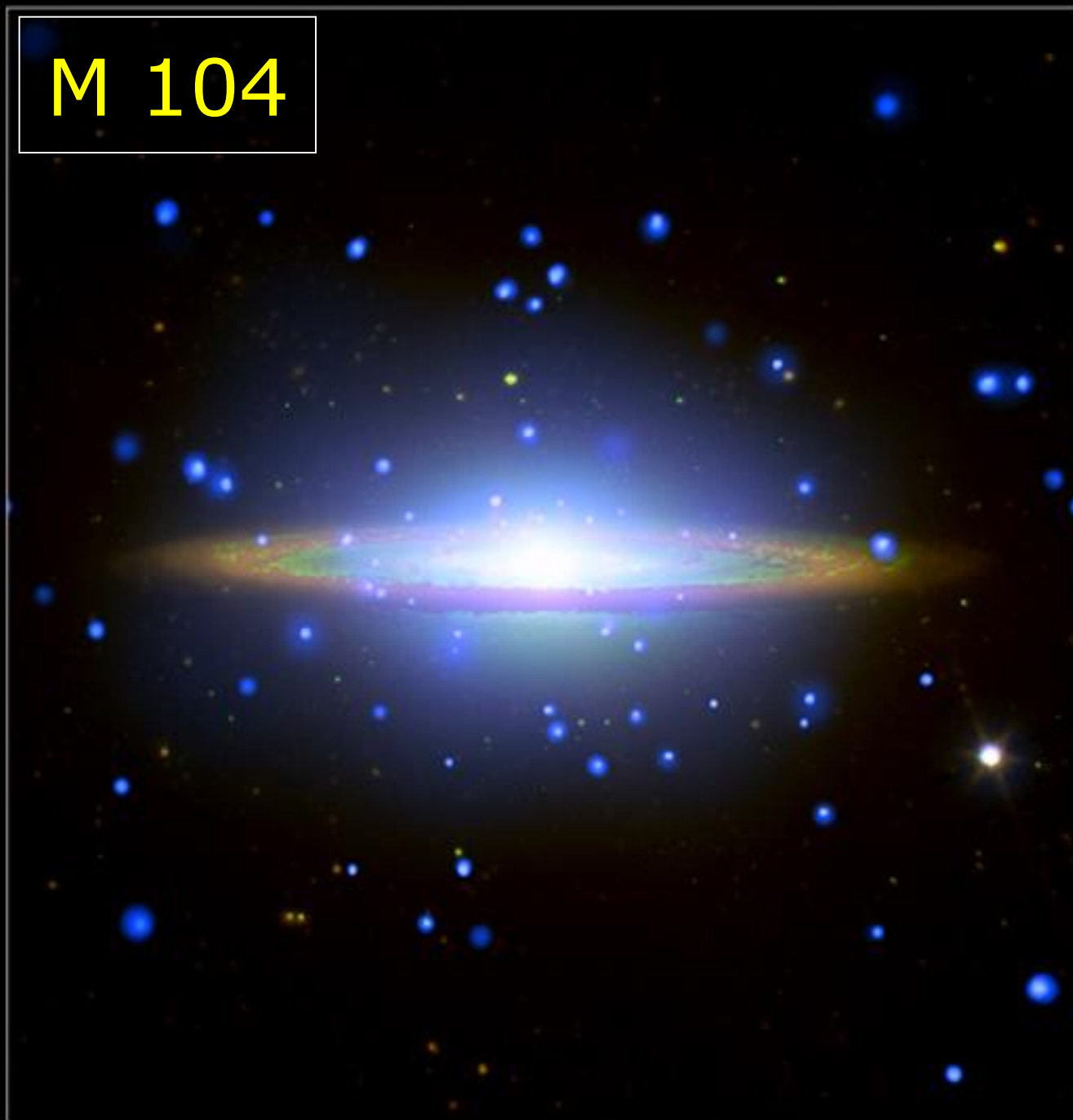
Courtesy of SINGS Team

NGC 1097

IR + optical
SPITZER



M 104



Chandra X-ray



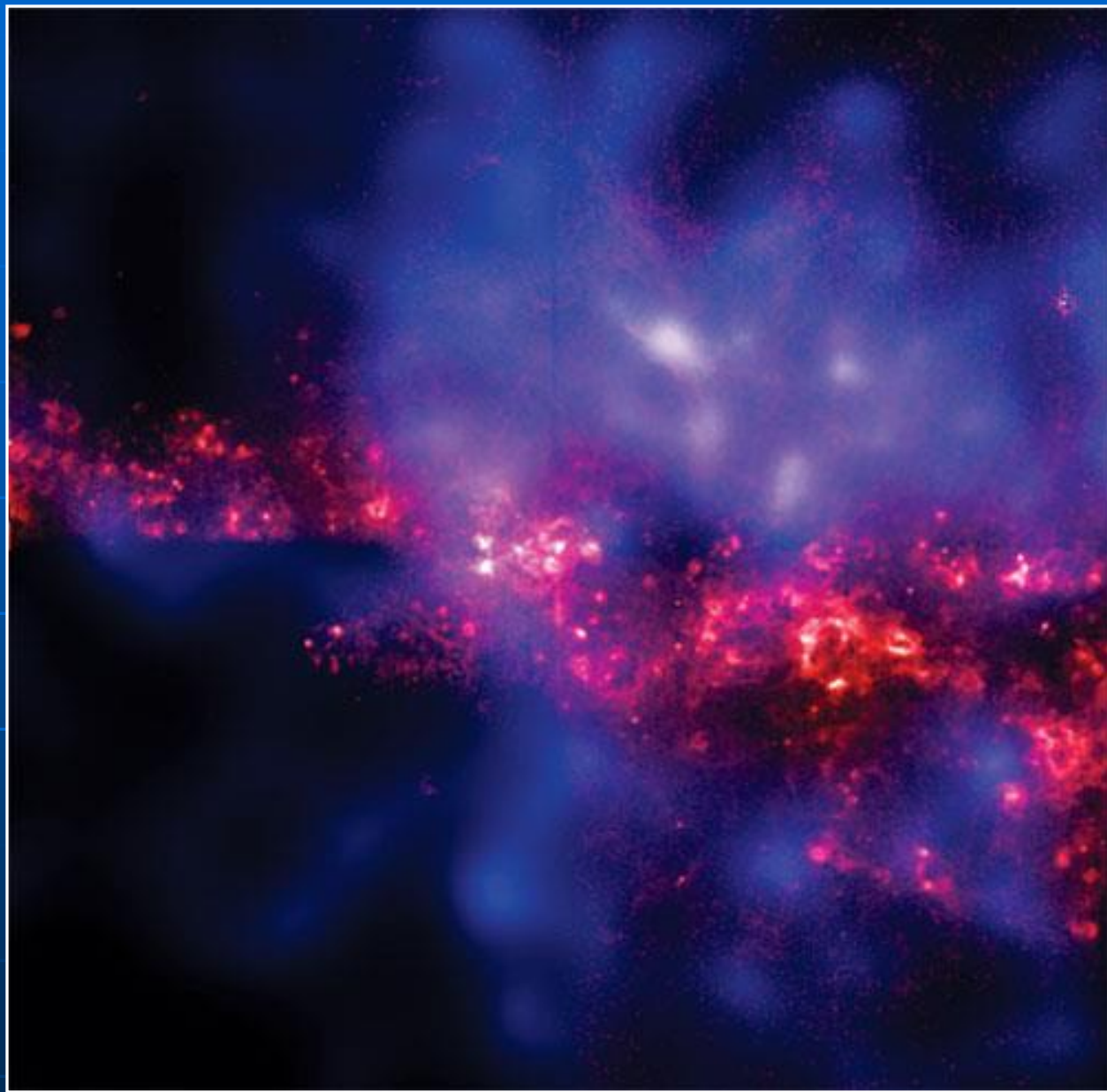
Hubble Optical



Spitzer Infrared

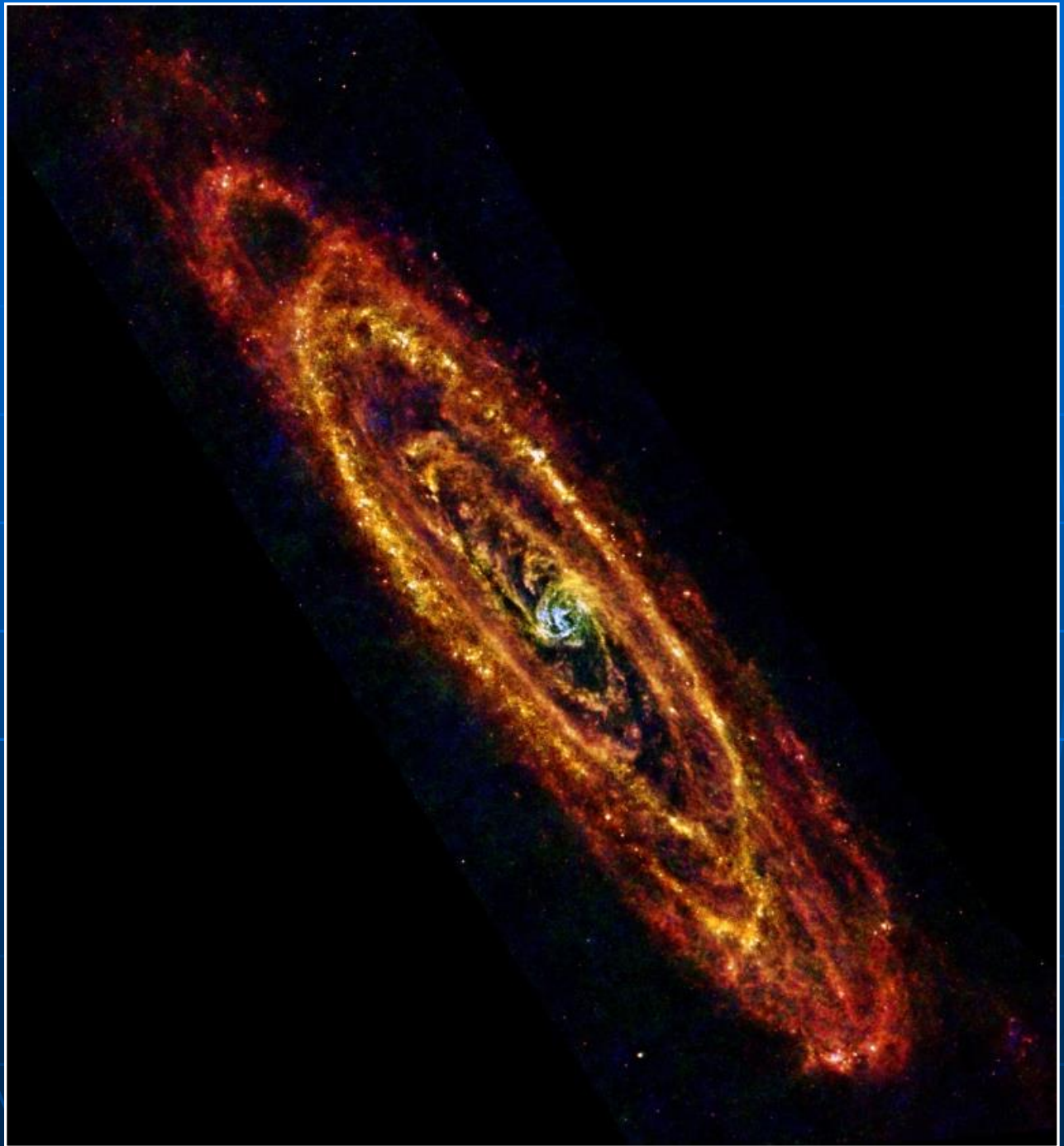
NGC 4631

X-rays
CHANDRA



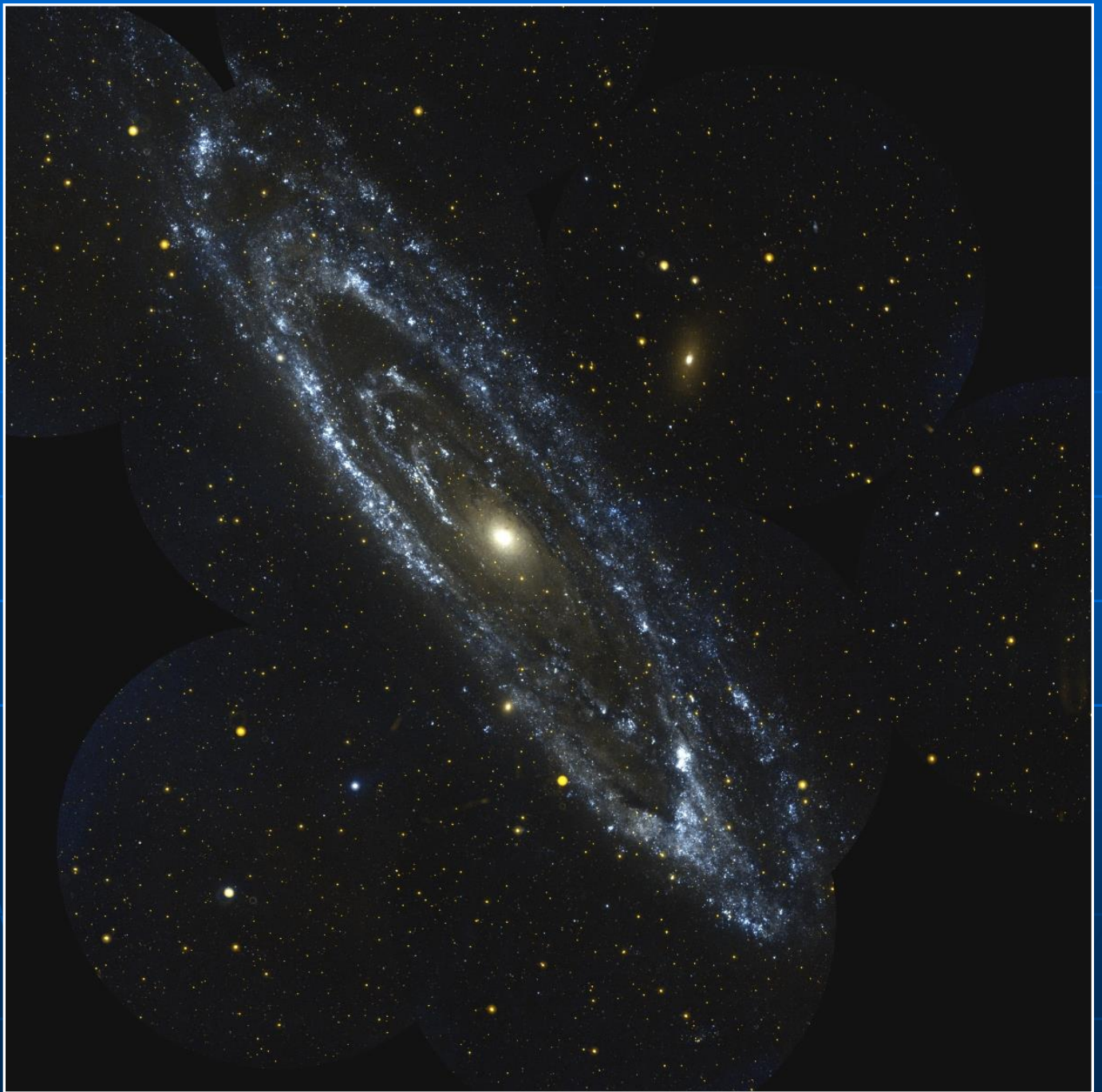
M 31

Infrared (dust)
HERSCHEL



M 31

UV
GALEX

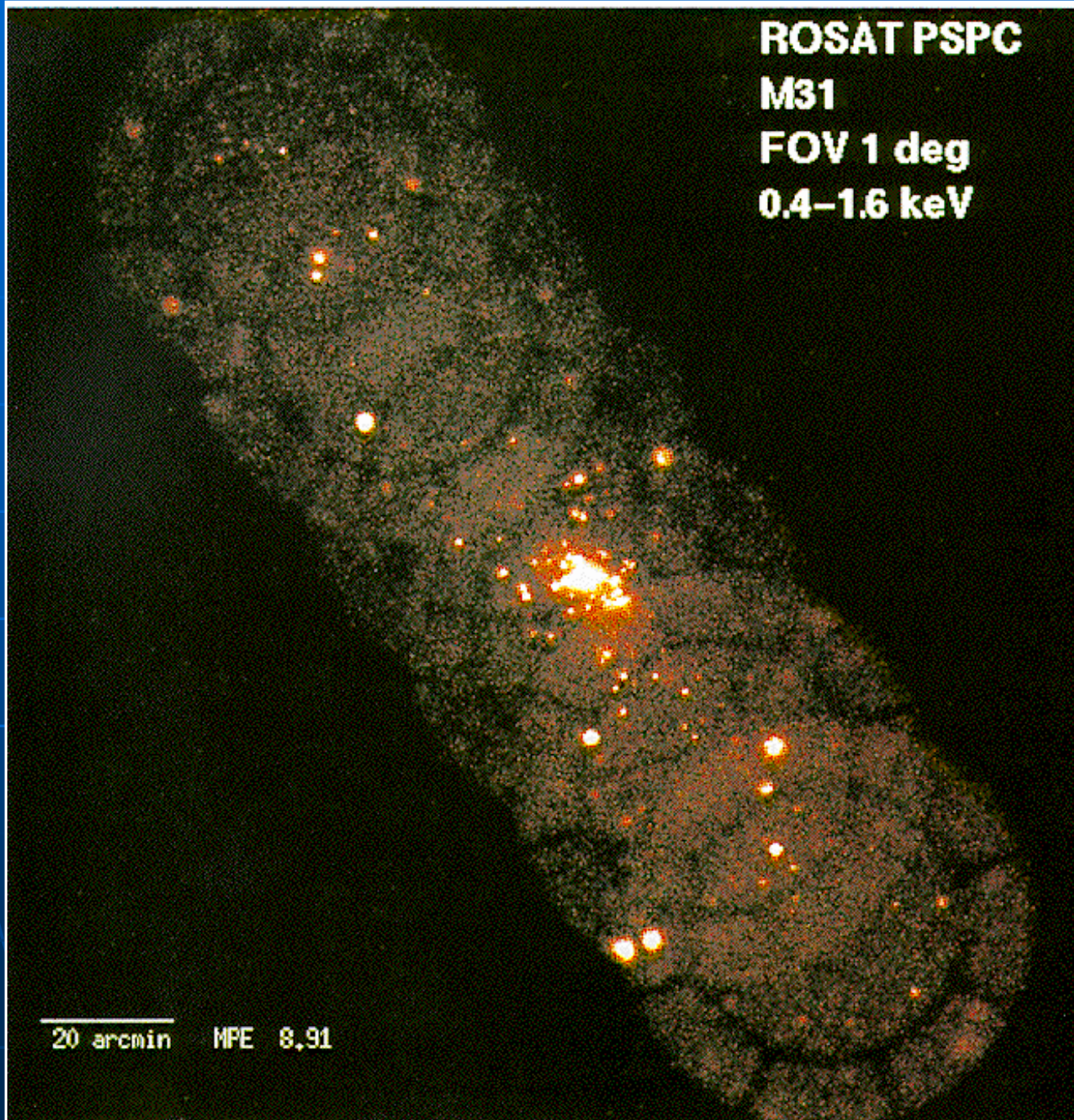


M 31

X-rays
ROSAT

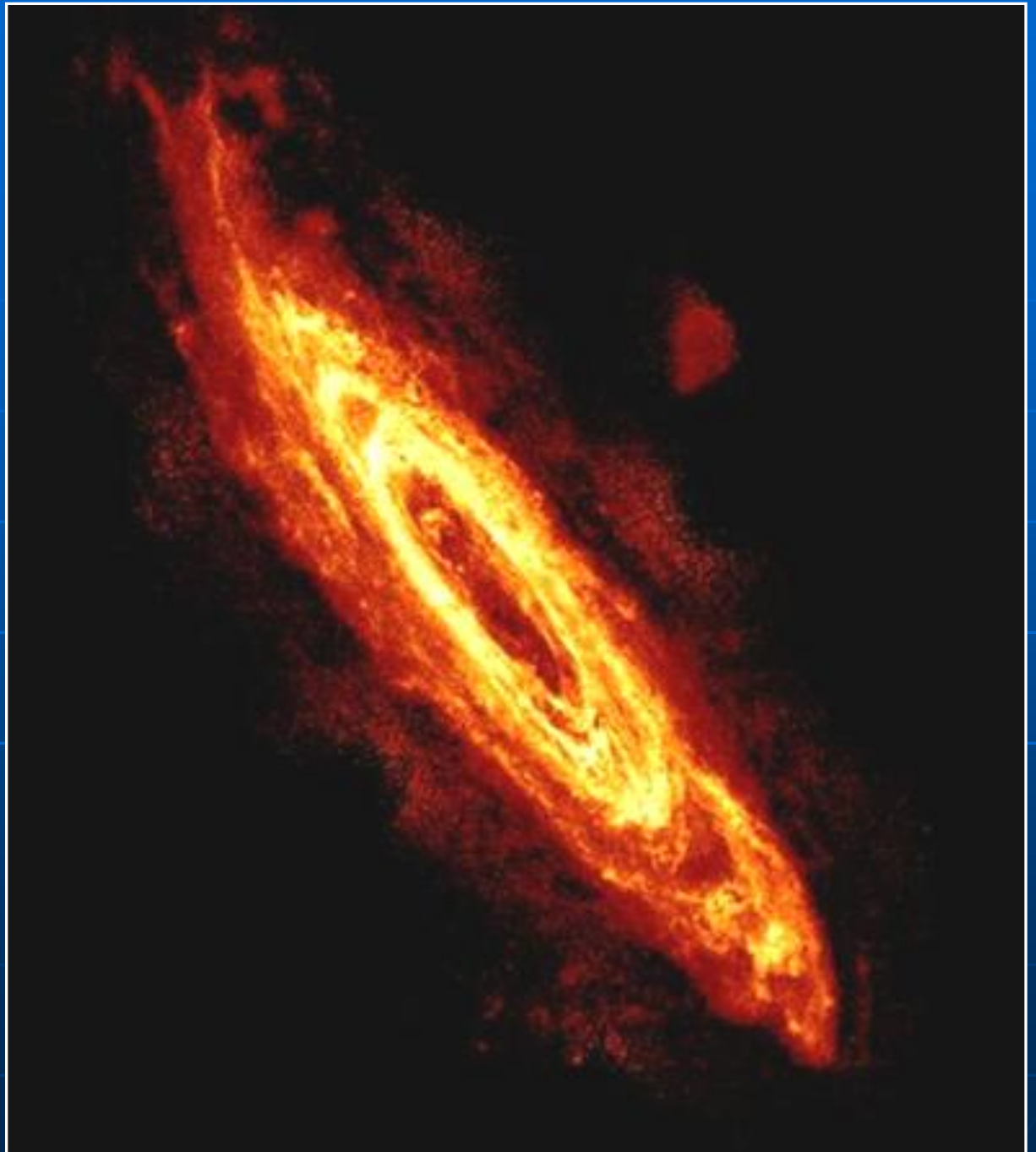
ROSAT PSPC
M31
FOV 1 deg
0.4–1.6 keV

20 arcmin MPE 8,91



M 31

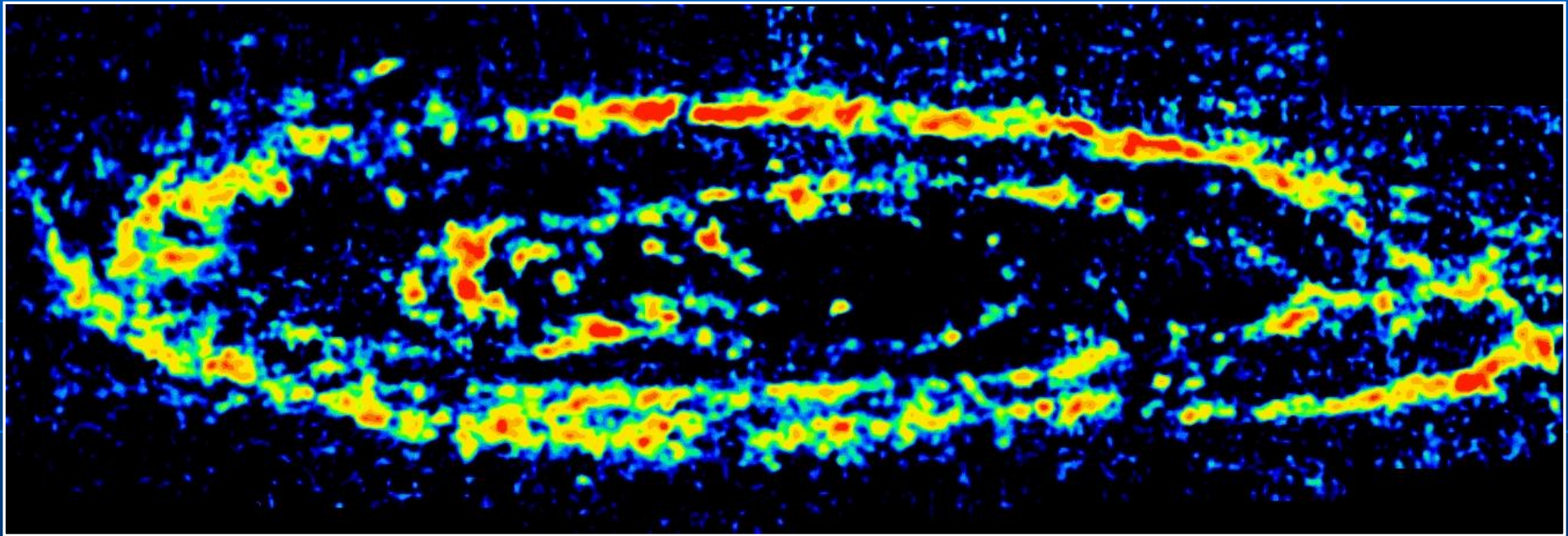
Neutral hydrogen
line emission (HI)
21.1cm
Westerbork



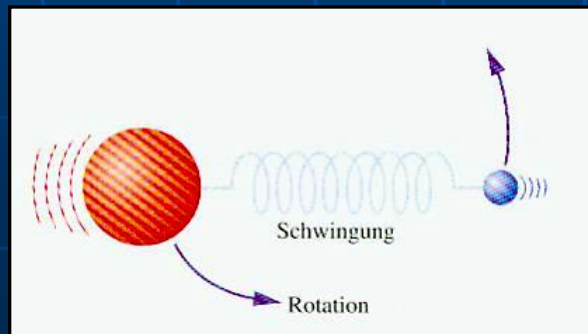
Braun et al. 2005

M 31

Molecular gas (CO)
2.6mm line emission
IRAM/Pico Veleta



Nieten et al. 1999

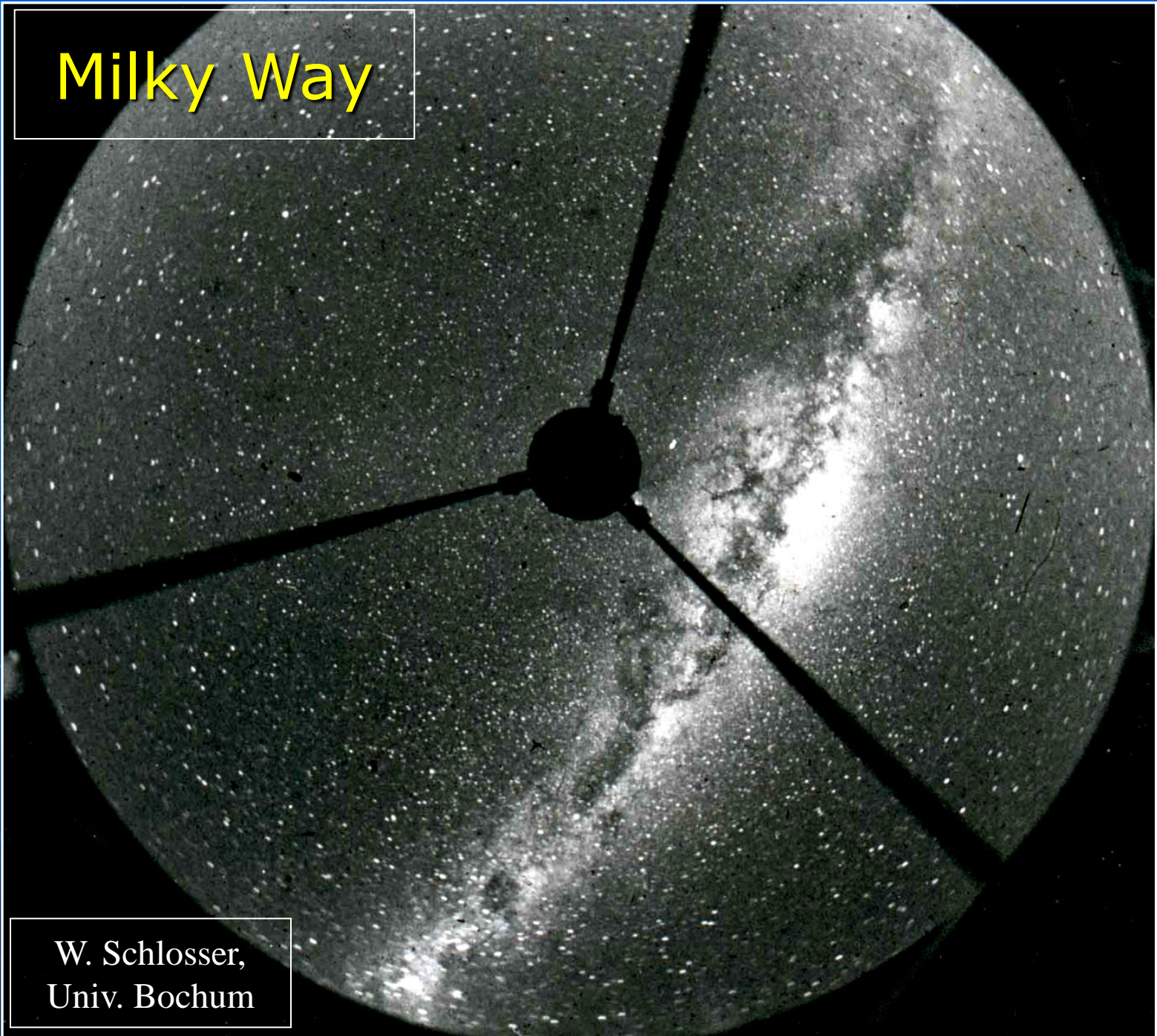


Basic properties of galaxies

- Typical size: $10^4 - 10^7$ light years
- Number of stars: $10^7 - 10^{11}$
- Mass: $10^8 - 10^{12}$ solar masses
- Gas mass: $10^6 - 10^7$ solar masses
- Dust mass: $10^5 - 10^6$ solar masses
- Rotation velocity: 100 – 300 km/s
- Rotation period: $10^8 - 10^9$ years
- Age: $13 \cdot 10^9$ years

Our Milky Way

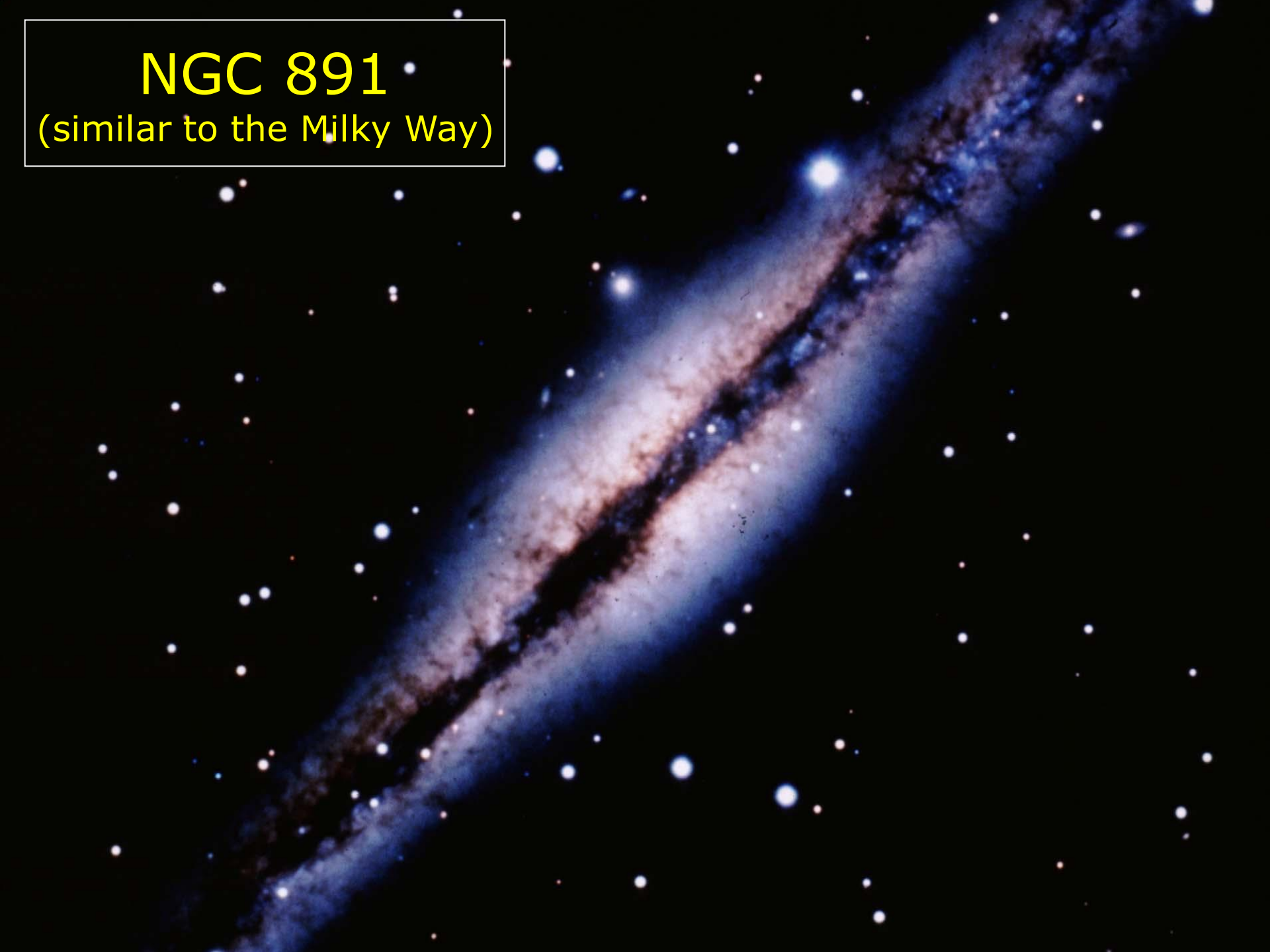
Milky Way

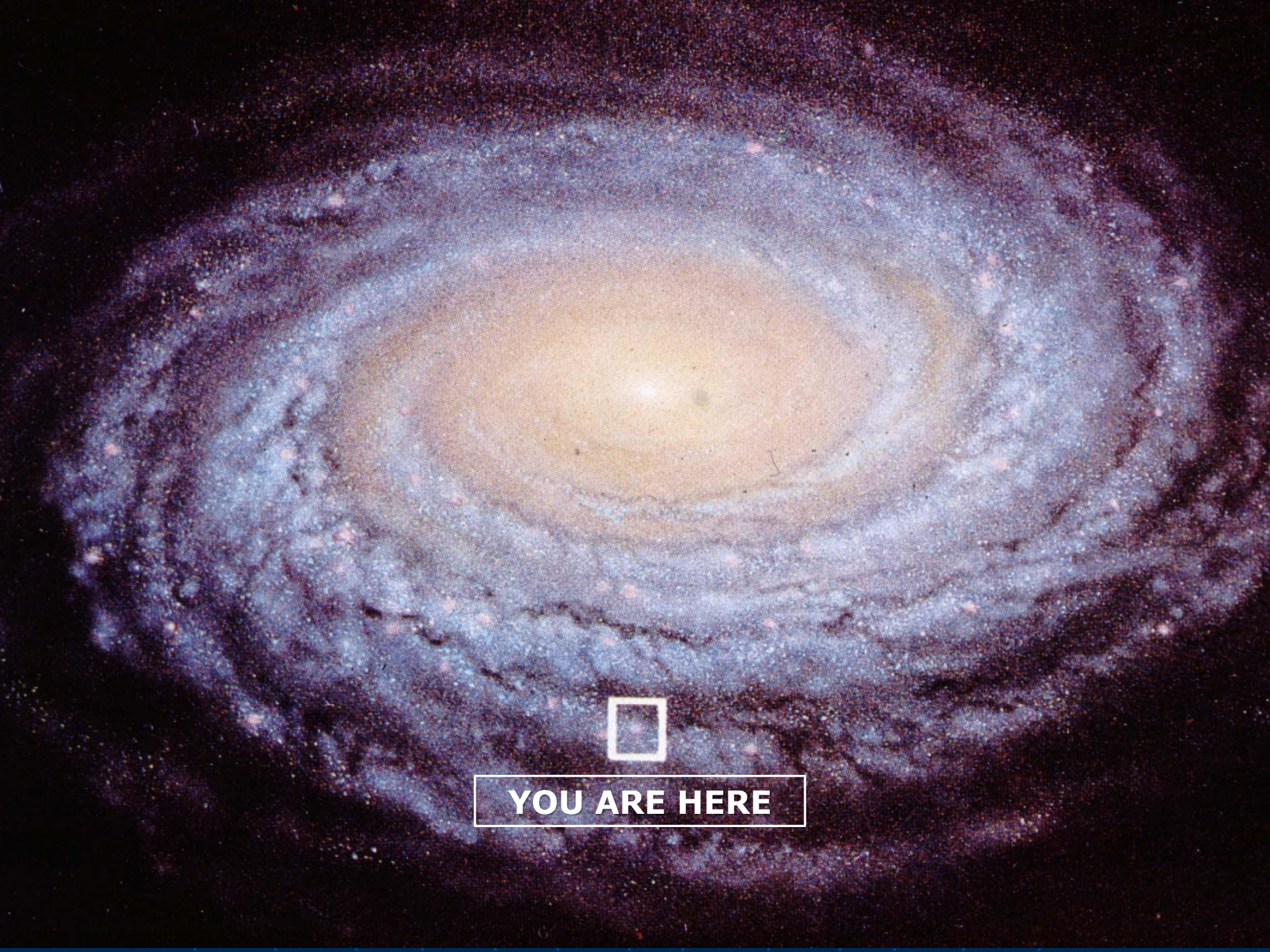


W. Schlosser,
Univ. Bochum

NGC 891

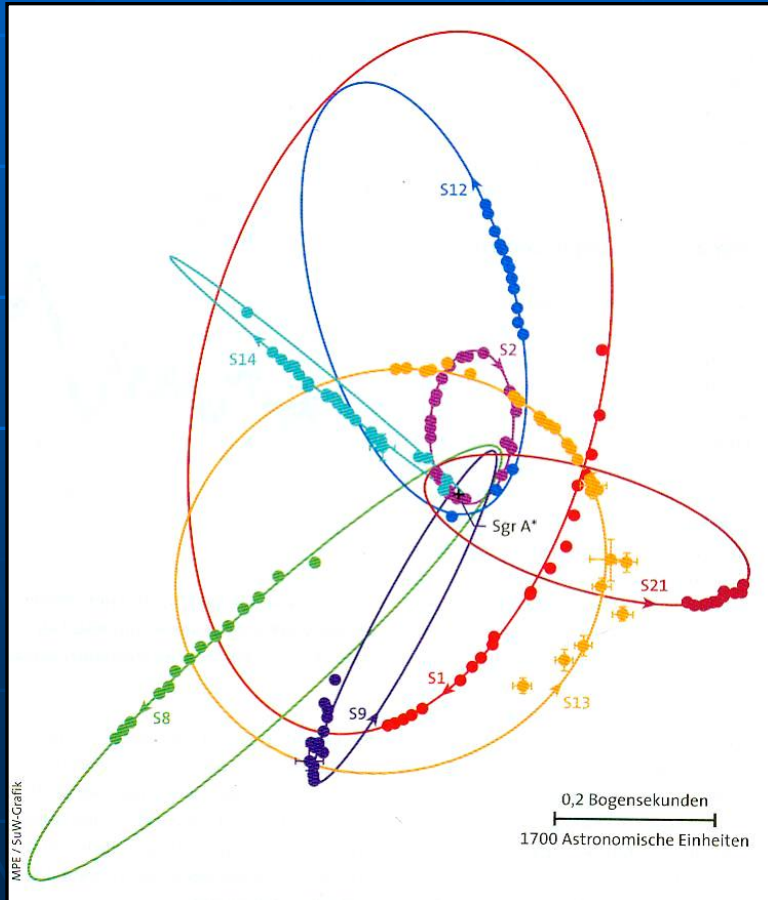
(similar to the Milky Way)





YOU ARE HERE

The Black Hole in the Galactic Center



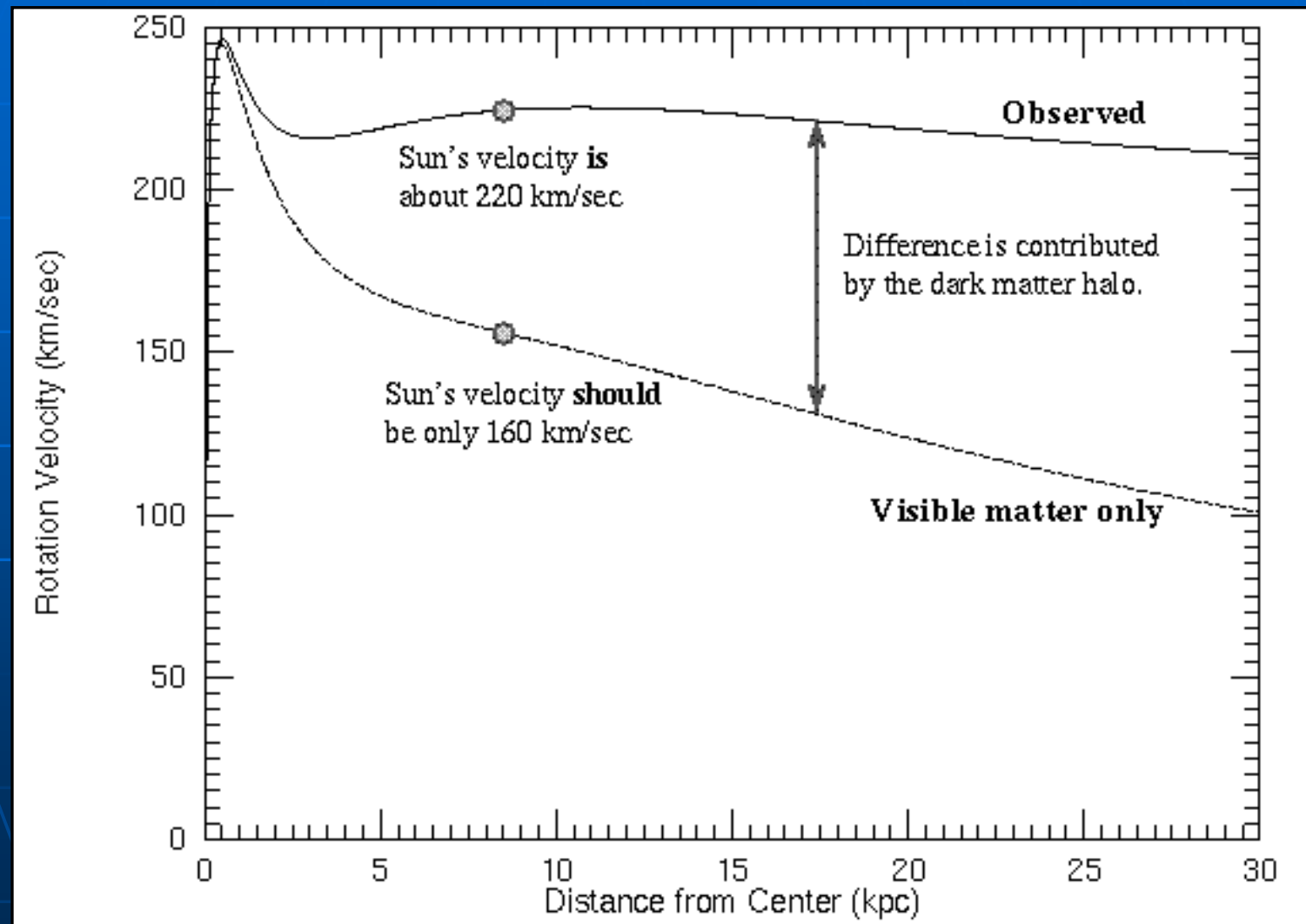
The Centre of the Milky Way
(VLT YEPUN + NACO)

ESO PR Photo 23a/02 (9 October 2002)

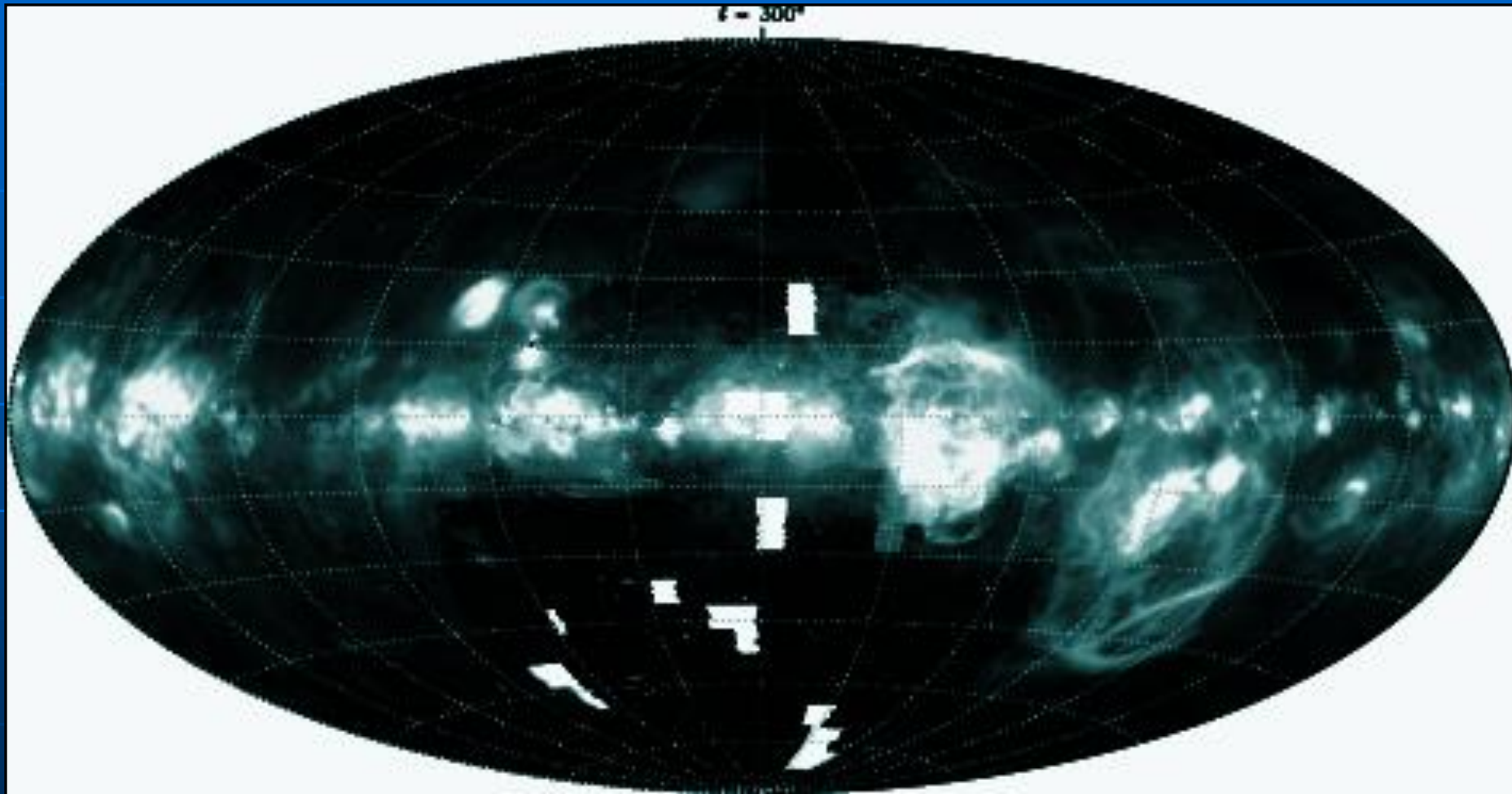
© European Southern Observatory



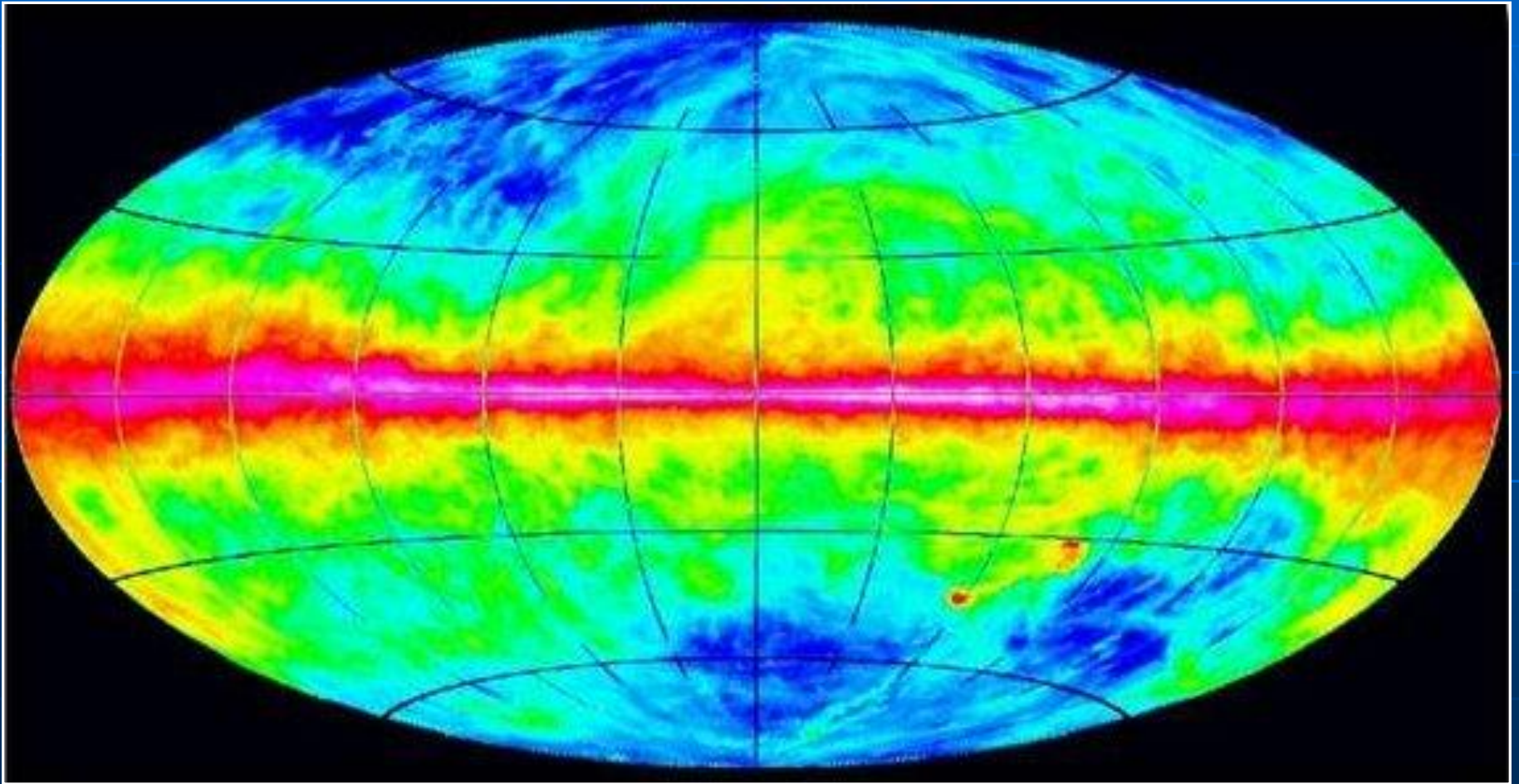
Rotation curve of the Milky Way



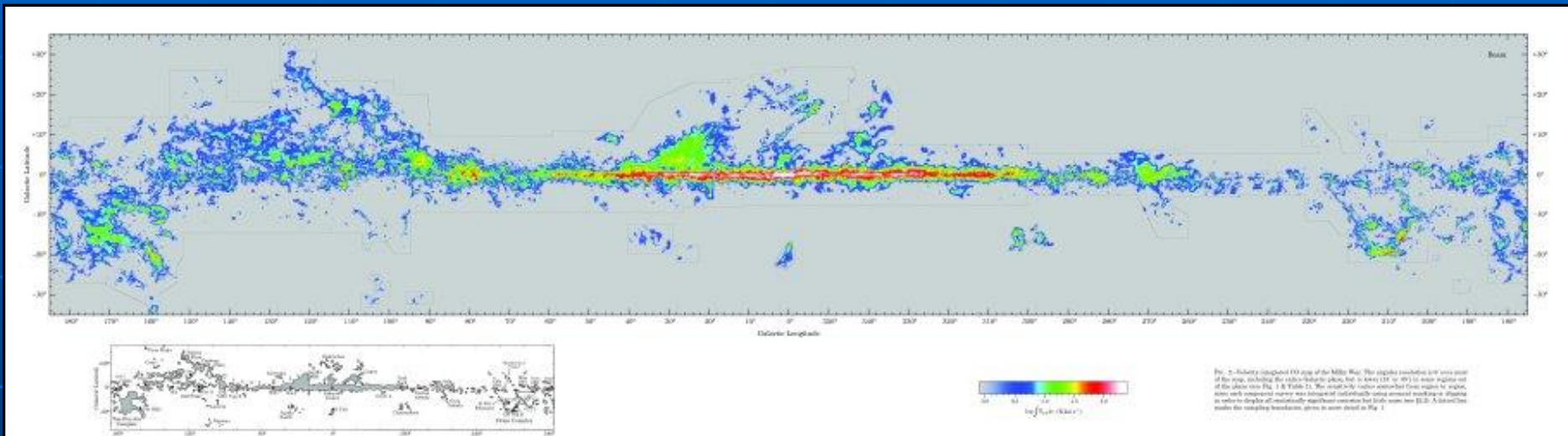
The Milky Way in optical H α emission of ionized hydrogen



The Milky Way in HI line emission of neutral hydrogen (Netherlands/Argentina/Germany)

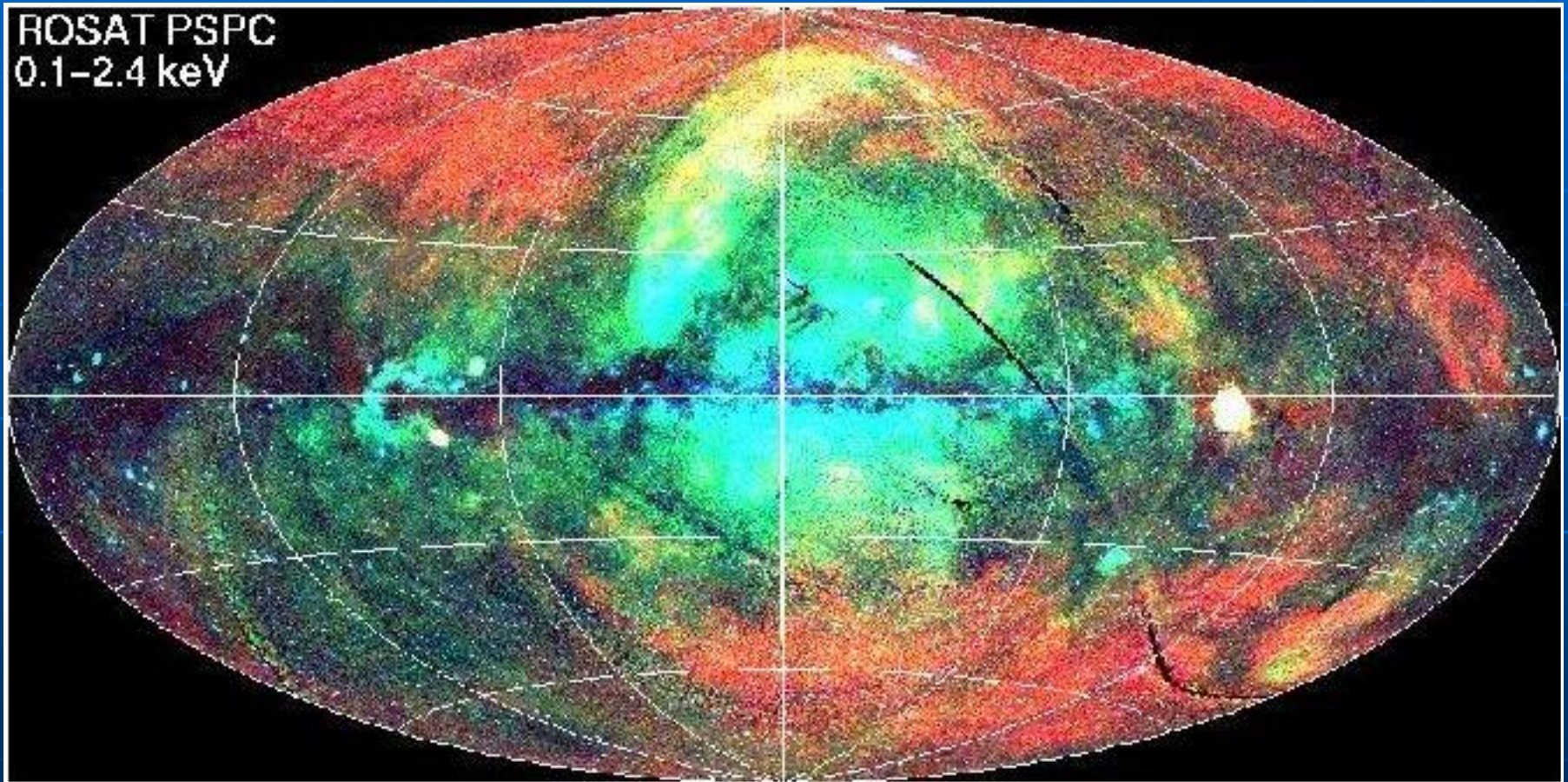


The Milky Way in CO line emission



Dame et al. 2001

The Milky Way in soft X-rays



ROSAT

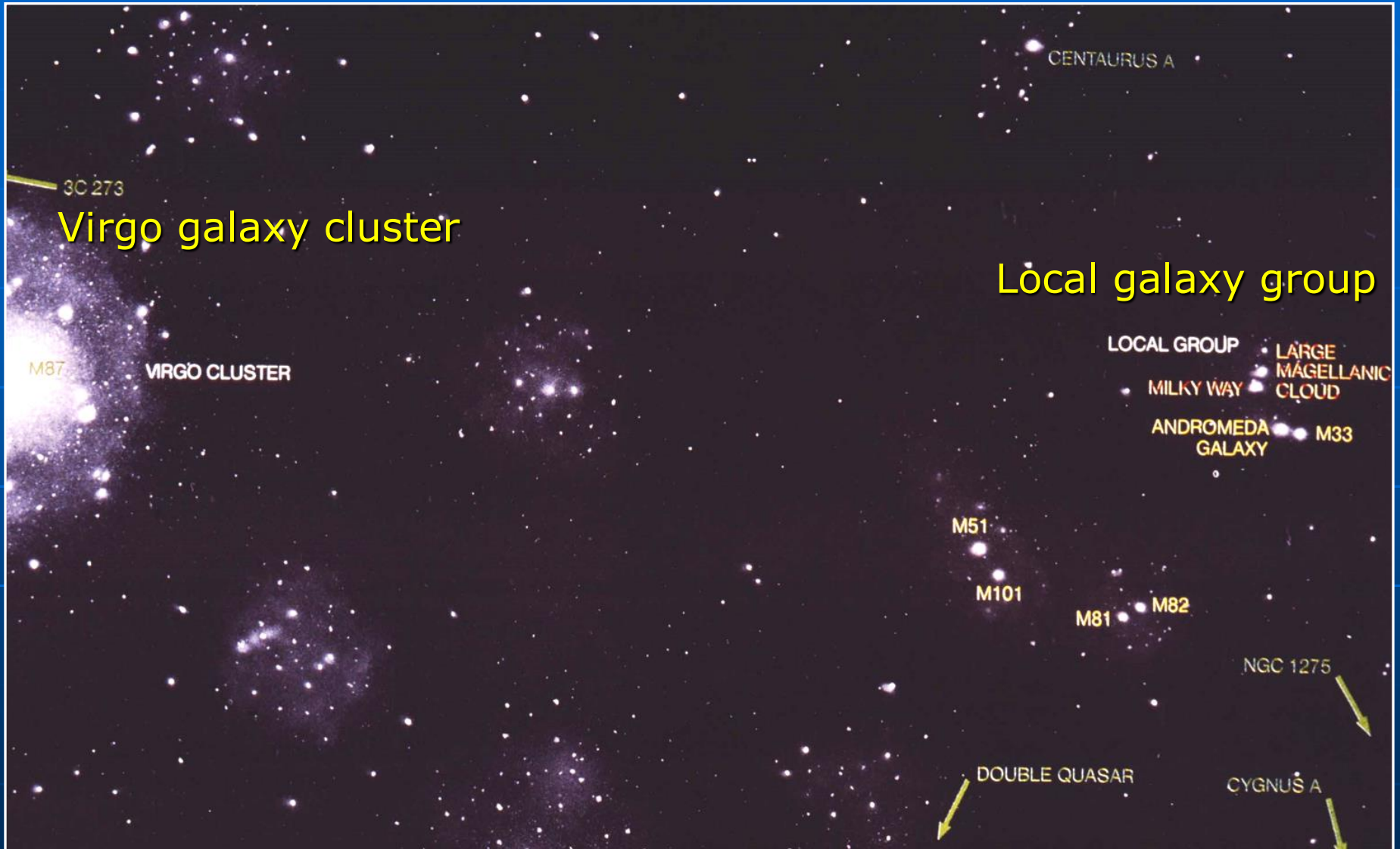
Components of the Interstellar Medium

Ferrière 2001

Table 1: Components of the interstellar medium^[2]

Component	Fractional Volume	Scale Height (pc)	Temperature (K)	Density (atoms/cm ³)	State of hydrogen	Primary observational techniques
Molecular clouds	< 1%	80	10—20	10 ² —10 ⁶	molecular	Radio and infrared molecular emission and absorption lines
Cold Neutral Medium (CNM)	1—5%	100—300	50—100	20—50	neutral atomic	H I 21 cm line absorption
Warm Neutral Medium (WNM)	10—20%	300—400	6000—10000	0.2—0.5	neutral atomic	H I 21 cm line emission
Warm Ionized Medium (WIM)	20—50%	1000	8000	0.2—0.5	ionized	H α emission and pulsar dispersion
H II regions	< 1%	70	8000	10 ² —10 ⁴	ionized	H α emission and pulsar dispersion
Coronal gas Hot Ionized Medium (HIM)	30—70%	1000—3000	10 ⁶ —10 ⁷	10 ⁻⁴ —10 ⁻²	ionized (metals also highly ionized)	X-ray emission; absorption lines of highly ionized metals, primarily in the ultraviolet

Galaxy clusters



Virgo galaxy cluster

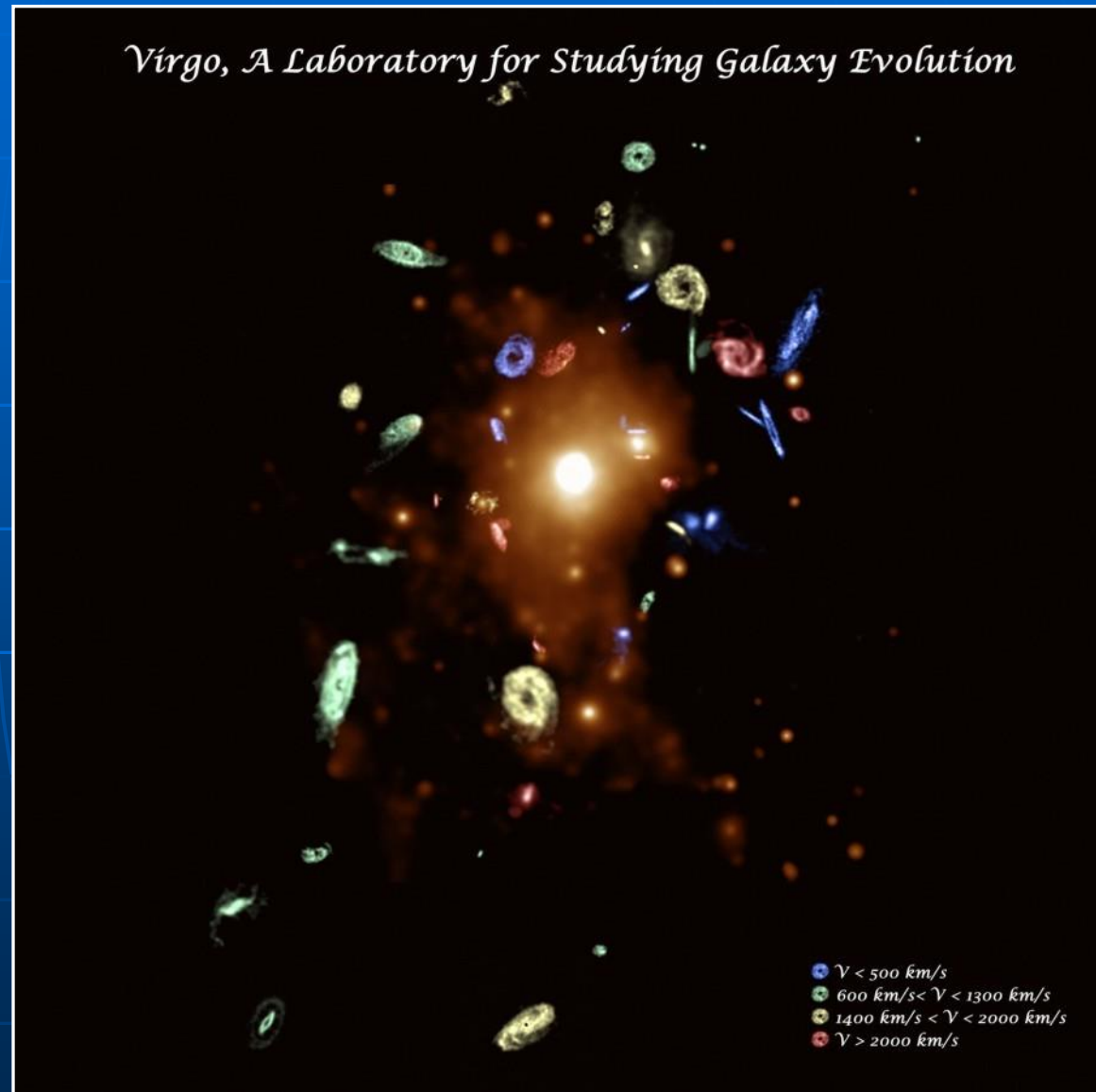
Local galaxy group

←----- ≈ 50 million light years -----→

Virgo cluster (optical)



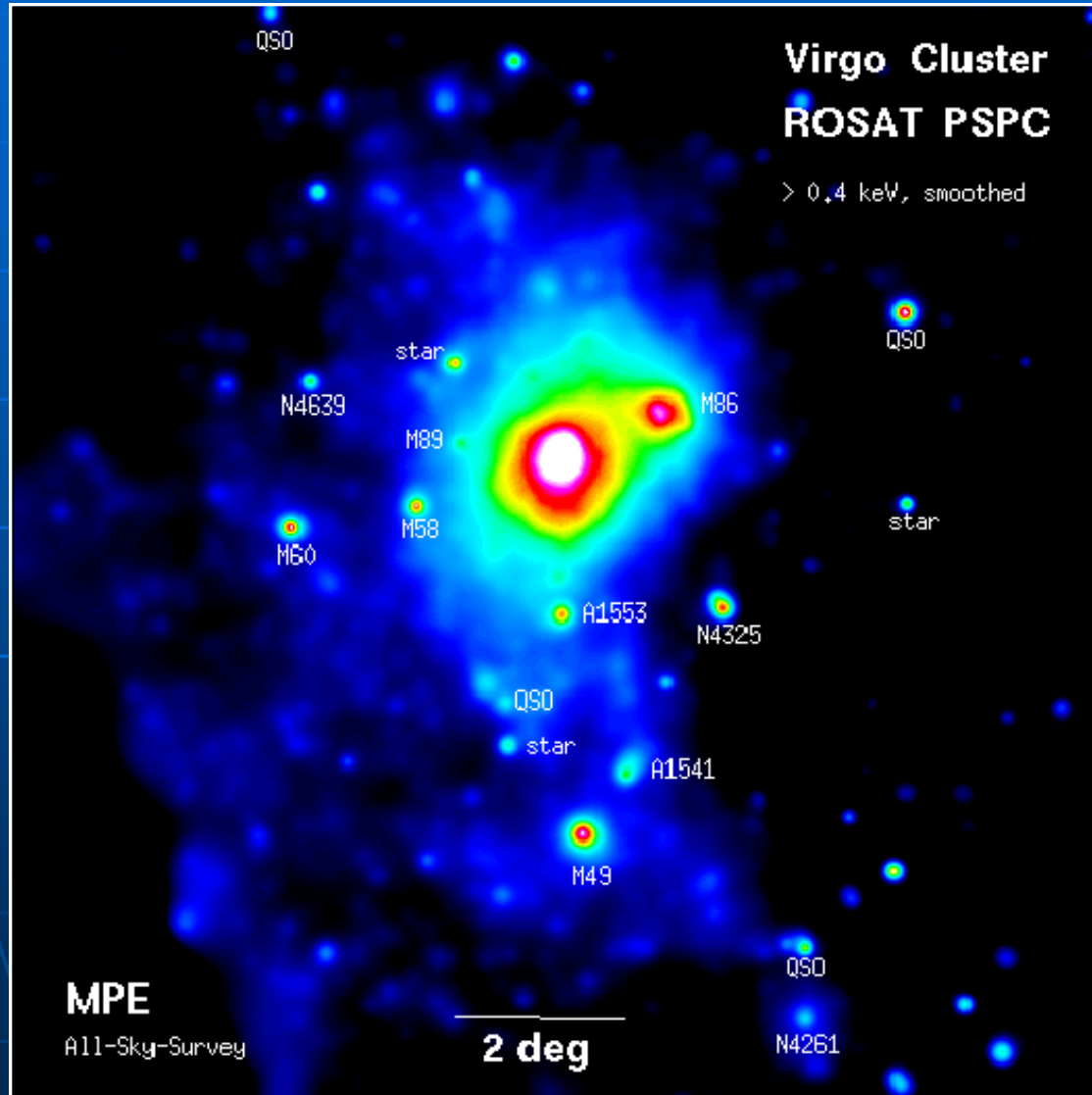
Virgo cluster (neutral hydrogen)



Chung et al. 2009

Virgo cluster (X-rays)

Stabilized
by
dark matter



ROSAT

Fundamental "galactic" questions

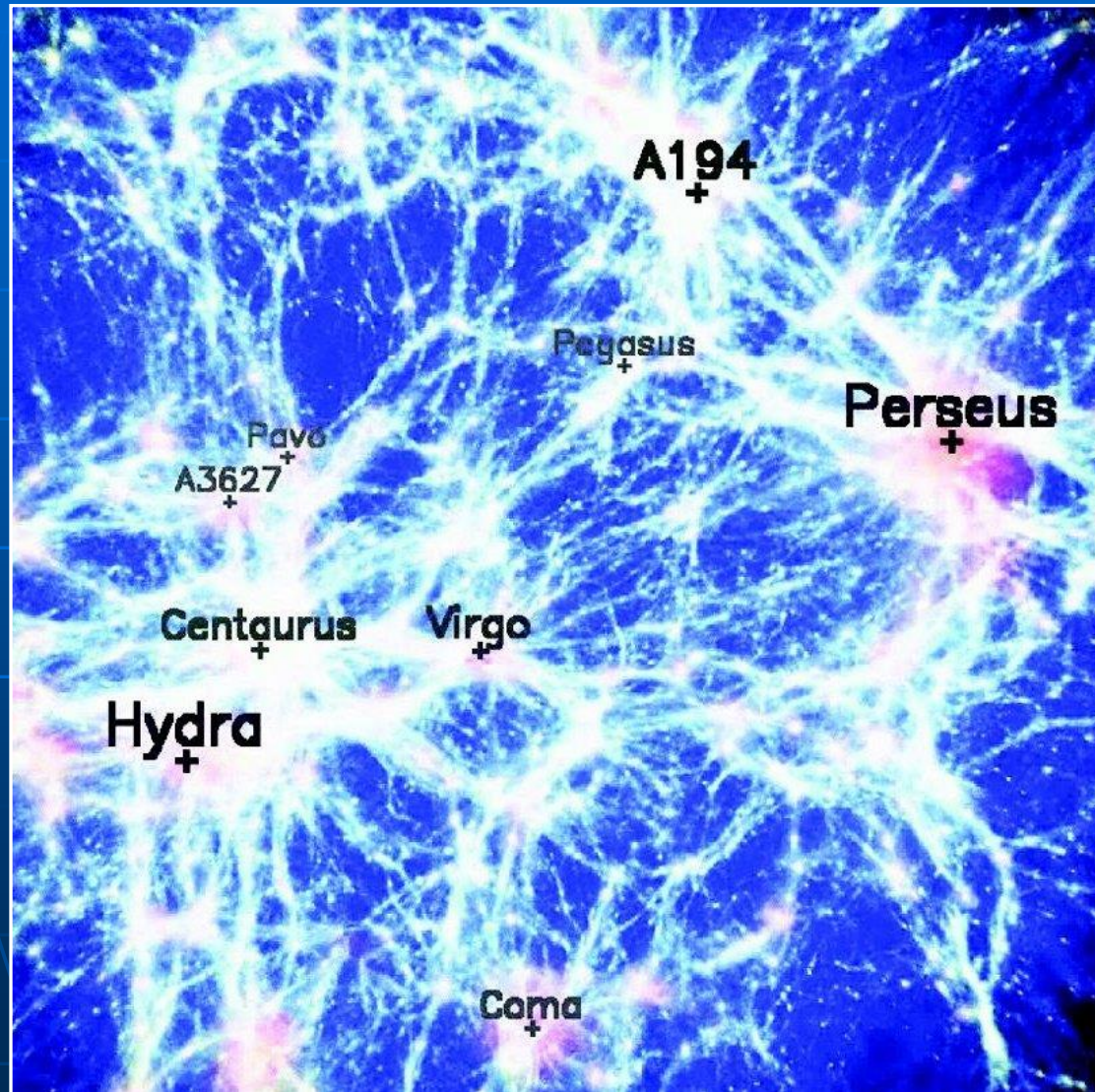
- What is the full extent of galaxies ?
- How are spiral arms formed ?
- What is dark matter ?
- How are magnetic fields formed and what is their role in galaxies ? (see Lectures 4 - 6)
- When and how were galaxies formed ?
- What is dark energy ?

*When and how
were galaxies formed ?*

Distribution of galaxies in the nearby Universe

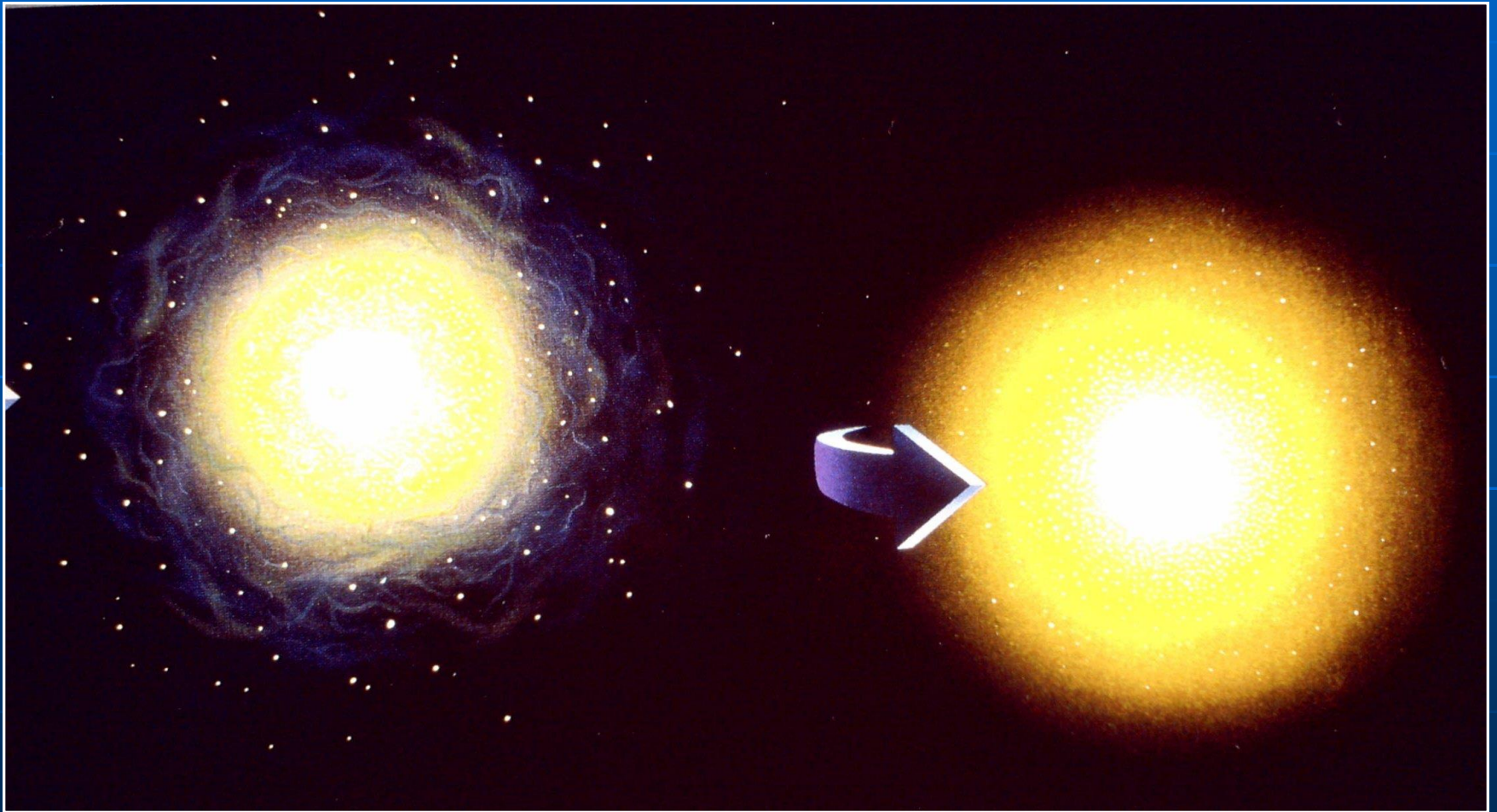


Structure formation in the early Universe

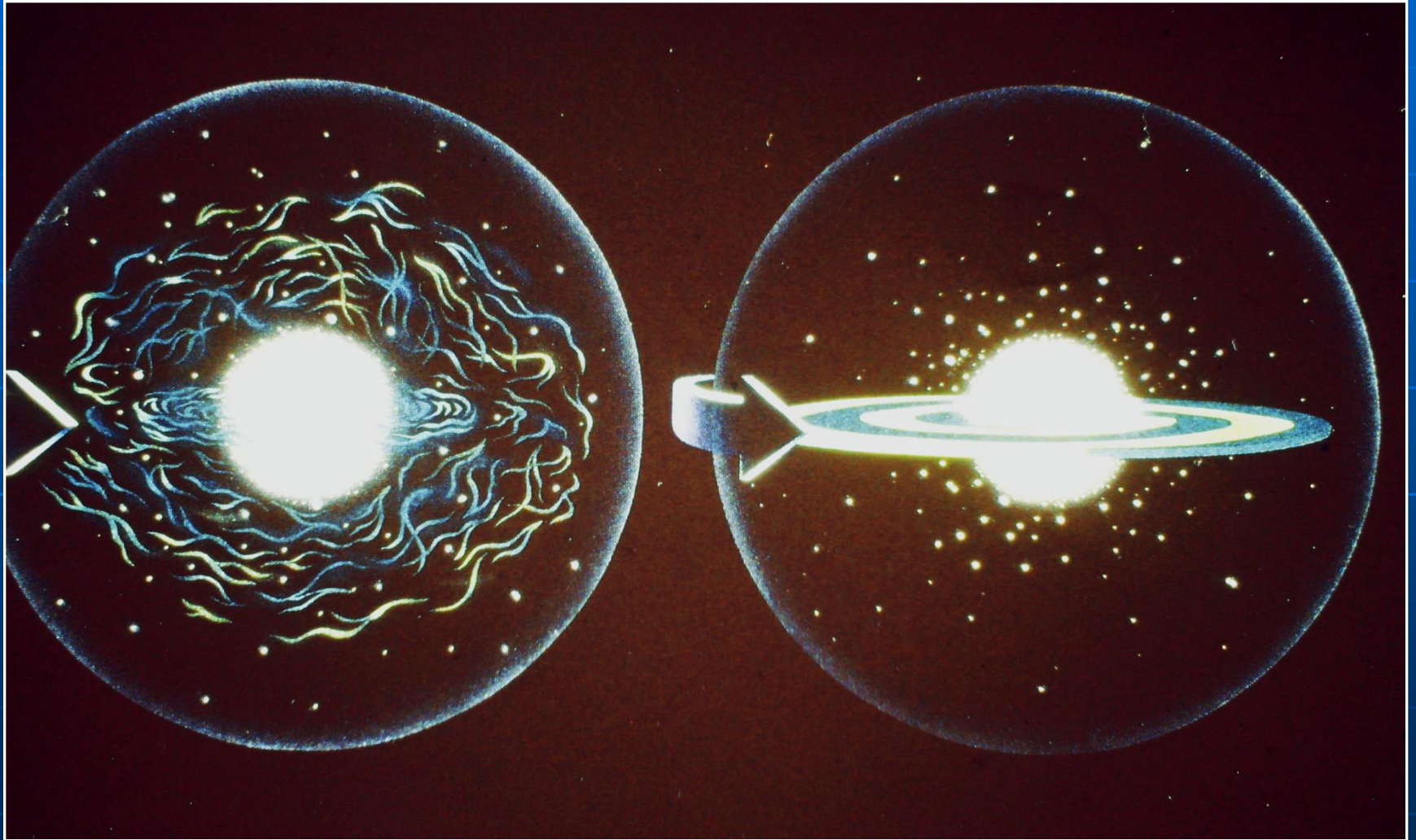


Klaus Dolag

Formation of elliptical galaxies: The classical picture



Formation of spiral galaxies: The classical picture

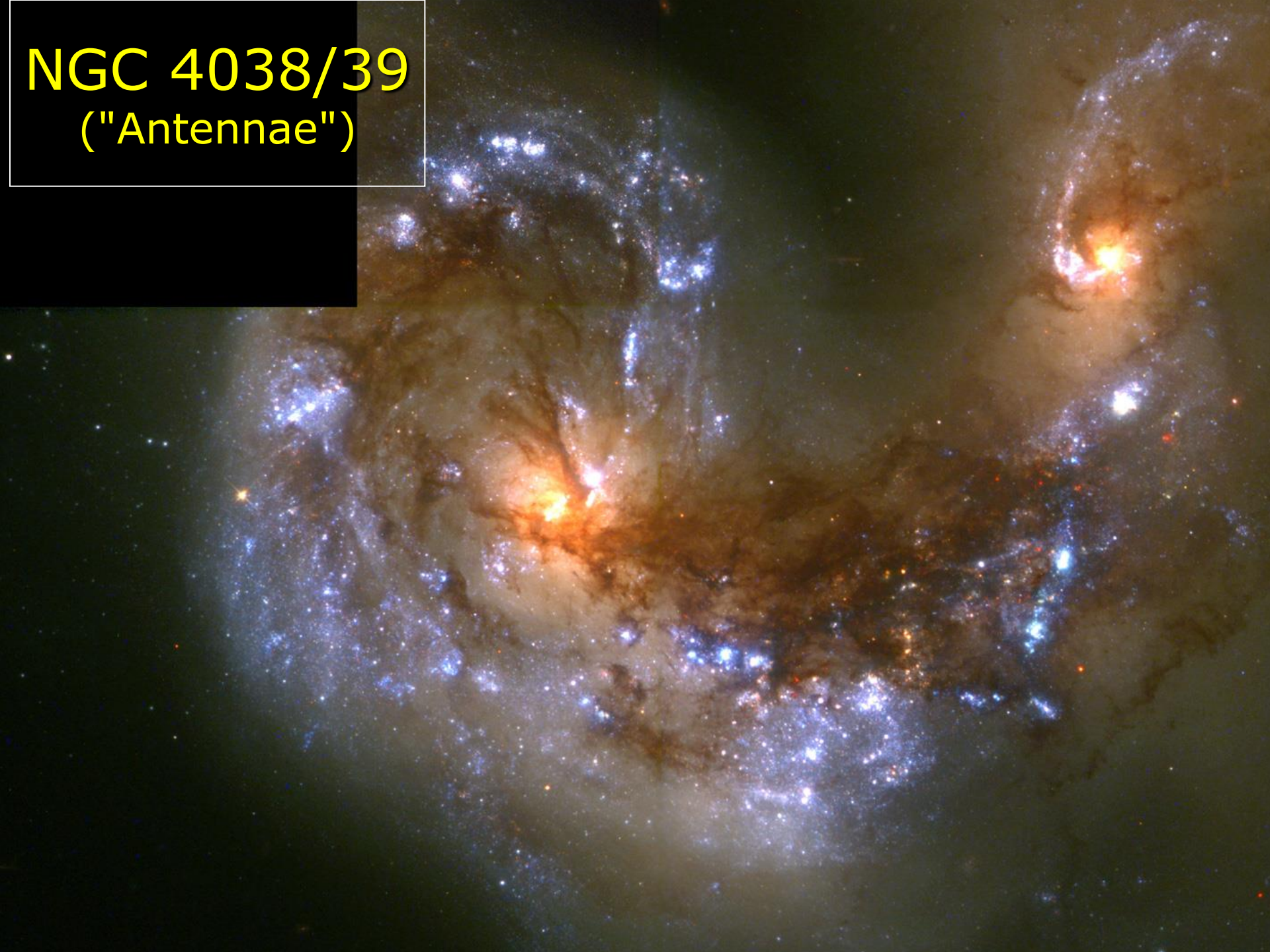


*New view:
Interactions
play a major role
for galaxy evolution*

NGC 4676
("Mice galaxy")



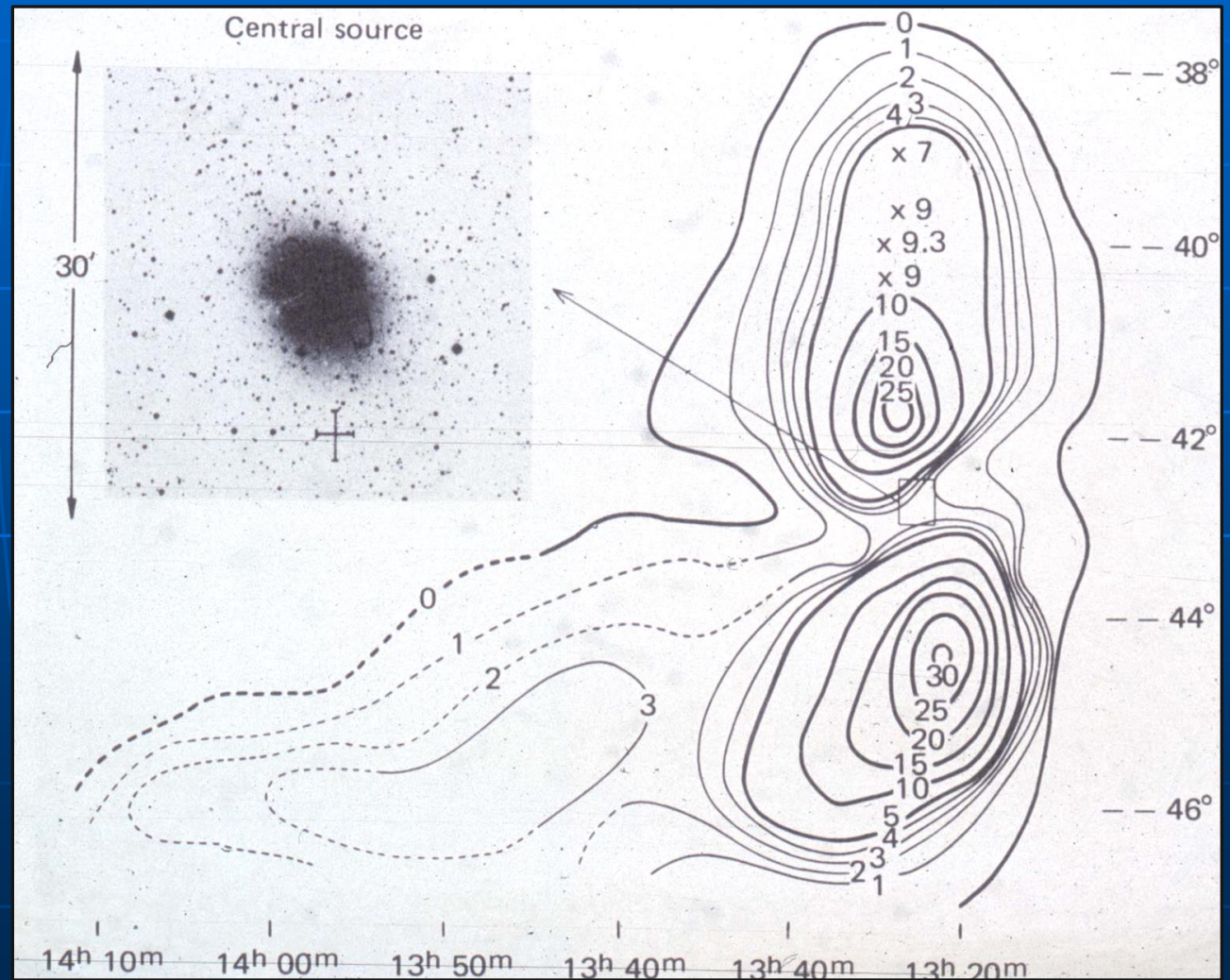
NGC 4038/39
("Antennae")



Radio galaxies

Radio galaxy Centaurus A

Parkes 20 cm



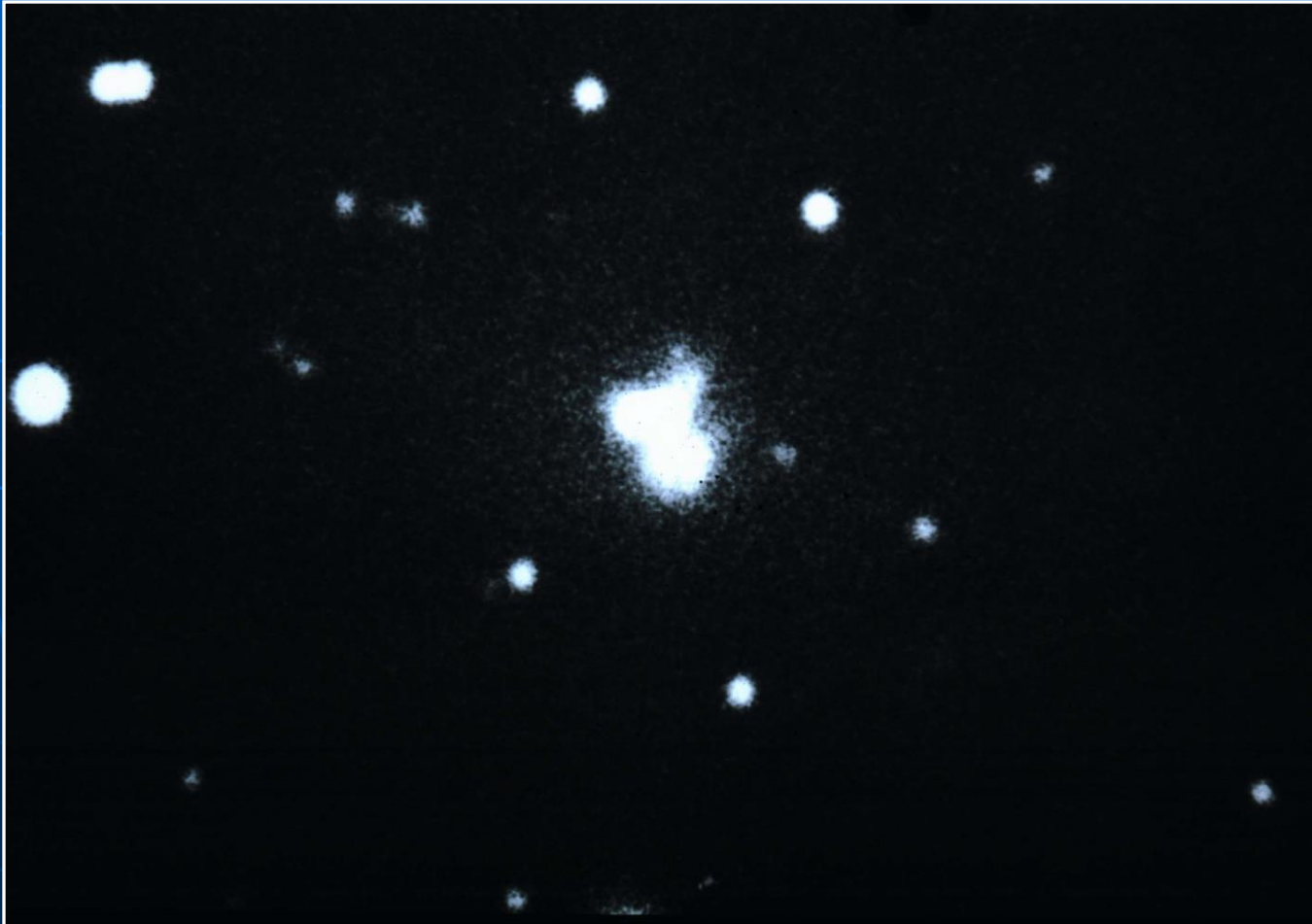
Cen A

Optical
+
radio
+
X-rays



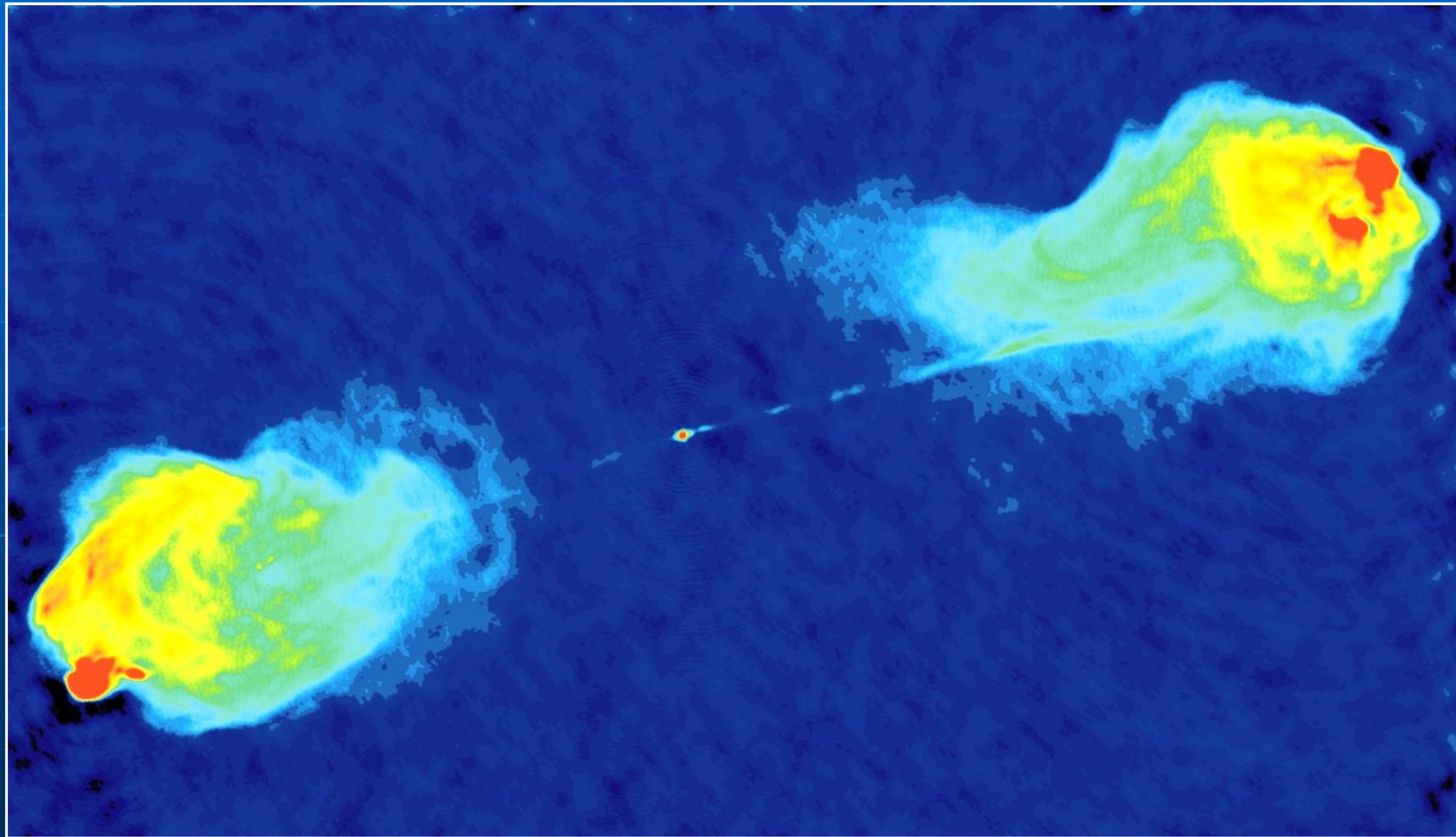
NASA / NRAO

Radio galaxy
Cygnus A
optical



Cyg A

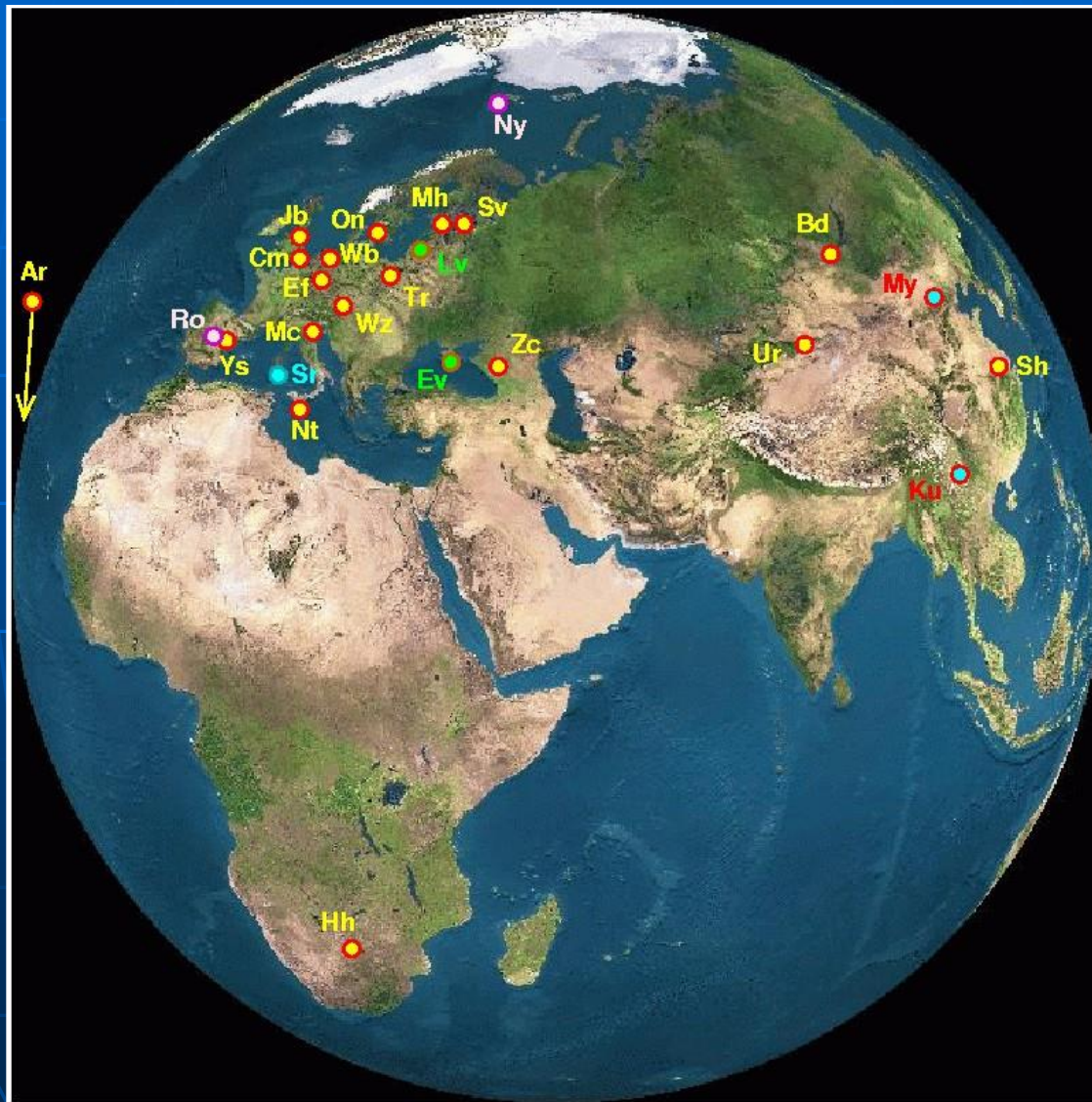
VLA 6 cm



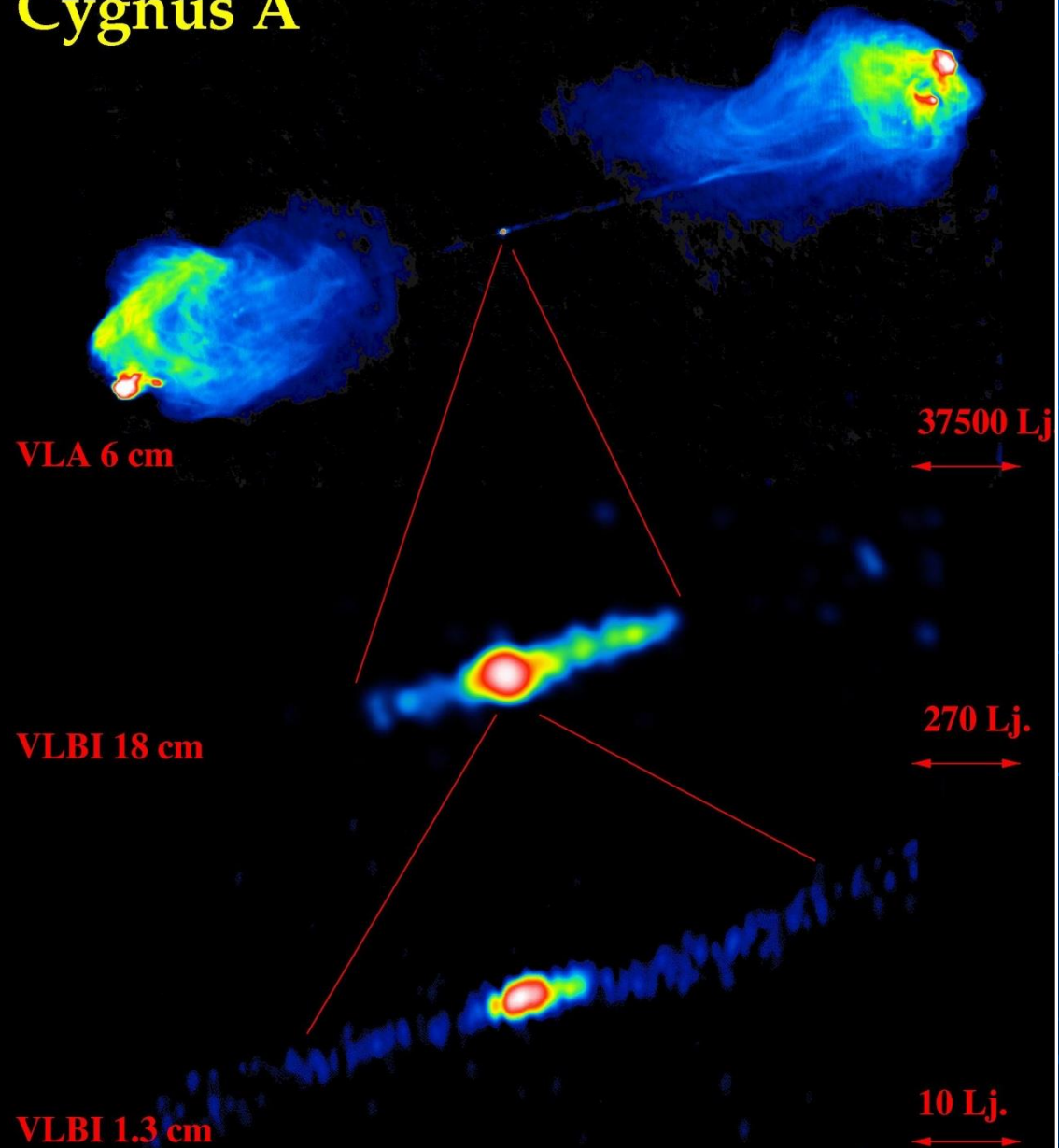
R. Perley, NRAO

*Jets:
Supersonic streams
of gas and magnetic fields*

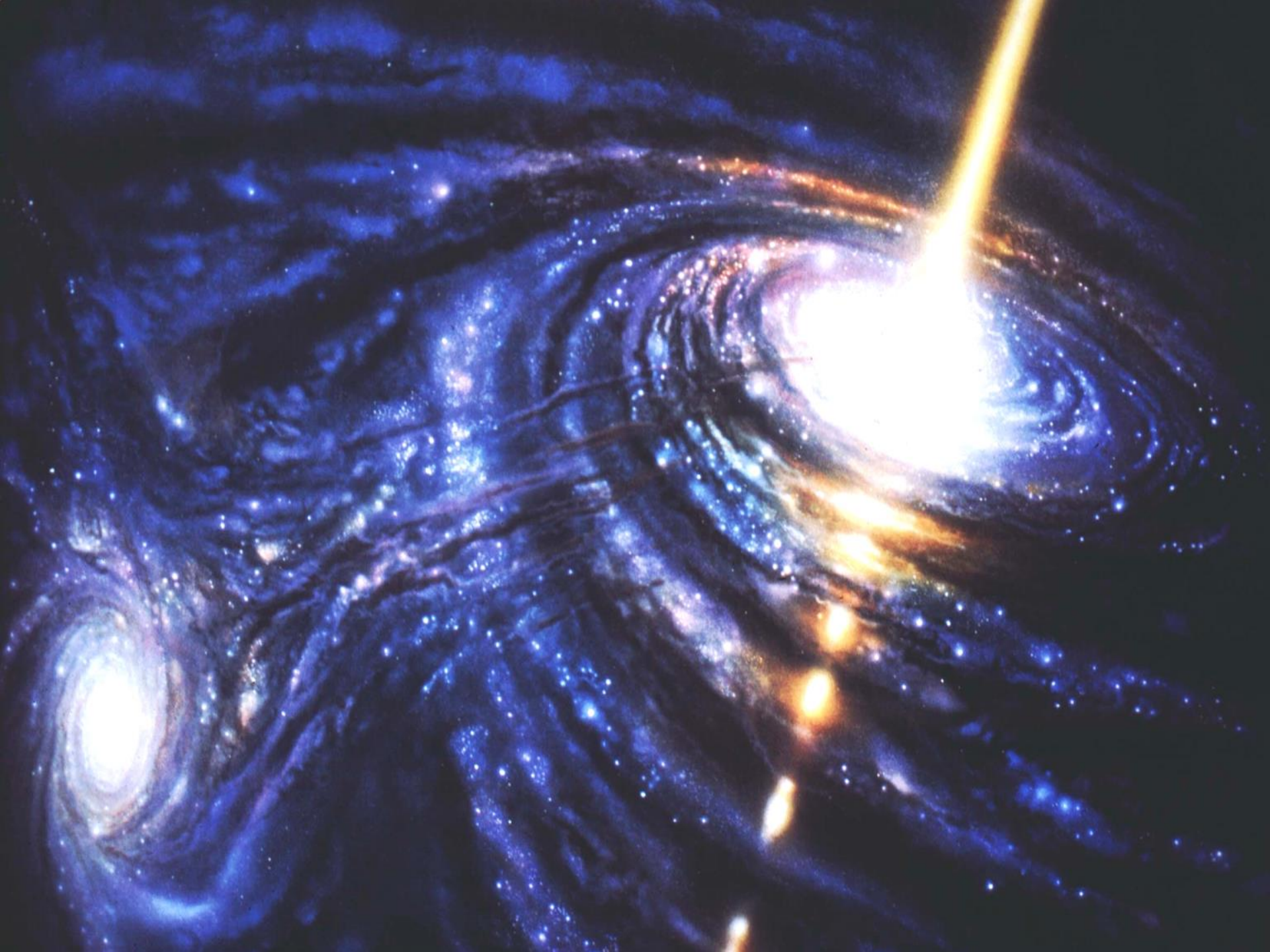
Very Large Baseline Interferometry (VLBI)



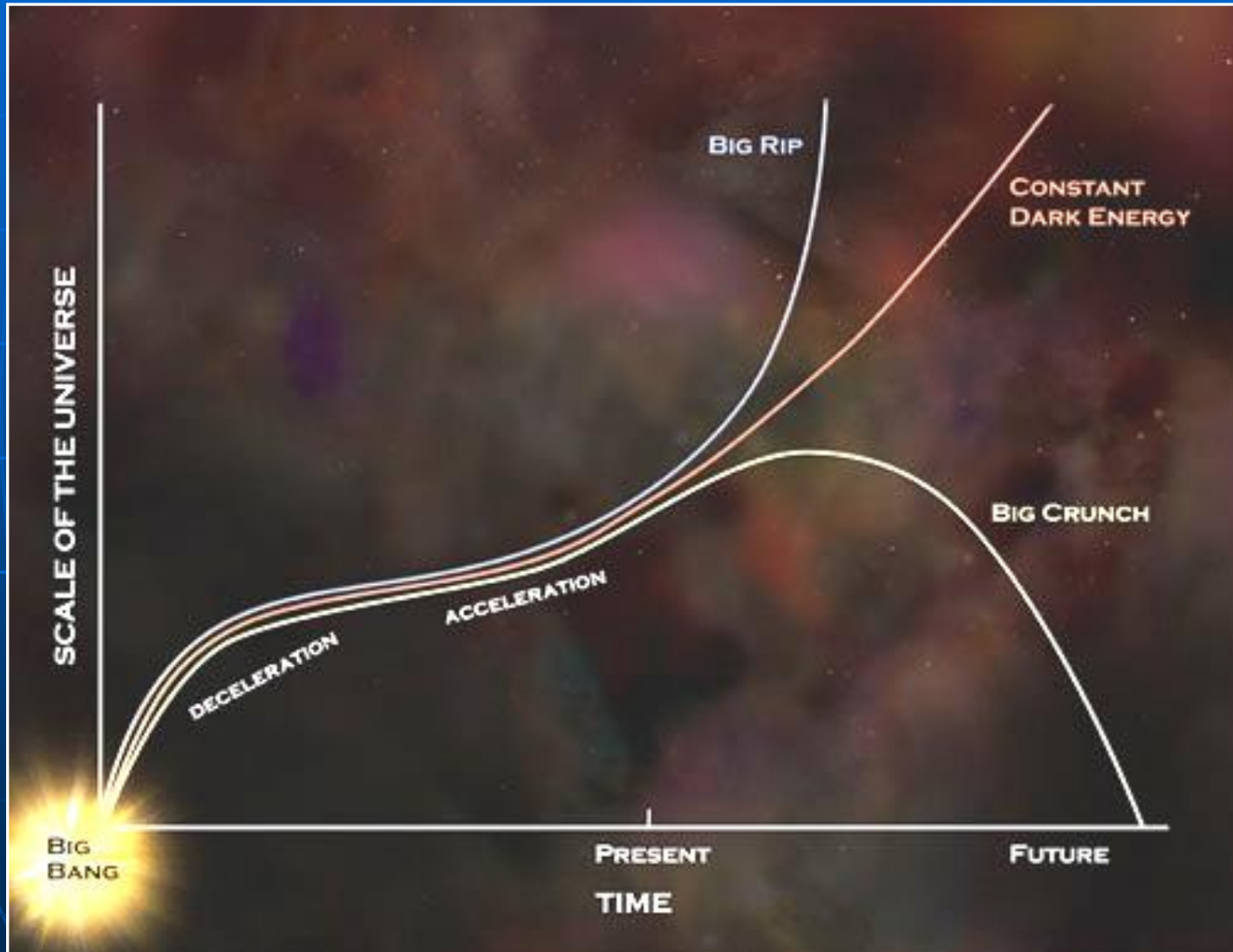
Cygnus A



*Quasars:
Magnetic whirlpools*



Cosmic expansion is accelerating !



What is Dark Energy ?

Key project for future telescopes: Measuring redshifts of distant galaxies (optical or HI line emissions)

1.4 MHz (200m)	14 MHz (20m)	140 MHz (2m)
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1.4 GHz (21cm)

Cosmological Redshift -
Hydrogen line is seen at:

