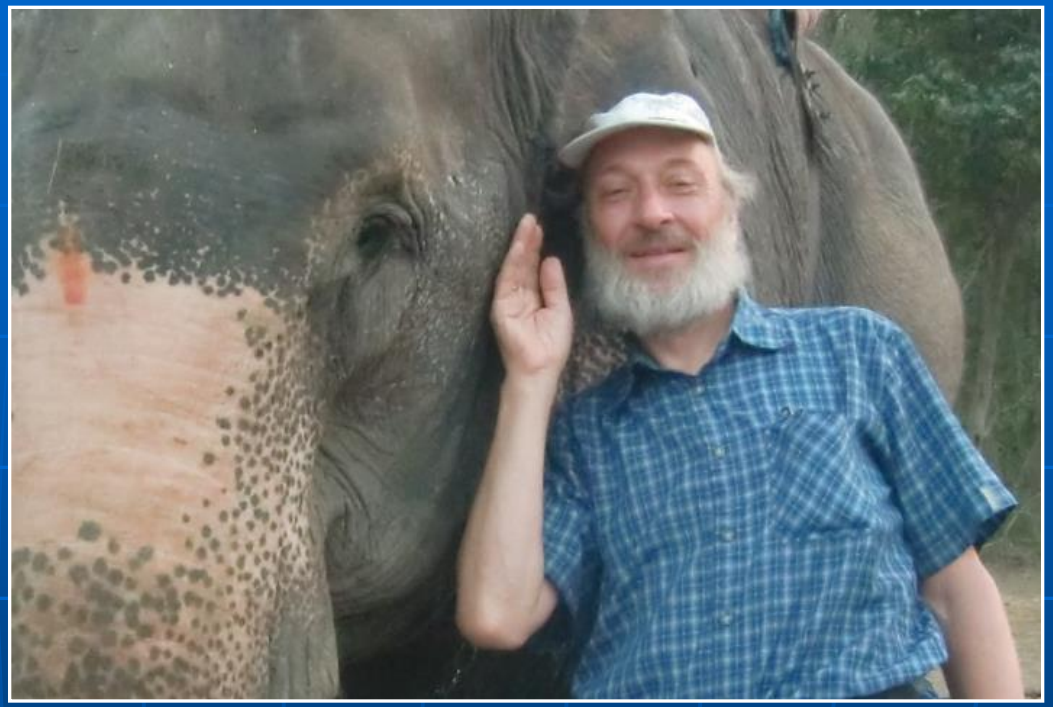
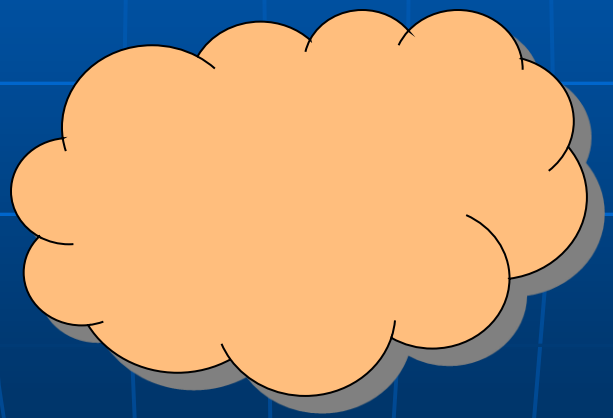

# Cosmic Magnetic Fields

"The elephant in the astrophysical room"

"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)

# *Barred galaxies*

# M 83

ESO

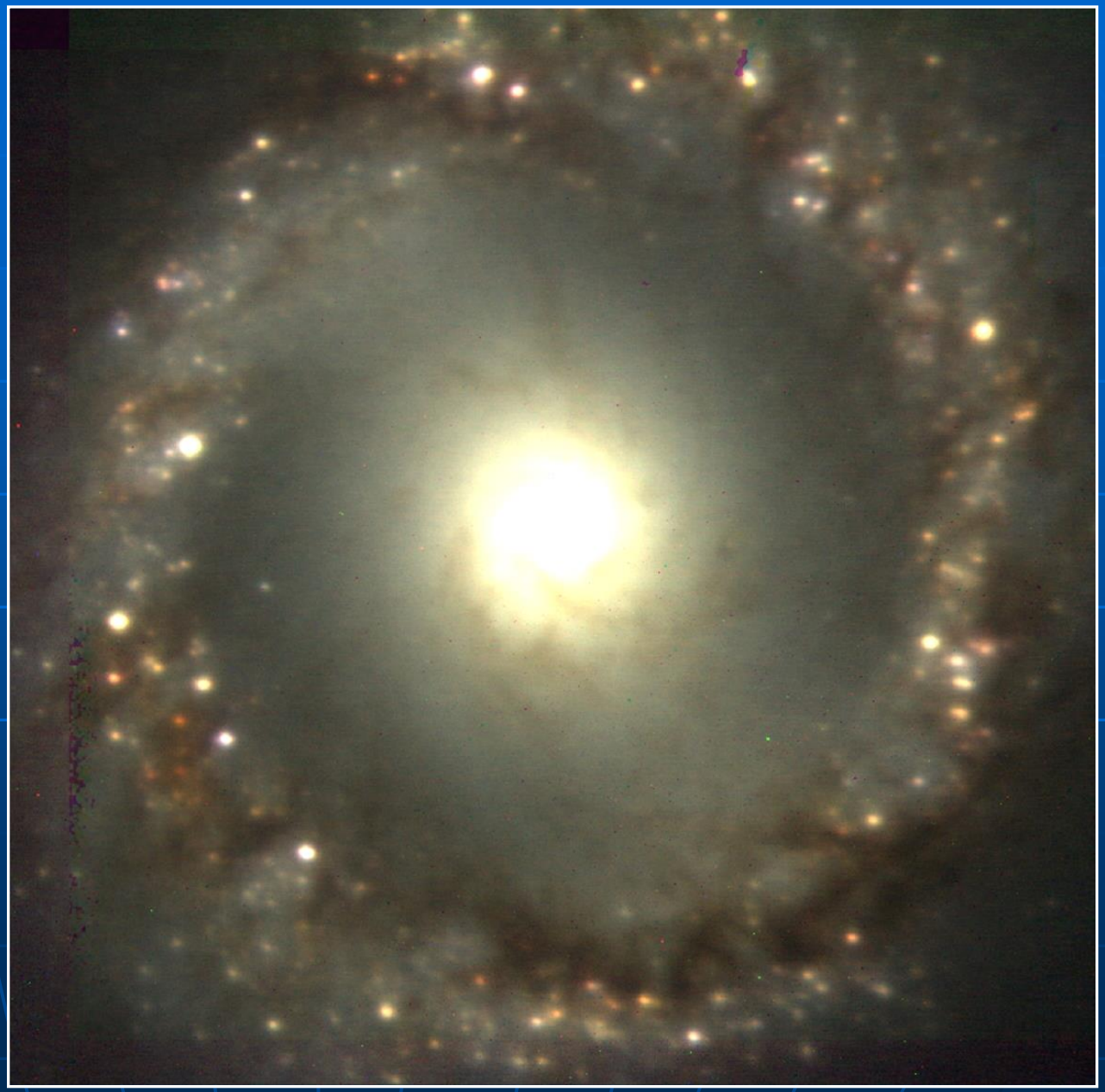
# NGC 1097

Gendler/ESO

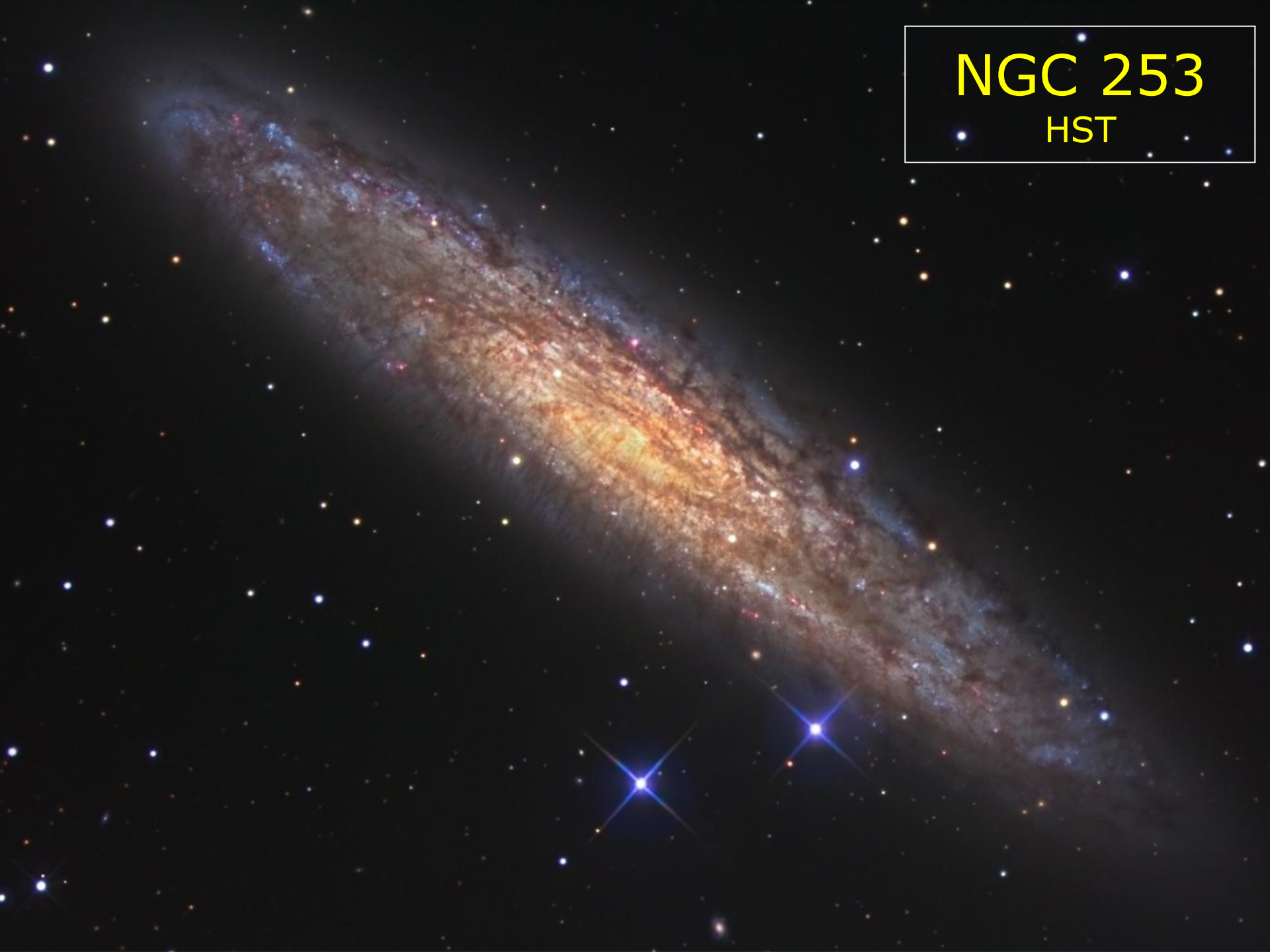
# NGC 1097

## Central region

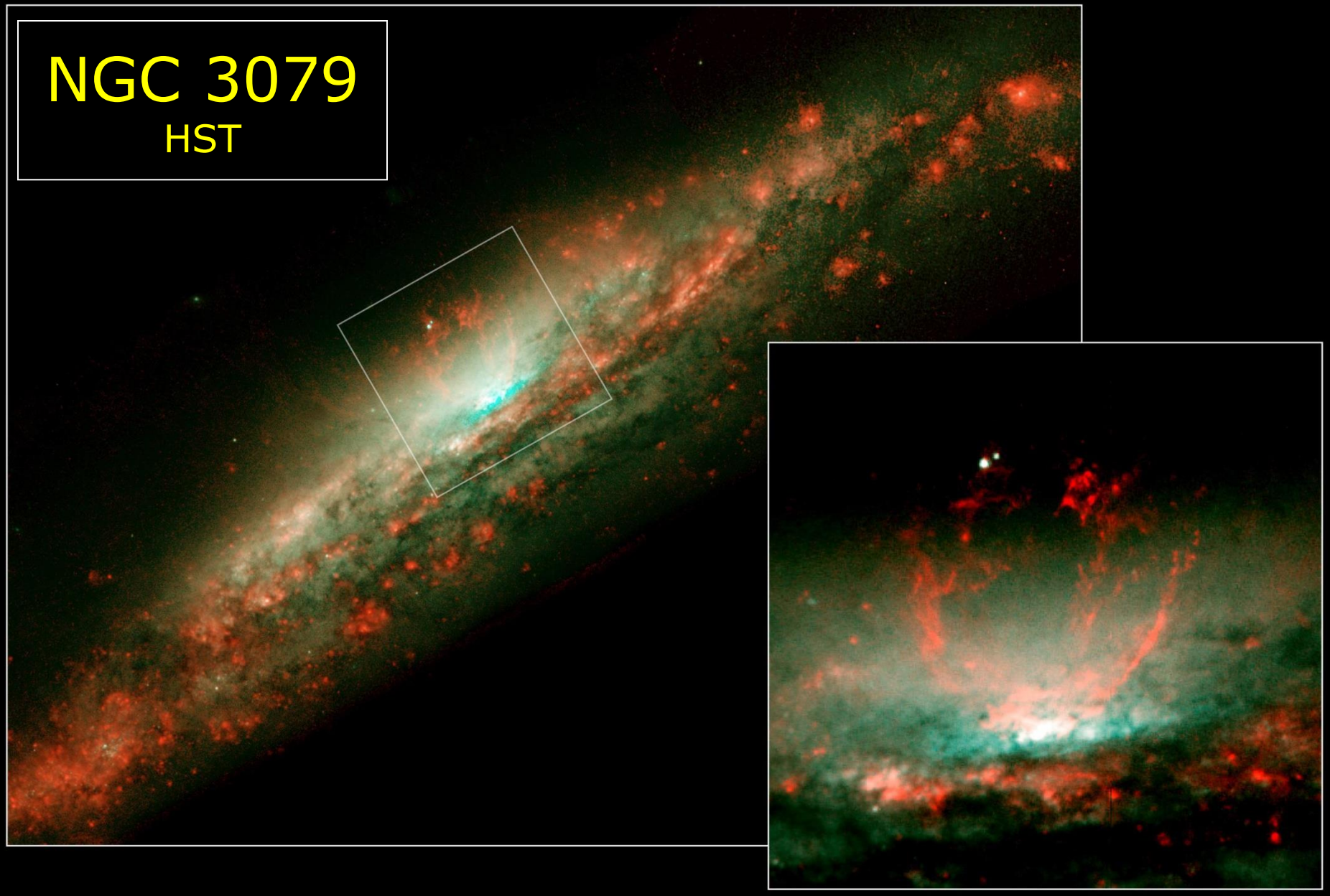
HST



# *Edge-on galaxies*


NGC 253
HST


NGC 4631
Misti Mountain

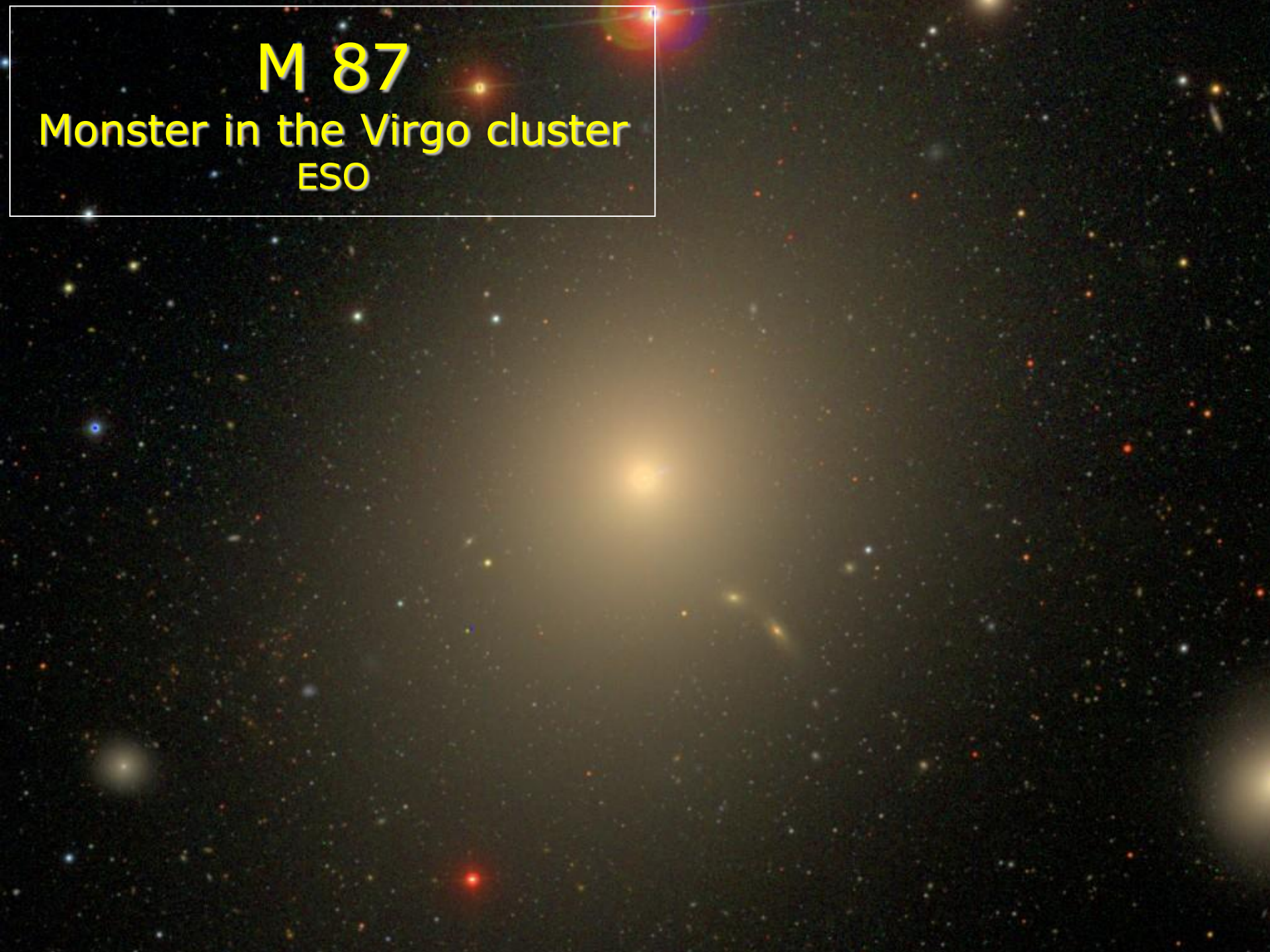



**Galaxy NGC 3079**
**Hubble Space Telescope** • WFPC2

NASA and G. Cecil (University of North Carolina) • STScI-PRC01-28

# *Elliptical galaxies*

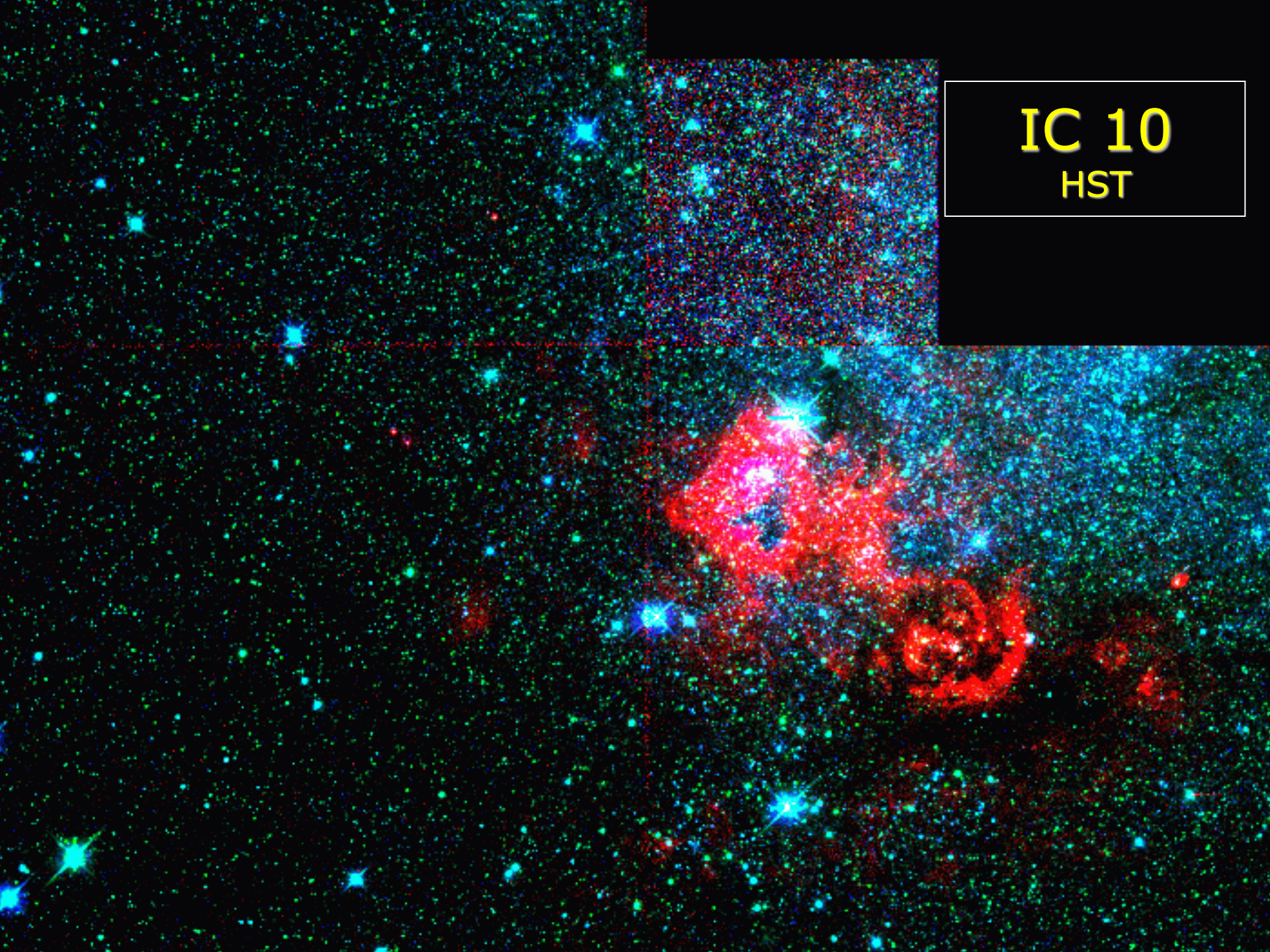

M 104
Sombrero galaxy
ESO


M 87
Monster in the Virgo cluster
ESO


Jet of M 87

# *Irregular galaxies*

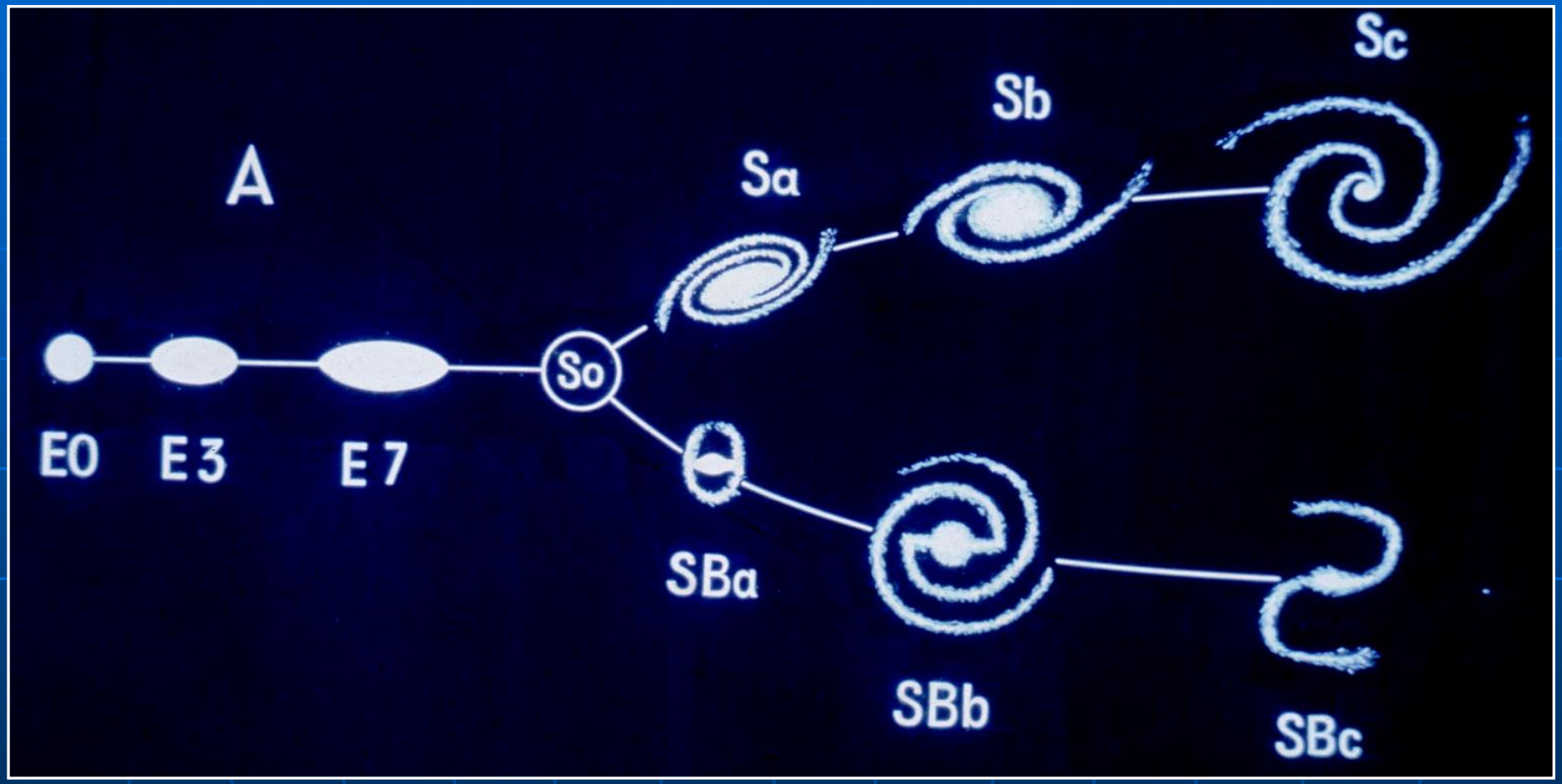

Large Magellanic Cloud


IC 10
HST

# *Dwarf galaxies*


NGC 6822
(local group)

# Hubble classification

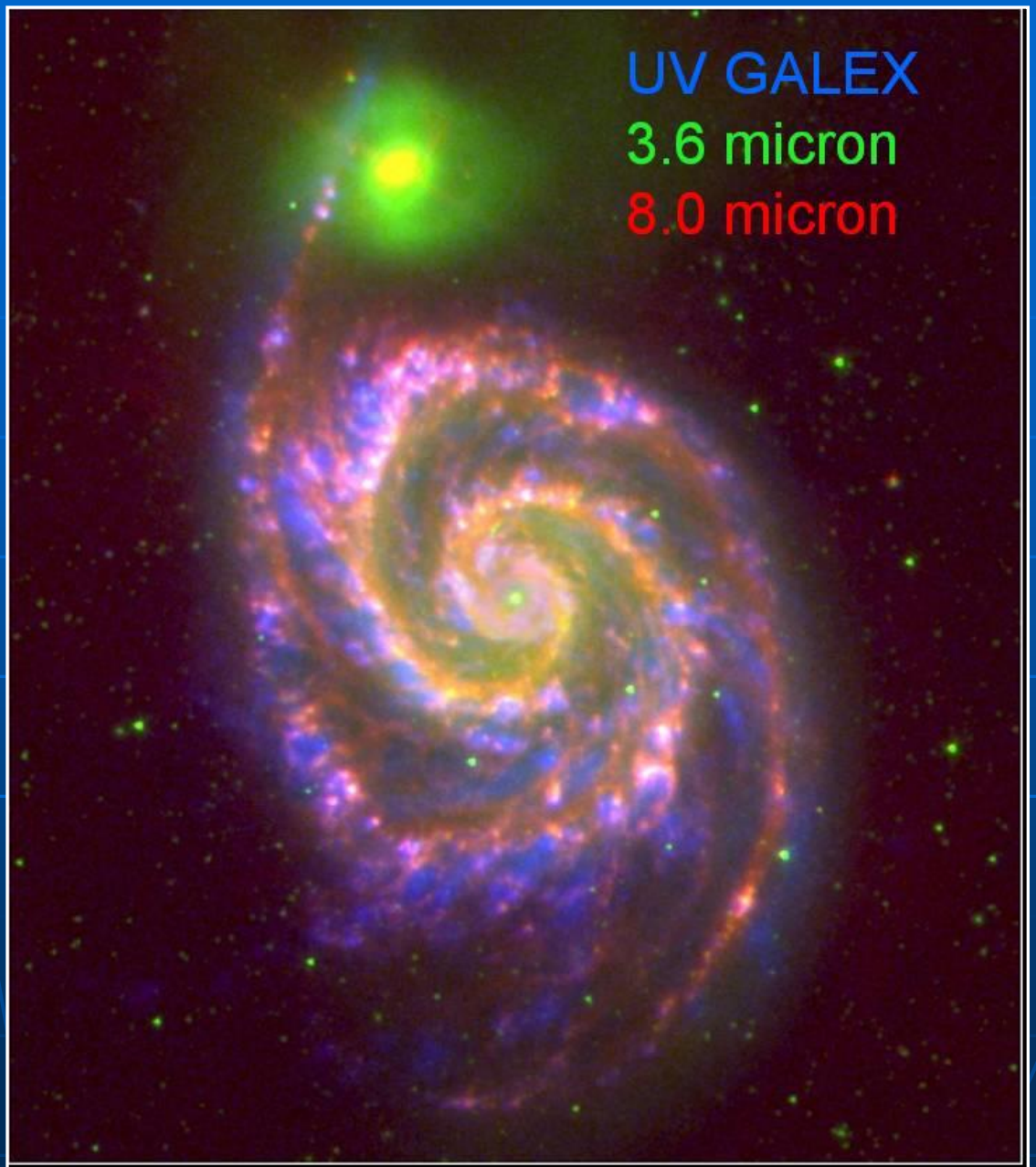



Gas fraction → → →

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

# M 51

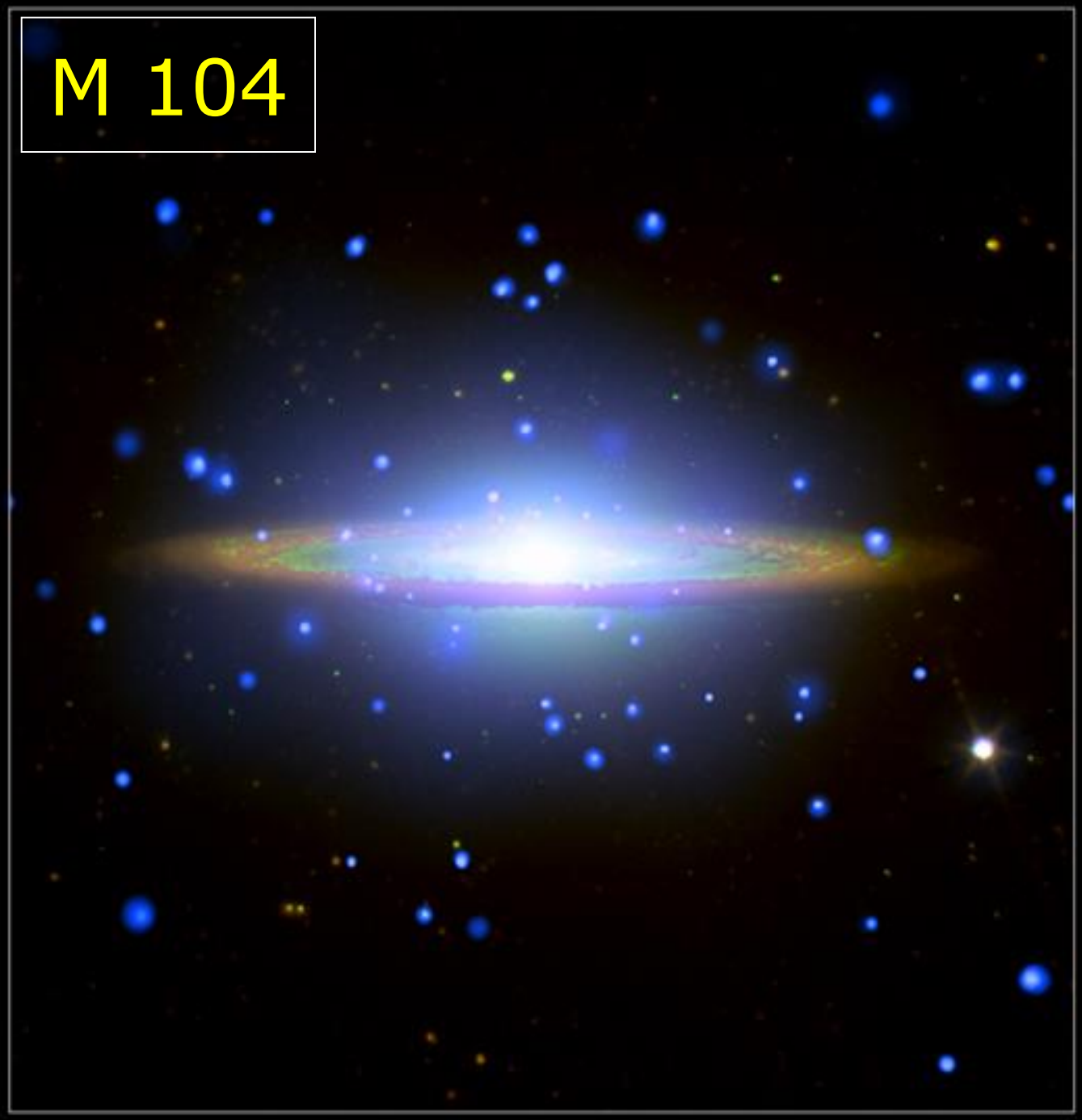
UV + infrared
GALEX + SPITZER




Courtesy of SINGS Team

# NGC 1097

IR + optical
SPITZER


M 104


Chandra X-ray

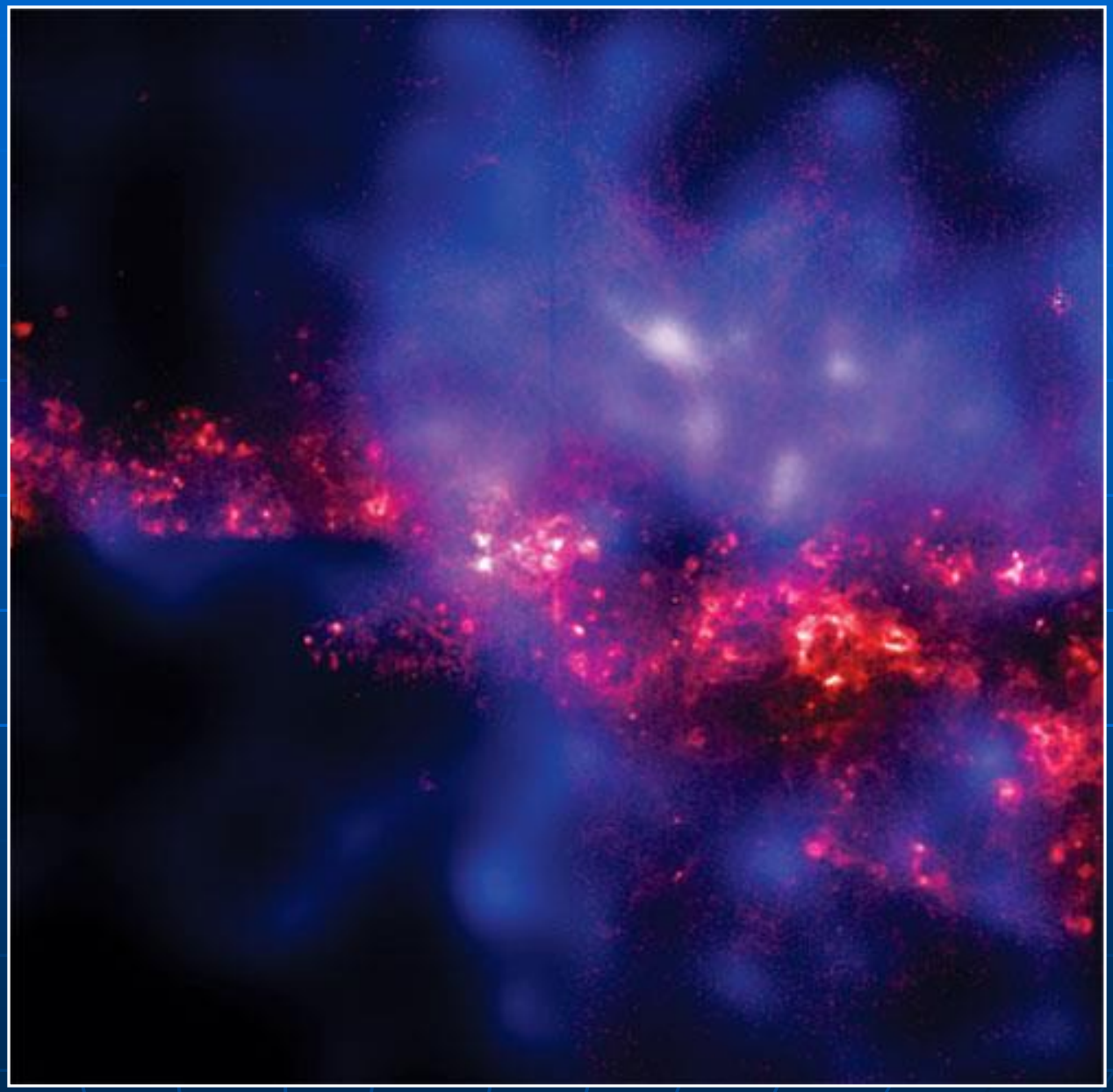

Hubble Optical


Spitzer Infrared

# NGC 4631

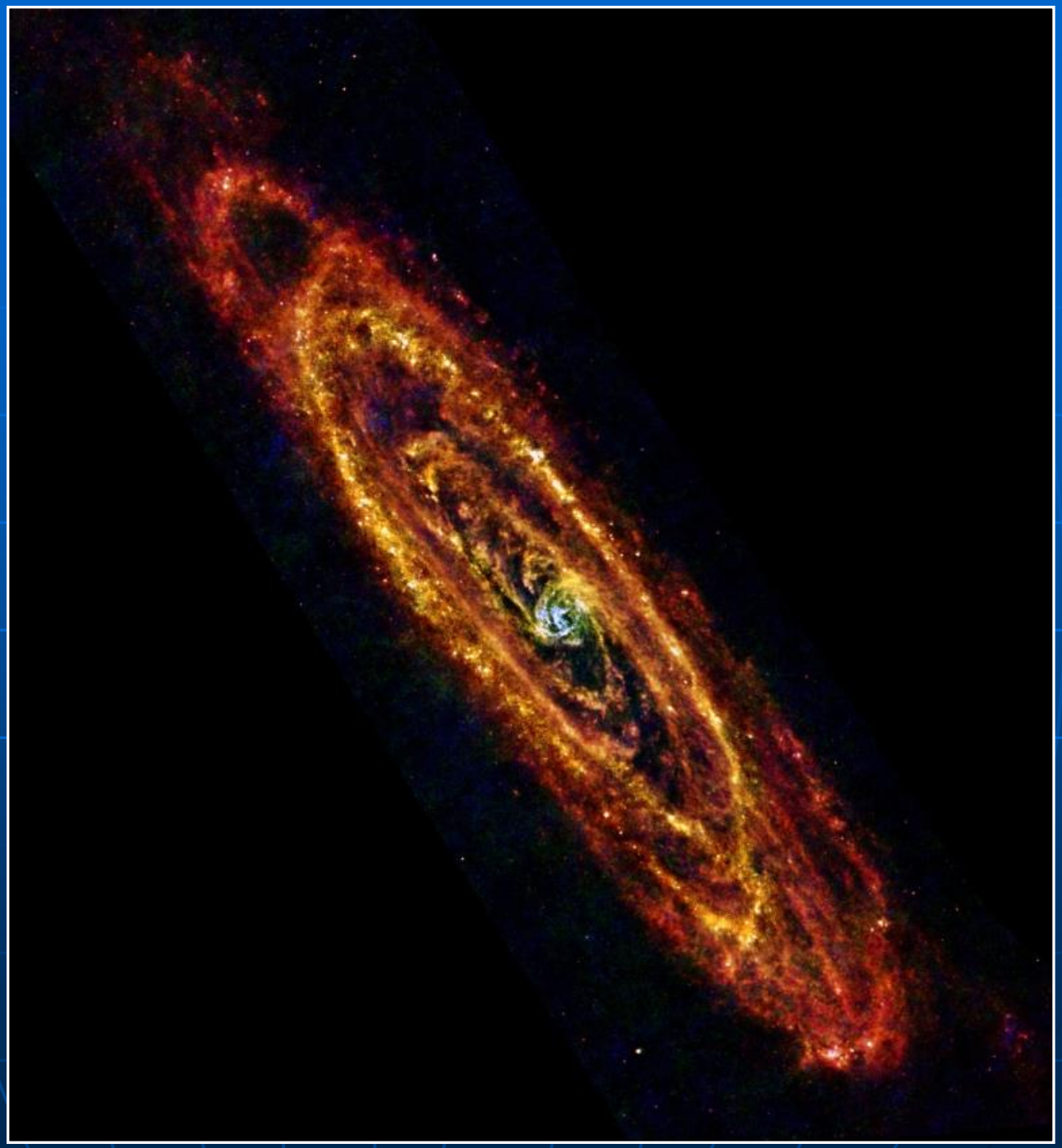
X-rays

CHANDRA

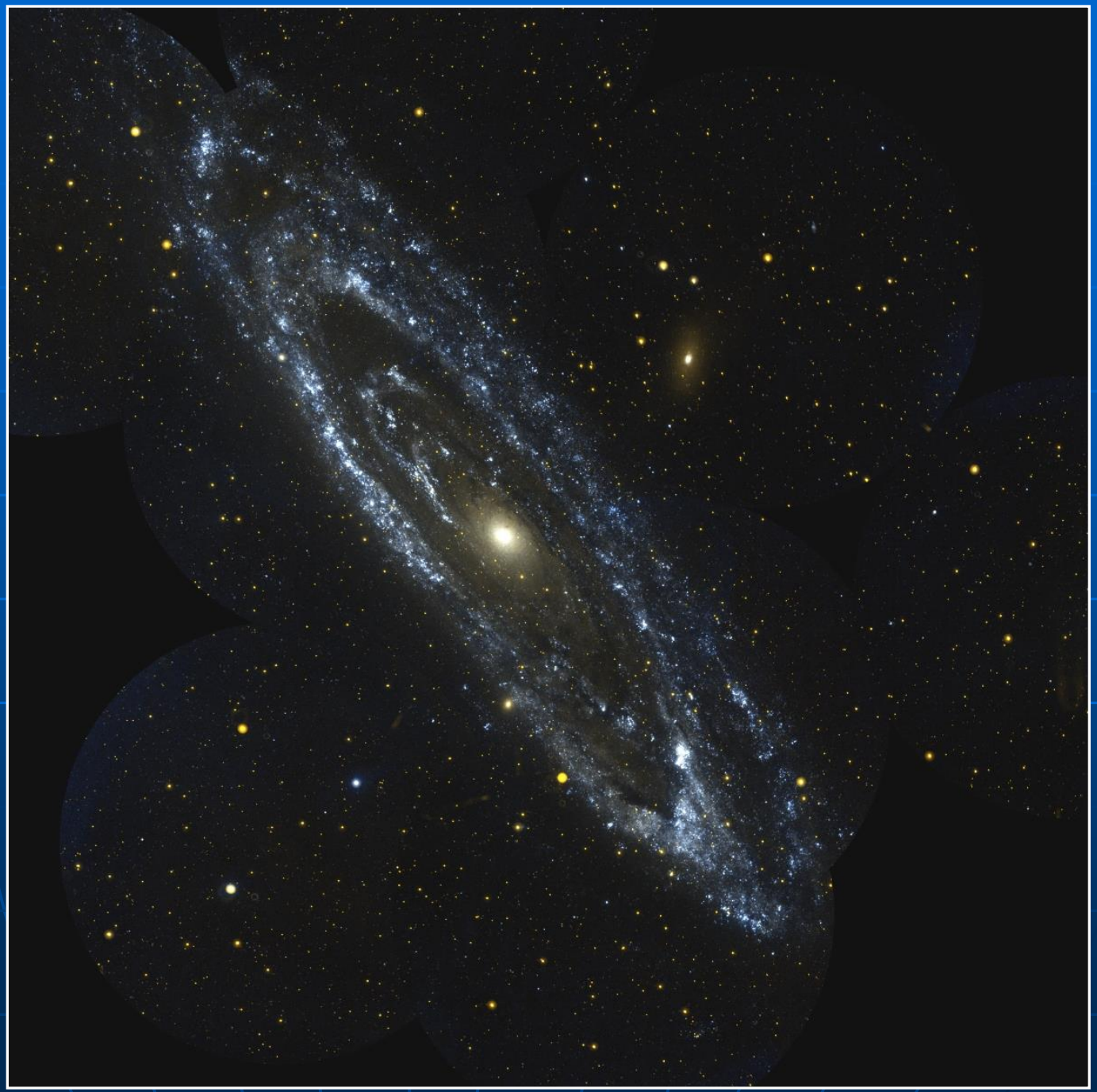


# M 31

Infrared (dust)
HERSCHEL

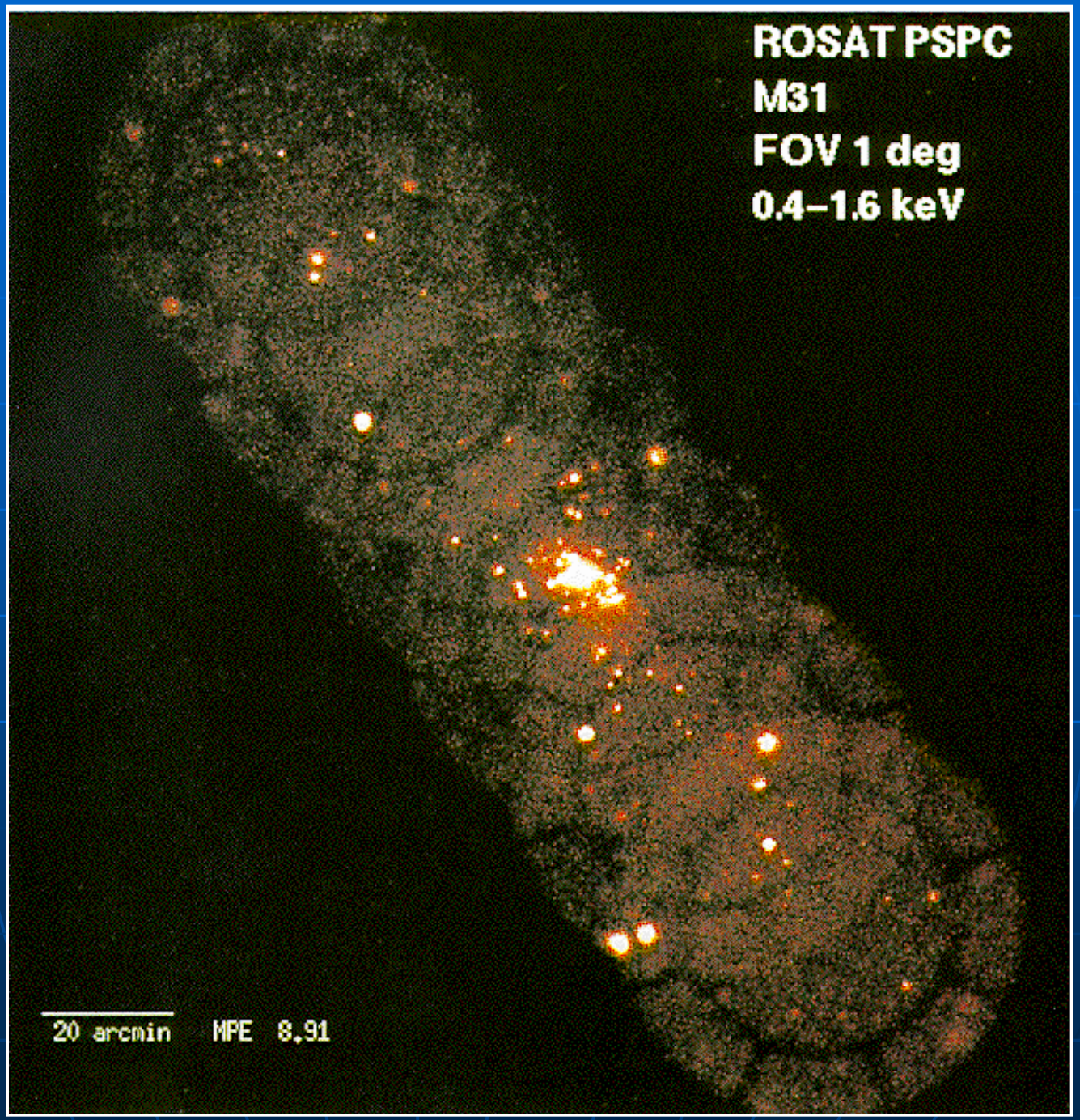


# M 31
UV
GALEX



# M 31

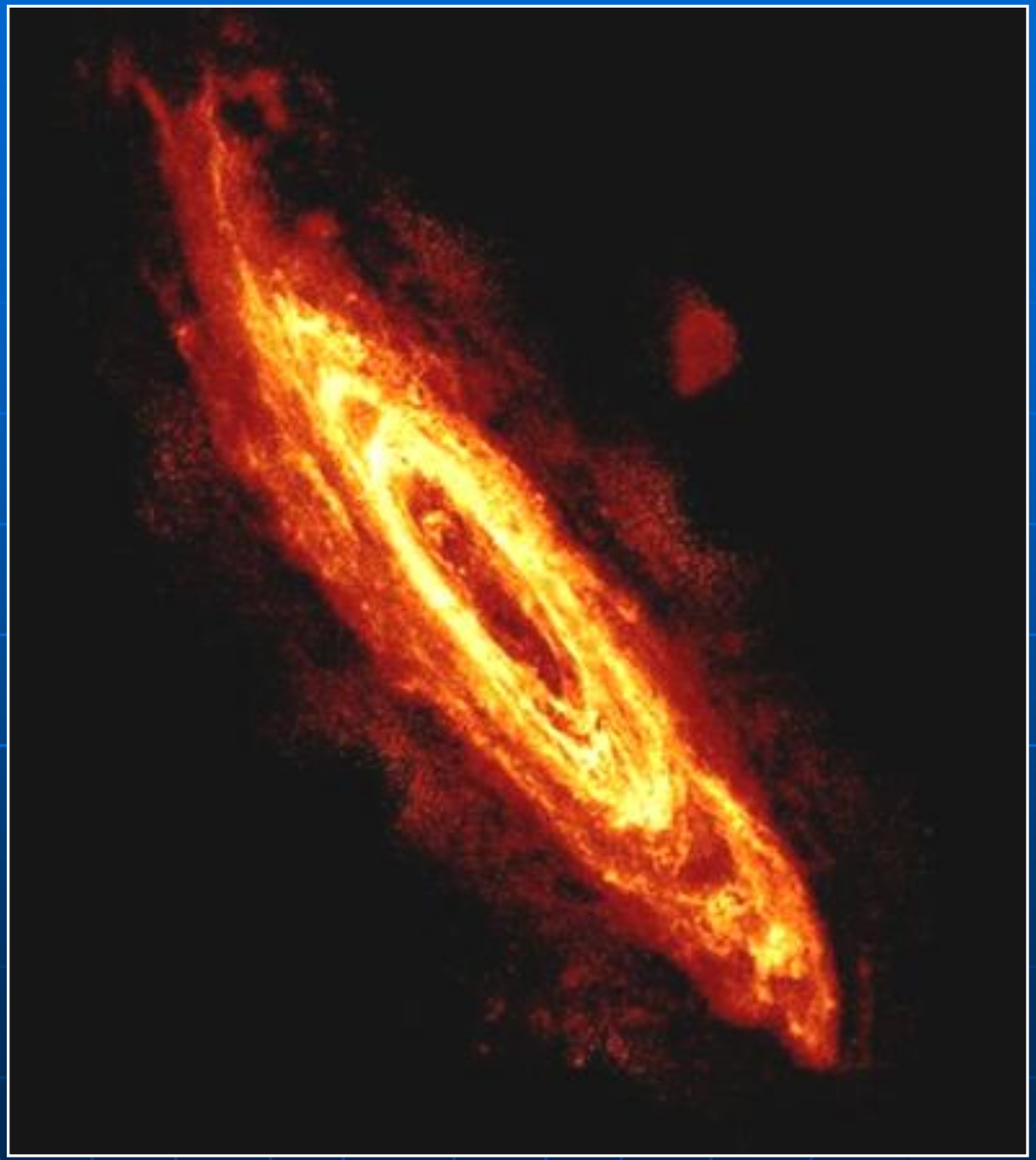
X-rays
ROSAT



# M 31

Neutral hydrogen line emission (HI) 21.1cm

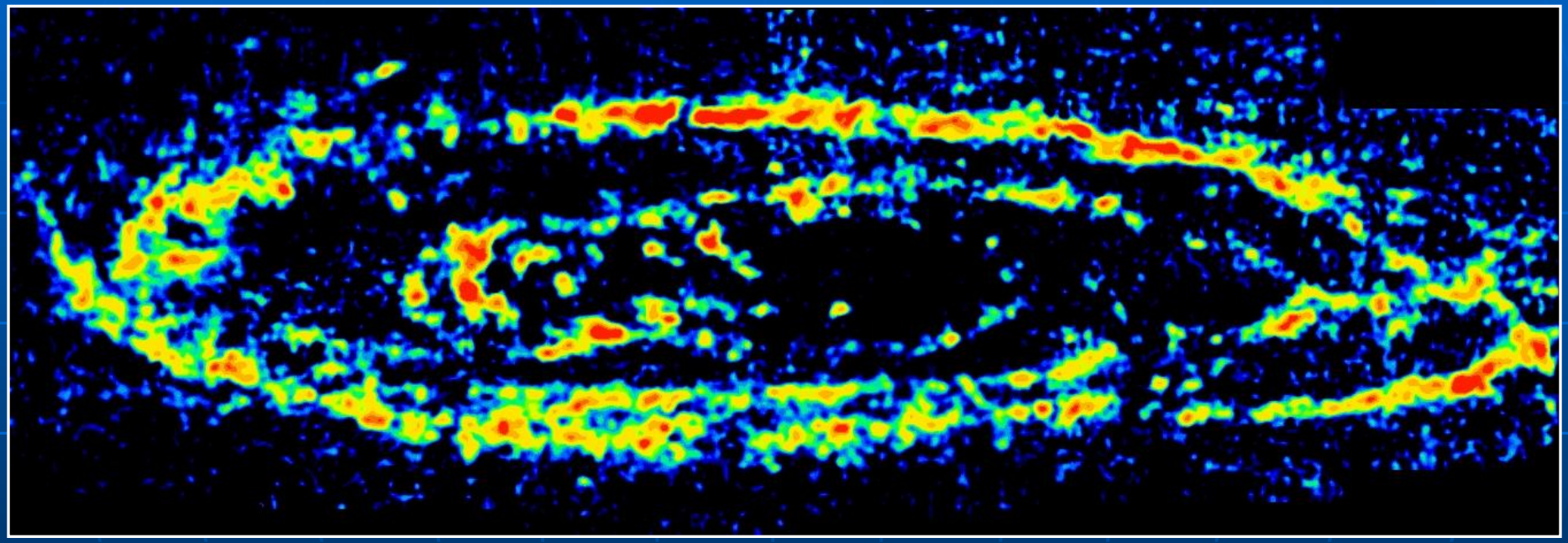
Westerbork



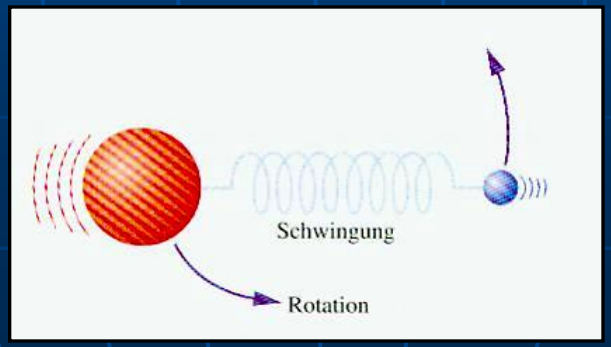
Braun et al. 2005

# M 31

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



Nieten et al. 1999

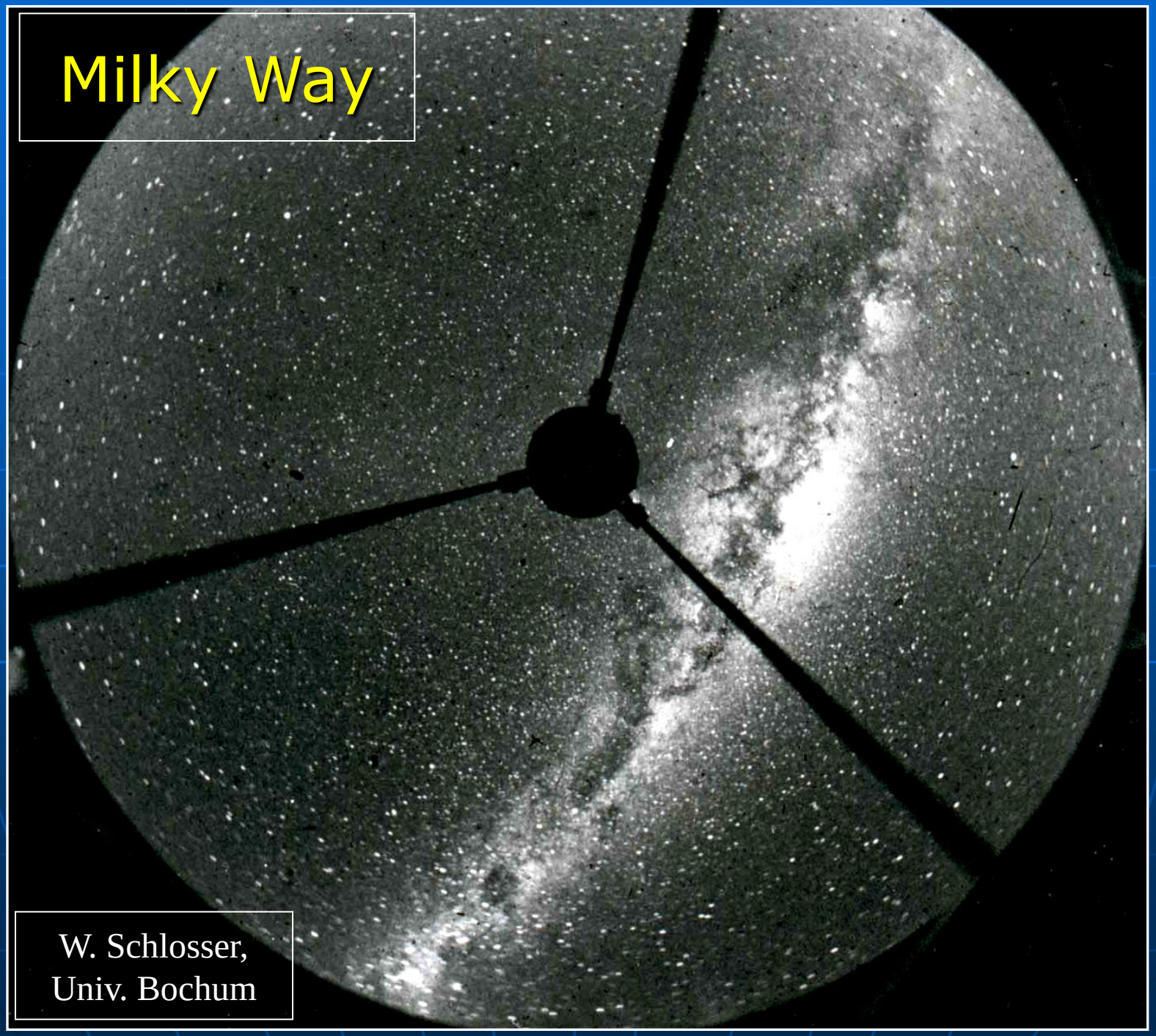


# Basic properties of galaxies

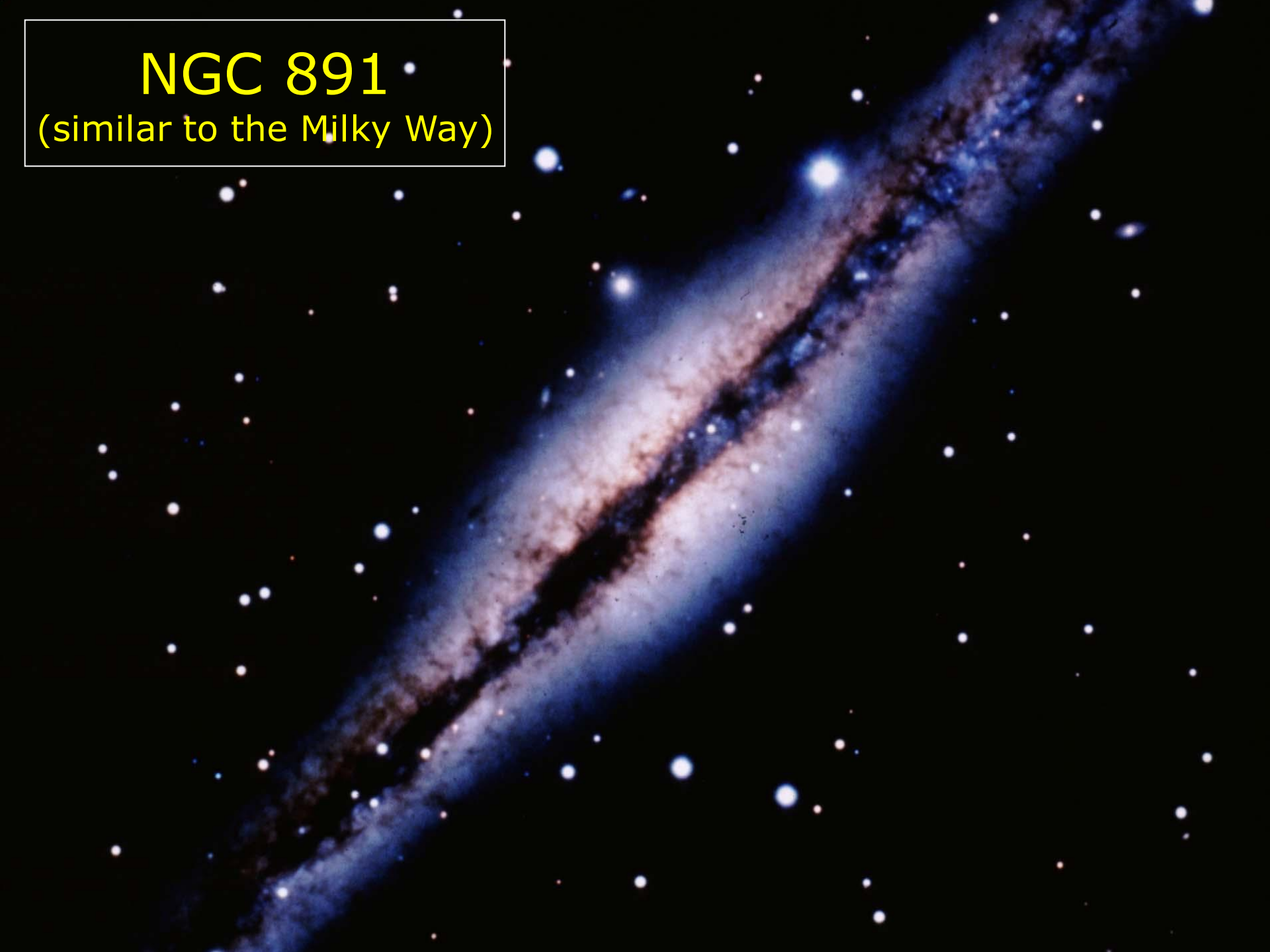
- Typical size: $10^4$ – $10^7$ light years
- Number of stars: $10^7$ – $10^{11}$
- Mass: $10^8$ – $10^{12}$ solar masses
- Gas mass: $10^6$ – $10^7$ solar masses
- Dust mass: $10^5$ – $10^6$ solar masses
- Rotation velocity: 100 – 300 km/s
- Rotation period: $10^8$ – $10^9$ years
- Age: 13 $10^9$ years

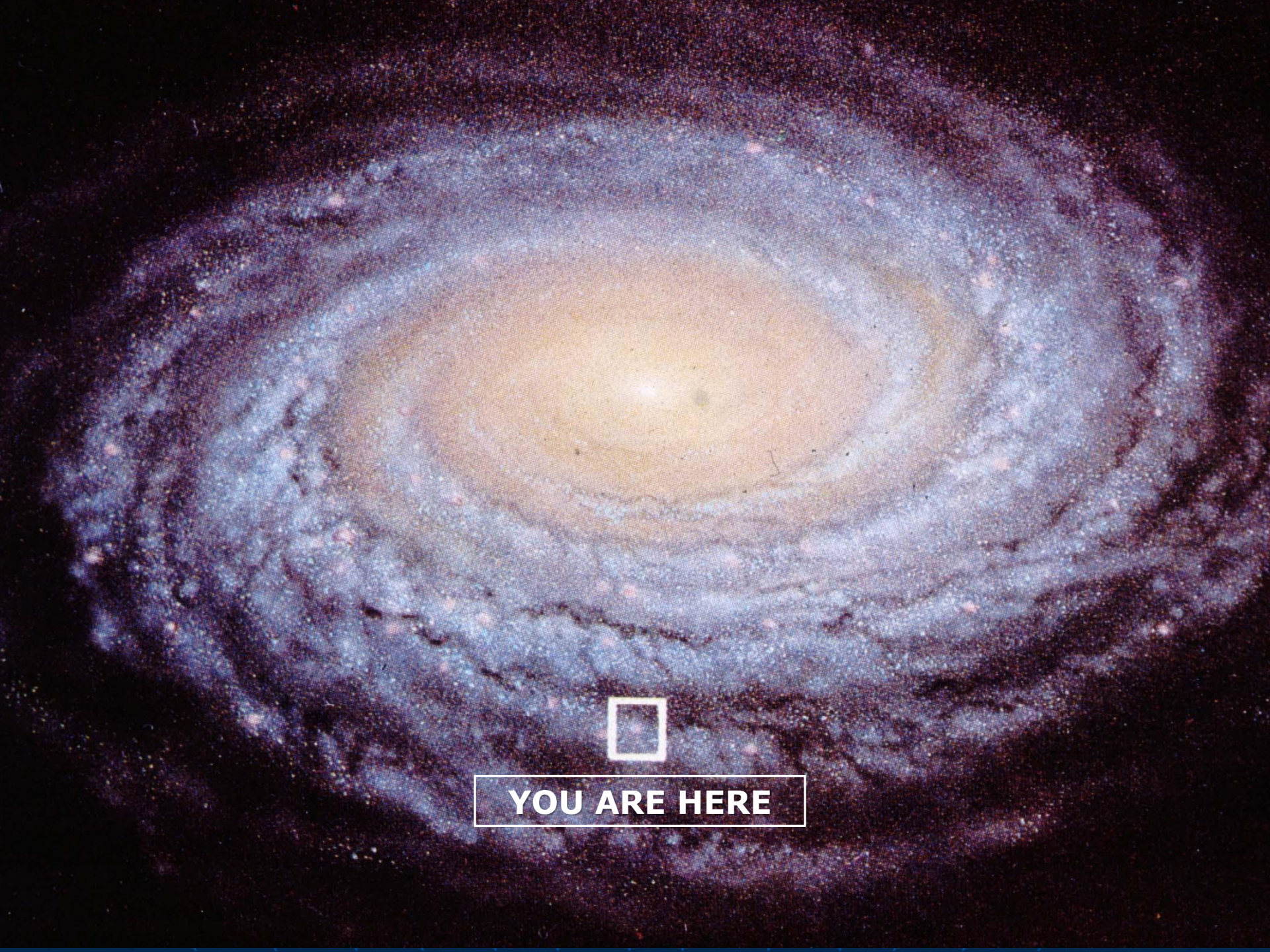
# *Our Milky Way*

# Milky Way

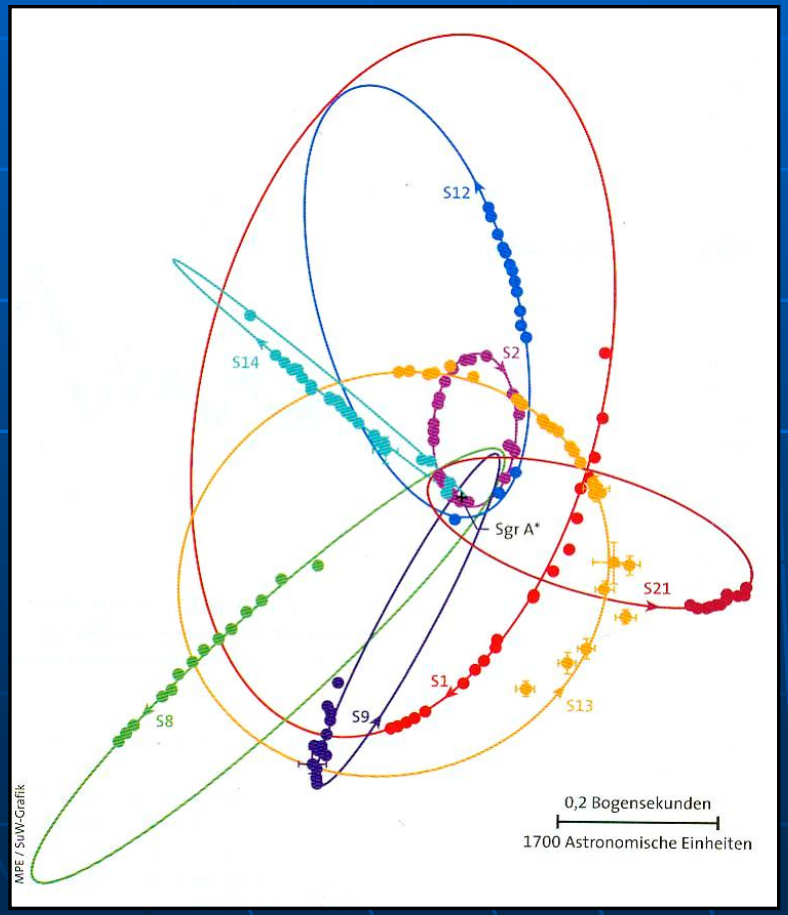


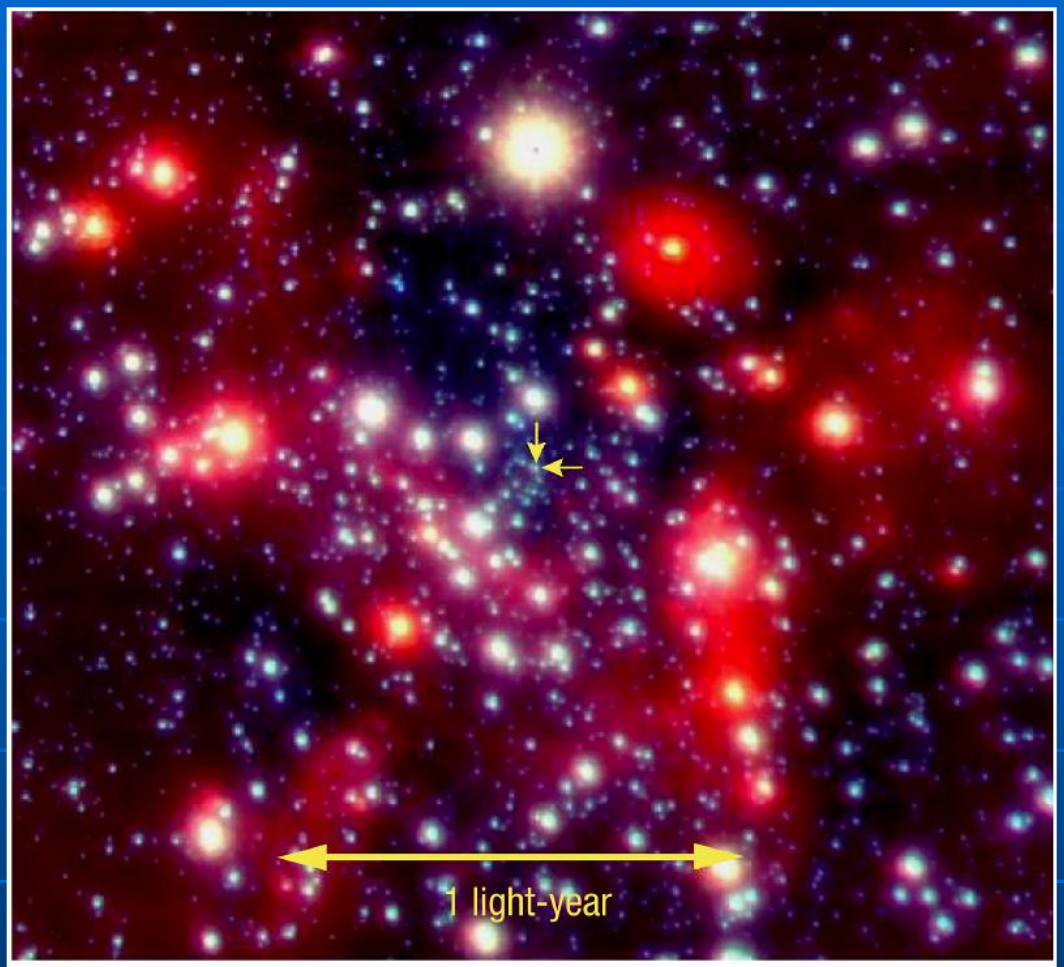
W. Schlosser,
Univ. Bochum


NGC 891
(similar to the Milky Way)


YOU ARE HERE

# The Black Hole in the Galactic Center

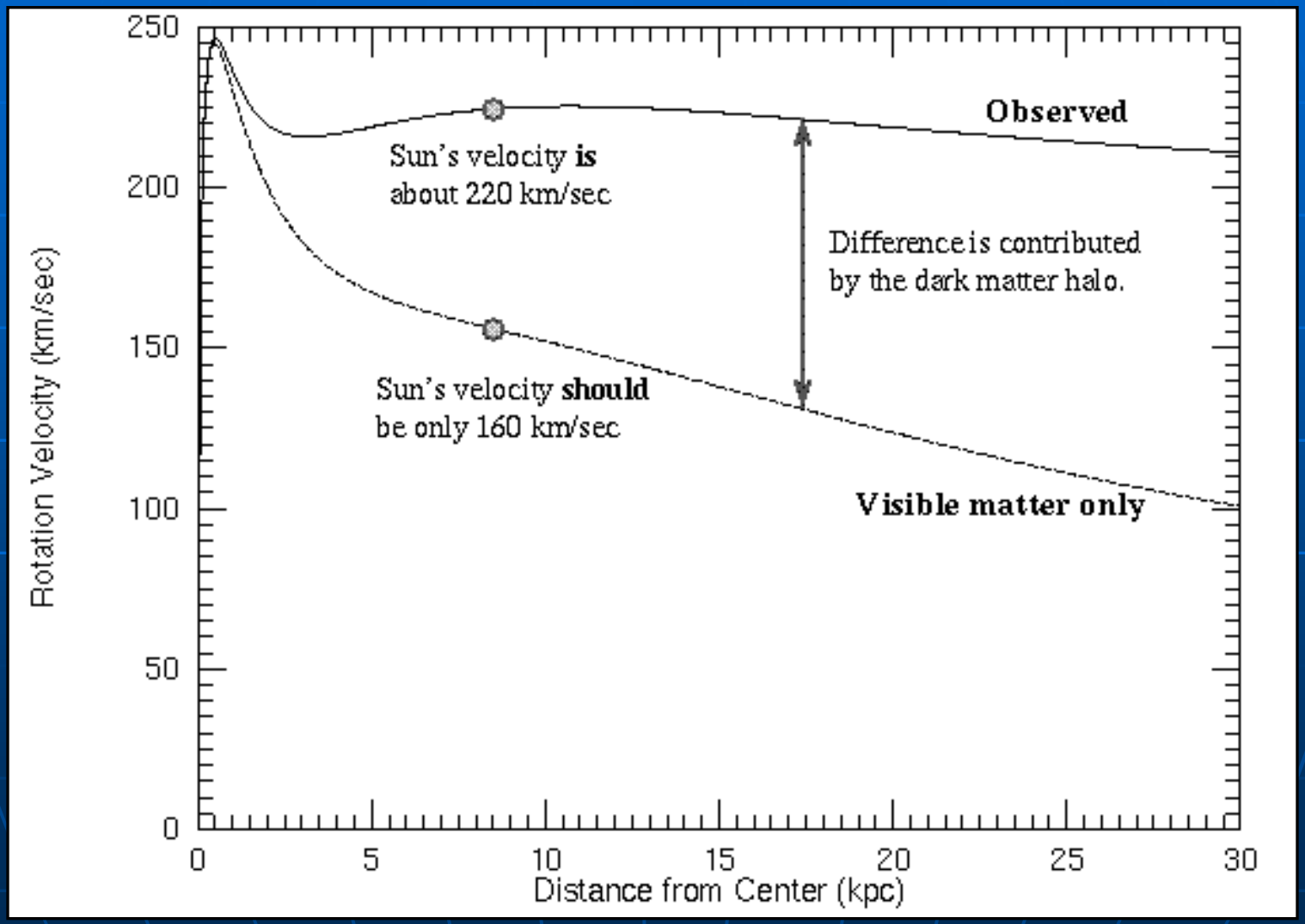


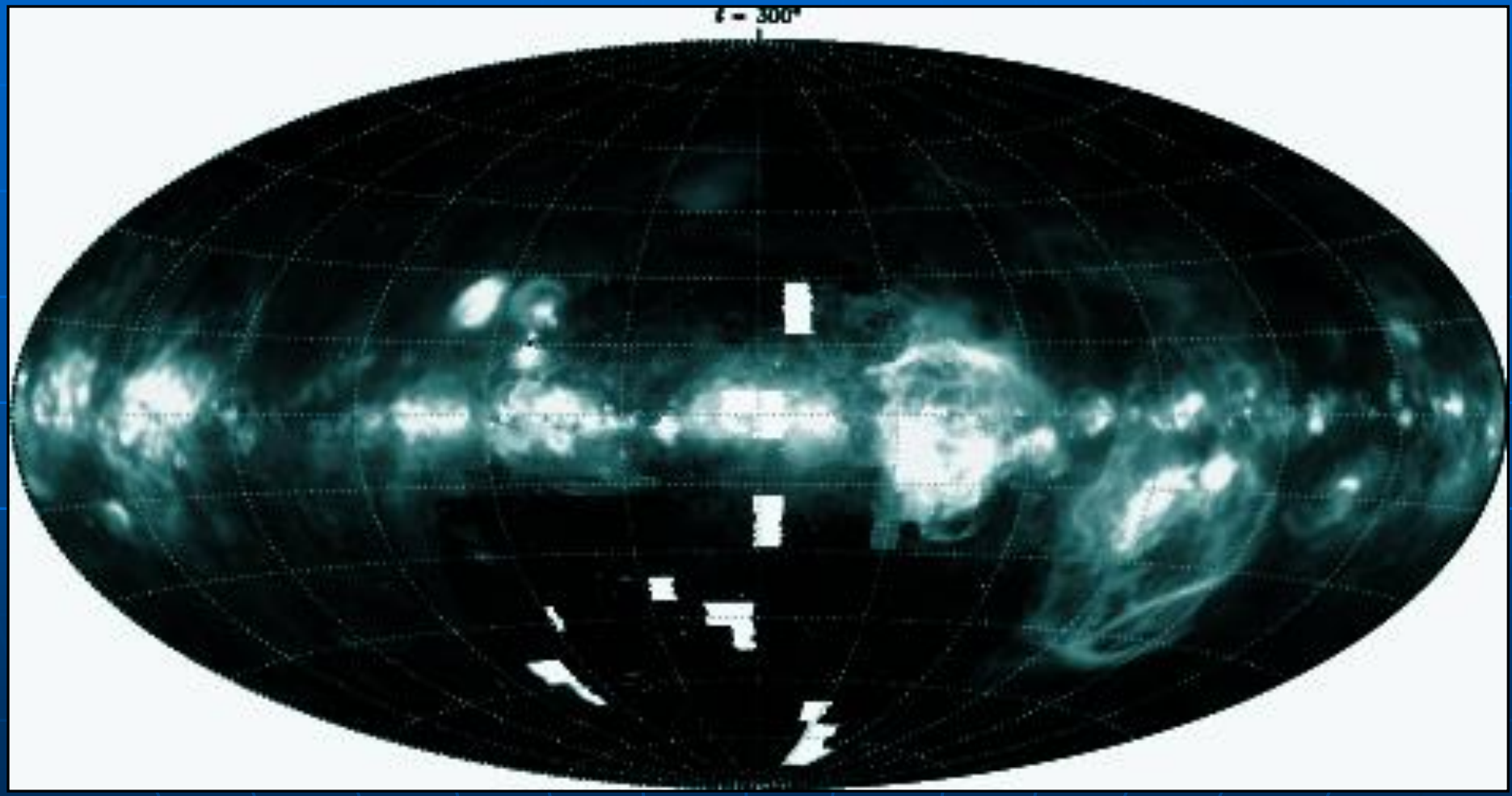

The Centre of the Milky Way
(VLT YEPUN + NACO)

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

# Rotation curve of the Milky Way



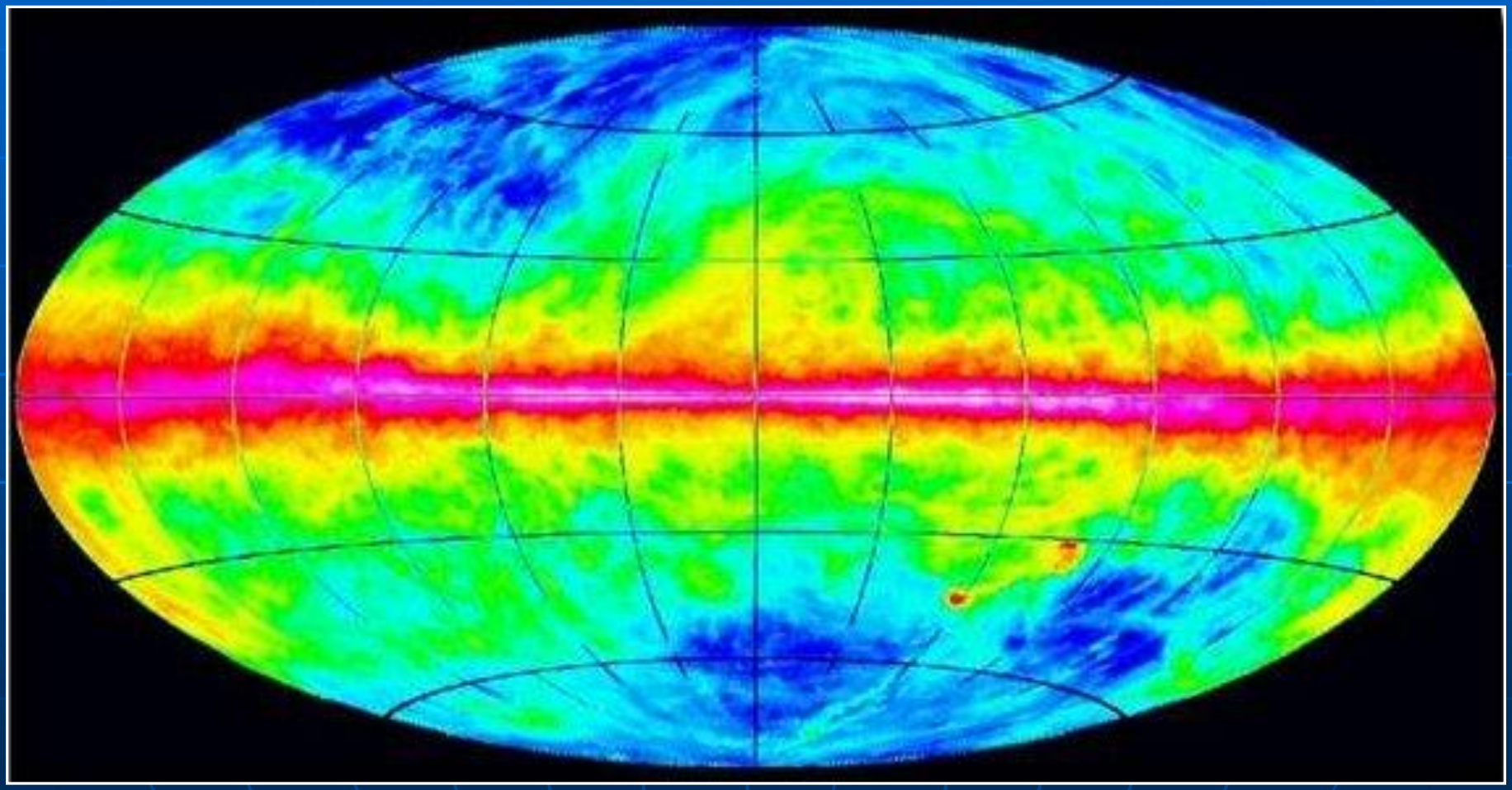
# The Milky Way in optical Hα emission of ionized hydrogen



Wisconsin Hα Mapper

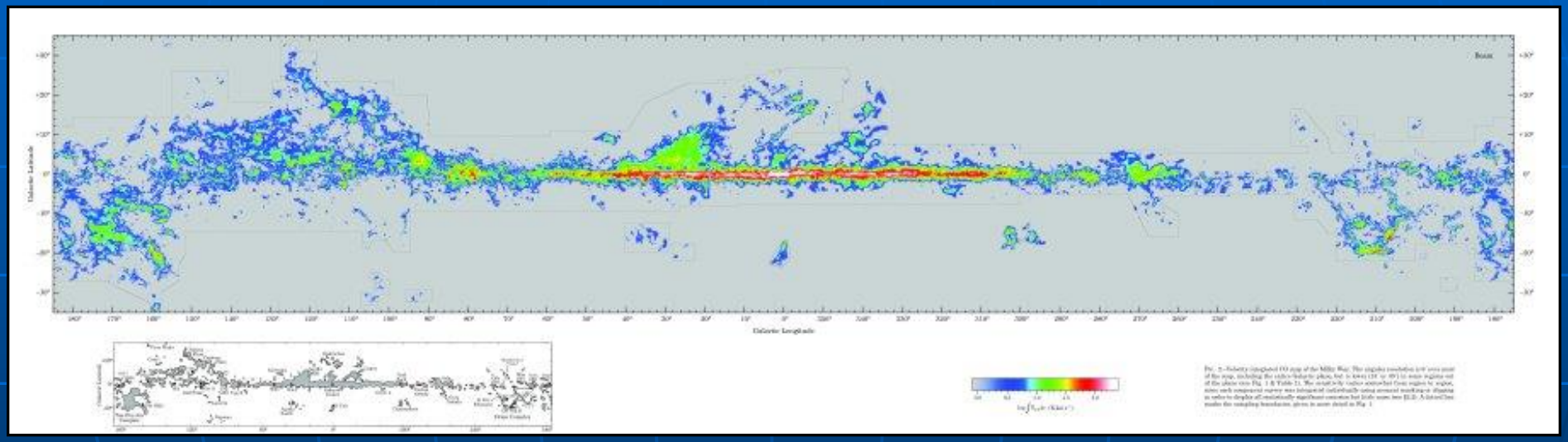
# The Milky Way in HI line emission of neutral hydrogen

(Netherlands/Argentina/Germany)



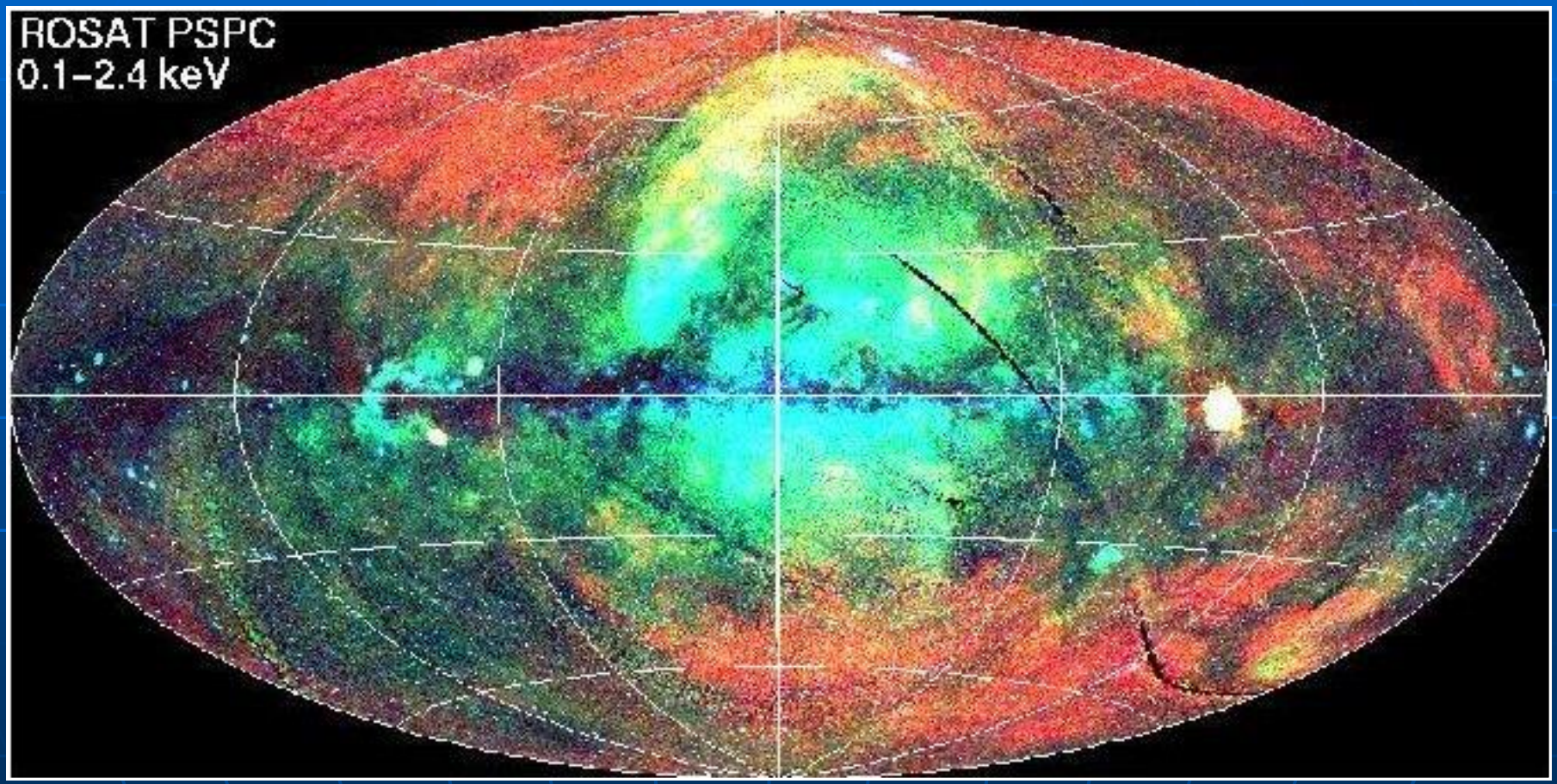
AIfA, Bonn University

# The Milky Way in CO line emission



Dame et al. 2001

# The Milky Way in soft X-rays




ROSAT

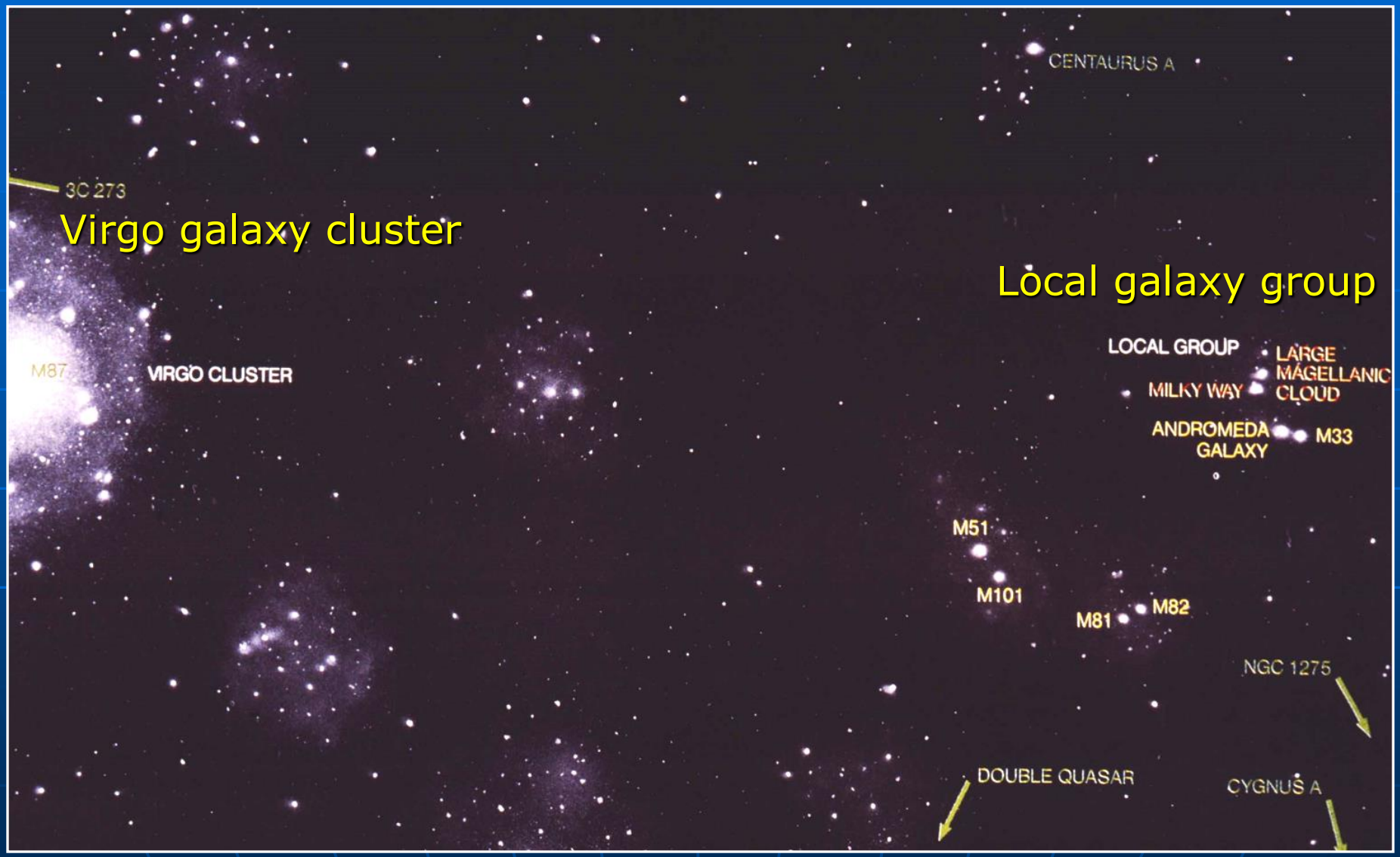
# Components of the Interstellar Medium

Ferrière 2001

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

| Component | Fractional Volume | Scale Height (pc) | Temperature (K) | Density (atoms/cm³) | 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 | Hα emission and pulsar dispersion |
| H II regions | < 1% | 70 | 8000 | $10^2$—$10^4$ | ionized | Hα 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 |

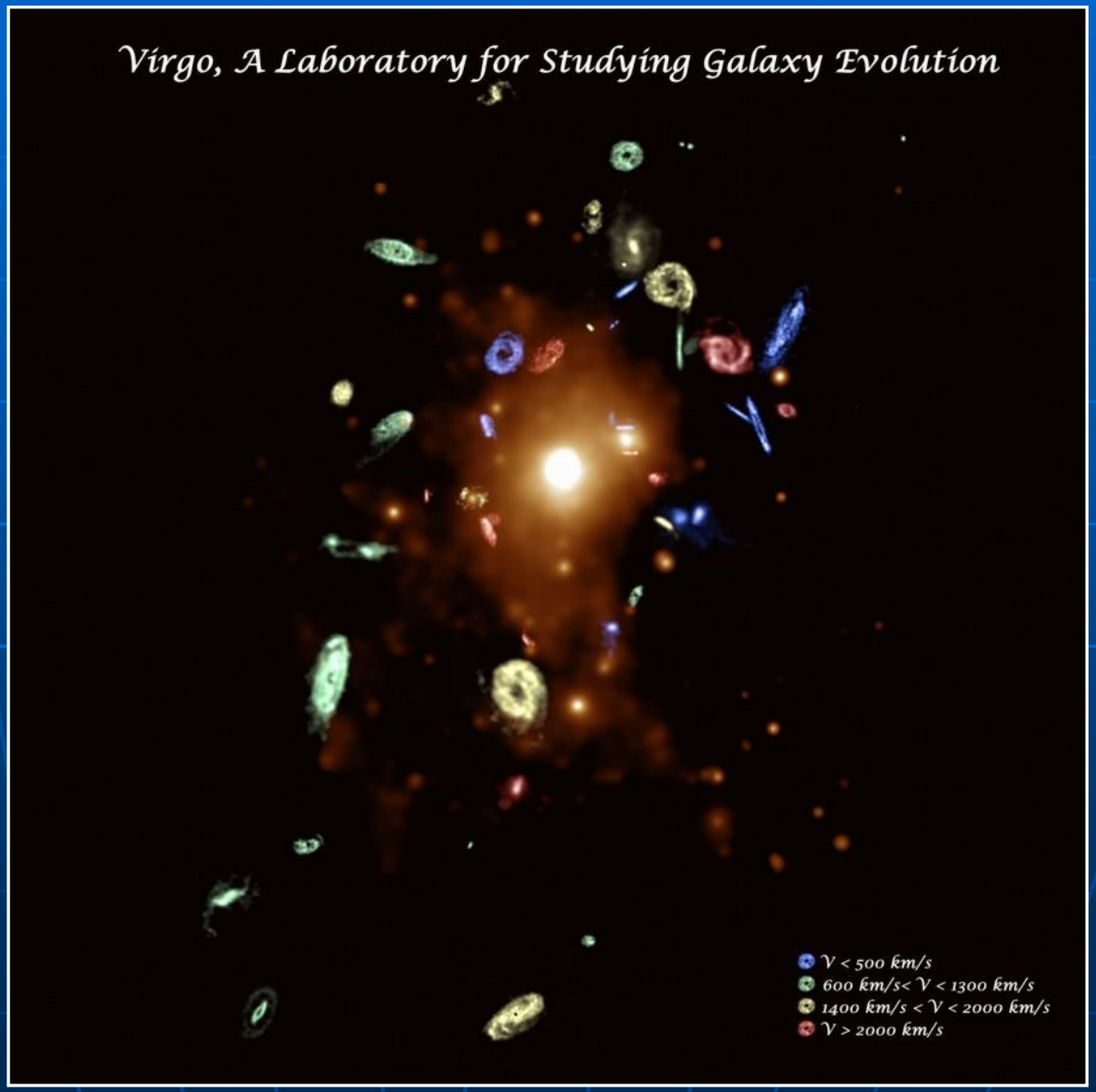
# *Galaxy clusters*




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

# Virgo cluster (optical)

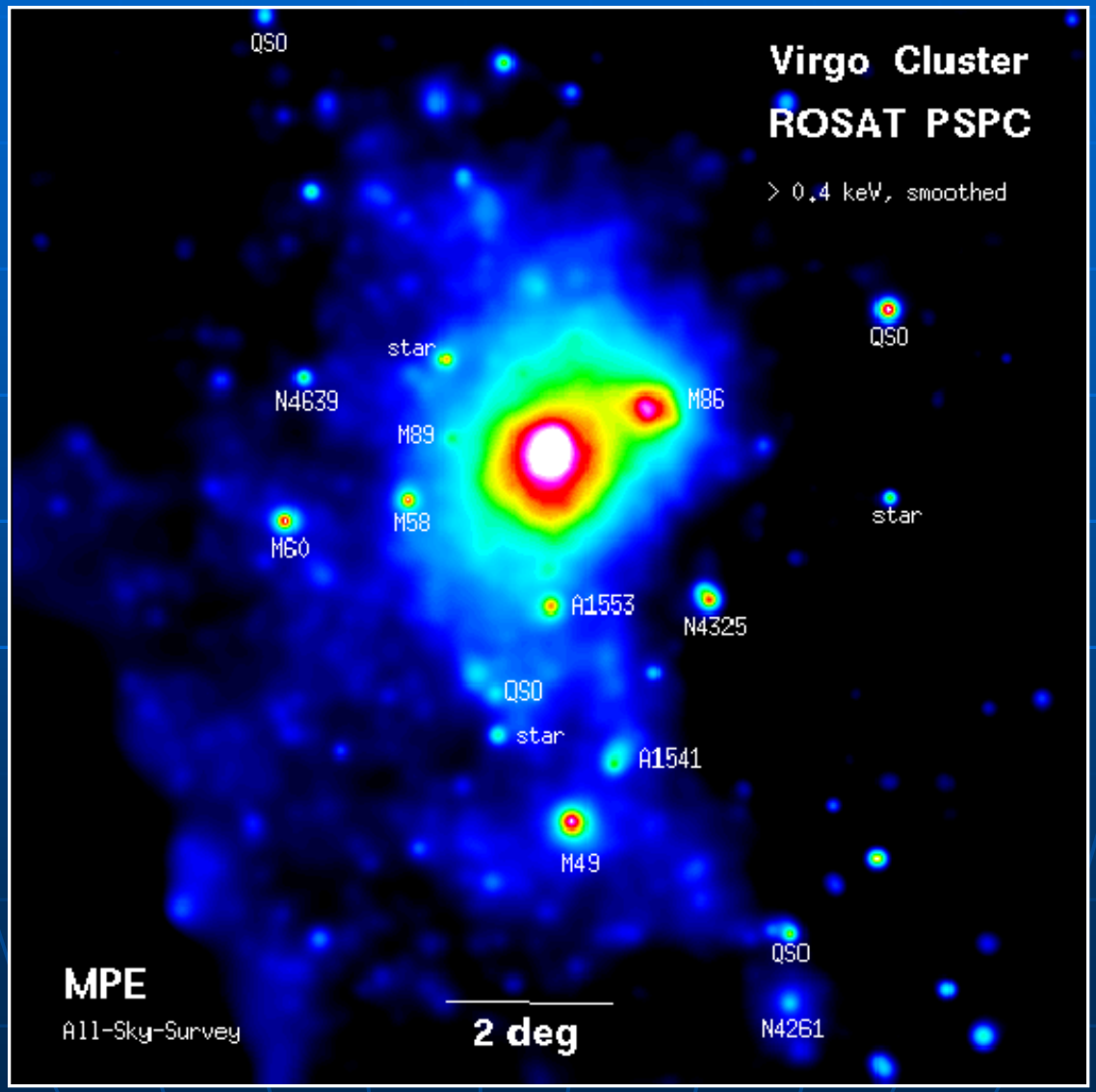
# Virgo cluster (neutral hydrogen)




Chung et al. 2009

# Virgo cluster (X-rays)

Stabilized
by
dark matter




ROSAT

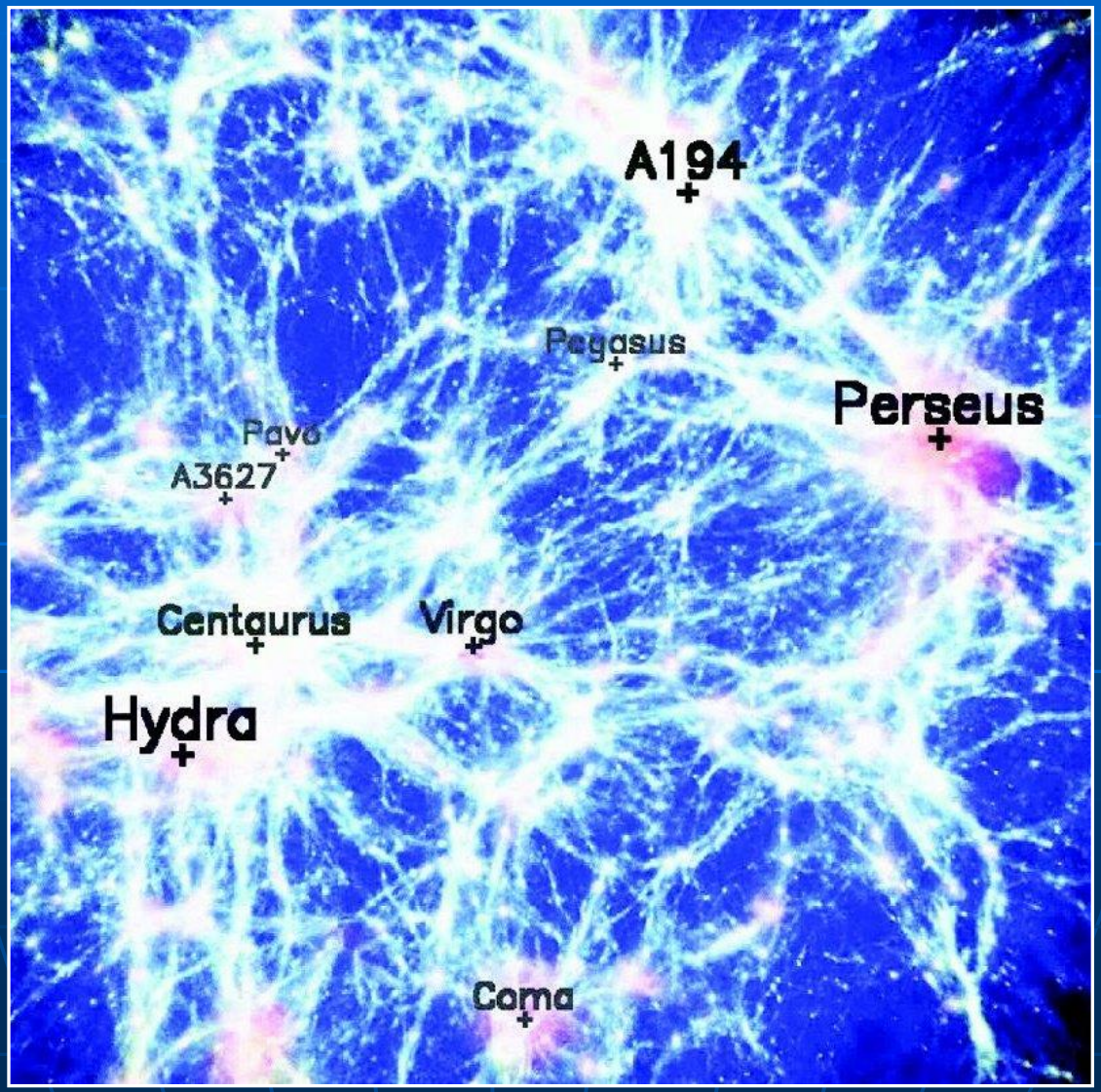
# Fundamental "galactic" questions

- 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 ?*

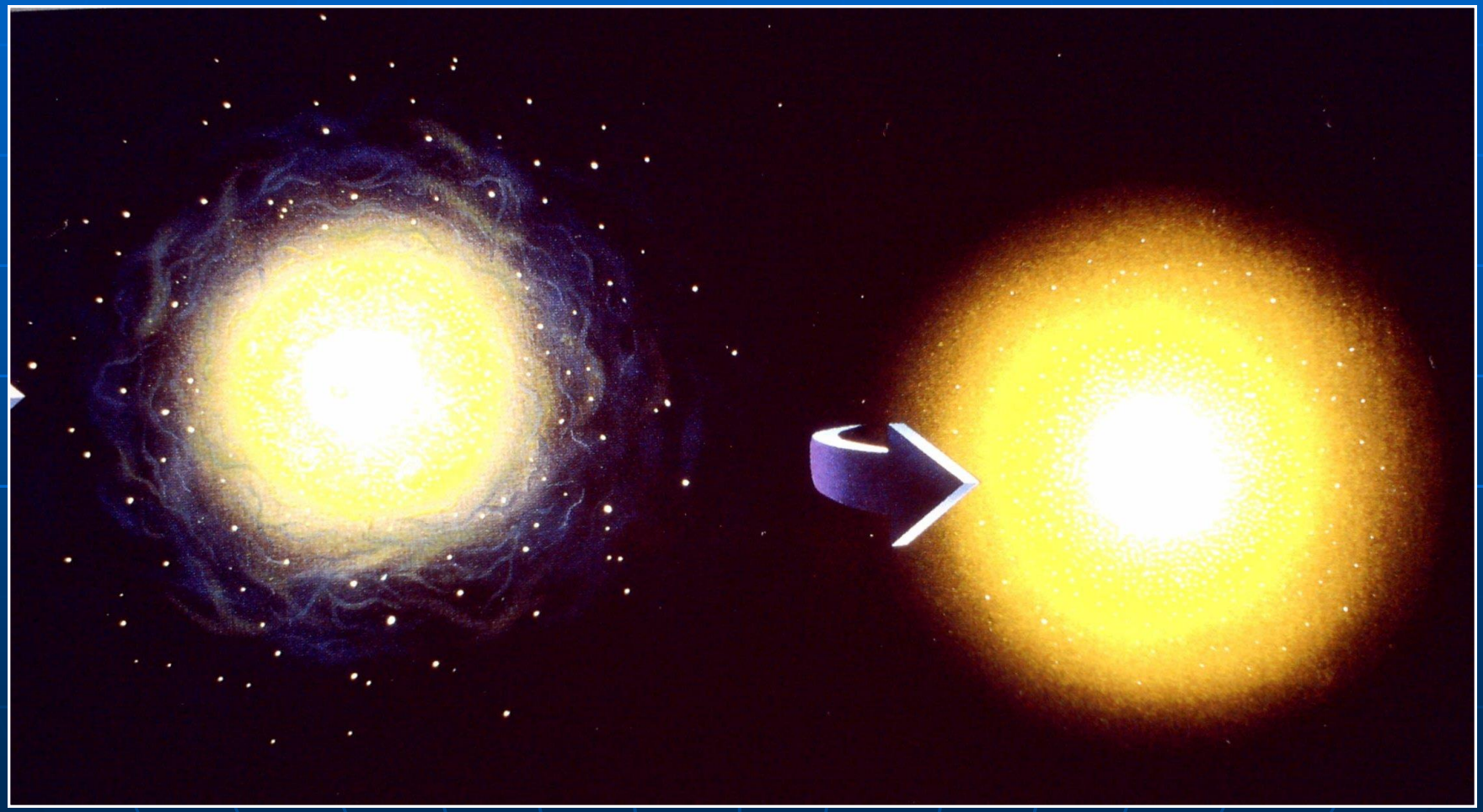
# Distribution of galaxies in the nearby Universe

# Structure formation in the early Universe

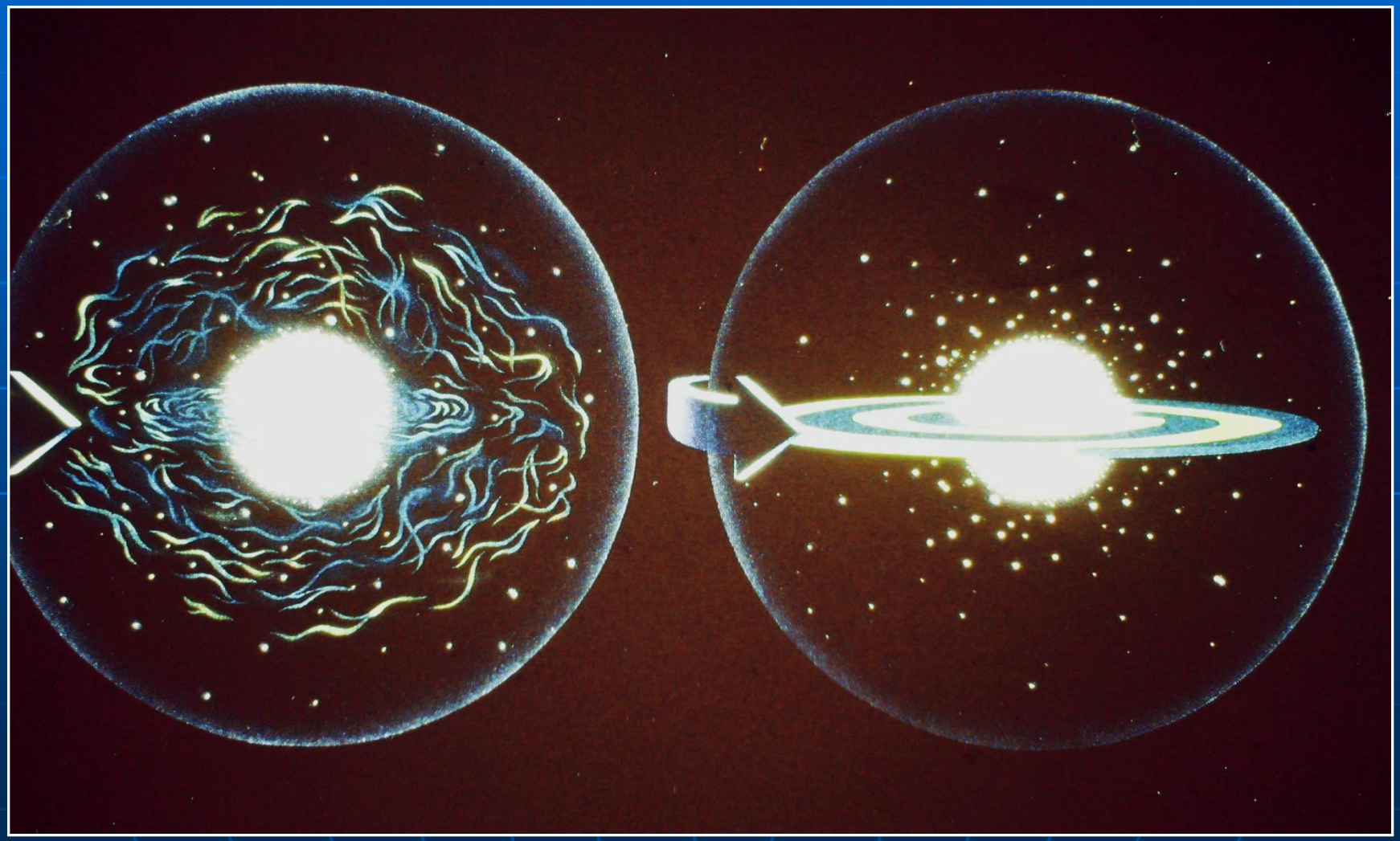



Klaus Dolag

# Formation of elliptical galaxies: The classical picture

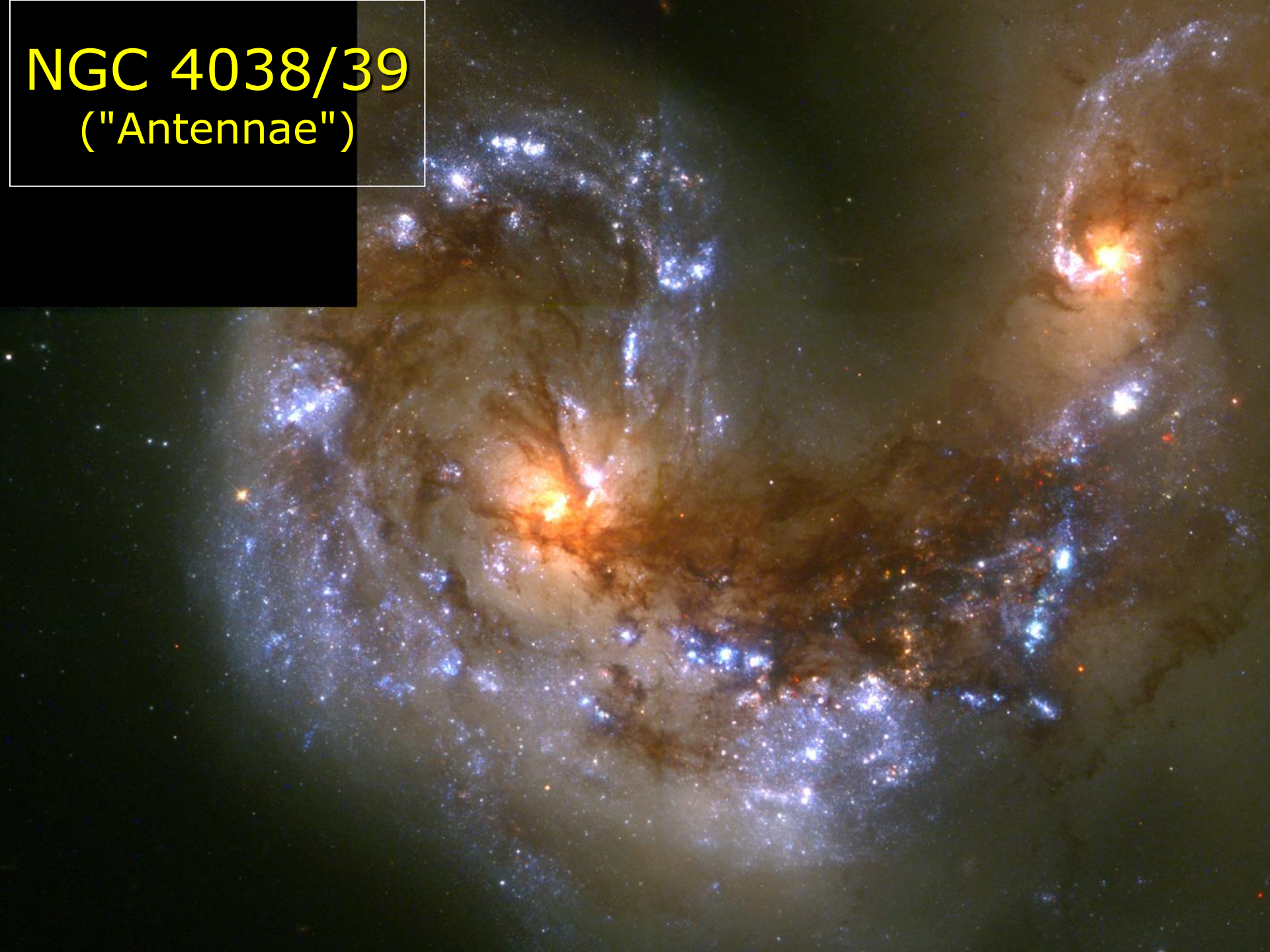


# Formation of spiral galaxies: The classical picture



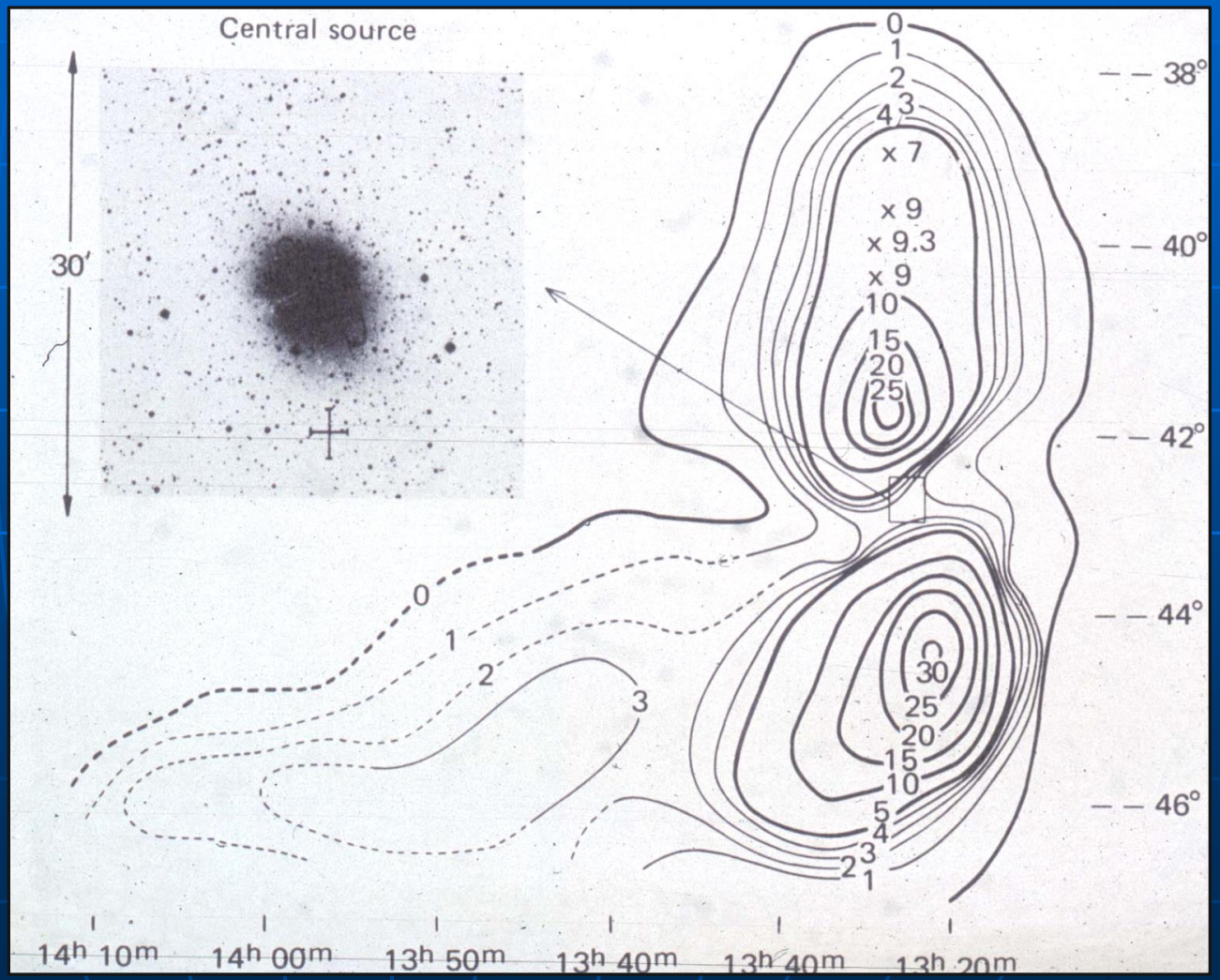
*New view:*
*Interactions*
*play a major role*
*for galaxy evolution*


NGC 4676
("Mice galaxy")


NGC 4038/39
("Antennae")

# *Radio galaxies*

# Radio galaxy
# Centaurus A
## Parkes 20 cm

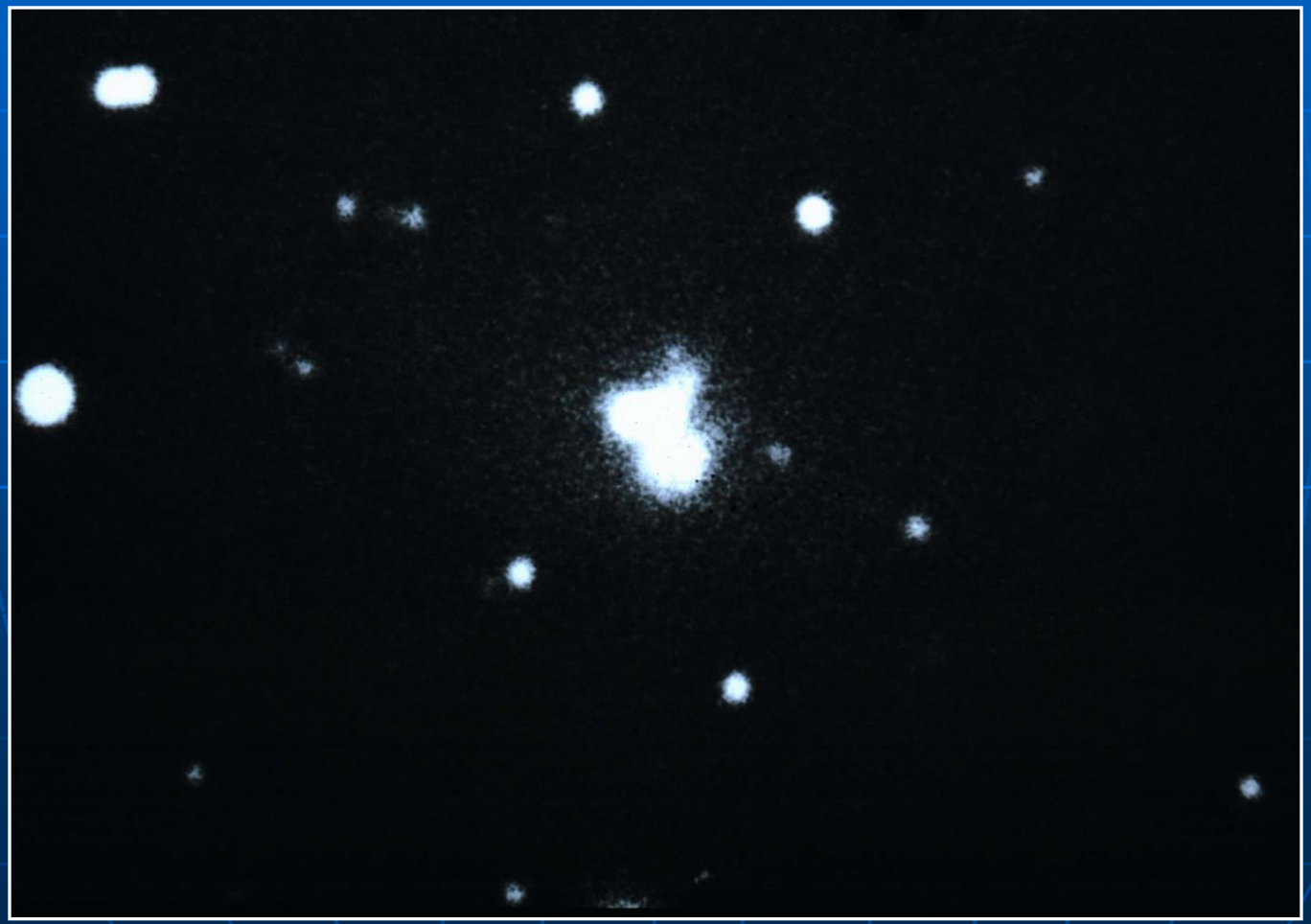


# Cen A

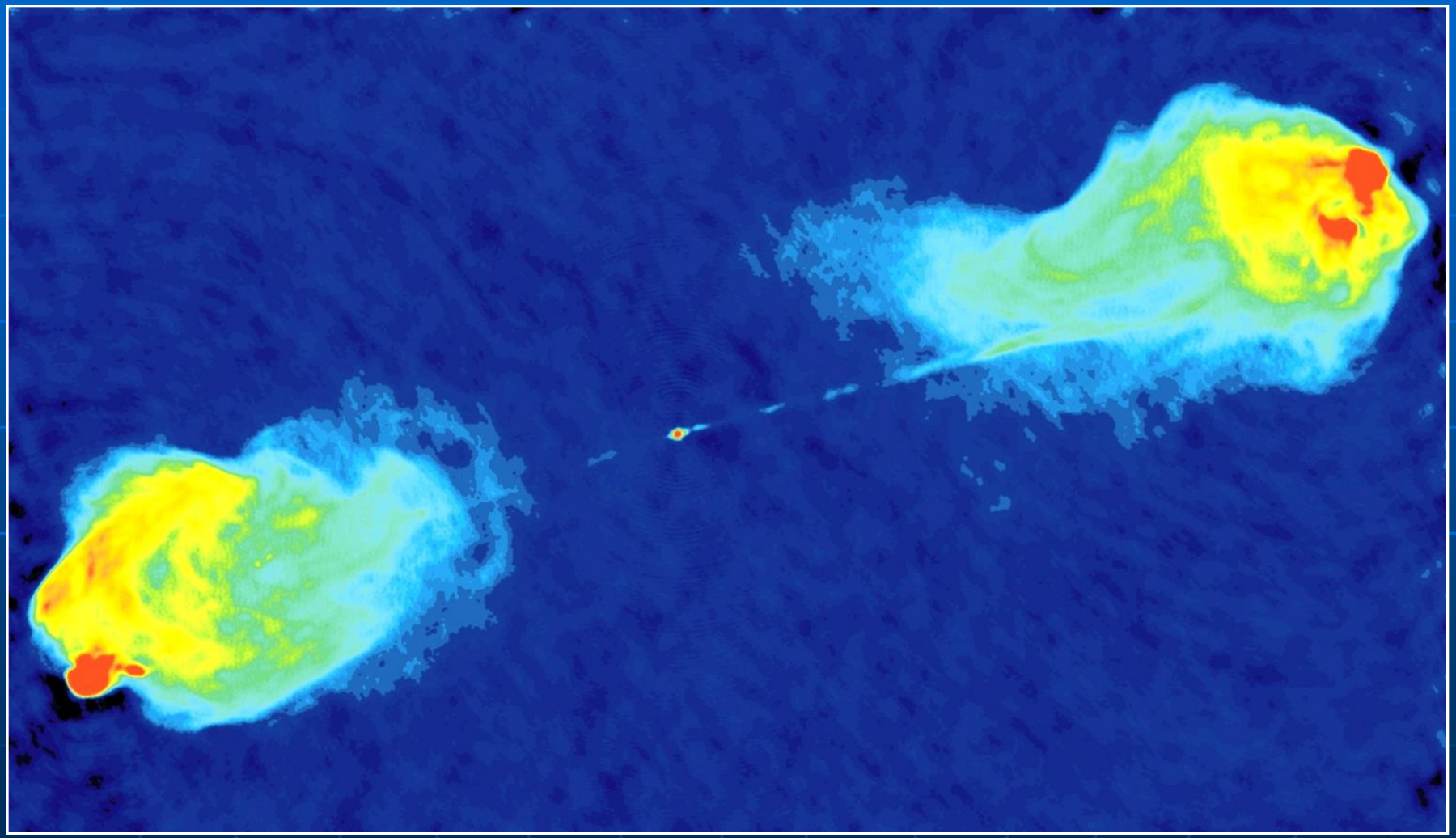
Optical
+
radio
+
X-rays

NASA / NRAO

# Radio galaxy
# Cygnus A
optical



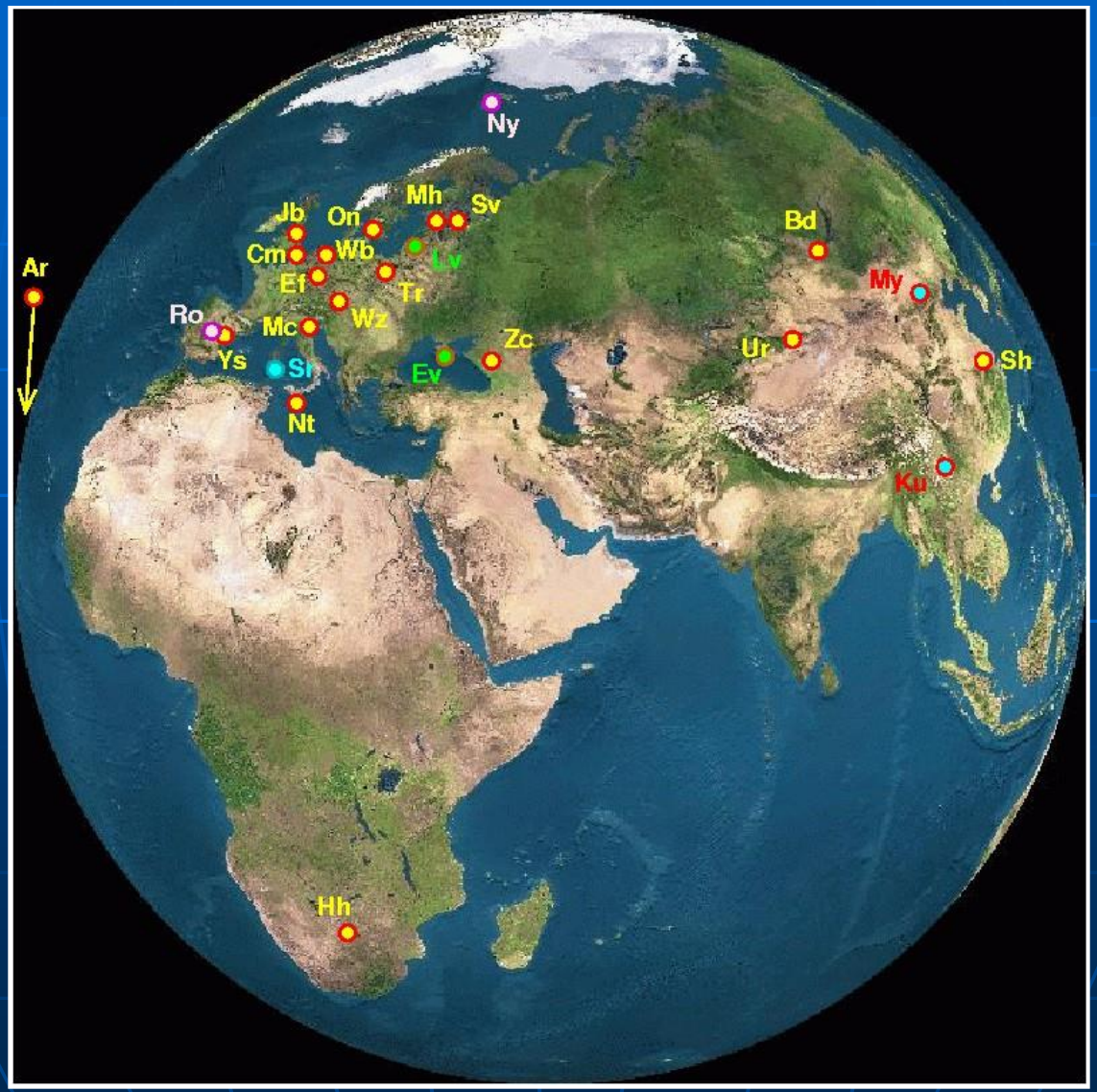
# Cyg A
VLA 6 cm

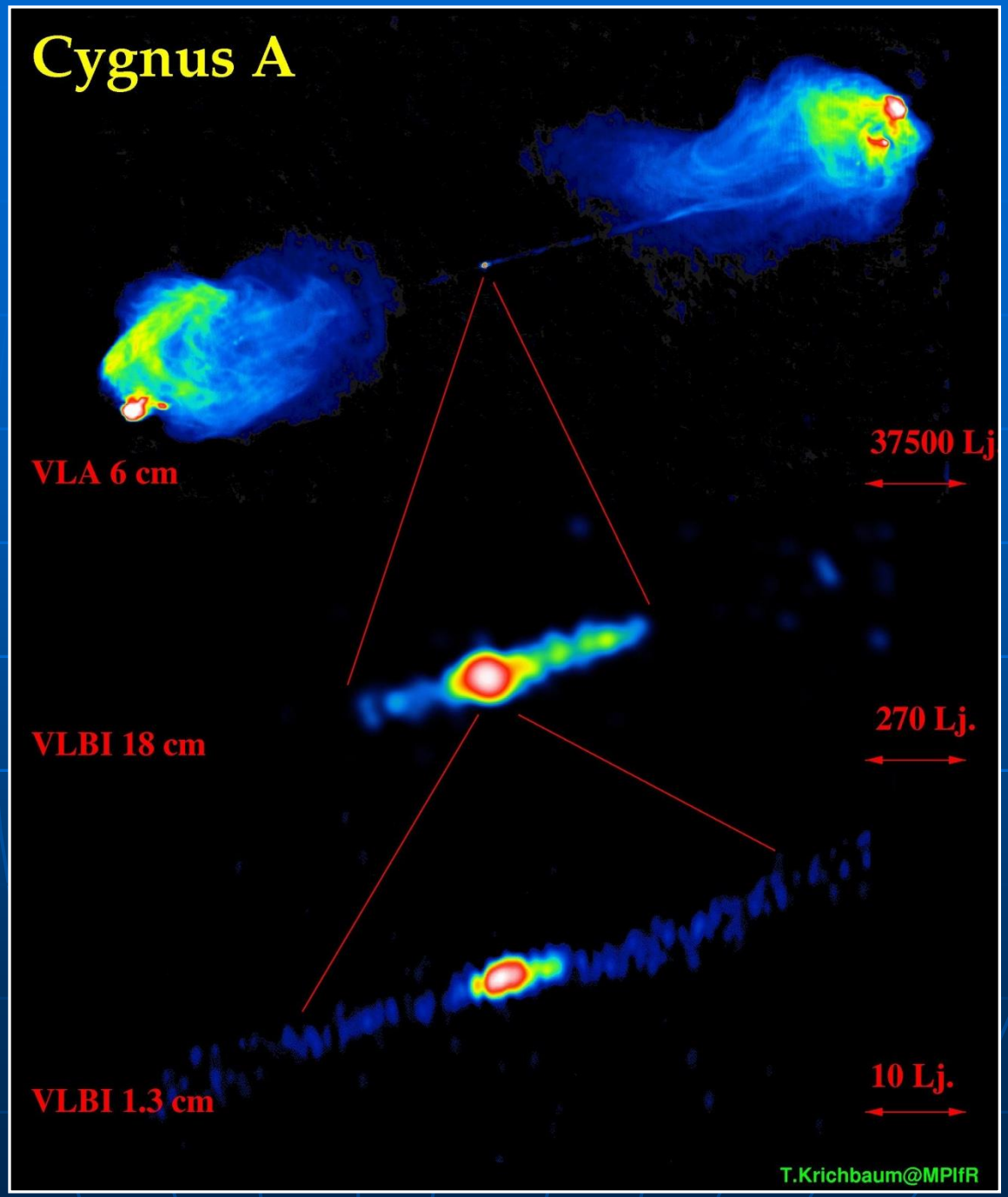


R. Perley, NRAO

# *Jets:*
# *Supersonic streams of gas and magnetic fields*

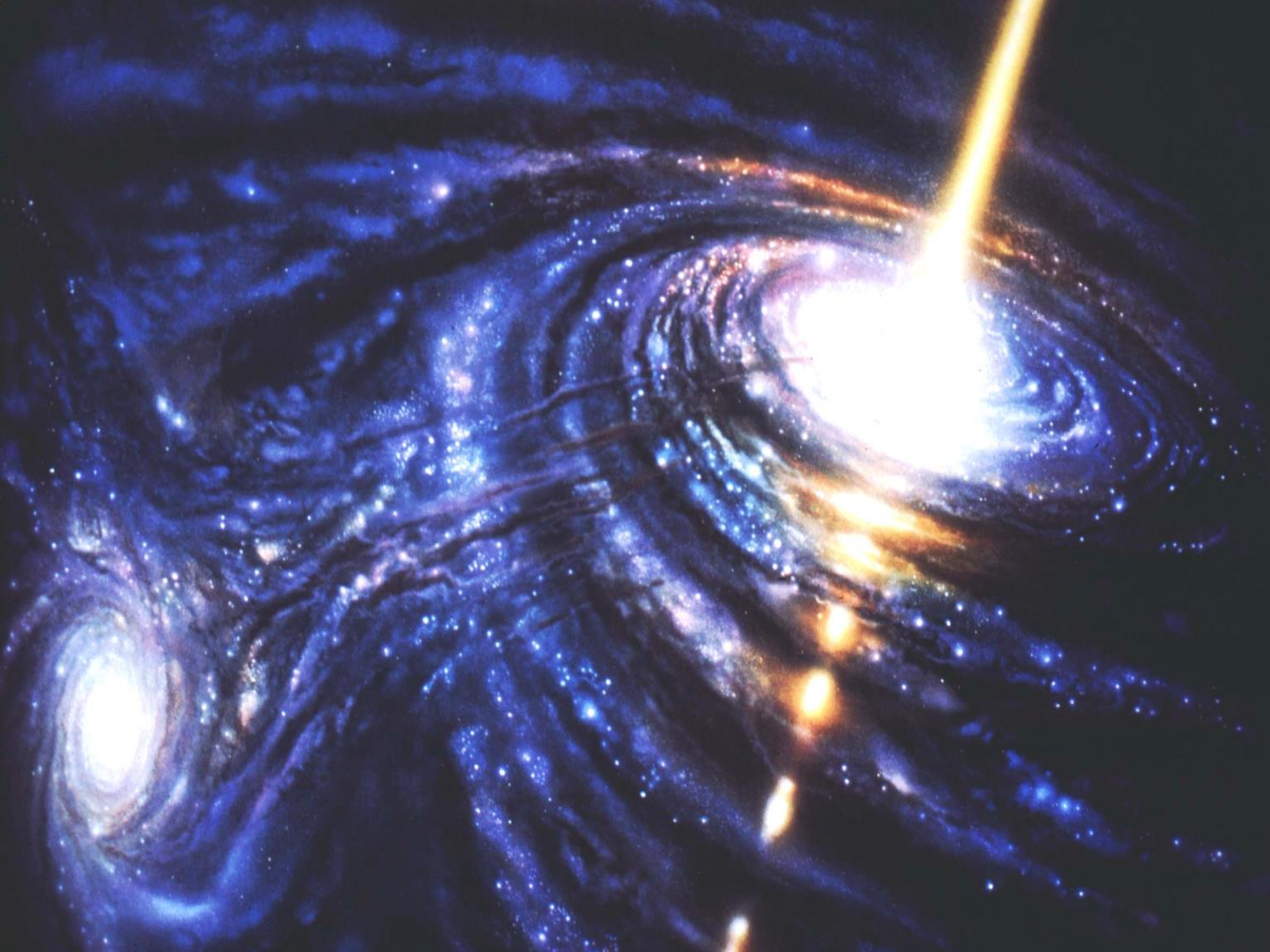
# Very Large Baseline Interferometry (VLBI)



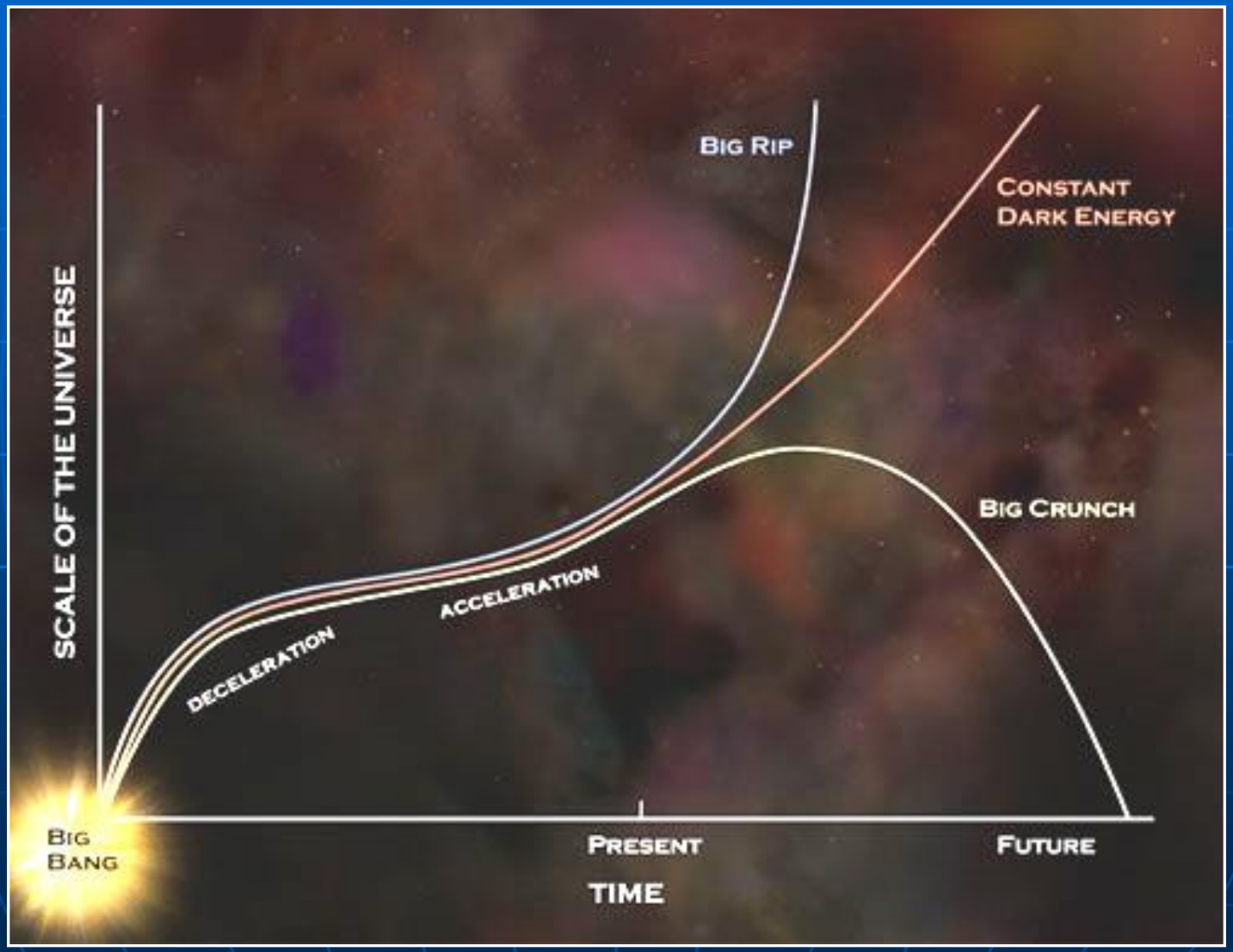



T. Krichbaum, MPIfR

# *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)