



Introduction to Cosmology

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Edwin Hubble
1889 - 1953



The Andromeda nebula - M 31

In 1923 Edwin Hubble identified first cepheids in M 31 and measured its distance



Shapley: "this letter [from Hubble] destroyed my model of the Universe"

Great discovery -
there are other galaxies !

Galaxies are the main building
blocks of the Universe !



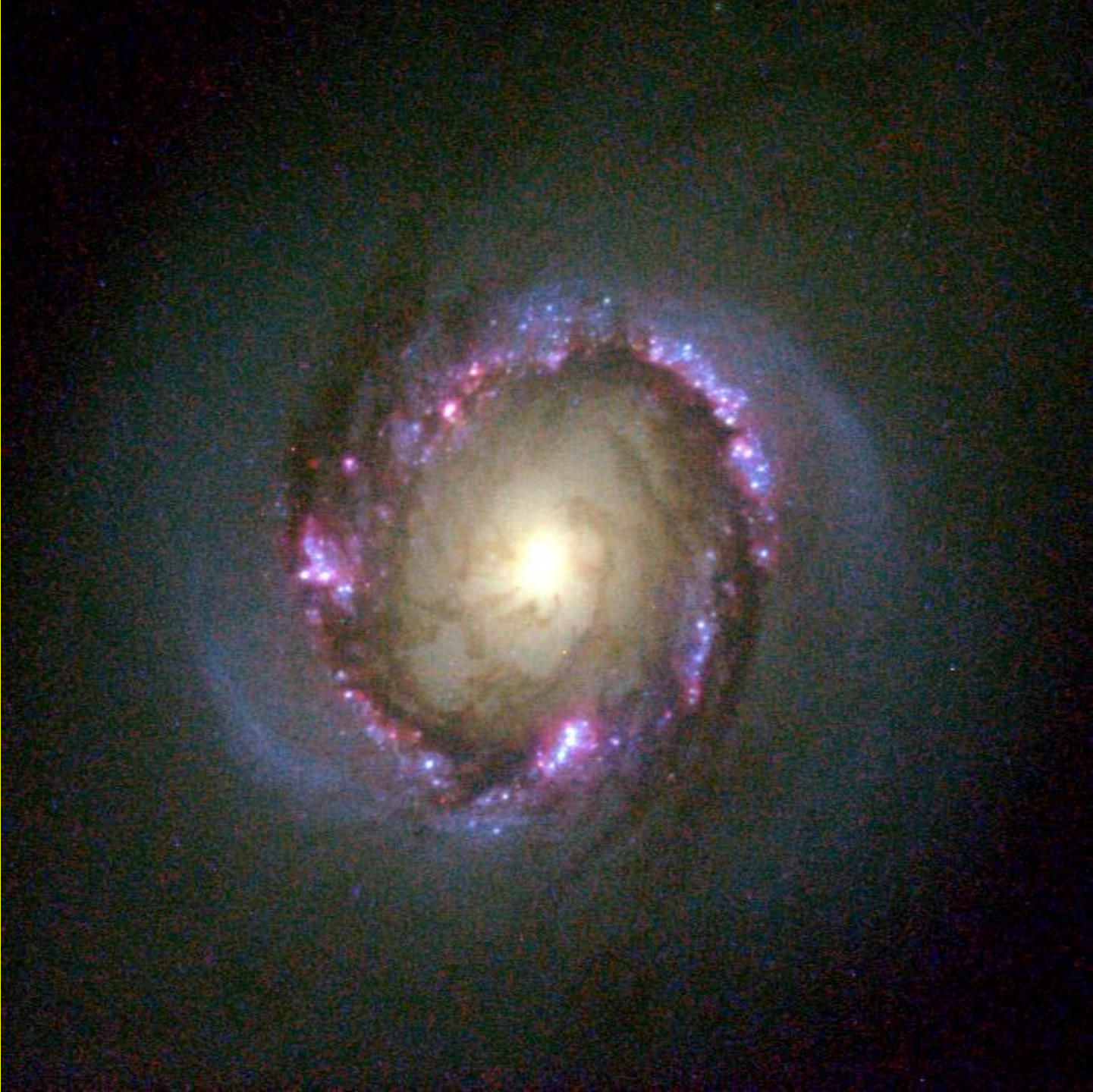
NGC
1232
ESO VLT

Whirlpool Galaxy • M51

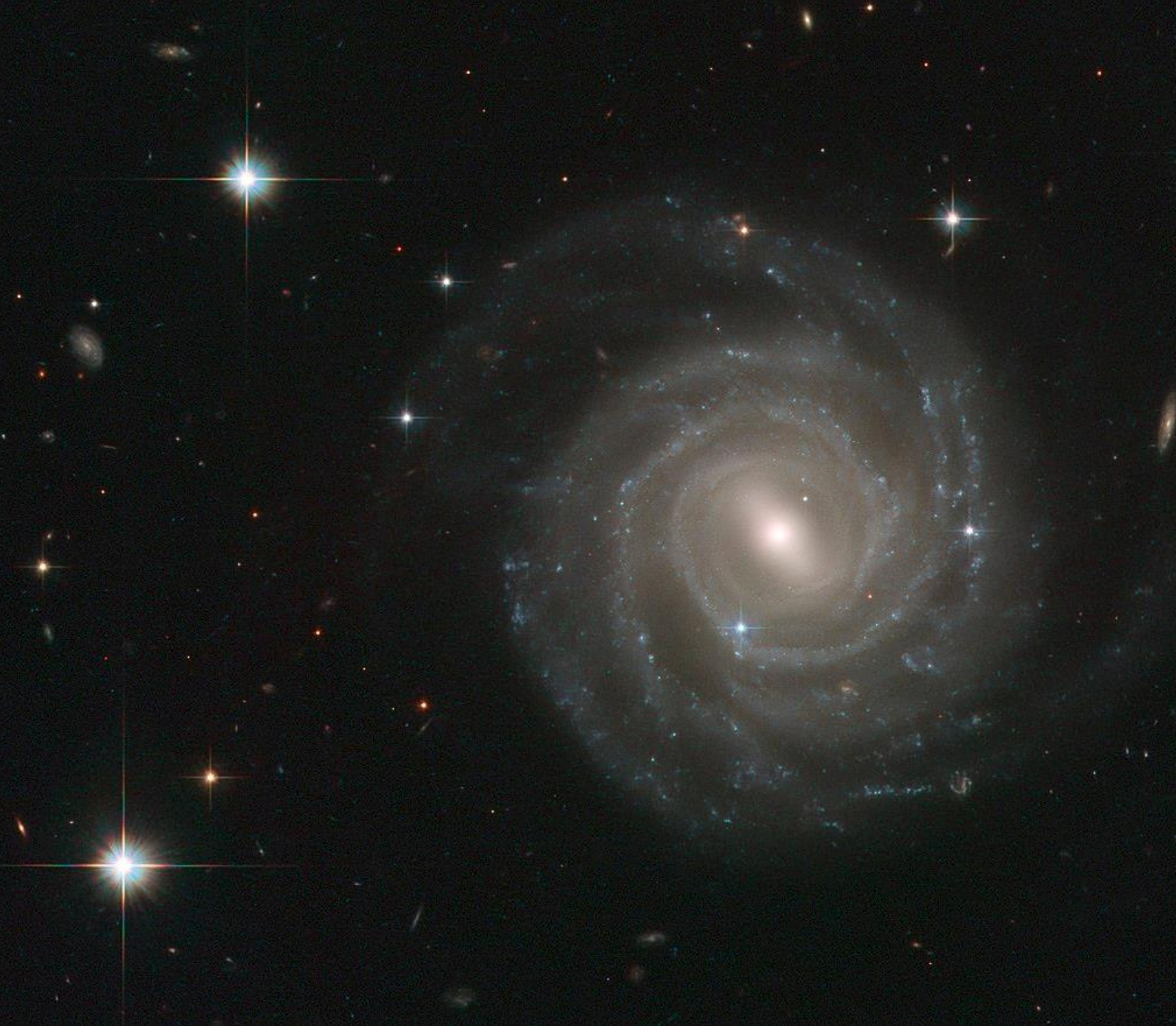


Hubble
Heritage

NASA and The Hubble Heritage Team (STScI/AURA)
Hubble Space Telescope WFPC2 • STScI-PRC01-07







UGC
12158

very
similar
to
MW



NGC 6744 is similar to MW







M 87



Small
Magellanic
cloud



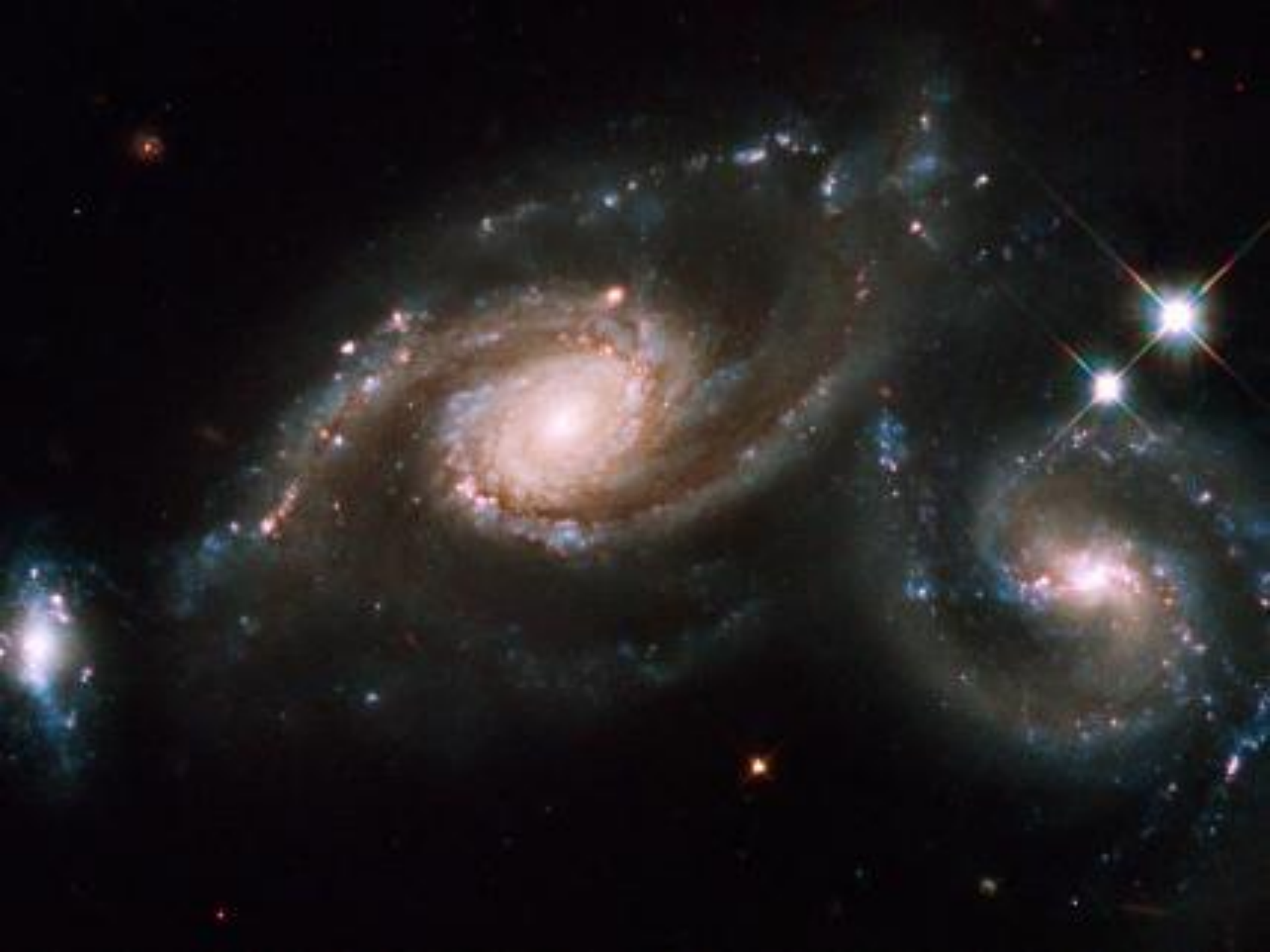
Large Magellanic cloud

Stars

$$\frac{\langle distance \rangle}{\langle size \rangle} \sim 3 \cdot 10^7$$

Galaxies

$$\frac{\langle distance \rangle}{\langle size \rangle} \sim 10$$





Spiral galaxies -

Disk shape, spiral arms, bulge or bar at the center, contain old stars but also young stars, lot of gas and dust.

$$M_S \approx 10^{10} - 10^{12} M_{\odot}$$

Elliptical galaxies -

round in shape, contain mostly old stars, no gas or dust.

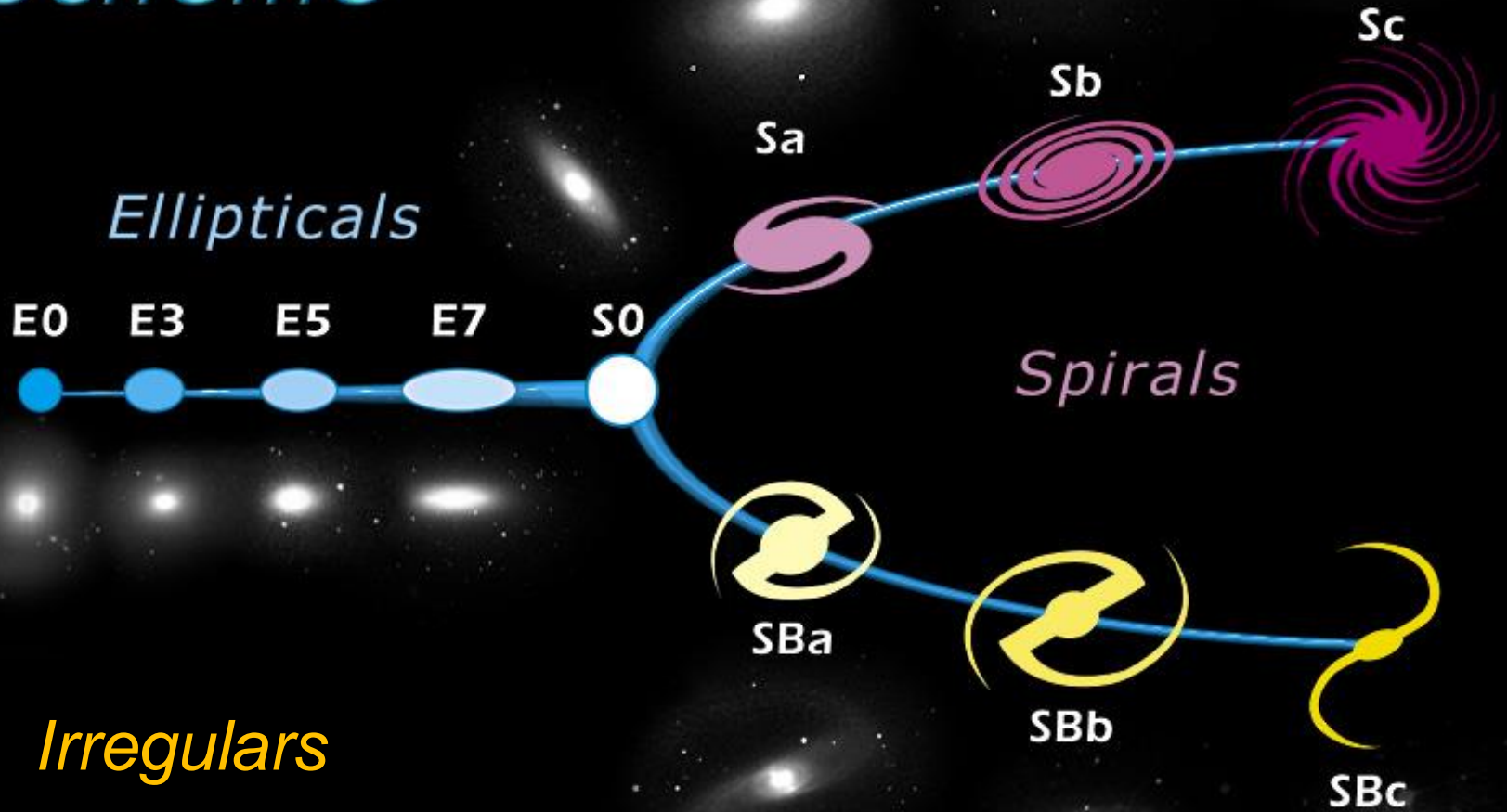
$$M_E \sim 10^8 - 10^{13} M_{\odot}$$

https://en.wikipedia.org/wiki/Spiral_galaxy#/media/File:M101_hires_STScI-PRC2006-10a.jpg

https://en.wikipedia.org/wiki/Elliptical_galaxy

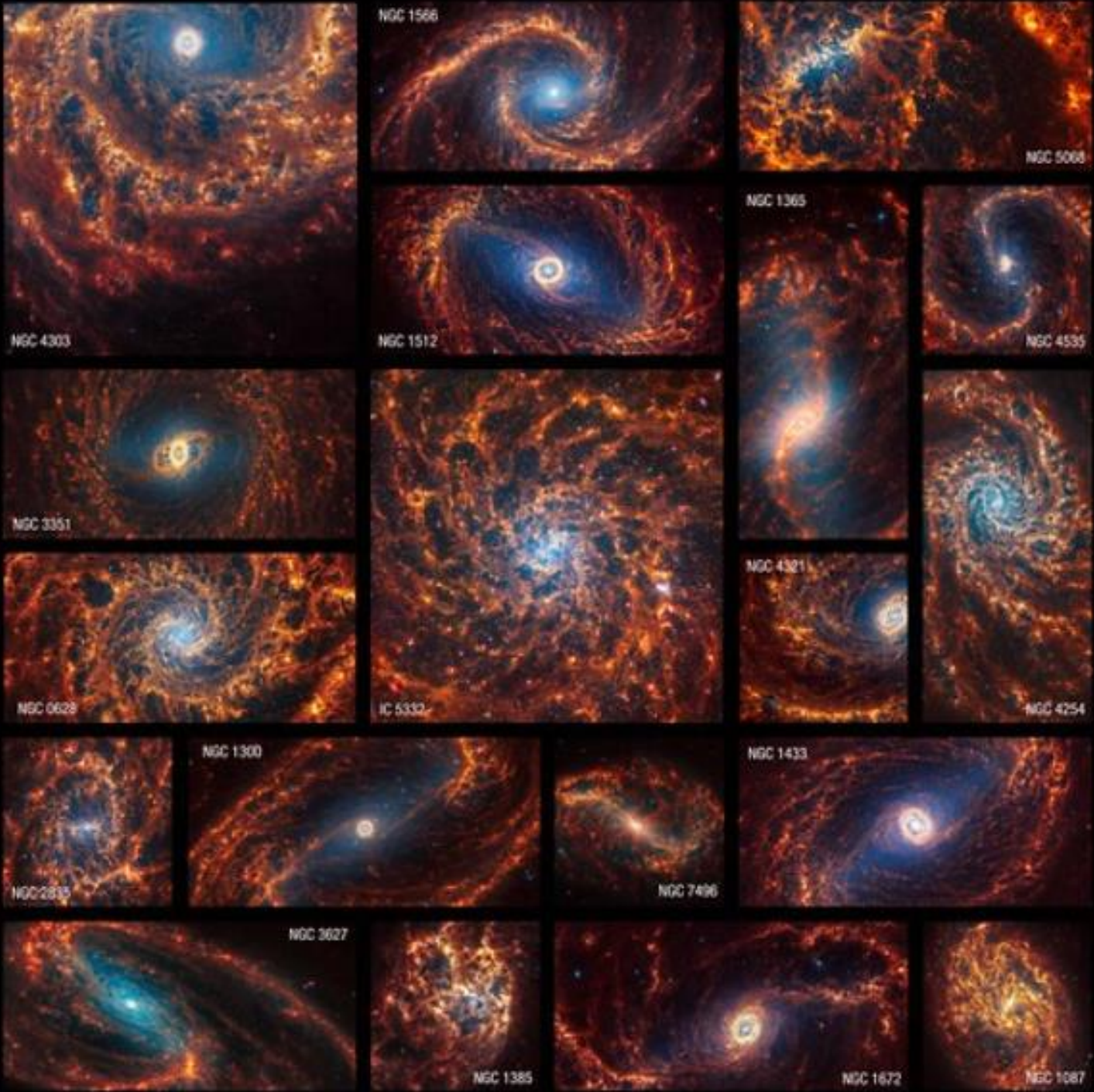
<http://www.galaxyzoo.org/>

Edwin Hubble's Classification Scheme



Types of galaxies

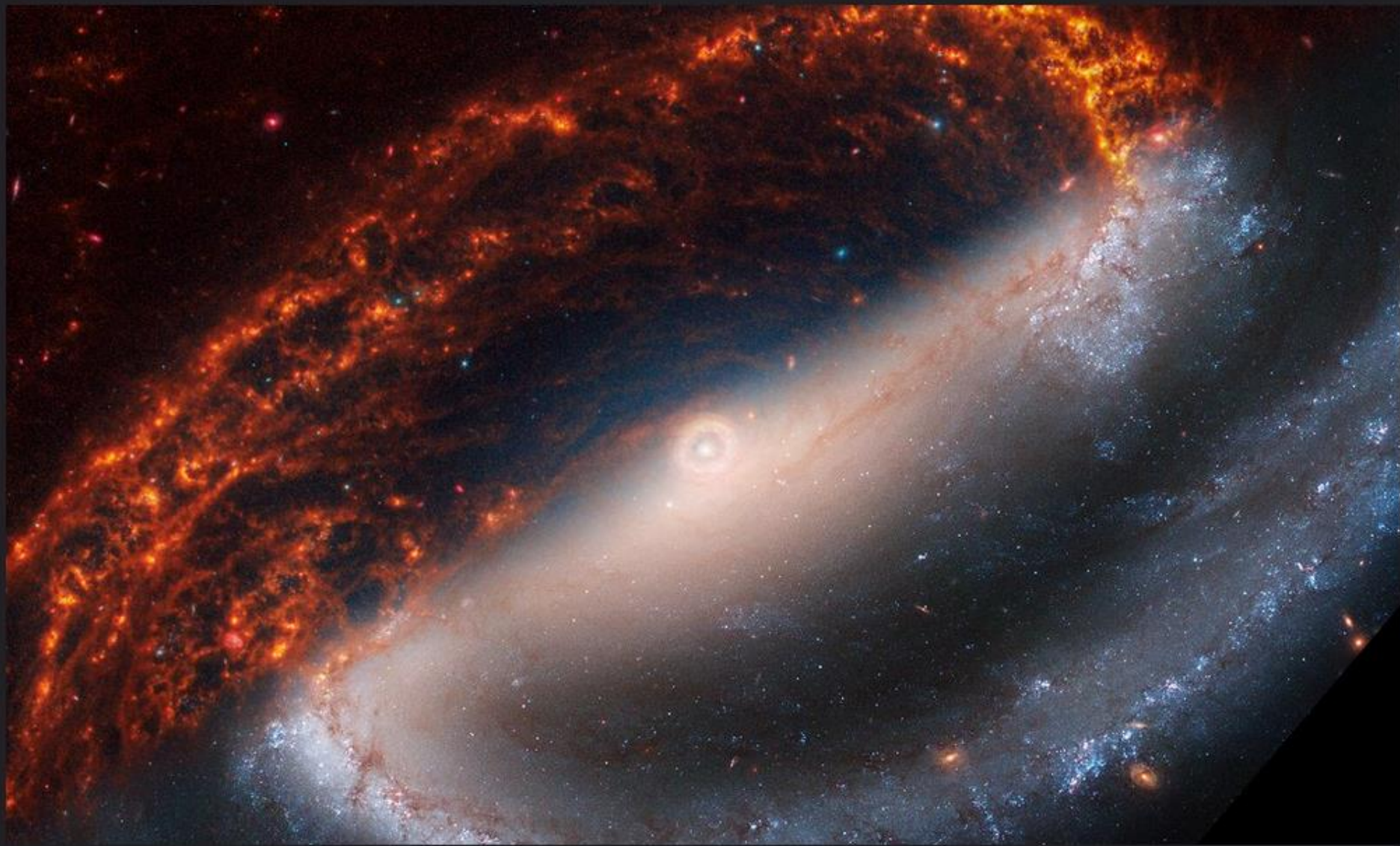
Standard spirals	}	75%
Barred spirals		
Elliptical		15 %
Irregular		10%



Galaxies as seen by JWST







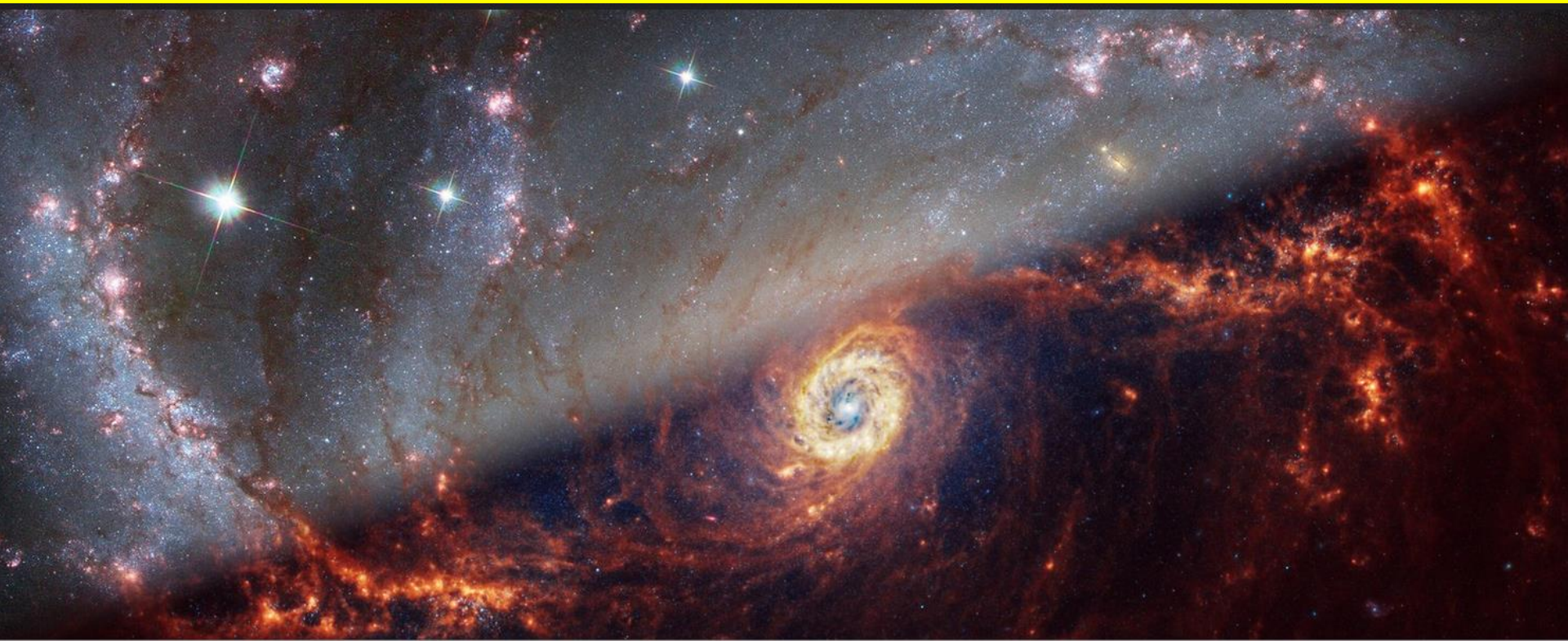




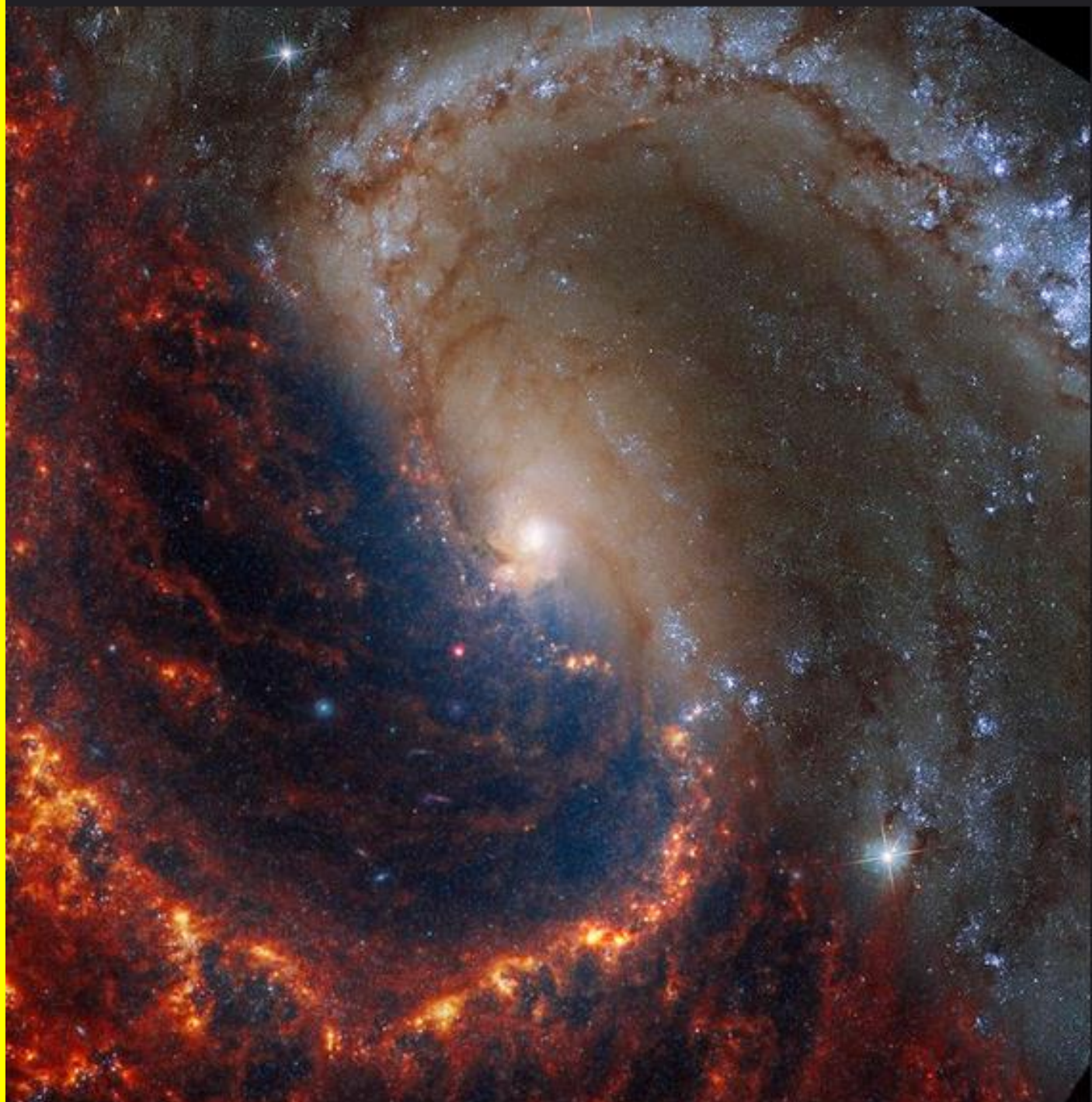














elongated appearance

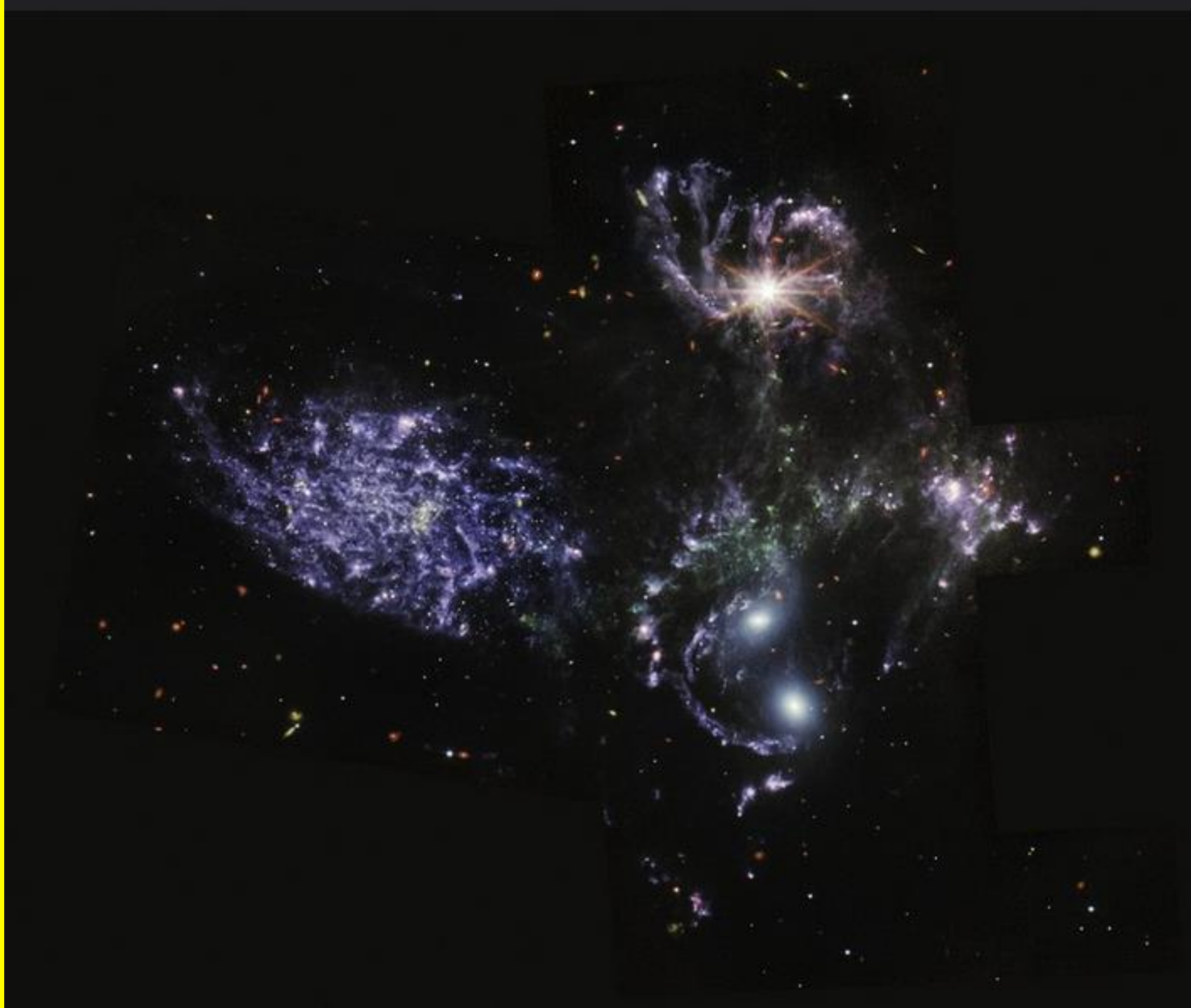


disk-like appearance

spherical appearance







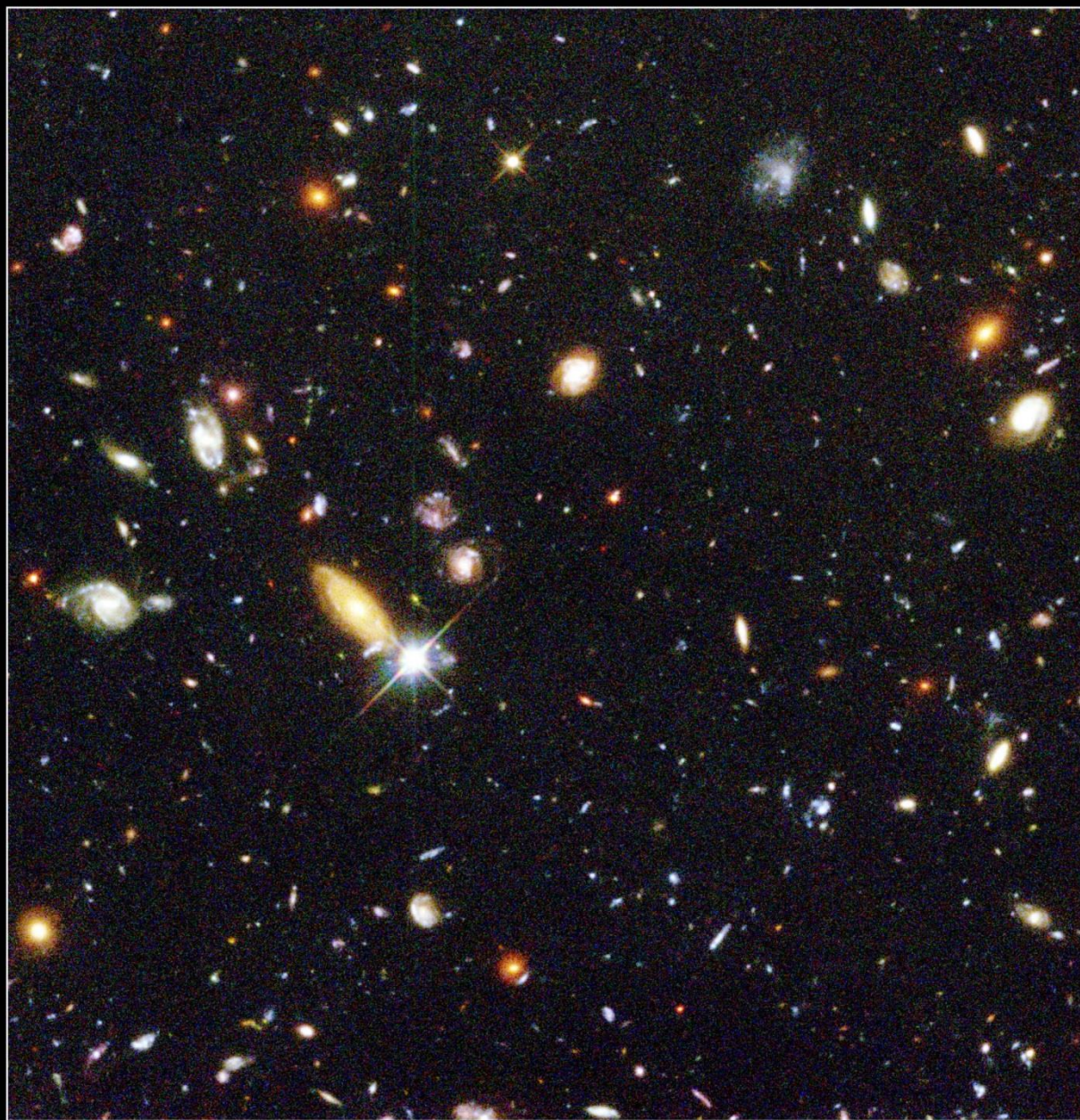
HOBBLE AND WEBB SPACE TELESCOPES
SPIRAL GALAXIES | IC 2163 - NGC 2207



14,500 LIGHT-YEARS
0.5 ARCMIN

Hubble WFFC Filters | [F438M](#) | [F439M](#) | [F439W](#) | Webb M101 Filters | [F110W](#) | [F110W](#) | [F110W](#)

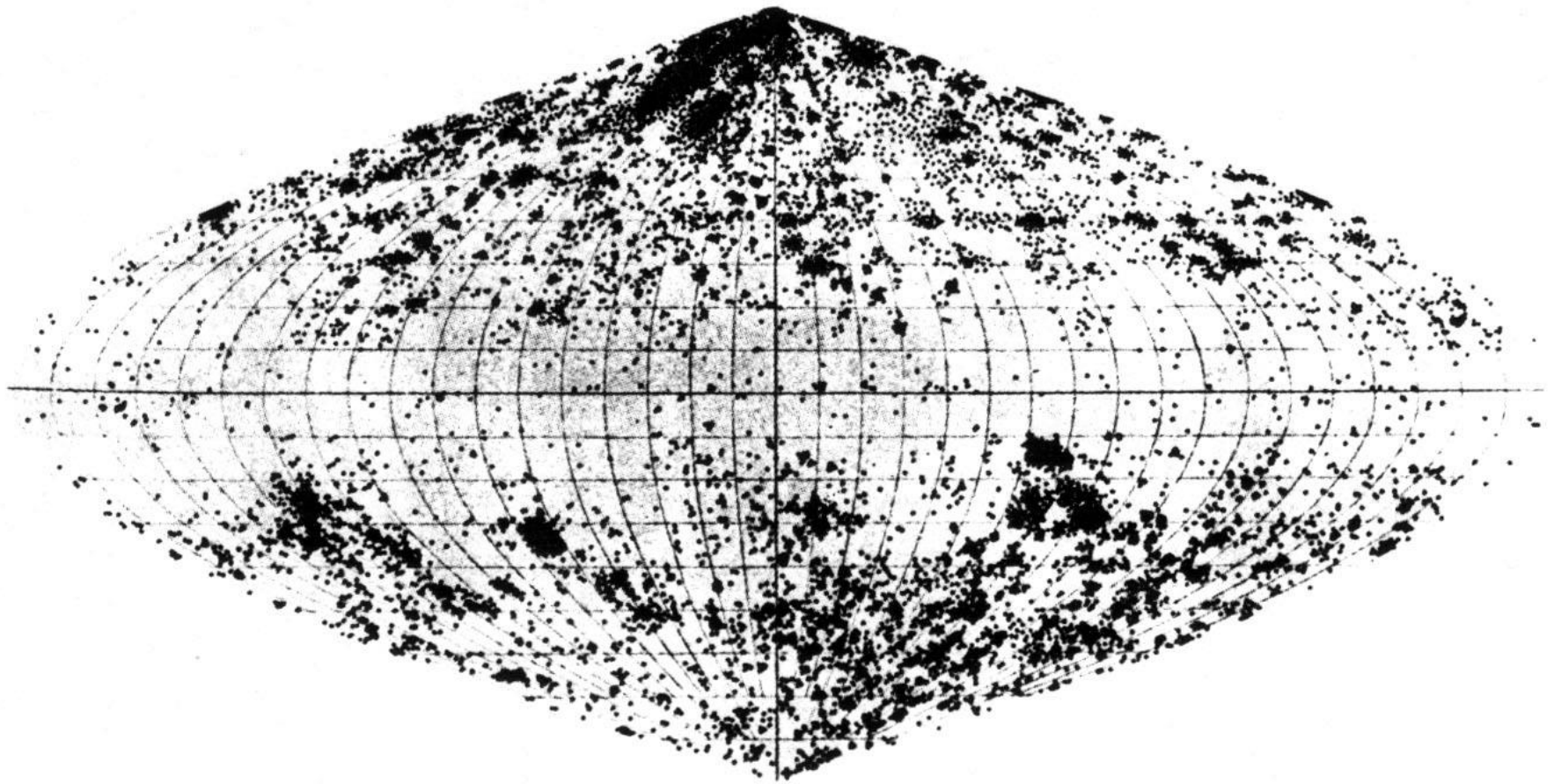




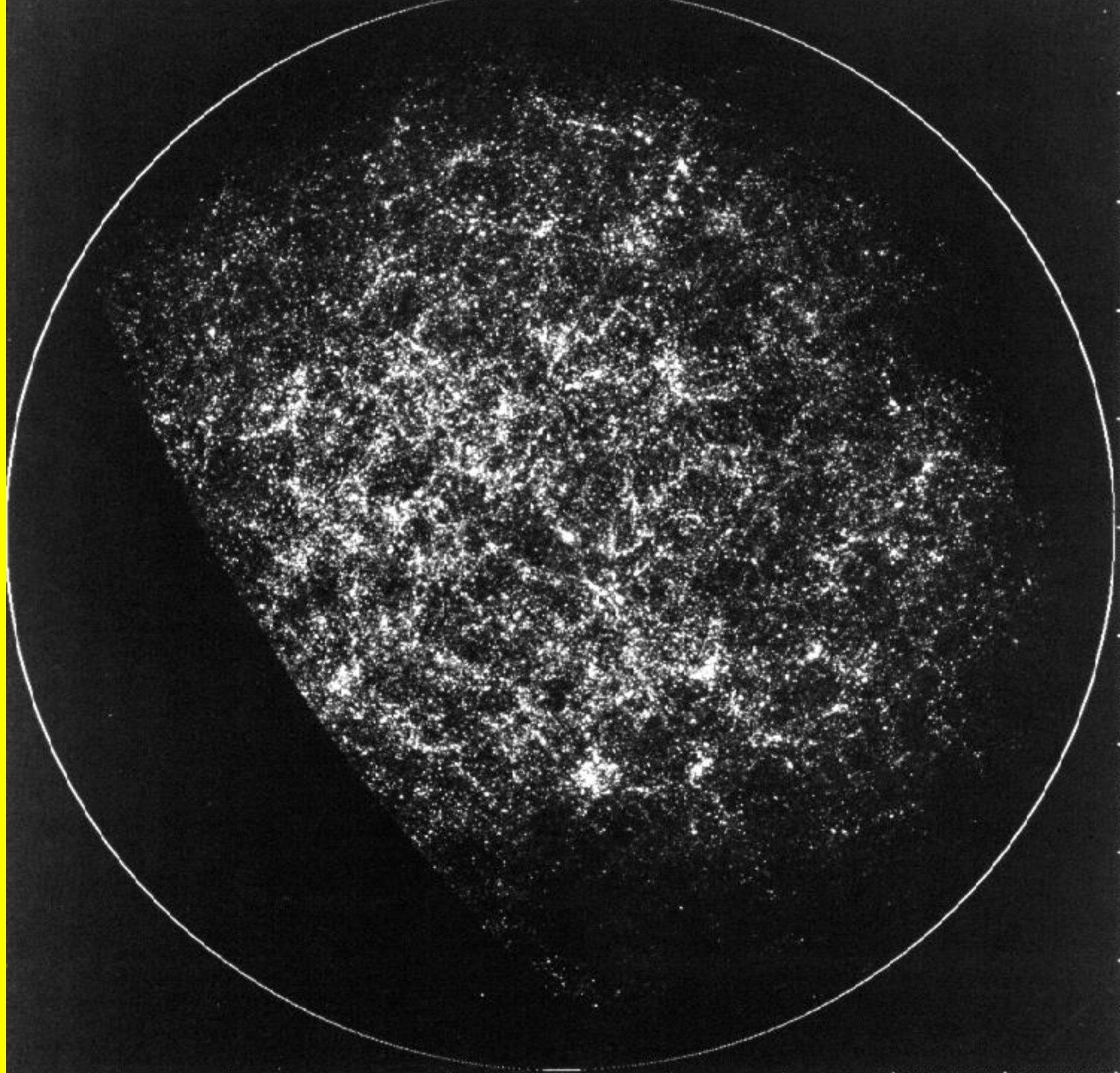
Hubble Deep Field
Hubble Space Telescope • WFPC2

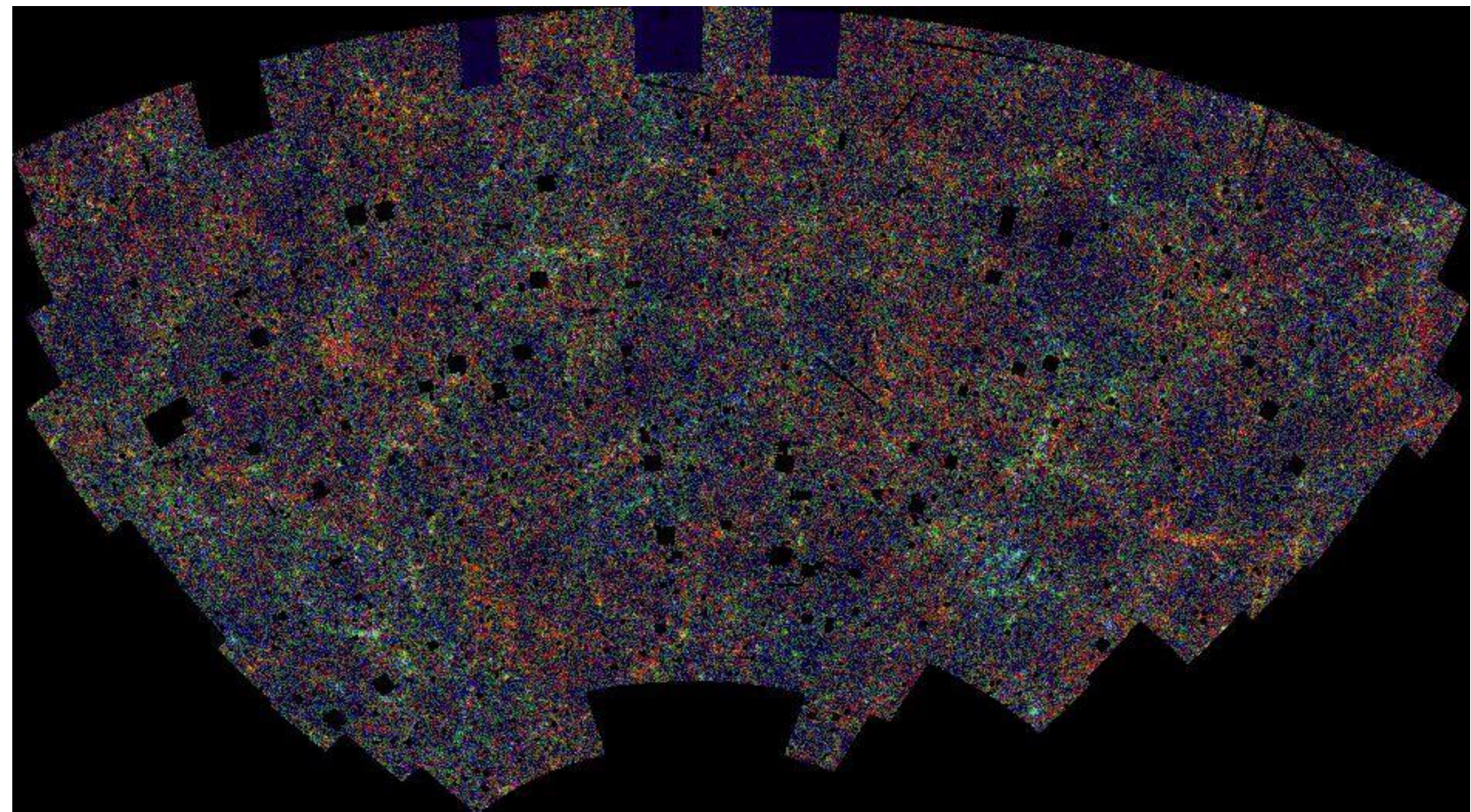


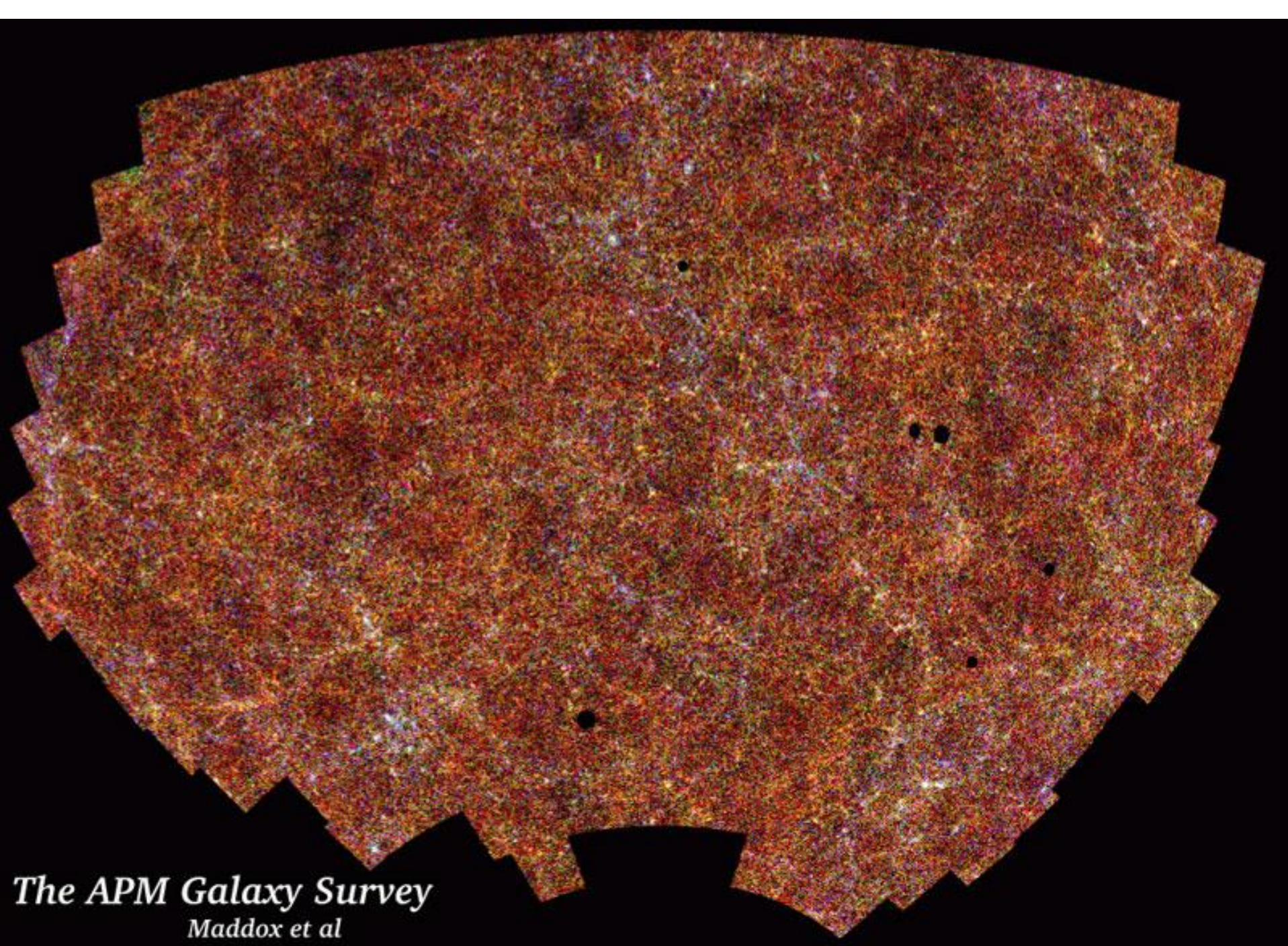
JWST
deep
field



Distribution of galaxies on
the celestial sphere

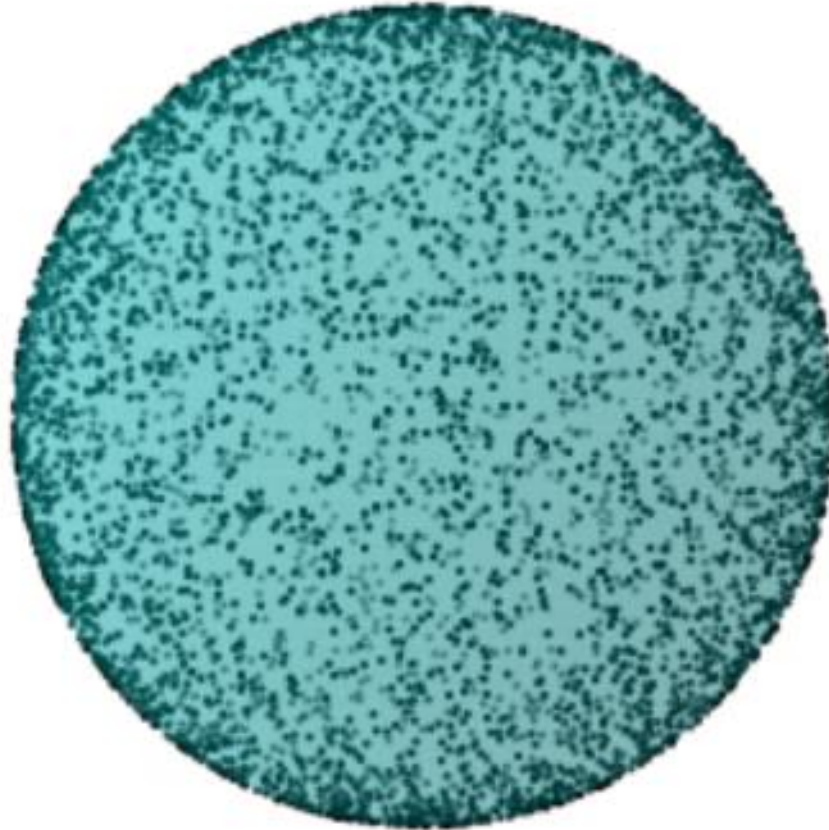






The APM Galaxy Survey
Maddox et al

Correctly distributed - Side View



Random distribution of points on a sphere

The angular correlation function

$$dP = n (1 + w(\theta))d\Omega$$

P - probability

n - the average surface number
density of galaxies

Ω - the solid angle

Groth and Peebles (1977)

$$w(\theta) \sim \theta^{1-\gamma} ; \gamma = 1.8$$

Clusters of Galaxies

Clusters of galaxies are the largest bound structures that currently exist in the Universe.

Clusters of Galaxies



- The Local Group is a small cluster of about 30 galaxies, some of which are binary or multiple galaxies.
- Its two dominant members are the Andromeda (M31) and Milky Way Galaxies.
- M33, the Triangulum Galaxy (*left*), is a smaller spiral. The inset shows a nebula in it.
- M31 and M33, at respective distances of 2.4 and 2.6 million light-years, are the farthest objects you can see with your unaided eye.
- The Local Group also contains four irregular galaxies, at least a dozen dwarf irregulars (*bottom left*) and four regular ellipticals. The rest are dwarf ellipticals or the related “dwarf spheroidals.”
 - The diameter of the Local Group is about 3 million light-years.

Clusters of Galaxies

- The Virgo Cluster (in the direction of the constellation Virgo, but far beyond the stars that make up the constellation), at a distance of about 50 million light-years, is the largest relatively nearby cluster (*top right*).
 - It consists of at least 2000 galaxies spanning the full range of Hubble types, covering a region in the sky over 15° in diameter—about 15 million light-years.
- The Coma Cluster of galaxies (in the direction of the constellation Coma Berenices) is very rich, consisting of over 10,000 galaxies at a distance of about 300 million light-years (*bottom right*)

© 1991 Royal Observatory Edinburgh/Anglo-Australian Observatory, photograph from original U.K. Schmidt plates by David Malin



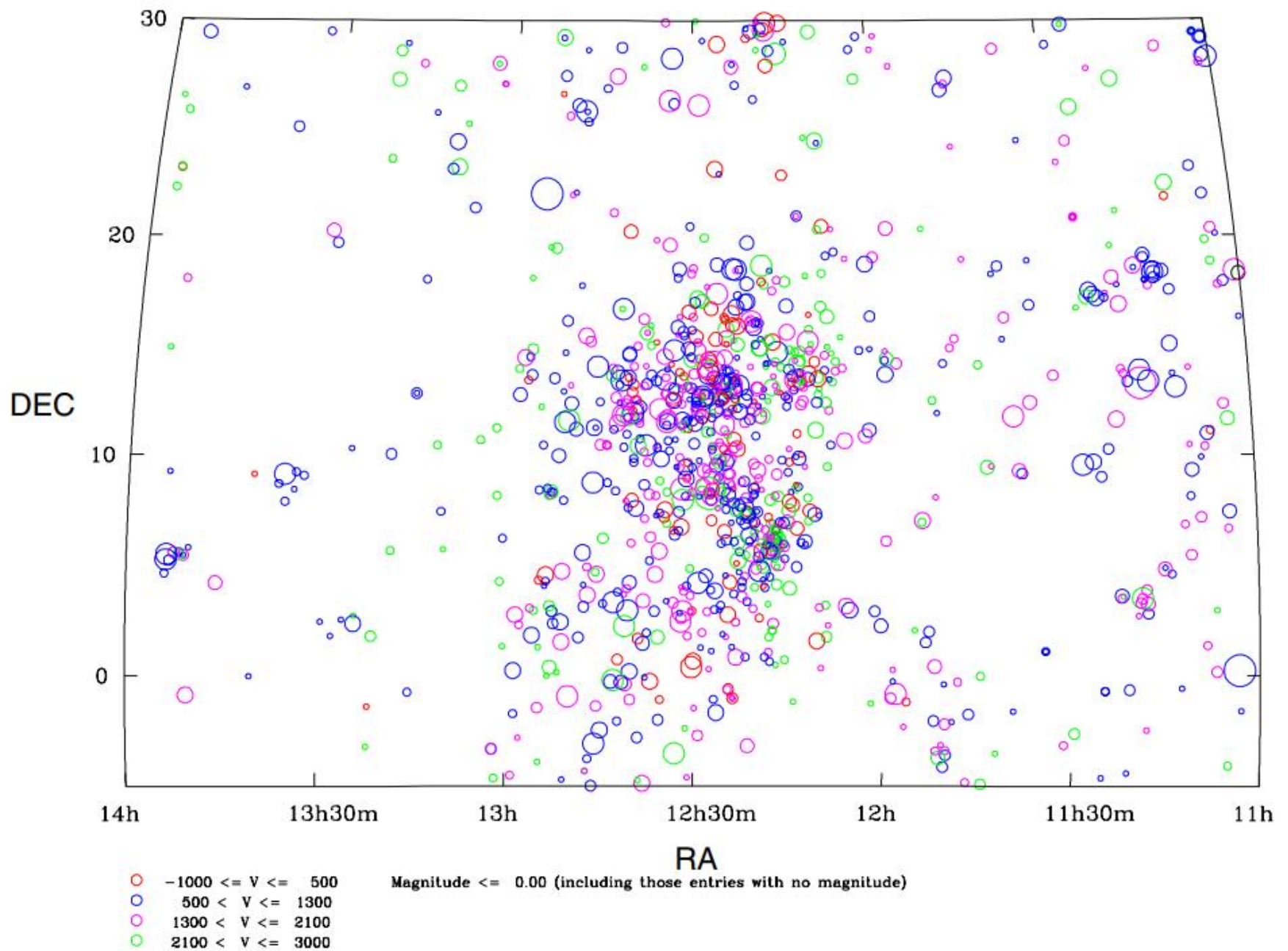
NOAO/Nigel Sharp





The Virgo cluster of galaxies

Virgo



NOAO/Nigel Sharp



Coma Cluster of galaxies

Coma Cluster
0.5-2.0 keV

in X-rays

0.5 Degree

The image is a false-color X-ray map of the Coma Cluster, showing the 0.5-2.0 keV energy range. The central region is the brightest, appearing as a dense core of red and orange, surrounded by a broad, diffuse glow of green and cyan. The outer regions are predominantly blue and purple, indicating lower intensity. Several smaller, distinct sources are visible as bright spots, some with red or orange cores, scattered throughout the field. The overall shape is roughly circular but irregular, following the distribution of the cluster's emission. A scale bar at the bottom left indicates a size of 0.5 degrees.