

Struktura a kinematika galaxií (F7567)

Bruno Jungwiert

I. Stručná historie objevu galaxií



**Astronomical
Institute**
of the Czech Academy
of Sciences

The Milky Way, star clusters, nebulae and galaxies

The historical perspective:

- 1. From Galileo Galilei to Thomas Wright and Immanuel Kant**
- 2. Catalogues of star clusters and nebulae:
From Messier's and Herschel's Catalogues to
the New General Catalogue**
- 3. The Leviathan telescope and the first spiral nebulae**
- 4. The advent of astrophotography:
From the Moon daguerrotype to the first photo of a spiral nebula**
- 5. *The Great Debate***



Image credit: National Geographic, Babak Tafreshi

Galaxy, galaxies – Etymology:

γαλαξίας

κύκλος

(galaxias kyklos = milky circle)



Origine della Via Lattea (The Origin of the Milky Way), Tintoretto, c. 1575

1.

**From Galileo Galilei to
Thomas Wright and Immanuel Kant**

Galileo Galilei (1564 - 1642)

S I D E R E V S
N V N C I V S

MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò

PHILOSOPHIS, atq; ASTRONOMIS, quæ à

GALILEO GALILEO
PATRITIO FLORENTINO

Patauini Gymnasij Publico Mathematico

PERSPICILLI

Nuper à se reperti beneficio sunt observata in LVNÆ FACIE, FIXIS IN-
NUMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,

Apprime verò in

QVATVOR PLANETIS

Circa IOVIS Stellam dispartibus interuallis, atque periodis, celesti-
tate mirabili circumuolutis; quos, nemini in hanc vsque
diem cognitos, nouissimè Author depræ-
hendit primus; atque

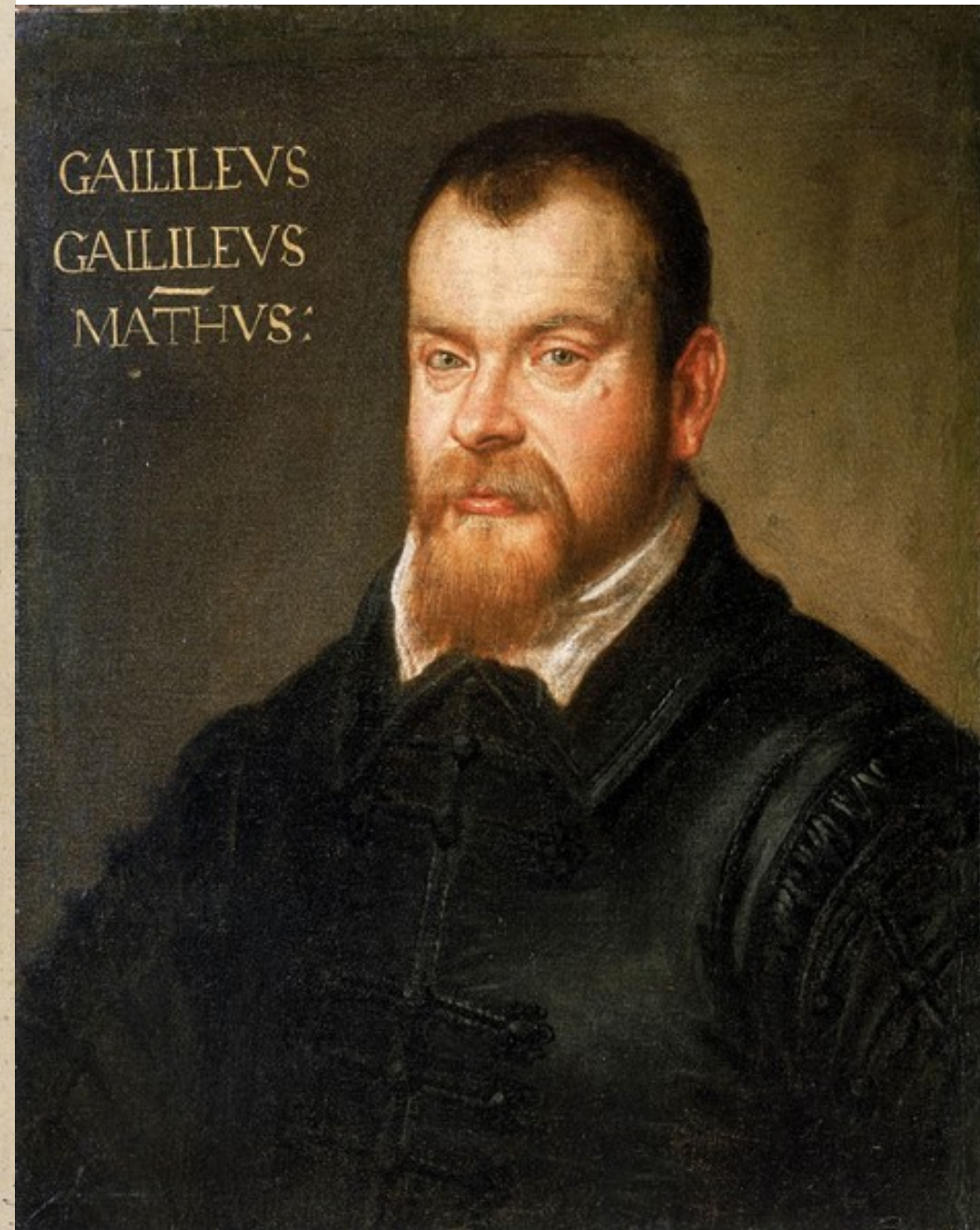
MEDICEA SIDERA
NUNCVPANDOS DECREVIT.



VENETIIS, Apud Thomam Baglionum. M D C X.

Superiorum Permissu, & Privilegio.

M VIII. 22. 1A.



Galileo's portrait by Tintoretto, 1607

In his book ***Sidereus nuncius*** (*Starry messenger*), published in **1610**, Galileo Galilei reports about his revolutionary discoveries (he made the first astronomical observations of the sky using a telescope):

- craters and mountains on the Moon's surface
- the phases of Venus
- four moons of Jupiter (later dubbed the *Galilean moons*)
- an extended structure around Saturn (later recognized to be a ring)
- dark spots on the Sun
- thousands of stars
- nebulae and star clusters (see next slides).

Watch the 1st chapter of the movie *Eyes on the Skies (400 years of telescopes)*:
<https://www.youtube.com/watch?v=jRUaQFsDcJQ>

He resolves the Milky Way light into individual stars unseen by the naked eye and conjectures that the whole Milky Way band on the sky is made of faint and distant stars. This idea is further developed by Thomas Wright, Immanuel Kant and William Herschel (see next slides).

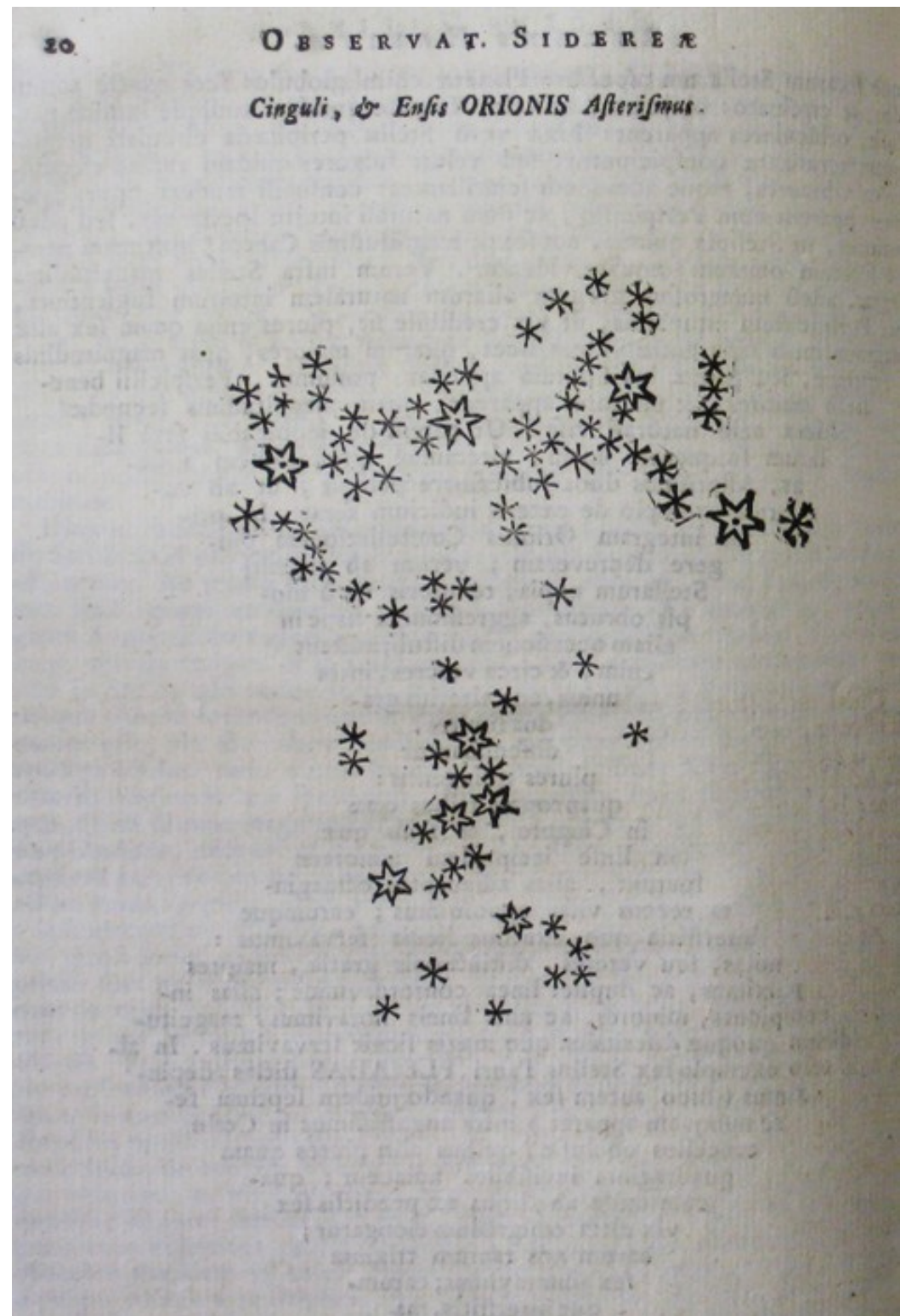
Some of the next slides show pages from the Galileo's book (the Orion nebula, the Beehive cluster, the Pleiades cluster): on them, symbols of stars visible by the naked eye show a central dot, to distinguish them from many more stars seen by Galileo through his telescope.



The Orion
constellation

and

*Nebulosa
Orionis*
(The Orion
Nebula, M42)



OBSERVAT. SIDEREAE

coetum offendes. Amplius (quod magis mirabilis) Stellae ab Astronomis singulis in hanc usque diem NEBVLOSAM appellatae, Stellarum mirum immodum confitarum grege sunt; ex quarum radiorum commixtione, dum unaqueque ob exilitatem, seu maximam à nobis remotionem, oculorum aciem fugit, candor ille confurgit, qui densior pars coeli, Stellarum, aut Solis radios retorquere valens, hucusque creditus est. Nos ex illis nonnullas obseruauimus; & duarum Asterismos subnectere voluimus.

In primo habes NEBVLOSAM Capitis Orionis appellatam, in qua Stellas viginti vnas numerauimus.

Secundus NEBVLOSAM PRAESEPE nuncupatam continet, quae non vna tantum Stella est, sed congeries Stellarum plurium quam quadraginta: nos praeter Afellos triginta sex notauimus in hunc, qui sequitur ordinem dispositas.

NEBVLOSA ORIONIS.



NEBVLOSA PRAESEPE.



The Orion Nebula (M42)

(Galileo's picture versus a modern photo taken by the Hubble Space Telescope)



Notes:

- **M42** is a diffuse **emission nebula**, located **1,350 light years** away
- it is the nearest large **region of ongoing star formation**
- angular size: **1 degree** (two full Moons), size of **25 light years**

Image credit: NASA/HST

The star cluster *Praesepe* (*Manger*, or *Beehive cluster*, M44) in the constellation of Cancer

OBSERVAT. SIDEREAE

coetum offendet. Amplius (quod magis mirabilis) Stellae ab Astronomis singulis in hanc usque diem NEBVLOSAE appellatae, Stellarum mirum immodum confitarum greges sunt; ex quarum radiorum commixtione, dum vnaqueque ob exilitatem, seu maximam à nobis remotionem, oculorum aciem fugit, candor ille confurgit, qui densior pars caeli, Stellarum, aut Solis radios retorquere valens, hucusque creditus est. Nos ex illis nonnullas obseruauimus; & duarum Asterismos subnectere voluimus.

In primo habes NEBVLOSAM Capitis Orionis appellatam, in qua Stellas vigintivnas numerauimus.

Secundus NEBVLOSAM PRAESEPE nuncupatam continet, quae non vna tantum Stella est, sed congeries Stellarum plurium quam quadraginta: nos praeter Afellos triginta sex notauimus in hunc, qui sequitur ordinem dispositas.

NEBVLOSA ORIONIS.



NEBVLOSA PRAESEPE.

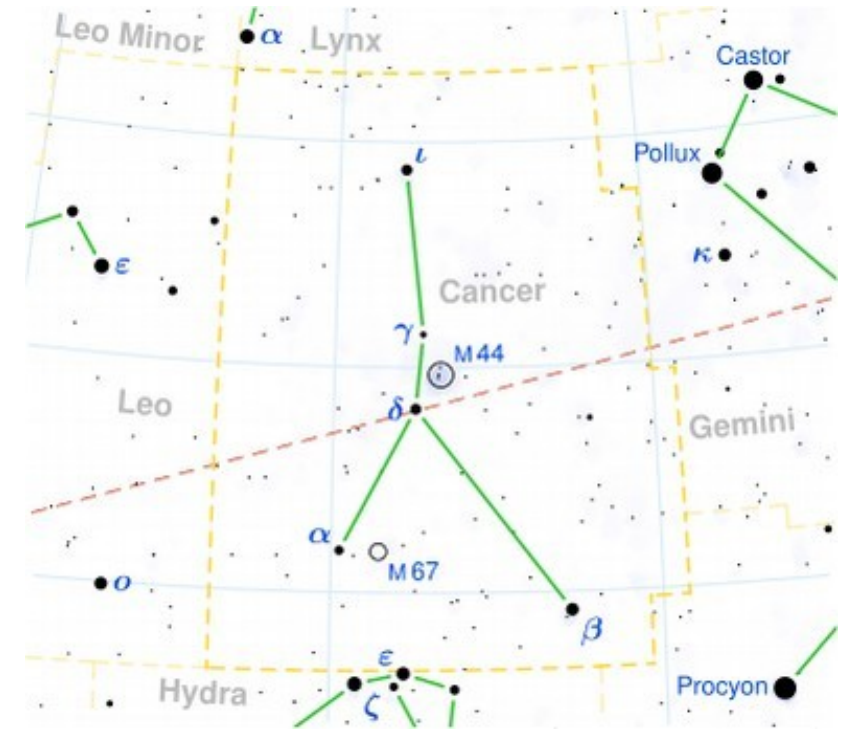


Image credit: Sloan Digital Sky Survey

- Notes:
- Ptolemy (2nd century A.D.): "nebulous mass in the breast of Cancer"
 - Galileo (in 1610) sees at this place 40 stars with his telescope
 - **M44** is one of the nearest **open clusters**, located **600 light years away**
 - **700 million years old**, it contains around **1,000 stars** with a total mass equivalent to approximately of 500 Suns
 - angular size: **1.5 degrees** (3 times the full Moon), **size of 80 light years**

The *Pleiades* (The *Seven Sisters*, M45)



- Notes:
- **M44** is one of the nearest **open clusters**, located **450 light years away**
 - **100 million years old**, it contains **over 1,000 stars**
 - angular size: **2 degrees** (4 times the full Moon), **size of 80 light years**



Pleiades by Elihu Vedder (1885)

Quod tertio loco à nobis fuit obseruatum, est ipsius-
net LACTEI Circuli essentia, seu materies, quam Per-
spicilli beneficio adeò ad sensum licet intueri, vt & alter-
cationes omnes, quæ per tot sæcula Philosophos excru-
ciant ab oculata certitudine dirimantur, nosque à verbosis
disputationibus liberemur. Est enim GALAXYA nihil
aliud, quam innumerarum Stellarum coaceruatim con-
sitarum congeries; in quamcunq; enim regionem illius Per-
spicillum dirigas, statim Stellarum ingens frequentia se se
in conspectum profert, quarum complures satis magnæ, ac
valde conspicuæ videntur, sed exiguarum multitudo pro-
fus inexplorabilis est.

At cum non tantum in GALAXYA lacteus ille candor,
veluti albicantis nubis spectetur, sed complures consimilis
coloris areolæ sparsim per æthera subfulgeant, si in illarum
quamlibet Specillum conuertas Stellarum conspiciatarum
cgtum



El nacimiento de la Vía Láctea (The birth of the Milky Way), Peter Paul Rubens, c. 1637



Thomas Wright
(1711-1786)

1750:
An original theory or
new hypothesis of
the Universe

A N
ORIGINAL THEORY
O R
NEW HYPOTHESIS
O F T H E
U N I V E R S E,

Founded upon the
L A W S of N A T U R E,
AND SOLVING BY
MATHEMATICAL PRINCIPLES
T H E

General PHÆNOMENA of the VISIBLE CREATION;
AND PARTICULARLY
The VIA LACTEA.

Compris'd in Nine Familiar LETTERS from the AUTHOR to his FRIEND.
And Illustrated with upwards of Thirty Graven and Mezzotinto Plates,
By the Best MASTERS.

By **THOMAS WRIGHT**, of DURHAM.

*One Sun by Day, by Night ten Thousand shine,
And light us deep into the DEITY.* Dr. YOUNG.

L O N D O N:
Printed for the AUTHOR, and sold by H. CHAPPELLE, in Grosvenor-Street.

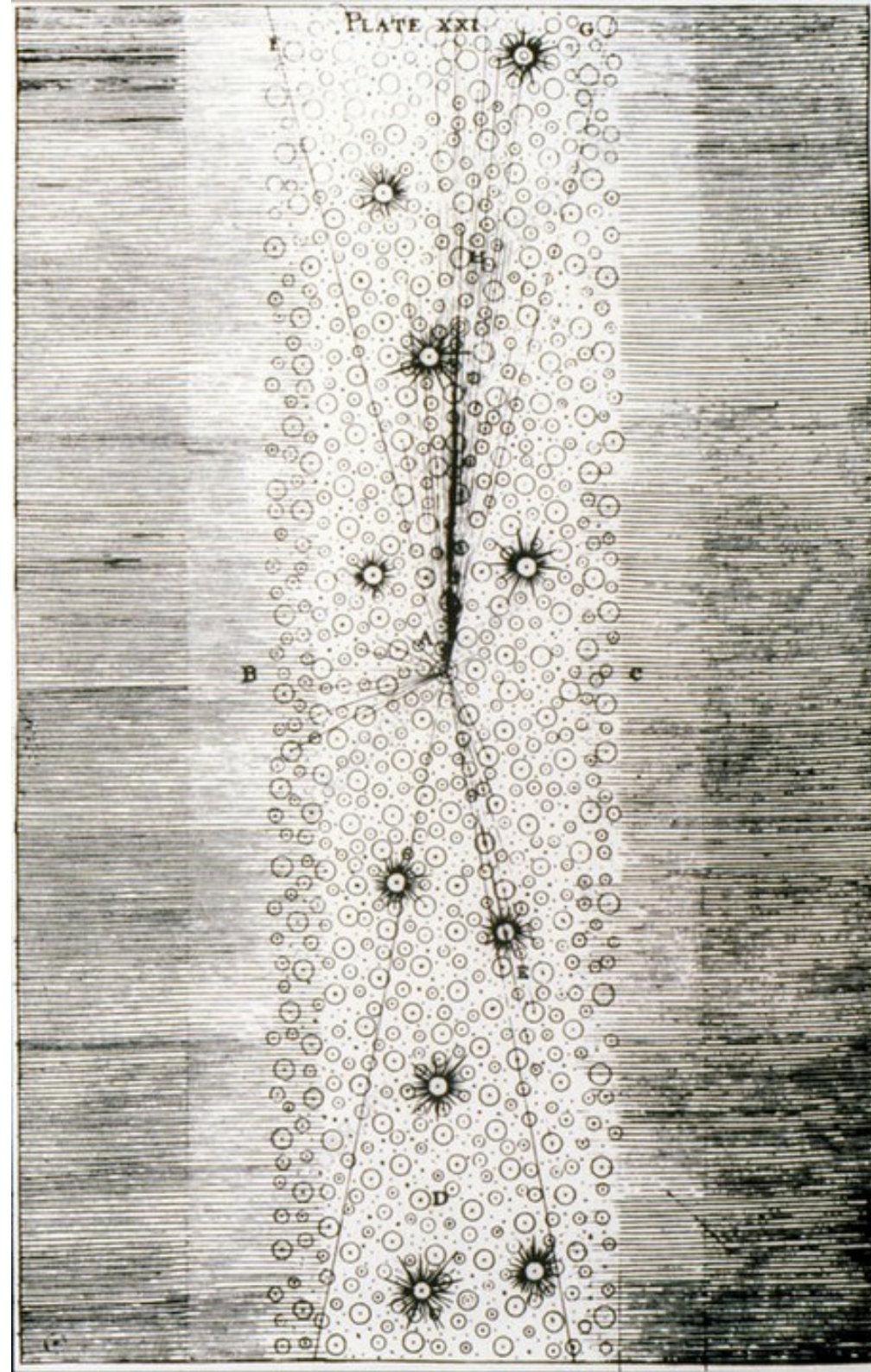
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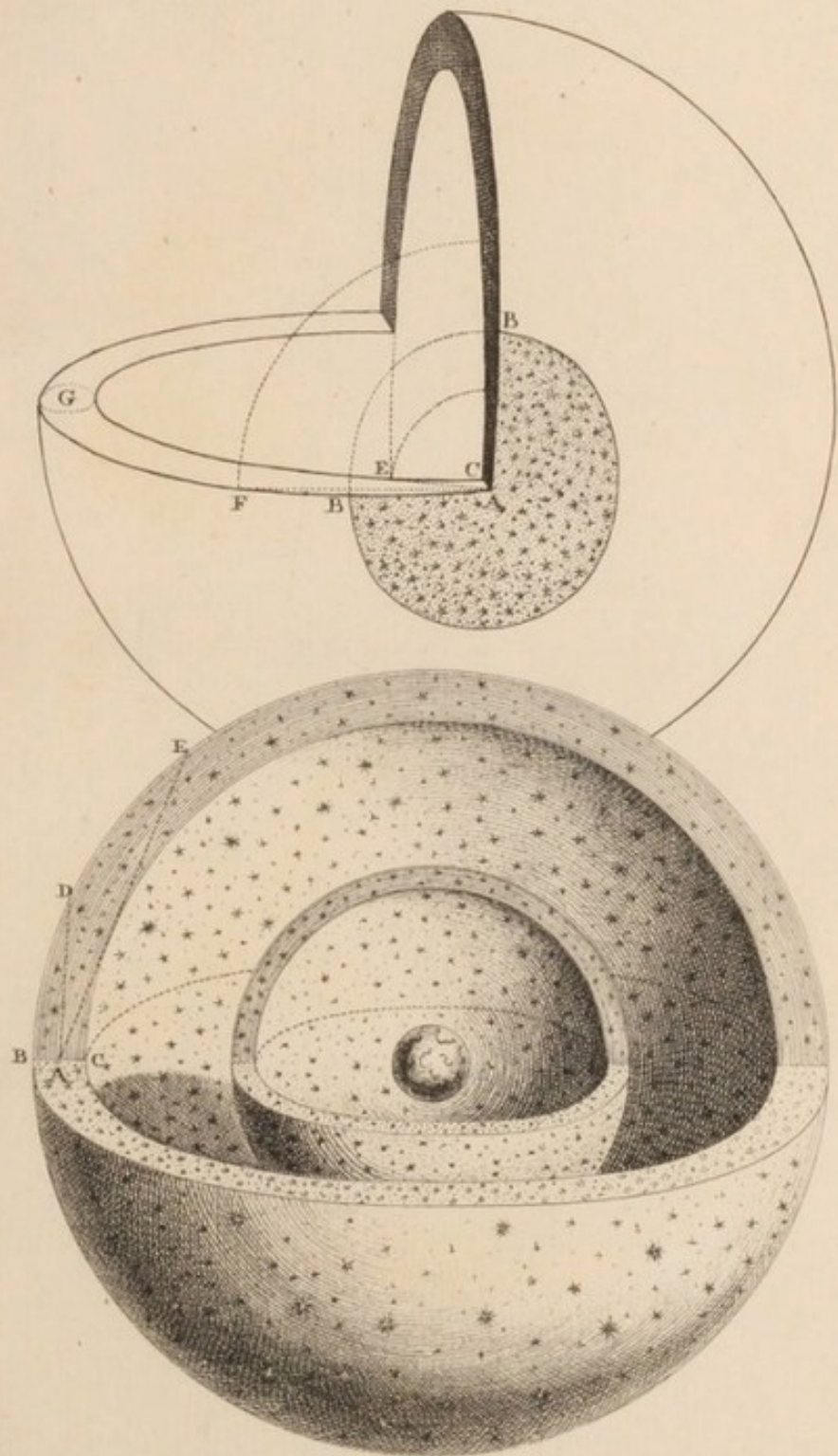


**Thomas Wright's
New hypothesis of the Universe
(1750):**

The appearance of the Milky Way
explained as:

*"an optical effect due to our
immersion in what locally
approximates to a flat layer of
stars."*

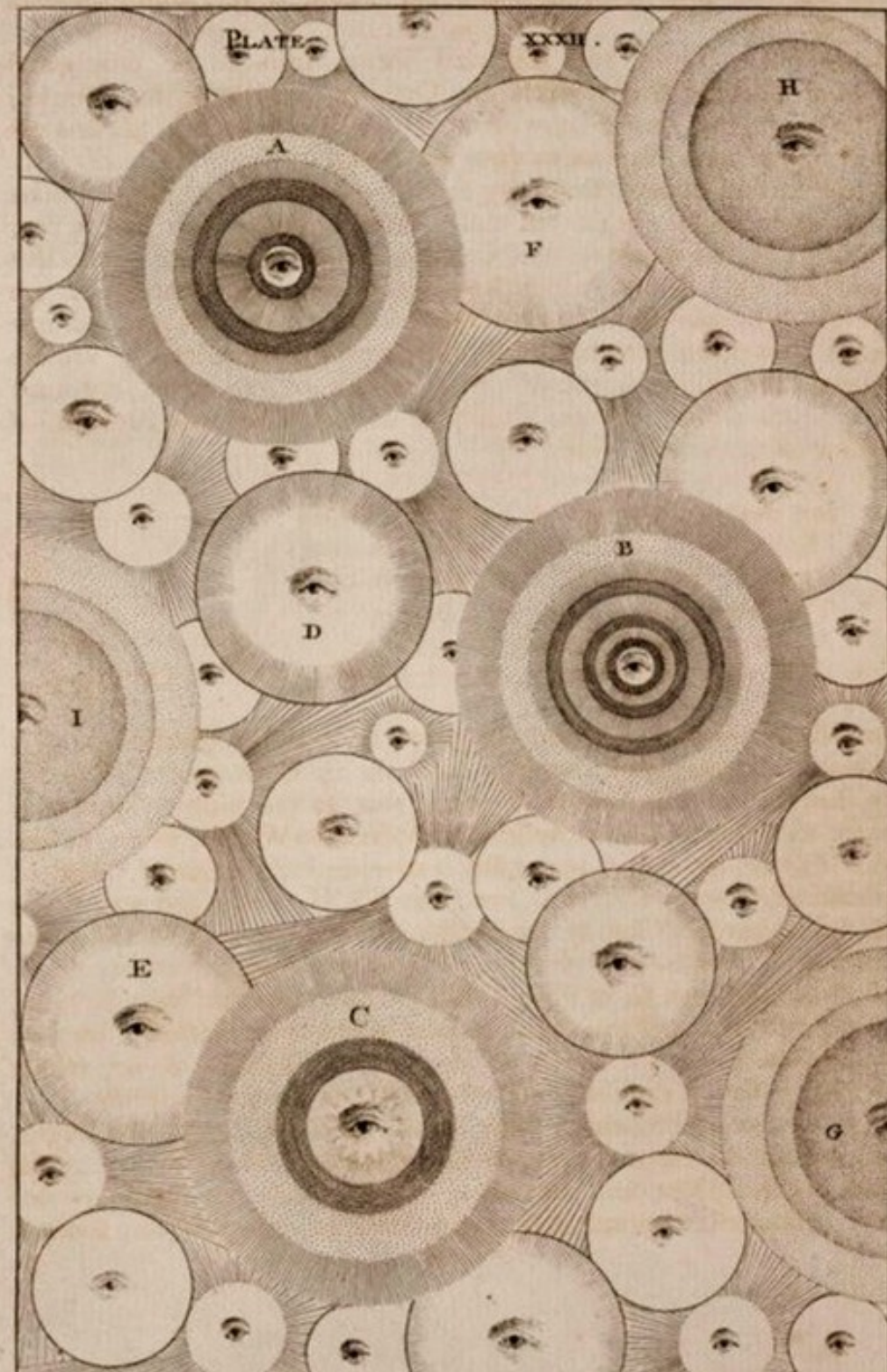




Developing Wright's ideas further: this locally flat layer of stars could be part of a larger, globally non-flat system, possibly a spherical shell. More spherical shells could be nested inside each other.

Wright conjectures that many faint nebulae are actually distant galaxies:

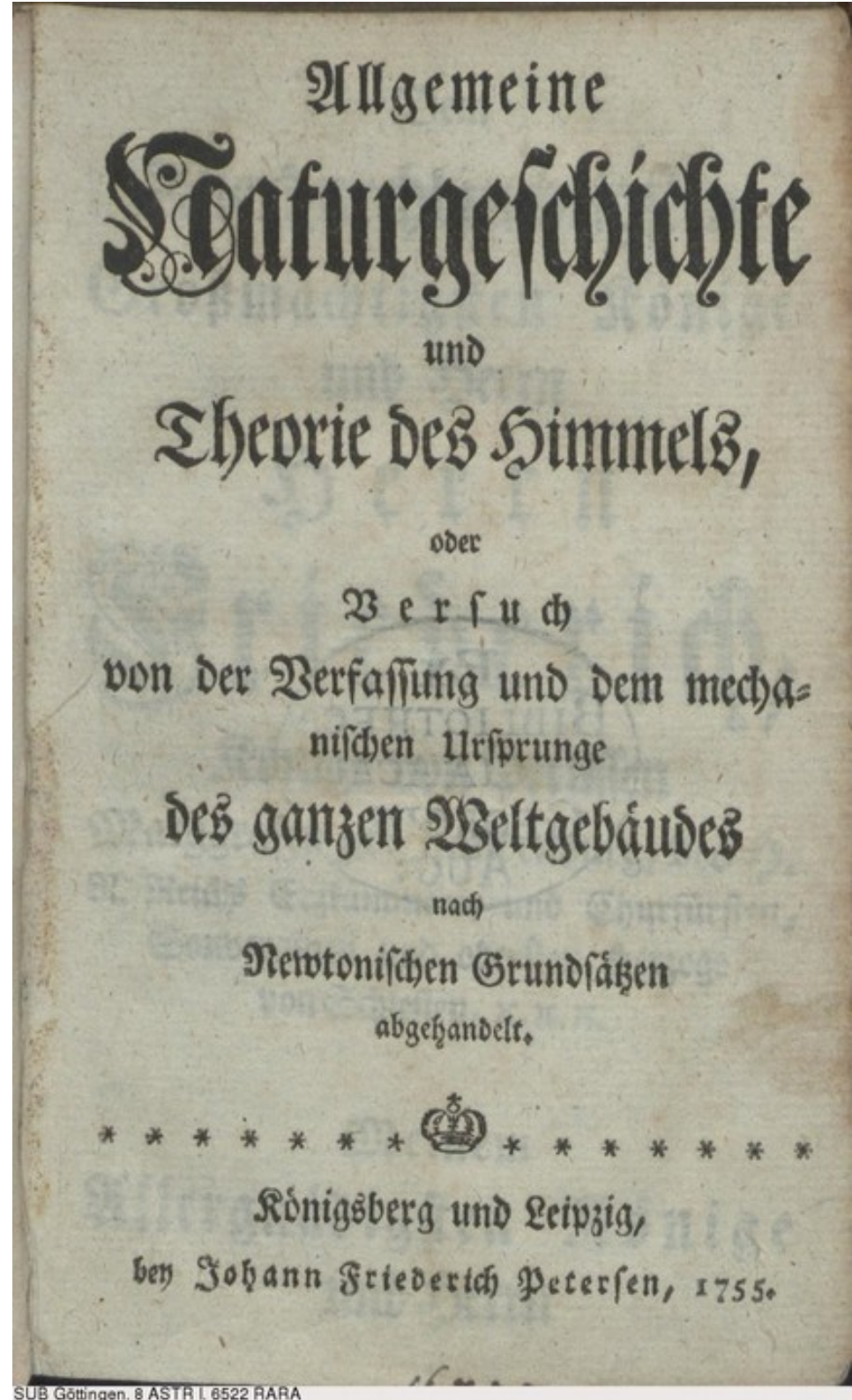
“... the many cloudy spots, just perceivable by us, ..., in which tho' visibly luminous spaces, no one star or particular constituent body can possibly be distinguished; those in all likelihood may be external creation, bordering upon the known one, too remote for even our telescopes to reach.”





**Immanuel Kant
(1724-1804)**

**1755:
*Universal natural history and
theory of the heavens***



Kant's ... *Theory of the Heavens* (1755):

Immanuel Kant speculates that the Milky Way might be a **rotating body** of a huge number of **stars**, held together by **gravitational forces** akin to the Solar System but on much larger scales (the Newton's theory of gravity, successfully explaining the planetary mechanics within our Solar System, emerges in 1680s).

The resulting **disk of stars** would be seen as a band on the sky from our perspective inside the disk.

He also conjectures that some of the nebulae visible in the night sky might be separate "**galaxies**" themselves, similar to our own. He refers to these "**extragalactic nebulae**" as "**island universes**".



2.

Catalogues of star clusters and nebulae:

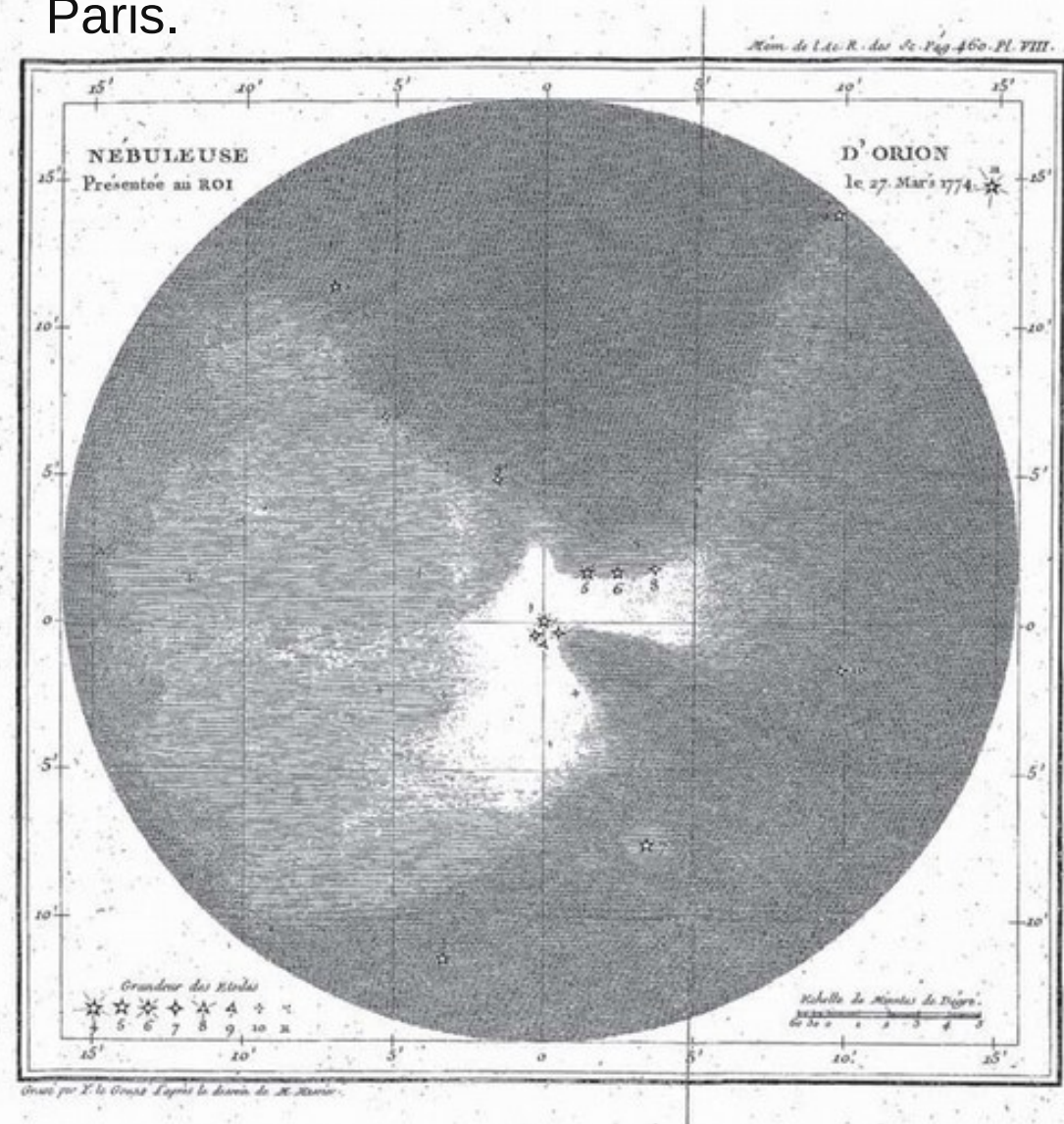
**From Messier's and Herschel's Catalogues
to the New General Catalogue**

Charles Messier (1730-1817):
Catalog of nebulae and star clusters
(1st version: 1774 – 45 objects,
final version: 1781 – 103 objects,
+ 7 objects added later)

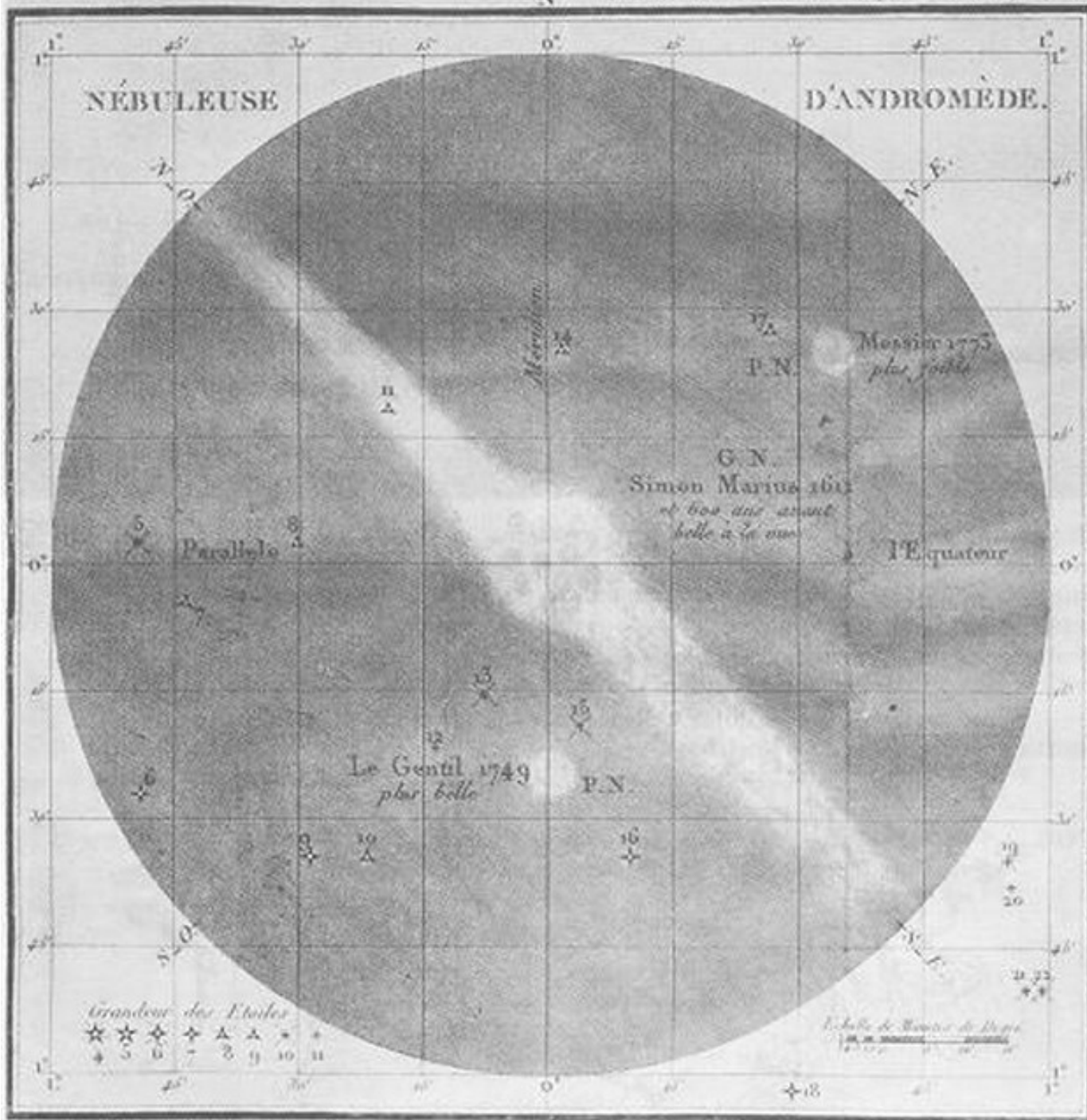


Messier is a “comet hunter”. He creates his catalog with the goal to make identification of newly arriving comets easier.

Observations are made from *Hotel du Cluny*, Paris.



Messier's drawing of the Orion nebula (M42)

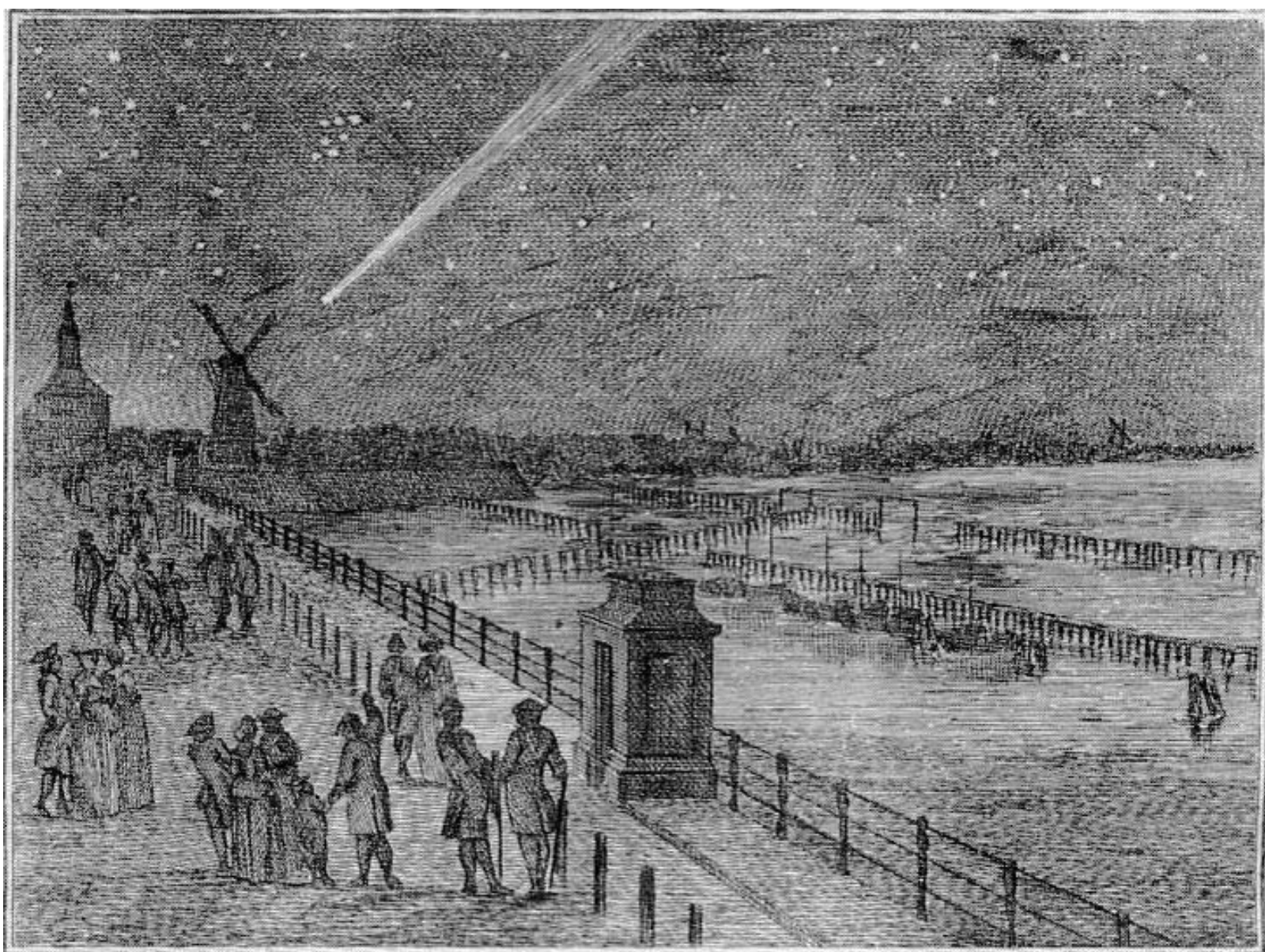


Messier's drawing of the Andromeda nebula M31 (today known as The Andromeda galaxy)



A modern photo of the Andromeda galaxy

Image credit: By Adam Evans - M31, the Andromeda Galaxy
<https://commons.wikimedia.org/w/index.php?curid=12654493>



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De Comect of Staart Ster te zien vande Amstel sluyste Amsterdam 1699.

Messier 45 (M 45): The Pleiades (Seven Sisters) star cluster



The Pleiades and the Moon

<http://www.derekscope.co.uk/moon-pleiades/>



The Pleiades and the comet Lovejoy C/2014 Q2

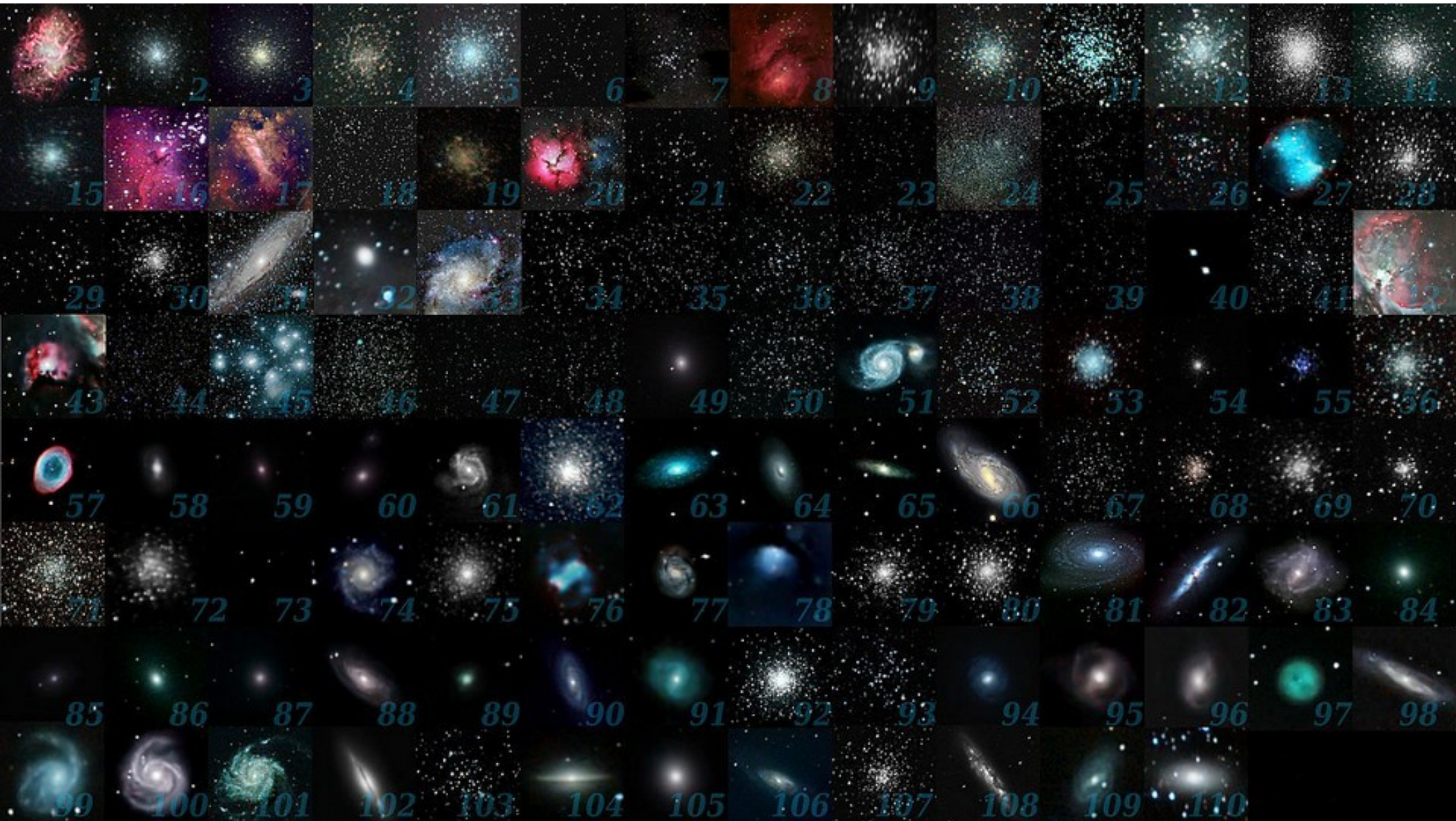
(Photo by Rick Bryant on 1/17/15)



The *Nebra disk* with Pleiades, 1600 B.C.
https://en.wikipedia.org/wiki/Nebra_sky_disk

A nebula, a galaxy or a star cluster ?

110 objects in the Messier's Catalogue of nebulae and star clusters
(images in this mosaic contain modern photos of Messier's objects)



Note:

The stars clusters, nebulae and galaxies contained in the Messier's catalog are often referred to, even today, by their numbers in this catalog, preceded by capital *M* (for Messier), for example:

M 1 = the Crab nebula

M 13 = the Great globular cluster in the constellation of Hercules

M 31 = the Great Andromeda nebula (the Andromeda galaxy)

M 33 = the Triangulum galaxy

M 42 = the Orion nebula

M 44 = the Praesepe (Beehive) cluster

M 45 = the Pleiades (Seven sisters) cluster



Comparing angular sizes of the Moon and nearby nebulae & galaxies

Image credit:

<https://stargazerslounge.com/topic/208533-comparing-the-size-of-deep-sky-objects/>

1 – Moon, 2 – Andromeda galaxy (M31), 3 – Triangulum galaxy (M33), 4 – Orion nebula (M 42), 5 – Lagoon nebula (M 5), 6 – Pinwheel galaxy (M 101), 7 – Sculptor (Silver coin) galaxy (NGC 253), 8 – Veil nebula (NGC 6960), 9 – SN1006, 10 – Helix nebula (NGC 7293), 11 – Sombrero galaxy (M 104), 12 – Crab nebula (M 1), 13 – Comet Hale-Bopp.

Color coding: galaxies – star forming nebulae – supernova remnants – planetary nebulae

Star forming nebulae in the Orion constellation, seen above Pico del Teide volcano



© Cesar & Carlos Tedejor
Orion's Belt & Sword over Teide's peak (Tenerife)

<http://apod.nasa.gov/apod/ap160328.html>



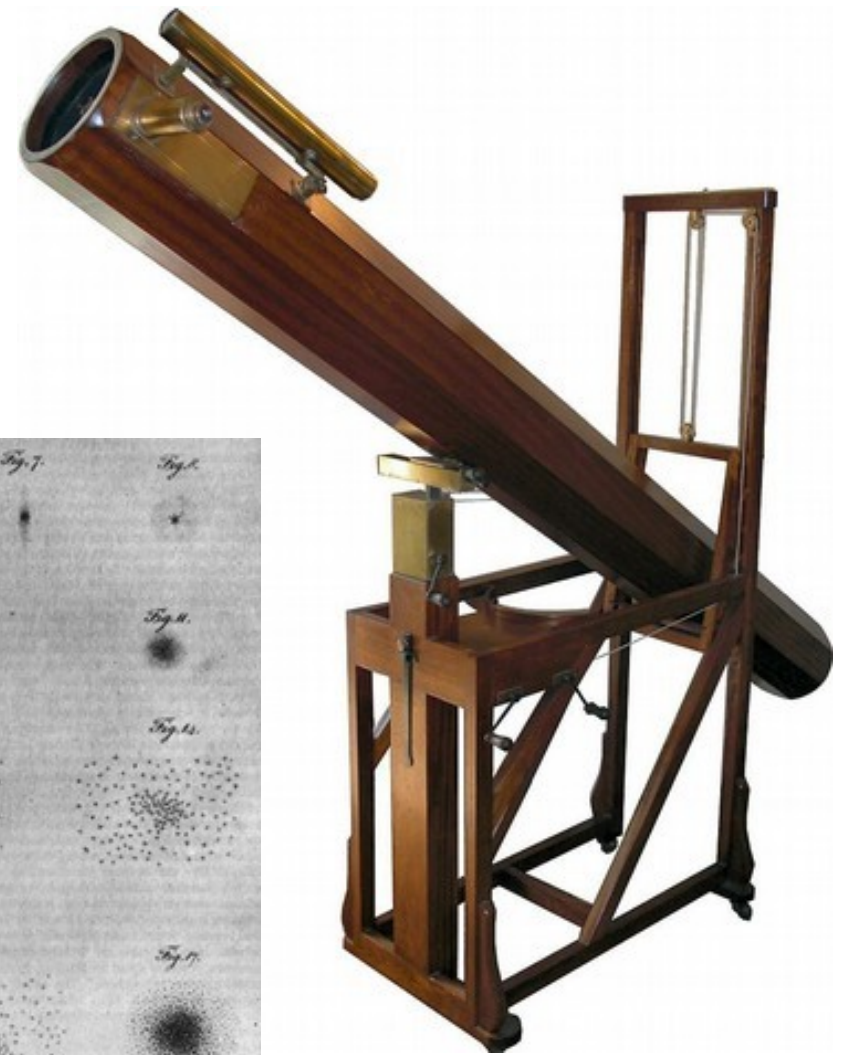
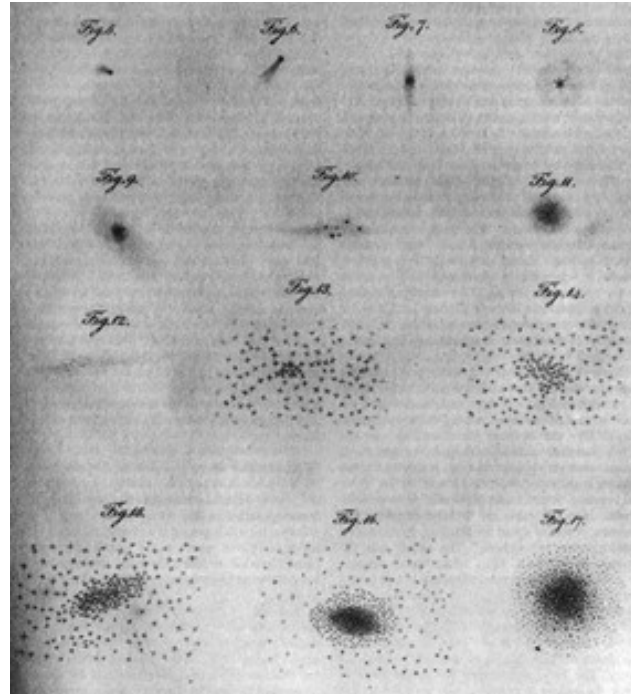
Image credit: Stephen Rahn / Tom Buckley-Houston

The Moon (half a degree angular size) and the Andromeda galaxy (M31) (3 degrees).

The image is a collage of two separate photos: 1) an ordinary camera photo of the sky showing the Moon, Venus and Mercury; 2) a UV photo of the Andromeda galaxy taken by the NASA's GALEX space telescope. Angular sizes are respected, positions are not.



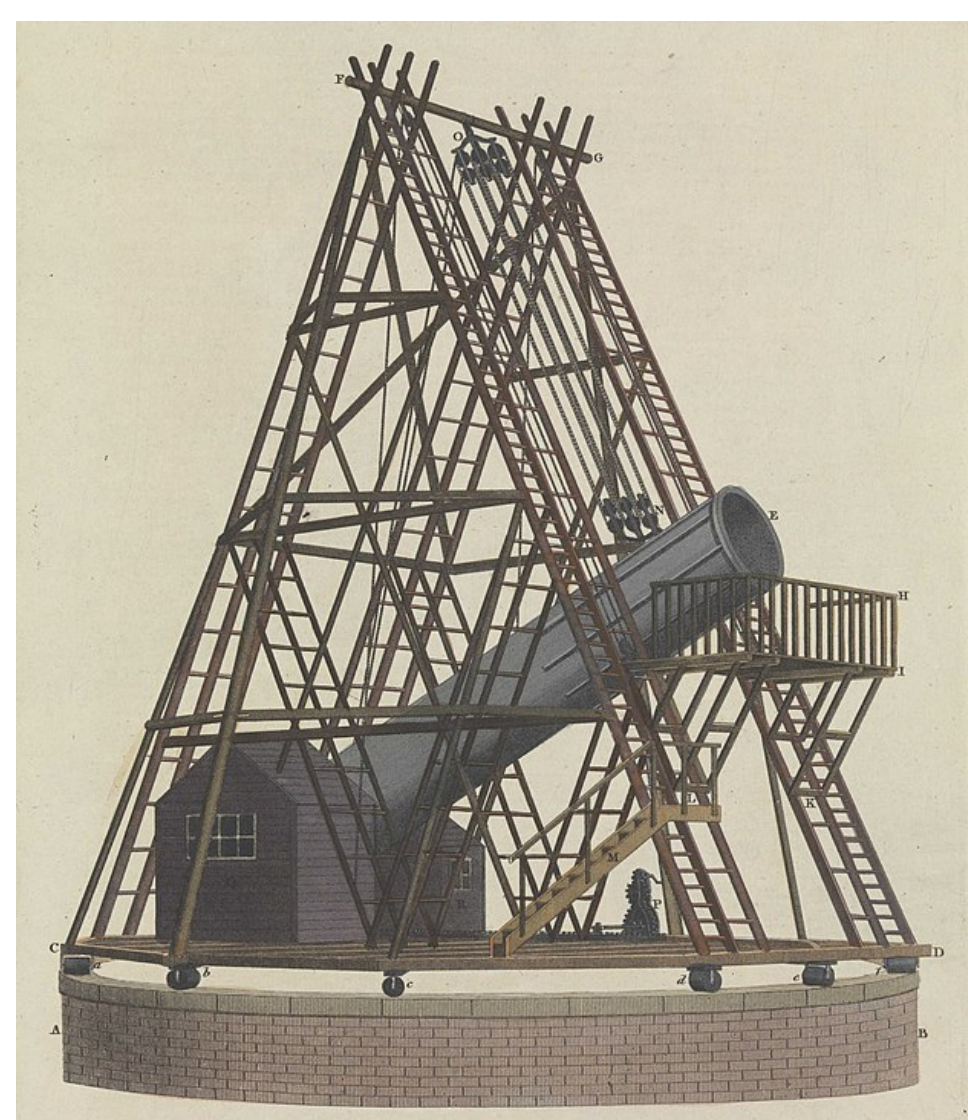
William Herschel:
(1738 - 1822)



Catalogue of nebulae and clusters of stars

1786: 1,000 entries
1789: 2,000 entries
1802: 2,500 entries

(Note:
in 1781, Herschel discovers Uranus,
the 7th planet of our Solar system)

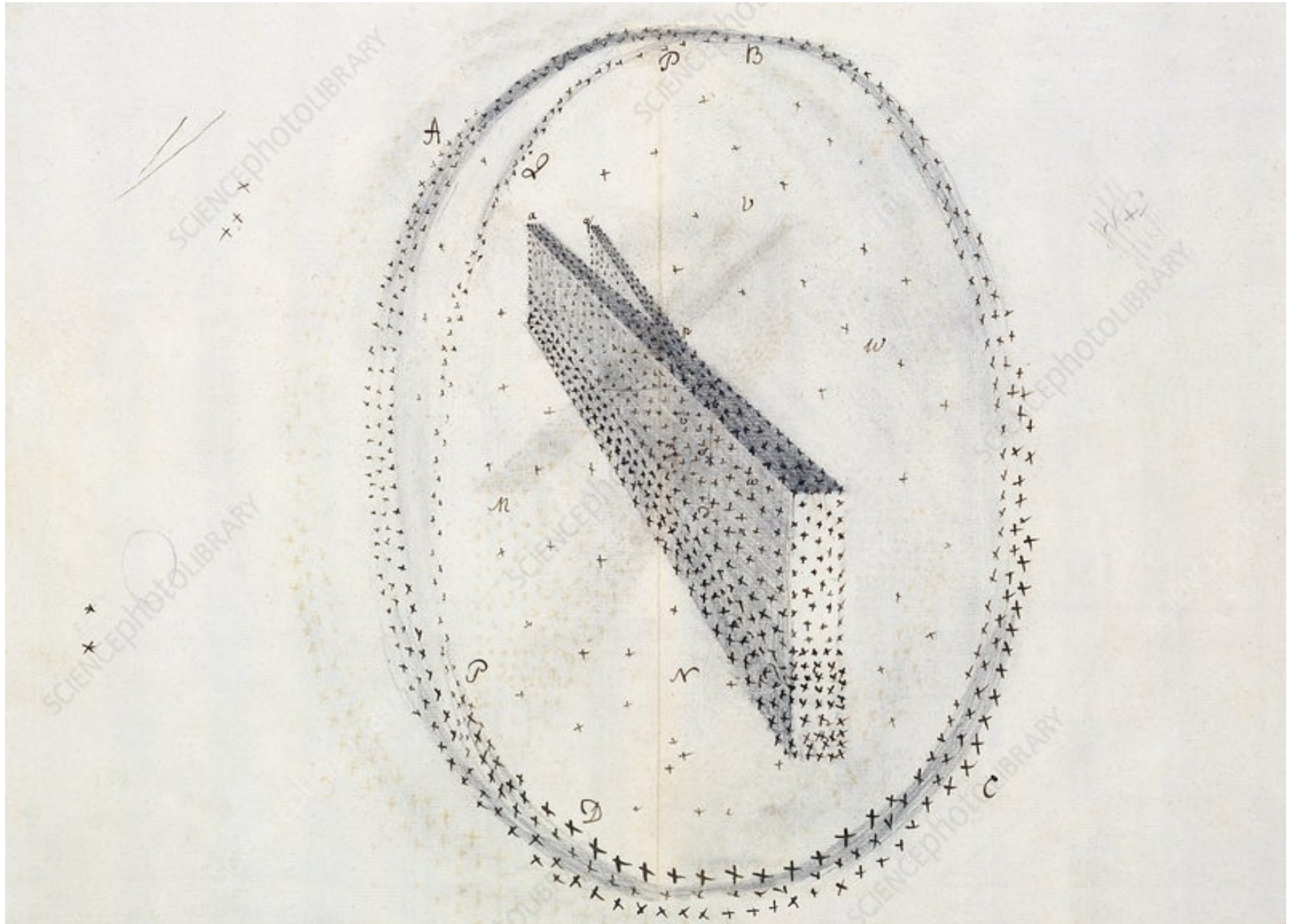


Herschel's Great Forty-Foot telescope, 1789
(48-in/120-cm mirror, 12-m focal length;
the largest mirror until 1845)

Image credit: By
<http://wellcomeimages.org/indexplus/image/V0002731.html> Wellcome
Collection gallery (2018-04-03):
<https://wellcomecollection.org/works/hs76suwh> CC-BY-4.0, CC BY 2.0,
<https://commons.wikimedia.org/w/index.php?curid=59410576>

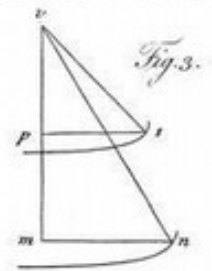
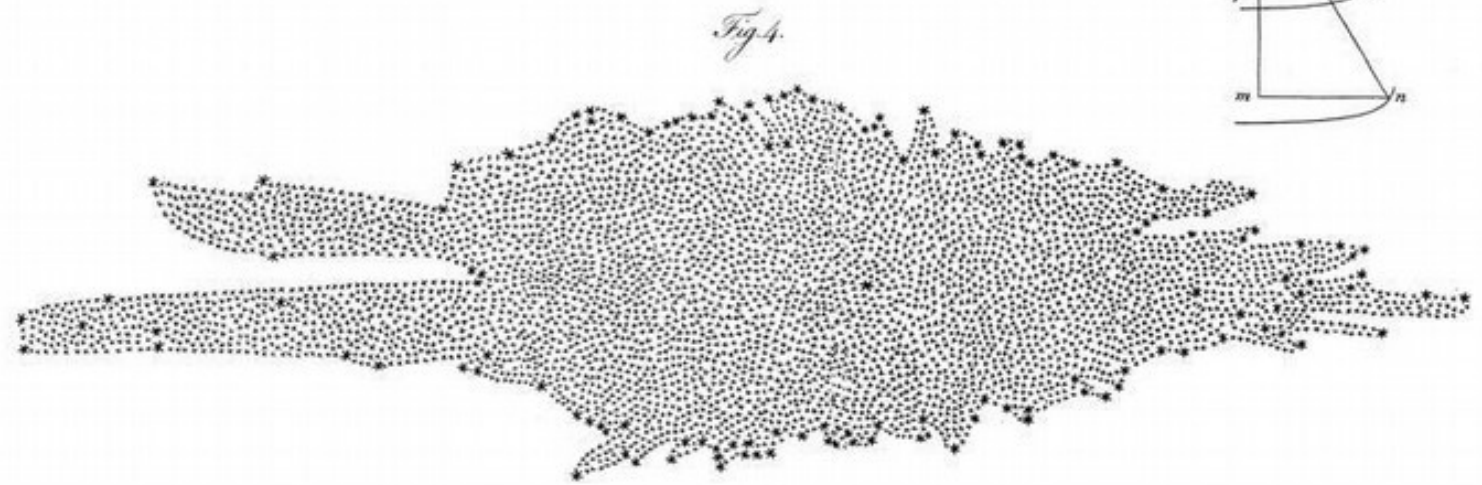
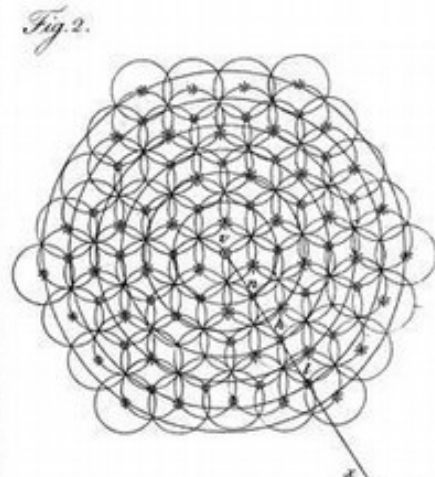
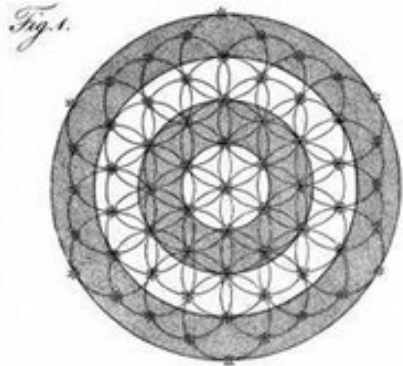
William Herschel's model of the Milky Way, 1784

(in: *Account of Some Observations Tending to Investigate the Construction of the Heavens* (Philosophical Transactions of the Royal Society of London, Vol. 74, 1784))



William Herschel's model of the Milky Way, 1785

- the first attempt to describe the shape of the Milky Way and the position of the Solar system in it; based on “star gauging” (star counts) in more than 600 directions
(note: interstellar extinction due to dust is not known at that time; it will not be discovered until 1930)
- W. H. also measures *proper motions* of 19 stars, finding that the Sun is moving towards the constellation of Hercules

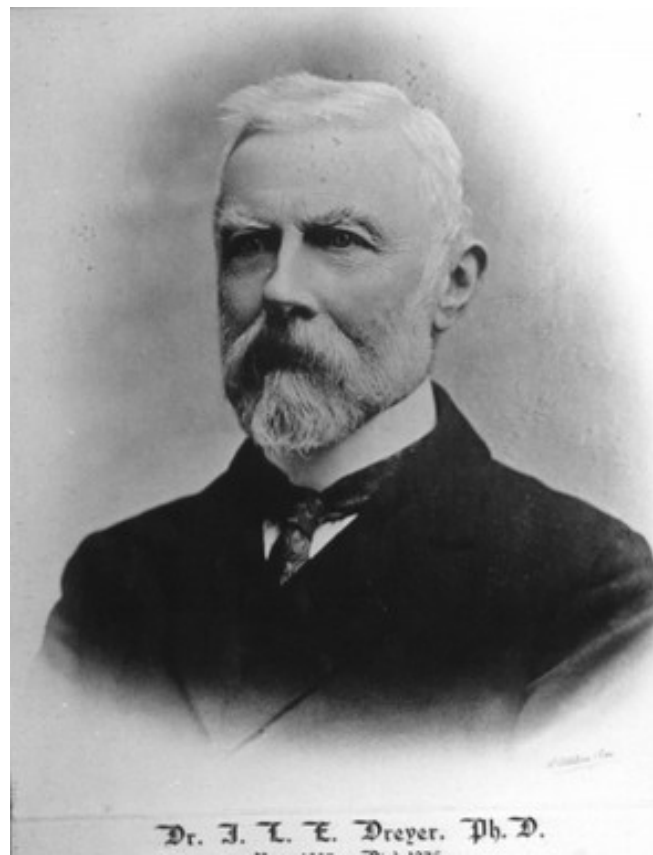




John Herschel:
(son of William Herschel)

***General catalogue of nebulae
and clusters of stars (GC)***

1864: 5,079 objects



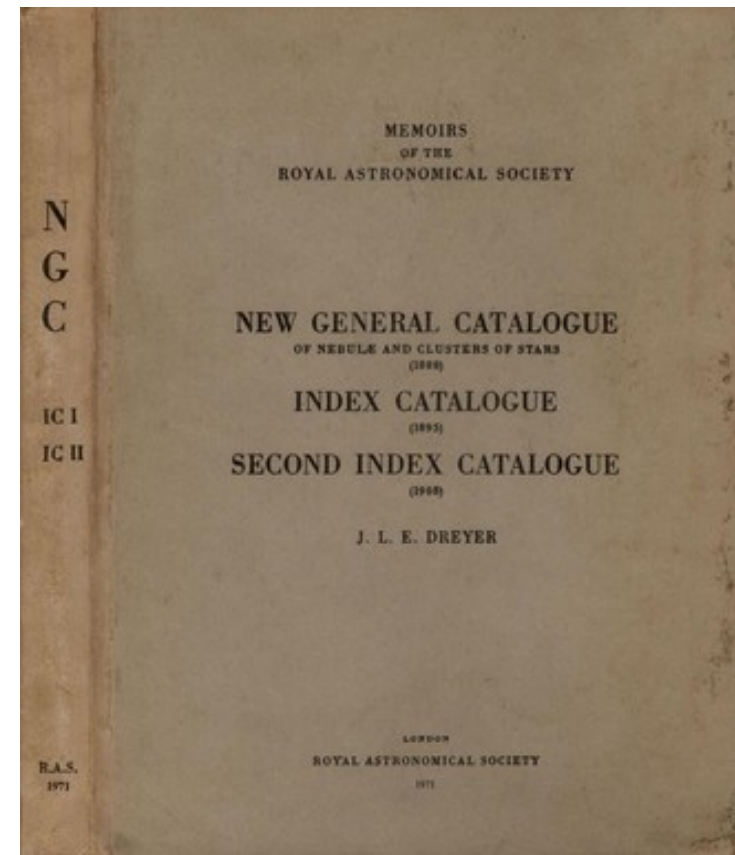
Dr. J. L. E. Dreyer. Ph. D.

John Dryer:

***New General catalogue of nebulae
and clusters of stars (NGC)***

1888: 7,840 objects

Index Catalogues (IC)
1895 & 1908: additional 5,386 objects



3.

**The Leviathan telescope and
the first spiral nebulae**

Leviathan Telescope

(w/ 72-inch / 1.8-m mirror) – the largest telescope of its time

Parsonstown, Ireland (1845):

spiral nebulae discovered
by William Parsons (lord Rosse)

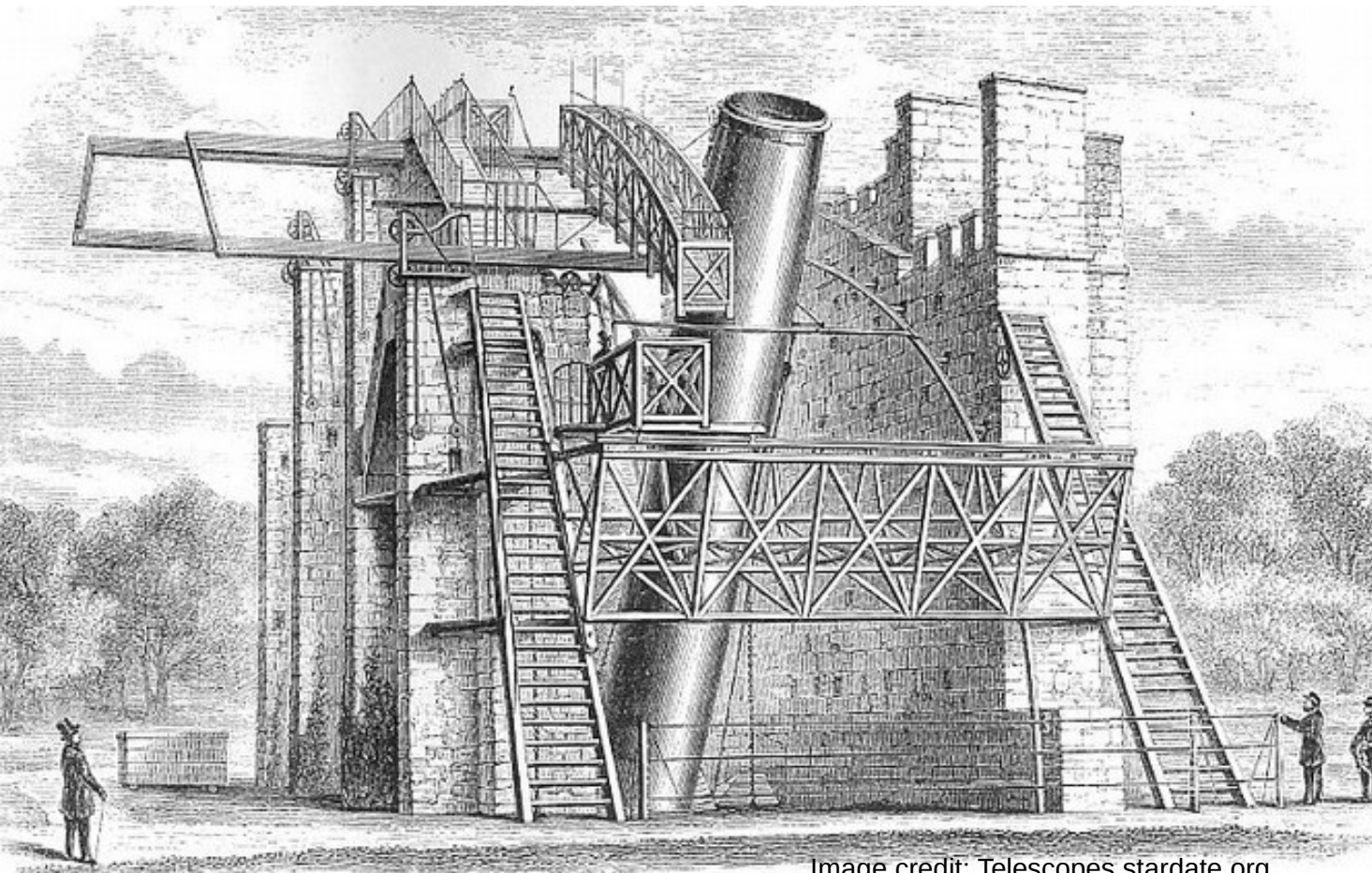


Image credit: Telescopes.stardate.org

To be compared to:

Galileo's telescopes:

1.5-cm (1609); 2.6-cm (1612)
3.7-cm (1620)

William Herschel's

40-foot telescope:

48-inch / 1.2-m (1789)

60-inch Hale telescope

60-inch / 1.5-m (1908)

Hooker telescope

100-inch / 2.5-m (1917)

Hale telescope

200-inch / 5-m (1949)

Hubble Space Telescope (HST)

94-inch / 2.4-m (1990)

Keck Telescopes

2 x 10-m (equivalent to a single 14-m telescope) (1993 + 1996)

Very Large Telescope (VLT)

4 x 8.2-m (equivalent to a single 16-m telescope) (1998)

James Webb Space Telescope (JWST),

6.5-m (2022)

Giant Magellan Telescope

25-m (2029)

Extremely Large Telescope (ELT),

39-m (2027)

Lord Rosse's drawings of M51, his "Question Mark" "Spiral Nebula"



left: Rosse's drawing (1846) - of the first "spiral nebula", *M51* (recognized as a nebula already by Messier in his 1781 catalogue)

Right: a 20-th century photo of *M51* (now called "Whirlpool galaxy")

(see also its *HST* image – next slide)

http://messier.seds.org/more/m051_rosse.html

Lord Rosse's drawing of M99



William Parsons' (Lord Rosse's) drawings of spiral nebulae seen through his *Leviathan* telescope:

M51 (1846)

M99 (1848)

But ***the true nature of spiral nebulae***, today called ***spiral galaxies*** (large systems composed of stars and lying outside our own Galaxy, as independent stellar islands), ***remains unknown until 1924.***

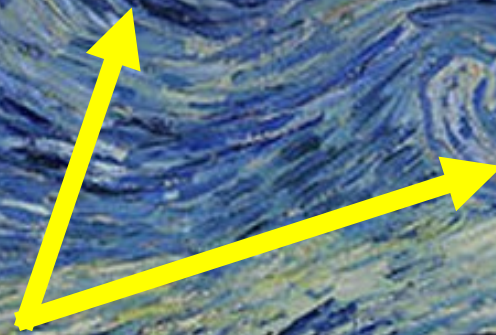
http://messier.seds.org/more/m099_rosse.html

Whirlpool Galaxy • M51



Hubble
Heritage

Vincent van Gogh, *Starry Night*, 1889



Colliding galaxies?

Just whirls in the wind? Or whirls in his mind?

Could Van Gogh have known about galaxies by 1889?



Painting: V. van Gogh; Digital Collage ©: Ronnie Warner

Starry Night Scavenger Hunt
Digital Collage & Copyright: Ronnie Warner

Image Credit: Vincent van Gogh;

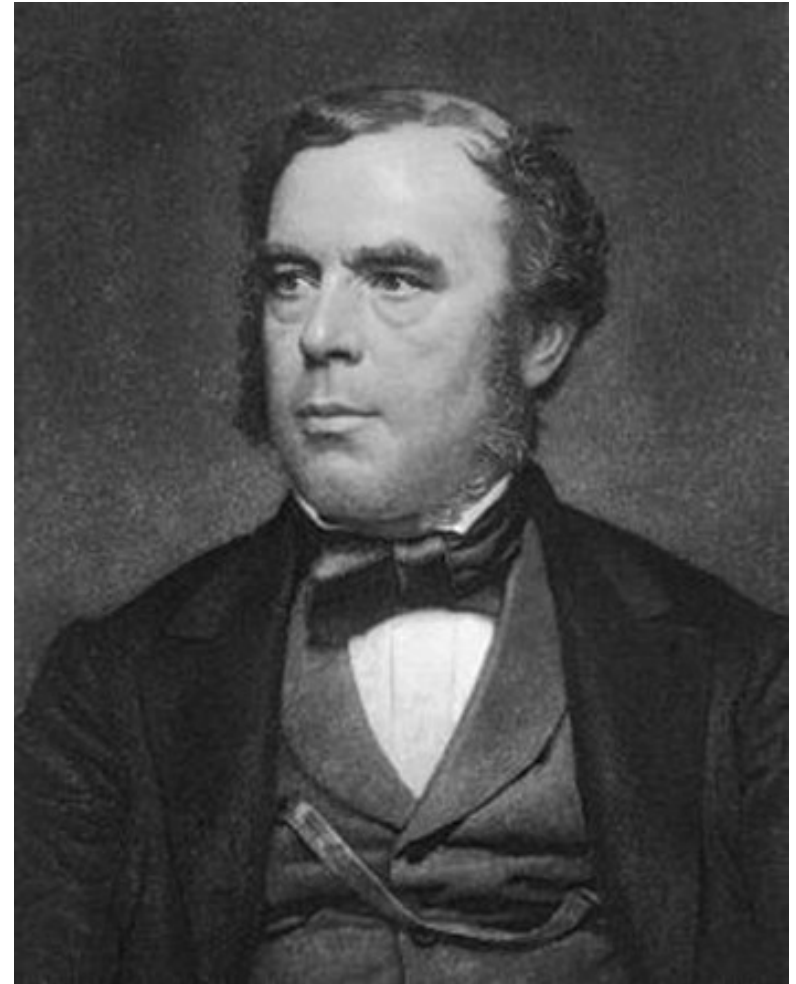
4.

The advent of astrophotography



Louis Daguerre, 1838:
The first photography of human beings (Paris, Boulevard du Temple).
Exposure time: 5 minutes

John Draper, 1840:
**The first astrophotography –
a daguerreotype of the
Moon.**





Henry Draper, 1880: **The first photo of a nebula ever taken – the Orion nebula.**
A 51-minutes exposure with 11-inch (28 cm) Alvan Clark's reflecting telescope.



Andrew Common, 1883: a photograph of the Orion nebula, the first to show that a long exposure could record stars and nebulae invisible to the human eye (a 60-minute exposure with a 36-inch (91 cm) telescope).

Isaac Roberts, 1888:

The first photography of a “spiral nebula”.

The Great Andromeda nebula

(today known as *The Andromeda galaxy*).

Exposure taken with a 20-inch reflecting telescope.



5.

From nebulae to galaxies:


“The Great Debate”

National Academy of Sciences, Washington, April 26th, 1920:

A debate on the Scale of the Universe
between Harlow Shapley and Heber Curtis

(it later became known as “*The Great Debate*”)

Form 127a

CLASS OF SERVICE	SYMBOL	WESTERN UNION		CLASS OF SERVICE	SYMBOL
Telegram				Telegram	
Day Letter	DL	TELEGRAM		Day Letter	DL
Night Message	NM	NEWCOMB CARLTON, PRESIDENT GEORGE W. E. ATKINS, FIRST VICE-PRESIDENT		Night Message	NM
Night Letter	NL			Night Letter	NL

RECEIVED AT 2029 SHATTUCK AVE., BERKELEY, CALIF.
4SF YN 49 NL

PASADENA CALIF FEB 18 1920

DR HARLOW SHAPLEY
30 FACULTY CLUB BERKELEY CALIF

PROGRAM COMMITTEE NATIONAL ACADEMY PROPOSES DEBATE BETWEEN YOU AND
HEBER CURTISON SUBJECT SCALE OF UNIVERSE AT WASHINGTON MEETING APRIL
TWENTY SIX OR TWENTY SEVENTH FORTY FIVE MINUTES EACH HONORARIUM FOR
EACH SPEAKER ONE HUNDRED FIFTY DOLLARS HOPE YOU WILL WIRE
ACCEPTANCE TO ABBOT SMITHONIAN INSTITUTION AND INFORM ME

GEORGE E HALE
705A FEB 19 1920

“Large galaxy” hypothesis

vs

“Island universes” hypothesis

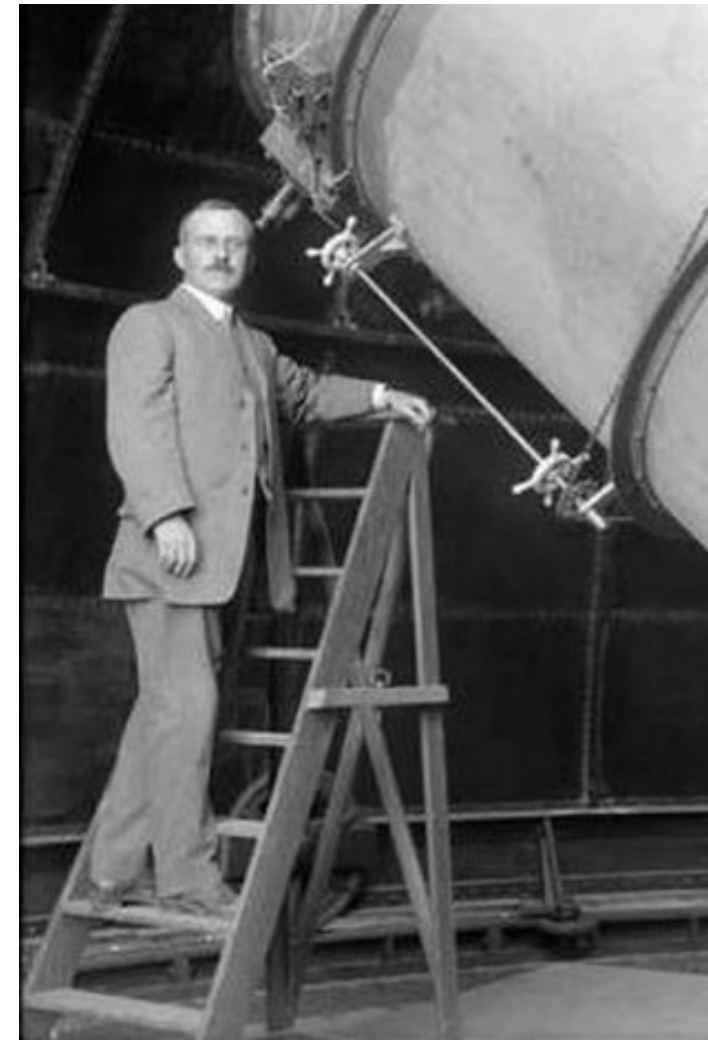
***“The Great Debate”* of 1920**

(see [https://en.wikipedia.org/wiki/Great_Debate_\(astronomy\)](https://en.wikipedia.org/wiki/Great_Debate_(astronomy)))

Harlow Shapley (1885 – 1972)



Heber Curtis (1872 – 1942)



Models of our Galaxy in 1900-1920:

- diameter between 7,000 – 30,000 l.y.
- flattened (disk shaped)
- the Sun near its center
- possibly with spiral structure

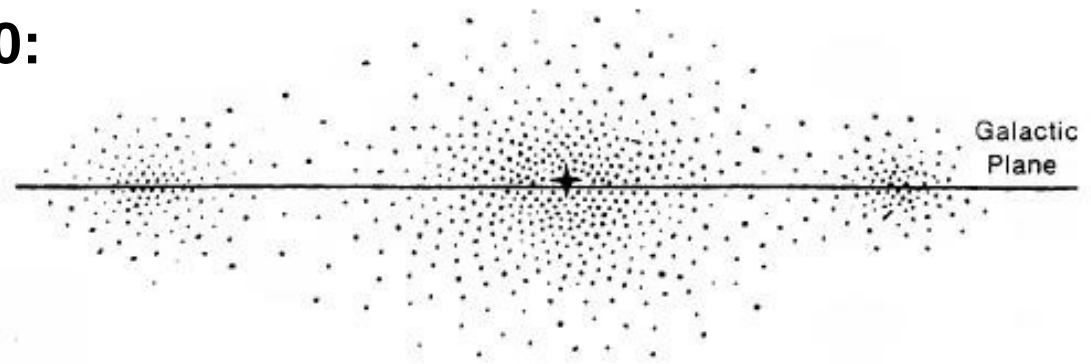


FIG. 3—Arthur Eddington's (1912) galaxy placed the Sun's position 60 LY above the center of the galactic plane. Image credit: Trimble, V., 1995

By 1920, our Galaxy represents the whole known Universe. It is not clear whether anything lies beyond it.

In general, astronomers at that time agree that the Galaxy is a flattened disk of stars with the Sun at or near its center ("S" in the left "face-on" view of the disk, the cross in the above "edge-on" view). The diameter of the disk is estimated, at that time, to be 30,000 light years at most (for comparison, the distance to the nearest star is 4 l.y.; the diameter of the outermost planet in the Solar system, Neptune, is 0.001 l.y.).

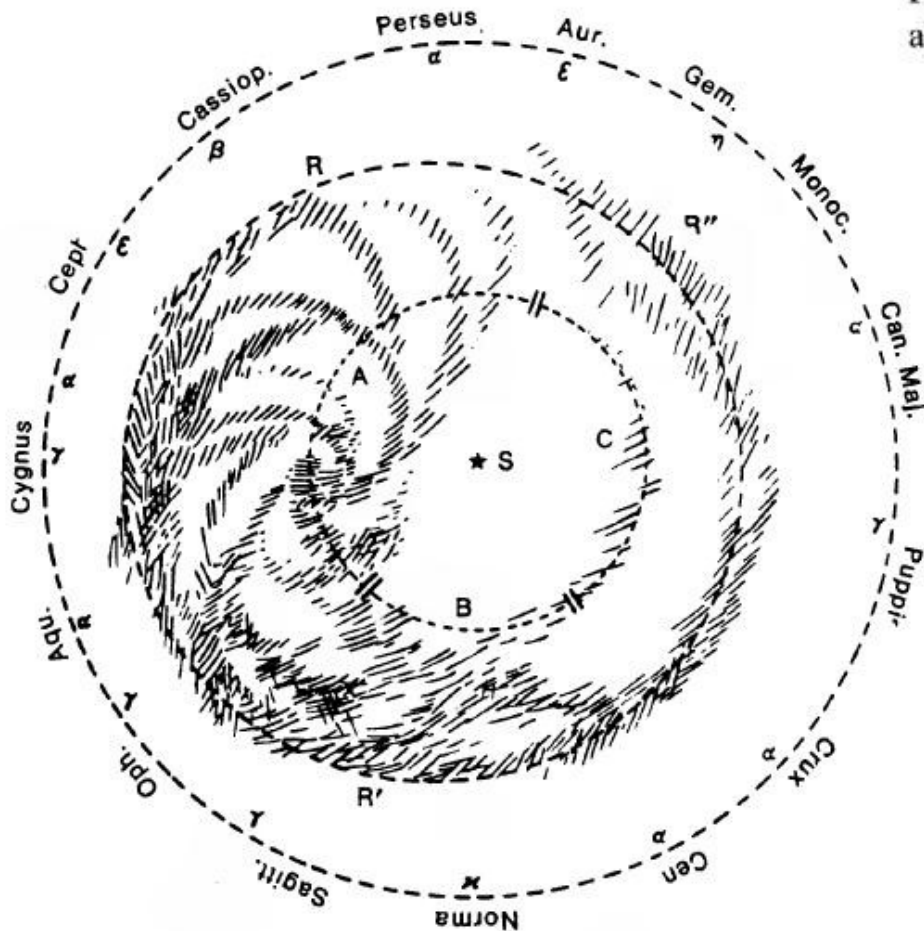


FIG. 2—Cornelius Easton's model of the Galaxy in 1900. He was the first to give the Milky Way spiral arms.

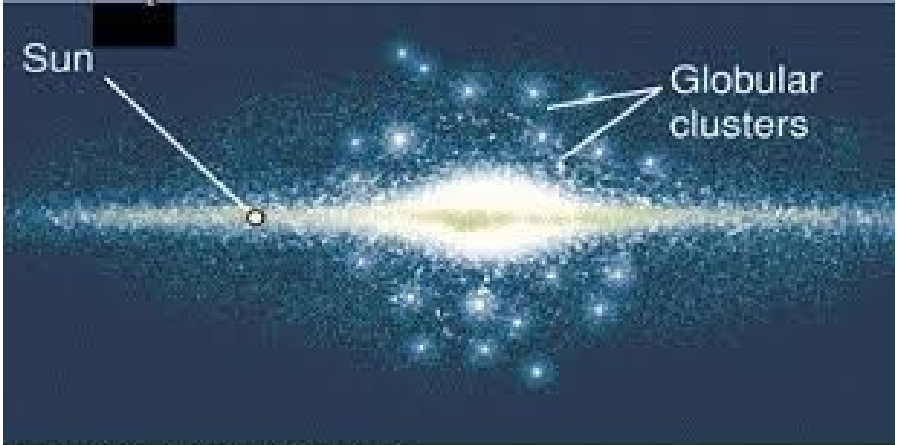
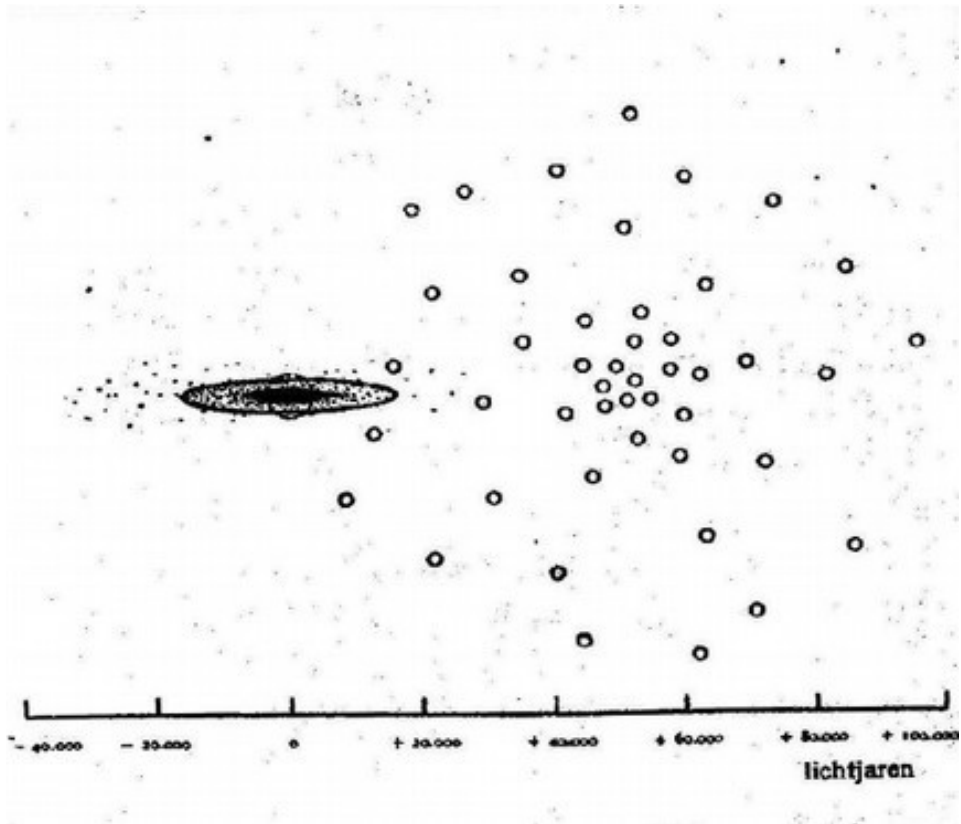
Shapley suggests that our Galaxy is much bigger than thought, with a diameter of **300,000 light years** (the modern value for the diameter of the stellar disk of our Galaxy is close to 200,000 l.y.).

He also places the Sun and its planetary system far (**65,000 l.y.**) from the Galaxy's center (the modern value is 27,000 l.y.)

He prefers to think that spiral nebulae are gaseous objects inside our Galaxy.

Curtis believes that the Galaxy is much smaller, with a diameter not exceeding 30,000 l.y. He keeps the Sun close to the center. In his opinion, **spiral nebulae** are **extragalactic island universes made of stars – galaxies** like our own.

Shapley bases his suggestions on the observed distribution of **globular clusters** for which he measures distances using the **period-luminosity relation** of **Cepheid stars** (the same relation Edwin Hubble used a few years later to determine the distance of the Great Andromeda nebula/galaxy). He notices that the center of the globular cluster system is shifted with respect to what is considered to be the center of our Galaxy (*top image*). He believes that the two centers in reality coincide (*bottom*) which makes its Galaxy larger and at the same time drives the Sun well off its center.



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5.b

Galaxies - island universes



The Andromeda nebula, photographed at the Yerkes Observatory around 1900.

Is it a gaseous nebula inside our Galaxy or an independent galaxy (a stellar “island” external to our Galaxy)? Until 1924, nobody knows.

The New York Times.

Section

1

"All the News That's
Fit to Print."

THE WEATHER

Cloudy and cooler today; rain to-
morrow; northwest winds.
Temperature Yesterday—Max. 51; Min. 45.
For weather report see Section 10, Page 1.

Section

1

VOL. LXXIV...No. 24,410.

NEW YORK, SUNDAY, NOVEMBER 23, 1924.

Including Telegram Picture Section in this paper—FIVE CENTS In Manhattan, 12th Street and Broadway FIVE CENTS

FINDS SPIRAL NEBULAE ARE STELLAR SYSTEMS

**Dr. Hubbell Confirms View That
They Are 'Island Universes'
Similar to Our Own.**

WASHINGTON, Nov. 22.—Confirmation of the view that the spiral nebulae, which appear in the heavens as whirling clouds, are in reality distant stellar systems, or "island universes," has been obtained by Dr. Edwin Hubbell of the Carnegie Institution's Mount Wilson observatory, through investigations carried out with the observatory's powerful telescopes.

The number of spiral nebulae, the observatory officials have reported to the institution, is very great, amounting to hundreds of thousands, and their apparent sizes range from small objects, almost star-like in character, to the great nebulae in Andromeda, which extends across an angle some 3 degrees in the heavens, about six times the diameter of the full moon.

"The investigations of Dr. Hubbell

were made photographically with the 60-inch and 100-inch reflectors of the Mount Wilson observatory," the report said, "the extreme faintness of the stars under examination making necessary the use of these great telescopes. The revolving power of these instruments breaks up the outer portions of the nebulae into swarms of stars, which may be studied individually and compared with those in our own system.

"From an investigation of the photographs thirty-six variable stars of the type referred to, known as Cepheid variables, were discovered in the two spirals, Andromeda and No. 33, of Messier's great catalogue of nebulae. The study of the periods of these stars and the application of the relationship between length of period and intrinsic brightness at once provided the means of determining the distances of these objects.

"The results are striking in their confirmation of the view that these spiral nebulae are distant stellar systems. They are found to be about ten times as far away as the small Magellanic cloud, or at a distance of the order of 1,000,000 light years. This means that light traveling at the rate of 186,000 miles a second has required a million years to reach us from these nebulae and that we are observing them by light which left them in the Pliocene age upon the earth.

"With a knowledge of the distances of these nebulae we find for their diameters 45,000 light years for the Andromeda nebulae and 15,000 light

years for Messier 33. These quantities, as well as the masses and densities of the systems, are quite comparable with the corresponding values for our local system of stars."

FUNDS FOR SCHENCK HOUSE

**William C. Redfield Says It Was
Built of Timbers of Old Ship.**

William C. Redfield, formerly Secretary of Commerce and now the President of the Netherland-America Foundation, 17 East Forty-second Street, was one of the many who were interested in the news printed in yesterday's TIMES that an offer had been submitted to Murray Hulbert, President of the Board of Aldermen, to sell to the city for \$10,000 the old Schenck homestead at Mill Basin, Brooklyn, which is believed to be the oldest house in New York City.

Mr. Redfield, in a letter to Mr. Hulbert yesterday, said that the Schenck house was built out of the timbers of an ancient ship. The old beams are visible and the knees of the old vessel still support the upper floors.

"I earnestly hope that funds may be made available, in order that this exceptional landmark of our city's history may be preserved," wrote Mr. Redfield. Mrs. Redfield is connected by marriage with the Schenck family.

The New York Times

Published: November 23, 1924

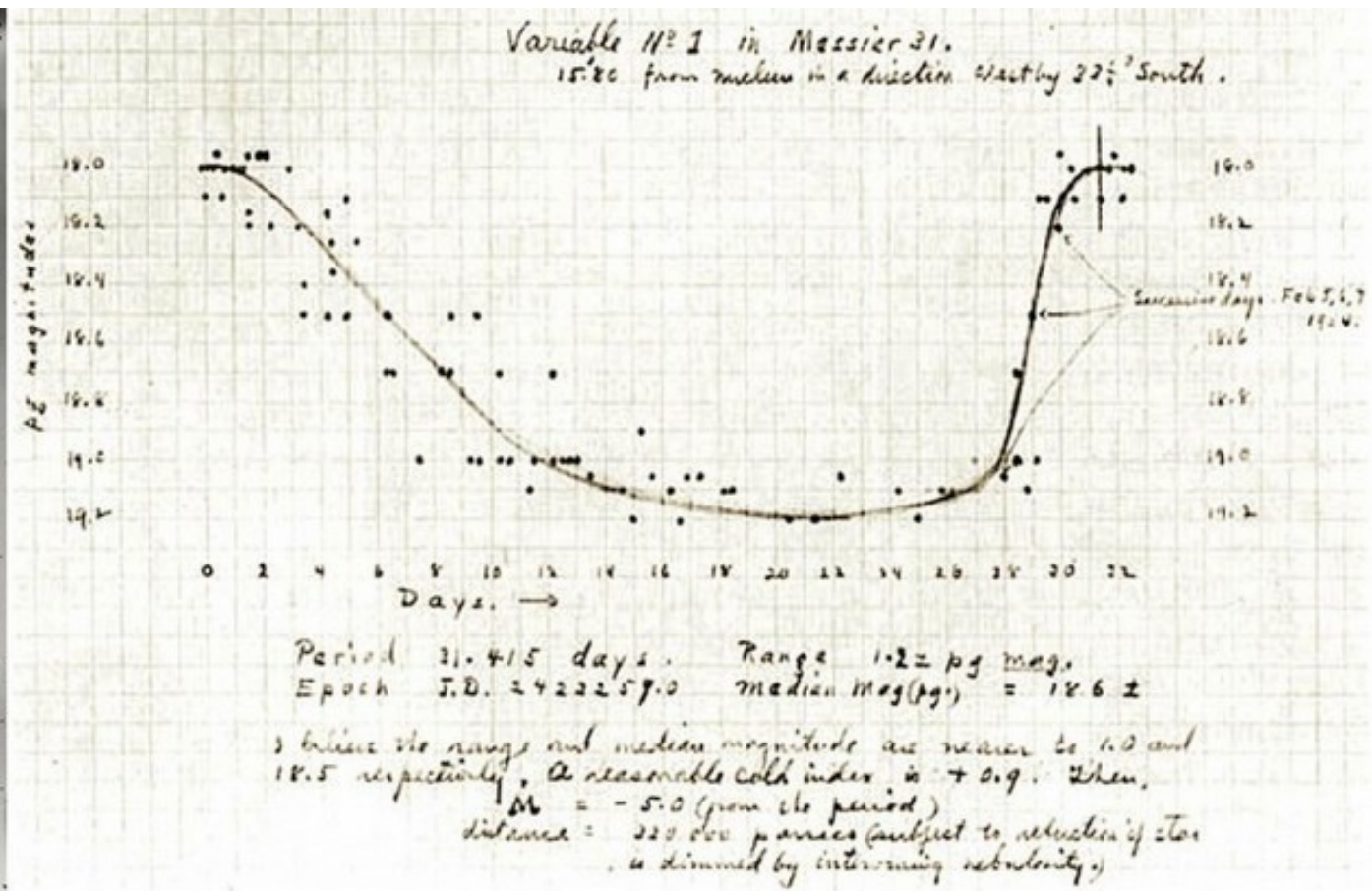
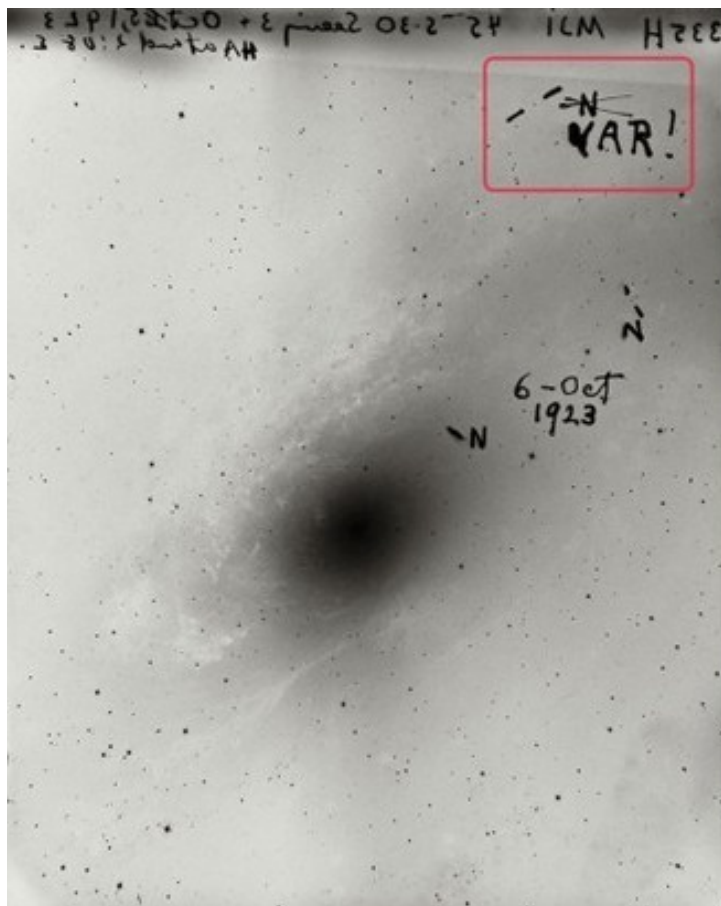
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In October 1923 (a year before the announcement is published in the NYT), **Edwin Hubble** finds a **Cepheid variable star** in the **Andromeda nebula**. Using the **Period-Luminosity relation** for **Cepheids** (https://en.wikipedia.org/wiki/Period-luminosity_relation), he estimates the distance of the nebula to be **930,000 light years** (37% of the modern value of 2.5 million l.y.), well beyond our Galaxy periphery. The linear size of the known Universe thus grows by a factor of ~ 30 (and the corresponding volume by a factor of $30 \times 30 \times 30$, or nearly 30,000). At the same time, it appears clear that spiral nebulae (and perhaps some non-spiral ones) are indeed external stellar islands as hypothesized by Kant in 1755, some 170 years earlier. For the story of the **Cepheid variables** and their famous **Period-Luminosity relation**, watch:

<https://www.youtube.com/watch?v=QcChCeX2VrY>
https://www.youtube.com/watch?v=E9gvk_OkrPw



Image credit: Carnegie Observatories / Huntington Library



Summary:

the timeline of main hypotheses and discoveries related to galaxies

1609 – Galileo Galilei builds a 1.5-cm aperture telescope and points it to the skies. Among others, he resolves some parts of the Milky Way into individual stars. In 1610, he publishes *Sidereus Nuncius (Starry Messenger)* in which he suggests that all the Milky Way light originates in myriads of distant stars, too faint to be seen individually.

1750 – Thomas Wright explains, in his *Original theory or new hypothesis of the Universe*, the Milky Way's appearance as "an optical effect due to our immersion to what locally approximates to a *flat layer of stars*. He also speculates that "many cloudy spots (= nebulae) may be *external creations* too remote for even our telescopes to reach".

1755 – Immanuel Kant, in *Universal natural history and theory of the heavens*, speculates that the Milky Way might be a *rotating body* of a huge number of stars, held together by *gravitational forces* in a similar way as the Sun and its planets in the Solar System but on much larger scales. The resulting *disk of stars* would be seen as a band on the sky from our perspective inside the disk. Kant also conjectures that some of the nebulae visible in the night sky might be separate "*galaxies*" themselves, similar to our own. He refers to these "*extragalactic nebulae*" as "*island universes*".

1785 – William Herschel presents the first scientific model of the Milky Way based on star counts in hundreds of directions. The model is a flat disk with an irregular boundary; the Sun is located off-center.

1845 – William Parsons (lord Rosse) discovers several "spiral nebulae" with his 72-inch (1.8-m) *Leviathan* telescope, the largest astronomical instrument built until then. The nature (composition) and distances of those nebulae remain unknown.

1888 – Isaac Roberts takes the first photo of a spiral nebula (The Great Andromeda Nebula).

1912 – Vesto Slipher measures, for the first time, *redshifts* of a spiral nebula. Redshift can be converted to speed via so-called *Doppler formula*.

1920 – “The Great Debate” is held between **Harlow Shapley** and **Heber Curtis** about the size of the Milky Way Galaxy (at that time equivalent to the whole known Universe) as well as about the nature of spiral nebulae (gaseous or starry?, internal or external to our Galaxy?).

1924 – Edwin Hubble settles *The Great Debate* issues by announcing the discovery of an individual star within the Great Andromeda nebula and the measurement of its distance (930,000 l.y., later corrected to 2.5 million l.y.). Soon other individual bright stars are resolved, and their distances measured, in the Great Andromeda nebulae and a few other spiral nebulae. Spiral nebulae (henceforth called “spiral galaxies”) are identified as stellar islands external to our Galaxy, confirming both the 1920 Curtis’ view and the 1755 Kant’s conjecture.

1926 – Edwin Hubble presents the *first morphological classification of galaxies* (later known as the **Hubble sequence** or the *Hubble tuning fork*), dividing them into *elliptical galaxies*, *lenticular galaxies* and *spiral galaxies* (this latter class being in turn subdivided into *normal spirals* and *barred spirals*).

1927 – George Lemaître for the first time interprets measurements of galactic redshifts (speeds) and distances as a sign of an **expanding Universe**. In doing so, he relies on the General Theory of Relativity, a new theory of gravity, formulated by Albert Einstein in 1915.

1929 – Edwin Hubble publishes, independently of Lemaître’s work, his own discovery of the expanding Universe. The relation between distance and speed of galaxies becomes known as **Hubble’s law** (or *Hubble’s relation*). The idea of an expanding Universe naturally leads to a Universe with a *beginning* (now referred to as the *Big Bang*). Between 1929 to 1998 it was believed that the Universe had been expanding – since the Big Bang – in a decelerated fashion, the expansion being slowed down by gravity of all the matter found within galaxies (initially, from 1924, galaxies were believed to be essentially *stellar* systems; later on, starting from 1951, various forms of *gas* were discovered in them, in addition to stars; since 1970s, existence of **dark matter**, an invisible component dominating masses of galaxies, was established).

1998 – The expansion of the Universe is found to be accelerating rather than decelerating This is being explained by the existence of **dark energy**, another invisible component of the Universe. It appears that **68%** of the Universe’s content is made of **dark energy**, **27%** of **dark matter** and only **5%** by **baryonic matter**.