INTERSTELLAR MEDIUM

- Stefano Bovino -

Discovery and history of the interstellar medium

What is the Intersteller Medium

- The stuff between the stars in around galaxies
- ISM is the most important part of a galaxy
- ISM is responsible for forming stars (dominant sources of energy)
- Baryons account for 10% of the total mass of the galaxy
- ISM turbulent and out of equilibrium

Why do we study the ISM?

- Stars form from the ISM, and then activate it dynamical and chemically. Gas is the active chemical ingredient of galaxies.
- Understanding the ISM means understanding the physical processes which drive mass, momentum and energy exchange between the stars and the components of the ISM

Discovery of the ISM

Around the start of the 20th century, astronomers started to recognize that there was material between the stars in the MW

History of the ISM

Optical - Naked eyes

Optical - Photographic plates / Imaging

Optical - Spectroscopy

Radio

UV / X-ray / IR

mm

Pre-20th-century

1608 - Galileo Galilei: invented the telescope

1610 - Discovery of the Orion Nebula (Nicolas Fabri de Peiresc)
- *"surprised to find a small illuminated cloud"*

1656 - First detailed description of the Orion Nebula (Christian Huygens)

"Systema Saturniun (book)"

Early 18th-century people were a lot into comets

Early 18th-century people were a lot into comets

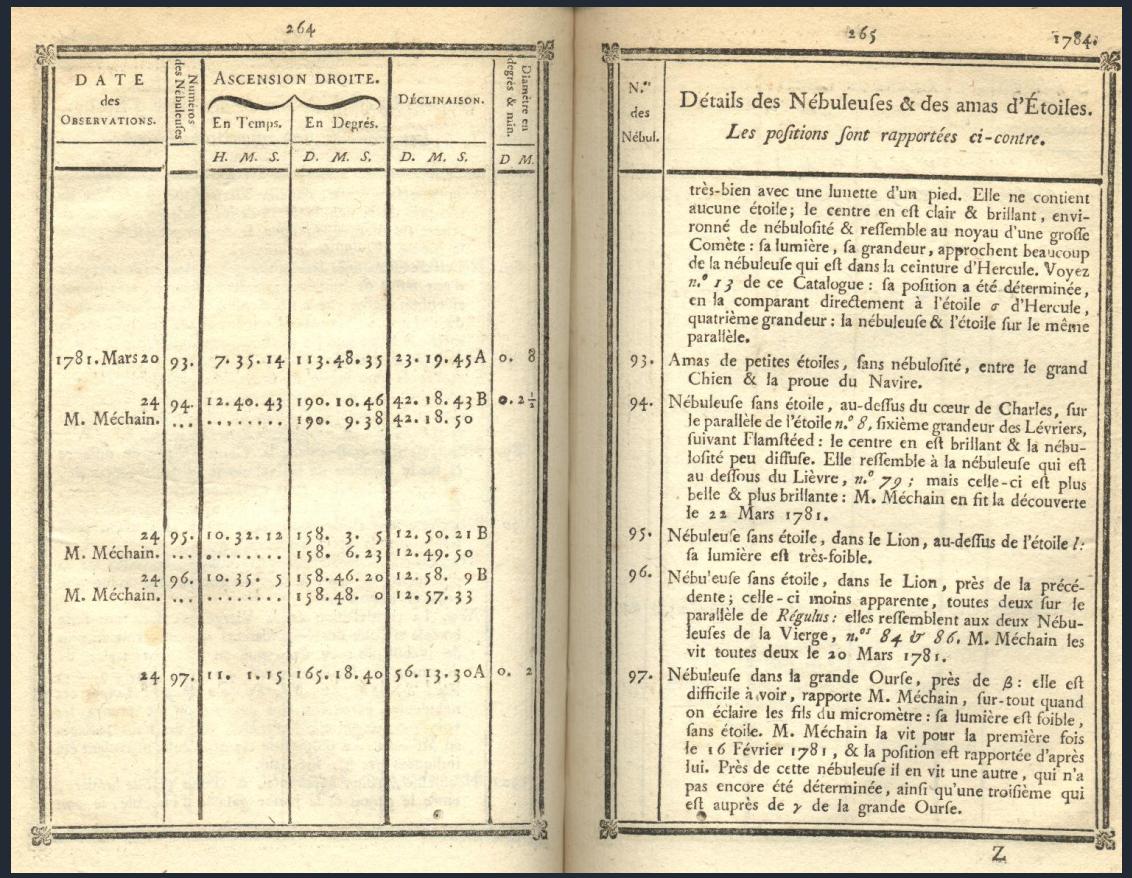
Comets look like little fuzzy patches of light

Can easily be confused with nebulae or star clusters (seen as a blurry celestial light source)

During his studies on Halley's comet he observed a small patch of light with no movement (later called M1). This was the Crab Nebula.

1781 - Charles Messier compiled a catalogue of 103 objects

- The majority clusters of stars
- galaxies (35)
- nebulae (11)



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DATE des OBSERVATIONS.	Numéros des Nébuleuses.	ASCENSION DROITE. En Temps. H. M. S.	ASCENSION DROITE. En Degrés. D. M. S.	DÉCLINAISON. D. M. S.	Diamètre en degrés & min. D. M.
1781. Mars 20	93.	7. 35. 14	113. 48. 35	23. 19. 45 A	0. 8
24	94.	12. 40. 43	190. 10. 46	42. 18. 43 B	0. 2½
M. Méchain.	...	.....	190. 9. 38	42. 18. 50	
24	95.	10. 32. 12	158. 3. 5	12. 50. 21 B	
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24	96.	10. 35. 5	158. 46. 20	12. 58. 9 B	
M. Méchain.	...	.....	158. 48. 0	12. 57. 33	
24	97.	11. 1. 15	165. 18. 40	56. 13. 30 A	0. 2

265 1784.

N.° des Nébul.	Détails des Nébuleuses & des amas d'Étoiles. *Les positions sont rapportées ci-contre.*
	très-bien avec une lunette d'un pied. Elle ne contient aucune étoile; le centre en eſt clair & brillant, environné de nébuloſité & reſſemble au noyau d'une groſſe Comète : ſa lumière, ſa grandeur, approchent beaucoup de la nébuleuſe qui eſt dans la ceinture d'Hercule. Voyez *n.° 13* de ce Catalogue : ſa poſition a été déterminée, en la comparant directement à l'étoile σ d'Hercule, quatrième grandeur : la nébuleuſe & l'étoile ſur le même parallèle.
93.	Amas de petites étoiles, ſans nébuloſité, entre le grand Chien & la proue du Navire.
94.	Nébuleuſe ſans étoile, au-deſſus du cœur de Charles, ſur le parallèle de l'étoile *n.° 8*, ſixième grandeur des Lévriers, ſuivant Flamſtéed : le centre en eſt brillant & la nébuloſité peu diffuſe. Elle reſſemble à la nébuleuſe qui eſt au deſſous du Lièvre, *n.° 79* ; mais celle-ci eſt plus belle & plus brillante : M. Méchain en fit la découverte le 22 Mars 1781.
95.	Nébuleuſe ſans étoile, dans le Lion, au-deſſus de l'étoile *l* : ſa lumière eſt très-foible.
96.	Nébuleuſe ſans étoile, dans le Lion, près de la précédente; celle-ci moins apparente, toutes deux ſur le parallèle de *Régulus* : elles reſſemblent aux deux Nébuleuſes de la Vierge, *n.os 84 & 86*. M. Méchain les vit toutes deux le 20 Mars 1781.
97.	Nébuleuſe dans la grande Ourſe, près de β : elle eſt difficile à voir, rapporte M. Méchain, ſur-tout quand on éclaire les fils du micromètre : ſa lumière eſt foible, ſans étoile. M. Méchain la vit pour la première fois le 16 Février 1781, & la poſition eſt rapportée d'après lui. Près de cette nébuleuſe il en vit une autre, qui n'a pas encore été déterminée, ainſi qu'une troiſième qui eſt auprès de γ de la grande Ourſe.

Z

217 1784.

CATALOGUE
DES
NÉBULEUSES ET DES AMAS D'ÉTOILES

Obſervées à Paris, par M. Meſſier, à l'Obſervatoire de la Marine, hôtel de Clugni, rue des Mathurins.

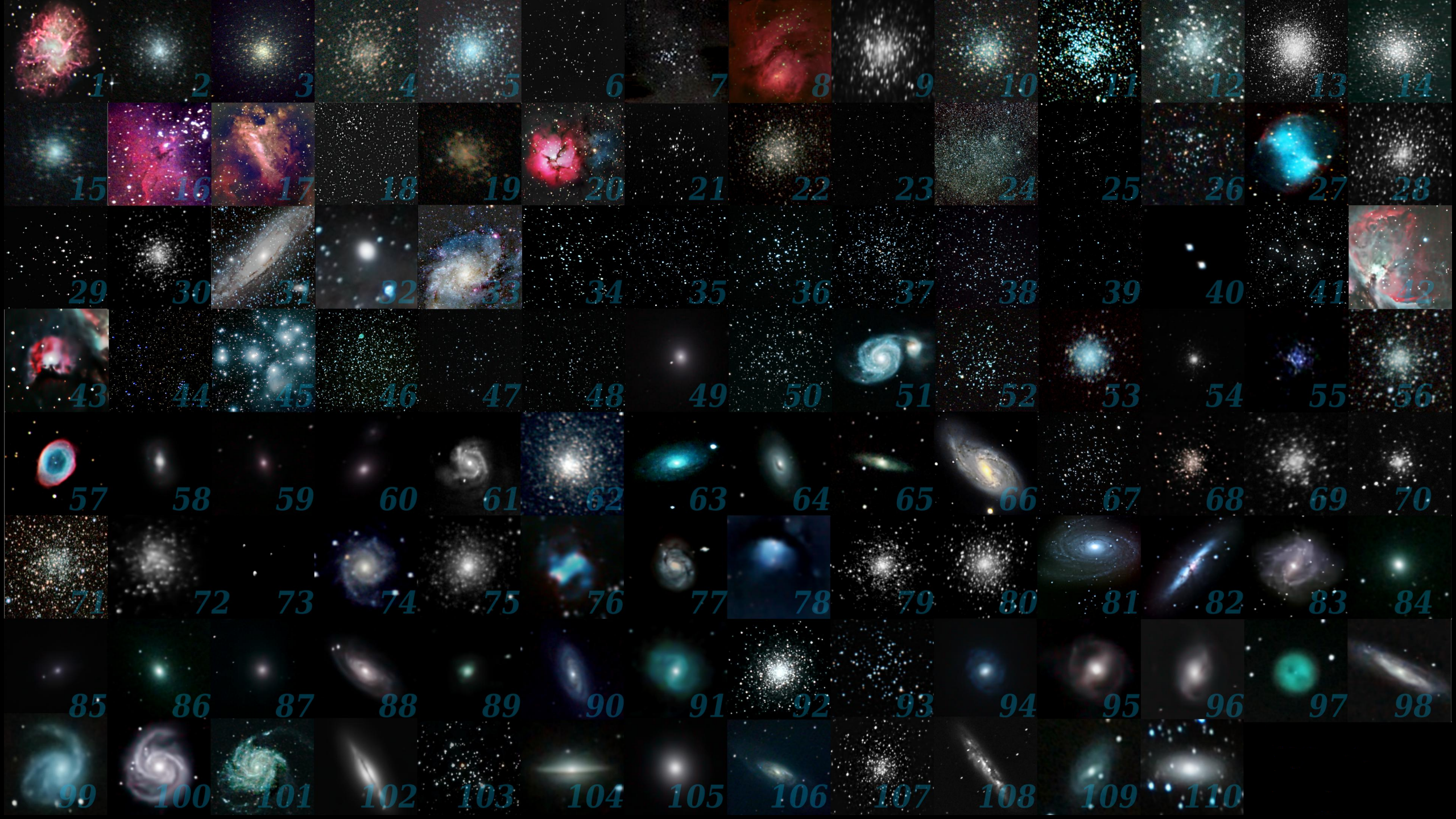
M. MESSIER a obſervé avec le plus grand ſoin les Nébuleuſes & les amas d'Étoiles qu'on découvre ſur l'horizon de Paris; il a déterminé leur aſcenſion droite, leur déclinaiſon, & donné leurs diamètres, avec des détails circonſtanciés ſur chacune : ouvrage qui manquoit à l'Aſtronomie.

Il entre auſſi dans des détails ſur les recherches qu'il a faites des différentes Nébuleuſes qui ont dû être découvertes par différens Aſtronomes, mais qu'il a cherchées inutilement.

Le Catalogue des Nébuleuſes & des amas d'Étoiles, de M. Meſſier, eſt inſéré dans le volume de l'Académie des Sciences, *année 1771, page 435*. Il rapporte à la fin de ſon Mémoire, un deſſin tracé avec le plus grand ſoin de la belle Nébuleuſe de l'épée d'Orion, avec les étoiles qu'elle contient. Ce deſſin pourra ſervir à reconnoître ſi dans la ſuite des temps elle n'eſt pas ſujette à quelque changement. Si l'on compare dès-à-préſent ce deſſin avec ceux de M.rs Huyghens, Picard, de Mairan & le Gentil, on ſera étonné d'y trouver un changement tel qu'on auroit peine à ſe figurer que c'eſt la même nébuleuſe, ſi l'on n'avoit égard qu'à ſa figure. On peut voir ces deſſins, donnés par M. le Gentil dans le volume de l'Académie, de 1759, *page 470, planche XXI.*

Au Catalogue imprimé de M. Meſſier, que nous donnons ici, nous rapporterons encore un grand nombre de nébuleuſes & d'amas d'étoiles qu'il a découvertes depuis l'impreſſion de ſon Mémoire, & qu'il nous a communiquées.

Aux poſitions des nébuleuſes, M. Meſſier a rapporté des numéros qui ſont les mêmes à la page ſuivante, & qui donnent le détail de chacune des nébuleuſes obſervées.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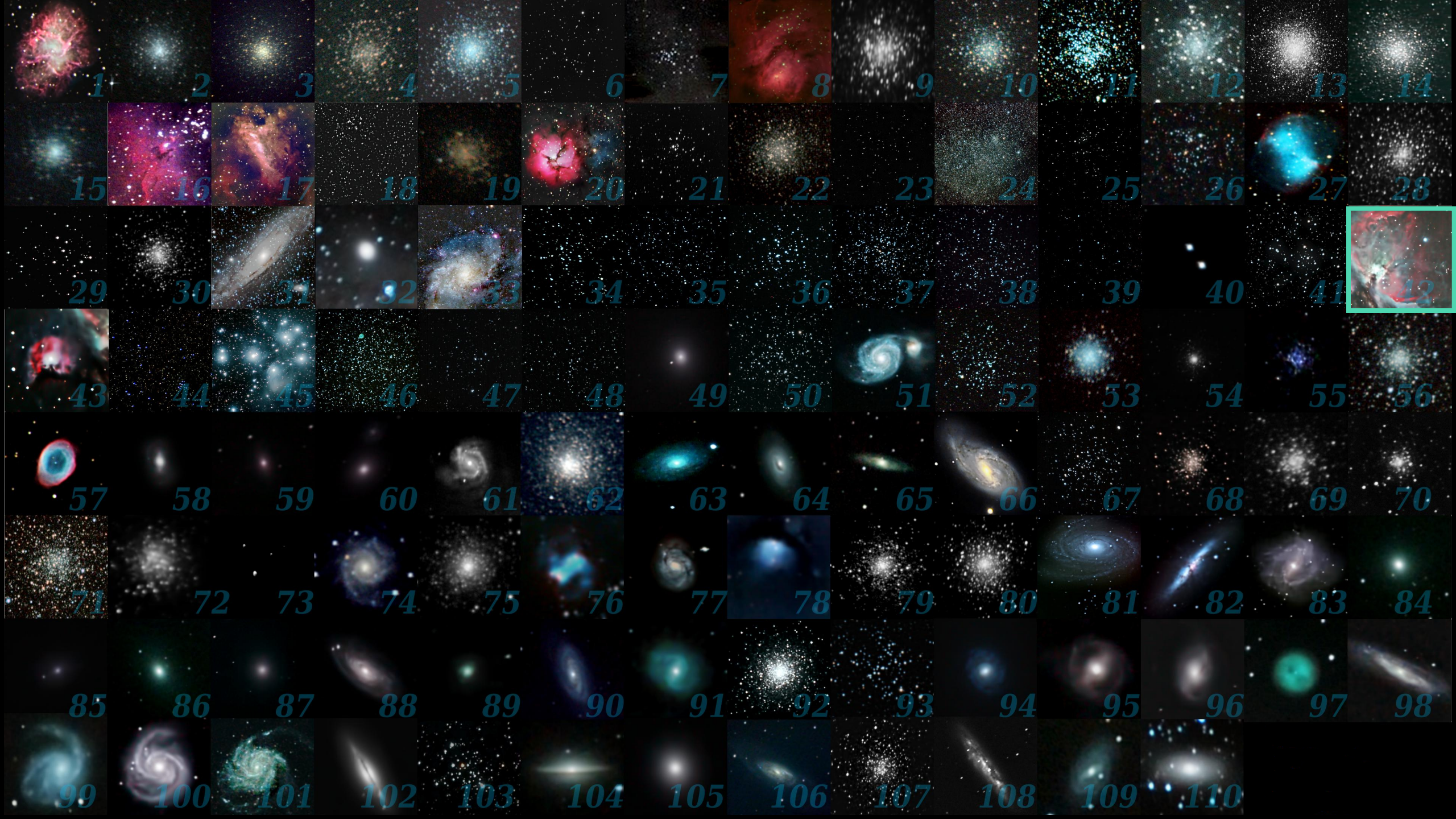
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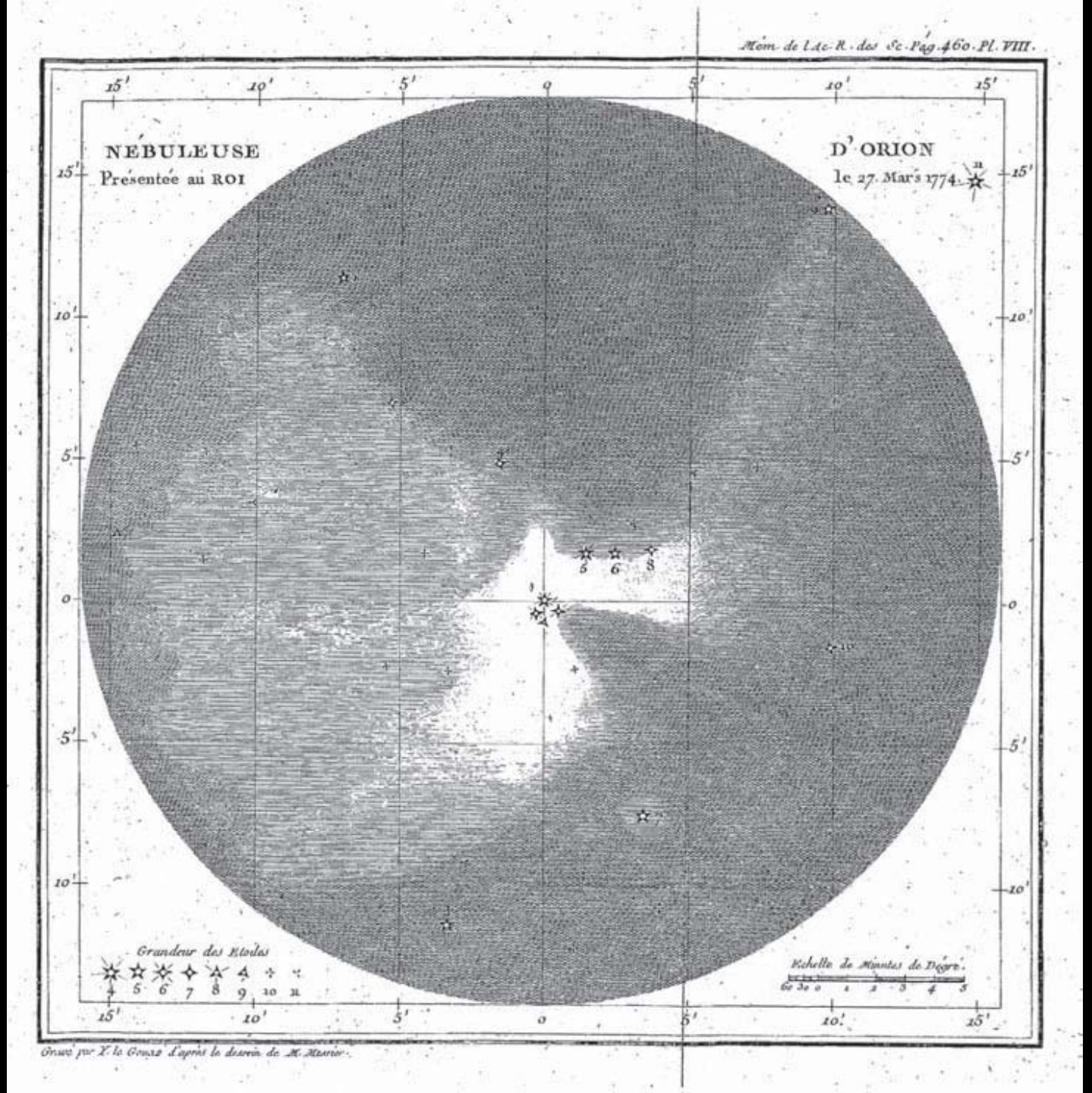
M42: Orion Nebula

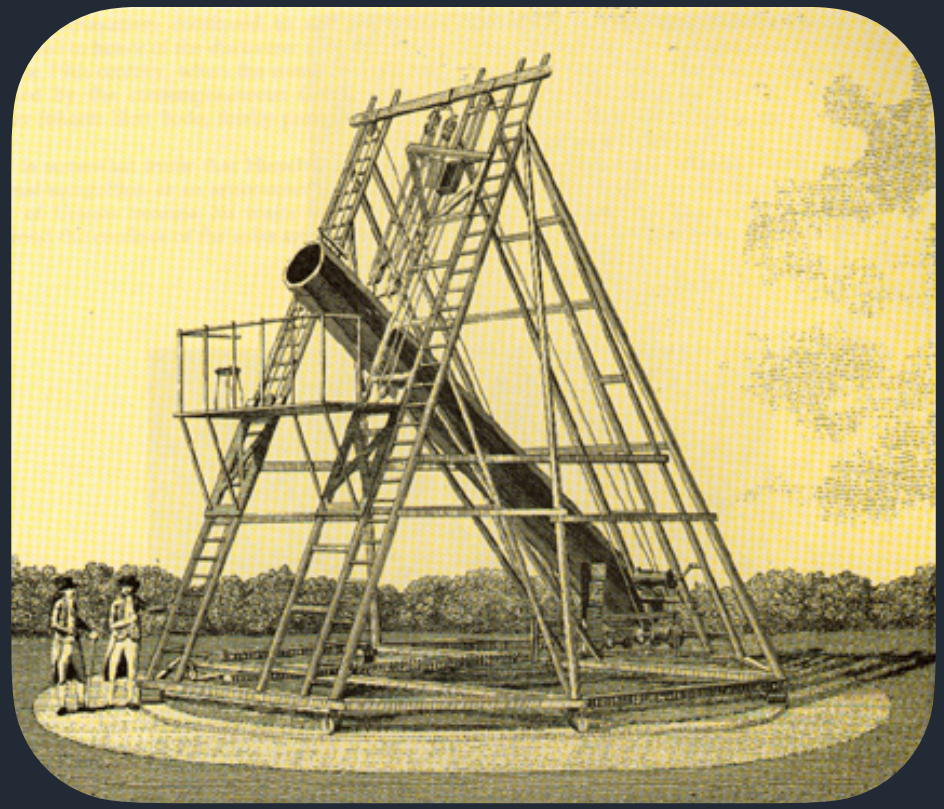


Early-middle 19th-century: The Herschel's era

1786-1802 - 2,500 objects

Many of these were dark clouds

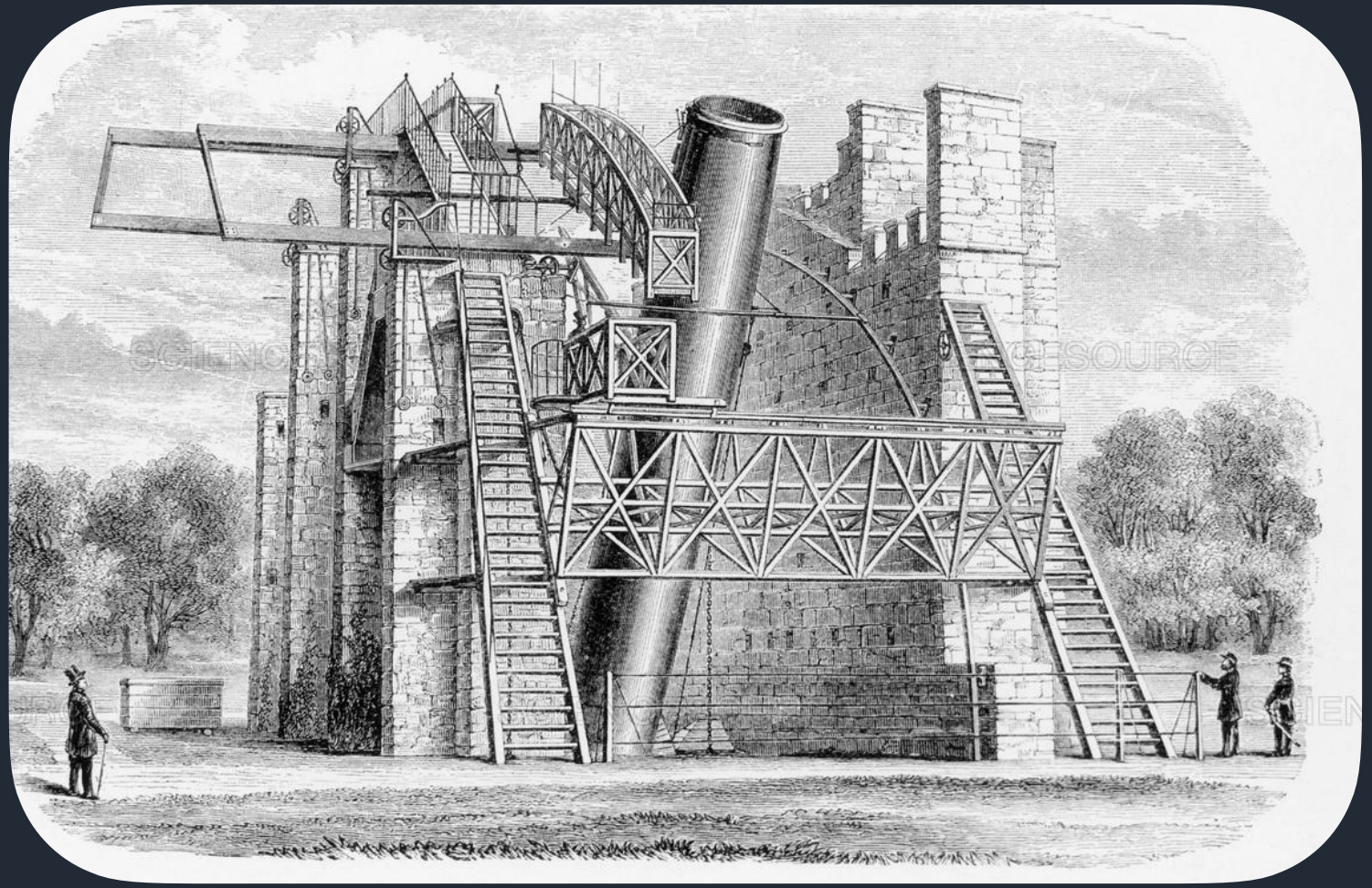
"here is truly a hole in Heaven"



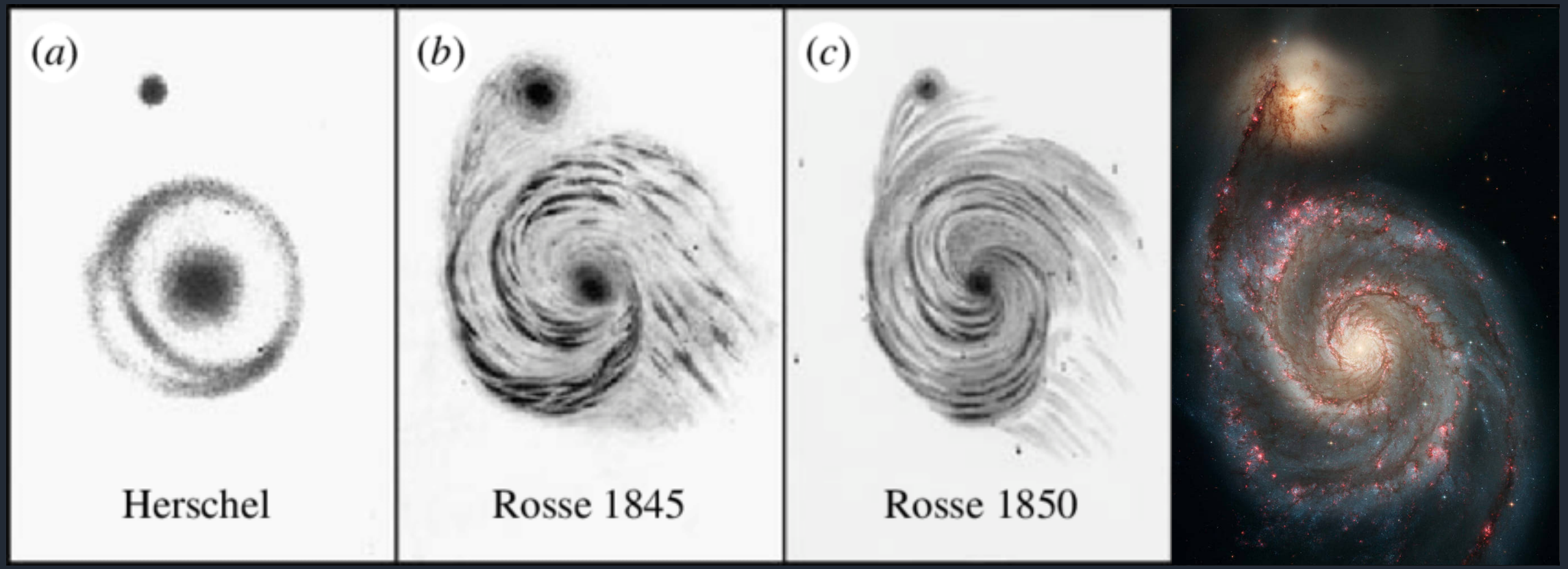
John later added 2,200 objects

1888 - *New General Catalog* (NGC) by J.L. Dreyer was published (13,000 objects)

Lord Parsons



Evolution of reflector: M51



Credits: NASA, ESA, S. Beckwith (STScI) and the Hubble Heritage Team (STScI/AURA)

Nebular Hypothesis

Herschel was also the first distinguishing between stellar and non stellar content in the galaxy.

1796 - Laplace (based on Kant's idea in 1755)

- Bodies of the solar system had the same origin
- Large fluid of material evolved into a central condensation (sun formed)

19th-century: Advent of photography

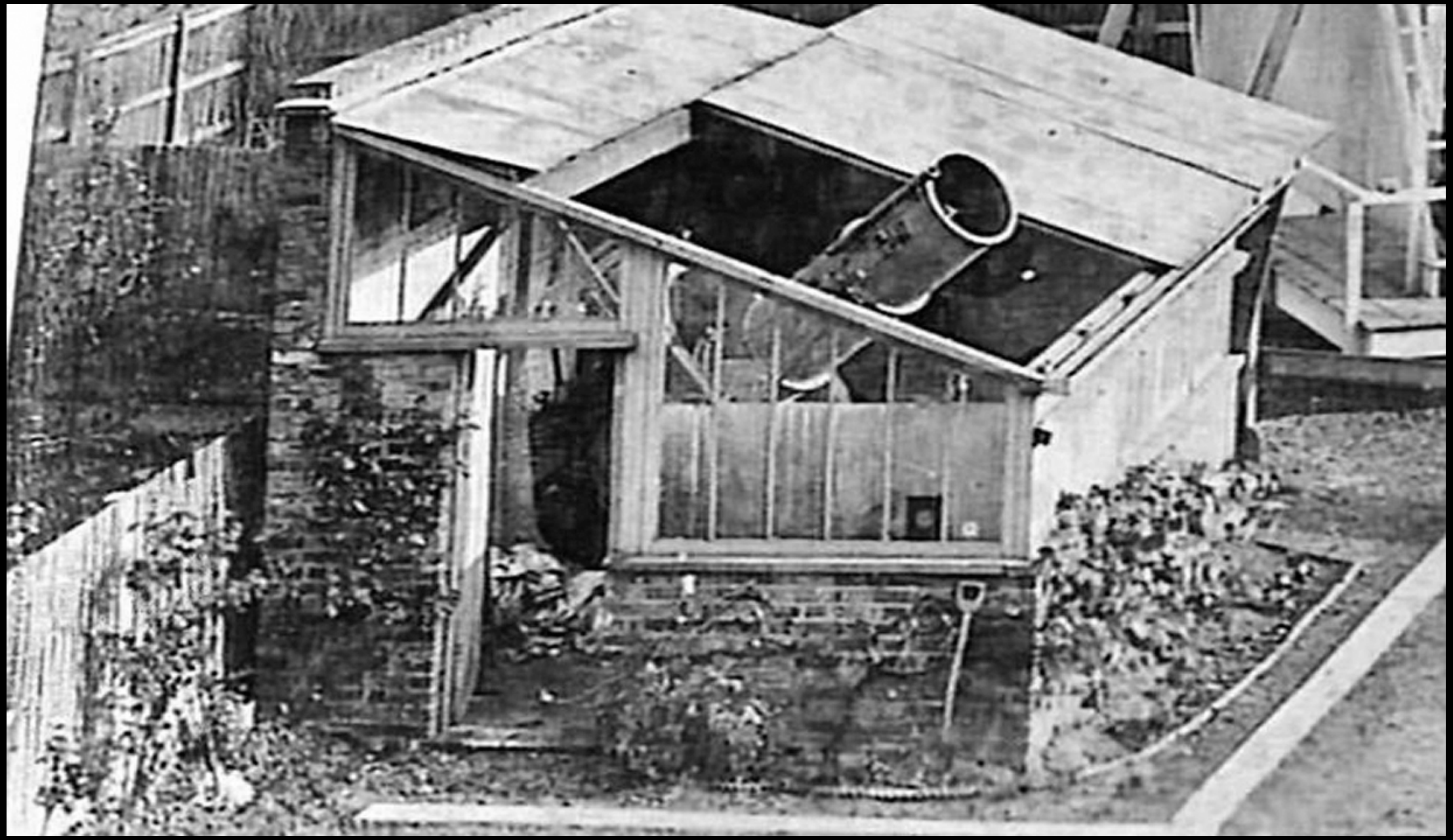
Caused a revolution in the understanding of nebulae

Allowed to see faint details invisible to the naked eye

1880 - Henry Draper: First photograph of Orion Nebula

1883 - Andrew Ainslie Common

Andrew Ainslie Common: 45 cm reflector



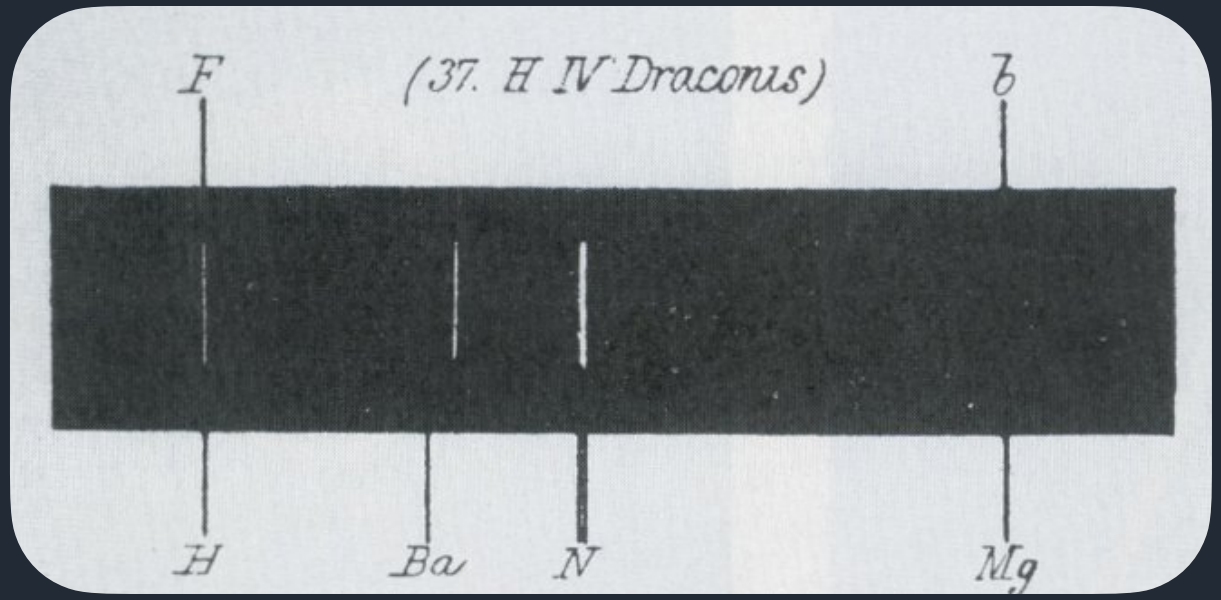
Andrew Ainslie Common

“although some details are lost in the enlargement, sufficient remains to show that we are approaching the time where a photograph will give us the means to recording in its own inimitable way the shape of a nebula and the relative brightness different parts, in a better manner than the most careful hand drawing”

19th-century: Advent of spectroscopy

Helped distinguish between stellar and gas content

Distinction between galaxies (stellar) and nebulae (gas) was appreciated



1860-1900 - W. Huggins & J. E. Keeler

Cat's eye nebula

The first spectrum

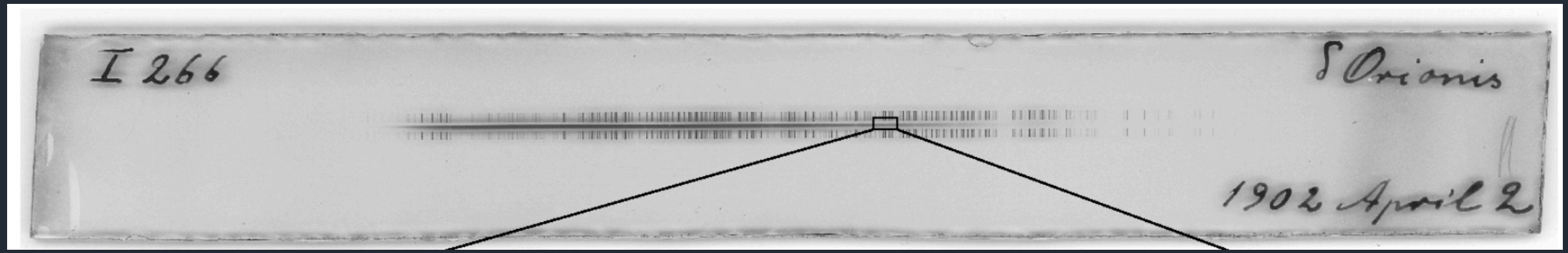
1864 - Three bright lines in NGC6543

- Proved the gas content of some nebulae
- Confirmed the Herschel hypothesis
- Other nebulae showed a continuous spectrum
- These lines were attributed to an anonymous element called *Nebulium*

1927 - Ira Sprague Bowen showed that these lines belonged to forbidden transitions of known elements (doubly ionized oxygen)

20th-century

1904 - Johannes Hartmann, stationary CaII H & K in the spectrum of binary delta-Orionis (first interstellar absorption lines)



Original plate

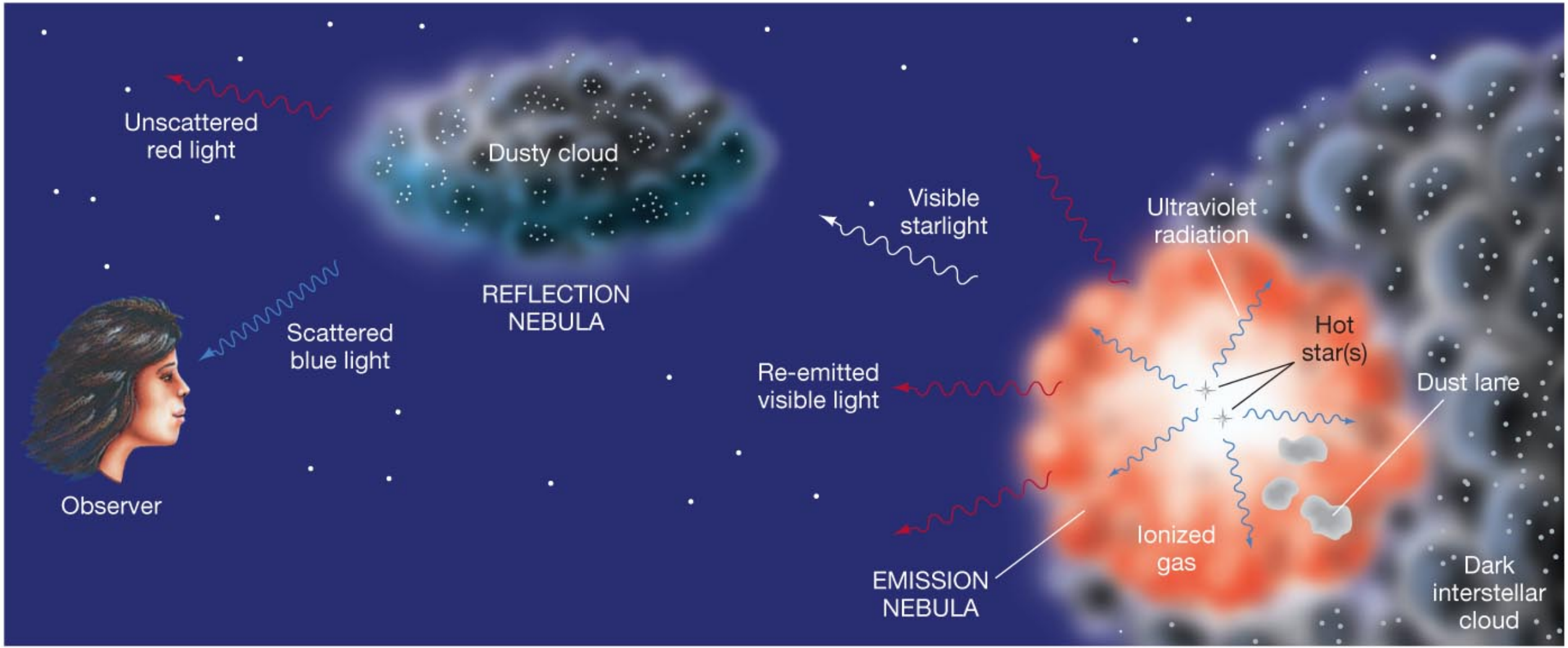
20th-century

1913 - Vesto Melvin Slipher proved the existence of *reflection nebulae*

Image Credits: De Martin / ESA / ESO / NASA

The Witch Head IC2118

Why the reflection nebulae look like we see



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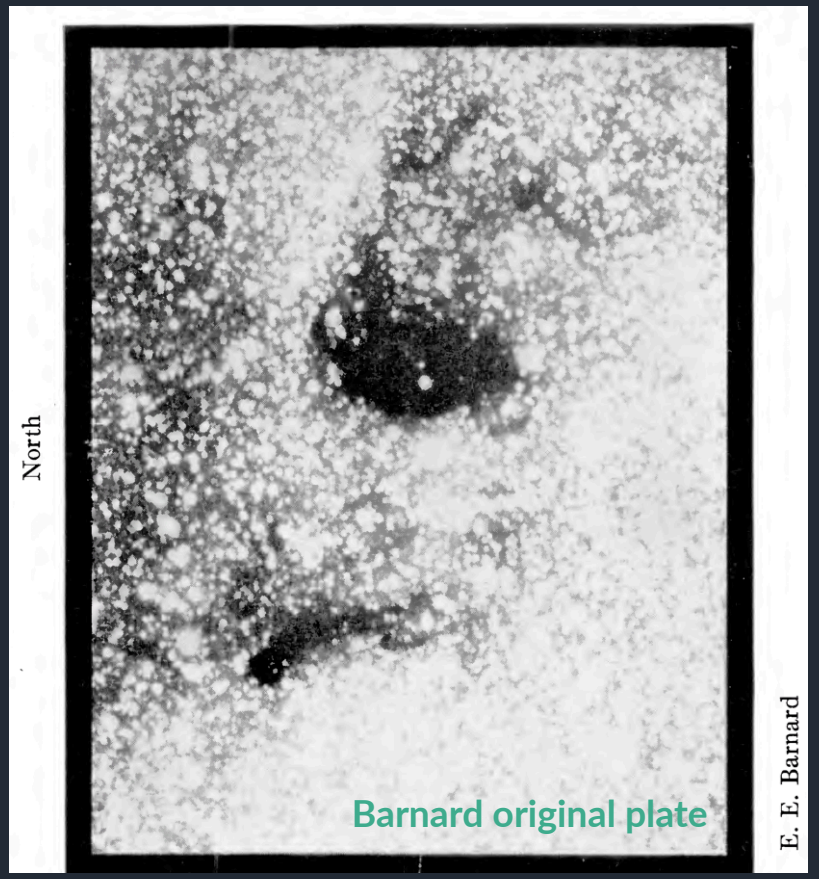
20th-century

1910-1927 - **E. E.** Barnard: no hole in the distribution but some obscuring matter, catalog of dark nebulae

DARK REGIONS IN THE SKY SUGGESTING AN OBSCURATION OF LIGHT

By E. E. BARNARD

The so-called "black holes" in the Milky Way are of very great interest. Some of them are so definite that, possibly, they suggest not vacancies, but rather some kind of obscuring body lying in the Milky Way, or between us and it, which cuts out the light from the stars. This explanation seems to become more and more plausible the more we know of these objects. In previous papers I have called attention to this possible obscuring matter, splendid examples of which are connected with the great nebulosities about the stars *ρ Ophiuchi* and *ν Scorpii*. See *Astrophysical Journal*, 31, 8, 1910, for an article bearing on this subject.



Barnard original plate

20th-century

1910-1927 - **E. E.** Barnard: no hole in the distribution but some obscuring matter, catalog of dark nebulae

1926 - A. Eddington predicts interstellar H_2

1930 - Trumpler: proof of interstellar extinction (existence of dust)

1937 - CH: Swings & Rosenfeld

1940 - CH & CN: McKeller

1941 - CH^+: Douglas & Herzberg

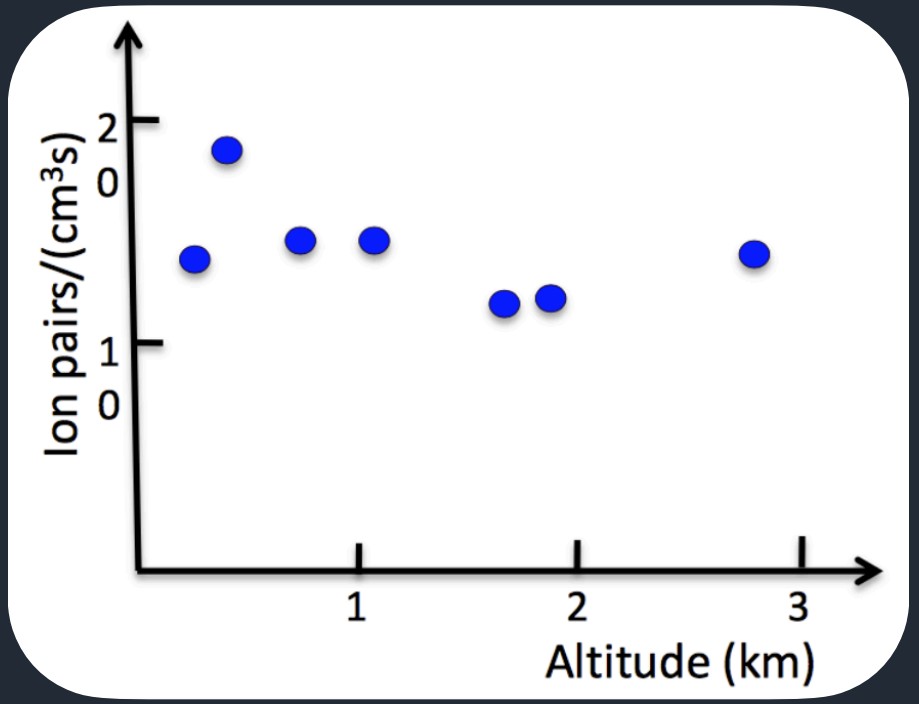
Optical absorption lines

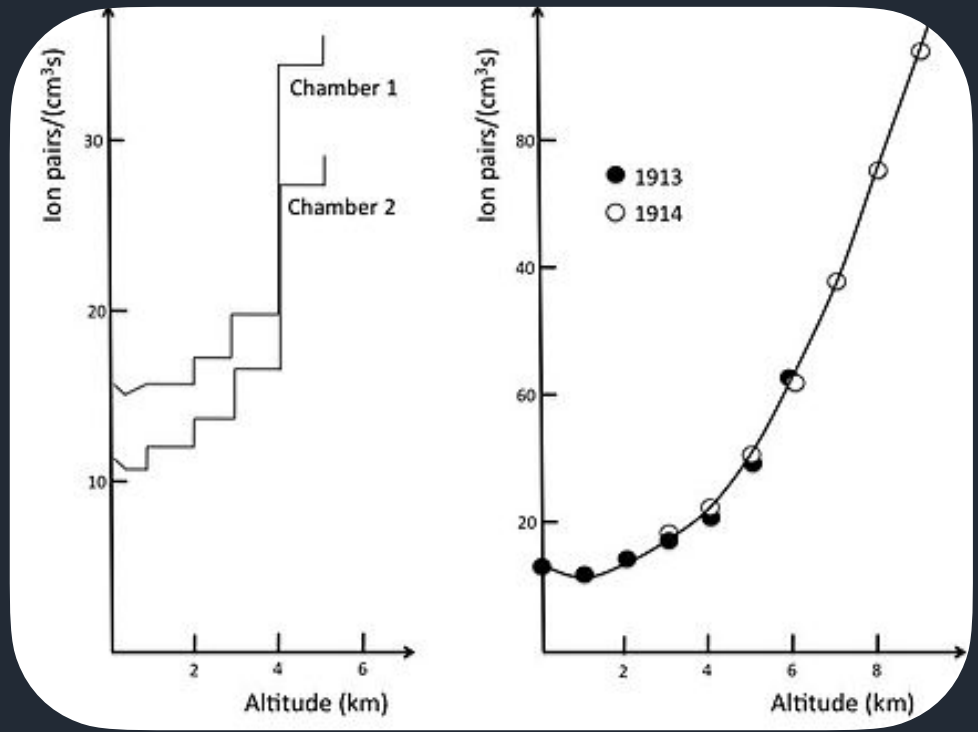
20th-century

1909 - Albert Gockel: balloon flight, ionizing radiation

1912 - Victor Hess: balloon flight, discovery of cosmic rays

1913-1914 - Werner Kolhörster: 10x more radiation (compared to sea lev)





Meantime

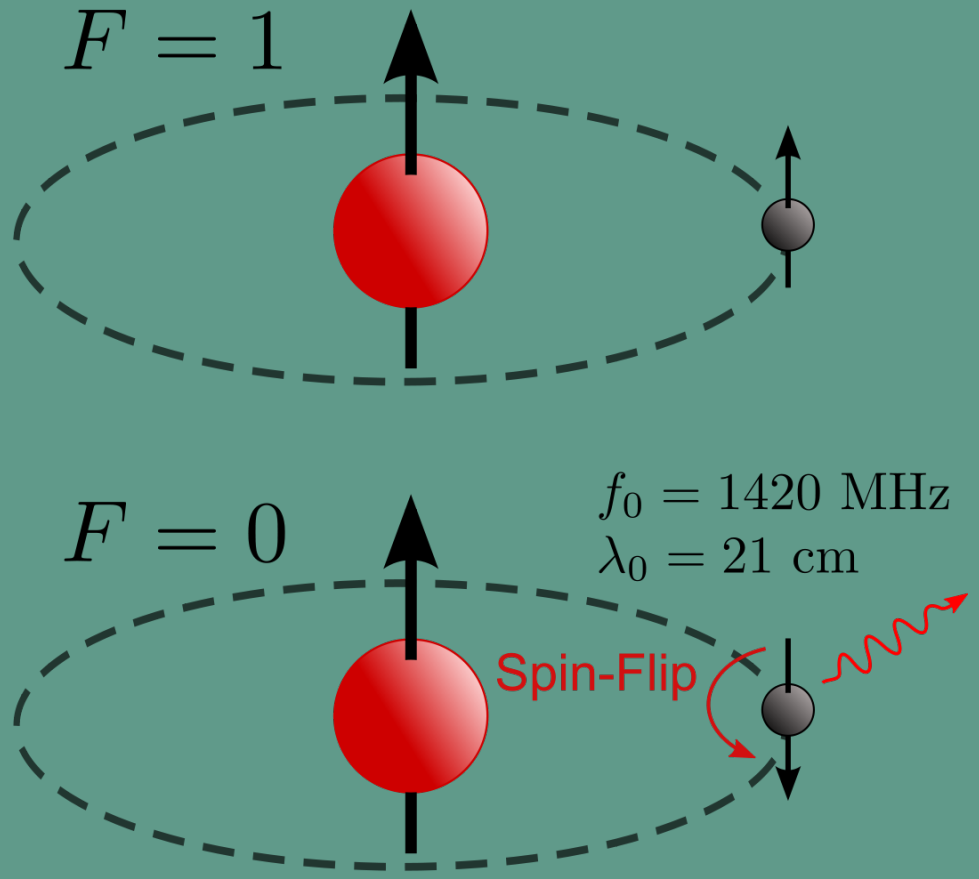
1931 - Jansky showed that radiation at 14.6 m (20.5 MHz) must be emitted by an extraterrestrial source (no the Sun)

1937 - Grote Reber (radio-engineer) published observations at 1.87 m following Jansky hypothesis

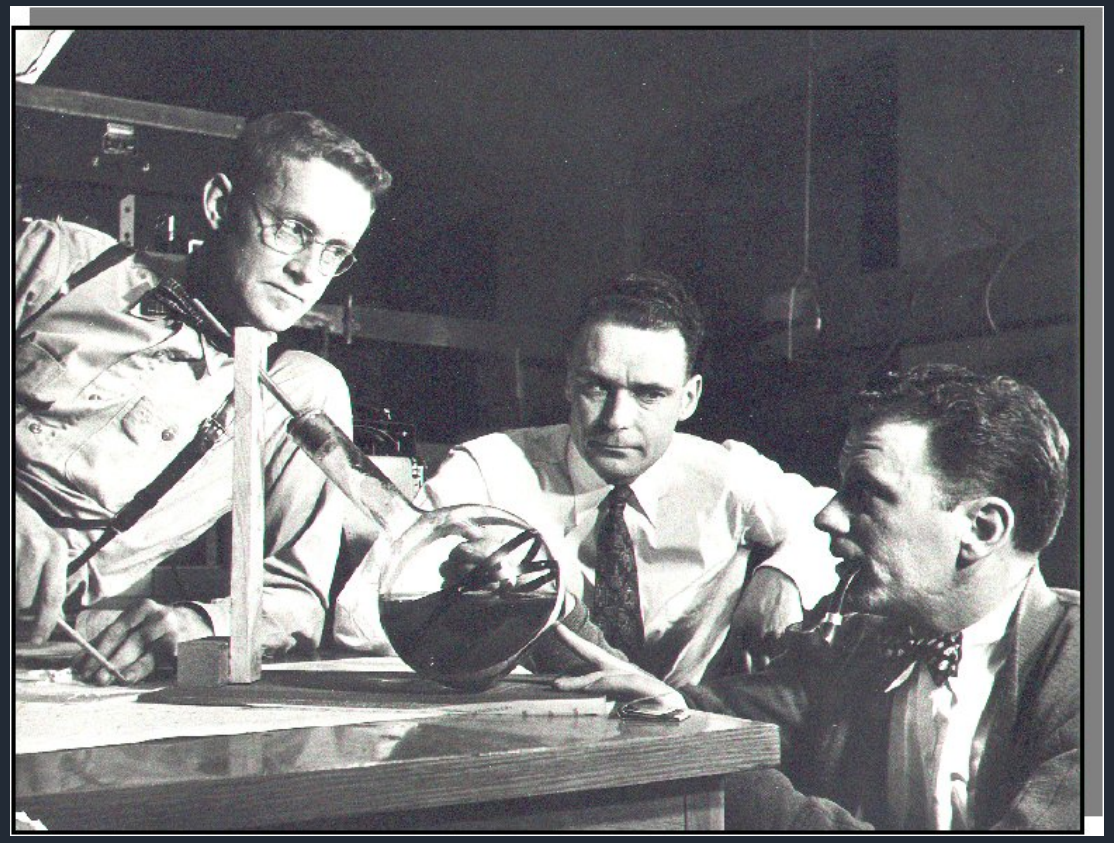
WWII - Radar equipment and new radio receivers developed

Radioastronomy & HI 21 cm line

1944 - Hendrik van de Hulst predicts the existence of the HI 21-cm Hyperfine spin-flip transition



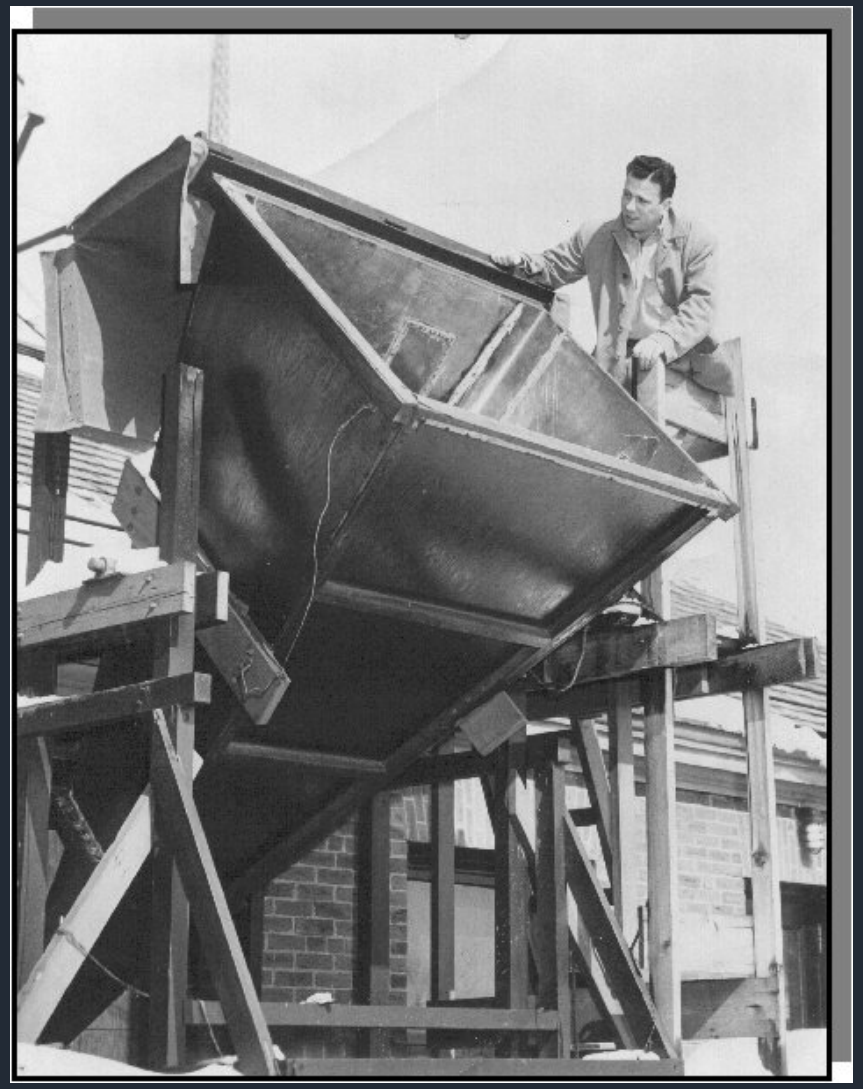
1950 - Doc Ewen worked 40 hours a week to design and build the apparatus for the new cyclotron at Harvard



+ he has to complete his PhD (working at nights and week-ends)

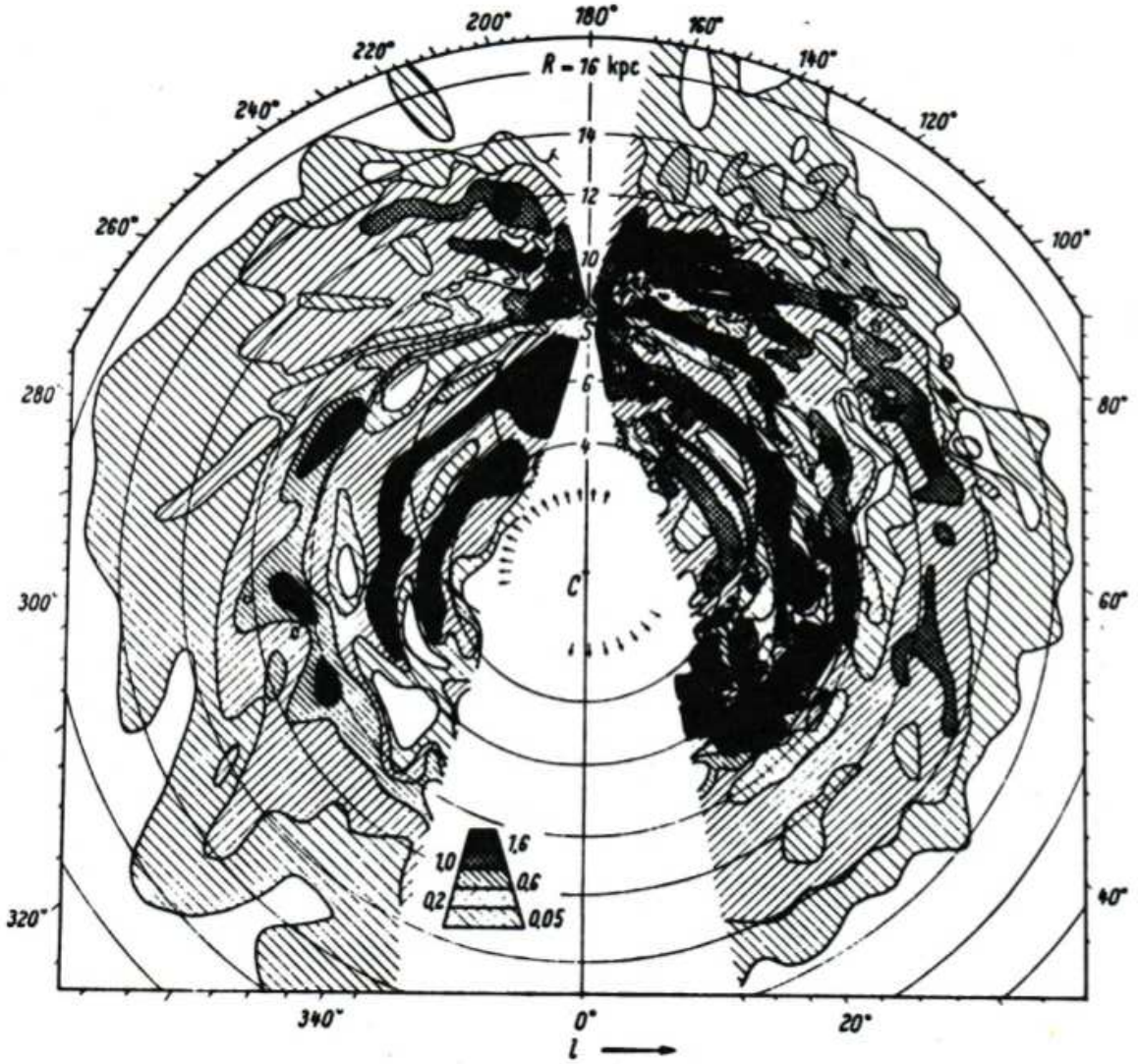
+ Building a receiver to detect 21 cm HI line (supervised by Purcell)

1950-1951- Purcell received 500 USD to build the antenna



6 weeks later - Muller & Oort confirmed the detection

Discovery of spiral arms (neutral HI)



Oort, 1958

Cold HI emitting @ 21-cm makes up most of the mass of the ISM gas in the Milky Way

Its observation represented a revolution

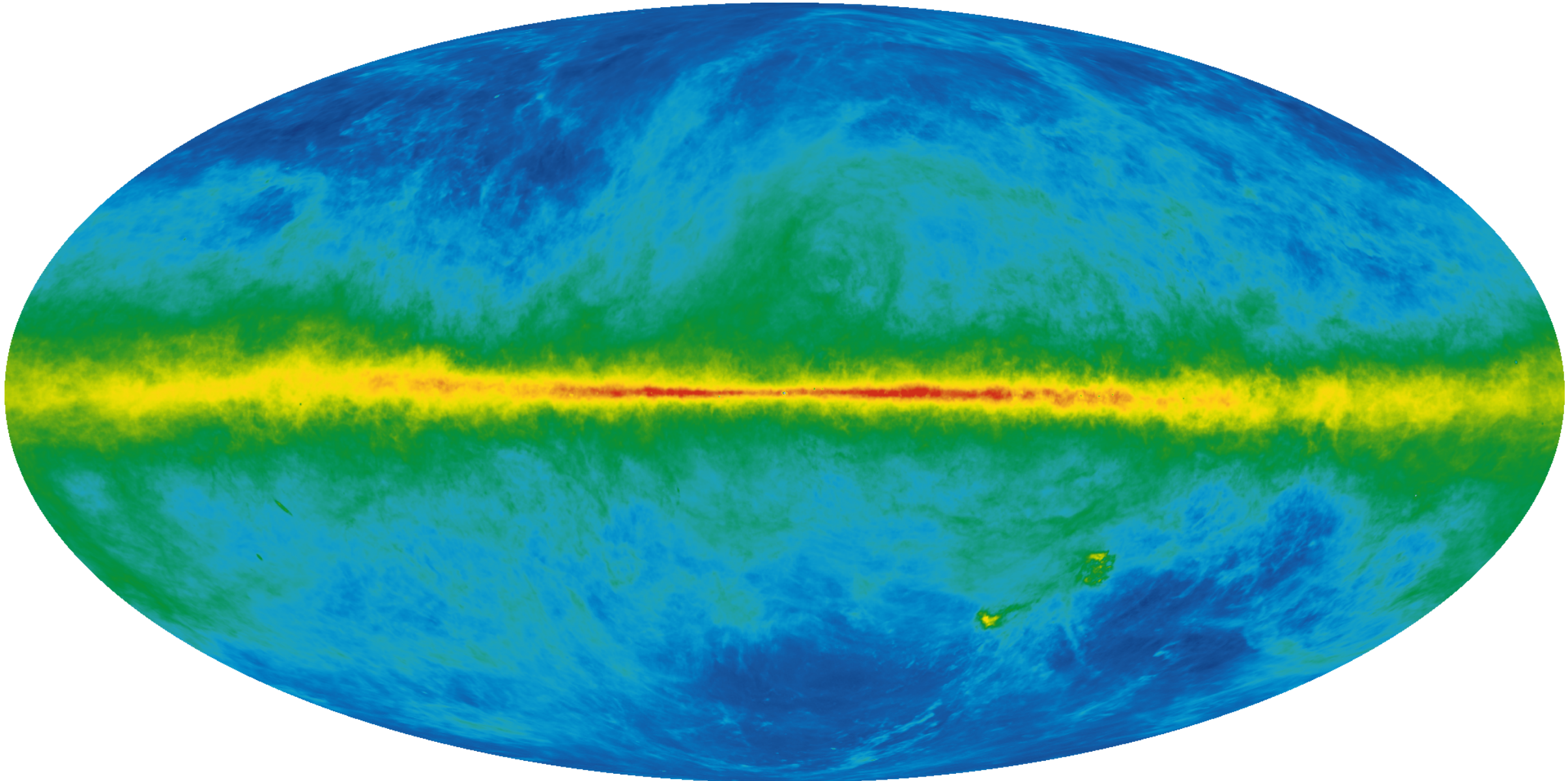


Image Credits: N(HI) HI4PI Collaboration 2016

Late 20th-century

1949 - J. Hall & W. A. Hiltner show polarization of starlight is correlated with extinction (importance of magnetic fields and alignment with dust)

1963 - OH observed @ 18 cm by Weinreb & Townes

1968 - NH_3 first polyatomic molecules observed @ 1 cm (Cheung, Townes)

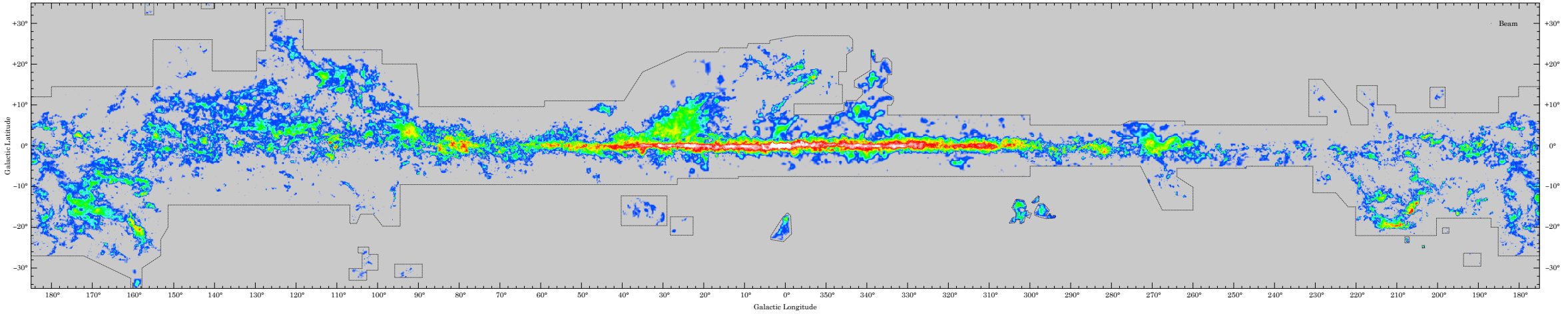
UV & mm astronomical techniques development

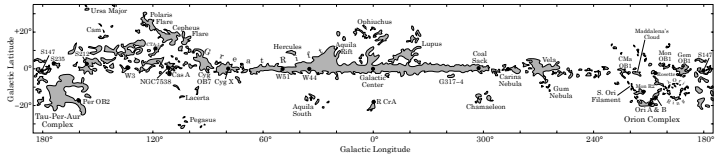
1970 - Wilson, Jefferts & Penzias observe 2.6 mm CO J=1-0 line

1973 - Detection of H_2 line in UV, Carruthers

Late 20th-century

- CO shows there are cold, dense regions of gas associated with star formation





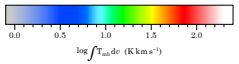


FIG. 2.–Velocity-integrated CO map of the Milky Way. The angular resolution is 9′ over most of the map, including the entire Galactic plane, but is lower (15′ or 30′) in some regions out of the plane (see Fig. 1 & Table 1). The sensitivity varies somewhat from region to region, since each component survey was integrated individually using moment masking or clipping in order to display all statistically significant emission but little noise (see §2.2). A dotted line marks the sampling boundaries, given in more detail in Fig. 1.

Dame 2000 CO-survey of the galaxy

Late 20th-century

- CO shows there are cold, dense regions of gas associated with star formation
- Interstellar chemistry complex
- 1980-until now: many complex molecules have been discovered

Space Astronomy (1980-now)

1973-1980 - Copernicus UV satellite
+ detection of H_2
+ Highly ionized atoms (e.g. O VI)
+ Depletion of refractory elements from gas to grains

1983 - IRAS
+ first full-sky survey @ 12, 25, 60, & 100 micron
+ Observation of dust particles and PAH

IRAS all sky view: Blue 10 micron, Green: 60 micron, Red: 100 micron

Temperature

Image credits: NASA/JPL-Caltech

Space Astronomy (1980-now)

1990-1991 - COBE satellite
+ Galactic distribution of CII & NII

1995-1998 - ISO satellite
+ MIR & FIR
+ Nature and composition of grains and PAHs
+ H_2 in shocks
+ First survey @ 2-200 micron (C_6H_6, CH_3, CO_2)

2003-2009 - SPITZER
+ High sensitivity
+ Ices, silicates, PAHs

Summarising

- ISM is the matter in between the stars
- ISM is a vast medium of extremes
- Lengths vary from parsec/kparsec
- Density variation 5-6 orders of magnitude (even more in MCs)
- Velocity range: from diffusion to hypersonic
- Temperatures from a few K to 10^7 K
- Fuel for the birth of stars