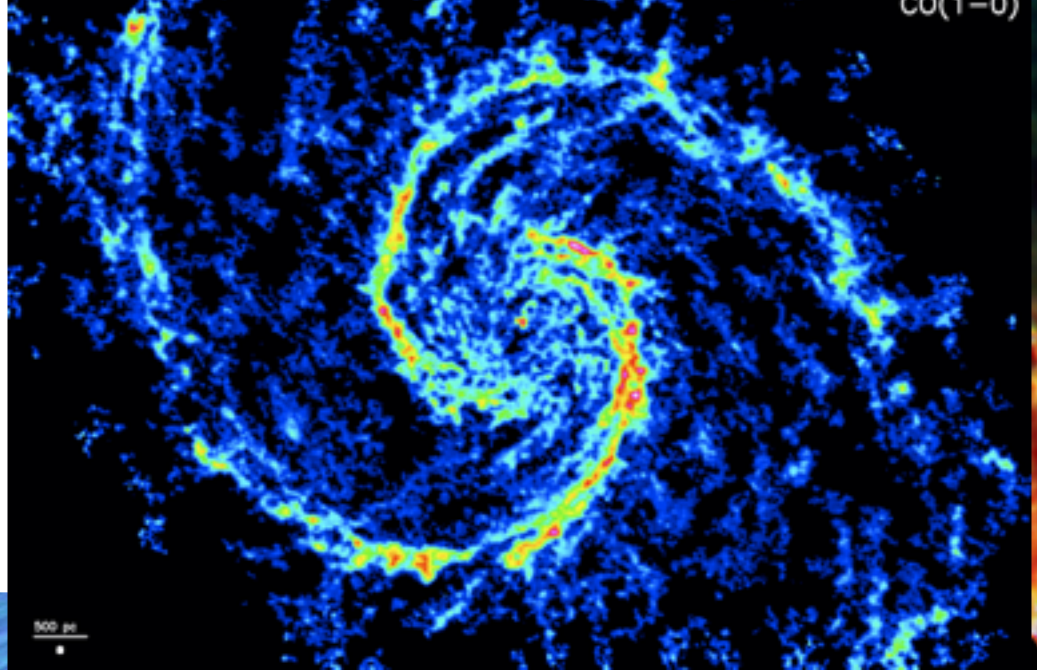
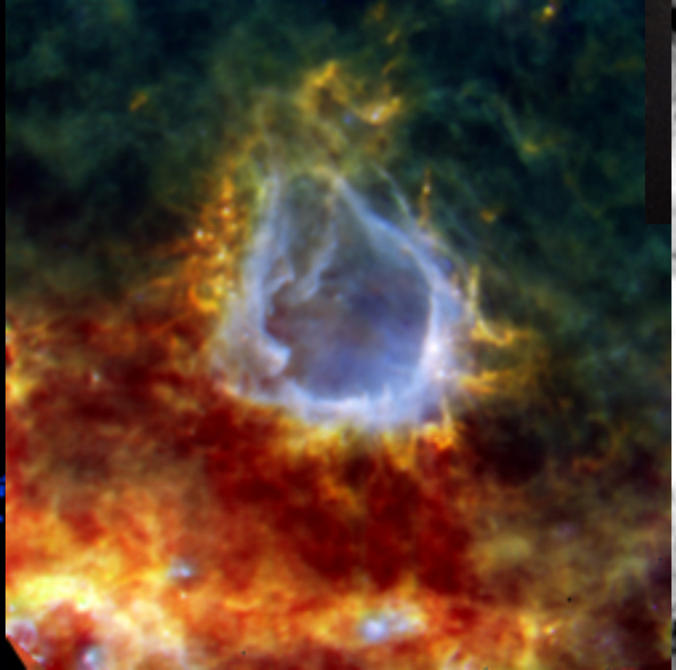
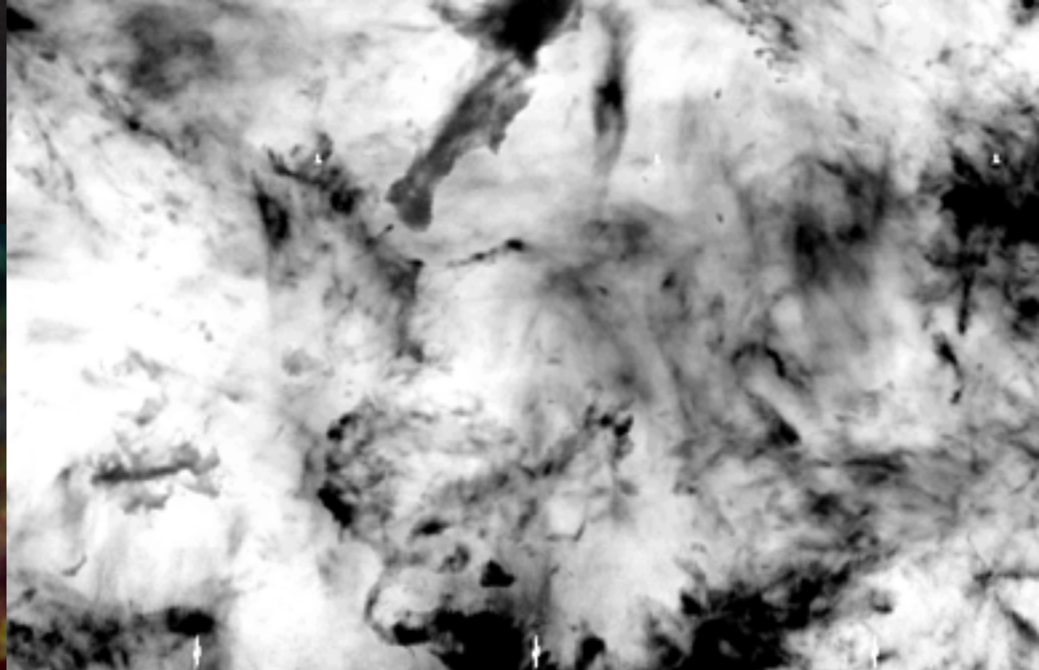
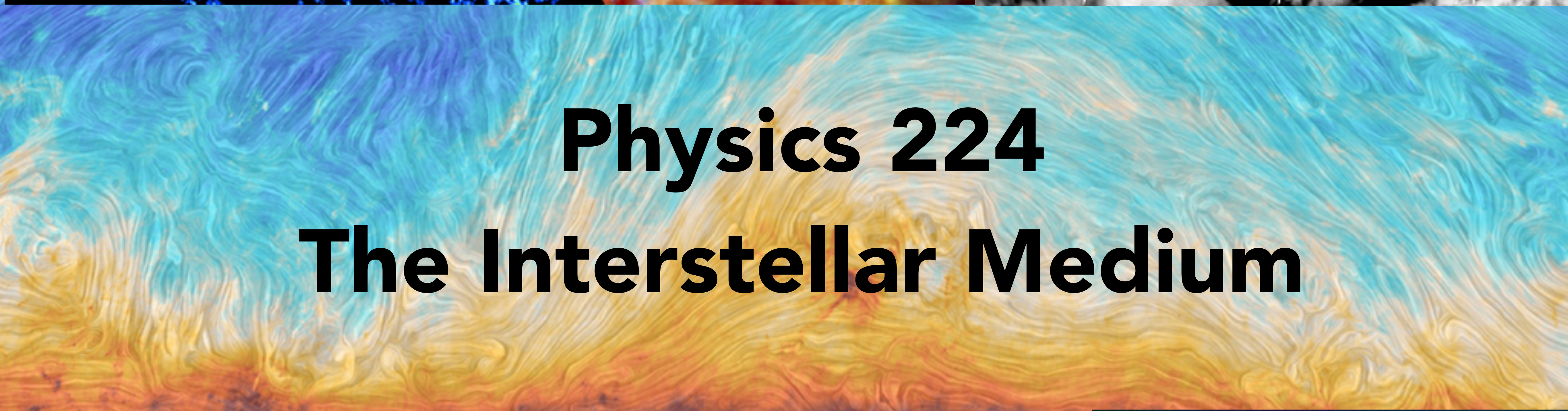
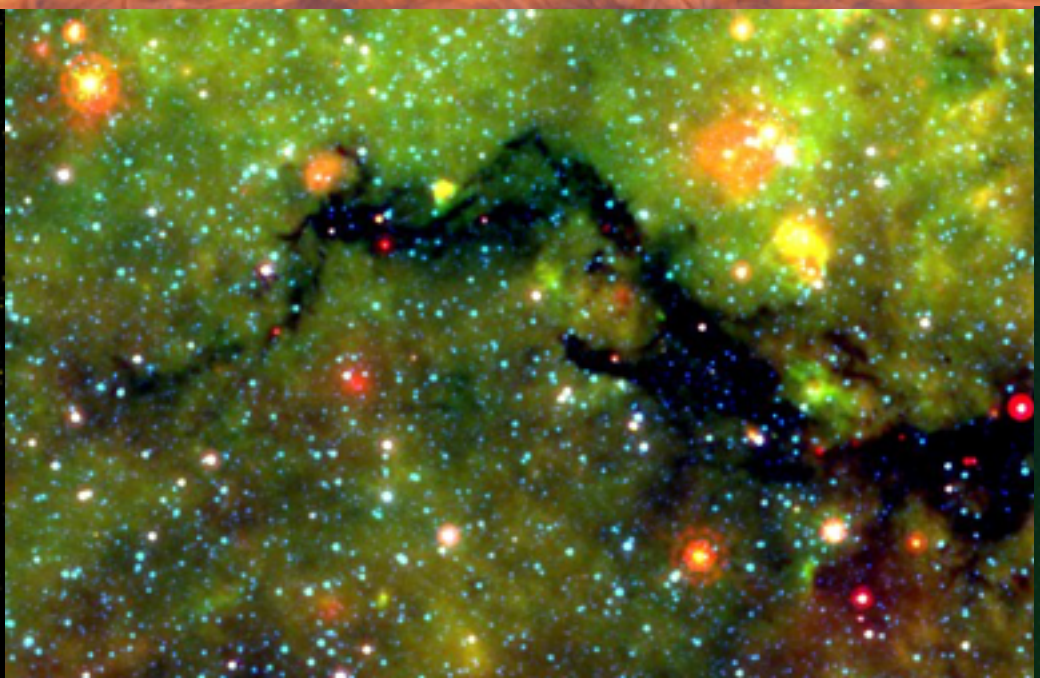
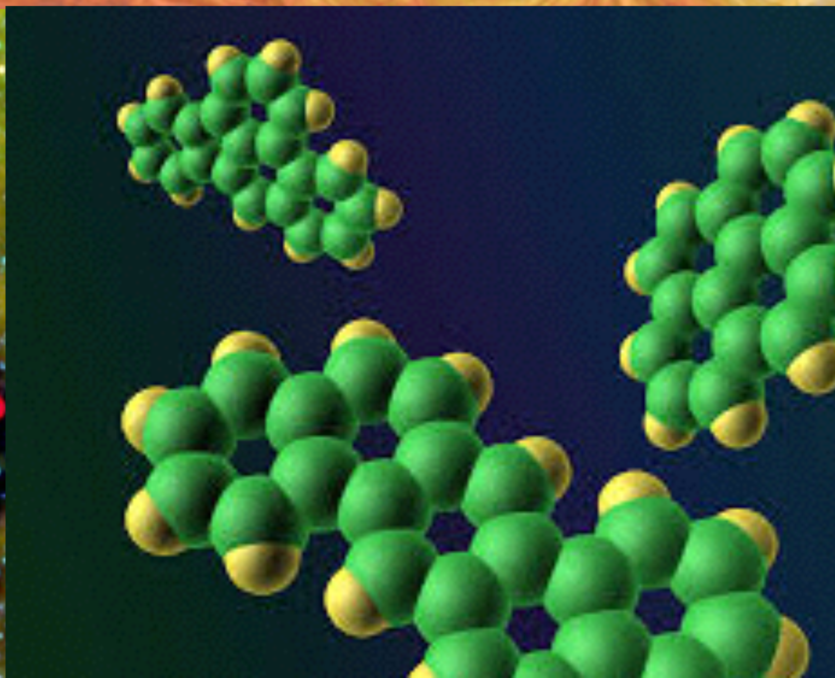




Physics 224
The Interstellar Medium



Outline

- Part I: About this class
- Part 2: Historical Perspective
- Part 3: An Overview of the ISM

Syllabus & Website

Course webpage:

http://karinsandstrom.github.io/sp16_phys224.html

Syllabus is on the webpage - still in progress!

My Goals for this Class

- I want you to leave this class familiar with the big picture of the interstellar medium, the unsolved problems, & observational techniques for studying it.

- I intend to make the assigned work for this class serve as training for actual skills you will need in your research career: presentations, proposals, dealing with data, reading literature, etc.

About this class

- MWF 10-10:50am meetings
  - most weeks: lecture MW and discussion of papers on Friday
  - some weeks Friday will be a seminar on other aspects of astronomy careers
- This Friday will be a normal lecture
- I will post lecture slides on the website.

Homework

~4 homework assignments throughout the class

Homework should be turned in as a typeset pdf, LaTeX is recommended, but not required.

Online LaTeX editors:
www.sharelatex.com or www.overleaf.com

Homework

You are encouraged to work together on the homework if you would like, but *<u>each person must turn in their own individual write up!</u>*

Use standard practice in our field for citing literature and relevant sources you used in your work.

If you do not feel like you know the standard practice yet, no problem - just ask and we can talk about it.

Homework

Some of the homework will require making plots or dealing with data & making measurements.

I recommend doing this in **python**, but any programming language you'd prefer is fine (IDL, matlab, etc).

You will have to read in fits files (typical data storage format for astronomy). I will post some links about fits files in python to the class webpage.

If some of you would like to learn python (recommended) we can arrange for a workshop!

Reading

The required textbook is:
The Physics of the Interstellar and Intergalactic Medium
by Bruce Draine

We will not cover everything in the book.
Suggested reading for each lecture is listed in the syllabus.

Try to read through the suggested chapters before lecture.

Paper Presentation

One of the key aspects of our research careers is *reading scientific literature.*

On 5 Fridays during the class we will have discussions of 10 classic papers from the ISM literature (2 per Friday). *Each of you will lead one of the discussions.*

Please sign up for leading a discussion at the link on the course webpage by the end of the week!

Paper Presentation

You will be expected to read the paper and put together a ~15 minute presentation about it that highlights:

- big picture context of the paper
- technical approach
- key findings
- impact on subsequent work in the field (cite a recent paper that builds on this work)*

* for those unfamiliar with NASA ADS for finding astro literature, I can give you a tutorial

Paper Presentation

Everyone else in the class will be expected to read the papers and submit substantive comments or questions for discussion by 5pm on the Thursday afternoon before the discussion.

This will be done via google form linked from the class webpage. I will send a link prior to the first discussion.

These are not easy reads! Some tips:

Start reading early. Google often. Take notes. Discussion leaders will most likely need to read their paper more than once.

"Lean in" to confusion! It is perfectly fine to be confused, try to understand specifically what you find confusing. Feeling confused is a big part of research!

Don't take things for granted - some of the stuff in these papers is old and may have been superseded. Dig deeper into the literature to understand the landscape.

Read critically, note the flaws, but also try to understand why these papers are classics - they all made a big impact on the field.

I am happy to chat with you about the papers beforehand - just set up an appointment.

Final Project

50% of your grade is based on a final proposal project submitted in the last week of class.

You will be expected to write a proposal, following standard practices in the field, asking for observations, supercomputer time, funding or other resources addressing a question about the ISM.

After the proposals are due, we will hold a review panel meeting to evaluate the proposals (although I get final say on grades :-)

Final Project

On April 8*, we will have a more detailed discussion of proposals, going over some of the options.

Note, if you get into this project deeply - you could actually submit your proposal!

*fittingly this is the HST proposal deadline, so your professor will hopefully be semi-coherent.

Final Project

Some key dates:

April 8: discussion in class of proposal & formats
April 29: seminar on scientific writing
May 11: submit proposal abstract & bibliography
May 27: full proposal deadline
June 1: review panel discussion

I am available to talk about this throughout the quarter, just email to set up an appointment.

Grades

Your grade is based on:

15% paper presentation
10% participation in paper discussions
25% homework
50% final proposal project

Any Questions?

My Perspective on the History of Studying the ISM

Our conception of the ISM is closely tied to how we are able to observe it.

Time ↓

- Optical - Naked Eye
- Optical - Photographic Plates & Imaging
- Optical - Spectroscopy
- Radio
- UV/X-ray/Infrared
- mm

The ISM is a pretty uniform, wrinkly gray patch.

The ISM is very spiky
and made of hard stuff.

The ISM is mostly big tree trunk like patches of wrinkly gray stuff.

The ISM is a giant complex system that is hard to study piece by piece.

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

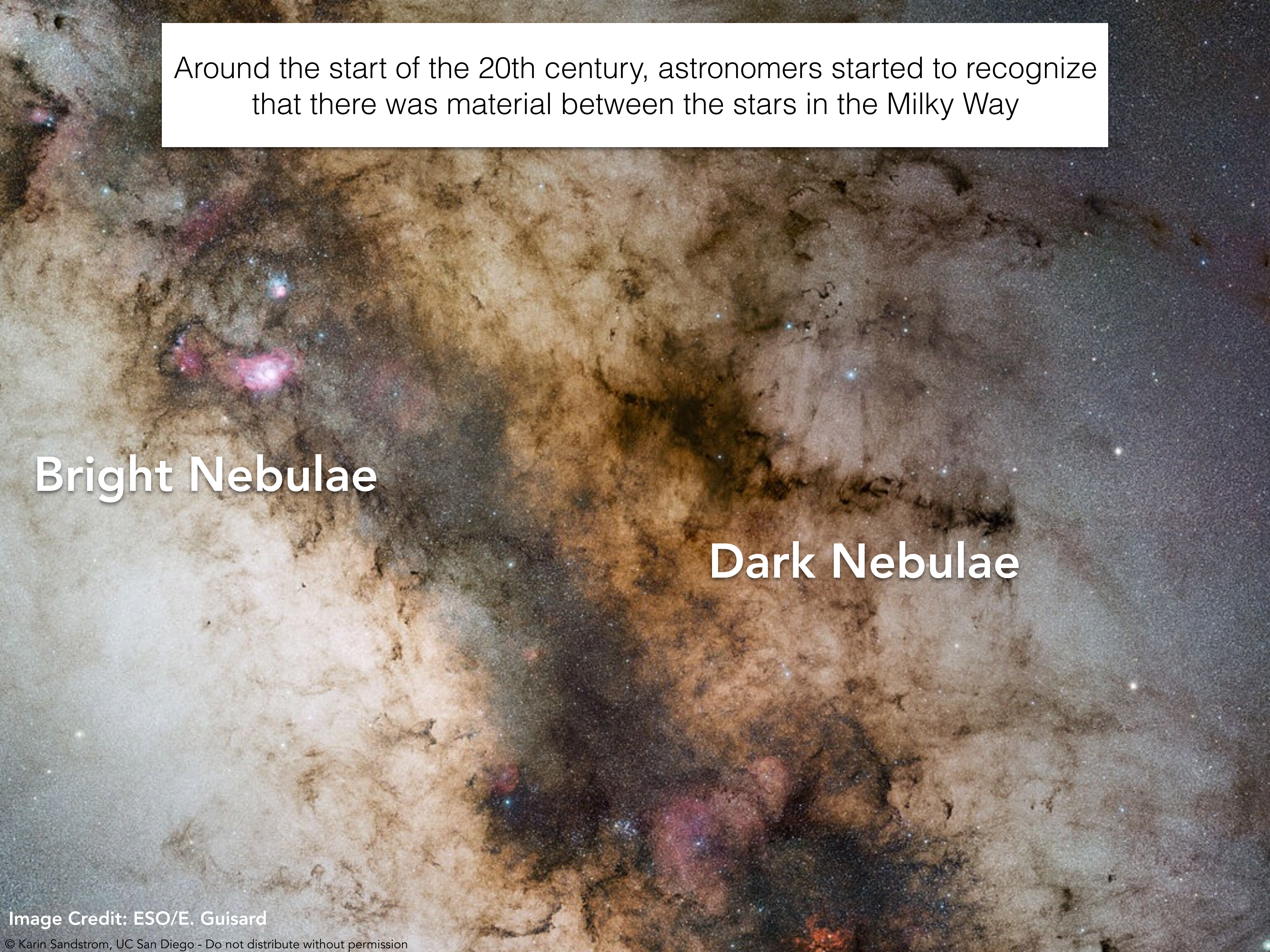


Image Credit: ESO/E. Guisard

"Hier ist wahrhaftig ein Loch im Himmel!"

"Here is truly a hole in Heaven."

712 STAR-GAGES FROM THE 358TH TO THE 1111TH SWEEP

VACANT PLACES

[*Extracted from the Sweeps. Places for the Year of Observation.*]

Sweep.	R.A.	P.D.	Stars.	
383 Mar. 10 1785	16 5 22	109 25	0	
	16 6 22	109 20	0	
	16 6 32	109 31	0	
	16 7 22	109 49	0	
	16 7 42	109 12	0	
	16 11 52	110 17	0	
	16 12 22	109 11	0	
	16 12 40	110 25	0	
	16 13 0	111 29	2	
485 Dec. 7 1785	4 17 37	65 29		Upper border of a vacancy, but it is a very irregular one.
	4 18 30	65 27		Do.
	4 19 17	65 29		Do.
	4 21 35	64 31	0	
	4 22 26	64 22	0	
	4 23 53	64 4	0	and many such in the neighbourhood.
	4 25 17	..		There is a vacancy between the bright row of stars in the direction of Orion's belt and the Bull's head, Perseus' body and the Milky Way, and I am now in that vacancy.
	4 27 26	65 4	0	Intermixed with places that have many stars.
	4 28 6	64 10	0	
	4 28 42	65 11	0	
	4 29 24	65 15	0	
	4 30 54	65 16	0	
	4 37 51	65 16	0	
	4 39 16	..		The straggling stars of the Milky Way seem now to come on gradually, most small.
	4 43 20	..		They begin now to be intermixed with some larger ones.
516 Jan. 30	5 32 16	98 30	0	
	5 32 42	100 21	0	Vacant spaces picked out, between stars

William and Caroline Herschel cataloged dark clouds or "holes".

1912 *The Scientific Papers of Sir William Herschel*, (London: The Royal Society & Royal Astronomical Society), Vol II, pg 712.

Optical Photographic Spectroscopy demonstrates some nebula have emission line spectra indicating “gaseity”.

II. “On the Spectrum of the Great Nebula in the Sword-handle of Orion.” By WILLIAM HUGGINS, F.R.A.S. Communicated by the Treasurer. Received January 11, 1865.

In a paper recently presented to the Royal Society*, I gave the results of the application of prismatic analysis to some of the objects in the heavens known as nebulæ. Eight of the nebulæ examined gave a spectrum indicating gaseity, and, of these, six belong to the class of small and comparatively bright objects which it is convenient to distinguish still by the name of planetary. These nebulæ present little indication of probable resolvability into discrete points, even with the greatest optical power which has yet been brought to bear upon them.

Spectrum of some nebulae shows a stellar spectrum, light is reflected off of small particles.

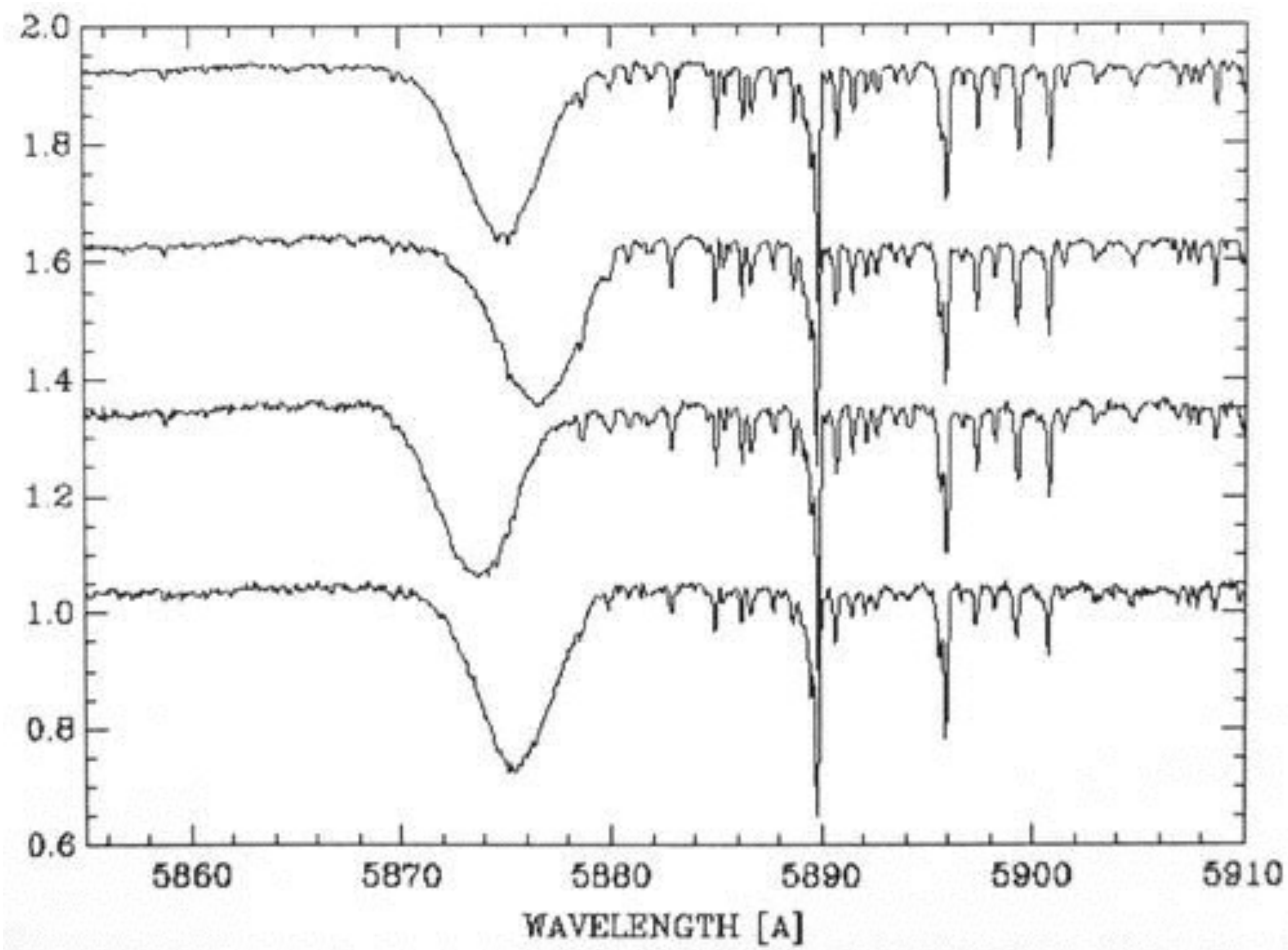
V. M. Slipher
Lowell Observatory
Bulletin, vol. 2, pp.26-27

by the star light to be visible, and thus there seems to be support for the conclusion that the Pleiades nebula shines by reflected light.

This observation of the nebula in the Pleiades has suggested to me that the Andromeda Nebula and similar spiral nebulæ might consist of a central star enveloped and beclouded by fragmentary and disintegrated matter which shines by light supplied by the central sun. This conception is in keeping with spectrograms of the Andromeda Nebula made here and with Bohlin's value for its parallax.

V. M. Slipher.

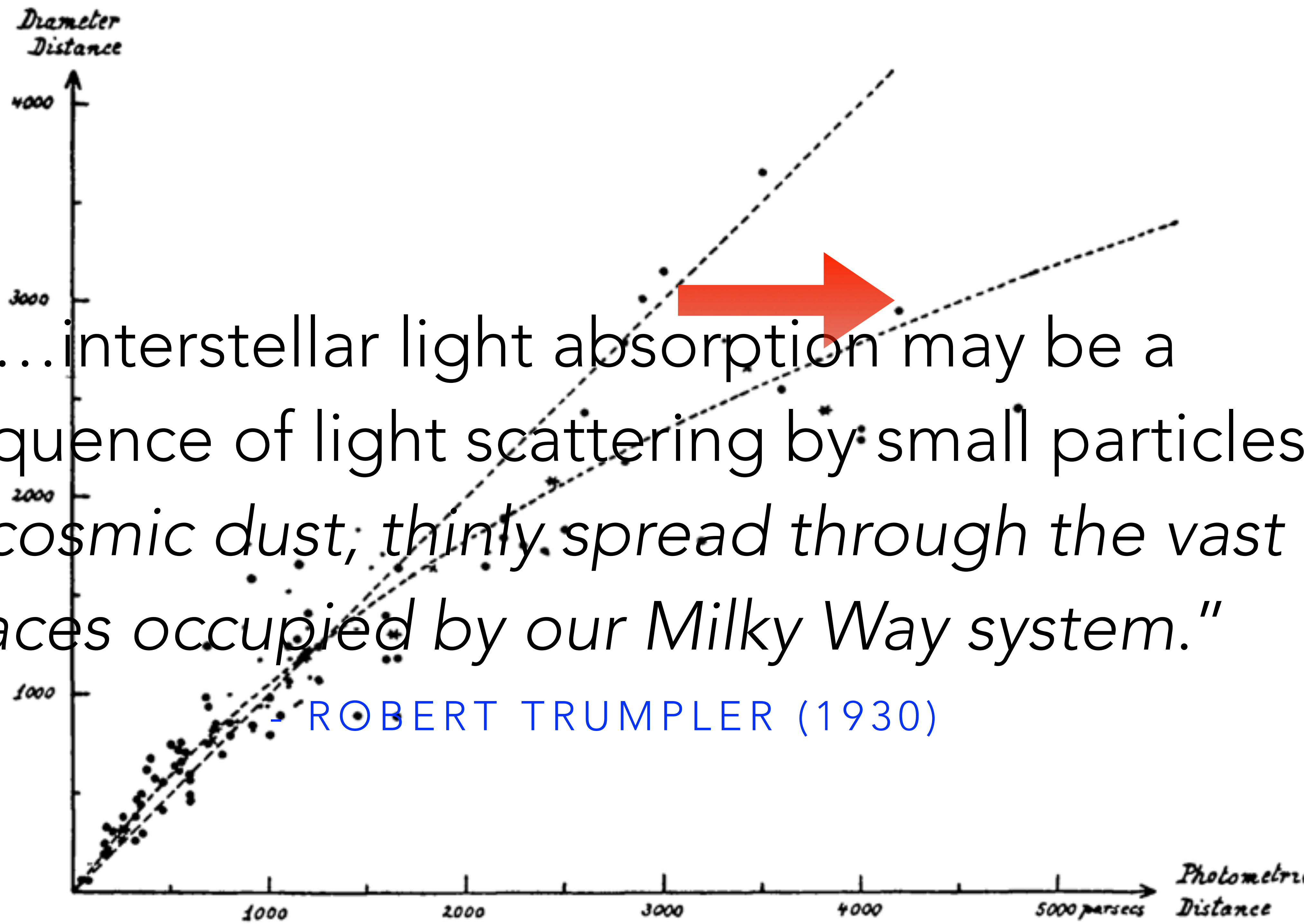
Hartmann 1904 shows narrow, stationary absorption lines in the spectrum of binary star δ Orionis - velocity different than the stars.



These lines turn out to be CaII H & K (3933 and 3968 Å) .

Similar measurements show the “stationary” NaI D doublet (5890 and 5896 Å)

Distance expected from size,
i.e. distant things look smaller



"…interstellar light absorption may be a consequence of light scattering by small particles, *fine cosmic dust, thinly spread through the vast spaces occupied by our Milky Way system.*"

- ROBERT TRUMPLER (1930)

Distance expected from brightness,
i.e. distant things look fainter

ISM Paradigm Pre-1930's

Diffuse material, absorption from small particles, constant density, velocity.

Advances in high resolution spectroscopy show this isn't the case! Narrow NaI and CaII lines resolve into multiple velocity components.

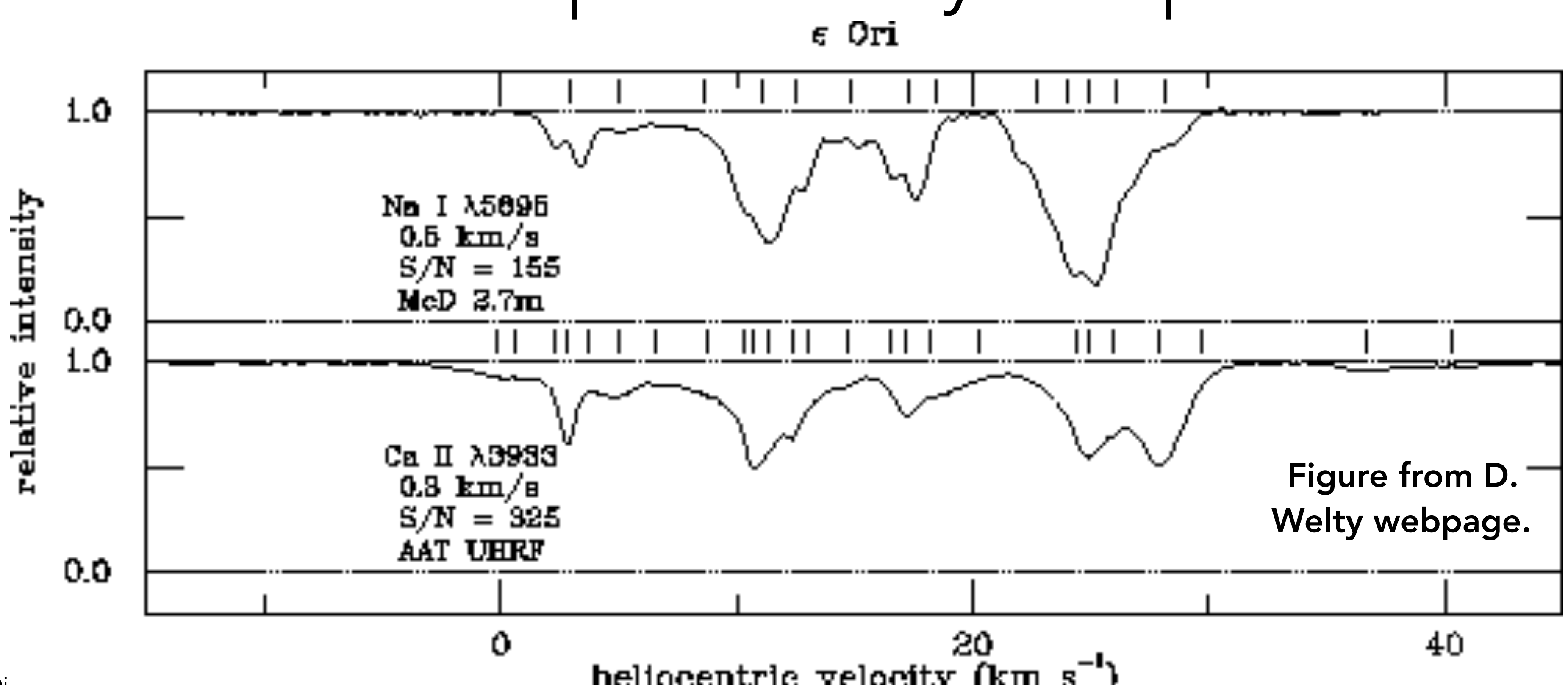


Figure from D. Welty webpage.

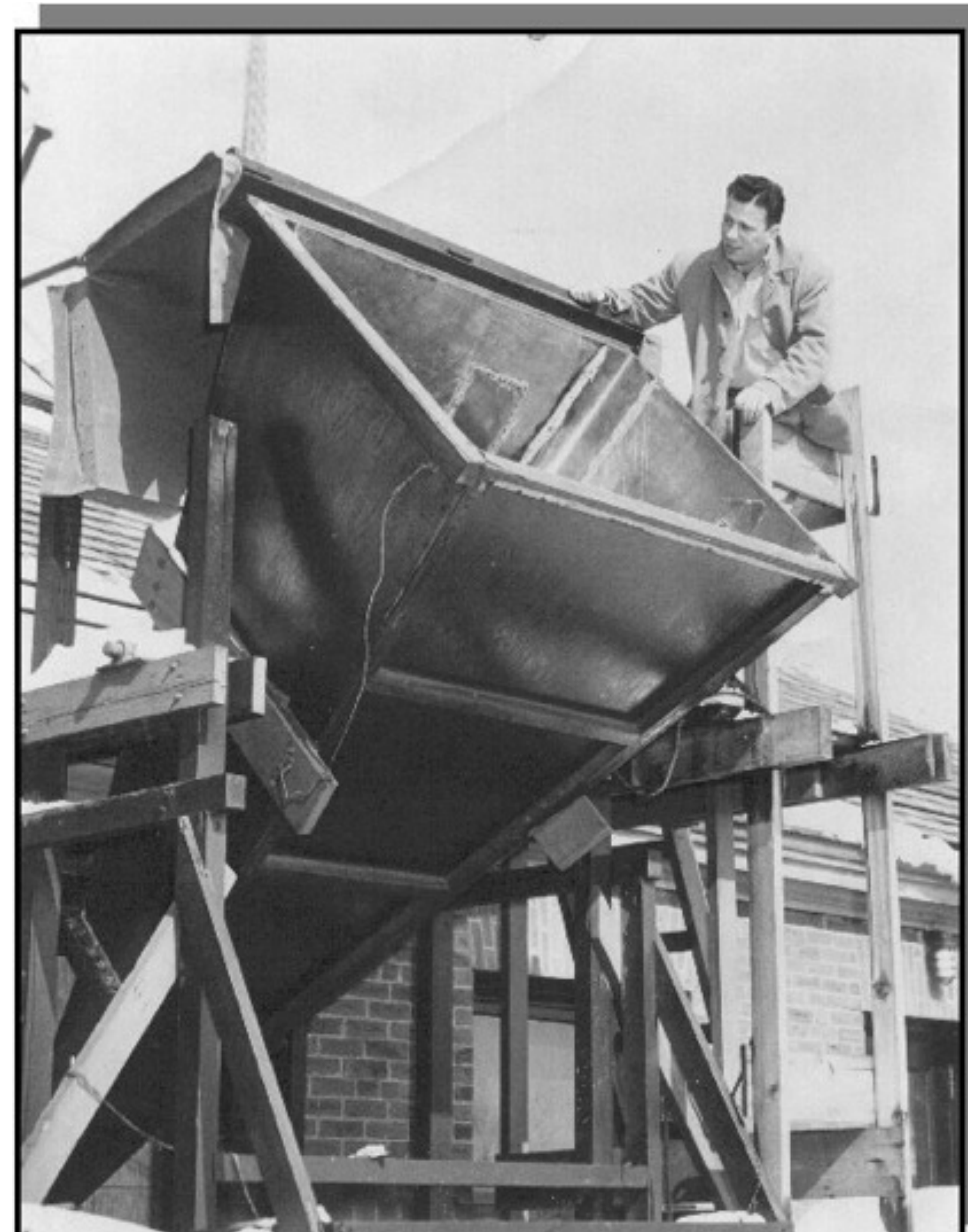
Cosmic Ray History

- 1912: V. Hess balloon flights over 5km in altitude, finds some form of ionizing radiation which increases with altitude. 1912 flight during solar eclipse argues for interstellar origin. Nobel prize!

- 1927-34: Clay, Bothe, Kohlörster & Alvarez, cosmic rays are high energy charged particles not γ rays

Radio Astronomy & The 21-cm Line

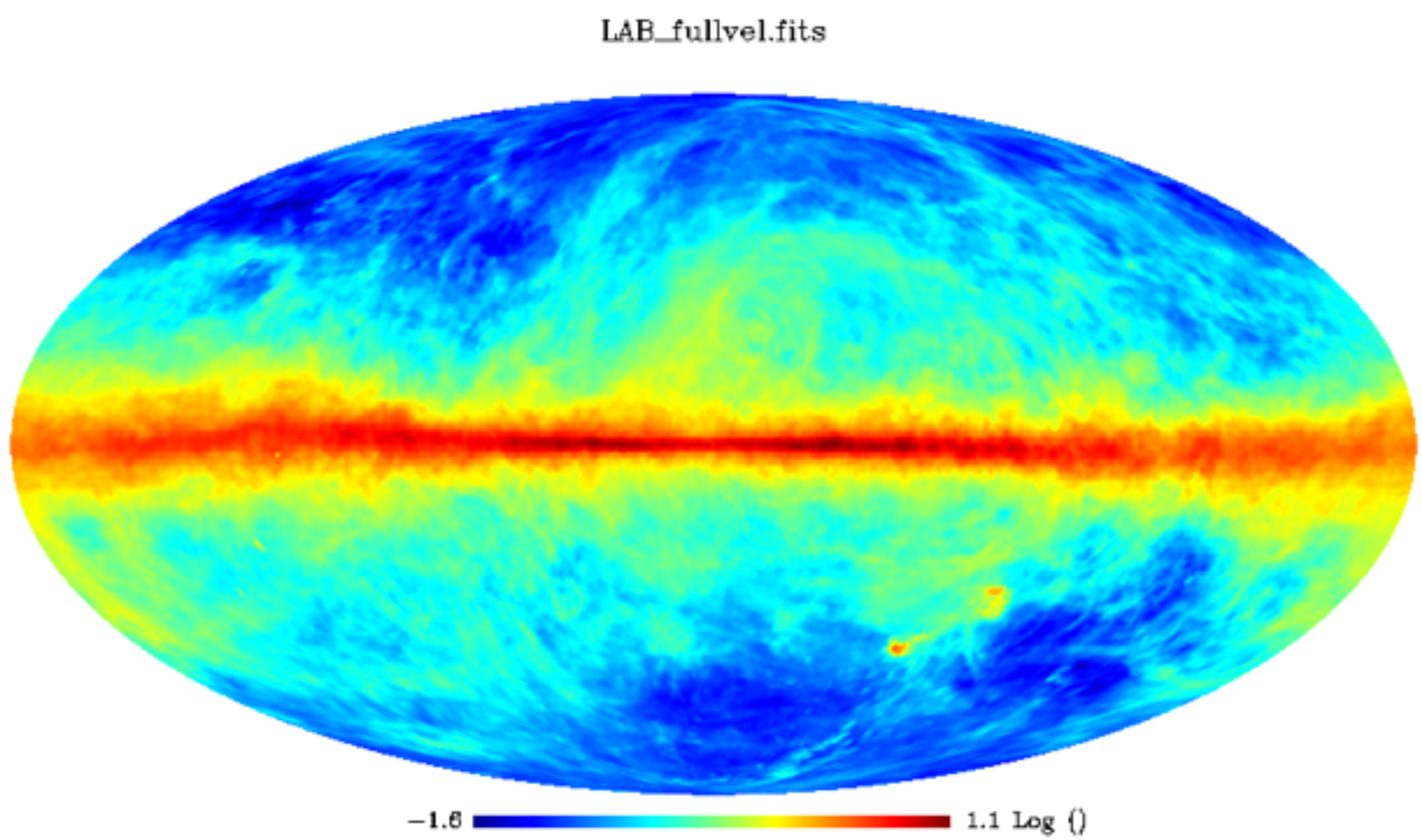
- 1944: Hendrik van de Hulst predicts the existence of the HI 21-cm hyperfine spin-flip transition.
- During WWII, development of radio astronomy parallels radar technology - lots of interesting history.
- 1951: Ewen & Purcell (6 weeks later Muller & Oort) measure the 21-cm line.



http://www.nrao.edu/whatisra/hist_ewenpurcell.shtml

Radio Astronomy & The 21-cm Line

Cold HI emitting at 21-cm makes up most of the mass of ISM gas in the Milky Way, so being able to observe this directly was a revolution in how we understood the ISM.

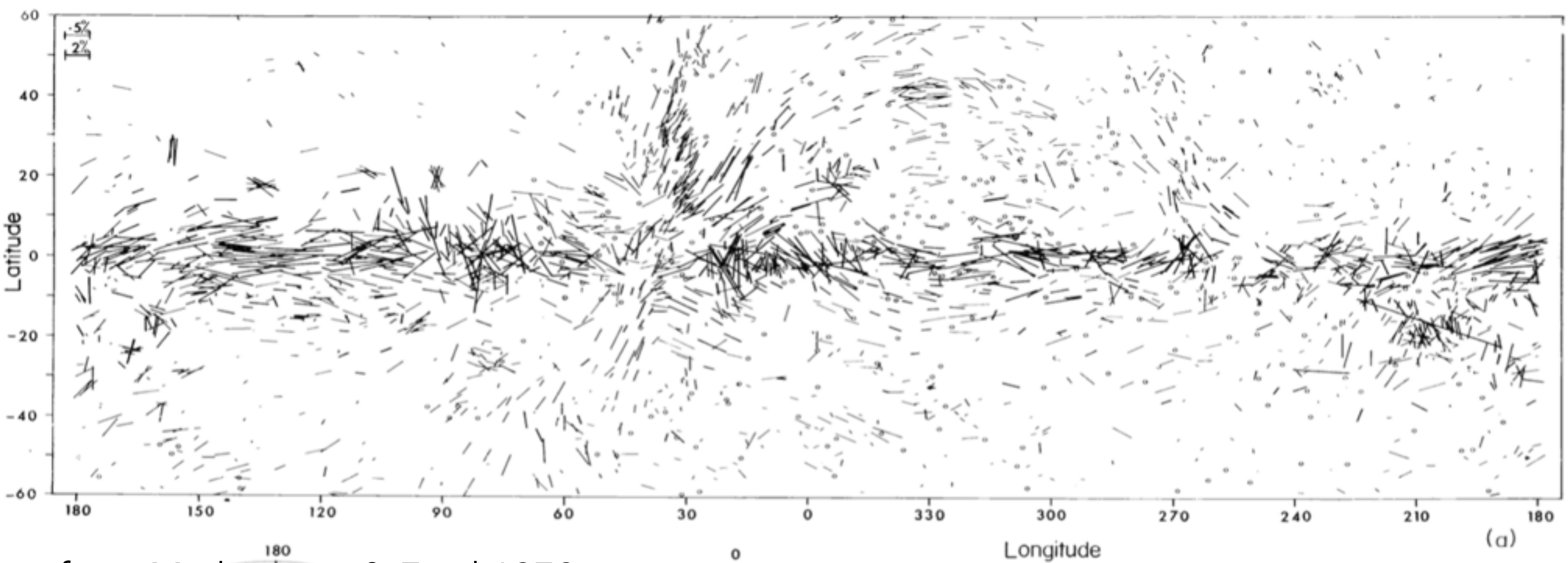


Can see gas is clumpy, turbulent, highly non uniform.

http://irsa.ipac.caltech.edu/data/Planck/release_1/external-data/external_maps.html

Magnetic Fields

1949: Hall & Hiltner show polarization of starlight correlated with reddening.



from Mathewson & Ford 1970

mm Astronomy & molecules

- 1937-40: optical absorption lines demonstrate there is interstellar diatomic molecules CH, CH^+, CN.

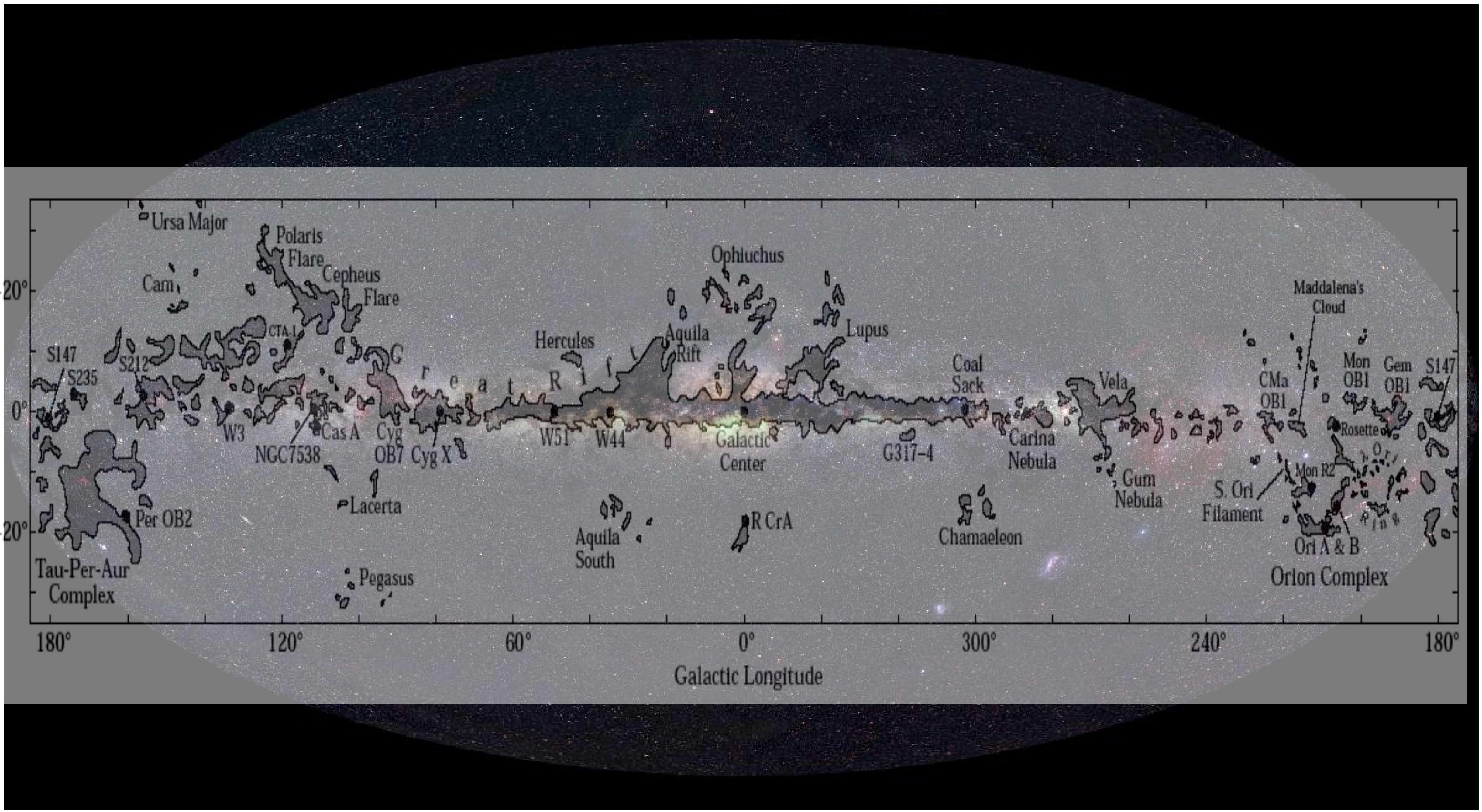
- 1963: radio observations of OH by Townes et al.

- 1968: NH_3 (ammonia) and H_2CO (formaldehyde) observed towards individual clouds.

- 1970: Wilson, Jefferts, & Penzias observe 2.6mm rotational line of the CO molecule.

- 1980s-now: many more & more complex molecules are observed in the ISM.

mm Astronomy & molecules



mm Astronomy & molecules

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

Reveals interstellar chemistry to be important & complex!

Sensitivity of mm telescopes initially shows only the densest regions - “cloud” paradigm.

Space Astronomy (1980s-now)

- γ-rays: high energy particles interacting with ISM gas
- X-ray: there's lots of hot (10^5-10^6 K) gas!
- Ultraviolet: H_2 absorption, UV extinction curve of dust
- Infrared: warm dust everywhere, H_2 rotational lines, far-infrared fine structure lines of carbon, oxygen, etc reveal cooling of ISM gas, small/hot dust grains