Astronomy 496/596:

Observational ISM and Star Formation

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Drop by or by appointment

http://eeyore.astro.uiuc.edu/~lwl/classes/astro596/spring07

This Class (Lecture 1):

Introductions/History

Next Class:

The ISM

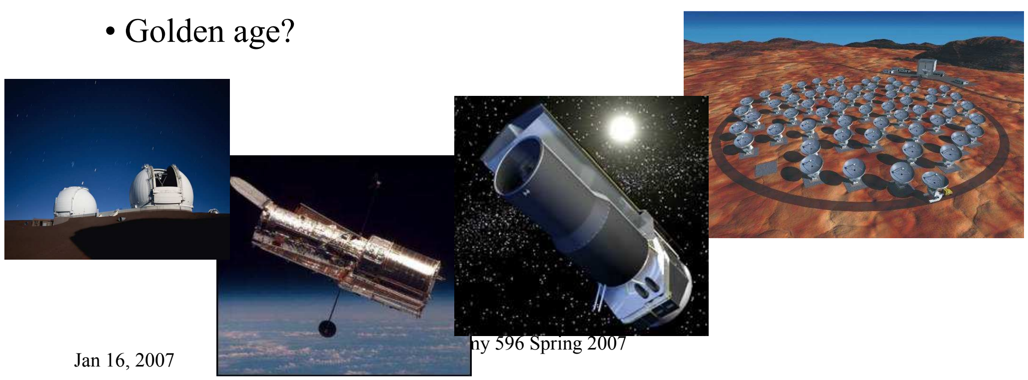
Music: *Astronomy* – Metallica

Outline

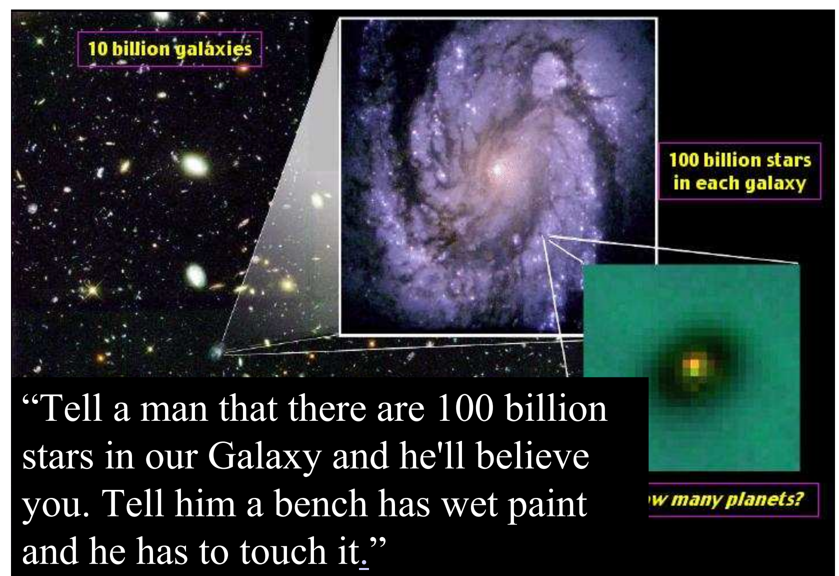
- Class Introductions
- Class Goals
- Syllabus
- A Star is born
- History lesson 101

Welcome to Astro 596

- It's a great time to take this course!
- New instruments are putting theories and observations of star formation at the cutting-edge of astrophysics.
- New observations and theories are bringing together a much better picture of star formation
- Golden age?



The Universe: Some Facts to Help you Live in it



"Tell a man that there are 100 billion stars in our Galaxy and he'll believe you. Tell him a bench has wet paint and he has to touch it."

http://astron.berkeley.edu/~kalas/disksite/learnframes.htm

Star Formation

"We had the sky up there, all speckled with stars, and we used to lay on our backs and look up at them, and discuss about whether they was made or only just happened. Jim he allowed they was made, but I allowed they happened; I judged it would have took too long to MAKE so many. Jim said the moon could a LAID them; well, that looked kind of reasonable, so I didn't say nothing against it, because I've seen a frog lay most as many, so of course it could be done."

The Adventures of Huckleberry Finn by Mark Twain

http://content.answers.com/main/content/wp/en/3/3f/Huck-and-jim-on-raft.jpg

http://antwrp.gsfc.nasa.gov/apod/ap021122.html

Course Goals

After this course one should be able to:

- Understand our current scientific view of star formation in the universe/galaxy.
- Conceptualize how observations are used in addressing the main outstanding questions in start formation.
- Propose what the future may hold for the field.
- Make informed decisions about star formation.
- Summarize a scientific journal in the field of observational star formation and make a judgment on quality/topic/and conclusions.

Course Outline

Topics:

- ISM (InterStellar Medium)
- GMCs (Giant Molecular Clouds)
- Cores (Prestellar/starless)
- Protostars
- Binarity
- Massive star evolution
- Jets and outflows from YSOs (Young Stellar Objects)
- Circumstellar disks
- Massive stars
- Take part of the journey, and let's enjoy the ride.

Course Requirements

Requirement	Percentage of Grade	Points
Class Participation	40%	40
Discussion Paper Summary	10%	10
Discussion Lead	35%	35
Discussion Secondary	15%	15
Total	**100%**	**100**

- Main format will be a 20-30 minute lecture, followed by discussion of a current journal or review article
- Main thrust of course is ability to read observational star formation papers, get the point, understand observational evidence, and see possibly difficulties.

http://www.public.asu.edu/~atjlb/

Class Participation: 40%

- You are expected to attend lectures.
- We can not discuss the journal articles if no one is here.
- I find this is a very effectual teaching tool, so I am using class participation as 40% of the class grade.
- On the other hand, I, of course expect some absences, but please try to tell me in advance of any missed classes.

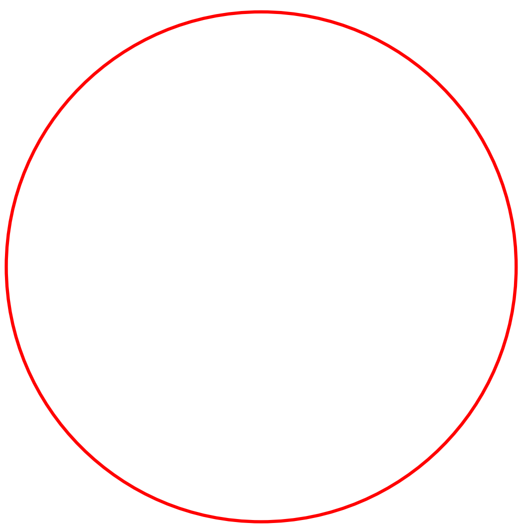
http://www.fhp.state.fl.us/academy/ClassActs/Class107/images/107PG012804T.jpg

Discussion Paper Summary 10%

- Schedule of papers is posted
  http://eeyore.astro.uiuc.edu/~lwl/classes/display.cgi?s=spring07&c=596&t=s
- Each class a student is chosen (randomly before class).
- That student gives a 5 minute (MAXIMUM) verbal summary of the paper.
  - What are the fundamental conclusions of the paper?
  - Include impact based on class lectures and previous discussions.

Procrastination

- Pie chart illustrating important procrastination solutions for this course
- Ah, I haven't gotten around to filling this out yet.



Class Discussion Lead: 35%

- Each student has to lead at least one discussion.
- Papers are all observational majority content.
- An electronic presentation is given using ppt or pdfs or whatever.
- The presentation MUST be less than 20 minutes without interruptions (can be longer if questions interrupt).

Class Discussion Lead: Slides

1. Introduction
   - Describe issues of paper and background
   - Use concepts from class.
   - Set observations in scientific background
2. Observations
   - Discuss the most relevant observations in paper.
   - What are the difficulties/advantages of the observations?
   - What is being traced? How is it related to main points?
3. Main Points (core)
   - What do the observations suggest? Relationship to theory?
   - Make sure to show figures from the paper that help lead a discussion.
4. Outstanding issues.
   - What would affect these results? Issues in sample or interpretation?
5. Conclusions
   - Place observations in overall context of star formation.

Class Discussion Lead: Slides

Should not include

1. Step by step details of observations.
2. Step by step details of connection to theory.
3. Too much information such that the main points are not clear.

Should include

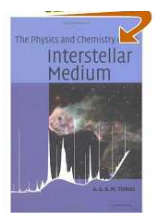
1. Careful, well thought out goals
2. Informed decision on what to include and what to exclude
3. Humor as well as insight

Discussion Secondary

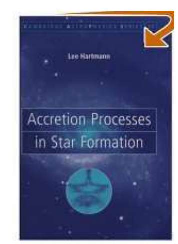
- Each paper will have a discussion secondary.
- This student must also read one of the important referenced papers from the reviewed paper.
- I recommend that the secondary work with the primary to discuss which paper to chose from the references.
- The student will give a 5 minute maximum verbal summary of that paper.
- The decision on timing of the summary (beginning, middle, or end of the primary discussion) should be decided by the secondary and primary ahead of time.

Textbooks

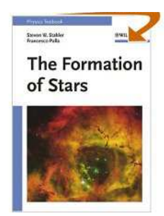
- No textbooks are required for this class
- But, here are some useful books



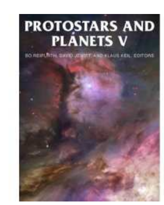
"The Physics and Chemistry of the Interstellar Medium" by A.G.G.M. Tielens



"Accretion Processes in Star Formation" by Lee Hartmann



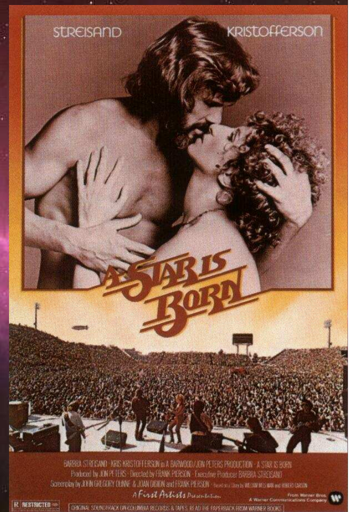
"The Formation of Stars" by Steve Stahler



"Protostars and Planets V" edited by Bo Reipurth and David Jewitt

A Star is Born!

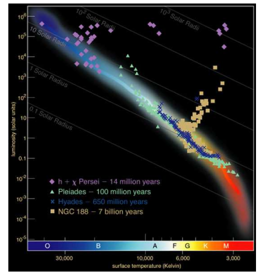
- Actually a new-ish concept
- Still, let's compare Hollywood to Star Formation
- How much do we know?



http://www.alyon.org/generale/theatre/cinema/affiches_cinema/a/a-ac/a_star_is_born_(2).jpg

A Star is Born

- Marilyn Monroe is not the #1 box office star today
- And likewise, stars are not permanent fixtures of the Milky Way.
  - We know this from interpretation of the HR diagram in the 1920's
  - Stars evolve

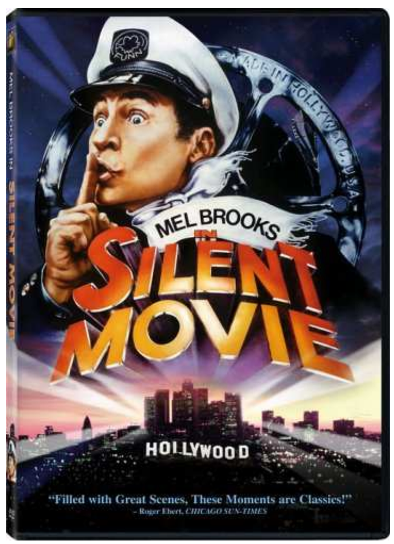


http://www.astro.princeton.edu/~esirko/sky/supplemental/hr.jpg

http://www.gallerym.com/images/work/big/associated%20press_marilyn_monroe_seven_yr_itch_L.jpg

Time Scales

- Hollywood has been making stars since 1910 (almost 100 years)
  - First Hollywood movie was "In Old California"
- The Universe is 13.7 billion years old, and has been making stars for ~13.5 billion years
  - Hubble's Law shows finite Universe age (1929)
  - Evidence of Universe age from WMAP (2004)
  - Globular cluster ages (1930's)



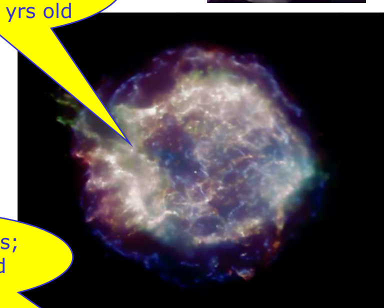
http://images.amazon.com/images/P/B000G6BLVA.01.LZZZZZZZ.jpg

Massive Stars: $>10M_{sun}$ The James Dean of Stars

Live Fast

Star life is struggle vs gravity
Nuclear fires keep hot, stable

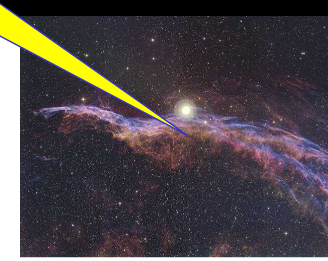
Million-degree gas seen in X-ray vision; 300 yrs old



Die Young

- Fuel exhaustion ⇒ collapse
- Core becomes dense, "bounce"
- Shock wave launched
  - ⇒ ***Supernova explosion!***

Hot, shocked gas; > 5,000 yrs old



Leave a Beautiful Corpse

- Ultradense "cinder"
  neutron star/black hole
- Most material ejected at high speed

How to Make A Star Fast and Easy

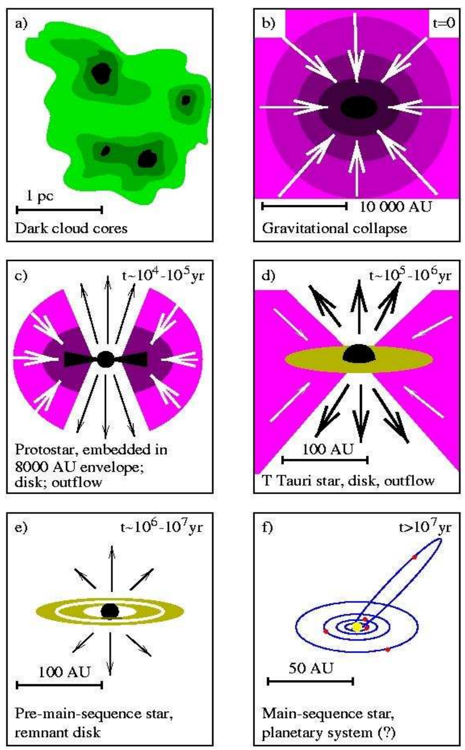
1. Find a whole lot of gas
2. Add gravity
3. Wait about 1 million years for slow gravitational collapse
4. Turn on fusion
5. Voilà, you're a (proto)star

The Hard Road To Stardom

1. Find (more than) a whole lot of gas & dust, break it into many pieces & stir it up all the time
2. Add gravity, magnetic fields & plenty of harsh light
3. Wait about 1 million years for (slow?) gravitational collapse
   …While this happens, a disk & outflow will form, thanks to the spin the stirring gave your creation…Oh, and watch out for other stars & blobs whizzing by, trying to mess up your plans
4. Turn on fusion (of deuterium, and worry about hydrogen later)
5. Voila, you're a new star, with a spinning disk of hanger-on groupies that can form planets
6. Start Fusing hydrogen & join the "main sequence" (Actors' Equity)

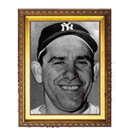
Cartoon of Star Formation = Isolated Star Formation

a) **Starless cores**
b) **Class 0: Initial phase of collapse with massive envelope**
c) **Class I: Disk/Envelope increases/decreases in mass**
d) **Class II: Accretion fades**
e) **Classical PMS contraction with planet building**
f) **Main-sequence star**



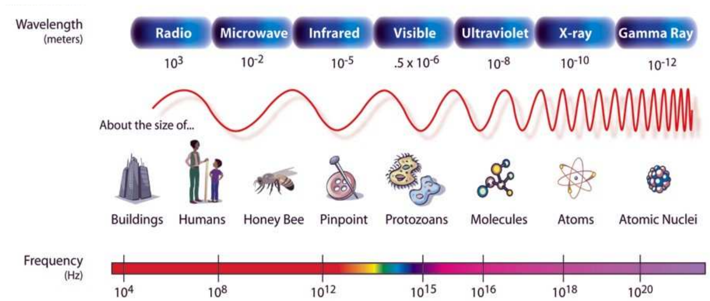
Hogerheijde 1998, after Shu et al. 1987

"You learn a lot by watching"



Yogi Berra

- Astronomy does not advance by experiment
- We can't arrange for "star birth" or "star death"
- We have to watch and wait for things to happen
- We have to take what we are given
  - mostly the electromagnetic spectrum



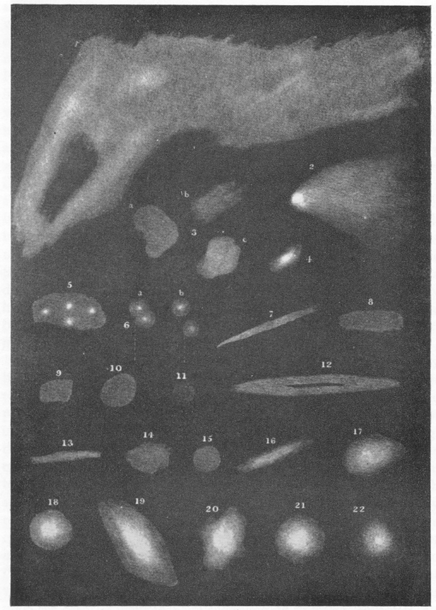
http://www.stlouiswalkoffame.org/inductees/yogi-berra.html

History Lesson 101: Universal Gravity and Star Formation

"But if the matter was evenly diffused through an infinite space, it would never convene into one mass but some of it convene into one mass & some into another so as to make an infinite number of great masses scattered at great distances from one another throughout all the infinite space. And thus might the Sun and Fixt stars be formed supposing the matter were of a lucid nature"

Newton to Richard Bentley, 10 December 1692

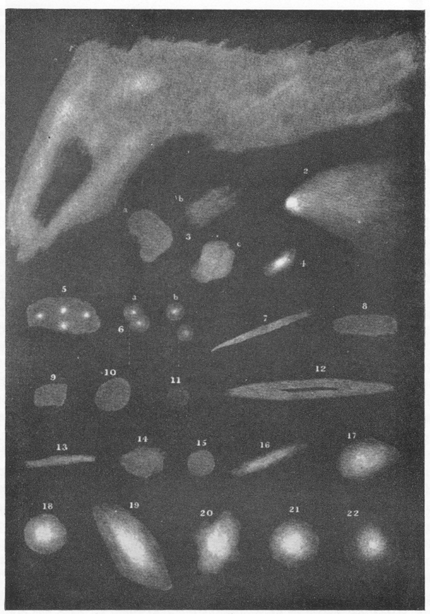
The Nebulae



William Herschel
1738-1822

Observations relating to the Construction of the Heavens, 1811, *Phil. Trans., CI*, 269-336.

The Nebulae



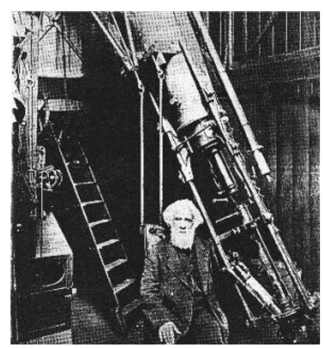
""…if I could use the comparison, …an annual description of the human figure, were it given from the birth of a child till he comes to be a man in his prime."

"but… why should we not look up to the universal gravitation of matter as the cause of every condensation, accumulation , compression and concentration of the nebulous matter?

Observations relating to the Construction of the Heavens, 1811, *Phil. Trans., CI*, 269-336.

Nature of Nebulae

"The riddle of nebulae was solved. The answer which had come to us in the light itself read: Not an aggregation of stars, but luminous gas…the light of this nebula had been emitted by a luminous gas."



William Huggins
1824 - 1910

The New Astronomy of the Nineteenth Century, June, 1897

Relationship to Stars?

At that time it did not fit together.

The composition of these "luminous fluids", being composed of hydrogen and nitrogen, differed from stars and planets and could not be the material from which stars formed as Herschel had suggested!

http://www.virtualtravel.freeuk.com/images/hollywood_stars2.jpg

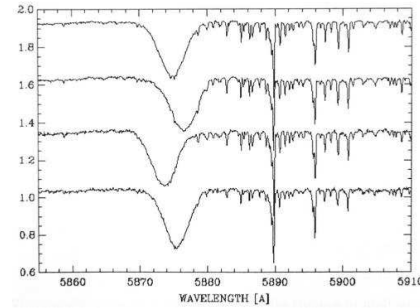
"The conclusion is strongly indicated that the order of the abundance of the elements in the solar atmosphere is much the same as in the earth's crust."

Russell, Dugan & Stewart 1927 in *Astronomy, Ginn & Co., 502.*

Much of the this slide was borrowed from Charles Lada

But clearly interstellar

- **1904** (Johannes Hartmann): detects stationary Ca II lines in spectrum of spectroscopic binary δ Ori.
  → Must be interstellar → *Discovery of ISM*



Na lines:
http://www.aip.de/highlight_archive/hartmann/index2.html

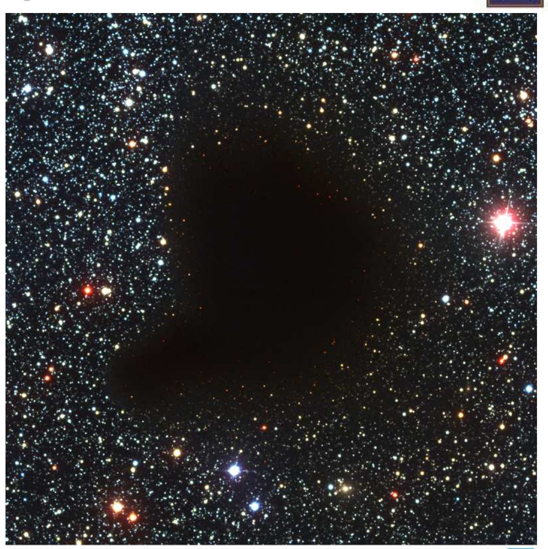
Notation for Degrees of Ionization

Suffix	Ionization	Examples	Chemist's Notation
I	Not ionized (neutral)	H I, He I	H, He
II	Singly ionized	H II, He II	H^+, He^+
III	Doubly ionized	He III, O III	He^{++}, O^{++}

http://csep10.phys.utk.edu/astr162/lect/light/ionization.html

But clearly interstellar

- **1919**: Edward Barnard, catalog of dark nebulae → holes in stellar distribution or obscuring matter?
- As Herschel called B86, "Loch im Himmel"



The "Black Cloud" B68 (VLT ANTU + FORS1)
ESO PR Photo 20a/99 (30 April 1999)
© European Southern Observatory

http://antwrp.gsfc.nasa.gov/apod/ap990511.html

Setting the Stage

***Stellar Atmospheres*: Phd Thesis Harvard 1925**

Two fundamental results:

1- Stars have uniform composition and

2- Stars are primarily made up of hydrogen

C. Payne-Gaposchkin
1900-1980

"It is the best doctoral thesis I have ever read" H.R. Russell

"undoubtably the most brilliant PhD thesis ever written in astronomy" O. Struve

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First Proof: Expanding OB Associations

V. A. Ambartsumian
1906 - 1996

Ambartsumian (1949) identified loose associations of OB stars with stellar densities less than the general galactic field and he demonstrated that such groups are *unstable* and will dissolve into the field on timescales of *10^7* years, considerably less than the age of the Galaxy.

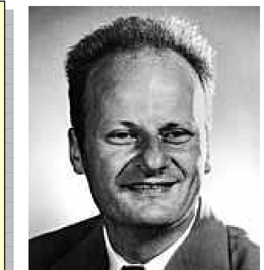
Much of the this slide was borrowed from Charles Lada

Second Proof: Nuclear Powered Stars

In 1938 Bethe and others worked out the fusion reactions (CNO and p-p cycles) that powered stars:

Stars are thermo-nuclear reactors that fuse the primary product of the big bang into heavier elements of the periodic table releasing enormous amounts of energy in the process.

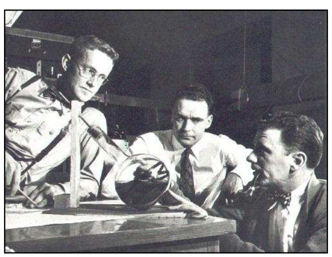
Massive OB stars burn nuclear fuel at such prodigious rates that their lifetimes must be less than 10^7 years, considerably less than the age of the universe.

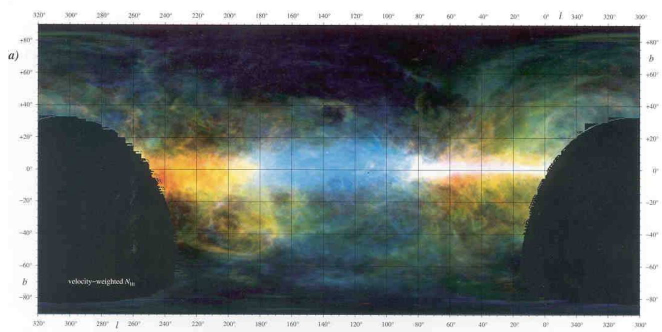


Hans Bethe
1906 - 2005

Much of the this slide was borrowed from Charles Lada

Third Proof: A Hydrogen Rich ISM





The discovery of pervasive HI emission in the galaxy by Ewen and Purcell in 1951 convincingly demonstrated that the raw material for building stars existed in substantial concentrations between the stars. HI emission was predicted by van de Hulst in 1945.

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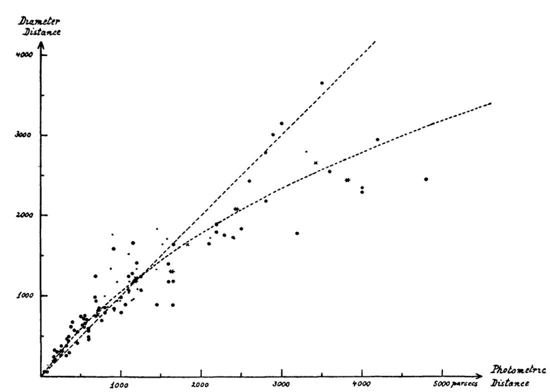
Dusty ISM

- 1930 (Robert Trümpler): Discovered interstellar extinction, (distance to open clusters is overestimated)
  - Extinction followed a $\sim\lambda^{-1}$ law



http://spiff.rit.edu/classes/phys230/lectures/ism_dust/ism_dust.html

Diffuse Interstellar Bands

- 1918 (Mary Lea Heger): Discovery of the Diffuse Interstellar Bands (DIBs)
  - Merrill and Wilson, 1938
  - About 250 DIBs are known
  - The carriers of most DIBs are unidentified
  - Some DIBs may be due to large carbon-bearing molecules

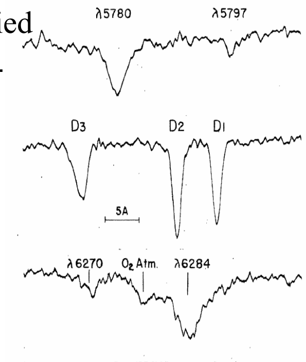
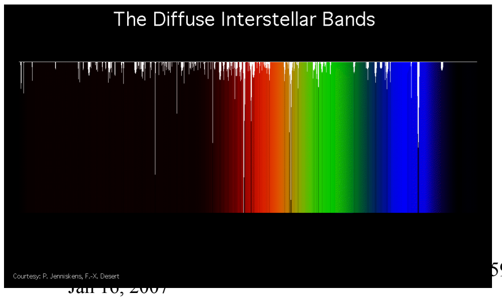


Fig. 1.—Tracings of interstellar lines in the spectrum of HD 183143

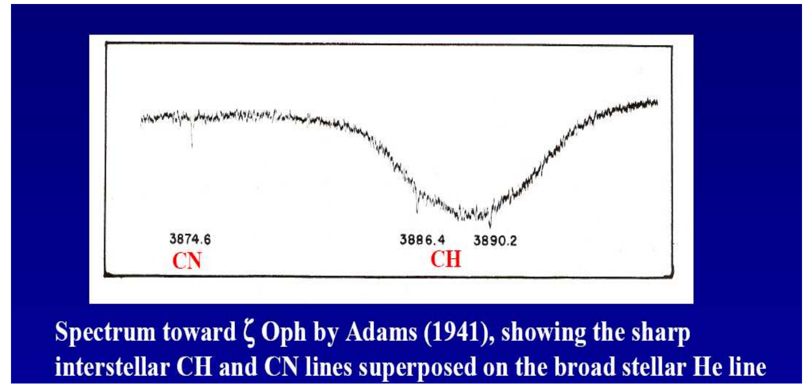
Merrill & Wilson, ApJ 87, 9 (1938)



http://leonid.arc.nasa.gov/DIBspectrum.gif

Molecules in the ISM

- 1937 – 40 (Swings & Rosenfeld, McKellar, Adams): first small interstellar molecules (CH, CH+, CN)



Spectrum toward ζ Oph by Adams (1941), showing the sharp interstellar CH and CN lines superposed on the broad stellar He line

http://www.strw.leidenuniv.nl/~dave/ISM/lecture1.pdf

Magnetic Field

- 1949 (John Hall & William Hiltner): Correlation of polarization of starlight with reddening → aligned grains → interstellar magnetic field
  - Confirmed by discoveries of synchrotron radiation, Faraday rotation, and Zeeman splitting in the 21 cm line

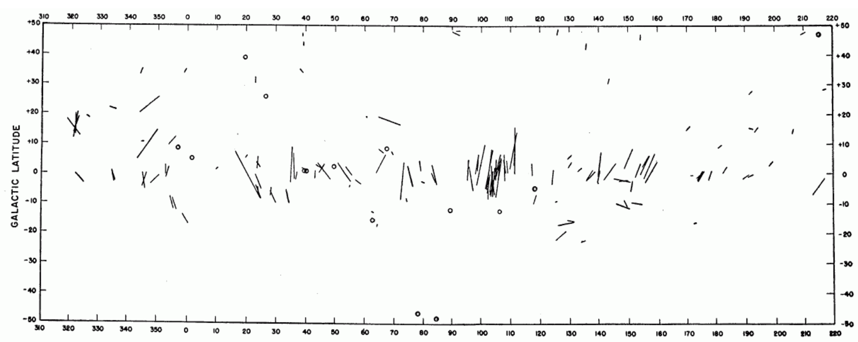
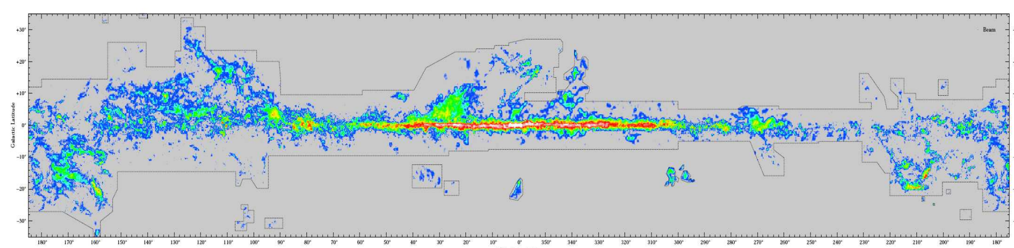


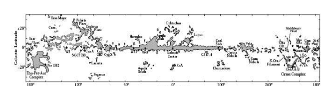
Figure 1. Vector diagram showing polarization of individual stars.

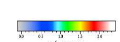
Hall & Mikesell, 1949, AJ, 54, 187

And…And.. And..

- 1960s: Discovery of soft X-ray background from hot, ionized gas
- 1950's – 60's: 21 cm maps → galactic disk contains $5x10^9$ $M_\odot$ of gas (≈ 10% of disk mass) and <n> = 1 cm^{-3}
- 1968: NH^3 (first polyatomic molecule)
- 1970: CO J = 1–0 emission at 2.6 mm



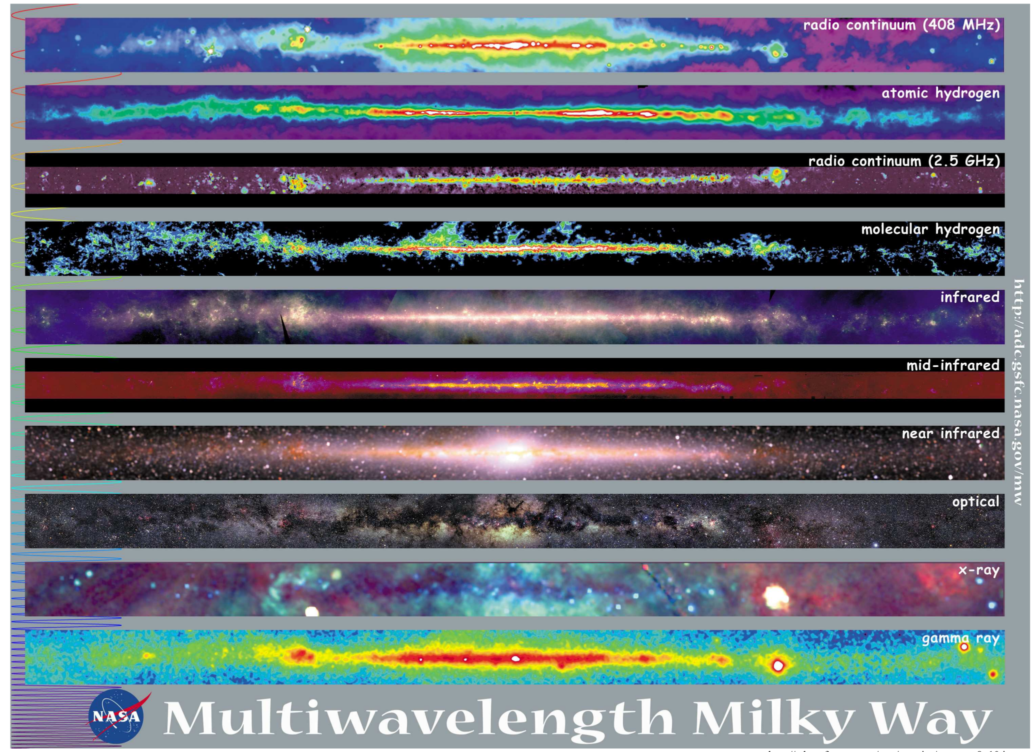




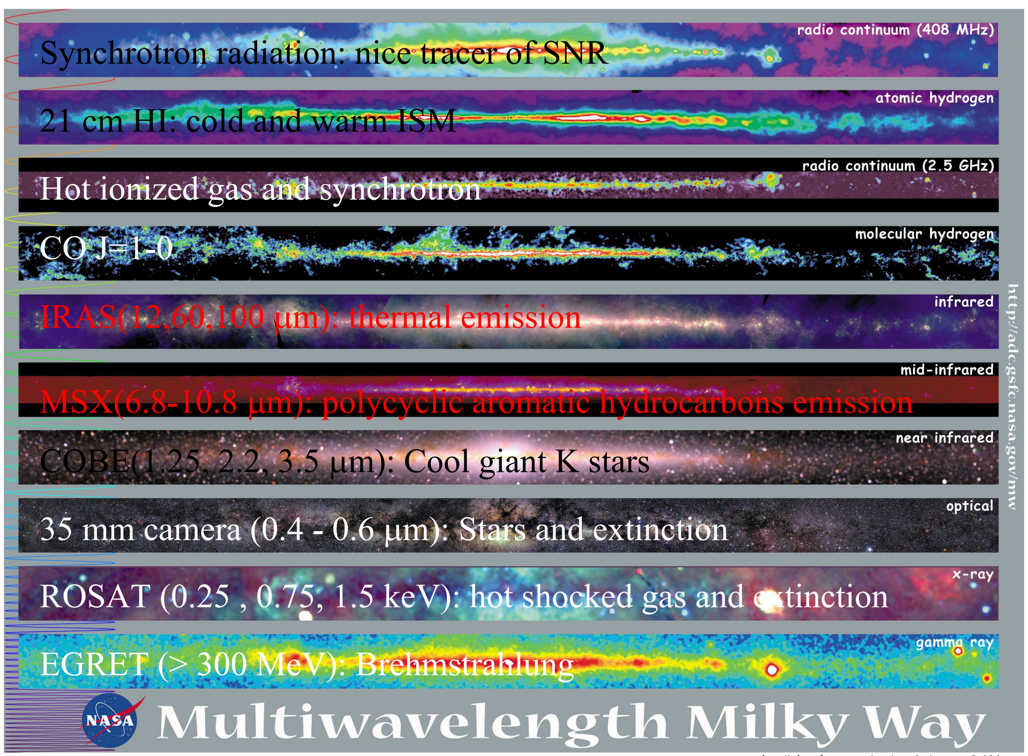
http://cfa-www.harvard.edu/mmw/MilkyWayinMolClouds.html

And…And.. And..

- **1970's-1980's**: Galactic distribution of CO Distribution molecular vs atomic gas
- **1970's-now**: Many new interstellar molecules found (>100); some very exotic
- **1970's – 80's**: Infrared astronomy (H_2 infrared lines, small dust particles, very large molecules)
- **1980's – 90's**: Submillimeter astronomy (warm interfaces of molecular clouds, cold protostellar regions)



http://adc.gsfc.nasa.gov/mw/mwpics/mwmw_8x10.jpg



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