Astronomy 496/596:

Star Formation

MW 1400-1520

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Office Hours:

Drop by or by appointment

http://eeyore.astro.uiuc.edu/~lwl/classes/astro505/spring15

<u>This Class (Lecture 1):</u>

Introductions/History

<u>Next Class:</u>

Terms

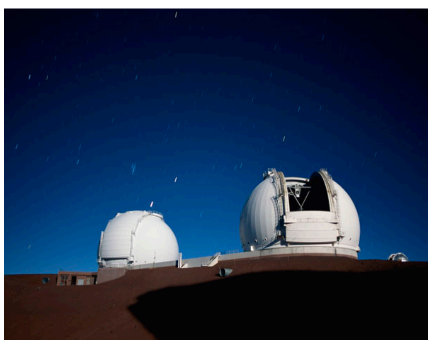
Music: *Astronomy* – Metallica

Outline

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

Welcome to Astro 505

- 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 someone that there are 100 billion stars in our Galaxy and they'll believe you. Tell them a bench has wet paint and they have 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

ON THE RAFT.

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.
- Summary 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) cores
- Protostars
- Binarity
- Massive star evolution
- Jets and outflows from YSOs (Young Stellar Objects)
- Circumstellar disks
- Evolution of planets and exoplanets
- Take part of the journey, and let's enjoy the ride.

Course Requirements

- Focus on PP VI review papers
- PP happens every 6 years
- Good resource for people in the field
- All papers have associated talks on YouTube too

Course Requirements

- No homework (except reading 12 giant review papers)
- No exams
- But much participation and presentation

Course Requirements

- 12 Review Papers: ~1 paper per week
- Each week of class, there will be a discussion leader (DL) in charge of paper

Formation of Molecular Clouds and Global Conditions for Star Formation

Clare L. Dobbs
University of Exeter

Mark R. Krumholz
University of California, Santa Cruz

Javier Ballesteros-Paredes
Universidad Nacional Autónoma de México

MONDAYS

- DL and instructor creates list of terms before class
- Class breaks into groups of 2-3 and researches terms (NEED LAPTOPS)– different groups each week
- After ~30 mins, each group presents terms to class (relevancy to paper)
- Presentations are peer plus instructor graded:
  - Presentation: full credit for clarity
  - Explanation: full credit for well explained term
  - Context: full credit for placing term in paper context

WEDNESDAY

- DL presents paper to class (no more than 40 mins without interrupts), placing paper into class context
- Everyone in class asks questions
- Everyone submits a conclusion slide to instructor before class. Someone is chosen to present conclusions. Instructor grades.
- Presentations are peer plus instructor graded:
  - Presentation: full credit for clarity
  - Explanation: full credit for well explained paper
  - Context: full credit for placing paper in class context

Course Requirements

Requirement	Percentage of Grade	Points
Paper Presentation	20%	20
Paper Conclusions	20%	20
Group Presentations	25%	25
Class Participation	20%	20
Peer Grading	15%	15
Total	**100%**	**100**

- Main thrust of course is ability to read observational star formation papers, get the point, understand observational evidence, and see possibly difficulties.
- Also get presentation experience

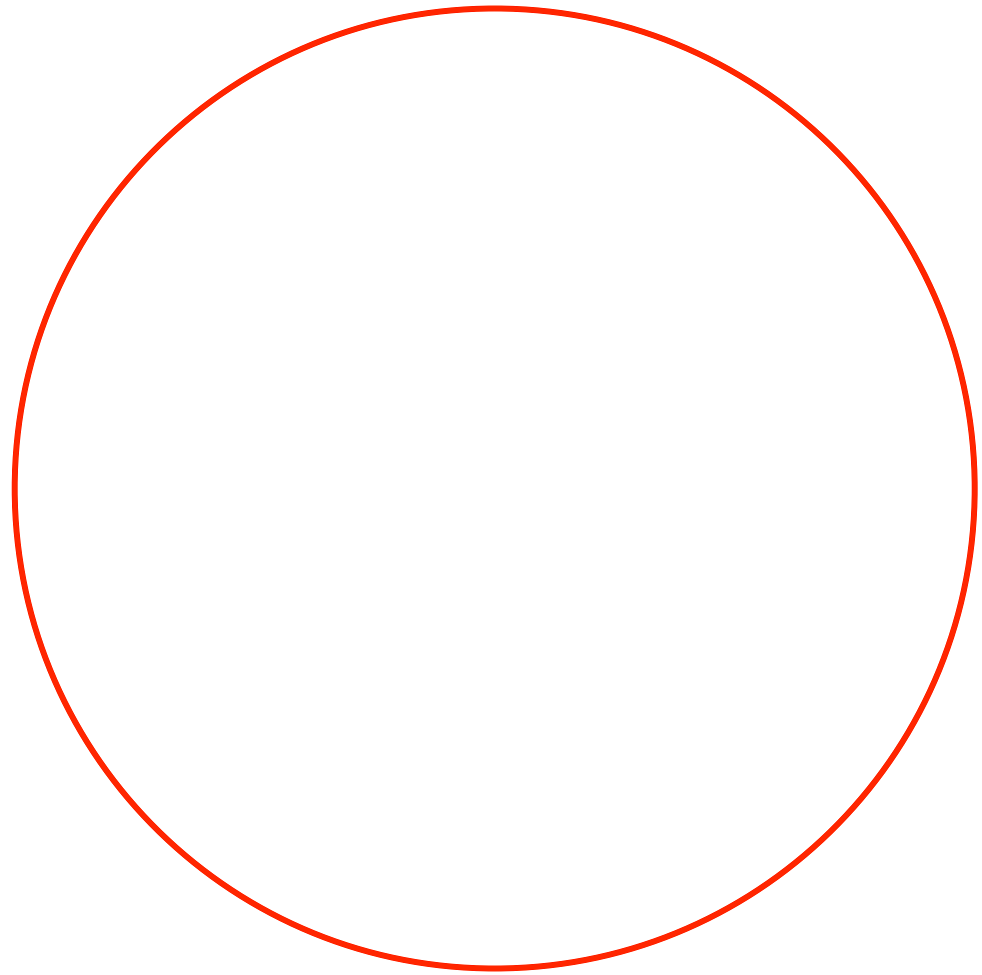
http://www.public.asu.edu/~atjlb/

Class Participation: 20%

- 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 20% of the class grade.

Procrastination

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



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

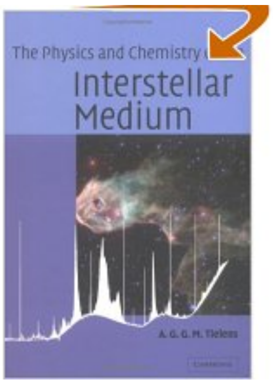
1. Step by step details of observations.
2. Step by step details of connection to theory.
3. Too much information such that the main points are not clear.

Should include

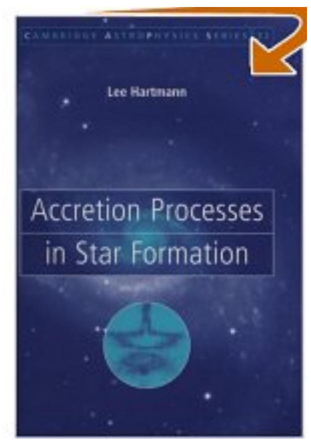
1. Careful, well thought out goals
2. Informed decision on what to include and what to exclude
3. Humor as well as insight

Textbooks

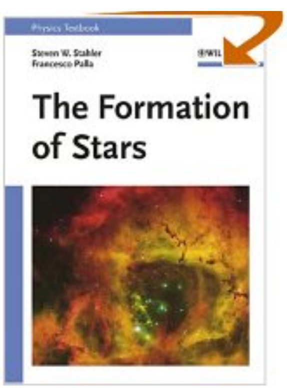
- No textbooks are required for this class
- But, here are some useful books



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



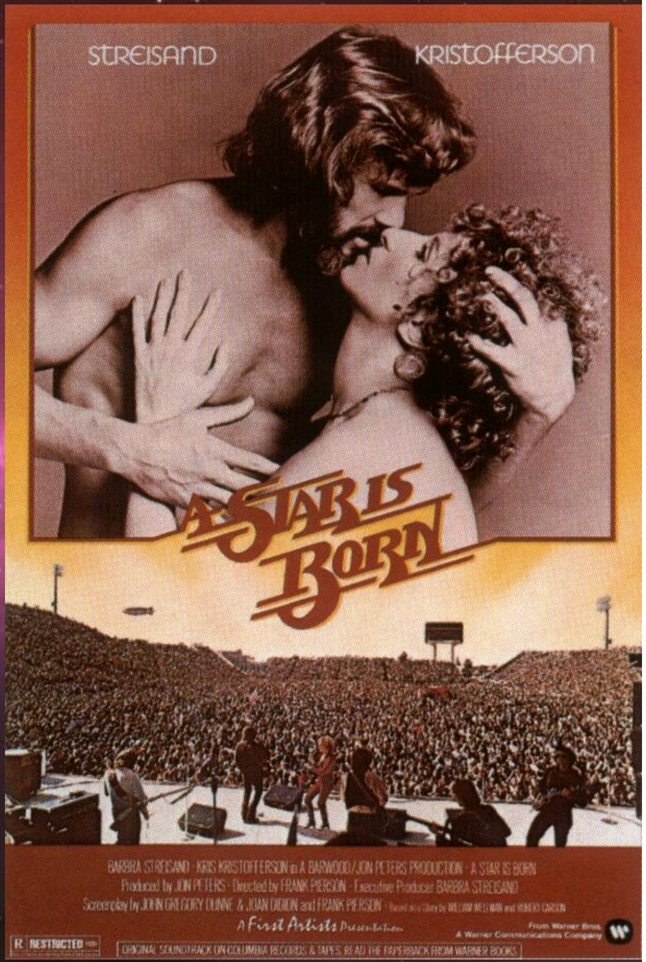
"Accretion Processes in Star Formation" by Lee Hartmann



"The Formation of Stars" by Steve Stahler

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

Small Groups of 2-3

- Why/how do stars form?
- What do you think are the hardest questions?

How to Make A Star Fast and Easy

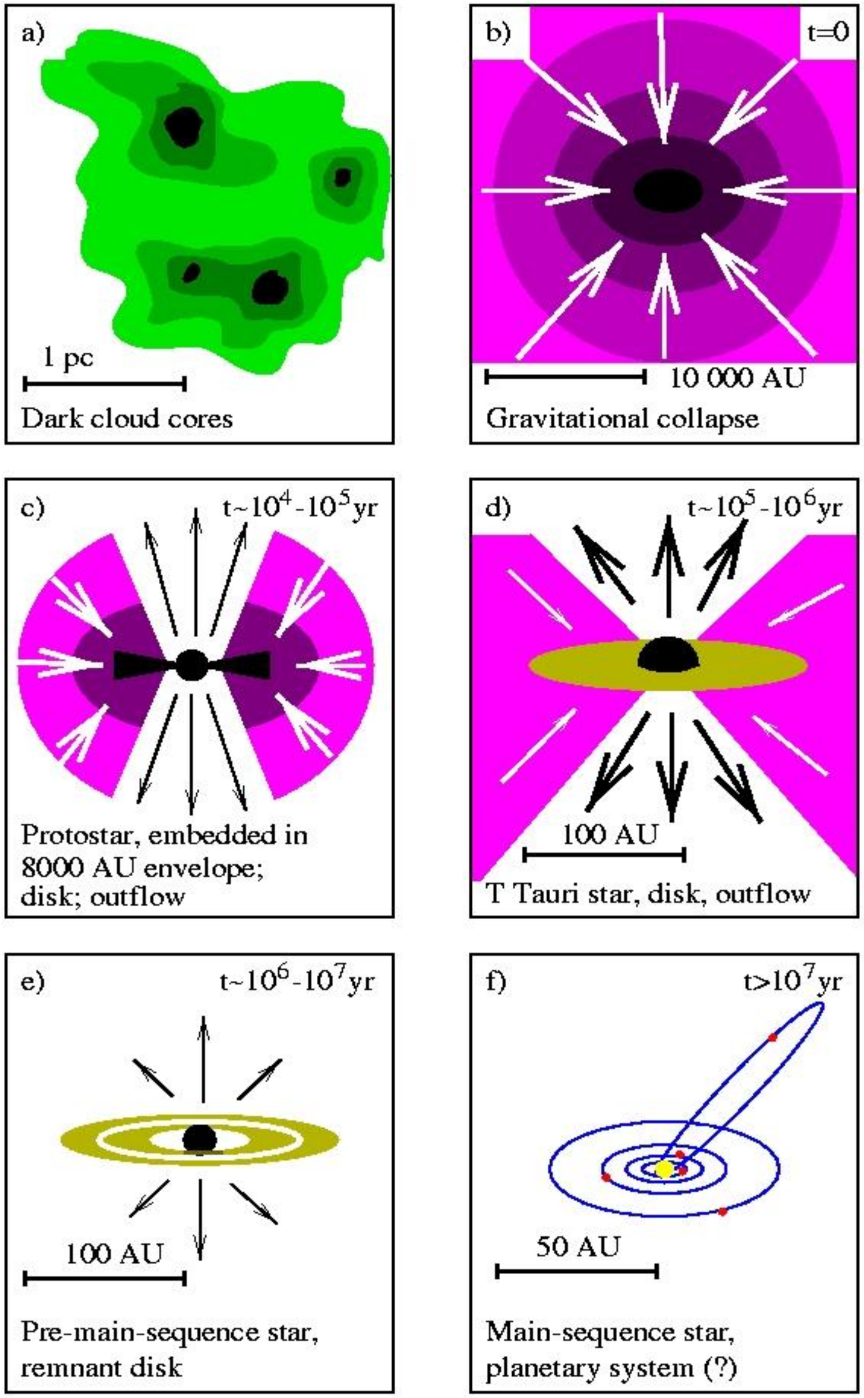
1. Find a whole lot of gas
2. Add gravity
3. Wait about 1 million years for slow gravitational collapse
4. Turn on fusion
5. Voilà, you’re a (proto)star

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 <u>planets</u>
6. Start Fusing hydrogen & join the "main sequence"

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

Setting the Stage

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

Two fundamental results:

1- Stars have uniform composition and

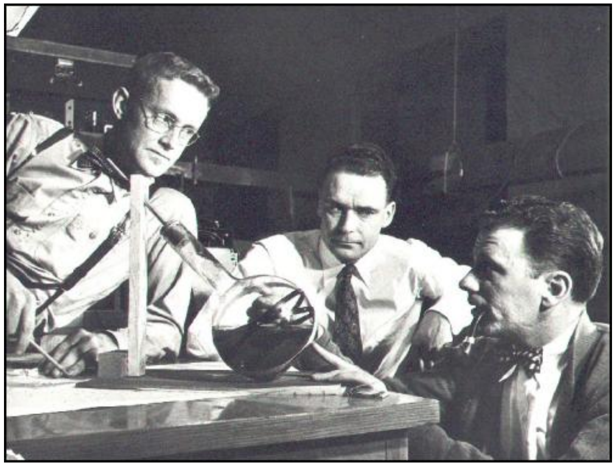
2- Stars are primarily made up of hydrogen

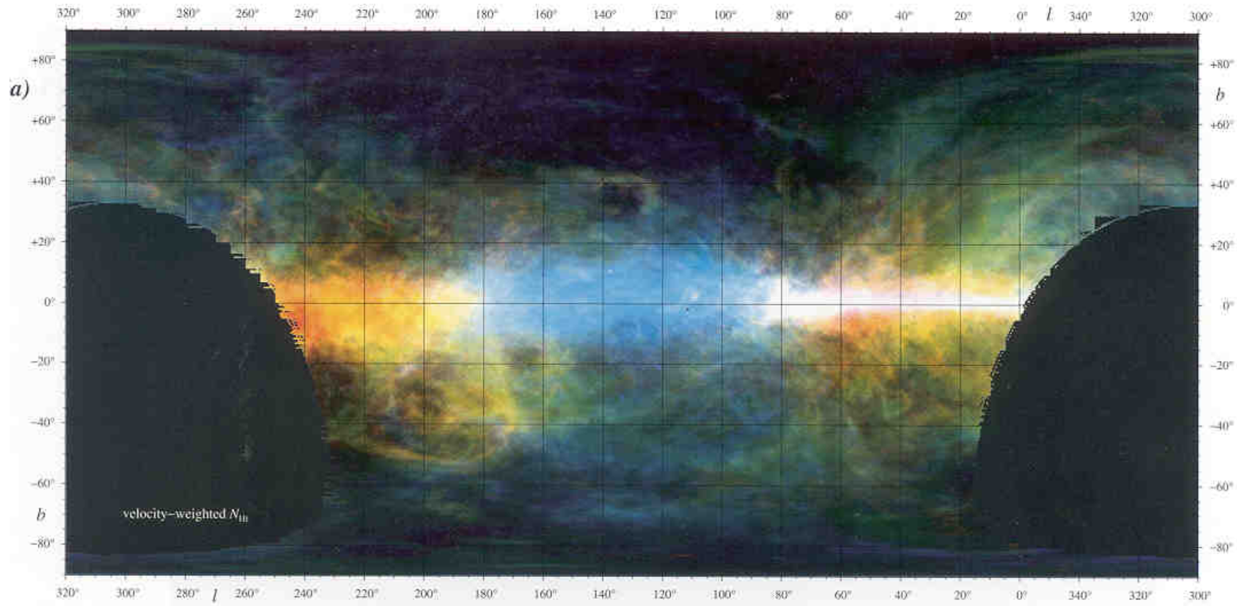
C. Payne-Gaposchkin
1900-1980

"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

A Hydrogen Rich ISM

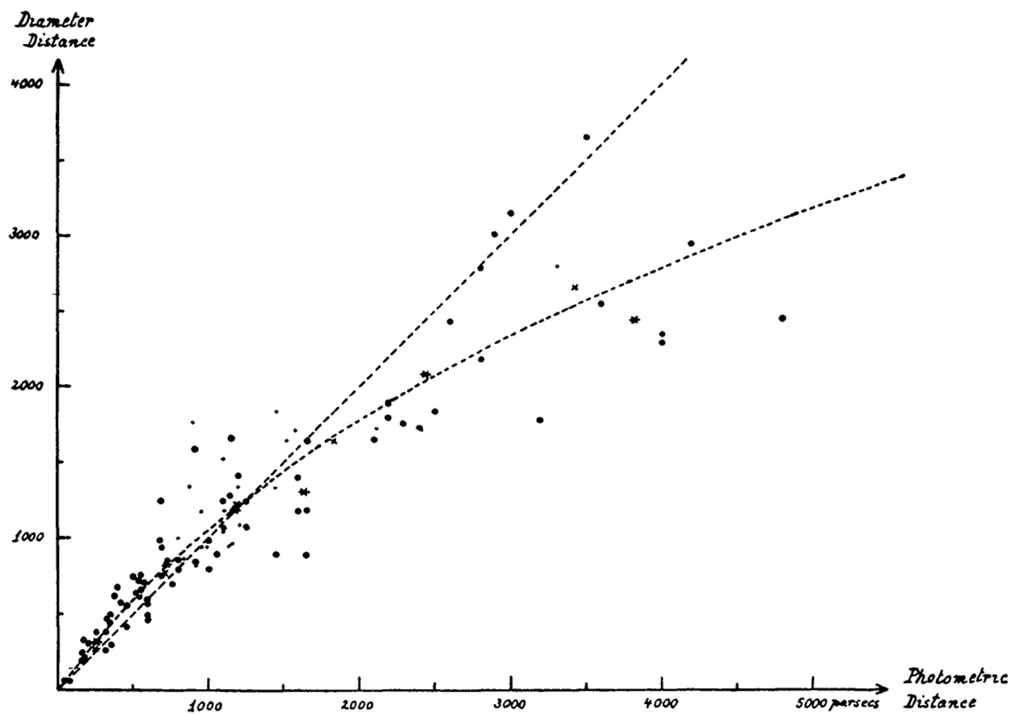




The discovery of pervasive HI emission in the galaxy by Ewen and Purcell in 1951 convincingly demonstrated that the **raw material** for building stars existed in **substantial** concentrations between the stars. HI emission was predicted by van de Hulst in 1945.

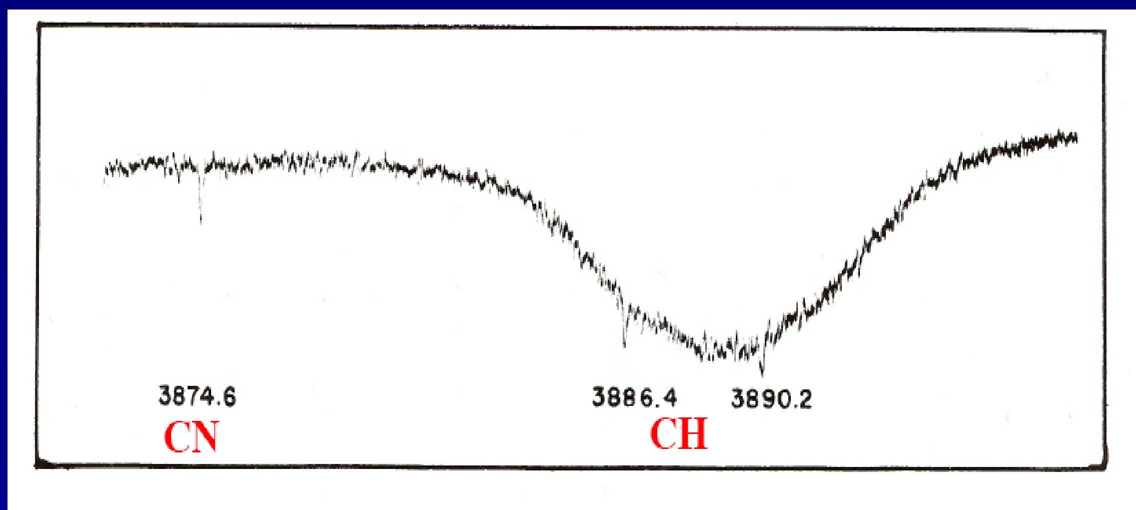
Dusty ISM

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



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

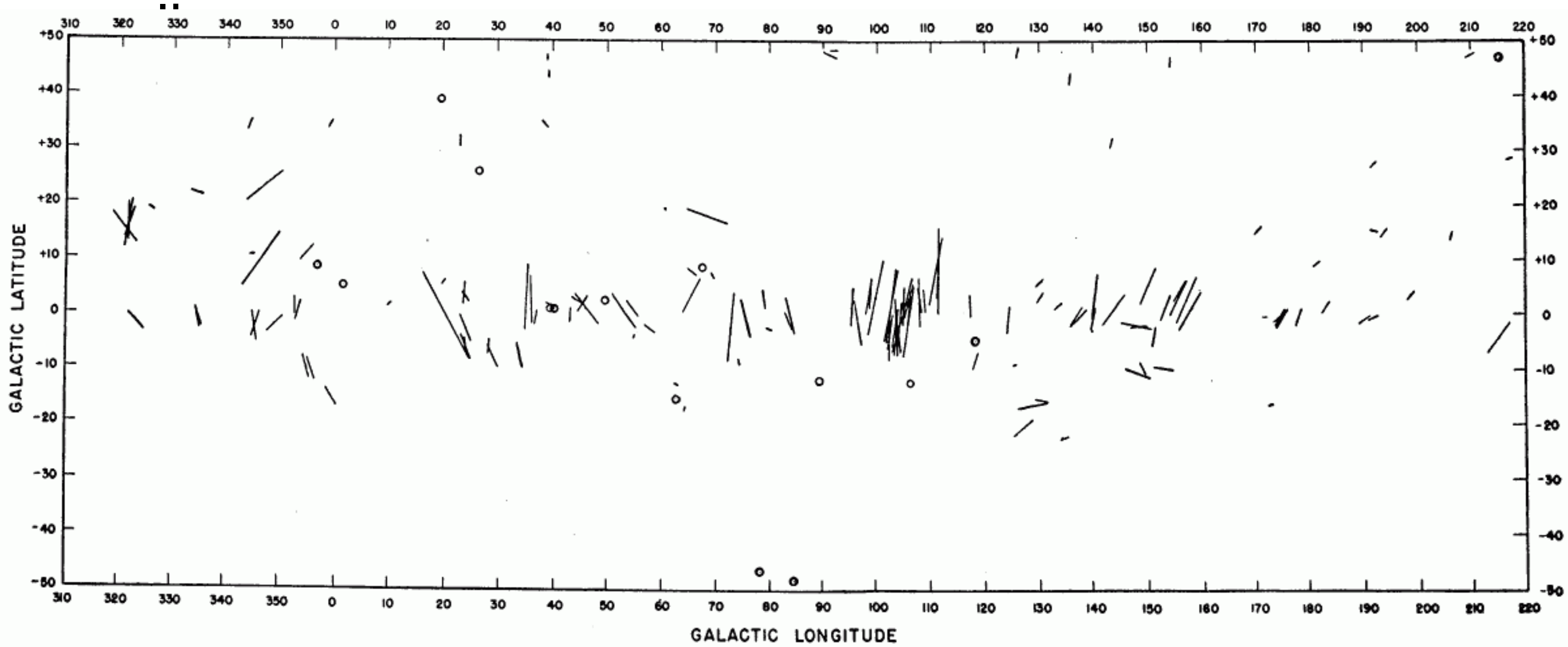
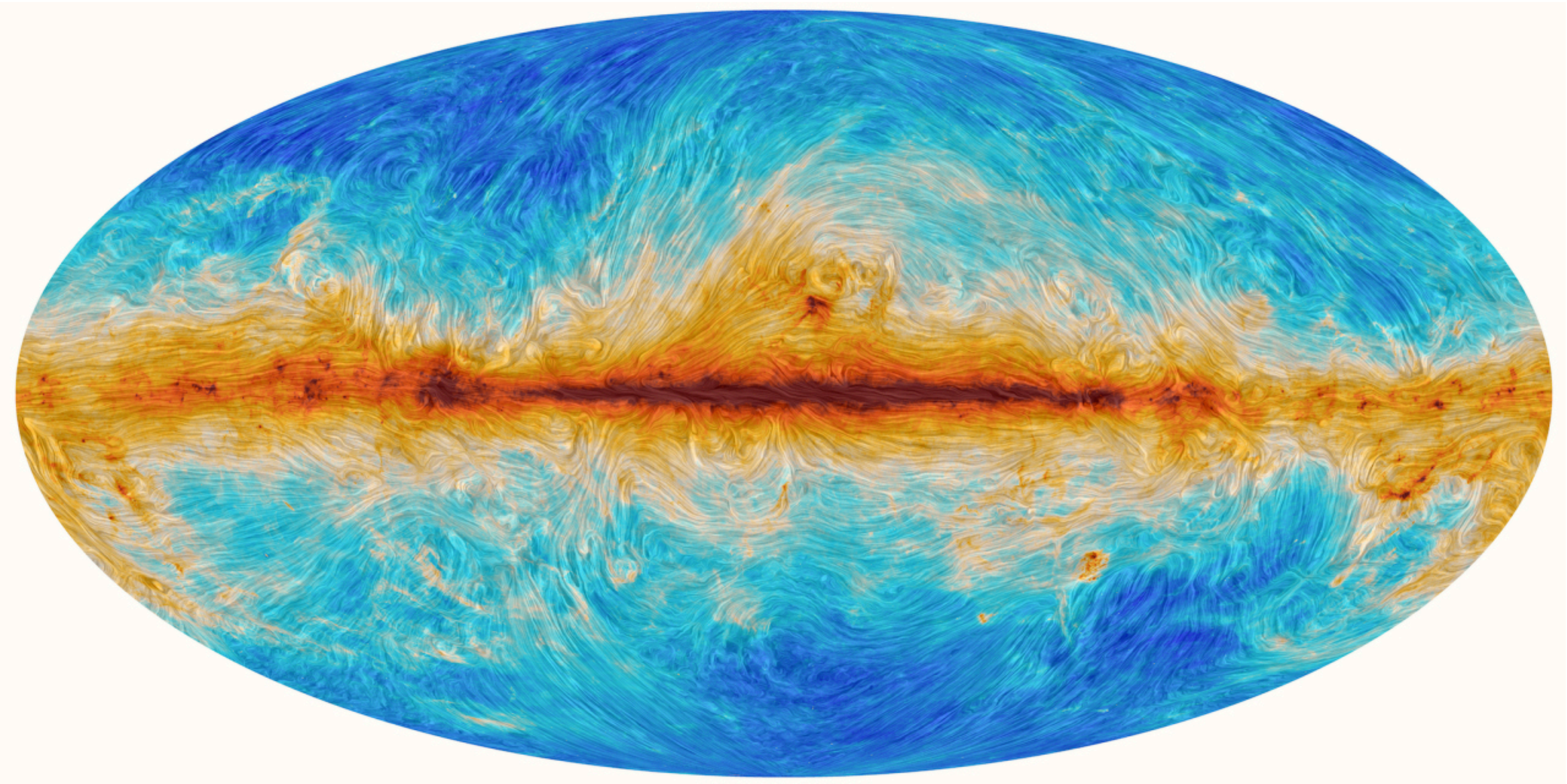


Figure 1. Vector diagram showing polarization of individual stars.

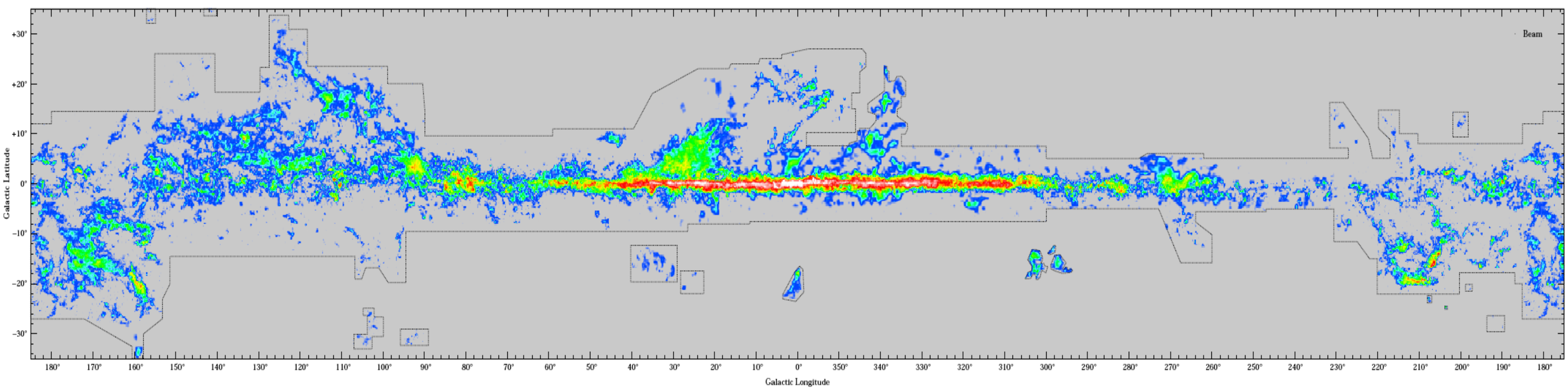
Hall & Mikesell, 1949, AJ, 54, 187

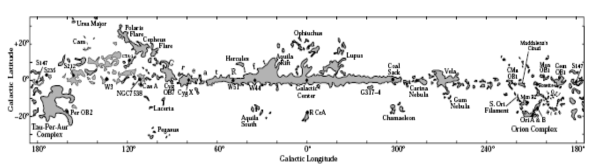
Planck: Magnetic Field



And…And.. And..

- **1960s**: Discovery of soft X-ray background from hot, ionized gas
- **1950's – 60's**: 21 cm maps → galactic disk contains $5 \times 10^9\ M_\odot$ of gas (≈ 10% of disk mass) and $\langle n \rangle = 1\ cm^{-3}$
- **1968**: NH_3 (first polyatomic molecule)
- **1970**: CO J = 1–0 emission at 2.6 mm





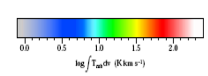


FIG. 2.–Velocity-integrated CO map of the Milky Way. The angular resolution is 9′ over most of the map, including the entire Galactic plane, but is lower (15′ or 30′) in some regions out of the plane (see Fig. 1 & Table 1). The sensitivity varies somewhat from region to region, since each component survey 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.

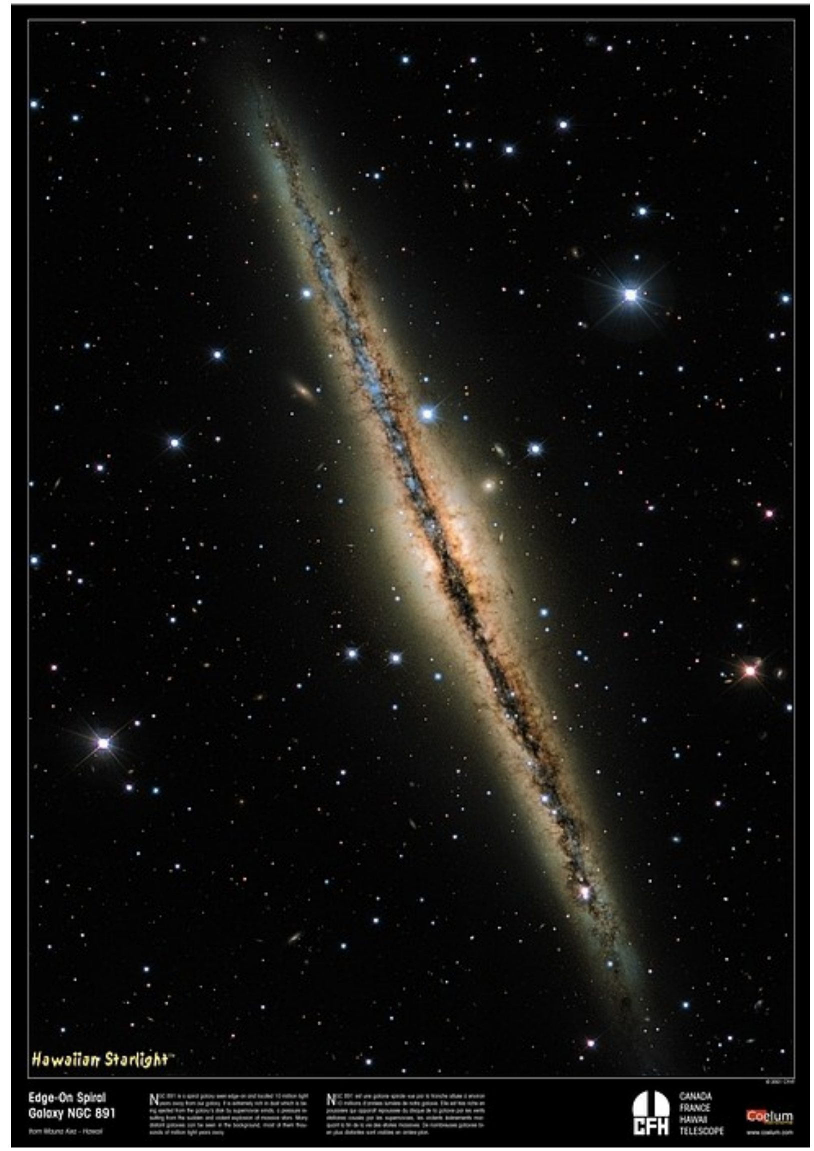
http://cfa-www.harvard.edu/mmw/MilkyWayinMolClouds.html

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)

The ISM

- Makes beautiful dust lanes
  - Mostly confined to the disk, with a little gas in the halo
- In optical only notice the extinction
  - Most of the ISM is either cold (< 100 K: IR) or very hot (> 10^6 K: x-ray)
  - Only in the last 50 years has the nature & importance of the ISM become evident
- Density can be vastly different (n ~ 10^{-3} to 10^6 cm^{-3})
  - Still "ultra-high vacuum" (10^{-10} Torr is n ≈ 4 × 10^6 cm^{-3}, compare to air at STP n ≈ 3 × 10^{19} cm^{-3})



http://antwrp.gsfc.nasa.gov/apod/ap020703.html

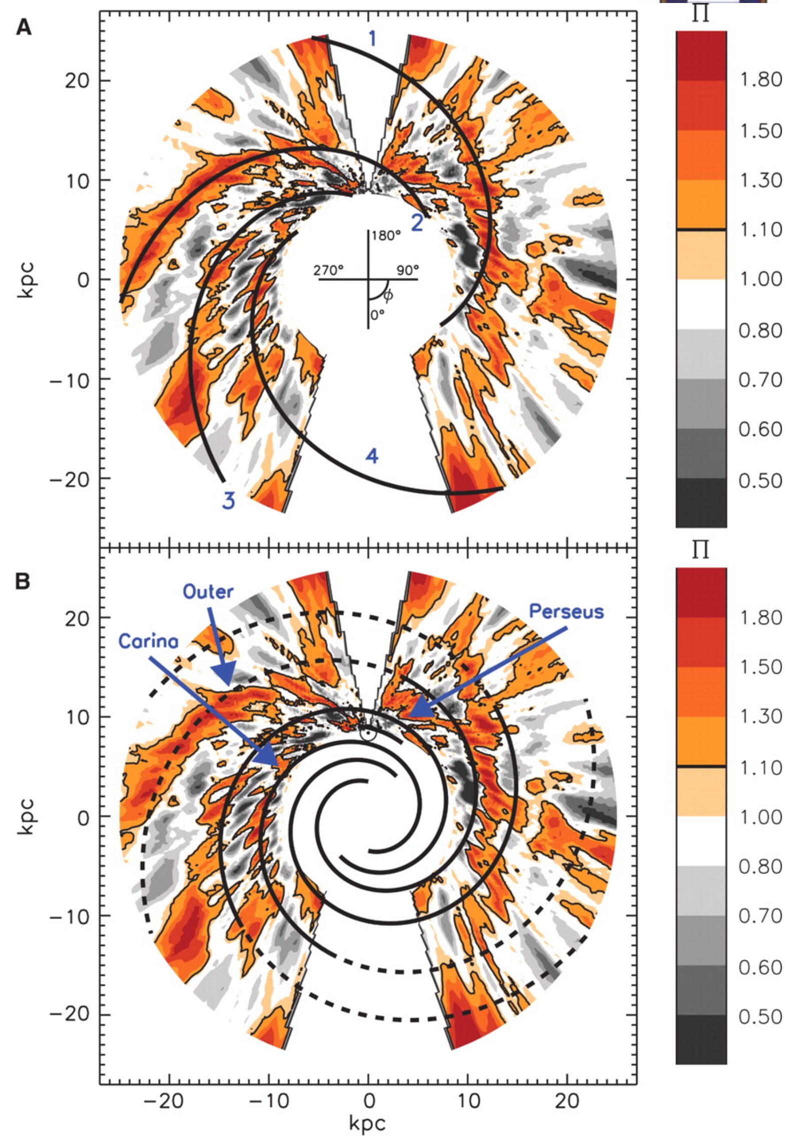
The ISM

- Composition of ISM is similar to Solar System
  - Hydrogen is most abundant element (≥ 90 % of atoms)
- ISM regions characterized by state of hydrogen
  - *Neutral atomic hydrogen* (H^0 or H I): "H-one"
  - *Ionized atomic hydrogen* (H^+ or H II)" "H-two"
  - *Molecular hydrogen* (H_2): "H-two" - yeah get use to it
- Regions are nearly pure (100 % H II, H I, or H_2)
- Transition regions H II ↔ H I ↔ H_2 are thin

http://cse.ssl.berkeley.edu/bmendez/ay10/2000/cycle/keyhole_sm.jpg

H I: Atomic Gas

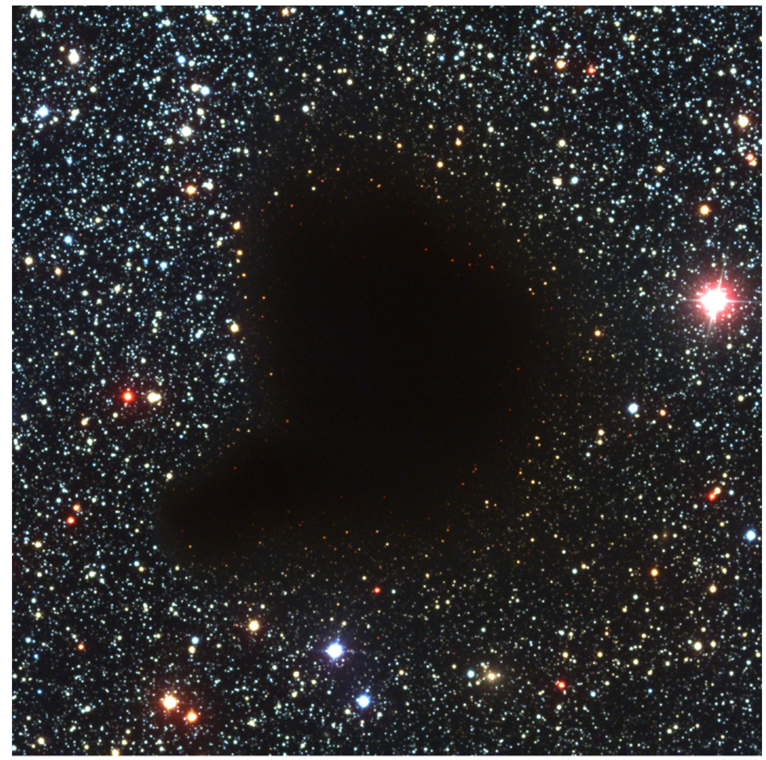
- “Cool” Clouds (CNM)
  - $T \approx 80$ K
  - $n \approx 1$ cm^{-3}
- Warm neutral gas (WNM)
  - $T \approx 6000$ K
  - $n \approx 0.05$ to 0.2 cm^{-3}



Levine et al. 2006

H_2: Molecular Gas

- Cold dark clouds ($M \approx 10 - 1000\ M_\odot$)
  - $T \geq 10$ K
  - $n \approx 10^2 - 10^4$ cm^{-3}
- Giant molecular clouds ($M \approx 10^3 - 10^6\ M_\odot$)
  - $T \geq 20$ K
  - $n \approx 10^2 - 10^4$ cm^{-3}
- Molecular material exhibits complex structure including cores and clumps with $n \approx 10^5 - 10^9$ cm^{-3}
- Molecular clouds are the sites of star formation



The "Black Cloud" B68
(VLT ANTU + FORS1)

ESO PR Photo 20a/99 (30 April 1999)

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

H II: Ionized Gas

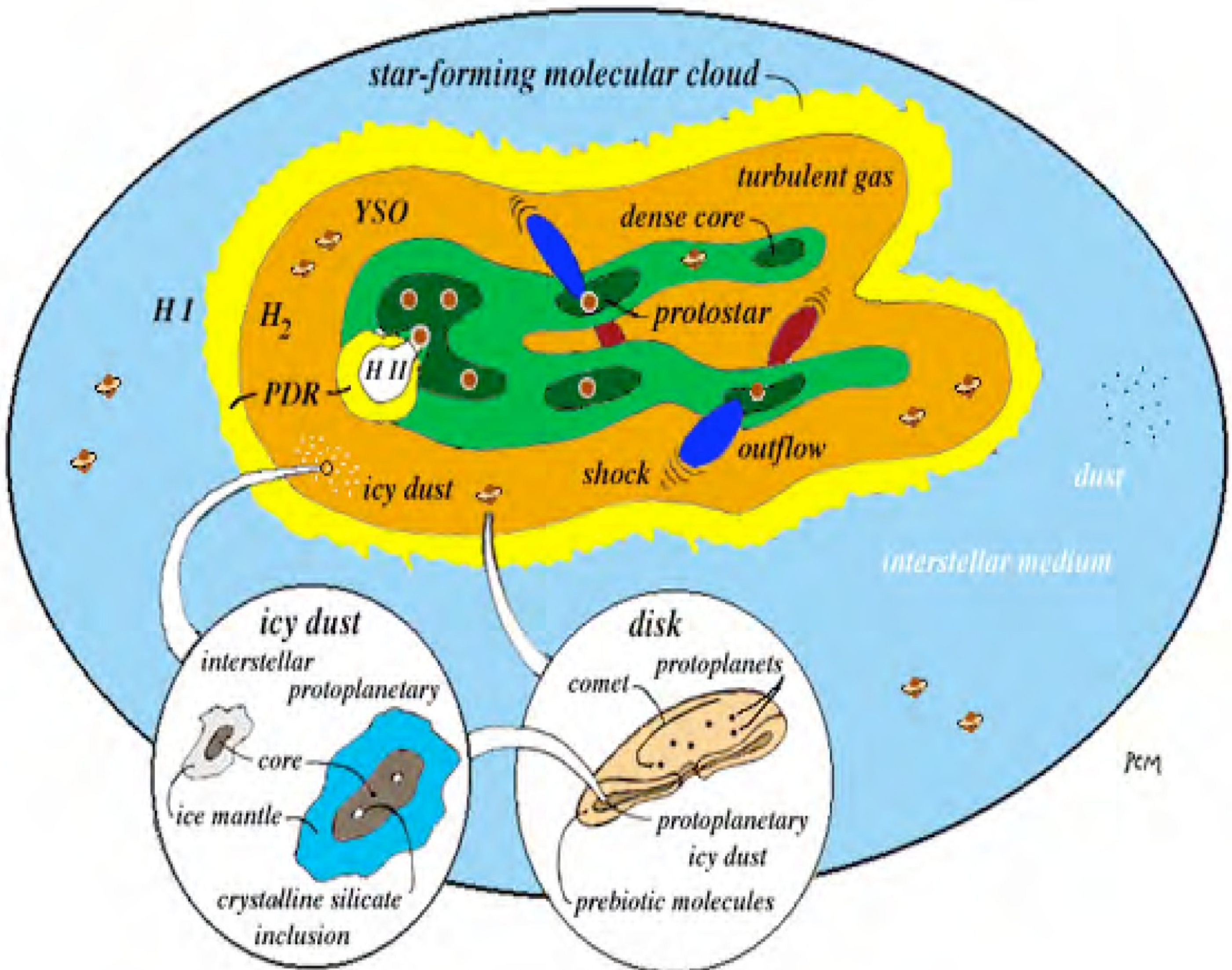
- H II regions surrounding early-type (OB) stars
  - Photoionized
  - $T \approx 10^4$ K
  - $n_e \approx 0.1$ to 10^4 cm^{-3}
  - Bright nebulae associated with regions of star formation & molecular clouds
- Warm Ionized Medium
  - $T \approx 8000$ K
  - $\langle n_e \rangle \approx 0.025$ cm^{-3}
- Hot Ionized Medium: tenuous gas pervading the ISM
  - Ionization by electron impact
  - $T \approx 4.5 \times 10^5$ K
  - $n \approx 0.0035$ cm^{-3}

http://astro.berkeley.edu/~ay216/06/NOTES/ay216_2006_01_Intro.pdf
http://antwrp.gsfc.nasa.gov/apod/ap060120.html

Other Stuff

- Heavy elements
  - He (≈ 10 % by number)
  - C, N, O (≈ "cosmic" abundances)
  - Si, Ca, Fe (depleted onto grains)
  - Dust grains (≈ 0.1 μm size, silicates or carbonaceous material ≈ 1% by mass of ISM)
- Photons
  - CMB
  - Star light—average interstellar radiation field
  - X-rays—from hot gas & the extragalactic background
- Magnetic fields & cosmic rays

The Cycle



http://astro.berkeley.edu/~ay216/06/NOTES/ay216_2006_01_Intro.pdf