Astro 301/ Fall 2006

(50405)

Introduction to Astronomy

http://www.as.utexas.edu/~sj/a301-fa06

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Lecture 19: Tu Nov 7

Lecture 19: Announcements

1) Exam 2 : Th Nov 9. See class website for details.
2) Quiz 4 is on Tu Nov 14. See class website for details
3) Please use the new updated course calendar and reading list online.
4) Erratum: The chapter on telescopes to read for Week 10 is Chapter 6 in 4th edition of textbook and Chapter 7 in 3rd edition.
5) Today: Lecture will include some review based on questions emailed to me.

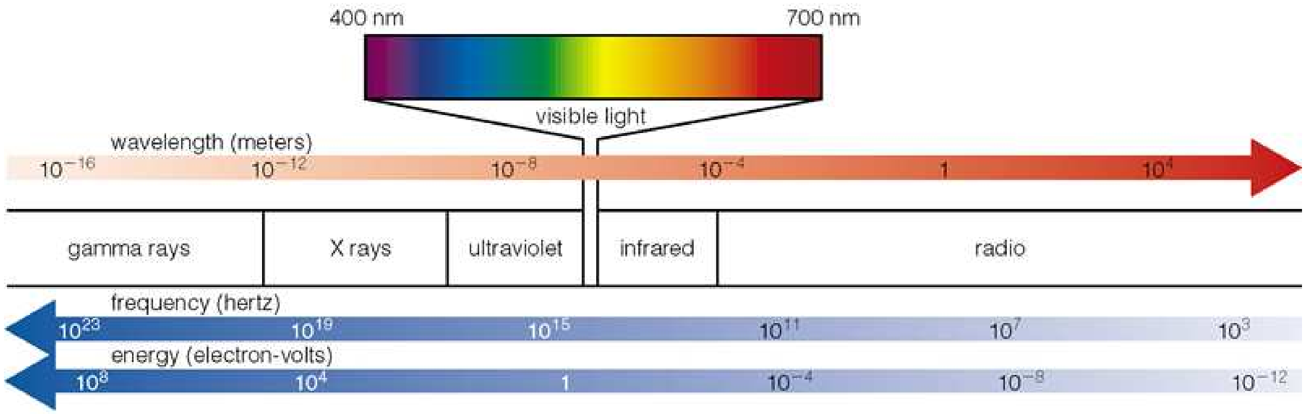
Upcoming topics in class today

1) Recapitulation of main concepts in last lecture
2) Tracing cold gas via observations at radio wavelengths
3) In-class discussion
4) Galaxies
   Types of galaxies
   Galaxy interactions and mergers

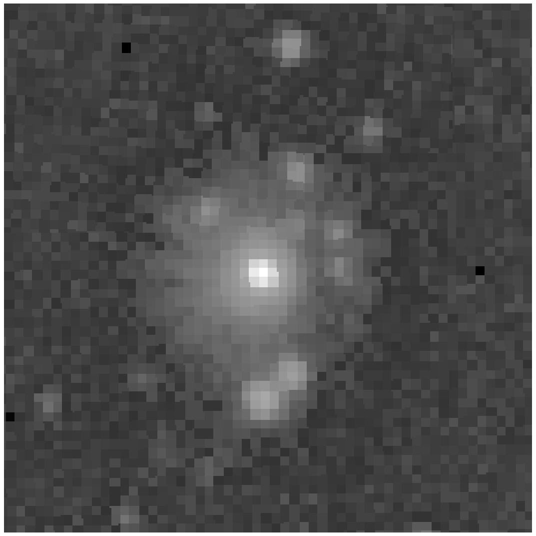
Recapitulation of main concepts in last lectures

Recall: light can be considered as electromagnetic waves of different wavelengths

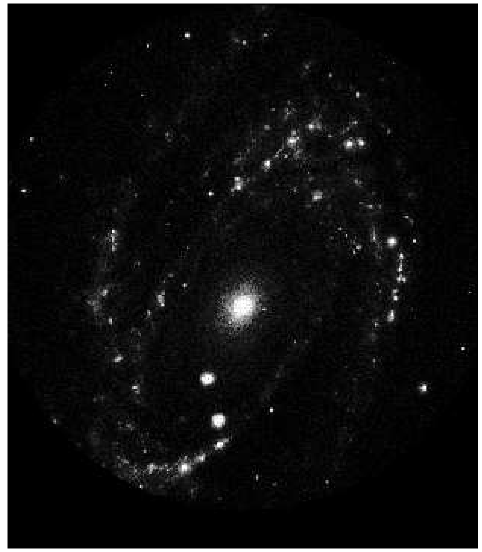
Gamma rays	10^{-16} m
X rays	10^{-12} m
Ultraviolet	3×10^{-7} m
Optical	4 to 9×10^{-7} m = Violet, blue, green, yellow, orange, red
Infrared	10^{-6} m to 10^{-4} m
Radio	10^{-3} m to 10 m



Multi-Wavelength view of M81



X-ray/ROSAT



Ultraviolet/ASTR0-1

Visible light

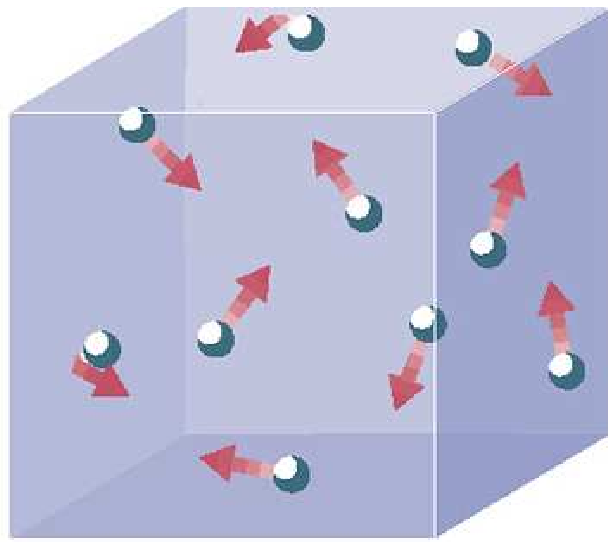
Near infrared/Spitzer

Mid-infrared/Spitzer

We can use Kirchoff's law and Wien's law to infer the nature of the sources that are traced by observations at X-ray to far-infrared wavelengths !

The continuum spectrum of a source depends on surface temperature

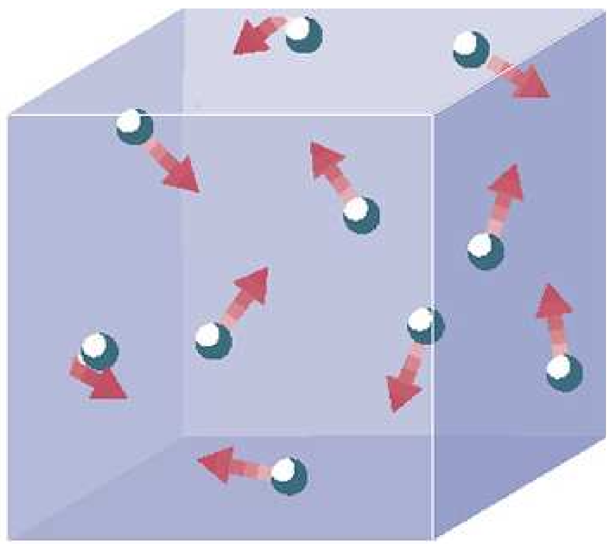
Recall two important concepts covered in earlier lectures

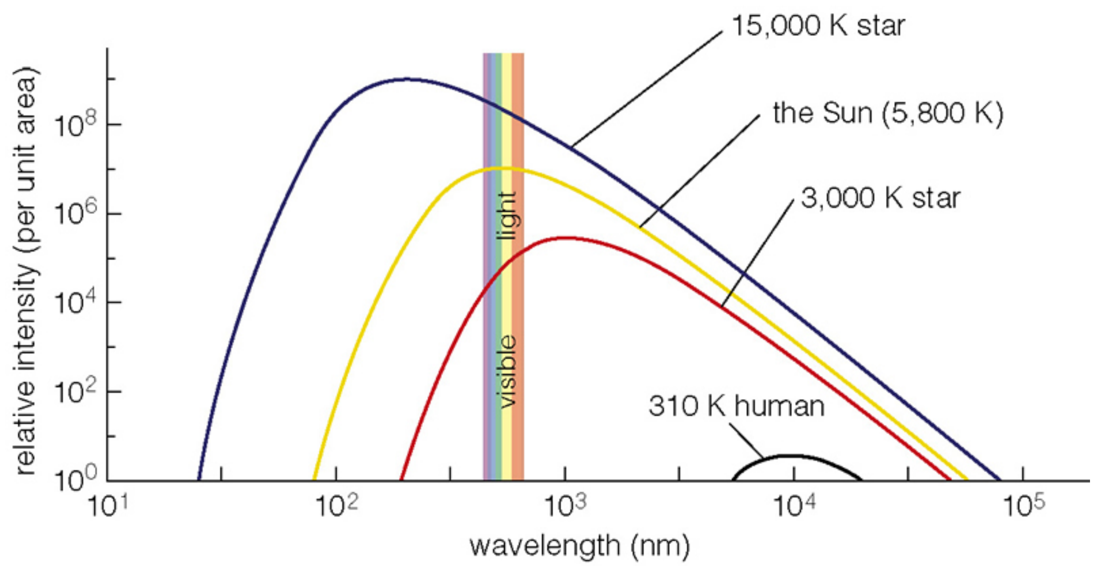


Kirchoff's first law:

Any hot solid, liquid or opaque gas emits light (as a continuum spectrum). In a hot object, the atoms are moving randomly (vibrating) with an energy set by the temperature of the body. The vibrating electrons in the atoms cause vibrating electric fields à this is light

The continuum spectrum of a source depends on surface temperature





Wien's law

The continuum emission of a star or blackbody peaks at a wavelength λ_{peak} that depends inversely on its surface temperature T

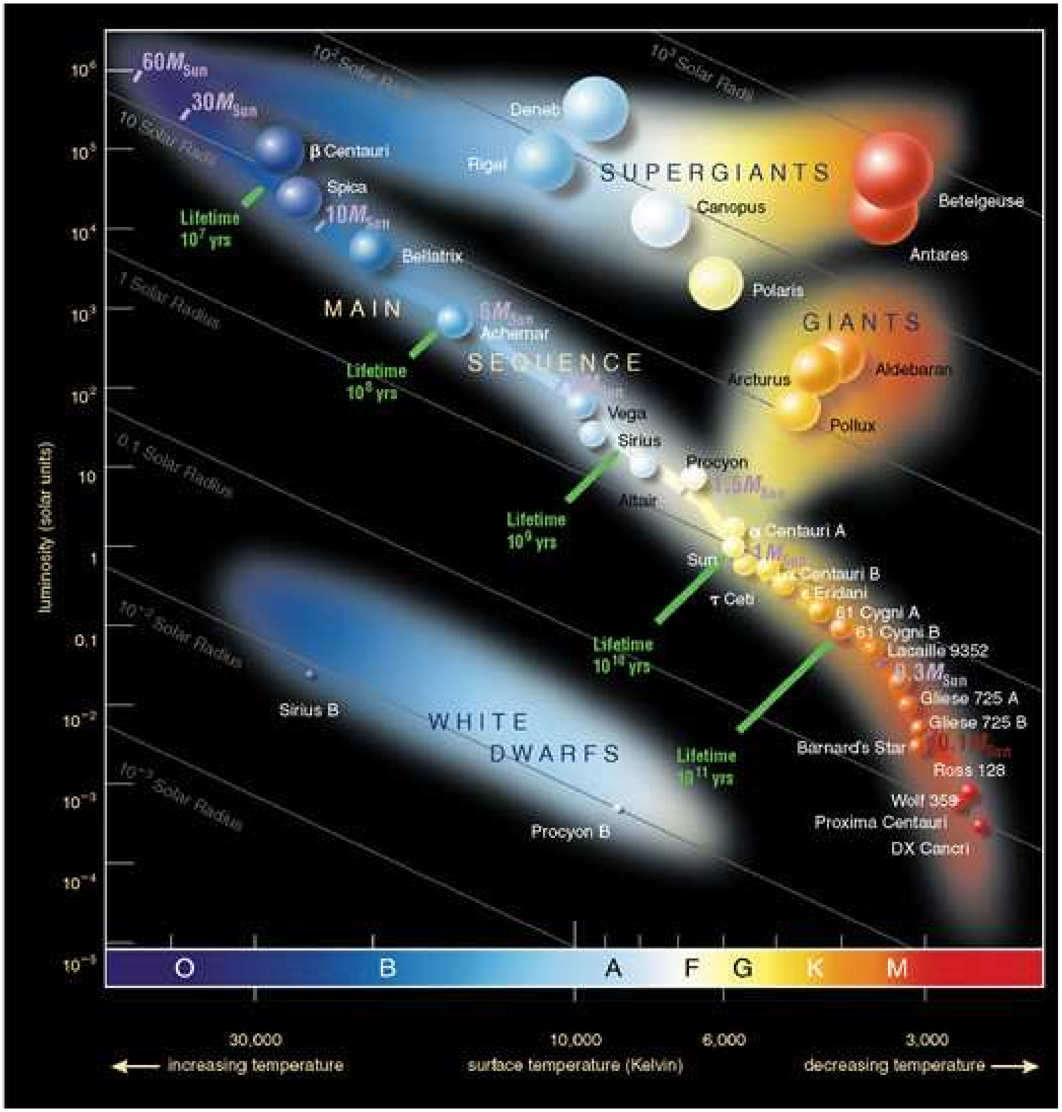
λ_{peak}= W/ T , where W = Wien's constant = 2.9×10^{-3} m K

In-class exercise: Use Wien's law to calculate the temperature of the source which emits most of its light at the wavelengths below

Wavelength of peak emission		Surface Temperature of emitting source
X rays	3×10^{-10} m	
Ultraviolet	1×10^{-7} m	
Optical	blue= 3×10^{-7} m	
Optical	yellow=5×10^{-7} m	
Optical	red= 7×10^{-7} m	
Near infrared	1×10^{-6} m	
Mid-infrared	3×10^{-5} m	
Far-infrared	1×10^{-4} m	

In-class exercise: Use Wien's law to calculate the temperature of the source which emits most of its light at the wavelengths below

	Wavelength of peak emission	**Surface Temperature of emitting source**
X rays	3×10^{-10} m	10^{7} K
Ultraviolet	1×10^{-7} m	30,000 K
Optical	blue= 3×10^{-7} m	10,000 K
Optical	yellow=5×10^{-7} m	6,000 K
Optical	red= 7×10^{-7} m	4,300 K
Near infrared	1×10^{-6} m	3,000 K
Mid-infrared	3×10^{-5} m	100 K
Far-infrared	1×10^{-4} m	30 K



UV trace sources at 30,000K. à these are high mass (>8 M o) stars

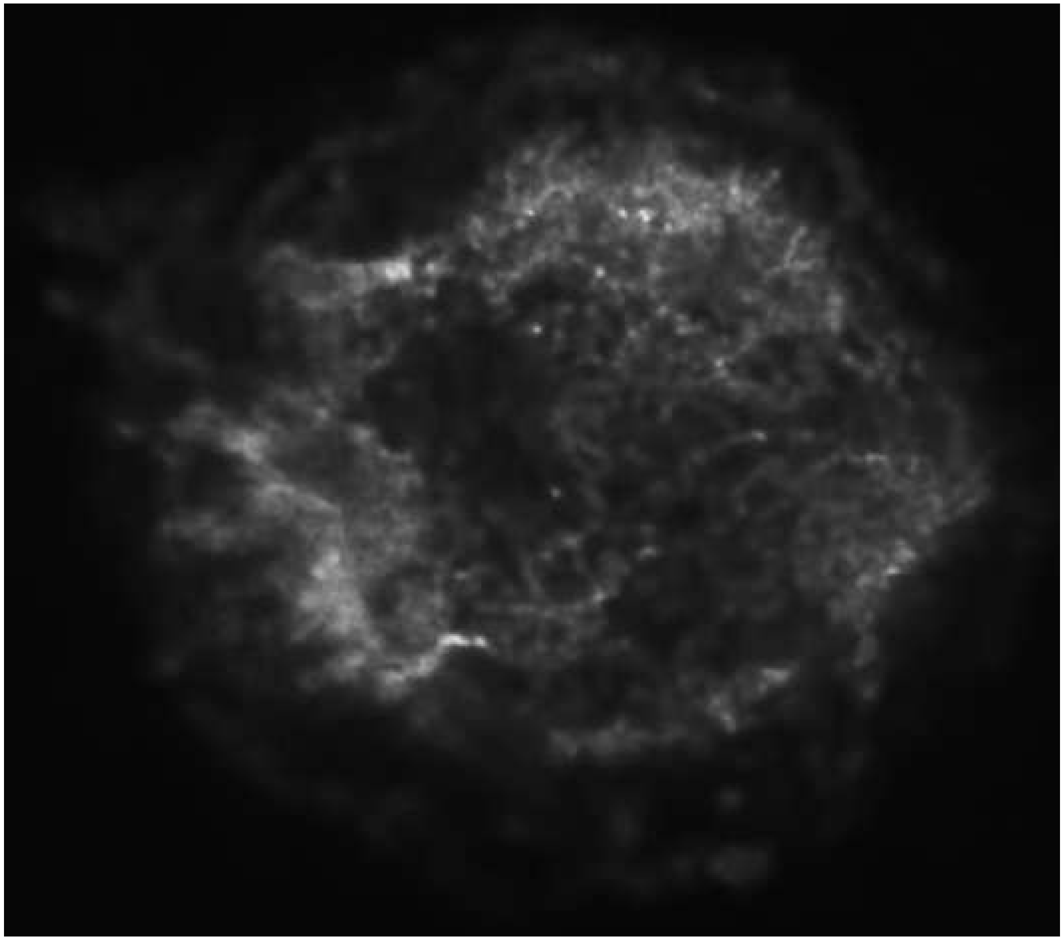
Blue, yellow, red light trace sources at 10,000 K, 6000 K, 4300 K

à these are stars with mass 3 Mo, 1 Mo , ~0.7Mo

Wavelength of peak emission		Surface Temperature of emitting source	Nature of source
X rays	3×10^{-10} m	10^7 K	?
Ultraviolet	1×10^{-7} m	30,000	Very massive (M>10Mo) stars
Optical	blue= 3×10^{-7} m	10,000 K	Intermediate mass (5Mo stars)
Optical	yellow=5×10^{-7} m	6,000 K	Low mass (1 Mo stars)
Optical	red= 7×10^{-7} m	4,300 K	Very low mass (< 1Mo stars)
Near infrared	1×10^{-6} m	3,000 K	Lowest mass (~0.3 Mo) star
Mid-infrared	3×10^{-5} m	100 K	?
Far-infrared	1×10^{-4} m	30 K	?

- The sources emitting most of their light
  - at X-ray wavelength are too hot to be a star
  - at mid-IR or far-IR wavelengths are too cold to be a star
- What is the nature of these sources?

X-Ray Wavelengths



Supernova Remnant
Cassiopeia A

X-ray shows a hot bubble of 10^7 K gas that is heated by shocks from the supernova remnnant

Wavelength of peak emission		Surface Temperature of emitting source	Nature of source
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Ultraviolet	1×10^{-7} m	30,000	Very massive (M>10Mo) stars
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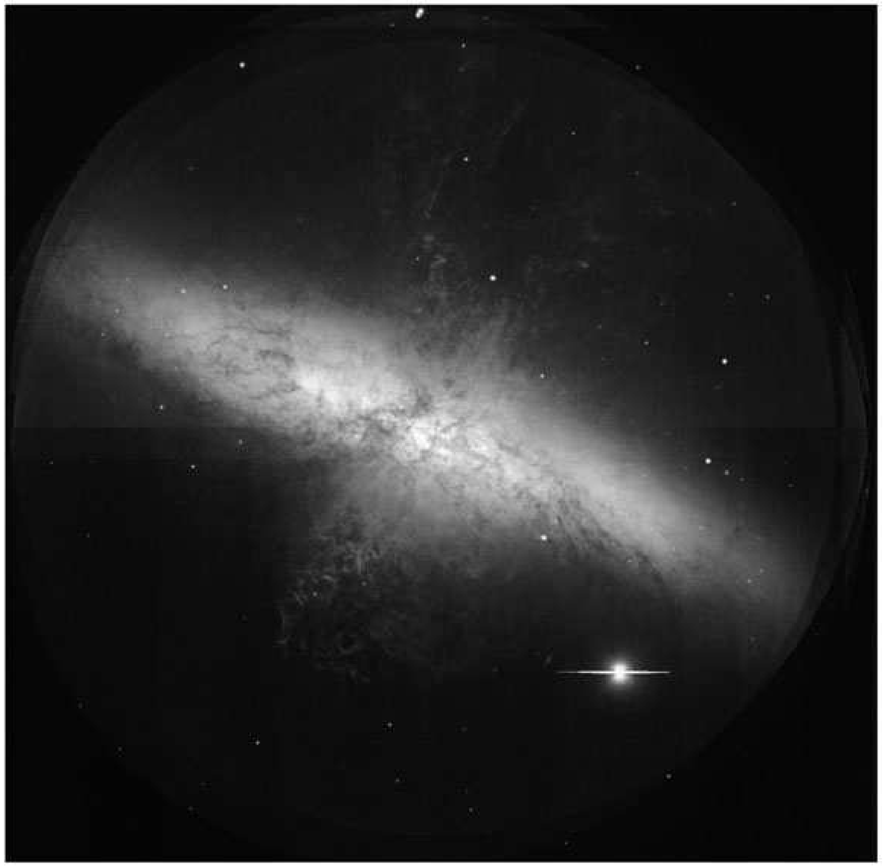
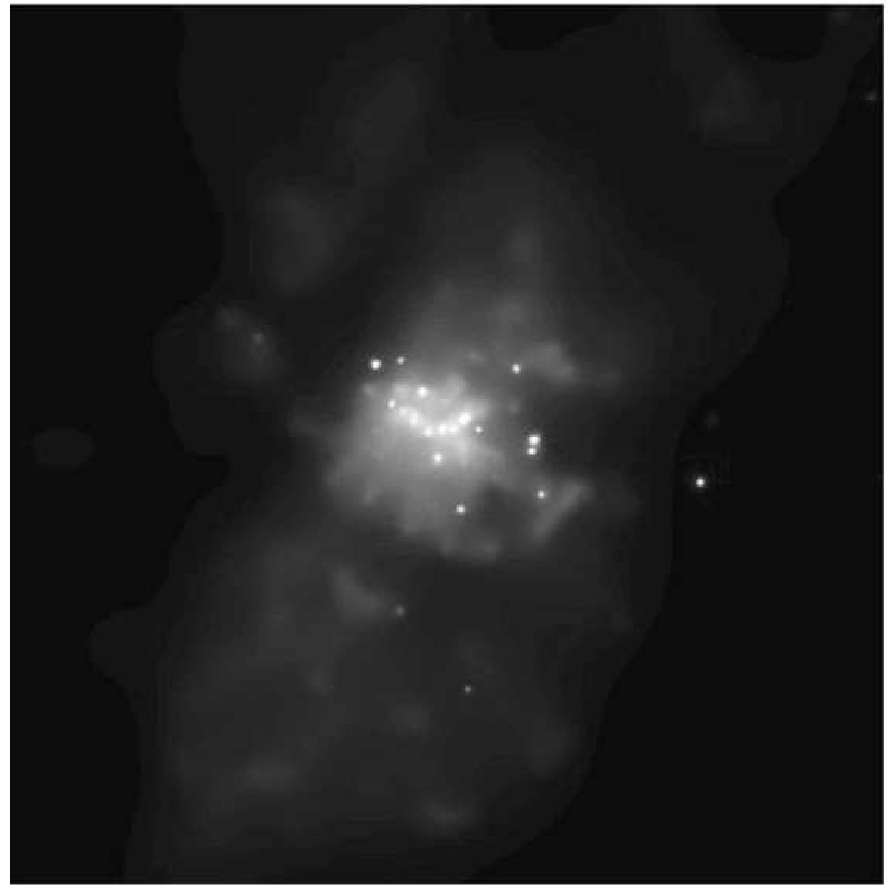
X-Ray Wavelengths

Starburst Galaxy M82: central starburst driving an outflow



Visible light



X-ray
Hot gas and neutron stars

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Mid-infrared	3×10^{-5} m	100 K	?
Far-infrared	1×10^{-4} m	30 K	?

Near-IR and Mid-IR images

M81 galaxy

(Courtesy: NASA/Spitzer)

Near infrared light
- comes from cool low mass stars
- penetrates through intervening dust to reach us

à See in-class figure

Mid-IR light is emitted by

à warm (100 K) dust and gas that is heated by UV/blue light from hot massive young stars

à See in-class figure

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Mid-infrared	3×10^{-5} m	100 K	Hot dust heated by UV/optical light coming from high mass stars behind the dust
Far-infrared	1×10^{-4} m	30 K	Warm dust heated by UV/optical light coming from high mass stars behind the dust

See in-class figure for reprocessing of light by dust for mid-IR and far-IR

Infrared Wavelengths

Movie: From optical to IR view of M81 (Courtesy: NASA/Spitzer)

à Near-IR at 1 to 3 micron: penetrate the dust and shows **old stars**

à Mid and far-IR from 10 to 100 micron shows **hot dust and gas forming young stars**

Infrared Wavelengths

Movie : From visual to infrared look at dark globule in IC 1386
(Courtesy:NASA/Spitzr)

- Visual image shows one star + dark patch of dust in globule head
- Near-IR 3.6 mu image penetrates the dust to show 2nd star and cavity in globule head
- Mid IR 8 and 24 mu images trace hot dust+ gas filaments made when winds from massive stars compress gas à Thick dusty discs around young stars = precursor of planetary systems

Summary

Summary of sources traced at X-ray to Far-IR Wavelengths

Wavelength of peak emission		Surface Temperature of emitting source	Nature of source
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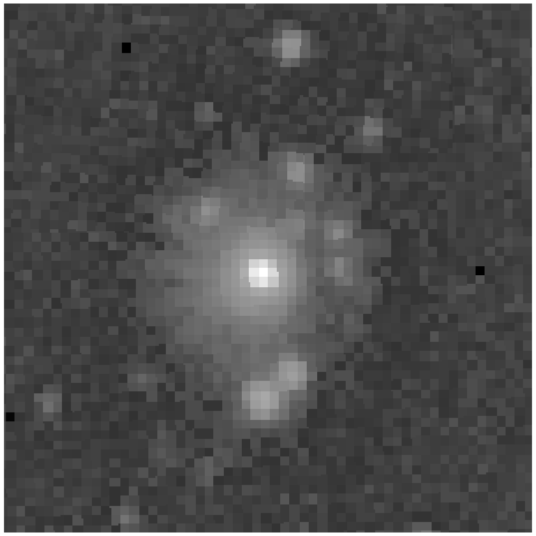
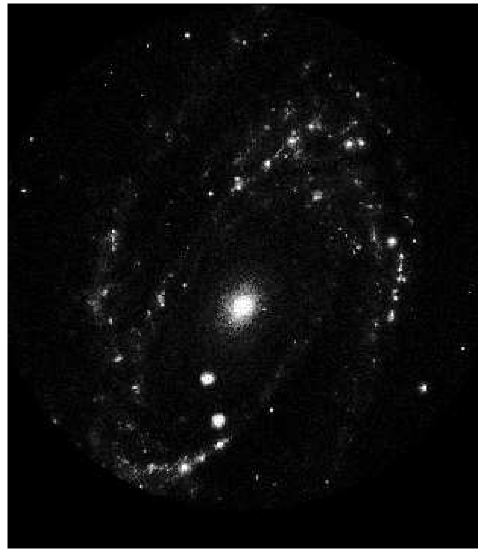
Multi-Wavelength view of M81



X-ray/ROSAT



Ultraviolet/ASTR0-1

Visible light

Near infrared/Spitzer

Mid -infrared/Spitzer

Observations at X-ray to far-infrared wavelengths trace
- hot 10^7 K gas (+ NS)
- very massive stars at 30,000 K
- intermediate mass stars at 10,000 to 4,500 K
- very low mass stars at 3000 K
- hot dust at few hundred K
- warm dust a few tens of K

Tracing cold gas at radio wavelengths

Cold gas in galaxies: atomic and molecular hydrogen

- In addition to hot gas, stars of different masses, hot and warm dust, galaxies also contain cold hydrogen gas
- Two forms of cold hydrogen gas
  - atomic hydrogen (called HI) made of atoms of hydrogen.
    Traced by radio observations of emission lines at 21cm

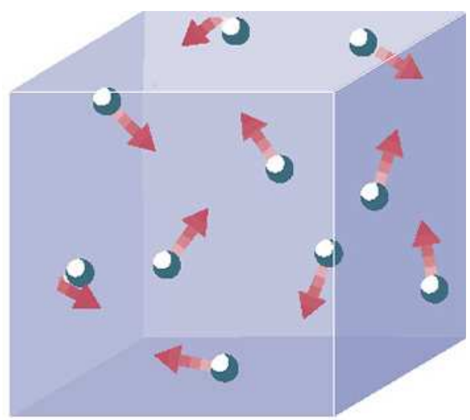
  - molecular hydrogen (called H_2) made of molecules of hydrogen
    Traced by radio observations of emission lines at 3mm

- A cold gas cloud made of atomic hydrogen or molecular hydrogen can reach high densities by collapsing under the force of gravity (or via compression by shocks)

- Question : What are the forces that oppose the collapse of a cloud under its force of gravity?

à thermal pressure exerted by atoms that are moving at random speeds determined by their temperature

à Coriolis forces which are forces associated with the rotation motion of the cloud. A fast rotating cloud will be less inclined to collapse



Cold gas in galaxies : atomic and molecular hydrogen

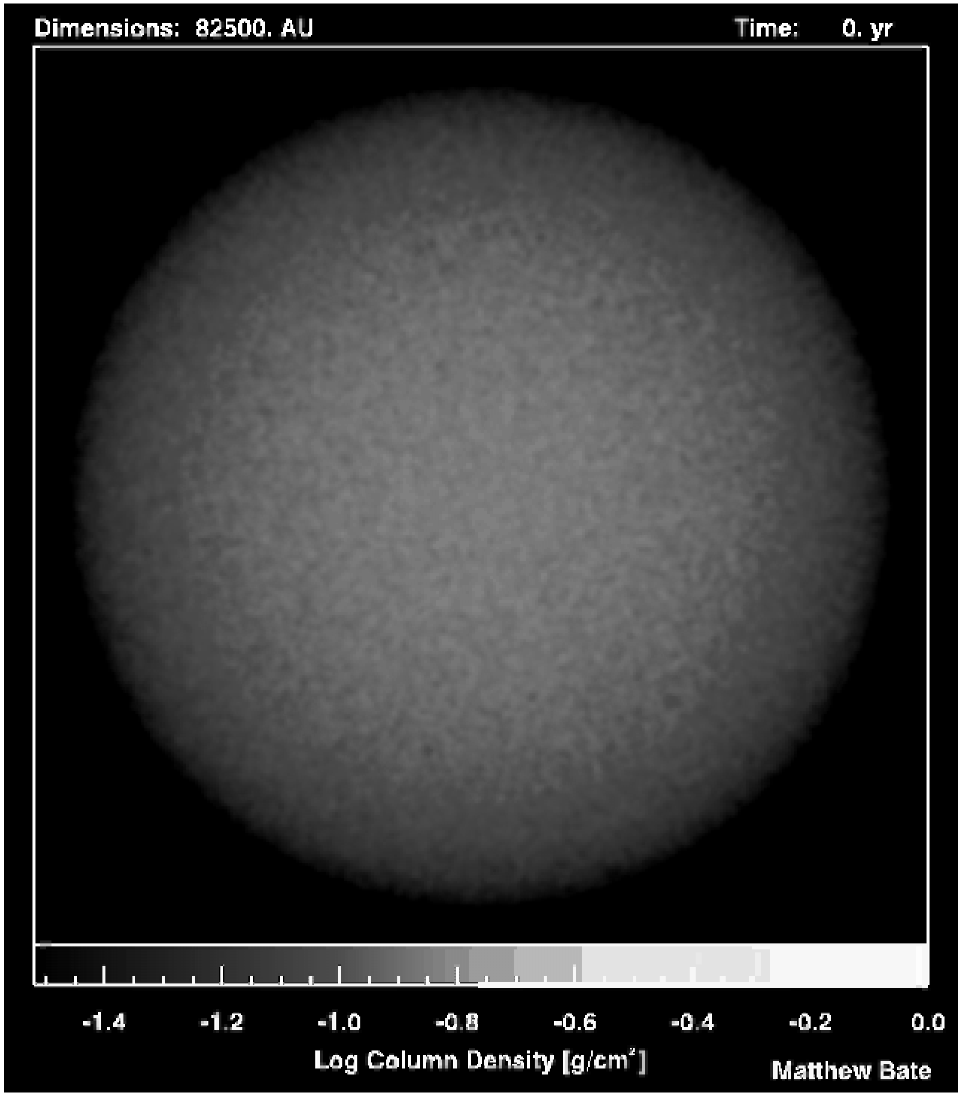
- Question : Why is it easier for a cold cloud at 10 K to undergo gravitational collapse for a warm cloud at 300 K or for very hot gas at 10^{7} K?

à the thermal pressure opposing collapse is lower at lower temperature

- When cold atomic hydrogen collapses to high densities à it forms cold molecular hydrogen
- When cold molecular hydrogen collapses under gravity à it forms new stars

à Cold molecular hydrogen gas is the direct fuel from which new stars are born

Collapse of a molecular hydrogen cloud to form stars and possible planetary systems

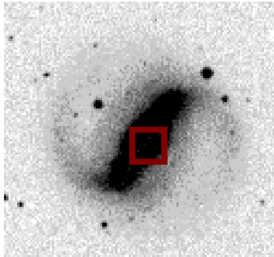


Start with a **gas cloud** whose
- mass ~ 50 times that of our Sun.
- diameter~1.2 light years (~10^{16}m)
- temperature ~ 10 K.

(low density=red, high density=yellow

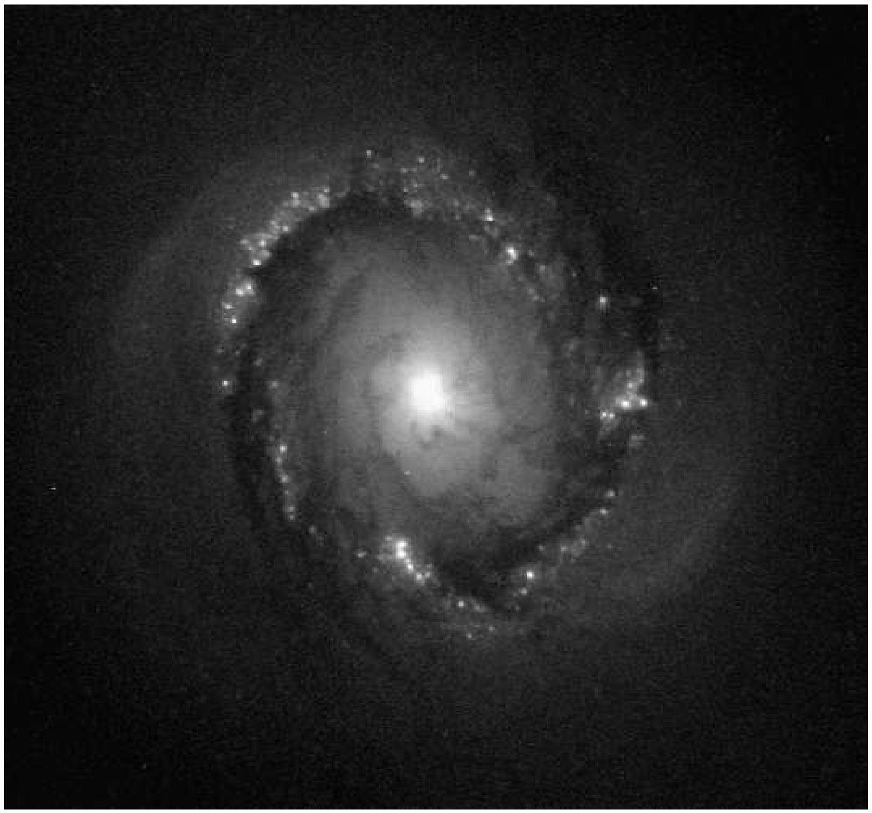
The cloud collapses under its own gravity, and fragments to form **dense gas clumps and eventually stars.**

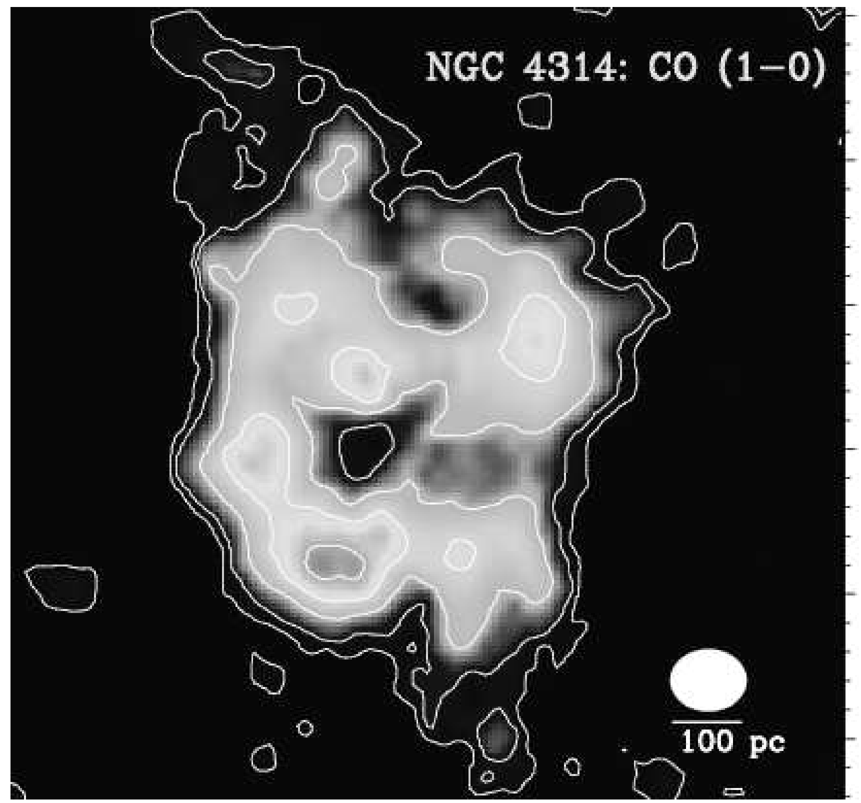
Swirling discs of gas around the newly born stars may later form **planetary systems like our own Solar System.**



Radio observations at 3mm tracing molecular hydrogen

Cold molecular hydrogen gas, traced by 3mm radio observations, is the direct fuel from which new stars are born. Its distribution is similar to that of recently formed stars, traced by UV and blue light!

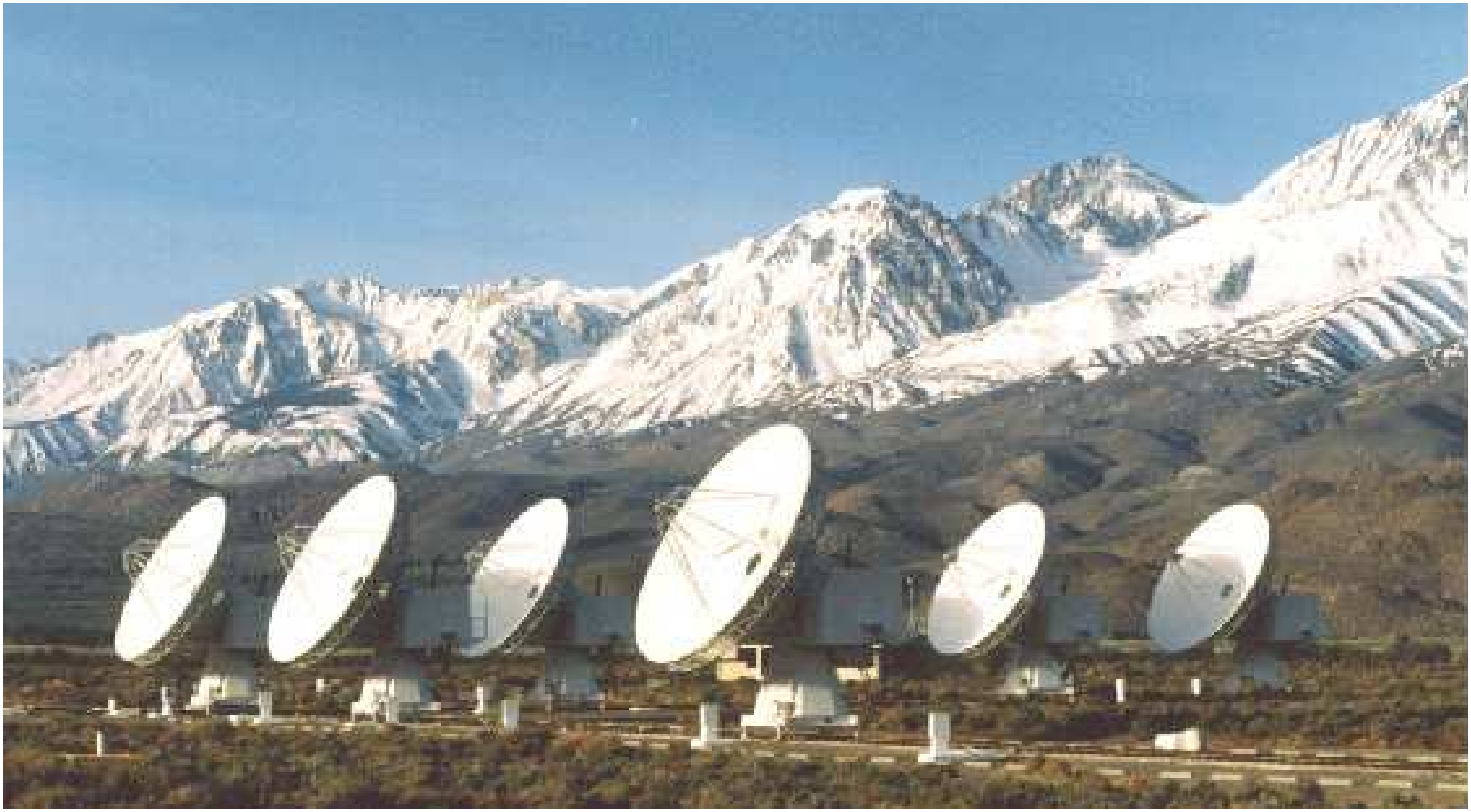




UV and visible images from HST show a spectacular ring of young stars, a few million yearrs old. Courtesy: Benedict/ NASA)

Radio observation at 3 mm trace molecular hydrogen from which the stars are forming. (Jogee et al . 2004)

Caltech's Radio Observatory for observations at 3mm



- Caltech's Owens Valley Radio Observatory (OVRO)
  - located on east side of the Sierra Nevadas in California, ~250 miles north of Los Angeles.
  - has an array of 8 radio telescopes, each 10.2 m in size, operating at mm wavelengths
- At radio λ : observe 24 hrs a day. Only shut down in the summer when humidity is high….

The importance of atomic hydrogen

- Atomic hydrogen, traced by 21 cm radio observations :

à is an indirect fuel for star formation
Why "indirect?": it is only under the right conditions that atomic hydrogen will form molecular hydrogen. The latter then forms new stars

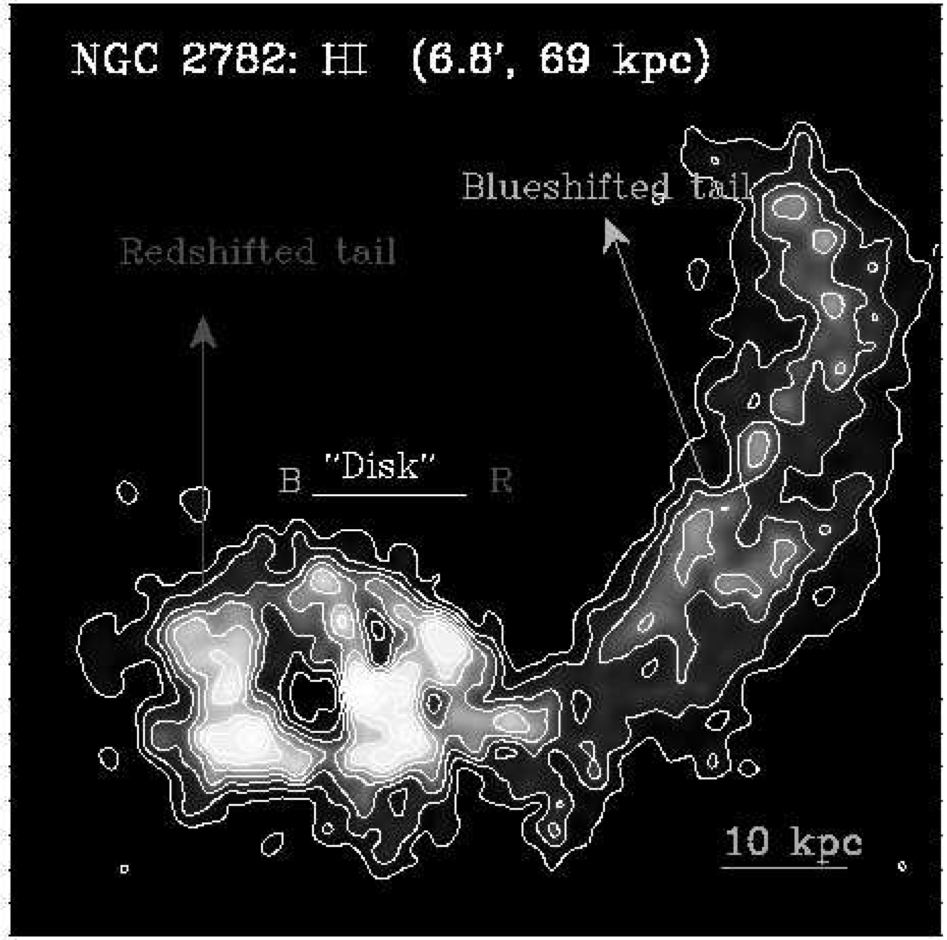
à exists very far out in galaxies, well beyond the radius where we see visible stars.
e.g., optical radius = 20,000 pc
HI radius = 50,000 pc

à is easily disturbed (in terms of distribution and velocity) by the passage of another galaxy

à reveal interaction features, such as tidal tails at large radii and powerfully unravels the interaction history of a galaxy

à is used to estimate the amount of dark matter in galaxies (see next lectures)

Radio observations of atomic hydrogen at 21 cm



The visible light image shows
- a relatively undisturbed disk
- a 20,000 pc tail to the left
- NO disturbance to the right

Image at 21 cm (atomic H) shows the disk and a HUGE 50,000 pc tail to the right