Earth 101
Introduction to Astronomy

Instructor:
Erin O'Connor

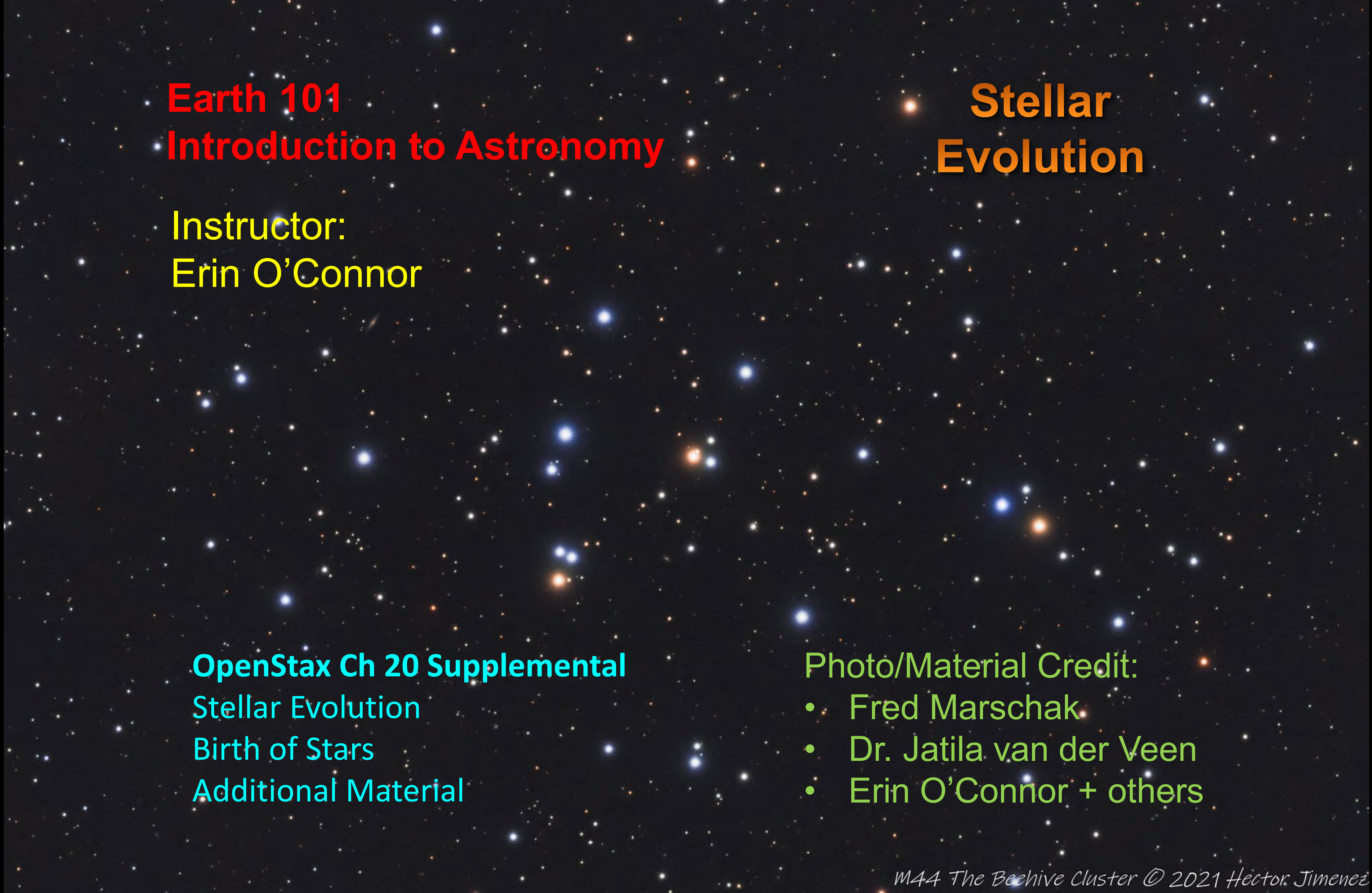
Stellar Evolution

OpenStax Ch 20 Supplemental

Stellar Evolution
Birth of Stars
Additional Material

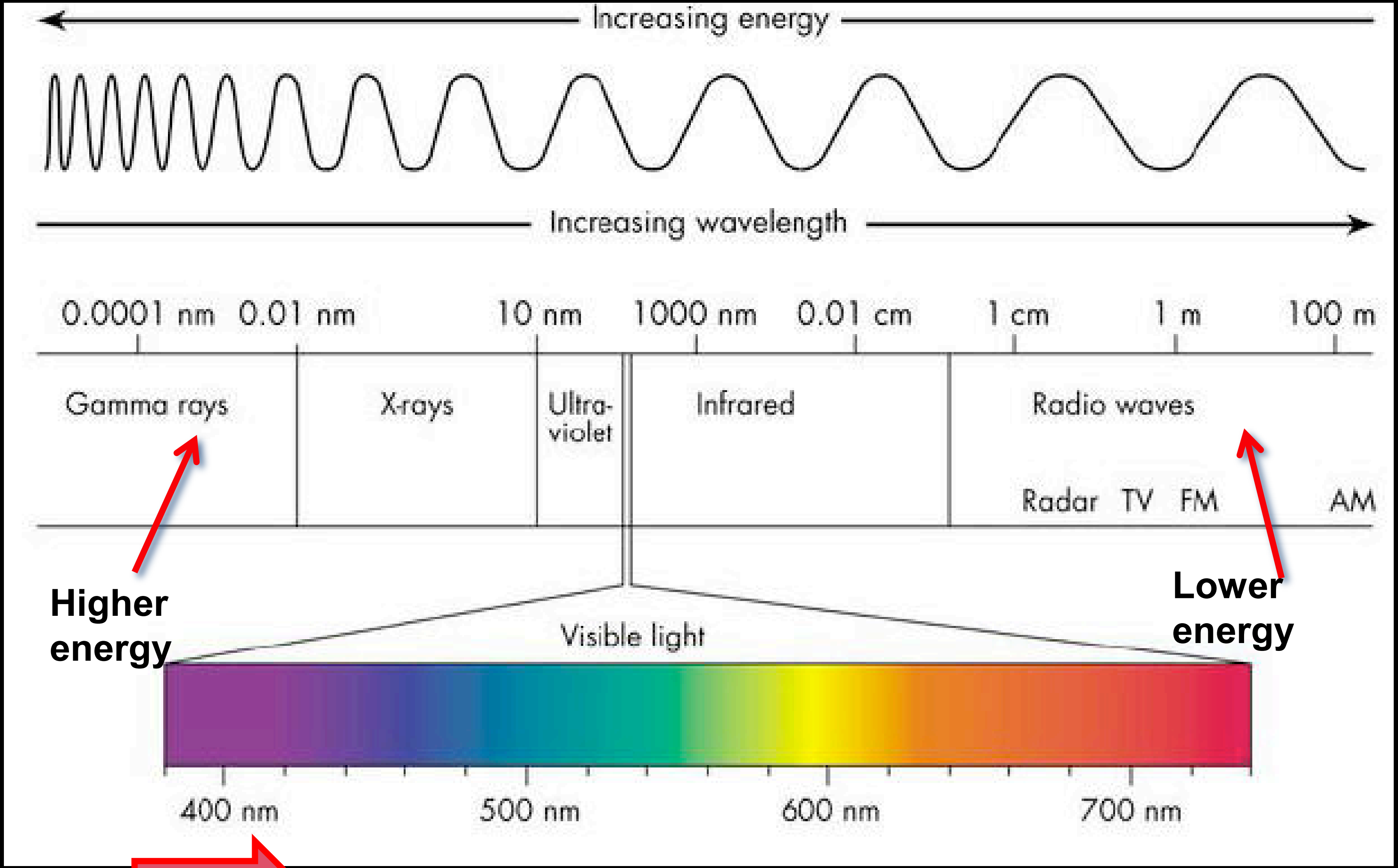
Photo/Material Credit:

- Fred Marschak
- Dr. Jatila van der Veen
- Erin O'Connor + others



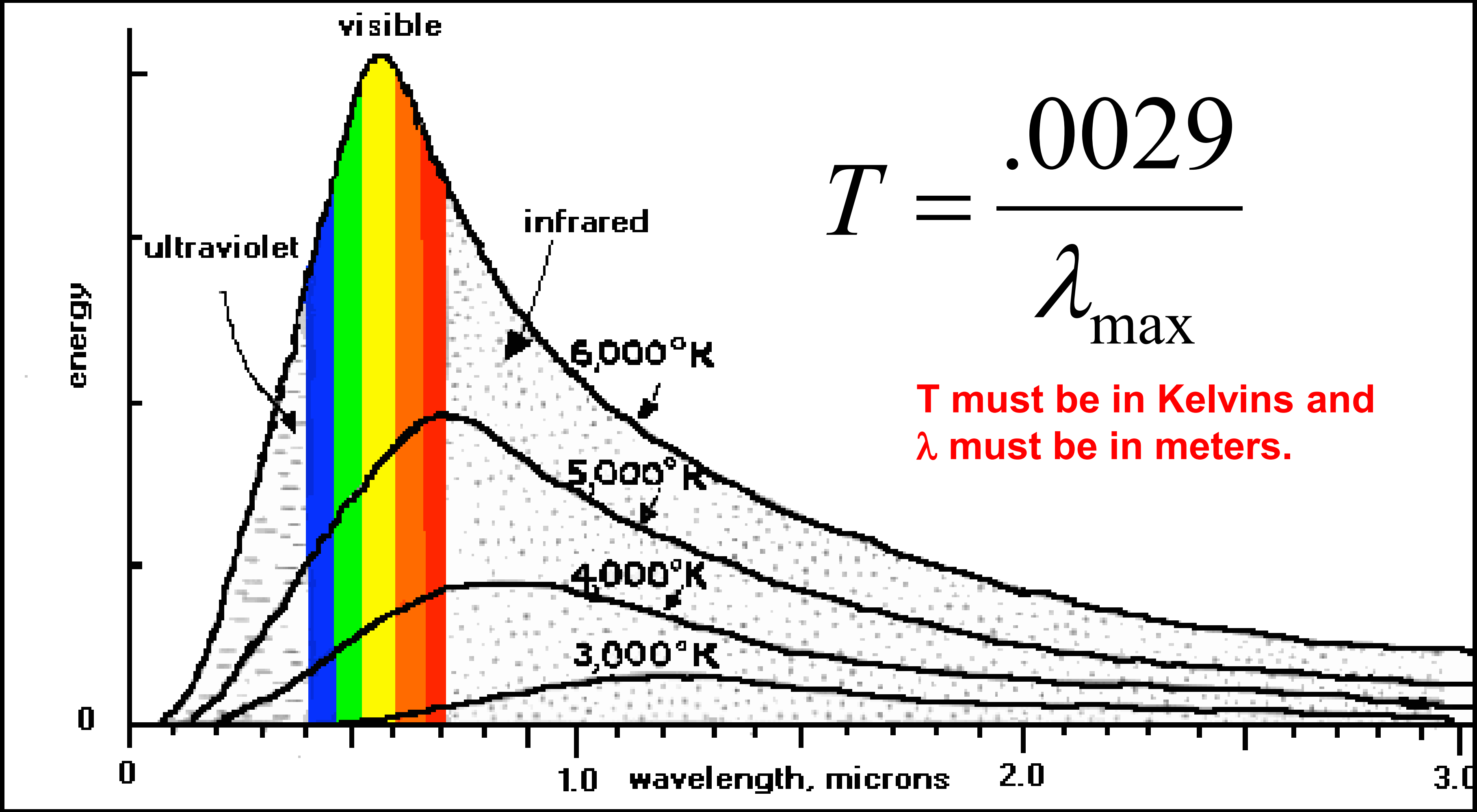
The electromagnetic spectrum.

Visible light – those few wavelengths between approximately 400 and 700 nanometers – is the only range we can see. For the rest, we use special detectors, and then map the measurements into colors we can see.



KNOW THIS: nm = nanometer = 10^{-9} meter = 1 billionth of a meter

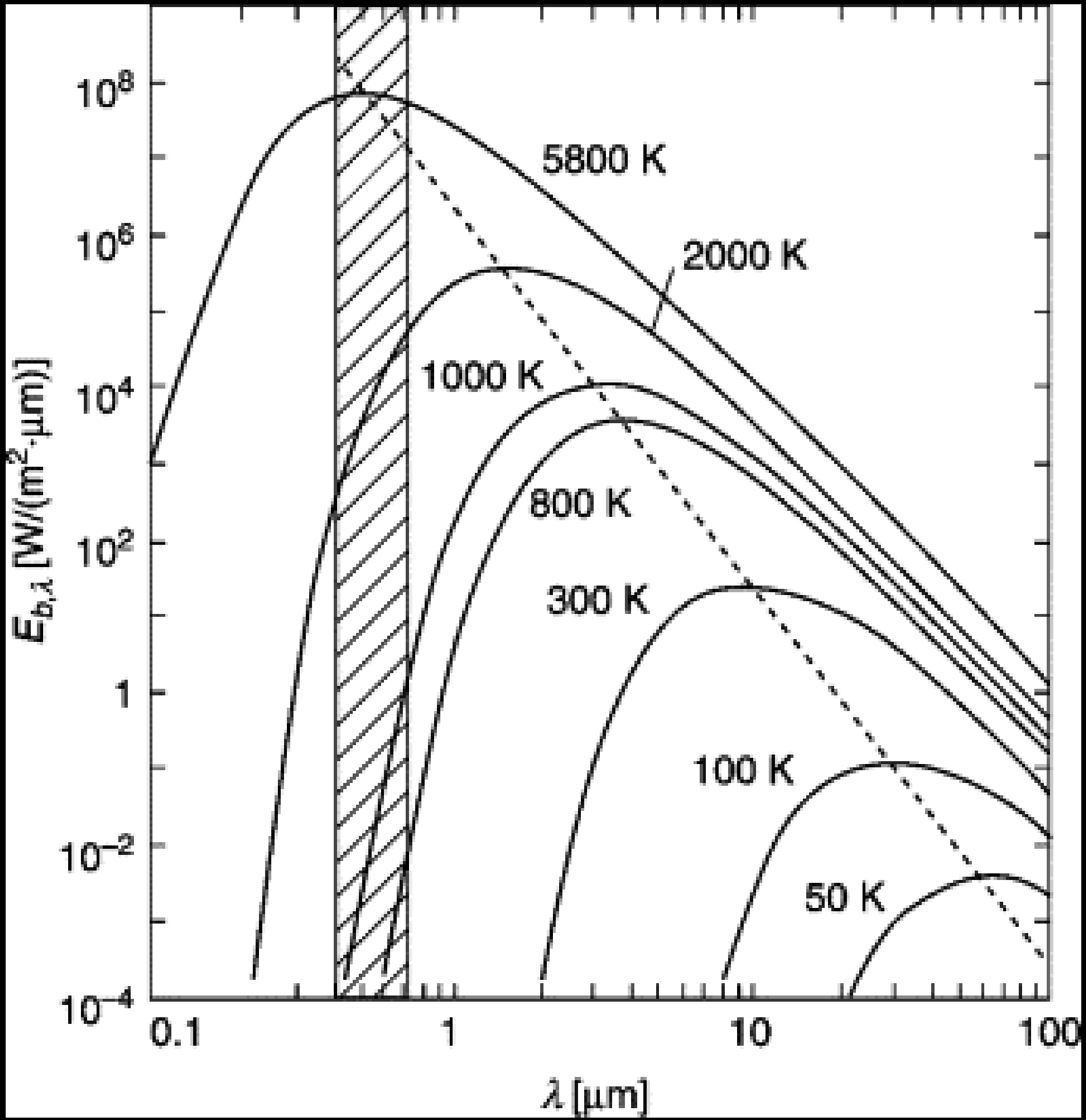
Recall: measuring surface temperature from the wavelength at the peak of the black body spectrum:



$$T = \frac{.0029}{\lambda_{max}}$$

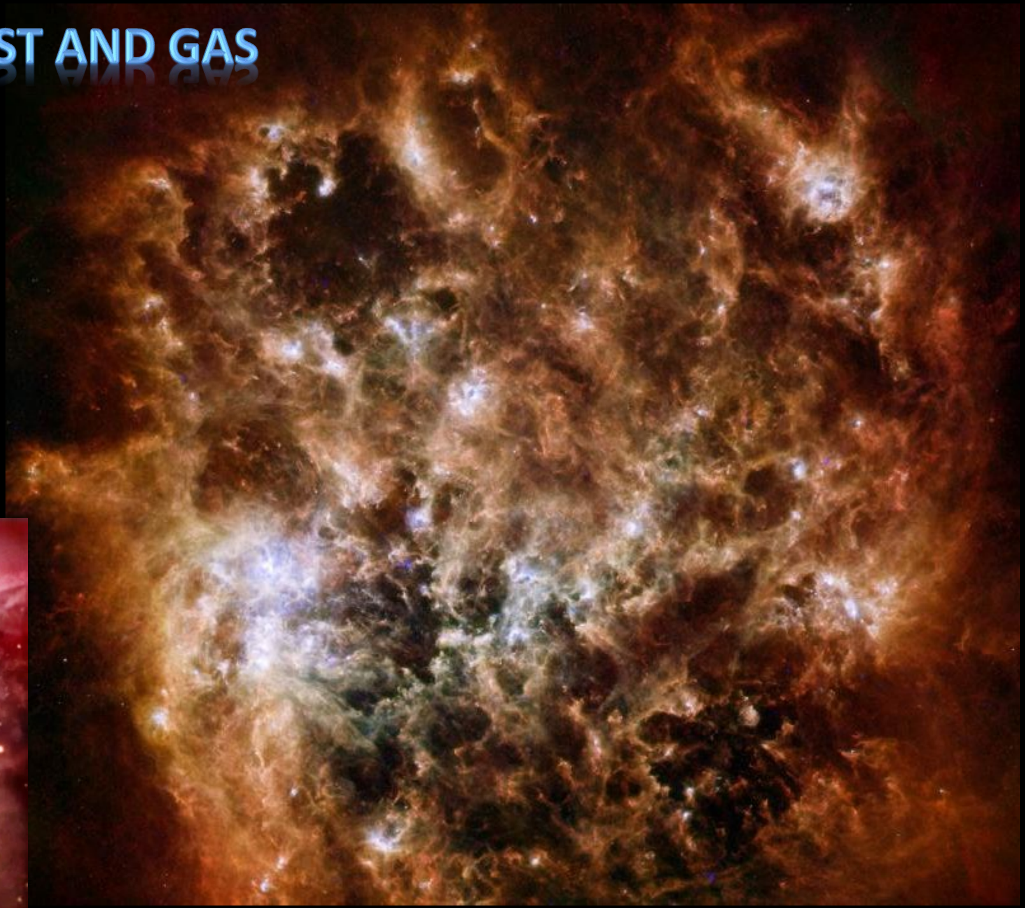
T must be in Kelvins and
λ must be in meters.

An expanded view of thermal emission spectra from Sun-like stars (5800 K) to dust in the galaxy.



STARS FORM FROM INTERSTELLAR DUST AND GAS

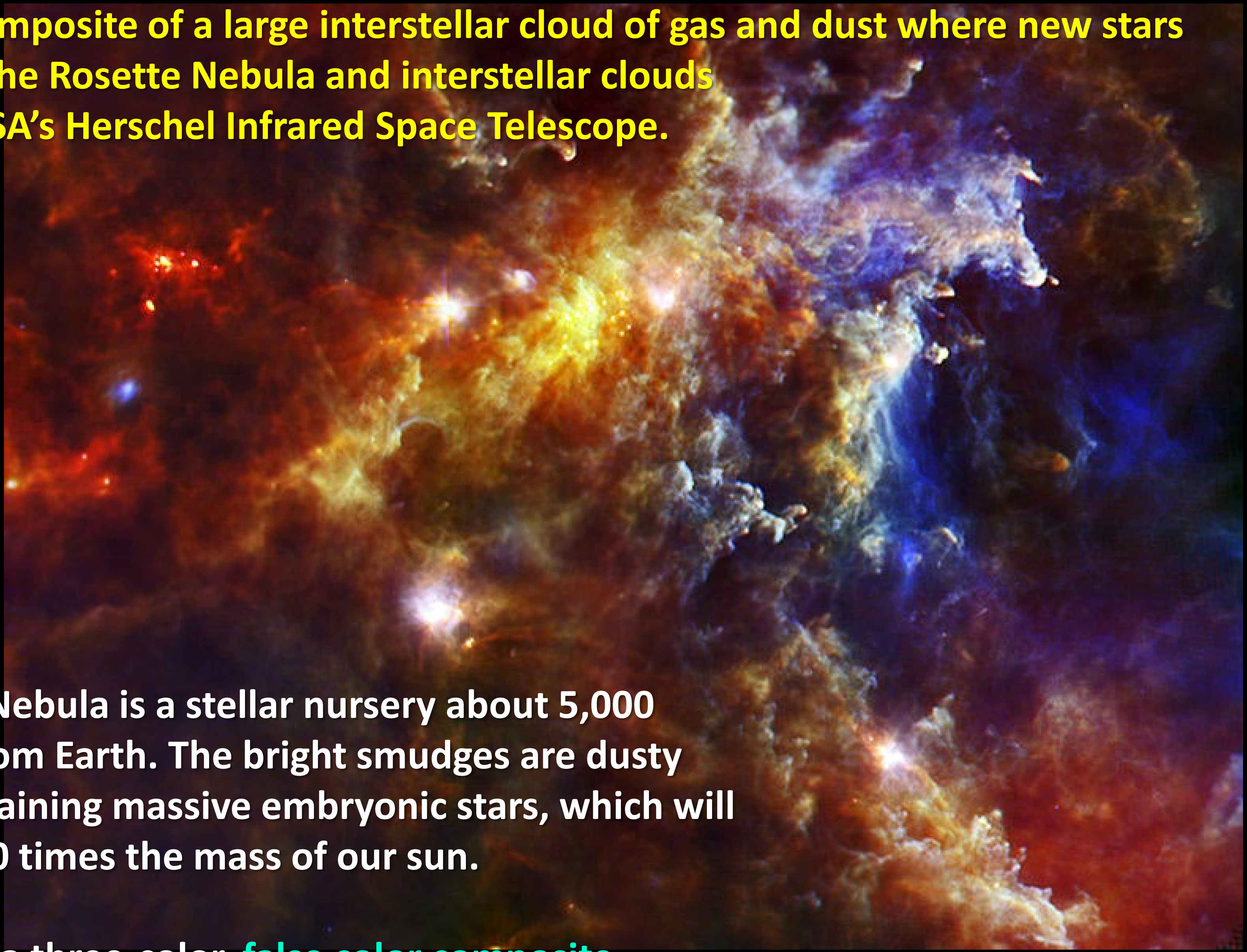
In this lecture you will learn about star-forming regions where young stars can be found, ***mostly by observing in infrared, microwave, and radio wavelengths because visible light can't get through the cold dust and gas.***



Above: Large Magellanic Cloud star forming region imaged in infrared light. Composite false color image at 250, 160, and 100 microns. Credit: ESA/NASA/JPL

Left: Hubble Space Telescope image of the Horsehead Nebula in visible light. The Horsehead Nebula is part of the Orion Molecular Cloud Complex.

An infrared composite of a large interstellar cloud of gas and dust where new stars are forming: The Rosette Nebula and interstellar clouds captured by ESA's Herschel Infrared Space Telescope.



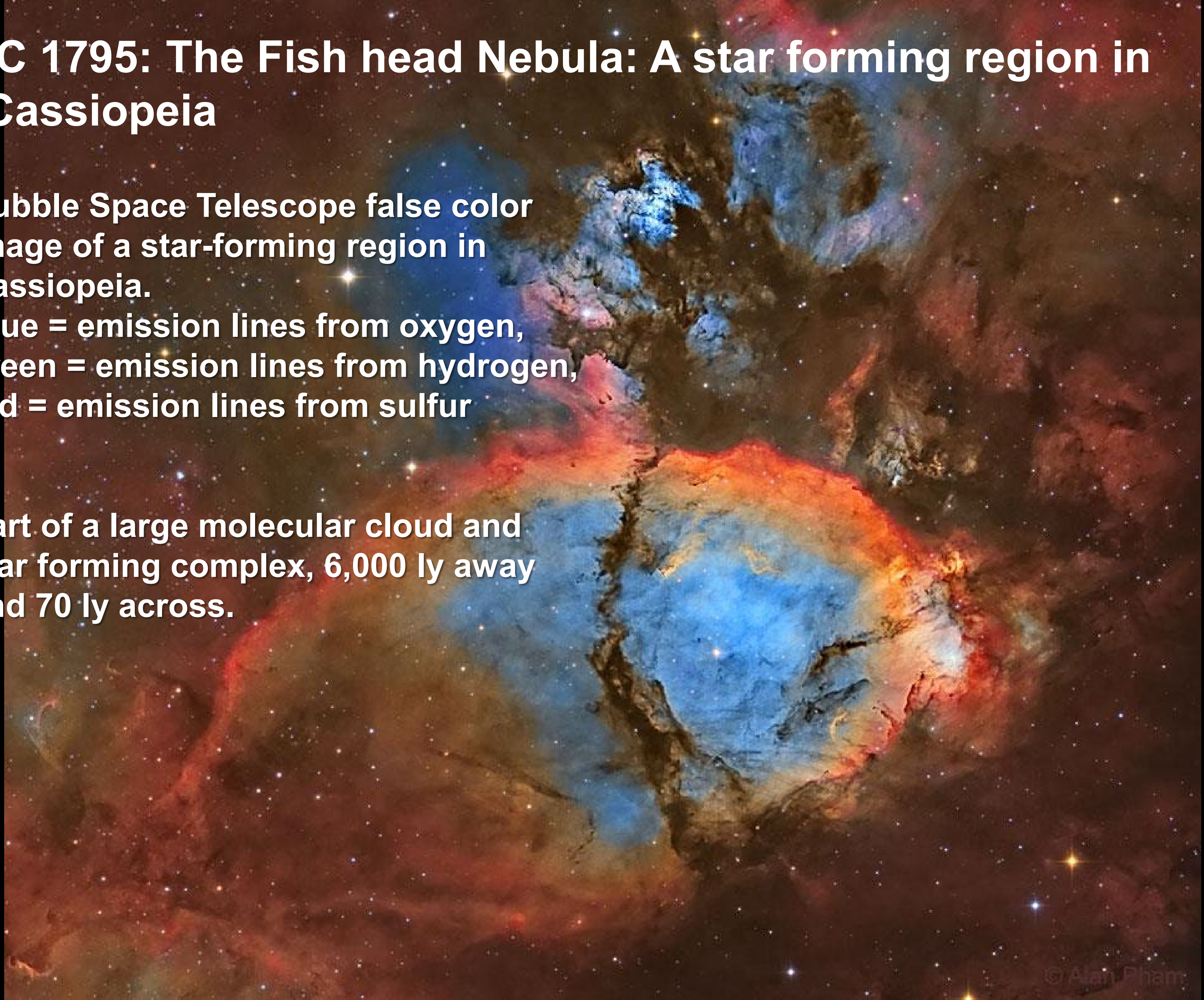
The Rosette Nebula is a stellar nursery about 5,000 light-years from Earth. The bright smudges are dusty cocoons containing massive embryonic stars, which will grow up to 10 times the mass of our sun.

This image is a three-color, false color composite showing infrared wavelengths of 70 microns (blue), 160 microns (green), and 250 microns (red).

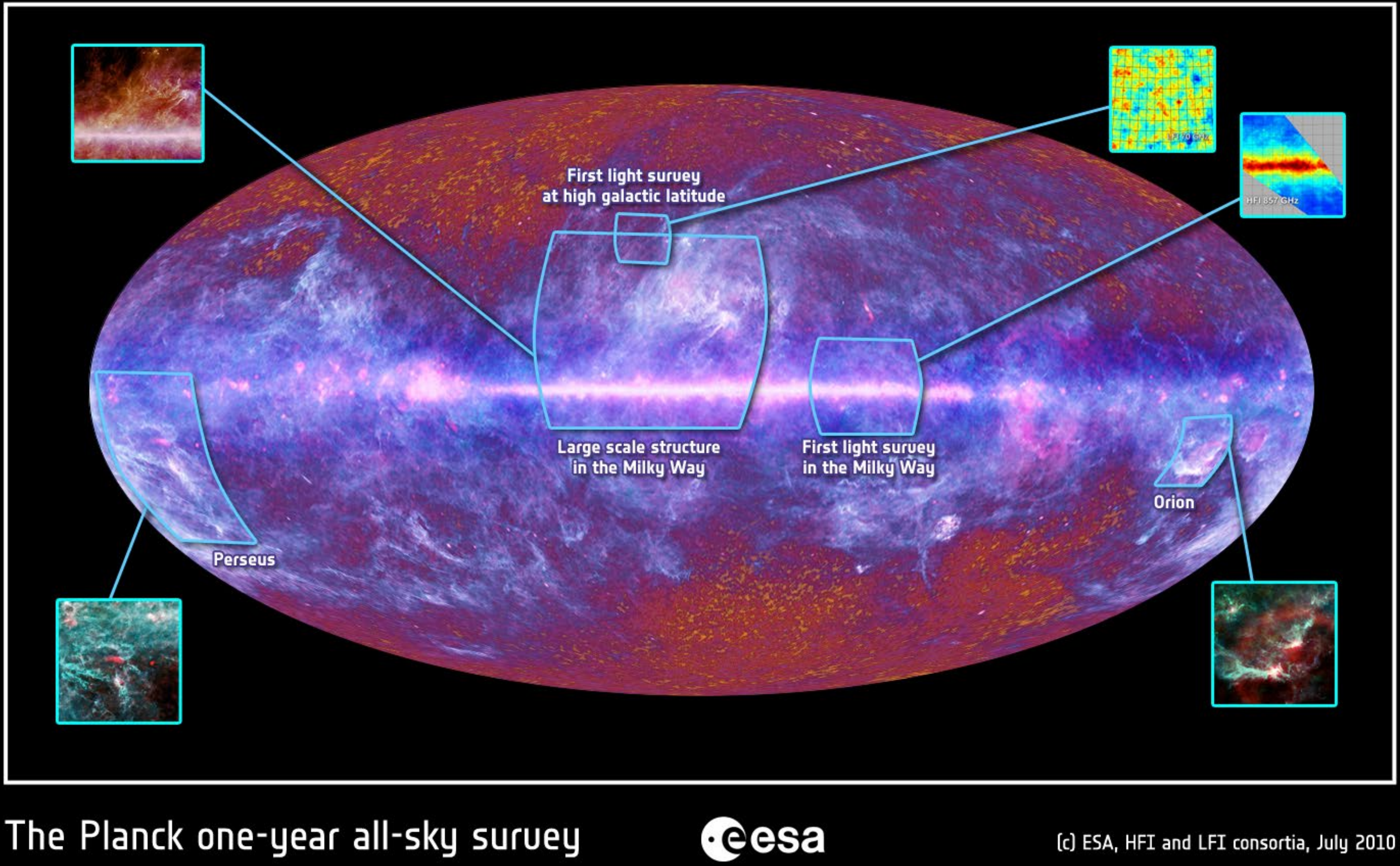
IC 1795: The Fish head Nebula: A star forming region in Cassiopeia

Hubble Space Telescope false color image of a star-forming region in Cassiopeia.
Blue = emission lines from oxygen,
green = emission lines from hydrogen,
red = emission lines from sulfur

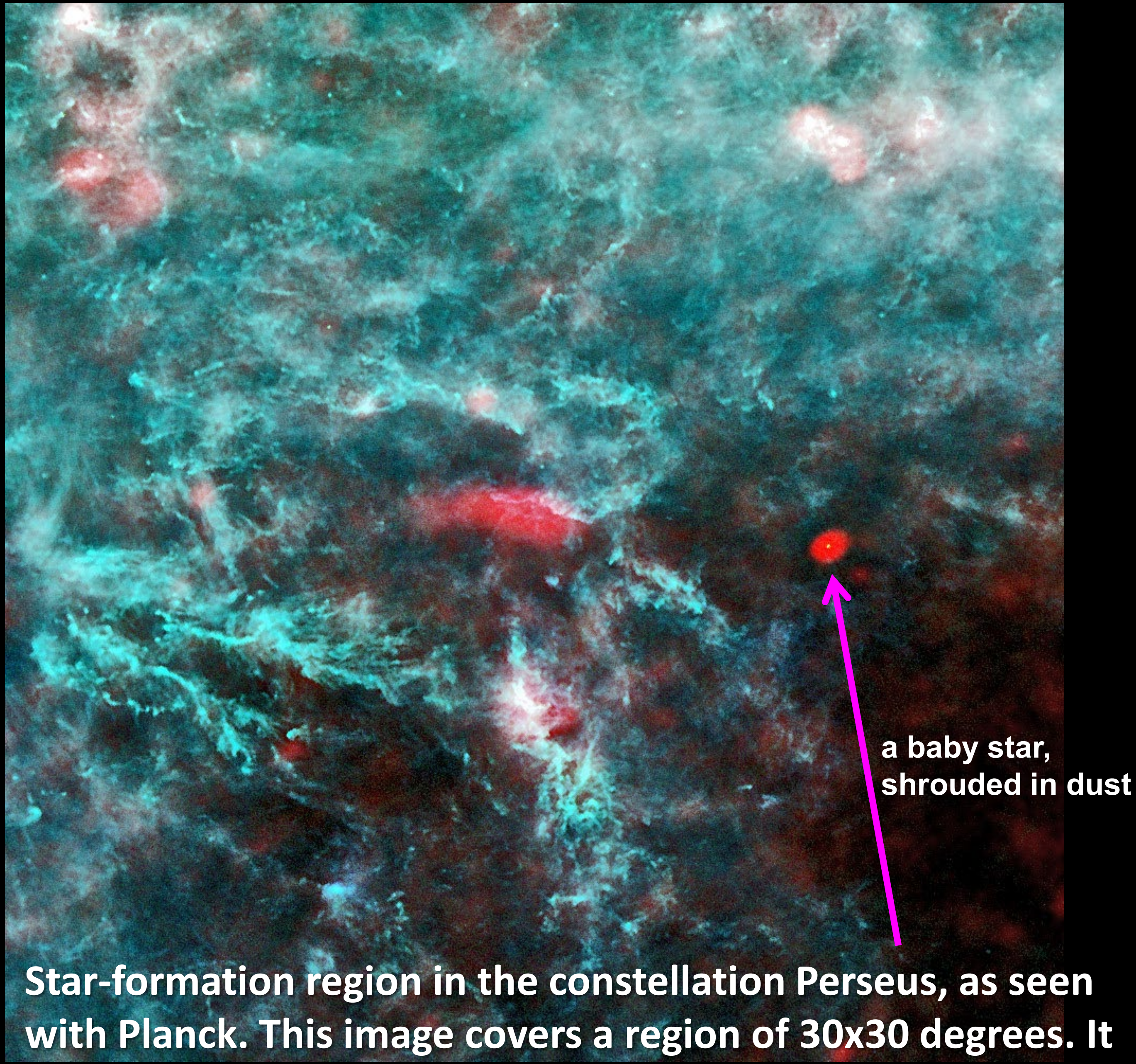
Part of a large molecular cloud and star forming complex, 6,000 ly away and 70 ly across.

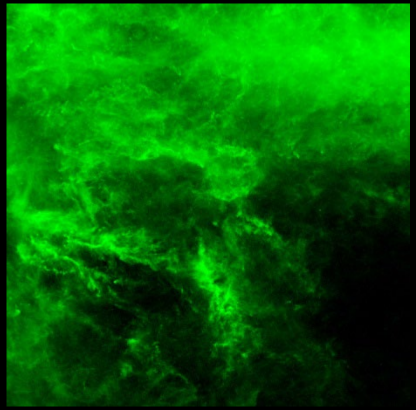


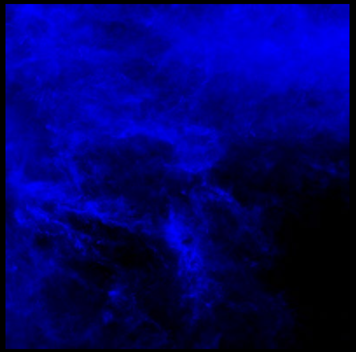
Planck Mission: 2009 - 2016

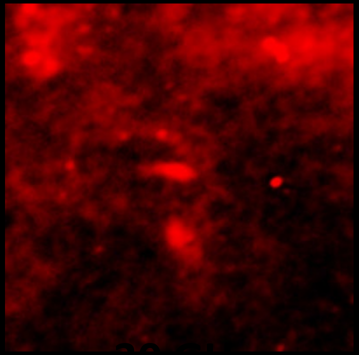


Composite map of the sky as seen through our galaxy in 9 frequency channels, from microwave to infrared, 30 GHz to 857 GHz by the Planck Space Telescope

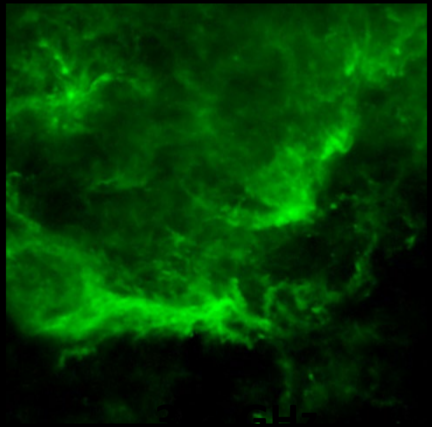


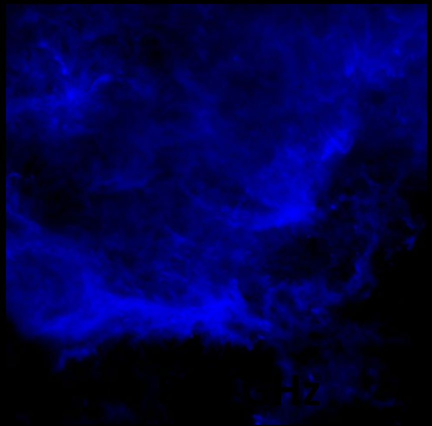


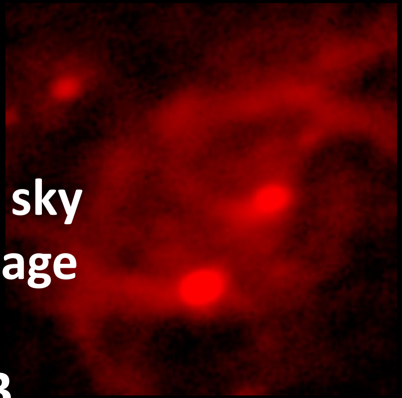




Star-formation region in the constellation Perseus, as seen with Planck. This image covers a region of 30x30 degrees. It is a three-color combination constructed from three of Planck's nine frequency channels: 30, 353 and 857 GHz.







An active star-formation region in the Orion Nebula (location in the sky noted by pink arrow in the insert above), as seen By Planck. This image covers a region of 13x13 degrees. It is a three-color combination constructed from three of Planck's nine frequency channels: 30, 353 and 857 GHz.

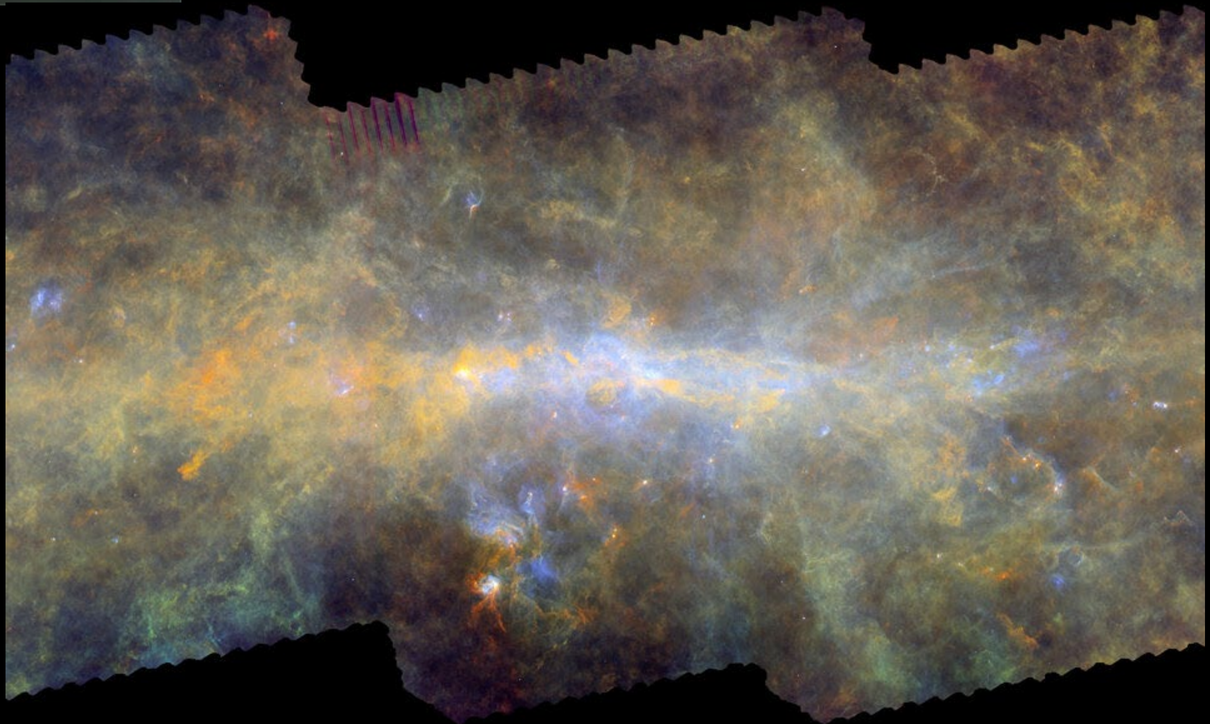
Herschel Infrared Space Telescope

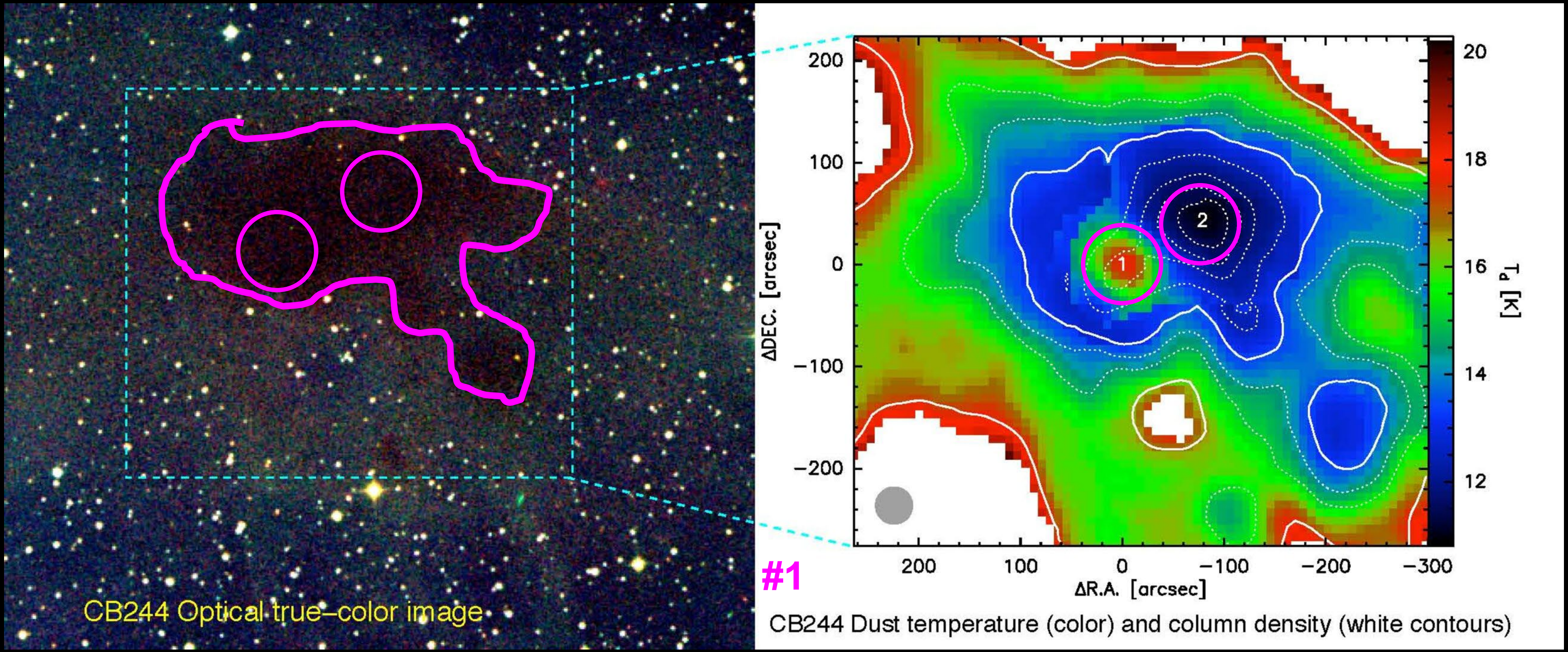
Launched with Planck in 2009

Objective:
To study cool objects across the Universe and in our Solar System, in particular the formation and evolution of stars and galaxies and their interaction with the interstellar medium.

Herschel's view of the galactic center in IR wavelengths →

At the galactic center, cold clouds of gas and dust appear distributed along a giant, twisted ring, over 600 light-years wide, encompassing the supermassive black hole sitting at the Galaxy's core.
European Space Agency





With the Herschel Space Telescope, the European Space Agency mapped the temperatures of dark star-forming clouds, identifying two regions of future stars. Here's one example. See another example on p. 323 in your textbook.

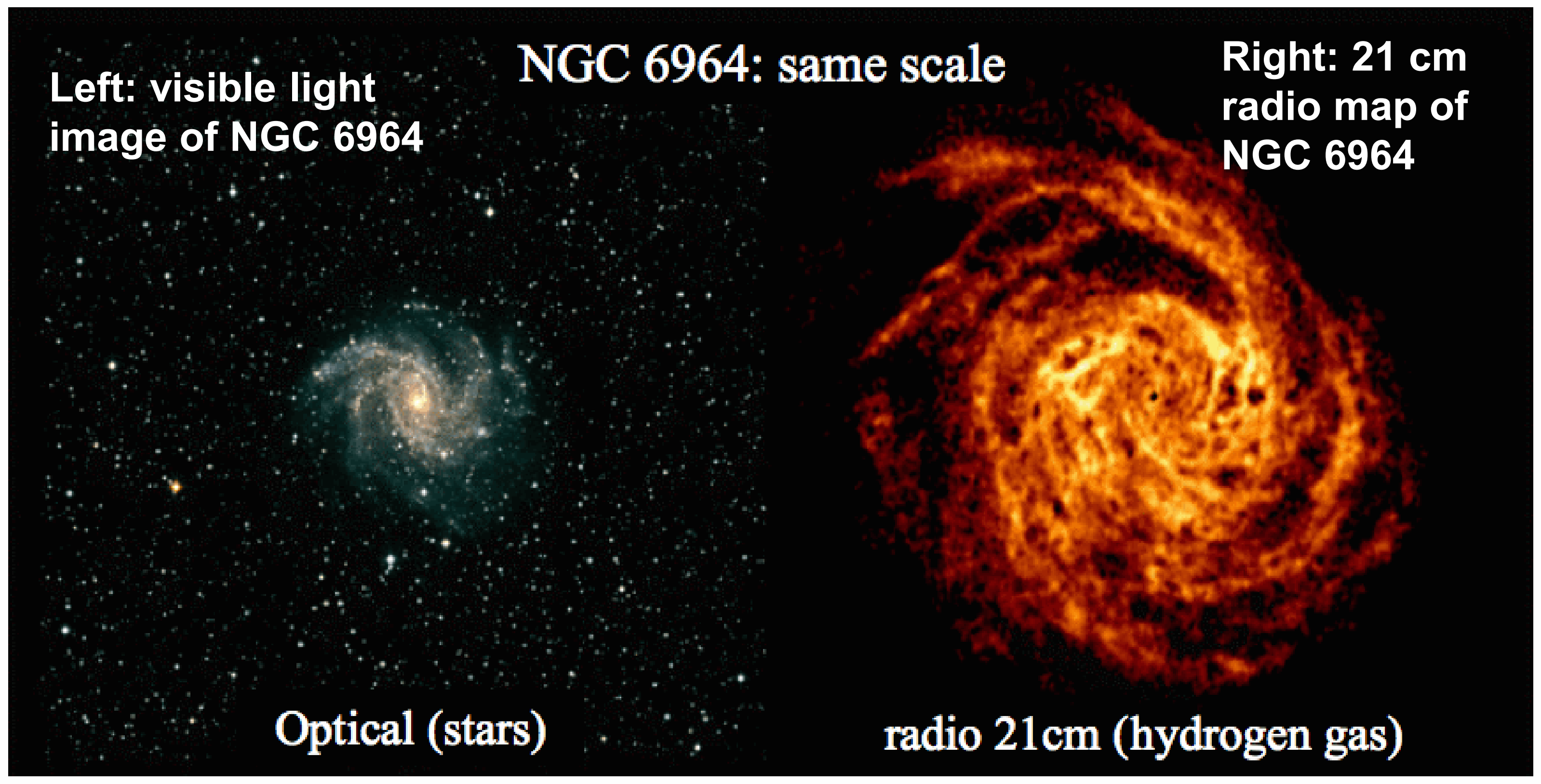
#1: 1.6 times the Sun's mass. At a temperature of 18K, a young star is already beginning to form.
#2: 3 – 7 times the Sun's mass. At a temperature of 10-12K, it is still a cold cloud of dust,

A three-color composite of a region of star formation in the constellation of Aquila. Credit: ESA

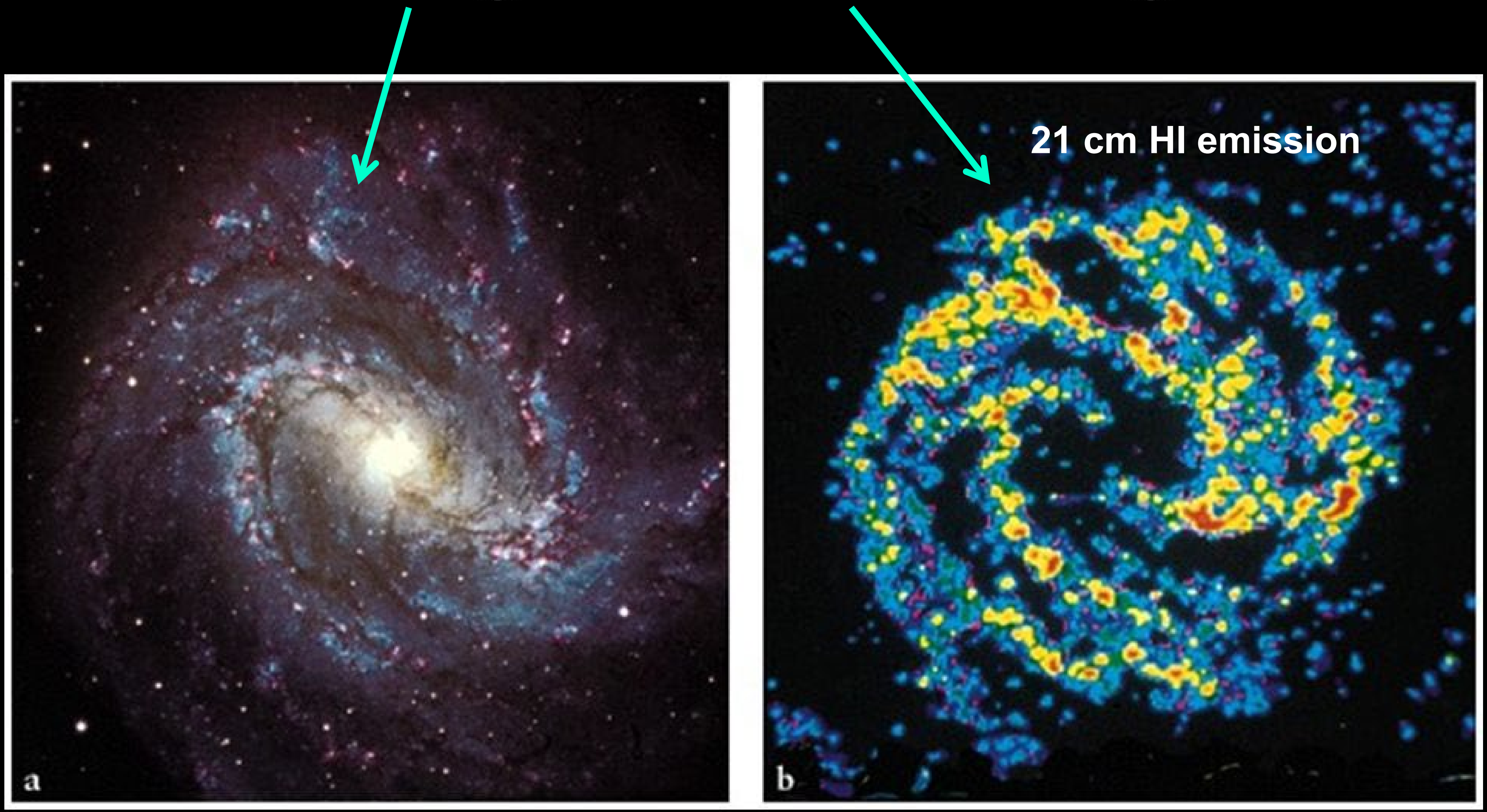
HI, HII, AND H_2 REGIONS

HI Clouds

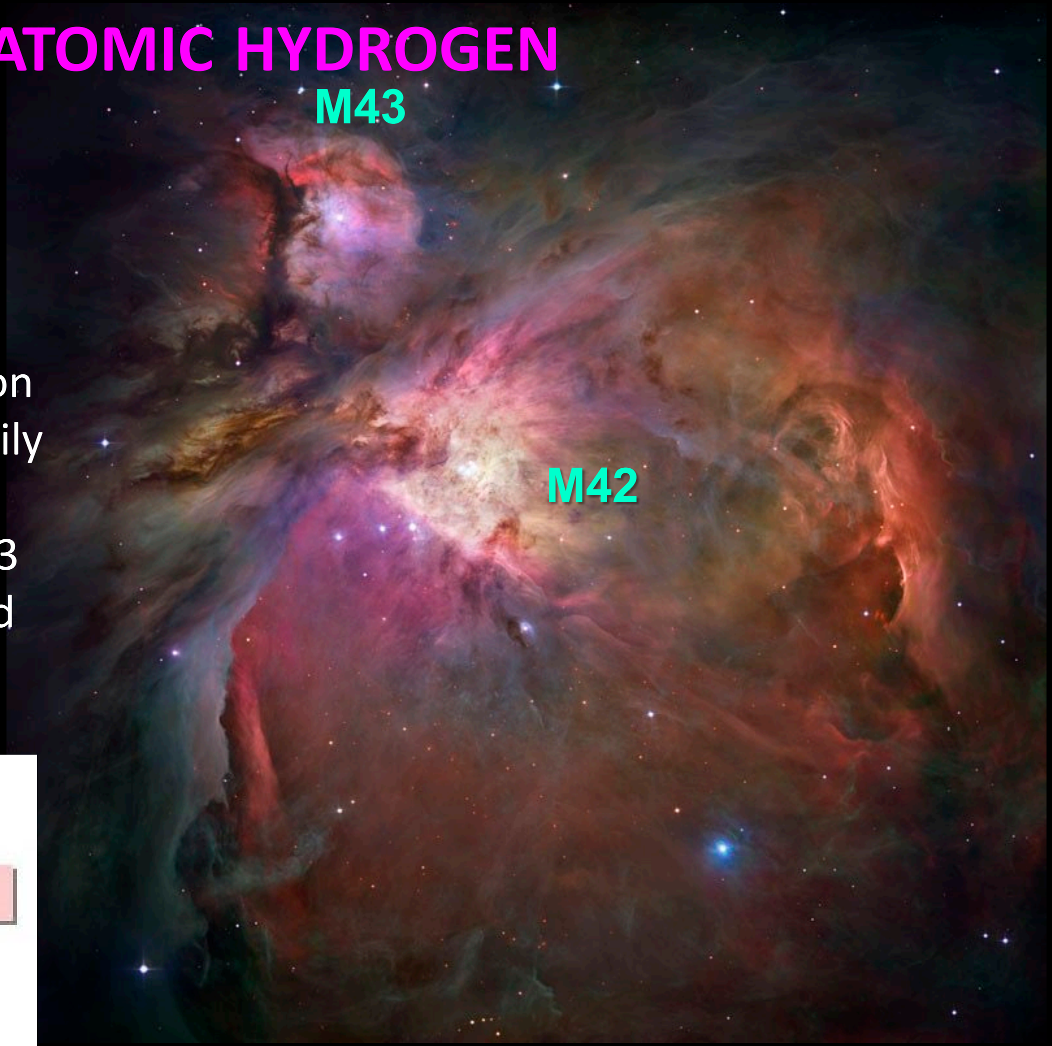
Interstellar gas clouds consisting mostly of **neutral hydrogen atoms** are usually referred to as **HI ("H-one") clouds**. They are very abundant, but mainly confined to the **spiral arms** in the disks of **galaxies** in a layer less than 300 **light years** thick. They have an **average temperature of about 100 Kelvin** .
Because they are cold, they do not emit radiation in the visible part of the spectrum. Rather, **they are detected using the spin-flip transition at 21cm in the radio region of the EM spectrum, and have been particularly important in mapping out the structure of our own Galaxy. See p. 316 in your text for an explanation of this.**



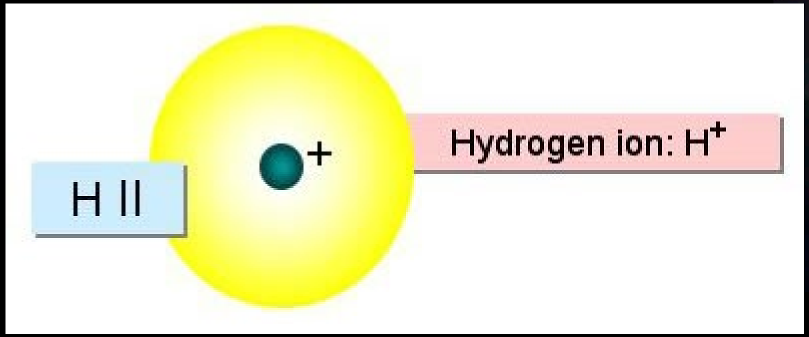
Spiral Galaxy M83 observed in both visible light and radio wavelengths.



HII Clouds – ionized atomic hydrogen



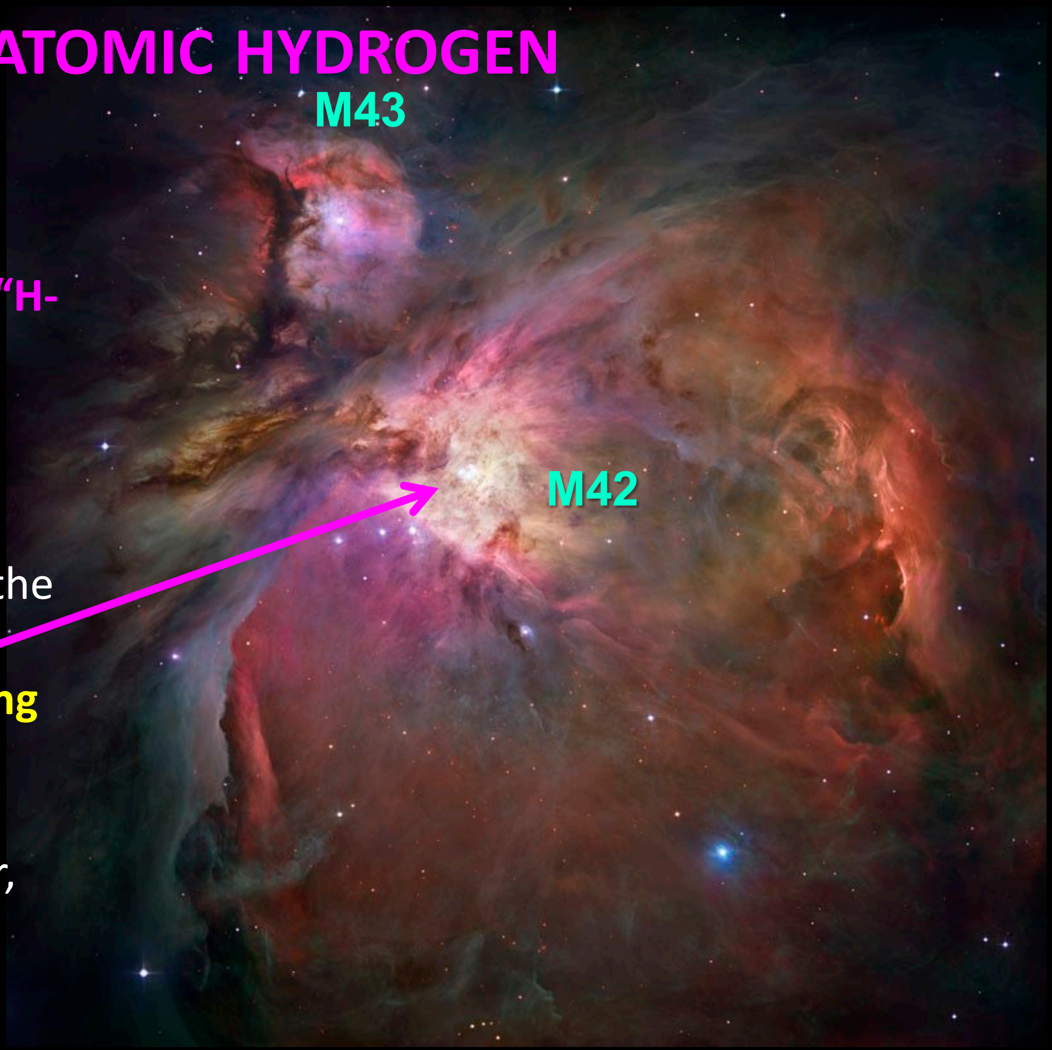
Ionized hydrogen, commonly called HII (pronounced H-two), is a hydrogen atom that has lost its electron and is now positively charged. It is easily detected at optical **wavelengths** as it releases a **photon** of **wavelength** 656.3 nm when it recaptures an electron and returns to its **neutral** state.



Ionized hydrogen is positively charged, and results when a hydrogen **atom** loses its **electron**.

Credits: Swinburne University
https://astronomy.swin.edu.au/cosmos/i/ionised+hydrogen

HII Clouds – ionized atomic hydrogen



This Hubble image shows the Orion A complex, which harbors two large **HII ("H-2") regions, M43** to the Northeast (top left) the brighter **Orion Nebula (M42, center**). (Refer to p. 317 in your text.)

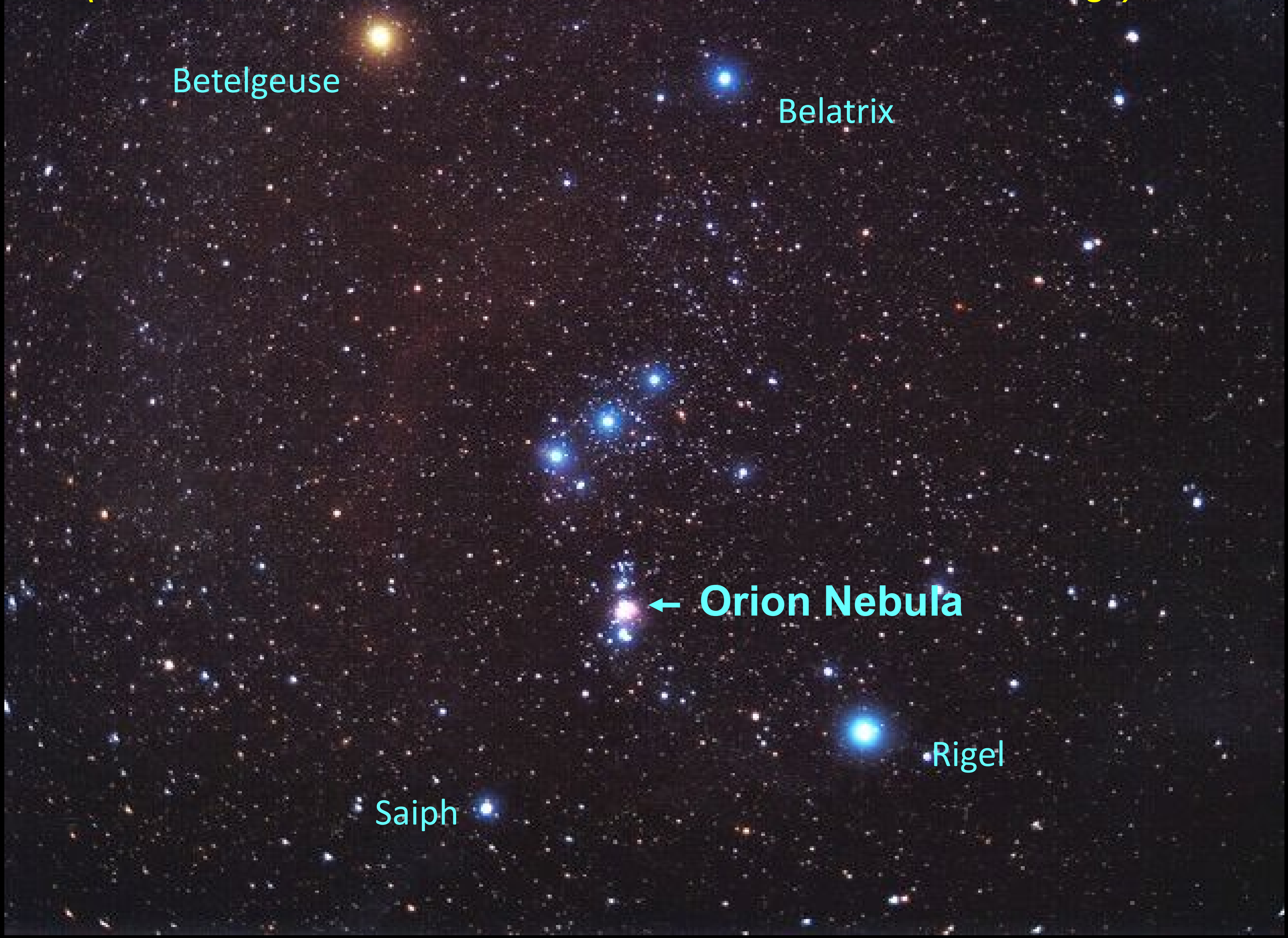
The **HII photoionization region** within the center of M42 is carved out by the **Trapezium cluster of four hot, young stars,** which is located at its center.

M43 is ionized primarily by a single star, NU Ori (spectral type B0.5).

Located in Orion, 1500 ly away, this nebula (about 300 solar masses of material) contains numerous protostars.
HST image, NASA/ESA

On the next 4 slides: A closer look at the Orion Nebula, H II clouds and region of star formation in Orion

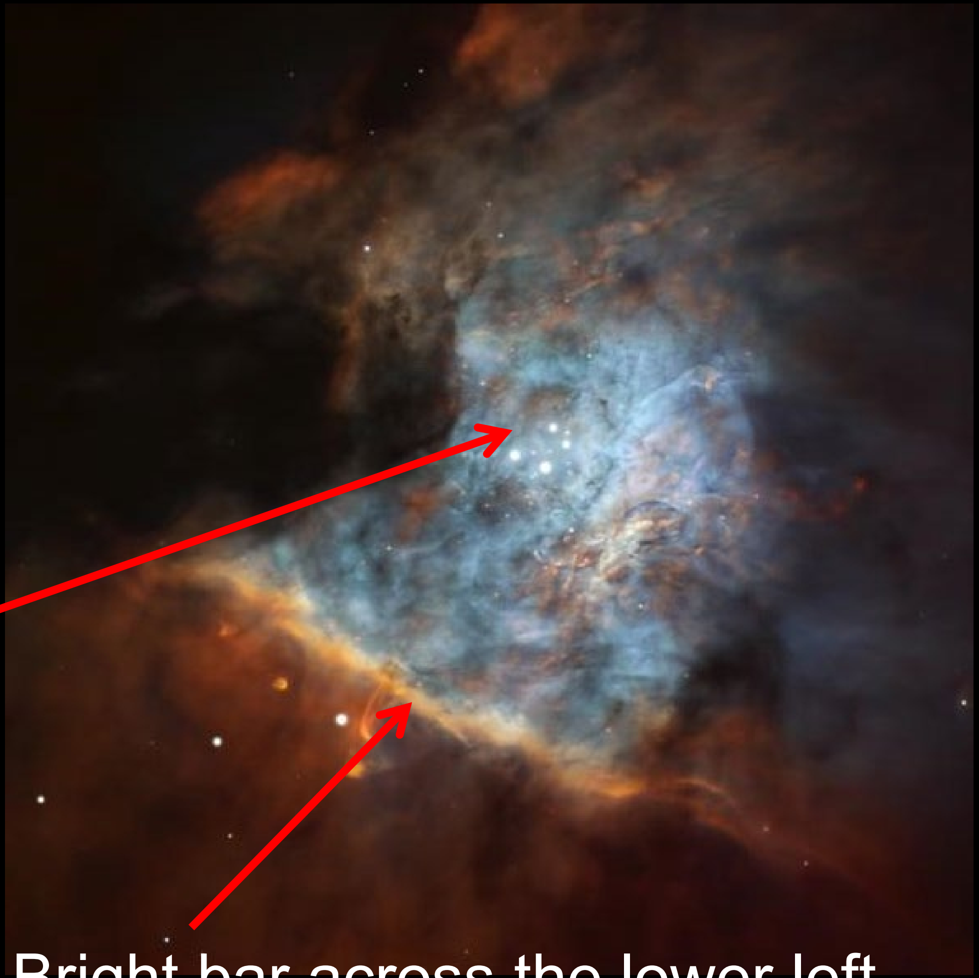
(which we looked at on slide 22 in a false-color microwave image)



Photoionization: One or more electrons are stripped off their atoms due to being hit by UV or higher energy photons. See definition and diagram on p. 317 of your text.

Photodissociation: Molecules are separated when they are hit by UV or higher energy photons.

M42 (Orion Nebula)

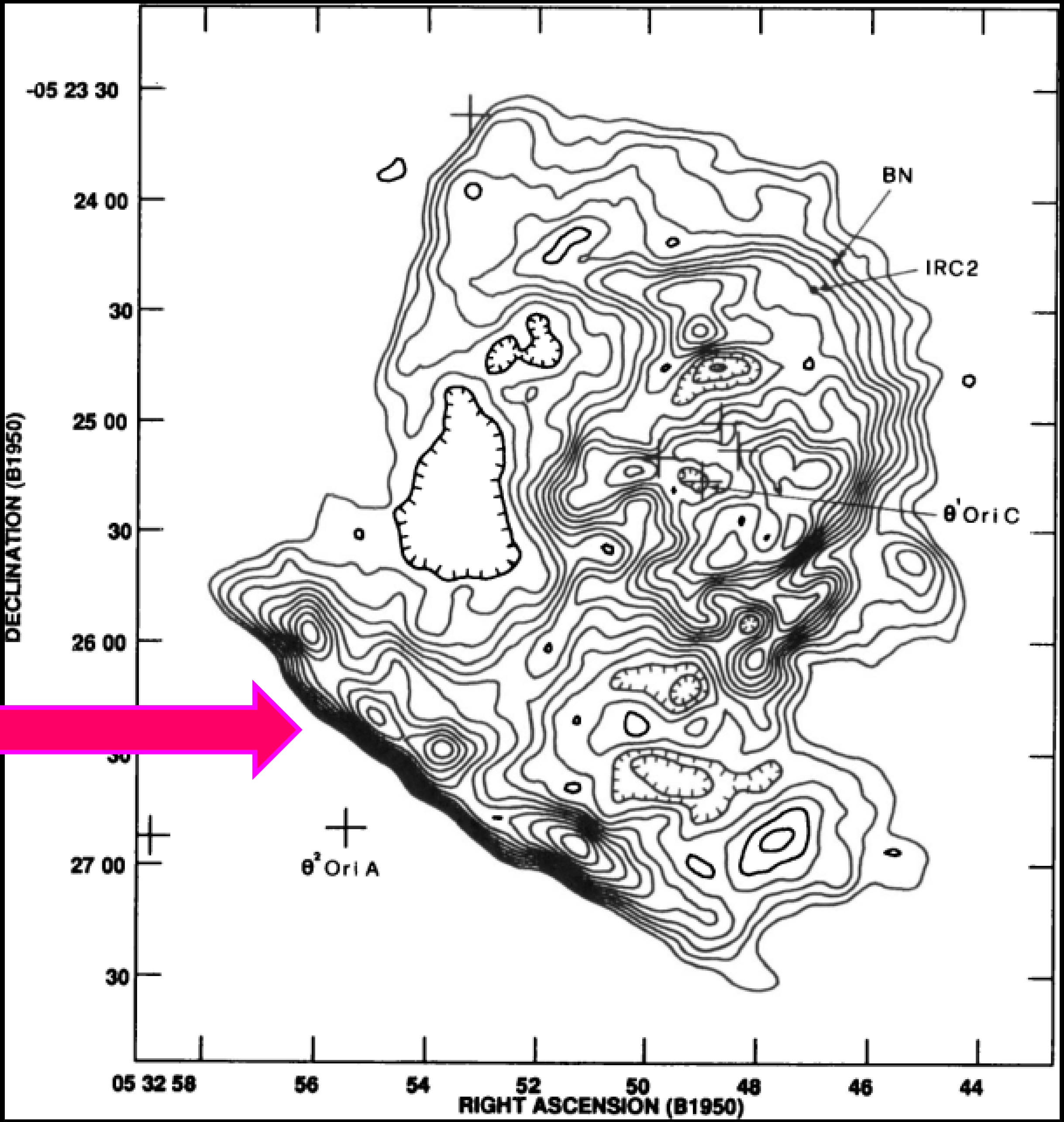


Note the four bright stars – these are called the Trapezium, hot O stars emitting a lot of UV. Photoionization of atomic hydrogen in the center of M42 from the UV radiation of these stars.

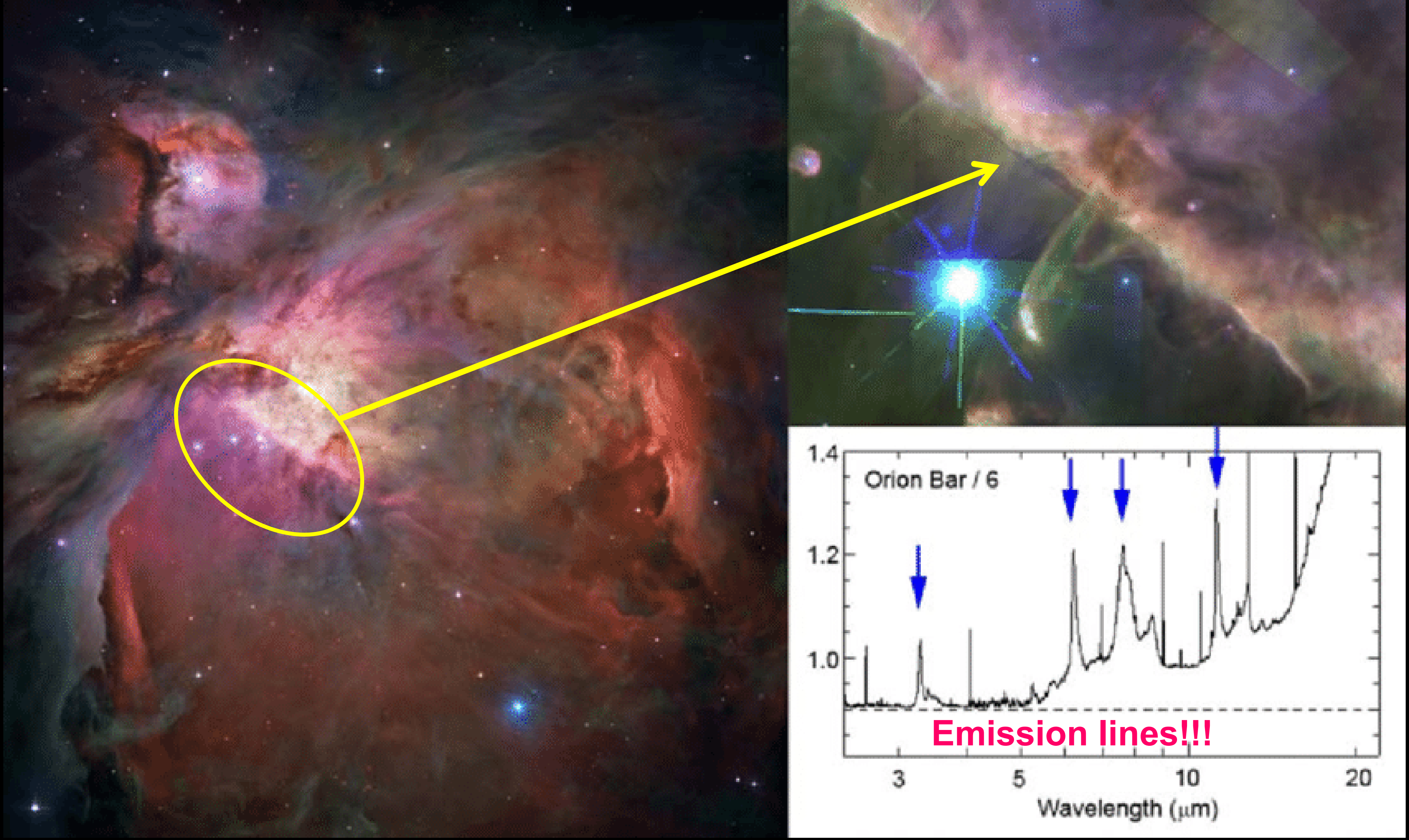
Bright bar across the lower left is region of photodissociation of the molecular cloud due to UV emission from the Trapezium.

Image from https://www.cloudynights.com/topic/521063-m42-center-oiiihasii-c11qhy5l-iiasi224mc/

Radio map at λ=20 cm of radio emissions from Orion Nebula. These radio emissions are from scattering of electrons off H+ ions. (Not the same as the 21-cm spin-flip emission of cold neutral hydrogen.)



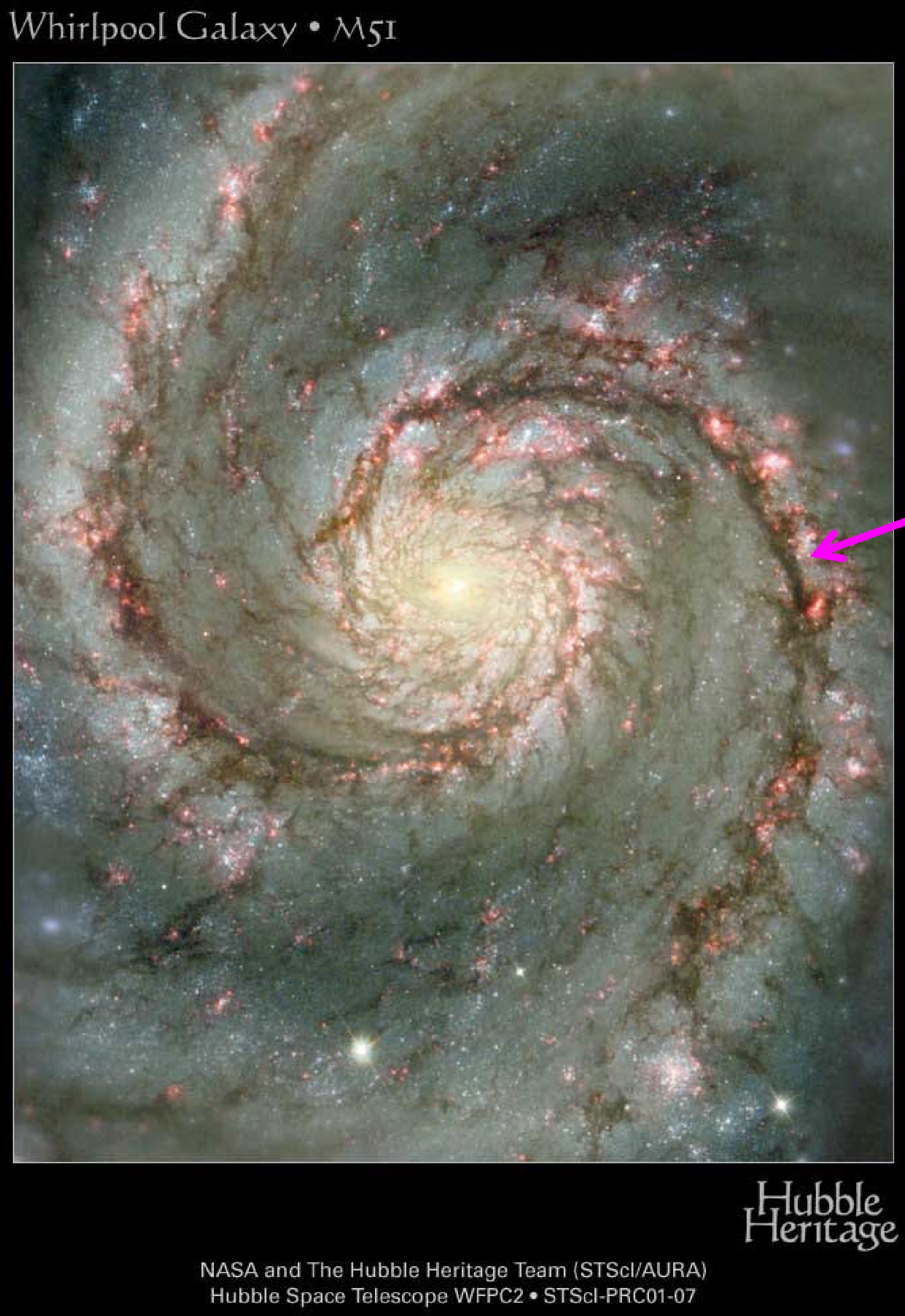
Seen clearly in this radio map of the Orion Nebula, the Orion Bar is the interface between the ionized region around the "Trapezium" – the four young hot stars at the center – and the Orion molecular cloud.



Polycyclic Aromatic Hydrocarbons found in the Orion **photodissociation region** (Orion Bar) (HST/ACS Mosaic from STScI).

UV light from the Trapezium chemically breaks down molecular compounds. Notice the EMISSION LINES in the inserted spectrum.

HII regions in M51, the Whirlpool Galaxy



View of M51 in optical wavelengths

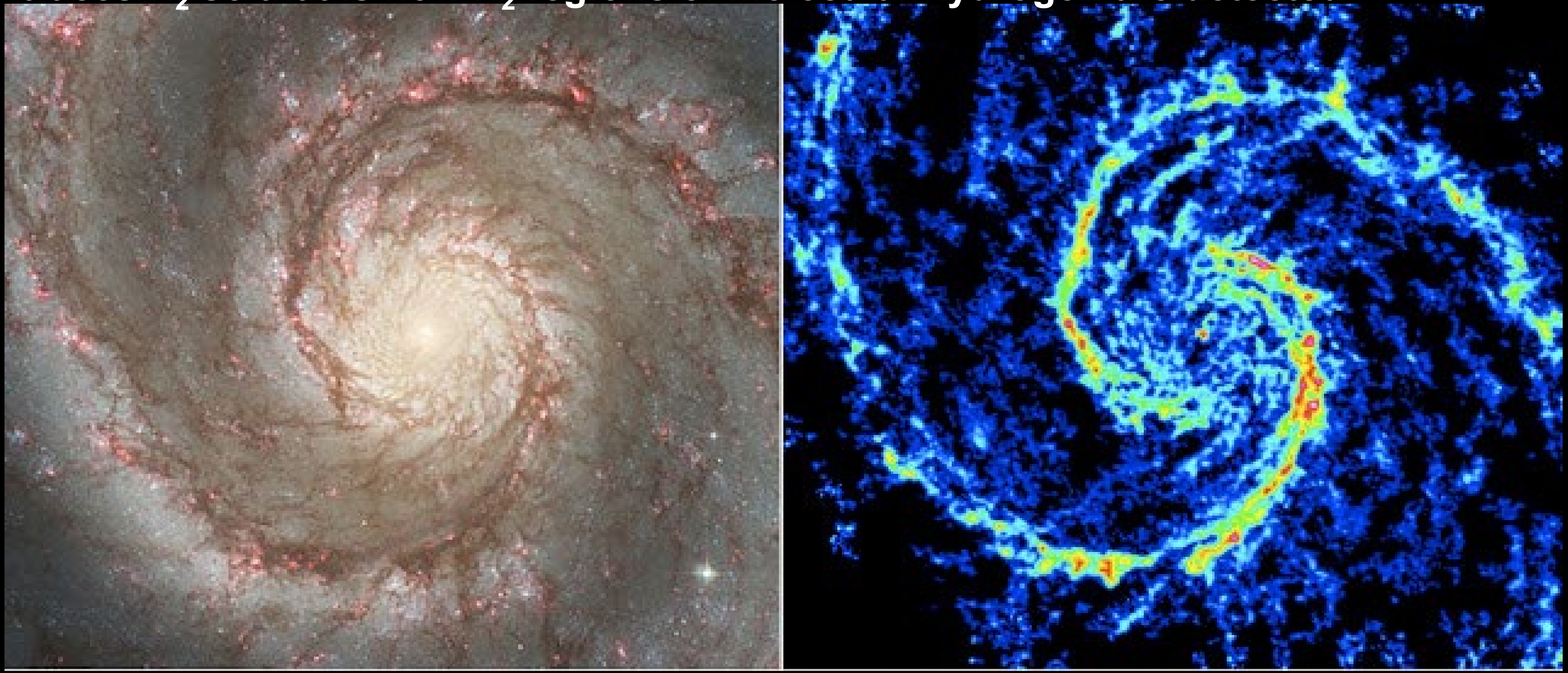
around 23 light years away

Notice the reddish H II regions in the spiral arms!

These are regions of active star formation.

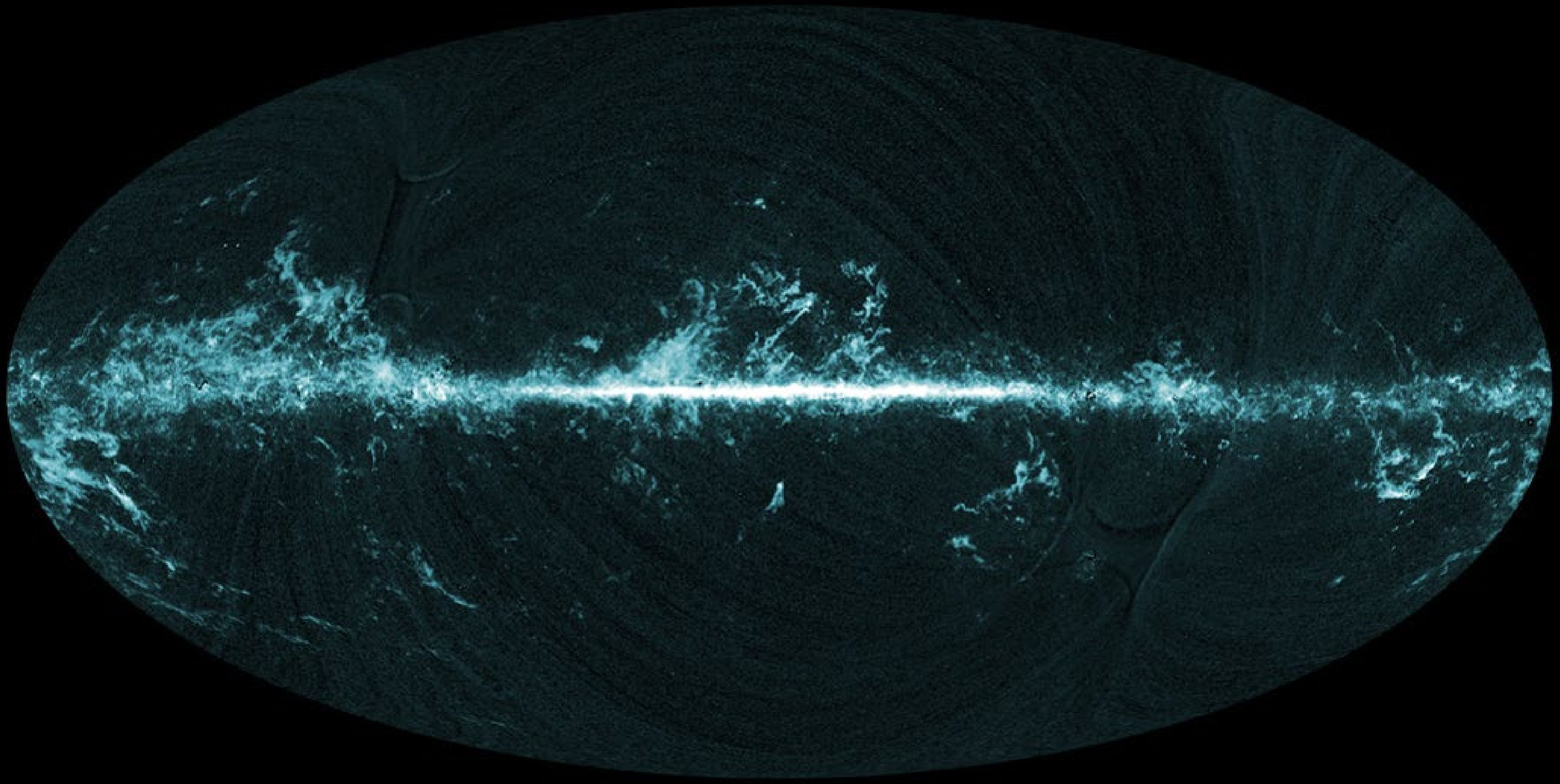
H_2 REGIONS – MOLECULAR HYDROGEN

M51 (the Whirlpool Galaxy) seen in visible light (left) and radio waves of .87 – 2.6 mm, mapping the distribution of CO (Carbon Monoxide) in the spiral arms. CO traces H_2 so that is how H_2 regions of molecular hydrogen are detected.

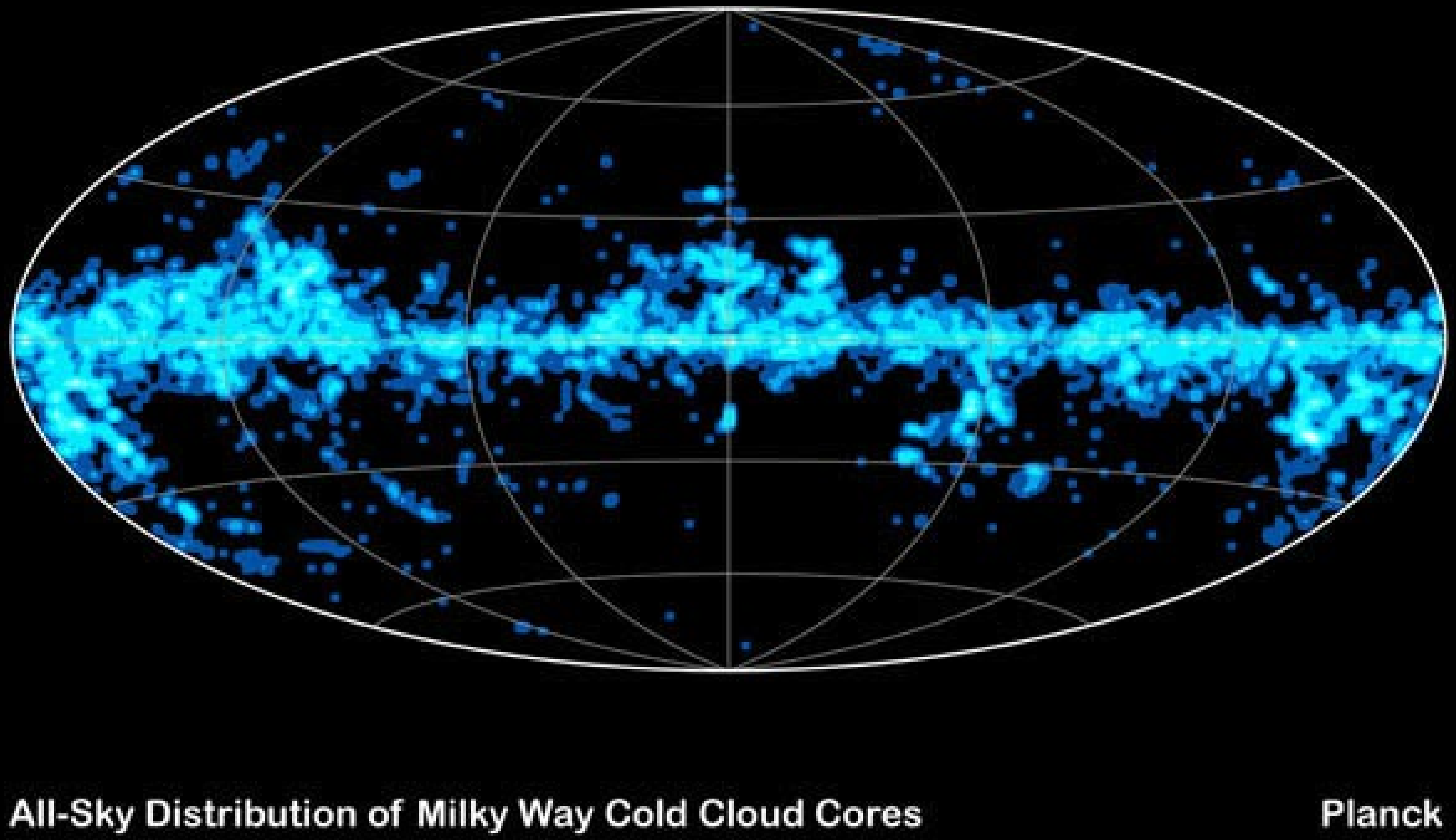


The Whirlpool galaxy imaged in visible light (left) showing young stars and star-forming regions delineating the spiral arms and a radio image (right) showing emission from the CO molecule tracing the molecular clouds in which stars form. **The CO molecules are used as tracers for molecular hydrogen. (Credit: NASA / PAWS)**

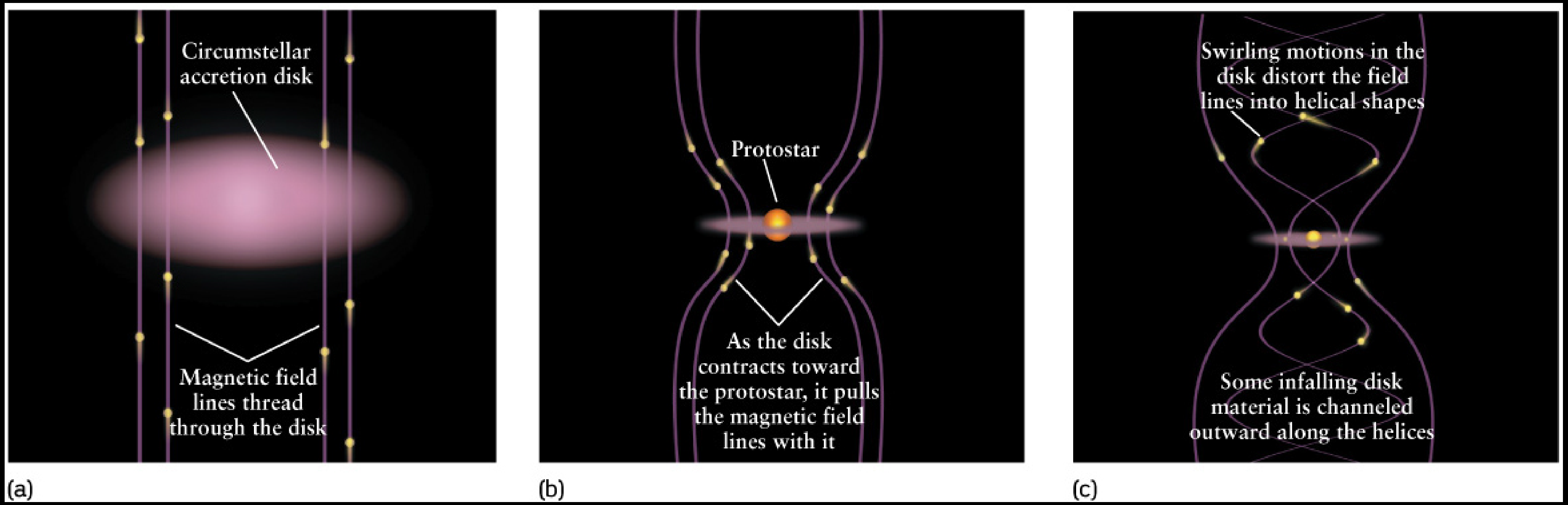
Map of CO in our galaxy – International Planck Mission



Carbon monoxide is indicative of molecular clouds, which are star forming regions. Here is a good discussion of this.
Also, see section 12.3 and Table 12.2 in your text book.

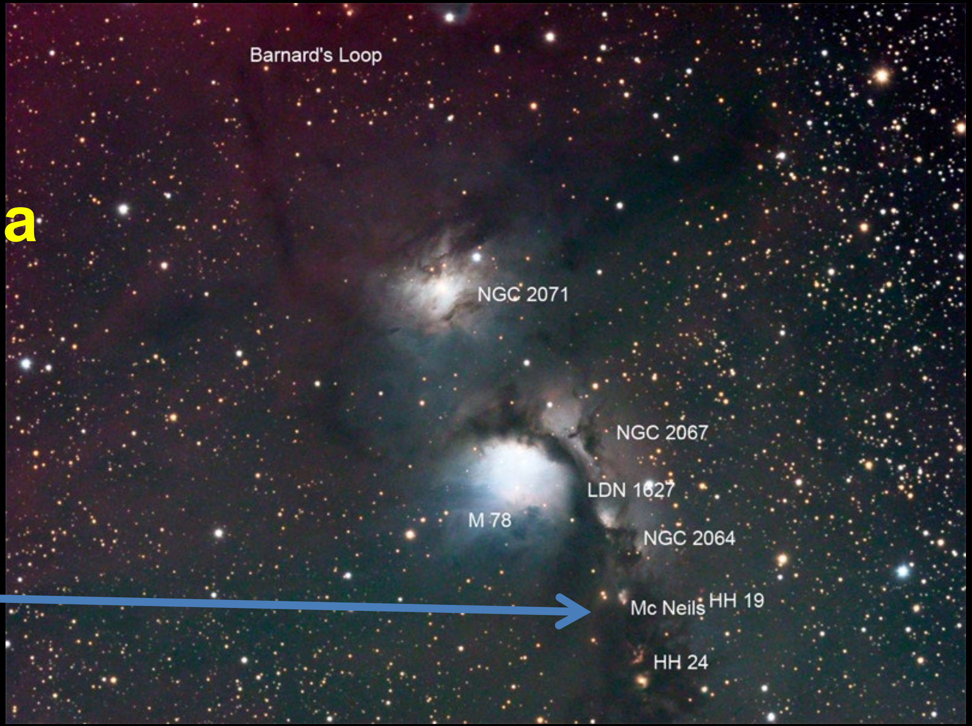


The coldest concentrations of molecular gas and dust in our galaxy lie mostly along the galactic plane. The Planck satellite measured their temperatures at less than 10K! Each ‘blob’ is a potential star forming region.

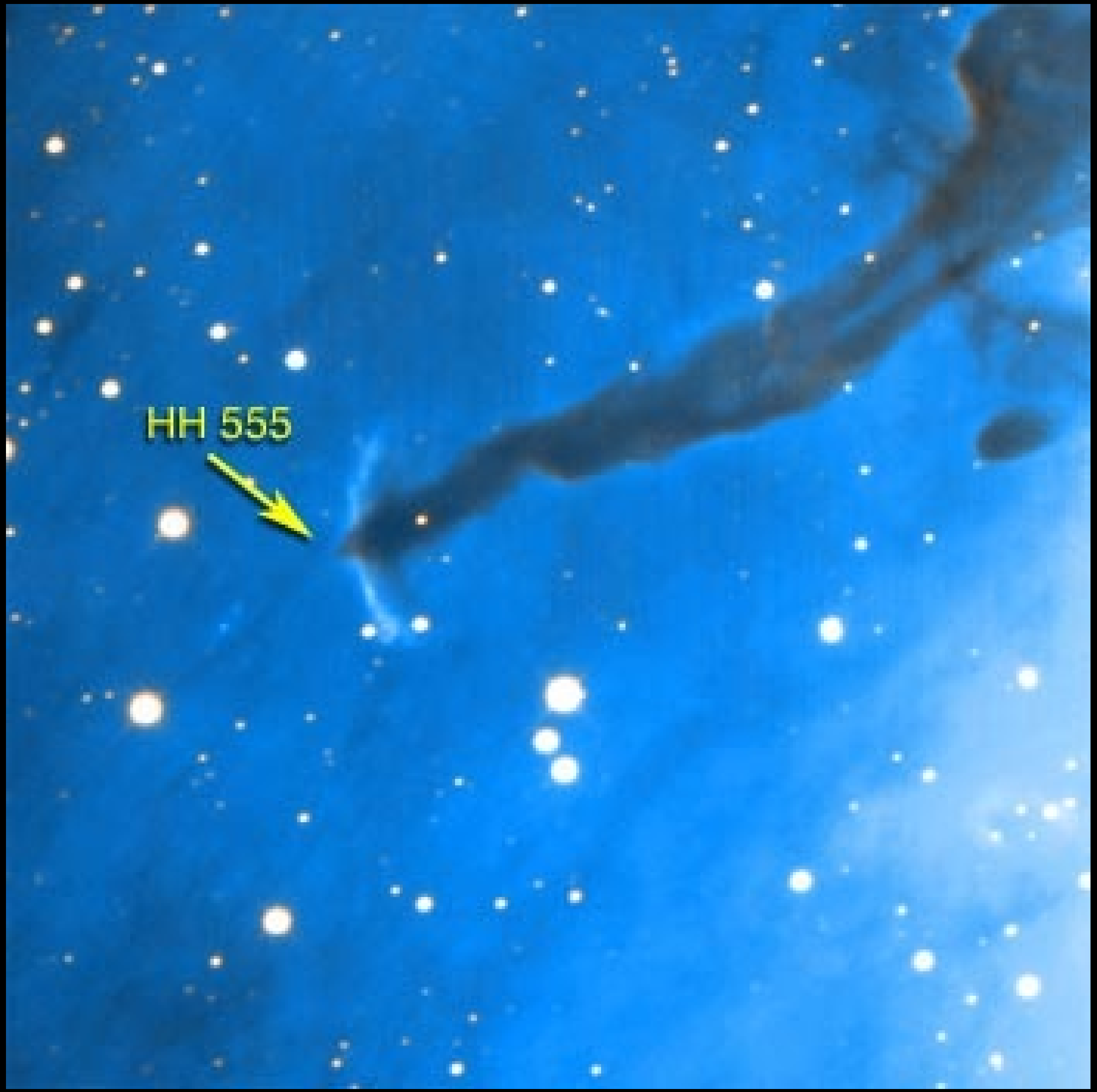


http://www.youtube.com/watch?v=ISRLLFBenWc&list=PL_bezXk0YQuNdRQj1XIXIA3HaPqQu0RIU

T Tauri star in McNeil's nebula near M78, reflection nebula in Orion



Pelican Nebula Herbig-Haro (HH) Object 555



knots of hot, ionized gas thrown out by twisted magnetic field lines in the bipolar jets from spinning protostars

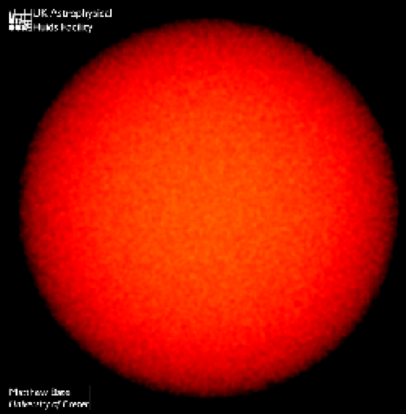
T Tauri star with protoplanetary disk and evidence of planets being formed

ALMA image of the young star HL Tau and its protoplanetary disk. This best image ever of planet formation reveals multiple rings and gaps that herald the presence of emerging planets as they sweep their orbits clear of dust and gas.

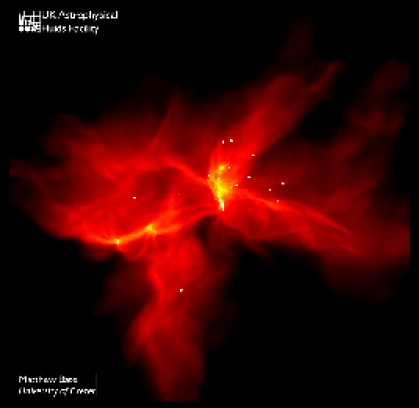
HL Tauri is a very young T Tauri star in the constellation Taurus, approximately 450 light-years from Earth in the Taurus Molecular Cloud.

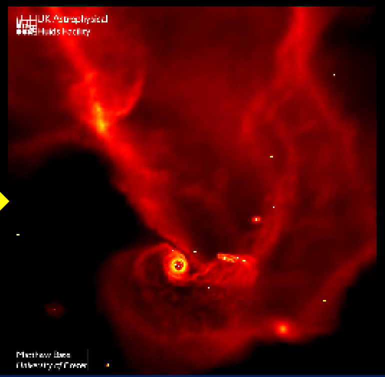
Atacama Large Millimeter Array (ALMA)

Computer models of star formation from large interstellar clouds show how solar systems form.



Start with a
large, cold molecular cloud...





Authors: Matthew R. Bate, Ian A. Bonnell, and Volker Bromm, UK Astrophysical Facility

The calculation models the collapse and fragmentation of a molecular cloud with a mass 50 times that of our Sun.

The cloud is initially 1.2 light-years (9.5 million million kilometres) in diameter, with a temperature of 10 Kelvin (-263 degrees Celsius).

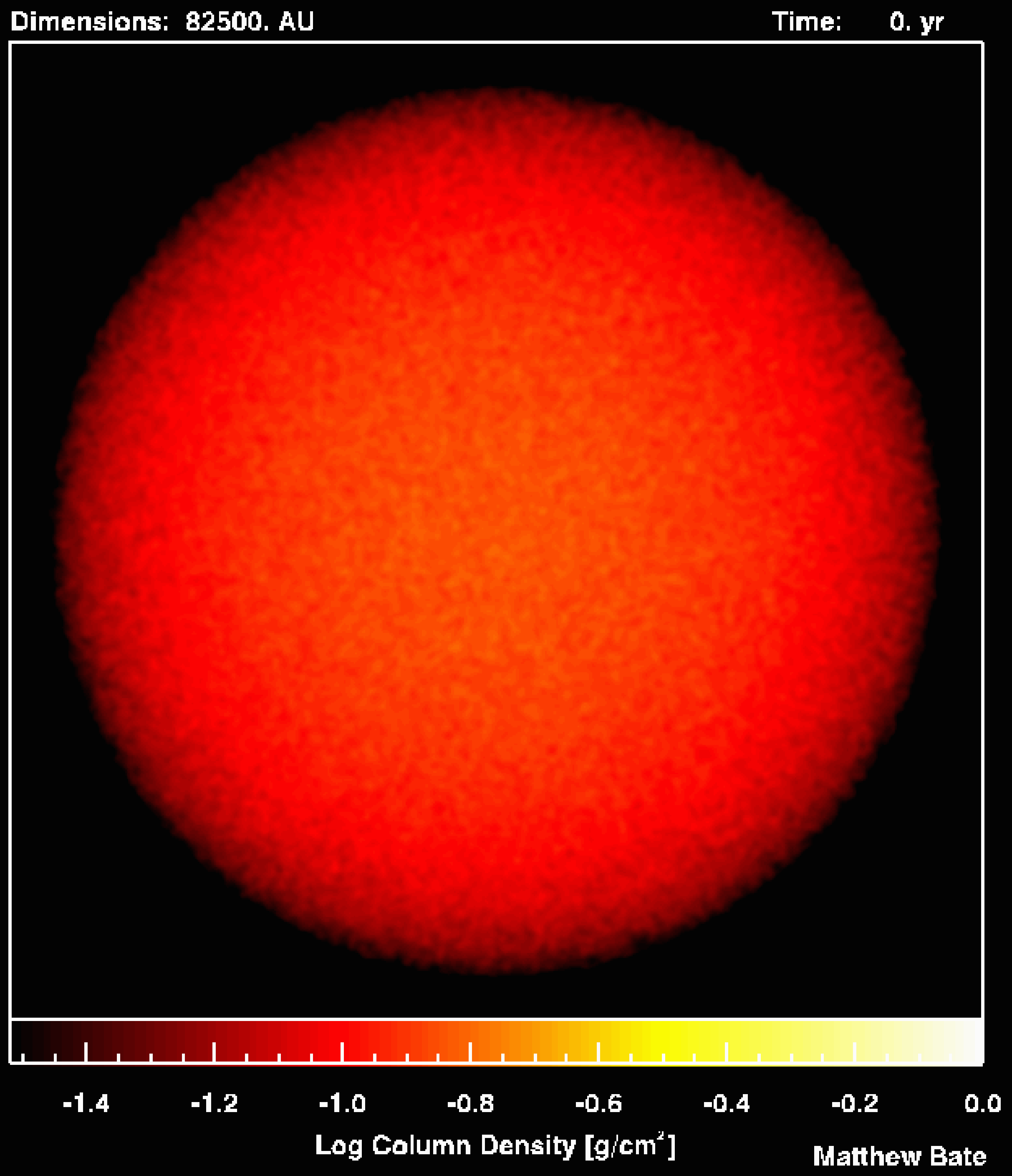
The cloud collapses under its own weight and very soon stars start to form.

Surrounding some of these stars are swirling discs of gas which may go on later to form planetary systems like our own Solar System.

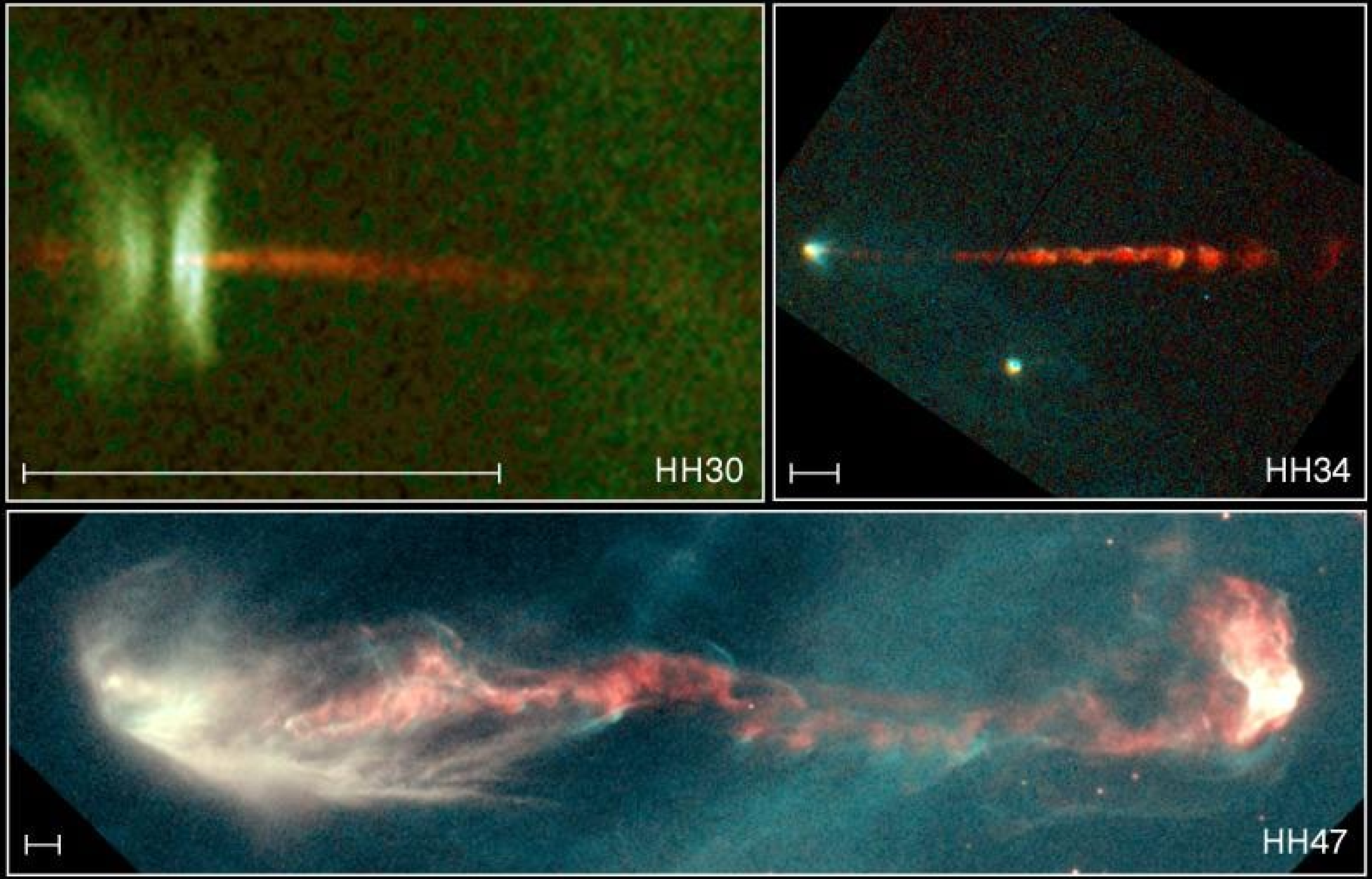
https://www.ukaff.ac.uk/starcluster/

The cloud is initially 1.2 light-years (9.5 million million kilometres) in diameter, with a temperature of 10 Kelvin (-263 degrees Celsius).

In the ppsx slide show, click on the arrow below the image to see the animation. If you are reading the pdf file, go to this website: https://www.ukaff.ac.uk/starcluster/ to download the animations or see the sequence of snap shots.



Hubble images of edge-on protostars (visible light)



Jets from Young Stars HST • WFPC2

PRC95-24a · ST ScI OPO · June 6, 1995

C. Burrows (ST ScI), J. Hester (AZ State U.), J. Morse (ST ScI), NASA

Stellar Evolution