HOW DID STARS FORM?

AND HOW DO STARS DIE?

Joseph Silk
Gresham Lecture
Sep 20, 2017
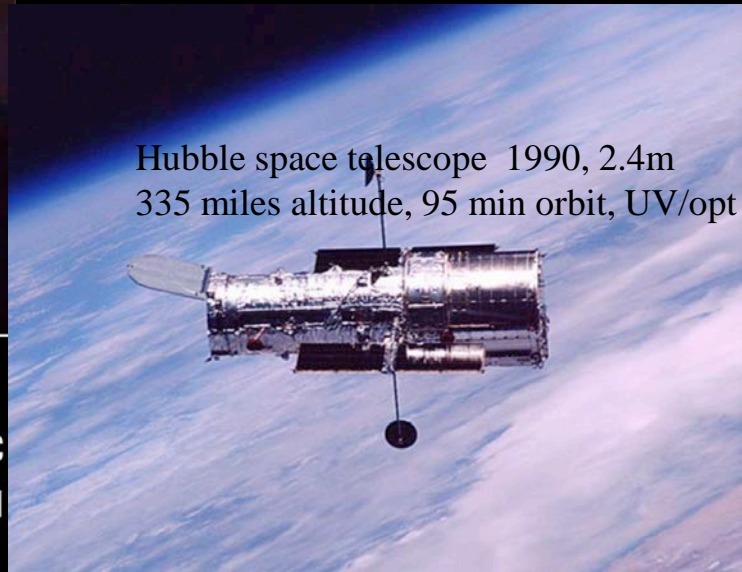
Taurus

Orion

M42 Orion Nebula
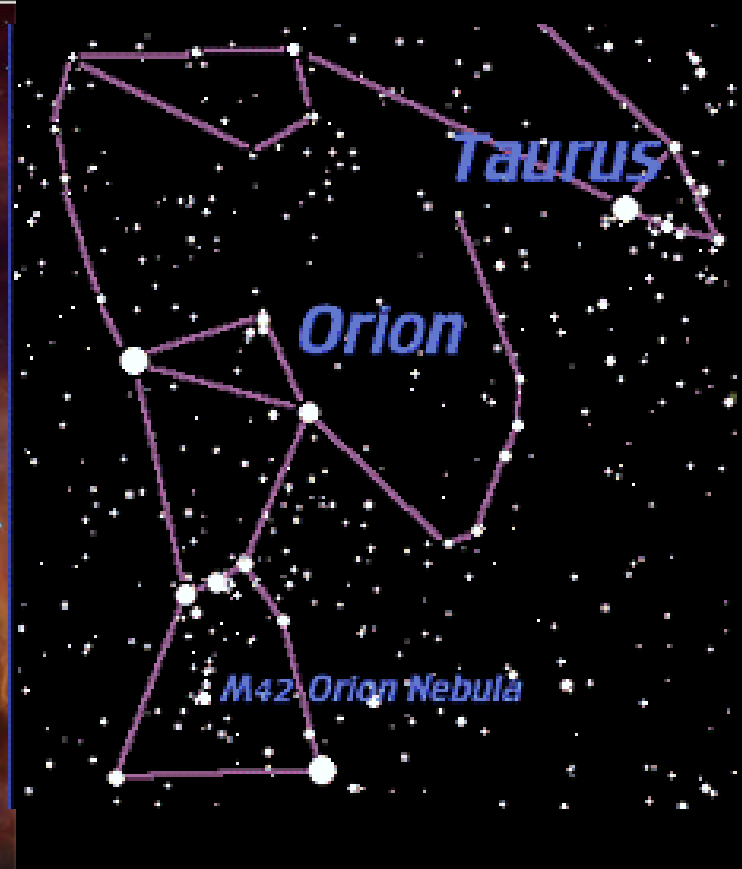
Spitzer Space Infrared Telescope
2003, 0.85m

Hubble space telescope 1990, 2.4m
335 miles altitude, 95 min orbit, UV/opt

Spitzer Space Telescope • IRAC
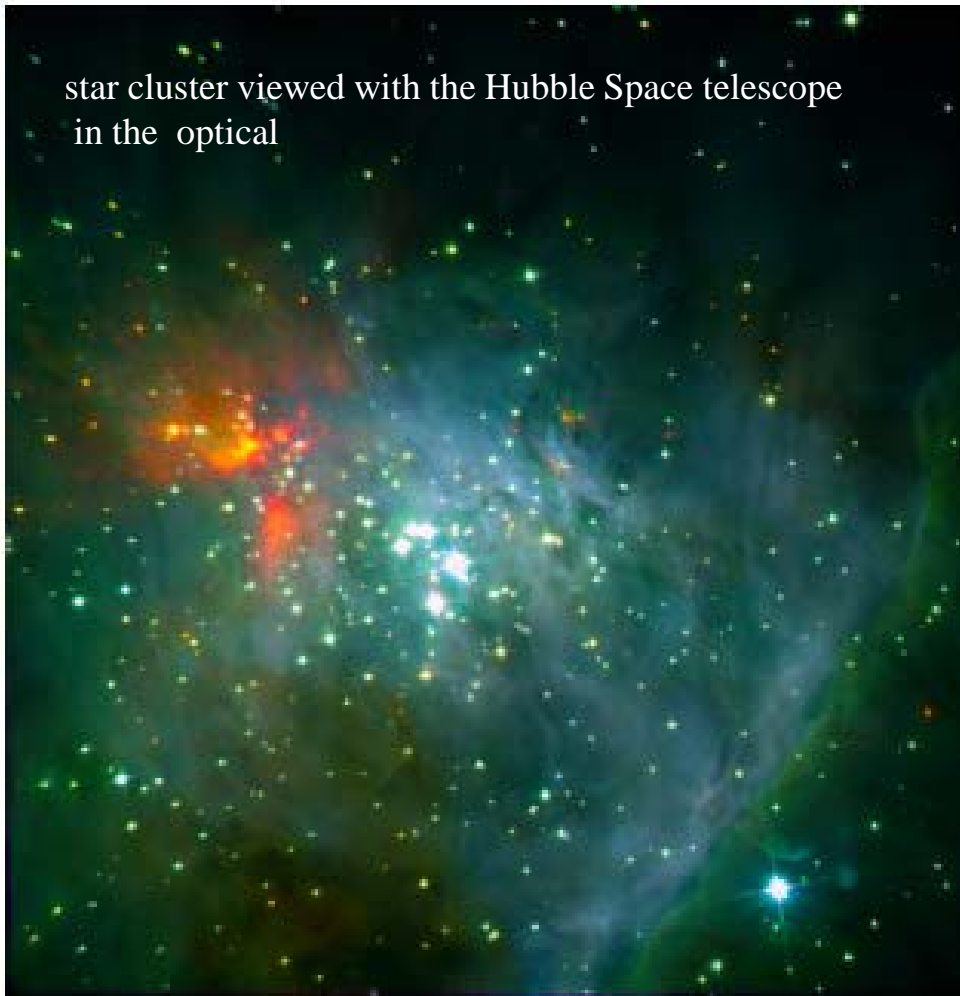Hubble Space Telescope • ACS • WFI

Dust is everywhere in the universe

star cluster viewed with the Spitzer Space telescope
in the infrared

star cluster viewed with the Hubble Space telescope
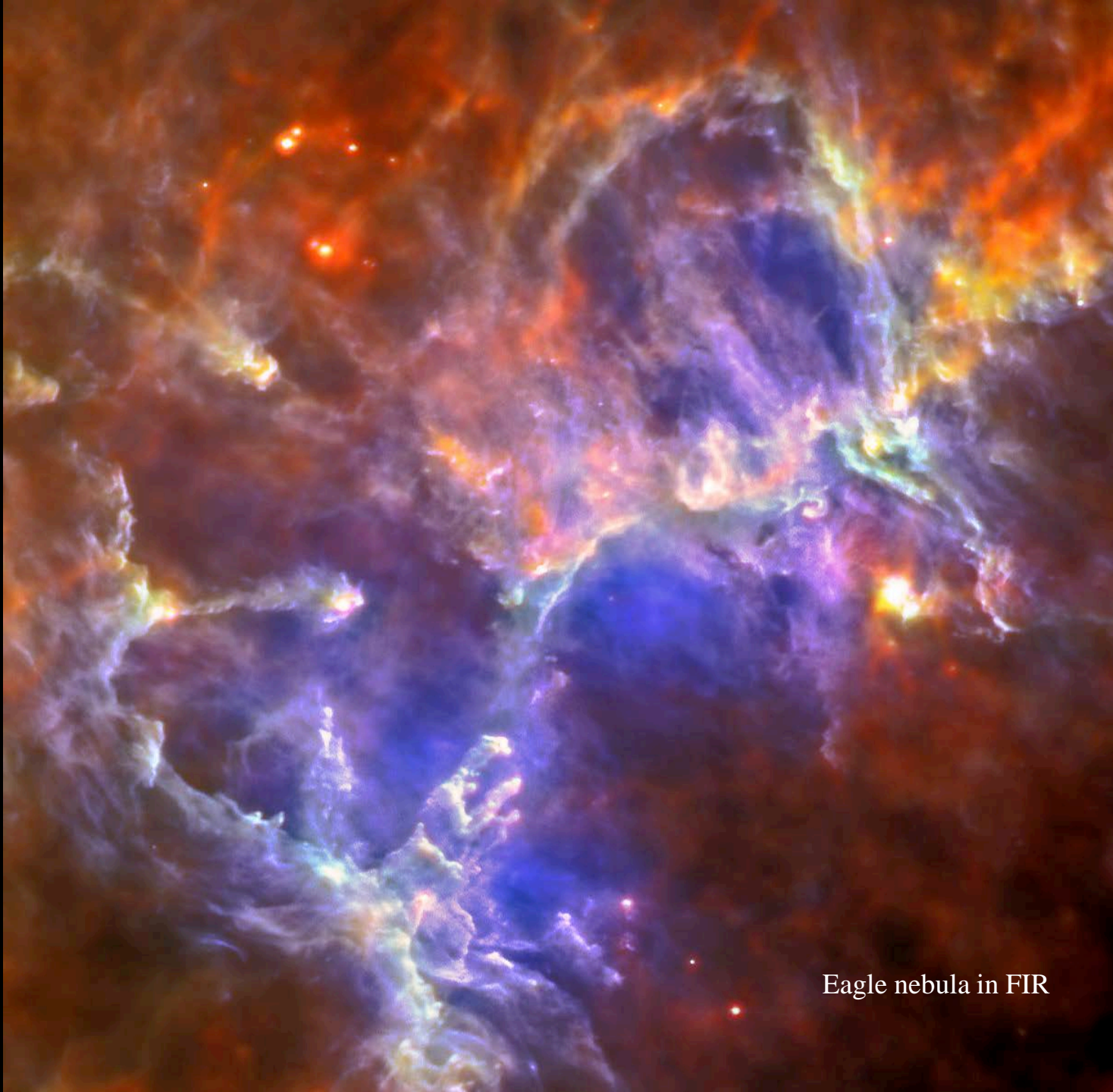in the optical

Stellar birth

Eagle nebula

Cone nebula

Eagle nebula in FIR

Herschel Space Telescope
2009-2013
3.5m,   55-672 μm (FIR)
3.4 tons
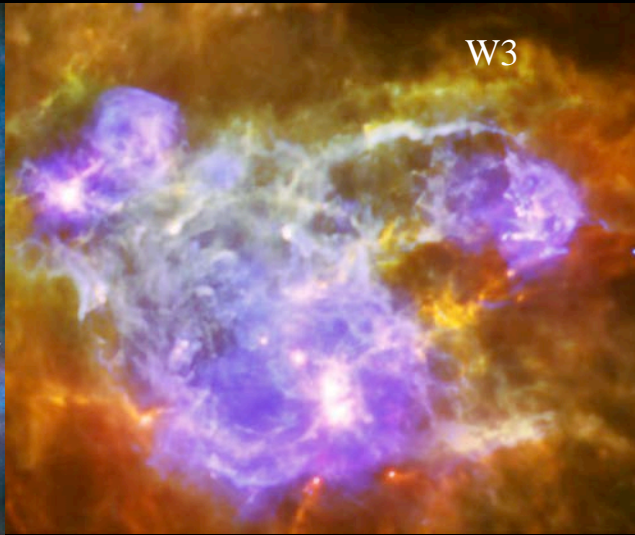1.5million km from earth,
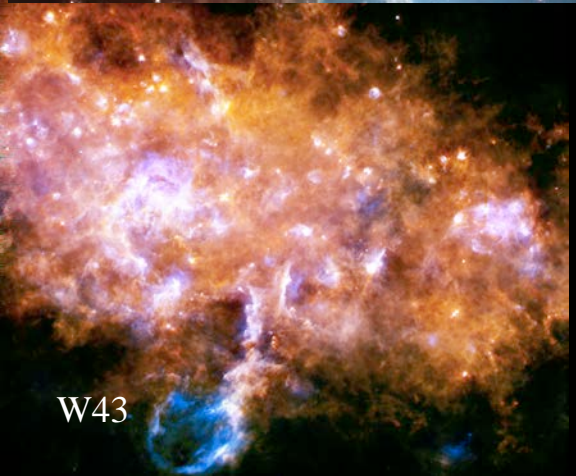opposite sun
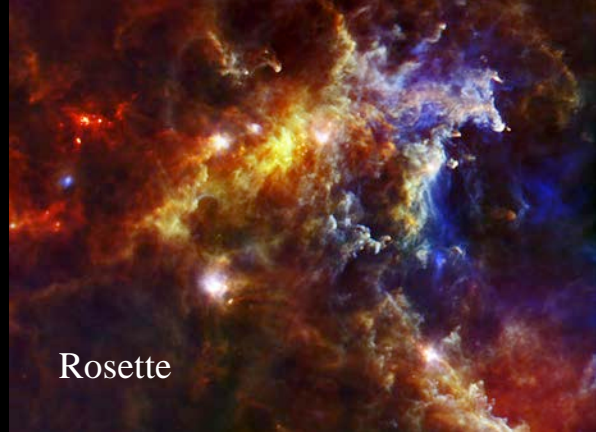
DFR21 in Cygnus

Horsehead nebula

Monkey nebula

Carina

W3

W43

Rosette

Omega nebula

30 Doradus in the Large Magellanic Cloud

Centre of our galaxy

STARS

- What is a star ?

- Our galaxy contains a hundred billion stars

- We are formed from the ashes of the stars
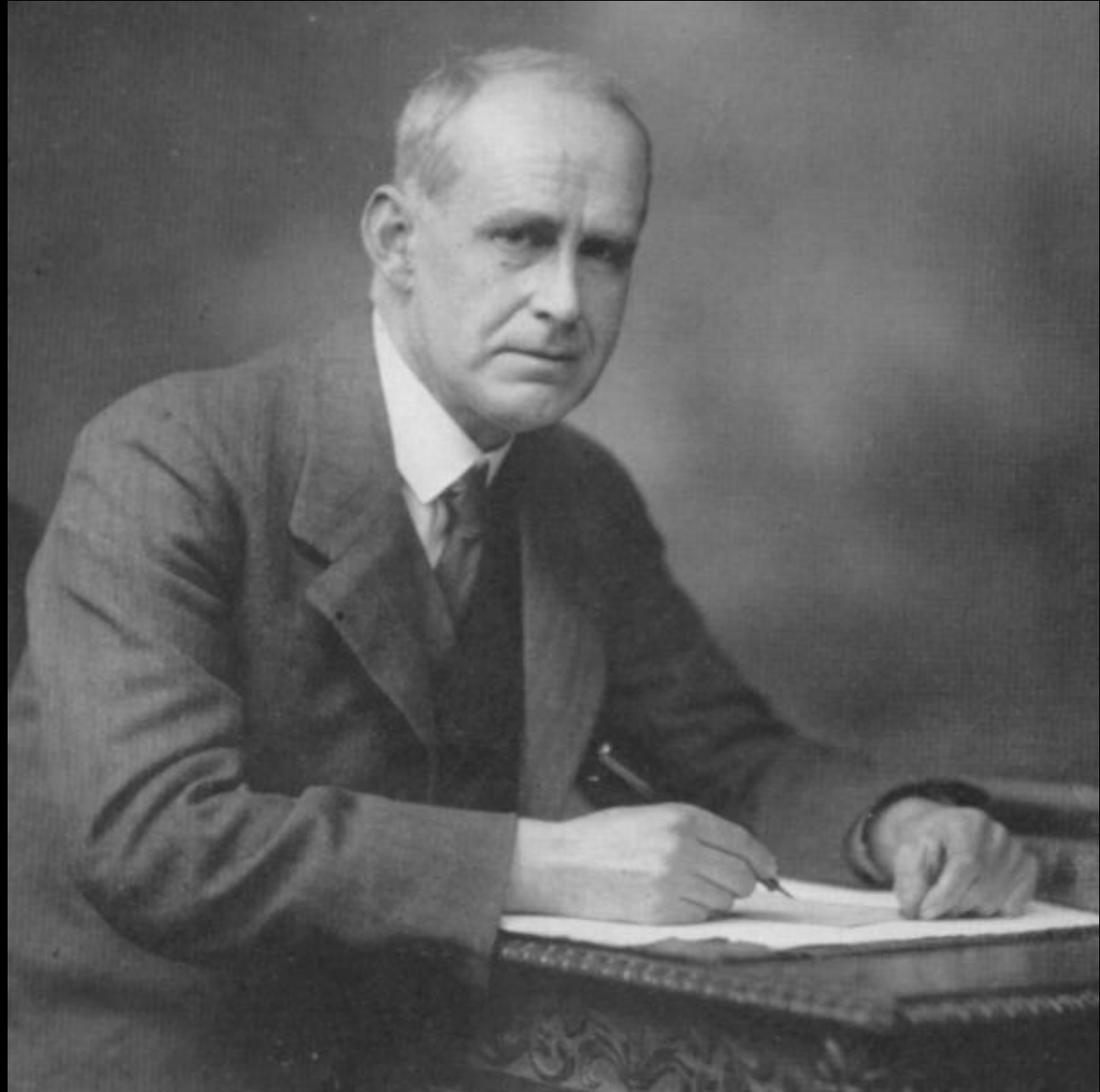
- How are stars formed?

All celestial bodies originate by a process of fragmentation of nebulae out of chaos, of stars out of nebulae, of planets out of stars and satellites out of planets.

James Jeans (1877-1946)

imagine a physicist calculating on a cloud-bound planet and ending with the dramatic conclusion, "What 'happens' is the stars."

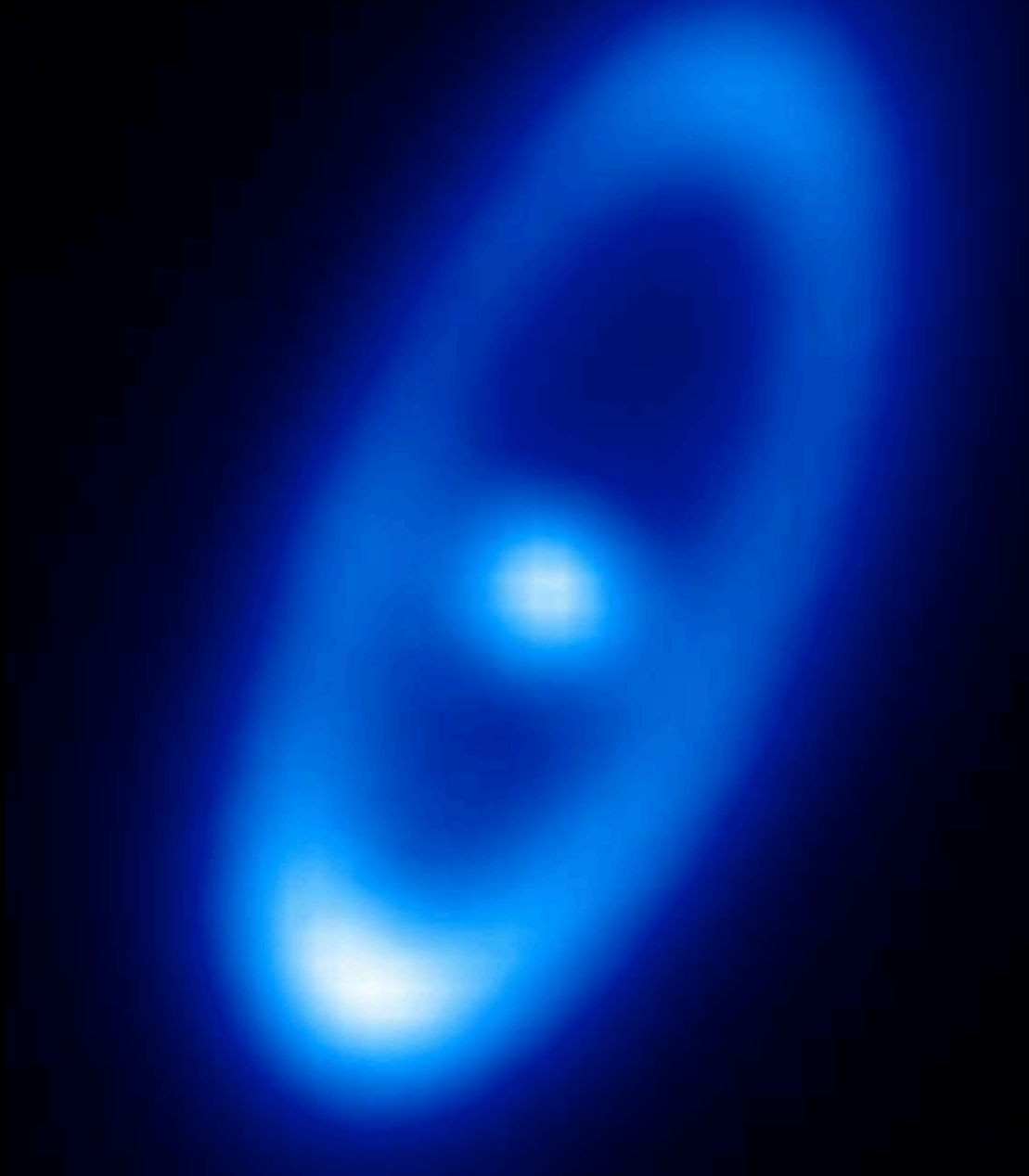**Arthur Eddington (1882-1946)**

A dark cloud

Vulpeculas star forming region

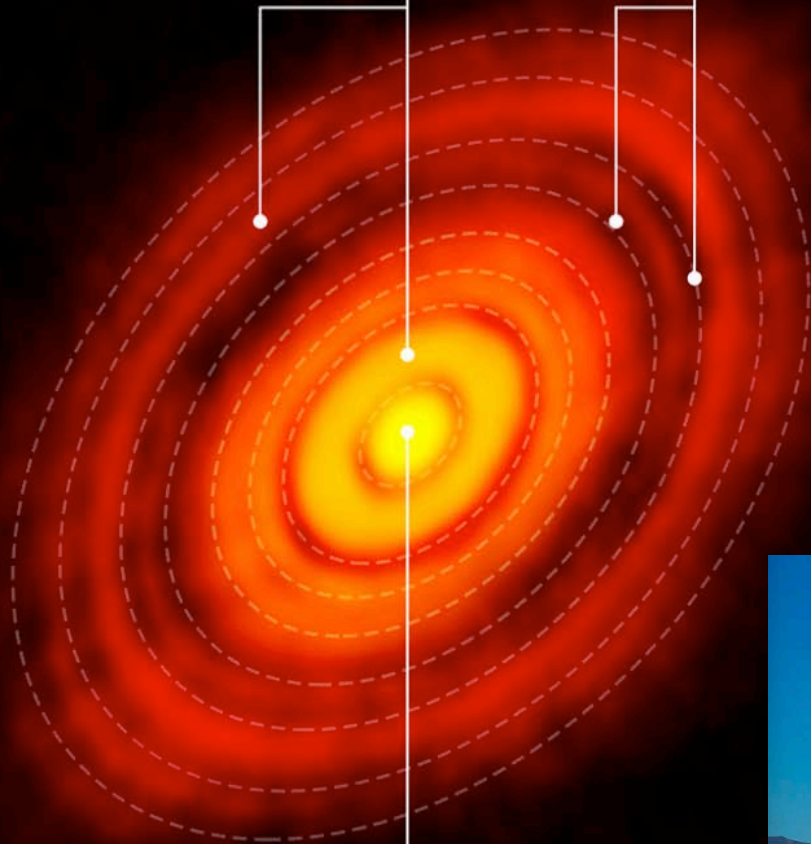# A star is born along with a disk of planetesimals

Herschel Space Telescope

Rings
Gaps

HLTauri

150pc distance, in Taurus cloud
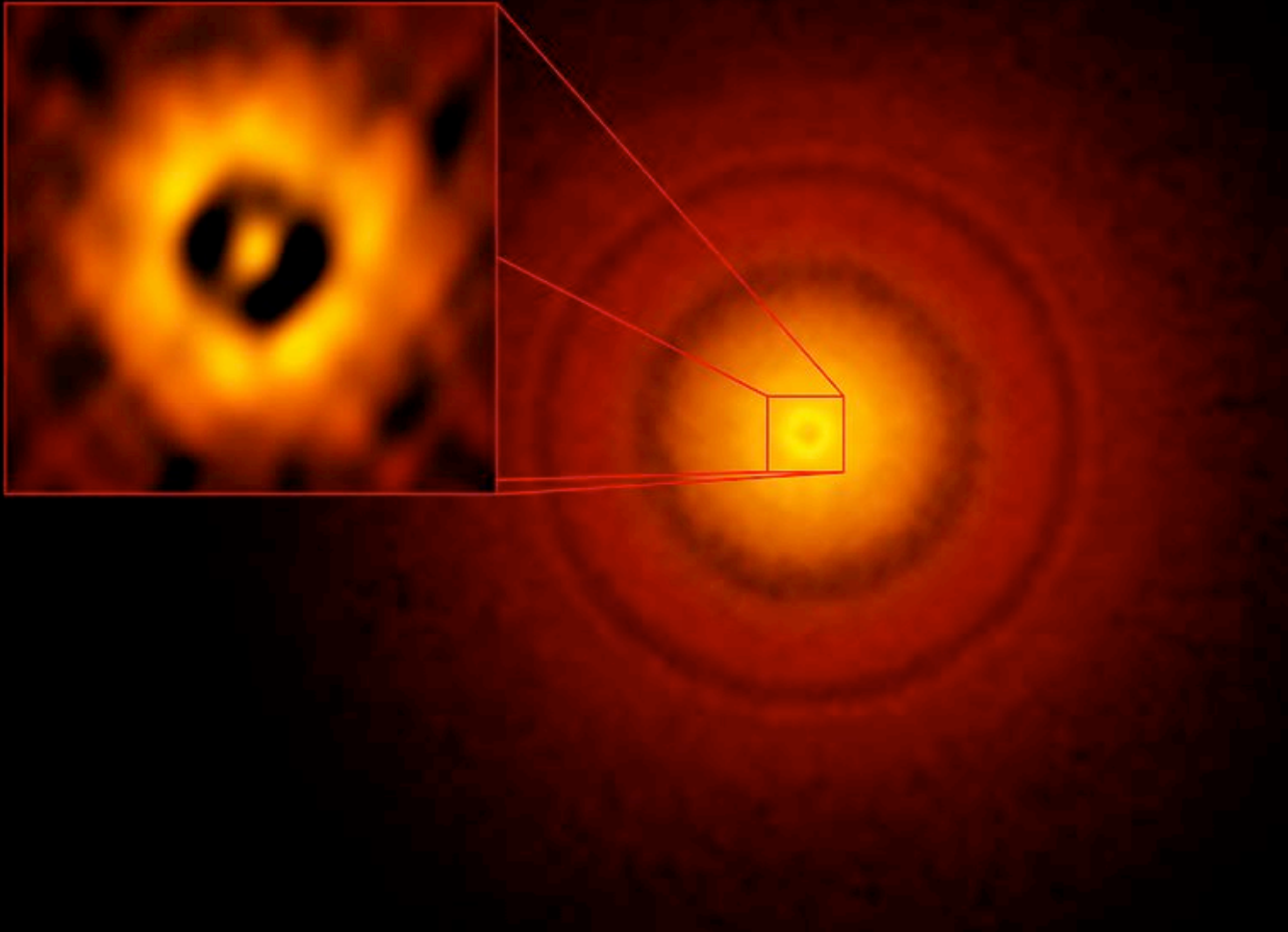about a hundred thousand years old

66 radio telescopes at 16000 ft

ALMA: Atacasma Millmeter Arrazy

HL Tauri

TW Hydrae, imaged by ALMA radio array. 5Myrs old

A planet in formation at earth distance from young sun

A star is born along with a disk of planetesimals

An artist's view
Keck Observatory

The lifetime of a star depends mostly on its mass (and composition)

Thermonuclear fuel supply is proportional to hydrogen mass M

Energy radiated into space is proportional to mass cubed: M^3

So lifetime of a star is proportional to M/M^3 or $1/M^2$

The sun will live for ten billion years.....
but a $100M_{sun}$ star only lives a million years!

10^6 years is a mere instant in the lifetime of the Milky Way, so we should see many dying stars!
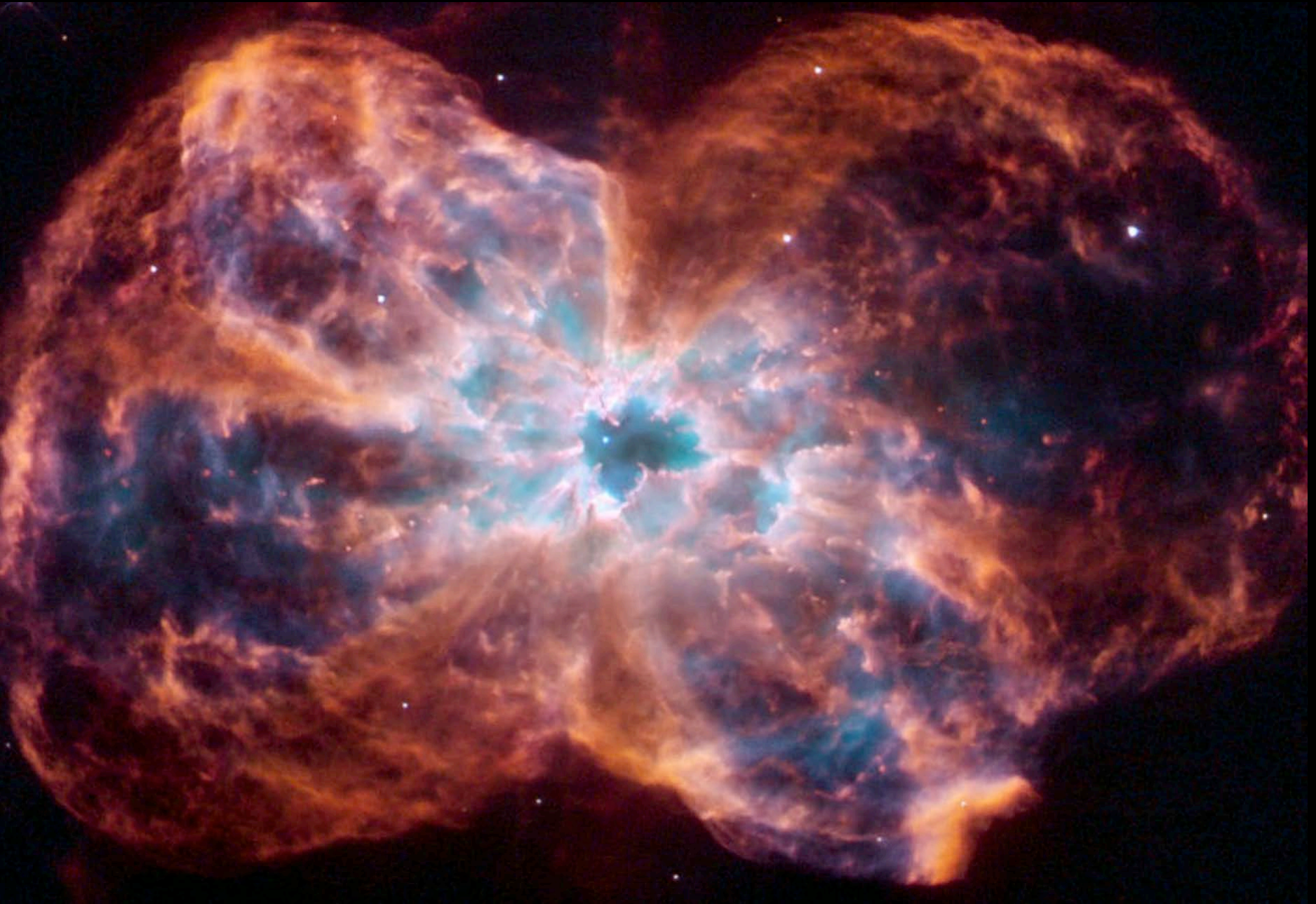
Stellar death

Gentle for a star like the sun

Violent for a massive star

A planetary nebula, with white dwarf
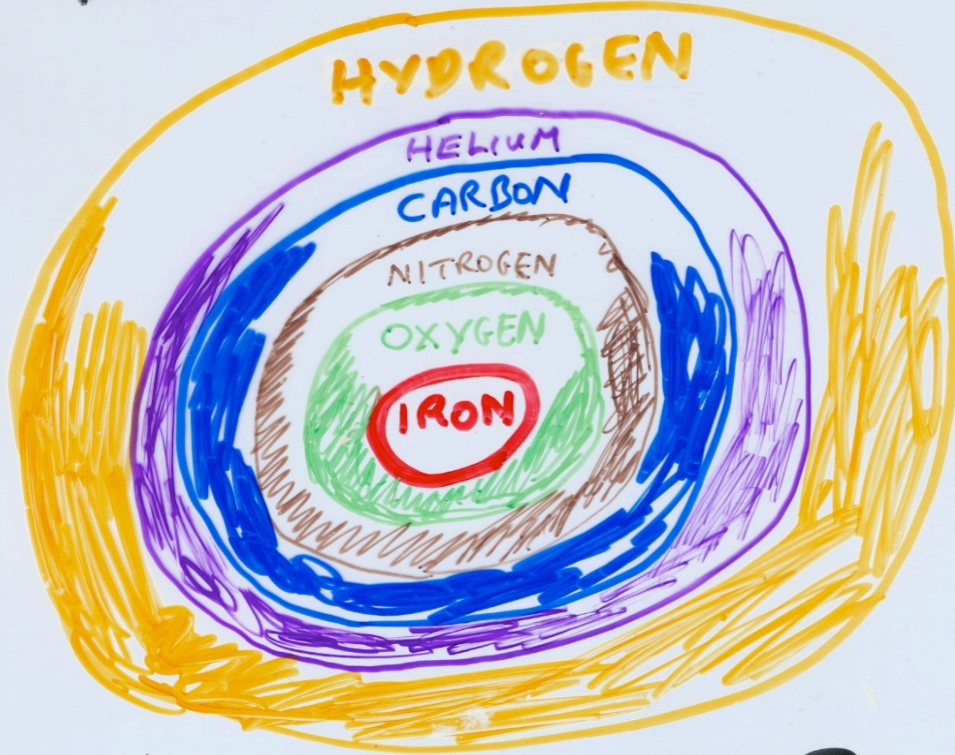
A planetary nebula, with white dwarf

A planetary nebula, with white dwarf

A MASSIVE STAR EVOLVES

HYDROGEN
HELIUM
CARBON
NITROGEN
OXYGEN
IRON

AND EXPLODES

FROM ITS ASHES OUR SOLAR SYSTEM FORMED

Wolf-Rayet star…before the explosion
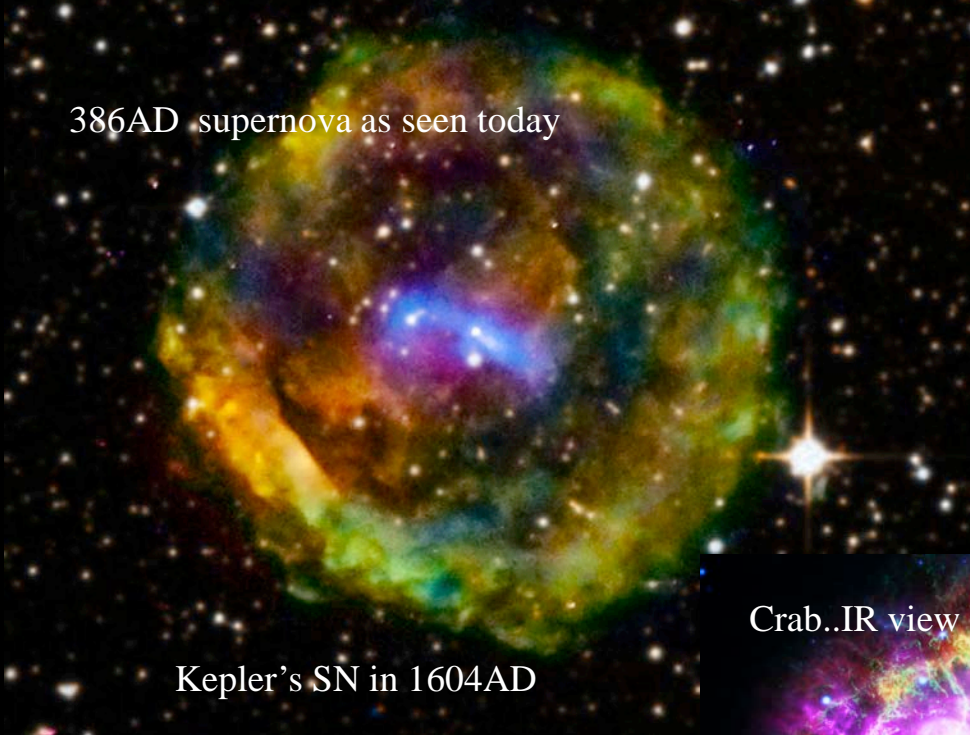
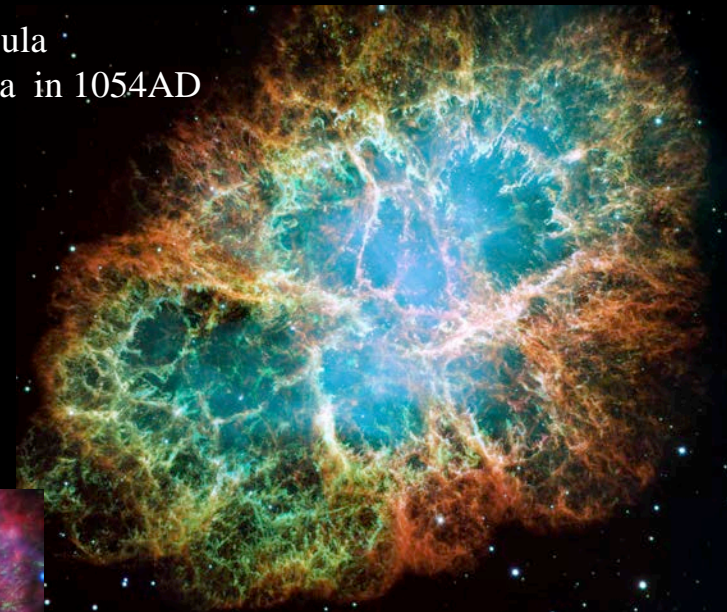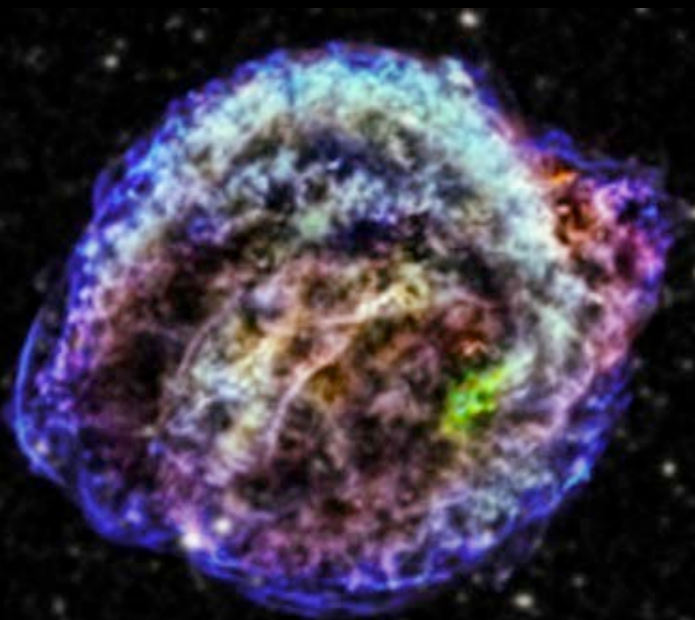Eta Carinae, on the verge of explosion

SNR + pulsar, after the explosion

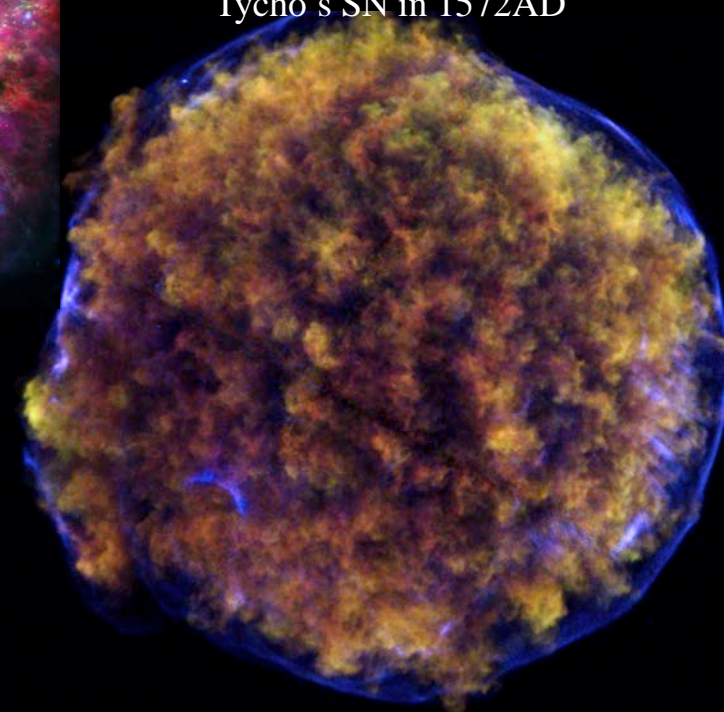386AD supernova as seen today

CRAB nebula
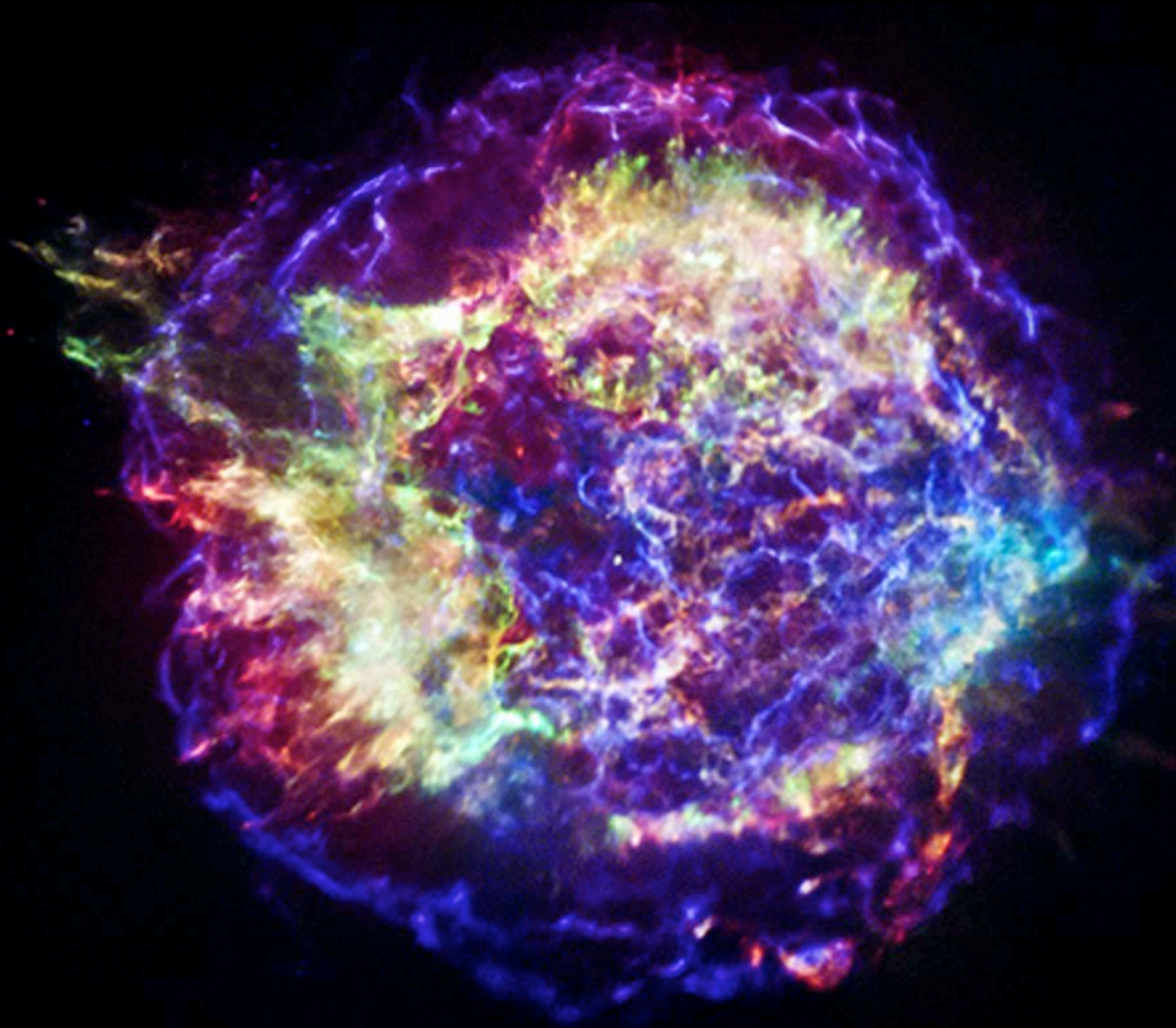a supernova in 1054AD

Crab..IR view

Kepler's SN in 1604AD

Tycho's SN in 1572AD

Casseiopeia A exploded 300 hyrs ago but noone reported a supernova: an x-ray image
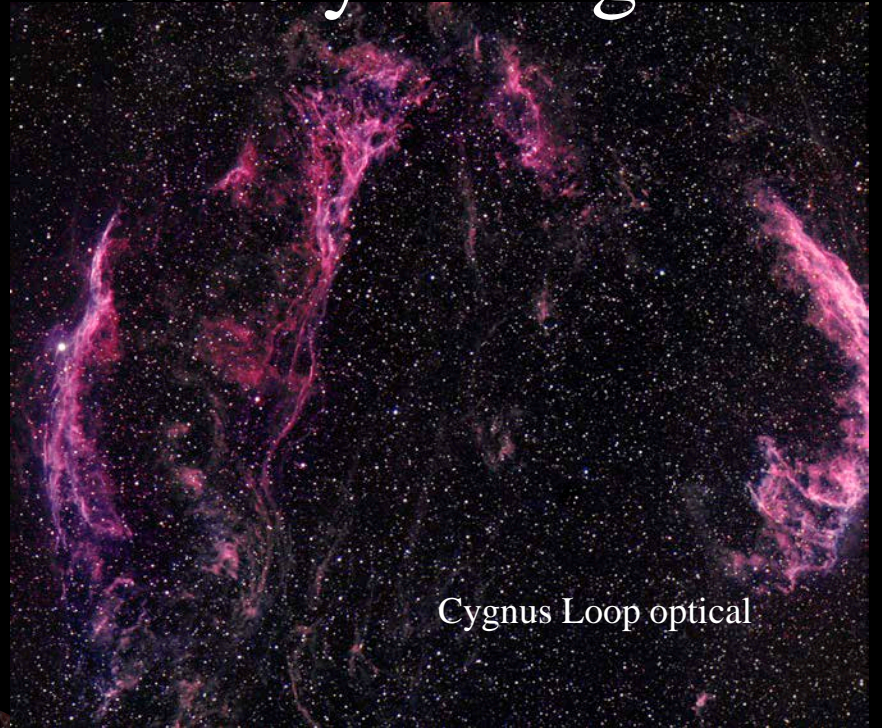
These exploded around 10000 years ago
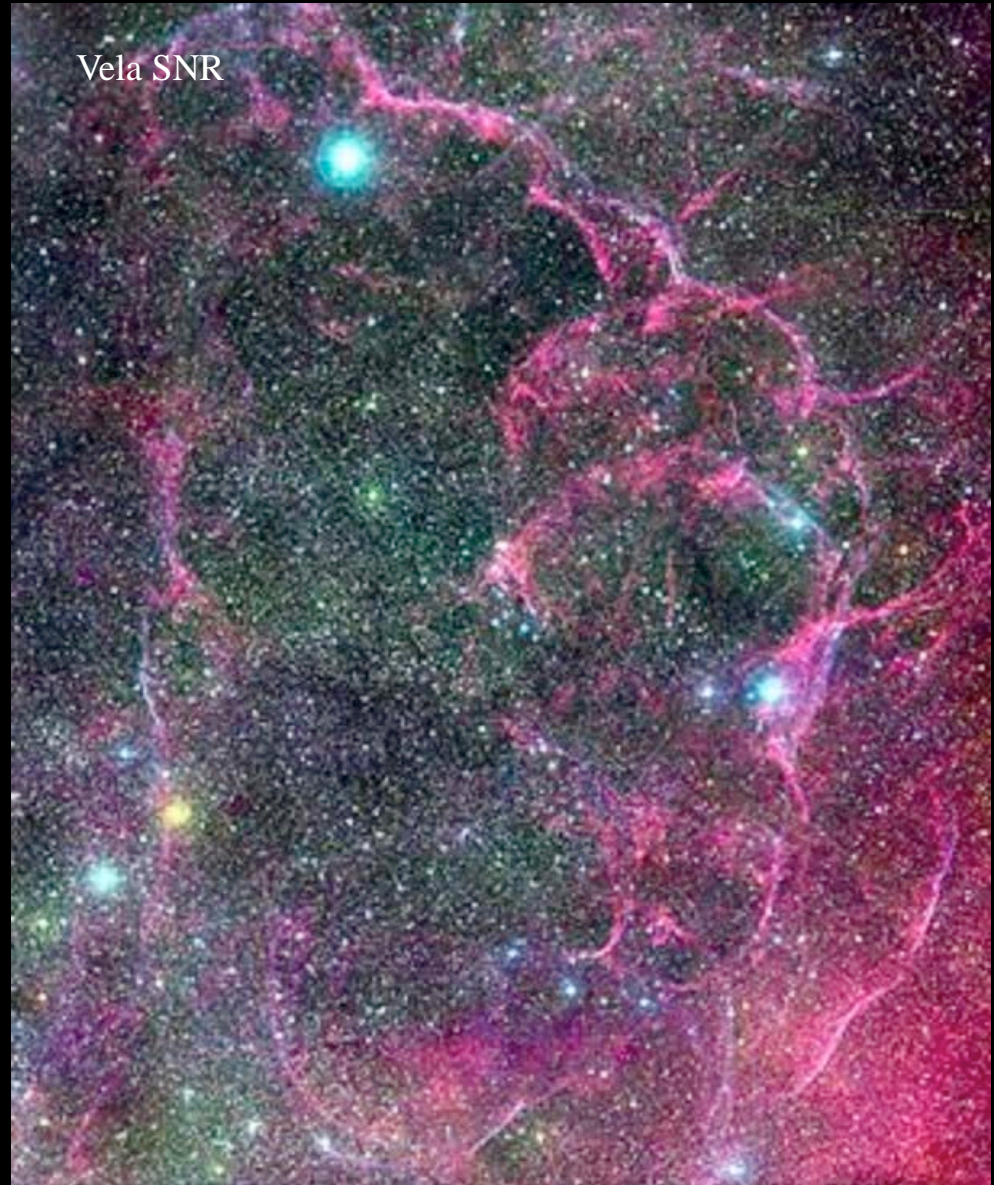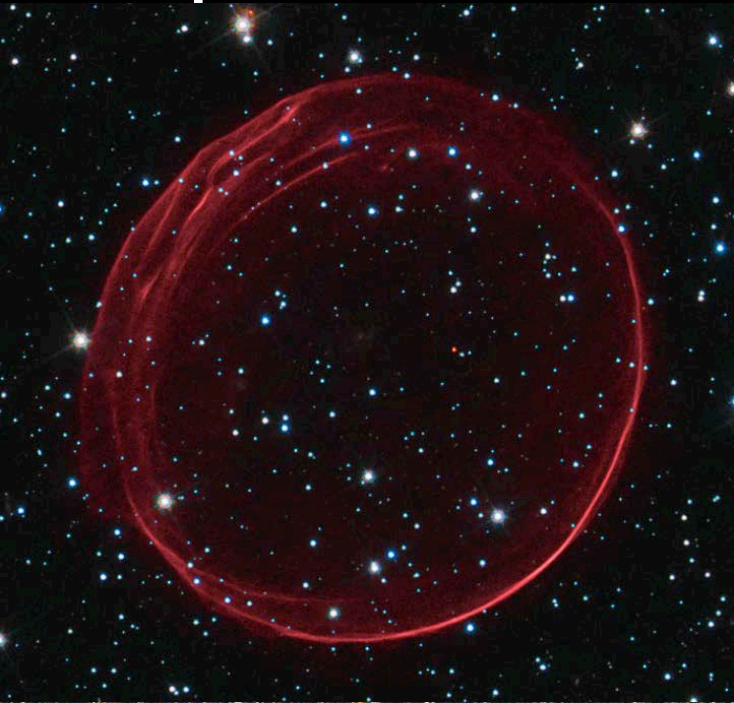

Cygnus Loop UV

Cygnus Loop optical

Veil nebula (Cygnus loop arc) in XR

supernova remnants after ten thousand years
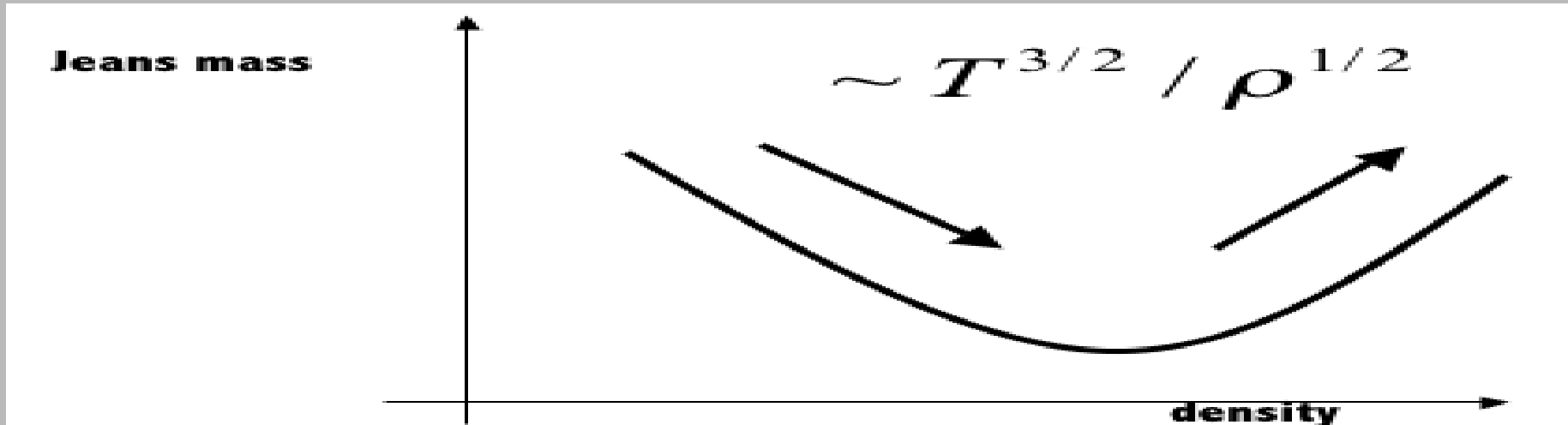

Vela SNR

Fragmentation into stars

Jeans mass

$$\sim T^{3/2} / \rho^{1/2}$$

density

- Fundamental theory applied to a diffuse interstellar cloud that is collapsing under self-gravity

$$\approx \alpha_g^{-3/2} \alpha m_p \approx 0.01 M_{sun}$$

- Minimum **fragmentation** mass

This is a robust but wrong result!

- Resolution: *fragmentation* + continuing *accretion* of cold gas, halted by *feedback* that taps stellar energy via magnetic turbulence

- Accretion stops when wound-up magnetic fields drive outflows, after a million years or so and the protostar becomes a star

α is the fine-structure constant =1/137 m_p is the mass of a proton $\alpha_g \equiv G m_p^2 e^{-2} \approx 3.10^{-37}$

Magnetic fields are everywhere in the universe. They control the rate at which stars form today
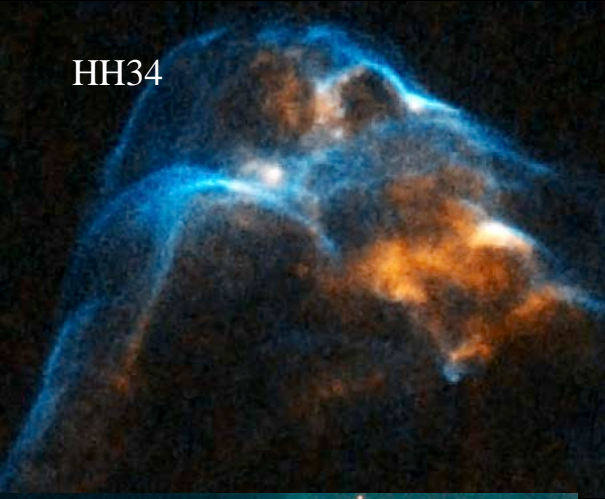

HL Tauri

Li & Nakamura 2008
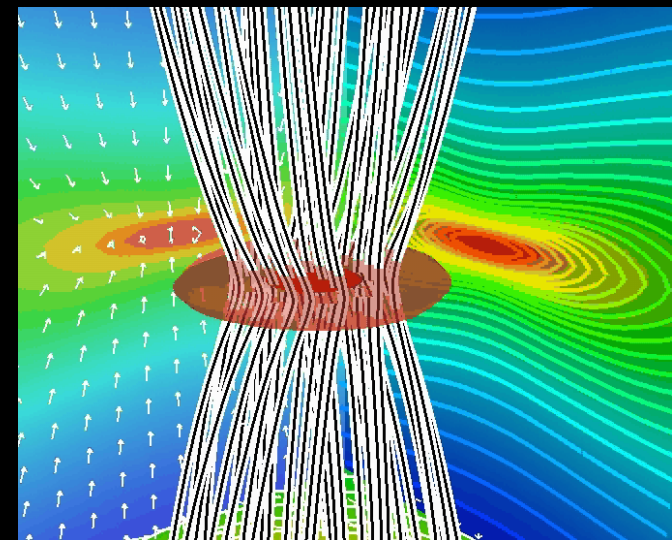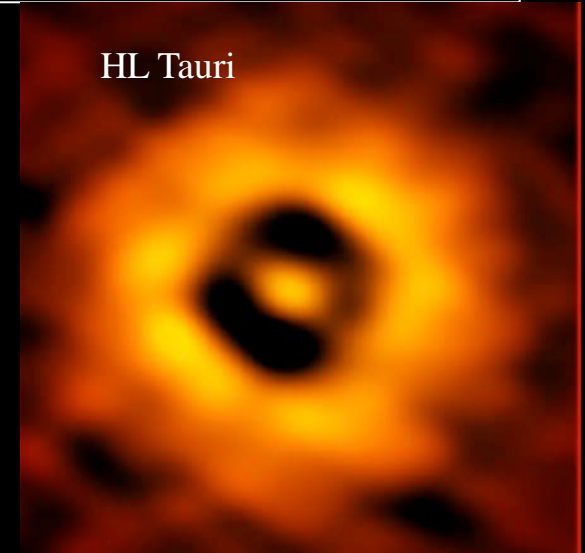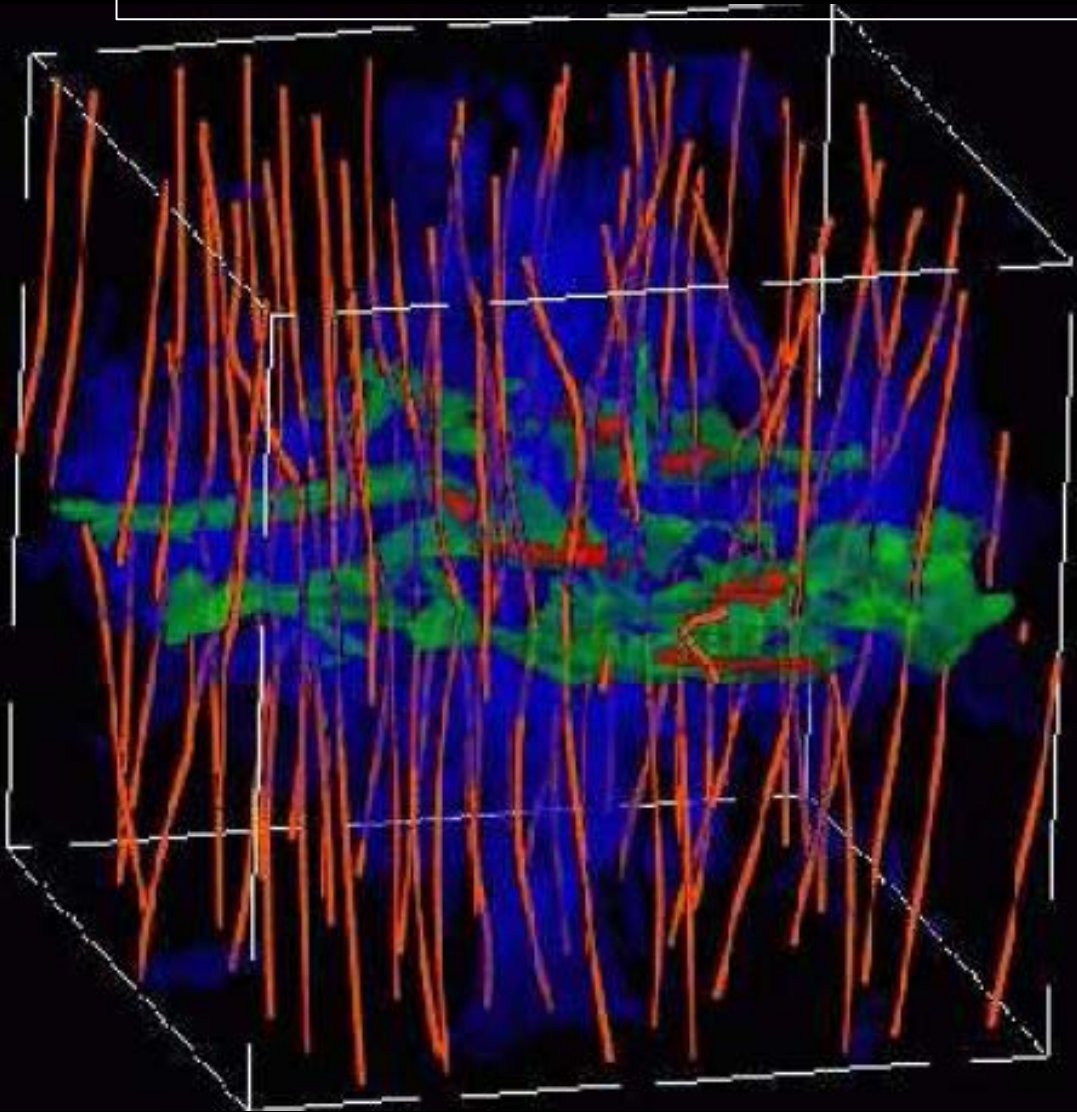
T-Tauri stars and feedback

HH34

HH47

Pelican

Liberty

Powerful jets and outflows
from very young stars

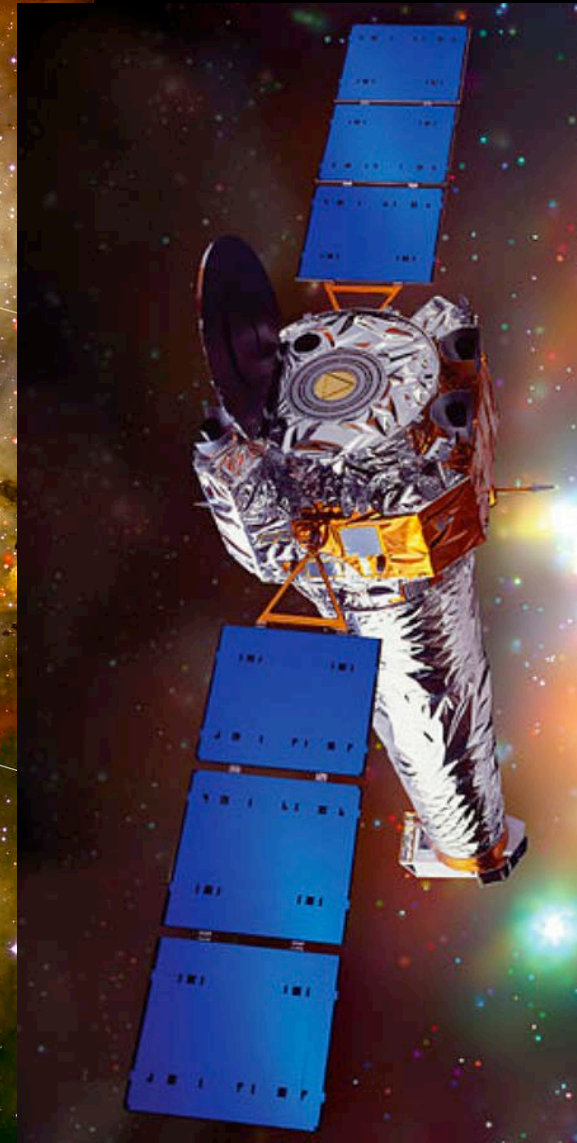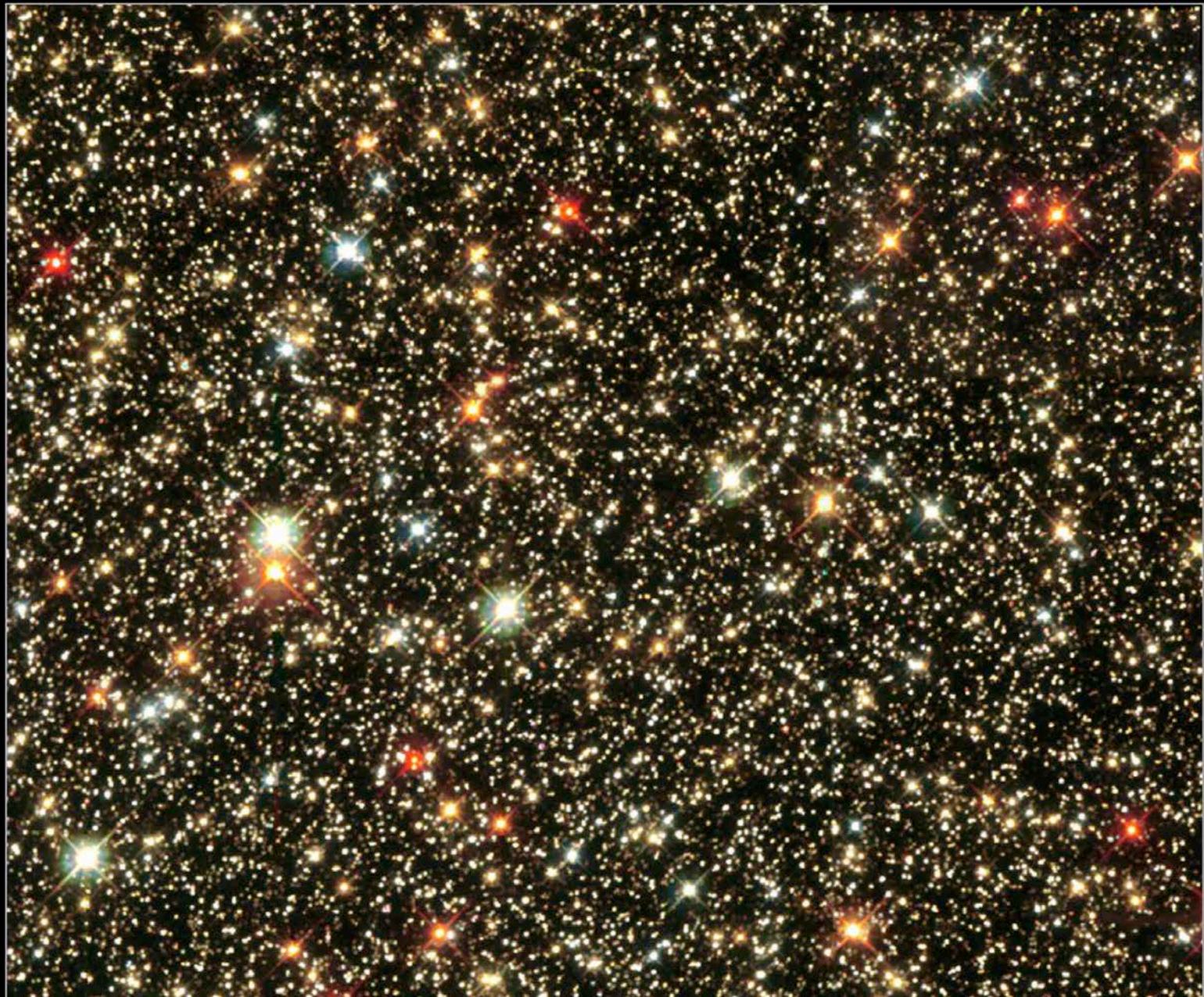Carina

Very young stars have inflows that shine in x-rays

Chandra x-ray telescope
Launched 1999, 1.2m diameter

Sagittarius Star Cloud

Many stars are not alone: a globular star cluster
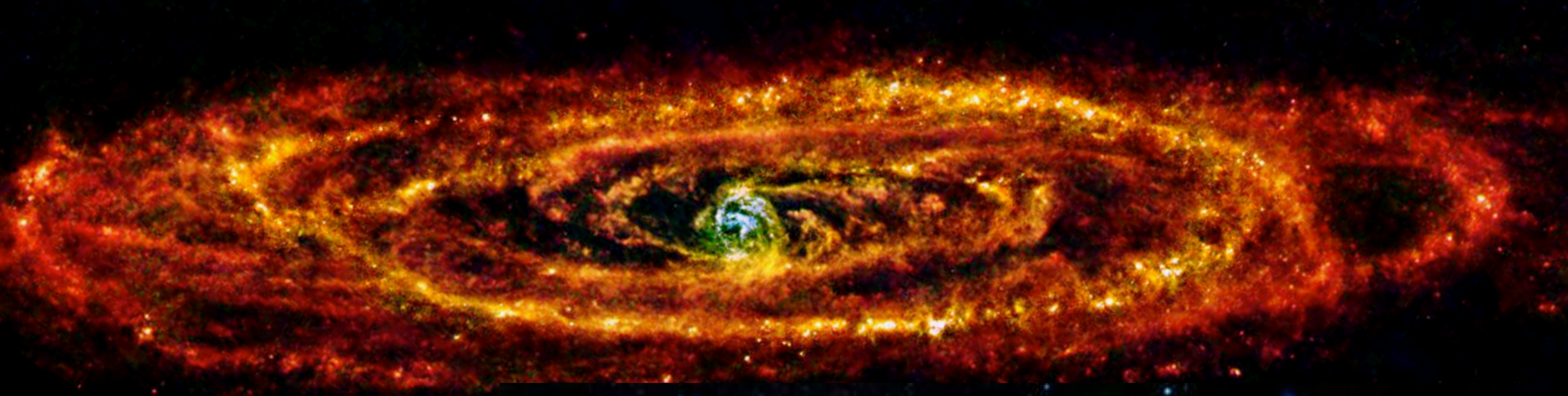
What triggers clouds to collapse?

- Clouds orbit the galaxy in circles
- The orbits are perturbed by a central stellar bar
- Congestion spreads into a spiral density wave
- Clouds collide and merge in a cosmic traffic jam
- Clouds grow in mass, and gravity prevails
- Clouds collapse and fragment into stars
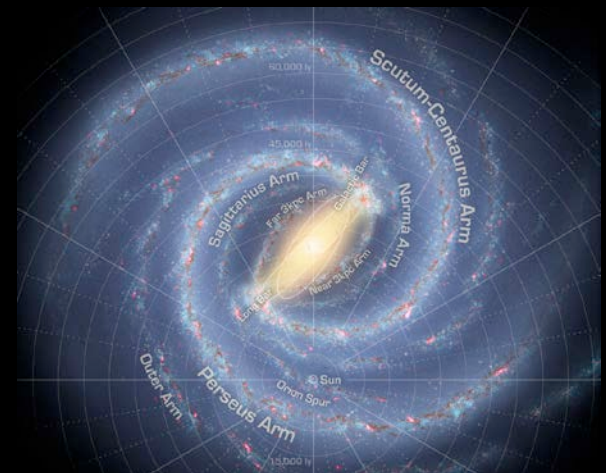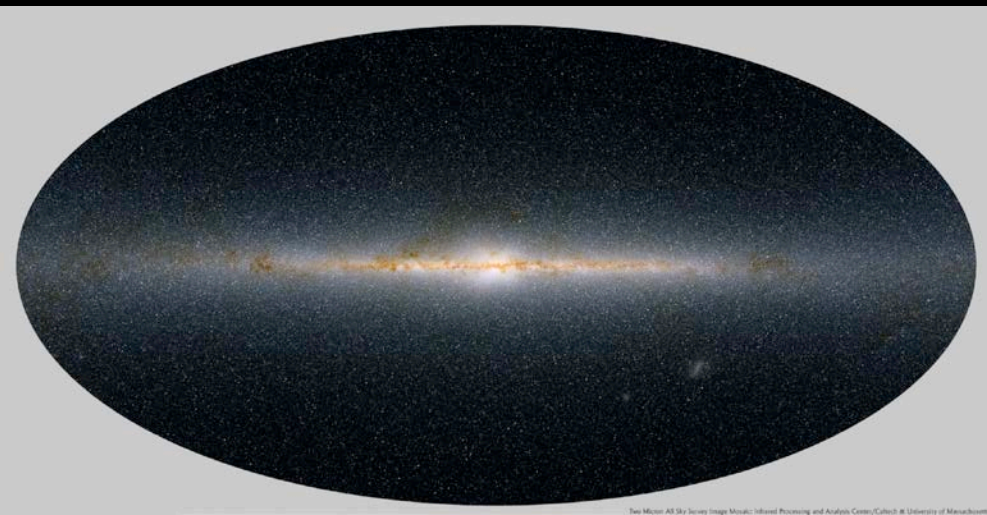
The Andromeda galaxy
2 million light years away

Messier 81
12 million light years away