# *Searching for Other Worlds: The context*


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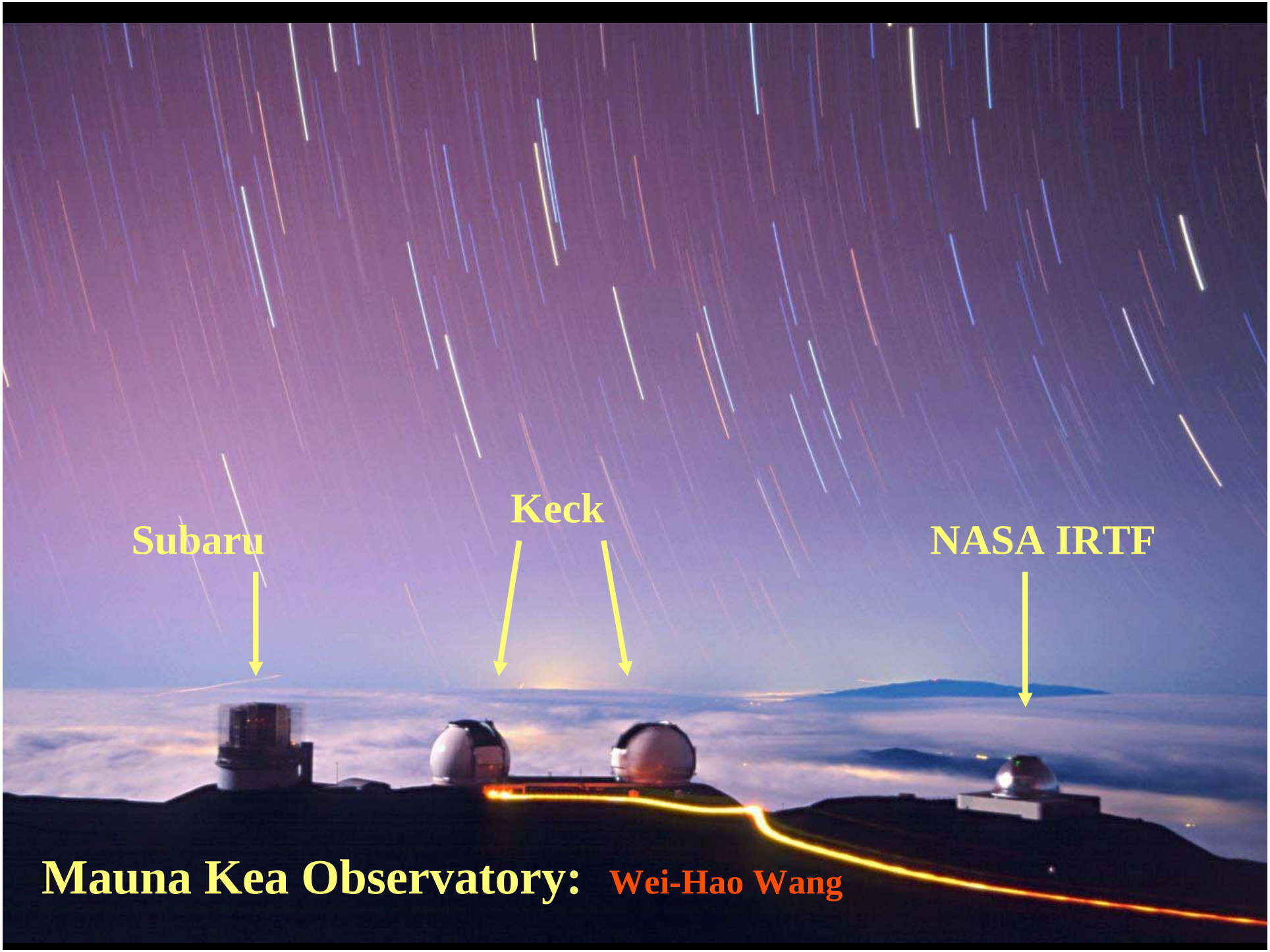
# The Search for Exo-planets:

- **The Context: The Age of Discovery**
  - Our generation is charting the Universe!
  - Origns of the cosmos, stars, planets, and life
- **How common are terrestrial (habitable) planets?**
  - History
  - Astrobiology: The origins of life on Earth
    In-situ searches in the Solar System
    Remote-sensing biosignatures
- **Methods of Discovery: Past, present, future (Saturday talk).**
  - Astrometry
  - Radial velocity
  - Transits
  - gravitational lensing
  - Direct detection, imaging, characterization
- **Mission Development: From Concept to Flight to Science**
  - COROT, Kepler, SIM, TPF, Darwin , Starshade, Planet Imager, ….

# The Age of Astronomical Discovery

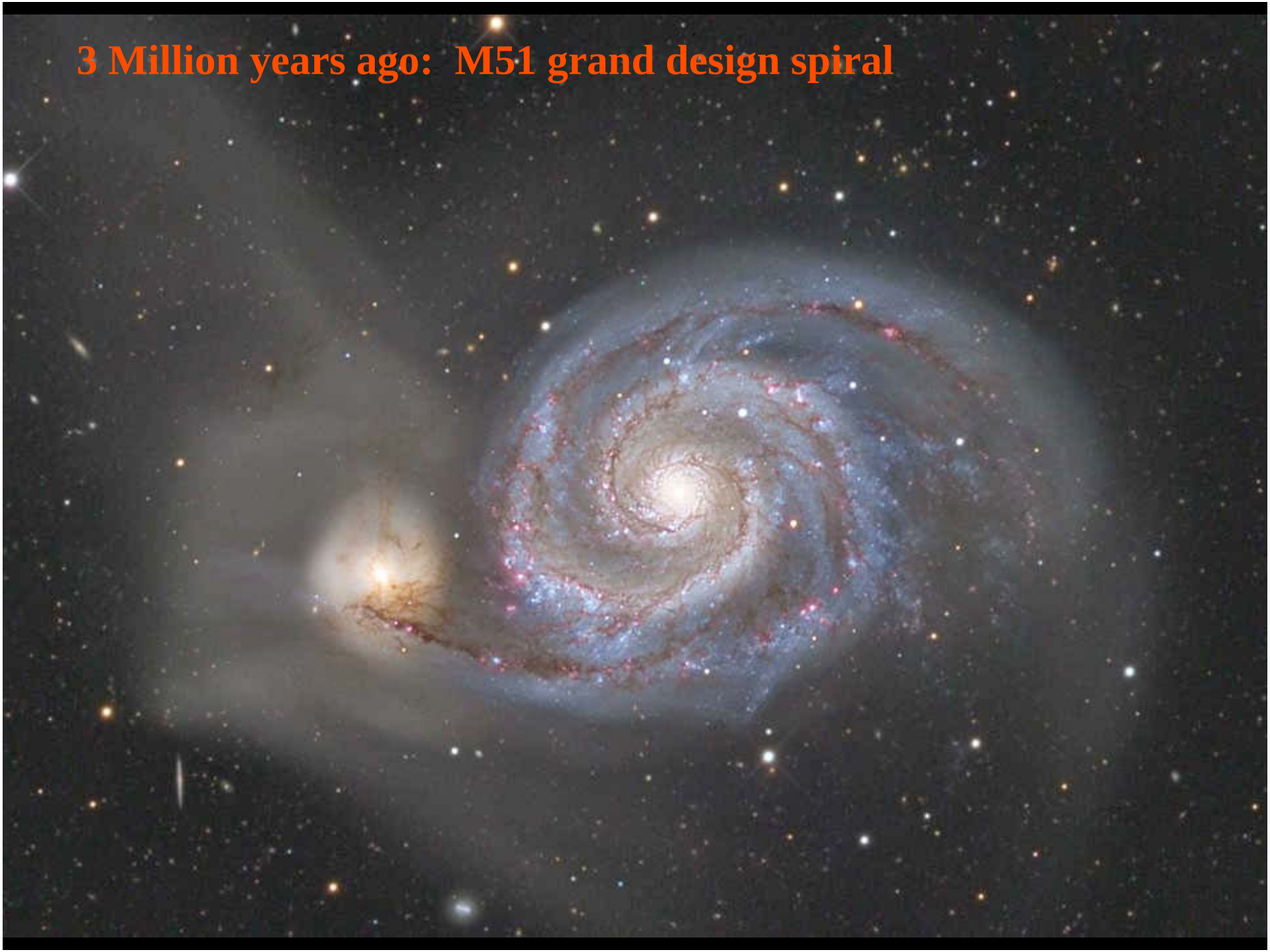
- **Access to all wavelengths of the spectrum**
  - Silicon technology
    => sensors at most wavelengths
  - Large telescopes
- **Powerful computers**
- **Access to space**
  - No atmosphere
    => Sharp images (Hubble Space Telescope)
    => Access to all wavelengths (Spitzer)
- **Connections to Physics**
  - Scales: $10^{28}$ to $10^{-33}$ cm, $10^{17}$ to $10^{-43}$ sec
  - 4 forces: gravity, electro-magnetism, weak, strong
  - Matter (4%), Dark matter (24%), Dark energy (72%)




**Mauna Kea Observatory:** Wei-Hao Wang

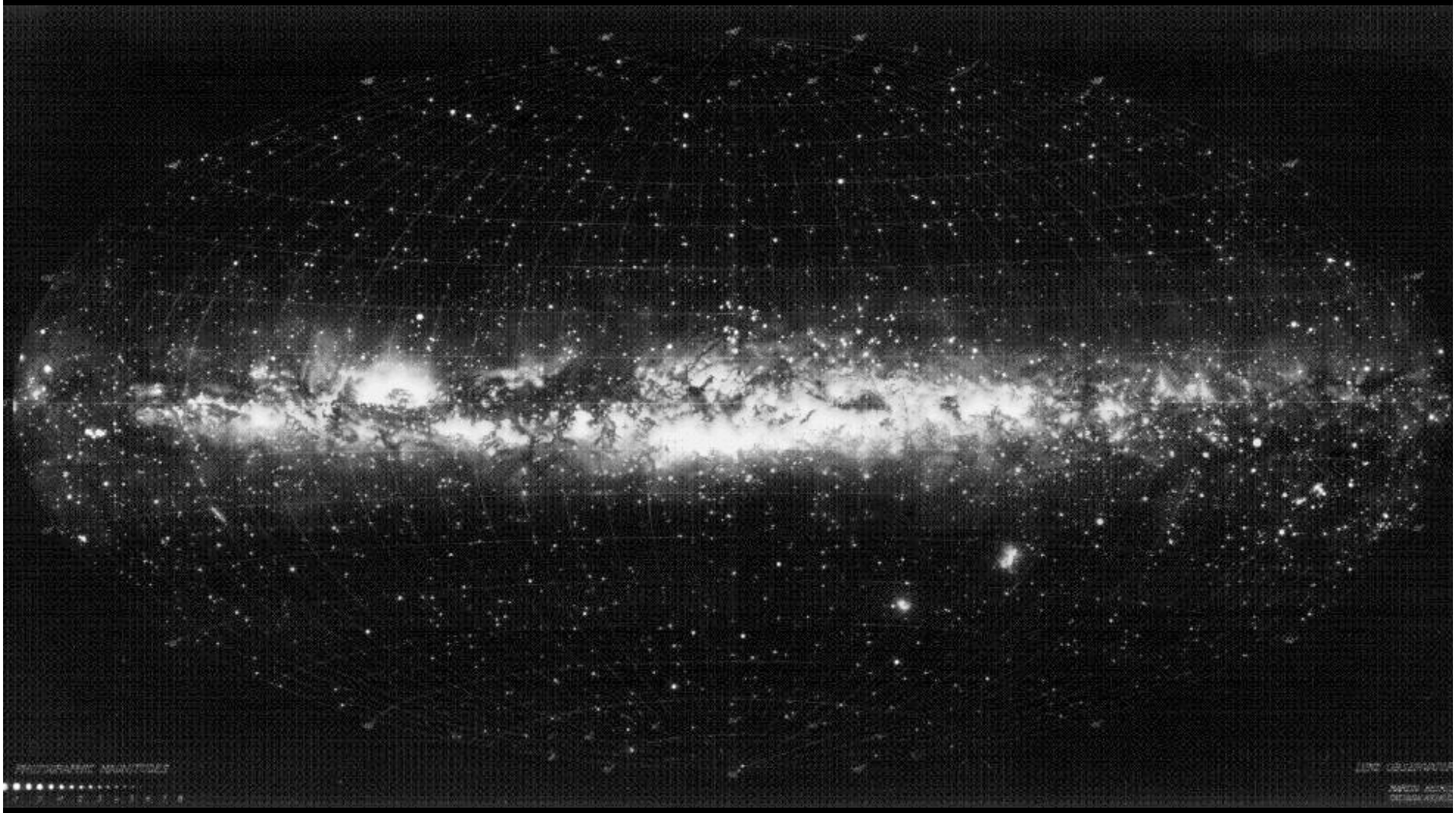
Gemini N
8 meter on
Mauna Kea

Hubble Space Telescope

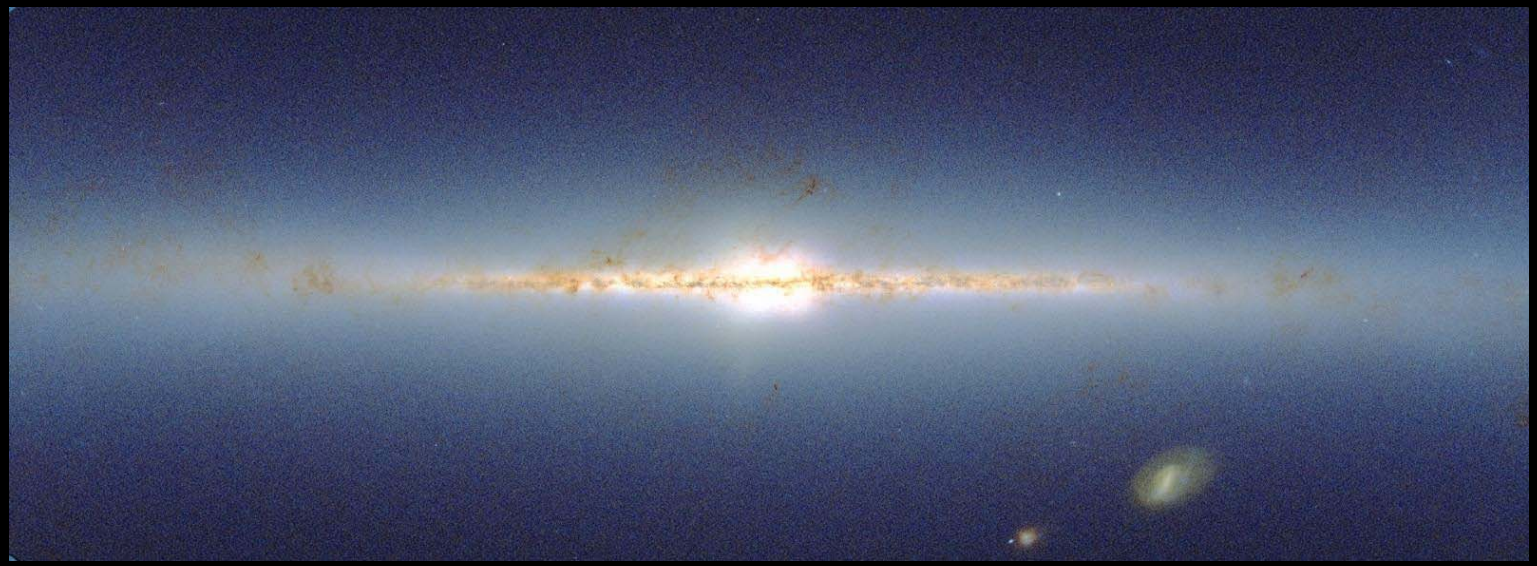

3 Million years ago:  M51 grand design spiral

Summer Milky Way
Wei-Hao Wang

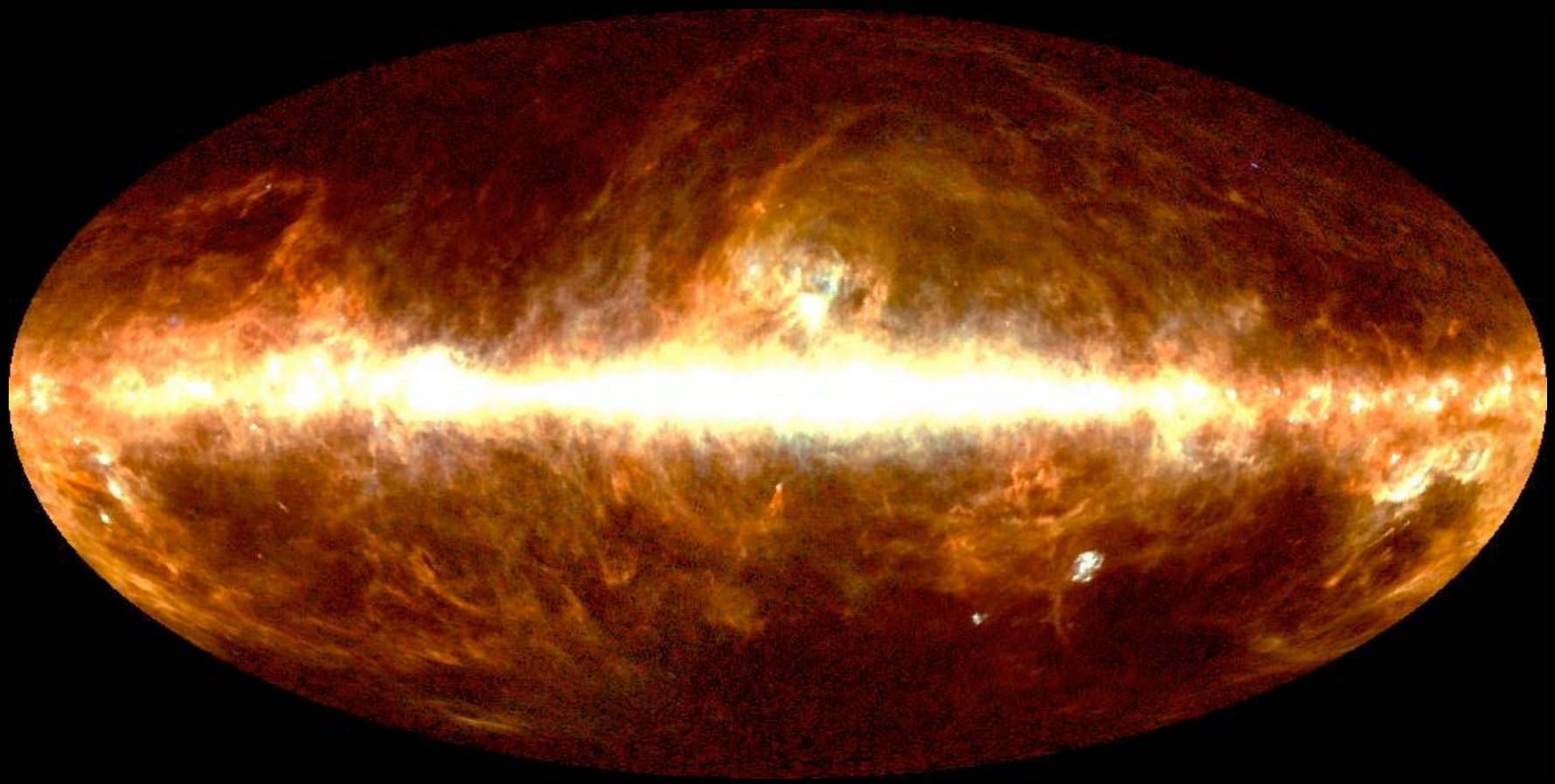
# Our Milky Way @ visual wavelengths



# Our Milky Way @ near infrared wavelengths



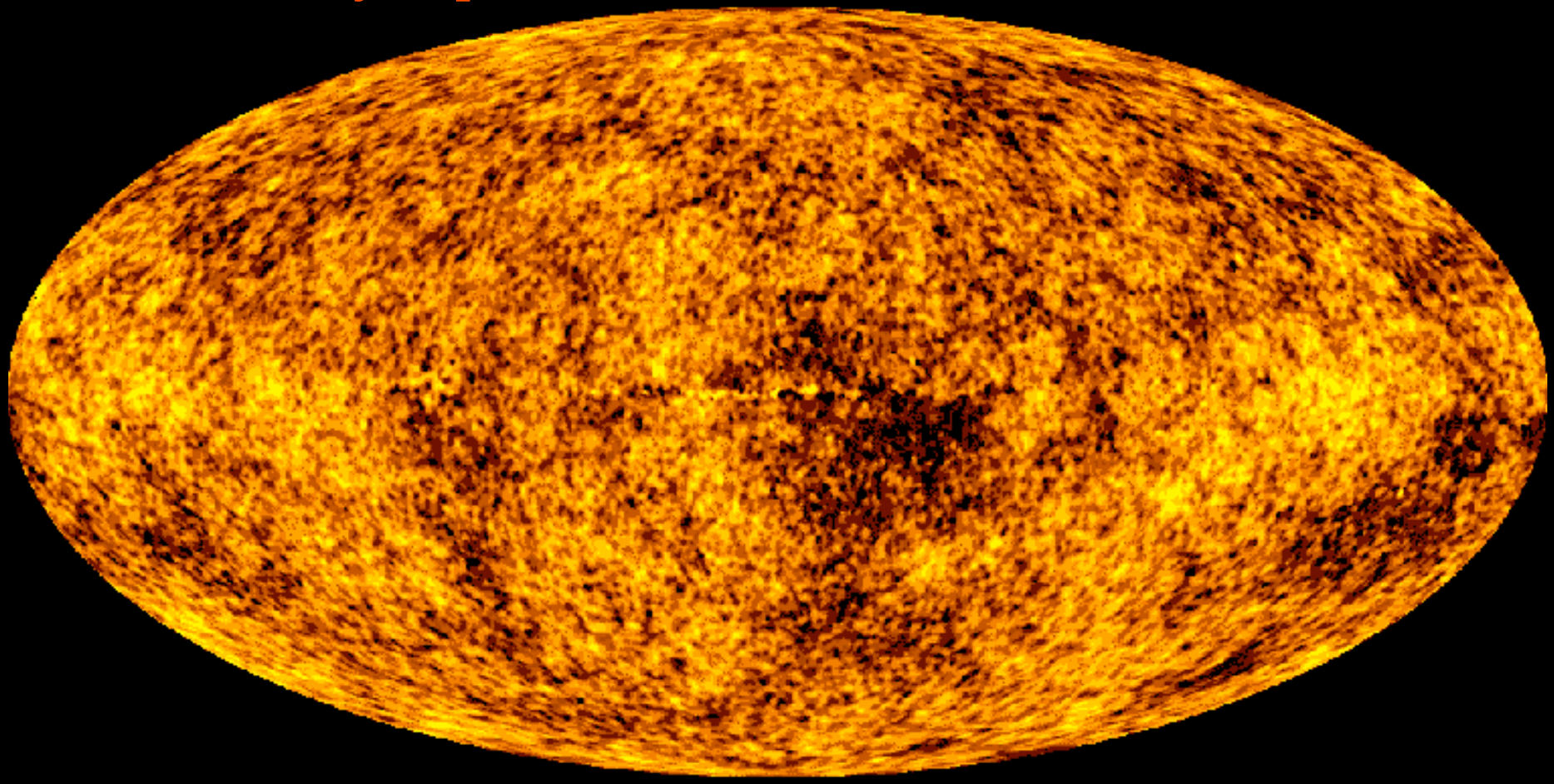
# Our Milky Way @ far infrared wavelengths



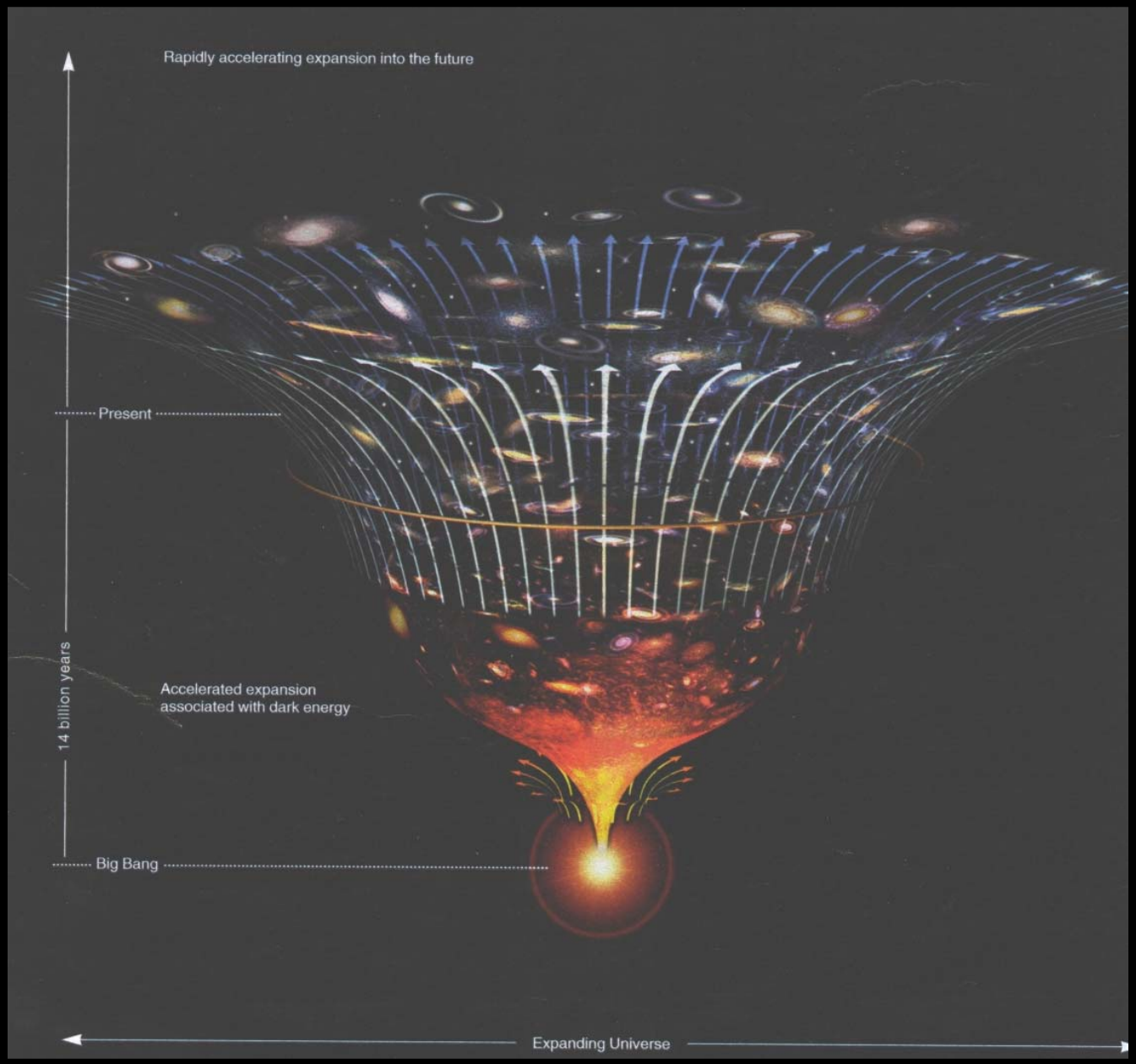
**Cosmic Microwave Background:**

**Snapshot of 3,000 K plasma when Universe was 300,000 yrs old**

**Redshifted by Expansion of the Universe x1,000 => 3 K**



# Dark Energy:  Expansion is accelerating!



# The Evolution of the Universe:

- Cosmology: Baryons = 4% 13.7 Gyr
  Dark Matter = 26% (1 Gyr = $10^9$ years)
  Dark Energy = 70%
- Cosmic Microwave Background:
  The young Universe 400,000 years
  Hot, ionized plasma 3,000 Kelvin
  (1/2 temperature of Sun)
  Smooth to $1:10^5$
- The Cosmic Dark Ages: 0.0004 – 0.6 Gyr
- The First Stars: Massive 0.6 – 1 Gyr
- Formation of Galaxies > 1 Gyr
- Solar System Formation: 9.1 Gyr
- Star & Planet Formation today

# Stars

**Stars: The fundamental building blocks of the Universe**

## High mass: (8 - 100 times Mass of Sun)

**Sources of light, chemical elements**

**Short lived: < 30 million years**

**Luminous: Thousand => million times Sun**

**Source of energy in interstellar medium**
**Explode as supernovae**

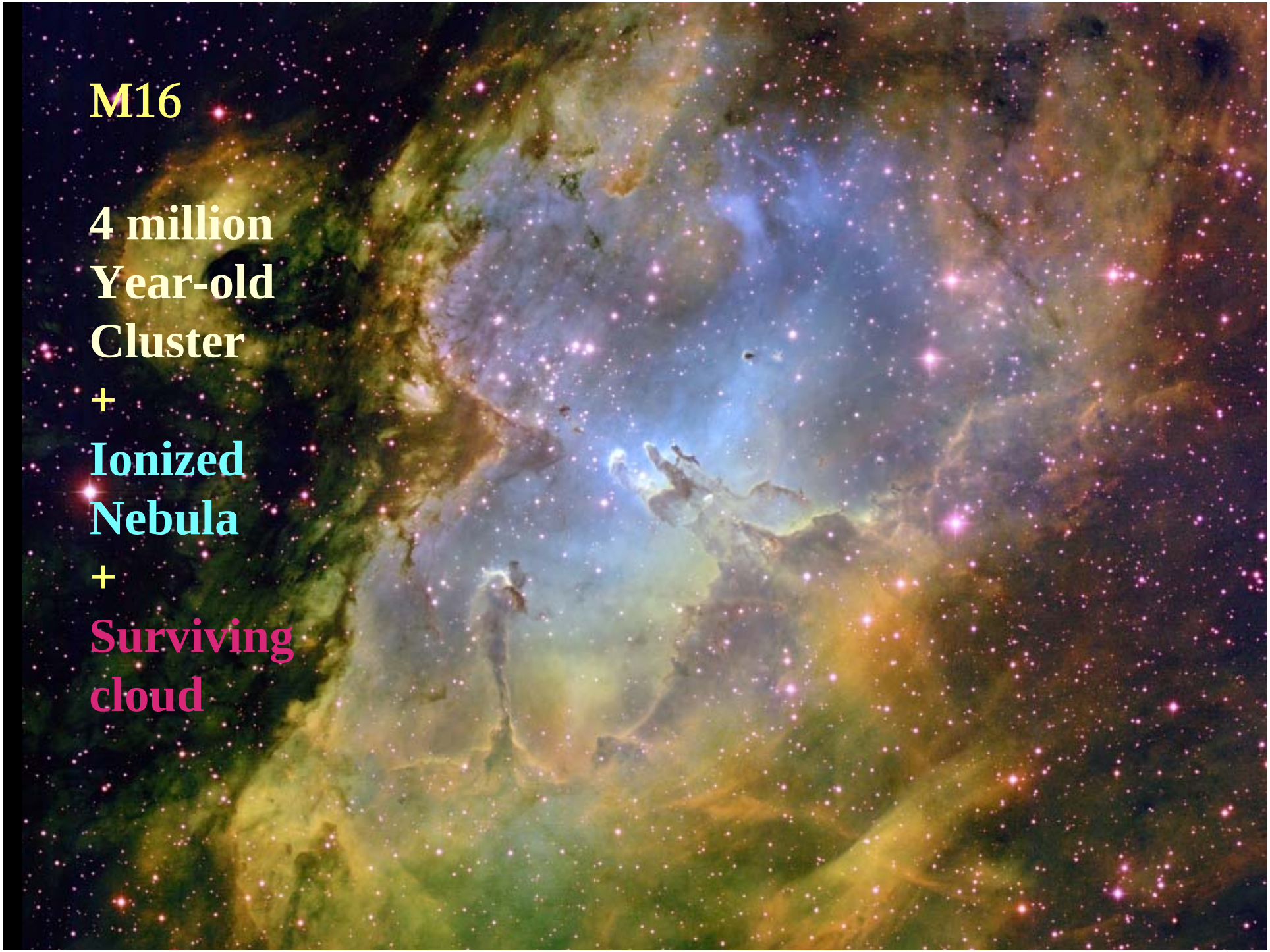
## Low Mass: (< 2 times Mass of Sun)

**Long Lived: > Billion years**

**(Lock up mass for long time)**

**Planets: Abodes of life**

**Faint:**


M16
4 million
Year-old
Cluster
+
Ionized
Nebula
+
Surviving
cloud

**M16**
**(HST)**

**Surviving cloud**

# Star Formation

**Shrink size by $10^7$; increase density by x $10^{21}$ !**

***Where planets also form***

- **Giant Molecular Cloud Core**

  **Raw material for star birth**

- **Gravitational Collapse & Fragmentation**

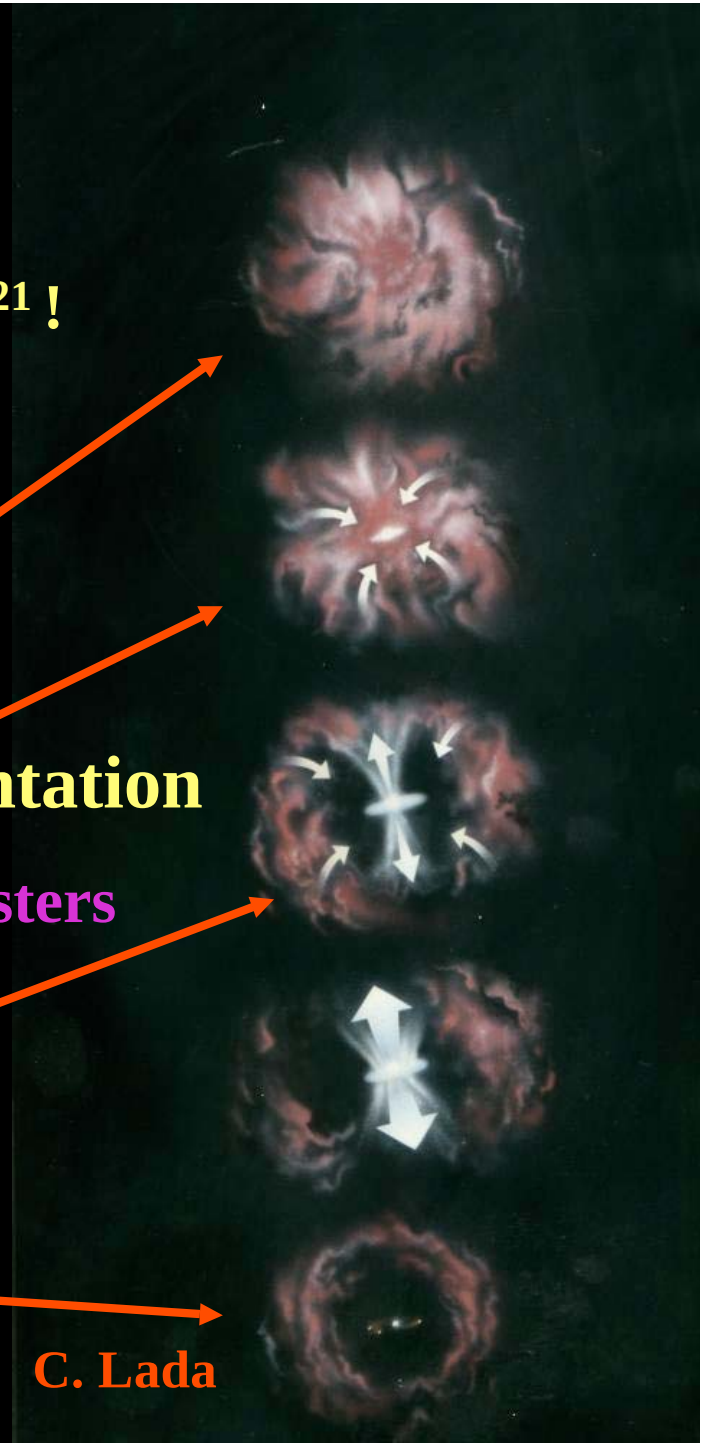
  **Proto-stars, proto-binaries, proto-clusters**

- **Rotation & Magnetic Fields**

  **Accretion disks, jets, & outflows**

- **Planets**

  **Most may form in clusters!**

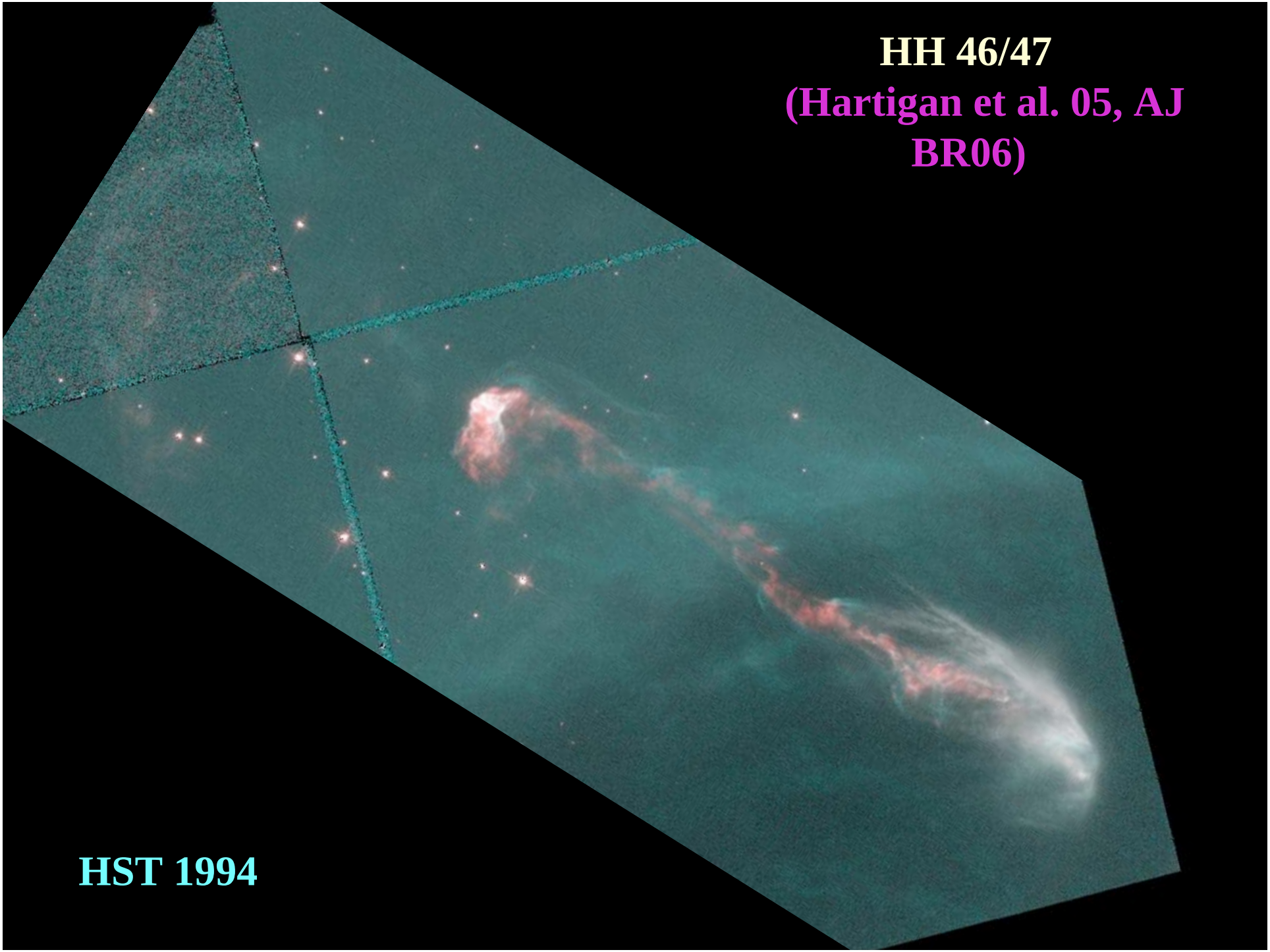


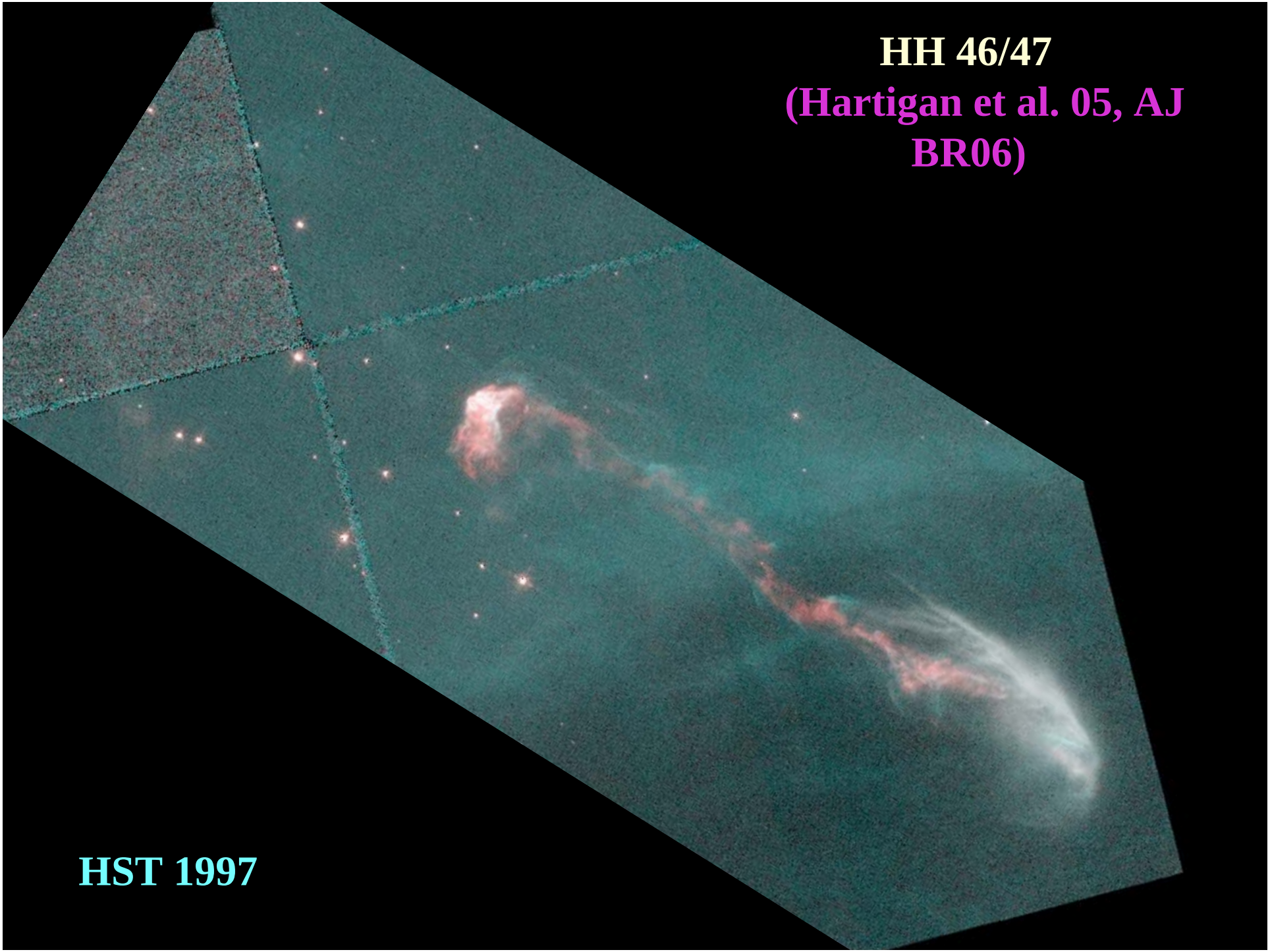
**C. Lada**

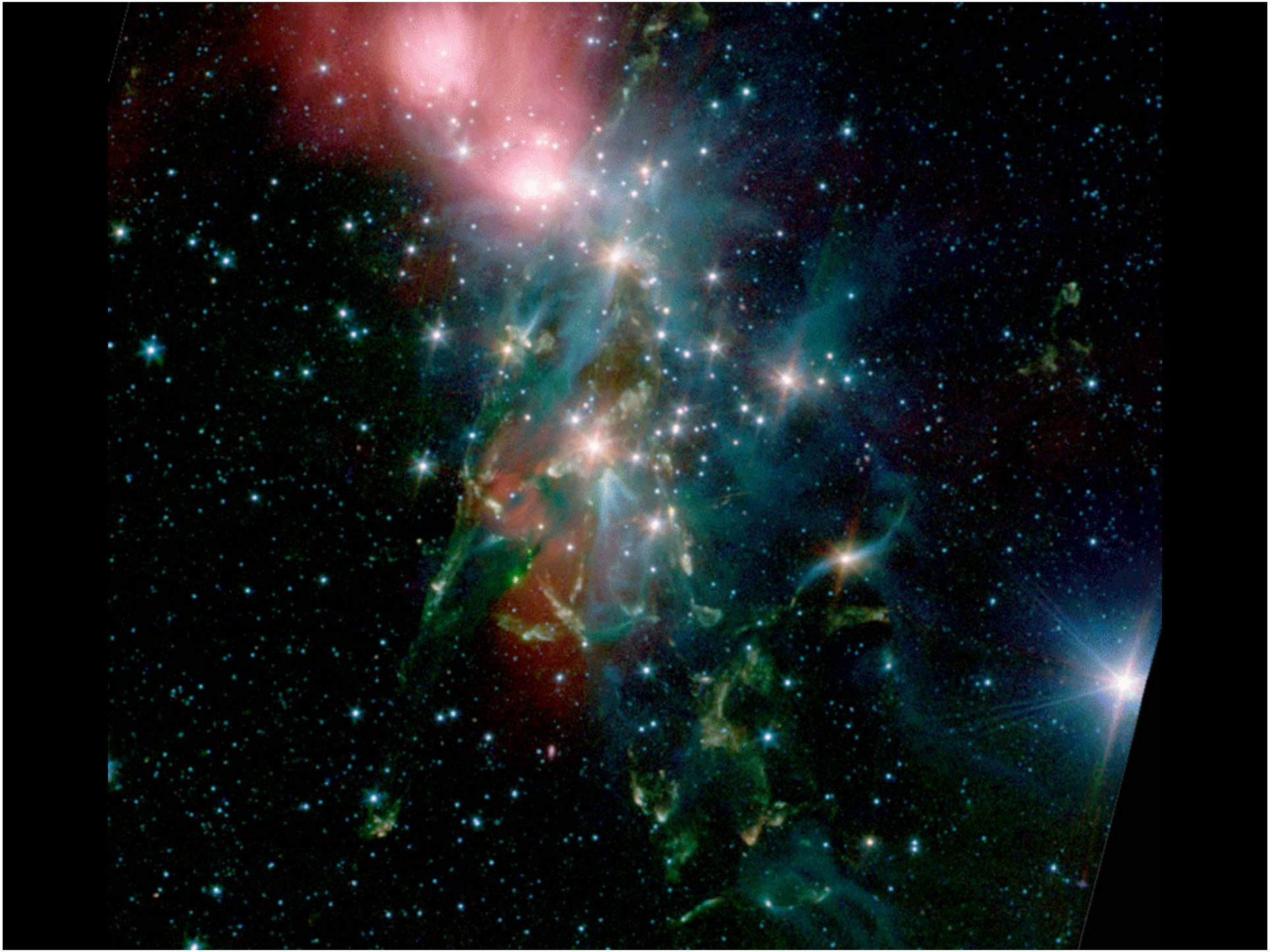
Class I Outflow: HH 46/47
Hα [SII] [OII]

# Class I Outflow: HH 46/47

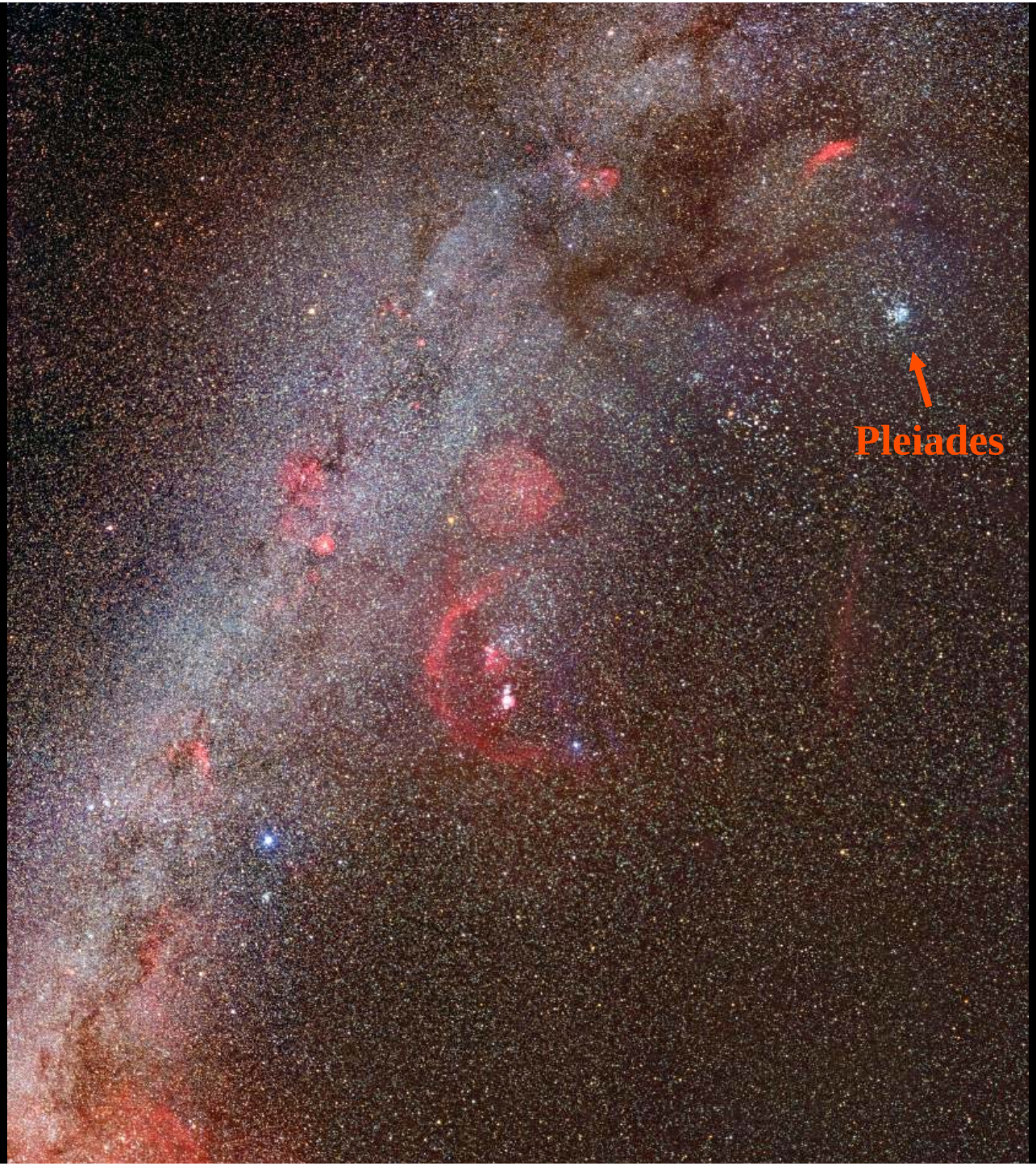
**Spitzer IRAC:** **3 – 8 μm**


HH 46/47
(Hartigan et al. 05, AJ BR06)
HST 1994

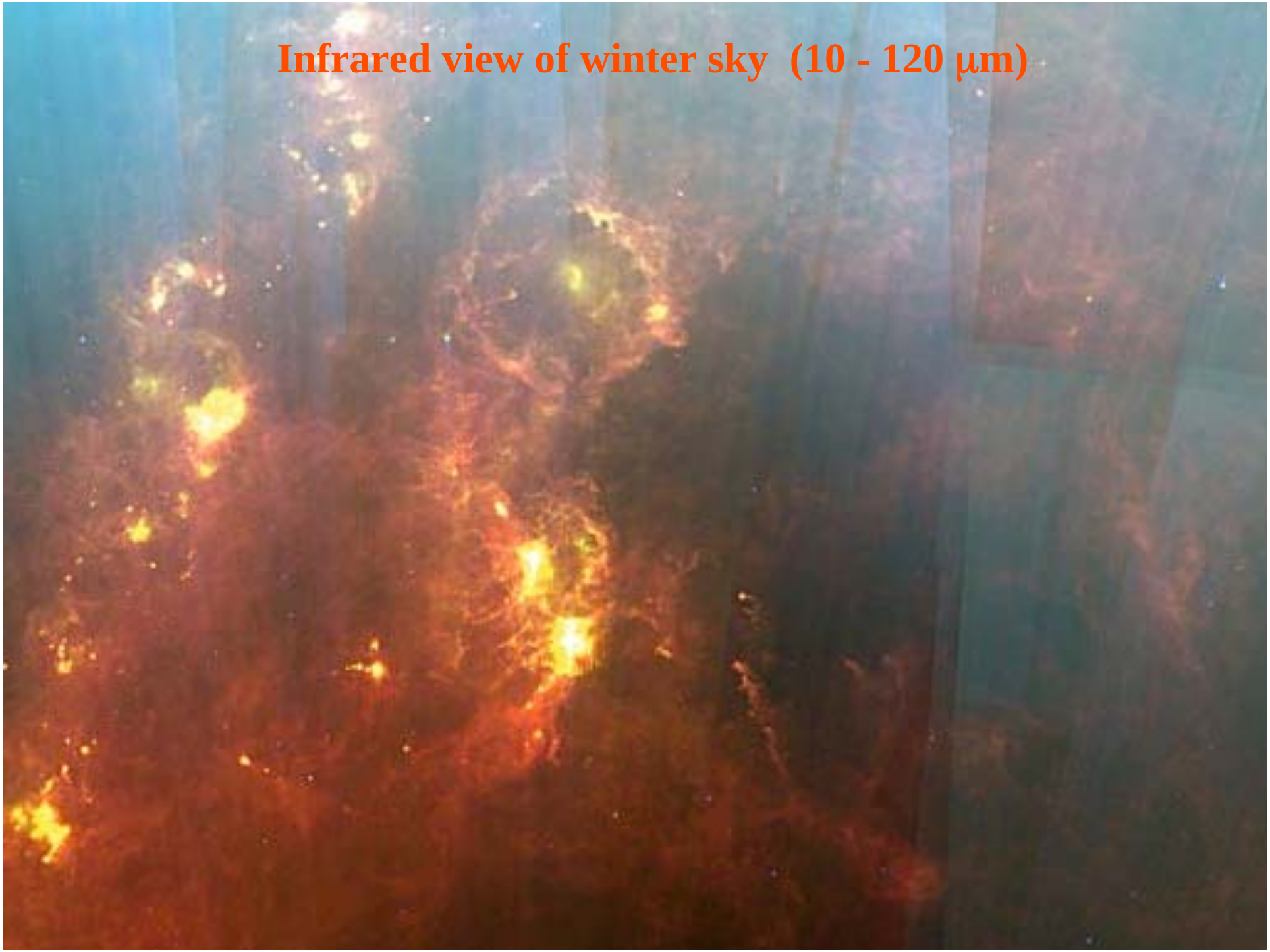

HH 46/47
(Hartigan et al. 05, AJ BR06)
HST 1997



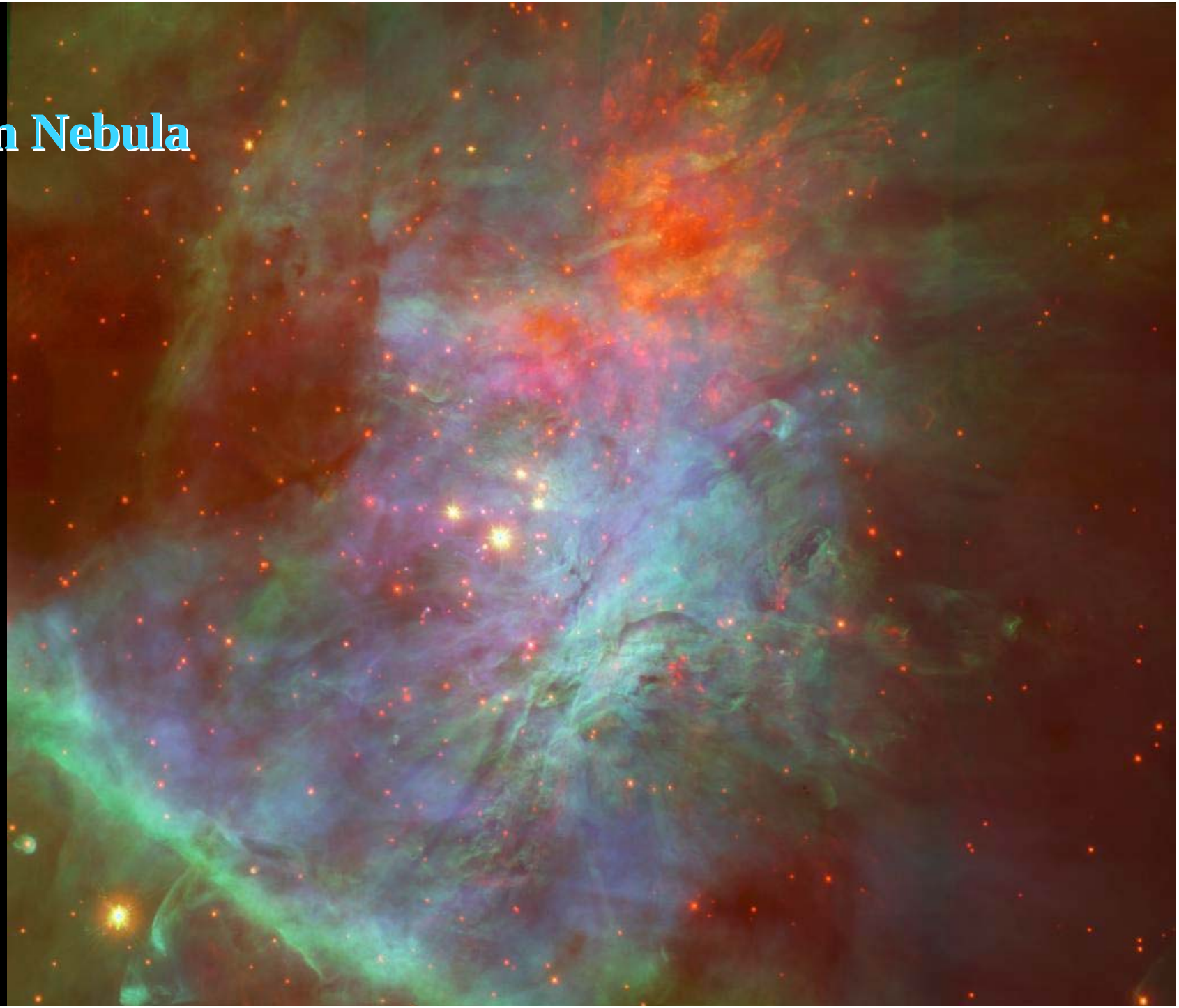
# The Orion Star Forming Complex




Wei-Hao Wang


Infrared view of winter sky (10 - 120 μm)

# Orion Nebula

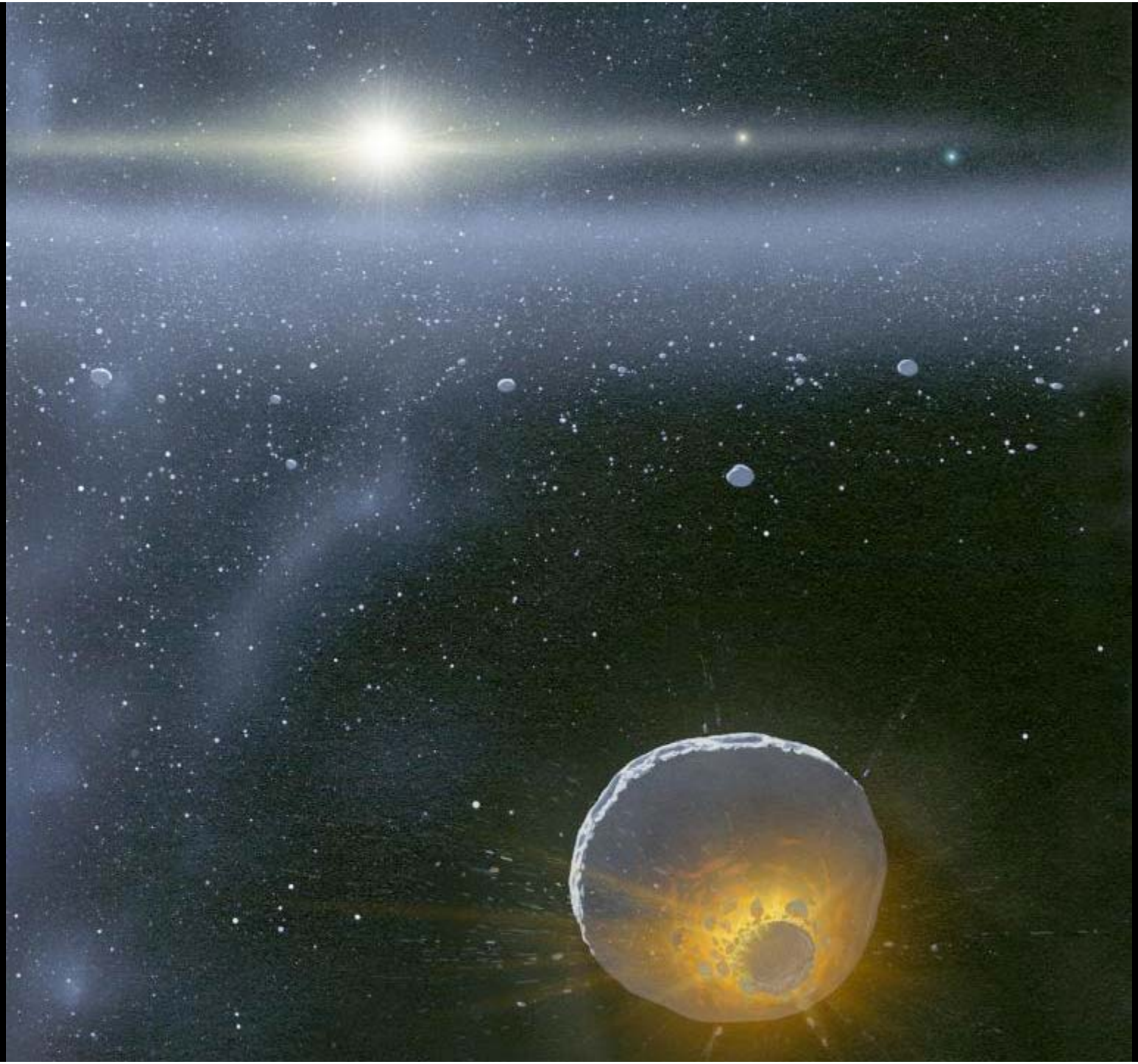


# Planets in Formation?

d253-535 in M43

Smith et al. 05

# Young Proto-planetary Disk



# Evolution of A Star:

- **Birth**

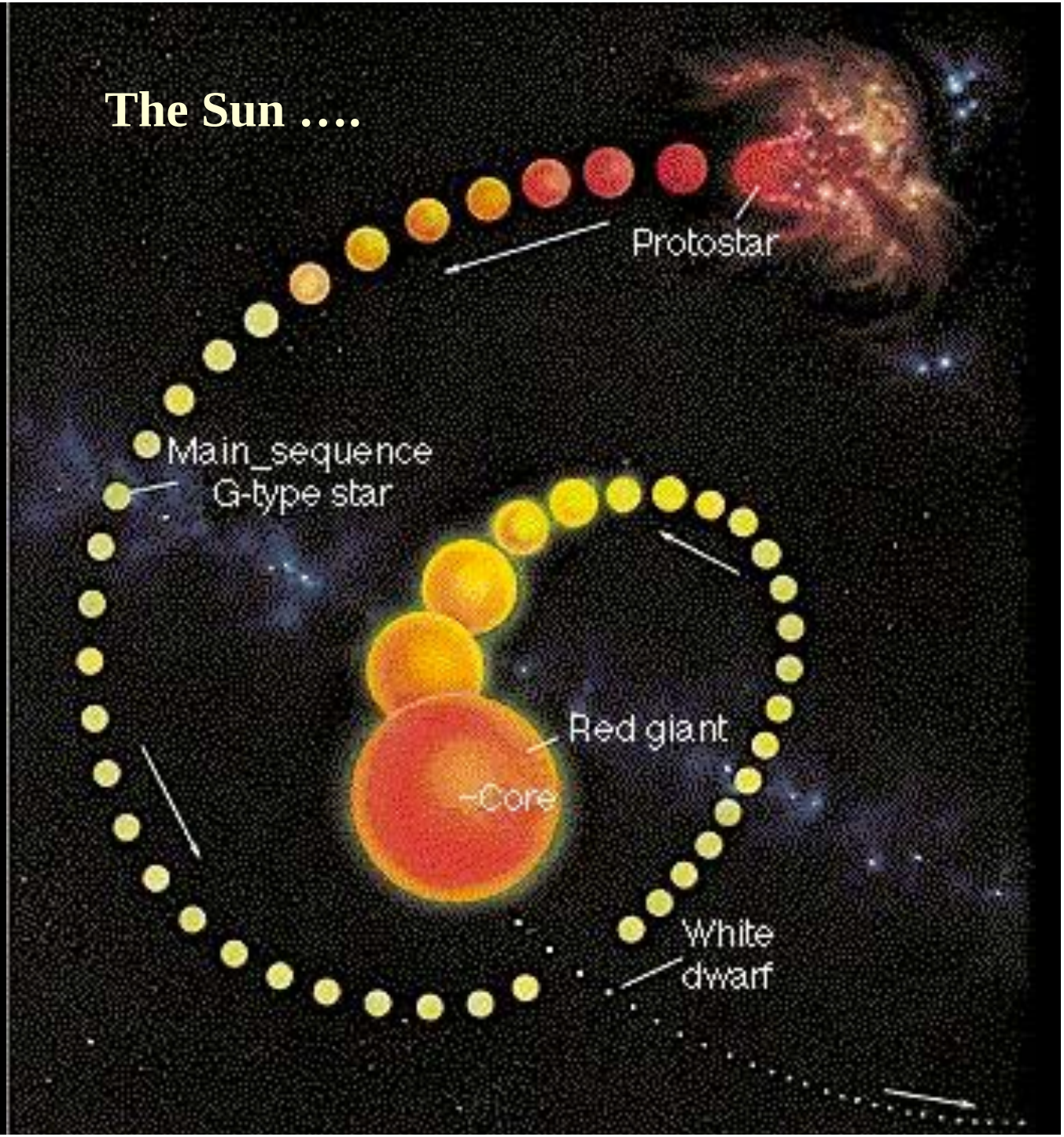
- **Main-sequence life**
  - **fusion: H=>He**

- **Death**

**> 60 M:**
**black hole**

**8 – 60 M:**
**neutron star**

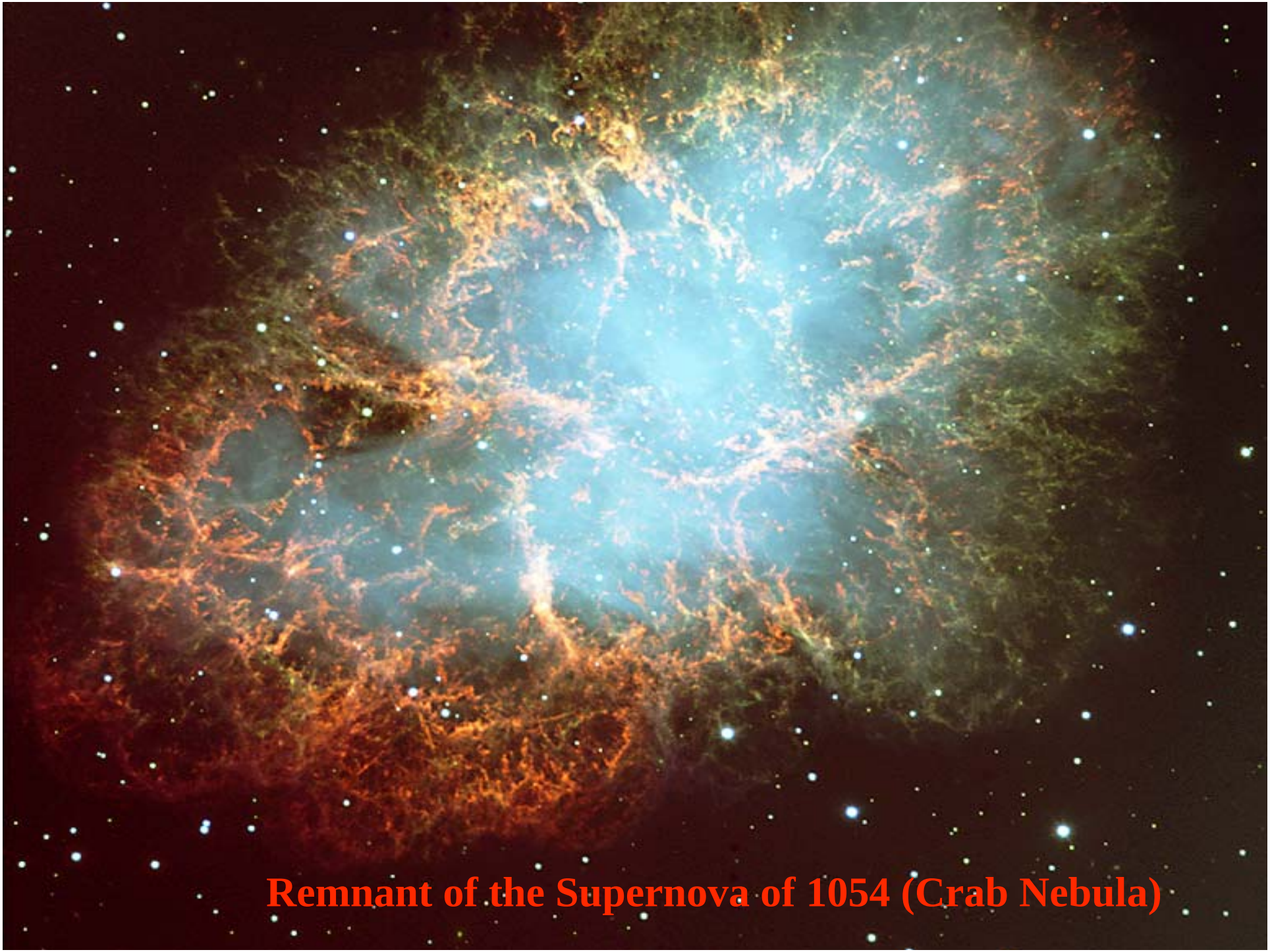
**< 8 M:**
**white dwarf**



**Death of a low-mass star: Core collapses to for white dwarf**

# Eta Carina nebula

# Eta-Carina: Massive star about to die

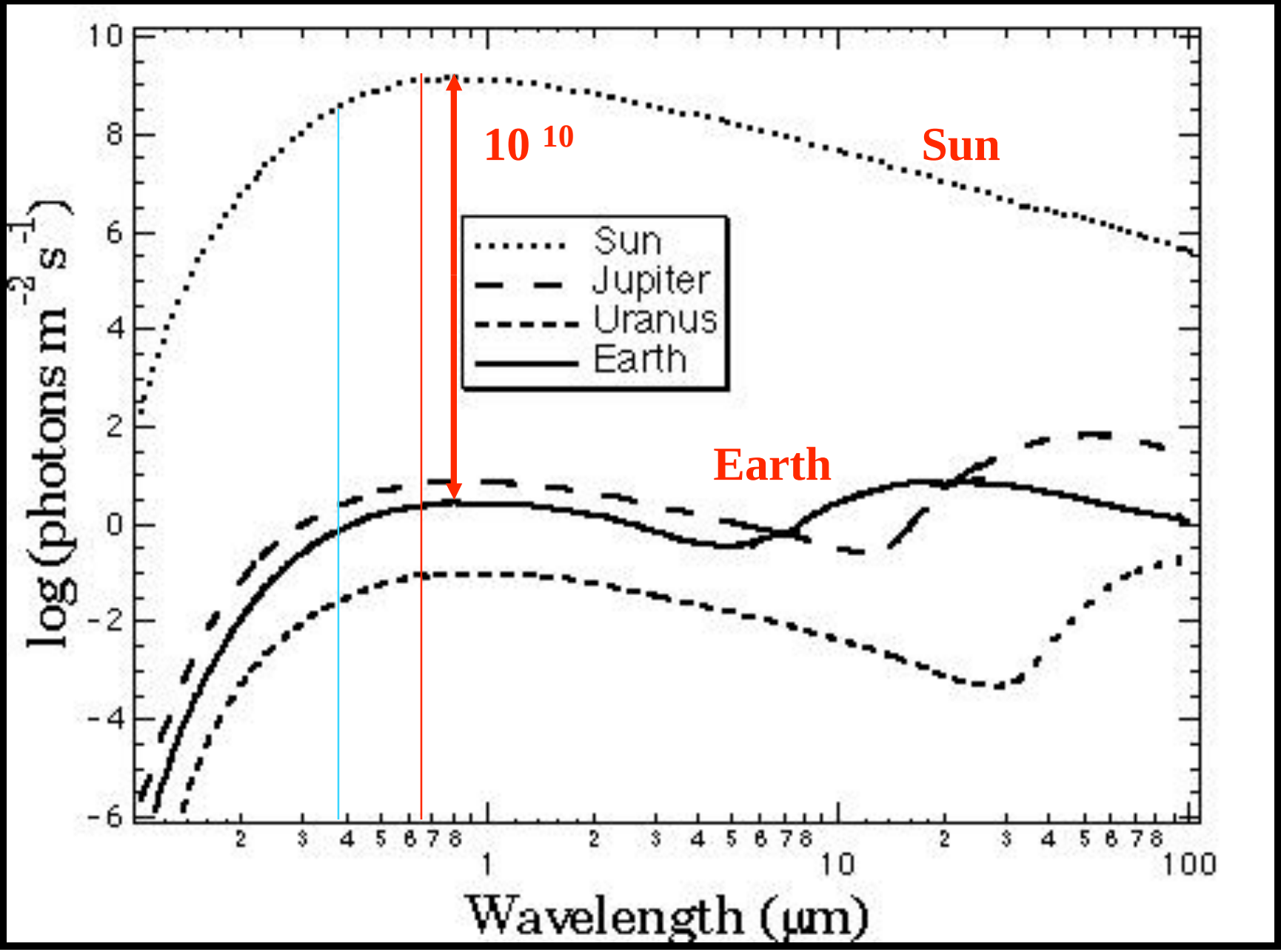

Remnant of the Supernova of 1054 (Crab Nebula)

# The Search Extra-Solar Planets

**Hard: Earth $10^{10}$ (10 billion) x fainter than Sun!**

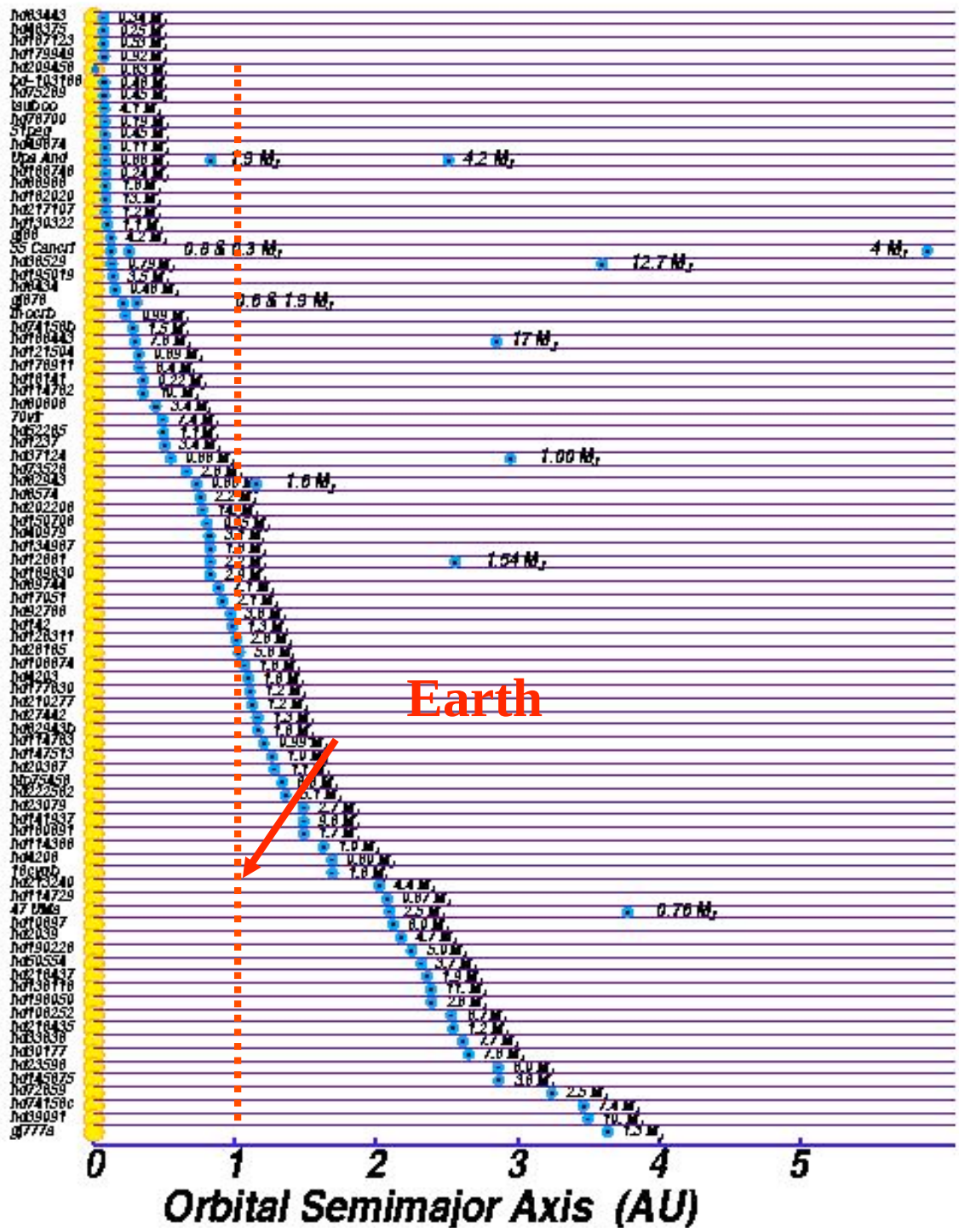
- Stellar Reflex Motion:
  - Periodic Doppler variation
  - Periodic Position change
- Transits (planet blocks light)
- Gravitational Lensing
- Direct detection in images

# Direct imaging of exo-planets is Hard:



# > 200 planets:

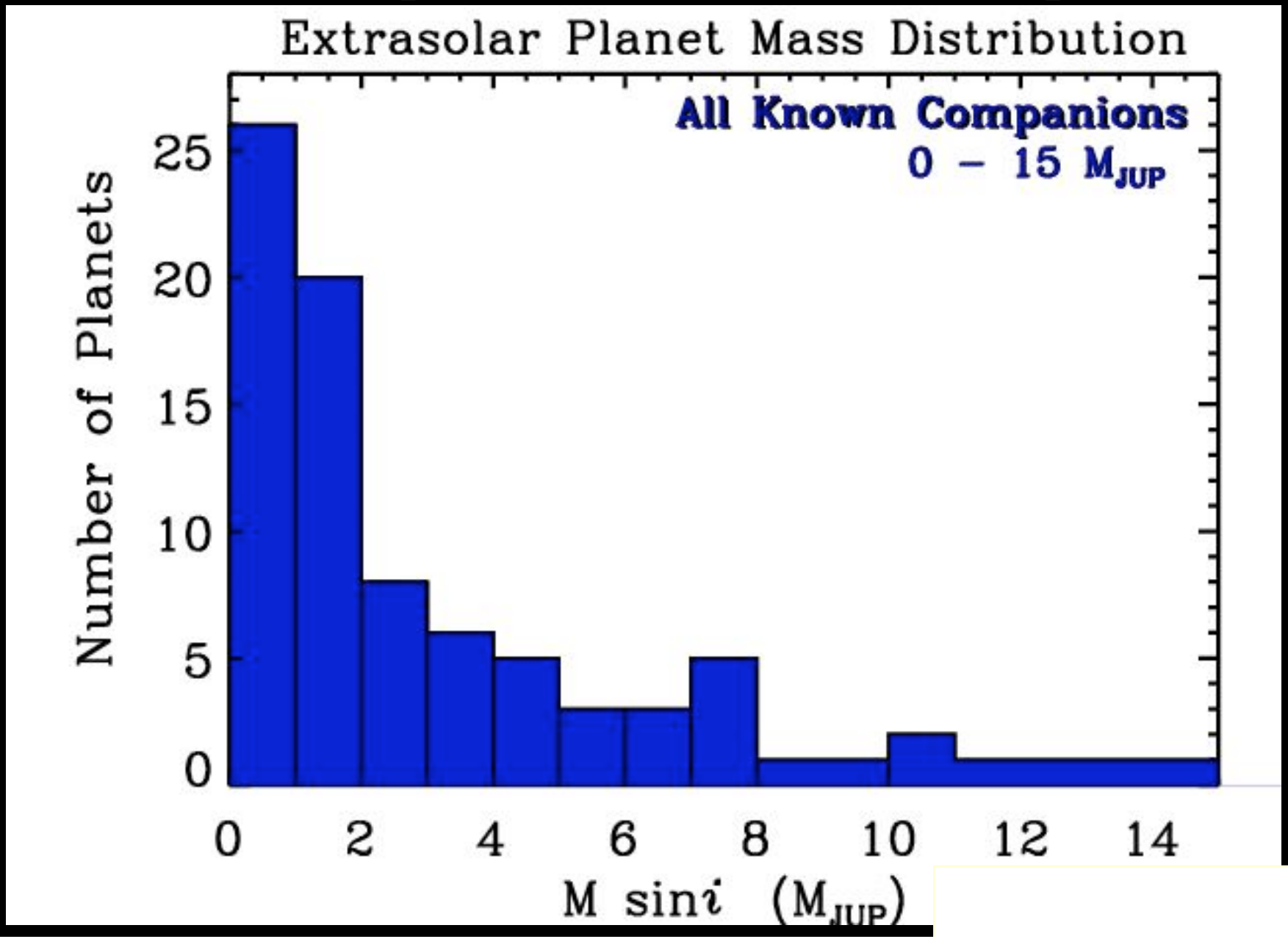
## Most located inside Earth's orbit



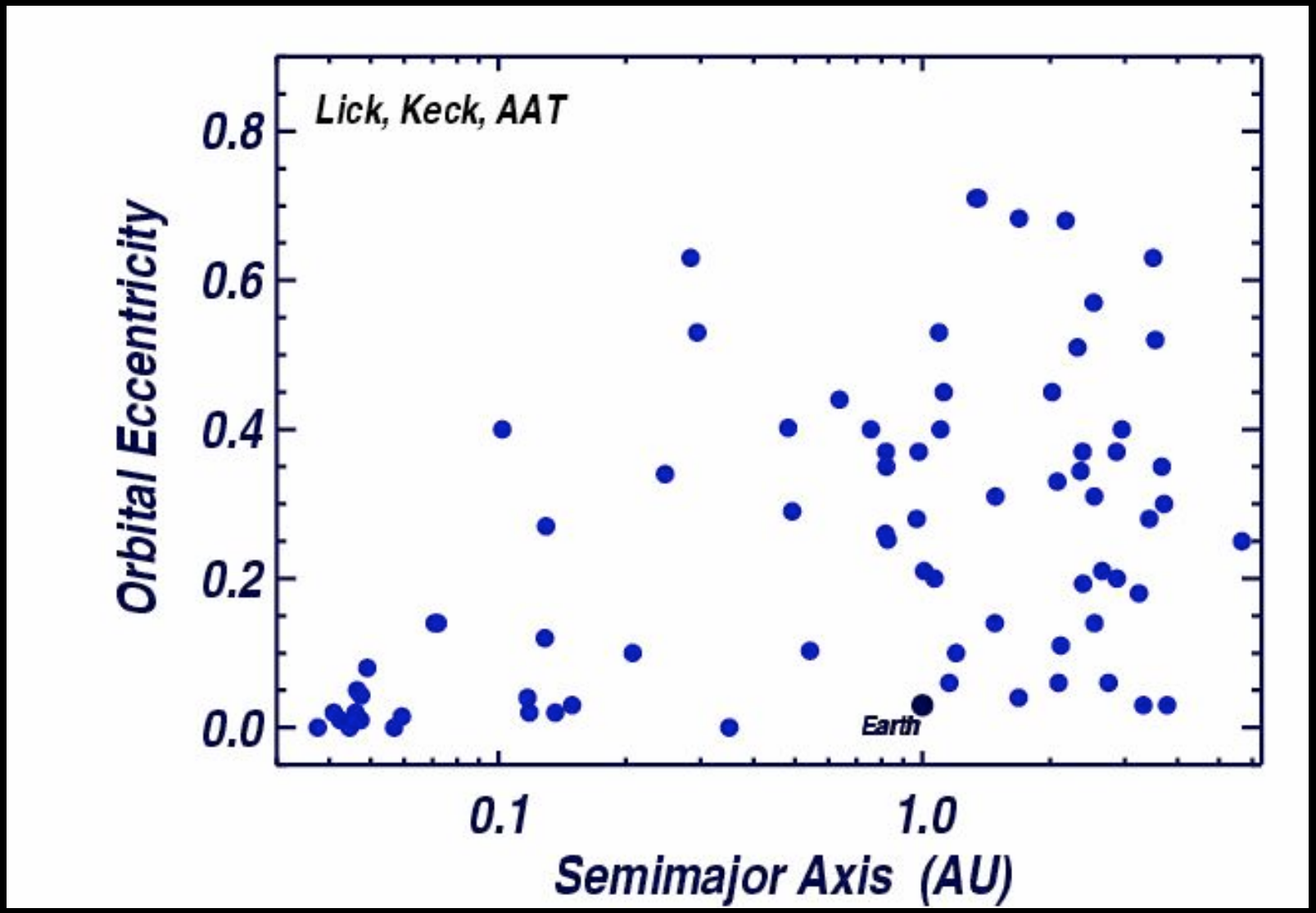

**Goeff Marcy**
**Paul Butler**

**radial velocity method**

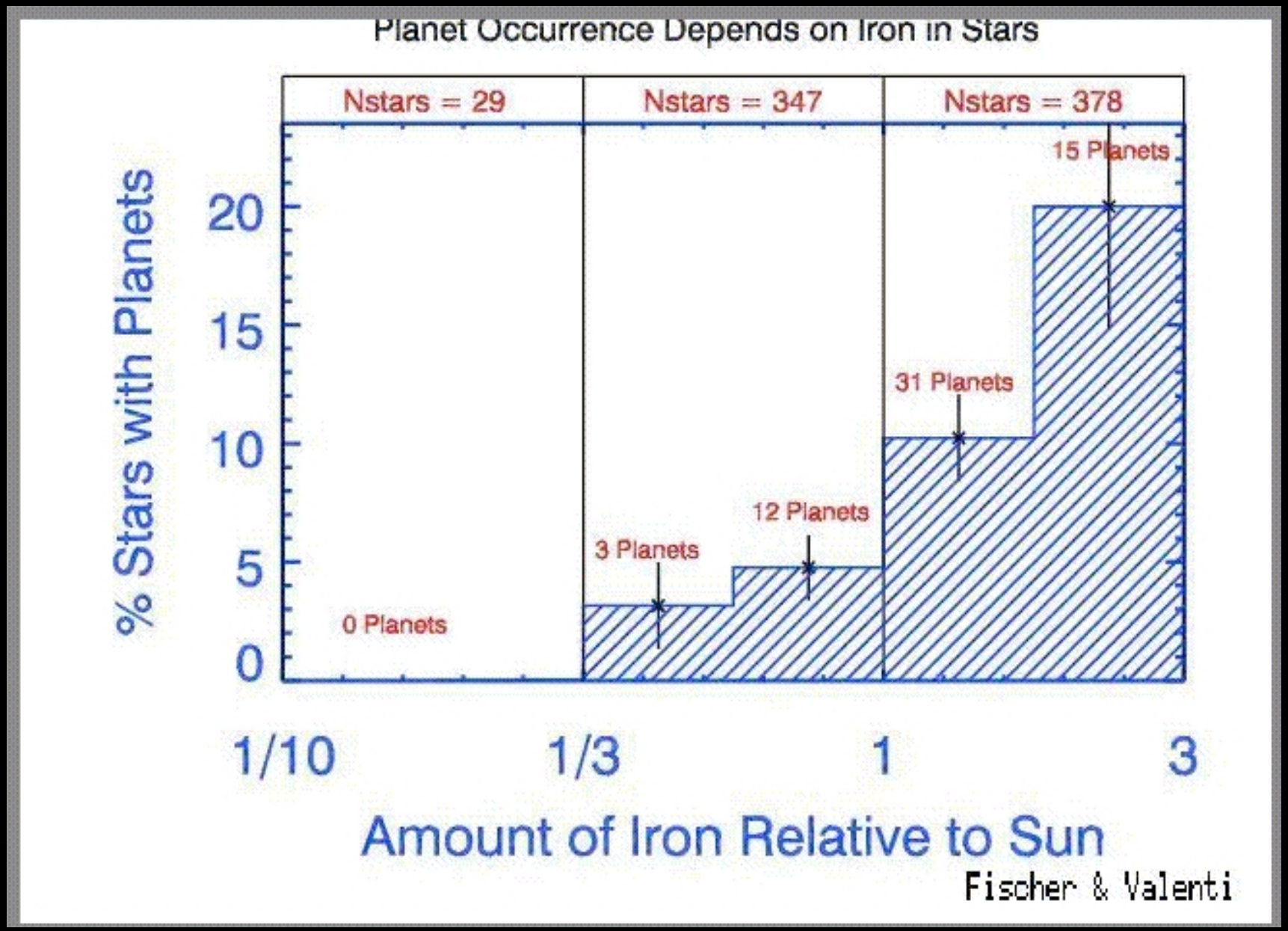
# > 200 planets: Gas Giants like Jupiter



# Orbit eccentricity



# The Metallicity Effect:



The End