

Interstellar Gas

- Interstellar Medium
- Ionized gas
- Atomic gas
- Molecular gas
- Supernova remnants

Interstellar Medium

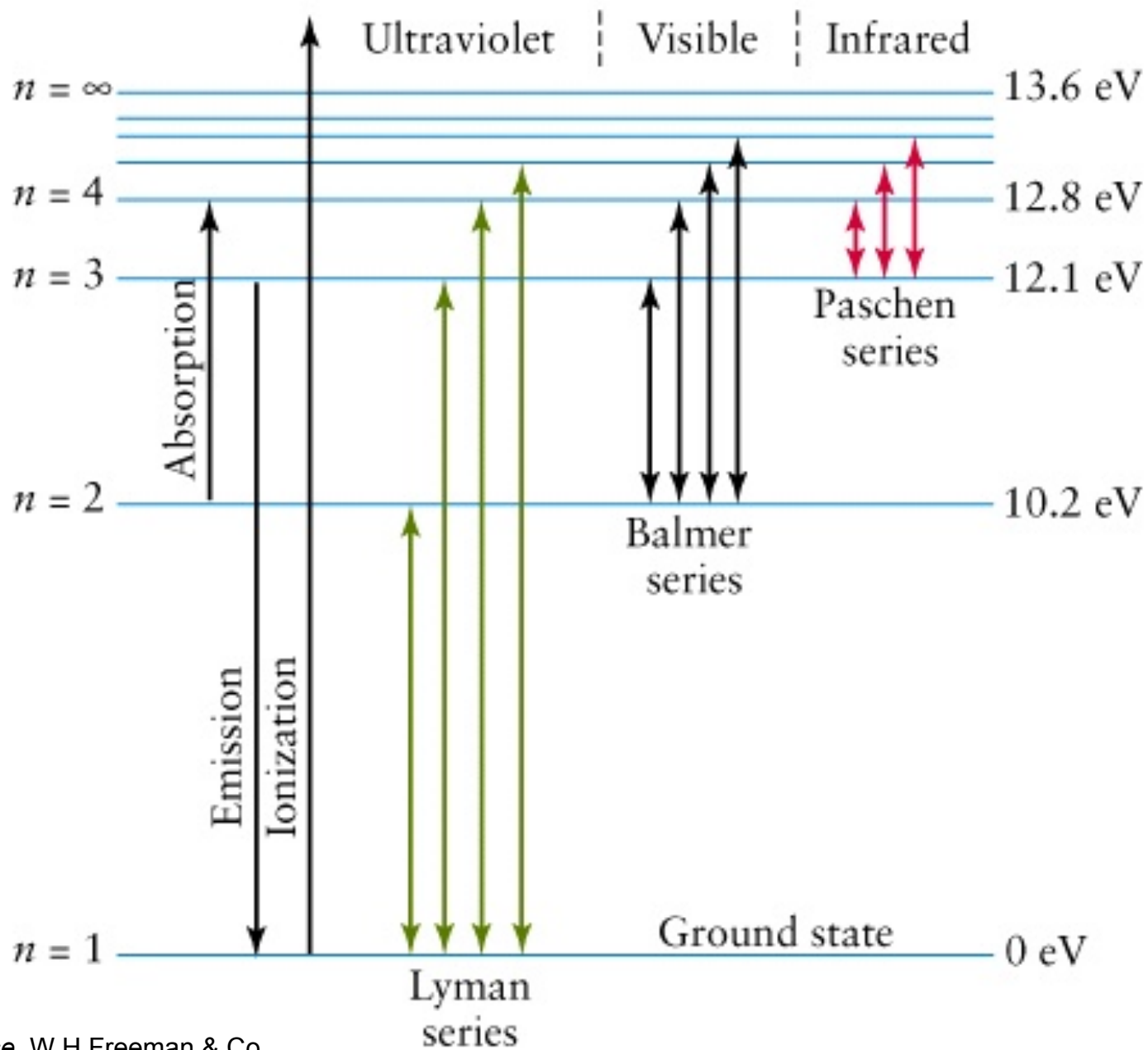
- The space between stars in spiral and irregular galaxies is not empty but contains gas and dust at very low density
- A typical average number density is about 10^6 m^{-3} or 1 particle per cubic centimetre
- However, the interstellar gas exists in a vast range of temperatures and densities



Gemini Observatory

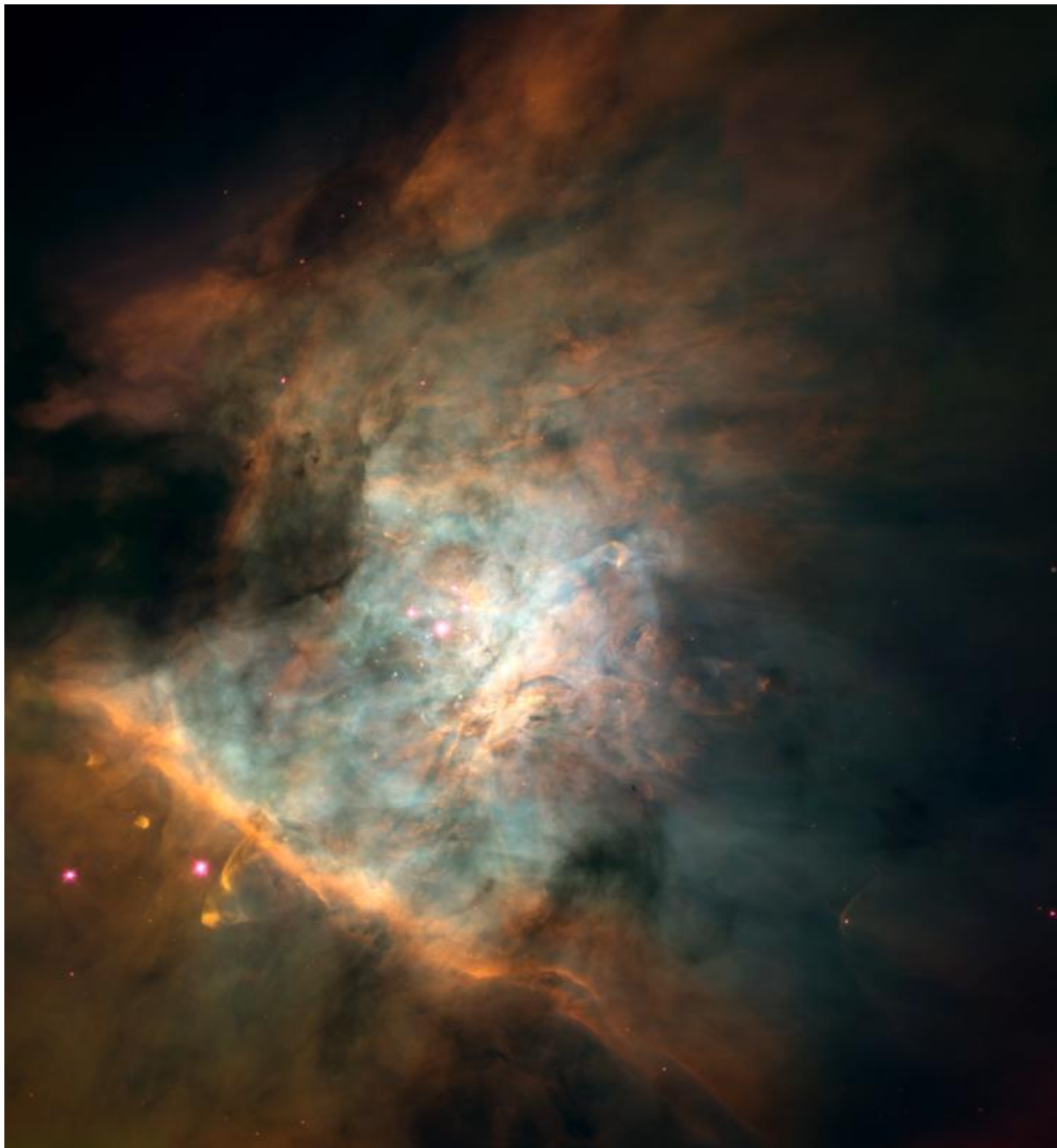
Ionized Gas

- When interstellar gas exists near hot stars it becomes ionized
- Hydrogen (by far the most abundant element) is ionized by photons with energy > 13.6 eV or with a wavelength shorter than 91.2 nm (far ultra-violet)



H II Regions

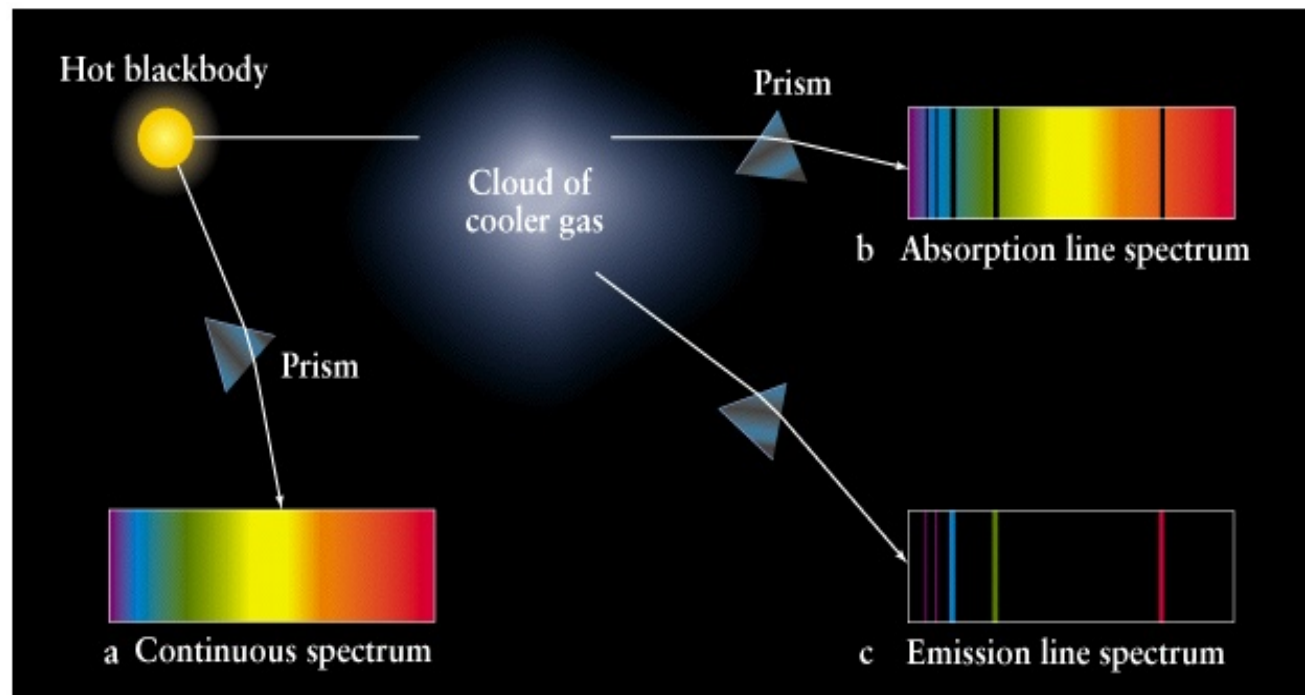
- Massive main sequence stars have $T > 30\,000\text{ K}$
- Young stars are also still surrounded by dense (10^{10} m^{-3}) gas
- gives rise to ionized nebulae called H II regions
- The gas is hot $T \sim 10\,000\text{ K}$ and fluoresces



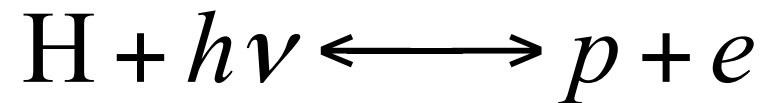
Credit: [NASA](#) and C.R. O'Dell (Vanderbilt University): HST (Optical)

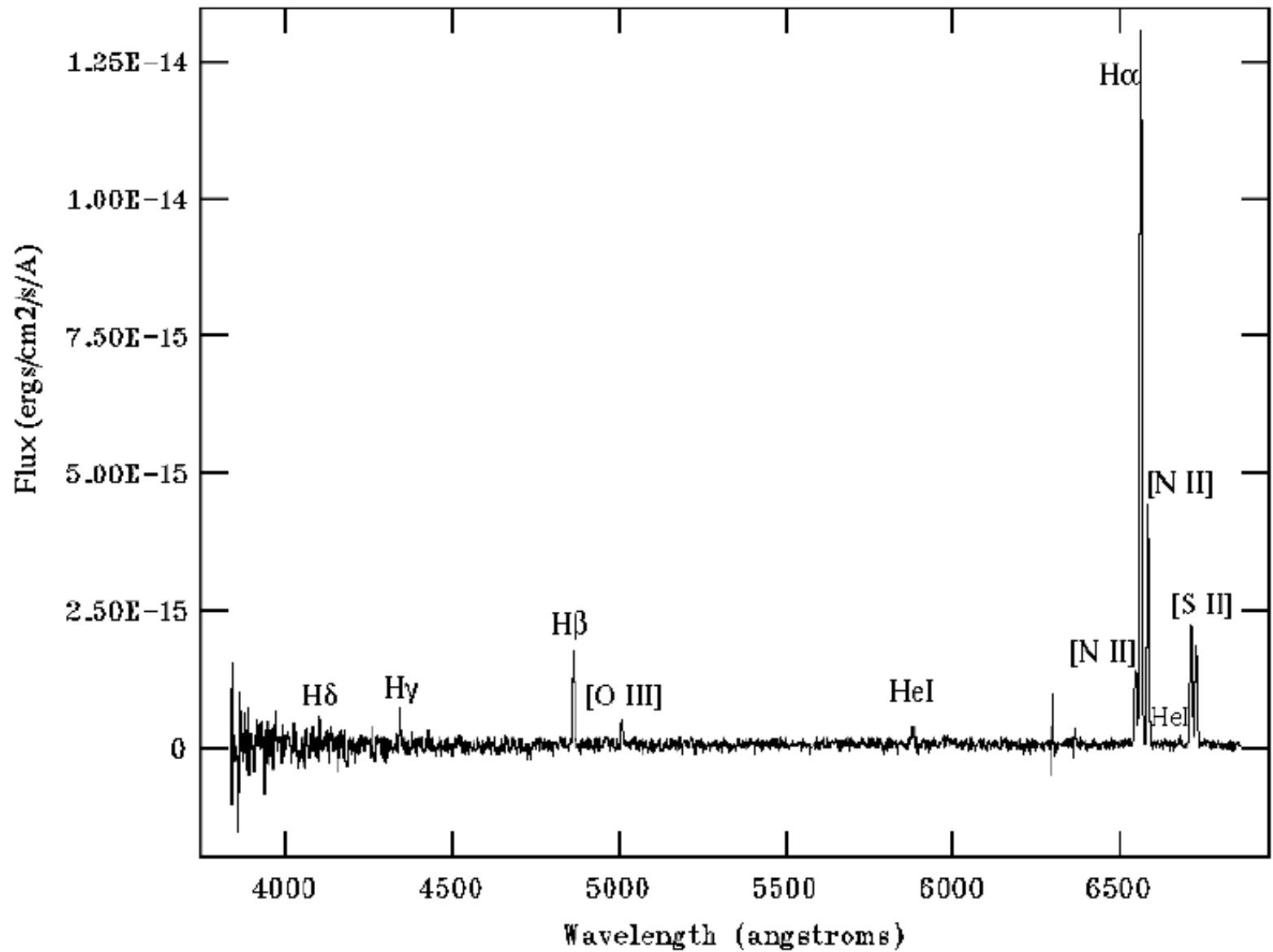
Emission Line Spectrum

- Arise when hot gas is viewed against a colder background



- Optical spectrum is made up of emission lines
- The strongest being the H α line
- These result from the recombination of an electron and a proton following photo-ionization

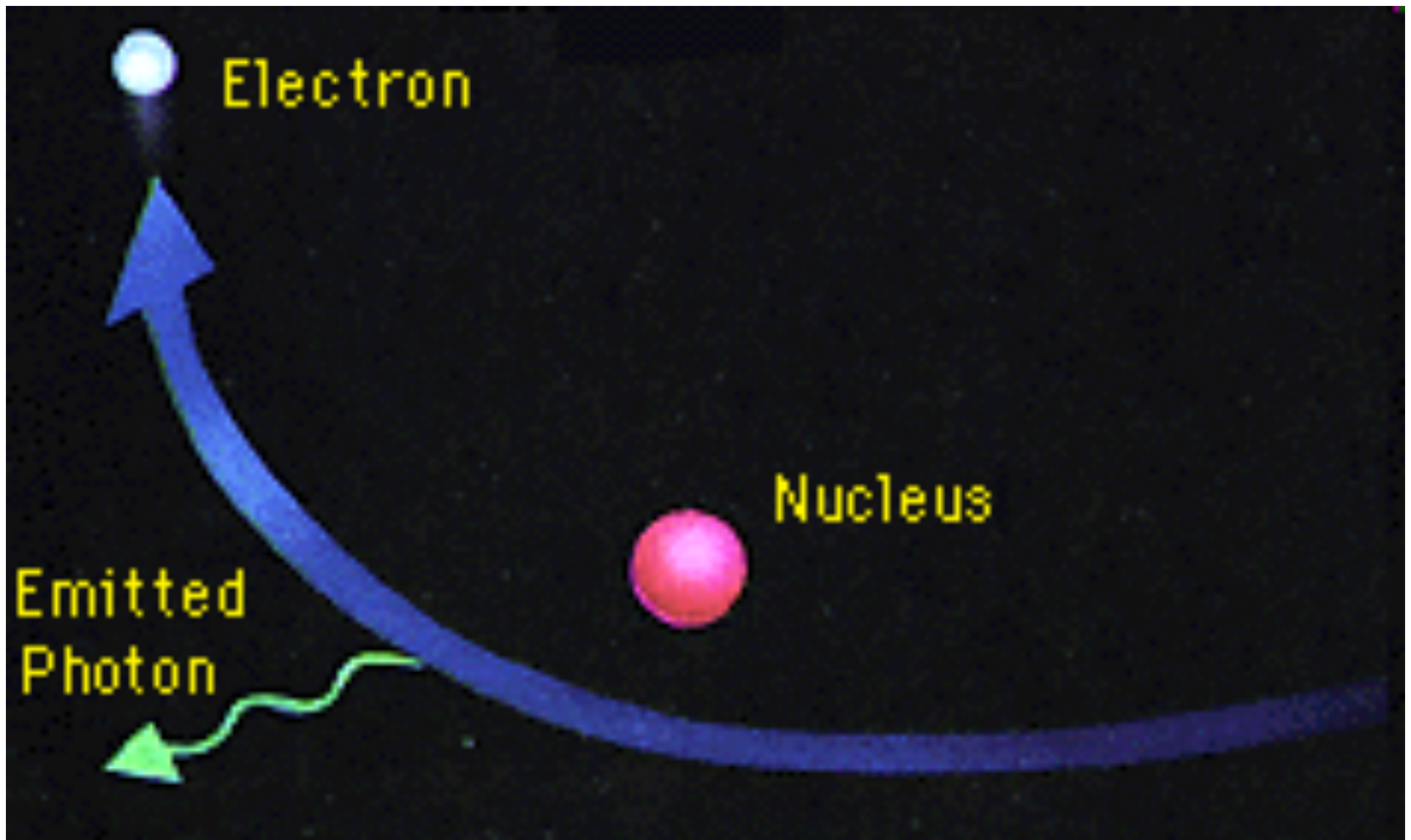




H II Region optical spectrum. S. Temporin_ & R. Weinberger, A&A 420, 225 (2004), Copyright ESO.

Radio Emission

- H II regions also emit strong radio continuum emission
- Occurs when free electrons are accelerated by ions
- This is called thermal bremsstrahlung
- Strong at cm wavelengths

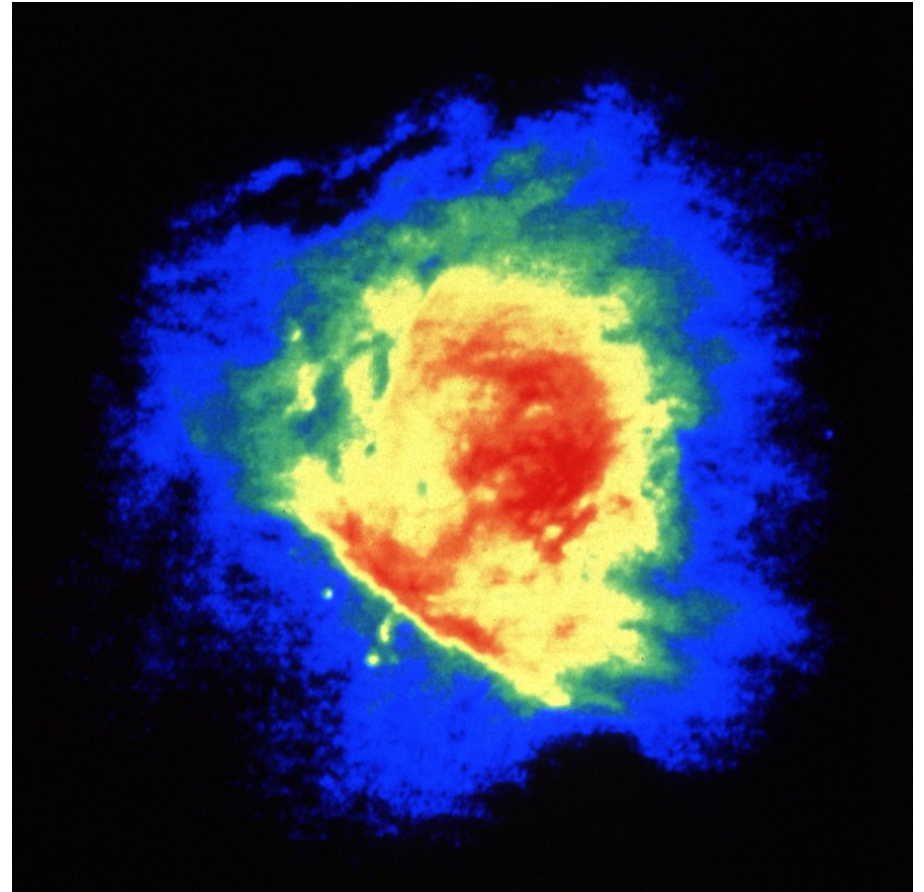


Bremsstrahlung mechanism. NASA [Goddard Space Flight Center](https://www.nasa.gov/goddard).



HST (Optical)

Credit: [NASA](#) and C.R. O'Dell
(Vanderbilt University):

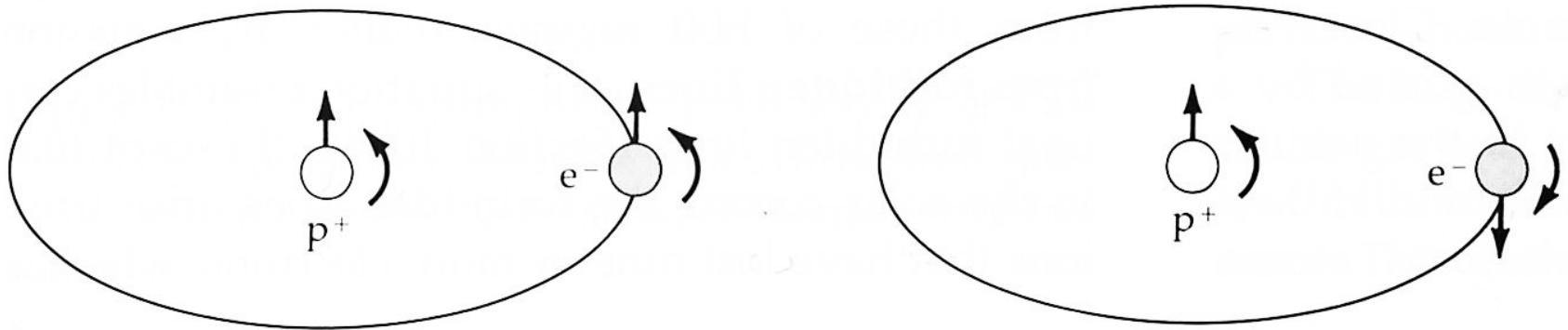


VLA Radio

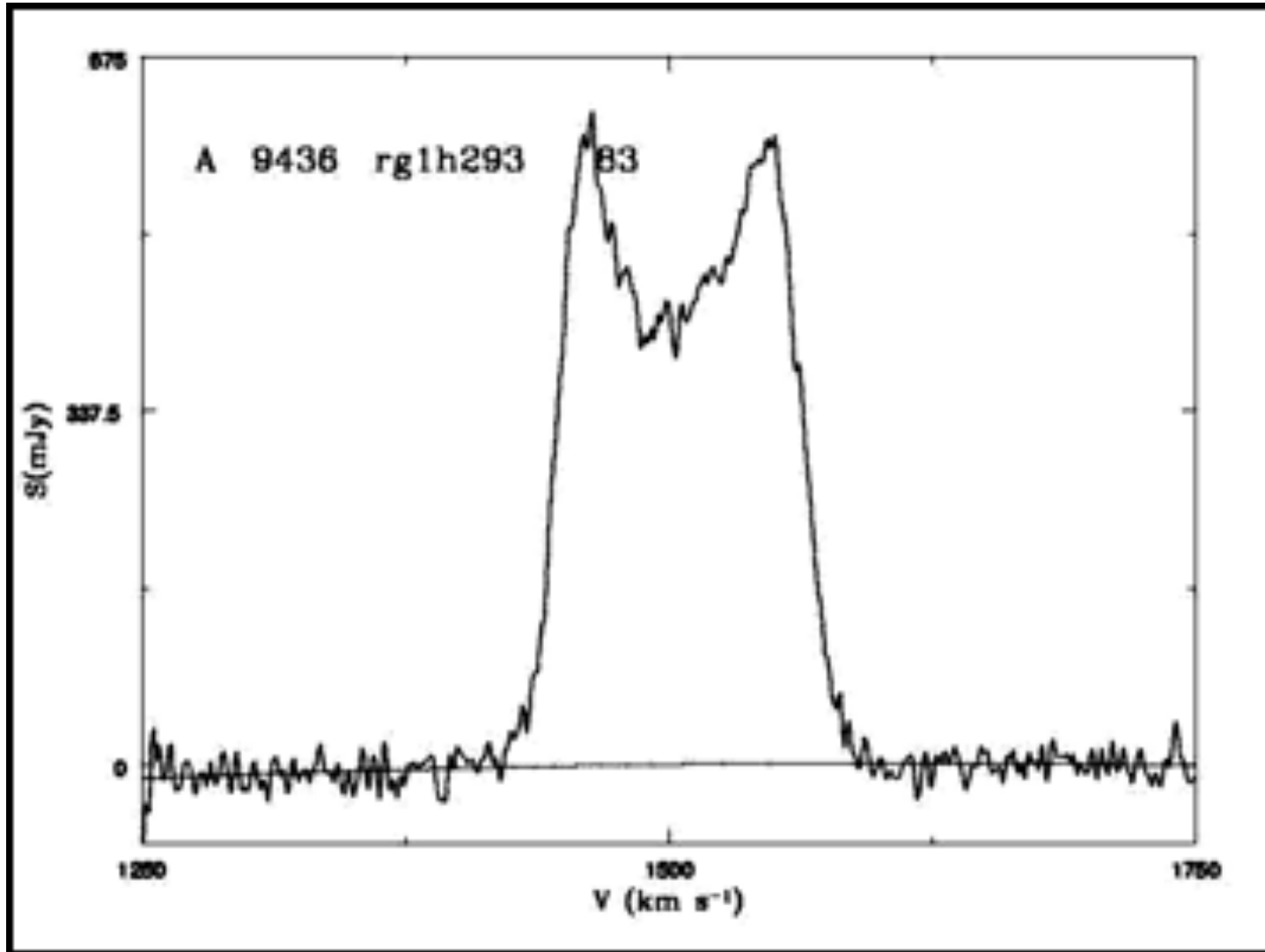
Image courtesy
of NRAO/AUI

Atomic Gas

- Most of the mass of interstellar gas is in atomic form or H I
- Typical densities of 10^6 m^{-3}
- It is cool ($T \sim 100 \text{ K}$) and in the ground state
- Can only emit via a hyperfine transition that occurs at a wavelength of 21 cm in the radio part of the spectrum



21 cm Hyperfine transition in atomic hydrogen. Zeilik Fig 15-12



Example H I line profile for a galaxy



Shell of H I emission in our Galaxy

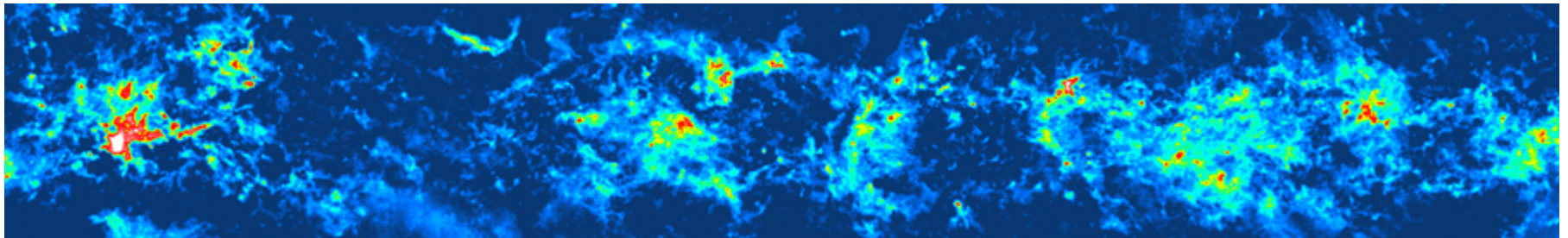
Image courtesy of NRAO/AUI and Jayanne English (U. Manitoba) & Jeroen Stil, supported by Russ Taylor (U. Calgary)

Molecular Gas

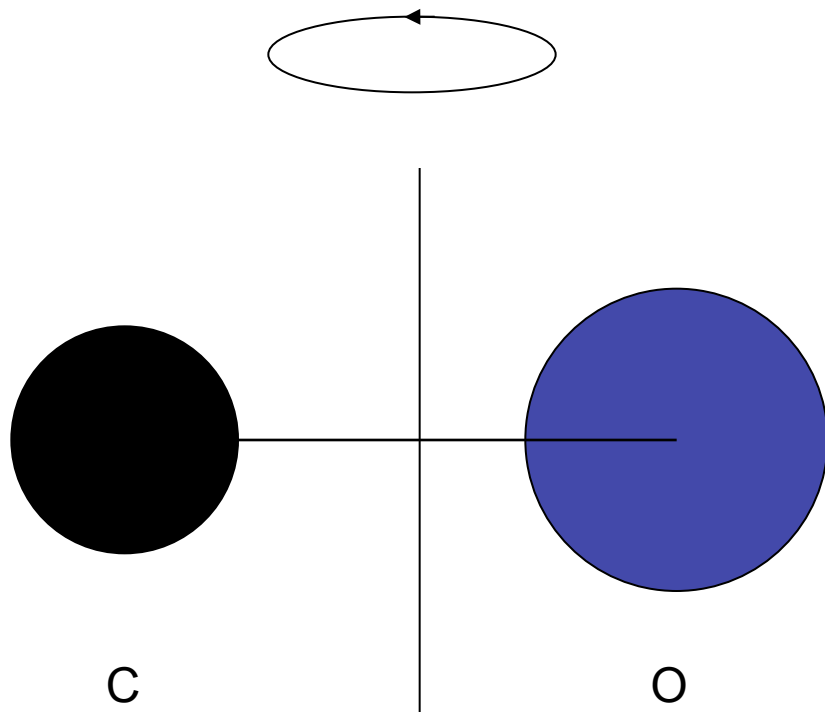
- In dense (10^{10} m^{-3}), cold ($T < 30 \text{ K}$) regions molecules form from the atomic phase
- Molecular hydrogen (H_2) does not normally emit
- Other trace molecules have to be observed instead, principally carbon monoxide (CO)

CO Observations

- The CO molecule emits due to rotational transitions excited by collisions
- The ground state transition is at $\lambda \sim 3$ mm
- Many other molecules are observed
- These and H_2 are destroyed (dissociated) by ultra-violet radiation ($\lambda \sim 120$ nm)



¹³CO survey of the Milky Way



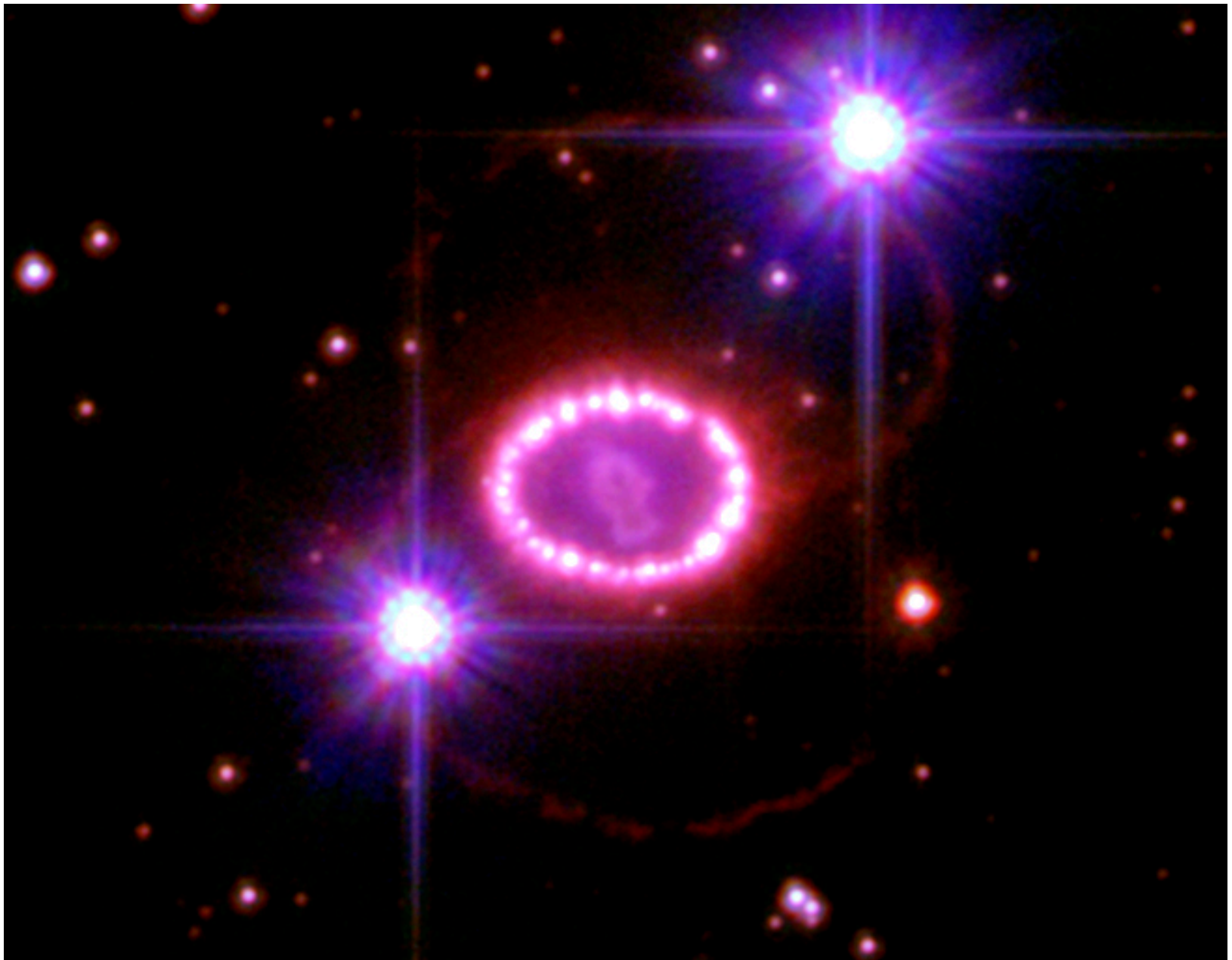
Rotational transition of the CO molecule.

Supernova Remnants

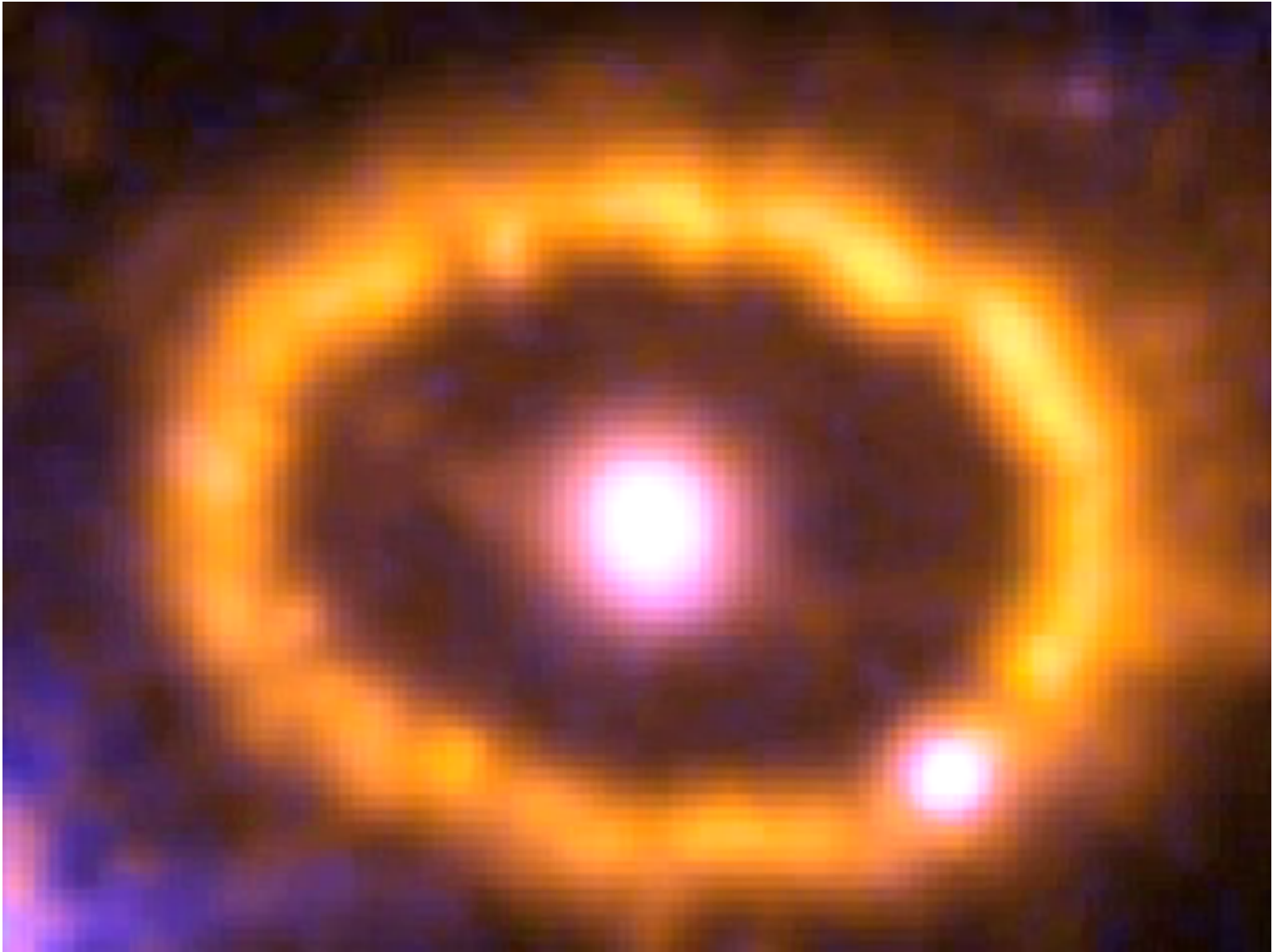
- The exploding material is initially ejected at mildly relativistic speeds
- Shocks to very high temperatures $\sim 10^6$ K which emits at X-ray wavelengths
- They continue to expand for \sim million years before reaching equilibrium and hence fill a large volume of the galaxy with a tenuous hot phase of the ISM



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NASA HST image of SN 1987A



NASA HST movie of SN 1987A

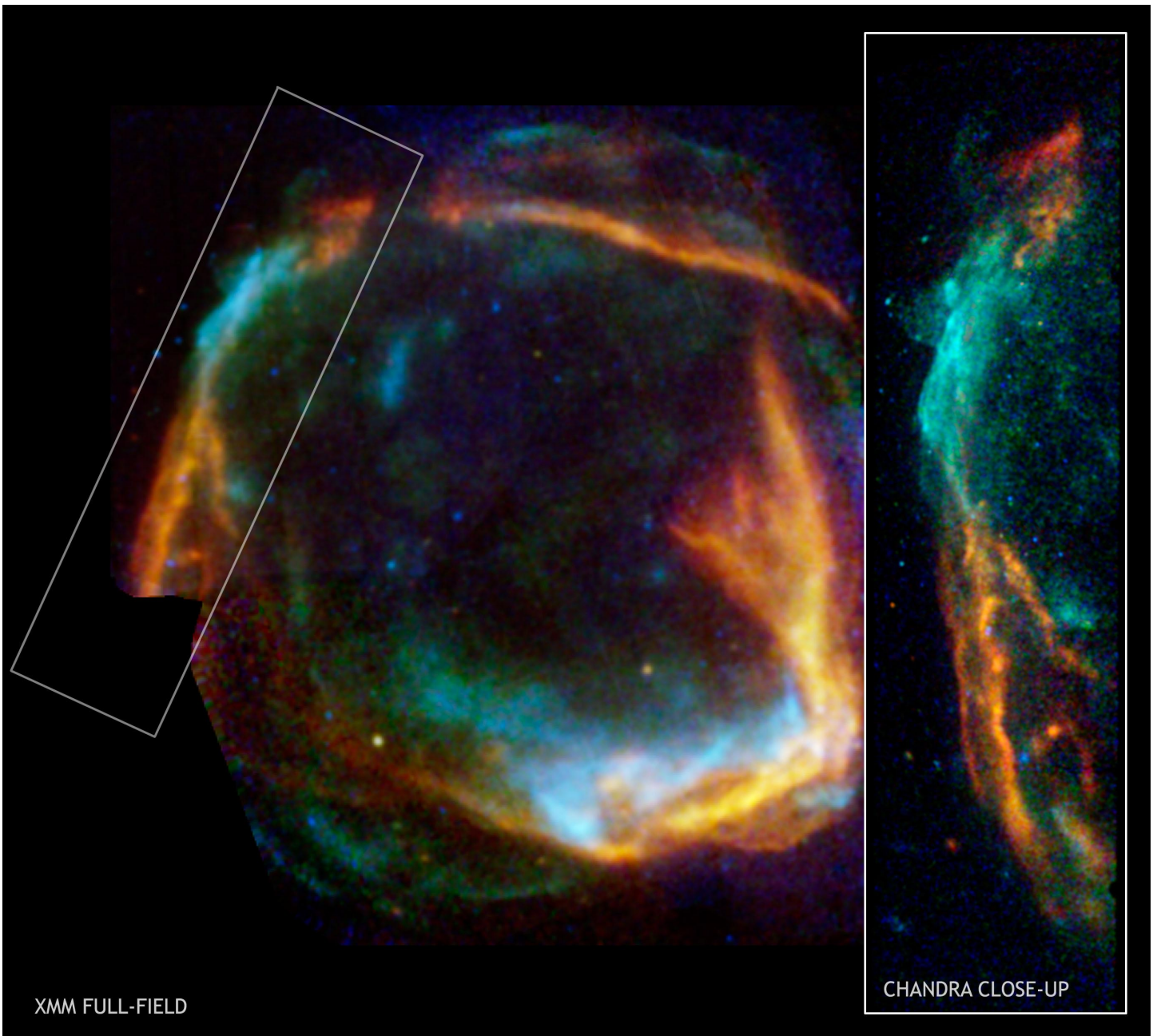
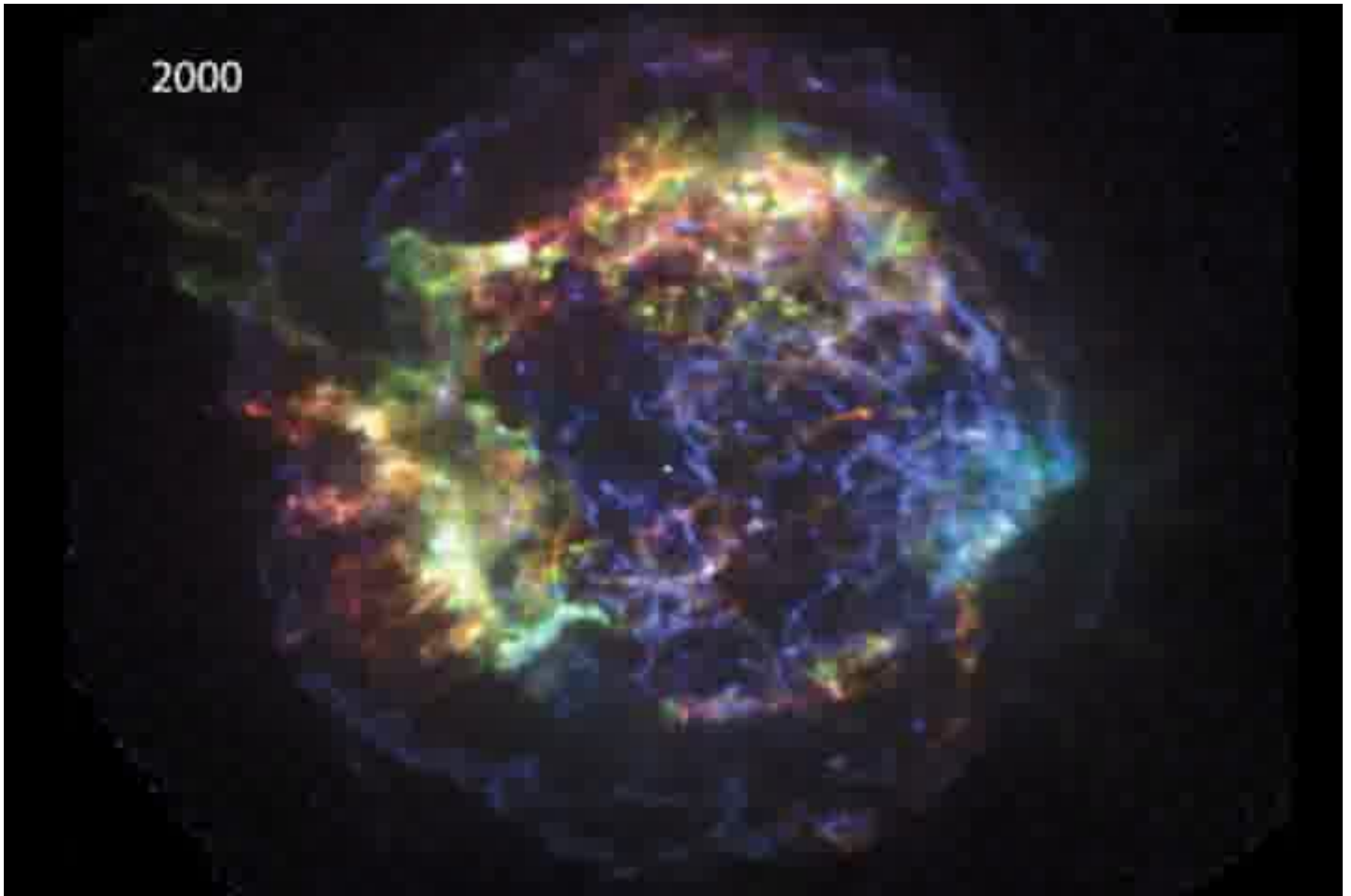


Image courtesy of Jacco Vink (SRON Utrecht)

Oldest-recorded supernova unveiled by XMM-Newton and Chandra

European Space Agency

Credit: Chandra: NASA/CXC/Univ. of Utrecht/J.Vink et al. XMM-Newton: ESA/Univ. of Utrecht/J.Vink et al.

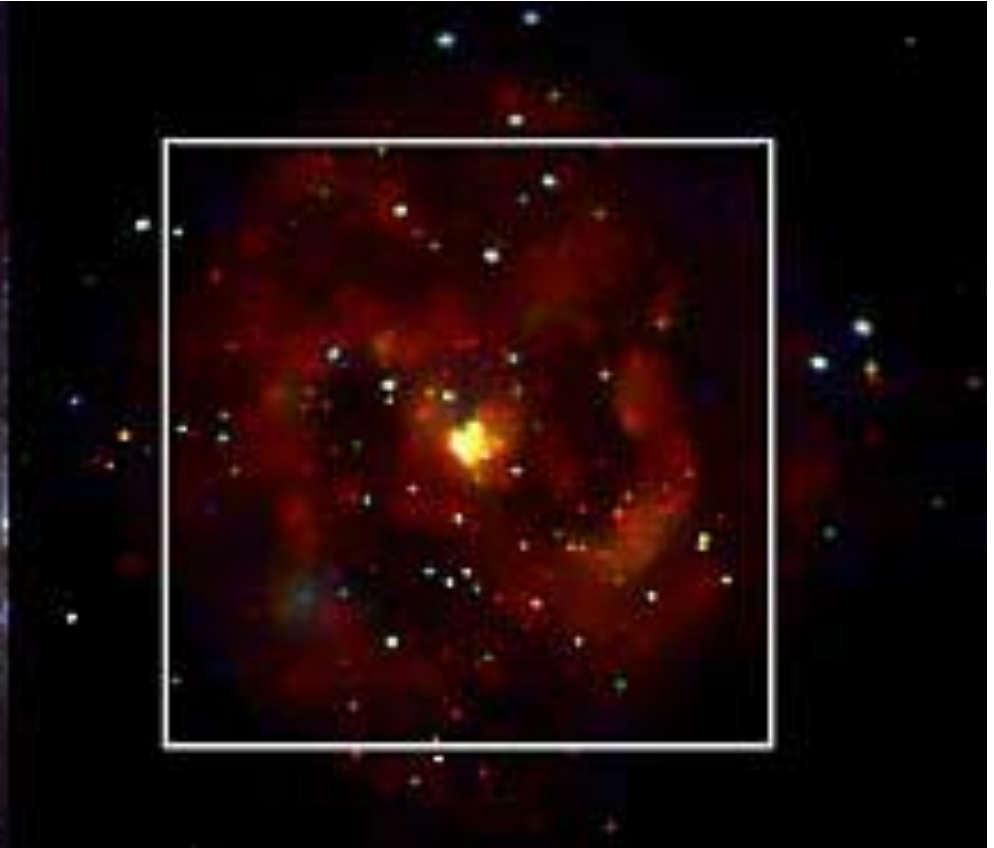


Cas A SNR Movie

Credit: NASA/CXC/SAO/D.Patnaude et al.



Optical from ESO

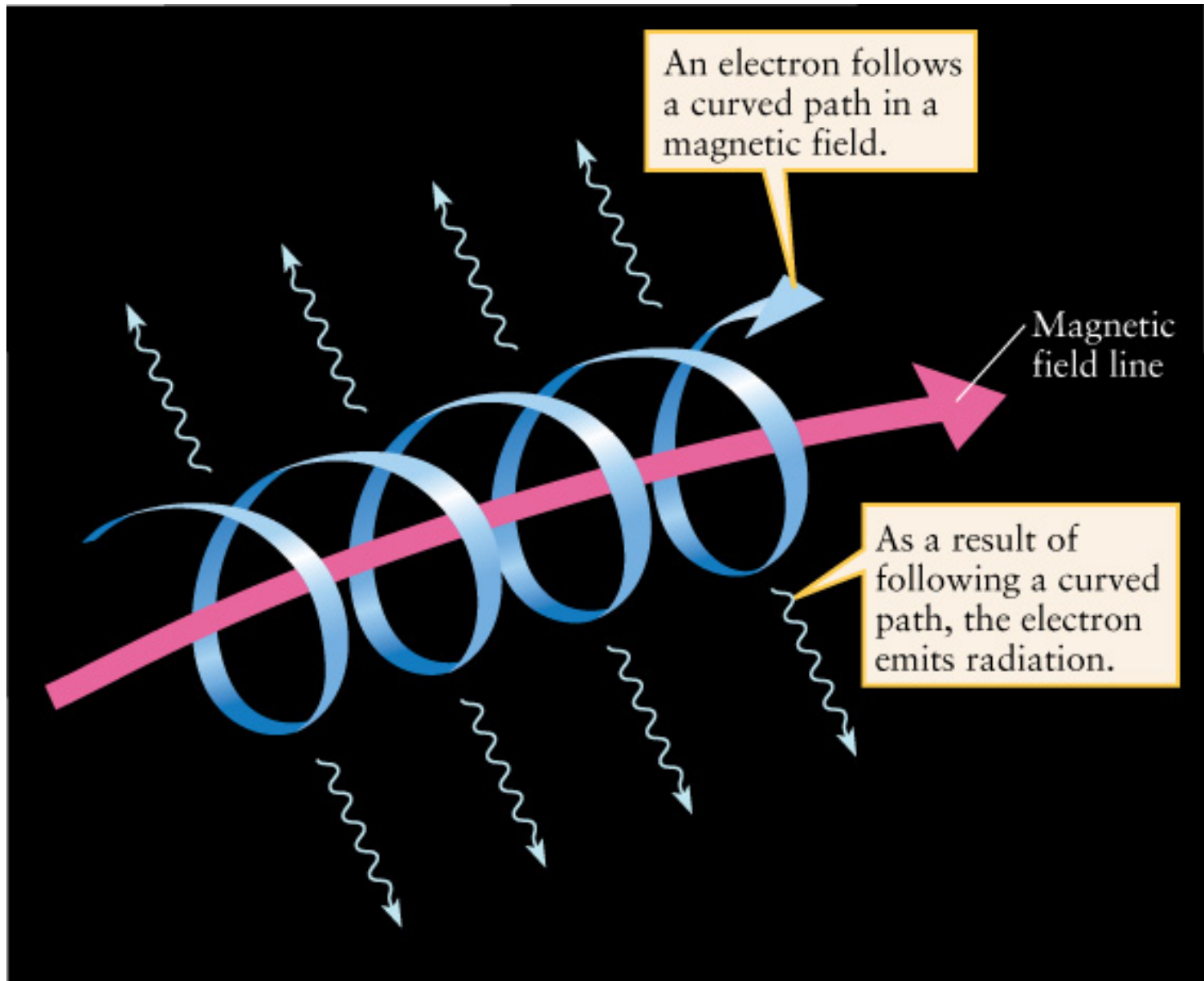


X-rays from NASA Chandra Satellite

Spiral galaxy M83 showing diffuse X-ray emission along the spiral arms from hot phase of the ISM

Radio Emission

- Supernovae also emit strongly at radio wavelengths
- The combination of fast moving electrons and magnetic fields gives rise to synchrotron radiation
- The electrons spiral around the magnetic field





SN1006

X-ray: (blue)

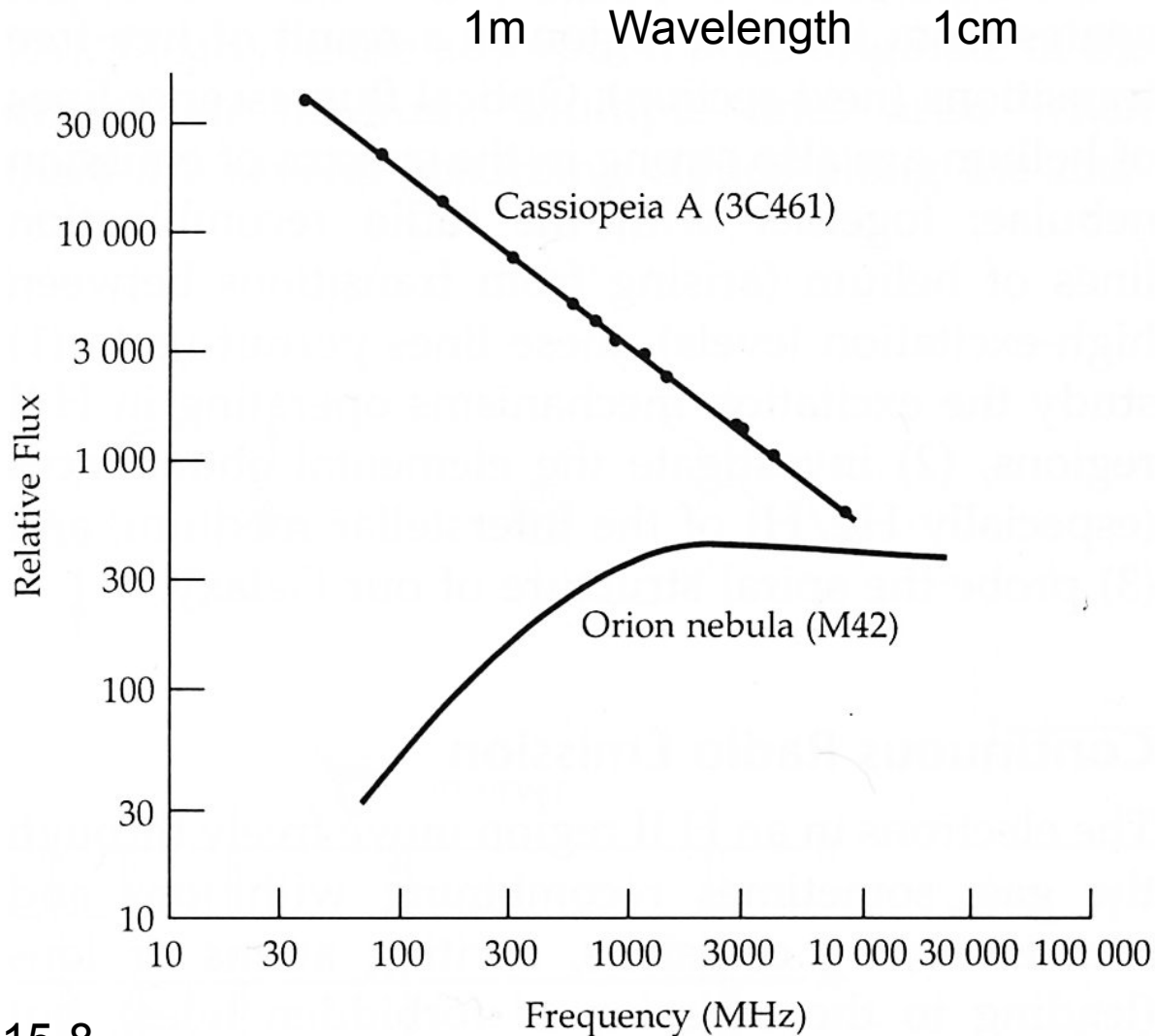
Radio: (red);

Optical:(yellow)

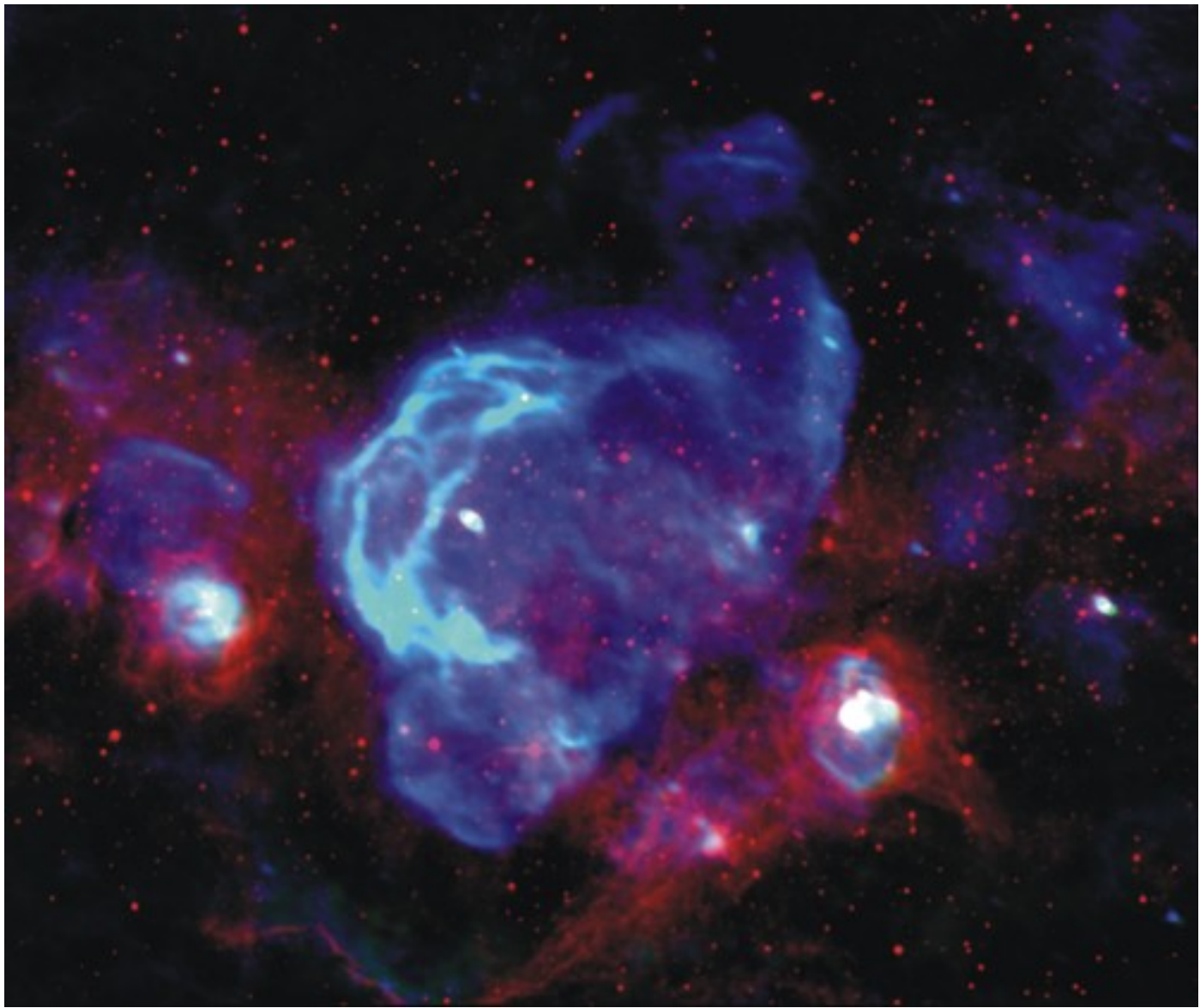
Credit: X-ray: (blue) NASA/CXC/Rutgers/G.Cassam-Chenaï, J.Hughes et al.; Radio: (red) NRAO/AUI/NSF/GBT/VLA/Dyer, Maddalena & Cornwell; Optical: (yellow) Middlebury College/F.Winkler, NOAO/AURA/NSF/CTIO Schmidt & DSS

- The synchrotron radiation is strongest at long radio wavelengths ($\lambda \sim 1$ m)
- Also referred to as non-thermal radio emission to distinguish it from thermal bremsstrahlung

- Note the different slopes of the radio spectra for thermal sources like the H II region M42 and non-thermal sources like the SNR Cas A



Zeilik Fig 15-8



W28 region with SNRs and H II regions

Blue: radio 90 cm; Red mid-infrared 8 microns

Image courtesy of NRAO/AUI and Brogan et al.

Summary

- H II regions arise where massive stars form and are observed mainly in H α and cm-wave radio continuum
- H I is observed using the 21 cm line and makes up most of the mass of the ISM
- H₂ is traced using mm lines from molecules such as CO and is the material from which stars form

- Supernova remnants are one of the main sources of energy input into the interstellar medium
- They can be observed at X-ray and long wavelength (m) radio wavebands
- They are responsible for the hot phase of the interstellar medium