Astronomy & Astrophysics : An Introductory Survey

A lecture series by Prof. G. Srinivasan

A ‘Golden Jubilee Celebration’ Event of the Astronomical Society of India

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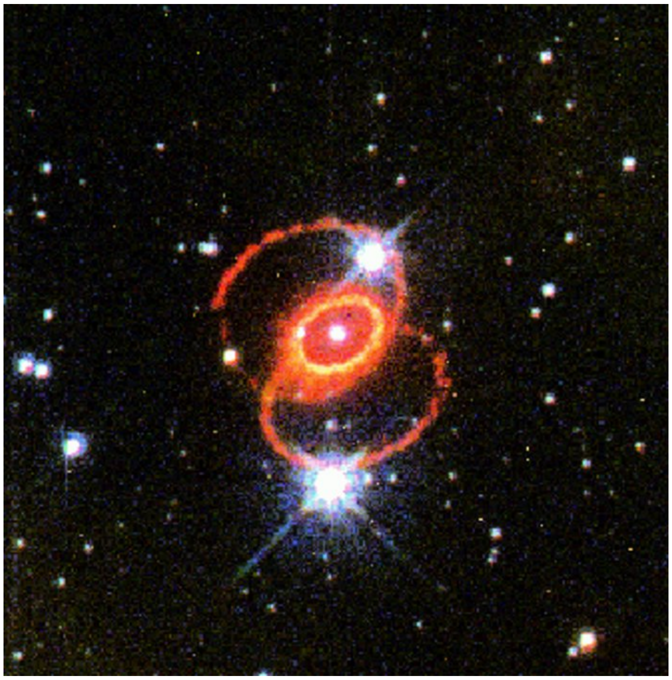
Lecture 13 : Life History of Stars III

Massive Stars



On 23 February, 1987, modern astronomers had their first opportunity to study a supernova in detail. Seen above is SN 1987A, a supernova in the Large Magellanic Cloud. This has been the closest supernova to be observed since Kepler’s Supernova seen in CE 1604. After eluding the astronomers for over thirty years, indirect evidence for the existence of the neutron star within the supernova remnant has finally been found in 2019. [Image from : https://esahubble.org]

In massive stars (mass greater than roughly 10 solar mass) fusion reactions proceed all the way till Iron the most stable nucleus is formed. That signals the end of the ‘stellar drama’. When the mass of the iron core increases to a critical value, it collapses, triggering the explosion of the envelope of the star, known as a Supernova. This lecture builds up this ‘stellar drama’ from first principles.

Youngsters following the lecture course must read the following paper (at least the first two sections) by S. Chandrasekhar discussed in this lecture. This is a classic paper of great import, but has not really received its due (perhaps completely shadowed by the phenomenal success of Chandrasekhar’s other papers written before and after).

- S. Chandrasekhar, 1932, ***Zeitschrift fr Astrophysik***, 5, 321

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Lecture 13 : Massive Stars

[Supplementary Material : Dr. Sushan Konar]

Suggested Problems

1. Stellar evolution time-scales are very large compared to human life-times. How can our theories of stellar evolution be tested against observation?
2. Consider a large region of the galaxy in which star formation is, on the average, continuously occurring over a very long period of time. In such a region (unlike in a single cluster), the HertzsprungâĂŞRussell diagram would not evolve with time. What ratio of super-giant stars to main sequence stars is to be expected for $25\mathrm{M}_\odot$stars? (Hint: Think about the time such a star spends on the main sequence.)
3. Imagine that a star only 1 pc from Earth goes supernova and achieves a luminosity of 10^{11} $\mathrm{L}_\odot$(solar luminosity).
   - (a) What is the flux at Earth in cgs units?
   - (b) By what factor is the flux on the Earth's surface increased over that from the Sun alone?
   - (c) What will be the temperature of the Earth when it reaches a new thermal equilibrium?
   - (d) Would life on Earth survive?
   - (e) How distant would the supernova have to be if the temperature on the Earth is to remain below 140° F?
   - (f) Assuming the density of stars in the galaxy is $0.1/\mathrm{pc}^3$, there are 10^{11} stars in the galaxy, and there is one supernova every 30 years, how often would a supernova that raises Earth's temperature above 140°F occur?
   - (g) Severe high energy radiation would hit the Earth if the supernova were within 20 pc. How often does this happen?
4. The centers of massive stars are hot enough for radiation to provide a significant fraction of the total pressure. Consider stellar interiors made up on fully ionized non-degenerate gas, where the gas and radiation field are at the same temperature.
   - (a) Obtain the relationship between density and temperature in a gas for which $\beta = 0.1$, i.e. gas provides only 10% of the total pressure. Evaluate the temperature required to satisfy this condition for $\rho = 10\ \mathrm{gm.cm}^{-3}$.
   - (b) Instead of a gas-radiation fluid of fixed density and temperature, consider one of fixed density and total (gas plus radiation) pressure. Derive a quartic equation for β in terms of P and ρ. Obtain solutions to the equation in the limits of $P \to 0$ and $P \to \infty$.
   - (c) Let $U = U_{gas} + U_{rad} = \int_0^M (u_{gas} + u_{rad})\, dm$ be the total internal energy in a star, including both gas and radiation. Assume that β is uniform throughout the star. Show that the virial theorem implies that the total energy of the star is $E = U + \Omega = (\beta/2)\Omega$, where Ω is the gravitational binding energy. What do you conclude about how strongly bound a massive, radiation-dominated star is compared to a low-mass star that has negligible radiation pressure support?

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