Astronomy 404
November 20, 2013

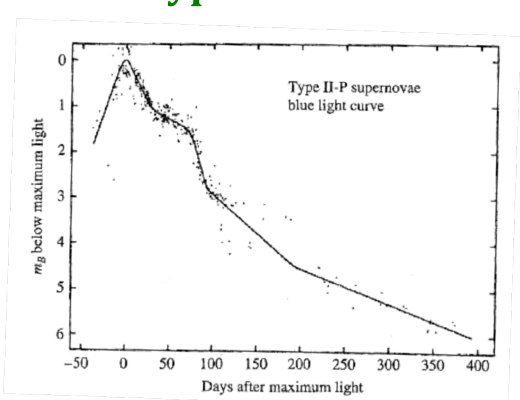
The collapse of the core of a massive star starts with the **photodisintegration of Fe and He**, which consumes thermal energy. The subsequent **capture of e^- by p^+** reduced the number of electrons that provided degeneracy pressure. These events lead to the **core collapse**. The collapse produces a neutron star ($M_{ZAMS} < 25\ M_\odot$) or a black hole ($M_{ZAMS} > 25\ M_\odot$).

Supernova explosion releases ~10^{46} J of energy, but only 1% is in the form of kinetic energy in the ejecta, 0.1% in radiation, and 99% in neutrinos.

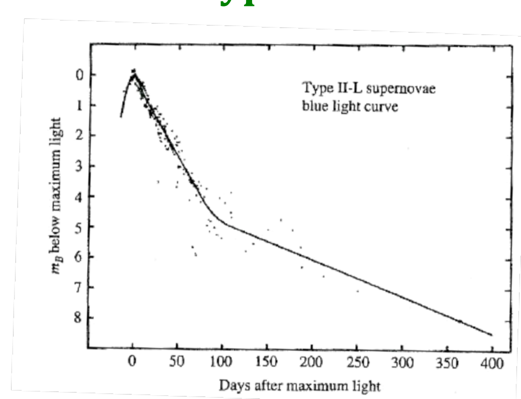
s-process and **r-process nucleosynthesis**. Compare the neutron capture timescale with the beta-decay time scale. Stellar interiors have s-process reactions and supernovae have r-process reactions.

Gamma-ray bursts (GRBs) are at cosmological distances. The long-soft GRBs are associated with energetic supernovae, called collapsars or hypernovae. Rapid rotation of a collapsing core leads to an accretion disk and bipolar relativistic jets.

Type II-P



Type II-L



Light Curves of SNe and the Radioactive Decay of the Ejecta

The most common type of core-collapse SNe is Type II-P.
The SN light is due largely to the energy deposited by the shock into the H-rich envelope. The gas in the envelope is shock-ionized and recombines to release energy at a nearly constant temperature ~5000 K. The plateau of the light curve is further supported by energy deposited in the envelope by the radioactive decay of unstable nuclei produced in the explosive nucleosynthesis (r-process reactions).

The half-life of ${}^{56}_{28}\mathrm{Ni}$ is $\tau_{1/2}$ = 6.1 days

${}^{56}_{27}\mathrm{Co}$ is $\tau_{1/2}$ = 77.7 days

${}^{57}_{27}\mathrm{Co}$ is $\tau_{1/2}$ = 271 days

${}^{22}_{11}\mathrm{Na}$ is $\tau_{1/2}$ = 2.6 years

${}^{44}_{22}\mathrm{Ti}$ is $\tau_{1/2}$ = 47 years

$${}^{56}_{28}\mathrm{Ni} \rightarrow {}^{56}_{27}\mathrm{Co} + e^{+} + \nu_e + \gamma. \qquad \tau_{1/2} = 6.1 \text{ days}$$

$${}^{56}_{27}\mathrm{Co} \rightarrow {}^{56}_{26}\mathrm{Fe} + e^{+} + \nu_e + \gamma \qquad \tau_{1/2} = 77.7 \text{ days}$$

The beta decay of ${}^{56}_{28}\mathrm{Ni}$ generates energy, which is deposited in the optically thick expanding shell before radiated away. This "holds up" the light curve for a period of time, extending the observed plateau in light curve. After the plateau, the deta decay of ${}^{56}_{27}\mathrm{Co}$ provides the energy of the SN light.

Progenitors of Type II-L SNe have reduced hydrogen envelopes, which are not optically thick to dam up the radiation for a plateau in light curve. Their light curves show signatures of radioactive decay almost immediately.

Radioactive decay: there is 50% chance that any given atom will decay during a time interval of half-life $\tau_{1/2}$

$$\frac{dN}{dt} = -\lambda N$$

$$\boxed{N(t) = N_0 e^{-\lambda t},}$$

where

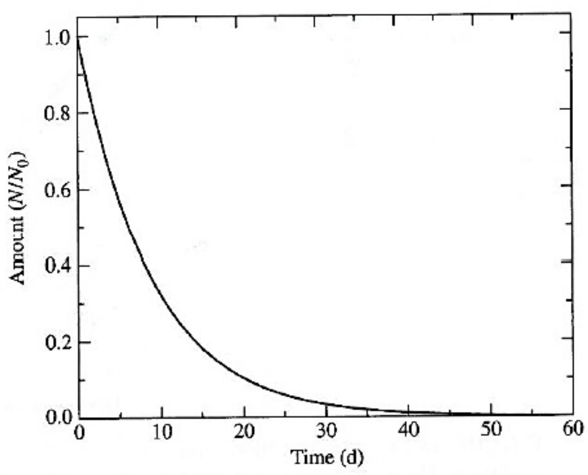
$$\lambda = \frac{\ln 2}{\tau_{1/2}}$$

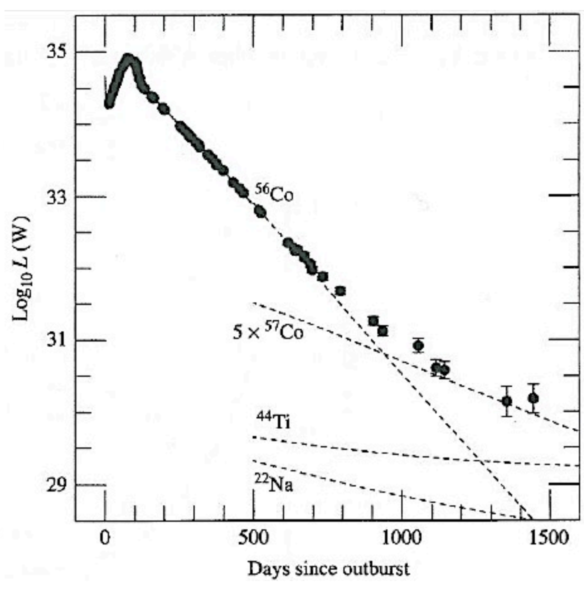
As $L \propto dN/dt$, the slope of the light curve is

$$\frac{d \log_{10} L}{dt} = -0.434\lambda$$

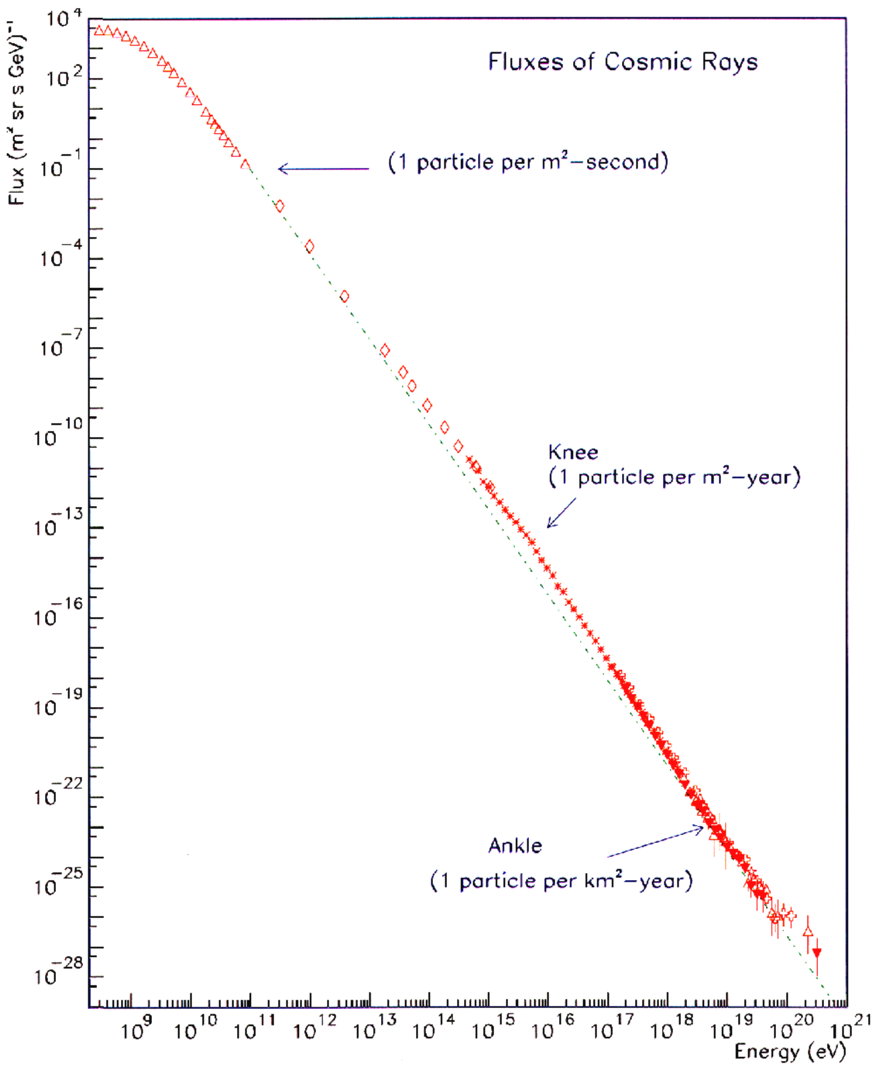
or

$$\frac{dM_{\text{bol}}}{dt} = 1.086\lambda$$





Cosmic Rays



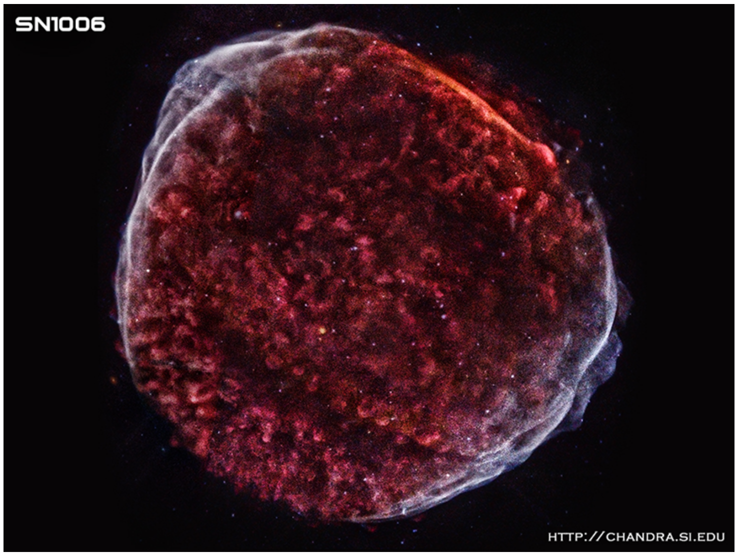
When a charged particle goes upstream through a diffusive shock with a magnetic field, it will gain energy. If magnetic field moves in opposite direction of the cosmic ray particle, it gains energy. This is Fermi acceleration.

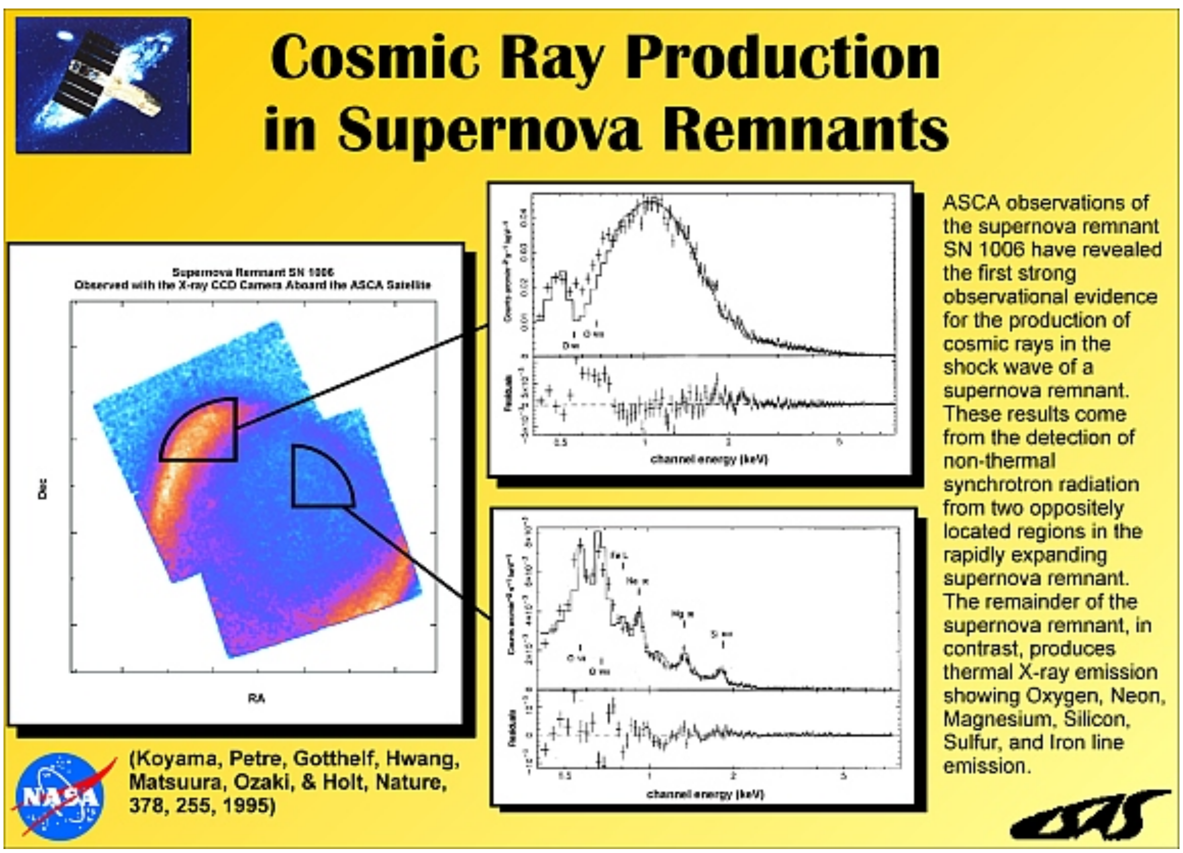
$F_B = q\,v\,B$, $\gamma\, m\, v^2 / r = q\, v\, B$

The Larmor radius (gyroradius) is $r = \gamma\, mv/\,(qB)$.

When $v \sim c$, $r = mc^2/\,(qcB)$. For $B = 10^{-10}$ T, a proton with an energy of 10^{15} eV, the Larmor radius is ~ 1 pc.

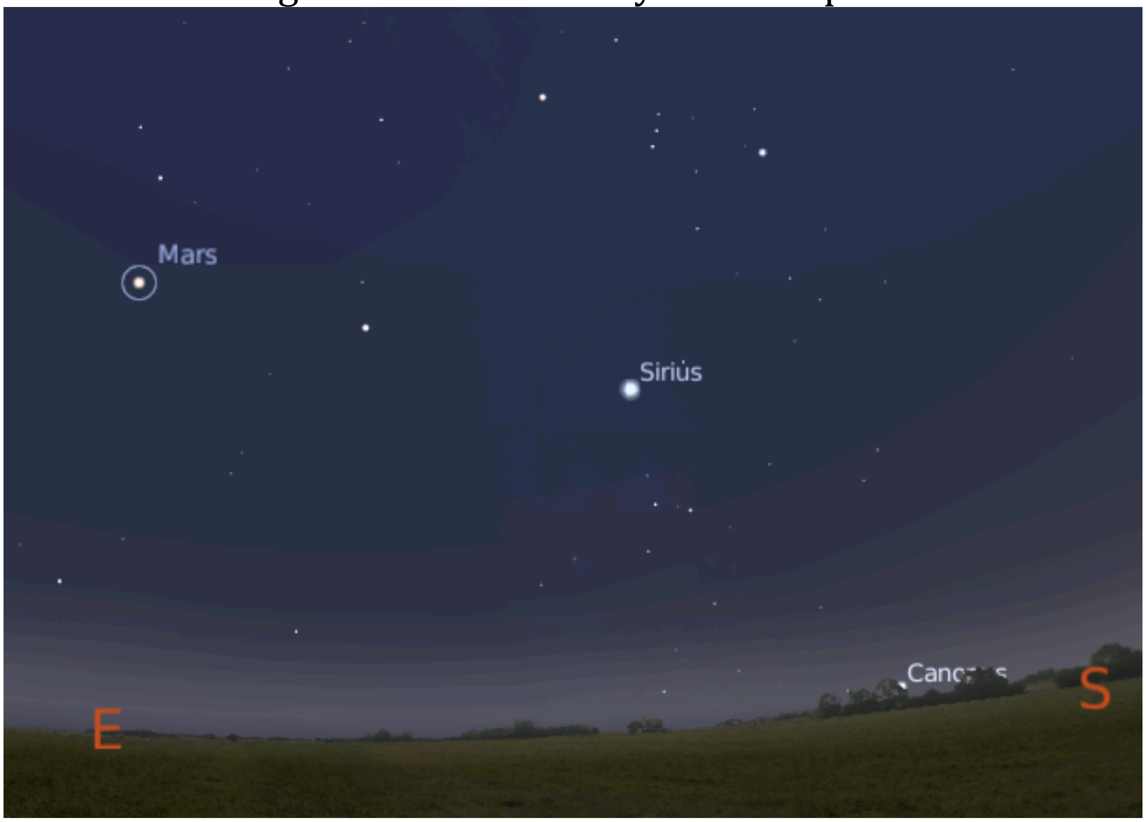
Cosmic rays with energies less than ~10^{15} eV may be produced in supernova remnant shocks.

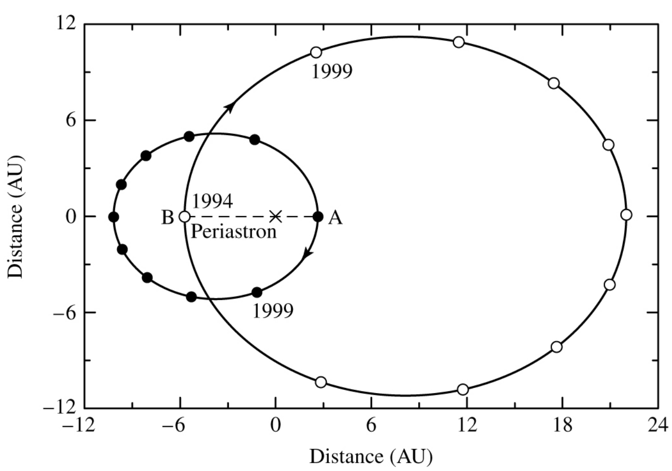




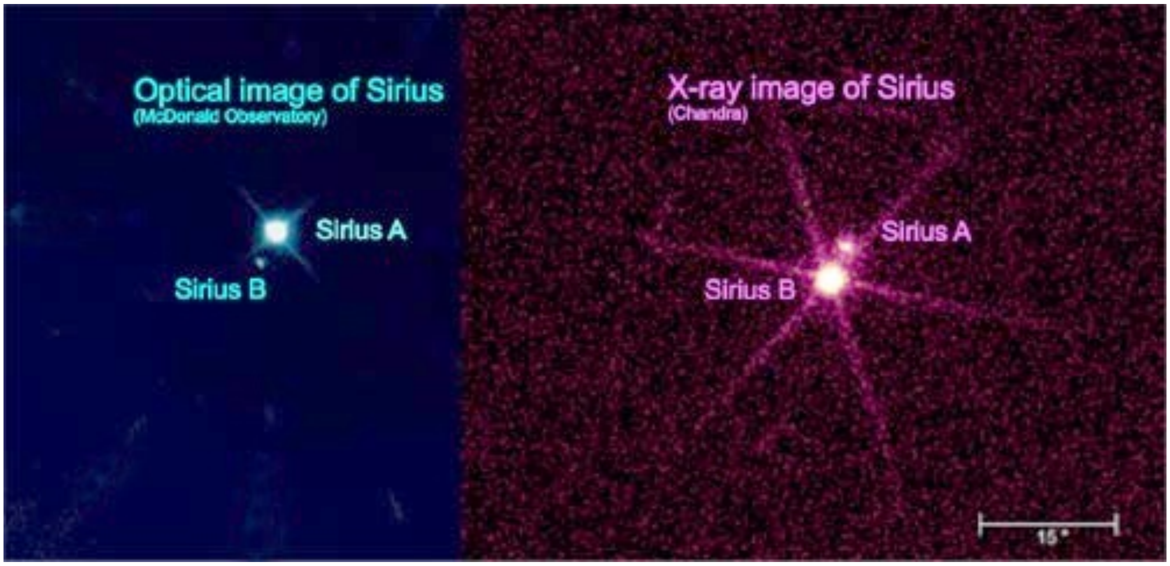
Chapter 16. The Degenerate Remnants of Stars

Sirius is the brightest star in the sky. It has a parallax of 0.379".





Sirius is a binary system. Sirius A has 2.5 $M_{\odot}$ and is an A1V star. Sirius B has 1 $M_{\odot}$, but it appears much hotter than Sirius A. The T_{eff} of Sirius A is 9910 K, and Sirius B is 27,000 K. The temperature and luminosity of Sirius B implies that its radius is ~0.008 $R_{\odot}$, comparable to the Earth's radius!   **White dwarf**.



In optical wavelengths, Sirius A dominates the emission, but in X-rays, Sirius B dominates the emission.

Sirius B was originally a ~5 $M_{\odot}$ star. Some of its mass loss has been accreted by Sirius A, which shows higher Fe abundance on its surface.

The surface gravity on a white dwarf is ~500,000 times that on the surface of the Earth! Spectra show pressure-broadened line profiles.

Classes of White Dwarf Stars

White dwarfs are not "white". Depending on their temperatures, they can be of any colors. [Blackbody spectrum modified by absorption lines from atmospheres.]

DA - show broadened H lines; ~2/3 of all WDs are DA
DB - show only He absorption lines; ~8% of WDs are DB
DC - featureless spectrum, no lines; ~14% of WDs are DC
DQ - show C features
DZ - show metal lines