ASTRONOMY 220C

ADVANCED STAGES OF STELLAR EVOLUTION AND NUCLEOSYNTHESIS

Spring, 2011

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This is a one quarter course dealing chiefly with:

a) Nuclear astrophysics (and nuclear physics)
b) The evolution of massive stars - especially their advanced stages
c) Nucleosynthesis – the origin of each and every isotope in nature
d) Supernovae of all types
e) Gamma-ray bursts, novae, x-ray bursts…

Our study of supernovae will be extensive and will cover not only the mechanisms currently thought responsible for their explosion, but also their nucleosynthesis, mixing, spectra, compact remnants and light curves, the latter having implications for cosmology.

The student is expected to be familiar with the material presented in Ay 220A, a required course in the UCSC graduate program, and thus to already know the essentials of stellar evolution, as well as basic quantum mechanics and statistical mechanics.

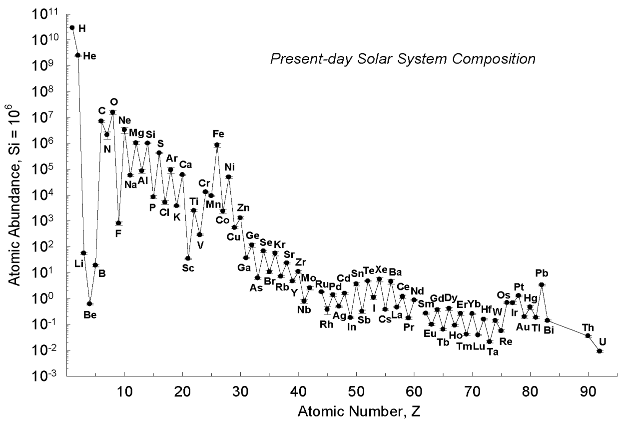
The course material is extracted from a variety of sources, much of it the results of local research. It is not contained, in total, in any one or several books. The powerpoint slides are on the web, but you will need to come to class. A useful textbook, especially for material early in the course, is Clayton's, *Principles of Stellar Evolution and Nucleosynthesis.* Also of some use are Arnett's *Supernovae and Nucleosynthesis* (Princeton) and Kippenhahn and Weigert's *Stellar Evolution and Nucleosynthesis* (Springer Verlag). I am checking out Boyd's and Illiadis' new texts.

Course performance will be based upon four graded homework sets and an in-class final examination.

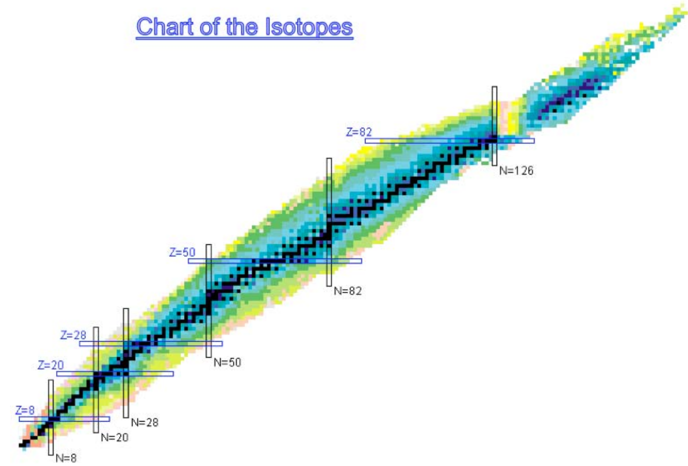
The anticipated class material is given, in outline form, in the following few slides, but you can expect many alterations as we go along. The course will begin with material that is more "classical" in nature, especially some basics of nuclear reaction theory. By mid-quarter however, we should advance to more current, and consequently less certain results and challenges.

Author	Title	Approximate price	Comments
Richard Boyd	*An Introduction to Nuclear Astrophysics*	$66.30	Good overall introduction to the subject. Focuses on nuclear reactions and processes
Christian Illiadis	*Nuclear Physics of the Stars*	$103.60	Covers nuclear astrophysics well. Not so thorough or current on stellar evolution, Expensive
David Arnett	*Supernovae and Nucleosynthesis*	$61.50	Good on things Arnett has worked on. Abundances, reaction rates peripherally. Massive star evolution and supernova models very good, but becoming dated
Don Clayton	*Principles of Stellar Evolution and Nucleosynthesis*	$42.00	A classic. Good on nuclear physics and basic stellar physics. Good on the s-process. But quite dated otherwise.

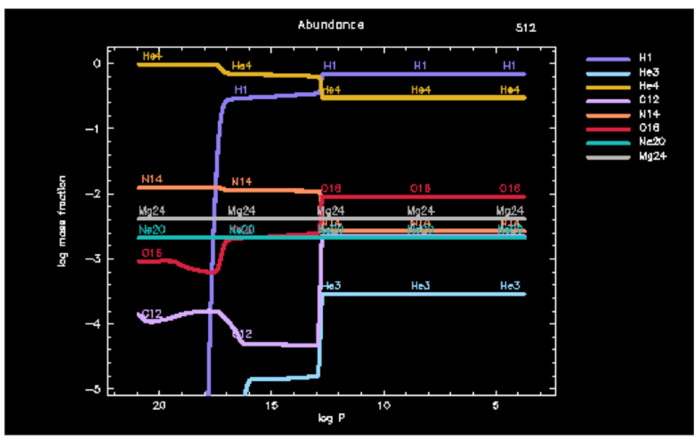
Isotopes are us… *Where, how and why?*



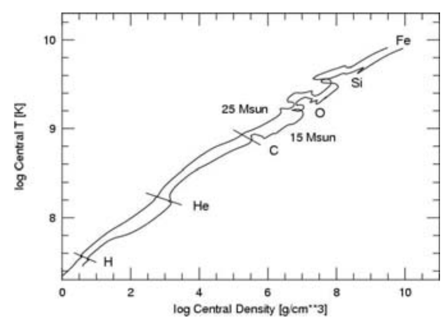
[Chart of the Isotopes](#)



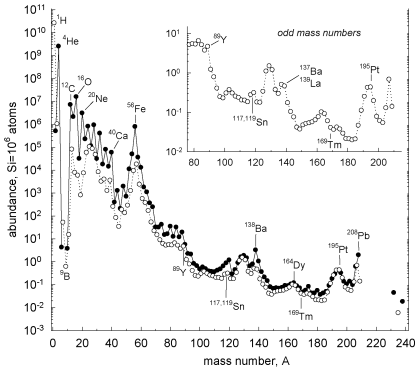
[Mesa stellar evolutionary code](#)



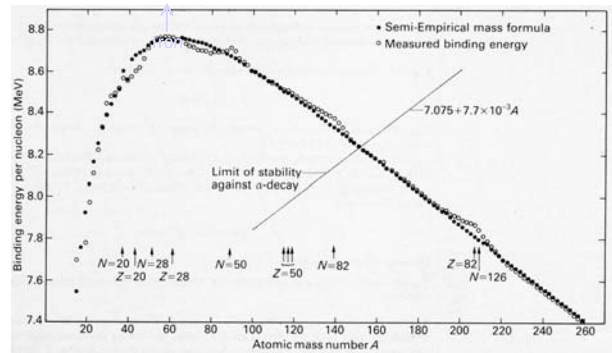
1) Introduction and overview – course overview. General principles of stellar evolution – temperature-density scalings, critical masses, entropy, abundances in the cosmos, some simple aspects of Galactic chemical evolution.



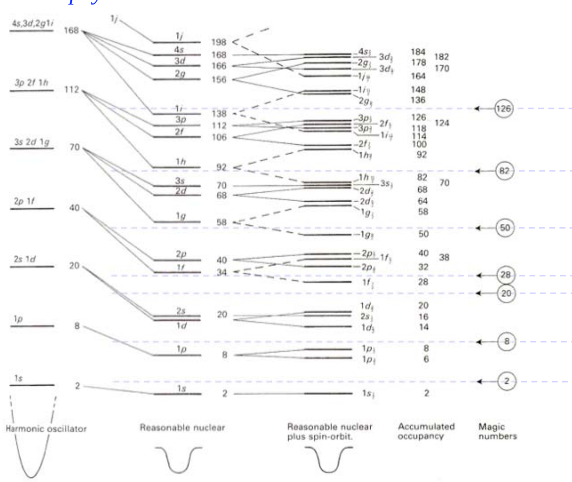
2) Abundances – Abundances in the sun and meteorites. Abundances in other stars, especially low metallicity stars. Abundance evolutionary trends. Some aspects of galactic chemical evolution



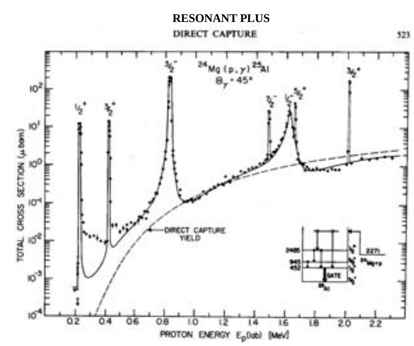
3) Nuclear Physics - 1- The nuclear force. Physics of the atomic nucleus. Binding energy. The liquid drop model.



4) Nuclear physics – 2 The shell model



5) Nuclear Physics - 3 – Nuclear reaction theory. Astrophysical reaction rates. Resonant and non-resonant rates



6) Nuclear physics – 4 – Some key rates for astrophysics.

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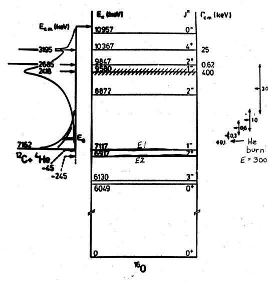
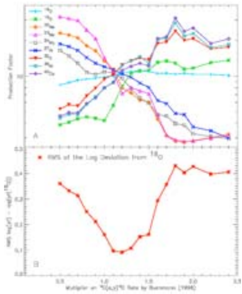
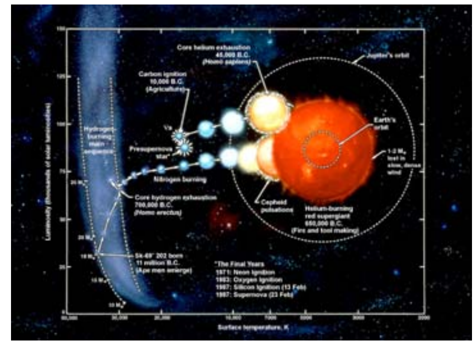
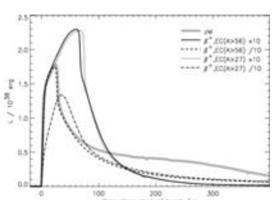


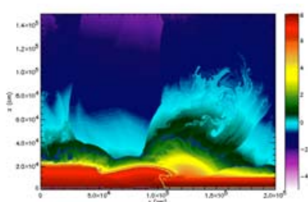


7) and 8) The evolution of massive stars on the main sequence and as red giants – general properties of massive stars, convection, semi-convection, mass loss, rotation, nucleosynthesis, metallicity dependence, Wolf-Rayet stars.

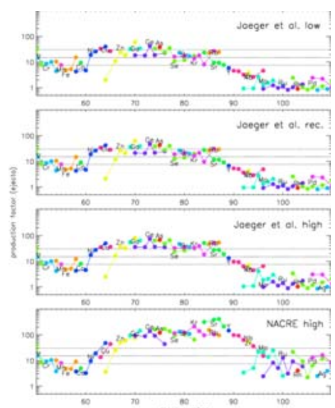


9) Hot hydrogen burning – classical novae (including models), x-ray bursts on neutron stars

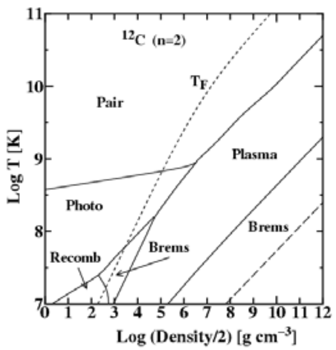




10) The s-process – Helium burning and the s-process
Relevant nuclear physics, abundance systematics, solving the rate equations, occurrence in massive stars and AGB stars

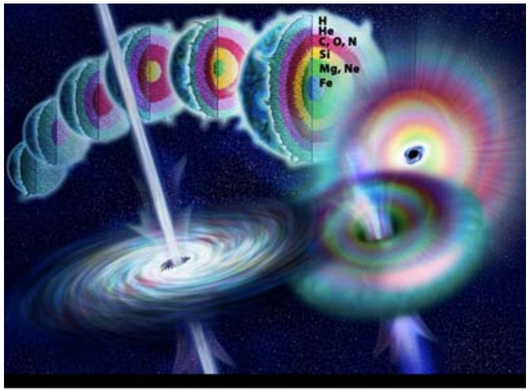


11) Neutrino losses and the advanced burning stages in massive stars – Thermal neutrino losses, nuclear physics of carbon, neon, oxygen and silicon burning. Concepts of balanced power and nuclear quasi-equilibrium.

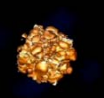


Physical processes dominating the energy loss from plasmas at different temperatures and densities.

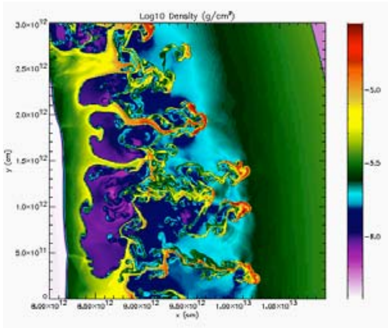
12) Advanced evolution of model stars in the 8 to 100 solar mass range – Silicon burning, quasiequilibrium, nuclear statistical equilibrium. Onset of core collapse



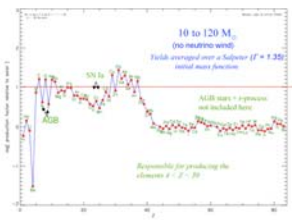
13) Presupernova models, core collapse and bounce – Current models in 1, 2 and3D. Limits of the mechanism. Role of rotation and magnetic fields.

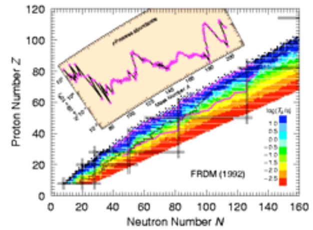


14) Explosion and mixing – Observation and physics. Fall back. Neutron star and black hole birth.

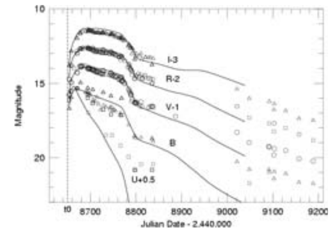


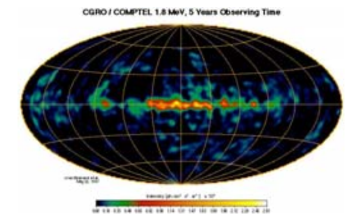
15) Explosive nucleosynthesis and the r-Process – General properties. Products and uncertainties. Possible sites. The neutrino powered wind.



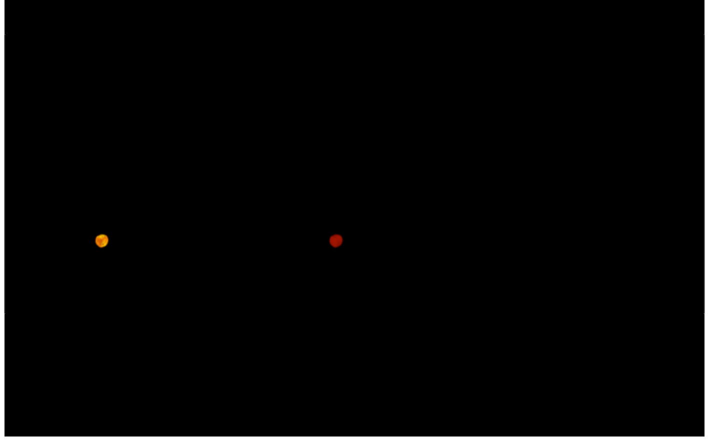


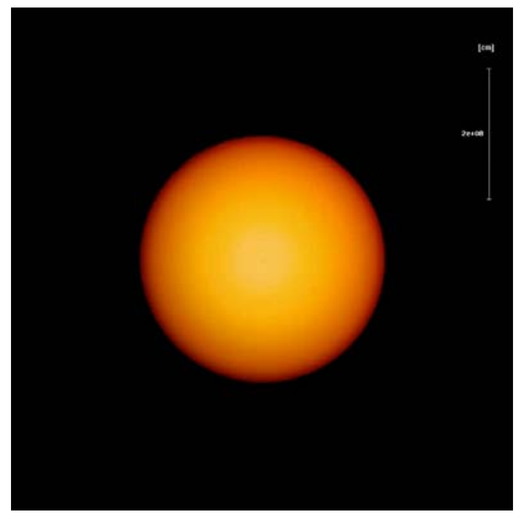
16) Observational aspects of core-collapse supernovae
- spectra and light curves. Neutrino signal. Gamma-ray line astronomy. Shock break out.



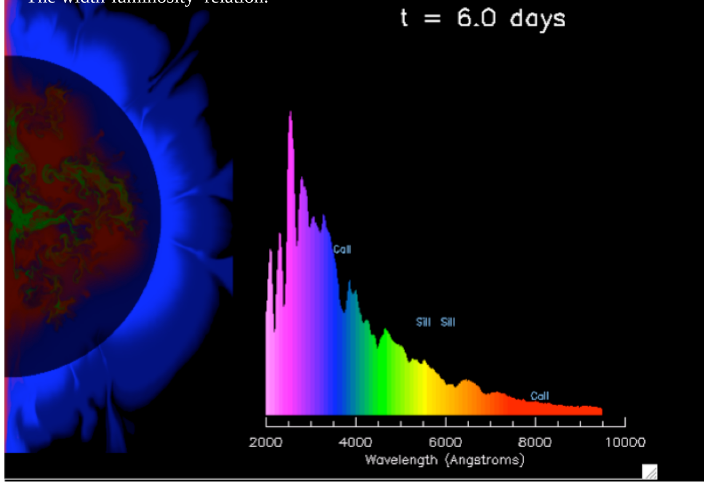


17) Type Ia supernovae – Models and how they explode. Physics of degenerate carbon ignition. Turbulent flame propagation.

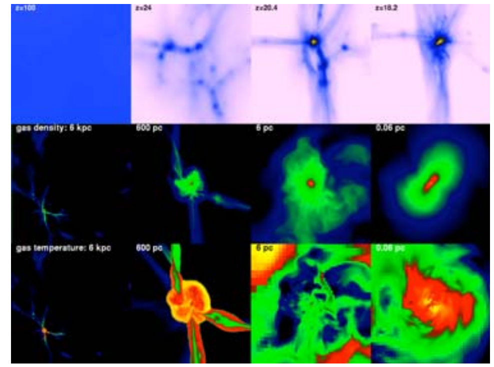




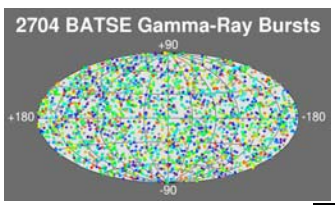
18) Type Ia supernovae – Light curves and spectra.
The width-luminosity relation.



19) Population III Stars – Evolution, pair instability
20) and pulsational pair instability supernovae, formation and stability of Pop III stars, nucleosynthesis, light curves.



20) Gamma-ray bursts –



Observations

Models: Collapsars and others