# Nuclear Astrophysics with Exotic Beams

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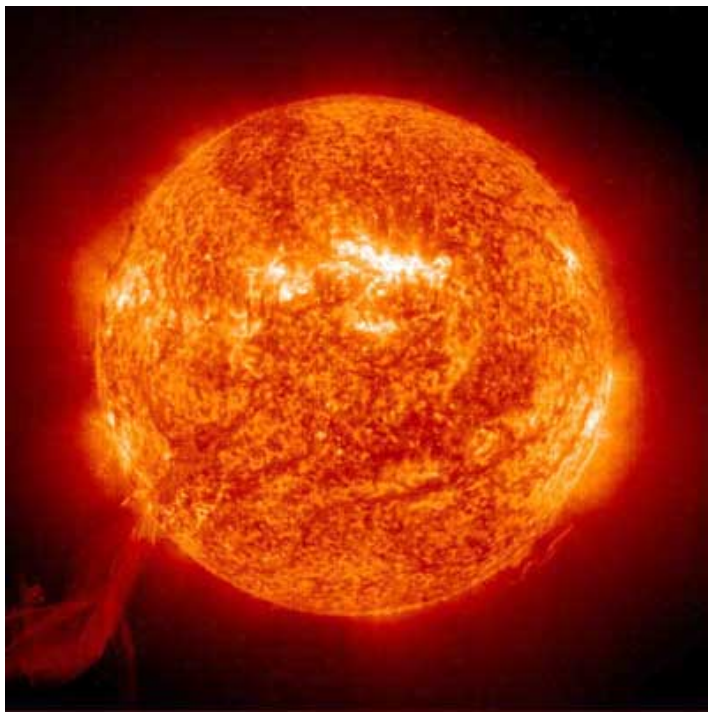
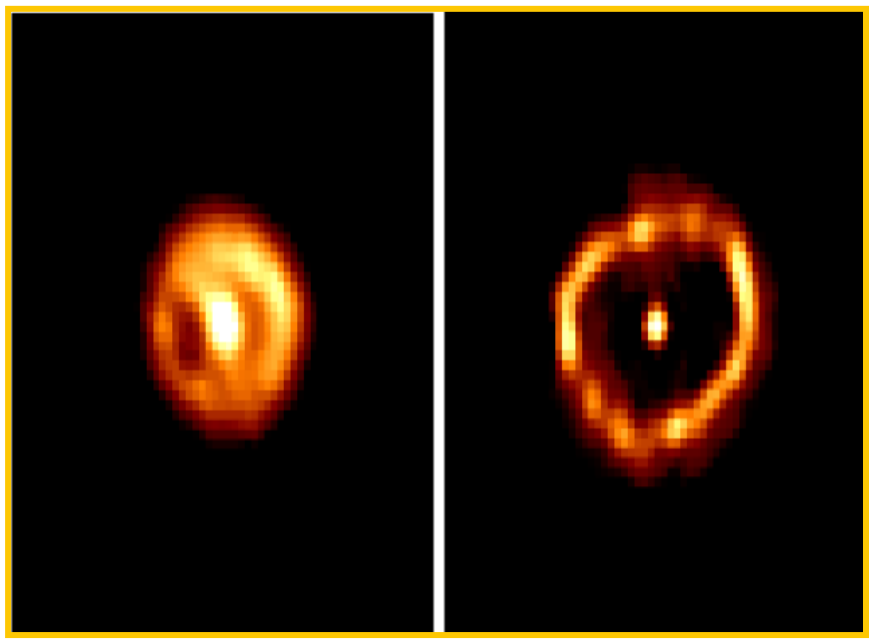


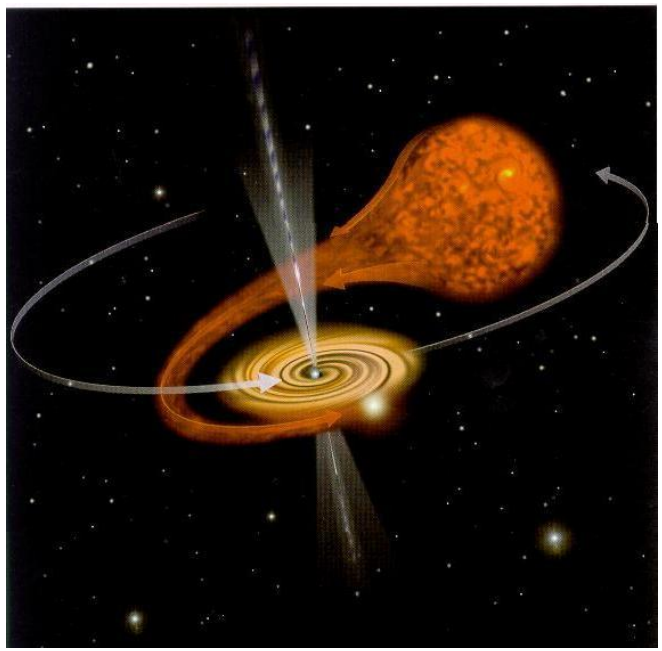
The sun is currently in a quiescent, low T, low density state. Consequently energy generation from nuclear reactions on stable nuclei predominates. However, even here reactions with radioactive species can be important

$^{7}$Be(p,$\gamma$)$^{8}$B reaction rate determines high energy solar $\nu$ flux

However nature can be dynamic….



accretion process - artist's impression



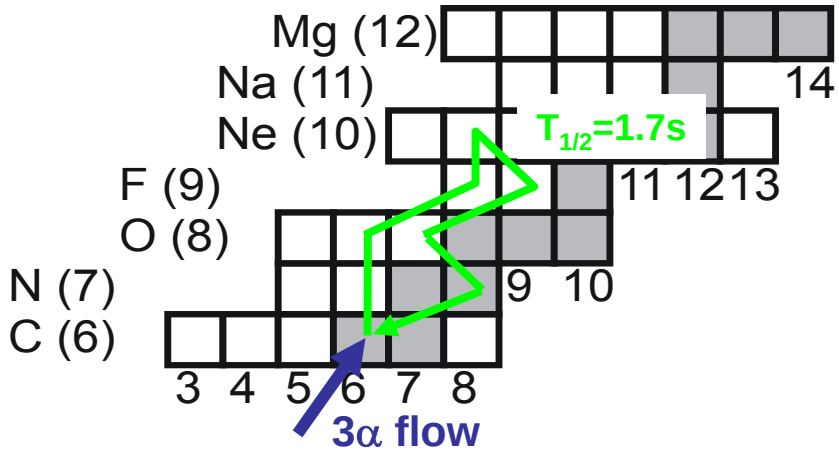
On surface of white dwarf explosive hydrogen burning takes place at high T and density

Nuclear reactions with radioactive nuclei dominate energy production and determine composition of novae ejecta

# Hot CNO Cycle

T~3*$10^8$ K

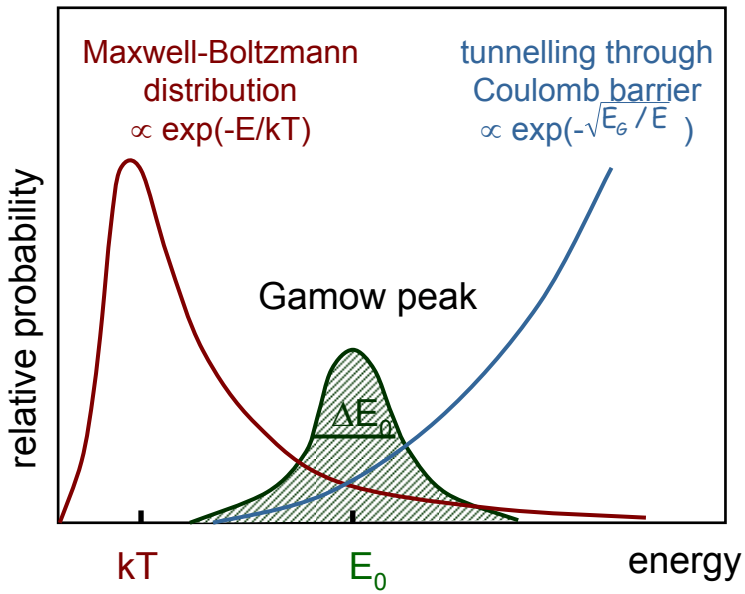
$\rho \sim 10^3$ gm.cm$^{-2}$




Key unknown reaction rates are dominated by resonance reactions

$^{17}F(p,\gamma)^{18}Ne$, $^{14}O(\alpha,p)^{17}F$, $^{18}F(p,\alpha)^{15}O$

Experiments require intense radioactive beams ~1 MeV/u




Resonances sitting inside the Gamow window can dominate reaction rate

These reactions cannot be reliably calculated from theory, and must be measured experimentally

For X-ray bursters a similar scenario prevails although in this case material accretes onto the surface of a neutron star rather than a white dwarf

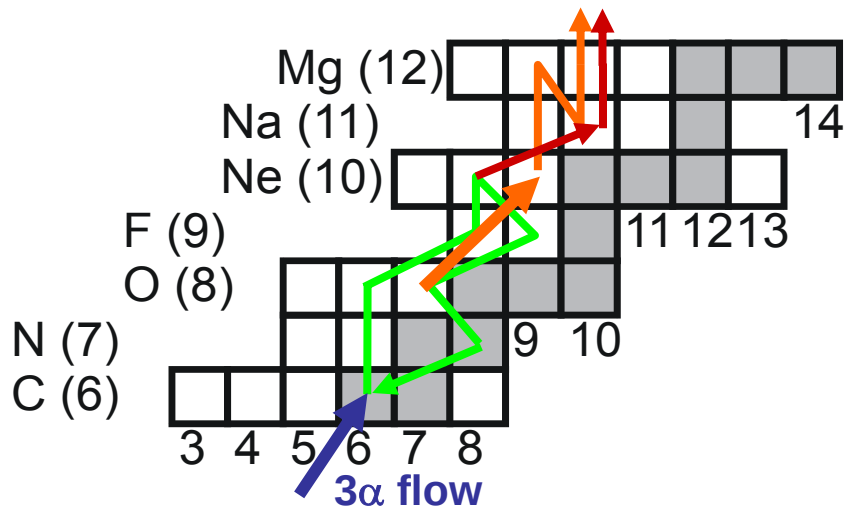
Consequently higher T and $\rho$ can result in breakout from the hot CNO cycles

breakout

processing beyond CNO cycle after breakout via:

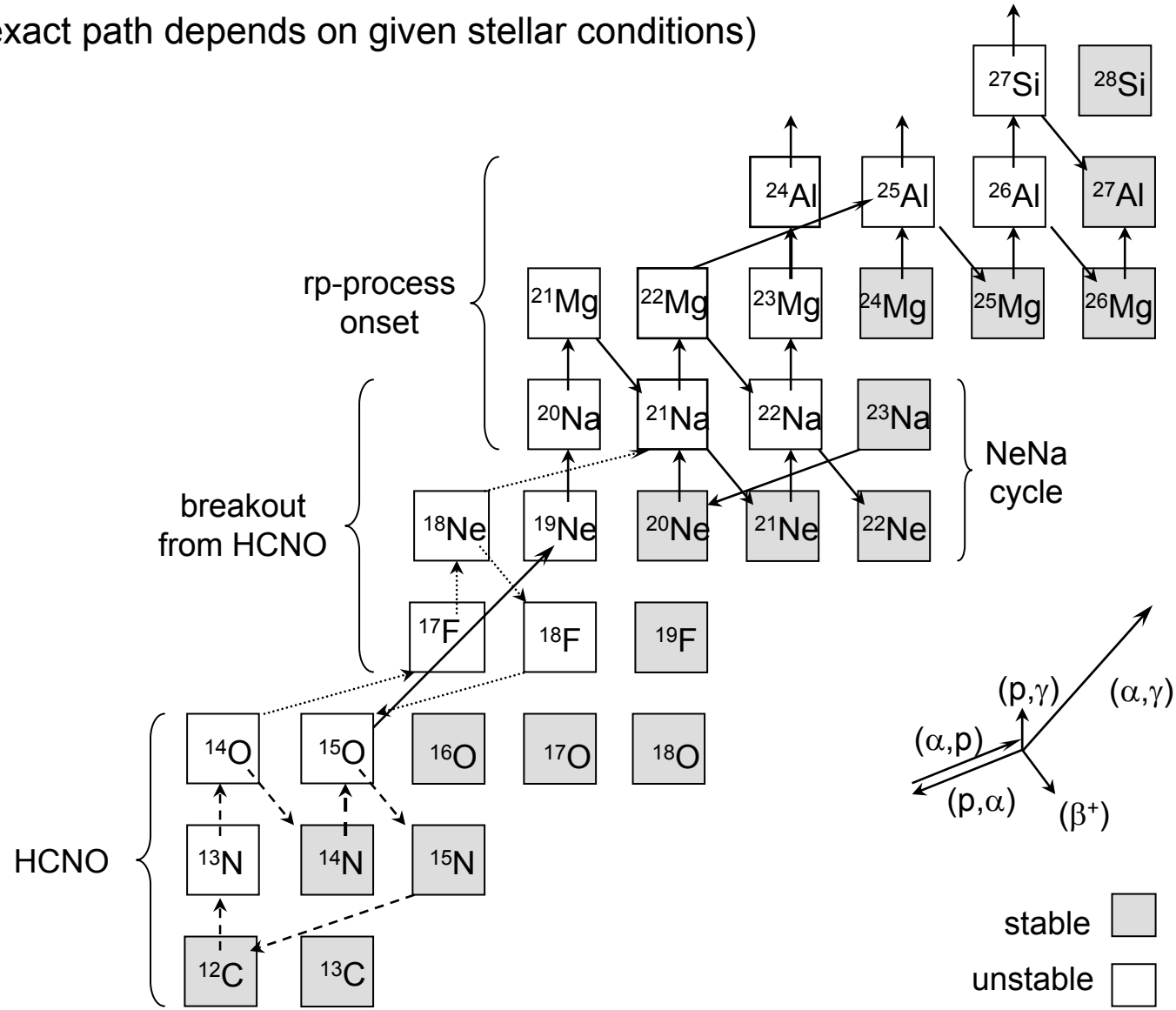
$T_8 \geq 3$ $^{15}O(\alpha,\gamma)^{19}Ne$

$T_8 \geq 6$ $^{18}Ne(\alpha,p)^{21}Na$

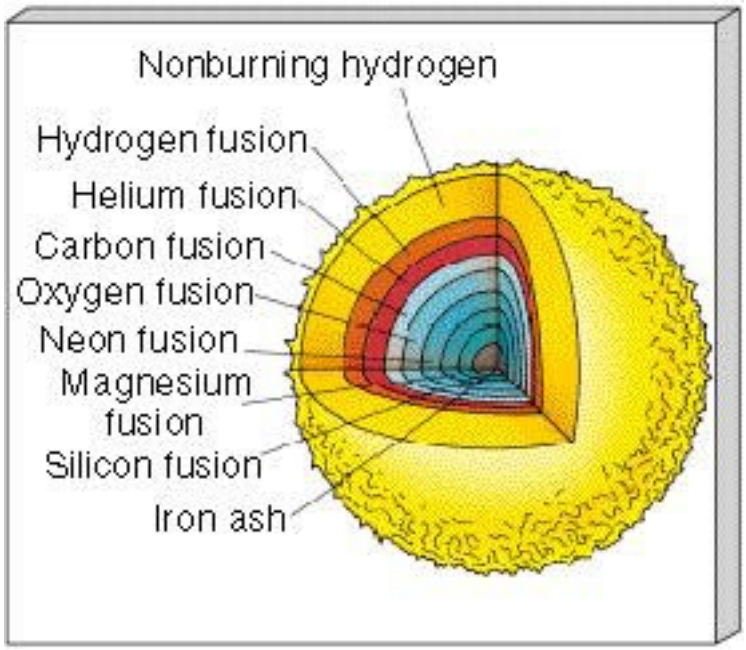


reaction network for explosive hydrogen burning

(exact path depends on given stellar conditions)



Supernovae are thought to be responsible for the production of the heaviest elements via a rapid succession of n-capture processes…..




…embarrassingly stellar modellers cannot make stars explode, and the site  and mechanism for the r-process is unknown

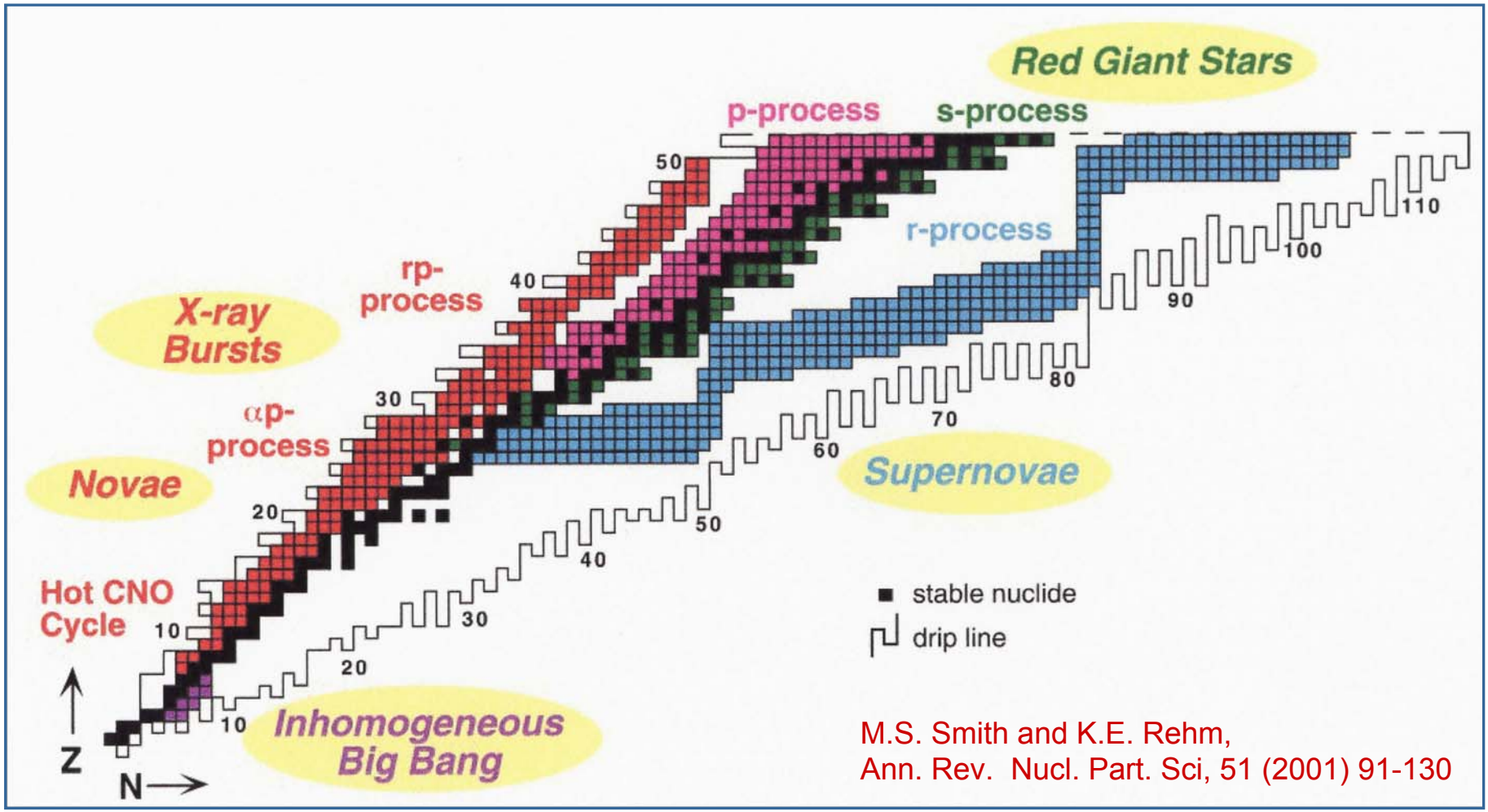
Key source of uncertainty are the properties of highly neutron-dilute nuclear matter

Shell structures/magic numbers for neutrons are unknown for such nuclei

Closed shell nuclei have low (n,$\gamma$) capture cross-sections giving rise to waiting points in the r-process….

….these in turn influence the energy generation and final isotopic abundances from supernovae ejecta

# Overview of main astrophysical processes




M.S. Smith and K.E. Rehm,
Ann. Rev. Nucl. Part. Sci, 51 (2001) 91-130

the vast majority of reactions encountered in these processes involve UNSTABLE species

hence the need for **Radioactive Ion Beams**

# Summary

Radioactive Beams are a key tool for explosive nuclear astrophysics research

Existing ISOL based radioactive beam facilities are not presently providing beams of sufficient intensity for direct measurements of a range of the most important astrophysical reactions

For major progress in this field it is essential to develop a new world class ISOL based radioactive beams facility. The beta-beam project offers the opportunity to develop just such a facility within a European framework