Nucleosynthesis from Black Hole Accretion Disks

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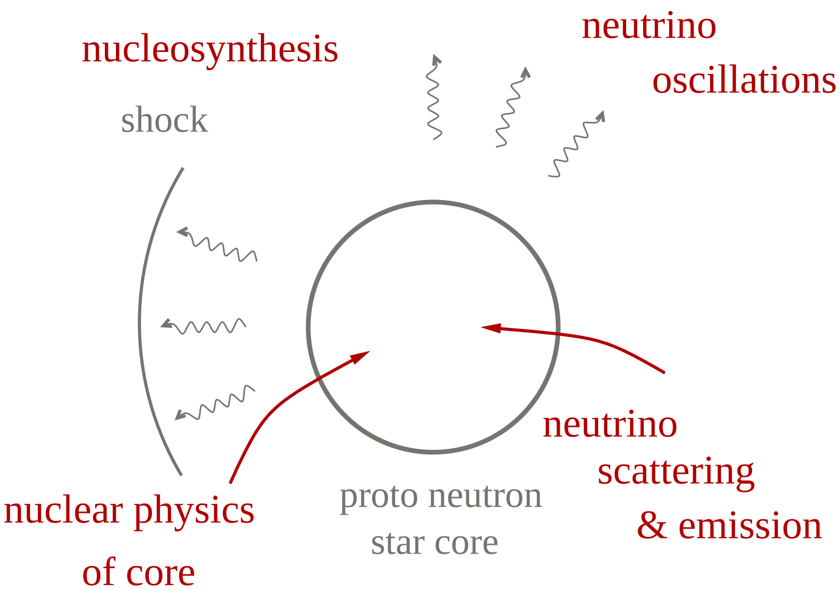
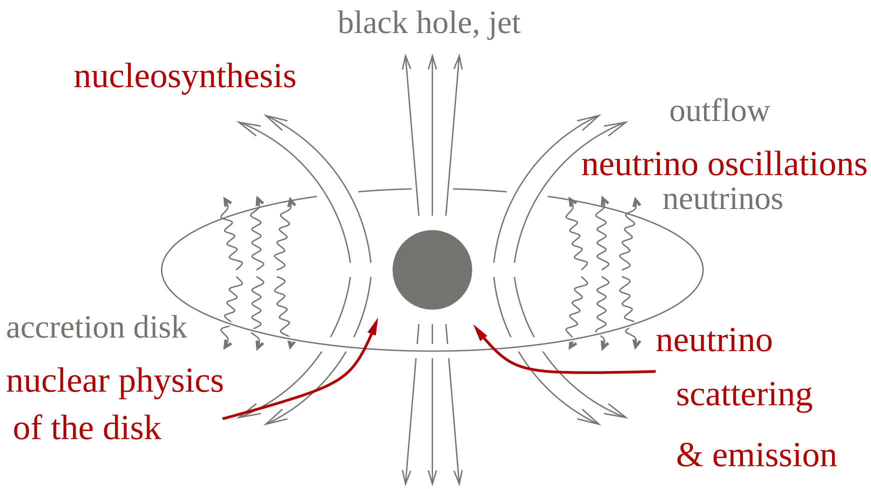
Explosions of Massive Stars:
Where is the nucleosynthesis-neutrino physics?



Standard core core collapse SN



Accretion disk SN, compact object merger, gamma ray burst

Neutrino - Nucleosynthesis connection

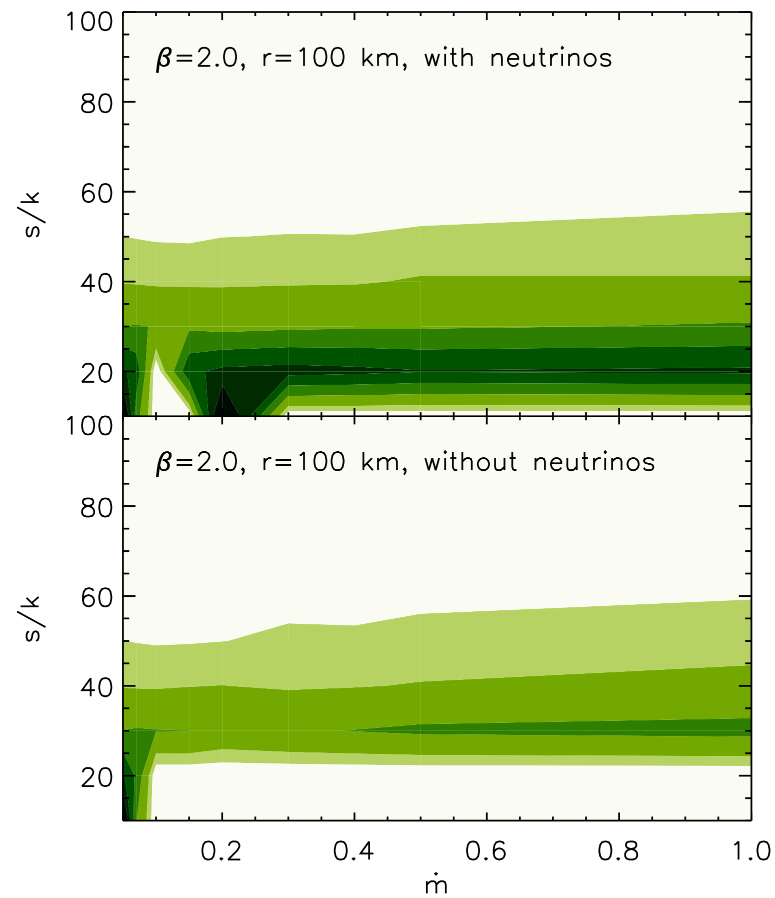
If neutrinos have most of the energy in an object, they are key to determining the astrophysical conditions.

Also, they determine the relative numbers of neutrons and protons...

- $\nu_e + n \leftrightarrow p + e^-$
- $\bar{\nu}_e + p \leftrightarrow n + e^+$

Nickel in Hot Outflows from Disks

n,p $\rightarrow^4$ He $\rightarrow$ iron peak nuclei $\rightarrow$ heavier nuclei

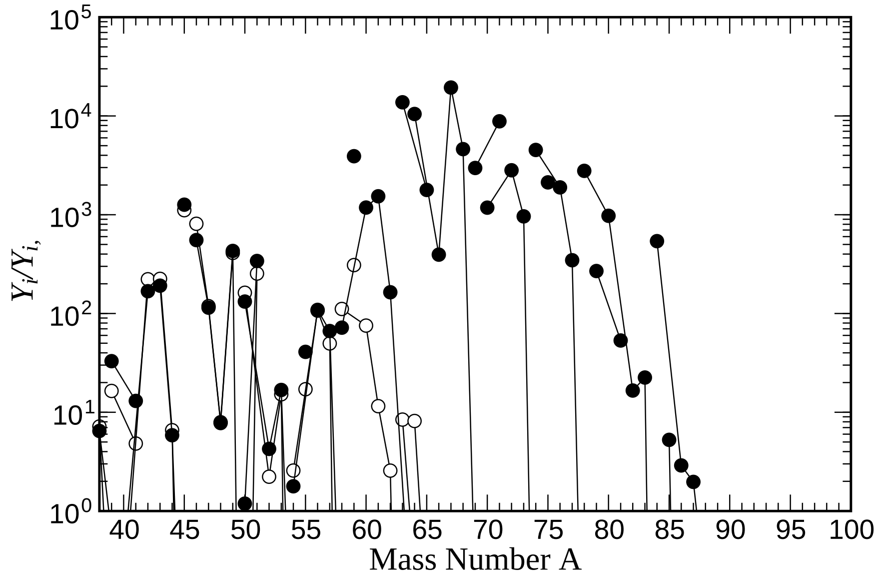


Surman et al 2010

Neutrinos and light p-nucleosynthesis

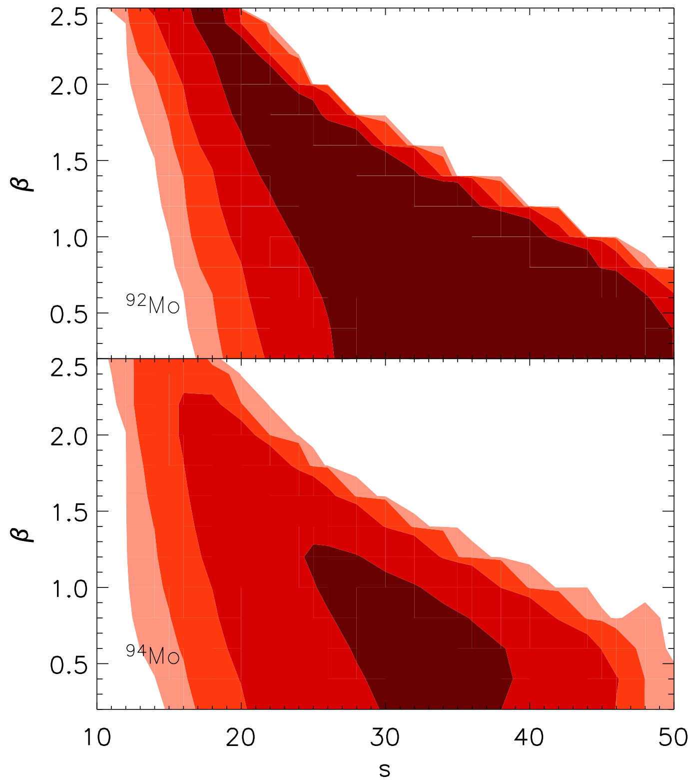
Thought to occur in supernovae and in accretion disk outflows

ν-p process



Frohlich et al 2007, Kizivat et al 2010

p-process

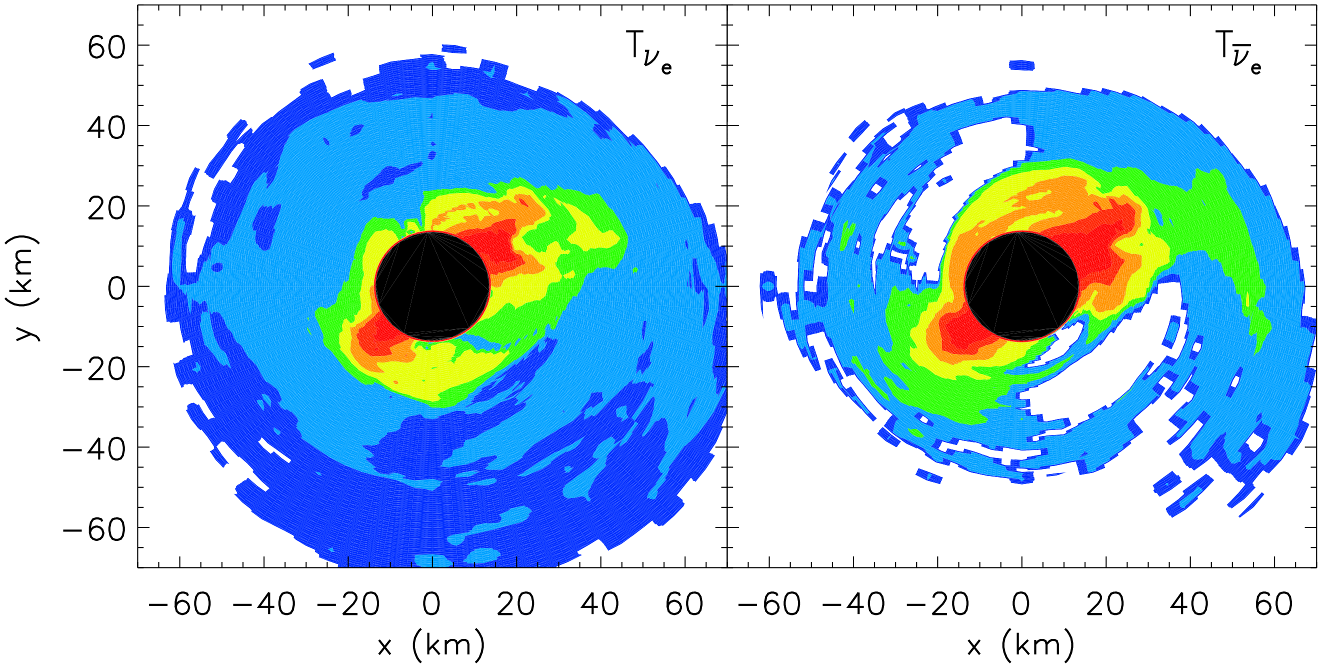


Pruet et al, Surman et al 2005, 2010

Nucleosynthesis: Compact Object Merger Models

Neutrino Emission Temperatures

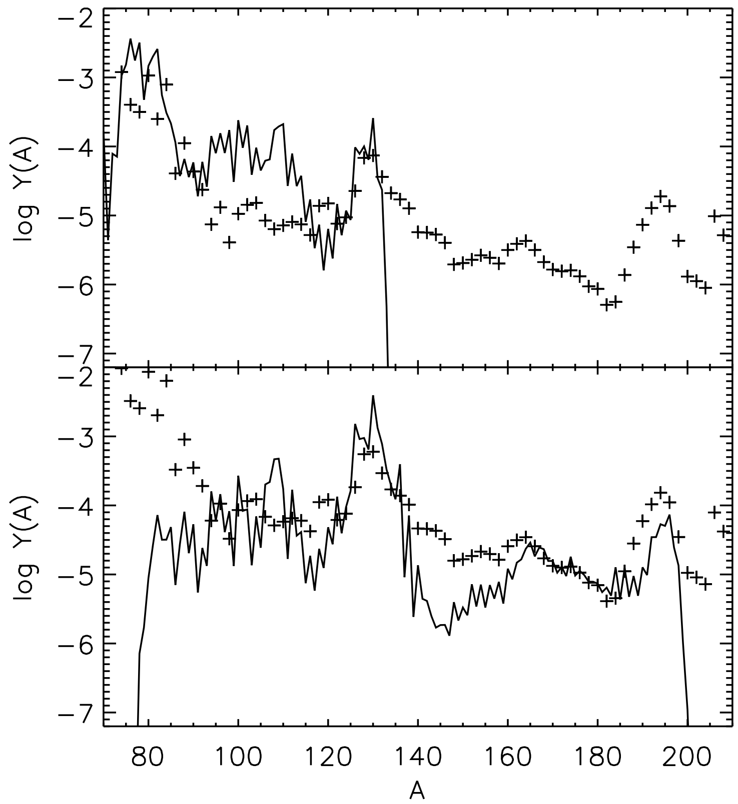
Electron Neutrinos | Anti-electron Neutrinos



Snapshot of a hydrodynamic model from Ruffert & Janka, postprocessed, from Surman et al 2010

Hot Outflow Nucleosynthesis

Black Hole Neutron Star Merger



R-process occurs in the wind

Surman et al. 2008

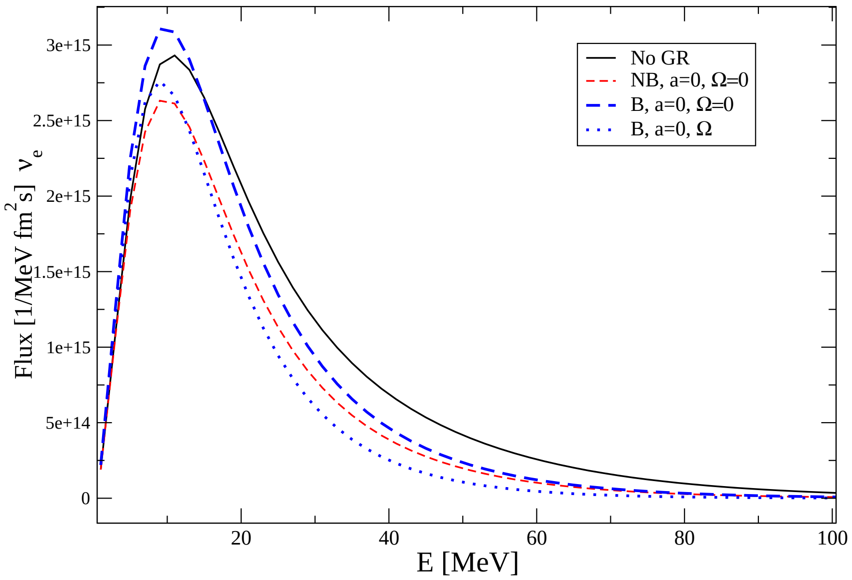
GR effects after the neutrinos leave the accretion disk surface

Effects from Schwarzschild metric and rotation of the disk

black curve: no GR effects

red dotted: E shift, no bending

blue dashed: bending + E shift



GR effects on spectra, figure by Liliana Caballero

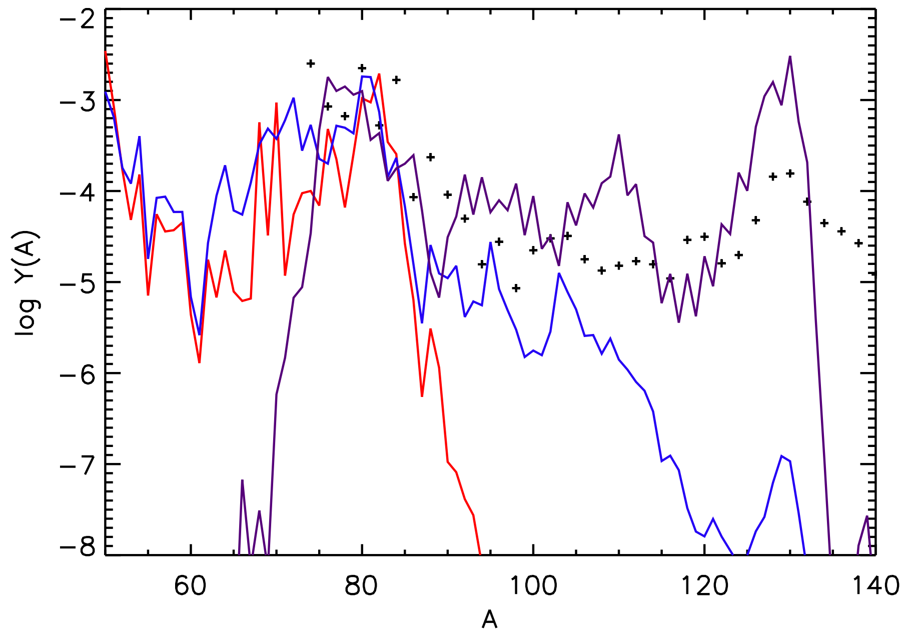
Example of neutrino GR effects on abundance pattern

Effects from Schwarzschild metric and rotation of the disk

purple: no ν GR effects

blue: geodesic tracing, E_ν shift

red: GR includes Ω_{disk}



one angle, outflow trajectory

Neutrino Flavor Transformation: Collective Effects

Study in SN, where does the oscillation start?

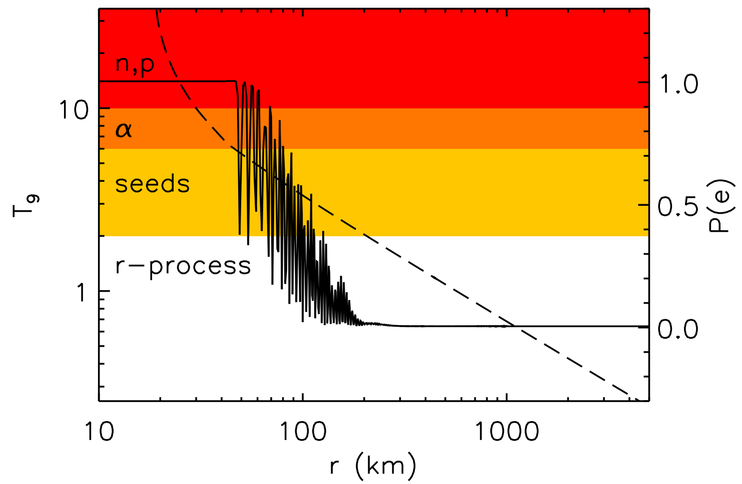


figure by Rebecca Surman

- stages of nucleosynthesis are shown
- $E_{\nu_e} < E_{\nu_x}$
- oscillation moves you toward $Y_e = 0.5$
- starts before or after alpha effect?

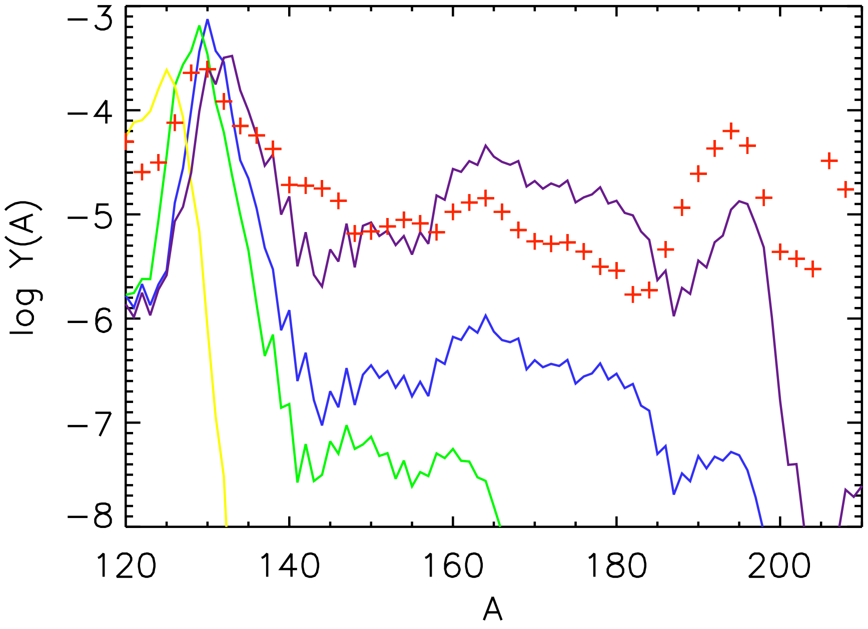
Neutrino Flavor Transformation: Collective Effects

Let's try out some conditions

- $T_{\nu_e} = 2.6\,\mathrm{MeV}$, $T_{\bar{\nu}_e} = 4.0\,\mathrm{MeV}$
- $L_{\nu_e} = 6.6 \times 10^{51}\mathrm{ergs\,s^{-1}}$, $L_{\bar{\nu}_e} = 8.8 \times 10^{51}\mathrm{erg\,s^{-1}}$,
  $L_{\nu_\mu} = 12.7 \times 10^{51}\,\mathrm{erg\,s^{-1}}$
- two component wind, first $\tau = 25$ms, then power law decay
- entropy per baryon s/k $= 200$

Neutrino Flavor Transformation: Collective Effects

Single angle vs. multiangle: Where does the oscillation start?



purple: no neutrino interactions

blue: neutrinos on, oscillations off

yellow: single angle oscillations

green: multiangle oscillations

Normal hierarchy in SN, s/k = 200, figure by R. Surman neutrino flavor transformation calculations from Duan and Friedland 2010

Summary

- Black hole accretion disks make a lot of nickel, and likely some other rare elements
- Compact object mergers make the r-process in hot outflows
- Neutrinos play an important role in determining the type of elements formed, as do oscillations
- General relativistic effects on neutrinos are important for nucleosynthesis in the merger scenario