Low Energy Neutrinos from Black Hole - Accretion Disks

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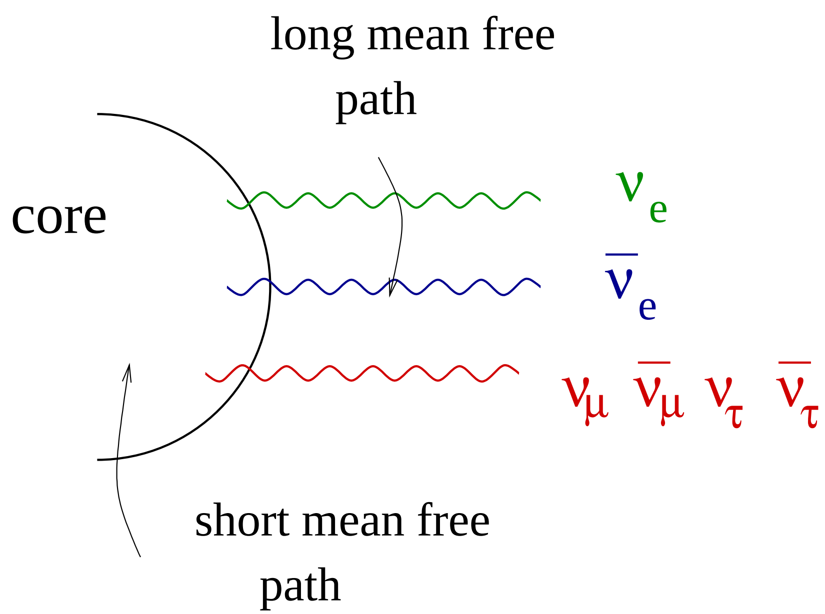
- General remarks about neutrinos from hot dense environments
- Detection of accretion disk neutrinos
- Accretion disk - black hole nucleosynthesis
- Neutrinos from ordinary supernovae: r-process

Supernova Neutrinos

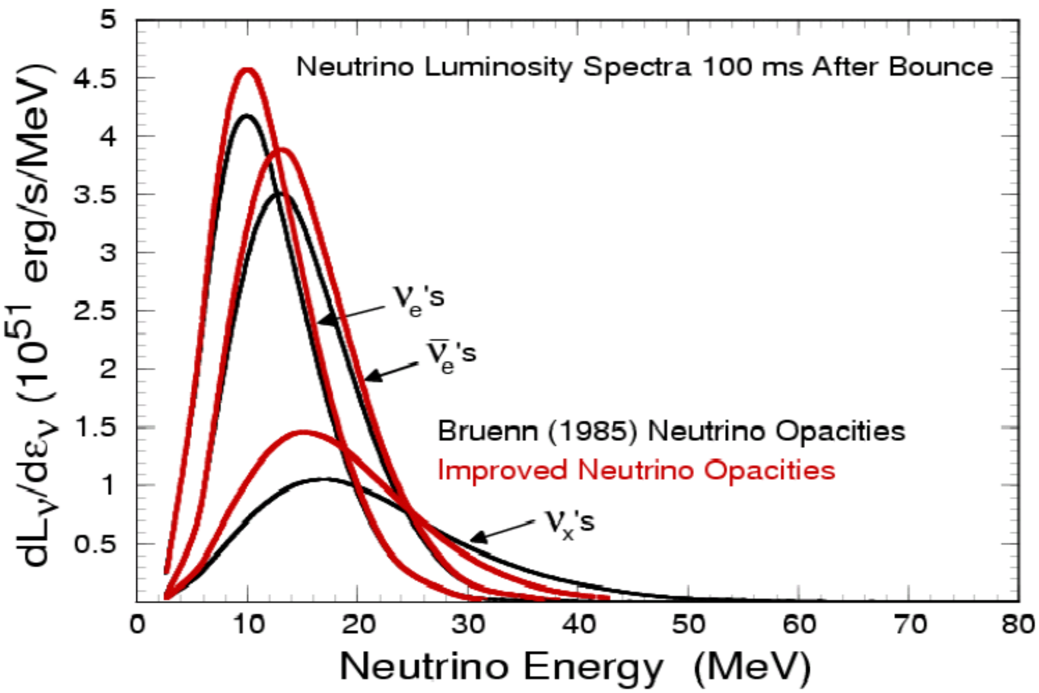
All types of neutrinos emanate from the proto-neutron star core. They travel through the outer layers of the SN, then to earth.



SN neutrinos:

- may be detected
- oscillate
- nucleosynthesis
- explosion dynamics

Supernova Neutrino Spectra



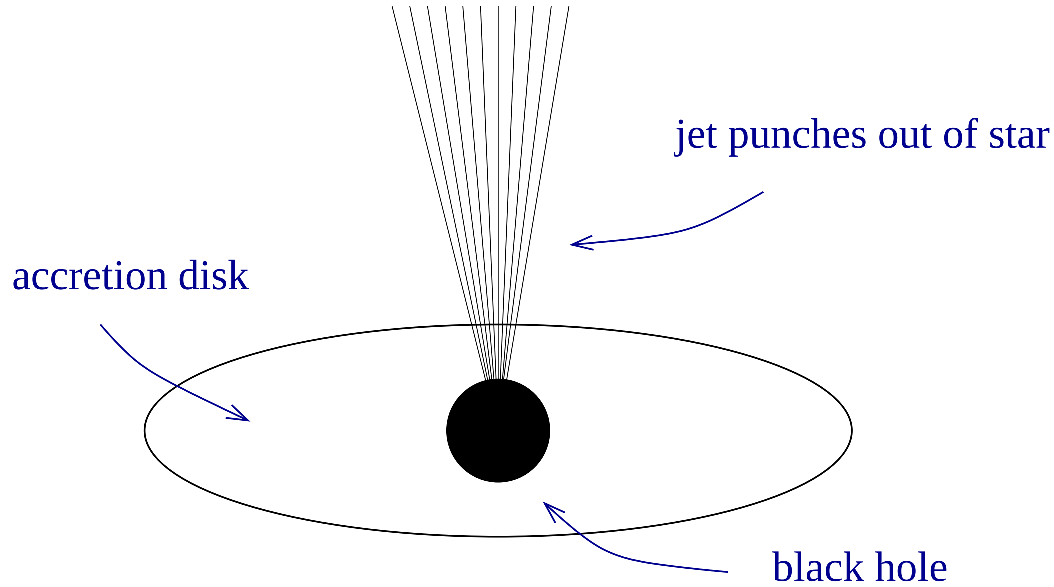
Roughly the energy range is

- $\langle E_{\nu_\mu} \rangle = \langle E_{\bar{\nu}_\mu} \rangle = \langle E_{\nu_\tau} \rangle = \langle E_{\bar{\nu}_\tau} \rangle = 20 - 30\,\mathrm{MeV}$
- $\langle E_{\bar{\nu}_e} \rangle = 13 - 19\,\mathrm{MeV}$
- $\langle E_{\nu_e} \rangle = 8 - 13\,\mathrm{MeV}$

Supernova Neutrino Diffusion: Mezzacappa, Cardall, Pons, Prakash, Burrows, Bruenn, Janka and more

Collapsar/Hypernovae Model of Long Duration Gamma Ray Bursts

- Failed Supernova
- Too much rotation for real collapse & bounce

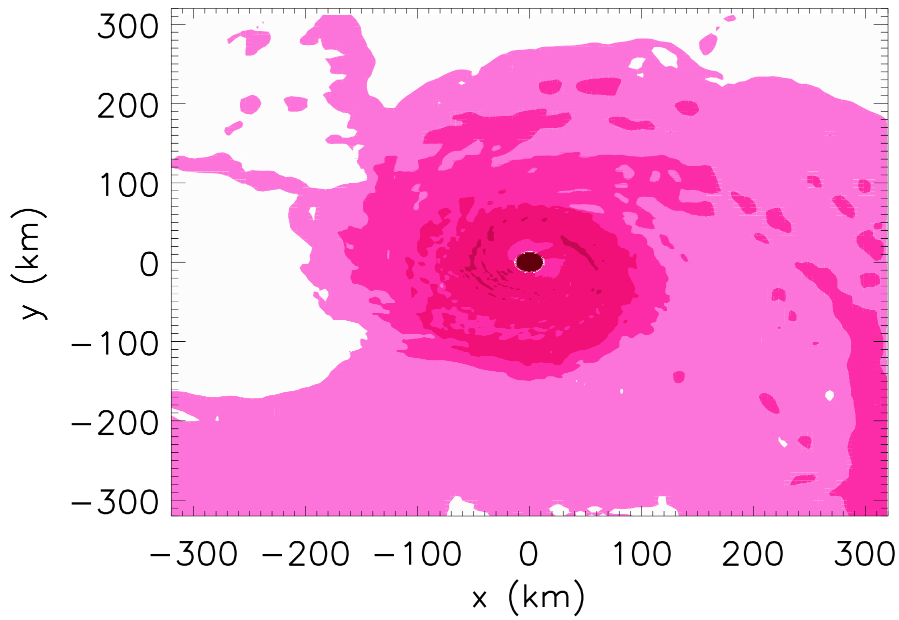


Neutrinos from the disk may provide some of the energy required to power the jet.

Woosley 1993, MacFadyen and Woosley 1999

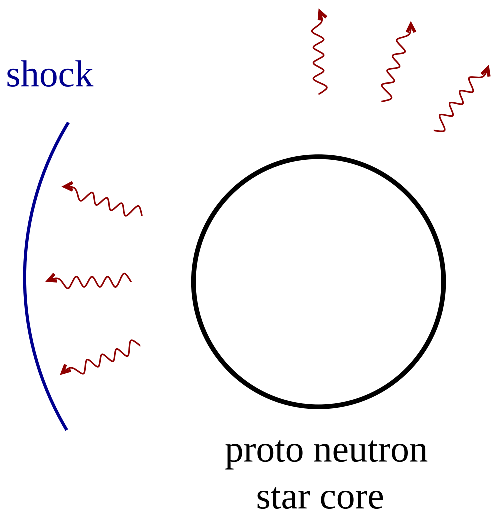
Short Gamma Ray Bursts: Compact Object Merger Models

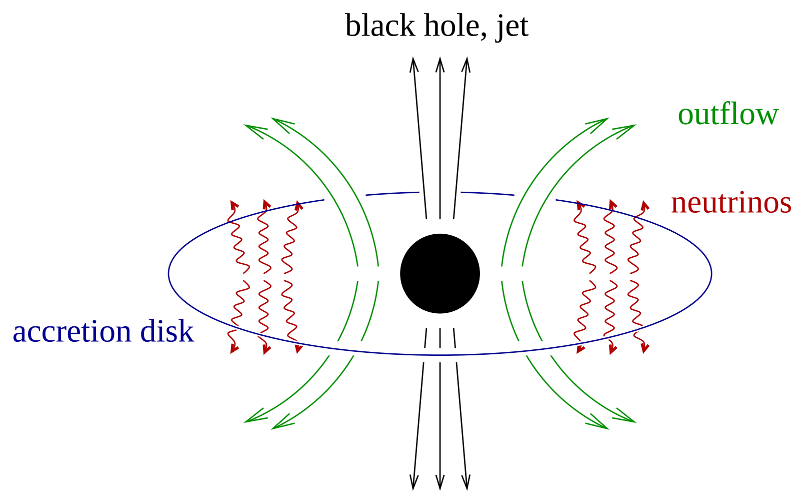
- Neutron star and black hole spiral in
- Create an accretion disk around a black hole



density data from M Ruffert

Explosions of Massive Stars: What's happening at the Center?

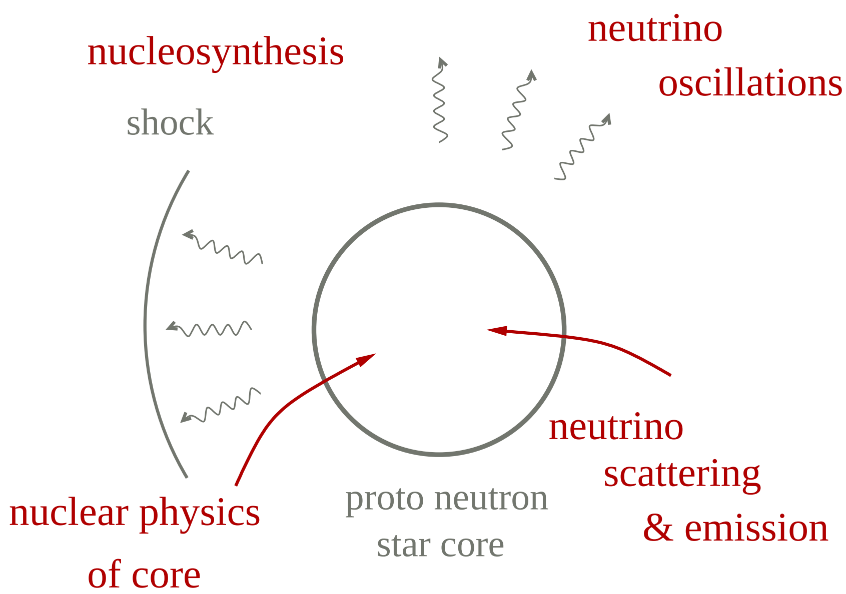


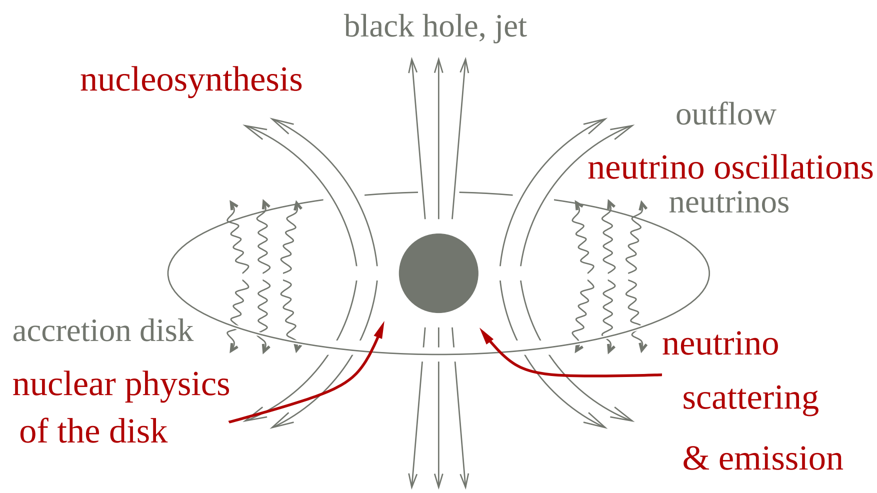


Standard core core collapse SN

accretion disk - black hole

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





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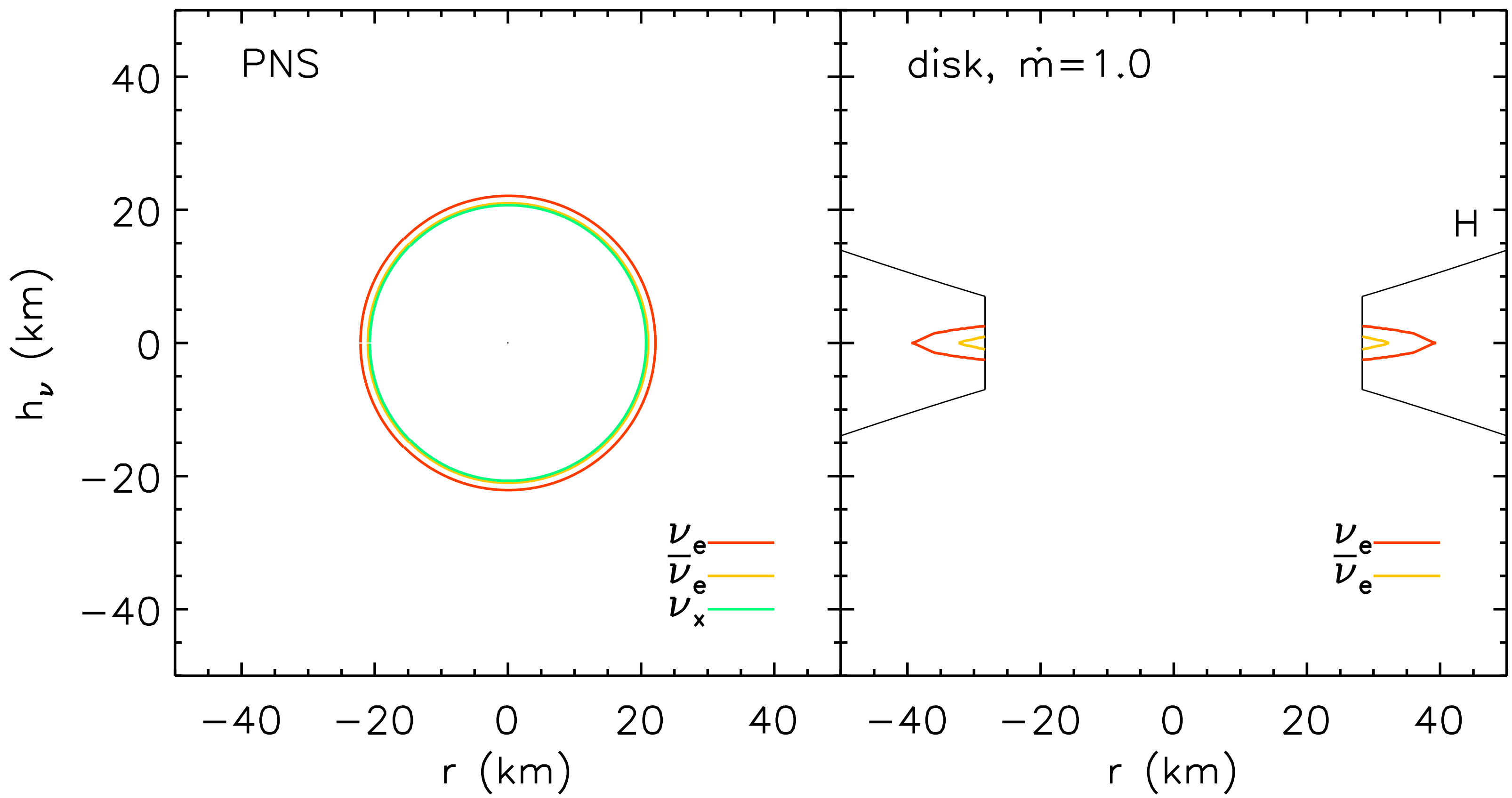
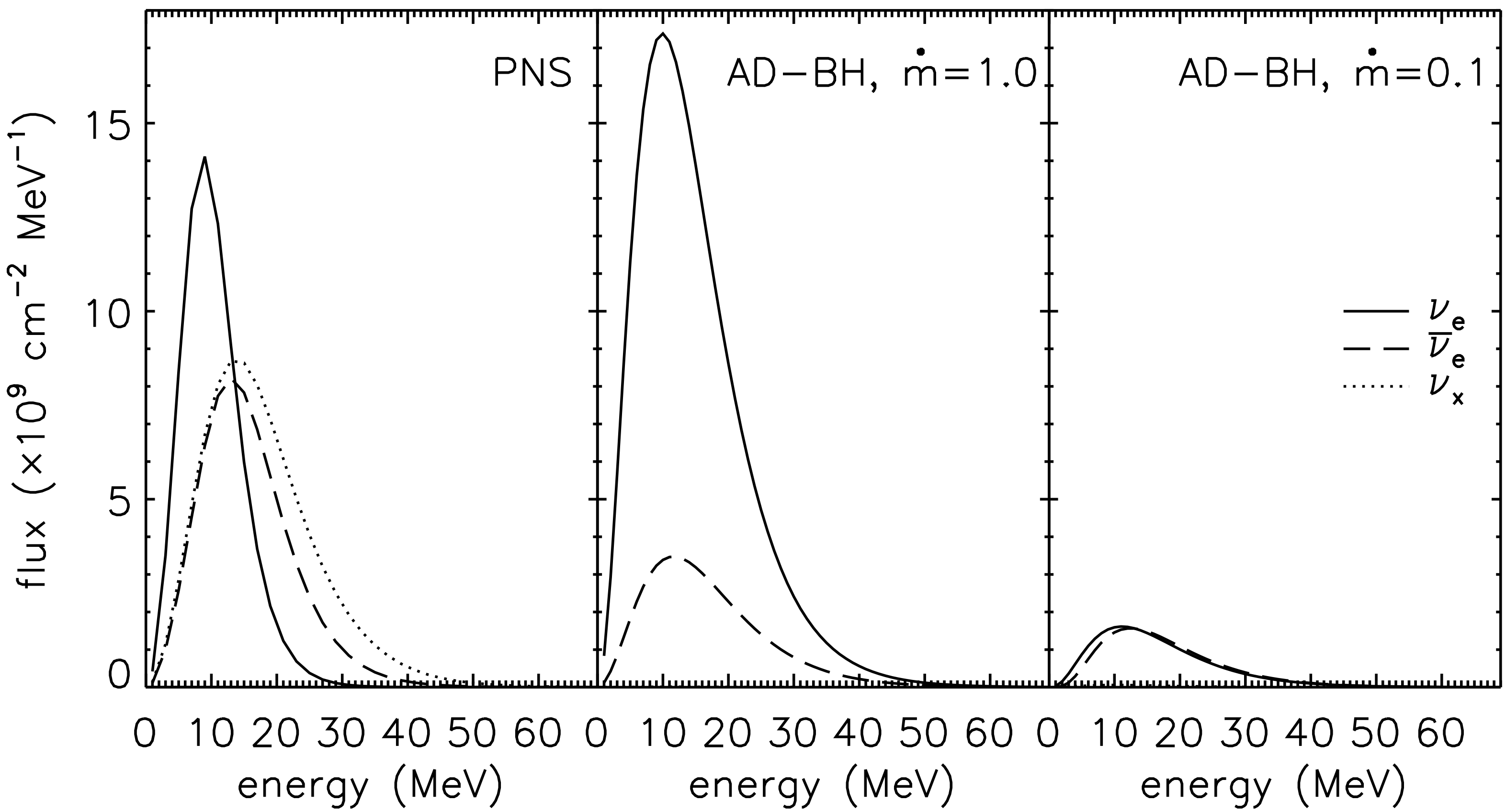
Comparison of neutrino surfaces:



In the disk electron neutrinos and antineutrinos have similar energies to the protoneutron star. Although few muon and tau neutrinos are produced.

Comparison of Spectra:



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Rates in SuperKamiokande for a Milky Way black hole accretion disk

In comparison with supernova (PNS), neutrinos arrive on a different timescale, and with a different NC to CC ratio

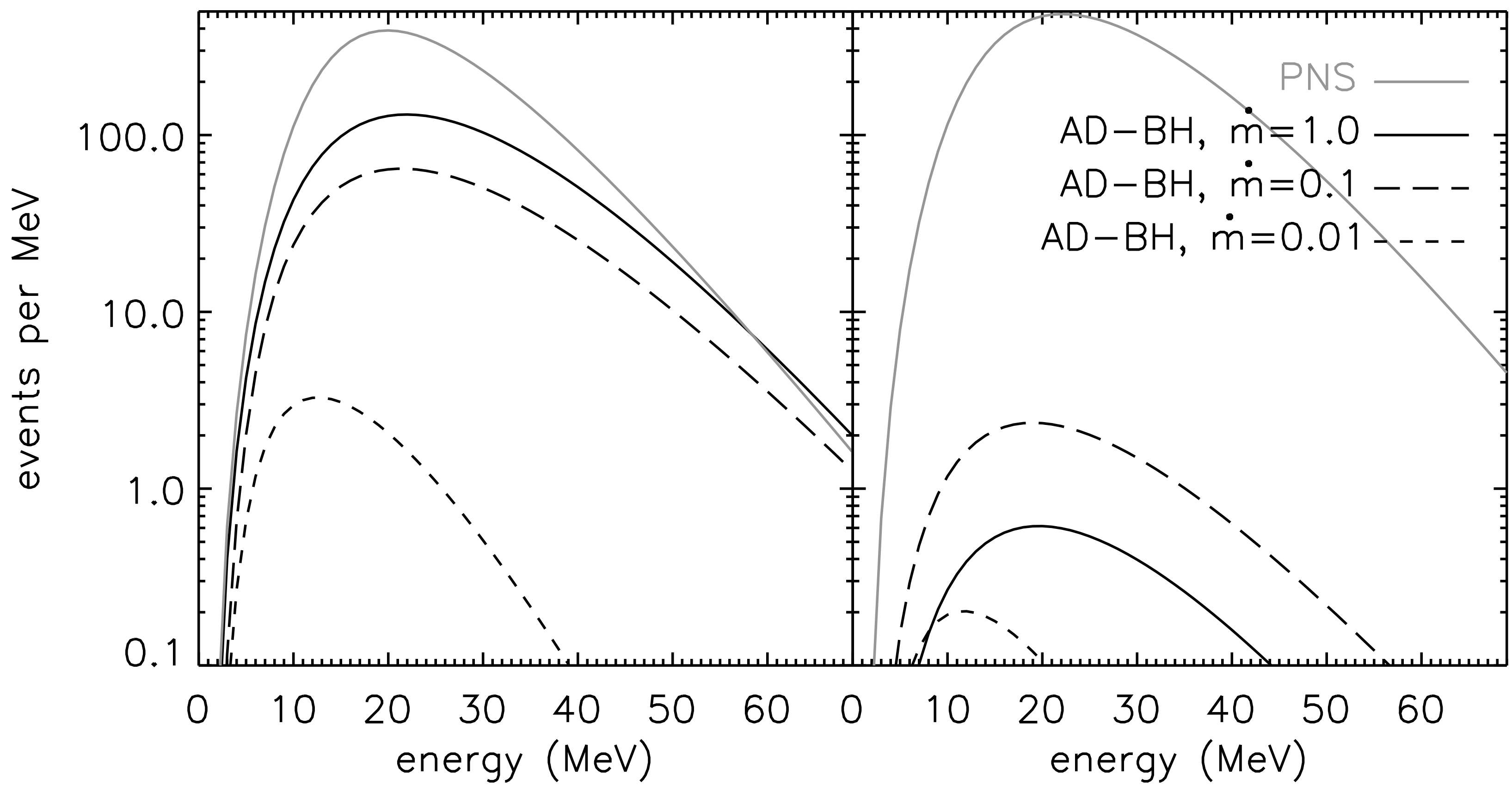
Rates:

- Regular supernova ~ 7000 events, 10 seconds
- Accretion Disk of $\dot{M} = 1 M/M_{\odot}$, 2800 events, 1 second
- Accretion Disk of $\dot{M} = 0.1 M/M_{\odot}$, 1400 events, 10 seconds
- Accretion Disk of $\dot{M} = 0.01 M/M_{\odot}$, 50 events, 100 seconds

Times and rates should be scaled by $M/M_{\odot}$ where M is the amount of material processed by the accretion disk.

McLaughlin and Surman 2006

Milky Way black hole accretion disk signal



$\bar{\nu}_e + p$ events in SuperK for two oscillation scenarios and 3 accretion disks

McLaughlin and Surman 2006

How to tell what's at the center of a supernova using neutrinos

- timescale - BH-AD - time material is accreting onto the disk
- timescale - PNS - time it takes neutrinos to diffuse out
- energetics - BH-AD: fraction of gravitational binding energy of material processed through disk
- energetics - PNS - gravitational binding energy of core
- neutrino energy - BH-AD and PNS are similar
- neutrino flavor: BH-AD: no ν_μ, ν_τ before oscillations
- neutrino flavor: PNS: all flavors emitted before oscillations

How neutrinos determine the nucleosynthesis from accretion disk outflow

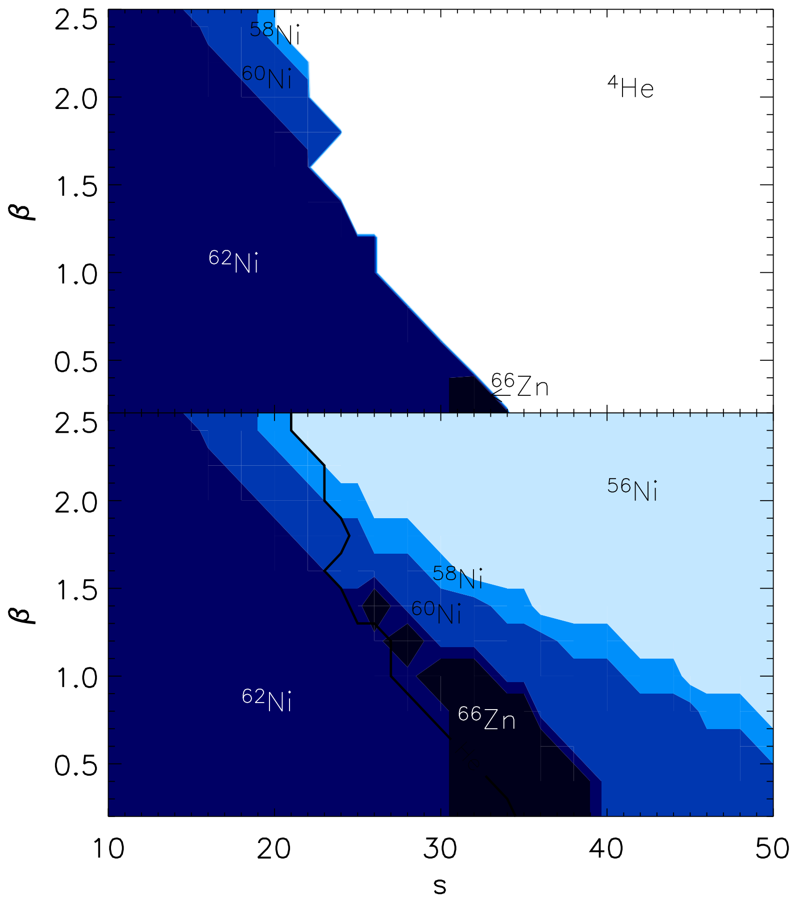
$$e^- + p \leftrightarrow n + \nu_e$$
$$e^+ + n \leftrightarrow p + \bar{\nu}_e$$

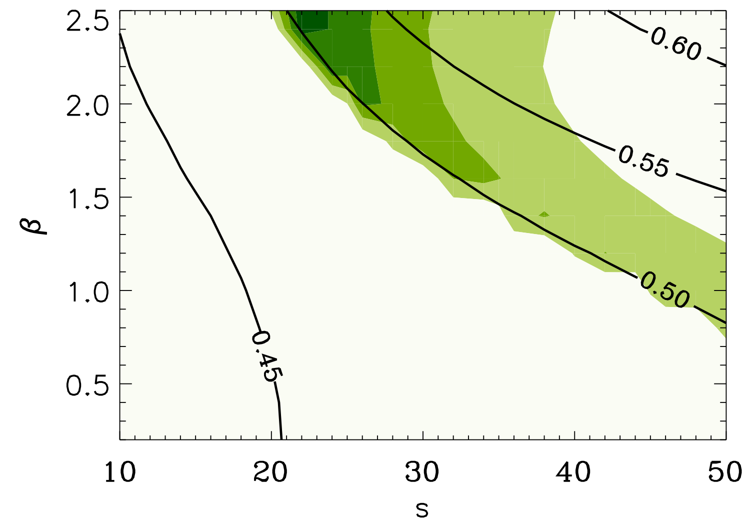
$+$ capture on nuclei

Calculations:

- Start with accretion disk models, e.g. Popham, Woosley, Fryer (PWF), DiMatteo, Perna, Narayan (DPN), Chen and Belaboradov (CB).
- Recalculate Y_es, neutrino trapping, neutrino fluxes
- Parameterize outflow trajectories, s- entropy, β - outflow
- Perform nucleosynthesis calculations

Nucleosynthesis from slowly accreting disks: $\dot{M} = 0.1\, M_\odot/\,\mathrm{s}$



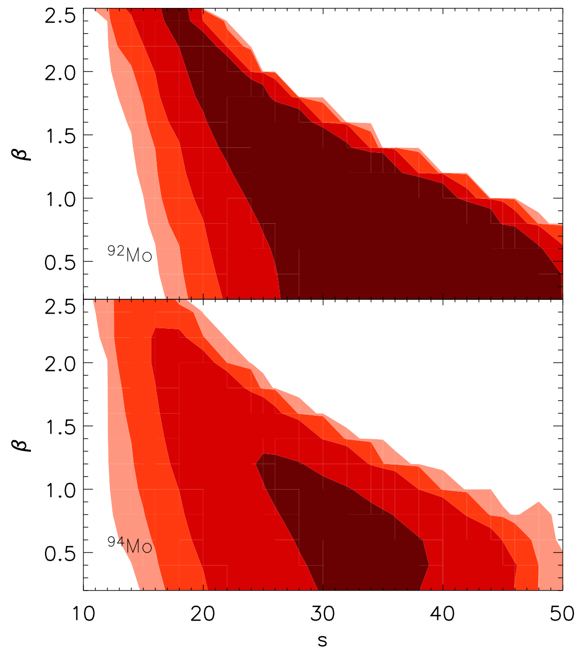


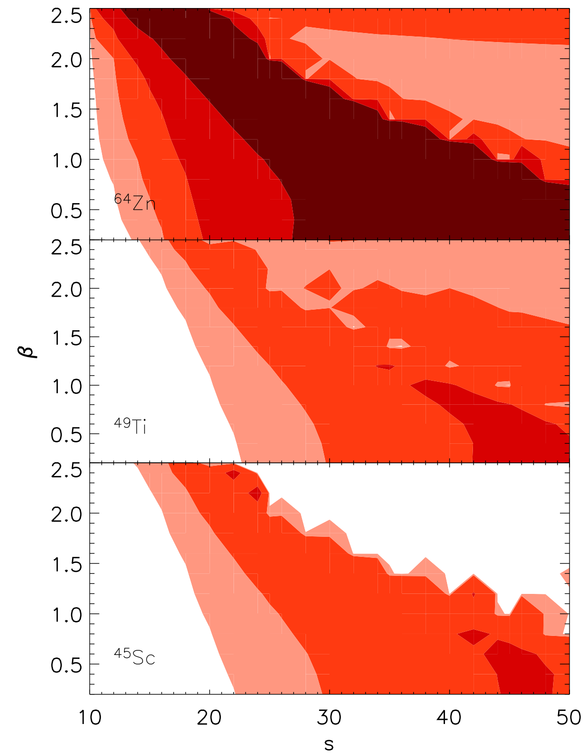
Y_e (lines), Nickel-56 (green)

Surman, McLaughlin, Hix 2005

Maximum mass fraction (upper),
excluding Helium (lower)

Overproduction factors for slowly accreting disks:





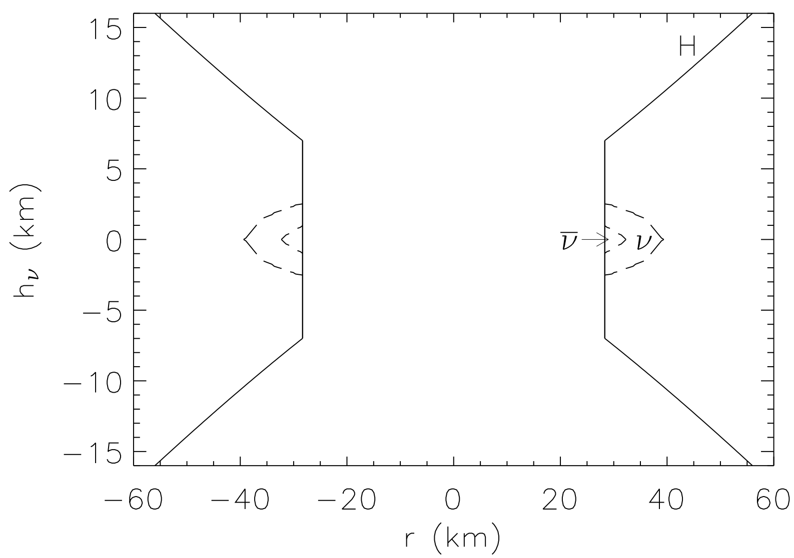
$^{92}\mathrm{Mo}, ^{94}\mathrm{Mo}$

Zinc-64,Titanium-49,
Scandium-45

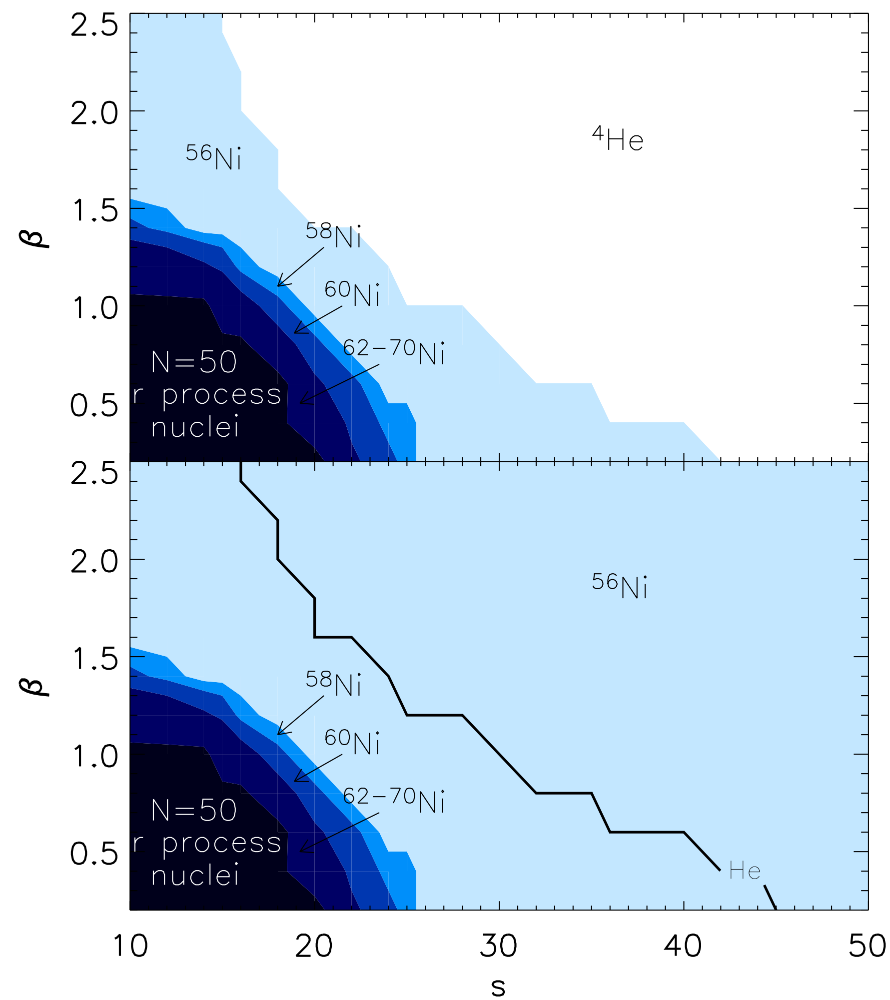
Compare with ways to make p-process in supernova (1) Fine tune Y_e (2) ν_e captures on nuclei Fuller and Meyer 1995, (3) late time captures on nucleons Frohilch et al, Pruet et al

Nucleosynthesis from moderate accretion rate disks:

$$\dot{M} = 1\,M_\odot/\,\mathrm{s}$$

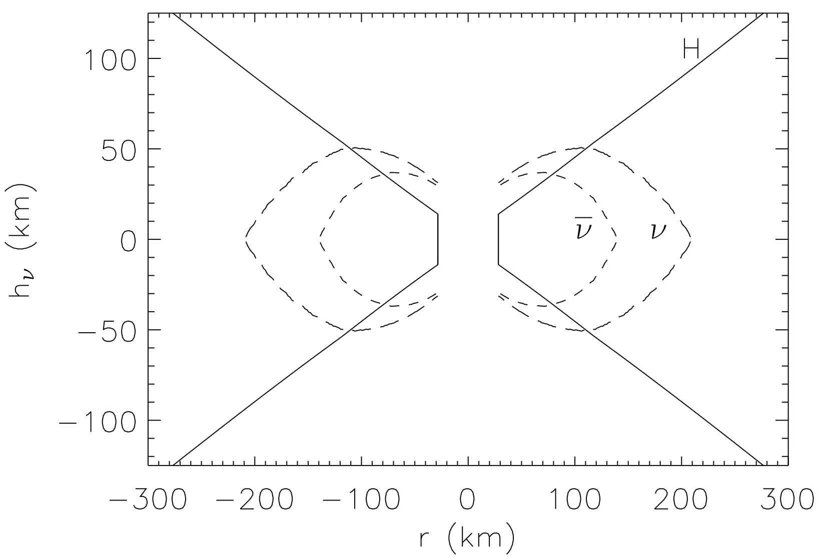


Neutrino Surfaces

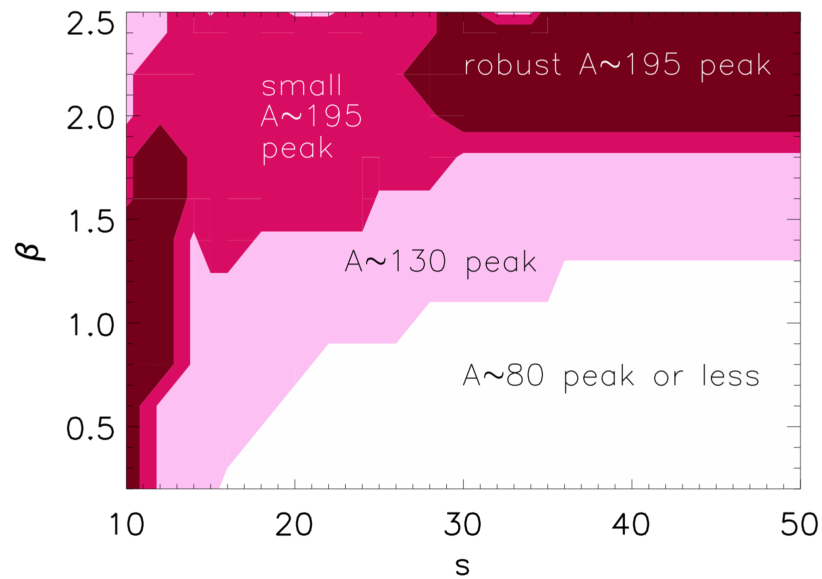


Maximum mass fraction

Nucleosynthesis from high accretion rate disks: $\dot{M} = 10\, M_\odot /\, \mathrm{s}$



Neutrino Surfaces

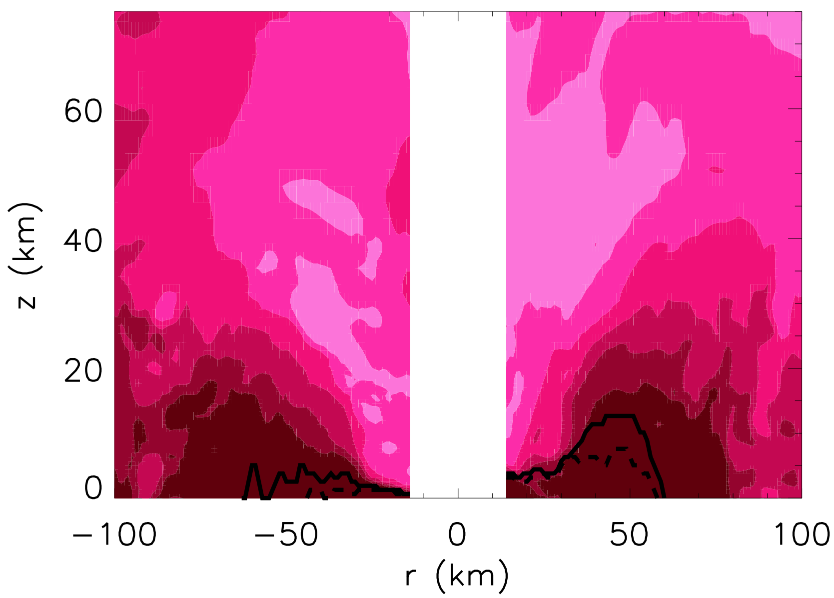


r-process peaks

$\bar{\nu}_e + p \rightarrow e^- + n$ produces many neutrons. The electron neutrino flux is not strong enough to produce the problems in the traditional supernova environment.

McLaughlin and Surman 2004, Surman, McLaughlin and Hix 2005

"Data" from a dynamical calculation:



BH-NS merger

density contours side view

black line - ν_e surface

dotted line - $\bar{\nu}_e$ surface

speculate that Y_e's in an outflow would be around one half

density data from M. Ruffert, ν surfaces by R. Surman

How charged current weak interactions determine the nucleosynthesis in a supernova neutrino driven wind

Neutrinos provide the energy to lift nucleons off the surface of the proto-neutron star. Then neutrinos set the electron fraction in the wind.

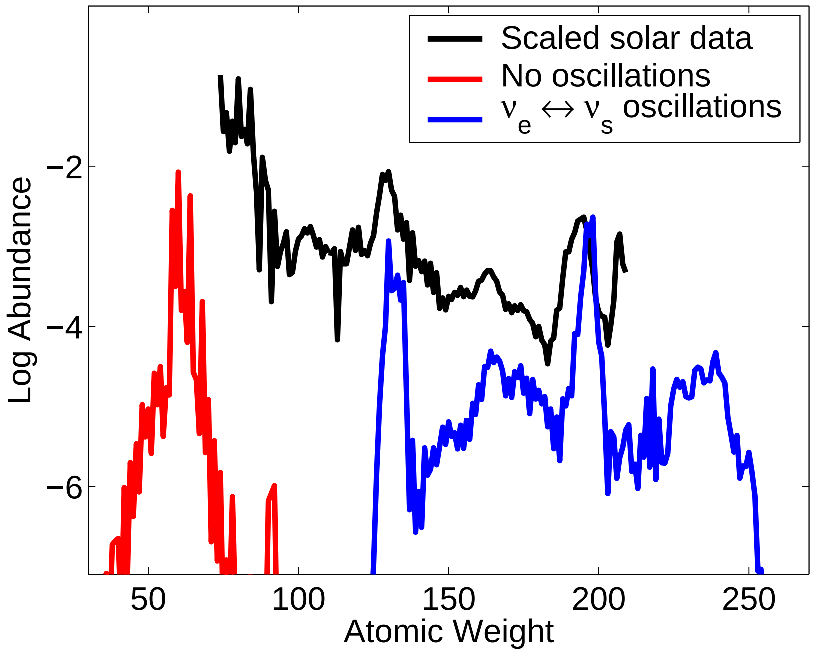
$$e^- + p \leftrightarrow n + \nu_e$$
$$e^+ + n \leftrightarrow p + \bar{\nu}_e$$

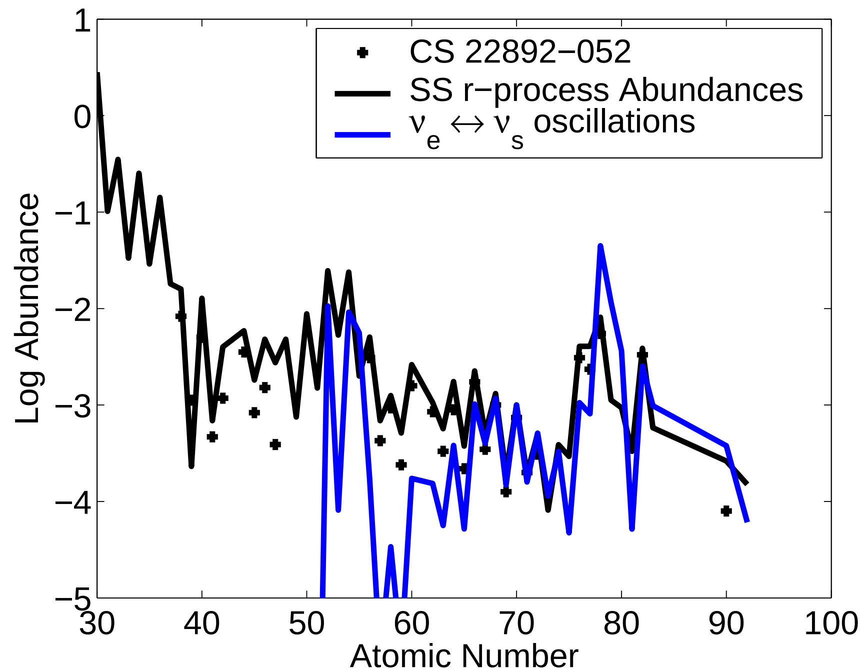
$+$ capture on nuclei

$+$ beta decay

Neutrinos and nuclesynthesis in supernovae: fission cycling and the r-process

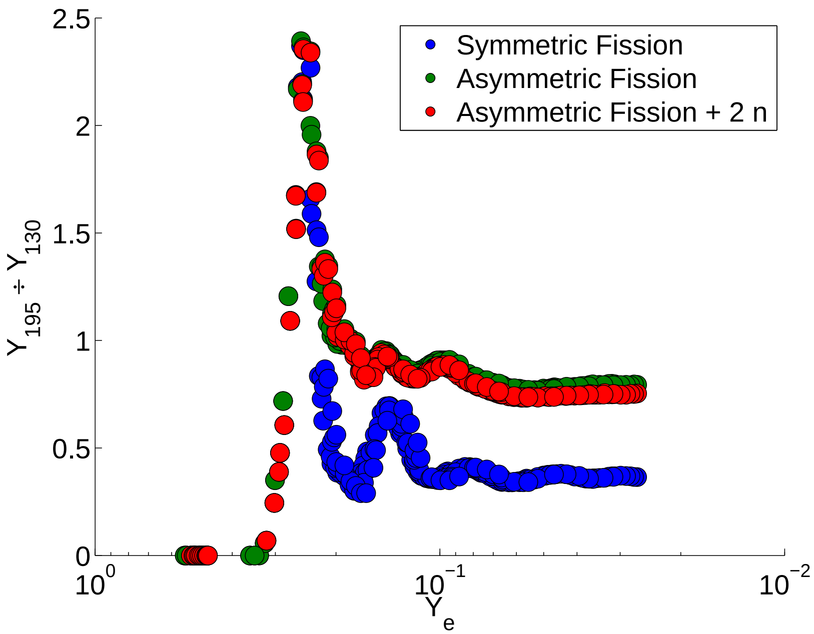
Beun et al 2006





s $= 100$, $\tau = 0.3\,\mathrm{s}$ Conclusion: Although some calculations do better than the red curve e.g. Mathews et al, standard winds and neutrinos do not provide a sufficiently neutron rich environment to produce fission cycling. Blue curves were produced by “artificially” lowering the electron fraction.

Fission cycling and the electron fraction



Different electron fractions produce different peak height ratios, but below a certain threshold, a stable pattern emerges.

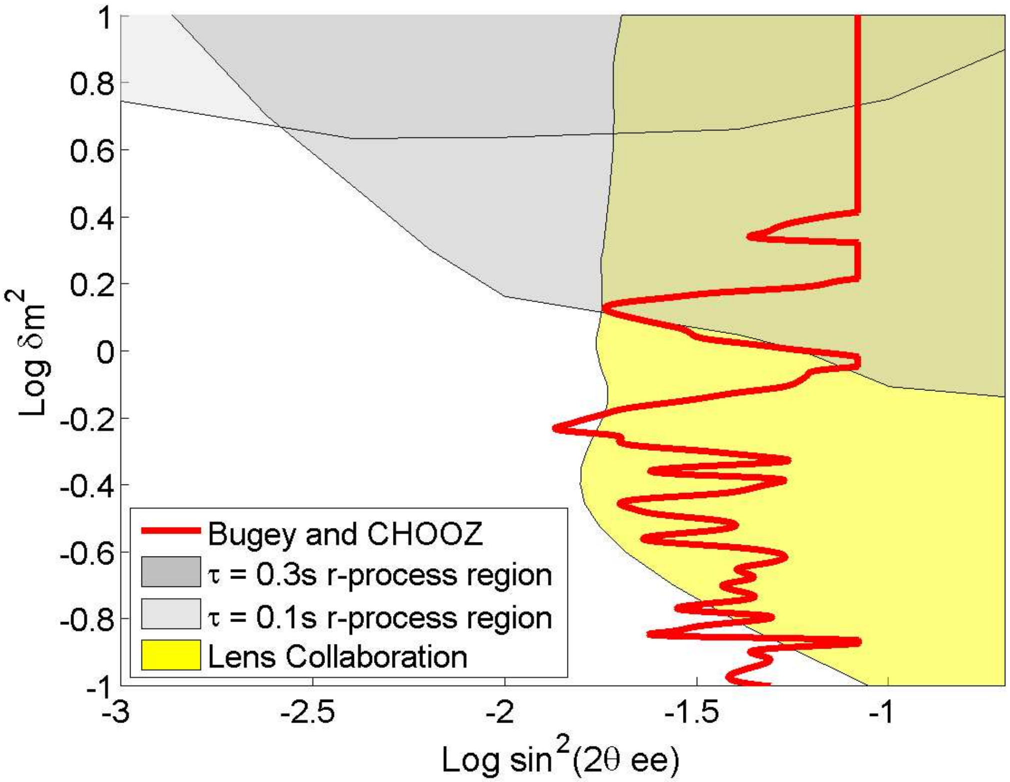
Beun et al 2007

We need better calculations of fission barriers and daughter products,

e.g. look for work by Kelic, Panov

One way to get the stable pattern is to remove the ν_es, but not the $\bar{\nu}_e$s.

Sterile Neutrinos and the r-process



Beun et al 2007

Gray regions show r-process models. Area to the right of the red line is excluded. Yellow is area which is proposed to be measured by LENS.

Conclusions

- Black hole accretion disks may form from exploding stars and compact object mergers
- Rate of occurance is not well constrained by data
- 10's of MeV neutrinos would be detectable from an event in the Milky Way
- they can produce a range of nucleosynthesis products, including the r-process, some light p-process and other rare elements
- Standard neutrino driven wind in SN does not produce fission cycling
- Sterile neutrinos may help