Supernova Neutrinos

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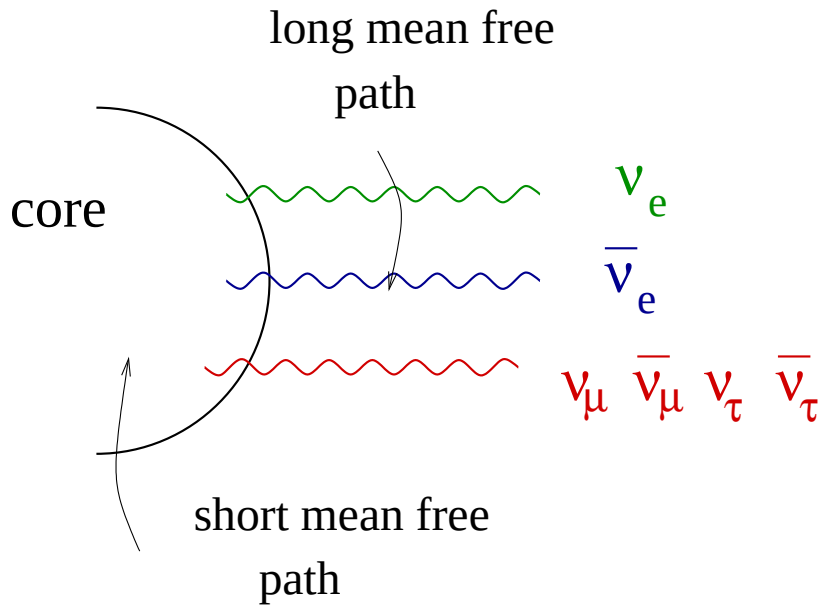
- General remarks about neutrinos from hot dense environments
- Oscillations
- Detection of astrophysical neutrinos
- ν cross sections: needed in astrophysical objects & for ν detection
- The nucleosynthesis - neutrino connection

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.

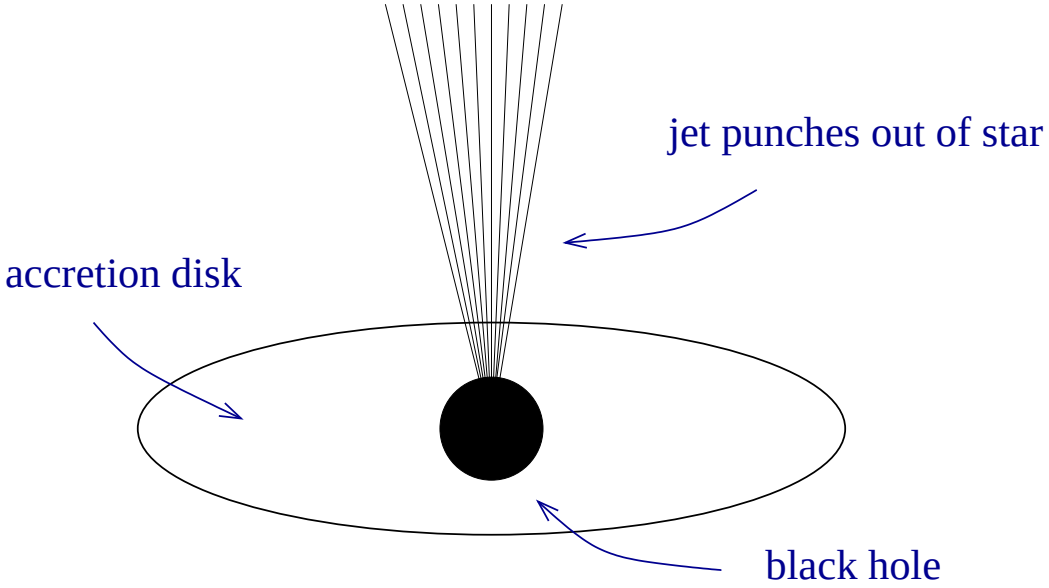


SN neutrinos:

- may be detected
- oscillate
- nucleosynthesis
- explosion dynamics

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.

Compact Object Merger Models

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

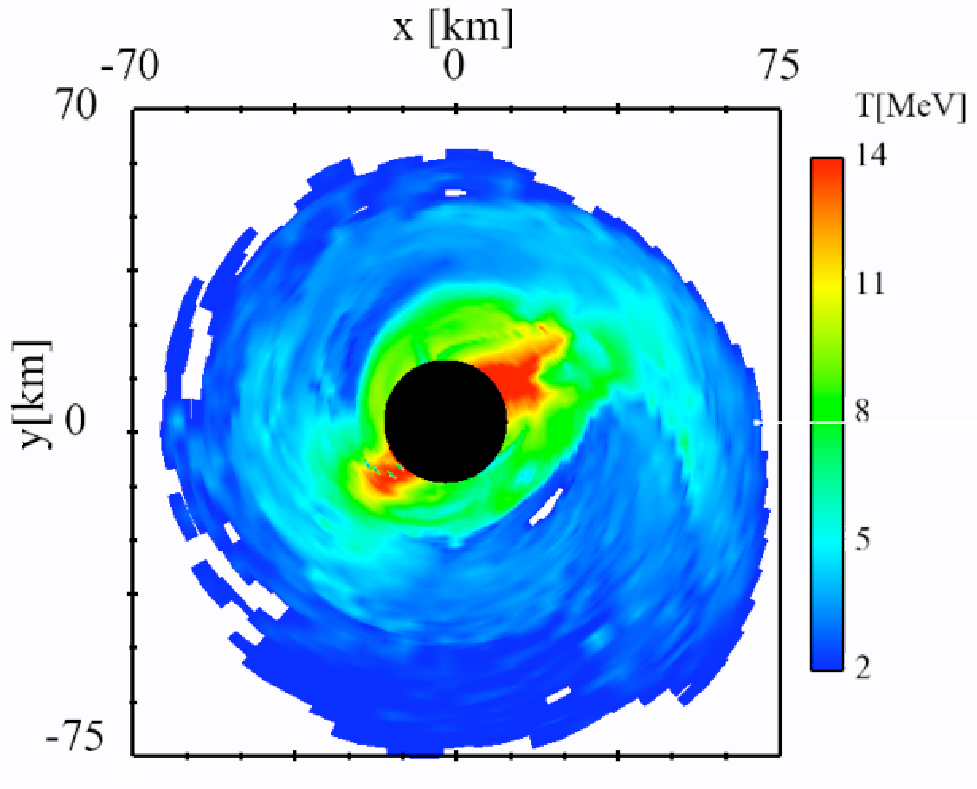
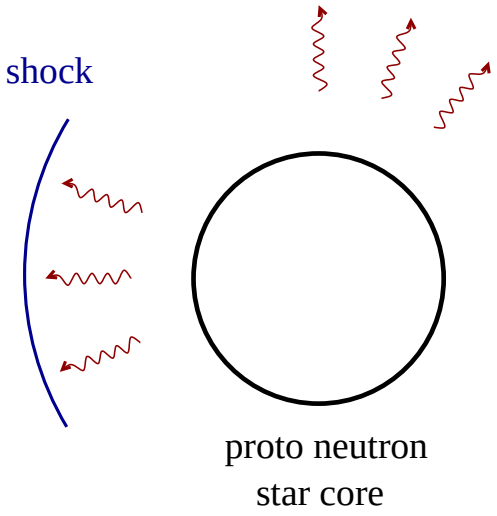
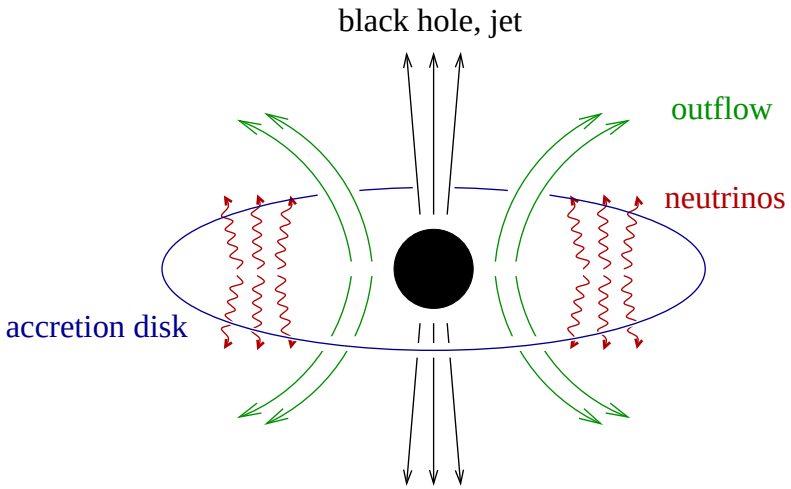


figure from Liliana Caballero

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

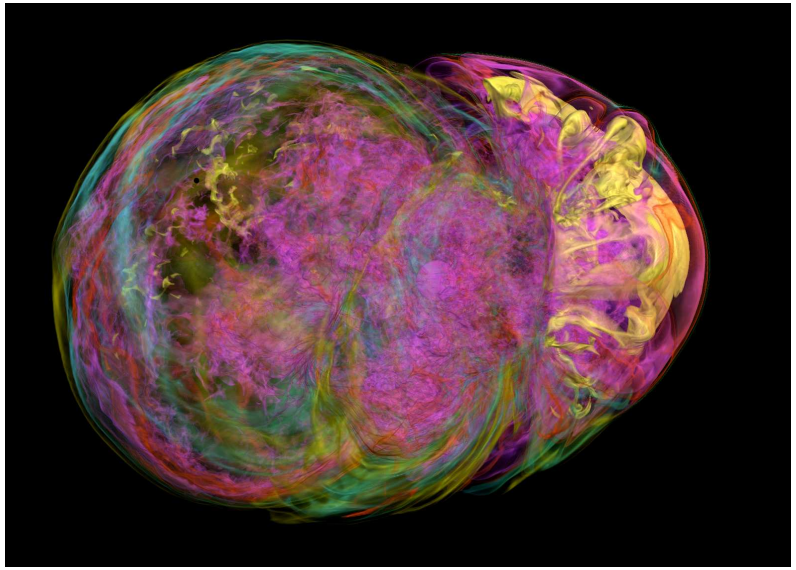




Standard core core collapse SN

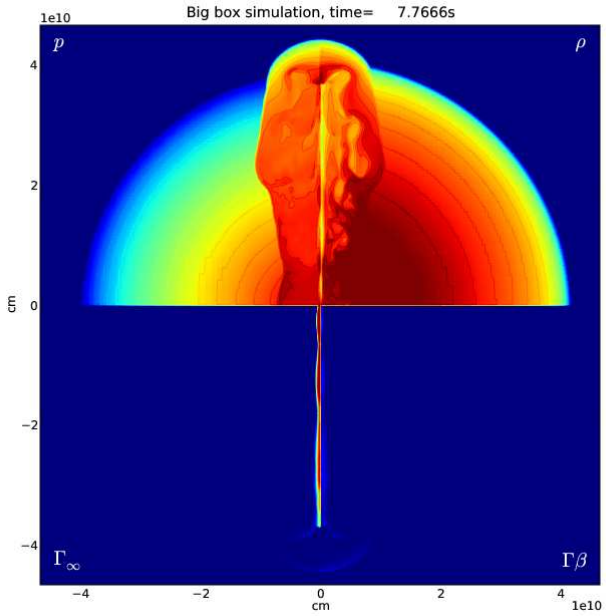
accretion disk - black hole

Explosions of Massive Stars: Hydrodynamical Calculations



Core core collapse SN

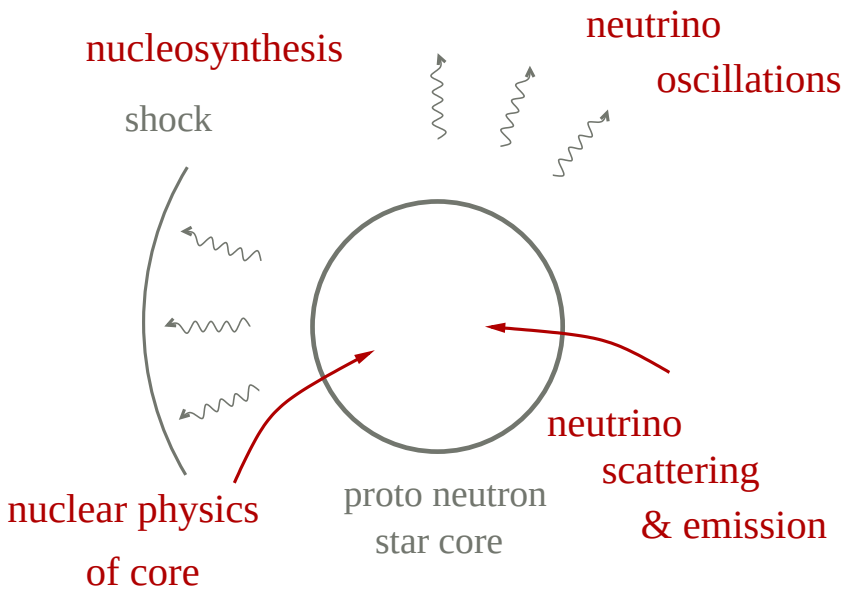
Blondin & Mezzacappa (2007)

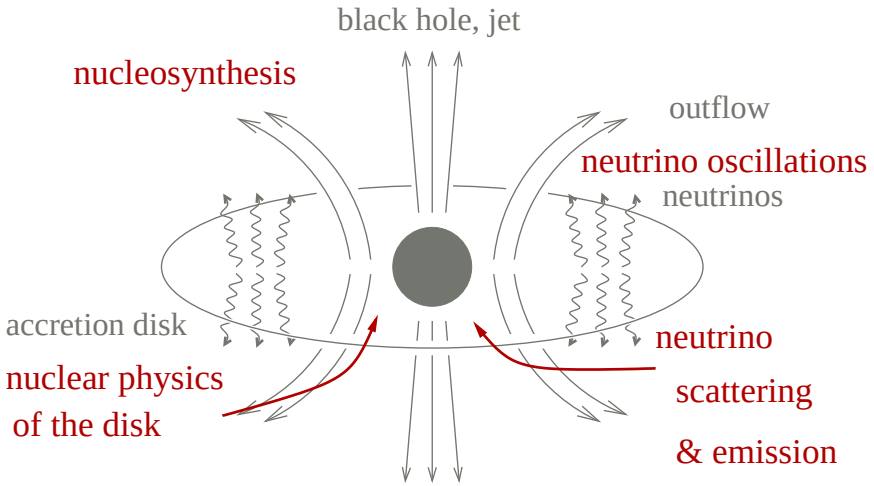


Gamma ray burst jet

Morsony, Lazzati, & Begelman (2007)

Explosions of Massive Stars: Where is the neutrino physics?





Standard core core collapse SN

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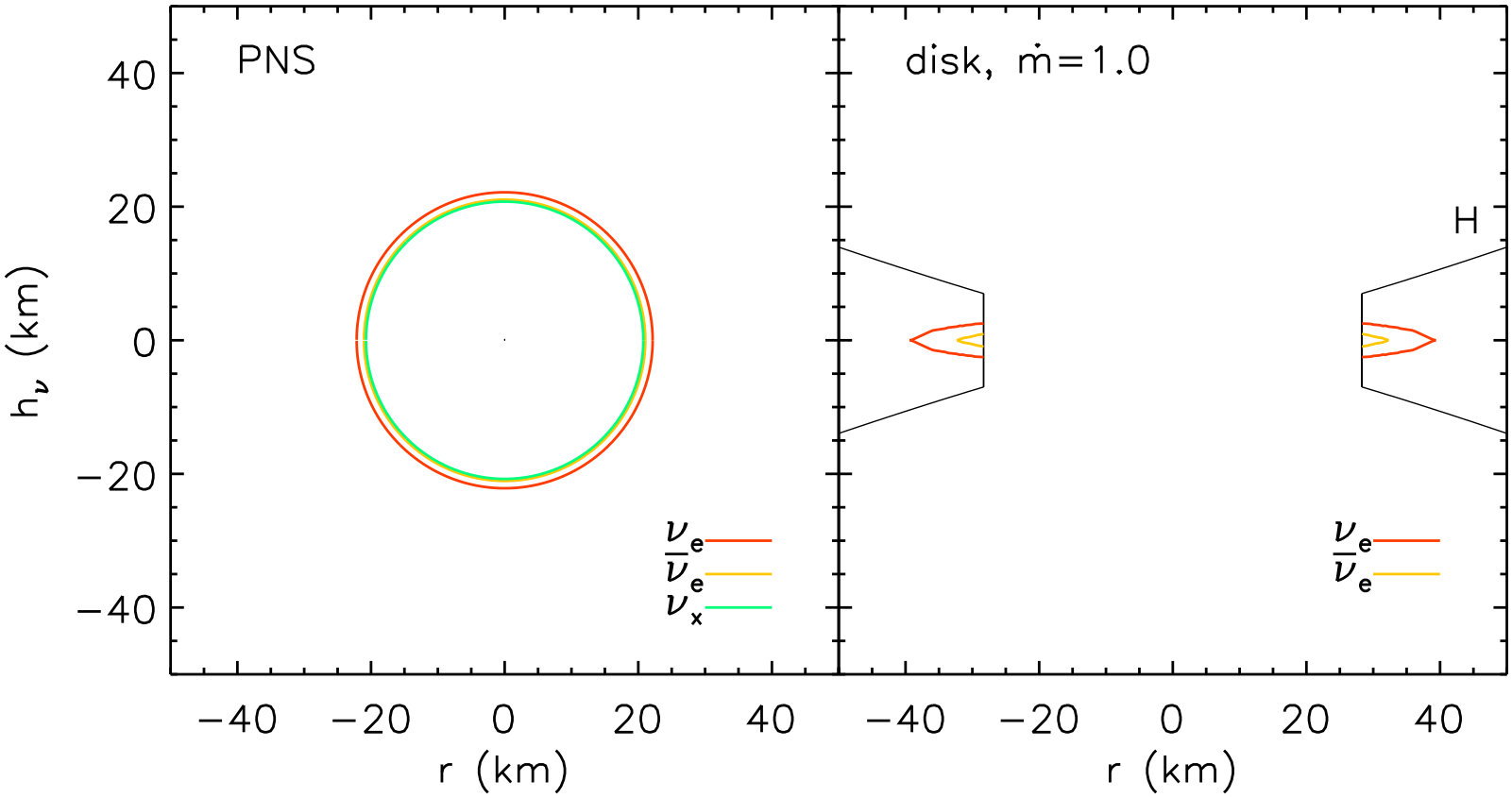
Neutrino surfaces:

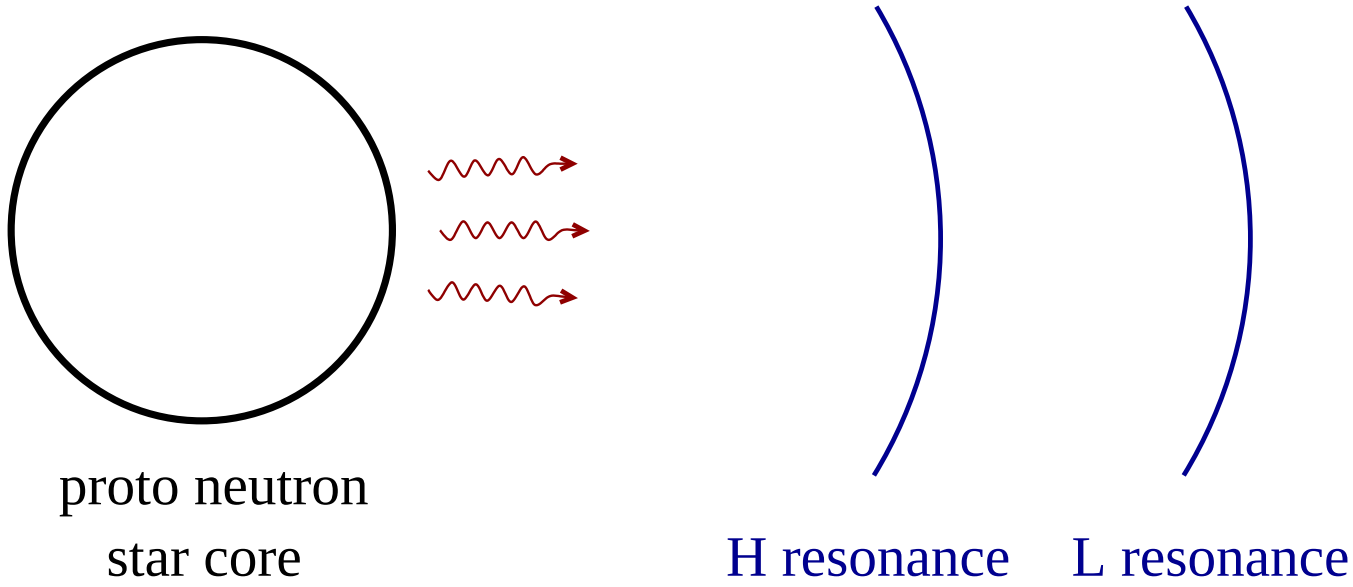


Neutrino Oscillations

After neutrinos are emitted, they undergo flavor transformation.

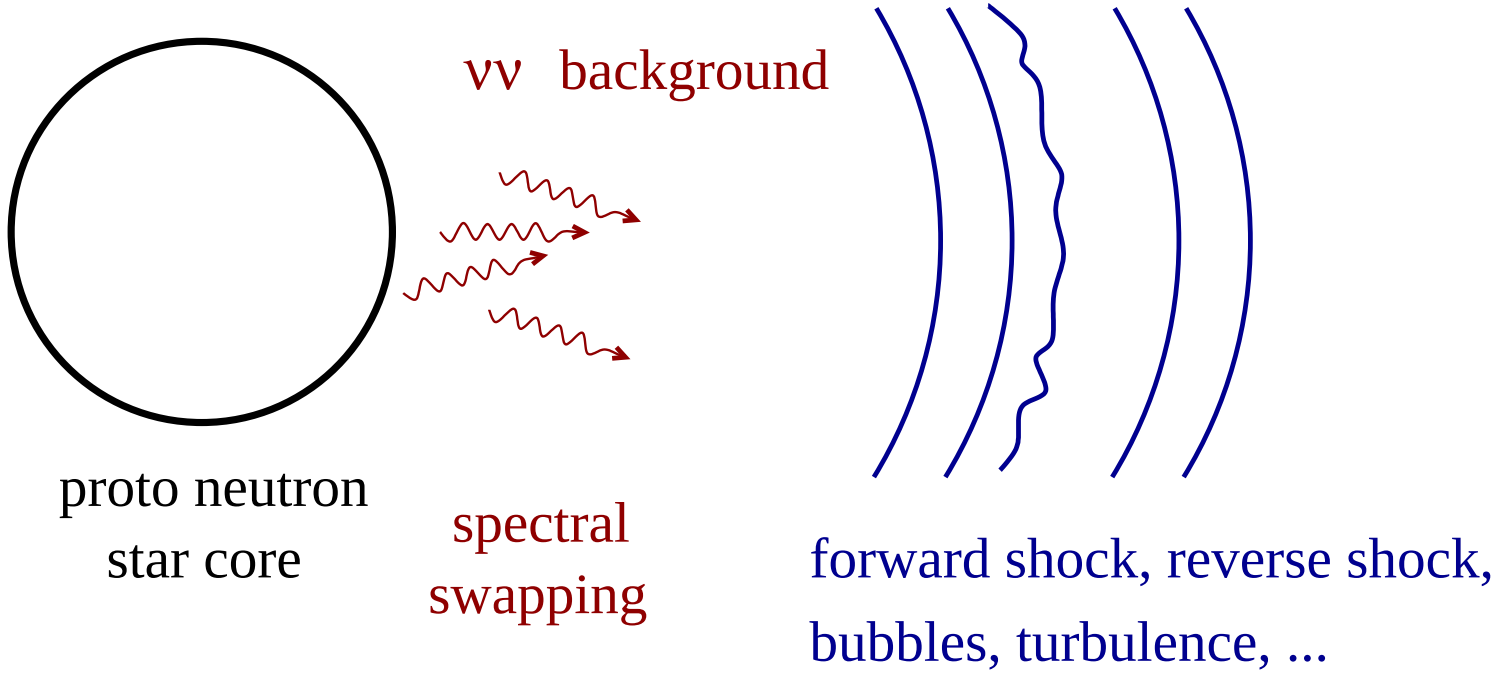
Old Picture of Supernova Neutrino Transformation

Static density profiles, collective effects not included...



Primary uncertainties in evolution: Hierarchy, θ_{13} e.g. Dighe and Smirnov 2000

New Picture of Supernova Neutrino Transformation

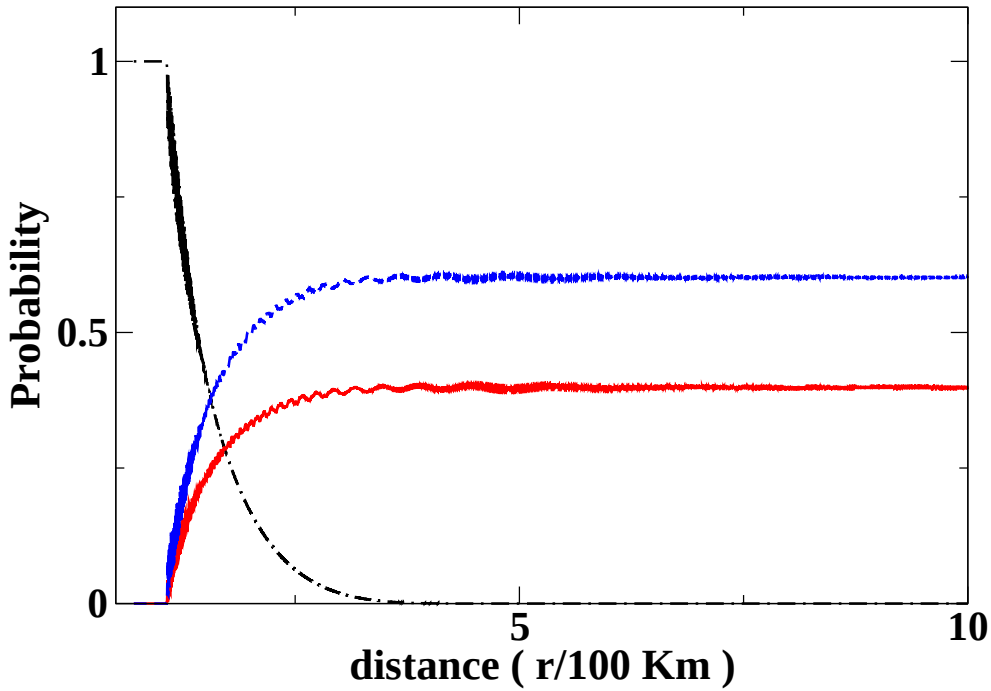


Many more possibilities, depending on: hierarchy, θ_{13}, evolution of density profile

Neutrino evolution calculations much more complex

New Flavor Transformation behavior when $V_{\nu\nu}$ included

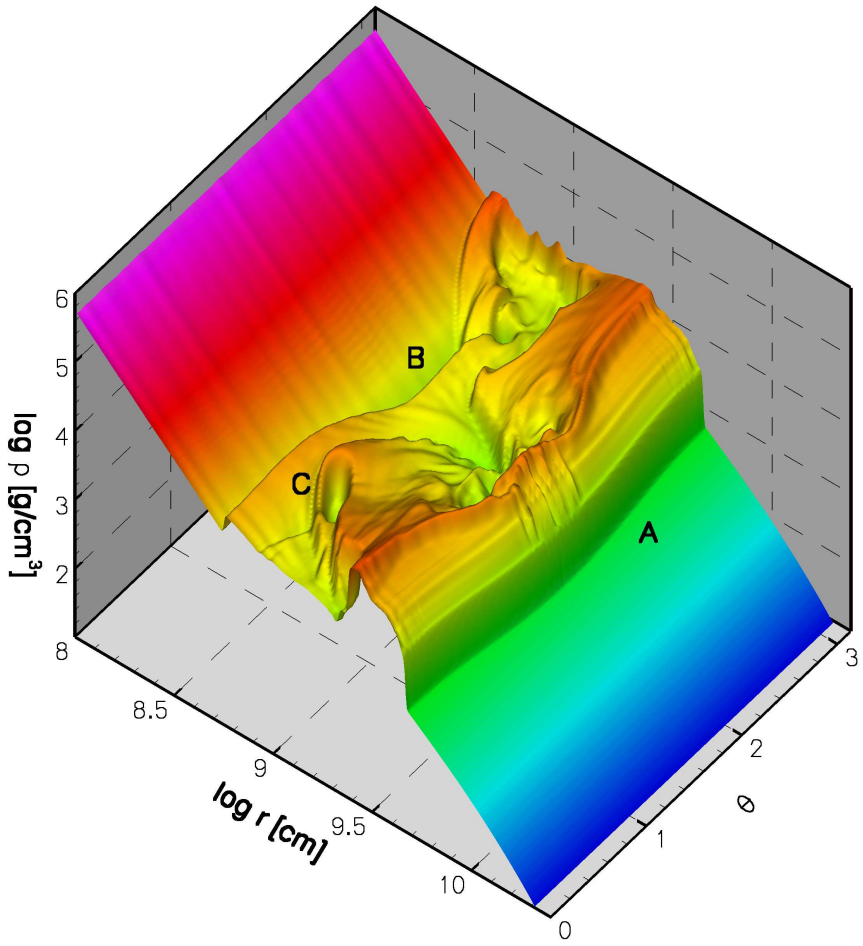
It used to be assumed that close to the ν-sphere neutrinos were matter suppressed...

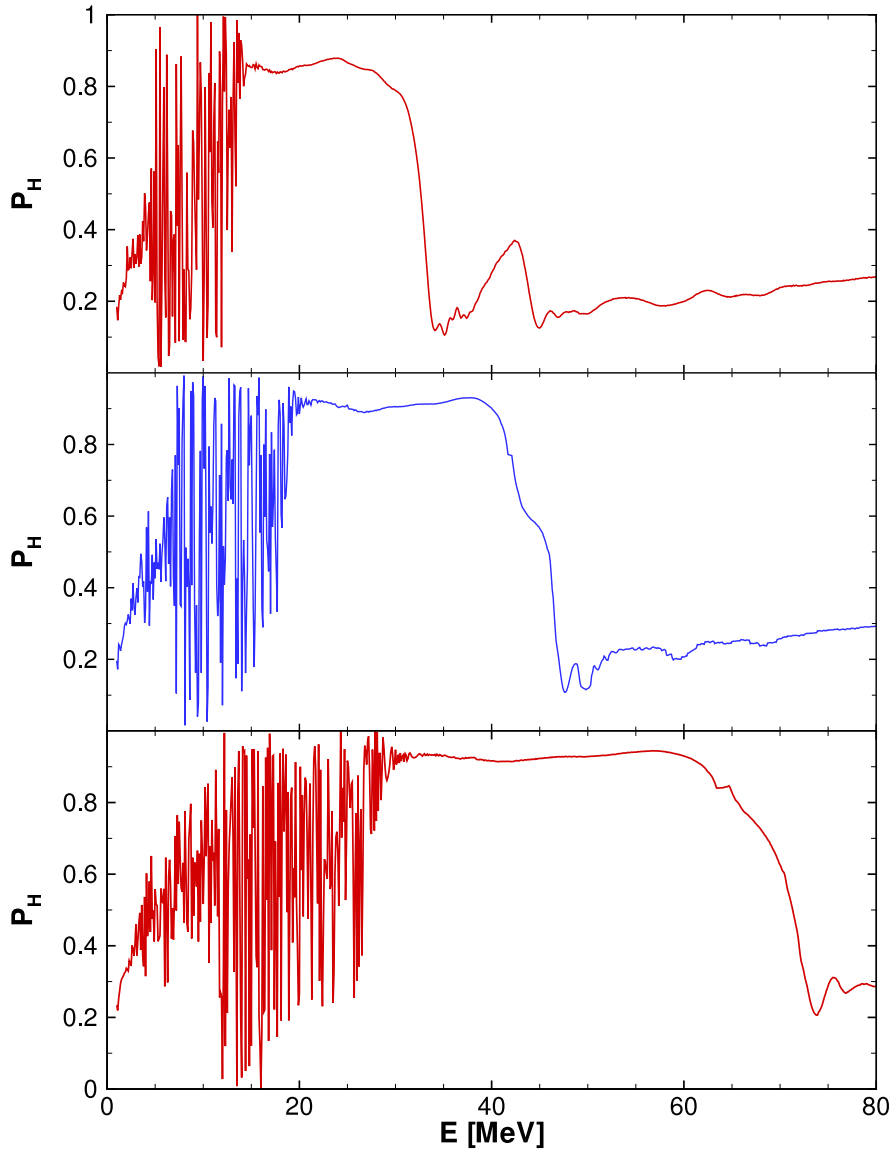


Shows survival probablilities for 15 MeV antineutrinos as a function of distrance from the neutrino surface figure from Gava et al 2009

Black: Electron $\bar{\nu}$, Blue: muon $\bar{\nu}$, Red: tau $\bar{\nu}$

Multi-resonance phase effects





Kneller et al 2007

Neutrino Detection

After neutrinos flavor transform, we might detect them on earth

- direct detection
- diffuse supernova neutrino background
- disentangling neutrino signal

Direct detection: many detectors that could see a Milky Way supernova

Some running experiments, events at 10 kpc

- SuperK, ∼7000
- KamLAND, ∼300
- Borexino, ∼100
- Mini-BooNE, ∼200
- IceCube ∼600,000

Some proposed experiments

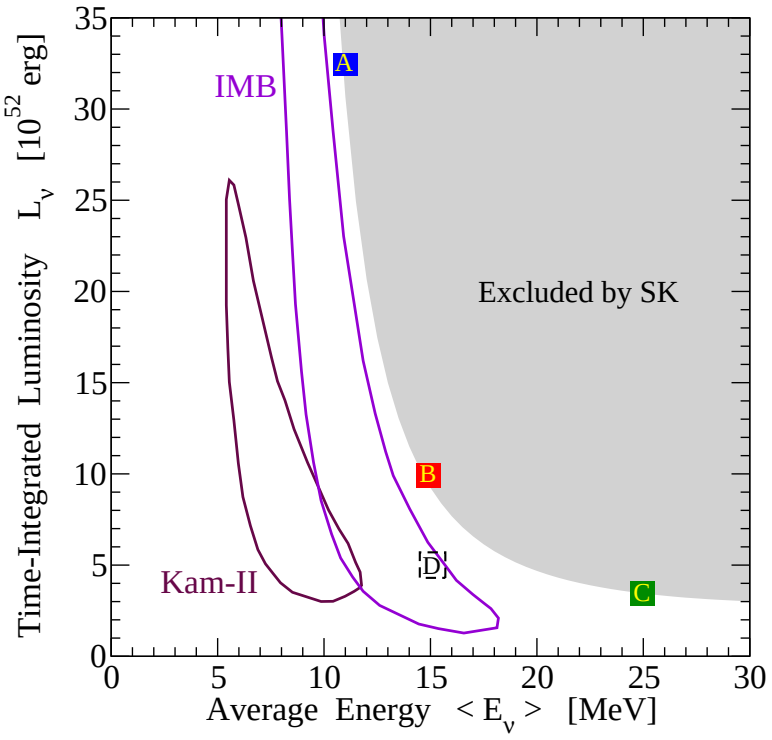
- CLEAN, ∼30
- HALO, ∼40
- OMNIS,∼1000
- UNO, ∼100,000

Supernova Early Warning Network (SNEWS) established

Possible events are sent to central server: alert sent to astronomers.

Approaching constraints on SN models from the diffuse supernova neutrino background

Past supernova emitted neutrinos which are present today as a "background". Detect/place limits on the neutrinos by looking for this background.



Yuksel et al

Disentangling the signal

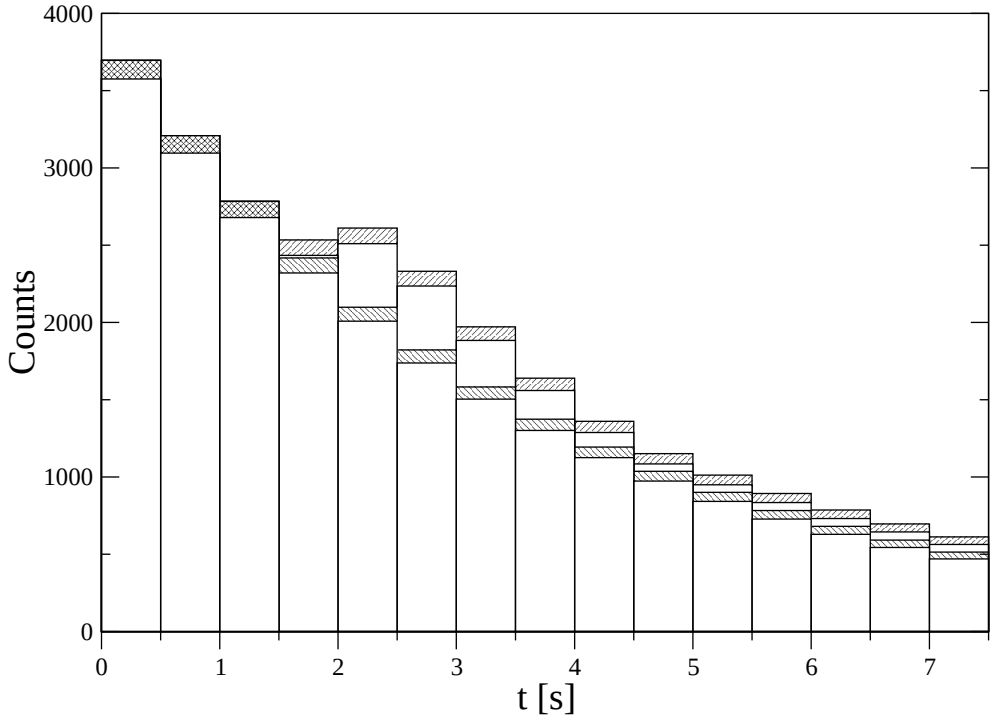
Extreme: What if its not a "traditional" core collapse supernova?

Rates ofr events at 10 kpc:

- Regular supernova ~ 7000 events, 10 seconds
- Accretion Disk of $\dot{M} = 0.1 M/M_{\odot}$, 1400 events, 10 seconds
- Black Hole - Neutron Star merger, 9000 events, 0.01 seconds

Similar numbers of events, but time structure is likely different.

Can we see the time dependent changes in the density structure of the star?



In some cases... but the more we know about neutrino parameters, like the hierarchy, the easier it is to rule out other possibilities

Figure from J. Kneller

Neutrino Cross Sections

We need to understand how neutrinos scatter on nuclei

Cross sections for neutrinos interacting with nuclei

- in terrestrial detectors
- in astrophysical environments

An example...

Neutrino Cross Sections

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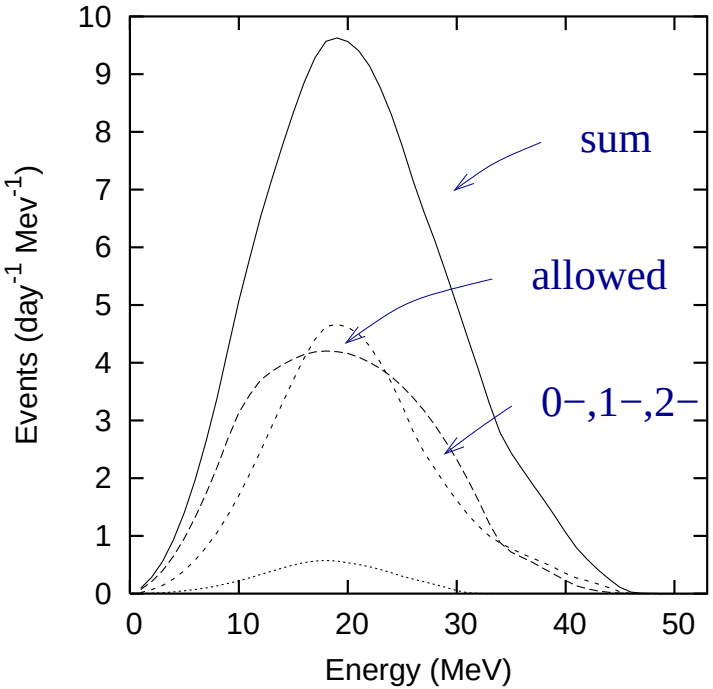
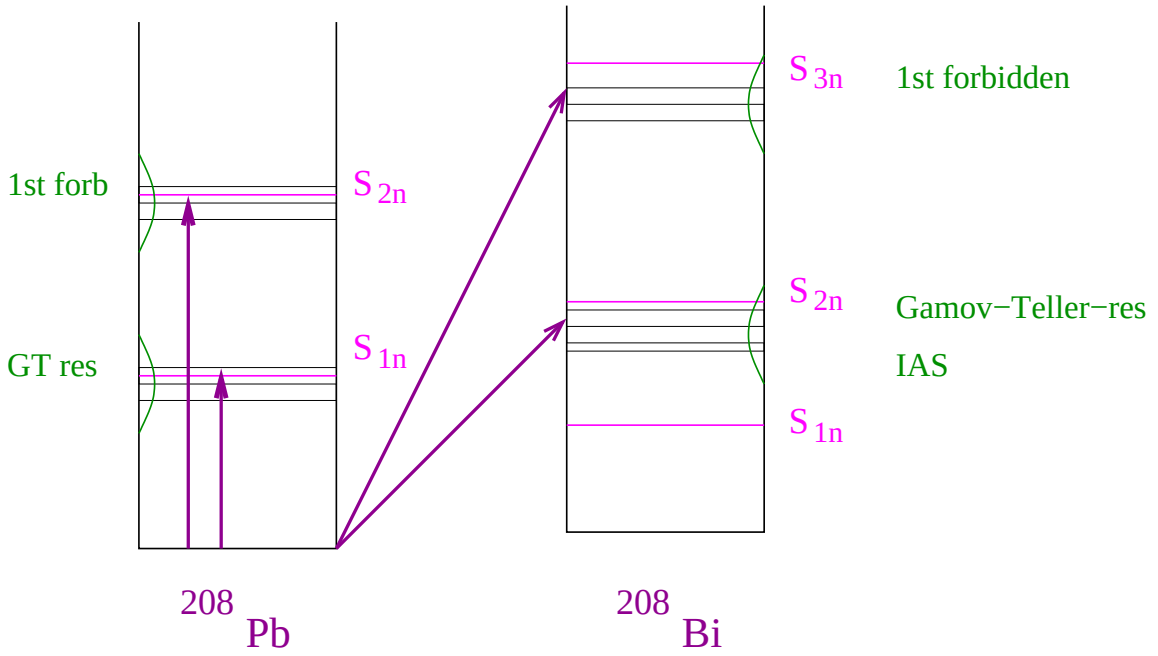
An example...

Understanding the neutrino-nucleus cross sections

Very Low energy beta beam would be extremely useful



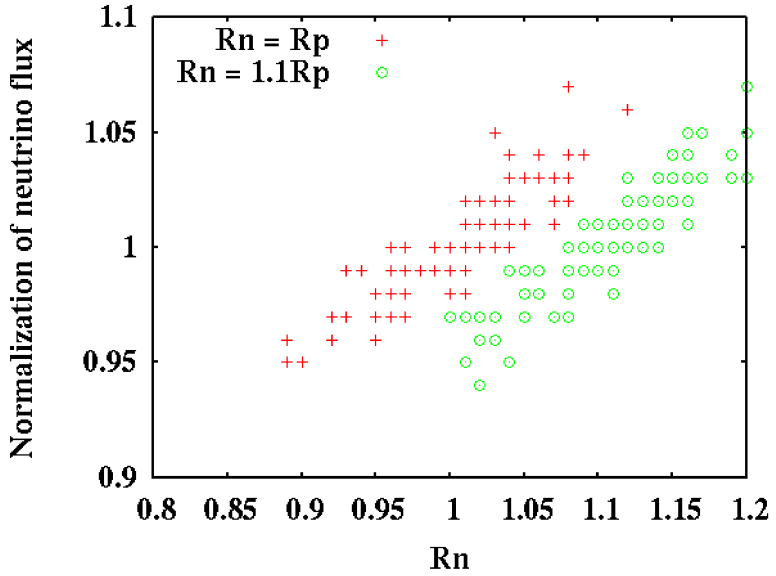
Multipole contributions to ν_e-lead scattering GM 2004

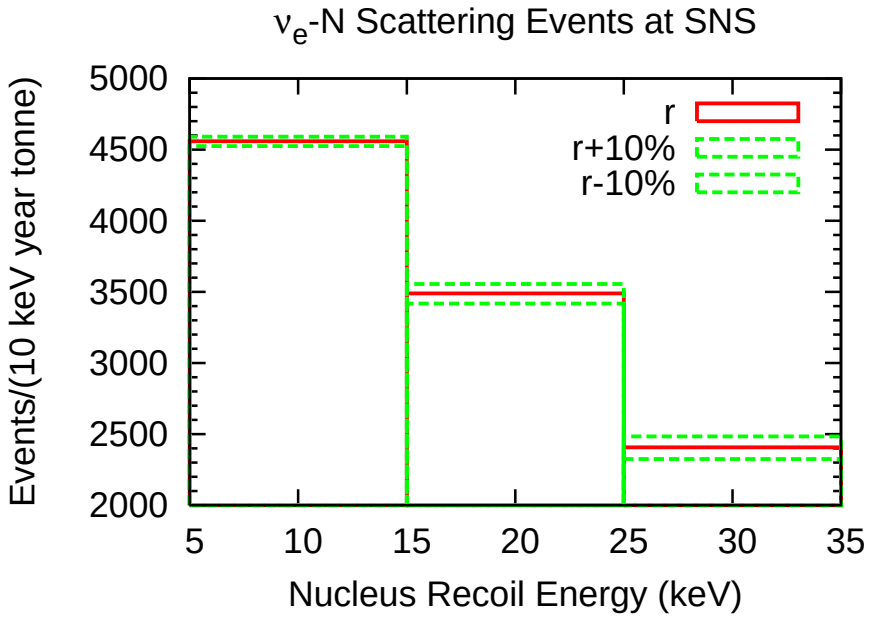


Schematic of resonances in lead for ~ 40 MeV neutrinos

Cross sections: ν-nucleus coherent scattering

A very low energy beta beam would be useful here as well





A one ton detector might determine R_N at 10% or better.

Events for different form factors

figure by Kelly Patton

Neutrino - Nucleosynthesis connection

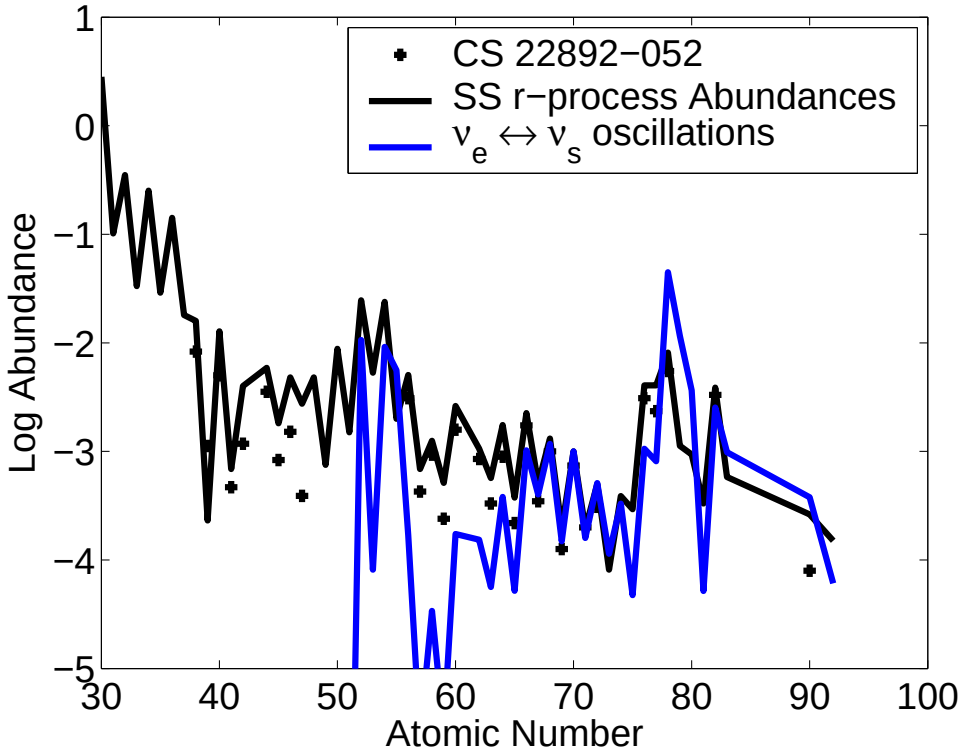
If neutrinos have most of the energy in an object, they are key to determining the astrophysical conditions.

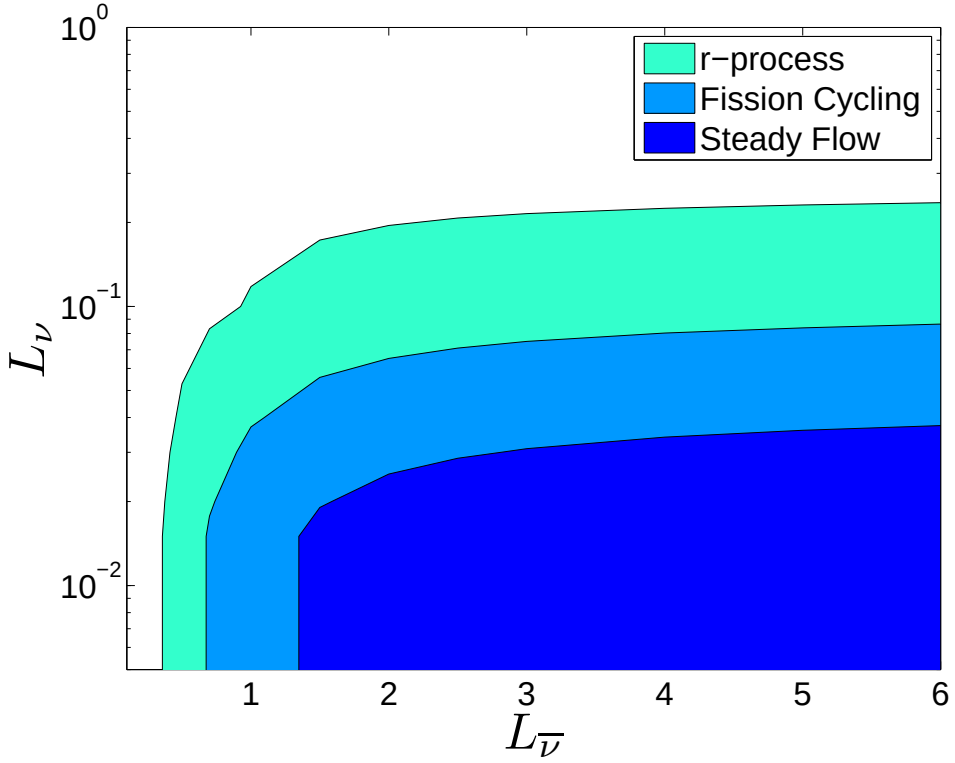
Also, they determine the relative numbers of neutrons and protons...

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

Therefore, the results are sensitive to the neutrino spectrum, and therefore to oscillations, sterile neutrinos and other new physics...

Neutrinos and the r-process in supernova

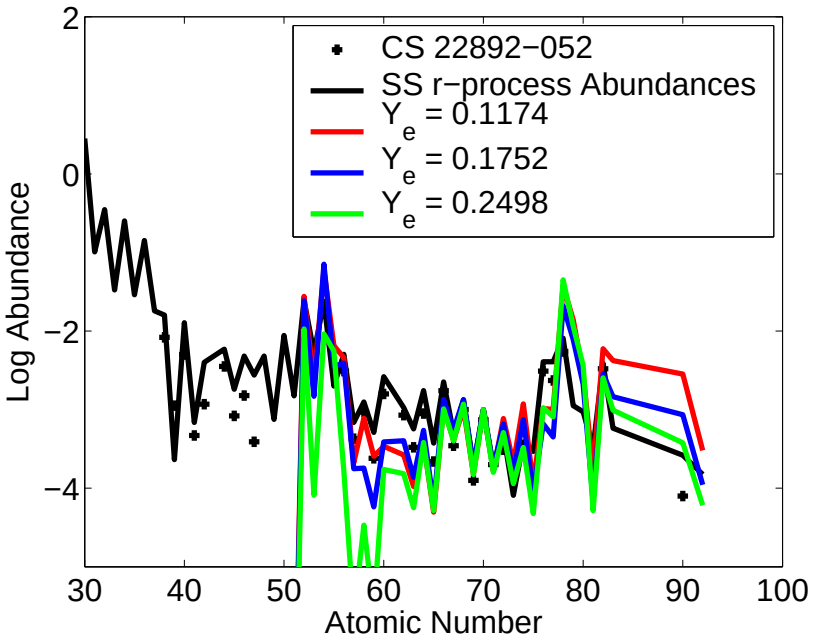




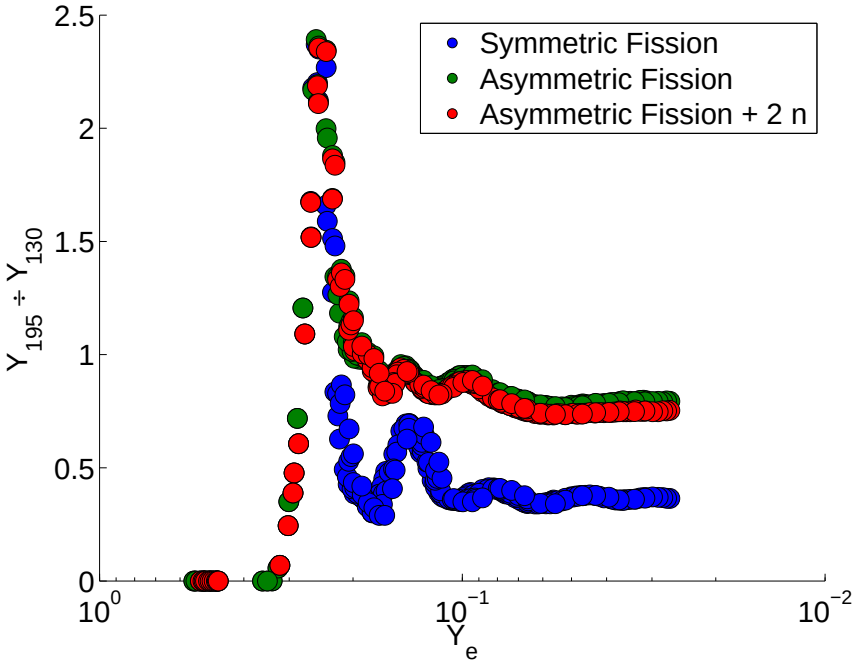
To achieve fission cycling, neutrino luminosity in the supernova must be considerably reduced. $\nu_e \leftrightarrow \nu_s$ is an option

Beun et al 2007

Fission Cycling in the r-process



astrophysical data hints at fission cycling



fission cycling requires many neutrons

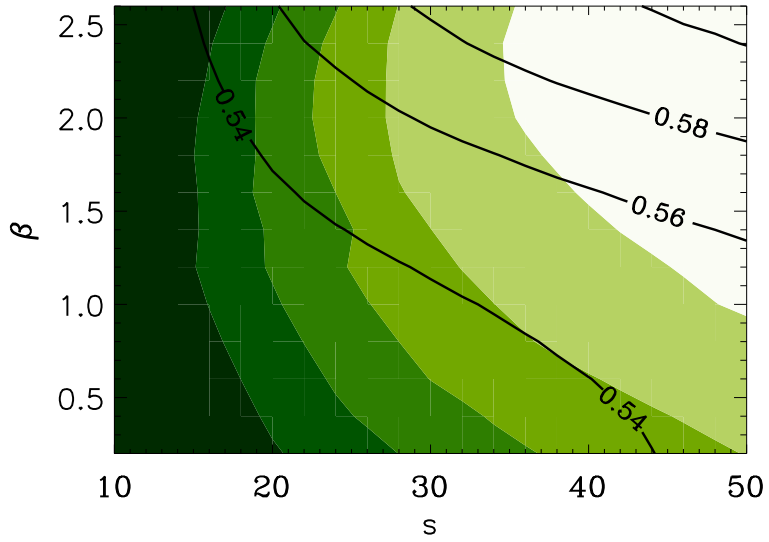
Very little data on the relevant fission rates and daughter products

Beun et al 2006, Beun et al 2008

Neutrinos and nucleosynthesis in GRB's

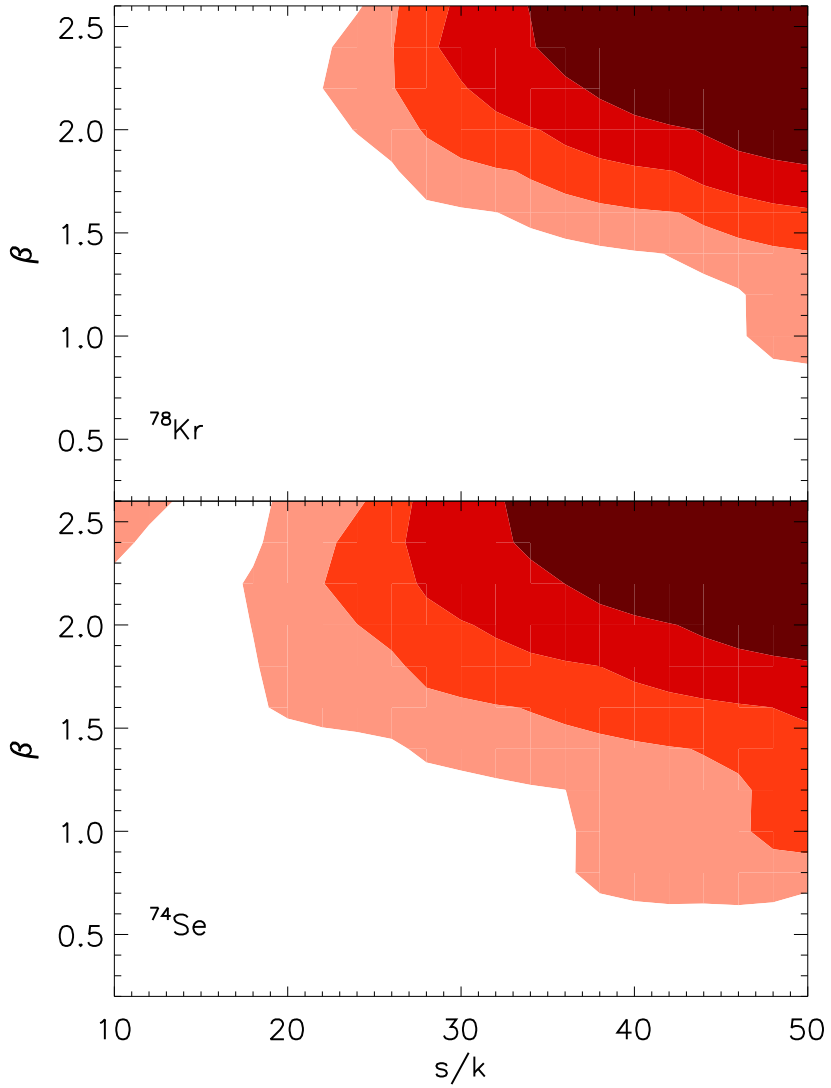
Accretion disk outflows are a "new" site for nucleosynthesis

Nickel-56



Surman et al 2005

p-process



Conclusions

Lots of exciting work on supernova neutrinos

- several astrophysical environments have hot dense matter
- these neutrinos oscillate and exhibit a much richer behavior than terrestrial and solar neutrinos
- we need to understand neutrino cross sections
- neutrinos and nucleosynthesis are tied together