Neutrinos from Accretion Disks

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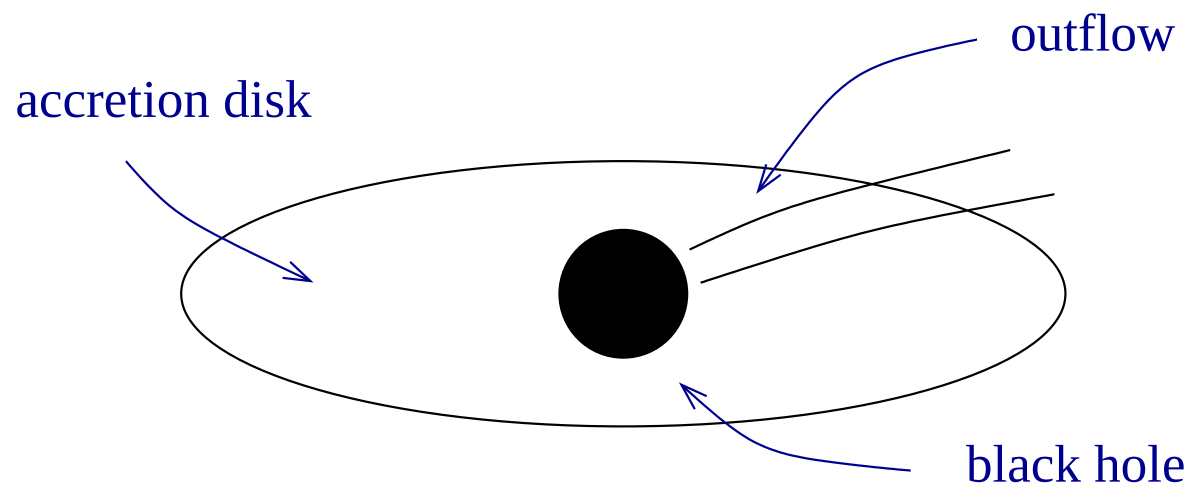
Accretion Disks From GRBs, Hypernovae

- Core Collapse (e.g. Collapsar) may make disks 0.1 $M_\odot$ s - 1.0 $M_\odot$ s
- Neutron star merger may make disks 1.0 $M_\odot$ s - 10 $M_\odot$ s
- Hypernovae may make disks too either with or with a gamma ray burst

Black Hole Accretion Disk



- material spirals in toward the black hole
- it is ejected by the disk
- nucleosynthesis

Temperature, density, velocity profiles from disk models needed:

Popham, Woosley & Fryer 1999 Narayan, DiMatteo & Perna 2002

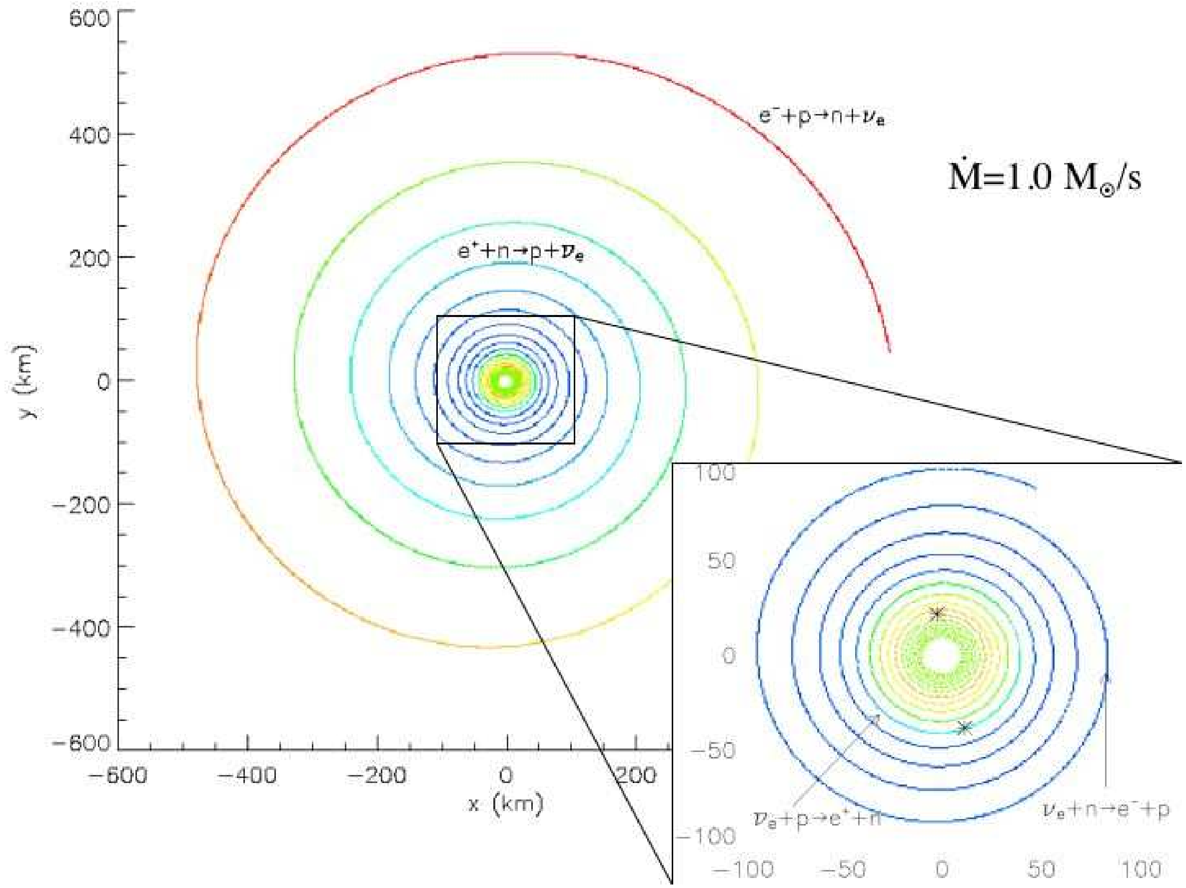
Neutrinos in the Disk:

Neutrino production and neutrino absorption:

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

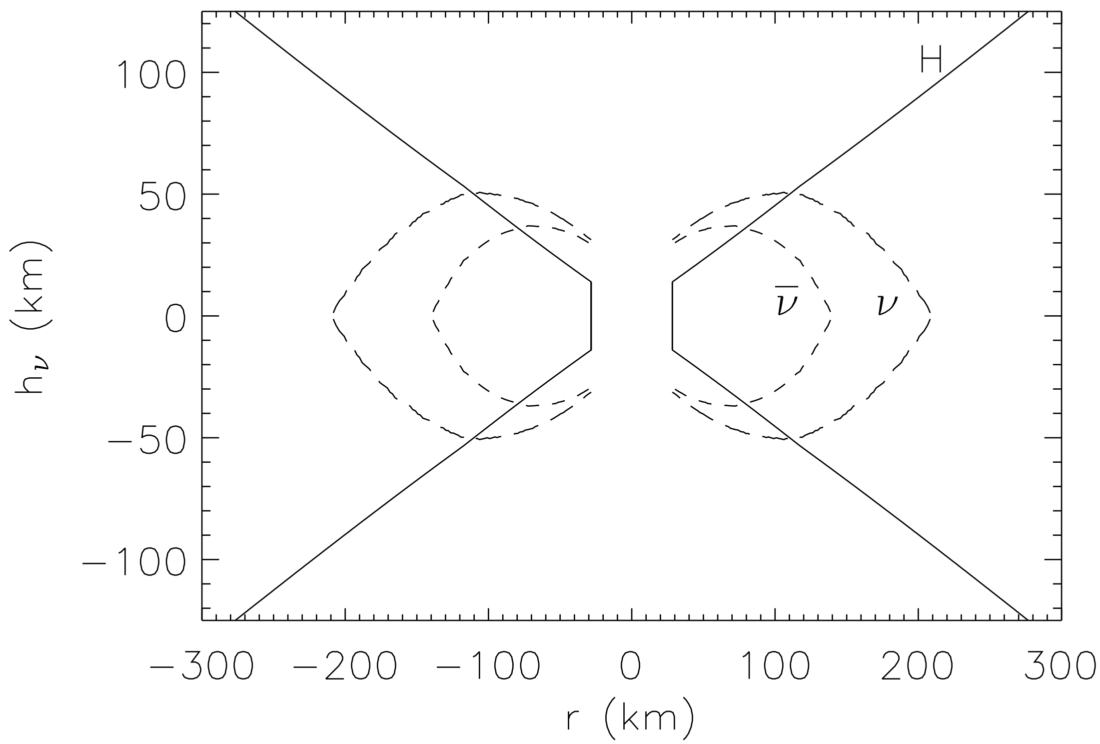
- These aren't the neutrinos km^3 detectors might see, but they might power the jet
- And affect the nucleosynthesis
- In high accretion rate and/or spin parameter disks, neutrinos become trapped, through $\nu + n \rightarrow \nu + n$ and other reactions

Following a mass element in the disk:



Surman and McLaughlin (2004)

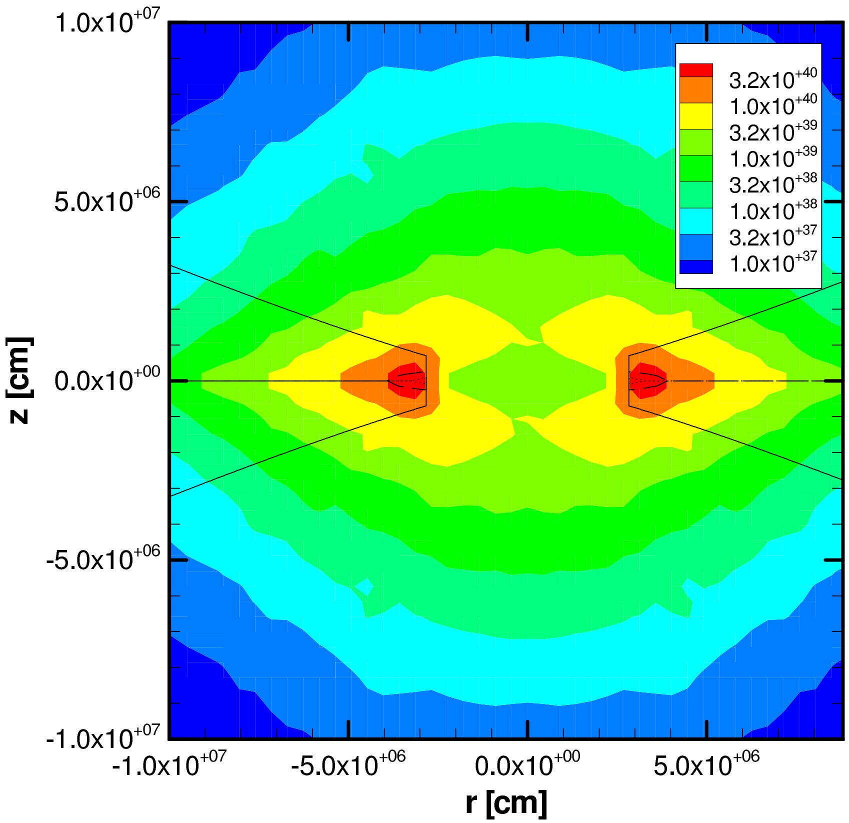
Neutrino and Antineutrino Surfaces:



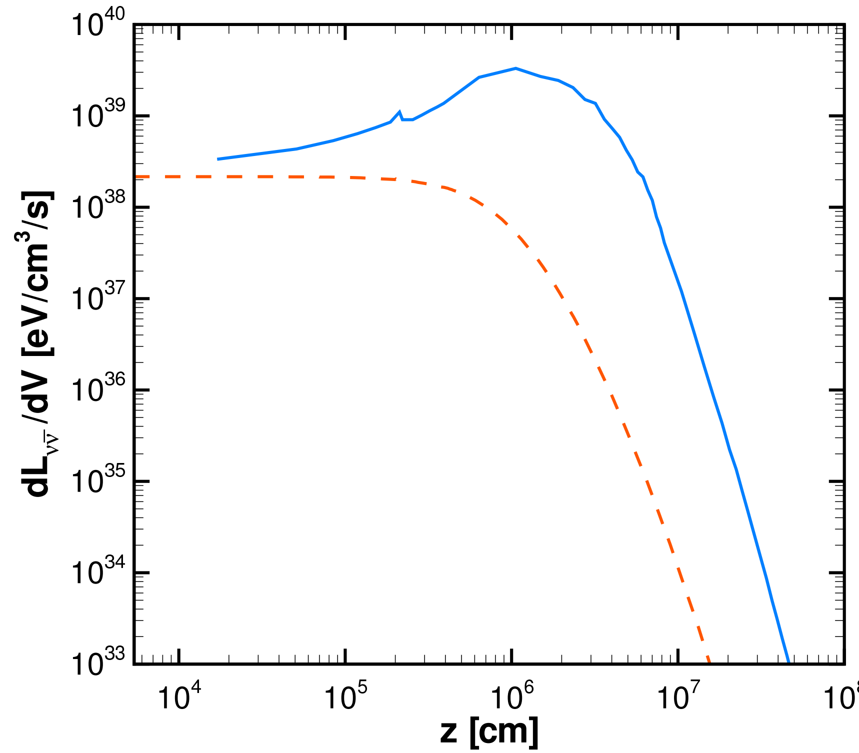
For $\dot{M} = 10\,\mathrm{M}_{\odot}/\,\mathrm{s}$, a = 0 DPN
Trapped region falls rapidly as $\dot{M}$ decreases

Depending on the model we find $T_{\nu_e} = 2.5$ MeV to 4.5 MeV and $T_{\bar{\nu}_e} = 3.6$ MeV to 5.1 MeV

Neutrino-Antineutrino Annihilation



DPN $\dot{m} = 1\,\mathrm{M}_\odot\,\mathrm{s}^{-1}$, in $\mathrm{eV\,cm^{-3}\,s^{-1}}$.



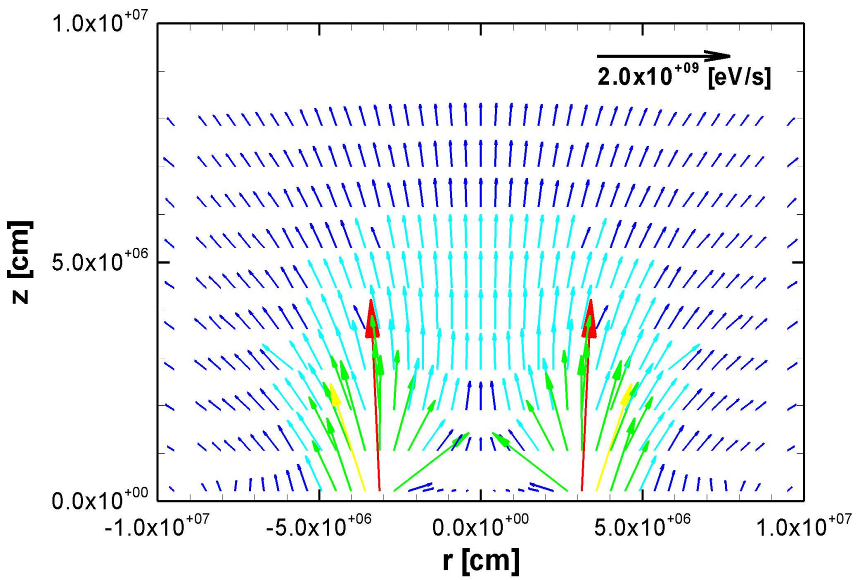
Solid line is DPN $\dot{m} = 1\,\mathrm{M}_\odot\,\mathrm{s}^{-1}$, dashed line is PWF $\dot{m} = 0.1\,\mathrm{M}_\odot\,\mathrm{s}^{-1}$.

$$\dot{m} = 1\,\mathrm{M}_\odot\,\mathrm{s}^{-1},\ L_{\nu\bar{\nu}} = 10^{50}\mathrm{erg\,s}^{-1},\ L_{\nu\bar{\nu}}/L_\nu = 10^{-3}$$

$$\dot{m} = 0.1\,\mathrm{M}_\odot\,\mathrm{s}^{-1},\ L_{\nu\bar{\nu}} = 4\times10^{47}\mathrm{erg\,s}^{-1},\ L_{\nu\bar{\nu}}/L_\nu = 10^{-4}$$

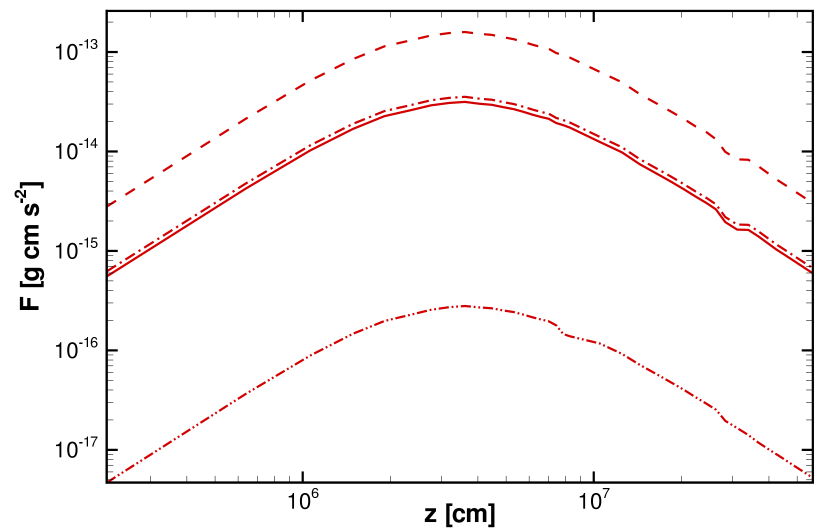
Kneller, McLaughlin and Surman 2005

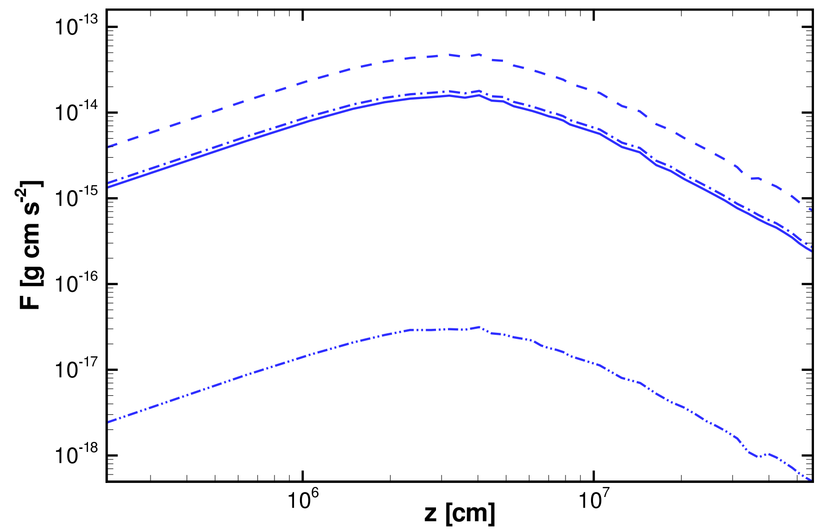
Momentum transfer from neutrino scattering



Neutrino-proton scattering in the DPN $\dot{m} = 1\,\mathrm{M}_\odot\,\mathrm{s}^{-1}$ model.

Kneller, McLaughlin and Surman 2005

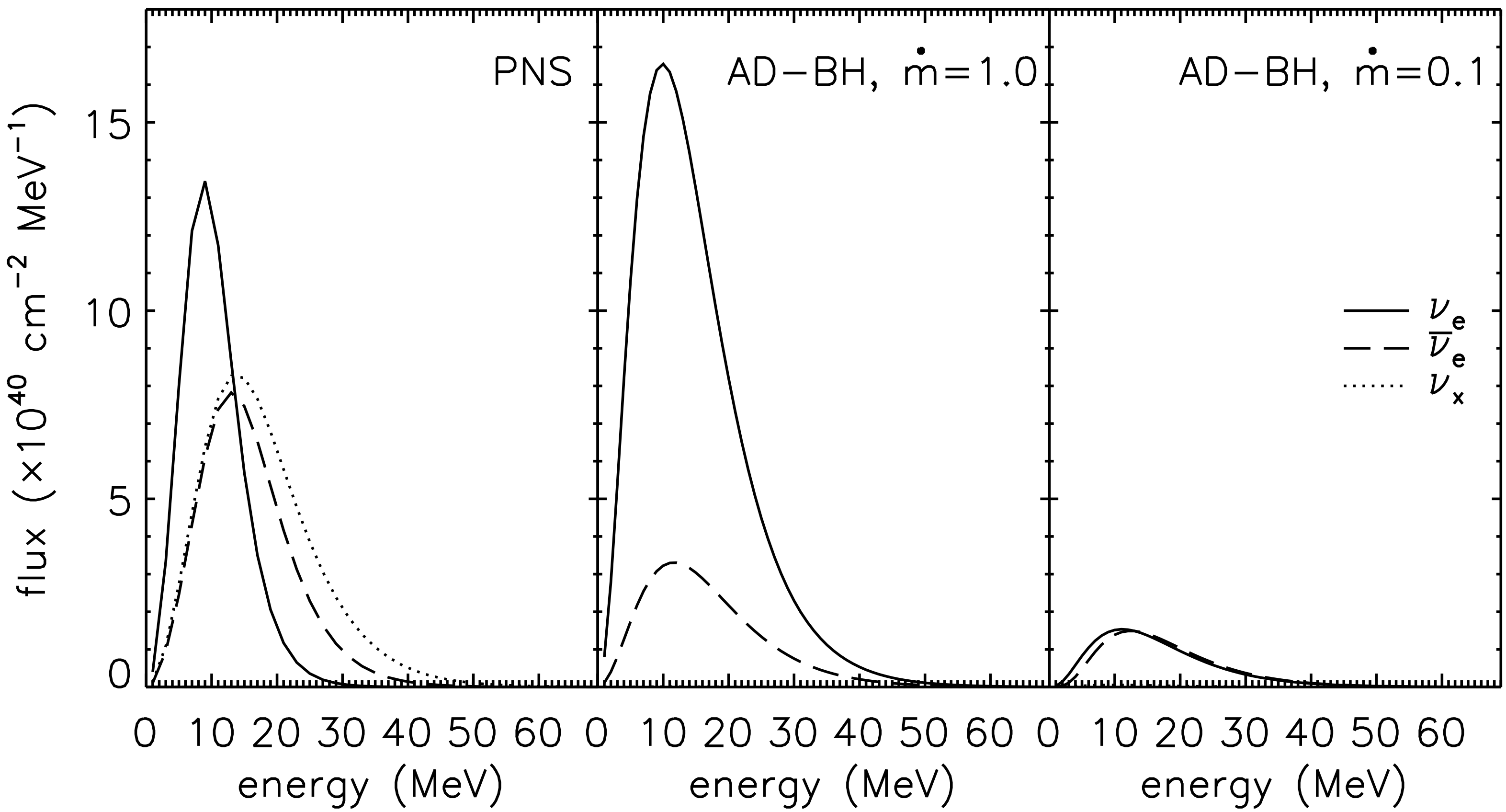




Right top: $\nu_e + n \rightarrow p + e^-$ (dashed), $\nu_e + n \rightarrow \nu_e + n$ (dash-dot), $\nu_e + p \rightarrow \nu_e + p$ (solid), $\nu_e + e \rightarrow \nu_e + e$ (dash-double dot).

Spectra of Neutrinos Emitted from the Disk

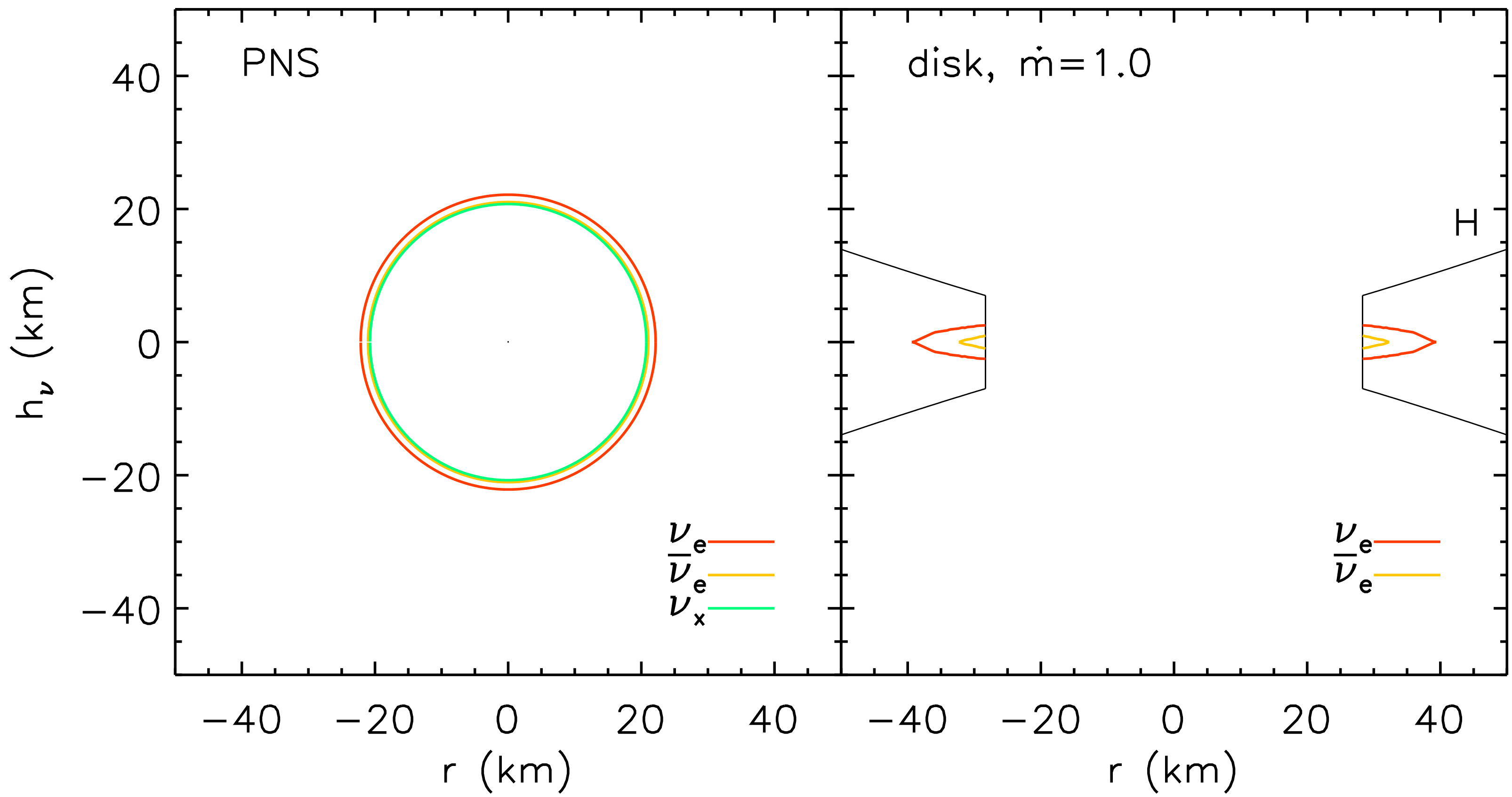
as viewed from 100 km, no oscillations



Similar to proto-neutron star spectra **but many less** ν_μ, ν_τ, $\bar{\nu}_\mu$, $\bar{\nu}_\tau$.

McLaughlin and Surman 2006

Comparison of Neutrino Surfaces



proton neutron star (left), accretion disk around black hole (right)

ν_μ, ν_τ, $\bar{\nu}_\mu$, $\bar{\nu}_\tau$ **are not trapped**

Galactic Core-Collapse Supernova

- occur every 30-50 years
- 3×10^{53} ergs in neutrinos
- Neutrinos can be seen in SuperK, KamLAND, MiniBooNE
- Neutrinos will be used to constrain core-collapse models

When the SN neutrinos arrive, how do you know they are from a proto-neutron star and not a disk?

- Disks are more rare (but how much more?)
- Different timescales, SN neutrino luminosity decays as $\exp(-t/\tau)$
- Neutral Current Signal

Neutrino Oscillations

By far the biggest detection cross section is in $\bar{\nu}_e + p \rightarrow e^+ + n$...

Two no background options:

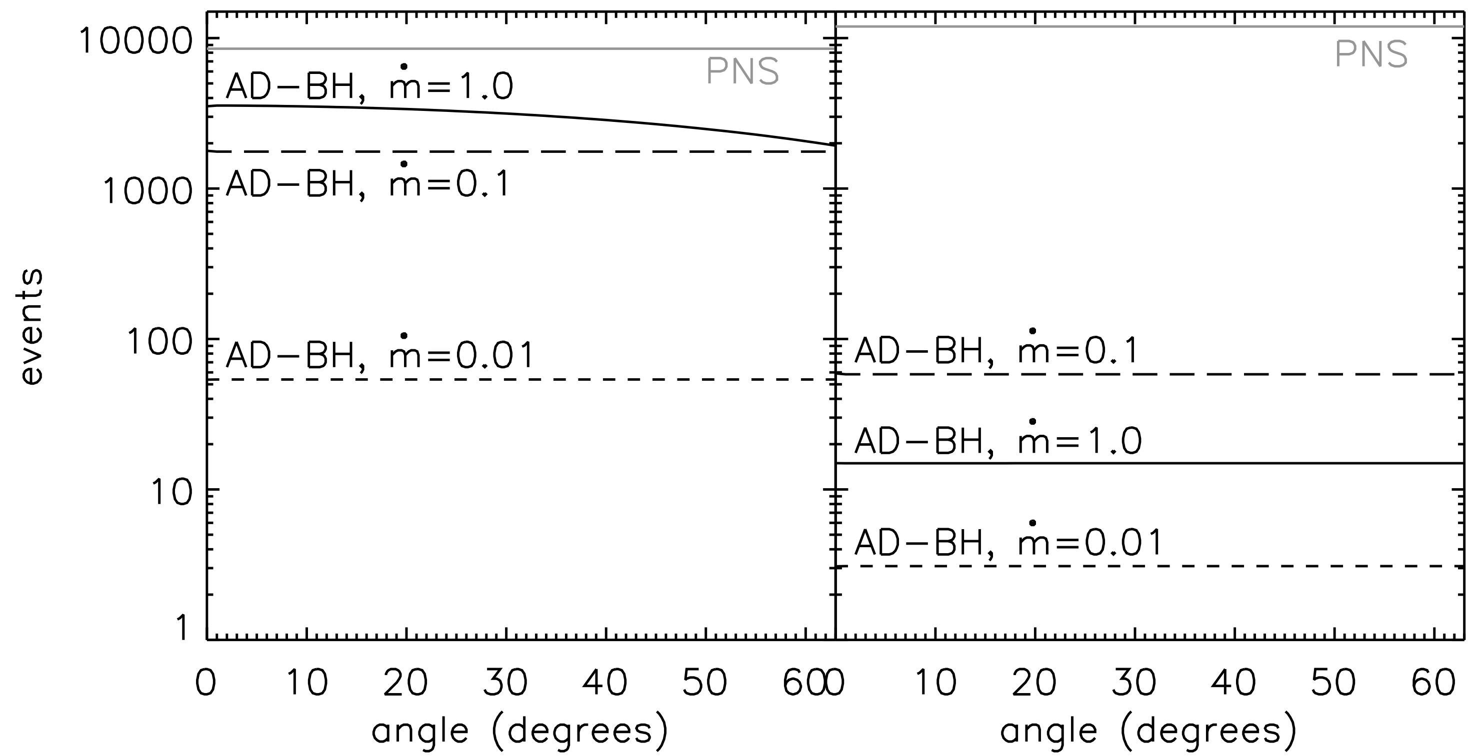
1. all cases besides 2.: $\sin^2\theta_{12} \sim 1/3$ of the $\bar{\nu}_e$s transform to $\bar{\nu}_\mu$, $\bar{\nu}_\tau$
2. inverted hierarchy, large $\theta_{13} \rightarrow$ all $\bar{\nu}_e$s transform to $\bar{\nu}_\mu$ and $\bar{\nu}_\tau$

PNS: These options produce similar results, to the extent that the spectra of $\bar{\nu}_e$ are similar to the spectra of $\bar{\nu}_\mu$, $\bar{\nu}_\tau$.
AD-BH:These options produce very different results:

1. Large $\bar{\nu}_e$ signal.
2. Greatly reduced $\bar{\nu}_e$ signal

Charged Current Signal at SuperK

$$\bar{\nu}_e + p \rightarrow n + e^+$$



Count rates in SuperK as a function of viewing angle. The two oscillation scenarios are shown. Accretion disk rates should be scaled by $M/M_{\odot}$, where M is the mass processed by the disk.

McLaughlin and Surman 2006

Neutral Current Flux: Doesn't change with oscillations

Ratio of Neutral Current to Charged Current Flux

Oscillation scenario 1:

- PNS 7:1
- AD-BH $\dot{m} = 0.01$, 3:1
- AD-BH $\dot{m} = 0.1$, 3:1
- AD-BH $\dot{m} = 1.0$, 9:1

Oscillation scenario 2:

- PNS 6:1
- AD-BH $\dot{m} = 0.01$, 40:1
- AD-BH $\dot{m} = 0.1$, 70:1
- AD-BH $\dot{m} = 1.0$, 1600:1

McLaughlin and Surman 2006

Neutral Current Signal

Independent of Oscillation Scenario

At SuperK for a Galactic Supernova

- $\nu +^{16}\mathrm{O} \rightarrow \nu +^{15}\mathrm{O} + n$
- $\nu +^{16}\mathrm{O} \rightarrow \nu +^{15}\mathrm{N} + p$
- $^{15}\mathrm{N}$ and $^{15}\mathrm{O}$ decay by characteristic emission of gamma rays

  Langanke et al. 1995

- Expected counts in the NC for the protoneutron star are ~ 34.
- In the AD-BH $1.0 M_{\odot}/s$ scenario it is $\sim 17\, M/M_{\odot}$
- In the AD-BH $0.1 M_{\odot}/s$ scenario it is $\sim 3\, M/M_{\odot}$
- In the AD-BH $0.01 M_{\odot}/s$ scenario it is $\sim 0.3\, M/M_{\odot}$

This result is senstive to the high energy tail of the spectrum.

Other options for a neutral current signal

1. $\nu + p \to \nu + p$ at KamLAND, Detect recoil of proton, Beacom et al
   PNS has ~ 100 events above 0.2 MeV

2. Proposed Lead Detectors, $\nu + Pb \to \nu + Pb + n$ and
   $\nu + Pb \to \nu + Pb + n + n$ ADONIS, OMNIS, LAND, HALO,
   $\sim$ 200 - 300 events from the PNS.

3. Heavy Water Detector (like SNO)

Other options for a ν_e current signal

1) Proposed Lead Detectors: $\nu_e + Pb \to e^- + Bi + n$ and
$\nu_e + Pb \to e^- + Bi + n + n$

2) Heavy Water Detector (like SNO)

How rare is rare?

How often can you form rapidly accreting disks of $\dot{m} = 0.01$ and larger?

- lower limit? zero
- expected rate: GRB rate, 10^{-5} per year
- upper limit? what is the ratio of black holes to neutron stars? 10%?

Perhaps we should try to check the next galactic neutrino signal to see if the neutrinos are really coming from a proto-neutron star

Conclusions

Neutrinos from the disk are interesting for a number of reasons

- They may provide the energy for the burst
- They determine the nucleosynthesis (Rebecca Surman's talk)
- We might detect them and learn something about the disk
- Check the time profile and NC signal to try to distinguish them from "ordinary" core-collapse supernova