Neutrinos and Nucleosynthesis in Gamma Ray Bursts (black hole accretion disks)

NIC 2006
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Nucleosynthesis in GRBs

- In the exploding shell
- In the outflow from the accretion disk
- In the jet
Nucleosynthesis in GRBs

In the exploding shell

In the outflow from the accretion disk

Pruet, Guiles, and Fuller (2002)
Lemoine (2002)
Nagataki (poster ID: 49)
Nucleosynthesis in GRBs

in the exploding shell
Inoue, Iwamoto, Orito, and Terasawa (2003)
Nagataki, Mizuta, Sato (2006)

in the jet

in the outflow from the accretion disk
Nucleosynthesis in GRBs

In the outflow from the accretion disk

$\rightarrow ^{56}\text{Ni}$ ?

$\rightarrow$ rare nuclear species?
Nucleosynthesis in GRBs

- In the exploding shell
- In the outflow from the accretion disk

in the jet
Nucleosynthesis in the Outflow

Follow material
• through disk
• as ejected in outflow

Electron fraction set by:

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

Disk models:
Low accretion rate disks - \( \dot{m}Y < 1 \), where \( \dot{m}Y = 1 \Rightarrow 1 \) solar mass/second
Popham, Woosley, and Fryer (1999)
High accretion rate disks - \( \dot{m}Y \geq 1 \)
DiMatteo, Perna, and Narayan (2002)
Evolution of $Y_e$ in the disk

DPN $\dot{Y} = 1.0$

Take velocity as a function of radial distance from the black hole to be
\[ u = v_\infty \left( 1 - \frac{R_o}{R} \right)^\beta \]
where \(5,000 < v_\infty < 50,000\) km/s, \(0.2 < \beta < 3.0\)

Take flow to be vertical at first, then radial

Consider adiabatic flows with entropy \(10 < s < 50\)
Neutrino flux coming from disk is dominated by contribution from optically thick region

⇒ When antineutrino surface is large, the antineutrinos tend to dominate (higher $T_{\nu}$)

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

⇒ If antineutrino surface is small or nonexistent, neutrino flux dominates

\[
\nu_e + n \rightarrow p + e^- 
\]
Full nuclear network code:
  (J. Beun, R. Surman)

$r$-process nucleosynthesis code:
  J. Walsh, B.S. Meyer, R. Surman

Look for:
  * $^{56}$Ni
  * rare nuclear species:
    * $p$ process
    * $r$ process
Low accretion rate => Nickel Synthesis

\[ PWF \]
\[ \dot{Y} = 0.1 \]
\[ r_o = 100 \text{ km} \]
\[ v_\infty = 0.1c \]

\[ ^{56}\text{Ni mass fraction} \]

Lines indicate Ye

Moderate accretion rates $\Rightarrow$ Nickel Synthesis

$DPN$

$\dot{m} = 1.0$

$r_o = 250 \text{ km}$

$v_\infty = 0.1c$

$^{56}\text{Ni mass fraction}$

Overproduction Factors

\[
O(j) = \left( \frac{M_{\text{wind}}}{M_{\text{SN ejecta}}} \right) \times \left( \frac{X_{\text{wind}}}{X_{\text{solar}}} \right)
\]

\[
O(j) > \begin{array}{cccc}
1000 & 100 & 10 & 1 \\
\end{array}
\]

PWF

\[\dot{m} = 0.1\]

\[r_o = 100 \text{ km}\]

\[v_\infty = 0.1c\]
\[ ^{64}\text{Zn} \]

Slow outflow - enhancement due to neutrino interactions

\[
\begin{align*}
\dot{n}Y &= 0.1 \\
\rho_0 &= 100 \text{ km} \\
\nu_\infty &= 0.1c
\end{align*}
\]

\[ O(j) > \\
5000 \ 1000 \ 100 \ 10 \ 1 \]

$p$-process nuclei
High accretion rate => $r$-Process Nucleosynthesis

DPN

$\dot{\mathcal{M}} = 10$

$r_o = 250$ km

$v_\infty = 0.1c$

Metal-poor Halo Star data

From J. Cowan’s talk, 6/27/06
Conclusions

Given disk and outflow parameters, we can determine what nucleosynthesis will result from an understanding of the neutrinos.

Nucleosynthesis in accretion disk outflows provides a promising mechanism for GRB nickel production.

Additionally, GRBs may contribute to the galactic abundances of certain rare nuclear species, such as $r$-process nuclei or light/intermediate mass proton-rich nuclei such as $^{64}\text{Zn}$, $^{45}\text{Sc}$, and $^{92}\text{Mo}$.