# Potential effects of accretion disk neutrinos on high-energy neutrino produced in GRBs and CCSNe

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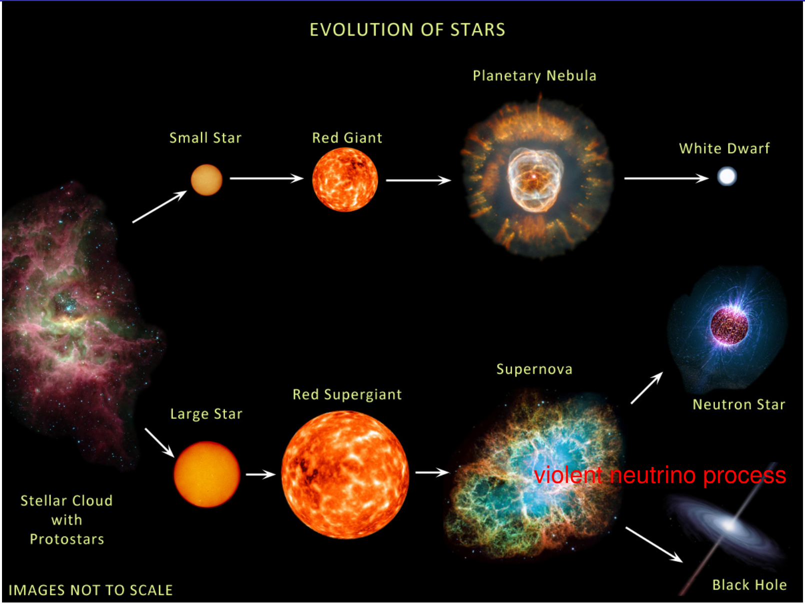
# Stellar Evolution Vs Neutrino Astronomy



# BH-AD: source of MeV neutrinos and HE neutrinos

core-collapse

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stellar-mass BH with accretion disk (AD)

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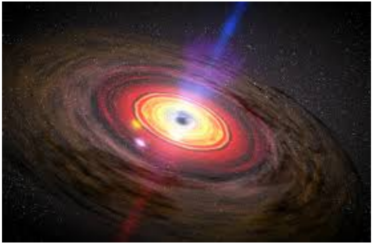
GRB jets



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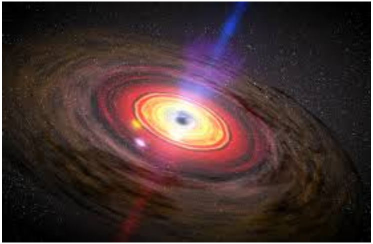

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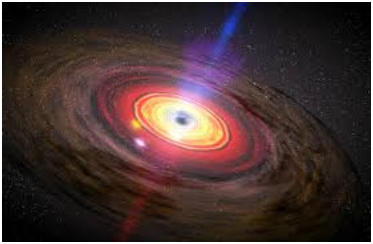

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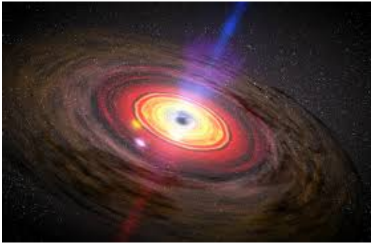

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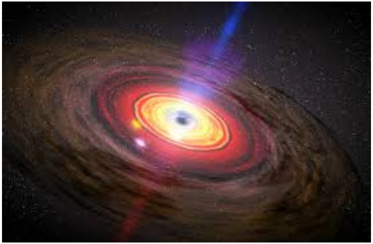

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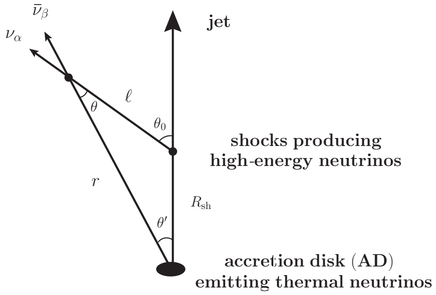
- relativistic jets powered by AD $\nu\bar{\nu}$ annihilation or MHD processes.
- particle acceleration by shocks, or magnetic process such as magnetic reconnection, etc.
- HE neutrinos emerge naturally from $p\gamma$ or $pp$.

# $\nu\bar{\nu}$ annihilation between AD $\nu$s and HE $\nu$s



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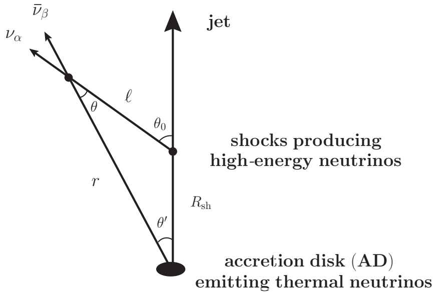

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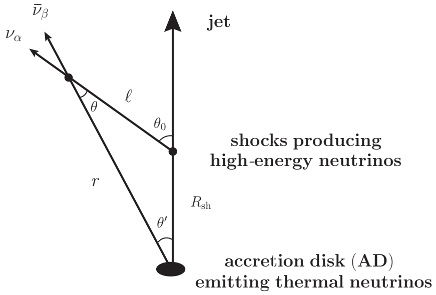
The probability for the HE $\nu_\alpha$ to survive annihilation, $P_{\nu_\alpha}(E, \theta_0) = \exp[-\tau_{\nu_\alpha}(E, \theta_0)]$, is determined by the "optical" depth

$$\tau_{\nu_\alpha}(E, \theta_0) = \sum_\beta \int (1 - \cos\theta) \sigma_{\nu_\alpha \bar{\nu}_\beta}(s) \times dn_{\bar{\nu}_\beta}(E', r) d\ell.$$



# the basics of AD neutrinos

- simultaneity is guaranteed if the duration of AD neutrinos $\Delta T \gtrsim R_{\rm sh}/(2\Gamma_j^2 c) \sim 0.1-1$ s, for $R_{\rm sh} \sim 10^{10-12}$ cm and $\Gamma_j \sim 2-10$ (mildly relativistic shocks inside stars).

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- Energy-differential number density of AD neutrinos,

$$dn_{\bar{\nu}_\beta}(E', r) = \frac{E'^2 dE'}{\exp(E'/T_\nu) + 1} \frac{R_\nu^2 \cos\theta'}{8\pi^2 r^2} \bar{f}_\beta(r),$$

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- initially $\nu_e$ and $\bar{\nu}_e$, with $T_\nu = T_{\bar{\nu}}$ for simplicity (dominated by $e^\pm$ capture).
- flavor conversion $f_\beta(\bar{f}_\beta)$: (1) no evolution (NE), $f_\beta(r) = \bar{f}_\beta(r) = \delta_{\beta e}$; (2) MSW only with (NH), $f_\beta(r) = |U_{\beta 3}|^2$ and $\bar{f}_\beta(r) = |U_{\beta 1}|^2$; (3) MSW only with (IH), $f_\beta(r) = |U_{\beta 2}|^2$ and $\bar{f}_\beta(r) = |U_{\beta 3}|^2$, and (4) exotic evolution (EE), $f_\beta(r) = \bar{f}_\beta(r) = \delta_{\beta\mu}$.

| | NH, $\nu$ | NH, $\bar{\nu}$ | IH, $\nu$ | IH, $\bar{\nu}$ |
|---|---|---|---|---|
| $f_\beta(\bar{f}_\beta)$ | $\lvert U_{\beta 3}\rvert^2$ | $\lvert U_{\beta 1}\rvert^2$ | $\lvert U_{\beta 2}\rvert^2$ | $\lvert U_{\beta 3}\rvert^2$ |
| $(f_e, f_\mu, f_\tau)$ | (0.025, 0.409, 0.565) | (0.677, 0.257, 0.067) | (0.298, 0.334, 0.368) | (0.025, 0.409, 0.565) |

# $\nu\bar{\nu}$ annihilation between AD $\nu$s and HE $\nu$s

$$\nu_\alpha \bar{\nu}_\beta \to \begin{cases} f\bar{f}, & \alpha = \beta \\ l_\alpha \bar{l}_\beta, & \alpha \neq \beta \end{cases}$$

The probability for the HE $\nu_\alpha$ to survive annihilation, $P_{\nu_\alpha}(E, \theta_0) = \exp[-\tau_{\nu_\alpha}(E, \theta_0)]$, is determined by the "optical" depth

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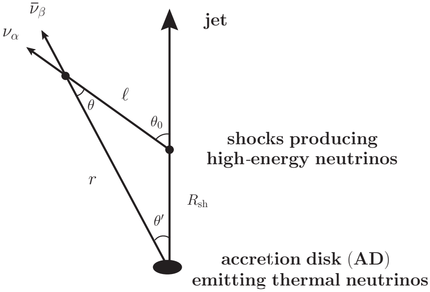
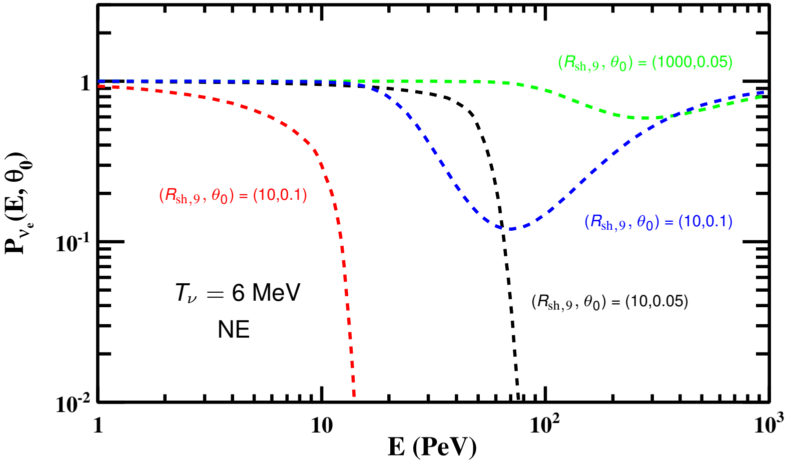


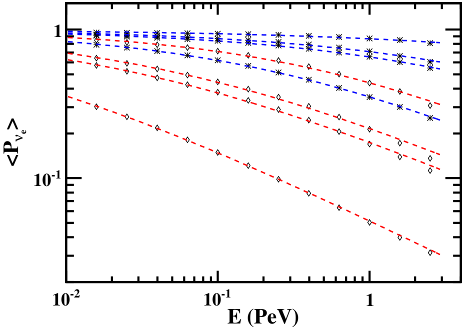
# cutoff or dip for a nearby source with $\theta_0$ fixed

effects of Z-resonance



$$\langle P_{\nu_\alpha}(E)\rangle = \int \exp[-\tau_{\nu_\alpha}(E,\theta_0)] g(\theta_0) d\cos\theta_0,$$

where $g(\theta_0) = \frac{1-\beta^2}{2(1-\beta\cos\theta_0)^2}$, and $\beta \equiv (1-\Gamma^{-2})^{1/2}$. $\langle\theta_0\rangle \sim \Gamma^{-1}$.




NE; $\Gamma = 3, 10$; $T_\nu = 5, 8$ MeV;

$R_{\rm sh} = 3\times 10^9, 10^{11}$ cm

A nice fit for $\langle P_{\nu_\alpha}(E)\rangle$:

$$\langle P_{\nu_\alpha}(E)\rangle = \frac{1}{[1+(E/E_0)^n]}$$

# analytic approximation and scaling parameter

Taking $\theta \sim \theta_0 \ll 1$, $\ell \sim r \sim R_{\rm sh}$, and $\sigma_{\nu_\alpha \bar{\nu}_\beta} \sim G_F^2 s$, we get

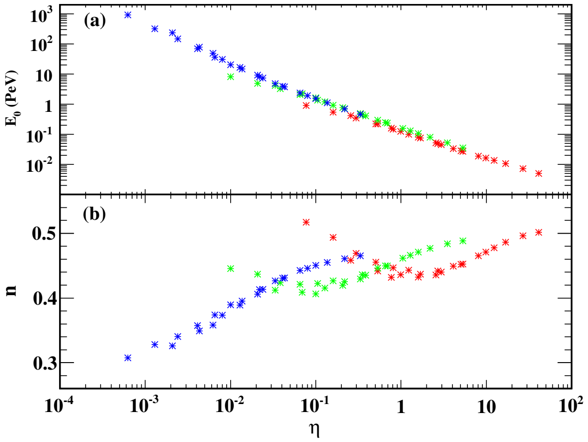
$$\begin{aligned}\tau_{\nu_\alpha}(E,\theta_0) &= \sum_\beta \int (1-\cos\theta)\sigma_{\nu_\alpha\bar{\nu}_\beta}(s) \times dn_{\bar{\nu}_\beta}(E',r)d\ell \\ &\sim \frac{\theta_0^2}{2}[G_F^2 E(3T_\nu)\theta_0^2]\left[\frac{7\pi^2}{1920}\frac{R_\nu^2 T_\nu^3}{R_{\rm sh}^2}\right]R_{\rm sh} \\ &\sim 25 E_{\rm PeV} R_{\nu,7}^2 T_{\nu,{\rm MeV}}^4 \theta_0^4 R_{{\rm sh},9}^{-1},\end{aligned}$$

and

$$\begin{aligned}\langle P_{\nu_\alpha}(E)\rangle &= \int \exp[-\tau_{\nu_\alpha}(E,\theta_0)]g(\theta_0)d\cos\theta_0 \\ &\sim \exp[-\tau(E,\bar{\theta})]\end{aligned}$$

depending on $\underline{E T_\nu^4 \Gamma^{-4} R_{\rm sh}^{-1}}$ only.

# scaling parameter




$\Gamma = 3, 5, 10$

$T_\nu = 5, 6, 7, 8, 9, 10$ MeV

$R_{\rm sh} = 3 \times 10^9, 10^{10}, 3 \times 10^{10}, 10^{11}$ cm.

$$\eta \equiv T^4_{\nu,\rm MeV} R^{-1}_{\rm sh,9} \Gamma^{-4}$$

$E_0 \sim 0.1/\eta$ PeV,

and $n_0 \sim 0.4 - 0.5$ for $\eta > 0.1$

# spectral and flavor change of HE neutrinos

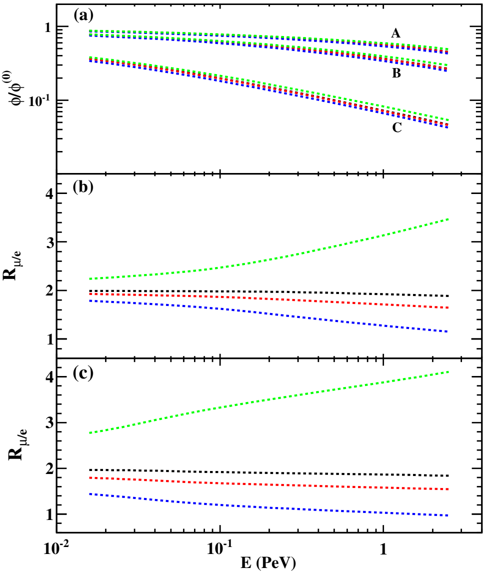
Assuming an initial HE neutrinos with all-flavor total flux $\phi^{(0)}$ and flavor ratio ($\nu_\mu$:$\bar{\nu}_\mu$:$\nu_e$:$\bar{\nu}_e$) = (2:2:1:1). After $\nu\bar{\nu}$ annihilation,

$$\frac{\phi}{\phi^{(0)}} = \frac{\langle P_{\nu_\mu}(E)\rangle + \langle P_{\bar{\nu}_\mu}(E)\rangle}{3} + \frac{\langle P_{\nu_e}(E)\rangle + \langle P_{\bar{\nu}_e}(E)\rangle}{6},$$

and the corresponding flavor ratio is

$$R_{\mu/e} \equiv \frac{\phi_{\nu_\mu} + \phi_{\bar{\nu}_\mu}}{\phi_{\nu_e} + \phi_{\bar{\nu}_e}} = \frac{2[\langle P_{\nu_\mu}(E)\rangle + \langle P_{\bar{\nu}_\mu}(E)\rangle]}{\langle P_{\nu_e}(E)\rangle + \langle P_{\bar{\nu}_e}(E)\rangle}.$$

# spectral and flavor change of HE neutrinos



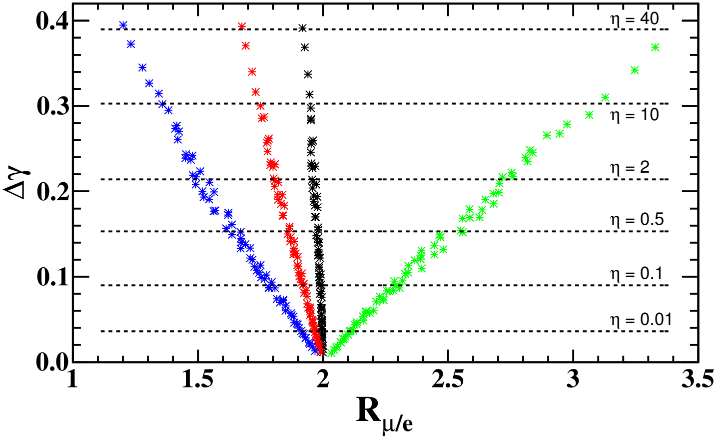

$(T_{\nu,\mathrm{MeV}}, R_{\mathrm{sh},9}, \Gamma) =$

- (5,10,5) for case A
- (8,10,5) for case B
- (10,3,3) for case C

AD neutrino flavor evolutions:

NE, IH, NH, EE

# Correlation between spectral change and flavor change




$E = 0.1$ PeV

AD $\nu$ flavor evolution: NE, NH, IH, EE

# Discussions

- Spectra and flavour content of HE neutrinos in GRBs/CCSNe may be affected by AD neutrinos.
- No specific model has been applied for HE neutrino production in a consistent way, but the above effects should be considered for proper values of $(\Gamma, R_{\rm sh}, T_{\nu})$, etc.
- These effects may be detected by IceCube if more statistics are accumulated in the near future.

# Thank you

# back up

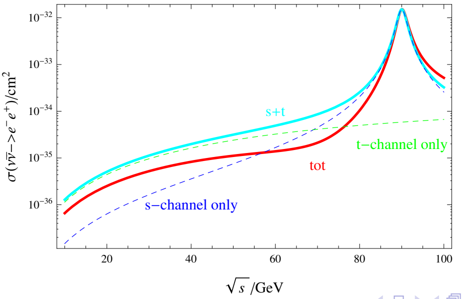
# effects of AD neutrinos on proton acceleration

$$t'_{\rm acc} \sim \kappa \frac{E'_p}{ecB'} \simeq 4 \times 10^{-9}\ {\rm s}\ \kappa \left(\frac{E'_p}{\rm PeV}\right) \left(\frac{R^2_{\rm sh,10}\Gamma^2_{0.5}}{\epsilon_{B,-1} L^{\rm iso}_{53}}\right)^{1/2},$$

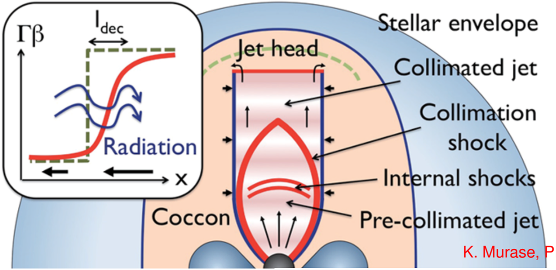
$$t'_{\rm AD} \sim \frac{E_p}{\Delta E_p} \frac{1}{\Gamma \sigma_{p\nu} n_\nu (1 - \cos\theta) c} \sim \frac{E_p}{\Delta E_p} \frac{2\Gamma}{\sigma_{p\nu} n_\nu c}$$

$$\sim 6.8 \times 10^{-3}\ s \times \Gamma^2_{0.5} (5\ {\rm MeV}/T_\nu)^4 R^2_{\rm sh,10} ({\rm PeV}/E'_p),$$

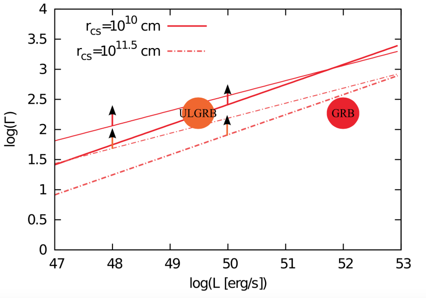
Processes of AD neutrino are typically slow, so that they don't affect particle acceleration and HE neutrino production. The only exception is $\nu\bar{\nu}$ annihilation between AD neutrino and HE neutrinos, as discussed above.

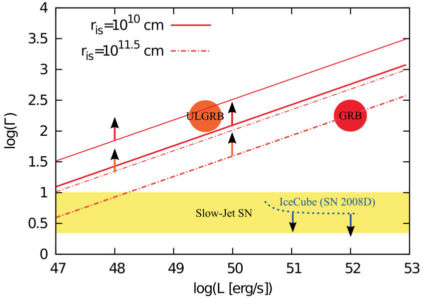


# Choked jets and radiation constraints




K. Murase, PRL 111, 121102 (2013)



# $\nu_\alpha \bar{\nu}_\alpha$ pair annihilation: s-channel

The same flavor annihilation case is dominated by the Z-resonance process ($\nu_\alpha \bar{\nu}_\alpha \rightarrow Z^* \rightarrow f\bar{f}$), with the leading order cross section given by

$$\sigma_Z^s(s) = \frac{2G_F^2}{3\pi} \sum_f n_f s P_Z [t_{f3}^2 - 2t_{f3} Q_f s_W^2 + 2Q_f^2 s_W^4],$$

where s is the square of the CM energy, $t_{f3}$, $Q_f$ are the isospin and charge for each fermion, and $n_f$ = 1 (3) for leptons (quarks). $s_W \equiv \sin\theta_W$, and $\theta_W$ is the Weinberg angle. $P_Z$ is defined as

$$P_Z = \frac{M_Z^4}{(s - M_Z^2)^2 + \Gamma_Z^2 M_Z^2},$$

with $M_z$ and $\Gamma_z$ the Z-boson mass and decay width.

# $\nu_\alpha \bar{\nu}_\beta$ pair annihilation: t-channel

For both $\alpha = \beta$ and $\alpha \neq \beta$, annihilation process can occur via t-channel process (exchanging Z-boson for $\alpha = \beta$ and W-boson for $\alpha \neq \beta$). The leading order cross sections are calculated as

$$\sigma_Z^t(\nu_\alpha \bar{\nu}_\alpha \to \nu_\alpha \bar{\nu}_\alpha) = \frac{G_F^2}{2\pi} s F_1(s/M_Z^2),$$
$$\sigma_W^t(\nu_\alpha \bar{\nu}_\beta \to l_\alpha^- l_\beta^+) = \frac{2G_F^2}{\pi} s F_1(s/M_W^2),$$

with $F_1(x) = [x^2 + 2x - 2(1+x)\ln(1+x)]/x^3$. For $\alpha = \beta$, there are also interference terms between s-channel and t channel processes. All contributions above are included in our calculations.

# MSW case

Take $\nu_e$ for demonstration: since the matter density near the BH center is very high, $\nu_e$ is almost coincident with $\nu_{3m}$ for NH ($\nu_{2m}$ for IH); it then evolves adiabatically when propagating to the region where HE$\nu$s are produced, and we have

$$f_\alpha(r) = \begin{cases} |U_{\alpha 3}|^2, & \text{(NH)} \\ |U_{\alpha 2}|^2, & \text{(IH)} \end{cases}$$