Detecting Gamma-ray Bursts with Ultra-high Energy Neutrinos

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Outline

- Ultrahigh Energy Neutrino Sources
  - Gamma-Ray Bursts (GRB)
  - Active Galactic Nuclei (AGN)
- New Neutrino Flux components
  - Need special environment
  - Model dependent
- What can we learn about GRB's with neutrino telescopes?

Proton Interactions in GRB

Photomeson: $p\,/\,n+\gamma\rightarrow\Delta\rightarrow n\,/\,p+\pi^{\pm}$

$E_pE_\gamma\cong 0.3\,\mathrm{GeV}^2$ at Δ-threshold

Hadron-Hadron: $pp\,/\,pn\rightarrow\pi^{\pm}\,/\,K^{\pm}$

Typically $\frac{n_\gamma}{n_p}>\frac{\sigma_{pp}}{\sigma_{p\gamma}}\Rightarrow\ p\gamma$ dominates

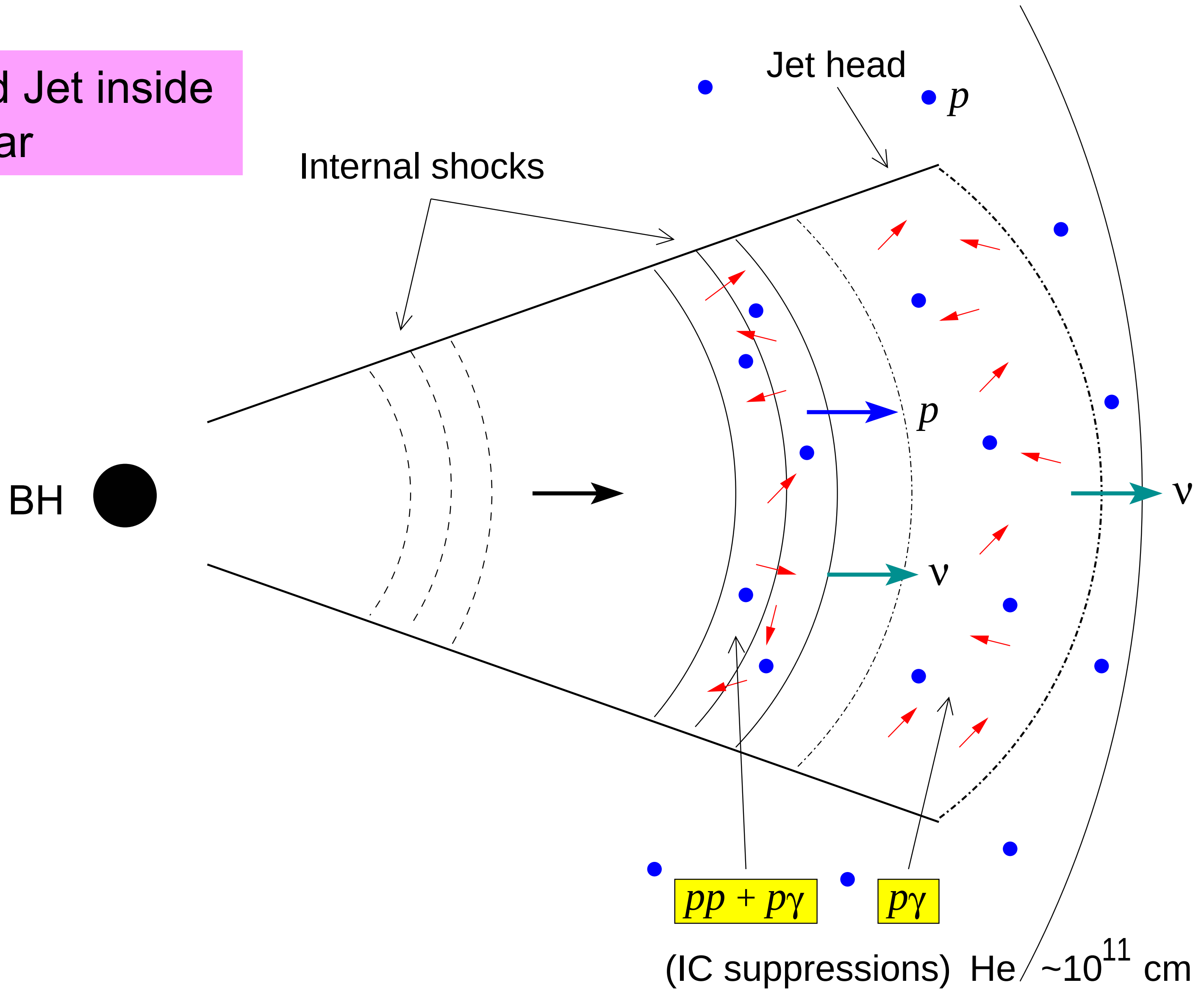
pp can be important if $\tau_{pp}\geq 1\ ;\ E_pE_\gamma<0.3\,\mathrm{GeV}^2$

Neutrino production channels:

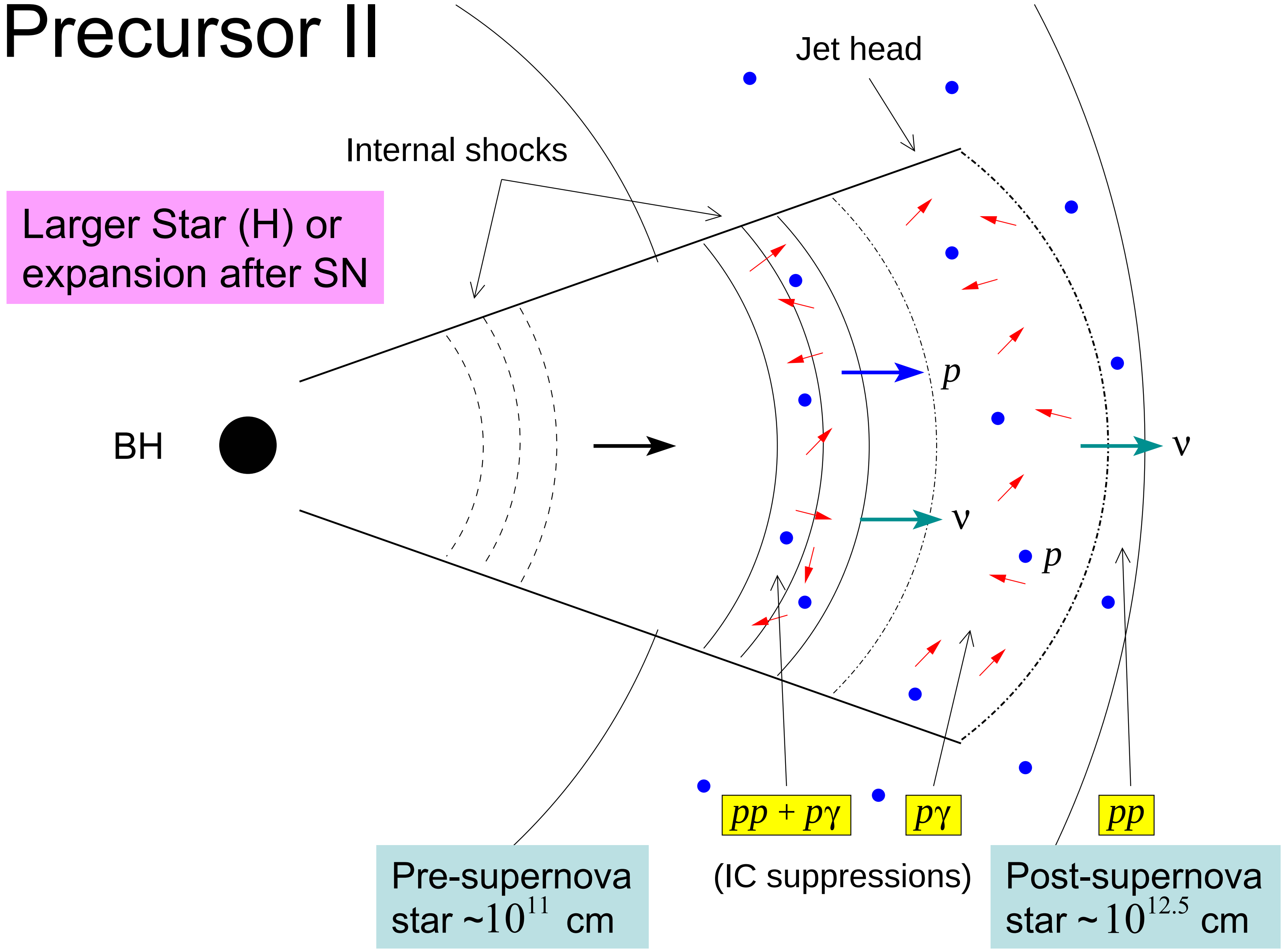
$$\pi^{+}\,/\,K^{+}\rightarrow\mu^{+}\nu_{\mu}\rightarrow e^{+}\nu_{e}\overline{\nu}_{\mu}\nu_{\mu}$$

Precursor I

Buried Jet inside
He Star

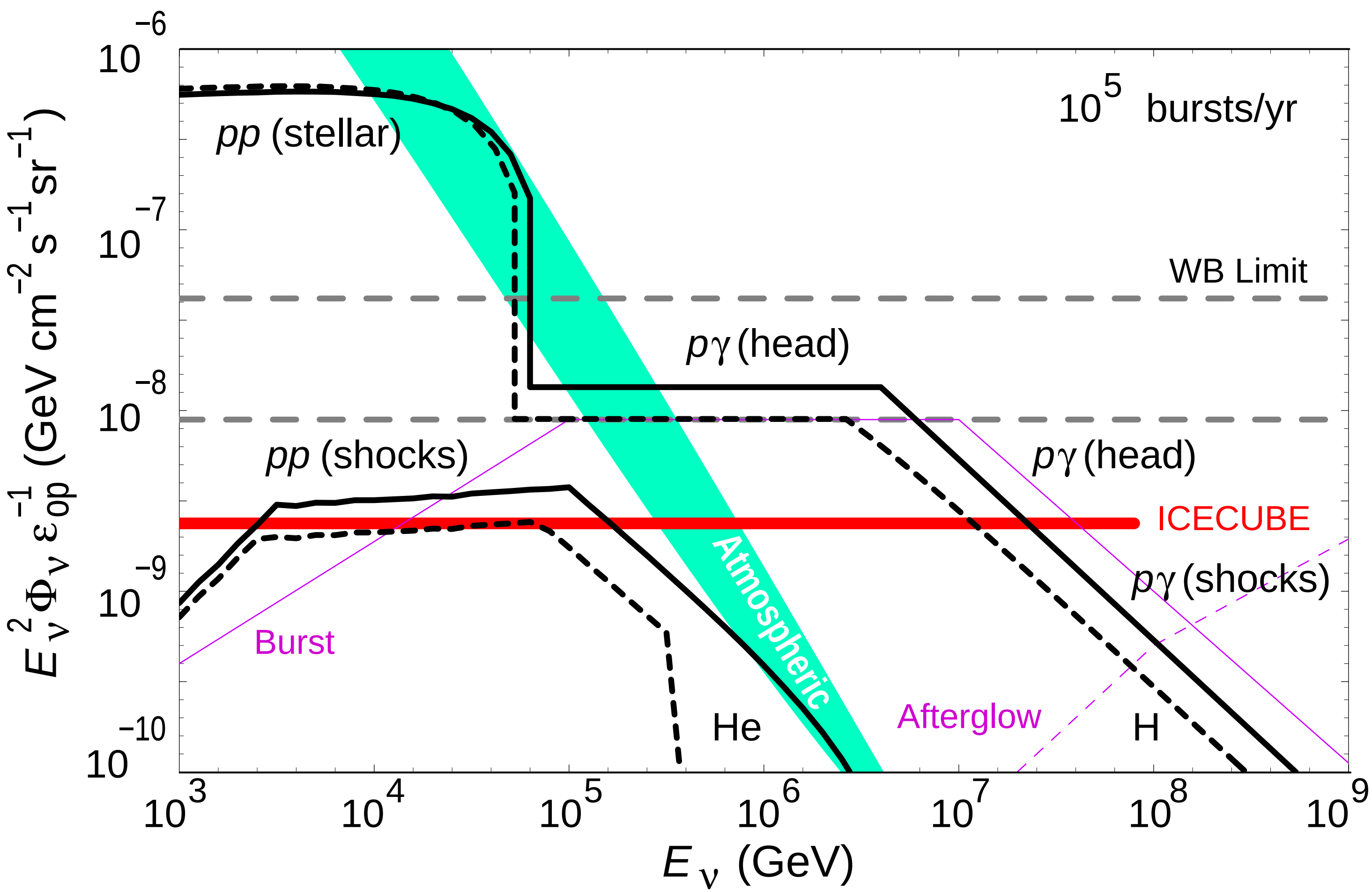


Precursor II



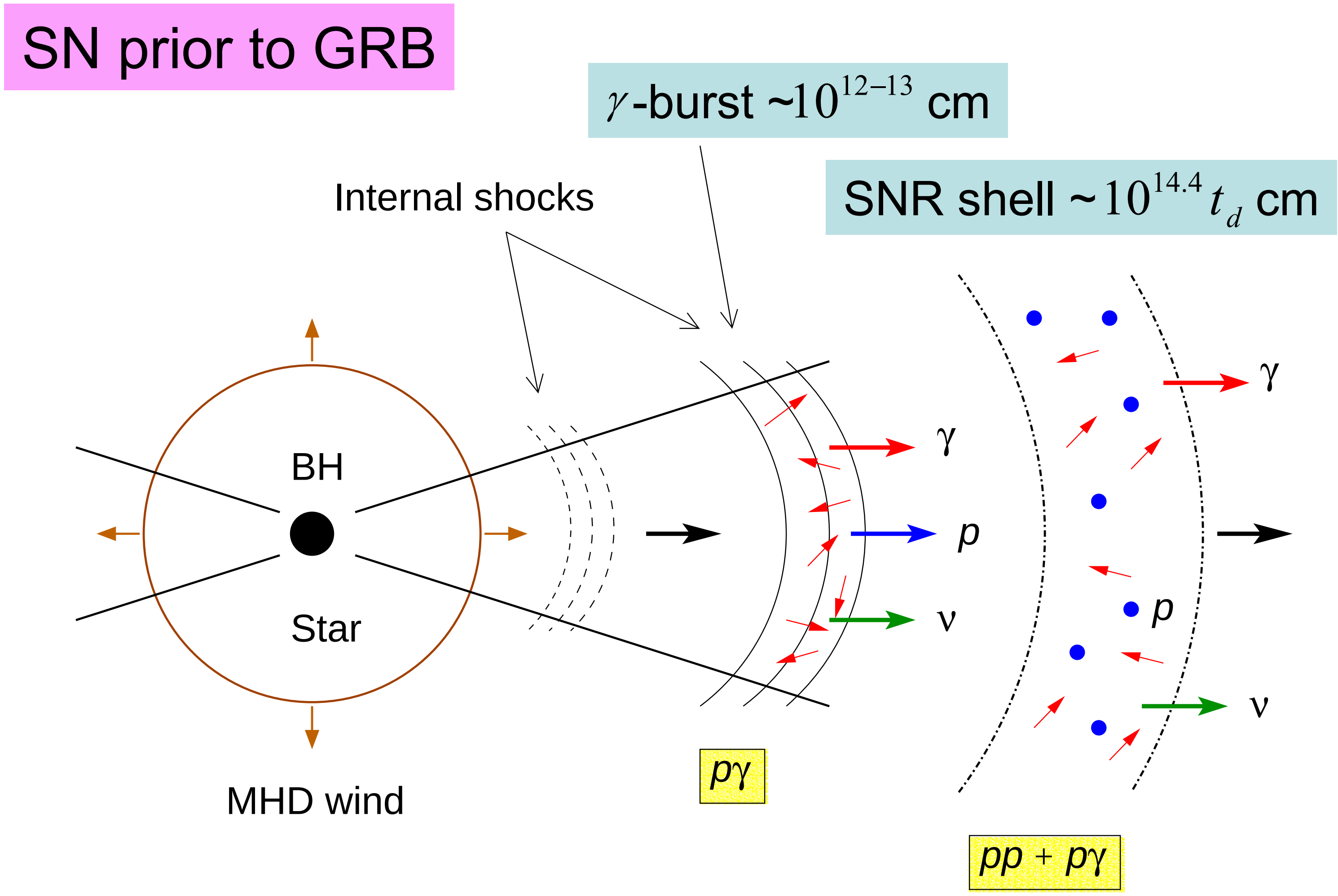
Buried Jet Diffuse ν-Flux

All GRBs having pre-cursor neutrino signal



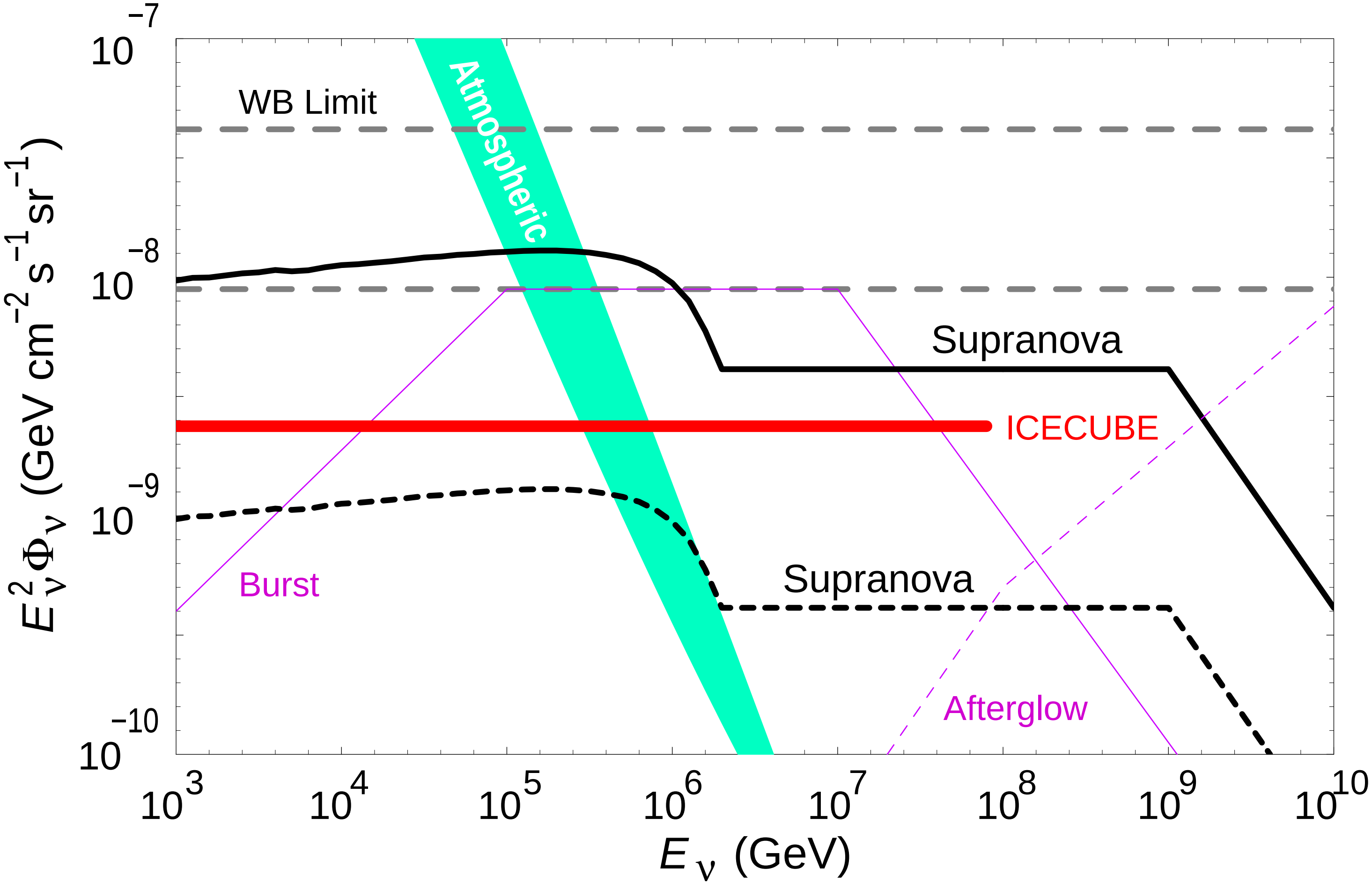
S. Razzaque, P. Meszaros & E. Waxman, PRD68, 083001, 2003

Supranova Model



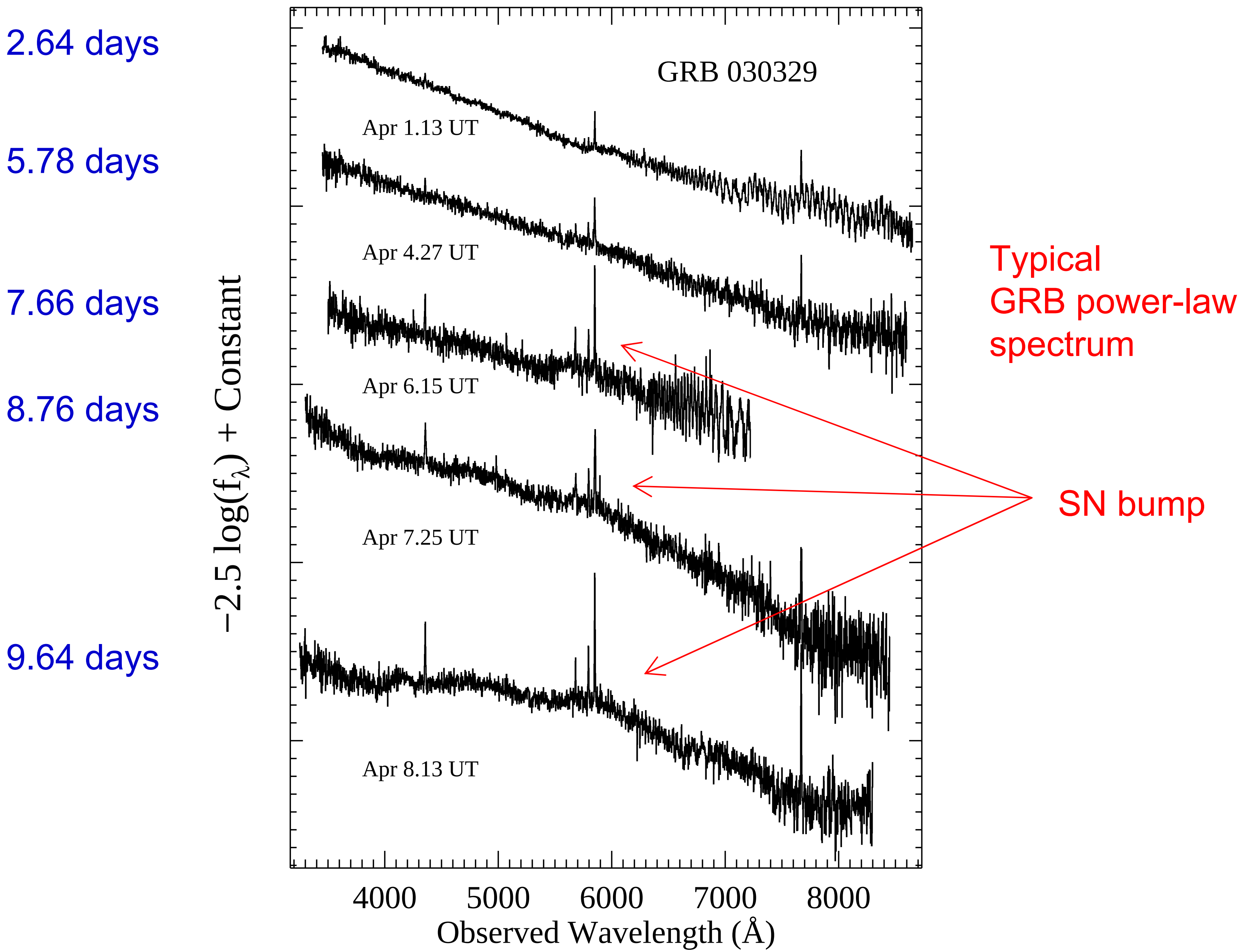
Supranova Diffuse ν-Flux

1 out of 10 GRBs has a SN association



10% of protons interact with SN shell

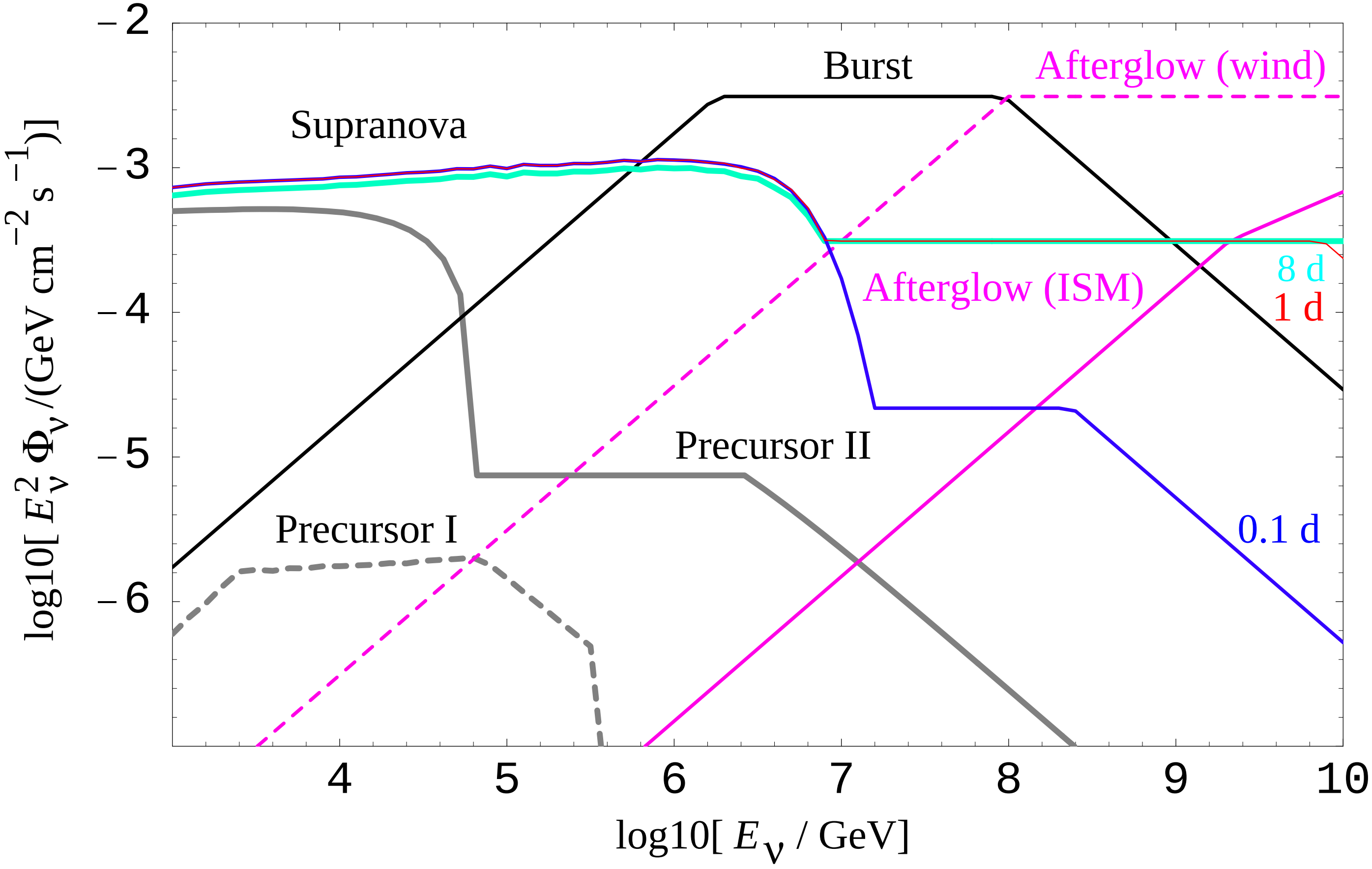
S. Razzaque, P. Meszaros & E. Waxman, PRL90, 241103, 2003



K.Z. Staneck et al., ApJL 2003

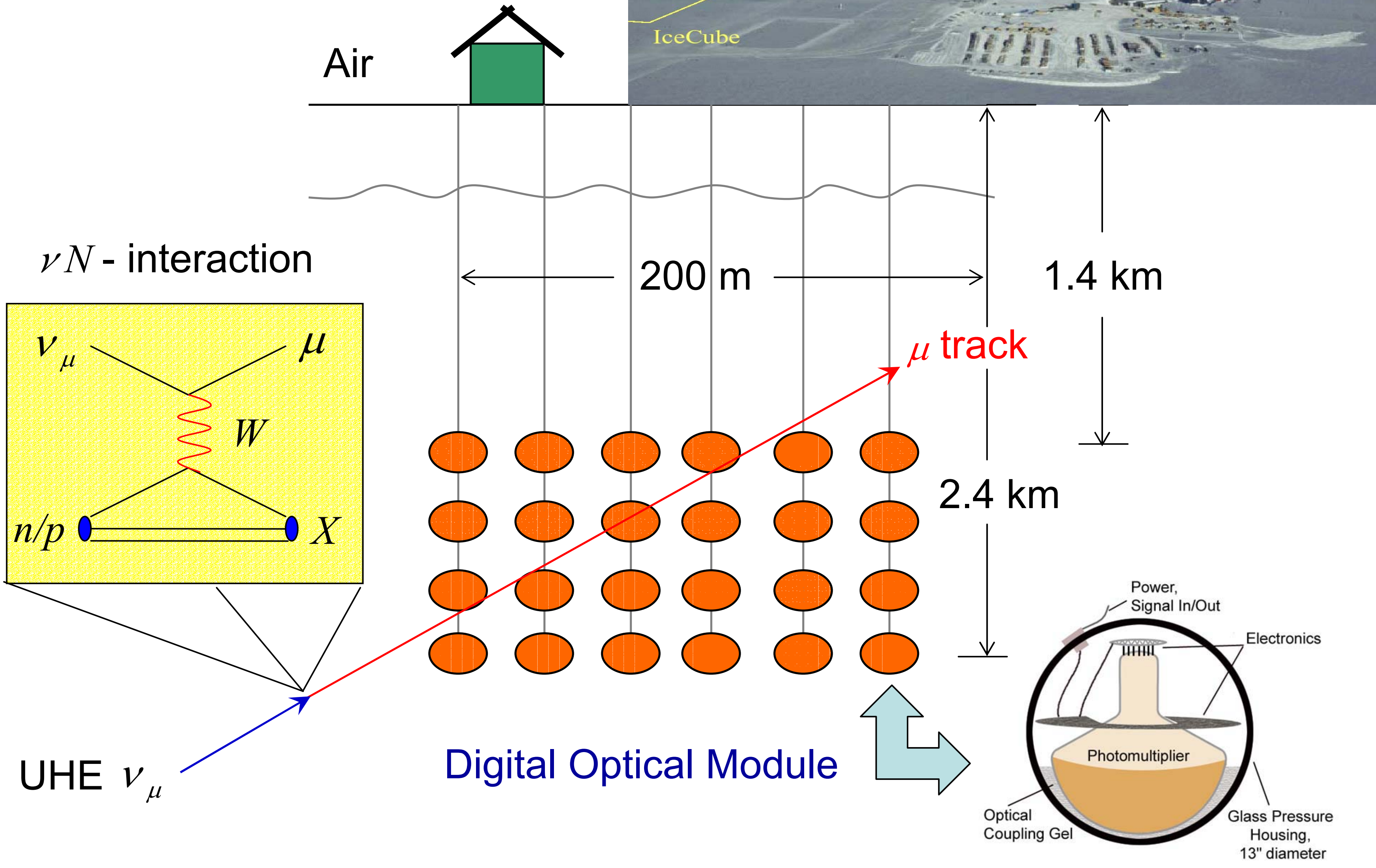
ν-Fluxes from GRB 030329

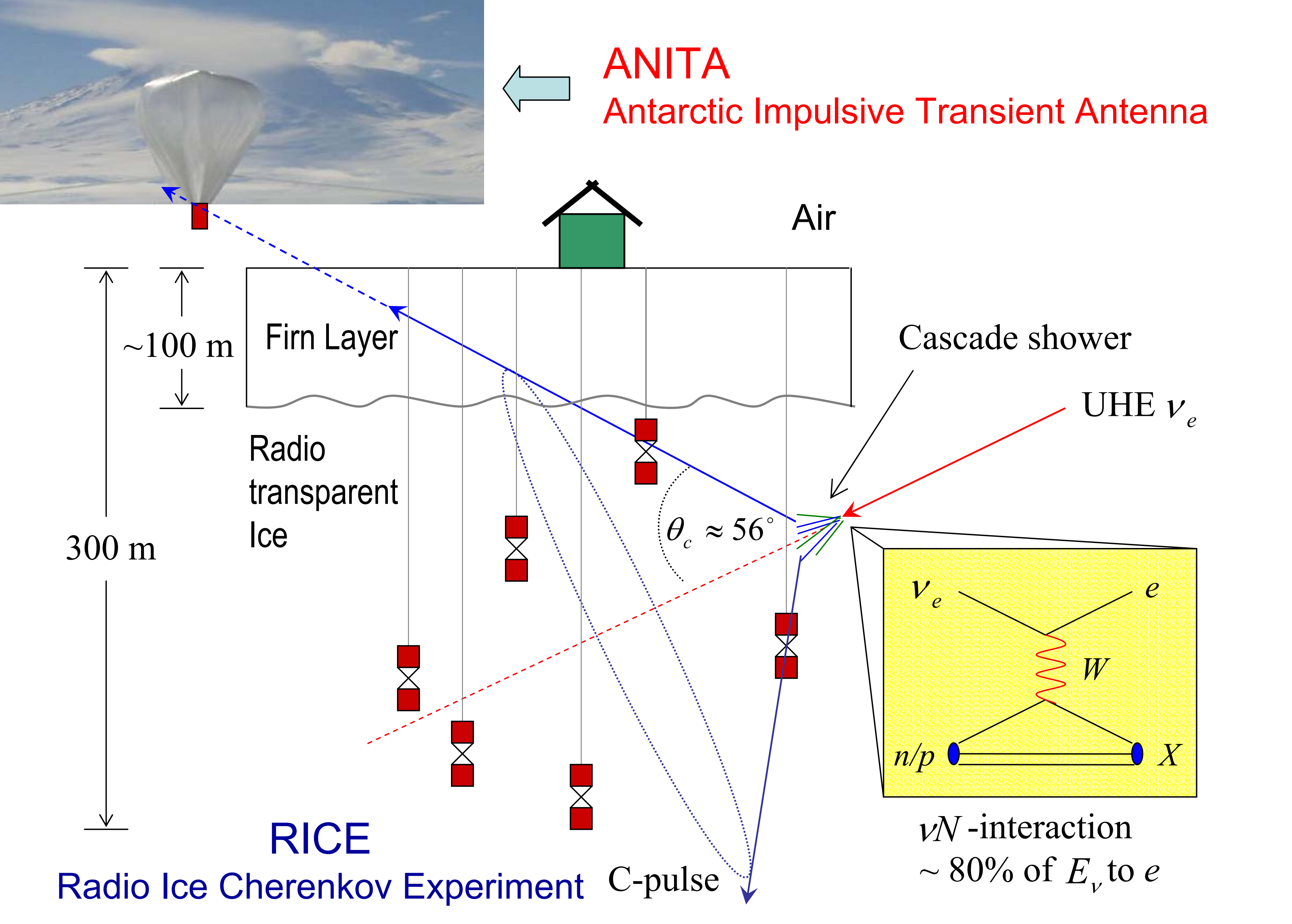
Flux duration ~30 s



S. Razzaque, P. Meszaros & E. Waxman, PRD69 023001, 2004

IceCube
Neutrino Telescope





ANITA
Antarctic Impulsive Transient Antenna
Air
~100 m
300 m
Firn Layer
Radio transparent Ice
Cascade shower
UHE ν_e
$\theta_c \approx 56^\circ$
ν_e
e
W
n/p
X
νN -interaction
$\sim$ 80% of E_ν to e
C-pulse
RICE
Radio Ice Cherenkov Experiment

ν-Propagation inside Earth

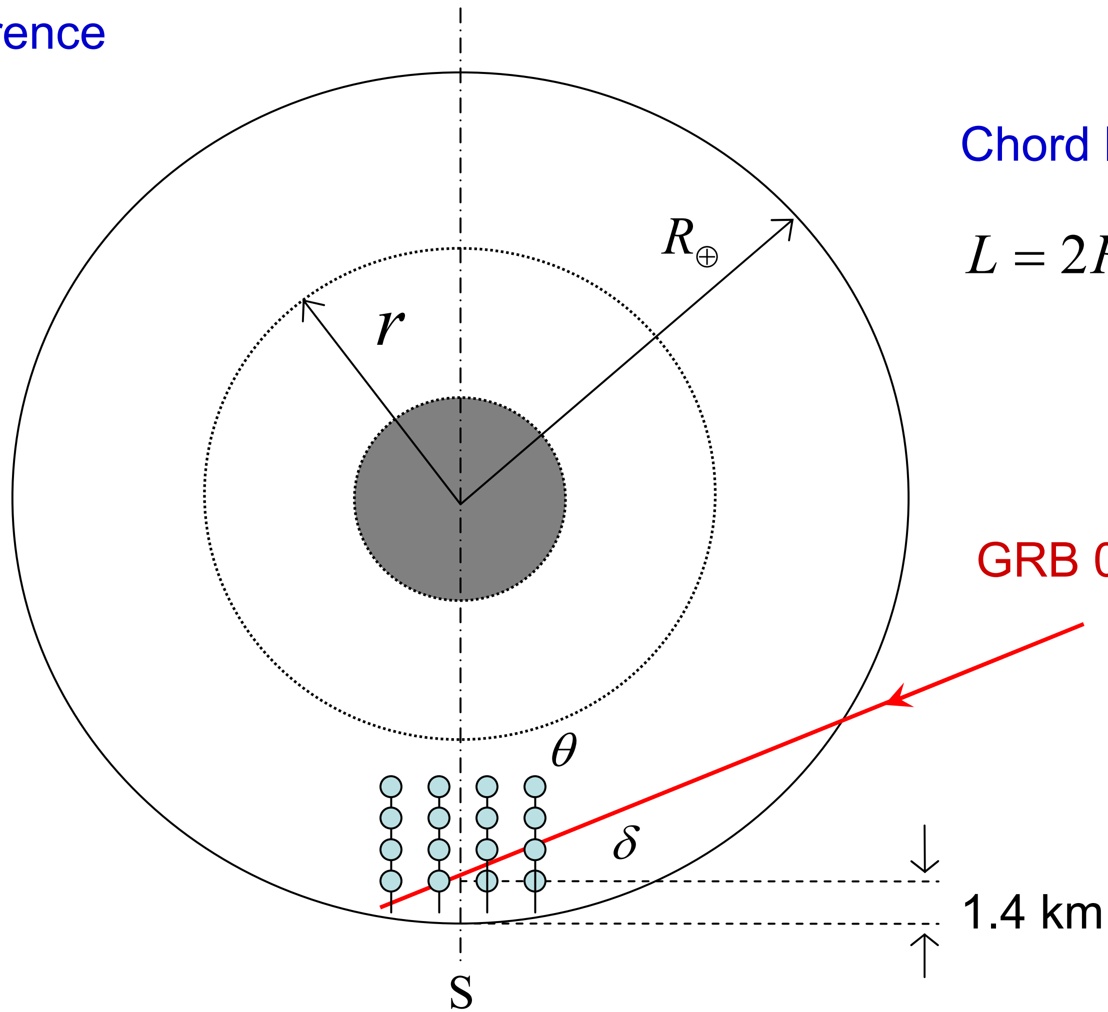
Preliminary Reference Earth Model

Matter density

$$\rho(r;\theta,l)$$

Column depth

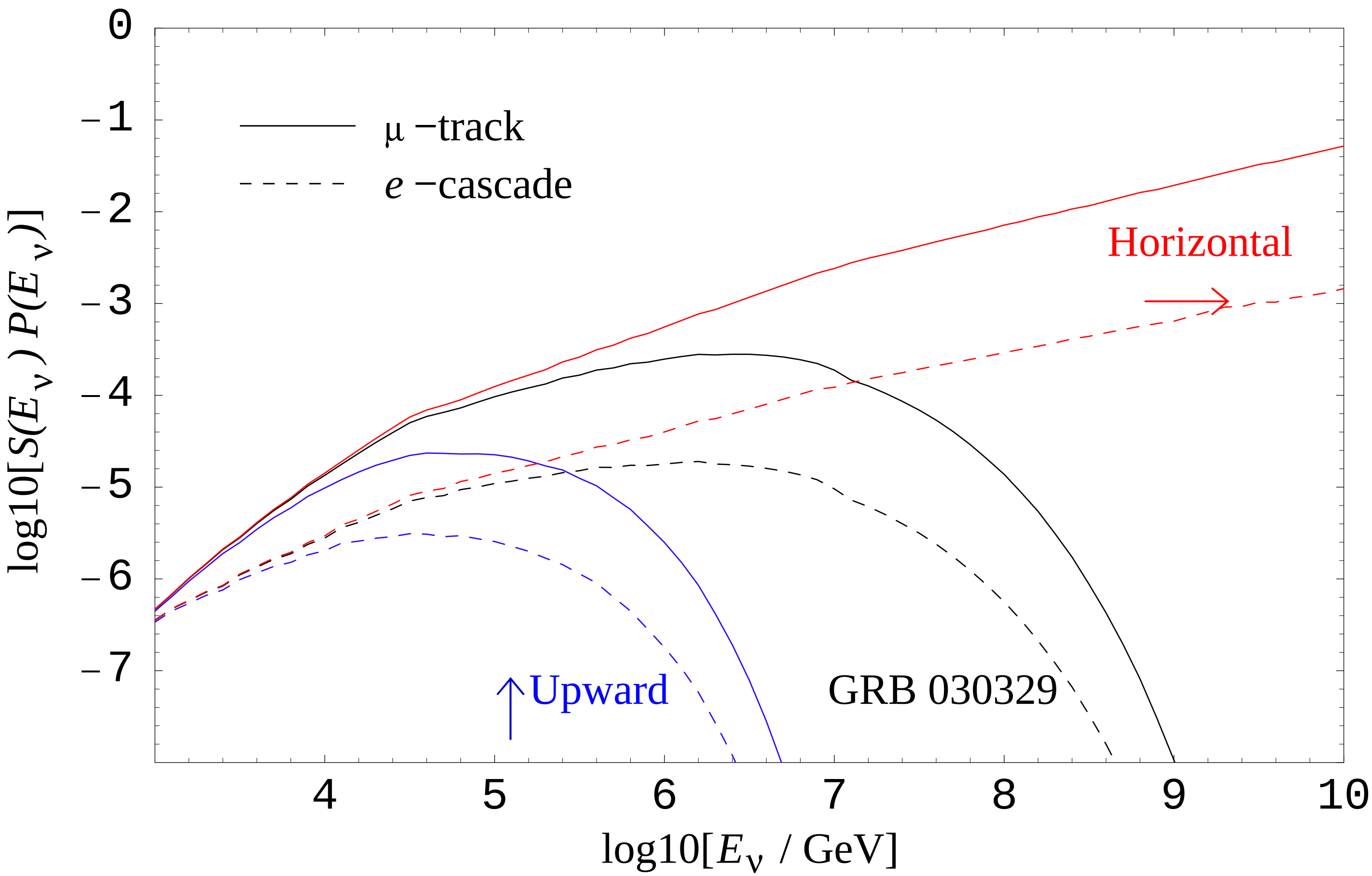
$$\int_0^L \rho(r;\theta,l)dl$$



Chord length

$$L = 2R_\oplus \cos\theta$$

ν-Detection Probability



S. Razzaque, P. Meszaros & E. Waxman, PRD69 023001, 2004

Neutrino Events GRB 030329

Flux Component	TeV – PeV		PeV - EeV	
	muon track	e-cascade	muon track	e-cascade
Precursor I	9×10^{-3}	2×10^{-3}		
Precursor II	4.1	1.1	3×10^{-3}	2×10^{-4}
Burst	1.8	0.2	1.4	0.1
Afterglow ISM	2×10^{-4}	2×10^{-5}	2×10^{-4}	1×10^{-5}
Afterglow (wind)	0.03	3×10^{-3}	0.05	3×10^{-3}
Supranova 0.1d	12.4	2.4	0.5	0.03
Supranova 1d	12.4	2.4	0.5	0.03
Supranova 8d	10.9	2.2	0.4	0.03

Neutrino Events

Flux Component	TeV – PeV		PeV - EeV	
	muon track	*e*-cascade	muon track	*e*-cascade
Precursor I	9x10^{-3}, 0.01 →	2x10^{-3}		
Precursor II	4.1, 2.9↑, 4.4 →	1.1, 0.9↑, 1.2 →	3x10^{-3}, 0.01 →	2x10^{-4}
Burst	1.8, 0.3↑, 2.9 →	0.2, 0.04↑, 0.3 →	1.4, 7.6 →	0.1, 0.4 →
Afterglow ISM	2x10^{-4}	2x10^{-5}	2x10^{-4}, 0.01 →	1x10^{-5}
Afterglow (wind)	0.03, 0.05 →	3x10^{-3}	0.05, 1.4 →	3x10^{-3}, 0.06 →
Supranova 0.1d	12.4, 6.1↑, 14.9 →	2.4, 1.6↑, 2.7 →	0.5, 1.6 →	0.03, 0.1 →
Supranova 1d	12.4, 6.1↑, 14.9 →	2.4, 1.6↑, 2.7 →	0.5, 1.9 →	0.03, 0.1 →
Supranova 8d	10.9, 5.4↑, 13.2 →	2.2, 1.4↑, 2.4 →	0.4, 1.7 →	0.03, 0.1 →

Summary

- SN-GRB relationship can be studied with ν's independently from γ-ray, x-ray, UV, optical
  - Constrain SN-GRB delay (better than electromag?)
  - Improves ultra-high energy ν detection ability (added flux components ⇨ more events)
- Detection of pre-cursor is useful to learn about GRB/SN progenitor star
  - Star mass
  - Core collapse or Pulsar?

When there will be another burst like 030329??