Probing Dark Energy via ν & SN Observatories

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Joseph Baker, Haim Goldberg, G.P., & Ina Sarcevic, in preparation.

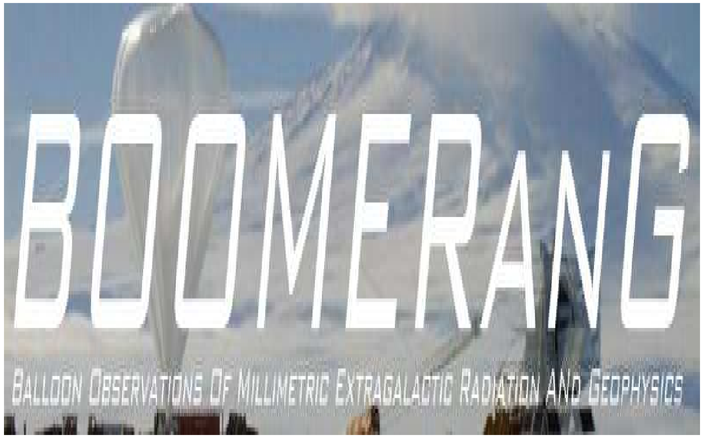
Outline

- Introduction.
- Main Idea.
- SN core collapse rate & SNAP.
- Observing the Relic SN ν.
- SN & ν flux.
- Discussion (ex. mini Z').

Introduction

98 - great year for ν (Atm') & Cosm' (SN,CMB).

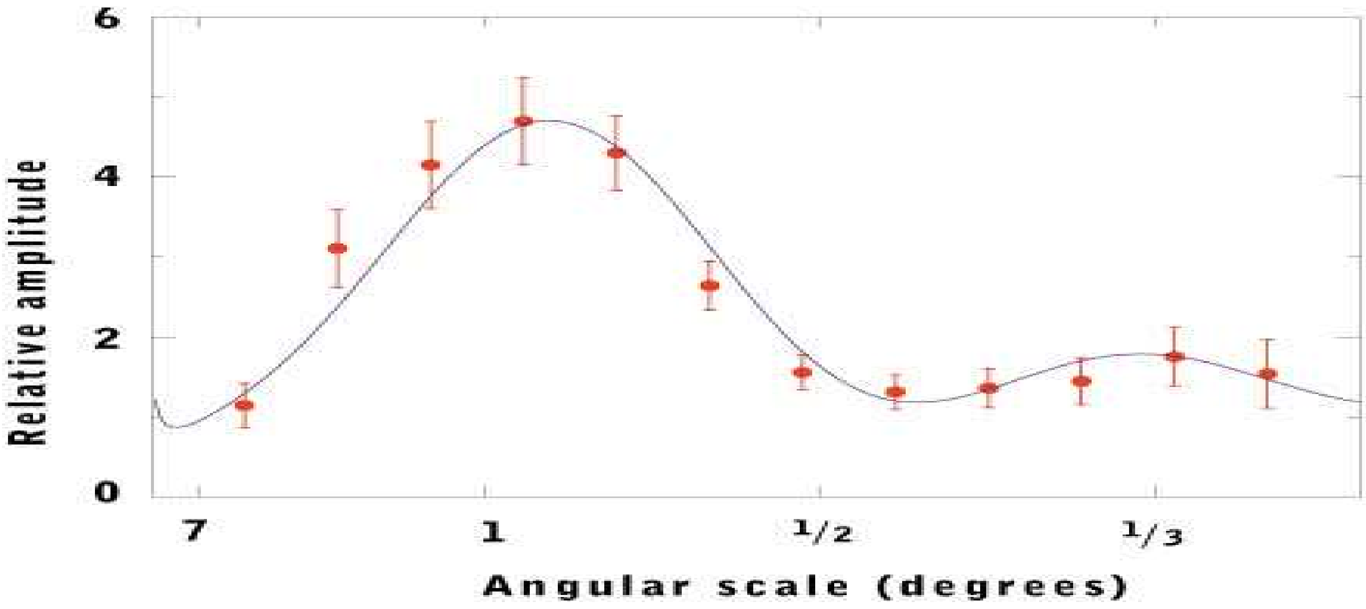
KAMIOKA OBSERVATORY



Supernova Cosmology Project

CMBR: Flat Universe

$\Omega_M + \Lambda = 1$ (assumed below)

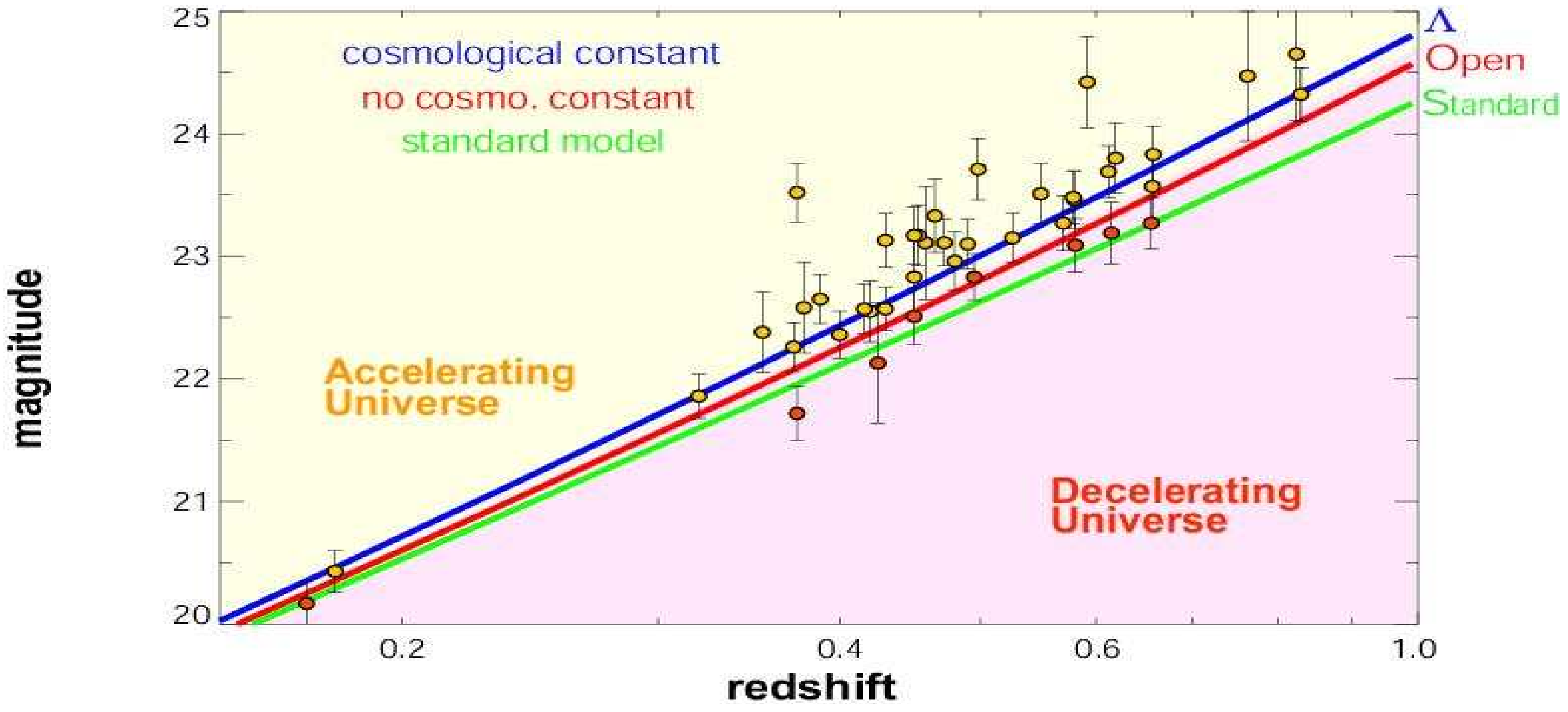


Deceleration was obvious (SCDM):

$$ds^2 = dt^2 + a^2 dx^2 \,, \quad \ddot{a} \propto -\Omega_M (1+z)^3$$

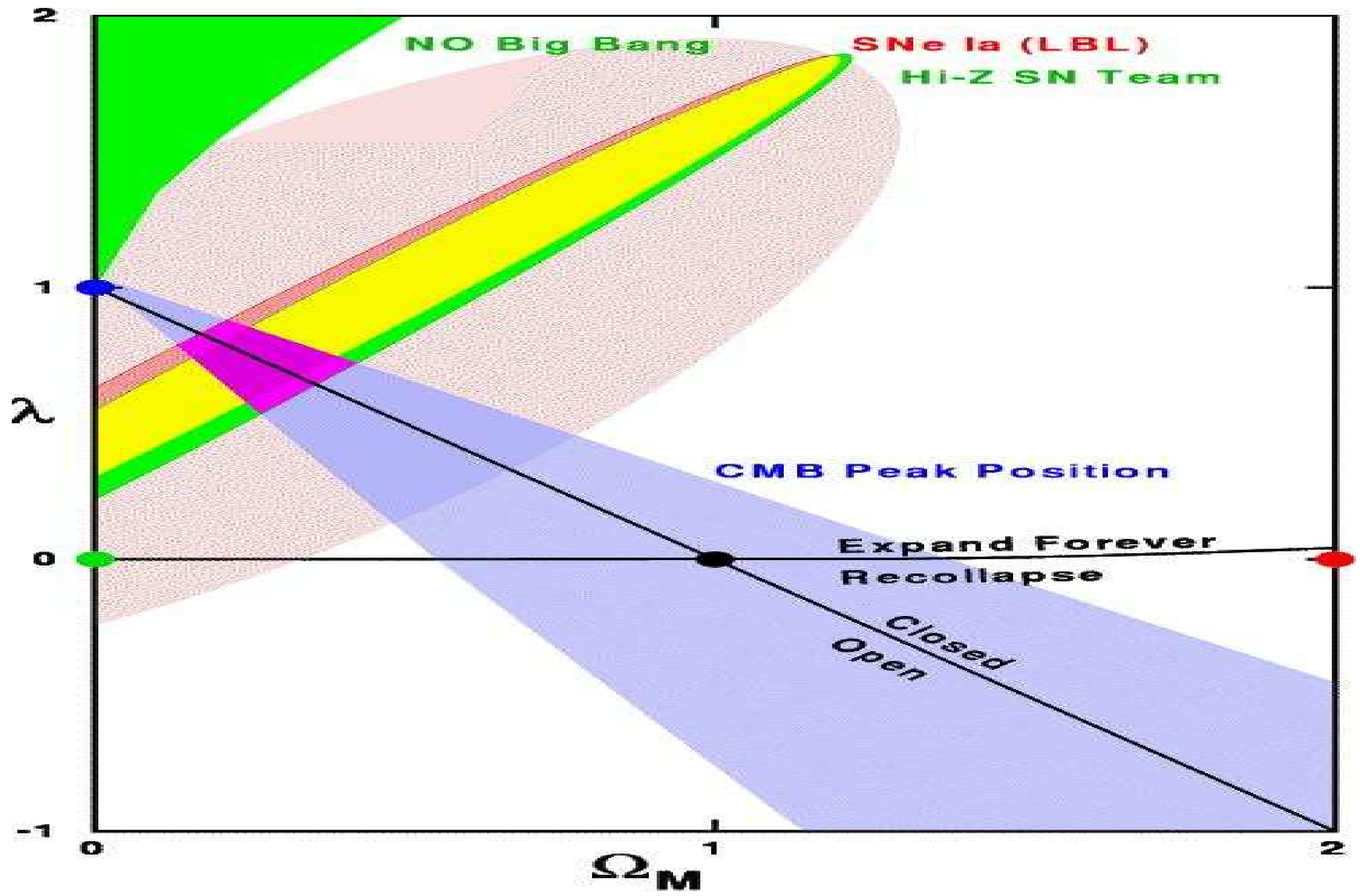
SNe: Looks fainter

$$L = F^{Ia}/d_L^2(z, \Lambda)$$

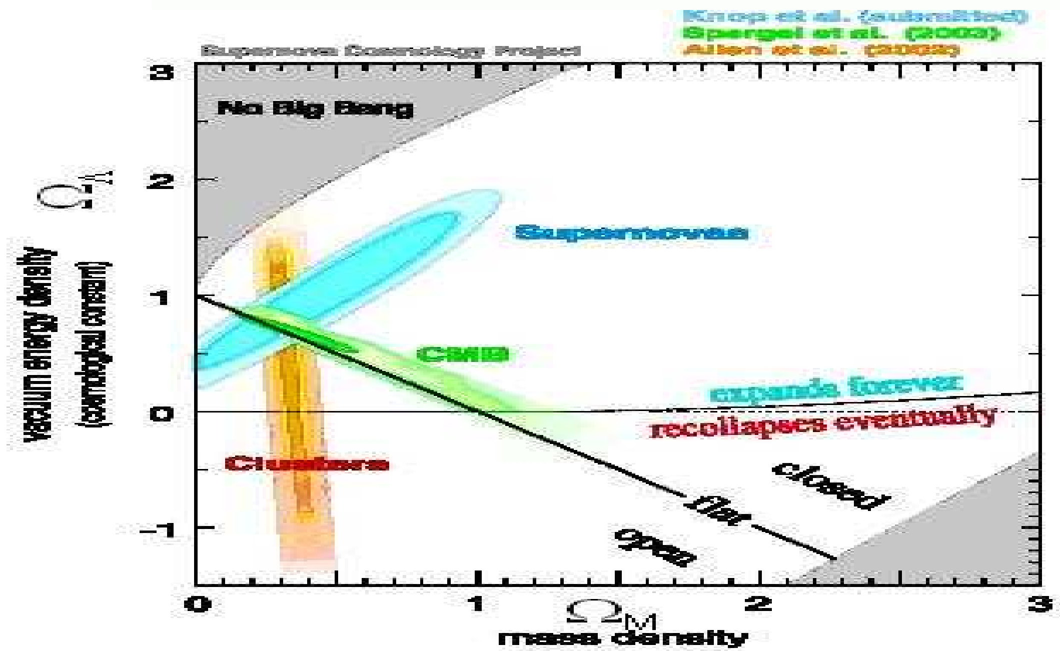


CMB $\rightarrow$ flat + SN $\rightarrow$??

Dark Energy, $\Lambda \sim 0.7$!



More indirect evidences



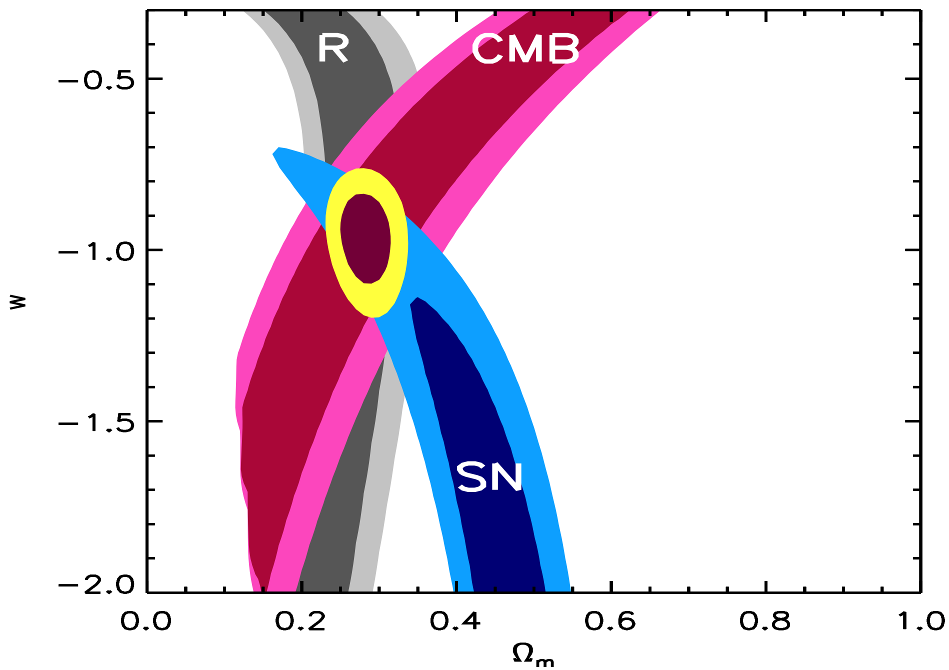
- SNe - the strongest (direct) evidence.
- Others mostly measu' $\Omega_{m,B}$ (however ISW,SZ ...).

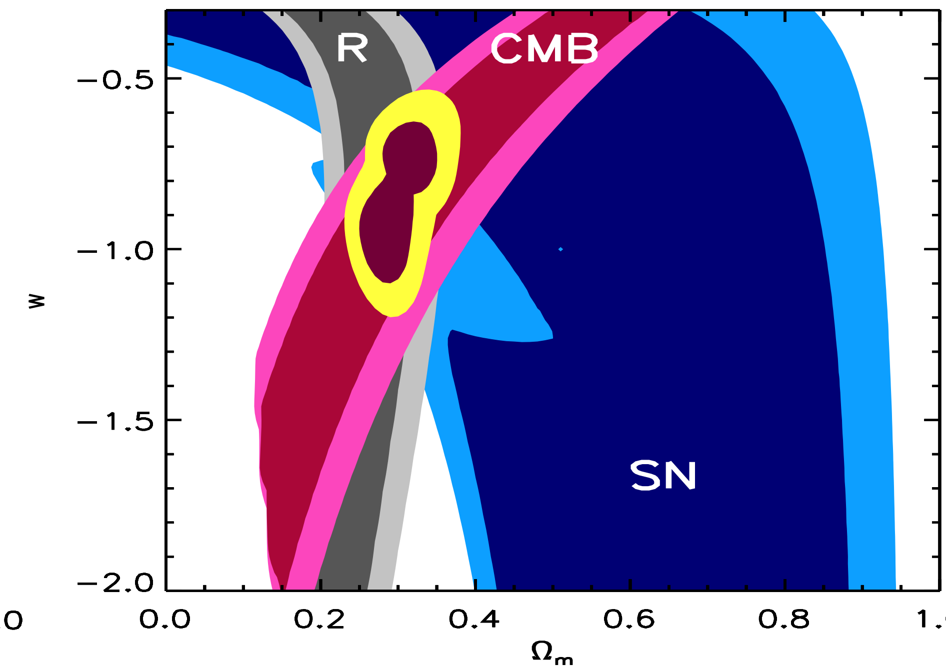
Next: *w* $= p/\rho$ *?*

- Must control intensity loss:
- Dust extinction.
- NP (*e.g.* axions Csaki, Kaloper& Terning).

SN ⇒ particular phys. + syst

W vs. Ω_M (CMB+baryon osc' & SNe /w & /wo axions)



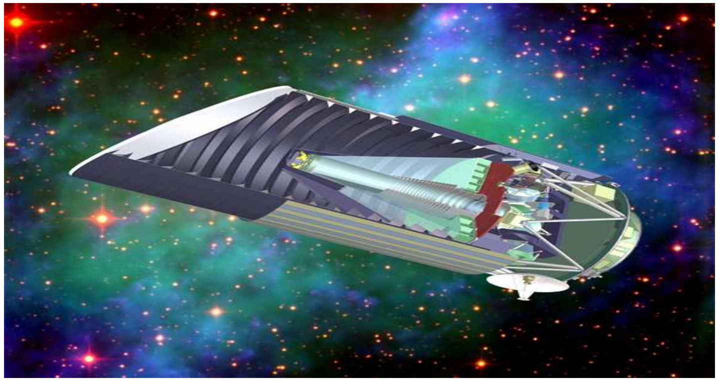


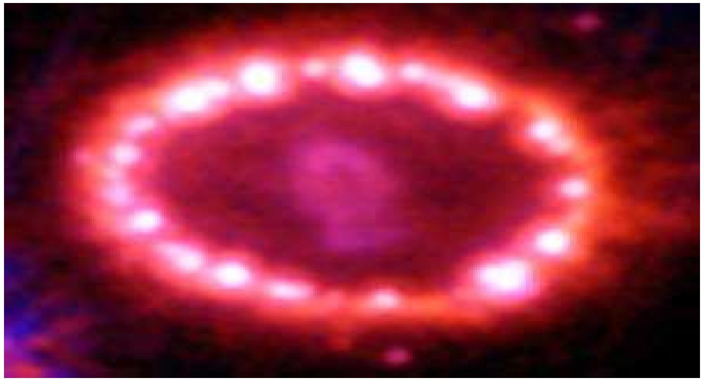
- SNe like w< -1 ?

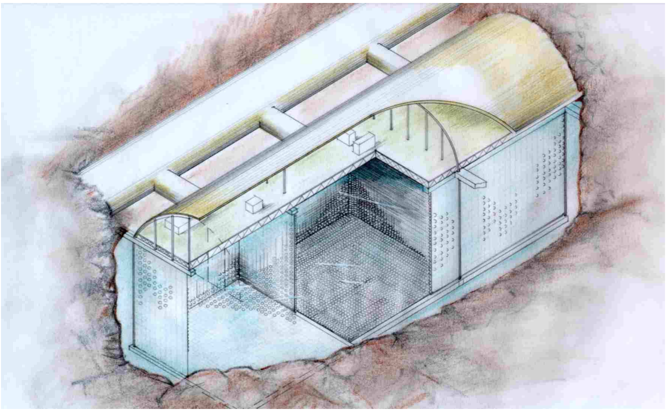
Song & Hu (05)

Different probe (ν, gravity waves) ?

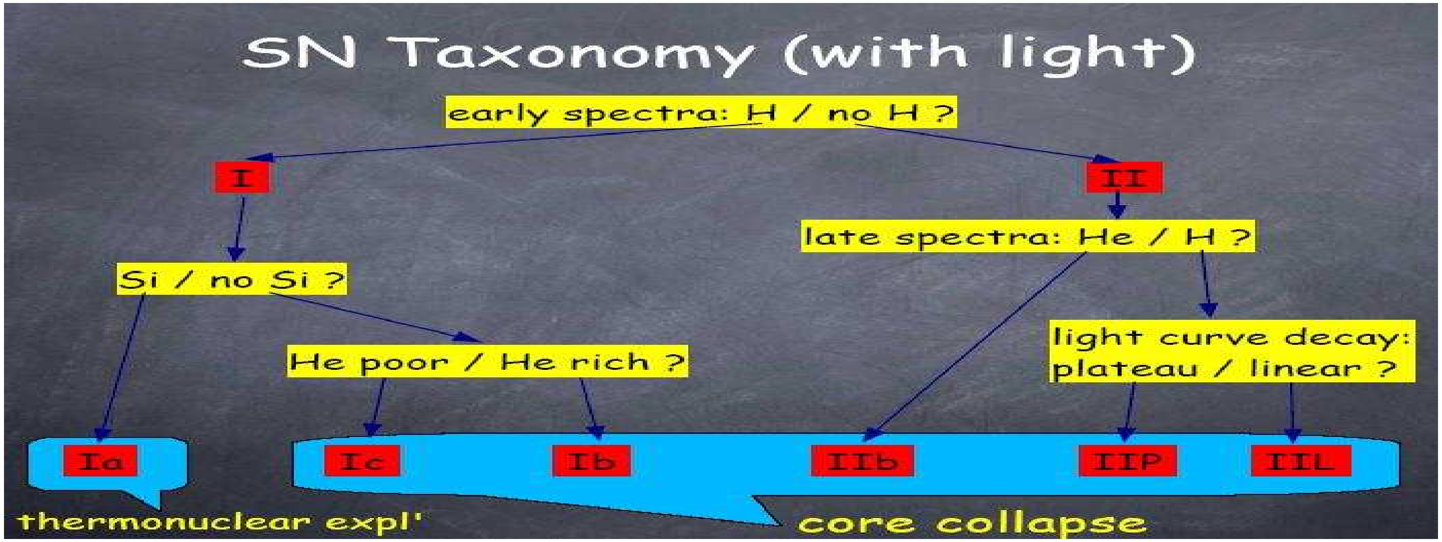
Main Idea

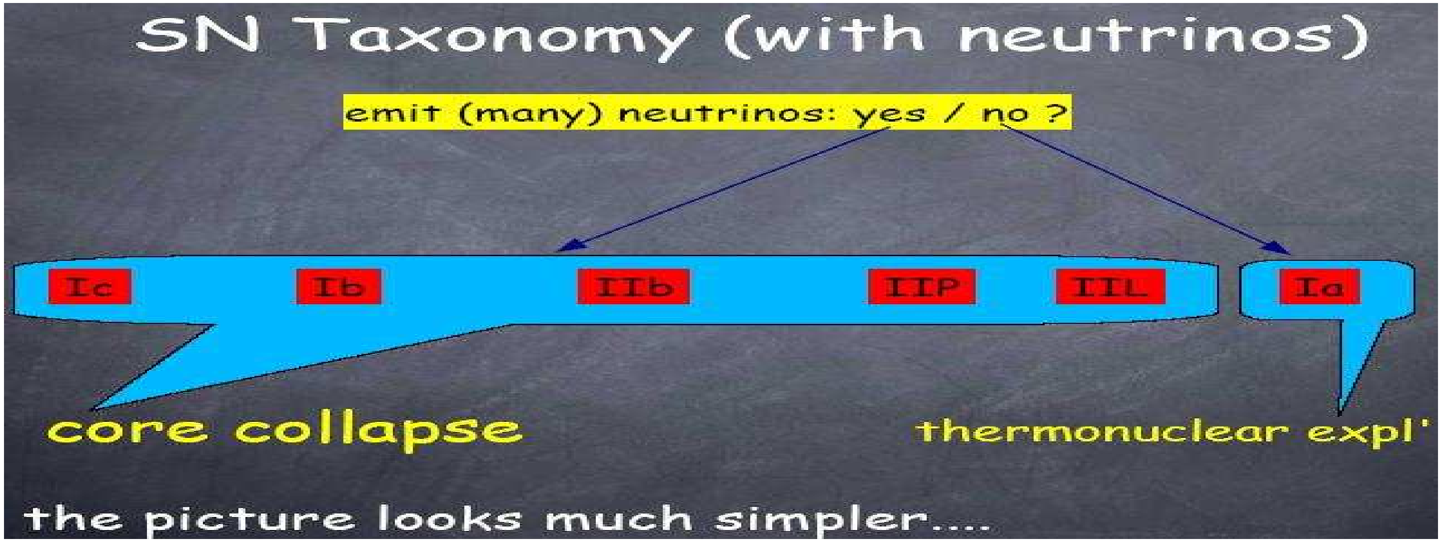






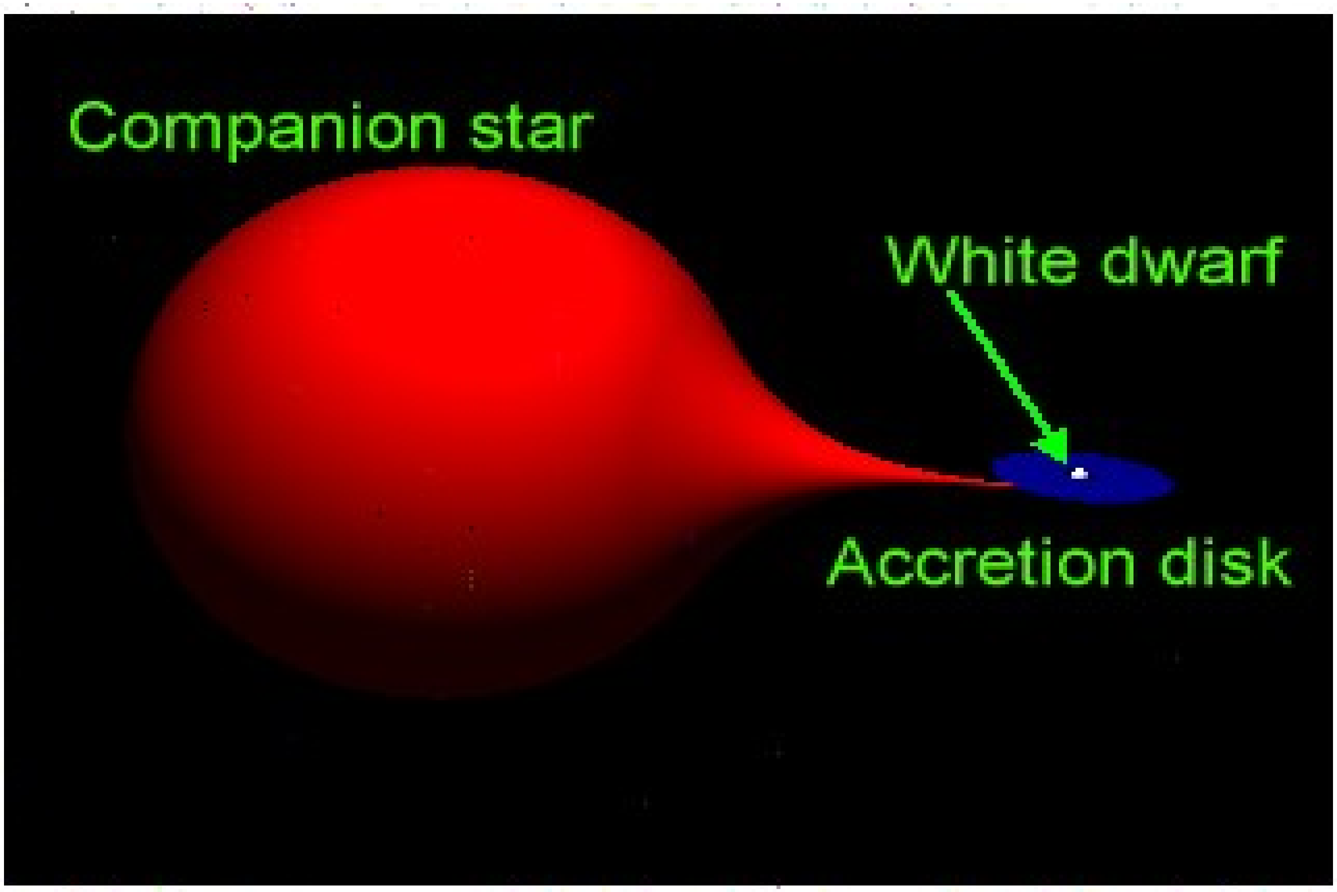
Type Ia vs. Core Collapse (CC)





Type Ia vs. Core Collapse (CC)

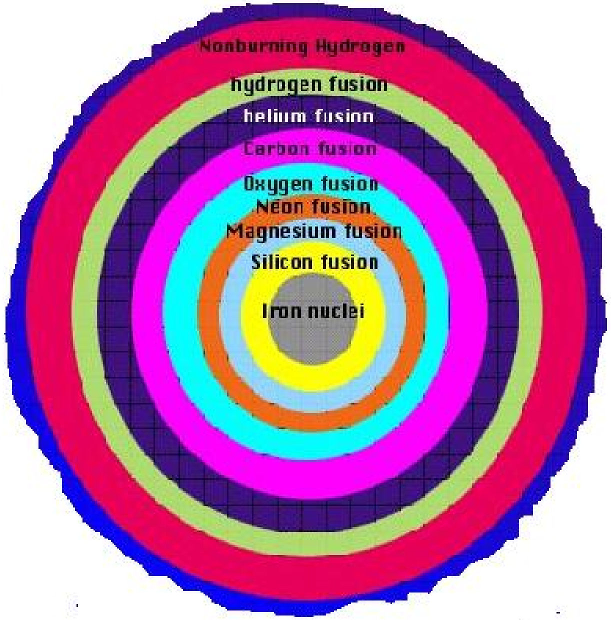
Ia: small, old prog', binary



CC SN *Ib,Ic, IIx*

ν CC: big, young prog' ν

ν ν



ν ν

ν ν

Main Idea

- Replace SN-γs with SN-νs.
- Combine info' from ν & SN obs'.
- HyperK/UNO - $\frac{10^2}{\text{year}}$ relic SNν $\Rightarrow$ $\Phi^\nu(\epsilon)$.
- SNAP - $\frac{10^3}{\text{year}}$ CC SN $\Rightarrow$ $R_{\rm SN}(z)$.
- $\Phi^\nu(\epsilon)$ & $R_{\rm SN}(z)$ $\Leftrightarrow$ Cosm' dependent!
- $\Phi^\nu(\epsilon)$,$R_{\rm SN}(z)$- uncertain due to $R_{\rm SN}^{\rm co}$.

$R_{\rm SN}$ + Φ^{ν} *Cosm' sensitive*

- Φ^{ν} is a function of $R_{\rm SN}$ (& $\frac{dN^{\nu}}{d\epsilon}$ see later):

$$\Phi^{\nu} \propto \int dz\, R_{\rm SN}\, \frac{dN^{\nu}}{d\epsilon}\, \frac{1}{d_L^2(\Omega_M, \Lambda)}\ ,$$

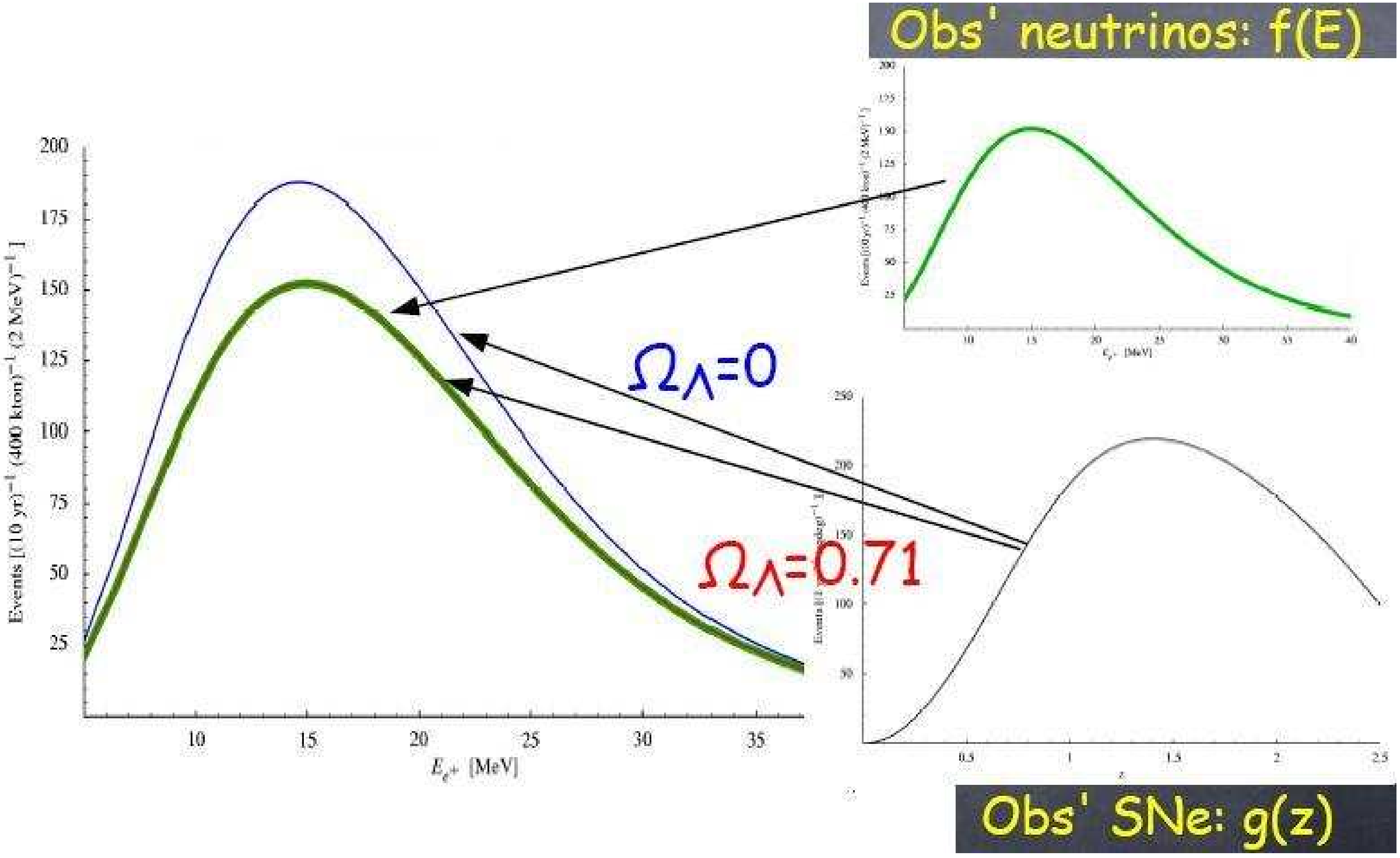
$$\Downarrow$$

- The dependence on $R_{\rm SN}^{\rm co}$ cancel.

$$\Downarrow$$

Still cosm' dep' (SN -"standard" ν candle)!

ΛCDM vs. SCDM - naive picture



Main idea - summary

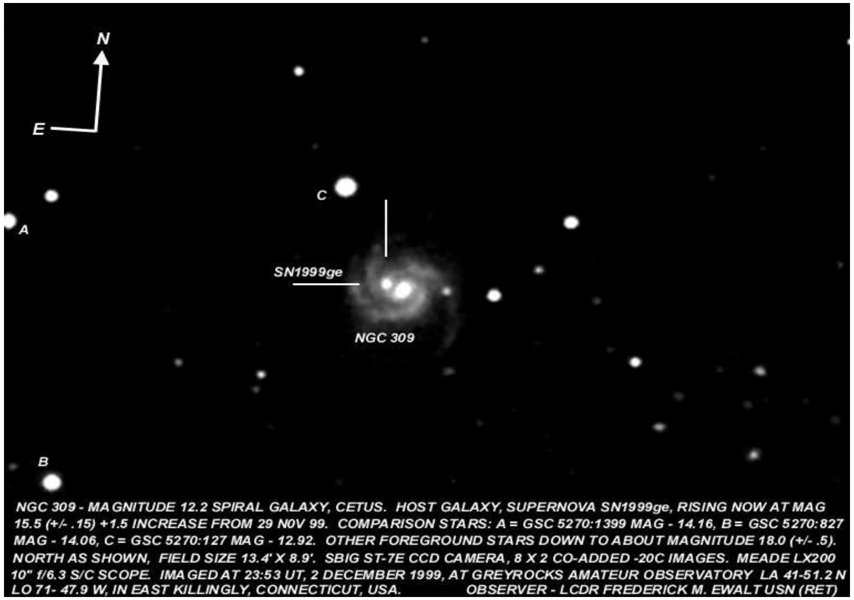
$$\Phi^\nu \propto \int dz\, R_{\rm SN} \frac{dN^\nu}{d\epsilon} \frac{1}{d_L^2(\Omega_M,\Lambda)}$$

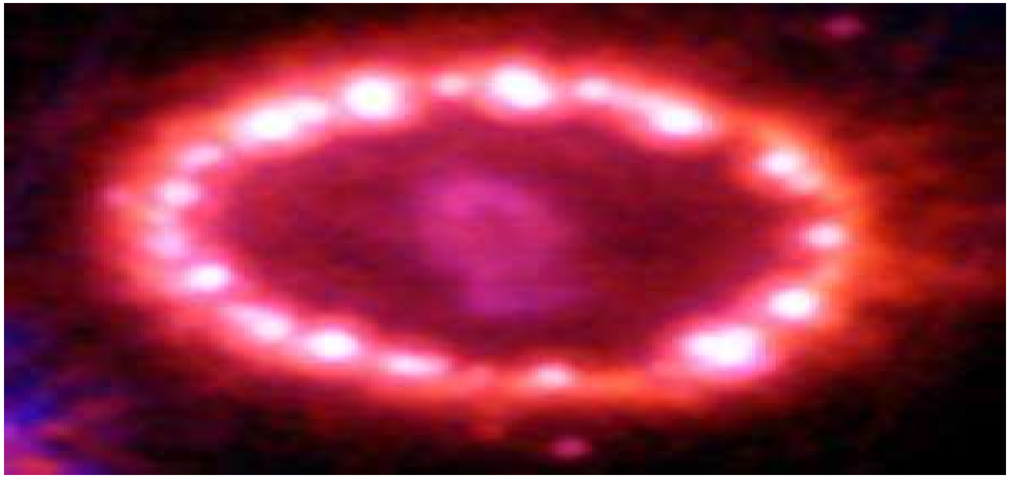
- Measure Φ^ν. (MT detectors+Gd ~ 1000)
- Measure $R_{\rm SN}$. (SNAP $\sim$ 3000)
- Theo' + exp' speculation to fight $\frac{dN^\nu}{d\epsilon}$.

Go after cos' anomalies $\Rightarrow d_L^2(\Omega_M, \Lambda/w)$.

OR use the above + cos' $\Rightarrow \frac{dN^\nu}{d\epsilon}$.

R_{SN} & SN observatories





Measurement of R_{SN}

- $R_{\mathrm{SN}}(z)$ from light bad^2:

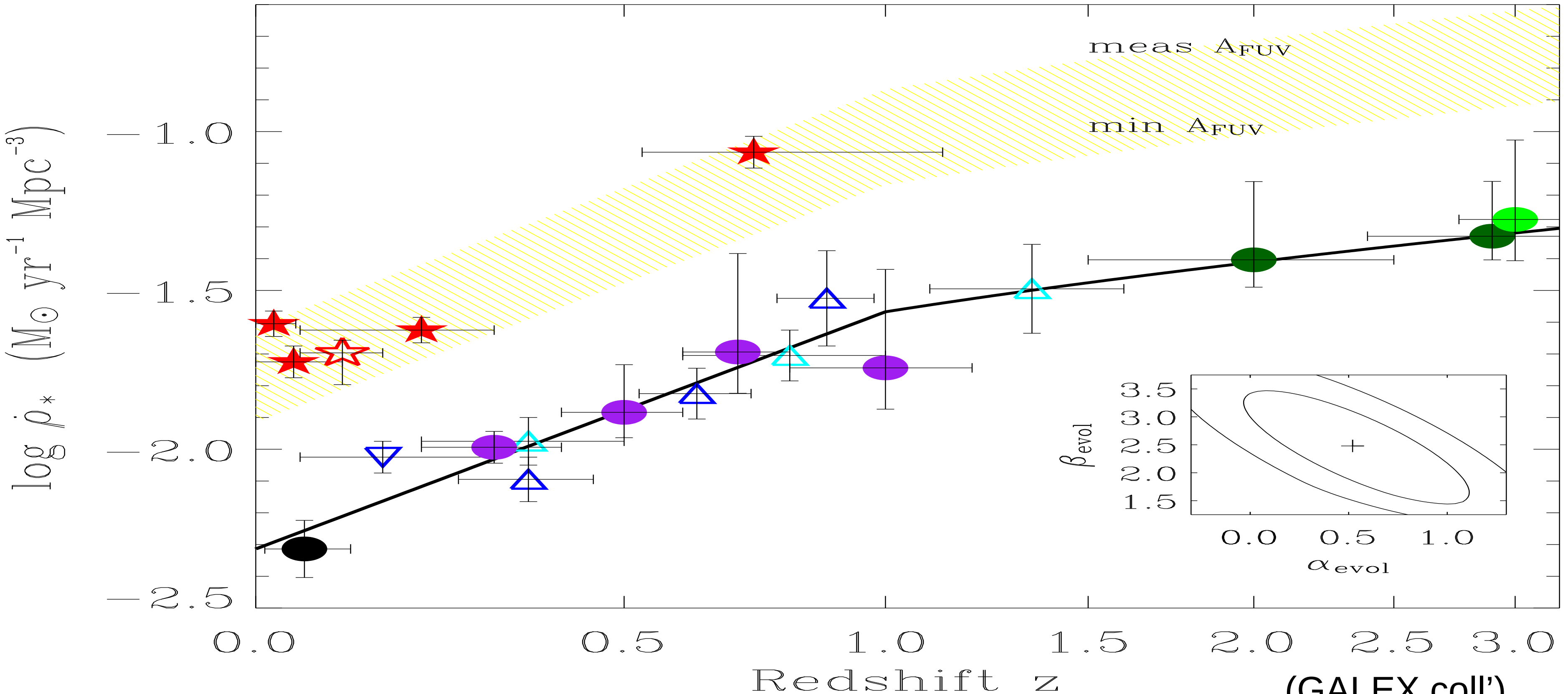
(i) flux$^\gamma \longrightarrow$ flux$^\nu$ translation $\Rightarrow$ Cosm' cancel. (Ando & Sato)

$$R_{\mathrm{SN}}^{\mathrm{co}} \propto L^{\mathrm{obs}} \frac{d_L^2(\Omega_M, \Lambda)}{dV/dz(\Omega_M, \Lambda)} ,$$

$$\Phi^\nu \propto \int dz \, R_{\mathrm{SN}}^{\mathrm{co}} \frac{dV/dz(\Omega_M, \Lambda)}{d_L^2(\Omega_M, \Lambda)} \frac{dN^\nu}{d\epsilon} .$$

$R_{\rm SN}$ ***from light bad*** ^{2}

(ii) Rough $R^{\rm co}_{\rm SN} \propto \left[\left(\frac{1+z_p}{1+z}\right)^{5\alpha} + \left(\frac{1+z_p}{1+z}\right)^{5\beta} \right]^{-\frac{1}{5}}$ $(\alpha, \beta = .5 \pm .4, 2.5 \pm .7)$



(GALEX coll').

SNAP ***precise SN counts***

SNAP $\Rightarrow$ dramatic improvement!

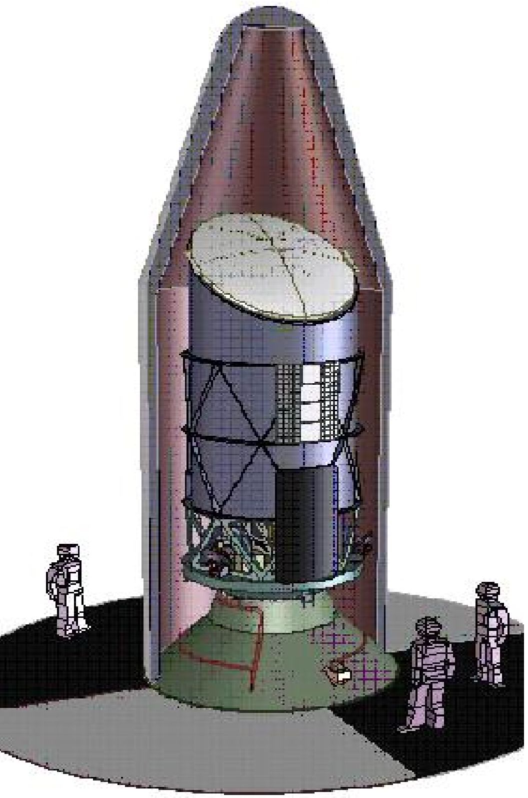
Will collect both CC and 1a SNe.

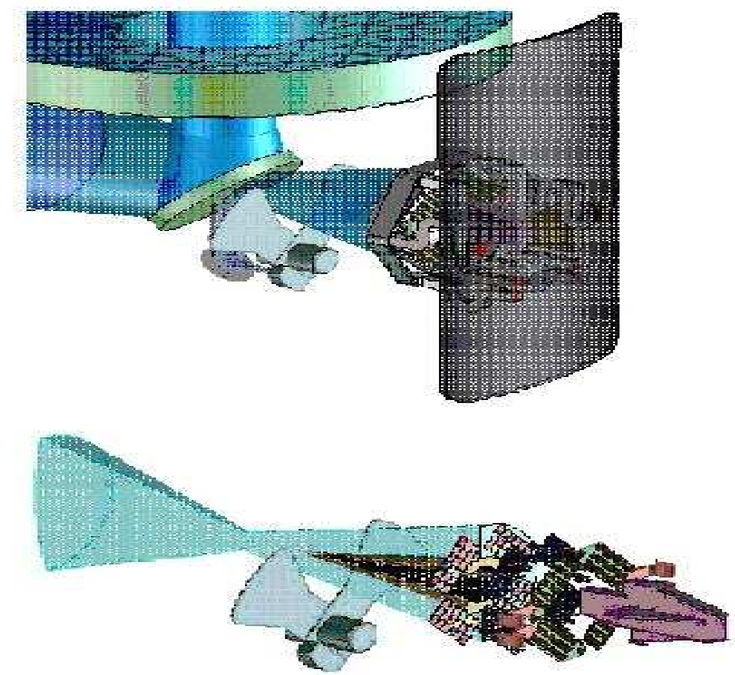
$$\Downarrow$$

Precision R_{SN}.

(Dif' dep' $R_{\mathrm{SN}} \propto R^{\mathrm{co}}_{\mathrm{SN}} \frac{dV}{dz}(\Omega_M, \Lambda, z)$;vol'$\rightarrow$flux)

SNAP





- 2 years on *L2*, 4 days scan, 1deg^2.

SNAP Olympics & $R_{\rm SN}$

- In practice

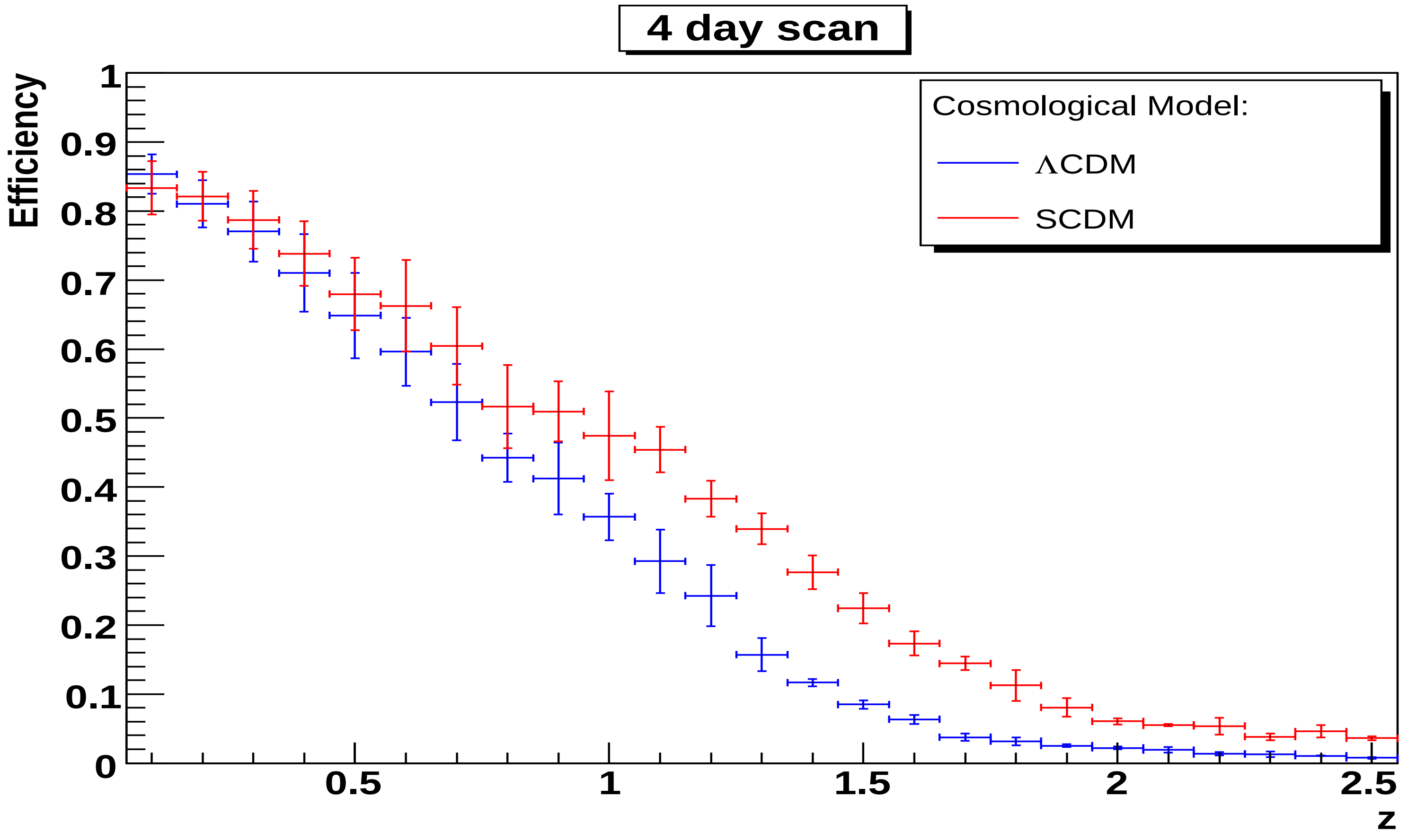
$$R_{\rm SN} \propto R_{\rm SN}^{\rm co} \frac{dV}{dz}(\Omega_M, \Lambda, z) \times \epsilon(z, d_L; {\rm dust}, ...)$$

$$\frac{dV}{dz} \propto \chi^2 \frac{d\chi}{dz},\ \chi \propto \int \frac{dz}{H(\Omega_M,\Lambda,z)} = \int \frac{dz}{\sqrt{\Omega_M(1+z)^3+\Lambda}}.$$

- ϵ corrects finite detection efficiency.
- MC to estimate efficiency. (**SNOC**: Goobar *et. al.*)

Efficiency type IIx

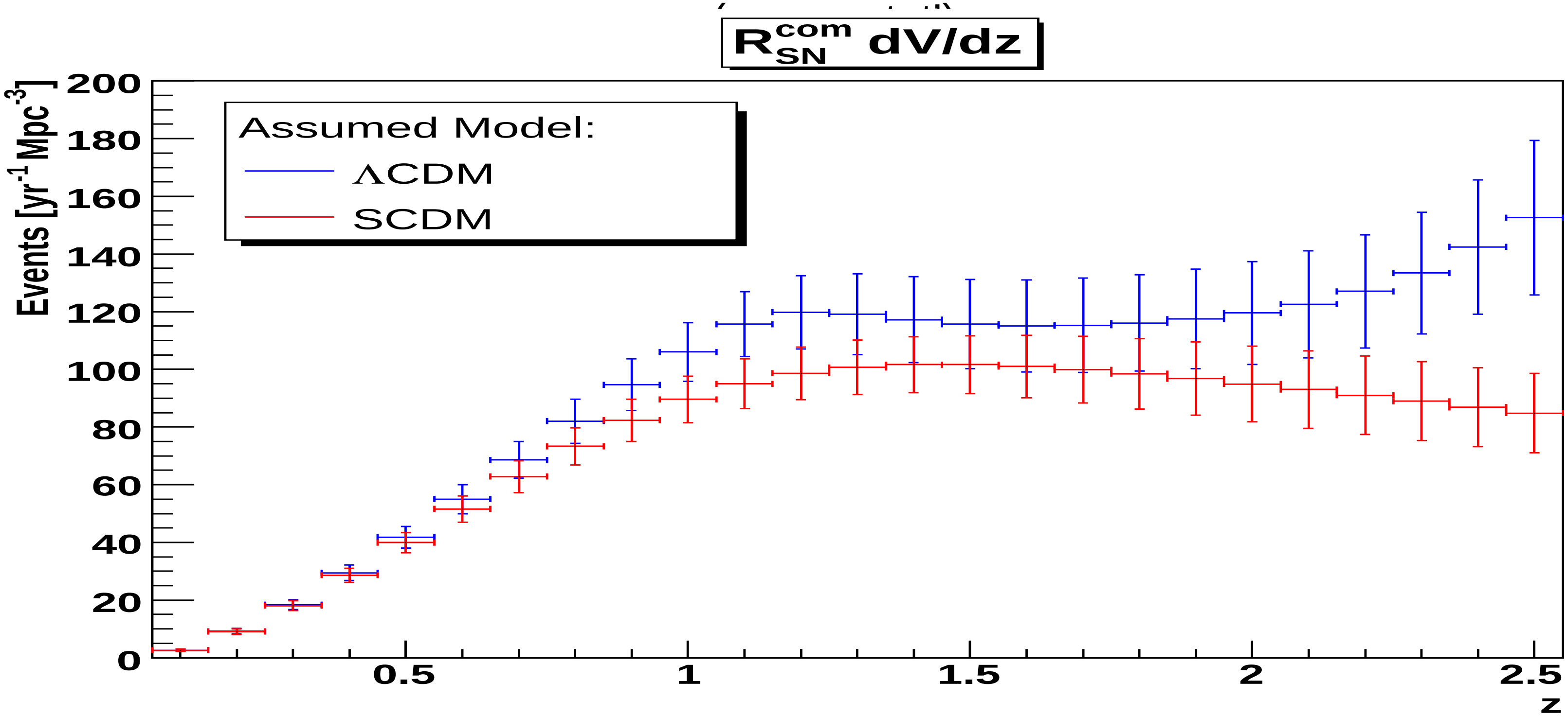
High dust, 4 days int' (mag. 27).



$R_{\rm SN}^{\rm co}$ from measured rate

$$\frac{R_{\rm SN}}{\epsilon(z, d_L, \ldots)} = R_{\rm SN}^{\rm co} \frac{dV(\Omega_M, \Lambda, z)}{dz} \sim \mathcal{O}(3000) \text{ SNe!}$$

ΛCDM ($\Omega_M = 0.3, \Lambda = 0.7$), SCDM ($\Omega_M = 1, \Lambda = 0$), for **median** $R_{\rm SN}^{\rm co}$

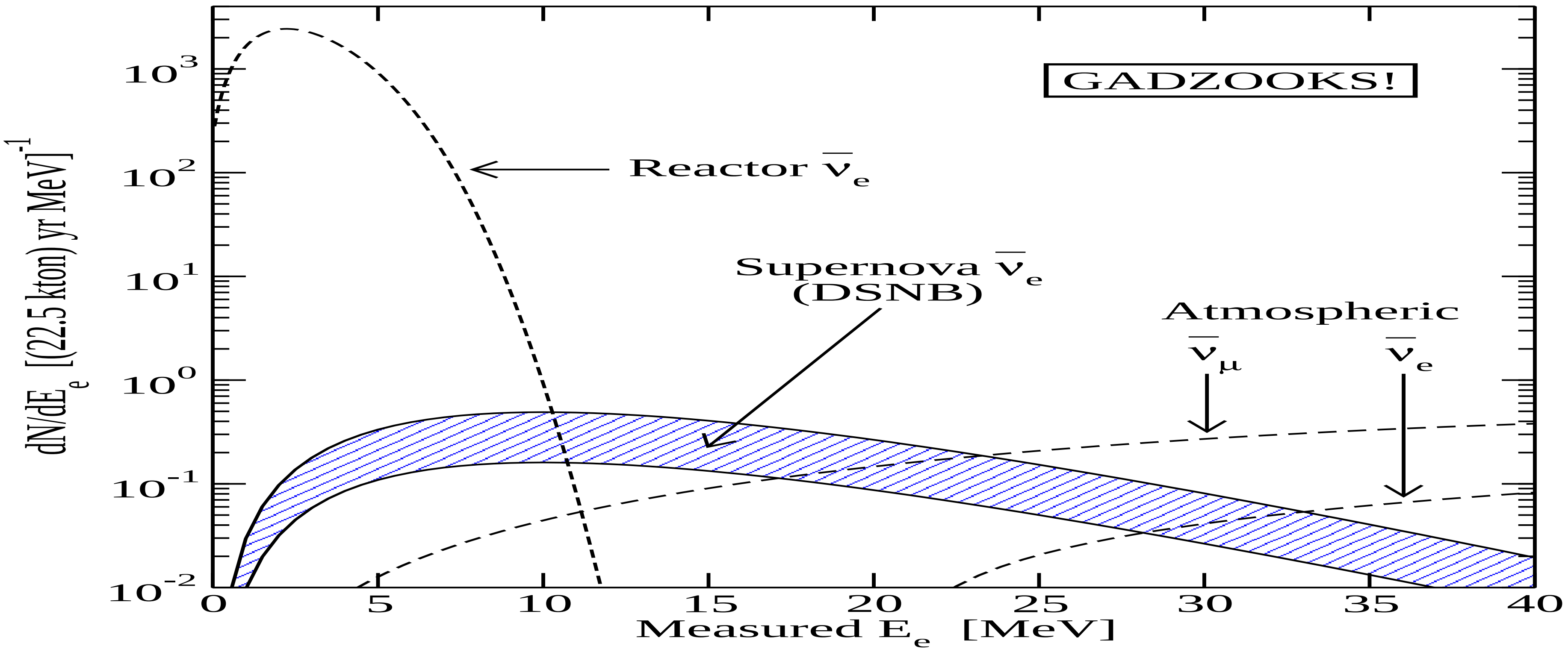


RSN & ν Observatories

Future exp': MT GADZOOKS

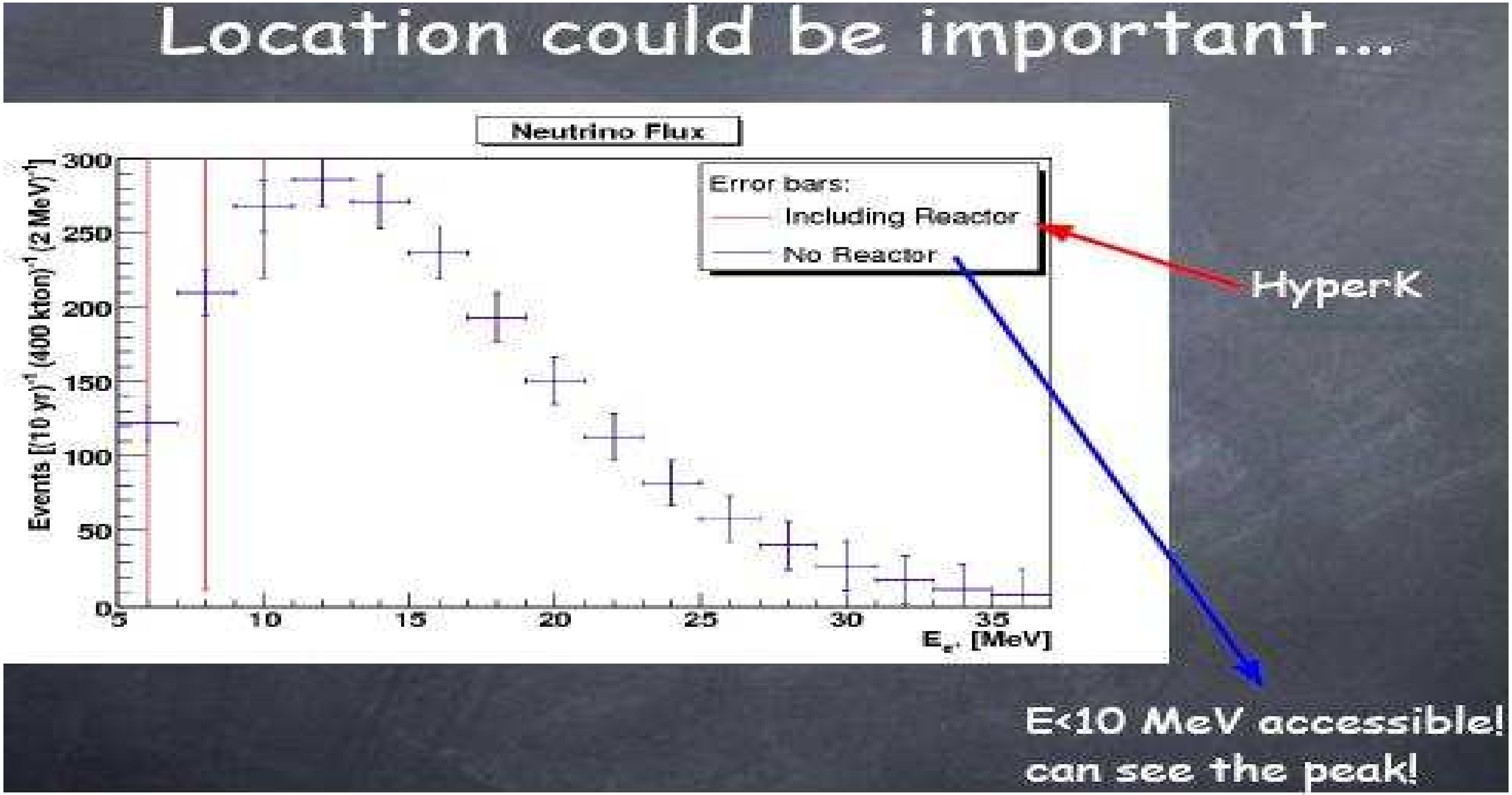
MT water + $GdCl_3 \Rightarrow \frac{100\bar{\nu}_e}{\text{year}}$, $E \gtrsim 10$MeV.

$\bar{\nu}_e + p \longrightarrow e^+ + n$ (GADZOOKS Beacom & Vagins)



Uncer’: ν diff’ event rate

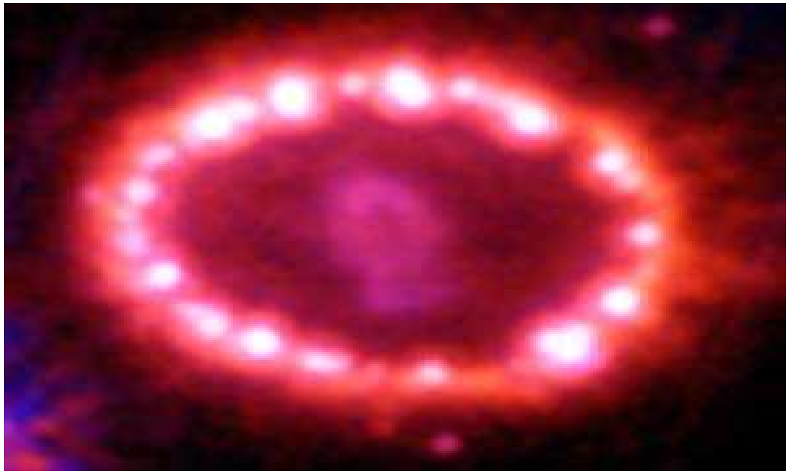
MT Cerenkov + $GdCl_3$



SN & ν flux

ν ν

ν ν



ν ν

ν ν

SN & ν flux

Roughly, $\Phi^{\nu} \leftrightarrow$ grav'+nucl'+thermo'.

$$\Downarrow$$

ν spheres, thermal spectrum: $\frac{dN^{\nu}}{d\epsilon} \propto \frac{10^{53}\mathrm{erg}}{e^{\frac{\epsilon}{T_{\nu}}}+1}$.

Hier' spectrum $T_{\nu_e} < T_{\bar{\nu}_e} < T_{\nu_x} = T_{\bar{\nu}_x}$

Various corrections & systematics:

$\circledast$ MSW $\surd$ $\circledast$ Spectral distort' $\surd$ $\circledast$ Progenitor dep' $\surd$

$\circledast$ Shock wave $\times$ $\circledast$ Nonlinear evol' $\times$.

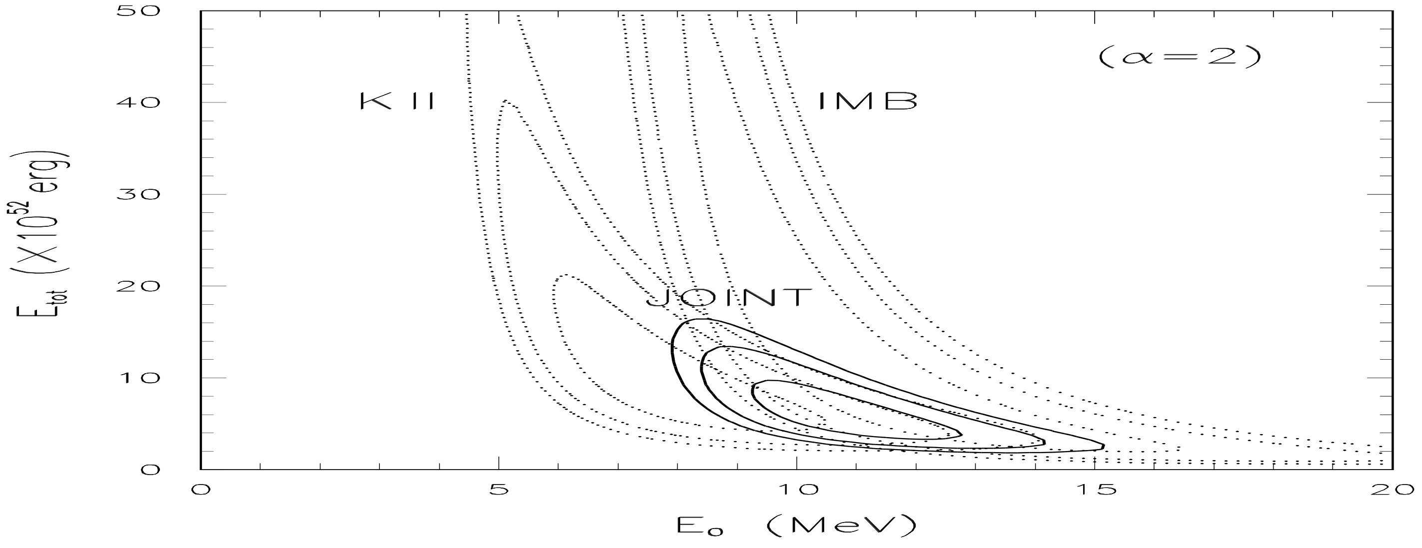
Spectral Distortion

(Keil, Raffelt & Janka.)

Elast' scatt' + NC $\Rightarrow$ pinch + mean E
+ luminous' distor', β_{ν^i}, $\bar{E}_{\nu^i}$, L_{ν^i}:

$$\frac{dN^{\nu^i}}{d\epsilon} \propto L_{\nu^i} \frac{\epsilon}{\bar{E}_{\nu^i}} \exp\left[-(1+\beta_{\nu^i})\frac{\epsilon}{\bar{E}_{\nu^i}}\right] .$$

Data - SN 1987a $\Rightarrow$ β_ν, $\bar{E}_\nu$, L_ν . (Mirizzi & Raffelt; Lunardini)



Projected uncer'

Future measur' improve the errors.

Progenitor dep' is 25%. (Takahashi, *et. al.*; Buras, *et. al.*)

Matter effects accom' (as long as spec' is known).

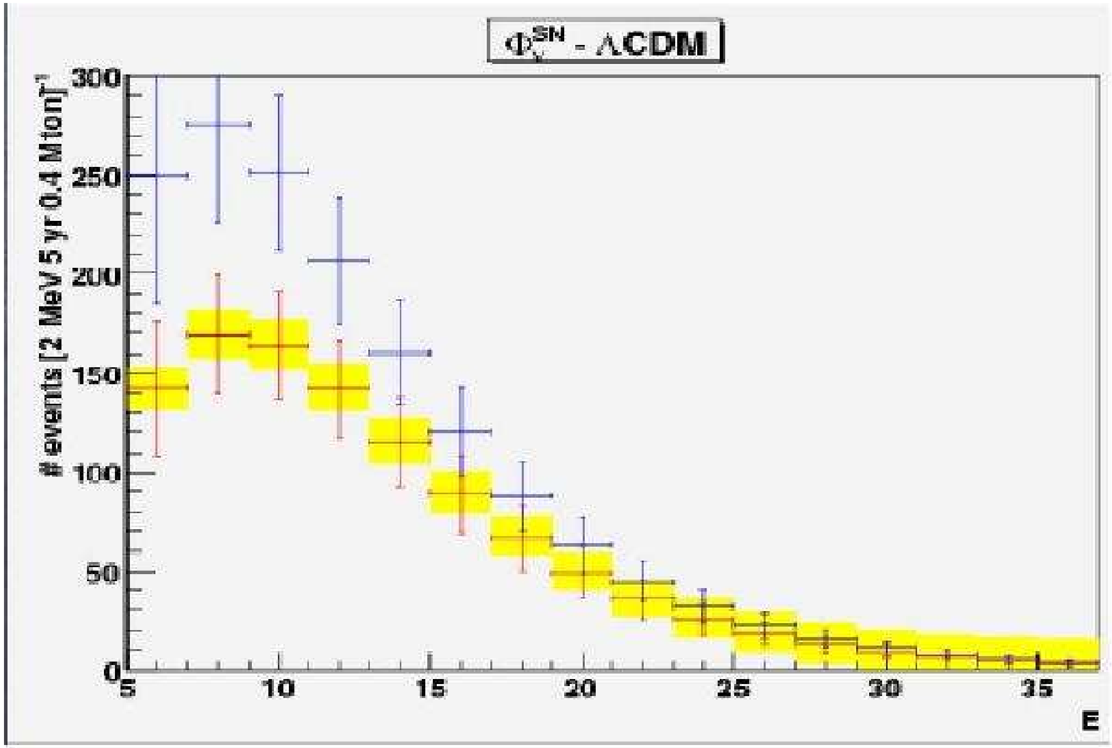
Use $\beta_\nu = 3 \pm 0.25,\ \frac{\bar{E}_\nu}{\mathrm{MeV}} = 12.2 \pm 1.4,\ \frac{L_\nu}{10^{52}\mathrm{erg}} = 5.5 \pm 0.75$

Combine observation Φ^{ν} + R_{SN}

- Modest goal: ΛCDM vs SCDM;
  Or w $= -1$ vs. w $= 0$.
- For each case gen' mock pull.
- Marginalize over neutrino para'.
- Compute χ^2 ...

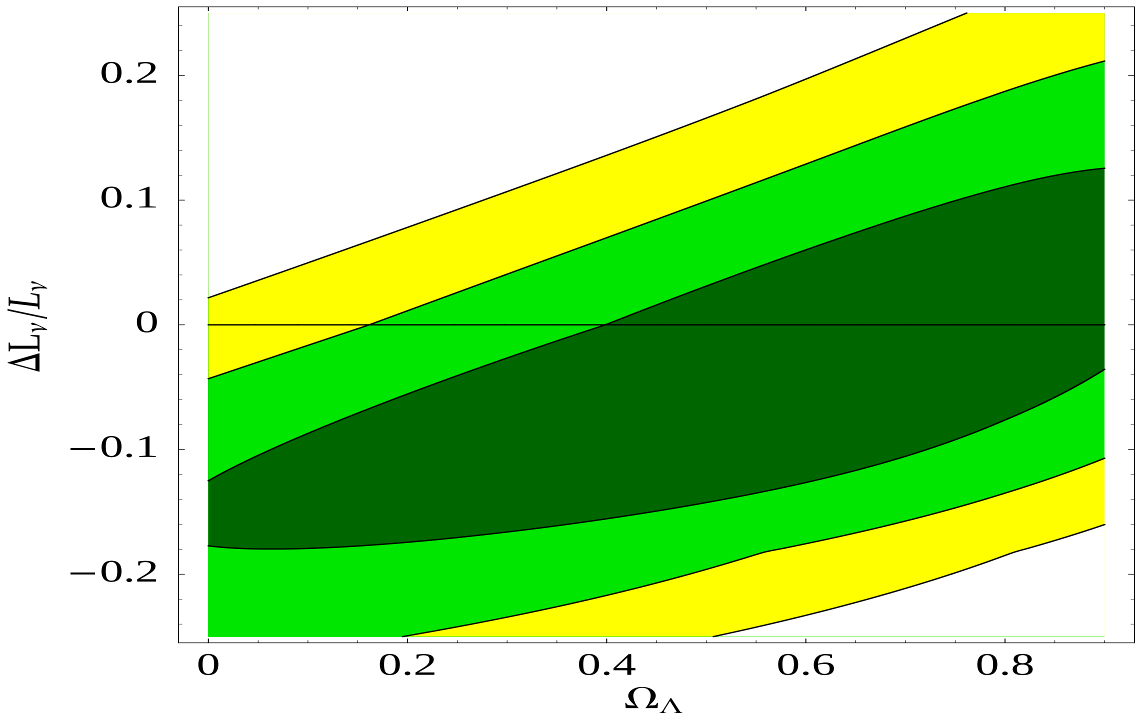
Combine observation Φ^{ν} + R_{SN}

Only statistical errors assumed (+SNOC)



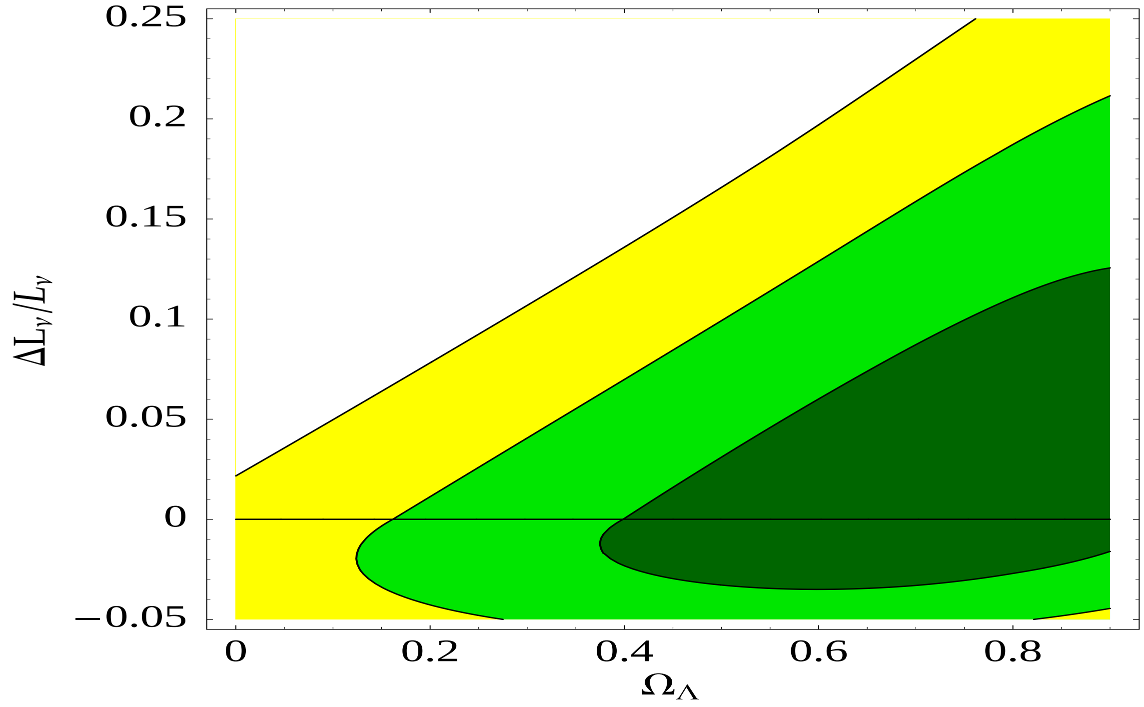
Marginalizing over $\bar{E}_\nu, \beta_\nu$

Flat direction in L_ν



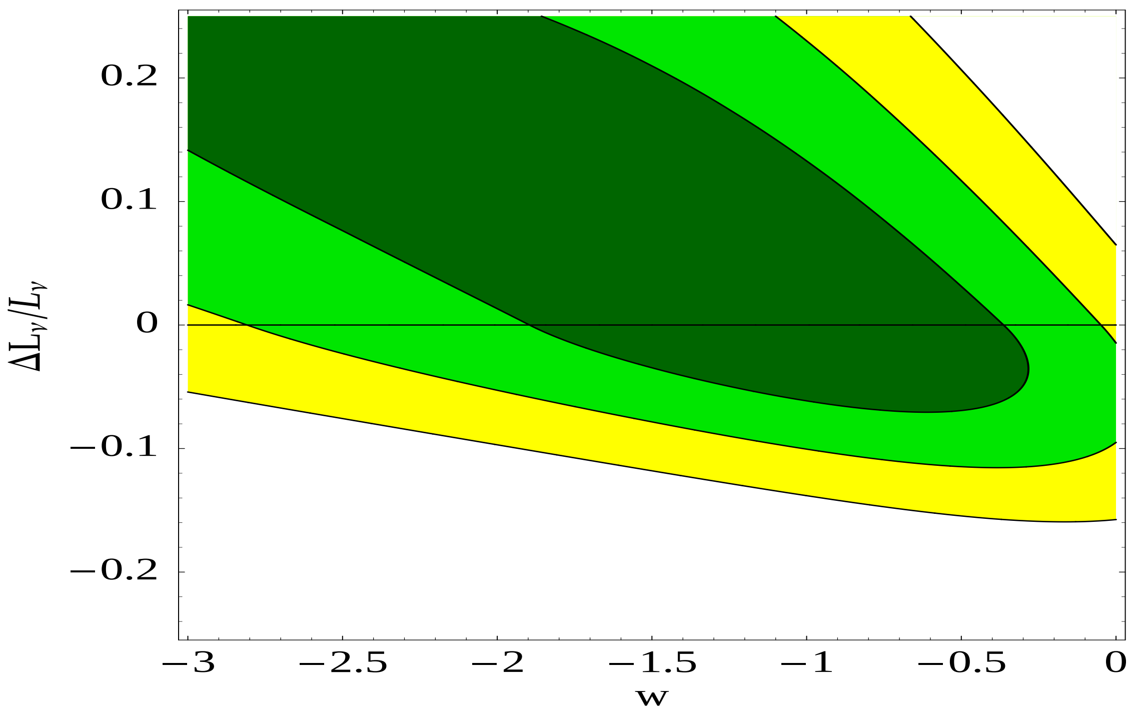
Salpeter function helps

Large prog' $\Rightarrow$ large L_ν



w vs. L_ν

For $\Omega_\Lambda \sim 0.3$



Conclusions

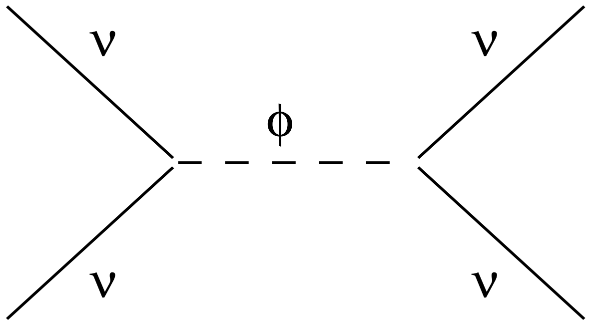
- Future ν data carry cosm' info' (CC SNe "standard" candles).
- Univ' with νs “looks” diff' from γs?

  [MaVaNs $\&$ ultra light PGB ν]
- No dedicated exp' ($GdCl_3$ required)!
- See ex.: late ν masses (Goldberg, GP & Sarcevic).

Main Idea

Step I - Resonance

- ϕ Burst!



- UV Supernova ν + CMB $\nu \Longrightarrow \phi$.
- $\phi \Longrightarrow \nu\,\nu$.
- $E_\nu^{\rm final} \sim 0 - E_\nu^{\rm SN}$.

Step II - Accumulative Resonance

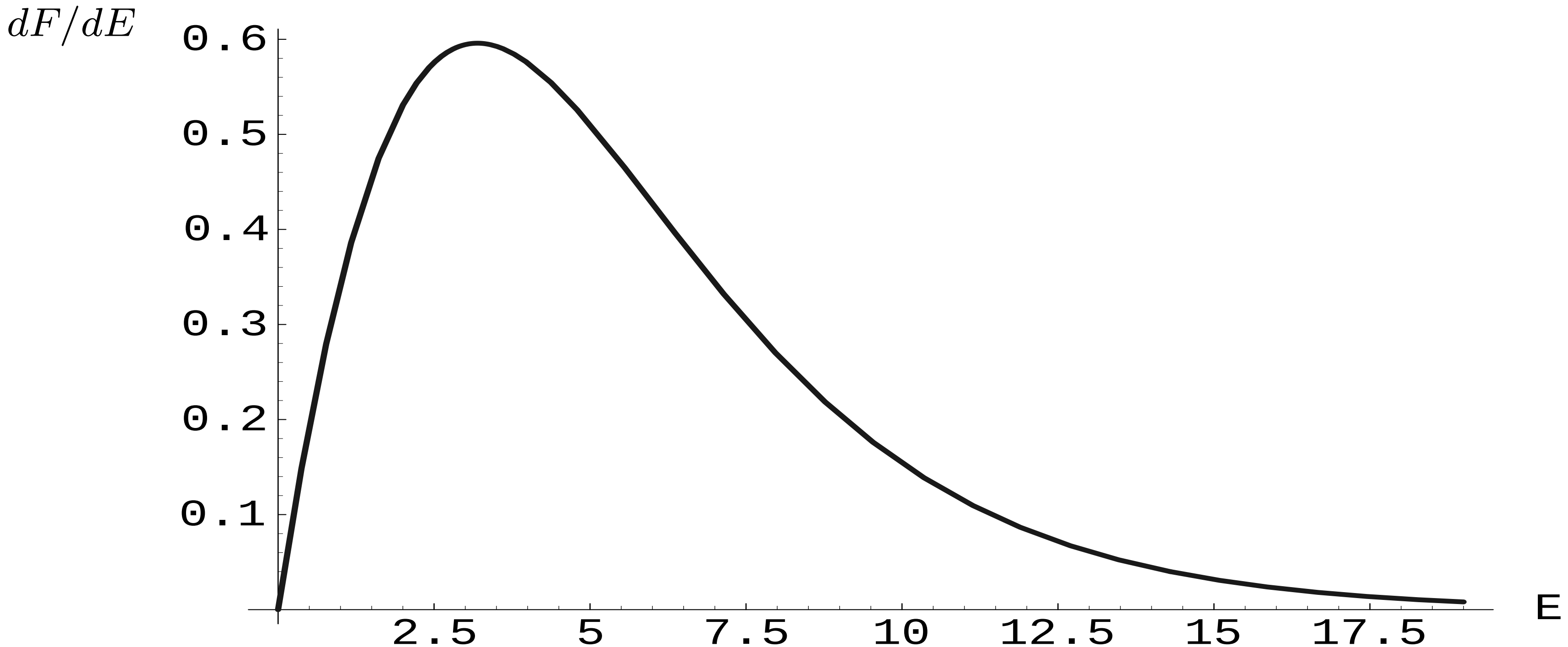
- SN ν comes from far away, $z \lesssim 3$.
- Expansion $\Rightarrow$ shift ; ${E_\nu}^{\rm Obs} \sim \frac{{E_\nu}^{\rm SN}}{(1+z)}$.
- $\sqrt{\frac{{m_\phi}^2}{2m_\nu}} \lesssim {E_\nu}^{\rm SN} \lesssim \sqrt{\frac{{m_\phi}^2}{2m_\nu}}(1+z) \Leftrightarrow$ Reson'.

$$\Downarrow$$

Accumulative Resonance !!

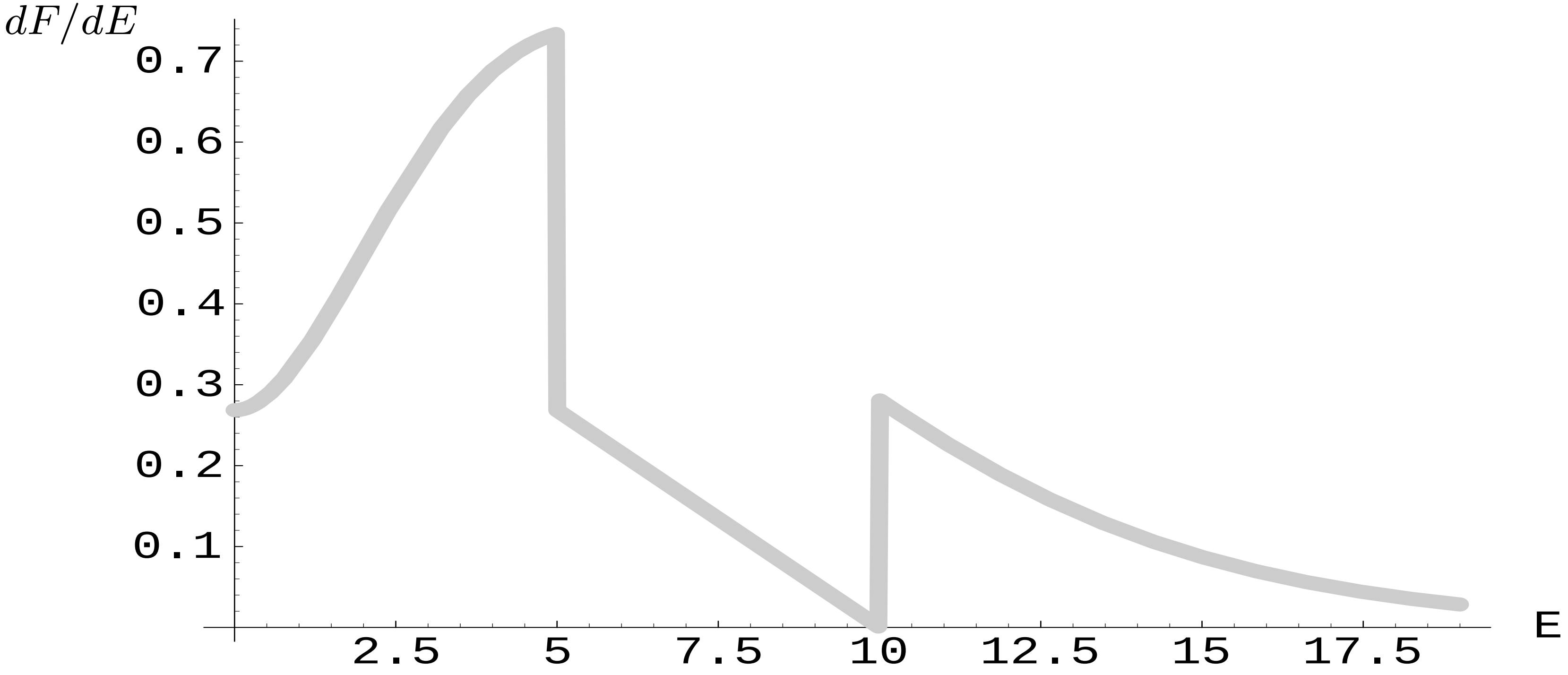
No Resonance

$$z^{\mathrm{SN}} = 2\,.$$



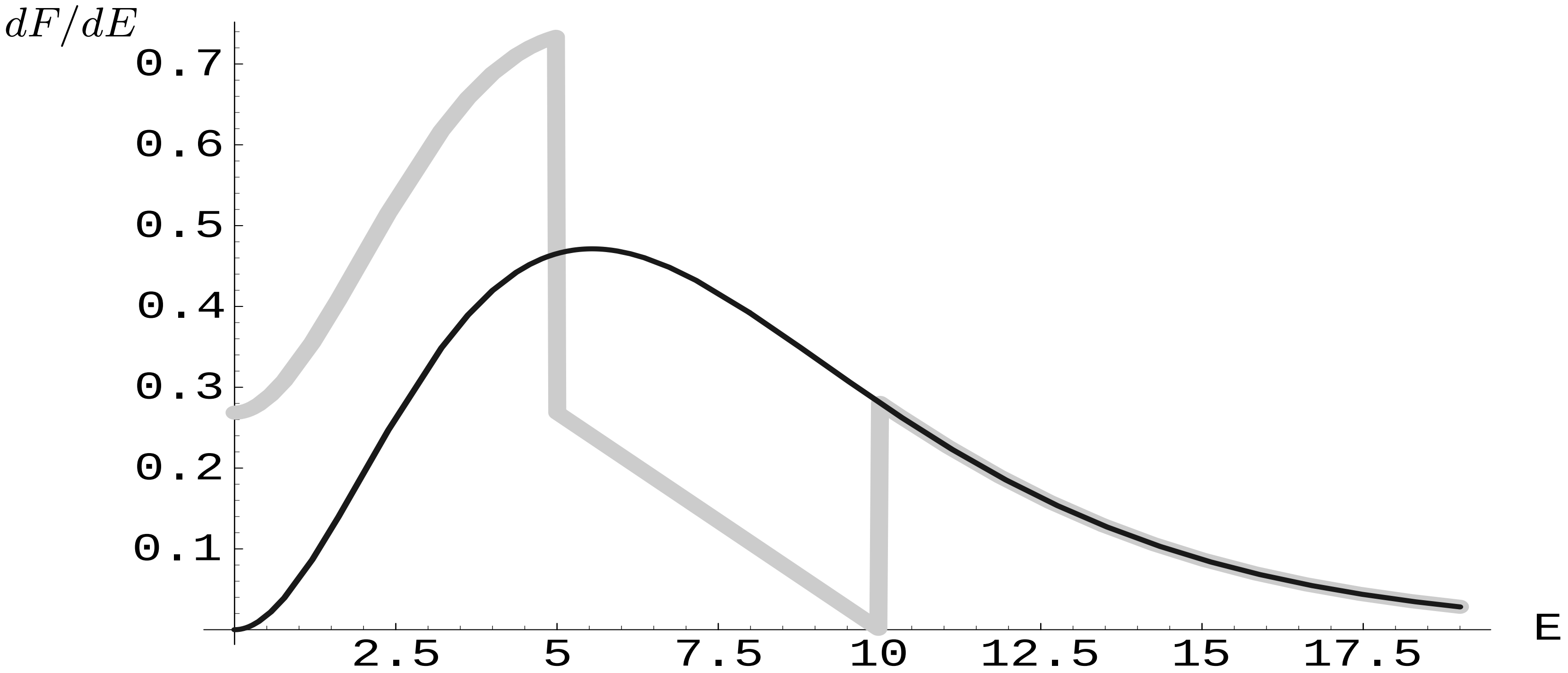
Accumulative Resonance

$$m_\phi \simeq 1\,\text{KeV}\,, \quad z^{\rm SN} = 2\,.$$



Comparison

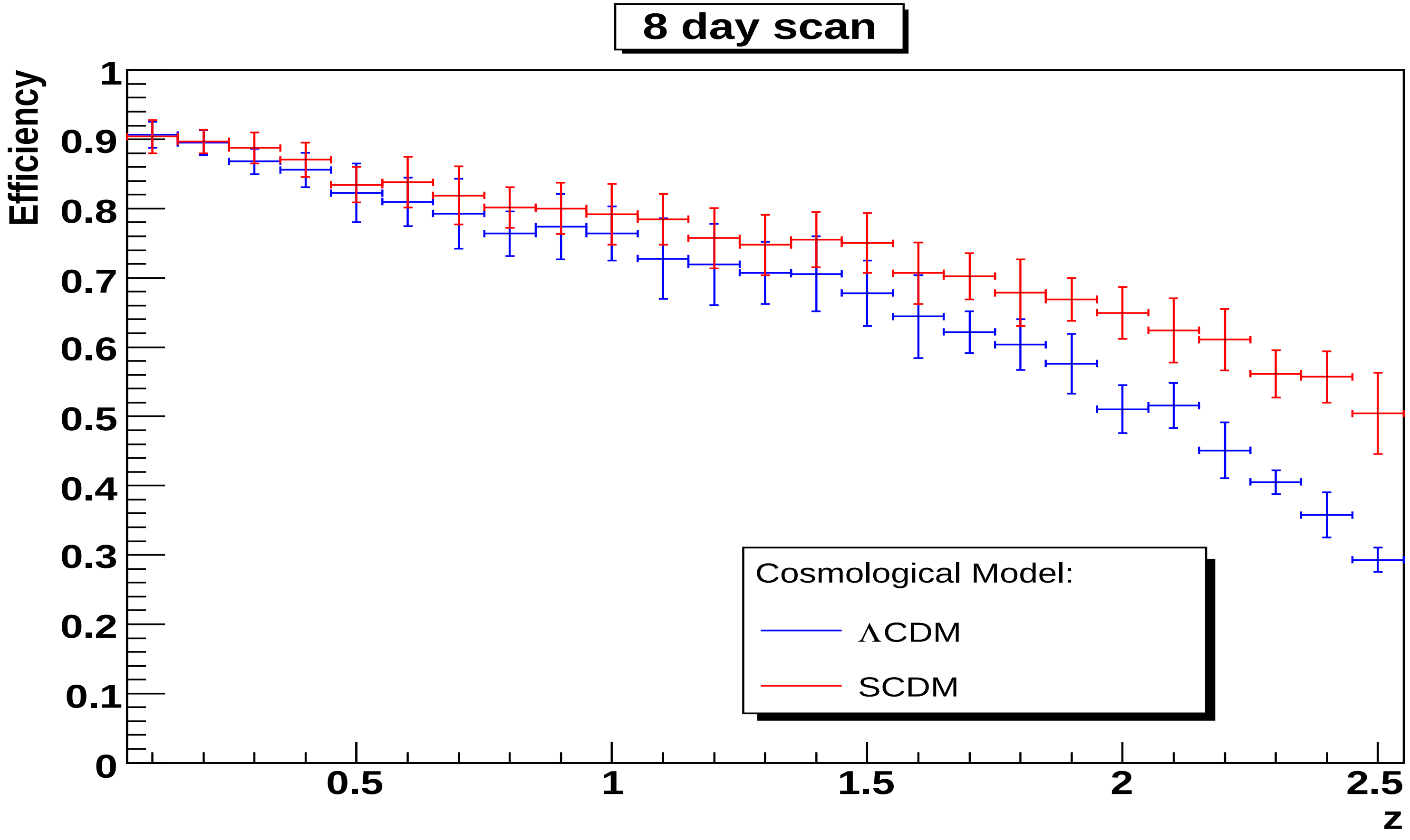
$m_\phi \simeq 1$ KeV , $z^{\rm SN} = 2$; z indep' dip!



Backups

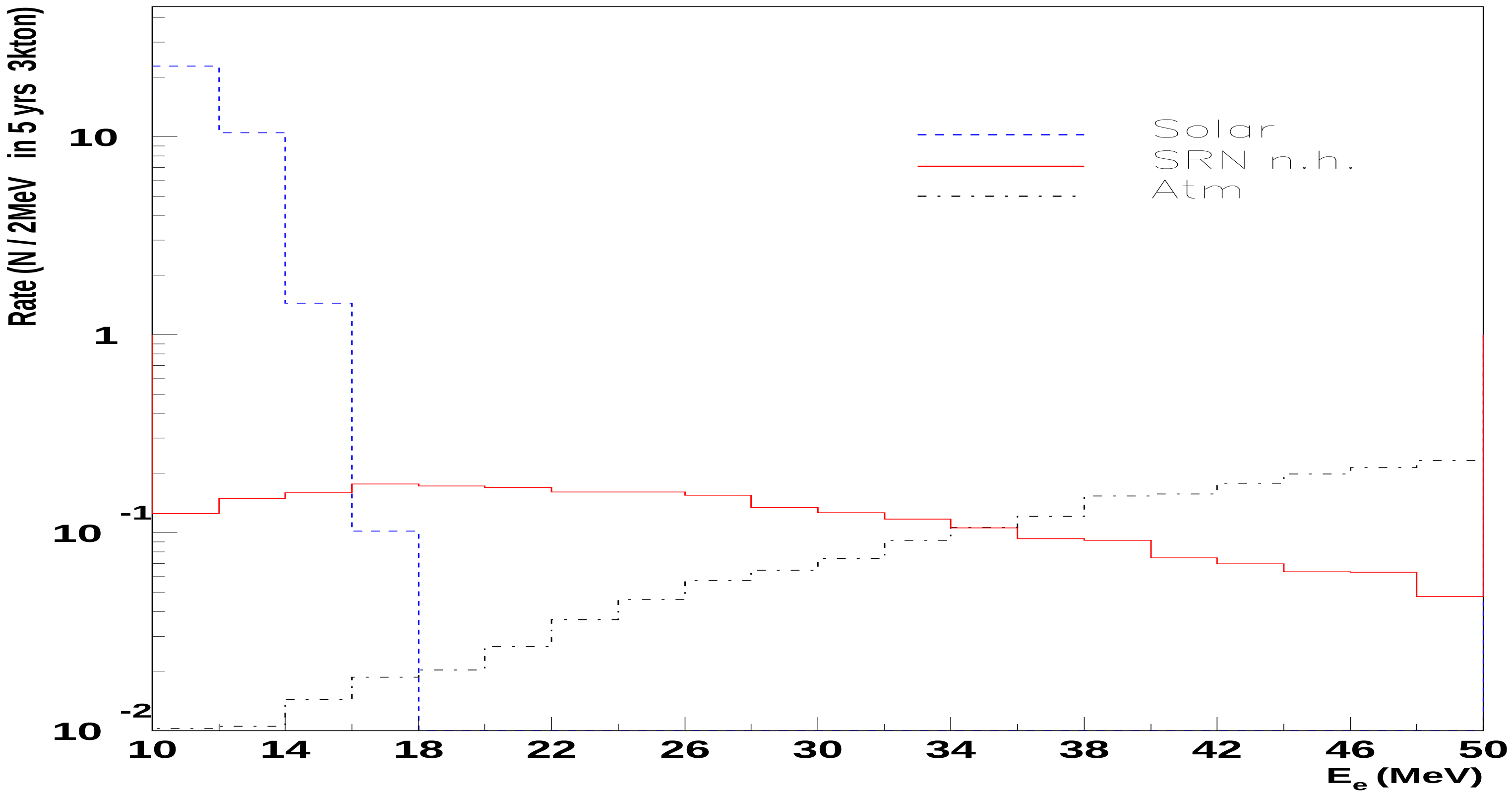
Efficiency type IIx

High dust, 8 days int' (mag. 30).



Future exp': 100KT ALD

ALD (Cline *et. al*) $\Rightarrow \frac{10\nu_e}{\text{year}}$, $E \gtrsim 14$ MeV (Cocco *el. al*).



(Cocco *el. al*)

Matter effect & Inv' Hier

(Lunardini & Smirnov; Dighe & Smirnov.)

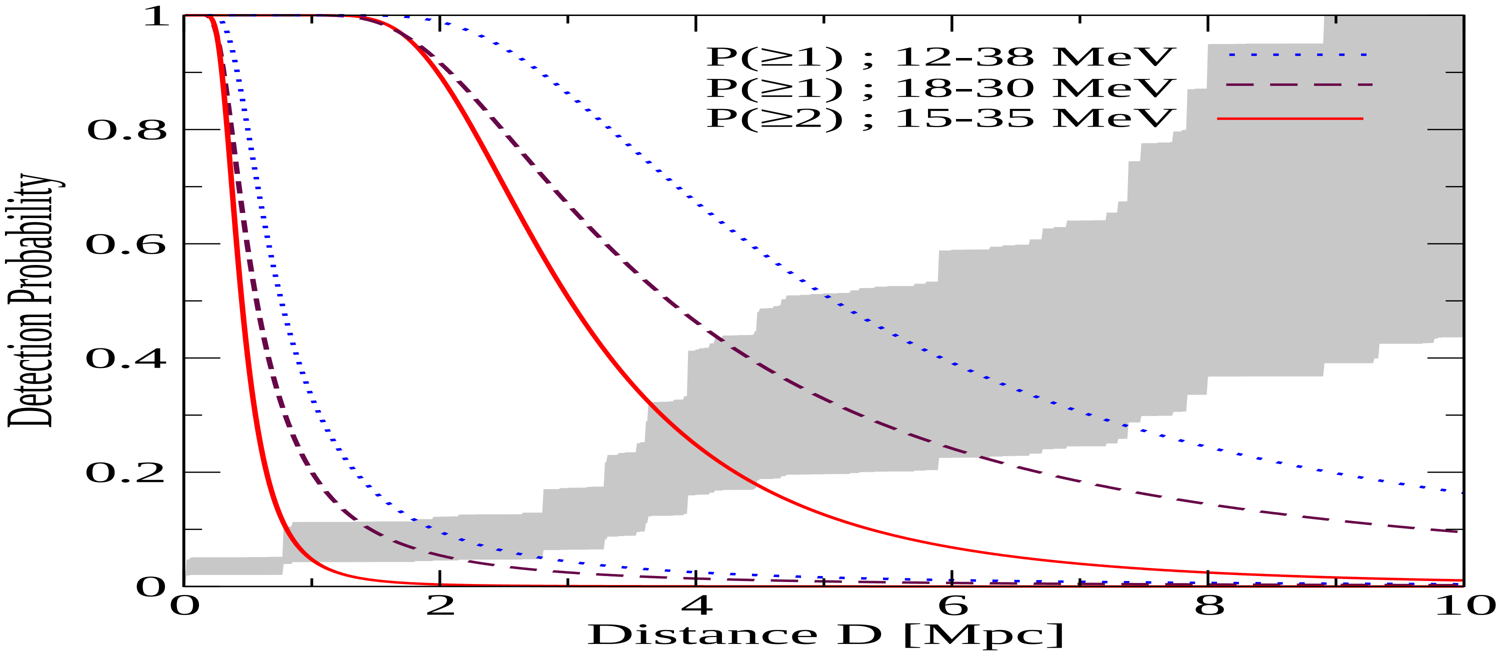
- 2$\times$MSW $\Leftrightarrow$ Outer layers propagation.
- Spectrum is modified.
- Inv' hier' $\theta_{13} \gtrsim .1\%$ $\bar{\nu}_e \leftrightarrow \bar{\nu}_x$.

	mass hierarchy	θ_{13}	$P(\nu_e \to \nu_e)$	$P(\bar{\nu}_e \to \bar{\nu}_e)$
I	normal	large	$\sin^2\theta_{13}$	$\cos^2\theta_{12}$
II	inverted	large	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$
III	normal/inverted	small	$\sin^2\theta_{12}$	$\cos^2\theta_{12}$

More data in future

(Ando, Beacom & Yüksel.)

- MT det’ $\longrightarrow$ direct burst upto 10Mpc.
- Coin’ 2events + corr’ with optical.
- Rate $\gtrsim$ 10/10years or 10^5 for local.



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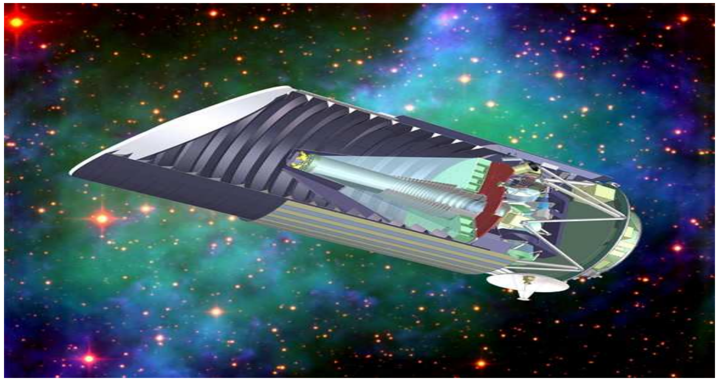
Probing Dark Energy via ν Detectors



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