IAP Supernova Workshop, June/July 2010

Physics potential of supernova neutrino and gamma ray detection

with John F. Beacom (CCAPP, Ohio State) and Eli Dwek (NASA Goddard)
SH, Beacom & Dwek PRD 79, 083013 (2009)
SH & Beacom, arXiv:1006.5751

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Probing SNe: γ-rays and ν

- **Model:** thermonuclear and core-collapse SNe
- **Prediction:** produce nuclear γ-ray and thermal ν
- **Testability:** γ-ray satellites, underground ν detectors
- **Implications:** Confirmation/surprises

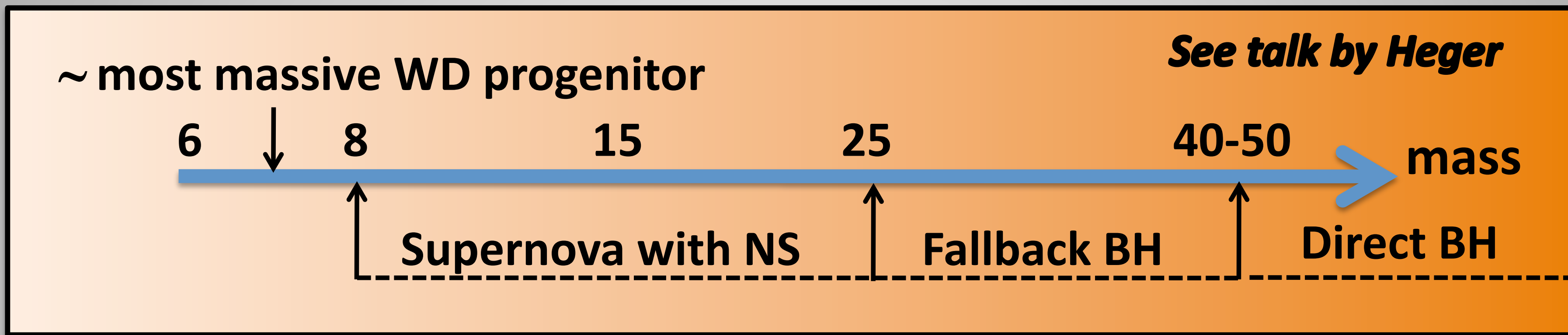
The aim is to fill this table:

distance

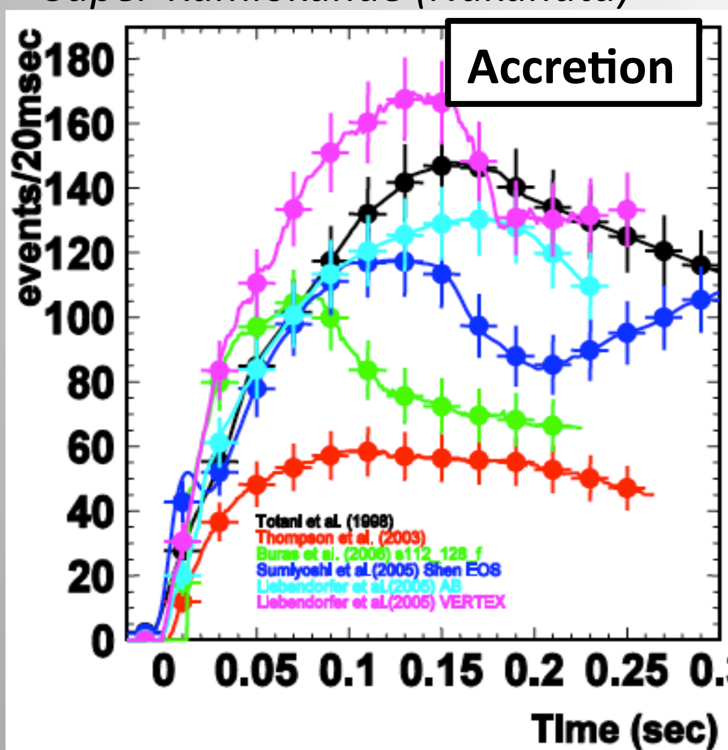
SN location	SNIa gamma rays	Core collapse neutrinos
Milky Way		
Local: few Mpc		
Local: > 10 Mpc		
Cosmic		

Neutrinos

Core-collapse ν



Super-Kamiokande (Nakahata)



- **Progenitors:** up to and including fallback BH, i.e, approx. 8 – 40 Msol
- **Galactic SNe ν detection**
  - Excellent statistics (~10^4 events)
  - Directional, energy, timing
  - Reveals core temperature
- **But rare:** few per century (in MW)

To a higher rate…

- **Core-collapse in nearby galaxies: not feasible with current neutrino telescopes (~1 event from Andromeda); task for next-generation detectors** *[e.g. Ando et al. (2005), Kistler et al. (2008)]*
- **Neutrinos from all past core collapse:** emission is averaged, no timing or direction information, **but signal is always there**
  - *[e.g., Bisnovatyi-Kogan & Seidov (1982), Ando & Sato (2005), Beacom (2010)]*

Diffuse supernova neutrino background (DSNB)

$$\psi\left(E_{e^+}\right) = c\,\sigma\left(E_\nu\right)N_t \int R_{CCSN}(z)\,\frac{dN\left(E_\nu'\right)}{dE'}(1+z)\frac{dt}{dz}\,dz$$

Detector properties — SNe rate — Emission per supernova

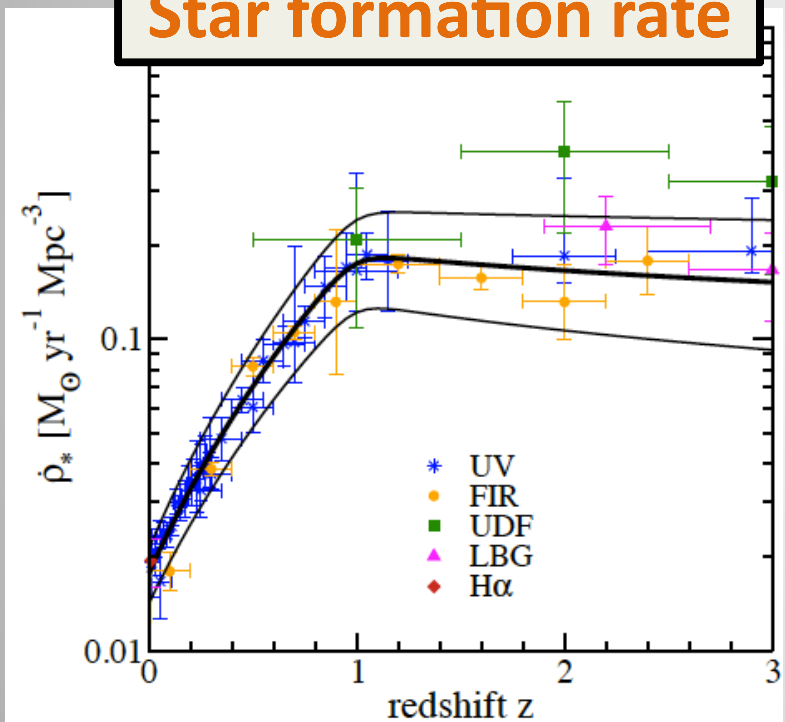
Need to know (SNe rate)

Want to study (Emission per supernova)

Predicting the DSNB

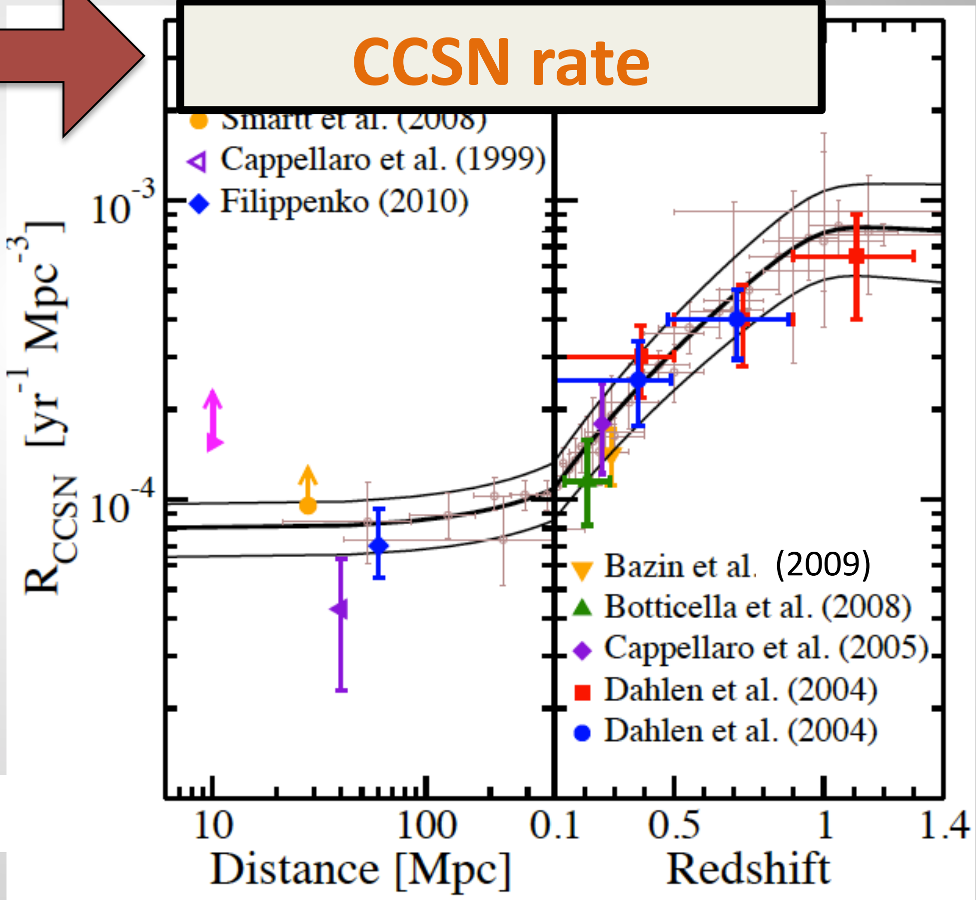
- **We have a good handle on the core-collapse supernova rate**

Star formation rate

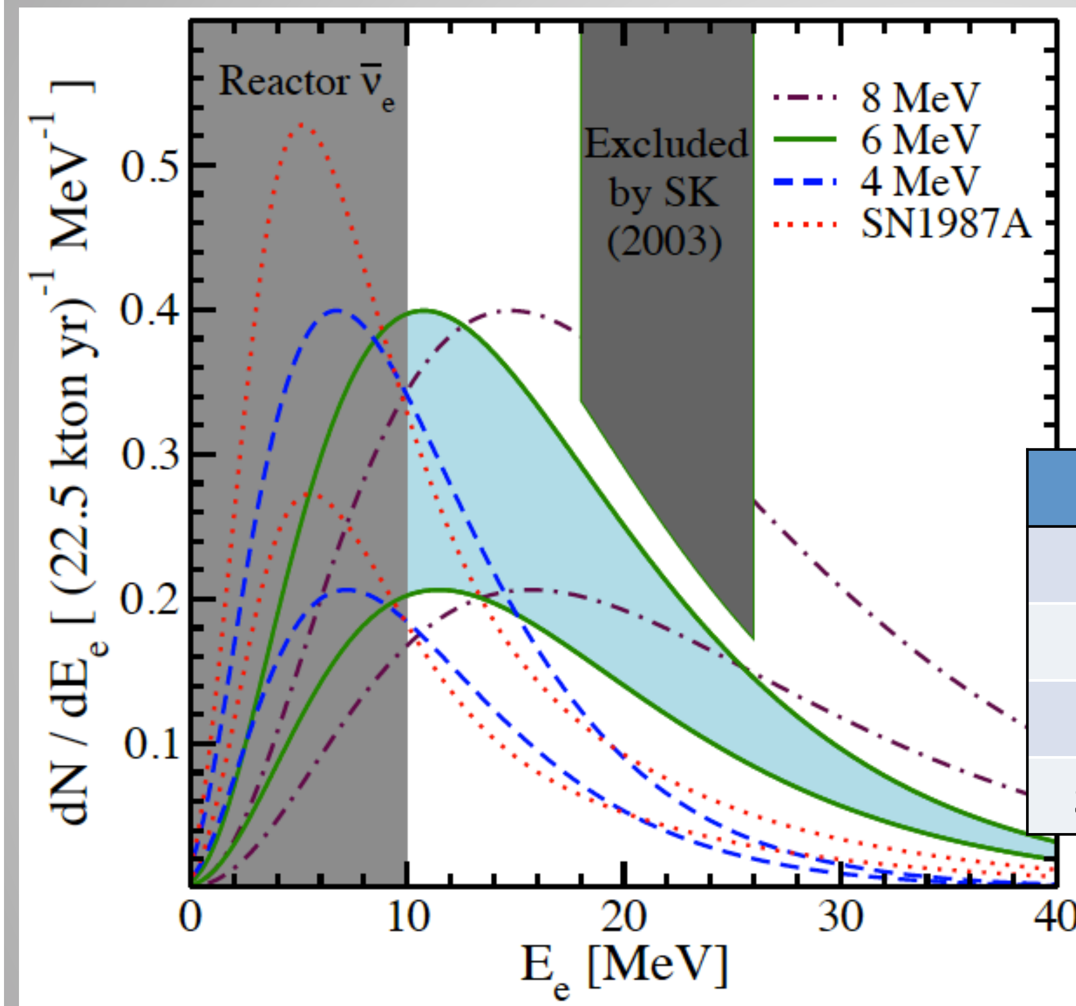


[Horiuchi et al (2009)]

CCSN rate



DSNB limits and implications



[Horiuchi et al (2009)]

- **Super-Kamiokande SK-I limit** *[Malek et al. (2003)]*
- **Upgrading Super-K (doping with Gd) to reduce backgrounds in progress (PI: Vagins)**
- **Event rate: per year, at Super-K:**

Spectra	Current SK	Upgraded SK
8 MeV	1 – 3	3 – 5
6 MeV	1 – 2	2– 4
4 MeV	0.4	1 – 2
SN 1987A	0.5	1 – 2

- **The neutrino spectrum can be measured using data over several years**

Where to look

Distance	SN Ia gamma rays	Core collapse neutrinos
Milky Way		Rare and waiting
Local: few Mpc		Next-generation
Local: > 10 Mpc		Future
Cosmic		POSSIBLE VERY SOON

Gamma rays

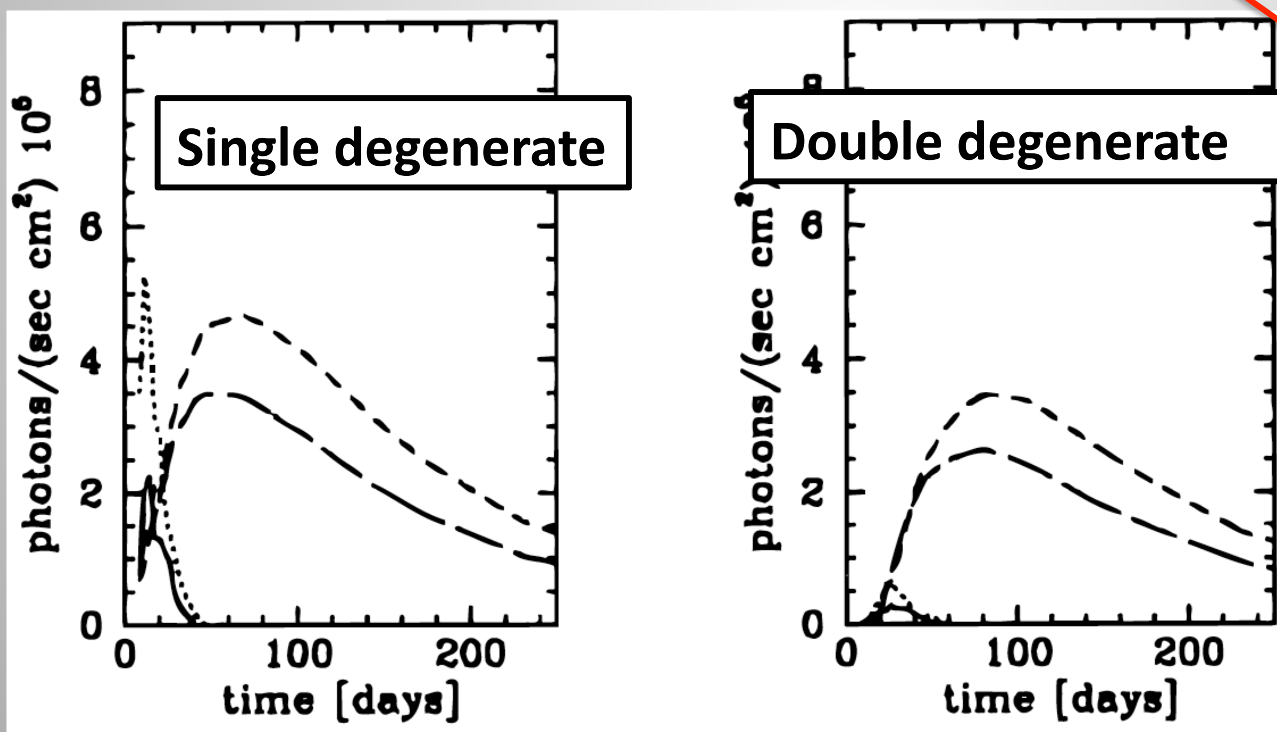
Type Ia supernova gamma rays

- **Progenitors:** approx. 2 – 8 Msol binaries
- **Physics:** nuclear MeV gamma rays from Ni and Co decays
  - Initially trapped (→ powers optical LC)
  - Eventually escape (50% by ~40 days)
- **Rate:** SNIa are rare

Burning location

Tomography

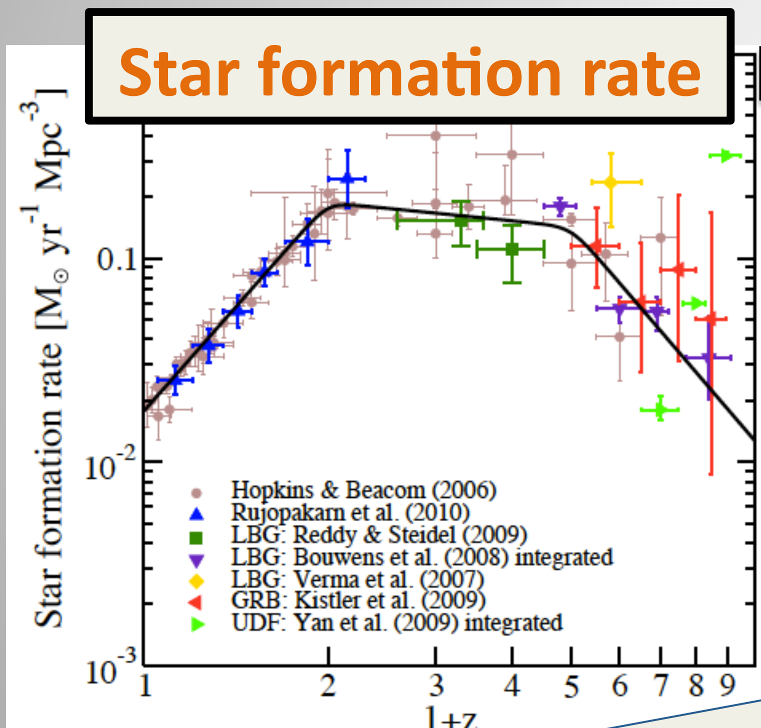
Total Ni mass

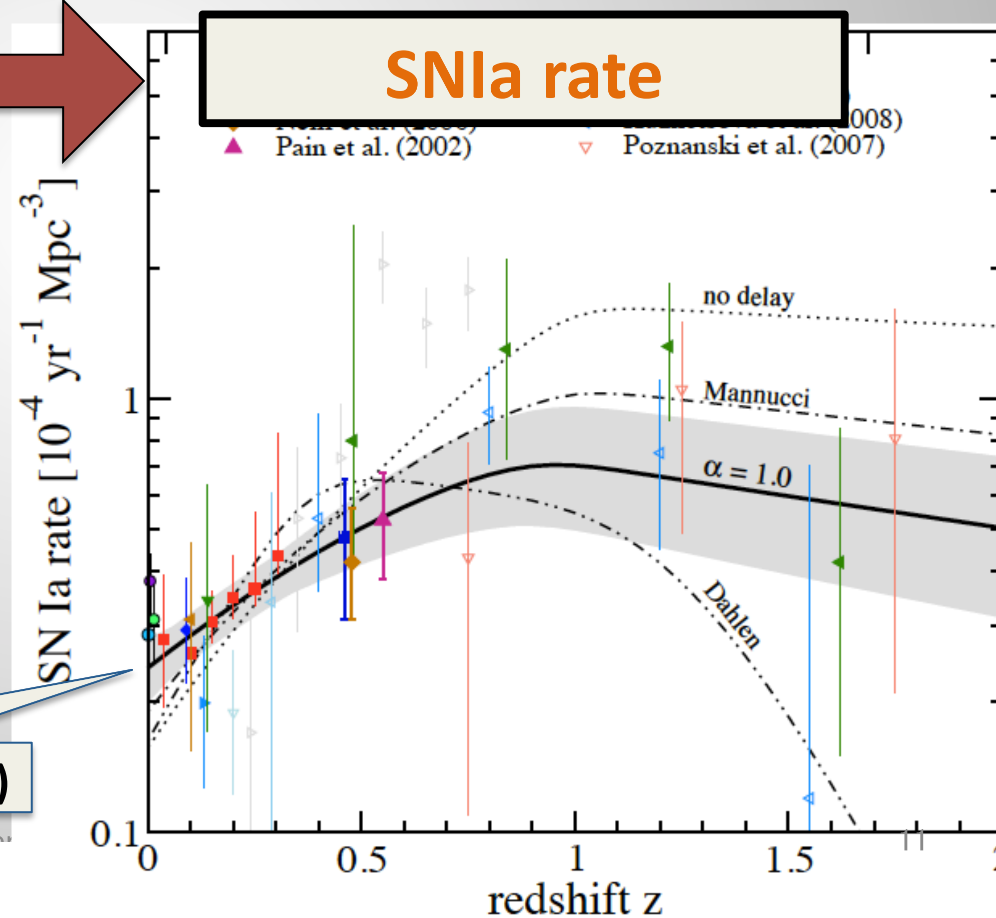


Hoeflich (1998)

To a higher rate…cosmic SNIa rate

- **Compare the SNIa progenitor birth rate ←→ SNIa rate**
  fit the delay-time distribution $\propto t^{-\alpha}$ **and the SNIa efficiency**
- **we find** $\alpha = 1.0 \pm 0.3$ **and normalization as shown:**





Slightly lower than Li et al. (2010)

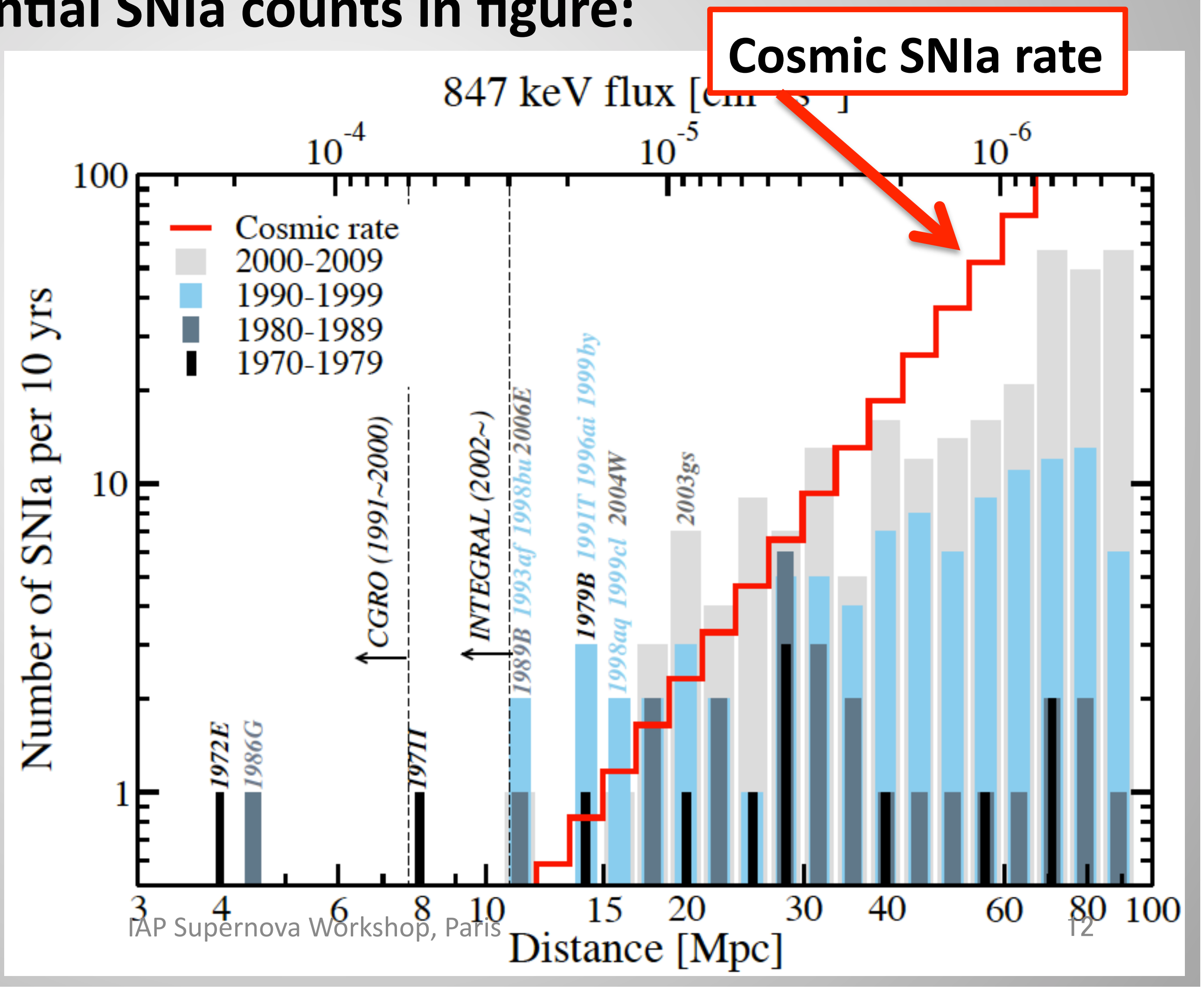
[Horiuchi & Beacom (2010)]

Detection prospects

- **Cosmic SNIa: background contribution is small** *[e.g. Strigari et al. (2005), Horiuchi & Beacom (2010)]*
- **Local SNIa: differential SNIa counts in figure:**

Cumulative within 100 Mpc: expect ~1000 SNIa per decade.
But discovered:
20 per decade (1987)
55 per decade (1996)
400 per decade (2009)
Becoming more complete!

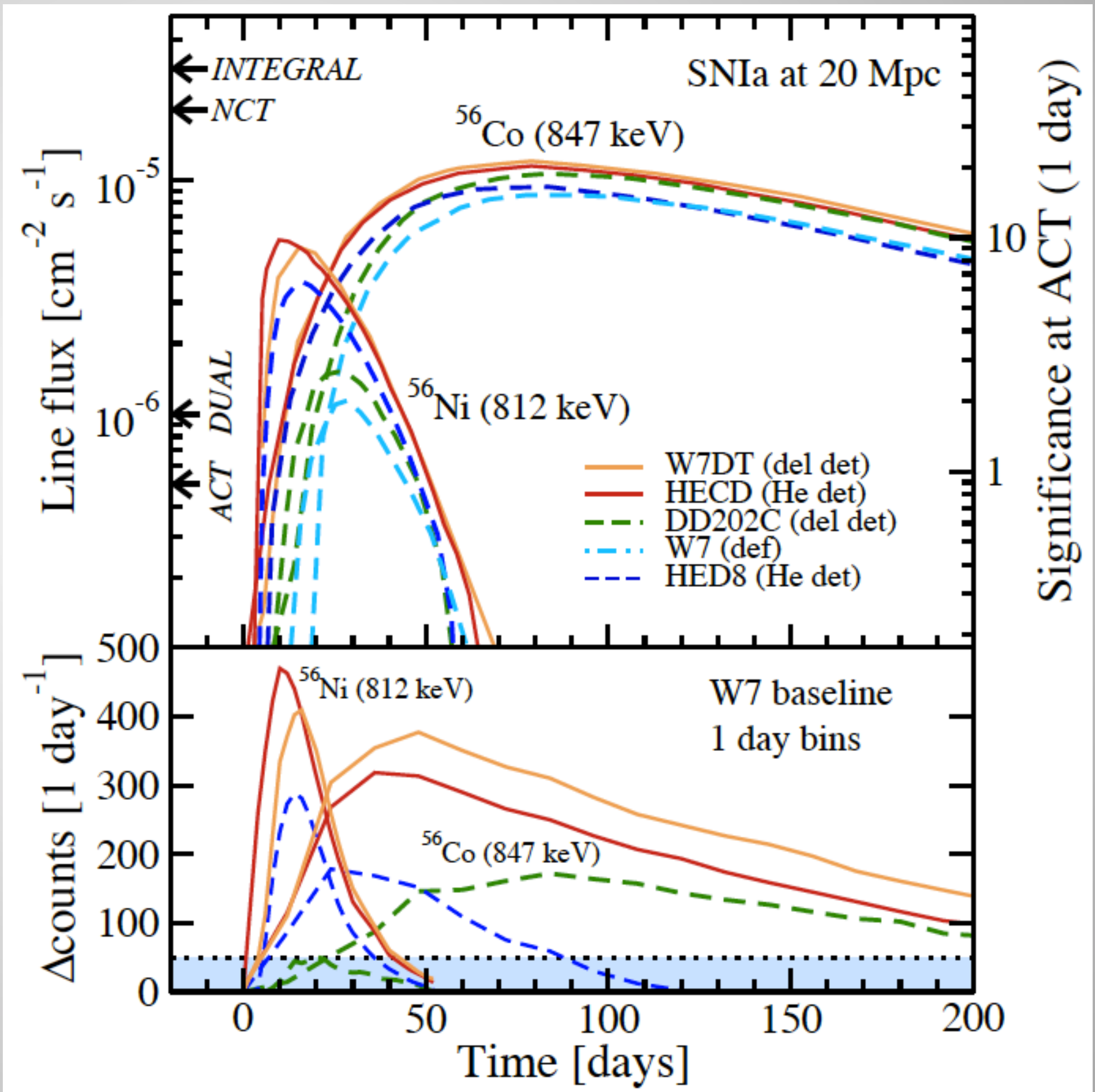
Gehrels et al (1987)
Timmes & Woosley (1996)
Horiuchi & Beacom (2010)



Physics potential

[Horiuchi & Beacom (2010)]

- **1 SNIa per year by increasing INTEGRAL sensitivity by ~ 3**
- **With the Advanced Compton Telescope, *~100 SNIa per year***
- **Next-generation γ-ray detector would give revolutionary discrimination power:**
  - **single or double degenerate?**
  - **Deflagration or detonation?**



Conclusions

Distance	SN Ia gamma rays	Core collapse neutrinos
Milky Way	Too rare	Rare and waiting
Local: few Mpc	Rare and waiting	Next-generation
Local: > 10 Mpc	EXCITING PROSPECTS	Future
Cosmic	Large background	POSSIBLE VERY SOON

- **Neutrinos: the DSNB will measure the *averaged* neutrino spectrum, revealing *averaged* core temperatures, including progenitors from NS to BH forming stars**
- **Gamma rays: satellites will measure annual gamma-ray light curves, revealing Ni production and tomography of the expanding ejecta, including SD and DD discrimination**