Future Space-based Gamma-ray Observatories, Feb 5-6th 2015

Detectability of nuclear gamma-ray lines from nearby and distant supernovae

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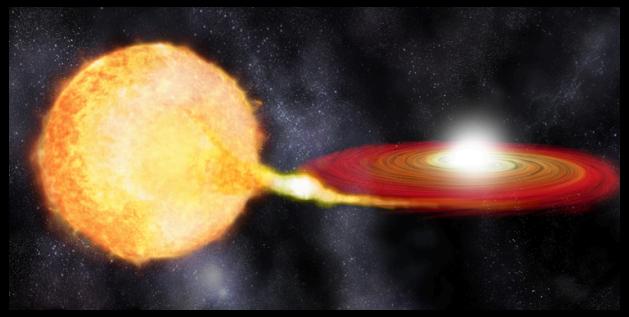
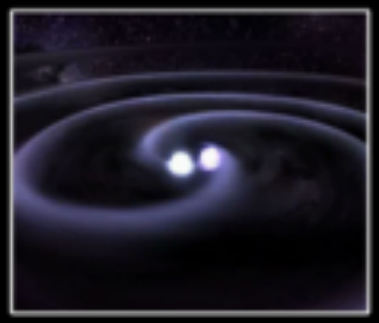
Image credit: NASA/JPL-Caltech/O.Krause (Steward Observatory)

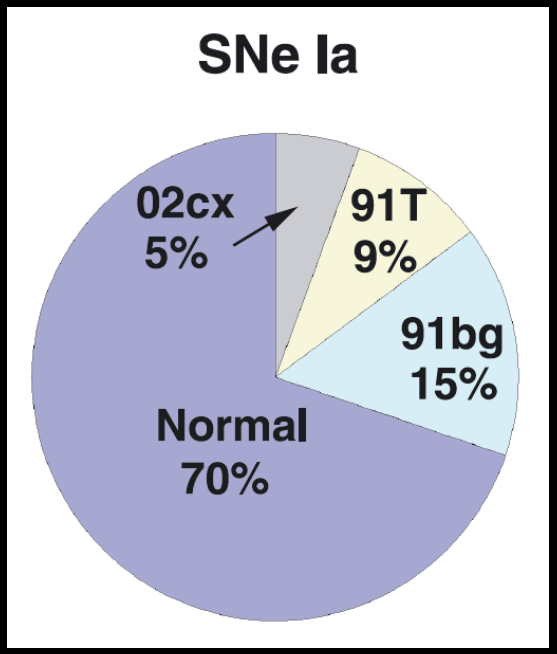
Type Ia supernova (SNIa)

- Extensive use in cosmology, galaxy chemical evolution, sources of energy and cosmic rays, important stellar evolution, etc.
- SNIa are not as standard as we might like: “Normal”, “SN1991T-like”, “SN1991bg-like”, “SN2002cx-like”, etc
- Zeroth-order picture: “burning“ of a ~1 Msun C/O white dwarf
- But there are many unknowns
  - Progenitor system?
  - Ignition?
  - Flame propagation?

Gamma rays offer unique probes of these unknowns!



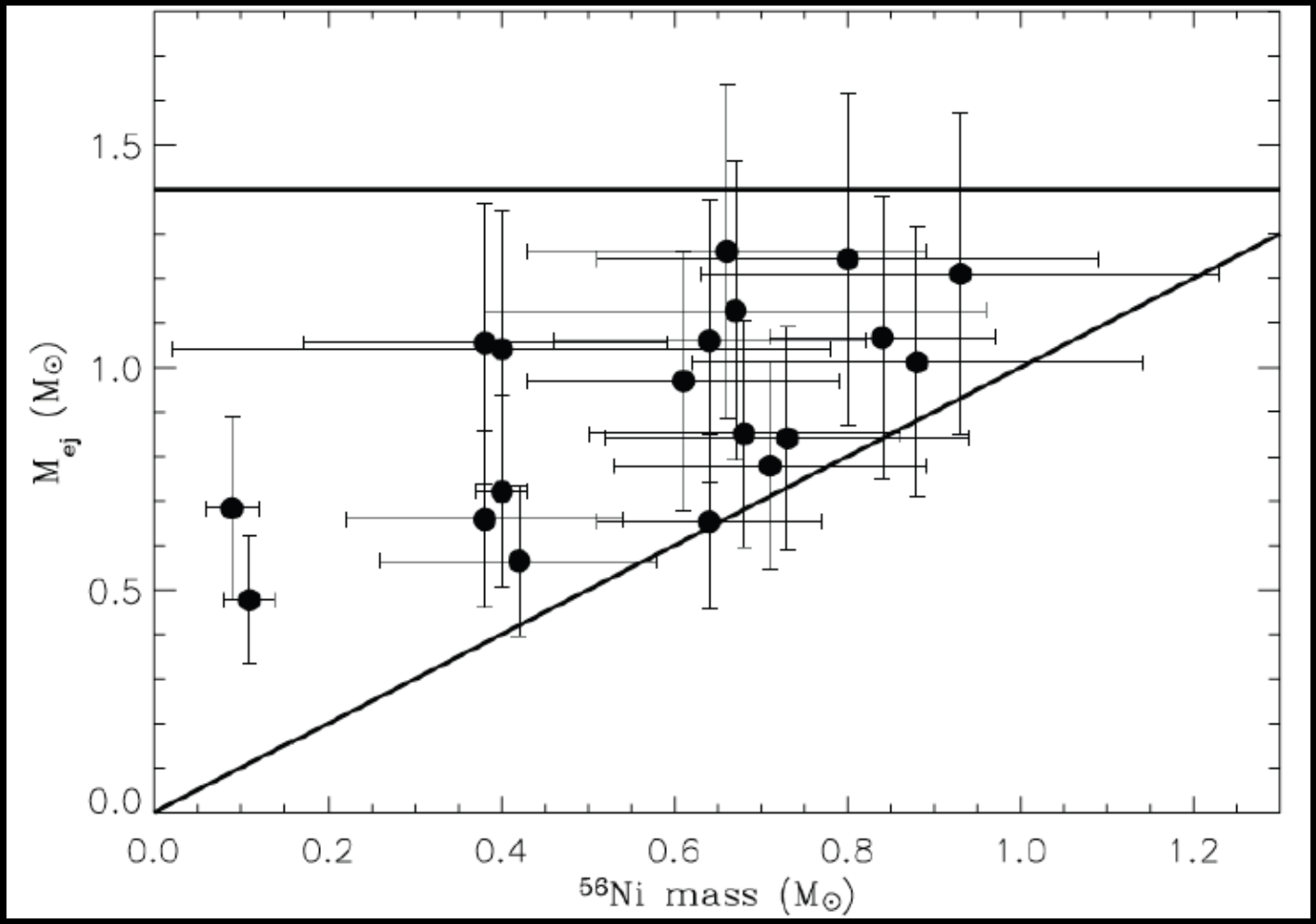




Li et al (2011)

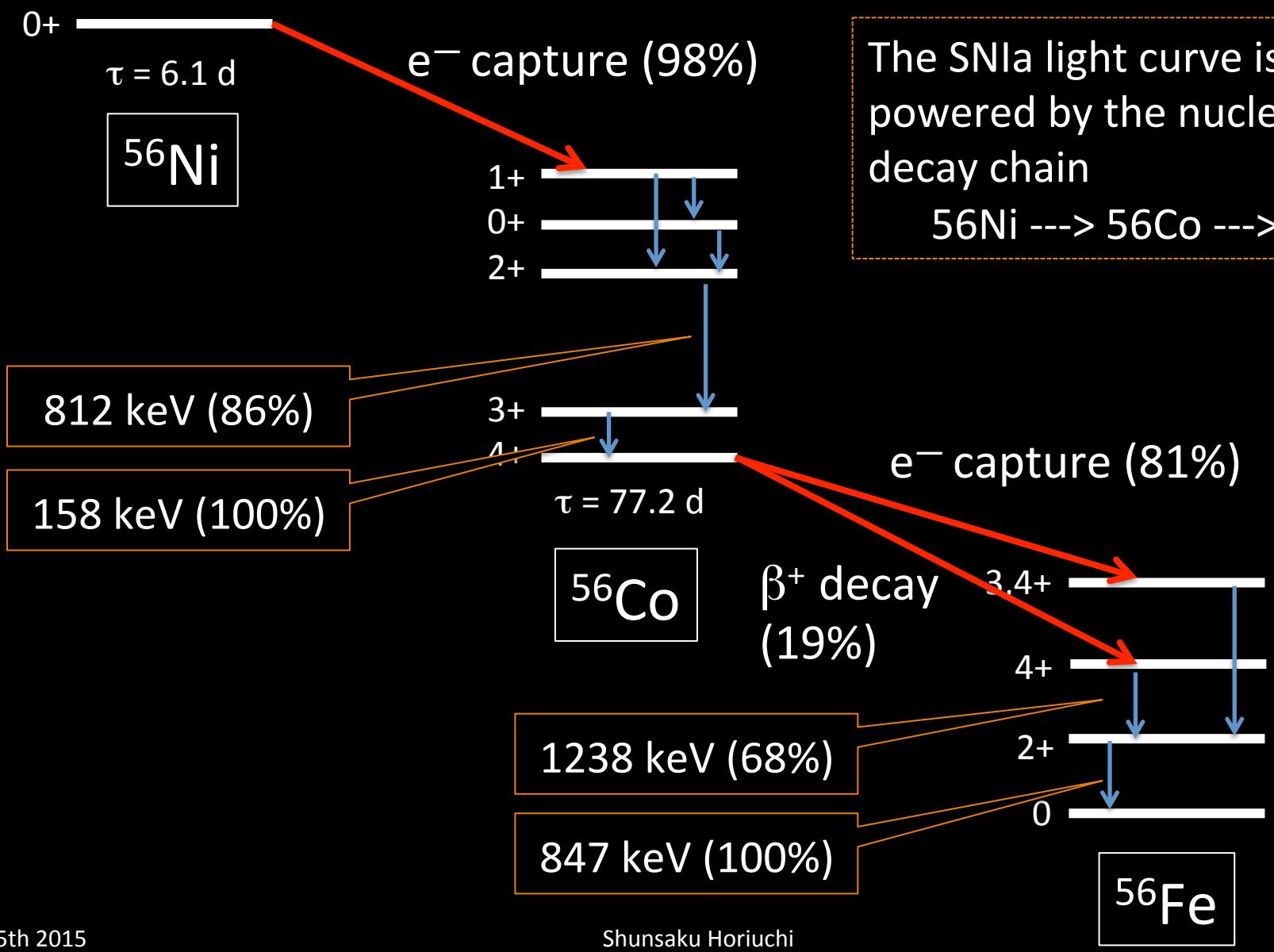
Nucleosynthesis

- Thermonuclear explosion generates ~0.6 Msun of Nickel-56



Data from *Stritzinger et al (2006)*

Nickel decay chain and gamma rays



The SNIa light curve is powered by the nuclear decay chain

56Ni ---> 56Co ---> 56Fe

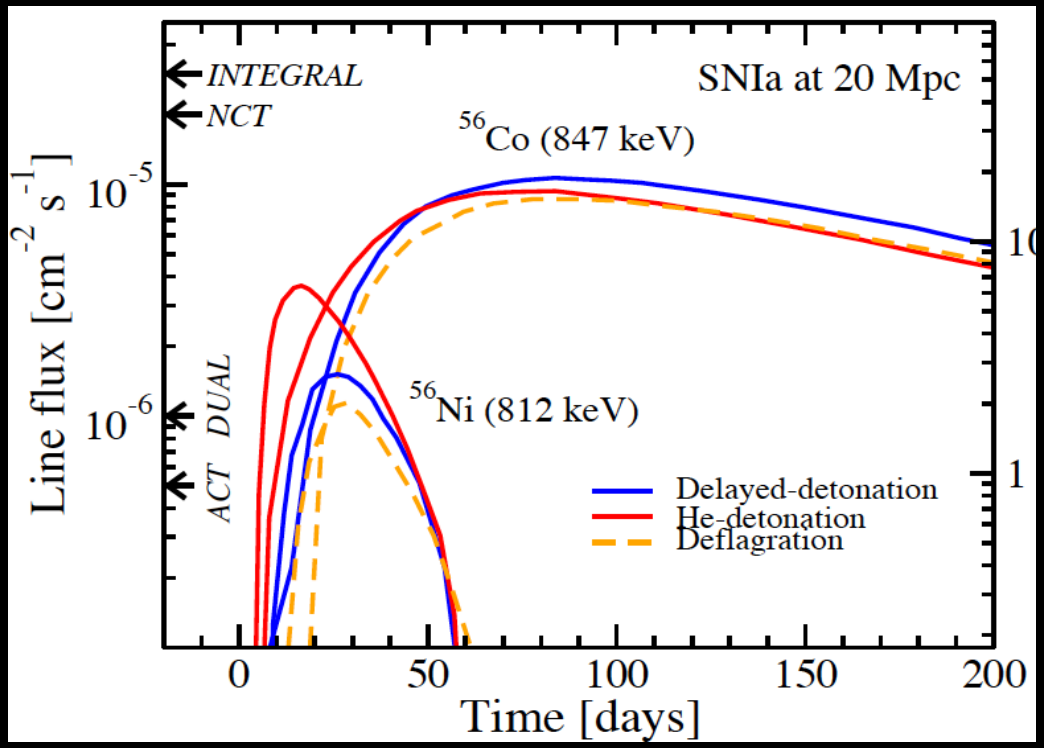
Gamma-ray tomography

- The gamma-ray escape fraction encodes useful information of the matter density morphology and Nickel-56 distribution.
- Both of these depend strongly on the progenitor system and ignition site

$$S_\gamma(t) = p_{\rm esc}(t) \left[\frac{M_{\rm Ni} N_A}{56}\right] \left[\frac{e^{-t/\tau_{\rm Co}} - e^{-t/\tau_{\rm Ni}}}{\tau_{\rm Co} - \tau_{\rm Ni}}\right] \gamma\ {\rm s}^{-1},$$

Escape faction

- Line shape (widths, shifts, asymmetries) reveals the dynamics of the ^{56}Ni and surrounding ejecta



Horiuchi & Beacom (2010)

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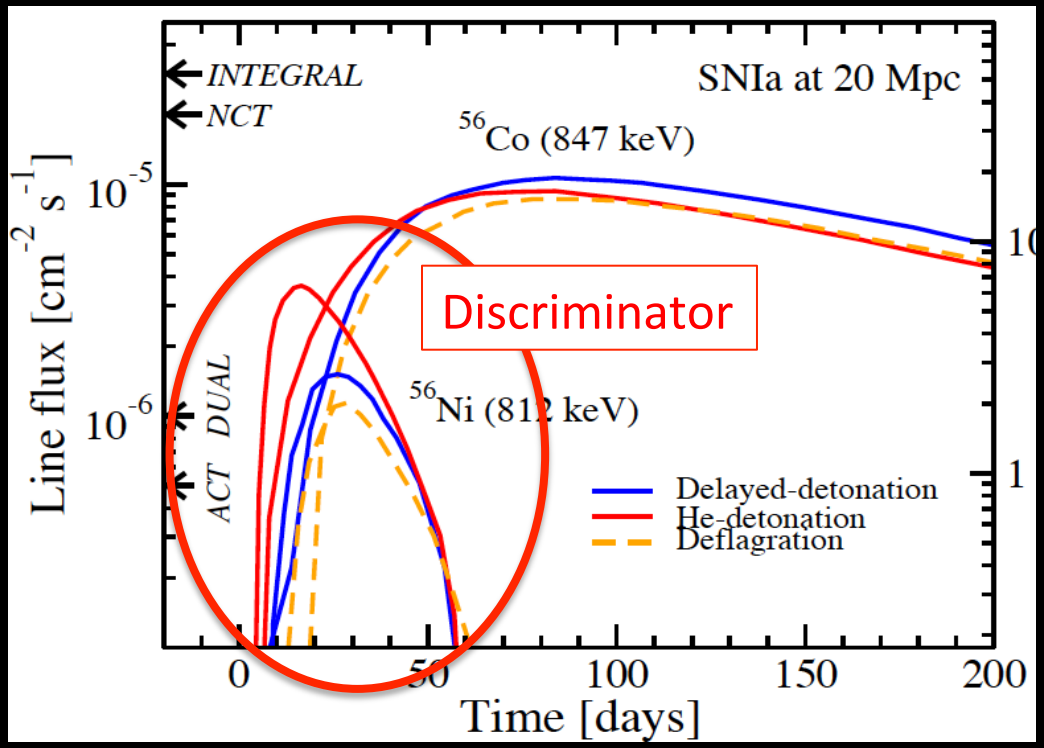
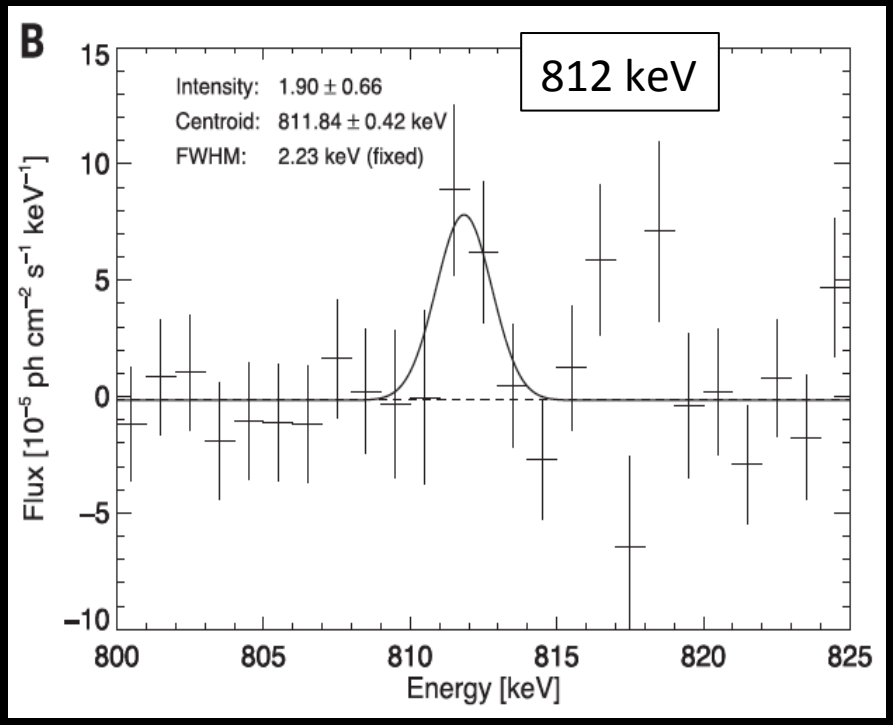
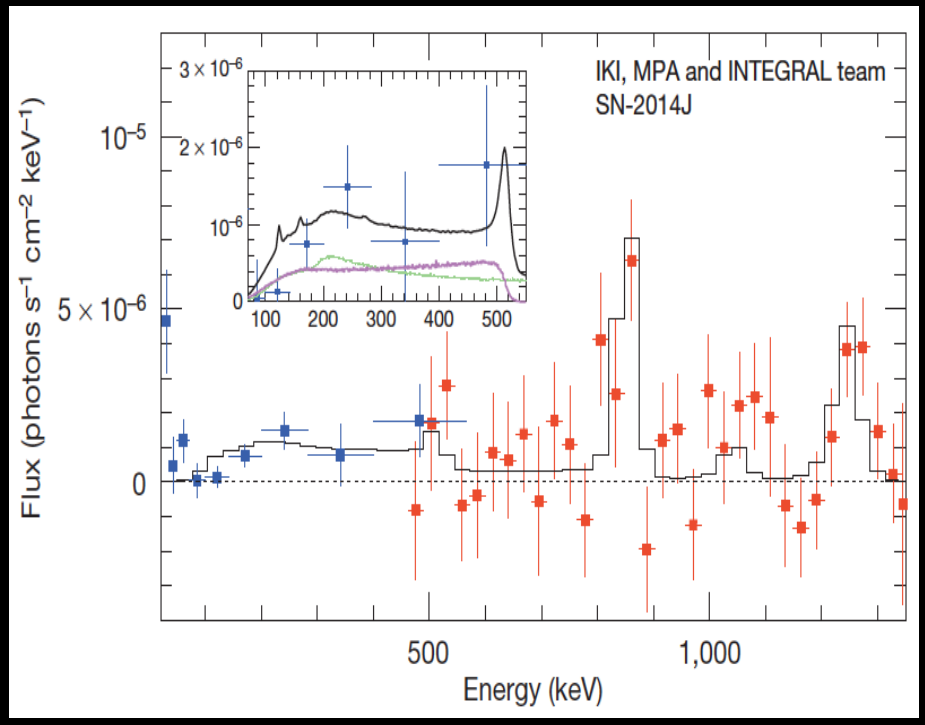


Horiuchi & Beacom (2010)

SN2014J: closest SNIa in decades



Diehl et al (2015)



Churazov et al (2014)

INTEGRAL-SPI

- 158 keV and 812 keV lines from Ni-56 decay, ~1-2e-4 ph /s /cm^2
- 847 keV and 1238 keV lines from Co-56 decay, ~2-4e-4 ph /s /cm^2

- 56Ni lines started early (~20 days)
- Inferred velocities ~2000 km/s

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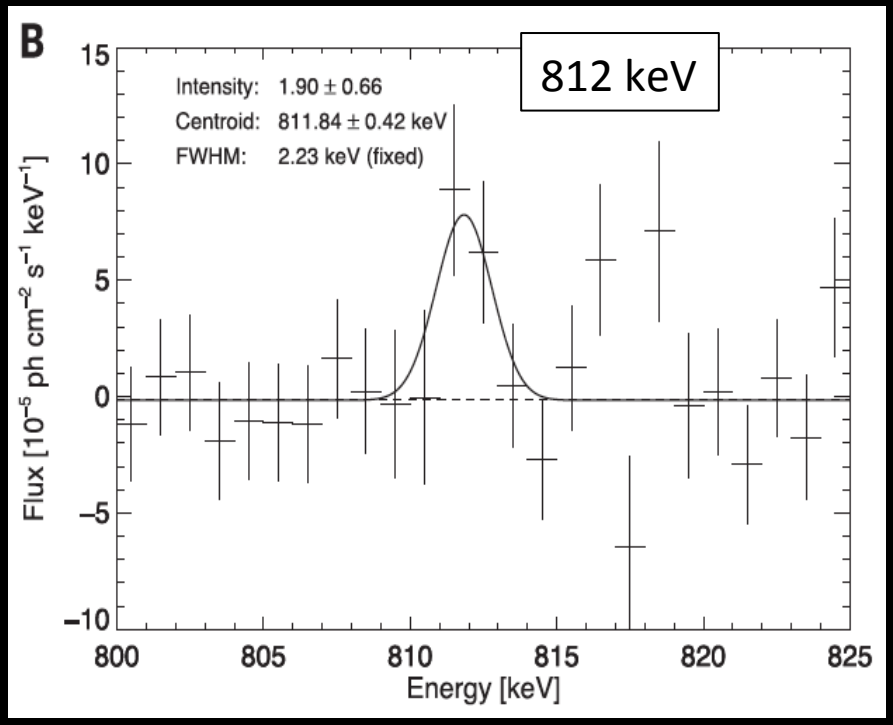

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INTEGRAL-SPI

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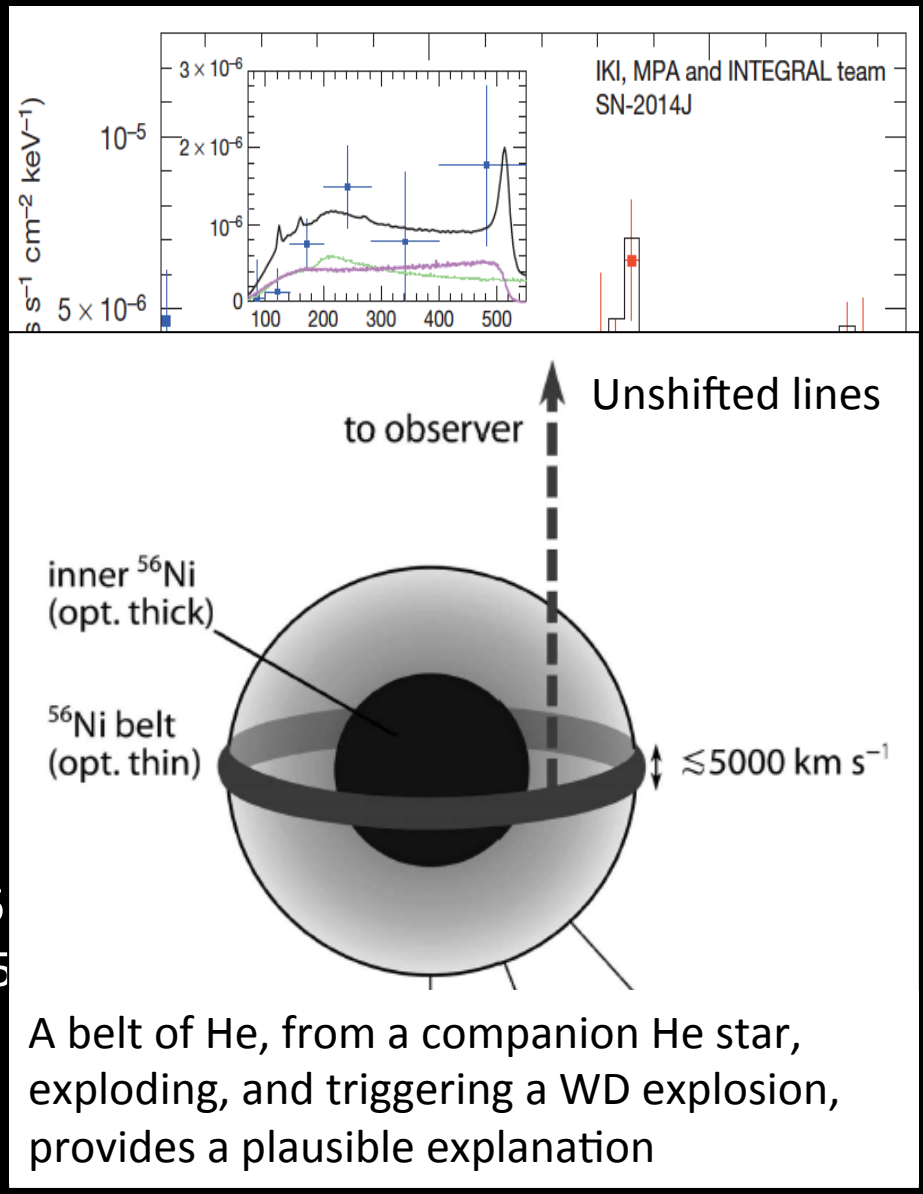


A belt of He, from a companion He star, exploding, and triggering a WD explosion, provides a plausible explanation

Diehl et al (2015)

What next in gamma ray?

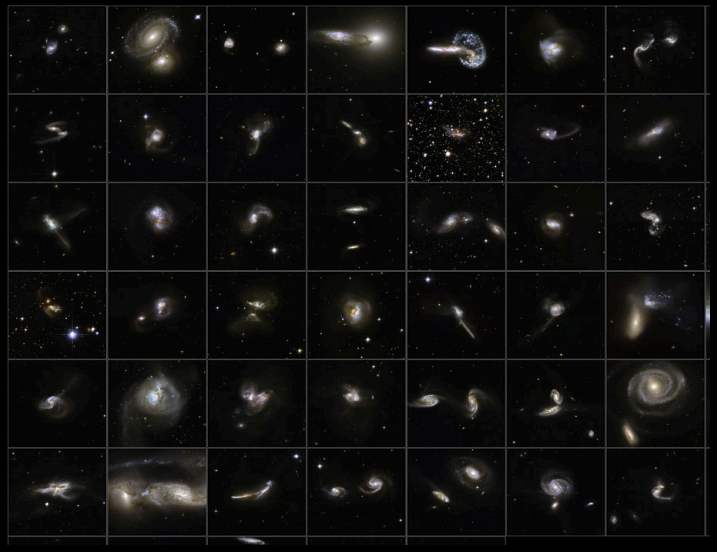
1. *More Ia supernovae*: will tell us about variations
2. *More Ia supernovae*: given the prominence of Ia supernovae in cosmology and many topics in astrophysics
3. *More* gamma rays: given the unique information gamma rays provide us

Supernova rates tell us the required sensitivity to satisfy reasonable physics return over some time duration

Updates of Gehrels et al (1987), Timmes & Woosley (1997)

Two methods for supernova search

1. Galaxy survey:
   - Repeated observations of a list of galaxies
   - Galaxy sample bias (e.g., may miss faint galaxies)
   - Can strategically cover large angular regions of the sky
   - E.g., LOSS



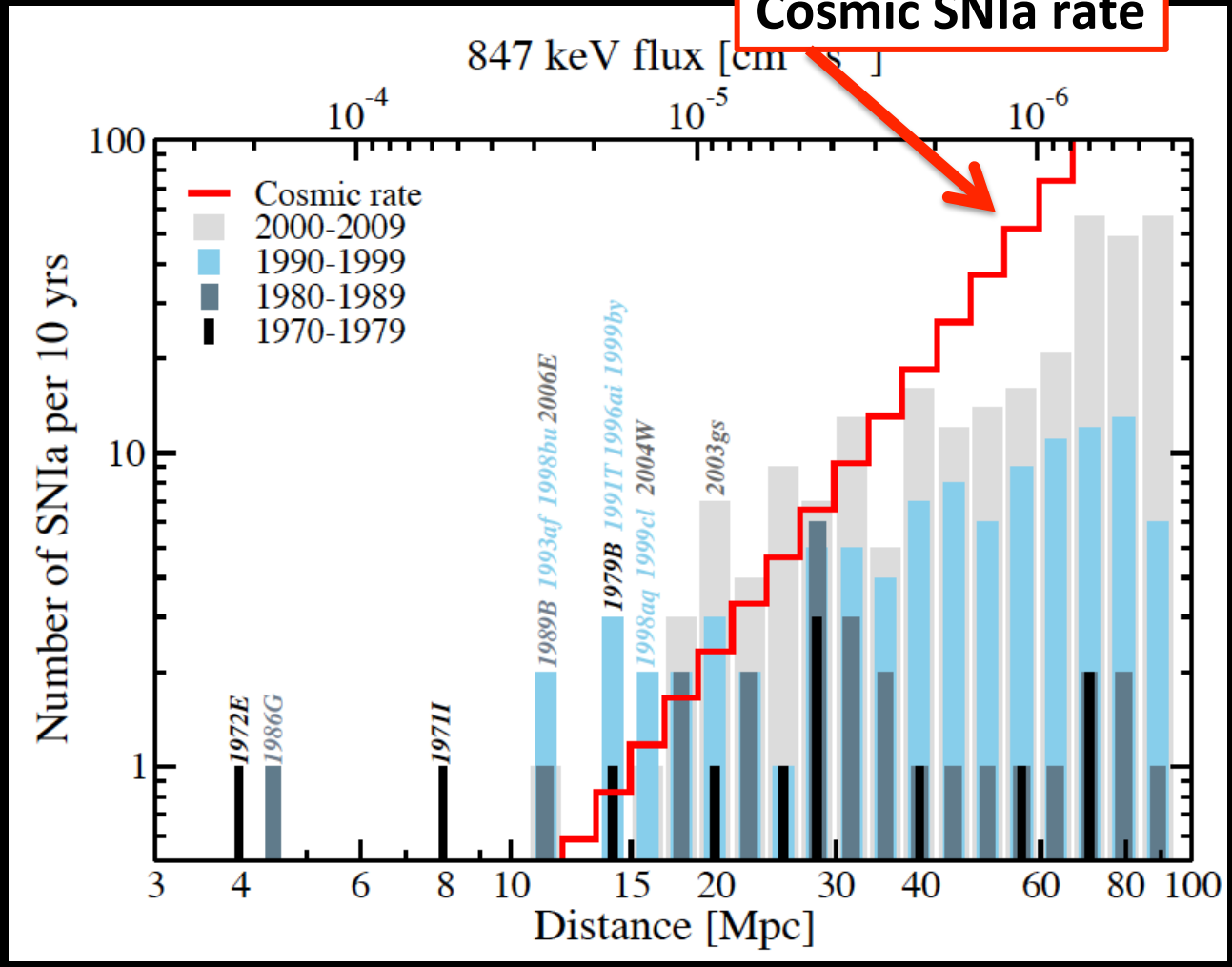
2. Patch survey:
   - Repeated observations of patch(es) of sky
   - Can survey large volumes if deep enough
   - Completeness and volumetric rate simpler to estimate
   - E.g., DES

What next: nearby detection

How frequently do Ia supernovae go off locally in nearby galaxies?
Raw counts gives us lower limit.

Three regimes:

1. Within 10 Mpc: rare, great science returns, typically 1 per decade or less
2. Within 20-30 Mpc: nearby galaxy clusters raise the SNIa rate. Good target to aim for in future plans?
3. Beyond 30 Mpc: close to the cosmic extrapolation



Horiuchi & Beacom (2010)

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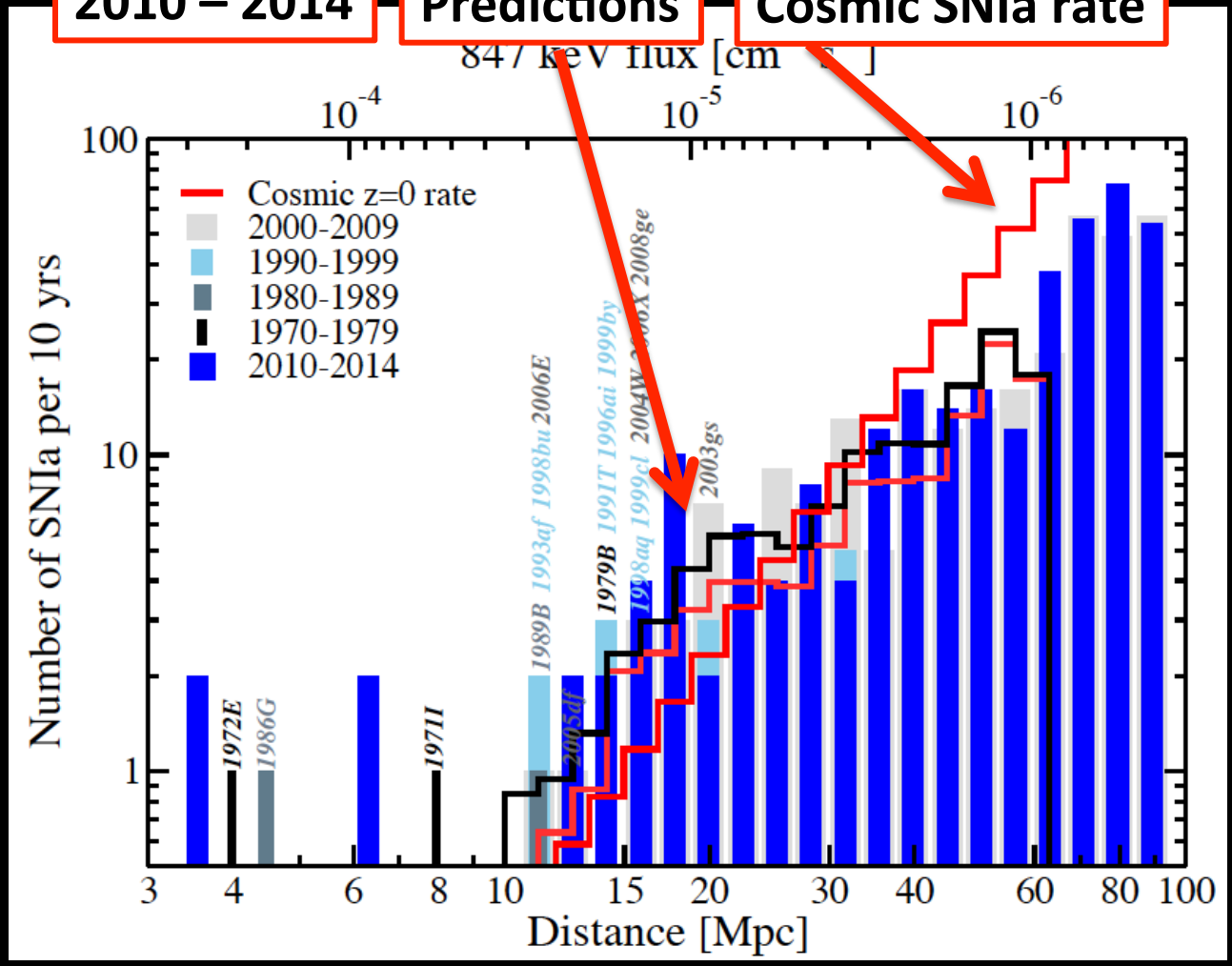
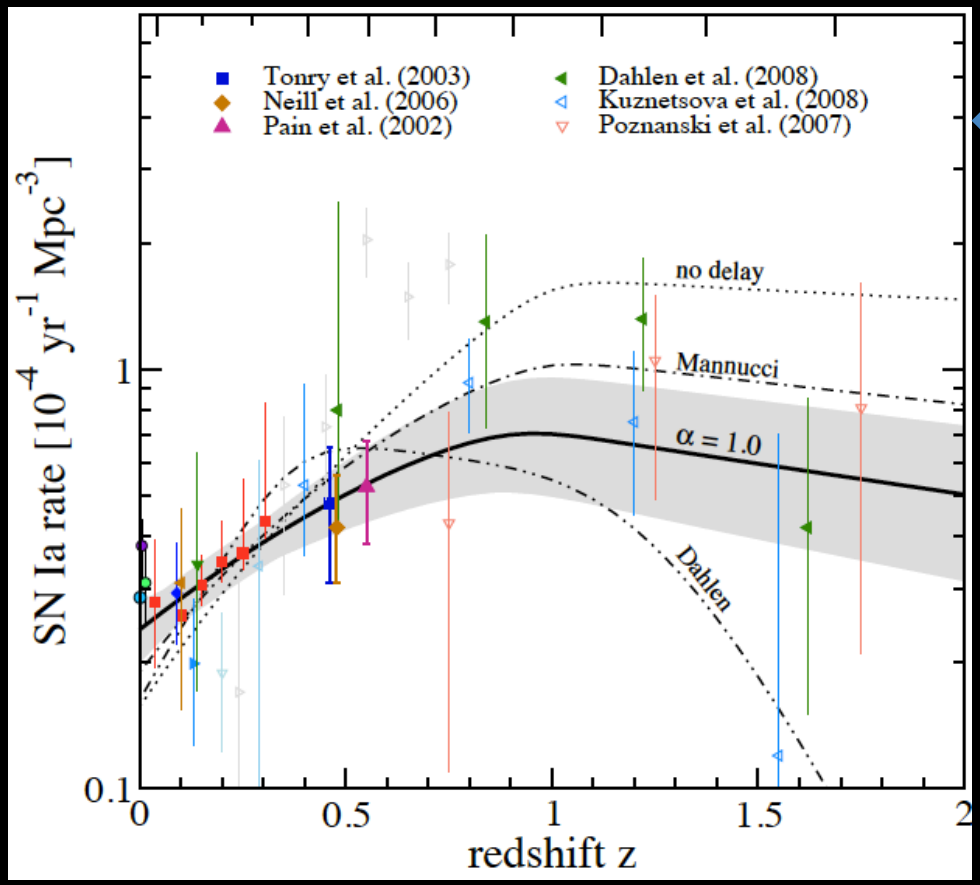


Horiuchi & Beacom (2010)

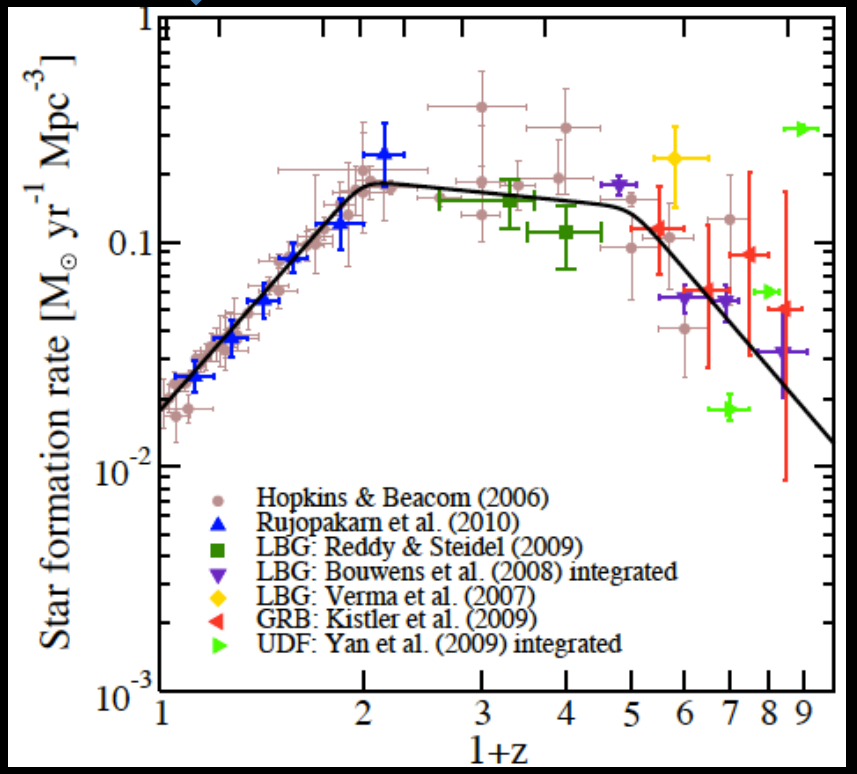
What next: cosmic detection

The cosmic SNIa rate is now increasingly better known.
Select measurements with good spectroscopic ID:



Horiuchi & Beacom (2010)

The rate can also be cross-checked with the star formation rate through the delay-time distribution (DTD)



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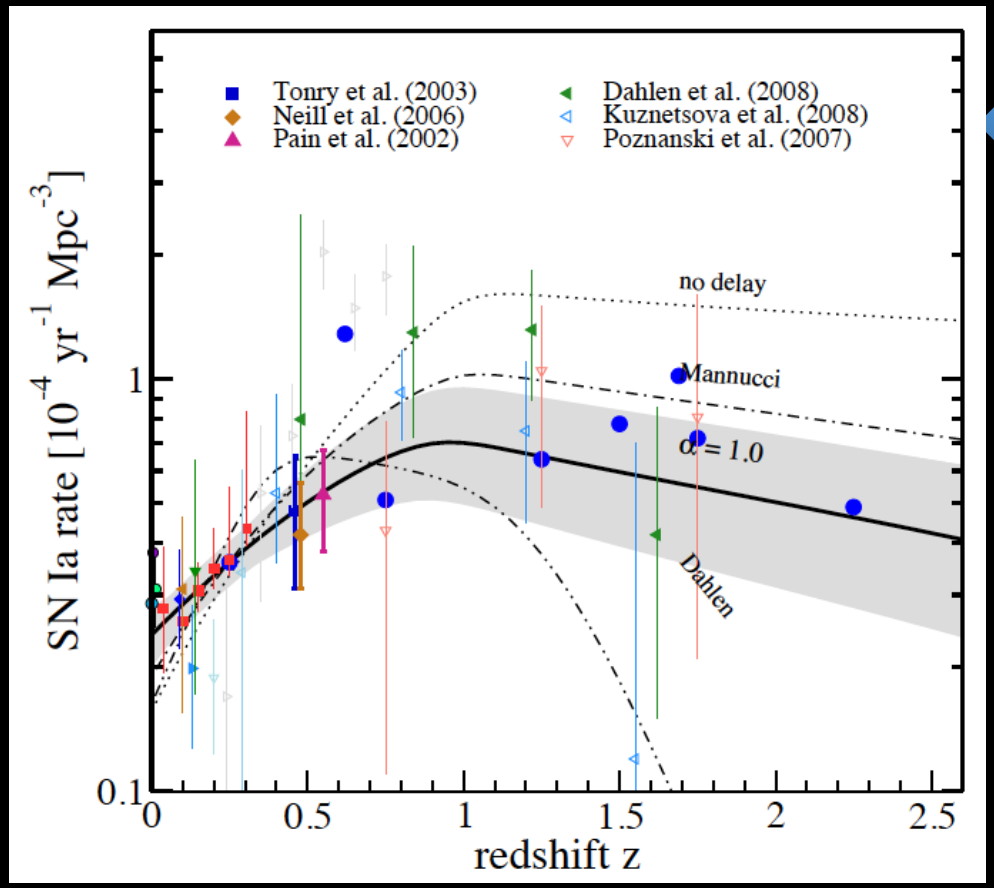

Horiuchi & Beacom (2010); additional measurements confirms the solid line (CANDLES, CSS, Subaru, VIMOS; Graur et al 2011, Barbary et al 2012, Perrett et al 2012, Rodney et al 2014)

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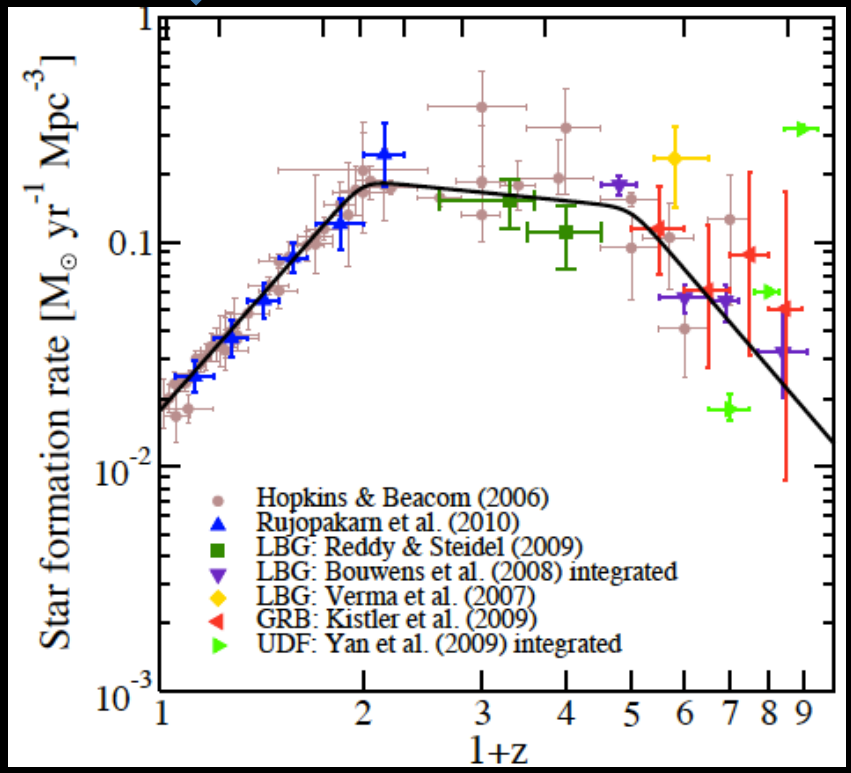
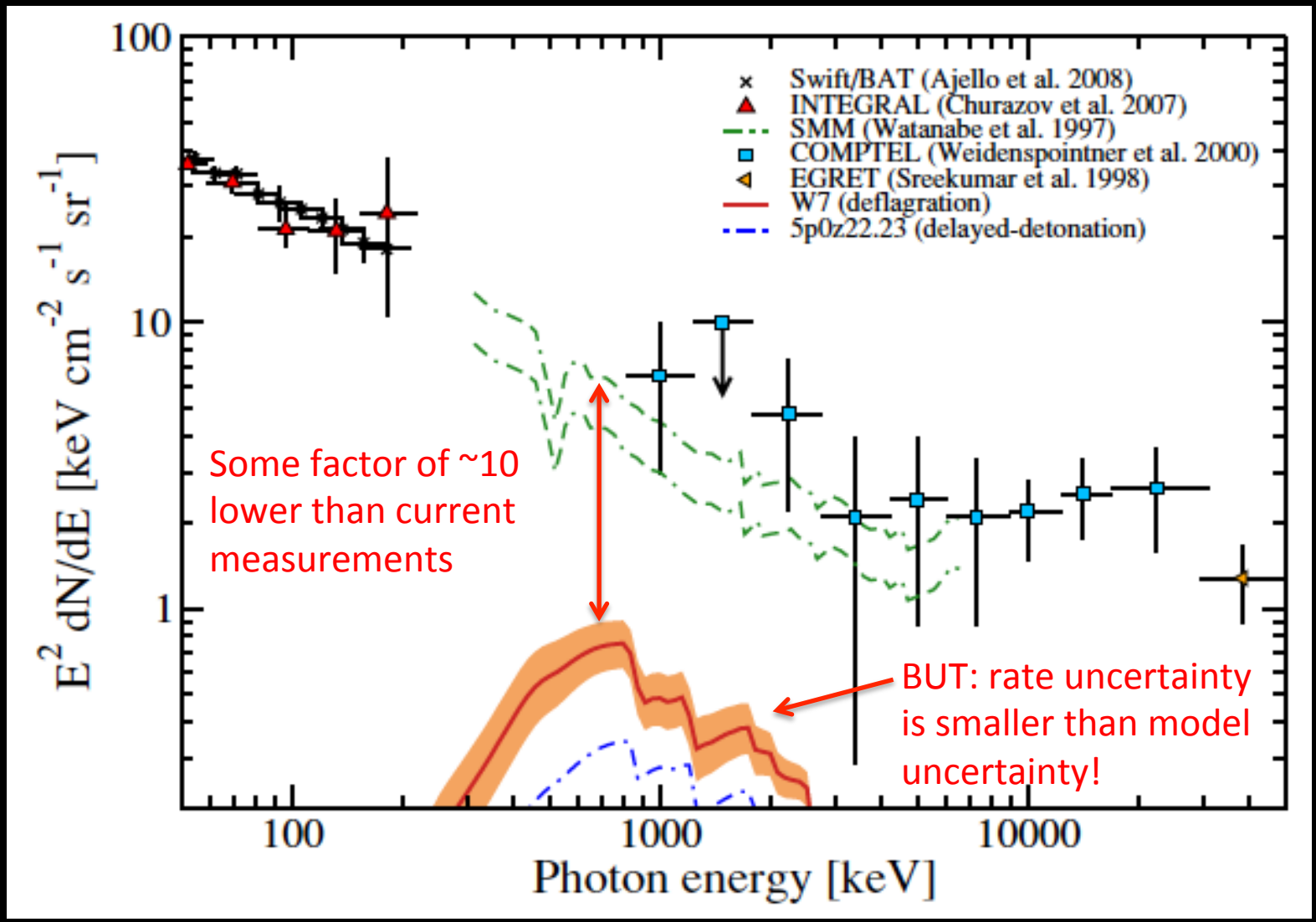


Contribution to the MeV diffuse gamma



Horiuchi & Beacom (2010)

Conclusions

- Nuclear gamma rays provide useful tomography of SNIa
- Recent progress in SNIa gamma-ray detections
    - SN2014J in particular
- Supernova rates determine the required sensitivity to satisfy reasonable physics return over some time duration
- Supernova rates are now better determined
    - Locally: close to annual SNIa within ~20 Mpc, with ~10^{-6} ph cm^{-2} s^{-1} ^{56}Ni (812 keV) and ~10^{-5} ph cm^{-2} s^{-1} ^{56}Co (847 kV) line intensities, respectively.
    - Cosmologically: contributes to diffuse gamma rays at the 1 keV cm^{-2} s^{-1} sr^{-1} level, but good potential since SNIa model variations dominate the uncertainty