SN Ia Progenitor Signatures in Supernova Remnant Abundances

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Motivation and Apology

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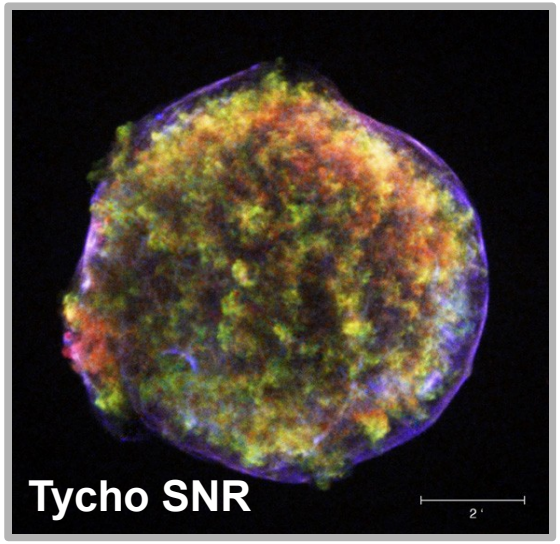
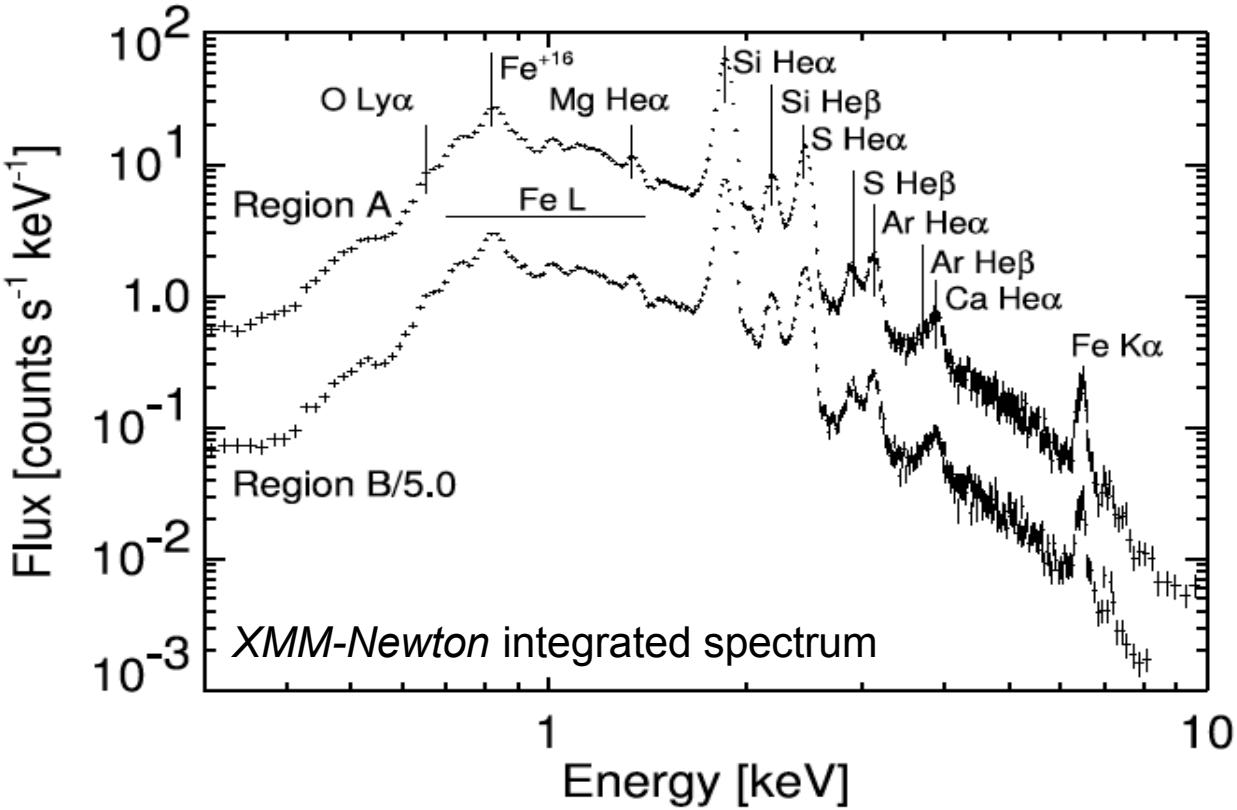
Abundance determination in SNRs as a tool to study SN explosions:

What is in here? ⇒ **Easy**

How much of X? ⇒ **Requires modeling**



- Many **open issues in Type Ia SNe require yields** (explosion mechanism).
- **Bulk yields** (as they can be measured now) **do not shed much light onto the progenitor problem!**
- **SNRs are nearby** ⇒ can be studied in great detail.



SNRs: A New Window Onto SN Explosions

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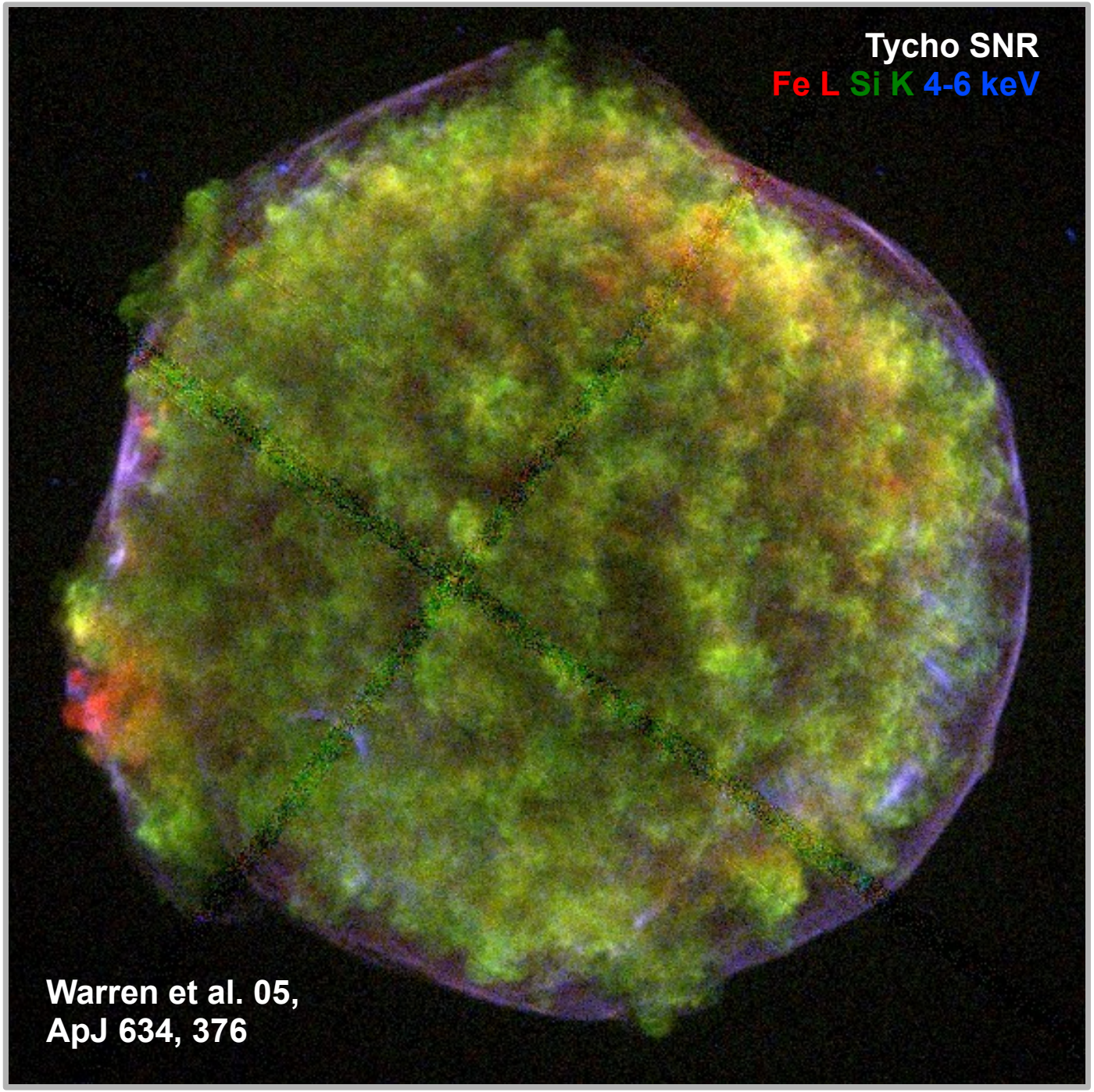

- *Chandra* and *XMM-Newton* provide **excellent data sets** [Badenes 10, PNAS 107, 7141].
- No longer a single line of sight into a distant object! ⇒ **Detailed view of the ejecta structure and the immediate surroundings (CSM, stellar populations)**.
- We **KNOW the environment affects SN Ia explosions** [Howell, Mannucci talks].
- If we can connect SNRs to their SNe, we can hope for progress...

Nonequilibrium Ionization in SNRs

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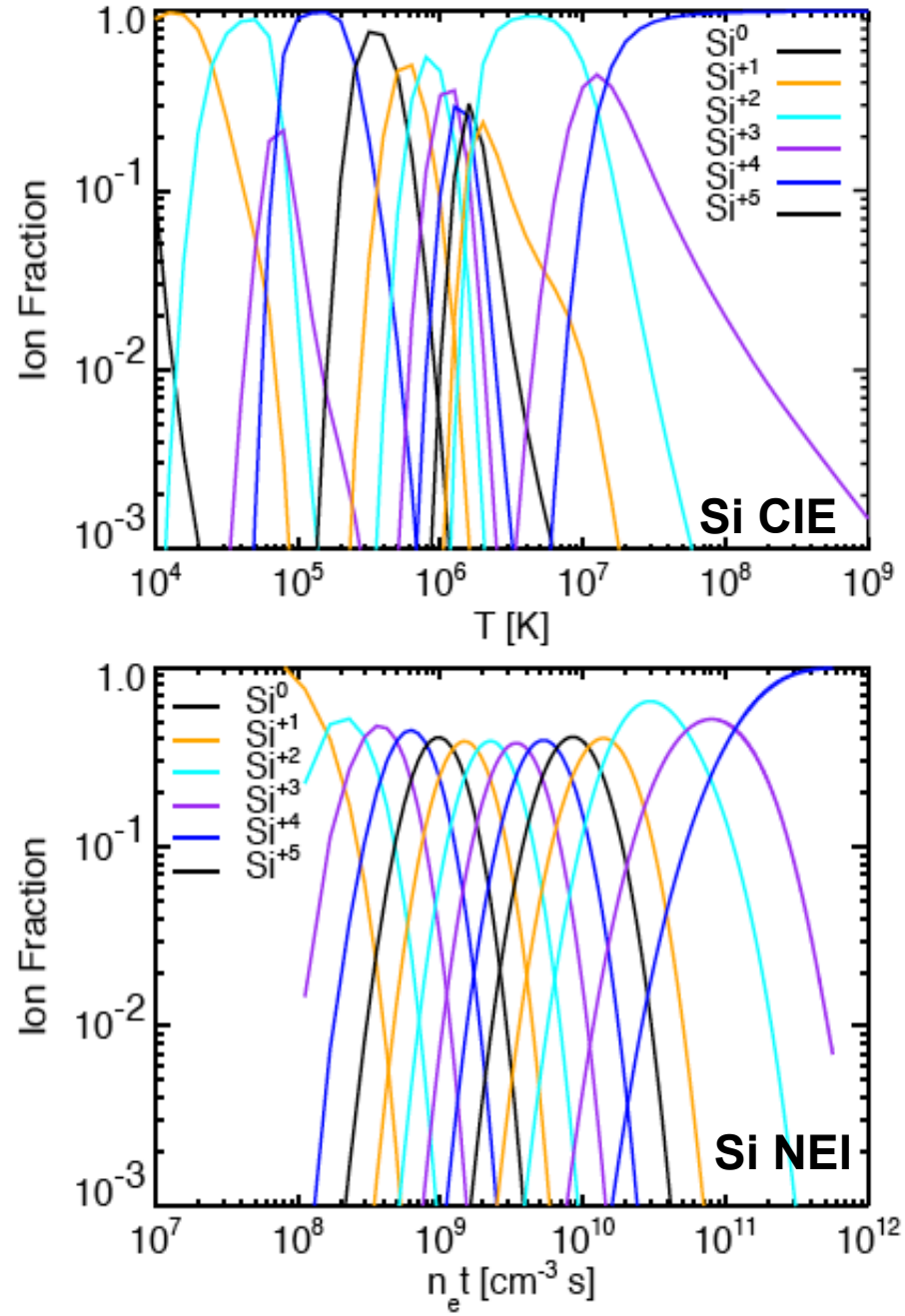
The plasma in SNRs is in nonequilibrium ionization (NEI) ⇒
The X-ray spectrum is tied to the hydrodynamics

[talk by Jacco Vink]

Two approaches:

- **Simplify the hydro** (e.g., plane shock models [Hughes et al. 00, ApJ 543, L61; Borkowski et al. 01, ApJ 548, 820]) ⇒ Relative abundances, $n_e t$, T_e ⇒ Study local plasma. ⇔ **SYNOW**

- **Full-fledged HD+NEI** [Hamilton & Sarazin 84 ApJ 287, 282; Badenes et al. 03 ApJ 593, 358; Sorokina et al. 04, Ast. Lett 30, 737] ⇒ Bulk yields ⇒ Compare to SN physics (**so far, 1D!**).
⇔ **Rad. Transfer**



Type Ia SNRs: Tycho

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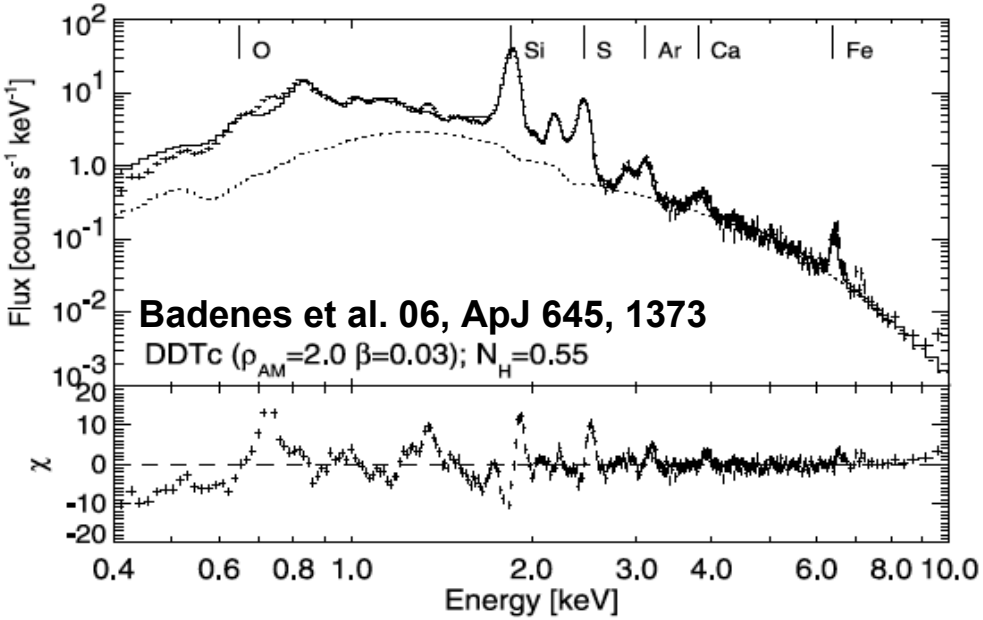
The X-ray spectra from Type Ia SNRs can be used to estimate peak the brightness of SN Ia

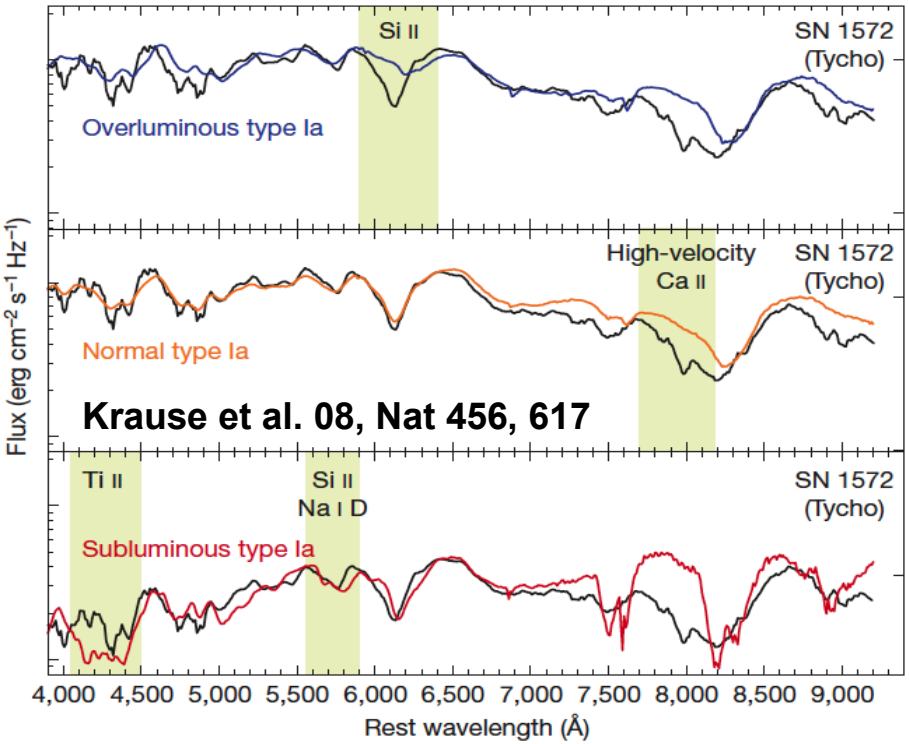
[Badenes et al. 03 ApJ 593, 358; Badenes et al. 05 ApJ 624, 198.]



- Type Ia SN **brightness estimate based on 1D DDT models** ⇔ **M_{56Ni}**. These models work very well [Gal-yam talk]!

- **Tycho SNR: M_{56Ni}=0.74 $M_\odot$** [Badenes et al. 06, ApJ 645, 1373], a normal SN Ia.

- This result was **later confirmed by light echo spectroscopy** [Rest et al. 08, ApJ 681, L81; Krause et al. 08, Nat 456, 617].



Type Ia SNRs: Tycho

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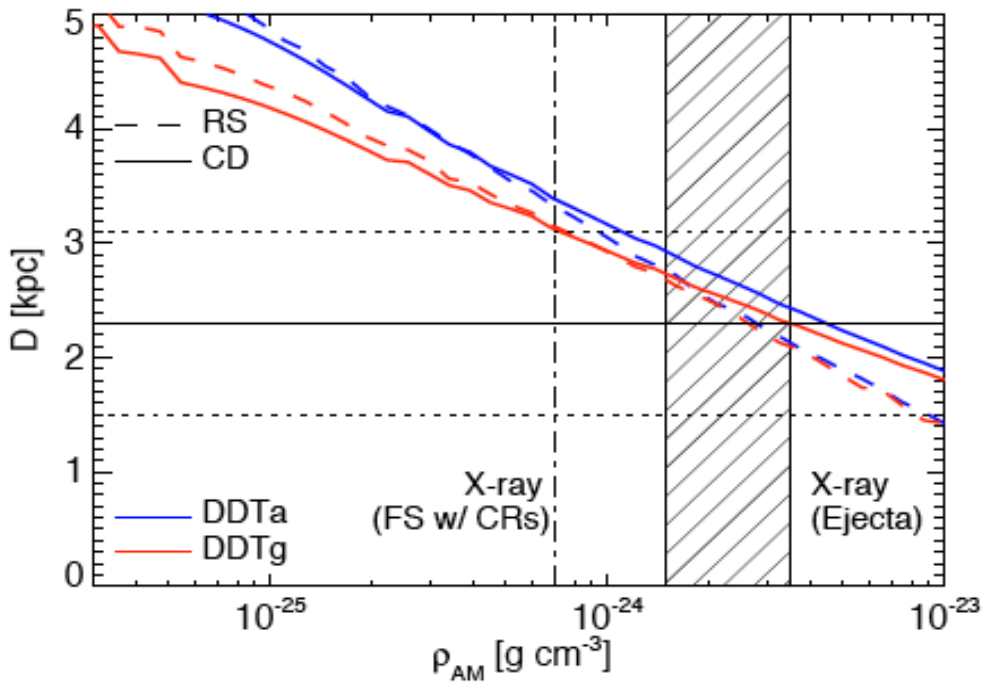
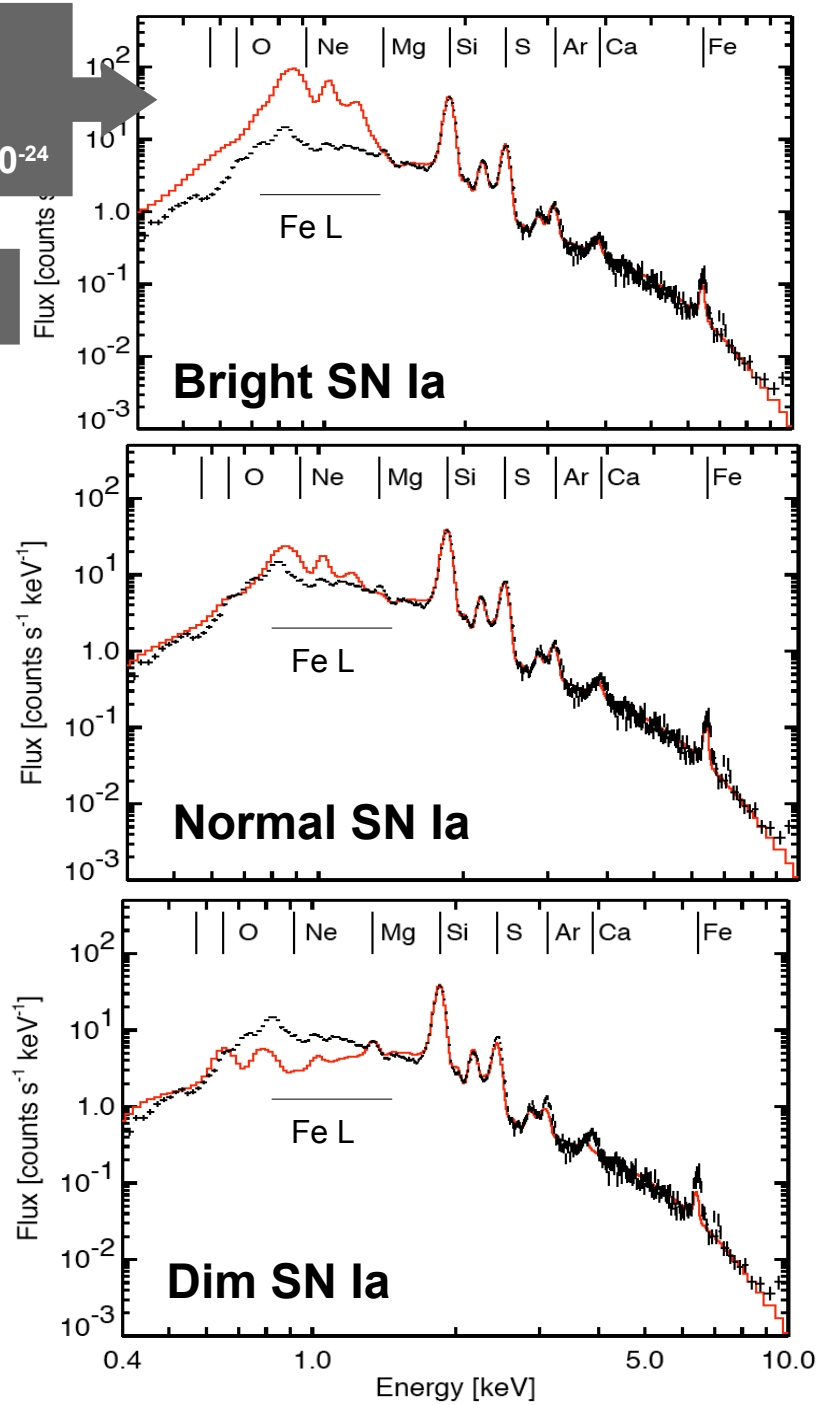
Age is known (SN1572). SNR size forces a **correlation between D and**



- Only **1D DDT models** can **reproduce both X-ray spectrum and SNR dynamics**.
- **Crucial sanity check on yields**.
- **Warning:** comparison of models and observations is not trivial!

DDT models
$\rho_{AM} = 2\times10^{-24}$

^{56}Ni



Type Ia SNRs: Tycho

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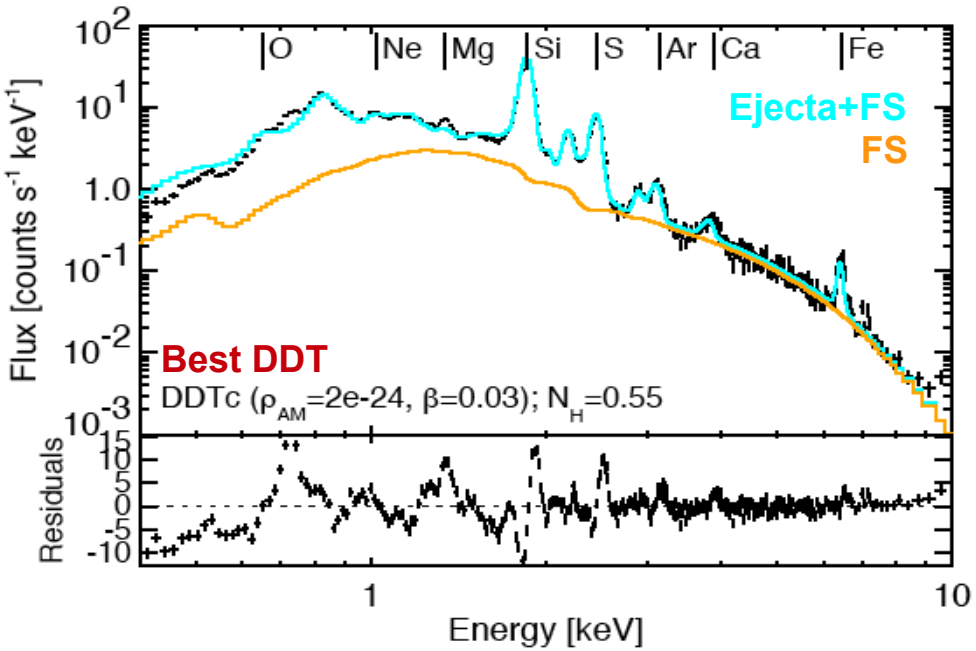

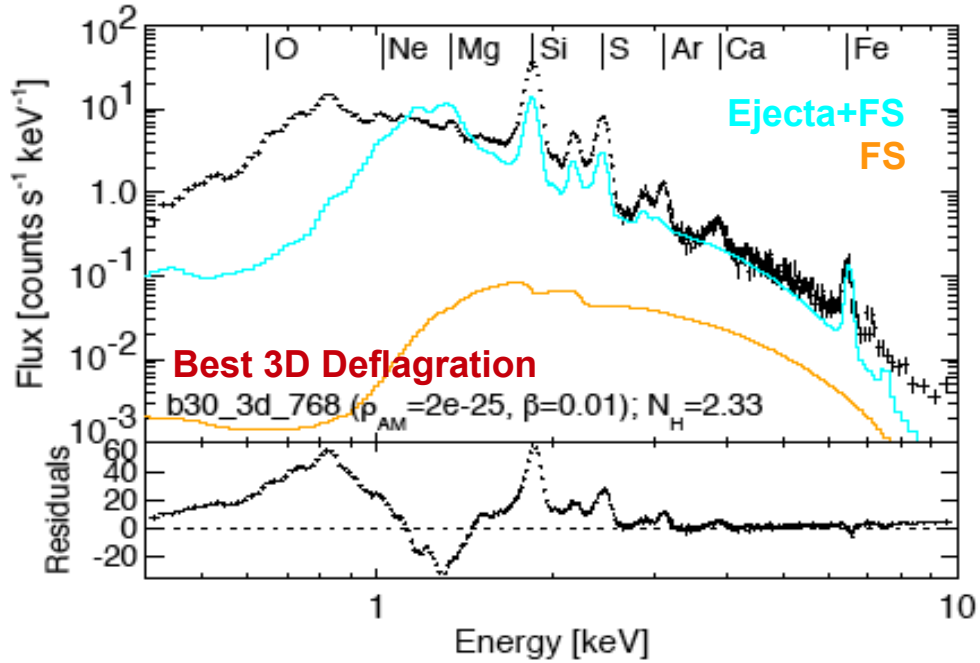

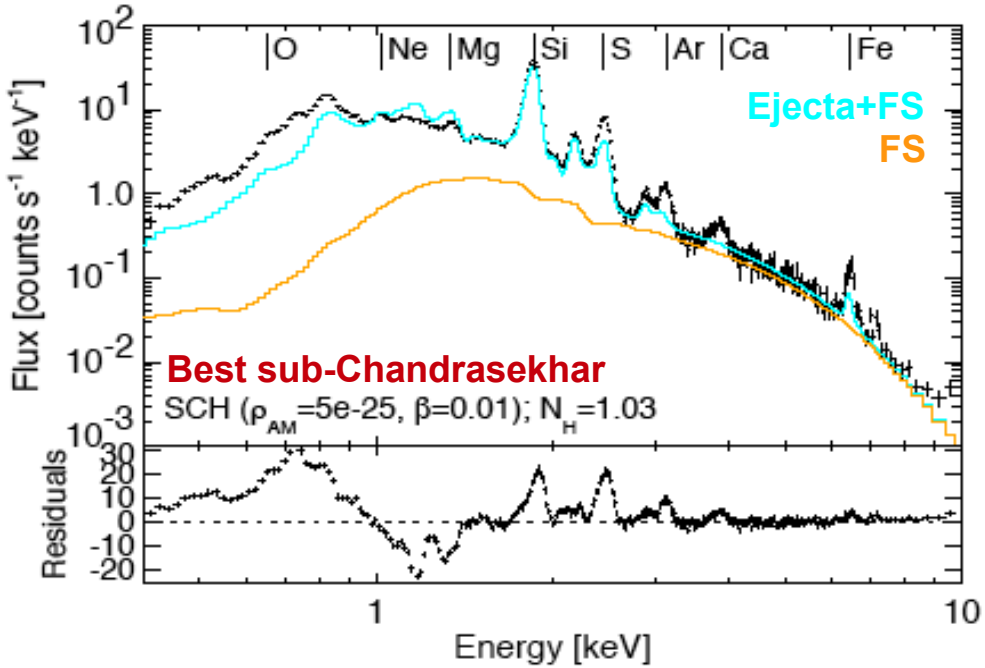

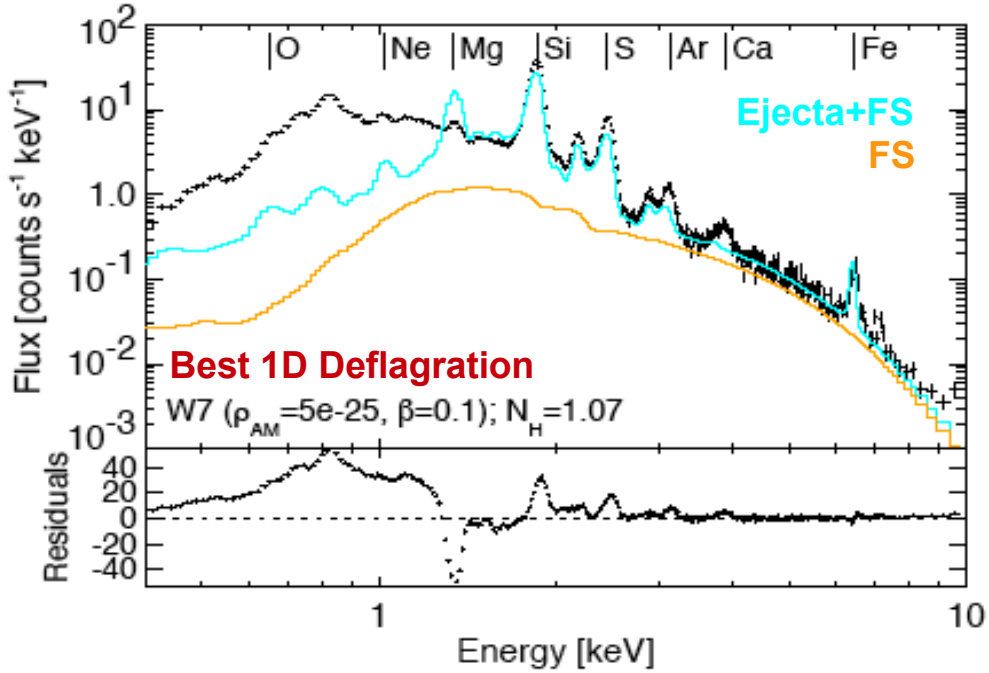

Type Ia SNRs: SNR 0509-67.5

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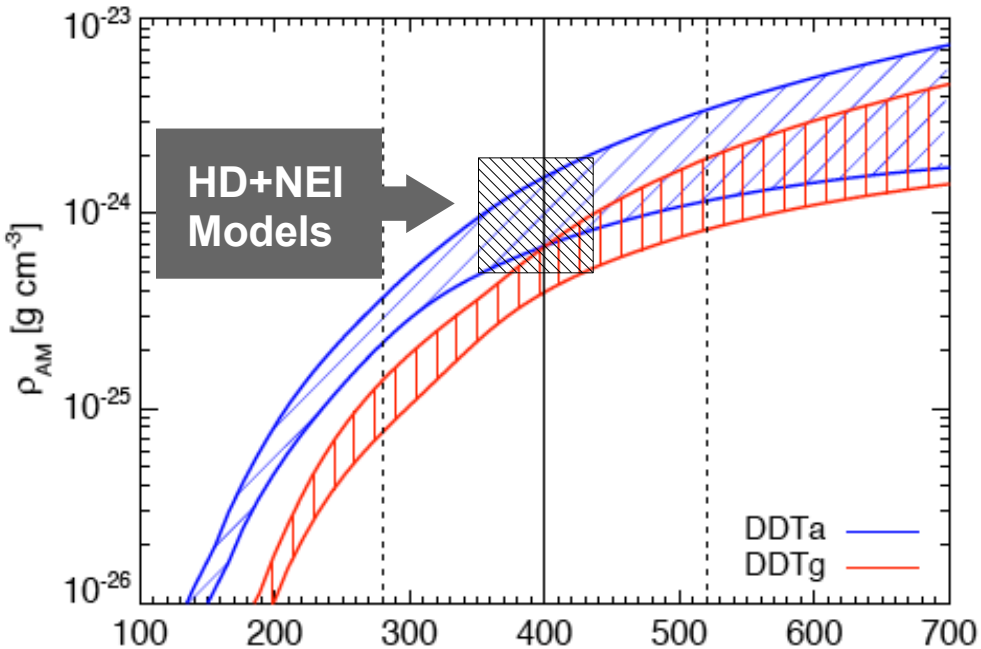
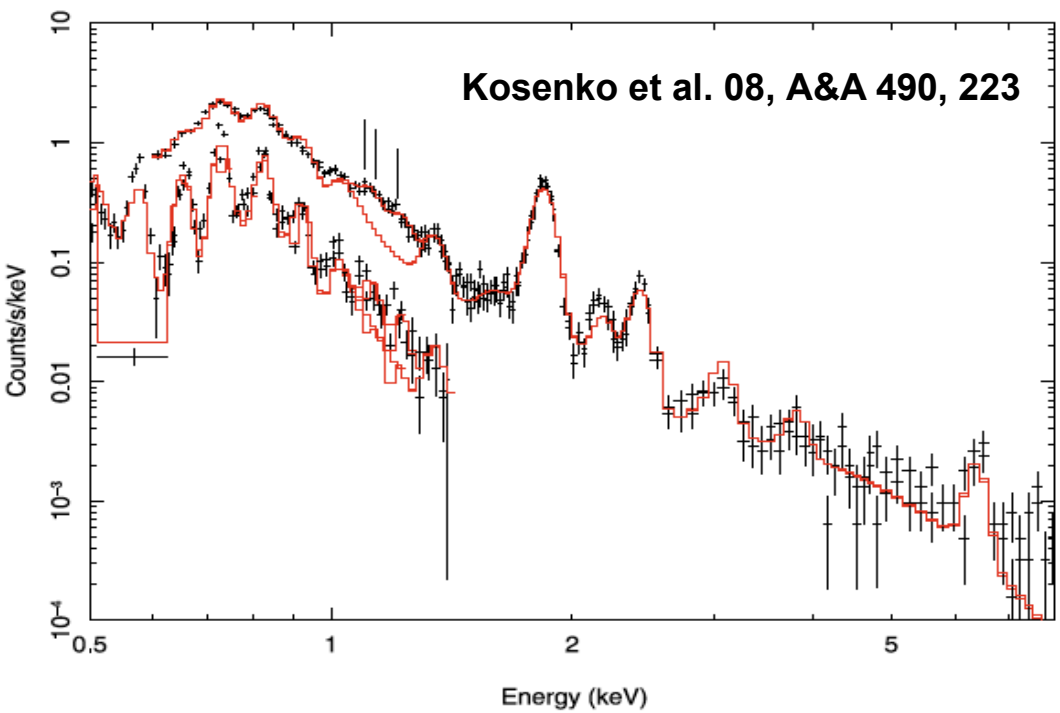
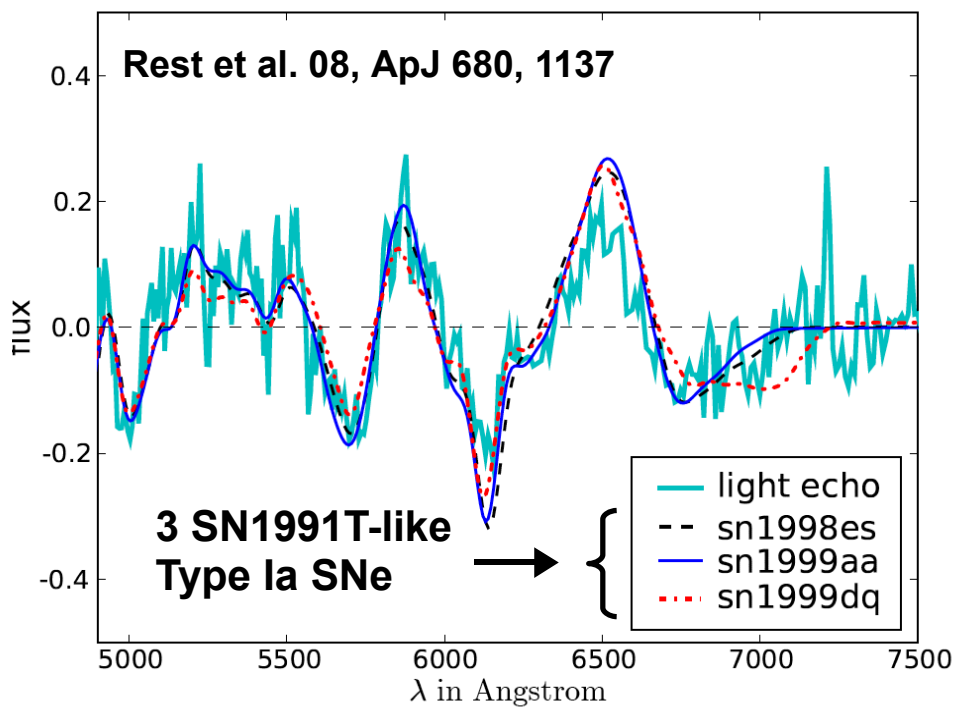
- **SNR 0509-67.5** in the LMC ⇒ **M_{56Ni}=0.97 $M_\odot$** [Badenes et al. 08, ApJ 680, 1149]. **Also confirmed by the light echo** [Rest et al. 08, ApJ 680, 1137].
- [Kosenko et al. 08, A&A 490, 223] ⇒ O, Ne, Fe L, Mg from **XMM RGS: no Ne/Mg in the ejecta**; N from the ISM ⇒ ISM density, line broadening.







SNR 0519-69.0

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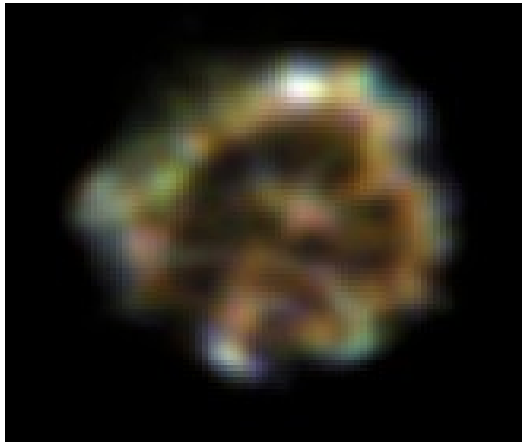

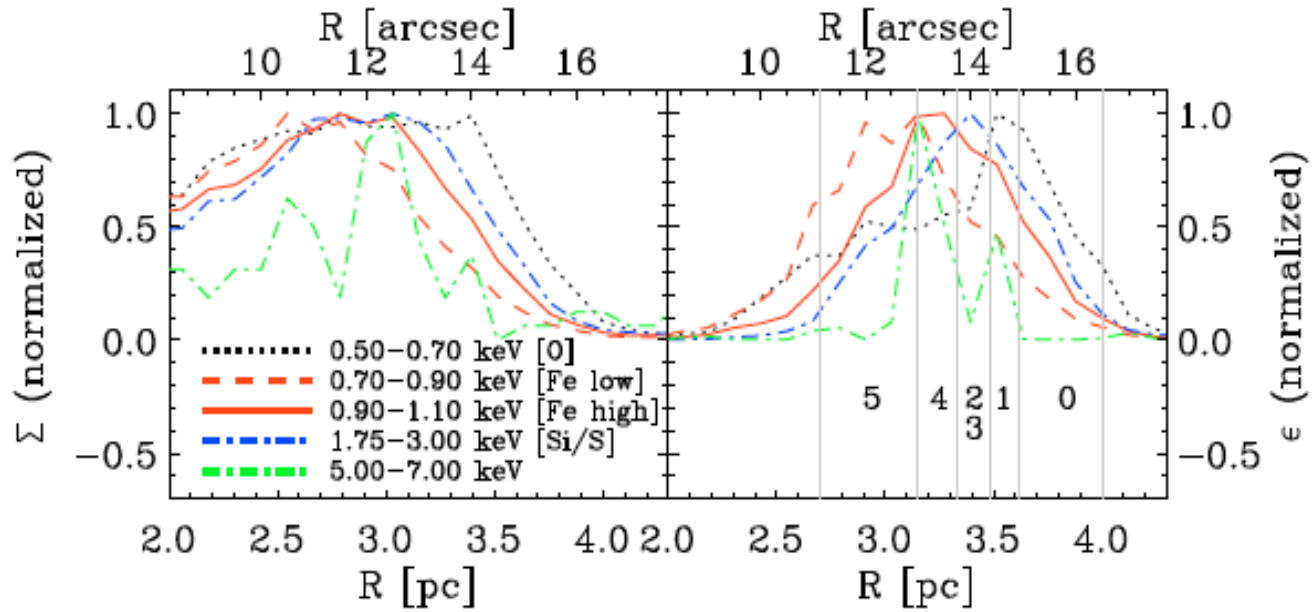

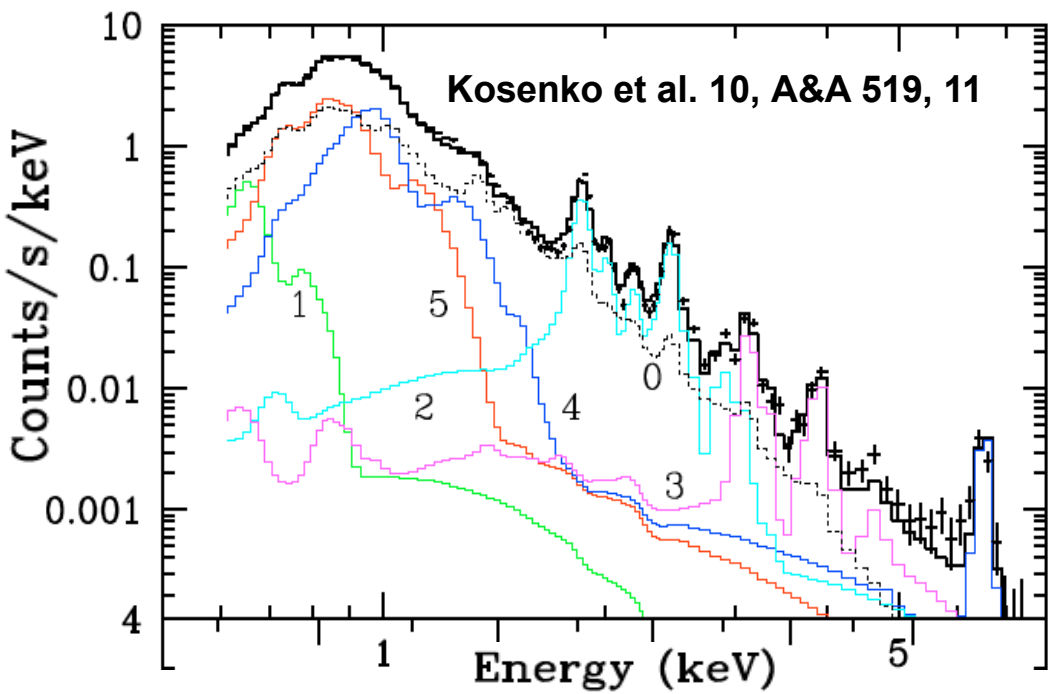

- **Spatial stratification** in the ejecta (O/Si/Fe) [Kosenko et al. 10, A&A 519, 11] ⇔ spectral stratification (Tycho, 0509-67.5). Contrast: CC SNRs (Cas A)

- Fe/Si abundance ratios consistent with a **normal SN Ia**. No need for Ne, Mg.

Mn/Cr as a Metallicity Tracer

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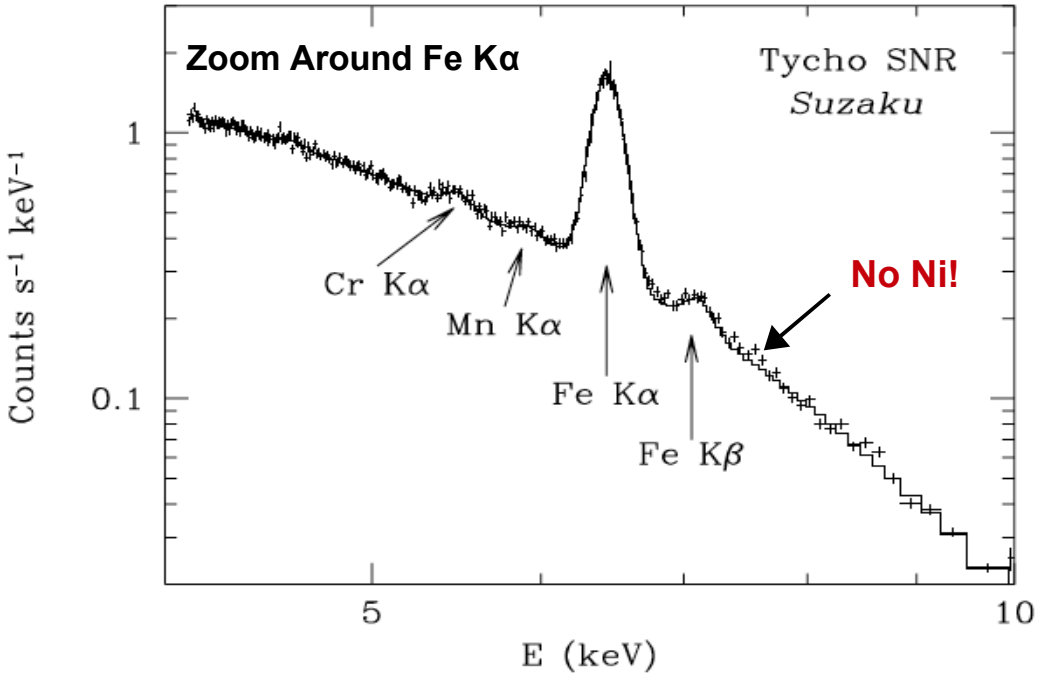
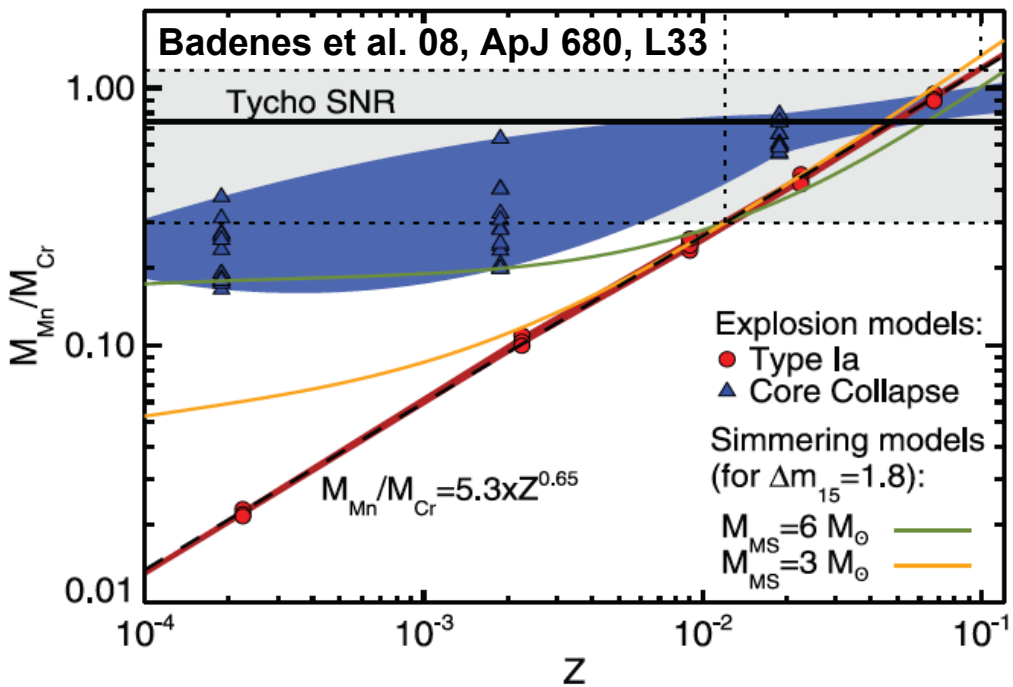
- With *Suzaku* we can **detect the weak lines from elements like Mn and Cr in bright SNRs like Tycho** [Tamagawa et al. 09 PASJ 61, 167].

- CO WDs have trace amounts of ^{22}Ne (relic from CNO cycle + He burning): $^{14}N(\alpha,\gamma)^{18}F(\beta^+,\nu_e)^{18}O(\alpha,\gamma)^{22}Ne \Leftrightarrow$ **$\eta = 1-2[Z_A/A_A] = 0.101xZ$** [Timmes et al. 03, ApJ 590, L83].

- It is **unclear how η is affected by the simmering phase** in the pre-explosion WD [Chamulak et al. 08, ApJ 677, 160].

- Outside the central ~0.2 $M_\odot$ of ejecta, **the Mn/Cr ratio is a good tracer of η**, independent of explosion brightness (^{56}Ni mass) ⇒ **Z~0.05 for Tycho**.





Why Study Type Ia SNRs?

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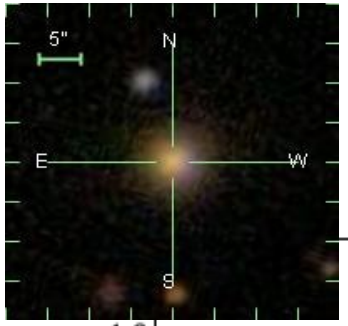
- Much of what we know about **Type Ia SN progenitors** comes from the **stellar populations in their host galaxies** ⇒ **metallicities, ages, SFRs, SFHs**.

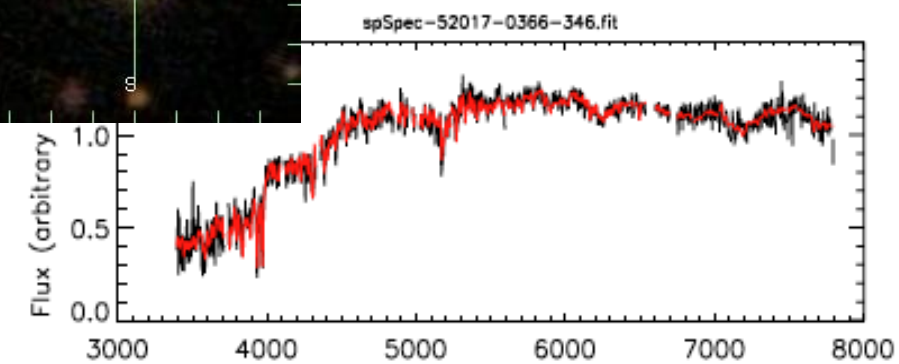
- **Issues** [Manucci, Maoz talks]**:**
  - **Unresolved stellar populations** ⇒ luminosity weighted spectra/SED [Conroy et al. 09, ApJ 699, 486].
  - **Measurements are not local** ⇒ age and metallicity gradients.

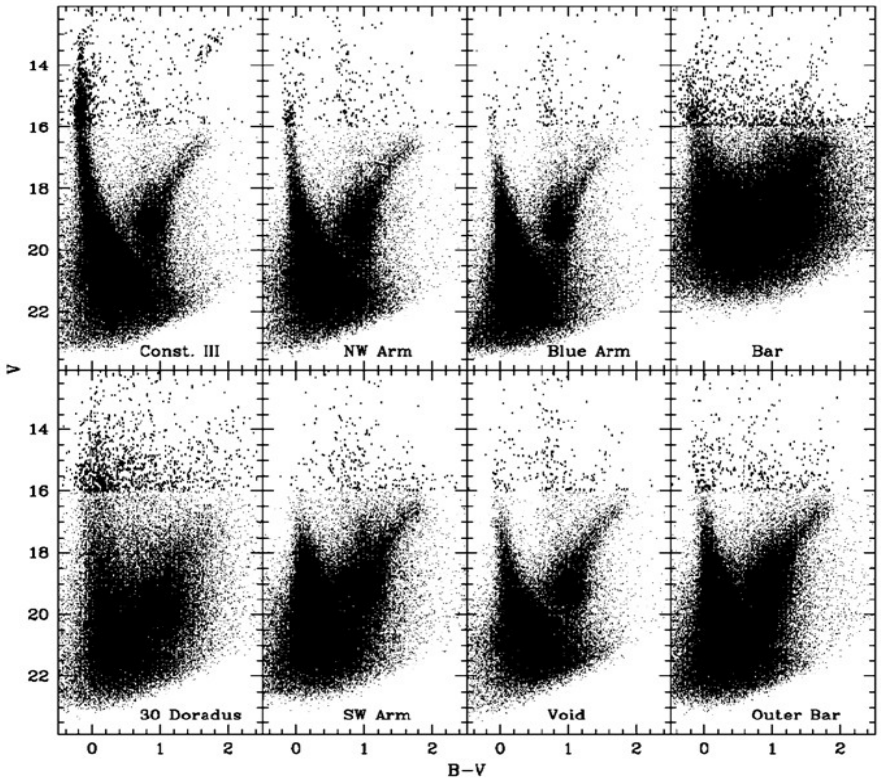
- By using **supernova remnants (SNRs)**, it possible to study **resolved stellar populations (RSPs) at the location of the SN progenitors** ⇒ Milky Way, LMC, SMC, M31, M33...

Key Window onto SN Ia progenitors!



Typical SDSS galaxy
[Tojeiro et al. 09, ApJS 185,1]





Core Collapse SNRs

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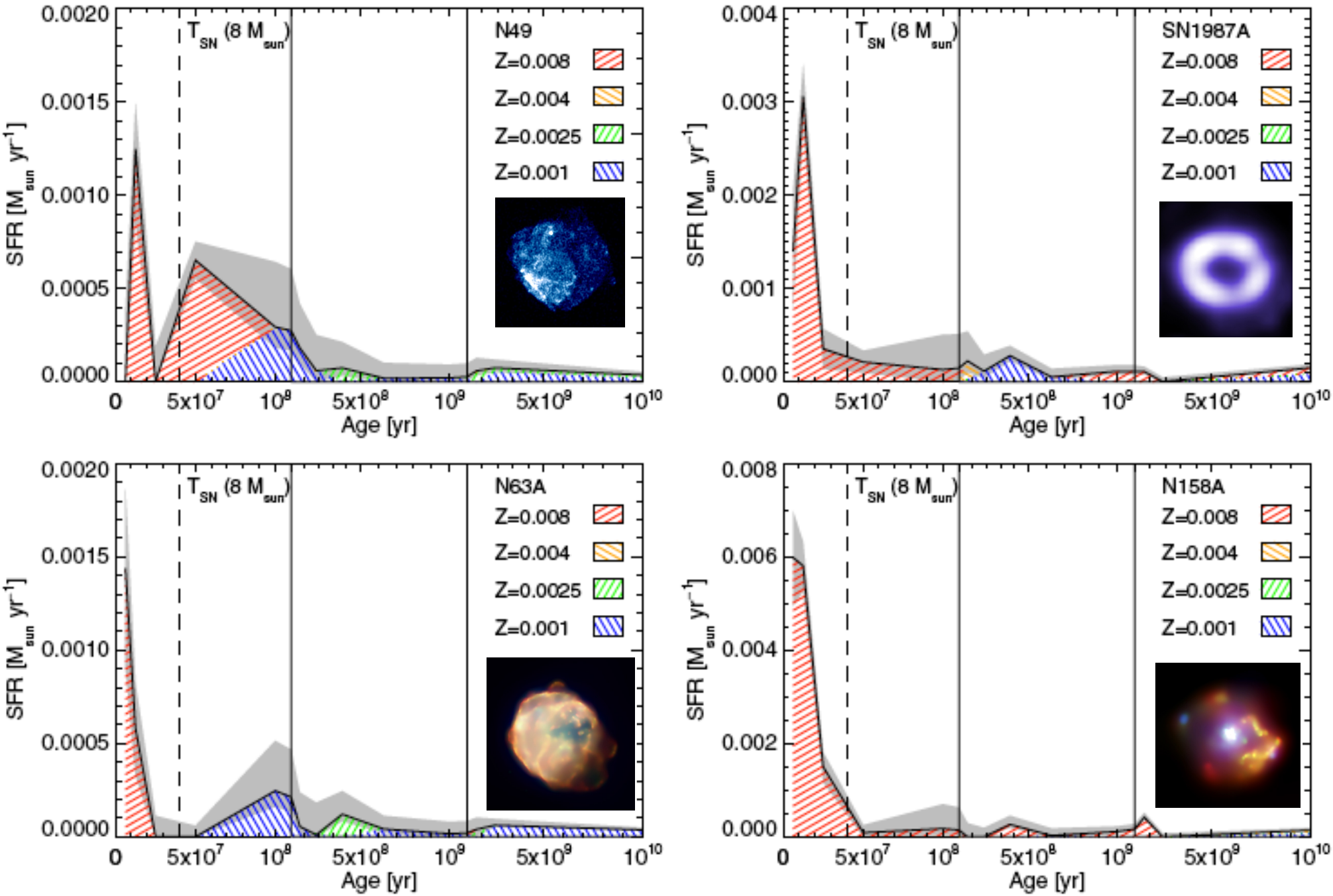

Type Ia SNRs

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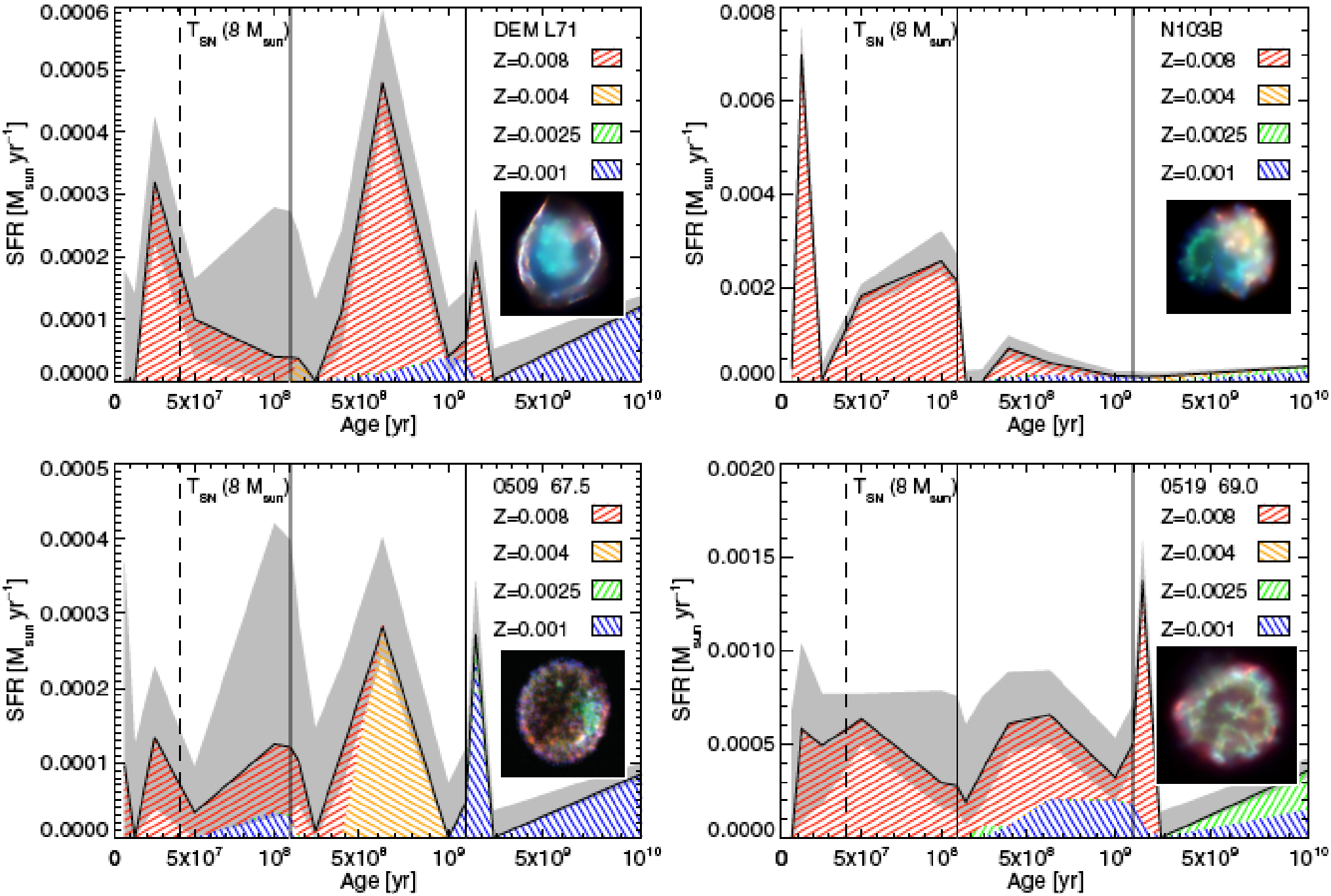

SNRs 0509-67.5 and N103B

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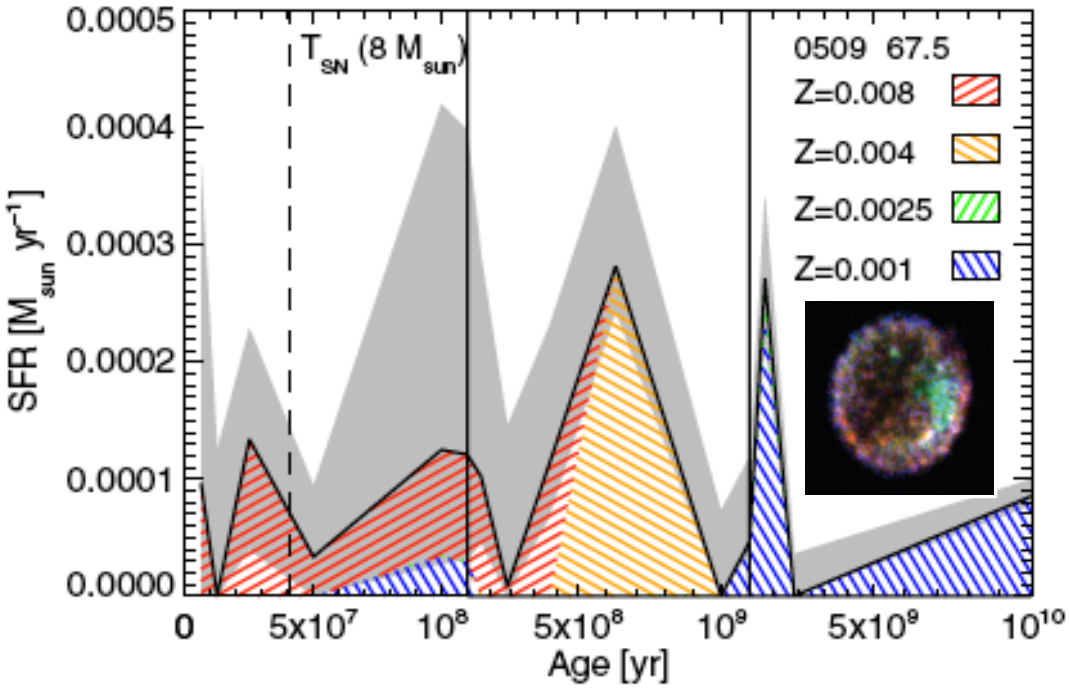
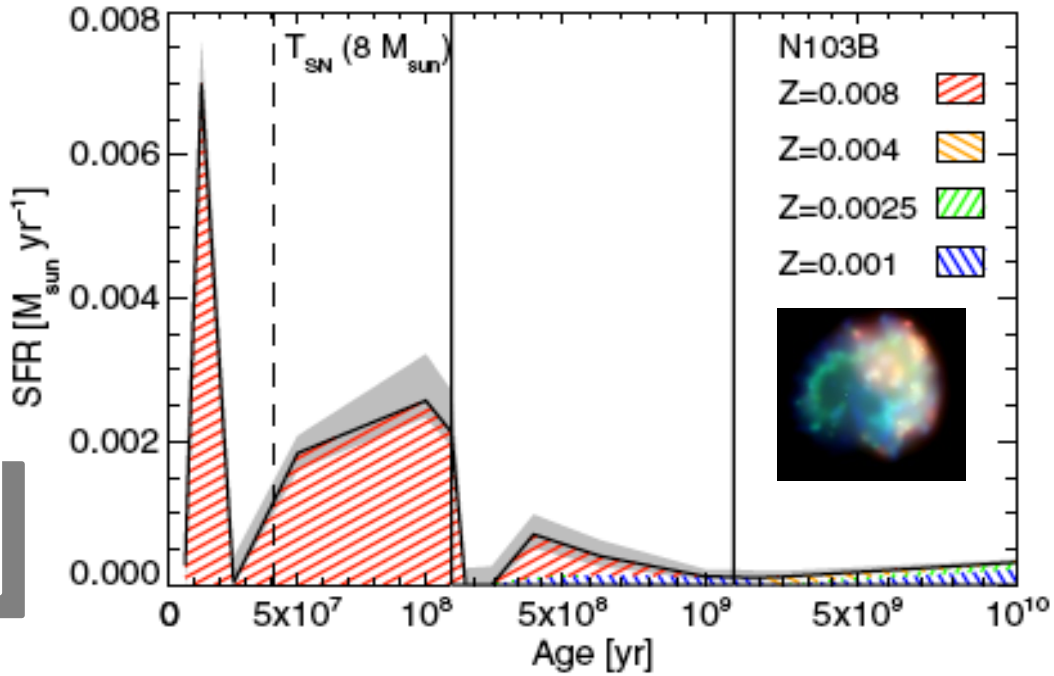
- **SNR 0509-67.5** was originated by a very **bright Type Ia SN** (M_{56Ni}~$1M_{\odot}$). Δ_{m15}<0.9 [Rest et al. 08, ApJ 680, 1137] ⇒ M_V ~ -19.5. Yet, it is embedded in an **old (7.9 Gyr) and metal-poor (Z=0.0014) stellar population**.

- **SNR N103B**, on the other hand, is **associated with vigorous SF in the recent past** (t<100 Myr). Its morphology shows signs of interaction [Lewis et al. 03, ApJ 582, 770]. Maybe it had a young(er), more massive progenitor that lost a large amount of mass before the explosion.





No definitive claims about the progenitors can be made from the SFHs alone!

Use the entire SNR population!

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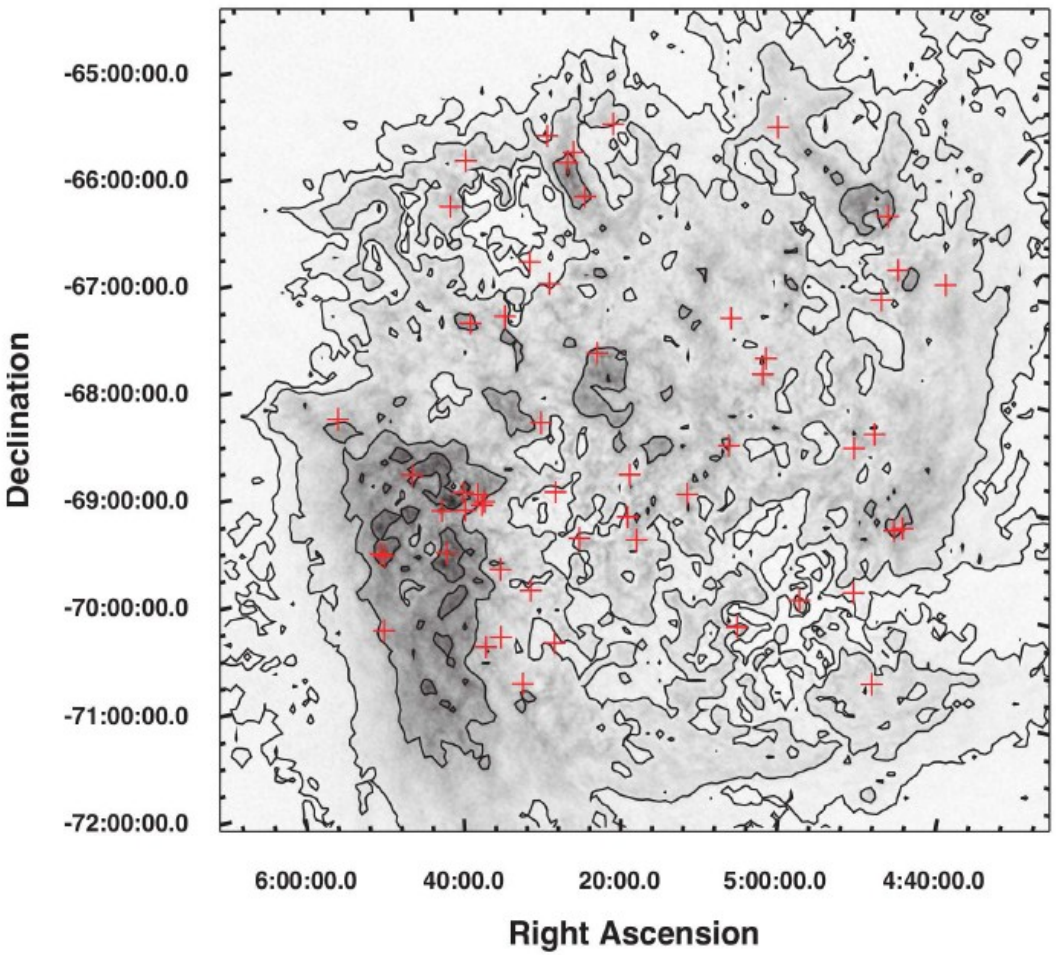
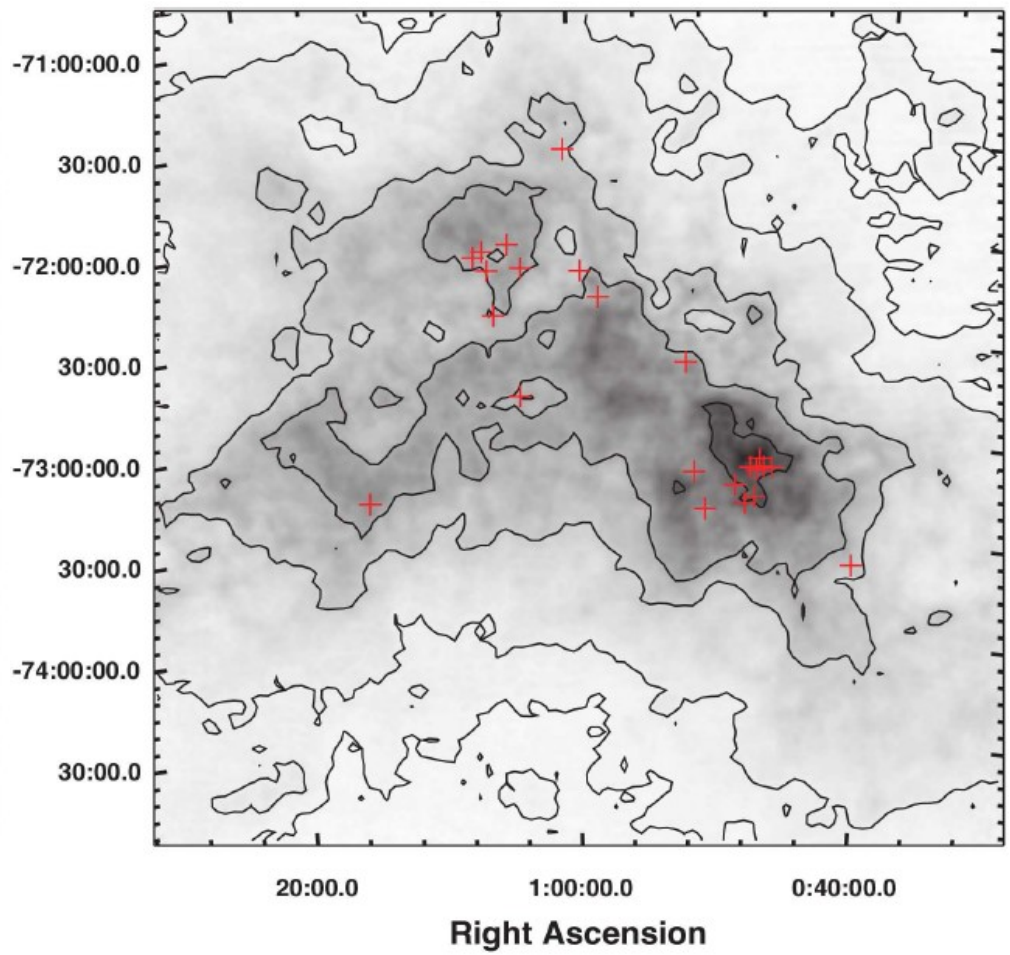
- There are **77 known SNRs in the MCs** (54 in the LMC, 23 in the SMC) ⇒ clean record of the environments where SNe explode.

- We don't know the **types** or the **ages**, we just know the **sizes**. Type is not a problem if DTD has enough resolution. **Age** is more delicate ⇒ **control time**.





SN Rates and DTD from RSPs!

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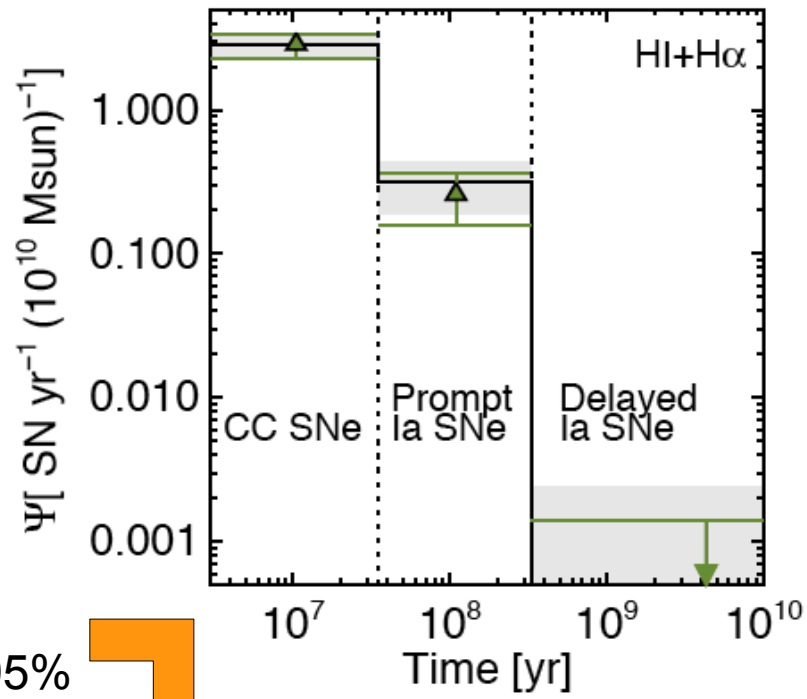
- **Use all available information to derive DTD** (avoid a-posteriori statistics).
- SN rate ~ 1/200 to 1/500 yr, consistent with historical records [Badenes et al. 08 ApJ 680, 1149].
- **1st resolved stellar population DTD**, but limited quality (only 77 SNe!).



Rates typical of dwarf galaxies

Prompt (<330 Myr) SNe Ia detected > 95%

Density Tracer	Mean SNR Visibility [kyr]	SN Rate [10^{-3} SN yr^{-1}]	SN Rate [SNuM]	Ψ_i [SNe yr^{-1} (10^{10} M$_\odot$)$^{-1}$] Ψ_1[a] 0-35 Myr	Ψ_2 35-330 Myr	Ψ_2 (95% low lim.)	Ψ_3 0.33-14 Gyr
HI	13.3	4.1 ± 0.9	3.0 ± 0.7	$2.86^{+0.66}_{-0.50}$	0.389 ± 0.131	(> 0.171)	< 0.0014
SFR (Schmidt law)	22.5	2.4 ± 0.4	1.7 ± 0.3	$2.86^{+0.50}_{-0.43}$	0.091 ± 0.057	(> 0.016)	< 0.0014
Hα (Schmidt law)	13.9	3.3 ± 0.6	2.3 ± 0.4	$2.86^{+0.54}_{-0.50}$	0.194 ± 0.086	(> 0.060)	< 0.0016
No Scaling	13.4	5.8 ± 0.1	3.5 ± 0.7	$2.86^{+0.61}_{-0.50}$	0.316 ± 0.125	(> 0.143)	< 0.0024
HI+Hα	12.6	3.8 ± 0.8	2.6 ± 0.5	$2.86^{+0.57}_{-0.52}$	0.260 ± 0.100	(> 0.104)	< 0.0014
HI+SFR	15.9	3.1 ± 0.6	2.1 ± 0.4	$2.86^{+0.51}_{-0.51}$	0.165 ± 0.080	(> 0.058)	< 0.0013

High Velocity Calcium?

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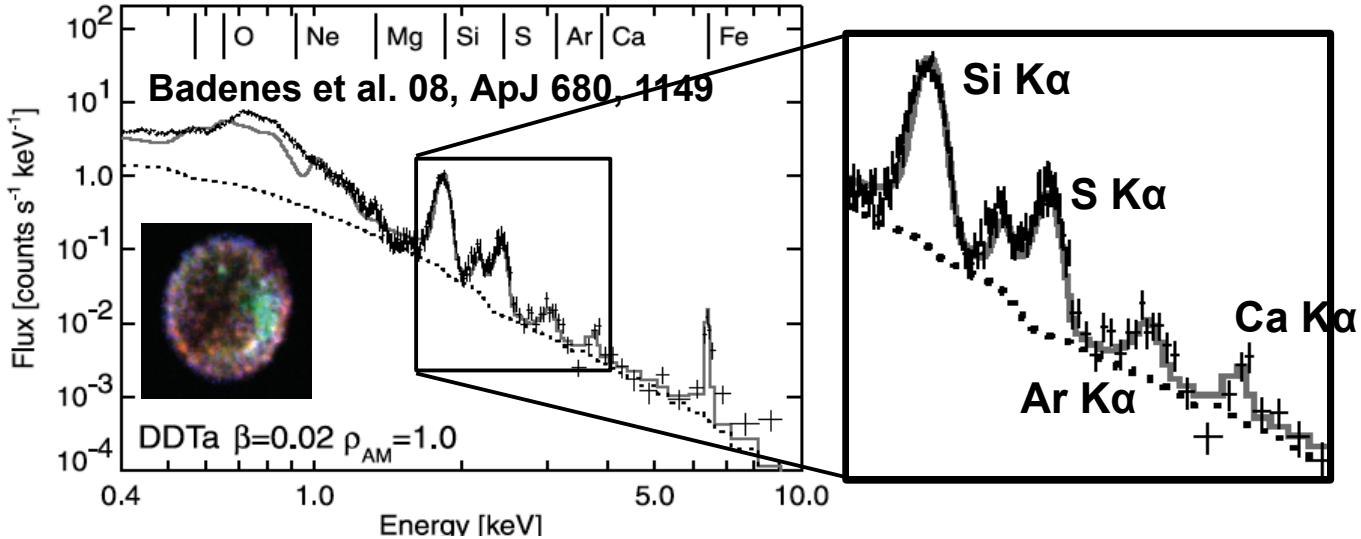
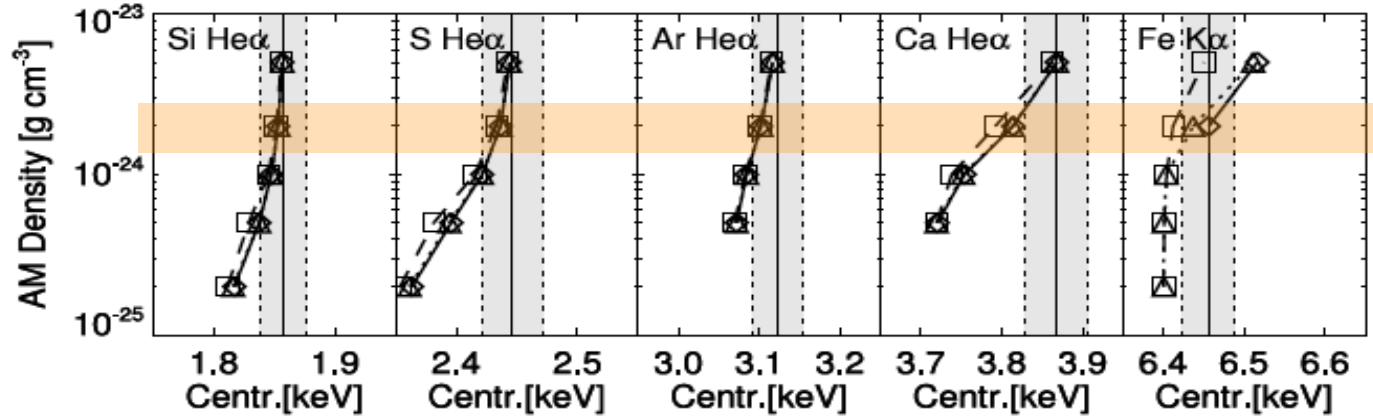
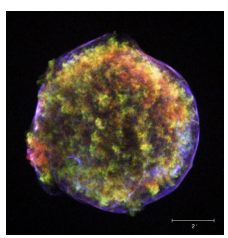
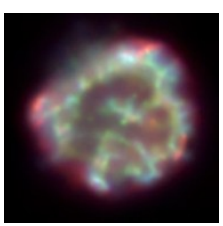
- In several Ia SNRs, **Ca appears to be more ionized than Ar and Si** (either wrt to 1D DDT models or in absolute terms) ⇒ **shocked earlier, at higher density**.
- HV Ca??? [Mazzali et al. 05 ApJ 623, L37].





Badenes et al. 06, ApJ 645, 1373





Kosenko et al. 10, A&A 519, 11

Component number	1		2		3	4	5	0
Layer	O	Si	S	Ar	Ca	Fe-high	Fe-low	CSM
EM_X (10^{54} cm^{-3})	$8.87^{+3.39}_{-0.45}$	$2.47^{+0.31}_{-0.14}$	$1.56^{+0.20}_{-0.09}$	$0.78^{+0.63}_{-0.38}$	$0.60^{+0.49}_{-0.29}$	$2.52^{+0.32}_{-0.35}$	$2.15^{+0.17}_{-0.36}$	$2.36^{+0.50}_{-0.11} \times 10^5$
kT_e (keV)	$0.72^{+0.70}_{-0.24}$	$7.00^{+3.00}_{-2.26}$	$7.00^{+3.00}_{-2.26}$	$2.67^{+10.00}_{-1.17}$	$2.67^{+10.00}_{-1.17}$	$2.73^{+0.07}_{-0.27}$	$1.26^{+0.44}_{-0.26}$	$0.64^{+0.02}_{-0.06}$
$n_e t$ (10^{10} s cm^3)	$1.52^{+3.66}_{-0.92}$	$3.63^{+0.27}_{-0.18}$	$3.63^{+0.27}_{-0.18}$	$27.2^{+N/A}_{-18.8}$	$27.2^{+N/A}_{-18.8}$	$3.78^{+0.34}_{-0.26}$	$2.55^{+0.56}_{-0.39}$	$80.0^{N/A}_{-13.4}$
n_e/n_X	6.6	21.2	33.7	30.5	39.6	19.6	17.5	1.2

Conclusions: SN Ia Progenitors from SNRs

Jacco's talk:

- **No evidence for ionized bubbles** (no "naked" SSSs).
- **No evidence for fast accretion winds** (lack of cavities).
- Ia SNRs are "well behaved" (**spherical** explosions/CSM).

At least **one object (Kepler/SN1604) shows evidence for slow wind/non-conservative mass accretion**.

This talk:

- X-ray spectra of Type Ia SNRs are **well reproduced by M_{Ch} 1D DDT** models (except maybe the spatial distribution of Ca).
- This can be used to **determine the SN Ia subtype** (dim/bright ⇔ ^{56}Ni ⇒ Fe). Two confirmations with light echoes (Tycho, SNR 0509-67.5).
- The **key advantage of SNRs is the ability to study the environment: CSM + Resolved stellar populations**.
- **Mn/Cr ratio is a diagnostic for fundamental pre-explosion physics** (neutron excess, progenitor metallicity?) [Borkowski talk].

Models vs. Observations: SNR 0509-67.5

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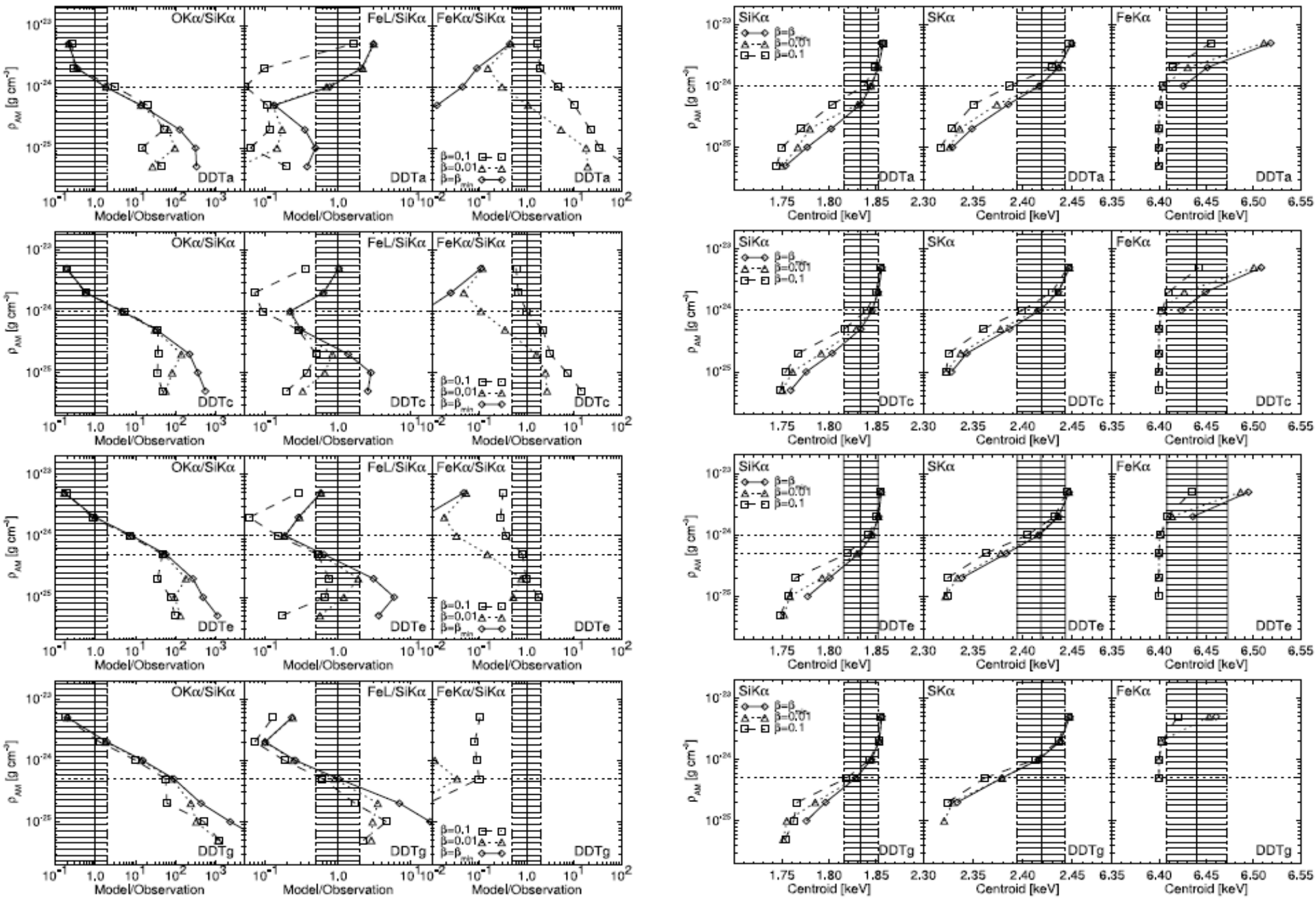

The Future: IXO

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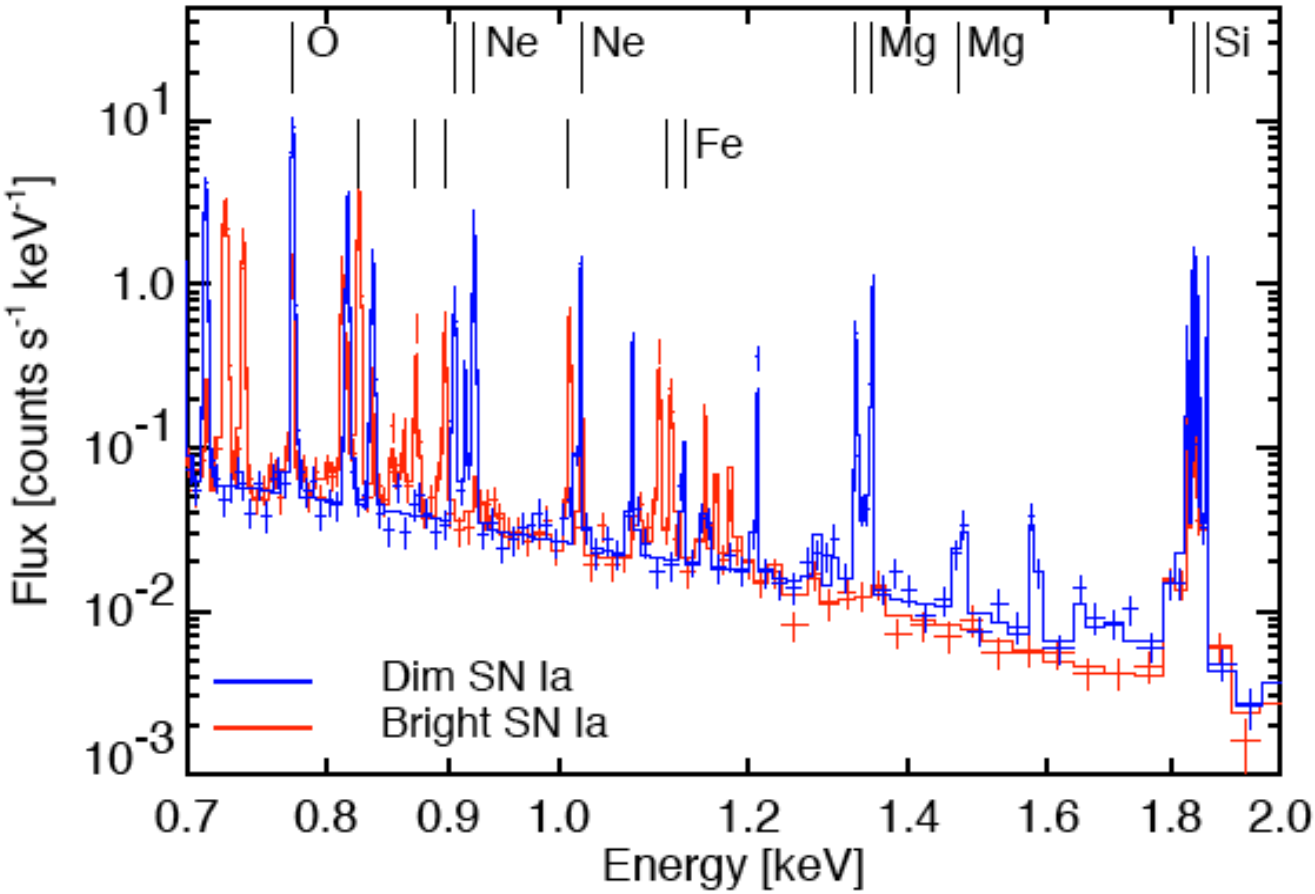
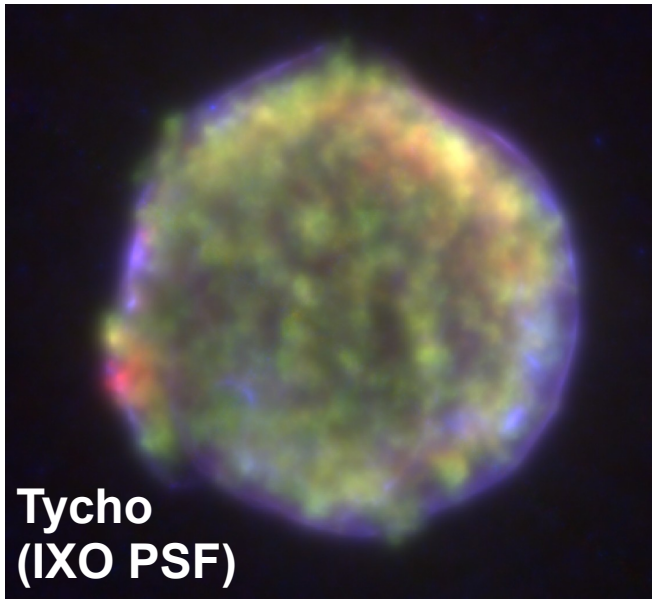
- **CCD spectra** have been used to determine bulk yields and relative abundances ⇒ next step: Multi-D HD+NEI.
- **Non-dispersive high resolution spectroscopy of extended sources** will open new frontiers: local velocity measurements, disentangling the Fe L complex, measuring the metallicity of SN Ia progenitors...





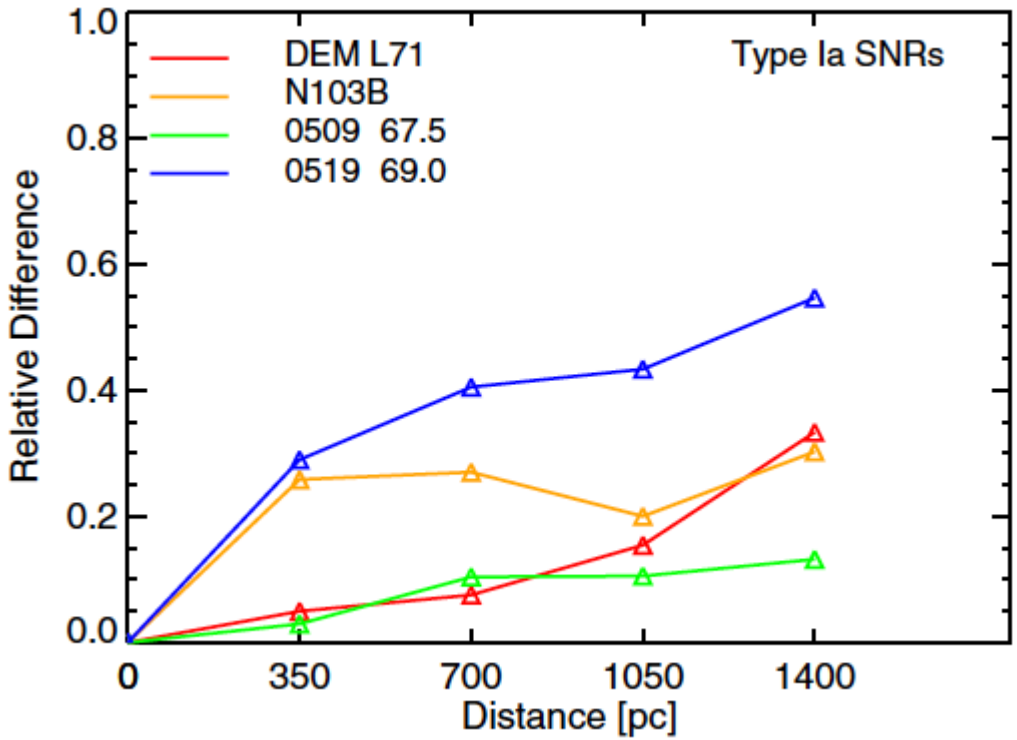
Simulated IXO spectra of t~400 yr SNRs from a dim (blue) and bright (red) Type Ia SN

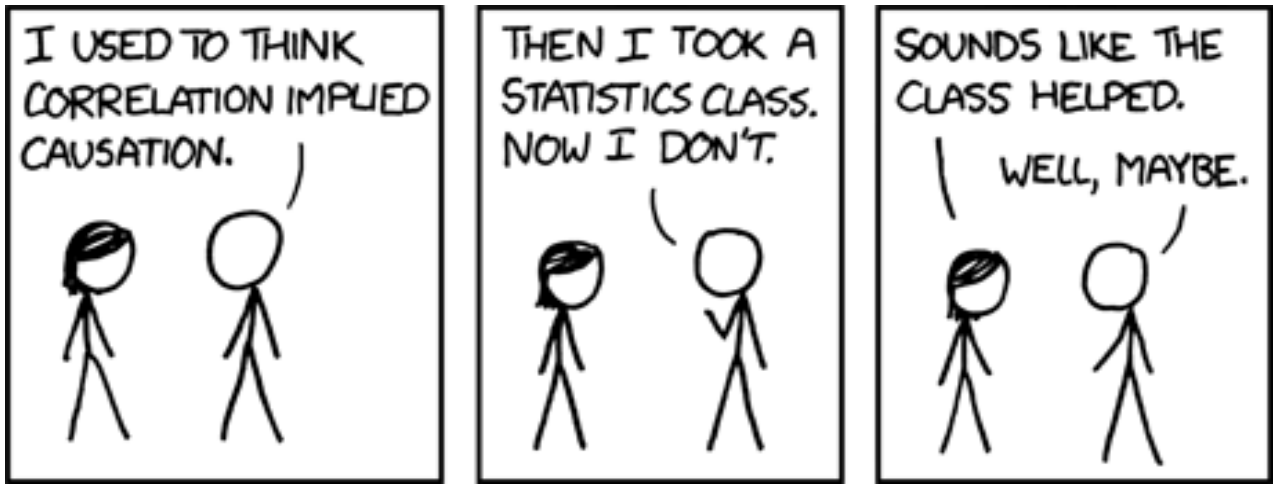
Beware of statistics!

- It is extremely dangerous to **overinterpret the results from single objects**.

- **Diffusion** will affect SN progenitors on timescales of ~few 100 Myr.

- Watch out for **a posteriori statistics**.





DTD from RSPs: the future

Carles Badenes
Leiden 09/23/10

- **Homogeneous SNR catalog** of 144 SNRs [Long et al. 10 ApJS 187, 495].
- Work in progress (w/ S. Trager and A. Monachesi).