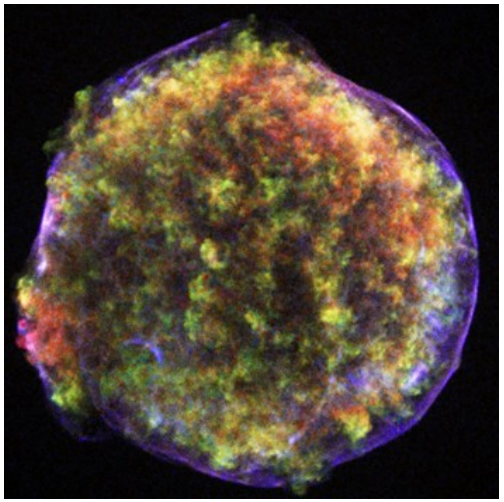

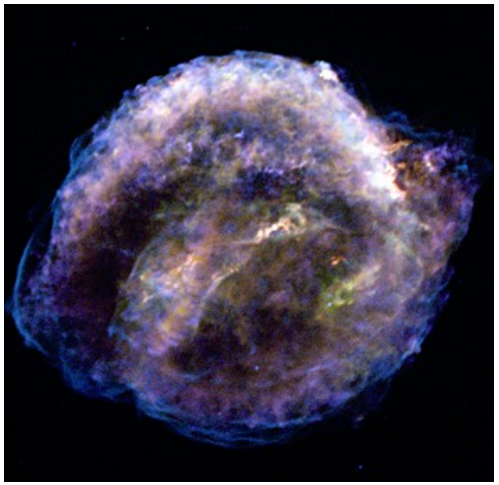

Spectral Diagnostics in Type Ia SNRs

ATOMDB Workshop
Cambridge, MA, 08/10/12

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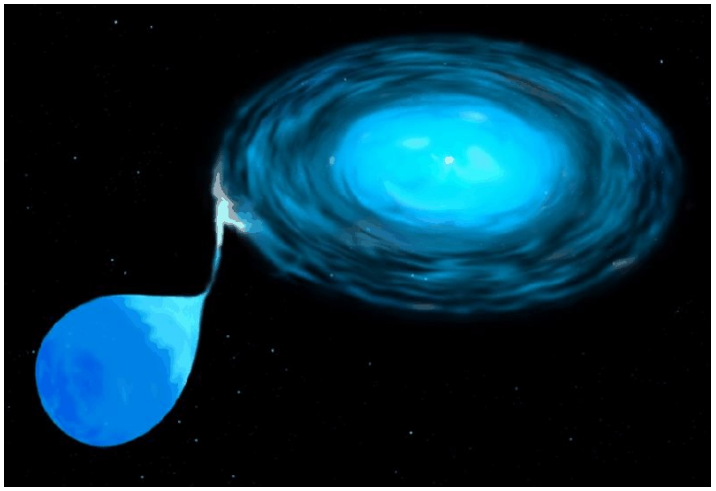
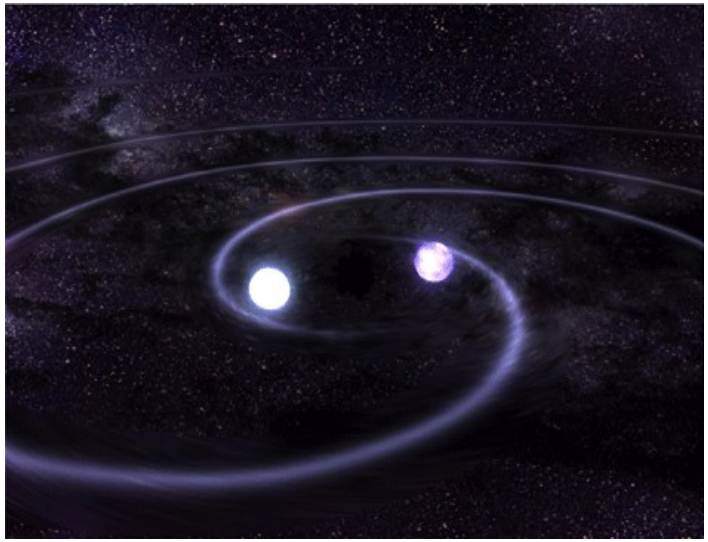
Matt Schell (U. Pitt), **Dan Patnaude** (SAO), **Sangwook Park** (UT Arlington), **Kris Eriksen** (LANL), **Jack Hughes** (Rutgers)

Motivation and Outline

We know very little about the progenitors of Type Ia SNe

- **Progenitor models: single degenerate / double degenerate.**
- **Direct clues are scarce and ambiguous.**
- **SN Ia produce most of the Fe-peak elements in the Universe.**
- **SNRs are much closer than SNe and can be studied in greater detail.**

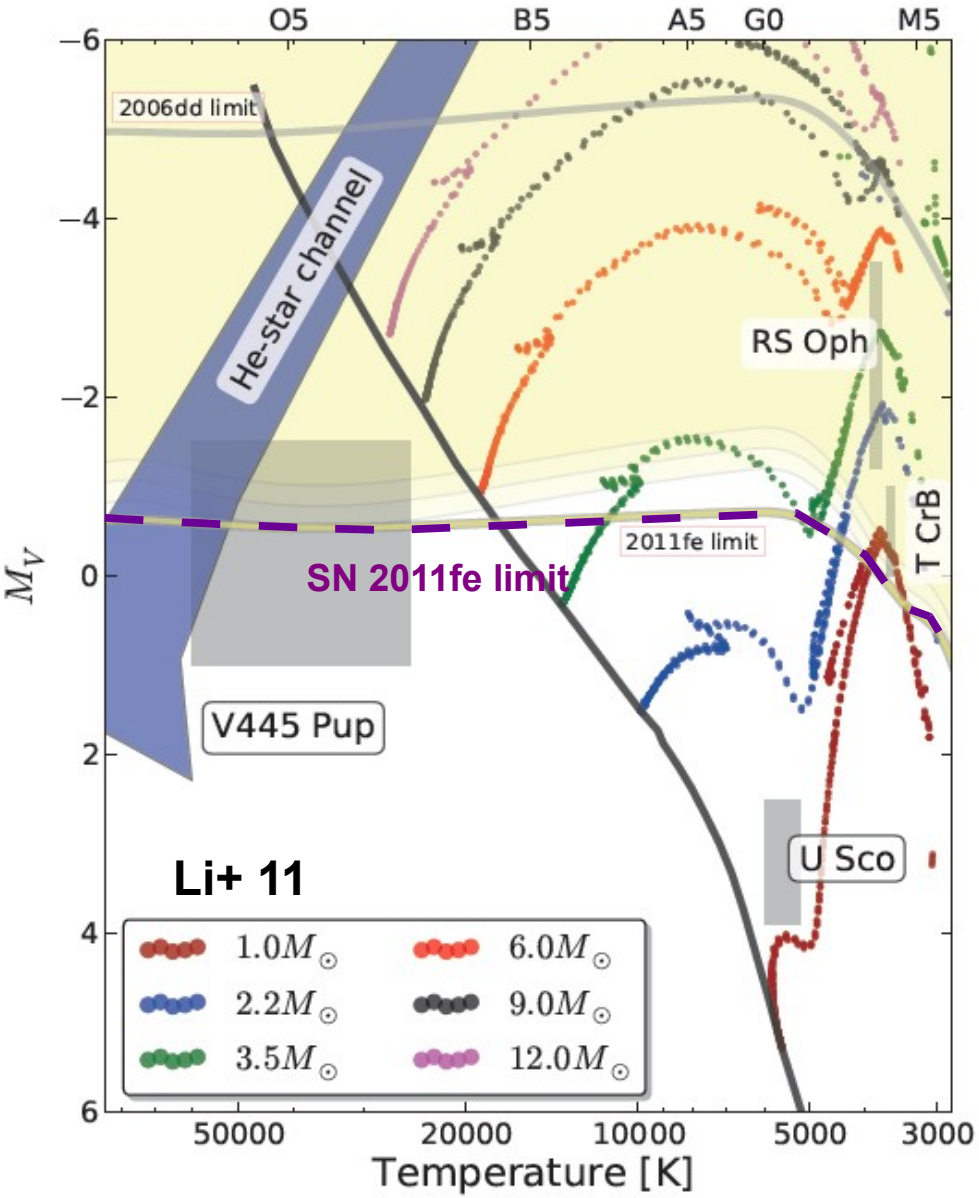




SN Ia Progenitors: Clues

SN Ia are thermonuclear explosions of C/O WDs destabilized by accretion in binary systems.

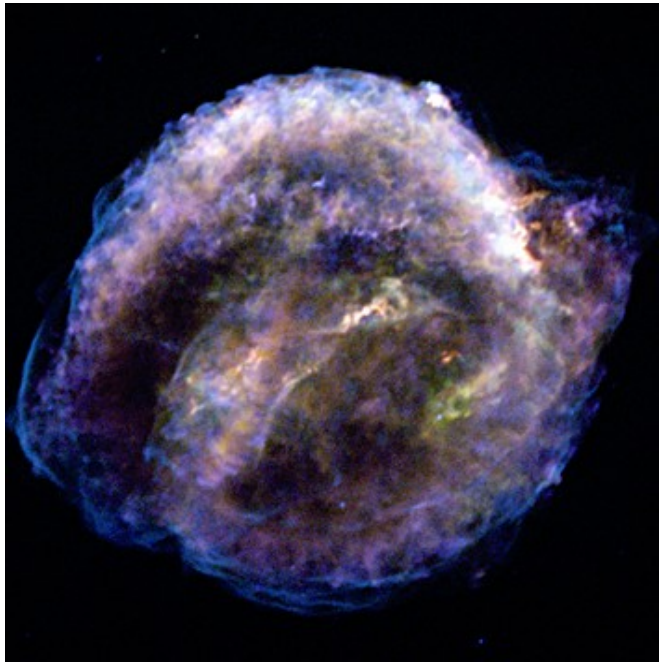
- **Very little H** [Leonard 07].
- **Small** (~R_{WD}) [Nugent + 11, Bloom+ 11].
- **Faint** [Maoz & Mannucci 08, Li+ 11].
- **No early interaction** [Bianco+ 11].
- **Not much CSM near** [Hughes+ 07, Horesh+ 11, Chomiuk+ 11] **or far** [Badenes+ 06,07,08, Patnaude+ 12, but see Williams+ 11].
- **No bright companion left behind** [Kerzendorf+ 09, Schaefer+ 12].

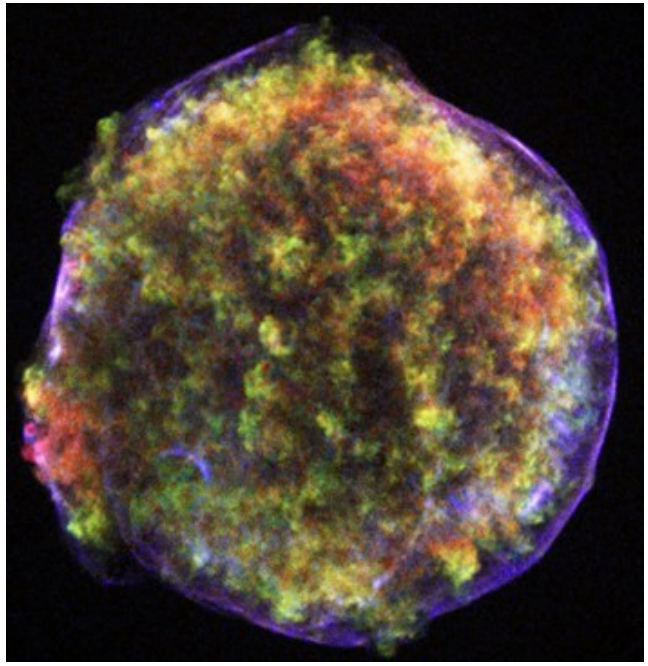


Type Ia SNRs

Type Ia SNRs allow us to study SN Ia explosions and their progenitors in great detail

- **Detailed view of the ejecta structure** thanks to the angular resolution of *Chandra*.
- **Young SNRs might be still interacting with the CSM expelled by the SN progenitor**.
- **New perspective on SN Ia** [Badenes 10].

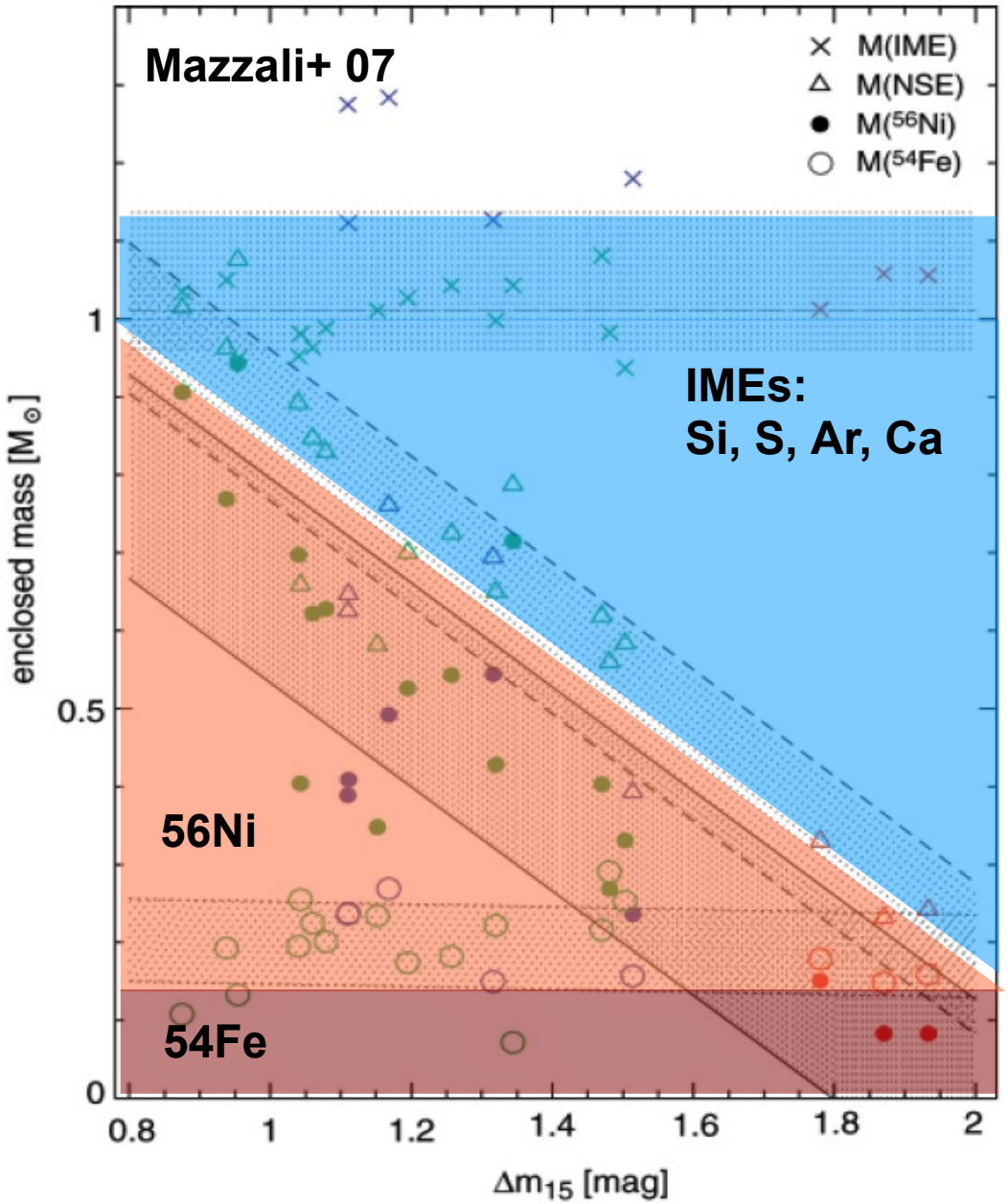




The SNR road to Stockholm

SN Ia: Nucleosynthesis

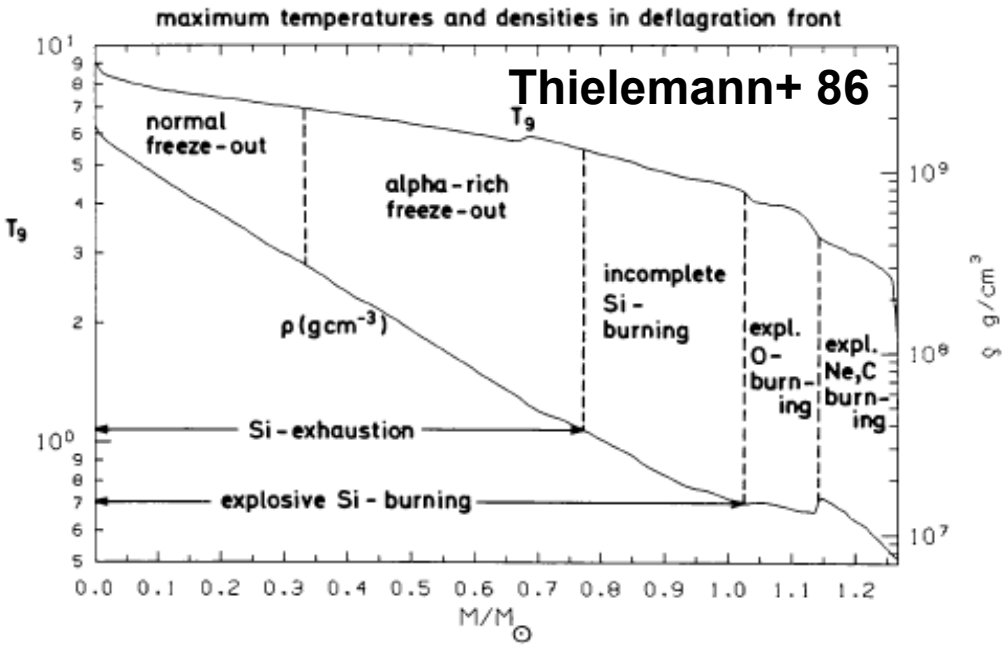
- **Phillips Relation: Brighter SNe have broader LCs** [Phillips 93].
- **LCs powered by ^{56}Ni decay**.
- **Brighter SN Ia have more ^{56}Ni** (up to ~1 $M_\odot$). They **explode in star-forming galaxies** [Sullivan+ 06].
- **Stratified ejecta**: Fe-peak nuclei on the inside, IMEs on the outside [Mazzali+ 07].
- **Explosive nucleosynthesis** in a C/O WD: deflagrations, detonations and delayed detonations [Nomoto+ 84, Thielemann+ 86].

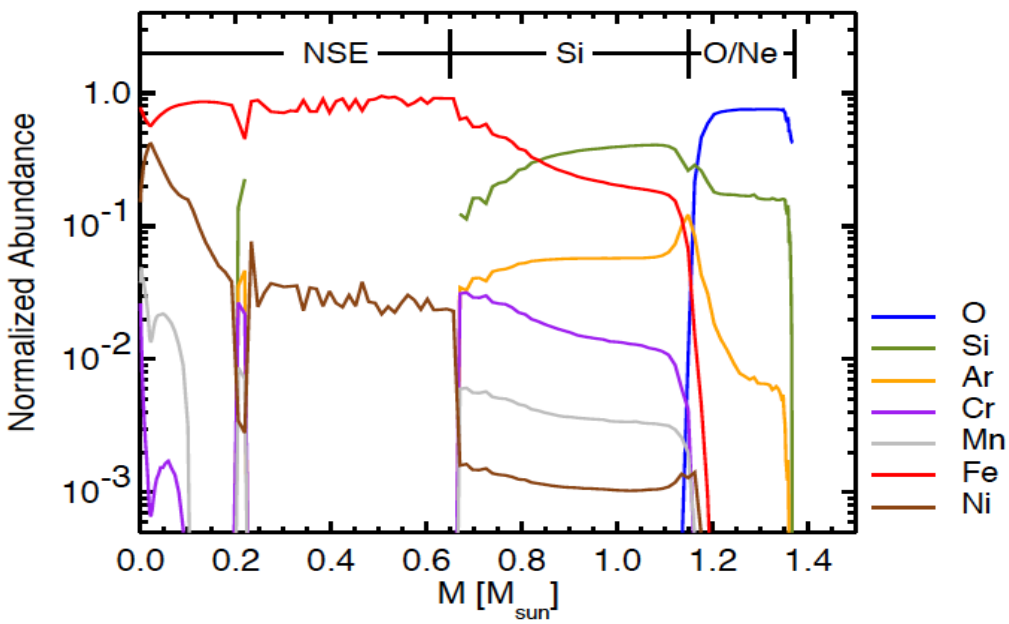


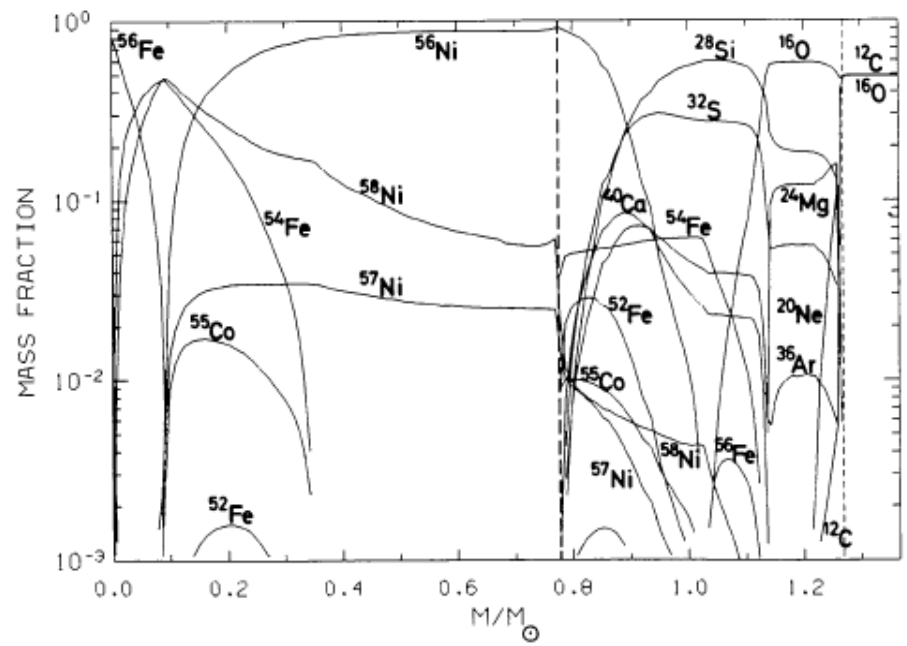
SN Ia: Nucleosynthesis

- Burning regime controlled by peak temperature (and density) [Thielemann+ 86] ⇔ **explosion physics**.

- **NSE** (n-rich) / **Incomplete Si burning** / **Incomplete O burning** ⇒ **ejecta stratification**.







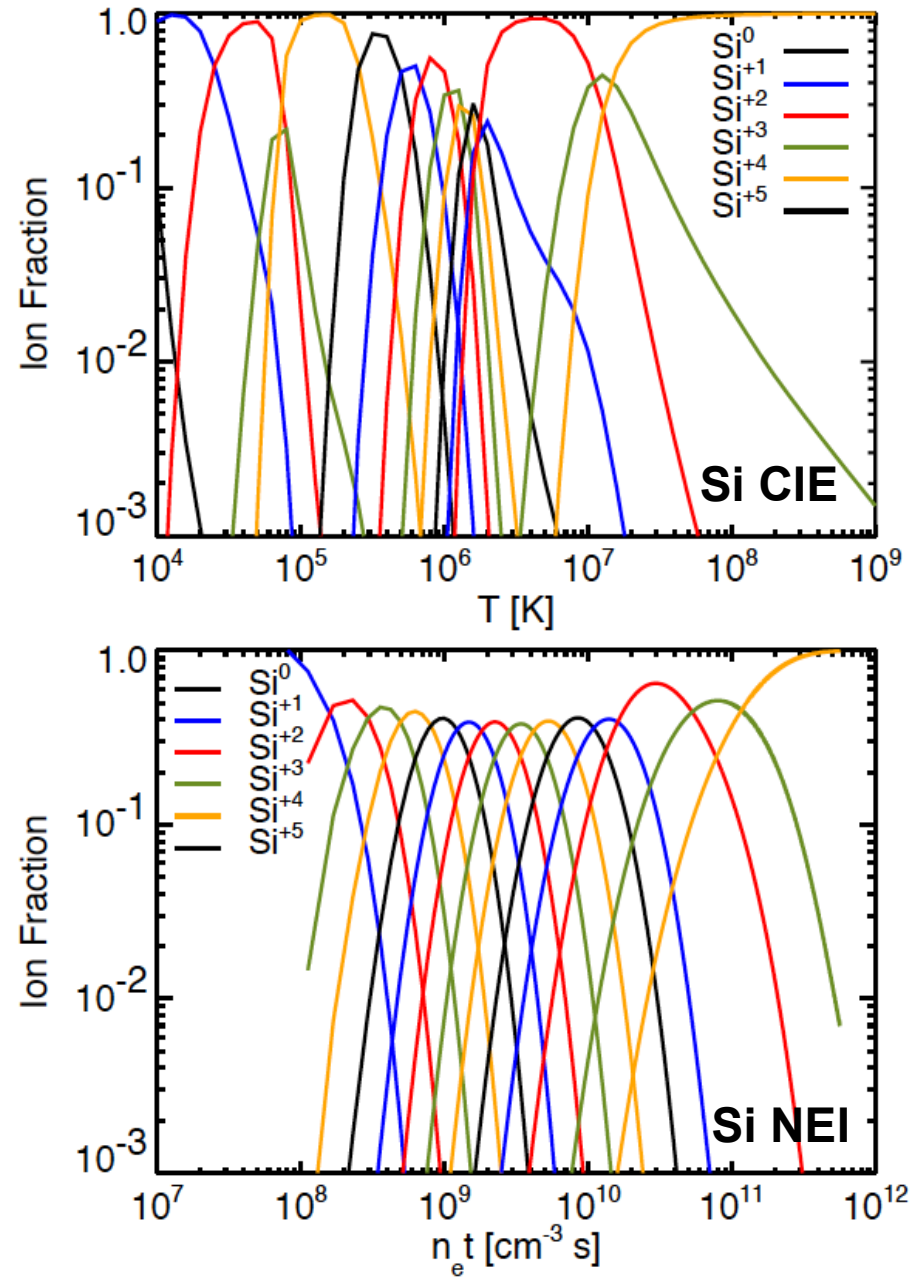
NEI Plasma in SNRs

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

- **Cannot interpret the X-ray spectrum without understanding the bulk dynamics of the ejecta**. Two approaches:

- **Simplify the hydro** (e.g., plane shock models [Hughes+ 00, Borkowski+ 01]) ⇒ Relative abundances, $n_e t$, T_e ⇒ Local plasma.

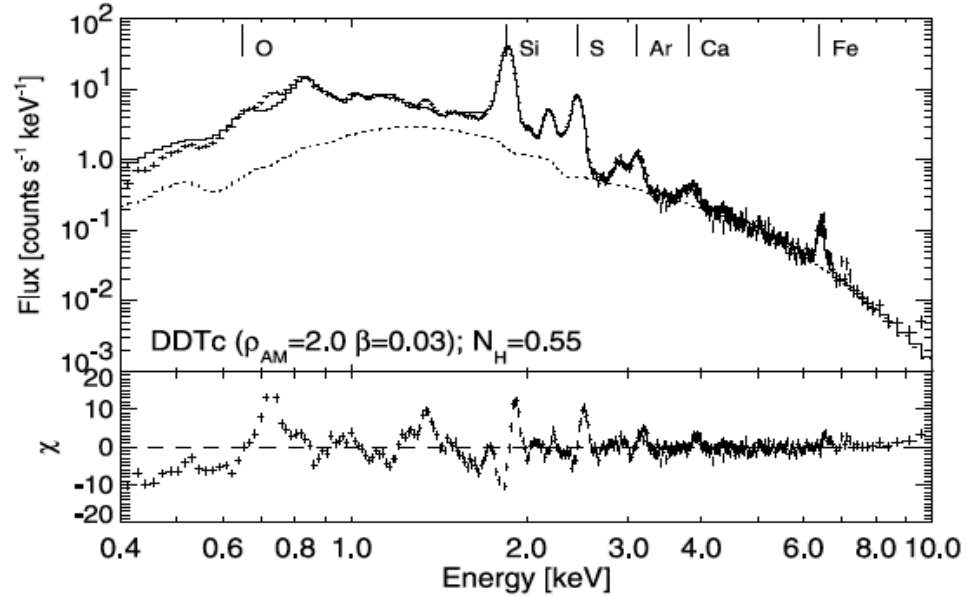
- **Full-fledged HD+NEI** [Hamilton & Sarazin 84; Badenes+ 03; Sorokina+ 04] ⇒ Bulk yields ⇒ Compare to SN physics (so far, 1D!)

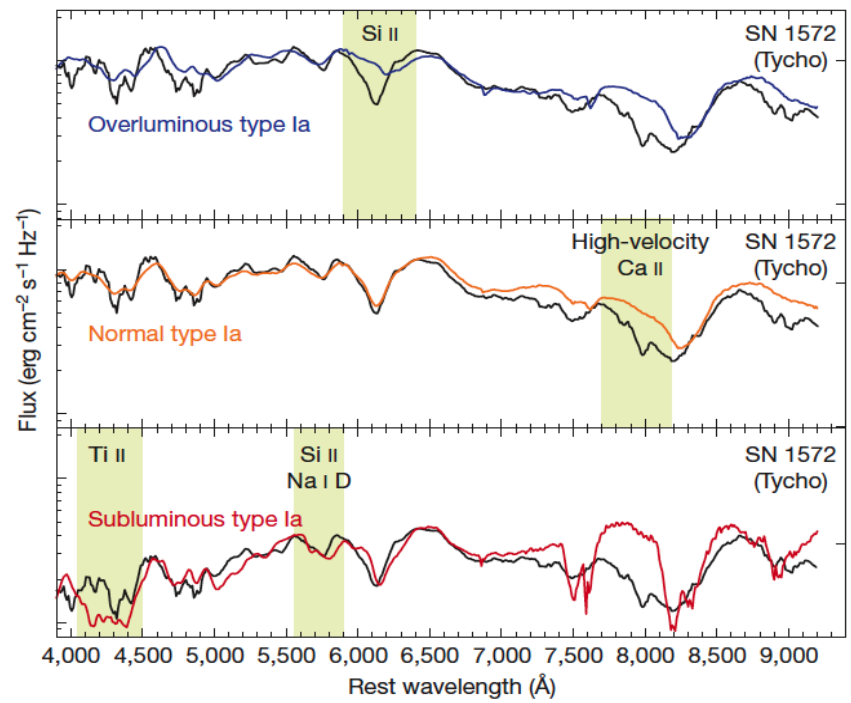


Tycho SNR

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

- See **Badenes+ 03, 05**.
- **SN Ia brightness estimate based on 1D DDT models** ⇔ M_{56Ni}. These models work quite well.
- **Tycho SNR: M_{56Ni}=0.74 $M_\odot$** [Badenes+ 06], a normal SN Ia.
- Later confirmed by **light echo spectroscopy** [Rest+ 08, Krause+ 08].
- **HD+NEI ⇒ synthetic spectrum (APED)**

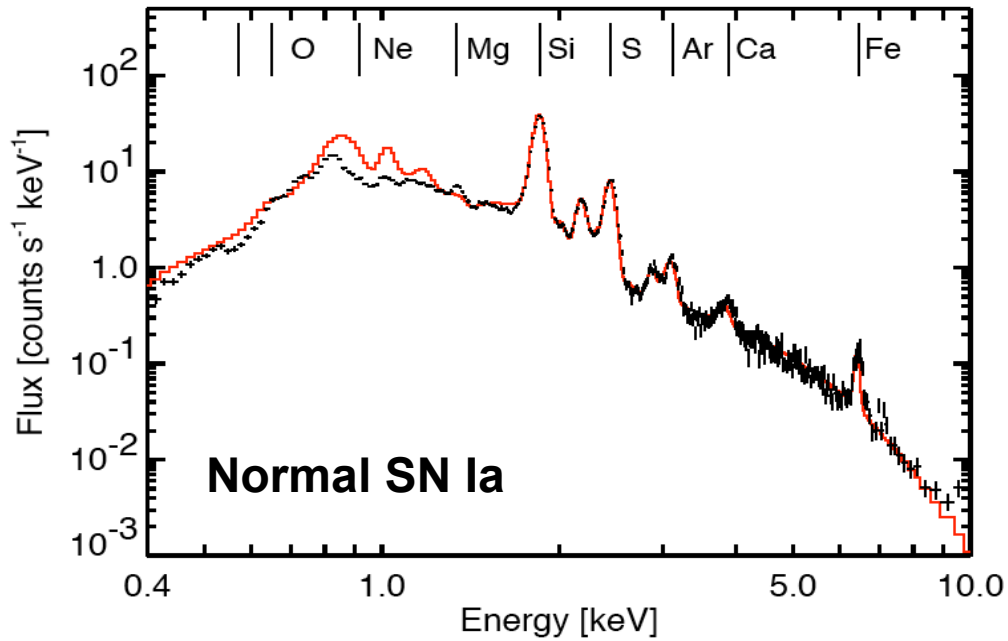


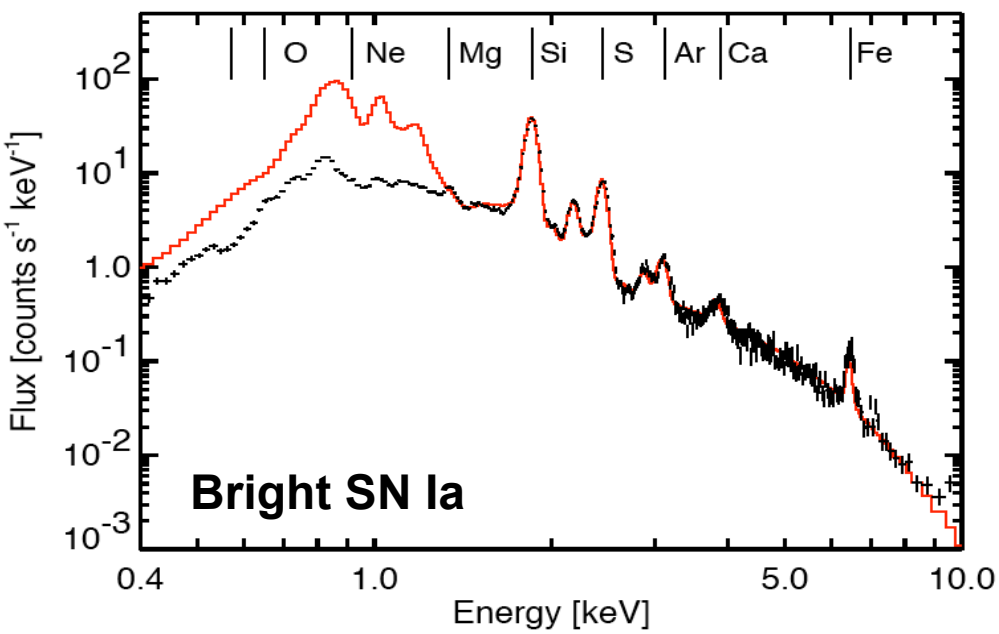


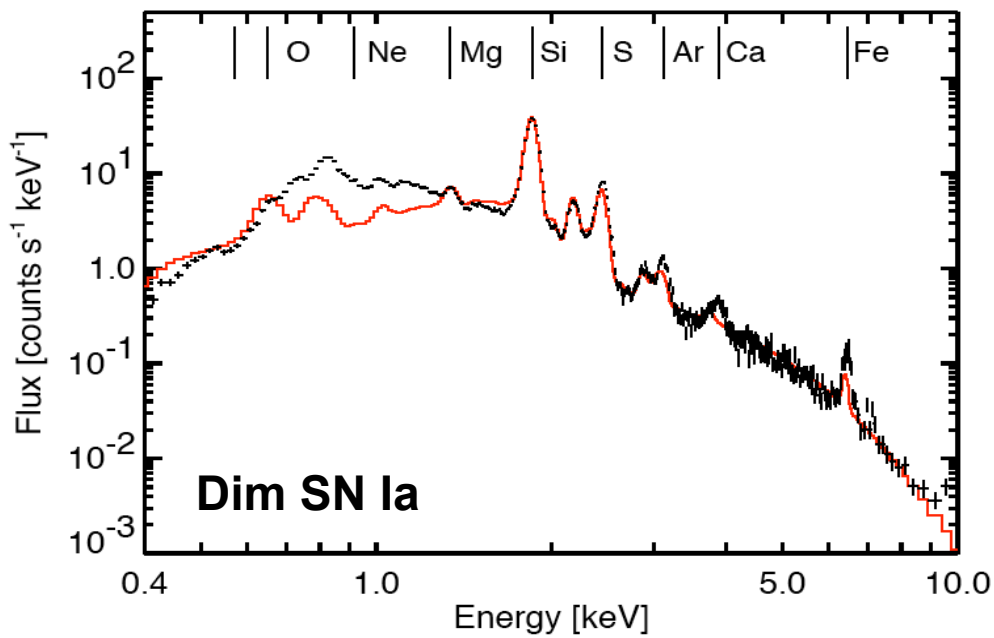
Models vs. Data

- What are we doing here? We are making **extremely crude comparisons between models and data (no χ^2!!!)**.

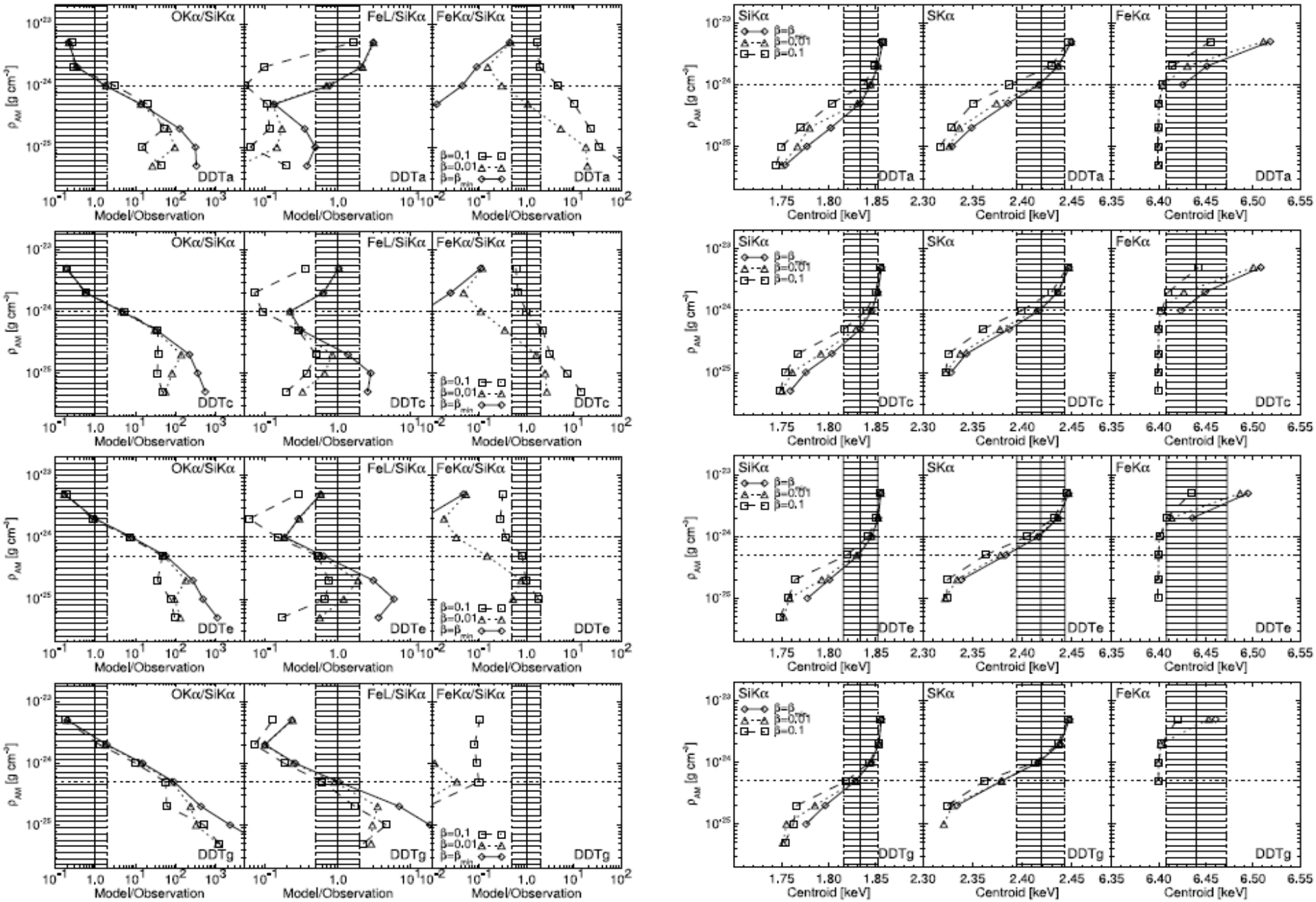
- Given the uncertainties, we can only **constrain the bulk properties of the SN ejecta!**



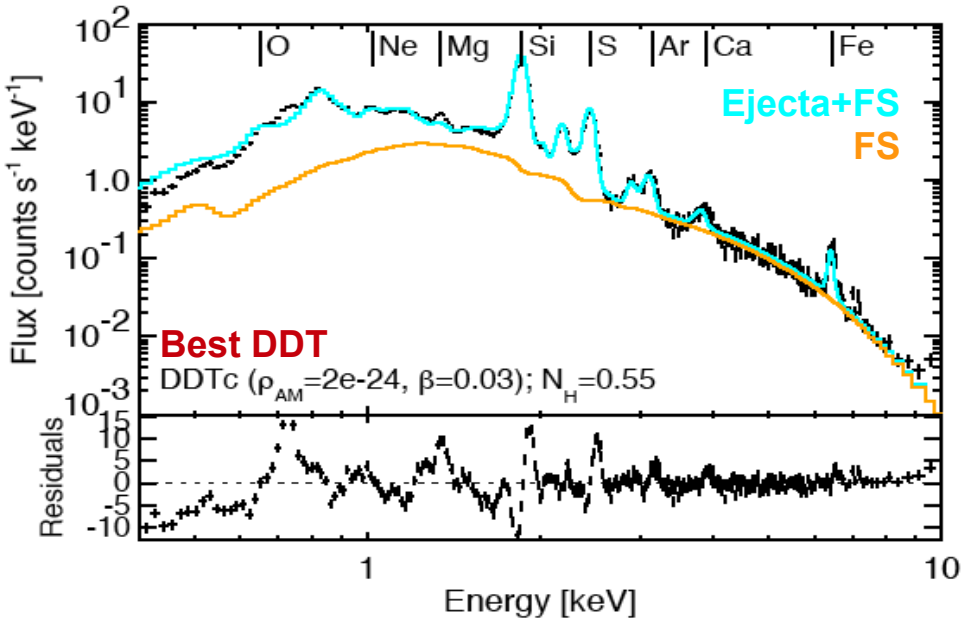


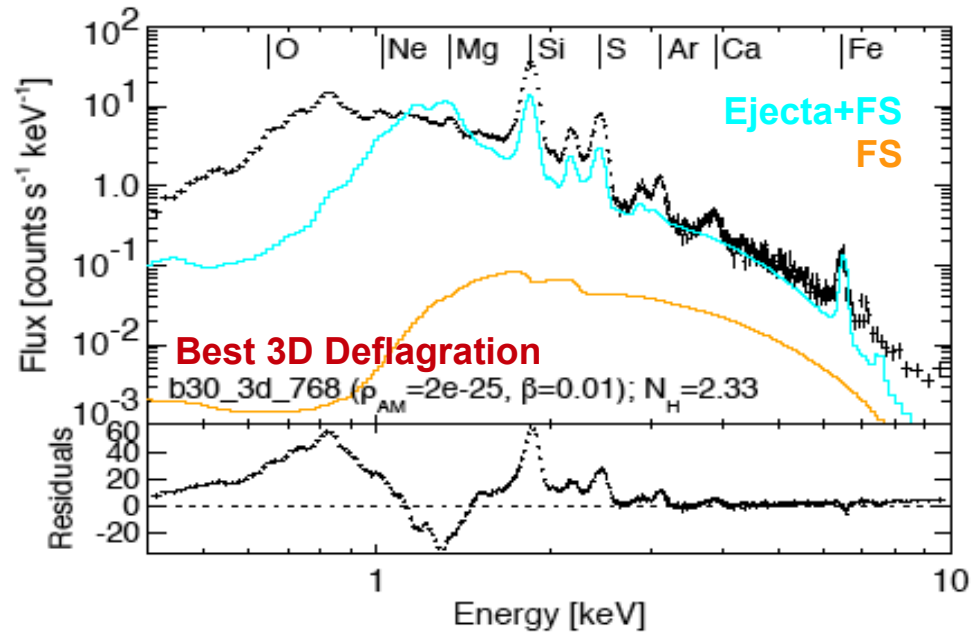


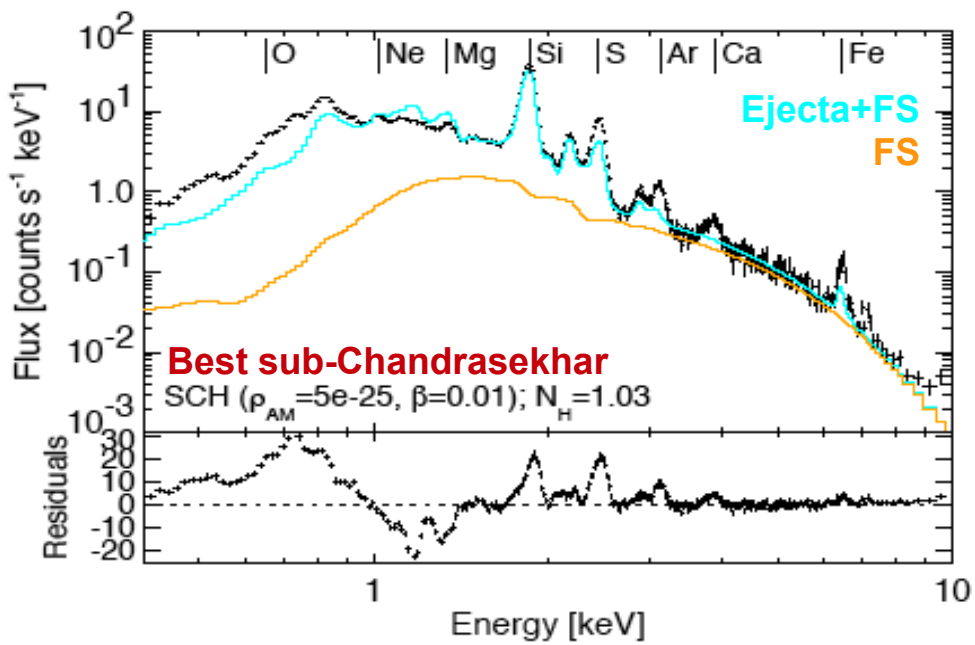
Data vs. Observations

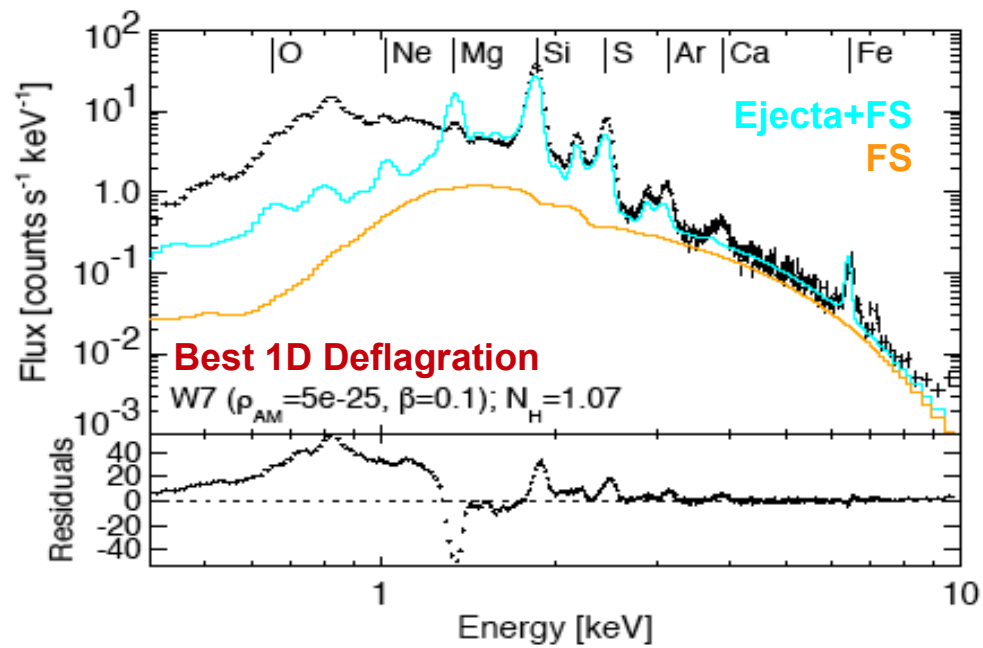


Tycho SNR


O
Ne
Mg
Si
S
Ar
Ca
Fe
Ejecta+FS
FS
Best DDT
DDTc (ρ_{AM}=2e-24, β=0.03); N_H=0.55
Flux [counts s^{-1} keV^{-1}]
Residuals
Energy [keV]


O
Ne
Mg
Si
S
Ar
Ca
Fe
Ejecta+FS
FS
Best 3D Deflagration
b30_3d_768 (ρ_{AM}=2e-25, β=0.01); N_H=2.33
Flux [counts s^{-1} keV^{-1}]
Residuals
Energy [keV]

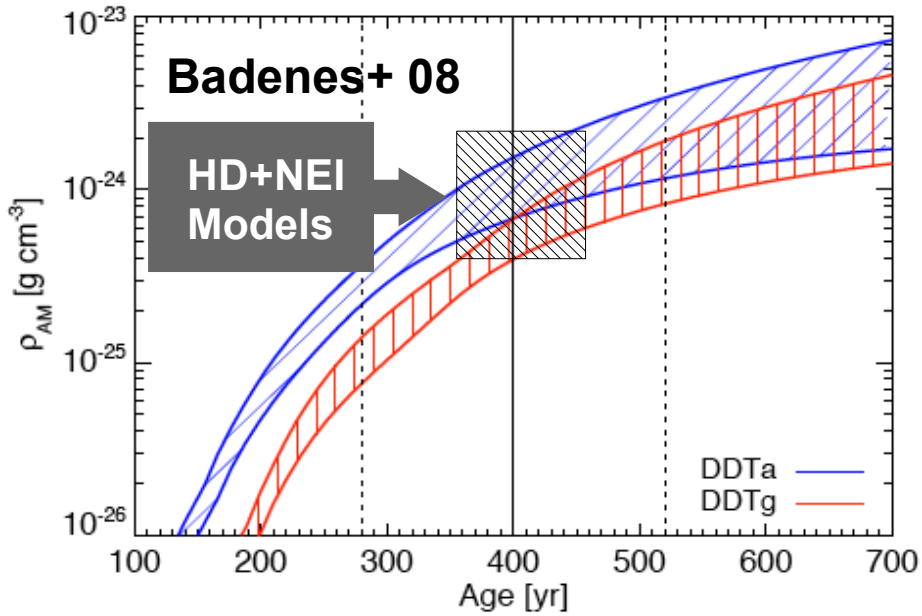

O
Ne
Mg
Si
S
Ar
Ca
Fe
Ejecta+FS
FS
Best sub-Chandrasekhar
SCH (ρ_{AM}=5e-25, β=0.01); N_H=1.03
Flux [counts s^{-1} keV^{-1}]
Residuals
Energy [keV]

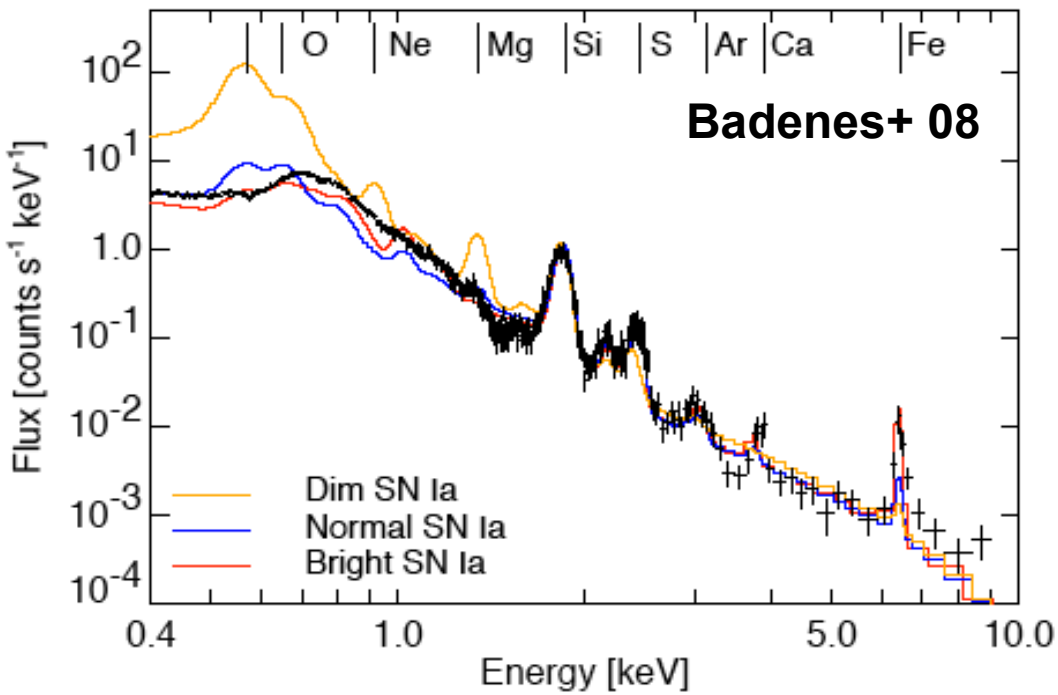

O
Ne
Mg
Si
S
Ar
Ca
Fe
Ejecta+FS
FS
Best 1D Deflagration
W7 (ρ_{AM}=5e-25, β=0.1); N_H=1.07
Flux [counts s^{-1} keV^{-1}]
Residuals
Energy [keV]

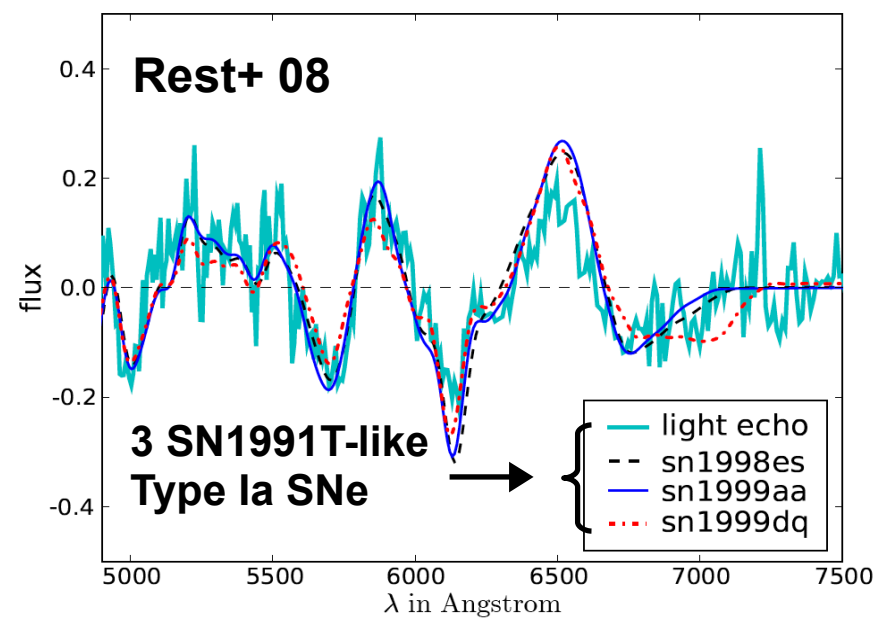
SNR 0509-67.5 in the LMC

- **Underlying HD model must also make sense!!**

- **SNR 0509-67.5 ⇒ M_{56Ni}=0.97 $M_{\odot}$** [Badenes+ 08]. Also confirmed by the light echo [Rest+ 08].

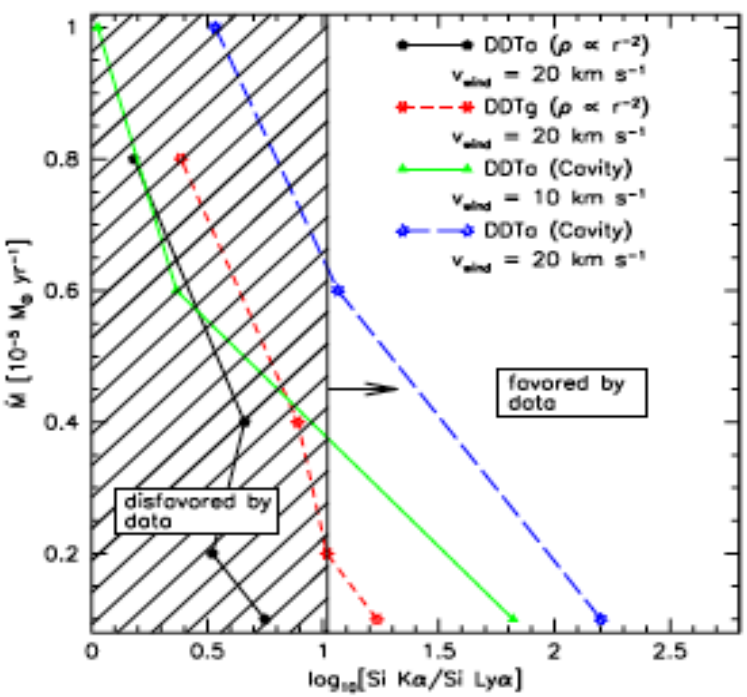


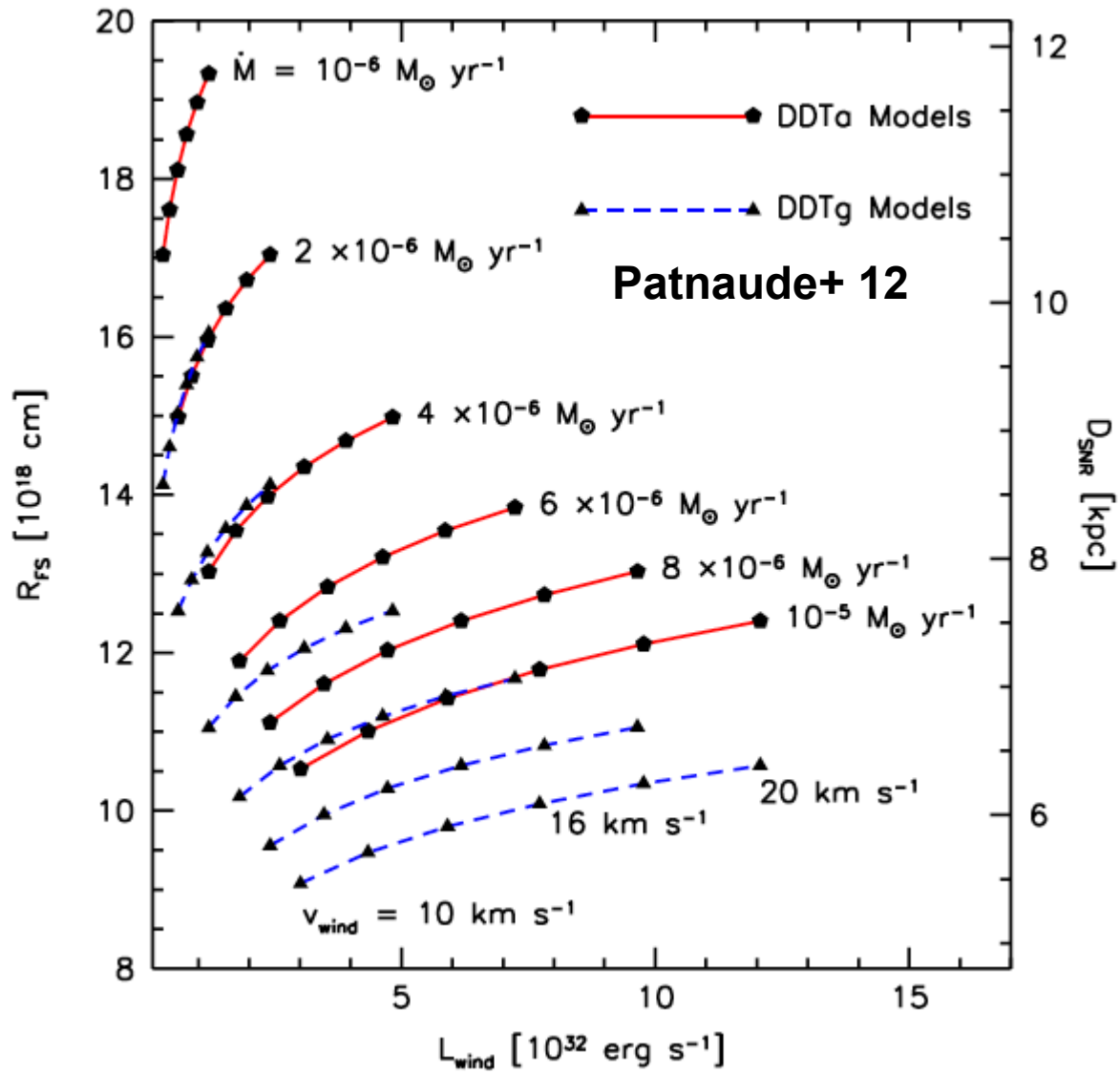




Kepler and the Progenitor Connection

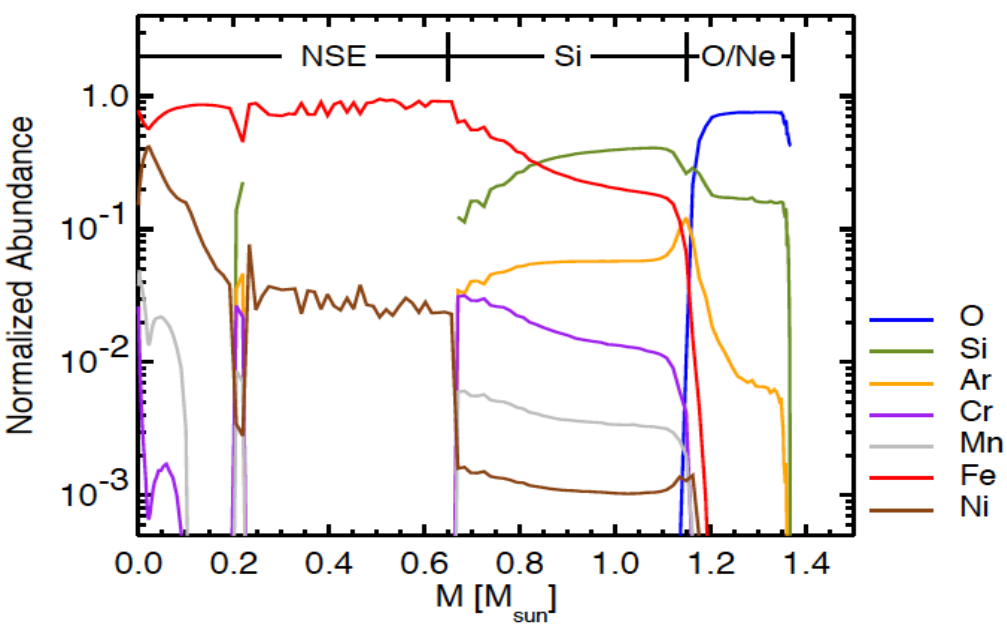
- **Kepler shows evidence for strong CSM interaction** [Blair+ 91, Borkowski+ 92,94, Reynolds+ 07].
- What does this mean? **Not an isotropic stellar outflow!** Maybe a small cavity? [Patnaude+ 12].

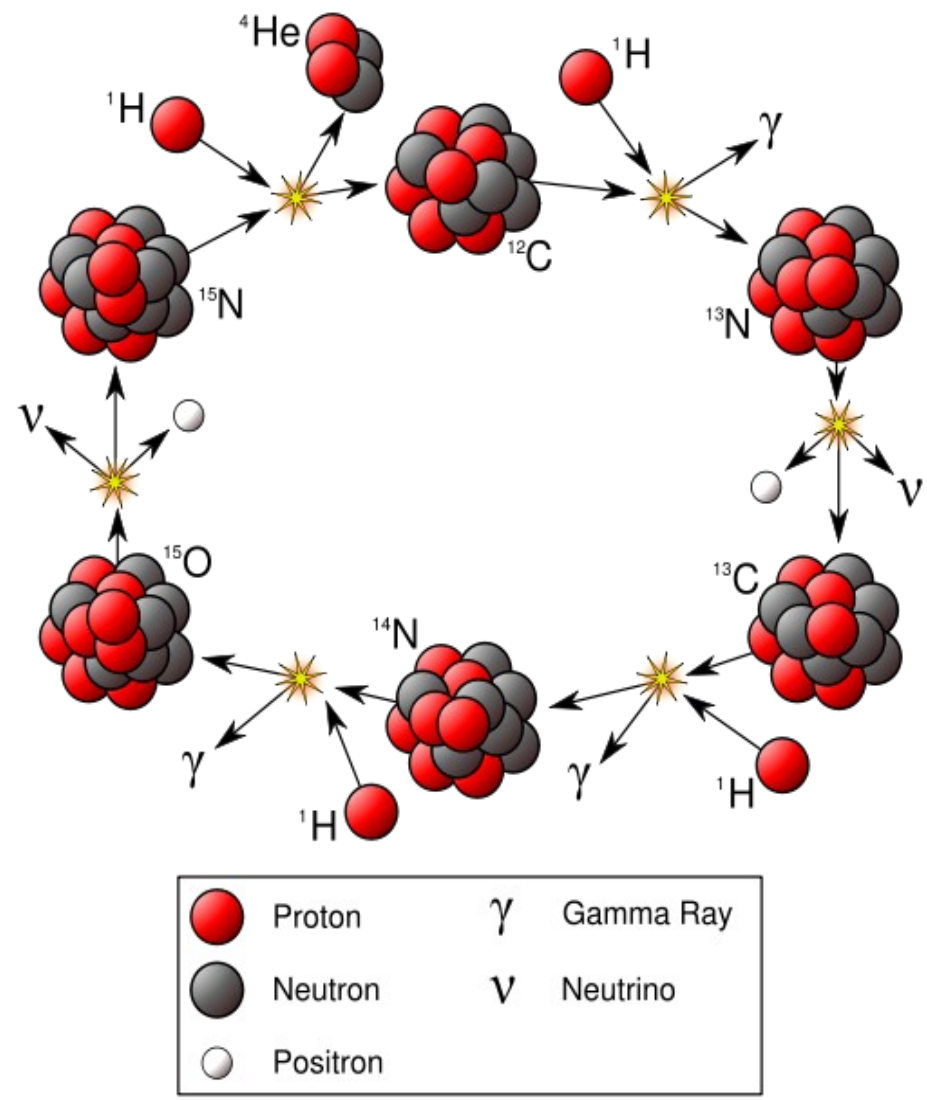




Mn and Cr: Why do we care?

- CO WDs have **trace amounts of ^{22}Ne** (relic from CNO cycle) [Timmes+ 03]
- $^{14}N(\alpha,\gamma)^{18}F(\beta+,\nu_e)^{18}O(\alpha,\gamma)^{22}Ne \Leftrightarrow$
  $\eta = 1-2[Z_A/A_A] = 0.101xZ$
- Outside the central ~0.2 $M_\odot$, **Mn/Cr ratio traces η, independent of explosion brightness** (^{56}Ni mass).

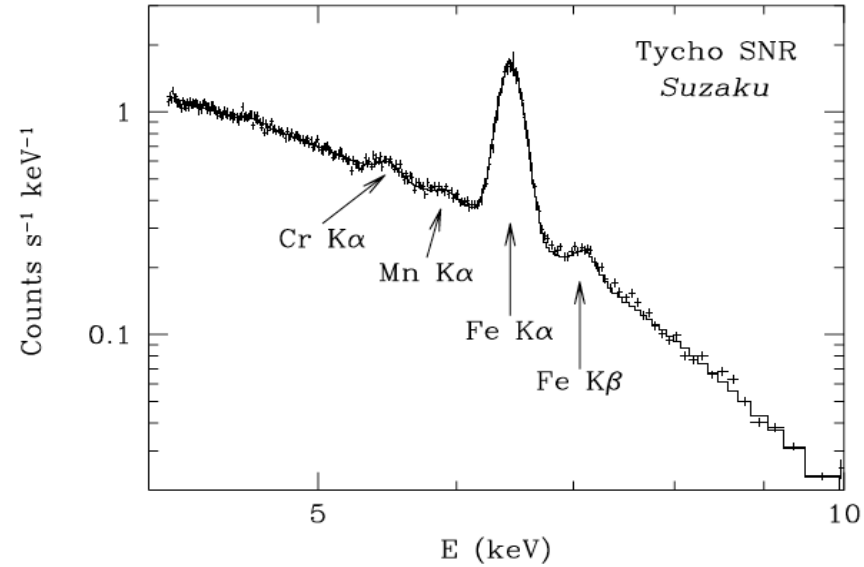


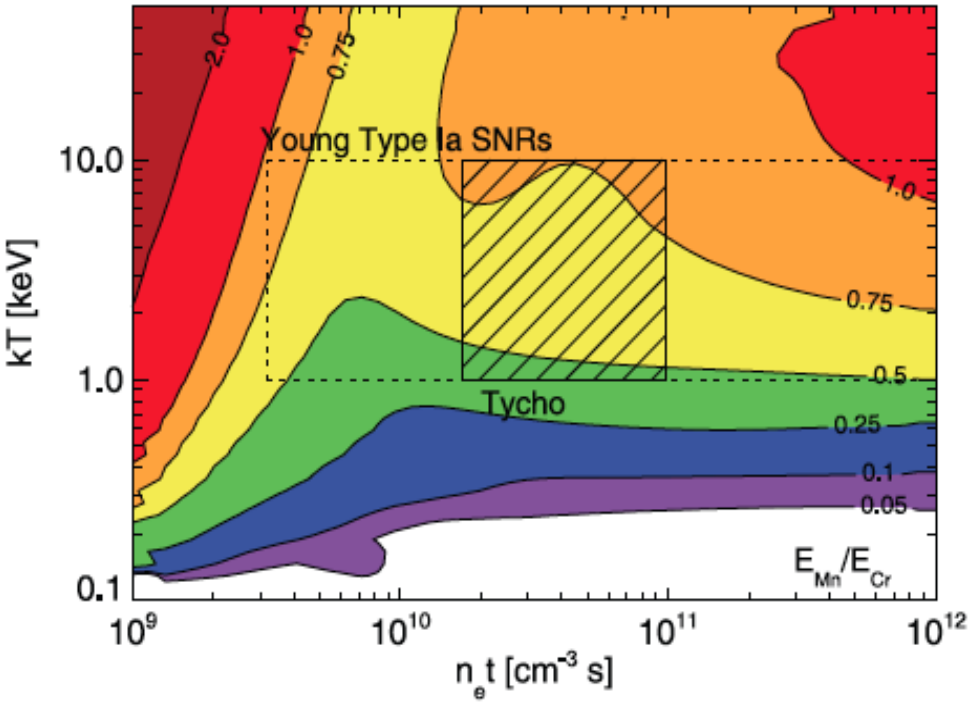


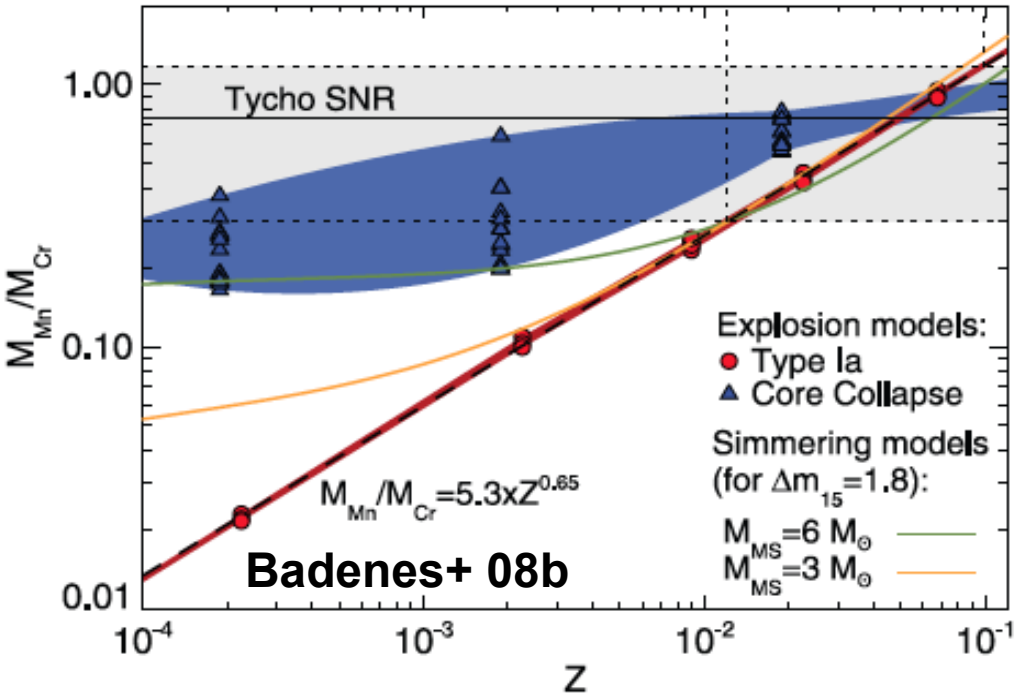
Mn and Cr: Why do we care?

- **Mn/Cr mass ratio is insensitive to the explosion mechanism**, and behaves like $Z^{0.65}$ [Badenes+ 08b].

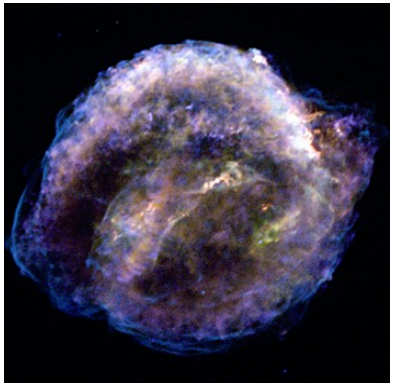
- We need to infer the mass ratio from the flux ratios in X-ray spectra [Tamagawa+ 09].

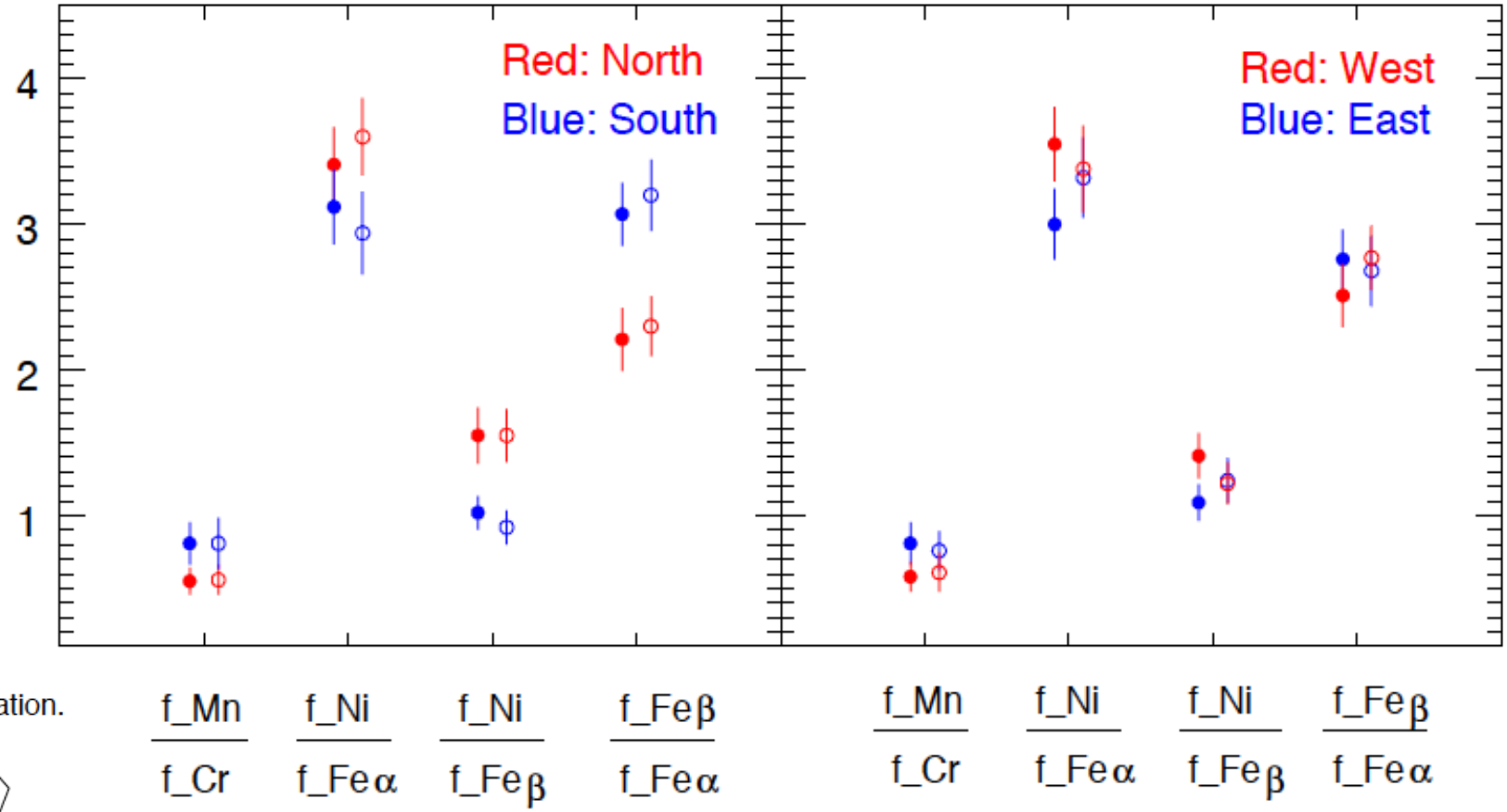




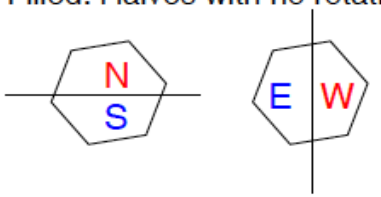


Mn and Cr: Why do we care?

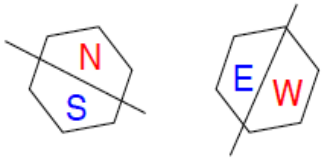




Filled: Halves with no rotation.



Open: Halves with a 45 deg rotation.

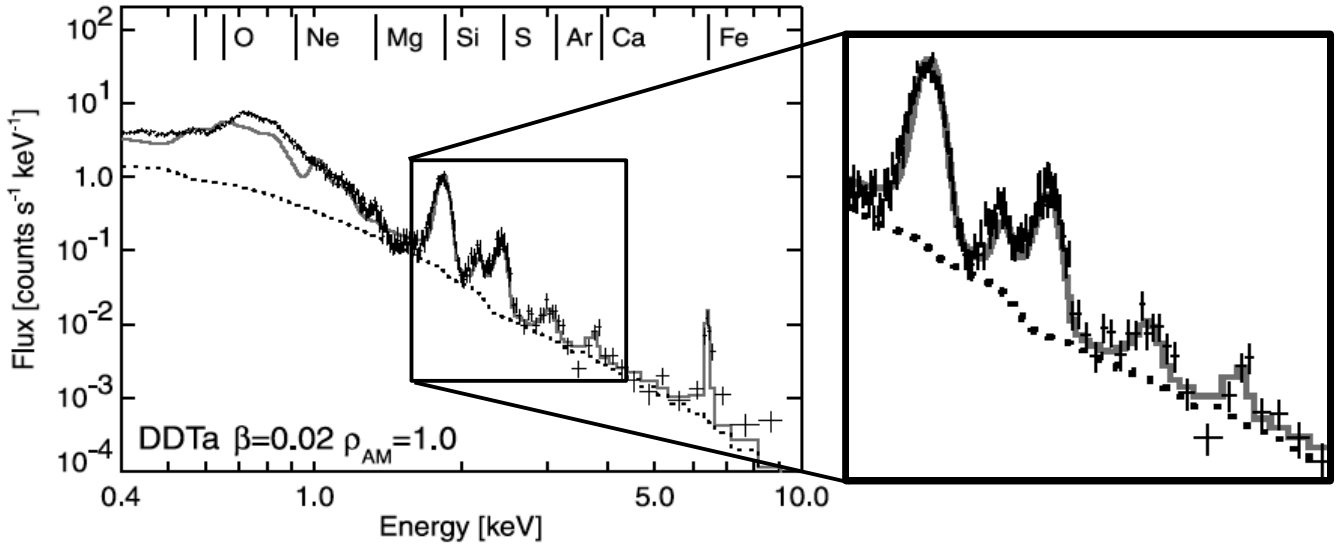


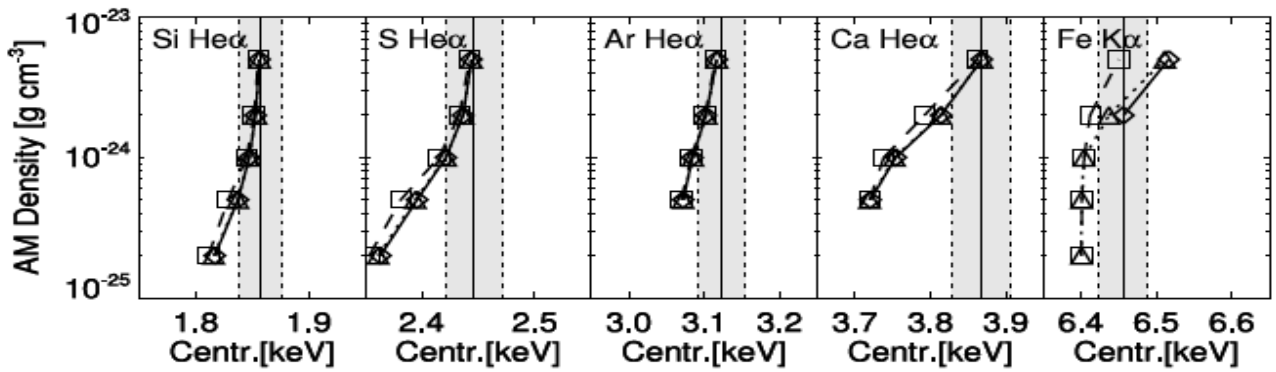
$\frac{f\_Ni}{f\_Fe\alpha}$ and $\frac{f\_Fe\beta}{f\_Fe\alpha}$ are multiplied by 100.

Park+ in prep.

The Calcium Conundrum

- **Evidence for over-ionized Ca in several Ia SNRs**.
- Tycho and 0509 from HD+NEI [Badenes+ 06,08].
- 0519 from plane shock model fits [Kosenko+ 11].
- What does this mean?





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

Some Thoughts (in lieu of Conclusions)

Type Ia SNRs allow us to study SN Ia explosions and their progenitors in great detail

- We can explore **key parameters** like the **brightness of the explosion** (^{56}Ni mass), the **structure of the CSM**, and the **metallicity of the progenitor**.
- All this requires **good spectra and good atomic data**.
- Our approach to 'fitting' and 'measuring' needs to be revised.