Numerical Modeling of Thermal and Non-thermal Emission from SNRs

Towards a Synergy of Gamma-ray and X-ray Observations

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CR-HYDRO-NEI CODE

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Jack Hughes (Rutgers U)
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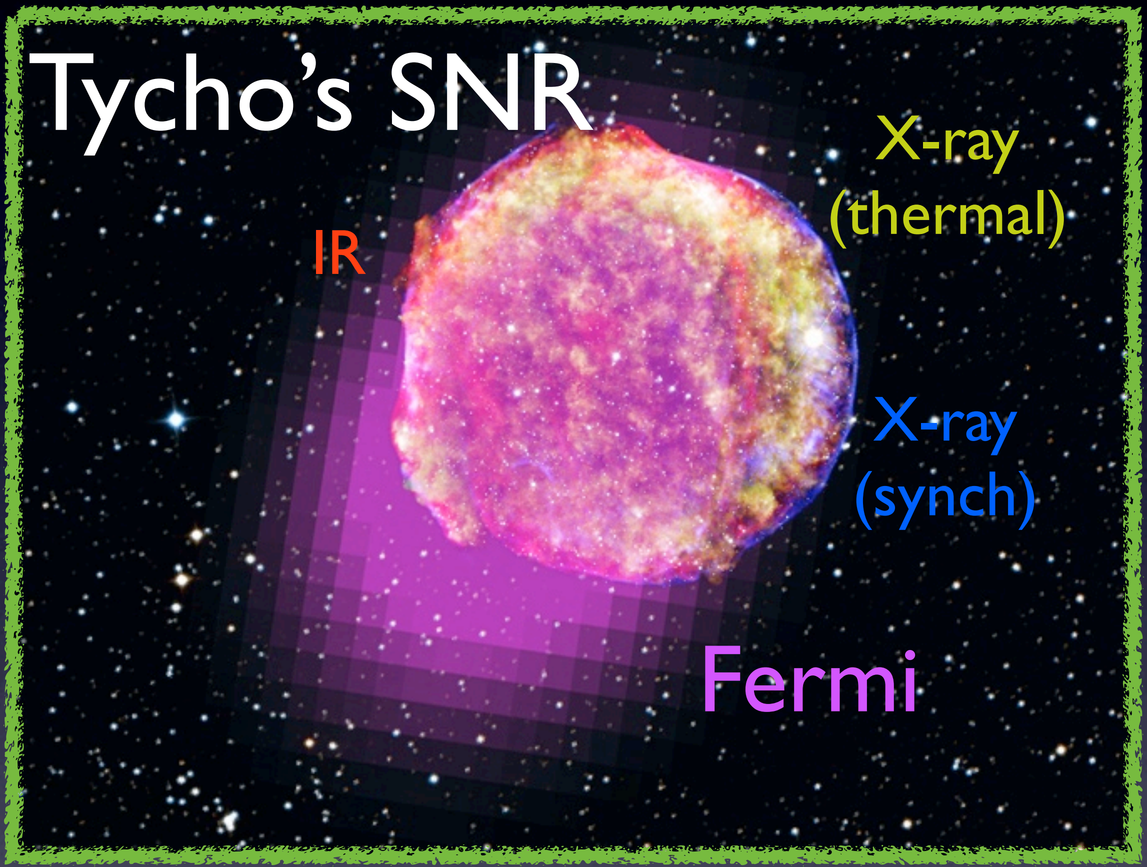
And you!

(Part of preliminary results are removed)

Behold!

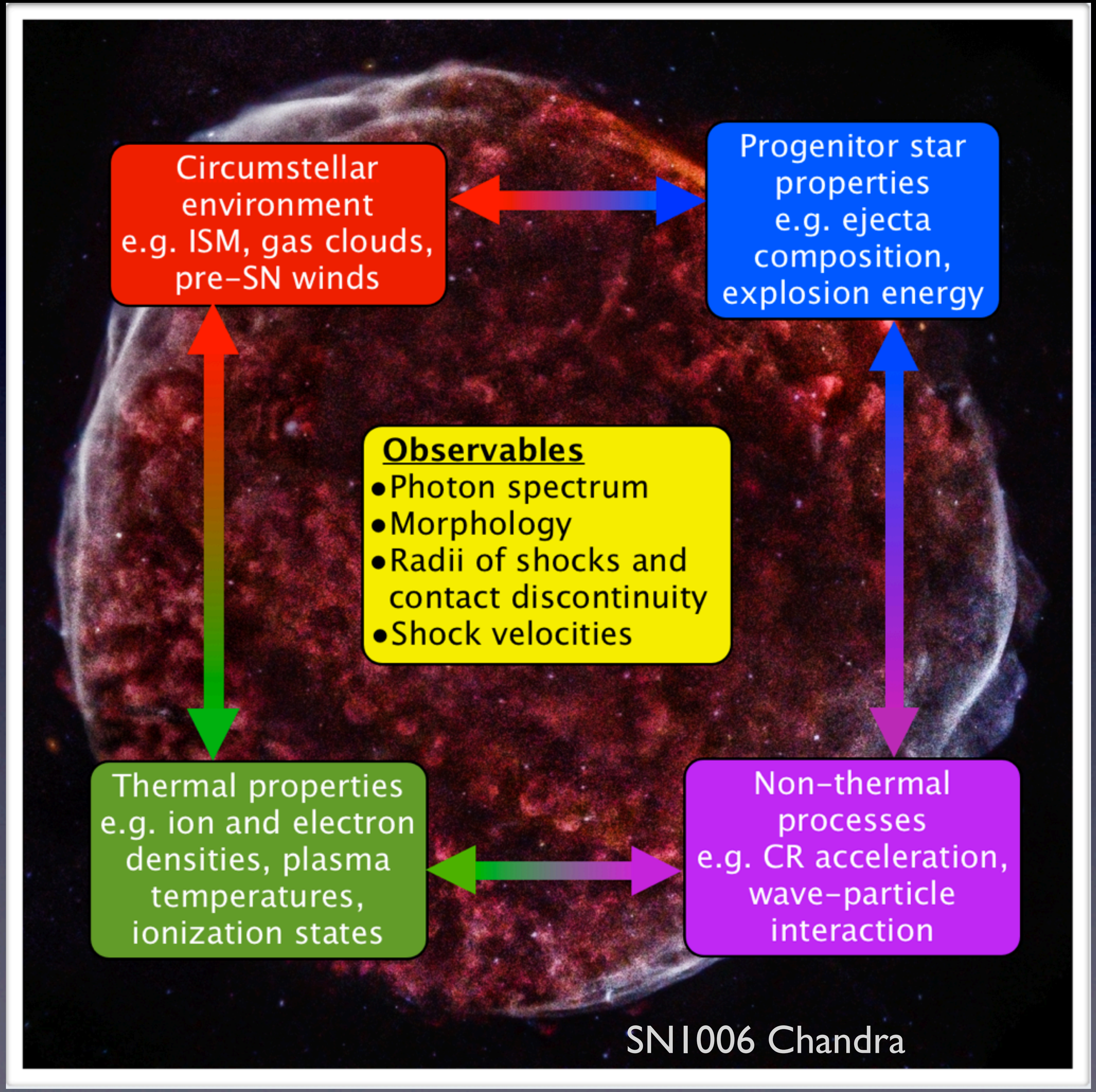
The multi-wavelength era has come



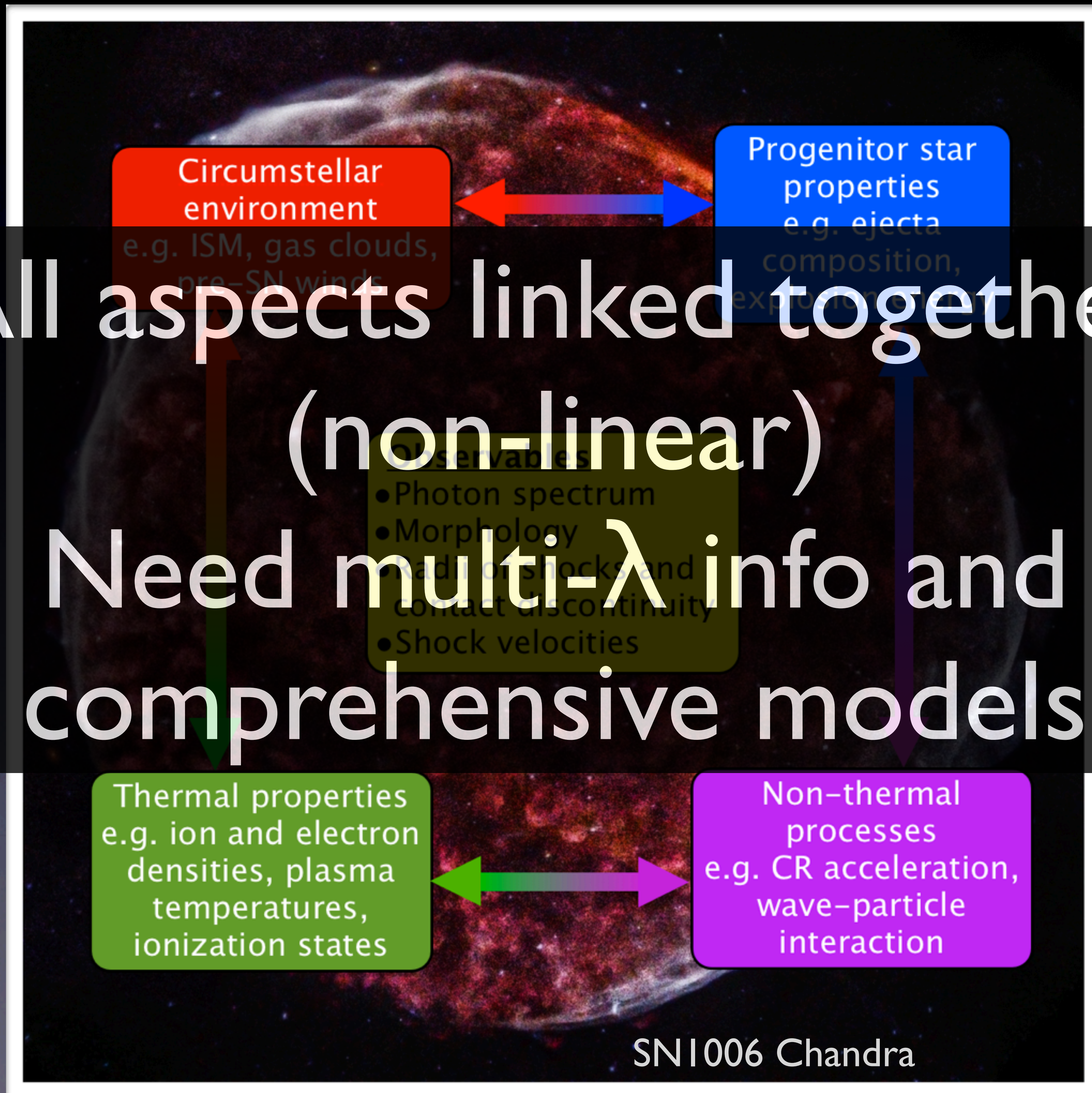
Plenty of data now available, and *lots more* to come.

But synergy of data in different energy bands is lacking.

SNRs are complex stuff



SNRs are complex stuff



All aspects linked together (non-linear)

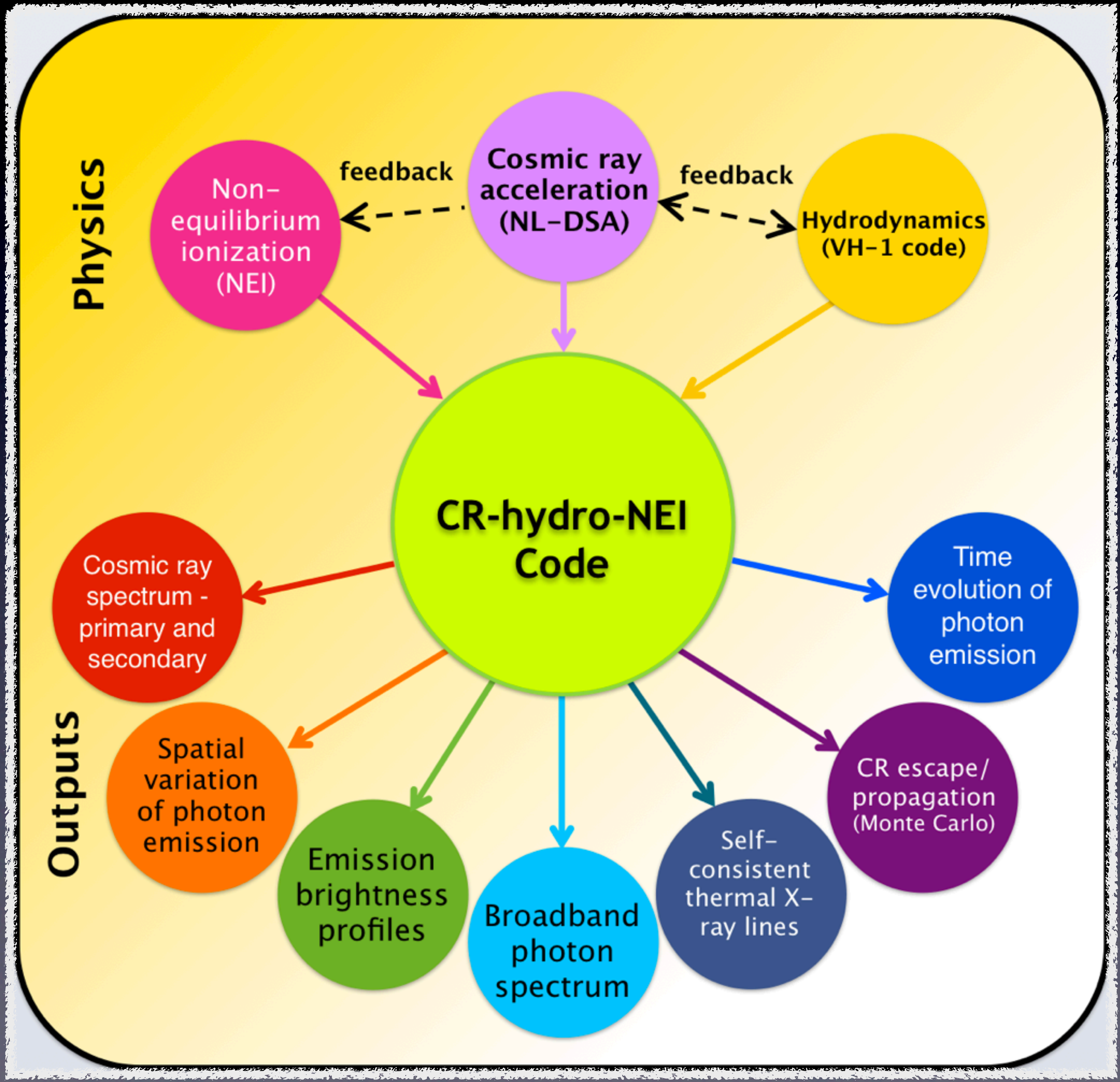
Need multi-λ info and comprehensive models

Outline

1. Our recipe for modeling broadband emission from SNR shells using our powerful numerical tool 

2. Recent work on detailed calculations of thermal X-ray emission from SNRs
3. Applications to future missions including CTA and Astro-H

A recipe to model SNR emission properly



Broadband Spectrum

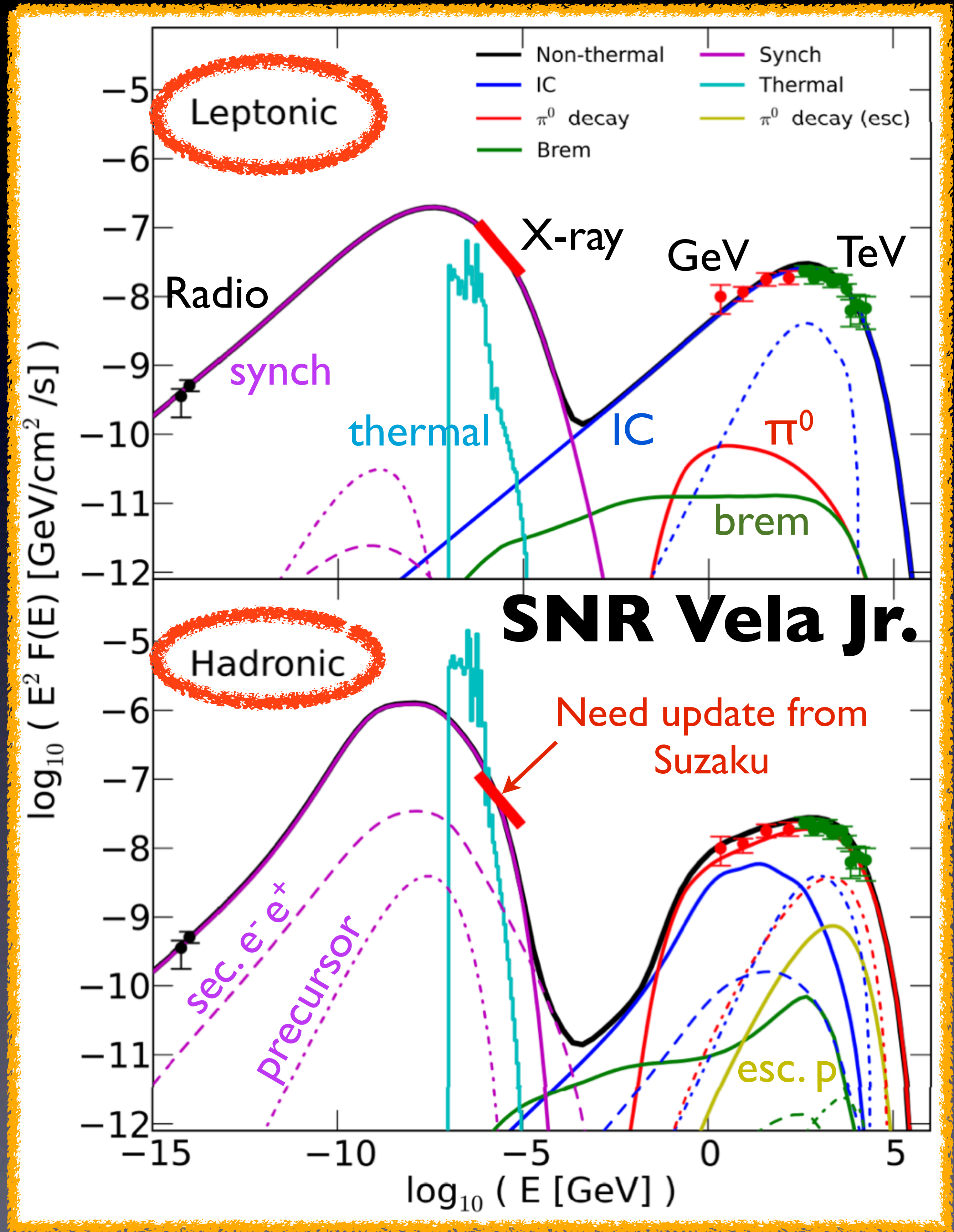
HL+ 2013 ApJ

The 1st hurdle any model must pass through

Must check consistency:

- Radio to TeV flux
- Spectral shapes
- Inferred CR energetics
- Required B-field, CSM, E_{SN}

Resort to next hurdles if still can't single out best model



13年9月4日水曜日

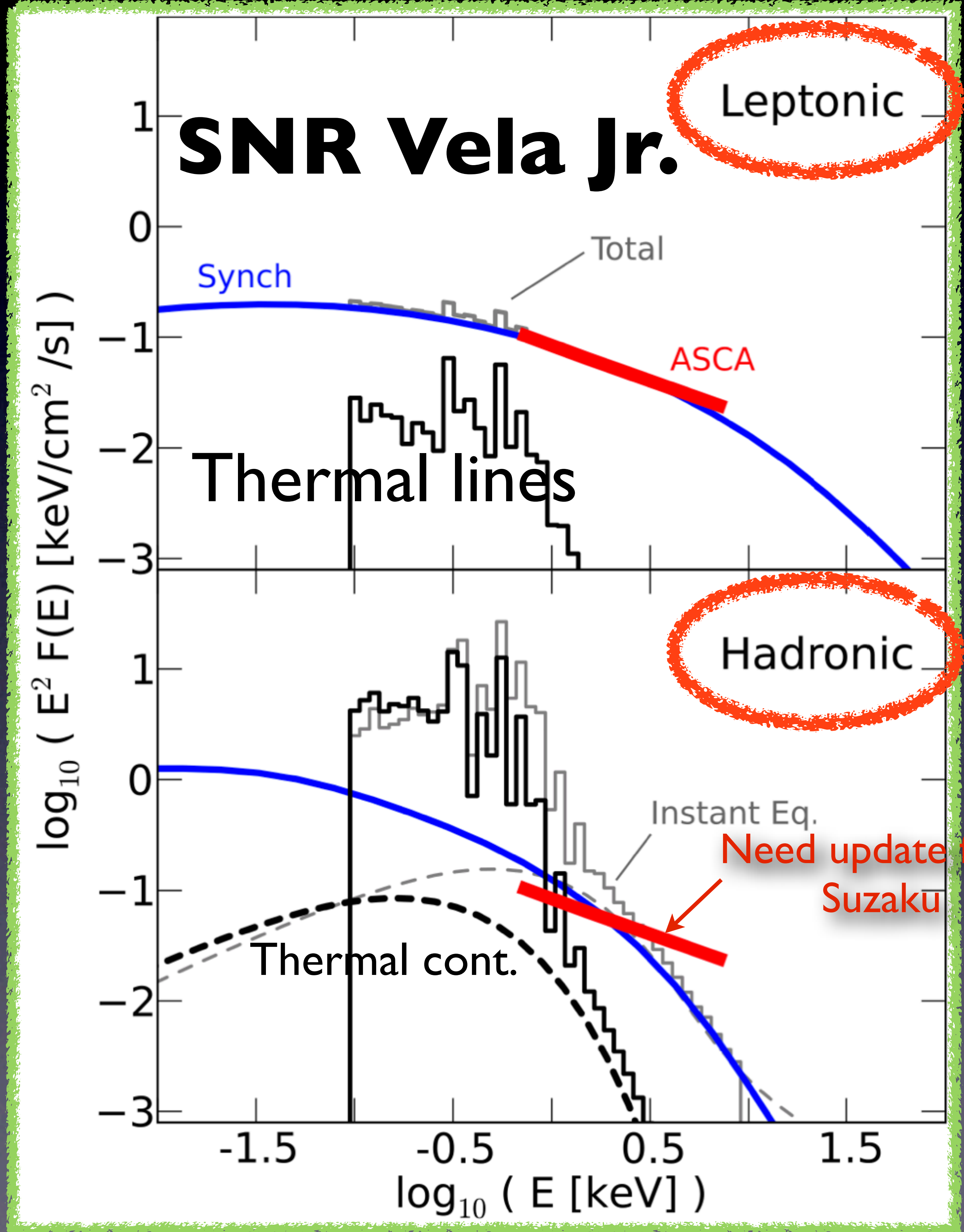
Thermal X-ray constrains Gamma-ray origin

HL+ 2013 ApJ

Hurdle #1.5

In SNRs, thermal X-ray flux is coupled to broadband emission!

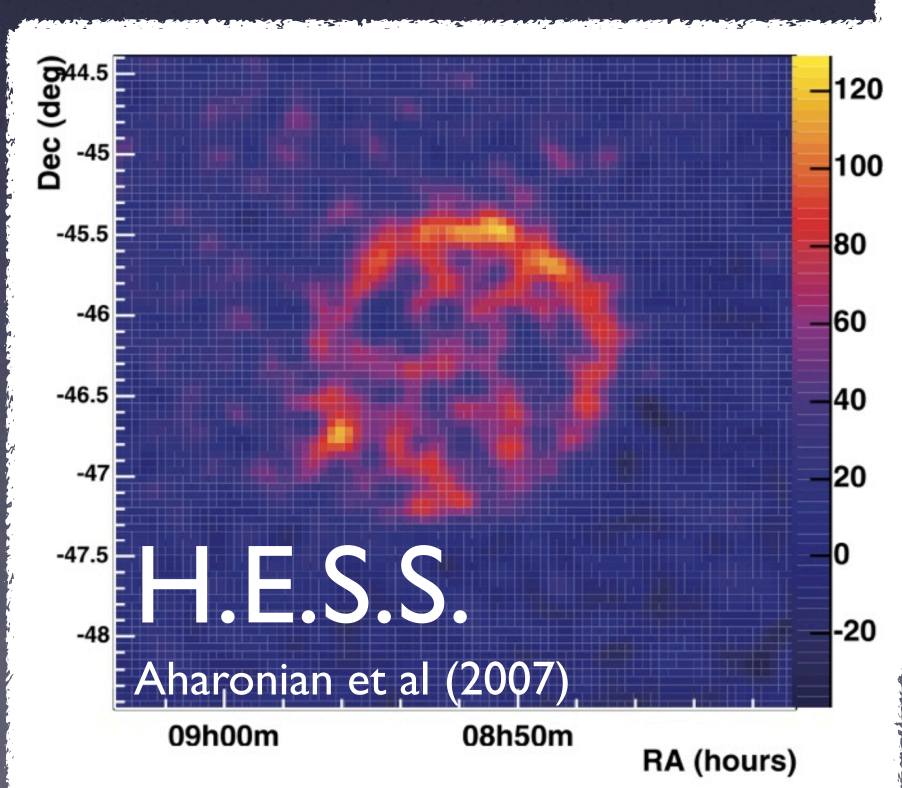
Very important:
Predicted thermal flux must not violate X-ray observations

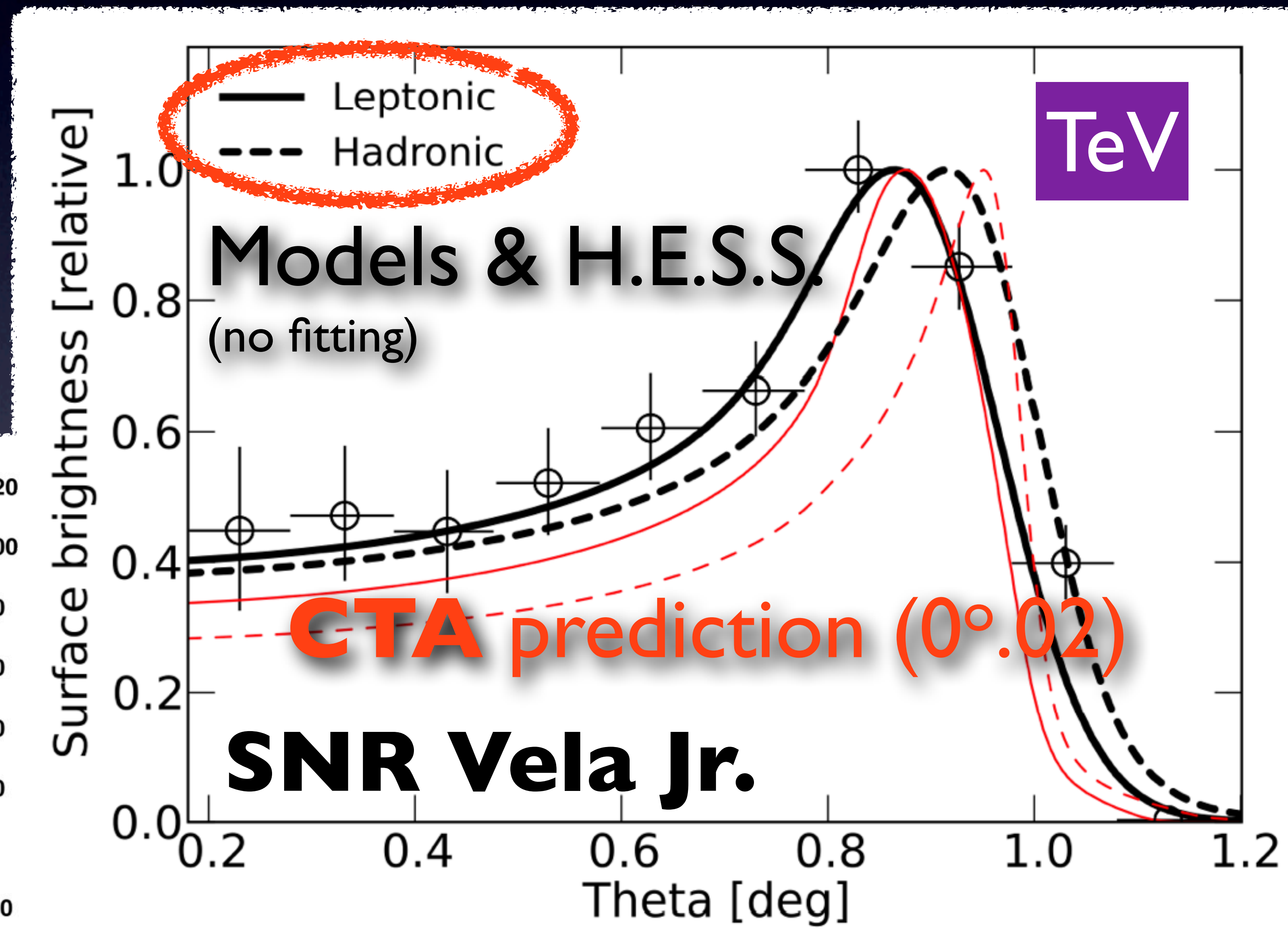


Radial emission profile probes Gamma-ray origin & CR accel efficiency

Hurdle #2

Radio, X-ray and TeV morphology constrain CR accel. and E loss history





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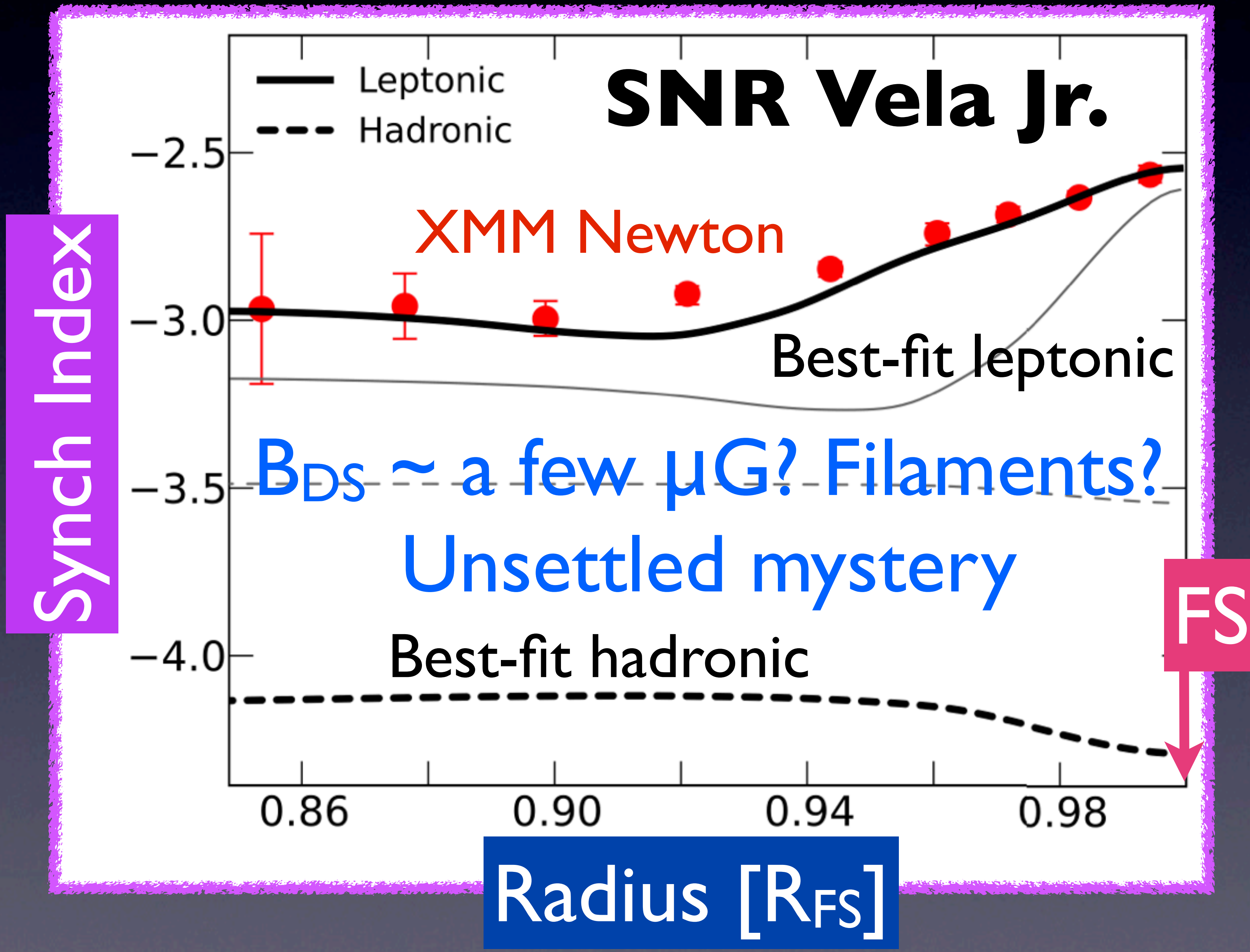
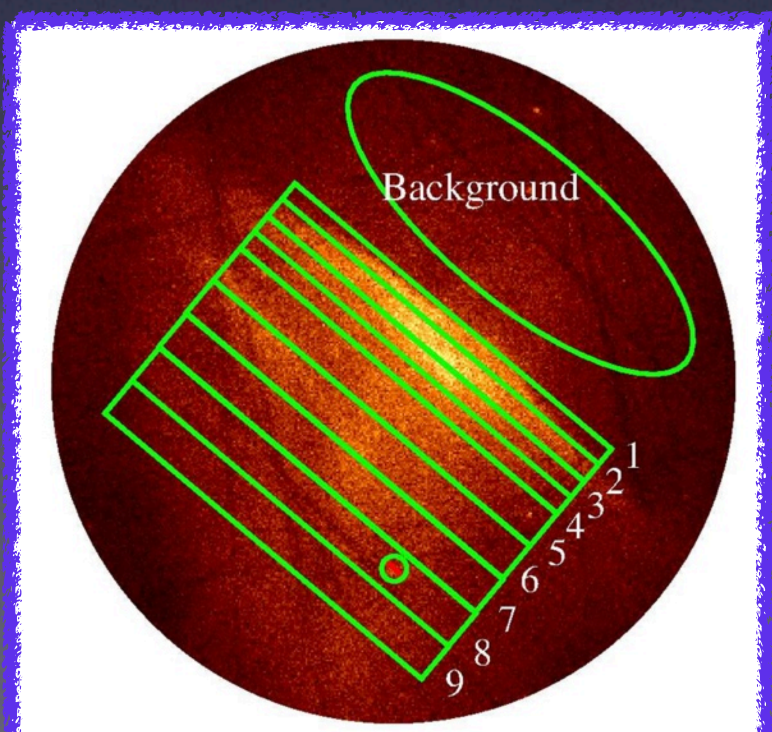
X-ray synchrotron index distribution constrains gamma-ray origin

Hurdle #3

Hadronic and leptonic models often predict very different synch index distributions (e.g. CSM, B-field)



Kishishita & Uchiyama 2013
XMM-Newton



HL+ 2013 ApJ

What do we learn?

- A best-fit broadband model passing all the observation hurdles tells us the gamma-ray origin of a SNR (i.e. CR ion or e^-, or both)

  Note: Leptonic does NOT mean there is no CR ion

- But the ultimate goal is to constrain total energy in CR different types of SNR can produce in its lifetime (hadronic and leptonic models often predict very different values)

- Sometimes though, the progenitor nature of a SNR is not even clear

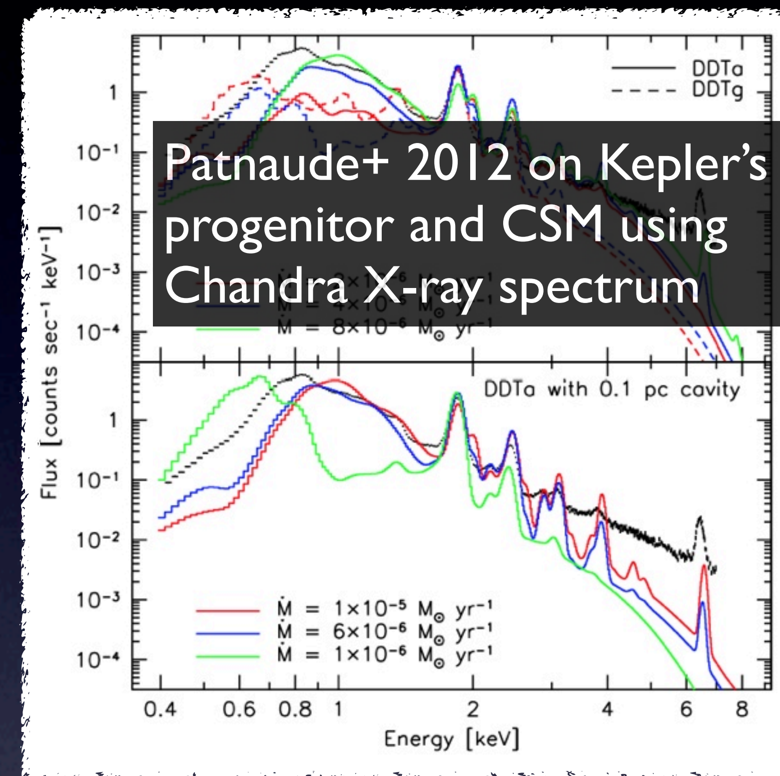
Detailed study of thermal X-ray from SNR ejecta and shell

Purposes:

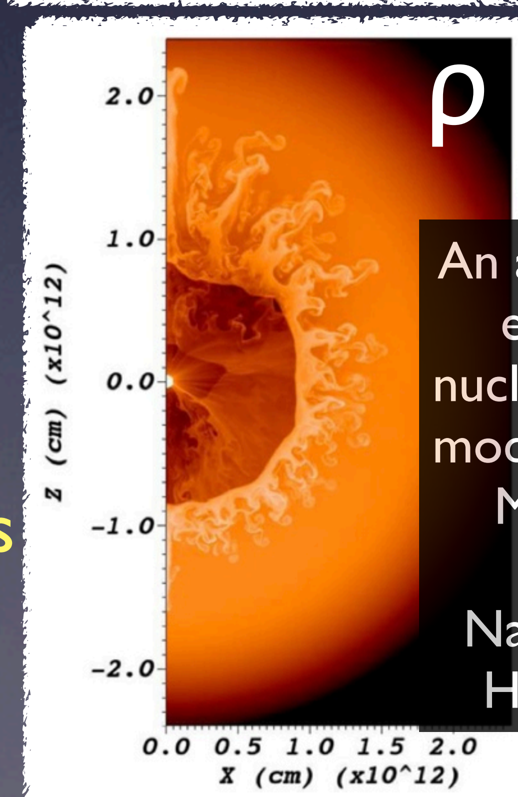
1. Unambiguously reveal progenitor properties (e.g. metallicity in type Ia's and core-collapses)
2. Constrain explosive nucleosynthesis in various SNe
3. Correlate with CSM environments and broadband emission, better understanding of SNR populations

Key:

1. Future X-ray spectroscopy by Astro-H SXS!
2. Self-consistent simulation of X-ray spectra by a CR + hydrodynamical model using inputs from SN simulations (connect SN and SNR phase)

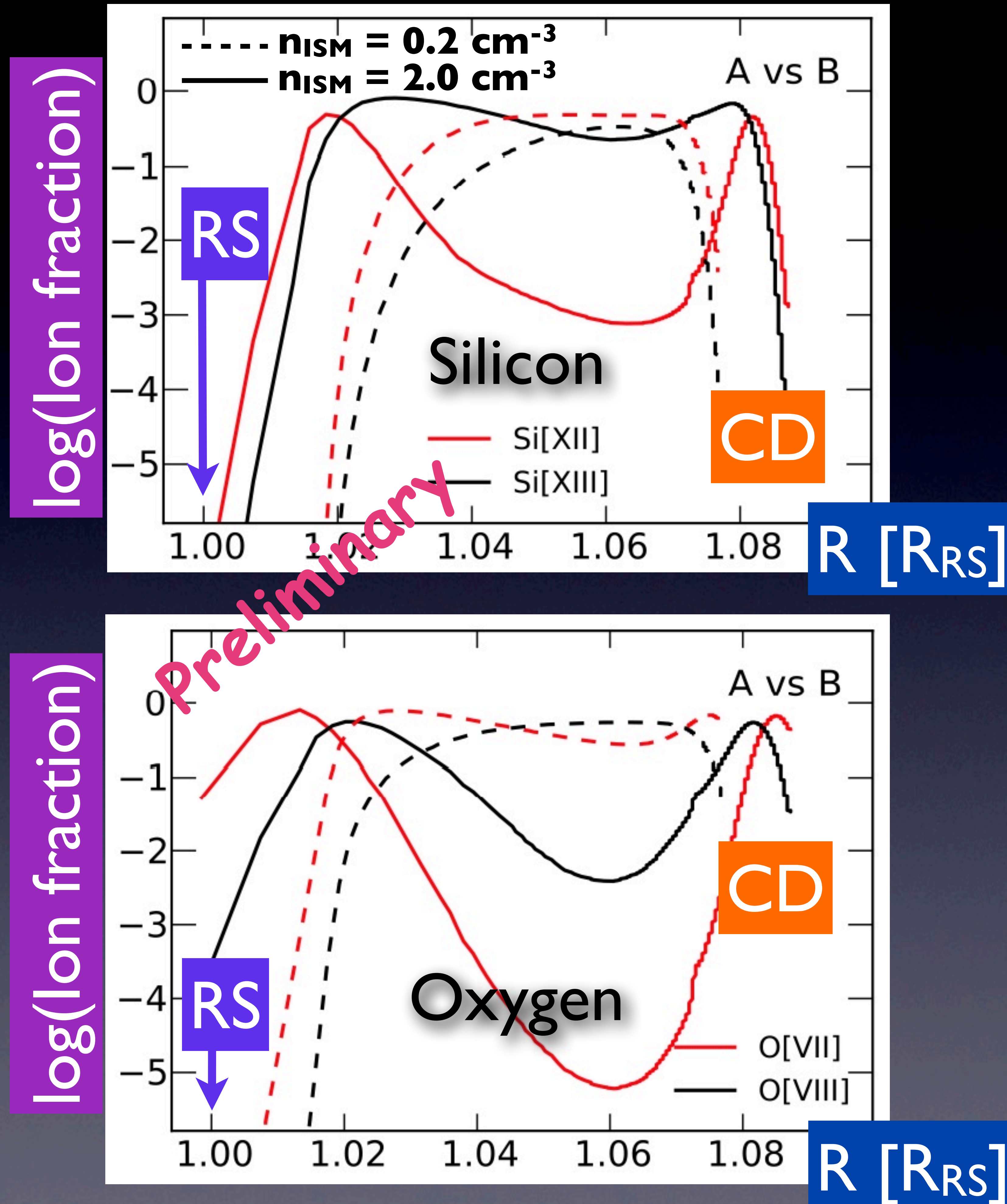


Patnaude+ 2012 on Kepler's progenitor and CSM using Chandra X-ray spectrum



An asymmetric explosive nucleosynthesis model of a 16.3 Msun star (Ono, Nagataki, Ito, HL+ 2013)

Non-equilibrium ionization in SNR ejecta



Following ionization fractions of key elements like O, Si, S and Fe using full NEI coupled with hydro is crucial

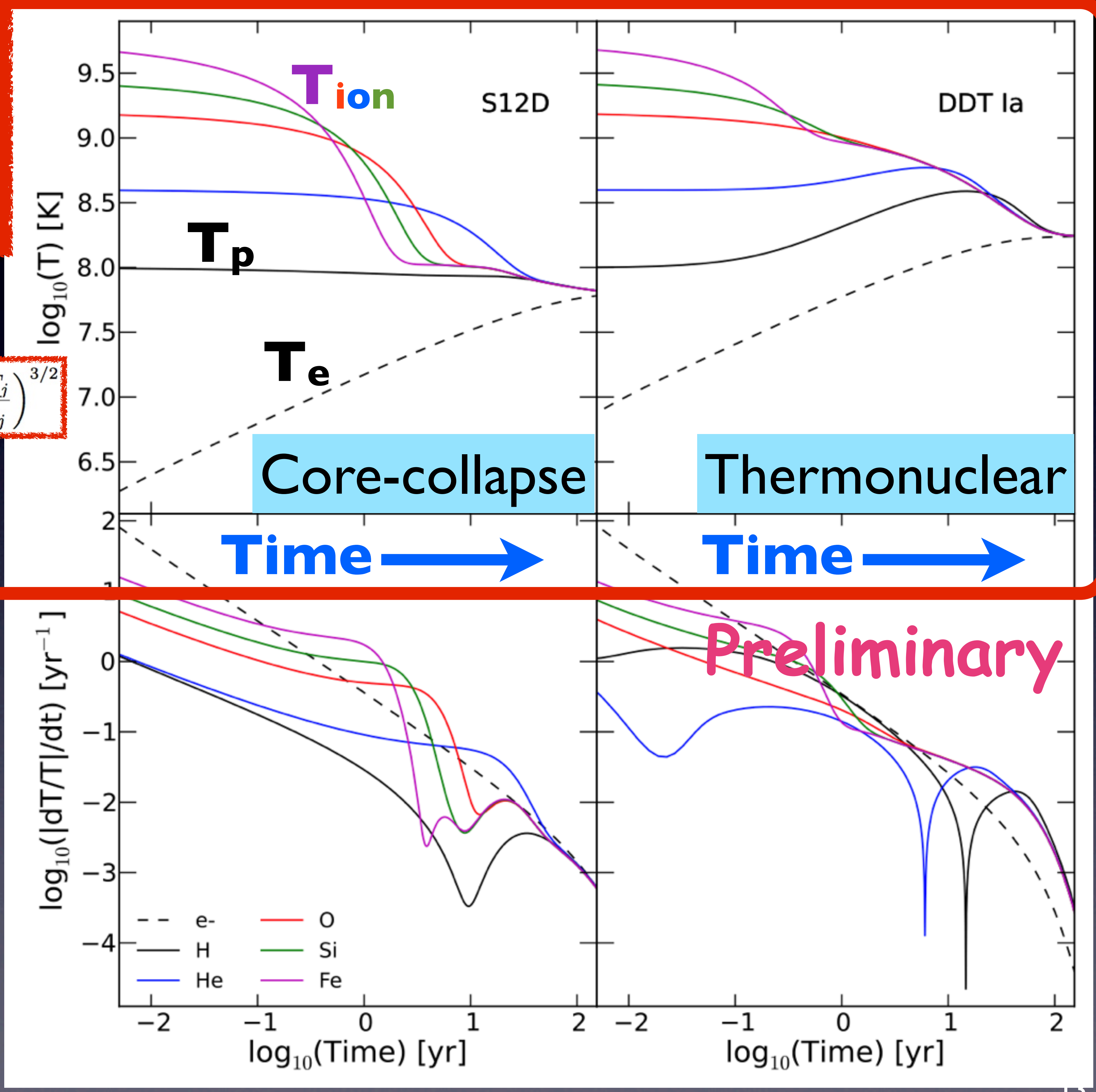
Heavy ion temperature equilibration

Test cal. of equilibration in a Lagrangian cell

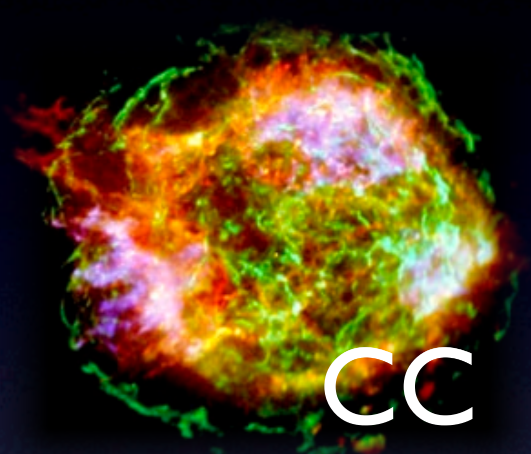
$$t_{\rm eq}(i,j) = f_{\rm eq} \times \frac{3}{8\sqrt{2\pi}} \frac{m_i m_j}{n_j Z_i^2 Z_j^2 e^4 \log\Lambda} \left(\frac{kT_i}{m_i} + \frac{kT_j}{m_j}\right)^{3/2}$$

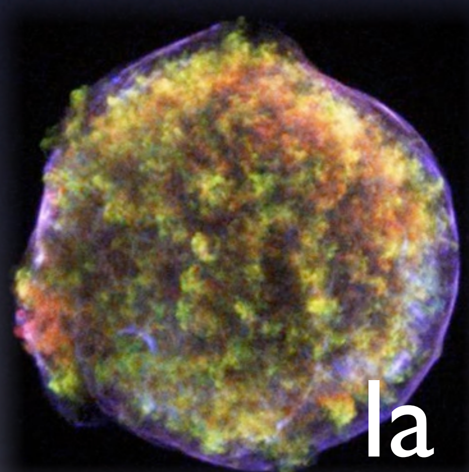
Individual heavy ion temperatures must be followed to predict line profiles

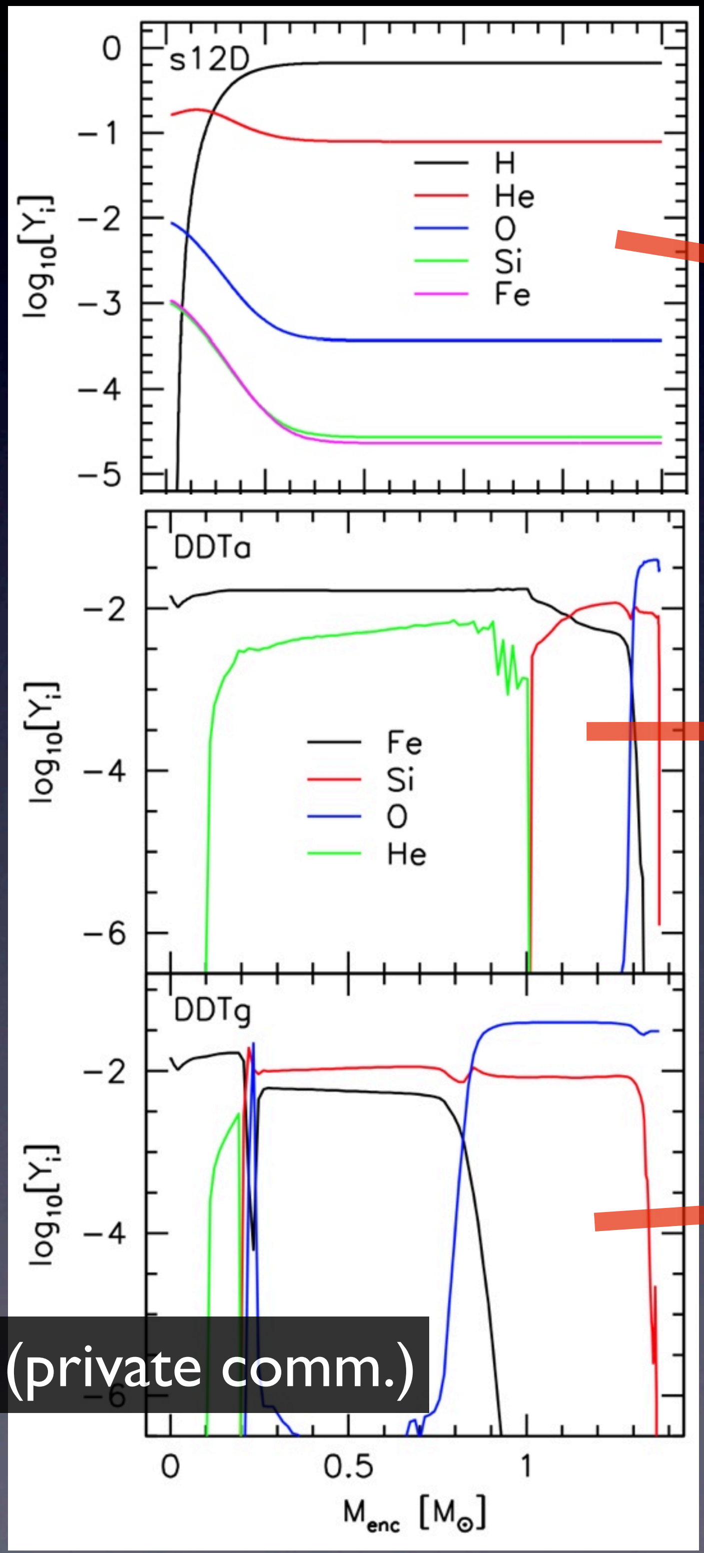
e^- temperature controls NEI rates and continuum in shocked ejecta

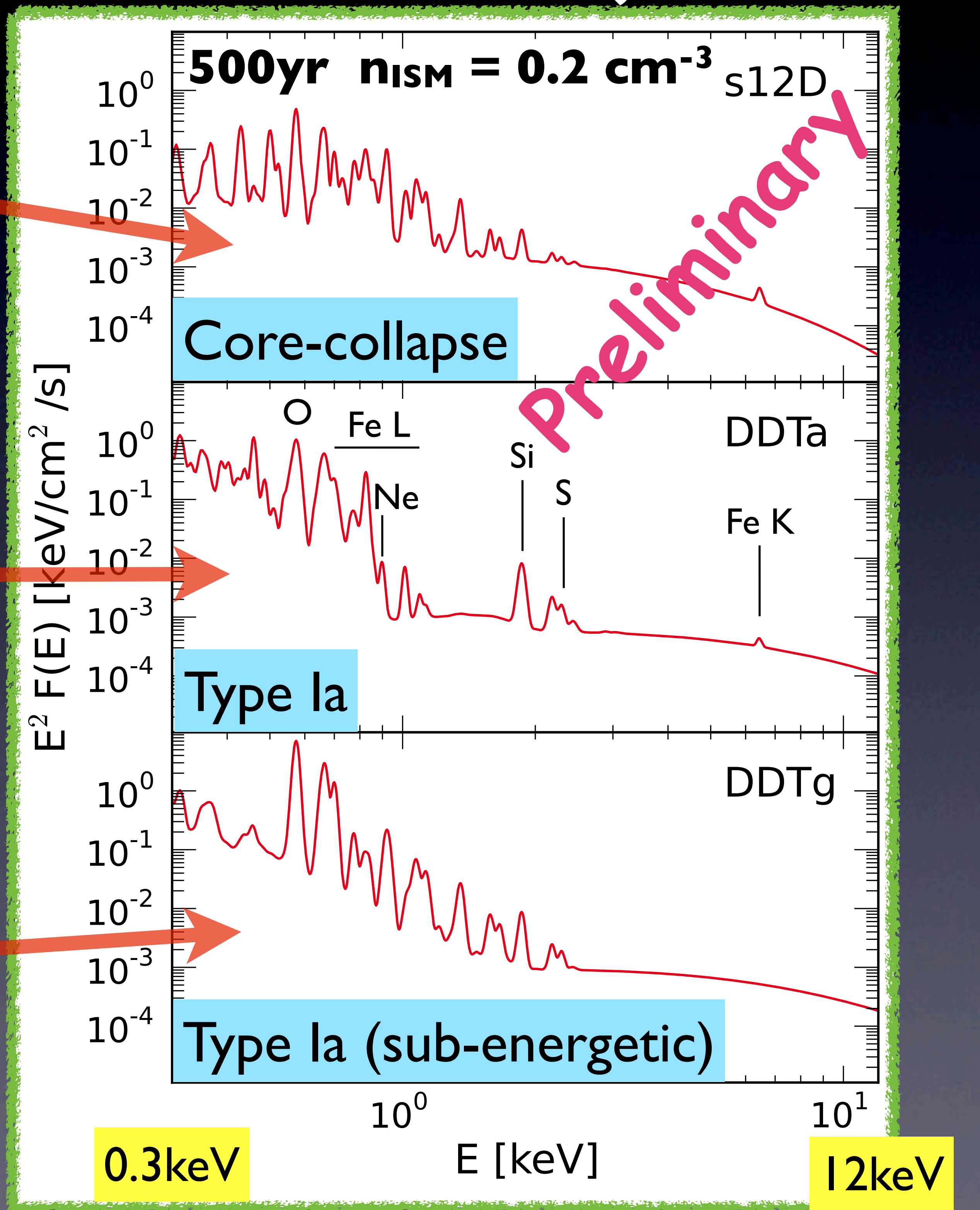


Progenitor models and X-ray spectra from SNR ejecta







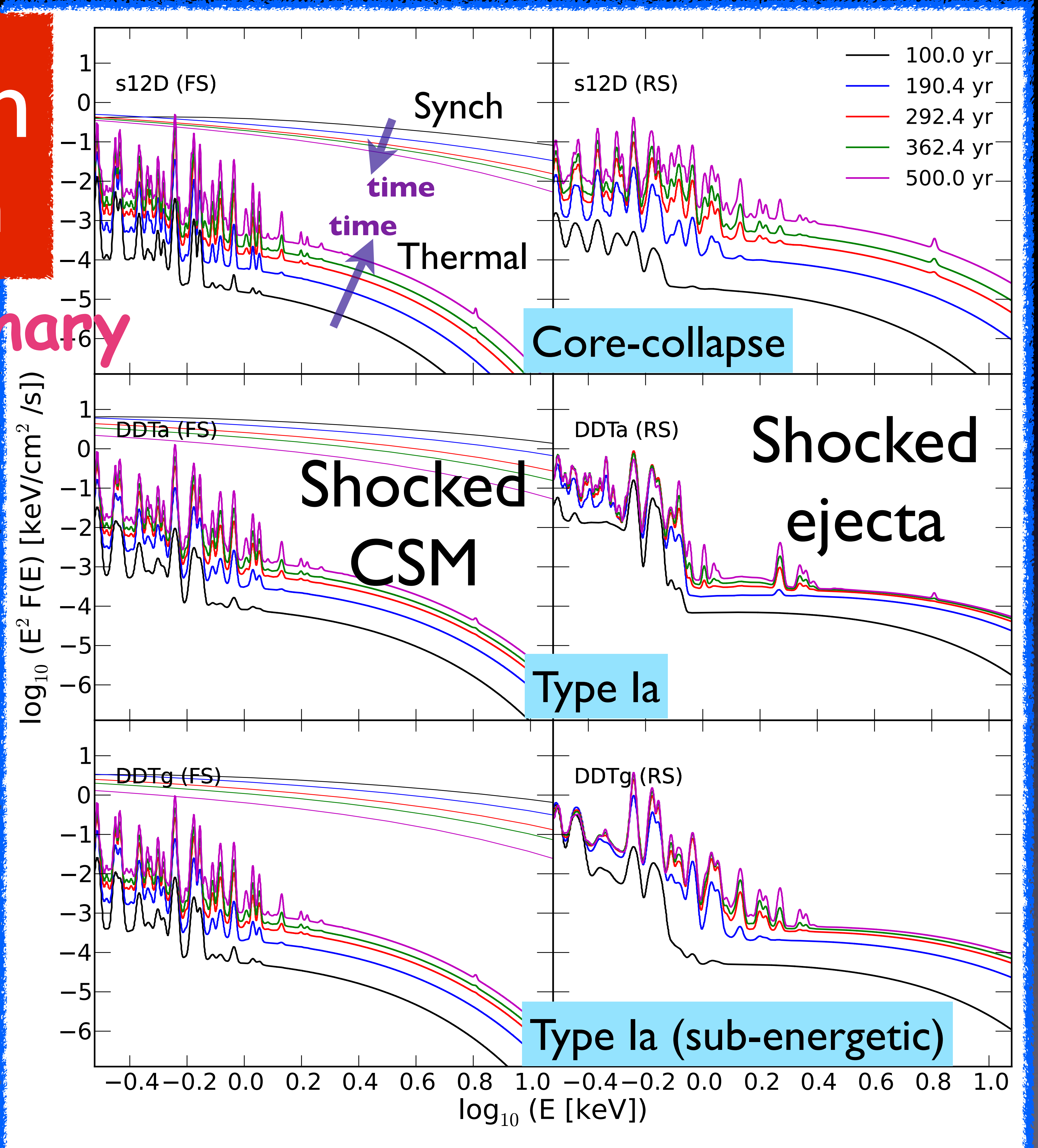


data from Carles Badenes (private comm.)

Time evolution
II) X-ray spectrum

Preliminary

We can explore evolutionary relation between thermal X-ray and non-thermal emission as the multi-λ sample of SNRs increases in size



Synergy of future super telescopes for SNR research

Hi-res X-ray spectroscopy

- Ejecta/CSM composition from faint lines
- Unveil progenitor properties of Ia and core-collapse SNRs
- SN explosion mechanisms, matter mixing and nucleosynthesis
- Broadened line profiles: gas dynamics, temperature equilibration

Hi-sensitivity, hi-res imaging

- Many new gamma-ray SNR discoveries
- Low-noise spectrum measurement from ~20GeV to >100 TeV
- Measure roll-over region of CR spectra!
- 3x better TeV morphology measurement to contrast with radio/IR/X-ray images

Summary

- We stressed the importance of synergy of multi-wavelength data to understand SNR emission and their contribution to CR
- We introduced our strategy on modeling current and future SNR observations using our powerful numerical tool
- We elaborated on examples of new SNR sciences achievable by next-generation telescopes in conjunction with our code.