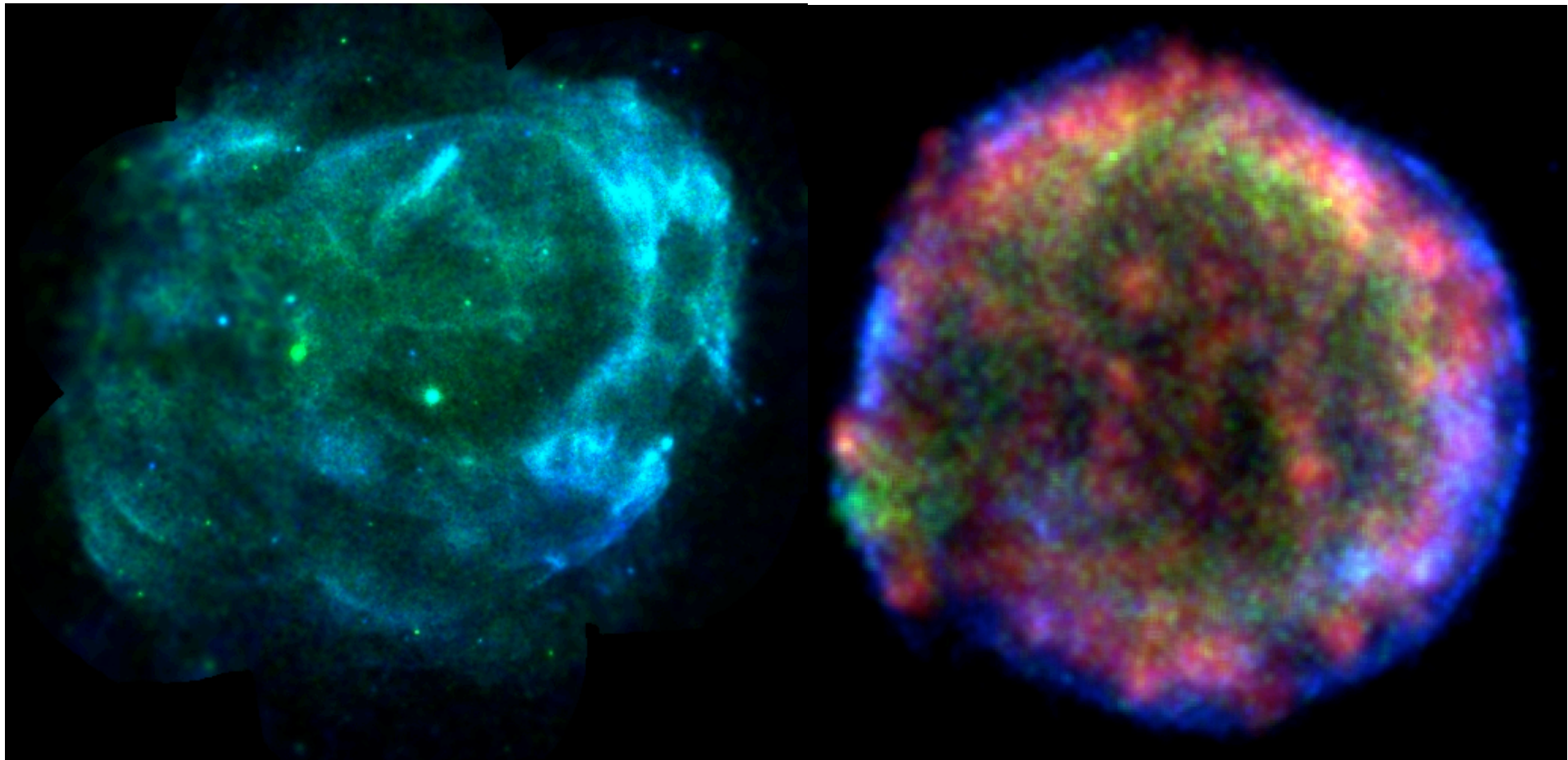


Supernova remnants: X-ray observations with XMM-Newton

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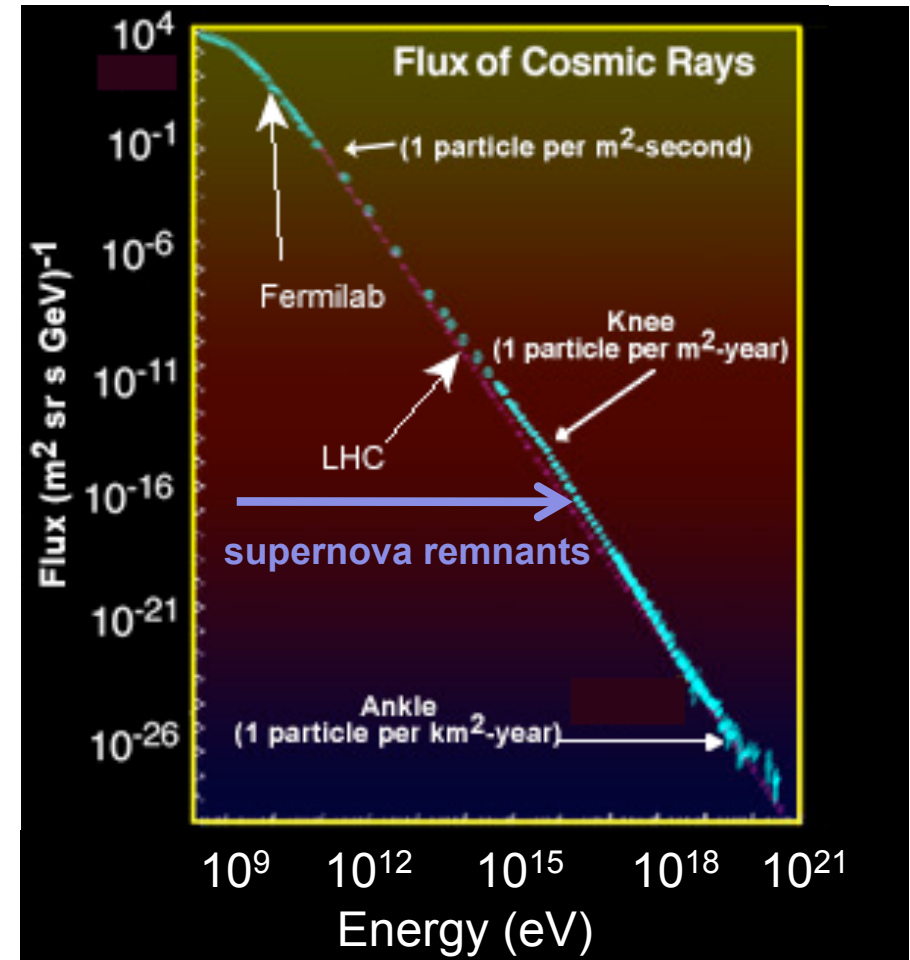
Chemical enrichment, heating et turbulence of the interstellar medium of galaxies

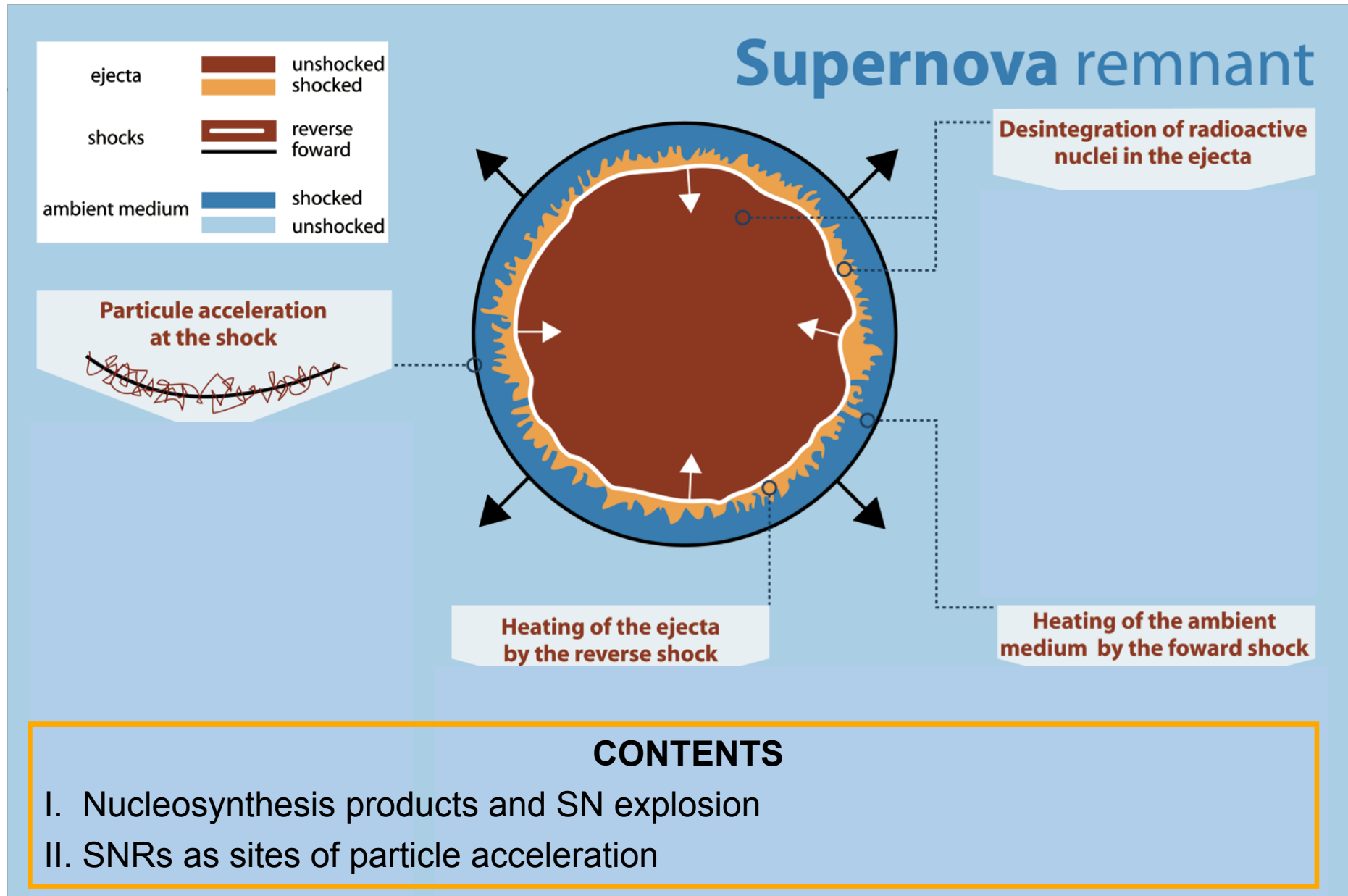
Physics of supernova explosions

- Core collapse supernovae : SN II, Ib, Ic
 - Thermonuclear explosion : SN Ia
- => standard candles for cosmology

Origin of Galactic Cosmic Rays

Best candidate : shock at SN remnants





Xrays: a path to nucleosynthesis products

OBJECTIVES

- to understand how heavy elements are produced, mixed and then dispersed in the ISM.
- to understand the explosion of stars, their explosion mechanism, and their progenitors

How: by characterizing the thermal emission from the shocked ejecta in young SNRs

Access to the elements synthesized by the supernovae

- determination of the SN type of the remnant

Access to the repartition and kinematics of the synthesized elements

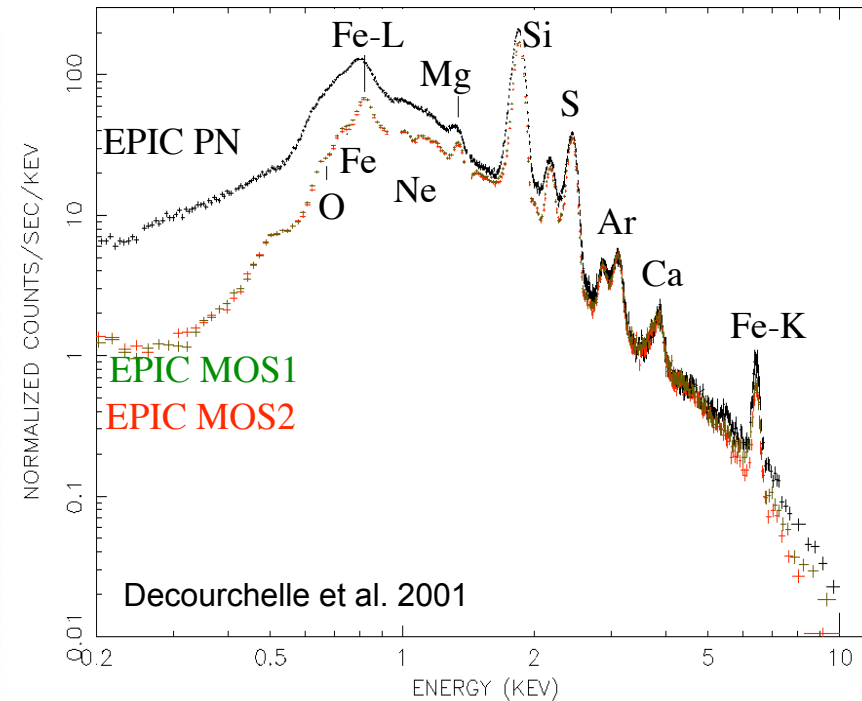
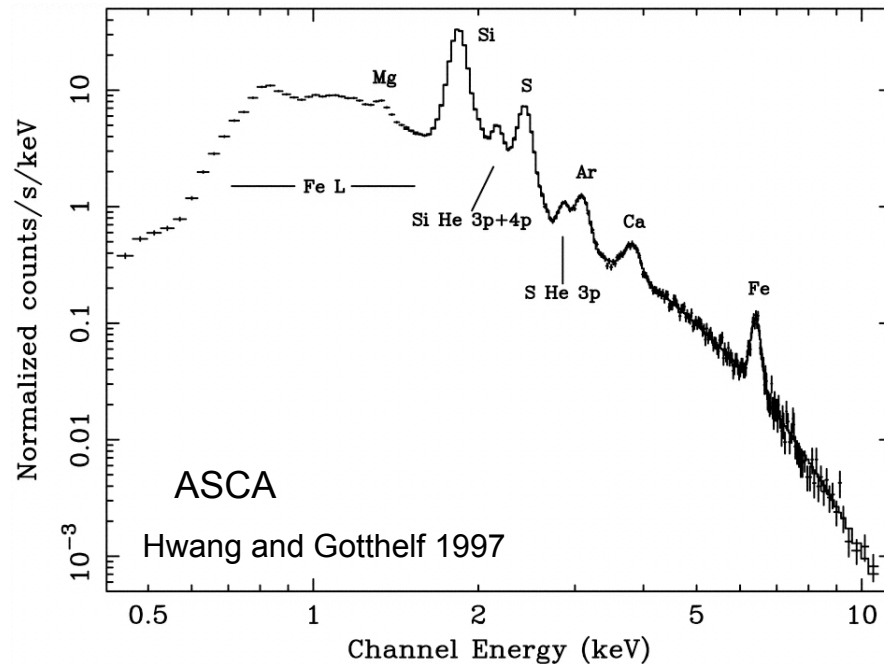
- understanding SN explosion: asymmetry, level of mixing of elemental layers
- level of mixing with the ambient medium (chemical enrichment in galaxies)

Access to the emitting conditions in the ejecta (density, temperature)

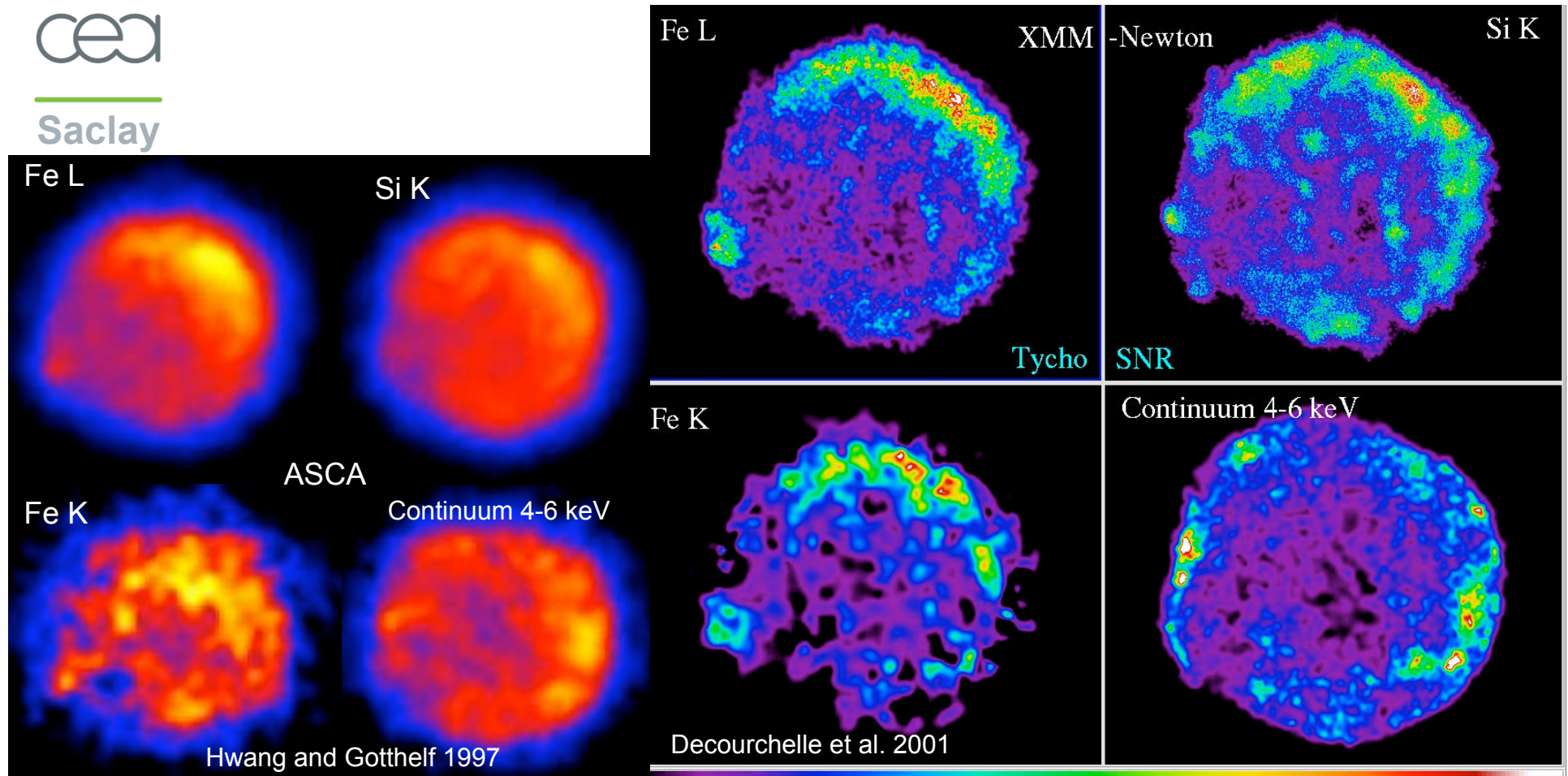
- constraining the progenitor and explosion

⇒ Spatially resolved X-ray spectroscopy

XMM-NEWTON, ideal instrument for this task as it combines a high throughput sensitivity, a good spatial and spectral resolution.

Tycho'SNR : an historical SN Ia supernova remnant (SN 1572)

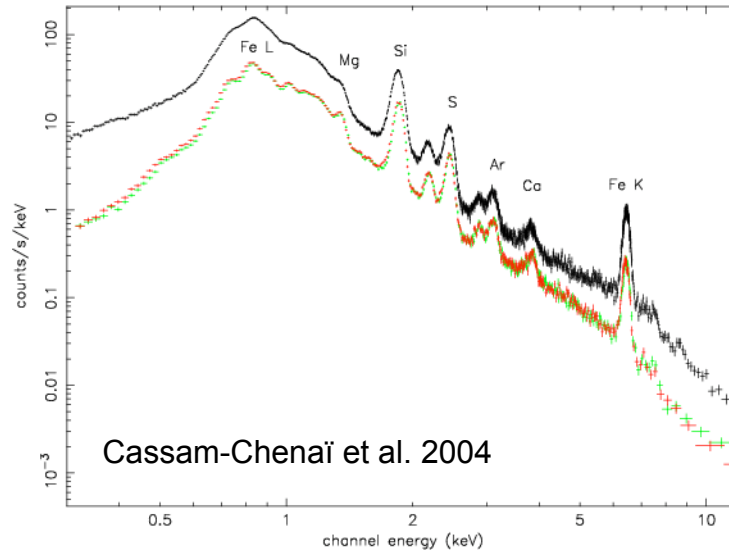
An order of magnitude more counts than with ASCA, better spectral resolution notably at low energy and an order of magnitude better spatial resolution
=> improvements required to perform spatially resolved X-ray spectroscopy



- Efficient overall mixing of the Si and Fe layers, but inhomogeneities at small scale.
- Fe K emission peaks at smaller radius than Fe L : higher temperature towards the interior
- Continuum emission associated with the forward shock (shown by Chandra to be nonthermal)

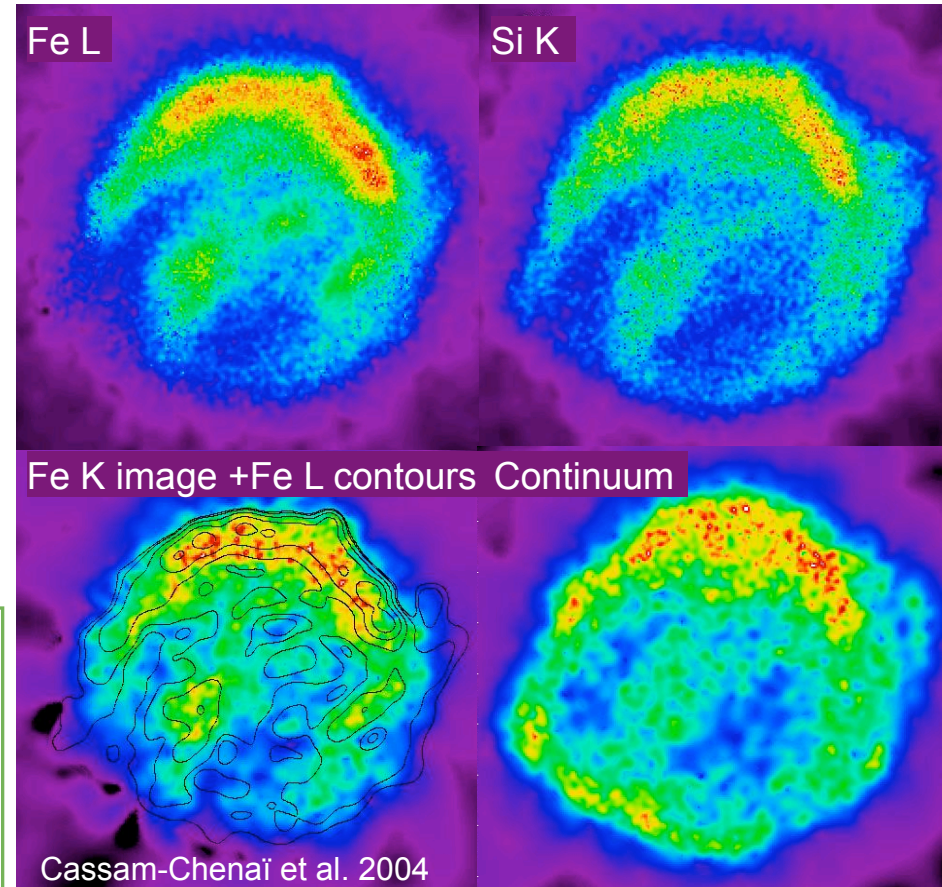
Characterization of the elements synthesized in Kepler's SNR

Kepler's SNR :
an historical debated SN Ia supernova remnant (SN 1604)

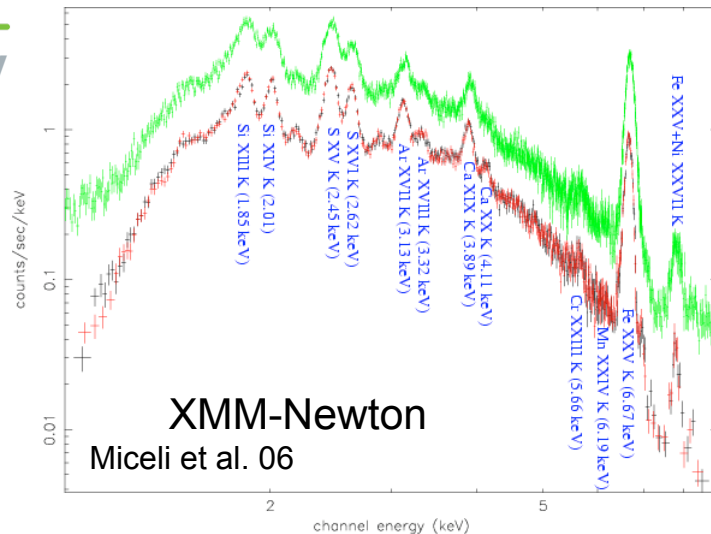


Similarity with Tycho SN Ia

- Line emission (Si, S, Ar, Ca, Fe)
- Overall mixing of the Si and Fe layers.
- Higher temperature in the interior (Fe K / Fe L)
- Nonthermal forward shock emission

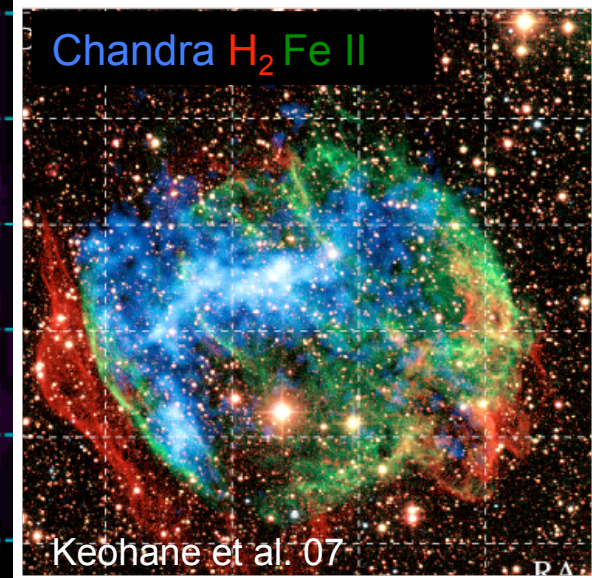
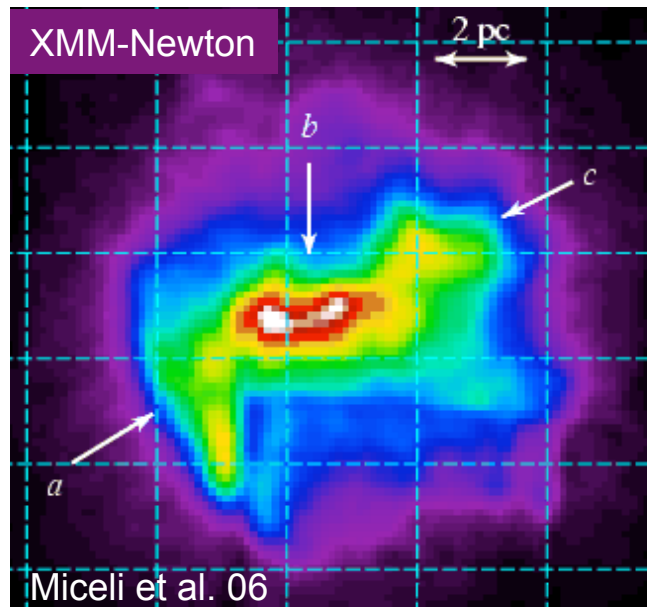
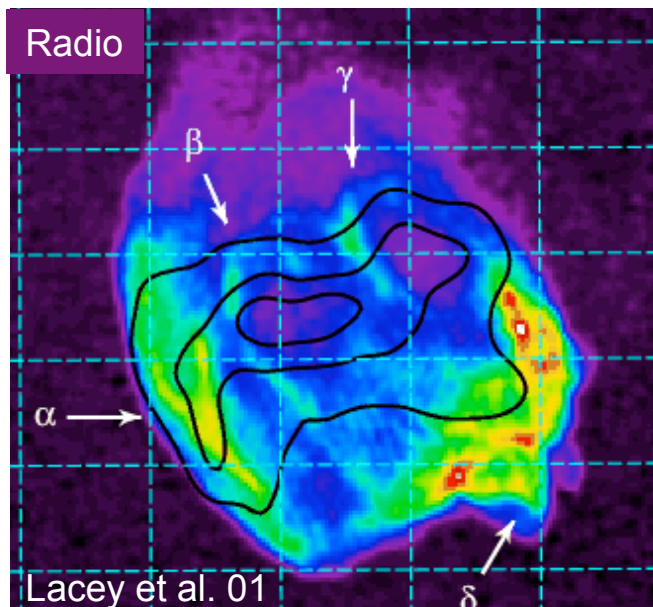


Difference : strong asymmetry of the X-ray morphology => due to a circumstellar wind
 => SN Ia explosion in a more massive progenitor : a different path to produce SN Ia ?

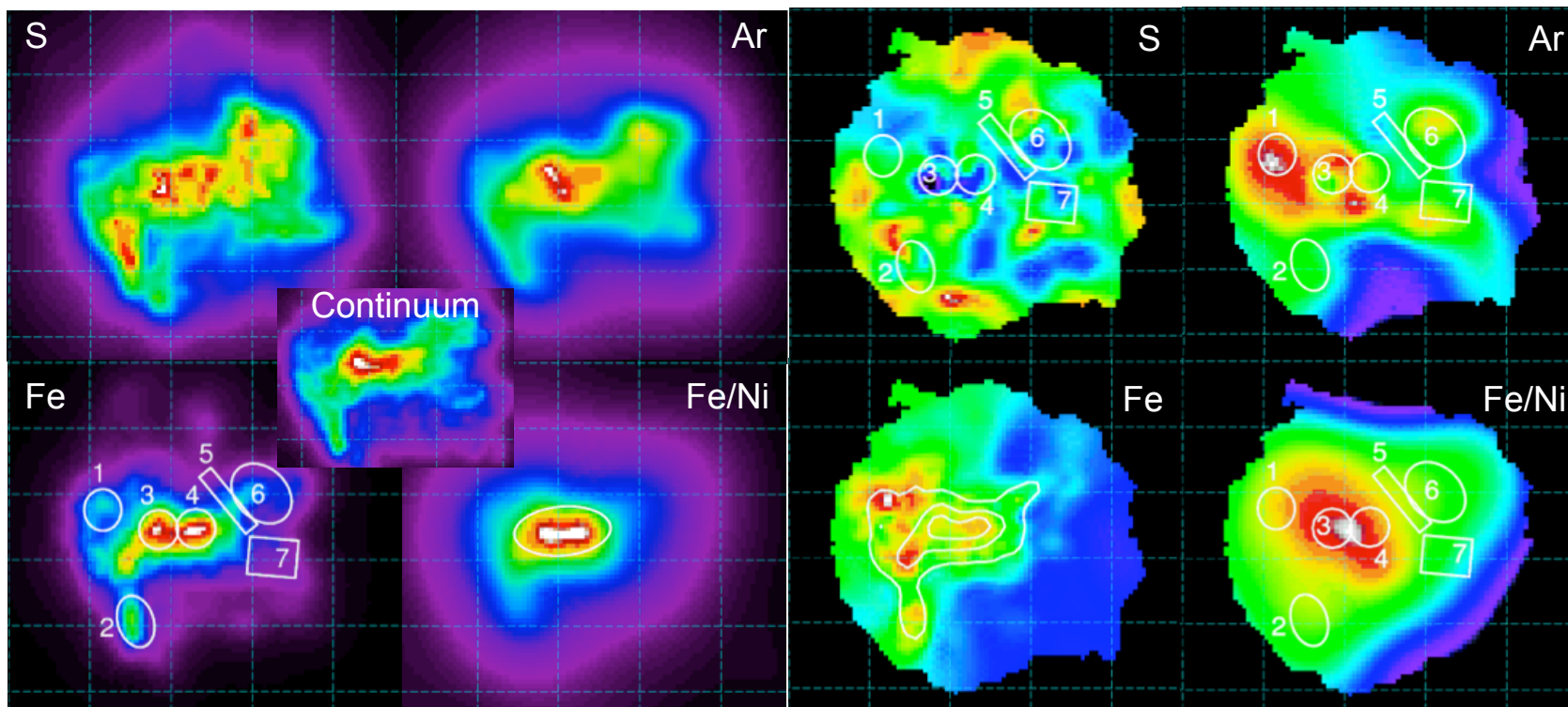


- Presence of rare elements (Cr, Mn, Ni)
- Strong bipolar X-ray ejecta emission :
asymmetry of the explosion or circumstellar and interstellar environment ?

How are distributed the synthesized elements in the ejecta ?



Distribution of the synthesized elements in W 49B

Line emission maps = $f(n_e, Ab_z, T_e)$ Equivalent width maps = $f(Ab_z, T_e)$ 

Distribution of elements

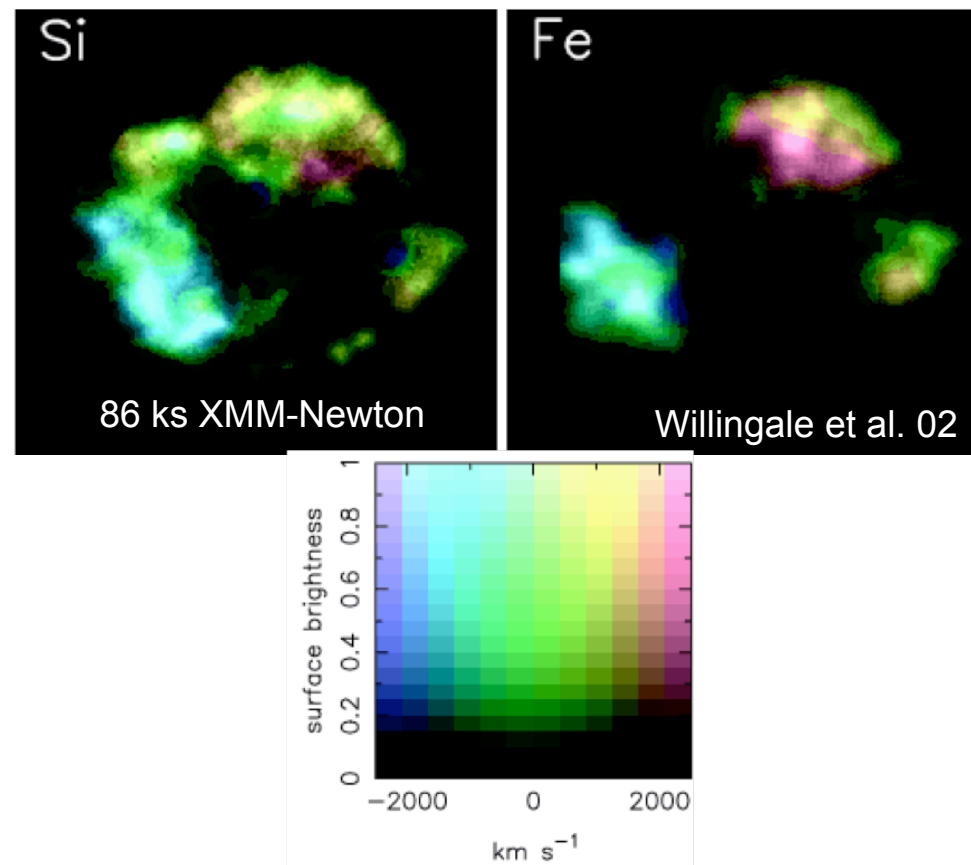
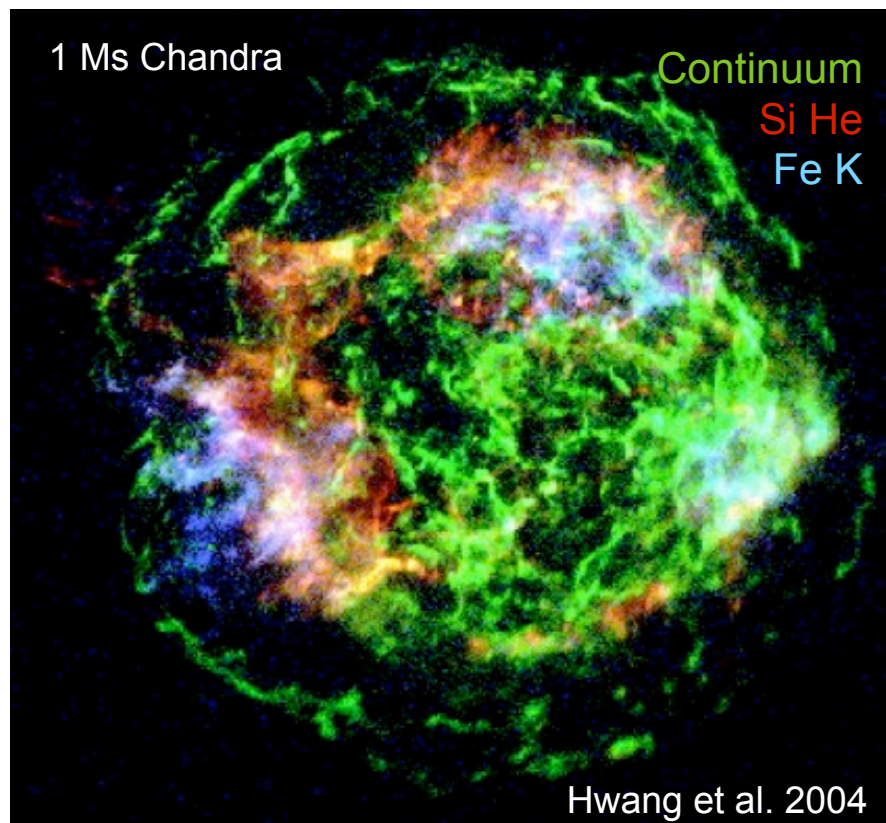
=> equivalent width images and spatially resolved spectroscopy

Strong asymmetry in the Fe distribution:
 Ab_{Fe} and temperature larger in the east side.

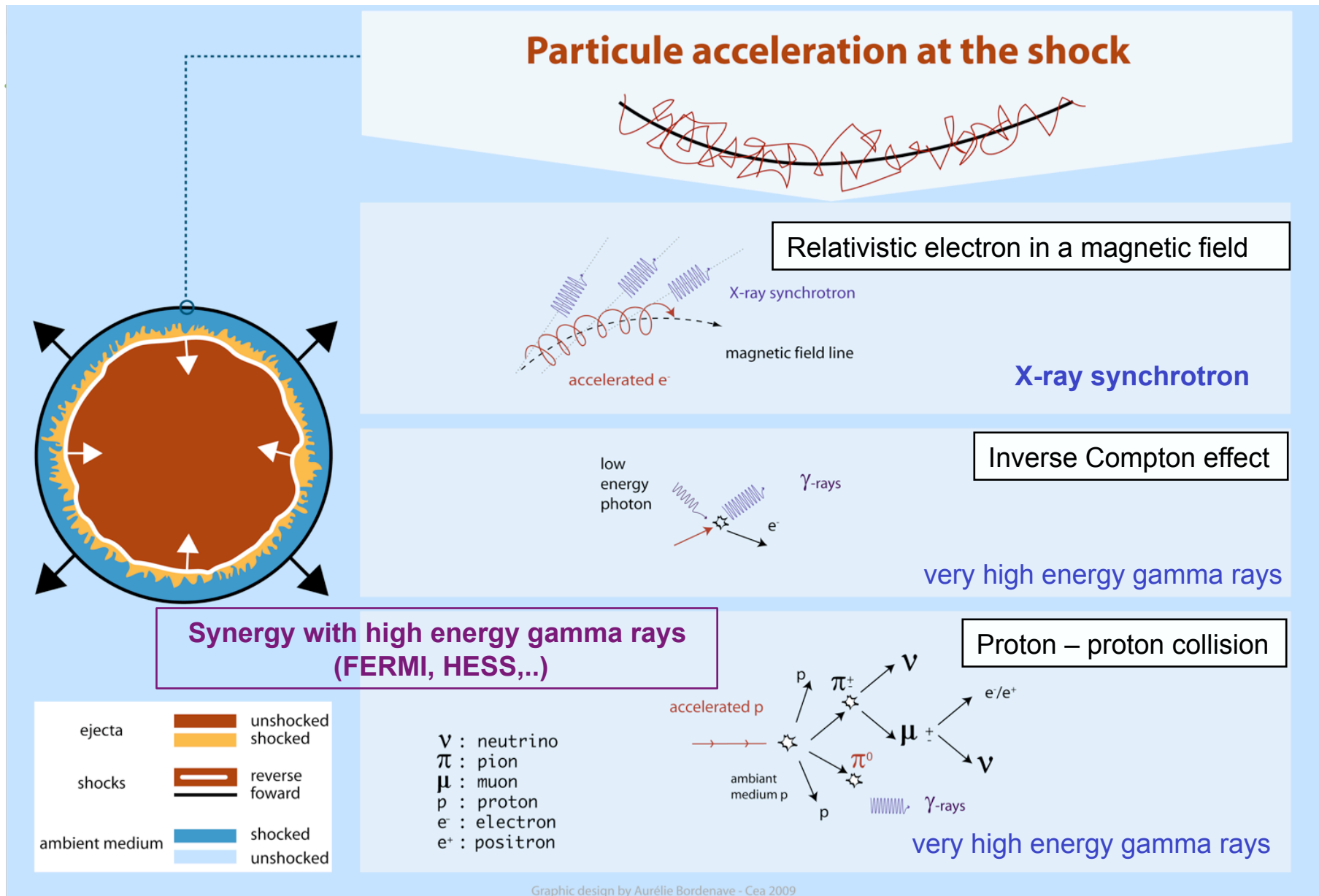
=> Kinematics of the ejecta required



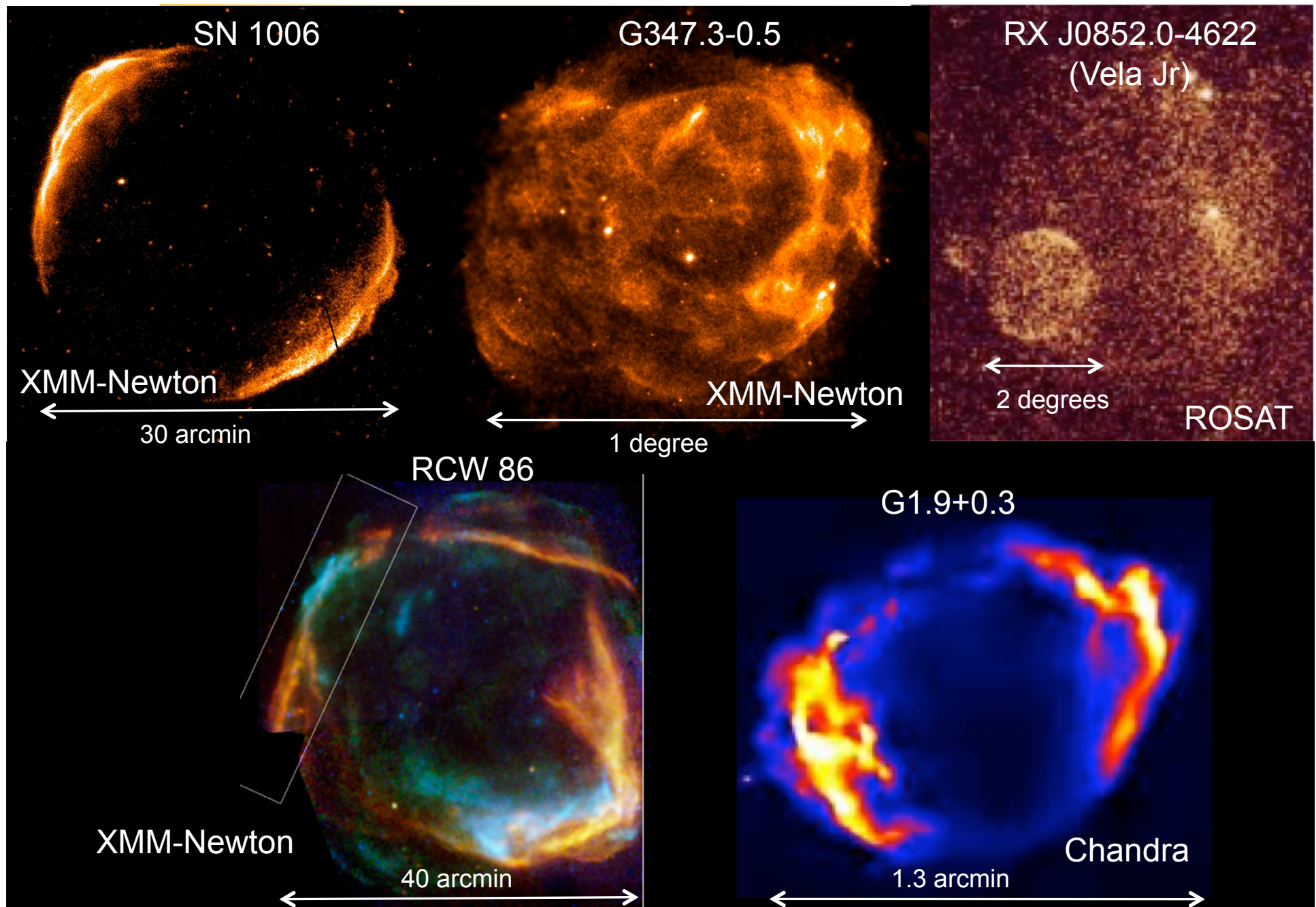
Doppler shift maps, 20" x 20 " images



- Line and Doppler images: spatial inversion of a significant portion of the Fe core (Hughes et al. 2000, W02)
- Spatially resolved spectroscopy: abundance ratios ~ core collapse of a 12 M star (Willingale et al., 2002)



Synchrotron-dominated supernova remnants



Particle acceleration at shocks in SNRs

Objective : to understand the process of particle acceleration and the origin of Galactic cosmic rays

- What is the level of magnetic field amplification at the shock ?
- What is the maximum energy of the accelerated particles ?
- What is the efficiency of particle acceleration ?
- ...

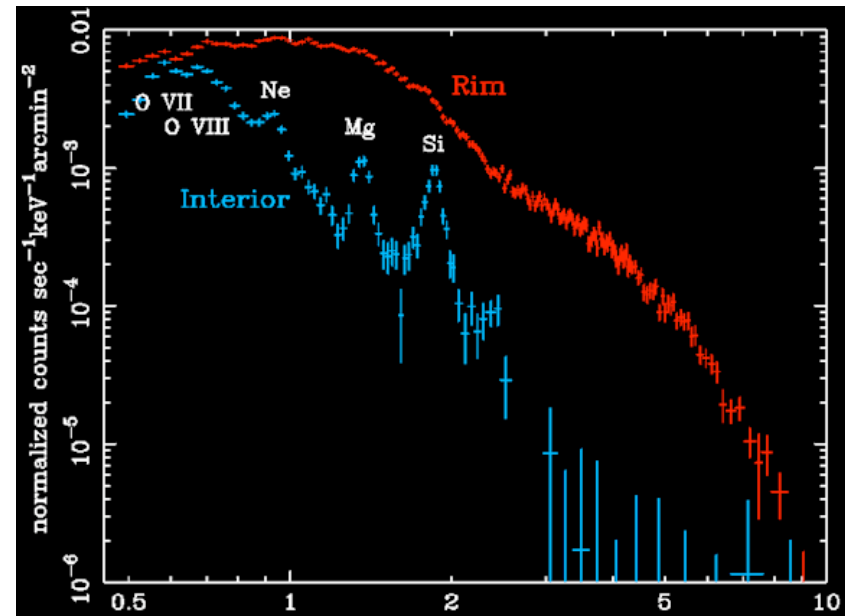
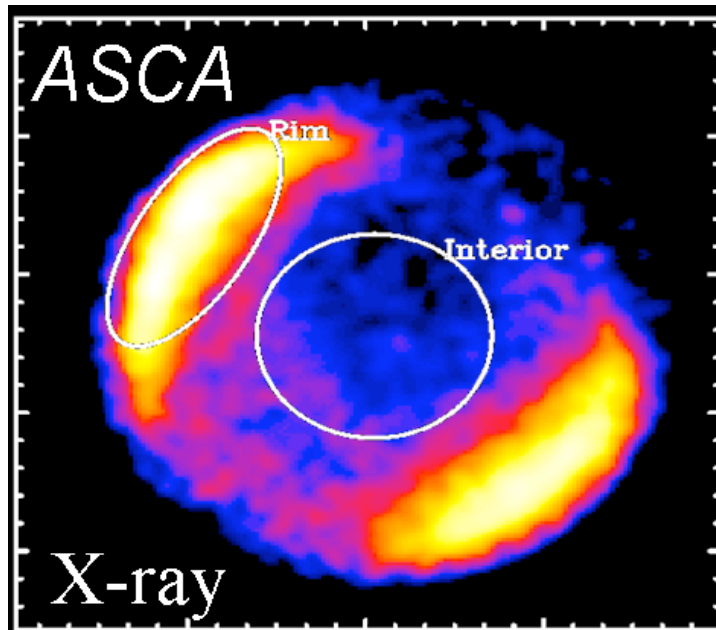
Why are X-rays crucial to investigate particle acceleration ?

- Physics of the synchrotron emission of the electrons accelerated at the highest energy
- Physics of the thermal gas
 - Global parameters of the remnant
 - Back-reaction of accelerated protons
- Capability of performing spatially-resolved spectroscopy at small scale
(< 10 arcsec while VHE gamma-ray instruments ~ 0.1 deg at best)

Particle acceleration in supernova remnants: a new observational domain

1954 : Radio synchrotron of Tycho

=> electrons accelerated at GeV energies in supernova remnants

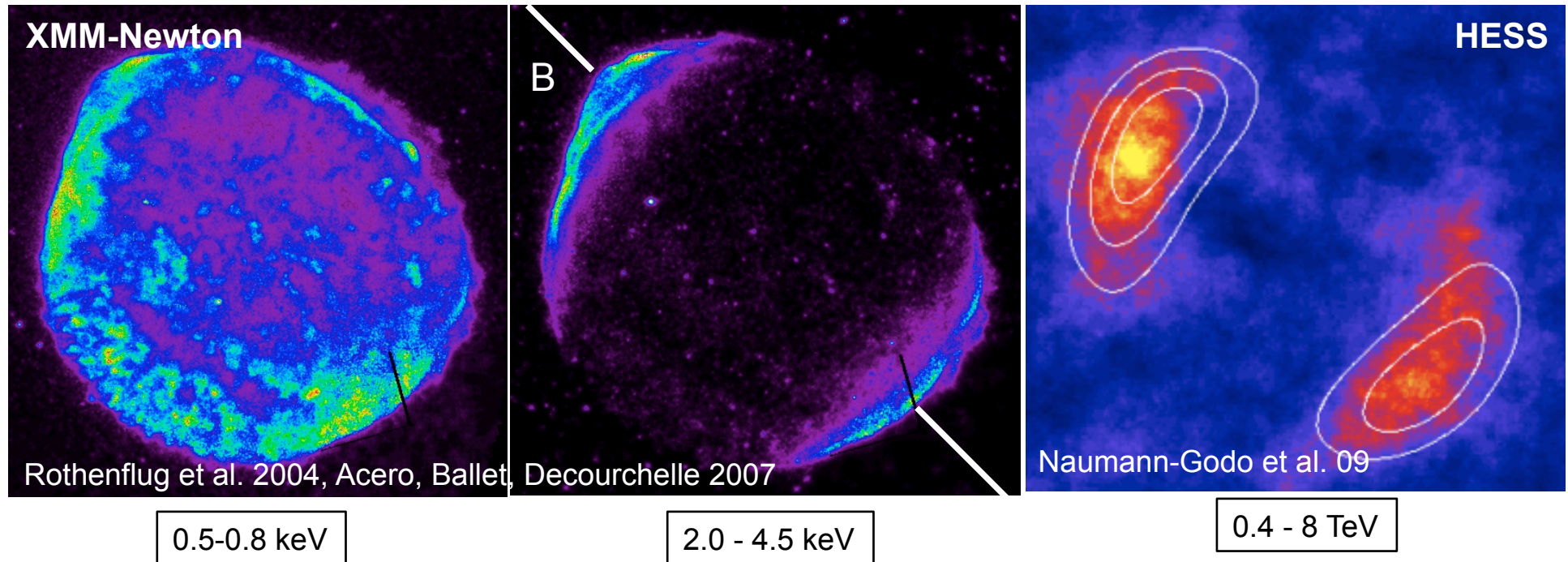


1995: X-ray synchrotron in SN 1006 by **ASCA** (Koyama et al. 1995, Nature)

1997: X-ray synchrotron in RX J1713.7-3946 by **ASCA** (Koyama et al. 1997)

=> electrons accelerated at TeV energies, approaching the knee at a few 10¹⁵ eV

SN 1006: a SN Ia at high latitude evolving in a relatively uniform interstellar medium
=> determine the dependence of the acceleration with orientation of the magnetic field

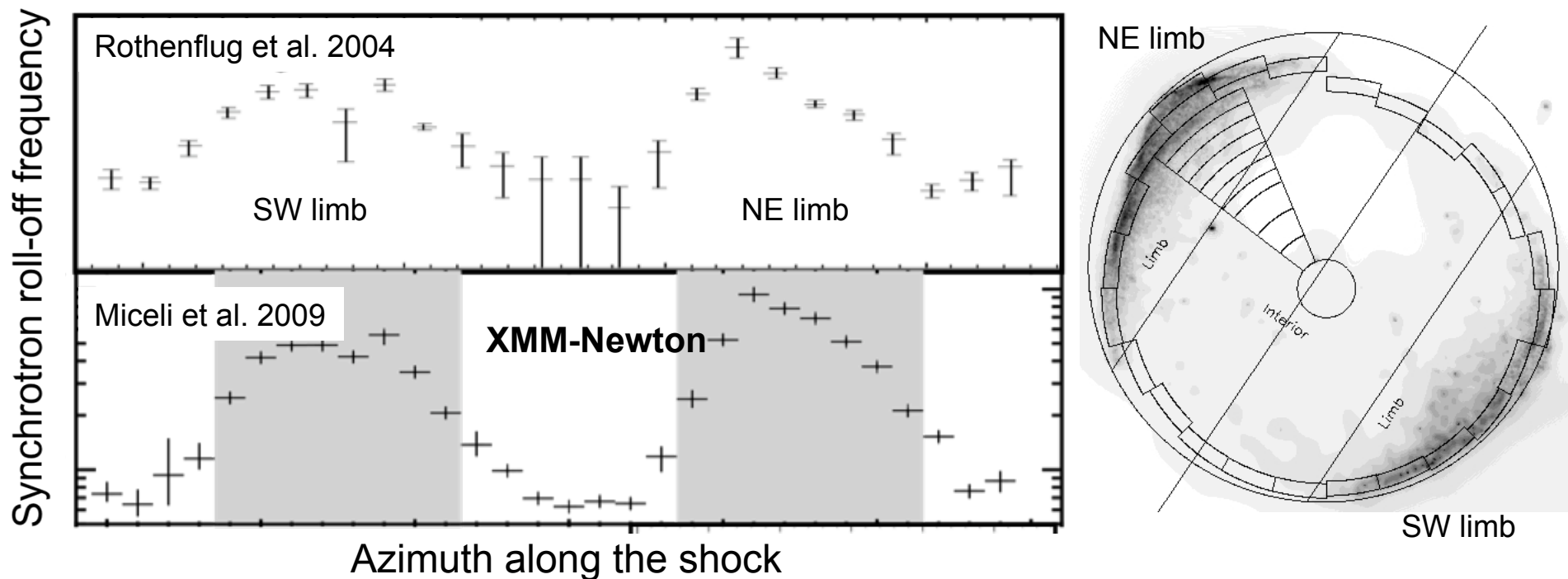


Synchrotron X-ray morphology indicates limbs are polar caps rather than an equatorial belt
(Rothenflug et al. 2004)

=> particles are accelerated where the magnetic field is parallel to the shock velocity

Spatially resolved spectroscopy of the synchrotron emission (+ radio flux)

=> Measurement of the averaged azimuthal variation of the synchrotron roll-off frequency along the shock



SN 1006: very strong variations of the synchrotron roll-off frequency

=> Maximum energy of accelerated particles must be higher at the bright limbs than elsewhere

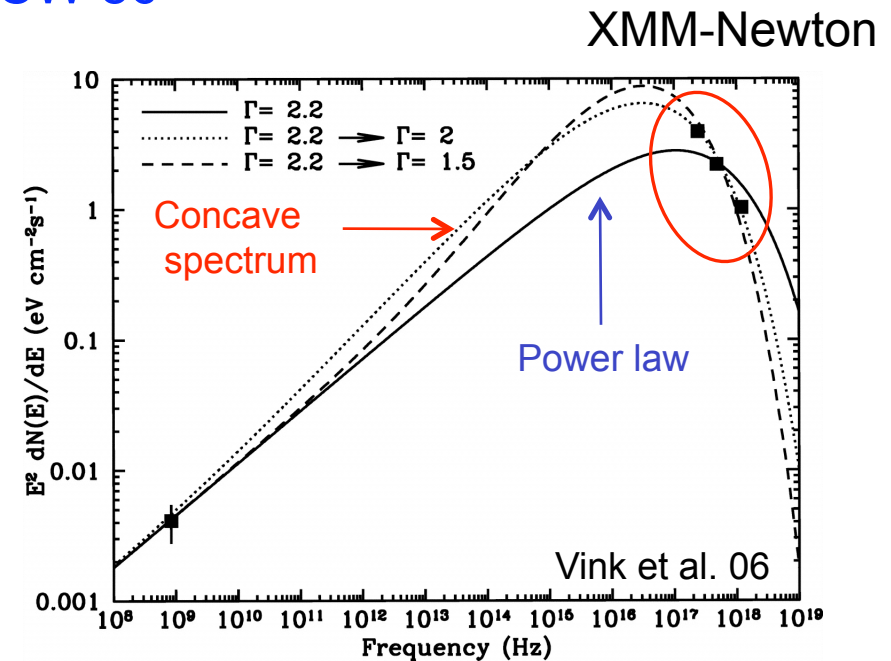
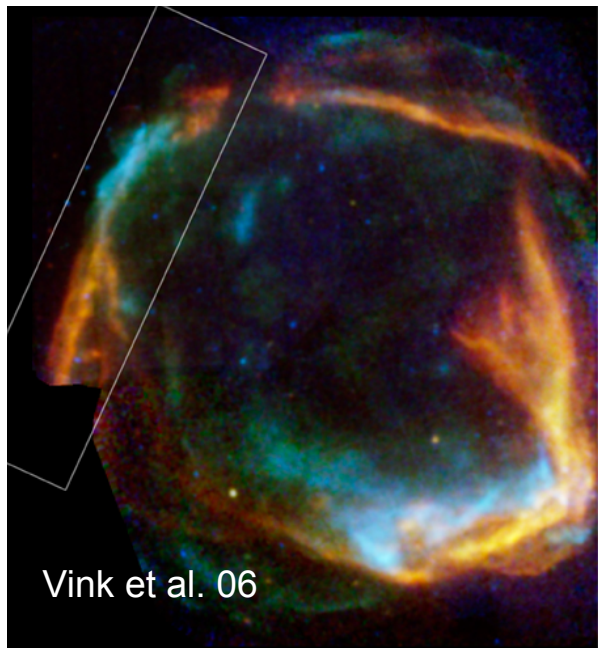
What fraction of the shock energy can be tapped by cosmic rays ?

Evidence for ion acceleration in SNRs ?

Predictions from nonlinear diffusive shock acceleration

=> curvature of the particle spectra (Berezhko & Ellison 99, Ellison & Reynolds 91,...)

RCW 86



Curvature of the spectrum: indications in a few SNRs combining radio and X-ray data

SN 1006 (Allen et al. 08) et **RCW 86** (Vink et al. 06)

Perspectives with XMM-Newton

XMM-Newton and Chandra have demonstrated that most of the physical processes in supernova remnants occurs at relatively small scales:

- spatial distribution and kinematics of the synthesized elements
- thermodynamic conditions (electron temperature, density)
- properties of particle acceleration

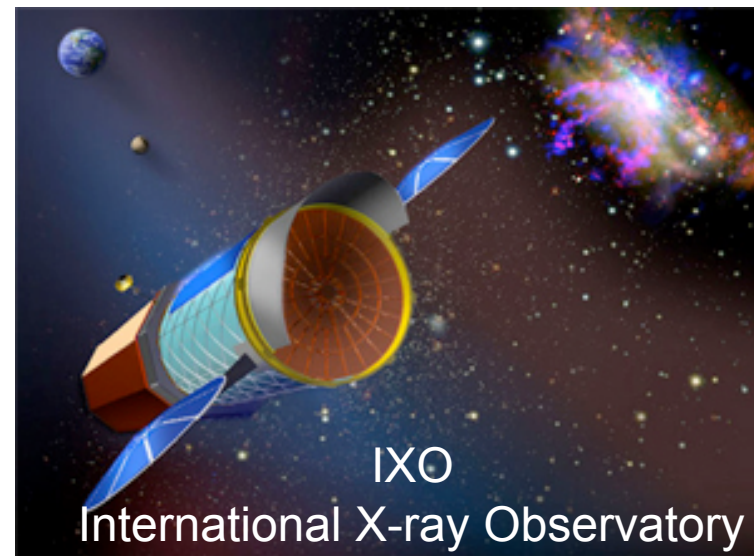
To understand the explosion mechanism and particle acceleration, we need spectral information at the relevant spatial scales

Full strength of XMM-Newton is required to perform spatially resolved spectroscopy close to the size of the PSF in a number of relevant supernova remnants.

This is important to provide the most pertinent science and to prepare IXO



XMM-Newton



IXO
International X-ray Observatory