THERMAL X-RAYS FROM EJECTA AND SHOCKED INTERSTELLAR MEDIUM IN SN1006

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Introduction

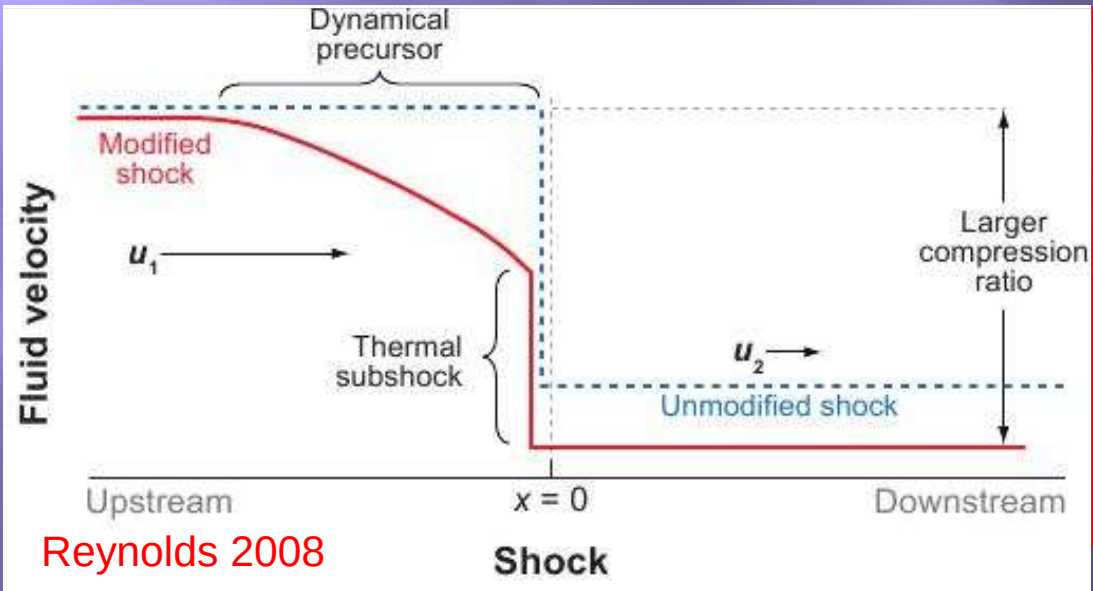
- Additional goals of the XMM-Newton SN1006 LP (see A. Decourchelle talk at this meeting) includes:
  - The detection of the X-ray emission from the shocked interstellar medium
  - A deep, spatially resolved X-ray study of the ejecta emission

Why it is importat to see the shocked ISM?

In case of efficient particle acceleration, relativistic particle ram pressure may dominate over thermal pressure

➡ $r_{tot}=(\gamma+1)/(\gamma-1)=7$ **and not 4 !!**

Shock is not adiabatic anymore, it is ***"modified"*** !!



Reynolds 2008

Thermal X-ray emission as a tracer of shock modification

Because of **larger compressibility, and lower post shock temperature** (e. g. Decourchelle et al. 2000, Blasi 2002)

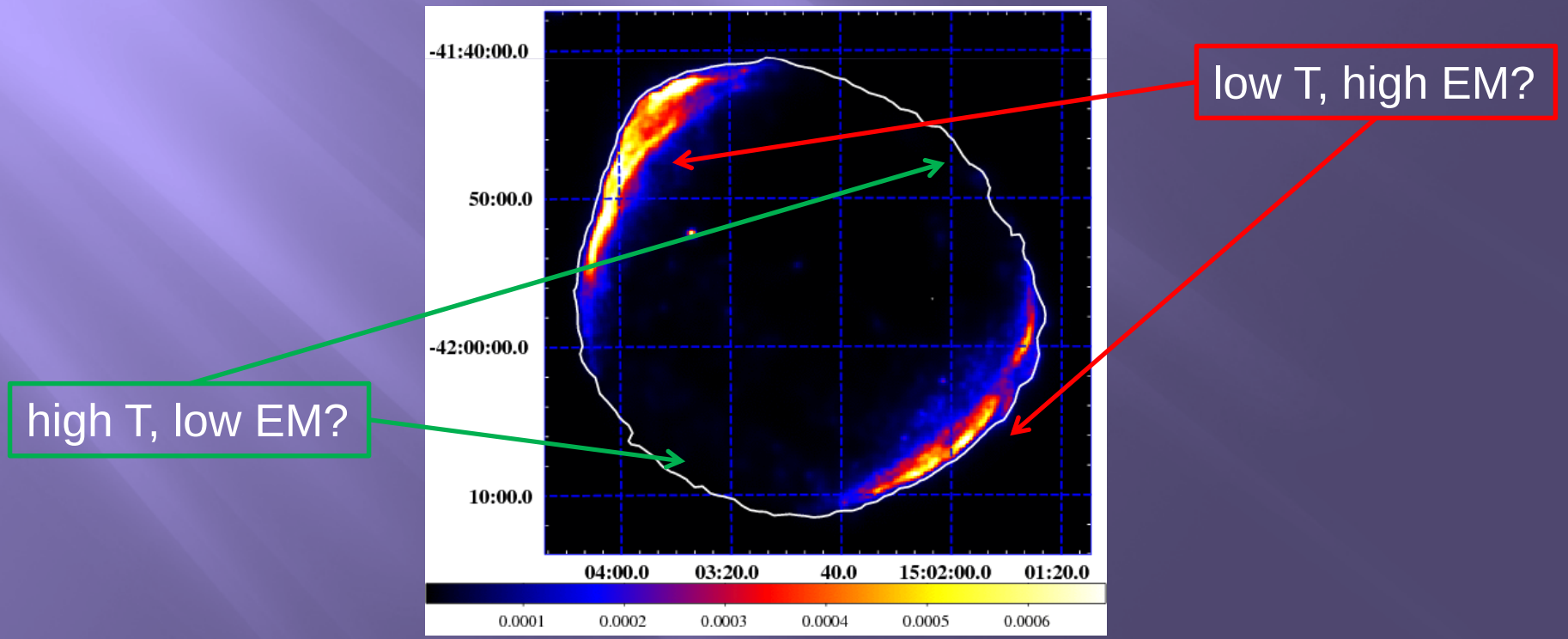
CR modified shocks are (indirect) proof of proton acceleration

Where is the interstellar medium X-ray emission?

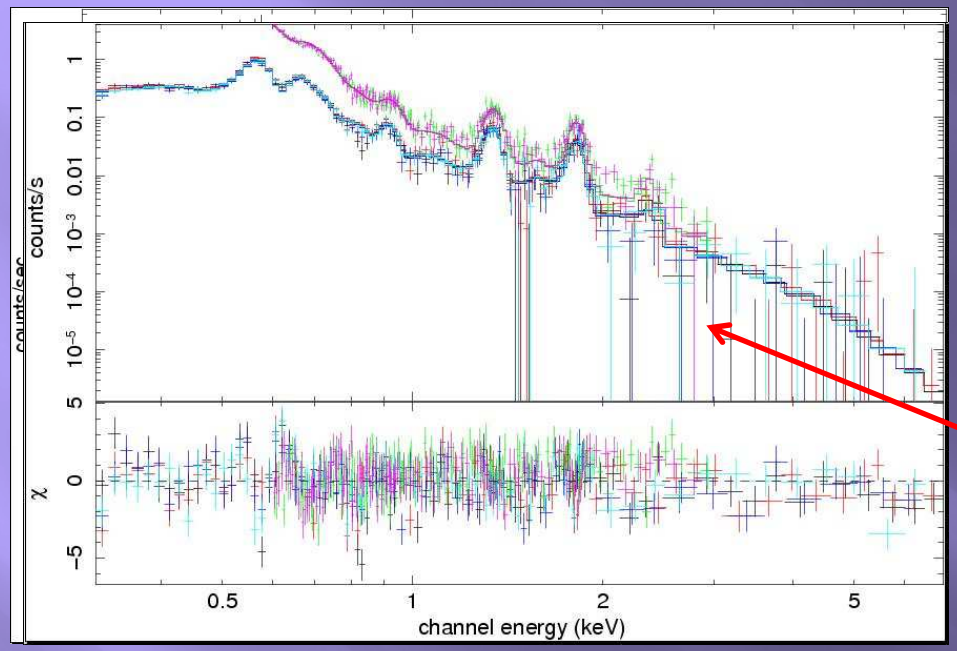
- **No detection of** X-ray emitting **ISM** in accelerating SNRs (e. g. Cassam-Chenai et al. 2004 for RX J1713.7-3946 and Cassam-Chenai & Hughes 2007 for Tycho)
- The possible detection of shocked ISM in SN1006 by Acero et al. (2007) may be due to residual non-thermal synchrotron emission (Miceli et al. 2009)

X-rays from shocked ISM

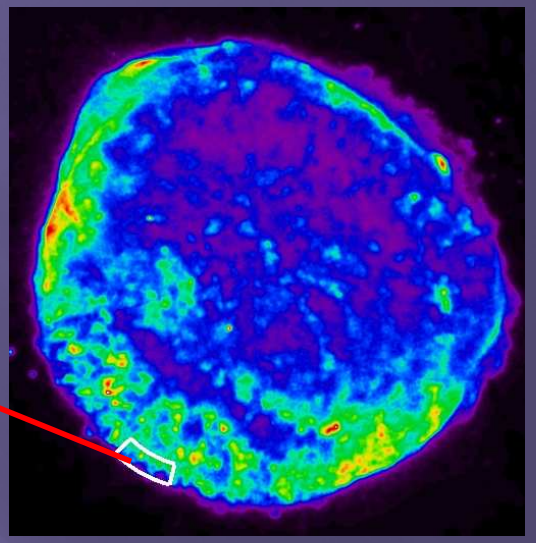
- The key point is that in a remnant like SN1006 we may have both efficient and inefficient acceleration regions



New results form the LP



0.5-0.8 keV

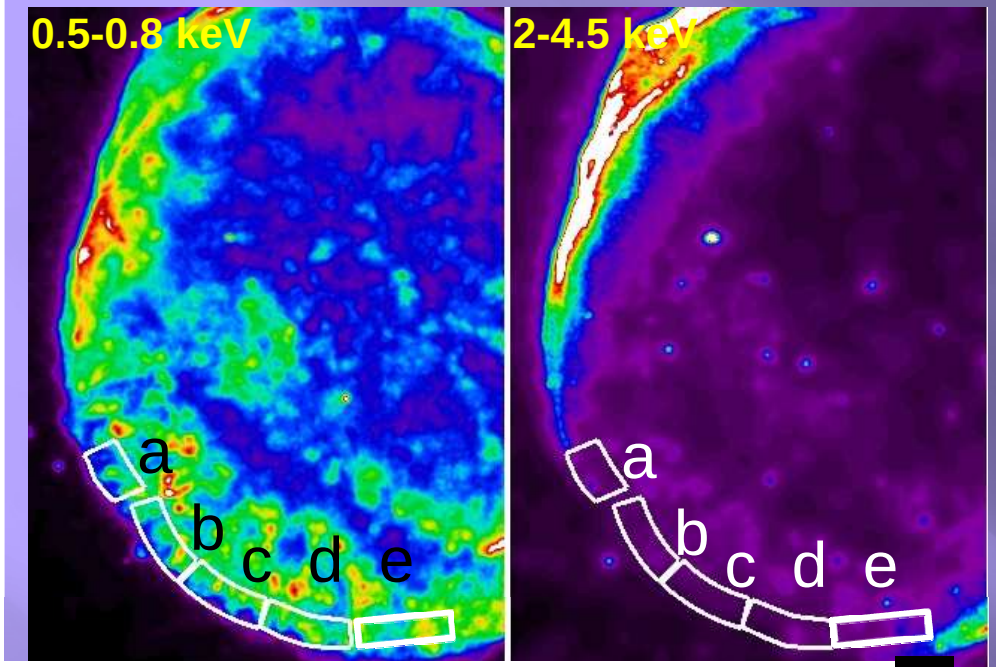


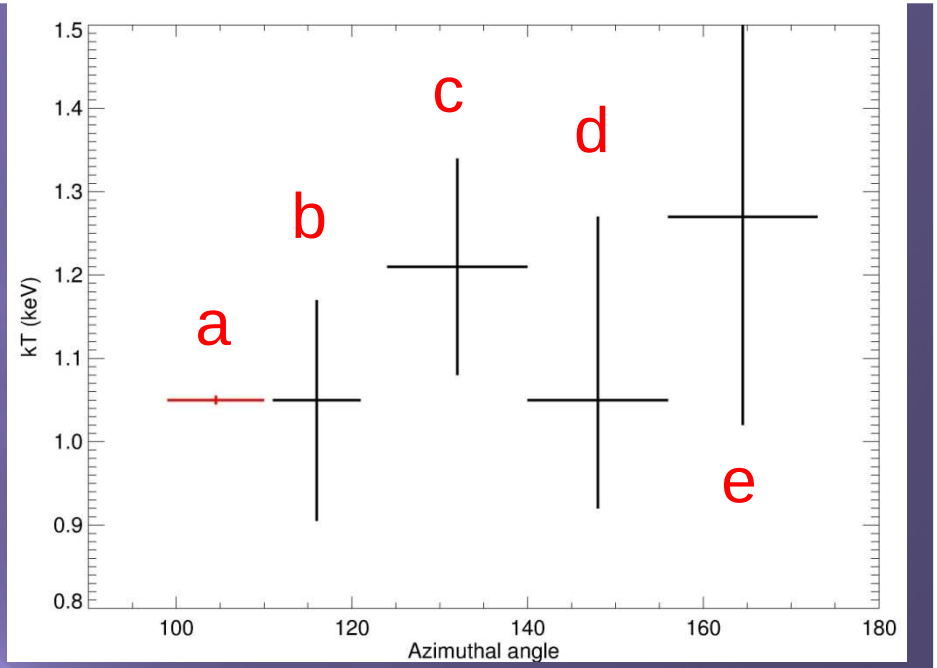
- SRCUT + 1 Thermal component: χ^2=1190 (660 d.o.f.)
- SRCUT + 2 Thermal components: χ^2=1050 (657 d.o.f.)

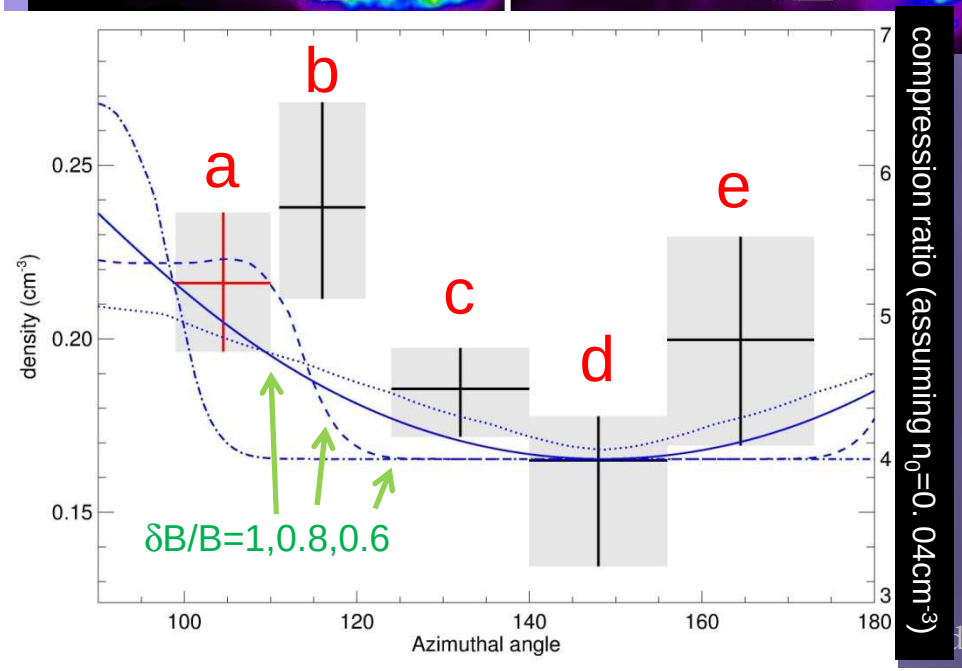
The additional thermal component (with solar abunances) significantly improves the quality of the fits!

Detection of shocked ISM

Azimuthal profiles







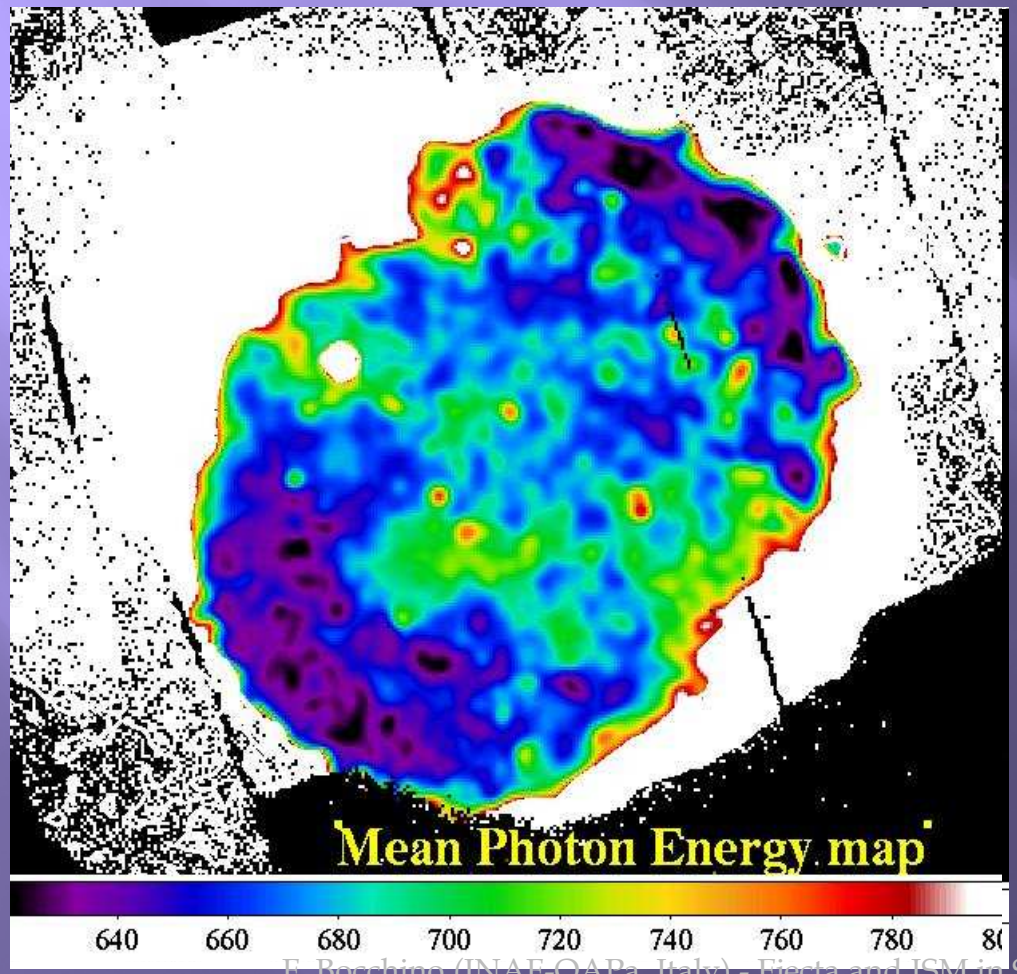
Comparison with oblique shocks model of Volk+(2003, δB/B is the upstream random field)

First direct evidence of shocked ISM and obliquity dependence of shock modification ?

Part II
An X-ray study of ejecta

An X-ray study of SN1006 ejecta

- Introducing the Mean Photon Energy (MPE) map

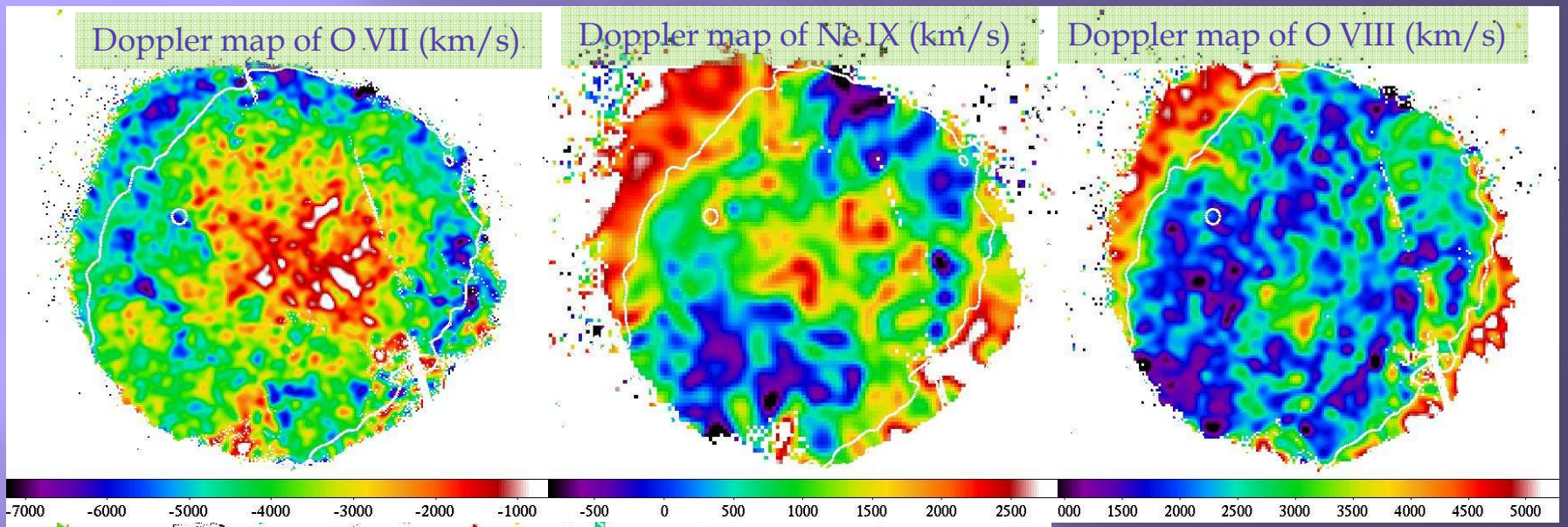


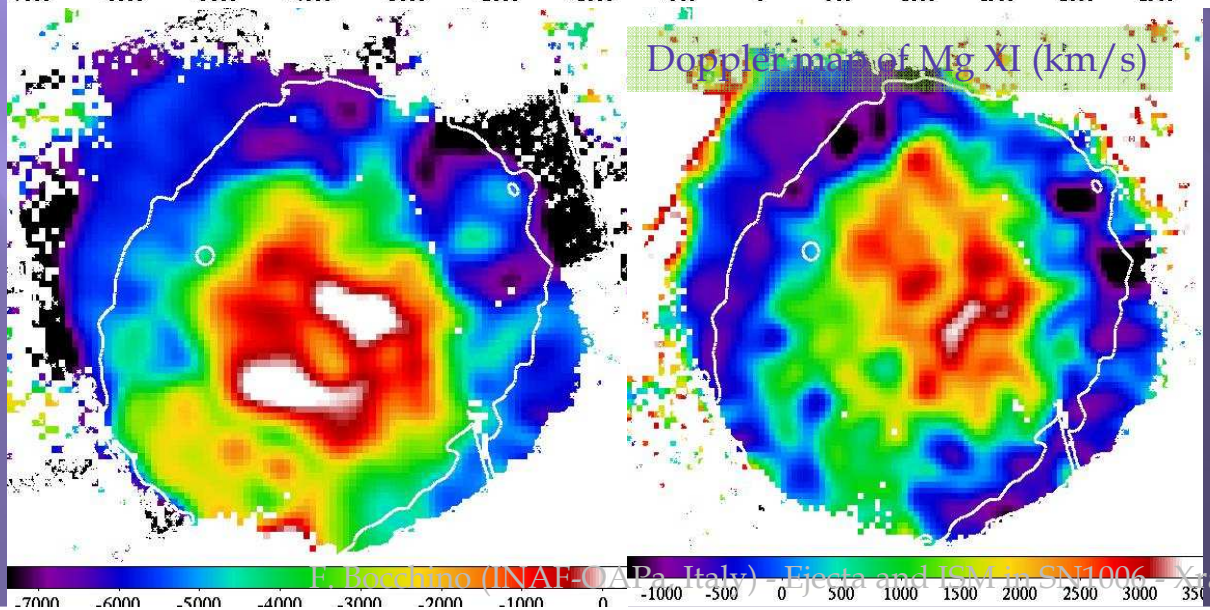
MPE maps combine at the same time the 3 main instrumental features in a single image:

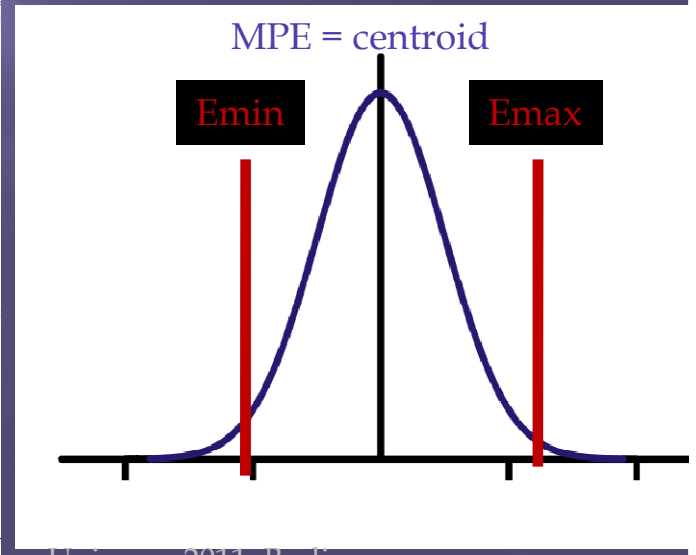
1. Spatial resolution
2. Spectral resolution (low MPE uncertainties)
3. Effective area (at least 4 cnt/pixel to compute MPE)

Inner regions have higher mean photon energy !!!!

Narrow band MPE maps

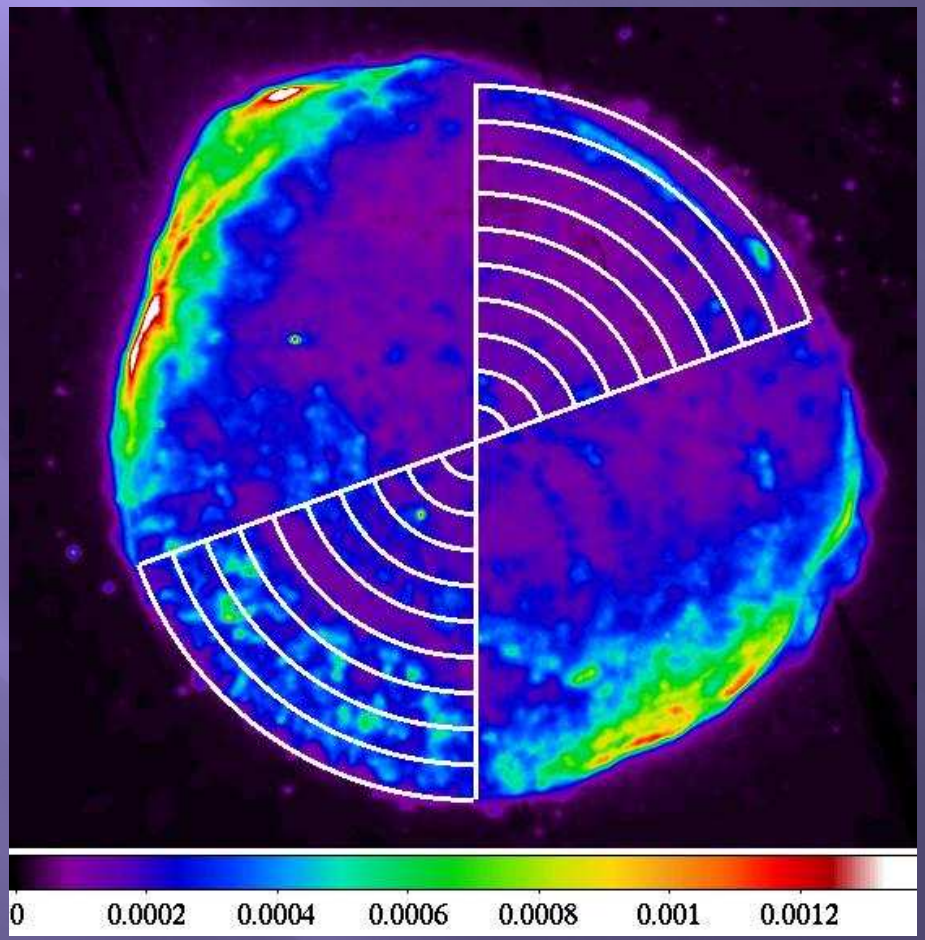




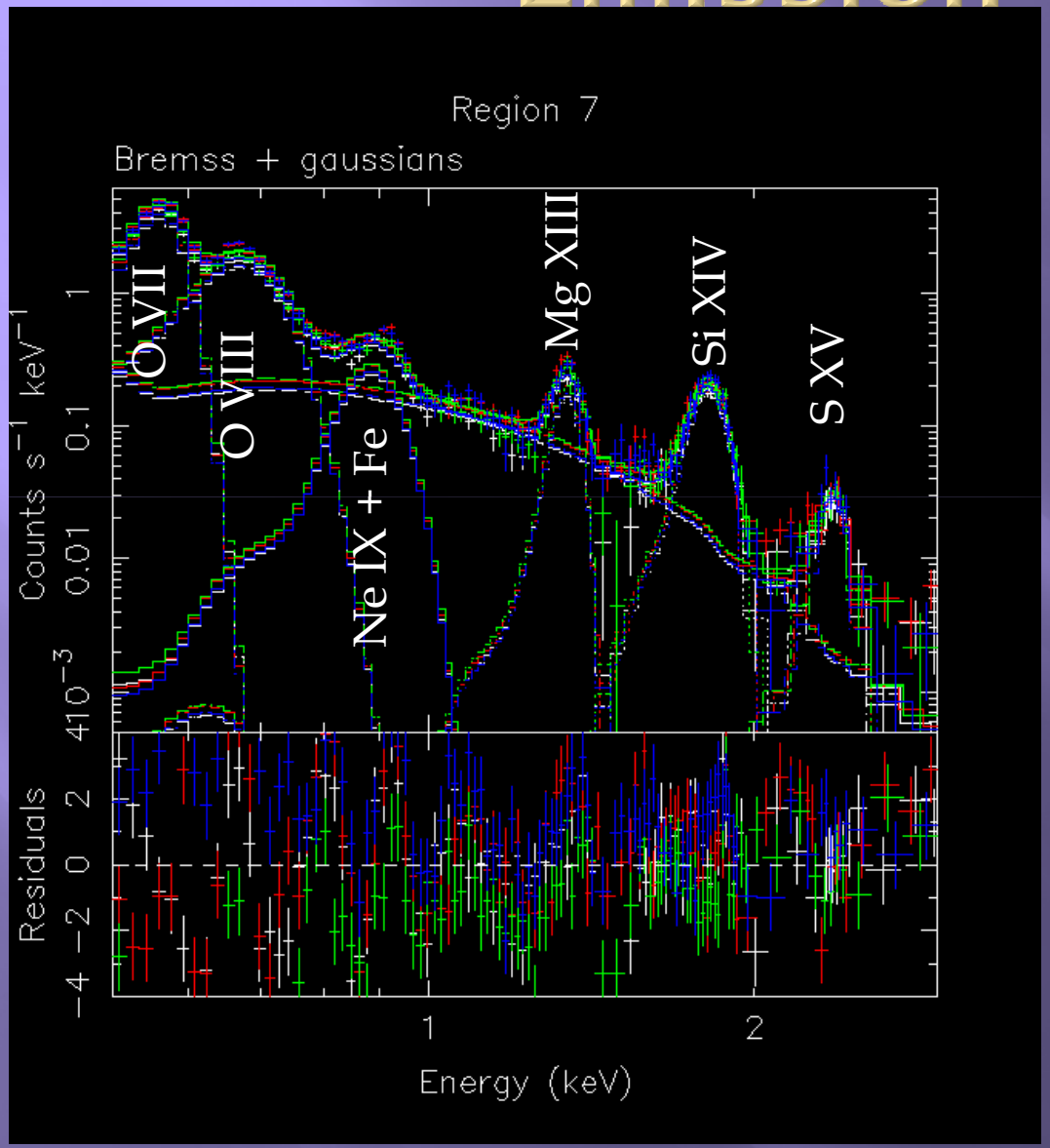


Spectral fittings

- Sampling the NW-SE direction

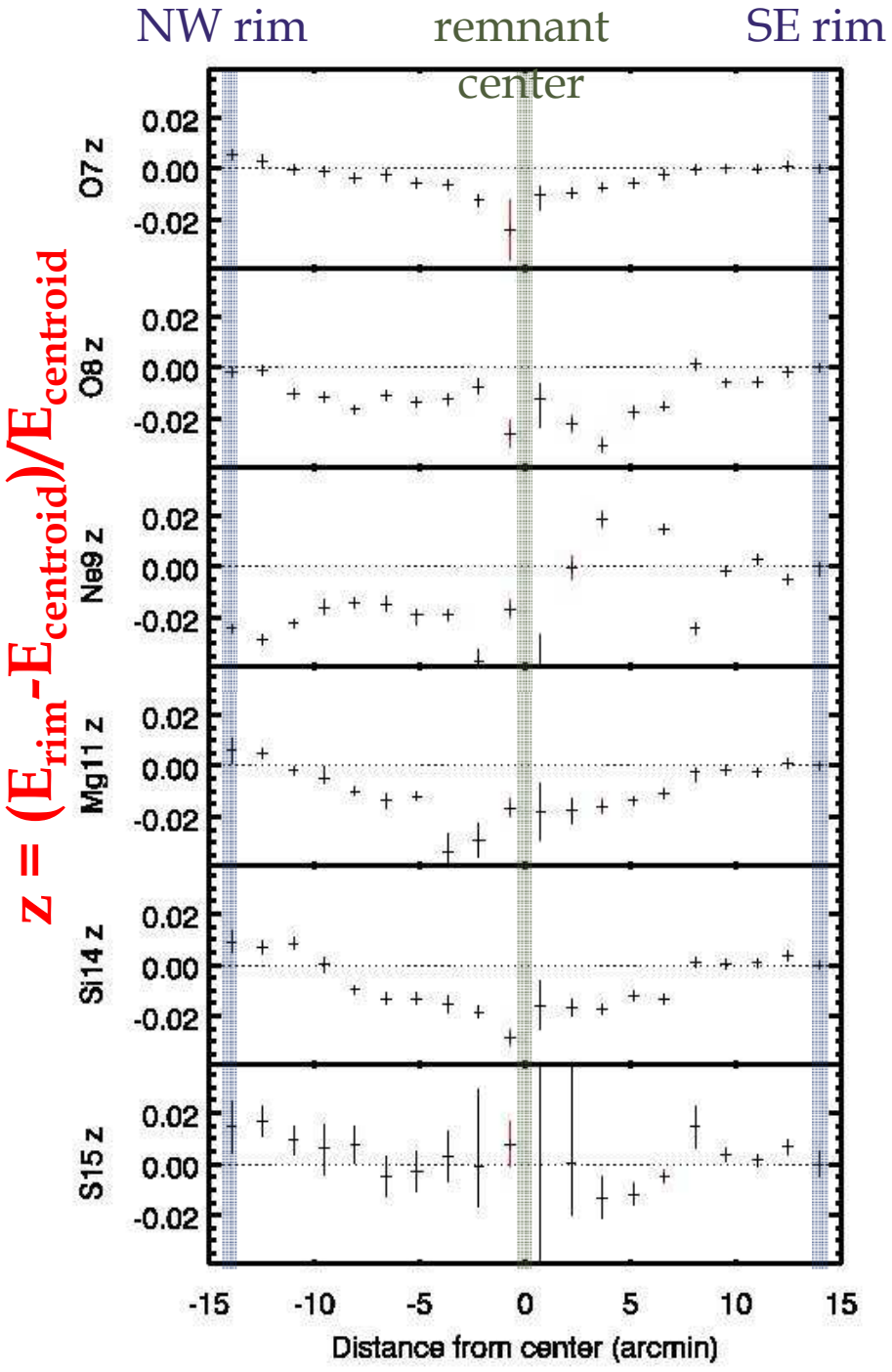


Emission lines



Spectral fits with a bremsstrahlung and gaussian lines to measure line centroids and widths

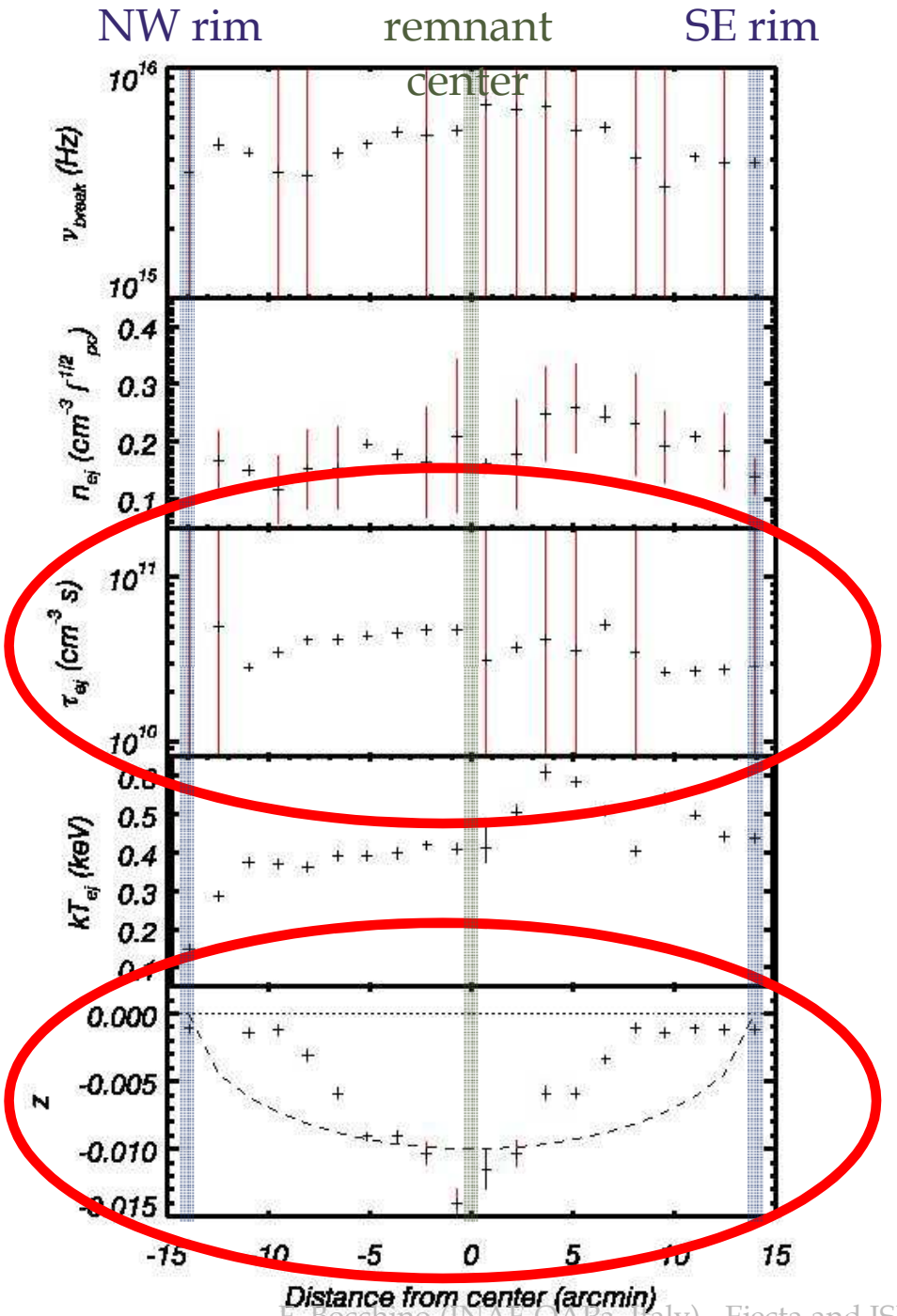
Same technique as in Hayato et al. (2010) for Tycho



- Emission lines centroids are generally **blueshifted (z < 0) at the center of the remnant** w.r.t. the rims
- more clear for O, Mg and Si, less clear for Ne and S
- if interpreted in terms of velocity, the max value of z=-0.02 correspond to a max velocity 2% of c

Interpretations

- Doppler shifts: l.o.s. velocity of the expanding layers of ejecta (approaching side only)
  - $z \approx v/c = 0.01\text{-}0.02$ (3000-6000 km/s)
  - In nice agreement with proper motion of X-ray filaments in NE rim (4800±400 km/s, Katsuda+09) and radio filaments (4400±1300 km/s, Moffett+93)
  - **Receding side not visible !! (lower density?)**
- Non-equilibrium of ionization (NEI)
  - In general, centroids are expected to redshift, the more the further the plasma is from Collisional Equilibrium of Ionization (CIE)



ISM + ejecta + synchrotron

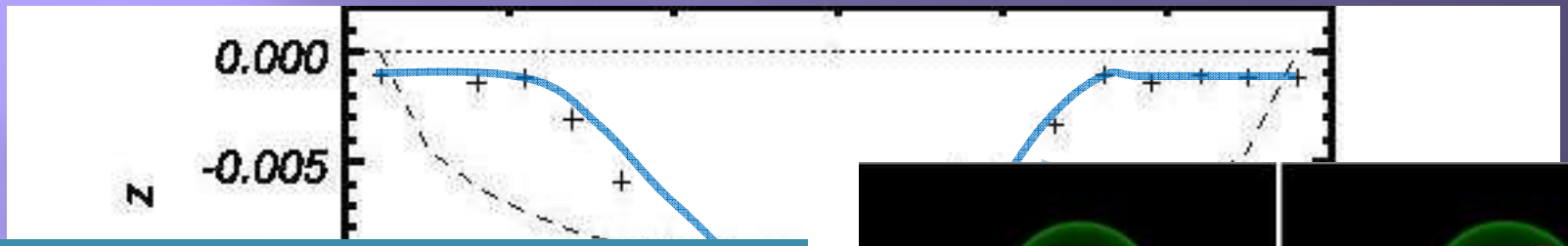
- Very limited variation of ejecta ionization time

  Blueshift is NOT a NEI effect !!!

- Very clear indication of blueshift at the center of the remnant !!!

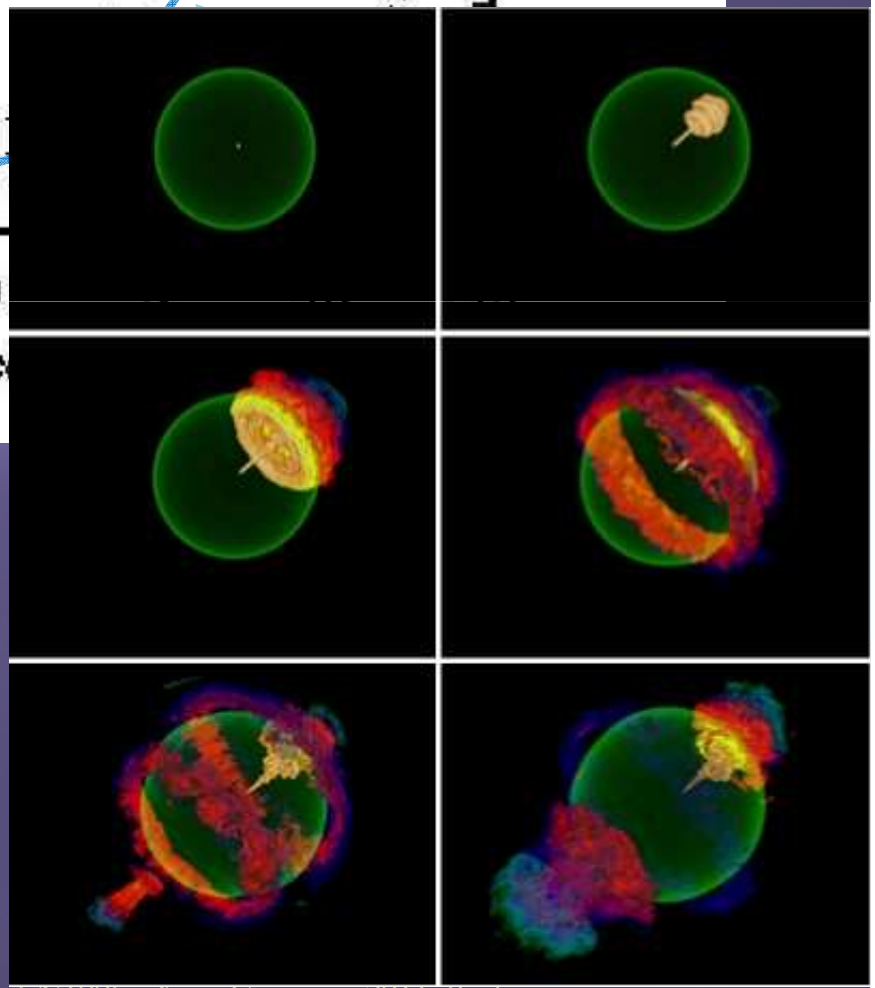
  z_{max} = -0.015

Interpretation of z profile



Asymmetric explosion !!!

In agreement with recent advances in modelling type Ia explosions, for instance ***off-center ignition*** (Maeda+2010, 2011) or the ***Gravitationally Confined Detonation model*** developed by the Chicago FLASH center (Plewa+04;Kasen+05; Meakin+09)



Summary

- New XMM-Newton observations of SN1006 allowed us to **detect the X-ray emission of shocked ISM**
  - Elusive in all the young SNRs
- There is evidence for azimuthal dependance of compression factor, revealing directly and for the first time the **obliquity variations of CR acceleration**
  - Still mostly an unexplored field for theory
- Line emission doppler maps indicate **blueshift at the center of the remnant**
  - Receding shocked ejecta must have lower mass or density
- The doppler-shift radial profile **suggests an asymmetric explosion**
  - In agreement with recent advances in modeling type Ia explosions