Istituto Nazionale di Astrofisica
Osservatorio Astronomico di Palermo

Supernova Remnants @ OAPa

Fabrizio Bocchino
Ricercatore astronomo

Human resources

Past and present

- The supernova remnant group in Palermo (born in 1993)
  - *F. Bocchino (INAF OAPa, RU, full time)*
  - ***M. Miceli (Consorzio COMETA fellow, full time)***
  - *E. Troja (INAF-IFC Palermo, PhD, now moved to GRB)*
  - *S. Orlando (INAF OAPa)*
  - *F. Reale and G. Peres (UNIPA)*
  - *A. Maggio, S. Sciortino, S. Serio (INAF-OAPa, UNIPA, < 2004)*
- External collaborations
  - *R. Bandiera, E. Amato (INAF- Arcetri)*
  - *L. Sidoli, S: Mereghetti, A. Paizis (IASF-Milano)*
  - *G. Cusumano, T. Mineo, V. Mangano (INAF-IFC Palermo)*
  - *A.M Bykov , A. Krassiltchikov (Ioffe Inst. St. Petersburgh, Russia)*
  - *A. Decourchelle, J. Ballet (Service d'Astrophysique, CEA, Saclay, France)*
  - *J. Vink (SRON, Utrecht, NL), E. van der Swaluw (NWO, NL)*
  - *O. Petruk (Inst. For Applied Mechanics and Mathematics, Lviv, Ukraine)*
  - *R. Chevalier (UVA), J. Hughes (Rutgers), U. Hwang (JHU), R. Petre (Goddard)*
  - *P. Slane, P. Plucinsky, D. Patnaude, T. Gaetz (CfA), W. Blair (JHU)*
  - *Y. Gallant (IN2P3, CNRS, Montpellier, France)*

Approved fund programs

- 1997, CS ASI, PI A. Maggio: *Osservazioni BeppoSAX, IUE ed ottiche di resti di supernova: analisi dati e interpretazione modellistica*
- 1998, ASI, PI locale F. **Bocchino**: *Osservazioni BeppoSAX di RSN "oxygen-rich" e di tipo "a shell"*
- 1999, ASI ARS 99-15, PI locale F. **Bocchino**, *Osservazioni BeppoSAX di RSN*
- 2000, ASI/I/R/27/00, PI locale F. **Bocchino**, *Osservazioni BeppoSAX di RSN*
- 2002, ASI/I/R/73/02, PI locale F. **Bocchino**, *Osservazioni BeppoSAX di RSN*
- INAF PRIN 2002, PI locale F. **Bocchino**, *The impact of high-resolution X-ray data on the study of supernova remnants*
- INAF PRIN 2005, PI F. Reale, *Modeling Astrophysical Plasma Dynamics Through High Performance Computing*
- ASI ADAE 2005, PI F. **Bocchino**, *Thermal and nonthermal X-ray emission from supernova remnants shocks*
- ASI ADAE 2006, PI locale F. **Bocchino**, *High energy emission from shell and filled-center supernova remnants*

Mobility, Consumables, Desktops: *between 10 and 20 kE per year*

Human resources on soft money: *between 20 and 30 kE per year*

Total 30-50 kE per year (HPC infrastructures not included)

Accepted observing programs dedicated to SNRs 2004–2007

with a member of our group as PI or CoI

- XMM-Newton: 6 (340 ks)
  - *3 with F.B. as PI, 1 with M.M. as PI*
  - *UPDATE: 526 ks LP on SN1006 approved (PI: A. Decourchelle, CEA Saclay, France)*
- Chandra: 1 (60 ks)
- Suzaku: 1 (100 ks)
- INTEGRAL: 1 (1 Ms)
- ESO/VLT: 1 (1.5 nights)

THE SCIENTIFIC RATIONALE

Why is so important to study SNRs?

- SNRs shocks make the ISM *observable*
- The effects of SNR-ISM interactions
  - *Mass and energy exchange (SN heating efficiency)*
  - *Metal enrichment*
  - *Structure formation and destructions*
    - *Triggered star formation*
    - *Bubbles*
    - *Dust grains*
  - *Particles accelerations (origin of the cosmic rays)*
- SNR shocks make stellar ejecta *observable*
  - *Explosive nucleosynthesis, hydrostatic layers burning, physics of SN explosions*
- Rotation powered pulsars and their nebulae
  - Physics of highly magnetized relativistic plasma

Our approach

- High-resolution multi-λ data
  - *Spatially resolved spectral analysis*
- More realistic models
  - *Non equilibrium processes*
  - *Concurrent radiative losses and thermal conduction*
  - *Magnetic fields*
  - *Circumstellar environments*
- An unbiased, objective methodology for comparison between new data and new models

HIGHLIGHTS 2004-2007
the evolutionary stages of SNRs

- Young SNRs (Type Ia SN): SN1006
  - Age: 1001 yr. Ref.: *Work in progress*
- Middle aged SNRs: IC443
  - Age: 4000-5000 yr. Ref.: *Bykov, Bocchino, Pavlov (2005); Troja, Bocchino, Reale (2006), Bocchino, Krassilchtchikov, Kretschmar, Bykov, Uvarov, Osipov (2007), Troja, Bocchino, Miceli, Reale (2007, submitted)*
- Old SNRs: Vela
  - Age: 10000 yr. Ref.: *Bocchino, Miceli, Maggio (2004); Miceli, Bocchino, Maggio, Reale (2005, 2005b);Miceli, Reale, Orlando, Bocchino (2006), Miceli, Bocchino, Reale (2007)*

Total refereed publications of our SNR group in 2004-2007: 22

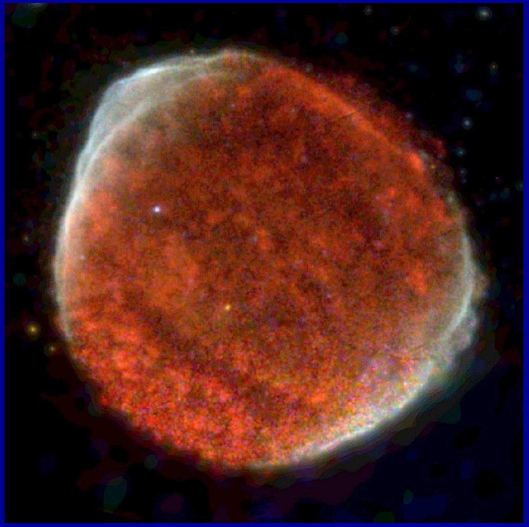
SN1006: a CR accelerator

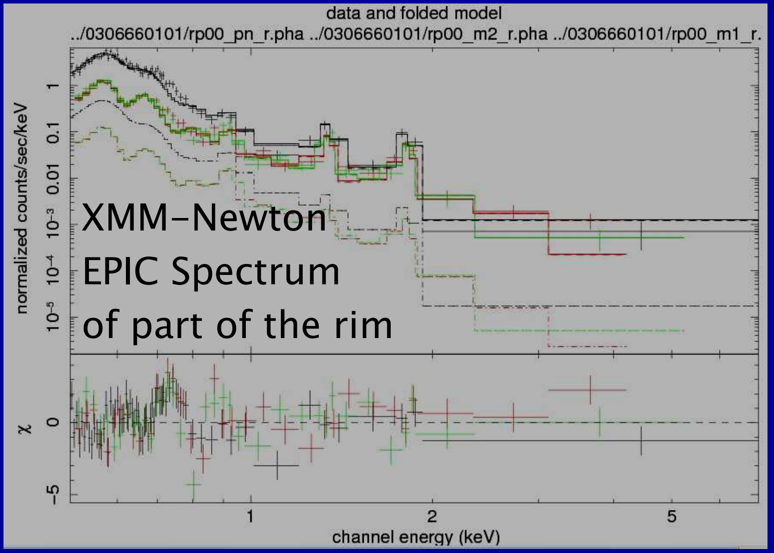
Age: 1001 yr, 7 months and 18 days (+/- 2 days). Type: pure shell

Aims: young SNRs are efficient cosmic ray accelerator, but…..
What is the dependence of acceleration from the direction of magnetic fields?
Is the thermal structure of the shock modified by acceleration?
What is the spatial distribution of stellar ejecta?

Methods: Narrow band flux-calibrated images in the X-ray band.
Spatially resolved spectral analysis of XMM-Newton spectra of the rim and inner regions of SN1006.
Comparison with particle acceleration models
Comparison with cosmic ray modified shock models
Comparison with SN nucleosynthesis model. Estimate of yield masses.

Chandra composite image
red 0.5–0.8 keV
white 2.0–5.0 keV

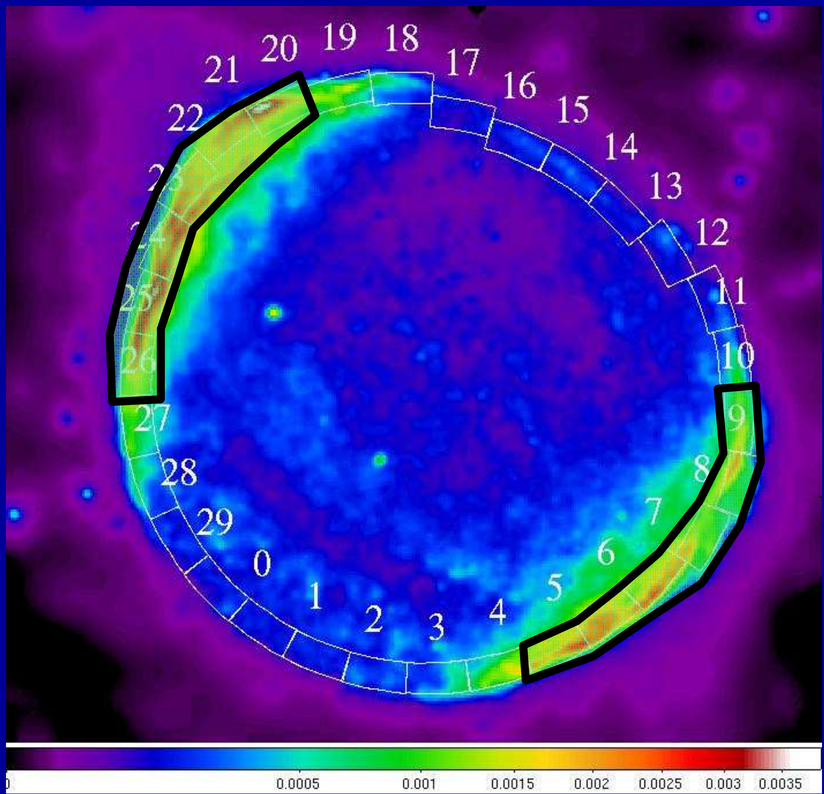


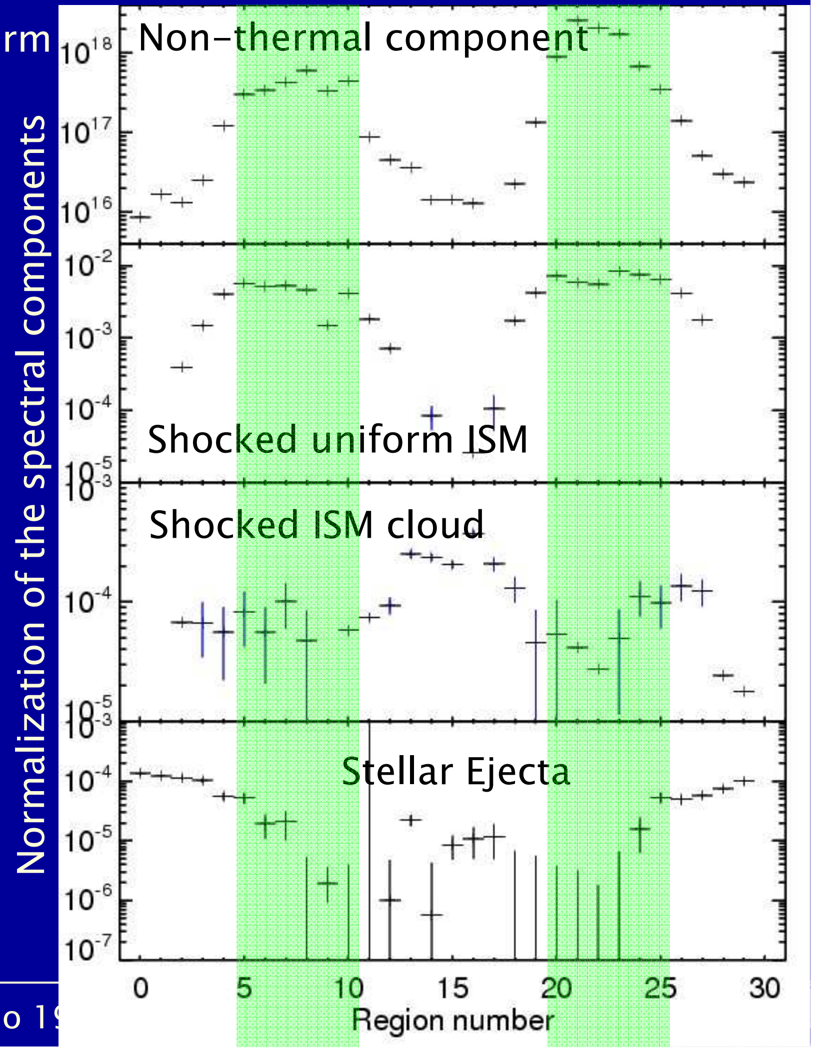


SN1006: a CR accelerator

Preliminary Results:

- The compression ratio of pre and post-shock ISM is HIGHER in non-thermal dominated limbs (i.e. where acceleration efficiency is higher)
- Agreement with cosmic rays modified shocks is not excellent
- Spatial distribution of stellar ejecta is not uniform





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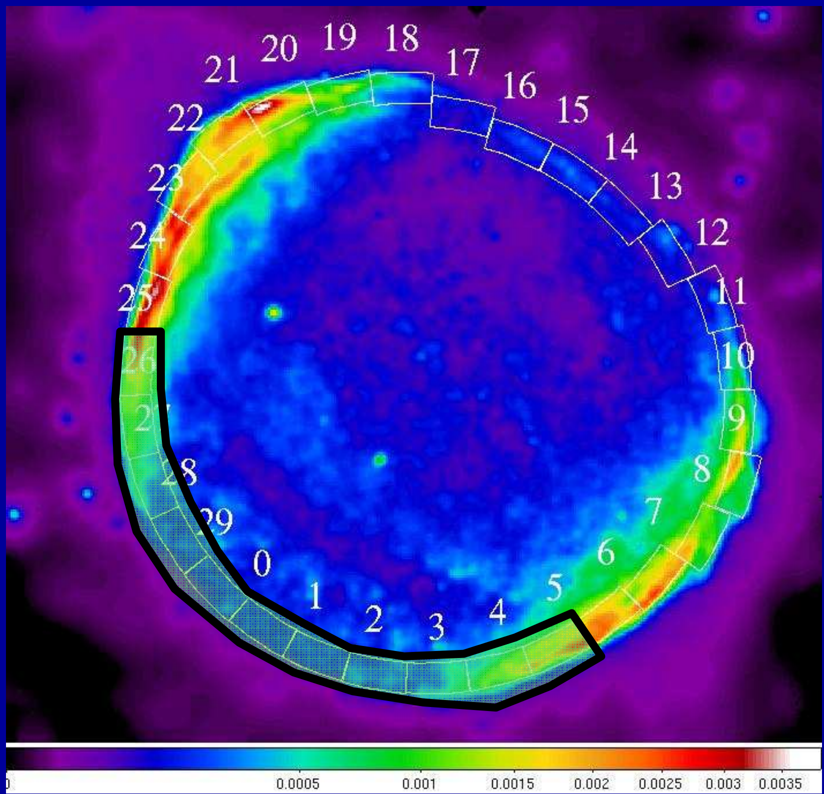
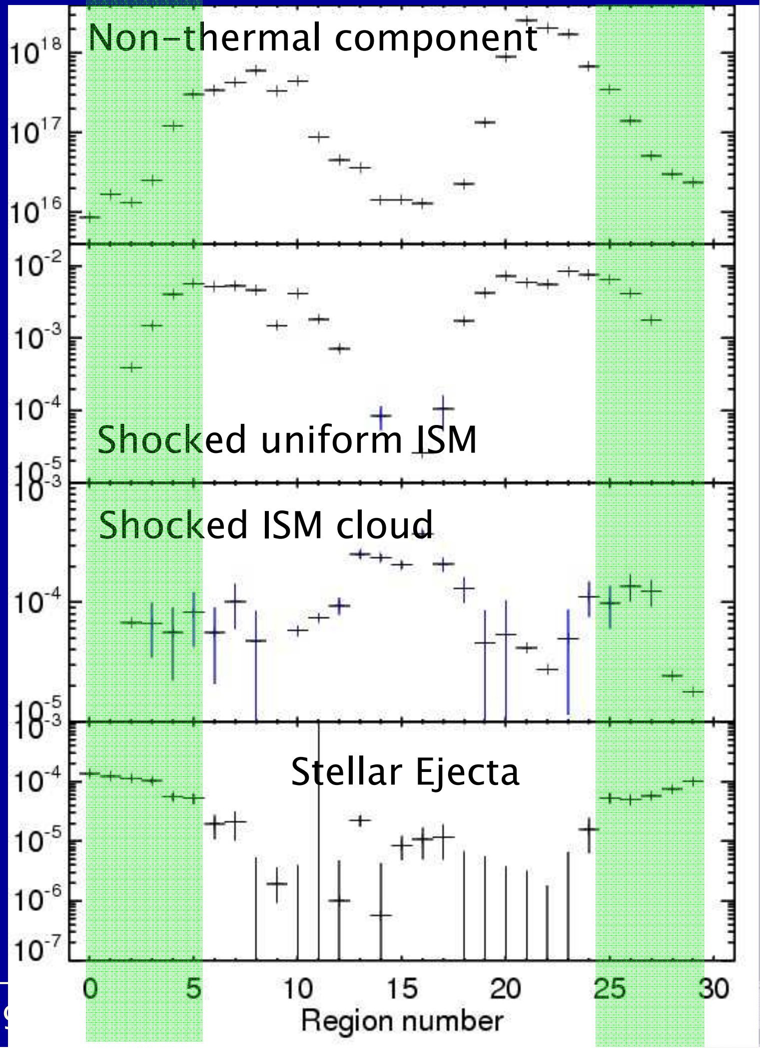




The remnant of SN1006

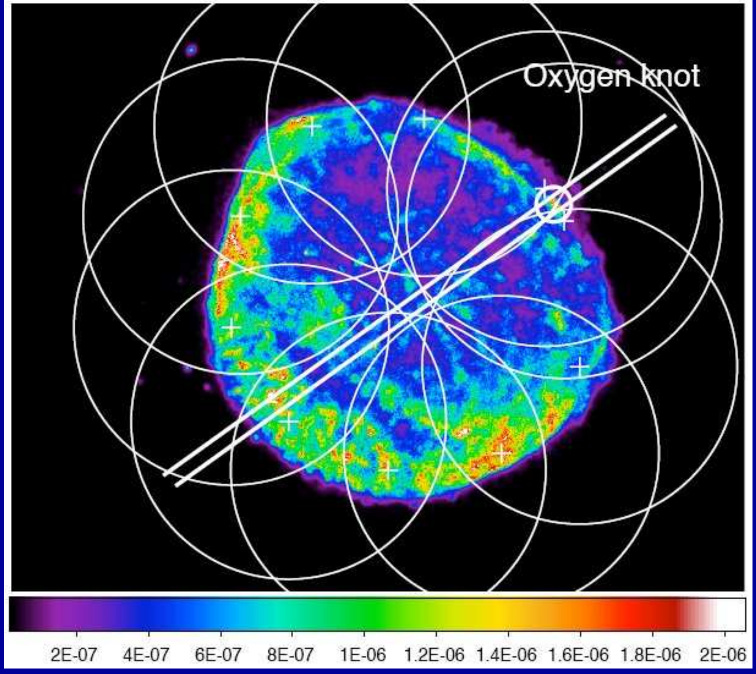
Future Perspectives:

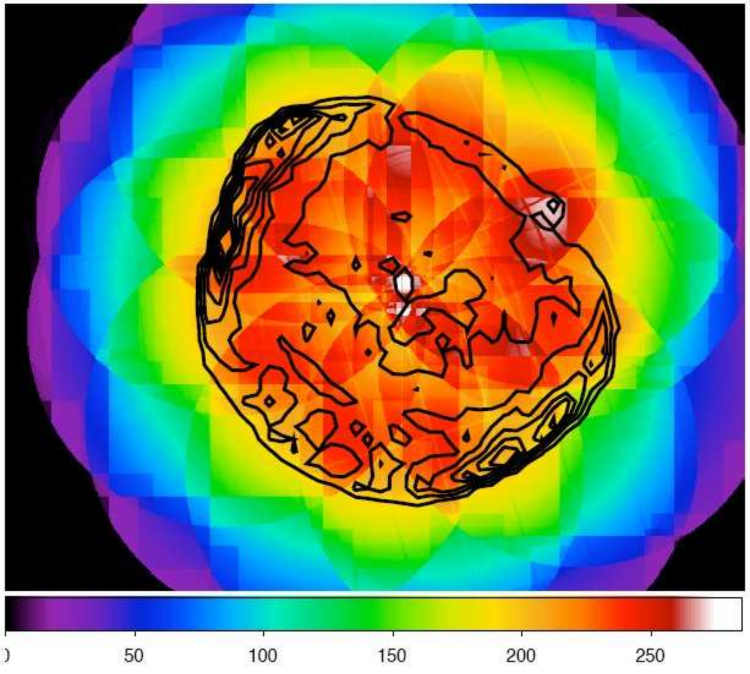
Confirm, refine and interpret the results obtained so far

Large XMM-Newton project to study the small scale mixing of thermal and non-thermal emission (UPDATE 14 Dec 07: APPROVED 526 ks).

MHD simulations with cosmic ray modifications and synthesis of synchrotron emission

Hard X-ray imaging and spectra (SIMBOL-X)



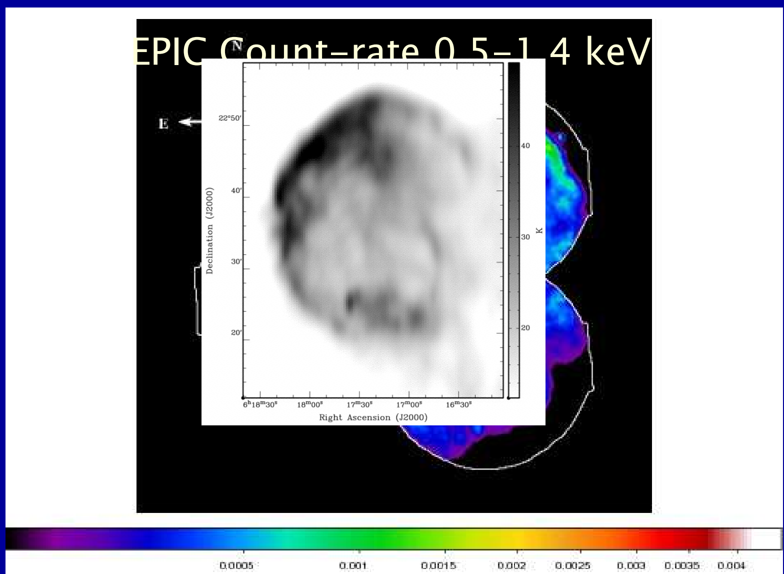


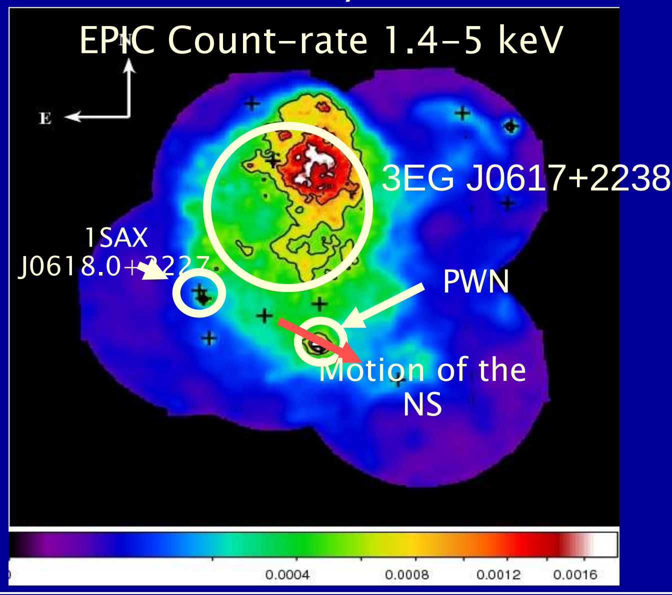
IC443: molecular clouds and SNRs

Age: 4000-5000 yr. Type: mixed morphology (radio shell + centrally peaked in X-rays)

Aims: physical characteristics of the environment of massive star remnants
Explanation of peculiar morphology
Nature of the gamma ray emission of SNRs
Interaction between pulsar wind nebula and surrounding shell
Where are the ejecta in middle-aged SNRs?

Methods: Narrow band flux-calibrated images in the X-ray band. Equivalent width maps.
Maps of Median Photon Energy (MPE) in different energy bands
Spatially resolved spectral analysis of XMM-Newton spectra.
Comparison with SNR dynamical models
Comparison with SN nucleosynthesis model. Estimate of yield masses.



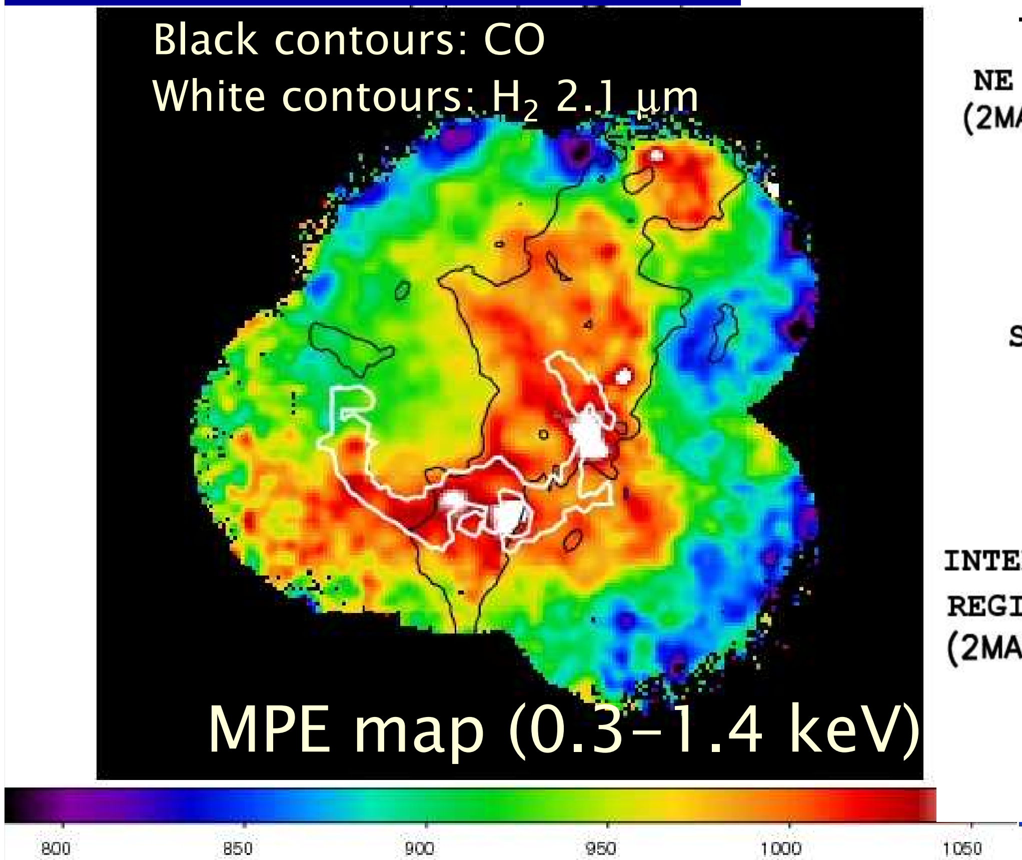


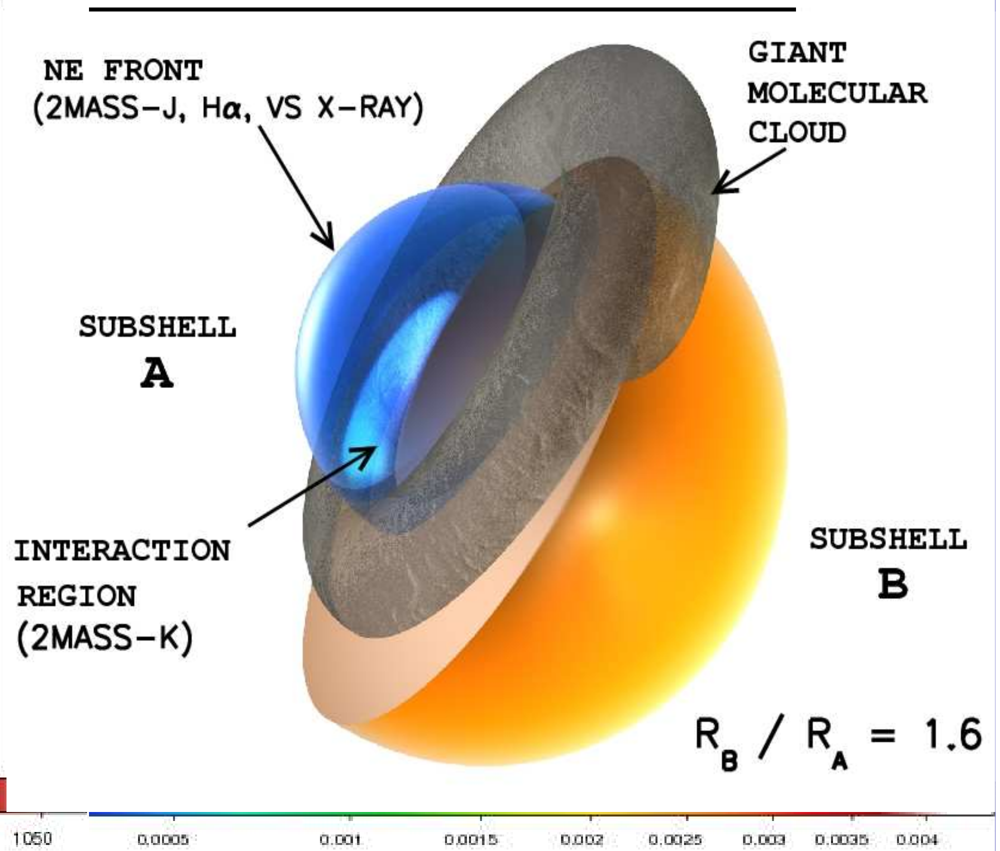
IC443: molecular clouds and SNRs

Results: **Characterization of 3D geometry of remnant environment**

Discovery of a new population of hard X-ray sources associated to remnants interacting with molecular clouds

Detection of ejecta. Characterization of progenitor SN. New estimate for age.





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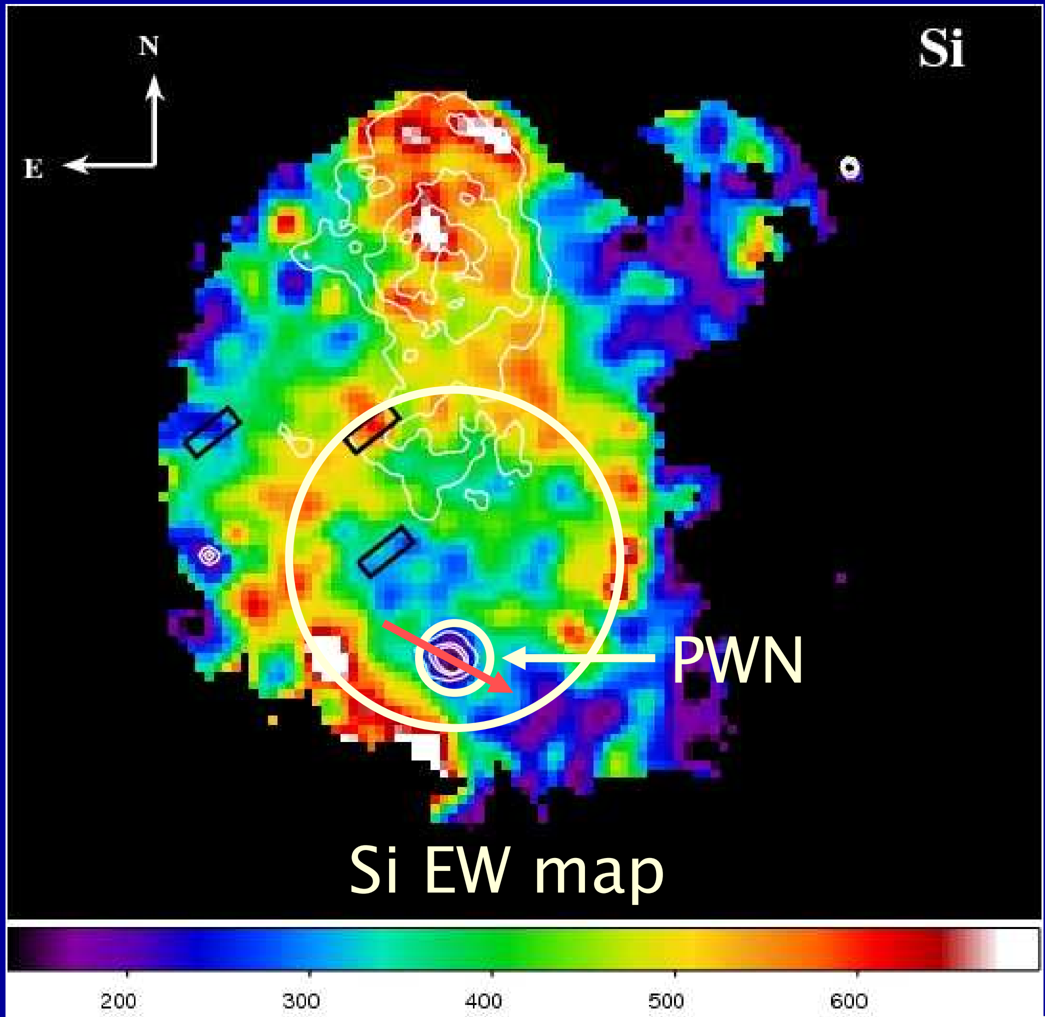
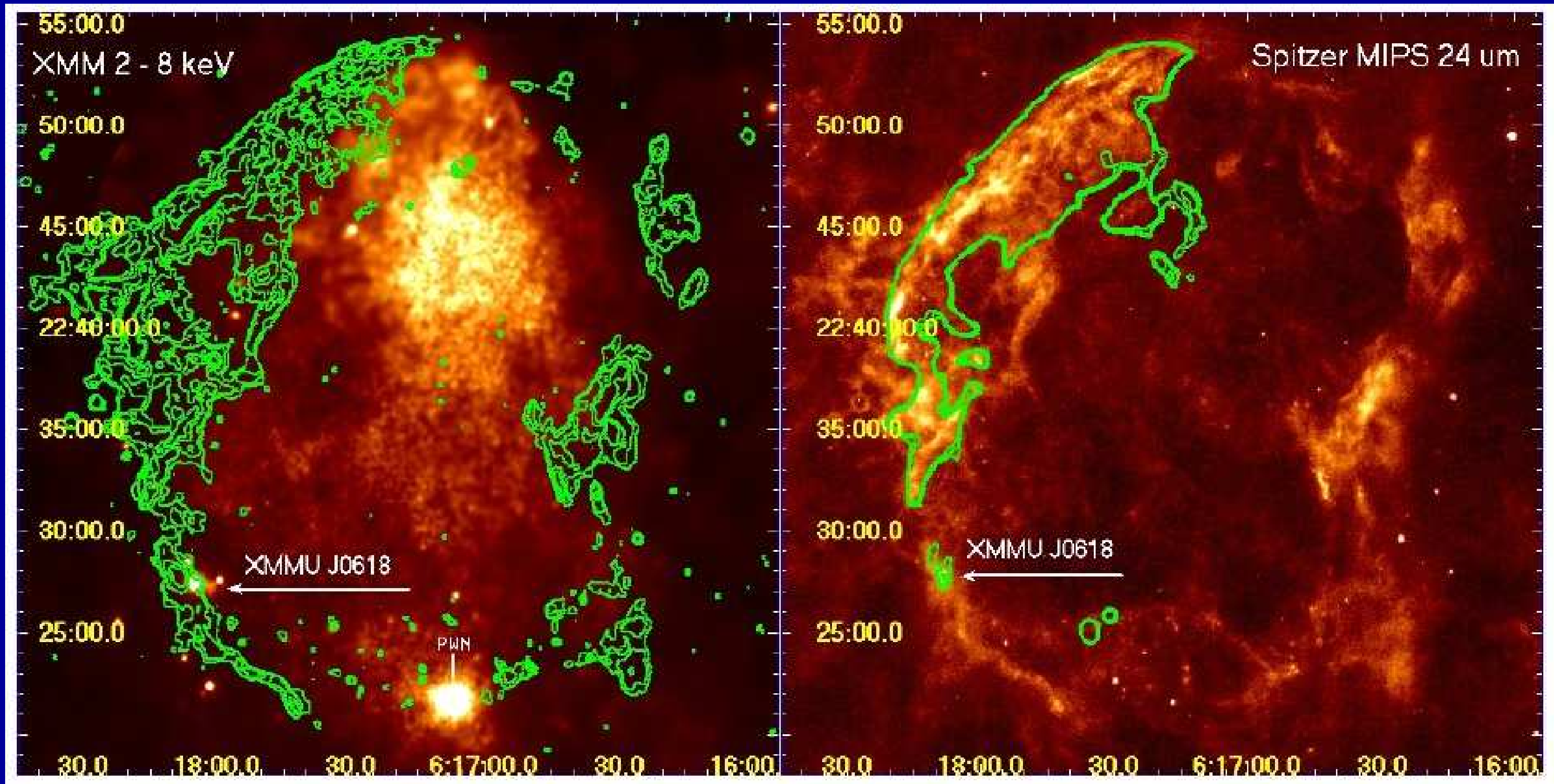


- Location of PWN and ejecta ring consistent with a dynamical age of ~4500 yr. Older estimates revisited.
- Mg/Si, S/Si, Fe/Si abundances ratios in the ejecta ring favors core collapse progenitor (Type II) instead of white dwarf deflagration/detonation (Type Ia)

IC443: molecular clouds and SNRs

Future perspectives:

- Deep IR imaging of shock-MC interaction regions (SPITZER, in progress)
- Deep X-ray imaging to find fluorescence lines in shock-MC interaction regions
- New MeV-GeV observations to refine/correct position of 3EG J0617+2238 and to obtain gamma ray spectrum (AGILE/GLAST)

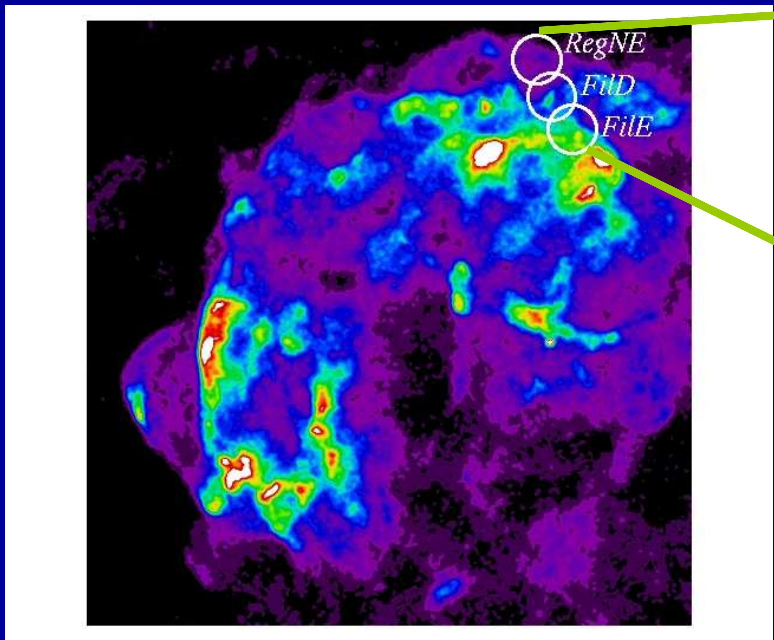


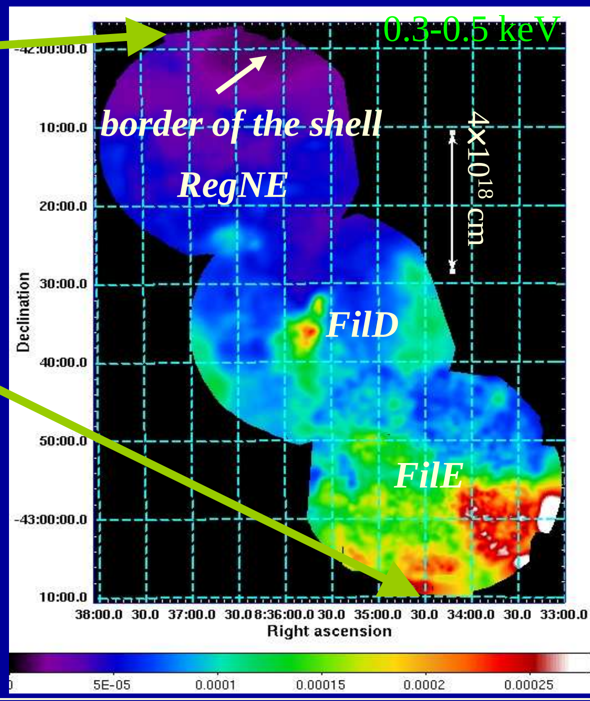
The Vela SNR

Age: ~10000 yr. Type: composite (shell + PWN)

Aims: What is the physical origin of the patchy and irregular X-ray emission of the shell?
What is the physical origin of the multi-temperature nature of X-ray spectrum?
Is the plasma in Collisional Equilibrium of Ionization or not?
Where are the ejecta in the old SNRs?

Methods: Comparison between optical and X-ray emission
Spatially resolved spectral analysis of XMM-Newton spectra of knots
MHD numerical simulations of shock-cloud interactions
Synthesis of X-ray emission from models





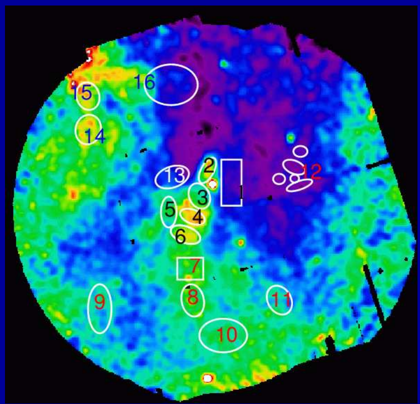
The Vela SNR

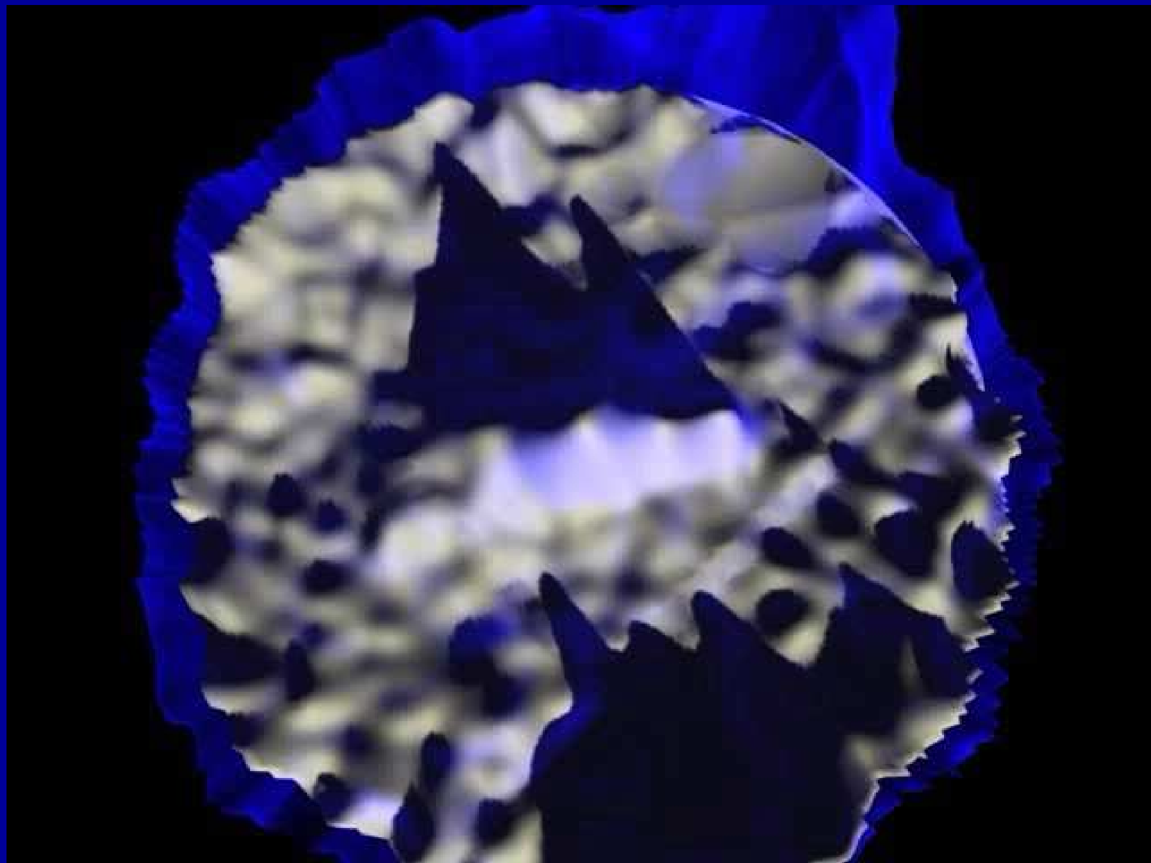
Results: Two temperature nature of the X-ray emission is confirmed.

Reconstruction of 3D distribution of the emitting plasma.

Comparison between model and observations unveils the physical origin of the X-ray emission components

Detection of stellar ejecta





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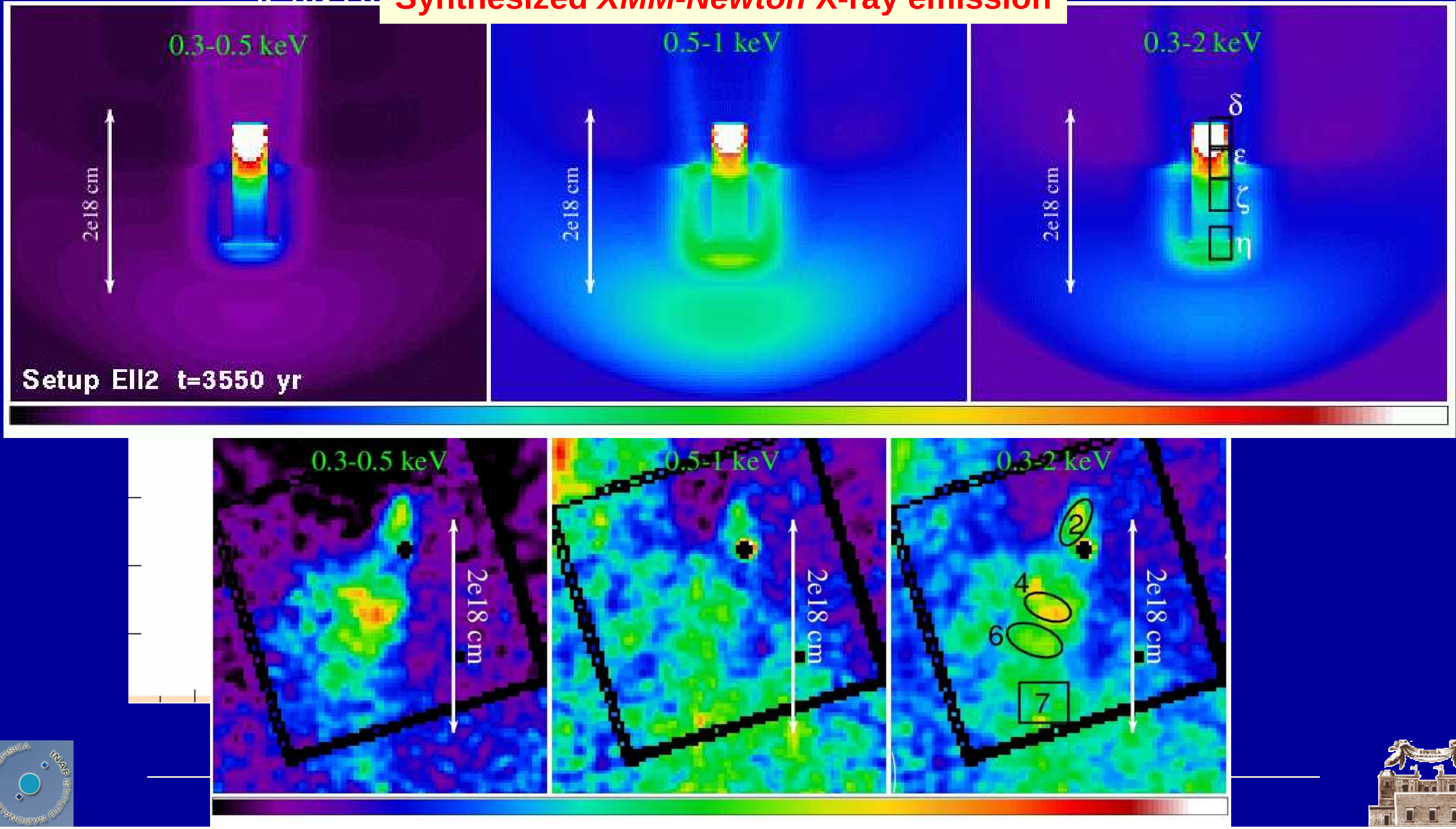
Synthesized *XMM-Newton* X-ray emission



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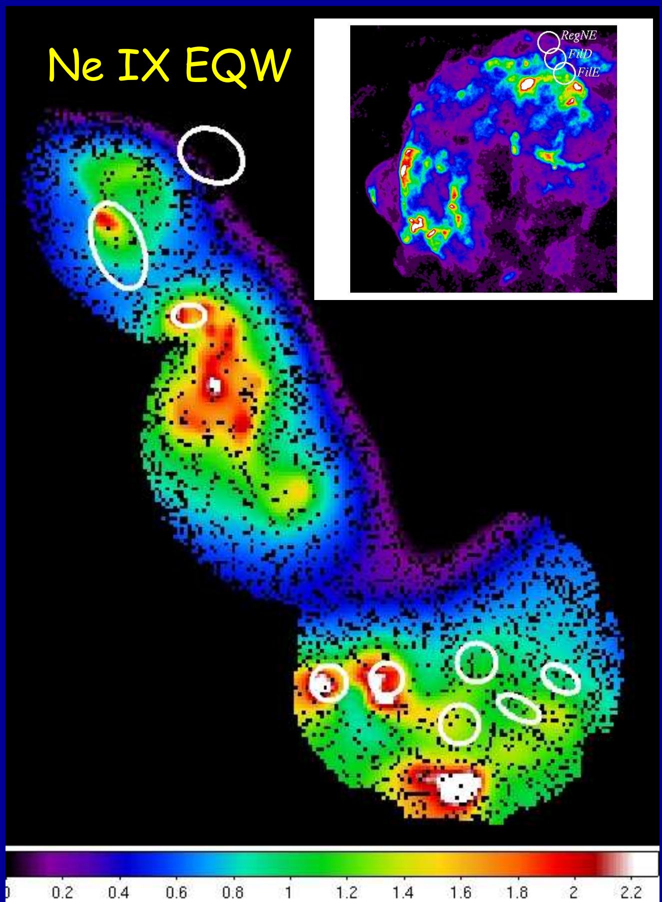


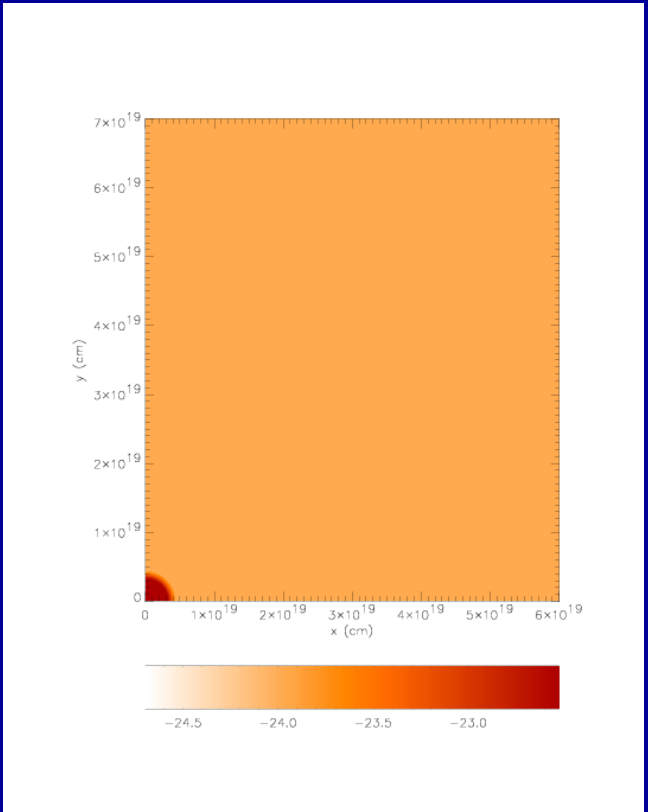
The <u>position of the shrapnels</u> depends on their initial velocity (i.e. their initial position in the ejecta profile)

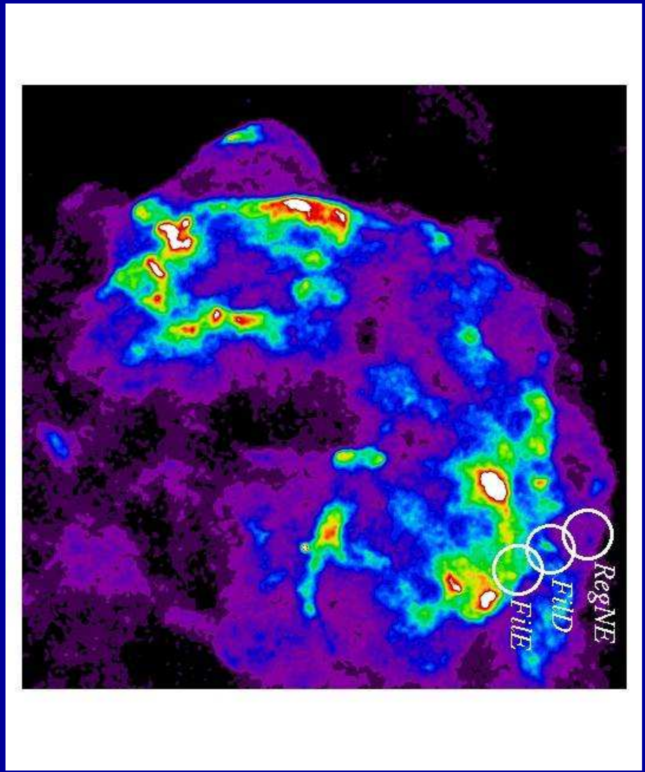
The <u>chemical abundances of the shrapnels</u> depends on their initial position (burning layer) during the SN explosion

The Vela SNR

Future perspectives:

- Evolved SNR may represent a complementary approach to the study of SN nucleosynthesis w.r.t. remnants of historical SNe
- MHD model of ejecta shrapnels, mixing ejecta-ISM
- X-ray calorimeter arrays will allow for unprecedented spectroscopy of spatially extended cosmic x-ray sources (XEUS)





FINAL REMARKS

- What is good….
  - *People are well motivated*
  - *Level of support is more or less ok (consumable, computers, etc.)*
  - *Level of funding have been more or less ok so far*
  - *Good level of intl. collaborations*
  - *The group is overall cost-effective*
- What is bad….
  - *If positive trends in intl. collaborations continue as we have planned, we will face a man-power problem in 2008*