COSMIC RAYS ACCELERATION IN SN 1006

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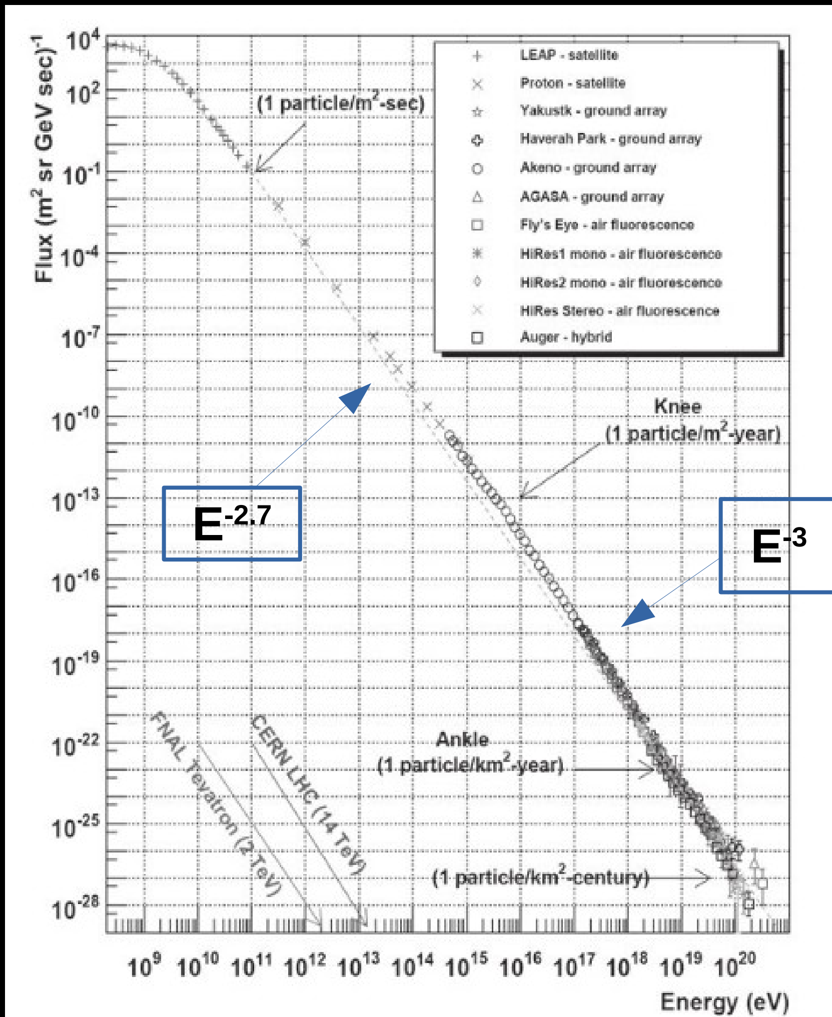
University of Palermo
INAF – Observatory of Palermo

EAS – Annual meeting - Valencia
28/06/2022

INTRODUCTION

Cosmic rays



$$I_N(E) \approx 1.8 \times 10^4 E^{-2.7}$$

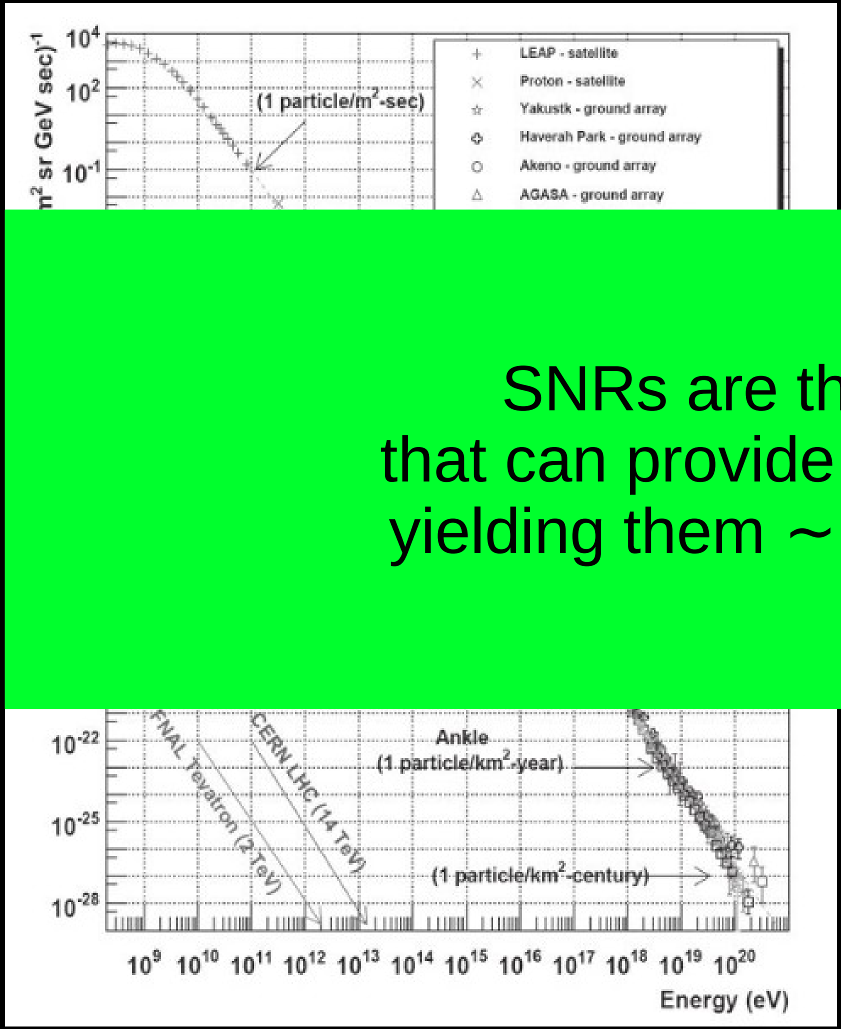
Rate of SNe in the Milky Way ~ 2.5/century

$E_{explosion} = 10^{51}$ erg

Required power to accelerate cosmic-rays = 2×10^{50} erg/century

INTRODUCTION

Cosmic rays

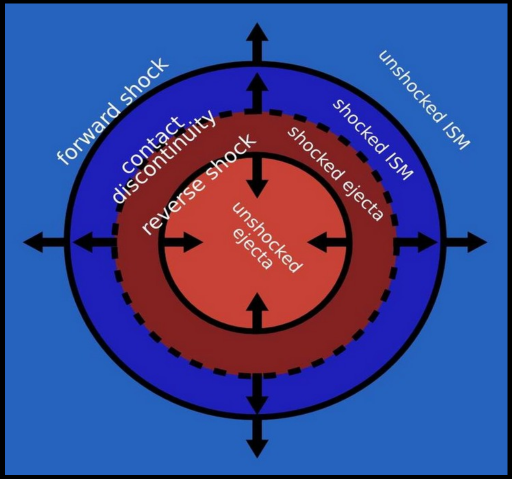


SNRs are the only galactic sources
that can provide the required power to CRs,
yielding them ~ 10% of their kinetic energy

accelerate cosmic-rays = 2 x 10^{50} erg/century

INTRODUCTION

Shock modification



Rankine – Hugoniot equation for adiabatic shock

$$\rho_2 / \rho_1 = 4$$

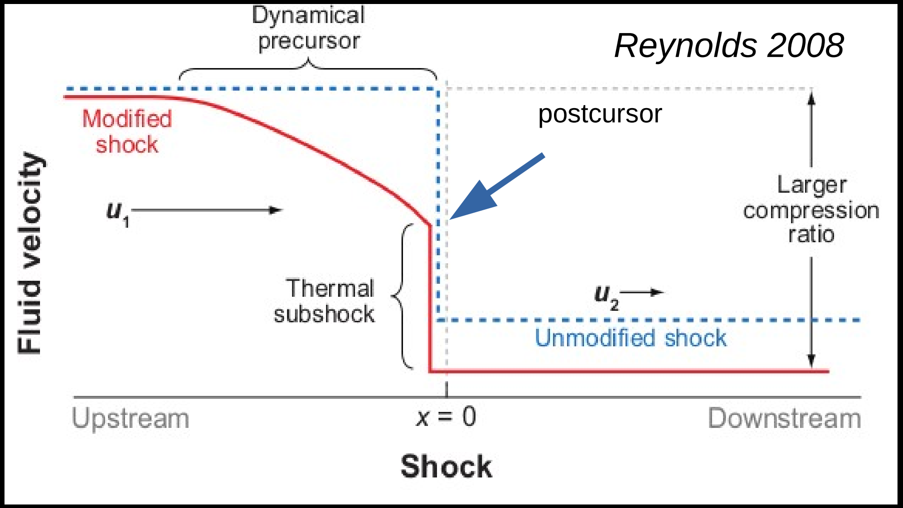
Drury et al. 1983, Decourchelle et al. 2000, Blasi et al. 2002, Vink et al. 2010

Shocks of SNRs give part of their kinetic energy to accelerate CRs → NON adiabatic shock

$$\rho_2 / \rho_1 > 4$$

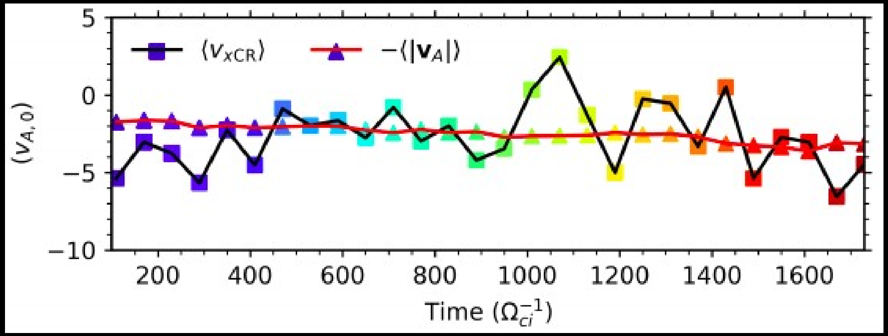
→ **Shock modification**

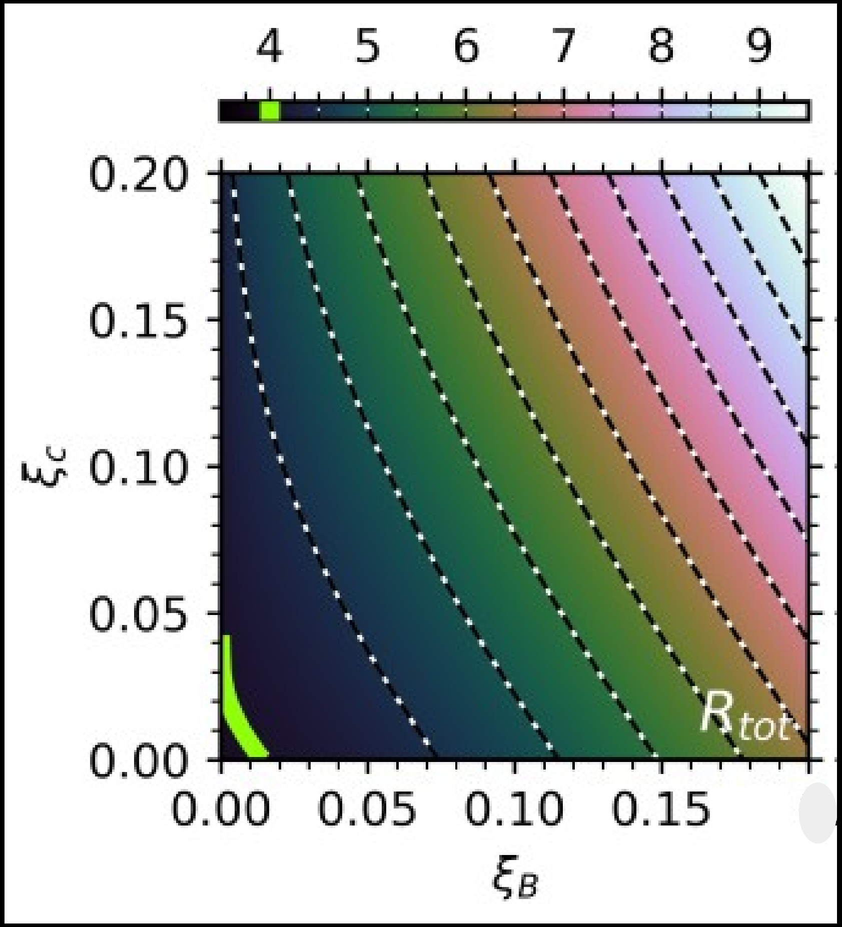
- Upstream CR precursor
- overshoot at the shock
- rise in the downstream



INTRODUCTION

Haggerty et al. 2020





Postcursor model

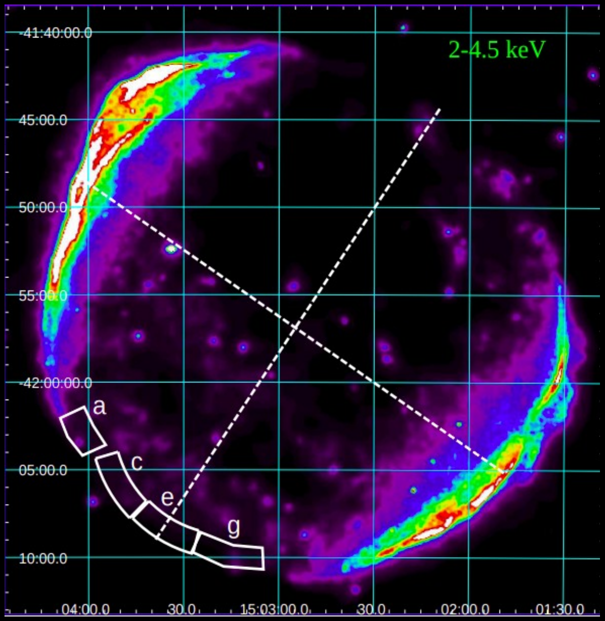
the downstream Crs drift away from the shock with respect to the thermal plasma at a speed comparable to the local Alfvén speed.

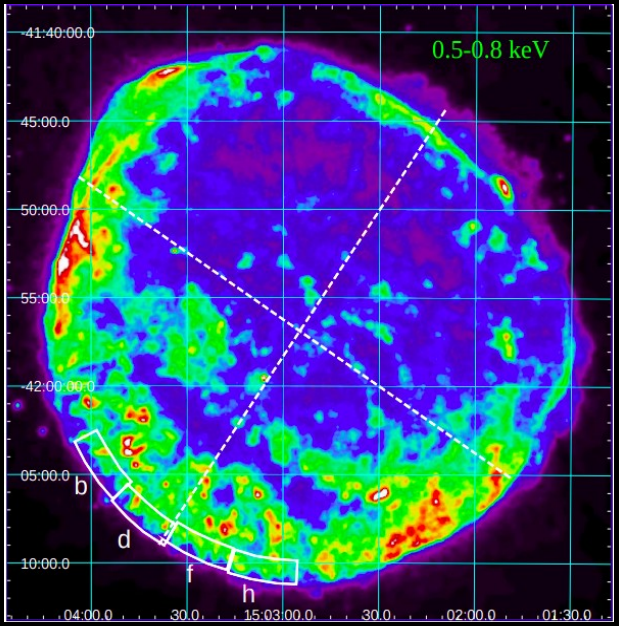
Energy sink → $\rho_2 / \rho_1 > 4$

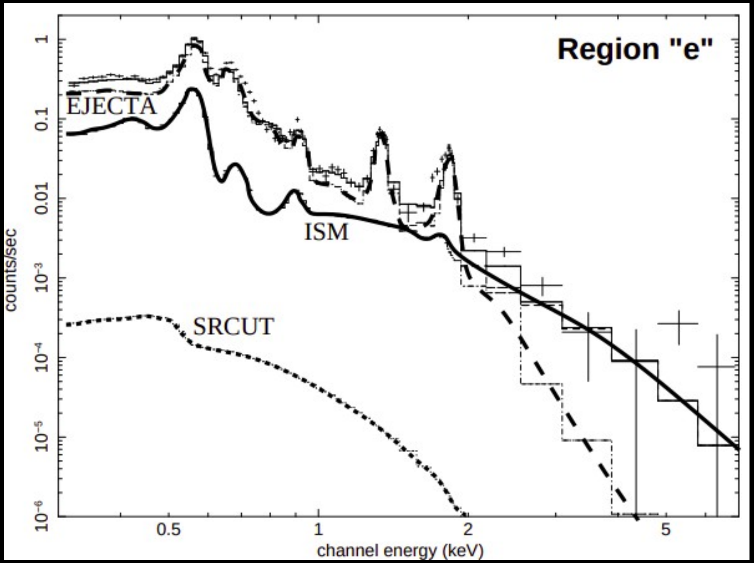
PARTICLE ACCELERATION IN SN 1006

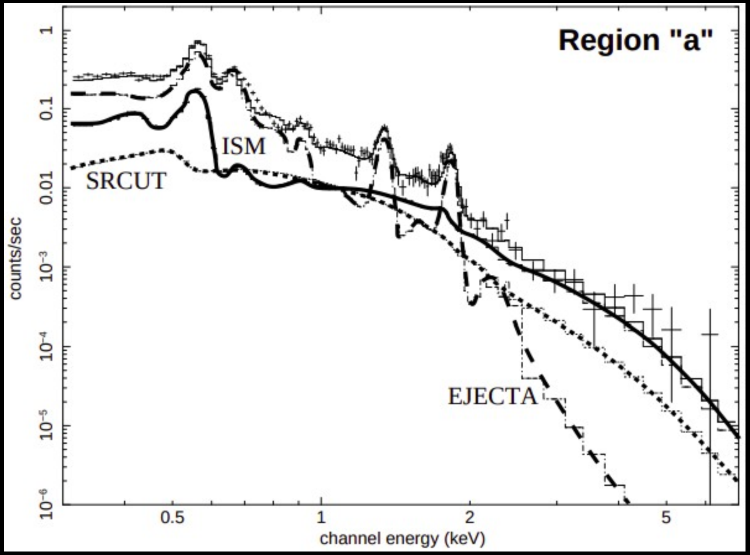
XMM-Newton analysis

Miceli et al. 2012









Quasi parallel condition (*Rothenflug et al. 2004, Reynoso et al. 2013,Bocchino et al. 2011)*

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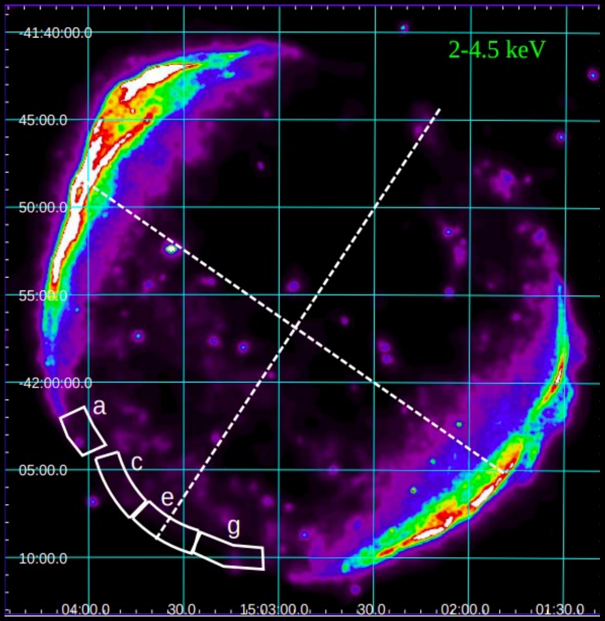

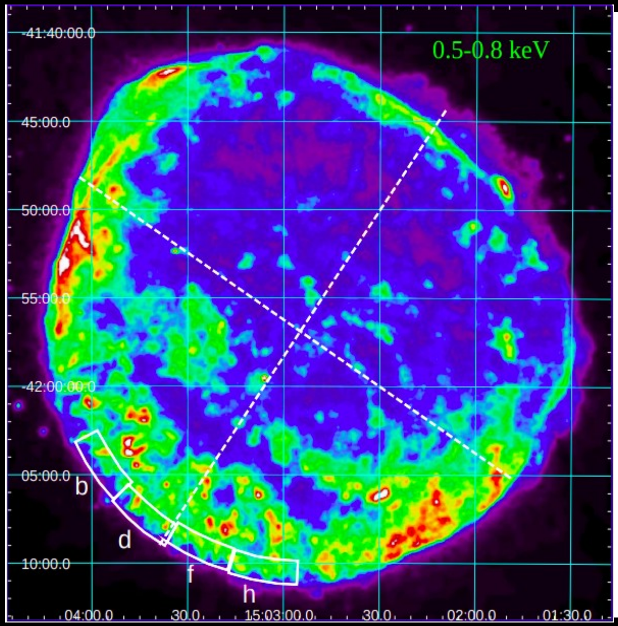

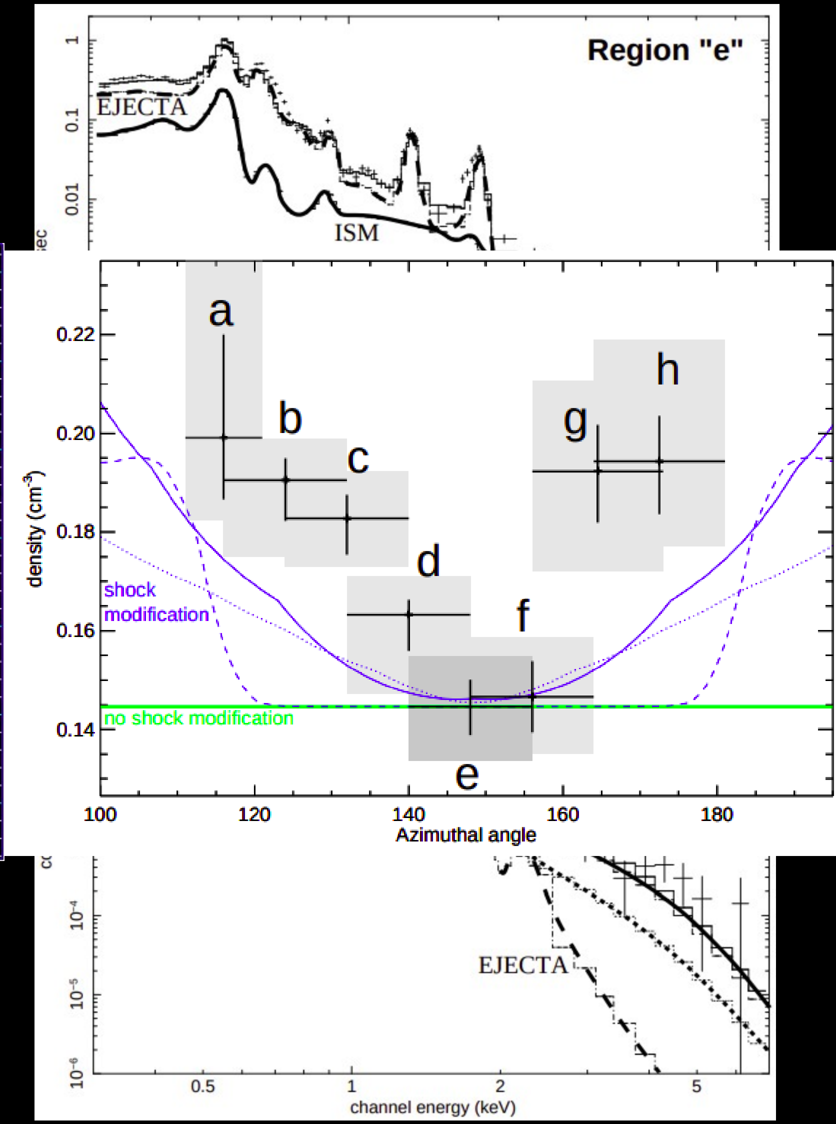

Quasi parallel condition (*Rothenflug et al. 2004, Reynoso et al. 2013,Bocchino et al. 2011)*

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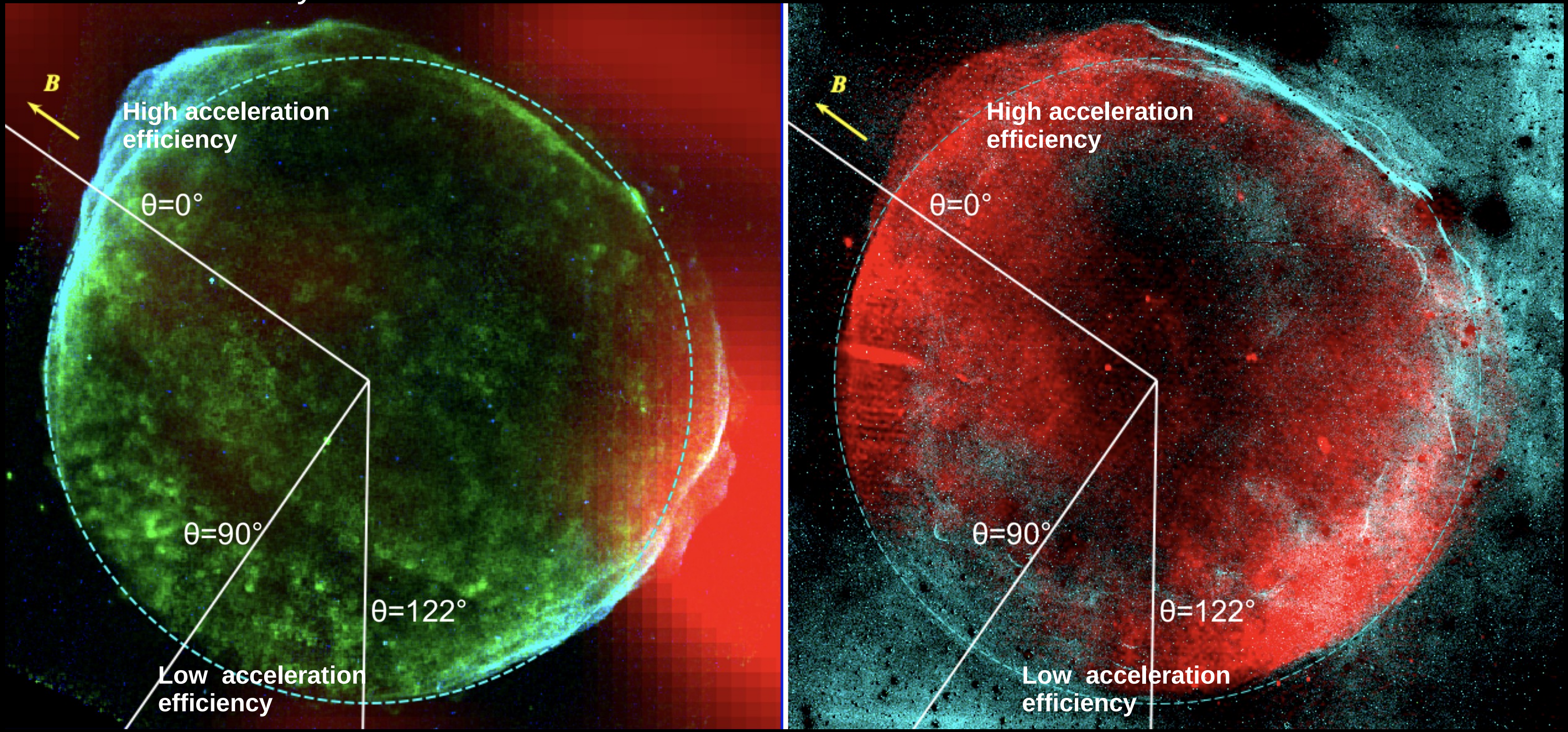
Giuffrida et al. in review

0.5 – 1 keV
2.5 – 7 keV
Column density of HI

Balmer Hα emission
Radio map at 1.4 GHz



NO denisty variation + regular shape of shock front = uniform pre-shock density

POST SHOCK DENSITY MODULATION AS COMPRESSION RATIO MODULATION

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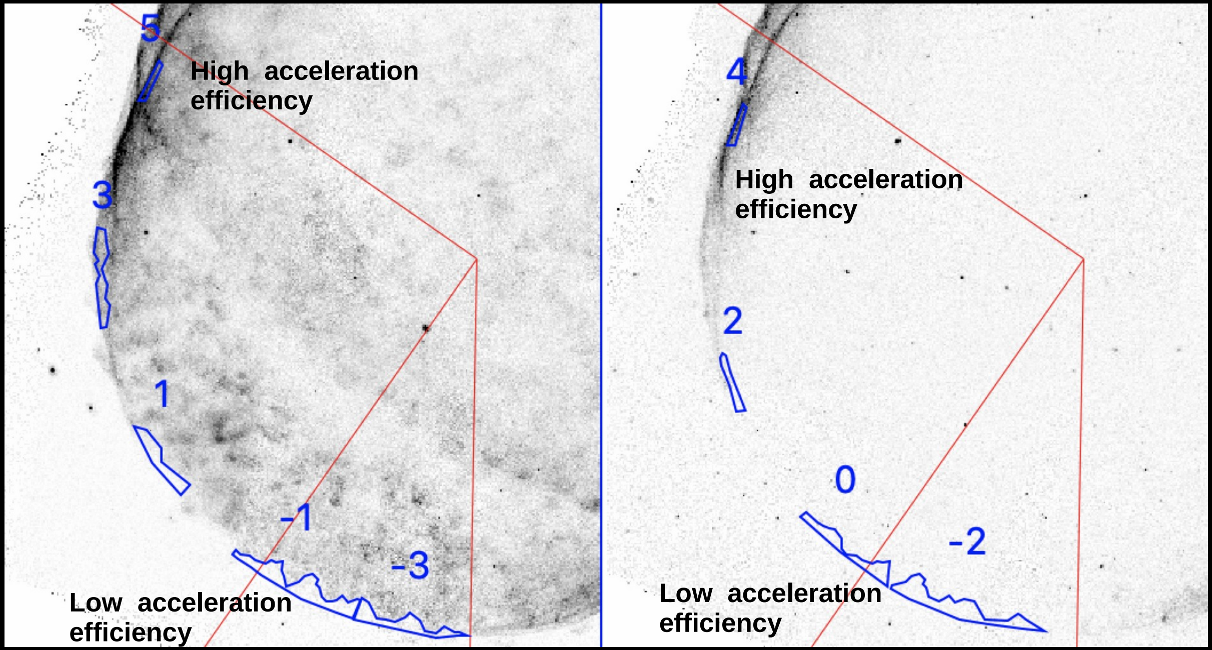
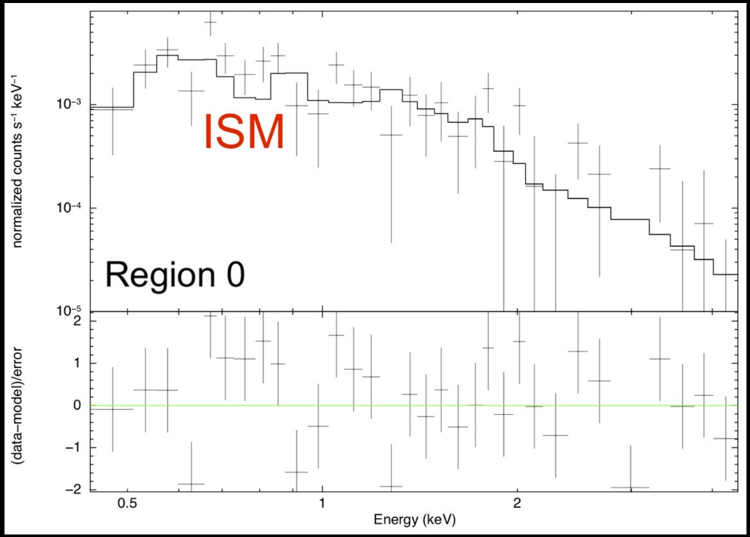
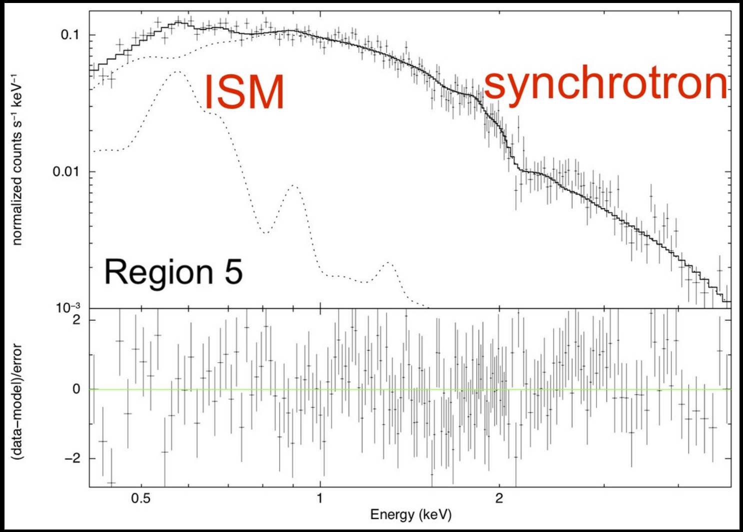
Chandra analysis

Giuffrida et al. in review







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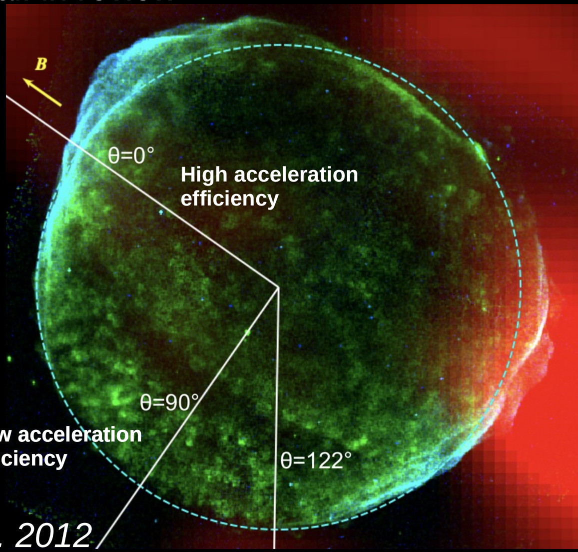
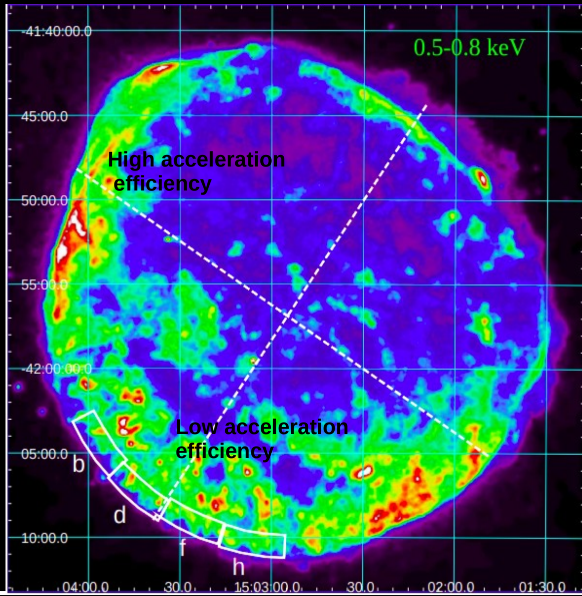


Miceli et al. 2012



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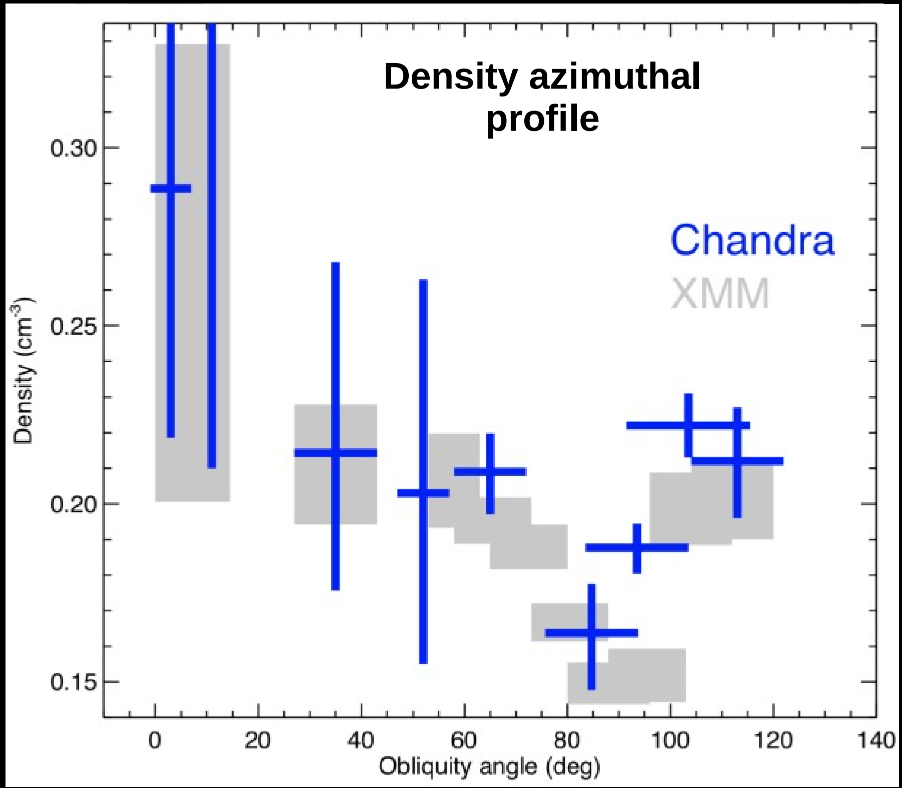

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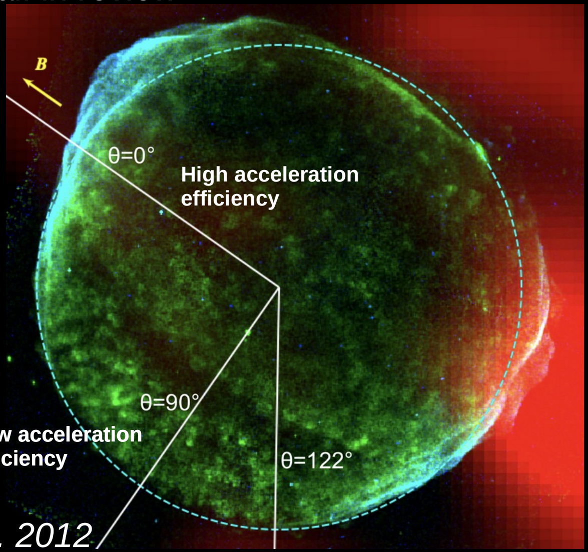

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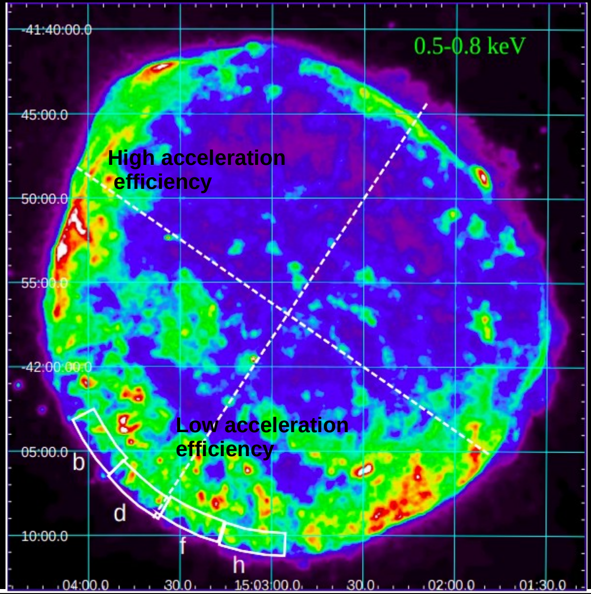

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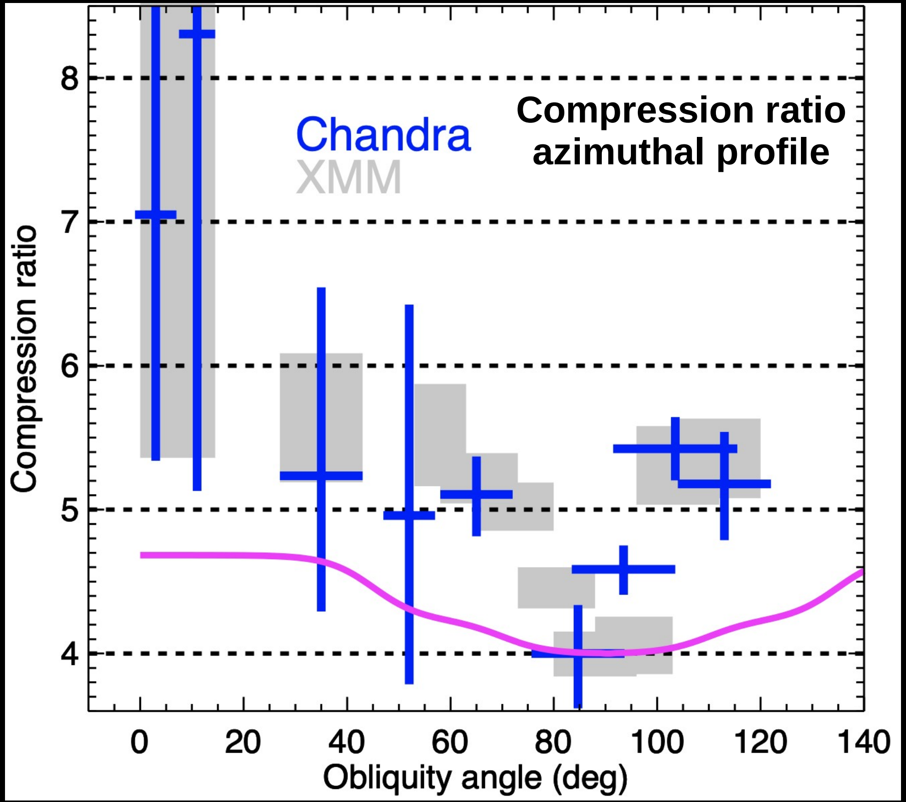

$\xi_p = 12\ \%$
$\xi_s = 6\ \%$
$\xi_B = 0\ \%$

Caprioli et al. 2014,
Caprioli et al. 2018,
Haggerty et al. 2020,
Caprioli et al. 2020

PARTICLE ACCELERATION IN SN 1006

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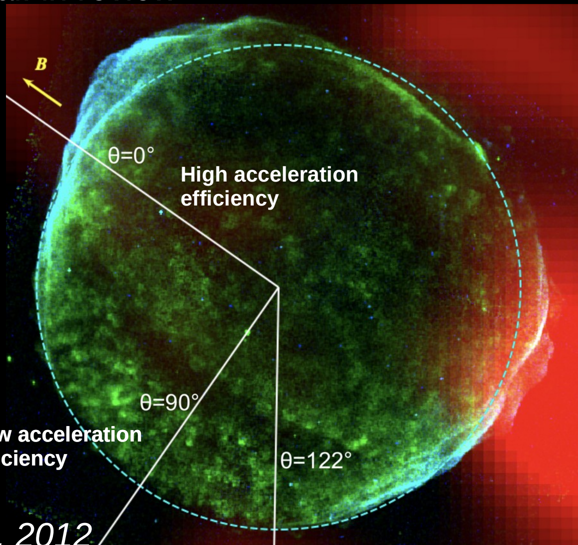

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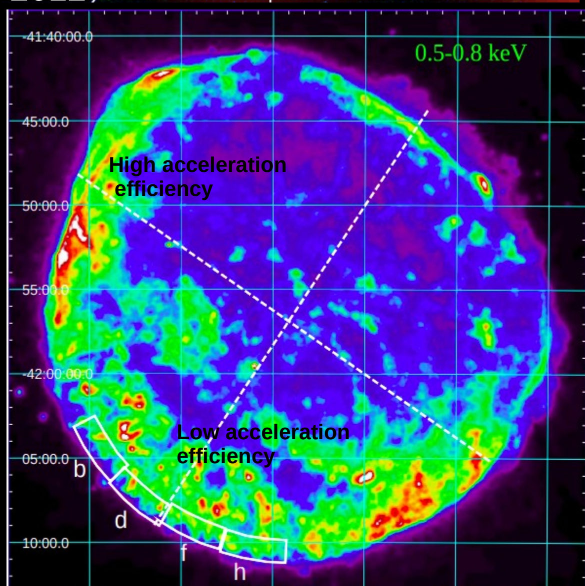

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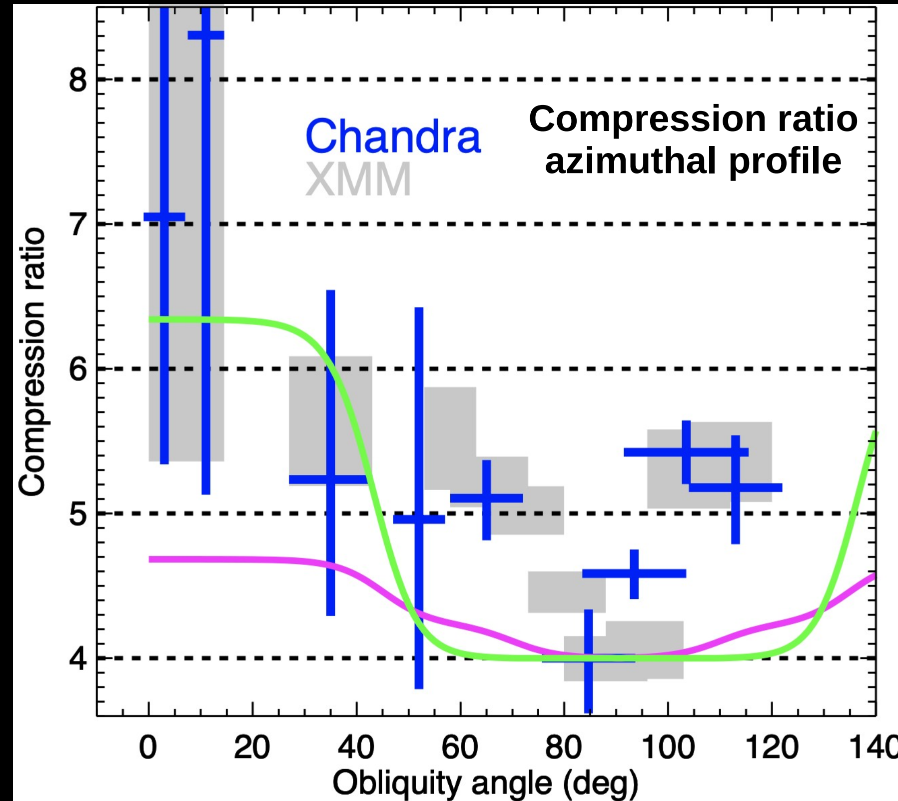

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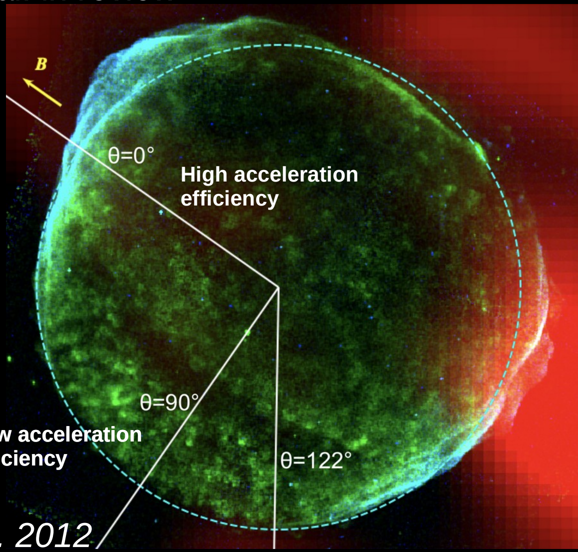

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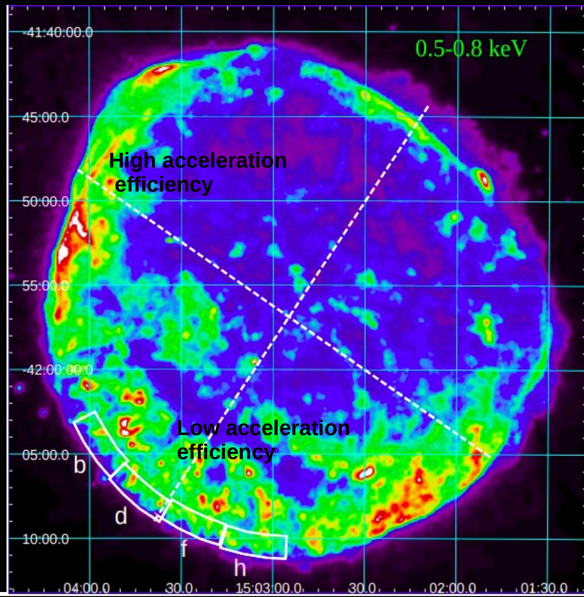

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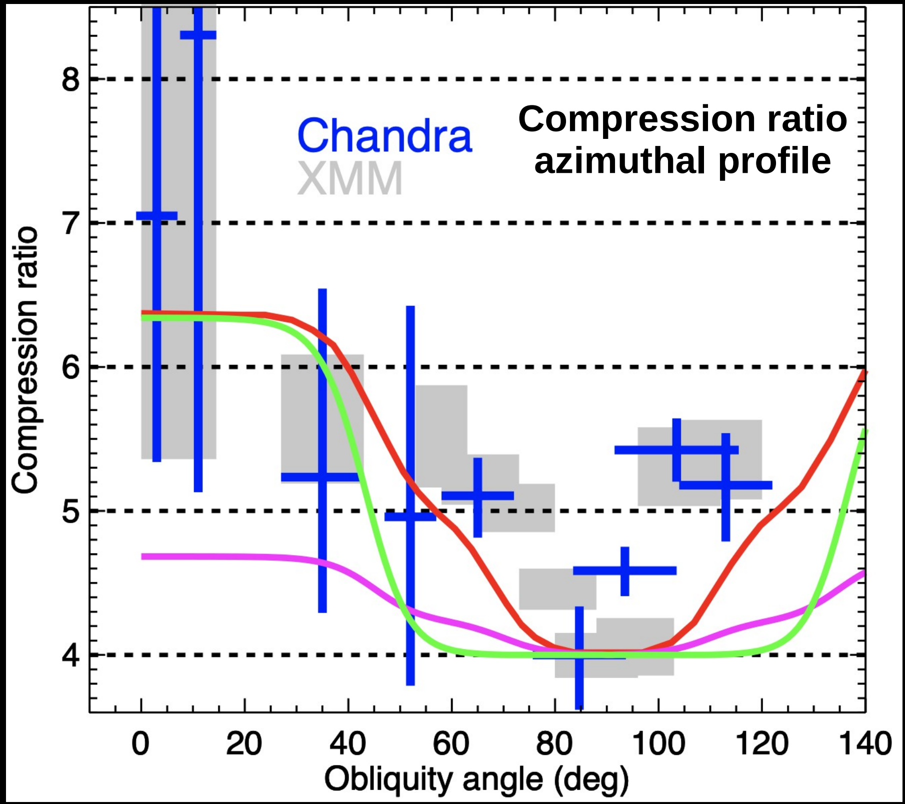

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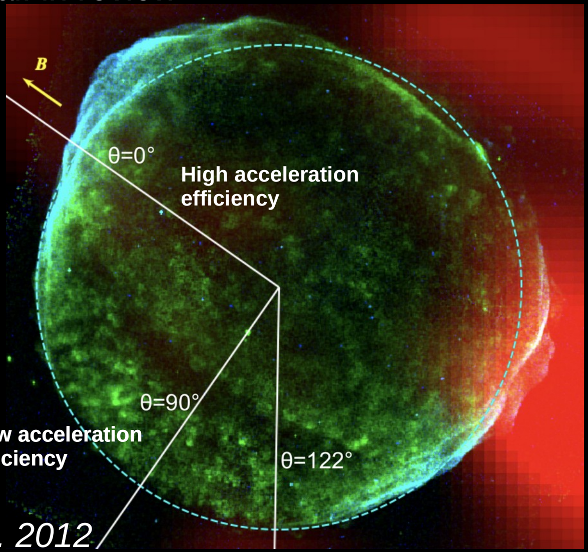

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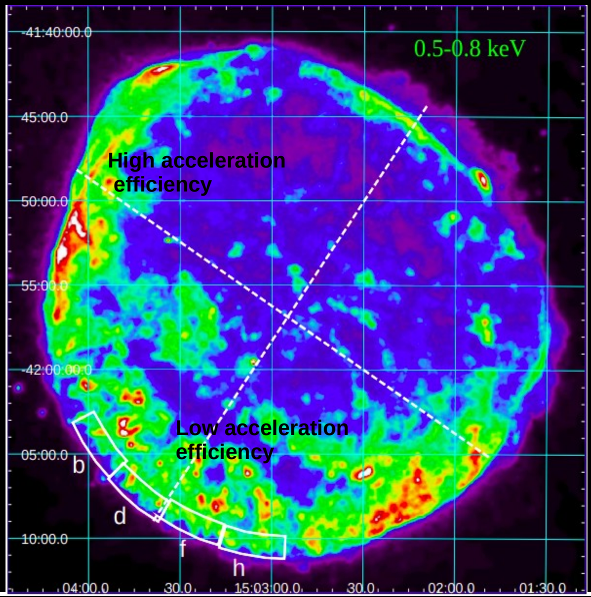

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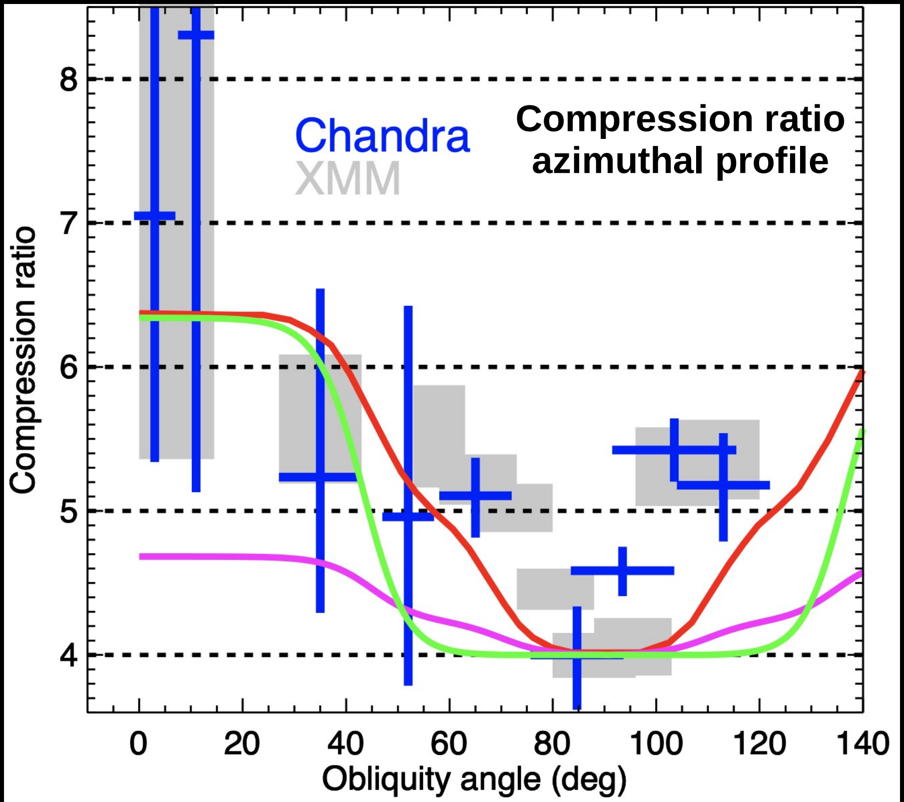

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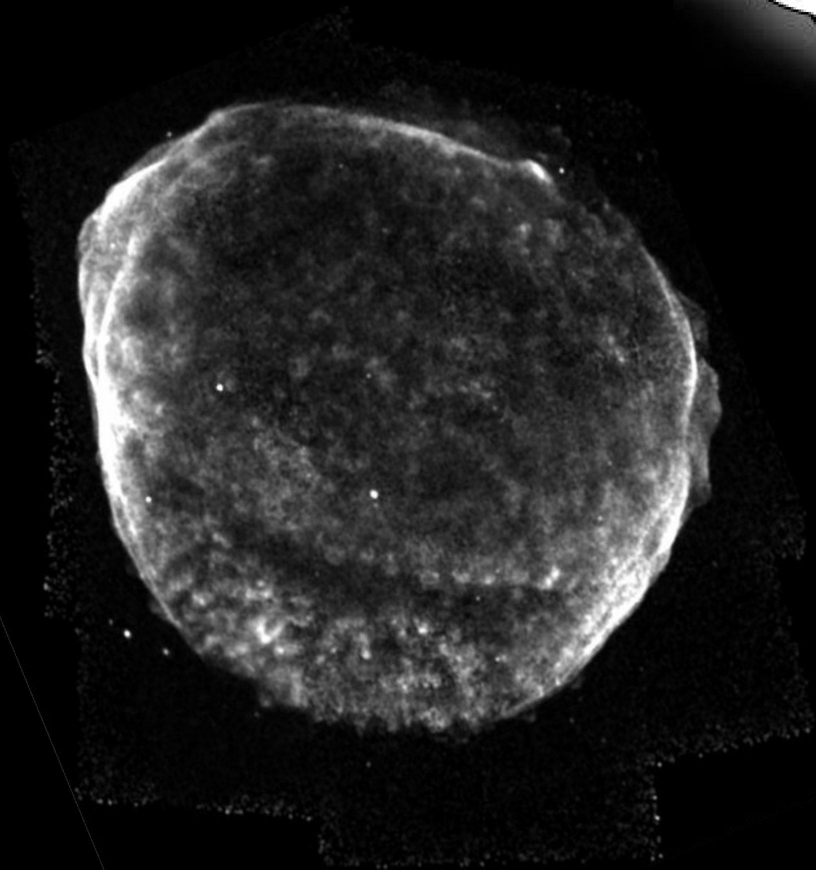
Particle acceleration causes shock modification.
SN 1006 is tranferring part of its kinetic energy to accelerate hadrons.




YES!

CONCLUSION

- Measure of post-shock ISM density in SE and NE limbs of SN 1006 and of the compression ratio
- Increase of compression ratio from the caracteristic value of 4 in thermal limb up to ~7 in nonthermal regions
- SN 1006 is transferring >10% of its kinetic energy to CRs
- Comparison with “postcursor model”:

1) quasi parallel acceleration efficiency ξ_p = 12%
2) reaccelerated CRs with effciency ξ_s = 6%
3) presence of postcursor $\longrightarrow$ magnetic field amplification ξ_B = 5%

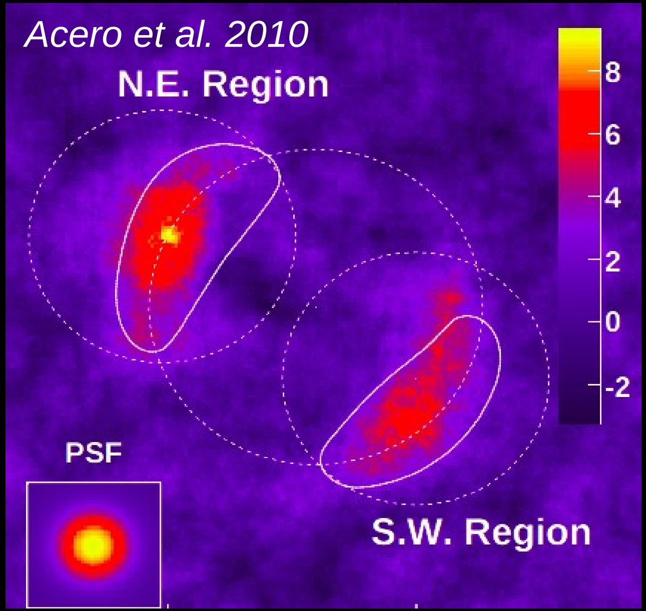
Thanks for your attention

FUTURE WORKS

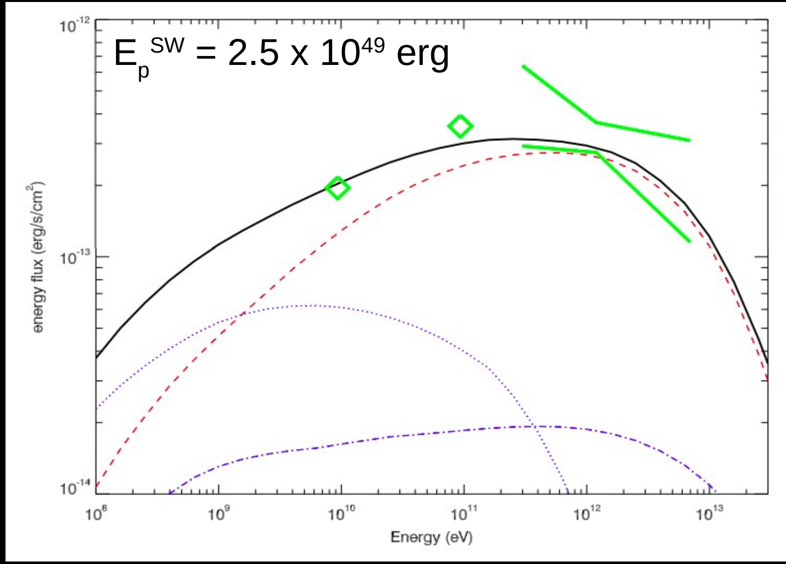
γ−rays emission

Leptonic scenario
(Inverse Compton)

Hadronic scenario
(π^0 decay)



Miceli et al. 2016



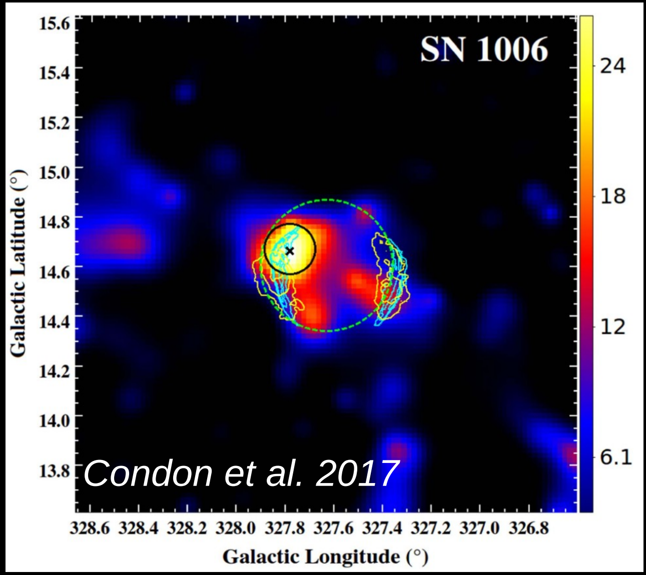
--- Inverse Compton

--- hadronic contribution of the shocked cloud

-·-· shocked ISM emission

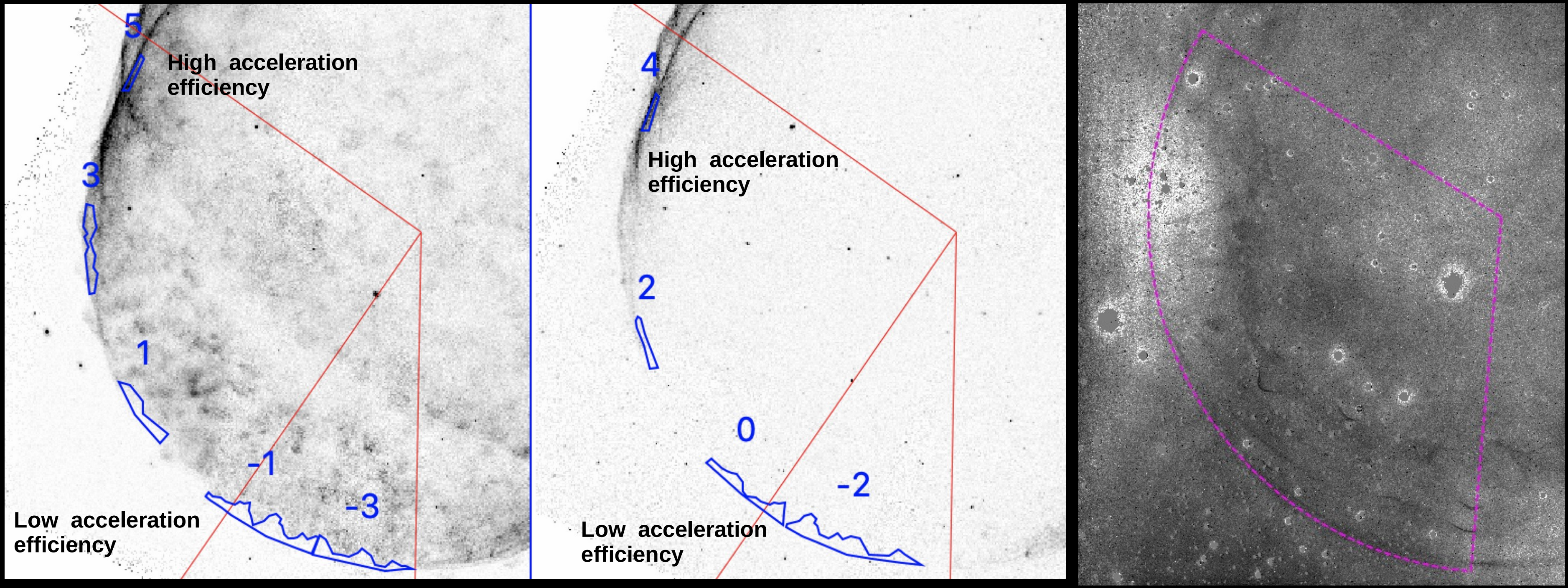
γ−ray spectrum observed with HESS

Fermi− LAT upper limits



AND IF THERE ARE INHOMOGENEITIES IN THE UPSTREAM MEDIUM?

Giuffrida et al. in review



V_s proportional to the inverse of the square root of the ambient density → $\Delta v \sim 1200$ km s^{-1} between region 0 and region 5, difference in the shock radius of $\sim 10^{18}$ cm