Gamma-rays from thermal X-ray composites

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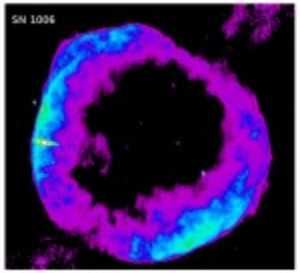
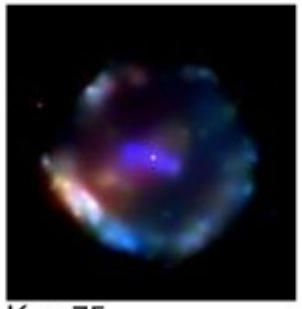
Morphology of SNRs

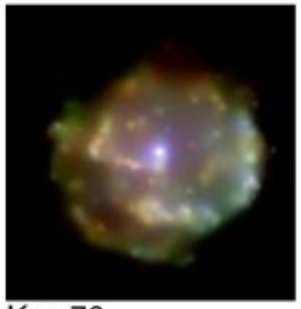
There are three morphological classes of shell-like SNRs based on the radio and X-ray morphologies:

- shell-like (SNRs are shells in radio and X-rays);
- composite (SNRs with central object and shell);
- thermal X-ray composites (TXCs) or mixed-morphology (shell in radio, centrally bright in thermal X-rays).



sn 1006


Kes 75

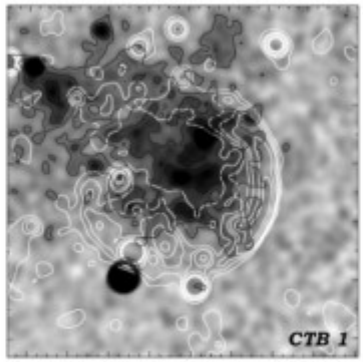

Kes 79

Thermal X-ray composites (or mixed-morphology)

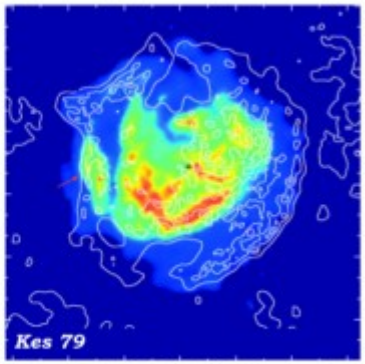
Thermal X-ray composites (TXCs)

- SNRs with shell in radio and centrally peaked in thermal X-rays;
- ∼20 SNRs - TXCs.

Name of the class: mixed-morphology SNRs (Rho & Petre 1998) thermal X-ray composites (Jones et al. 1998)



Lazendic & Slane 2006



Sun et al. 2004

Radio - contours, thermal X-ray - colors

Three models for thermal X-ray composites

White R., & Long K. (1991).

That the central thermal emission is caused by increased internal density due to evaporated material of numerous swept-up cloudlets

Cox D. et al. (1999).

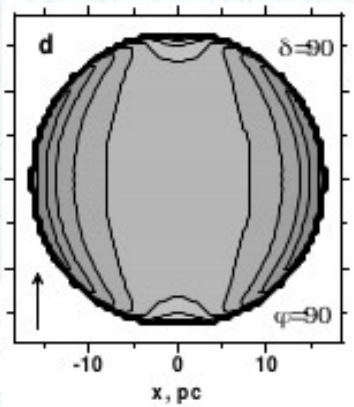
Shock temperature is small due to essential cooling; very soft emission of the shell is absorbed by ISM and only the interior region remains visible

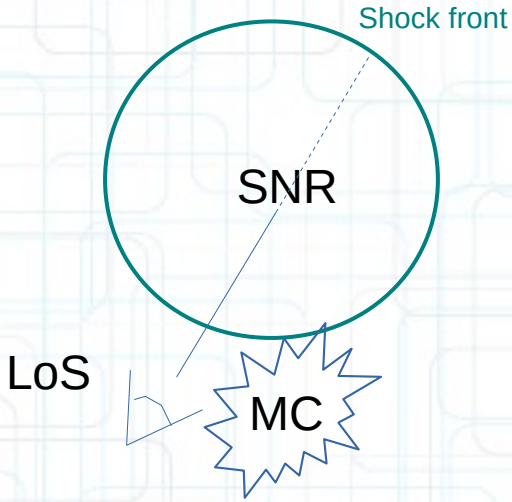
Petruk O. (2001).

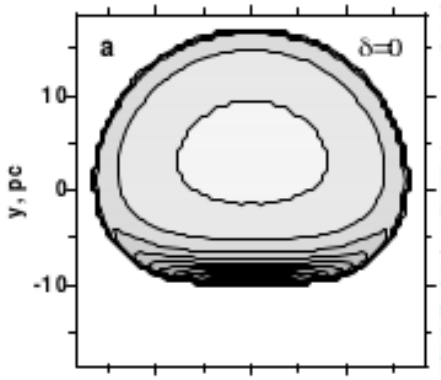
An effect of projection of SNR in ISM with strong density gradient

The projection effect for TXCs

Molecular cloud near the SNR (not along of line of sight)



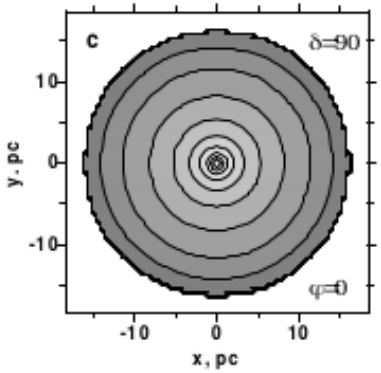


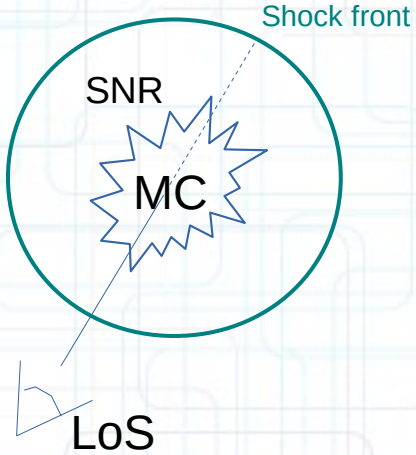


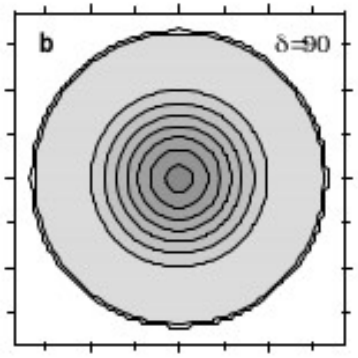
Radio ~ n

Thermal X-ray ~ n^2

Molecular cloud along of line of sight





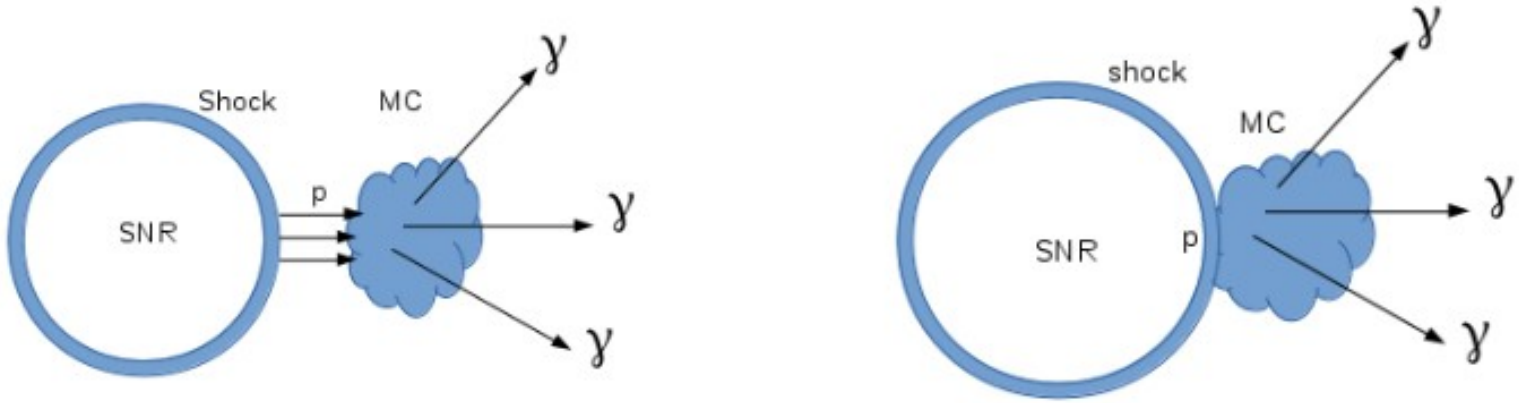


A consequence: TXCs may be promising sources of gamma-rays

SNRs near molecular clouds

Two scenarios for hadrinic γ-rays from SNR + MC

- SNR and MC are separated: protons diffuse toward MC
- SNR and MC are interacting: protons illuminate MC directly



Jiang et al. (2010):

64 SNRs total: 31 shells (48%), 17 TXC+5 composites (34%)

19 of these 64 SNRs are observed in γ-rays: 8 shells, 8 TXC+2 composites NB: almost half are TXCs!

The aim of our work

- **3-D MHD simulations (Pluto code, Mignone A. et al. 2007)**
- **Maps of surface brightness in radio and thermal X-ray**
- **Maps of surface brightness distribution in gamma-rays**

Parameters for numerical simulations

Uniform ambient MF

Model:

- MHD simulation
- $n(x) = n_o + n_c \exp(-x/h)$

Parameters:

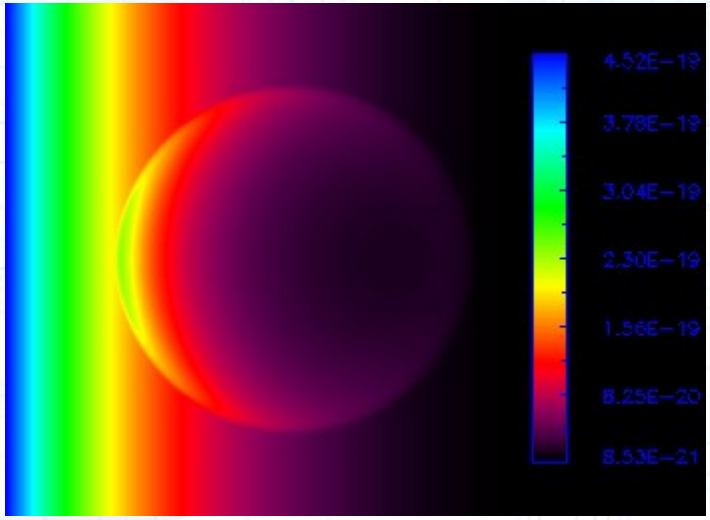
- $n_o = 0.1\ cm^{-3}$; $n_c = 100\ cm^{-3}$
- $E_o = 10^{51}\ erg$

Model:

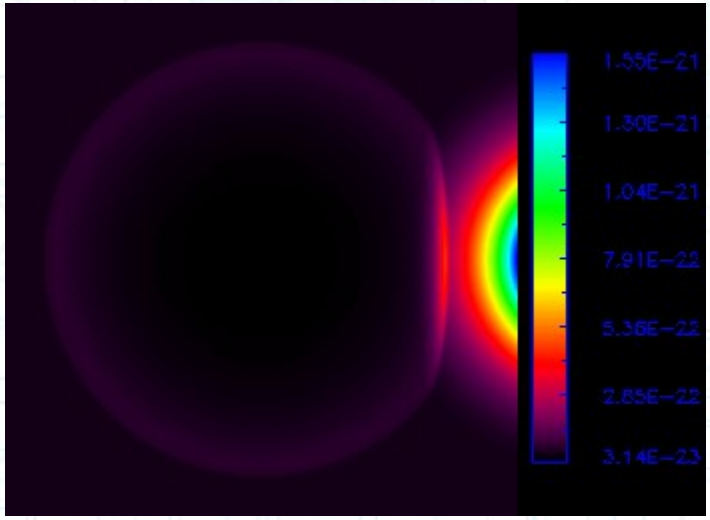
- MHD simulation
- R(MC)= 17.6 pc
- R(SNR)=R(MC)

Parameters:

- $n_o = 0.1\ cm^{-3}$; $n_c = 100\ cm^{-3}$
- $E_o = 10^{51}\ erg$
- $t = 6.8\ kyrs$; $h = 2.5\ pc$



density

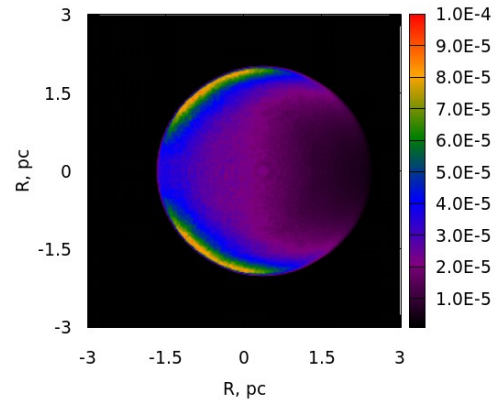


Images for different orientations

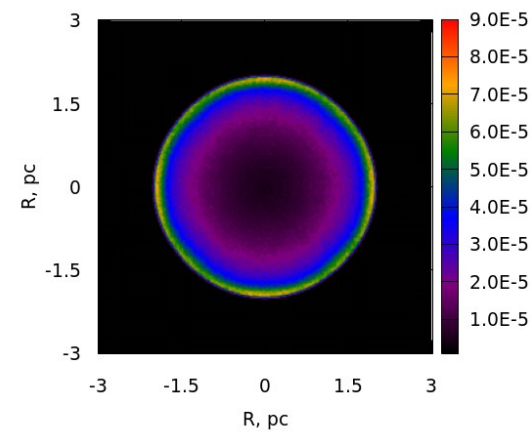
density gradient

Radio ~ $KB^{3/2}$ ~ n

$\phi_o = 0$



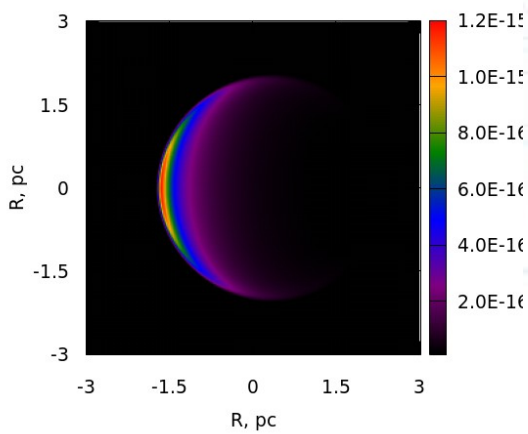
$\phi_o = 90$

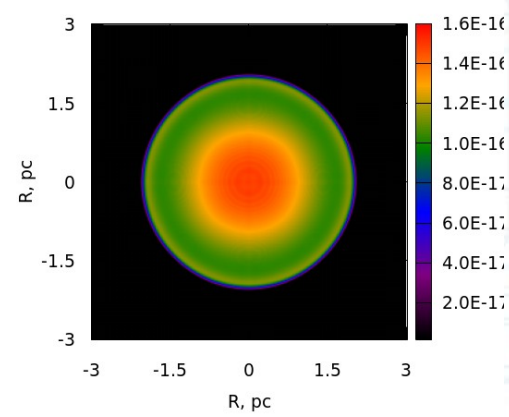


h = 1.5 pc

Thermal X-ray ~$n^2 \Lambda(T)$ ~ n^2

h = 1.5 pc

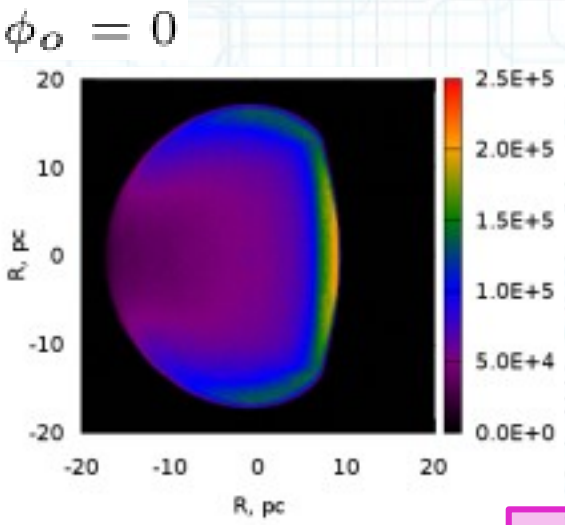


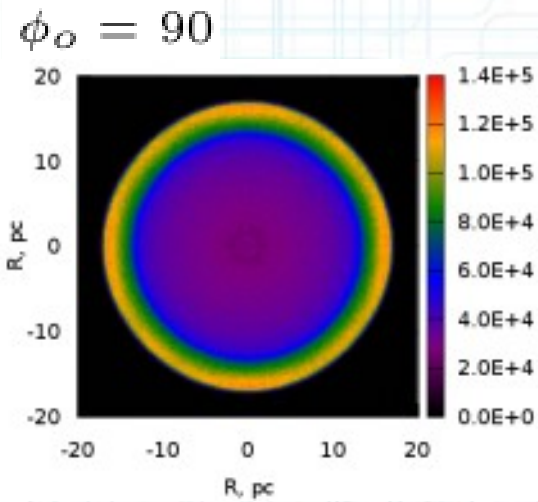


Images for different orientations

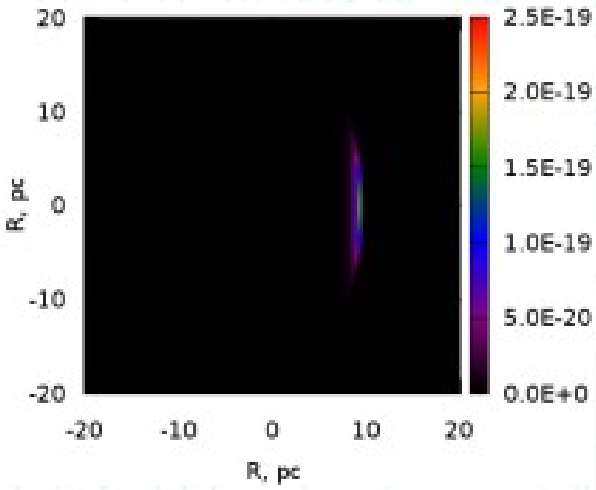
MC

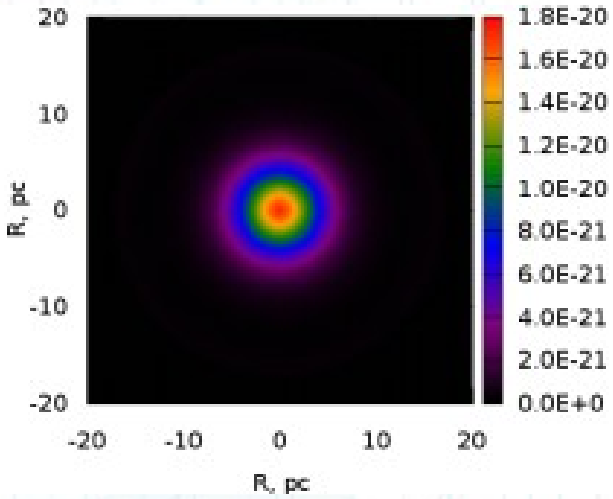
Radio ~ $KB^{3/2}$ ~ n





Thermal X-ray ~$n^2 \Lambda(T)$ ~ n^2

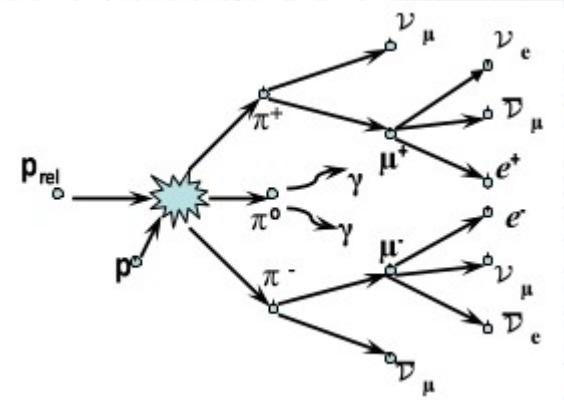




Radiation in gamma-rays

Protons

Pion decay



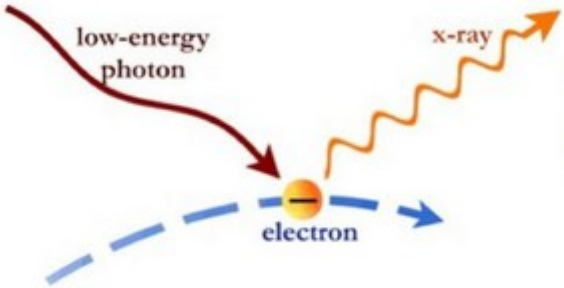
Spectrum of particles

$N(E) = E^{-s}\exp(-E/E_{max})$

$I_{pp} \sim n^2$

Electrons

Inverse Compton scattering



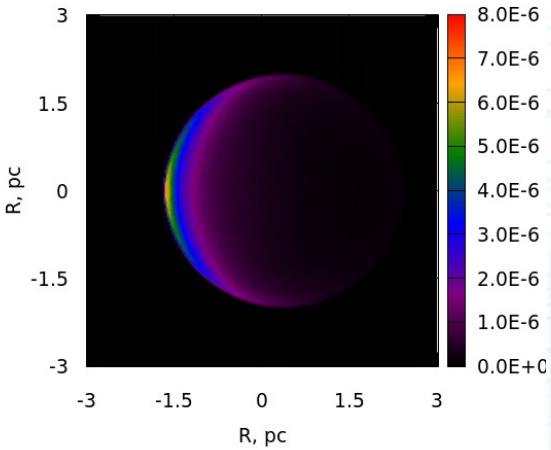
$I_{IC} \sim n$

We don't consider escape and illumination of the cloud by accelerated protons, in order to clearly see the SNR morphology

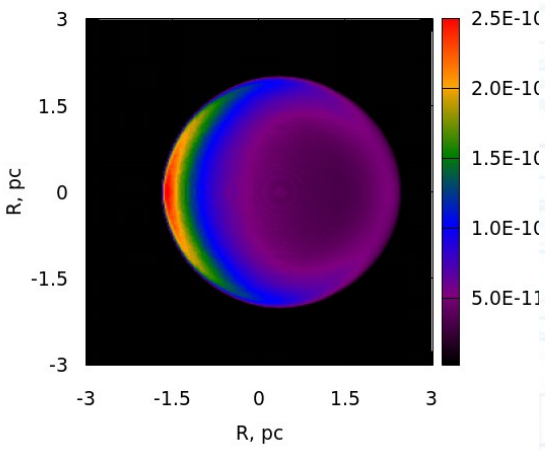
Images in gamma-rays
density gradient

Protons
(Pion decay)

Electrons
(Inverse Compton)



$\phi_o = 0$



h = 1.5 pc

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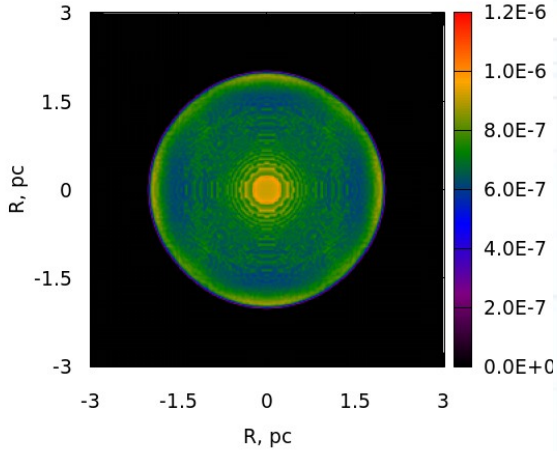
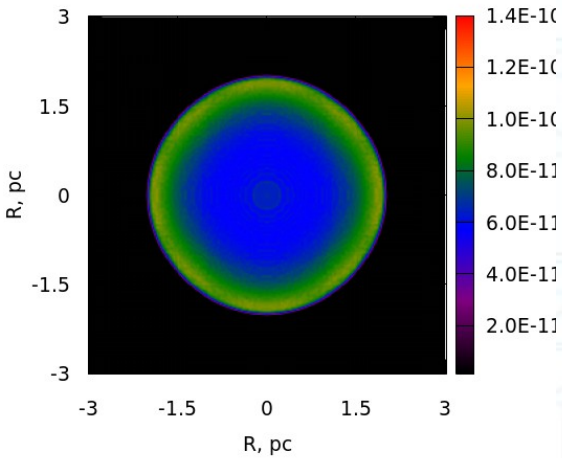


$\phi_o = 90$



Conclusions

- It is known that SNRs interacting with molecular clouds are sources of hadronic cosmic rays
- We used MHD simulations to create images of SNRs near molecular clouds from radio to gamma-rays
- Effect of projection of SNR interacting with cloud on LoS is demonstrated: TXCs morphologies are restored
- TXCs may be (and are!) the promising sources for hadronic gamma-rays