On the chemical abundances of mixed morphology supernova remnants

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Mixed Morphology SNRs

- **DEFINITION**: shell-like (asymmetric) morphology in the radio band and centrally peaked thermal emission in the X-ray band. Flat kT profile. (Rho et al. 1998)

- They seem to be located close to molecular clouds or high density regions

- *A mechanism responsible for producing such an unexpected morphology has not yet been uniquely identified*

**W44 (NRAO / AUI / NSF)**

Radio, X-ray (ROSAT, Rho et al. 1994), IR (Spitzer, Reach et al. 2006)
Cloud evaporation vs. radiative model

- Both models try to increase the central density
  - White & Long (1991), Shelton et al. (1994)

- Both model have general difficulties in reproducing some of the MM SNRs features
  - Surf.bri. profile too shallow
  - Central density too low

Radiative shell

The X-ray Universe 2008, Granada, 27-30 May
Enhanced abundances in MM SNRs

- Lazendic & Slane (2006) compiled a new list of MM SNRs
  - 10 out of 26 seems to have high Z
  - Multiple and single thermal components (seems not to be related to Z)
  - Evaporating clouds and thermal conduction radiative model do not address the mixing of ejecta and ISM

- In this work, we study the metal abundances of IC443 and G166.0+4.3
  - Listed in Lazendic & Slane (2006) as standard abundances MM SNRs
IC443 X-ray emission

EPIC Count-rate 0.5-1.4 keV

EPIC Count-rate 1.5-5 keV


Troja et al. 08, A&A, in press

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The X-ray Universe 2008, Granada, 27-30 May
IC443 metal abundance

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Sulphur EW map

Troja et al. 08, A&A, in press

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More in IC443 metallicity

- Extraction regions defined in term of surface brightness contours
- Cross-region contamination may be an issue
  - SAS support still experimental
- Look for variations of temperature and metallicity vs. surface brightness
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The X-ray Universe 2008, Granada, 27-30 May
G166.0+4.3 (a.k.a. VRO 42.05.01)

- Interesting radio morphology (small shell and large “wing”)
- X-ray emission centrally peaked (between shell and wing, perhaps in the hot tunnel)
- Possibly explained in terms of expansion in a “hot tunnel”, bounded by 2 dense regions

G166.0+4.3 (Vro 42.05.01)
1420 MHz CGPS DRAO radio image
XMM-Newton/EPIC image (0.3-5 keV)

The X-ray Universe 2008, Granada, 27-30 May
IC443 and G166.0+4.3 both show evidence of high metal abundances!!!
A new model for MM SNRs

- We explore the possibility that MM SNRs are the results of interaction with progenitor CSM
- 3D HD model
  - Thermal conduction includes flux saturation effects
  - Ejecta mat. with enhanced metallicity
  - 8-fold symmetry assumed
  - FLASH code
MM-SNRs: 3D modeling

Ejecta concentrated at the center of the SNR
**MM-SNRs: 3D modeling**

Ejecta concentrated at the center of the SNR

![Ejecta and Log mass density](image-url)
**X-ray emission**

Morphology in the X-ray band changes during the evolution

**Phase I:** maximum X-ray emission at the (forward) shock front
  -> shell-like morphology

**Phase II:** X-ray emission centrally peaked
  -> MM SNRs

Thermal conduction very effective and contributes to enhance central emission
Temperature and Metallicity

During the MM phase:
- Temperature decreases with radial distance
- Average T of shocked ejecta > average T of shocked CSM
- Enhanced metallicity at the center of the remnant
- Metallicity gradually decreases with radial distance

Agreement with observations of metal-rich MM SNRs?
Conclusion

- Emerging new class of remnants
  - MM SNRs with enhanced metallicity
  - What fraction of MM belongs to the new class?
  - IC443 and VRO are high-Z, once thought to be low-Z
    - High-Z MM SNRs may be very common

- (M)HD simulations of CSM-shock interactions
  - May help to understand MM, even with high Z, easing the difficulties of traditional models
    - $kT$, $n$ and $Z$ profiles are desperately needed...
      - Challenging data analysis task