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MIXED MORPHOLOGY SUPERNOVA REMNANTS AND THE CONTRIBUTION OF MARGARITA ROSADO TO THE DETECTION OF EXTENDED X-RAY EMISSION FROM SUPERBUBBLES

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RESUMEN

Recordamos la primera propuesta exitosa para detectar emisiones de rayos X de superburbujas empujadas por vientos y la formación de tres astrónomos mexicanos especializados en observaciones de rayos X de fuentes nebulares extendidas. Basándonos en este entrenamiento, damos los resultados de varias propiedades de una clase definida de remanentes de supernova: los remanentes de supernova de Morfología Mixta. Hemos estudiado varios casos en al menos tres dominios de longitudes de onda: radio, rayos X y óptico. Establecemos varias de sus propiedades y favorecemos el modelo de evaporación de nubes densas que sobreviven al choque de supernova utilizando una importante herramienta de modelado.

ABSTRACT

We recall the memories of the first successful proposal to detect X-ray emission from wind-blown superbubbles and the training of three Mexican astronomers specialized in X-ray observations of extended nebular sources. Based on this training we give the results of several properties of a defined class of supernova remnants: the Mixed Morphology supernova remnants. We have studied several cases in at least three wavelengths domains : Radio, X-rays and Optical. We establish several of their properties and we favor the model of evaporation of dense cloudlets surviving the forward supernova shock using an important modeling tool.

Key Words: galaxy: kinematics and dynamics — ISM: bubbles — ISM: kinematics and dynamics — ISM: supernova remnants

1. GENERAL

Most of you do not know but I have the honor of having contributed with my small grain of sand to the discovery of X-ray emission from superbubbles. I was a PhD student when my observing proposal with the Einstein Satellite of deep exposures of several superbubbles in the Large Magellanic Cloud including the superbubbles N70 and N185 was accepted. Indeed, at that time I have just measured the high expansion velocities of N70 and N185 by means of Fabry-Perot interferometry (about 70 km/s) and I have computed the X-ray luminosities submitting a proposal to the Einstein Observatory together with my adviser Guy Monnet. The Rosado and Monnet proposal was accepted by Einstein Observatory board and the observations carried out giving the result of the detection, for the first time, of X-ray emission from the superbubbles N70 and N185, among other superbubbles. We submitted an article reporting those successful results that was rejected by an anonymous referee that argued that it was only noise (at that time the Einstein Observatory instrumental function was concealed for alien users as me, so that it was really hard to answer to the aggressive referee). Years after, our observations were used by You-Hua Chu and Mordecai Mac Low showing that indeed there was X-ray emission from those superbubbles. In fact, bubbles and superbubbles were unexpected objects that successful emit in X-rays besides the binary compact X-ray sources. Thanks to that observing proposal the X-ray emission from superbubbles started to be studied from the X-ray observatories. You-Hua Chu kindly invited Margarita Rosado to collaborate with her on X-ray emission from superbubbles by training three of her students: Patricia Ambrocio-Cruz, Jorge Reyes-Iturbide and Lorena Arias who spent several months at Urbana University learning to reduce X-ray data from You-Hua's team. One of our works, derived from this

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knowledge, refer to the multiwavelength study of several supernova remnants (SNRs) belonging to a conspicuous class, the Mixed Morphology SNRs .

2. MIXED MORPHOLOGY SUPERNOVA REMNANTS

Mixed Morphology Supernova Remnants (MM-SNRs) is a special class of SNRs characterized by being shell-type at radio wavelengths whereas their X-ray emission is filled-center . Other characteristics are their gamma-rays emission (pointing to an association with molecular clouds and thus with core-colapse supernovae progenitors) and a roughly uniform radial distribution of temperature of the hot interior gas. However, it is not well-known how is their optical emission and how to explain their conspicuous morphology and origin.

Regarding the explanation of the properties of MM-SNRs there are two main models:

1. Thermal conduction in the remnant interior (Cox et al. 1999)

Or:

2. Evaporation of dense cloudlets surviving the forward shock, and increasing the gas density at the center (White & Long 1991) (White & Long 1991).

In studying these MM-SNRs we used an important tool, a Python code modeling SNR evolution considering several models. including a clumpy interstellar medium, ISM, equivalent to the second model listed above (Leahy & Williams 2017; Leahy & Ranasinghe 2018; Leahy et al. 2019, 2020).

We are studying several MM-SNRs using mainly archive XMM-Newton X-ray observations and optical spectroscopic and interferometric observations of the optical counterparts of the SNRs.

2.1. *Determination of MM-SNRs properties from X-ray observations*

From archive XMM-Newton X-ray observations we are able of determining the following properties:

– Electron temperature of the hot interior.

– Velocity of the primary shockwave.

– Age of the SNR (together with the linear diameter determination).

– Electron density of the hot interior gas.

– Initial energy deposited in the ISM from the supernova explosion.

2.2. *Determination of MM-SNRs properties from optical observations*

From optical emission line imaging, slit spectroscopy and Fabry-Perot 2D spectroscopy of various emission lines such as H_α, [SII] and [OIII] being the most important, we can derive:

– Detection of the optical counterpart of the SNRs by means of the high [SII]/H_α line-ratio..

– Kinematic distance for Galactic SNRs, obtained from the measure of the SNR systemic velocity, equivalent to the SNR's rotation velocity around the Galactic Center.

– Linear diameter. Mostly derived from radio-shell angular diameter and kinematic distance.

– Electron density of the dense clouds.

– Velocity of the secondary shock induced in the dense cloudlets.

3. LIST OF STUDIED MIXED MORPHOLOGY SUPERNOVA REMNANTS

Until now we have studied the following three MM-SNRs:

– SNR 0520-69.4 in the Large Magellanic Cloud galaxy (Ramírez-Ballinas et al. 2020)

– Galactic SNR W51C (Reyes-Iturbide et al. 2022).

– Galactic SNR CTB1 (Reyes-Iturbide et al. 2024).

4. CONCLUSIONS

– The three cases of MM-SNRs are consistent with a SN explosion interacting with dense (molecular) cloudlets.

– Under that condition, optical emission should be detected unless high interstellar absorption hide it.

– Optical lines are quite helpful to determine important SNRs quantities, combined with radio and X-rays.

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