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SNR J0506 – 7009


The Daily
Sunday, August 30, 2024
A Star found Dead in the LM
The all-sky survey carried out by the extended Roentgen Survey with an Imaging Telescope Array (eROSITA) on board Spektrum-Roentgen-Gamma (Spektr-RG, SRG) has provided spatially and spectrally resolved X-ray data of the entire Large Magellanic Cloud (LMC) and its immediate surroundings in the soft X-ray band down to 0.2 keV, with an average angular resolution of 26″ in the field of view.
In their observation, they study the supernova remnants (SNRs) and SNR candidates in the LMC using data from the first all-sky surveys (eRASS:4). From the X-ray data, in combination with results at other wavelengths, we obtain information about the SNRs, their progenitors, and the surrounding interstellar medium (ISM). Studying the entire population of SNRs in a galaxy aids in understanding the stellar populations, the environments in which the SNRs are evolving, and the stellar feedback on the ISM. Methods. The eROSITA telescopes are the best instruments currently available for the study of extended soft

Master's Thesis by

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under

Prof. Dr. **Manami** Sasaki

28.07.2025

First Information Report

First study of the supernova remnant population in the Large Magellanic Cloud with eROSITA

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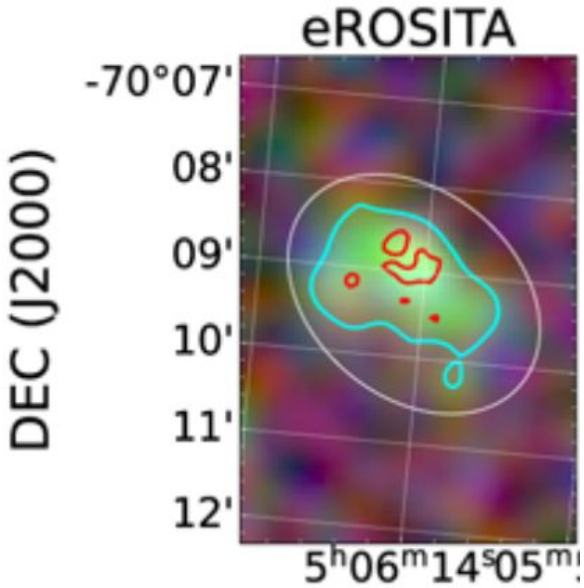


The eROSITA count rate three-colour image with red: 0.2–0.7 keV, green: 0.7–1.1 keV, and blue: 1.1–5.0keV

Who? SNR

Stars explode - Supernova
What remains - Supernova Remnant

- Type Ia
- Core Collapse

**Image Credit: X-ray: NASA/CXC/SAO;
Infrared: NASA/ESA/CSA/STScI/D. Milisavljevic (Purdue Univ.),
I. De Looze (UGent), T. Temim (Princeton Univ.);
Image Processing: NASA/CXC/SAO/J. Major, J. Schmidt and K. Arcand**

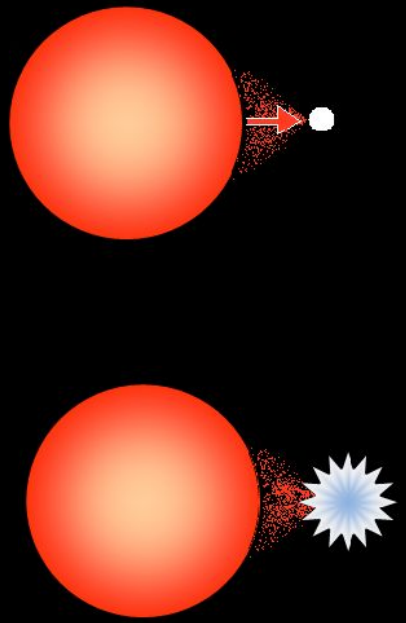
Type Ia

White dwarf accretes mass from the companion.

Chandrasekhar limit: **1.4 $M_\odot$**

As soon as mass > 1.4 $M_\odot$, star explodes.

Iron is created along with many other elements.



Credit: Wikimedia

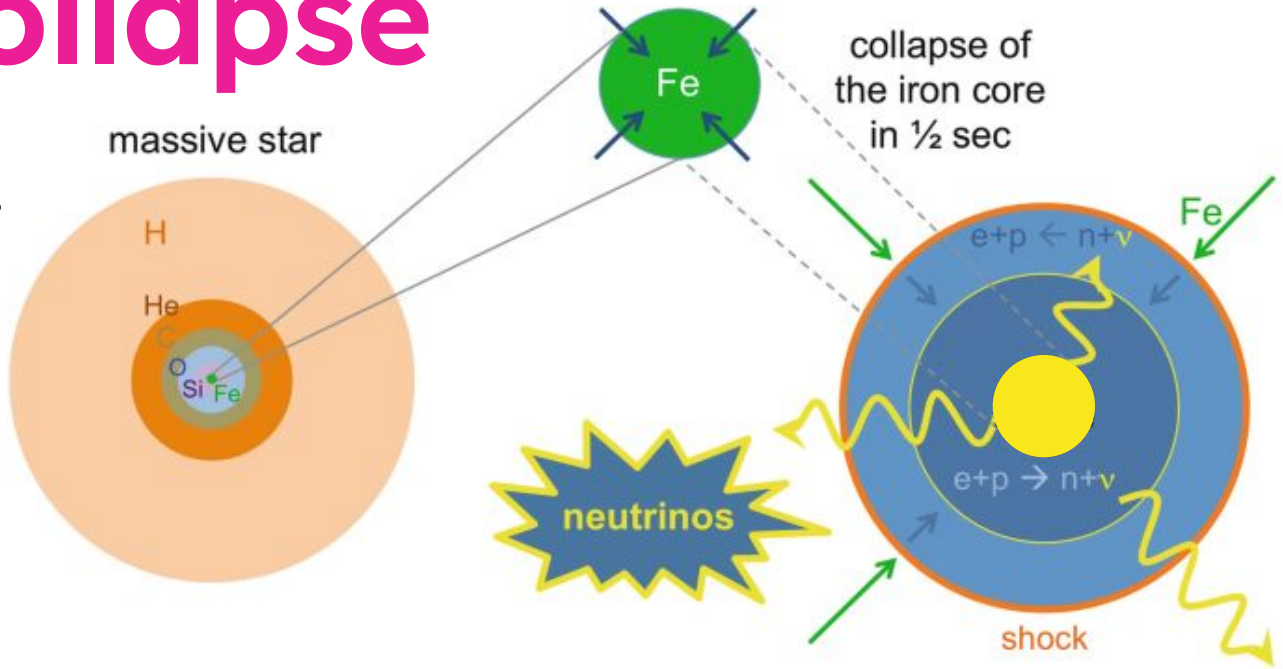
Core Collapse

No fusion past iron.

Gravity crushes the iron core.

Core collapses.

In the explosion, Fe is destroyed.



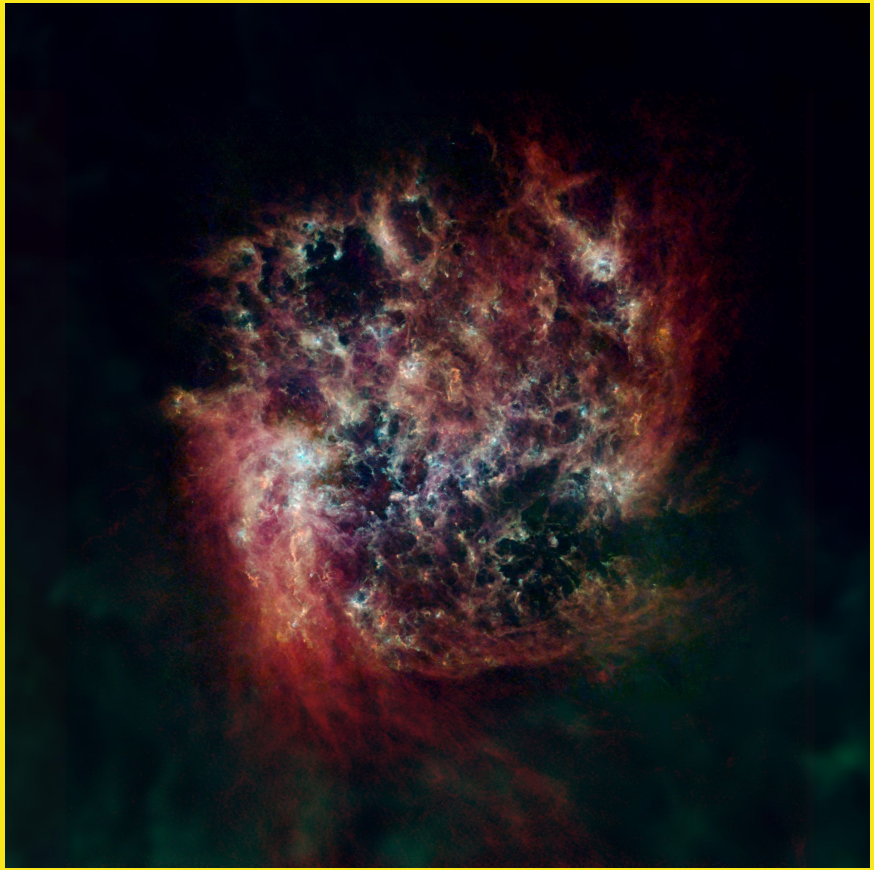
Credit: Foglizzo, T. (2017). Explosion Physics of Core-Collapse Supernovae. In: Alsabti, A., Murdin, P. (eds) Handbook of Supernovae. Springer, Cham. https://doi.org/10.1007/978-3-319-21846-5_52

Where? LMC

Large Magellanic Cloud

Our neighbour galaxy
50,000 pc from Earth.

Nearly face-on.



Credit: ESA/NASA/JPL-Caltech/CSIRO/C. Clark (STScI)

‘The Crime Scene’

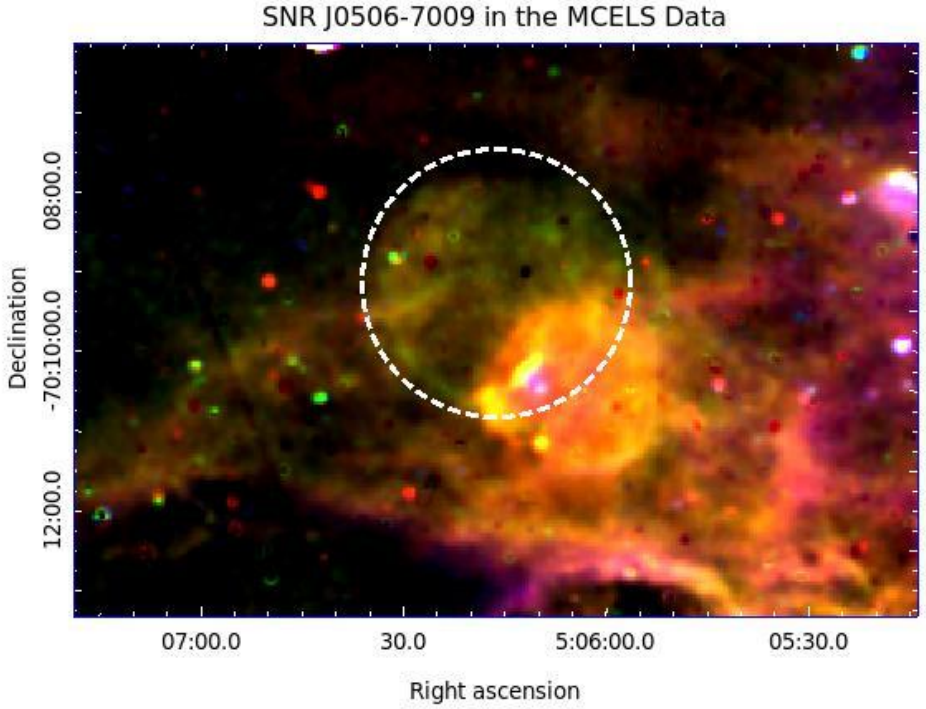
Magellanic Cloud Emission-line Survey.

Beautiful!

What are the secrets of this beauty?

I studied in X-rays

using XMM-Newton.



XMM-Newton

X-ray Multi-Mirror Mission by ESA
Launched on December 10, 1999.

Studies X-ray sources across the Universe

XMM-Newton has
European Photon Imaging Camera (EPIC)

- **3 CCD cameras for X-ray imaging**
- **Energy range of 0.15 to 15 keV**
- **Field of view: 30′**

Credit: ESA/D. Ducros

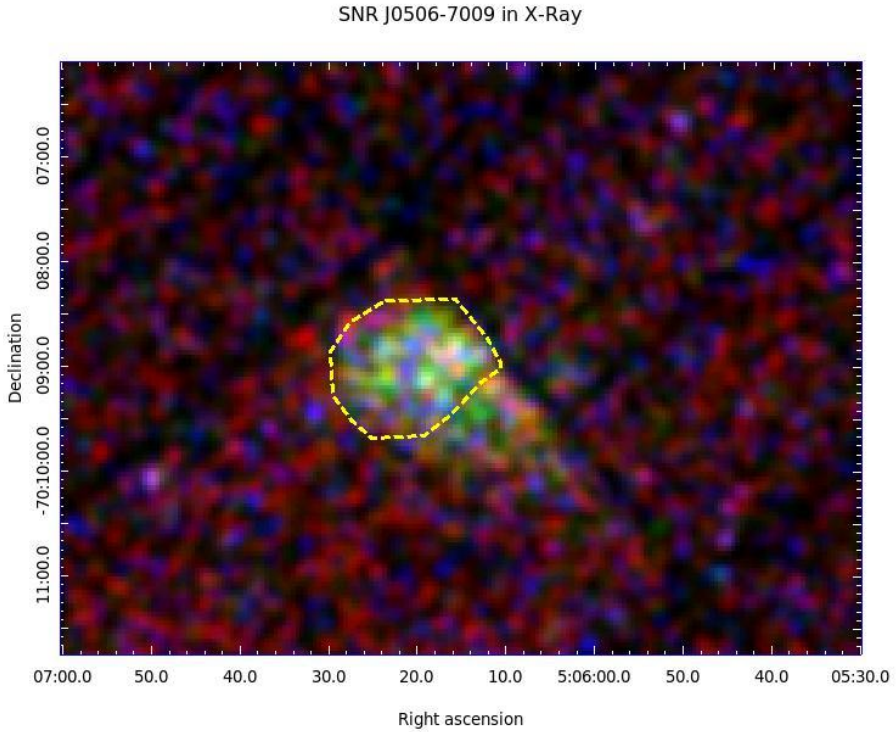
The exposure time was ~ 40 ks for each detector for our observation.

What XMM saw

R (300-700 eV)
G (700-1100 eV)
B (1100-1500 eV)

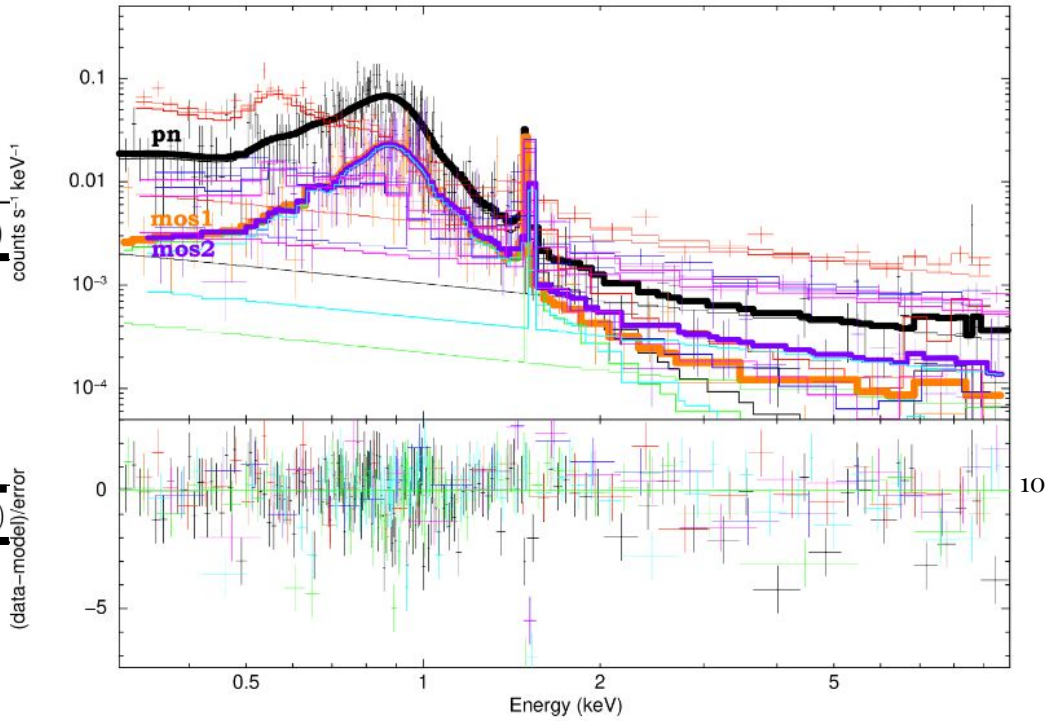
obtained by combining the three CCDs' data in three different energy bands.

We see 'green' emission ⇒
Higher 700-1100 eV emission
⇒ Likely, high Fe abundance,
energy range of Fe L-shell lines



What XSPEC Fitted

Parameter (Unit)	$cstat - fit(a)$	$cstat - fit(b)$
Temperature kT (keV)	$0.76^{+0.04}_{-0.03}$	$0.76^{+0.05}_{-0.04}$
Oxygen abundance $(X/X_{\odot})$	$0.75^{+3.45}_{-0.54}$	0.21^{frozen}
Iron abundance $(X/X_{\odot})$	< 5.82	$1.19^{+0.49}_{-0.33}$
Ionization timescale τ $(10^{11} s/cm^3)$	>3.75	>3.4
Normalization K $(10^{-6}/cm^5)$	13.2	$15.4^{+4.4}_{-6.6}$
Fit Statistic (dof)	2082.84(6007)	2056.99(6006)

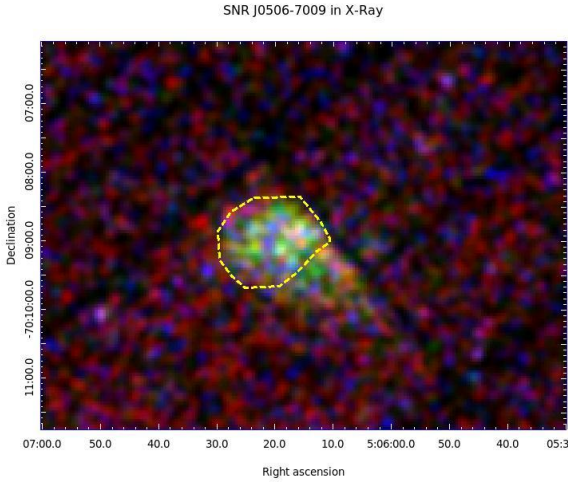


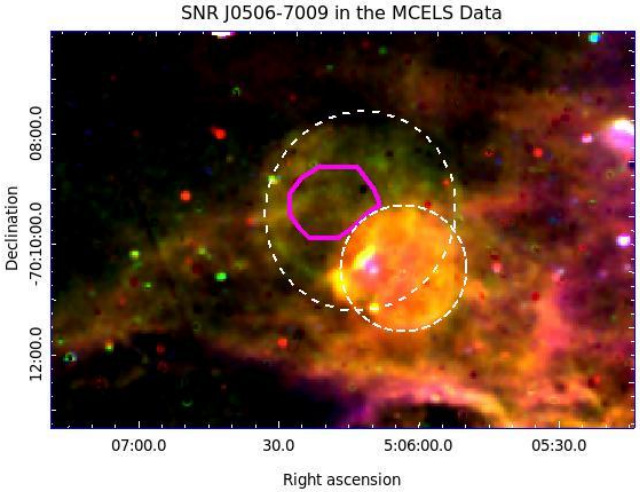
Model

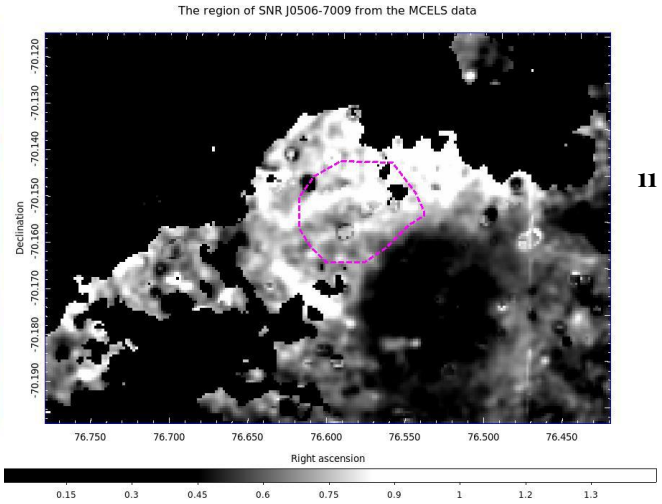
vnei: non-equilibrium collisional ionization plasma model with variable abundances.

How did the progenitor die?

Or, who was the progenitor?

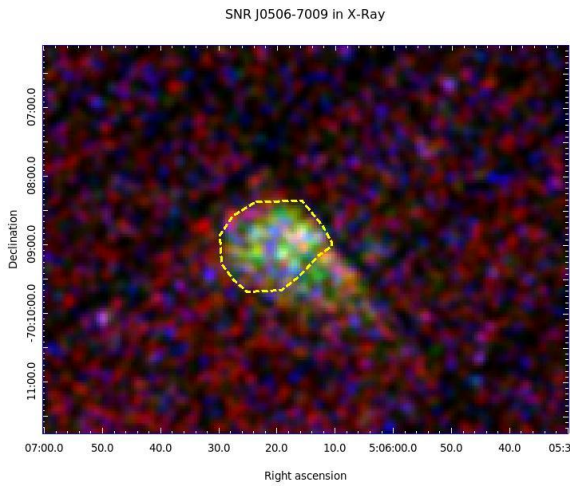




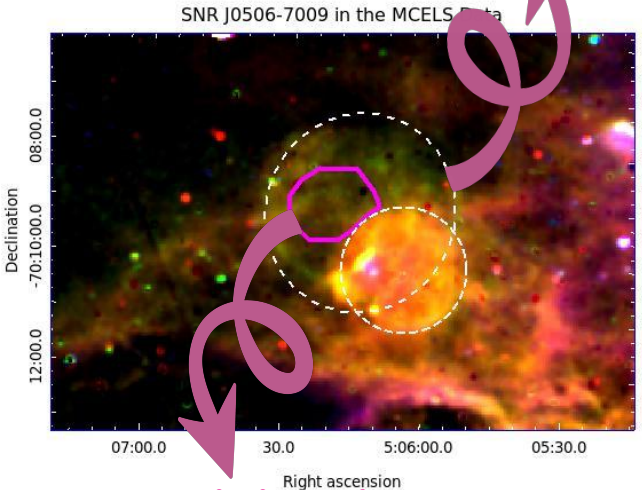


How did the progenitor die?

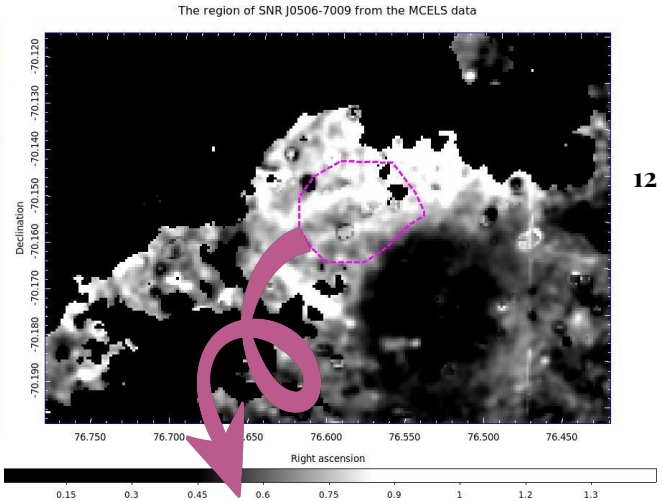
Or, who was the progenitor?



Radiative shell



X-ray emitting ejecta.



Shocked gas

What Fits Ratioed

Type Ia?

Likely.

But, large uncertainties.

Not enough data to constrain.

	[O]/[Fe]	$\frac{[O]/[Fe]}{[O]/[Fe]_{LMC}}$
LMC	0.60	1
c-stat fit (a)	0.53	0.88
c-stat fit (b)	0.18	0.3
c-stat fit (c)	0.40	0.67

$$\frac{[O]/[Fe]}{[O]/[Fe]_{LMC}} \ll 1$$ ⇒ Type Ia progenitor

Maggi et al. 2016

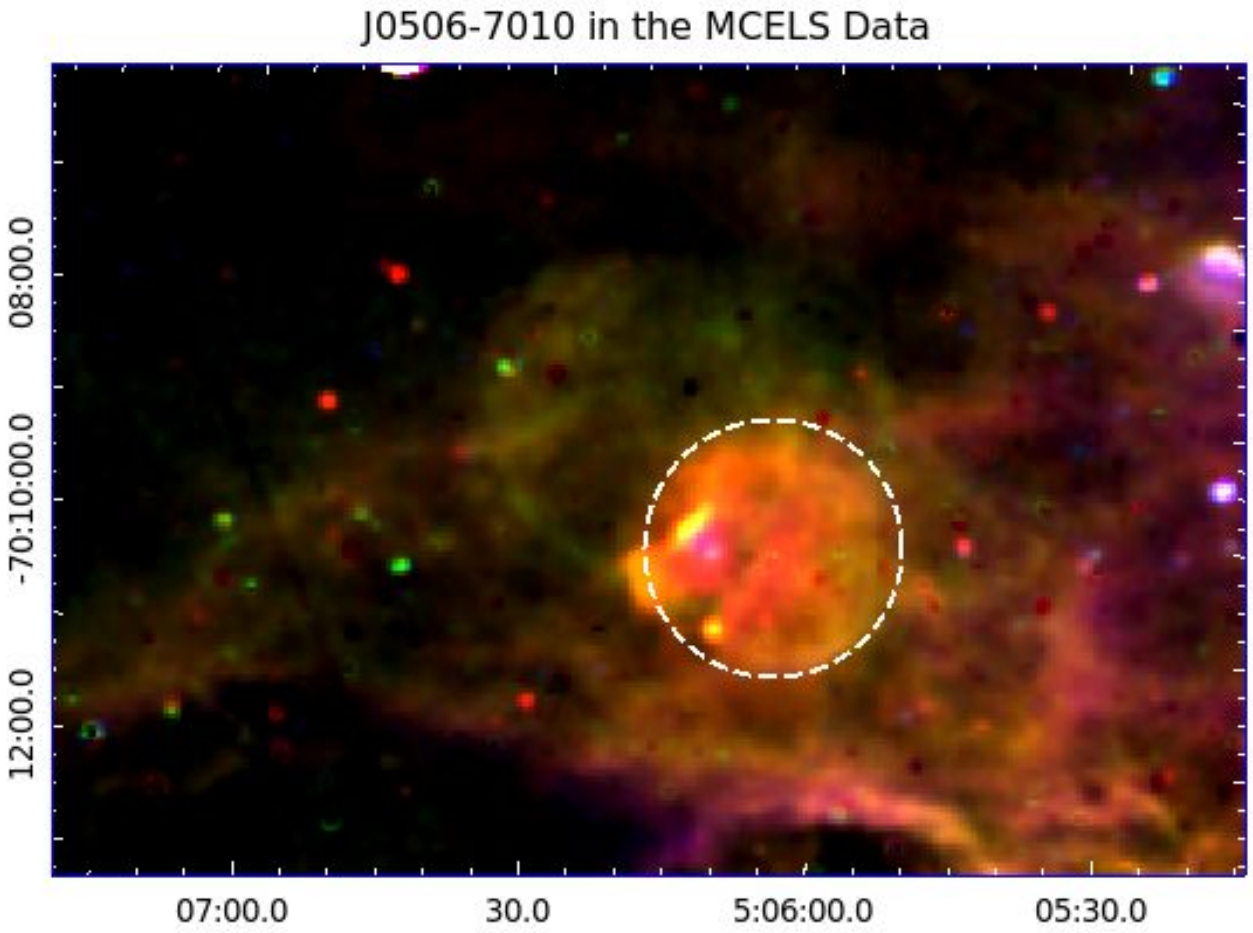
More secrets need to be unveiled.

Neighbours need to be interrogated.

Maggi et al. [2016]: The population of x-ray supernova remnants in the large magellanic cloud. 2016. doi: 10.1051/0004-6361/201526932.

Suspicious Neighbour

‘Strange Orange’



A Graveyard?

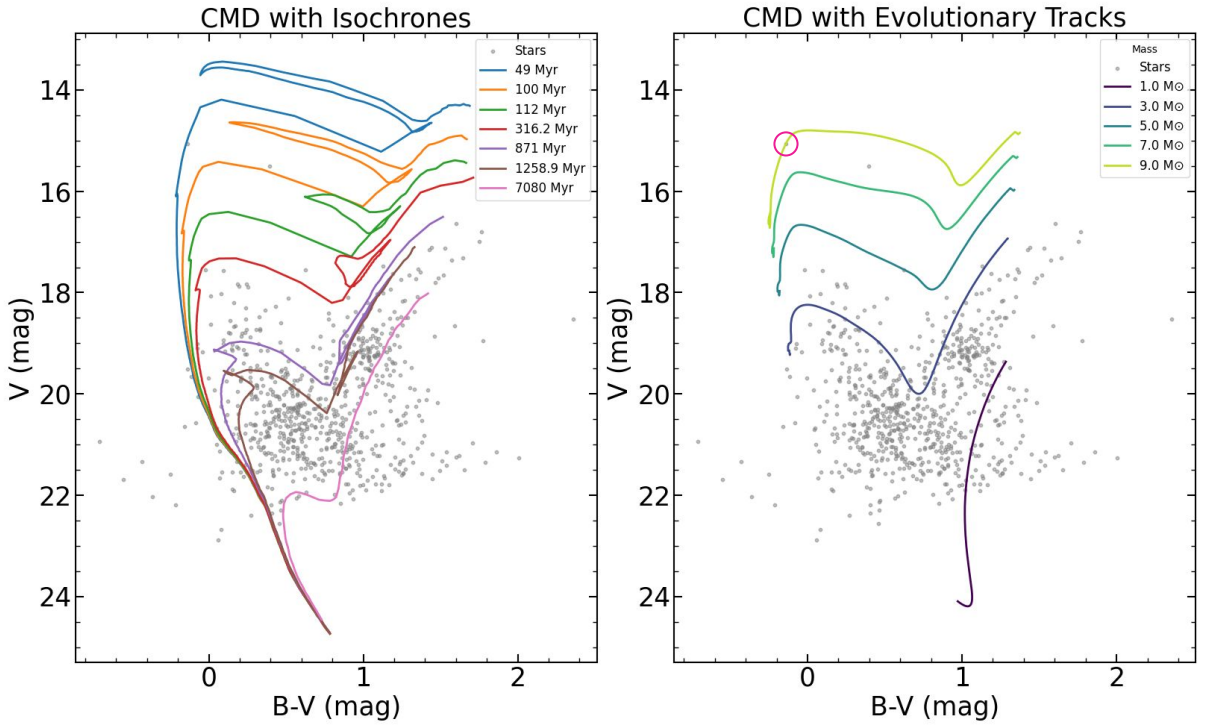
We estimate

1 massive star alive,

~9 $M_\odot$

2 massive stars dead

>8 $M_\odot$



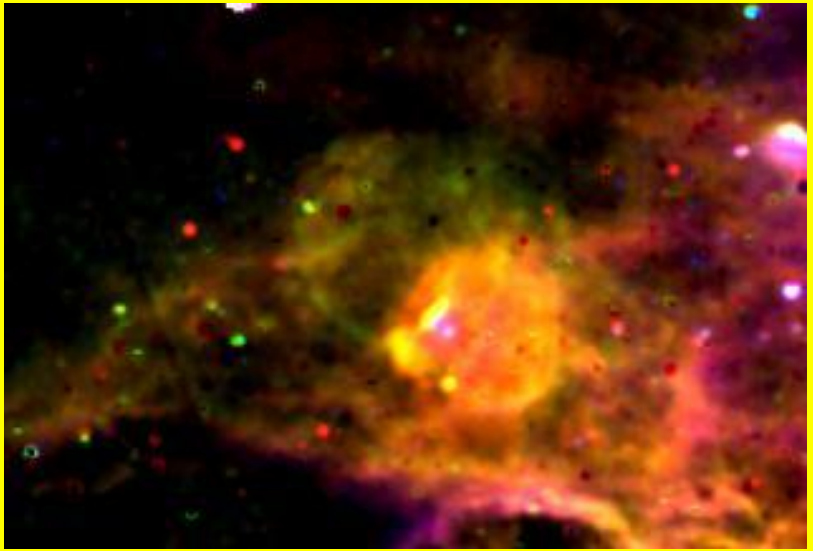
Zaritsky et al. [2004]: The magellanic clouds photometric survey: The large magellanic cloud stellar catalog and extinction map. Oct 2004. doi: 10.1086/423910.

T. Lejeune and D. Schaerer. Database of Geneva stellar evolution tracks and isochrones for UBVRIJHKLL'M, HST-WFPC2, Geneva and Washington photometric systems.doi: 10.1051/0004-6361:20000214.

Knock, Knock, Who?

The ‘Strange Orange’ could be a region affected by the stellar feedback of these 3 massive stars, of which 1 is still active.

The proximity of these massive stars indicates that the progenitor of our SNR could have been a massive star which exploded in core collapse. However, [O], [Fe] abundances suggest a Type Ia.



Case Unsolved!

(like most cases of an SNR)

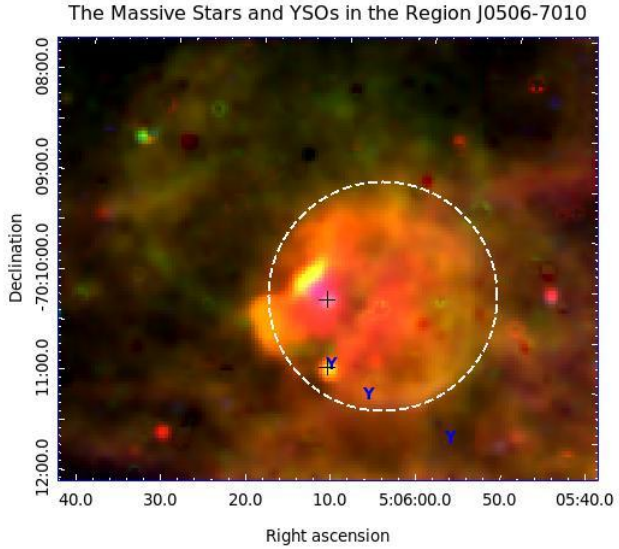
What else glows ‘orange’?

We see

2 massive stars still alive,

4 massive stars dead,

3 YSOs



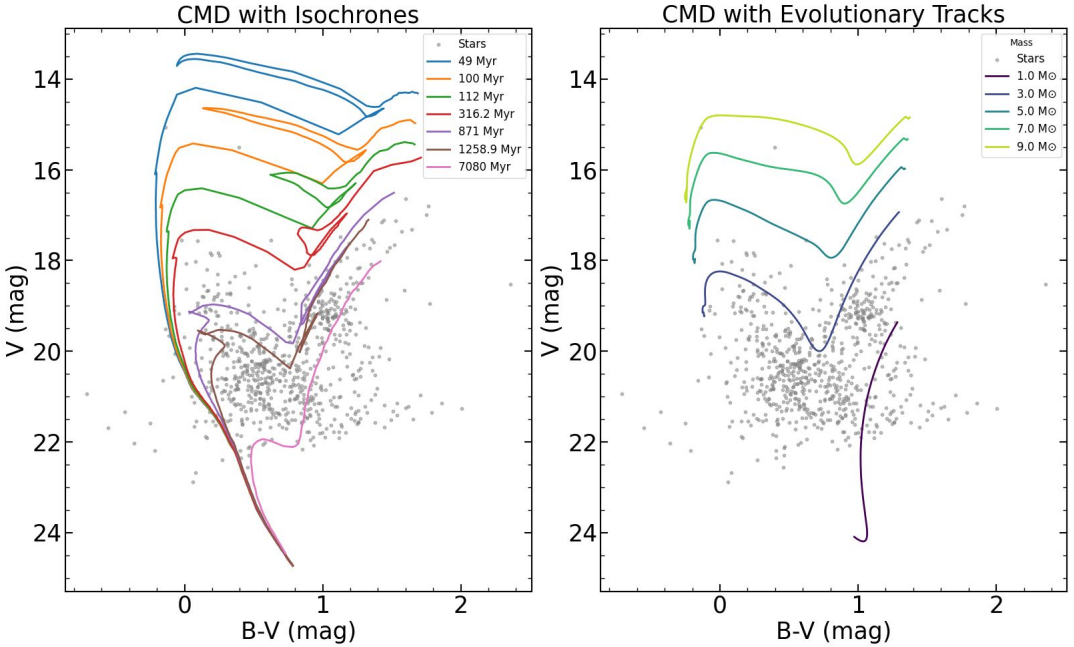
What HRD says

We see

2 massive stars still alive,

4 massive stars dead,

3 YSOs



Zaritsky et al. [2004]: The magellanic clouds photometric survey: The large magellanic cloud stellar catalog and extinction map. Oct 2004. doi: 10.1086/423910.

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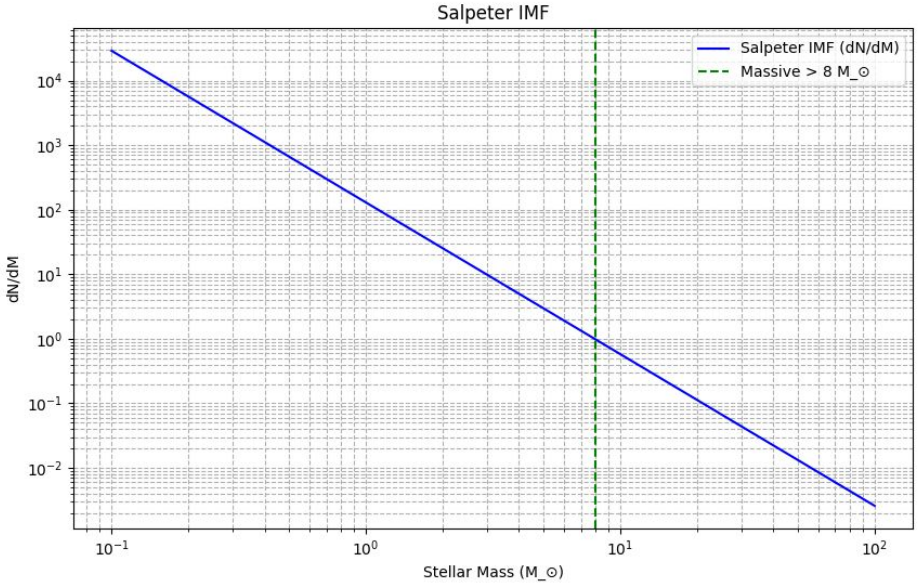
A Graveyard?

We see

2 massive stars still alive,

4 massive stars dead,

3 YSOs



What secrets did X-Rays whisper?

Parameter	χ^2 -fit	c-stat fit
Effective X-ray Radius	11.74 ± 2.345 pc	
	$(3.62 \pm 0.725) \times 10^{19}$ cm	
Semimajor Axis	12.30 ± 2.46 pc	
	$(3.78 \pm 0.76) \times 10^{19}$ cm	
Semiminor Axis	11.18 ± 2.24 pc	
	$(3.45 \pm 0.69) \times 10^{19}$ cm	
Volume (X-ray emitting ellipsoid)	$(1.89 \pm 0.847) \times 10^{59}$ cm^3	
Emission Measure (EM)	$(2.76^{+0.06}_{-0.35}) \times 10^{56}$ cm^{-6}	$(4.53^{+1.29}_{-1.94}) \times 10^{56}$ cm^{-6}
Hydrogen Density (n_H)	0.035 ± 0.012 cm^{-3}	0.031 ± 0.016 cm^{-3}
X-ray emitting Mass	5.5 ± 3.1 M$_\odot$	10.21 ± 6.06 M$_\odot$
Age	43000 ± 2000 years	
Shock velocity	232.76 ± 47.71 km/s	

What XSPEC Fitted

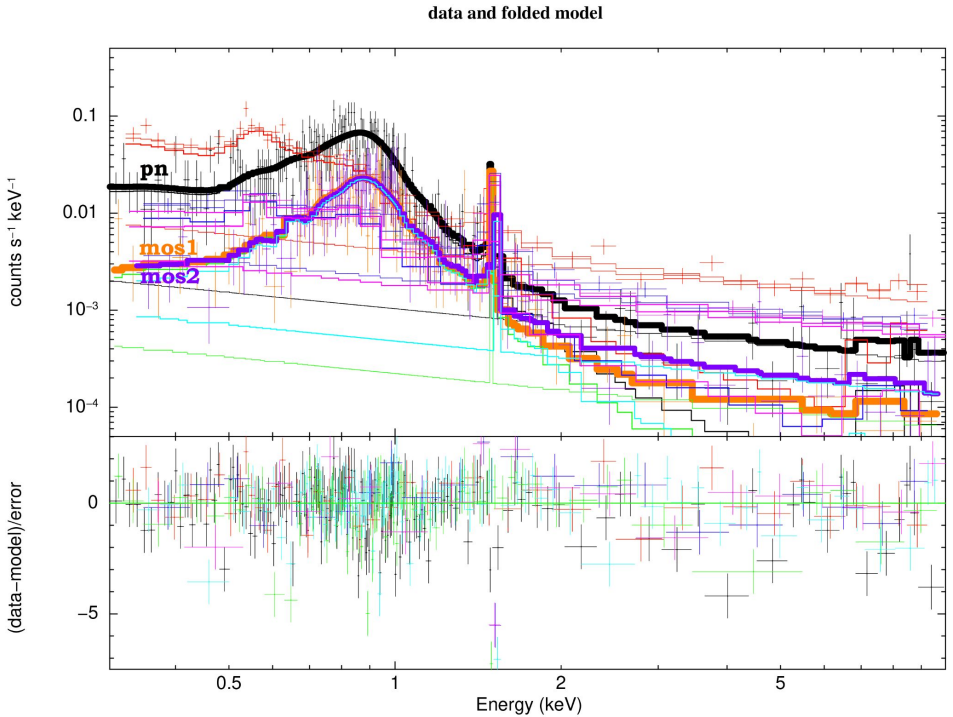
C-stat Fit

Almost same fit values

except Fe, O abundances.

But,

Fe, O abundances are critical

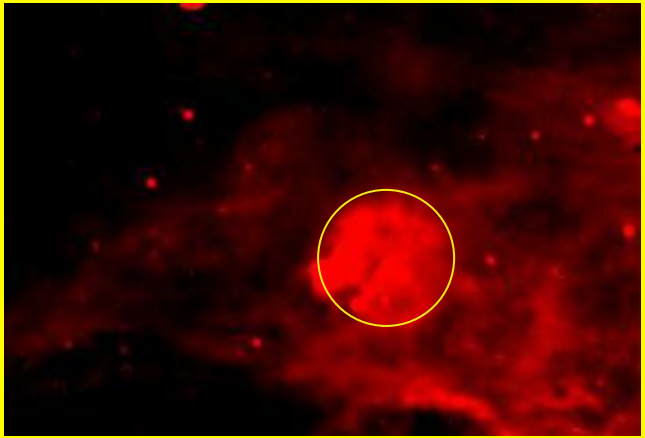


Suspicion: HII Region

- Because, high H-α emission,
- High absorbing hydrogen column density,
  $N_H=(0.8\pm0.1)\cdot10^{22}\ cm^{-2}$

- Radius ~ 16.5 pc
- In front of the SNR

'Strange Orange' in MCELS Hα map



Kim et al. [2003]: A neutral hydrogen survey of the large magellanic cloud: Aperture synthesis and multibeam data combined. Oct 2003. doi: 10.1086/376980.

What does it look like?

Circular

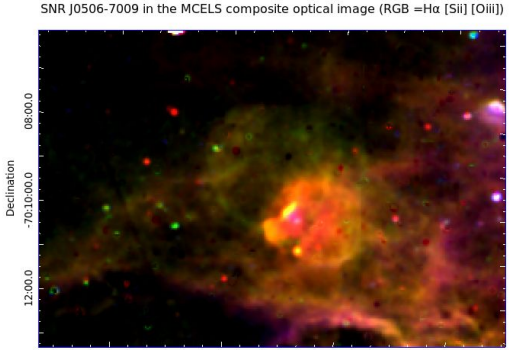
Statistically,

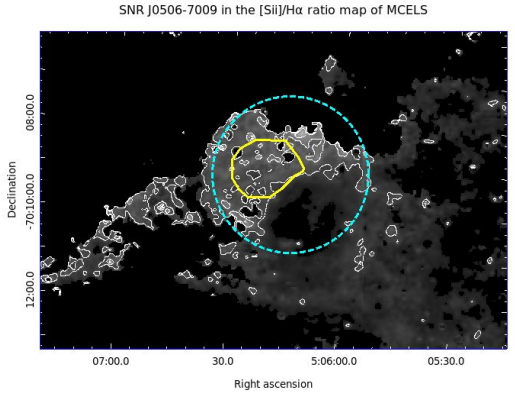
Peters et al. [2013]

Circular Remnant ⇒ Type Ia SN.

But,

there are counter-examples.





Peters et al. [2013]: Constraining Explosion Type of Young Supernova Remnants Using 24 μm Emission Morphology. July 2013. Doi: 10.1088/2041-8205/771/2/L38.

Typing the Explosion

O, Ne, Mg, Si...

- CC SNe: ⇧ alpha elements, ⇩Fe
- Type Ia: ⇩alpha elements, ⇧Fe

$$\frac{[O]/[Fe]}{[O]/[Fe]_{LMC}} \ll 1$$ ⇒ Type 1a progenitor — Maggi et al. 2016

- [O]/[Fe] = 0.3–0.7 for Type Ia events — Bozzetto et al. 2014

Maggi et al. [2016]: The population of x-ray supernova remnants in the large magellanic cloud. 2016. doi: 10.1051/0004-6361/201526932.

Bozzetto et al. [2014]: Multifrequency study of a new Fe-rich supernova remnant in the Large Magellanic Cloud, MCSNR J0508-6902. March 2014. Doi: 10.1093/mnras/stu051.

XMM-Newton

X-ray Multi-Mirror Mission by ESA
Launched on December 10, 1999.

Studies X-ray sources across the Universe

XMM-Newton has

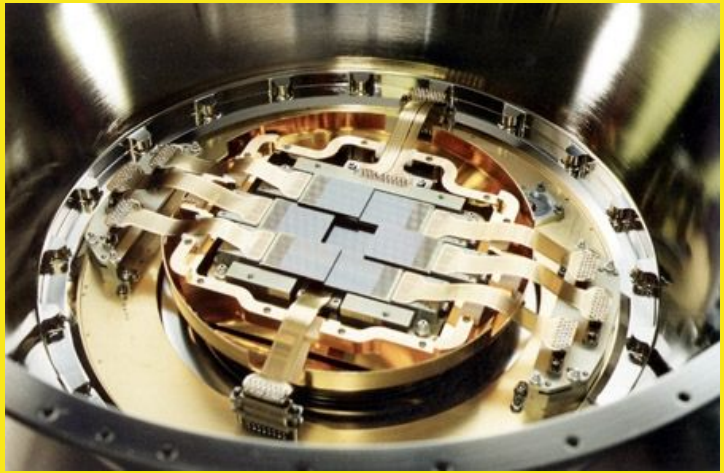
1. European Photon Imaging Camera (EPIC)

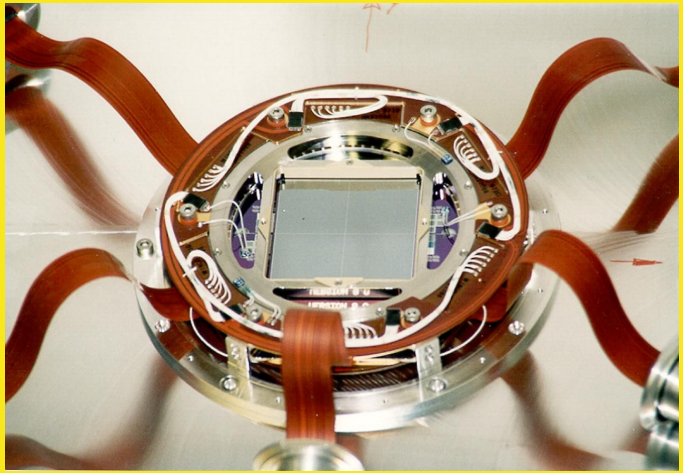
   3 CCD cameras for X-ray imaging

2. Reflection Grating Spectrometer (RGS)
3. Optical Monitor (OM)

Image courtesy of D.Ducros and ESA. Credit: ESA/XMM-Newton

mos and pn





Credit: ESA/XMM-Newton