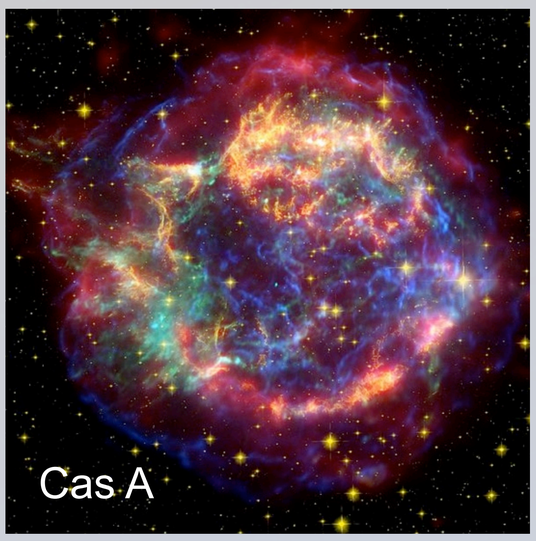
Metals in galaxy clusters, groups, and massive galaxies

François Mernier[1,2], *N. Werner, N. Truong, and the CHEERS collaboration*

1. MTA-Eötvös University Lendület Hot Universe Research Group; 2. SRON Netherlands Institute for Space Research

Core-collapse supernovae (SNcc)

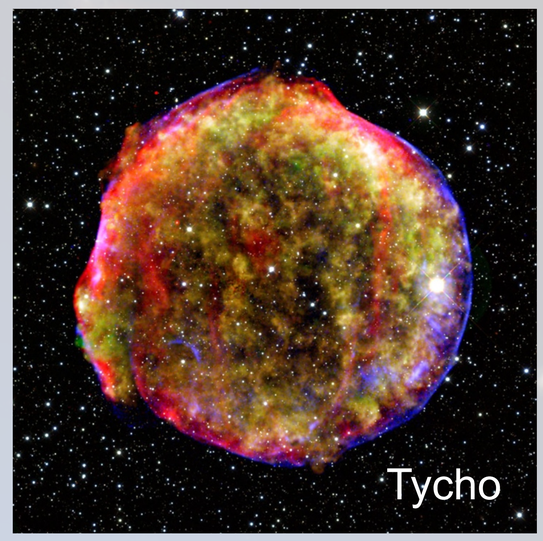


Since the emergence of the nucleosynthesis theories, it is well established that all the elements heavier than He have been produced by stars and stellar remnants[1]. In particular, **core-collapse supernovae** (SNcc) synthesise mostly O, Ne, Mg, and Si, while **Type Ia supernovae** (SNIa) synthesise mostly Si, S, Ar, Ca, Cr, Mn, Fe and Ni.

Since the major epoch of star formation ($z \sim 2$-3)[2], all these metals, produced by billions of SNcc and SNIa, easily escape from their galaxy hosts and enrich the hot, X-ray emitting **intracluster medium** (ICM, here in blue) pervading galaxy clusters, groups, and elliptical galaxies. Metals can then be probed in **X-ray spectra** via their K-shell and L-shell emission lines.

Measuring **chemical abundances** of these elements in the ICM provides us with invaluable clues on how and when the largest structures of the Universe got chemically enriched[3].

Type Ia supernovae (SNIa)



In this work, we use *XMM-Newton* observations to measure the **O**, **Ne**, **Mg**, **Si**, **S**, **Ar**, **Ca**, **Fe** and **Ni abundances** in the central ICM regions ($0.1\,r_{500}$) of 44 nearby cool-core galaxy clusters, groups, and ellipticals (the CHEERS sample).

These 4.5 Ms of net exposure, fitted with a recent major update of the spectral code SPEX (v3), allows us to:

(i) Measure and compare the overall **central metallicity** (traced by Fe) of these individual systems[4];

(ii) Measure the average abundance ratios (X/Fe) of our sample, hence revealing the **chemical composition** of the ICM[5].

(i) The recent SPEX update reveals that on average, clusters, groups and ellipticals have a **similar central metallicity**. For the first time, these observations agree quantitatively with simulations[6].

(ii) Remarkably, and as confirmed independently by *Hitomi*[7,8], the chemical composition of the ICM is **similar** to that of **our own Solar System**. This suggests that the "red-and-dead" stellar population of central dominant galaxies (presumably containing no SNcc) has little to do with metals found in the ICM.

While an early enrichment scenario was already favoured for cluster outskirts[9], **the central ICM may have also been enriched early on**, during or even before the formation of the dominant galaxy ($z > 1$).

References:

[1] Burbridge, E. M., Burbridge, G. R., Fowler, W. A., Hoyle, F., 1957, Rev. Mod. Phys., 29, 547

[2] Madau, P. & Dickinson, M., 2014, ARA&A, 52, 415

[3] Mernier, F., Biffi, V., Yamaguchi, H. et al., 2018c, Space Sci. Rev., 214, 129

[4] Mernier, F., de Plaa, J., Werner, N. et al., 2018a, MNRAS, 478, L116

[5] Mernier, F., Werner, N., de Plaa, J. et al., 2018b, MNRAS, 480, L95

[6] Truong, N., Rasia, E., Biffi, V. et al, 2019, MNRAS, 484, 2896

[7] Hitomi Collaboration, 2017, Nature, 551, 478

[8] Simionescu, A., Nakashima, S., Yamaguchi, H. et al., 2019, MNRAS, 483, 1701

[9] Werner, N., Urban, O., Simionescu, A., Allen, S. W., 2013, Nature, 502, 656

Acknowledgements:

This work is part of the CHEERS (CHEmical Enrichment Rgs Sample) collaboration. The authors thank its members for useful discussion. This work was supported by the Lendület LP2016-11 grant awarded by the Hungarian Academy of Sciences.