Live fast, die young: supernova remnants as autopsies of stellar explosions

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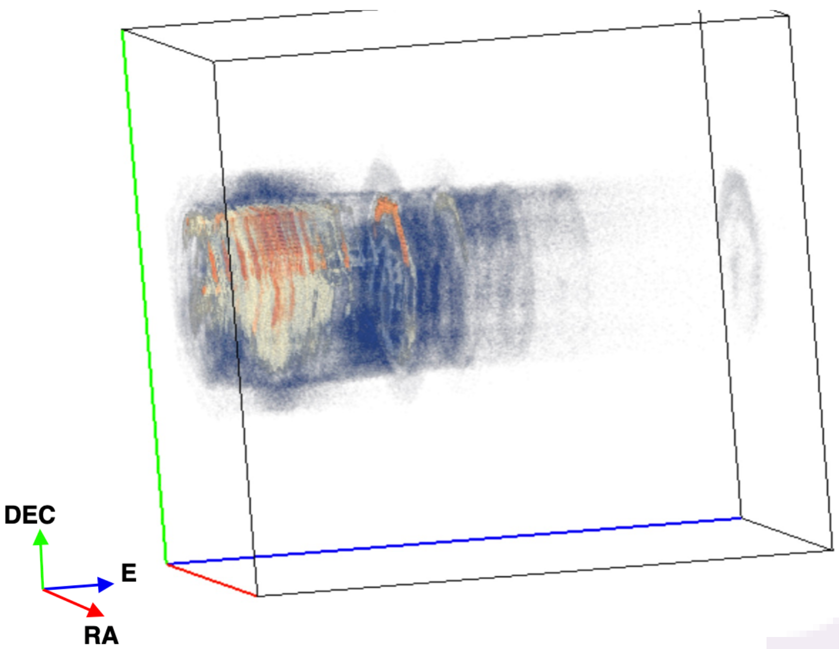

Simulation of an X-IFU observation of the historic Type Ia supernova described in 1604 by Johannes Kepler. The data cube (RA, Dec, Energy) shows the counts density in the 0.5-7 keV energy range (yellow and red hues illustrate a higher number of photon count per pixel). The visual impression of slices is due to the many atomic emission lines that X-IFU spectral resolution will allow to detect. Such observation will allow us to map the metallicity of the ejected material and perform a 3D (X, Y, Z) reconstruction of the explosion thanks to the Doppler effect.

Supernovae are among the most energetic events in the Universe. They are the main factory producing heavy elements from Oxygen to Rubidium in the Universe. The large amount of kinetic energy released in the explosion also creates a fast shock wave (~30 millions km/h) which is a major source of kinetic and thermal energy in galaxies.

Supernova remnants (SNRs) are the remains of these stellar explosions where the shock wave heats the circumstellar medium and the ejected material up to million-degree temperatures, therefore shining in the X-ray band. Studying SNRs with X-ray telescopes, therefore, provides a unique window to probe the mechanisms of stellar explosions, the nucleosynthesis yield, plasma physics in extreme conditions, and particle acceleration in shocks.

The high-resolution spectro-imaging capabilities offered by the *Athena*/X-IFU will allow us to tackle these key questions by mapping the gas temperature, velocity, ionisation state and abundances along different lines of sights in the remnant. Thanks to Doppler shift measurements, a 3D view of the plasma conditions and ejecta distribution can be reconstructed, which will provide unprecedented 3D observational constraints to compare with numerical simulations of stellar explosions.

Focusing on rare elements (e.g. Cr and Mn) with weak line emission, X-IFU will carry out accurate abundance measurements to provide direct insight into the metallicity of the supernova progenitor, and on the single or double degenerate origin in type Ia supernovae. For core-collapse, these measurements probe the exposure to intense neutrino radiation, a key ingredient in the explosion mechanism. In the study of shock physics, the plasma in SNRs is usually out of ionisation and temperature equilibrium. While the ionisation equilibrium has been partially studied with current generation telescopes, the temperature equilibrium can only be studied with high spectral and spatial resolution telescopes such as X-IFU, near the border of the remnant. Measuring the thermal line broadening directly determines the ion temperature, which allows us to estimate the fraction of kinetic energy injected into particle acceleration.