Diagnostics to trace shocked ejecta in SN 1987A with XRISM - Resolve

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SN 1987A

Distance (kpc)	Age (yrs)	Physical origin
51.4	36	core collapse SN

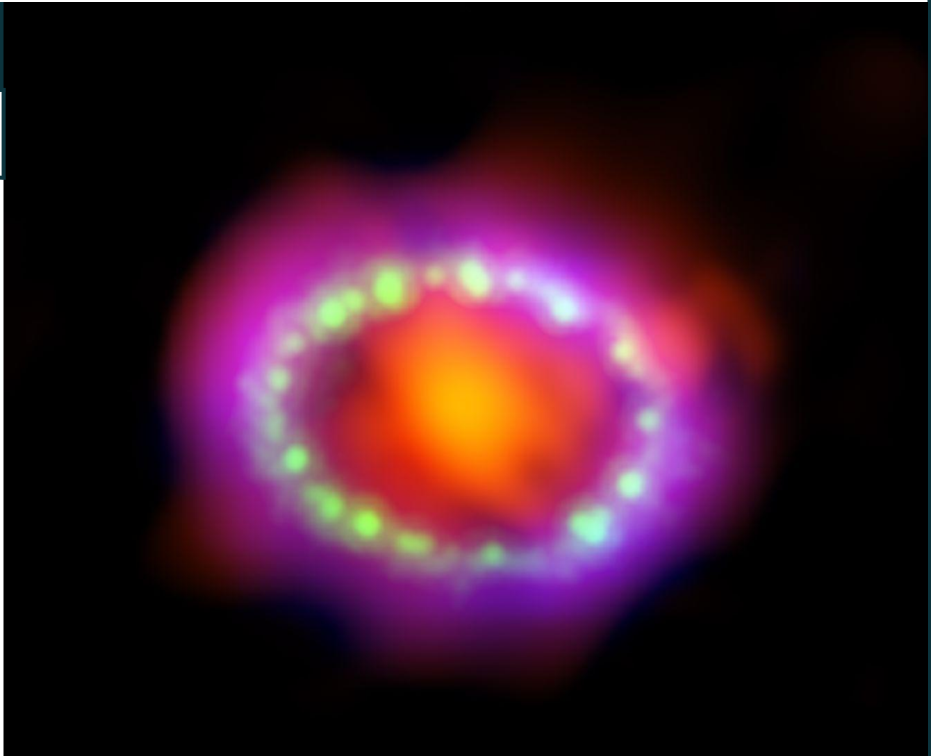
Interacting with complex circumstellar medium:

- Dense and clumpy Equatorial Ring
- Diffuse hourglass-like H II region

CSM dominated the X-ray emission in the past

But

Fast moving outer ejecta started to be shocked



SN1987A, Image credit: Radio (ALMA, red); Optical (HST, green) X-ray (Chandra, blue)

Hybrid approach: data and models

Chandra HETG data of SN 1987A

+

3D HD model from Orlando et al. 2015 which self-consistently reproduce:

- Bulk motion Doppler broadening
- Thermal Doppler broadening

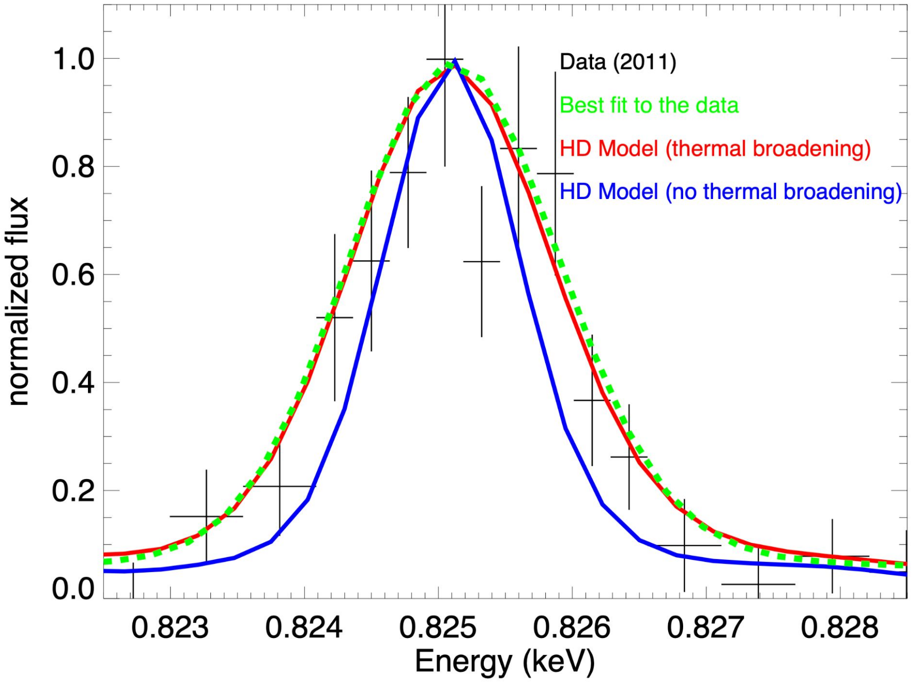
=

They measured the Ions temperature

N.B.: Study conducted when the ring dominated the emission

In next epochs we expect more ejecta emission

Can we disentangle ejecta and CSM?



Miceli et al. (2019): Chandra data and models derived from the HD simulation of the Fe XVII emission line

Tracing ejecta signatures with XRISM

XRISM mission launched 06/09/2023

Resolve spectrometer High-resolution Spectroscopy

It will observe SN 1987A during the PV phase

Adopting a similar approach of Miceli et al. (2019)

Credit: JAXA

AIM:

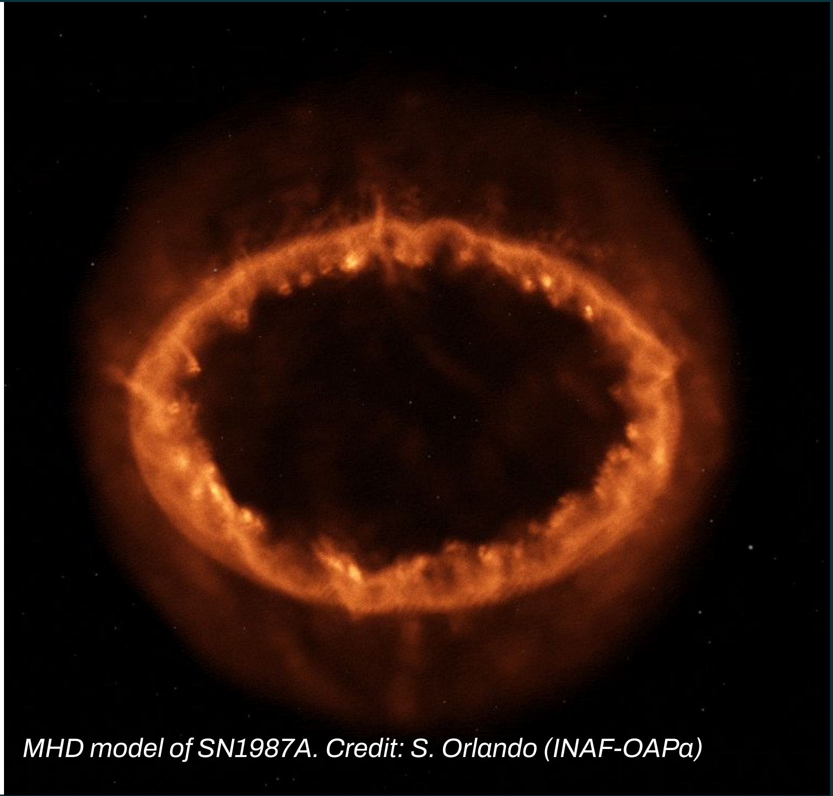
Synthesize the XRISM - Resolve spectrum of SN1987A to find a new diagnostic to trace ejecta signature

The MHD model *(Orlando et al. 2020)*

From the SN explosion (Ono et al. 2020) to the SNR

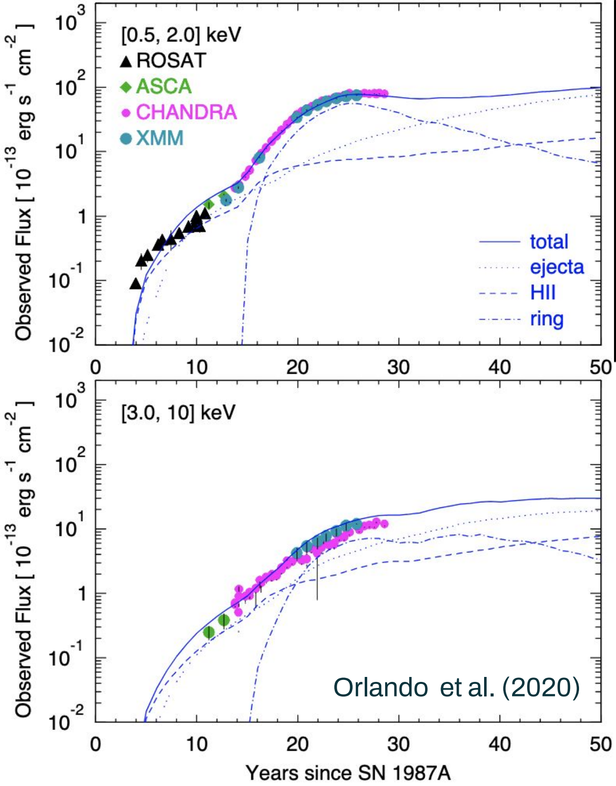
Progenitor star: 18.3 $M_\odot$ Blue supergiant

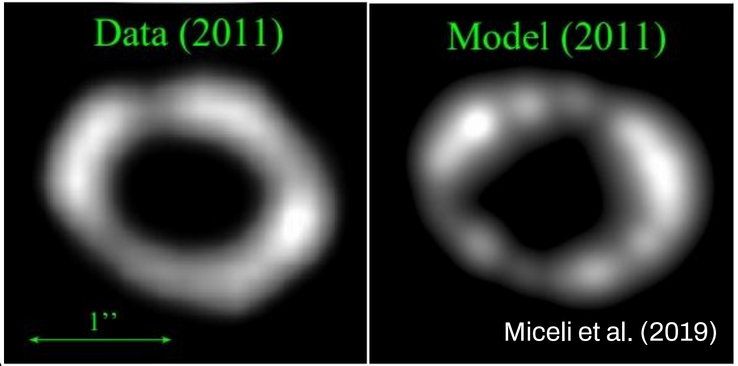
Merging of two massive stars (14 $M_\odot$ and 9 $M_\odot$)

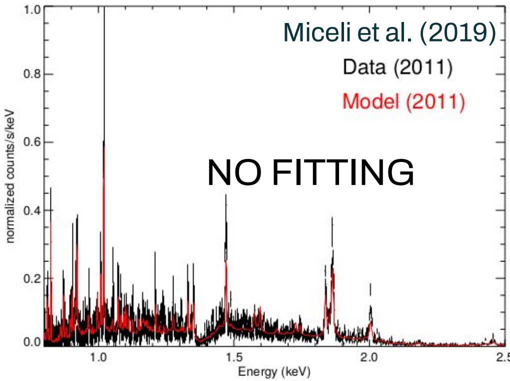


MHD model of SN1987A. Credit: S. Orlando (INAF-OAPa)

Model vs. Data





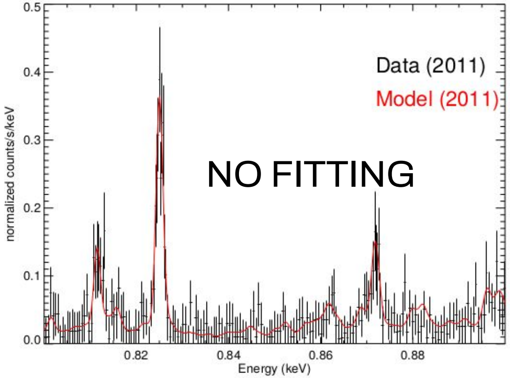


Reproduces size and morphology

Able to describe X-ray observations

Accurate description of:

- X-ray evolution
- X-ray emitting Plasma
- Plasma ionization state



Synthesis procedure

In-house developed tool to synthesize the X-ray

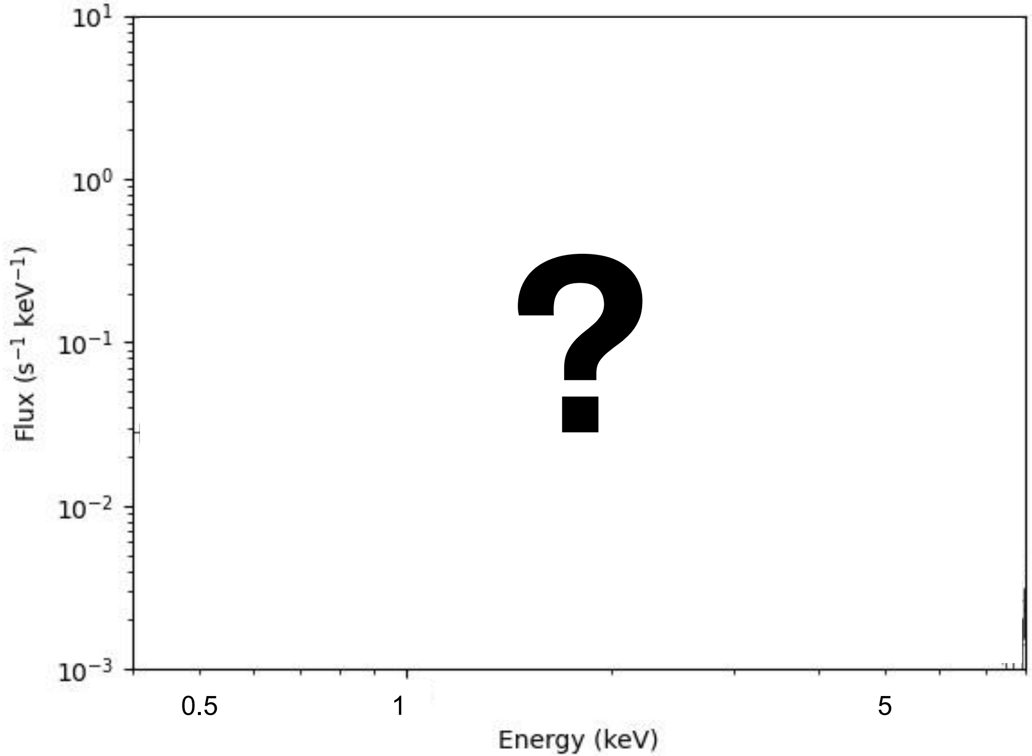
In each cell we calculate kT, $n_e t$, n_e

Input to a *vnei* model absorbed by a *tbabs* ($n_H = 0.235 \times 10^{22}$ cm^{-2})

Only shocked ejecta from the outer mantle

Abundances fixed to Zhekov et al. (2009)

But see Larsson’s Talk



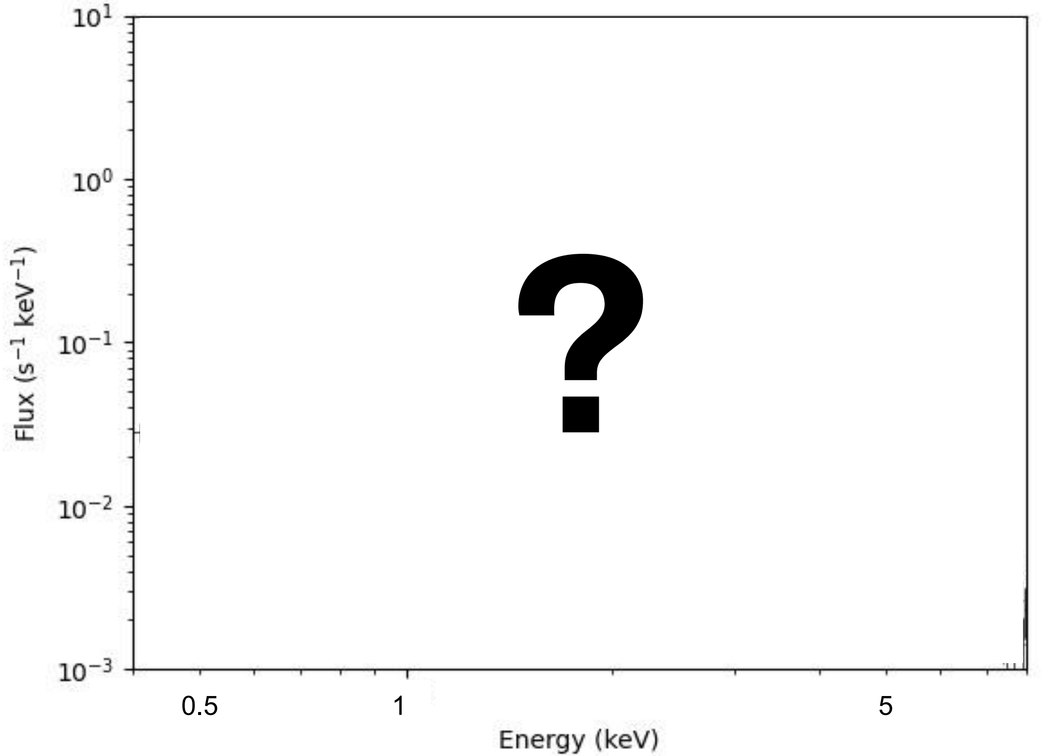
Synthesis procedure

Folded through the response matrix (*resolve_h7ev_2019a.rmf)* 7eV res.

Summed cell by cell

Ability to distinguish the emission from:
- Ejecta
- CSM (Ring and HII region)

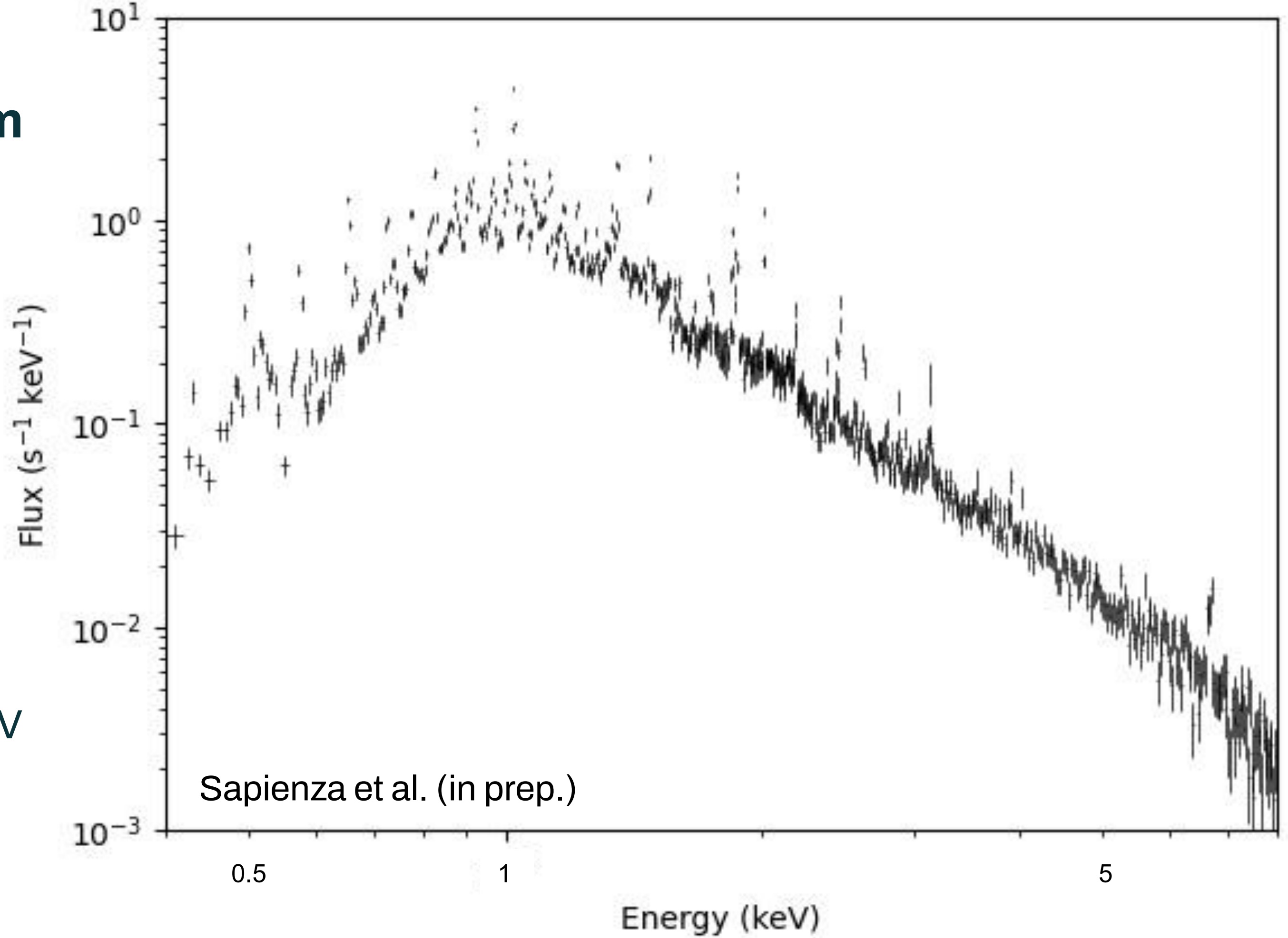
Ability to add line broadening:
- Bulk motion velocity
- thermal motion from the ions



Synthetic spectrum of SN1987A

Simulation with:

- no lines broadening
- 100 ks exposure (PV phase time)



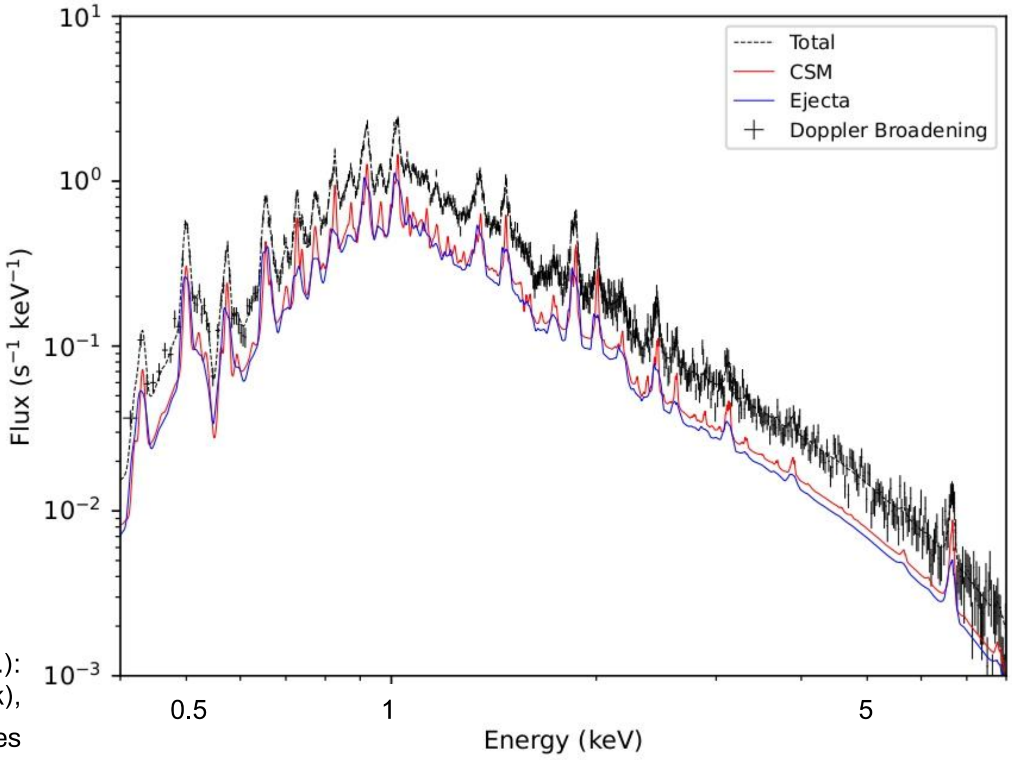
Applying the bulk motion broadening

This effect largely broadens the emission lines

complex profile and line blending

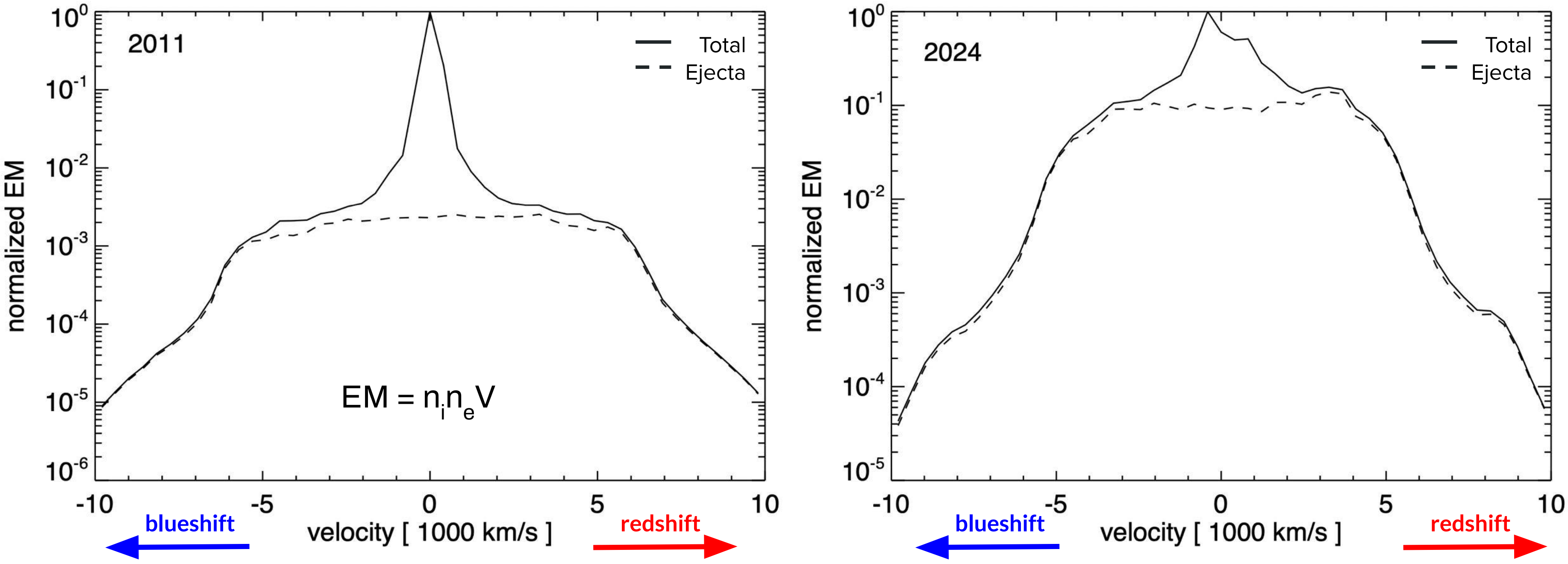
Ejecta (Blue line) emission comparable to CSM (Red line)

Major contribution to the broadening comes from the ejecta



Sapienza et al. (in prep.):
SN 1987A spectrum with Bulk motion broadening with total (black), ejecta(blue) and CSM(red) spectral models superimposes

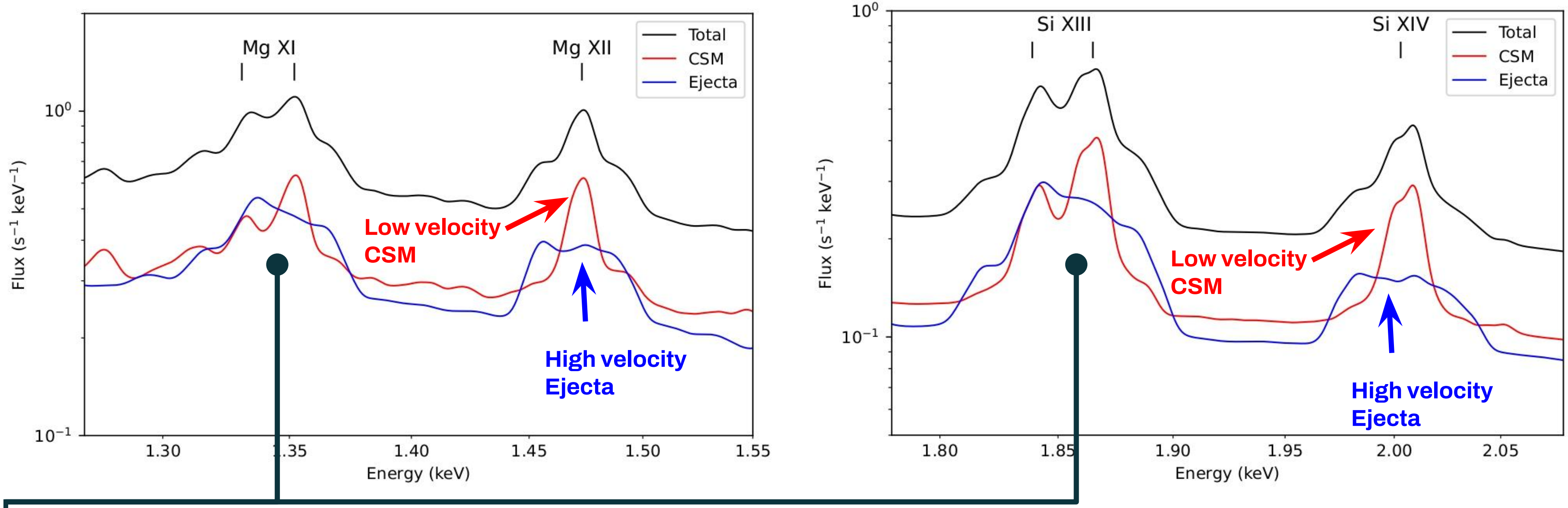
Comparison between epochs



Sapienza et al. (in prep.): Normalized Emission Measure (EM) distribution as a function of the velocity along the line of sight for the 2011 (left panel) and 2024 (right panel).

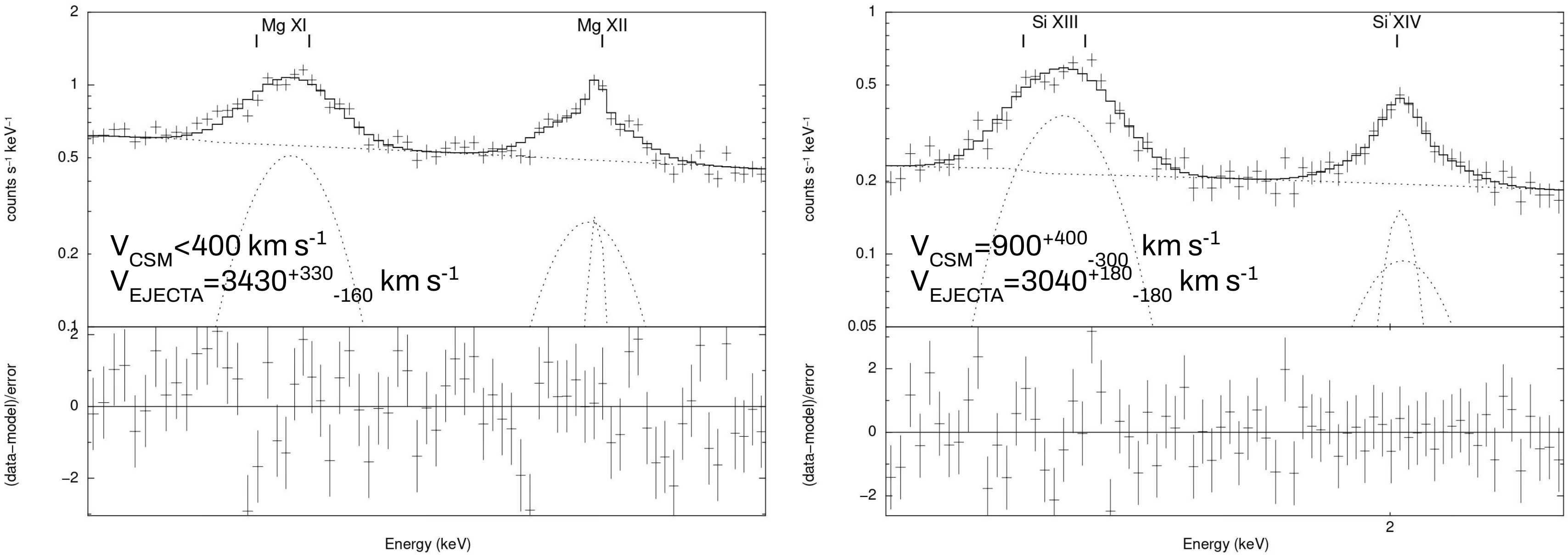
Examining the lines profile

Sapienza et al. (in prep.): Close-up view of in the 1.27-1.55 keV band (left) and 1.78-2.08 keV band (right).



Heavy under-ionized ejecta = Higher contribution to the X-ray emission in He-like lines

A diagnostic to retrieve ejecta dynamics



Sapienza et al. (in prep.): Close-up views of the synthetic XRISM - Resolve spectrum in 1.27-1.55 keV band (left) and 1.78-2.08 keV band (right), with the corresponding best-fit model and residual.

Synthesis of XRISM observation of SN 1987A

The synthetic spectrum show largely broadened lines due to plasma bulk motion

Measurement of the broadening will provide direct evidence for shocked ejecta expansion

We demonstrated that we can provide direct evidence for shocked ejecta

disentangling:

- Peaked CSM emission (low velocity)
- Ejecta broad emission (high velocity)

Line Broadening: Ions Temperature

Optically thin plasma in Non equilibrium of Ionization

The heating process is collisionless $l_{sh} \ll \lambda_{coulomb}$

Temperature of the ions $\propto$ Mass of the ions

Thermal motion of Ions results in a Doppler broadening

The width of the emission line $\propto T^{1/2}$

Line Broadening: Plasma Bulk Motion

Shocked plasma moves with high velocity in every direction

Redshift if it moves away from us

+

Blueshift if it moves towards us

=

Doppler Broadening effect

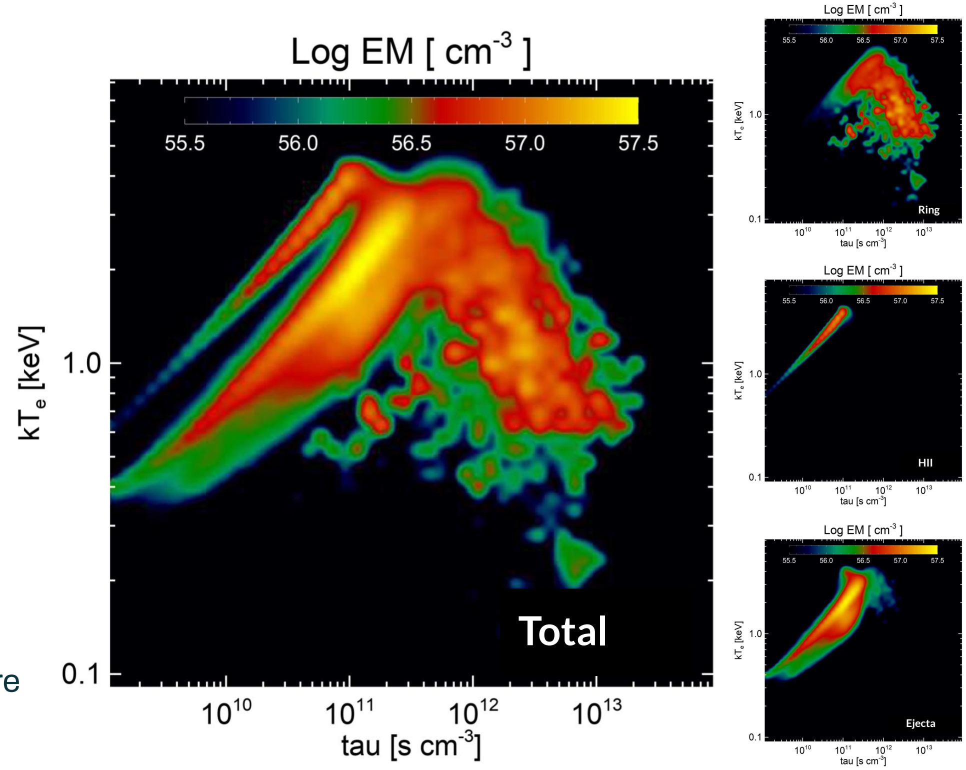
Contribution to X-ray emission

Contribution from the ejecta increased

Comparable to the EM of the ring

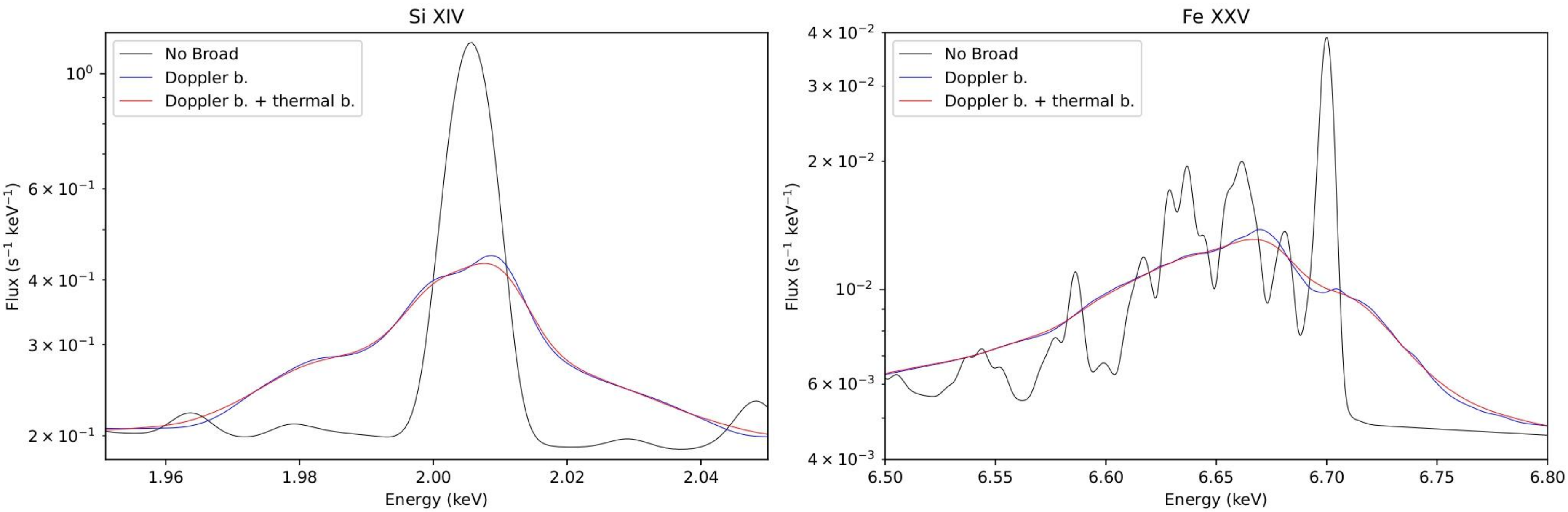
CSM emission dominated by the ring

The ring has on average higher $n_e t$



Sapienza et al. (in prep.): Distribution of the emission measure as a function of the temperature *kT* and the ionization parameter $n_e t$ (τ) for the year 2024

Adding the thermal broadening



Sapienza et al. (in prep.): Comparison between the spectral models with No broadening (black), Bulk motion (Blue) and bulk motion plus thermal (red), for the Si XIV and Fe XXV lines.