Measure of the initial mass of ^{44}Ti in SN 1987A through the ^{44}Sc emission line

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1. INTRODUCTION

Supernova explosions are important sources to study the chemical evolution of the Universe. The supernova ejecta carry information on the explosive nucleosynthesis processes, and elements synthesized in the inner layers of core-collapse supernvoae can "keep memory" of the physical mechanisms governing the explosion. Important issues can be addressed by studying the radioactive emission of the ^{56}Ni and ^{44}Ti isotopes, which are synthesized in the central part of the exploding star. In particular the ^{44}Ti can be studied through its products decays, such as ^{44}Sc and its emission line at 4.09 keV. We here detect a significant level of ^{44}Sc emission line in the central part of SN 1987A through multi-epoch *Chandra* data analysis.

Previous works based on the ^{44}Ti emission lines (67.87 keV and 78.32 keV) in SN1987A found **different values**

- ○ Boggs et al 2015 - *NuSTAR* results: $M_{44} = (1.5 \pm 0.3) \times 10^{-4} M_\odot$
- ○ Grebenev et al. 2012 - *INTEGRAL* results: $M_{44} = (3.1 \pm 1.8) \times 10^{-4} M_\odot$

→

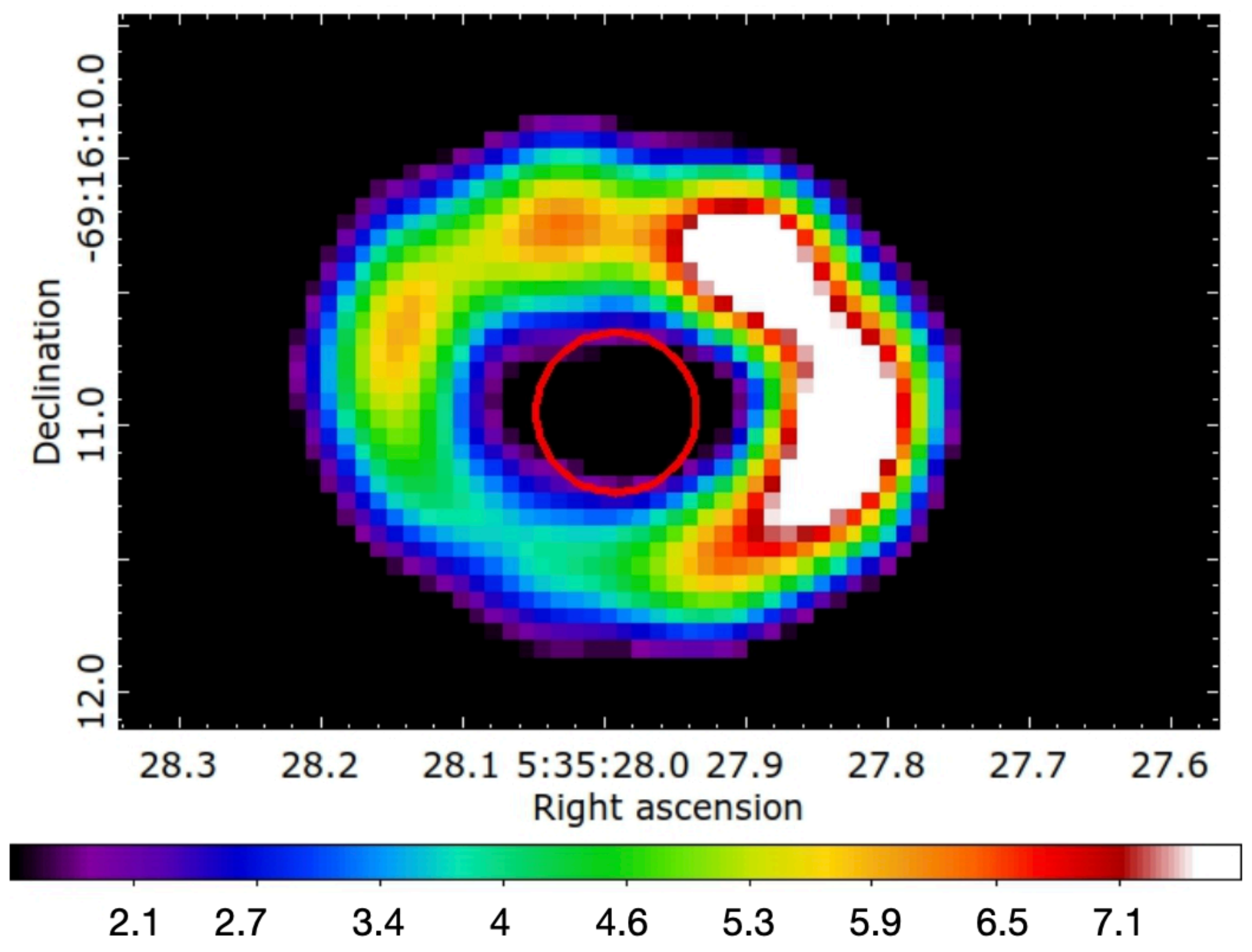
***NuSTAR* (Boggs et al. 2015)**

Anisotropy in the inner ejecta: redshift of ~ 0.23 keV in the ^{44}Ti X-ray emission lines at 67.87 keV corresponding to 700 km/s (in the rest frame of SN 1987A).

Eq. 1: $$F_i = \frac{M_{44} W_i}{4\pi d^2 44 m_p t_{44}} e^{-t/t_{44}}$$

F_i = flux of the radioactive emission line
M_{44} = initial mass of ^{44}Ti
W_i = emission eff. (17.4% for the line at 4.09 keV)
t_{44} = 85 yr
d = 51.4 ppc

2. DATA ANALYSIS



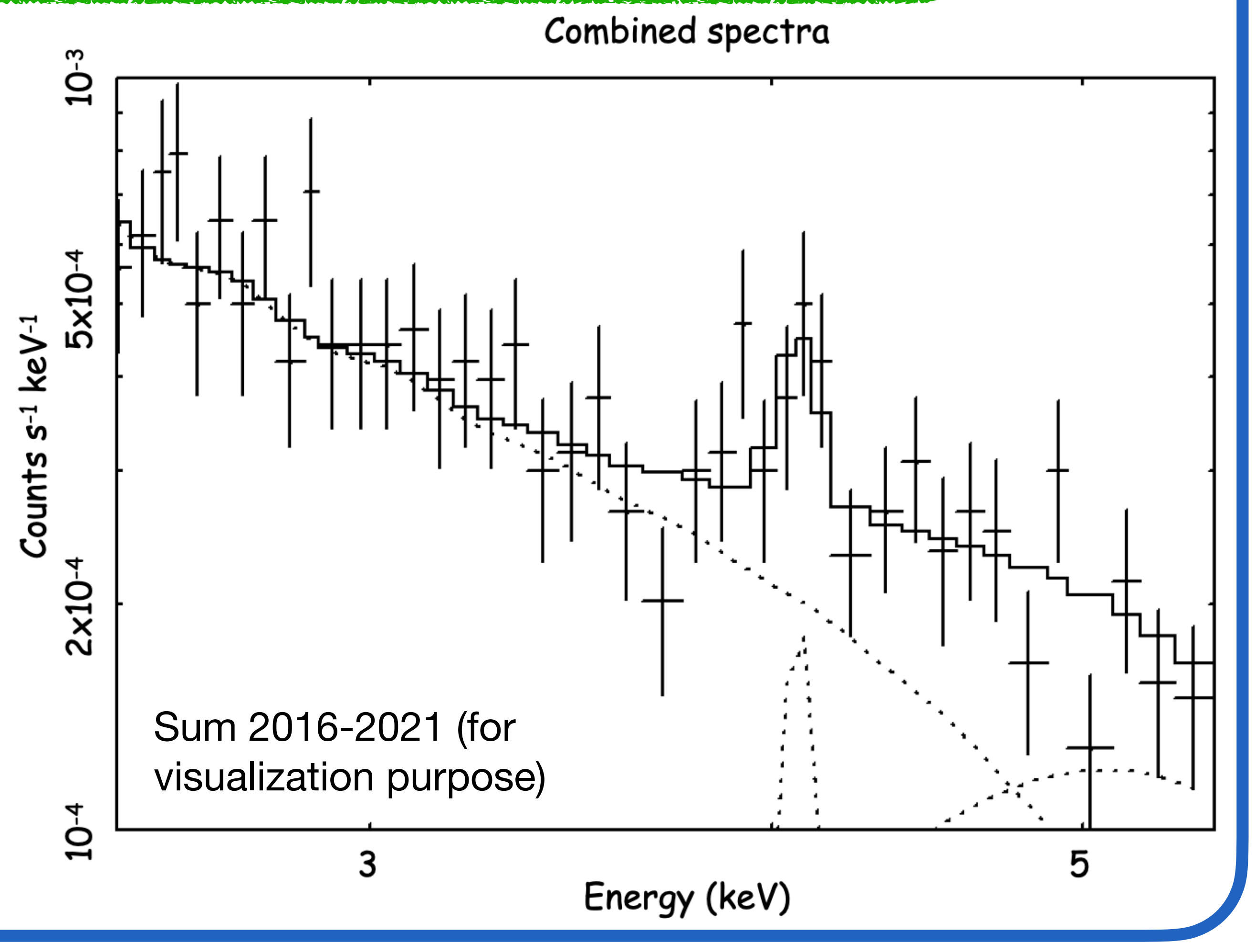
Multi-epoch (from 2000 to 2021) spectral analysis on a circular region located at the center of the remnant with radius 0.3'' (red circle in Figure) to minimize the contamination from the X-ray emission stemming from the shocked plasma.

*Model = Tbabs(vphabs*pow + vnei + gauss)*

Tbabs = 2.35 x 10^{21} cm^{-2} (Park et al. 2006)
Pow - (Greco et al. 2022)
Vphabs and vnei - Greco et al. 2022, Zhekov et al. 2009
Gauss: centered according with the redshift of ^{44}Ti

To improve the statistics we simultaneously fitted spectra from multiple observations.

- 2000-2004
- 2005-2009
- 2010-2015
- 2016-2021

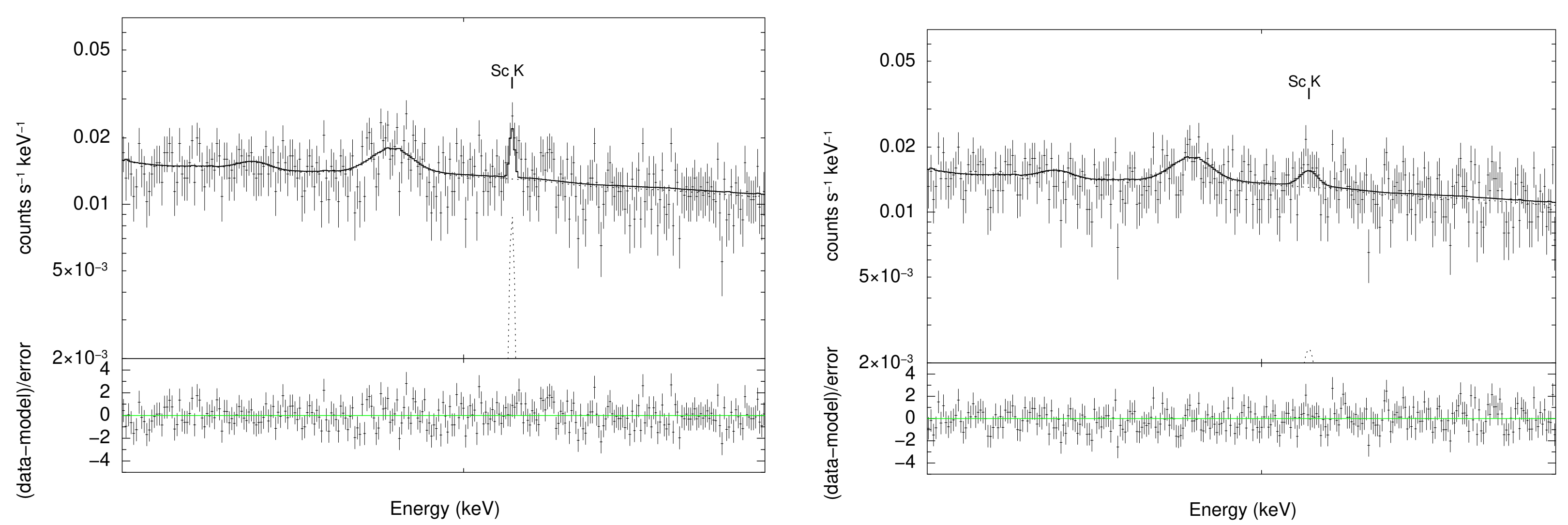


Sum 2016-2021 (for visualization purpose)

4. FUTURE PERSPECTIVES

Detection of the ^{44}Sc with 500 ks **XRISM**.
SN1987A will not be spatially resolved but the high spectral resolution will help in making the line visible. Spectra synthesized from Sapienza et al. (2024) adding the ^{44}Sc gaussian line.

Synthetic spectra



3. RESULTS AND CONCLUSIONS

Table 1. ^{44}Sc line flux for each data set. Error bars are at 68% significance level.

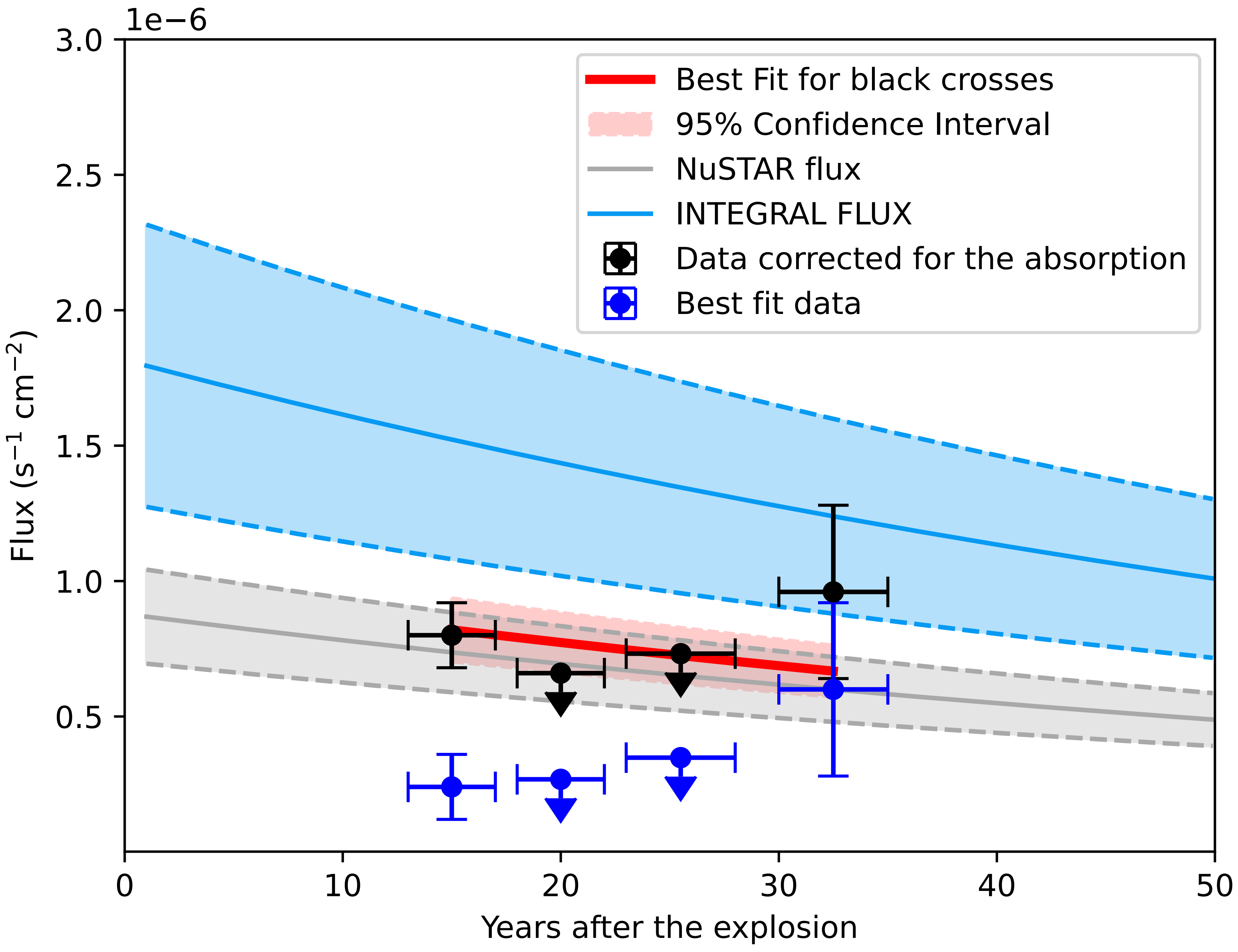
Group	^{44}Sc flux (s^{-1} cm^{-2})	Significance
1 (2000-2004)	$(2.4 \pm 1.2) \times 10^{-7}$	95.5%
2 (2005-2009)	$< 2.7 \times 10^{-7}$	< 68%
3 (2010-2015)	$< 3.5 \times 10^{-7}$	< 68%
3 (2016-2021)	$(6 \pm 3) \times 10^{-7}$	95.5%

Lowest contamination from the thermal X-ray emission → 1 (2000-2004)

Lowest absorption from the cold ejecta → 3 (2016-2021)

Absorption effects

Cold ejecta partially absorb the ^{44}Sc emission line, especially for moving away regions, as for the ^{44}Ti (Boggs et al. 2015).



MHD simulation by Orlando et al. 2020 and Ono et al. 2020 were used to model the absorption from cold ejecta between bulk ^{44}Ti and the observer.
We consider the absorption to originate in the computational cells where the Ti abundance is < 20% of its maximum. Model-dependent approach.

Red curve in Figure: fit with the exponential trend (see Eq. 1)
Results in remarkable agreement with *NuSTAR* robservations.

2016 - 2021: emission less contaminated by the absorption.
$M_{44} = (1.54 \pm 0.7) \times 10^{-4} M_\odot$