X-raying winds in distant QSOs: the case of the Einstein Cross

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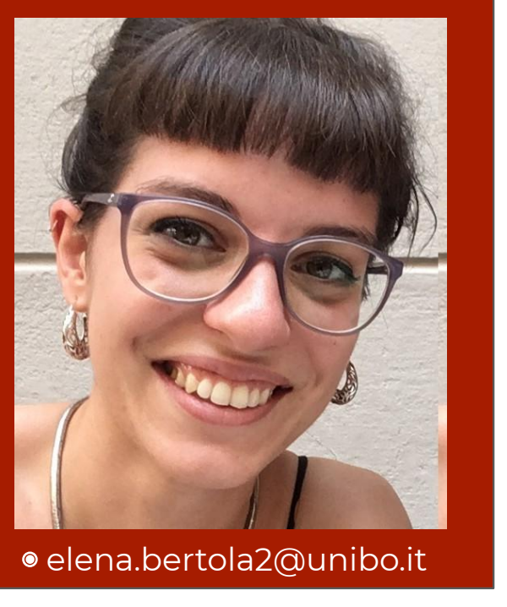

ABSTRACT

The characterization of AGN feedback is still an open issue. Theories and simulations indicate that AGN-galaxy co-evolution and feedback processes could be established through the generation of gas outflows. These arise from the innermost regions as powerful winds at sub-pc scales, visible in the X-ray band. We present the results from a systematic analysis of all the available *Chandra* and XMM-*Newton* data (as of September 2019) for Q2237+030, the Einstein Cross, a radio-quiet quasar at z_Q=1.695, quadruply-imaged by a spiral galaxy at z_L=0.0395. We detect, for the first time in this object, a fast X-ray wind outflowing at v_{out}~0.1c, which seems to be powerful enough to significantly affect the host galaxy evolution ($\dot{E}_{kin} \simeq 9\% L_{bol}$). Given the absorption features detected throughout the data, we report also on the possible presence of a faster component of the wind (v_{out}~0.5c). Evidence for outflows is found in ten spectra out of the sixteen analyzed, which allows us to give a rough estimate of the wind duty cycle as ≳ 60%.

Chandra data

***Chandra* sample:** **37 observations** spanning in total over 18 years (≃ 6.7 yrs in the source rest frame).

The **individual images** are **spatially resolved** (Fig. 1), allowing us to carry out a spatially and timing resolved spectral analysis.

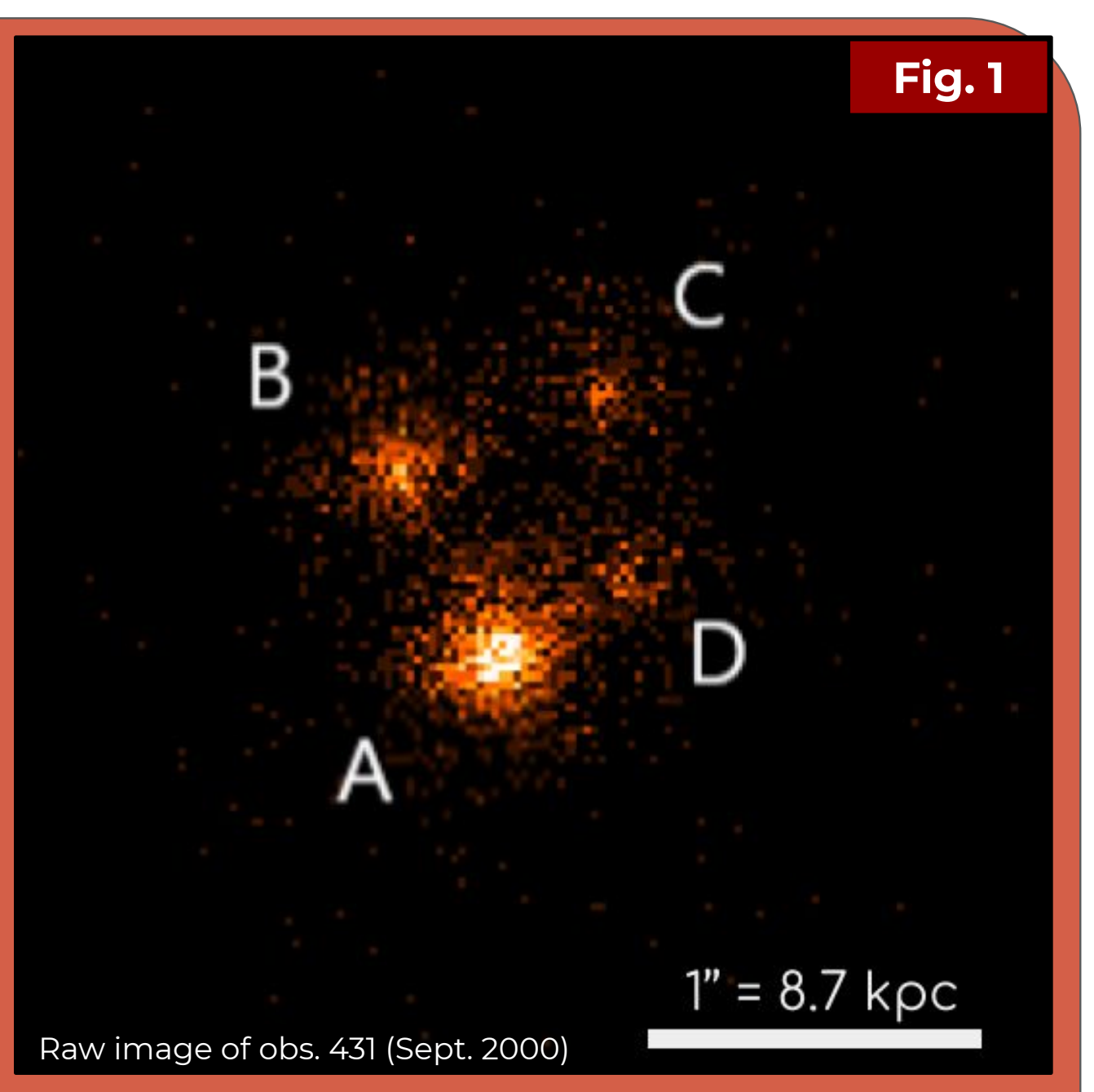

Fig. 1

Raw image of obs. 431 (Sept. 2000)

- **Individual-image spectral variability** (0.4 – 7.0 keV observed-energy band) **probed via photon-index evolution through** the various **epochs** (Fig. 2)
  - Photon-index evaluated by modeling the data with a single power-law absorbed by our Galaxy (N_H=5.06 x 10^{20} cm^{-2}; Kalberla et al, 2005).
- **The spectral shape shows significant variations** (>99% confidence) **through time that are consistent with each other among the four images**, in agreement with Chen et al. (2012).

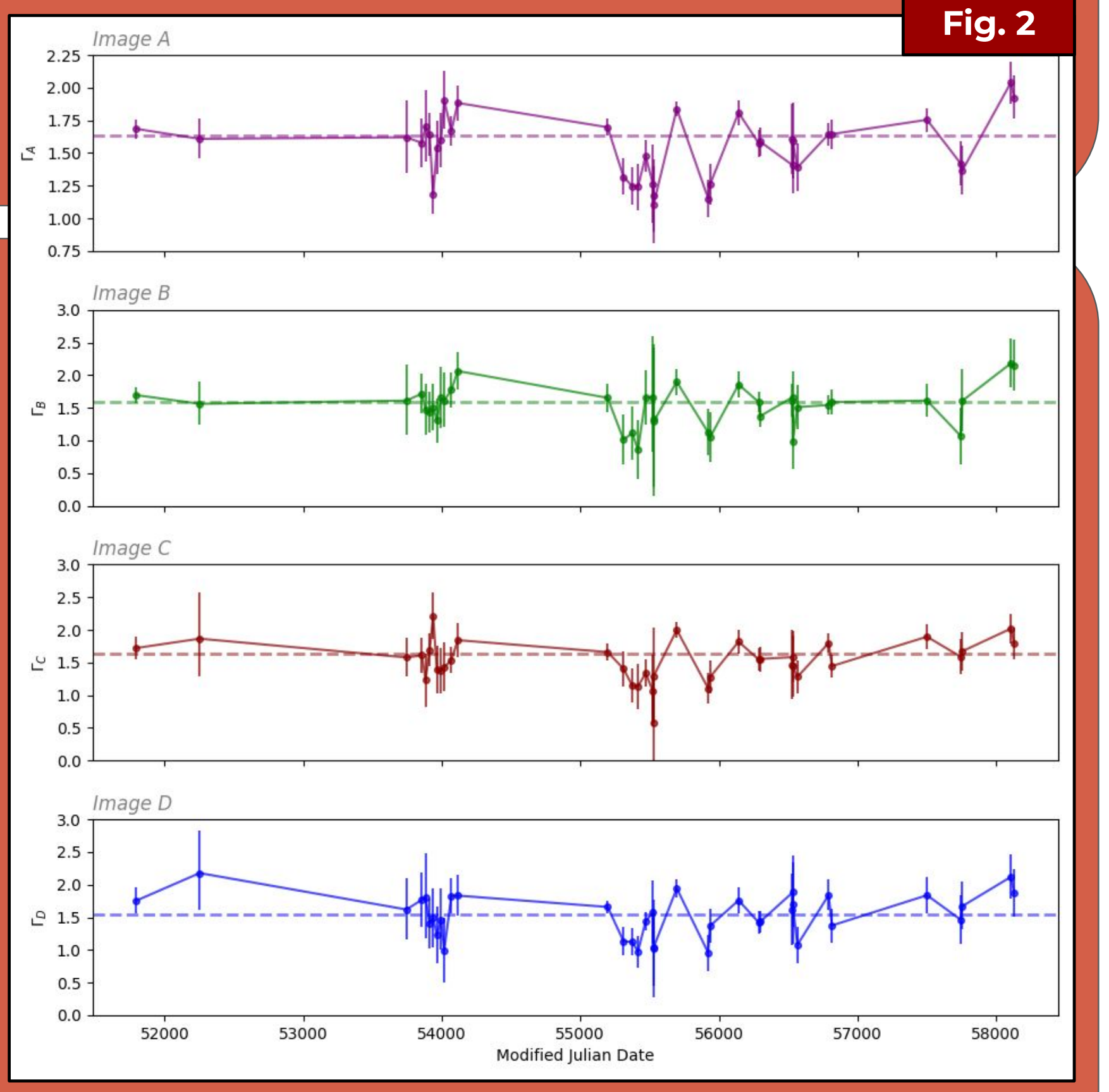

Fig. 2

High-statistics sample (HSS): fourteen spectra showing more than 500 counts in the 0.4 – 7.0 keV observed-energy range

- Grouped to obtain at least 20 cts per bin
- **Probe the presence of a cold absorber** intercepting the line of sight at the quasar redshift
  - Only four spectra actually require this component
    - Column density: $N_H \simeq 1 - 3$ x 10^{22} cm^{-2}
    - Minimum time variability: ≃ 0.3 yrs
- Thus, **photon-index variability likely ascribed to a variable absorber**.
- Blind search for **narrow absorption/emission features** applying the tool developed by Tombesi et al. (2010).
- **Significance** of each line evaluated through the **addition of a Gaussian component** to the model; Fig. 3 and 4 show the 1.6σ confidence contours of those lines detected at more than 90% confidence (those in blue at more than 99% confidence).

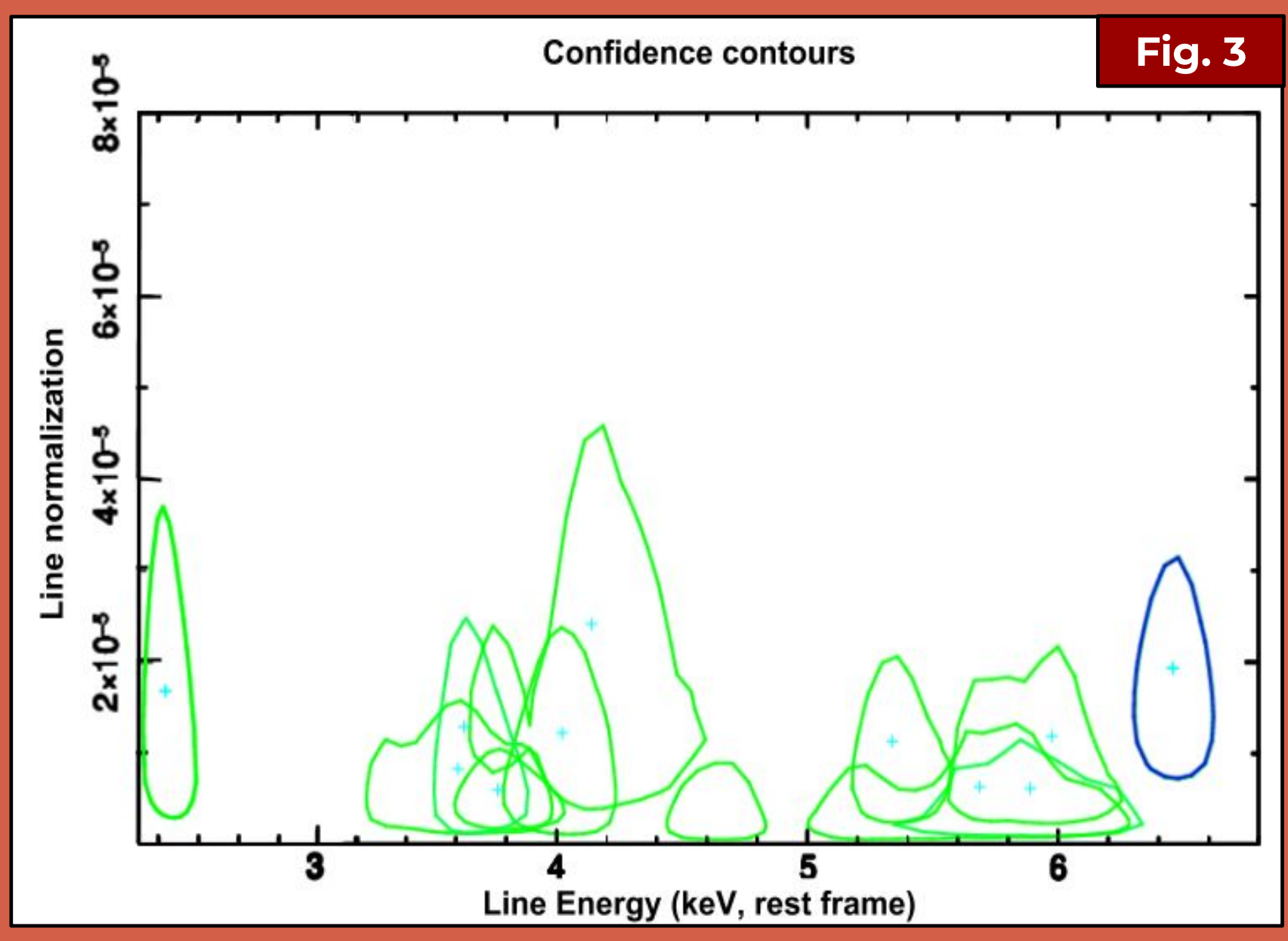

Fig. 3

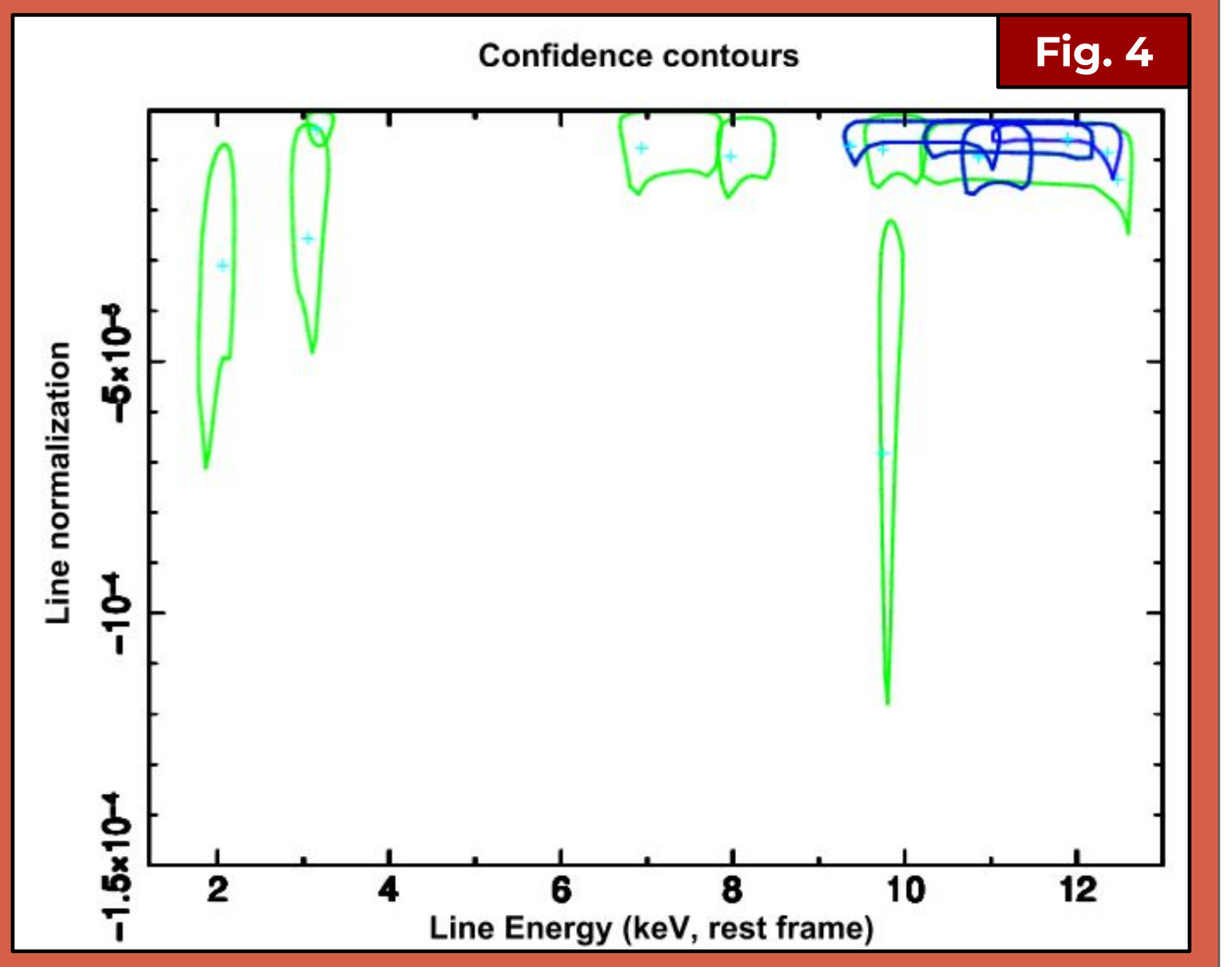

Fig. 4

- Following Protassov et al. (2002), the actual significance of the **absorption lines at E_{rest}> 6.0 keV** was evaluated through **Monte Carlo simulations** (1000 steps)
  - **Nine spectra** out of the HSS show an **absorption line detection above 6.0 keV at more than 90% confidence**.
  - The probability of obtaining this result by chance is $p = 1.2 \cdot 10^{-6}$, yielding an **overall significance** of the detection of such absorption features in the Fe resonant lines range that is **higher than 4σ**.

XMM-Newton data

XMM-*Newton* sample:

1. May **2002**, exp. 42.87 ks (Fedorova et al., 2008)
2. November **2016**, exp. 24.90 ks
3. May **2018**, exp. 141.69ks Proprietary - PI: M. Dadina

The first two observations (2002, 2016) are highly affected by soft-p^+ flares, which made the latter useless in terms of spectral analysis. Hence, we **focus on** analysing the **data** from **2002** and **2018**. Both spectra are grouped at more than 20 counts per bin, with minimum energy width set to 1/3 of the energy resolution of the instrument.

XMM-Newton data are needed to better investigate what originates the source spectral variability, thanks to the higher-statistics spectra it provides.

XMM 2002

Figure 5 shows the observed-frame residuals obtained using a single power law plus Galactic absorption model.

- **Two significant narrow absorption lines**
  i) $E_{rest} \simeq$ 7.4 keV   ii) $E_{rest} \simeq$ 11.8 keV
- Hints of emission line at $E_{rest} \simeq$ 5.9 keV
  - Consistent with Dai et al. (2003), possible micro-lensed Kα

XMM 2002 data are best reproduced by a **rather thick, highly ionized absorber, outflowing at v~0.1c.** The wind is **consistent with the absorption line at ~7.4 keV**, but fails to explain the one at ~11.8 keV.

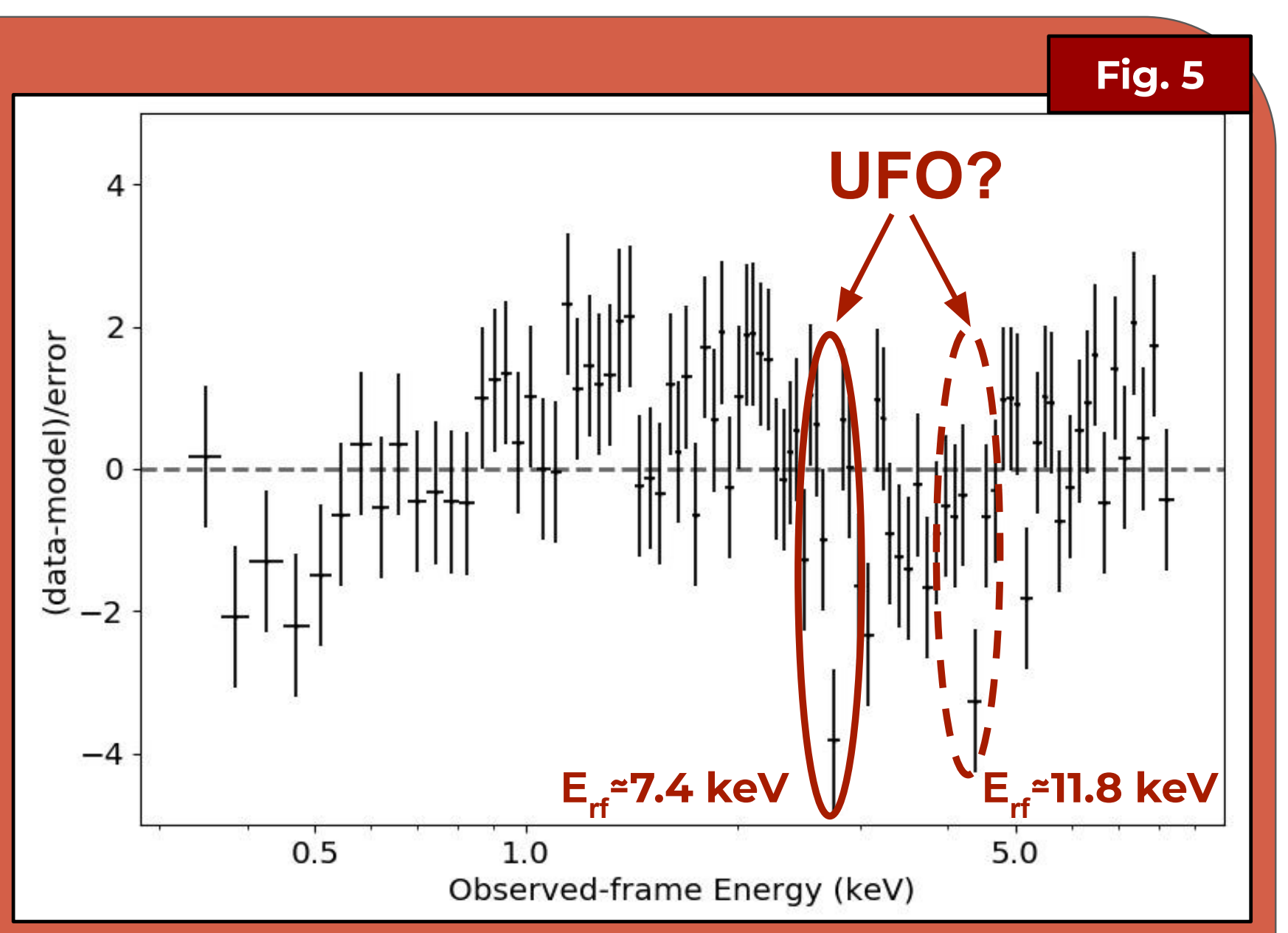

Fig. 5

Wind parameters

- $N_H = (2.1 \pm 0.5) \cdot 10^{23}$ cm^{-2}
- $\log(\xi/\mathrm{erg\ s^{-1}\ cm}) = 3.0 \pm 0.1$
- $E_{rest} = 7.4 \pm 0.1$ keV (Fe XXV)
- $v_{out} = (0.10 \pm 0.01)c$
- $L_{bol} \approx 1.4 \cdot 10^{46}$ erg s^{-1} (from $L_{1450Å}$)
- $\dot{M}_{out} \approx 4\ M_\odot\ yr^{-1}$
- $\dot{E}_{kin} \approx 1.2 \cdot 10^{45}$ erg s^{-1} $\hookrightarrow \dot{E}_{kin} \approx 9\% L_{bol}$

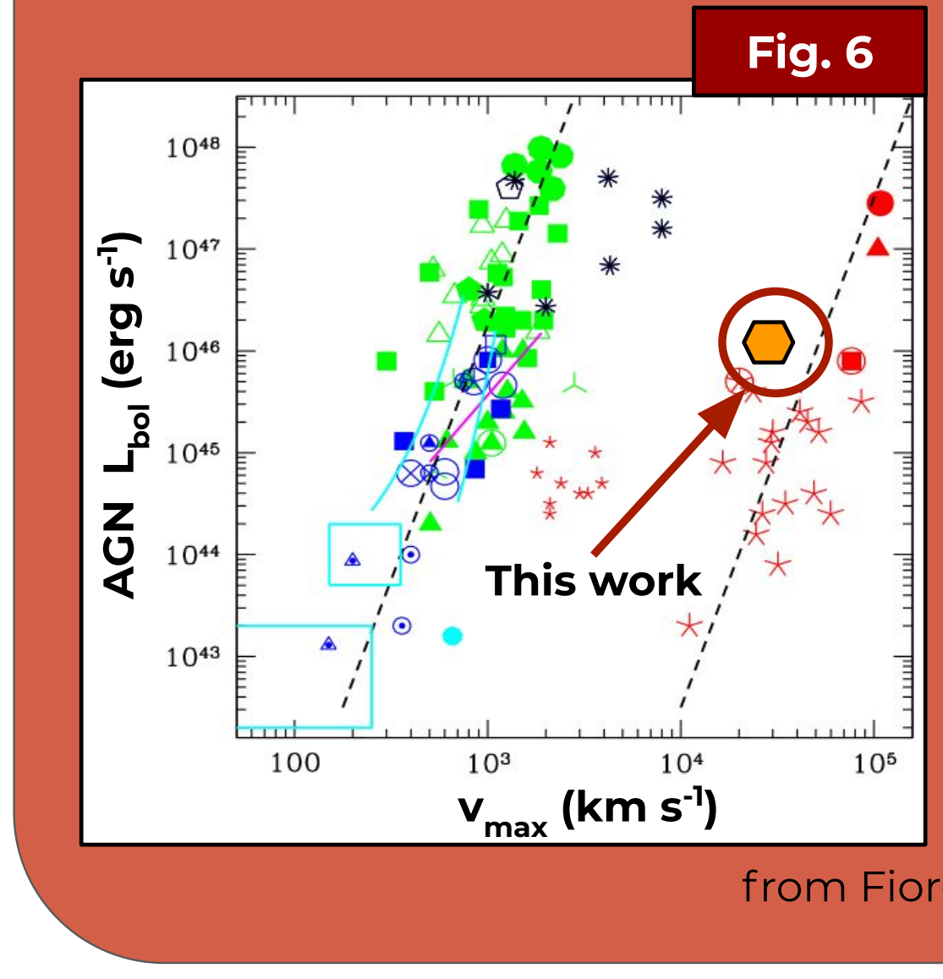

Fig. 6

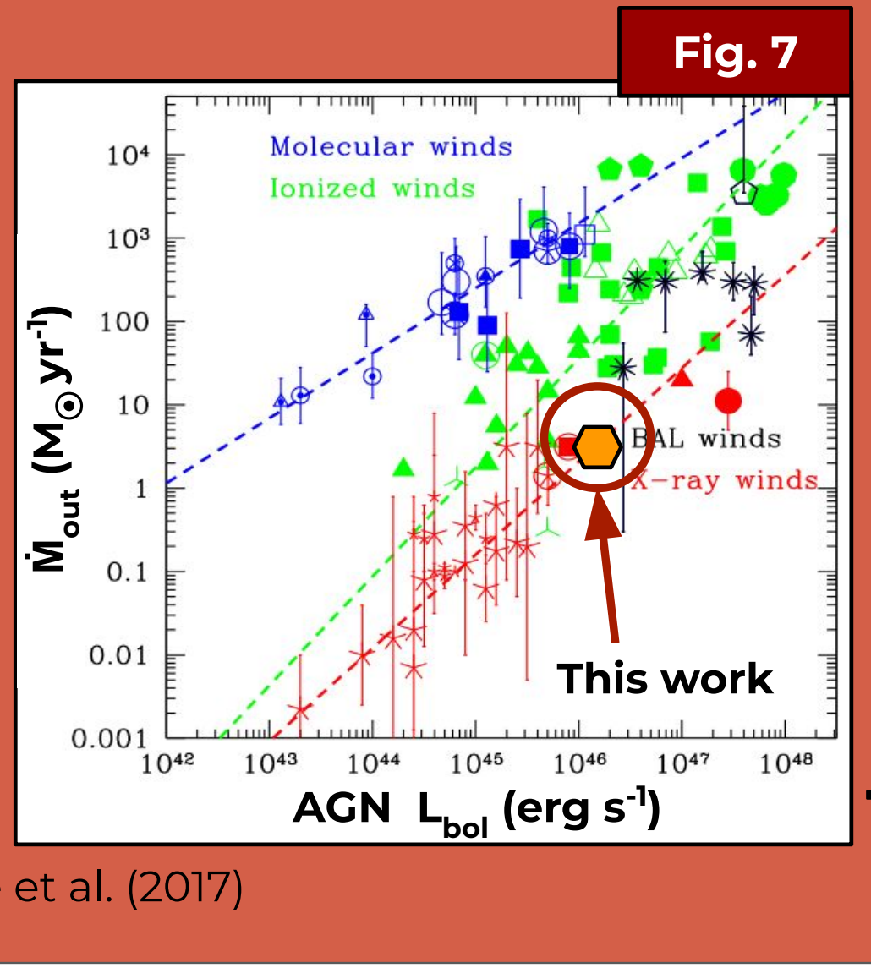

Fig. 7

from Fiore et al. (2017)

This work is in agreement with the relations Fiore et al. find for local AGN X-ray winds (Fig. 6-7).

XMM 2018

Figure 8 shows the observed-frame residuals obtained using a single power law plus Galactic absorption model.

- **One significant narrow emission line** at E_{rest}= 6.8 ± 0.1 keV ($E_{obs} \simeq$ 2.5 keV), consistent with Reynolds et al. (2014).
- No significant absorption lines at energies above 7.0 keV.

XMM 2018 data are best reproduced by a **rather thick, neutral and partial covering absorber**.

The absorber ionization state **fails to explain the emission line**.

→ Hint of an additional ionized component?

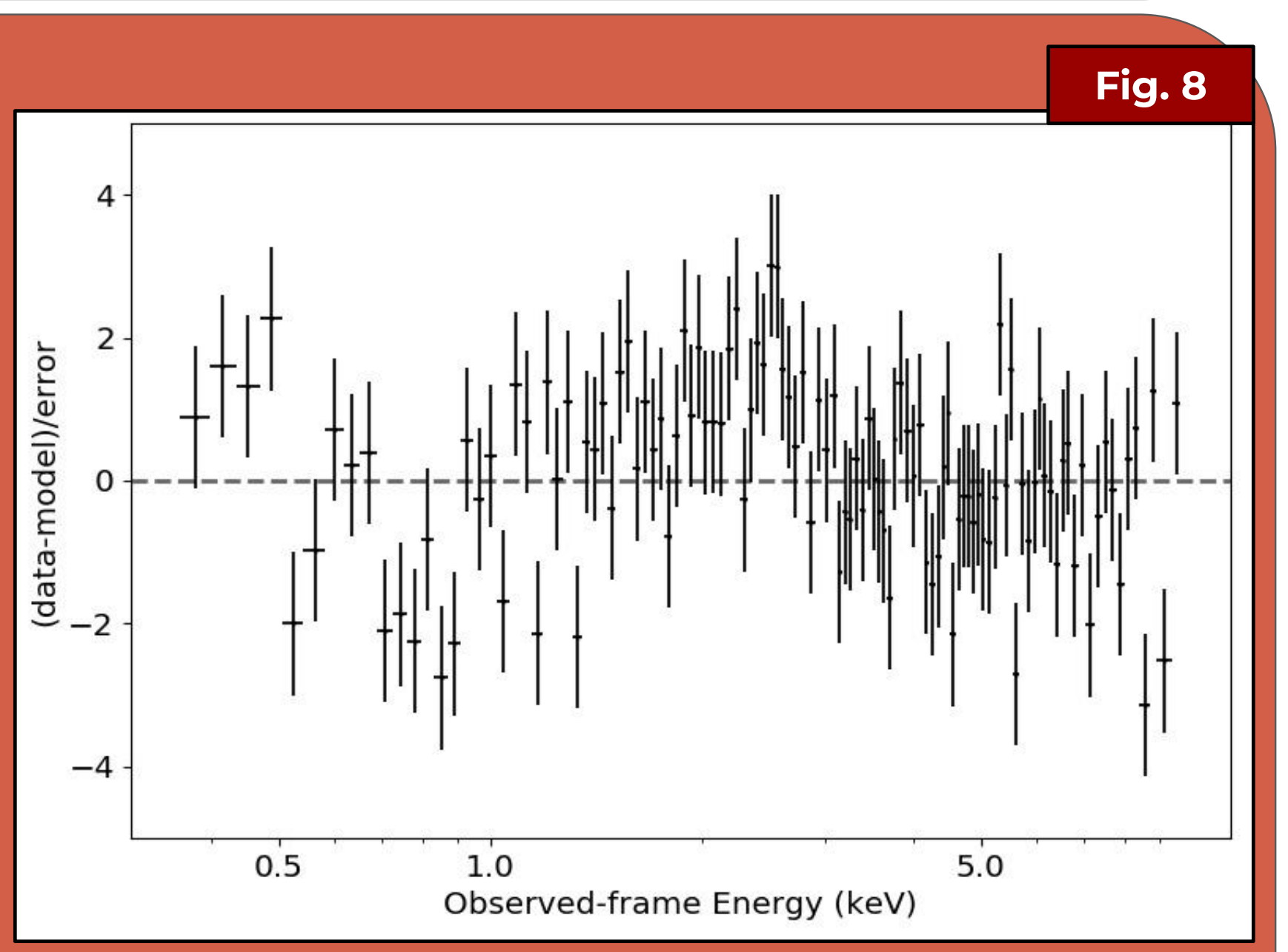

Fig. 8

Absorber parameters

- $N_H = (1.1 \pm 0.2) \cdot 10^{23}$ cm^{-2}
- CF = 54% ± 8%
- $\log(\xi/\mathrm{erg\ s^{-1}\ cm}) < 2.1 \longrightarrow r \geq 4.9$ pc
- $E_{rest} = 6.8 \pm 0.1$ keV

RESULTS

- **Detection**, for the first time, of **fast X-ray wind** in the **Chandra and XMM 2002 data**
  - XMM 2002: $\dot{E}_{kin} \approx 9\% L_{bol}$ can actually **affect the evolution of the host galaxy** (threshold from models: > 1% - 5%; Di Matteo et al., 2005; King & Pounds, 2015)
- Differences between the absorption lines in Chandra and XMM spectra
  - Energies of **Chandra lines require v_{out}~ 0.3 - 0.5c >> v_{out}** of the significantly detected line at ~ 7.4 keV in XMM 2002 (assuming Fe XXVI Kα)
  - … but **consistent with the tentative detection at ≃ 11.8 keV** in **XMM 2002**
- **Rough** estimation of the **wind duty cycle: ≳ 60%**
  - **10 spectra out of 16** (14 from *Chandra* HSS and two from XMM) have **UFOs with EW_{rest}> 250 eV** (we cannot exclude the presence of lines with lower EW due to the low statistics - Fig. 9)
- **Detection** of a **variable cold absorber** at distances consistent with the **torus**

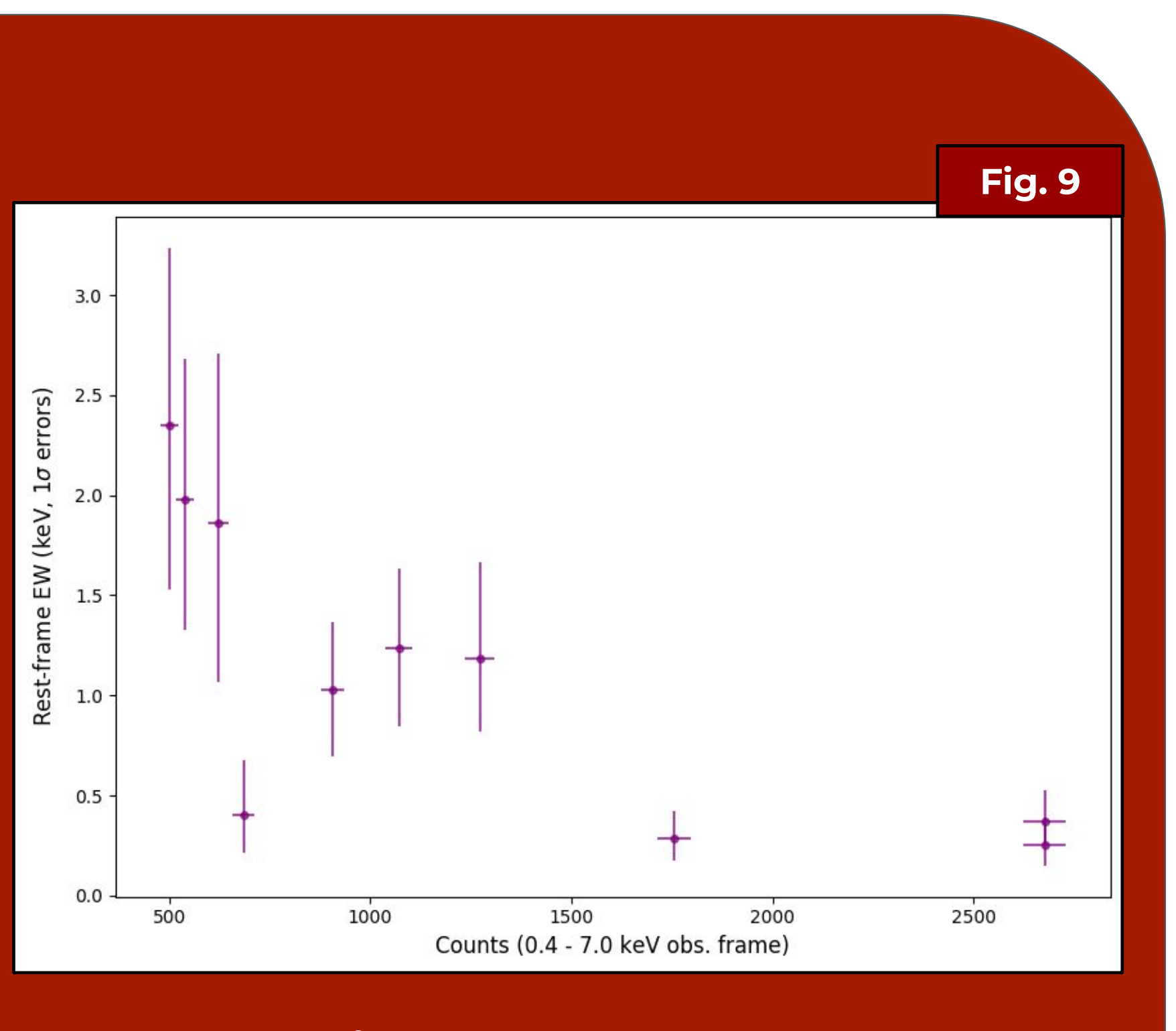

Fig. 9

References

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