Background related challenges in extended source analysis

A few things we have learned over the last quarter century and how useful they might be over the next

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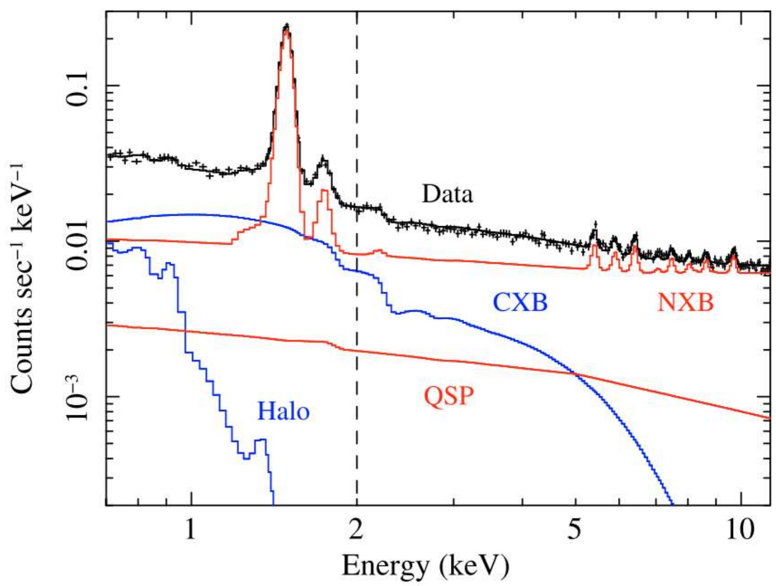
Subtraction vs modeling

When XMM-Newton and Chandra were launched background subtraction was the norm.

Leccardi & SM 08



Background comprises several components that vary independently in time and space

Subtraction vs modeling

Different background components that vary independently in time and space cannot be subtracted together, they need to be individually characterized and modeled.

Starting from scratch

- Not much attention to background in XMM-EPIC design
- Design ATHENA experiments with Background mitigation in mind

Criteria

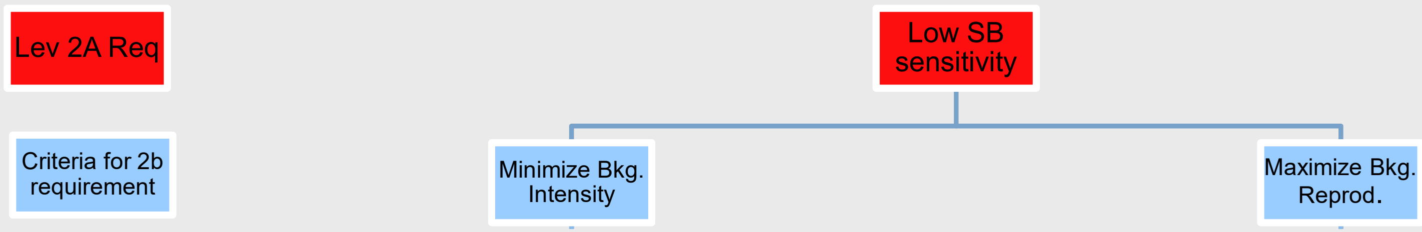
- Minimize Bkg. Intensity
- Maximize Bkg. Reproducibility (few % level)

2A to 2B flowdown

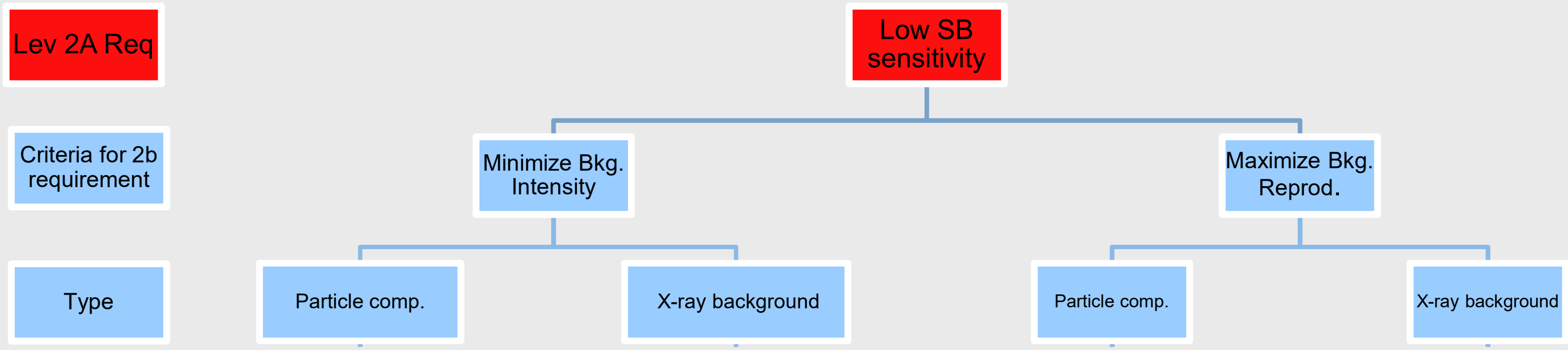
Lev 2A Req

Low SB sensitivity

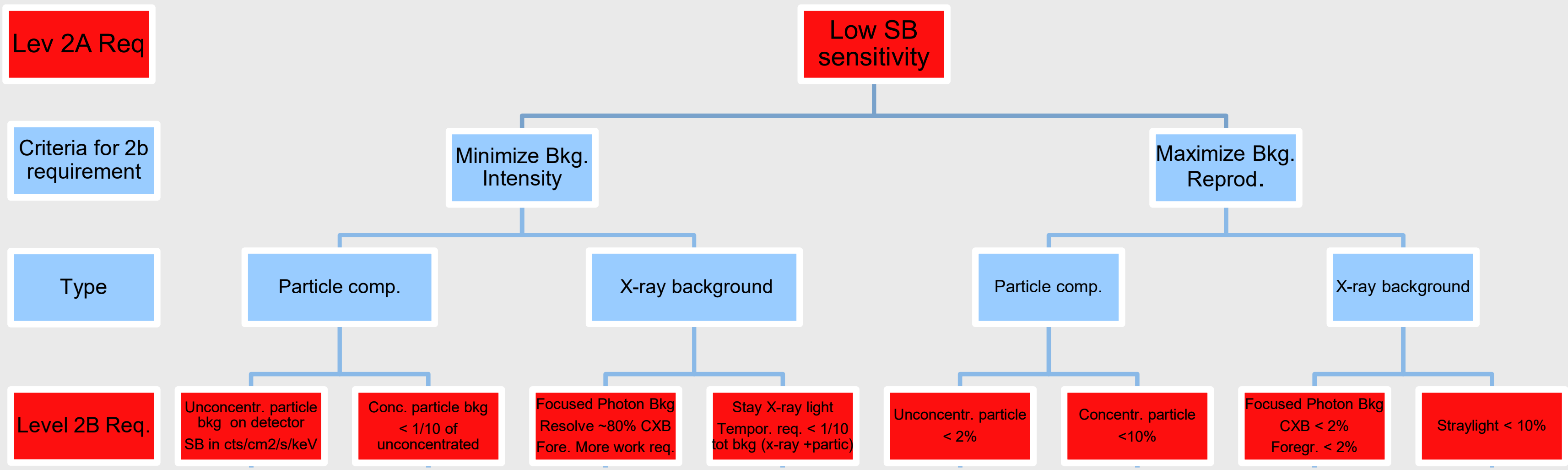
2A to 2B flowdown



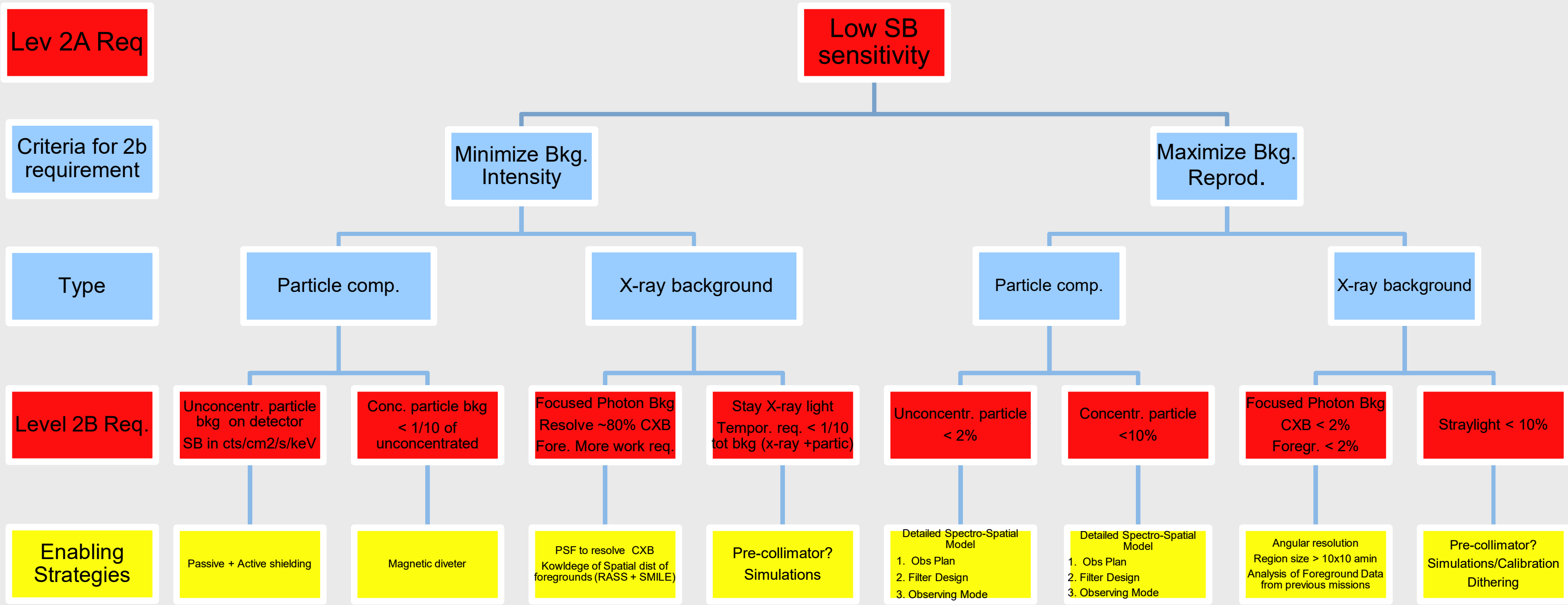
2A to 2B flowdown



2A to 2B flowdown



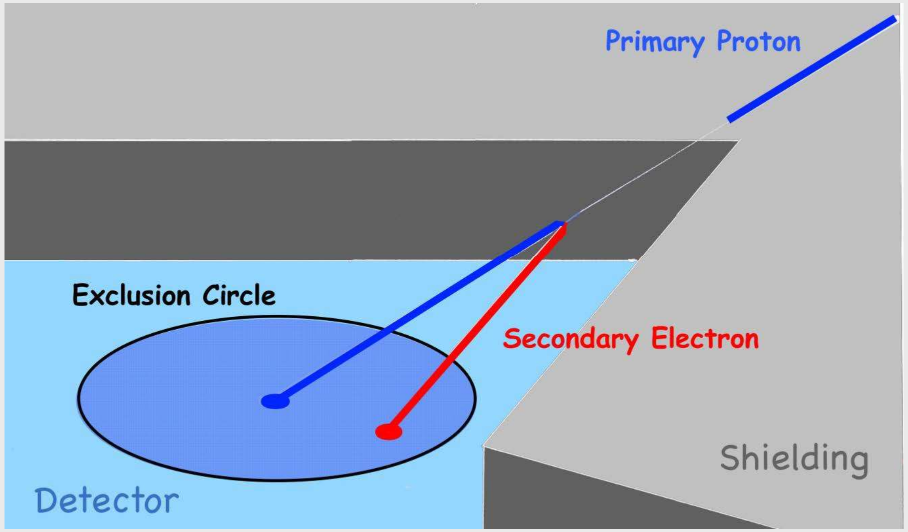
2A to 2B flowdown

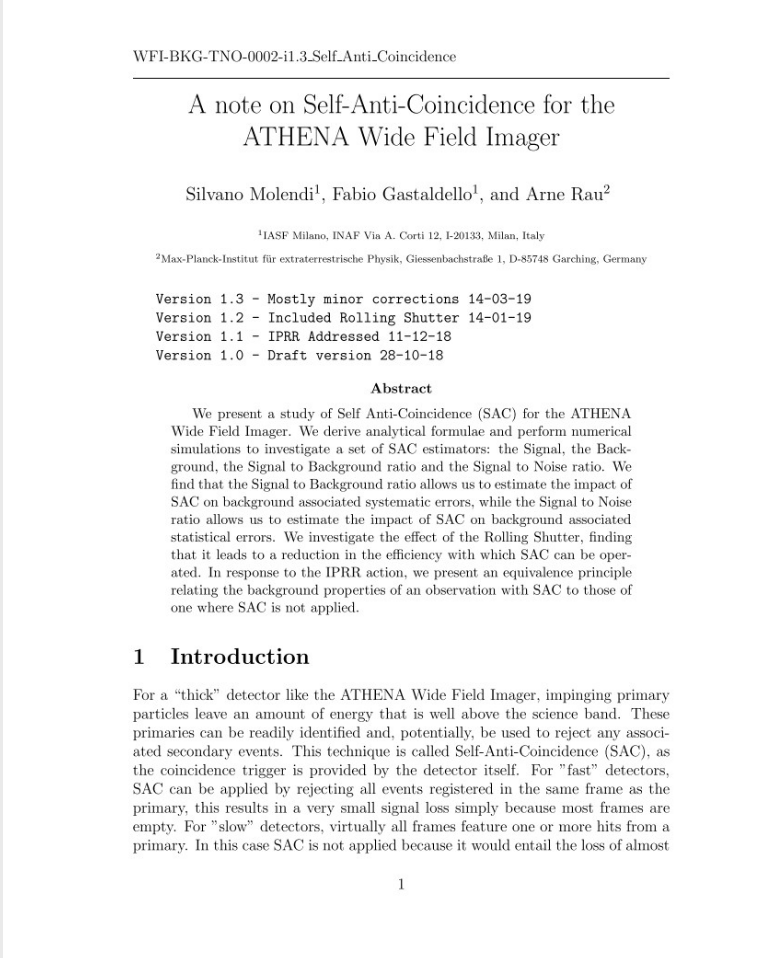


Particle Background minimization

XIFU Anti-Coincidence

WFI SAC (Self Anti-Coincidence)





WFI-BKG-TNO-0002-i1.3_Self_Anti_Coincidence

A note on Self-Anti-Coincidence for the ATHENA Wide Field Imager

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Version 1.3 - Mostly minor corrections 14-03-19
Version 1.2 - Included Rolling Shutter 14-01-19
Version 1.1 - IPRR Addressed 11-12-18
Version 1.0 - Draft version 28-10-18
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Abstract

We present a study of Self Anti-Coincidence (SAC) for the ATHENA Wide Field Imager. We derive analytical formulae and perform numerical simulations to investigate a set of SAC estimators: the Signal, the Background, the Signal to Background ratio and the Signal to Noise ratio. We find that the Signal to Background ratio allows us to estimate the impact of SAC on background associated systematic errors, while the Signal to Noise ratio allows us to estimate the impact of SAC on background associated statistical errors. We investigate the effect of the Rolling Shutter, finding that it leads to a reduction in the efficiency with which SAC can be operated. In response to the IPRR action, we present an equivalence principle relating the background properties of an observation with SAC to those of one where SAC is not applied.

1 **Introduction**

For a "thick" detector like the ATHENA Wide Field Imager, impinging primary particles leave an amount of energy that is well above the science band. These primaries can be readily identified and, potentially, be used to reject any associated secondary events. This technique is called Self-Anti-Coincidence (SAC), as the coincidence trigger is provided by the detector itself. For "fast" detectors, SAC can be applied by rejecting all events registered in the same frame as the primary, this results in a very small signal loss simply because most frames are empty. For "slow" detectors, virtually all frames feature one or more hits from a primary. In this case SAC is not applied because it would entail the loss of almost

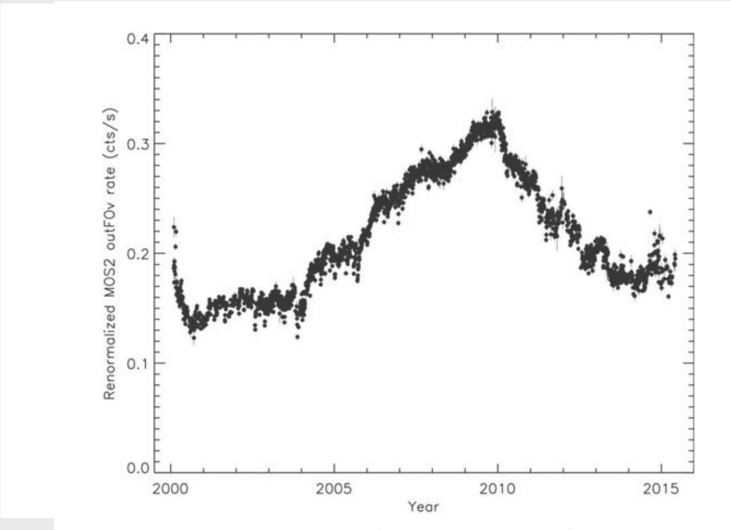
1

5ms to 2 ms framerate

Repoducibility maximization

Improve understanding of how praticle background componet is generated

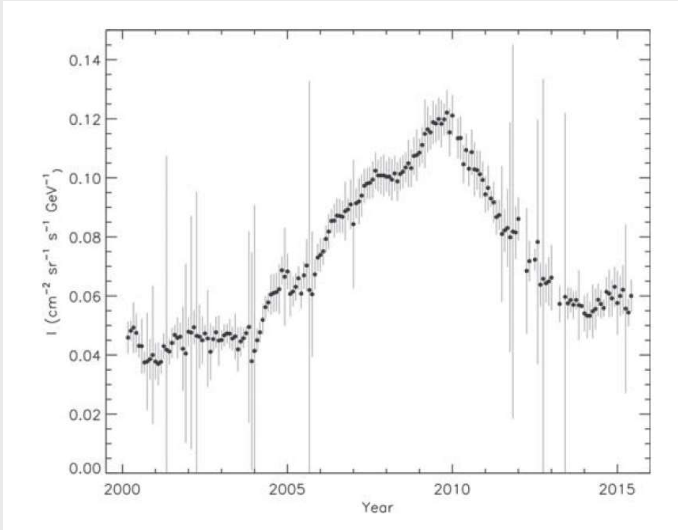
EPIC MOS2 in HEO



Gastaldello,,SM+22

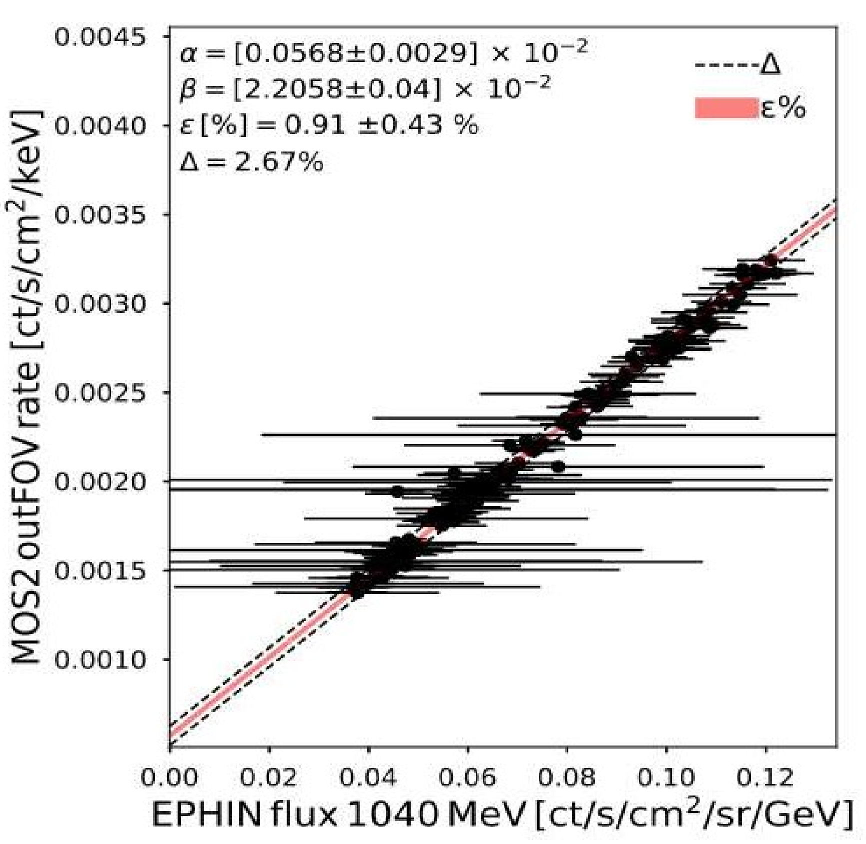
SOHO EPHIN in L1

Khuel+16



High Energy Protons

Gastaldello,SM+22

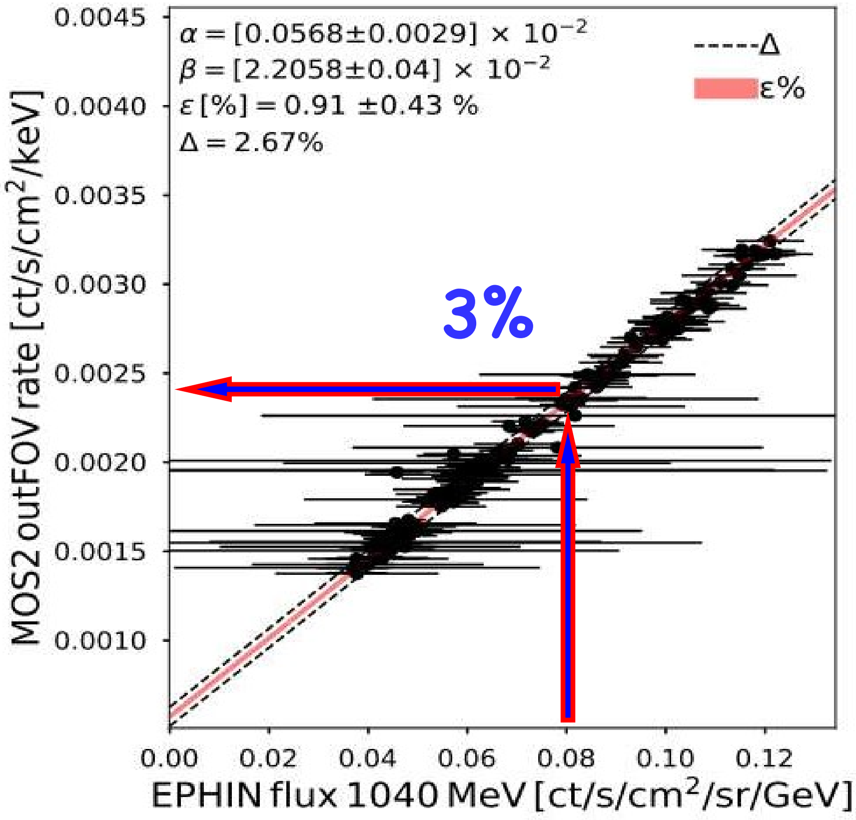


MOS bkg mostly due to high E protons

Same in HEO & L1

High Energy Protons

Gastaldello,SM+22



MOS bkg mostly due to high E protons

Same in HEO & L1

AHEPaM

MWG5.2-TN-0001-i2.2

Requirements for the ATHENA High Energy Particle Monitor AHEPaM

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May 29, 2020

Version 2.2

Abstract

While useful, current strategies to control background systematics offer no guarantee of achieving the required reproducibility requirements. The very tight correlation recently measured between high energy proton flux and instrumental background rate demonstrates that a high energy particle monitor capable of tracking high energy protons, electrons and alpha particles will contribute decisively to reaching the reproducibility requirement. In this note we provide requirements for an ATHENA High Energy Particle Monitor (AHEPaM) as well as some background information to help understand the logic that has lead to their formulation. The AHEPaM will monitor protons, electrons and He ions with energies from ~ 0.1 GeV to a few GeV on timescales down to few ks.

1 Motivation or the inadequacy of current background reproducibility strategies

Over the past few years several strategies have been proposed to characterize the instrumental background of the XIFU and WFI experiments. These are all based on a phenomenological approach developed from past X-ray missions, mainly XMM-Newton. For example, in one study (Molendi et al. 2018) we considered moving the filter wheel every 10ks, for 1ks, to closed position, during background sensitive observations. We showed that, given the large FoV of the experiment under consideration (WFI), we could measure the background intensity during the closed intervals with a 2% precision. A similar approach, see XCAT-TN-004,

Dedicated particle monitor to improve background reproducibility

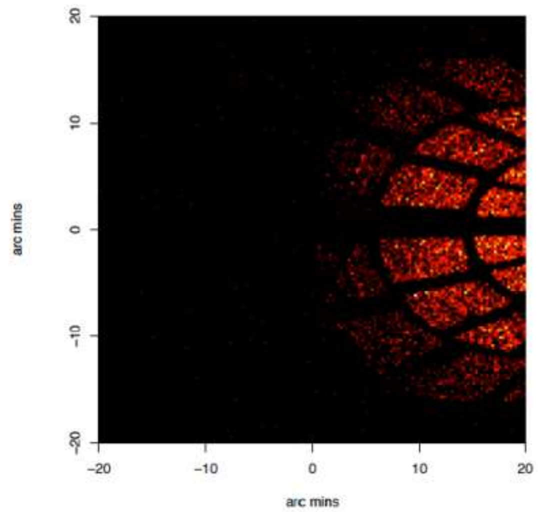
Lost in ATHENA to NewATHENA transition

Currently under study by Polish group

Straylight

Willingale 18

Stray distribution in WFI FOV from a single point source



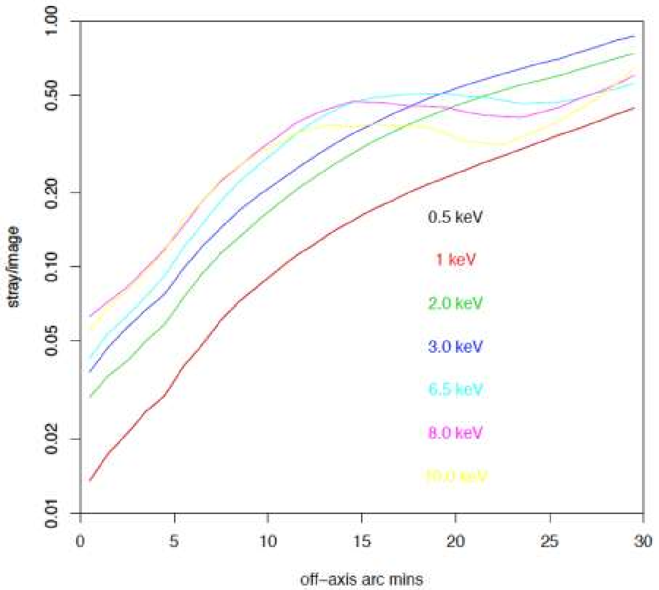
- Projected pattern from SPO module apertures
- Details of distribution depend on off-axis position of source and source spectrum
- Stray flux confined to same quadrant as the off-axis angle of source
- Stray surface brightness <1×10^{-5} for same source strength in FOV

Initial studies for a precollimator abandoned / No minimization

Straylight

Willingale 18

Ratio of stray/image vs. radius in FOV



- Within X-IFU FOV <0.02 at 1 keV and <0.05 at all energies – the stray loading near the centre of the FOV for the v2.4 mirror is a factor of ~2 higher than for the large aperture mirror
- Maximum at corners of WFI FOV 0.4 at 1 keV, 0.5 at 6.5 keV – similar to the large aperture mirror
- Modulation of ratio at 6.5, 8 and 10 keV due to inner ring of modules

On-going activities to include straylight in SIXTE

Minimize Straylight impact

CXB + Foregrounds

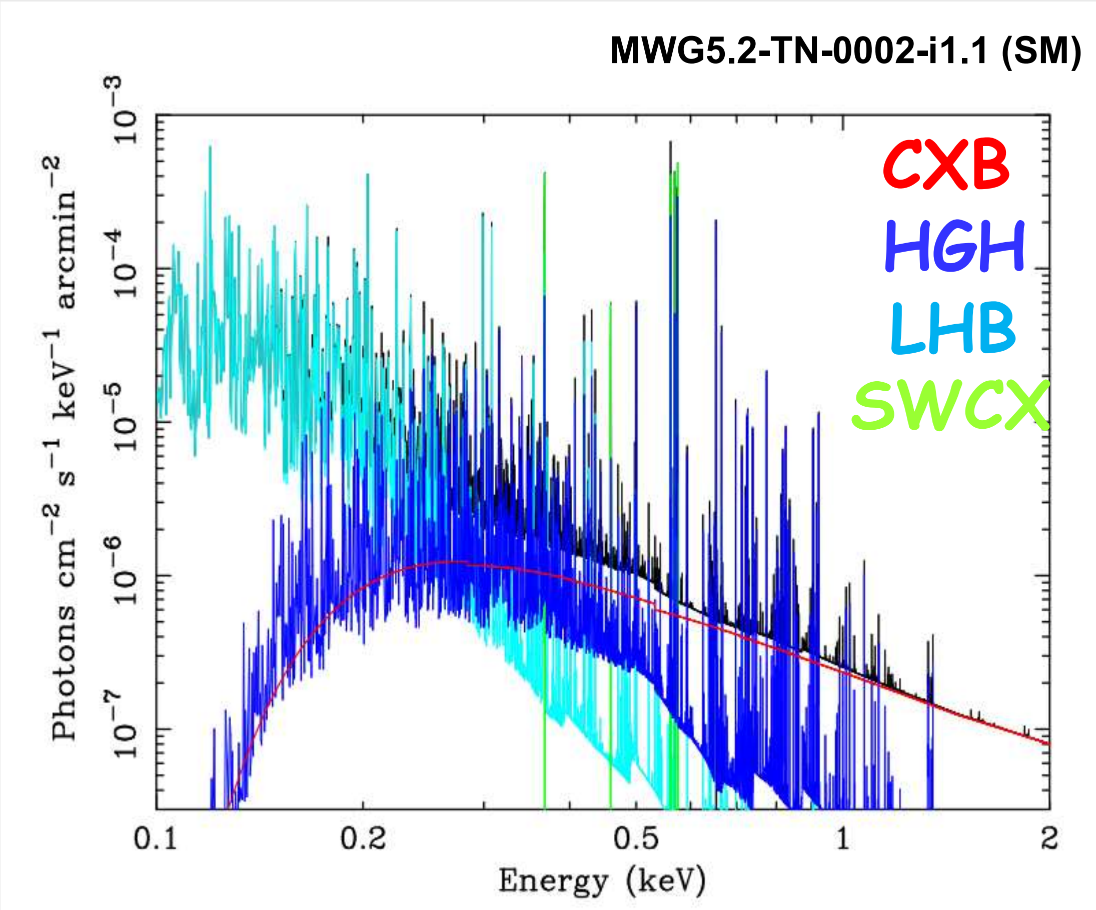
Not much work done here

Instrumental background has taken precedence

Knowledge of astrophysical background (E<2KeV):

1) Spatial distrib. RASS -> eRASS
2) Spectral distrib. sounding rocket (Wulf+19) -> XRISM

Foreground



Emission from plasmas in 0.1-0.5 keV range, dominated by emission lines

Data analysis strategies

1. Experiment design
2. Observational strategy
3. Data analysis strategy

Background Modeling

Use data from several sources:

- Particle monitors/detectors,
- X-ray Detectors (closed data, auxiliary data etc.)
- Simulations of particle interactions with detectors and surrounding structure
- Simulations of straylight
- Astrophysical data for foregrounds

Build a multi-parametric background model

- Provide both best estimates and uncertainties on parameters
- Take Bkg model, integrate with source model, and apply to data

Background Modeling/2

Example on current mission spectral-domain only CHEX-MATE
(see Chiara's talk)

Modular system, there are several background components, and for a specific analysis you may need to include only some.

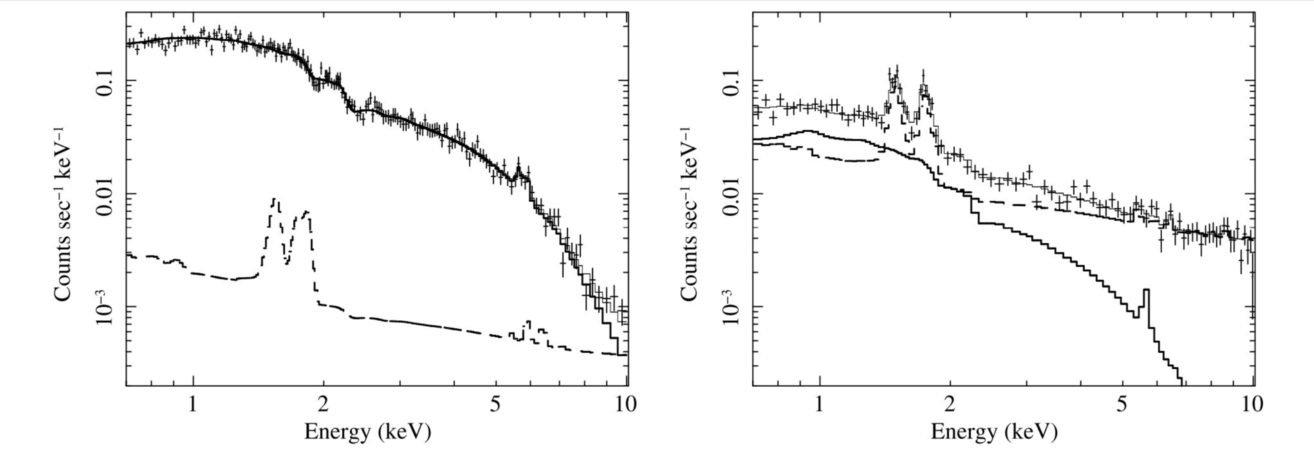
Observers should be allowed (within limits) to assemble modules into a model that is tailored to their specific needs.

Analysis techniques & the modeling hubris

Background modelling is a powerful tool,
but, its not without limitations.

An example: temperature profiles

Leccardi & SM 08



As we move outwards measurement becomes more sensitive to the background level

Use knowledge of the background to reduce systematics affecting our measurement.

Knowledge of background can improve but, it will never be perfect

Systematics

Systematics can be reduced not eliminated

Residual systematic errors become comparable to statistical errors

$$\varepsilon_{sys} \sim \varepsilon_{stat}$$

Here statistical inference will fail

Stop analysis when:

$$\varepsilon_{sys} \sim \varepsilon_{stat}$$

When statistical inference and systematics collide

Residual systematics are a form of ignorance over which you cannot marginalize

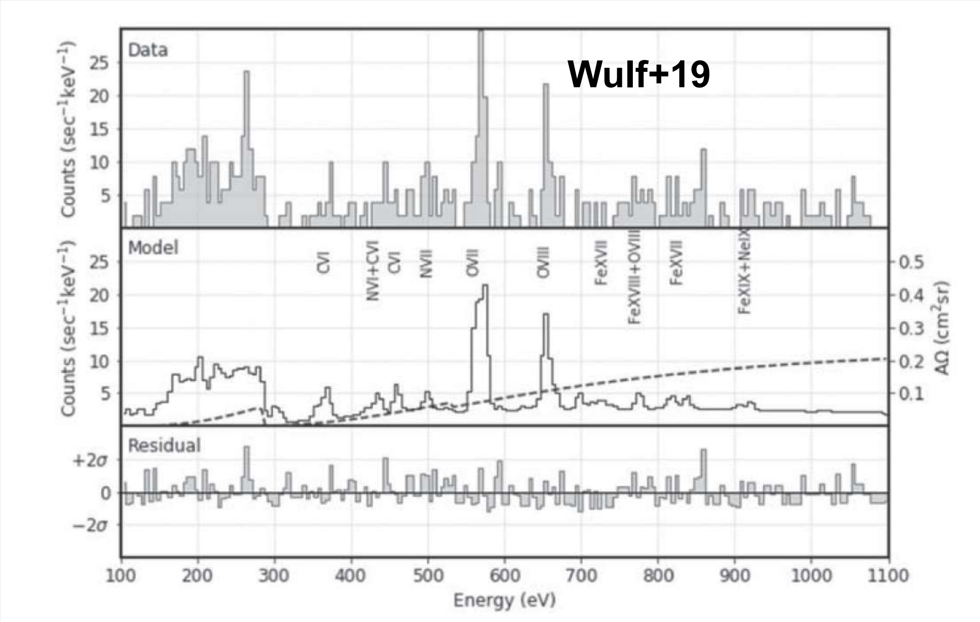
Knowing where to stop

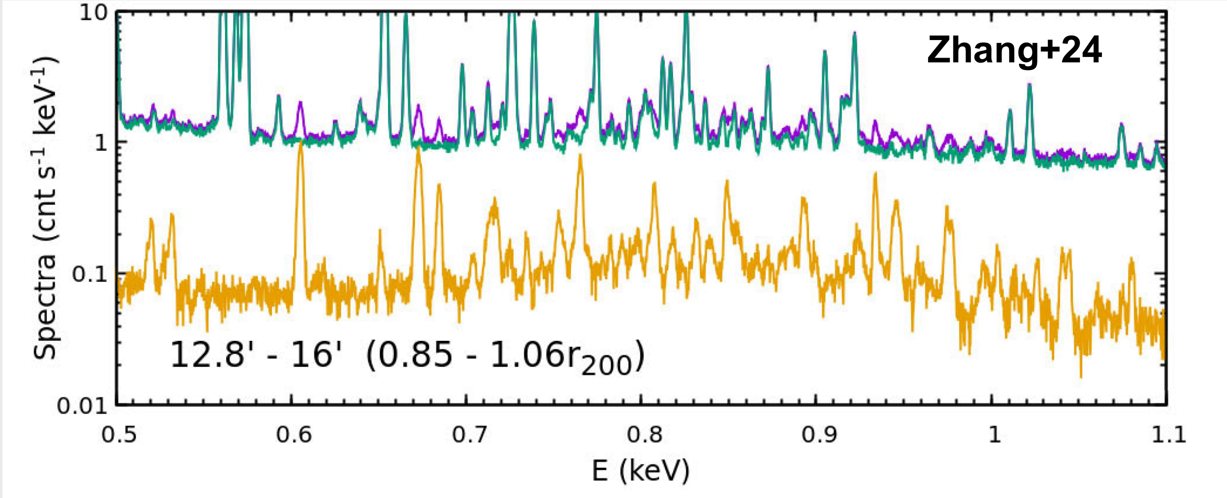
There is no algorithm to estimate residual systematics
An approach adopted in several cases is to derive independent estimates of key quantity and associate differences to residual systematics.

This is why we have searched for many different high energy particle background proxies

Not the full story

Cases where background modeling and evaluation of systematics might not be too important





Soft X-ray foregrounds

- No consensus on metallicity of foreground emission
- CIE ?
- Clumping ?

Don't know what foreground emission will look like

XRISM could have been a big help…

At least first XIFU data analysis of soft low SB emission from galaxies/group/cluster will have to be approached in a very cautious fashion.

Summary

- Lots of work on characterizing instrumental bkg
- Some work on astrophysical components, an important part will have to await XIFU observations.
- Modular model for background informed by work on bkg characterization.
- Statistical inference and systematics
- Line detection and characterization at low energies