ATHENA End-To-End Simulations

J. Wilms, T. Dauser, P. Peille
What are End-to-End Simulations?

End-to-end (e2e) simulations: Simulation of the full detection chain for an astronomical instrument, from the astrophysical source through the imaging and detection process to the final data product.

⇒ Full model of observational setup

E2e simulations have two major “customers”:

**Scientists:**
- Gauge *effect of design onto science*: Can science goals be reached with the instrument? e.g., imaging quality, spectroscopy, . . .
- What other “observatory” science is possible?
- Plan future observations

**Instrumentalists:**
- Use *science examples to study design*: What is impact of design onto science goals?
- Translation of instrument parameters ⇐⇒ Science goals
- Estimate instrument performance
e.g., telemetry constraints, CPU constraints

⇒ Core component of mission design and implementation!

To be useful, e2e software should always represent best understanding of real instrumental performance.
What is the purpose of this meeting?

- Demonstrate current status of e2e design for ATHENA
  - same underlying engine
  - same inputs can be used for both instruments
  - similar outputs
  \[\Rightarrow\] What is already possible?

- Training in performing e2e simulations
  - basic simulations
  - advanced simulations
  - other missions

- Discuss future developments
  \[\Rightarrow\] What do you need?
  \[\Rightarrow\] What is missing?
  \[\Rightarrow\] How can we meet?
<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
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<tbody>
<tr>
<td>09:00–09:30</td>
<td>JW: Overview e2e simulations (SIXTE, Simput)</td>
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<td>09:30–09:50</td>
<td>Brief introduction of everybody</td>
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<td>09:50–10:10</td>
<td>TD: WFI</td>
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<td>10:10–10:30</td>
<td>PP: X-IFU</td>
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<td>10:30–11:00</td>
<td><strong>Coffee</strong></td>
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<tr>
<td>11:00–12:00</td>
<td><strong>Session I: Basic Simulations</strong></td>
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<td>12:00–13:00</td>
<td><strong>Break for Lunch</strong></td>
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<td>13:00–13:15</td>
<td>Carpano: Occultations</td>
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<td>13:15–16:00</td>
<td><strong>Session II: special topics</strong></td>
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<td>PP: group I: clusters, extended sources</td>
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<td>TD: group II: wide field surveys</td>
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<td>JW: group III: variability, X-ray analysis</td>
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<td>16:00–16:30</td>
<td><strong>Coffee</strong></td>
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<td>16:30–17:30</td>
<td><strong>Session II: continued</strong></td>
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<td>17:30–18:00</td>
<td><strong>Feedback</strong></td>
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<td>20:00–</td>
<td><strong>conference dinner</strong>: Les Caves de la Maréchales</td>
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Agenda

09:00–10:00  TD: Bright sources with the WFI
10:00–10:30  JW: TES simulations
10:30–11:00  Coffee
11:00–11:30  PP: Bright sources with X-IFU
11:30–12:00  JW/TD/PP: eROSITA, XMM-Newton, Suzaku,…
12:00–12:30  Suggestions for further developments
12:30–13:30  Break for Lunch

This is a workshop – please ask questions, voice your disagreements, express your praise…
Source model: Define properties of the sources: Positions, Extended source/point source, spectral shape, variability,...

Instrument model: Define properties of the instrument: Imaging parameters, detection process, data processing chain

Output: Data that can be analyzed using standard astronomical analysis software (FTOOLS, XMM-SAS, XSPEC, ISIS,...)
Real sources are characterized by:

- position: \((\alpha, \delta)\)
- spectral shape: \(F(E)\)
- flux distribution: \(F(\alpha, \delta, E)\)
- variability: \(F(\alpha, \delta, t, E)\)
- foreground absorption: \(N_H(\alpha, \delta)\)

Aim for e2e:

- be as close as possible to reality
- no artificial limitations on source spectral shape, images, etc.
- be compatible w/other simulators
  - reached with simx and MARX, unfortunately not with heasim.

\[ \implies \text{SIMPUT} \]
Data format describing source: SIMPUT
Formal description: FITS Standard Document:
http://hea-www.harvard.edu/HEASARC/formats/simput-1.1.0.pdf

- catalogs with **arbitrary number of sources**
- characterization of sources:
  - spectra
  - positions
  - light curves, pulse profiles, power spectra...
  - spatial extent
  - photon lists from MHD simulations
  - “data cubes”

- format allows **reuse of common properties of sources**
  e.g., reuse AGN spectra for multiple sources, reuse images of extended sources,...
### Source Catalogue Extension

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<th>IMAGE</th>
<th>TIMING</th>
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**Structure of source catalogue:** *reuse of common source properties possible*
Source description

Library and tools to build SIMPUT files:

http://www.sternwarte.uni-erlangen.de/research/sixte/simput.php

Library also contains tools to generate SIMPUT files:

- **simputfile**: generate SIMPUT file for one source
  Inputs are source position, flux spectral shape (XSPEC or ISIS par, ASCII), lightcurve, FITS image, PSD parameters, foreground absorption.

- **simputmultispec, simputmulticell**: powerful tools: generate SIMPUT for extended source w/spatial variation of spectral parameters

- **simputmerge**: Merge different SIMPUT catalogues

Helpers:

- **galabs**: Add galactic absorption from LAB-catalogue to SIMPUT catalogue

- **simputrotate**: rotate images in a SIMPUT file
  e.g., generate different sources from smaller source image catalogue

still to develop: simputselect
e2e environment: SIXTE, a generic Monte Carlo simulation framework for X-ray instruments (ATHENA, eROSITA, GRAVITAS, IXO, LOFT, XMM, ARCUS)
http://www.sternwarte.uni-erlangen.de/research/sixte

• modular software → reuse existing algorithms for multiple detectors

• uses calibration data (response files, PSF, . . . ) or physics-based instrument model

• output: FITS event list (time, energy, pixel)

⇒ one simulator for science & technology development
Instrument model

- **Telescope model**
  - pointing (attitude, e.g., for dithering)
  - ARF
  - vignetting
  - PSF

- **Instrument model**
  - device simulator:
    - **simple/fast simulation**: RMF sampling
    - **advanced simulation**: physics
      (e.g., $T(t)$ for X-IFU, photon effects in Si for WFI)

  flexible focal plane description (XML)

  - other effects considered: pile-up, crosstalk, background, readout

- **Output**: FITS event files

⇒ Talks by T. Dauser and P. Peille
WFI and X-IFU simulations of the Chandra Deep Field South, based on the CDFS source catalogue (T. Brand/T. Dauser)
Chandra deep field south with the WFI w/dither (A. Rau/T. Dauser)
Cas A (WFI, 1 ks)

Tycho (WFI, 1 ks)

M 82 (WFI, 100 ks)
Abell 2146 with X-IFU (T. Dauser/E. Pointecouteau)
Access:

  Works on Linux and Mac, git and release versions.
- **WWW interface:** [http://hydrus.sternwarte.uni-erlangen.de/~athenasim/](http://hydrus.sternwarte.uni-erlangen.de/~athenasim/).
Open Issues

Compared to other missions, we’re already in an extremely good position!

- **Finalize initial X-IFU and WFI models:**
  - WFI: physics based model for photon interaction
  - X-IFU: finish physics based model
- **Further SIMPUT, SIXTE tools**
  - simputselect
  - particle background
  - ray tracer?
- **documentation**: first draft manual available
- Further **improvements on WWW pages**
- **Develop higher level scripts for common tasks**
- **Tomorrow: brain storming session**