



# End-To-End Simulations with SIXTE

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# 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  $\longleftrightarrow$  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.

## Purpose of this Workshop

### What is the purpose of this meeting?

- **Demonstrate current status of SIXTE**
  - multi instrument simulator
  - input independent of mission
  - standardized output for post processing
- **Training in performing e2e simulations**
  - use (mainly) Athena as an example
  - basic simulations
  - advanced simulations
  - other missions
- **Discuss your projects**
  - ⇒ What do you need?
  - ⇒ How would you set up your simulations?
  - ⇒ Next steps

# Agenda

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## Tuesday

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14:00–14:15	Introduction of participants
14:15–15:15	Introduction to SIXTE (Jörn W)
15:15–16:00	Athena simulations (Christian/Max)
16:00–16:30	Coffee
16:30–18:30	Point sources

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# Agenda

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## Wednesday

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09:30–11:00	Simple point source simulations Multiple point sources
11:00–11:30	Coffee
11:30–13:15	Variable sources
13:15–14:15	Lunch
14:15–15:45	Extended sources
15:45–16:05	Coffee
16:05–17:35	specifying imaging detectors for SIXTE (Jörn W)
17:35–19:00	Transition edge detectors

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# Agenda

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## Thursday

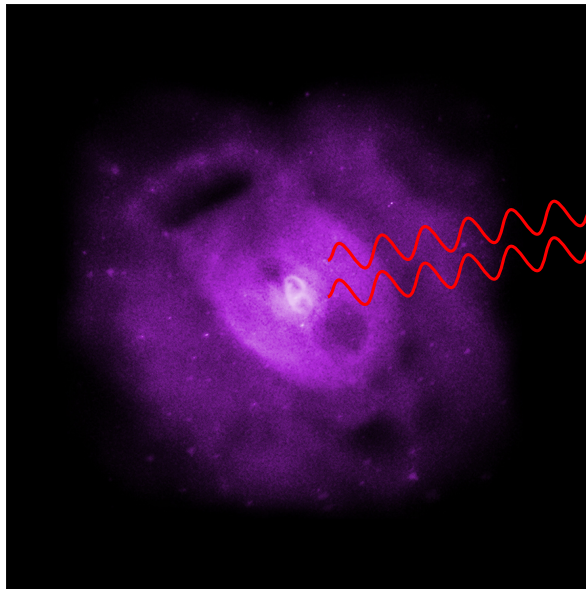
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09:30–11:00	Extended sources and Mosaics
11:00–11:30	Coffee
11:30–13:00	High resolution spectroscopy

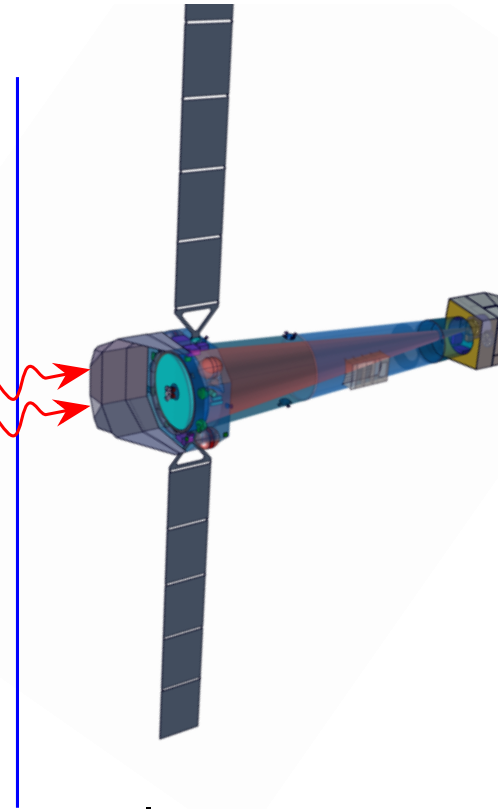
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**This is a workshop** – please ask questions, voice your disagreements, express your praise...

# Modeling



Source model



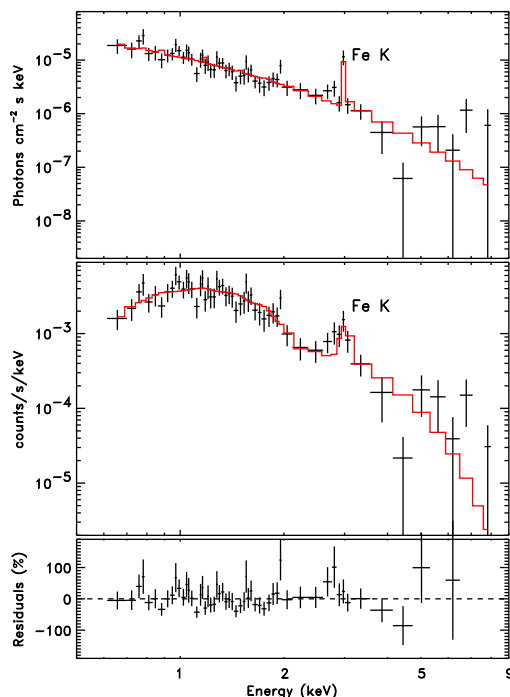
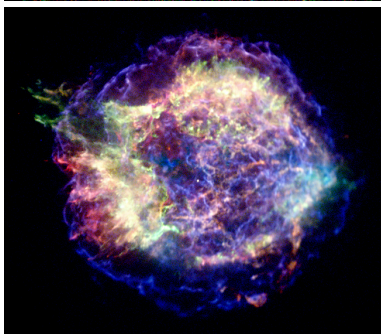
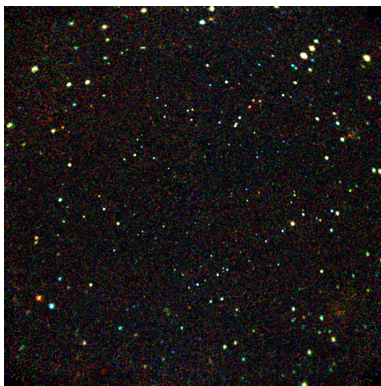
Instrument model

**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,...)

# SIMPOT



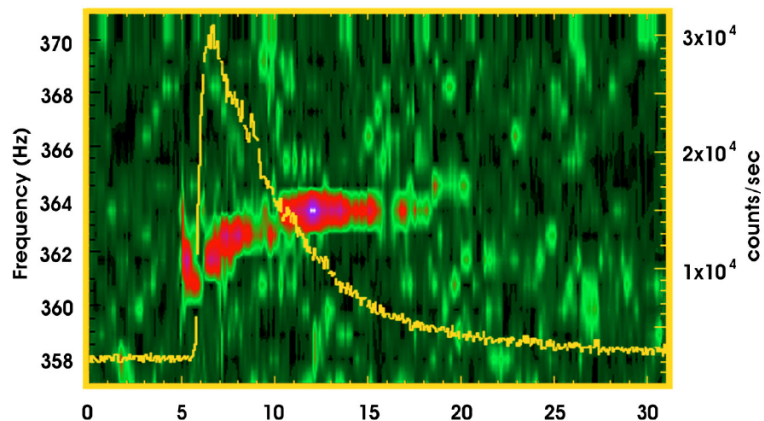
Real sources are characterized by:

- 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`.

⇒ SIMPUT



# 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, . . .

## SIMPUT A File Format for SIMulation inPUT

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Version: 2013 Dec 18  
(HDUVERS = 1.1.0)

### SUMMARY

We present a standard format for source input files to be used in simulations of astronomical observations. Each source file contains a catalog with one or multiple sources, which are described by specific properties such as position, brightness, energy spectrum, as well as optional characteristics such as time variability, polarization, and spatial extent. This file format defines a common basis to exchange data between different software packages and scientific groups. It was developed in particular for the simulation of X-ray telescopes, but can also be used in different wavelength domains.

# SIMPOT

## Source Catalog Extension

SRC_ID	SRC_NAME	RA	DEC	IMGROTA	IMGSCAL	FLUX	E_MIN	E_MAX	SPECTRUM	IMAGE	TIMING
1	...	...	...	...	...	...	...	...	SPEC01	NULL	LC01
2	...	...	...	...	...	...	...	...	SPEC01	IMG01	LC02
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

SPEC01

IMG01

LC01

LC02

Structure of source catalogue: **reuse of common source properties** possible

# SIMPUP

## 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:

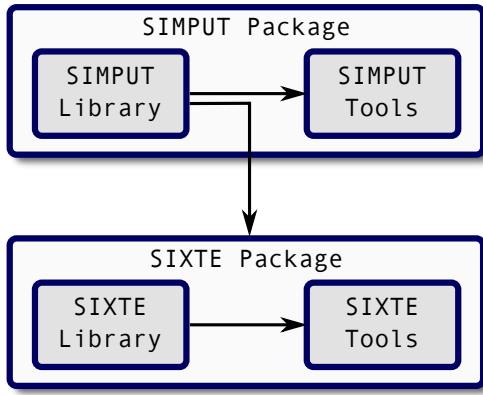
- `simputfile`: generate SIMPUT file for one source  
Inputs are source position, flux spectral shape (XSPEC or ISIS par, ASCII), lightcurve, FITS image, PSD parameters, foreground absorption.
- `simputmultispec`, `simputmulticell`: powerful tools: generate SIMPUT for extended source w/spatial variation of spectral parameters
- `simputmerge`: Merge different SIMPUT catalogues

## Helpers:

- `labnh`: get Galactic  $N_{\text{H}}$  value to apply to a source spectrum
- `simputrotate`: rotate images in a SIMPUT file  
e.g., generate different sources from smaller source image catalogue

further tools: `simputverify`, `simputpsd`, `simputlc`,...

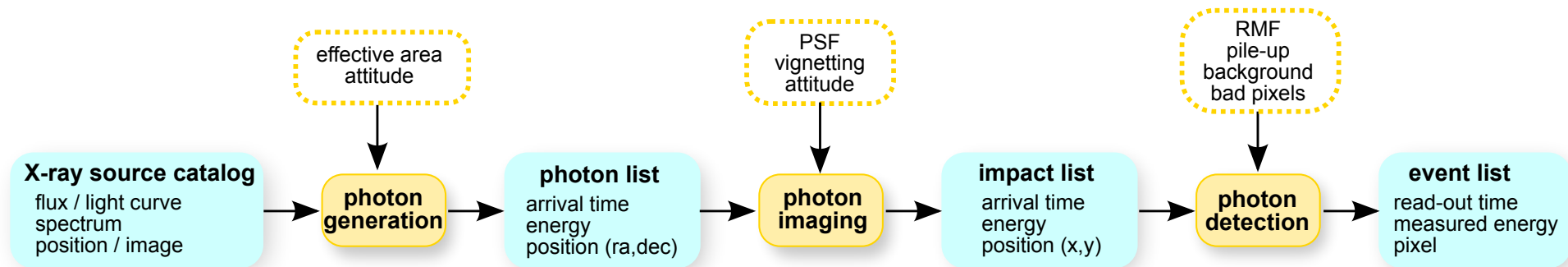
# SIXTE



e2e environment: **SIXTE**, a generic **Monte Carlo** simulation framework for X-ray instruments  
(Athena, eROSITA, ARCUS, XMM, LOFT, IXO, GRAVITAS,...)

<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

- **Imaging module**

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

- **Instrument module**

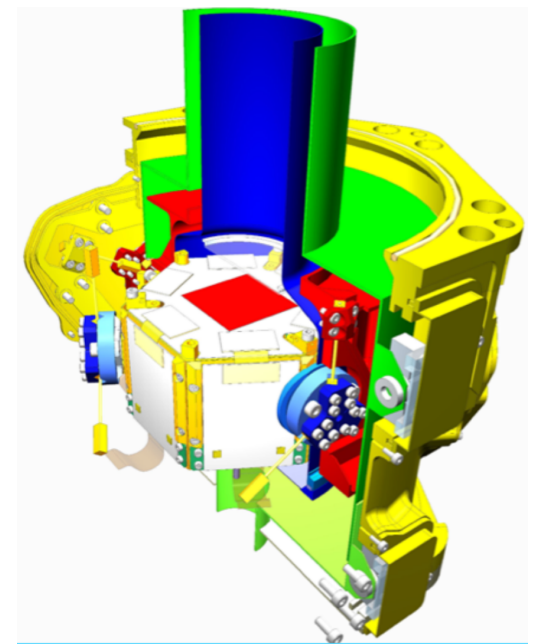
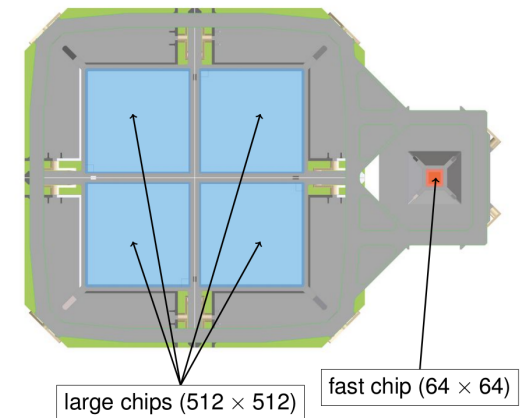
- device simulator:
  - **simple/fast simulation:** RMF sampling
  - **advanced simulation:** physics  
(e.g.,  $T(t)$  for X-IFU, photon effects in Si for WFI)

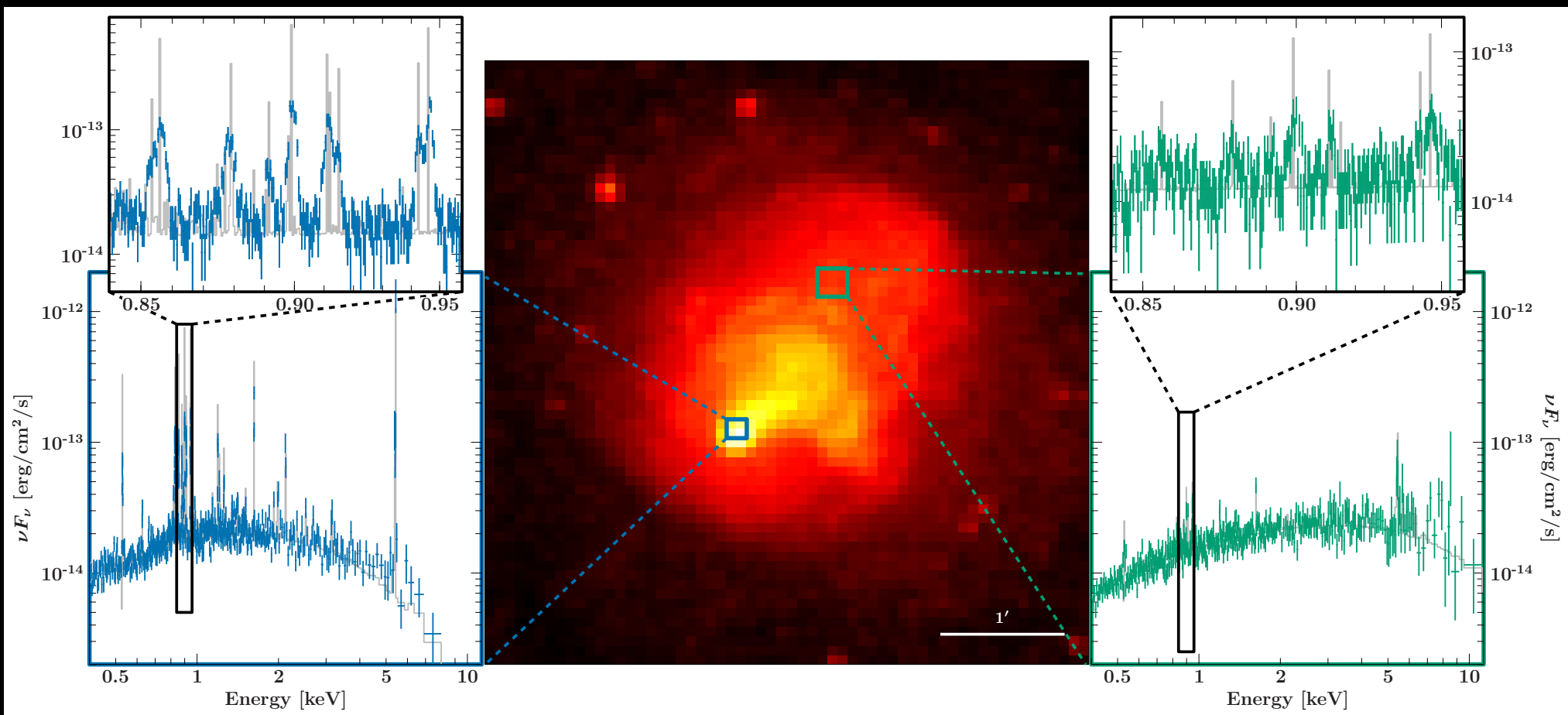
**flexible focal plane description (XML)**

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

- **Output:** FITS event files

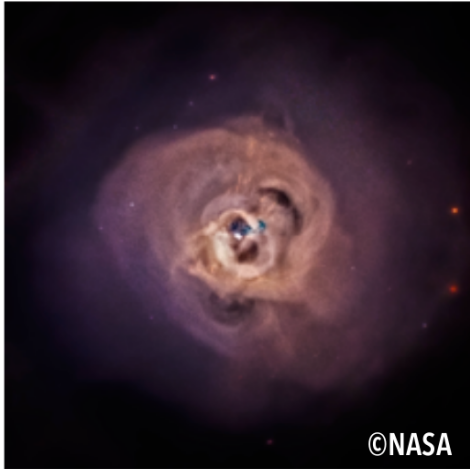
⇒ Talk by T. Dauser





Abell 2146 with X-IFU (T. Dauser/E. Pointecouteau)

# Example: Galaxy cluster observations



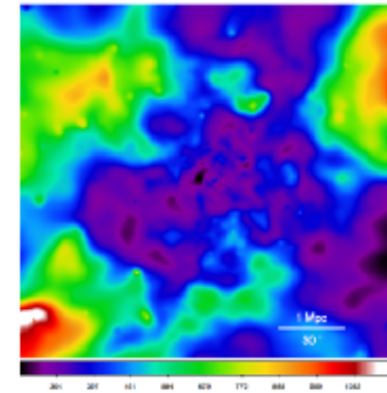
Astrophysical data



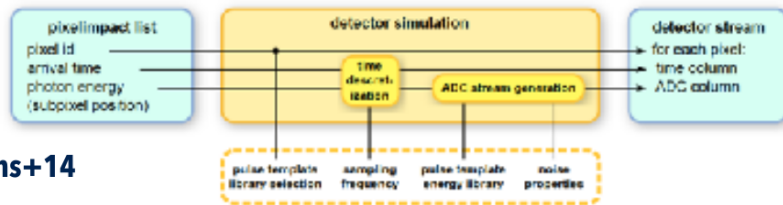
Comparing input/output  
**Verifying performances!**



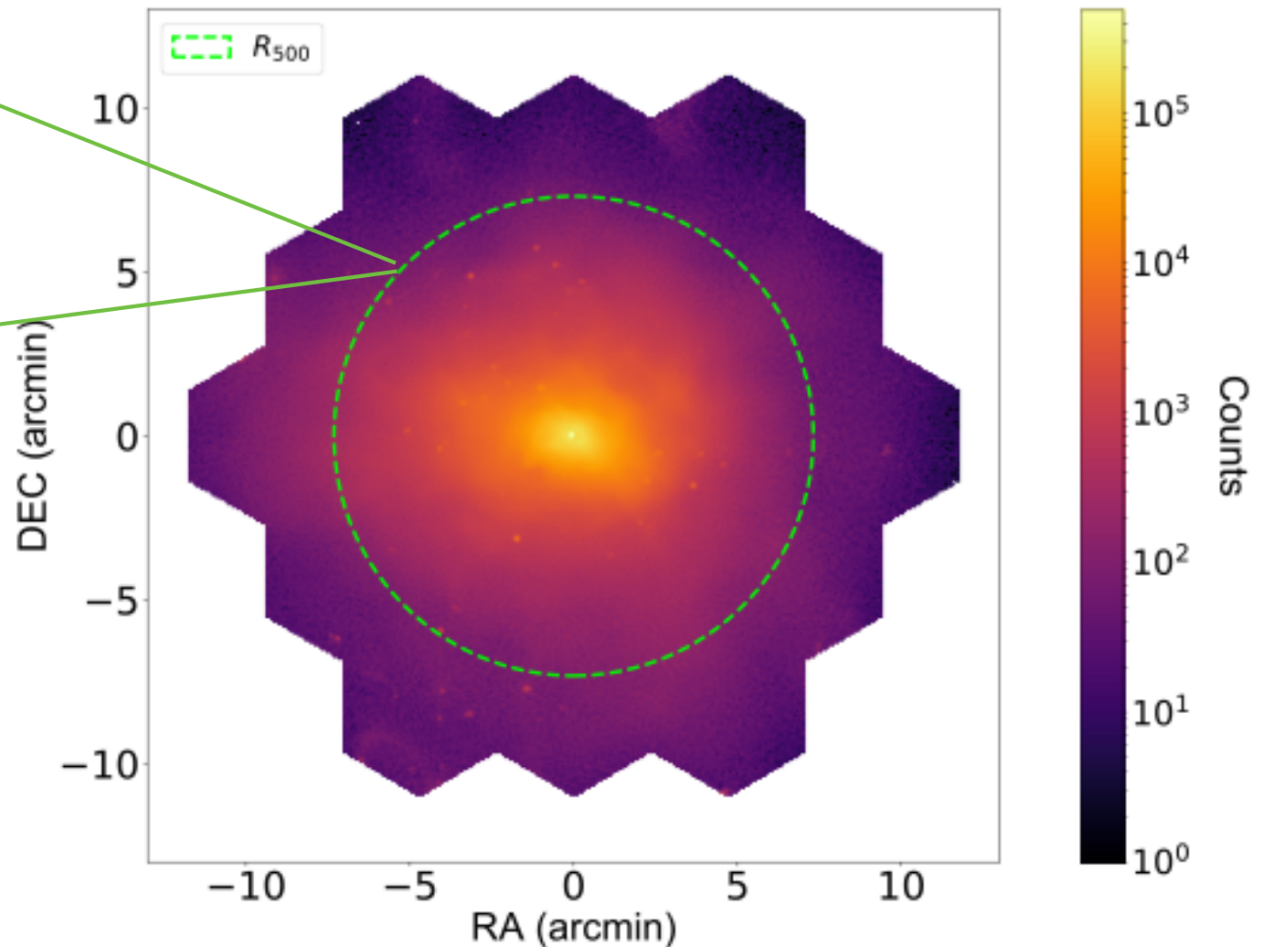
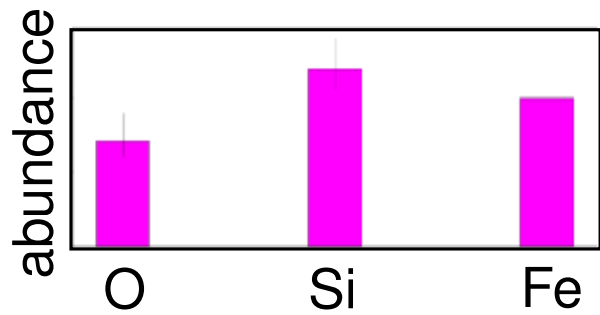
Simulated projected velocity field (courtesy P.Peille)



Wilms+14



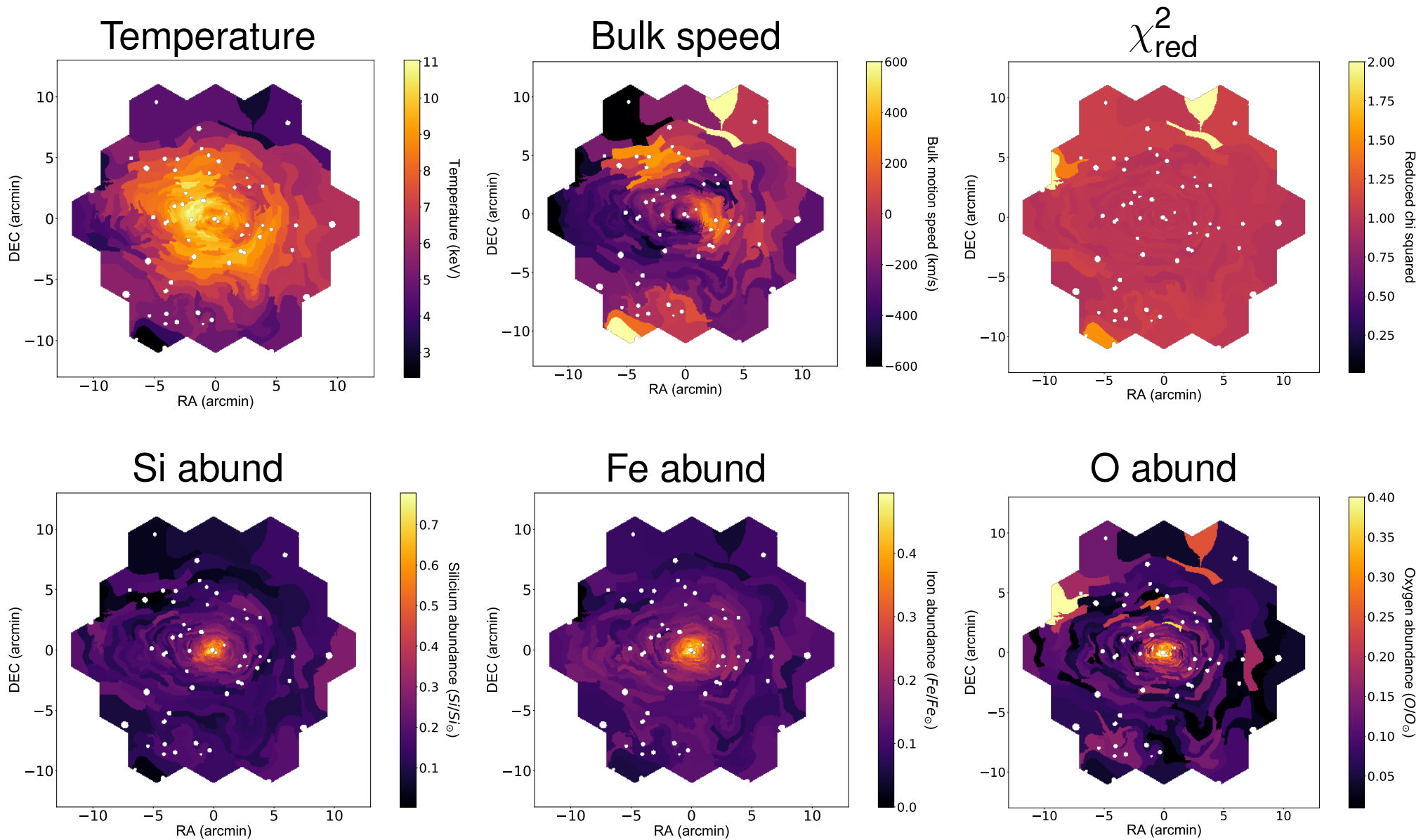
# Example: Galaxy cluster observations



Galaxy cluster simulation:  
19 pointings à 100 ks

E. Cucchetti

# Example: Galaxy cluster observations



E. Cucchetti

# Photon generation

## SIMPOT source model:

- spectral shape
- position
- lightcurve
- source extent (image)
- cosmic X-ray background
- Galactic diffuse emission

Simput

phogen

## Input data:

- effective area
- vignetting information
- point spread function
- S/C attitude
- S/C jitter

Impact File  
PhotonList  
/ ImpactList

# Photon detection

Impact File  
ImpactList

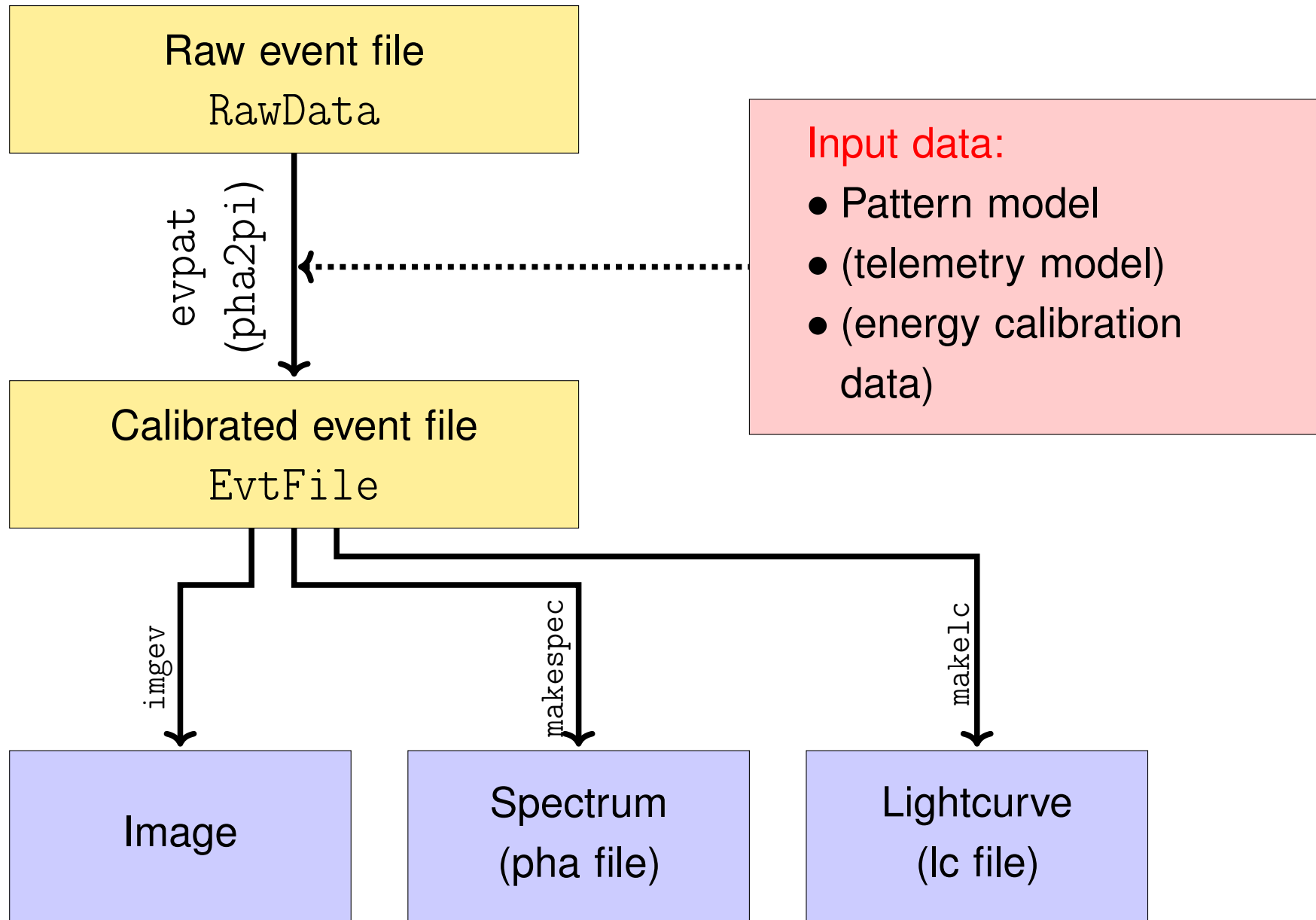
gendetsim

Raw event file  
RawData

## Input data:

- Pixel size
- Quantum efficiency
- Detector resolution
- Charge cloud model
- Readout mode
- Lower energy threshold
- ADC model

# Photon processing







**Simulation Parameters**

Instrument: X-IFU  
 Mirror Assembly: X-IFU  
 Detector mode: baseline  
 Filter:

Detailed explanations of the WFI detector modes can be found in the [WFI bright source report](#) ?

Attitude  
 pointed Observation RA:  deg Dec:  deg

**Spectral Components** [Add simple point source](#)

Upload source description ([SIMPOT format](#) or XSPEC parfile)

Cosmic X-ray Background (logN-logS AGN)  
 ROSAT All-Sky Survey (Bright & Faint Source Catalogs) + Sco X-1  
 Galactic Ridge X-ray Emission

Exposure time:  ks   
 Tstart:  0 s

Returned Data Products  
 Event file  
 Image  
 SIMPUT file (source only)

Questions and bug reports: [sixte-dev@lists.fau.de](mailto:sixte-dev@lists.fau.de)



Access:

- Source code:

<http://www.sternwarte.uni-erlangen.de/research/sixte/index.php>

Works on Linux and Mac, git and release versions.