Financiado por la Unión Europea NextGenerationEU
GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Plan de Recuperación, Transformación y Resiliencia
GENERALITAT VALENCIANA Conselleria de Educación, Universidades y Empleo
GVANEXT Fondos Next Generation en la Comunitat Valenciana
Universitat d'Alacant Universidad de Alicante
LAEX LABORATORIO DE ASTROFÍSICA ESPACIAL DE RAYOS X

Technological development and preparation for scientific exploitation of Athena XIFU

ASFAE/2022/02 project

- 1st objective: *"Conducting Large Surveys with Athena-XIFU"*
- 2nd objective: *"Contributing to the simulator: Parallel Computing, GPUs, Minimization and Optimization Algorithms, Machine Learning"*

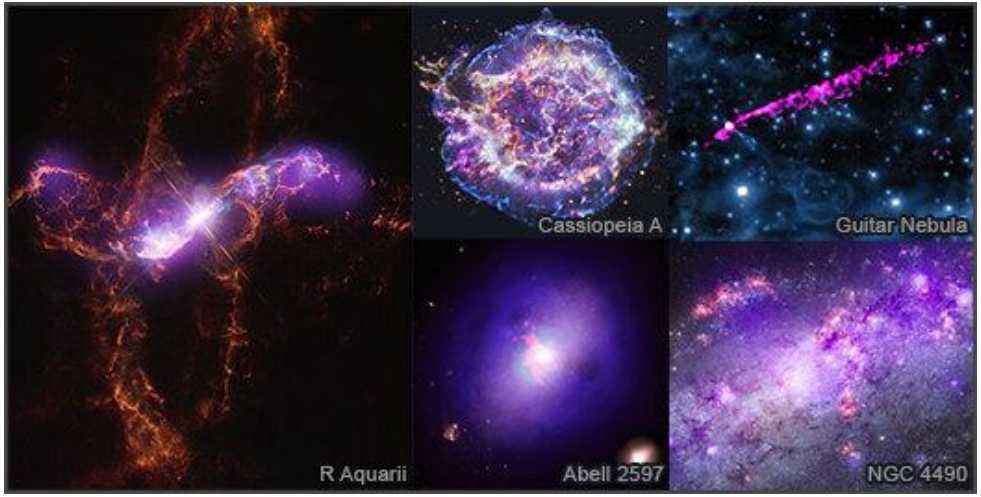
Graciela Sanjurjo
José Miguel Torrejón
José Joaquín Rodes
Jessica Planelles

Financiado por la Unión Europea NextGenerationEU
Gobierno de España · Ministerio de Ciencia, Innovación y Universidades
Plan de Recuperación, Transformación y Resiliencia
Generalitat Valenciana · Conselleria de Educación, Universidades y Empleo
GVA NEXT · Fondos Next Generation en la Comunitat Valenciana
Universitat d'Alacant · Universidad de Alicante
LAEX · Laboratorio de Astrofísica Espacial de Rayos X

Introduction to X-ray Astronomy:

Revolutionizing Our Understanding of the Universe

- X-ray astronomy provides a new observational window.
- Studies extreme cosmic phenomena like black holes, neutron stars, supernovae, and galaxy clusters.
- X-rays penetrate regions opaque to other wavelengths, revealing the universe's structure and evolution.



Financiado por la Unión Europea NextGenerationEU
Gobierno de España Ministerio de Ciencia, Innovación y Universidades
Plan de Recuperación, Transformación y Resiliencia
Generalitat Valenciana Conselleria de Educación, Universidades y Empleo
GVA NEXT Fondos Next Generation en la Comunitat Valenciana
Universitat d'Alacant Universidad de Alicante
LAEX Laboratorio de Astrofísica Espacial de Rayos X

High-Mass X-ray Binary Systems (HMXBs):

Insights into Binary Star Systems

- HMXBs consist of a massive star and a compact object (neutron star or black hole).
- Intense X-ray emissions from the interaction between components.
- X ray radiation is produced when the donor's matter is accreted by the compact object.
- Studying HMXBs helps understand binary system evolution and potential sources of gravitational waves and gamma-ray bursts.

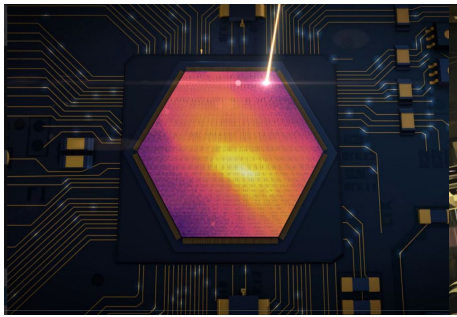
Financiado por la Unión Europea NextGenerationEU
Gobierno de España Ministerio de Ciencia, Innovación y Universidades
Plan de Recuperación, Transformación y Resiliencia
Generalitat Valenciana Conselleria de Educación, Universidades y Empleo
GVA NEXT Fondos Next Generation en la Comunitat Valenciana
Universitat d'Alacant Universidad de Alicante
LAEX Laboratorio de Astrofísica Espacial de Rayos X

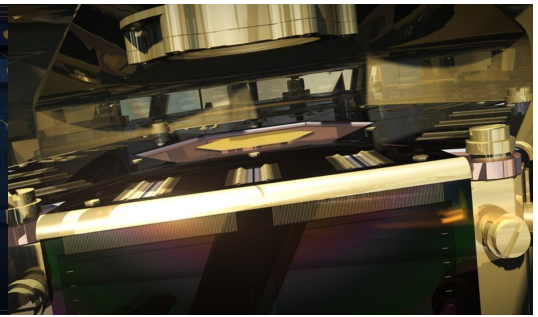
Future ESA's mission: ATHENA

The XIFU Telescope

- Exploring the Hot and Energetic Universe
- Instrument of the future space telescope of the European Space Agency, Athena (Advanced Telescope for High Energy Astrophysics).
- X-IFU is an X-ray spectrometer designed to capture the universe in high spectral resolution, with microcalorimeters.
- High spectral resolution + high-quality images

X-IFU	
Spectral resolution	2.5 eV (E<7 keV)
Energy range	0.2-12 keV
Pixel size	~ 5"
Field-of-view	Hexagon Equiv. 5 arcmin Ø
Non X-ray background	< 5.10^{-3} cts/s/cm^2/keV
Detector	3840 TES





ATHENA X-ray Integral Field Unit

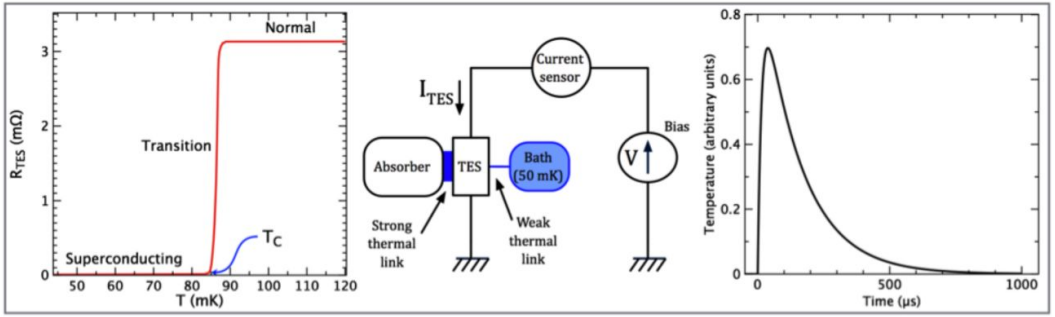
Financiado por la Unión Europea NextGenerationEU
Gobierno de España · Ministerio de Ciencia, Innovación y Universidades
Plan de Recuperación, Transformación y Resiliencia
Generalitat Valenciana · Conselleria de Educación, Universidades y Empleo
GVA NEXT · Fondos Next Generation en la Comunitat Valenciana
Universitat d'Alacant · Universidad de Alicante
LAEX · Laboratorio de Astrofísica Espacial de Rayos X

TES (Transmission Edge Sensors)

- TES are thin superconducting thermistors that operate in the transition region between superconducting and normal states.
- The absorption of a photon increases the temperature of the TES and, therefore, the resistance of the TES.
- Each X-ray photon generates a current pulse, the intensity varies depending on its energy, used to measure precisely the energy and arrival time of the photon.
- Measures are used to reduce the background effects of particles, such as the Cryogenic Anticocidence (CryoAC) detector.

X-IFU – Principle

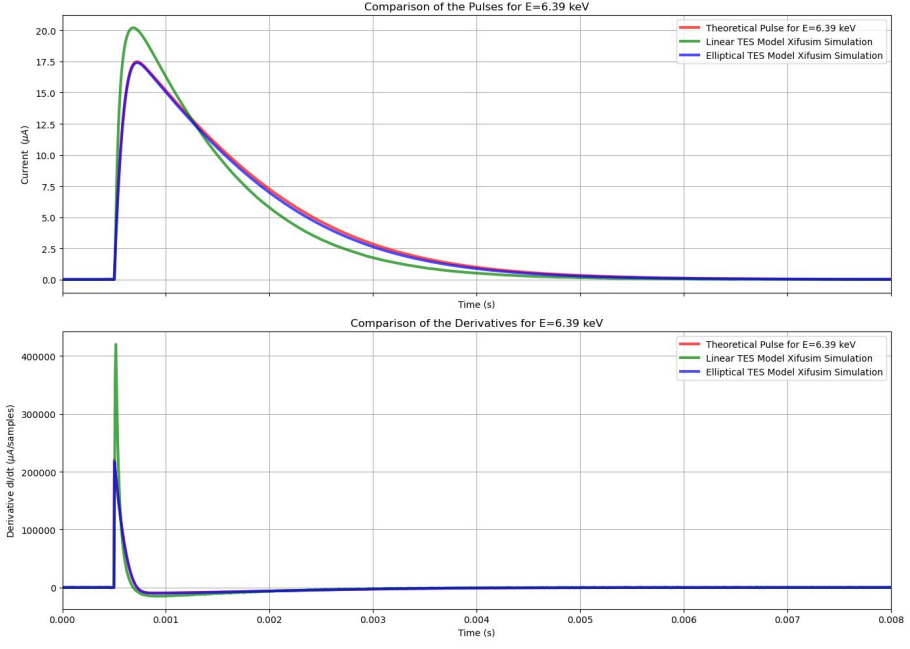
X-IFU-pixels are single *Transition Edge Sensors*, operated at 50 mK
⇒ **measure temperature increase** of photon hitting the pixel



Development of the XIFU Simulator

Ensuring XIFU's Success

- Advanced simulator developed by FAU+IFCA+UA collaboration team.
  - Software development for TES Elliptical Response Model
  - Integrated developed software into Xifusim Simulator
  - Comparison of simulated data under elliptical response model of the TES with laboratory data
- Simulator calibrates the instrument and simulates photon pulses.
- Essential for testing, optimizing XIFU's performance, and interpreting real data.
- The simulator will ultimately be integrated in the Ground Segment software of the telescope



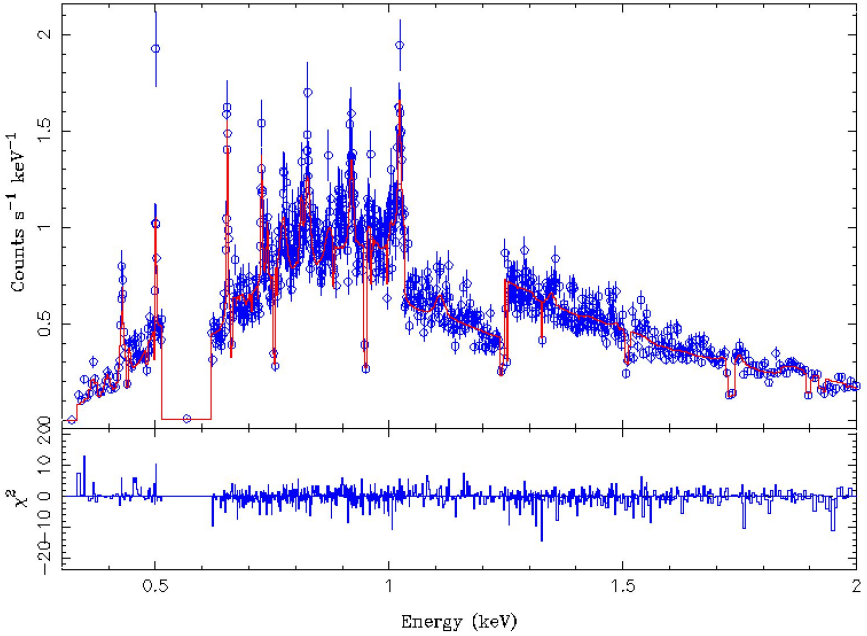
Financiado por la Unión Europea NextGenerationEU
Gobierno de España Ministerio de Ciencia, Innovación y Universidades
Plan de Recuperación, Transformación y Resiliencia
Generalitat Valenciana Conselleria de Educación, Universidades y Empleo
GVA NEXT Fondos Next Generation en la Comunitat Valenciana
Universitat d'Alacant Universidad de Alicante
LAEX Laboratorio de Astrofísica Espacial de Rayos X

Analyzing High-Resolution Spectra: Line detection

Innovative Analytical Tools

- High-resolution spectra reveal chemical composition, motion velocities, and physical conditions.
- Requires sophisticated algorithms and computational tools for full data exploitation.
- We have developed an automatic line detection algorithm that can be used either in Python or within a fitting package like ISIS (Interactive Spectral Interpretation System).
- This code will save a lot of time compared to manually detecting and adding the emission lines present in the spectra.

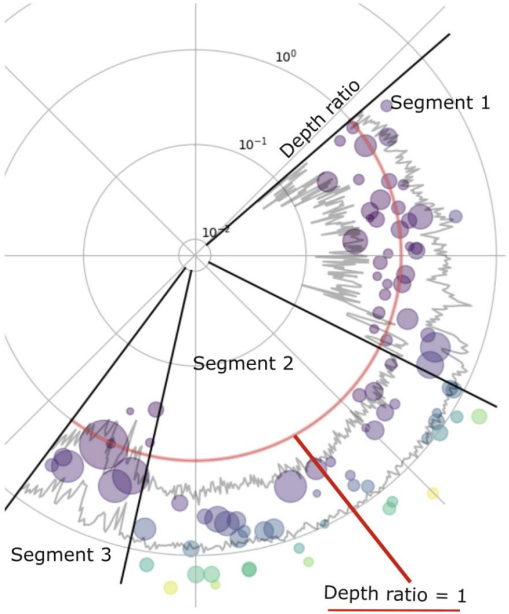
Automatic line detection algorithm example



Financiado por la Unión Europea NextGenerationEU
Gobierno de España · Ministerio de Ciencia, Innovación y Universidades
Plan de Recuperación, Transformación y Resiliencia
Generalitat Valenciana · Conselleria de Educación, Universidades y Empleo
GVA NEXT · Fondos Next Generation en la Comunitat Valenciana
Universitat d'Alacant · Universidad de Alicante
LAEX · Laboratorio de Astrofísica Espacial de Rayos X

Dips within the light curves

- Light curves study variations in X-ray intensity over time, providing clues about dynamic processes and wind structures.



Methods to distinguish real astrophysical phenomena from noise:

Gaussian Mixture

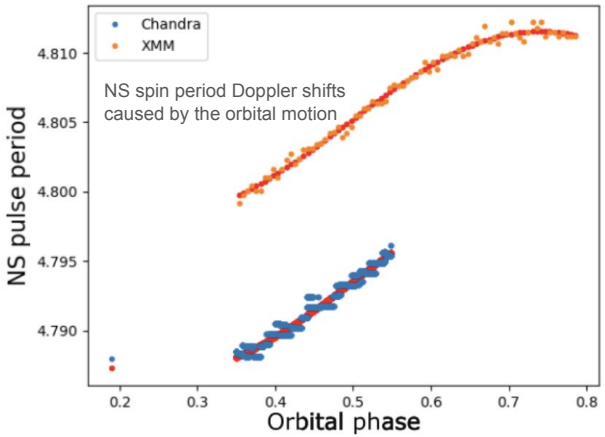
Autoencoders

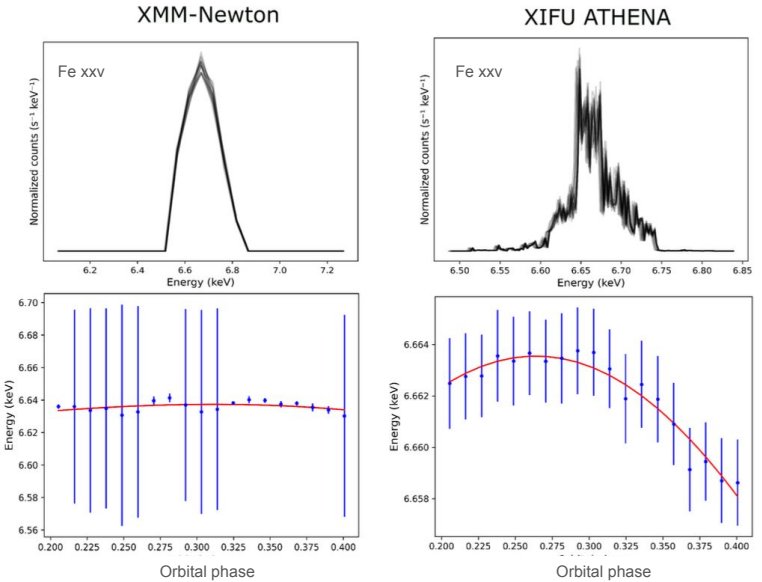
Financiado por la Unión Europea NextGenerationEU
Gobierno de España · Ministerio de Ciencia, Innovación y Universidades
Plan de Recuperación, Transformación y Resiliencia
Generalitat Valenciana · Conselleria de Educación, Universidades y Empleo
GVA NEXT · Fondos Next Generation en la Comunitat Valenciana
Universitat d'Alacant · Universidad de Alicante
LAEX · Laboratorio de Astrofísica Espacial de Rayos X

New possibilities: Doppler analysis in X-ray astronomy

Until now, only detectable if very prominent, the new XIFU simulations reveal that Doppler analysis will provide valuable insights into X-ray Dynamics

Real data: Cen X-3





	System	*XMM*	*XIFU*
Distance to barycenter (R*)	2.2	2.8±0.3	2.8±0.6
Orbital period (d)	3.2	3.1 ± 0.1	3.4 ± 0.1
Eccentricity	0.1	0.2 ± 0.06	0.04 ± 0.05
Angle to the periapsis	40	29± 12	46±8
Inclination	86	89 ± 4	89 ± 8
χ^2		0.2	0.9

Financiado por la Unión Europea NextGenerationEU
Gobierno de España · Ministerio de Ciencia, Innovación y Universidades
Plan de Recuperación, Transformación y Resiliencia
Generalitat Valenciana · Conselleria de Educación, Universidades y Empleo
GVA NEXT · Fondos Next Generation en la Comunitat Valenciana
Universitat d'Alacant · Universidad de Alicante
LAEX · Laboratorio de Astrofísica Espacial de Rayos X

Conclusions

Advancing X-ray Astronomy

- The Elliptical Response Model of the TES, has been implemented in Xifusim (the simulator for Athena XIFU), and has been tested.
- Comparing simulated data with laboratory data shows that our model achieves the highest precision in photon response.
- Our analytical tools have been useful in several publications. Doppler analysis has helped us define orbital parameters, and dip detection has clarified the state transition of Cen X-3.

Financiado por la Unión Europea NextGenerationEU
GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Plan de Recuperación, Transformación y Resiliencia
GENERALITAT VALENCIANA Conselleria de Educación, Universidades y Empleo
GVANEXT Fondos Next Generation en la Comunitat Valenciana
Universitat d'Alacant Universidad de Alicante
LAEX LABORATORIO DE ASTROFÍSICA ESPACIAL DE RAYOS X

Future Prospects

- Athena XIFU will enhance new discoveries in X-ray astrophysics.
- We are developing and improving analytical tools to be prepared for the high resolution that Athena will provide once it is launched, and be ready to analyse the data provided by this observatory.
- Broader applications in other scientific and technological domains include:
    - Optimization and improvement of TES detectors for future X-ray telescopes, in collaboration with companies specialized in aerospace technology and sensors.
    - Real-time data multiplexing and readout is applicable to quantum communication and computing.
    - Advanced simulation techniques are transferable to climate studies, genome decoding, and cybersecurity.

Financiado por la Unión Europea NextGenerationEU
GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Plan de Recuperación, Transformación y Resiliencia
GENERALITAT VALENCIANA Conselleria de Educación, Universidades y Empleo
GVANEXT Fondos Next Generation en la Comunitat Valenciana
Universitat d'Alacant Universidad de Alicante
LAEX LABORATORIO DE ASTROFÍSICA ESPACIAL DE RAYOS X

THANK YOU VERY MUCH!

jessica.planelles@ua.es