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Dark Matter, X-ray Astronomy & Medical imaging

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Dark Matter

Credit: NASA Goddard Space Flight Center
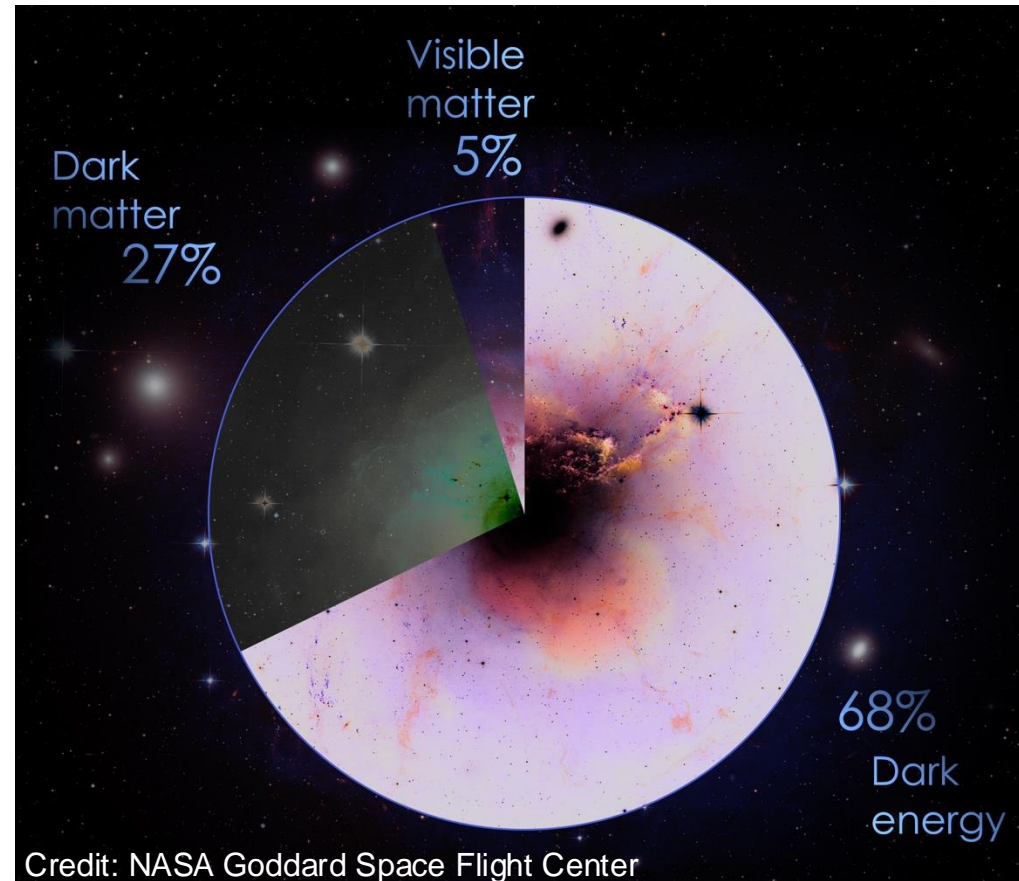
Axions in a nutshell

- **Strong CP problem**

CP violation expected in QCD, but not observed (θ, nEDM)
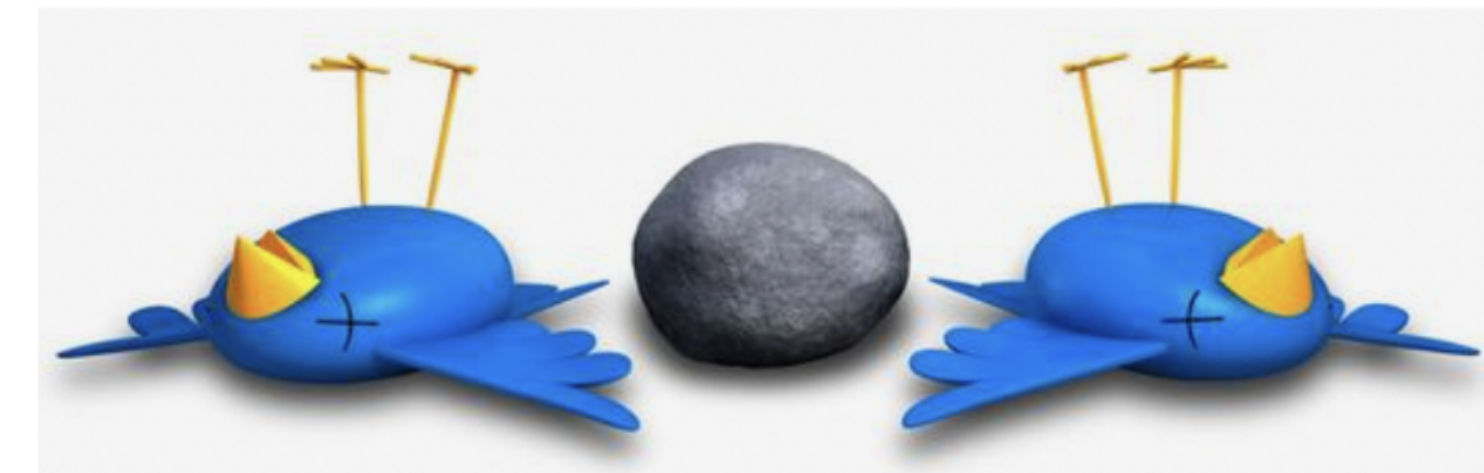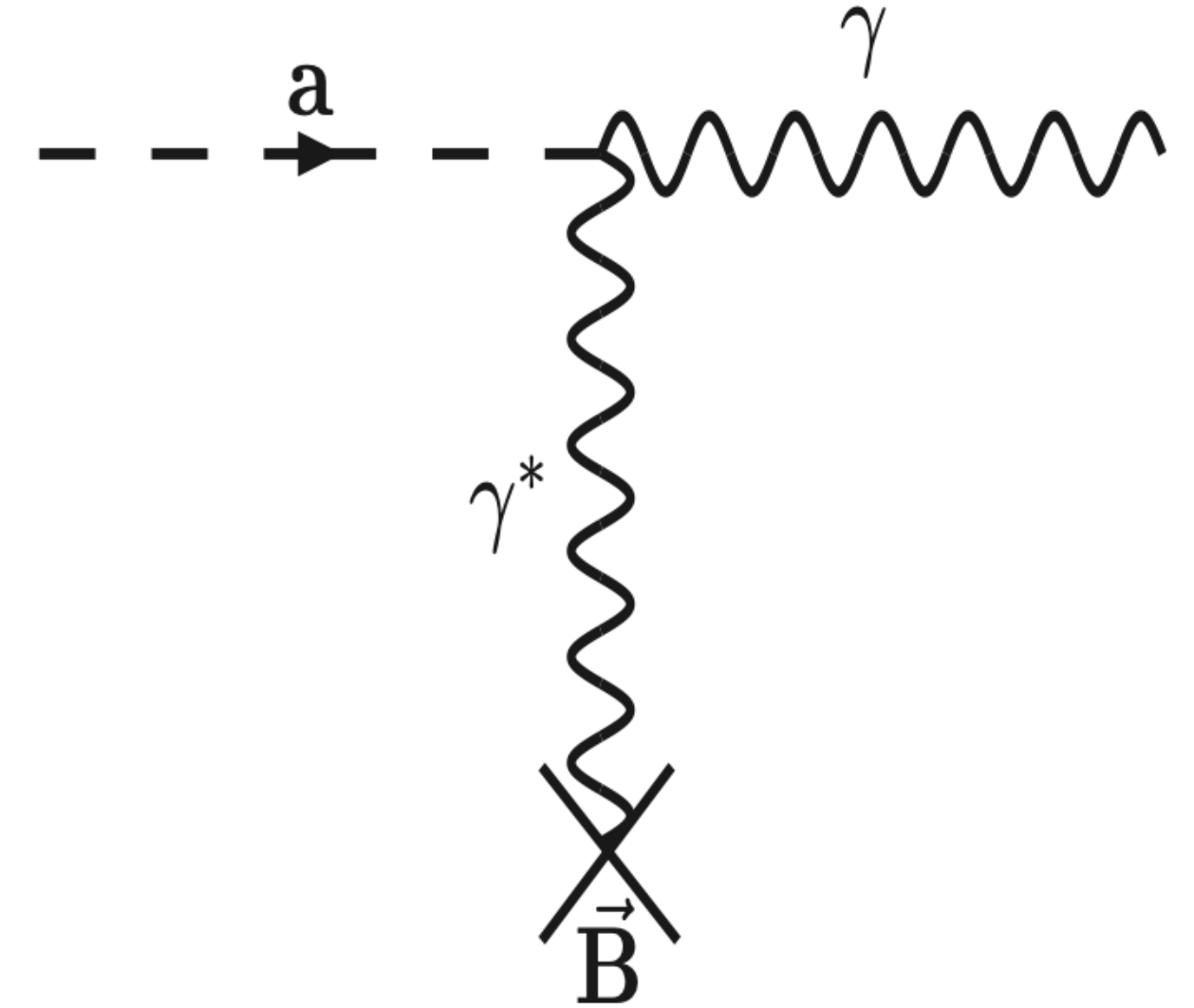
- **Peccei-Quinn solution**

New global U(1) symmetry, θ turn into a dynamical variable

- **Axion**

Pseudo Goldstone-Boson of spontaneous symmetry breaking of PQ at unknown scale f_a

- **Properties of this potential DM candidate**

- Extremely weakly-coupled fundamental pseudo-scalar
- Generic coupling to 2 photons, mass unknown $m_a \propto g_{a\gamma,}$

  → Dark matter candidate & solves strong CP

The International Axion Observatory (IAXO)

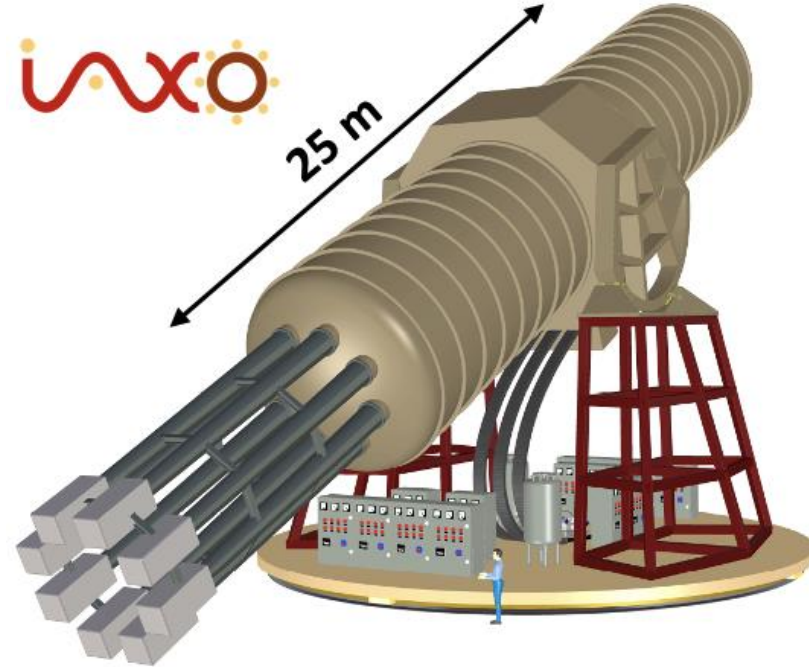► AXION HELIOSCOPES: laboratory axion searches looking for solar axions
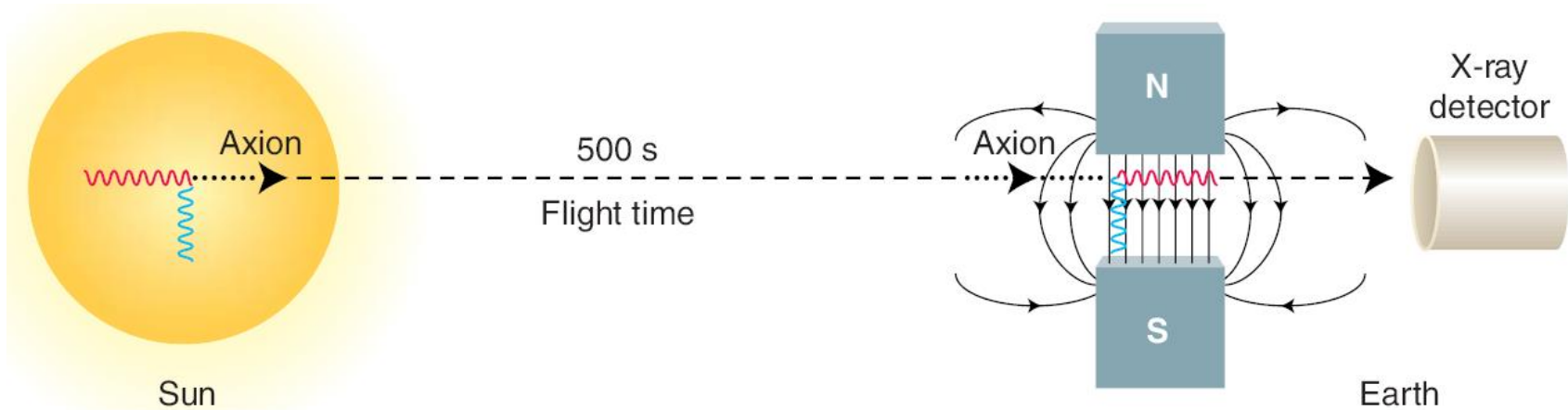
P. Sikivie 1983 PRL 51 1415

van Bibber et al 1989 PRD 39 2089

The International Axion Observatory (IAXO)

► AXION HELIOSCOPES: laboratory axion searches looking for solar axions


CAST

Baby **IAXO**

10 m

IAXO

25 m

Dark Matter Topic 1: Ray tracing simulations of X-ray optics and study of multilayer coatings

- X-ray optics have many applications (dark matter searches, x-ray astronomy, …)

- Multivariable optimization challenges tuned to experiments

- What we will do:
  - Setup of geometry (Python or IDL)
  - Design and optimization of coating (metallic, multilayers)
  - Analysis of design and physics impact

Understand, design and optimize next-generation x-ray optics

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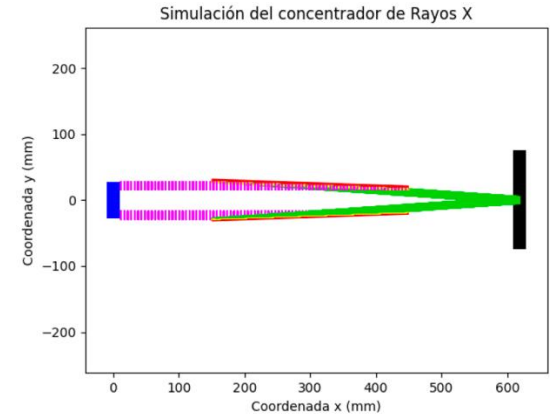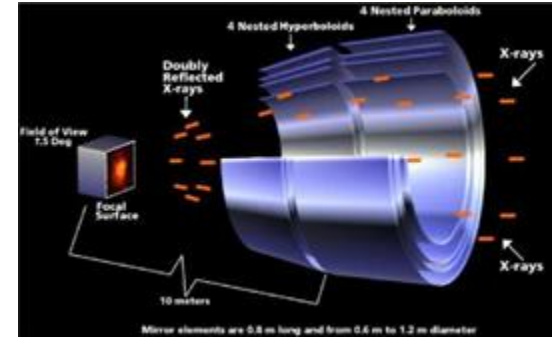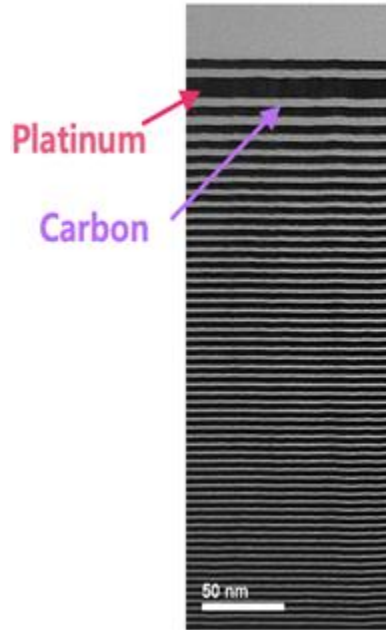
Dark Matter Topic 2: Simulation and implementation of measurement of radiopurity of the x-ray mirror substrates for IAXO

- Dark matter searches require ultra-low background levels:
  $< 10^{-7} - 10^{-8}$ cts/keV/cm^2/s

- Less than 1 evt per 6 mo of data taking!

- Need to use radiopure components!

- What we will do:
  - Simulate effect of radio-impurities on x-ray telescope performance in the Rare Event Searches Toolkit (REST)
  - Implement data measured at Canfranc
  - Evaluate performance of IAXO

  Impact of contamination on DM sensitivities and implementation in end-to-end simulator

LSC
Laboratorio Subterráneo Canfranc

REST

IAXO
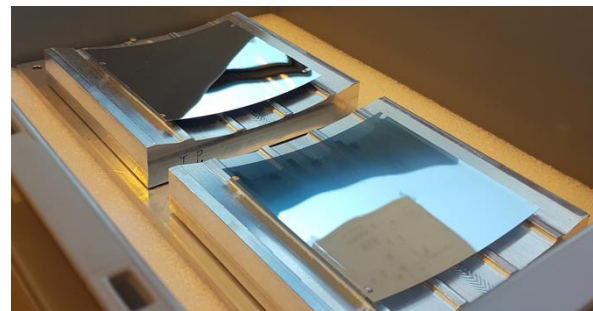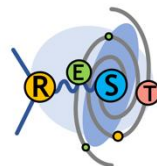
Dark Matter Topic 3: Ultra-low background levels in searches for light dark matter through active particle discrimination in liquid scintillators

- Ultra-low background detectors are key in dark matter searches
- This requires active particle discrimination in addition to other techniques to suppress background (PSD with EJ301/309 Liquid scintillator)
- What we will do:
  - Learn about axion DM searches
  - Study different strategies to implement micromegas (MM) detectors in IAXO
  - Maximize experimental sensitivity
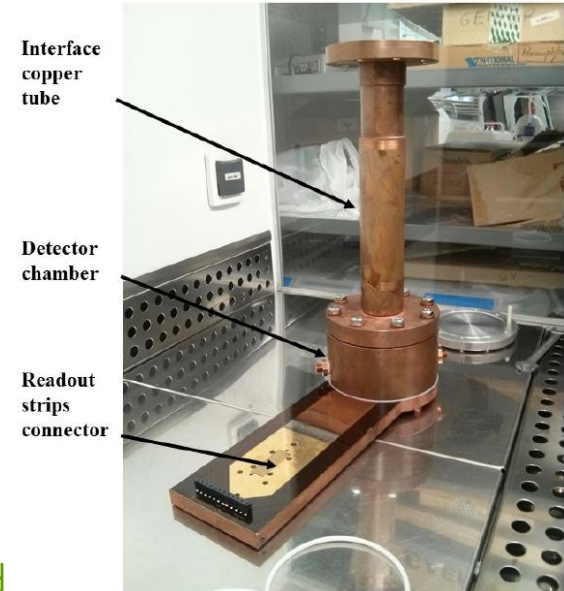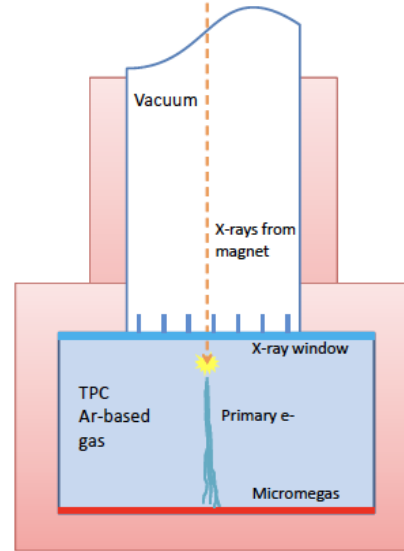
Work with real IAXO prototype data and use Monte Carlo techniques within the REST software to analyze results obtained in terms of stability, gain and efficiency of micromegas

X-Ray astronomy

- X-ray astronomy done from Space
- Very recent field, full of surprises
- "Where the action happens":
  - Black hole physics
  - Neutron star observations
  - Ultra-luminous X-ray binaries
  - X-ray pulsars and magnetars
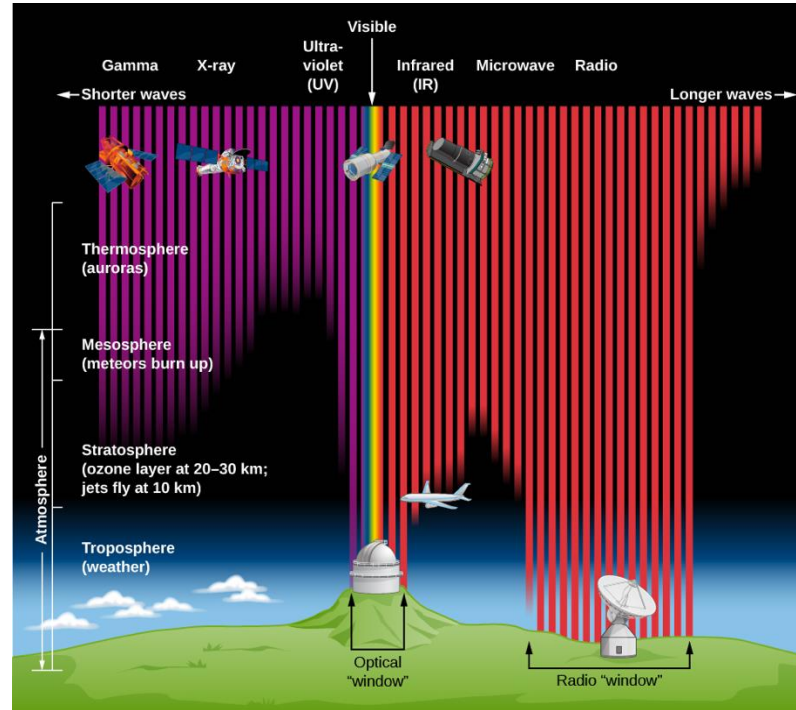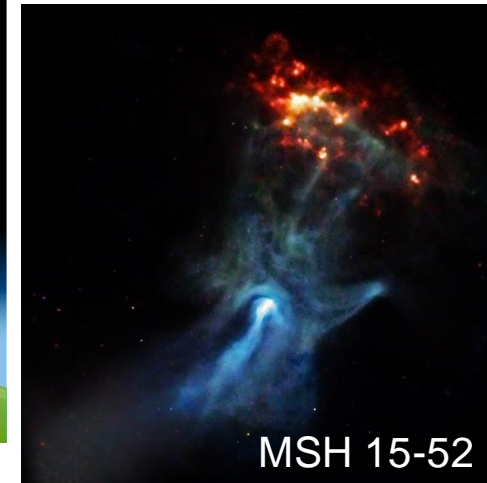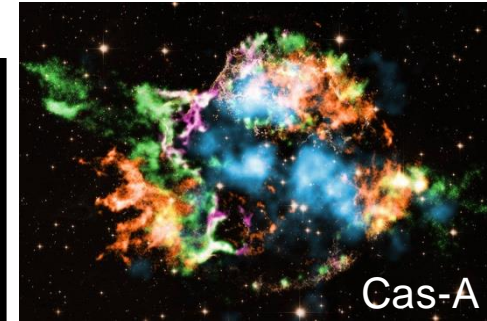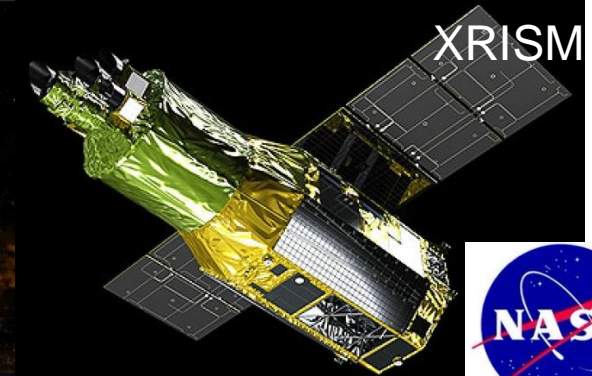 - γ-ray bursts (which are gravitational wave counterparts!)

Cas-A

MSH 15-52

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X-Ray astronomy missions

XMM-Newton

INTEGRAL

Chandra

NuSTAR

Swift

XRISM
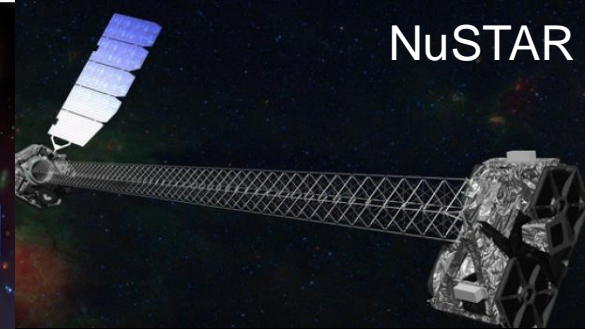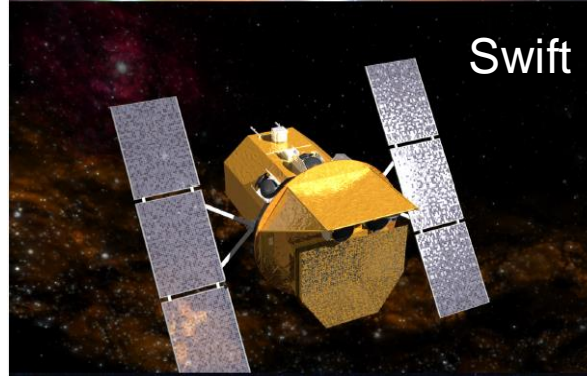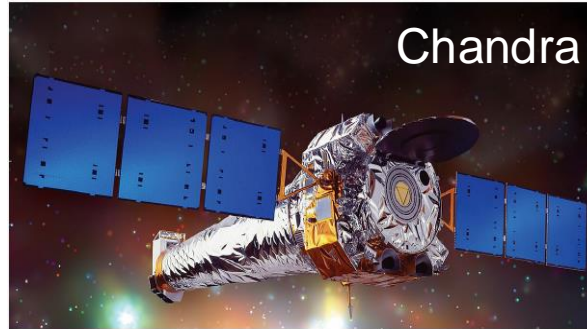
X-ray Topic: Astroparticle physics analysis of observational data from space-based x-ray telescopes

- Learn how to analyze and interpret observational data from state-of-the-art x-ray space missions
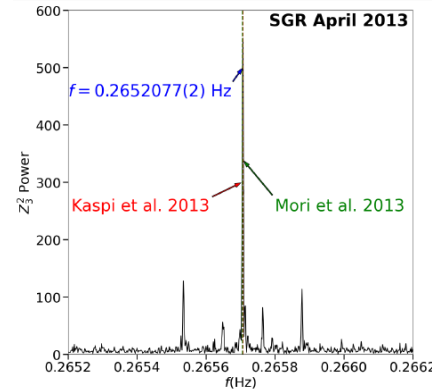
- E.g. observations of neutron stars, magnetars, binary systems

- What we will do:
  - Learn about the physics of neutron stars
  - Get to know different space observatories
  - Use NASA and ESA tools to process data
  - Analyze and interpret observations

▶ Use processing pipelines, analyze and apply results to improve understanding of stellar objects

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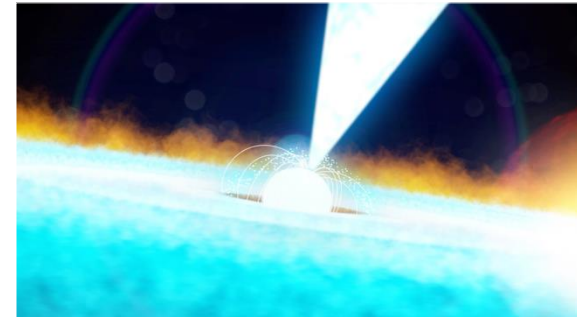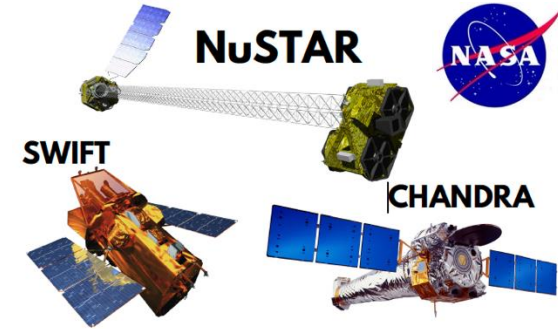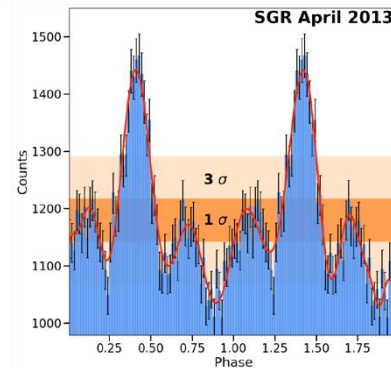
Medical Imaging Topic: Advancing focusing optics for small-animal radionuclide imaging in biomedicine: SPECT with multilayer-coated Wolter-I microscopes

- Imaging based on pinholes: small pinhole, need higher dose you will get bad resolution
- Wolter optics can decouple this! But need smooth mirrors
- Recent developments for HED physics enable this!
- What we will do:
  - Learn about X-ray microscopes
  - Setup simulations and implement latest technological advances

▶ Study feasibility of X-ray optics for medical imaging application
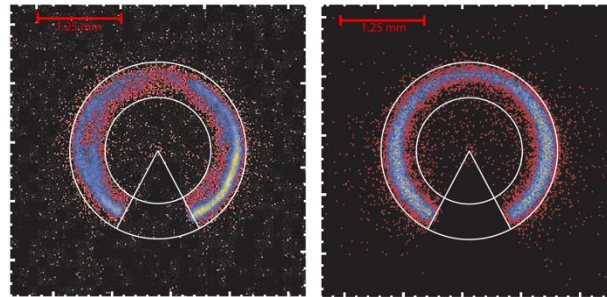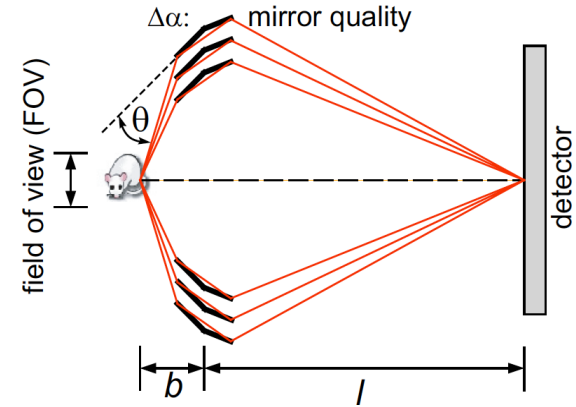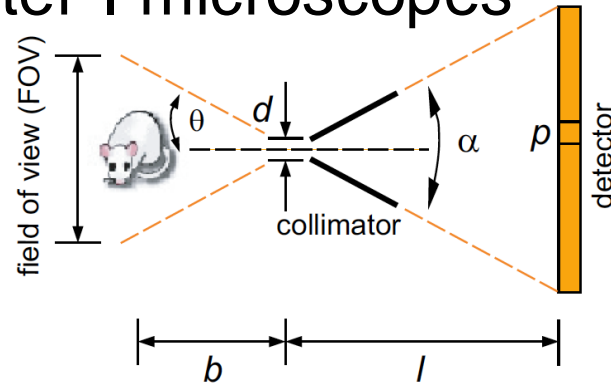
Interested?
Wanna know more?

Feel free to contact us:

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