

High-Energy Astrophysics

AA2019-20

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The role of high-energy emission

- Probe of the innermost regions of compact source (X-ray binaries, AGN, etc)
- Solar-system bodies, stars, galaxies (also in their non-active phase) emit X-rays
- Cherenkov emission (CTA) is one of the ways to go in the future
- Event Horizon Telescope: probing the innermost regions of M87

What you may expect from the course

- Far from being complete, impossible to cover all the high-energy astrophysics issues
- Overview of emission mechanisms and the way detectors work at high energies
- How do sources emit at high energies? Some answers, but many open questions
- Books vs. papers: the way to proceed to have a proper view of what's going on in astrophysics

Basic rule: you have a question, you try and find the way (method: data, simulations, theory) to possibly answer that question

General on X-ray Astrophysics

- J. Trumper & G. Hasinger: "The Universe in X-rays",
- Frederick D. Seward, Philip A. Charles: "Exploring the X-ray Universe",
- Malcolm S. Longair: "High-Energy Astrophysics",
- Fulvio Melia: "High-Energy Astrophysics",

X-ray and Gamma-ray detectors, and data analysis

- Glenn F. Knoll: "Radiation Detectors for X-Ray and Gamma-Ray Spectroscopy",
- Hale Bradt: "Astronomy Methods",
- S.M. Kahn, P. von Ballmoos, R.A. Sunyaev: "High-Energy Spectroscopic Astrophysics",
- G. W. Fraser: "X-ray detectors in astronomy"
- Keith Arnaud, Randall Smith, Aneta Siemiginowska: "Handbook of X-ray Astronomy"

Emission Processes

- Gabriele Ghisellini: "Radiative processes in high energy astrophysics",
- Hale Bradt: "Astrophysics Processes: The Physics Of Astronomical Phenomena",
- S.M. Kahn, P. von Ballmoos, R.A. Sunyaev: "High-Energy Spectroscopic Astrophysics",
- Anil K. Pradhan & Sultana N. Nahar: "Atomic Astrophysics and Spectroscopy",
- George B. Rybicky, Alan P. Lightman: "Radiative Processes in Astrophysics",
- Charles D. Dermer & Govind Menon: "High energy radiation from black holes",

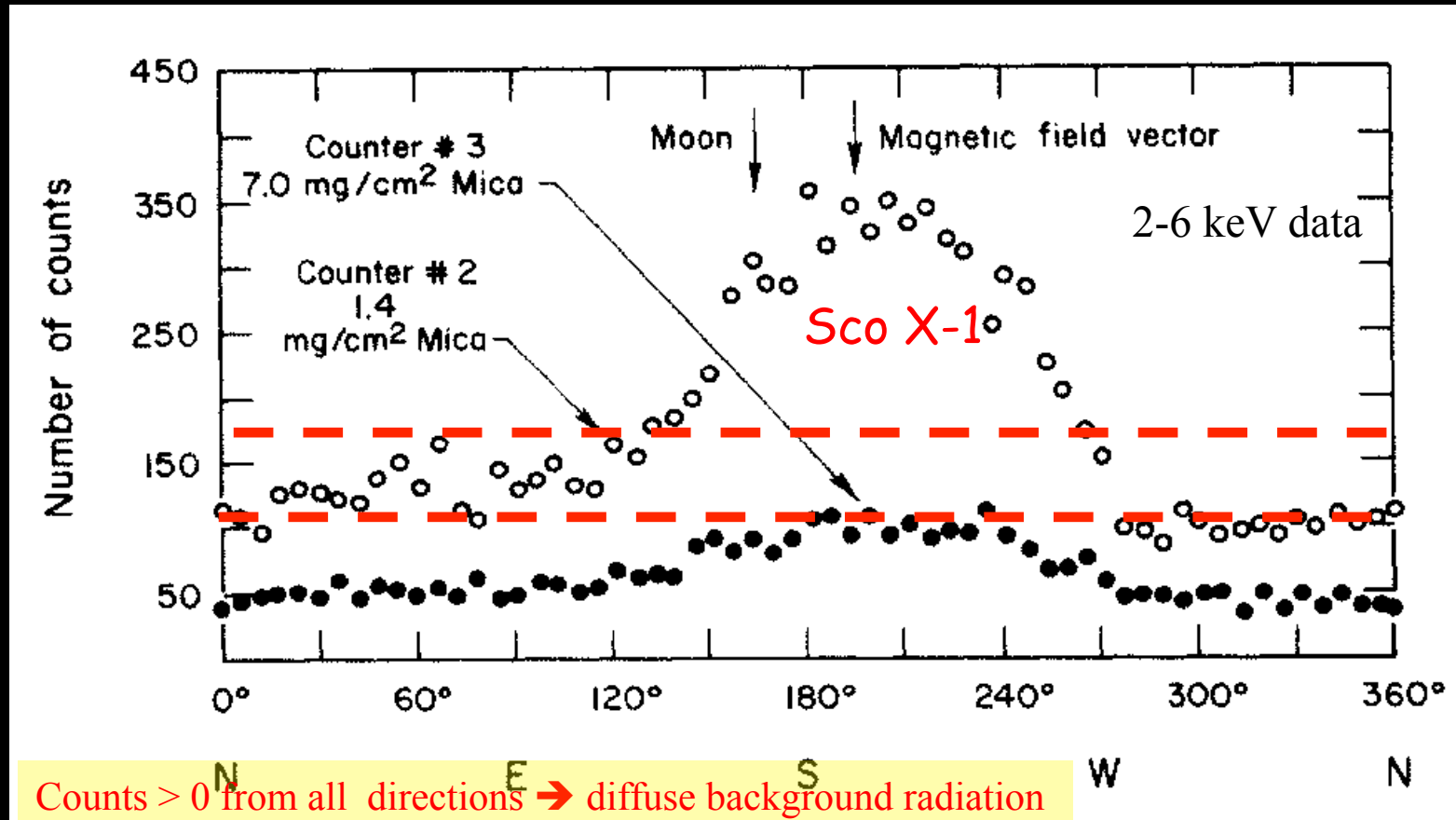
Accretion, AGN and compact stellar X-ray sources

- J. Frank, A. King & D. Raine: "Accretion Power in Astrophysics",
- Hagai Netzer: "The Physics and Evolution of Active Galactic Nuclei",
- Bradley M. Peterson: "An introduction to Active Galactic Nuclei",
- Julian H. Krolik: "Active Galactic Nuclei. From the Central Black Hole to the Galactic Environment",
- Walter H.G. Lewin, Michiel van der Klis: "Compact Stellar X-ray Sources",

Books
+ specialistic papers
– see also arXiv
(<https://arxiv.org>)
on a daily basis

Slides: useful as
'threads'
but please study
on textbooks

The dawn of X-ray Astronomy



- First X-ray detected source: Sco X-1
- Discovery of the X-ray background

Rocket experiment (Aerobee):
Giacconi et al. (1962), Physical Review Letter 9,
439

High-Energy Astrophysics

I part: Introduction to high-energy astrophysics

- Detection techniques for high-energy photons
- X-ray satellites
- A quick look to emission mechanisms and matter-radiation interactions

II part: Galactic X-ray Astrophysics

- X-ray emission from Solar System bodies
- (Pre-)main sequence stars
- White dwarfs, cataclismic variables, neutron stars, pulsars, pulsar wind nebulae X-ray binaries
- The Galactic Center and its past/current activity

III part: Extragalactic X-ray Astrophysics

- Clusters of galaxies
- Active Galactic Nuclei (AGN) and Unified Model
- Accretion: AGN vs. X-ray binaries
- X-ray surveys and X-ray background
- High-redshift AGN

IV parte: additional possible topics

- Dual (multiple) AGN systems – galaxy growth & evolution;
- X-ray emission from galaxies – link with data at longer wavelengths;
- Accretion physics onto compact objects – physics of accretion disks, ADAFs, etc.;
- SNe and SNRs;
- GRBs... AND MANY MORE

I part: Introduction to High-Energy Astrophysics

DETECTION TECHNIQUES OF HIGH-ENERGY PHOTONS

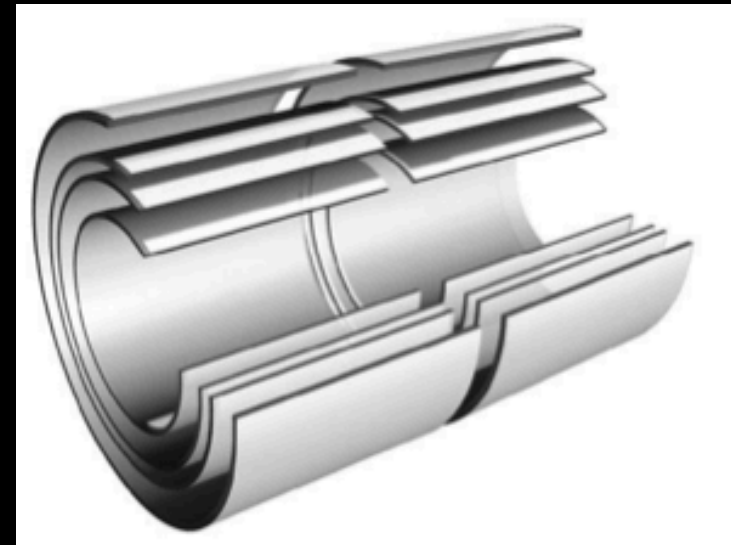
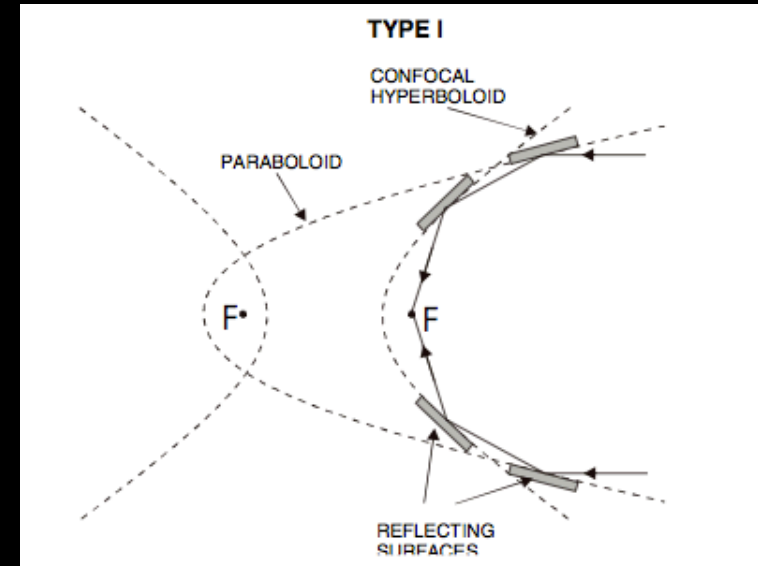
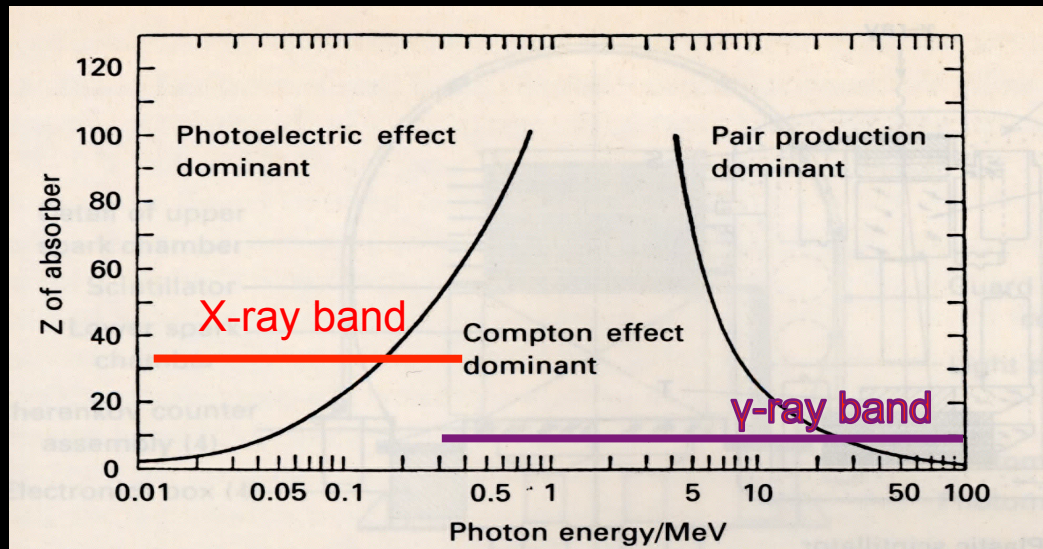
- **X-ray and γ -ray detectors:** properties, radiation-matter interaction, cross-sections
- Using CCDs in X-rays (vs. optical band)
- Collimators, focusing (Wolter-I) optics, coded masks, etc.
- **History of high-energy astrophysics**
- **Properties of currently flying X-ray and γ -ray telescopes**

EMISSION MECHANISMS IN A NUTSHELL

- Blackbody
- Bremsstrahlung
- Synchrotron
- Scattering processes (Thomson/Compton/Inverse Compton)
- Examples in the high-energy field
- Einstein coefficients
- Emission- and absorption-line processes
- Collisional/ionization equilibrium

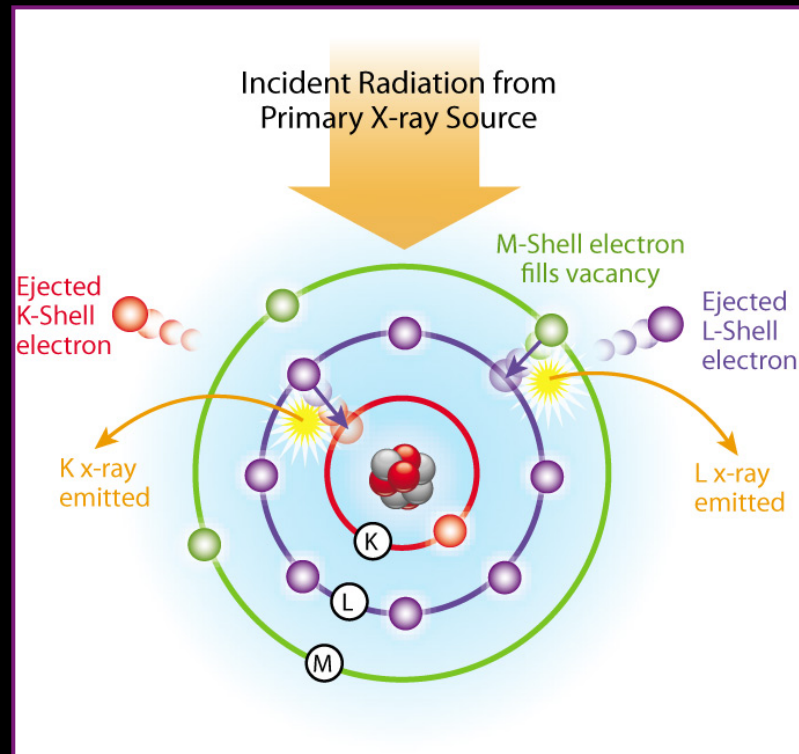
Some instrumental topics in Astrophysics Laboratory course
Much more on emission mechanisms in Prof. Dallacasa's course

Introduction to High-Energy Astrophysics



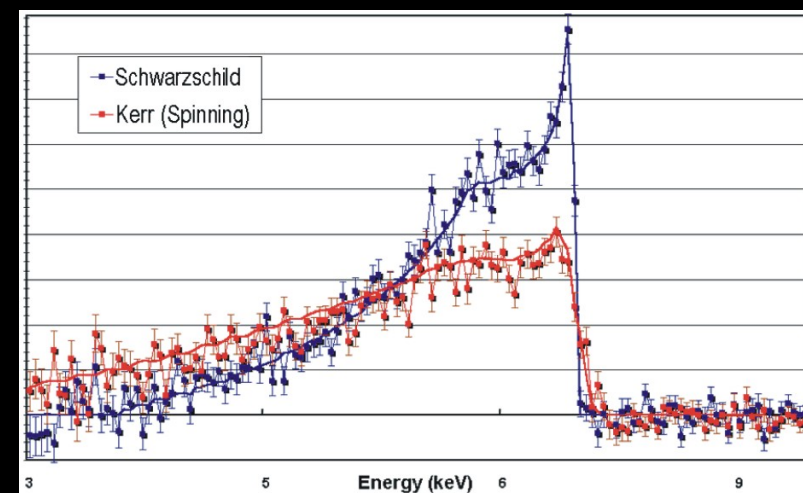
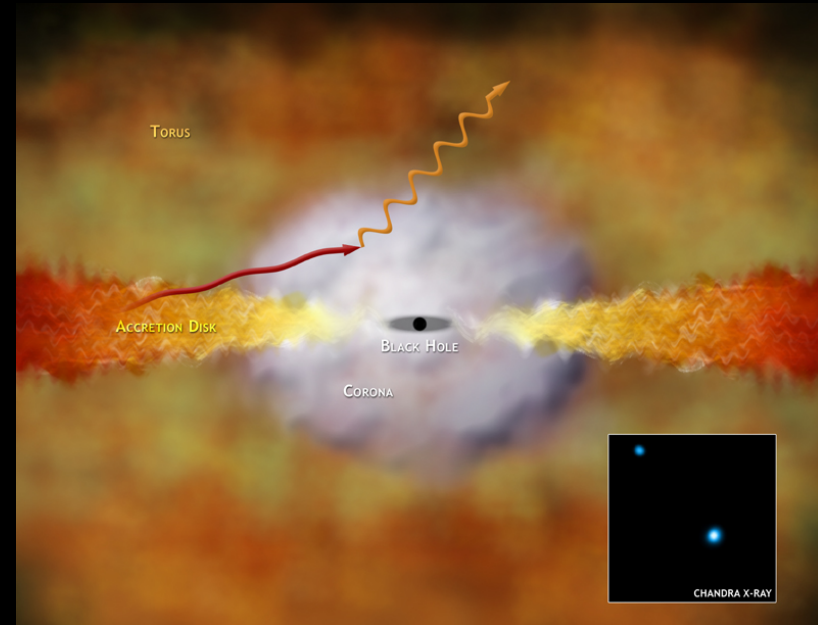
Wolter-I configuration
H. Wolter, Ann. Der Phys., NY10, 94 (1952)

Introduction to High-Energy Astrophysics



Fluorescence emission vs. Auger

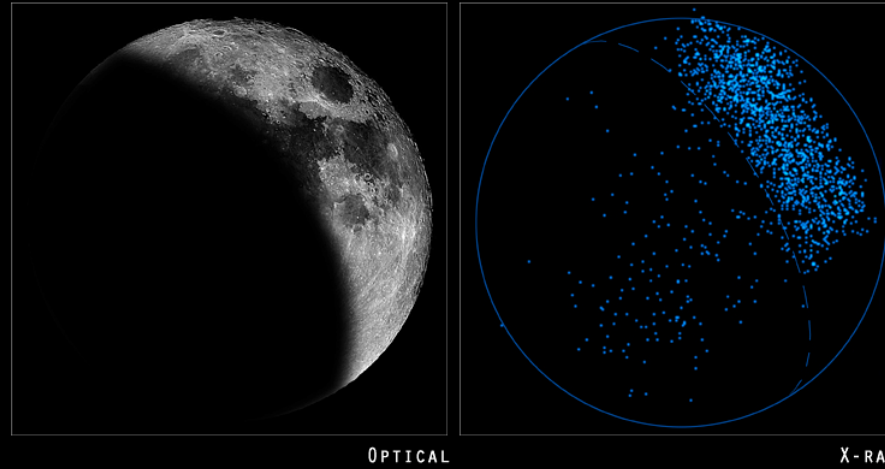
Iron line emission probing the innermost regions of compact objects (AGN, binaries, ...)



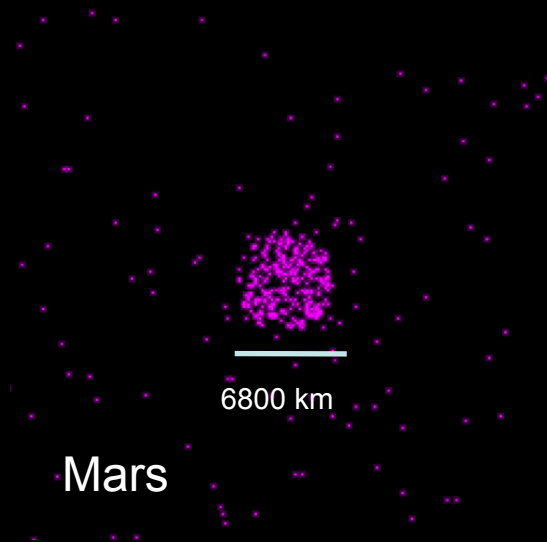
II part: **Galactic X-ray Astrophysics**

- X-ray emission from the bodies of the **Solar System**
 - X-ray emission from **stars**: (pre-) main sequence, low-mass stars
- X-ray emission from **compact objects**: white dwarfs, cataclismic variables, novae, neutron stars, pulsars and pulsar wind nebulae
- **X-ray binaries**: classification and properties. Principles of accretion physics
- A multi-wavelength view of the **Galactic Center**: properties from point-like and extended sources (bubbles, chimneys, etc.)
- Past, current, and future activity of SgrA*: what can we learn from the closest super-massive BH (but one of the least active)

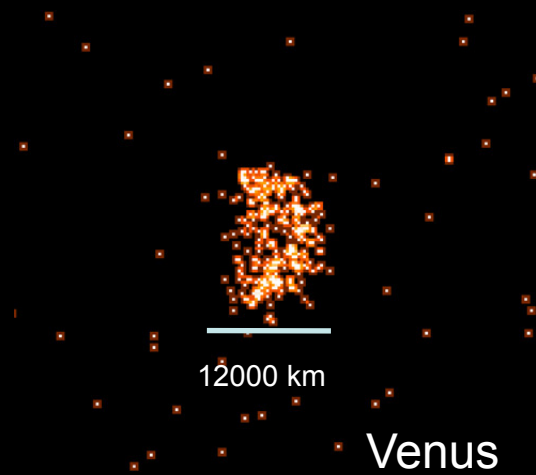
Galactic X-ray Astrophysics



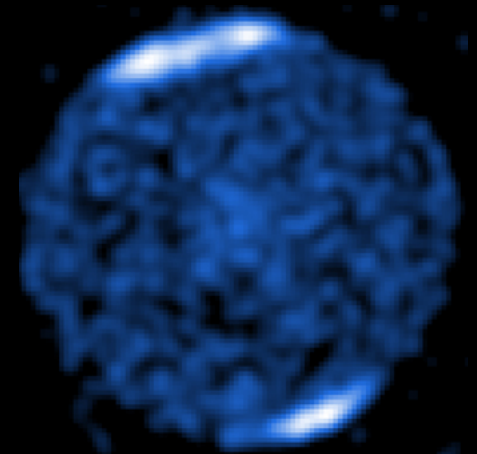
The Moon in X-rays



Mars



Venus



Jupiter

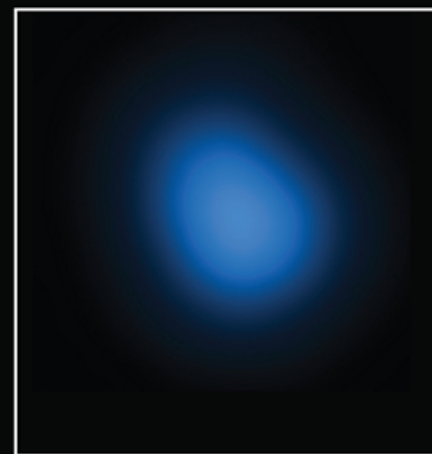
New Horizons

Not to scale



OPTICAL

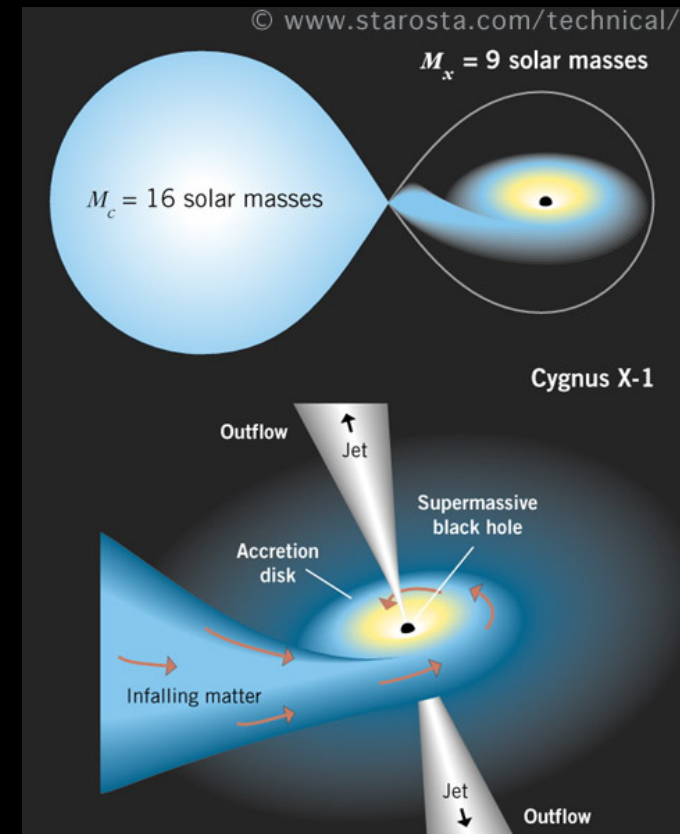
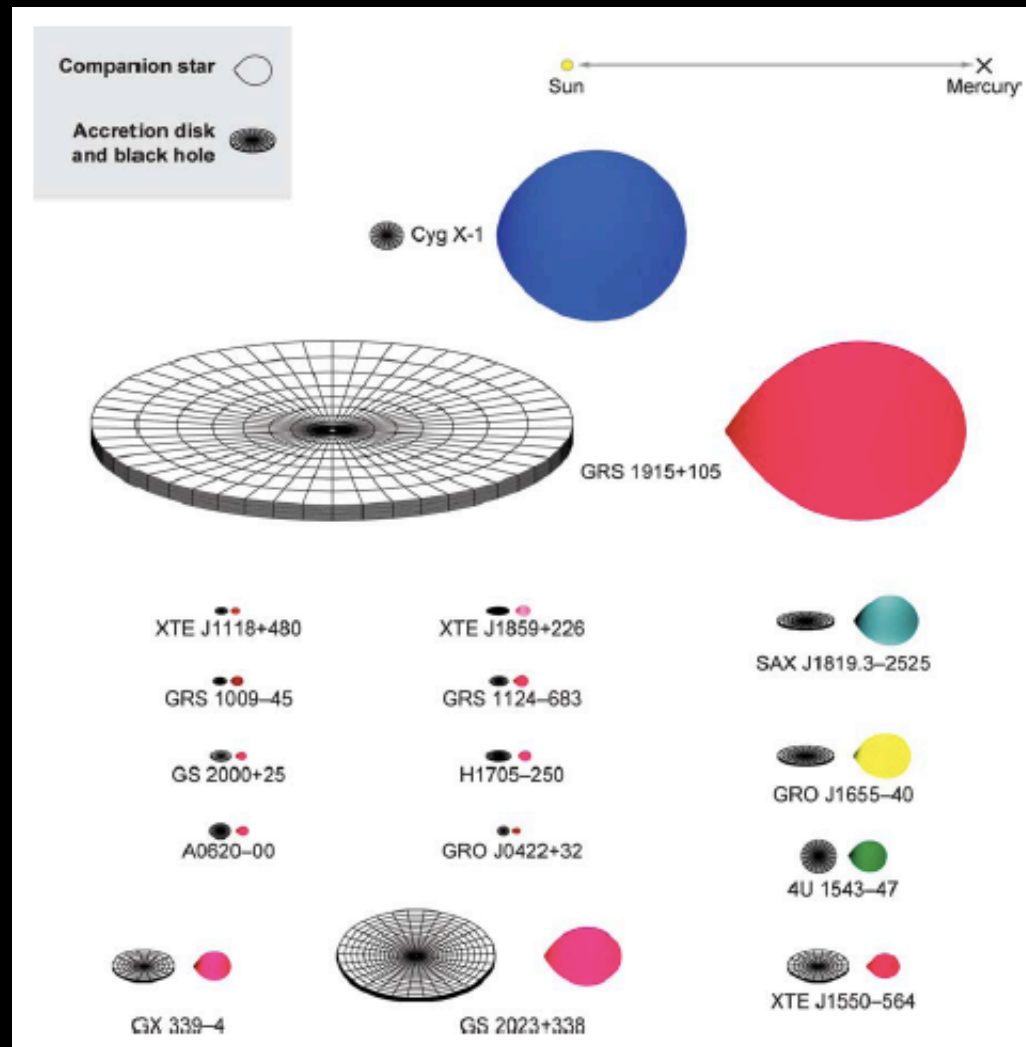
Chandra



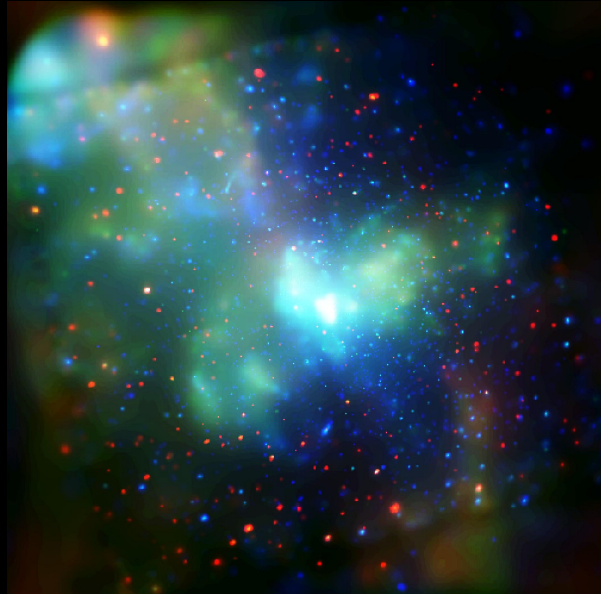
X-RAY
Chandra at its best (in terms of sensitivity)

Galactic X-ray Astrophysics

X-ray binaries



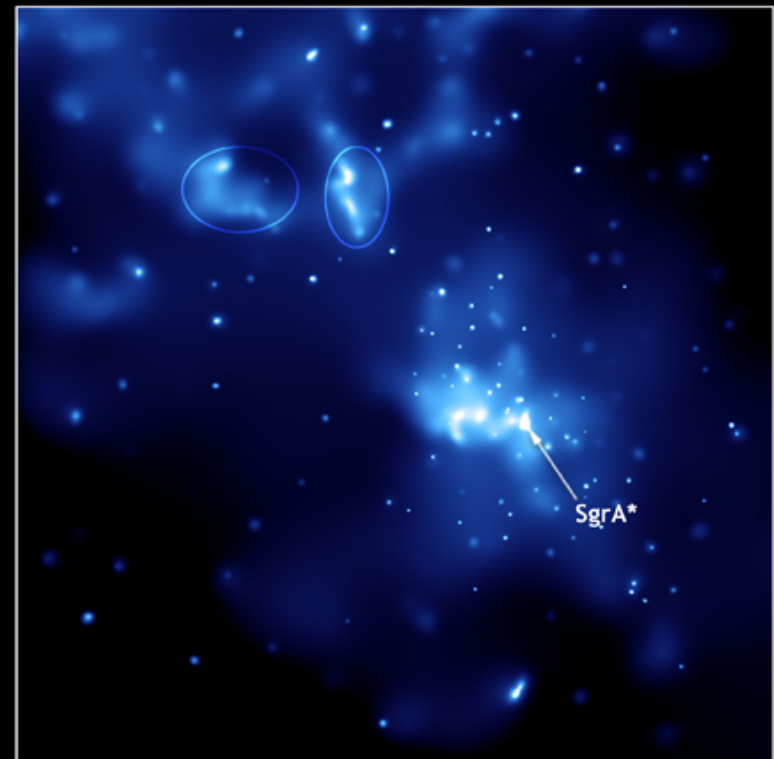
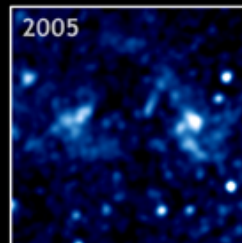
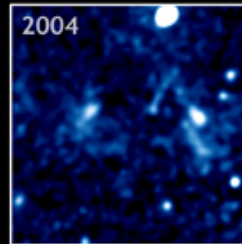
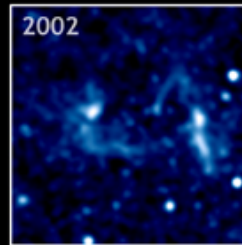
Galactic X-ray Astrophysics



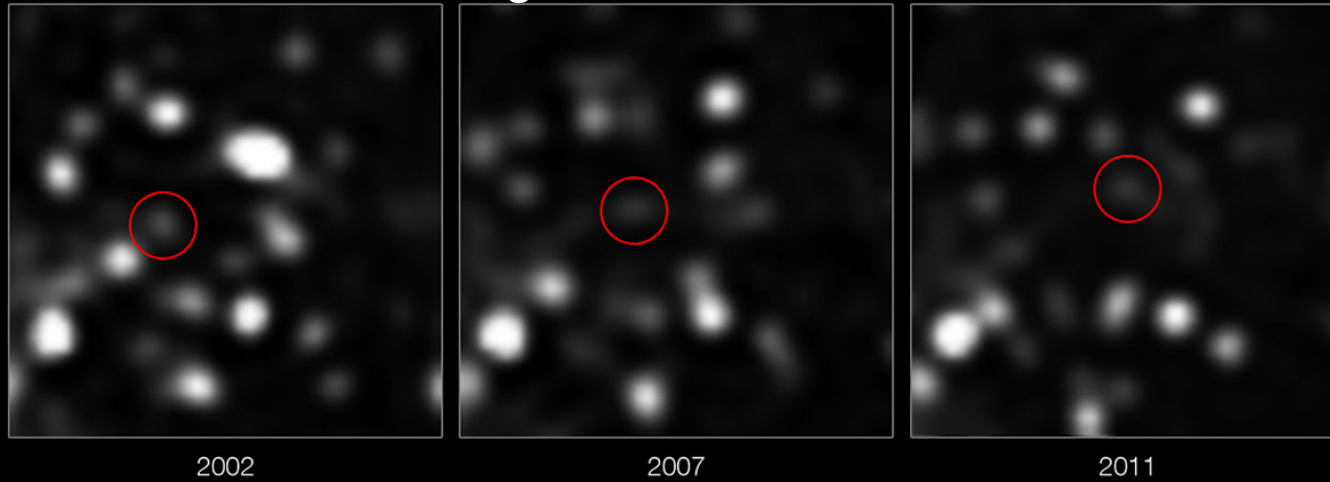
Several million-second exposure
in the Galactic Center and
Galactic Plane region

Intensive multi-wavelength
coverage

The Galactic Center



Monitoring of the Galactic Center



One of the possible
mechanisms to fuel the BH
in SgrA*

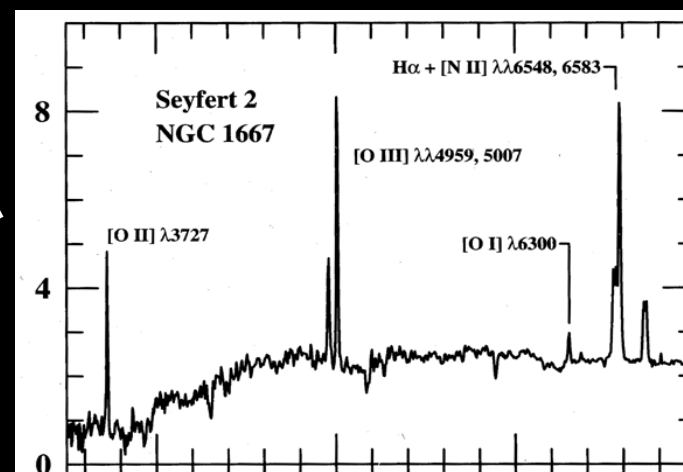
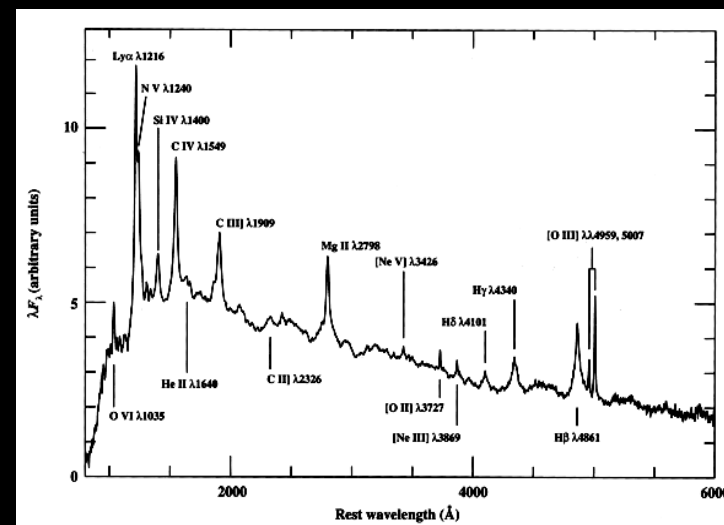
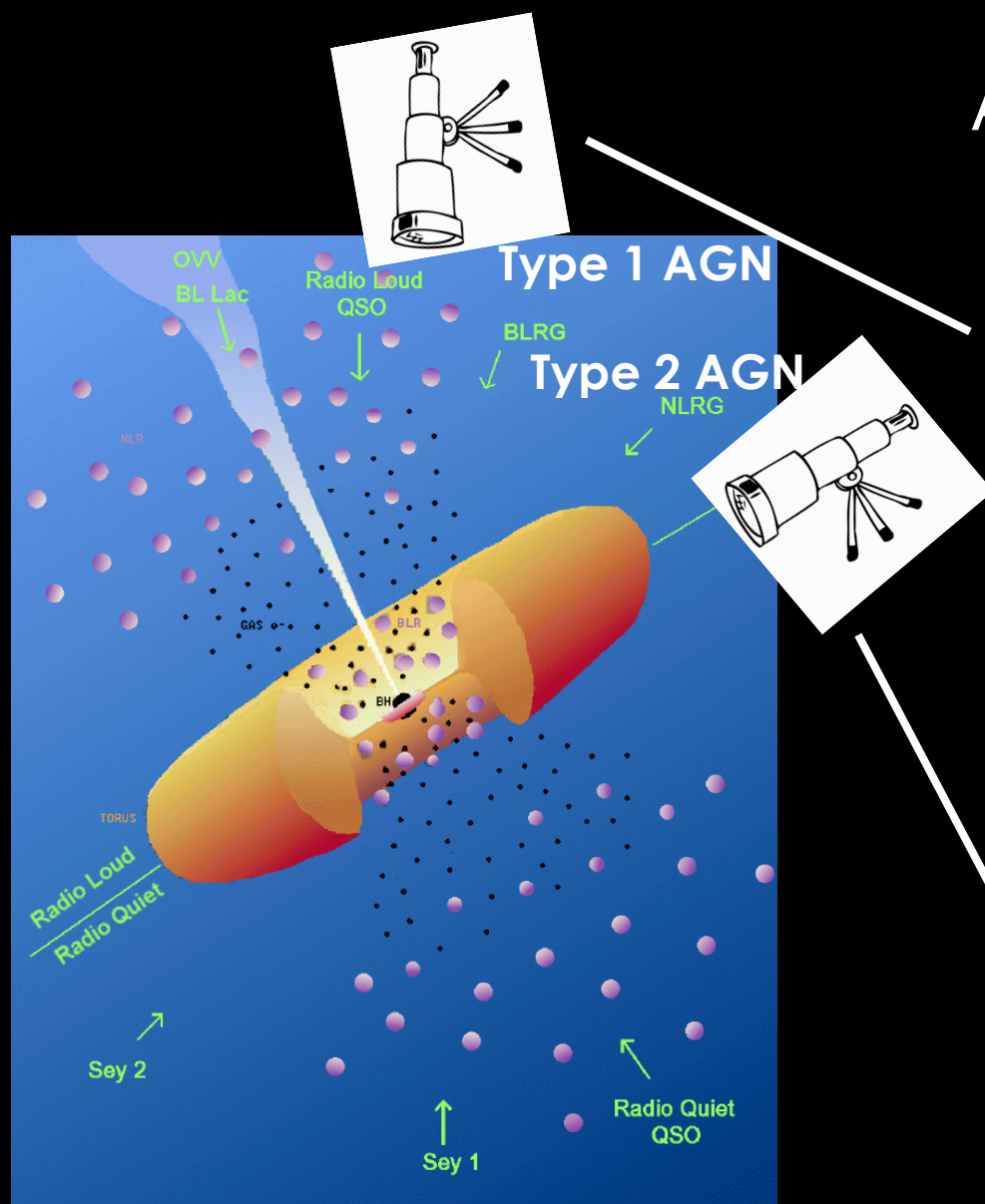
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III part: **Extragalactic X-ray Astrophysics**

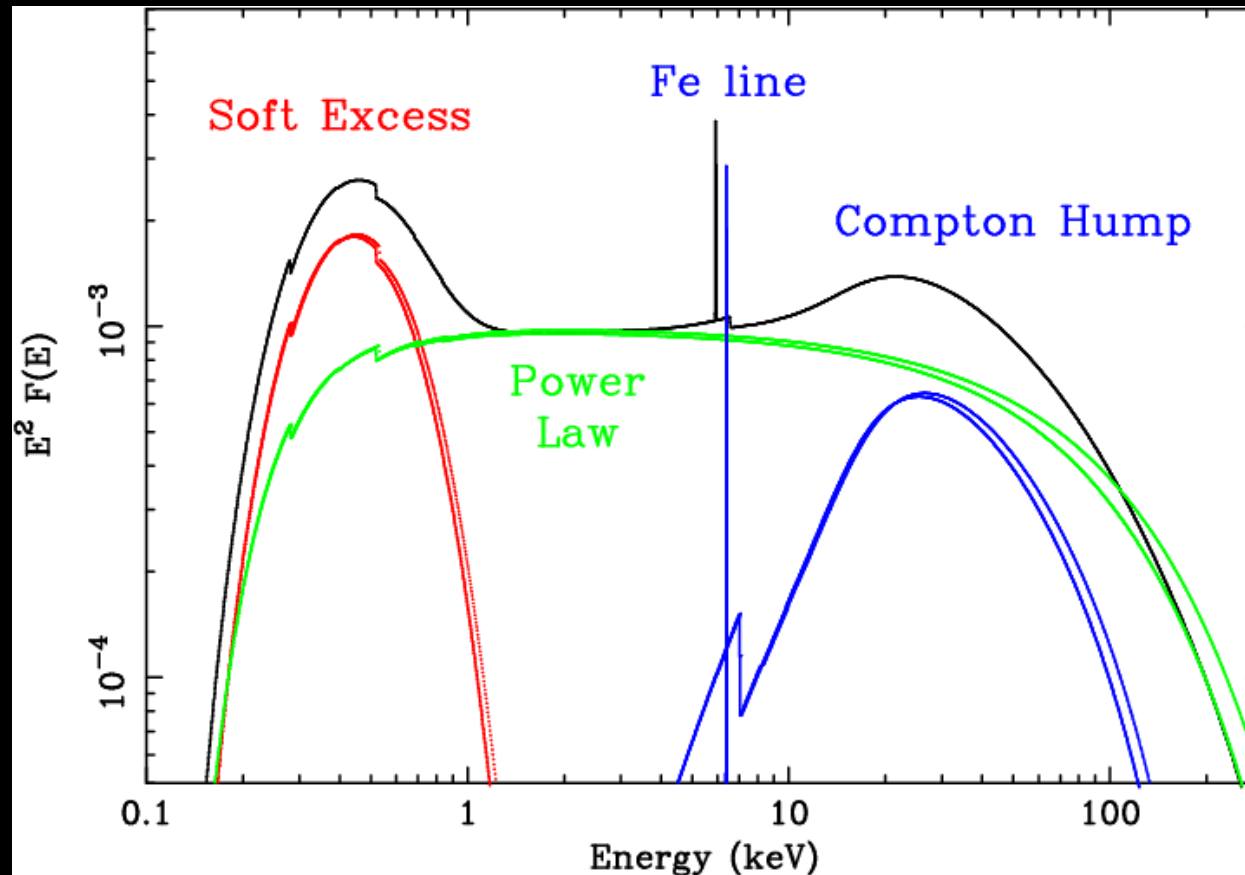
- **Clusters of galaxies** (Dr. M. Sereno, INAF-OAS)
- **Active Galactic Nuclei:** X-ray spectral components and emission properties. Theory vs. observations. Multi-wavelength properties (SED) and classification. Unified model
 - **EHT: the shadow of M87**
 - **AGN vs. X-ray binaries**
- **X-ray surveys:** “cosmological” evolution of AGN
- AGN contribution to the **cosmic X-ray** background: what is known and open issues
- **High-redshift AGN** and their link with primordial structure formation. Models of seed black holes and comparison with observations. Reviewing the highest redshift AGN made accessible by *Chandra* and *XMM-Newton*

Extragalactic X-ray Astrophysics

Active Galactic Nuclei (AGN)



Extragalactic X-ray Astrophysics



X-rays as a probe
of the innermost
region of AGN

Insights on
accretion
processes (flow,
both inflow and
and outflow) and
feeding of the BH

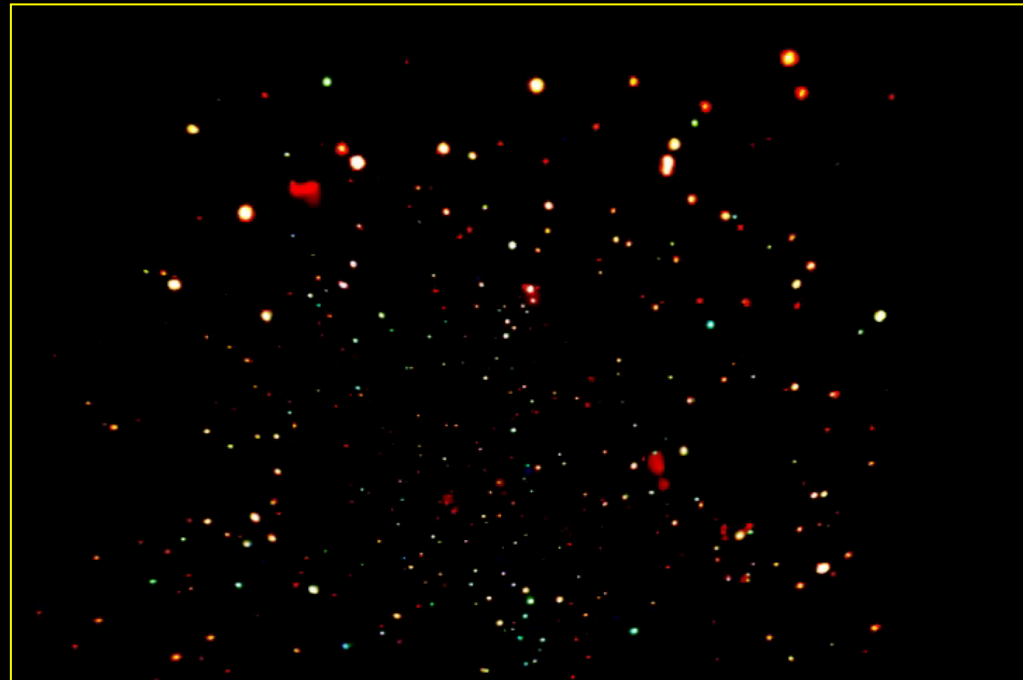
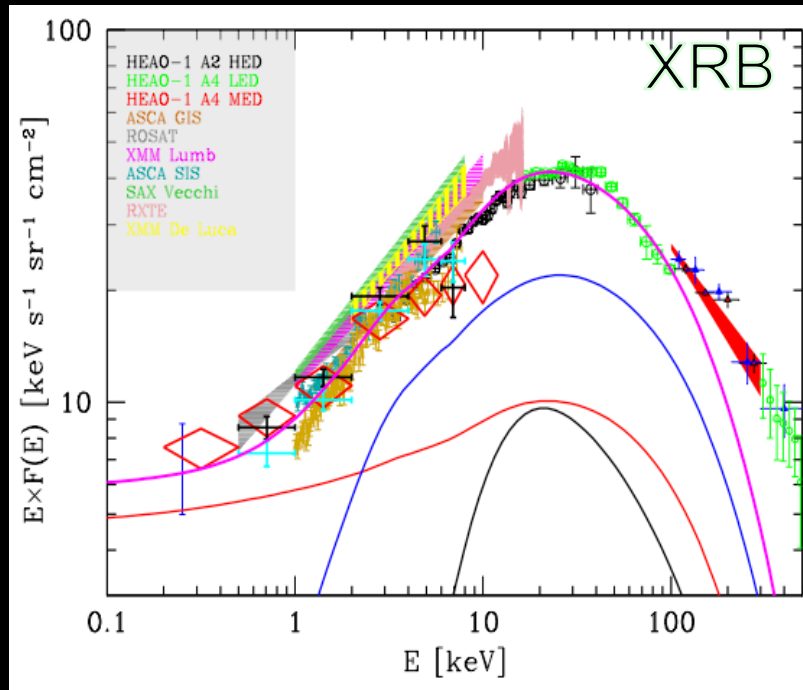
Soft excess (Black body? Reflection? Complex absorption?)

Power-law Component (Thermal Comptonization)

Reflection component (Fluorescence Lines + Compton hump)

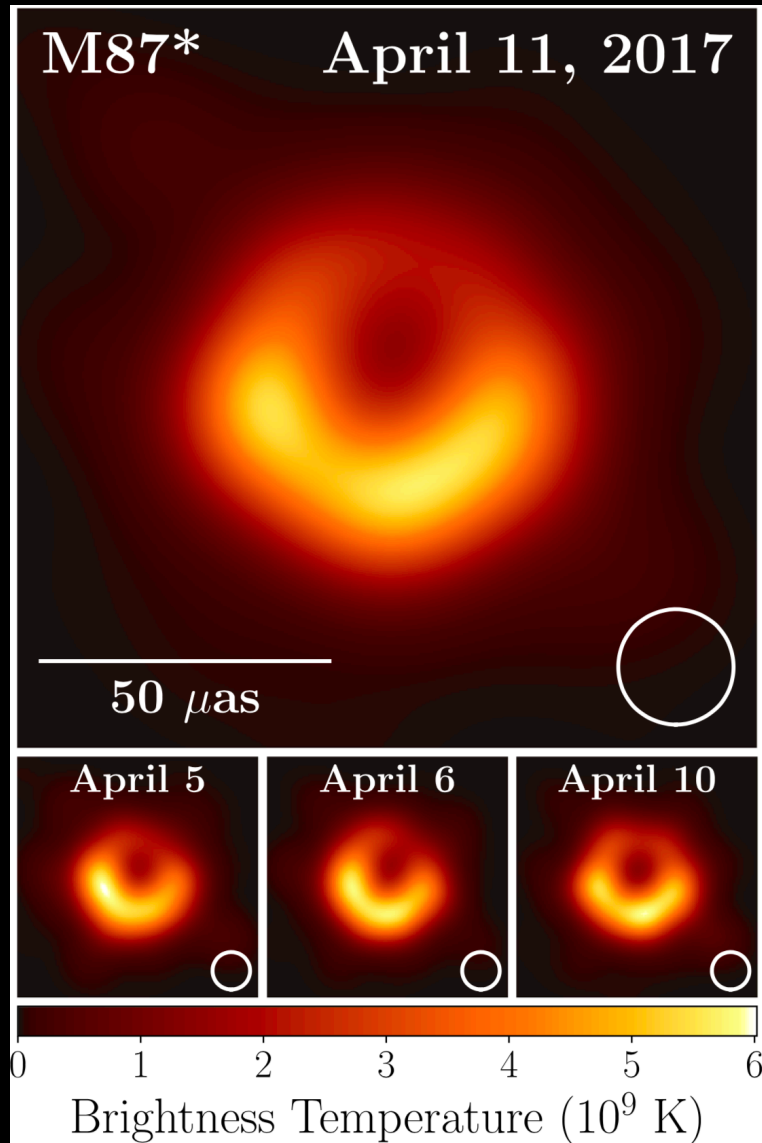
Warm absorber (~50% local Seyfert galaxies)

Extragalactic X-ray Astrophysics



X-ray surveys as a cosmological tool
Population studies to have an almost complete (and possibly unbiased) census of all AGN facets (i.e., including obscured AGN and high-redshift AGN)

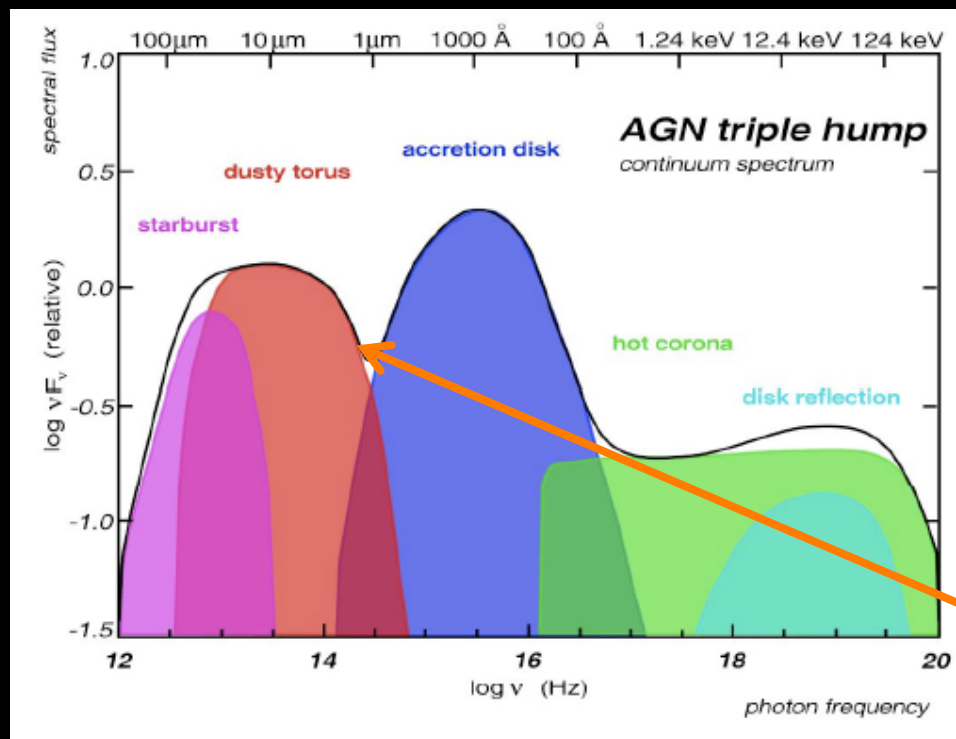
Extragalactic X-ray Astrophysics



Event Horizon Telescope (EHT)
observational campaign: 5-10 April, 2017
Average of three different imaging methods

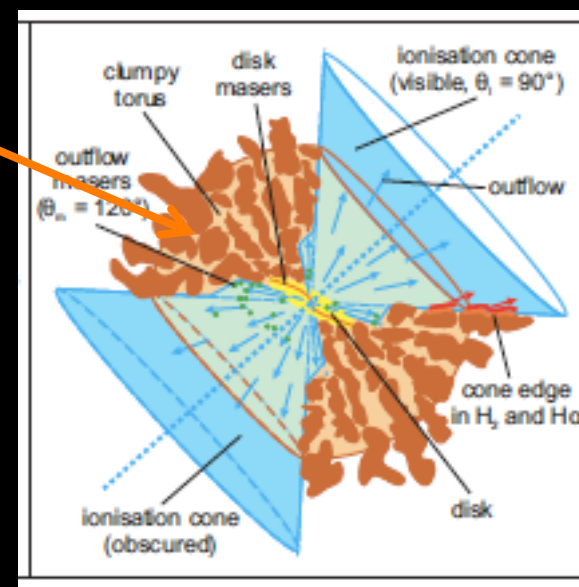
- ❑ **Shadow of the Kerr BH as predicted by General Relativity**
- ❑ Asymmetrical bright emission resolved into a ring (crescent) with diameter of $42 \pm 3 \mu\text{as}$. Asymmetry due to relativistic beaming from a plasma rotating at $v \sim c$ around and very close to the BH

Extragalactic X-ray Astrophysics



The Spectral Energy Distribution as a tool to study the “link” between accretion and star formation (BH vs. host galaxy)

Mid-IR (torus) vs. X-rays correlation




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- Oral examination (one topic at your choice, then possible questions on all the topics of the course)
- Books + specialistic papers + slides (as a “guideline”)

Slides as http://www.bo.astro.it/~vignali/Astrofisica_Alte_Energie/AA2019-20/
and on Insegnamenti OnLine <https://iol.unibo.it/course/view.php?id=52498>