High Energy Astrophysics

Presentation of the course

AA 2023/2024

Second semester
End of February / End of May

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

marcella.brusa3@unibo.it

Office: 4S6 (4 floor, UE3 Navile)

Prof. Marcella Brusa
DIFA - Dipartimento di Fisica e Astronomia "Augusto Righi"

What is High Energy Astrophysics

high energy astrophysics (M. Longair):
"I take this term to mean the astrophysics of ***high energy processes*** *and their application in astrophysical and cosmological contexts"*

> *"For example, we need to explain how* ***the massive black holes*** *present in the nuclei of active galaxies can be studied, how* ***charged particles are accelerated*** *to extremely high energies in astronomical environments, the origins of enormous* ***fluxes of high energy particles and magnetic fields*** *in active galaxies, the physical processes in the* ***interiors and environments of neutron stars****, the nature of the* ***dark matter,*** *the expected fluxes of* ***gravitational waves*** *in extreme astronomical environments, and so on".*

What is High Energy Astrophysics

More in general, High Energy Astrophysics studies:

OBJECTS WHERE GRAVITY IS VERY STRONG - COMPACT OBJECTS
(e.g. White dwarves, Neutron stars, X-ray binaries, black holes, SMBHs/AGN)

MATERIAL MOVING VERY FAST - RELATIVISTIC
(e.g. jets, supernovae)

PROCESSES 'VERY HOT' OR ENERGETIC
(e.g. gas in clusters of galaxies, SNR)

THE UNIVERSE ITSELF
(cosmology)

The study of such objects and processes covers a very wide range of physics and a large variety of different types of physical objects

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high energy astronomy/astrophysics (Wikipedia):

*"the study of astronomical objects that release **electromagnetic radiation of highly energetic wavelengths.** It includes **X-ray astronomy, gamma-ray astronomy, and extreme UV astronomy,** as well as studies of **neutrinos and cosmic rays**. The physical study of these phenomena is referred to as high-energy astrophysics. Astronomical objects commonly studied in this field may include **black holes, neutron stars, active galactic nuclei, supernovae, supernova remnants, and gamma ray bursts.**"*

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For certain classes of objects a **large** fraction of the emitted energy *is* in the high energy band of the electromagnetic spectrum

We will focus on high frequencies (X, gamma)

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Sometimes these phenomena also manifest at longer wavelengths

We will use multi-wavelength info to *understand*

High Energy Astrophysics

Radiation vs. Particles vs. GW (no *neutrinos, cosmic rays, gravitational waves*)

see ***"Astroparticle Physics"***
"Gravitational Waves Astrophusics and Cosmology"

Theory:

physical processes and emission mechanisms that imply high energy release; thermal and non thermal phenomena

Observational perspective:

Focus* on cosmic sources emitting at High frequencies in the E.M. spectrum (extreme UV*, ***X-ray*, *Gamma ray*)**

Multiwavelength (and multimessenger) connections

Instrumental perspective:

see ***"Astronomical Instrumentation"***

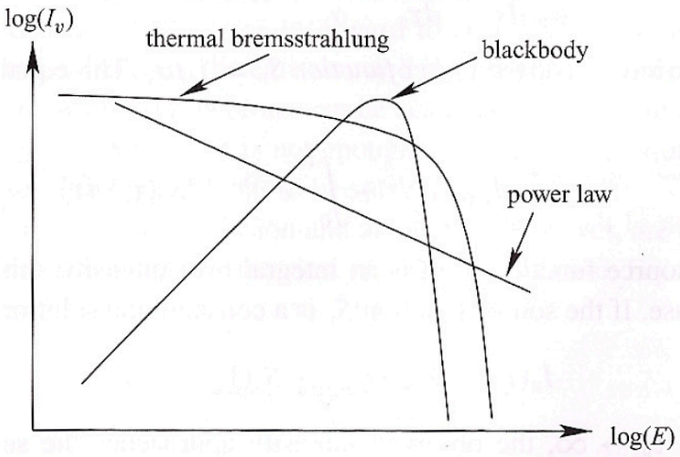
how data can be obtained: instruments, telescopes, detectors

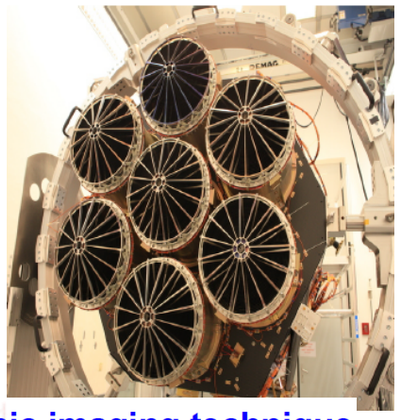
focus on *space* missions *(the 2000 revolution: Chandra, XMM, Fermi, eROSITA)*

Content of the course

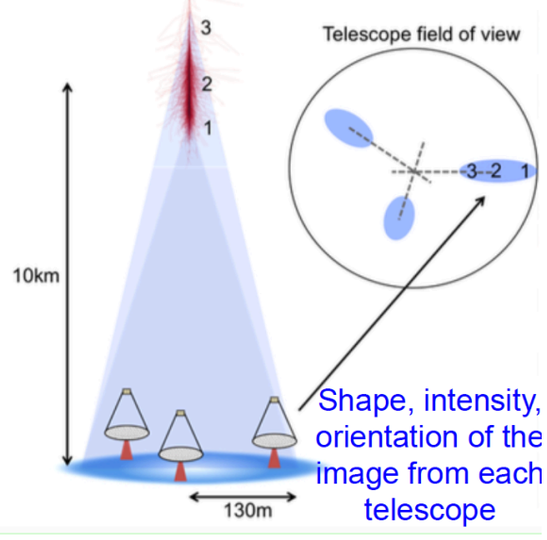
INTRODUCTION TO HIGH-ENERGY ASTROPHYSICS

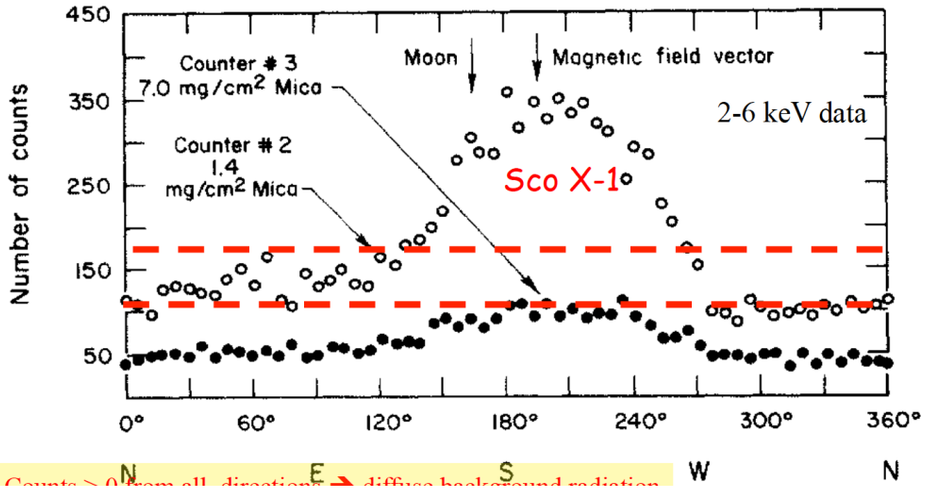
- **Recap on emission mechanisms:** blackbody/bremsstrahlung/Synchrotron
  Scattering processes; Plasma physics;
  Line production; collisional and ionization equilibrium.
- **History of the high-energy Astronomy**.
  Excursus on the properties of the main X-ray/Gamma-ray telescopes, future perspectives
- **Detection techniques for high-energy photons:**
  CCDs in X-rays. Wolter-type telescopes and coded-aperture masks. Cerenkov radiation.





Stereoscopic imaging technique

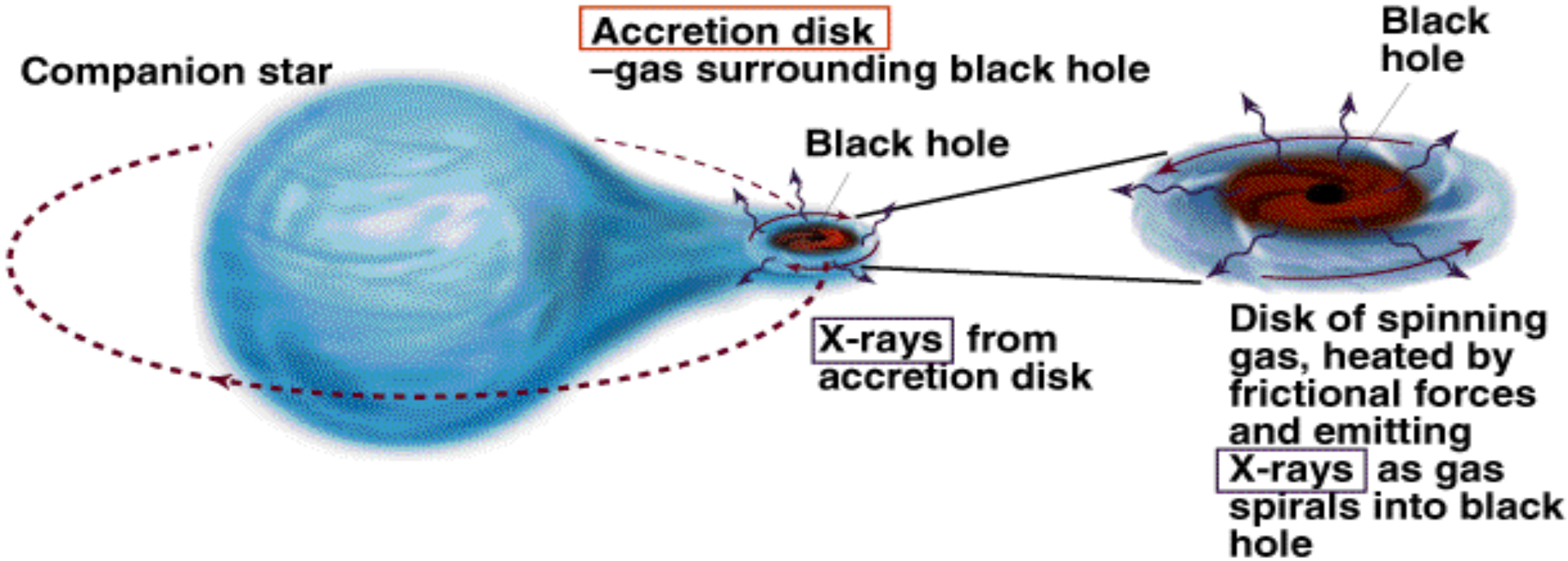




Content of the course

ACCRETION PHYSICS:

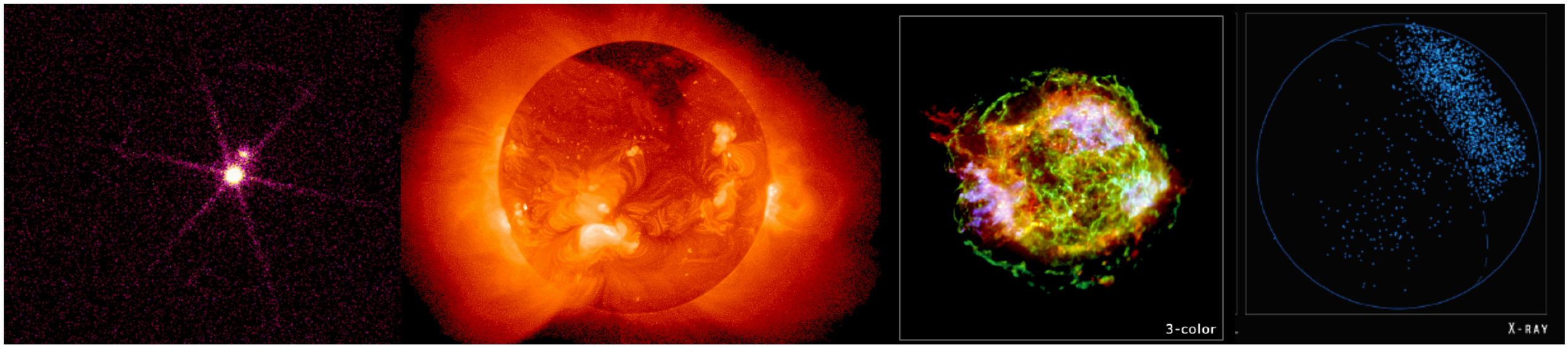
- **Theory:** Eddington limit, accretion discs. Accretion and ejection processes (jets, winds).
- **Physics of compact objects**: white dwarfs, neutron stars, Chandrasekhar limit, pulsars, black holes (with some mentions on relativistic astrophysics)



Content of the course

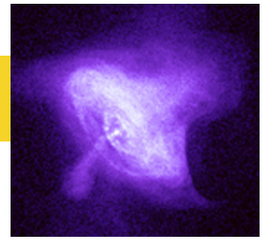
GALACTIC HIGH-ENERGY SOURCES:

- **X-ray emission from Solar System objects**
- **X-ray Emission from stars**: main-sequence (MS) and pre-MS stars/very low-mass stars; the Sun
- **Low- and High-mass X-ray binaries:** phenomenology, classification and physical properties. Candidates black holes.
- **Supernova Remnants**



http://chandra.harvard.edu/photo/2004/casa/ http://www.lmsal.com/SXT/ . http://chandra.harvard.edu/photo/2000/0065/

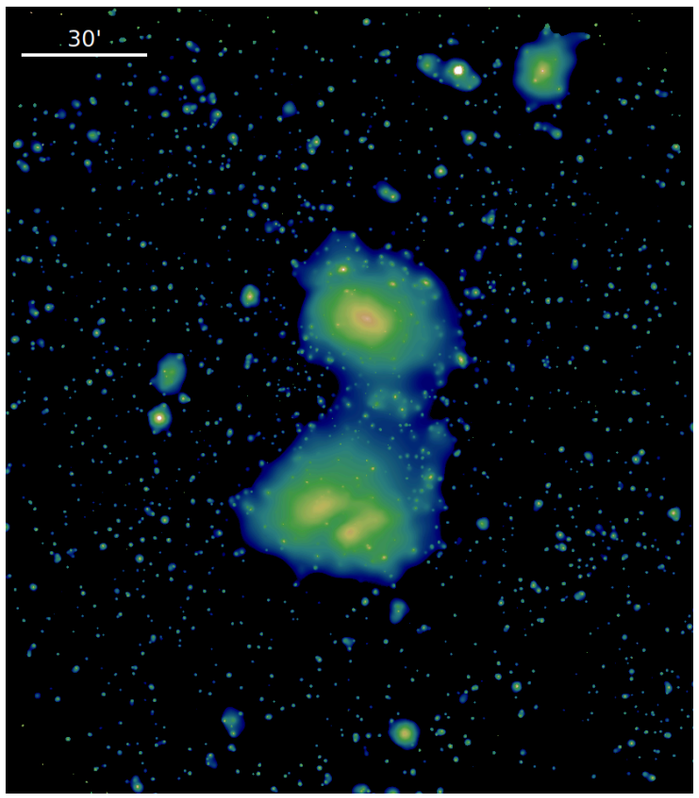
MW CONNECTION (1): SNR, The Crab Nebula



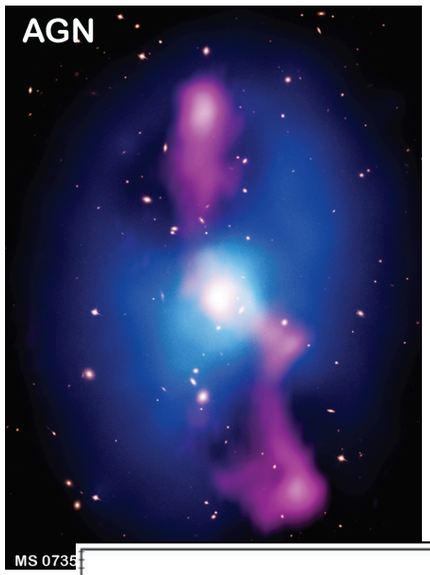
Content of the course

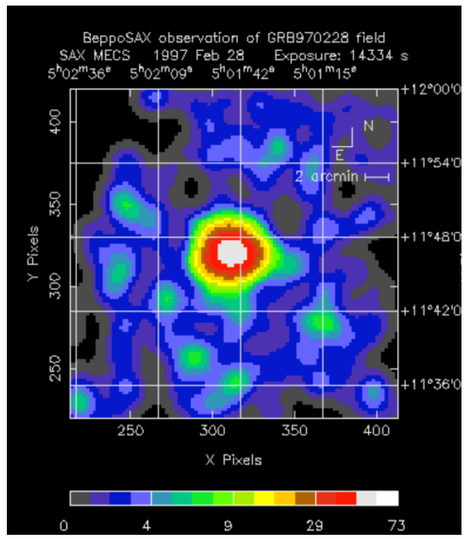
EXTRA-GALACTIC HIGH-ENERGY SOURCES:

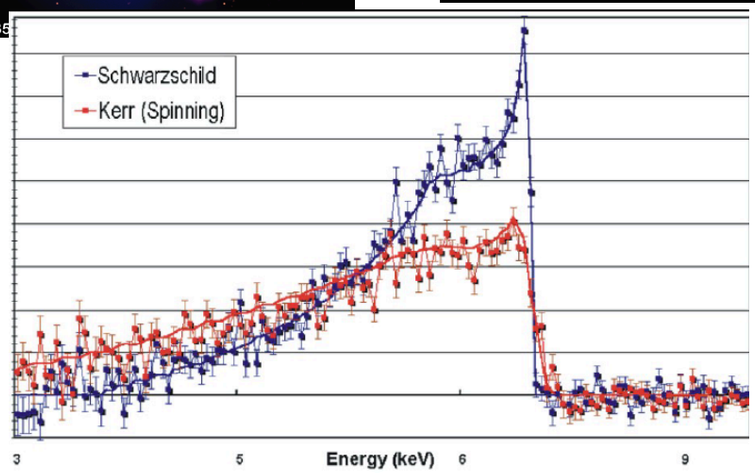
- **Clusters of galaxies and cooling flows**
- **Active Galactic Nuclei (AGN):** X-ray spectral components: models vs. observations.
- **X-ray surveys:** obscured AGN contribution to cosmic X-ray background and feedback
- **Ultraluminous X-ray sources**
- **Gamma ray bursts:** phenomenologies, origin and emission mechanisms

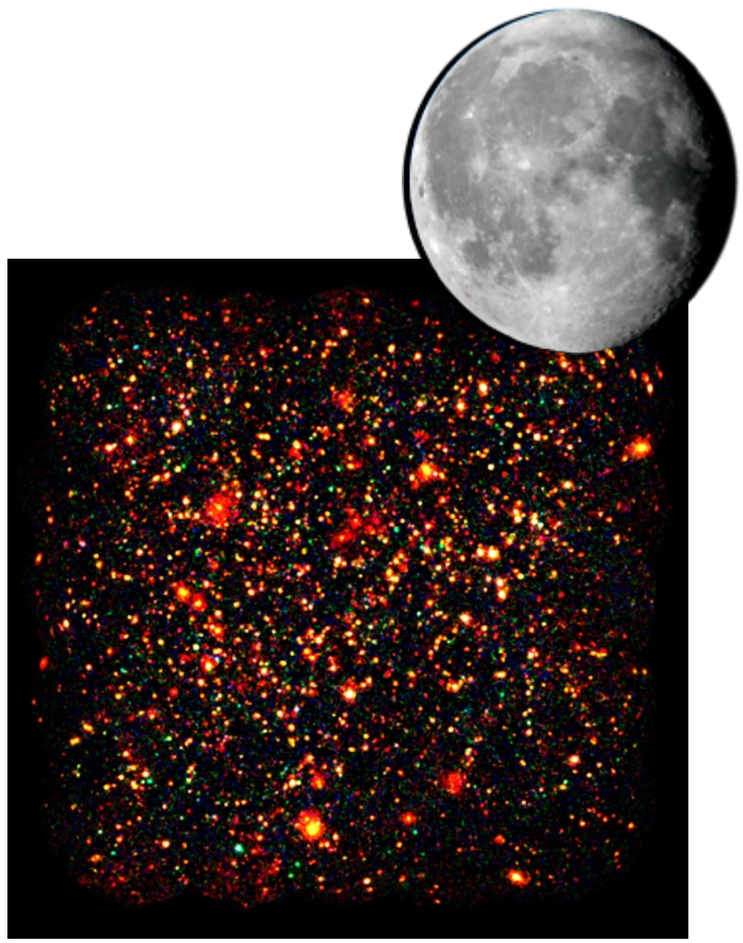


eROSITA image of A3391/3395









XMM-Newton onbservations of the COSMOS field

MW/Multimessenger CONNECTION (2): The Kilonova and GW detection

MW CONNECTION (3): The Galactic center

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Organization of Lectures

THEORY (~7)

TECHNOLOGIES (~3)

HE EMISSION FROM CLASSES OF SOURCES (SEMINAL AND MOST RECENT RESULTS) (~7)

+ MULTIWAVELENGTH CONNECTIONS (~3)

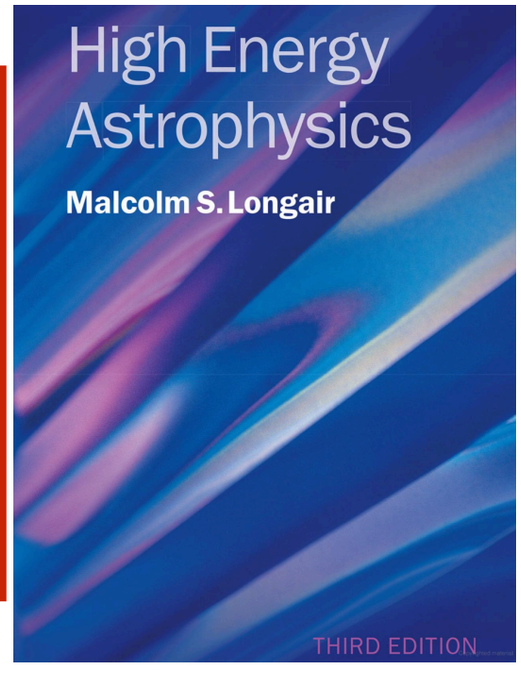
SPECIALISTIC SEMINARS (~4)

(by colleagues of OAS/CTA on future directions in HEA)

Textbooks

Main textbook:

Malcolm S. Longair:
"*High-Energy Astrophysics*" (2011)
Cambridge University Press



Other textbooks:

Frank, A. King & D. Raine:
"*Accretion Power in Astrophysics*"
Cambridge University Press

George B. Rybicky, Alan P. Lightman:
"*Radiative Processes in Astrophysics*"
Wiley

Camenzind, Max:
"Compact Objects in Astrophysics"

Freedman, R. & Kauffmann W:
"Universe"

Other Resources:

papers and review articles on specific topics to discuss most recent advances and results from state-of-the art observations

Material

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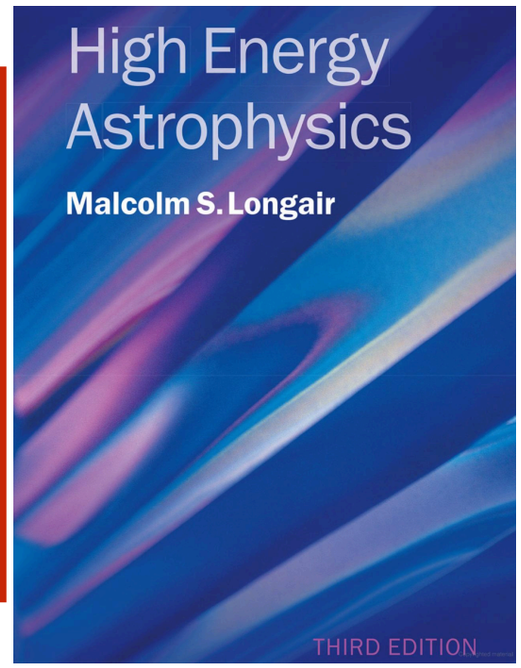

Final thoughts and assignments

Longair, "*High-Energy Astrophysics*" (2011)
Read **Chapter 6** *(Section 6.2.3 fac.)*
Read **Chapter 7.1** *(all the rest fac.)*
Read **Chapter 8.1-8.8** *(Section 8.4 only the results 8.4.4; Sect. 8.7.2 fac.)*

Refresh **"The radio emission of the Galaxy" (Chapt. 8.9)**

Optional:
Read *derivation of Larmor formula from classic electromagnetism (6.2.3)*

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Final thoughts and assignments

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Read **Chapters 14.7-14.8**

Read **Remillard & McClintock 2006 review on Black Hole binaries**

Read **Miller-Jones et al. 2021 (https://arxiv.org/abs/2102.09091) and understand how the new value of BH mass for Cy X-1 has been calculated**

Homework:
- research how many XRBs in galaxies other than the Milky Way
- update the numbers of known BH binaries

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Questions?