

# ACTIVE GALACTIC NUCLEI



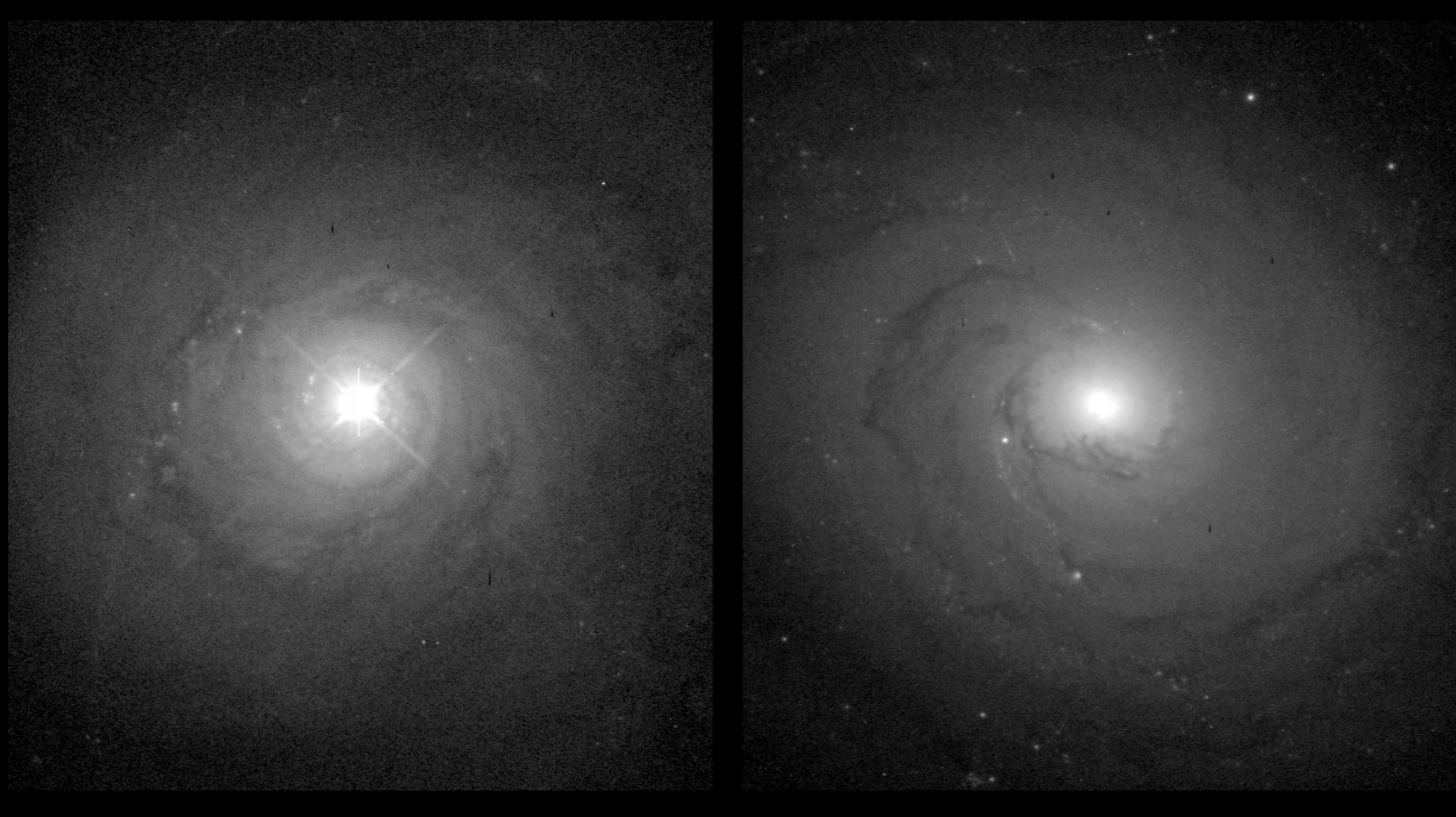
## WHAT IS ACTIVE GALACTIC NUCLEUS OR AGN?

A galaxy is said to be **active** when it shows evidence of an energy source other than the known processes associated with stars (star formation, stellar death, etc).

Signs of activity are almost always observed in or associated with a very compact region at the center of a galaxy. Hence, we call it **nuclear activity** and the galaxy is said to possess an **“active galactic nucleus”**, abbreviated as **AGN**. Figure shown below are optical HST (Hubble Space Telescope) images of active galaxy NGC 5548 (Left) and a normal spiral galaxy NGC 3277 (Right). As you see, the brilliant nucleus of NGC 5548 has saturated the detector while it is not so in case of normal galaxy NGC 3277.

### SIGNS OF NUCLEAR ACTIVITY

- Intense emission of radio waves, infra-red light, X-rays. This phenomenon is often called emission of “non-stellar” radiation i.e. radiation that could not have been produced by stars.
- Rapid fluctuations in the intensity of light, most notably the X-rays, from the nucleus of an active galaxy.
- Ejection of plasma (plasma=ultra-hot gas) from the nucleus of an active galaxy.
- Emission lines from very hot gas (not excited by stars).



The NGC 5548 image is from Matt Malkan's snapshot survey of AGN, and NGC 3277 is from a survey program by Carollo, Stiavelli, and Mack.

## THE CENTRAL ENGINE OF AN ACTIVE GALAXY

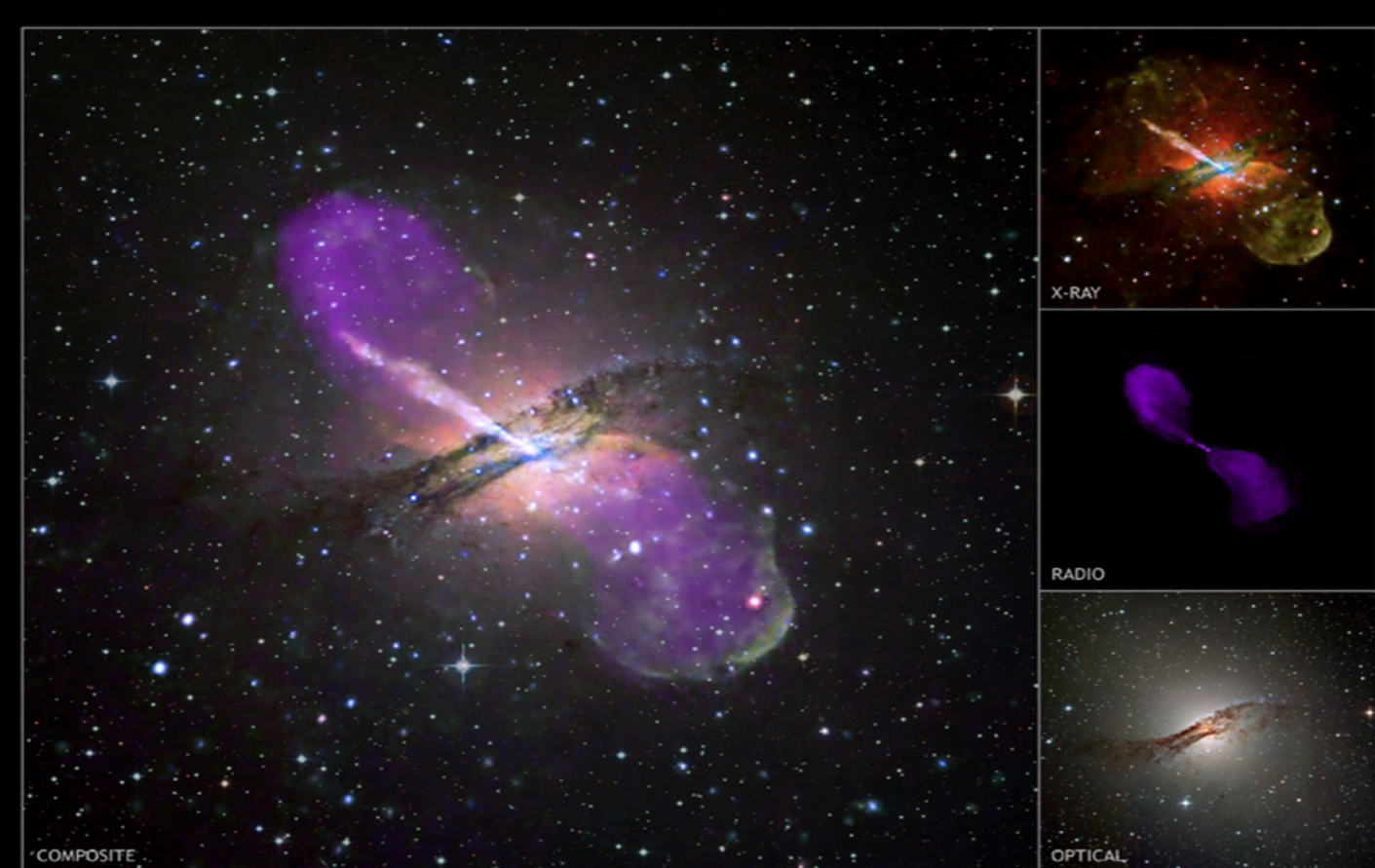
- The central engine of AGN is thought to be powered by accretion of gas onto a supermassive black hole. This gas is referred to as the fuel of the central engine. [black hole mass: 1 - 100 million Msun (1 Msun~ $10^{30}$  kg)]
- Such supermassive black hole accretes (i.e., swallows) gas from its host galaxy. The gas is the fuel that keeps the central engine going.
- On the way into the black hole, the gas forms a disk, which is called an accretion disk. The disk resembles the swirl that forms in sink as the water goes down the drain. It rotates differentially (i.e., different rings in the disk rotate at a different rate). Accretion disks follow Kepler's laws, so the rotation rate is faster at the inner parts of the disk.
- Gas in the disk is heated by friction and it gets hotter as it moves closer to the center. As a result, it glows, giving off visible light, ultraviolet light, and X-rays. This is what makes up the non-stellar radiation that we observe from AGN.

(Artist's imagination of AGN)  
[http://heasarc.gsfc.nasa.gov/docs/cgro/images/epo/gallery/agns/agn\\_cartoon.gif](http://heasarc.gsfc.nasa.gov/docs/cgro/images/epo/gallery/agns/agn_cartoon.gif)

Current instruments cannot resolve the innermost regions; multiwavelength studies involving spectral and timing studies play vital role.

In the innermost regions of AGN, strong gravity and relativistic matter coexist. X-rays originate very close to the black hole hence acts as a natural probe to test/verify the predictions of General theory of relativity and to understand the physical processes.

On the right is the spectacular image of “Centaurus A”. The small panel shows the images of the same object taken in X-ray, optical and radio wavelengths which are combined together to make a composite image shown in the main panel.



Credit: X-ray: NASA/CXC/CIA/R. Kraft et al.; Radio: NSF/VLA/Univ. Hertfordshire/M. Hardcastle; Optical: ESO/WFI/M. Rejkuba et al.)

### MAIN TYPES OF AGN

- Seyfert Galaxies (Luminosity  $10^{41}$ - $10^{44}$  erg/s)**
  - Seyfert 1:** very broad Balmer H lines, He I & He II emission lines FWHM  $\sim 1.5 \times 10^3$  km/s, narrow forbidden lines FWHM  $\sim 500$  km/s
  - Seyfert 2:** narrow permitted & forbidden lines FWHM  $\sim 500$  km/s
- Quasars (Luminosity  $10^{44}$ - $10^{46}$  erg/s, Large redshifts)**
- Type 1 & Type 2 Quasar:** Similar to Seyferts 1 & 2
- Blazars (Optically Violent Variables and BL Lacs)**
- Featureless continuum with weak/no emission lines. Radio loud.**
- Radio galaxies (radio loud equivalent of Seyfert 1 and 2)**
- BLRG: Broad line radio galaxies
- NLRG: Narrow line radio galaxies

## UNIFICATION MODEL OF AGN

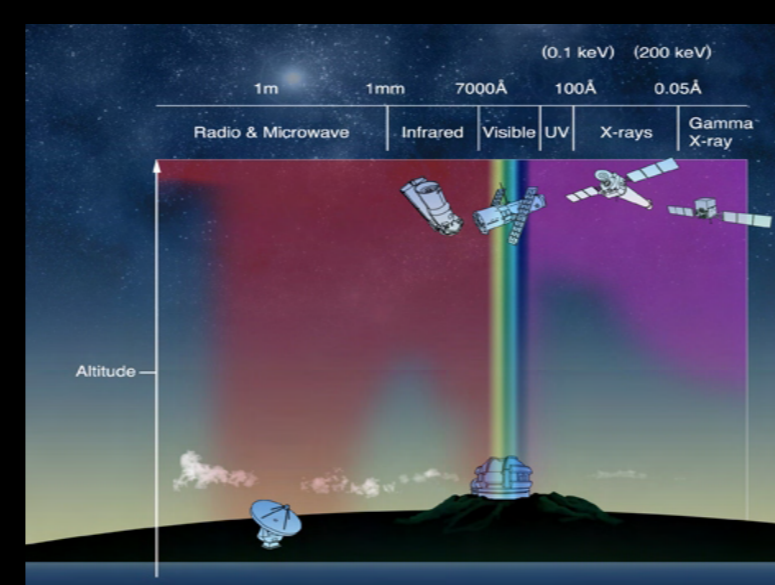
According to a popular theory, Type 1 and Type 2 AGN are same objects viewed from a different angle.

The central black hole is assumed to be surrounded by a thick donut shaped cloud of gas and dust. The source appears different, depending on the observer's line of sight as shown in the spectra above and on the right.

Blazar is seen if the observer's line of sight is along the jet.

## X-RAY OBSERVATIONS OF AGN

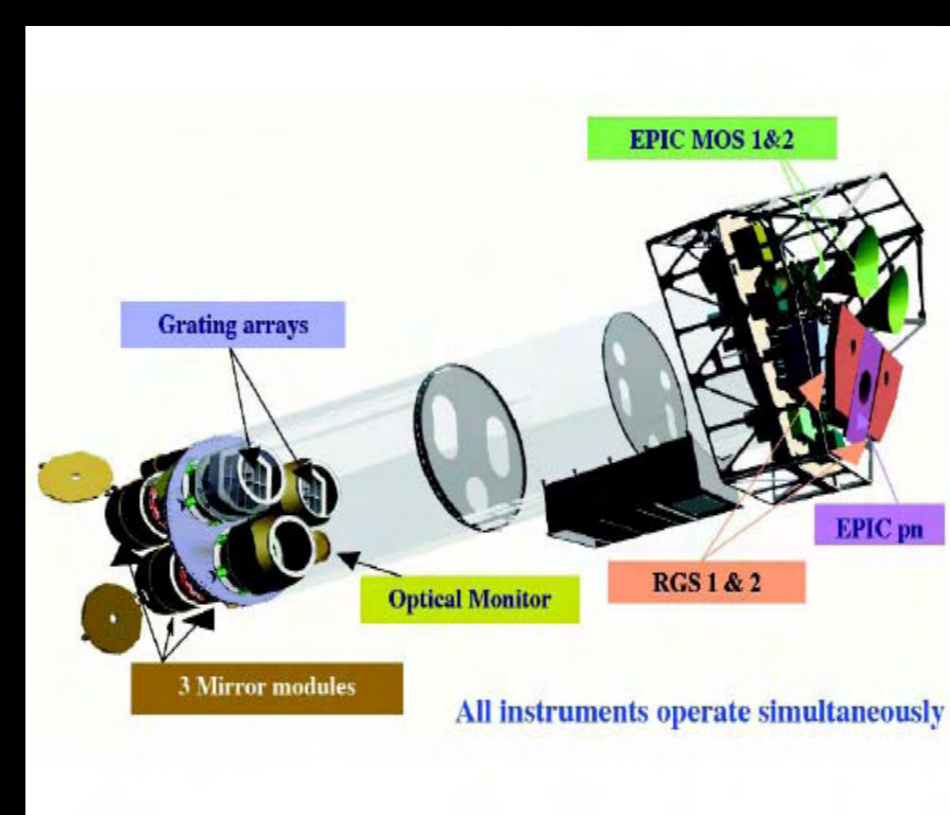
- X-ray variability studies, timing and spectral analysis offer best ways to probe these regions indirectly.
- This helps to provide constraints on existing physical models and test/verify the predictions of General theory of relativity.
- X-ray emission region is too small to image with current instrumentation.
- X-rays are too energetic and are photoelectrically absorbed in the Earth's atmosphere.



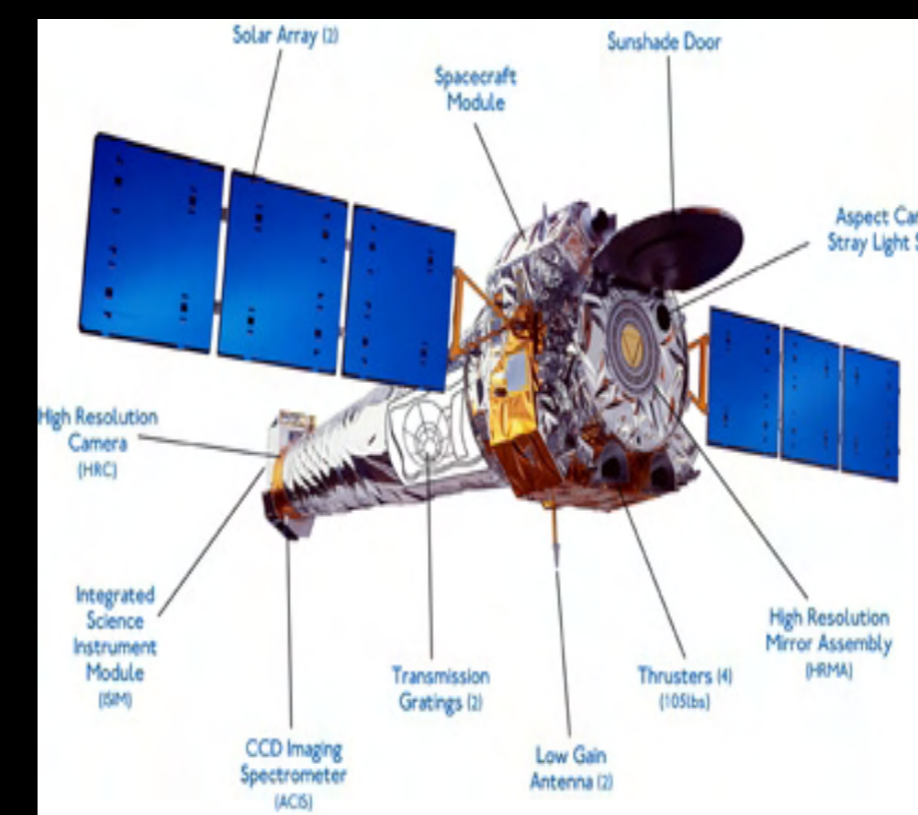
[http://chandra.harvard.edu/graphics/resources/illustrations/absorption\\_new2.jpg](http://chandra.harvard.edu/graphics/resources/illustrations/absorption_new2.jpg)

- We need to depend on Space-borne X-ray observatories to obtain X-ray data for AGN studies.
- CHANDRA, XMM-NEWTON, SUZAKU, NuSTAR are examples of satellites dedicated to X-ray observations.

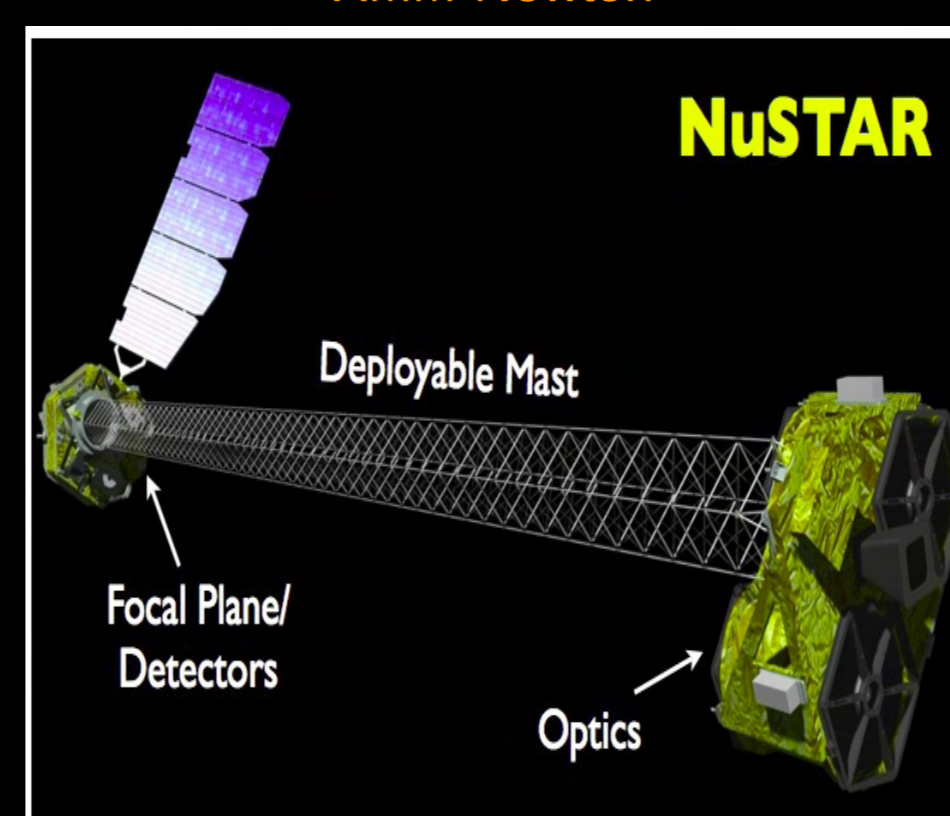
## X-RAY SATELLITES



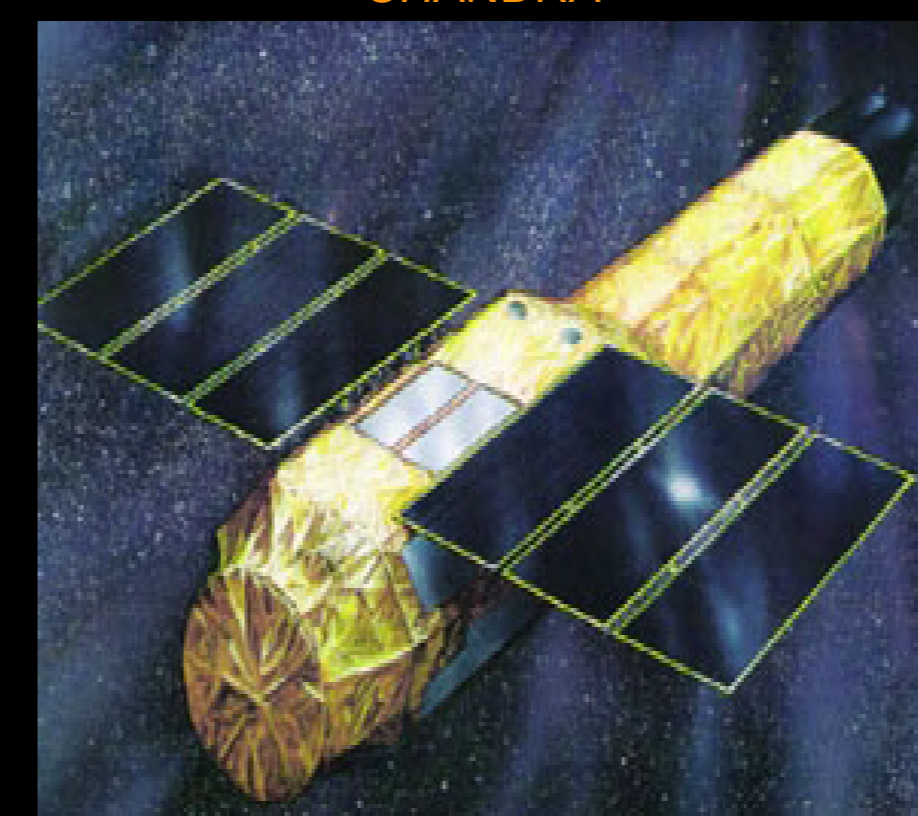
XMM-Newton



CHANDRA



NuSTAR

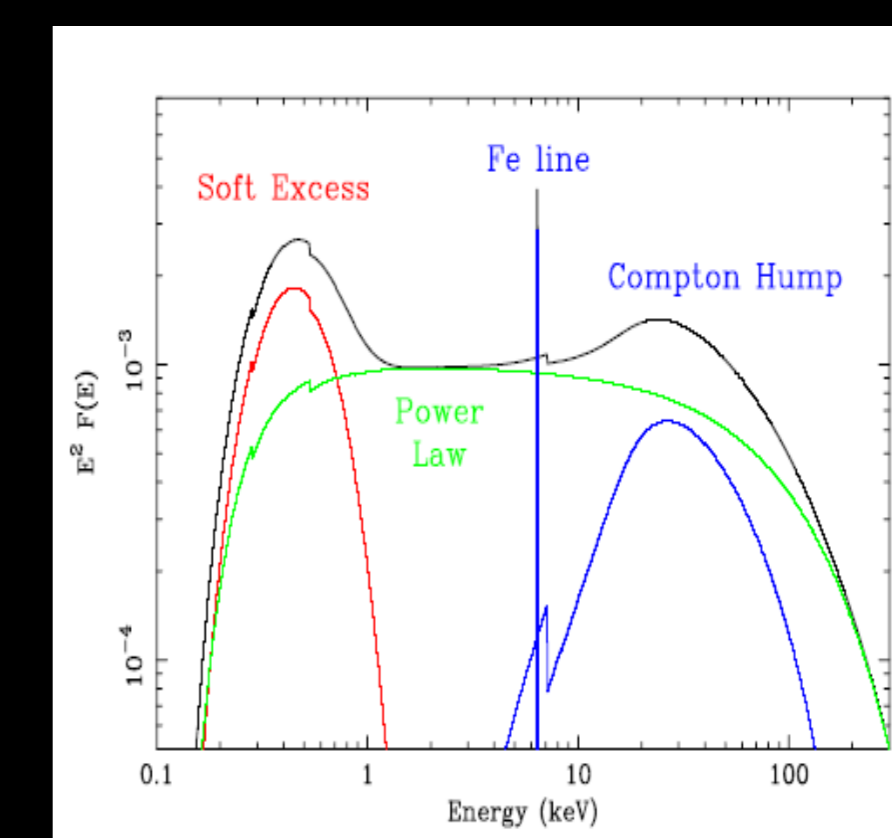


SUZAKU

X-ray observations are carried out by these satellites and the data are stored in the archive for data reduction.

After data reduction, further analysis and/or interpretation of resulting scientific products is done.

## OBSERVATIONAL FEATURES OF AGN X-RAY SPECTRA



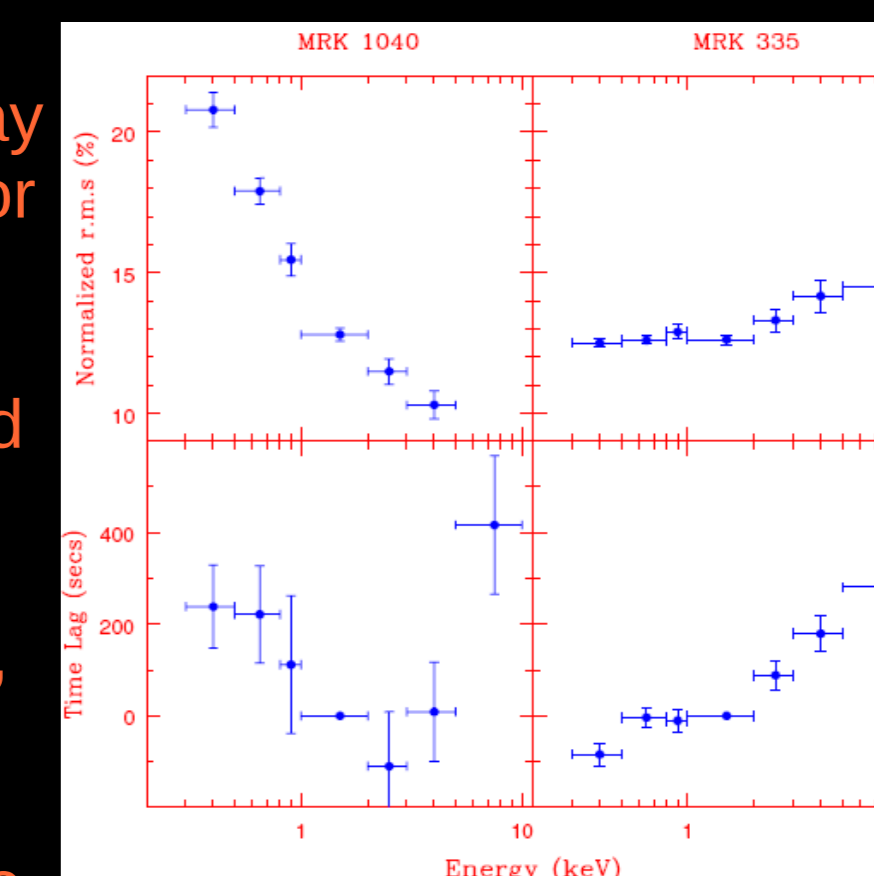
Fabian & Miniutti, (2005).

- A power law continuum in 0.1-10 keV, photon index  $\sim 1.7$ - $2.0$
- A ‘soft excess’ is often observed between 0.2–1keV.
- Compton hump/reflection seen over 20-40 keV, peaking at roughly 30 keV.
- A fluorescent emission line is observed at  $\sim 6.4$  keV which is the  $K\alpha$  line from cold Iron. Transition energy depends on the ionization state of the Iron.
- An exponential high energy cut off is also observed above several tens to hundreds of keV.

## RESEARCH AT IUCAA

### Time Lag Studies of AGN in X-rays

- Fluxes in different energy bands may vary in a similar way and can do it simultaneously, or with a delay.
- Typically, AGN and Galactic black hole systems exhibit hard time lags.
- The opposite trend or SOFT LAG is seen in very few cases, Mrk 1040 is second such observation.
- X-ray soft lags revealed in the 70.4 ks XMM-Newton data in the dominant variability timescale of  $10^4$ s.

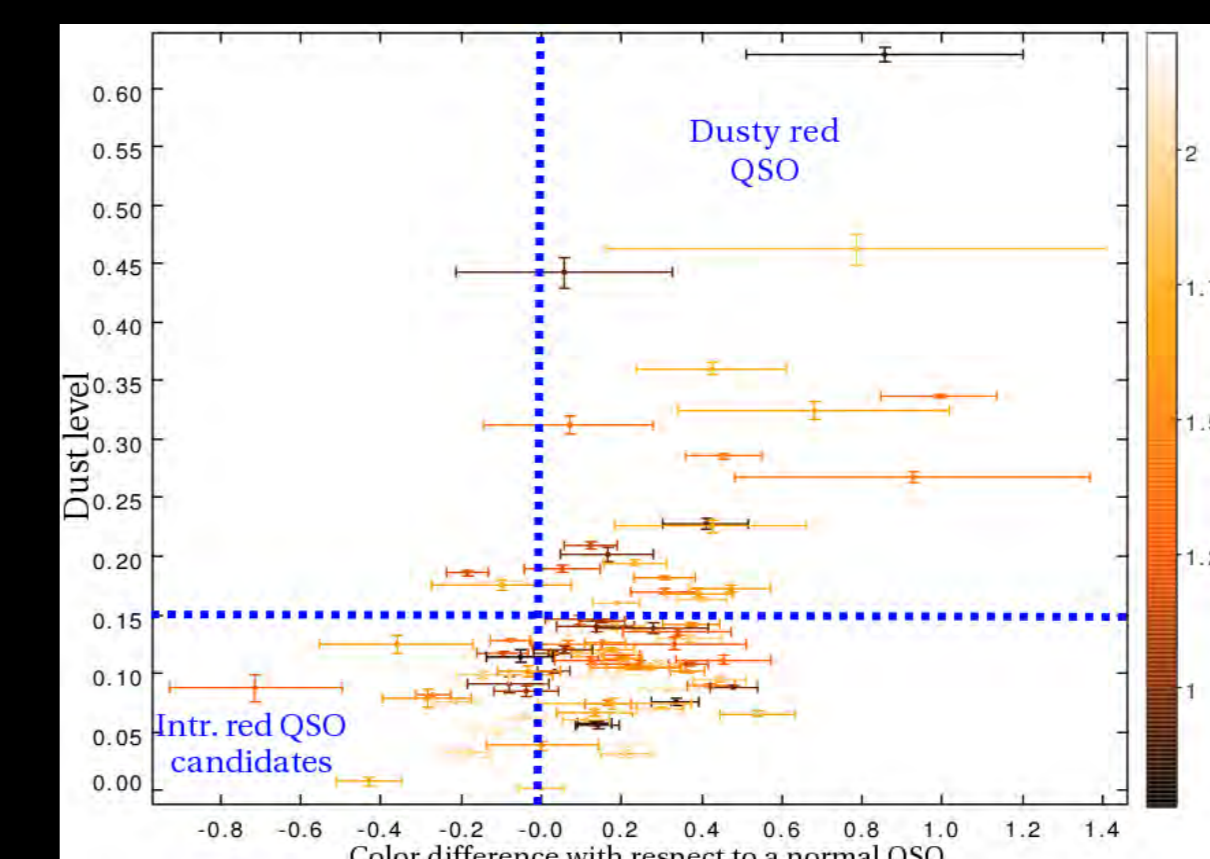


RMS variability and time lag as a function of energy for Mrk 1040 (left) & Mrk 335 (right).

- Below 2 keV, the time lag decreases with energy.
- For energies  $> 2$  keV, time lag increases with energy as in case of hard lags.
- Compared with Mrk 335, rms and time lag computed using an identical analysis of its similar length XMM-Newton observation.
- RMS varies differently with energy but time lag for Mrk 335 increases with energy (i.e. hard lags).

### Optically red quasars

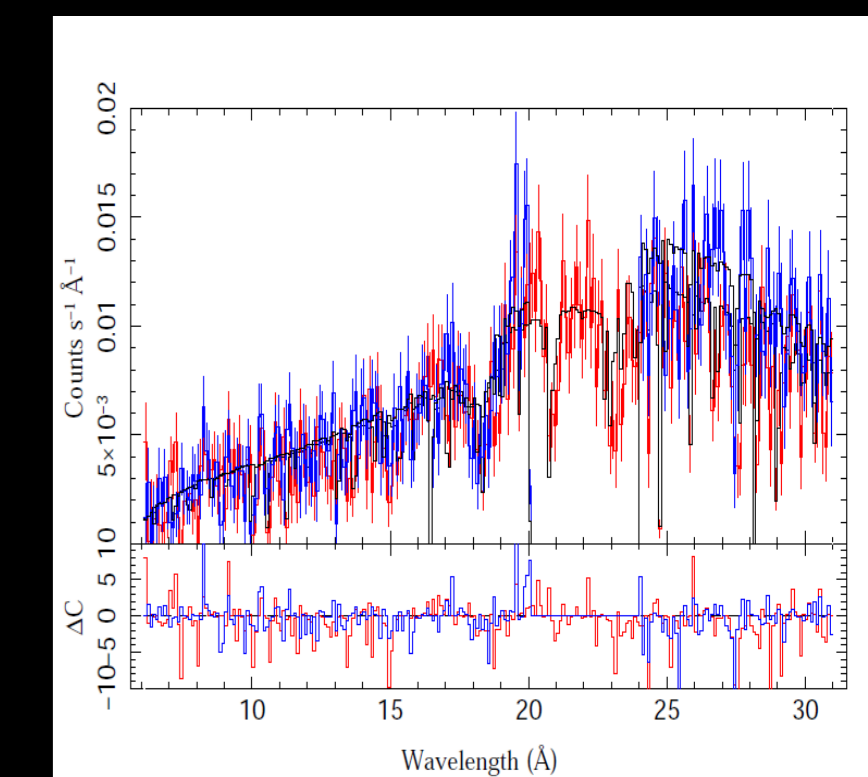
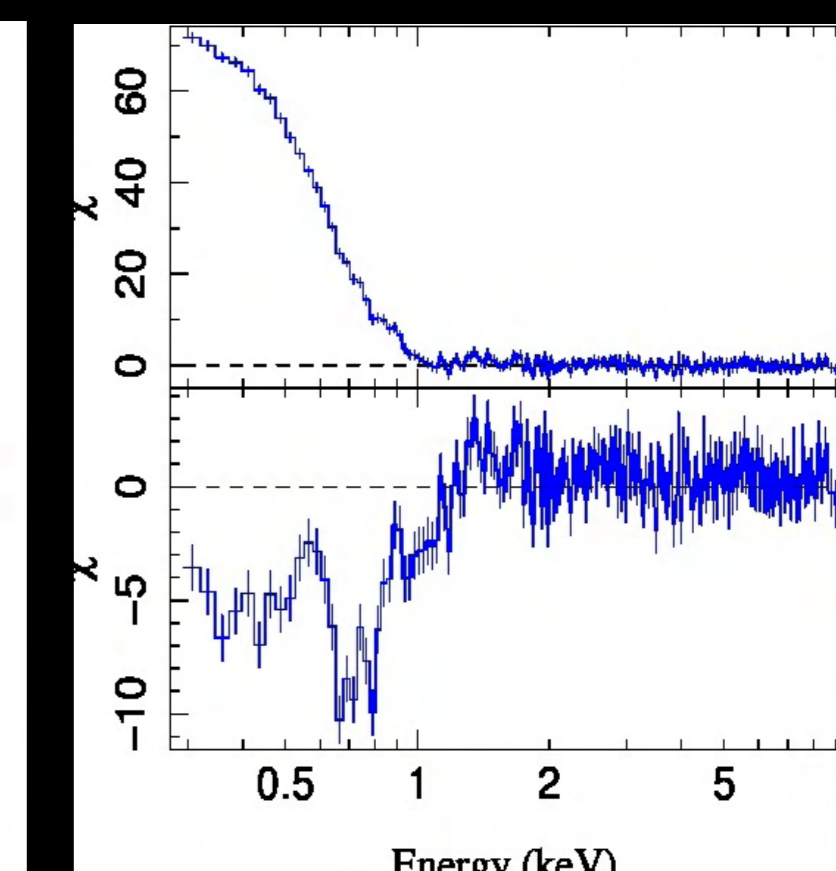
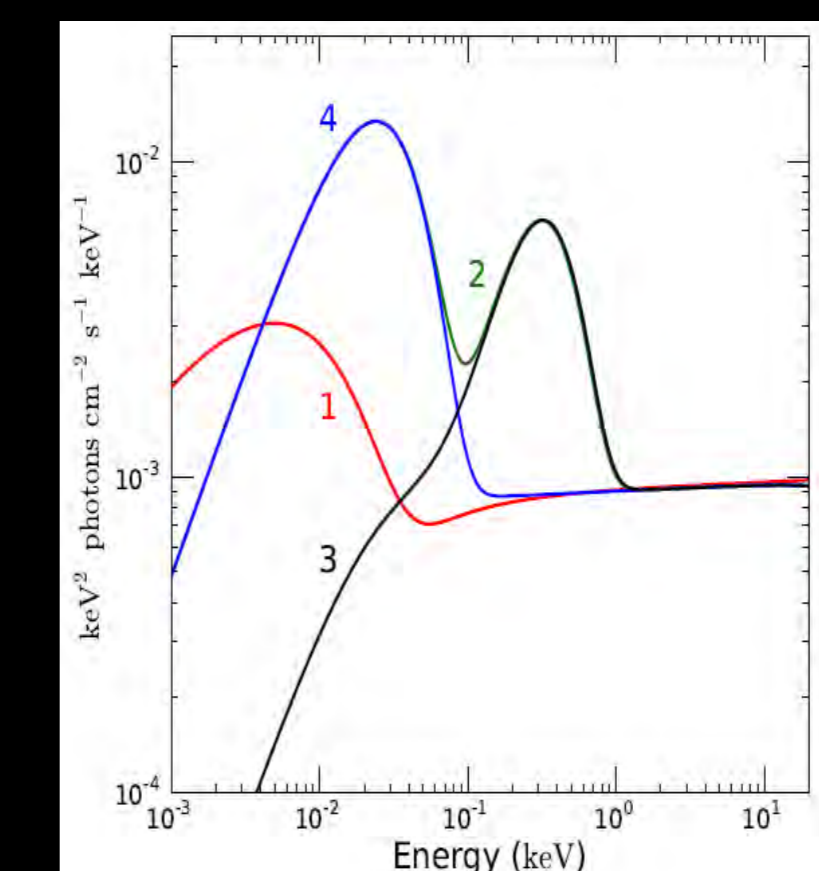
- Quasars commonly show a broad emission feature in the UV (the big blue bump). In recent years it has been discovered a growing population of quasars with no big blue bump.
- The absence of this feature is usually explained as an effect of dust absorption, although there is some evidence of intrinsically red QSO.
- Combined observations with optical and X-ray telescopes can help to differentiate these kind of objects.
- Intrinsically red quasars seem to be AGN with cooler accretion disks. This is caused by lower accretion rates (the amount of matter per unit of time that is falling into the central black hole) than in normal quasars.



The quantity measured in the vertical axis gives an idea of the amount of dust in the galaxy, while the horizontal axis is related with the shape of the optical continuum emission. An intrinsically red quasar shows a low level of dust (bottom region) and a flatter continuum (left region).

### Studies of Warm Absorbers in AGN

The study of outflowing winds known as Warm absorbers from the central nuclear engine of an AGN is an active branch of study. The atomic transitions detected as absorption lines in X-rays and UV give us the information on the dynamics and nature of these winds.



The two plots here show how the typical AGN continuum looks like in the 1eV to 10 keV energy band. The left plot shows four such model continua describing four scenarios. The plot on the right is the ‘data’ from the XMM-Newton satellite. The right plot upper panel shows the presence of some excess emission in the soft X-rays over a powerlaw emission, while the lower panel shows the presence of warm absorption.