X-ray Astronomy and Telescopes

Some plasmas (hot gas) in space are **100,000 to hundreds of millions of degrees Kelvin** meaning they mostly give off **X-rays**.

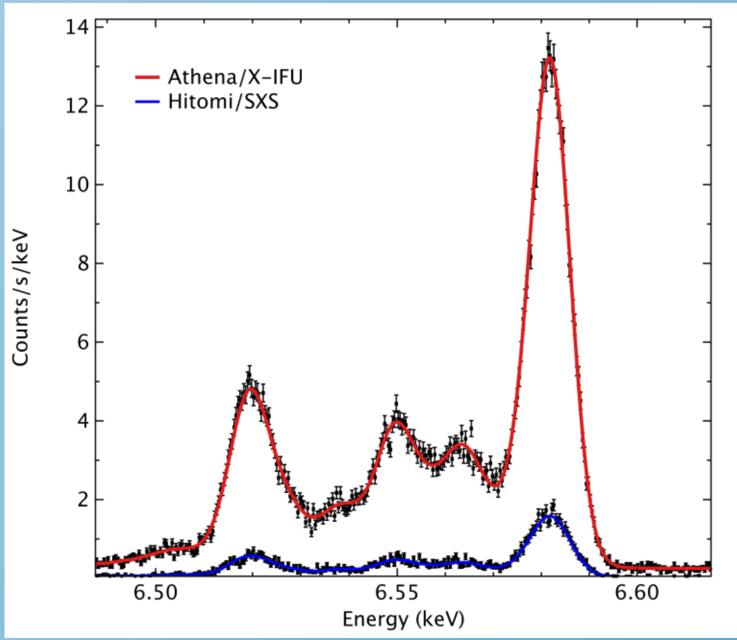
High resolution X-ray spectroscopy provides astronomers with information about the hot and energetic Universe.

- Two major X-ray space-observatory facilities were launched in 1999 - **Chandra and XMM-Newton**.
- The spectra from these X-ray telescopes have resulted in **major scientific breakthroughs**

XMM Newton. ESA.

- **How to process this overload of data?**
- Development of technology and scientific instruments such as ATHENA is great news to astronomers
- **However** the progression of this technology is advancing so fast that it takes a long time to process all the data.
- Creating algorithms and software that enable computers use to process data automatically (and very quickly) is essential

- The **ATHENA X-ray observatory** is to be launched in 2028. It will carry the **most sensitive X-ray telescope** yet launched.
- Below is a comparison of the Perseus cluster seen **by Hitomi** grating spectrometer SXS (X-ray telescope launched in 2016) and a simulation of **ATHENA** grating spectrometer X-IFU.
- This illustrates the improvement of sensitivity due to effective area increase between the two instruments.

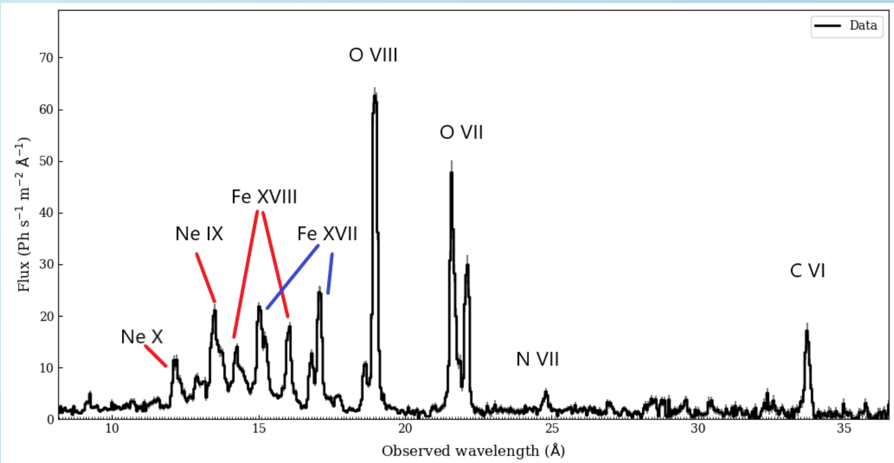


Source: the-athena-x-ray-observatory.eu

Identifying Ions in 3 different Spectra

Three celestial objects' X-ray spectra were analyzed manually. These were **AB Doradus,** a **binary star system; DEM L71** a **supernova remnant** and lastly **MCXC J1023.6+0411** a **galaxy cluster** taken from a mega catalogue of clusters MCXC. These were chosen due to their differences in nature and so would cover a wide range in spectral features. The data for these spectra came from the CIELO-RGS catalog which gets it's data from XMM-Newton.

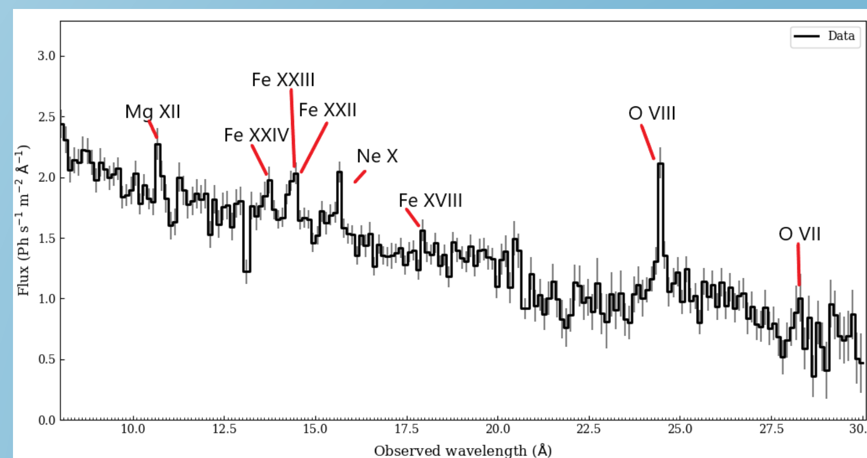
Spectrum of supernova remnant DEM L71



- Spectral lines of Hydrogen-like and Helium-like ions are some of the most well known features in X-ray spectra. . (Hydrogen meaning only one electron, helium 2 electrons)
- He-like ions often produce a series of triplet lines. The emission line O VII (which come as a triplet) have enormous diagnostic power.
- Ions in DEM L71:
  Hydrogen - like ions: Fe XXVI, O VIII, C VI
  Helium - like ions: Fe XXV, O VII, Ne IX

- The spectrum of both **AB Doradus and DEM L71 were very similar.** The spectrum for MCXC J1023.6+0411 looked very different as it contained a redshift.
- The strongest line in the MCXC J1023.6+0411 spectrum was at a wavelength of 24.5 A° and assumed to be O VIII, in which case it's actual wavelength is 18.97 A° . From this the redshift was able to be calculated in the spectrum using equation:

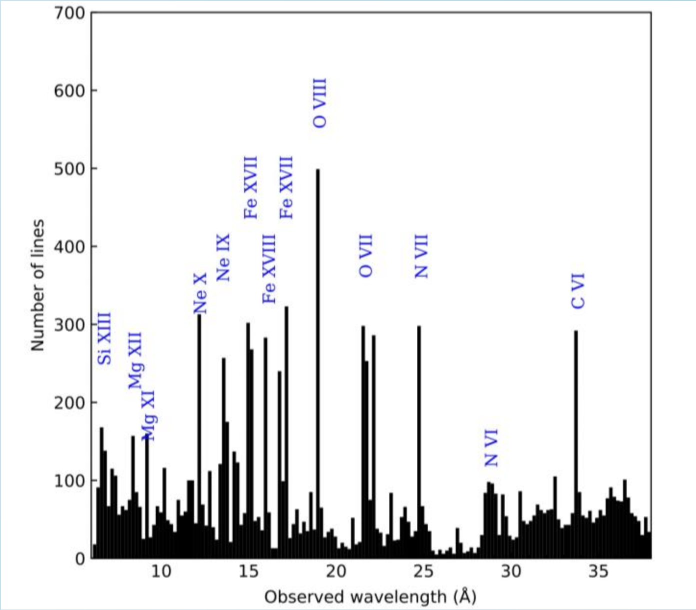
$$z = \frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}} = \frac{24.5\ A^{\circ} - 18.97\ A^{\circ}}{18.97\ A^{\circ}} = 0.295$$



Spectrum of MCXC J1023.6+0411 with rest wavelengths calculated with the appropriate redshift.

CIELO-RGS and AtomDB

- **CIELO-RGS** is a Catalog of Ionised Emission Lines Observed by the Reflection Grating Spectrometer (CIELO-RGS) on board the XMM-Newton space observatory.
- The aims of the catalogue is to make easier use of emission features in the archive of public RGS spectra.
- Catalog includs over 12000 emission lines from X-ray binaries, active galactic nuclei, supernovae remnants, stars and clusters of galaxies.



This is a histogram of the CIELO-RGS catalog which shows the most common lines in all the catalog. Source: Mao et al.

- **AtomDB is an atomic database designed for X-ray plasma spectral modeling.**
- A small subset of ions were selected from the enormous AtomDB database.
- This was done by selecting the most prominent emission lines from 2D intensity plots of the 3 astronomical objects (binary star, supernova and galaxy cluster), and then matching these prominent lines with the closest and strongest ions from AtomDB.

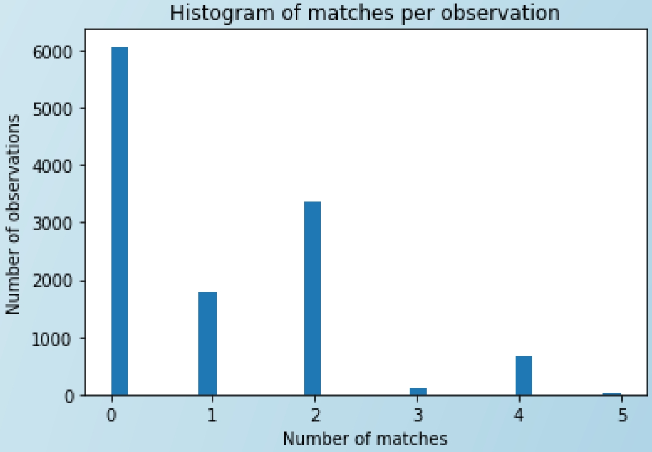
Wavelength (A)	Ion	Wavelength (A)	Ion	Wavelength (A)	Ion
6.18	Si XIV	13.447	Ne IX	16.78	Fe XVII
6.186	Si XIV	13.497	Fe XIX	17.051	Fe XVII
8.419	Mg XII	13.518	Fe XIX	17.096	Fe XVII
8.425	Mg XII	13.553	Ne IX	18.627	O VII
10.619	Fe XXIV	13.699	Ne IX	18.967	O VIII
10.663	Fe XXIV	14.208	Fe XVIII	18.973	O VIII
10.981	Fe XXIII	14.208	Fe XVIII	21.602	O VII
11.254	Fe XXII	15.014	Fe XVII	21.804	O VII
12.132	Ne X	15.261	Fe XVII	22.098	O VII
12.137	Ne X	16.004	Fe XVIII	22.73	Ca XV
12.284	Fe XXI	16.006	O VIII	24.779	N VII
12.846	Fe XX	16.007	O VIII	24.785	N VII
12.864	Fe XX	16.071	Fe XVIII	33.734	C VI
				33.74	C VI

Identified ions from AtomDB. Amalgamation of 40 lines from these three objects in to one table.

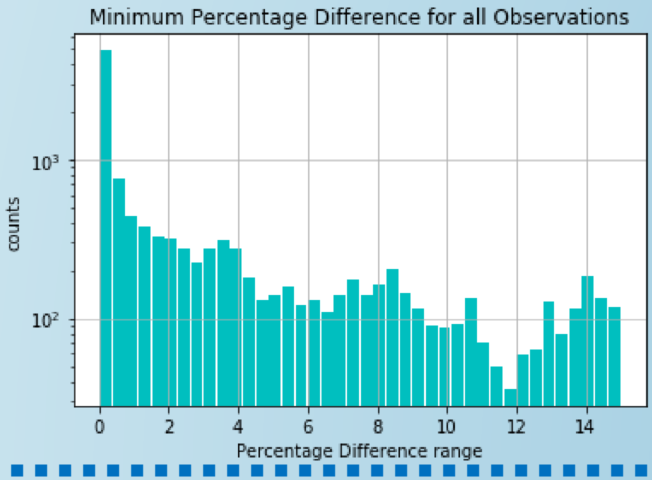
Algorithm and results

An algorithm was made to match identified ions from AtomDB with the CIELO-RGS catalog.

The program matches each (astronomic) line from CIELO-RGS with one or more ionic emission lines from the table of identified ions from AtomDB. A match between the catalog and ions in the AtomDB database is based on a difference in wavelength within 1%.



- Histogram for the number of matches in the 12000 observation lines in the catalog.
- As can be seen from the graph most of the observations have no "suitable" match ie. no match within 1% tolerance.
- The number of observations with zero matches is 6071, which is over half the catalog.



This graph portrays the minimum percentage difference for matches for ALL observations. Most of the minimum percentage differences are below the 1% category more than any other percentage.

Conclusion

- The final algorithm successfully takes data directly downloaded from CIELO-RGS catalog and can find the nearest matches within a percentage and also the match with the minimum percentage difference for each observation.
- This algorithm would not be replicable on a bigger scale. To be expanded to more spectra, a bigger database than 40 ions would have to be created.
- For future work to make it more accurate a probability could be assigned to each line. With the relative probability being, for example, whether this line was likely to be seen in a supernovae or not.
- Overall this algorithm was a small step towards automating spectroscopy in astronomy.

References:

[1] J. Mao et al, "CIELO-RGS: a catalog of soft X-ray ionized emission lines," A&A, vol. 625, p. A122, May 2019.

[2] R. Braunholtz, "Atomic Processes for Astrophysical Plasmas", May 2020