Turbulence measurements in two giant elliptical galaxies

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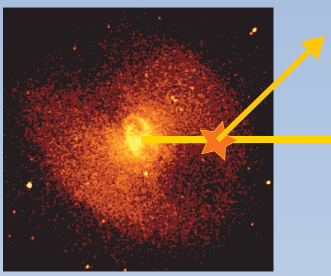
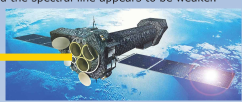
Abstract

Turbulent pressure is thought to contribute significantly to the total pressure in the hot intra-cluster medium. Due to the limited spectral resolution of current X-ray observatories, it is very difficult to detect turbulence directly from line broadening and quantify this important pressure term. There are, however, other methods to estimate the level of turbulence. We study the effect of resonant scattering on Fe XVII lines in deep XMM-Newton RGS spectra of two giant elliptical galaxies. In the spectra, we find significant differences in Fe XVII line ratios between the galaxies, which are explained by a difference in the level of turbulence. Combined with information from deep Chandra images, we discuss the magnitude differences and the origin of the turbulence in these objects.

What is resonant scattering?



Resonant scattering can occur in spectral lines with a high oscillator strength. A line photon emitted in the central region then has a resonable chance to be absorbed and re-emitted (i.e. scattered) in a random direction by the hot gas. Along the line of sight, the net effect is that photons are scattered out of the line of sight and the spectral line appears to be weaker.



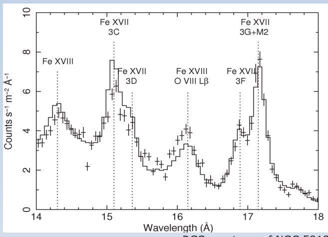
When the hot plasma in the galaxy is turbulent, the Doppler motions prevent the line photons to be absorbed and re-emitted by the ion in the gas that emitted the line. For high turbulent velocities, the observed line has its original strength. The line strength thus provides a measure for the magnitude of gas motions along the line of sight.

Fe XVII lines

One of the most suitable ions to study resonant scattering in the RGS band is Fe XVII. Between 15 and 18 Angstrom, Fe XVII has about five bright lines. One of these (3C) has a high oscillator strength (f) and is therefore sentitive to resonant scattering. Exploiting the high-resolution of RGS, the line ratios between these lines can be accurately measured. Especially the ratio between 3C and 3G+M2 is very interesting, because 3G+M2 is bright and much less sensitive to resonant scattering.

	Transition	λ (Å)^a	f^b	f^c	f^d
3C	$2s^2\,2p^6\,{}^1S_0$–$2s^2\,2p^5\,3d\,{}^1P_1$	15.015	2.31	2.73	2.49
3D	$2s^2\,2p^6\,{}^1S_0$–$2s^2\,2p^5\,3d\,{}^3D_1$	15.262	0.63	0.61	0.64
3F	$2s^2\,2p^6\,{}^1S_0$–$2s^2\,2p^5\,3s\,{}^3P_1$	16.777	0.11	0.11	0.10
3G	$2s^2\,2p^6\,{}^1S_0$–$2s^2\,2p^5\,3s\,{}^1P_1$	17.054	0.12	0.13	0.13
M2	$2s^2\,2p^6\,{}^1S_0$–$2s^2\,2p^5\,3s\,{}^3P_2$	17.097		5×10^{-8}	5×10^{-8}

a) NIST b) Shorer 1979/NIST c) Liedahl/SPEX d) AtomDB 2.0



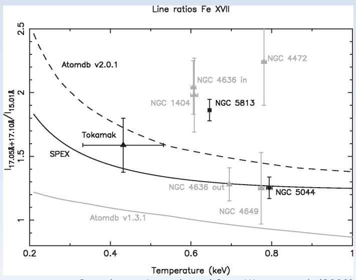
RGS spectrum of NGC 5813

Atomic data uncertainties

Although the Fe XVII ion is very suitable for resonant scattering from the observational point of view, its 'unscattered' or original line properties are very uncertain.

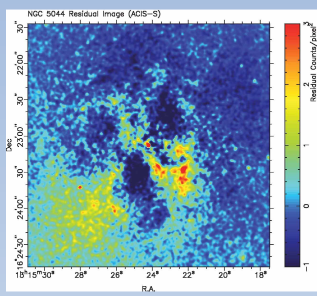
The plot on the right shows the ratio (3G+M2) / 3C obtained from different spectral codes for a range of temperatures. The curves show differences up to a factor of two in line ratio. The most recent codes generally provide a higher line ratio.

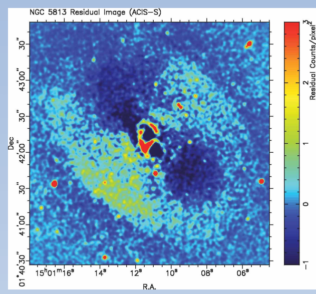
The reason for these discrepancies is the continuing discussion in the atomic physics community. For a long time, theoreticians and experimental physicists could not agree amongst themselves about the properties of these Fe XVII lines, because they are both hard to calculate and hard to measure directly. Although the atomic physicists appear to converge to a more accurate solution, the systematic uncertainty on the line ratio remains considerable.



Gray data points adapted from Werner et al. (2009)

NGC 5044 and NGC 5813





These are Chandra images of the elliptical galaxies NGC 5044 (left) and NGC 5813 (right). To show their internal structures, we have subtracted the average ICM emission profile from the original images. The 'residuals' above show that NGC 5044 has AGN blown bubbles rising in all directions, while the bubbles NGC 5813 appear to rise in only one direction. The ICM of NGC 5044 appears to be more disturbed than that of NGC 5813, possibly due to a recent merger in NGC 5044.

Turbulence estimates

Interestingly, we find a significantly different (3G+M2)/3C ratio for both galaxies in the XMM-Newton RGS spectra (see table on the right). The ratio in NGC 5813 is 1.87, while in NGC 5044, the ratio is 1.25, which is close to the predicted ratio from SPEX, but below the Atomdb 2.0 value (which cannot be explained by resonant scattering, because then the measured point should be above the curve in the figure on the left, i.e. the line at 15 A can only become weaker). If this observation is confirmed, it could have interesting consequences for the atomic data community.

Using the measured line ratios and predicted ratios from SPEX (assumption), we can estimate the turbulent velocities along the line of sight in the two galaxies. The results are shown in the Table on the right. Although the uncertainties are large due to the atomic data, the turbulent velocities in NGC 5044 appear to be clearly higher than in NGC 5813, suggesting that NGC 5044 is indeed more disturbed as could be deduced from the Chandra images.

NGC 5044			NGC 5813		
M	V_{turb}^{a}	Pred.^{b}	M	V_{turb}^{a}	Pred.^{b}
0.00	0	1.76	0.00	0	2.94
0.25	115	1.53	0.25	104	2.13
0.50	230	1.42	0.50	208	1.75
0.75	345	1.37	0.75	311	1.61
∞	∞	1.27	∞	∞	1.30
Observed		1.25 ± 0.08	Observed		1.87 ± 0.08
Lower Limit		>320 km s^{-1}	Lower Limit		>140 km s^{-1}
Upper Limit^c		<770 km s^{-1}	Upper Limit^c		<540 km s^{-1}

Notes. $^{(a)}$ Equivalent turbulent velocity estimate in km s^{-1} using the Mach number and the adiabatic sound speed, which is 460 km s^{-1} for NGC 5044 and 415 km s^{-1} for NGC 5813. $^{(b)}$ Emission weighted average of the predicted $(I_{17.05} + I_{17.10})/I_{15.01}$ ratio over the RGS extraction region. $^{(c)}$ 90% upper limits on the turbulence derived from the line width in RGS.

Summary & Conclusions

The turbulent velocities in NGC 5044 appear to be higher than in NGC 5813. A more quantitative statement is hard to make due to the uncertainties in the atomic data of the Fe XVII ion. Actually, the precision of the measured line ratio with RGS is very high, which means that the turbulence measurements are limited by systematic uncertainties in the atomic data. Since the different atomic physics teams appear to be converging to a solution, resonance scattering measurements will prove to be a very useful tool for measuring turbulence in the future.

References

This poster was based on the work presented in:
de Plaa, J., Zhuravleva, I., Werner, N., et al., 2012, A&A, 539, A34
(see references therein)

More information about the SPEX spectral fitting package:
http://www.sron.nl/spex

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