X-ray spectral analysis of non-equilibrium plasmas in supernova remnants

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Localisation and characterisation of circumstellar material in Kepler using a principal component analysis.

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To be submitted

Abstract

The Galactic supernova remnant Kepler is an ideal testcase for the interaction of a type Ia supernova with circumstellar medium. A better understanding of the characteristics and the morphology of this shocked circumstellar medium
6. The CSM morphology of Kepler

can provide constraints on the progenitor system of the supernova. We performed a principal component analysis on Chandra data of Kepler’s supernova remnant, in order to characterise the different emitting plasmas. Three principal components select strongly for the presence of shocked ambient medium. We find the presence of shocked ambient medium across the whole boundary of the remnant, with the strongest concentration in the band orientated in the southwest-northeast direction, which has also prominent optical emission. Based on the locations of the CSM components combined with the distribution of the X-ray synchrotron emission, we propose a 3d, diabolo-like morphology for the remnant. This morphology is probably the result of a dense disk-like CSM structure surrounding the progenitor system. This has implications for searches for the location of the putative companion star.
6.1 Introduction

Type Ia supernovae (SNe Ia) in their role as cosmological standard candles played a crucial part in the discovery of the accelerating expansion of the Universe (Riess et al. 1998; Perlmutter et al. 1999). The fact that their origin is still unclear has therefore been a pressing problem for some time. There is an agreement that a SN Ia explosion is the result of a thermonuclear combustion of a carbon oxygen white dwarf (CO WD). Two main paths have been suggested which potentially lead to the runaway nuclear fusion in the core of a WD: The so called single-degenerate (SD) scenario, in which the CO WD accretes material from a non-degenerate companion star, and the so called double degenerate (DD) scenario, in which the explosion is triggered by the merging of two CO WDs (see Maoz & Mannucci 2012, for a review).

In the case of the DD scenario no large scale circumstellar medium effects are expected. However, in the case of a non-degenerate companion star, the CSM is formed by outflows from the secondary star, which will leave an imprint in the supernova remnant (SNR). Therefore by identifying the characteristics of the CSM around a Type Ia SNR, we get important information on the nature and the evolution of its progenitor system.

The remnant of the historical supernova SN 1604, to which we will refer to as Kepler from here on, is an important test case to study such an ejecta/CSM interaction. Kepler reveals a bright optical nebulosity with prominent N II emission lines in its northeastern region. This indicates that in this portion of the remnant, the ejecta interacts with dense, nitrogen rich material which origin is most likely circumstellar Blair et al. (1991); Reynolds et al. (2007). Based on the X-ray kinematics of the interacting region of Kepler Vink (2008) estimated the mass of this CSM to be at least 1 M⊙.

The presence of this nitrogen-rich shell originally led to the belief that Kepler was the result of a Type Ib SN, where the CSM was shaped by the ejection of the outer envelope of its progenitor star (Bandiera 1987). However, recent observations suggest that Kepler has a Type Ia origin. The main arguments for this are: 1) the chemical composition of the spectrum which reveal prominent Fe L emission and weak oxygen emission (Kinugasa & Tsunemi 1999; Reynolds et al. 2007) 2) the lack of an X-ray emitting neutron star and/or pulsar wind nebula (Reynolds et al. 2007) 3) the presence of Balmer-dominated shocks characteris-
tic of type Ia SNRs 4) its high galactic latitude.

Within the framework of a Type Ia single degenerate model, (Chiotellis et al. 2012) performed 2D hydrodynamical simulations and found that the morphology and dynamics of Kepler can be explained, assuming that the WD exploded in a bow-shaped wind bubble blown by an AGB donor star. Burkey et al. (2013) isolated the shocked CSM from the SN ejecta using a Gaussian mixture model with Chandra spectral data and found substantial concentrations of CSM in the bright northern rim and central bar of the remnant. This central bar is also a prominent feature in the optical emission of Kepler, which is another hint that it originates from CSM. Retaining the idea of an AGB donor star, they interpreted the central CSM concentration as evidence for a disc distribution around the explosion center formed by a non-isotropic stellar wind. Finally, Patnaude et al. (2012) simulated the southern region of Kepler and found that the X-ray spectrum of this portion is consistent with a wind shaped CSM as long as a small cavity is introduced around the explosion center. A major problem for the aforementioned models is the absence of such a bright giant companion star in the central region of Kepler’s SNR (Kerzendorf et al. 2014). An alternative model, which is essentially a DD model, but which can explain CSM around Type Ia, is the so-called core-degenerated model (Tsebrenko & Soker 2013). In this scenario prior to the explosion the WD and its companion have a common envelope phase, which removes the outer layers of the companion star, creating a planetary nebula-like nebula. The degenerate core of the companion star and the primary WD will later merge, while the nebula is still present. Whether Kepler has a SD or DD origin, it remains an intriguing object since, while the majority of Type Ia SNRs are consistent with evolution in a homogeneous ambient medium (Badenes et al. 2007; Yamaguchi et al. 2014), it reveals such a remarkable interaction with high density CSM. It is therefore a unique laboratory in which, by revealing the properties of the surrounding CSM, we can provide strict constraints on its progenitor system. In addition, detailed information on the morphology of the CSM provides crucial input for hydrodynamical simulations of Kepler.

For the study of the interaction of a SN with its environment, X-ray is a very suitable wavelength band. In general X-ray emission of SNRs highlights regions where the ejecta and ambient medium plasmas are shocked to tens of millions of degrees. The plasmas are optically thin, which allows for the detection of emission from both outer and inner parts of the remnant. In addition, X-ray
spectroscopy allows one to distinguish between different elements and plasma conditions in the remnant. As such, interaction of the SN blast wave with the surrounding material will leave a clear imprint in the observed plasma properties, which we can then use to determine the ambient medium properties. The X-ray morphology of Kepler (see Fig. 6.1) is characterised by a bright arc of emission in the north of the remnant, and a bright band across the center in the southeast-northwest direction. The X-ray synchrotron filaments (blue) are clearly distinguishable, and the intermediate mass elements Si, S, Ar and Ca are present across the remnant as well (green).

In this paper we perform a principal component analysis (PCA) on Chandra X-ray data of Kepler with the aim to localise and characterise the different emitting plasmas in the remnant, in order to isolate the shock-heated CSM component and study its morphology.
6.2 Data Analysis

Kepler has been observed by *Chandra* on numerous occasions. The long total observing time and resulting good statistics in combination with the high spatial resolution of *Chandra* make this an ideal dataset to study the detailed shock and plasma physics in SNRs. Such a high quality and large dataset, in general, increases the usefulness of statistical techniques, especially in extended sources. Examples where advanced statistical techniques were successfully applied to SNRs are the PCA used by Warren et al. (2005); Broersen et al. (2014) and the Gaussian mixture method used by Burkey et al. (2013). The PCA technique (Jolliffe 1986) we use here is a statistical technique which is used to reduce the dimensionality of a dataset, while retaining as much as possible of the information in the dataset. The output of a PCA consists of several principal components (PCs), which are essentially eigen vectors with which the data set can be described. The PCs are sorted based on the amount of variance they represent in the data, so that the first PCs account for the largest amount of variance. The technique is described in more detail in previous work (Broersen et al. 2014).

As input for the PCA we created images in different energy bands (see Tab. 6.1), which each contain a spectral feature, so that the resulting PC can be physically interpreted. In order to create the images, we used the *Chandra* data analysis software package ciao version 4.5 to merge the observation IDs 6714-6718 and 7366 together into one large event file with a total observation time of \( \sim 740 \) ks, from which we extracted the images. Note that PCA is a purely statistical technique, but that the relevant search parameters that go into the analysis come from selecting the right energy bands.

6.3 Results

As mentioned in the introduction, we aim to determine the properties of the CSM emitting plasma in Kepler. Emission from shocked ambient medium is characterised by emission from elements which are not produced in large amounts in SNe Ia nucleosynthesis, i.e.: O, Ne and Mg (Maeda et al. 2010). Si, S, Ar, Ca and Fe on the other hand are produced in copious amounts in the SN itself, and large concentrations of these elements are an indication of the presence of ejecta emission. Our PC analysis gives us a number of images which
show regions which have enhanced emission in certain energy bands, and reduced emission in others. Although the first principal components by definition accounts for most of the variance in the data, the resulting correlations and variations in the data do not always have a straightforward physical interpretation. Here we analyse the results of those PCs that clearly correspond to the shocked CSM in Kepler, namely PC 2, 3 and 9. In the appendix we provide an overview of the remaining PCs from 0 to 9. We start here with the first and most prominent shocked CSM related PC, PC 2.

The scores of PC 2 are shown in Fig. 6.2, bottom left. As mentioned above, the top PC image can be reconstructed by adding all wavelength band images together multiplied with their corresponding score (save some normalisation factor). As such, we expect from this figure that the positive pixels in the resulting PC show enhanced emission in the He-like Si (1.85 keV) and S (2.46 keV) energy range, while the negative pixels show mainly enhanced Fe L/Ne X and Mg XI (1.35 keV) emission. The resulting spectra are shown in Fig. 6.2, bottom middle. The red spectrum was extracted from positive pixels with values >0.007, while

### Table 6.1: The energy ranges of the the images created as input for the PCA.

<table>
<thead>
<tr>
<th>Energy range (eV)</th>
<th>Spectral characteristic</th>
<th>Energy range (eV)</th>
<th>Spectral characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>500-600</td>
<td>O VII</td>
<td>1980-2119</td>
<td>Si XIV</td>
</tr>
<tr>
<td>600-719</td>
<td>O VIII</td>
<td>2120-2269</td>
<td>Si XIII He-(\beta)</td>
</tr>
<tr>
<td>720-949</td>
<td>Fe L</td>
<td>2270-2749</td>
<td>S XV</td>
</tr>
<tr>
<td>950-1049</td>
<td>Ne IX / Fe L</td>
<td>2750-2979</td>
<td>S XVI</td>
</tr>
<tr>
<td>1050-1259</td>
<td>Ne X / Fe L</td>
<td>2980-3299</td>
<td>Ar XVII</td>
</tr>
<tr>
<td>1260-1439</td>
<td>Mg XI</td>
<td>3300-3599</td>
<td>Ar XVIII</td>
</tr>
<tr>
<td>1440-1599</td>
<td>Mg XII</td>
<td>3600-4099</td>
<td>Ca XIX-XX</td>
</tr>
<tr>
<td>1600-1699</td>
<td>Continuum</td>
<td>4300-5199</td>
<td>Ca XIX He-(\beta)</td>
</tr>
<tr>
<td>1700-1849</td>
<td>Si XIII, red</td>
<td>5200-6099</td>
<td>Continuum</td>
</tr>
<tr>
<td>1850-1979</td>
<td>Si XIII, blue</td>
<td>6100-6700</td>
<td>Fe K</td>
</tr>
</tbody>
</table>
the black spectrum was extracted from negative pixels with values $< -0.008$. The expected emission pattern is clearly visible, as the red spectrum shows strong Si and S emission (even compared to Fe L), indicating ejecta emission, while the black spectrum shows enhanced Ne X and Mg XI, indicating shocked ambient medium. Morphologically, the Si and S enhanced ejecta regions are located in a layer around Fe-rich ejecta. This can be seen by comparing the bright, Si-rich region in PC 2 to the bright, Fe L rich, region in PC 3 below. This is an additional clue that ejecta in type Ia SNRs are stratified (Kosenko et al. 2010). Interestingly, the Si and S rich regions are very closely correlated to the radio morphology (e.g. Matsui et al. 1984), note especially the filaments in the northeastern ‘ear’ of the remnant. The negative, CSM related, regions have a more complicated and asymmetric morphology, in the sense that they are located in a filament in the middle and in a filament in the northern part of the remnant. However, even though the negative pixels are related spectrally, there can still be differences between them, since each location is characterised by several PCs. In PC 2, there is an ambiguity in the sense that the emission band which is strong in the negative pixels can be both from Fe-L and from Ne emission. It is possible to distinguish between Ne and Fe L at ACIS spectral resolution, although the difference is subtle. Fe L emission has the most prominent lines at 0.73 and 0.83 keV, while Ne IX-X have centroids of 0.92 and 1.02 keV. In order to distinct between these two possibilities we extracted spectra from the negative pixels with value $< -0.003$ from different regions of the remnant, indicated with white boxes in Fig. 6.2, top. The brightest, red, spectrum was extracted from the northeastern region, the black spectrum from the centre, the green spectrum from the north and the blue spectrum from the small blob in the eastern part of the remnant. Of these spectra, the red and black ones show CSM related emission in the form of prominent Ne, Mg and also O lines, the green and blue ones, however, show mainly strong emission from Fe L. We therefore conclude that CSM emission is present most strongly in the black filaments in the center and northeastern part of the remnant.

PC 3 is the next PC which shows shocked ambient medium related emission, and is shown in Fig. 6.3. From the bottom left figure we obtain that the positive pixels show strongly enhanced Fe L emission, while the negative pixels show enhanced O VIII, Mg XI and lowly ionized Si. This is clear from the spectrum shown in the bottom right corner, of which the black spectrum was extracted from pixels with value $< -0.003$, while the red spectrum was extracted
Figure 6.2: Top: PC 2. The positive pixels show regions of strong Si ejecta emission, while the negative pixels show regions of strong shocked ambient medium emission. The regions from which the spectra in the bottom right are extracted are indicated. Bottom left: PC scores. This shows that the negative pixels in the top figure show enhanced Ne X, Mg XI, which are associated with shocked ambient medium emission, while the positive pixels show strong Si and S, which are associated with shocked ejecta. Bottom middle: The black line shows the spectrum of the negative pixels with values $< -0.008$, while the red line shows the spectrum of the positive pixels with values $> 0.007$ of the complete remnant. Bottom right: spectra from pixels with values $< -0.003$ from different regions of the remnant. The red spectrum is extracted from the northeastern part of the remnant, the black spectrum from the centre, the green spectrum from the north and the blue spectrum from the negative pixels in the eastern central part.
6. The CSM morphology of Kepler

from pixels with value $> 0.003$. The red spectrum is completely dominated by Fe L emission, which, contrary to PC 2, is stronger than Si. Interestingly, the continuum emission in the red spectrum is low compared to the emission line strengths, which suggest that the plasma consists purely of metals and little hydrogen is present. The black spectrum indeed shows enhanced O VIII and Mg XI, and also shows the presence of Ne IX-X, again indicating shocked ambient medium emission. This component therefore creates a clear distinction between shocked ejecta and shocked ambient medium, which is also evident from the “fingers” located in the northern part of the remnant. These fingers, which probably result from Rayleigh-Taylor instabilities, generally mark the location of the contact discontinuity, which separates the shocked ambient medium from the shocked ejecta. Both PC 2 and PC 3 are indicative of locations of shocked ambient medium emission, but their properties are slightly different. In PC 2 the Mg XI line is stronger relative to Si XIII than in PC 3, and the Ne X line is also stronger. This stronger Ne X line indicates a higher ionisation timescale in the plasma, which in turn suggests a higher density. We therefore conclude that PC 3 shows shocked ambient medium in general around the remnant, while PC 2 shows purely shocked CSM in a central band in Kepler, which has probably the highest density.

The final PC we show here related to shocked ambient medium is PC 9 (see Fig. 6.4). PC 9 shows strongly enhanced O VII emission compared to O VIII, as is clear from the bottom left figure. A spectrum of the pixels with values $< -0.006$ is shown in the bottom right in black, this time not combined with a spectrum of the positive pixels, but with the shocked ambient medium spectrum of PC 3 plotted in red for reference. The black spectrum shows a subtle, but significant, enhancement in O VII emission at $\sim 0.54$ keV, while the rest of the spectrum is largely similar. This image clearly shows the power of a PCA, as even at the spectral resolution of Chandra’s ACIS instrument, it is still possible to distinguish between O VII and O VIII emission! The morphology of PC 9 shows an almost perfect correlation with optical H$\alpha$ emission images (Blair et al. 1991), with its enhancement in the northern rim and the central region of the remnant. Interestingly, there are also weak traces of O VII enhanced plasma tracing the outer boundary of the complete remnant, where H$\alpha$ has, as of yet, not been detected.
Figure 6.3: Top: The third PC. The positive pixels show regions of strong Fe ejecta emission, while the negative pixels show regions of strong ambient medium emission. Bottom left: PC scores. This shows that the negative pixels in the top figure show enhanced O VIII, Mg XI, and low ionized Si emission, while the positive pixels show strong Fe L. Bottom right: The black line shows the spectrum of the negative pixels with values < -0.003, while the red line shows the spectrum of the positive pixels with values > 0.003, extracted from the whole remnant.
Figure 6.4: Top: PC 9. We show only the negative pixels here, which have a strong presence of O VII emission compared to the red spectrum.

The black spectrum shows clearly enhanced O VII emission compared to the red spectrum.

Below: The PC scores, which show strongly enhanced O VII emission for the negative pixels. Bottom right: The black points label the negative pixels, which have a spectrum of O VII emission. Bottom left: The PC scores, which show strongly enhanced O VII emission for the negative pixels. Bottom right: The black points label the negative pixels, which have a stronger presence of O VII emission compared to the red spectrum.
6.3. Results

Discussion

We have shown three different PCs which all trace shocked ambient medium or ejecta emission. The three shocked ambient medium related PCs show different morphologies. With PC 2 we showed that there is a strong presence of shocked CSM in a band across the remnant in the southwest - northeast direction. Given the location and correlation with dense, optically emitting, N knots, this component selects for the most dense CSM. PC 3 shows a presence of shocked ambient medium over the whole remnant, and overlaps with PC 2 in the central region. PC 3 selects for less dense CSM. PC 9 shows enhanced O VII emission in the central part of the remnant, but also around the outer edges. This component correlates almost perfectly with the Hα morphology in the North and central parts of the remnant.

From this we conclude that, although there is shocked ambient medium present in all outer parts of the remnant, the strongest concentration of shocked CSM is present in the central region of the remnant. Burkey et al. (2013) also show that CSM emission is present in this part, but our results differ slightly from theirs, as they also claim the presence of strong CSM emission in a northern region of the remnant which we do not find (see PC 2). They propose that there runs a band of dense CSM material of which the plane lies directly in our line of sight, which impedes the expansion of ejecta in certain directions. They perform hydrodynamical simulations which show the resulting morphology of such a CSM distribution. We agree with the idea of a disc-like CSM structure around the remnant and the resulting morphology, but would like to propose a different orientation. We illustrate this in Fig. 6.5, top, which shows an image of Kepler in the 4.3-6.1 keV band. This band shows no meaningful line emission (since the Ca XIX He-β emission is generally weak) and therefore is a good tracer of X-ray synchrotron emission, which in turn is a tracer of the forward shock in the remnant. The reverse shock in supernova remnants may also accelerate particles as observed in Cas A (Helder & Vink 2008). However in this case the non-thermal filaments also trace filaments associated with shocked ambient medium, so that we take the synchrotron filaments to be the location of the forward shock.
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Figure 6.5: Top: Kepler in the 4.3-6.1 keV energy band, which shows X-ray synchrotron emission. The arrows denote X-ray synchrotron filaments which are indicative of an empty region in the remnant. The top arrow shows a filament which crosses the edge of the remnant and goes 'inward' into the empty region (shown in orange in the figures below). The bottom arrow shows a point where a filament which runs across the western boundary terminates, suggesting a sharp boundary in the surface of the remnant. Bottom left: schematic proposed morphology for Kepler. A band of CSM emission around the explosion center impedes the expanding ejecta. The band is rotated $40^\circ$ with respect to the line of sight, and the model is also tilted $35^\circ$ towards us.

Middle: same as the left image, but now the model is oriented so that the inner part of the remnant is facing inward. The band is rotated $40^\circ$ with respect to the line of sight, and the model is also tilted $35^\circ$ towards us.

Bottom: same as the left image, but now the model is rotated so that the inner part of the remnant is facing toward us. The band is rotated $40^\circ$ with respect to the line of sight, and the model is also tilted $35^\circ$ towards us.

Middle: same as the left image, but now the model is oriented so that the inner part of the remnant is facing inward. The band is rotated $40^\circ$ with respect to the line of sight, and the model is also tilted $35^\circ$ towards us.

Bottom: same as the left image, but now the model is rotated so that the inner part of the remnant is facing toward us. The band is rotated $40^\circ$ with respect to the line of sight, and the model is also tilted $35^\circ$ towards us.
The continuum image shows several interesting features, marked with white arrows. The left arrow shows a small synchrotron filament which runs over the edge of the remnant and continues ‘inward’ towards the center. The bottom white arrow shows the point at which a filament which runs from east to west across the remnant suddenly terminates. Both of these features in the synchrotron morphology can be explained if this region in the eastern part of the remnant is ‘empty’. An empty region in this part of Kepler has been noted before, and has been attributed to, among others, the companion star blocking part of the ejecta (Burkey et al. 2013). Although this is certainly an interesting possibility, we suggest here a 3D morphology that is shaped by the immediate CSM of the progenitor. We schematically show the morphology in the bottom part of Fig. 6.5. We propose that the bright central emission band of Kepler (shown in pink) has a surface normal pointing outward through the empty region and that this empty region is therefore created by a band of dense CSM impeding the expanding SN ejecta. The plane of the disc is rotated $\sim 40^\circ$ with respect to the line of sight, and the is tilted with $\sim 35^\circ$ towards us. The overall morphology of Kepler could then be similar to a shape which is often seen in planetary nebulae, and which we show in an exaggerated fashion in the bottom middle figure. In planetary nebulae open hourglass like shapes are observed, which are the result of a dense disc of material which impedes the outflowing stellar wind. A similar disc of material may have shaped Kepler which would provide the depicted morphology. The right figure illustrates which filaments of the remnant correspond to which location in this particular morphology.

Obviously the situation in Kepler is more complicated than the schematic that we show, in particular since the remnant has a bulk motion towards the north, and different parts of the remnant may break through the dense disc of CSM on different timescales. Further deviations from this morphology may arise from asymmetries in the surrounding ambient medium. Overall, however, the different emitting plasmas are well-reproduced by the proposed morphology.

The complexity of Kepler and asymmetries in surrounding material and explosion make it difficult to test the hypothesis of this morphology. It could be tested theoretically with hydrodynamical simulations. These simulations should be performed in 3D, since the proper motion of Kepler and the proposed CSM disc structure have different axes. Observationally, future high-resolution X-ray telescopes such as Astro-H may be able to test the proposed morphology, as their resolution allows one to obtain line of sight velocity information of the
shocked X-ray emitting plasma.

An interesting implication of the proposed morphology is that searches for a possible remnant companion star should be aimed more towards the south than has been done so far, as the explosion center is ill-determined by the outer edges of the X-ray emission.

### 6.4 Conclusion

We have used Chandra X-ray data to perform a PCA on Kepler’s SNR. From this analysis we show three principal components which can be readily interpreted to show shocked CSM / ISM related material. These PCs clearly correspond to optical emission from N-rich material, but also point to regions at the outer edges for which not yet optical emission has been reported. We find traces of shocked ambient medium across the whole boundary of Kepler, but find that the strongest presence of shocked CSM is in a band running from the southwest to the northeast. Based on the shocked ambient medium and synchrotron morphology we propose that Kepler has a ‘diabolo’-like morphology, in which a band of CSM emission with an angle of 40° with respect to the line of sight impedes the expanding ejecta. We see the direct result of this impediment in an empty region in the southwest of the remnant, and in the morphology of the X-ray synchrotron emitting filaments.

Our results have implications for searches for the possible companion star of the WD, which location should be sought more towards the south of the remnant.

### Acknowledgements

The scientific results reported in this article are based on data obtained from the Chandra Data Archive.

### 6.5 Appendix
Figure 6.6: PC 0 selects for the presence of Fe. In this figure there are no negative pixels, since the flux in the Fe L bands is always higher than the flux in the rest of the energy range. Brighter regions are brighter in the Fe L band.

Figure 6.7: PC 1 shows an anti correlation between low (negative pixels) and high (positive pixels) ionized Fe. The lower ionized Fe is found at smaller radii.

Figure 6.8: PC 4 shows a correlation between O VIII and highly ionized Fe L emission in the negative pixels, while the positive pixels show stronger Fe xvii emission.
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**Figure 6.9:** PC 5. This component selects strongly for Fe L.

**Figure 6.10:** PC 6 shows an anti correlation between the red and the blue wing of the 1.85 keV Si line. Positive pixels show stronger flux in the blueshifted wing, while the negative pixels show stronger emission in the redshifted wing. It is unclear if this is due to velocity or ionization age effects.

**Figure 6.11:** PC 7 is a noisy PC which shows an anti correlation between emission in the blue wing of the Si line, and S emission.
Figure 6.12: Finally PC 8 shows an anti correlation between the two magnesium bands. Interestingly the positive pixels in the image correspond perfectly with X-ray synchrotron emission shown in Fig. 6.5. This can be explained by the fact that the Mg XII line region falls between the bright Fe L line complex and the bright Si at 1.85 keV. Stronger emission in this band therefore means the continuum is stronger, which corresponds to synchrotron emission.