Abstract

Gravitational lensing of quasars can be used as an invaluable cosmological tool, however lens models often require a strong external aid in addition to the intrinsic uncertainty of the lensing galaxy to produce the observed asymmetry in the lensed images. The shear may be from a galaxy cluster associated with the lensing galaxy or otherwise along the line-of-sight to the quasar. We are searching for X-ray emission from groups and clusters in the fields of strong gravitational lenses using Chandra’s resolving power to separate the bright quasar images from the much fainter diffuse emission. We present Chandra images and luminosities or luminosity limits for 30 candidate clusters associated with multiple multiply imaging lensed quasars. We also discuss our search for extended X-ray emission in the fields of lensed quasars that are not yet known to contain a galaxy group.

Introduction

Gravitational lenses that produce multiple images of background quasars can be invaluable tools for measuring cosmological parameters, to better study the magnified distant quasars, and to explore the structure of the lensing galaxy. Models require knowledge of the gravitational potential along the line of sight to the quasar including the lensing galaxy and any additional structure. Keeton et al. (2000) predict that a quarter of lensing galaxies are associated with a group or cluster that would perturb the gravitational potential. There are a handful of spectroscopically confirmed groups or clusters that have been associated with a multiply imaged quasar. In addition there are many lensing systems that require additional shear components in order for models to reproduce the positions and fluxes of the quasar images. Among other possibilities, the additional shear could be due to a galaxy or cluster associated with the lensing galaxy or otherwise along the line of sight.

Groups or clusters have been previously studied in the X-ray in five of these systems including MG0413+0456 (Chartas et al. 1998), HST1417+5226 (Mao & Chartas 2005), and PG1115+080 and B1422+231 (Chartas et al. 2001). We are searching for X-ray emission from groups and clusters in the fields of strong gravitational lenses using Chandra’s resolving power to separate the quasar images from diffuse emission. We have selected thirty multiply imaged quasars that are considered to be good lensing candidates and that have remained as candidates in the Chandra public archive. The previously studied groups are included in our sample to provide a useful comparison for the remaining targets.

Data Preparation

The thirty gravitational lenses were observed in fifty observations with a range in exposure time from as short as a few days up to many months. The images were primarily obtained using ACIS-S in standard full frame mode, however a few used the ACIS-I array, a subdivided or the HETE inserted Si photocathode array (SPA) for a range from 1.5 to 100 hours. The data were reduced using standard CIAO tools, including filtering by event grade and statistic and renaming time periods with arc confusion. Multiple observations of the same source were merged into a single event file. To minimize the diffuse signal and maximize the background, the event files were filtered to include only photon energies between 0.5 and 2 keV, where the relative contributions of the particle background for the ACIS-S3 detector is at its lowest.

Image Analysis

Developing a lens model and using an external tension from the faint quasar images is a complex task. Source detection detection algorithms such as dmfilth and dmfilthx are effective in detecting extended objects, but are less useful at differentiating multiply coroded point sources and extended structures. To better resolve the complex distribution of the X-ray emission, a model was constructed for the lens, with positions fixed to those measured in the optical and radio, and fit to the data in Sherpa. This model was then subtracted from the original image. Any remaining point sources in the image were excised and filled in using dmfilthx. The images were then smoothed with a 30 pixel FWHM Gaussian and normalized for exposure variations and instrumental factors.

Discussion

We have discovered possible new diffuse X-ray emission towards our targets. These are a wide range in luminosity and size, real, represent both groups and clusters along the line of sight to these lenses. The most significant of these, towards HS1800+2534, is consistent with a galaxy in the SPT0449 and IRAS catalogue. It has not been detected in the ROSAT and XMM-Newton fields found by any other X-ray survey. Examining the original event list, the emission is peaked at the galaxy location but is clearly diffuse, as seen in a hot galactic halo or a small galaxy group. Two of the targets, B1422+231 and MG0413+0456, have extended emission that is coincident with lensed quasars. The emission towards PG1115+113 is coincident with the lensing galaxy which may be a part of a small group. The nature of the emission in the remaining three targets, Q0137-307, MG2016+112, and HE2149-2745, is not clear.

Possible New X-ray Detections

<table>
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<th>Name</th>
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<th>Signal-L</th>
<th>Signal-M</th>
<th>Signal-S</th>
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<td>0.50</td>
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<tr>
<td>Q0137-307</td>
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<td>1.20</td>
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<tr>
<td>MG0413+0456</td>
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<td>0.15</td>
<td>0.50</td>
<td>0.80</td>
<td>1.20</td>
</tr>
</tbody>
</table>

Contour Plots

The quasar-subtracted, smoothed images of the possible new X-ray detections are shown as contour plots. The contour levels are set at 2σ above the background level and the contours are spaced by 2σ. In the case of HS1800+2534 where the detection is highly significant, the contours are spaced by 10σ. The blue diamonds are the lensed quasar images. The filled red triangles indicate spectroscopically confirmed galaxies in the group or cluster while the open red triangles are optically selected galaxies in the group or cluster. The green square is the location of the photometrically determined galaxy coordinates. North is up and east is to the left.

References


Acknowledgments

The gravitational lens information was obtained from the lensing database maintained by Brian Keeton at MIT. The Chandra data were obtained from the Chandra X-ray Center, which is operated by the Smithsonian Astrophysical Observatory for the National Aeronautics and Space Administration by NASA under the contract number NAS8–03060. The images were obtained from the M. H. Schmidt catalogue maintained by Gerhard Hasinger. The ROSAT images were obtained through the ROSAT Imaging Survey. The optical images were obtained through the NASA/IPAC Extragalactic Database (NED). The HST images were obtained from the Hubble Legacy Archive (HLA).

Finding Galaxy Groups in the Fields of Lensed Quasars

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