MG0414+0534 Gravitational Lensing and
HI Absorption Line Analysis using the Very Large Array Archive Data

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Abstract

This paper explores the use of the Very Large Array (VLA) archive data to explore several astronomical concepts. The author processed the VLA data on the quasar MG0414+0531. This object demonstrates gravitational lensing, HI absorption line analysis and relativistic red shift distance calculations.

Introduction

The Very Large Array (VLA) provides an archive of past observations (VLA Archive, 2020). There are also tutorials that provide training in processing the archive data (VLA CASA Tutorials, 2020). The MG0414+0534 gravitation lens tutorial provides an excellent example of calculating the distance of an object by observing the redshift of the HI absorption line that is a product of processing the VLA archive data. The tutorial was based on the VLA observations of Moore, et.al (Moore, Carilli, & Menten, 1998).

MG0414+0534

MG0414+0532 is a high redshift quasar that is seen through a gravitational lens as four objects. Figure 1 shows a high resolution (22 GHz VLA) image which resolves the lensed components as A1, A2, B, and C. (C.A.Katz, Moore, & Hewitt, 1996)

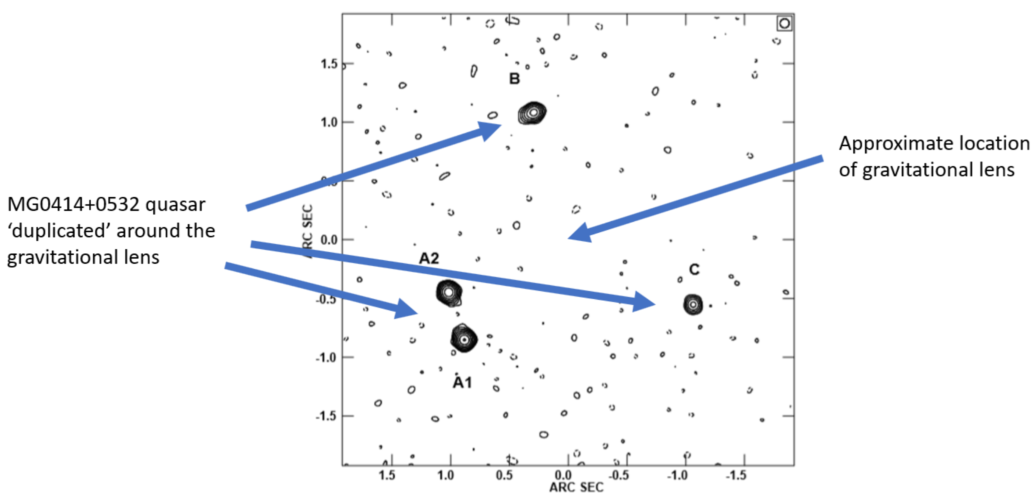

Figure 1: Contour Plot of MG0414+0534 at 22 GHz VLA Observation (blue arrows added by author)

The lens is a high mass galaxy (MG0414+0435) which has been determined to be at z=0.9584 redshift. (Tonry & Kochanek, 2007) This galaxy has significant mass and is positioned between the quasar and

Earth in a geometry that results in the quasar photons being bent around the lens resulting in the four images. A rough depiction of the geometry is shown in figure 2. The objects depicted as A1, A2, B and C are duplicate images as the photons from MG0414+0532 are bent around the gravitational lens.

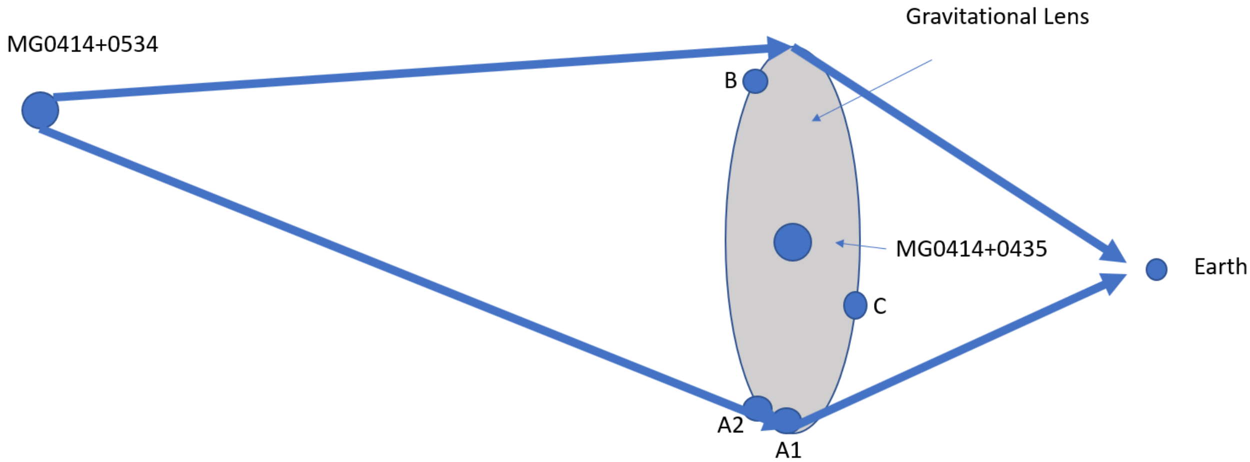

Figure 2: Simplified Gravitational Lens Geometry

HI Absorption Line

Moore, Carilli and Menten imaged the HI absorption line in MG0414+0534 in 1998 with the VLA. (Moore, Carilli, & Menten, 1998) The redshift was calculated to be z=2.6365.

There are three main causes for redshift (Redshift, 2020): 1) Relative movement of objects in space – referred to as Doppler; 2) Space itself is expanding – cosmological redshift; and 3) Gravitational redshift – due to strong gravitation that distorts space-time (usually associated with a black hole.

The calculation of the correct observation frequency assumed that the redshift was primarily caused by the cosmological redshift. The formula to calculate redshift is:

$$z = \frac{f_{emitted} - f_{observed}}{f_{observed}}$$

Z: redshift

$f_{emitted}$:: originating frequency at the source

$f_{observed}$: the final frequency at the observation

The HI line frequency is 1420.406 MHZ. The redshift value of Z = 2.6365. Therefore the observation frequency can be calculated as:

$$f_{observed} = \frac{f_{emitted}}{1+Z}$$

$$f_{observed} = \frac{1420.406}{1+2.6365} = 390.597 \text{ MHz}$$

The P-Band (230-470 MHz) of the VLA is in this range and was chosen for the observation. Figure 3 shows the observer log heading. The principle investigator was Frazer Owen and the observation was made on September 14, 2016.

VLA OBSERVING LOG **2016-09-14_0620_TSUB0001**

Observing Date:	14-Sep-2016
Configuration:	B=>A
Decommissioned:	11

Project:	TSUB0001	**# Subarrays:** 1		**Observation Type:**	Test
Observer(PI):	Frazer Owen			**Band(s) Used:**	X P
SBID(s):	32720781				
Source File(s):	TSUB0001_sb32720781_1				
Observer E-mail:	fowen@nrao.edu				
Operator(s):	Blythe Guvenen				

Figure 3: VLA Observing Log Header

The author reprocessed the archive data on October 18, 2019 as part of training using the VLA tutorial scripts: https://casaguides.nrao.edu/index.php/MG0414%2B0534_P-band_Spectral_Line_Tutorial_-_CASA_5.5.0

The data was processed using Common Astronomy Software Applications 5.5.0: (Common Astronomy Software Applications, 2020) The resultant products were a continuum picture and a spectral line plot. The continuum picture (figure 4), shows the overall a single oval feature which does not resolve into the 4 objects as shown in figure 1. This illustrates the difference in resolution taking the observation at 390 MHZ as apposed to 22 GHz.

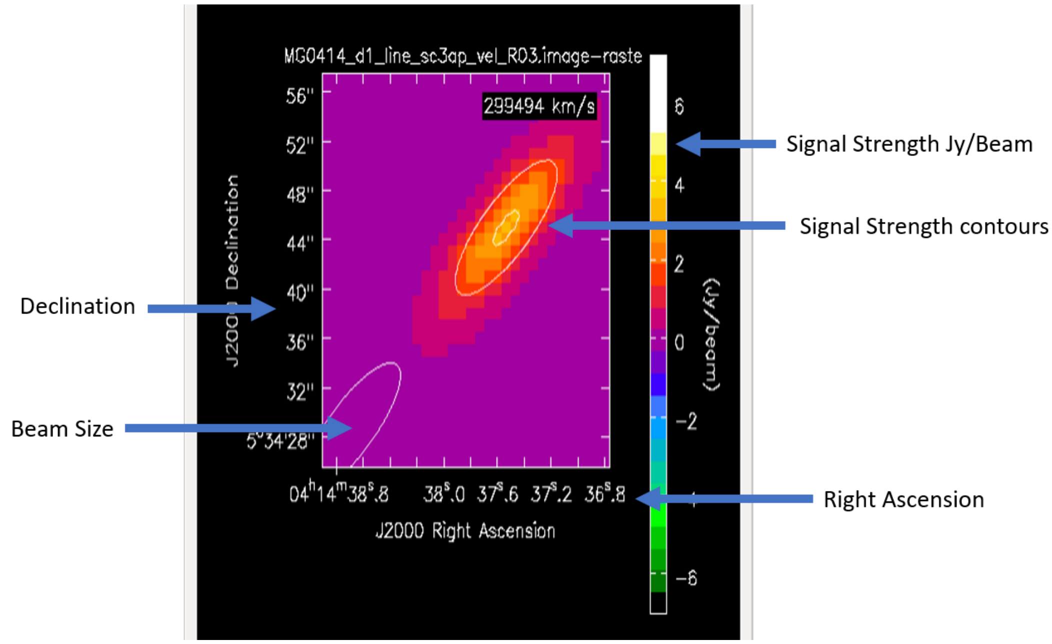

Figure 4: MG0414+0534 VLA P-Band Continuum Product from Archive Data

The processing also resulted in a frequency plot which clearly shows a dip in signal related to the expected HI absorption line. (figure 5)

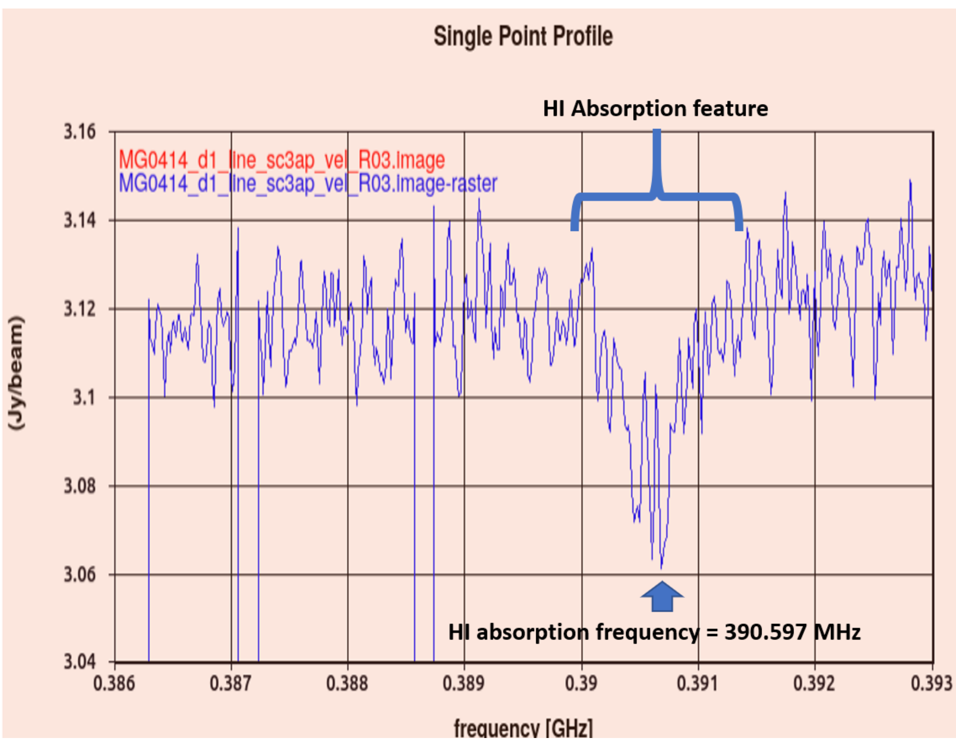

Figure 5: MG0414_0534 Signal Strength vs. Frequency Plot – showing HI absorption feature

Calculating Distance to the Source and the Gravitational Lens

The conversion from redshift (z) to distance in mega-parsecs (MPc) is related to the Hubble constant (Ho) and the receding velocity (v) of the object. (Gelderman, 2020).

$$D = \frac{v}{H_o}$$

The redshift of the source quasar, MG0414+0532 can be recalculated fro the results of the archive data analysis as shown in figure 5. The f observed = 390.597 MHz. Therefore the redshift value is: z=2.6365

$$z = \frac{1420.406 - 390.597}{390.597} = 2.6365$$

The redshift value for the gravitational lens, MG0414+0435, was provided in (Tonry & Kochanek, 2007) as z=0.9584.

The author used the ICosmos calculator http://icosmos.co.uk/index.html to calculate the distance and age of the the two sources. (figure 6)

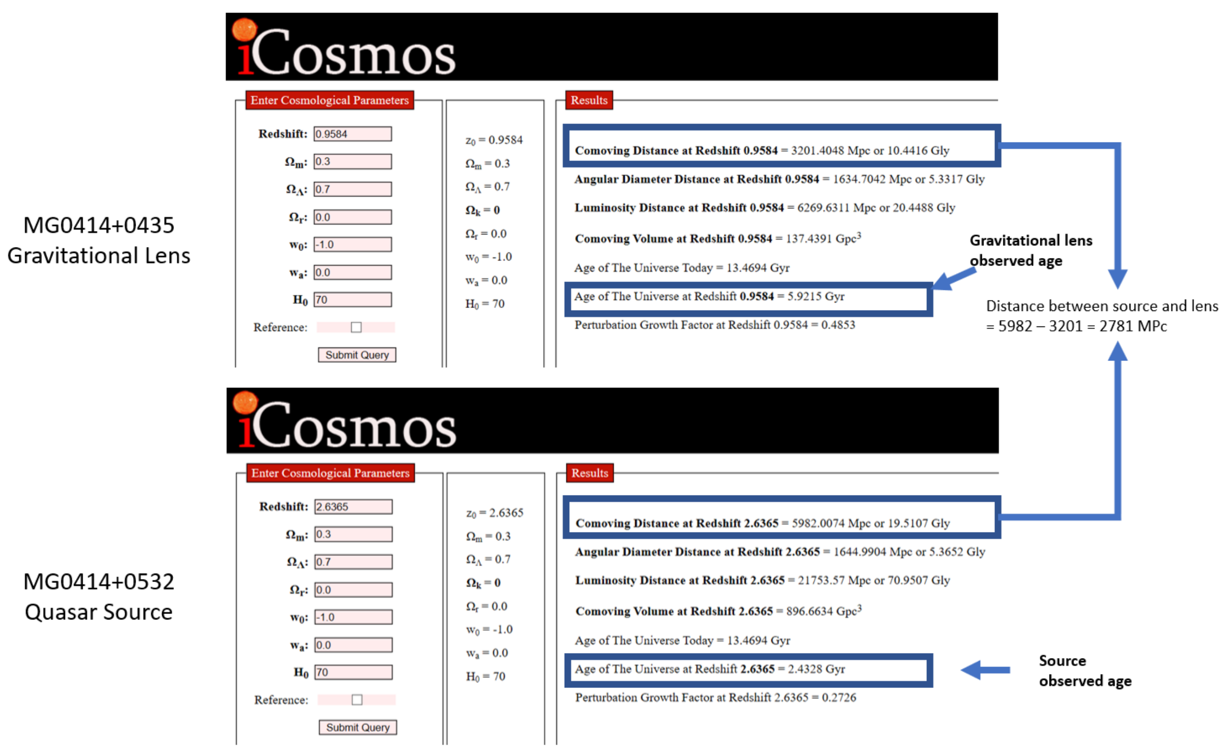

Figure 6: ICosmos Calculator used to determine distance and age of the Gravitation Lens (MG0414+0435 and the quasar source (MG0414+0532

The observed age of the two objects are calculated relative to the Big Bang. MG0414+0435 is 5.9 GYr while MG0414+0532 is 2.4 GYr. The calculated age of the universe for this model is 13.47 GY at z=0.

Summary

The VLA archives contain a wealth of observation data that can be processed to derive data that the original principal investigators did not utilize. The data obtained from the processing of the MG0414+0532 data has improved the author's knowledge of gravitational lensing, HI absorption line analysis, and redshift calculations.

The next steps are to use the processes derived in this paper on similar VLA archive data.

Acknowledgements

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