Identification of New QSOs to Better Understand Foreground Components of the Universe

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ABSTRACT.

High redshift QSOs are oftentimes used in studies to determine the foreground components of the Universe. This primarily includes gaseous clouds that would absorb the spectrum of the QSO. However, an insufficient number of background QSOs are known. Some of the promising candidates for new QSOs are among two categories: those behind nearby galaxies that have a very large angular size to permit the possibility of several bright background QSOs close to the galaxy's center, and QSOs that lie within an arcmin of each other, which represent the possibility of finding multiple sight lines through a single foreground object. The objective of this research was to observe a list of QSO candidates at the Kitt Peak National Observatory and then determine if these candidates are background quasars or quasars that lie within an arcmin of another known quasar. Candidates were observed using the 2.1 m telescope and GoldCam CCD spectrograph for seven nights on June 1-7 2003 approximately from wavelengths 4000 to 7000 Ǻ.

Eleven quasar candidates were observed and ten were found to be quasars.

1. INTRODUCTION

Quasi-stellar objects (QSOs) are thought to be supermassive black holes surrounded by luminous accretion disks. New QSOs will be useful in determining the extent and properties of the gaseous and dark matter components of nearby galaxies and the size of foreground gaseous structures in the Universe at very high redshifts as an insufficient number of background QSOs are known. Some of the promising candidates for new QSOs are among two categories: those behind nearby galaxies that have a very large angular size to permit the possibility of several bright background QSOs close to the galaxy's center, and QSOs that lie within an arcmin of each other. Identification of small angular separation QSOs would allow follow-up studies of the size scales of foreground gaseous structures in the Universe up to very high redshifts. Follow-up observations of QSOs behind galaxies will give information on the extent of galactic gas. This includes such things as its ionization and kinematic properties and the dark matter content of the galaxy through extension of its rotation curve. New data from Sloan Digital Sky Survey color images and existing data that have become available over the last few years, especially in radio and x-ray, suggest that new searches for QSOs behind galaxies will be a successful endeavor. Scientific issues concerning QSOs are presented below.

Nearby galaxies. A lot of our knowledge of the extent and properties of neutral and ionized gas (HI and ionized metals) comes from the search for the visible objects that correspond to the absorption lines seen in background QSO spectra (1, 2). From this data, some have concluded that luminous galaxies have very extended gaseous halos, while others have concluded that the luminous galaxies identified at the absorption redshifts are just the brightest member of a cluster, and that the absorption might be primarily produced by dwarf members of the cluster (3). There is an insufficient amount of QSOs behind nearby galaxies (QSOs with redshift less than 0.01), and therefore, significant studies of the extent of the gas more directly and the possibility of extending a galaxy's rotation curve to study the dark matter have not previously been possible.

QSO Pairs. There are not presently many good known pairs of QSOs less than an arcmin apart. However, measurements of the size-scales of gaseous structures in the

Universe seem most promising in studies of this type of QSO pair. Most often either the pairing is too large to find much common absorption (4), or it is too close, as in gravitationally-lensed components (5) to perform sensitive size-scale measurements. Studies of QSO clustering would be immediately possible upon identification of QSO pairs as well.

2. QUASAR SELECTION.

The Sloan Digital Sky Survey, SDSS, database and associated radio, x-ray, and galaxy catalogs were searched in order to find the most promising QSO candidates behind galaxies as well as pairs within an arcmin of each other. QSO apparent magnitude was limited to $r < 19$, the redshift to $z < 2$, and galaxies with radii > 30 arcsec on the sky or in the UGC catalog. Using SDSS QSO candidate selection algorithm (6), the following matches for QSO pairs were found: (1) 25 high probability (70% success) candidate pairs within 1 arcmin and (2) 70 moderate probability (50% success) candidate pairs within 1 arcmin. A candidate pair is defined as one for which one of the QSOs has a measured fiber redshift $z < 2$ and magnitude $r < 19$, while the other member has $r < 19$ but only has a probable redshift $z < 2$ and no spectrum. For galaxy matches the following were found: 8 QSO candidate matches behind galaxies more extended than 30 arcsecs and 50 QSO candidate matches behind UGC galaxies, where the candidate QSOs have $r < 19$ and probable redshift $z < 2$ with no spectrum. Galaxy matches were not concentrated on during this run although a few were observed.

SDSS cannot generally observe QSO candidates within 55 arcsec of each other because of fiber spacing limitations; therefore observation on large telescopes is crucial to filling in the gaps in observed QSOs.

3. OBSERVATIONS.

Data was collected using the 2.1 meter telescope at the Kitt Peak National Observatory June 1, 2003 through June 8, 2003. Observations were taken from dusk until dawn each night. The 240-groove/mm grating in the first order was used along with the GoldCam CCD spectrograph, covering about 4000-7000 Å. Helium-Argon, closed shutter (bias), and flat field observations were taken each night, as well as standard star observations, along with the observations of the actual QSO candidates. Table 1 is a list of facts about the GoldCam CCD used in the 2.1 m telescope at Kitt Peak taken from the Kitt Peak website (31). Table 2 is a list of spectrograph facts for the 2.1 m Kitt Peak telescope (31). Table 3 is a list of facts about the grating used on this run (31).

Facts About the CCD						
		Pixel	Default Gain			Linear(0.1%)
Instrument	CCD	Size	Gain	Read-noise	$\#e^-$	to
		(um)	(e^-/ADU)	RMS (e^-)	@65,000 ADU	(e^-)
2.1m GoldCam	F3KC	15	1.4	8.5	91,000	80,000

Table 1 CCD Facts

General Facts About the Spectrographs							
Instrument	**Resolution**	**Detector**		**Slit Length**	**Scale**		**Multiplexing?**
	(R=λ/Δλ)	**CCD**	**Useful Area**	**(arcmin)**	**Detector**	**Slit**	
					" /pixel	**1" =**	
2.1m GoldCam	300-4500	F3KC	400x2000	5.2	0.78	79 m	single

Table 2 Spectrograph Facts

2.1m GoldCam Gratings						
Name	**l/mm**	**order**	**Blaze**	**Coverage(Å)**	**Dispersion**	**Resolution**
			(Å)	**2000 pixels**	**(Å/pixel)**	**(Å)**
240	500	1	5500	3040	1.52	4.1

Table 3 Grating Facts

4. DATA REDUCTIONS.

Data reductions were done on 28 of the most promising QSO spectra, gathered at the Kitt Peak National Observatory in June 2003. This included 10 candidates, six candidates with two observations, and four candidates with three observations Image Reduction and Analysis Facility, IRAF, software was used in these reductions.

The steps for data reduction are outlined in the IRAF manuals (18, 19). Overscan regions are regions to either side of the raw spectra that are unusable mainly because they are on the end and do not get clear reading and these were subtracted first from each of the spectra. They are there to monitor bias levels on each observation. (Insert plot with overscan region in it). Then, flat fields were combined, normalized, and then the data were divided by them. Flat field frames are pictures of the CCD chip itself and the data is divided by them to take out any imperfections in the frames due solely to the imperfections (i.e. quantum efficiency variations) in the chip.

Reduction then includes steps characterized as "Extraction and Calibration" in the manual. Each observation has an "aperture" in the two-dimensional CCD frame where the spectrum of the QSO candidate lies, and this must be extracted. This means that from each two-dimensional image, a one-dimensional spectrum was extracted. Helium-Argon frames were also observed each night as comparison frames so that the wavelength scale of a spectrum could be calibrated. The identify task was run on the comparison spectra to determine a dispersion solution, which allowed identification of which comparison lines have what laboratory wavelengths and later allowed a function to be fit to the data. The dispersion solution was then used to set a wavelength scale for the data and applied to all the spectra.

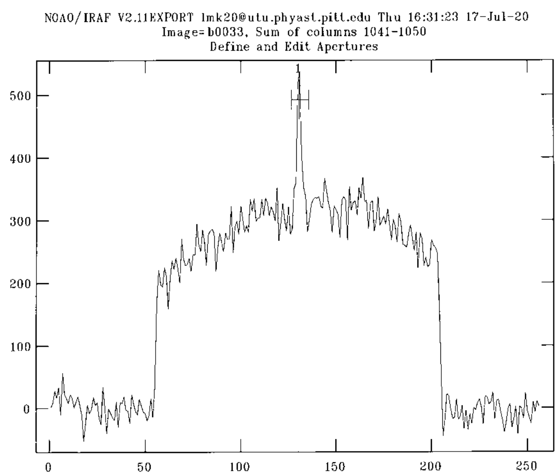


Figure 1 Defining Apertures

A standard star spectrum was observed every night as well. The standard stars are catalogued in the IRAF database. They are used to determine a flux calibration, which can be applied to the spectra. Thus, finally a sensitivity function was determined and applied to all the data. The sensitivity function produces two plots, one above the other.

The top is the sensitivity function vs. the wavelength and the bottom shows the residuals (magnitude) vs. wavelength (Fig. 2). Once applied, a final fluxed spectrum is obtained for each raw spectrum collected.

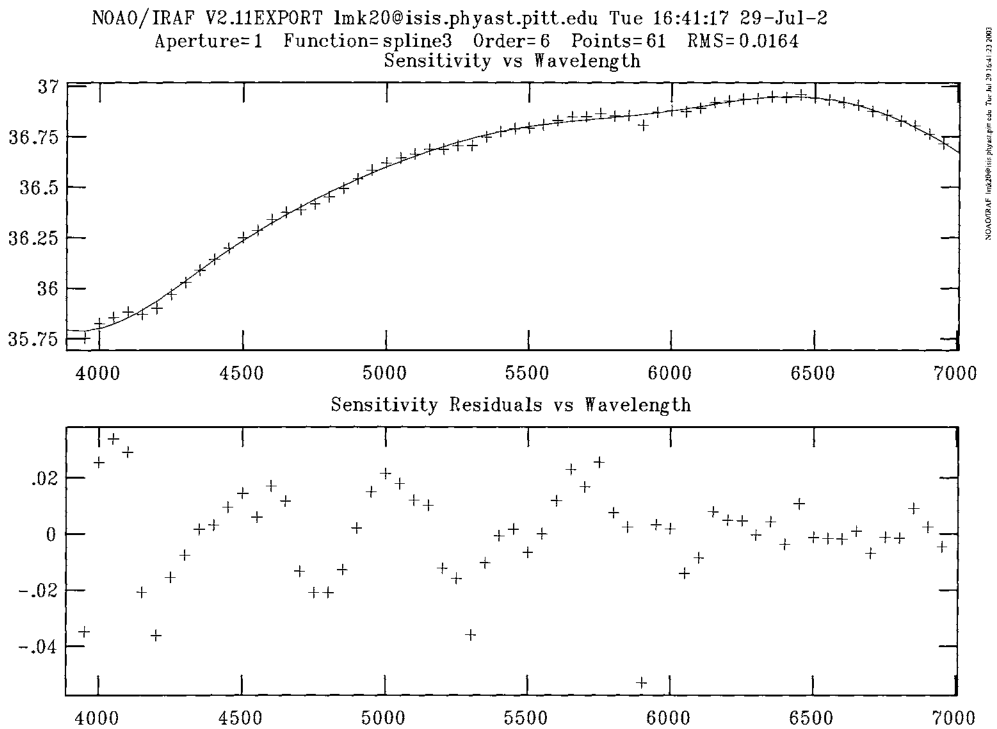


Figure 2 Sensitivity Function

5. RESULTS.

The results of the data reductions are shown below. After individually reducing each spectrum, the reductions for each QSO candidate were averaged into one combined spectrum, and these combined spectra reductions are the ones shown below. It was determined that all of the candidates reduced, except QC2 (Fig. 4), were QSOs. QC2 was determined to be a star.

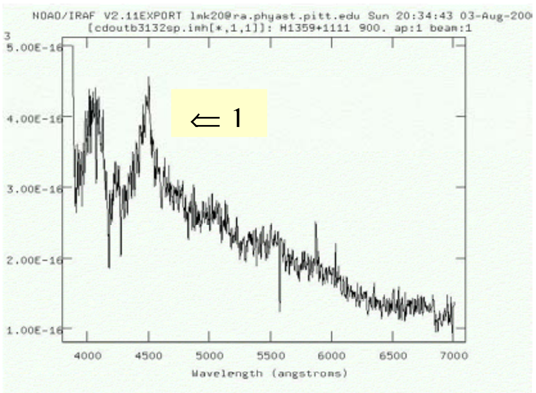


Figure 3 QC1

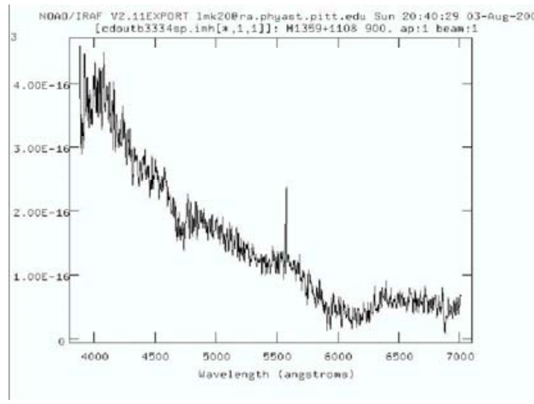


Figure 4 QC2

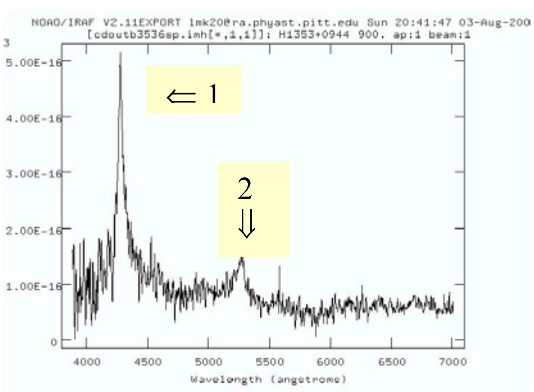


Figure 5 QC3

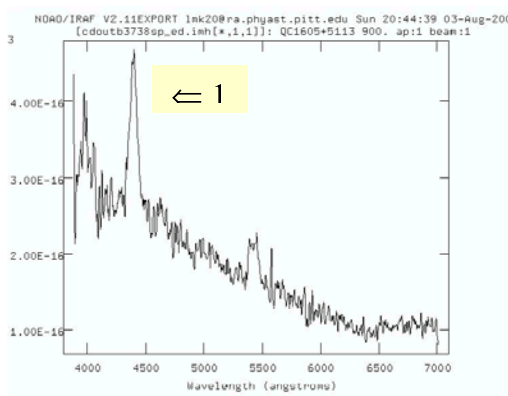


Figure 6 QC4

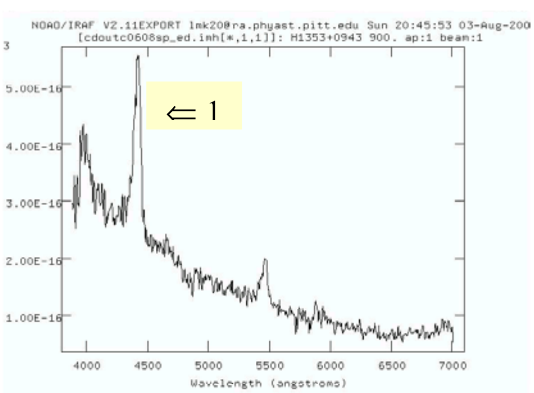


Figure 7 QC5

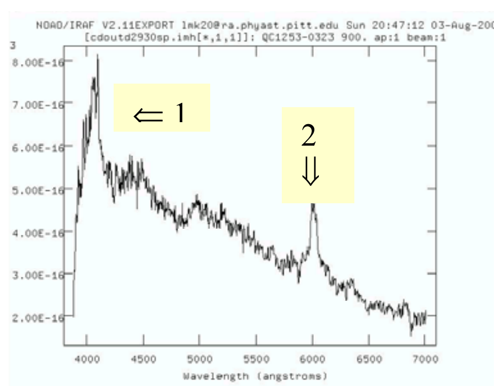
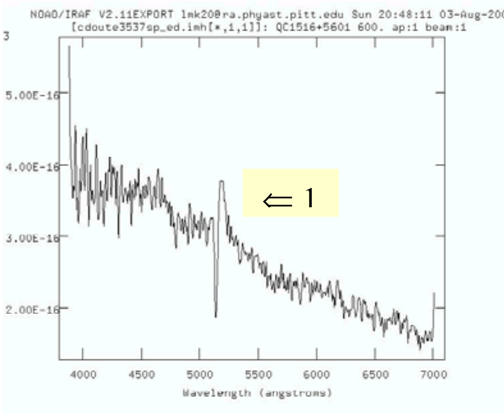


Figure 8 QC6



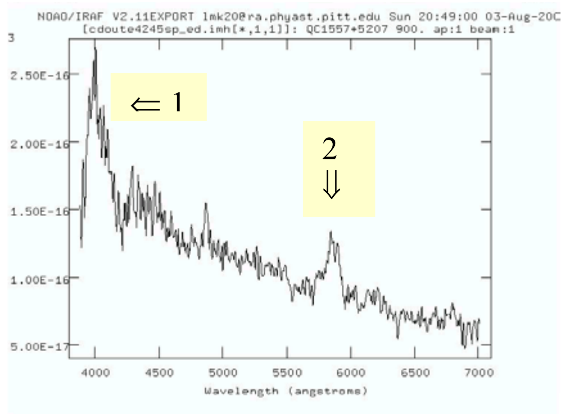
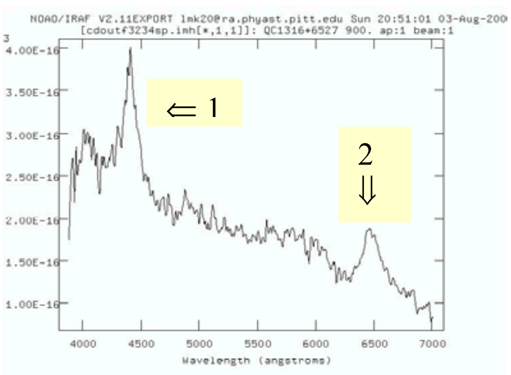


Figure 9 QC7 **Figure 10 QC8**



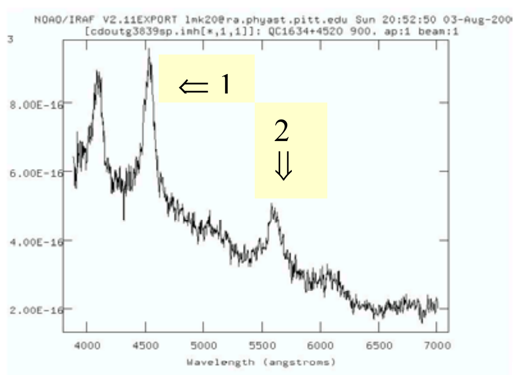


Figure 11 QC9 **Figure 11 QC10**

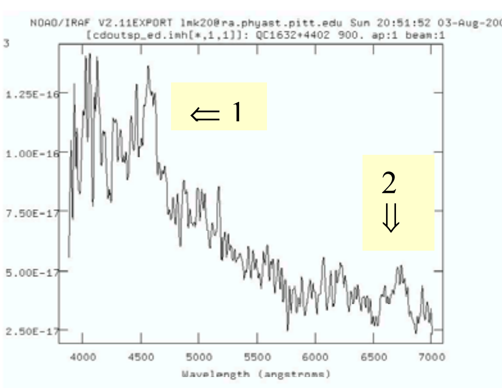


Figure 12 QC11

After the QSOs were determined, the redshifts were found using the peaks in the resulting graphs. The arrows in each QSO graph points to a peak that corresponds to a certain emission type. The emission type is listed in Table 6, along with the determined wavelength of the peak in the graph. The known rest wavelength and the determined wavelength of the peak were then used to calculate the redshift of the QSO using formula 1.

$$1 + z = \lambda_{observed} / \lambda_{rest} \quad (1)$$

The redshift is important because it tells how far away the QSO is. The higher the redshift, the farther away the QSO is, because the wavelengths will be shifted more toward the red the faster the QSO is moving away from the earth. This is due to Hubble's Law, which says that the earth is expanding an that the farther away an object is from a point, the faster it will be going moving away from that point. Hubble's Law is stated in formula 2 (37).

Recessional Velocity = Hubble's constant times distance (2)

$$V = H_o D$$

$$H = 500 \text{ km/sec/Mpc}$$

QSO candidate	Redshift, z
QC1	1.90
QC2	star
QC3	1.76
QC4	1.81
QC5	1.85
QC6	1.15
QC7	2.35
QC8	1.09
QC9	1.31
QC10	1.93
QC11	2.41

Table 4 QSO Redshifts

Absorption Type	Rest Wavelength, Å
Mg II	2798
C III	1909
C IV	1549

Table 5 Emission Peak Wavelengths

QSO Candidate	Peak #	Emission Type	Wavelength,
QC1	1	CIV with broad absorption lines	4493.507
QC2 (star)	N/A	N/A	N/A
QC3	1	CIV	4280.719
QC3	2	CIII	5269.259
QC4	1	CIV	4346.353
QC5	1	CIV	4422.534
QC6	1	CIII	4101.399
QC6	2	Mg II	6015.971
QC7	1	CIV with associated absorption	5190.083
QC8	1	CIII	3992.921
QC8	2	Mg II	5840.688
QC9	1	CIII	4405.866
QC9	2	Mg II	6462.253
QC10	1	CIV	4535.179
QC10	2	CIII	5594.692
QC11	1	CIII	4560.183
QC11	2	Mg II	6725.048

Table 6 Emission Peak Wavelengths

6. SUMMARY.

Ten of the eleven candidates I processed were determined to be quasars and the redshifts of each were determined. The QSOs are generally characterized by one or more broad emission lines, as seen in each of the QSO graphs.

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