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Time-Delay Cosmography: Spectroscopy of Galaxies in the Environment of the J1537 Lensed Quasar System

George V. Kharchilava – SULI Intern at Fermi National Accelerator Laboratory
Advisors: Elizabeth Buckley-Geer & Huan Lin

Introduction

- The Hubble constant (H_0) still remains one of the most debated constants in the field of cosmology.
- Early and late Universe measurements are used to calculate H_0, however both disagree at a staggering 4σ level, as shown in Figure 1. **[4]**
- With the discovery of gravitational lensing, researchers turned to lensed systems for cosmological measurements (see Figures 2 & 3).
  - Lensed supernovae were the first targets, but due to their rarity, researchers started to look at lensed quasars; objects distant enough to be subject to lensing by an obstructing galaxy or group of galaxies **[3]**.
- Other galaxies in the environment of the lensing system may affect the light paths. The redshifts of these potential *perturbers* need to be measured to construct an accurate lens model.
- H_0 can be measured by using redshifts, lens modeling, and measuring time-delays of multiply-imaged quasars (especially quads!).

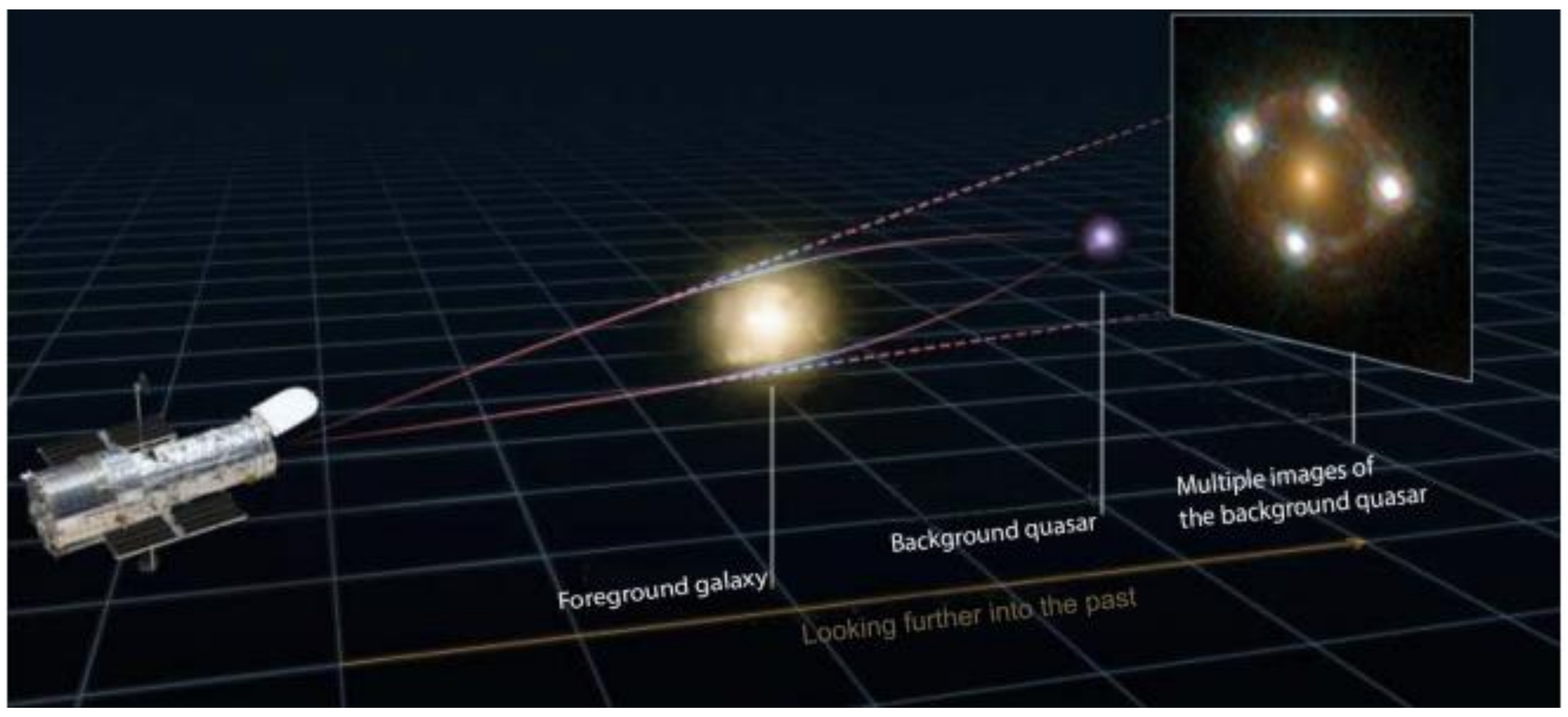


FIG 3. Diagram of a typical lensing event. Light from the background quasar is lensed by a massive object. Quasar imaged by Hubble **[5]**. Diagram credit: Martin Millon. **[1]**

Data Collection & Reduction

- Data is collected using the Gemini Multi-Object Spectrograph (GMOS) at the Gemini South Observatory. We look at the J1537-3010 lensed "quad" quasar system and its environment to identify potential perturbers.
  - The data consist of four masks, totaling 136 targets, 12 alignment stars, and 2 images of the lensed quasar.
- We use Gemini IRAF **[6]** and RASCAL **[7]** to reduce the data. A custom Python package is used, alongside visual inspection, to identify emission lines and determine redshifts (see Figure 5).

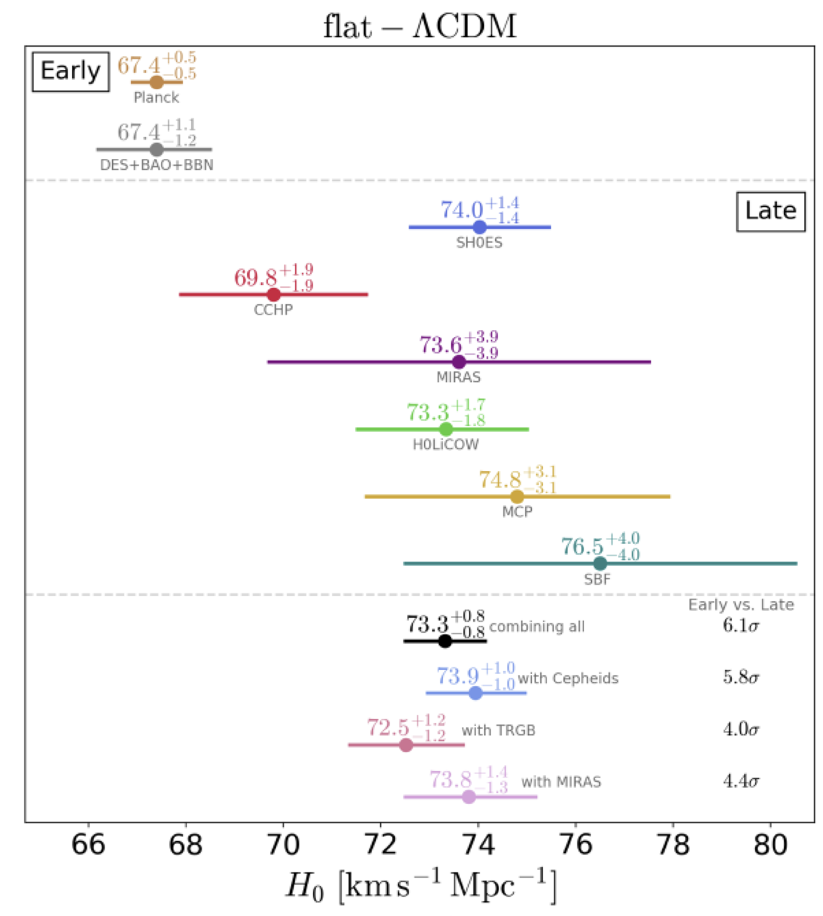


FIG 1. H_0 measurements from across a few different studies. The two regimes, "Early" and "Late", are shown and there is clear disagreement. Image credit: Vivien Bonvin. **[4]**

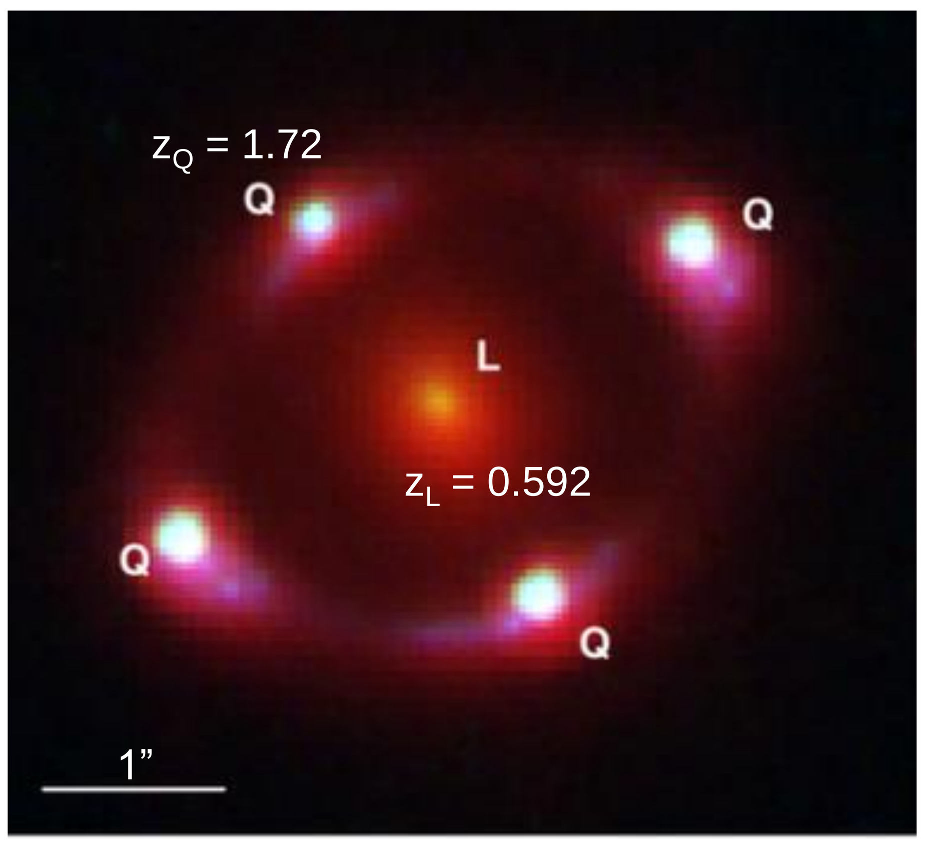


FIG 2. Lensed quasar from dataset J1537-3010 in an RGB color composite image made using HST Wide Field Camera 3 (WFC3) data. L denotes the position of the lensing galaxy and Q denotes the lensed quasar. Image credit: Elizabeth Buckley-Geer.

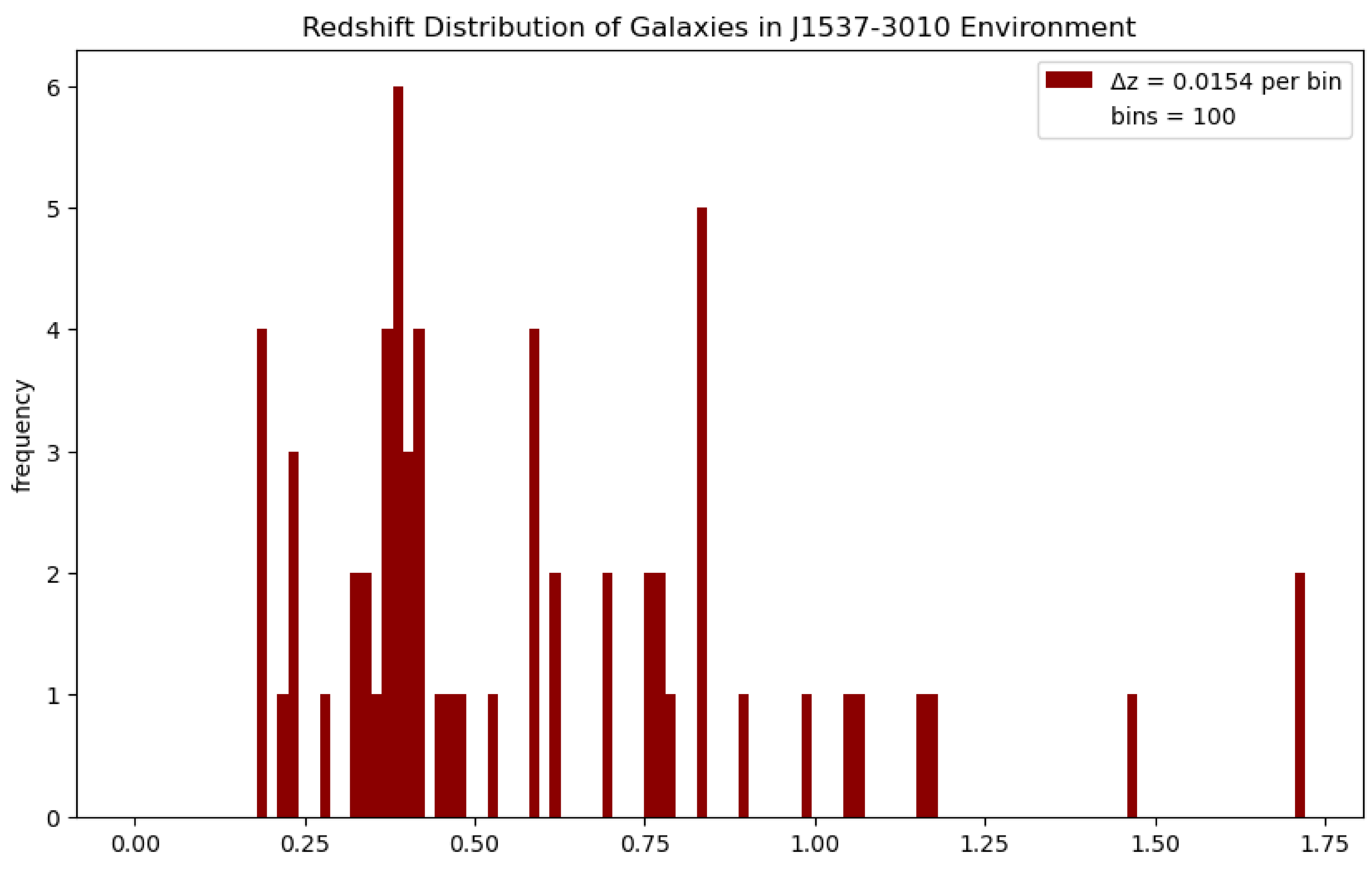
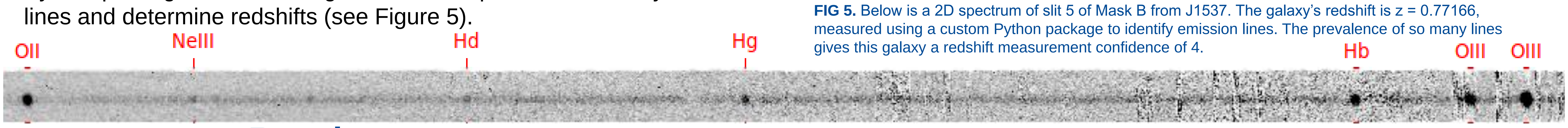


FIG 4. The histogram above shows the redshift frequency for the objects which have confident redshift measurements. The confidence is based on abundance of emission lines and data quality. Confidence of 4 is certain, while 3 denotes single-line confidence, and 2 is uncertain. Only those with confidences of 3 or 4 were considered here.

FIG 5. Below is a 2D spectrum of slit 5 of Mask B from J1537. The galaxy's redshift is z = 0.77166, measured using a custom Python package to identify emission lines. The prevalence of so many lines gives this galaxy a redshift measurement confidence of 4.



Results

- A total of 62 redshifts were confidently (confidence = 3 or 4) determined from all four masks.
- Masks A,B,C, and D had successful redshift measurement rates of 44%, 54%, 39%, and 45%, respectively.
- The two objects in Figure 4 to the far right is the quasar from Mask A and B, with z = 1.72. The largest peak at z ~ 0.4 indicates the presence of a galaxy cluster.
- The increased counts at z ~ 0.225 and z ~ 0.875 could also indicate galaxy groups.

Conclusions & Future Direction

- Under normal circumstances, the success rate for redshift calculations would have been higher, around 60-70% per mask on average.
  - Emission lines likely fell into a bad amplifier region, where we mask out a portion of the CCD due to a malfunction of amplifier 5.
  - There were also problems with wavelength calibration of the blue setting of the masks. Potentially poor viewing conditions may have affected the observations.
- The next steps are to calculate flexion shifts **[2]**. Flexion shifts will probe whether a galaxy has enough influence to be considered for the lens model.
- A more accurate model will allow for better measurements and constraints on H_0.

References

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Acknowledgements

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Abstract

Due to their sufficient distances and prevalence, lensed quasars have been a key site for research in gravitational lensing to constrain Hubble's constant H_0. However, a lens model will need to be created that accounts for any perturbers or galaxy groups that are gravitationally influential. The J1537-3010 lensed quasar environment is investigated, and redshifts of 77 targets have been measured from GMOS and MUSE. The success rate is ~45% across all four masks, less than the expected 60%-70%. We expect that masking out a bad amplifier contributed to the lower redshift calculation rate. Flexion shifts were then measured to determine if the observed target or identified group should be included in the lens model. An accurate lens model is fundamental for constraining the measurements of the time-delays of the quasar images and, thereby, constraining measurements for H_0. Only a single group and three single galaxies passed the flexion cut.