N° PROYECTO : 1100214 DURACIÓN : 4 años AÑO ETAPA : 2013
TÍTULO PROYECTO : FRESH CLUES TO GALAXY FORMATION: HIGH-REDSHIFT BARYONS TOWARD QUASARS AND GAMMA-RAY BURSTS.

DISCIPLINA PRINCIPAL : ASTRONOMIA
GRUPO DE ESTUDIO : ASTRON.,COSMOL.Y PAR
INVESTIGADOR(A) RESPONSABLE : SEBASTIAN VICTOR CLAUDIO LOPEZ MORALES
DIRECCIÓN :
COMUNA :
CIUDAD : Santiago
REGIÓN : METROPOLITANA

FONDO NACIONAL DE DESARROLLO CIENTIFICO Y TECNOLOGICO (FONDECYT)
Moneda 1375, Santiago de Chile - casilla 297-V, Santiago 21
Telefono: 2435 4350 FAX 2365 4435
Email: informes.fondecyt@conicyt.cl
# INFORME FINAL

## PROYECTO FONDECYT REGULAR

### OBJETIVOS

Cumplimiento de los Objetivos planteados en la etapa final, o pendientes de cumplir. Recuerde que en esta sección debe referirse a objetivos desarrollados, NO listar actividades desarrolladas.

<table>
<thead>
<tr>
<th>Nº</th>
<th>OBJETIVOS</th>
<th>CUMPLIMIENTO</th>
<th>FUNDAMENTO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Expand spectroscopic sample of lensed QSOs</td>
<td>PARCIAL</td>
<td>The team submitted a Hubble Space Telescope/STIS proposal (PI Kulkarni) to obtain resolved spectra of the lensed QSOs in our sample. Such spectra will allow us to constrain the neutral hydrogen content of the absorption systems in each line of sight and look for spatial structure. Unfortunately, the proposal was not accepted. A proposal is in preparation for the upcoming HST Cycle.</td>
</tr>
<tr>
<td>2</td>
<td>Expand the Quasar behind Clusters Survey</td>
<td>TOTAL</td>
<td>We are expanding the survey in two fronts: (1) high-redshift proto-clusters as probed by CIV and (2) low-redshift Large-scale Structure, as probed by CIV+OVI. For (1) we have cross-correlated SPARCS clusters with SDSS QSOs and are submitting a spectroscopic QSO proposal during 2014B to look for CIV. The SPARCS fields did not allow us to submit for the 2014A semester. On (2), an HST was submitted in 2013 but did not make it. The panel comments were positive (&quot;This is a good proposal that seeks to study the WHIM associated with (primarily) the outskirts of groups and clusters of galaxies&quot;). and we will re-submit in upcoming HST Cycle.</td>
</tr>
<tr>
<td>3</td>
<td>Characterize high-redshift molecular gas</td>
<td>PARCIAL</td>
<td>PhD student Paula Lopez is currently analyzing the sample of UVES MgII systems that show neutral species.</td>
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<tr>
<td></td>
<td>Characterize host and intervening Gamma-Ray Burst galaxies</td>
<td>TOTAL</td>
<td></td>
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<td></td>
<td>We have analyzed a new (and larger) sample of GRB spectra to check the incidence of MgII systems. As a response to a previous report on significant differences between QSO and GRB sightlines, our recent study suggests the original results were affected by statistical fluctuations. The result by Tejos et al. (former student of this PI) on the weak systems is confirmed.</td>
<td></td>
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</table>

Otro(s) aspecto(s) que Ud. considere importante(s) en la evaluación del cumplimiento de objetivos planteados en la propuesta original o en las modificaciones autorizadas por los Consejos.

1. The ESO Large Programme led by this PI is making further progress (explained more in detail in section "Achievements")

2. Two graduate students presented posters at the XIV LARIM conference of the IAU in Brazil. Paula Sanchez presented her work on XSHOOTER QSOs from the Large Program, where she did a first estimate of the median opacity of the Ly-alpha forest. Paula Lopez presented her work on UVES MgII systems that show neutral species.
RESULTS OBTAINED:
For each specific goal, describe or summarize the results obtained. Relate each one to work already published and/or manuscripts submitted. In the Annex section include additional information deemed pertinent and relevant to the evaluation process.
The maximum length for this section is 5 pages. (Arial or Verdana, font size 10).

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1. Galaxy Clusters in the Line of Sight to Background Quasars. III. Multi-object Spectroscopy


We present Gemini/GMOS-S multi-object spectroscopy of 31 galaxy cluster candidates at redshifts between 0.2 and 1.0 and centered on QSO sight-lines taken from Lopez et al. (2008). The targets were selected based on the presence of an intervening MgII absorption system at a similar redshift to that of a galaxy cluster candidate lying at a projected distance <2 h_71^{-1}Mpc from the QSO sight-line (a “photometric-hit”). The absorption systems span rest-frame equivalent widths between 0.015 and 2.028 Å. Our aim was 3-fold: 1) identify the absorbing galaxies and determine their impact parameters, 2) confirm the galaxy cluster candidates in the vicinity of each quasar sightline, and 3) determine whether the absorbing galaxies reside in galaxy clusters. In this way we are able to characterize the absorption systems associated with cluster members. Our main findings are: 1) the identification of 10 out of 24 absorbing galaxies with redshifts between 0.2509 ≤ z_{gal} ≤ 1.0955, up to an impact parameter of 142h_71^{-1} kpc and a maximum velocity difference of 280 km/s. 2) The spectroscopic confirmation of 20 out of 31 cluster/group candidates, with most of the confirmed clusters/groups at z < 0.7. This relatively low efficiency results from the fact that we centered our observations on the QSO location, and thus occasionally some of the cluster centers were outside the instrument FOV. 3) Following from the results above, the spectroscopic confirmation of 10 out of 14 photometric hits within ~650 km/s from galaxy clusters/groups, in addition to 2 new ones related to galaxy group environments. These numbers imply efficiencies of 71% in finding such systems with MOS spectroscopy. This is a remarkable result since we defined a photometric hit as those cluster-absorber pairs having a redshift difference Δz = 0.1.

The general population of our confirmed absorbing galaxies have luminosities L_B ∼ L_B^* and mean rest-frame colors (R_c − z') typical of Scd galaxies. From this
sample, absorbing cluster-galaxies hosting weak absorbers are consistent with lower star formation activity than the rest, which produce strong absorption and agree with typical MgII absorbing galaxies found in the literature. Our spectroscopic confirmations lend support to the selection of photometric hits made in Lopez et al. (2008).

2. Fundamental constants and high-resolution spectroscopy


Absorption-line systems detected in high resolution quasar spectra can be used to compare the value of dimensionless fundamental constants such as the fine-structure constant, \( \alpha \), and the proton-to-electron mass ratio, \( \mu = m_p/m_e \), as measured in remote regions of the Universe to their value today on Earth. In recent years, some evidence has emerged of small temporal and also spatial variations in \( \alpha \) on cosmological scales which may reach a fractional level of \( \approx 10 \) ppm (parts per million). We are conducting a Large Programme of observations with the Very Large Telescope’s Ultraviolet and Visual Echelle Spectrograph (UVES), and are obtaining high-resolution (\( R \approx 60000 \)) and high signal-to-noise ratio \( (S/N \approx 100) \) spectra calibrated specifically to study the variations of the fundamental constants. We here provide a general overview of the Large Programme and report on the first results for these two constants, discussed in detail in Molaro et al. and Rahmani et al.

\[ \frac{da}{a} \text{ is obtained for the absorber at } z_{\text{abs}} = 1.6919 \text{ towards HE 2217-2818. The absorption profile is complex with several very narrow features, and is modeled with 32 velocity components. The relative variation in } \alpha \text{ in this system is } +1.3 \pm 2.4_{\text{stat}} \pm 1.0_{\text{sys}} \text{ ppm if AlIII } \lambda 1670 \text{ Å and three FeII transitions are used, and } +1.1 \pm 2.6_{\text{stat}} \text{ ppm in a slightly different analysis with only FeII transitions used. This is one of the tightest bounds on } \alpha \text{-variation from an individual absorber and reveals no evidence for variation in } \alpha \text{ at the 3-ppm precision level (1-σ confidence). The expectation at this sky position of the recently-reported dipolar variation of } \alpha \text{ is } (3.2-5.4) \pm 1.7 \text{ ppm depending on dipole model used and this constraint of } da/a \text{ at face value is not supporting this expectation but not inconsistent with it at the 3σ level. For the proton-to-electron mass ratio the analysis of the } H_2 \text{ absorption lines of the } z_{\text{abs}} \approx 2.4018 \text{ damped Ly} \alpha \text{ system towards HE 0027-1836 provides } \Delta \mu/\mu = (-7.6 \pm 8.1_{\text{stat}} \pm 6.3_{\text{sys}}) \text{ ppm which is also consistent with a null variation. The cross-correlation analysis between individual exposures taken over three } \]
years and comparison with almost simultaneous asteroid observations revealed the presence of a possible wavelength dependent velocity drift as well as of inter-order distortions which probably dominate the systematic error and are a significant obstacle to achieve more accurate measurements.

3. The UVES large program for testing fundamental physics - II. Constraints on a change in towards quasar HE 0027-1836


We present an accurate analysis of the H2 absorption lines from the zabs 2.4018 damped Ly system towards HE 0027-1836 observed with the Very Large Telescope Ultraviolet and Visual Echelle Spectrograph (VLT/UVES) as a part of the European Southern Observatory Large Programme ‘The UVES large programme for testing fundamental physics’ to constrain the variation of proton-to-electron mass ratio, \( \mu = m_p/m_e \). We perform cross-correlation analysis between 19 individual exposures taken over three years and the combined spectrum to check the wavelength calibration stability. We notice the presence of a possible wavelength-dependent velocity drift especially in the data taken in 2012. We use available asteroids spectra taken with UVES close to our observations to confirm and quantify this effect. We consider single- and two-component Voigt profiles to model the observed H2 absorption profiles. We use both linear regression analysis and Voigt profile fitting where \( \Delta \mu/\mu \) is explicitly considered as an additional fitting parameter. The two-component model is marginally favoured by the statistical indicators and we get \( \Delta \mu/\mu = -2.5 \pm 8.1\text{stat} \pm 6.2\text{sys} \text{ppm} \). When we apply the correction to the wavelength-dependent velocity drift, we find \( \Delta \mu/\mu = -7.6 \pm 8.1\text{stat} \pm 6.3\text{sys} \text{ppm} \). It will be important to check the extent to which the velocity drift we notice in this study is present in UVES data used for previous measurements.

4. An Independent Measurement of the Incidence of Mg II Absorbers along Gamma-Ray Burst Sight Lines: The End of the Mystery?


In 2006, Prochter et al. reported a statistically significant enhancement of very strong Mg II absorption systems intervening the sight lines to gamma-ray
bursts (GRBs) relative to the incidence of such absorption along quasar sight lines. This counterintuitive result has inspired a diverse set of astrophysical explanations (e.g., dust, gravitational lensing) but none of these has obviously resolved the puzzle. Using the largest set of GRB afterglow spectra available, we reexamine the purported enhancement. In an independent sample of GRB spectra with a survey path three times larger than Prochter et al., we measure the incidence per unit redshift of $z=1$ rest-frame equivalent width Mg II absorbers at $z=1$ to be $l(z) = 0.18 \pm 0.06$. This is fully consistent with current estimates for the incidence of such absorbers along quasar sight lines. Therefore, we do not confirm the original enhancement and suggest those results suffered from a statistical fluke. Signatures of the original result do remain in our full sample ($l(z)$ shows an 1.5 enhancement over $l(z)_{QSO}$), but the statistical significance now lies at 90% c.l. Restricting our analysis to the subset of high-resolution spectra of GRB afterglows (which overlaps substantially with Prochter et al.), we still reproduce a statistically significant enhancement of Mg II absorption. The reason for this excess, if real, is still unclear since there is no connection between the rapid afterglow follow-up process with echelle (or echellette) spectrographs and the detectability of strong Mg II doublets. Only a larger sample of such high-resolution data will shed some light on this matter.

5. The UVES Large Program for testing fundamental physics I. Bounds on a change in towards quasar HE 2217-2818


Context. Absorption-line systems detected in quasar spectra can be used to compare the value of the fine-structure constant, , measured today on Earth with its value in distant galaxies. In recent years, some evidence has emerged of small temporal and also spatial variations in on cosmological scales. These variations may reach a fractional level of 10 ppm (parts per million). Aims: To test these claims we are conducting a Large Program of observations with the Very Large Telescope’s Ultraviolet and Visual Echelle Spectrograph (UVES), and are obtaining high-resolution ($R \approx 60,000$) and high signal-to-noise ratio (S/N > 100) UVES spectra calibrated specifically for this purpose. Here we analyse the first complete quasar spectrum from this programme, that of HE 2217-2818. Methods: We applied the many multiplet method to measure in five absorption systems towards this quasar: $z_{abs} = 0.7866, 0.9424, 1.5558, 1.6279$.
Results: The most precise result is obtained for the absorber at $z_{\text{abs}} = 1.6919$ where 3 Fe ii transitions and Al ii 1670 have high S/N and provide a wide range of sensitivities to $\alpha$. The absorption profile is complex with several very narrow features, and it requires 32 velocity components to be fitted to the data. We also conducted a range of tests to estimate the systematic error budget. Our final result for the relative variation in $\alpha$ in this system is $d\alpha/\alpha = +1.3 \pm 2.4\text{stat} \pm 1.0\text{sys}$ ppm. This is one of the tightest current bounds on $\alpha$-variation from an individual absorber. A second, separate approach to the data reduction, calibration, and analysis of this system yielded a slightly different result of -3.8 ppm, possibly suggesting a larger systematic error component than our tests indicated. This approach used an additional 3 Fe ii transitions, parts of which were masked due to contamination by telluric features. Restricting this analysis to the Fe ii transitions alone and using a modified absorption profile model gave a result that is consistent with the first approach, $d\alpha/\alpha = +1.1 \pm 2.6\text{stat}$ ppm. The four other absorbers have simpler absorption profiles, with fewer and broader features, and offer transitions with a narrower range of sensitivities to $\alpha$. They therefore provide looser bounds on $\alpha$ at the 10 ppm precision level. Conclusions: The absorbers towards quasar HE 2217-2818 reveal no evidence of any variation in $\alpha$ at the 3-ppm precision level (1σ confidence). If the recently reported 10-ppm dipolar variation in $\alpha$ across the sky is correct, the expectation at this sky position is $(3.2-5.4) \pm 1.7$ ppm depending on dipole model used. Our constraint of $d\alpha/\alpha = +1.3 \pm 2.4\text{stat} \pm 1.0\text{sys}$ ppm is not inconsistent with this expectation.
ACHIEVEMENTS OF THE PROJECT:
- Research visit(s) to other institution(s).
- Outreach activities related to the projects main topic.
- Any other contribution, not addressed elsewhere, that you consider important.

The maximum length for this section is 1 page. (Arial or Verdana, font size 10).

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1. The ESO "Large Programme" (LP) awarded during 2011 to this PI is making fast progress. A face-to-face meeting was held in Copenhagen in November 2013, where several project aspects were discussed and new members welcomed. Among the most important points discussed during the meeting are: (a) data reduction, legacy data and related issues; (b) science objectives and paper preparation; (c) Follow-up projects. Several working sessions were held to discuss paper objectives in depth. A first data paper is in preparation by this PI. Several other paper will come in line soon on the various scientific topics covered by the LP, from cosmology with the Ly-a forest to AGN physics. The observations have been completed in February 2014.

2. A new PhD student, Paula Lopez, has started her thesis under this PI supervision. Paula is currently funded by a CONICYT PhD Studentship.

3. The Quasars behind Clusters (QbC) Survey (PI Lopez) is doing further progress. A face-to-face meeting with Dr. J. Hennawi (MPI Heidelberg) took place at Cerro Calan to discuss further avenues. In particular, we wish to extend the technique developed in the 3 papers already published to high−z clusters probed by CIV, a species which is sensitive to higher ionization conditions. On the other hand, the HST proposal described in 2012 report did not make it. The panel comment, though, was encouraging: “This is a good proposal that seeks to study the WHIM associated with (primarily) the outskirts of groups and clusters of galaxies.” A new HST proposal is in preparation.
PRODUCTOS

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1

Autor (a)(es/as) :

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2

Autor (a)(es/as) : Cucchiara et al. incl. Lopez

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Nombre Completo de la Revista : Monthly Notices of the Royal Society
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CONGRESOS

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Autor (a)(es/as) : Lopez, S.
Título (Idioma original) : Program overview
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País : DINAMARCA
Ciudad : Copenhagen
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Autor (a)(es/as) : P. Lopez, S. Lopez
Título (Idioma original) : Detection of neutral species in high redshift QSO absorbers
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Ciudad : Florianapolis
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Autor (a)(es/as): P. Sanchez, S. Lopez
Título (Idioma original): Evolucion of the HI mean opacity of the Lyman--&series#8203;&series#945; forest from a sample of high--&series#8203;&series#945;redshift QSO X--&series#8203;&series#945;SHOOTER spectra
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TESIS/MEMORIAS
Nº: 1
Título de Tesis: Ionization conditions in high-redshift MgII absorbers
Nombre y Apellidos del(de la) Alumno(a): Paula Lopez
Nombre y Apellidos del(de la) Tutor(a): Sebastian Lopez
Título Grado: Doctorado
Institución: Universidad de Chile
País: CHILE
Ciudad: Santiago
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