NAHUAL: PRELIMINARY CONCEPT OF NEAR-INFRARED HIGH-RESOLUTION SPECTROGRAPH FOR THE GTC

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Abstract

NAHUAL is a proposed high-resolution near-infrared echelle spectrograph for the 10.4-m GTC (Gran Telescopio de Canarias) which is now almost completed at the Observatorio del Roque de los Muchachos on the island of La Palma. The main science driver of this instrument is to carry out a high precision radial velocity survey of exoplanets around late type stars and brown dwarfs. Other motivations include chemical abundance studies of cool stars and solar-system bodies; measurements of the magnetic field strength of late type objects; dynamics of circumstellar disks; asteroseismology of cool stars; detailed studies of ultracool dwarf atmospheres; and follow-up observations of the gamma ray bursts. While the details of the instrument are subject to the final results of the ongoing feasibility study, the main technical requirements have already been defined. In contrast to other high resolution IR spectrographs, this instrument will be especially designed to achieve the highest possible accuracy for radial velocity measurements. The goal is to reach an accuracy of a few m/s. It is thus required that the instrument is cross-dispersed, so that at least one spectral band ($J, H,$ or $K$) is covered. Absorption cells will be placed in front of the slit which will allow a simultaneous self-reference similar to an iodine-cell in the optical regime. It is planned to place the instrument at one of the Nasmyth platform of the GTC behind the Adaptive Optics system. It is currently foreseen that the instrument should reach a resolution of $\lambda/\Delta\lambda=100,000$ with the AO-system and 40,000 with natural seeing.

Keywords: instrumentation: spectrographs; minor planets, asteroids; stars: general; stars: low-mass, brown dwarfs; stars: oscillations; planetary systems; planetary systems: protoplanetary disks; infrared: stars; infrared: solar system.

Introduction

In about two years from now, the 10.4-meter GTC (Gran Telescopio de Canarias) is expected to start scientific operations. Three first-light instruments are well under development, ELMER and OSIRIS (optical imaging and low-resolution spectroscopy) and Canari-Cam (a mid-infrared imager). A second-generation instrument, EMIR (a near-infrared (NIR) imager and multi-object spectrograph) is also under construction (Garzon et al. 2003). Another second-generation GTC instrument will be FRIDA (a NIR imager and low-resolution spectrograph for the adaptive optics focus).

In this paper we present the preliminary concept and an outline of the scientific case for NAHUAL (a NIR high-resolution spectrograph). This instrument will cover the niche of near-infrared high-resolution spectroscopy for the GTC community. The goal is to start scientific operation of NAHUAL at the GTC in 2009. Few other large telescopes will have similar instruments. CRIRES at the VLT will have similar spectral resolution than NAHUAL but it is not cross-dispersed, and hence the free spectral range will be much smaller (Moorwood et al. 2003). Gemini South currently offers Phoenix, a visiting NIR high-resolution spectrograph but it is also not cross-dispersed. Two teams have been selected by Gemini to produce a conceptual design of a new NIR echelle spec-
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trograph. The schedule for this new Gemini instrument aims at first light in 2009. Hence, it is possible that NAHUAL and the Gemini NIR echelle will be coeval. They are in fact complementary instruments because they are located in different hemispheres of the Earth.

In the last decade the most successful method to discover exoplanets has been high-precision radial velocity (RV) surveys of hundreds of stars. This situation may change with the advent of the Corot and Kepler satellites, which will survey thousands of stars for transits. These satellites will yield hundreds of candidate exoplanets that will need follow-up radial velocity observations with ground-based large-aperture telescopes. NAHUAL will offer the possibility of carrying out these necessary observations. Moreover, the main exoplanet search methods use only the optical wavelength window. NAHUAL will allow for a high-precision exoplanet RV survey at NIR wavelengths. This is the main design driver of NAHUAL. The instrument will be optimized to search for planets around M, L and T dwarfs, which typically have $R - J$ colors larger than 4. These cool stars and brown dwarfs (BDs) constitute the majority of the nearest stars. By looking at lower mass primaries, NAHUAL will allow to detect exoplanets that are typically nearer and have lower masses than those currently known. In this paper we describe primarily the main scientific driver of NAHUAL, and we also discuss briefly additional scientific topics that are of interest for the team.

1. Scientific drivers

Exoplanets around cool stars and brown dwarfs

Precise RV-measurements of stars have led to the discovery of more than 100 extrasolar planets. A statistical analysis of the currently available data by Lineweaver & Grether (2003) shows that the frequency of planets with masses $m \sin i \geq 0.3 M_{\text{Jup}}$ orbiting old G to K-stars at distances of $\leq 5$ AU is about 9%. In a few cases (Charbonneau et al. 2000; Alonso et al. 2004; Bouchy et al. 2004; Torres et al. 2004) eclipses have been observed which confirm that these objects are planets. Additionally, in the case of Gl 876, the planetary masses of the companions are confirmed by astrometric observations (Benedict et al. 2002).

The frequency of massive planets of 9% (distance $\leq 5$ AU) is quite similar to the fraction of binaries, which is 13%, and 8.1% for G and M-stars, respectively (distance $\leq 3$ AU; Mazeh et al. 1992; Fischer & Marcy 1992). However, the distribution of exo-planet masses is not a continuation of the distribution of binary stars. Inbetween the stars and planets, there is a brown dwarf (BD) desert. The frequency of BDs orbiting normal stars at a distance of $\leq 3$ AU is only $0.5 \pm 0.2\%$ (Marcy et al. 2003).
In contrast to the planets of the solar system, the eccentricity of exoplanets usually is high. There seems to be little, if any, difference between the eccentricity distribution of exo-planets and binary stars. Another surprise was that there are massive planets at very small distances from the host stars. Last, but not least, studies of the metallicity of the host stars showed that the frequency of planets is higher for very metal rich stars (Gonzalez & Laws 2000; Santos et al. 2001).

The new discoveries have inspired a large number of theoretical efforts aimed at explaining the observational properties. Planet formation models appear divided in basically two different fronts: Giant planets may form either by a gravitational instability of the disk, or by core accretion of planetesimals until a 10 $M_{\text{Earth}}$ planet is formed and has enough gravitational pull to accrete gas from the nebula (see Wuchterl et al. 2000 for a review). The strange properties of the known exoplanets have been interpreted as evidence that planets form in both ways (Santos et al. 2004).

However, all these results are based on studies of old, solar-like F-K stars, which all have about one solar mass. A few surveys for planets of M-stars have been carried out (Marcy et al. 1998; Delfosse et al. 1998; Butler et al. 2004) but only 3 exoplanets have been detected so far. Remarkably, one of them is the lowest mass exoplanet found to date, with a minimum mass of only 0.12 Jupiter masses. These surveys of M-stars are limited to small samples because they use optical spectrographs, and they are hampered by the high activity levels of many targets.

There are several advantages of going to the NIR. One is to observe not only many M-stars, but also VLMSs ($M \leq 0.2M_\odot$) and BDs. Another important advantage is that the effect of starspots on the RV-accuracy is expected to diminish by about a factor of 10 from optical to NIR wavelengths. Among the key questions that could be addressed by a RV-survey for exoplanets around VLMSs and BDs we underline the following:

- Is the frequency vs. separation distribution for solar-mass stars, VLMSs and BDs the same, or are they different?
- Does the mass of the planets of VLMSs and BDs simply scale with the mass of the central object and/or the mass of the disc?
- Do we find the same eccentricity distribution as in solar-mass stars?
- Do we find the same dependence with the metallicity as in solar-mass stars?

Surveys of visual companions of BDs already have identified a number of BD-BD binaries (Bouy et al. 2003; Martin et al. 2003). The first dynamical masses of BDs have been obtained from orbital monitoring of some of these
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binaries (Bouy et al. 2004; Zapatero Osorio et al. 2004). Additionally, a spectroscopic BD-BD binary in the Pleiades has also been found (Basri & Martin 1999). This binary consists of two BDs with masses of 0.06 to 0.07 $M_\odot$ and an orbital period of 5.8 days. By searching for close BD-BD companions, one might hope to find a eclipsing binaries which will then allow the determination of the accurate masses and radii.

![Figure 1](image)

Figure 1. Left panel: NAHUAL sensitivity to planets around a BD with mass 40 $M_{Jup}$. The curved lines show the RV-amplitude ($\times \sin i$) of 2, 5, 10, 20, 50 m/s (the 5 and 20 m/s are full lines). Also shown are the positions for the “scaled” Io and Ganymede. Right panel: The accuracy of RV measurements that are foreseen with NAHUAL. The curved lines shows the exposure-times need for an accuracy of 5, 10, 20, 50, and 200 m/s (again 20 m/s shown as full line). With an exposure time of 20 minutes, it would thus be possible to detect planets of 4 to 8 $M_{Earth}$ if the brown dwarf is brighter than 12.5 mag in $H$.

Young BDs have accretion disks when they are young, and thus might also form planets. If the disk of BDs are just scaled down versions of disks of young stars, we may speculate that the resulting planets are just scaled down versions of the planets of stars. In this case, 10% of the BDs should have planets with the mass of a few $M_{Earth}$. Since also the snow-radius of the disk scales with the mass of the central object, such planets would be located at a distance of $\leq 0.1$ AU from the BD (Stevenson & Lunine 1988). Another view is that the planetary systems of BDs could be scaled up version of the Jovian moon-system. In contrast to our planetary system, where most of the angular momentum is in Jupiter, and not in the sun, in the case of the Jovian moon-system most of the angular momentum is in Jupiter, and not in its moons. If the planetary systems of BDs resemble the Jovian moon-system, we would again expect planets of a few $M_{Earth}$ but at much closer distance from the central
The third possibility, of course is that the distribution of companions is continuum, so that BDs also have planets of $M_{\text{Jup}}$. In any case, we expect that possible planets have periods of 40 days or less, which implies that they have to be searched for by means of RV-monitoring.

A survey for planets of VLMSs and BDs would be of key-importance for understanding the formation of stars and planets. Fig. 1 (left) shows that if the planets of BDs are scaled-down versions of exo-planets of solar like stars, or scaled up versions of Jovian moons, an accuracy of $\sim 10$ m/s will allow to detect them. Fig. 1 (right) shows that an accuracy of 20 m/s can be achieved with NAHUAL for objects with an $H$-magnitude of about 13 in an hour. There are more than 300 known VLMSs and BDs in the solar neighborhood and in nearby open clusters and associations for which such studies can be carried out. Certainly, NAHUAL will revolutionize this field of research.

**Activity and RV-measurements: The infrared advantage.** One problem in detecting exoplanets by RV-measurements is stellar activity. The problem is that spots cause periodic RV-variations like orbiting planets. A spot creates a hump in the line-profile, and the hump then causes a shift of the center-of-mass of the line-profile. This hump moves over the line-profile, when the star rotates, thus causing periodic variations of the RV of the star. IR-observations will help in this case. Because star spots are cool, the brightness difference between the spot and the photosphere is smaller in the IR than in the optical. Measurements by Albregtsen & Maltby (1981) show that on average a sun-spot has only $0.057 \pm 0.015$ of the intensity of the photosphere at 0.579 $\mu$m but $0.525 \pm 0.043$ at 1.67 $\mu$m. Thus, the hump is a factor of ten smaller in the H-band than in the visual, and the RV-variations induced by spots thus will also be correspondingly smaller. In contrast to this, the RV-signal of a planet remains unchanged. RV-measurements in the IR thus help in two ways: Planets of active stars can be more easily detected in the IR, and in the case of doubtful planets IR-measurements will allow to distinguish between spots and planets.

**Atmospheric studies of exoplanets.** Occultation spectroscopy of transiting exoplanets provides a method to study their atmospheres. A search for NIR features in HD 209458b with IRTF/Spex set a limit to the planet’s K-band flux of $3 \times 10^{-4}$ of the stellar flux (Richardson et al. 2003). Thanks to the higher spectral resolution of NAHUAL, it will be possible to search for fainter absorption lines. We estimate that we can set a limit of $10^{-5}$ of the stellar flux by observing inside and outside two eclipses of HD 209458b. With NAHUAL the study of exoplanet atmospheres by occultation spectroscopy can be extended to fainter stars, such as those discovered by COROT, OGLE and STARE.

Theoretical calculations (T. Barman, priv. comm.) have shown that faint emission lines at the level of a few times $10^{-4}$ of the stellar flux may be present...
in the NIR spectrum of A- and F-type stars with very close exoplanets (orbital periods less than 5 days). We plan to carry out an exploratory study of a sample of these stars to search for faint NIR emission lines indicative of hot exoplanets. If successful, this would be a new method of searching for exoplanets in stars more massive than the sun.

The origins of very low-mass stars and brown dwarfs

BDs pose a new problem to the theory of star formation. Several formation mechanisms have been proposed, including formation like a star (from collapse and fragmentation of a molecular cloud, Padoan & Nordlund 2004), like a planet (from a circumstellar disk), as stellar "embryos", ejected from multiple systems before they have been able to accrete enough matter (Bate, Bonnell & Bromm 2002), or as evaporated low-mass cores by the influence of ultraviolet radiation from hot stars (Whitworth & Zinnecker 2004). These proposed mechanisms have different implications for their formation, their evolution and their properties. In particular, if BDs are created like stars, they should go through a phase of active accretion from a circum(sub)stellar disk, as low mass stars do (e.g., Shu, Adams & Lizano 1987).

There is growing evidence that very young BDs have active circum(sub)stellar disks analogous to those of T Tauri stars. Comeron et al. (2000) found an excess of the emission at 6.7 $\mu$m for 4 out of 13 VLMSs and BDs in the Chamaeleon I star forming region. Muench et al. (2001) concluded from the $JHK$ colour-colour diagram of the Trapezium Cluster in Orion that the disk-frequency of low-mass members of the cluster is 50 %, or higher. An excess of IR emission of low-mass objects was also observed with ISOCAM in the Chameleon I dark cloud (Persi et al. 2000). Young, low mass objects apparently not only have passive disks but also show signs of accretion, and outflow activity like in T Tauri stars (Martin et al. 2001, Fernandez & Comeron 2001; Barrado y Navascues & Martin 2003). Accretion from a disk seems to be present even for objects with a mass of only 8-12 $M_{Jup}$ (Testi et al. 2002). Disks of T Tauri stars have typically about 3% of the mass of the central object. If this is also true for BDs, the total mass of a typical BD disk would be only a few $M_{Jup}$. Recent observations in fact indicate that the masses of BD disks are of this order of magnitude (Klein et al. 2003).

The analysis of optical high-resolution spectra of young BDs has provided a way to measure mass accretion rates, as well as rotational velocities, effective temperatures, chemical composition and gravities (e.g. Mohanty et al. 2004). However, this type of analysis presents an important handicap: Class II sources have optical veiling, introducing additional elements of uncertainty in the analysis. This is specially true when determining the real strength of the emission and absorption lines (for instance, the derived accretion rate can be off by a sig-
nificant amount). Moreover, the core located at the center of a Class I source is not accessible at the optical wavelength. Only IR detectors can peer through the cocoon surrounding it. In the case of very low mass objects, they emit most of their luminosity in the IR, making even more beneficial the observations at this wavelengths. Note that BDs have effective temperatures lower than 2900 K for an age of 1 Myr, and much lower for older ages and/or less massive objects. We plan to chart this unexplored territory, the initial phases of evolution, including accretion and outflows, in VLMSs and BDs, as seen in the infrared.

Our goal is to carry out a comprehensive study of this phenomenology exploiting the state-of-the-art capabilities of NAHUAL (high efficiency combined with high spectral and spatial resolution). On one hand, accretion can be detected by using hydrogen lines such as Paschen $\beta$ in the J band and Brackett $\gamma$ in the K band (e.g., Folha & Emerson 1999). Fig. 2 shows a theoretical spectrum from the Lyon group (Allard et al. 2000) in the near IR range, where several interesting features have been marked. The J band is of particular interest in the case of Class II objects because the veiling of the spectrum is minimum. Moreover, several molecular bands, such as CO $\delta v=0-2$ (2.2935 $\mu$) can be used to study the rotational velocities (i.e., the angular momentum evolution and the interaction with the accretion disk), even in the case of embedded objects. Moreover, the signature of alkali elements is very conspicuous in L dwarfs, and they can be used for detailed analysis of the surface gravity. Finally, the use of Adaptive Optics in combination with NAHUAL provides not only a very high spectral resolution (up to R=100,000), but the possibility of studying the dynamics of circumstellar and circumsubstellar disks and the kinematics of the outflows.

**Magnetic fields in cool stars and brown dwarfs**

Magnetic fields play a crucial role in stellar physics across the entire HR diagram. According to the current paradigm, magnetic fields are responsible for several interesting characteristics such as non-thermal radio emission in early–type stars, jets in young stellar objects, all the activity phenomena (X-ray emission, flares, photospheric spots, angular momentum and loss) observed in the Sun, solar–type and lower mass stars. Most of these phenomena, in particular coronal and chromospheric activity, are indeed very often used as proxies of magnetic fields.

Focusing on stellar activity and low mass stars, *ROSAT* satellite X-ray observations of several open clusters have allowed gathering a general understanding of the so-called ARAP (age-rotation-activity paradigm, e.g., Randich 2000), but several important issues still stand that can only be addressed by direct knowledge of magnetic fields (both strengths and filling factors) in stars of different masses and ages. Among the other topics, we mention:
Figure 2. Synthetic spectrum in the J and K bands computed by Allard et al. (2000) for an effective temperature of 2500 K for a non-accreting object. We have labeled several hydrogen (corresponding to the Paschen and Brackett series) and alkali lines, and the CO $\nu=0-2$ bandhead.

- the dependence of magnetic field strength on stellar age, mass, and stellar rotation; does an age-rotation-magnetic field paradigm hold, as one would expect from the ARAP?
- what is the actual link between X-ray and chromospheric activity indices and the global magnetic field strength? In other words, can we "safely" use activity indicators as proxies of magnetic fields?
- What about the relationship between the filling factor and the activity level? Is there a connection between activity saturation and super-saturation and a certain value of the filling factor?
- Why does the rotation-activity relationship appear to break (and even to reverse) for late-M and L-type dwarfs (e.g., Basri, 2000)? Is the reason for this the insufficient conductivity due to the low ionization level in the atmosphere of these cool stars? Or is the dynamo unable to operate in these fully convective stars? Or, instead, are these objects characterized by large scale, relatively stable magnetic fields?

In summary, the comparison between the measured magnetic fields and the activity indicators with the values predicted by the models would provide key
constraints on both different dynamo models and on the models describing how magnetic energy is dissipated and transported along stellar atmospheres.

Despite their importance, magnetic field strengths have been so far measured in only a handful of field stars, while coronal and chromospheric activity levels are now available for thousands of field and cluster stars. The reason for the paucity of magnetic field measurements is that they are very difficult to make, particularly in the optical spectral region where the expected broadening due to Zeeman splitting—the most commonly used method for the determination of magnetic fields—is small relative to other sources of line broadening (e.g., Saar 1988).

The use of NIR lines to measure stellar magnetic fields offers several advantages; namely, i) Zeeman splitting of the two σ components is given by

\[ \Delta \lambda \propto \lambda^2 g B \]

where \( g \) is the Landé factor and \( B \) the magnetic field strength (in kG). Zeeman broadening is thus proportional to the square of the wavelength, while intrinsic line width is proportional to wavelength. Higher accuracy and/or lower field measurements can thus be achieved by using near-IR lines. For example, the splitting of the σ components of the Fe \( \text{i} \) line at 1.56485 \( \mu \)m is 2–3 times larger than the splitting in even the most-sensitive optical lines; ii) continuum opacity is lowest in the H band and thus lines form deepest in the atmosphere where higher magnetic fields are predicted; iii) the line density in the near-IR is lower than in the optical, and therefore blends are less of a problem. Until recently, however, the available instrumentation only allowed lower accuracy measurements in the optical (Saar 1988; Marcy & Basri 1989) or measurements of a few very bright (\( K < 2 \)), active stars in the IR (Saar & Linsky 1985; Valenti et al. 1995).

NAHUAL is an ideal instrument to carry out magnetic field measurements in a variety of cool stars and BDs. The large spectral coverage would allow using several magnetic sensitive lines, whose strengths vary with spectral type. For example, the Fe \( \text{i} \) 1.5904 \( \mu \)m and Fe \( \text{i} \) 1.5648 \( \mu \)m (\( g=3 \)) may be used for stars in the range G–mid K, while for later stars the Ti \( \text{i} \) near 2.2 \( \mu \)m can be used.

The large number of available lines, coupled with the high resolution and the high signal-to-noise ratio will permit very precise measurements of magnetic fields in cool stars in the field and along the main sequence of several open clusters in the Northern hemisphere (i.e., Hyades, Pleiades, Praesepe, etc.). For the first time measurements of magnetic fields in very low mass stars will be feasible, allowing us to gather insights on activity phenomena and on the dynamo process in these objects.

A resolving power \( R > 30,000 - 40,000 \) is required to measure magnetic fields. As for the instrument sensitivity, we aim at measuring magnetic fields (i.e., at S/N ratios > 100) in stars close to the substellar limit in the Pleiades and Hyades clusters (\( H = 15.3 \) and 13.9 and \( K = 14.9 \) and 13.6, respectively), as well as in field VLMSs and BDs. We mention that these sensitivity limits will
allow us to measure magnetic fields in brighter solar-type stars up to distances of about 1 Kpc, i.e., in the rather far-away old open clusters.

**Gamma-Ray Bursts**

Gamma-Ray Bursts (GRBs) are signals from titanic explosions in the remote universe, physically related to endpoints of stellar evolution. They appear as bright flashes in the gamma-ray sky, unpredictable in time and position. The all-sky GRB event rate, as determined by the sensitive BATSE experiment aboard the Compton Gamma-Ray Observatory, is about 800 per year.

GRB research was boosted considerably in 1997, when for the first time the optical afterglow of a GRB was discovered. It is now well established that the bursters are at cosmological distances. The current record holder is at a redshift of 4.5. The isotropic equivalent energy release of these bursts can exceed $10^{54}$ erg. This places the bursts among the brightest electromagnetic phenomena in the universe.

Observations in the gamma-ray band indicate that GRB explosions involve the expansion of an ($e^+e^-,\gamma$)-plasma (a fireball) with Lorentz factors in the order of some hundreds. Due to their giant luminosity, bursts could be detected with current gamma-ray detectors up to redshifts of about 15. If GRBs are physically related to star formation they might represent the most powerful observational tool we have in the near future to study the history of the star formation rate in the universe and to address several cosmological questions.

By the end of September 2004, about 50 optical/near-infrared afterglows of GRBs have been discovered and about 30 could be followed over several days. Recent spectroscopic identification of supernova light underlying the afterglows of the nearby bursts GRB 030329 (e.g., Hjorth et al. 2003) and 031203 (Malesani et al. 2004) convincingly demonstrated that a certain class of core-collapse supernovae is physically related to long-duration GRBs. Thereby, the stellar explosion is highly asymmetric (Greiner et al. 2003). Moreover, extra-light has been found in nearly a dozen optical afterglows up to redshifts of 1, which can be attributed to light from an underlying SN component with its peak about 20 (1+\(z\)) days after the event (Zeh et al. 2004). All this provides strong evidence for a general SN-GRB association.

Indirect evidence on the nature of the GRB progenitors comes from early spectroscopy of afterglows at redshifts around 2, such as GRB 021004 (Castro-Tirado et al. 2004) and GRB 030226 (Klose et al. 2004). These afterglows showed various absorption line systems of highly ionized ions C IV and Si IV. As an example, optical spectroscopy (5 hrs after the burst) of the afterglow of GRB 030226 using VLT/FORS2 show two absorption line systems at redshifts $z = 1.962 \pm 0.001$ and at $z = 1.986 \pm 0.001$, corresponding to a separation in velocity by 2400 km/s. The kinematics and the composition of the absorbing
clouds responsible for these line systems is very similar to those observed in the afterglow of GRB 021004, supporting the picture in which the line of sight passes through the stellar wind of the GRB progenitor, very likely a Wolf-Rayet star.

NIR spectroscopy of GRB afterglows is basically a question of timing, even though there is no need for a rapid response mode to trigger observations within seconds. Most of the known afterglows are brighter than $K=16$ within the first 2 to 3 hours after a burst, making them interesting targets for NAHUAL.

There are several reasons for a rapid NIR spectroscopy response. First, various independent studies suggest that up to about 10% of all bursts are at redshifts larger than 5, making optical spectroscopy basically impossible because of the intergalactic Lyman drop-out. Second, afterglows are bright light houses shining through the interstellar medium of their host galaxies. As such they provide unprecedented insight on the physical and chemical conditions in galaxies in the young universe. Third, several afterglows are affected by dust in their host galaxies, which makes them relatively faint in the optical bands but affects them much less in the NIR bands.

GRB afterglows might tell us more about the ISM of cosmologically remote galaxies than we can learn with any other sophisticated observational method in the near future. As an impressive example we note that while we have spectroscopic information about the ISM of the host of GRB 030226 at a redshift of $z=2$, the host itself remains undetected on deep VLT/FORS1 images down to $R > 26$ once the afterglow had faded away.

To summarize, we have argued that NAHUAL might not only provide us with redshifts of the most distant bursts but also allow us to gain a lot of insight onto the physical nature of GRB progenitors and their host galaxies in the early universe.

2. Summary of NAHUAL top level requirements

This is a summary of the top level requirements for NAHUAL in order to achieve the scientific goals outlined above.

- Large spectral coverage. Simultaneous observation of at least one NIR band ($J$, $H$ or $K$). This requirement calls for a cross-disperser and a large format NIR detector. The detector is likely to be a 2048 x 2048 HAWAII-2 PACE HgCdTe, similar the one used in EMIR.

- High throughput, hence the need to install it at the GTC.

- Sufficient spectral resolution to resolve spectral lines. Our design goal is to reach $\lambda/\Delta \lambda = 100,000$ in AO mode and 40,000 in natural seeing mode.
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- Stable environment. This requirement calls for a temperature controlled enclosure in one of the Nasmyth foci of the GTC.

- Self calibration for high-precision RV-measurements. Absorption cells for the NIR need to be developed and calibrated in the laboratory. A simultaneous fiber-fed emission spectrum from a lamp will also be studied.

- High spatial resolution to allow using a narrow slit for high spectral resolution. It is currently envisaged that NAHUAL will sit in an optical bench behind the GTC AO facility.

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