NEW GENERATION NEAR INFRARED SPECTROGRAPHS IN 3.5 m TO 10 m CLASS TELESCOPES

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Abstract: Here we present a review of the new generation near infrared spectrographs (1 to 5 microns) available in telescopes from 3.5 m to 10 m in diameter. These instruments have in common the new infrared (IR) detectors with a large 1024 x 1024 pixel format, low read-out noise and low dark current both in the 1-2.5 and 1-5 micron range.

1 Introduction

The study of the spectra of astronomical objects in the Near Infrared (NIR) has enormous scientific potential: by using NIR, the composition of the dust can be established, molecular hydrogen can be studied, and high redshift (z=1) galaxies, whose main emission lines of Active Galatic Nuclei (AGN) (for example, Halpha) lie in the NIR region, can also be observed. However, working in this spectral region (1-5 microns) is quite a challenge, posing several problems for the astronomer. The first problem is the transmission of the sky: since the earth's atmosphere is dominated by water vapour, only certain spectral regions can be observed, namely, the J, H, K, L and M band. An additional problem is that a black body with a temperature of 300 K will have a very important contribution to the K, L and M band. To avoid this emission, the whole instrument must be cooled to a temperature below 100 K, which results in a myriad of engineering problems to be solved. A third issue is the fact that very fast reads are necessary in order to avoid sky saturation, especially in the L and M band.

During the last 30 years, NIR spectroscopy has been limited by the availability of detectors and cryogenic technology. In the 70s only the Circular Variable Photometers (CVF) were available, with very poor resolution (R=100) and very poor throughput. In the 80s, linear arrays and small bidimensional arrays became available, with very high dark current and read-out noise, which limited their use to bright sources and small spectral ranges. In the mid 90s, new large format arrays with very low dark current and read-out noise made NIR spectroscopy more similar to the optical spectroscopy with CCDs in the 80s. NIR spectrographs are very complex cryogenic machines, and as a result the number of these spectrographs is currently rather scarce. Key points to consider when designing a NIR spectrograph include target acquisition and sky subtraction. Target acquisition is difficult due to the impossibility of using an optical slit view with CCD, since on the one hand differential sky refraction causes the optical and IR image to be shifted by several arcseconds (depending on the airmass), and on the other hand some sources are very red and therefore very weak in the optical image. Another factor to take into account is the strong sky emission in the NIR: for example, the sky emission in the Ks band is 13 magnitude per square arcsecond (3 and -0.5 in the L and M bands). Therefore, most NIR spectrographs have an imaging mode which makes it possible to use in the NIR the usual imaging technique of dithering the telescope around the target position in order to subtract the sky emission. As some of these spectrographs aim at very weak targets, such as M_K=20, target acquisition can be a very time-consuming task. Once the target is on the slit, the usual beam-switch technique is used; however, to allow for correct sky subtraction, beam-switching has to be done every 15 minutes. Thus the system (instrument+telescope+autoguider) has to be very stable in order to ensure that the target will be on the slit after several beam-switches (for a 3-hour integration on one target, 12 beam-switches will be necessary). The other key point is sky subtraction, as this spectral range is dominated by strong atmospheric OH emission lines. In order to allow for proper sky subtraction, the design should minimize flexures which will shift the spectral lines. As an example, the user requirement of LIRIS allows maximum flexure of 4-microns between the focal plane and the detector during one hour of integration time. All this makes the optical and mechanical design far more complex than that of an optical spectrograph. Regarding spectral resolution, in order to avoid the atmospheric OH lines, the optimal resolution is between 1000 and 3000. Another important point is the dispersion element. Some spectrographs use reflection gratings which provide high resolution, especially if echelle gratings are used, while for low resolution (R=1000) usually grisms (a combination of a prism and a refraction grating) are used.

Array	Pixels	Pixel size	Read out (e^{-1})	Dark current (e^{-1} s^{-1})	Working Temperature (K)
Hawaii	1024 x 1024	18	15	0.01	70
Hawaii-2	2048 x 2048	18.5	15	0.01	70
ALLADIN	1024 x 1024	27	40	0.01	30

Table 1: Characteristics of near-IR arrays

Two different detectors were manufactured in the late 90s, Hg:Cd:Te with a spectral coverage from 0.8 to 2.4 microns (Hawaii 1024 x 1024 and Hawaii-2 2048 x 2048, both manufactured by Rockwell), and InSb with a spectral coverage from 1-5 microns (ALLADIN 1024 x 1024, manufactured by Raytheon). These detectors require very precise temperature control, as their characteristics (bias, hot pixels, etc) can be altered if there is a difference of even a small fraction of a degree K. For LIRIS it was found that the optimal operation temperature was 70 ± 0.005 K. The spectral dimensions of NIR spectrographs have been divided into two ranges: 0.8 -2.5 microns when using Hawaii arrays, and 1-5 microns when using ALLADIN arrays. The main characteristics of these arrays are listed in Table 1. The spectrograhs in the two spectral ranges will be discussed in more detail below.

2 Spectrographs in the 0.8 to 2.4 microns range

Instrument	Telescope	Plate scale "/pixel	Resolution	Polarimetry	MOS	Coronography
IRIS2 [3]	AAT	0.45	2400	no	yes	no
ISSAC [2]	VLT	0.15	500-3000	yes	no	no
LIRIS [4]	WHT	0.25	1000-3000	yes	yes	yes
Omega-Cass [1]	Calar Alto	0.04,0.3	420,1050	yes	no	no
NICS [5]	TNG	0.25,0.13	50-1250	yes	no	no
SOFI [2]	NTT	0.14,0.27,0.29	600-1500	yes	no	no

Table 2: 1-2.5 microns spectrographs

These spectrographs make use of the Hawaii arrays, both the Hawaii and the Hawaii-2 (2048 x 2048). These arrays, which can be seen in Table 1, have very low readout noise and very low dark current, thus the observations are usually limited by background noise for integrations longer than 100 seconds. The low dark current combined with the spectral resolution make long integration times possible. Thus, these spectrographs make observations which are very similar to the observations in the optical wavelength.

All these spectrographs use the Hawaii array and have an imaging mode to allow for target acquisition. They also have full imaging capability with a wide set of astronomical filters. All except for ISSAC use grisms as disperser elements. Spectra resolution ranges from 50 for NICS to 3000 for ISSAC and LIRIS. All except for IRIS2 have polarimetry modes, and only IRIS2 (in the Southern Hemisphere) and LIRIS (in the Northern Hemisphere) have Multi-Objects (MOS) mode. LIRIS is the only spectrograph with coronographic mode, whereas ISSAC is the only spectrograph with two arms, one covering the 1-2.5 micron region and the other covering the 2.5-5 micron region. The diameters of the telescopes range from 3.5m (Calar Alto, NTT and TNG) to 8m (VLT).

Instrument	Telescope	Plate scale "/pixel	Resolution	Pola-rimetry	Corono-graphy
CISCO/OHS [9]	SUBARU	0.105	400	no	no
CONICA [2]	VLT	0.01,0.05	400-1100	yes	yes
GNIRS [7]	Gemini S.	0.15	1000-3000	yes	no
IRCS [9]	SUBARU	0.022,0.058	120-5000	no	no
ISSAC [2]	VLT	0.075	500-3000	yes	no
NIRCSPEC [6]	Keck	0.19	2000-20000	no	no
NIRI [7]	Gemini N.	0.02,0.11	460,1650	no	no
PHOENIX [7]	Gemini S.	0.23	50000	no	no
UIST [8]	UKIRT	0.06,0.12	475-2000	yes	no

Table 3: 1-5 microns spectrographs

3 Spectrographs in the 1 to 5 microns range

All these spectrographs use the ALLADIN detector. CONICA is used in combination with the adaptive optics (AO) system NAOS while NIRI is used with the AO system Altair. IRCS can be also used with the SUBARU AO system. Spectral resolution varies from 120 for IRCS, to 50000 for PHOENIX. CONICA, GNIRS, ISSAC, and UIST all have polarimetry modes, with CONICA being the only spectrograph with coronography mode. UIST is the only one with an Integral Field Unit (IFU). CISCO/OHS has an OH suppressor that removes the OH airglow lines which dominate the broad-band background. This gives a gain in sensitivity in the order of 0.5 magnitude in the J and H band. None of the spectrographs have MOS modes.

4 Future

Here we describe several other instruments which are being developed at present and will be operative in the near future. SINFONI, which will be on the VLT, uses a Hawaii-2 and has an IFU with 32 x 32 spatial pixels and 2048 spectral channels (first light in 2004). CRIRES, which will be on the VLT, will work in the 1-5 micron range with a 1024 x 4096 pixels array, giving a resolution of R=50000 (first light in 2004). LUCIFER, on the BLT, will use the Hawaii-2 array and have a resolution of R=10000-36000, as well as MOS mode (first light 2004). OSIRIS, on the Keck, will use a Hawaii-2 array, and have an IFU (64 x 16 spatial elements) and an OH suppressor with a resolution of R=3800. FLAMINGOS on the 4m Mayal (NOAO), uses a Hawaii-2, and will have R=1800 and a MOS mode. EMIR, which will be on GTC, uses a Hawaii-2 and will have a MOS mode with a FOV of 6 x 6 arcminutes and R=3000 (first light 2008).

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