led by P. Gray and J. Eschwey for their work in preparation to and during the commissioning of the MMU. Special thanks go to P. Sansgasset, P. Robert, U. Kaberger, E. Bugueño, M. Tapia, G. Gillet and P. Mardones.

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Figure 6: The Instrument Cabinet Robot. The four Instrument Cabinets corresponding to the four channels of VIMOS (or NIRMOS) are inserted in the stand.

First Astronomical Light with TIMMI2, ESO's 2nd-Generation Thermal Infrared Multimode Instrument at the La Silla 3.6-m Telescope

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Introduction

We report the first astronomical tests of TIMMI2 between October 6 and 11, 2000. A short overview of the project history and the project context is given. This is followed by a basic description of the instrument and its modes as well as a report on the achieved and projected sensitivities. A more in depth technical description including first operational experiences will be given in one of the upcoming issues of *The Messenger*. As to the scientific interest of TIMMI2, readers are referred to, e.g., Käufl 1993.

The TIMMI2 Project

In 1992, when ESO commissioned the original TIMMI instrument, visiting astronomers could use a modern competitive instrument featuring imaging and low-resolution spectroscopy in the wavelength region from $\lambda \approx 5$ µm to $\lambda \approx 17.5$ µm (cf. Käufl et al. 1992, 1994a, 1994b). Back in 1992, to the best of our knowledge, TIMMI was the only such instrument available as a common user instrument at any observatory. TIMMI was built under contract for ESO by the *Service d'Astrophysique,* Saclay, France (PI Pierre-Olivier Lagage). TIMMI, featuring a 64 × 64 gallium doped silicon array and mostly germanium refractive optics inside a solid-nitrogen/liquid-helium dewar, was in constant use until its decommissioning in 1999 (cf. Stecklum et al. 1999). By then, the development of detectors had progressed so rapidly, that the instrument no longer appeared competitive.

In fact, in 1993 ESO joined a consortium of French institutes to develop, based on the array used e.g. in TIMMI, a next-generation device (cf. e.g. Lucas et al. 1994). Already the format of this device (128 × 192 pixel) suggested that it would be desirable to build a new camera, rather than trying to use the new device in the existing set-up. Even larger arrays were announced by US suppliers. To that end ESO had developed some basic ideas for the optics of a next-generation instrument for the La Silla 3.6-m telescope (cf. Käufl & Delabre, 1994).

As a result of the *La Silla 2000 questionnaire* (see Anderson 1994) in *The Messenger* 78, ESO received a proposal from the *Astrophysikalisches Institut und Sternwarte* of the *Friedrich-Schiller-Universität* (FSU) in Jena, Germany, to build TIMMI2. This proposal, reflecting ESO's optical concept, was based on a modern cryostat cooled by a Closed Cycle Expansion Cooler Machine and was also featuring a polarimetric option (not available in TIMMI). Personnel cost and capital investments could largely be covered by funds raised by the Institute in Jena. The PI in Jena was Hans-Georg Reimann. After some negotiations, a *Memorandum of Understanding* was signed and the work began in early 1996. The design sketch of ESO (see above) was first transformed into a FEM[1] certified conceptual design, both for the optics and mechanics, by the company Jena-Optronik GmbH. Based on this work, the final design and the detail design of the instrument were done at the physics department of the FSU. To the extent that this was feasible, all mechanical parts were manufactured in the workshops of the FSU. In the course of the project, the group at the FSU could enlist a team from the *Sternwarte der Universität Wien* for

[1]A representative mechanical design for the optical bench was made and its flexure was modelled with the finite element method.

support, especially with the data-flow aspects of TIMMI2. Because of a concatenation of detrimental influences, most notably delays in the delivery of the detector and the associated electronics, the original schedule could not be kept. The instrument could be shipped only end of April 2000 from Jena to La Silla. During the extended assembly and commissioning phase in May, the TIMMI2 team took a short break to visit the upper Elqui valley. On the way back, a serious car accident occurred. The PI, Hans-Georg Reimann was killed and other members of the team were more or less seriously injured (cf. *The Messenger* No. 100).

Work on the project was resumed in July, and in early August the full functionality of the instrument was established on the observing floor of the 3.6-m telescope. End of September, the team reconvened and the instrument could be interfaced for the very first time with the telescope.

While TIMMI2 was under development, the 3.6-m telescope underwent fundamental improvements and an extensive upgrade. In a first stage, the image quality was substantially improved (S. Guisard et al. 1997). It should be noted that for an instrument working at $\lambda \geq 5$ μm at a 4-m-class telescope, the performance in terms of S/N is basically proportional to the Strehl ratio. Equally beneficial for the performance of TIMMI2 was the decision to change the telescope control system (TCS) to VLT standards. This involved a complete rebuilding of the by then more than 20-year-old hardware of the f35 chopping secondary/adapter (cf. Moorwood & van Dijsseldonk 1985). TIMMI2 can now be set up to execute in a semiautomatic way complicated exposure sequences (chopping, nodding, mosaic scans, etc.). Such sequences may be essential for observing moderately extended objects (e.g. Käufl 1995a,b).

TIMMI2 Technical Description

Optics

TIMMI2, like its predecessor TIMMI, or many other ESO instruments (e.g. SOFI, EFOSC, FORS) is a focal reducer with a collimated beam at the intermediate pupil. An aperture wheel allows for the selection of various field masks or slits. Behind the intermediate pupil a lens/grism wheel (3 grism and ≈ 25 filter positions) is located. It is followed by an objective wheel. TIMMI2 is equipped with a Raytheon 240 × 320 arsenic doped silicon blocked impurity band (BIB) array detector (cf. Estrada et al. 1998). The device has its peak quantum efficiency at $\lambda \approx 10$ μm and can be operated over an extended range (≈ 2 μm $\leq \lambda \leq 28$ μm). With this format, Nyquist sampling of the diffraction pattern of the telescope at $\lambda \approx 8$ μm (i.e. a pixel scale of 0.3 arcsec/pix) results in a field-of-view of 72 × 96 arcsec^2 compared to 19 × 19 arcsec^2 for TIMMI.

Thus the focal length of the collimator and consequently the size of the intermediate pupil had to be increased correspondingly. TIMMI2 is equipped with a spherical mirror ($f = 350$ mm, used in an off-axis configuration) which gives a beam diameter at the pupil stop of 10 mm. As the total length of the cryogenic optical train in the dewar is of the order of 2.5 × $f_{collimator}$, i.e. ≈ 900 mm, a double fold of the optical path was chosen. Therefore, between collimator and pupil stop, the optical axis passes a folding mirror which has some power to compensate the astigmatism introduced from the off-axis operation of the spherical mirror. This arrangement is extremely simple and robust while generally w.r.t. optical quality superior to the use of e.g. an off-axis parabola.

The lens wheel has 8 positions:

- Ge-lens (f = 143 mm) for imaging with 0.2 arcsec/pixel at $\lambda \approx 10$ μm
- Ge-lens (f = 95.5 mm) for imaging with 0.3 arcsec/pixel at $\lambda \approx 10$ μm
- CdTe-lens (f = 143 mm) for imaging with 0.2 arcsec/pixel at $\lambda \approx 20$ μm
- Si-lens (f = 89.5 mm) for imaging with 0.3 arcsec/pixel at $\lambda \approx$ 3–5 μm
- Ge-lens (f = 63.6 mm) for spectroscopy with 0.45 arcsec/pixel at $\lambda \approx$ 10 μm including the order sorting filter
- CdTe-lens (f = 47.8 mm) for spectroscopy with 0.6 arcsec/pixel at $\lambda \approx 20$ μm including the order sorting filter
- the other positions are reserved for technical/alignment purposes.

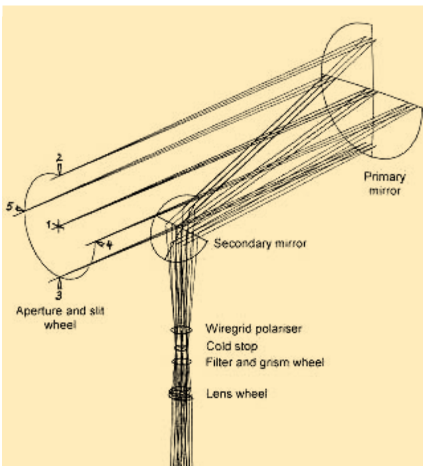

Figure 2: Schematics of the TIMMI2 Optics. Primary mirror: off-axis spherical mirror; secondary mirror: folding mirror.


Figure 1: Hans-Georg Reimann shortly before the accident during the re-assembly of TIMMI2 on the 3.6-m telescope observing floor.

All lenses used here are simple meniscus lenses and give basically for all configurations a theoretical image quality better than 0.5 arcsec. For more details on the optical design see Reimann et al. 1998 and 2000 or Dietzsch & Reimann, 1998.

The tests at the telescope have confirmed the theoretical image quality, i.e. TIMMI2 is for all practical purposes either diffraction- or seeing-limited.

TIMMI2 can be used in polarimetric mode. A, in principle, continuously rotating analyser can be inserted between the internal folding mirror and the cold pupil spot.

Cryostat

The TIMMI2 cryostat is extremely simple: it consists of two short ISO-standard stainless-steel tubes welded together under right angles. To the extent this was feasible, standard ISO-norm parts were used. To achieve good vacuum and cryogenic performance, all inner surfaces were polished and gold plated. The optical bench consists of a light-weighted aluminium structure supported (and thermally insulated) by a fibre-glass structure. The optical bench is enclosed by a radiation shield. Cooling of the instrument is achieved with a commercial 2-stage Gifford-McMahon Closed Cycle Cooler (supplied by Sumitomo Heavy Industries). The goal of the cryogenic design was to have all surfaces and components within the radiation shield cooled well enough that the instrument remains for all practical purposes (including medium-resolution

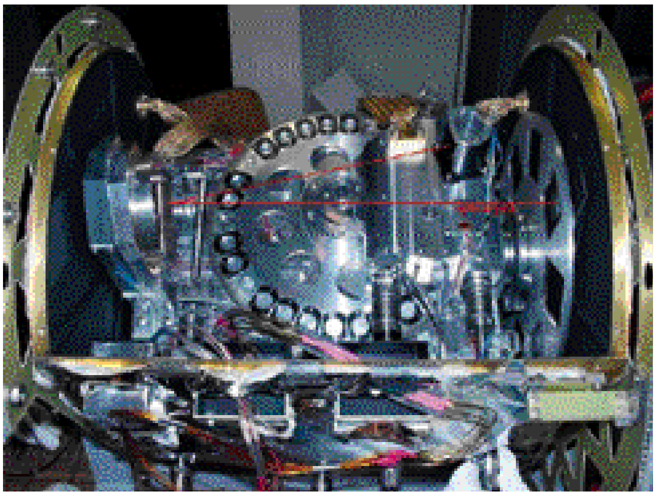

Figure 3: Close view from the top of the TIMMI2 cold optical bench (baffles and shields partially removed). Left and right in the picture the fibre-glass support structure and the solid parts of the radiation shield can be seen. To guide the eye, the optical path, starting on the right at the aperture/slit-wheel leading to the collimator and from there to the folding mirror is indicated. The folding mirror sends the light through the (encapsulated) polariser unit to the filter wheel, cold stop and lens wheel, then to the detector unit which is mounted to the back of the bench. The distance aperture/slit wheel to collimator is ≈ 350 mm. Three drive shafts are clearly visible, from left to right: filter-wheel, polariser movement and polariser insertion.

spectroscopy or L-band imaging) limited by the external background radiation (for details on the calculation of background noise limited operation see e.g. Käufl et al. 1991)[2]. Typical temperatures are 70 K for the radiation shield, 40 K for the optical bench, 34 K for the lens wheel and ≈ 8 K for the detector array. Temperatures are monitored with several PT-100 sensors for T ≥ 30 K and 2 Si-diodes for the detector area. The detector temperature is actively controlled with a commercial PID-controller.

Cooling down to operating conditions and starting with evacuation takes typically 48 hours. Several strong heaters are mounted to the cold bench to allow for baking during evacuation (T ≤ 50°C) and to speed-up the warming-up at the end of operation. In case of *target-of-opportunity* observations, additional filtres can be added to the filter wheel with a minimum intervention.

For motorising the 5 cryogenic functions, all bearings and gears were designed and assembled according to the principles also in use in other ESO infrared instruments (ISAAC, SOFI). As a thermal IR instrument is less critical with respect to light-tightness of the shields/baffles than a near-IR instrument, the motors of TIMMI2 are located outside the vacuum vessel. For the drive shafts, ferro-fluidics sealed penetrations are used. The penetrations at the radiation shield use an auxiliary bearing which ensures adequate light tightness and heat-sinking of the drive shafts.

Telescope Interface and Calibration

TIMMI2 is interfaced to the f35 adapter with a special interface plate allowing for pupil alignment. Integrated into this plate is a wheel with 12 positions allowing the insertion of a sky simulator, a flat-field source and spectral calibrators (plastic sheets with narrow spectral features).

Electronics

The TIMMI2 hardware is controlled via an Ethernet-IEEE488-bus interface. It is largely based on commercial electronics. The motor positions are monitored by means of inductive sensors which may be complemented by microswitches in the near future.

All functions (including the vacuum pumps and the closed-cycle cooler) can be controlled either by computer from a password-protected dialog box in the user-interface or directly using the corresponding front panel switches. For general routine operation, computer control is preferred as it appears safer; hand-operation, however, is essential as it is the only means to handle non-standard or error situations.

The detector is read out with a commercial electronics system (IR-Observer^{TM}) from Wallace Instruments. It generates all clocks and voltages for readout and chopping. The system is interfaced to a LINUX-PC.

Computer System and Data Flow

As mentioned above, in the thermal IR, detectors work under extremely high flux conditions which force – to avoid saturation – rapid readout of the detectors. In the case of the Raytheon 240 × 320 device in use in TIMMI2, 16 Analogue-to-Digital Converters work in parallel and generate of the order of 30 Mbyte per second. Storage and distribution of data at this rate is considered undesirable. Therefore, an automatic preprocessing pipeline has been developed. The scope of this pipeline is in a first processing step to simply co-add the data and in a second step to apply shift-and-add and cosmetic correction to the data while performing a simple consistency check (monitoring of average signal and variance). The scope and architecture are described in Relke et al. 2000. The ultimate goal is to provide one frame conforming to the ESO-DICB standards per target-instrumental mode configuration, or, in other words, e.g. in imaging, the output of TIMMI2 shall be equivalent to a dark, bias, flat-field and bad-pixel corrected CCD-image. At this stage of the project, however, it was not yet feasible to try the preprocessing pipeline.

First Results

The first commissioning was limited to 5 nights. After mechanical mounting, within hours, the first images could be obtained. Various electronic and software problems, however, did not allow to achieve acceptable performance from the beginning. Because of the

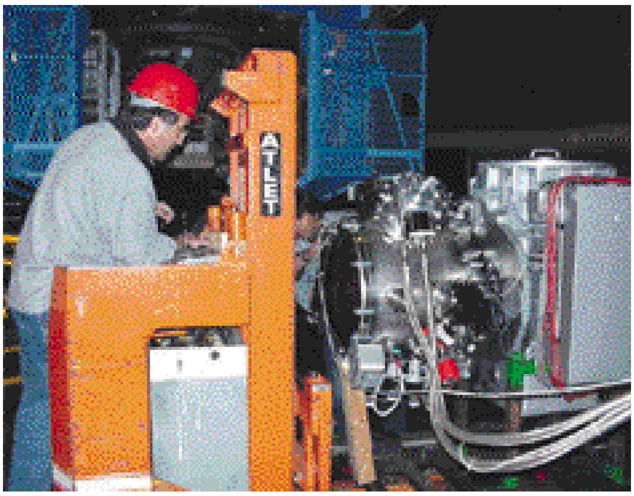

Figure 4: The TIMMI2-adapter assembly on its way to the telescope. While TIMMI could be hand-carried conveniently to the telescope, TIMMI2 needs a fork-lift and other special tools. The metal hoses lead to the closed-cycle cooler expansion machine attached to the top of the vacuum vessel. The TIMMI2 cryostat is interfaced to the recycled f/35 adapter by means of a special alignment plate which holds also a wheel with calibration targets.

[2] Readers not entirely familiar with this type of infrared instrumentation are reminded that the number of thermally emitted photons from telescope, atmosphere and dewar entrance window exceed by orders of magnitude those collected from the astronomical source: e.g. while a 1 Jy source at 10 µm will generate of the order of 10^7 photo-electrons, the background generates of the order of 10^{10} photo-electrons per pixel(!) per second.

residual risk associated with mounting of the TIMMI2 adaptor package with a mass of ≈ 400 kg, it was decided to use the engineering rather than the science-grade array for the first test. Another risk was that due to potential problems with the cable twist between the Closed Cycle Cooler Compressor and the instrument, the cooling machine could stall, which in turn could result in some contamination problems associated with the induced warming-up. Fortunately, none of these problems occurred and the results of the tests can be summarised as follows:

• The instrument mounting procedure is safe and the interruption of the cooling machine can be limited to ≈ 60 minutes; this in turn implies that the instrument is in stable operating conditions within 3 hours after mounting.

• The instrument works safely at least up to zenith distances ≥ 60°; the technical position South, telescope horizontal, can also be reached without any operational problems.

• The flexure between the guide probe CCD and the TIMMI2 optics is less then 1 arcsec up to 2 airmasses.

• The internal camera background and detector dark-current is negligible for all scientific instrument modes.

• The image quality is ≤ 0.8 arcsec for λ ≤ 13 μm and strictly diffraction limited for longer wavelengths.

• The instrument sensitivity is within expectations.[3]

• The optics does not produce any significant ghosts.

• The basic functionality of the user-interface could be established.

Improvements and Outlook

While the instrument configuration as tested gave already acceptable results, the TIMMI2 team will try, before the arrival of the first visiting astronomers in mid-January 2001, to implement a variety of improvements, both to boost performance and to make TIMMI2 more robust:

• The mechanics of the polarisation will be slightly modified to reduce mechanical friction.

• The inductive position sensors will be modified.

• The distance between Dewar entrance window and telescope focus will be increased.

• The signal preamplifiers in the read-out electronics will be modified.

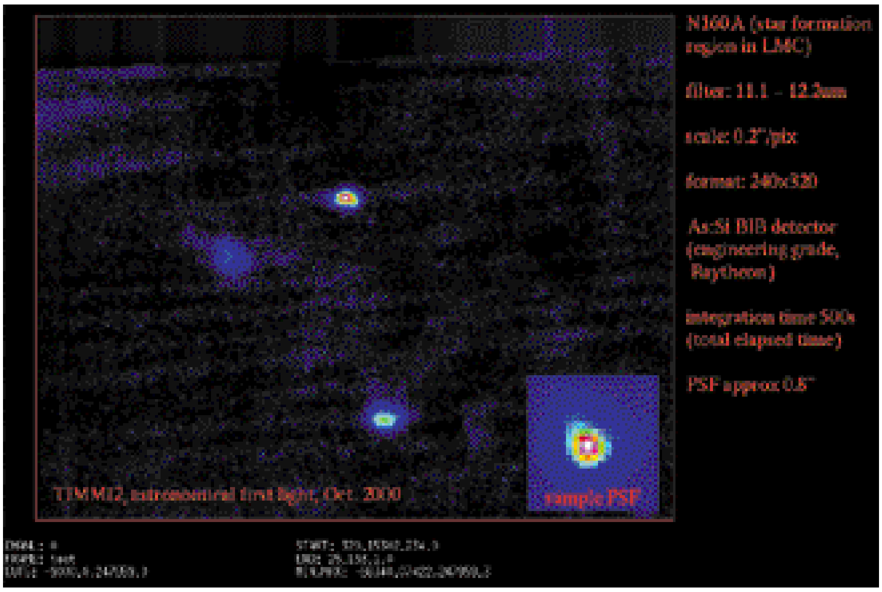

Figure 5: Image of the LMC star-formation region N160A. This was one of the first integrations on a scientifically interesting target with TIMMI2. The residual stripiness is due to grounding problems. While in principle this could be easily removed by Fourier filtering of the data, the cause is understood and the ground-loop problem will be solved while this article goes into print. The insert shows at a magnified scale a typical point-spread-function.

• The engineering grade array will be replaced with the science grade detector. At this point the detector will be carefully aligned with the instrument axis and the instrument orientation in turn with the celestial co-ordinates.

During operation the following problems occurred, which will be solved largely in the near future:

• Problems associated with the too high impedance of transient filters on the detector board in the cryostat will be resolved by modifying the filters as appropriate.

• Line frequency pick-up problems will be solved by opto-insulation of the chopping secondary interface; moreover the grounding scheme of the detector board will be re-examined.

• Saturation problems in the Q-band will temporarily be relieved by adding a neutral density filter until the final filters become available.

• The vibrations introduced from the Closed Cycle Cooler expansion machine produce some second-order artefacts. The immediate cure will be to reduce the CCC-head support resonance frequency by two, and in the coming months, the CCC-head will be supported independently on the telescope rotator.

With the above-mentioned improvements implemented, TIMMI2 has the potential to be the most sensitive and advanced instrument of its kind. Particularly in view of the rapid development of this project, future observers are invited to consult the TIMMI2 web page[4].

Some Special Remarks

The first commissioning of TIMMI2 was originally foreseen earlier this year. During the preparation phase, part of the TIMMI2 team set out for what was planned to be a weekend trip to the upper Elqui Valley. On Saturday, May 27, in the late afternoon, they suffered a serious car accident (cf. *The Messenger* 100, p. 56). The PI of TIMMI2, Hans-Georg Reimann from the University of Jena, was killed in the accident. While the team is reasonably satisfied with the successful installation of the instrument, they are all sad that Hans-Georg is no longer with them. To the whole team he had become a very close and good friend. Without his initiative, the project would never have had its kick-off meeting, and the smooth execution of the project was rooted in his equally optimistic and inspiring personality combined with his solid knowledge in the field of astronomy and its associated technologies.

Acknowledgements

In 1996, the Phase-A Study and the pre-design (by Jena-Optronik GmbH, Jena/Germany) of TIMMI2 was funded by the *Thüringer Ministerium für Wissenschaft, Forschung und Kultur* as Project B503-95025. Subsequently, from January 1997 through December 2000, funding of the manufacturing, assembly, and testing of the complete device came from the *Bundesministerium für Bildung und Forschung, Verbundforschung Astrophysik,* under grant Nr. 05 3JN204. The contribution of the *Institut für Astronomie der Universität Wien* was funded by the Austrian *Ministry of Science and Transport* and

[3]E.g., at λ ≈ 12 μm with a 1-μm bandwidth filter, the limiting flux for point sources is ≈ 40 mJy, 10σ in 1 hour (elapsed time, including all overhead). The performance of TIMMI2 as it was tested is competitive with all other instruments existing, but TIMMI2 has by far the largest field of view. Nevertheless, the TIMMI2 performance is a factor of 4 worse then the theoretical limit (BLIPperformance, see e.g. Käufl et al. 1991). We are very confident that we can do a factor of 2 better (see section **Outlook** below), and the implementation of the relevant improvements hopefully will have taken place before this article goes into print.

[4]http://www.ls.eso.org/lasilla/Telescopes/360cat/timmi/index.html

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Exploring the Lyman Forest at *z* = 2 with UVES

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1. The Signature of Neutral HI in the High-Redshift Universe

The Lyman-α resonance line of neutral hydrogen provides a sensitive probe to study the cosmological distribution of the baryonic matter and the conditions in the intergalactic medium (IGM) over a wide range of redshifts, up to $z \sim 6$. Observations of the "forest" of Lyman-α absorptions along the lines of sight to quasars, the most luminous objects known, reveal a wealth of structures, ranging from fluctuations of the diffuse IGM to the interstellar medium in protogalactic objects. The properties of the Lyman-α forest at different redshifts constrain the cosmological parameters, such as the density of baryons and the density parameter Ω, and are the key to issues like the formation of galaxies and large-scale structure, the origin and properties of the ionising radiation background. In particular, it was early recognised by Gunn & Peterson (1965) that, to avoid producing a very large HI opacity at wavelengths just below that of the quasar's Lyman-α emission line, a strong photoionisation by the metagalactic UV background is necessary, which at high redshift is produced by the first generation of stars, which also enrich the IGM with metals (also observed in the form of absorptions).

Unlike most of the other astronomical objects, Lyman-α absorbing "clouds"

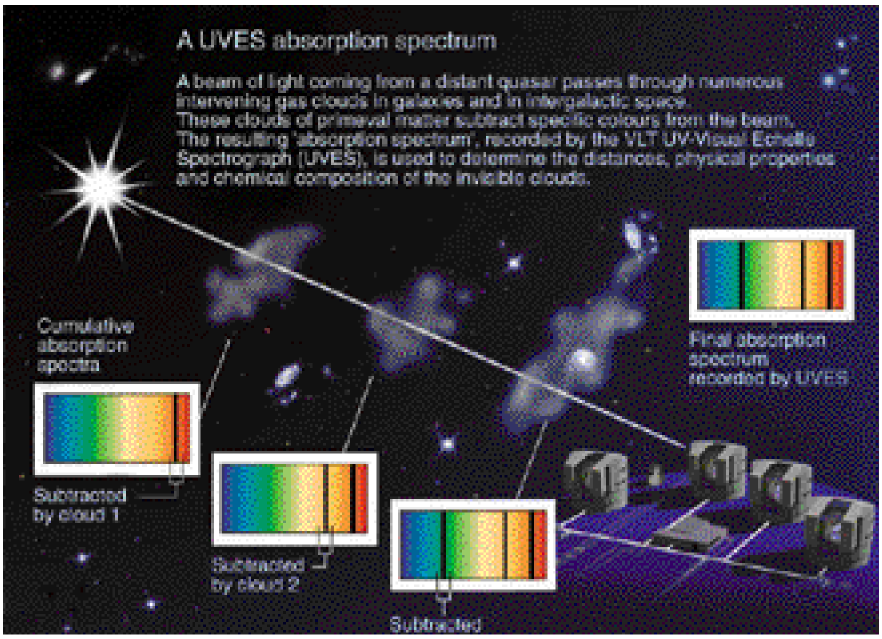

Figure 1: An artistic view (thanks to Ed Janssen) of how absorbing "clouds" distributed in the Universe leave their imprint in the spectrum of a distant, background quasar, which acts as a light beacon.