PART VI

FUTURE DIRECTIONS IN DIB RESEARCH

The Diffuse Interstellar Bands
Proceedings IAU Symposium No. 297, 2013
J. Cami & N. L. J. Cox, eds.

doi:10.1017/S1743921313016190

The Promise of Recent and Future Observatories and Instruments

L. Kaper[1]

[1]Astronomical Institute Anton Pannekoek, University of Amsterdam,
Science Park 904, 1098 XH, Amsterdam, the Netherlands
email: L.Kaper@uva.nl

Abstract. The identification of the carrier(s) of diffuse interstellar bands (DIBs) is one of the oldest mysteries in stellar spectroscopy. With the advent of 8-10m-class telescopes substantial progress has been made in measuring the properties of DIBs in the optical and near-infrared wavelength domain, not only in the Galaxy, but also in different environments encountered in Local Group galaxies and beyond. Still, the DIB carriers have remained unidentified. The coming decade will witness the development of extremely large telescopes (GMT, TMT and E-ELT) and their instrumentation. In this overview I will highlight the current instrumentation plan of these future observatories, emphasizing their potential role in solving the enigma of the DIBs.

Keywords. Instrumentation: spectrographs, Stars: early-type, Galaxies: Local Group

1. Introduction

At a symposium in Noordwijkerhout, close to Middelburg where Hans Lipperhey worked as an optician, and to The Hague where he demonstrated the telescope to Prince Maurits, the Stadholder of Zealand and Holland, and (unsuccessfully) requested patent on his telescope, it seems appropriate to briefly memorize the telescope as a Dutch invention. The invention of the telescope has always been a matter of much controversy, but a recent publication of a newsletter distributed in 1608 (Zoomers 2008) provides supporting evidence that the telescope, as a tool to study the stars, was invented by Lipperhey.

The newsletter *Ambassades du Roy de Siam envoyé a l'Excellence du Prince Maurice, arrivé à La Haye le 10 Septembre 1608* reports on three important events: the first visit of a Siamese diplomatic mission to Europe, the peace negotiations with Spain, *and* the demonstration of the newly invented telescope by Hans Lipperhey at The Hague†, almost one year before Galileo Galilei was able to discover the moons of Jupiter with an improved version of the telescope. Since 1568, the Dutch Republic was in a state of war with the Spanish empire of King Philips II. This "Eighty Years War" would last until 1648, but was interrupted by a Twelve Years Truce from 1609–1621. In 1608, the commander-in-chief of the Spanish forces, Ambrogio de Spinola, was in The Hague to represent Spain in the peace negotiations. In those years, the Dutch East India Company (VOC), the world's first multinational, was setting up a trade mission in the small Malay state Patani (today a southern province of Thailand), considered by the Dutch as the entrance to Siam and to China. The Portuguese had started the rumour that the Dutch were buccaneers without a country of their own, and so the Dutch welcomed the initiative of the Siamese King Ekathotsarot to send a mission to Holland.

† The newsletter was intended to bring the news of the arrival of the Siamese embassy, leaving two and a half blank pages which were used to add the news of the telescope. Only three remaining copies of the newsletter are currently known.

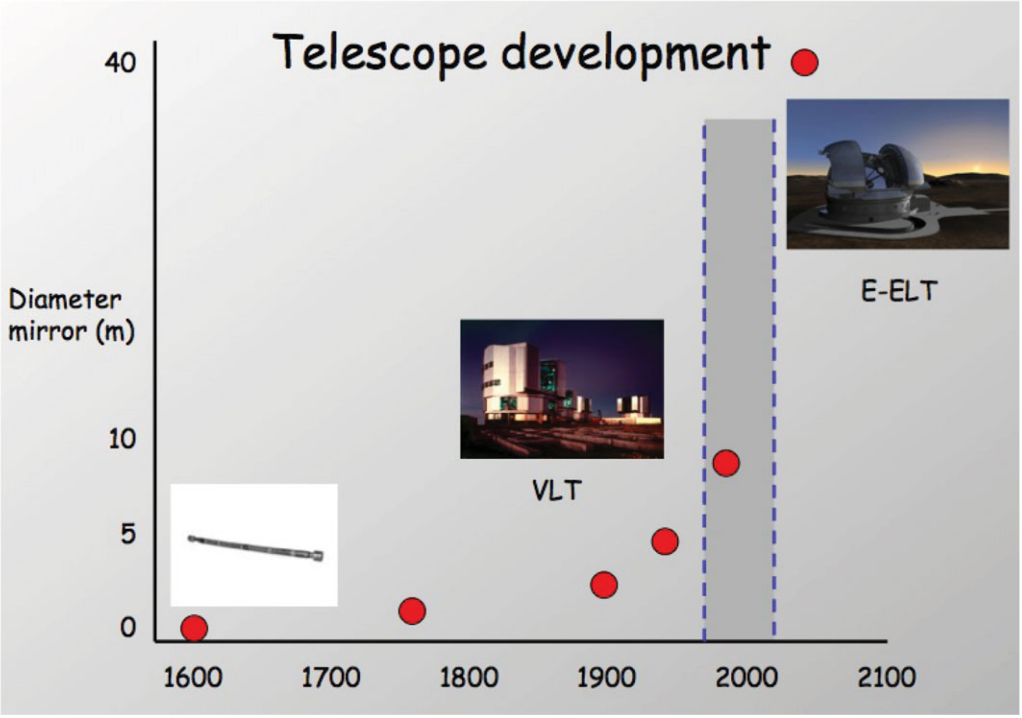

Figure 1. Increase in telescope primary mirror (c.q. lens) diameter since its discovery in 1608.

The newsletter reports that "A few days before the departure of Spinola from The Hague, an optician from Middelburg offered a few glasses to His Excellence ... with which it is possible to see the windows of the church in Leiden. [...] the mentioned glasses are very usefull to inspect objects at a distance of a mile and further, as if they are very nearby. Even the stars that are usually invisible due to their small size and our poor sight, can be seen with this instrument." Late November 1608 the newsletter had reached the Italian philosopher Paolo Sarpi in Venice, and although his correspondence seems to minimize its importance, in 1609 Sarpi became the key intermediary in the contacts established by his friend Galileo Galilei with the Venitian government regarding the telescope. The newsletter is very specific about Hans Lipperhey being the inventor and demonstrator of the telescope in 1608. One has to keep in mind, however, that both Jacob Metius of Alkmaar and Sacharias Jansen of Middelburg also claimed the invention of the instrument. This more general knowledge of the instrument and its construction was the main reason Lipperhey did not receive the patent he requested.

Since 1608 the diameter of the primary mirror/lens has grown exponentially with time (Fig. 1). Sir William Herschel, discoverer of Uranus in 1780, built fantastic telescopes with apertures exceeding a meter that were used on several sites. Early 20th century the first telescope with a 2.5 m mirror was constructed, the *Hooker* telescope of Mount Wilson Observatory used by, among others, Edwin Hubble. With the construction of the 5 m *Hale* telescope in 1948, the maximum size of the conventional reflector had been reached. Just before the millenium change, alternative designs (segmented mirror, supported meniscus mirror) resulted in the first 8–10m class telescopes (e.g. the *Keck* telescopes and the ESO *Very Large Telescope*). Although we are still exploring their scientific potential, the next generation of 30 m telescopes (*Giant Magellan Telescope* (GMT), the *Thirty Meter*

https://doi.org/10.1017/S1743921313016190 Published online by Cambridge University Press

Telescope (TMT) and the ESO *Extremely Large Telescope* (E-ELT)) is planned to see first light in the next decade.

Obviously, it is not only the telescope diameter that counts; also the available suit of instruments determines for a large part the scientific power of the observing facility. For the study of the diffuse interstellar bands (DIBs), the identification of which termed "the oldest mystery in stellar spectroscopy", the development of wide-band, high spectral resolution spectrographs (and spectropolarimeters) is of special relevance. In the following sections we present a (biased) view on current and future instrumentation relevant for DIB research, with emphasis on the current 8–10m telescopes and on the future ELTs.

2. A biased view on current (and planned) instrumentation relevant for DIB research

2.1. *DIBs in the Local Group and beyond*

The prominent DIBs at 5780 and 5797 Å were first encountered in B-star spectra and suspected to be of interstellar origin almost a century ago (Heger 1922, Herbig 1975). Since then, several hundred DIBs have been registered in various Galactic sightlines (e.g., Tuairisg *et al.* 2000, Cox *et al.* 2005, Hobbs *et al.* 2009, Van Loon *et al.* 2009, Vos *et al.* 2011), while the nature of their carrier(s) has, so far, remained illusive (Herbig 1995, Sarre 2006).

Taking advantage of the increasing light collecting power of telescopes, spectrographs and detectors, it became possible to search for DIBs in extragalactic environments, and to study their behaviour as a function of metallicity, extinction, interstellar radiation field, etc. The first detections of DIBs in Local Group galaxies focussed on the presence of the 4430 Å DIB in the Magellanic Clouds in the sixties and seventies (cf. review by Snow 2002). The first clear detections of LMC DIBs were obtained in the sightline towards SN1987A (Vladilo *et al.* 1987). A more systematic study of DIBs in the Magellanic Clouds was initiated by Ehrenfreund *et al.* (2002) requiring 8+m-class telescopes for high-resolution spectroscopy towards reddened OB stars: see Cox *et al.* (2006), Welty *et al.* 2006, Cox *et al.* (2007b), Van Loon *et al.* (2013), the latter study exploring the capacities of a multi-object spectrograph. Significantly more challenging regarding DIB detection are the about ten times more distant spiral galaxies M31 (Cordiner *et al.* 2011) and M33 (Cordiner *et al.* 2008, Smith, these proceedings).

Extremely bright point sources (supernovae, gamma-ray burst afterglows, quasars) provide the opportunity to search for DIBs beyond the Local Group. DIBs are detected in high-resolution spectra of supernovae hosted in several spiral galaxies: NGC 1448 ($d \sim$ 17 Mpc, Sollerman *et al.* 2005), M 100 ($d \sim 16$ Mpc, Cox & Patat 2008), and NGC 2770 ($d \sim 26$ Mpc, Thöne *et al.* 2009), and in some starburst galaxies (Heckmann & Lehnert 2000). Damped Lyman α (DLA) systems in quasar spectra have also been inspected for the presence of DIBs. Although these systems are gas rich ($N_{\rm H} > 2 \times 10^{20}$ cm^{-2}), only a few DLAs (12 out of 68, Noterdaeme *et al.* 2008) show evidence for a molecular content (mainly H_2, a few including HD and/or CO). Junkkarinen *et al.* (2004) reported the 4428 Å DIB in a moderate-redshift DLA (towards the BL Lac object AO 0235+164 at a redshift $z = 0.52$); the spectrum also includes a strong 2175 Å feature. York *et al.* (2006) also detected the 5705 and 5780 Å DIBs in this sightline. A systematic search for DIBs in another 6 DLAs resulted in upper limits only (Lawton *et al.* 2008). Ellison *et al.* (2008) reported another detection of the 5780 Å DIB in the DLA and Ca II absorber towards J0013–0024 at $z = 0.1556$.

Since the discovery of the first gamma-ray burst (GRB) optical afterglow in 1997 (Van Paradijs *et al.* 1997), about two hundred GRB afterglows have been followed-up spectroscopically (e.g., Fynbo *et al.* 2009). The GRB host galaxy often produces a DLA from which the redshift of the GRB can be determined (current record holder is GRB090423 at $z = 8.2$, Tanvir *et al.* 2009). The dust and metal content of the GRB host galaxies is very low; up to now, no DIBs have been detected in GRB hosts (the most prominent DIBs will be redshifted into the near-infrared wavelength domain). The 2175 Å extinction bump has been detected in only four GRB host galaxies (Zafar *et al.* 2012). Recently, Krühler *et al.* (2013) discovered H_2 (also vibrationally excited H_2 due to the GRB) in the DLA towards GRB120815A at $z = 2.36$, but no DIBs were encountered ($EW_{\lambda 6284} < 0.6$ Å).

2.2. *Current (and upcoming) instrumentation*

The previous section (and other authors in these proceedings) report on DIB observations carried out with medium- to high-resolution spectrographs mounted at 2–10m-class telescopes. Excellent DIB spectra can be obtained with the high-resolution spectrograph FEROS on the ESO 2.2m telescope, UVES on the ESO *Very Large Telescope* (VLT), HARPS on the ESO 3.6m telescope, MIKE on the *Magellan Telescope*, UCLES on the *Anglo-Australian Telescope*, ARCES on the ARC 3.5m at Apache Point Observatory, HDS on the *Subaru Telescope*, HIRES on the *Keck Telescope*, etc. DIBs may also produce linear and circular polarisation, although so far no polarisation signal has been detected in DIB spectra (Cox *et al.* 2007a). High-quality spectropolarimetry can be obtained on relatively bright targets with, among others, ESPaDOnS on the CFHT, NARVAL on the 2-m telescope *Bernard Lyot* and HARPSpol.

Several high-resolution spectrographs are currently being developed; here we mention two running projects: PEPSI on the *Large Binocular Telescope* (LBT) and ESPRESSO for the combined focus of the VLT. PEPSI is a fibre-fed high-resolution echelle spectropolarimeter for the LBT (Strassmeier *et al.* 2008). It is designed to use the two apertures of the LBT so that both circular and linear polarisation signals can be simultaneously obtained. The spectropolarimetric mode has a resolving power R =120,000; PEPSI works in non-polarimetric mode at three different spectral resolutions: R =32,000, 120,000 or 320,000. The wavelength range from 390 − 1050 nm can be covered in three exposures. The spectrograph is contained inside a pressure- and temperature-stabilized room. Commissioning of PEPSI on the telescope is scheduled in 2013.

ESPRESSO, the Echelle SPectropgraph for Rocky Exoplanet and Stable Spectroscopic Observations, is a very stable spectrograph for the combined Coudé focus of the VLT (Pepe *et al.* 2010). It can be operated by either one of the VLT unit telescopes (UTs) or combine the light of all four together. The wavelength coverage is limited, 380 − 686 nm, at a resolving power $R = 120,000$; with 4 UTs $R = 30,000$. The aimed instrumental radial-velocity precision is better than 10 cm/s. The main scientific drivers for ESPRESSO are high-precision radial-velocity measurements of solar-type stars to search for rocky planets, the measurement of the variation of the physical constants, and the analysis of the chemical composition of stars in nearby galaxies. First light on the telescope is planned for 2016.

2.3. *Demonstrating the potential with VLT/X-shooter*

With the growth in telescope size we have witnessed the development that traditionally Galactic studies have branched out into the Magellanic Clouds and beyond. My expectation is that with the advent of the ELTs extragalactic astronomy and astrophysics will merge. With the ELTs it will be possible to take spectra of "individual" massive stars in a representative sample of about 1500 galaxies out to 35 Mpc (Table 1). To demonstrate

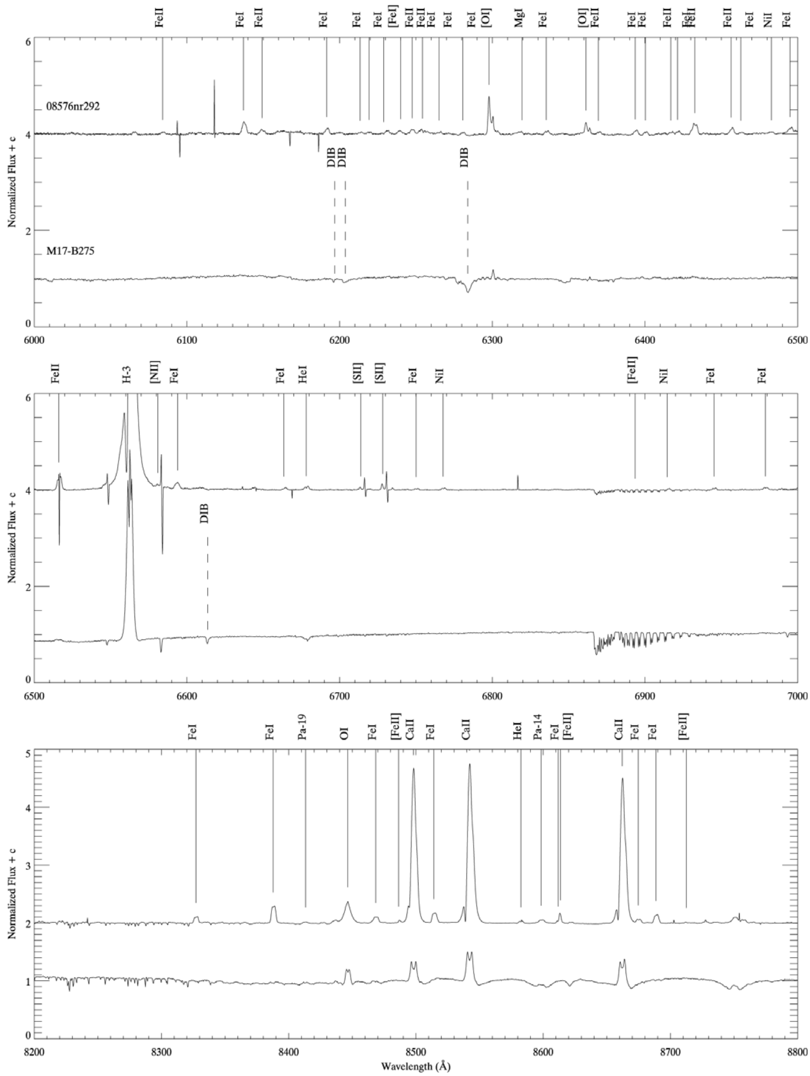

Figure 2. Part of the visual spectrum covered by VLT/X-shooter (6000–8000 Å) of the reddened massive Young Stellar Objects 08576nr292 in RCW 36 (*top*, Ellerbroek *et al.* 2011, $A_V = 8$) and B275 in M17 (*bottom*, Ochsendorf *et al.* 2011, $A_V = 6$). The spectrum of 08576nr292 includes many emission lines produced by the circumstellar disk and jet. Also B275 exhibits (doubly-peaked) emission lines originating in a rotating disk; the spectrum, however, also includes photopsheric absorption lines allowing for accurate spectral classification: B6. Although both sightlines are severely reddened, the DIBs are relatively weak, especially towards 08576nr292 (figure adapted from Kaper *et al.* 2011).

this potential, we show a few examples obtained with VLT/X-shooter, currently the most powerful spectrograph in the world.

X-shooter is a medium-resolution ($R \sim 8000$), wide-band echelle spectrograph covering the wavelength range 300–2500 nm in one "shot" (Vernet *et al.* 2011). Its three-arm design, with each arm optimized for the covered wavelength band, and its location in the Cassegrain focus of the VLT, make X-shooter a very efficient instrument. It is one of the few spectrographs covering both the optical and near-infrared wavelength range. This

Table 1. Obtaining spectra of O stars ($M_V \sim -6$) in the Local Group (and beyond) to detect DIBs will be possible up to the Virgo cluster with the ELTs. The current limit of VLT/X-shooter is $m_V \sim 22$ at a spectral resolving power $R \sim 8,000$, $S/N = 10$ in a 1 hour exposure (Vernet *et al.* 2011). The spatial resolution ($\theta = 1.22\lambda/D$, with D the diameter of the primary mirror) is important to avoid confusion, especially when moving out to more distant galaxies. The angular separation of two stars at a distance of 0.3 pc from each other is listed in the last column.

Target O star in	Distance (kpc)	m_V	Separation 0.3 pc (arsec)
SMC	68	13.2	1.0
IC1613	730	18.3	0.09
Cen A	4000	22.0	0.017
Virgo cluster	1600	25.0	0.004

is interesting for DIB research given the recent discovery of DIBs in the near infrared (Geballe *et al.* 2011, Cox *et al.* in prep.).

The formation process of massive stars is still poorly understood. Their birth sites are deeply embedded in star-forming regions and obscured by surrounding dust ($A_V \simeq 10-100$ mag). Optical to near-infrared spectra of massive Young Stellar Objects (YSOs) provide information on the physical conditions of the forming star(s), and on the nature of the accretion process (disk/jet). We obtained X-shooter spectra of the YSO 08576nr292 in the massive star-forming region RCW36 (Ellerbroek *et al.* 2011) revealing the presence of a circumstellar disk and supersonic jets, demonstrating that the object is still actively accreting (Fig. 2). The X-shooter spectrum of the mYSO B275 shows photospheric lines from which the effective temperature and luminosity class are accurately determined. It turns out that this B6 pre-main-sequence star has the dimensions of a giant and is apparently still contracting towards the main sequence (Ochsendorf *et al.* 2011). Fig. 2 also shows the presence of DIBs in these reddened sightlines, though much weaker than expected on the basis of their E(B–V) (Ellerbroek *et al.* 2013, and see Oka, these proceedings).

With 8–10m telescopes one can spectroscopically access the massive star population in the Local Group and even beyond (e.g., Tramper *et al.* 2011, Bresolin & Kudritzki 2013). With X-shooter we obtained spectra of a previously identified bright O-type star C1_31 in NGC 55, a spiral galaxy in the Sculptor group at a distance of ~ 2 Mpc (Fig. 3). Analysis of both the stellar and nebular spectrum yields that the source is a composite object, likely a stellar cluster, which contains at least one hot WN star and a dozen OB supergiants (Hartoog *et al.* 2012). The C1_31 sightline contains a hint of the 4430 Å DIB, clearly present in the O6.5 Ib(f) comparison spectrum. This result shows both the potential of massive star spectroscopy in more distant galaxies and the limitations due to crowding and confusion.

3. Extremely Large Telescopes

The next decade is expected to revolutionize astronomy (again). With the next generation Space Telescope, the NASA *James Webb Space Telescope* (JWST), the full array of the ESO *Atacama Large Millimeter Array* (ALMA), the *Square Kilometer Array* (SKA) and, hopefully, a new large X-ray mission, the planned Extremely Large Telescopes (ELT), with about a factor 10 more collecting area than the current 8-10m-class telescopes, will complement the coverage of the full electromagnetic spectrum. At economically difficult times, two US-led projects (*Giant Magellan Telescope* and *Thirty*

https://doi.org/10.1017/S1743921313016190 Published online by Cambridge University Press

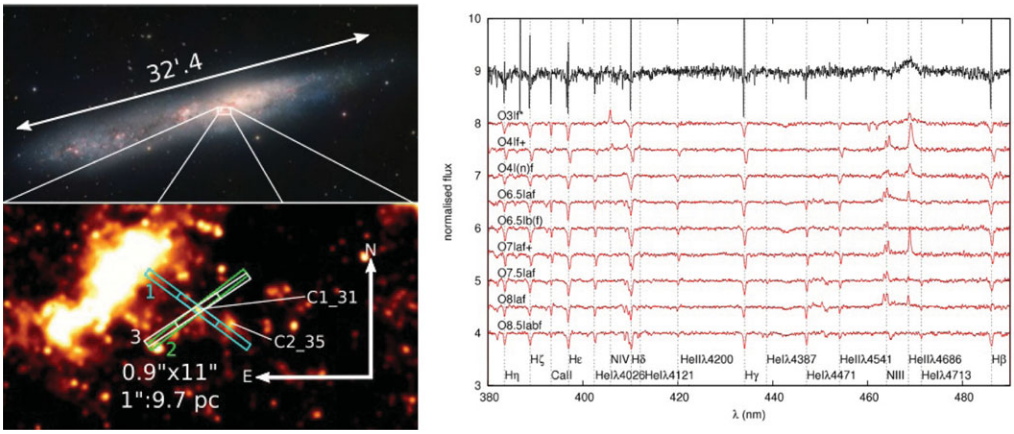

Figure 3. *Left:* The top panel shows a B – V – Hα image of NGC 55, a spiral galaxy in the Sculptor group ($d = 2$ Mpc). The bottom panel demonstrates the location of the slit of X-shooter centered on the massive star C1_31. *Right:* The normalized sky-corrected X-shooter spectrum of NGC_C1_31 (top) compared to spectra of standard O supergiants ranging from spectral type O3 to O8.5. The C1_31 sightline contains a hint of the 4430 Å DIB, clearly present in the O6.5 Ib(f) comparison spectrum. Figures adopted from Hartoog *et al.* (2012).

Meter Telescope) and one European-led project (ESO *Extremely Large Telescope*) will likely result in two ELTs in Chile and one in Hawaii early next decade.

The scientific motivation to build an ELT is to address key astronomical questions ranging from the formation of stars and planets to unraveling the formation history of galaxies and large-scale structure in the Universe. In order to exploit not only the collecting area of an ELT, but also its spatial resolution, a sophisticated adaptive optics (AO) system is required employing rapidly deformable mirrors. The AO system takes advantage of several natural and/or artificial (laser guide star) point sources in the field of view of the telescope to reconstruct the image plane that got disturbed by the Earth's atmosphere.

3.1. *Giant Magellan Telescope (GMT)*

The GMT is the smallest of the ELTs, but has fewest reflections and the largest field of view (20 arcmin). The primary mirror consists of seven 8.4 m segments, resulting in a diameter of 25.4 m and an effective area of a 21.9 m telescope. The secondary is also a segmented mirror built up with seven 1.1 m segments. Las Campanas, in the Atacama dessert in Chile, will be the site of the GMT. Commissioning of the telescope is planned for 2019. The instruments will all be located on a platform below the primary mirror. The suite of candidate first generation GMT instruments (Jacoby *et al.* 2012) contains two survey instruments, two high-resolution spectrographs, and two AO imaging spectrometers (Table 2): GMTNIRS, MIISE, HRCAM, NIRMOS and GMACS. Likely a down-selection will be made after each of the instrument concepts has been developed to the point of maturity. The "Magellan philosophy" is to keep the instruments simple, and to do a few things well. MANIFEST, the planned robotic fiber feed facility will provide a very efficient way to distribute the costy telescope time to the different optical (fiber-fed) instruments.

Table 2. Planned optical and/or near-infrared medium- to high-resolution spectrographs for the three ELTs: GMT, TMT and E-ELT.

Instrument	Function	λ range (μm)	Resolving power ($R = \frac{\lambda}{\triangle\lambda}$)	Field of view
Giant Magellan Telescope (GMT)				
G-CLEF	High-res. spectrometer	0.35 – 0.95	20,000 – 100,000	single object
GMACS	Optical MOS	0.36 – 1.00	1500–4000, 10,000	40–50 arcmin^2
NIRMOS	Near-infrared MOS	0.9 – 2.5	2700–5000	42 arcmin^2
GMTNIRS	AO-fed high-res. spectr.	1.2 – 5.0	50,000 – 100,000	single object
Thirty Meter Telescope (TMT)				
WFOS	Wide-field opt. spectrometer	0.31 – 1.1	1000 – 8000	40.3 arcmin^2
HROS	High-res. opt. spectrometer	0.31 – 1.3	50,000	5 arcsec slit
NIRES	Near-IR AO-fed echelle	1 – 5	20,000 - 100,000	2 arcsec slit
ESO Extremely Large Telescope (E-ELT)				
HARMONI	Single-field IFU spectr.	0.47 – 2.45	4000 – 20,000	1" × 0.5"
CODEX	High-res. visual spectr.	0.37 – 0.71	135,000	0.82 arcsec
EAGLE	AO-assisted near-IR MOS	0.8 – 2.45	4000 – 10,000	1.65" × 1.65"
OPTIMOS-EVE	Opt-NIR fibre-fed MOS	0.37 – 1.7	5000 - 30,000	240 objects or IFUs
SIMPLE	NIR echelle spectr.	0.8 – 2.5	135,000	4 arcsec

3.2. *Thirty Meter Telescope (TMT)*

The TMT primary f1 mirror has a diameter of 30 meter consisting of 492 mirror segments of 1.45 m each; the field of view is 20 arcmin. It will be a fully integrated adaptive optics telescope with a multi-instrument Nasmyth mounted suite. Mauna Kea on Hawaii is the preferred site for the TMT. The first scientific observations with the TMT are planned in 2022. Eight instruments have been conceived to attack the science problems (Simard *et al.* 2010); the three first light instruments are the Wide Field Optical Spectrometer (WFOS), the Infrared Imaging Spectrometer (IIS) and the Infrared Multi-object Spectrometer. High-resolution spectrographs are planned to arrive at a later stage.

3.3. *ESO Extremely Large Telescope (E-ELT)*

Although the original plan started with a study of a 100 m diameter telescope†, the *Overwhelmingly Large Telescope* (OWL), the E-ELT design has shrunk from a 42-m to a 39-m primary mirror to make sure that the project fits within its budget envelope, and that the main scientific goals can still be met. The E-ELT will be the largest optical/near-infrared telescope in the world. The optical design of the E-ELT differs from that of the other ELTs, as it includes adaptive mirrors in the telescope. The novel five-mirror design should result in an exceptional image quality with no significant aberrations in the 10-arcmin field of view (physically about two by two meter!). The E-ELT is planned to be able to correct for the atmospheric distortions from the start, providing images 16 times sharper than those from the *Hubble Space Telescope*. The E-ELT's technical first light is scheduled for 2022.

The first steps in developing the E-ELT instrumentation plan included so-called phase-A studies of eight instrument concepts that were completed in 2010 (Ramsay *et al.* 2010).

† It turns out that a telescope of such a diameter is required to image an Earth-like planet orbiting a nearby star, one of the key scientific motivations to build an ELT.

https://doi.org/10.1017/S1743921313016190 Published online by Cambridge University Press

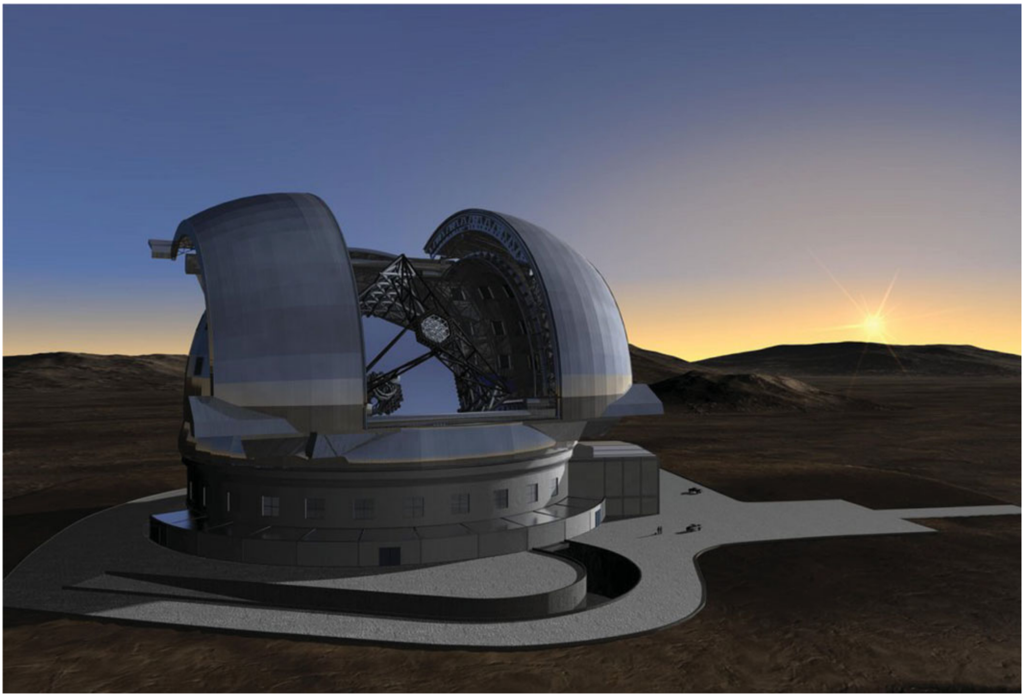

Figure 4. Artist impression of the ESO *Extremely Large Telescope* to be built on Cerro Armazones in the Atacama dessert in Chile, about 20 km from Paranal. First light is scheduled for 2022.

Two instrument concepts have been selected for first light: a diffraction-limited near-infrared imager (MICADO) and a single-field near-infrared wide-band integral field spectrograph (HARMONI). The third to fifth instrument will be a mid-infrared imager and spectrometer (METIS), an optical/near-IR MOS, and a high-resolution spectrograph. The EAGLE and OPTIMOS-EVE MOS consortia are investigating the possibility to merge their respective instrument concept into one, called MOSAIC (Evans *et al.* 2013), and aim for the third slot on the E-ELT Nasmyth platform. GMT and TMT have recognized the importance of a MOS for an ELT and have one or more MOS concepts included in the first generation of instruments.

Astronomy has a bright future ahead; with a bit of luck we manage to identify the DIB carrier(s) within 100 yr after the discovery of DIBs and will be able to explore the information they provide on the physical and chemical nature of the interstellar medium in the Galaxy, the Local Group and beyond.

References

Bresolin, F. & Kudritzki, R. P. 2013, *in proc. IAU Symp. 289*, p. 203
Cordiner, M. A., Smith, K. T., Cox, N. L. J., *et al.* 2008, *A&A*, 492, L5
Cordiner, M. A., Cox, N. L. J., Evans, C. J., *et al.* 2011, *ApJ*, 726, 39
Cox, N. L. J., Kaper, L., Foing, B. H., & Ehrenfreund, P. 2005, *A&A* 438, 187
Cox, N. L. J., Cordiner, M. A., Cami, J., *et al.* 2006, *A&A* 447, 991
Cox, N. L. J., Boudin, N., Foing, B. H., *et al.* 2007a, *A&A* 465, 899
Cox, N. L. J., Kaper, L., Ehrenfreund, P., *et al.* 2007b, *A&A* 470, 941
Cox, N. L. J. & Patat, N. 2008, *A&A* 485, 9
Ehrenfreund, P., Cami, J., Jiménez-Vicente, J., *et al.* 2002, *ApJ* (Letters), 576, 117

Ellerbroek, L. E., Kaper, L., Bik, A., *et al.* 2011, *ApJ* (Letters), 732, L9
Ellerbroek, L. E., Bik, A., Kaper, L., *et al.* 2013, *A&A*, in press
Ellison, S. L., York, B. A., Murphy, M. T., *et al.* 2008, *MNRAS*, 383, L30
Evans, C., Puech, M., Barbuy, B., *et al.* 2013, *arXiv*, 1303.0029
Fynbo, J. P. U., Jakobsson, P., Prochaska, J. X., *et al.* 2009, *ApJS*, 185, 526
Hartoog, O. E., Sana, H., De Koter, A., & Kaper, L. 2012, *MNRAS*, 422, 367
Heckmann, T. M. & Lehnert, M. D. 2000, *ApJ*, 537, 690
Heger, M. L. 1922, *Lick Obs. Bulletin*, 10, 337, 146
Herbig, G. 1975, *ApJ*, 196, 129
Herbig, G. H. 1995, *ARAA*, 33, 19
Hobbs, L. M., York, D. G., Thorburn, J. A., *et al.* 2009, *ApJ*, 705, 32
Geballe, T. R., Najarro, F., Figer, D. F., *et al.* 2011, *Nature*, 479, 200
Jacoby, G. H., Bouchez, A., Colless, M., *et al.* 2012, *SPIE*, 8446E, 1GJ
Junkkarinen, V. T., Cohen, R. D., Beaver, E. A., *et al.* 2004, *ApJ*, 614, 658
Kaper, L., Ellerbroek, L. E., Ochsendorf, B. B., *et al.* 2011, *AN*, 332, 232
Krühler, T., Ledoux, C., Fynbo, J. P. U., *et al.* 2013, *ApJ*, in press
Lawton, B., Churchill, C. W., York, B. A., *et al.* 2008, *AJ*, 136, 994
Noterdaeme, P., Ledoux, C., Petitjean, P., & Srianand, R. 2008, *A&A*, 481, 327
Ochsendorf, B. B., Ellerbroek, L. E., Chini, R., *et al.* 2011, *A&A* (Letters), 536, L1
Pepe, F. A., Cristiani, S., Rebolo Lopez, R., *et al.* 2010, *SPIE*, 7735E, 14P
Ramsay, S., D'Odorico, S., Casali, M., *et al.* 2010, *SPIE*, 7735E, 71R
Sarre, P. J. 2006, *Journal of Mol. Spectr.* 238, 1
Simard, L., Crampton, D., Ellerbroek, B., & Boyer, C. 2010, *SPIE*, 7735E, 70S
Snow, T. P. 2002, in proc. *17^{th} IAP Astroph. Coll. June 2001 Paris*
Sollerman, J., Cox, N. L. J., Matilla, S., *et al.* 2005, *A&A*, 429, 559
Strassmeier, K. G., Woche, M., Ilyin, I., *et al.* 2008, *SPIE*, 7014E, 21S
Tanvir, N. R., Fox, D. B., Levan, A. J., *et al.* 2009, *Nature*, 461, 1254
Thoöne, C. C., Michalowski, M. J., Leloudas, G., *et al.* 2009, *ApJ*, 698, 1307
Tramper, F., Sana, H., De Koter, A., & Kaper, L. 2011, *ApJ* (Letters), 741, L8
Tuairisg, S. O., Cami, J., Foing, B. H., *et al.* 2000, *A&AS*, 142, 225
Van Loon, J. T. h., Smith, K. T., McDonald, I., *et al.* 2009, *MNRAS*, 399, 195
Van Loon, J. T. h., Baily, M., Tatton, B. L., *et al.* 2013, *A&A*, 550, 108
Van Paradijs, J. A., Groot, P. M., Galama, T., *et al.* 1997, *Nature*, 386, 686
Vernet, J., Dekker, H., D'Odorico, S., *et al.* 2011, *A&A*, 536, 105
Vladilo, G., Crivellari, L., Molaro, P., & Beckman, J. E. 1987, *A&A*, 182, L59
Vos, D. A. I., Cox, N. L. J., Kaper, L., *et al.* 2011, *A&A*, 533, 129
Welty, D., Federman, S., Gredel, R, *et al.* 2006, *ApJS*, 165, 138
York, B. A., Ellison, S. L., Lawton, B., *et al.* 2006, *ApJ* (Letters), 647, L29
Zafar, T., Watson, D., Elíasdóttir, *et al.* 2012, *ApJ*, 753, 82
Zoomers, H. 2008, in *Louwman Collection of Historical Telescopes*, Ed. H. Zuidervaart, ISBN 978-90-79817-01-6