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Infrared Surveys from Antarctica

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Abstract: The very low background observed from Antarctica in a window from about 2·25 to 2·45 μm can be exploited as a way of making deep near-IR surveys over wide areas of sky. Imaging surveys using the entire window can cover large areas of sky to limits of around $K = 20$, and can be used to study galaxy evolution and to search for high-redshift quasars, dust-obscured quasars and brown dwarfs. It is also possible to make spectroscopic surveys in this window. The window includes molecular hydrogen emission and CO absorption in galactic sources, and can also be used to search for emission lines such as Hα in high-redshift star-forming galaxies.

Keywords: galaxies: evolution — galaxies: formation — quasars: general — infrared: general — infrared: galaxies — stars: low-mass — brown dwarfs

1 Introduction

Detectors for the near-infrared region have been improving dramatically in performance over the last few years. We expect to shortly have available detectors in 1024×1024 pixel formats with high quantum efficiency and very low readout noise and dark current (Vural 1994). With such detectors the sensitivity limit for most observations is set by the background radiation from the sky and telescope. In the near infrared the source of background is predominantly OH airglow emission from the upper atmosphere, as well as thermal emission which becomes particularly important at the long-wavelength end of the K band near 2·5 μm.

In Antarctica the low temperatures result in a substantial drop in the thermal emission. Since there are no strong airglow lines in the region from 2·25 to 2·45 μm it was predicted that very low background levels could occur in this window. The existence of this low background window has recently been confirmed by measurements with the UNSW IRPS system (Ashley 1995) and the CARA SPIREX telescope (Rauscher 1995) at the South Pole.

For background-limited observations a reduction in background level provides the same improvement in sensitivity as a corresponding increase in telescope collecting area. Thus a 2 m telescope on the Antarctic Plateau could equal or exceed the performance of the 8 m-class telescopes now under development on conventional ‘good’ IR sites such as Mauna Kea and Chile.

For wide-field survey work there are a number of practical advantages in using the smaller Antarctic telescope rather than the equivalent 8 m telescope. It is optically much simpler to image large pixels on the sky onto small detector pixels with a 2 m telescope. The fields of currently proposed IR cameras for 8 m telescopes are typically 2 arcmin or less, and the IR configurations of these telescopes are often limited by the telescope design to fields of a few arcmin. A 2 m telescope could easily be designed with a much wider field feeding a number of 1024×1024 detectors. A telescope of this size could be built as a dedicated survey instrument which would allow time for very extensive surveys which could not be contemplated as part of the program of a general-purpose telescope.

2 Imaging Surveys

2.1 Survey Parameters and Spectroscopic Follow-up Options

Such surveys would be made using a filter matched to the low-background window (i.e. essentially a narrow K filter). In order to make effective use of such a survey it would in most cases be necessary to make spectroscopic follow-up observations to determine the nature of the sources detected and determine properties such as redshifts. Thus the appropriate depth for such a survey is set by the performance of the available spectroscopic follow-up instruments. At present it would be difficult to do useful spectroscopic follow-up to an IR survey deeper than about $K = 18$. If the follow-up is done in the optical a $K = 18$ galaxy would typically have $I = 21$ or $B = 23$, which is about the limit of multi-object spectroscopic facilities such as the 400 object 2° field (2dF) system (Gray et al. 1993) on the AAT. $K = 18$ is also about the limit of current IR spectroscopy. However, over the next few years we expect a number of developments to make possible spectroscopy of objects down to $K = 20$. OH suppression techniques are being developed to improve performance in the J and H bands, while IR spectrometers will become available on 8 m telescopes. For example, ISAAC on the VLT will provide low-resolution spectroscopy with a 3σ sensitivity of $K = 20{\cdot}5$ in 1 hour, and NIRMOS will provide similar performance on multiple objects.

An interesting possibility is to upgrade the AAT 2dF system for operation in the near IR as a means of following up large-scale Antarctic surveys. Ray-tracing of the 2dF corrector shows that it gives acceptable performance at near-IR wavelengths. With new fibre bundles and spectrographs optimised for wavelengths up to about $1{\cdot}8\,\mu$m it could provide a very powerful facility for multi-object IR spectroscopy. The spectrographs could operate at sufficently high dispersion to be able to exploit the low-background gaps between the OH airglow lines, making possible spectroscopy down to $H = 20$ or deeper. Operating over a wavelength range of $0{\cdot}9$ to $1{\cdot}8\,\mu$m it would be possible to observe a number of useful lines in extragalactic objects, such as Hα in galaxies with $0{\cdot}4 < z < 1{\cdot}8$, [O II] (372·7 nm) at $1{\cdot}4 < z < 3{\cdot}8$, and C IV (155·0 nm) in quasars with $z > 5$.

With such follow-up facilities available an appropriate depth for an IR survey would therefore be $K = 20$. In order to survey a square degree of sky to $K = 20$ (10σ) using a 1024×1024 detector, the times given in Table 1 are required.[1] The results assume background-limited performance and a total system throughput of 30%. The figures are independent of image size (e.g. due to seeing) provided that the pixels are matched to the image size. If the seeing is good, smaller pixels and shorter integrations can be used, but more frames need to be taken to cover the same area with the reduced field.

The corresponding time for the current AAO and MSSSO IR cameras is about 1000 hours. A dedicated Antarctic survey telescope could therefore survey about 1500 square degrees to this depth in a single Antarctic winter. By using multiple 1024×1024 detectors at the focal plane it would be quite feasible to survey the entire sky accessible from the pole over a period of a few years. Such a survey would be about six magnitudes deeper than the DENIS (Epchtein 1994) and 2MASS (Kleinmann et al. 1994) surveys.

Table 1. Time to survey 1 square degree of sky to $K = 20$

Telescope	Survey time (hr)
2 m Antarctic	1·25
8 m Mauna Kea	4
4 m Mauna Kea	16

Such a survey would provide a similar resource for IR astronomy to the Palomar/UKST sky surveys in the visible. In fact the IR survey would be deeper for many classes of objects, and would provide a cleaner view of the sky since it would suffer much less extinction by dust.

2.2 Science with IR Imaging Surveys

Science projects which can be carried out with such a survey include the following.

2.2.1 Galaxies

The majority of objects in deep K-band surveys will be galaxies. Near-IR wavelengths provide a good way to study galaxy evolution to higher redshifts than can easily be achieved with visible surveys. At the K band the light is dominated by old stars and so evolutionary corrections are smoother and more easily modelled than in the visible. As galaxies get redder with increasing redshift, K-band-selected samples include more high-redshift galaxies than optical samples of similar size. A survey to $K = 20$ should include significant numbers of galaxies with $z > 1$. To determine the redshifts of these galaxies and thus examine the evolution of the luminosity function, it will be necessary to provide large-scale spectroscopic follow-up in the red and near-IR to measure Hα (where present) or the Ca II H and K absorption lines.

2.2.2 High-redshift Quasars

The majority of quasars with $z > 4$ have been found by multi-colour (BRI) surveys which exploit the distinctive colours resulting from the steep drop in the spectrum below the wavelength of Lyα. However, this technique becomes ineffective for redshifts above about $4{\cdot}5$ as Lyα moves through the R band. To find quasars at higher redshift requires the use of longer wavelengths. Such objects could be found by selecting red stellar objects from the Antarctic K-band survey as compared with a shorter-wavelength CCD survey. Multi-object spectroscopy would be used to identify the quasars and measure their redshifts. These objects are likely to be rare and large areas would need to be surveyed. However, the results are important as they probe the Universe at the highest observable redshifts, and tell us about the cosmological epoch at which stars and galaxies first formed.

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[1] In this Table and throughout this paper a backgound level of $K = 18$ arcsec^{-2} been assumed for the Antarctic window. The results presented at this Workshop (Rauscher 1995; Ashley 1995) show that this figure may occasionally be achieved at the South Pole but figures of a magnitude or more brighter are more typical. However, earlier theoretical predictions had suggested that the background level could be much lower than this. Observations are continuing during the 1995 season at the South Pole, and measurements from other sites on the Antarctic Plateau are also being planned. The integration times and sensitivities given in this paper will need to be adjusted appropriately when definitive values are obtained.

It is desirable to find enough high-redshift objects with sufficient completeness to be able to characterise the decline in quasar density which is believed to occur at very high redshifts. It is also important to find the brightest examples of high redshift objects, as these can be used for absorption line studies, which provide another way of studying the Universe at high redshifts.

2.2.3 Dust-obscured Quasars

Webster et al. (1994) have recently reported finding a number of quasars associated with 'empty field' Parkes radio sources which were easily detected in the near IR. The red colour is presumably due to extinction by dust. They suggest that such objects may be common, and that if they exist among the population of radio quiet quasars, current quasar surveys, based mostly on UV excess selection for $z < 2 \cdot 2$, may be very incomplete.

Such objects could be found as part of the same study described above for high-redshift quasars.

2.2.4 Brown Dwarfs

The Antarctic survey could also be an effective way of finding brown dwarfs. Such objects would be found in a sample of red stellar objects, and such a search could easily be combined with the quasar projects described above. Large-area surveys are needed for this project also as these objects are not likely to be common.

3 Spectroscopic Surveys

It is also possible to make spectroscopic surveys through the low-background window. A tunable Fabry–Perot filter could be used to make a set of images scanning the $2 \cdot 25$–$2 \cdot 45\ \mu$m window at low spectral resolution. This spectral region includes H_2 emission lines, and the CO absorption feature in cool stars. These features could be usefully studied in surveys of the Galactic plane and Magellanic clouds. However, the most interesting possibility is to use deep spectroscopic surveys to search for redshifted lines from galaxies.

3.1 Star-forming Galaxies at High Redshift

In order to understand galaxy formation and evolution it is particularly interesting to find the progenitors of present-day normal galaxies undergoing their first major burst of star formation. Searches for such galaxies by means of their Lyα emission have been unsuccessful (Thompson et al. 1993). This is likely to be a result of dust obscuration, in which case a longer-wavelength line should be more suitable.

In the Antarctic low-background window we can observe Hα at redshifts of about $2 \cdot 4$–$2 \cdot 7$. This line is a good choice as it is strong, is believed to be a good indicator of star formation rate, and is the longest-wavelength line accessible in the near IR at useful redshifts.

In 1000 s integration per wavelength surveys we should be able to detect to 4σ line fluxes of $1 \cdot 2 \times 10^{-20}$ W m^{-2} using a 2 m Antarctic telescope. Using the relationship given by Kennicutt (1983), an Hα line of this strength corresponds to a star formation rate of about 1 $M_\odot$ yr^{-1} ($6 \cdot 3 \times 10^{22}$ kg s^{-1}). Such objects should be just about bright enough to allow follow-up spectroscopy with 8 m telescopes to confirm the line identification by detecting other spectral features.

Other lines can be used to study higher-redshift regions. [O III] ($500 \cdot 7$ nm) and Hβ could be detected at redshifts of $3 \cdot 5$–4 while [O II] ($372 \cdot 7$ nm) could be observed at redshifts of 5–$5 \cdot 5$. However, the star formation rate required for detection of [O II] would be about 100 $M_\odot$ yr^{-1}.

The above figures are for a short enough integration time to allow us to scan the whole available redshift range and therefore survey a large volume of space. If the redshift of the object is known, e.g. if we look for a galaxy associated with a known quasar or quasar absorption line system, it is possible to use much longer integration times and achieve line flux limits a factor of 5 or so deeper.

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The use of spectroscopic surveys in the Antarctic low-background window was first suggested by David Allen. The concept of tunable Fabry–Perot filters for this type of application has been developed by Joss Bland-Hawthorn and Keith Taylor.

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