The Stellar Content of Local Group Galaxies
IAU Symposium, Vol. 192, 1999
Patricia Whitelock and Russell Cannon, eds.

Thermal Infrared Survey of LMC, SMC and Sagittarius Dwarf Galaxy

H.U. Käufl, E. Tolstoy and G. Wiedemann

European Southern Observatory, Karl-Schwarzschildstr. 2, D-85748 Garching bei München, Germany

C. Loup

Institut d'Astrophysique de Paris, 98bis, Boulevard Arago, F-75014 Paris, France

H.G. Reimann

Universitäts-Sternwarte Jena, Schillergäßchen 2, D-07745 Jena, Germany

L.B.F.M. Waters

Universiteit Amsterdam, Sterrenkundig Instituut Anton Pannekoek, Kruislaan 403, NL-1098 SJ Amsterdam, Netherlands

A. Zijlstra

University of Manchester Institute of Science and Technology (UMIST), Department of Physics, Astrophysics Group, P.O. Box 88, Manchester M60 1QD, United Kingdom

Abstract. The ESO VLT with its suite of infrared instruments (e.g. ISAAC, VISIR) allows for an area-limited deep survey for infrared-bright point sources in nearby local group galaxies. Data in four colours can be collected: 3, 5, 10, and 20μm; the 10/20μm data can be complemented with TIMMI2, a new instrument presently under construction for ESO's 3.6m telescope on La Silla. The scientific result will be a complete catalogue of obscured Asymptotic Giant Branch Stars in the LMC, the SMC and the Sagittarius Dwarf Galaxy (SDG). Using mostly twilight time, such a survey can be done for an area of $\approx$ 100 □arcmin per year per galaxy. At 10μm the limiting flux is expected to be 2-3 orders of magnitude fainter than the IRAS point source catalogue. This catalogue would give the first coherent sample of AGB stars with precise distances and consequently absolute bolometric luminosities. It may lead to a substantially better understanding of the mass loss of AGB stars, an important, but as of today largely enigmatic phase of stellar evolution. As a by-product many more IR-bright objects in the Magellanic Clouds, e.g. dust envelopes around *normal* stars, luminous blue variable stars (LBV) or compact obscured HII-regions, will be discovered. For the SDG no LBVs or YSOs are expected as it had no star formation for the past 5 Gyr.

https://doi.org/10.1017/S0074180900204555 Published online by Cambridge University Press

1. Introduction

The European Southern Observatory's Very Large Telescope, which is presently entering the operational phase will be equipped with a suite of multimode instruments. In the final stage there will be four 8m telescopes, each equipped with 3 instruments, whereby all these instruments are quasi-simultaneously operational. This means that, e.g. a change from large field deep optical imaging to far-infrared medium resolution spectroscopy can be done in 10-15 minutes. For this reason the project was already proposed and sketched in an earlier phase of ESO's VLT (Käufl et al. 1995).

For ground based thermal infrared imaging (i.e. $\lambda \geq 3\mu$m) the sensitivity no longer depends on the technicalities of the observations, but is entirely dominated by the thermal background produced by atmosphere, telescope and other warm optics. This regime is usually referred to as Background Noise Limited Performance (BLIP). The special aspects of this observing regime are described, e.g. by Käufl et al. (1991) and references therein. In this regime, dark-time, twilight time or even daytime are equally valuable for scientific observing. It is therefore proposed to use part of the morning and evening twilight every day (and potentially other unused time resulting from, e.g. Moon constraints) to perform a 4 color thermal infrared survey, literally without stealing a single photon from any other project. With the three closest neighbour galaxies spread almost perfectly in right ascension throughout the year, at least one galaxy is available at nearly any moment. On the other hand astronomical, nautical and civil twilight for the Paranal site last typically 25 minutes each.

It needs, however, to be seen how much of this time, not useful for scientific observations, will be necessary for calibrations (incl. sky flats). Depending of the outcome, the available free-time for this survey is somewhere between 10 and 60 minutes per twilight. If we assume a total of 600 useful twilights per year at two telescopes and an average time available per twilight of 20 minutes, then the twilight survey could provide for an equivalent of up to 40 observing nights. At 10μm the limiting flux for this survey is expected to be 2-3 orders of magnitude fainter than the IRAS point source catalogue.

2. Resources

There are at least three instruments available for this survey: ISAAC, the Infrared Spectrometer and Array Camera on VLT unit telescope #1, which is presently being commissioned; VISIR, the VLT Imager and Spectrometer for InfraRed, to be installed on the VLT unit telescope #3 in 2001; and TIMMI2, the Thermal Infrared Multi Mode Instrument, available from Aug. 1999 on at ESO's 3.6m telescope on La Silla. The latter could be used to bridge the gap until the release of VISIR. For a description of ISAAC see, e.g. Moorwood 1997, for VISIR, e.g. Rio et al. 1998 and for TIMMI2, Reimann et al. 1998. The performance of the three instruments is summarized in Table 1. The sensitivities in Table 1 have been calculated assuming the BLIP case, whereby neither particularly optimistic nor particularly conservative assumptions have been made. The performance of ISAAC at M may be worse by a factor of typically three, as one may be forced to use narrow-band filters to trade in field versus sensitivity. Also the sensitivity at Q needs experimental verification. In all cases the sensitivity has been corrected for an estimated degradation in image quality, taking into account the fact that the VLT active optics may not work in closed loop during twilight conditions.

			field[arcsec]	sensitivity[$1\sigma/600s$]
ISAAC	L-band	$\lambda \approx 3.8\mu$m	30×30	19μJy
	M-band	$\lambda \approx 4.76\mu$m	30×30	23μJy
VISIR	N-band	$\lambda \approx 11.0\mu$m	38×38	225μJy
	Q-band	$\lambda \approx 19.0\mu$m	38×38	1533μJy
TIMMI2	N-band	$\lambda \approx 11.0\mu$m	70×90	1200μJy
	Q-band	$\lambda \approx 19.0\mu$m	48×64	7700μJy

Table 1: Sensitivity of Various ESO Thermal Infrared Instruments

All observations will be carried out in standardized configurations using ESO standard observing templates. In that sense the data reduction by the ESO supplied tools (pipelines) will be sufficient. What is required is only an adapted source extraction algorithm, some way to correlate sources (or upper limits) observed at different wavelengths and some way to detect variabilities.

3. Scientific Rationale

The primary goal of this survey is to identify and characterize Asymptotic Giant Branch stars, especially those which are obscured and therefore show exceptional infrared brightness. Variability shall be assessed qualitatively.

The following aspects are well established for AGB stars:

- all stars with a main-sequence mass of less or equal $8M_\odot$ follow the evolutionary track:
  MS $\rightarrow$ Red Giant $\rightarrow$ Asymptotic Giant $\rightarrow$ Planetary Neb. $\rightarrow$ White dwarf
- total mass loss $\int_{t_1}^{t_2} \dot{M} dt$ can be as high as $\approx 6.6M_\odot$ (c.f. Weidemann 1993 or Koester & Reimers 1996).
- it is a very fast process, e.g. $t_2 - t_1 \approx 10^4 - 10^5$ year (see, e.g. Iben & Renzini 1983)
- they are of great importance for their mother galaxies (e.g. bol. luminosity, chem. evolution, source of dust)

The detailed physical processes involved on all scales (e.g. the mass-loss mechanism or the physics of dust-formation) remain enigmatic. The evolution (AGB, proto-PN, PN + White Dwarf) is extremely fast, so that the structure of the star is not in equilibrium which is indeed a major problem for model calculations. Systematic analysis suffers from at least the following reasons:

- catalogues which exist or are presently being built (e.g. using DENIS data: Cioni et al. 1999, Loup et al. 1998; or based on IRAS: van der Veen &

Habing 1988) can only demonstrate the potential of this research, but suffer from selection effects (e.g. incompleteness or bias against or towards obscured objects)

- trigonometric parallaxes (Hipparcos) to get absolute bolometric luminosities for IRAS sources are no help: the diameters of the patchy and partially obscured photospheres of AGB stars are measured in AUs, thus the trigonometric parallaxes are smaller than the apparent diameters and strongly affected by systematic errors; moreover, within 200pc, there are only few AGB stars and none of those shows strong mass-loss.

A complete catalogue of AGB-stars with variability flag and with distances known by association will allow for a new approach for research in this field, especially also as the VLT and its suite of instruments allow for a spectroscopic[1] follow-up on extragalactic stars (see Käufl et al. 1995). Of particular value in this context will be ESO's Cryogenic Infrared Echelle Spectrometer, as it will allow to observe fully resolved molecular absorption lines (e.g. CO, SiO, H_2O) in the 1 to $5\mu m$ wavelength region. CRIRES will approach a resolving power of 2 to 3 $\mathrm{km\,s^{-1}}$ (see, e.g. Wiedemann 1998). As can be seen in the next section, the location of a star in *color-color* or *color vs. absolute magnitude* diagrams alone will already allow for a quite rigorous classification of the objects discovered in this survey.

4. Sensitivity and Completeness

The amount of time available for the project will only influence the area which can be surveyed but not the completeness. For an assessment of the completeness a simple stellar model is being used: the star has a given absolute bolometric luminosity L_{bol}, a photosphere with a Planck spectral energy distribution of a certain temperature T_{photo}; it is enshrouded by a grey body dust envelope of a given optical depth τ_{dust} which by itself re-emits the absorbed photospheric radiation with a black-body spectrum of a certain temperature T_{Dust}. L_{bol} has been chosen to represent intrinsically faint stars in the respective class. Three *prototype stars* are being considered:

- AGB star with low mass loss: $L_{bol} = 10^3 L_\odot$, $T_{photo} = 3000K$, $\tau_{Dust} = 0.04$
- AGB star with high mass loss: $L_{bol} = 10^3 L_\odot$, $T_{photo} = 2500K$, $\tau_{Dust} = 1.00$
- luminous blue variable star: $L_{bol} = 10^5 L_\odot$, $T_{photo} = 50000K$, $\tau_{Dust} = 0.04$

The following tables give the maximum distance d_{max} in *kpc*, up to which these *model stars* are detectable in 600s in the four colors, depending on the effective temperature of the dust-envelope (T_{dust}). In a separate column the change of magnitude (reddening) Δ_{dust}^{mag} introduced by the dust envelope compared to the bare photosphere is given.

[1] In the BLIP case, the signal-to-noise-ratio depends only on $\sqrt{\frac{\Delta\lambda}{\lambda}}$; see, e.g. Käufl et al. 1991.

https://doi.org/10.1017/S0074180900204555 Published online by Cambridge University Press

As can be seen from Tables 2-3 the prototype AGB stars will be detected by the survey in at least two colours up to 80 kpc. As they represent rather the faint part of the population, the completeness for the survey can be guaranteed for AGB stars. A major fraction of LBVs will be detected as well.

λ_{eff}	$T_{dust} = 500K$		$T_{dust} = 200K$		$T_{dust} = 100K$		$T_{dust} = 75K$	
	d_{max}	Δ^{mag}_{dust}	d_{max}	Δ^{mag}_{dust}	d_{max}	Δ^{mag}_{dust}	d_{max}	Δ^{mag}_{dust}
$3.8\mu m$	180kpc	-0.0^{mag}	180kpc	-0.0^{mag}	180kpc	-0.0^{mag}	180kpc	-0.0^{mag}
$4.8\mu m$	140kpc	-0.1^{mag}	140kpc	-0.1^{mag}	140kpc	-0.1^{mag}	140kpc	-0.1^{mag}
$11.0\mu m$	28kpc	-0.5^{mag}	28kpc	-0.4^{mag}	23kpc	-0.0^{mag}	23kpc	-0.0^{mag}
$19.0\mu m$	7.7kpc	-0.7^{mag}	11kpc	-1.6^{mag}	8kpc	-0.9^{mag}	6kpc	-0.3^{mag}

Table 2: Maximum Detection Distance and Reddening of Prototype AGB star with little mass loss

λ_{eff}	$T_{dust} = 500K$		$T_{dust} = 200K$		$T_{dust} = 100K$		$T_{dust} = 75K$	
	d_{max}	Δ^{mag}_{dust}	d_{max}	Δ^{mag}_{dust}	d_{max}	Δ^{mag}_{dust}	d_{max}	Δ^{mag}_{dust}
$3.8\mu m$	230kpc	-1.2^{mag}	135kpc	-0.0^{mag}	135kpc	-0.0^{mag}	135kpc	-0.0^{mag}
$4.8\mu m$	280kpc	-2.1^{mag}	110kpc	-0.0^{mag}	110kpc	-0.0^{mag}	110kpc	-0.0^{mag}
$11.0\mu m$	140kpc	-4.4^{mag}	120kpc	-4.0^{mag}	25kpc	-0.8^{mag}	18kpc	-0.0^{mag}
$19.0\mu m$	44kpc	-5.0^{mag}	80kpc	-6.3^{mag}	47kpc	-5.2^{mag}	24kpc	-3.7^{mag}

Table 3: Maximum Detection Distance and Reddening of Prototype AGB star with high mass loss

λ_{eff}	$T_{dust} = 700K$		$T_{dust} = 200K$		$T_{dust} = 100K$		$T_{dust} = 75K$	
	d_{max}	Δ^{mag}_{dust}	d_{max}	Δ^{mag}_{dust}	d_{max}	Δ^{mag}_{dust}	d_{max}	Δ^{mag}_{dust}
$3.8\mu m$	350kpc	-5.0^{mag}	37kpc	-0.0^{mag}	37kpc	-0.0^{mag}	37kpc	-0.0^{mag}
$4.8\mu m$	380kpc	-5.9^{mag}	34kpc	-0.5^{mag}	27kpc	-0.0^{mag}	27kpc	-0.0^{mag}
$11.0\mu m$	130kpc	-7.7^{mag}	150kpc	-7.9^{mag}	22kpc	-3.8^{mag}	6kpc	-0.5^{mag}
$19.0\mu m$	12kpc	-8.3^{mag}	100kpc	-9.9^{mag}	60kpc	-9.2^{mag}	30kpc	-7.7^{mag}

Table 4: Maximum Detection Distance and Reddening of Prototype LBV star

At least for the SDG the majority of AGB-stars will be detectable in three or more filters. Compared to surveys at shorter wavelengths (e.g. K', 2μm) the *false alarm probability* is low. To be detectable at $\lambda \geq 3\mu m$, stars need to be either exceptionally bright or red. Hence there will be little confusion with, e.g. normal red giants. The variability flag will be valuable in this context as well.

https://doi.org/10.1017/S0074180900204555 Published online by Cambridge University Press

The annual area coverage of the survey can be estimated as follows: Under the above assumptions 2000 minutes exposure time per galaxy per year per filter can be expected. With VISIR for the LMC/SMC the observing time should be of order of 8 minutes for a $38 \times 38\Box arcsec$ field; i.e. a total area of $100\Box arcmin$ per year can be expected. With ISAAC substantially shorter frame times than 8 minutes are sufficient for completeness; this will be used to repeat the survey in the L and M band for different epochs (typically 3) to be able to flag the variability of the objects. In case of the SDG, the time required per exposure in the N and Q-band may be substantially shorter and consequently the survey area may be substantially larger, but the details depend on the overhead times involved in repositioning the telescopes.

5. Outlook and Conclusions

The feasibility of a survey of the nearest local group galaxies for AGB stars has been demonstrated. An official VLT proposal to test the validity of the assumptions has been submitted. In a next step, the requirements for the data reduction infrastructure to cope with the potential cornucopia of images/data need a detailed assessment. Once this is completed the project will be submitted officially as a *Large Programme* to the ESO observing programme committee.

References

Cioni, M.R., Habing, H.J., Loup, C., Groenewegen, M.A.T., Epchtein, N., the DENIS Consortium, 1999, these proceedings

Iben, I., Renzini, A. 1983, ARA&A, 21, 271

Käufl, H.U., Bouchet, P., van Dijsseldonk, A., Weilenmann, U. 1991, Experimental Astro. 2, 115

Käufl, H.U., Wiedemann, G., Zijlstra, A., Waters, R. 1995, in: *Science with the VLT*, ESO Workshop, Springer Verlag, (eds.) J.R. Walsh & I.J. Danziger, p. 114

Koester, D., Reimers, D. 1996, A&A, 313, 810

Loup, C., Omont, A., Duc, P.A., Fouqué, P., Bertin, E., Epchtein, N. 1998, in: *The Impact of Near-Infrared Sky Surveys on Galactic and Extragalactic Astronomy*, (ed.) N. Epchtein, Kluwer, p. 115

Moorwood, A. 1997, SPIE, 2871, p. 1146

Reimann, H.-G., Weinert, U., Wagner, S. 1998, SPIE, 3354, p. 865

Rio, Y., Lagage, P.O., Dubreuil, D., Durand, G., Lyraud, C., Pel, J.W., de Haas, J., Schoenmaker, A., Tolsma, H. 1998, SPIE, 3354, p. 615

van der Veen, W.E.C.J., Habing, H.J. 1988, A&A, 194, 125

Weidemann, V. 1993, in: *Mass Loss on the AGB and Beyond*, 2nd ESO/CTIO Workshop, (ed.) H.E. Schwartz (European Southern Observatory) p. 55

Wiedemann, G. 1998, SPIE, 3354, p. 599

Discussion

Lloyd Evans: Optical spectroscopists use much of the twilight time for calibrating observations!

Käufl: The morning/evening twilight from the onset of astronomical twilight to sunrise/sunset is 80-90 minutes. For the sensitivity estimate we assume to get effective access of 10-20 minutes of that time 300 days per year.