Wide Field Infrared Imaging Working Group Report
WIRCAM Science Cases

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Introduction

The scope of this document is to present the scientific drivers for a wide field infrared camera for CFHT and to discuss the results of the conceptual study. This document has been prepared with contributions from the following people: J.-F. Le Borgne, J. Bouvier, D. Crampton, T. Davidge, A. Lançon, J. Lequeux, A. Omont, R. Pelló, J.-P. Picat, A. Robin, G. Soucail.

Science cases

1 Galactic astronomy

1.1 Star formation

Large-scale near-IR imaging surveys are most suited to understand the triggering and propagation of star formation in molecular clouds. Nearby star forming regions extend over tens of square degrees and contain up to several thousands of embedded young stars (e.g. Carpenter et al. 1997, AJ 114, 198). Most imaging surveys so far have either covered very limited areas of giant molecular clouds (e.g. Hillenbrand & Carpenter 2000, ApJ 540, 236) or, when more extended, have been limited to the detection of the brightest sources (K$\leq$14, e.g. Kenyon, Lada & Barsony 1998, AJ 115, 252). As a result, no star forming region has been properly probed yet so as to provide a complete census of the protostellar population it contains.
A unbiased census of young populations in molecular clouds is needed to address many unsolved issues related to the star formation process: is the cloud collapse and the propagation of star formation triggered by external processes (e.g., SN blast, cloud collisions, protostellar jets), what is the distribution and lifetime of circumstellar disks as revealed by their IR excess, is the initial mass function down to brown dwarfs and free floating giant planets universal or does it depend upon local conditions in the cloud (e.g., turbulence, magnetic field, temperature, etc.)? All these questions and many other require deep extended surveys of nearby star forming regions capable of piercing through intracloud extinction that can sometimes reach up to several 10 mag in the visual, corresponding to only a few magnitudes of extinction in the near-IR.
Several giant molecular clouds located at less than 500 pc (Orion, Taurus, Ophiuchus, etc.) are accessible from Mauna Kea and represent the various modes of global star formation, from extremely dense protostellar clusters (Orion Nebula Cluster, with about 10^4 stars per cubic parcsec) to loose associations (Taurus, with about 10 stars pc^{-3}). At an age of a few million years, the stellar and

substellar populations of these clouds are brighter than K$\simeq$17 down to 0.02 $M_\odot$. The specific interest of near-infrared surveys, compared to optical ones, will be their ability to detect these low-mass populations even in the densest parts of the cloud where A_v can reach up to 50 magnitudes. For instance, according to current models of low-mass objects (Baraffe et al. 1998), a 0.02 $M_\odot$ (20 Jupiter masses) object in Orion (460 pc, 1Myr) seen trough a visual exitnction of A_v=30 still has a K=19, easily accessible with WIRCAM at CFHT. Hence, moderately deep JHK surveys covering several square degrees have the potential provide a complete census of the newly formed embedded objects in galactic molecular clouds.

Target brightness As faint as K = 20.

Filters Broad-band JHK for detection of young stellar and substellar objects and their associated circumstellar disks (IR excess); Br_γ to diagnose active accretion onto low-mass objects.

1.2 The Initial Mass function (IMF)

1.2.1 Young brown dwarfs and isolated Jupiter-mass objects

Studies of substellar objects in young open clusters, through deep large-scale optical imaging surveys, show that the mass function continues to rise in the brown dwarfs domain down to at least 40 Jupiter masses (Martín et al. 1998, Bouvier et al. 1998, Zapatero Osorio et al. 1999, Bejar et al. 1999). A number of substellar objects are also detected in nearby star forming regions like the Orion molecular cloud (Luhman et al. 2000, ApJ 540, 1016) down to masses as low as 10 Jupiter masses, i.e., reaching the domain of the so-called free-floating giant planets (Zapatero Osorio et al. 2000, Science 290, 103). While these recent discoveries raise puzzling issues regarding the formation of these objects whose mass is much smaller than the minimum Jeans mass required for gravitational collapse to occur, they empirically show that substellar objects are to be found by hundreds in star forming regions and open clusters, while only a few tenths have been identified so far.
Young brown dwarfs are both intrinsically brighter and slightly warmer than field ones and are therefore relatively easily detected at optical wavelengths (I$\sim$20-24). However, at an age between 1 and 100 million years, these objects are still excessively red (e.g., I-K = 3-4 magnitudes) and sometimes embedded into molecular clouds. Hence, near-IR searches for young brown dwarfs are expected to be much more efficient than those performed so far in the optical, with the brown dwarf domain starting at typically K$\sim$13-15 in nearby star forming regions and open clusters, while the detection of free-floating giant planets requires K$\sim$18-21.
Theoretical models of brown dwarfs and giant planets provide more reliable predictions in the NIR domain than in the optical due to the stronger impact of molecular opacities at visual wavelengths (Chabrier et al. 2000, ApJ 542, 464). The NIR colors of the candidate brown dwarfs can thus be used to infer the mass of the object through magnitude-mass relationships provided by the models, from which the estimate of the mass function directly follows. Hence, large-scale, deep surveys of molecular clouds and young open clusters in the near-infrared are expected to provide robust estimates of the mass function at low stellar masses and in the substellar domain.

Target brightness K=15-21

Filters JHK

1.2.2 Field brown dwarfs

The all sky surveys (DENIS, 2MASS, Sloan) are extremely efficient at finding nearby field brown dwarfs, ideal for follow-up studies (high resolution spectroscopy, trigonometric parallax, etc), and will identify of order ~1000 L dwarfs (1500K<T_{eff} <2000K) and a few dozen methane dwarfs, with temperatures down to T_{eff} ~1000K. While their limiting distances for significantly cooler objects become very small, and these surveys will presumably find none, current estimates of the local mass function suggest that it is midly rising in the substellar domain (Reid et al. 1999).
Brown dwarf are thus numerous, down to masses as low as 12 M_J and perhaps less, and may in fact be more numerous than stars in the disk of our galaxy. They don't significantly affect its dynamics though, which is just as well since the disk apparently has no dark matter in the end (VCRézé et al, 1998). The mass function of the halo, which does have a dark matter matter problem, and already that of the thick disk, are on the other hand completely unconstrained in the brown dwarf domain, and of considerable interest.
To find cooler brown dwarfs than the all sky surveys and to count them in the halo, one needs deeper, targeted, surveys, for which the MEGACAM+WIRCAM combination (with I and J filters) filters is ideally suited. Using one optical band to look for objects whose energy distribution peaks in the near-IR may seem contrived at first sight, but L dwarfs actually have near-IR colours which stay relatively close to the bulk of a magnitude limited sample (methane dwarfs even have blue near-IR colours, I−J=-0.2 for Gl 229B). Their colours are much more distinctive in the red part of the CCD sensitivity range, where their spectra are steepest. All searches to date have thus combined an optical filter and a near-IR one, and the I−J combinations represent the best compromise between detecting the objects and unambiguously recognizing their unusual colours. The I−z combination (accessible with MEGACAM alone) is the second best choice, but is not nearly as distinctive.
As a representative example (to be discussed and optimised in conjunction with other programs; a deeper and narrower survey for the same total observing time would find somewhat fewer very cool dwarfs but provide a more accurate halo luminosity function), we discuss a survey of 200 square degrees at high galactic latitude ($|b_{II}| > 30°$) observed for 1 h at I and 30 mn at J. We estimate that in 0.7" seeing this will reach 5 sigma limiting magnitudes for point sources of I=26 and J=22.5. As all L dwarfs (and methane dwarfs) have I−J>3.5, the sample will be flux-limited at I beyond spectral L0. Limiting distances will range from 2 kpc (probing somewhat into the halo) for L0 dwarfs (M_I=14.5) to 500 pc (probing into the thick disk) for L6 dwarfs (M_I=18), to 80 pc for a methane dwarf (M_I=21.5). Such a survey will sample a volume which is 100 times that accessible to the all sky IR surveys, and large enough to gather good statistics on halo L dwarfs if any significant number of them exist. Halo objects will have typical proper motions of ~25mas/yr at 1 kpc, and can therefore be distinguished over a few years from contaminants in the tail of the thick disk.

Target brightness As faint as K = 22.5

Filters J

1.3 Galactic structure and stellar populations

The largest part of the most important stellar and interstellar component of the Galaxy, the disk, has large visual extinctions (Av≥5-10) which impede much more visible observations than infrared ones. The infrared surveys 2MASS and DENIS provide for the first time a comprehensive view of the near-infrared Galactic disk. However, these full-sky surveys were not optimised for the Galactic disk; in particular they have poor angular resolution (2" and 3",respectively), which severely limits their sensitivity because of source confusion in the most crowded areas.

Large infrared cameras with large telescopes can do much better in good sites. In particular WIRCAM can easily increase the sensitivity with respect to 2MASS by 3 magnitudes, and the number of detected sources by more than an order of magnitude. It will be most efficient in probing the galactic disc by taking advantage of both the lower extinction at near-IR wavelengths and good image quality, and will thus be much complementary to MEGACAM in this respect. In particular, it will be possible to detect the edge of the galactic disk in any direction (except towards the galactic center) as well as the warp and its tilt relative to the galactic plane. Large-scale, deep near-IR surveys of resolved point-like sources will also probe the structure of the galactic bar as far as its remote edge, i.e., much further away than current optical/NIR surveys can reach.

However, as the most important goals concern the inner Galaxy, similar Southern facilities, such as VISTA, will have an advantage with respect to WIRCAM. Nevertheless, WIRCAM will keep good opportunities for the northern part of the Galactic disk and even for the central regions because of its earlier operation.

The most important regions of the Galactic disk to survey in the infrared are the most extincted ones, i.e. in latitude $|b| < 1$ deg, and in longitude $7 < |l| < 70$ deg. A possible goal for a WIRCAM survey would be to complement, in the northern half of the disk, the SIRTF Legacy Program, GLIMPSE (PI E. Churchwell), which will survey the whole inner disk ($|b| < 1$, $|l| < 70$) in four bands from 3.5 to 8 micron. GLIMPSE will be comparatively deeper than 2MASS at 3.5 micron. A WIRCAM survey 3 magnitudes deeper than 2MASS will be a perfect complement to GLIMPSE and the joint catalogue of $\sim$5 10^7 sources will remain as a joint legacy product.

More precisely, the main goals of such a WIRCAM survey, in J, H, K and $-7 < l < +70$, $|b| < 1$, would be to:

- Contribute to the production of a consistent deep 7-band infrared catalogue, from 1.2 to 8 micron, of the whole half disk.
- Include in this catalogue (up to the Galactic Center and beyond) important classes of stars mostly missed by 2MASS, in particular early giants up to $\sim$K3,4, late B (B2V-A0V) and young stars.
- Resolve blended 2MASS sources and reduce the number of ambiguous identifications and of misidentifications between 2MASS bands and between 2MASS and other surveys such as GLIMPSE.
- Improve red giant statistics (10 times more sources than 2MASS; complete detection of the "red clump"; etc.) for determination of stellar Galactic structures and stellar populations, in particular the bar (extending the present work of C. Alard with 2MASS data, in preparation), the molecular ring and the inner spiral arms.
- Improve in parallel the use of red giants for determining the interstellar extinction, for 2D-maps (Schultheis et al. 1999, Alard in preparation, Cambresy et al.), and future 3D-determinations in conjunction with extant and future CO surveys and GLIMPSE data : smaller "pixels' (down to radius $\sim$20", instead of present value $\sim$60"), large extinctions (Av>25), etc.
- Find near-infrared counterparts of very red mid-IR sources (GLIMPSE, ISOGAL, MSX) without complete JHK 2MASS counterparts, mainly for many young stars in such a situation. The accurate identification of such faint counterparts and of their environment (finding charts) are important for subsequent near-IR spectroscopy with 8-10m telescopes.
- Contribute to a better analysis of star formation and of the IMF through the whole Galactic disk, firstly by adding a census of B stars, and also by many other aspects : better dereddening and, hence, better determination of distances and luminosities; better characterisation of dusty Ae and Be stars through the Galaxy, and of T Tauri stars up to several kpc; deeper analysis of all open clusters allowed by the much better angular resolution than 2MASS; etc.
- More generally, improve the multiwavelength classification and characterisation of stellar populations, in particular for rare classes of peculiar stars, by a better dereddening and a greater near-IR sensitivity.

While the large scale distribution of stellar populations at higher galactic latitudes is usually better probed at visible wavelengths, extremely red objects will be more easily detected by WIRCAM. In particular, it may be feasible to detect the outer edge of the galactic halo by investigating the distribution of Mira-type variables outside the galactic disc. This would require a large surface coverage which will also provide a measurement of the luminosity and mass functions of low mass populations in the thick disc and the halo.

Target brightness As faint as K = 18

Filters JHK

1.4 Galaxy evolution

There are two broadly different approaches for studying galaxy evolution. The most direct route is to observe galaxies at high redshift, when they are in the early stages of evolution. Another approach is to infer the history of nearby galaxies by studying selected samples of stars in these objects. Each approach has obvious benefits and shortcomings; nevertheless, they should ultimately provide similar pictures of galaxy evolution.
A wide field IR camera at CFHT would undoubtedly be used to pursue scientific programs covering both approaches to galaxy evolution.

1.4.1 Population synthesis

A proper modelling of the spectral energy distribution (SED) of galaxies is required for reliable measurements of photometric redshifts and for the interpretation of galaxy light in terms of galaxy history. The near-infrared SED carries most of the information related to intermediate age or old stellar populations. It contains features that in principle provide strong constraints on low and intermediate redshifts (Charlot 1998, in: NGST-Science Drivers and Technical Challenges, ESA-SP 429, p.135, eds. P. Benvenuti et al.). However, the near-infrared light is dominated by red giants and supergiants whose spectral properties are still poorly known, due to, e.g., the uncertain processes that drive mass loss, the difficult treatment of convection during core-helium burning, the occurrence of thermal pulses near the tip of the AGB, Mira-type pulsation and uncertainties in the modelling of cold and extended atmospheres dominated by molecular blanketing. Since the advanced stage of evolution are also the brightest, these uncertainties limit our ability to model the integrated spectra of galaxies in the near-IR.
Systematic studies of large samples of evolved stars are needed to investigate the impact of metallicity on their spectral properties and to better understand stellar evolution along the red supergiant, asymptotic giant and red giant branches. These bright red stars can be observed individually in the galaxies of the Local Group. Only the Magellanic Clouds have been covered in a satisfactory way so far (with EROS, MACHO, DENIS, 2MASS and follow-up observations); observations in other galaxies are limited to a few individual fields. To avoid the need to disentangle the effects of stellar evolution from those of galaxy evolution in galaxy fields, the integrated light of star clusters can be observed. Systematic near-IR surveys of star clusters around galaxies can and must be carried out to larger distances, and thus more varied environments. The use of narrow-band filters allows a good characterization of the dominant near-IR stars (Lançon et al. 1998, A&A 344, L21). In low and intermediate mass clusters such as those of the most nearby galaxies ($\leq 10^4\ M_\odot$), stochastic fluctuations in the small numbers of luminous red stars are too important, and must be compensated for with larger samples of clusters (Lançon & Mouhcine, 2000, in: Massive Stellar Clusters, ASP Conf. Ser. 211, 34).

Going from younger to older populations, important questions to address include: (i) does the relative number of red supergiants in young populations (10^7 yrs) increase or decrease with increasing metallicity (Langer & Maeder, 1995, A&A 295, 685)? (ii) with what precision does the relative number of O-rich AGB stars, C-rich stars and OH/IR sources in intermediate age populations allow us to recover age and metallicity? (iii) what secondary parameters, in addition to metallicity, govern the evolution along the red giant branch? As many of the coolest stars are long-term variables, large-scale observations of evolved stars in the galaxies of the local group need to be repeated over a timescale of a couple of years in order to derive time-averaged properties.

1.4.2 The Mass Function at Low Masses

Studies of the mass function of metal-poor stars in globular clusters have revealed tantalizing clues that the slope of the IMF may depend on metallicity, although the interpretation of the results are complicated by the dynamical state of the target clusters. Moreover, it is not clear if the mass function in clusters and in the field were comparable.

The only way to resolve this issue is to obtain wide-field surveys of stars near the lower end of the main sequence in clusters and in the field. Surveys of this nature must be conducted in the near-infrared since moderately metal-poor objects near the bottom of the main sequence are intrinsically faint ($M_K \sim 10.5$) and have very red colors (V-K $\sim$ 9, so that $M_V \sim 19.5$). For the nearest globular clusters, such as M4, the faintest stars will have K $\sim$ 22, so it should be able to sample the entire main sequence in these systems. For the moderately large sample of clusters with distance moduli < 15 it will be possible to sample objects with masses as low as 0.2 solar masses. Surveys of the halo field will be able to cover the entire main sequence out to distances of 2 kpc, and to 0.2 solar masses out to distances of 10 kpc.

Contamination from low mass background stars and faint galaxies will be a major issue, and these sources could be culled using narrow-band photometry based on the strength of the 2 micron H2O bands. If multi-epoch datasets are obtained then proper motions could also be employed to define a sample of low mass stars.

In addition, it would be appealing to trace by micro-lensing in the K-band the very-low-mass stellar population in the Galactic plane towards the inner bulge, through the whole disk and the bulge/bar, in order to compare it to the one on more outer bulge lines of sights observed in the visible by EROS, MACHOS and OGLE. In the central 10-20 sq. deg., one expects $\sim$10 micro-lensing events per year per 10^6 stars (see e.g. Evans 1994 ApJ 437, L31). Since one expects $\sim 10^6$ detected stars per sq. deg in WIRCAM images, one might expect $\sim$100 events by observing 20 sq. deg., in one hour, every couple of days, for about six months ($\sim$100 WIRCAM hours); i.e. about one micro-lensing events per WIRCAM hour (plus perhaps a similar number of "pixel" events of fainter stars not normally detected). However, such crude preliminary estimates should be carefully checked by specialists. An interesting byproduct would be the monitoring of short variables in the inner bulge, including Cepheids.

Target brightnesses As faint as K = 22

Filters J, Kshort, H2O, 2.3 micron continuum

Crowding Crowding will be an issue for globular cluster fields, so there is a need to properly sample the PSF to have the best image quality

Spectroscopy Will need spectra with low R to measure the SED and estimate Teff. This information could be obtained with narrow-band filters

1.5 Nearby Galaxies

The two closest spiral galaxies, the Andromeda galaxy M 31 and the Triangle galaxy M 33, are very different from our own Galaxy: M 31 has a high metalliciy with little gradient, and has currently a small rate of star formation per unit mass hence a weak UV radiation field. Conversely, M 33 has a rather low metallicity with a strong gradient, and a high rate of star formation per unit mass hence a strong UV radiation field. From these properties, it is clear that the evolution of both galaxies has been quite different from that of our Galaxy. It will be very important to understand better these evolutions and to understand why they were so different from each other.

The metallicity distribution function (MDF), which is the histogram distribution of chemical compositions, is a signature of the environment in which an ensemble of stars form. For low mass systems the MDF is skewed towards low metallicities, while high mass systems the MDF is skewed towards higher metallicities. The physical cause of this behaviour is large-scale mass loss driven by supernovae winds, and the well-established relation between galaxy mass and mean metallicity is one of the most obvious signatures of this effect. The K, J-K CMD provides the most direct tool for studying the MDF of stars in nearby galaxies.

High-resolution imaging is an excellent way to address these problems. Due to their large angular size, M 31 and M 33 can only be imaged at high resolution with big detector mosaics. M 33 has already been imaged in 4 colors in the visible with the CFHT 12K mosaic, and M 31 is planned to be imaged in the same way with MEGACAM. From these data, the distribution of blue stars will be derived together with a rough extinction map, as well as the distribution of red giant-branch stars and of AGB stars. It would be extremely important to add near–IR imaging with WIRCAM, which offers the following advantages with respect to visible imaging.

1. The better images in the infrared would allow to separate fainter stars in the very confused fields of these galaxies. This will be particularly useful for red giants, which are extremely dense even at the outskirts of the disks.

2. One would get rid of extinction which hampers the interpretation of the visible images, especially in M 31 which is very inclined on the line of sight.

3. The study of red giants would be considerable easier in the near-IR, because their visible brightness is severely depressed by molecular and atomic line blanketing.

4. Narrow-band observations in the 2.3 micron CO bands would give band strength information allowing a refined classification of red giants and supergiants.

5. Narrow-band observations around 2.2 micron would provide imaging in the H2 v=1-0 line at 2,12 microns, in the continuum e.g. at 2.14 microns and in the Brackett gamma recombination line at 2.16 microns (this filter combination is available in several NOAO telescopes but only with a small field of view).

These observations would allow to attack the following astrophysical items (the figures between parentheses refer to the observational points above):

A. Space distribution of red giant-branch and AGB stars, giving in combination with the space distribution of young stars a handle on the history of star formation and evolution in these galaxies (1,2,3).

B. Study of the metallicity and metallicity distribution of red giants, which will also tell about evolution of M 31 and M 33 and in particular about the origin of their halos which are very different from that of our Galaxy (1,2,3,4).

C. Systematic survey of dust-enshrouded AGB stars, post-AGB stars, protostars and obscured compact HII regions (1,5).

D. Systematic survey and study of photodissociation regions and shocks from the H2 line observations, combined with observations of the [SII] and other forbidden lines in the visible (5).

E. Dust-free study of the ionized gas, and determination of extinction by comparing the Brackett gamma line and 2.14 micron continuum intensity (which is dominated by the free-free and free-bound emissions of ionized gas) with existing H alpha and radio continuum maps (5).
For these programs, we recommend the following filters: - J, H, Ks broad-band filters - CO 2.3 micron, H2 2.12 micron, Br gamma 2.16 micron, continuum 2.14 micron narrow-band filters (all centered at rest wavelengths: this would allow observations of our Galaxy, of M 31, of M 33 and of several other galaxies of the Local group).

Target brightness K = 19 - 20 (the RGB-tip in M31 occurs near K $\sim$ 19, and one would want to obtain photometry for stars roughly one mag fainter than this)

Filters J, H, Kshort, CO 2.3μ, H2 2.12μ, Br_γ 2.16μ, continuum 2.14μ narrow-band filters (all centered at rest wavelengths: this would allow observations of our Galaxy, of M 31, of M 33 and of several other galaxies of the Local group).

Crowding Crowding will be an issue for fields in the inner halos and bulges of the target galaxies, so there is a need to properly sample the PSF and have the best possible image quality

Spectroscopy Multi-object spectroscopy with R $\sim$ a few hundred would be desirable, but is not essential if narrow-band information is available Its drawback is the increased confusion.

2 Extragalactic Astrophysics and Cosmology

2.1 Galaxy counts and cosmology

Infrared observations are becoming of increasing importance in the study of distant galaxies, especially at high redshift. Photometric determination of redshifts has proven to be a powerful technique and photometry of galaxies in the visible domain (filters from U to I) provides good redshifts estimates for $z < 1$, but access to IR photometric bands (JHK) is needed for higher redshifts (see, e.g., Pelló et al. 1999, Bolzonella et al. 2000) (figures 1). This is especially important since there is an increasing evidence of a star formation peak near $z \sim 2$. The Hubble Deep Field (HDF) data show that galaxies in that domain of redshifts are detected in significant numbers for K>19 and the fraction of galaxies at $z > 1$ reaches 50% ttypically for K$\sim$22.5-23. This raises the importance of selecting a sample of high-redshift galaxies from IR data in the K-band as the k-correction is reduced compared to optical bands. Therefore the fraction of high redshift galaxies is favoured, whatever the processes of galaxy evolution are. In addition, IR surveys are much less biased towards some peculiar strongly star forming galaxies as they essentially trace the old stellar population of the galaxies. This is important to map the light distribution of galaxies at high redshift for several scientific programmes.
Deep galaxy surveys represent invaluable observations to address several questions related to galaxy evolution and cosmology. First, deep number counts are quite sensitive to the geometry of the Universe and provide good constraints on the cosmological density parameter Ω_0 (and also the cosmological constant Λ). In addition, they are strongly related to the evolution of the spectral content of the galaxies, driven by physical processes of stellar evolution. Although most of the deep number counts have been observed in optical bands and will then be followed with MEGACAM, the interest in accessing the near-IR window has been pointed out recently (Djorgovski et al. 1995). In particular, the evolution factor appears to be different in the blue and the near-IR and the question of the evolution and the nature of the red galaxies is still open.

2.2 Extending the study of galaxy properties up to the faintest magnitudes

In the near future, different wide-field spectroscopic surveys, using 4m or 10m class telescopes will become available. Near-IR photometry shall allow to extend the study of galaxy properties to fainter limits in magnitude using photometric redshifts, provided that these z_{phot}s could be calibrated on suited training sets. This is an obvious application of such a technique. Among the possible issues of this program we could mention:

- The study of clustering properties through the spatial correlation function of galaxies, using the angular correlation together with the z_{phot} information. In this case, the relatively high number of objects accessible to photometry allows to enlarge the spectroscopic sample towards the faintest magnitudes, and also to strongly reduce the errors.
- The study of the luminosity function and the redshift distribution of galaxies of different types. The study of the near-IR luminosity function in different environments is crucial to constrain the scenarios of galaxy formation and evolution. The comparison between the the predicted and the observed LF in different density regimes (field, groups or clusters), together with the distribution of galaxies as a function of their morphological type is important, in particular to evaluate in which extend observations could be accommodated within the results expected from hierarchical modeling (Kauffmann & Charlot, 1998). Among the important clues we could mention the formation epoch of bulge and early-type galaxies (Renzini and Cimatti, 1999; Cimatti et al. 1999).
- The study of spatial correlation function and luminosity function of QSOs and AGNs.

In this case, a wide field as close as possible to that of MEGACAM is needed. Taking into account the typical sizes of distant galaxies detected on the HDF, with typical half-light radius of $0.2" \leq r \leq 0.5"$ (Lanzetta et al. 1998), a good sampling is needed for this program, with a pixel size as close as possible to $\sim 0.1"$ to 0.2", to take advantage of the excellent seeing conditions at CFHT.
In order to extend the study of the LF in B to redshifts of the order of ~ 4, the K band is needed. This will allow to access the stellar population contributing to the flux at $\lambda \geq 4000$ Å, and to directly compare the LF obtained at low redshifts all the way to redshifts beyond 4. This is particularly important for objects at $z \geq 1.5$, and the only way to access the population of early-type or bulge galaxies beyond such redshift. According to a straightforward calculation using the Bruzual & Charlot (1993) models (1998 version), it is shown that a local ($z \sim 0$) L^* early-type galaxy will be seen through WIRCAM up to $z \sim 2.5$ with a good S/N ratio in 1h, and this is the most pessimistic scenario for such a galaxy, because the estimate is based on a simple k-correction. According to Lowenthal et al. (1997), the number of galaxies brighter than L^* at redshifts $z \geq 2$ could be of the order of 10^4 per square degree. Taking into account evolutionary effects and different scenarios for galaxy evolution, we could expect to observe galaxies with corresponding to the local L^* up to redshifts $z \sim 4$. Thus, WIRCAM could contribute to constrain the models because of the availability of the K band.

2.3 Clusters of galaxies

2.3.1 Identification of Clusters

Extending the photometric database towards the near-IR domain is important to improve the cluster detection at any redshift when including photometric redshifts, whatever the detection algorithm adopted (see for instance the cluster-finders produced by Kepner et al. 1998, Olsen et al. 1998, or Kawasaki et al. 1997). The main idea is that the contrast between the cluster and the foreground

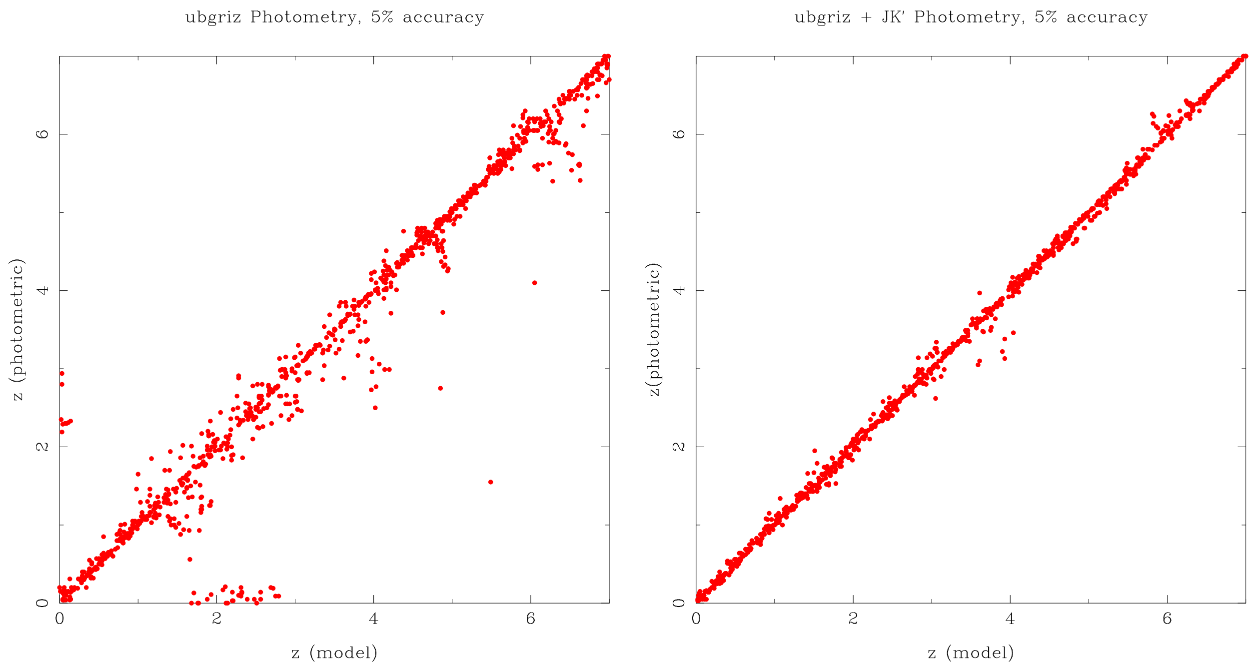

Figure 1: Comparison of photometric redshift determination using MEGACAM filters + 2 IR filters, J and K' (courtesy Roser Pello). Photometric uncertainties are 0.05 magnitudes.

and background population is the leading factor. According to the simulations by Pelló et al. (1998), when using z_{phot}s the S/N in the $0.8 \leq z \leq 2.2$ redshift region is improved only when the photometric selection includes the J and K filter bands. In this case, the S/N is improved by a factor of 3 to 6 up to $z \sim 1$, depending on the redshift and magnitude limits, compared to conventional methods. At high redshift ($z \gtrsim 2.0$), the photometric-redshift filtering provides a detection efficiency which is almost insensitive to the redshift, for a given kind of structure, provided that the photometry is deep enough and that near-IR photometry is included.
A particular application for WIRCAM is the search for the visible counterpart of clusters detected through X-ray and Sunyaev-Zeldovich wide-field surveys. In this case, the important point will be the field size. XMM deep surveys may discover some new high redshift clusters, depending on the rate of evolution in the cluster distribution with redshift. More secure will be the detection of distant clusters through their action on the Cosmic Microwave Background (the so-called Sunyaev-Zeldovitch effect) as the intensity of the effect is quite independent of the cluster distance. Within the next 5 years, several ¡SZ observatories will be operating (some are already being developed) and the near-IR identification of the SZ agent will be of primary importance to understand the mass function of the structures able to distort the CMB. Note that the expected size of any SZ survey will be of a few square degrees, well matched to the size of any complementary survey proposed with WIRCAM.

2.3.2 Luminosity function and properties of cluster galaxies up to $z \sim 1-2$

The near-IR luminosity functions of clusters are still poorly known. So far, they have been measured for a few clusters, but to bright limiting magnitudes (Barger et al. 1996, Trentham & Mobasher 1998), and on different portions of the Coma cluster (De Propris et al. 1998, Andreon & Pelló, 2000), down to relatively faint magnitudes. Kauffmann & Charlot (1998) have shown that the apparent passive evolution and the slope of the color–magnitude relation can be accommodated within a hierarchical model, even if the galaxies themselves grow by mergers until late times. One of the important remain-

ing issues is the comparison between the predicted and the observed LF in clusters, in particular, the distribution of galaxies as a function of their morphological type, at least for early–type galaxies. One of the main limitations till now has been the lack of suitable observational data to compare with model expectations. A straightforward estimate shows that WIRCAM shall allow to attain a magnitude in the K band equivalent to the local $M_k^* + 2 - 3$ at $z \sim 1.5$, and at least $M_k^* + 4$ at $z \sim 1$, with a reasonable exposure time ($\sim 1h$).
In this particular program, observations could correspond to both targeted pointings or to wide-field surveys. A large field-of-view (as close as possible to MEGACAM) could be an important benefit. The access to the K band is crucial.

2.3.3 Mass-distribution of clusters and mass-to-luminosity ratios

Another approach to understand the mass distribution in distant clusters of galaxies is to study the distortion effect of the background galaxies due to gravitational lensing (Mellier 1999). Although this will mainly be done in the optical, especially with the MEGACAM project, strong constrains are brought by the knowledge of the redshift of the background lensed population of galaxies. This will be done through photometric redshifts preferably including IR filters. The shear detection due to distant clusters (say $z \sim 1$) will be optimally detected in the near-IR for several reasons: first, at K=22.5, about 50% of the galaxies are expected to lie at $z > 1$, giving a fairly large number of potential sources for the lensing distortion. In addition, as already mentioned, the shape of the galaxies in the near-IR is more compact than in the optical, so their detection is easier, and also the measurement of their shape. A better estimate of the shear induced by structures will provide a better mass reconstruction, even with a relatively small number of sources.

2.3.4 Mass function of cluster galaxies up to $z \sim 1 - 2$

The LF is the convolution of the mass function with the corresponding M/L distribution. When measuring the luminosity through near-IR bands we obtain a better estimate of the galaxy mass (Gavazzi, Pierini & Boselli 1996). The near-IR domain is rather insensitive to short time-scale events (such as starbursts) induced by interactions among cluster components, and to the presence of dust. The dynamical mass for cluster galaxies could be determined through weak-lensing studies in cluster-lenses, as shown by Natarayan & Kneib (1998). The accurate determination of the cluster mass per unit (IR) luminosity could be used also to estimate the universe luminosity density, assuming that cluster galaxies have the same LF as field galaxies (Calberg et al. 1996).

2.4 WIRCAM as a tool for the optimization of large spectroscopic surveys

One of the main issues when using z_{phot} is the optimization of the visible versus near-IR bands for subsequent spectroscopic surveys. The aim is to produce a criterion based in z_{phot} to discriminate between objects showing strong spectral features in the optical and in the near-IR. To perform this exercise, both the redshift and the SED characteristics have to be estimated for each object. Because of the degeneracy between the different parameters (A_V, spectral type, (A_V, spectral type, metallicity and age), the relevant information shall be the redshift and the rough SED type, i.e. “blue” or “red” continuum at the given z. Near-IR photometry in at least 2 filter bands, spanning a large wavelength, is absolutely needed for this exercise.

2.5 Detection and study of supernovae events at different redshifts

WIRCAM will allow to complement the systematic supernovae surveys with MEGACAM, in the field as well as in clusters of galaxies. Extending the photometry to the near-IR domain will allow to improve the z_{phot} determination for the parent galaxy, and thus help on the selection of distant events for the subsequent spectroscopic follow-up allowing to identify the sn type (Perlmutter et al, 1999). Near-IR photometry is crucial to accurately discriminate between events at $z \geq 1$ and low-redshift ones. Also, near-IR light-curves could be obtained for different supernovae types at different redshifts. In the case of type Ia supernovae, this will allow to improve the use of such standard candles in a wavelengths domain which is less affected by extinction.
In this case, the important point is the field size, which shall be as close as possible to the MEGACAM field. The sampling is of second order: a pixel size of $\sim$ 0.3" to 0.5" is enough. Large wavelength coverage is recommended (J to K bands).

2.6 Quasars

A survey with NIR bands (WIRCAM) added to visible bands (MEGACAM) could give an unbiased sample of compact objects at given limits on magnitudes and redshifts. Many programs can be made from such a sample using photometric data (with photometric z techniques) or from a spectroscopic follow-up on 8m telescopes when possible.
Some of these programs are:

- Determination the relative contribution of stars, QSO and AGNs to a given magnitude. This is poorly known and essentially because of the selection biases which affect the different samples. This is essential to study the global evolution of AGNs and its links with normal galaxies.

- Discrimination between luminosity and density evolution by deriving the luminosity function over a large redshift range. At redshift less than 2.2, there is evidence for a QSOs strong evolution but it seems that the quasar luminosity function reverse between z=2 and 3 (Shaver et al. 1998). In fact this has been found from data in the visible. Quasars selected at longer wavelengths show a constant density from redshift 2.5 to 4. The corresponding theoretical understanding is in progress but it is necessary to check the importance of selection biases.

- Study of large-scale structure of the universe through the clustering of QSOs and the QSOS-QSOs and QSO-galaxy correlations functions. A few QSOs groups are presently known to be statistically significant. A cosmological test like the count of gravitational lenses can also be made on a sample of quasars. If the population of intervening galaxies is dusty, sampling from optical observations could be incomplete. This uncertainty could be reduced by using infrared observations.

- Select and get informations on absorbers on the light of sight (DLA). From a large sample, with a spectroscopic follow-up, it should be possible to infer: the fraction of galaxies surrounded by envelopes, their properties, the relationship between the halo and the underlying galaxy. The selection of objects is very dependent of the dust effect and infrared observations are necessary.

For all these programs, the key factor is a complete sample at given magnitude and redshift limits. Multicolor techniques (UVX or BRX) are very efficient to select quasars candidates in various redshift ranges, up to z=2.2 for UVX and z=3 for BRX but failed in the region 2.2<z<3.2 because of the quasars "stellar like colors".In optical, flux limits samples: obscured quasars by dust could be lost. A fraction of 2/3 at high redshift is claimed. This number is controversial but could be studied by observations in NIR.

Warren et al (1999) suggest the "KX" method (by analogy with UVX) for selecting quasars flux limited in K by comparing V-J (or R-J) and J-K colors. Hatziminaoglou et al (2000) discussed the "efficiency" of different set of filters (including the J,H,K bands) to select QSOs from multicolor photometric observations, in absence of any morphological criteria. They adapted to quasars a photometric redshift code (Bolzonella et al 2000) based on a standard SED fitting.

The strategy should be to select candidates to find at least 1000 QSOs. To put some numbers, from previous deep surveys we can expect 7500 compact objects up to I=22.5 per sq. deg., with about 7000 stars, 200 QSOs and 300 AGNs. So to get 1000 QSOs will require about 6 sq. deg (which is a small fraction of the MEGACAM survey). The time required for photometry in J,H,K to K=22 (assuming image quality of 0.4") should be less than 30 nights, which is a number well fitted to the expected size of WIRCAM. This program would strongly benefit for excellent seeing.

Other projects on 4 and 8-meter telescopes

- CIRSI at WHT: 11'x11' with 0.72"/pixel, 4 1kx1k HgCdTe detectors. Now in operation. Northern hemisphere.
- IRIS2 at the AAT: 8'x8' (at F/8 with 0.45"/pixel) FOV and moderate resolution spectroscopy (R>2500): based on a 1kx1K HgCdTe array. Expected in 2001. Southern hemisphere.
- OMEGA 2000 on 3.5-m Calar Alto: 15'x15' with 0.45"/pixel. detector: 2kx2k HgCdTe array. Expected 2001.
- FLAMINGOS at the Mayall 4-m telescope: 10'x 10' (at F/7 with 0.6"/pixel) FOV. Multislit spectroscopy at resolution 1000 and 2400 with a separate cryogenic dewar to hold focal plane masks (cycling time: 6h). Based on a 2kx2k HgCdTe array. Available beginning of 2001 but to be shared with Gemini South. Northern hemisphere.
- NEWFIRM at the Mayall telescope: 30' FOV with 0.44"/pixel and an array of 4 2kx2k. Spectroscopy could be considered. Under study and expected before 2005. A spectroscopic facility could be considered as a second goal. Northern hemisphere.
- WFCAM at UKIRT: 30' FOV with 0.4"/pixel and 4 2kx2k arrays. Construction approuved by PPARC. Expected 2005. A spectroscopic facility could be added later. Northern hemisphere.
- VISTA at ESO: This is a large field new 4-m telescope with large arrays in visible and NIR. Installation at Paranal has been approved by ESO. 30' FOV with 0.3"/pixel and an array of 9 2kx2k. Expected in 2005. Southern hemisphere.
- NIRMOS on VLT: 14'x14' FOV with 0.21"/pixel, 4 2kx2k HgCdTe detectors. Expected spring 2002. Southern hemisphere.

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