Semester 2012A

# CHILEAN NATIONAL TAC

Prop. #:

**Deadline: 17 October 2011**

**Submit your proposal at** http://www.das.uchile.cl/cntac/form_prop_cntac.php

**1. Title**

Clusters and Evolution: A MMTF study of z∼1 Clusters and z>3 Candidate Protoclusters

**2. Abstract**


High redshift clusters are unique laboratories to test cosmology and galaxy evolution, but studies are restricted by the limited sample of clusters. Only ∼90 clusters at z>0.8 are known; most have only ∼5–100 spectroscopically-identified members. At z>3, only a handful of protoclusters have been confirmed. Narrow-band imaging, to detect Ly$\alpha$, [O$II$], or [O$III$]-emitters at a specific redshift, is a powerful 'unbiased' method to confirm cluster membership and study evolution. The few such studies have produced interesting results but are limited by requiring a coincidence between redshift and narrow band filter wavelength. MMTF-IMACS is a uniquely powerful instrument which provides a narrow band (∼17$\AA$) filter tunable over 5000$\AA$–9300$\AA$. We propose MMTF observations of three z∼0.8 clusters (to identify [O$II$] and [O$III$] emitters) and one z>3 protocluster candidate (to identify Ly$\alpha$ emitters).

Our immediate science goals include: (a) an 'unbiased' and 'large-number statistics' study of membership, star formation ([O$II$] and Ly$\alpha$) and AGN activity ([O$III$]) in cluster galaxies (including nuclear 'ellipticals'); (b) constraining galaxy evolution in clusters using MMTF, and other, cluster samples at z ∼ 0–3.


**3a. Number of requested nights, or hours, on each telescope/radiotelescope (see also #15)**

**CTIO**

| Blanco | SOAR | 1.5m | 1.3m | 1.0m | 0.9m | Prompt | Curtis-Schmidt | SARA |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

**LCO**

| Baade | Clay | du Pont | Swope |
|---|---|---|---|
| 4 | | | |

**3b. Instrument(s) requested**

IMACS f/2

**National Telescopes**

| Warsaw | Danish | Euler | REM | TAROT | ESO-Schmidt | TRA-PPIST | Mini-TAO |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

**Radio**

| ASTE | NANTEN | QUIET | ACT |
|---|---|---|---|
| | | | |

**4. Principal investigator** **Status (A,S,V):** S


◁ **Name** Gustavo Orellana

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**5. Co-investigators (names and institutions)**


◁ Neil Nagar (U. de Concepción, Chile)
Sylvain Veilleux (U. of Maryland, USA)
Mike McDonald (U. of Maryland, USA)

**6a. Preferred months**

first choice: Mar/Apr second choice: Feb,May

**6b. Other scheduling constraints** (use also box 16)

None

**7. Moonlight constraints**

No restriction ☐

Max. # of days from new moon [4]

Dark time is highly recommended for best results with MMTF

**8a. Past and future of this project**

i) Time already awarded to this project: 3n

ii) Time required to complete this project (excluding this semester): 0 to 5n

**8b. Long-term status request*** ☐

**Refer to the CNTAC policy for long-term programs.*

**9. Service/remote observing**

Mark if this is a service/remote observing proposal ☐

No service observing at Magellan. And we enjoy observing at LCO!

**10a. If this proposal is part of a MSc or PhD thesis project** *in a Chilean institution*, **write here the name of the student, the thesis title, and briefly describe the importance of the requested observations to achieve the goals of the thesis.**

G. Orellana (Ph.D. thesis). The data obtained in this proposal will form an important part of Gustavo Orellana's thesis (2011 to 2014 expected). Results from this proposed project are expected to lead to an immediate publication(s). Once the technique is shown to work efficiently with MMTF, we plan to pursue a "large program" in order to build up a statistical meaningful sample of high redshift clusters and protoclusters. Identified SFR and AGN candidates will also be followed up with ALMA.

**10b. Describe how the proposed observations complement data from non-CNTAC facilities. For each of the latter, indicate the nature of the observations (yours or those of others), and describe the importance of the observations proposed here in the context of the entire program.**

None. MMTF+IMACS is a highly unique instrument and is likely the most effective and efficient option with which to address these science goals. The main limitation is that the 6.5m aperture makes observations of z>1 clusters very time consuming. The only (future) competing instrument is OSIRIS on the 10 meter GranTeCan.

**11a. CNTAC observing time allocated **to this particular project** in the last 2 years**

| Proposal code | Proposal title |
|---|---|
| CN2011B-64 | Clusters and Evolution: A MMTF study of z$\sim$0.8 Clusters and z>3 Candidate Protoclusters |

| Dates | Telescope | Awarded time | Loss (%) | Reason(s) |
|---|---|---|---|---|
| 28 Jul 2011 | Baade 6.5m | 1 n | 100 | Cloudy skies |
| 30-31 Oct 2011 | Baade 6.5m | 2n | | to be observed |

**11b. Brief description of the status of this project, including publications.**

We were awarded three nights for our previous proposal with similar science goals (proposal code, title, and observing nights listed above). On the first night, 28 July 2011 we lost the first 75% of the night to clouds. For the final 25% of the night we attempted our backup program (imaging with narrow band filters and without MMTF) but given that the telescope could not acquire a guide star or Shack-Hartmann star, and the cloud cover was highly variable (transparency varying rapidly between $\sim$0%-30%) the final data turned out to be useless.
Our next two nights are scheduled for end October: on these nights we plan to obtain data on two clusters at $z = 0.87$ and $z = 1.185$. Following the recommendations of the TAC, we are concentrating on the highest-z clusters accessable - within reasonable integration times - to MMTF.

**11c. Other publications in the course of the past 3 years on the topic of this proposal (including article titles).**


Orellana, G., Nagar, N.M. et al., *Sub-millimeter Detected z $\sim$2 Radio-quiet QSOs: Accurate Redshifts, Black Hole Masses, and Inflow/Outflow Velocities*, 2011, A&A, 531, A128

McDonald, M., Veilleux, S., Rupke, D., Mushotzky, R., Reynolds, C. *Star Formation Efficiency in the Cool Cores of Galaxy Clusters*, 2011, ApJ, 734, 95

McDonald, M., Veilleux, S., Mushotzky, R., *The Effect of Environment on the Formation of H$\alpha$ Filaments and Cool Cores in Galaxy Groups and Clusters*, 2011, ApJ, 731, 33

McDonald, M., Veilleux, S., et al. *On the Origin of the Extended H$\alpha$ Filaments in Cooling Flow Clusters*, 2010, ApJ, 721, 1262

Veilleux, S., et al., *MMTF: The Maryland-Magellan Tunable Filter*, 2010, AJ, 139, 145

McDonald, M., & Veilleux, S. *MMTF-H$\alpha$ and HST-FUV Imaging of the Filamentary Complex in ABELL 1795*, 2009, ApJ, 703, 172

**12. Description of the programme (1 page of text and up to 2 pages for references, tables and figures.)**

*A) Scientific rationale* Galaxy clusters represent the highest density environments and are thus useful to constrain cosmological parameters (e.g. $\Omega_M$ y $\sigma_8$; Eke+1998), the epoch of reionization (e.g., Tilvi+2010), and galaxy formation and evolution. Many open questions remain. Elbaz+2007 have claimed a reversal of the star-formation density relationship in the field at z∼1. However, massive cluster galaxies at z∼1 are 'fully formed' (Lemaux+2010, Hayashi+2011, Gobat+2011). Study of a diversity (e.g. in mass, morphological type, SFR) of galaxies in multiple clusters over a range of redshifts is required to constrain galaxy formation and evolution, and pinpoint the effects of environment (e.g. Hayashi+2011, Gobat+2011). About $\sim 90$ galaxy clusters are now identified at redshifts z>0.8 (e.g. Bignamini+2008, Mei+2009, Dawson+2009, Hayashi+2011 and references therein). At z>3, radio galaxies are being used to identify protoclusters (about six currently confirmed) and protocluster candidates (e.g. Venemans+2004, 2005, 2007; Miley & de Breuck 2008).

Robust cluster identification and membership requires multi-object spectroscopy (MOS); expensive at high redshifts. With success rates of <50% of targeted objects, this results in few (∼5-100) confirmed members per cluster. More importantly, the pre-selection by color, e.g. red sequence - leads to large biases in the spectroscopically confirmed populations. A powerful complementary method is the use of narrow band (NB) imaging to identify strong line emitters at the cluster redshift. While this technique has been shown to be highly successful (e.g. Venemans+2004; 2005; Hayashi+2011) it is limited in having to find a suitable coincidence between an existing NB filter and the cluster redshift. The bright [O$II$] $\lambda 3727\AA$ and Ly$\alpha$ lines are especially useful in this respect. Ly$\alpha$ emitters at high redshift are very young, and relatively dust free, starburst galaxies; their masses are lower than those traced by Lyman-break galaxies at the same redshift. The [O$II$] line can also used as a tracer of starformation activity, though as Lemaux+2010 and Hayashi+2011 note, the AGN contribution to the [O$II$] flux should be taken into account. *The [OIII] $\lambda 5007\AA$ line is a bright and useful tracer of AGNs and bolometric luminosity; [O$II$] and [O$III$] can together be used to cleanly separate AGN from star formation (SF).*

The science impact of NB imaging of clusters can be judged by Hayashi+2010,2011. These authors present the results of a NB survey of [O$II$] emitters in a 32'x23' FOV centered on the z=1.46 cluster XMMXCS J2215.9−1738. They detect 380 emitters and find that these are distributed along filamentary large-scale structures around the cluster. They find a high density of [O$II$] emitters in the core of the cluster, which they (in 2011) interpret as AGN powered. Finally, they suggest that SF activity in the cluster core becomes as high as those in low density environments, i.e. there is not a strong environmental dependence.

*B) Scientific aim* The Maryland Tunable Filter (MMTF; Veilleux+2010) on IMACS uniquely provides a narrow bandpass (∼17$\AA$) tunable from 5000 to 9000$\AA$, limited only by the availability of order blocking (OB) filters. Thus, exquisite velocity (redshift) resolution can be obtained on any southern cluster (with the only cost that multiple settings are required to fully sample the cluster velocity dispersion). The monochromatic FOV (∼10') is sufficient to cover most clusters, and the full IMACS 25'–30' FOV is usable at slightly offset velocity ranges. The narrow bandpass of MMTF (compared to the ∼120$\AA$ FWHM NB filters used by previous investigations) permits the reliable detection of emission lines with much smaller equivalent widths (EW). Long exposures are not required as we have accurate positions for most galaxies from broad band imaging and the very narrow bandpass minimizes problems of continuum subtraction; typical Ly$\alpha$ or [O$II$] emitters detected thus far have EWs $\gtrsim$ 20, so that the continuum is negligible within our bandpass: available broad-band imaging will be used for continnum subtraction if necessary. Photometric redshifts from existing broad-band photometry can be used to avoid confusion from other emission lines from a different redshift; identified members can be followed up with a 100% success rate with MOS in future projects.

Here we propose MMTF observations to identify [O$II$] and [O$III$] emitters in three intermediate redshift (z∼0.8) clusters and Ly$\alpha$ emitters in one z∼3 protocluster candidate (note that previous followups of the HzRG list have shown a 75% success rate (Pentericci+2007).

**The immediate goals are:** (a) z∼ 0.8 clusters: unbiased identification of new members via [O$III$] and [O$II$] emission, increasing membership statistics by factor 2 to 10 or more; (b) z>3 protocluster: test for the presence of a cluster via Ly$\alpha$ emitter overdensity, and constrain its size and the Ly$\alpha$ luminosity function (cf: tests of reionization); (c) search for large scale and filamentary structures over the full 30' (25' unvignetted) IMACS FOV; (d) characterize SF activity ([O$II$]or Ly$\alpha$) and AGN activity ([O$III$]) and evolution.

Finally, a major goal is to demonstrate this projects improved efficiency over other narrow-band (∼100$\AA$) filter searches. The immediate results of this proposal are expected to be sufficient for one or more publications. Once success has been demonstrated we will propose for a large program to observe a larger sample of 0.8<z<3.5 clusters with MMTF and thus help pin down the formation epoch of both cluster core and outer cluster galaxies.

In our two approved nights (Oct. 2011) we will observe two clusters at z= 0.87 and 1.185 in [O$II$] and (limited velocity coverage) [O$III$]. Co-I Mcdonald has observed cluster samples at z 0.3 and 0.5. We will thus have in hand a preliminary cluster sample for evolutionary studies. In response to the TACs comments last semester we clarify the following: we are attempting to follow up the highest redshift clusters, within the constraints of the current OB filters and keeping to reasonable integration times (e.g. 1 night per cluster). Once we are able to prove the success of this method we can push to higher redshifts by (a) purchasing the corresponding OB filters and (b) requesting longer integration times and thus more nights per (high redshift) cluster.

## References


- Bignamini et al. 2008. A&A, 489, 967
- Dawson et al. 2009. AJ, 138, 1271
- Demarco et al. 2010. ApJ, 711, 1185
- Elbaz et al. 2007. A&A, 468, 33
- Eke, V. et al. 1998, MNRAS, 298, 1145
- Gobat et al. , 2011, 2011, A&A, 526, 133
- Hayashi et al. 2010. MNRAS, 402, 1980
- Hayashi et al. 2011. MNRAS, 415, 2670
- Lemaux et al. 2010. ApJ, 716, 970
- Mei et al. 2009. ApJ, 690, 42
- Miley & De Breuck. 2008, A&A, 15, 67
- Pentericci et al., 2007, Deepest Astronomical Surveys, 380, 219
- Tilvi, V., et al. 2010, ApJ, 721, 1853
- Veilleux, S., et al., 2010, AJ, 139, 145
- Venemans et al. 2004, A&A, 424, L17
- Venemans et al. 2005, A&A, 431, 793
- Venemans et al. 2007. A&A, 461, 823


**Figure 1:** Histogram of [O$II$] + continuum (solid line) and continuum-only (dashed line) fluxes of galaxies in the z=0.83 cluster studied by Lemaux et al. (2010) using narrow band imaging.

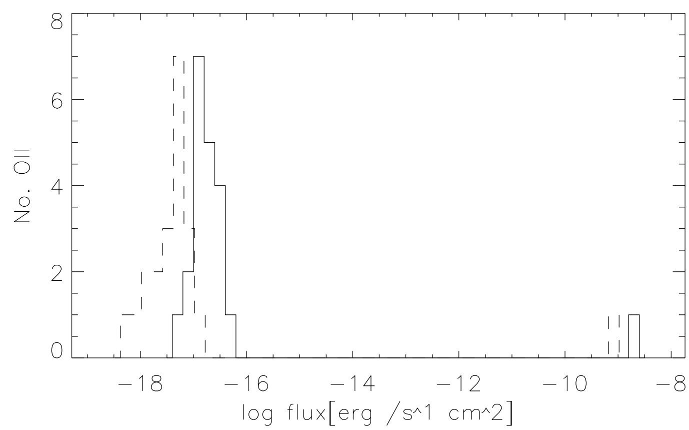



**Figure 2:** Histogram of Ly$\alpha$ + continuum (solid line) and continuum-only (dashed line) fluxes of galaxies in the z$\sim$3.1 cluster studied by Venemans et al. (2005) using narrow band imaging.

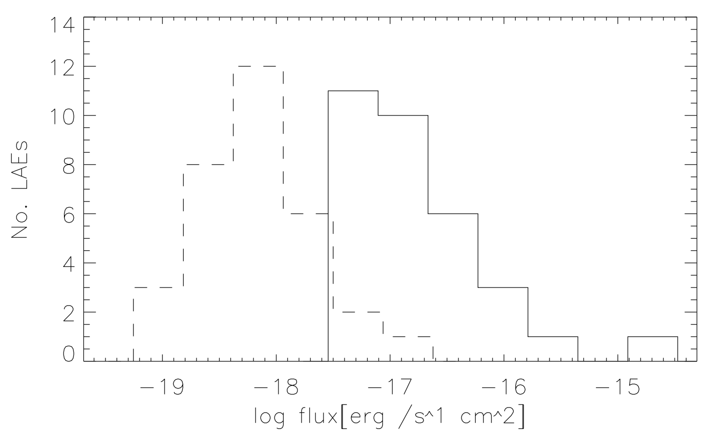
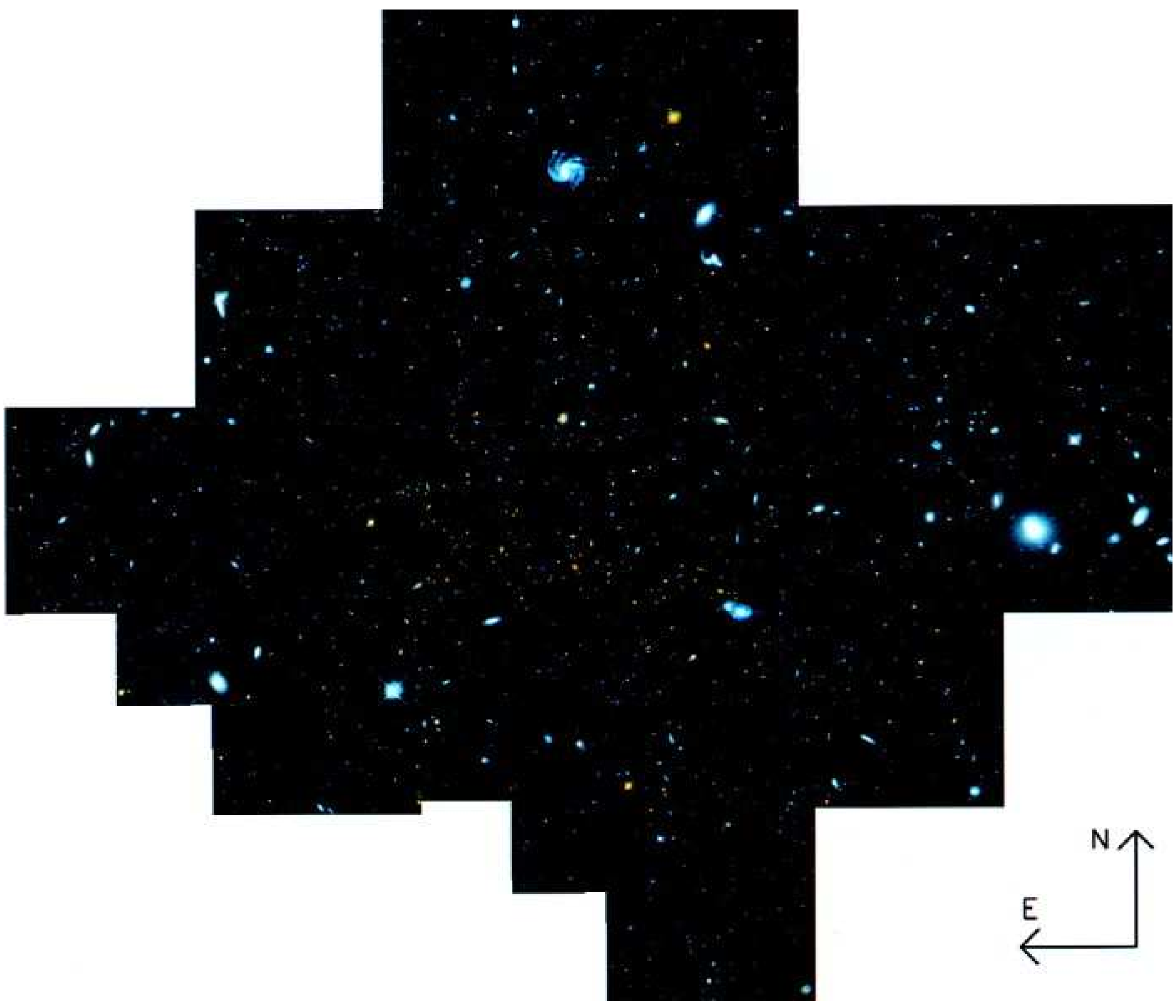


**Table 1:** Cluster Sample & Observations

| Cluster/R.G. Name | $z_{spec}$ (and error) | $\lambda$ line $\AA$ | $\lambda_{cen}$ Order Filter | %Trans OBF | Vel. coverage MMTF setting (km/s) | Cluster Disp km/s | Best Month |
|---|---|---|---|---|---|---|---|
| NVSS J094724-21050 | 3.377 ± — | 1215.24 | 5290. | 84.7 | 635.2 | — | Mar/Apr |
| MS 1054-0321 | 0.8307 ± 0.0004 | 3729.00 | 6800. | 95.9 | 451.1 | 1152 | Mar/Apr |
| | | 5008.24 | 9163. | 94.5 | 560.9 | | |
| RCS 110634-0408.9 | 0.823 ± 0.001 | 3729.00 | 6800. | 95.6 | 453.0 | 2000 | Mar/Apr |
| | | 5008.24 | 9163. | 94.8 | 563.3 | | |
| RCS 110708-0355.3 | 0.825 ± 0.001 | 3729.00 | 6800. | 95.6 | 452.5 | 1000 | Mar/Apr |
| | | 5008.24 | 9163. | 94.7 | 562.7 | | |

Targets at z >3 are high redshift radio galaxies (protocluster candidates). Others are spectroscopically-confirmed clusters. Columns are: (1) cluster or radio galaxy name; (2) spectroscopic redshift and its error; (3) rest wavelength of observed line, corresponding to Ly$\alpha$ (1215Å), [O$II$] (3729Å), and/or [O$III$] (5008Å); (4) central wavelength of MMTF Order Blocking Filter to be used; (5) percentage transmission of the Order Blocking Filter at the observed wavelength; (6) velocity coverage of one MMTF setting for the mode we will use (z(coarse)=-2); (7) velocity dispersion of spectroscopically confirmed cluster members; (8) best month to observe the cluster.

**Figure 3:**Hubble Space Telescope WFPC2 mosaic of the cluster MS 1054-03 at z = 0.83 from van Dokkum et al. (2000). This color image was created from the F606W and F814W exposures, and spans roughly 4' × 6' (2 × 3 h Mpc). The red cluster galaxies are conspicuous. Note their irregular and elongated distribution.



**13. List of targets (absence of a proper object list and information will weaken your proposal). You can include an hyperlink to online catalogs (e.g., Simbad, Vizier, NED, etc.)**

| Name | $\alpha$ | $\delta$ | Epoch | Mag. | Additional Information (e.g., redshift, reddening, angular size, etc.) |
|---|---|---|---|---|---|
| x | | | | | See previous page for target list |

**14. Observational strategy and justification of instrument and requested time (including overheads).**

To guide us we use the results of Lemaux et al (2010; [O$II$] emitters in a z=0.83 cluster) and Venemans et al. (2005; Ly$\alpha$ emitters in a z$\sim$3.1 protocluster). Figs. 1 and 2 show the distribution of [O$II$] and Ly$\alpha$ fluxes from the above two works. Using the MMTF integration time calculator (airmass 1.2, seeing 1.0, lunar phase 4 days, 2x2 binning) we find that a 1 hr (3 hr) integration can detect all of the Lemaux et al. [O$II$] emitters at S/N>5 (S/N>8). Note that our proposed z$\sim$0.8 clusters all have luminosity distances similar to the Lemaux et al. cluster.

For Ly$\alpha$ at z$\sim$3.1, the median Ly$\alpha$ emitter (flux $= 1.61 \times 10^{-17}$[erg s$^{-1}$ cm$^{-2}$]) of Venemans et al. is detectable at S/N $\sim$ 3 in 2hr of integration. The main variation in integration time for individual targets depends on the transmission of the order blocking filters. Table 1 lists the proposed sample of clusters suitable for observation with MMTF-IMACS in Semester A, 2012.

For [O$II$] and [O$III$] imaging, we will use 8 adjacent and slightly overlapping MMTF settings to cover the full velocity range of the cluster ($\pm$2000 km/s around the listed central redshift). In the case of Ly$\alpha$, a single MMTF setting (14$\mathring{A}$ FWHM at 5000$\mathring{A}$) represents 840 km s$^{-1}$. Given the long integration times required we will use only one setting centered on the HyzRG redshift. If Ly$\alpha$ emitters are identified in this observation (i.e. confirming a cluster) then future observations can search a more extended velocity range. Note that the redshift errors of the clusters chosen are smaller than an individual MMTF setting.

Thus for MS1054, we require 8 x 1hr for each of [O$II$] and [O$III$](2 nights) For the two RCS clusters we will obtain shallower (30min per setting) [O$II$] imaging (one night in total). For the z>3.37 protocluster candidate we will obtain a 6 hr integration at one wavelength setting. We therefore request a total of four nights.

The very narrow bandpass of the MMTF etalon considerably eases the requirement of "off-band" subtraction: for the typical high EW emitter, the line emission dominates the continuum emission. Existing excellent broadband imaging of the clusters will be used to extrapolate the continuum flux of detected sources within the MMTF band if required. It would not be surprising, however, to detect some low surface brightness galaxies (not detected in broad band imaging) in the emission-line only images.

**15a. Optical/IR telescopes: requested instrument(s) setup**

IMACS with MMTF; filter wheel with all MMTF Order Blocking Filters and SDSS filters installed

**15b. Radio**

| Telescope | LST interval | Obs. periods | Total # of hours | Type | Lines | Rec/Spec (bandwidth) |
|---|---|---|---|---|---|---|
| ASTE | | | | | | |
| NANTEN | | | | | | |
| QUIET | | | | | | |
| ACT | | | | | | |

**16. Scheduling constraints, special requirements and other remarks**

No constraints or special requirements

**17. Backup program (if proposal needs outstanding weather)**

We do not require exquisite seeing as most potential cluster members have separations of more than a few arcsec. Relatively stable non-photometric weather can be calibrated out. With increasingly bad (unstable) weather we will make shorter exposures to obtain emission line images in targets with decreasing redshift (e.g. Halpha, OIII and OII in $z<0.3$ redshift clusters) or even in local bright galaxies. In the latter case, the nod and shuffle mode of MMTF allows acceptable on-off imaging even in variable weather, at the cost of a smaller FOV. Having said this, if the weather is as bad as our last run (28 July), i.e. 0-30% highly variable transparency, then even our backup program is probably useless.