IRAM 300, rue de la Piscine
38406 ST. MARTIN d'HERES (France)
Fax: (33/0) 476 42 54 69

PROPOSAL FOR 30M TELESCOPE
Deadline: 12 Sep 2013 Period: 01 Dec 2013 — 31 May 2014

For IRAM use
Registration N°:
Date:

TITLE **Confirming $z \geq 2$ cluster candidates observed by Planck and Herschel (NIKA guaranteed time proposal)**

Type: *Solar system:* continuum○ lines○ other○ *Extragalactic:* continuum● CO lines○ other○
Galactic: continuum○ lines○ circumstel. env.○ young stel. obj.○ cloud struct.○ chem.○ other○

ABSTRACT

Catching massive galaxy clusters during their major formation period at high redshift remains a challenge. The Planck all-sky survey has the unique capability of systematically finding the rarest, brightest high-redshift sub-millimeter sources across all of the extragalactic sky. We have collected a catalog of hundreds of Planck high-z candidates, and have now Herschel/SPIRE photometry for 230 of them. Our analysis shows significant overdensities of strongly clustered red-excess sources consistent with groups or clusters of dusty starbursts at high-z. Here we propose to follow-up 23 of these candidates with NIKA GT as part of a coordinated FIR/submm/mm follow-up including also GISMO and SCUBA2, with the goal of characterizing the SED and dust properties, and ultimately, to obtain photometric redshifts. This synergy between space and ground based submm/mm leading facilities will shed new lights on these enigmatic episodes of structure formation.

Is this a resubmission of a previous proposal ? no● yes○ – proposal number(s): ....
Is this a continuation of (a) previous proposal(s) ? no● yes○ – proposal number(s): ....

Hours requested for this period

Total 27 EMIR [ ] HERA [ ] GISMO [ ] NIKA 27

LST range(s) and number of intervals
from: to: intervals:
from: to: intervals:

Special requirements: Large Program○ pooled obs● service obs○ remote obs○ polarimeter○

Scheduling constraints: None ....

Receivers: EMIR○ HERA○ GISMO○ NIKA● Other○

List of Objects (give most common names)

Epoch: J2000.0

Source	RA	DEC	V_{LSR} or z
23 sources			z∼2-4

(for additional sources which do not fit here use the \extendedsourcelist macro)

Principal Investigator:

Herve Dole & J.F. Macías-Pérez
Institut d'Astrophysique Spatiale
bat 121, Univ. Paris Sud
91405 Orsay (France)
Tel: (+33) 1 69 85 85 72 Fax: (+33) 1 69 85 86 75
Email: herve.dole@ias.u-psud.fr & macias@lpsc.in2p3.fr

Other Investigators (name, institution):

NIKA Collaboration – see http://ipag.osug.fr/nika2/Collaborators.html (–); A. Adam (LPSC – France); A. Adane (IRAM – France); P. Ade (Cardiff University – UK); P. André (CEA Saclay – France); A. Beelen (IAS – France); B. Belier (IEF – France); A. Benoît (Institut Néel – France); A. Bideaud (Cardiff University – UK); N. Billot (IRAM – Spain); O. Bourrion (LPSC – France); M. Calvo (Institut Néel – France); A. Catalano (LPSC – France); G. Coiffard (IRAM – France); B. Comis (LPSC – France); A. D'Addabbo (Institut Néel – France); F.-X. Désert (IPAG – France); S. Doyle (Cardiff University – UK); J. Goupy (Institut Néel – France); C. Kramer (IRAM – Spain); S. Leclercq (IRAM – France); J. Martino (IAS – France); P. Mauskopf (Cardiff University – UK); F. Mayet (LPSC – France); A. Monfardini (Institut Néel – France); F. Pajot (IAS – France); E. Pascale (Cardiff University – UK); L. Perotto (LPSC – France); F. Pointecouteau

Expected observer(s) J.F. Macías-Pérez

join to this form: scientific aims ≤ 2 typed pages (≤ 4 pages for Large Programs) and ≤ 2 pages Figs., Tabs., and Refs.

Technical Summary

Variables used:

T_A^*	expected line antenna temperature	T	requested telescope time per setup
Δv	required velocity resolution	pwv	precipitable water vapor: 1, 2, 4, 7, or 10 mm.

⋆ NIKA

Mapping parameters

S_ν = expected source flux density

setup	1.3 mm S_ν mJy	1.3 mm aimed for rms mJy	2 mm S_ν mJy	2 mm aimed for rms mJy	map size [a] Δx	$\times \Delta y$
1	3	0.75	1	0.25	2.0	2.0

[a] use minimum size ($1.0' \times 1.0'$) for compact ($\leq 40''$) sources.

Observings times

setup	priority band [a]	pwv [mm]	number of sources	T [hours]	remark
1	1	4	23	27	
Total NIKA time requested:				27	

[a] Specify which of the two NIKA bands has scientific priority. Enter 1 (2) for the 1.3 mm (2 mm) band, or 0 if both bands have equal priority. Observing time and pwv requirement are to be based on the priority band.

Confirming $z \geq 2$ cluster candidates observed by Planck and Herschel (NIKA guaranteed time proposal)

Some of the greatest challenges of our hierarchical paradigms of galaxy evolution and structure formation are at the high end of the mass function, which traces the most extreme density fluctuations of the primordial dark-matter distribution. Galaxy clusters are natural probes of structure formation as well as galaxy evolution: with masses of up to 10^{15} $M_\odot$, they are at the nexus of galaxy evolution and cosmology, and they are the sites where most of the massive galaxies in the nearby Universe are found (e.g., Renzini 2006). Archeological constraints like the remarkably tight red sequence of passively evolving early-type galaxies in clusters out to z ~0.8 (e.g., Jaffe et al. 2011) and beyond (e.g., Kodama et al. 2007) clearly show that massive cluster galaxies must have formed most of their stars over short timescales in vigorous bursts of dust-enshrouded, intense star formation at redshift $z \geq 2$, giving rise to bright FIR dust emission which is redshifted into the submm range.

In the *Herschel* era catching massive high-z *galaxies* during their major growth period may no longer be a challenge, however identifying the most massive, most intensely star-forming *galaxy clusters* remains remarkably difficult. With short star-formation time scales of few 10^8 yrs and the intrinsic scarcity of very massive objets at high-z, such objects are very rare. For example, Mo & White (2002) predict only 1 cluster with 10^{15} $M_\odot$ per 10^8 Mpc^3 at $z \sim 1$. Collecting a significant sample of the most massive, most rapidly evolving high-z density peaks continues to be a challenge even for the wide *Herschel* surveys. This is a "hot topic" where any new selection can provide valuable discoveries.

***Planck* is the first sub-mm all-sky survey** with the depth and spatial resolution necessary to probe the brightest end of the high-z FIR/sub-mm luminosity function down to ~100 mJy *and over the full 1/3 of the sky which is not dominated by Galactic foregrounds*. Sky coverage is essential to robustly identify the most outstanding sources along the exponentially declining tail of the luminosity function. We identify few hundreds of potential high-redshift objects, about 1 per 30 deg^2 using color-color criteria (Fig. 3). These targets are too rare to fall into the large Herschel surveys in significant numbers. The only high-z Planck source with published Herschel observations, a gravitational lens at z =3.2 (Fu et al. 2012), was taken from the Planck Early Release Compact Source Catalog (Planck Collab 2011, VII) which has a different selection not optimized for high-z galaxies like our sample. From the sample, we have now 200 sources observed with Herschel/SPIRE photometry (OT1, OT2, and exceptional must-do allocation).

Most of our sources with existing Herschel observations are significant overdensities of red sources that peak at 350μm or 500μm, consistent with galaxy groups and clusters at $z_{phot,SPIRE} \geq 2$ (Fig. 2 & 3). Their joint emission boosts their flux in the large (5'; 2.5 Mpc at z =2) beam of Planck. Our sample is the only uniformly selected all-sky sample of high-z submm candidates currently available. Since there are no similar, brighter high-z submm regions at cluster scales on the observable FIR-submm sky, our targets have an immense potential of being the most rapidly growing, most actively star-forming overdensities of massive galaxies in the early Universe, and the likely progenitors of the most massive galaxy clusters today seen during their most rapid phase of star formation.

What are the intrinsic properties of these objects? We have embarked on a broad, on-going spectroscopic and photometric multi-wavelength follow-up with sub-mm and optical/NIR facilities across the world to find this out. This includes in particular SCUBA-2 (16 sources reduced, 17 to be observed, 39 proposed), Spitzer DDT photometry at 3.6 μm and 4.5 μm for 25 targets (DDT+GO9 ongoing), as well as CFHT and VLT observations (11 targets observed): we may have at least 1 cluster in J-K (analysis ongoing). For 1 source we obtained 2mm PdBI interferometry through DDT W–1 (see below and Fig. 2). **SPIRE alone already reveals a significant excess of strongly clustered, red sources, and likewise, other bands reveal unambiguous concentrations of sources.** We are currently working on cross-identifying our sources in different wavebands for individual sources where multi-wavelength data are already available (Figs. 1 & 2). The SPIRE photometry of our sources is generally consistent with a broad redshift range of z =2–4, albeit with large uncertainties owing to the small wavelength coverage of the three SPIRE bands which only probe the very peak of the dust SED. The imperative next step to further characterize our sources is to comprehensively sample the Rayleigh-Jeans tail of the dust SED at several wavelengths. This is the primary motivation of our proposal.

Immediate Objectives

We propose a deep 1.2 and 2.1 mm continuum imaging of 23 red, high-z Planck and Herschel cluster candidates. Our primary goal is to identify the mm counterparts of the Herschel sources. (Sub-)mm photometry in addition to SPIRE FIR photometry is required to characterize the dust SED. Note that our proposed sources are expected to have flux densities larger than Ivison et al. (2013). Multiwavelength data exist in some sources (see table 1). Our first GISMO run in April 2013 was successful (see figs 1, 4,5) and proves the feasibility of the project.

• **Measure the dust SED** We will probe the Rayleigh-Jeans tail of the dust heated by star formation over a much larger wavelength range than our SPIRE data alone, which only cover 250μm, 350μm and 500μm, and longwards 850μm for which we have some SCUBA2 data. *The goals is to combine SCUBA2, NIKA and SPIRE photometry* whenever possible. This is ideal to probe the dust peak of high-z galaxies, and hence to confirm the high-redshift nature of our sources. However, the proximity in wavelength boosts the uncertainties of SPIRE-only photometric redshift estimates owing to the unavoidable measurement uncertainties (Fig. 2). With NIKA we expect to significantly tighten our photometric redshift constraints (modulo the unavoidable degeneracy with T_d). Since the 30-m beam is smaller than the SPIRE beam, we will have no uncertainties from missing flux due to potential extended dust emission (Ivison et al. 2012 – and see our fig. 4 a-d).

• **Synergy with shorter wavelength photometry** We already have extensive CFHT and Spitzer (DDT and GO9) photometry for some sources (fig. 1), and are currently extending this sample. This will allow us to fully characterize the stellar and star-formation content of our targets and to directly compare with the specific star formation rates in the general high-z galaxy population (are they star-forming or on the main sequence, Elbaz et al. 2011, or is star formation perhaps suppressed relative to the MS, which would perhaps indicate accelerated galaxy ages as seen in nearby clusters?). For galaxies with a 'simple' Herschel/SCUBA-2/NIKA dust SED consistent with a single source this can already be done with our 30-m data alone, in more complex cases we will follow-up using the PdBI to disentangle individual sources.

• **Towards a sample for PdBI**. This sample observed at 1/2mm will serve as a criterion for further observations at the PdBI, based on the flux density measured, and on the refined SED and photo-z. The goals will be to spatially resolve the dust emission (and maybe CO lines) and correlate it with the NIR data (WISE or Spitzer when available) to perform a co-analysis of stellar mass and star formation rate where multiple sources contribute to the SPIRE/NIKA fluxes with 10-15 arcsec beams.

Depending on the outcome in 2014, our observations may serve as a pilot for a future 30-meter Large Program, to observe the full SPIRE sample that we collected. This would be complementary to the detailed, on-going multi-wavelength follow-up of smaller samples such as proposed here, and allow us to characterize the ensemble properties of our sample in a statistical way (e.g., photometric redshift distribution once the range of dust temperatures is known). This would be mandatory to fully exploit the immense and unique potential that our all-sky survey has for cosmology (i.e., early collapse of massive dark-matter halos).

Technical Justification

Sample size: With almost 500 Planck high-z candidates and 230 SPIRE targets, why pick these 23 sources? Our overall sample is too large to follow up each and every source in all wavebands, however to be able to characterize our sample overall, we must reach a minimal statistical robustness, in particular to characterize dust temperatures and FIR/mm redshifts. For this goal, we need to reach a statistical uncertainty of $\sqrt{N}/N < 20\%$ or better, i.e. more than 25 sources. Given our success in identifying the Planck sources with Herschel, 'contamination' of our sample with very bright gravitational lenses, etc., and taken into account the available time slot, we require 23 sources to have a decent statistical value: an uncertainty of 21%. Table 1 highlights the source characteristics.

Time estimate: Using SED templates redshifted at $z = 2$, for example Arp220, we expect flux ratio of 20 between 350 and 1.2 mm and 70 between 350 and 2.1 mm. To consider the SED follow-up of sources already detected with SPIRE with a minimum flux of 60 mJy at 350 μm we need to detect at 4σ a 1.2 mm flux of about 3 mJy which corresponds to 0.75 mJy rms. Fig. 5 shows that Arp220 SED is a reasonable, although far from perfect, approximation.

Assuming point sources distributed within a 2 arcmin diameter, Lissajous scans of 2 arcmin size are optimized to ensure homogeneous sensitivity within 1 arcmin of radius of the center of the source. Assuming winter weather conditions we expect a sensitivity of 40 mJy $s^{1/2}$. We therefore need to observe for 40 minutes each source. We choose to observe 23 sources for a total of 18 hours of observation on source and thus request 27 hours in total considering a third of the time is spent for calibration (focus, pointing and photometry). We note that the data reduction pipeline for Lissajous scans has already been used successfully in the last NIKA run.

We thus request **27 hours in total for 23 sources (40min on source + overheads).**

Fig. 1. Top: a) and b): an example of one of our candidates (PLCK_G82.5) seen by Herschel/SPIRE (left, a) and SCUBA2 (b, right). Black line indicate the same locations. **Bottom: c) and d):** Spitzer 3.6um image (left, c) and GISMO 2mm image (right, d) with SPIRE 350um contours (yellow). Yellow arrow indicates an overdensity candidate detected in the NIR and mm. NIKA will help constraining the SED.

Fig. 2 (below): the need for 1mm NIKA photometry: PdBI 2mm, SPIRE, and IRAC observations of G83.3. Blue lines show two modified black-bodies at z=3.8, with T=20 and 40 K, respectively, and beta = 2.0. This is only one possible fit to the dust SED. The dashed black line shows Arp-220 for comparison, redshifted to z=4.0. This figure illustrates that how much more constraining the combination of **1mm+SPIRE** is compared to SPIRE photometry only, in particular since we have no PACS or Spitzer-MIPS photometry for our targets. The 1 mm band has the advantage of having larger observed flux than at 2mm for our targets.

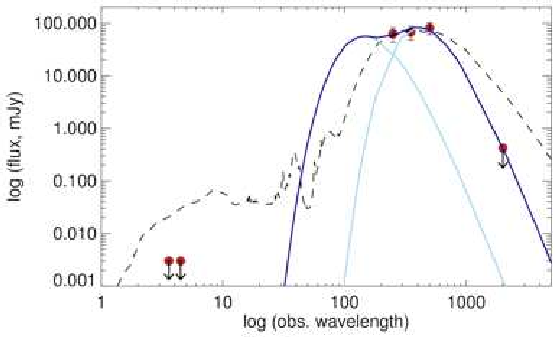

fig. 2.

Fig. 3. (right): Herschel/Spire 250/350 vs. 350/500 color-color diagram of all our high-z cluster candidates combined (diamonds), illustrating that our sources are good candidates of being dusty, intensely star-forming galaxies at high redshift (Planck Collaboration 2012); colors: models of Amblard et al., 2011.

Fig. 4. (below) Preliminary results of our Spring 2013 GISMO run at 2mm. **Top: a)-d):** image of G045.1 illustrating the power of IRAM: a-b-c: SPIRE 250um to 500um; d: GISMO. GISMO sensitivity and resolution is impressive. NIKA will do better at 1mm. **Bottom line: e)-g):** another 3 GISMO detections, suggesting NIKA will provide good detections.

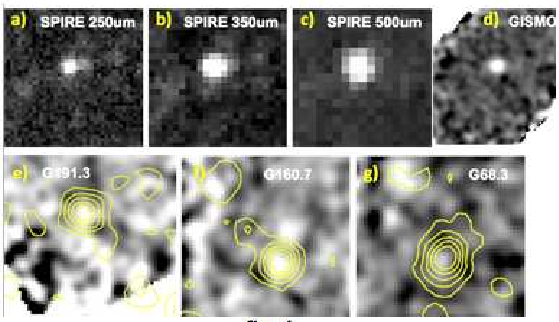

fig. 4.

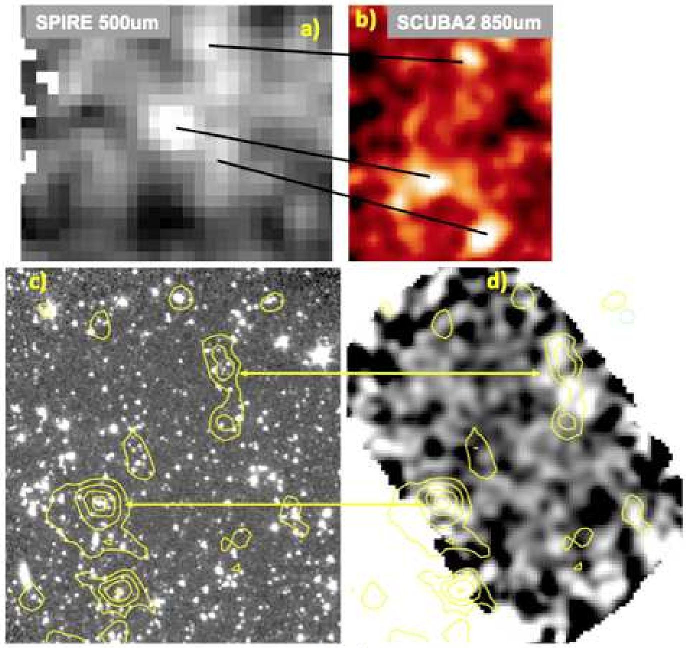

fig. 1.

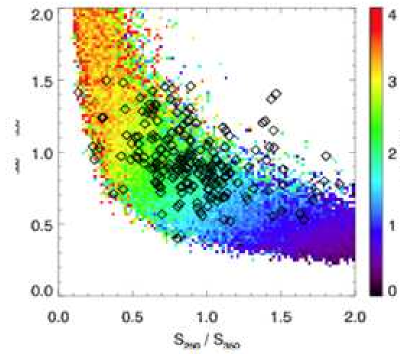

fig. 3.

Fig. 5. (below) SED of G191.3 (also shown in fig 4e) (blue points: SPIRE + GISMO) and overplot of Arp220 redshifted at z=3.0. Photometry at millimetric wavelengths is thus crucial.

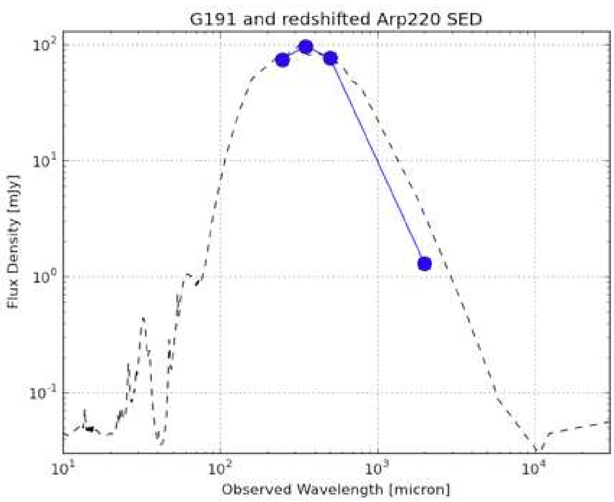

fig. 5.

TABLE 1 - Source follow-up status

Source Name	Spitzer GO9	Spitzer GO10	GISMO
G237.1+54.0	yes	no	yes
G191.3+62.0	yes	no	yes
G198.7+67.9	no	yes	no
G143.6+69.4	no	yes	no
G124.1+68.8	no	yes	no
G303.6+81.3	no	yes	no
G322.1+62.3	no	yes	no
G325.0+63.2	no	yes	no
G104.0+64.2	no	yes	no
G071.1+73.6	no	yes	no
G026.6+74.4	no	yes	no
G112.4+45.8	no	yes	no
G102.1+53.6	no	yes	no
G006.1+61.8	yes	no	yes (pending)
G058.5+64.6	no	yes	no
G57.3+63.0	no	yes	no
G56.7+62.6	yes	no	yes (pending)
G083.8+52.5	yes	no	no
G078.9+48.2	yes	no	yes (pending)
G107.6+36.9	no	yes	no
G063.7+47.7	yes	no	no
G059.1+37.4	no	yes	no
G052.2+28.1	no	yes	no

Targets have also been selected in SPIRE images to be concentrated, i.e. allowing an efficient folow-up w/ NIKA within a 2 arcmin diameter.

Extended source list (cont'd from cover page)

Source	RA (J2000.0)	Dec (J2000.0)	LSR Velocity (km/s)
G237.1+54.0	10h39m46s	+08d52m48s	$z_p > 2$
G191.3+62.0	10h44m50s	+33d49m58s	$z_p > 2$
G198.7+67.9	11h11m30.00s	+30d17m59.6s	$z_p > 2$
G143.6+69.4	12h10m12.96s	+46d04m20.6s	$z_p > 2$
G124.1+68.8	12h48m59.76s	+48d19m57.4s	$z_p > 2$
G303.6+81.3	12h51m50.76s	+18d26m39.0s	$z_p > 2$
G322.1+62.3	13h26m34.56s	+00d43m54.8s	$z_p > 2$
G325.0+63.2	13h30m27.84s	+01d59m32.2s	$z_p > 2$
G104.0+64.2	13h43m19.20s	+50d57m54.0s	$z_p > 2$
G071.1+73.6	13h55m34.90s	+36d22m22.9s	$z_p > 2$
G026.6+74.4	13h59m35.64s	+24d23m12.8s	$z_p > 2$
G112.4+45.8	14h17m17.29s	+69d31m15.5s	$z_p > 2$
G102.1+53.6	14h29m25.57s	+59d22m21.2s	$z_p > 2$
G006.1+61.8	14h33m39.48s	+12d12m54.62s	$z_p > 2$
G058.5+64.6	14h44m27.12s	+35d13m53.0s	$z_p > 2$
G57.3+63.0	14h52m38.65s	+34d57m51.6s	$z_p > 2$
G56.7+62.6	14h54m38.21s	+34d45m12.3s	$z_p > 2$
G083.8+52.5	15h23m55.20s	+51d26m11.8s	$z_p > 2$
G078.9+48.2	15h56m01s	+50d03m48s	$z_p > 2$
G107.6+36.9	16h07m38.23s	+73d47m09.2s	$z_p > 2$
G063.7+47.7	16h07m53.70s	+40d02m40.6s	$z_p > 2$
G059.1+37.4	16h58m48.52s	+36d06m03.2s	$z_p > 2$
G052.2+28.1	17h35m22.95s	+28d17m03.9s	$z_p > 2$