Program Title(s) (One line per program)
A. An intensive survey of the *Chandra* Deep Field North
B.
C.
D.
E.

Abstract(s) (One single abstract or one abstract per program)

With the advent of the *Chandra X-ray Observatory* and the imminent launch of both *HST's* Advanced Camera for Surveys (ACS) and the *SIRTF Great Observatory*, a new generation of ultradeep surveys has begun whose wide-field coverage and broad wavelength information will enable a detailed study of the evolution of the star formation and AGN activity in the Universe to the very highest redshifts. In the Northern Hemisphere the primary field will be the region around the HDF-N, which has already been extensively observed with *Chandra* and is the designated target for the GOODS Legacy program with *SIRTF*. In addition, several groups have proposed *HST* Treasury programs of this region using ACS. All of these data will immediately move into the public domain, regardless of the observing team that carries out the observations. We are on the team that is carrying out the *Chandra* observations and are key members of one of the Treasury teams. We are also collaborating with Mark Dickinson, who is PI of the GOODS proposal.

The enormous scientific potential of this incredible data set can only be realized with corresponding ground-based observations. The purpose of the present proposal is to provide the optical, near-infrared (NIR), and submillimeter data necessary (in combination with existing ultradeep 20 cm VLA data) to identify and interpret the X-ray sources and to prepare the field for the subsequent *SIRTF* and ACS observations. In particular, we propose (1) to deepen existing *B*, *V*, *R*, *I*, and *Z* Subaru SUPRIME imaging to make optical identifications of the X-ray and radio sources over this very large area to the deepest limits possible, (2) LRIS and GMOS spectroscopic observations to determine the redshifts and spectral characteristics of the X-ray and radio samples, (3) UH88 QUIRC and Subaru CISCO imaging to make NIR identifications of the NIR bright but optically faint hard X-ray sources that may be evolved galaxies at high redshift, and (4) SCUBA observations to obtain complete submillimeter coverage of the areas to be observed with *SIRTF* and ACS. The combined ground-based and space-based data on this field will constitute the deepest, largest, and most uniform panchromatic set ever assembled to study the distant Universe and will provide the basis for planning future experiments with telescopes such as *NGST* and ALMA.

Because of the importance and time critical requirements in obtaining the ground-based data and the large amount of data involved, we have chosen the slightly unusual course of submitting this as a joint proposal and will both focus our entire efforts on this project.
# TELESCOPE TIME REQUESTED

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# COLLABORATORS

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<td><a href="mailto:niel@astro.psu.edu">niel@astro.psu.edu</a></td>
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<tr>
<td>Gordon Garmire</td>
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2
TELESCOPE TIME AWARDED TO PI IN THE LAST 2 YEARS

Include upcoming awarded time. Give date, number of nights, telescope, instrument, program title, and briefly list status, results, and publications. Use an additional page if necessary.

Jan 22–29, 2002; 8 nights; UH 2.2m; QUIRC; “Optical Spectroscopy and NIR Imaging of Chandra Sources in the Lockman Hole”; data not yet taken
Jan 10–11, 2002; 2 nights; KeckI; LRIS; “Optical Spectroscopy and NIR Imaging of Chandra Sources in the Lockman Hole”; data not yet taken
May 10–11, 2001; 1.5 nights; Subaru; CISCO; “The Nature of the Chandra Hard X-ray Sources in the Region Around the HDF”; 0.5 night had thick cirrus; paper in prep (Barger et al.)
April 21, 2001; 1 night; Subaru; Suprime; “The Nature of the Chandra Hard X-ray Sources in the Region Around the HDF”; data being reduced
April 16–17, 2001; 2 nights; KeckI; LRIS; “The Nature of the Chandra Hard X-ray Sources in the Region Around the HDF”; mostly weathered out (only 3 hrs usable data); paper in prep (Barger et al.)
September 27, 2000; 1 night; KeckI; LRIS; “Submm Detections and Multiband Study of Faint Galaxies Behind Lensing Clusters”; completely fogged out
Queue, 2000b; 8 shifts; JCMT; SCUBA; “Submm Detections and Multiband Study of Faint Galaxies Behind Lensing Clusters”; <1.5 shifts obtained due to bad weather and instrument problems; Cowie, Barger, & Kneib, AJ, submitted
June 18, July 14–15, 2000; 1 night; Subaru; CISCO; “Submm Detections and Multiband Study of Faint Galaxies Behind Lensing Clusters”; Cowie et al. 2001, ApJL, 551, L9; second paper nearly completed (Hedrick & Barger)
Queue, 2000a; 6 shifts; JCMT; SCUBA; “Targeted Submm Observations of Optically Faint microjansky Radio Sources”; only 2 shifts obtained due to bad weather and instrument problems; Barger et al. 2001, ApJL, 560, L23; second paper nearly completed (Chapman et al.)
April 9–10, 2000; 2 nights; KeckII; NIRSPEC; “Near-infrared Spectroscopy of Submm Sources”; program not possible due to instrument problems
December 2–3, 1999; 2 nights; KeckII; LRIS; “Spectroscopic Redshifts and Properties of a Lensed Submm Sample”; completely weathered out
Queue, 1999b; 6 shifts; JCMT; SCUBA; “Deep Submm Detections of Very Faint Galaxies Behind Lensing Clusters”; only 3.75 shifts obtained due to bad weather; Cowie, Barger, & Kneib, AJ, submitted

Is this proposal part of an approved thesis program? If yes, list ALL telescope time awarded for the thesis above, and summarize the total amounts of time here:
LIST OF PUBLICATIONS OF THE PI OVER THE PAST 2 YEARS
Include only refereed and invited papers published or in press within two years prior to due date of application.
List facilities used for each paper.

[CHANDRA - ACIS, KECK - LRIS, CFHT - 8K]


on Relativistic Astrophysics, Austin, TX, eds. H. Martel, J.C. Wheeler, American Institute of Physics,
in press [SUBARU - CISCO, CHANDRA - ACIS, KECK - LRIS]

560, L23 [CHANDRA - ACIS, JCMT - SCUBA, KECK - LRIS]

[SUBARU - CISCO, CHANDRA - ACIS, KECK - LRIS]

[CHANDRA - ACIS, KECK - LRIS and ESI, CFHT - 8K]

[CHANDRA - ACIS, JCMT - SCUBA, KECK - LRIS, VLA, UH88 - QUIRC]

[CFHT - 8K, JCMT - SCUBA]

[JCMT - SCUBA, KECK - LRIS, CFHT - UH8K, VLA, UH88 - QUIRC]

[CHANDRA - ACIS, KECK - LRIS, UH88 - QUIRC]

315, 209 [JCMT - SCUBA, UKIRT - CGS4, KECK - LRIS]

Barger, A. J., 2000, “Submillimeter Surveys of High Redshift Galaxies,” in Highlights of Astronomy,

Surveys: Implications for Galaxy Formation and Evolution, Amherst, MA, eds. J. Lowenthal, D.H. Hughes, World
Scientific, in press [JCMT - SCUBA, CHANDRA - ACIS, KECK - LRIS, VLA]

Galaxies,” in Photometric Redshifts and High Redshift Galaxies, eds. Weymann, R.J., Storrie-Lombardi, L.J., Sawicki, M.,
Brunner, R.J., ASP Conference Series, Vol. 191, 279
[JCMT - SCUBA, KECK - NIRC, KECK - LRIS, VLA, CFHT - UH8K]


[JCMT - SCUBA, KECK - LRIS]

Richards, E. A., Fomalont, E. B., Kellermann, R. A., Windhorst, R., Partridge, B., Cowie, L. L., Barger,

Smail, I., Ivison, R. J., Kneib, J.-P., Cowie, L. L., Blain, A. W., Barger, A. J., Owen, F. N., Morrison, G. E.,

SCIENTIFIC JUSTIFICATION(S)
On the following pages, give the scientific justification for your program(s). Use any format you choose (e.g., an
integrated discussion of closely related programs, separate discussions for each program, or a general introduction
with separate detailed discussions). The scientific justification has a total limit of 5 pages of text, 2 pages of
figures or tables, plus references (no limit). You may embed figures and tables in the text, and you may substitute
figures or tables for text, but not vice versa. Use no less than an 11-point font and half-inch margins. Proposals
that exceed these limits will be returned to the submitter.
SCIENTIFIC JUSTIFICATION

Introduction

One of the fundamental goals of the Great Observatory program is to map the history of star formation and AGN activity throughout the lifetime of the Universe. To obtain a comprehensive and unbiased view, panchromatic observations of selected survey fields to great depths are needed.

The first generation of such surveys was compelled to target relatively small areas, such as the HDF-N and the HDF-S, due to the small camera size. However, because of the limited areas, the fields are probably not fully representative. In addition, some essential observations, such as deep X-ray observations to find obscured AGN and deep far-infrared (FIR) observations to obtain a comprehensive understanding of the dusty galaxy population, either had to await the launch of Chandra or are currently awaiting the launches of SIRTF and the new wide-field ACS camera on HST.

Now that the ultradeep X-ray observations with Chandra are well underway and the launches of SIRTF and ACS are imminent, we expect that over the next two or three years we will see a revolution in deep surveys: much wider fields will be targeted at a wide range of wavelengths, providing the most detailed accounting of the deep Universe ever obtained. Fortunately, the choice of northern field is already clear since the HDF-N region has been recognized as the main survey field. In X-rays, where this region is known as the Chandra Deep Field North (CDF-N), we have already obtained a 1 Ms exposure covering over 300 square arcminutes of sky, and a further 1 Ms is scheduled to be obtained in Cycle 3, which is just starting. The deepest SIRTF observations from the NIR to the MIR are also scheduled to be obtained on a roughly 100 square arcminute region around the HDF-N as part of the SIRTF Legacy program (PI Dickinson). It is expected that the HDF-N region will be intensively studied with ACS as part of the new HST Treasury program, although a final decision awaits the current review process. All of these programs will involve public release of the data and catalogs to the general community as soon as technically feasible. This method of operation has been extremely constructive in allowing a wide range of astronomers use the information for many different studies.

In the upcoming semester we will focus on the follow-up of the existing Chandra data, but it should be kept in mind how important the data will also be for the SIRTF and ACS programs.

X-ray surveys with Chandra

The apparent close correspondence between the evolution of nuclear activity in galaxies and their star formation rates (at least up to $z \sim 3$) and the observed relationship between the mass of supermassive black holes and that of their host galaxy bulges (Ferrarese & Merritt 2001; Gebhardt et al. 2001), suggests a fundamental connection between the histories of galaxy evolution and of energy production from accretion onto supermassive black holes. However, the physical nature of this relationship and its role in galaxy evolution remain unknown.

AGN are our window on supermassive black hole evolution since they directly trace accretion onto black holes. The observational tasks are to measure supermassive black hole properties, such as number density and mass distribution, as a function of redshift and to determine the nature of the host galaxies and their immediate environments. It is likely that most of the accretion power in the Universe is absorbed by substantial column densities ($> 10^{23} - 10^{24}$ cm$^{-2}$). Thus, the main challenge is to construct a complete census of AGN, including sources which are heavily obscured from soft X-ray energies to the NIR, back to the earliest epoch. This work is well underway for unobscured ‘type 1’ sources (i.e., quasars with broad emission lines and big blue bumps), but the obscured ‘type 2’ population is not well characterized at high redshift, except for the relatively rare radio galaxies.

X-ray surveys provide the most direct and unbiased probe of massive black hole accretion activity throughout the Universe, particularly in the hard X-ray band above 2 keV where most of the energy density of the extragalactic X-ray background (XRB) resides. At these energies the photons can penetrate all but the highest column densities of gas and dust. Thus, almost all obscured AGN will be detected and only the lowest redshift Compton-thick sources will not be seen. One of the driving goals behind the construction of Chandra was to create the deepest possible X-ray images of the Universe. The two recent 1 Ms exposures with Chandra (the Chandra Deep Field
North—CDF-N—and the Chandra Deep Field South—CDF-S) have now resolved $> 80 - 100\%$ of the 2–8 keV X-ray background into point sources (Brandt et al. 2001; Campana et al. 2001; Cowie et al. 2001), with the main uncertainty being the normalization of the background itself. Our recent analyses directly demonstrate that Chandra can efficiently probe the X-ray Universe $> 5$ times deeper in flux than that achieved with the 1 Ms exposures, before fundamental instrument limits begin to be reached. Following our doubling of the exposure time in the CDF-N to 2 Ms in Cycle 3, our ultimate goal is to obtain a 5 Ms exposure of the CDF-N over the next $\approx 5$ years. There are no plans to deepen any other field beyond the 1 Ms level, so the CDF-N will be an unique resource.

The flux limit decreases linearly with increasing exposure time. Even with the 1 Ms images we have very large samples. In the recently released CDF-N 1 Ms source catalog, there are 370 sources (Brandt et al. 2001). A similar number of sources are seen in the CDF-S (R. Giacconi et al., in preparation). Analyses of the number counts show a shallow but ongoing rise in the counts. In Fig 1 we show the differential 2–8 keV counts determined by Cowie et al. (2001), based on the CDF-N and CDF-S fields and the two Hawaii fields SSA13 and SSA22. The counts have a power-law slope of $-1.6$ at the faint end. Extrapolating this, we expect a sample of more than 500 sources in the 2 Ms exposure and 700 – 800 in the 5 Ms exposure of the CDF-N.

![Graph showing number of sources vs. X-ray flux.](image)

**Figure 1:** The combined differential counts from four Chandra deep fields are shown by the solid boxes with 1$\sigma$ uncertainties. The y-axis units are relative to a unit flux of $10^{-15}$ ergs cm$^{-2}$ s$^{-1}$. The solid lines show the maximum likelihood power-law fits over the flux ranges above and below $10^{-14}$ ergs cm$^{-2}$ s$^{-1}$. The dashed lines show counts from the ASCA and the BeppoSax satellites.

**The role of ground-based observations**

As can be seen from the preceding dicussion, our understanding of the X-ray counts to very faint fluxes has progressed rapidly; however, in order to understand in detail the nature and evolution of these sources, we need to cross-identify them with their optical and radio counterparts and spectroscopically determine their redshifts, or, where this is not possible, estimate their redshifts from their optical and NIR colors. We also need to obtain submillimeter measurements of the sample to study the contribution of AGN to the submillimeter background and to estimate how much of the energy in obscured AGN is being reradiated into the FIR. We have been able to make a substantial start on this (e.g., Barger et al. 2001c) by using existing spectroscopy and deep wide-field
imaging, as well as by using the portion of the CDF-N region previously observed with SCUBA. However, this essential follow-up work is still in the early stages, and much more data are needed.

The present proposal seeks to obtain follow-up optical spectroscopy with LRIS on Keck I and GMOS on Gemini, optical imaging with the CHF12K and SUPRIME on Subaru, NIR imaging with CISCO on Subaru and with QUIRC on the UH2.2 m, and submillimeter imaging with SCUBA on the JCMT of the X-ray sources identified in the 2 Ms observation of the CDF-N.

Our early Chandra follow-up observations

The excellent < 1" X-ray positional accuracy of Chandra permits the secure identification of the optical counterparts to the X-ray sources. One of the most interesting results obtained from our optical follow-up observations (e.g., Barger et al. 2001a,b) of the shallower 100 − 300 ks Chandra images is that almost half of the hard X-ray light arises in optically bright galaxies (I < 23.5) in the z < 1.5 redshift range. Almost all of the optically bright sources can be spectroscopically identified, and most are bulge-dominated galaxies with near-L* luminosities. Contrary to the situation for the faint ROSAT soft X-ray sources (Schmidt et al. 1998), the vast majority (> 80%) of the optically identified sources do not have broad optical or ultraviolet lines, and almost half show no obvious high ionization signatures of AGN activity (classed as 'normal' galaxies). The hard to soft X-ray flux ratios suggest that these 'normal' galaxies are highly absorbed systems whose high column densities could effectively extinguish the optical, ultraviolet, and NIR continua from the AGN and render traditional identification techniques ineffective.

Figure 2: An extremely high redshift AGN found in the Chandra sample of the CDF-N, compared with an SDSS quasar at a similar redshift.

The bulk of the remaining hard X-ray light arises in optically faint galaxies (I > 23.5), many of whose redshifts likely lie in the range z = 1.5 to 3 based on their colors (e.g., Cowie et al. 2001). However, a very intriguing possibility suggested by Haiman and Loeb (1999) is that a fraction of the optically faint sources may instead be low luminosity quasars at very high redshift (z > 5), since cold dark matter models indicate that a large number of such high redshift AGN should exist. In the model of Haiman & Loeb, each ultradeep Chandra ACIS-I exposure should detect ~ 100 moderate-luminosity AGN with z > 5. There are no obvious candidates for this class of object at the higher X-ray fluxes, but as we progress to lower fluxes, we have begun to see possible Haiman &
Loeb objects. One such object, whose spectrum was obtained last semester with LRIS on Keck I, is shown in Fig. 2. Continued spectroscopic follow-up at the fainter X-ray flux levels is needed to identify more such sources.

The 1–2 Ms exposures

Apparently normal galaxies continue to be significant contributors to the number counts at the faintest X-ray fluxes probed by the 1 Ms exposures. In the HDF-N proper we have detected X-ray emission from all galaxies with $z < 0.15$ and $M_T < -18$. The large number of normal galaxy detections is understandable, as we have now achieved the sensitivity needed to detect the most luminous ($> 2 \times 10^{39}$ ergs s$^{-1}$) X-ray binaries and supernova remnants at $z < 0.15$. The populations of X-ray binaries in galaxies are likely to show evolution with redshift in response to changes in the cosmic star formation rate (e.g., White & Ghosh 1998; Ptak & Griffiths 2001). Our 2 Ms Chandra observations will probe the X-ray emission from normal galaxies to moderate redshift and may reveal that AGN cease to dominate the X-ray number counts at extremely faint fluxes in a manner analogous to the dominance of star forming galaxies rather than AGN at very faint radio flux densities (e.g., Moran et al. 1999). It is important that we obtain redshifts for the X-ray sources in the 2 Ms exposure to determine this.

One of the most exciting avenues in the study of the hard X-ray source populations is determining the times and duration of distant supermassive black hole activity. Barger et al. (2001b) found that about 4% of the $> L^*$ galaxy population is X-ray luminous at any time and hence that black hole accretion has a duration of about half a Gyr. Furthermore, these authors found that about 30% of the summed hard X-ray flux is from sources at $z < 1$. Barger et al. (2001b) determined maximal mass inflow rates onto the supermassive black holes in the centers of the galaxies, from which they were able to evaluate the time history of the accretion rate density. They found the maximal integrated value to be reasonably consistent with the value inferred from the local black hole mass to bulge mass ratio.

The 2 Ms observation will provide strong X-ray constraints on obscured black hole activity at redshifts of $2 - 4$ and larger so that models for evolution of the X-ray luminosity function can be tested (e.g., Miyaji et al. 2000). At such redshifts, we might directly detect the obscured growth of many of the massive black holes in the Universe (e.g., Fabian 1999). Substantial numbers of the Haiman-Loeb $z > 5$ AGN may also be found in the 2 Ms sample, and if this does indeed turn out to be the case, will provide us with crucial information on the earliest stages of massive black hole formation.

PROPOSED OBSERVATIONS

Introduction

We currently have in hand $B$ (100 min), $V$ (100 min), $R$ (216 min), $I$ (62 min) and $Z$ (188 min) observations taken with SUPRIME in the spring semester 2001. These observations cover the entire Chandra field and are deep enough for most of the X-ray sources to have optical identifications. There is also a substantial archival database of spectroscopically identified objects in this region with the combined Hawaii and Caltech samples containing slightly more than 700 redshifts.

The optical properties of the X-ray sample are illustrated in Figure 3 where we plot the I magnitudes of the 186 objects in the $2 - 8$ keV selected sample in the 1 Ms CDF-N as a function of X-ray flux. The X-ray objects have a wide range of magnitudes at all fluxes but show a general trend towards fainter magnitudes at fainter fluxes as would be expected if we are picking up higher redshift or more obscured sources. The Chandra sources detected in softer bands show a similar trend. Where redshifts are known from the archival data or from earlier observations in this program we show the objects with a solid symbol. Experience with the X-ray sources in the 100 – 300 ks exposures, together with this archival material shows that essentially all Chandra sources brighter than $I = 23.5$ can be identified together with a fraction of sources with $I = 23.5 - 24.0$. Very few sources at fainter magnitude can be spectroscopically identified.

Spectroscopy

Only a small amount of progress has been made so far in spectroscopically identifying the unidentified objects in the 1 Ms Chandra sample since, while 2 nights of LRIS time was allocated to the program in spring 2001, nearly all of the time was weathered out with only 3 hours being usable. The $z = 5.18$ object shown in Figure 2
Figure 3: I magnitudes for the 2 – 8 keV sample of 186 sources detected in the 1 Ms CDF-N exposure. Objects fainter than $I = 25.8$ are shown at that value. Solid boxes show objects with spectroscopic redshifts and open boxes those without.

was observed during this period. This has left us with a sample of 106 unidentified objects with $I < 23.5$ and a further 20 objects between $I = 23.5 - 24$ which have yet to be spectroscopically observed. We expect the 2Ms will add very roughly 50 – 100 additional $I < 24$ objects to the sample bringing us to a total list of some 200 spectroscopically identifiable objects.

We propose to identify these primarily with Keck I LRIS which experience has shown is well suited to determining the redshifts and spectral characteristics of the faint X-ray sources. At the surface density of the X-ray sources we can include about 10 sources in an LRIS mask and include a further 10-15 sources selected in the radio (20cm) and optical to complete the mask. In general a 1 hour exposure will be sufficient to identify the sources and we can observe about 4 masks on the field per night when overhead is allowed for. We should be able to complete much of the sample in a four night run. Ideally this should be separated into two 2 night runs split by a month so that the more marginal objects can be reobserved. For the reddest objects we also wish to test whether GMOS, with its red optimization, can do a better job than LRIS and we have requested the equivalent of one night of observations to test this. For this type of observation the number of objects which can be fitted in a GMOS mask is similar to that of the LRIS mask and this request will allow us to obtain two hour observations of some of the faintest and reddest objects which might be observed in approximately 3 masks when overhead and the required setup observations are allowed for.

Optical Imaging

We also propose to deepen the optical data with the CFH12k and SUPRIME on Subaru to try to identify the faintest optical counterparts to the X-ray sources but more importantly to allow us to make precision photometric redshift estimates for the sources which are too faint to allow spectroscopic identifications. TBD......

References

TECHNICAL JUSTIFICATION

Discuss the feasibility of the observations and justify the amount of telescope time requested. The technical justification is limited to one-half page per run. Use an additional page for each run.

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Our observing goal is to determine redshifts and spectral characteristics for the hard X-ray sources detected in our *Chandra* 1 Ms exposure of the CDF-N region. The 300 line/mm grating will maximize our spectral coverage (3900-9000Å) and enable us to identify standard emission lines in AGN and star forming galaxies. Based on our past experience with LRIS hard X-ray source follow-up, we anticipate that each object will require ~ 1.5 hours integration time. Our proposed strategy is to make masks for our observations. The ACIS-I field-of-view is large (16.9' × 16.9'), and there will be some overlap of sources, so we expect to need about 12 masks to adequately cover the region. With overheads, this will require three nights of LRIS time. We will fill out our LRIS masks with radio and soft X-ray sources. If dark LRIS time is highly oversubscribed, some of these observations could be done with ESI; however, that instrument does not currently have a multi-slit capability, which means that the efficiency is much lower and therefore more nights will be required to do the same science. The spectroscopic observations should ideally come after the Subaru SUPRIME imaging to aid in source selection.

**LIST OF PRINCIPAL OBJECTS** *(to be studied in run justified above)*

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<td>A</td>
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<td>12 36</td>
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TECHNICAL JUSTIFICATION
Discuss the feasibility of the observations and justify the amount of telescope time requested. The technical justification is limited to one-half page per run. Use an additional page for each run.

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<tr>
<td>A</td>
<td>Subaru</td>
<td>SUPRIME</td>
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The proposed observations are to obtain $B$, $V$, $R$, and $I$-band VLA radio sources detected in the HDF region. In Barger, Cowie, & Richards (2000), we found that 40 $\mu$Jy radio sources fainter than $I = 25$ are generally detectable in the submillimeter, while those brighter than this are not; thus, it is reasonable to choose this magnitude as the 5$\sigma$ benchmark for the current observations. In order to make color redshift estimates, we require deeper observations at the bluer wavelengths, so we take $R = 26$, $V = 26.5$, and $B = 27$ as the necessary 5$\sigma$ limits. Using a 3'' diameter aperture, which is optimal for the high redshift galaxy work even in good seeing conditions, we require a 40 minute exposure in $I$. (Subaru uses a small 1.5'' aperture for its posted limits.) Star streaking is an extremely severe problem with SUPRIME, and a fraction of the sources will be lost to this effect if the image is taken in only one orientation; thus, we must take two exposures at a 90 degree rotation. Filter placement and readout times (4 minutes) are very long, so the on-target efficiency is about 50%, and we need approximately 3 hours per color. Allowing time for calibrations and other overheads, we request 2 Subaru nights with SUPRIME. The SUPRIME observations ideally need to be taken as early as possible to aid in source selection for the Keck LRIS and Subaru CISCO observations.

LIST OF PRINCIPAL OBJECTS (to be studied in run justified above)

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TECHNICAL JUSTIFICATION

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| Run No: |  | Telescope: Subaru | Instrumentation: CISCO |
|---------|------------------------|------------------------|

The proposed observations are to obtain K′-band imaging with CISCO of the optically faint hard X-ray sources detected in our 1 Ms Chandra exposure. Based on CISCO data previously obtained for other programs, we have prepared fully operational reduction programs and characterized the device and its limits. The plate scale is measured at 0.111″, giving a field of view of 1.9′ on a side (slightly smaller than advertised on the Subaru site but still 9 times the NIRC field-of-view!) The K′ sky surface brightness is slightly high (∼ 13.1 mags per square arcsecond). The CISCO data reduce extremely well, and the image quality of Subaru is superb. We wish to obtain $K' = 23$ ($5\sigma$) on the optically faint hard X-ray sources. This will require a 3 hour exposure in K′ for each field targeted. The surface density of optically faint sources will be high enough that we will be able to pick regions that contain several sources per field to observe with CISCO. Given the observing overheads (∼ 25%), we will need a total of two nights to obtain a statistically significant sample. Since no guiding is required (the Subaru tracking is good enough), the program can be executed in any sky brightness, including full moon. The Subaru CISCO observations should ideally come after the Subaru SUPRIME imaging to aid in source selection.

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TECHNICAL JUSTIFICATION

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<th>Run No: A</th>
<th>Telescope: JCMT</th>
<th>Instrumentation: SCUBA</th>
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We expect ~ 190 hard X-ray sources in the Chandra 1 Ms exposure of the CDF-N region. If the source distribution is similar at faint X-ray fluxes, then based on our 100 Ks SSA13 hard X-ray survey, we expect 35% to be optically faint; these are potentially highly obscured sources at $z > 1$ detectable by SCUBA. Chapman et al. (2000) achieved a $3\sigma$ sensitivity of 4 mJy in an effective integration time of ~ 30 min using a three bolometer chop. Since the 850\(\mu\)m flux limits obtainable with SCUBA are quite close to the expected fluxes from obscured AGN, we would aim for a $3\sigma$ sensitivity of 2 mJy, which would require ~ 2.2 hrs integration or ~ 3 hrs per source with overheads. We could do 2 – 3 sources per night. We request 8 shifts of SCUBA time to target a statistically significant sample. Queue scheduling is fine for this program. The observations require $\tau(\text{CSO}) < 0.08$.

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