Black Holes from Stars to Galaxies – Across the Range of Masses
Proceedings IAU Symposium No. 238, 2006
V. Karas & G. Matt, eds.

doi:10.1017/S1743921307005169

A survey of AGN and supermassive black holes in the COSMOS Survey

Chris D. Impey,[1]† Jon R. Trump,[1] Pat J. McCarthy,[2] Martin Elvis,[3] John P. Huchra,[3] Nick Z. Scoville,[4] Simon J. Lilly,[5] Marcella Brusa,[6] Günther Hasinger,[6] Eva Schinnerer,[7] Peter Capak[4] and Jared Gabor[1]

[1]Steward Observatory, University of Arizona, Tucson, AZ 85721, USA
[2]Carnegie Observatories, 813 Santa Barbara Street, Pasadena, CA 91101, USA
[3]Harvard-Smithsonian Center for Astrophysics, 60 Garden Str., Cambridge, MA 02138, USA
[4]California Institute of Technology, MC 105-24, Pasadena, CA 91101, USA
[5]Department of Physics, Swiss Federal Institute of Technology, CH-8093 Zurich, Switzerland
[6]Max Planck Institut für Extraterrestrische Physik, D-85478, Garching, Germany
[7]Max Planck institut für Astronomie, Königstuhl 17, Heidelberg, D-69117, Germany

Abstract. The Cosmic Evolution Survey (COSMOS) is an HST/ACS imaging survey of 2 square degrees centered on RA = 10:00:28.6, Dec = +02:12:21 (J2000). While the primary goal of the survey is to study evolution of galaxy morphology and large scale structure, an extensive multi-wavelength data set allows for a sensitive survey of AGN. Spectroscopy of optical counterparts to faint X-ray and radio sources is being carried out with the Magallen (Baade) Telescope and the ESO VLT. By achieving ~80% redshift completeness down to $I_{AB} = 23$, the eventual yield of AGN will be ~1100 over the whole field.

Early results on supermassive black holes are described. The goals of the survey include a bolometric census of AGN down to moderate luminosities, the cosmic evolution and fueling history of the central engines, and a study of AGN environments on scales ranging from the host galaxy to clusters and superclusters.

Keywords. Active galactic nuclei – supermassive black holes – surveys

1. Introduction

The Cosmic Evolution Survey (COSMOS) is the first survey with the ideal combination of depth and area to study the coupled evolution of large scale structure, star formation, and nuclear activity in galaxies, see Scoville *et al.* (2007a). The core data set is a 2 deg^2 HST/ACS mosaic made up of single orbit exposures in the F814W (I) band that reach a 5σ depth of $I_{\rm AB} = 28.6$ for point sources. The field is aligned N-S, E-W, and is centered at RA = $10^{\rm h}\ 00^{\rm m}\ 28.6^{\rm s}$, Dec = $+02^{\rm o}\ 12'\ 21''$. Astrometry across the field has a relative precision of 0.05 arcseconds (absolute to ~0.2 arcseconds) and relative fluxes are accurate to 1% (absolute to ~10%). Parallels with WFPC2 and NICMOS cover 55% and 5% of the field, respectively. Details of the HST observations are in Scoville *et al.* (2007b).

The COSMOS field is accessible to all major observing facilities and is the subject of an extensive campaign of multi-wavelength observations. Ground-based imaging from Subaru, CFHT, UKIRT, and NOAO in 7 bands from U to $K_{\rm s}$ has yielded $\sim 8 \times 10^5$

---

† Based on observations with the NASA/ESA *Hubble Space Telescope*, obtained at the Space Telescope Science Institute, which is operated by AURA Inc, under NASA contract NAS 5-26555; also based on data collected at the Magellan Telescope, which is operated by the Carnegie Observatories, and the VLT, which is operated by the European Southern Observatory.

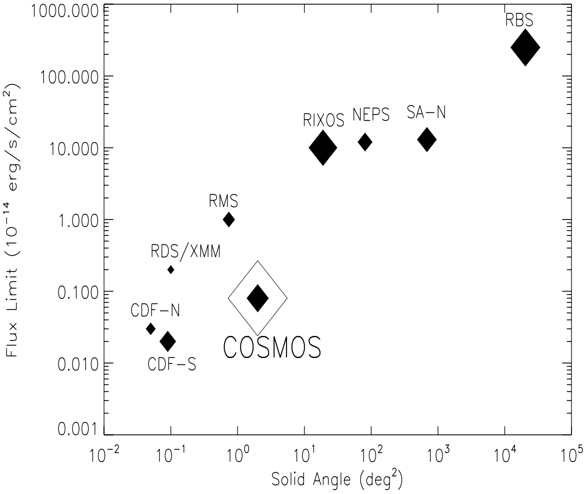

Figure 1. The power of the COSMOS survey for AGN studies is shown when the depth and solid angle of various X-ray surveys are compared. Symbol size is proportional to the number of spectroscopically-confirmed AGN; the solid diamond for COSMOS is the yield for this paper and the companion paper of Trump *et al.* (2006) and the open diamond shows the expected yield after the spectroscopic survey is complete. From left to right, the surveys plotted are the twin Chandra Deep Fields, the ROSAT/XMM deep survey of the Lockman Hole, the ROSAT Medium Deep Survey, ROSAT International X-ray Optical Survey, the ROSAT North Ecliptic Pole and Selected Areas North Surveys, and the ROSAT Bright Survey.

photometric redshifts from among the $\sim 2 \times 10^6$ galaxies in the ACS catalog, and VLT observations over the next 2-3 years will deliver $\sim 38,000$ galaxy redshifts. The VLT and Magellan telescopes are being used to measure spectroscopic AGN redshifts, as described here. Beyond the optical and near infrared parts of the spectrum, full coverage of the field has been obtained at radio (VLA), infrared (Spitzer/IRAC), ultraviolet (GALEX), and X-ray (XMM) wavelengths, and partial sub-millimeter coverage will come from the CSO and IRAM facilities. Deep Spitzer/MIPS and Chandra observations are scheduled. A more complete description of ancillary data is presented by Scoville *et al.* (2007a).

The significance of the COSMOS survey for AGN is conveyed in Figure 1, which shows the X-ray flux limit and areal coverage of a number of recent surveys, with a symbol size proportional to the number of spectroscopically-confirmed Type 1 AGN. The statistics for other surveys are taken from a compilation of Hasinger, Miyaji & Schmidt (2005). The filled diamond for COSMOS reflects the outcome of the 2005 season of Magellan observing, as described by Trump *et al.* (2007), with 106 new AGN adding to 40 existing SDSS AGN. The open diamond projects the eventual yield from our single pass survey, 350 Type 1 AGN, easily exceeding any other contiguous deep field.

2. Optical spectroscopy

The majority of the AGN candidates are being observed with the Magellan (Baade) telescope at Las Campanas, using the IMACS imager and spectrograph. We use IMACS with the 200 line prism and a 565–920 (or OG 570) filter, giving wavelength coverage of 5400–9200 Å (or 5500–9100 Å). The dispersion was 2 Å pixel^{-1} and the FWHM of an unresolved line was 5 pixels, giving effective resolution of 10 Å, or ~ 1000 km s^{-1}, sufficient to distinguish broad emission line (Type 1) from narrow emission line (Type 2) AGN. IMACS is most effective when used in nod–and–shuffle mode, see Abraham *et al.* (2004). We generally adopted a slit 11 arcseconds long and 1 arcsecond wide, with a 1.8 arcsecond nod between the two positions. Additional details of slit placement efficiency and redshift yield are given in the companion paper that presents spectra from the first season of observing, see Trump *et al.* (2007).

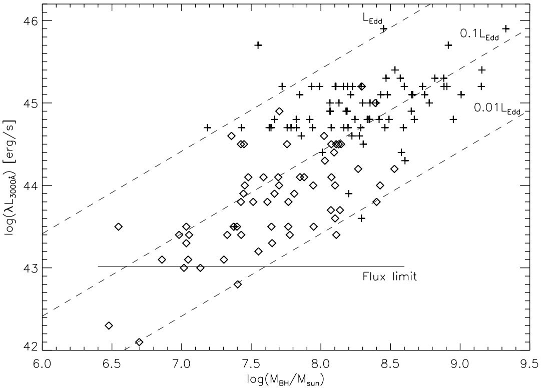

Figure 2. Optical luminosity versus black hole mass for Type 1 AGN in the COSMOS field from the IMACS (diamonds) and SDSS (crosses) surveys. The black hole masses are calculated from scaling relations applied to broad line velocity widths: CIV, MgII and Hβ depending on the redshift, using the techniques of McLure & Jarvis (2002) and Vestergaard & Peterson (2006). Tracks of luminosity relative to the Eddington value are shown as dashed lines. The solid horizontal line corresponds to the flux limit of the spectroscopic survey.

3. Black hole science

After one season of spectroscopic follow-up, the survey has produced 86 new Type 1 AGN and 130 new Type 2 AGN with high reliability classification and redshifts, as detailed by Trump *et al.* (2007). An additional 18 Type 1 AGN and 11 Type 2 AGN had lower reliability classification. The projection is ∼850 AGN at the end of the one-pass Magellan survey in 2007, counting only the high reliability redshifts. The total yield of AGN with all qualities of classification and redshift will be ∼1100, and the VLT multi-pass survey will add to this number by going deeper and picking up the brighter objects that IMACS will not target. This total includes ∼90 AGN from the SDSS spectroscopic coverage of the COSMOS field.

A first look at the black hole demographics revealed by the COSMOS survey is shown in Figure 2. Monochromatic optical luminosity is plotted against black hole mass for 63 Type 1 AGN with IMACS observations and 59 Type 1 AGN from SDSS observations of the COSMOS field. We will move to working with the (more physically meaningful) bolometric luminosities now that recent Spitzer data are in hand. The luminosity is rest-frame, calculated using a power law fit to the continuum after subtraction of Fe blends, the same continuum fit is used for broad line fitting. The same procedure was used for SDSS and IMACS spectra. The black hole masses are based on broad line width scaling relations of CIV, MgII and Hβ, as described by McLure & Jarvis (2002) and Vestergaard & Peterson (2006). The dashed lines show tracks for 100%, 10%, and 1% of the Eddington luminosity, based on an assumption that the monochromatic optical luminosity at 3000Å is 20% of the bolometric luminosity.

This one region of sky yields SMBH spanning three orders of magnitude in mass and the fainter COSMOS sample extends to less efficient accretors than the SDSS. The data in Figure 2 occupy the same parameter-space as the three dozen local reverberation mapping calibrators, from work by Peterson *et al.* (2004). The spectroscopic flux limit of $I_{AB} = 23$ prevents the detection of the extremely low accretion efficiencies; it is represented approximately in Figure 2 as a horizontal line at a luminosity corresponding to $z = 0.6$, the 90% envelope of the AGN sample. Very low mass black holes are censored from the lower left part of the plot in a more complex way since the mass scales as $(FWHM)^2$ and $(\lambda L)^{0.7}$ and emission lines become undetectable or unmeasurable due to a combination of strength and breadth. Selection effects will be modeled in future work.

4. Conclusions

The COSMOS survey was primarily designed to trace the evolution and large scale structure of normal galaxies, but superb multi-wavelength data and the unique combination of areal coverage and depth make it an ideal vehicle for studying the evolution of supermassive black holes down to lower masses than has been possible in any other AGN survey. AGN activity will also be linked to fueling mechanisms on scales from the host galaxy to surrounding clusters.

Acknowledgements

We acknowledge the dedicated efforts of everyone on the COSMOS team who contributed to the reduction of ACS data and the generation of catalogs. We are grateful to Alan Dressler and the IMACS team for a superbly functioning instrument, and the staff at Las Campanas Observatory for excellent technical support on the mountain. We are very grateful to Marianne Vestergaard for giving us access to results ahead of publication. The HST COSMOS Treasury program was supported through NASA grant HST-GO-09822.

References

Abraham, R. G. *et al.* 2004, AJ, 127, 2455
Hasinger, G., Mijayi, T. & Schmidt, M. 2005, A&A, 441, 417
McLure, R. J. & Jarvis, M. J. 2002, MNRAS, 337, 109
Peterson, B. M. *et al.* 2004, ApJ, 613, 682
Scoville, N. Z. *et al.* 2007a, ApJS, in press
Scoville, N. Z. *et al.* 2007b, ApJS, in press
Trump, J. R. *et al.* 2007, ApJS, in press
Vestergaard, M. & Peterson, B. M. 2006, ApJ, 641, 689

DEBORAH DULTZIN-HACYAN: Comment: With respect to companions to AGN, there is an important difference between type 1 and type 2 objects. Recently, we (Koulouridis *et al.* 2006) confirmed, by applying a three-dimensional analysis, that Sy2s do have excess companions with respect to a control sample of non-active galaxies of the same redshift distribution, the same morphology apart from the nucleus, etc. On the other hand, Sy1s don't show such excess. Can you comment any preliminary results in this context?

CHRIS IMPEY: In our analysis we do not have enough statistics to perform such analysis of structures.

MARGARITA SAFONOVA: Can you comment on AGN without any host galaxies in your sample

CHRIS IMPEY: There have been several celebrated and refuted claims of naked AGN at low redshift – this could happen e.g. if one has a binary supermassive black hole of which one member gets ejected and is floating in the space – but with sufficient sensitivity people always found a host galaxy in the end.

SUZY COLLIN: Comment: Regarding the reverberation mapping studies, there can be a selection effect for small broad-line region which point toward small masses.