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Synergizing Deep Field Programs Across Multiple Surveys

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Abstract:
A critical component of many past, present and future astronomical surveys is a dedicated deep field program. Relative to normal survey or general observing programs, these programs commit multiples of observing time to specific parts of the sky. As we enter the era of systematic limited cosmology surveys these fields will become critical for multiple scientific and calibration purposes and typically constitute $5-20\%$ of observing time. Furthermore, with more powerful telescopes and experiments being planned, the potential of multi-factor (e.g. wavelength, resolution) synergy is becoming increasingly important and it is hence imperative the community co-ordinate plans for the deep field programs with current and future facilities. Here we discuss missed opportunities from past lack of deep-field coordination and typical deep field selection criteria. To help with this process, we release a public repository of information on deep fields aimed at collecting that information in order to reach a consensus on future co-ordinated observations. We created a common template that captures information about the observing strategy and characteristics of each field and survey, and reached out to the community to fill in this template. With this process, we have created an easy-to-understand website that presents information on each deep field including position, wavelength coverage, resolution, depth, cadence, etc. We discuss tools that can be used with this database, and encourage future missions to contribute to this in order to better build more synergy across the next generation of surveys. A repository of information with example files can be found at: https://github.com/pcapak/Astronomy-Deep-Feild-Information.

1 Introduction

Deep fields have been a fixture of modern astrophysics since the advent of digital detectors allowed for co-addition of background limited imaging and spectroscopy. Early efforts such as the *Hubble* and Hawaii Deep fields imaging [1] were focused on counting faint sources to constrain galaxy evolution to high redshifts and were closely coupled with follow-up spectroscopic efforts [2, 3] to understand galaxy surveys.

It was quickly realized that significant synergy existed between these deep imaging surveys and searches for transient events, such as Type-Ia supernova used for cosmology measurements [4]. Thus, to maximize science, surveys began to co-optimize for multiple scientific goals. During this era, imaging surveys such as the Canada-France-Hawaii Legacy Survey (CFHT-LS) [5] began planning deep fields that were optimized for both galaxy evolution and cosmology. With the advent of the great observatories in the early 2000's, researchers began to co-ordinate multi-wavelength and multi-epoch imaging campaigns to ensure that a broad range of scientific issues could be tackled with the same data. That approach resulted in major collaborations such as the Great Observatories Origins Deep Survey (GOODS) [6], the Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (CANDELS) [7, 8], and the Cosmic Evolution Survey (COSMOS) [9] teams, as well as many smaller but high-impact groups [e.g. 10, 11].

The current generation of imaging and spectroscopic surveys such as the Dark Energy Survey (DES), the Large Synoptic Survey Telescope (LSST), *Euclid*, WFIRST, the Subaru Hyper-Suprime Cam Survey (HSC), The Subaru Prime Focus Specrograph Survey (PFS), and the Dark Energy Spectroscopic Explorer Instrument (DESI) all include deep fields for scientific and calibration reasons. For instance, recent work on photometric redshifts in DES has highlighted the importance of choosing deep fields in a synergistic way [12]. By using the wealth of data available in the COSMOS field, DES was able to improve the cosmological constraints by 60%. However, COSMOS was not in the original DES survey design and the required data for this analysis was observed by DECam as GO program [13].

For scientific, technical, and sociological reasons, deep field efforts have seldom been coordinated. The result has been a significant investment of telescope resources in areas of the sky that are not subsequently followed up by other facilities. In those cases, data are of limited use and the maximum scientific potential is not achieved. Contemporary spectroscopic surveys such as DEEP2 [14] and VVDS [15] and imaging surveys such as the Subaru XMM Deep Field [16] and CFHT-LS did not necessarily coordinate observations with each other resulting in deep fields that are sometimes only a few degrees degree apart on the sky. For instance hundreds of nights of telescope time were spent on the CFHT-LS D1, SXDS, UKIRT-UDS, VVDS ultra-deep, and the DEEP2 2h field which have targets within a few degrees of each other that were not coordinated. This contrast with the COSMOS survey where observations were coordinated on one area of the sky. As a consequence, the impact of COSMOS in the literature is considerably higher ($\sim$80 publications per year, a factor $3-4$ with respect to the other mentioned fields).

In this white paper, we argue that the community should coordinate deep field observations with future facilities. Decades of experience with extra-galactic surveys have yielded a well defined set of criteria for selecting deep fields across wavelengths. Considering these constraints only a limited number of sky areas are truly optimal.

Ideally, the locations of these fields on the sky should be considered when designing future facilities. In the current paradigm, the location of deep fields is often an afterthought, decided when hardware and global observing strategy have already been designed. Persisting with such approach while planning next-generation surveys will result in a significant loss in scientific synergy. We argue that deep fields should be identified during the early stage of hardware and science design, as the amount of time dedicated to them will be comparable to the other sky regions to be covered. To this purpose it is pivotal to know what are the existing and planned deep-field data that may be beneficial to the new project.

2 Deep Field Selection Criteria

By definition deep fields require significant amounts of observing time and so are often chosen to be optimal for a given facility. Unfortunately, the optimal choice is different for ground- and space-based observatories and for different wavelengths. Despite the different optimization Rhodes et al. [17] and Jain et al. [18] show there are several clear advantages in having observatories such as LSST, *Euclid*, and WFIRST observe the same regions of the sky even if for some of these telescopes the observing strategy is sub-optimal. The primary benefit comes from maximizing the overlap of observations to increase the amount of information available for calibration and galaxy evolution studies. Here we outline the collective constraints on deep field choices and in the next section we will outline several existing deep fields and suggest the community

Space Based Considerations: In space, the entire sky is visible, and the primary background at optical and near-infrared wavelengths is the zodiacal light. Therefore sensitivity varies strongly with ecliptic latitude, exponentially decreasing as observations approach the ecliptic plane. In addition orbital geometries mean observing windows and potential visits frequency is considerably higher at the ecliptic poles. Specifically, the need for solar shielding, power generation, and earth/moon avoidance means the satellite-sun-earth angles are constrained. This results in areas at the ecliptic poles that are continuously observable in fixed semi-annual windows, with the time interval of such windows that becomes shorter as approaching the ecliptic plane. The exact observability depends on the geometric design of the satellite and its orbit, so knowing deep fields in advance could place constraints on the system design. Finally, the Large Magellanic Cloud is near the south ecliptic pole so its necessary to avoid the exact pole.

Ground Based Considerations: From the ground, the latitude of the observatory on earth and atmospheric characteristics determine which are the accessible sky regions and what level of sensitivity can be reached. Furthermore, higher atmospheric column (airmass) degrades data quality due to increased absorption by the atmosphere. Higher airmass also increases the background at infrared and sub-mm wavelengths further reducing sensitivity. This drives deep field optimization to the sky area perpendicularly above the observatory, where the airmass is minimized with no strong dependence on ecliptic latitude.

In practice the best observing sites are split between the northern and southern hemisphere at mid latitudes. Furthermore, unique facilities exist in each hemisphere, with no comparable counterpart on the other (for instance VLA and Subaru in the North and ALMA and LSST in the South). So collectively, the combination of sensitivity and multi-facility observations drives optimization to equatorial fields which are equally good for all observatories.

The need to observe at night and during periods of good weather also places a cadence constraint on ground-based observations. This means fields are often chosen to be in regions of the sky that correspond to dry seasons for a given observing site.

Galactic Extinction/Emission: Ideal deep fields for cosmology and extra-galactic studies should be in regions of the sky with low and uniform galactic extinction. By definition, these regions also corresponds to the ones with low infrared and HI emission, which are problematic for infrared, sub-millimeter, and radio observations as well as observations of the cosmic microwave background.

Bright Objects: Bright objects cause considerable problems in long exposure observations. In deep fields they produce reflections and/or imaging side-band effects in interferometers, and can even damage some types of detectors. The light halo generated from the extended point-spread function of these objects also causes pixels relatively far from thm to be unusable. Even bright sources several degrees away from the field of view can cause problems with scattered light and reduced sensitivity.

Problematically, flux of many bright objects varies considerably as a function of wavelength, so they are not considered consistently by different surveys. For instance R-Doradus is the brightest star on the sky at near-infrared wavelengths but is 8 magnitudes fainter in the optical. Complicating matters, many of the brightest objects are saturated and hence missing from modern astronomical databases; thus, they can be (and have been) inadvertently missed in planning observations.

Stellar density and proximity to the galactic plane: The density of stars in a field increases the scattered background light from ultraviolet through near-infrared pass-bands, decreasing the overall sensitivity of the observations and leading to increased confusion noise. Background further increases for observations in space proximity to the galactic plane, and sensitivity decreases.

3 Suggested Field Optimization

It is surprisingly difficult to collect information detailed enough for planing observations on current deep fields. To facilitate planning and synergies between surveys we have created a template for describing observations of the deep fields. We envision this as two database tables, one detailing the overall observations for an entire project and one detailing the detailed time domain cadence of the observations. Table 1 and 2 in this paper describe the rows in the overall and time domain tables respectively. The overall idea of this structure is to facilitate the collection of this information with the goal of selecting a consensus set of fields for deep field observations going forward.

To make the best use of future facilities we strongly suggest the extra-galactic and cosmology community undertake an effort to define a fixed set of deep fields that are incorporated into future design decisions. It is clear from the above discussion of constraints that multiple fields will be needed, but the possible choices are limited both by existing data and overall constraints. In this white paper we have provided a facility to collect the relevant information on existing deep field observations to facilitate this process.

We request observers with relevant data sets provide these meta data to facilitate future co-ordinated planning of observations and missions. We are providing facilities to convert these information to standardized JSON files and to plot/overlay the results for future observation planning.

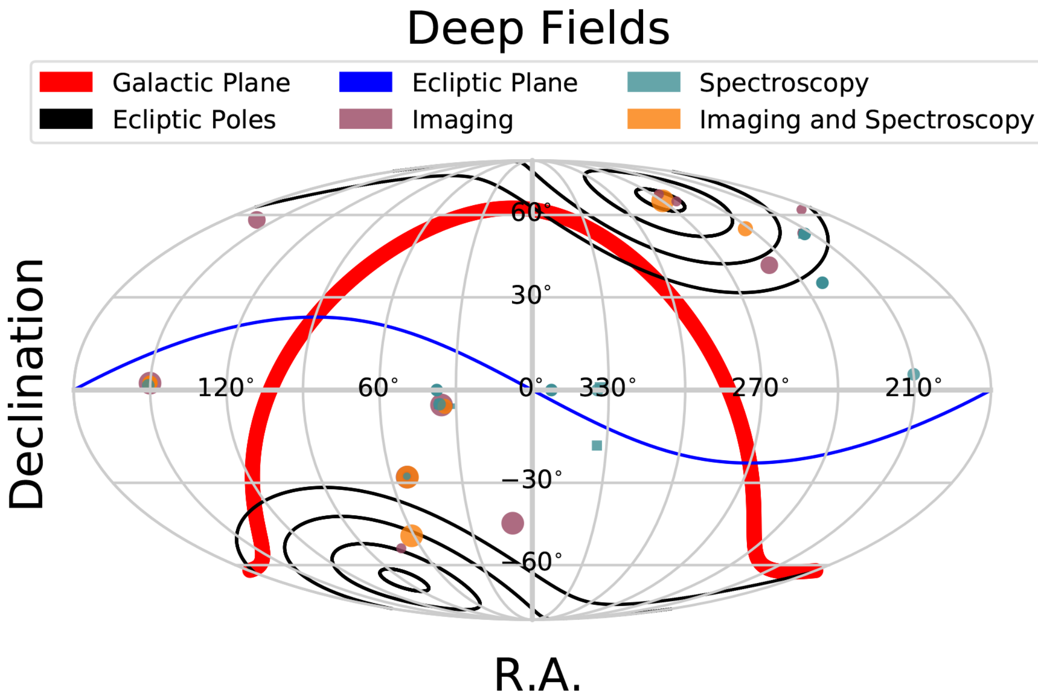

Figure 1: The locations of various existing deep fields on the sky are shown. Black lines 5, 15, 25, and 35 degrees from ecliptic poles are marked in black and the ecliptic plane is marked in blue. The galactic plane is indicated with a red line.

Simply collecting this information highlights several common but non-identical choices. For instance, it is clear an area within a few degrees of the North Ecliptic pole should be defined. All space observatories carry out calibrations in this area, but these have been at slightly different locations with JWST on track to create a new area offset from the previous ones. A region of low-extinction near the south ecliptic pole should be chosen. The Akari Deep Field is in the search area and has been heavily observed, but contains stars that are too bright for observations with Euclid or LSST. Furthermore, the areas on the celestial equator (DEC=0) at RA=30 (2h, CFHT-LS, SXDS, VVDS, DEEP2, UDS) and RA=150 (10h, COSMOS) near the celestial equator have clearly been chosen by many surveys as has the Chandra-Deep Fields South at RA=52.5 (3.5h), DEC=-33 and the Extended Groth Strip at RA=215 (14.3h), DEC=+52.9.

4 Conclusions

Dedicated deep field programs will be a key element of the next generation of astronomical surveys. Given the importance of synergy from different surveys to address different science issues, we strongly advocate for a renewed focus on coordinating planning of deep-field programs. To help with coordination, we release a repository that collects common information about past, present and future deep field programs. We ask astronomers to contribute to this repository and coordinate future deep field programs. A repository with examples is provided at https://github.com/pcapak/Astronomy-Deep-Feild-Information.

Table 1: Summary Information for Each Survey.

Key	Explanation[a]
Unique identifier	[Surveyname_Fieldname_Dataname]
Survey name	
Field name	[Unique human readable identifier for location on sky]
Telescope	
Instrument	[Camera/spectrograph name]
Data type	[Spectroscopy/Imaging/IFU/Prism/Grism]
Data name	[Imaging Band or Spectral Setup (e.g., grating, blocking filters)]
Data status	[Acquired/In Progress/Planned/Planning]
Area of data set	[In square degrees]
Pixel size	[In arcseconds]
Total integration time	[In hours]
Average PSF FWHM	[Over all exposures, in arcseconds]
Total point source sensitivity	[5σ in AB mag]
Effective wavelength	[In Angstroms]
Spectral resolution	[$\lambda/\Delta\lambda$]
Min wavelength	[In Angstroms]
Max wavelength	[In Angstroms]
URL to data if public	
Citation	[DOI to document that explains deep field program]
Modified Julian Date start	
Modified Julian Date end	
Definition of nominal 'visit' unit	[For cadence purposes, define here what a typical visit is]
Total number of visits over survey	
Cadence Type	[Text description of general cadence routine in units of visits]
Average Cadence	Visit intervals in days, could be list if repeated cadence
Depth per visit	[5σ in AB mag]
Exptime per visit	[In seconds]
URL to survey layout	[DS9 `.reg` file(s)]
URL to depth map layout	[`healpix` file(s) in units of AB mag]

[a] when a key does not apply to the given survey, a special value ("N/A" or -99) will be inserted.

Table 2: Summary Information for Each Survey.

Key	Explanation
Unique identifier	[Matching to table 2]
Modified Julian Date	
Exposure Time	[In seconds]
PSF FWHM	[In arcseconds]
Point Source Sensitivity	[5σ depth in AB mag]
FOV Center (RA/DEC)	[In decimal degrees]
FOV Position Angle	[In degrees, east of north]
FOV Type	[ellipse OR rectangle]
FOV shape	[a, b OR $dxdy$, in degrees]
URL to survey layout	[DS9 `.reg` file(s)]
URL to depth map layout	[`healpix` file(s) in units of AB mag]

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