HST Frontier Fields Midterm Review Committee Report 2014

TO: K. Sembach, I. N. Reid, M. Mountain, and K. Flanagan
FROM: The HST Frontier Fields Midterm Review Committee

This committee was tasked with reviewing the HST Frontier Fields program and asked to evaluate the scientific progress, data quality, and STScI's stewardship of the initiative to date. We were further asked to discuss the science case for observing the two remaining clusters and paired blank fields and to make recommendations for improvements to the existing program.

Executive Summary:

- The Frontier Fields program is addressing the original science goals outlined by the HDF Working Group, the data are of very high quality, and STScI has been an exceptionally responsible steward of the initiative.
- The Frontier Fields have generated considerable enthusiasm within the community. There are three international workshops occurring in the 2014-2015 academic year dedicated to the FF and approximately 40 papers referenced FF data within a year of the first data release. Multiple campaigns to obtain ancillary data are underway (including Spitzer, Chandra, ALMA, VLA, VLT, HAWK-I, MUSE, Gemini, and Keck) and three complementary HST GO programs were approved in Cycle 22.
- Our recommendation is to complete the remaining two cluster fields. The original motivations laid out by the HDFWG are sound and the rate of detections so far is consistent with their expectations. Moreover, the community has been investing and preparing for these targets by collecting auxiliary data. With momentum building, it is our view that HST should proceed as planned. Doing otherwise would compromise science goals and disrupt the progress of the community.
- Challenges remain with updated and accurate lens maps. We recommend that STScI fund a program to provide new lens maps for completed FF clusters that utilize the updated HST images and any new redshifts that have become available since the program began. We further suggest that STScI work to promote efforts among lensing groups to use simulation mocks to improve and test the modeling techniques that are used to produce these maps

Overview:

In addressing the questions asked of us, this committee looked closely at the science output of the FF program so far and sought the opinions of outside experts in the area of deep-field science and cluster/lensing science. We met in Baltimore on October 13-14,

2014 to interview leaders of the FF implementation program and data archive teams (D. Coe, A. Koekemoer, and J. Lotz) and to hear presentations by nine outside community users of the data (M. Bradac, S. Finkelstein, R. Livermore, S. Rodney, B. Siana, T. Treu, and A. Zitrin). The Chair of this committee (Bullock) was present at an independent workshop focused on the Frontier Fields held at Yale in November 2014 and he interviewed the organizer of this workshop (P. Natarajan) afterwards. We further requested and received four written letters from additional experts, who provided their opinion on the progress of the FF program (all five were positive: R. Bouwens, T. Broadhurst, J. Richard, B. Robertson, and R. Windhorst).

Before providing our point-by-point response to the questions put to us, it is important to emphasize that it is still too early to know the ultimate science impact of the Frontier Fields program. The first cluster was complete only on 7/25/14 and the second cluster was complete on 9/24/14, less than a month before this committee's October meeting. Moreover, cluster field searches for faint high-z galaxies require a more nuanced approach than corresponding searches in blank fields. We expect stable science results will take more time to emerge given that this is fresh territory for exploration. Accurate high-z galaxy identification in lensing fields will require an understanding of lens magnification and the associated difficulty in detecting sources that are spatially distorted. In addition, foreground intra-cluster light must be accounted for in searches for distant background galaxies (R. Livermore presented encouraging work in this direction in October). Based on the presentations we have seen, the astronomical community appears to recognize these challenges and is on track to surmount them.

Against these words of caution is the tremendous enthusiasm the FF program has generated in the field. Including the recent meeting at Yale, there are three international workshops focusing on the Frontier Fields planned for the 2014-2015 academic year (Yale 11/14, Sesto 2/15, and IAU Honolulu 8/15). Multiple campaigns to obtain ancillary data are underway (with Spitzer, Chandra, ALMA, VLA, VLT, HAWK-I, MUSE, Gemini GEMS AO, and Keck, among others) and three complementary HST GO programs were approved (PIs Treu, Siana, and Rodney). This enthusiasm is also apparent in the literature: 37 papers referenced HFF data within a year of the first cluster data release. This is a higher rate per year than UDF09 (18), CLASH (11), UDF12 (10), and PHAT (7), and comparable to the very large CANDELS program (40). Of course, the publication count is not an ultimate judge of merit, but it is indicative of a high level of engagement from the community.

The boldness of the FF program has further spurred activity within the theory community, and has generated something of a call to arms among strong gravitational lensing groups. The cluster lensing community has realized, based on the FF data in hand, that their own modeling approaches need to be improved and compared for consistency. Motivated by the FF program, six different groups (traditionally competitors) are taking part in a FF lens modeling comparison project (Meneghetti et

al.) using mock clusters to test and refine approaches. Members of the community who are interested in "auxiliary science" have also been engaged in the FF data. For example, the detection of lensed supernovae behind FF clusters is among the most exciting new discoveries (Kelly et al. 2014, arXix 1411.6009).

We now turn to the questions posed to our committee.

Q1. Is Frontier Fields program is addressing scientific goals outlined by Hubble Deep Fields Working Group?

Yes.

The Deep Fields Working Group discussed a number of scientific goals associated with both deep-field and auxiliary science. A key aim of the cluster field observations is to reveal populations of $z > 5$ galaxies that are much fainter intrinsically than any presently known. The six blank-field parallels strategy was designed to roughly triple the count of $\sim L_*$ galaxies at high-z, and thus constrain the shape of the LF. Though it remains early, detections of this kind are coming in roughly as expected. As illustrated in the right panel of Figure 1, Atek et al. 2014 have used the FF cluster field A2744 to push the z~7 LF two magnitudes fainter than the HUDF (pink and blue points). Moreover, they have used the HFF data themselves to improve the lens model, with pink points corresponding to the old, pre-HFF lens model and blue points using an updated model based on HFF images themselves. The left panel of Figure 1 shows the results of Finkelstein et al. 2014, who have used two FF parallel "blank" fields to detect many new galaxies at intermediate luminosities. The blank field program is on track to triple the count in this magnitude range upon the completion of the six fields.

The HDF Working Group further outlined auxiliary science aims for the FF program, many of which were associated with a deeper understanding of clusters themselves: dark matter distributions, substructure detection, intra-cluster light, etc. Due to the early status of the program, this committee focused most of our effort on evaluating the progress for deep field science aims, however we know of several indications to suggest that the cluster science is also on track as expected. For example, Montes & Trujillo (2014) have used FF data to study the intra-cluster light in A2744. At the Yale meeting in November, Priya Natarajan showed an analysis of dark matter halos traced by galaxies in the same cluster and indicated that FF data will enable subhalo mass function explorations that push the lower mass limit 3 orders of magnitudes smaller than previous efforts.

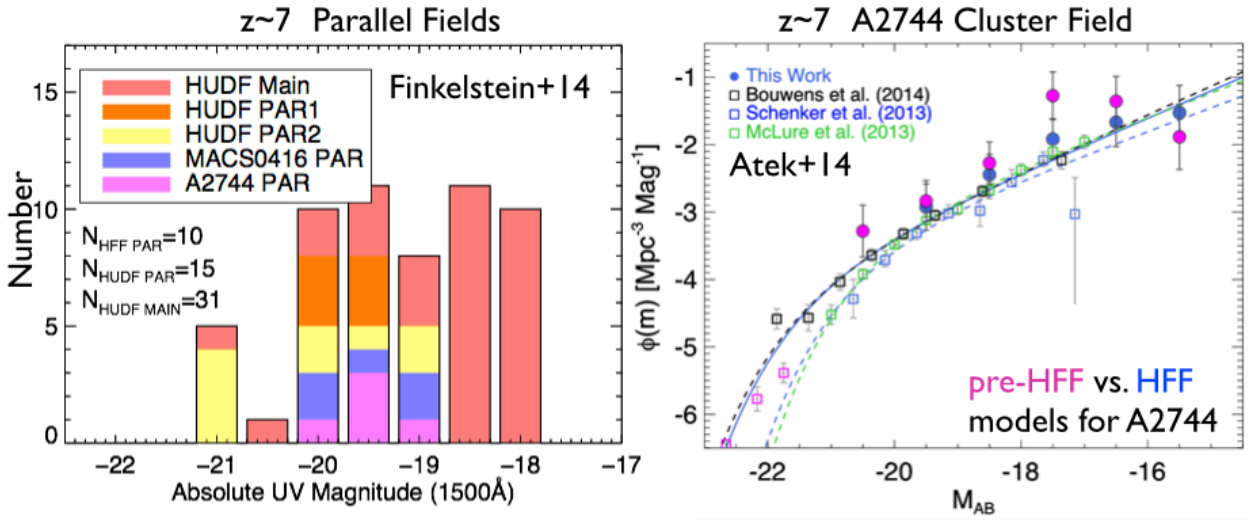

Figure 1 - Redshift z~7 luminosity function improvements from FF parallel fields (left; Finkelstein et al. 2014) and the A2744 cluster field (right; pink and blue points, Atek et al. 2014). On the right, the pink points rely on a pre-HFF lens model. The blue points use an updated model based on HFF data. These figures were shown at the Yale Frontier Fields meeting in November 2014.

Based on these results and many other results presented to us during the October 2014 meeting and the subsequent meeting at Yale in November 2014, the FF program appears to be on track in addressing the scientific goals outlined by the HDF Working Group.

Q2. Are the FF data of a quality sufficient to advance deep field science?

Yes.

By every indication, the HST data releases and pipeline have been executed extremely well. This committee commends Anton Koekemoer and his colleagues at STScI for excellent work.

Q3. Has STScI been a responsible steward of the Frontier Fields program?

Yes.

Jennifer Lotz and her team have done an excellent job coordinating the FF effort, which was a complicated endeavor to set up with many variables to consider. The lensing model coordination (spearheaded by Dan Coe) was also well executed and provided the community with the tools needed to "level the playing field" in utilizing the cluster field data for high-z searches.

Q4. Should the remaining two Frontier Fields observations be done?

Yes.

The original HDF Working Group provided a quantitative science case for six cluster fields + six parallel fields. This recommendation was based on a) the need to fill in a "gap" in area/depth space for blank fields, with the six parallel fields delivering a factor of ~3 increase in counts at intermediate depth in high-z luminosity function constraints; and b) the goal of providing a fair sample volume in the cluster fields to beat down cosmic variance concerns. This second point is important for lensing fields because the volumes are compressed compared to blank fields (as has been quantified more recently in the literature by Robertson et al. 2014, who again make a case for six clusters).

This committee took the original recommendation as a starting point and asked whether, based on the results so far, HST should complete the original six as proposed. *Our unanimous answer is yes.* We were unable to identity any red flags in the original projections. The discovery rate appears to be in line with expectations (see Figure 1, above).

Our recommendation to complete the remaining two cluster fields is further motivated by the fact that a significant amount of auxiliary data has been taken by other instruments on the two remaining fields (including a large investment by Spitzer). The community has been investing and preparing for these targets to be completed. With the momentum building, it is our recommendation that the FF program should proceed as planned.

Finally, it is the view of this committee that there is another reason not discussed by the Working Group for obtaining data for six clusters. Namely, each cluster has its own lensing attributes and its own challenges for modeling the lensing correctly. Six clusters, as opposed to four, provide more opportunities to both capture rare, important lensing events and to refine modeling techniques with new configurations. Among the remaining lenses is S1063. This is an ideal lens from a modeling perspective as is the most relaxed of the six. It will likely provide an ideal case for testing and refining models.

Q5. Can you recommend improvements that will maximize the science return?

Fund a program to provide updated lens maps for each FF cluster for which HST data are available and promote efforts among lensing groups to use simulation mocks to improve and test lens techniques used to produce these maps.

Along with its primary recommendation, the HDF Working Group recommended that STScI sponsor multiple teams to produce lensing maps for each of the FF clusters based on an agreed upon set of data available for each cluster at that time. The aim of this original recommendation was to level the playing field: to allow astronomers without a background in strong lensing to make use of the FF data to search for high-z galaxies. The team at STScI, lead by Dan Coe, did an outstanding job of coordinating this effort and making these maps available to the community. By all accounts the resultant maps were easy to use and provided a valuable service to astronomers all over the world.

However, the very nature of the FF program has made the original images used in creating the lens maps obsolete. The FF images are revealing many new arcs and ancillary data are providing new spectroscopic redshifts. While some of the lens groups have provided updated maps to the community as data for each cluster has improved, the current status is less than ideal. Specifically, because of the new HST FF data and ancillary data that have been obtained since the original call, the playing field is no longer level. Some lens groups are in much better position to make use of the FF data than general astronomers in the community because they have access to the best maps. We strongly recommend that the institute fund a new round of lens models that make use of the newest data available. The precise nature of this new call should be worked out in consultation with the lensing models coordination team and other experts. The first round of calls would be an excellent starting model for this new effort.

Another issue of concern is the accuracy of the lens models themselves. While the precision is no doubt improved as the HST images improve, the accuracy of the approach needs to be tested with some urgency. Some progress in this direction is underway, as Meneghetti et al. are leading a coordinated effort to compare lens code predictions to mock clusters. However, given that these maps are crucial to science return of the FF program, we encourage STScI to promote such comparison projects in a way that results in timely improvements to current techniques. This might involve funding multiple groups to improve their models based on tests against mocks. Alternatively, STScI might consider requiring maps for several mock clusters along with the FF cluster maps in the updated call. This will at least ensure some public test for accuracy is well established.

This committee is not in position to micromanage the implementation of updated lens maps or to propose detailed requirements to test the accuracy of the maps. We

encourage STScI to develop a suitable plan that meets the broad aims of our recommendation in consultation with the current FF lens model coordination team and other experts.

In addition to facilitating the lens effort, it would be beneficial for both science output and the lens modeling efforts if STScI could encourage scientists to contribute their redshifts to the community and to perhaps make them available on clearinghouse webpages, as has been the case for the HDF and HUDF. A similar storehouse for ICL maps from the community would be valuable as well.

Summary Statement:

The Frontier Fields initiative has been implemented extremely well. It is producing high-quality data products and the data releases have fostered considerable interest in the community. By harnessing the power of galaxy cluster lenses, HST is revealing high-redshift galaxy populations hitherto inaccessible, providing a glimpse into the universe we had otherwise expected to remain hidden until JWST. The cluster-science community is also making use of the FF data and we foresee that with further advertising and as the FF data become more widely known, the local galaxy community will begin producing returns on the science as well.

It is our recommendation that the final two cluster field observations proceed as planned and that every effort be made to make updated lens maps available to the community. We further suggest that STScI use the great opportunity afforded by these observations to encourage the lensing community to improve their techniques via mock comparisons and coordinated efforts.

Sincerely,

James Bullock (UC-Irvine, Chair)
Mark Dickinson (NOAO)
Richard Ellis (Caltech)
Mariska Kriek (UC-Berkeley)
Sally Oey (U. Michigan)
Stella Seitz (Munich U. Obs)
S. Adam Stanford (UC-Davis)
Jason Tumlinson (STScI)