

Field Selection Criteria for the ACS Ultra Deep Field

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1. Selection Criteria

The basic criteria for selecting a field suitable for deep observations are:

- Low extinction and low cirrus. Unless otherwise stated, we require $E(B - V) \leq 0.02$ and adopt the maps by Schlegel et al. (1998, ApJ 500, 525). The Schlegel et al. (1998) map is based on 100 μm COBE/DIRBE and IRAS data. We use the low $E(B - V)$ constraint to capture also the low cirrus requirement.
- Low HI column density. Unless otherwise stated, we require $n_{HI} \leq 2 \times 10^{20}$ and adopt the map by Dickey and Lockman (1990, ARAA, 28, 215).
- Absence of known bright sources. Bright stars, galaxies, radiosources should not be present in, or near, the field so as not to alter the statistics nor create background. For radiosources we require that no source brighter than 10 mJy be present in the ACS field and no source brighter than 100 mJy be present within 10 arcmin.
- General convenience. Possibility of CVZ observations, accessibility by major facilities on the ground.
- High ecliptic angle (> 30 degrees, possibly close to 75 degrees) so as to minimize zodiacal background.
- Sufficiently large area. The area satisfying the above criteria should be large enough to enable wide field follow-up studies from the ground.

2. Implementation

The first step to search fields satisfying these criteria is to collect the required supporting data. For $E(B - V)$ we started out from the maps made available by Schlegel et al. (1998) in Lambert's coordinates, which we adopted as our working coordinate system. The $E(B - V)$ maps are shown in Figures 1 and 2 for the North and South Galactic caps, respectively.

Various catalogs in electronic form were used to select against other types of sources. Positions of bright stars were obtained from the PPM catalog by Roser and Bastian (1988, AAS, 74, 449) which includes 378,910 stars. Galaxies were obtained from the RC3 catalog (de Vaucouleurs et al. 1991), including a total of 23011 objects. Quasar positions were obtained from Version 10 of the Veron and Veron catalog (2001, AA 374, 92), including a total of 30119 objects. We selected

radiosources from the First catalog (White et al. 1997, ApJ, 475, 479), which includes 549,707 sources and covers 5450 square degrees in the North Galactic cap and 610 square degrees in the South Galactic cap.

A mask for each hemisphere was created in order to exclude areas with known sources. The $E(B - V)$ and the HI column density maps were then searched at a resolution of about 4 arcmin² to identify areas with low extinction and low HI column density and not containing known sources. The list of all such areas was sorted in order of increasing extinction and scanned again in order to identify (grow) larger (square) fields.

The software we developed selects fields larger than some threshold value, allowing or avoiding known QSOs. The search is repeated also for additional requirements, namely for fields in the CVZ of HST, observable from both Hawaii and Paranal (i.e. within 50 degrees of zenith angle for both observatories, we will refer to these fields as “equatorial”), and outside the ecliptic (i.e. above 30 degrees of ecliptic latitude).

3. Automated Search Results

We are able to recover some of the fields selected for other surveys. If all criteria (except for the area one) are enforced, we can recover SDF, one of the DEEP fields, and EISDeep1. By relaxing the QSO avoidance criterion, one can recover also, e.g., HDFN, FORS-DF, Lockman, CDFS. In Table 1 we list a number of well studied survey fields listing their coordinates, and the values of $E(B - V)$ and of the HI column density n_{HI} . We give in boldface the name of those fields satisfying the extinction and HI column density requirements.

Requiring that each field be of at least 1200 arcmin² restricts the number of viable fields to 7/8 fields in the North (with/without QSO avoidance) and 9/13 fields in the South. Of these, 13/17 fields are observable both from Hawaii and from Paranal (with/without QSO avoidance). Of these “equatorial” fields, only 3 have an ecliptic latitude larger than 30 degrees. Close inspection reveals that none of these 3 fields is acceptable since they all contain clusters of galaxies.

The number of available fields increases rapidly if the minimum area constraint is relaxed. A summary of the results is given in Table 2.

We also find that it is very difficult to find fields satisfying our conditions and lying in the CVZ of HST. No CVZ field exists satisfying all constraints. In total, 7 fields can be found by relaxing the QSO avoidance criterion and the extinction and HI column density criteria to $E(B - V) \leq 0.03$ and $n_{HI} \leq 3 \times 10^{20}$. Alternatively, 27 CVZ fields are found if the minimum area requirement is reduced to 300 arcmin² (see also Table 2).

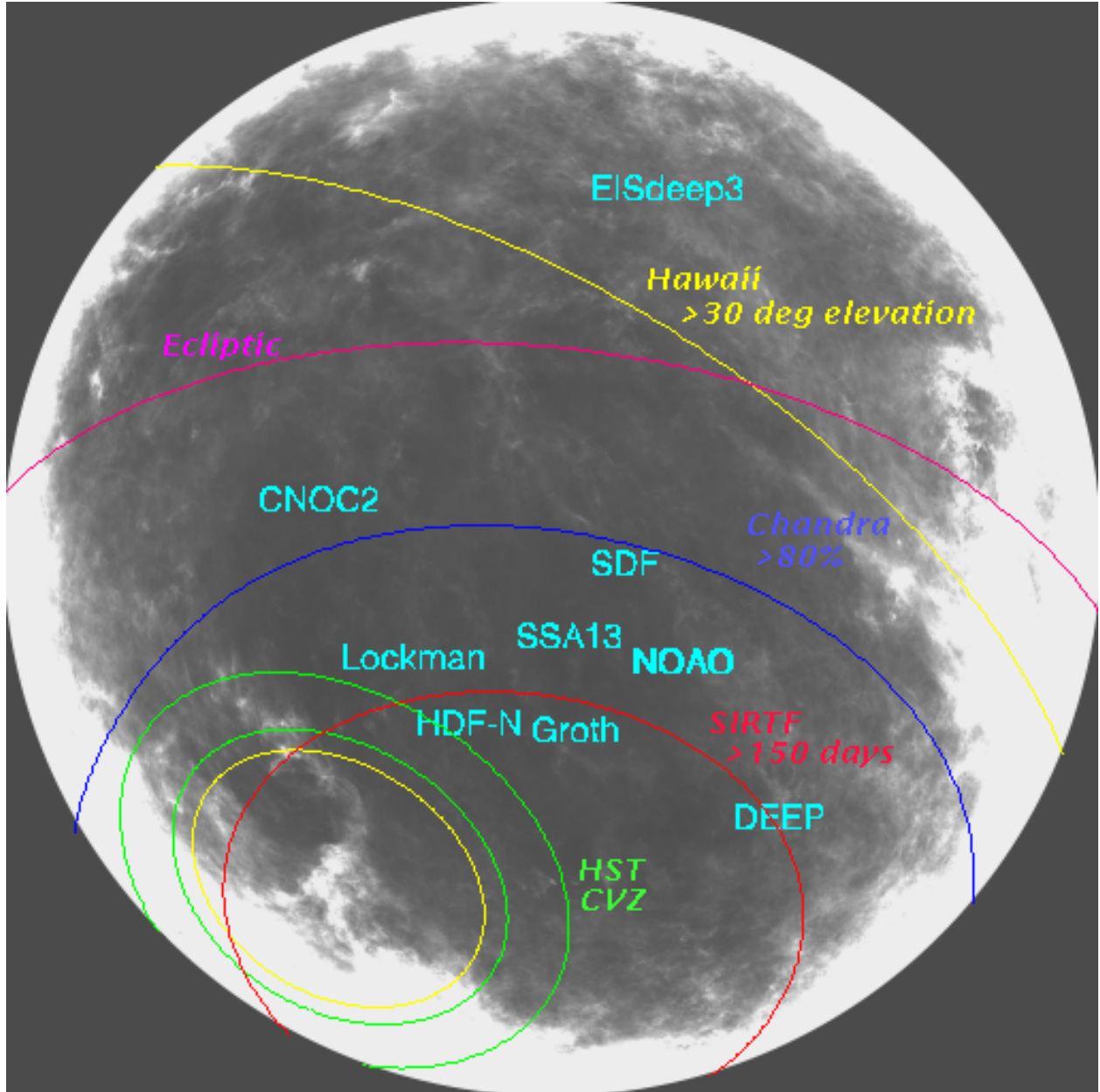


Fig. 1.— Map of $E(B-V)$ for the North galactic cap in Lambert's coordinates. The yellow curves identify 30 degrees of elevation from Hawaii. The green curves identify HST's CVZ. The magenta curve identifies the ecliptic. The blue and red curves identify the Chandra 80 % zone and the zone with more than 150 days per year of observability for SIRTf, respectively.

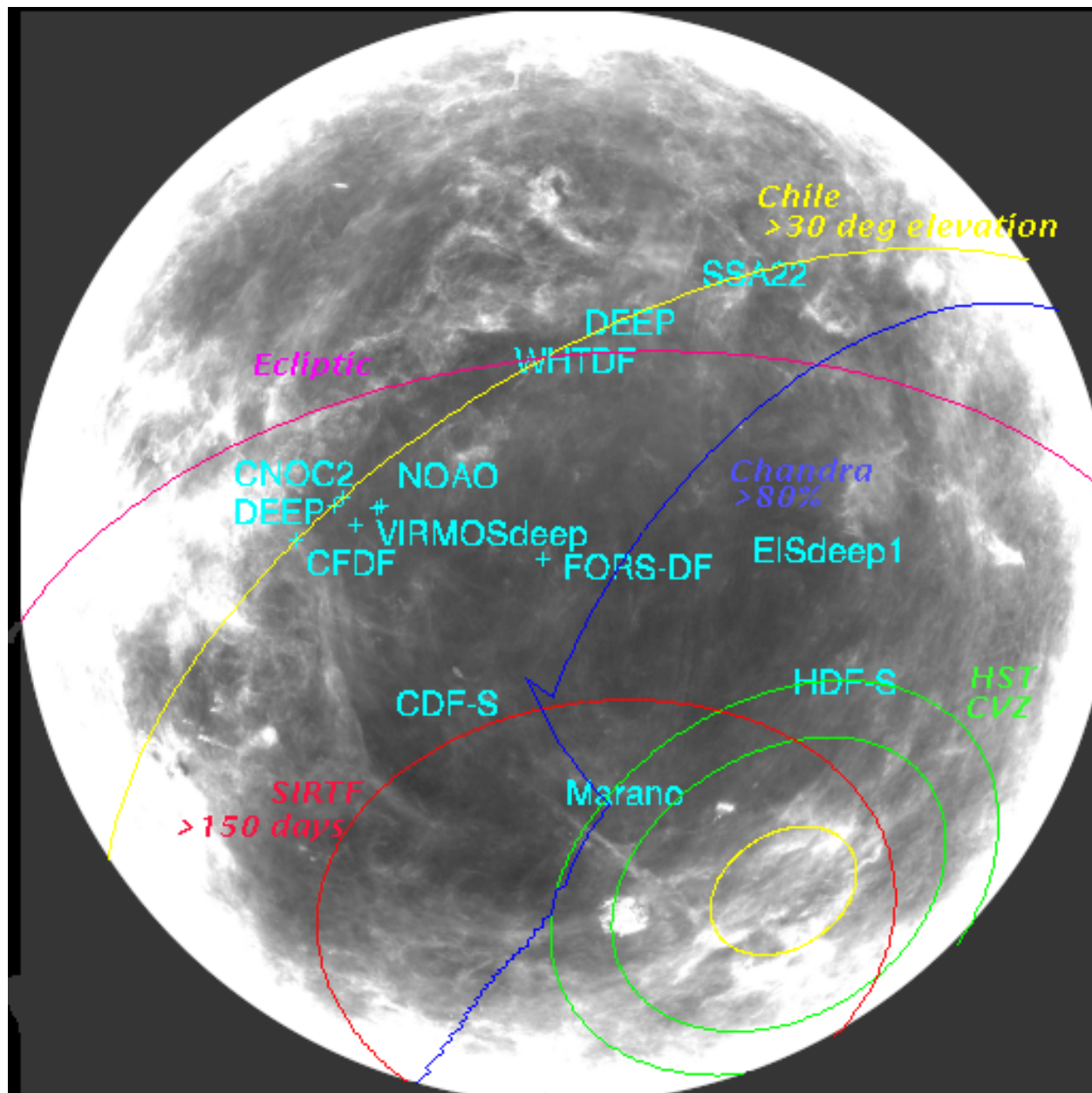


Fig. 2.— Map of $E(B-V)$ for the South galactic cap in Lambert's coordinates. The yellow curves identify 30 degrees of elevation from Paranal. The green curves identify HST's CVZ. The magenta curve identifies the ecliptic. The blue and red curves identify the Chandra 80 % zone and the zone with more than 150 days per year of observability for SIRTF, respectively.

Table 1. Properties of known survey fields. None satisfies the 1200 arcmin² area criterion. The fields with name in boldface satisfy the extinction and HI column density criteria.

| Field Name | RA (J2000) | Decl (J2000) | l | b | Ecl.Lat. | $E(B - V)$ | n_{HI} ($\times 10^{-20}$) |
|-----------------|---------------|-----------------|-------|-------|----------|------------|-----------------------------------|
| WHTDF | 0:19:59.50 | 0:04:20.0 | 106.1 | -61.8 | -1.9485 | 0.030 | 2.6900 |
| WHTDF | 0:22:33.30 | 0:20:57.0 | 107.6 | -61.7 | -1.9617 | 0.025 | 2.5613 |
| FORS-DF | 1:06:03.60 | -25:45:46.0 | 191.1 | -86.5 | -30.0380 | 0.018 | 1.8800 |
| NOAO | 2:07:29.15 | -4:44:08.2 | 165.3 | -61.2 | -16.5755 | 0.022 | 2.4473 |
| NOAO | 2:10:00.00 | -4:30:00.0 | 166.0 | -60.6 | -16.5444 | 0.022 | 2.9199 |
| CNOC2 | 2:23:00.00 | 0:00:00.0 | 165.7 | -55.1 | -13.4375 | 0.039 | 2.7125 |
| DEEP | 2:30:00.00 | 00:00:00.0 | 168.1 | -54.0 | -14.0161 | 0.022 | 2.5505 |
| VIRMOSdeep | 2:26:00.00 | -4:30:00.0 | 172.0 | -58.1 | -17.9482 | 0.027 | 2.3767 |
| CFDF | 3:00:00.00 | 0:00:00.0 | 177.0 | -48.9 | -16.3572 | 0.096 | 7.2208 |
| Marano | 3:15:09.00 | -55:13:57.0 | 270.2 | -51.8 | -67.5384 | 0.016 | 2.6910 |
| CDF-S | 3:32:30.00 | -27:48:47.0 | 223.6 | -54.4 | -45.2118 | 0.008 | 0.7872 |
| CNOC2 | 9:20:00.00 | 37:00:00.0 | 186.6 | 44.7 | 20.3266 | 0.011 | 1.5234 |
| Lockman | 10:52:43.00 | 57:28:48.0 | 149.3 | 53.1 | 45.3732 | 0.008 | 0.5684 |
| EISdeep3 | 11:20:35.00 | -21:42:00.0 | 276.4 | 36.5 | -23.6886 | 0.045 | 4.1814 |
| HDF-N | 12:36:49.40 | 62:12:58.0 | 125.9 | 54.8 | 57.2971 | 0.012 | 1.4346 |
| SSA13 | 13:12:21.40 | 42:41:21.0 | 109.0 | 73.9 | 45.4351 | 0.014 | 1.3752 |
| SDF | 13:24:21.38 | 27:29:23.0 | 37.6 | 82.7 | 33.3845 | 0.019 | 1.2060 |
| Groth | 14:16:00.00 | 52:10:00.0 | 96.3 | 60.4 | 59.4113 | 0.013 | 1.3000 |
| NOAO | 14:30:00.00 | 34:30:00.0 | 58.2 | 67.7 | 45.9519 | 0.012 | 1.0356 |
| NOAO | 14:32:05.72 | 34:16:47.5 | 57.4 | 67.3 | 45.9647 | 0.016 | 1.0091 |
| DEEP | 16:52:00.00 | 34:55:00.0 | 57.4 | 38.3 | 56.8681 | 0.016 | 1.7100 |
| HDF-S | 22:32:56.20 | -60:30:02.7 | 328.3 | -49.2 | -46.5559 | 0.027 | 2.2200 |
| SSA22 | 22:17:35.00 | 0:15:30.0 | 63.1 | -44.0 | 10.1609 | 0.066 | 4.8500 |
| EISdeep1 | 22:50:00.00 | -40:12:59.0 | 357.5 | -61.7 | -30.0832 | 0.011 | 1.4700 |
| DEEP | 23:30:00.00 | 00:00:00.0 | 85.0 | -56.7 | 2.9507 | 0.037 | 3.8460 |

Table 2. Number of candidate fields. “Equatorial” indicates fields that are observable from both Hawaii and Paranal with less than 50 degrees of zenith angle.

| Field Type (area in arcmin ²) | $E(B - V)$ | n_{HI} ($\times 10^{-20}$) | allow QSOs | allow QSOs ecl. lat. > 30 deg. | avoid QSOs | avoid QSOs ecl. lat. > 30 deg. |
|--|------------|-----------------------------------|------------|-----------------------------------|------------|-----------------------------------|
| North 1200 | 0.02 | 2.0 | 8 | 0 | 7 | 0 |
| South 1200 | 0.02 | 2.0 | 13 | 7 | 9 | 6 |
| Equatorial 1200 | 0.02 | 2.0 | 17 | 3 | 13 | 3 |
| CVZ 1200 | 0.02 | 2.0 | 0 | 0 | 0 | 0 |
| North 1200 | 0.03 | 3.0 | 104 | 89 | 97 | 84 |
| South 1200 | 0.03 | 3.0 | 27 | 16 | 19 | 13 |
| Equatorial 1200 | 0.03 | 3.0 | 32 | 6 | 24 | 5 |
| CVZ 1200 | 0.03 | 3.0 | 7 | 7 | 4 | 4 |
| North 600 | 0.02 | 2.0 | 735 | 32 | 682 | 29 |
| South 600 | 0.02 | 2.0 | 699 | 624 | 587 | 515 |
| Equatorial 600 | 0.02 | 2.0 | 1084 | 306 | 966 | 241 |
| CVZ 600 | 0.02 | 2.0 | 0 | 0 | 0 | 0 |
| North 600 | 0.03 | 3.0 | 1771 | 497 | 1683 | 483 |
| South 600 | 0.03 | 3.0 | 1559 | 1293 | 1378 | 1125 |
| Equatorial 600 | 0.03 | 3.0 | 2117 | 579 | 1949 | 497 |
| CVZ 600 | 0.03 | 3.0 | 46 | 46 | 40 | 40 |
| North 300 | 0.02 | 2.0 | 1040 | 51 | 962 | 46 |
| South 300 | 0.02 | 2.0 | 1484 | 1231 | 1166 | 963 |
| Equatorial 300 | 0.02 | 2.0 | 1762 | 520 | 1511 | 372 |
| CVZ 300 | 0.02 | 2.0 | 27 | 27 | 27 | 27 |
| North 15 | 0.02 | 2.0 | 23735 | 2816 | 23628 | 2810 |
| South 15 | 0.02 | 2.0 | 37530 | 30829 | 36363 | 30020 |
| Equatorial 15 | 0.02 | 2.0 | 30304 | 6680 | 29669 | 6278 |
| CVZ 15 | 0.02 | 2.0 | 915 | 915 | 914 | 914 |

4. The constraint of a minimum angle from the ecliptic

Low values of ecliptic latitude enhance the zodiacal background which is an important background contribution for imaging from space both from HST and from JWST. We can estimate this effect by using the version of the Good’s IRAS model (1994, IRAS Sky Survey Atlas, Explanatory supplement) presented in the WFC3 ISR 2002-02. For visible wavelengths the variation of zodiacal background with sun angle and ecliptic latitude is given by Table 6.3 of the WFPC2 Handbook.

At ecliptic declination under 30 degrees the zodiacal background is very high and also increases rapidly at decreasing sun angles. A higher ecliptic angle both decreases the minimum background and increases visibility at low background levels. In the following we will exclude fields with ecliptic latitude under 30 degrees.

Sun angles at 120 ± 30 are relevant for JWST since the telescope architecture forces it to observe far from the anti-sun. At 120 degrees and the background is essentially flat for ecliptic angles above 45 degrees.

Zodiacal background is the most important background for HST observations when earthshine is minimized. As an example, for the ACS filters F606W, F775W, and F850LP, minimum zodiacal background represents 71 %, 61 %, and 45 % of the noise term N^2 , respectively. Thus, for F850LP at the minimum background, the dominant noise term is detector noise, while the remaining broad band ACS/WFC filters are background limited under any condition. In the same filters, the average earthshine contributes ~ 40 % of the minimum zodiacal background. On Table 3, we list for each field also the loss in limiting depth resulting from zodiacal background higher than the minimum value (based on Table 6.3 from the WFPC2 Handbook). The loss is computed assuming that observations are entirely background limited and will be executed over a period of 6 months (with sun angles ranging from 90 to 270 degrees). The loss in limiting depth would be roughly 50 % higher if the observations were scheduled over a period of 3 months (with sun angles ranging from 135 to 225 degrees. If the observations are not background limited, the loss of limiting magnitude is reduced (e.g. it is halved for F850LP).

Here, we have discussed mostly the reflected sunlight component of the zodiacal background but clearly the thermal component is also important for Far IR observations.

5. Screening the fields

The fields listed in Table 2 have been selected by software. The final field selection needs to be verified by making sure that additional disqualifying objects, not listed in the catalogs used for the automated search, are not present in an area of radius 30 arcmin centered on the field. Examples of such objects are bright stars not present in the PPM, clusters of galaxies, or bright radio sources not listed in the Veron or First catalogs. This additional search can be done by using NED. In Table 3, we list our best, verified, fields and those of the standard fields that satisfy the extinction

and hydrogen column density criteria (see also Figure 3).

The table does not include any “equatorial field” in the Northern hemisphere. This is mostly due to the requirement of a minimum ecliptic latitude of 30 degrees. Northern fields visible from both Paranal and Hawaii are available but only at an ecliptic latitude of about 10 degrees.

In order to increase the number of CVZ fields at an ecliptic latitude greater than 60 degrees, we have also screened the six 100 sq arcmin fields satisfying all constraints except for the area one. We have listed in Table 3 the two 100 sq. arcmin fields that do not include a cluster of galaxies (or a bright radio source) within 30 arcmin. Fields not including any radiosource brighter than 100 mJy within 30 arcmin (instead of 10 arcmin) are identified with the letter “R” in the Notes field in Table 3. Note that the CDF-S is not one of these fields since it contains two 300 mJy (at 365 MHz) radio-sources within 10 arcmin of the field center. A 100 mJy source at 4.85 Ghz (1 Jy at 408 Mhz) is present at 51 arcmin from the field center. The heterogeneity of the radio-data used for screening the fields suggests that a specific study of any candidate field would be required if radio-properties represent a driver for field selection. The fact that even the fields identified by the letter “R” often contain a Jy-level radiosource within a degree makes it unlikely that fields optimizing both the HST observations and possible radio follow-ups actually exist. Note also that none of the “standard” fields of Table 3, with the exception of CNOC2, satisfies the criterion of absence of 100 mJy sources within 30 arcmin. CNOC2 satisfies this criterion but includes a bright galaxy within 30 arcmin (IC2461).

6. Summary

Our findings can be summarized as follows. If one intends to optimize the field choice uniquely on the basis of the ACS observation, CVZ fields not including any 100 mJy radiosource within 30 arcmin can be found at the minimum zodiacal background (u10) or with background level close to the minimum (u3, u9). If instead observability from both hemispheres is important, one is faced with a loss of about 0.1 magnitudes in limiting depth. Fields can be found not containing any 100 mJy radiosource within 30 arcmin (u6, u8). The CDF-S field undergoes the same penalty in limiting depth but includes bright radiosources within 30 arcmin.

Table 3. List of verified fields.

| Field Name | RA (J2000) | Decl (J2000) | l | b | Ecl.Lat. | $E(B - V)$ | n_{HI} ($\times 10^{-20}$) | Δmag | Notes |
|------------|---------------|-----------------|-------|-------|----------|------------|-----------------------------------|--------------------|--------------|
| FORS-DF | 1:06:03.60 | -25:45:46.0 | 191.1 | -86.5 | -30.03 | 0.018 | 1.88 | 0.3 | Eq. |
| CDF-S | 3:32:30.00 | -27:48:47.0 | 223.6 | -54.4 | -45.21 | 0.008 | 0.79 | 0.1 | Eq. |
| CNOC2 | 9:20:00.00 | 37:00:00.0 | 186.6 | 44.7 | 20.32 | 0.011 | 1.52 | >0.3 | IC2461, R |
| Lockman | 10:52:43.00 | 57:28:48.0 | 149.3 | 53.1 | 45.37 | 0.008 | 0.57 | 0.1 | |
| HDF-N | 12:36:49.40 | 62:12:58.0 | 125.9 | 54.8 | 57.29 | 0.012 | 1.43 | 0.05 | CVZ |
| SSA13 | 13:12:21.40 | 42:41:21.0 | 109.0 | 73.9 | 45.43 | 0.014 | 1.38 | 0.1 | |
| SDF | 13:24:21.38 | 27:29:23.0 | 37.6 | 82.7 | 33.38 | 0.019 | 1.21 | 0.3 | |
| Groth | 14:16:00.00 | 52:10:00.0 | 96.3 | 60.4 | 59.41 | 0.013 | 1.30 | 0.02 | |
| NOAO | 14:30:00.00 | 34:30:00.0 | 58.2 | 67.7 | 45.95 | 0.012 | 1.04 | 0.1 | |
| NOAO | 14:32:05.72 | 34:16:47.5 | 57.4 | 67.3 | 45.96 | 0.016 | 1.01 | 0.1 | |
| DEEP | 16:52:00.00 | 34:55:00.0 | 57.4 | 38.3 | 56.86 | 0.016 | 1.71 | 0.05 | |
| EISdeep1 | 22:50:00.00 | -40:12:59.0 | 357.5 | -61.7 | -30.08 | 0.011 | 1.47 | 0.3 | |
| u1 | 0:13:49.00 | -63:55:05.0 | 309.7 | -52.7 | -56.57 | 0.017 | 1.49 | 0.05 | CVZ, 300 |
| u2 | 0:37:25.00 | -61:56:02.0 | 305.8 | -55.1 | -57.14 | 0.013 | 1.72 | 0.05 | CVZ, 300, R |
| u3 | 3:14:49.00 | -60:09:08.0 | 276.6 | -49.0 | -60.15 | 0.016 | 1.46 | 0.02 | CVZ, 100, R |
| u4 | 3:29:00.00 | -26:54:43.0 | 221.8 | -55.1 | -44.09 | 0.010 | 0.89 | 0.1 | Eq., 600 |
| u5 | 3:33:25.00 | -27:13:17.0 | 222.6 | -54.1 | -44.71 | 0.010 | 0.96 | 0.1 | Eq., 600 |
| u6 | 3:52:39.00 | -29:47:24.0 | 227.8 | -50.3 | -48.51 | 0.010 | 0.95 | 0.1 | Eq., 600, R |
| u7 | 3:53:15.00 | -27:50:39.0 | 224.8 | -49.9 | -46.70 | 0.009 | 0.98 | 0.1 | Eq., 600 |
| u8 | 3:54:10.00 | -29:37:24.0 | 227.6 | -50.0 | -48.46 | 0.009 | 0.97 | 0.1 | Eq., 600, R |
| u9 | 4:19:31.00 | -60:11:34.0 | 271.2 | -41.9 | -60.19 | 0.017 | 1.79 | 0.02 | CVZ, 100, R |
| u10 | 4:38:15.00 | -61:01:26.0 | 271.3 | -39.5 | -79.48 | 0.016 | 1.79 | 0.0 | CVZ, 300, R |
| u11 | 4:38:24.00 | -59:32:55.0 | 269.4 | -39.8 | -78.49 | 0.024 | 2.16 | 0.0 | CVZ, 1200 |
| u12 | 8:28:23.00 | 64:59:49.0 | 150.8 | 34.6 | 44.22 | 0.022 | 2.90 | 0.1 | CVZ, 1200 |
| u13 | 10:23:46.00 | 63:52:45.0 | 145.4 | 46.3 | 48.80 | 0.024 | 2.88 | 0.1 | CVZ, 1200, R |

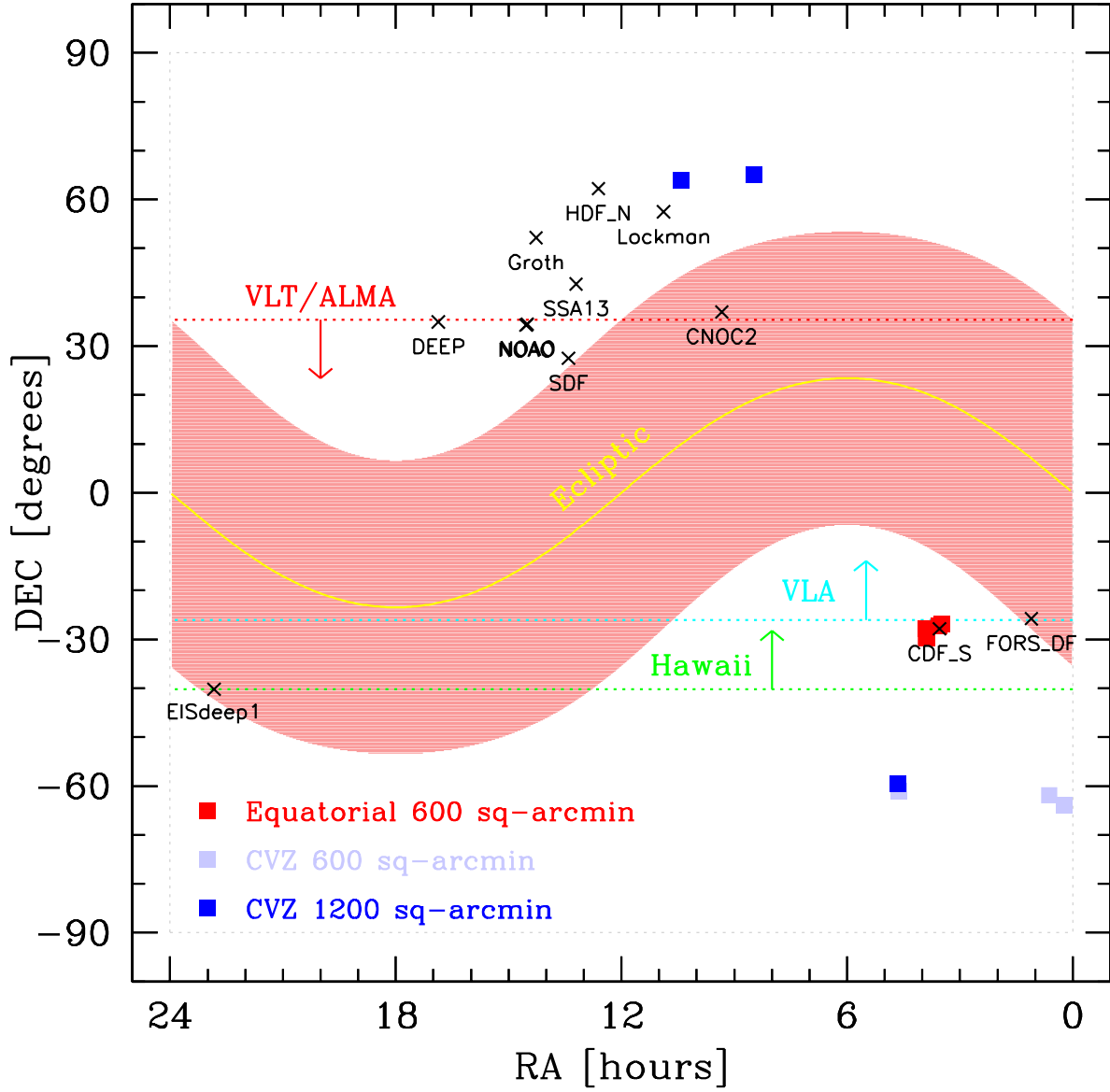


Fig. 3.— Location of the standard survey fields satisfying our extinction and column density constraints and of our best verified fields. We identify also the areas within 60 degrees of zenith angle from the VLA (cyan), Hawaii (green), and Paranal (VLT/Alma, red). The pink band identifies and exclusion zone within 30 degrees of ecliptic latitude. Note that the “equatorial” 600 arcmin² fields are close to the CDF-S.