********** *The COBRA and FIDUCIAL Coordinates and Numbering Scheme* **********

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This white paper addresses the PFS cobra and fiducial numbering and coordinate system and the mapping from the Subaru/WFC focal plane (Cobra Optical Bench (COB) to the spectrograph slits. This part of the document just describes and illustrates the coordinate system; the tables which connect the cobra number and PFI coordinates to the slit hole number and vice versa are posted separately as plain text files which can be searched and sorted more easily than pdfs, as is the table which gives the coordinates of the fiducials. We will give the names and discuss the contents of those files later when we have discussed the nomenclature of their contents.

The COB or PFI coordinate system has changed at least once since 2013, but now appears to be consistent in all the JPL material since the Delta CDR. Charlie's 2013 drawings have x and y rotated by 60 degrees with respect to that in the Delta CDR documentation, but the latter appears to be consistent and consistent with the late LNA documentation. The coordinate system looking toward the sky is left-handed and the focal plane documentation mostly displays the y axis DOWN and the x axis to the RIGHT, and that is how we will describe locations in the focal plane. The first field (Sector B in JPLese; the JPL `sectors' appear to be rotated counterclocwise from the fields by 120 degrees from the fields) is to the left of center and (mostly) above center. The fields go counterclocwise from this location, so field 2 is entirely below center, field 3 to the right and (mostly) above center. The modules run vertically in field 1, and this simplifies the mathematical prescription for the coordinates of the cobras quite appreciably.

*The cobras (and the fiducials, for the most part) are on a regular hexagonal grid over the whole focal plane The vertical spacing is 8.000mm in a given vertical row, and half that to the horizontal line joining the next cobras up. We will use this 4.000mm as the fundamental vertical unit Dely. The horizontal spacing is 8mm*sqrt(3)/2 =6.928203mm, which we will use as the fundamental horizontal spacing Delx. Note that the coordinate system looking toward the sky is LEFT-HANDED. Rotations are counterclockwise in this coordinate system, so be careful with coordinate transformations; the signs are different from what you may be used to. See the figures at the end, the first of which illustrates this grid. There are three parallelograms which fit together to make the hexagonal PFS focal plane; the grid described above is continuous across the boundaries of these parallelograms, which are called Sectors (A,B,C) by JPL and Fields (1,2,3) elsewhere in the project; unfortunately Sector A is displaced from Field 1 by one position, but both are counted counterclockwise looking at the sky. Each field carries 798 cobras and 32 fiducial fibers. This is illustrated by the second figure.*

The other fields are buildable from these by counterclockwise rotations through 120 degrees, field 2 by 120, field 3 by 240. The modules are numbered out from the center, 1-14 in field 1, 15-28 in field 2, 29-42 in field 3. Call this number m. The cobras are numbered out from the center in each module, staggered between rows, like

```
   3   4   6 ..... 28 \ 30  32  .....   54  56
 1   3   5        27  29 \ 31  33          55  57
```

Call this number cm (cobra-in-module)

There is, of course, one fiber per cobra, but there are two USCONEC multifiber connectors per module, one carrying the 29 fibers from cobras 1-29 in the module, the other carrying the 28 fibers from cobras 30-57, The connectors are labelled `A' and `B' for these groups, which we will also call `submodules' A and B, so submodule 14B is the group of cobras/fibers 30-57 on module 14.

```
      A connector           B connector
    3   4   6 ..... 28 \ 30  32  .....   54  56
  1   3   5       27  29 \ 31  33          55  57
```

This is shown in the third figure, and the way the modules and all the numbers fit together in the center in the forth.

There is also a RUNNING cobra number per field cf, cobra-in-field (1-798), which is just

cf = cm + 57(mf-1)*

*where cm is the cobra number in a module as above and mf is the module number *per field* (1-14), and a grand cobra number c:*

c = cf + 798(f-1)*
= cm + 57(mf-1) + 798*(f-1)*
= cm + 57(m-1)

where f is the field number (1-3).

The modules run vertically in field 1 and the expressions for the coordinates is particulary simple. The coordinates in field 1 are given by

x = -Delx[(cm-1)%2 + 2*mf -1)]*
y = -Dely[cm - 2*m]*

where cm is the cobra number in the module and the arithmetic in the brackets is integer; the modulus term in the expression for x is 0 if cm is odd, 1 if cm is even.

The coordinates in the other fields are obtained from these by rotating 120 or 240 degrees. if x1, y1 are the coordinates for a some cobra in field 1, the coordinates of the cobra with the same cf number in another field are

*x = x1*cos(2*Pi*(f-1)/3) + y1*sin(2*Pi*(f-1)/3)*
*y = -x1*sin(2*Pi*(f-1)/3) + y1*cos(2*Pi*(f-1)/3)*

Given a cf number, the grand cobra number c is given above; the cm number is

cm = (cf-1)%57 + 1

and the module number is

m = (cf-1)/57 (integer) + 14(f-1) + 1.*

(f is field number) We can also define a field-defined module number mf which runs from 1-14 in each field, as above:

mf = (cf-1)/57 + 1 (integer)
= (m-1)%14 + 1.

Given a c number, the cf number is

cf = (c-1)%798 + 1

and the field is

f = (c-1)/798 + 1 (integer)

and module is

m = (c-1)/57 + 1 (integer)

All the silliness with -1 and +1 above would be completely avoided if people learned to count from 0 instead of 1 ;-)).

To summarize:
cm = 1 -> 57 is the cobra number in a module
cf = 1 -> 798 is the cobra number in a field
c = 1 -> 2394 is the cobra number in the whole focal plane.
m = 1 -> 42 is the module number in the whole focal plane
mf = 1 -> 14 is the module number per field
f = 1 -> 3 is the field number

Dimensions: The nominal patrol radius is 4.75mm. Each arm is 2.375mm+/-0.1mm
The sweep radius is 1mm larger, 5.75mm, 11.5mm diameter. The elbow radius
is the nominal radius of the inner arm + 1mm for the fiber arm, 3.375mm.
The fiducials are 3.3mm nominal diameter.

FIDUCIALS

*There are 96 fixed fiducials, in three groups of 32, *almost* identical except for rotation by 120 and 240 degrees, and so associated with the field number f, and the latest revision of the fiducial numbers has fiducials 1-32 *mostly* adjacent to field 1, 33-64 field 2, and 65-96 field 3. So they belong in some sense to the fields (but not quite). They each have fibers which go to one 32-position USCONEC fiber connector, so three of these serve all the fiducials.*

*Geometrically, there are 14 along spokes from the center of the PFI field which run along the cm=1 edge of the modules, spaced at 16mm = 4*Dely, 14 which run along the edge of the outer module from the center to the end, also spaced 16mm = 4*Dely, and 4 which are in pairs beloning to 2 AG cameras; these 4 are regular, but the AG cameras do not really belong to the field, as we shall see. These three families will be called types, t (1->3); type 1 are spoke fiducials, type 2 edge fiducials, type 3 AG fiducials.*

The fiducials are numbered sequentially ff 1-96, 1-32 in field 1, 1-14 in field 1 type 1, 15-28 in field 1 type 2, and 29-32 in field 1 type 3.

The field is (ff-1)/32 +1 (integer); type is ((ff-1)%32)/14 + 1 (integer); the fiducial-in-field (fff), (1-32) which is also useful, is just (ff-1)%32 + 1.

The coordinates look like

field 1, type 1: (ff=1->14) (`spoke') fiducials.

*These are not *quite* on the hexagonal cobra grid because a screw got in the way, and are 2mm*

(=Dely/2) displaced radially; this is the source of the funny arithmetic. Note that ALL the fiducials are mounted on the optical bench, none on the modules.

*x1 = -0.25*Delx*(9 + 8*(fff-1))*
*y1 = 0.25*Dely*(9 + 8*(fff-1))*

field 1, type 2 (ff=15->28) (`edge' fiducials.)

*x1 = -Delx * 29*
*y1 = Dely * (25 - 4*(fff - 15))*

The four AG fiducials (type 3) flank the AG cameras AG4 and AG5 which are associated with Fields 1 and 2; the confusing nomenclature may be fixable, but apparently NOT the fact that the AGs in this fiber group cannot both be adjacent to field 1; the first is, but the second is adjacent to the NEXT field.

*These fiducials are at the ends of lines of length 136mm = 34*Dely perpendicular to radii of length 228.631mm = 33*Delx at 180 and 240 degrees from the X axis. In the field 1 group, the coordinates are*

*x1 = -Delx * 33*
*y1 = -Dely * 17 for ff29*

*x1 = -Delx * 33*
*y1 = Dely * 17 for ff30*

*x1 = -Delx * 25*
*y1 = Dely * 41 for ff31*

*x1 = -Delx * 8*
*y1 = Dely * 58 for ff32*

These AG fiducials can all be generated from the positions of ff29 and ff30 by rotations by 60 degrees around the periphery of the focal plane. A circle of radius 238.9mm encloses the extent of these (including their finite size) and represents the necessary coverage of the field of the metrology camera.

*The coordinates of the fiducials associated with the other fields can be generated by rotations of 120 and 240 degrees, just as for the cobras, with one set of exceptions. The edge cobras for Field 2 are arranged somewhat differently in order to disambiguate the otherwise 120 degree symmetry of the pattern. The fiducial which would otherwise occupy position 47 is missing, and the spacings at the end of the row are different, but there are still 14 in this row. For these fiducials, ff47->60, the coordinates are, *IF THIS WERE FIELD 1* -- we do this so we can generate the `canonical' Field 1 coordinates and rotate everything to generate the coordinates for other fields, so we operationally just adjust the x1 and y1 as if these were field 1 positions, and then rotate:*

*x1 = -Delx * 29 for all of these (ff47-60)*

*y1 = Dely * (21 - 4*(fff-15)) for ff47-57, fff=15-25*
*= -Dely * 21 for ff58 (fff=26) (half spacing from 57)*
*= -Dely * 25 for ff59 (fff=27) (full spacing from 58)*
*= -Dely * 27 for ff60 (fff=28) (half spacing from 59)*

*or, if one wants the *ACTUAL* coordinates for field 2, the expressions are a little more complicated,*

and are:

*x = Delx * (25 - 2*(ff-47))*
*y = Dely * (33 + 2*(ff-47)) for ff47-57*

*x = Delx*4*
*y = Dely*54 for ff58 (half spacing from 57)*

*x = Delx*3*
*y = Dely*56 for ff59 (full spacing from 58)*

x = Delx
*y = Dely*57 for ff60 (half spacing from 59)*

The fiducials are shown in a somewhat simplified diagram of the focal plane in the last figure.

The text files containing the information discussed here are

grandfibermap.20171114.txt, which gives the cobra, field, cf, m, mf, cm, submodule, PFI coordinates, spectrograph, spectrograph slit fiber hole, a running contiguous fiber number along the slits for all 4 spectrographs, and LNA fiber IDS, for the 2394 fibers indexed by the cobra number c in the PFI focal plane.

spXfibers.20171114.txt, X = 1,2,3,4, which, for each spectrograph X, gives the slit fiber hole, spectrograph, LNA fiber ID, PFI cobra number, field, mf, cf, module, cm, PFI coordinates, and the running fiber number, indexed by the fiber HOLE number (1-651) for each spectrograph.

Please note that both files give the HOLE number along the slit assembly, which is NOT contiguous; there are 651 holes occupied by 600 (for spectrographs 1 and 2) or 597 (for spectrographs 3 and 4) science fibers, some engineering fibers, and some blanks in the center of the slit. The holes are equally spaced along the slit and are numbered 1-651; the spacing is 0.21293 mm along the curved slit, which has a radius of curvature of 662mm. Both files have a contiguous fiber number along the slits (1-2394: 1-600 in Sp1, 601-1200 in Sp2, 1201-1797 in Sp3, 1798-2394 in Sp4, if that turns out to be useful.

5.The fiducial information is given in

fiducials.20171111.txt,

which gives the fiducial number, field, fff, type, and PFI coordinates.

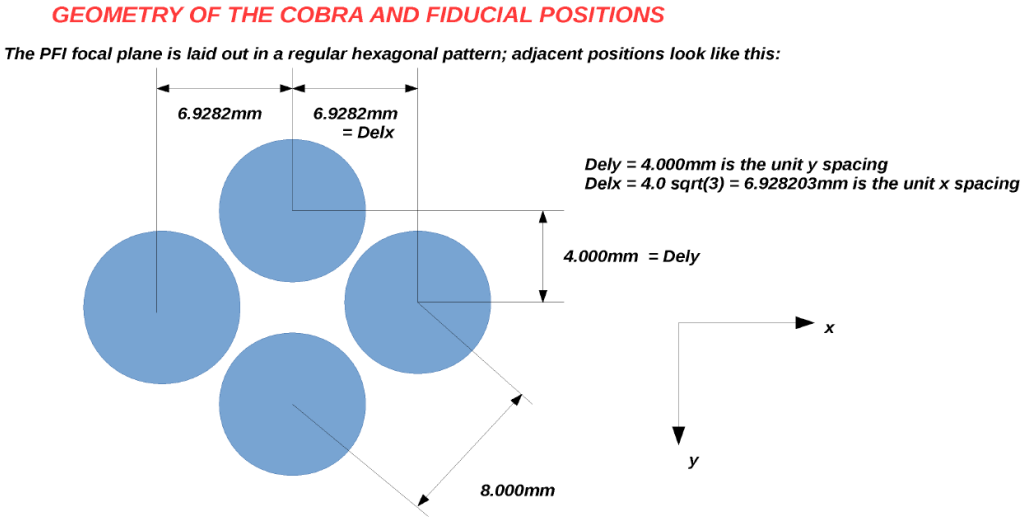

Figure 1. The Cobra Hex Grid

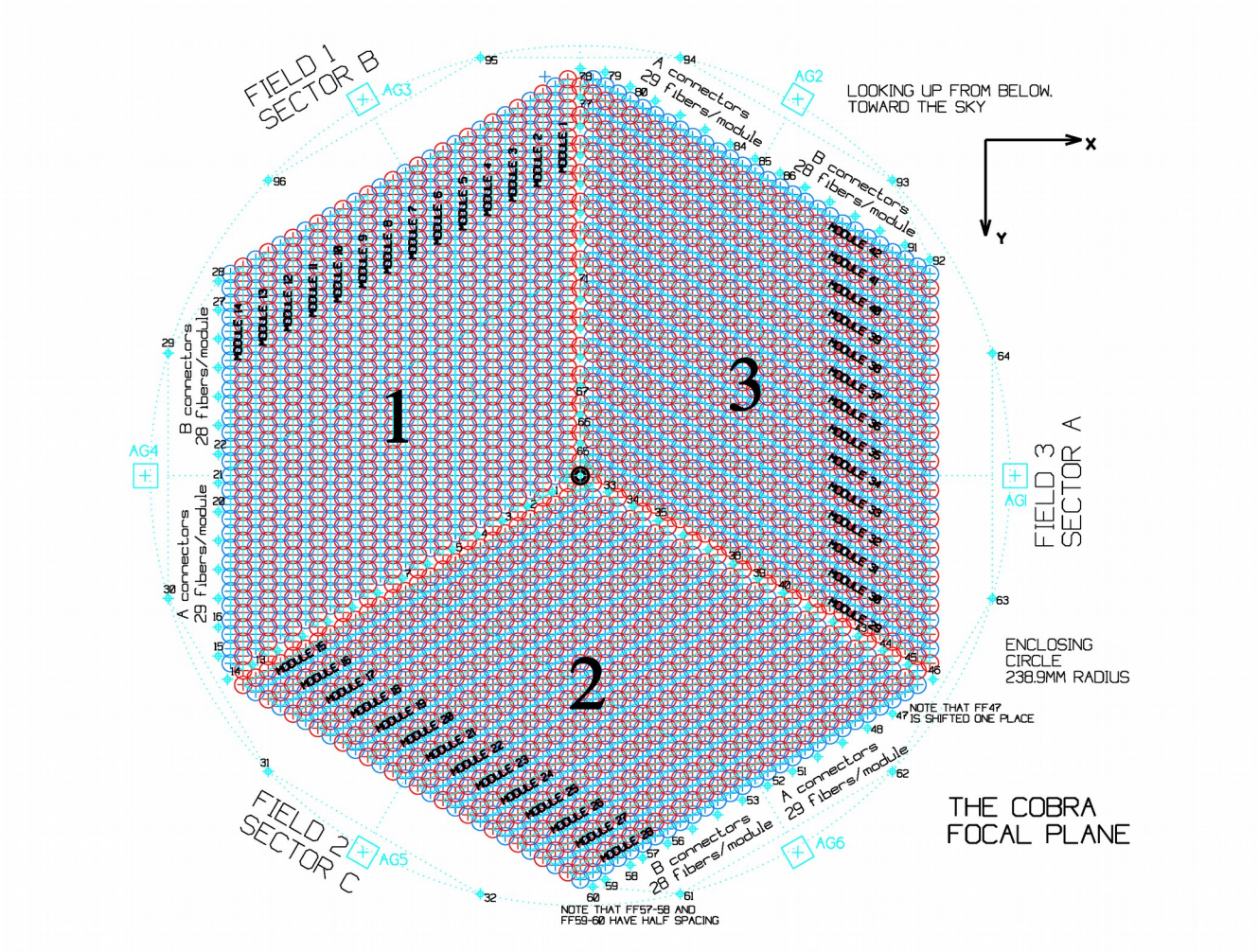

Figure 2. The PFI focal plane, showing all the fields, modules, cobras, and fiducials.

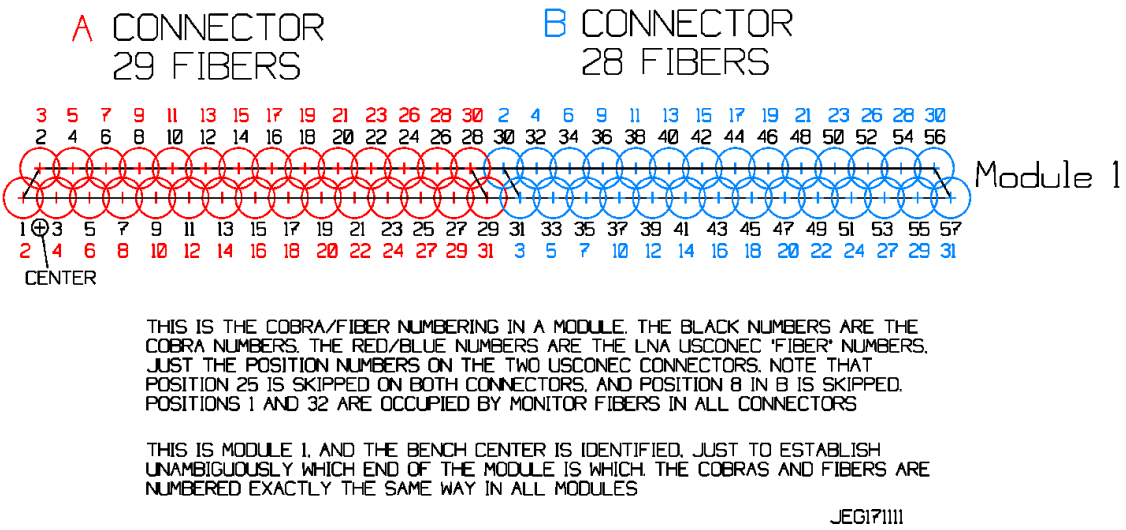

Figure 3. The numbering of the cobras and fibers in a module

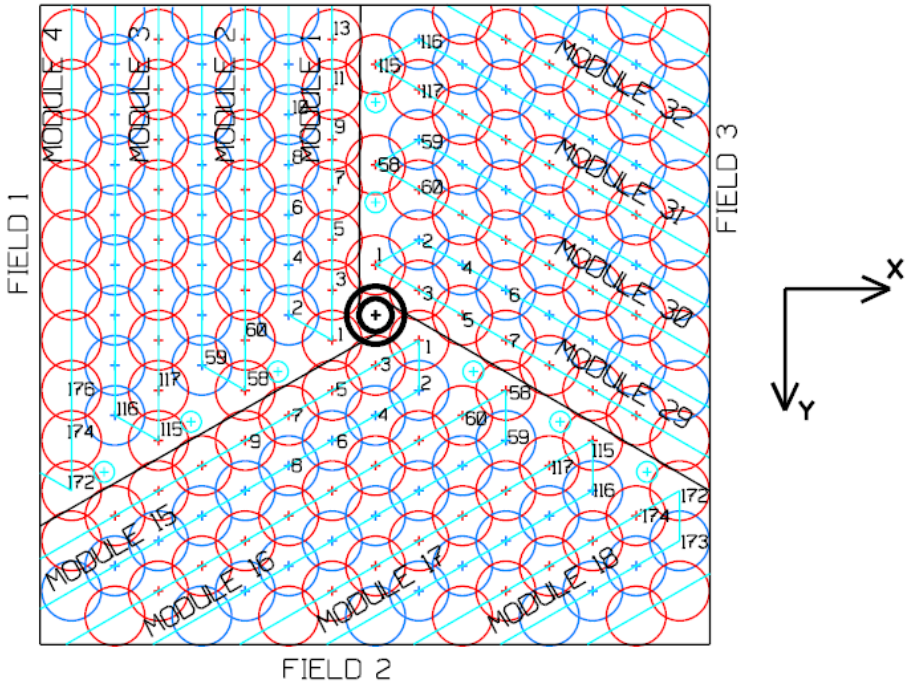

Figure 4. The central region of the focal plane, showing how the cobra (cm) and module numbers go.

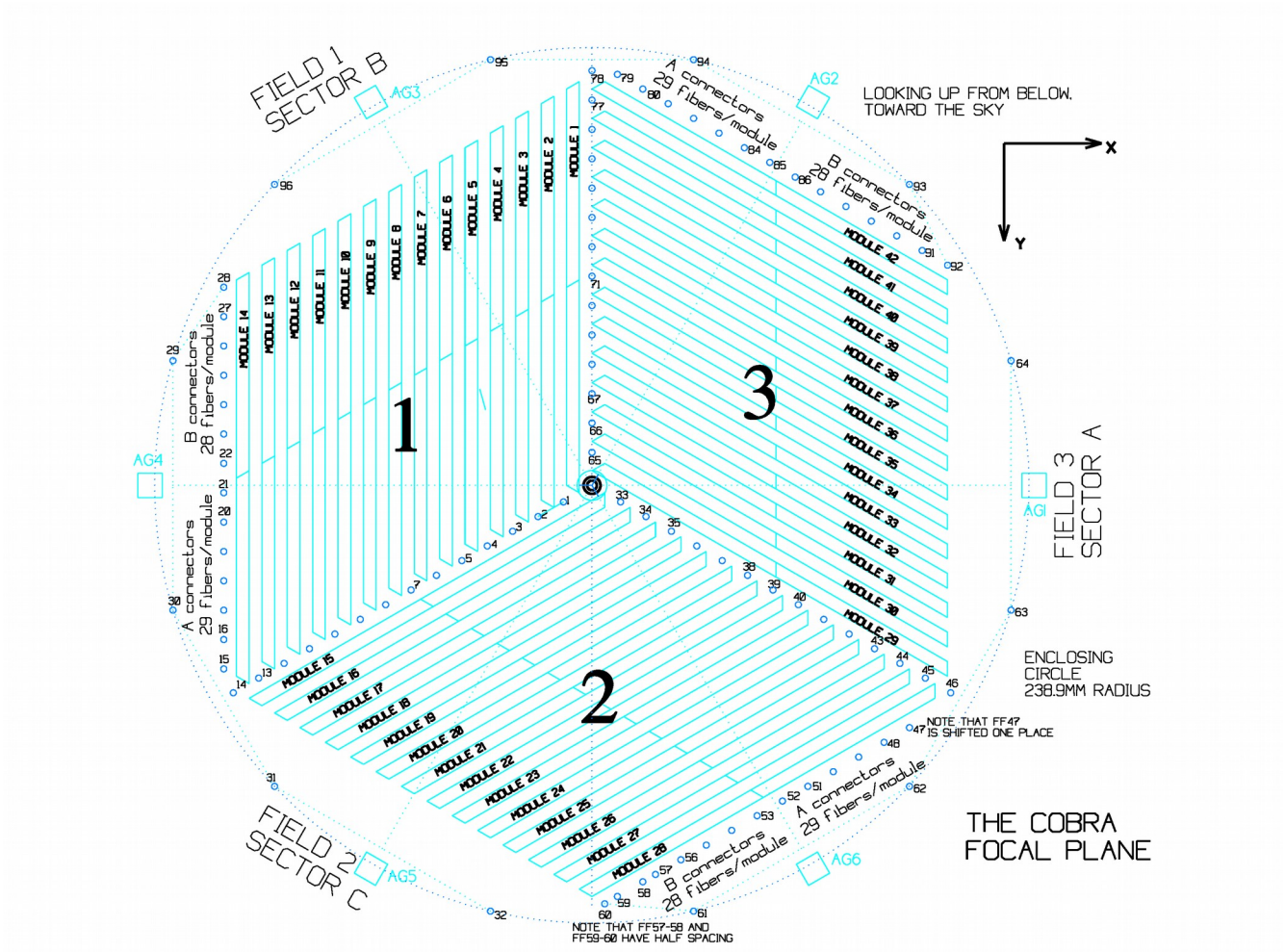

Figure 5. A somewhat simplified version of the focal plane drawing showing the fiducials and their relationship to the fields.