WHYDRA: A Program for Assigning Fibers

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1 Introduction

1.1 History and Acknowledgements

This document describes the program **whydra**, which takes an input file containing the celestial coordinates of objects and determines a "pretty good" assignment of fibers for the WIYN multi-object fiber positioner "Hydra". This code is an updated version of the **hydra** FORTRAN code that successfully computed fiber assignments for users at the 4-m during Hydra's incarnation at the Kitt Peak 4-m in the early 1990s; a similar version is in use on the CTIO 4-m. The original code was developed after extensive discussions with Taft Armandroff and Sam Barden, and includes a contribution by Tod Lauer. Mapping of the focal plane was achieved with the kind assistance of Dave Monet of the US Naval Observatory (Flagstaff), and many of the refraction/geometry subroutines were taken from Pat Wallace's extensive STARLINK collection. Major revisions to the focal plane model was made after the 2005 conversion to "Hydra_II" (really "Hydra_IV") at WIYN, and additional features added in 2006. The LINUX distribution package was put together by Behzad Abaresshi.

1.2 Overview

The input list should have objects listed in priority order, with the most important objects at the top of the list. The coordinates of clean sky positions and field-orientation-probe stars ("fop stars") should also be included in the same file. (Including a goodly number of fop stars and clean sky positions will provide greater flexibility for placement of fibers on program objects.) In addition, "extra" objects can be included in the file—these will not be used in the first-pass assignments, but if there are free fibers available at the end, these will be assigned to these "extra" objects. The file must also contain the coordinates of the field center, along with a number of things (wavelength, LST, exposure length) that are needed to properly account for the effects of differential refraction.

The output file will contain *all* of the input objects, assigned or not, with fiber assignments indicated with a numerical value in the "STATUS=" field. The stars with assigned fibers are rotated to the bottom of the list, but the input order is otherwise preserved; thus, one can successively use each output file as a new input file, with previously assigned stars dropped in priority.

The next section ($\oint$ II) will describe how the assignments are done. $\oint$ III will describe the input and output formats and how to use the program. $\oint$ IV will review the geometry and reveal the inter-workings of the astrometry (celestial coordinates $\Rightarrow$ plate coordinates) transformations.

2 How It Does It

Let us imagine that we begin with a list of 300 program objects, 50 clean sky positions, and 30 stars suitable for fops. In addition, assume that you have 100 "extra" program objects that you don't care that much about, but would like to observe if you can do so without compromising the assignments of the original 300. The program objects are in priority order—you'd rather observe the ones at the top of the list than those faint guys near the bottom. We would like to get as many of the program stars on using the red fiber cable (which contains 98 fibers), but we need to have at least 9 skys on each configuration. For good guiding and acquisition, we recommend using 5 fop stars; the system will not allow use with less than two as there is then no way to guide effectively (translation plus rotation).

The program begins by adopting an "offset angle" for the instrument rotator. Hydra is mounted on an instrument rotator which tracks during the exposure to remove the field rotation; however, since the rotator can travel only 360 degrees before running into hard stops, we begin with an offset angle (determined from the declination) that will assure that the rotator is in its mid-range of travel when the field transits. Next, the program computes the x and y positions relative for all the objects, skys, fop stars, and "extra" objects. It keeps track of which of these are in illegal positions (off the edge of the field of view) using the celestial coordinates of the field center you have provided. This astrometry may be a little different at the telescope, of course, as you may be observing at a slightly different LST and hence differential refraction will have moved objects around a little.

The assignments are first made on the first 98 *legal* objects. (By legal, we mean only that the objects are in the field of view.) The assignments are done ignoring collisions, but always by finding the unassigned fiber nearest in angle. We begin this process by first sorting the objects in this hopper radially. For objects near the edge of the plate there may be only one or two fibers we can assign to them without violating bending constraints on the fibers. As we move in towards the plate center we begin to be able to reach a position for an increasing number of fibers, until near field center we can reach a position with half of the fibers. Thus we start doing the assignments of fibers to objects starting with those with the greatest radius and working our way inwards. Once we get within the central portion of the plate (R=0.25) we ignore the radius and simply continue with the assignments in priority order.

Note that at this point the priorities have not played a very big role—they have determined what items got thrown in the hopper, and they have played a minor role in the assignment of fibers in the center portion of the field, but we could well have had an object of low priority gobble up the only fiber that could be assigned to a high priority object that was merely a little ways further inwards. In practice, this seldom seems to be a problem. In some cases we *may* find that there is no fiber that can be assigned to a star, as all the ones that can reach this location have already been assigned to other objects, but that's life. This procedure continues until we are either out of fibers or out of objects.

In doing the assignments we have so far ignored the resulting collisions: these preliminary assignments probably contain many crossings. We next try to resolve these by looking first at adjacently assigned fibers. If two fibers touch, we try swapping their assignments, IF by doing so we will remove the collision condition. (In the case of two objects that are too close to each, for instance, no amount of swapping will ever help!) Next we try this swapping more globally, making several passes trying to untangle the twisted net we've woven. Of course, this won't always work; the fibers can't bend by more than 4 degrees, and it may be that a fiber is colliding with a parked fiber of the *other* fiber bundle (the blue bundle in this case), or a parked fops fiber; some collisions won't resolve because the objects are too close together. It is also possible to simply have too big a mess to be resolved in this simple manner, but that turns out to seldom be the case: insisting that we assign a fiber that is nearest in angular distance does a lot to prevent collisions.

Once we've made numerous attempts to resolve the tangles, we check to see what collisions are left. In this "verification" pass we first check each fiber to see if it collides with an *unassigned* parked fiber. If so, we simply remove the assignment, as there is nothing we can do to straighten this out. Next, we start with the fiber assigned to the highest priority object and see if it collides with any other fibers. If so, we undo the assignment of the other fiber(s). This may result in your losing five stars that are only slightly lower in priority than the one being considered, but probably not—these other five are likely to be colliding with each other too! We then proceed to the next star down the priority list, and continue de-assigning fibers until we have a collision-free set.

Next we put on the required number of skys. First, we see if we can simply sneak any skys on for free—are there any unassigned fibers that can reach a sky position without colliding with anything? We do *not* allow any collisions at this point.[1] We put as many unassigned fibers on as many skys as we can at this point, up to a maximum of the required number of sky positions. (We will come back later and see if we can sneak on any more skys, but that is only after we have used any unassigned fibers on object positions. After all, which would you rather observe?)

If we have been unable to sneak on the required number of skys this way we now force the issue. For each fiber (assigned or not) that can reach any sky position, we consider how much damage we would do by that assignment. We consider what would have to be unassigned to make this happen collision-free. In choosing the lesser of evils, the user can specify any of three weighting schemes: a *strong* weighting scheme, in which the weight assigned in the inverse of the position in the hopper (i.e., item ten is worth one-tenth of the top item), a *weak* weighting scheme, which is the square root of the *strong* scheme, or *none*, in which all objects are considered of equal weight—at least for resolving collisions.[2] We then assign whatever fiber-sky combination does the least damage, undoing whatever previous assignments are necessary. We then reconsider the question *ab initio* (after all, the game has changed because

[1]We may want to change this at some point to allow collisions that can be untangled by a simple swap, but it hasn't happened yet.

[2]Note that these weights are used *only* for forcing the issue with the fops and skies.

of those de-assignments and the previous sky assignment), and continue doing whatever is the least damaging until we are done.

Next we do the same procedure to get the required number of fops on. Can we get our one required fops on? What does the least amount of damage if we have to force the issue? The skys that have been added in the previous step are considered sacred during this procedure and cannot be removed.

At this point we probably still have a number of unassigned fibers. Can we sneak them on *any* of the fiber-less objects? We consider the entire list of free objects here, including ones that were originally in the assignment hopper but got bounced out, proceeding in priority order.

Next, if there are unassigned fibers, we see if we can sneak these on to any of the "extra" objects.

Finally, if we have any unassigned fibers, and any unassigned sky positions, we attempt to sneak those on as well. This goes a long ways towards undoing previous sins.

Sometimes a small change in the position of the rotator offset angle, or the location of field center, will make allow more and/or higher priority objects to be assigned. Therefore there is an an option that allows the user to declare whether or not to tweak the rotator offset and/or search for the best field center in an $n \times n$ grid. For each angle/center combination, the assignment procedure is started from scratch, and sum of the weights of all the assigned objects is computed. (Remember, for "strong" weighting, the weight of an object is 1/[position in the list]; for "weak weighting, the weight of an object is $\sqrt{}(1/[position in the list])$, and for "no weighting", each object has equal weight.) At the end, the field center and rotator angle offset are changed to the grid point that has the greatest combined weight, as long as the requirements for the number of fops and skys assigned are met.

3 How to Use It

3.1 Input file

The input file must begin by specifying nine key-words, one per line. Each key-word ends with a colon and is followed by a "value". In the current scheme of things there should be at most one space between the colon and the value. These words, and the acceptable values, are given below: *Key-words:*

FIELD NAME: [$\leq$ 64 character ID]

INPUT EPOCH: (equinox of the input coordinates; must be 1855-2000)

CURRENT EPOCH: (epoch of the proposed observations, e.g., 2007.5 if you are observing at the end of June in 2007.)

SIDEREAL TIME: (LST at mid-exposure, must be 0.00-23.999)

EXPOSURE LENGTH: (Decimal hours expected for exposure, 0.0-10.0)

WAVELENGTH: (Wavelength of spectrograph; either 3200-10000, in which case the units are interpreted as Å, or 0.32-1.0, in which case the units are interpreted as μm.)

CABLE: (either RED, BLUE)

WEIGHTING: (possible answers are STRONG (default), WEAK, or NONE)

GUIDEWAVE: (wavelength of TV camera, defaults to 6000Å). Note that you have the option of installing a "blue" (BG39) or "red" (RG610) filter in front of the fops. In these cases I would assume that GUIDEWAVE is 5000Åand 7000Å, respectively.

The above key-words can be in any order at the top of the file.

After the key-words, we have the list of coordinates. Each coordinate entry consists of a *single line*, and includes the following. The format is fixed.

- Integer ID (4 digits or less). This should be a unique number that allows you to tell the fiber positioner what star you are talking about if you wish to drive the gripper over to that locale. It will also be kept as a secondary identifier when you reduce the data with IRAF. COLS 1-4

- Name (20 characters or less). This name is the principle object identifier; it will be kept with the individual spectrum when you reduce the data with IRAF. COLS 6-25

- RA. This should be specified the usual way, e.g., "02 12 14.123". The leading zeros are not required. Since we are reading these numbers in a fixed format, you may include colons (or anything else) where the spaces go. COLS 27-38

- DEC. This should be specified the usual way, e.g., "-01 12 13.21". For positive declinations the plus sign is optional. The value of the degrees must be between -89 and 89, and the values of the minutes and seconds < 60. The SIGN goes into COL 40; the rest go in COLS 41-51
- CLASS. This is a one letter code that specifies what type of object this is. COL 53. Possible answers are:

  C Center. There must be exactly one of these in the file; it is the coordinates of the plate center.

  O Object. This is the default if the item is unspecified, and is a normal program object. Currently the maximum number of objects is 2000.

  S Sky. Currently the maximum number of sky positions is 2000.

  F Field-orientation-probe star (FOPS). Currently the maximum number of FOPS is 2000.

  E "This is the key for "extra" objects, which will be assigned if possible, but without compromising the original list.

In order to provide some capability for you to document what you are doing, we interpret any line that begins with a pound sign ("#") to denote a comment field. These will be retained in the output file, although not in the place that you stick them (see below). Items with double pounds signs will not be retained; these are used in the output files to denote warning messages.

A sample file appears in Figure **??**.

3.2 How to Run It

This input file can have the extension ".ast", and should be located in the subdirectory "hydra_simulator/whydra". In order to run the program, you need to first source the csh environment: source hydra_simulator/hydra.env.csh. Chances are, you will want to put this in your .cshrc file so that it happens automatically when you log in.

You can simply type **whydra** (you don't need to be in any particular subdirectory). You will be given a list of all of the ".ast" files in the whydra subdirectory, and asked what input file you want. Note, however, that you

```
FIELD NAME: M33blue1
INPUT EPOCH: 2000.00
CURRENT EPOCH: 2006.7
SIDEREAL TIME: 1.50
EXPOSURE LENGTH:  3.00
WAVELENGTH: 4500.
CABLE: BLUE
GUIDEWAVE: 6000.
WEIGHTING: WEAK
#0000000011111111112222222222333333333344444444445555
6000 M33Center            01 33 51.00   +30 44 37.0  C
6001 USNOB1205-0021783123 01 34 21.99   +30 31 26.2  F
6002 USNOB1207-0020910113 01 34 36.94   +30 46 21.9  F
6003 USNOB1209-0020967113 01 33 46.58   +30 54 30.8  F
...
9173 Sky9173              01 34 21.00    30 04 55.7  S
9174 Sky9174              01 34 06.86    30 05 24.5  S
9175 Sky9175              01 34 14.85    30 07 30.7  S
9176 Sky9176              01 33 43.31    30 05 52.6  S
9177 Sky9177              01 33 56.12    30 09 22.6  S
0001 J013334.27+304136.7  01 33 34.27   +30 41 36.7  O
0002 J013406.63+304147.8  01 34  6.63   +30 41 47.8  O
0003 J013433.10+304659.0  01 34 33.10   +30 46 59.0  O
0004 J013410.93+303437.6  01 34 10.93   +30 34 37.6  O
0005 J013329.88+303147.3  01 33 29.88   +30 31 47.3  O
0006 J013352.39+303920.9  01 33 52.39   +30 39 20.9  O
...
0091 J013349.28+305250.2  01 33 49.28   +30 52 50.2  O
0092 J013334.29+303400.1  01 33 34.29   +30 34  0.1  O
0093 J013332.82+304146.0  01 33 32.82   +30 41 46.0  O
2001 J013314.70+304516.4  01 33 14.70   +30 45 16.4  E
2002 J013309.14+304954.5  01 33  9.14   +30 49 54.5  E
2003 J013347.33+303306.8  01 33 47.33   +30 33  6.8  E
2004 J013430.29+304039.8  01 34 30.29   +30 40 39.8  E
2005 J013352.19+303636.6  01 33 52.19   +30 36 36.6  E
2006 J013432.76+304717.2  01 34 32.76   +30 47 17.2  E
2007 J013431.97+304649.8  01 34 31.97   +30 46 49.8  E
```

Figure 1: Sample input file for **hydra**

```
[rmcneill@panda hydra_simulator]$ whydra
Available .ast files:
M33bluetest.ast
test_00.ast

 Input file name: M33bluetest5.ast
 Input file name: M33bluetest.ast
 Output root name: M33bluetest
 M33bluetest.hydra
 There are  131 fops stars found
 How many fops need to be assigned to fops stars?: 5
 There are   94 objects found
 There are    7 non-priority (extra) objects found
 There are  177 skies found
 How many skies are required?: 9
 The default angle of N rel to fib 0 is  88.814 degs
  Would you like to tweak the angle? y or n: n
 Would you like to tweak the center? y or n: n
There are 10 active fops fibers
There are  81 active fibers in the BLUE cable

 Field center=M33Center           01 33 51.000 +30 44 37.00  2000.00 Ag=  88.814
 Assigned:   44/  93 objs;   1/   7 exts;  29/ 177 skys;   4/ 131 fops;  Total wts=   9.86
Not enough FOPS assigned!
```

Figure 2: A sample run of **whydra**. The user requires 5 fops to be assigned from the sample of 131. The program only succeeds in assigning 4. The user requires 9 skys (from a list of 177) to be assigned; the program succeeds at assigning 29. Of the 94 objects, 44 are assigned; one of the 7 "extra" stars gets assigned. Can we do any better by letting the center and the rotator offset angle vary? See the next example.

can specify an output file as your input file—even though these aren't listed. You will also be asked for an output file name.

Sample runs are shown in Fig. **??** and **??**.

The output file will very much resemble the input file. However, (a) the center will now include the offset angle to use, (b) the comments will all have been collected under the header information, (c) the object code "O" will have been explictly stated for any program object without an "O" or "E" designation, (d) the ordering will have changed so that all the guide stars and skys will be at the top of the list, followed by the "extra" objects, followed by all the objects to which fibers could not be assigned, followed by all the objects to which fibers were assigned, and (e) the status will be listed after every object.

This status word contains the fiber number assigned if an assignment was made ("STATUS=240"). Otherwise, the status indicates whether the

```
 Input file name: M33bluetest.ast
 Output root name: M33try2
 M33try2.hydra

 There are  131 fops stars found
 How many fops need to be assigned to fops stars?: 5
 There are   94 objects found
 There are    7 non-priority (extra) objects found
 There are  177 skies found
 How many skies are required?: 9
 The default angle of N rel to fib 0 is  88.814 degs
 Would you like to tweak the angle? y or n: y
 How many times? (3, 5, 7...) : 11
By how much? (Suggest 0.1 deg...): 0.07
 Would you like to tweak the center? y or n: y
 How many grid points per side? (3, 5, 7...): 11
 How many arcmin per each of the121 grid points?: 1.0
...
 Original center=01 33 51.000 +30 44 37.00 Ag=  88.814 summed weights=      9.86
 Revised  center=01 33 48.673 +30 44 07.00 Ag=  88.884 summed weights=     10.24
There are 10 active fops fibers
There are  81 active fibers in the BLUE cable

 Field center=M33Center           01 33 48.673 +30 44 07.00  2000.00 Ag=  88.884
 Assigned:   45/  93 objs;   2/   7 exts;  26/ 177 skys;   5/ 131 fops;  Total wts=  10.24
```

Figure 3: . The same data is now run, allowing the center and rotator offset to be tweaked. We varied the rotator angle by 11x0.07 degrees, and let the center vary by an 11x11 grid of 1' each. (So, 1331 trails in all.) On a 3GHz Linux box this took just under 2 minutes to run. At the end we had 45 objects assigned, 26 skys, and all 5 fops. Two of the "extras" objects made it on.

object was off the edge of the plate ("STATUS=EDGE"),was fine ("STATUS=OK") but it just so happened that no fiber was assigned. Within the two categories of unassigned and assigned objects, the original ordering is preserved. Thus this output file can be used as an input file for constructing a new configuration, and the process continued until all the objects you really care about have been assigned fibers. In doing this, you may want to change the center slightly to take care of objects on the steps or off the edge. See Figure **??** for an example of the output file from the previous run.

The output file will have the extension ".hydra".

At this point, you might want to run the output file through **whydra** again with different field centers if you want several over-lapping fields. In this case one might want to change the code on the previously assigned fibers from "O" to "E". Or, maybe it's time to move the assigned file to hydra_assignment/fields, and run it through the hydra simulator **hydrasim** to see if you can make any improvements by hand in the assignments[3].

4 The Geometry

The focal plane of the instrument consists of a plate which, when the instrument is in use, is warped via a vacuum to approximate the curved focal surface.

There are 288 fiber positions located around the perimeter of the circle. Twelve of these are taken up with the field-orientation-probes (FOPS), which are currently located in positions 0, 24, 48, and so on. The red fibers occupy every third position beginning at location 1 and include fibers at position 276 and 279; the blue cable begins at location 2 and occupy every third position. There are 82 empty slots.

The following are the steps that we go through in determining where on the focal plane to plunk down a fiber to assure it is where it is supposed to be once the vacuum is turned on to the plate.

- Precess coordinates to current epoch. This removes the rotation that would otherwise be introduced.

- Remove the effects of differential refraction across the field. This relies upon the spectrograph wavelength for the object and sky fibers, and

[3]Note that at present, any "extra" objects are displayed as SKYS in the hydrasim graphics window.

```
FIELD NAME: M33blue
INPUT EPOCH: 2000.00
CURRENT EPOCH: 2006.70
SIDEREAL TIME:  1.50
EXPOSURE LENGTH:  3.00
WAVELENGTH: 4500.
CABLE: BLUE
GUIDEWAVE: 6000.
WEIGHTING: WEAK
#0000000011111111112222222222333333333344444444445555
6000 M33Center            01 33 48.673 +30 44 07.00 C  Ag=  88.884
6001 USNOB1205-0021783123 01 34 21.990 +30 31 26.20 F  STATUS=OK
6002 USNOB1207-0020910113 01 34 36.940 +30 46 21.90 F  STATUS= 216
6003 USNOB1209-0020967113 01 33 46.580 +30 54 30.80 F  STATUS=OK
6004 USNOB1208-0020963124 01 34 38.210 +30 51 31.30 F  STATUS= 240
6005 USNOB1204-0021132108 01 34 42.630 +30 25 28.00 F  STATUS= 168
...
9001 Sky9001              01 35 21.050 +30 38 21.90 S  STATUS= 200
9002 Sky9002              01 34 59.980 +30 38 37.30 S  STATUS=OK
9003 Sky9003              01 34 38.350 +30 39 01.90 S  STATUS=OK
9004 Sky9004              01 32 46.030 +30 41 59.40 S  STATUS=  77
9005 Sky9005              01 32 51.840 +30 42 05.70 S  STATUS=OK
9006 Sky9006              01 32 38.020 +30 41 26.20 S  STATUS=OK
...
2003 J013347.33+303306.8  01 34 33.100 +30 46 59.00 E  STATUS=OK
2004 J013430.29+304039.8  01 34 10.930 +30 34 37.60 E  STATUS=OK
2005 J013352.19+303636.6  01 33 29.880 +30 31 47.30 E  STATUS=OK
2006 J013432.76+304717.2  01 33 52.390 +30 39 20.90 E  STATUS=OK
2007 J013431.97+304649.8  01 33 33.220 +30 33 43.40 E  STATUS=OK
2001 J013314.70+304516.4  01 33 14.700 +30 45 16.40 E  STATUS=  59
2002 J013309.14+304954.5  01 33 09.140 +30 49 54.50 E  STATUS=  44
   7 J013333.22+303343.4  01 33 33.220 +30 33 43.40 O  STATUS=OK
   8 J013433.32+304660.0  01 34 33.320 +30 47 00.00 O  STATUS=OK
  11 J013341.28+302237.2  01 33 41.280 +30 22 37.20 O  STATUS=OK
  12 J013352.84+303914.9  01 33 52.840 +30 39 14.90 O  STATUS=OK
  17 J013401.44+303630.8  01 34 01.440 +30 36 30.80 O  STATUS=OK
...
  80 J013235.25+303017.6  01 32 35.250 +30 30 17.60 O  STATUS= 104
  81 J013426.11+303424.7  01 34 26.110 +30 34 24.70 O  STATUS= 176
  82 J013259.74+303854.8  01 32 59.740 +30 38 54.80 O  STATUS=  89
  84 J013335.32+303931.0  01 33 35.320 +30 39 31.00 O  STATUS= 110
  91 J013349.28+305250.2  01 33 49.280 +30 52 50.20 O  STATUS= 281
```

Figure 4: Output file from previous input file.

for the GUIDEWAVE wavelength for the fops. We also adopt a ground temperature typical for nighttime on Kitt Peak based upon the fraction on the "current epoch". This step is done using STARLINK routines.

- Convert to tangent-plane coordinates. This removes the projection effects of curved lines of declination.

- Remove pincushion distortion and convert to mm. The scale and distortion terms were measured from Lockheed camera plates, with special help provided by David Monet at the USNO. For those who are curious, the distortion curves through the wide-field corrector are of the form:

$$f = 1. + c * (\chi^2 + \eta^2)$$

  where χ and η are the tangent-plane coordinates (in radians), f is the actual (measured) distance from plate-center (in radians) in the presence of pincushion distortion, and the pincushion constant "c" was measured to have a value of 77.6 The actual measured plate scale is 9.384 arcsec/mm.

- De-project the warped plane coordinates to where we need to put a fiber when the vacuum is off. It turns out that the focal plan is free to expand into the curved spherical surface, and so we actually just plunk a fiber down where we want it to be on the curved surface.

- Correct for the offset to the rotator angle.

- Convert to encoder steps.

How well does all this work, when all is said and done? Our goal was to achieve 0.3" positioning RMS on the sky. After revisions to the measurements of the concentricities, plate scale, and distortion terms, and improved positioning in August 2005, we measured the throughput for a bunch of stars in h and Chi Per for which we knew the magnitudes. We show the results in Fig. **??**. Not too bad.

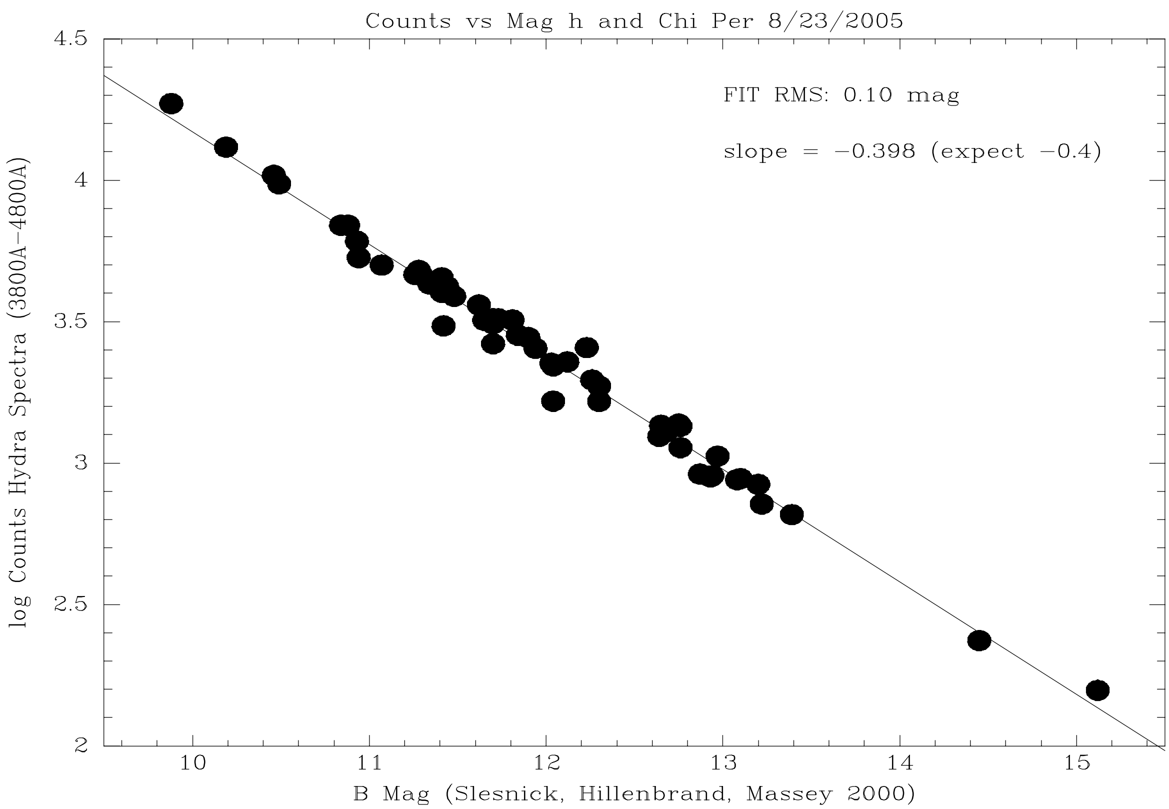

Figure 5: The number of counts show the expected correlation with magnitude for stars in our test field.