

Astrometry of the Neptune-Triton System

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Introduction

In this report I present the preliminary results of the astrometric reductions of the images from the Observatório do Pico dos Dias (OPD) in Brazil. The aim is to obtain precise positions for the Neptune - Triton system. The telescopes used was the Perkin-Elmer (160) with a diameter of 1.6m, the Boller & Chivens (IAG) with a diameter of 0.6m, and the Zeiss telescope with a diameter of 0.6m.

The observations were carried out since 1992 when a CCD big enough was installed in the OPD. The planet and satellite have been constantly observed, and still are, by our group. There were many CCDs (IKON, IXON, CCD101, CCD106, ...) and many filters (V, R, I, No Filter, ...) utilized.

In Table 1 it is summarized the number of images for Neptune and Triton for the 3 telescopes. It is also shown the number of positions where Neptune and Triton were identified automatically in the same image.

Table 1: Number of positions by object by telescope

| Telescope | N images | Neptune | Triton | Matches |
|-----------|------------|-----------|-----------|---------|
| 160 | 3423 (102) | 1683 (75) | 2133 (80) | 1614 |
| IAG | 5757 (114) | 4116 (97) | 3856 (98) | 3714 |
| Zeiss | 762 (16) | 511 (13) | 530 (11) | 481 |
| Total | 9942 | 6310 | 6519 | 5809 |

Number of positions identified of Neptune and Triton by telescope. In parentheses the number of nights where the observations are distributed. Matches: Number of positions where Neptune and Triton were identified automatically in the same image.

There were a total of 9942 images from June 1992 to September 2015. Many of the oldest images had no coordinates in header or they were wrong. Sometimes the filter was missing.

Fig. 1 shows the distribution of positions identified for Neptune and Triton over the years.

Reduction

The images were reduced using PRAIA, developed by Marcelo Assafin. To avoid the missing or wrong coordinates I used the coordinates of the ephemeris as input. This way PRAIA could identify reference stars in the images. The reference catalogue used was UCAC4. The ephemeris used to identify Neptune and Triton in the images was DE430+NEP081.

We applied the digital coronagraphy technique to test if the scattered light of Neptune would influence in the Triton's photocenter. No influence was identified in the 1 mas range.

From the offsets in the sense "position minus ephemeris" identified I made statistics night by night to eliminate discrepant positions with a sigma-clip procedure where offsets (modulus) larger than 80 mas or 2-sigma discrepant from the mean offset were removed.

Figs 2 e 4 show the offsets of Neptune and Triton, respectively, in RA e DEC for all the positions not eliminated in the previous procedure. Figs 3 e 5 show the mean offsets of each night and respective discrepancy (error bars).

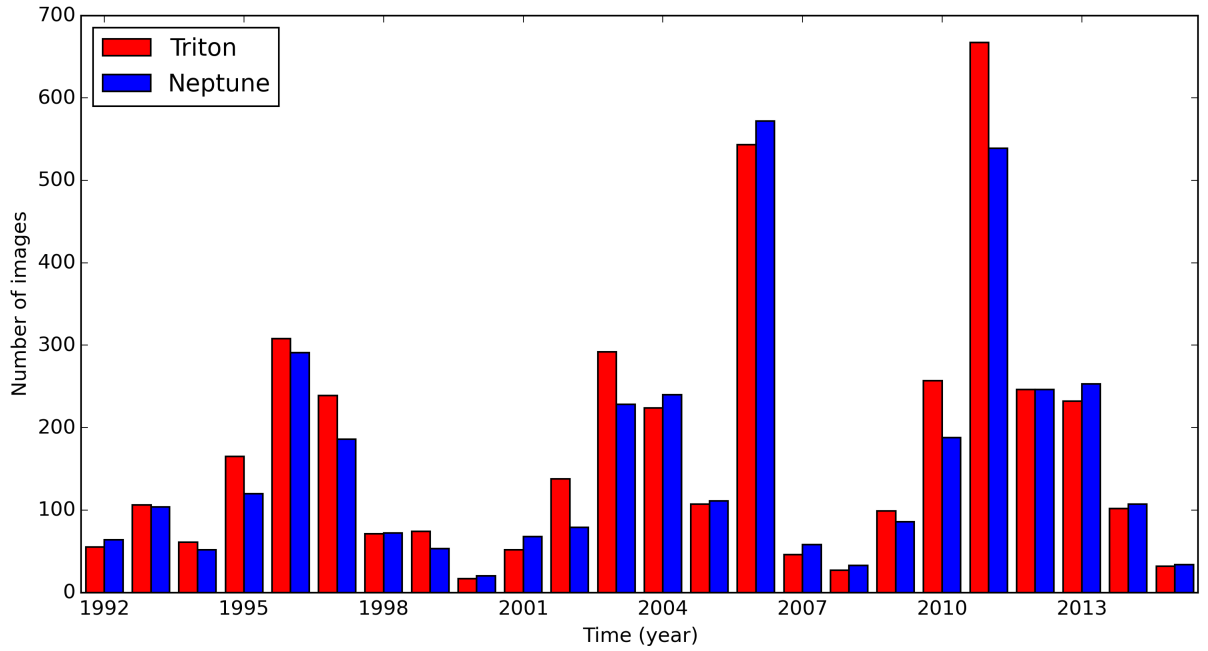


Figure 1: Distribution of positions for Neptune and Triton by year

Fig 6 shows the difference between the relative observed positions and the relative ephemeris positions of Triton and Neptune where they were identified in the same frame and not eliminated by the sigma-clip procedure.

Fig 7 shows the difference in the mean offsets night by night for all matched nights and not eliminated by the sigma-clip procedure. The dispersions (error bars) is the mean value of the dispersion in the night for each satellite.

We plan to do the following:

- Separate images by filter.
- Identify images where Neptune and/or Triton may be saturated. Filter + exposure time may be used for selection.
- Study the effects of chromatic refraction in the offsets (difference of offsets Triton - Neptune). I already have nights separated with observations distributed over six hours during the night.
- It may be required the use of a specific PSF for Neptune due to its large size.
- Further refinements in the data may be needed as we further investigate these position sets.

Figures 8-10 summarizes the distribution of positions by filter obtained in the Perkin-Elmer, the Boller & Chivens and the Zeiss telescopes, respectively.

In Tables 2 and 3 it is shown the mean offsets in Right Ascension and Declination night by night for Neptune and Triton, respectively, observed in the Perkin-Elmer telescope. The dispersion of the positions (standard deviation), number of frames that was not eliminated by the sigma-clip procedure, the mean date of the night and the average number of reference stars by frame is also available in the tables. The respective mean offsets night by night for the Boller & Chivens telescope is available in Tables 4 and 5.

As for the previous telescopes, tables 6 and 7 summarizes the offsets obtained with the Zeiss telescope.

In Table 8 it is presented the mean errors in X and Y of the bidimensional Gaussian used to fit the PSF of the objects. The average dispersion of the offsets in Tables 2-7 is also presented in the table.

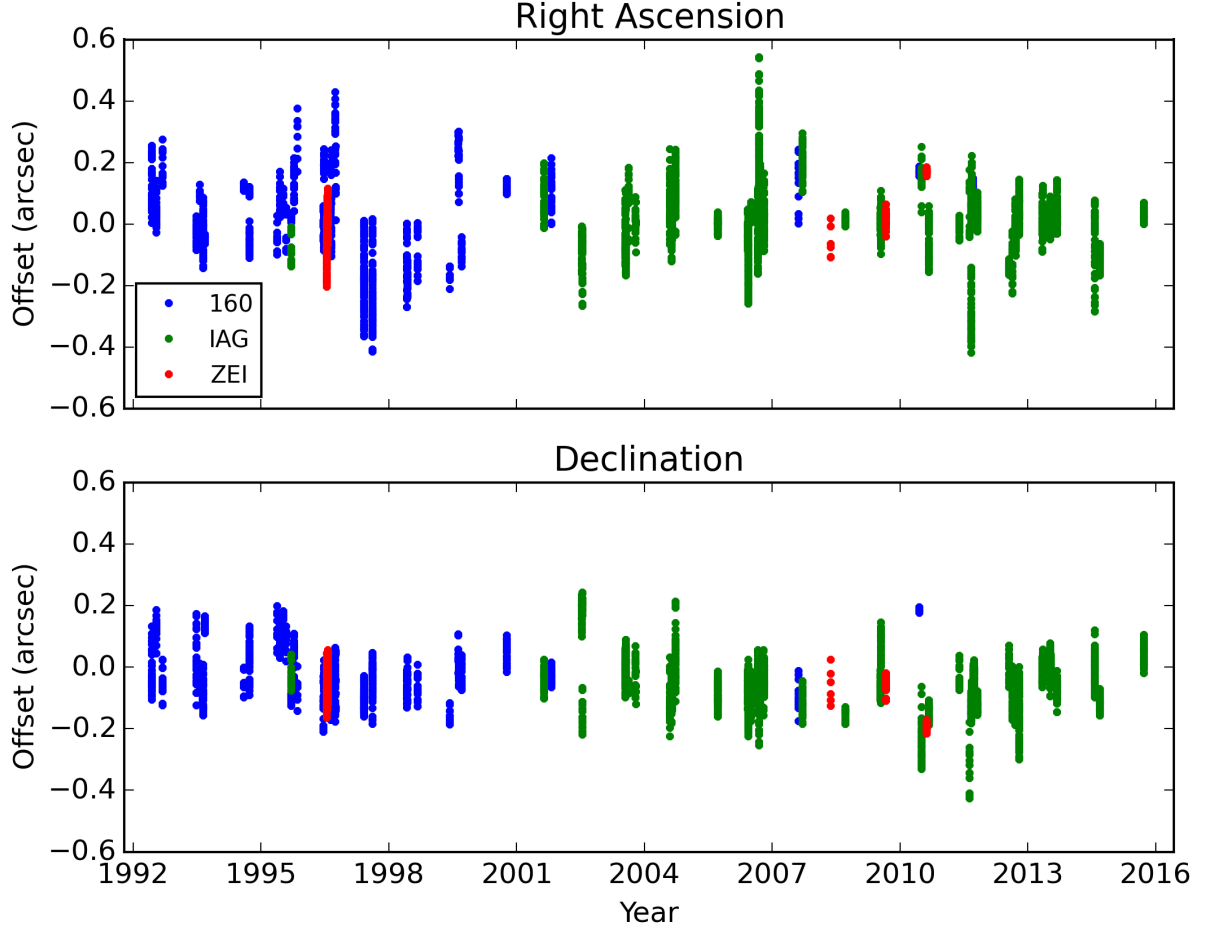


Figure 2: Neptune - All Offsets

Table 2: Mean offsets of Neptune night by night observed in the Perkin-Elmer telescope. Off-ra: mean offset em Right Ascension (mas). Off-de: mean offset in Declination (mas). E-ra: Dispersion (standard deviation) of the offsets in RA (mas). E-de: Dispersion in DEC (mas). Nfr: Number of observations per night. Date: the mean date of the observations. Ncat: average number of reference stars by frame.

| Off-ra | Off-de | E-ra | E-de | Nfr | Date | Ncat |
|--------|--------|------|------|-----|---------------------|------|
| 186.4 | 19.4 | 55.0 | 77.9 | 14 | 1992-06-09 07:51:19 | 10.0 |
| 47.7 | -52.6 | 25.5 | 19.6 | 11 | 1992-06-10 06:21:37 | 33.0 |
| 101.0 | -34.0 | 42.1 | 47.4 | 6 | 1992-06-11 06:45:25 | 16.0 |
| 46.6 | 118.8 | 48.0 | 37.8 | 18 | 1992-07-19 03:23:22 | 23.0 |
| 187.9 | -49.6 | 48.3 | 45.2 | 15 | 1992-09-11 01:11:36 | 25.0 |
| -22.5 | 4.0 | 31.1 | 75.6 | 15 | 1993-06-24 04:32:16 | 16.0 |
| -41.9 | 70.5 | 22.6 | 78.2 | 12 | 1993-06-25 04:43:38 | 9.0 |

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Table 2 – *Continued from previous page*

| off-ra | off-de | E-ra | E-de | Nfr | Date | Ncat |
|--------|--------|------|------|-----|---------------------|------|
| 95.0 | -33.9 | 19.2 | 30.8 | 7 | 1993-07-27 04:00:31 | 23.0 |
| -10.0 | -90.0 | 60.6 | 26.6 | 24 | 1993-08-21 00:31:24 | 29.0 |
| -50.6 | -73.9 | 55.6 | 43.9 | 35 | 1993-08-22 23:36:48 | 9.0 |
| -46.7 | 133.9 | 9.3 | 18.5 | 11 | 1993-09-06 22:33:58 | 9.0 |
| 121.9 | -54.4 | 10.5 | 35.2 | 8 | 1994-08-05 04:13:11 | 15.0 |
| 104.9 | 78.0 | 11.7 | 28.6 | 8 | 1994-09-22 00:43:05 | 11.0 |
| -39.5 | 54.0 | 69.3 | 46.3 | 13 | 1994-09-22 22:46:08 | 24.0 |
| -57.4 | 32.9 | 15.7 | 19.8 | 10 | 1994-09-23 23:11:52 | 26.0 |
| -43.5 | -20.4 | 30.0 | 76.1 | 13 | 1994-09-24 22:43:01 | 27.0 |
| -43.8 | 124.2 | 38.5 | 50.4 | 10 | 1995-05-19 07:11:17 | 11.0 |
| 91.6 | 86.9 | 45.3 | 38.1 | 14 | 1995-06-13 06:09:42 | 13.0 |
| 93.4 | 97.8 | 5.4 | 23.3 | 10 | 1995-06-27 05:34:17 | 8.0 |
| 71.3 | 166.3 | 33.8 | 10.0 | 9 | 1995-07-11 03:37:19 | 17.0 |
| -2.1 | 85.3 | 58.1 | 35.7 | 10 | 1995-08-07 01:38:00 | 21.0 |
| 19.2 | -104.3 | 7.6 | 13.6 | 15 | 1995-09-17 00:36:24 | 14.0 |
| 127.2 | 30.9 | 50.1 | 55.4 | 25 | 1995-10-11 23:16:34 | 23.0 |
| 123.0 | 19.0 | 60.0 | 31.0 | 4 | 1995-10-12 22:54:50 | 13.0 |
| 281.9 | -72.0 | 68.5 | 42.7 | 8 | 1995-11-10 22:46:56 | 6.0 |
| 7.8 | -127.4 | 38.3 | 56.2 | 16 | 1996-06-21 06:20:04 | 13.0 |
| -30.0 | -40.2 | 50.6 | 13.7 | 13 | 1996-06-22 05:17:12 | 15.0 |
| -43.1 | -42.2 | 8.8 | 13.8 | 17 | 1996-06-23 05:11:07 | 11.0 |
| 203.3 | -44.8 | 20.3 | 34.1 | 11 | 1996-06-24 06:57:46 | 12.0 |
| 171.0 | -57.6 | 16.2 | 48.8 | 5 | 1996-06-25 06:46:08 | 15.0 |
| 63.1 | -71.7 | 79.6 | 58.9 | 19 | 1996-08-22 03:18:27 | 13.0 |
| 152.6 | -48.1 | 69.6 | 40.1 | 9 | 1996-08-24 03:47:49 | 8.0 |
| -65.6 | -81.8 | 28.6 | 33.9 | 12 | 1996-08-25 01:03:19 | 10.0 |
| 243.1 | -26.8 | 58.0 | 47.2 | 11 | 1996-09-28 01:32:28 | 7.0 |
| 358.3 | -95.2 | 37.8 | 61.3 | 12 | 1996-09-29 02:18:58 | 12.0 |
| 123.0 | -60.1 | 67.8 | 76.4 | 8 | 1996-10-02 00:27:18 | 5.0 |
| -238.5 | -127.4 | 76.6 | 16.4 | 40 | 1997-06-01 05:10:31 | 10.0 |
| -116.2 | -77.6 | 79.9 | 25.4 | 41 | 1997-06-02 05:47:21 | 9.0 |
| -290.4 | -17.6 | 77.6 | 35.4 | 34 | 1997-08-12 00:34:48 | 10.0 |
| -34.3 | -6.4 | 31.1 | 24.8 | 15 | 1997-08-13 03:08:20 | 9.0 |
| -216.2 | -19.8 | 68.7 | 22.4 | 19 | 1997-08-13 23:57:27 | 5.0 |
| -284.3 | -70.5 | 73.0 | 57.3 | 20 | 1997-08-14 23:49:36 | 6.0 |
| -297.4 | -77.9 | 16.0 | 20.8 | 17 | 1997-08-15 23:17:19 | 14.0 |
| -123.9 | -68.9 | 77.2 | 33.8 | 30 | 1998-06-06 05:10:18 | 11.0 |
| -185.2 | -41.8 | 34.4 | 41.2 | 24 | 1998-06-08 04:20:38 | 19.0 |
| -82.7 | -63.3 | 66.8 | 37.5 | 18 | 1998-09-03 23:01:05 | 10.0 |
| -167.1 | -154.2 | 22.6 | 23.2 | 10 | 1999-06-06 04:38:42 | 12.0 |
| 260.6 | 55.5 | 24.8 | 46.2 | 8 | 1999-08-21 04:13:56 | 17.0 |
| 188.1 | -22.1 | 73.6 | 26.9 | 17 | 1999-08-22 03:35:44 | 14.0 |
| -85.6 | -24.0 | 26.3 | 37.6 | 18 | 1999-09-17 22:47:52 | 10.0 |
| 122.7 | 44.8 | 16.7 | 37.0 | 20 | 2000-10-09 23:56:21 | 9.0 |
| 106.9 | -44.5 | 34.0 | 12.1 | 13 | 2001-10-24 22:46:18 | 5.0 |

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Table 2 – *Continued from previous page*

| off-ra | off-de | E-ra | E-de | Nfr | Date | Ncat |
|--------|--------|------|------|-----|---------------------|------|
| 112.2 | -20.3 | 61.7 | 20.4 | 18 | 2001-10-27 22:38:36 | 9.0 |
| 141.9 | -92.7 | 77.6 | 44.4 | 14 | 2007-08-17 06:39:00 | 6.0 |
| 170.3 | 185.6 | 9.0 | 6.3 | 8 | 2010-06-16 08:52:32 | 5.0 |
| 102.7 | -101.8 | 23.5 | 18.5 | 60 | 2011-09-20 02:04:26 | 5.0 |

Table 3: Same as in Table 2 for Triton in the Perkin-Elmer telescope.

| Off-ra | Off-de | E-ra | E-de | Nfr | Date | Ncat |
|--------|--------|------|------|-----|---------------------|------|
| 9.5 | -14.2 | 19.2 | 16.5 | 13 | 1992-06-09 07:49:08 | 11 |
| -12.7 | -31.5 | 21.3 | 23.4 | 11 | 1992-06-10 06:20:08 | 30 |
| -3.8 | -32.3 | 31.9 | 41.7 | 6 | 1992-06-11 06:45:25 | 16 |
| -13.2 | 2.0 | 21.0 | 6.2 | 12 | 1992-07-19 03:28:00 | 23 |
| 143.8 | -63.2 | 64.5 | 55.7 | 13 | 1992-09-11 01:11:58 | 24 |
| 8.0 | 15.3 | 24.0 | 57.3 | 15 | 1993-06-24 03:57:40 | 12 |
| -37.6 | 10.8 | 63.8 | 20.4 | 16 | 1993-06-25 05:04:44 | 12 |
| -1.1 | 27.2 | 14.0 | 72.7 | 10 | 1993-07-27 04:03:11 | 23 |
| -11.7 | -39.4 | 15.8 | 21.5 | 20 | 1993-08-21 00:43:19 | 28 |
| -1.8 | -5.8 | 24.6 | 22.3 | 33 | 1993-08-22 23:49:13 | 13 |
| -14.5 | 13.0 | 15.9 | 11.8 | 12 | 1993-09-06 22:34:10 | 9 |
| -19.6 | -61.8 | 20.7 | 42.6 | 11 | 1994-08-05 04:13:04 | 15 |
| -22.7 | 19.7 | 43.4 | 71.6 | 12 | 1994-09-22 00:49:21 | 11 |
| -58.8 | 9.7 | 18.4 | 76.1 | 12 | 1994-09-22 22:45:45 | 16 |
| -53.3 | 1.7 | 13.1 | 54.6 | 15 | 1994-09-23 23:21:39 | 18 |
| -44.4 | -3.5 | 10.9 | 58.2 | 11 | 1994-09-24 22:49:53 | 26 |
| -1.0 | -25.9 | 9.8 | 13.4 | 10 | 1995-05-19 07:11:17 | 11 |
| 14.7 | -46.8 | 36.3 | 22.8 | 18 | 1995-06-13 06:15:21 | 14 |
| 41.6 | -26.0 | 28.3 | 18.6 | 14 | 1995-06-27 05:46:20 | 8 |
| 37.1 | 50.4 | 20.8 | 64.5 | 19 | 1995-07-11 03:53:15 | 17 |
| -7.4 | -40.4 | 7.7 | 18.1 | 9 | 1995-08-07 02:05:10 | 21 |
| 110.6 | -69.0 | 52.1 | 54.9 | 10 | 1995-08-09 04:40:34 | 4 |
| 11.2 | 5.0 | 51.7 | 79.0 | 10 | 1995-09-14 01:41:37 | 9 |
| 43.9 | -57.0 | 6.4 | 14.8 | 18 | 1995-09-17 00:34:02 | 13 |
| 24.1 | -40.6 | 18.1 | 22.6 | 20 | 1995-10-11 23:13:27 | 23 |
| 30.2 | 4.2 | 13.8 | 11.9 | 6 | 1995-10-12 22:57:46 | 18 |
| 24.0 | -74.7 | 74.5 | 42.6 | 10 | 1995-11-10 22:48:25 | 7 |
| -146.1 | -38.9 | 7.3 | 8.1 | 14 | 1996-06-21 06:15:10 | 15 |
| -89.5 | -5.5 | 23.9 | 25.8 | 30 | 1996-06-22 05:31:09 | 14 |
| -62.4 | -21.7 | 3.0 | 16.5 | 13 | 1996-06-23 05:14:30 | 11 |
| 36.4 | -17.0 | 14.1 | 40.1 | 11 | 1996-06-24 06:57:46 | 12 |
| 18.8 | -31.2 | 17.6 | 50.2 | 5 | 1996-06-25 06:46:08 | 15 |
| 6.8 | -36.0 | 51.2 | 17.7 | 6 | 1996-06-26 07:41:52 | 13 |
| 42.5 | -42.3 | 25.8 | 44.3 | 27 | 1996-08-22 03:36:50 | 12 |
| 72.0 | -32.4 | 69.7 | 45.0 | 10 | 1996-08-24 03:47:48 | 8 |
| 46.5 | -67.4 | 15.4 | 23.3 | 11 | 1996-08-25 01:11:06 | 10 |
| 35.4 | -4.0 | 25.0 | 55.9 | 12 | 1996-09-28 01:35:53 | 7 |
| 83.5 | -14.8 | 79.6 | 74.6 | 13 | 1996-10-02 00:53:04 | 5 |

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Table 3 – *Continued from previous page*

| off-ra | off-de | E-ra | E-de | Nfr | Date | Ncat |
|--------|--------|------|------|-----|---------------------|------|
| -73.8 | -110.7 | 62.0 | 49.4 | 95 | 1997-06-01 06:13:32 | 10 |
| 15.5 | -57.0 | 15.5 | 18.2 | 46 | 1997-06-02 06:13:06 | 9 |
| -29.8 | -23.1 | 47.0 | 27.8 | 33 | 1997-08-12 00:40:16 | 11 |
| 59.6 | 32.0 | 29.4 | 27.1 | 15 | 1997-08-13 03:08:20 | 9 |
| 46.6 | -5.6 | 21.2 | 17.0 | 17 | 1997-08-14 00:03:14 | 5 |
| -6.7 | -9.7 | 28.7 | 18.9 | 14 | 1997-08-15 00:00:59 | 6 |
| 8.6 | -41.3 | 18.7 | 16.9 | 19 | 1997-08-15 23:16:54 | 14 |
| -59.6 | -61.4 | 30.4 | 20.8 | 30 | 1998-06-06 05:01:22 | 11 |
| -72.9 | -52.3 | 15.7 | 45.2 | 23 | 1998-06-08 04:19:48 | 19 |
| 1.6 | -43.2 | 24.8 | 52.9 | 18 | 1998-09-03 22:56:37 | 10 |
| 14.8 | -65.2 | 42.2 | 42.8 | 26 | 1999-06-06 05:15:30 | 13 |
| 1.4 | -29.9 | 23.2 | 39.8 | 10 | 1999-08-21 04:13:36 | 17 |
| -30.1 | -5.3 | 31.4 | 11.8 | 22 | 1999-08-22 02:44:29 | 15 |
| -21.5 | -44.3 | 25.3 | 30.8 | 16 | 1999-09-17 22:45:18 | 11 |
| 65.9 | -104.9 | 19.5 | 12.6 | 17 | 2000-10-09 23:55:53 | 6 |
| 29.9 | 17.8 | 15.4 | 22.2 | 17 | 2001-10-24 22:45:22 | 5 |
| 43.9 | 33.9 | 42.8 | 11.9 | 16 | 2001-10-27 22:38:27 | 9 |
| -136.5 | 21.4 | 79.1 | 6.8 | 54 | 2002-08-10 02:47:41 | 5 |
| 113.1 | -64.1 | 13.3 | 8.0 | 20 | 2003-09-16 00:12:25 | 5 |
| 36.1 | -43.8 | 55.3 | 33.6 | 12 | 2007-08-17 06:40:09 | 6 |
| 140.1 | 91.7 | 1.7 | 3.3 | 7 | 2010-06-16 08:51:51 | 5 |
| 11.8 | -30.7 | 23.2 | 14.8 | 109 | 2011-09-20 02:15:14 | 5 |

Table 4: Same as in Table 2 for Neptune in the Boller & Chivens telescope.

| Off-ra | Off-de | E-ra | E-de | Nfr | Date | Ncat |
|--------|--------|------|------|-----|---------------------|------|
| -88.1 | -27.4 | 45.3 | 38.3 | 15 | 1995-09-17 00:20:52 | 12 |
| 84.6 | -37.8 | 57.0 | 33.2 | 37 | 2001-08-26 03:04:29 | 14 |
| -128.1 | 160.8 | 25.6 | 33.1 | 20 | 2002-07-15 02:26:50 | 15 |
| -43.4 | 194.3 | 22.6 | 22.4 | 18 | 2002-07-16 03:30:59 | 14 |
| -56.4 | 205.5 | 21.2 | 19.1 | 24 | 2002-07-17 03:16:02 | 15 |
| -185.5 | -155.8 | 49.9 | 46.2 | 17 | 2002-07-18 02:00:52 | 11 |
| 45.7 | -34.8 | 33.0 | 40.7 | 24 | 2003-07-22 05:21:32 | 16 |
| -80.5 | 7.4 | 27.9 | 24.9 | 25 | 2003-07-23 03:42:29 | 18 |
| -82.7 | -11.3 | 25.9 | 35.8 | 15 | 2003-07-24 02:27:29 | 18 |
| -104.4 | 25.9 | 33.4 | 23.8 | 35 | 2003-07-25 03:25:27 | 14 |
| -91.4 | -4.3 | 42.4 | 34.5 | 35 | 2003-07-26 04:14:22 | 15 |
| -13.7 | -1.1 | 77.4 | 40.0 | 16 | 2003-07-27 07:07:07 | 14 |
| -80.4 | 20.0 | 33.9 | 38.7 | 36 | 2003-07-28 04:24:57 | 16 |
| 85.9 | -63.9 | 75.2 | 11.3 | 20 | 2003-08-20 02:23:25 | 20 |
| 12.3 | 19.0 | 15.2 | 34.6 | 7 | 2003-10-14 23:10:27 | 29 |
| 3.2 | 7.7 | 32.2 | 17.8 | 6 | 2003-10-15 22:42:13 | 30 |
| -11.8 | -54.8 | 58.6 | 59.4 | 5 | 2003-10-16 23:48:10 | 23 |
| -3.2 | -69.0 | 67.1 | 44.0 | 4 | 2003-10-19 23:28:27 | 25 |
| 17.6 | -93.6 | 42.0 | 56.6 | 11 | 2004-08-05 05:30:15 | 13 |
| 63.6 | -144.2 | 77.4 | 51.9 | 9 | 2004-08-06 04:09:25 | 14 |

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Table 4 – *Continued from previous page*

| off-ra | off-de | E-ra | E-de | Nfr | Date | Ncat |
|--------|--------|------|------|-----|---------------------|------|
| 108.2 | -130.3 | 75.4 | 25.5 | 13 | 2004-08-07 03:14:48 | 19 |
| 22.8 | -88.1 | 63.5 | 69.0 | 8 | 2004-08-08 01:23:21 | 19 |
| 49.8 | -78.8 | 46.6 | 29.5 | 17 | 2004-08-20 02:42:31 | 24 |
| -30.4 | -79.9 | 48.7 | 55.3 | 28 | 2004-08-21 03:12:05 | 21 |
| -44.0 | -72.8 | 18.2 | 31.2 | 24 | 2004-08-22 01:17:29 | 20 |
| -7.0 | -77.2 | 40.3 | 33.7 | 51 | 2004-08-23 03:12:09 | 17 |
| -0.6 | -82.8 | 28.0 | 33.0 | 30 | 2004-08-24 03:24:43 | 17 |
| 104.7 | 13.1 | 52.9 | 75.7 | 12 | 2004-09-23 00:43:43 | 12 |
| 110.1 | 87.6 | 79.5 | 77.9 | 18 | 2004-09-24 01:04:29 | 14 |
| 150.9 | -1.4 | 64.3 | 43.4 | 19 | 2004-09-25 01:20:55 | 14 |
| -0.3 | -87.3 | 19.8 | 37.3 | 111 | 2005-09-24 02:57:13 | 16 |
| -26.8 | -79.8 | 38.7 | 35.2 | 38 | 2006-06-07 07:07:55 | 23 |
| -111.0 | -102.2 | 79.9 | 63.3 | 107 | 2006-06-08 06:33:44 | 27 |
| 42.1 | -82.5 | 18.8 | 48.6 | 28 | 2006-07-04 05:13:37 | 12 |
| -90.8 | -23.1 | 38.9 | 39.7 | 27 | 2006-08-30 00:57:08 | 16 |
| 52.8 | -37.7 | 33.1 | 36.0 | 18 | 2006-08-31 02:31:20 | 19 |
| 53.5 | -45.3 | 24.0 | 38.0 | 21 | 2006-09-01 02:34:07 | 19 |
| 45.0 | -54.5 | 21.6 | 25.4 | 21 | 2006-09-04 02:39:49 | 17 |
| 54.9 | -48.1 | 35.2 | 25.5 | 16 | 2006-09-05 03:07:34 | 13 |
| 68.5 | -42.3 | 26.8 | 34.4 | 41 | 2006-09-06 02:30:36 | 12 |
| 208.7 | -56.9 | 64.4 | 48.4 | 40 | 2006-09-09 04:00:58 | 18 |
| 277.6 | -59.8 | 64.3 | 79.7 | 34 | 2006-09-11 04:28:42 | 17 |
| 396.6 | -107.9 | 77.0 | 76.4 | 20 | 2006-09-12 05:10:52 | 15 |
| 146.4 | -39.4 | 25.2 | 46.1 | 38 | 2006-09-20 02:19:30 | 18 |
| 67.1 | -36.8 | 20.8 | 23.7 | 38 | 2006-09-22 01:39:33 | 20 |
| 93.8 | -38.2 | 15.0 | 23.8 | 18 | 2006-09-25 01:32:35 | 17 |
| 8.3 | -32.4 | 61.0 | 77.7 | 12 | 2006-10-20 23:04:59 | 9 |
| -13.6 | -40.7 | 38.5 | 29.4 | 20 | 2006-10-21 22:15:23 | 13 |
| 70.4 | -42.4 | 50.0 | 41.6 | 23 | 2006-10-22 23:17:17 | 12 |
| 3.1 | -18.4 | 49.9 | 26.0 | 12 | 2006-10-25 22:21:13 | 31 |
| 198.8 | -115.7 | 49.6 | 36.8 | 44 | 2007-09-17 03:26:02 | 19 |
| 13.1 | -155.5 | 12.7 | 16.3 | 27 | 2008-09-20 03:37:18 | 25 |
| 8.5 | -62.2 | 22.7 | 26.5 | 22 | 2009-07-18 03:58:13 | 18 |
| 34.2 | 78.1 | 26.6 | 40.4 | 22 | 2009-07-20 06:04:51 | 14 |
| -51.7 | -75.1 | 23.6 | 30.6 | 13 | 2009-07-21 07:07:08 | 13 |
| 20.5 | 11.1 | 54.8 | 68.0 | 11 | 2009-07-22 05:40:51 | 13 |
| 153.4 | -253.8 | 16.3 | 46.9 | 30 | 2010-07-04 08:22:47 | 15 |
| 151.8 | -192.4 | 68.7 | 75.9 | 10 | 2010-07-05 07:14:23 | 20 |
| -35.4 | -148.7 | 60.8 | 21.0 | 74 | 2010-09-05 02:30:35 | 12 |
| -12.7 | -26.9 | 25.3 | 36.5 | 18 | 2011-05-24 08:13:36 | 8 |
| 57.5 | -312.8 | 78.7 | 72.4 | 15 | 2011-08-19 04:17:47 | 10 |
| 73.2 | -162.4 | 33.6 | 10.8 | 26 | 2011-09-03 05:31:28 | 13 |
| 35.2 | -122.4 | 28.2 | 21.4 | 51 | 2011-09-04 03:54:40 | 18 |
| -290.8 | -121.0 | 79.4 | 22.3 | 48 | 2011-09-05 02:57:52 | 19 |
| 131.3 | -97.9 | 47.3 | 33.3 | 23 | 2011-09-10 05:57:17 | 10 |

Continued on next page

Table 4 – *Continued from previous page*

| off-ra | off-de | E-ra | E-de | Nfr | Date | Ncat |
|--------|--------|------|------|-----|---------------------|------|
| 14.0 | -18.6 | 13.2 | 14.6 | 72 | 2011-09-23 01:09:04 | 16 |
| 58.8 | -45.3 | 19.2 | 24.6 | 131 | 2011-09-26 02:41:36 | 17 |
| 35.9 | -5.4 | 12.8 | 13.9 | 42 | 2011-09-27 01:34:13 | 19 |
| 31.5 | -114.5 | 16.7 | 20.3 | 23 | 2011-10-24 23:19:04 | 21 |
| 43.5 | -134.9 | 35.3 | 11.8 | 30 | 2011-10-26 23:40:14 | 19 |
| -142.4 | -3.4 | 14.7 | 41.8 | 18 | 2012-07-22 04:06:19 | 7 |
| -116.4 | -94.6 | 60.6 | 53.6 | 28 | 2012-08-24 05:00:16 | 14 |
| 21.3 | -125.5 | 36.7 | 15.4 | 19 | 2012-09-15 02:35:47 | 11 |
| -54.8 | -107.4 | 22.3 | 22.6 | 26 | 2012-09-15 23:32:44 | 10 |
| -50.8 | -128.8 | 28.2 | 31.7 | 25 | 2012-09-17 00:57:30 | 12 |
| -30.6 | -127.9 | 26.8 | 22.5 | 24 | 2012-09-18 01:41:33 | 13 |
| -39.4 | -97.6 | 35.4 | 31.7 | 25 | 2012-09-19 01:11:55 | 15 |
| 54.9 | -153.3 | 47.4 | 79.0 | 81 | 2012-10-19 01:55:57 | 8 |
| 3.3 | -17.8 | 48.3 | 31.6 | 30 | 2013-05-05 08:00:52 | 15 |
| 16.3 | 20.8 | 14.7 | 21.3 | 17 | 2013-05-09 08:28:00 | 17 |
| 14.6 | 11.6 | 58.7 | 16.2 | 19 | 2013-05-10 08:22:58 | 16 |
| 3.5 | 27.4 | 26.4 | 25.6 | 39 | 2013-07-12 06:56:33 | 18 |
| 18.3 | -12.7 | 36.4 | 41.6 | 39 | 2013-07-13 06:13:34 | 18 |
| 0.0 | 8.5 | 22.7 | 19.2 | 37 | 2013-07-15 07:18:49 | 18 |
| 107.4 | -65.1 | 35.4 | 25.7 | 9 | 2013-09-06 04:24:17 | 8 |
| 2.9 | -73.1 | 18.8 | 20.3 | 42 | 2013-09-07 03:09:30 | 7 |
| 41.2 | -77.2 | 24.3 | 36.3 | 21 | 2013-09-10 03:29:31 | 10 |
| -170.5 | -8.3 | 76.1 | 65.7 | 20 | 2014-07-30 04:05:46 | 5 |
| 24.8 | -8.4 | 30.0 | 38.2 | 38 | 2014-07-31 02:40:38 | 5 |
| -109.9 | -114.0 | 28.8 | 22.8 | 49 | 2014-09-13 03:07:20 | 20 |
| 33.0 | 40.3 | 19.8 | 32.7 | 34 | 2015-09-25 04:19:27 | 15 |

Table 5: Same as in Table 2 for Triton in the Boller & Chivens telescope.

| Off-ra | Off-de | E-ra | E-de | Nfr | Date | Ncat |
|--------|--------|------|------|-----|---------------------|------|
| -93.3 | -58.1 | 39.7 | 22.2 | 21 | 1995-09-17 00:26:00 | 13 |
| -14.3 | -65.1 | 27.7 | 40.4 | 19 | 2001-08-26 02:53:22 | 14 |
| 11.7 | -26.7 | 27.5 | 16.2 | 36 | 2002-07-15 05:00:25 | 17 |
| -2.4 | -25.0 | 19.3 | 24.2 | 12 | 2002-07-16 03:30:20 | 15 |
| -7.1 | -43.5 | 20.0 | 20.8 | 17 | 2002-07-17 03:14:54 | 15 |
| 19.9 | -68.8 | 38.6 | 25.6 | 19 | 2002-07-18 03:12:12 | 14 |
| -11.6 | -0.9 | 38.2 | 27.7 | 22 | 2003-07-22 06:16:18 | 17 |
| -45.0 | -10.6 | 51.7 | 31.4 | 33 | 2003-07-23 03:16:44 | 16 |
| -71.5 | 2.9 | 36.2 | 32.5 | 15 | 2003-07-24 02:27:01 | 18 |
| -84.9 | 12.6 | 36.1 | 24.4 | 26 | 2003-07-25 03:42:51 | 15 |
| -70.7 | 32.0 | 77.4 | 33.8 | 32 | 2003-07-26 03:39:33 | 18 |
| -40.2 | 35.3 | 76.8 | 68.7 | 26 | 2003-07-27 07:08:17 | 13 |
| -76.3 | 26.0 | 22.5 | 33.3 | 28 | 2003-07-28 04:26:58 | 18 |
| 59.5 | -3.1 | 45.8 | 22.1 | 33 | 2003-08-20 03:29:36 | 21 |
| -5.5 | 15.4 | 15.8 | 16.1 | 11 | 2003-10-14 23:31:14 | 33 |
| -21.9 | -2.9 | 39.1 | 79.8 | 18 | 2003-10-15 23:12:31 | 33 |

Continued on next page

Table 5 – *Continued from previous page*

| off-ra | off-de | E-ra | E-de | Nfr | Date | Ncat |
|--------|--------|------|------|-----|---------------------|------|
| -18.5 | -14.6 | 68.0 | 38.4 | 8 | 2003-10-17 00:27:54 | 25 |
| 10.3 | 36.4 | 29.5 | 78.2 | 8 | 2003-10-17 23:59:42 | 28 |
| -7.2 | -45.2 | 41.4 | 36.1 | 12 | 2003-10-19 23:39:48 | 31 |
| -11.1 | -111.8 | 26.3 | 17.4 | 17 | 2004-08-05 05:23:17 | 16 |
| 98.5 | -92.8 | 9.7 | 20.5 | 15 | 2004-08-06 03:48:57 | 18 |
| 45.9 | -105.5 | 14.8 | 12.8 | 15 | 2004-08-07 03:00:16 | 21 |
| 21.9 | -95.5 | 38.3 | 46.0 | 8 | 2004-08-08 01:23:21 | 19 |
| -6.5 | -36.3 | 26.9 | 19.9 | 15 | 2004-08-20 03:13:55 | 24 |
| -9.6 | -45.8 | 38.6 | 40.7 | 23 | 2004-08-21 03:06:38 | 21 |
| -3.4 | -64.3 | 17.8 | 27.5 | 20 | 2004-08-22 01:20:47 | 21 |
| -8.5 | -37.1 | 20.1 | 23.1 | 27 | 2004-08-23 02:57:26 | 18 |
| -6.5 | -35.9 | 21.2 | 34.3 | 22 | 2004-08-24 03:12:56 | 17 |
| 95.9 | -3.9 | 76.2 | 72.2 | 7 | 2004-09-23 00:45:10 | 13 |
| 66.5 | 119.6 | 64.4 | 75.7 | 22 | 2004-09-24 01:38:04 | 14 |
| 50.6 | 93.8 | 67.2 | 50.3 | 29 | 2004-09-25 02:06:53 | 14 |
| -3.8 | 219.0 | 25.5 | 22.9 | 4 | 2004-10-08 23:29:18 | 20 |
| -18.6 | -85.6 | 24.5 | 29.3 | 107 | 2005-09-24 02:50:15 | 16 |
| 8.9 | -48.2 | 23.0 | 29.4 | 38 | 2006-06-07 07:03:05 | 24 |
| -5.9 | -55.8 | 42.7 | 38.9 | 96 | 2006-06-08 06:48:11 | 27 |
| -11.6 | -67.2 | 24.1 | 18.7 | 19 | 2006-07-02 06:36:56 | 17 |
| 33.0 | -67.3 | 31.7 | 46.8 | 32 | 2006-07-04 05:12:04 | 12 |
| 80.5 | -57.3 | 56.3 | 38.7 | 20 | 2006-08-30 00:56:45 | 17 |
| 24.9 | 12.0 | 13.1 | 35.9 | 20 | 2006-09-01 02:35:19 | 20 |
| -8.6 | 1.1 | 21.7 | 13.9 | 17 | 2006-09-04 02:40:26 | 17 |
| 21.0 | -4.9 | 14.4 | 35.6 | 12 | 2006-09-05 03:06:40 | 14 |
| -7.1 | -15.6 | 26.9 | 28.7 | 39 | 2006-09-06 02:31:52 | 13 |
| 26.6 | 36.1 | 61.8 | 46.7 | 34 | 2006-09-09 04:01:33 | 18 |
| -8.9 | 47.6 | 56.5 | 79.6 | 31 | 2006-09-11 04:28:38 | 16 |
| 20.4 | 1.8 | 78.8 | 78.2 | 20 | 2006-09-12 05:10:45 | 15 |
| 35.4 | 9.5 | 30.2 | 59.3 | 44 | 2006-09-20 02:18:01 | 17 |
| 20.4 | 1.8 | 12.1 | 29.1 | 35 | 2006-09-22 01:40:29 | 20 |
| 24.6 | -9.7 | 10.5 | 26.0 | 18 | 2006-09-25 01:31:52 | 19 |
| -0.2 | 26.3 | 59.9 | 78.8 | 12 | 2006-10-20 23:05:50 | 9 |
| -11.9 | 16.0 | 23.4 | 47.1 | 20 | 2006-10-21 22:16:11 | 14 |
| -0.0 | -48.8 | 46.0 | 44.3 | 22 | 2006-10-22 23:16:45 | 12 |
| 0.6 | 29.3 | 19.5 | 35.1 | 14 | 2006-10-25 22:14:59 | 30 |
| 15.5 | -29.0 | 50.0 | 31.9 | 34 | 2007-09-17 03:21:45 | 18 |
| -27.4 | -92.6 | 6.2 | 12.2 | 23 | 2008-09-20 03:38:08 | 24 |
| -44.9 | -23.3 | 15.3 | 22.5 | 26 | 2009-07-18 03:59:51 | 19 |
| -43.7 | 83.3 | 17.7 | 39.2 | 24 | 2009-07-20 06:04:37 | 15 |
| -24.3 | -24.6 | 36.9 | 34.9 | 16 | 2009-07-21 07:03:50 | 14 |
| 8.8 | 62.5 | 27.6 | 79.6 | 13 | 2009-07-22 05:32:58 | 14 |
| 108.9 | -218.5 | 25.7 | 43.3 | 26 | 2010-07-04 08:23:03 | 15 |
| 76.2 | -28.4 | 23.1 | 7.9 | 17 | 2010-07-05 07:16:59 | 20 |
| 24.9 | -56.1 | 5.5 | 12.3 | 41 | 2010-09-05 02:29:34 | 12 |

Continued on next page

Table 5 – *Continued from previous page*

| off-ra | off-de | E-ra | E-de | Nfr | Date | Ncat |
|--------|--------|------|------|-----|---------------------|------|
| -50.3 | 2.4 | 29.9 | 25.7 | 9 | 2011-05-24 08:13:00 | 8 |
| -28.4 | -12.9 | 23.5 | 21.6 | 29 | 2011-08-19 04:10:39 | 10 |
| 81.2 | -57.1 | 25.5 | 16.6 | 28 | 2011-09-03 05:33:52 | 13 |
| 80.3 | -6.5 | 18.1 | 23.4 | 60 | 2011-09-04 03:38:42 | 19 |
| 58.4 | -27.5 | 6.3 | 6.0 | 33 | 2011-09-05 02:47:44 | 19 |
| 64.0 | -24.4 | 48.0 | 36.6 | 24 | 2011-09-10 05:57:16 | 10 |
| 31.7 | 7.9 | 12.2 | 10.6 | 87 | 2011-09-23 01:09:14 | 16 |
| 41.3 | 16.9 | 10.6 | 29.2 | 154 | 2011-09-26 02:52:52 | 17 |
| 52.6 | 56.3 | 9.9 | 13.5 | 47 | 2011-09-27 01:34:30 | 19 |
| 76.0 | -34.4 | 11.9 | 17.2 | 42 | 2011-10-24 23:39:03 | 21 |
| 63.4 | -47.3 | 11.5 | 9.8 | 45 | 2011-10-26 23:48:39 | 19 |
| -133.3 | -6.4 | 41.4 | 53.8 | 25 | 2012-07-22 04:06:34 | 7 |
| -64.3 | -45.3 | 48.4 | 48.2 | 27 | 2012-08-24 05:00:16 | 14 |
| 34.4 | -76.0 | 42.0 | 23.0 | 25 | 2012-09-15 02:35:48 | 11 |
| 4.4 | -47.2 | 27.4 | 13.6 | 23 | 2012-09-15 23:32:26 | 10 |
| -19.7 | -61.4 | 30.8 | 21.9 | 23 | 2012-09-17 00:57:30 | 12 |
| 3.9 | -57.0 | 25.4 | 21.3 | 27 | 2012-09-18 01:41:38 | 13 |
| -6.4 | -51.5 | 36.4 | 31.0 | 28 | 2012-09-19 01:11:45 | 15 |
| 21.7 | -48.2 | 38.8 | 79.6 | 68 | 2012-10-19 01:56:38 | 8 |
| 16.3 | 7.4 | 46.8 | 38.6 | 30 | 2013-05-05 08:00:35 | 16 |
| 15.4 | 11.8 | 9.4 | 17.9 | 18 | 2013-05-09 08:27:37 | 17 |
| 1.1 | 23.7 | 7.6 | 7.5 | 15 | 2013-05-10 08:22:39 | 16 |
| 20.9 | 24.9 | 20.2 | 25.6 | 33 | 2013-07-12 06:56:06 | 18 |
| 8.5 | 25.8 | 26.0 | 30.3 | 31 | 2013-07-13 06:13:33 | 18 |
| 32.8 | 36.1 | 11.4 | 10.0 | 36 | 2013-07-15 07:19:03 | 18 |
| 0.9 | -7.5 | 27.7 | 51.5 | 10 | 2013-09-06 04:24:20 | 8 |
| 8.8 | -56.1 | 19.6 | 15.7 | 38 | 2013-09-07 03:08:47 | 7 |
| 10.3 | -24.2 | 43.2 | 29.1 | 21 | 2013-09-10 03:30:03 | 10 |
| -92.9 | -53.2 | 25.3 | 46.8 | 15 | 2014-07-30 04:05:39 | 5 |
| 10.4 | -2.0 | 26.5 | 35.8 | 37 | 2014-07-31 02:40:55 | 5 |
| -61.4 | -99.4 | 20.1 | 20.9 | 50 | 2014-09-13 03:06:59 | 20 |
| 22.3 | 17.5 | 16.5 | 18.8 | 32 | 2015-09-25 04:19:38 | 15 |

Table 6: Same as in Table 2 for Neptune in the Zeiss telescope.

| Off-ra | Off-de | E-ra | E-de | Nfr | Date | Ncat |
|--------|--------|------|------|-----|---------------------|------|
| -139.1 | -110.3 | 37.9 | 32.6 | 31 | 1996-07-17 00:52:38 | 9 |
| -51.4 | -41.4 | 36.5 | 45.8 | 46 | 1996-07-18 01:57:03 | 8 |
| 31.9 | -85.1 | 32.6 | 29.9 | 48 | 1996-07-24 03:24:16 | 12 |
| 24.8 | -30.3 | 48.5 | 46.3 | 33 | 1996-07-30 01:42:55 | 7 |
| -57.5 | -61.2 | 52.4 | 56.7 | 6 | 2008-05-15 04:57:18 | 7 |
| 35.1 | -54.0 | 16.3 | 16.5 | 8 | 2009-09-04 03:46:23 | 12 |
| 1.4 | -54.4 | 22.3 | 30.4 | 10 | 2009-09-05 01:16:48 | 15 |
| 169.5 | -194.4 | 7.9 | 11.9 | 66 | 2010-08-18 05:09:23 | 22 |

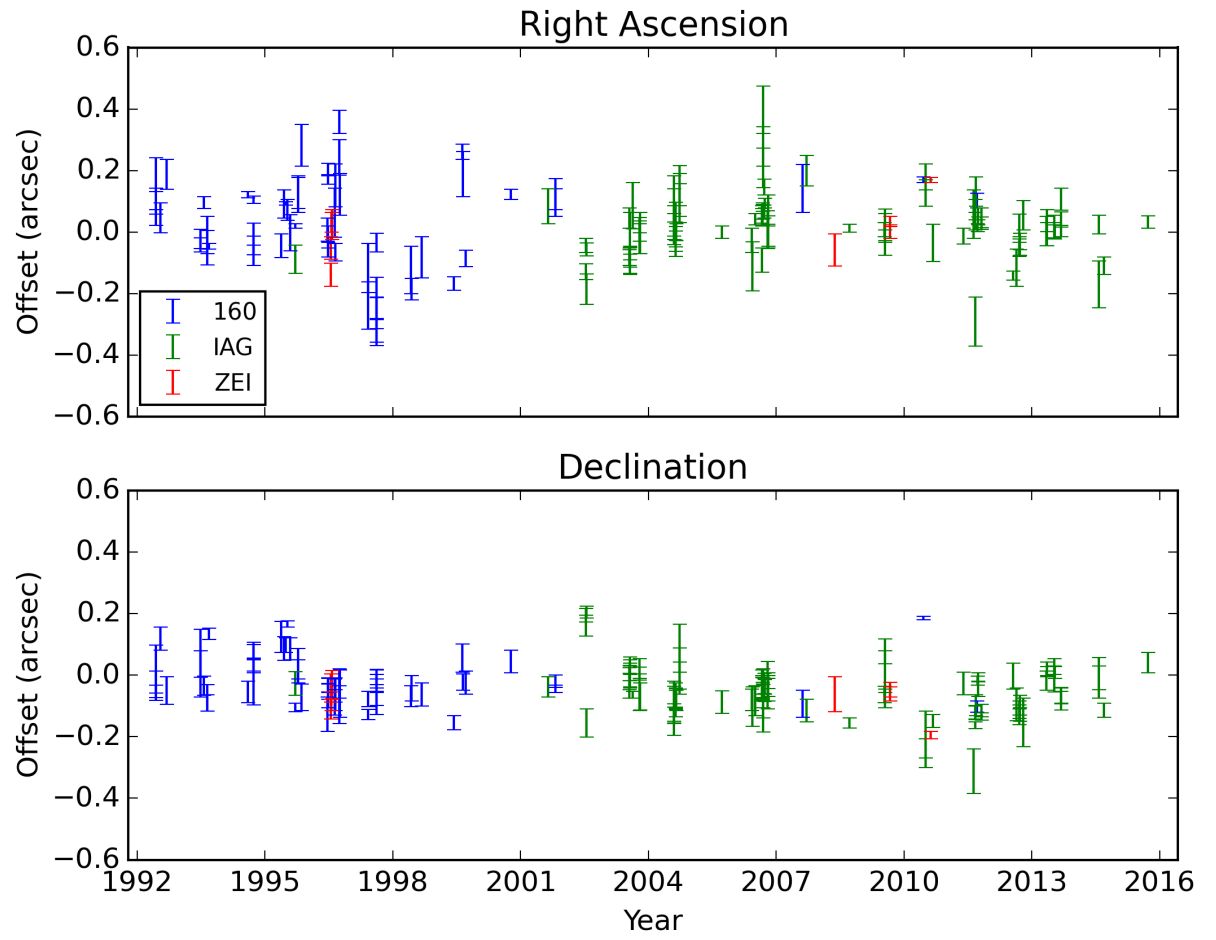


Figure 3: Neptune - Mean offsets by day

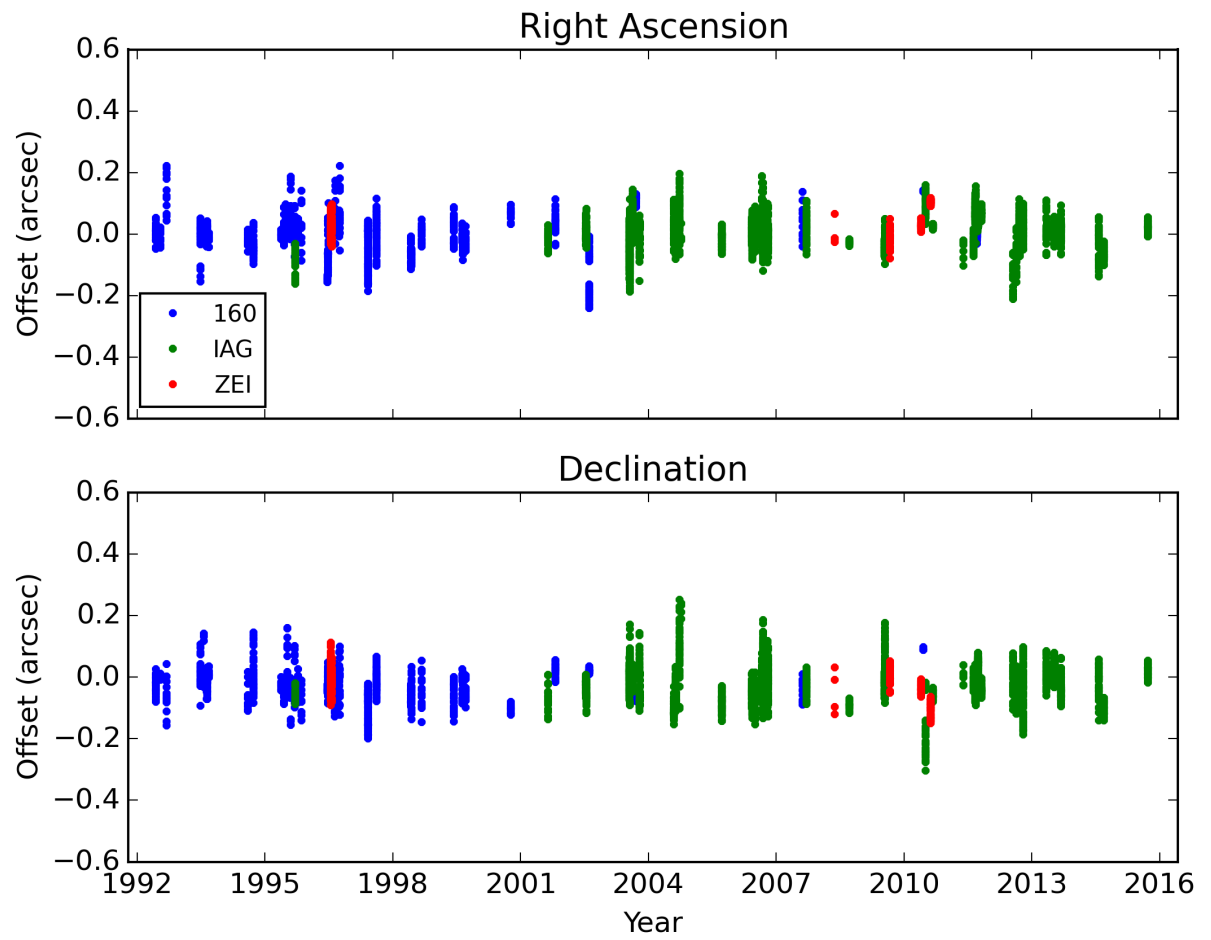


Figure 4: Triton - All Offsets

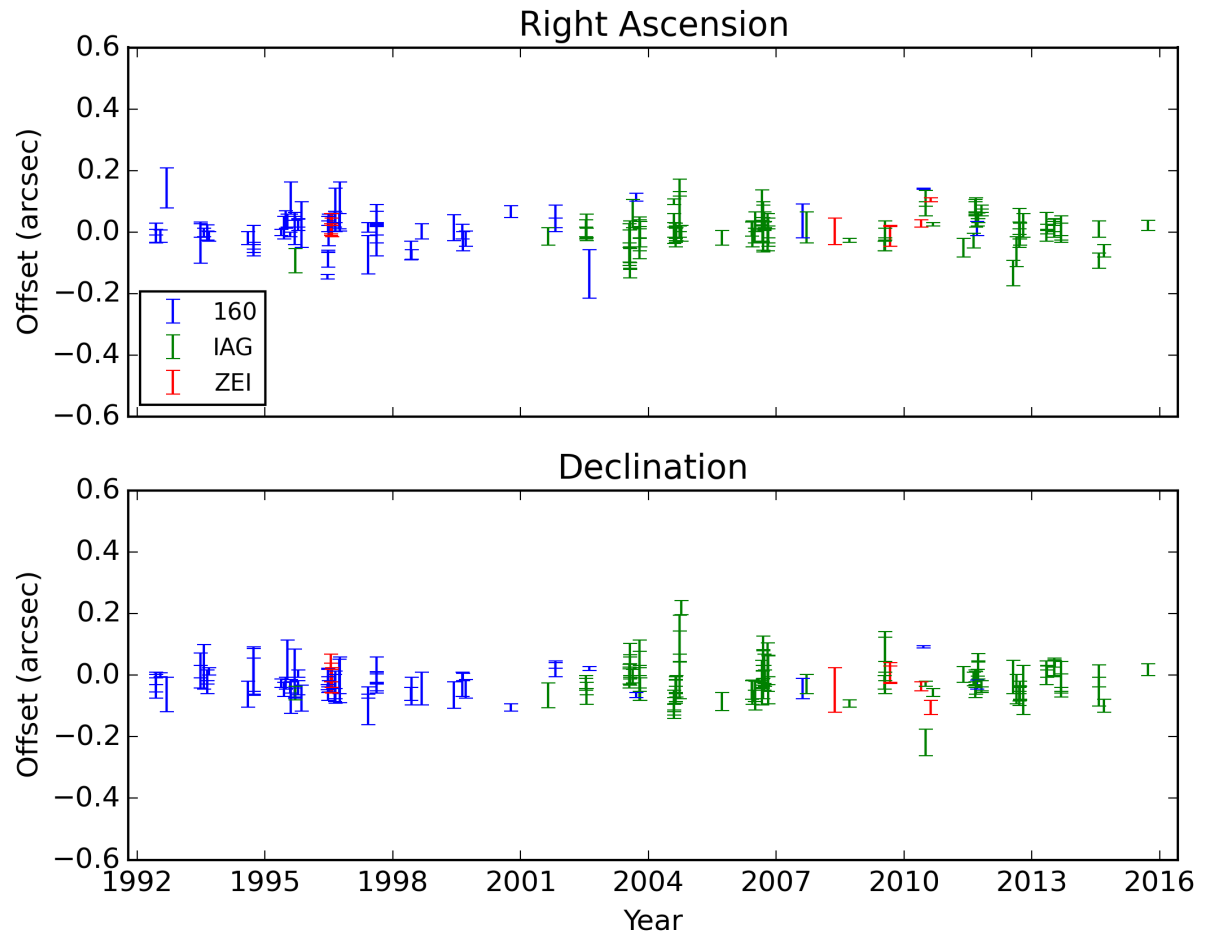


Figure 5: Triton - Mean offsets by day

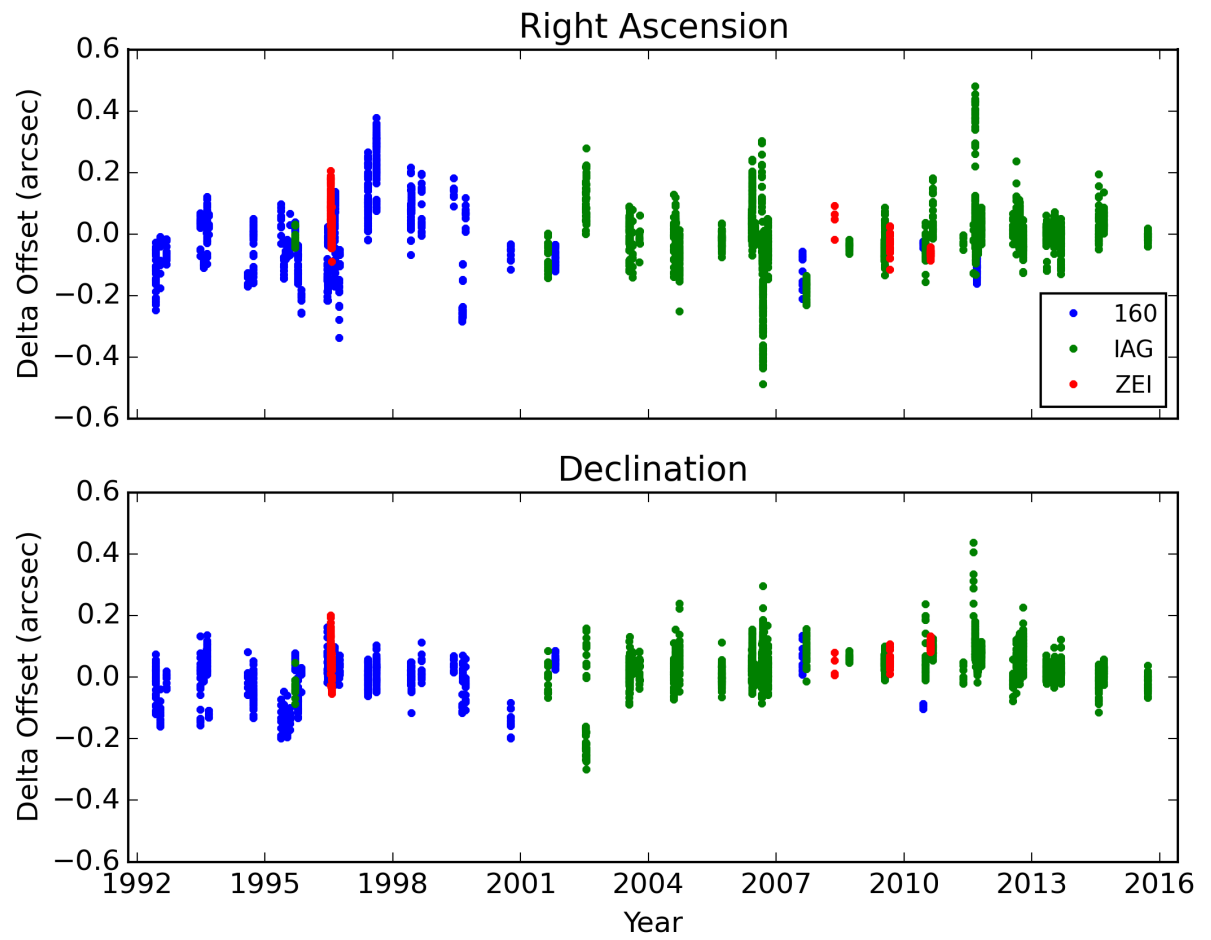


Figure 6: Difference between the offsets of Triton and Neptune - All data

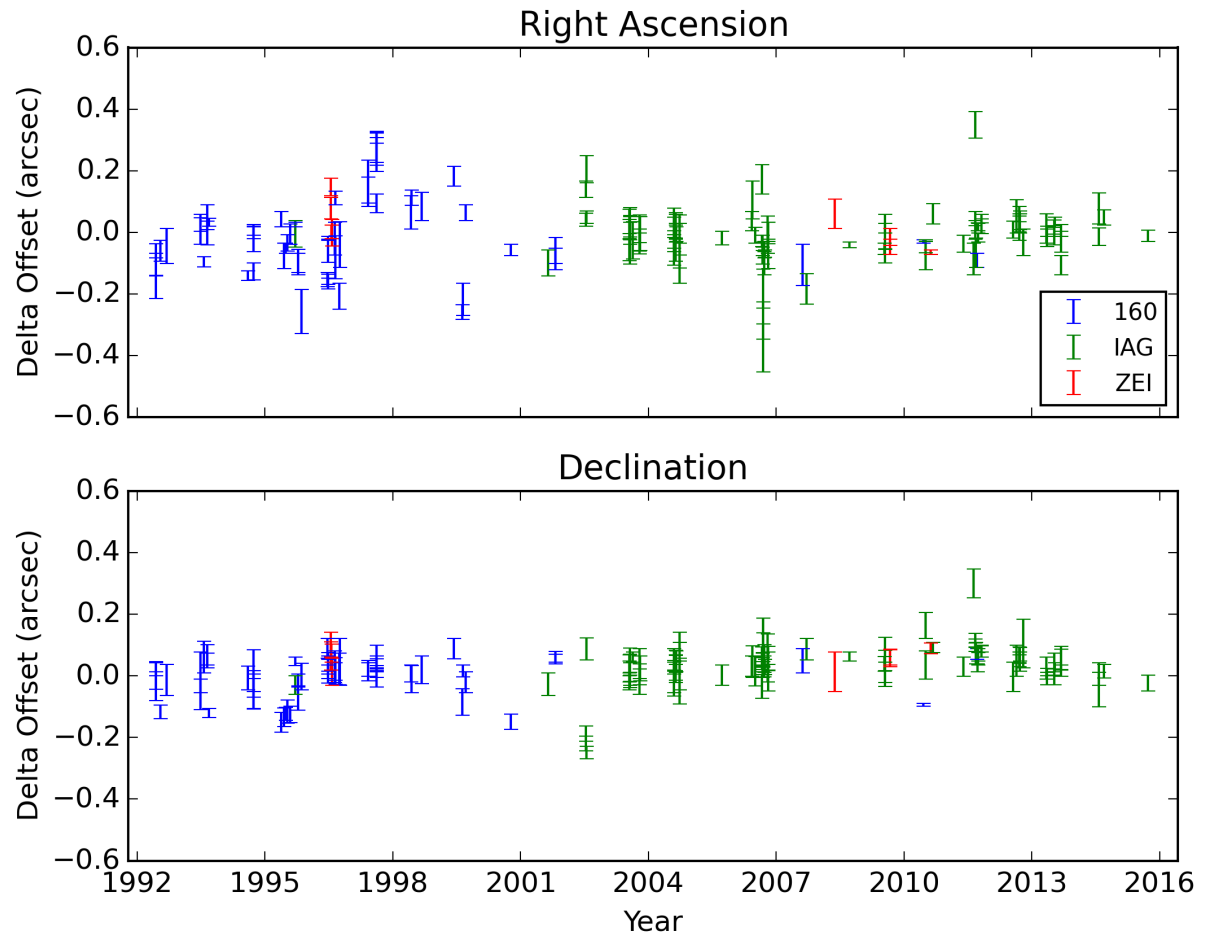


Figure 7: Difference between the offsets of Triton and Neptune - Mean offset by day

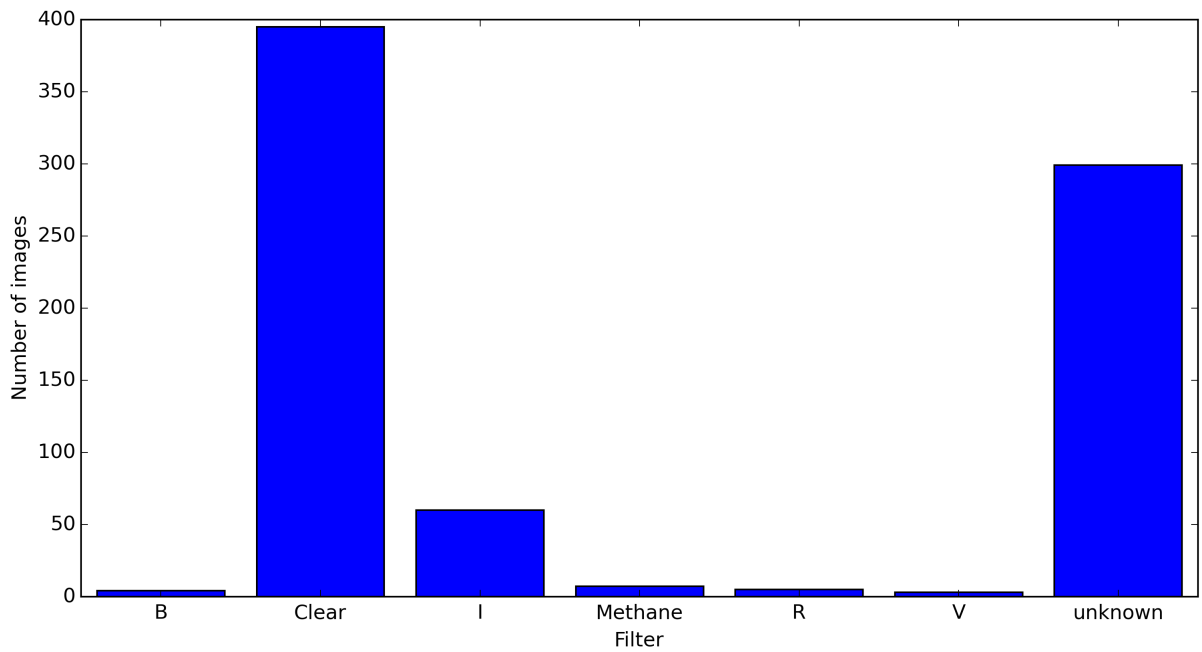


Figure 8: Distribution of positions by filter for the Perkin-Elmer telescope.

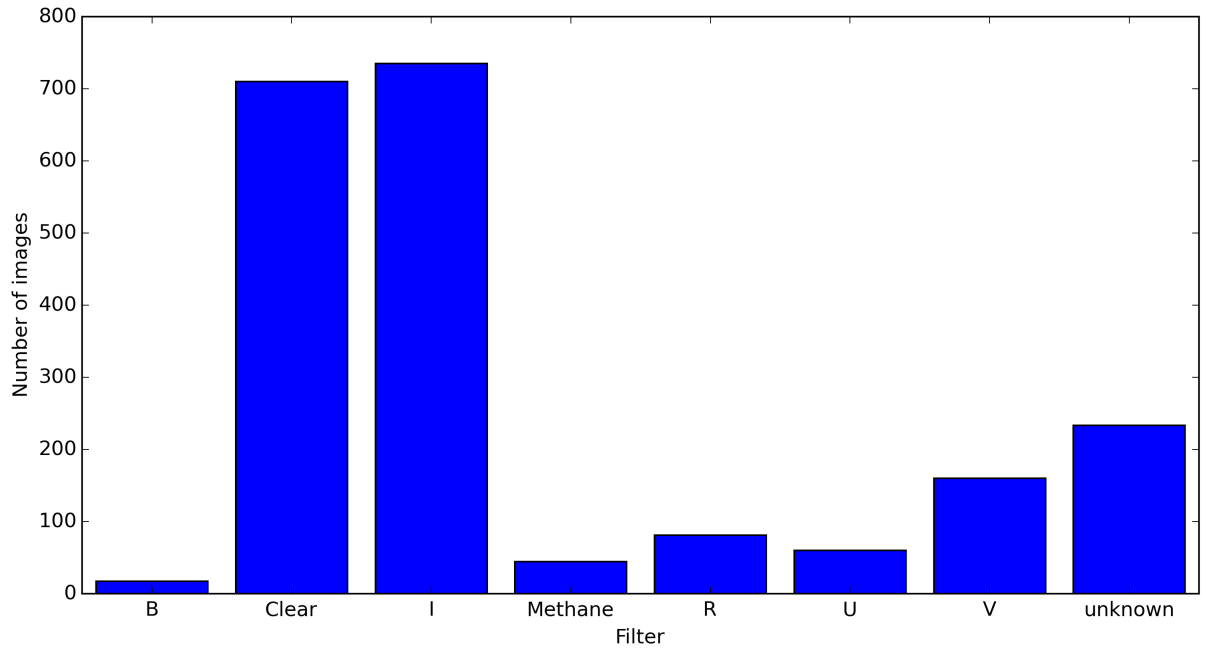


Figure 9: Distribution of positions by filter for the Boller & Chivens telescope.

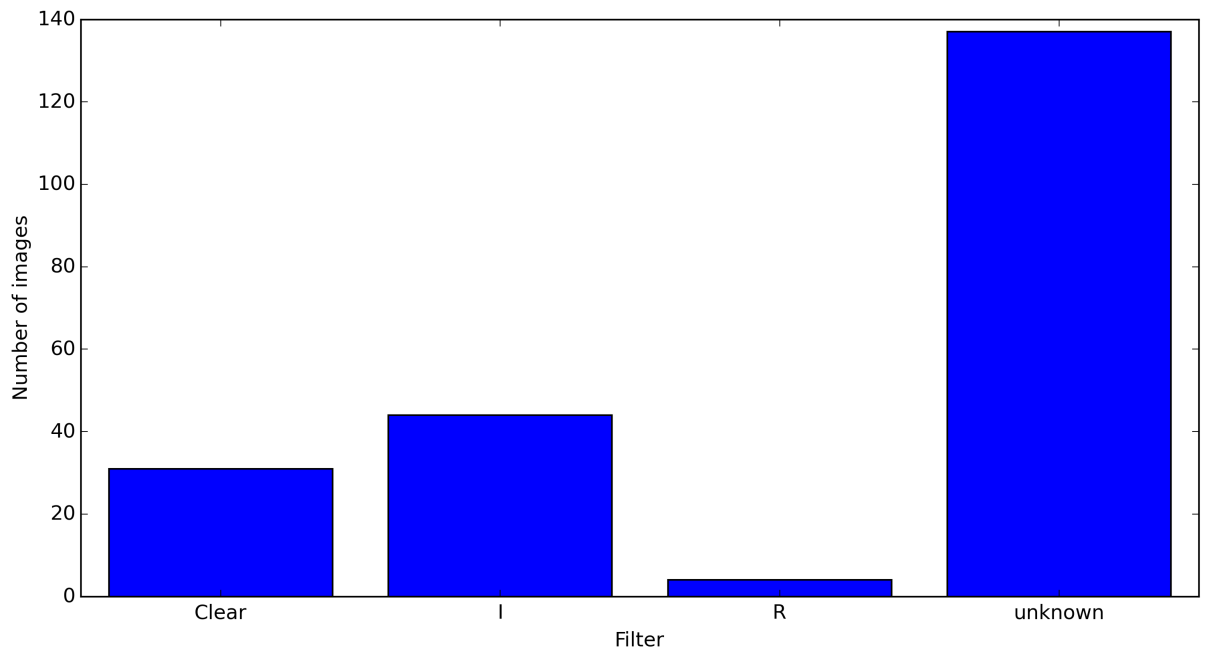


Figure 10: Distribution of positions by filter for the Zeiss telescope.

Table 7: Same as in Table 2 for Triton in the Zeiss telescope.

| Off-ra | Off-de | E-ra | E-de | Nfr | Date | Ncat |
|--------|--------|------|------|-----|---------------------|------|
| 8.4 | -9.1 | 19.5 | 48.0 | 40 | 1996-07-17 00:57:09 | 10 |
| 26.8 | 22.8 | 32.6 | 45.2 | 50 | 1996-07-18 01:59:54 | 8 |
| 33.3 | -11.1 | 11.5 | 29.3 | 36 | 1996-07-24 03:22:42 | 13 |
| 22.9 | -17.1 | 38.1 | 40.7 | 30 | 1996-07-30 01:43:06 | 7 |
| 2.5 | -48.0 | 42.7 | 71.9 | 4 | 2008-05-15 04:48:52 | 8 |
| -12.2 | 6.9 | 33.4 | 33.1 | 10 | 2009-09-04 03:46:53 | 11 |
| -13.7 | 2.9 | 31.9 | 26.3 | 10 | 2009-09-05 01:16:48 | 15 |
| 28.1 | -36.6 | 12.0 | 15.2 | 46 | 2010-05-29 08:34:42 | 23 |
| 105.0 | -104.6 | 7.0 | 22.9 | 120 | 2010-08-18 05:04:06 | 22 |

Table 8: Table of erros of the reduction. Gaussian error stands for the error in X and Y of the bidimensional Gaussian used to fit the PSF. Mean offset errors is the average dispersion of the positions in Tables 2-7.

| Telescope/Satellite | Gaussian error | | Mean offet errors | |
|---------------------|----------------|---------|-------------------|-----------|
| | X (mas) | Y (mas) | RA (mas) | DEC (mas) |
| 160/Neptune | 13 | 13 | 42 | 37 |
| 160/Triton | 14 | 14 | 29 | 32 |
| IAG/Neptune | 13 | 13 | 40 | 37 |
| IAG/Triton | 20 | 20 | 31 | 33 |
| Zeiss/Neptune | 11 | 11 | 32 | 34 |
| Zeiss/Triton | 27 | 27 | 25 | 37 |