Estimate of the Limiting Magnitudes of the Harvard College Observatory Plate Collection

Edward J. Los

Harvard College Observatory

ABSTRACT

This paper provides estimates of the number of plates in the Harvard College Observatory plate collection which show a given object. The estimate is a function of magnitude and sky location and is based on the analysis of 6041 plates scanned under the "Digital Access to a Sky Century @ Harvard" program and transcriptions of 199,921 plate centers of the approximately 530,000 plates in the HCO collection. We find that the deepest plates are in the region of the Milky Way disk and the Magellanic Clouds.

1. Introduction

A researcher making use of the Harvard College Observatory (HCO) plate collection needs to know whether his objects of interest are adequately covered by the collection. Until recently, plate limiting magnitude information was not codified and existed only in the form of researcher's notes for their particular objects under study. The "Digital Access to a Sky Century @ Harvard" program (DASCH[1]) has the goal of digitizing the HCO plate archive to bring it into the 21st century. With the successful completion of a plate digitizer (Simcoe 2006) and the methods for plate photometric analysis (Laycock 2008) we are working towards complete digitization of the 530,000 plates in the collection so that a researcher can obtain a lightcurve of any point in the sky by means of a web interface. As of this publication, however, we are not fully funded to undertake the scanning of the entire plate collection and are selecting a subsets of the plates to study objects and regions of interest. As of September 21, 2009, we have currently scanned 6486 plates and have successfully analyzed 6041 of these plates. As a result, we now have the ability to characterize the primary telescopes and emulsions used by the HCO in the generation of the archive. Given the assumptions described in this paper, we can extrapolate from the plates already analyzed to

[1]see http://hea-www.harvard.edu/DASCH/ for more information

the full collection for those telescopes where we have digitized all of the logbook entries. The results of this extrapolation will be useful in the selection of additional objects of interest for scanning and for researchers who visit the stacks before the full scanning project is completed.

2. Procedures

The basic procedure is to characterize each telescope's sensitivity as a function of emulsion quality and exposure time and then to apply this characterization to transcribed logbook information for all of the plates. Several assumptions are involved in the sensitivity characterization. The emulsion quality is assumed to be a function of plate exposure date, ignoring the use of multiple emulsions of varying color sensitivity and the use of color filters. The calculations also ignore the effect of sky conditions and the fact that some telescopes were occasionally stopped down with irises.

Each telescope which contributed to the HCO collection is uniquely identified by a "series" designation consisting of 1 to 6 letters. Within each series, plates are numbered in chronological order. Although there are more than 79 series in the HCO collection, this study is interested in the 11 series shown in Table 1 for which the majority of the logbook entries have been transcribed and digitized.

The photometry pipeline (Laycock 2008) recognizes that plate limiting magnitude is not uniform across each plate because of vignetting and image distortion. The pipeline, therefore, divides each plate into nine annular bins as shown in Figure 1.

The pipeline defines limiting magnitude by fitting the instrumental magnitudes for each plate to the GSC2.3.2 magnitudes as shown in Figure 2 and then setting the limiting magnitude at the point where the local standard deviation becomes excessive. Although this definition is used throughout this paper, our lightcurve plotting algorithms recognize that observations within 0.5 magnitude of the limiting magnitude are suspect. Ultimately, it is necessary to compare the limiting magnitudes derived by the photometry pipeline with limiting magnitudes found by researchers using the plate stacks. A survey of recent researchers produced responses from Bradley Schaefer[2] and Gary Billings[3] . Unfortunately, neither of these researchers observed in any of the fields scanned. Since results from a sample of five plates examined by Prof. Schaefer have too much scatter to be definitive, we would

[2]Louisiana State University Department of Physica and Astronomy

[3]AAVSO Member, 2320 Cherokee Drive NW, Calgary, Alberta, T2L0X7, Canada

appreciate any additional limiting magnitude estimates from users of the HCO plate stacks.

Table 2 shows that the limiting magnitude is not constant across the plate because of vignetting and distortion. The number of plates reaching limiting magnitude 16 drops to 60% after spatial bin 4 which has a radius of about 6 inches on an 8 inch by 10 inch plate. To simplify the estimate calculations, this paper assumes that the central 5 inch square region of the plate has a limiting magnitude comparable to the limiting magnitude of spatial bin 1.

The next step is to find the requirements for obtaining plates at a specified limiting magnitude and telescope. A plotting utility generates graphs such as the one in Figure 3 which shows all of the exposures for the "ac" plate series. Circles show the "deep points" where the plate has reached the expected limiting magnitude while dashes show the "shallow points" where the plate did not reach the expected limiting magnitude. These plots are used to form (somewhat subjective) judgements on the exposure time needed per series as a function of year to achieve the desired limiting magnitude in the center of the plate. For the "ac" series, Figure 3 shows that a limiting magnitude of 14 is likely after the year 1935 providing that the exposure time is at least 50 minutes. Table 3 contains all of the rules derived for this study. All of the figures similar to Figure 3 may be found on the DASCH website at http://hea-www.harvard.edu/DASCH/papers/coverage6041.

3. Results

Figures 4 through 9 show the estimated number of plates reaching reaching each limiting magnitude as a function of sky position.

Since the photometry pipeline truncates the GSC2.3.2 catalog to magnitude 19, no limiting magnitude derived from the pipeline will reach this truncation limit. Figure 9 shows relatively little sky coverage at magnitude 18, mostly in the Northern hemisphere.

Figure 4 shows peak coverage near the pole, mostly because many double exposures included the pole region for calibration against a standard sequence. The actual peak at the pole is under-represented, because the logbook Right Ascension and Declination was missing for 3238 exposures and would have put an artificial peak at 0h RA and 0 degrees declination.

Figure 8 is representative of the deepest plates in the collection. This figure is replotted in galactic coordinates in Figure 10 to highlight the fact that the collection favors the Milky Way disk. Other areas with good coverage include the Magellanic Clouds and Southern Hemisphere regions in general.

Remember that these estimates are based on 40% of the ultimate logbook transcriptions

and on a number of assumptions concerning the quality of individual exposures. No factor of 2.5 has been applied to account for the partial sampling because the characteristics of the non-transcribed series most likely will not match the characteristics of the transcribed series. The final results may show additional deep regions of the sky from non-patrol studies.

REFERENCES

R. J. Simcoe, J. E. Grindlay, E. J. Los, A. Doane, S. G. Laycock, D. J. Mink, G. Champine, A. Sliski. "An ultrahigh-speed digitizer for the Harvard College Observatory astronomical plates"in Applications of Digital Image Processing XXIX, edited by Andrew G. Tescher, Proc. SPIEVol. 6312, Oct 12, 2006

S. Laycock, S. Tang, J. Grindlay, E. Los, R. Simcoe, D. Mink, "Digital Access to a Sky Century at Harvard. II: Initial Photometry and Astrometry",Submitted to AJ,Nov 13, 2008

This work is funded by a grant from the National Science Foundation. The principal contributers to the DASCH project are Prof. Johnathan Grindlay (PI), Alison Doane, Robert Simcoe, Silas Laycock (now at the Gemini project), Sumin Tang and the author.

Rev 4, October 24, 2009.

Table 1. Plate Series Used for the Limiting Magnitude Estimates

Series	Plates Analyzed[a]	Transcribed[b]	Total[c]	Telescope
a	59	23595	27504	24-inch Bruce Doublet
ac	748	25534	32288	1.5-inch Cooke Lenses
ax	84	3522	4833	3 inch Ross-Tessar Lens
ay	20	1973	1974	2.6-inch Zeiss-Tessar
b	362	48652	76864	8-inch Bach Doublet
bm	348	3219	3222	3-inch Ross
ma	122	6154	11737	12-inch Metcalf Doublet
mc	497	21550	41475	16-inch Metcalf Doublet
mf	116	29917	40897	10-inch Metcalf Triplet
rb	686	17027	17030	3-inch Ross Fecker
rh	1038	16195	16201	3-inch Ross Fecker
OTHER	1961	2644	255975	-
TOTAL	6041	199982	530000	-

[a]Number of plates analyzed by the photometry pipeline.

[b]Number of plate entries transcribed from the logbooks.

[c]Estimated number of plates for the telescope series.

Table 2. Limiting Magnitude as a Function of Annular Bin

Annular Bin	All Plates	Mag 16 Plates
1	4082	1127
2	4133	1099
3	4110	920
4	4120	799
5	4117	702
6	4126	594
7	4045	536
8	3890	450
9	3811	433

Table 3. Limiting Magnitude Rules

Limiting Magnitude	Series	Rule[a]
13	a	10 min
14	a	10 min
15	a	10 min
16	a	10 min
17	a	10 min
18	a	999 min until 1948 90 min after
13	ac	55 min until 1935 22 min after
14	ac	999 min until 1935 50 min after
15	ac	999 min until 1950 50 min after
16	ac	999 min
17	ac	999 min
18	ac	999 min
13	ax	60 min
14	ax	60 min
15	ax	90 min
16	ax	999 min
17	ax	999 min
18	ax	999 min
13	ay	60 min
14	ay	999 min
15	ay	999 min
16	ay	999 min
17	ay	999 min
18	ay	999 min
13	b	1 min
14	b	10 min
15	b	60 min until 1895 10 min after
16	b	90 min until 1900 45 min after
17	b	999 min until 1935 45 min after
18	b	999
13	bm	22 min
14	bm	22 min
15	bm	999 min until 1936 50 min after
16	bm	999 min
17	bm	999 min
18	bm	999 min
13	ma	1 min
14	ma	1 min
15	ma	1 min
16	ma	60 min until 1932 40 min after
17	ma	60 min until 1936 50 min after
18	ma	100 min
13	mc	1 min
14	mc	1 min
15	mc	1 min
16	mc	1 min

Table 3—Continued

Limiting Magnitude	Series	Rule[a]
17	mc	10 min
18	mc	120 min until 1942 50 min after
13	mf	13 min
14	mf	15 min
15	mf	15 min
16	mf	43 min
17	mf	43 min
18	mf	999 min
13	rb	5 min
14	rb	15 min
15	rb	90 min until 1939 45 min after
16	rb	90 min until 1939 60 min after
17	rb	120 min until 1950 90 min after
18	rb	999 min
13	rh	5 min
14	rh	20 min
15	rh	999 min until 1933 56 min after
16	rh	999 min until 1933 60 min after
17	rh	999 min
18	rh	999 min

[a]a 999 means no exposure achieved the desired limiting magnitude

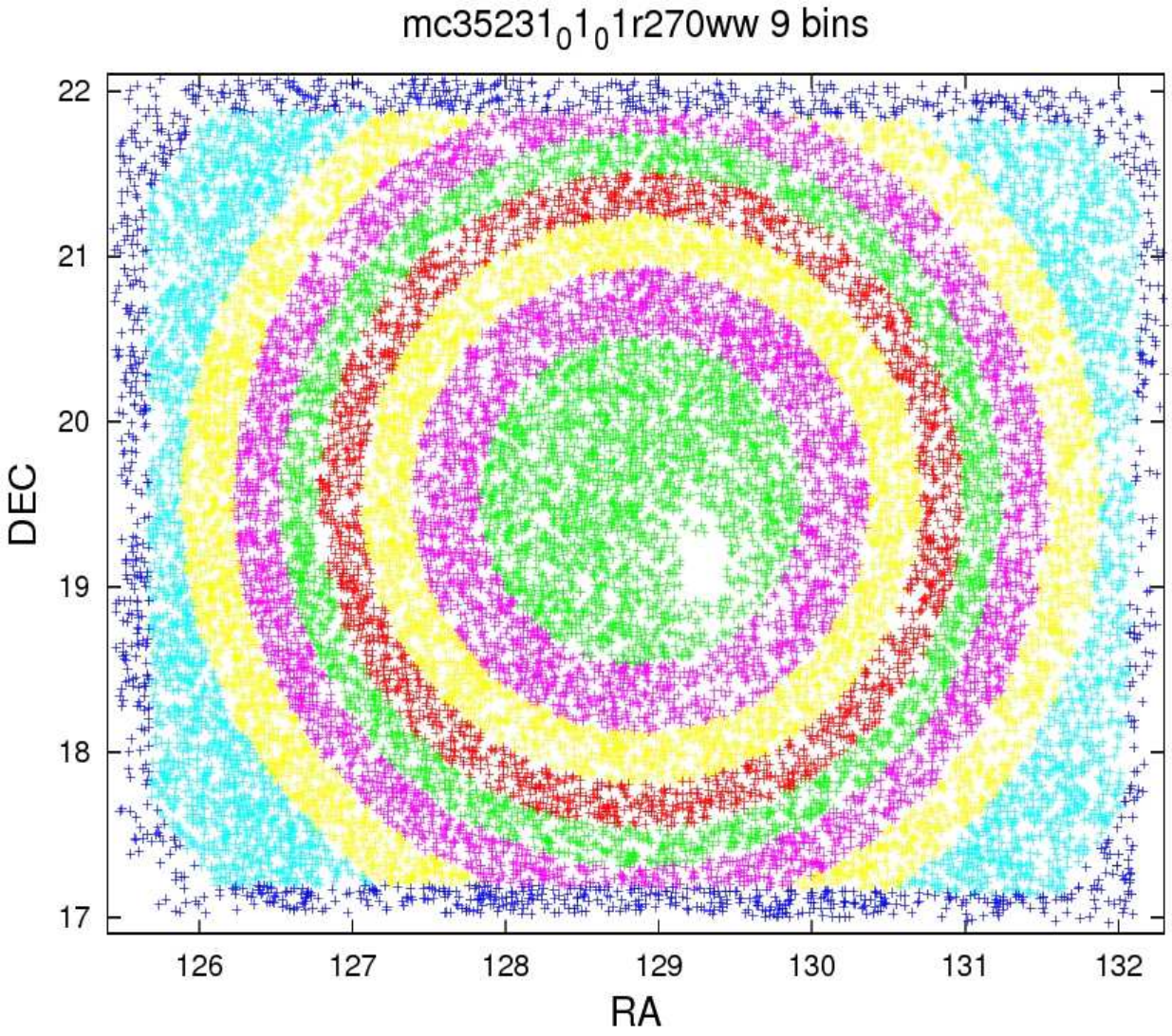

Fig. 1.— Division of Plate Analysis into 9 Annular Bins

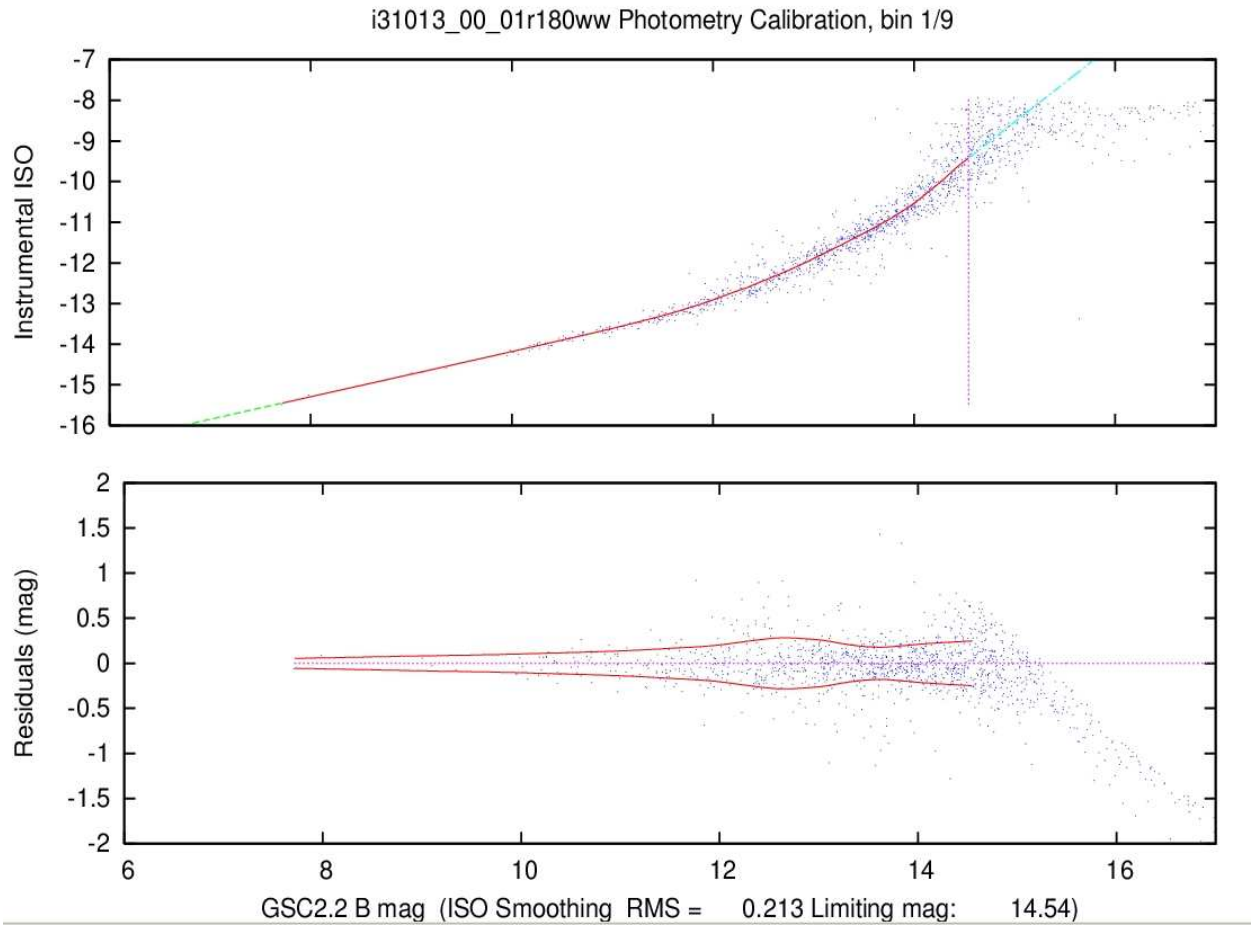

Fig. 2.— Determination of Limiting Magnitude

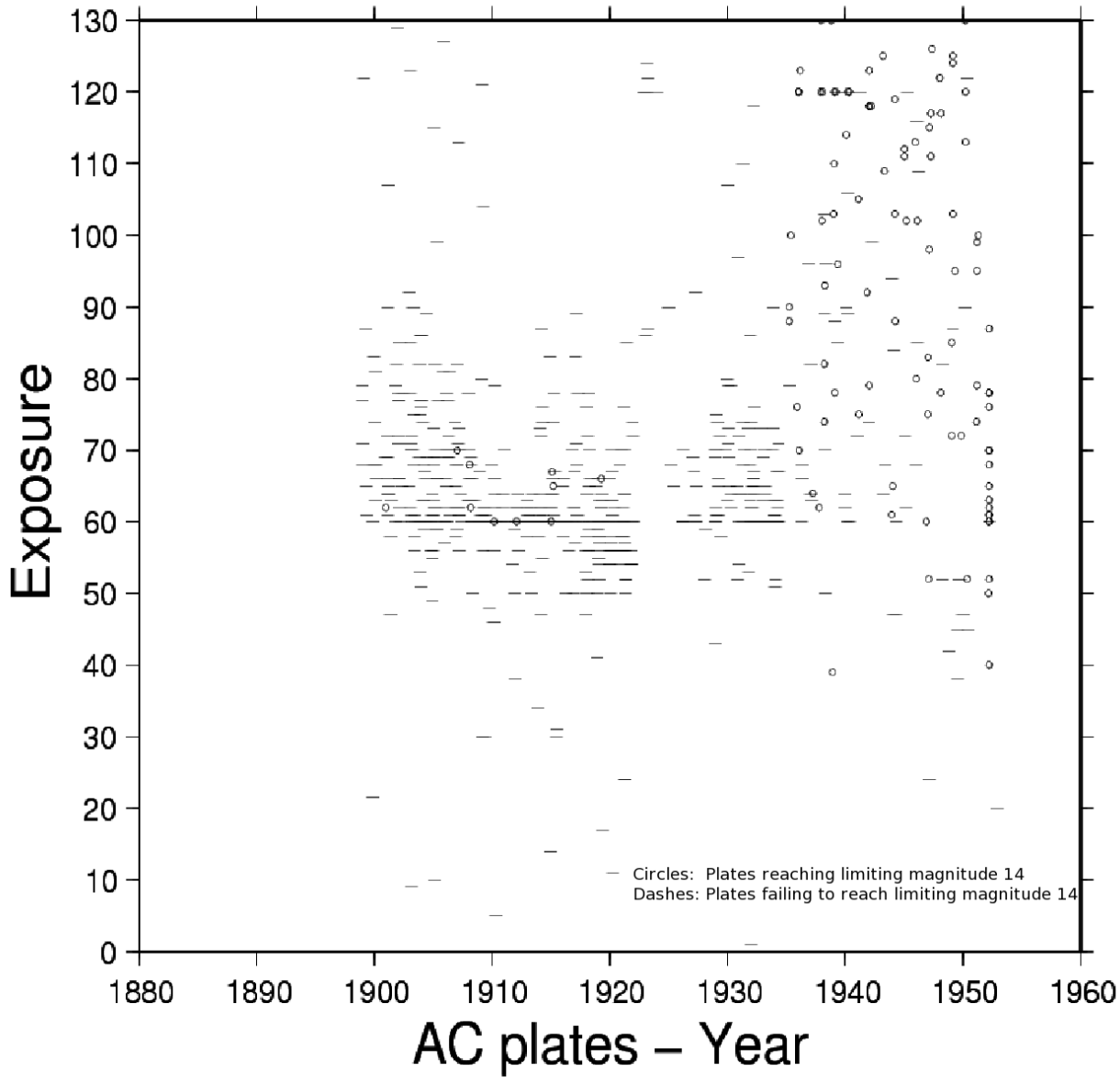

Fig. 3.— AC Plates Reaching Limiting Magnitude 14

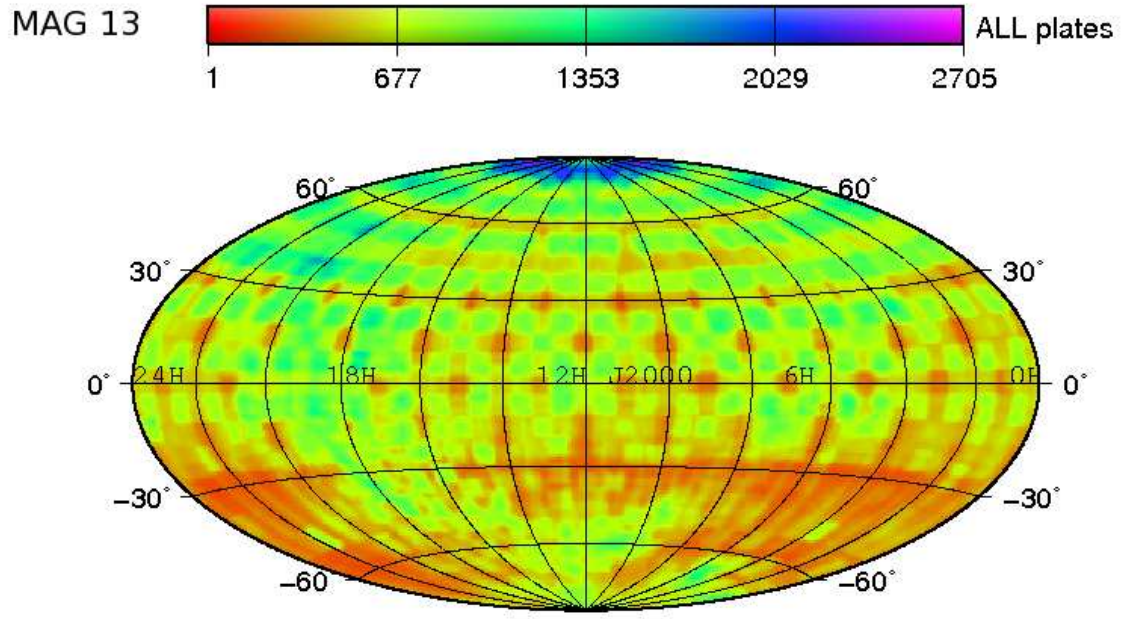

Fig. 4.— Estimated number of plates reaching limiting magnitude 13

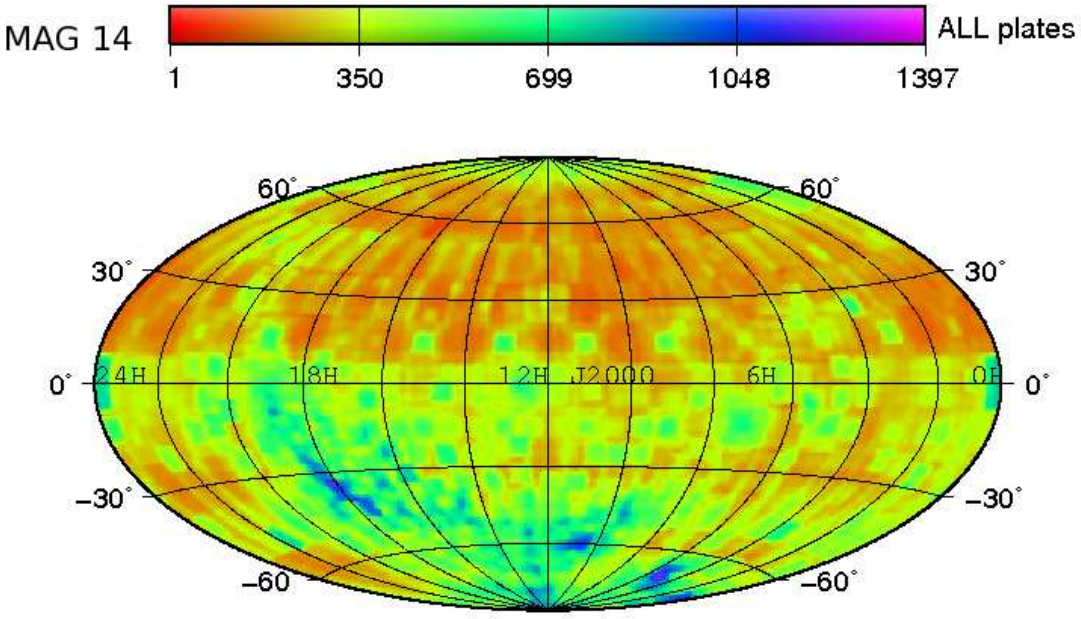

Fig. 5.— Estimated number of plates reaching limiting magnitude 14

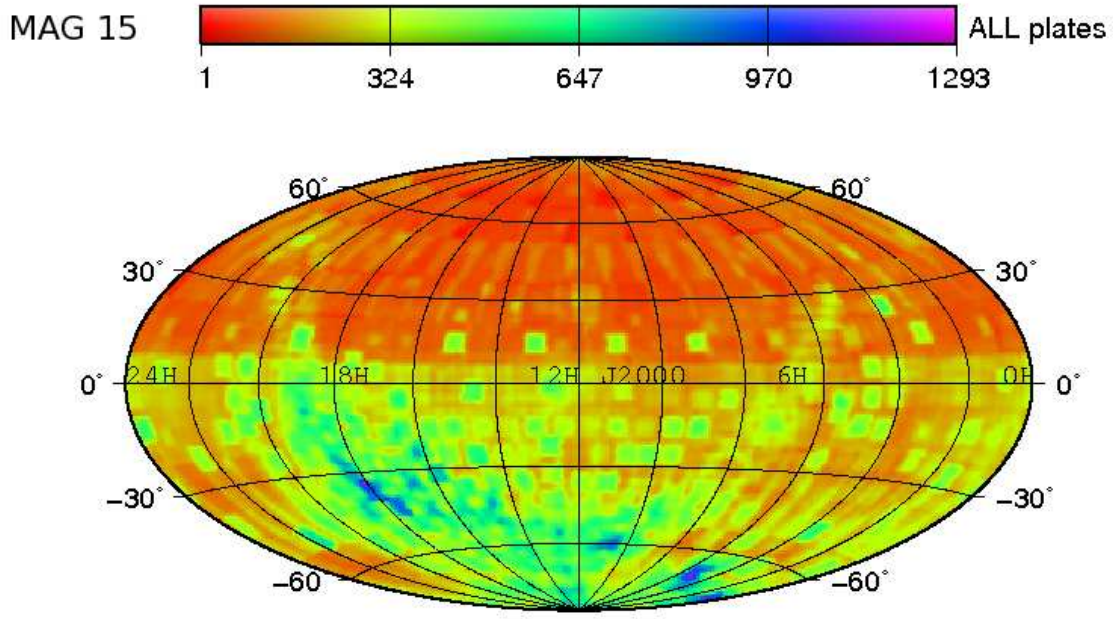

Fig. 6.— Estimated number of plates reaching limiting magnitude 15

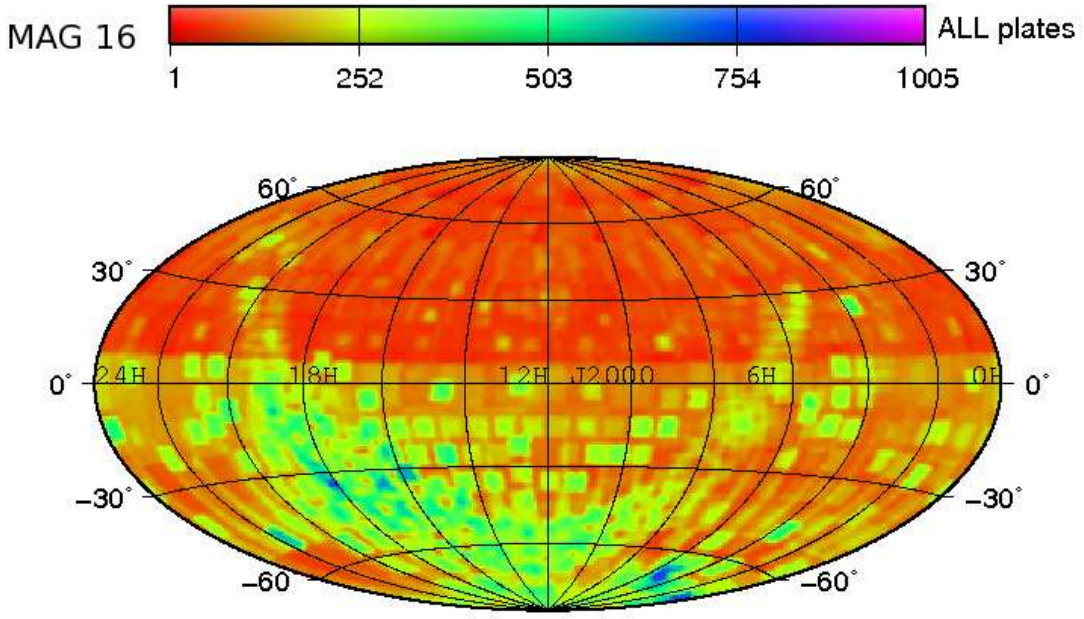

Fig. 7.— Estimated number of plates reaching limiting magnitude 16

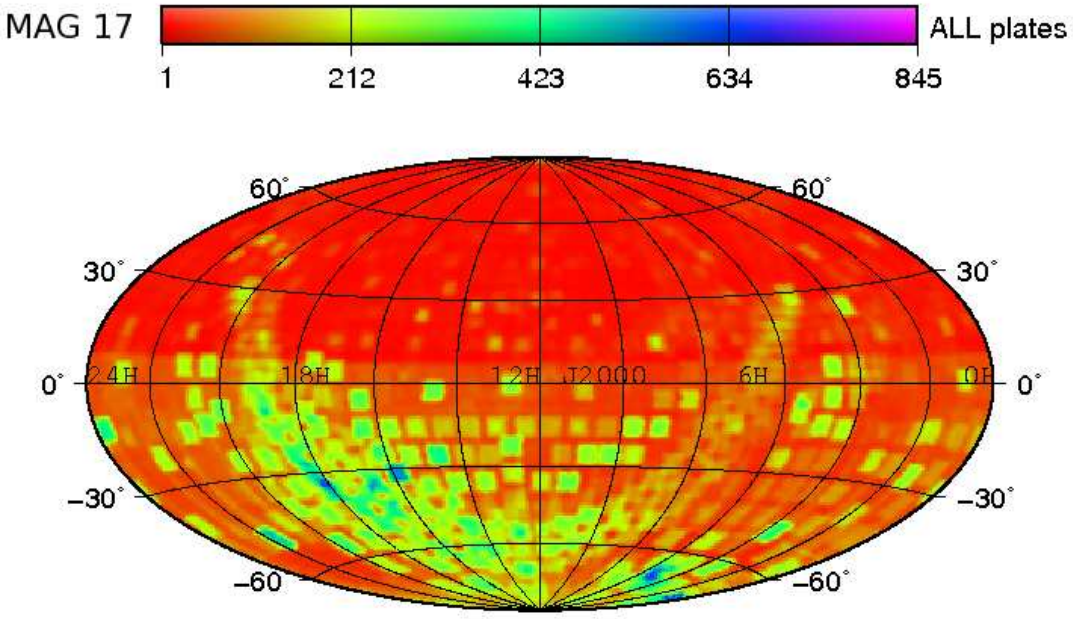

Fig. 8.— Estimated number of plates reaching limiting magnitude 17

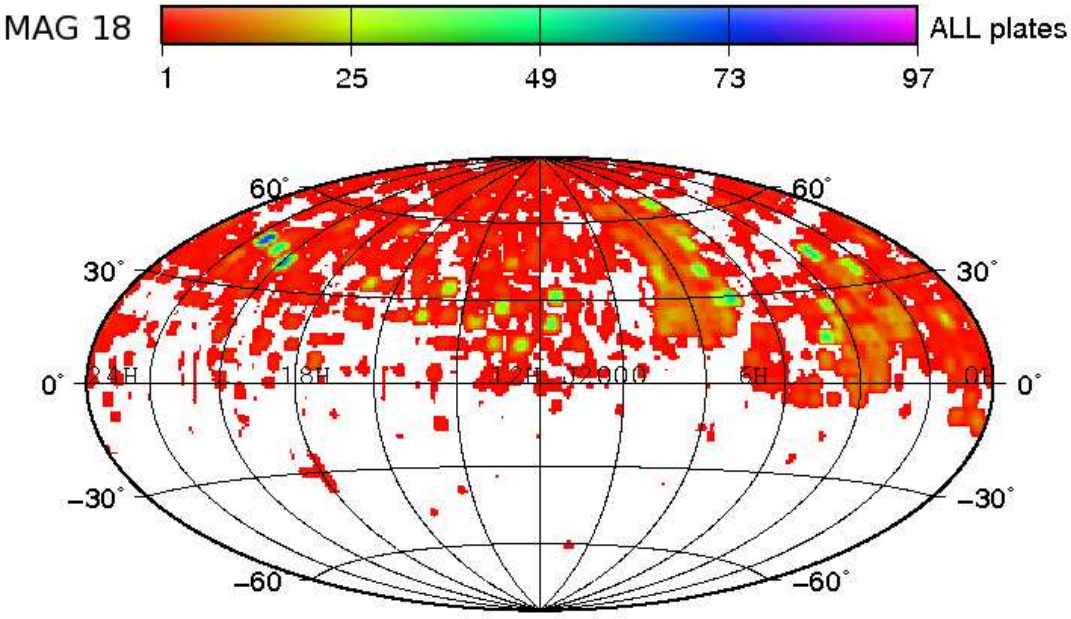

Fig. 9.— Estimated number of plates reaching limiting magnitude 18

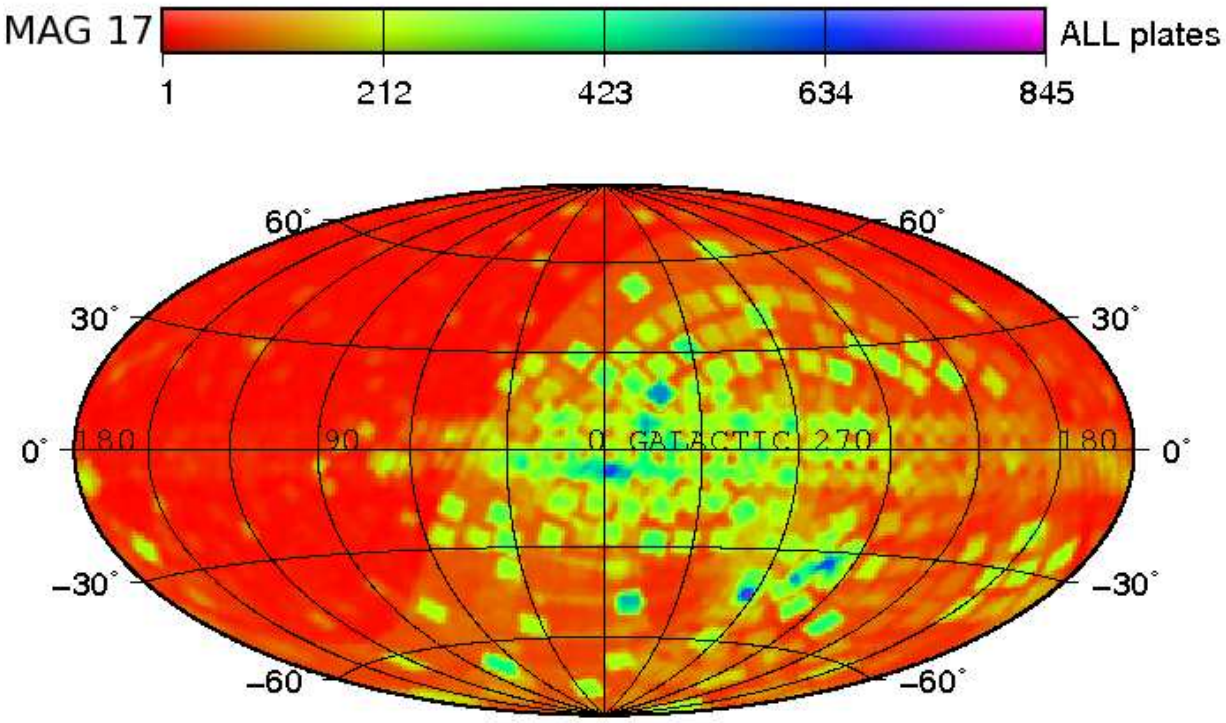

Fig. 10.— Limiting magnitude 17 results replotted in galactic coordinates