The atlas

The Pretty Deep Maps astronomical atlas is a large hyperlinked collection of pdf charts and indices. The atlas can be used on any device with a pdf reader capable of supporting within- and cross-document links. .

Not all pdf readers support links; and not all are efficient at processing detailed documents such as these charts. A good choice at the present time is Adobe Acrobat Reader, preferably a version which makes it easy to remove space-guzzling toolbars (unlike Acrobat DC)

The charts

The celestial sphere is divided into 6787 tiles, each covering 3 degrees of declination. The map scale is 11.74" per mm. The scale is somewhat academic; it is based on chart dimensions of 92 cm x 92 cm, although it should be stressed that these charts are not designed to be printed.

If case you *are* tempted to print, you should know that (a) the entire atlas at full scale would require a globe of approximately 40 *metres* in diameter; and (b) even at that scale, the use of tiny fonts ensures that it will not be completely readable.

Neighbouring tiles are overlapped by half a degree. A grid is placed at 0.5° intervals and labelled at each whole degree in declination. For right ascension, grid spacing ranges from 2′ at the equator to 20′ near the poles. All chart-internal grid intersections are labelled for ease of coordinate-based navigation.

A gnomonic projection is used in all charts[1]. This type of projection corresponds to the way in which a small region of the sky is mapped by a telescope on to the planar surface of a camera sensor, and enables the charts to be compared directly to images thus acquired.

[1] see, e.g., Snyder (1987), available here http://pubs.er.usgs.gov/publication/pp1395

Usage

The charts employ a hierarchy of font sizes. The larger fonts are designed to enable major objects of interest such as clusters (open, globular, galaxy) to be seen at a glance. Lesser or more numerous objects (e.g., double stars) have font sizes related to their magnitude. The smallest font size is used to provide further information about each plotted object (e.g., distance, magnitude). Consequently, the maps are designed to be zoomed.

Individual object properties are described in detail in *Objects* below

To get the best out of the charts, use a device equipped with a trackpad or touchscreen, along with an operating system that supports gestures for zoom/unzoom and panning.

Layout

In addition to the chart itself, each atlas page contains in the left portion a list of constellation codes, a finder map, and an object/catalogue listing used for rapid access to the index.

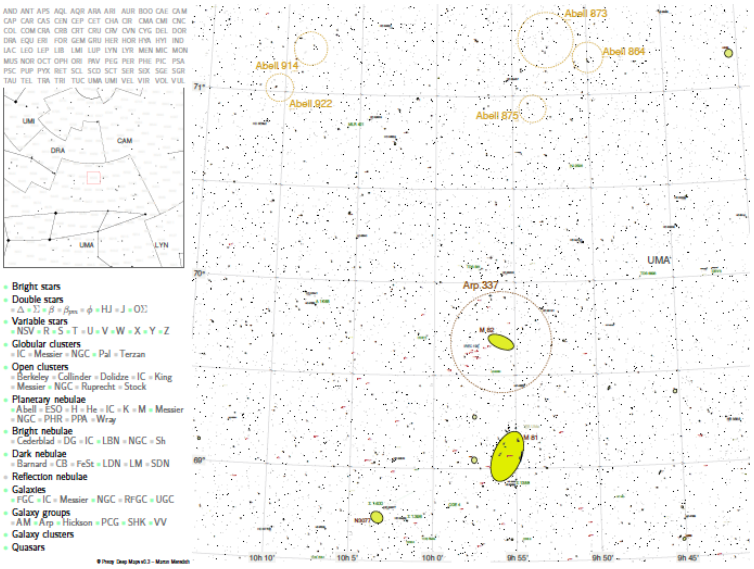

Figure 1: The M81/82 region of Ursa Major.

Selecting a constellation moves the chart to the centre of that constellation.

Clicking in the finder map moves the chart to the corresponding location.

Selecting an object type brings up the index for that type; selecting a catalogue jumps to the first instance of the catalogue; selecting the bullet next to the object type/catalogue confines the selection to the current constellation.

The indices

The atlas is accompanied by a set of hyperlinked indices which can be filtered by constellation and sorted on a number of object properties.

bright star double variable globular **open cluster** planetary bright neb dark neb reflection neb galaxy galaxy group galaxy cluster quasar

ALL AND ANT APS AQL AQR ARA ARI AUR BOO CAE CAM CAP CAR CAS CEN CEP CET CHA CIR CMA CMI CNC COL COM CRA CRB CRT CRU CRV CVN CYG DEL DOR DRA EQU ERI FOR GEM GRU HER HOR HYA HYI IND LAC LEO LEP LIB LMI LUP LYN LYR MEN MIC MON MUS NOR OCT OPH ORI PAV PEG PER PHE PIC PSA PSC PUP PYX RET SCL SCO SCT SER SEX SGE SGR TAU TEL TRA TRI TUC UMA UMI VEL VIR VOL VUL

Objects (1010)	Con	RA	Dec	Mag	Size	Dist/MLY	SB	Colour	Type	Other names
Messier 74	PSC	1h 36 41.8	+15° 47 0.5	9.7	10.00	34	22.5	0.6	Sc	NGC 628; UGC 1149
NGC 488	PSC	1h 21 46.8	+ 5° 15 24.5	11.1	5.01	108	21.7	0.9	Sb	UGC 907
NGC 660	PSC	1h 43 2.4	+13° 38 42.9	11.9	4.57	43		0.9	Sa	UGC 1201
UGC 1176	PSC	1h 40 9.9	+15° 54 17.3	14.4	4.37	32	25.1	0.6	I	
NGC 520	PSC	1h 24 34.7	+ 3° 47 39.1	12.2	4.07	102	22.0	0.8	Sa	UGC 966
NGC 100	PSC	0h 24 2.9	+16° 29 12.5	13.9	3.55	43	22.7	0.7	Sc	FGC 42; RFGC 95; UGC 231
NGC 514	PSC	1h 24 3.9	+12° 55 2.4	12.3	3.47	118	23.3	0.6	SABc	UGC 947
UGC 1133	PSC	1h 35 2.8	+ 4° 22 52.4	14.3	3.47	92		0.2	I	
NGC 524	PSC	1h 24 47.7	+ 9° 32 19.6	11.4	3.39	115	21.6	1.1	S0-a	UGC 968
NGC 128	PSC	0h 29 15.1	+ 2° 51 50.5	12.6	3.16	196	20.7	1.0	S0	UGC 292
UGC 477	PSC	0h 46 13.2	+19° 29 23.7	15.3	3.02	128			Sd	
NGC 7541	PSC	23h 14 43.8	+ 4° 32 2.2	12.5	3.02	128		0.7	SBc	UGC 12447
FGC 2469	PSC	23h 13 13.2	+ 6° 25 49.1	14.5	3.02	232	23.4	1.0	Sc	RFGC 4081; UGC 12423
NGC 266	PSC	0h 49 47.8	+32° 16 39.7	12.6	2.95	227	22.7	0.9	Sab	UGC 508
NGC 315	PSC	0h 57 48.9	+30° 21 14.1	12.2	2.88	242	22.0	1.0	E	UGC 597
NGC 470	PSC	1h 19 44.8	+ 3° 24 35.5	12.5	2.88	111	22.0	0.8	Sb	UGC 858
IC 34	PSC	0h 35 36.4	+ 9° 7 27.2	13.7	2.82	253			SBa	UGC 351
NGC 741	PSC	1h 56 21.0	+ 5° 37 43.6	12.3	2.82	264	22.8	1.1	E	UGC 1413
UGC 12709	PSC	23h 37 24.0	+ 0° 23 30.0	14.4	2.75	126	24.4	0.4	SABm	
NGC 718	PSC	1h 53 13.3	+ 4° 11 44.6	12.6	2.75	81		0.9	Sa	UGC 1356
NGC 676	PSC	1h 48 57.3	+ 5° 54 25.5	10.7	2.75	71			S0-a	UGC 1270
UGC 891	PSC	1h 21 19.1	+12° 24 42.0	14.7	2.75	32	23.9	0.6	SABm	
FGC 44	PSC	0h 25 47.7	- 2° 17 5.6	15.3	2.63	252			Sbc	RFGC 99
NGC 474	PSC	1h 20 6.7	+ 3° 24 55.2	12.4	2.63	111	22.0	0.9	S0	UGC 864
NGC 455	PSC	1h 15 57.6	+ 5° 10 43.4	13.8	2.57	250			S0	UGC 815
IC 1711	PSC	1h 30 55.3	+17° 11 18.5	14.6	2.51	136			Sb	FGC 18A; UGC 1082
NGC 7782	PSC	23h 53 54.0	+ 7° 58 13.7	13.1	2.45	256	22.1	0.8	Sb	UGC 12834
NGC 507	PSC	1h 23 39.9	+33° 15 21.0	12.6	2.45	241	22.1	1.0	E-S0	UGC 938
IC 1723	PSC	1h 43 14.2	+ 8° 53 21.5	14.0	2.45	261	23.2		Sb	UGC 1205

Figure 2: Index, showing galaxies in Pisces ordered by decreasing angular size.

Selecting an object name (left-hand column) brings up the chart containing the object.

Clicking a column header sorts by that property; clicking again sorts in the other direction.

The indices are context-sensitive. If the current selection is galaxies in Pisces, then clicking planetary nebulae brings up PNs in

Pisces. Only those constellations containing objects of a given type are highlighted. Similarly, if the list is sorted by magnitude, then the next selection is also sorted by magnitude.

If the index is currently sorted by some property that does not exist for another object type, you will not be able to select that object type; the solution is simply to sort by some other property that is shared with the new object type (e.g., Name, Dec, Mag).

While the primary purpose of the indices is to find the appropriate chart page for a given object, they can also be used for observation planning and make it straightforward to perform actions such as

- List the planetary nebulae in Sagittarius sorted by decreasing angular size
- Show all stars with exoplanets
- Find the most distant quasar in Draco
- Show all double stars in Gemini whose last observation date precedes 2000
- Find all Mira-type variables in Cassiopeia

Summary of atlas contents

	objects	
	indexed	plotted
bright stars	10 748	117 955
field stars	–	c. 600 million
variable stars	21 475	277 827
double stars	22 422	c. 110 000
open clusters	2167	2167
globular clusters	157	157
planetary nebulae	2411	2411
bright nebulae	1249	1249
reflection nebulae	159	159
dark nebulae	5004	5004
galaxies	21992	c. 2.4 million
galaxy groups	8955	8955
galaxy clusters	5250	5250
quasars/AGNs	2280	168070

Objects

Stars

Stars are displayed individually, using black circles whose *area* is approximately proportional to brightness, or collectively, in dense regions as part of a stellar density map. Variable and multiple stars have their own graphical representation described separately below.

No attempt has been made to merge bright, variable and multiple stars, leaving stars with up to 4 labels (a proper name, a Bayer designation, plus the variable and multiple labels). Future releases may rationalise these catalogues. The current approach at least has the virtue of making membership of these categories clear. Stellar circles are plotted independently of each other. In some cases, due either to catalogue disparities or – conceivably – stellar motion between the different compilation dates of the catalogues, the circles do not precisely overlap.

Figure 3: Relative stellar marker sizes.

Bright stars

Bright stars, defined here as those listed in the XHIP catalogue[2], are labelled with either one or two labels (e.g., a proper name such as Sirius and a Bayer designation α CMa). The size of the main label font is in the main related to magnitude, but is reduced slightly for the more populous stellar catalogues (HIP, HD, HR, Gliese), and is reduced to a minimum if the star is a member of an open cluster, to enable the configuration of the cluster to be better appreciated.

[2] E. Anderson and C. Francis. XHIP: An extended hipparcos compilation. *Astronomy Letters*, 38:331–346, May 2012

Further information is provided beneath the label in the **infoline**, a terse description of object properties. The infoline appears for all objects plotted on maps.

The infoline for bright stars maximally contains, in this order

Any values which are undefined are omitted from the infoline

- a magnitude value, to one tenth of a magnitude
- components (e.g., AB) for multiple stars
- a code for variability type
- spectral type
- $B - V$ colour index
- distance in light years
- age in million years
- number of exoplanets

C = no variability detected; D = duplicity-induced variability; M = possible micro-variable; P = periodic variable; R = revised colour index due to variability; U = other

The index also contains a luminosity value.

Selection criteria All 117955 members of the XHIP bright stars catalogue are plotted.

Indexing criteria All 10748 named stars (i.e., those that possess more than a HIP or HD number) are in the index.

Field stars

If the stellar density of any given chart is below the threshold of 3.2 stars per square arcmin, field stars from the PPMXL catalogue[3] are displayed, up to a magnitude of 18. Field stars are not labelled.

In open and globular clusters, field stars up to magnitude 20 are plotted where possible. The exception is for very large clusters in dense stellar regions, where a lower maximum magnitude is selected and noted on the cluster infoline.

[3] S. Roeser, M. Demleitner, and E. Schilbach. The PPMXL Catalog of Positions and Proper Motions on the ICRS. Combining USNO-B1.0 and the Two Micron All Sky Survey (2MASS). *Astronomical Journal*, 139:2440–2447, June 2010

Stellar density maps

In some regions of the sky, principally in the plane of our galaxy but also in the LMC and SMC, it is not currently practical to plot individual stars to magnitude 18 due to the greatly increased file size of the resulting chart. Instead, a detailed estimate of stellar density is depicted; in addition, individual stars up to a magnitude lower than 18 are plotted.

A grid of size 900 by 900 is used, corresponding to a resolution of 12"

The decision on whether to use a stellar density representation is based on the maximum observed stellar density in any square region in a lower resolution grid conceptually overlaid on the chart. The lower resolution grid is 5 by 5, corresponding to a side of 36′. If the maximum stellar density in *any* part of the chart exceeds the minimum required to display them individually, a stellar density map is computed for the entire chart.

Table 1: The maximum magnitude of individual stars plotted is adjusted based on the mean stellar density on any given chart

stellar density stars/arcmin^2	magnitude
$>$ 35	12
21-35	13
13-20	14
9-12	15
7-8	16
3.2-7	17
$<$ 3.2	18

The grayscale (actually, more of a greenscale; Fig. 4) maps almost linearly on to stellar density, but undergoes a slight compressive nonlinearity at high stellar densities (meaning relatively fewer bits are used to encode differences at the top end of the density range). The resulting density-based representation has a useful side-effect of showing up many dark nebulae as white regions within the density map (Fig. 11).

Stellar magnitude limits are significantly relaxed for stars within globular and open clusters. Here, the decision of limiting magnitude is based on the cluster diameter. Generally, for clusters with a small apparent size the limiting magnitude is 20; for very large clusters the limiting magnitude will be the same as the rest of the chart; in between these extremes the limiting magnitude takes on an intermediate value. The limiting magnitude used for any cluster is displayed on its infoline.

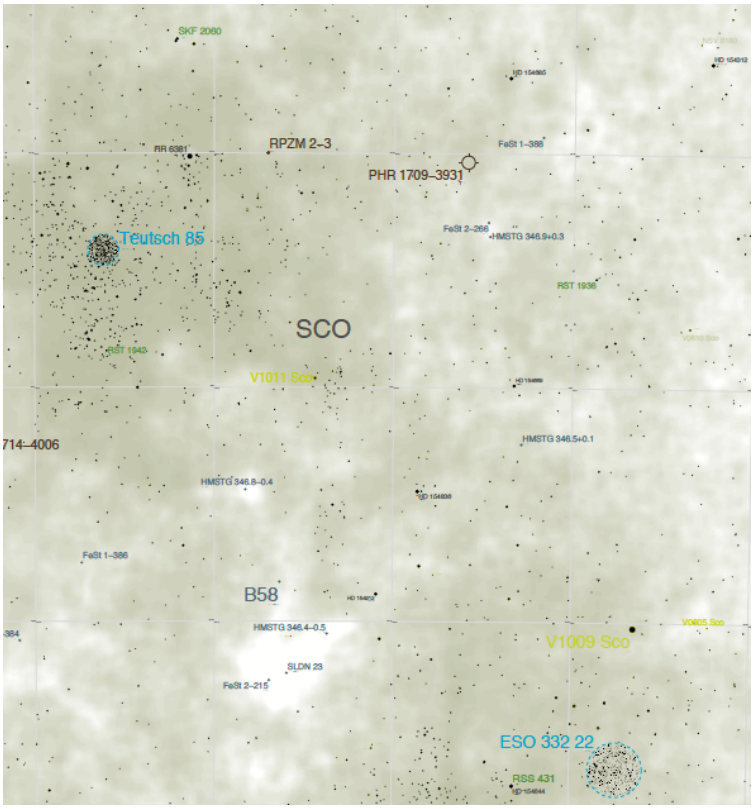

Figure 4: A stellar density map of a region in Scorpius. Note that the two open clusters depict stars down to a much lower magnitude than the rest of the chart.

Computation of the stellar density map uses all PPMXL stars to magnitude 20, unweighted by magnitude.

Variable stars

Variable stars come from the catalogue maintained by the AAVSO[4] and represented using two filled circles with a black outer rim. The inner black circle represents the star's magnitude at minimum while the outer rim corresponds to the magnitude at maximum. The interior filled circle is yellow. Thus, any variables stars with a large range stand out as appearing yellower.

Variables whose maximum magnitude exceeds 14 and whose range exceeds 0.25 are labelled with a font size related to maximum magnitude, using a bright yellow colour. In addition, the colour saturation of the label reflects the variability range; low saturation corresponds to a narrow range of variation. Variables within clusters, and those belonging to certain populous catalogues are unlabelled; in such cases the object's designation can be found on the infoline. The rules on labelling stem from the extremely high density of variables in certain regions of the sky. Even so, in a few regions (particularly in Sagittarius e.g., chart SGR1888) there remains a high density of quite bright and wide-ranging variables, presumably because of selective survey effects. Future releases may adopt a more selective label reduction policy.

[4] C. L. Watson. The International Variable Star Index (VSX). *Society for Astronomical Sciences Annual Symposium*, 25:47, May 2006

Figure 5: The Mira type variable S Tau

Populous catalogues include: 2MASS, ASAS, CSS, IRAS, LINEAR, MACHO, NSVS, OGLE, ROTSE, VSX

The infoline shows:

- range of variation (to the nearest hundredth of a magnitude)
- period (in hours or days as indicated)
- variability type
- designation, for unlabelled stars
- numeric AAVSO identifier

The AAVSO variability coding scheme is too extensive to be reproduced here; see `ftp://cdsarc.u-strasbg.fr/pub/cats/B/gcvs/vartype.txt`

Selection criteria Only known variables from AAVSO with both a stated minimum (or amplitude range) and maximum magnitude are included. This excludes 47051 variables (about 14% of the total of 324991), mainly unconfirmed candidates. Also, supernovae [N=92] are not currently included (name/type starts with SN). A small number of variables in AAVSO have mag at max fainter than mag at min [N=21]. These are also excluded.

Indexing criteria Some 21475 variables with a range of 0.5 magnitudes or more, and a magnitude at maximum of 12 or brighter, are included in the index.

Double stars

Double (strictly, multiple) stars come from the Washington Double Star (WDS) catalogue[5]. Doubles are plotted in black as for other stars, and labelled in green. To avoid map clutter, shorter Greek letter naming conventions are used for certain catalogues (see Tab. 2).

[5] B. D. Mason, G. L. Wycoff, W. I. Hartkopf, G. G. Douglass, and C. E. Worley. The 2001 US Naval Observatory Double Star CD-ROM. I. The Washington Double Star Catalog. *Astronomical Journal*, 122: 3466–3471, December 2001

All component pairs of multiple stars are plotted. Pairs are represented in one of 3 ways:

1. If the separation between pairs of components is large enough for both to be seen independently on the chart, they are plotted as separate stars. If in addition the pair is identified as a physical pairing, a faint solid line is drawn between the two. If a non-physical pair is exceptionally wide, a faint dotted line is drawn in order to aid identification. Where possible, components are labelled (e.g., A, B). If the stellar magnitude is sufficiently large, the label appears within the stellar disc, otherwise it is labelled next to the disc.
2. If the separation corresponds (pictorially) to more than 25% of the stellar disc, separate stars are plotted in overlap. Components of such pairs are not labelled.
3. If the separation is too small to allow either of the above solutions, a line of text oriented at the secondary position angle is drawn. The text contains the separation in arcsec, the position angle, and the magnitude of the secondary.

For a system with more than two components the infoline simply indicates the number of components (e.g., N = 5). For simple pairs (ie N=2 components) with a textual representation of the secondary (ie the third case above) the infoline indicates the magnitude and,

Figure 6: Struve 54 (also denoted STF 54 or $\Sigma 54$) and 55. The separation of $\Sigma 54$ is sufficiently large to show both stars; for $\Sigma 55$ the secondary is represented by a line of text at the appropriate position angle.

if available, the spectral type of the primary. For other simple pairs the magnitude of the A and B components is given, followed by their separation and primary spectral type if available.

Double stars follow the same constraints as field stars for dense regions: their magnitude has to exceed a threshold to be plotted as individual items. Multiples in clusters have their label font size heavily-reduced.

Selection criteria All members of the Washington Double Star (WDS) catalogue are plotted except for cases with

- no observations
- no magnitude for the primary
- no magnitude provided for the secondary
- the separation appears to be too wide (larger than 990)
- no last year of observation
- marked uncertain or dubious

Of the 113130 systems in the WDS at the time of compilation, the above constraints remove 3513 (3793 components).

Indexing criteria The index currently contains 22422 double star systems based on the following criteria:

- all members with the following discoverer codes: COU, HJ, DA, HU, J, P, SE, SHJ, STF, STFA, STFB, STT, STTA, H 1-6, H N, BU, BUP , DUN, and FIN.
- all systems not captured by these discoverers where the magnitude of the primary is brighter than 8.

Table 2: Discoverer code to symbols mapping; these designations correspond more or less to the Cambridge Double Star Atlas (1st. ed.)

WDS name	chart symbols
STF	Σ
STFA	Σ_I
STFB	$\Sigma_I I$
STT	$O\Sigma$
STTA	$O\Sigma\Sigma$
H 1 to H 6	H_I to H_{VI}
H N	H_N
BU	β
BUP	β_{pm}
DUN	Δ
FIN	ϕ

Open clusters

All members of the Dias[6] catalogue, some 2167 in all, are plotted and indexed. Clusters are bordered by a blue dotted line as shown in Fig. 7. Variables and doubles in clusters are labelled in a small font size so as to not disrupt the appearance of the cluster too much.

By default, stars in cluster regions are plotted down to magnitude 20. The exceptions are for large clusters in dense star regions, where a lower magnitude limit is progressively applied, as described earlier (the cluster *limiting magnitude* is indicated on the infoline). Note that no attempt has been made to plot only known or suspected cluster members; instead, all bright and field stars in the region of space occupied by a cluster are drawn.

The Dias catalogue does not provide integrated cluster magnitudes. For NGC and IC members the magnitude estimates from Wolfgang Steinicke's database[7] have been used. A future release of the atlas will re-estimate integrated magnitudes from cluster members where possible. A good idea of magnitude can be obtained simply by looking at the cluster as represented on the charts, since most if not all cluster members are plotted in each case.

[6] W. S. Dias, B. S. Alessi, A. Moitinho, and J. R. D. Lépine. New catalogue of optically visible open clusters and candidates. *Astronomy and Astrophysics*, 389:871–873, July 2002

If you cannot find the cluster you're looking for (e.g., Collinder 21), the most likely explanation is that it is no longer considered a cluster. The Dias release excludes clusters that have been removed for a number of reasons (e.g., reclassified as globulars, considered an asterism, duplicates, parts of other clusters or associations, not found).

[7] http://www.klima-luft.de/steinicke/index_e.htm

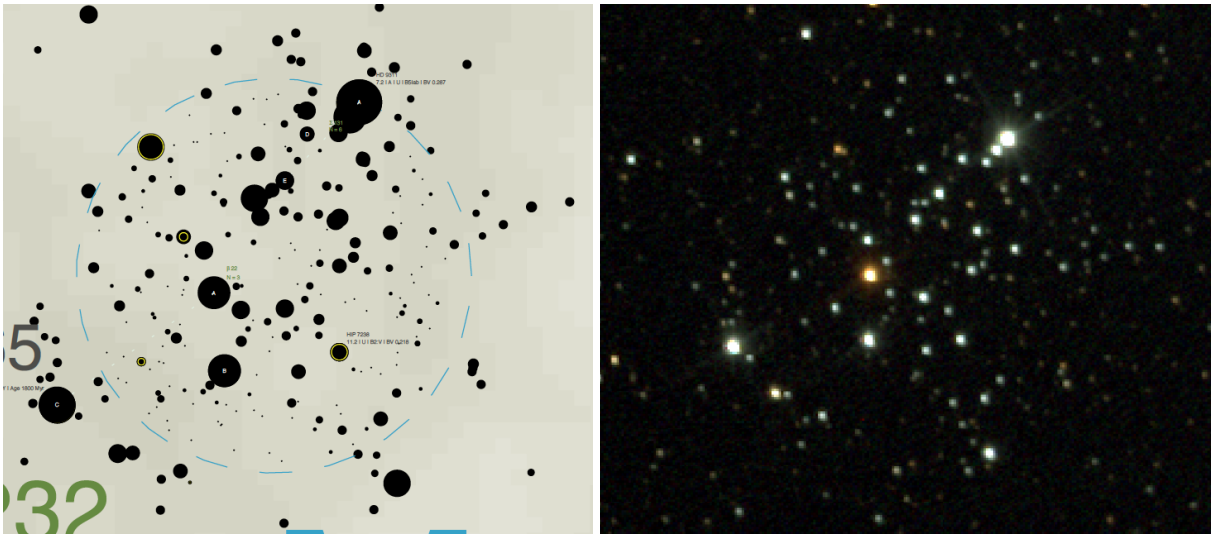

Figure 7: The open cluster M 103 (NGC 581). For comparison, also shown is a stack of 12 x 5s exposures through each of R, G and B Baader filters with a Lodestar X2 mono camera on an alt-az mounted Skywatcher Quattro 8" f4 Newtonian.

The infoline contains:

- Trumpler classification
- number of cluster members
- age in millions of years
- distance in light years
- $B - V$ colour index
- metallicity
- limiting magnitude
- other designations

Globular clusters

All 157 members of the list of galactic globular clusters provided by Harris[8] (2010 revision) are plotted and indexed. The display of globulars follows that of open clusters in terms of limiting magnitude and the representation of variables and multiples within clusters. Note that for the brighter globulars there is typically a star-free hole where PPMXL contains no resolved stars.

[8] W. E. Harris. A Catalog of Parameters for Globular Clusters in the Milky Way. *Astronomical Journal*, 112:1487, October 1996

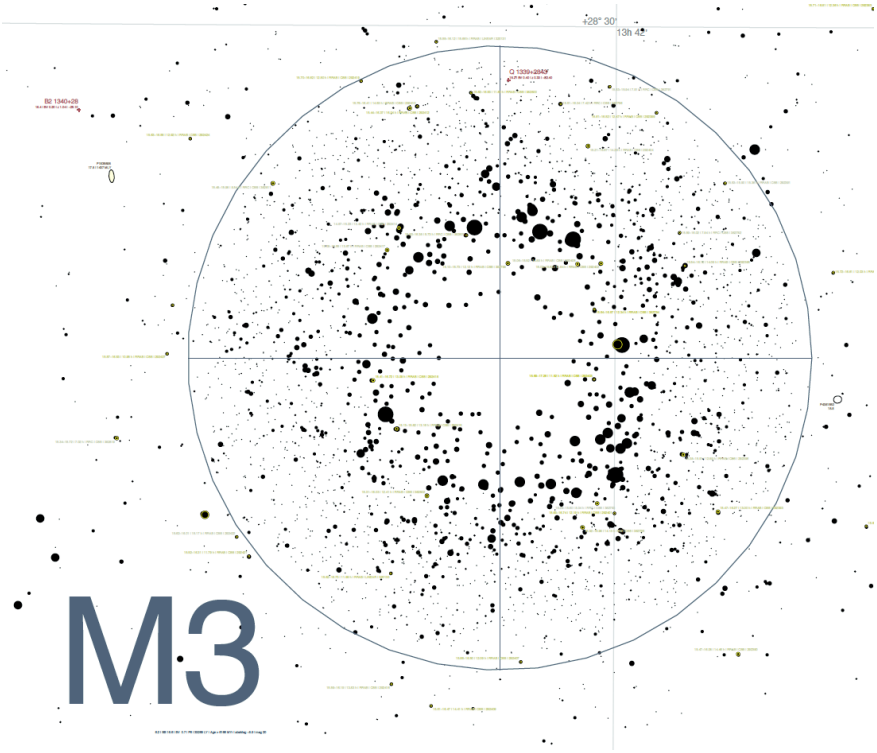

Figure 8: The globular cluster M3 (NGC 5272), the first Messier object discovered by Messier, just over 250 years ago. Note the large number of variables identified within the cluster.

The infoline for globulars contains

- magnitude
- surface brightness
- $B - V$ colour index
- spectral type of the integrated cluster light
- distance in light years
- age in millions of light years
- absolute magnitude
- limiting magnitude to which stars are plotted

age is actually the median relaxation time i.e. the time to stabilise the cluster, and provides a lower bound on age

The radius plotted is the *half-light radius* as opposed to the radius of the core.

Planetary nebulae

The charts and index contain 2411 planetary nebulae (PN), principally from the Strasbourg-ESO[9] and MASH[10] catalogues. Both catalogues contain true and possible PN candidates; relative numbers of these are contained in the cited articles. The MASH catalogue benefits from extensive notes that are reproduced on the infoline and in truncated form in the index. Two sources have been used to augment the information – mainly magnitude estimates – in the two principal catalogues, viz. Diego Barucco's website[11] and Wolfgang Steinike's aforementioned NGC/IC database.

An additional 20 candidates have been included based on a range of other catalogues. However, most of these are repeat entries (e.g., IC 5150, He 2-119, He 2-155, M 1-3) and will be removed in a subsequent release.

PNs with no reported apparent size are plotted with a diameter of 6" to ensure that they show up on the charts. Two different font sizes are used to label PNs: a larger font is used to label PNs with known or estimated magnitude brighter than 14.

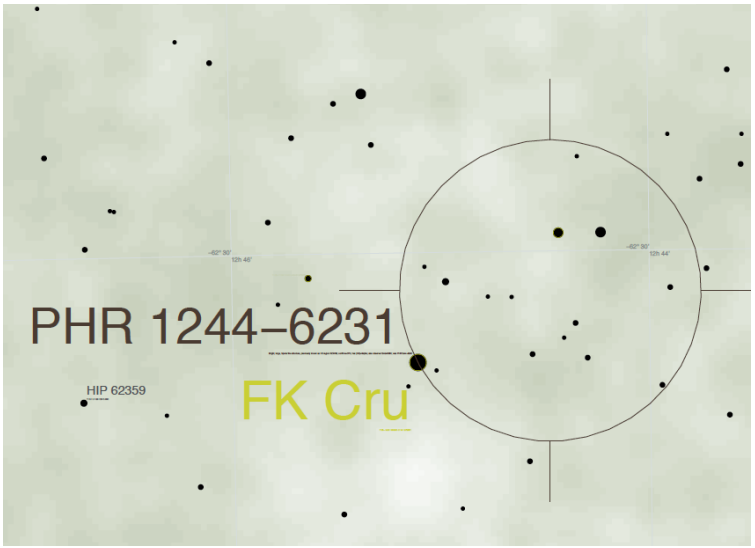

Figure 9: A member of the MASH PN catalogue in the constellation Crux. The comment reads "Bright, large bipolar like structure, previously known as HII region RCW69; confirmed PN, has [NII] > Halpha").

Information supplied with each PN includes

- magnitude
- surface brightness
- magnitude of the central star
- distance in light years
- $\log_{10}$ of the flux in Hβ line
- notes
- other designations

[9] A. Acker, J. Marcout, F. Ochsenbein, B. Stenholm, R. Tylenda, and C. Schohn. *The Strasbourg-ESO Catalogue of Galactic Planetary Nebulae. Parts I, II.* 1992

[10] Q. A. Parker, A. Acker, D. J. Frew, M. Hartley, A. E. J. Peyaud, F. Ochsenbein, S. Phillipps, D. Russeil, S. F. Beaulieu, M. Cohen, J. Köppen, B. Miszalski, D. H. Morgan, R. A. H. Morris, M. J. Pierce, and A. E. Vaughan. The Macquarie/AAO/Strasbourg Hα Planetary Nebula Catalogue: MASH. *Monthly Notices of the Royal Astronomical Society*, 373: 79–94, November 2006

[11] http://www.pnebulae.altervista.org

Other nebulosity

Some 1249 bright nebulae, 159 reflection nebulae, and 5004 dark nebulae are plotted, all of them indexed.

Bright nebulae, including HII regions

One source of bright nebulae is the data collected by Lynds[12], based on all bright diffuse areas detectable on the 48-inch Palomar Sky Survey. In addition to the Lynds Bright Nebulae (LBN) designations, this catalogue provides alternative names for objects identified in previous surveys (e.g., NGC, IC, Sharpless, Cederblad, Dorschner and Gurtler). These alternative names are used as the principal designations on the chart. In addition, the HII regions identified in Sharpless[13] are plotted.

[12] B. T. Lynds. Catalogue of Bright Nebulae. *Astrophysical Journal Supplement*, 12:163, August 1965

[13] S. Sharpless. A Catalogue of H II Regions. *Astrophysical Journal Supplement*, 4:257, December 1959

Due to the large size relative to the scale of atlas pages, only the centres of bright nebulae are indicated (Fig. 10). Information on the major/minor dimensions is given on the infoline. It is hope to add outlines of at least some bright nebulae in a future release.

The information line contains

- extent, in the form major x minor axes
- brightness class
- brightness; 'faint', 'moderate', or 'bright'
- form: 'circ', 'ellip' or 'irreg'
- structure: 'Amorphous', 'neutral', or 'filamentary'
- other designations

Brightness class is a value on a scale from 1 = brightest to 6 = barely detectable, as awarded by Lynds; to provide a comparable brightness indicator for the Sharpless data I have mapped his 3 categories 'faint', 'moderate' and 'bright' to the values 5, 3 and 1 respectively.

In addition, the index contains a star count for members of the Sharpless catalogue, and a colour class for items from Lynds catalogue.

Colour class is interpreted as "1 = brightest on blue plate; 2 = about equal on blue and red plates; 3 = brighter on red plate; 4 = visible only on red plate".

Reflection nebulae

Although the Lynds catalogue also contains some reflection nebulae, the main source is Van den Bergh's catalogue[14], supplemented by data on Messier 78. Since reflection nebulae tend to be smaller in extent, they are plotted as blue circles on the charts (Fig. 10); the diameter is taken from the red plates.

[14] S. van den Bergh. A study of reflection nebulae. *Astronomical Journal*, 71:990–998, December 1966

The infoline contains

- surface brightness (from the blue Palomar prints), coded as: VBR = very bright; BR = bright; M = moderate; F = faint; VF = very faint; : = uncertain.
- colour: VB = very blue; B = blue; MB = moderately blue; I = intermediate; MR = moderately red; R = red; VR = very red; : = uncertain
- absorption: STR = strong; MOD = moderate; WK = weak; ABD = absent

A future release may include data from the merged catalogue of reflection nebulae compiled by Magakian (2003).

- type: I = illuminating star embedded in nebulosity; II = star located outside the illuminted nebulosity; a P = peculiar qualifier may also be present
- spectral type
- an indication of whether the nebula shows variability

The index additionally distinguishes between the diameters on the red and blue plates.

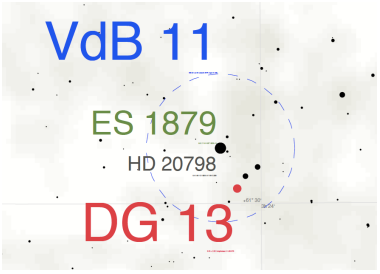

Figure 10: Bright nebula DG 13 and reflection nebula VdB 11.

Dark nebulae

Dark nebulae come from the Dutra and Bica compilation[15] which results from a study of 21 existing catalogues of dust clouds.

To reduce clutter in certain parts of the sky, a font size difference is used, with members of the Barnard, CB, LDN, LM and SDN catalogues beign labelled with a larger font than the remaining catalogues.

Dark nebulae are plotted in gray; only the central coordinate is indicated. However, since many dark nebulae occur in dense starfields, their outline is sometimes well-illustrated by a sudden drop in stellar density (Fig. 11).

[15] C. M. Dutra and E. Bica. A catalogue of dust clouds in the Galaxy. *Astronomy and Astrophysics*, 383:631–635, February 2002

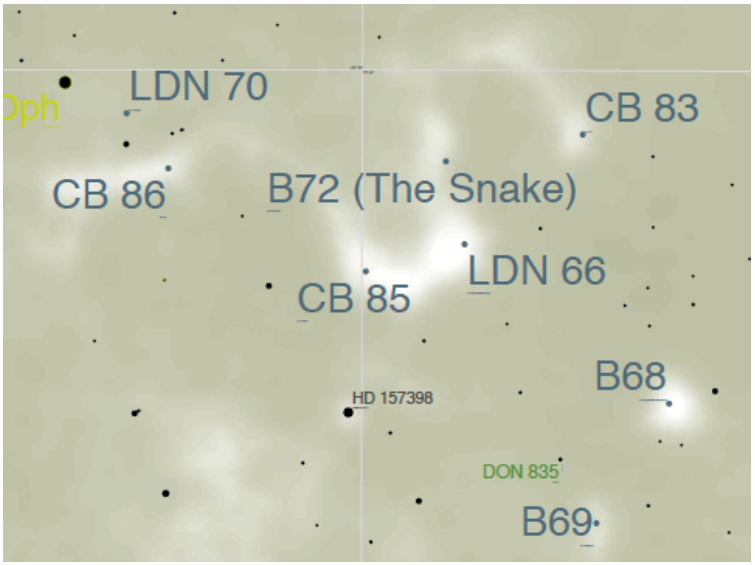

Figure 11: Barnard 72 and neighbouring dark nebulae show up as star-free holes in the map.

The infoline contains

- extent as major x minor
- opacity class: 1 = least opaque to 6 = most opaque
- other designations

The most opaque designation corresponds to a stellar density of 120 stars per square degree on average

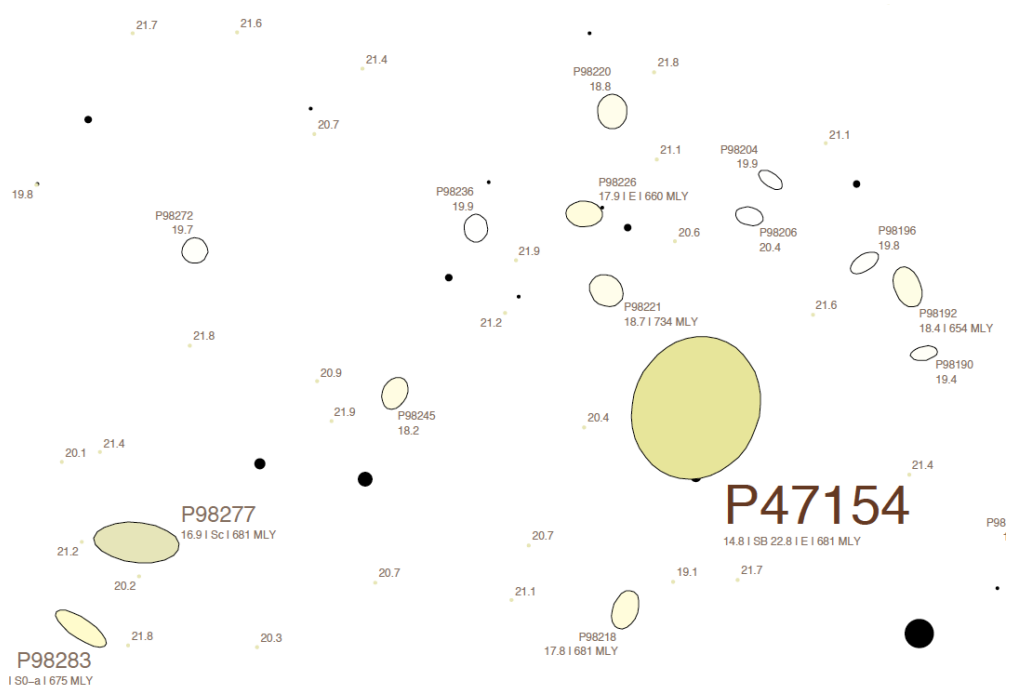

Figure 12: A small selection of galaxies in the very dense Abell 3558 galaxy cluster in Centaurus, illustrating the colour, label and object plot types described in the text.

Galaxies

Individual galaxies come from the HyperLEDA catalogue[16,17] compiled at the University of Lyon. This large dataset contains objects classified as galaxies and possible galaxies, as well as quasars, galaxy pairs and clusters, radio sources, HII regions, stars, nebulae and many other object types.

[16] G. Paturel, C. Petit, P. Prugniel, G. Theureau, J. Rousseau, M. Brouty, P. Dubois, and L. Cambrésy. HYPERLEDA. I. Identification and designation of galaxies. *Astronomy and Astrophysics*, 412:45–55, December 2003

[17] D. Makarov, P. Prugniel, N. Terekhova, H. Courtois, and I. Vauglin. HyperLEDA. III. The catalogue of extragalactic distances. *Astronomy and Astrophysics*, 570:A13, October 2014

Galaxies are plotted as correctly-oriented filled mustard-coloured ellipses apart from a (very) few larger specimens such as M31 which are plotted unfilled. The colour saturation of the patch is linearly related to magnitude. If the object is a probable galaxy, the colour is completely unsaturated (white). Any galaxy lacking both major and minor axis dimensions is plotted as a small yellow point and labelled only with its magnitude. Galaxy label size is related to magnitude too. Relatively bright galaxies (mag < 15) are labelled with a slightly deeper (more saturated) brownish label colour than less bright galaxies.

There are many such 'point' cases in and around Abell galaxy clusters. They can be used to measure your detection limit.

The infoline contains

- magnitude
- surface brightness
- galaxy type
- distance in millions of light years

Magnitudes are nearly always B-band; in around 8000 cases (0.3%) an I-band magnitude is used.

Selection criteria The atlas plots objects classified as galaxies or probable galaxies. In addition, since a small number of 'well-known' galaxies appear to be classified as 'extended source of unknown nature' or even quasars, these sections of the HyperLEDA database are also selectively processed. A cutoff magnitude

HyperLEDA types 'G', 'g','?' and 'Q' are considered for inclusion in the atlas. However, the majority of objects classified as Q have no major nor minor diameters and are not included in the atlas. *Due to an oversight, a small number of galaxies classified by HyperLEDA as part of a group or cluster are not plotted. This will be rectified in the next version.*

of 22 was chosen, although the catalogue is not complete down to that magnitude.

Steinicke's NGC/IC catalogue was used to filter out unlikely candidates from the HyperLEDA sample..

Any marked as of (non-galactic) type 2-6 and 9-10 in the NGC/IC database are removed apart from NGC 2363 which some regard as an irregular galaxy. Repeated entries (type codes 7 and 8) are retained and handled by a later processing stage which checks for duplicates

Indexing criteria Galaxies whose principle designation is as a member of one of the following catalogues are included in the index: Messier, NGC, IC, FGC, RFGC, UGC, UGCA. In the case of multiple designations, the earlier catalogue in the aforementioned list is chosen.

The inclusion of the Flat (FGC) and Revised Flat Galaxy Catalogue (RFGC) is a personal choice due to the often spectacular nature of these edge-on galaxies in images.

Galaxy groups

In some cases (typically amongst the peculiar cases) there is only a single member, so the term group is something of a misnomer.

Galaxies are plotted only once, as individual galaxies, and not a second time as part of galaxy groups. In cases where galaxy groups have identified members (e.g., the Hicksons and Shakhbazians), labels are added on top of already-plotted galaxies[18]. Plotting of galaxies and galaxy groups therefore is completely independent, and the fact that member labels land on the correct galaxy is a testament to the accuracy (mainly) of the galaxy group catalogues.

[18] In many cases there is no galaxy in LEDA at the identified position, particularly for the Shakhbazian groups; yet in all cases to date checked photographically at the 'scope by the author the location is correct and a faint galaxy emerges as expected.

All members of the various galaxy group catalogues are plotted and indexed. There are many duplicate designations amongst the galaxy group catalogues. Some have been identified; future releases will attempt a more complete identification of alternative designations. If you cannot find an object in the index, check the other catalogues.

When a group contains several members, the RA/Dec of the group centre, and the angular size, are computed from the members rather than from the value provided in the catalogue.

Interacting and peculiar galaxies, and other associations of galaxies

Gathered into this category of object are the Arp[19], Arp & Madore[20] and Vorontsov-Velyaminov[21] catalogues. The 2001 Vorontsov-Velyaminov et al. paper describes the unification of several studies from 1959 onwards.

[19] H. Arp. Atlas of Peculiar Galaxies. *Astrophysical Journal Supplement*, 14:1, November 1966

[20] H. C. Arp and B. Madore. *A catalogue of southern peculiar galaxies and associations*. 1987

[21] B. A. Vorontsov-Velyaminov, R. I. Noskova, and V. P. Arkhipova. The catalogue of interacting galaxies by Vorontsov-Velyaminov. *Astronomical and Astrophysical Transactions*, 20:717–959, December 2001

Catalogue	Type	Count
Arp	peculiar	338
Arp, Madore	Southern peculiar & associations	5973
Vorontsov-Velyaminov	interacting	2014

Members of the Arp & Madore catalogue are identified with the short label 'AM', and the rest of the identifier (encoding RA/Dec) is provided on the infoline.

Due to the non-trivial method of encoding group members, there are some instances where AM members are represented individually rather than as a group. This will be resolved in a future release.

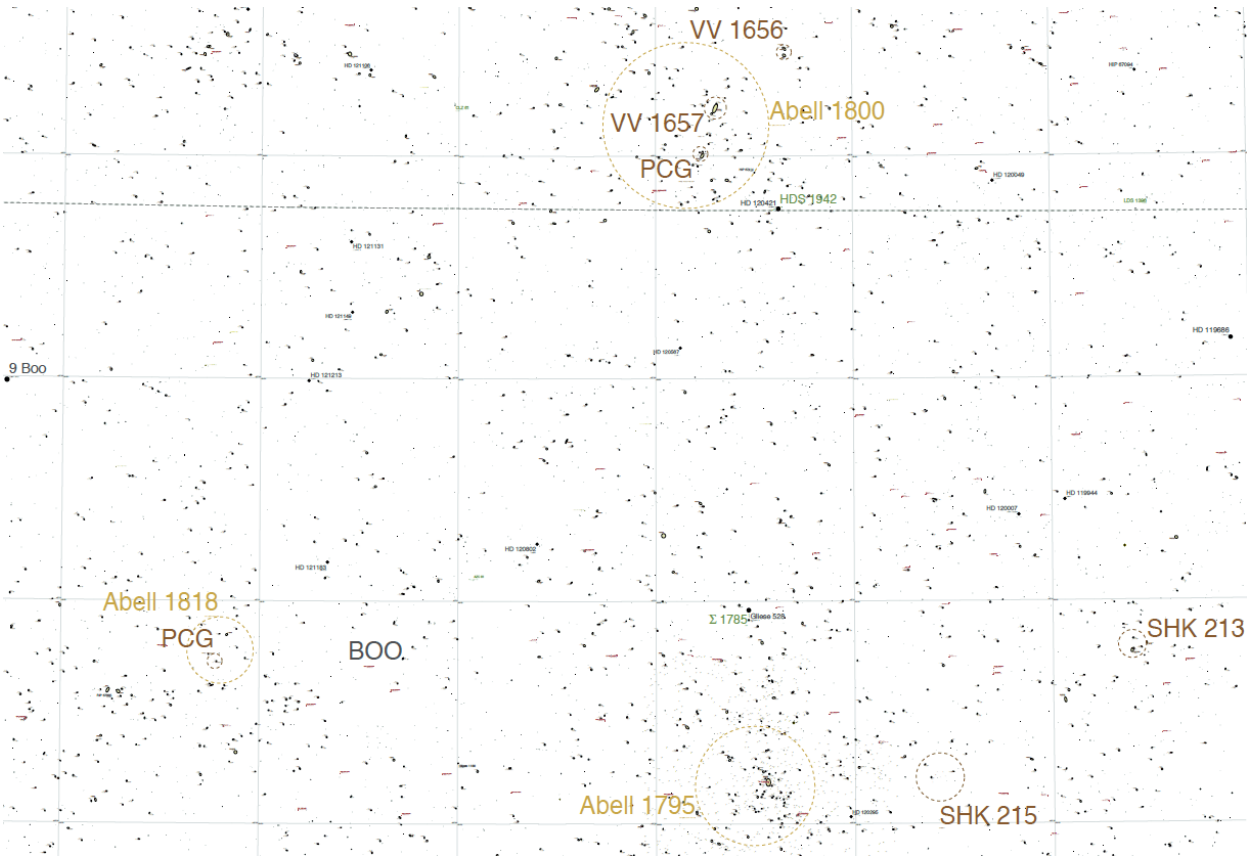

Figure 13: A number of galaxy groupings – V-V, Palomar, Shakhbazian, as well as Abell clusters – on the border between Canes Venatici and Bootes.

Galaxy groups are circumscribed and labelled in brown; for galaxy clusters, the colour is golden brown.

The infoline contains

- integrated magnitude
- ΔMag: difference in magnitude between brightest and faintest member
- surface brightness
- number of members
- type
- redshift
- a measure of compactness for some catalogues
- full name if designation shortened (AM or PCG)
- other designations

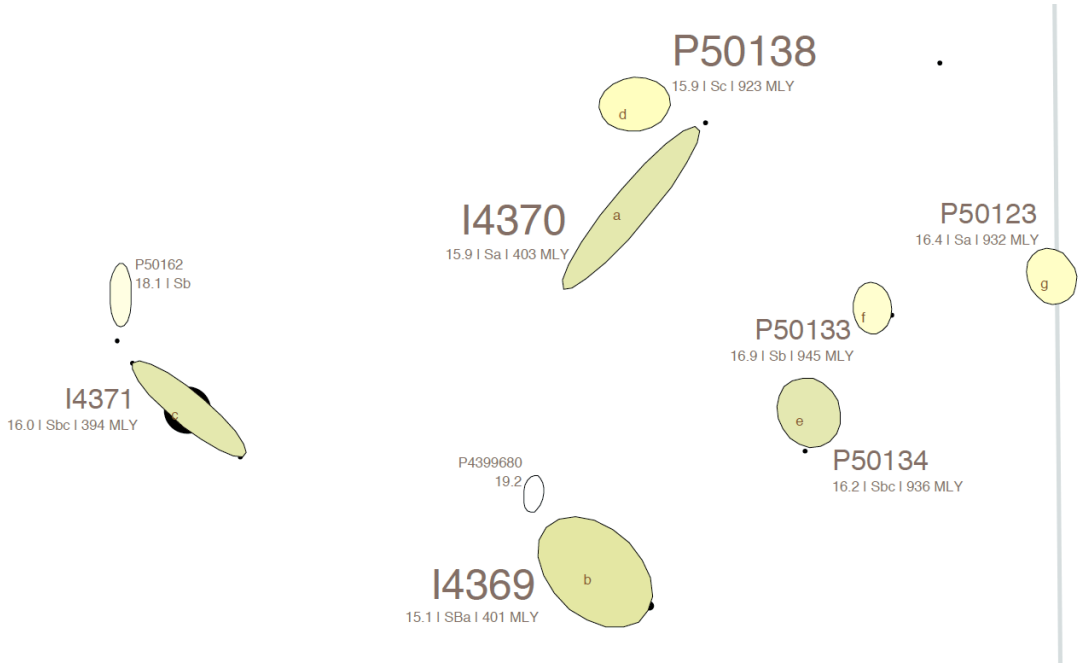

Figure 14: The 7-strong Hickson 70 compact group showing overplotting of component labels a-g.

Compact clusters

Three collections of compact groups of galaxies are currently plotted: the Shakhbazian[22] and Hickson[23] catalogues, and the combination of two studies of the Palomar Observatory Sky Survey (POSS). The Palomar groups come from both Iovino[24] and De Carvalho[25] surveys which constribute 84 and 459 groups respectively. However, some 56 appear to be duplicated across the two catalogues and are removed, leaving 487 groups.

Catalogue	Count
Shakhbazian	377
Hickson	100
Palomar	487

Six groups from the Shakhbazian catalogue have no members listed, although they do have an entry for number of known members. In these cases no members are plotted but the group is identified.

Plotting conventions are identical to those for interacting/peculiar groups. Palomar compact groups are identified by the label 'PCG', and the remainder of the identifier is provided on the infoline.

Galaxy clusters

All Abell galaxy clusters[26] from the Northern[27] and Southern Abell surveys, along with the Southern supplement – a total of 5250 groupings – are plotted and indexed. Some examples are shown in Fig. 13.

Some clusters lack a measure of apparent size. For these, an estimate is made based on distance class: clusters are assigned the

[22] R. K. Shakhbazian. Compact groups of compact galaxies. *Astrofizika*, 9:495–501, 1973

[23] P. Hickson. Systematic properties of compact groups of galaxies. *Astrophysical Journal*, 255:382–391, April 1982

[24] A. Iovino, R. R. de Carvalho, R. R. Gal, S. C. Odewahn, P. A. A. Lopes, A. Mahabal, and S. G. Djorgovski. A new sample of distant compact groups from the digitized second palomar observatory sky survey. *The Astronomical Journal*, 125(4):1660, 2003

[25] R. R. de Carvalho, T. S. GonÃğalves, A. Iovino, J. L. Kohl-Moreira, R. R. Gal, and S. G. Djorgovski. A catalog of distant compact groups using the digitized second palomar observatory sky survey. *The Astronomical Journal*, 130(2):425, 2005

[26] G. O. Abell, H. G. Corwin, Jr., and R. P. Olowin. A catalog of rich clusters of galaxies. *Astrophysical Journal Supplement Series*, 70:1–138, May 1989

[27] G. O. Abell. The Distribution of Rich Clusters of Galaxies. *Astrophysical Journal Supplement*, 3:211, May 1958

mean diameter for each distance class estimated from those with known diameters.

The infoline contains

- m10: magnitude of the 10th brightest member
- m1: magnitude of the brightest member
- member count
- distance class: 0=closer; 7=most distant
- redshift
- richness class: 0=sparse; 5=rich
- Bautz-Morgan classification

Distance class is determined by m10

class	members
0	30-49
1	50-79
2	80-129
3	130-199
4	200-299
5	300+

Quasars, BL Lacs, AGNs

The source catalogue for quasars is Véron-Cetty & Véron[28], which contains 168939 objects (133334 quasars, 34231 active galaxies and 1374 BL Lac objects).

[28] M.-P. Véron-Cetty and P. Véron. A catalogue of quasars and active nuclei: 13th edition. *Astronomy and Astrophysics*, 518: A10, July 2010

Quasars, BL Lacs and AGNs (henceforth simply quasars) are plotted with a red cross, the size of which varies with magnitude, but is never very large (to avoid obliterating host galaxies for AGNs).

The infoline reports on

- class: A = AGN, B = BL Lac (empty signifies quasar)
- magnitude and filter
- $B - V$
- redshift
- spectral type
- absolute magnitude

if photographic, filter is omitted; otherwise one of B, V, R, I or O (photographic O/J-plates)

Figure 15: A high redshift quasar in Pisces.

Selection criteria 168070 objects with a magnitude brighter than 24 are retained.

Indexing criteria Objects are indexed if they meet one or more of the following criteria:

1. Member of the 3C, 4C or 5C catalogue
2. Magnitude $<= 14$
3. Redshift > 4

These criteria are somewhat arbitrary, but lead to the inclusion of objects that have some historical interest (such as 3C 273), or are bright enough to be seen in a range of instruments, or provide an interesting challenge due to a high redshift. Some 2280 objects are indexed.

Known limitations

Data integrity

While previous celestial atlases have been small enough for the contents to be checked and re-checked, an atlas of nearly 7000 detailed charts containing millions of DSOs and hundreds of millions of stars cannot be fully validated. What's more, the underlying data itself is in the main based on automated analyses of large sky surveys, with a minimal amount of human intervention at the level of checking individual stars and galaxies. Consequently, the atlas certainly exhibits some defects and limitations. Some of these will be improved by the incorporation of data from future sky surveys.

Erroneous classification

The galaxy sample in particular suffers from cases where what is clearly on inspection of a photograph not a galaxy is labelled as a galaxy; many such cases correspond to fragments of larger galaxies e.g. HII regions; others appear to be misclassifications of stars in very dense star fields. Similarly, some stars in PPMXL appear to be galaxies.

Sampling and survey effects

PPMXL is not entirely free from artefacts, as will be evident on some of the stellar density representations that show clear blocky artefacts, presumably due to overlapping sampling regions. In dense stellar regions the star density in the immediate vicinity of a bright star is almost always zero; these appear as holes rather like circular dark nebulae. Halos and diffraction effects have not entirely disappeared. We urge the user of the atlas to apply common sense to any unnatural-looking stellar configurations.

For parts of the galaxy sample there are regions (usually associated with Abell galaxy clusters) where there are large numbers of faint galaxies indicated in a boxed region. Other sampling artefacts are almost certainly present in the data. The same applies to dense samples of variable stars in certain regions of Sagittarius.

The approach taken in the atlas is to leave such survey and other artefacts alone unless an obvious solution is available (and noted in

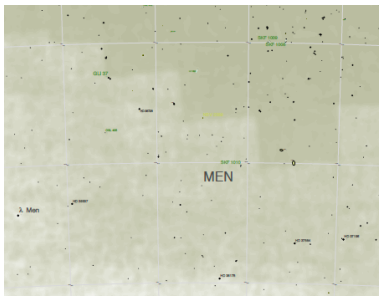

Figure 16: Sampling block artefacts.

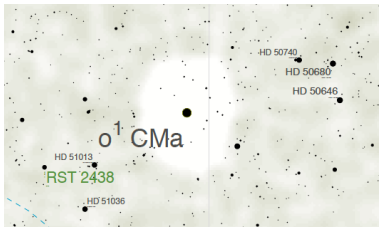

Figure 17: Stellar hole artefact.

the relevant section below). In many cases it is simply impractical to rectify these defects.

Label density

In some parts of the sky there are dense concentrations of certain kinds of object. This is especially the case for galaxy clusters, but, perhaps due in part to sampling effects also true for variable stars on some charts. There are compact groupings of galaxies and stars, notably the Trapezium in Orion. Many cause label placement headaches. While a reasonably sophisticated label placement algorithm has been used, there are still numerous cases of label overlap in crowded regions.

Take a look at Abell 3558 in Centaurus for such an example

Of course, manual label placement is out of the question.

Alternative designations and catalogue indexing

Astronomical objects typically have more than one designation, and in some cases they can have up to a dozen. In the current release, the handling of alternative identifiers is incomplete; this has a number of ramifications.

First, on the charts themselves the same object might be (over)plotted several times. This is most noticeable for galaxy groups where labels for individual members might be overprinted. Likewise, the same object might appear listed under more than one designation in the index. Tracking down all such cases is time-consuming but is planned for future releases.

The converse issue also affects the index. In cases where multiple designations have been identified, only one is indexed. This can cause issues when searching for the 'masked' designation. A better solution would be to maintain entries which are in named catalogues in the index when a user searches specifically by catalogue (i.e., by selecting a catalogue name from a chart page).

An example is SHK 5, which is indexed as Hickson 50; many VVs are listed as Arps.

Object name ordering in the index

Some attempt has been made to perform sensible object name ordering (e.g., ordered alphabetically by catalogue, and then numerically within catalogue), but this has not always been quite intelligent enough. A future release will improve matters.

Acknowledgements: This project simply would not be possible without public funding of science and open data access. A huge thanks to the team at the CDS, Strasbourg, France, for the use of their VizeR catalogue access tool, the proximate source of most of the raw data for the charts. Also to Dr Wolfgang Steinicke for his NGC/IC database which proved invaluable for checking and supplementing the other catalogues; similarly to Diego Barucco for his planetary nebulae website.

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B. A. Vorontsov-Velyaminov, R. I. Noskova, and V. P. Arkhipova. The catalogue of interacting galaxies by Vorontsov-Velyaminov. *Astronomical and Astrophysical Transactions*, 20:717–959, December 2001.

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