Astrometric Surveys:

Modern Astrometric Catalogues

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What is Astrometry?

- Astrometry is that part of astronomy dealing with the positions, motions and trigonometric distances of celestial objects.

What is an Astrometric Survey?

- An astrometric survey can be defined as a search oriented to finding those celestial objects meeting a given accuracy in their absolute or relative positions, motions or trigonometric distances.

- Some of these surveys have been conducted with ground-based meridan circles, astrolabes or astrographic telescopes. Others have used or will use space-based instrumets.

Detectors Used in the Construction of Astrometric Catalogues

The Very Early Beginning

- The compilation of catalogues including positions and proper motions is among the best known activities in astrometry. In the early beginnings of astronomy, providing positions of celestial bodies was a real necessity for many of the ancient cultures. With roots dating back to pre-Greek civilizations, astrometry provided the information for computing solar and lunar eclipses and, more importantly, for the determination of time.

The First Astrometric Catalogues

- **One of the first catalogues ever compiled was prepared by Hipparchus. It was completed around 129 BC.**

- **Previous compilations by Greek and Chinese astronomers date back to roughly 300 BC and even to 360 BC.**

- **During the Middle Ages the most important compilation worth mentioning is called the *Alfonsine Tables*, compiled under the reign of Alfonso the Wise and first published –probably- after 1277. The real purpose of the *Tables* was to offer a means to calculate the positions of the planets; one of the main users of the *Alfonsine Tables* was Copernicus.**

The Start of Systematic Surveys

- Tycho Brahe is among the first astronomers who started to make accurate systematic observations (mainly of Mars) during the pre-telescope years.

  Tycho was the last astronomer living under the geocentric paradigm. This prevented him from further pursuing the determination of stellar parallaxes.

Time for the Telescope

- **With the introduction of the telescope, many zone catalogues started to be observed by means of meridian circles. Most of the early to mid 1800s were limited to some specific areas and there was no agreement on the "system" that should be used (the convenience of having a system -in the modern sense of the term to which positions have to be refered- was first proposed in the late 1800s).**

- **One of the first attempts to carry out a comprehensive survey was started by Argelander with the observation of the zone from +80 to –2 degrees. The zones from –2 to the south pole were added later. This first survey -known as the Durchmusterungs- was made in three parts: Bonner, Córdoba, and Cape Photographic Durchmusterung.**

Modern Times

- **The most important work of the early years of the 20th century was the General Catalogue -GC- (published by Boss in 1937), a preliminary version of which was published in 1910. This version was called Preliminary General Catalogue (PGC). What is important to highlight about the PCG / GC project is Lewis Boss´ ultimate aim: the construction of a fundamental system. This goal was finally accomplished by his son, Benjamin Boss.**

The Photographic Plate Era

- When the photographic plate was finally accepted by the astronomical community as a detector (around 1880), the photographic astrometric surveys started to develop. Curiously, the first observing program with the newly introduced astrographic telescope (the accompanying instrument to the photographic plate) was the observation of the biggest international project of the last years of the 19th century: the Astrographic Catalogue (AC).

- The reign of the photographic plate lasted from 1880 to around 1990.

Astrometry's Major Landmarks

- 129 BC: Hipparchus publishes the first catalogue
- 1609: Galileo starts to use the telescope in astronomical research
- 1718: Halley* introduces the concept of proper motions
- 1802: Herschel notes the relative orbital motion of Castor (beginning of double stars)
- 1837: Bessel determines the trigonometric parallax of 61 Cyg
- 1887: The photographic plate is adopted as a detector
- 1989: ESA launches the Hipparcos satellite

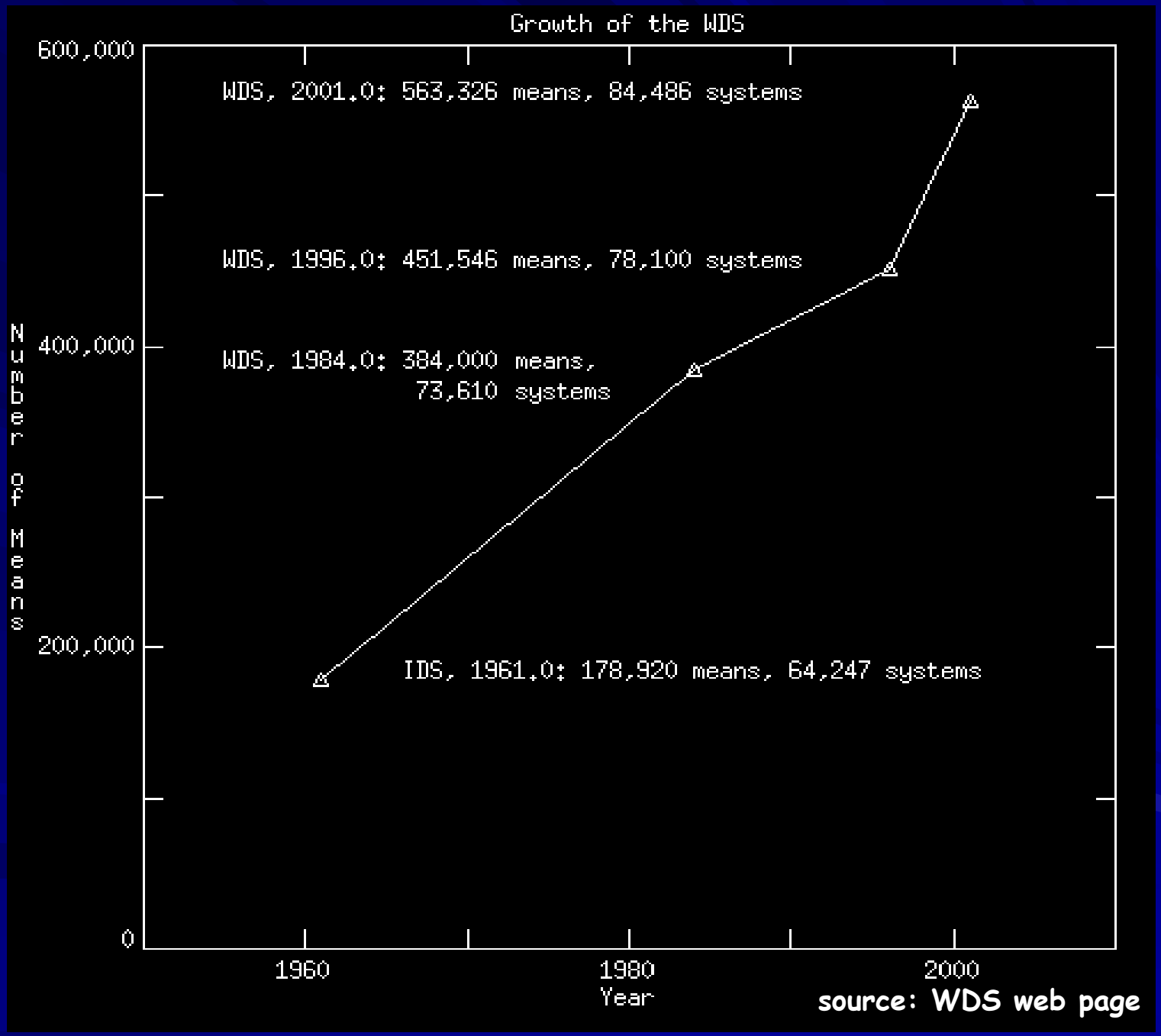
* There is some evidence indicating that it was actually Nicholas of Cusa (circa 1400) who first mentioned the proper motion of stars

Double Stars

- There is a first reference to ν1 and ν2 Sgr in the Almagest
- 1650 The duplicity of Mizar is annouced by Riccioli
- By the end of the XVII century the duplicity of α Cen and α Cru is announced
- 1779 Mayer publishes the first catalogue of double stars (80 entries)
- 1802 W. Herschel admits that the changes in Castor may be the consequence of an orbital motion
- 1827 Struve introduces the θ and ρ parameters. Catalogue with 3134 pairs

Double Stars (cont.)

- 1900 A new catalogue with 15,000 stars is published
- 1919 First interferometric observations by K. Schwarzschild
- 1921 Hertzsprung starts observations using photographic plates
- 1970 Speckle interferometry observations
- 1980 CHARA (Center for High Angular Resolution Astronomy) is formed
- 2002 The Tycho Double Stars Catalogue is announced by Fabricius et al.


Growth of the WDS
600,000
400,000
200,000
0
Number of Means
WDS, 2001.0: 563,326 means, 84,486 systems
WDS, 1996.0: 451,546 means, 78,100 systems
WDS, 1984.0: 384,000 means,
73,610 systems
IDS, 1961.0: 178,920 means, 64,247 systems
1960
1980
2000
Year
source: WDS web page

The Washington Double Stars (WDS) Catalogue in numbers

WDS Catalog (~12.5Mb)

00-06 hour section (~2.6Mb)

06-12 hour section (~3.6Mb)

12-18 hour section (~2.3Mb)

18-24 hour section (~4.0Mb)

Format of the current WDS

Notes file for the WDS (~1.0Mb)

References and discoverer codes (~0.7Mb)

Total of 99798 systems

The “Neglected stars”

List Set I:

Northern List (Dec > +20, num = 3072)
Equatorial List (-20 < Dec < +20, num = 2331)
Southern List (Dec < -20, num = 1039)

List Set II:

Northern List (Dec > +20, num = 1860)
Equatorial List (-20 < Dec < +20, num = 2710)
Southern List (Dec < -20, num = 2062)

List Set III:

Northern List (Dec > +20, num = 21,061)
Equatorial List (-20 < Dec < +20, num = 11,491)
Southern List (Dec < -20, num = 13,216)

Total of 58842 systems

Identification of LDS systems in 2MASS and SSS(R)

(sample table)

LDS#	cat	RA (J2000.0)	Dec	Epoch	pmRA (mas/yr)	pmDec (mas/yr)	Magnitudes (J/B)	(H/R1)	(K/R2)	I
5312 A	2mas	01 04 17.920	−08 25 33.90	1998.892			12.409	11.804	11.573	
5312 A	sssr	01 04 17.842	−08 25 33.14	1988.764	111.	−44.	16.308	99.999	14.251	12.996
5312 B	2mas	01 04 17.100	−08 21 33.20	1998.892			11.987	11.366	11.136	
5312 B	sssr	01 04 17.015	−08 21 32.89	1988.764	117.	−24.	16.960	99.999	14.768	12.882
5313 A	2mas	01 06 46.270	−03 45 50.30	1998.798			13.828	13.251	13.123	
5313 A	sssr	01 06 46.260	−03 45 50.37	1995.795	56.	−120.	19.137	99.999	17.130	15.236
5313 B	2mas	01 06 56.380	−03 47 12.30	1998.798			15.677	15.172	15.261	
5313 B	sssr	01 06 56.379	−03 47 12.40	1995.795	48.	−81.	20.280	99.999	18.098	17.115
3233 A	2mas	01 06 48.800	+01 48 45.20	2000.815			16.696	16.324	15.767	
3233 A	sssr	01 06 48.547	+01 48 45.40	1986.577	219.	−28.	17.489	99.999	17.242	17.144
3233 B	2mas	01 06 42.490	+01 46 17.60	2000.815			13.678	13.115	12.848	
3233 B	sssr	01 06 42.257	+01 46 17.60	1986.577	254.	−13.	19.514	99.999	17.431	15.345
5318 A	2mas	01 07 42.850	−11 42 45.00	2000.892			12.357	11.710	11.499	
5318 A	sssr	01 07 42.755	−11 42 45.28	1988.764	231.	−18.	16.396	99.999	14.337	12.668
5318 B	2mas	01 07 39.470	−11 44 55.60	2000.892			15.470	14.846	14.644	
5318 B	sssr	01 07 39.339	−11 44 55.36	1988.764	254.	−58.	20.278	99.999	18.166	16.462
5319 A	2mas	01 07 54.920	+01 15 34.50	2000.755			11.324	10.814	10.728	
5319 A	sssr	01 07 54.873	+01 15 35.39	1986.577	71.	−67.	13.880	12.658	12.415	11.921
5319 B	2mas	01 07 43.940	+01 15 32.40	2000.755			12.561	11.980	11.748	
5319 B	sssr	01 07 43.881	+01 15 33.62	1986.577	73.	−139.	17.982	99.999	16.155	14.009
5321 A	2mas	01 11 06.440	−11 08 06.90	2000.825			11.669	11.034	10.820	
5321 A	sssr	01 11 06.565	−11 08 07.32	1988.764	−137.	28.	15.421	99.999	13.111	11.439
5321 B	2mas	01 11 04.170	−11 08 26.40	2000.825			13.206	12.619	12.346	
5321 B	sssr	01 11 04.299	−11 08 26.93	1988.764	−150.	29.	18.079	99.999	15.800	14.042
3244 A	2mas	01 12 26.430	−13 08 33.50	1998.602			11.363	10.760	10.555	
3244 A	sssr	01 12 26.327	−13 08 33.05	1991.672	241.	−70.	17.628	99.999	13.873	12.177
3244 B	2mas	01 12 26.560	−13 08 18.90	1998.602			12.116	11.555	11.310	
3244 B	sssr	01 12 26.457	−13 08 18.65	1991.672	215.	−94.	17.087	99.999	14.955	13.100

Parallaxes

- 1580: First attempt by Tycho Brahe
- 1781: "…the displacement due to the parallax must be less than 1 arcsec" said James Bradley when he attempted to determine the γ Dra parallax
- 1837: Parallax of 61 Cyg determined by Bessel
- 1838: Parallax of Vega determined by Struve
- 1903: Systematic observations with photographic plates started by Schlesinger
- 1924: First edition of the YPC (~1680 star)
- 1983: Monet & Dahn determined the first parallaxes using CCD
- 1995: Fourth edition of the YPC (~8100) star
- 1997: Hipparcos results
- 1998: Nearby Star Databse established
- 2003: Teegarden et al. dicovery of a star between 2.7 and 3.6 pc (using SkyMorph)
- 2005: Jao et al. present new results from the CTIOPI program

Proper Motions

- 1718: Halley announces the proper motion of the stars
- 1775: Mayer publishes the first proper motions catalogue (998 stars)
- 1783: Herschel suggests the idea of solar motion
- 1887: the Astrographic Catalogue is started
- 1916: Barnard discovers his famous star
- 1926: Schlesinger starts the Yale Zones
- 1947: Wright starts the NPM
- 1950: Luyten starts to survey both hemispheres for high proper motion stars
- 1960: Giclas starts his surveys
- 1965: Brower, Schill and Cesco start the SPM (YSO)
- 1989: ESA launches the Hipparcos satallite
- 2000: Monet announces the USNO B

Summary of the Most Important Astrometric Catalogues

Year	Catalogue	# of Objects
360 BC	Chinese	?
260 BC	Aristillus & Timocharis	850?
129 BC	Hipparchus	850 (1,080?)
150 DC	Ptolemy's Almagest	1,080
1277	Alfonsine Tables	?
1437	Ulugh-Beg	1,018
1594	Rothman & Wilhelm	1,004

Summary of the Most Important Astrometric Catalogues

Year	Catalogue	# of Objects
1601	Tycho Brahe	1,005
1690	Hevelius	1,564
1725	Flamsteed	3,310
1751	Lacaile	9,766
1760	Lalande	50,000
1792	Piazzi	7,646
1847	British Assoc.	47,390

Summary of the Most Important Astrometric Catalogues

Year	Catalogue	# of Objects
1850	Durchmusterung	300,000
1887	Astrographic Catalogue	~4,000,000
1910	PGC	30,000
1926	Yale Zones	~150,000
1937	General Catalogue	33,000
1950	N30	5,000
1966	SAOC	257,997

Summary of the Most Important Astrometric Catalogues

Year	Catalogue	# of Objects
1984	FK5	1,535
1990	GSC 1.0	20,000,000
1992	4 Millions	4,000,000
1993	PPM	350,000
1996	USNO A1.0	488,000,000
1997	Hipparcos	118,218
1997	Tycho – 1	1,058,332

Summary of the Most Important Astrometric Catalogues

Year	Catalogue	# of Objects
1998	USNO A2.0	500,000,000
1998	AC2000	4,000,000
2000	GSC II	1,000,000,000
2000	Tycho – 2	2,500,000
2001	SPM	30,000,000
2002	UCAC	40,000,000
2002	SuperCosmos Sky Survey	1,000,000,000

Summary of the Most Important Astrometric Catalogues

Year	Catalogue	# of Objects
2003	USNO B1.0	1,000,000,000
2017?	Gaia	1,000,000,000
?	Origins Billion Star Survey	1,000,000,000

The Compilation of the Smithsonian Astrophysical Observatory Catalogue (SAO)

Declination Zone	Catalogue / Observatory
+90 a +85	Yale
+85 a +80	AGK2 – Greenwich AC
+80 a +60	AGK2 – AGK1
+60 a +50	Yale
+50 a +30	AGK2 – AGK1
+30 a -30	Yale
-30 a -40	CPC
-40 a -52	Cape Astrographic
-52 a -64	CPC
-64 a -90	Me3 – Me4

The MEGA Catalogues

- **During the past 15 years four astrometric catalogues -with well over a million entries- have been published. They are called MEGA Catalogues:**

Astrometric

- ✓ **Guide Star Catalogue (GSC)**
- ✓ **USNO (A and B series)**
- ✓ **SuperCosmos Sky Survey (SSS)**
- ✓ **UCAC**

Non-Astrometric

- ✓ **2MASS**
- ✓ **DENIS**
- ✓ **SDSS**

Guide Star Catalogue: the pioneer

- **The GSC was constructed as support for the HST.**
- **Over 19 million objects in the 6th to 15th mag. range.**
- **Astrometry is available at the epochs of the individual plates used in the GSC (no proper motions).**
- **Reference stars were slected from AGK3, SAOC, and CPC.**
- **Extensive analysis against the Carlsberg Automatic Meridian Circle data, showed that GSC absolute positional errors from plate center to edge vary from 0.5" to 1.1" in the north and from 1.0" to 1.6" in the south.**
- **Different improvments has yield the following realeses:**

  GSC I (1.0, 1.1, and 1.2)

  GSC II (2.0, 2.1, 2.2, and 2.3)

Comparison GSC 1.0 vs. CAMC (1, 2, and 3)

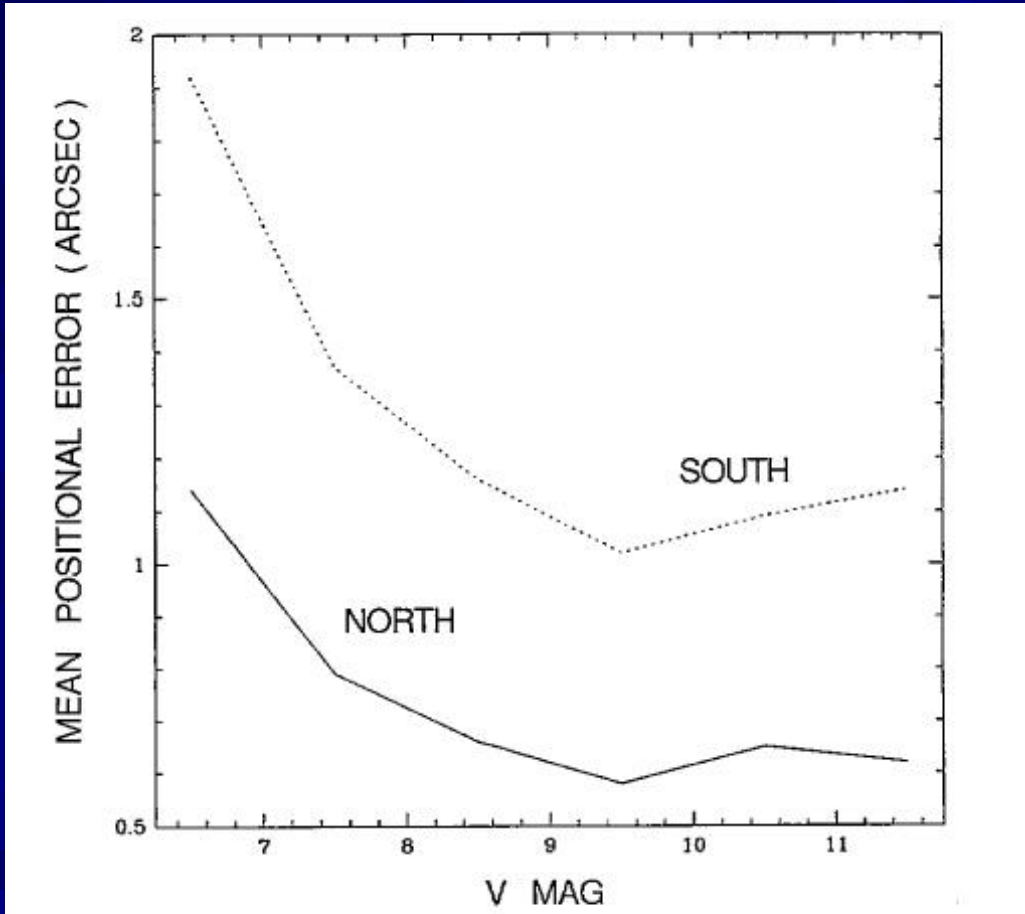
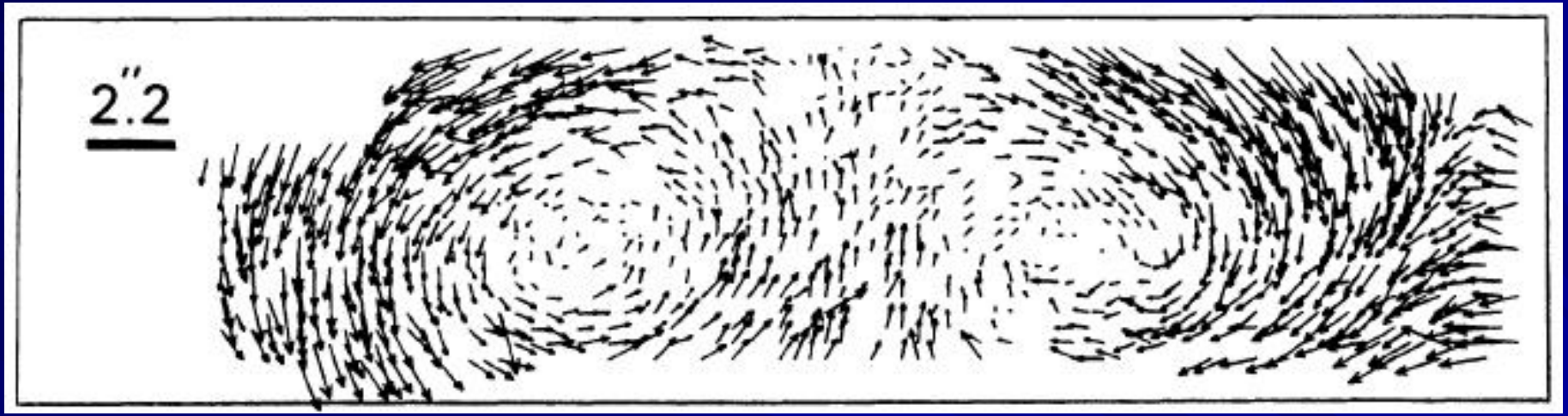


FIG. 3.—Absolute (total) positional error, averaged across a plate vs. CAMC-*V* magnitude.

Taff, L. et al. 1990. ApJ 353, L45 – L48

Properties of the GSC I



Typical astrometric residuals in the overlaping areas of a plate pair (about 6º x 1.5º)

Russel, J. et al., 1990, AJ 99, 2059.

The GSC I:
Mean residuals map

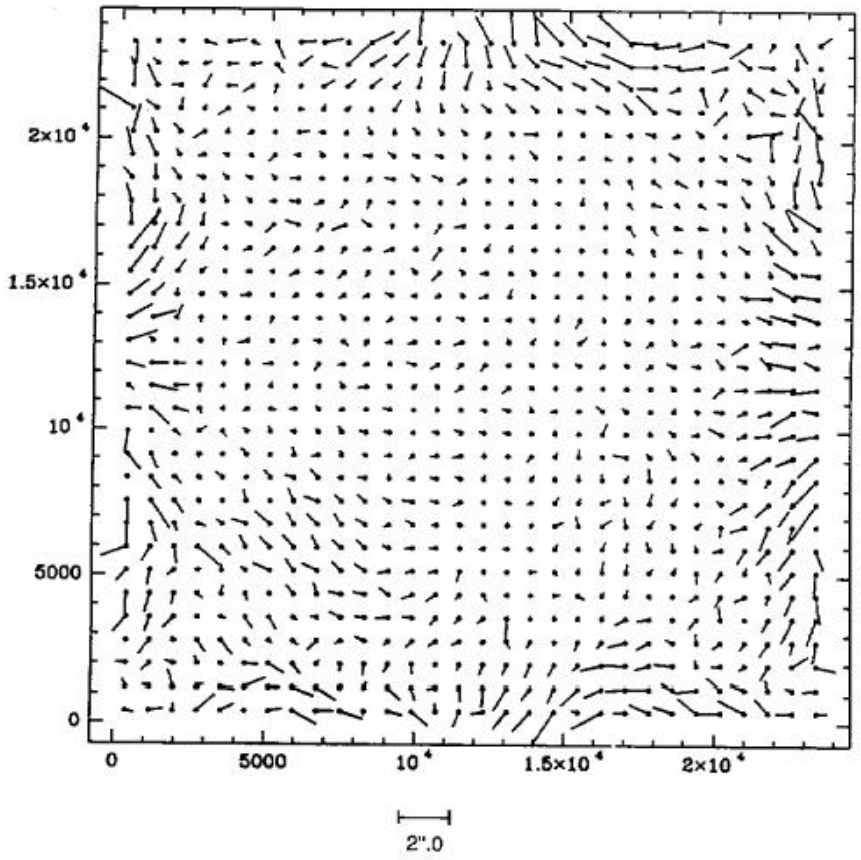


FIG. 2*a*

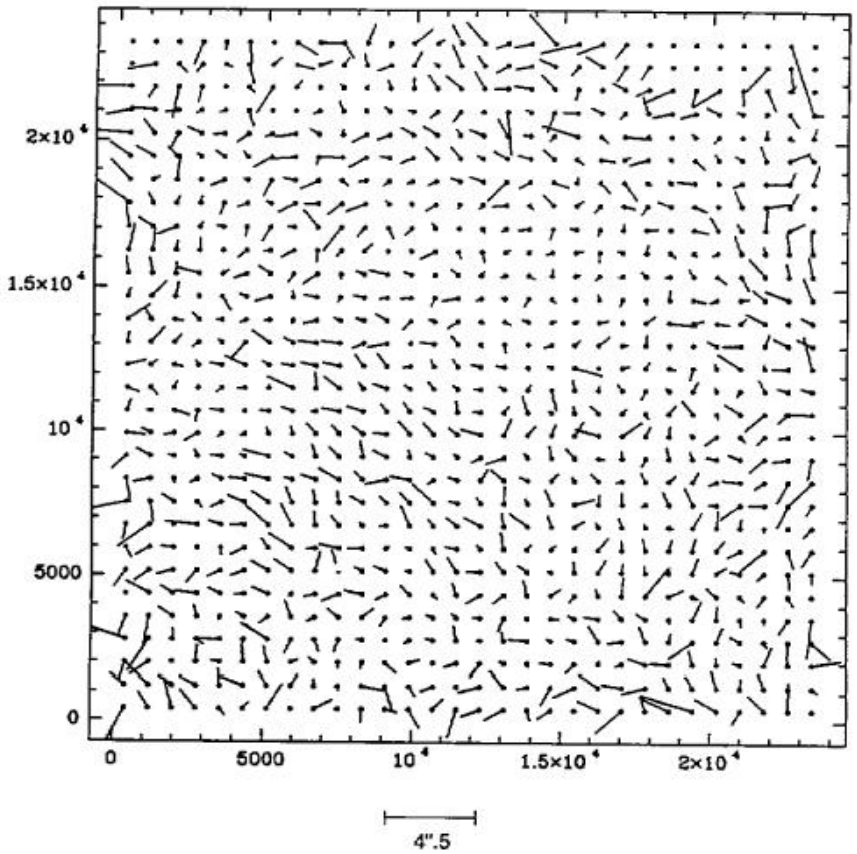


FIG. 2*b*

Comparison GSC 1.0 vs. GSC 1.2

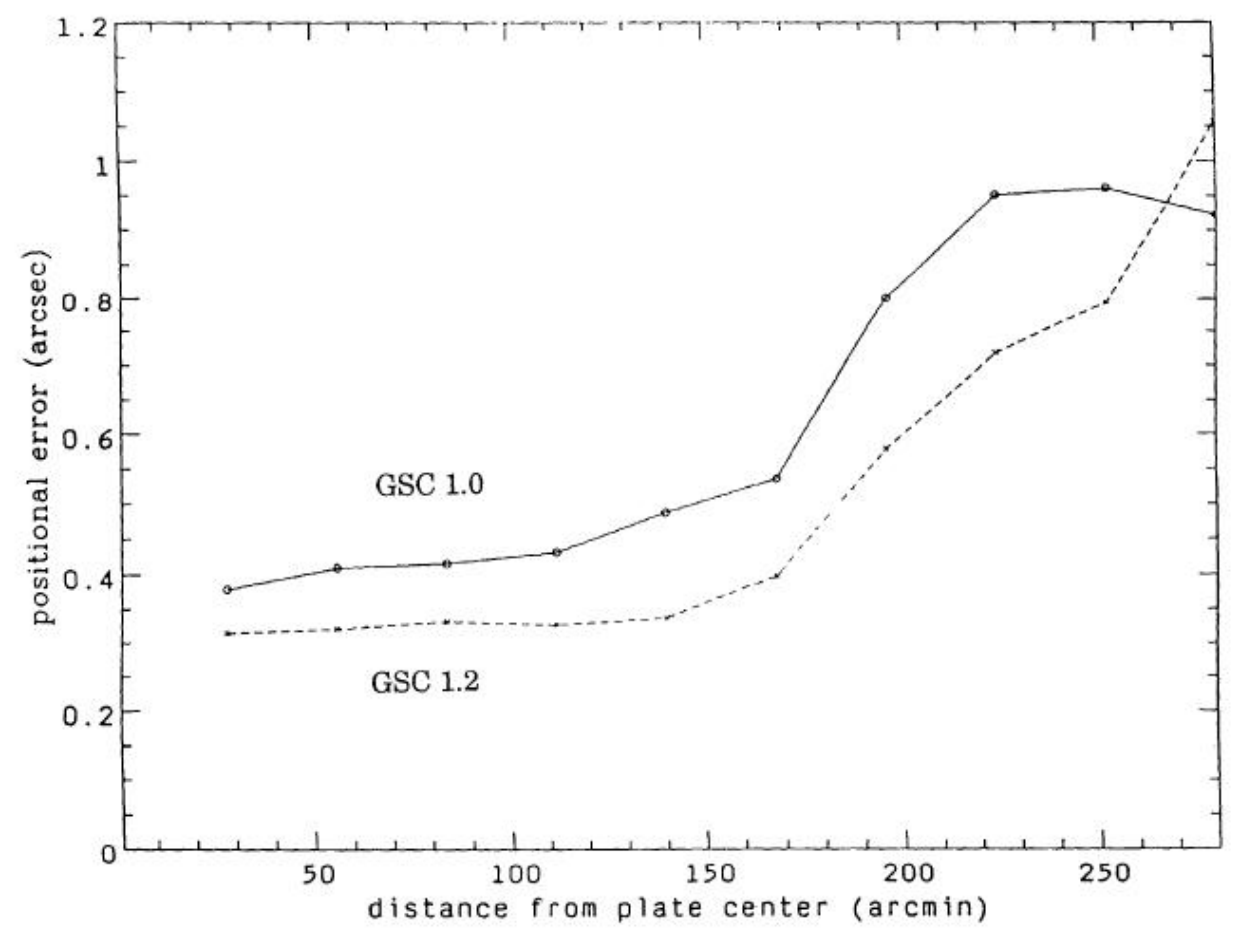


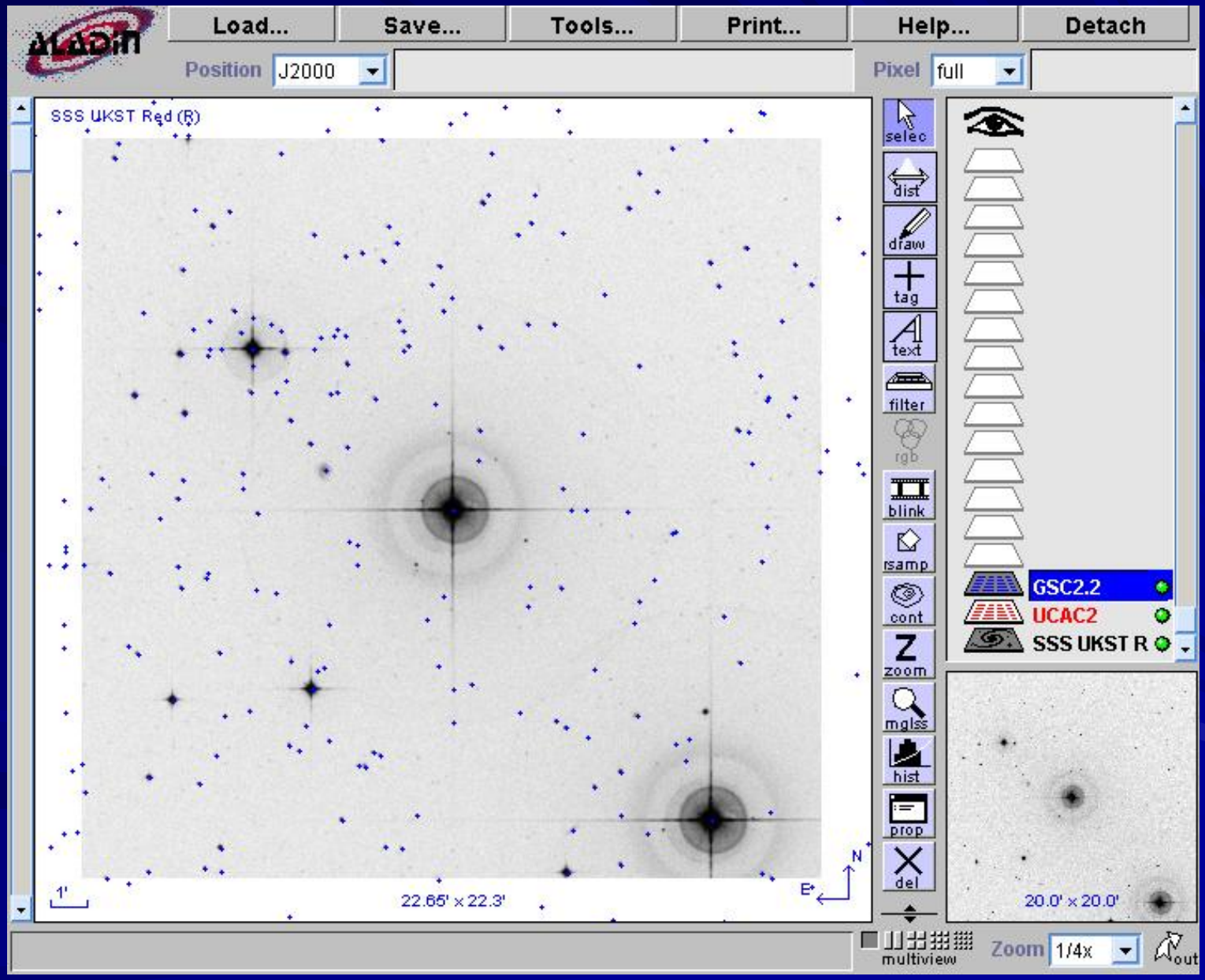
Figure 2. Average positional errors vs. distance from plate center.

Bucciarelli, B., et al. 1994. IAUS 161, 277.

Quick Fact Sheet on GSC 1.1 vs. GSC 2.2

Item	GSC 1.1	GSC 2.2
Total Objects	18,819,291	435,457,355
Mean epoch of catalog positions	1981.8	1992.2
Magnitude limit	15.5	18.5 F, 19.5 J
Complete to magnitude limit	No	Yes
Bandpass: North	V	F and J
Bandpass: South	J	F and J
Digitization resolution	1.7 arcsec	1 arcsec
Source for bright stars	Hipparchos Input Catalog	Tycho 2
Astrometry:		
Reference frame	FK4	ICRF
Reference catalogs	AGK3, SAO: 10^2 calibrators per plate	ACT, Tycho2: 10^3 calibrators per plate
Errors	0.5" - 1.2" errors increase near plate edges	0.3" - 0.75" errors increase near plate edges for F > 16

Zone of Hip 5164 (UKST-R frame) as shown by Aladin and GSC 2.2 detections



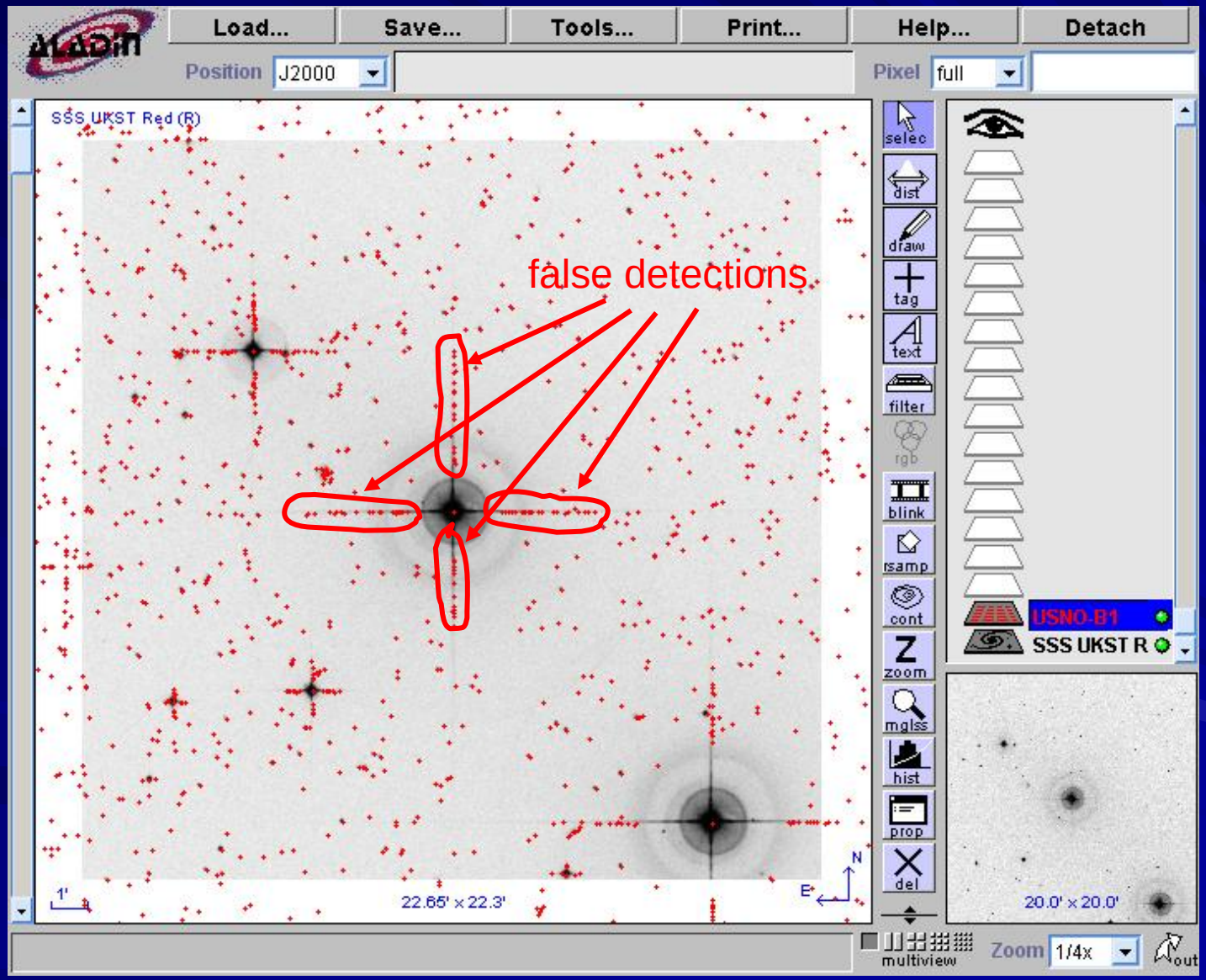
The USNO Series

Release	Number of Objects
USNO A1.0	491,848,883
USNO A2.0	526,280,881
USNO SA2.0	54,787,624
USNO B1.0	1,045,913,669

Summary of the USNO-B1

- Monet, D.; Levine, S.; Canzian, B. et al. 2003 AJ 125, 948
- Number of sources: 1,045,913,669
- Number of observations: 3,643,201,733
- Number of plates: 7,435
- Completeness down to V= 21
- 0.2 arcsec accuracy at J2000
- 0.3 mag accuracy in up to 5 colors

Zone of Hip 5164 (UKST-R frame) as shown by Aladin plus USNO B1.0 detections



The SuperCosmos Sky Survey (SSS) and The SuperCosmos Science Archive (SSA)

- The database contains over 1 billion multi-colour, multi-epoch sources and covers the southern celestial hemisphere ($\delta < +3.0$) in three passbands (BRI), with one colour (R) represented at two epochs.
- All SSA global astrometry is tied to the Hipparcos-Tycho reference frame via the Tycho-2 and ACT catalogues.
- Astrometry is globally good between 0.2 and 0.3 arcsec.
- New proper motions (with respect to the ones in SSS) have been computed using all available positions. Up to four different epochs have been used.
- The SSS and SSA are based on the same underlying data with the main differences arising in the construction of the SSA merged source table.

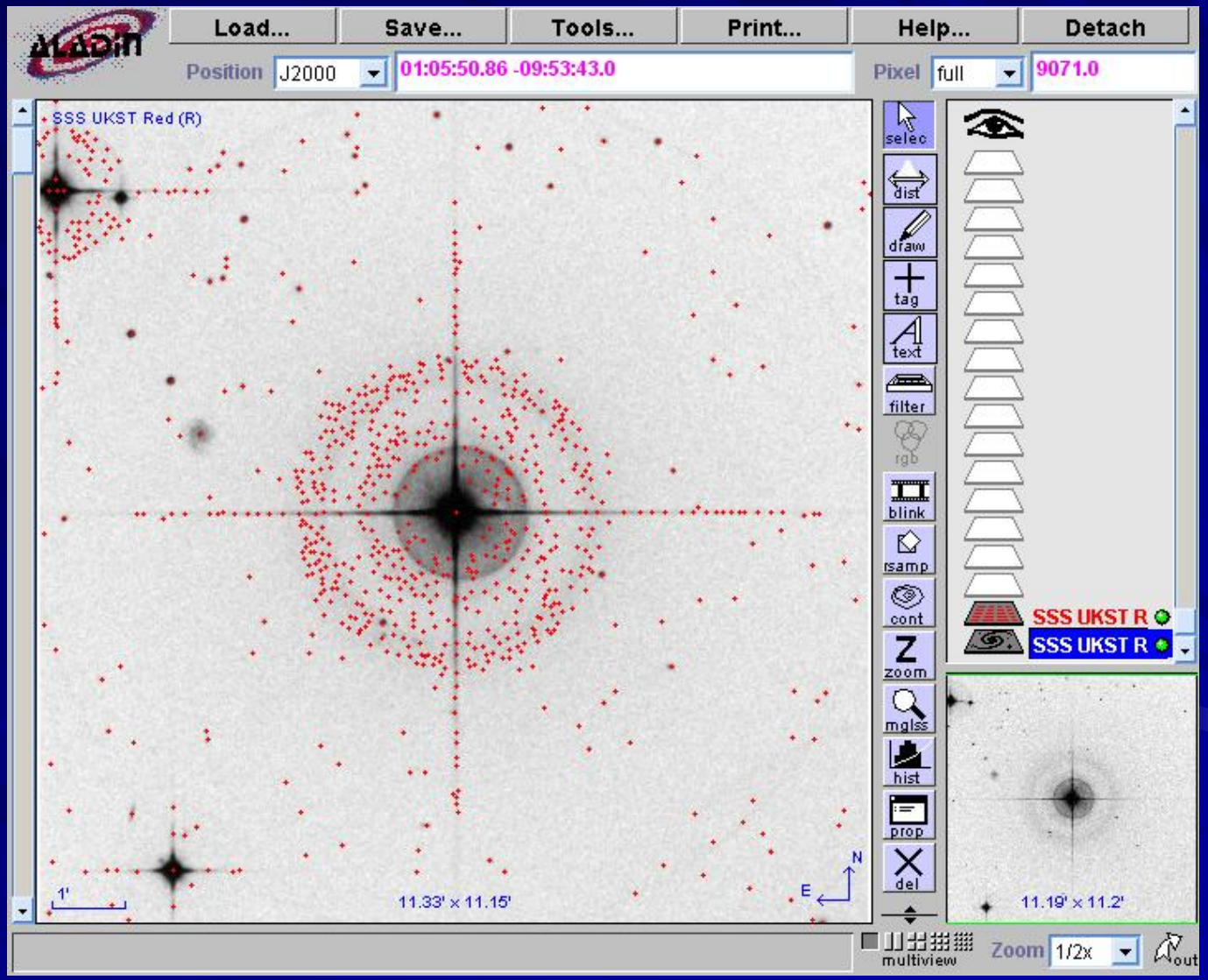
SuperCOSMOS Sky Survey

Plate Material

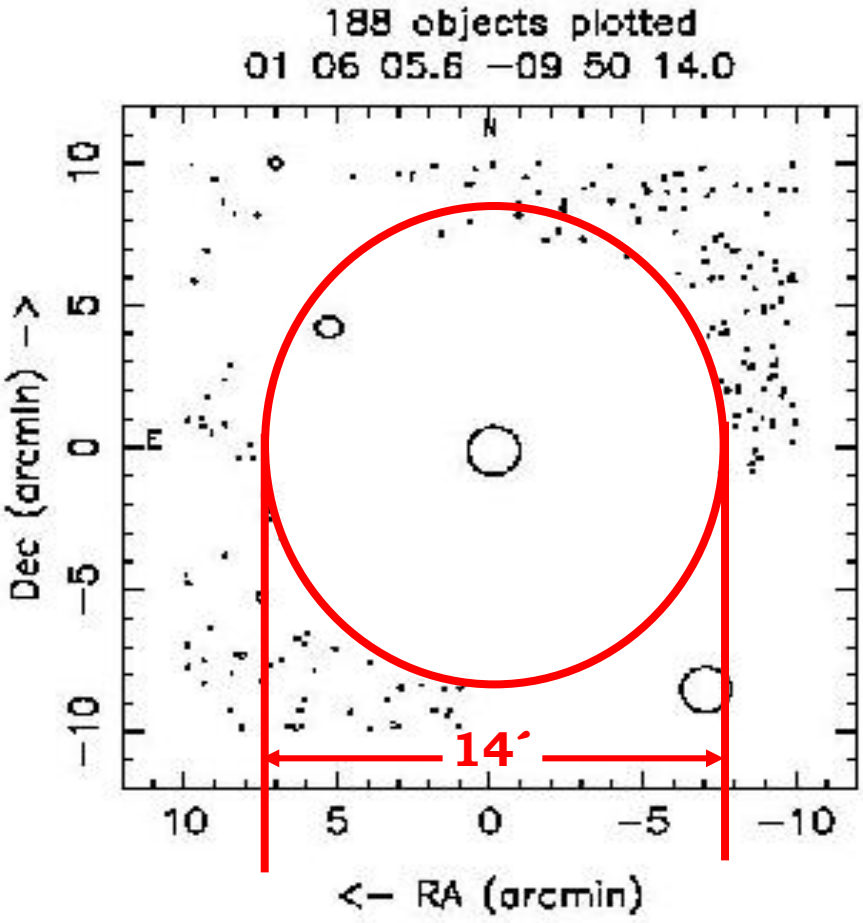
Survey	Dec centres	Plate limit	Dates of observation	Reference
Southern hemisphere survey:				
SERC–J/EJ[1]	$\delta \leq 0^\circ$	$B_J \sim 23$	1974 to 1994	Cannon (1984)
SERC–ER/AAO–R[2]	$\delta \leq 0^\circ$	$R \sim 22$	1984 to 2000	Cannon (1984); Morgan et al. (1992)
SERC–I	$\delta \leq 0^\circ$	$I \sim 19$	1978 $\longrightarrow$	Hartley & Dawe (1981)
ESO–R[3]	$\delta \leq -20^\circ$	$R \sim 22$	1978 to 1990	West (1984)
POSS–I E[3]	$-18^\circ \leq \delta \leq 0^\circ$	$R \sim 20$	1949 to 1958	Minkowski & Abell (1963)
Putative northern hemisphere survey:				
POSS–II B[3]	$\delta \geq 0^\circ$	$B_J \sim 22.5$	1987 to 1999	Reid et al. (1991)
POSS–II R[3]	$\delta \geq 0^\circ$	$R \sim 20.8$	1987 to 1999	Reid et al. (1991)
POSS–II I[4]	$\delta \geq 0^\circ$	$I \sim 19.5$	1989 $\longrightarrow$	Reid et al. (1991)
POSS–I E[3]	$\delta \geq 0^\circ$	$R \sim 20$	1949 to 1958	Minkowski & Abell (1963)

Notes:
[1]Original glass survey plates scanned with the exception of the following 6 fields: 31, 102, 167, 330, 555, 575 (replacement glass originals).
[2]Original glass survey plates scanned with the exception of the following 32 field numbers: 52, 54, 111, 114, 119, 244, 296, 298, 355, 412, 413, 472, 473, 476, 483, 540, 541, 549, 550, 611, 619, 632, 679, 686, 691, 758, 760, 765, 828, 831, 837, 838 (film originals).
[3]Glass atlas copies of survey glass originals.
[4]Film atlas copies of survey glass originals.

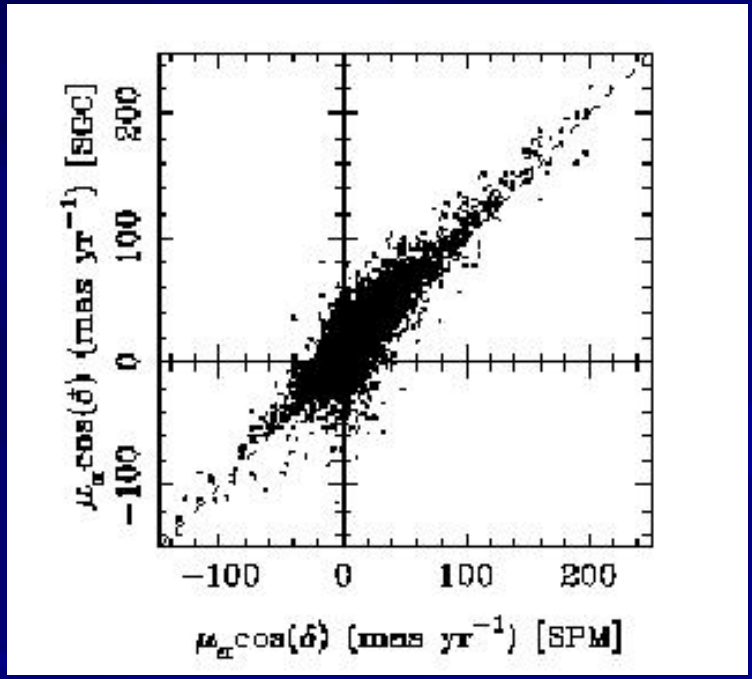
SSS Detections (as shown by Aladin) around Hip 5164



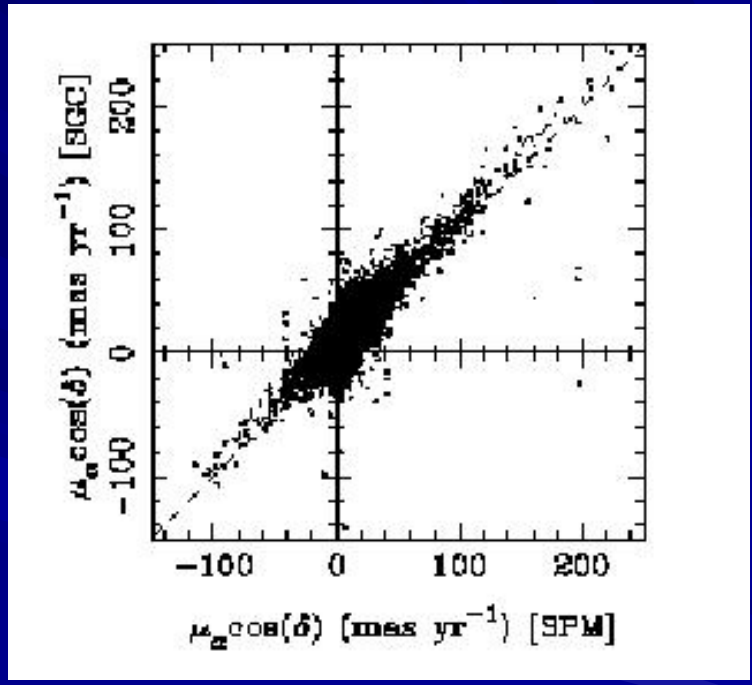
SSS Chart around Hip 5164



The SuperCosmos Sky Survey: Proper Motion Comparison with the SPM



10.0<V<14.0



14.0<V<16.0

Hambly, N. C. et al. 2001. MNRAS 326, 1315.

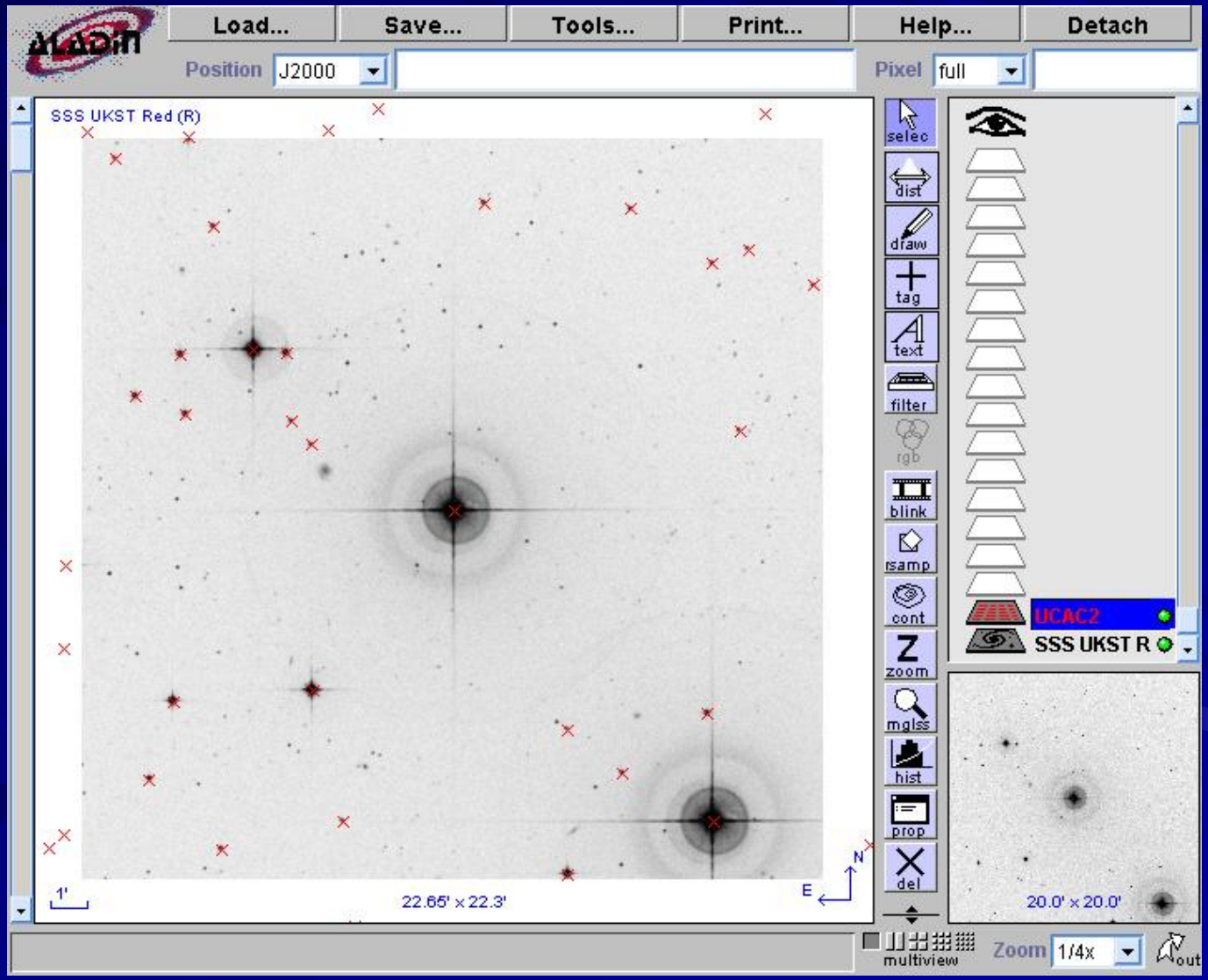
The UCAC Project

- **UCAC project goals**
  - ✓ **densification of the reference frame beyond Hipparcos/Tycho**
  - ✓ **improve accuracy of positions of faint end Tycho-2 stars**
  - ✓ **improve link between Hipparcos and the International Celestial Reference Frame**

The UCAC2

- Positions and proper motions for over 48 million sources (mostly stars).
- Precision on the positions is 15-70 mas (depending on magnitude).
- Proper motions are derived by using over 140 ground- and space-based catalogues. With errors about 1-3 mas yr^{-1} for stars to 12th mag., and about 4-7 mas yr^{-1} for fainter stars to 16th mag.
- Current epoch positions are obtained from observations with the USNO 8-inch Twin Astrograph equipped with a 4k CCD.
- The catalogue covers from -90º up to +48º (to +52º in some areas) and supersedes UCAC1 released in 2001.

UCAC2 Detections (as shown by Aladin) around Hip 5164



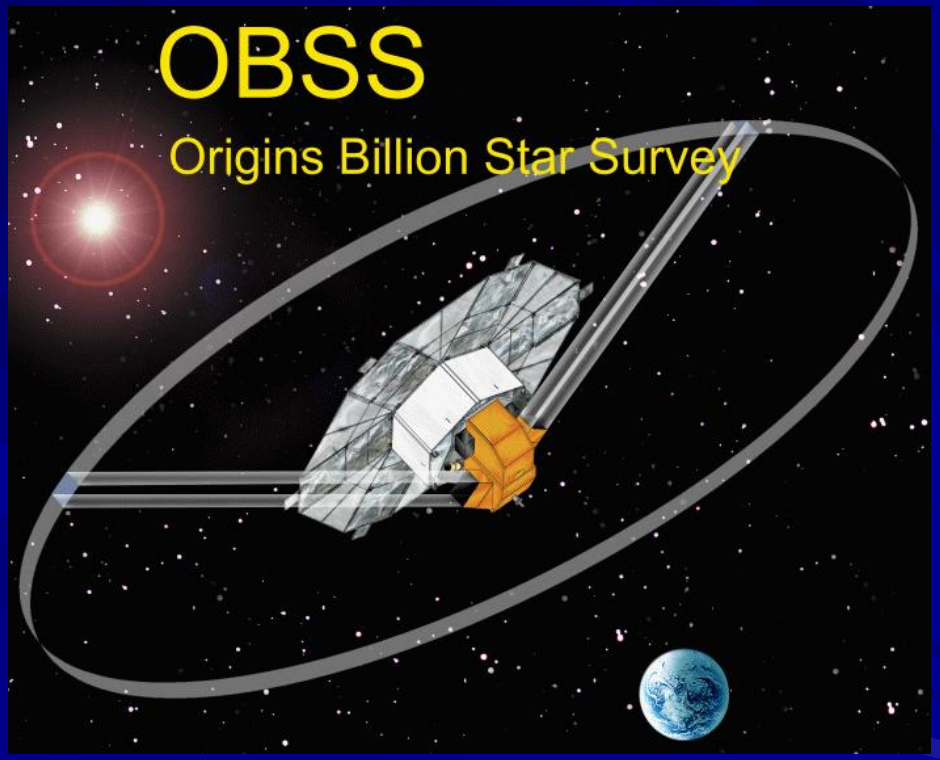
NOMAD

(Naval Observatory Merged Astrometric Database)

- **Astrometric and photometric data for over 1 billion stars.**
- **Source catalogues (for astrometry and optical photometry): Hipparcos, Tycho-2, UCAC2, and USNO-B.**
- **Photometry supplemented by 2MASS.**
- **NOMAD is not a compiled catalogue; that is, if a given star is presented in more than one of the above mentioned catalogues, only one catalogue entry is chosen.**
- **All source catalogues astrometric data are on the ICRF.**
- **100 GB of data.**

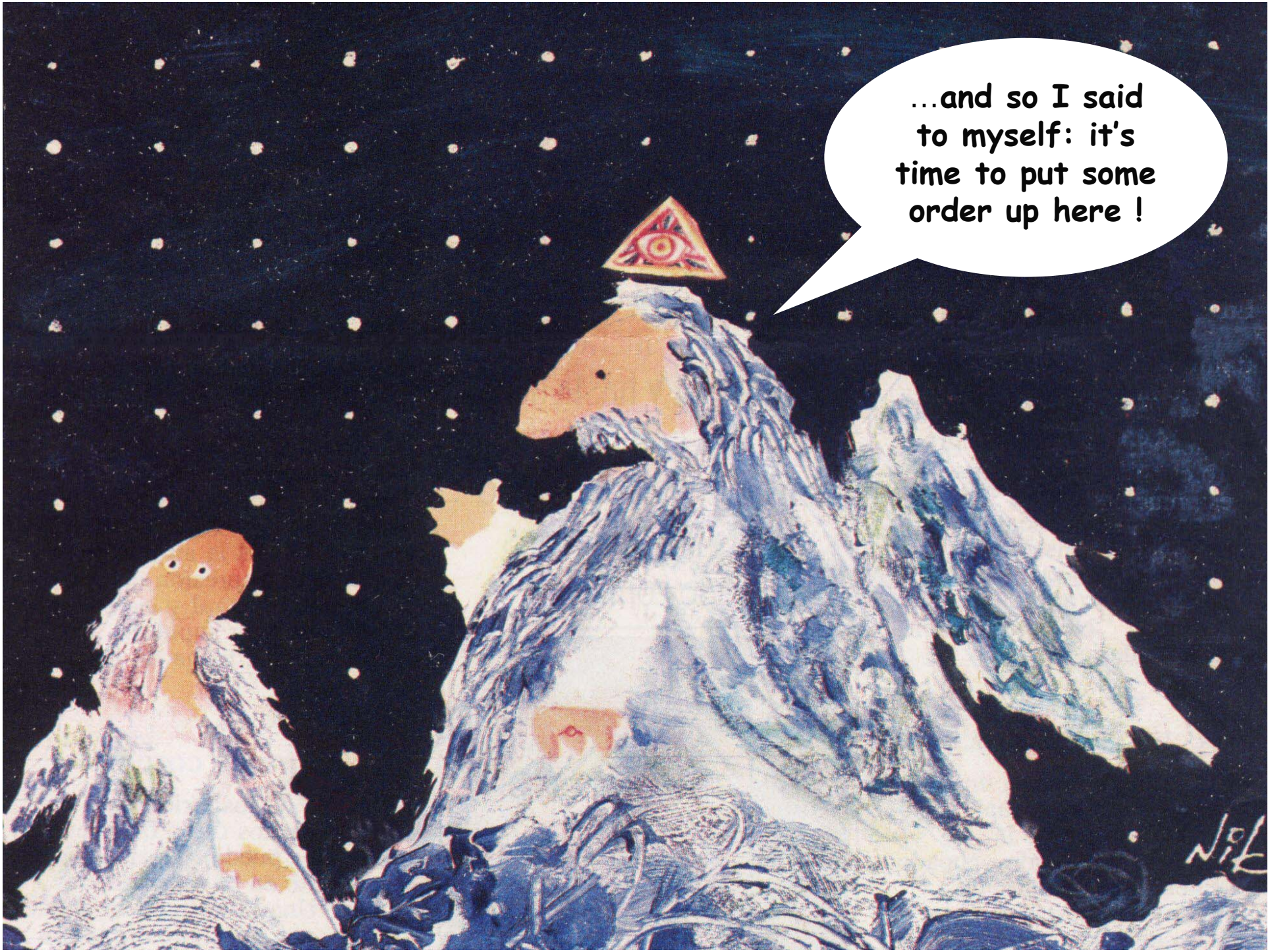
Zacharias, N., et al. 2004b. AAS 205, 4815.

The Next Two (Last?) Steps



“If the Almighty had consulted me before he embarked on creation, I should have recommended something simpler”

Alfonso the Wise


...and so I said to myself: it's time to put some order up here !
NIL