Study of common proper motion visual double stars - The CPDS catalogue

Panagiotis Gavras

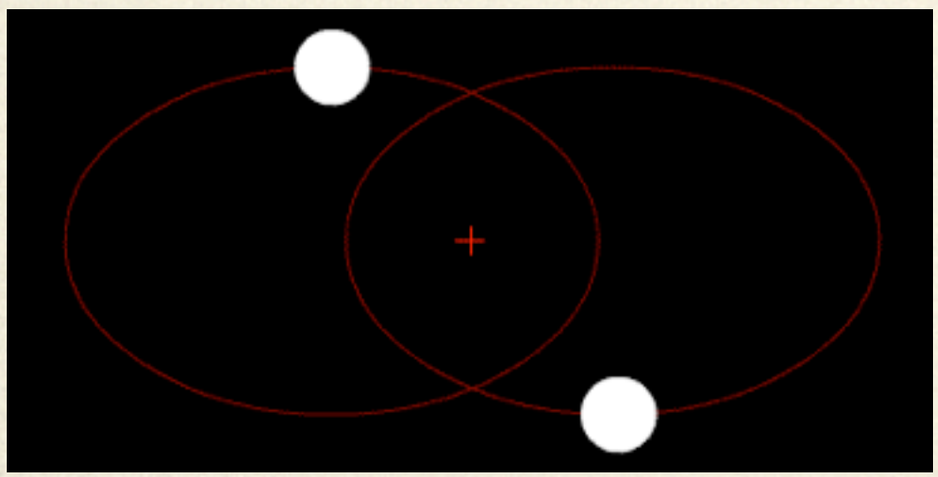
Study of common proper motion visual double stars- The CPMDS catalogue

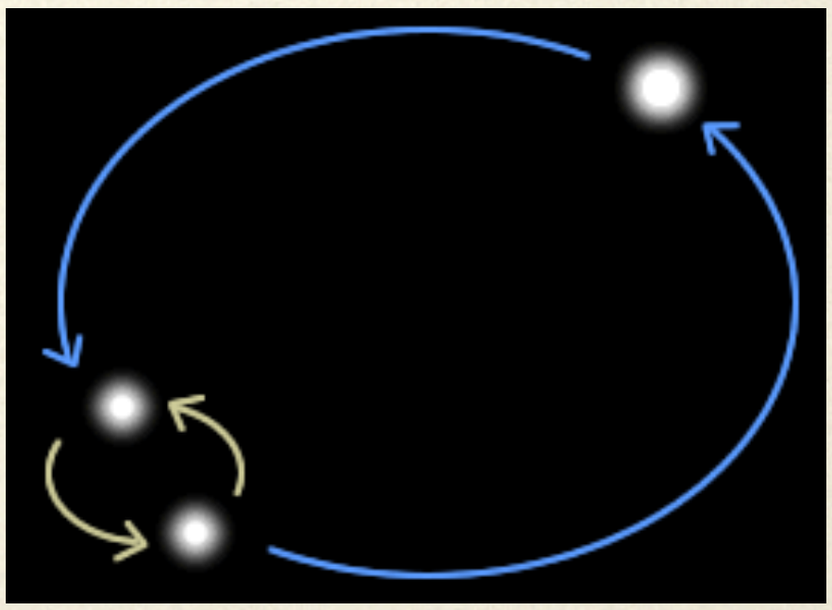
- Introduction - Definition of binary stars
- Types of double stars
- Double stars with common proper motion
- The CPMDS catalogue
- Known WDS double stars in PM2000
- Conclusions

Introduction - Definition of binaries

- Two or more stars held, by their mutual gravity attraction, in a long-term (usually lifelong) association are termed a double stars

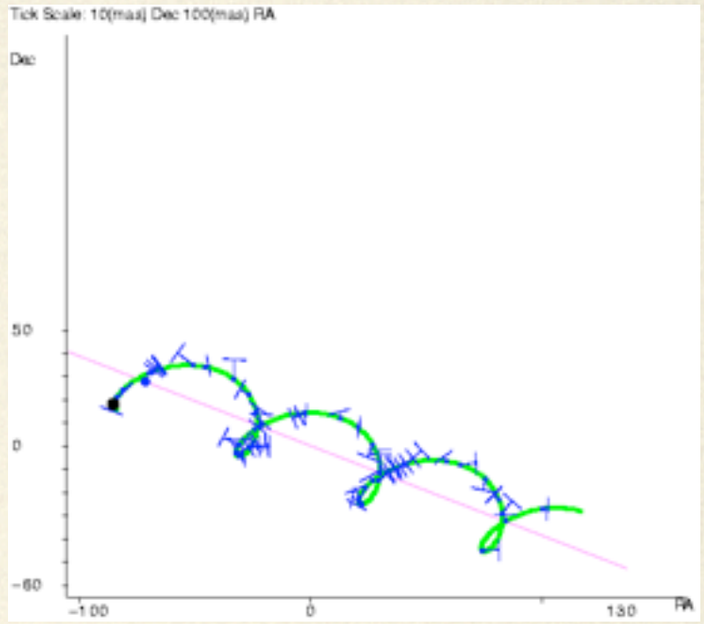
(Heintz W.D)





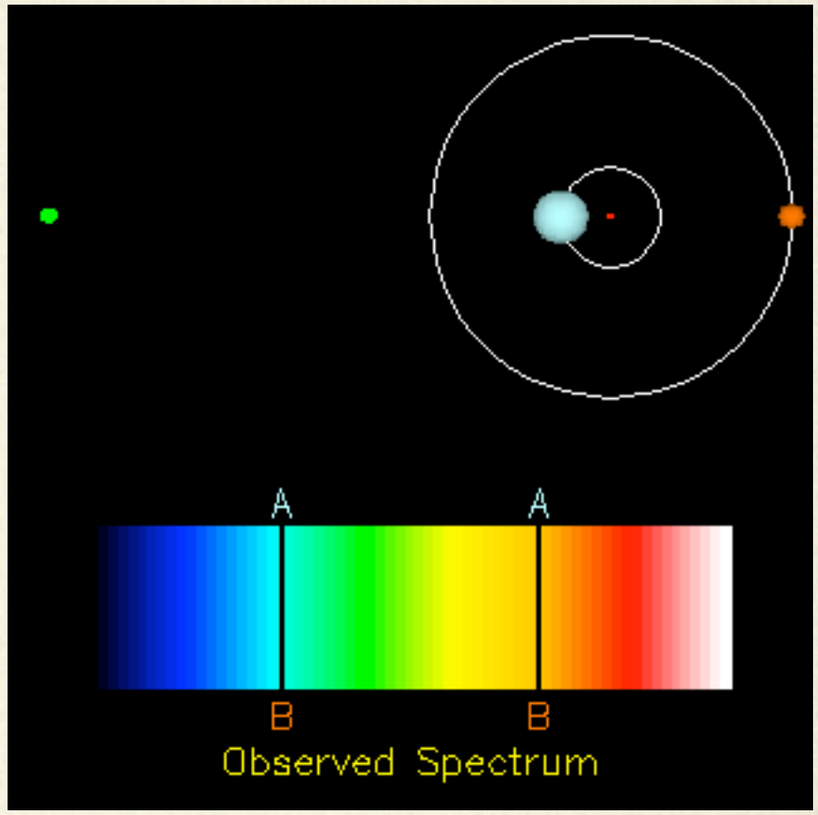
Types of binary stars

- Astrometric binaries



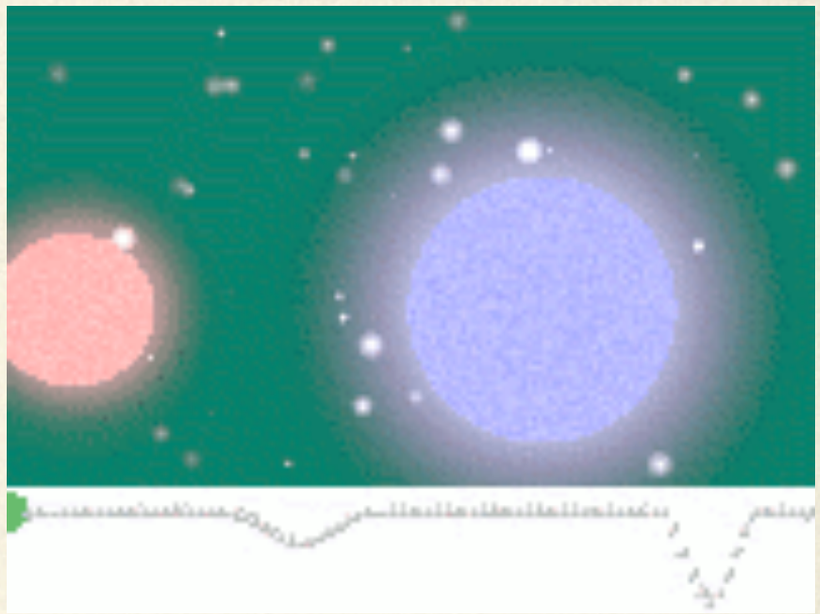
Types of binary stars

- Astrometric binaries
- Spectroscopic binaries



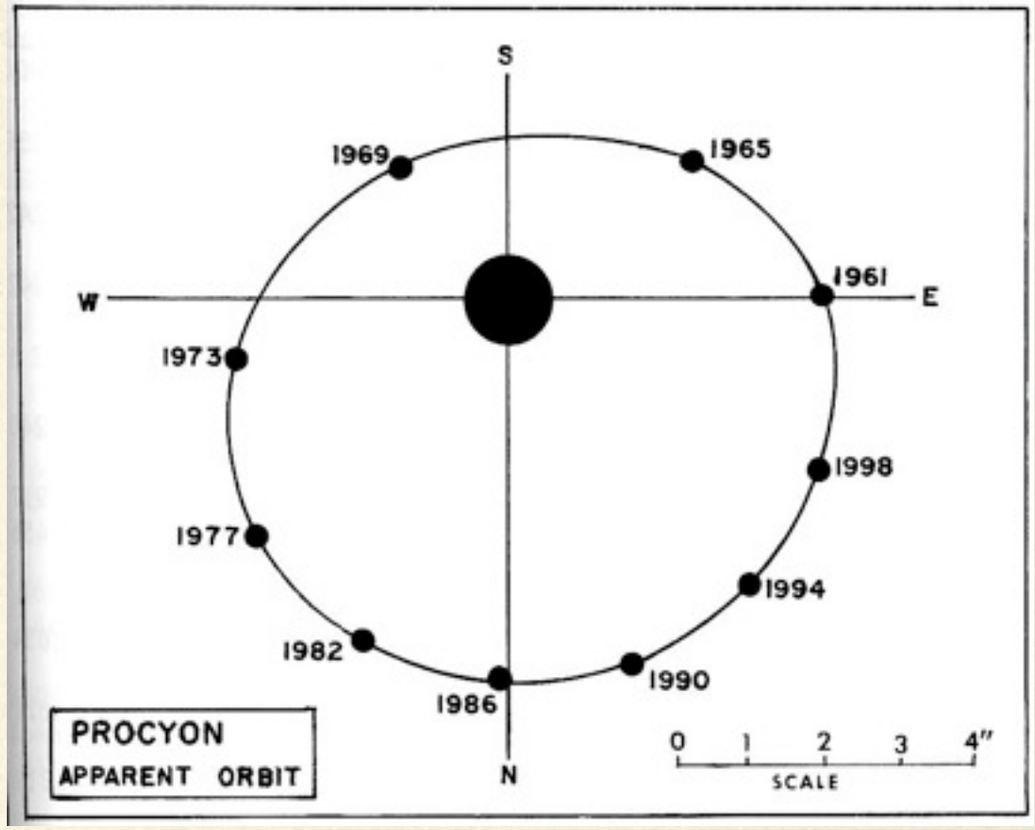
Types of binary stars

- Astrometric binaries
- Spectroscopic binaries
- Eclipsing binaries



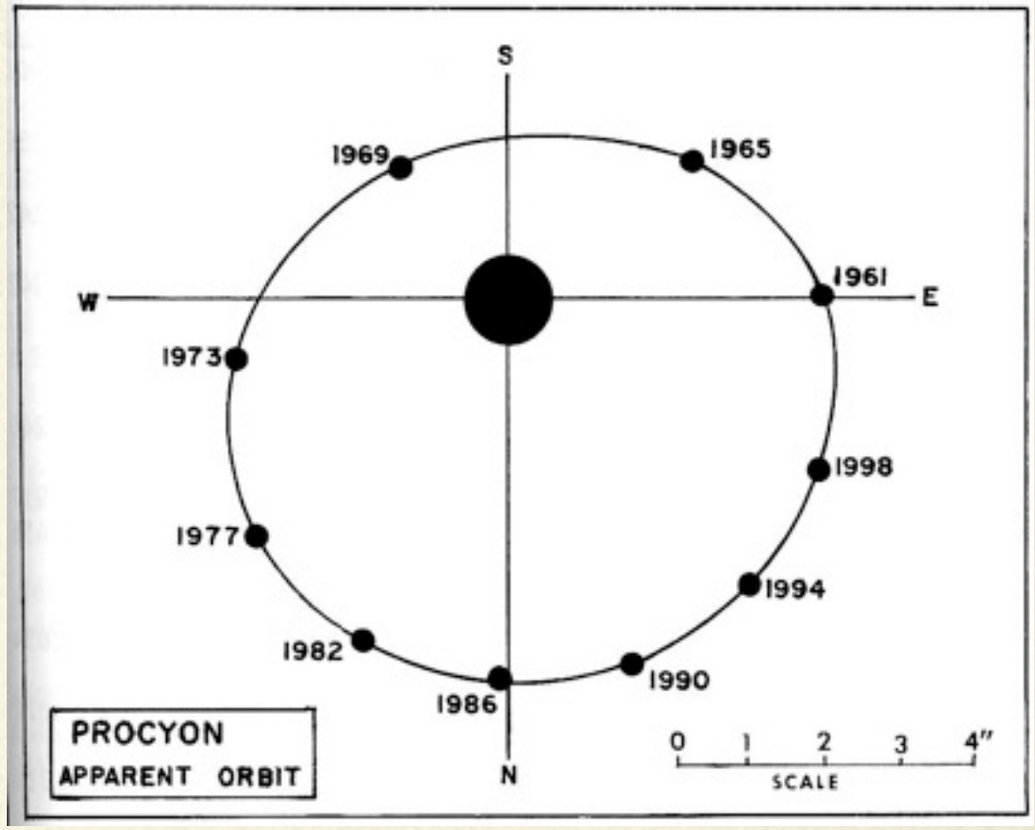
Types of binary stars

- Astrometric binaries
- Spectroscopic binaries
- Eclipsing binaries
- Visual binaries



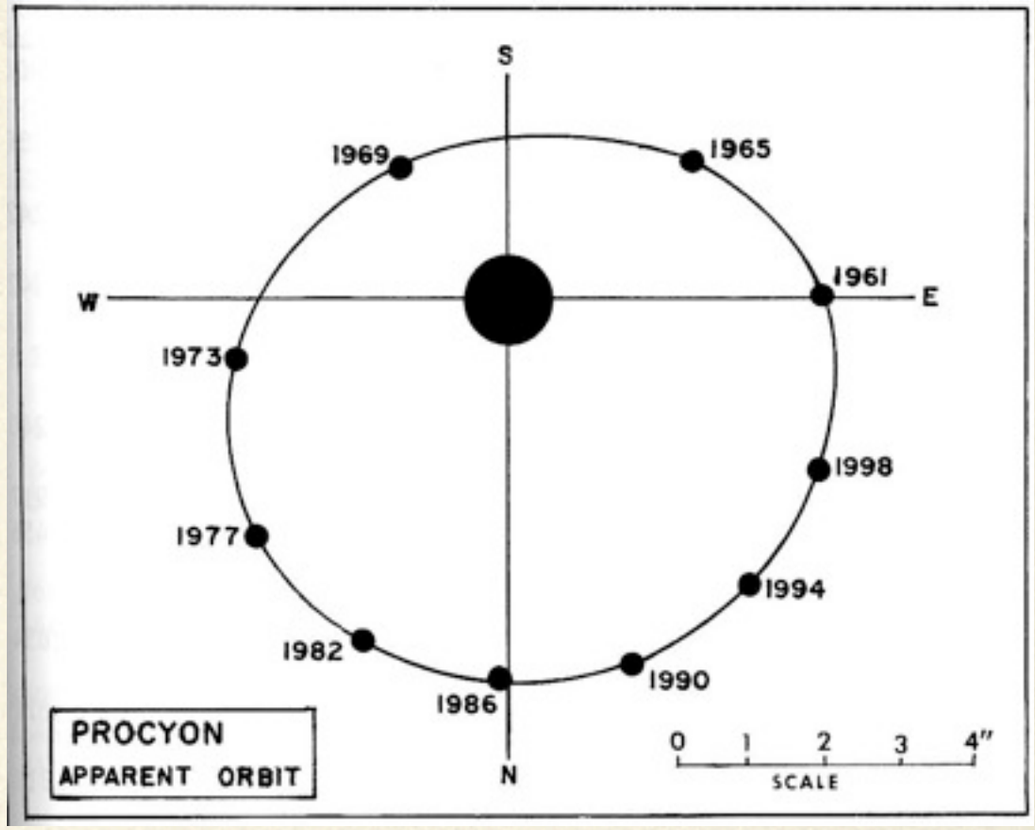
Types of binary stars

- Astrometric binaries
- Spectroscopic binaries
- Eclipsing binaries
- Visual binaries
  - Common proper motion double stars



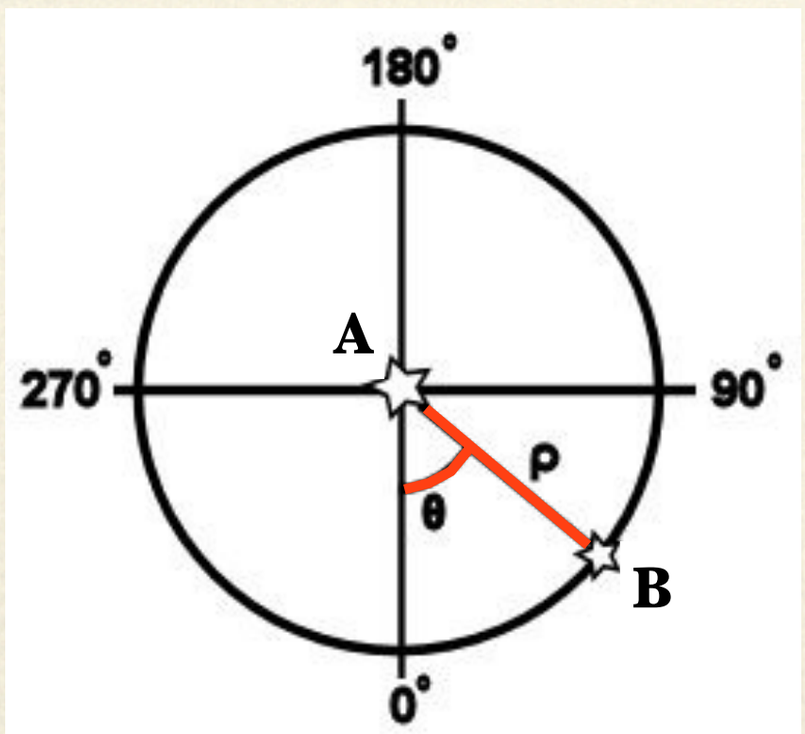
Types of binary stars

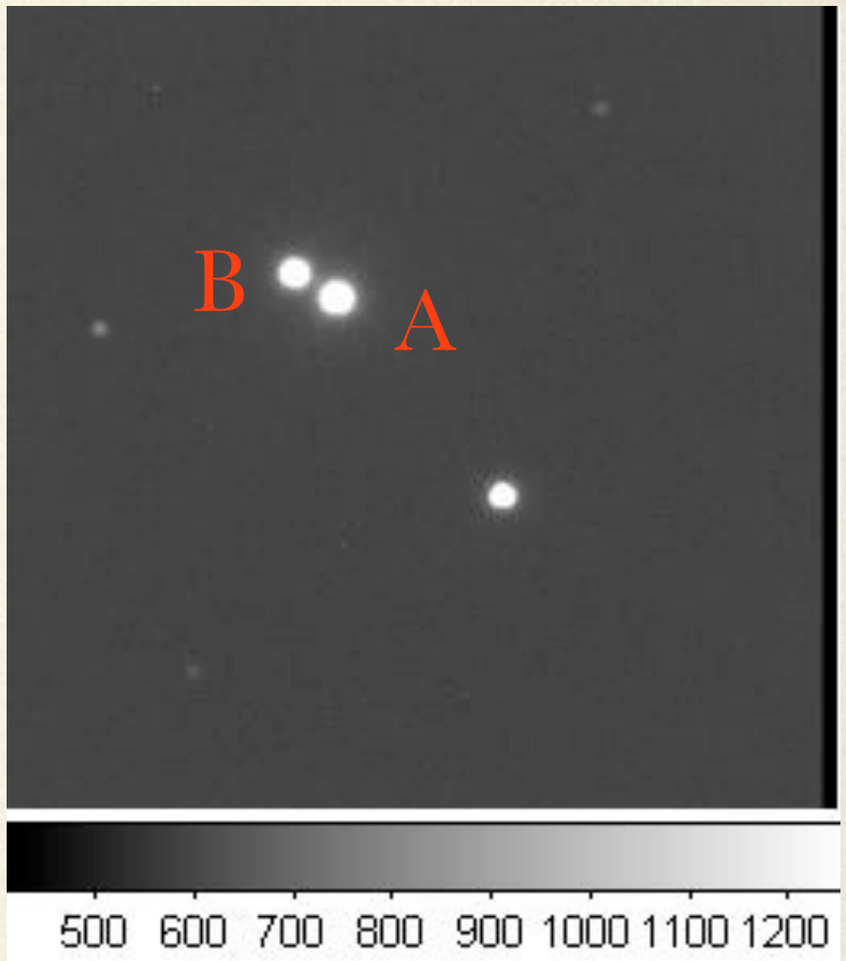
- Astrometric binaries
- Spectroscopic binaries
- Eclipsing binaries
- Visual binaries
  - Common proper motion double stars
- ⚠ Optical pairs



Typical exposure of a visual double star

- WDS15210+2022
  - Primary (A) 9,6mag
  - Secondary (B) 10,0mag





Common Proper Motion Double Stars*
Introduction

- Aim of this work:
  - Discover new CPM double stars
  - Study the nature of such pairs

* Hereafter CPM

Common Proper Motion Double Stars

Introduction

- First Report:
  - S.W. Burnham, "General Catalogue of 1290 double stars discovered from 1871 to 1899" (1900).
  - He notes that 360 double stars have common proper motion
  - He names them 61 Cygni

Common Proper Motion Double Stars

Introduction

- First report that the CPM double stars have physical connection: W.J. Lyuten
  - 1927, Sixteen double stars with large proper motions

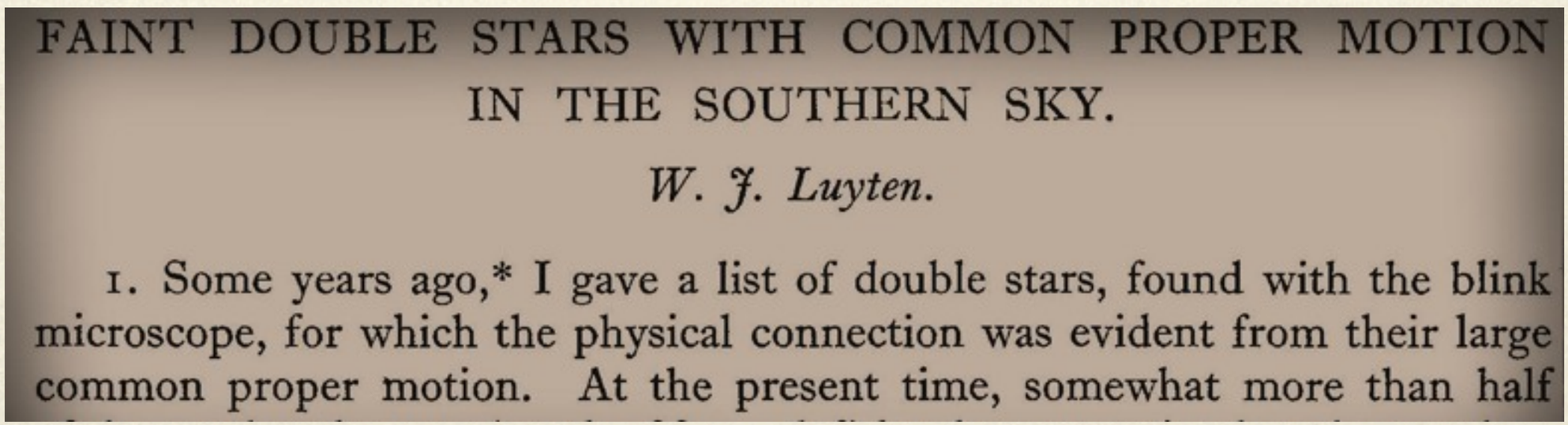
Sixteen Double Stars With Large Proper Motion. — In the table below are given the data for sixteen double stars found with the blink microscope to have common proper motion. It is believed that most of them actually belong together physically. Pair No. 4 was found by Miss M. Alberta Hawes, at the Vassar College Observatory. Miss Constance D. Boyd and Mr. Leland E. Cunningham participated in the measurements.

W. J. Luyten

Common Proper Motion Double Stars

Introduction

- First report that the CPM double stars have physical connection: W.J. Lyuten
  - 1927, Sixteen double stars with large proper motions
  - 1933, Faint double stars with common proper motion in the Southern sky



FAINT DOUBLE STARS WITH COMMON PROPER MOTION IN THE SOUTHERN SKY.

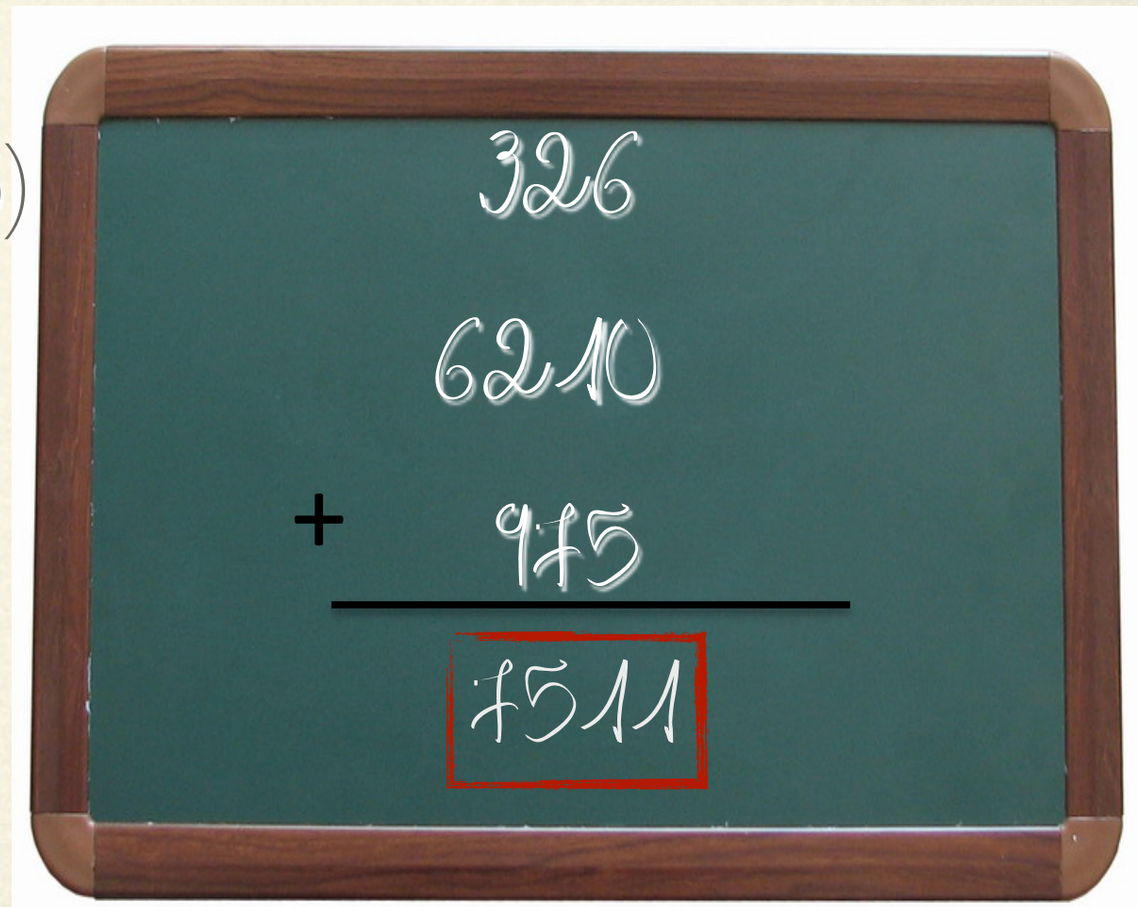
W. J. Luyten.

1. Some years ago,* I gave a list of double stars, found with the blink microscope, for which the physical connection was evident from their large common proper motion. At the present time, somewhat more than half

Common Proper Motion Double Stars

Introduction

- J.L. Halbwachs (1986)
- W.J. Luyten (1997)
- J. Greaves (2004)



Common Proper Motion Double Stars
Introduction

- In Vizier one may find dozens of astrometric surveys e.g.:
  - UCAC3: 100.765.502 stars
  - PPMX: 18.088.919 stars
  - PM2000: 2.670.974 stars

Common Proper Motion Double Stars

The PM2000 catalogue

- Purpose: The creation of a catalogue with accurate measurements of positions and proper motions for stars up to V_M=16,2
- Contains 2.670.974 stars
- In the Bordeaux Carte du Ciel zone ($+11^o \leq \delta \leq +18^o$)
- For the calculations of the proper motions uses data from 5 different catalogs

Common Proper Motion Double Stars

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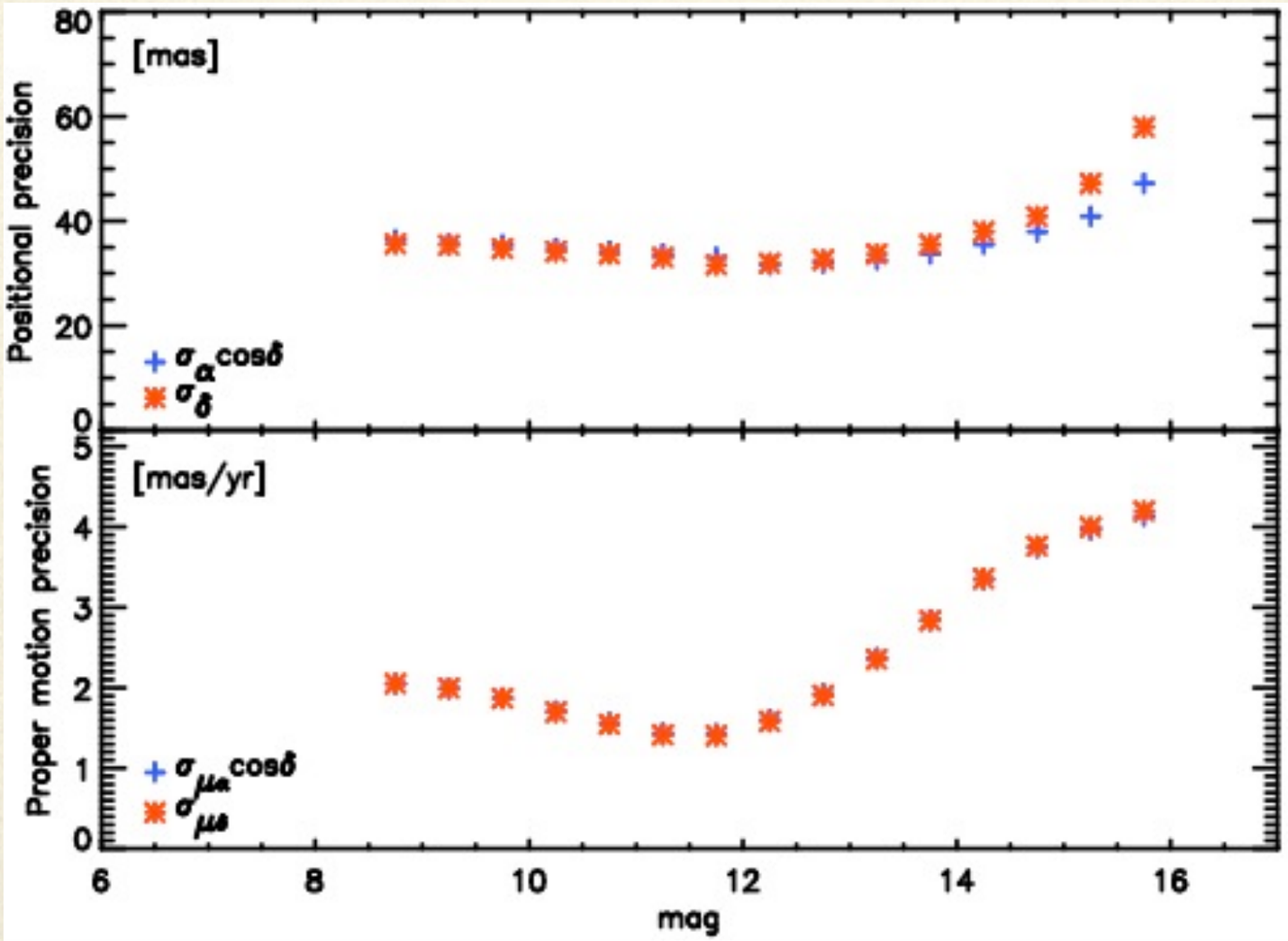
- For the calculations of the proper motions uses data from 5 different catalogs
  - AC2000.2 (~1900), CDC2000 (~1900), USNO-A2.0 (~1950), YS3.0 (~1978), M2000 (~2000)

Common Proper Motion Double Stars

The PM2000 catalogue

- The astrometric accuracy of PM2000 is comparable with this of Hipparcos
- BUT it contains data for fainter stars



Ducourant et al. (2006)

Common Proper Motion Double Stars

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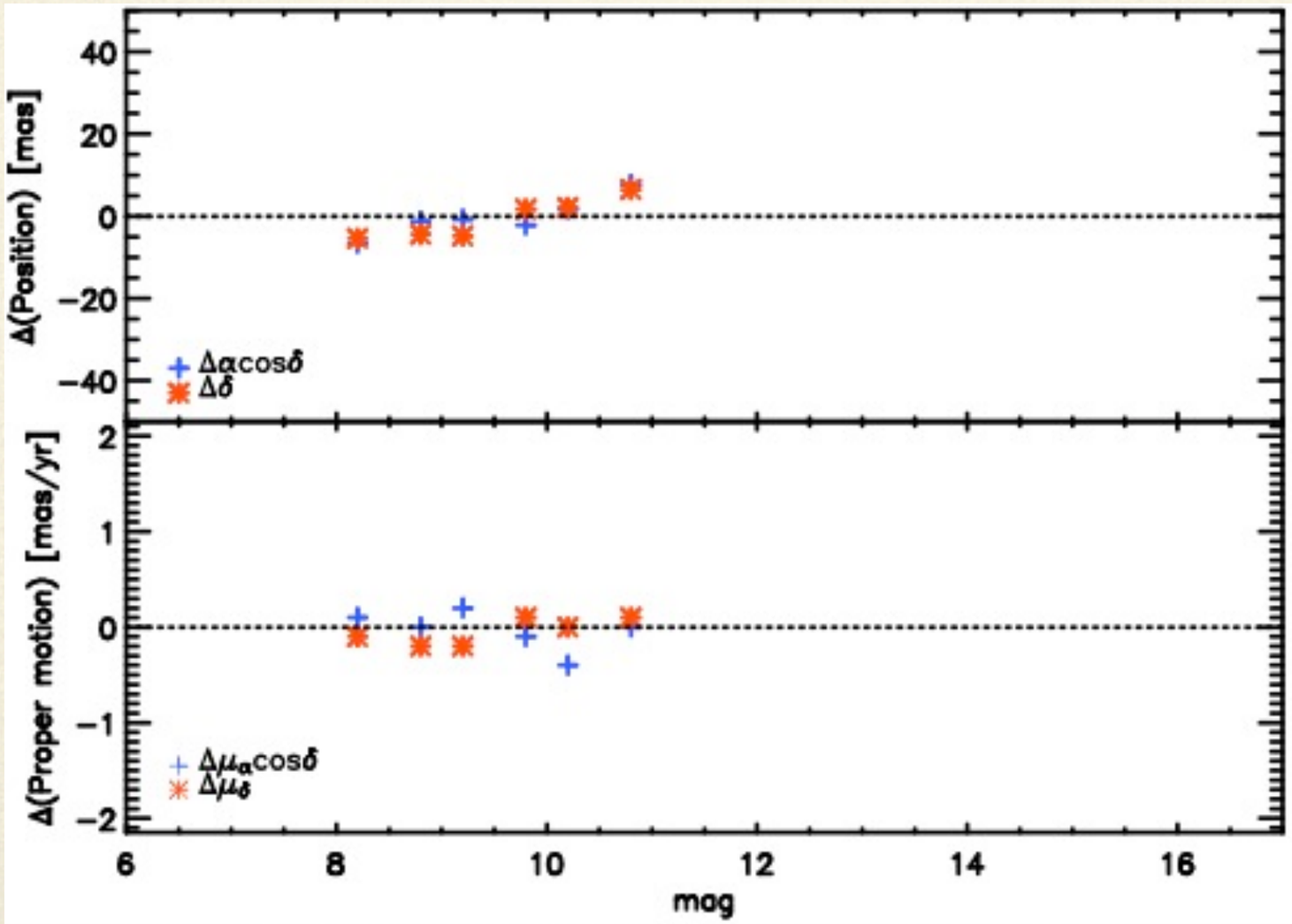


Ducourant et al. (2006)

Common Proper Motion Double Stars
Data Reduction

- Initial sample: 2.670.294 stars
- We selected only the stars with:
  - $\mu > 3\sigma_\mu$ and $\mu \neq 0$ (α,δ)
  - more than 3 observations
- Sample: 414.224 stars

Common Proper Motion Double Stars
Data Reduction

- We created candidate CPM pairs with "neighboring" stars of our sample with $\varrho \leq 2'$
- We checked for double entries
- Final sample: 213.215 CPM candidates

Common Proper Motion Double Stars
Hypothesis testing

- Primary star $\mu_{1\alpha}\cos\delta$ (hereafter $\mu^*_{1\alpha}$), $\mu_{1\delta}$,$S^*_{1\alpha}$, $S_{1\delta}$,$n_{1\alpha}$, $n_{1\delta}$
- Secondary star $\mu_{2\alpha}\cos\delta$ (hereafter $\mu^*_{2\alpha}$), $\mu_{2\delta}$,$S^*_{2\alpha}$, $S_{2\delta}$,$n_{2\alpha}$, $n_{1\delta}$
- Check whether the proper motions of these two stars are equal at 0,05 level of significance

Common Proper Motion Double Stars

Hypothesis testing

Null hypotheses

AND

$$H_{0\alpha} : \mu^*_{1\alpha} = \mu^*_{2\alpha}$$

$$H_{0\delta} : \mu_{1\delta} = \mu_{2\delta}$$

Alternative hypotheses

$$H_{1\alpha} : \mu^*_{1\alpha} \neq \mu^*_{2\alpha}$$

$$H_{1\delta} : \mu_{1\delta} \neq \mu_{2\delta}$$

$$Z_\alpha = \frac{\mu^*_{1\alpha} - \mu^*_{2\alpha}}{\sigma_\alpha \sqrt{\frac{1}{n_{1\alpha}} + \frac{1}{n_{2\alpha}}}} \qquad \sigma_\alpha = \sqrt{\frac{(n_{1\alpha}-1){S^*_{1\alpha}}^2 + (n_{2\alpha}-1){S^*_{2\alpha}}^2}{n_{1\alpha}+n_{2\alpha}-2}}$$

$$Z_\delta = \frac{\mu_{1\delta} - \mu_{2\delta}}{\sigma_\delta \sqrt{\frac{1}{n_{1\delta}} + \frac{1}{n_{2\delta}}}} \qquad \sigma_\delta = \sqrt{\frac{(n_{1\delta}-1){S_{1\delta}}^2 + (n_{2\delta}-1){S_{2\delta}}^2}{n_{1\delta}+n_{2\delta}-2}}$$

$$|Z_\alpha| \leq T_\alpha \quad \text{AND} \quad |Z_\delta| \leq T_\delta$$

T the value of the Student distribution for 0,05 level of significance and $n_{1\alpha}+n_{2\alpha}-2$ degrees of freedom for α and $n_{1\delta}+n_{2\delta}-2$ for δ respectively

Common Proper Motion Double Stars

Calculating β

- β: The probability to commit type II error
- Type II error: A pair is NOT a real CPM double star, but our t-test is unable to reject the null hypothesis
- The overall probability β will consist of the individual probabilities β_α and β_δ

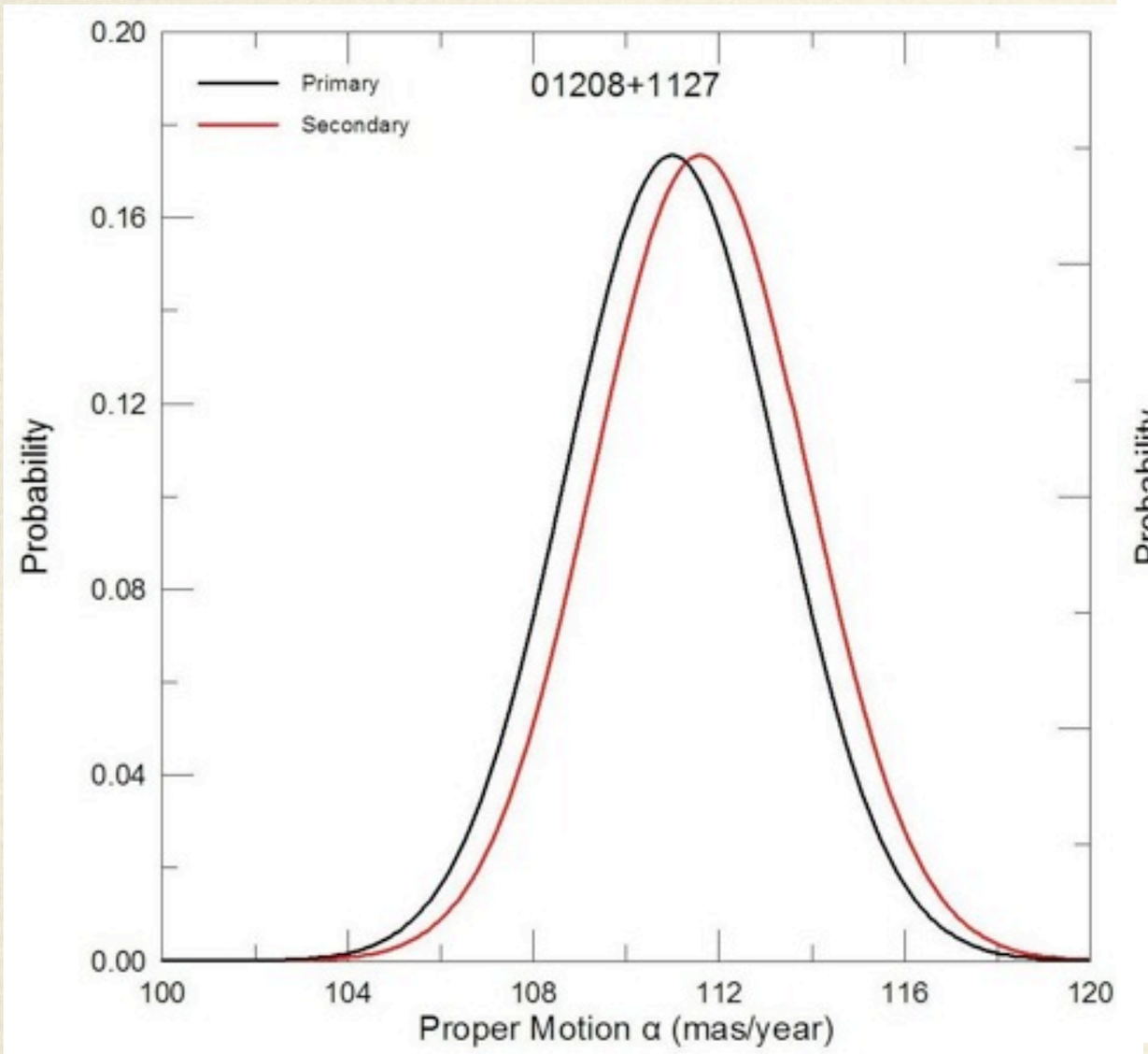
$$\Delta\mu^*_\alpha = T \cdot \sigma_\alpha \sqrt{\frac{1}{n_{1\alpha}} + \frac{1}{n_{2\alpha}}} \qquad \Delta\mu_\delta = T \cdot \sigma_\delta \sqrt{\frac{1}{n_{1\delta}} + \frac{1}{n_{2\delta}}}$$

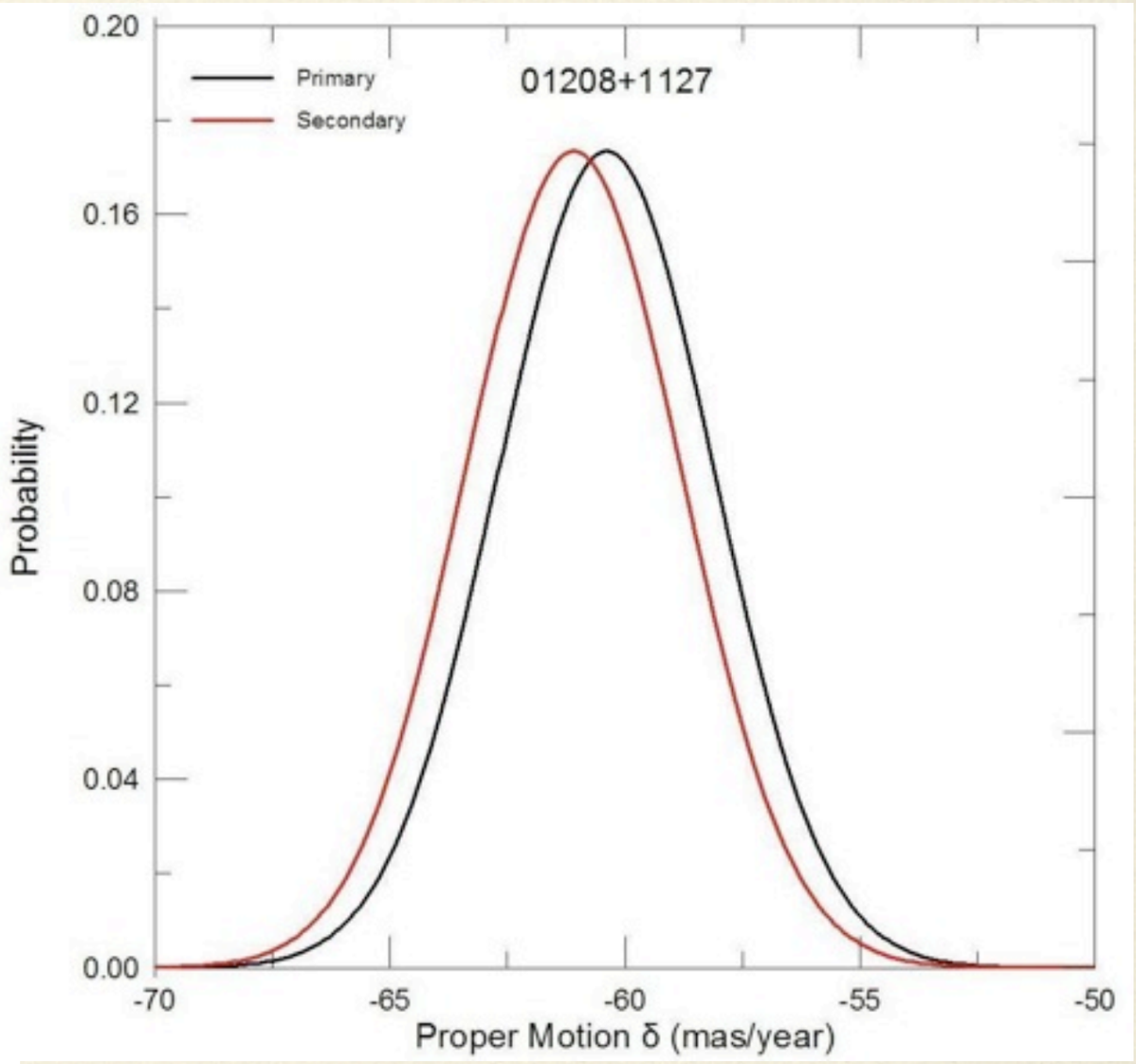
$$Z_{\beta\alpha} = \frac{\mu_{1\alpha} - \mu_{2\alpha} - \Delta\mu^*_\alpha}{\sigma_\alpha \sqrt{\frac{1}{n_{1\alpha}} + \frac{1}{n_{2\alpha}}}} \qquad Z_{\beta\delta} = \frac{\mu_{1\delta} - \mu_{2\delta} - \Delta\mu_\delta}{\sigma_\delta \sqrt{\frac{1}{n_{1\delta}} + \frac{1}{n_{2\delta}}}}$$

$$\beta = \beta_\alpha + \beta_\delta - \beta_\alpha \cdot \beta_\delta$$

The CPMDS catalogue

Example

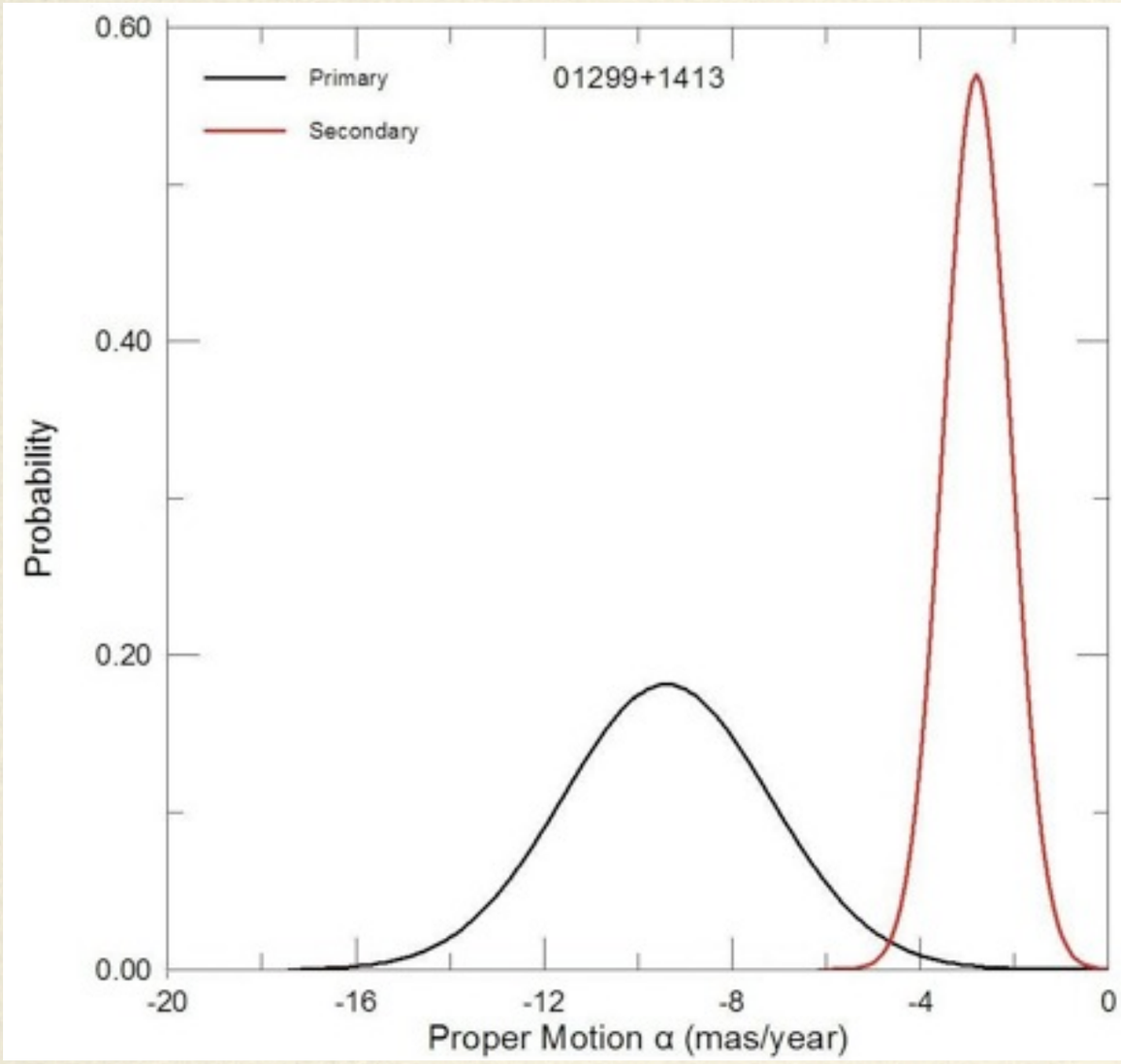


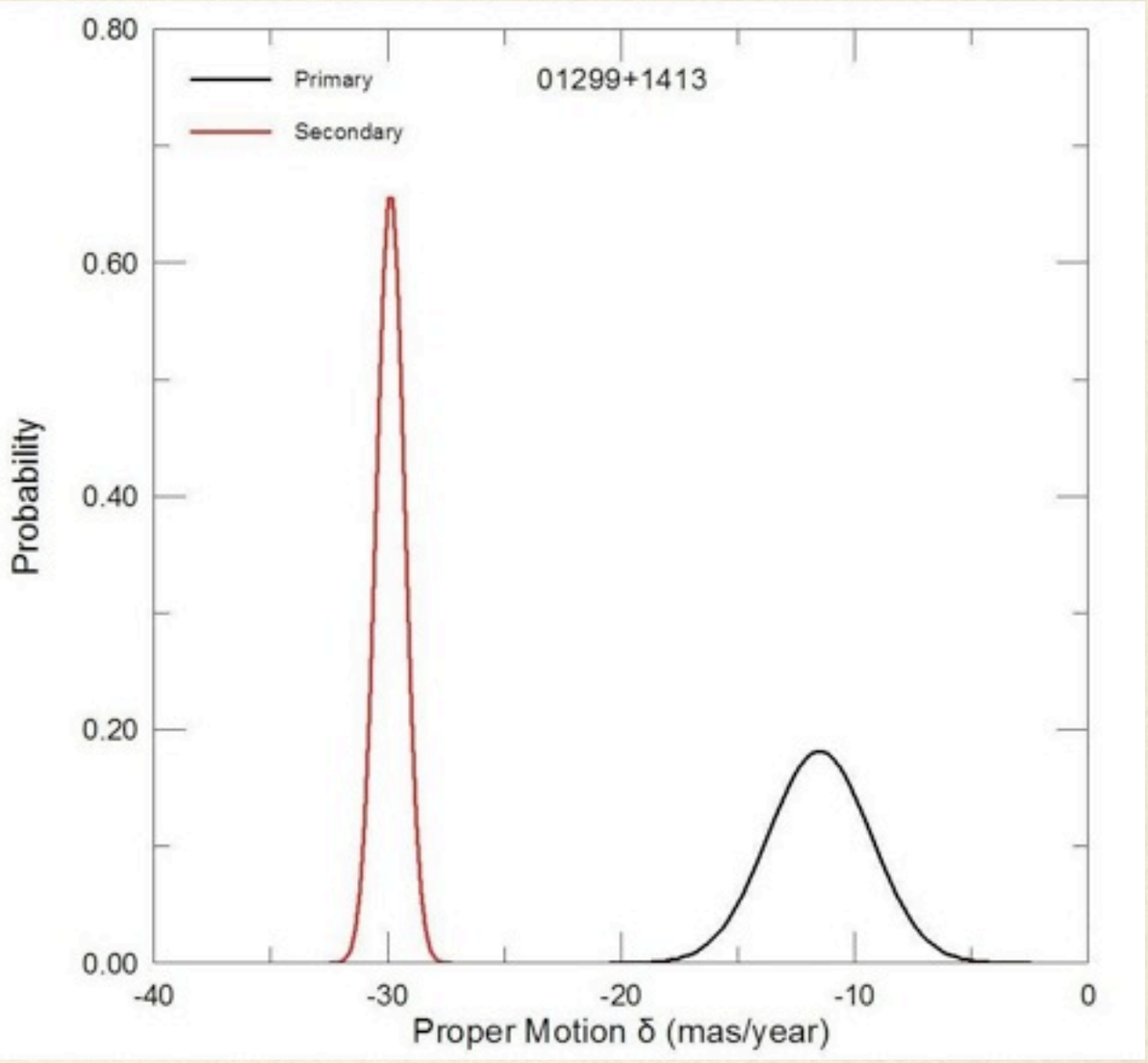


	μ^*_α (mas/yr)	μ_δ (mas/yr)
A	111,4±2,4	-60,4±2,3
B	111,6±2,4	-61,1±2,3

The CPMDS catalogue

Example





The CPMDS catalogue
Results

- 2572 CPM visual double stars with angular separation $\varrho \leq 2'$

+

- 259 CPM visual double stars with angular separation $2' < \varrho \leq 5'$ and $\mu > 50$ mas/yr

The CPMDS catalogue

Results

α_{2000}			δ_{2000}			Identification		ρ	σ_ρ	θ	σ_θ	$MagP$	$MagS$	$\mu^*_\alpha P$	$\mu_\delta P$	$\sigma_{\mu^*_\alpha} P$	$\sigma_{\mu_\delta} P$	No	$\mu^*_\alpha S$	$\mu_\delta S$	$\sigma_{\mu^*_\alpha} S$	$\sigma_{\mu_\delta} S$	No	Epoch	Class	β
h	m	s	°	′	″			″		°		mag.		mas/yr					mas/yr					yr		
0	2	20.009	+16	08	46.97	1692	1685	30.58	0.06	185.82	0.10	15.427	15.781	19.5	−12.5	4.8	3.8	7 8	21.6	−15.4	3.8	3.9	6 6	1994.94	I	0.35
0	2	46.393	+16	47	8.27	2010	1993	77.72	0.06	335.41	0.04	15.464	15.697	16.1	−25.5	4.4	3.6	9 8	13.9	−23.1	4.0	5.2	4 3	1994.94	II	0.19
0	3	44.683	+11	33	34.22	2710	2680	76.30	0.07	335.59	0.05	15.490	16.088	17.5	−11.6	4.7	3.6	6 7	14.3	−14.4	3.8	3.9	4 4	1992.78	I	0.44
0	5	24.297	+16	19	44.44	3857	3820	89.14	0.04	336.94	0.02	8.770	8.982	33.9	−31.3	2.1	2.1	9 9	34.9	−30.1	2.1	2.1	9 9	1996.57	I	0.01
0	12	34.144	+11	18	0.44	8713	8668	79.13	0.05	253.32	0.04	15.007	15.597	−10.7	−12.3	3.5	3.5	9 9	−13.6	−14.3	3.5	3.5	7 8	1995.18	I	0.60
0	13	41.298	+15	37	1.46	9457	9535	96.90	0.06	115.02	0.04	15.038	16.107	18.2	−20.5	3.5	3.6	9 9	19.7	−19.0	3.8	3.9	4 4	1993.95	II	0.03
0	14	23.006	+16	42	59.12	9941	9955	95.29	0.06	12.97	0.03	15.906	16.347	11.7	−15.3	3.6	3.7	4 4	14.2	−14.8	3.6	3.7	4 4	1995.72	I	0.05

- 53 triple systems
- 6 higher order of multiplicity
- 64 pairs are members of the open cluster M67

The CPMDS catalogue

Examples

ϱ(″)	**σ_ϱ(″)**	**θ(º)**	**σ_θ(º)**	**Epoch**
89.14	0.04	336.94	0.02	1996.57

	A	**B**
Magnitude	8.770	8.982
μ^*_α (mas/yr)	33,9 ± 2,1	34,9 ± 2,1
μ_δ (mas/yr)	-31,3 ± 2,1	-30,1 ± 2,1
N	18	18

The CPMDS catalogue

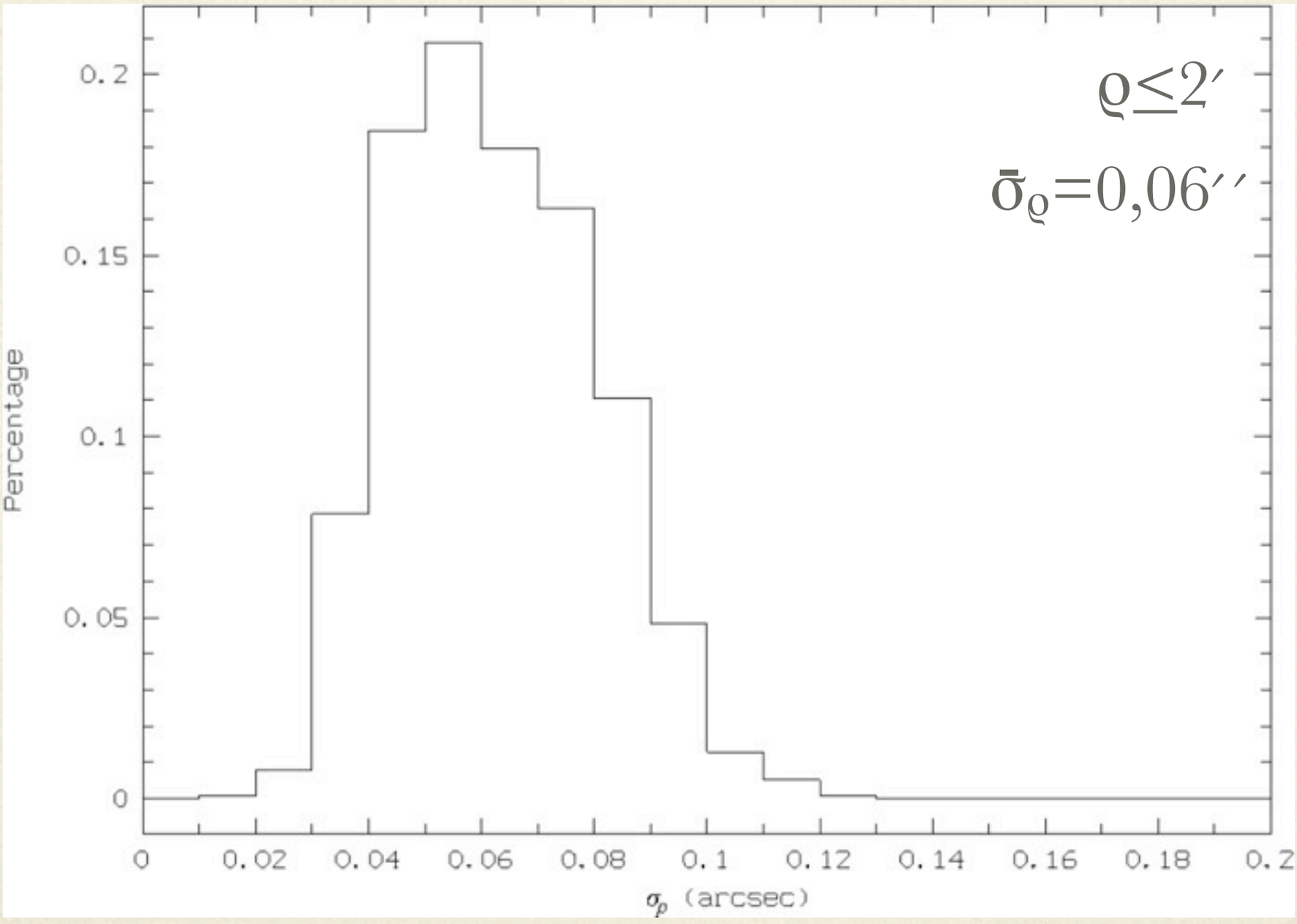
Examples

ϱ(″)	**σ_ϱ(″)**	**θ(º)**	**σ_θ(º)**	**Epoch**
293.63	0.10	25.60	0.02	1994.36

	A	**B**
Magnitude	15.632	15.810
μ^*_α (mas/yr)	-159,9 ± 6,1	-149,5 ± 6,2
μ_δ (mas/yr)	66,1 ± 6,1	62,6 ± 6,2
N	6	6

Properties of CPMDS

Angular Separation accuracy



Properties of CPMDS

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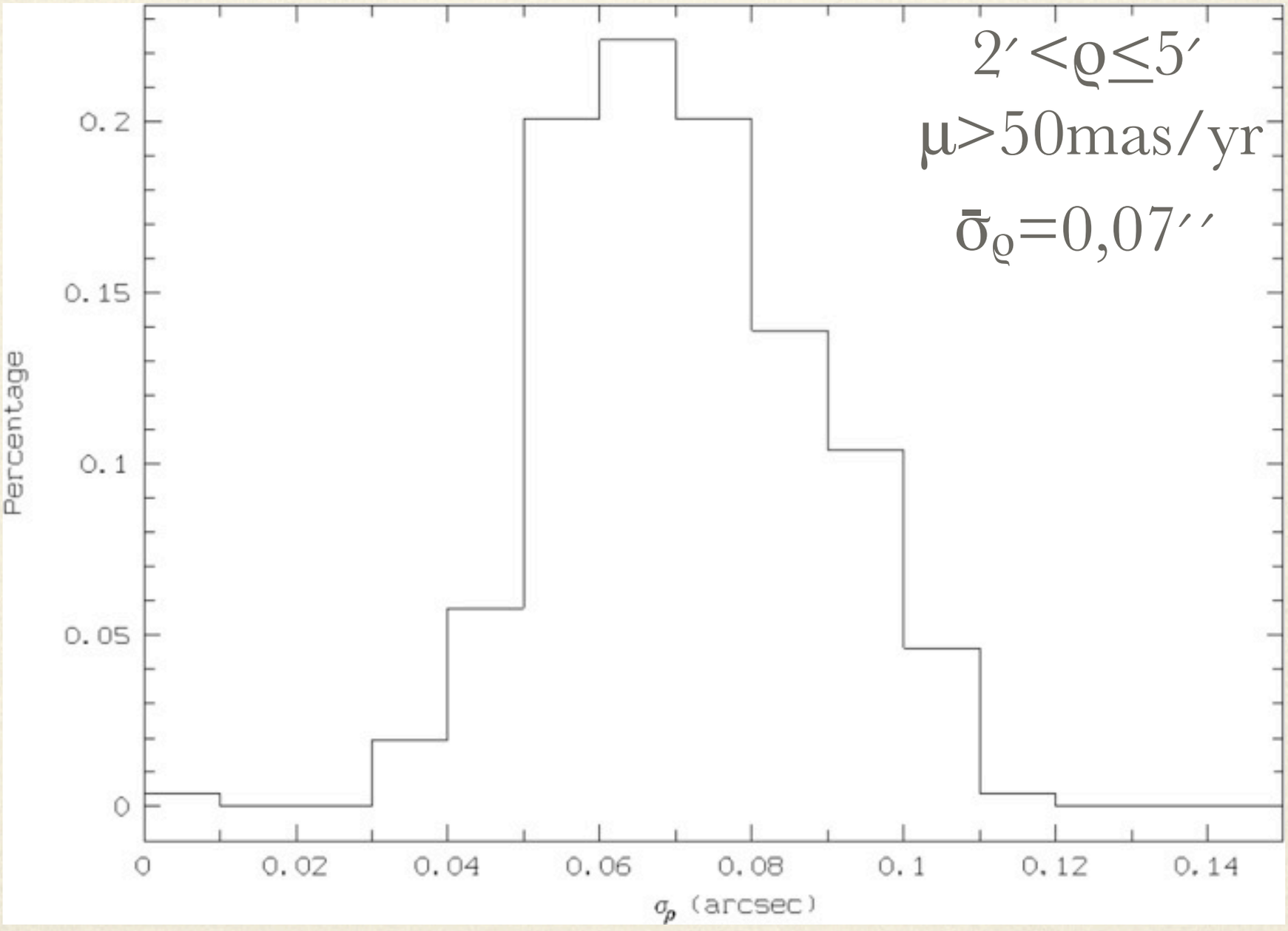
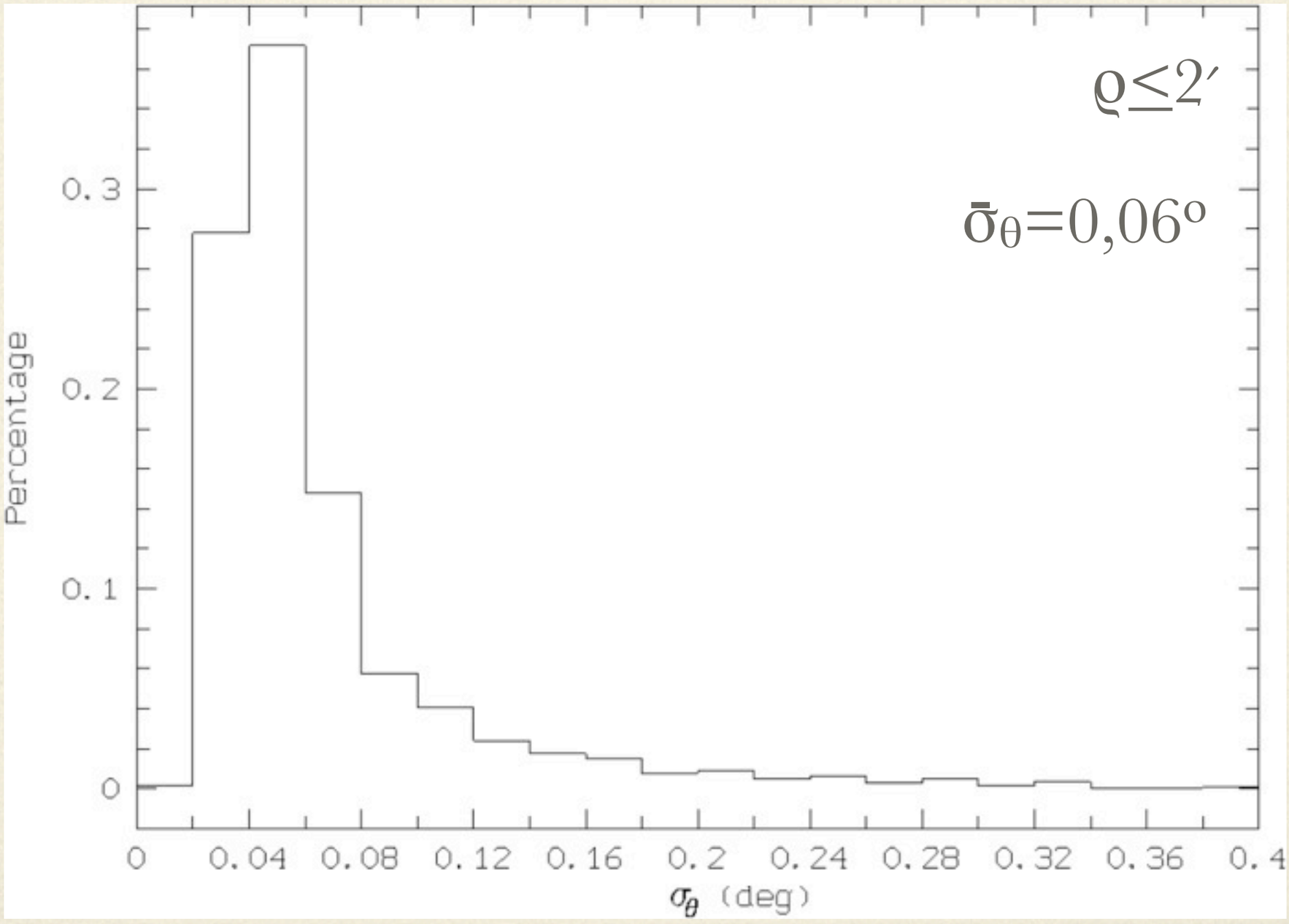


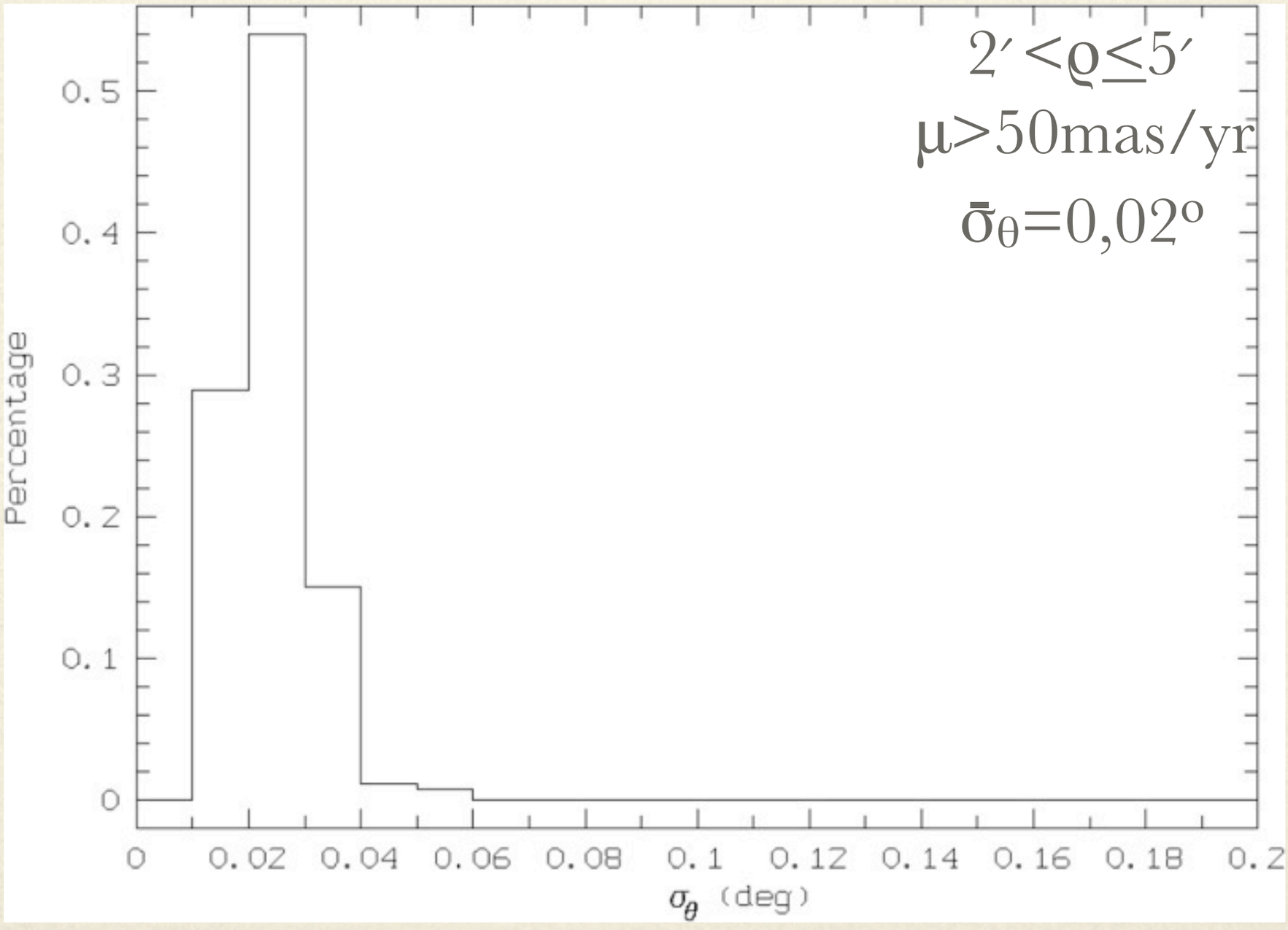
Properties of CPMDS

Position Angle accuracy



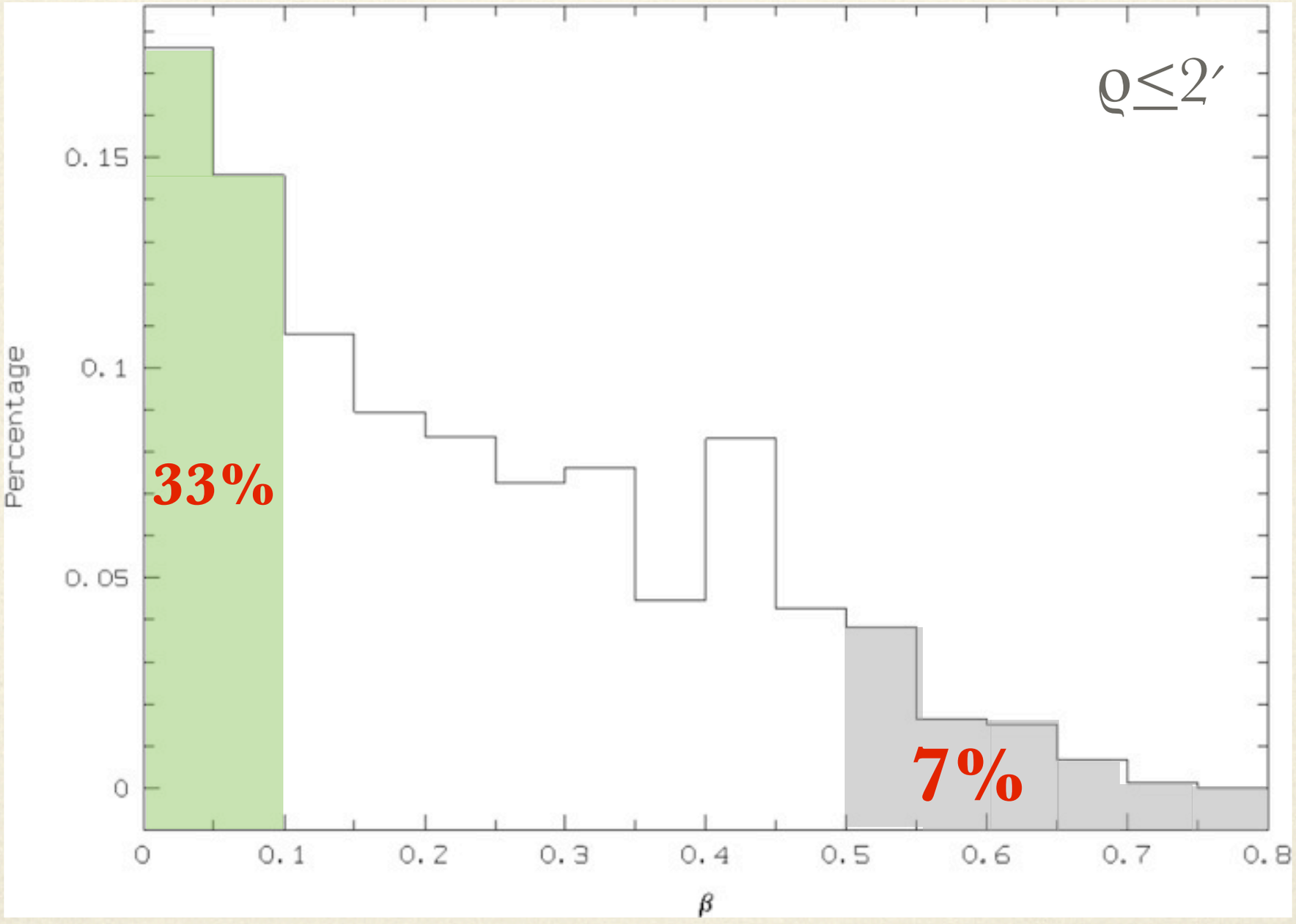
Properties of CPMDS

Position Angle accuracy



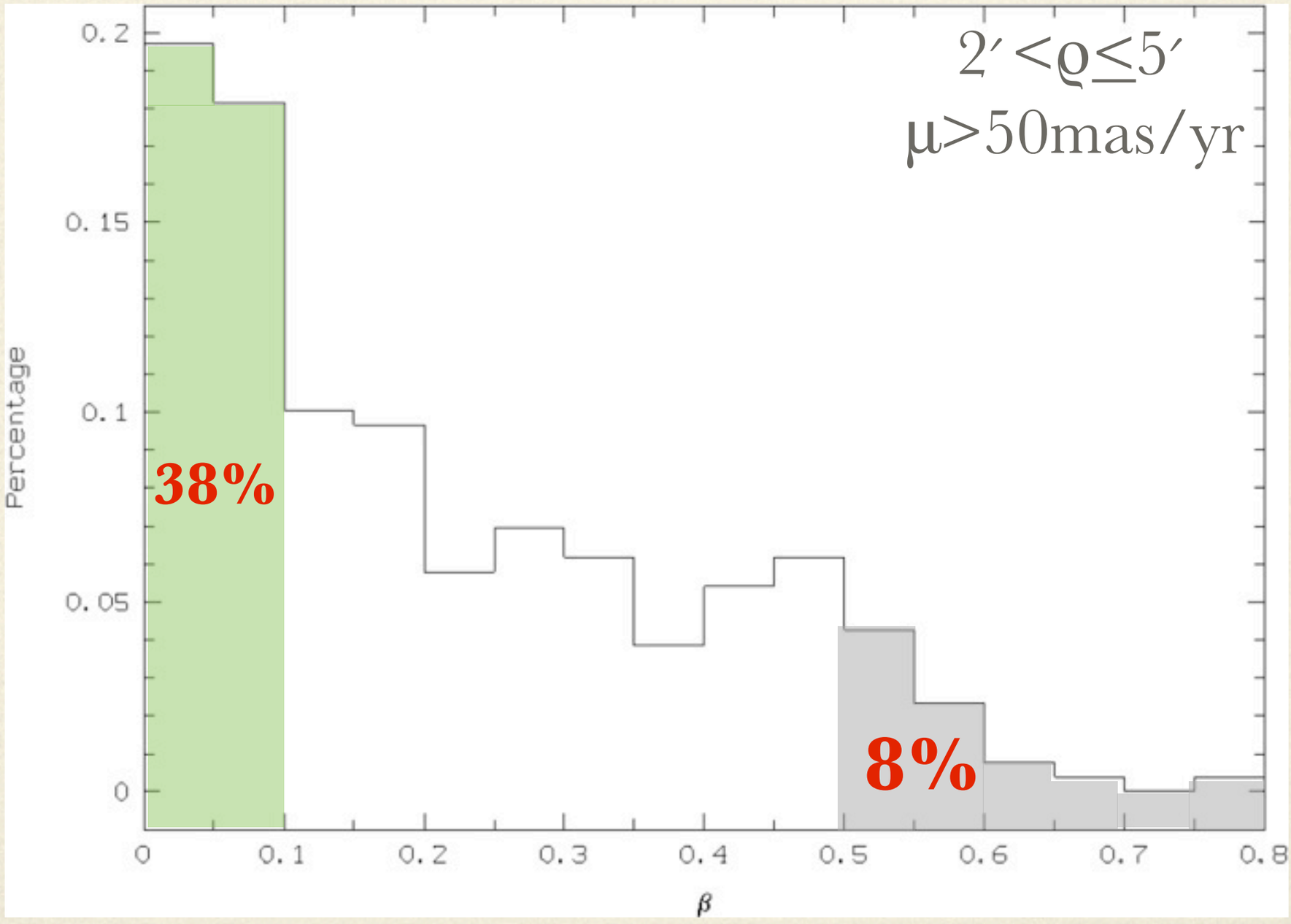
Properties of CPMDS

The Probability β



Properties of CPMDS

The Probability β



External Check
Introduction

- Comparison with LDS Catalogue: Doubles with common proper motion, Luyten (1997)
- LDS:
  - contains 6210 CPM double stars allover the sky
  - $1'' \leq \varrho$

External Check
Data reduction

- Using Vizier we selected the LDS double star found the Bordeaux CdC zone (+11º<δ<+18º)
- We rejected the doubles with faint components
- We rejected those with ϱ<8′′
- 64 LDS double stars found in PM2000

External Check

- Only 12 of the 64 (19%) LDS double stars were accepted as CPM and included in CPMDS
- The rest 42 pairs ????
- Maybe our criterion is too strict
  - We followed the same procedure with 0.01 level of significance
  - We accepted 10 more pairs as CPM
- The rest 32 ??????

External Check

- The origin of this discrepancy cannot be the quality of the proper motion measurements of PM2000

- We checked the proper motions of these discrepant pairs in other catalogues (PPMX,NOMAD,UCAC2) and they are fully compatible with those of PM2000

External Check

Example 1: LDS1066

PM2000 Id	Magnitude mag	μ^*_α mas/yr	μ_δ mas/yr	S^*_α mas/yr	S_δ mas/yr	No
2632815	7,14	-120,7	-82,3	2,2	2,2	18
2632786	10,29	-123,4	-96,2	0,7	0,7	22

Example 2: LDS862

PM2000 Id	Magnitude mag	μ^*_α mas/yr	μ_δ mas/yr	S^*_α mas/yr	S_δ mas/yr	No
9431	11,119	104,9	10,7	2,3	2,3	8
9349	13,939	94,1	-9,7	5,1	5,1	8

Classification of our CPM sample

- Study of the nature of the pairs CPMDS
- We studied the position of the components of the CPM pairs in an empirical H-R diagram
  - H-R diagram : 2MASS data for the open clusters M67 and Pleiades
- Then, using Vizier we identified the components of the CPMDS members in 2MASS.
- We used only the 2MASS data with high photometric quality flag
- We found data for 2603 CPMDS pairs at J(1,2μm), H(1,6μm), Ks (2,2μm)

Classification of our CPM sample

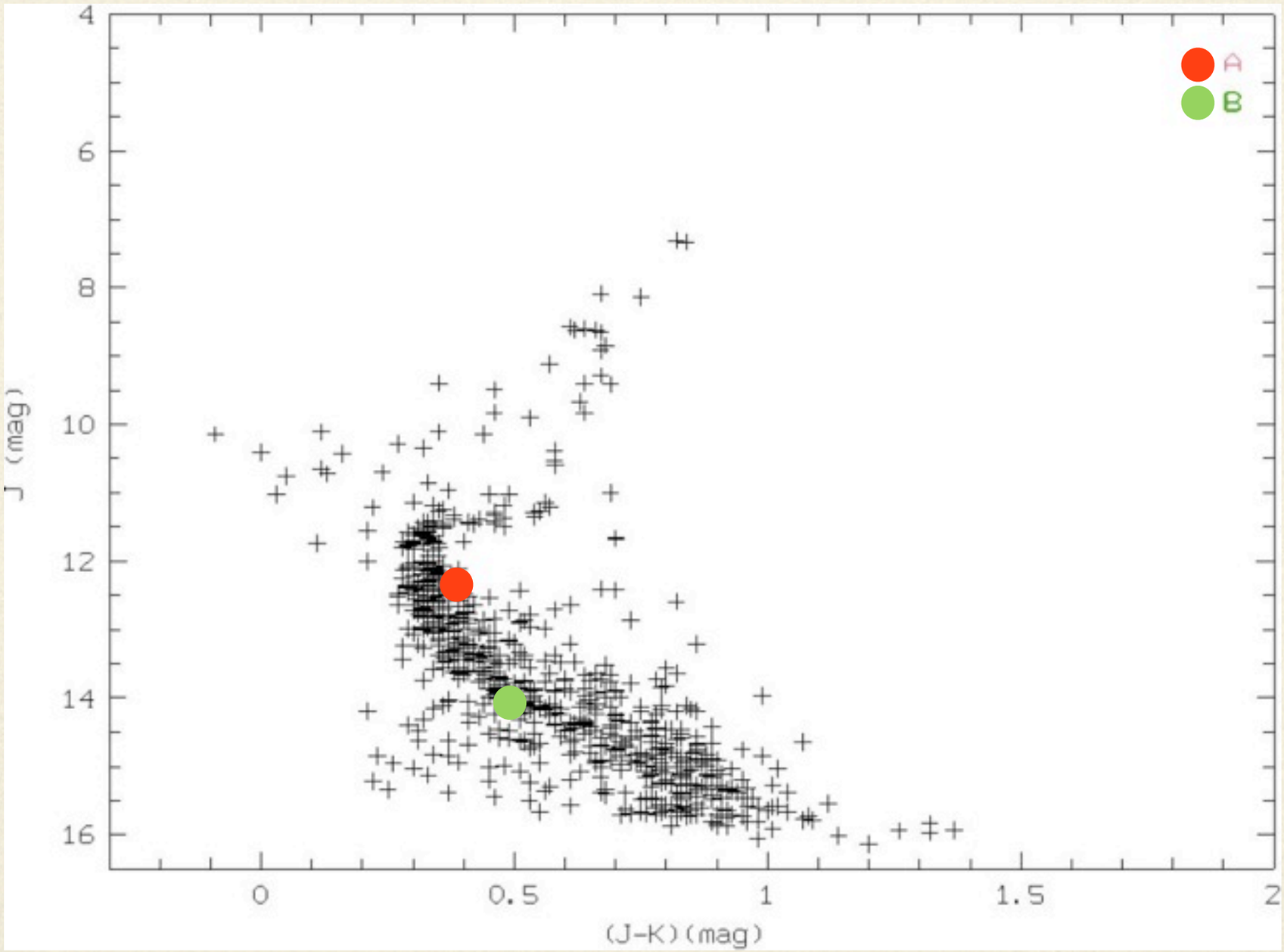
- Our idea is based on that double stars that their components have a physical connection will occupy specific “compatible” positions in an H-R diagram
- 5 classes
  - I
  - II
  - III
  - IV
  - V

I →
- Both components in the M.S.
- A giants branch while B is in M.S.
- Similar (J-K) και J

V →
- Incompatible positions in the H-R diagram
- B more evolved than A
- B brighter than A

Classification of our CPM sample

Examples



Classification of our CPM sample

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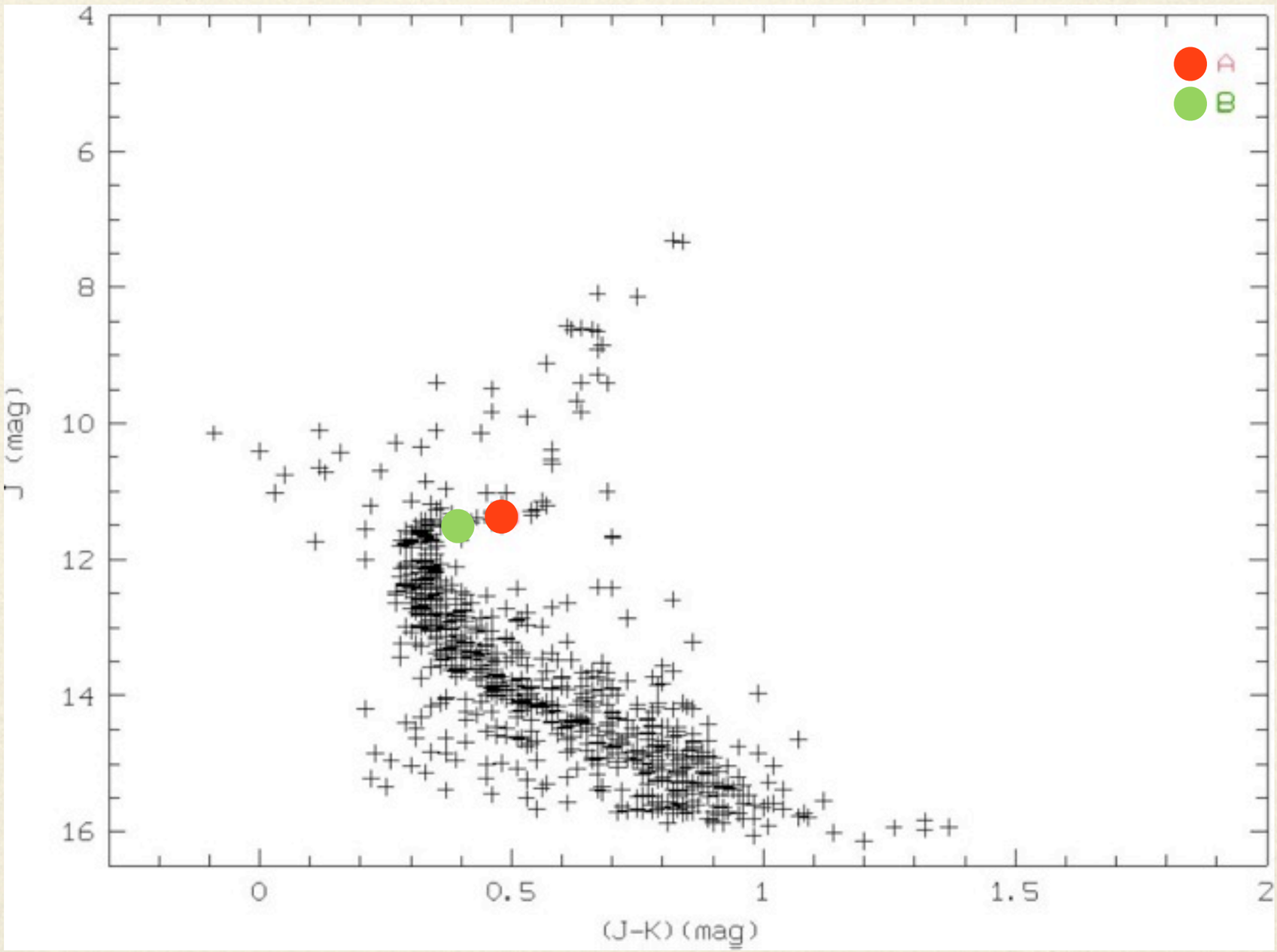
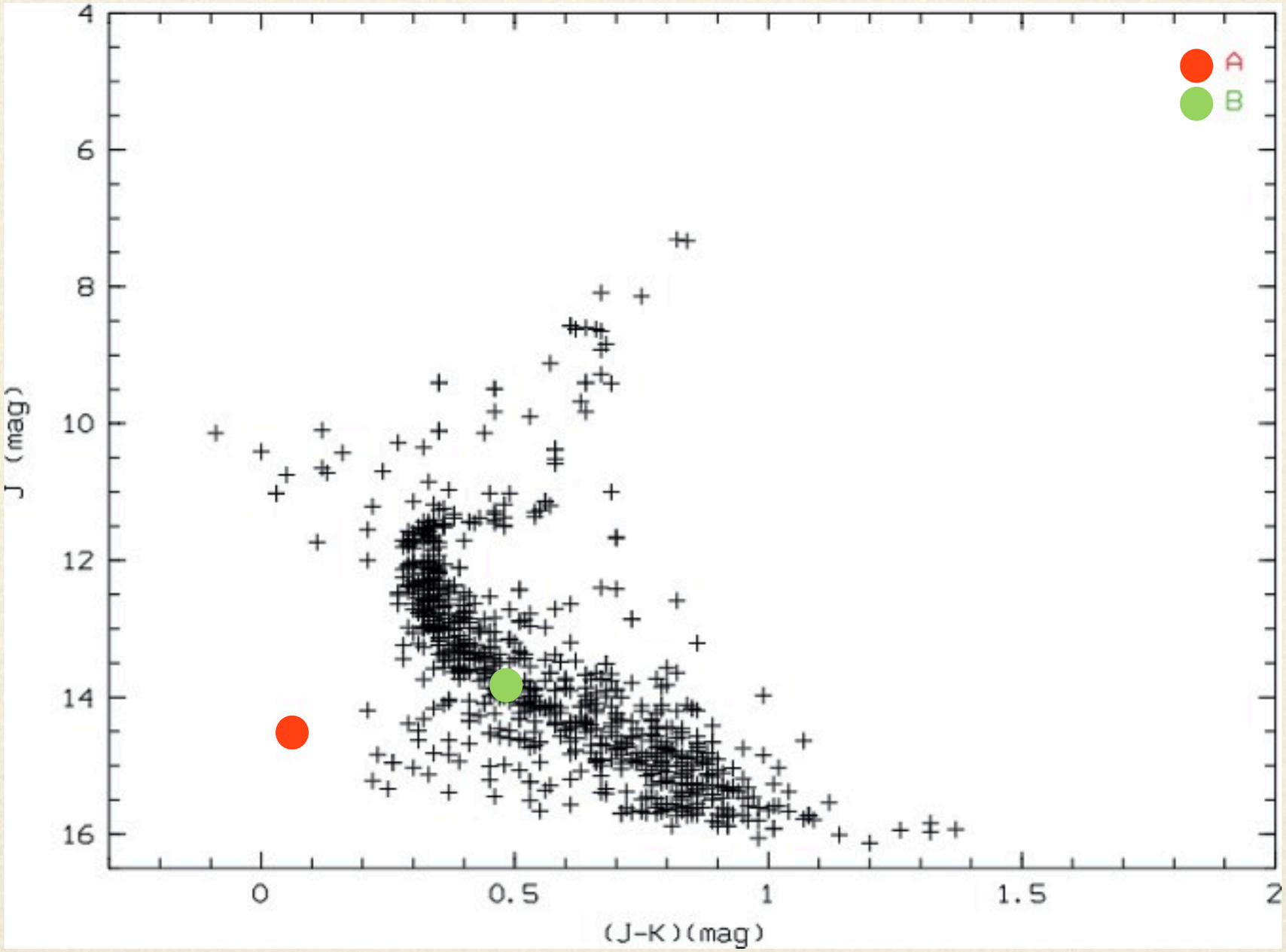


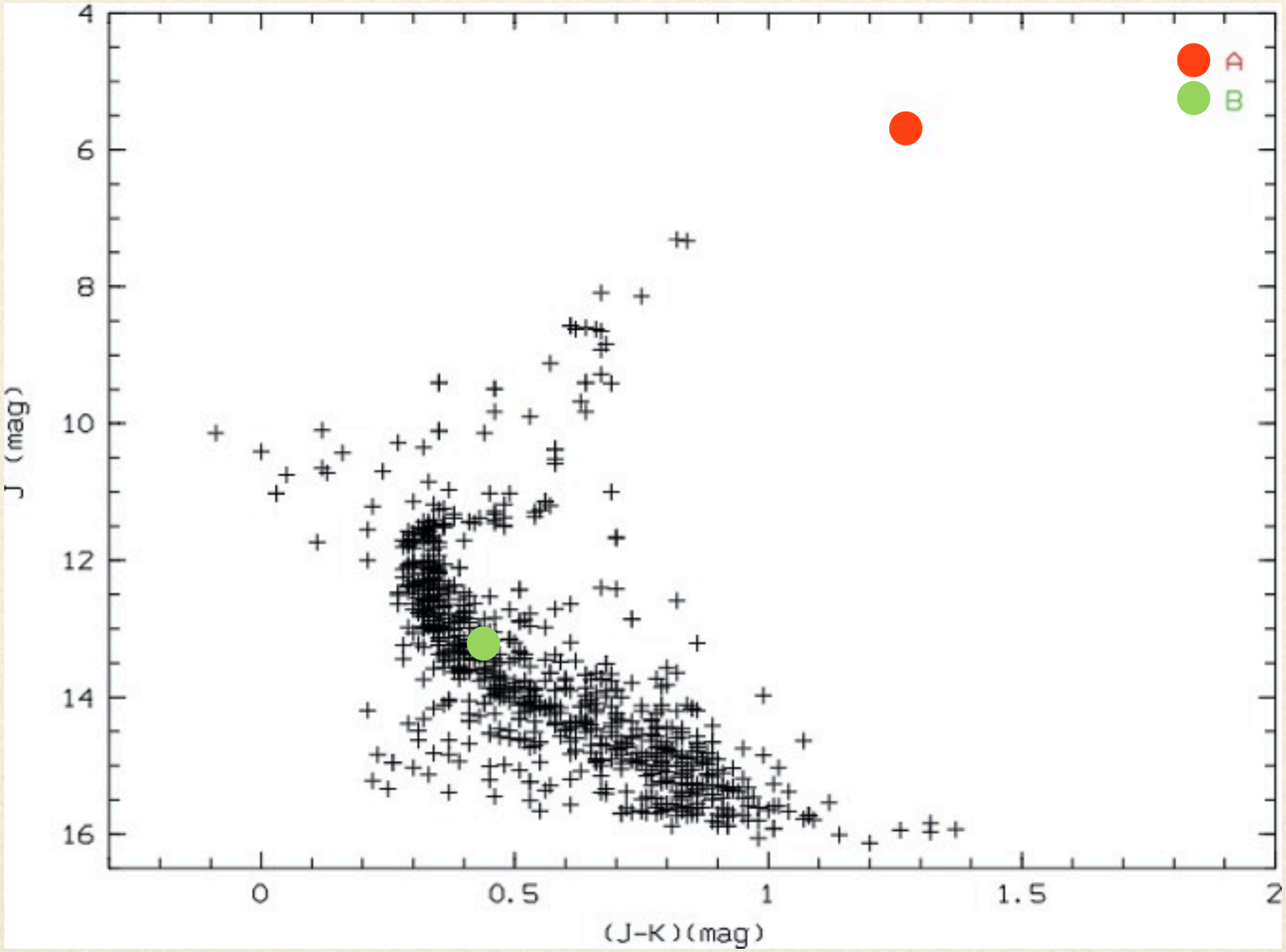
Classification of our CPM sample

Examples



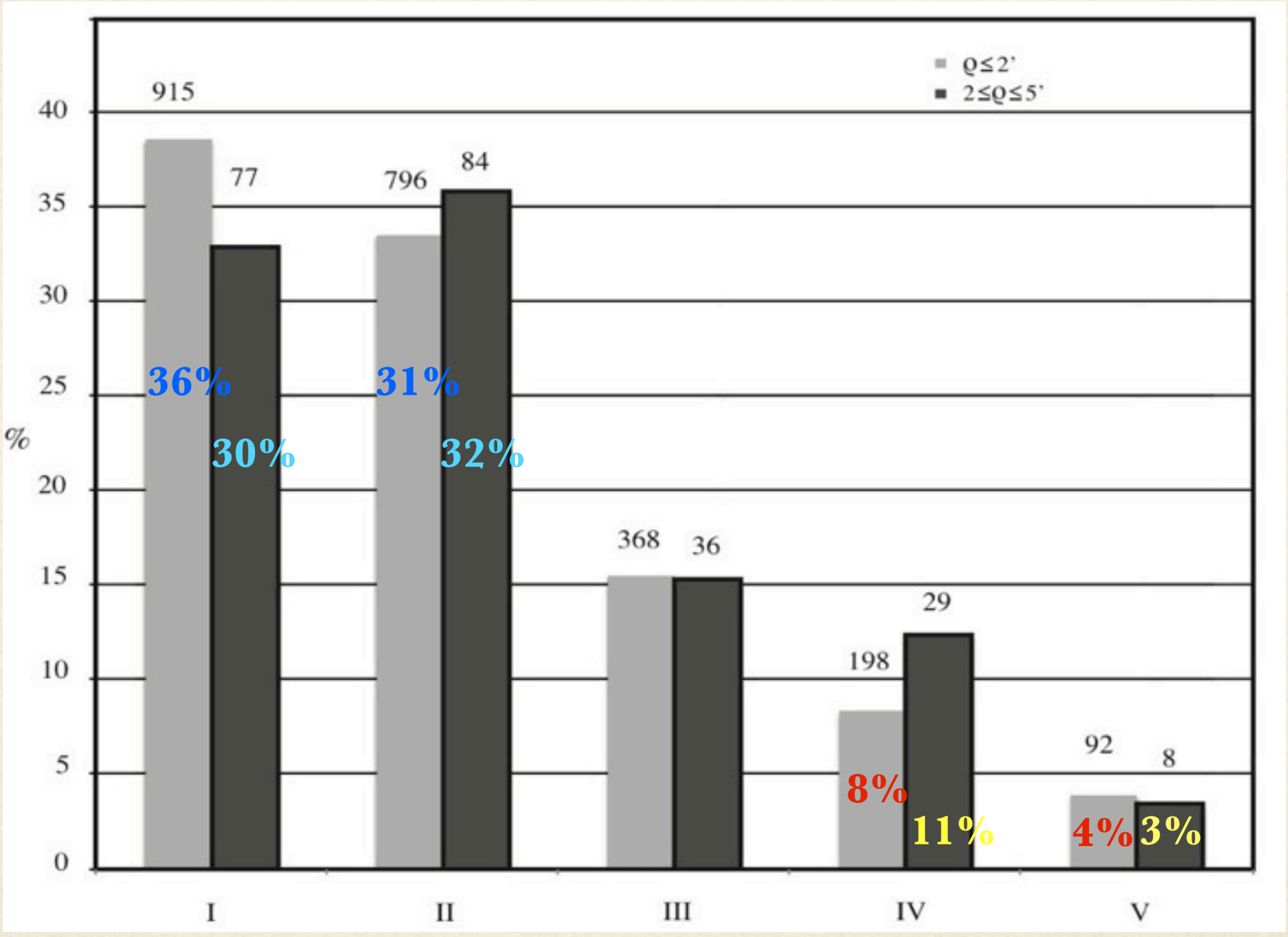
Classification of our CPM sample

Examples



Classification of our CPM sample

Results



Common Proper Motion Double Stars

Summary

- We discovered 2831 new CPM double stars
- We classified the according to their position in the H-R diagram
- +30% total number of the known CPM double stars
- Our catalog (CPMDS) is available from Vizier
- Included in W.D.S. (U.S.N.O)
  - +2,6% total number of the double stars included in WDS

Re-measurements of WDS pairs in PM2000

- Target: New astrometric measurements of angular separation and position angle for known WDS double stars.
- Data: PM2000

Re-measurements of WDS pairs in PM2000

Data Reduction

- We selected from WDS only those double stars that:
  - they are in Bordeaux CdC zone
  - have angular separation $\varrho \geq 8''$
  - are brighter than V=16,2 mag
- We created a list with 1500 WDS double stars

Re-measurements of WDS pairs in PM2000

Identification procedure

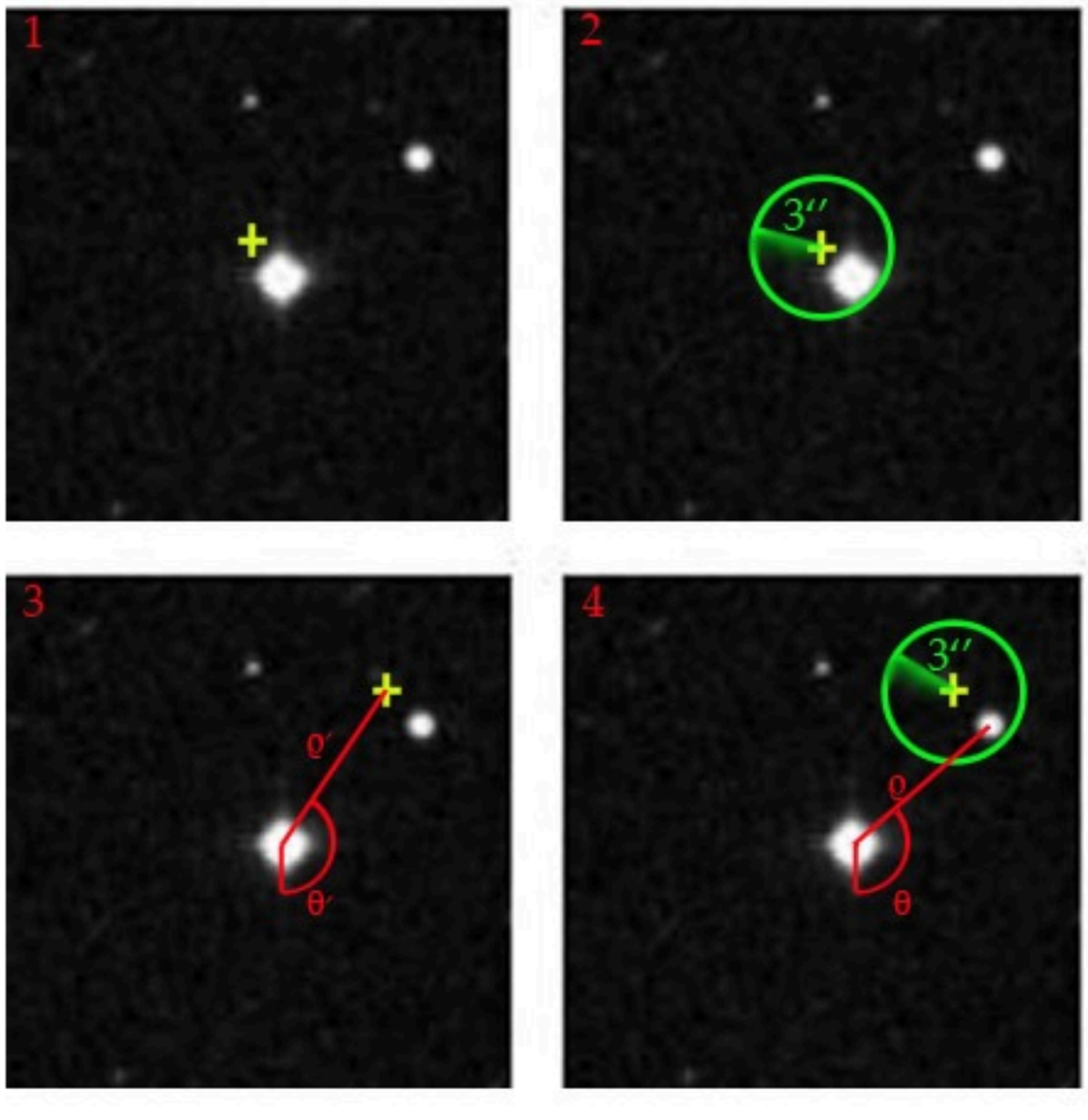
- Criterion: The coordinates of the stars in both catalogs MUST NOT differ more than 3′′

1. We used the WDS coordinates of the A at PM2000

2. We searched in a 3′′ radius to find A at PM2000

3. We used WDS ϱ,θ to predict the coordinates of B

4. We searched again in a 3′′ radius around the predicted position of B and we calculated ϱ,θ according to PM2000



Re-measurements of WDS pairs in PM2000

Data Reduction

- We selected only the stars that they had more than 3 observations for each component
- We also rejected 74 pairs due to low astrometric accuracy
- Finally we compiled a catalog with 926 WDS double stars

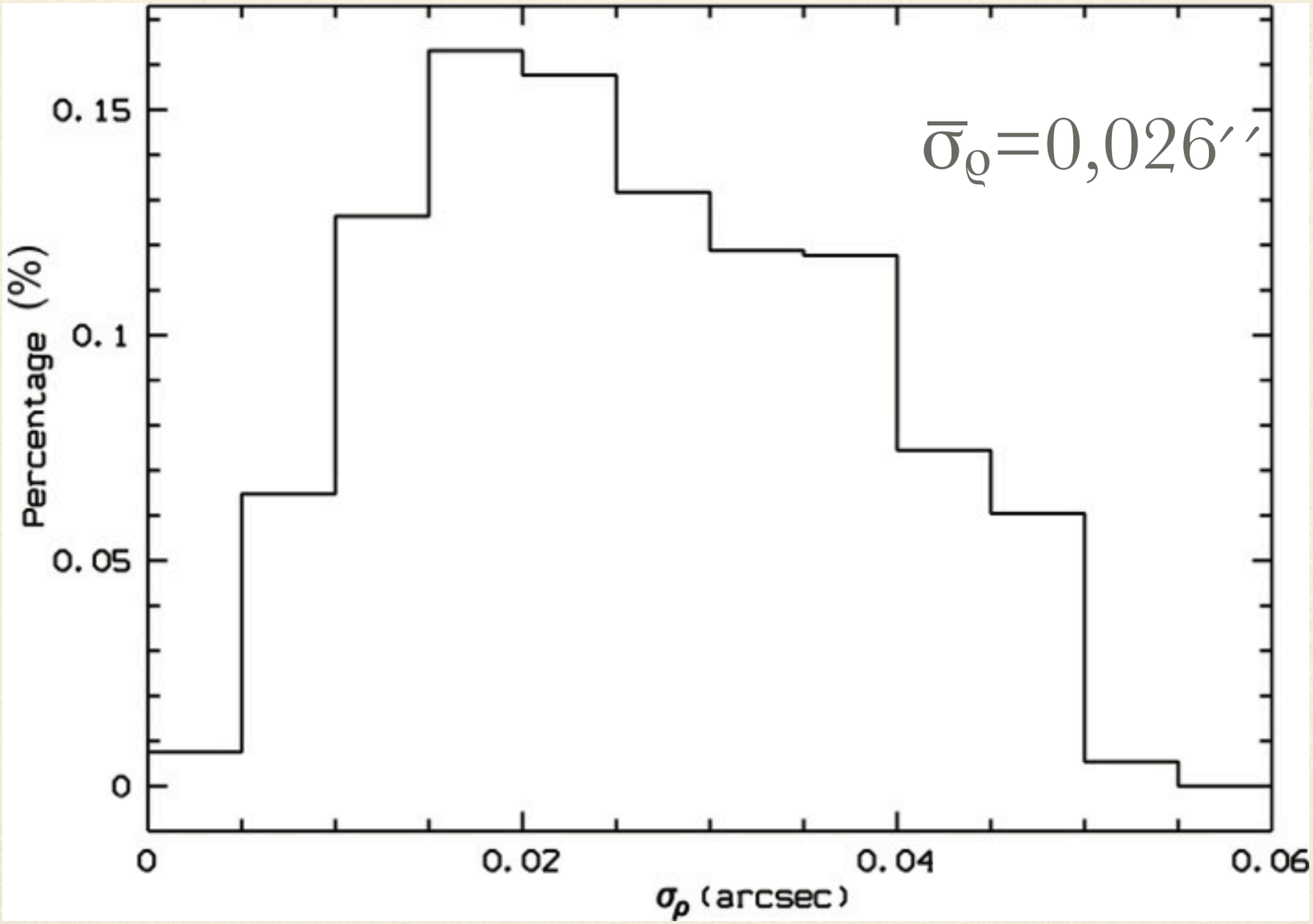
Re-measurements of WDS pairs in PM2000

Results

α_{2000}			δ_{2000}			WDS	ρ	σ_ρ	θ	σ_θ	$MagP$	$MagS$	Epoch	No
h	m	s	^{o}	$'$	$''$		$''$		^{o}		magnitudes			
0	00	13.8	+16	40	57	00003+1642	26.629	0.015	61.54	0.03	9.6	13.1	1999.1	10
0	01	13.1	+13	58	29	00012+1357	11.653	0.016	204.02	0.06	10.6	11.2	1999.0	8
0	05	24.2	+16	19	44	00054+1620	89.141	0.044	336.94	0.02	8.8	9.0	1998.6	8
0	09	37.4	+11	46	12	00096+1145	289.248	0.022	42.69	0.00	10.5	10.8	1997.7	9
0	09	51.8	+11	24	58	00099+1125	31.534	0.029	167.73	0.04	8.5	11.2	1998.8	7

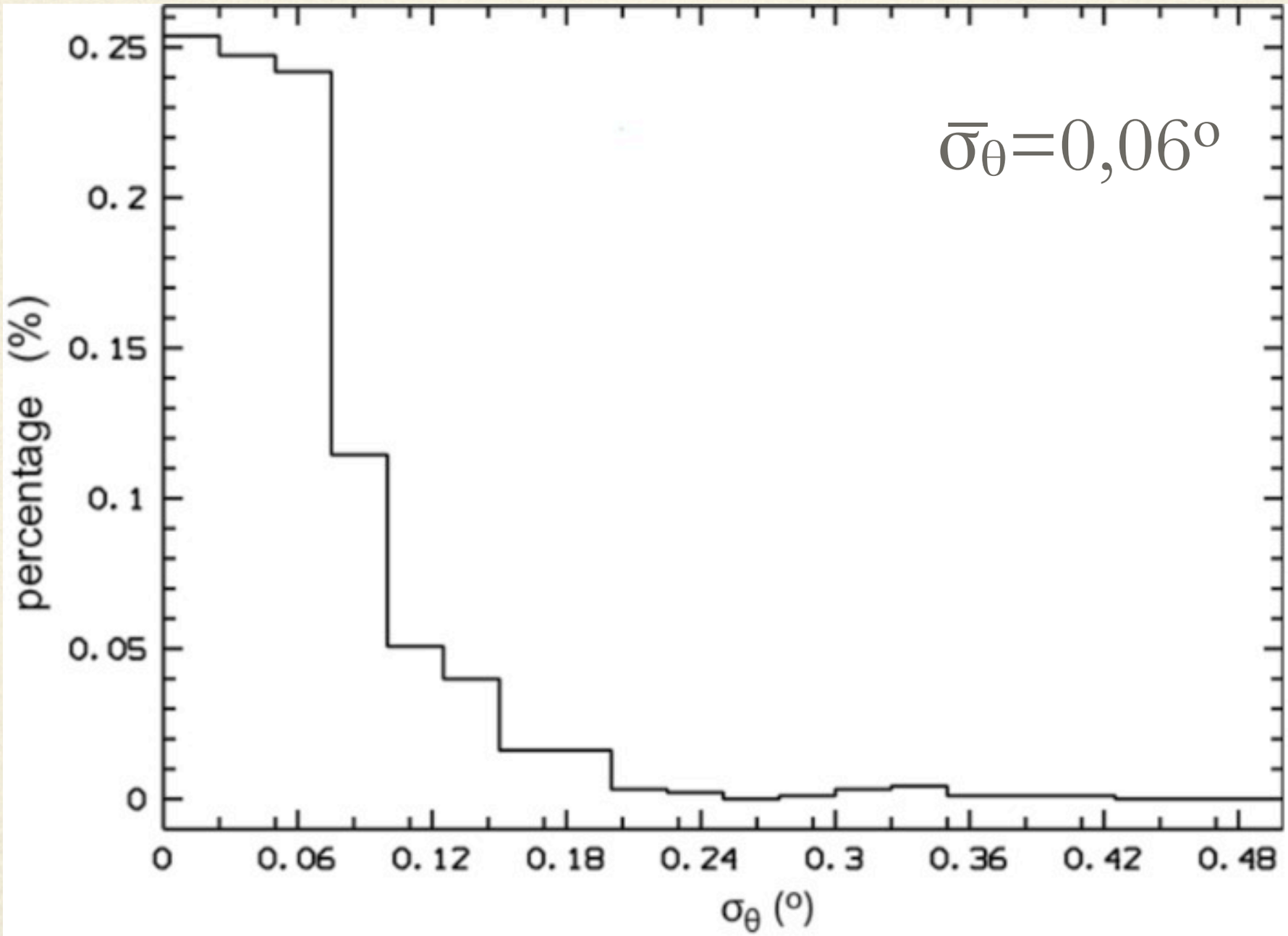
Re-measurements of WDS pairs in PM2000

Properties of our catalog



Re-measurements of WDS pairs in PM2000

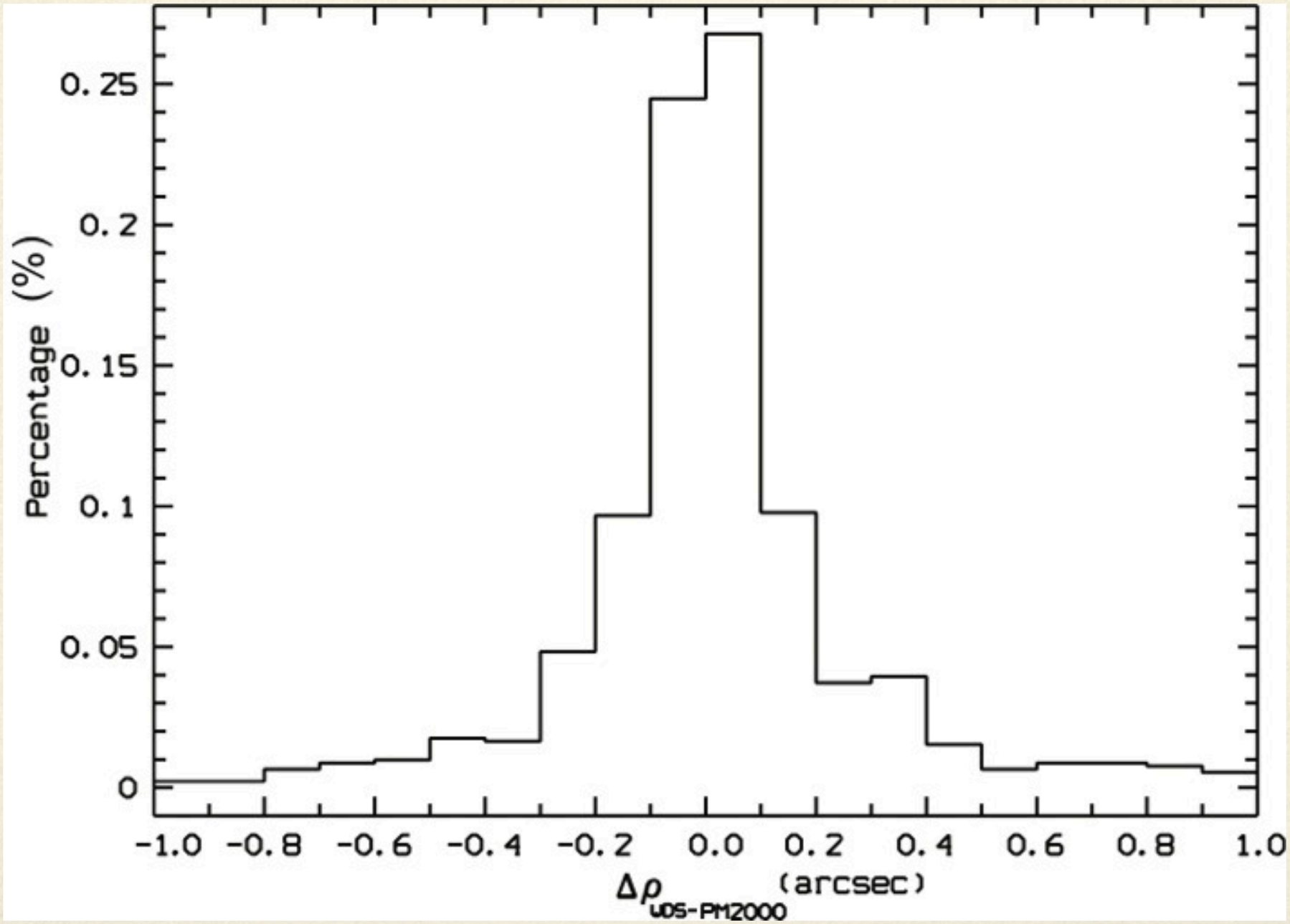
Properties of our catalog



Re-measurements of WDS pairs in PM2000

comparison with WDS measurements

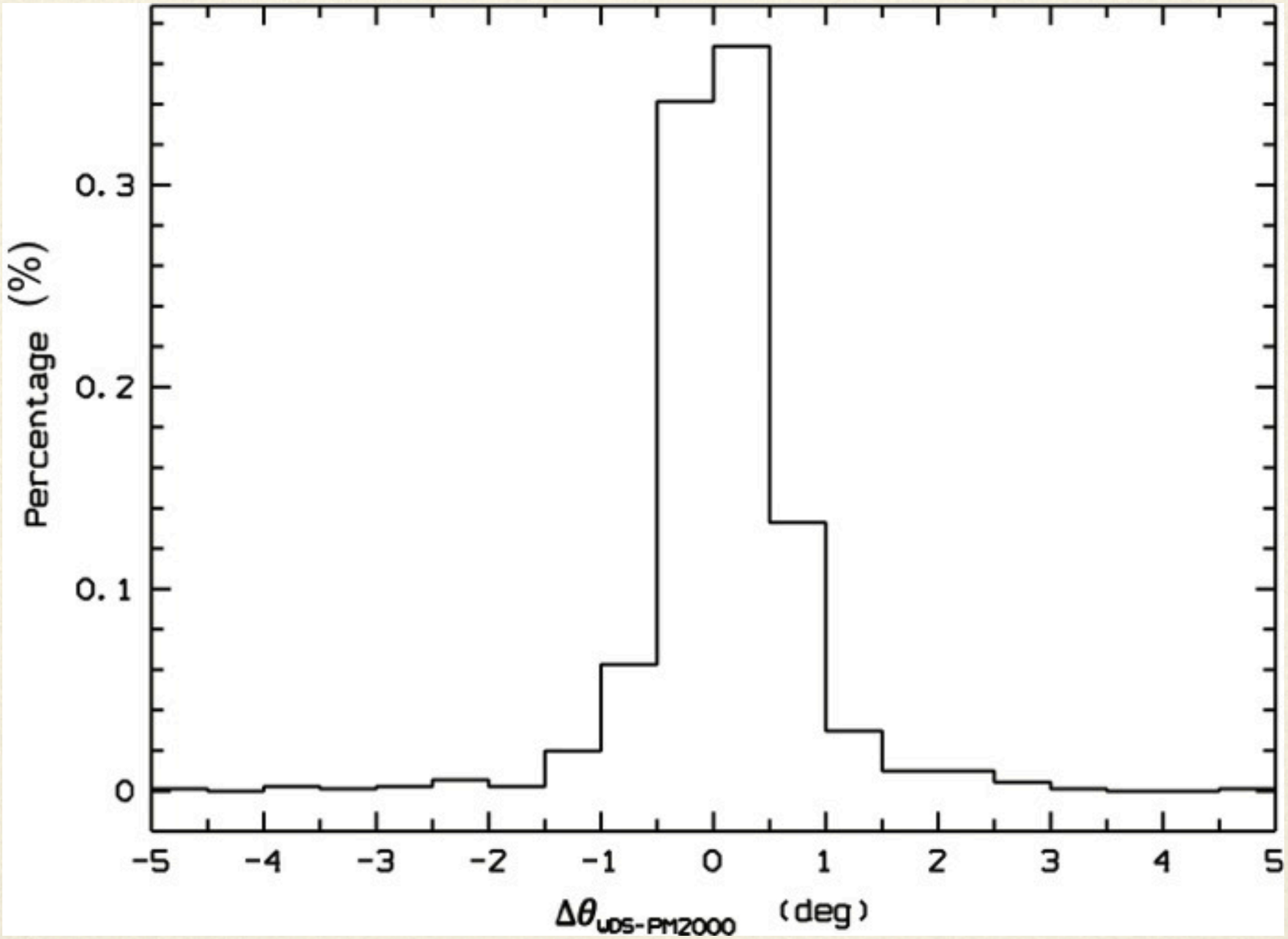
$\overline{\Delta\rho}=0{,}013'' \pm 1{,}055''$



Re-measurements of WDS pairs in PM2000

Comparison with WDS measurements

$\overline{\Delta\theta}=0{,}094^{o}\pm0{,}770^{o}$



Merci

Ευχαριστώ