Scientific use of digitized plates

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A summary

- Photographic plates has been by far the basic detector for astronomy for more than a century.
- Most plates used for sky patrol were blue sensitive, so this is the most covered band in plate archives.
- Many astronomical sources have evolutionary time scales much longer than the human life, so plate archives are the only mean to follow such phenomena.
- Examples are: AGN, Mira stars, cataclismic variables, YSO
- In the following some cases are shortly illustrated.

Active Galactic Nuclei

- Many AGN were discovered in radio and in X-rays surveys, even if they are relatively bright in optical.
- Many AGN are variable at all wavelengths, including optical.
- The variability is a tool to understand the physical process generating the electromagnetic emissions and the size of the emitting regions.
- The past variability history can be traced only with archival data.
- Though many AGN were present in archival plates, they were not studied until recognized at such. Only a few have a previous “variable star” name (e.g. BL Lac, AP Lib, GQ Com, W Com).
- Many plate archives must still be explored to this purpose.

Example papers

- Long term light curve of S5 0716+714; Nesci et al. (2005) AJ 130, 1466.
- GB6 1058+5628: a quasi periodic BL Lac object the from Asiago plate archive; Nesci et al. 2010 AJ 130, 2425.
- J004457+4123 (Sharov 21): not a remarkable nova in M31but a background quasar with a spectacular UV flare; Meusinger et al. 2010 A&A 512, A1.
- 3C 345: the historical light curve (1967-1990) from the digitized plates of the Asiago Observatory; Omizzolo et al. MNRAS 2005, 356, 336
- Optical variability of 1WGA J0447-0322; Nesci R., et al. 2007, AJ 133, 965.

S5 0716+714

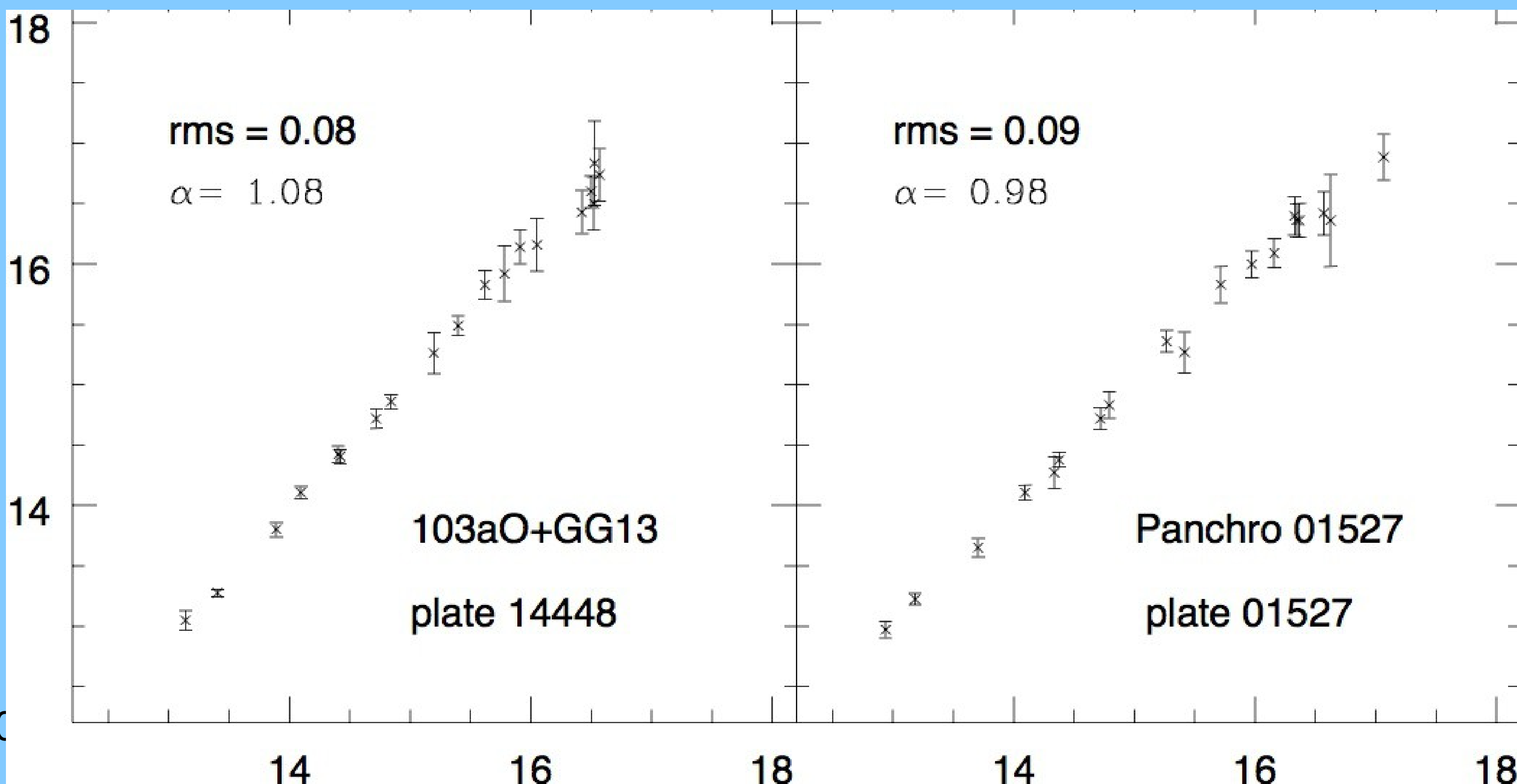
- This source was discovered as radio source in 1981.
- It was bright in the POSS I (B=14.0).
- We found 48 plates in Asiago archive from the 40/50/100 cm Schmidt telescope and 8 from the 65/92/215 cm one, covering the years from 1962 to 1985.
- A variety of emulsions and filter was used in this time span: Kodak 103aO, Panchro Royal, Kodak TriX, both filtered (GG13) and unfiltered.
- Luckily, in several nights images were taken with different filter/emulsion combinations, allowing an intercalibration.
- About 20 stars were selected as comparison from the GSC2 catalog, to build a calibration curve and assure photometric interpolation of the source magnitude.

S5 0716+714

- Digitization was made with an EPSON 1680 Pro scanner in grayscale transparency mode with 16 bit conversion, at a sampling of 1600 dpi (15.9 micron).
- This produces a sampling of 1.51 arcsec/pixel for the large Schmidt, and 3.26 arcsec/pixel for the small one.
- The sampling is sufficiently well matched to the grain of the scanned plates.
- The scans included the unexposed part of the plate, to measure the transparency of the plate+emulsion (FOG).
- The transparency of saturated stars was often not zero, due to scattered light or other systematic effects, so the actual BLACK value was derived
- Conversion from data number to intensity was made as:
- $$I=(DN-BLACK)/(FOG-BLACK)$$

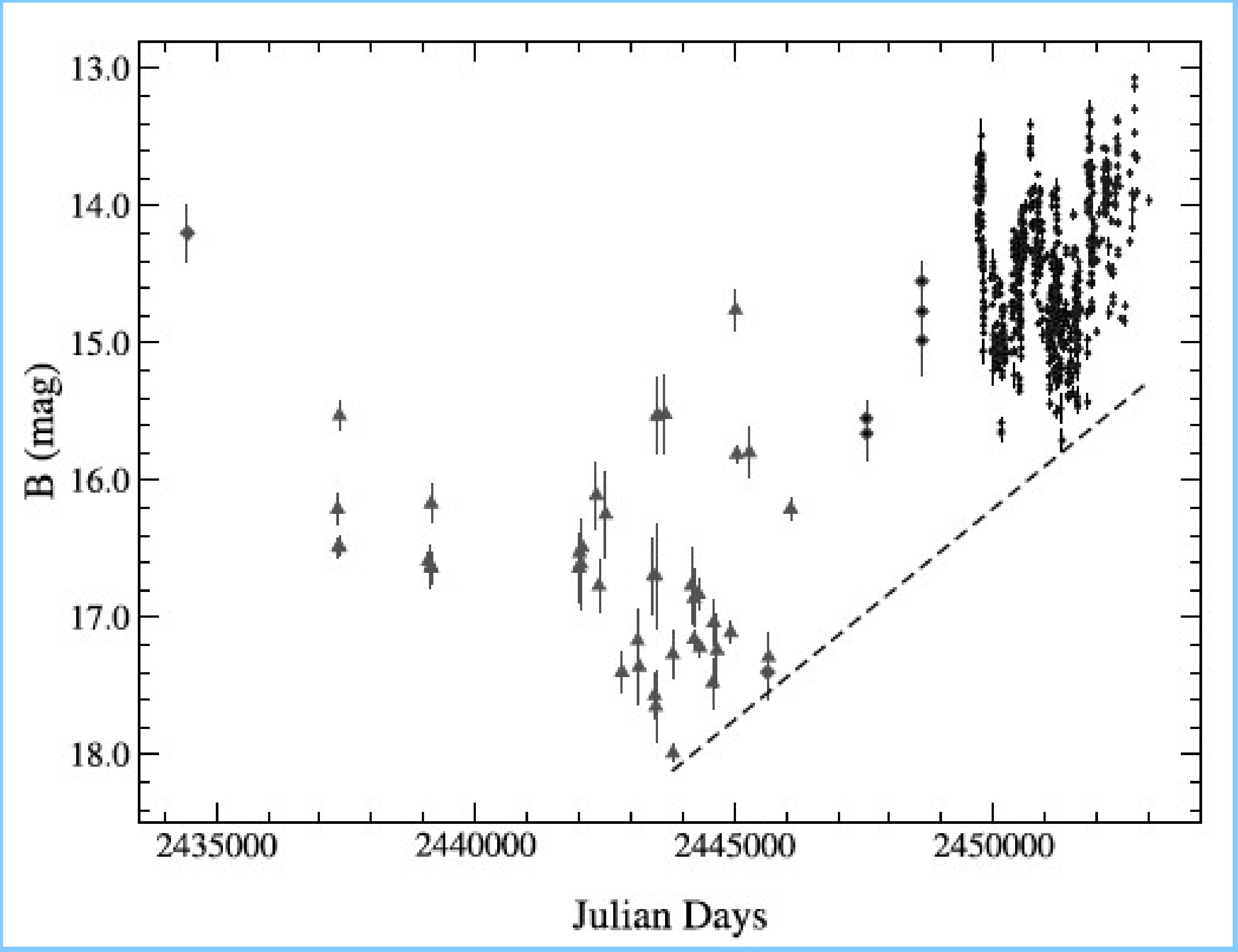
Photometric calibration

- Aperture magnitudes were performed with IRAF/apphot
- A linear fit was generally sufficient, in some cases a parabolic fit was necessary.
- The slopes of the linear fit were nearly 1, indicating that our scans made a good recovery of the intensity information.



Light curve

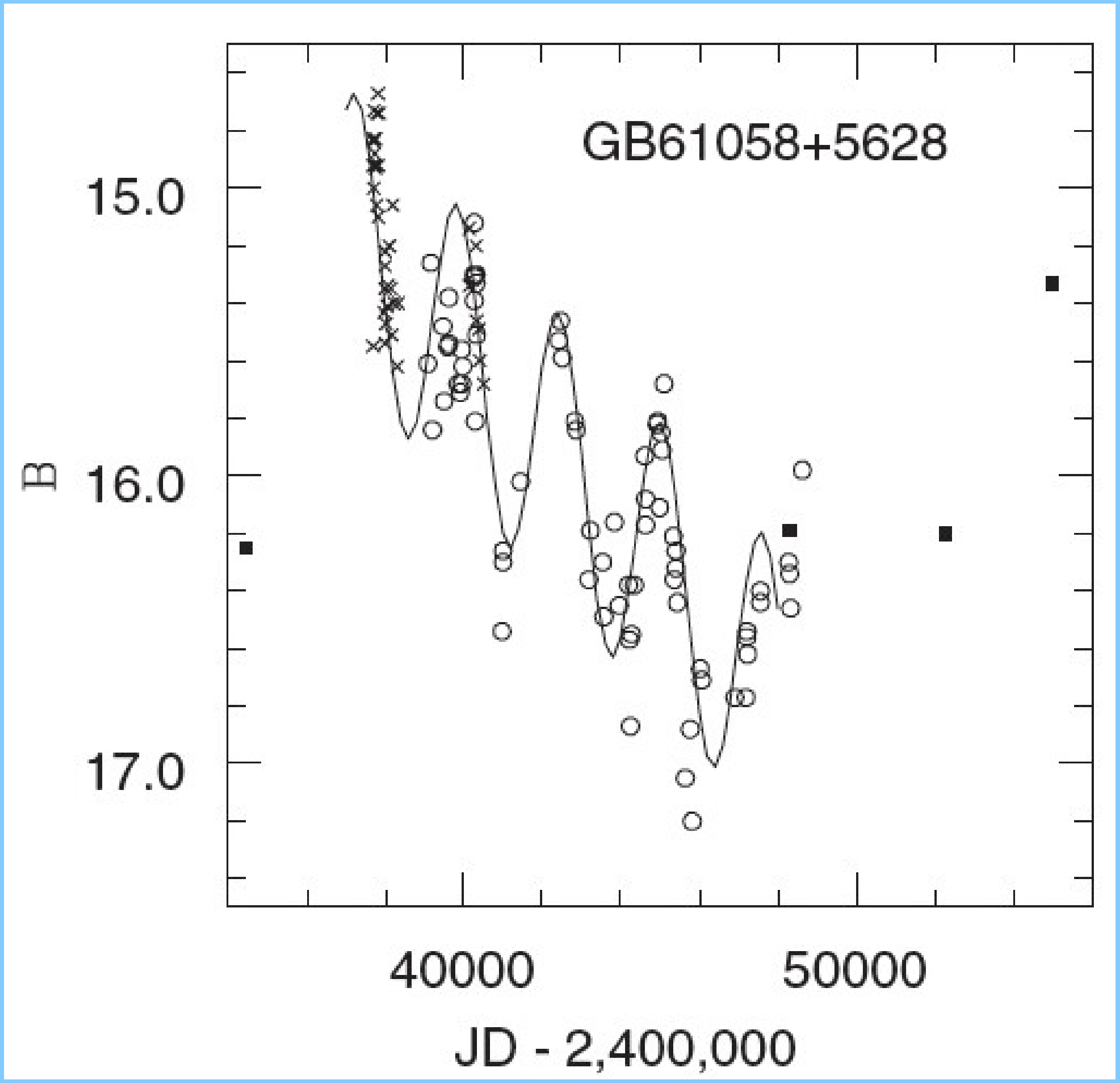
- The resulting historic light curve showed a large long term trend.
- A likely interpretation is a precession of the relativistic jet, producing a change of inclination with our line of sight and a variable Lorentz amplification factor.



GB6 J1058+5628

- Also this source is rather bright in the POSS I (B=16.2)
- 72 plates form the 67/92 Schmidt telescope were found in the Asiago archive, and 50 plates from the 40/50 one.
- Scanning and calibration procedure were the same used for S5 0716+714.
- The resulting light curve showed an average long term trend, similar to that of S5 0716+714, but with oscillations with time scale of about 7 years and 0.4 mag amplitude.

Light-curve of GB6 J1058+5628



SHAROV 21

- This source was initially interpreted as a Nova in M31
- Extensive searches in several plate archives allowed to build a light curve extending over 50 years

Table 1. Observational material for the construction of the light curve.

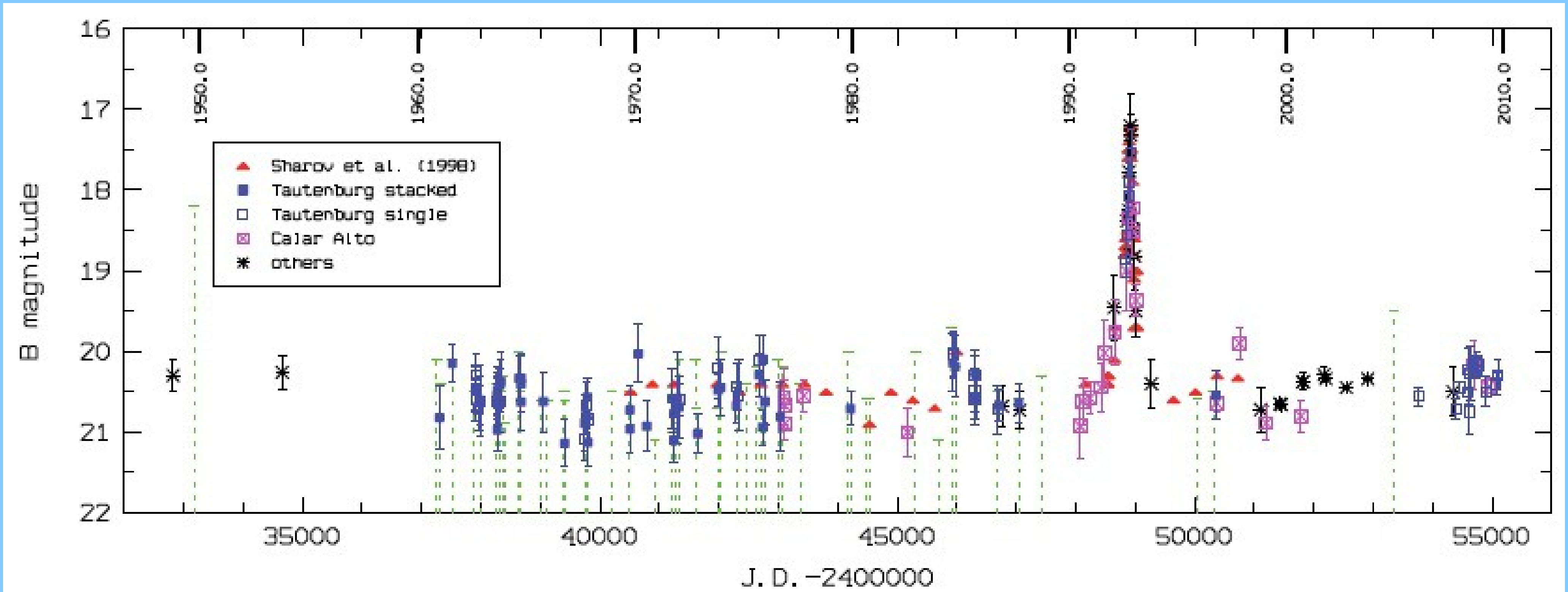
Telescope	N_t	N_e	Years	Source
(a) Digitized photographic plates:				
Asiago Schmidt	24	8	1968.8–1993.1	(1)
Calar Alto Schmidt	43	15	1983.0–2000.7	(1)
Calar Alto 1.2 m	8	5	1976.7–1982.6	(1)
Palomar Schmidt	4	4	1948.7–1989.7	(1), (3)
Sonneberg 40 cm	9	1	1992.2–1992.6	(1)
Tautenburg Schmidt	362	77	1961.5–1997.0	(1)
(b) CCD observations:				
Calar Alto 2.2 m	3	2	2008.7–2009.3	(1)
CFHT 3.6 m	1	1	1993.8	(1)
INT (WFS)	5	1	1998.8	(1)
INT	522	6	1999.7–2003.7	(2)
Kitt Peak 4 m	10	2	2000.8,2001.7	(4)
Skinakas 60 cm	5	1	2007.6	(1)
Tautenburg Schmidt	30	14	2006.1–2009.7	(1)
(c) Original data from Sharov et al. (1998):				
four other telescopes	~150	84	1969.0–1997.7	(5)

Table 2. Detection limits on plates taken before 1950.

Telescope	Plate	Date yyyy-mm-dd	$m_{pg, lim}$
Bruce astrograph LHK	23a	1900-09-14	18.8
Bruce astrograph LHK	265a	1901-08-18	18.0
Yerkes 24 inch reflector	?	1901-09-18	19.5
Bruce astrograph LHK	649a	1903-01-15	18.0
Bruce astrograph LHK	842a	1903-09-27	18.0
Bruce astrograph LHK	1384a	1905-12-26	18.0
Waltz reflector LHK	198	1907-11-02	17.5
Waltz reflector LHK	369	1908-08-20	18.3
Waltz reflector LHK	603	1909-10-19	18.5
Waltz reflector LHK	4484	1934-09-17	18.5
Bruce astrograph LHK	7163a	1949-09-20	18.2

faint to be detected in every plate archive. A high fraction of o
servations yields therefore upper limits only. In other cases t
detections are close to the plate limit resulting in relatively lar
photometric errors. Second, the epochs of the observations a

Sharov21 light curve



SHAROV 21

- Spectroscopy of the source allowed to identify its nature as a QSO
- The shape of the light curve and its uniqueness in a long time span support its origin as due to a Tidal Disruption Event (TDE) due to the capture by the central black hole of a massive star passing nearby.
- A microlensing event from a foreground star of the M31 galaxy cannot be exclude, but is less likely.

3C 345

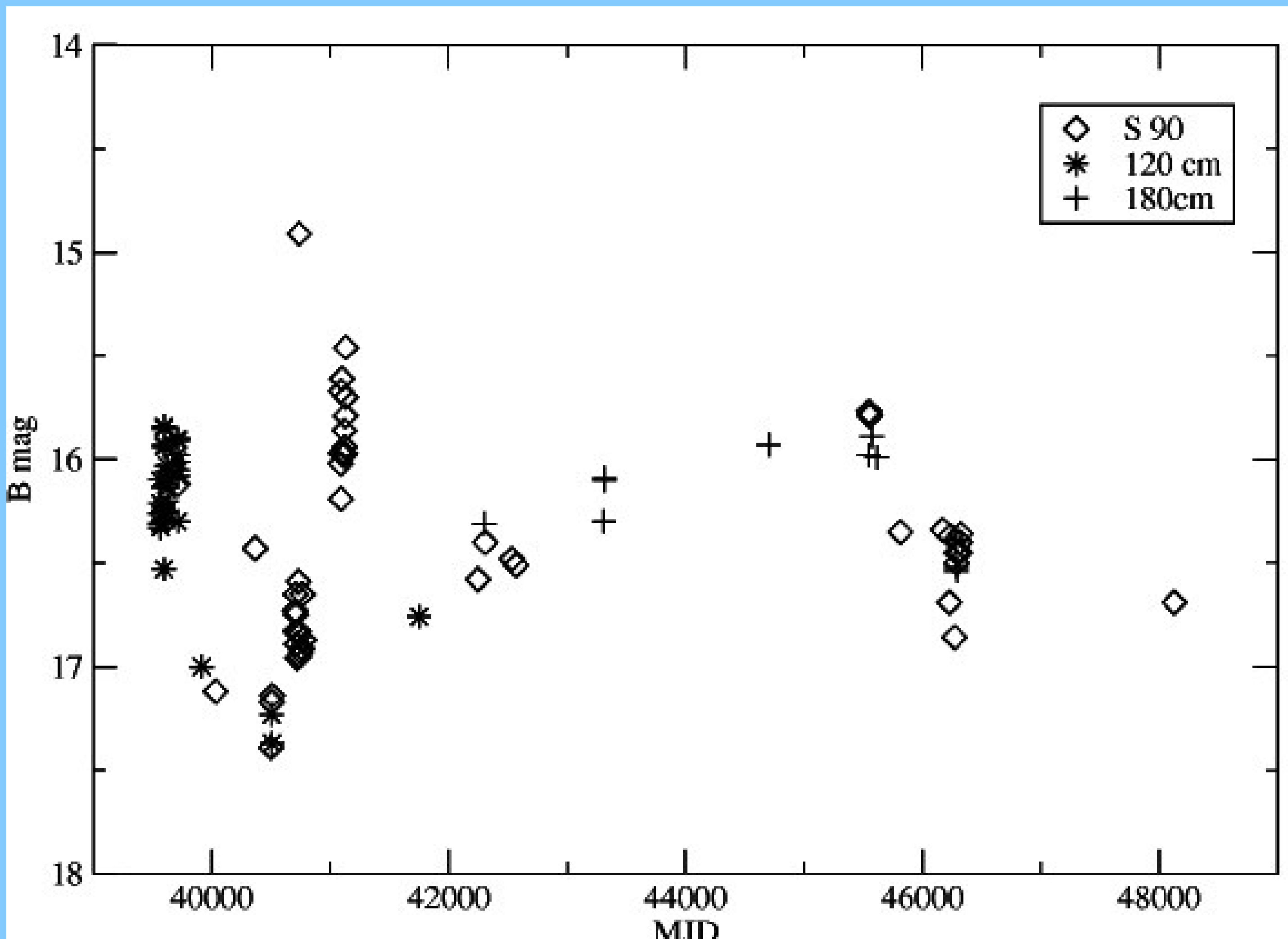
This QSO was discovered by its radio emission in 1965 as a 3C catalog source.

A comprehensive light curve form the Asiago archive was made by Omizzolo et al. (2005), including data from the 122 cm F/5 Newton, the 183 cm F/9 and the 67/92/215 Schmidt telescopes.

Photometric B sequence was taken from the USNO-B1: rms deviations of their measured values in the whole plate set were always smaller than 0.08 mag

15.6	16.4	16.3	16.6	16.4	16.8	16.3	16.5	17.3
15.53	16.72	16.46	16.66	16.45	16.98	16.17	16.16	17.48
0.07	0.06	0.04	0.06	0.05	0.05	0.01	0.04	0.08

3C 345


S 90
120 cm
180cm
B mag
MJD
14
15
16
17
18
40000
42000
44000
46000
48000

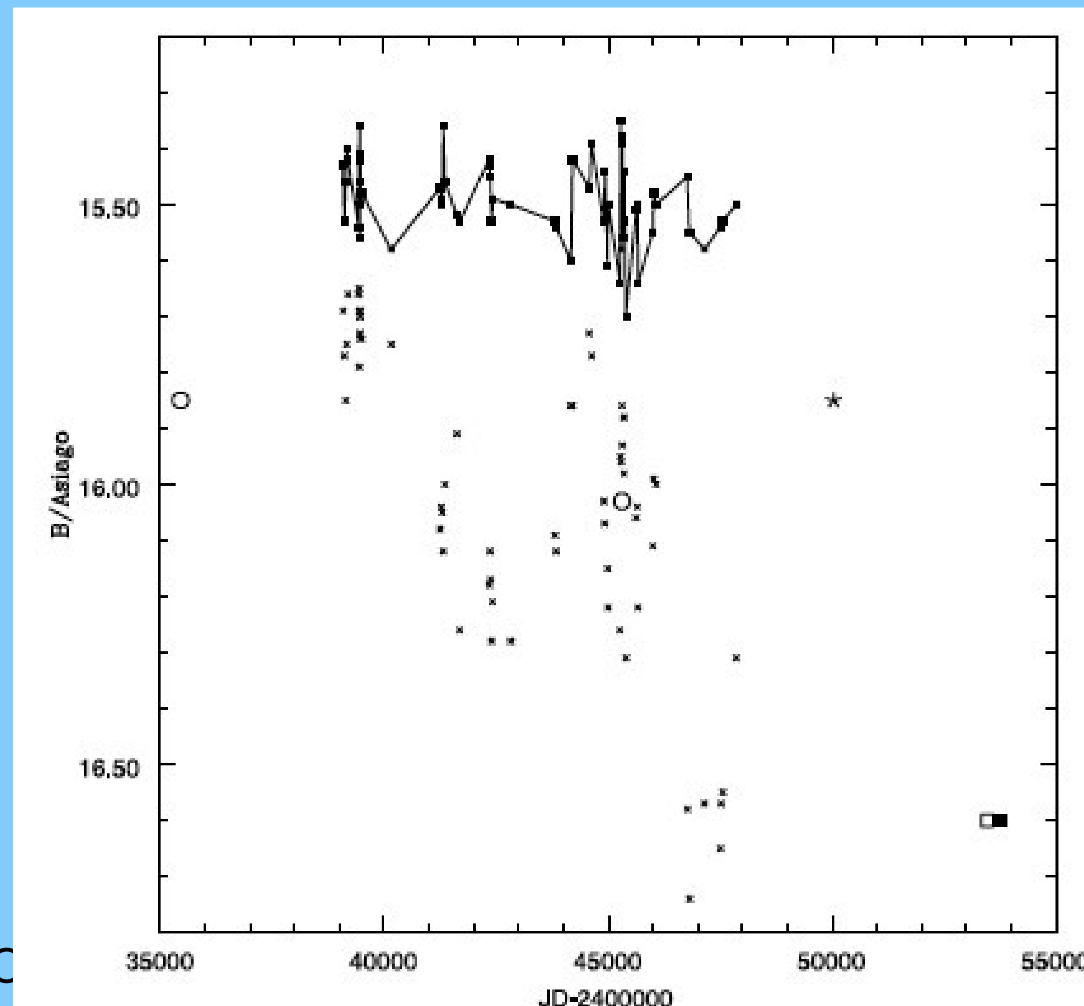
WGA J0447-0322

- Again a bright source (B=16.1) overlooked until discovered as a strong X-ray and Radio source in 1990 (ROSAT and PMN).
- Its nature was recognized only in year 2000 by Caccianiga et al., who classified it as a Flat Spectrum Radio Quasar.
- The peculiarity of this source was a high X-ray/optical flux ratio, unlikely other sources of this kind.
- An historic (1961-1990) light curve could be made from the plates of the 67/90 Schmidt for the Supernova patrol in the Asiago archive.

WGA J0447-0322

The source showed a large but not unusual variability (about 1 mag) for its class, confirming the measure of its X-ray/optical flux ratio.
The source remained therefore a counter-example against the simple model of a linear relation between the frequency peak of the SED and the X-ray power of a FSRQ.

Symbols: WGA0447-0322
Connected points: reference star



Variable stars

- Robotic telescopes for NEO, GRB and SN searches are discovering also a great number of previously unknown variable stars.
- Objects with rare flares, like Cataclismic Variables of the WZ Sge type, are being more easily detected, because a large fraction of the sky is monitored frequently and automatic searches for variability are performed.
- Searches for previous flares, to confirm the star nature and derive tentative time scales of exceptional flares can be made using plate archives.

Some examples

Historic outbursts of MASTER OT J023406.06+384142.4. Nesci 2013, IBVS 6083.

A prediscovery spectrum of KT Eri (Nova Eridani 2009); Nesci et al. 2009, Atel#2338.

The case of the pre-main-sequence star V582 Mon (KH 15D); Maffei et al. 2005, MNRAS 357, 1059.

J023406.06+384142

- This variable was discovered by the MASTER network of robotic telescopes.
- The star was included in three fields of the Asiago Supernova patrol in the years 1960-1990. Overall I checked 565 plates of the 50/40/100 cm and 86 of the 92/67/215 cm Schmidt telescope, covering about 24 years: the number of nights with useful observations was 384.
- Seven outbursts were detected, recorded in 31 plates.
- A recurrence around 320 days was inferred, which is within the range for Cataclysmic Variables of the SU UMa type, supporting the tentative classification of this star.

Nova Eridani 2009

- No previous outbursts of this Nova were known at the epoch of its discovery in 2009.
- A spectrum of this star was recorded in an objective-prism plate of the First Byurakan Survey taken in 1973 with 102/130/213 cm Schmidt telescope and 1.5 degree prism.
- The digitized plates of the Survey are on-line at the website byurakan.phys.uniroma1.it/index.php (see the presentation by Mickaelian at this Conference).
- Spectra are available also in VO format at

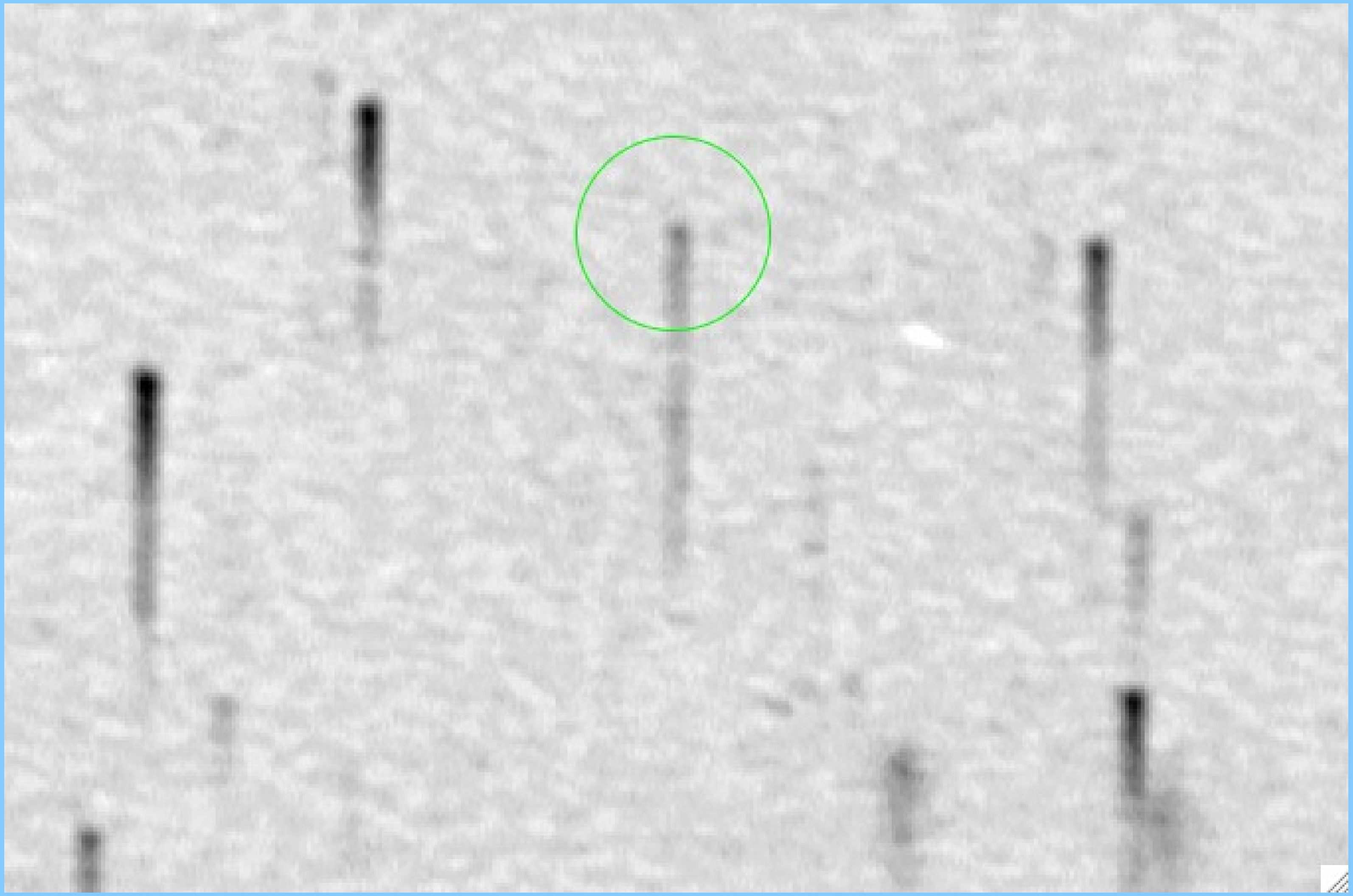
http://byurakan.oact.inaf.it

- The spectra of all known objects brighter than B=17 in the USNO-A2 catalog have been automatically extracted and are available on-line.

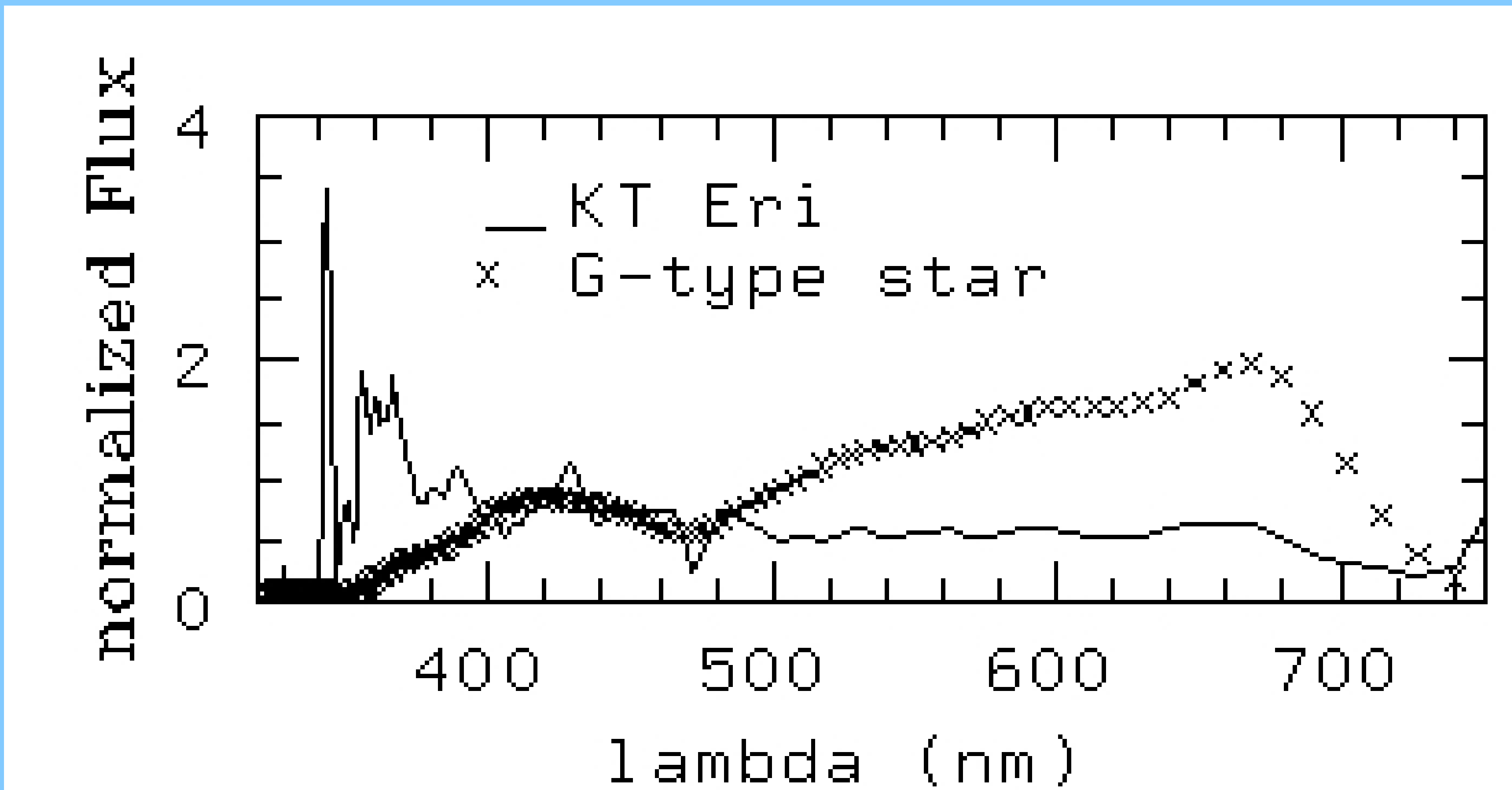
Nova Eridani 2009

- The spectrum of the Nova was present in the plate, but clearly was not automatically extracted because the star was not present in the catalog.
- Its spectrum was therefore manually extracted with IRAF/apall together with spectra of a few other stars on the same plate for comparison.
- It showed the presence of several strong emission lines up to the near UV, typical of the post-outburst nebular phase of the Novae.
- It was therefore possible to discover the nature of recurrent Nova for this interesting star.

Spectrum of KT Eri on DFBS



KT Eri (Nova Eri 2009)



Crosses: average G-type star on the plate; Line: KT Eri

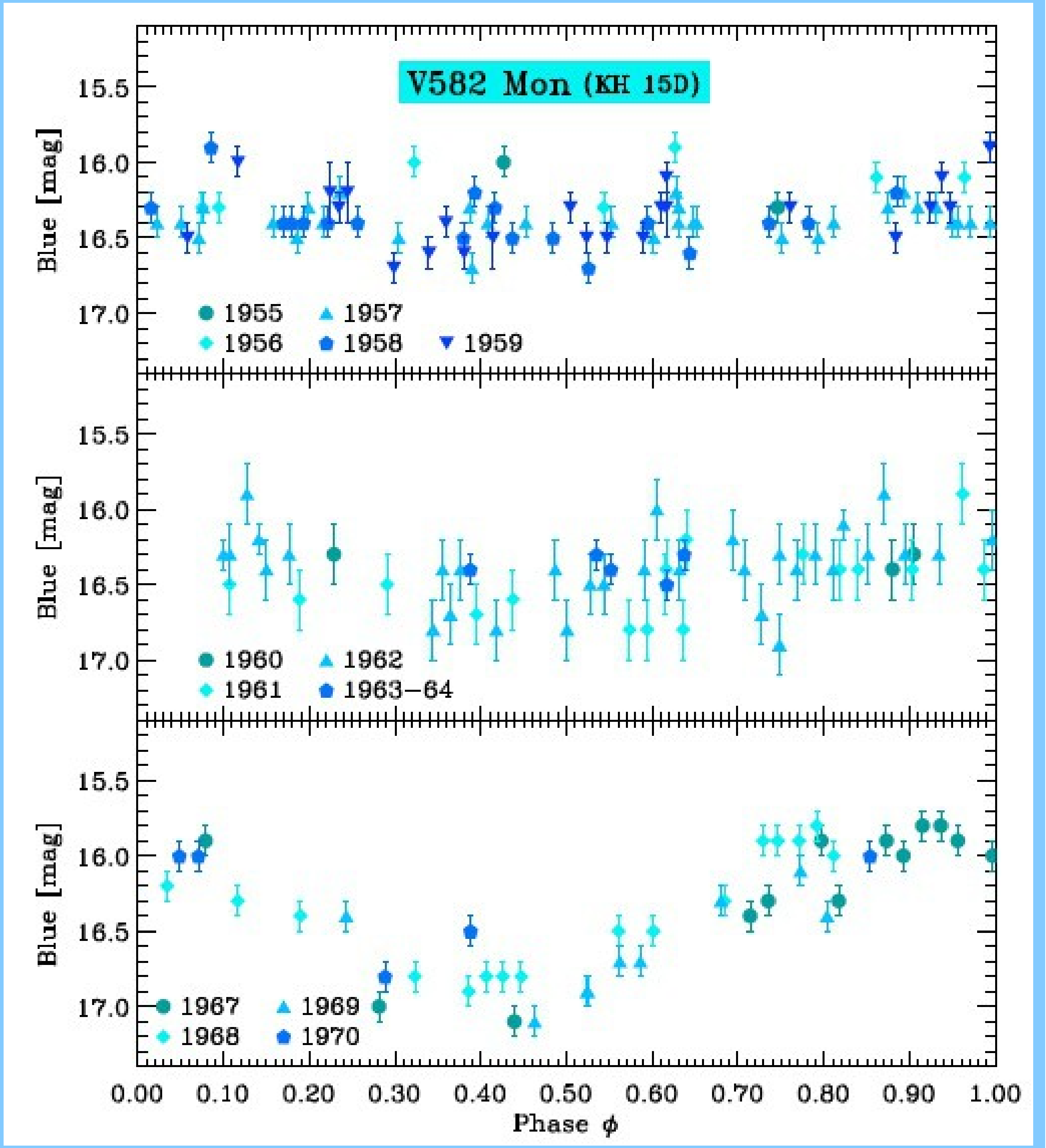
V 582 Mon (KH15D)

- Another example of the usefulness of long time monitoring, for scopes rather different from the original one, is the strange case of a Pre Main Sequence star, V 582 Mon, in the field of NGC 2264.
- This star was found to have regular eclipses with a period of 48.3 days (Kearns and Herbst 1998) with modern CCD photometry.
- A reanalysis of the plates in the B and I bands from the Asiago Observatory of this open cluster, much observed as reference field for comparison stars, was made by Maffei et al. (2005).
- Surprisingly, the star was stable from 1955 to 1958, then eclipses first appeared in the B band, in 1958, with the same period of the modern observations,
- only after four years they started to be visible also in the I-band.

Light curve of V582 Mon

Upper panel: years 1955-59
Middle panel: years 1961-64
Lower panel: years 1967-70

The onset of the eclipse in the B band and its deepening is evident.



V 582 Mon (KH15D)

- In the Asiago data the light - curve shape appears to be sinusoidal and is therefore different from the present one.
- The photometric behavior, determined with time-series and color-index analysis, suggests that V582 Mon could initially be surrounded by an accretion disc/torus seen edge-on, with subsequent thin dust formation at the beginning of the blue radiation absorption.
- The dust could then aggregate into larger particles providing the transition between selective and total absorption, accompanied with eclipsing variability in the IR.
- The minima of the periodic light curve become deeper owing to the increasing dimension and number of dust grains, and then flatten owing to a contraction in the disc.

The Perugia scan project

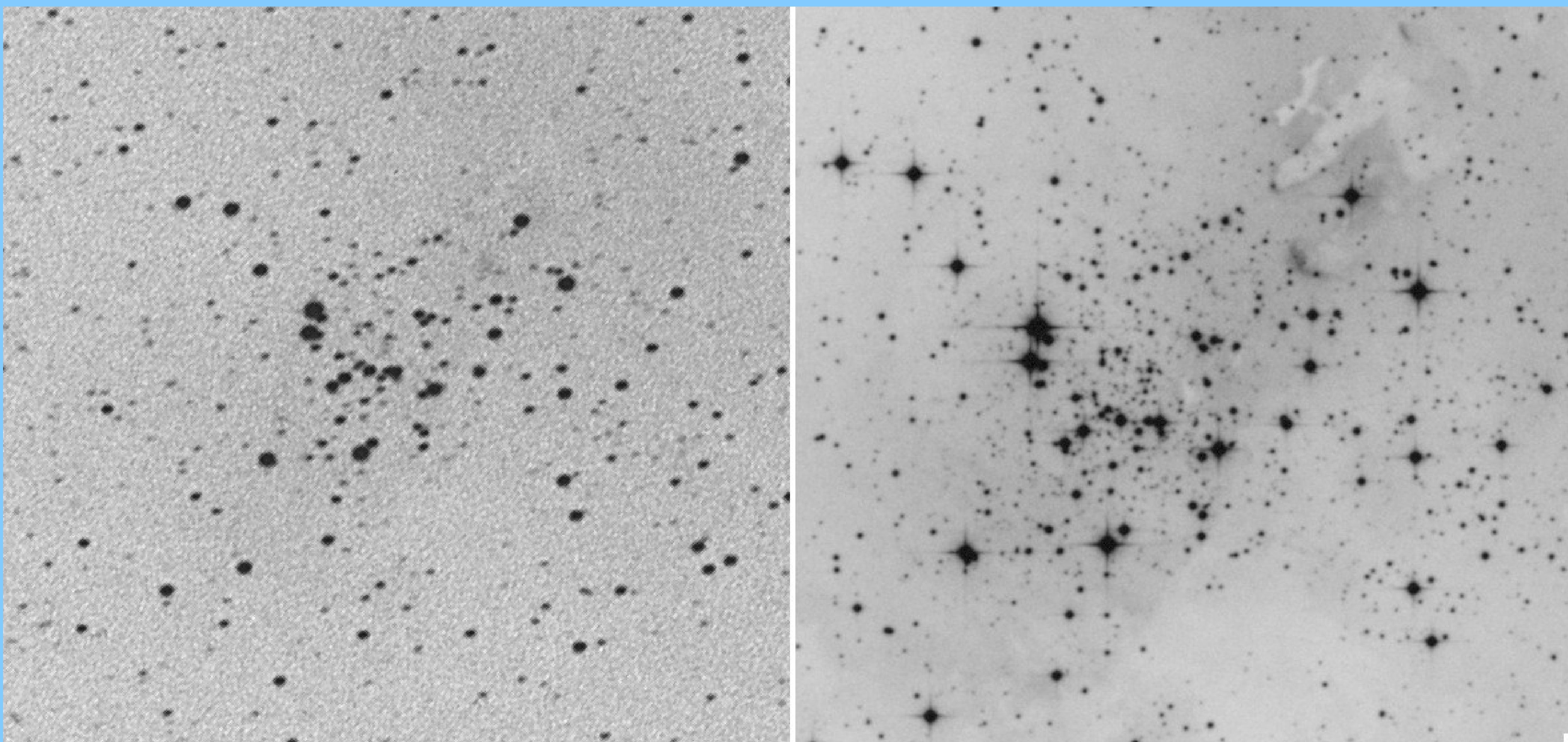
- At the death of prof. Paolo Maffei, a large number of Schmidt plates collected by himself were still at the Department of Physics.
- Before sending them back at their home Institutions, it was decided to scan those which fitted into the A4 size scanner of the Dept. an EPSON 1680 Pro.
- The plates regarded four fields along the galactic plane, centered at bright or remarkable objects for ease of identification, namely: M16 (long=16), Gamma Cyg (long=78), Gamma Cas (long=123), IC1805 (long=134).
- The plates covered a time interval form 1963 to 1983.
- Each night a couple of plates were taken, in the B and I bands (Kodak 103aO+GG13 and I-N+RG5).

The Perugia scan project

- Both Schmidts of the Asiago Observatory were used and, since 1980, also the Catania 40/50/120 cm Schmidt. The limiting magnitude is generally I=16.
- The aim was to compare the frequencies of Mira stars at different galactic longitudes and to study the behaviour of these stars in the blue and infrared spectral regions, which was supposed in the 60's to be much different.
- Lists of variables were published in several numbers of IBVS;
- For the field of M16 also a light curve catalog was published (CDS II/320)
- In total we have scanned 306 plates of M16 (of which 149 from the Catania Observatory), 45 plates of Gamma Cyg, 199 plates of Gamma Cas, 160 plates of IC 1805.
- Furthermore, we digitized also 45 images of NGC 2264 (l=203), which were taken for calibration purposes, and 9 images of the Baade window near the globular cluster NGC 6522 towards the galactic center (l=1). Three other plates, centered on SN 1971 I (nearly overlapping the Gamma Cas field) were also scanned.

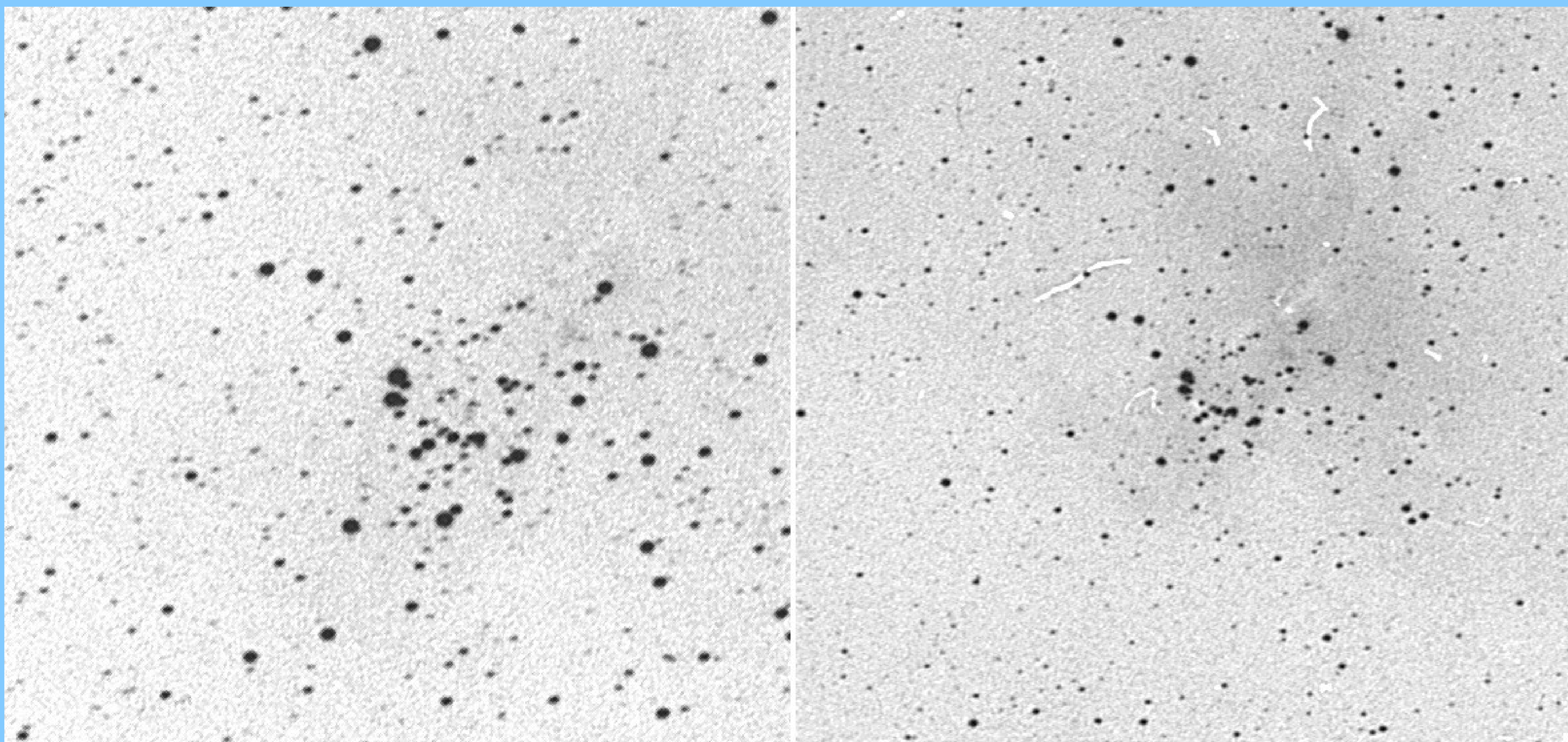
Scanned plates

Asiago 65cm (left) and UK120cm (right) Schmidt I-band M16 field



Scanned plates

Asiago 65 cm (left) and Catania 40 cm (right) Schmidt I-band M16 field



Next step

- We plan to perform the astrometric solutions of these plates and to make them available on line in a near future. This will allow an easy check of the light curves, identification of possible blended sources with nearby IR stars, and comparison with recent Mid Infra Red catalogs (e.g. AKARI, WISE).
- Overall more than 400 known variable stars are present in the digitized fields, and likely a number of others wait to be discovered.
- We hope that, for most of these stars, geometric parallaxes from the GAIA mission will be available, allowing a study of their 3D distribution on the galactic plane.

Some statistics

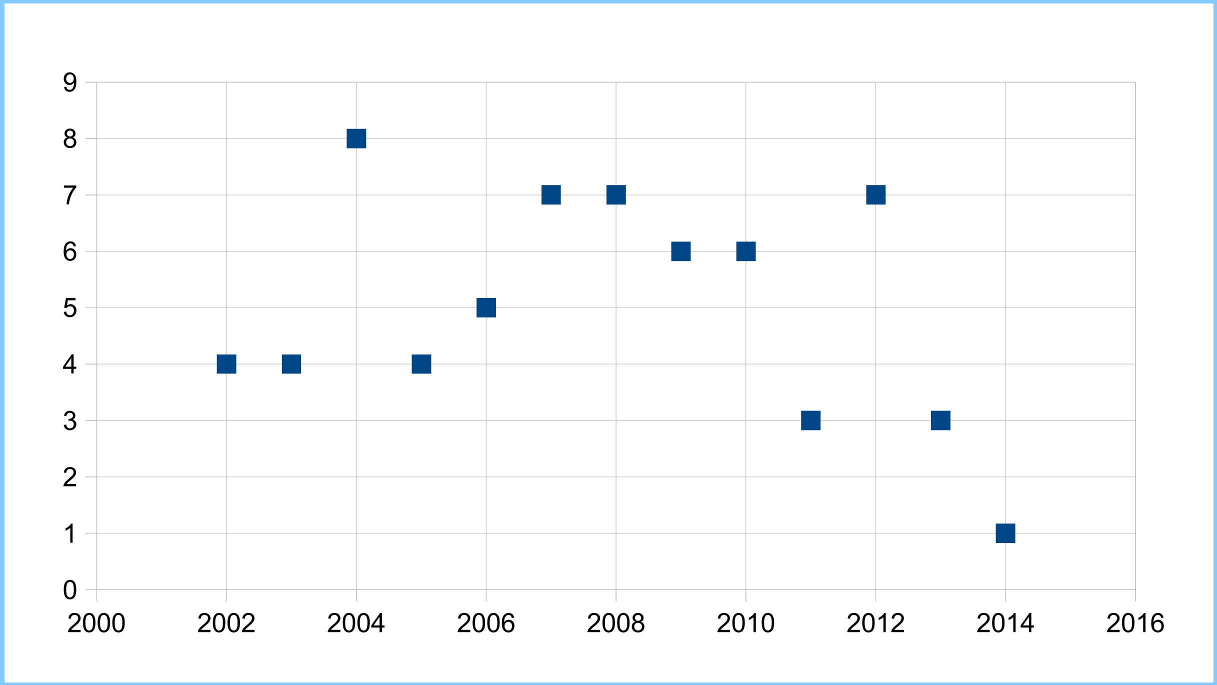
- Befor concluding, I would like to present a small statistical search on how many research papers are currently being written which make use (also) of data taken from astronomical plates.
- The simple use of the Digital Sky Survey as finding chart, though still fundamental in optical research and in follow-up of high-energy sources, has not been considered.
- Surely it is not complete, but the aim was jut to have a feeling of the impact of old data on current research.

Some statistics

- I made a statistical seach on ADS on how many papers include in the abstract the words PLATE and ARCHIVE since the year 2002.
- The starting year was selected because in that year the project of digitizing the Asiago plate archive with commercial flatbed scanners was started.
- After checking the real content of the 483 papers found by the automatic search, I found 380 papers with astrophysical content.
- Most of them are Conference Proceedings (including Bull. A.S.S.)
- Many are Astronomical Circulars (27 CBET; 5 Ate; 29 GCN; 14 IBVS; …)
- There are 7 books.
- But a number of papers is on refereed journals with high Impact Factor.

Main Journal Statistics

- A&A 21
- AJ 13
- PASP 8
- ApJ 7
- MNRAS 5
- SPIE 5
- Ap&SS 3
- Balt A 8
- TOTAL 71
- 3 of them were also put on arXiv.

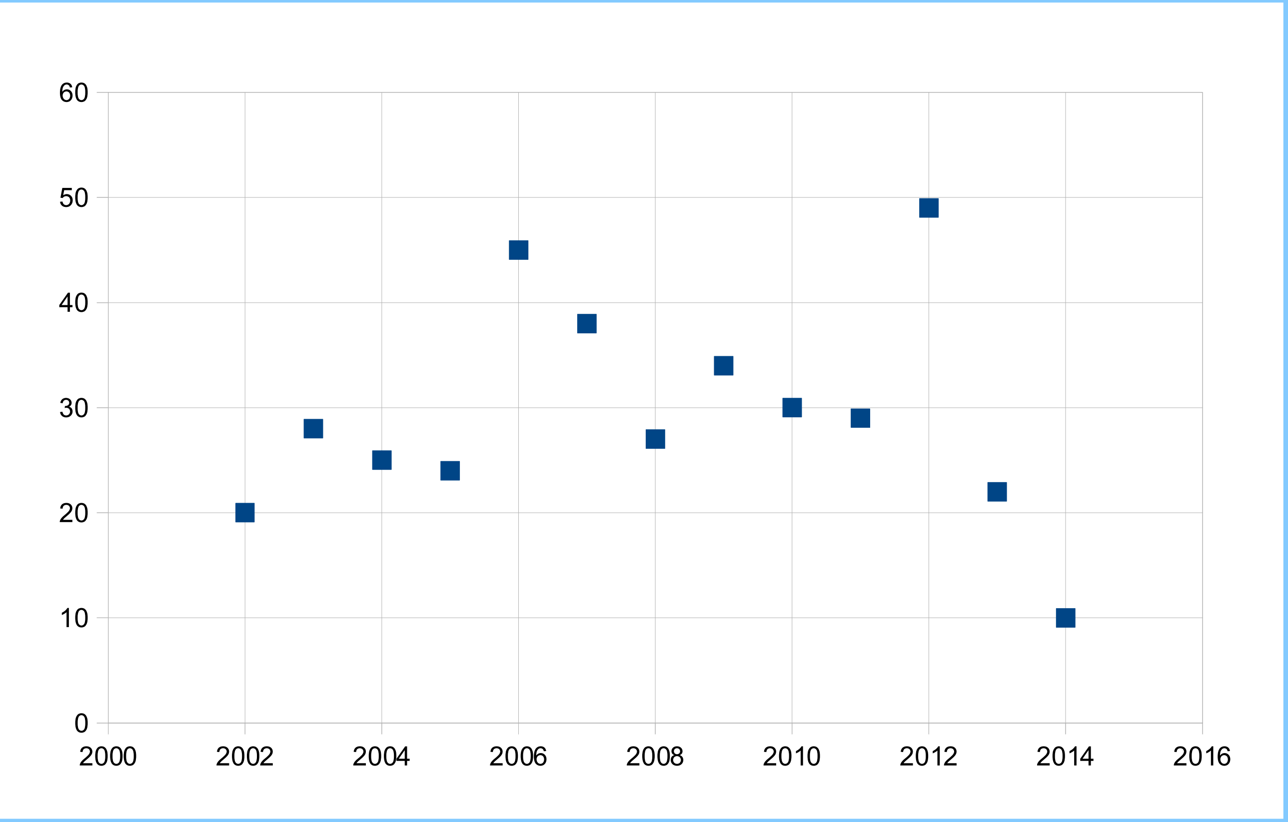


The publication rate may be considered constant, between 5 and 6, given the overall small numbers and assuming Poissons statistics.
Year 2014 is at the very beginning.

Overall statistics

Using all the papers published we get the following diagram:
The publication rate is stable around 30/years.

The peak in 2012 is due to GCN circulars.
Year 2014 is just at the beginning.



Conclusions

- We have shown a few examples, mainly from my direct experience, where the access to plate archives has been the key tool for astronomical research.
- Keeping this treasure of past observations available to the future generations of astronomers is, in my opinion, a duty for our community, not only for respect of the hard work of our forerunners, but to allow unsuspected discoveries to be made at a very low cost.