Re-reducing old observations: a challenge for the next decade

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Purposes of the astrometry of solar system bodies

- Space navigation (ephemerides)
- Dynamics, stability, evolution, scale of the solar system
- Impact hazard assessment (ephemerides)
- Space and ground based observations (ephemerides)
- Physics of the surfaces and interiors of solar system objects
- Gravitational and relativistic studies
- Reference systems

How re-reducing old observations can help?

Interest of old observations

- The interest of old observations is for the fitting of parameters of a “time-dependant” model.

- Old astrometric observations are necessary for:
  - Making of ephemerides accurate on a long interval of time with a better modeling of long periodic terms
  - Studying the evolution of solar system and quantifying accelerations

Ephemerides extrapolation

- When fitting the model on the observations, we calculate the external error <u>for the period of the observations</u>

- How to extrapolate the external error to <u>a period in the future</u> where no observation is available?

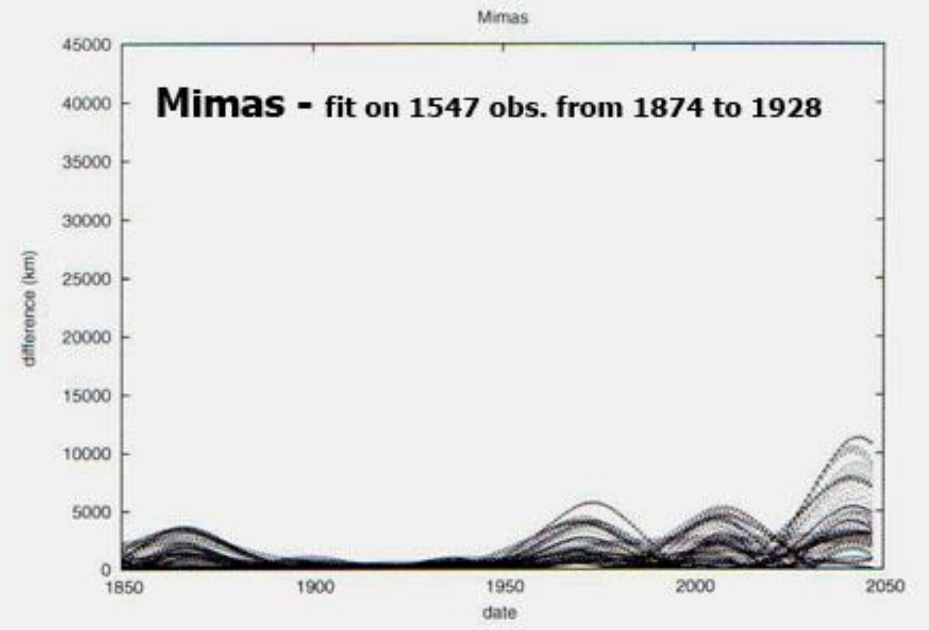
- This extrapolation depends on the use of old precise observations <u>enlarging the period of validity</u> of the ephemerides.

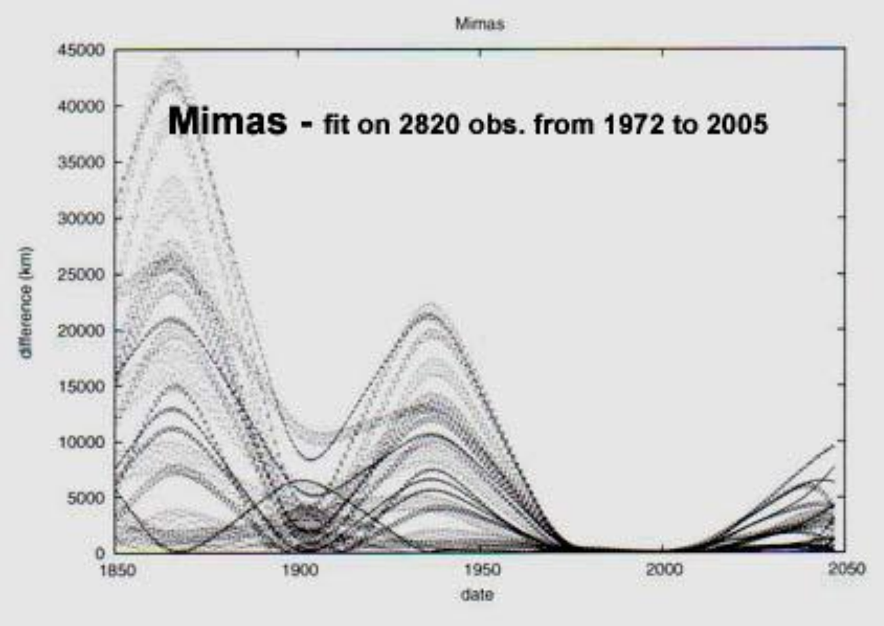
The extrapolated accuracy of the ephemerides: example of the Mimas ephemerides

- Several ephemerides based upon the same set of observations deduced by random hold-out (Desmars et al. 2009)

- This shows the importance of long period observations preferred to short period with better accuracy

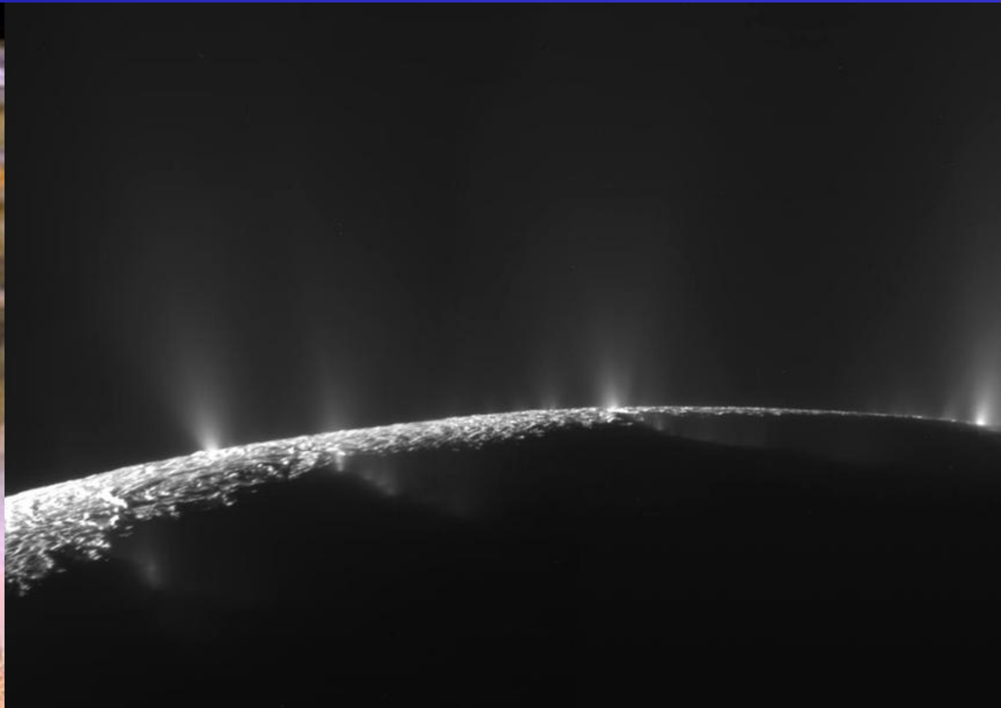
Case of Mimas: 50 years – 1547 obs. (accuracy: 0.30") preferable to 30 years – 2820 obs. (accuracy 0.15") due to short term libration (70 years)



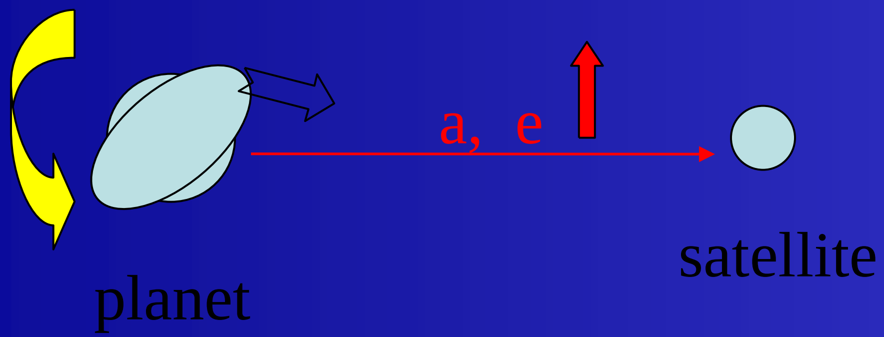


Searching for acceleration terms

- Examples:
  - Thermal equilibrium of Io
  - Geysers on Enceladus

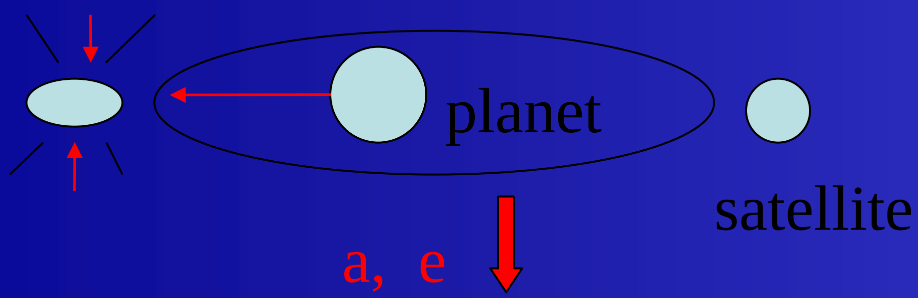


Tidal effects and acceleration in the motion



Tides from satellite to planet

Satellite escapes



Tides from planet to satellite

Satellite falls

Acceleration observable through astrometric observations

The Saturnian system

searching an explanation of the formation and evolution of the Saturnian system thanks to old data

Other examples

- The « pre-discoveries » of Pluto
  - Presence of Pluto on old observations never reduced will help because we did not observed a complete revolution of Pluto around the Sun
- Near Earth objects
  - Pre-discoveries
  - Better accuracy on old observations sensitive to ephemerides extrapolation

An old observation

- What is an old observation?
  - An observation made in the past
  - A genuine original observation under the form of a plate or a numerical image
  - An observation with all needed metadata
    - Date in a time scale linkable to UT, exposure time
    - Information on the instrument (aperture, focal length)
    - Information on the support (plates, CCD, filter, …)
- What about measurements without the observation itself?
  - Need of more information
    - Date, instrument
    - Reference frame
    - Corrections applied to the measurements
    - The measurements themselves

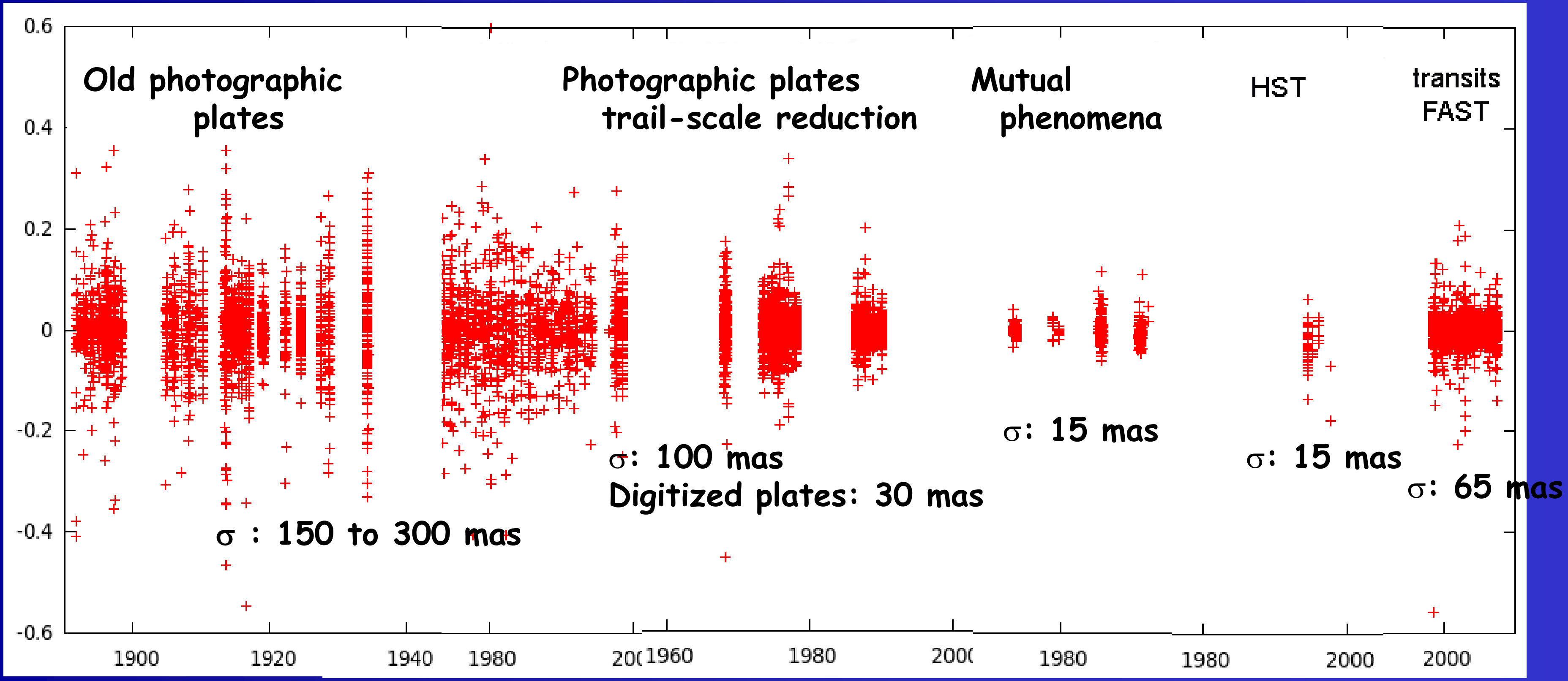
A new reduction

- What is the interest of a new reduction?
  - Modern techniques of measurements (automatic instead of manual: better?)
  - A position in a recent reference system?
  - The use of more complete models of reduction?
    - with a better refraction model
    - including differential refraction
    - correcting small effects such as coma
    - taking into account color effect in refraction or magnitude effect (plates)

Observational techniques

Technique	Present accuracy	Objects	Improvement
Transit circle	50 → 100 mas	mag 6-15	probably
Scanning telescope	50 → 100 mas	→ mag 20	possible
Tangential focal plane images	20 → 2000 mas	all	yes
Planets through satellites	20 → 50 mas	Mars, Giant planets	yes, only for giant planets
AO, IR	a few mas (relative)	inner objects	no?
Photometric events	1 → 10 km (relative)	main planetary satellites, asteroids	no, depends on size of objects
Gaia	0.1 → 1 mas	mag 7 → 20	50 obs./5 years
VLBI, Doppler space probes	2 → 10 mas	objects visited by space probes	yes for obs. with stars
Radar	10 → 100 m	Near Earth Objects	no
LLR	1 → 3 cm	The Moon	no

Compared accuracy of the observations



Old reductions might be improved (300 mas → 50 mas)

The main problem of the old observations

- Which star catalogue has been used?

- Unfortunately, old observations were reduced with the only tools available at that time. For example, star catalogues were very poor inducing directly a poor accuracy for the observations.

- What are the limits of a new reduction?
  - Only zonal corrections?
  - The present star catalogues are not able to describe the sky more than 30 years ago.
  - What about Gaia catalogue?

- From what is the inaccuracy of old observations?
  - The support (plates, old CCD targets,….)
  - The former manual measurements ?
  - A bad reduction?
  - The calibration (star catalogues, …) ?

The present star catalogues

Year	Name	Nb of stars	Mag limit	Accuracy mas	Accuracy pr motions	Origin
1997	Hipparcos	120 000	12.4	< 0.78	< 0.88 m/y	obs. from space
2000	Tycho 2	2 500 000	16	< 60	< 2.5 m/y	from Tycho and 143 sources
1998	USNO A2	526 280 881				
2001	GSC II	19 000 000		360		Schmidt plates
2003	USNO B1	1 billion	21	200		Schmidt plates
2004	UCAC 2	48 000 000	7.5 $\rightarrow$ 16	20 $\rightarrow$ 70	1 $\rightarrow$ 7 m/y	scans
2004	Bright stars	430 000	< 7.5			Hipparcos + Tycho2
2005	Nomad	1 billion				compilation of best entries
2006	Bordeaux	2 970 674	15.4	50 $\rightarrow$ 70	1.5 $\rightarrow$ 6 m/y	$+11° > \delta > +18°$
2003	2MASS	470 000 000	16	60 $\rightarrow$ 100		Infra red K
2015	GAIA	1 billion	20	< 0.01 mas		obs. from space

The re-reduction of old observations

- Using the original reduction
  - Necessary when no plates are available
  - By making only a zonal correction?

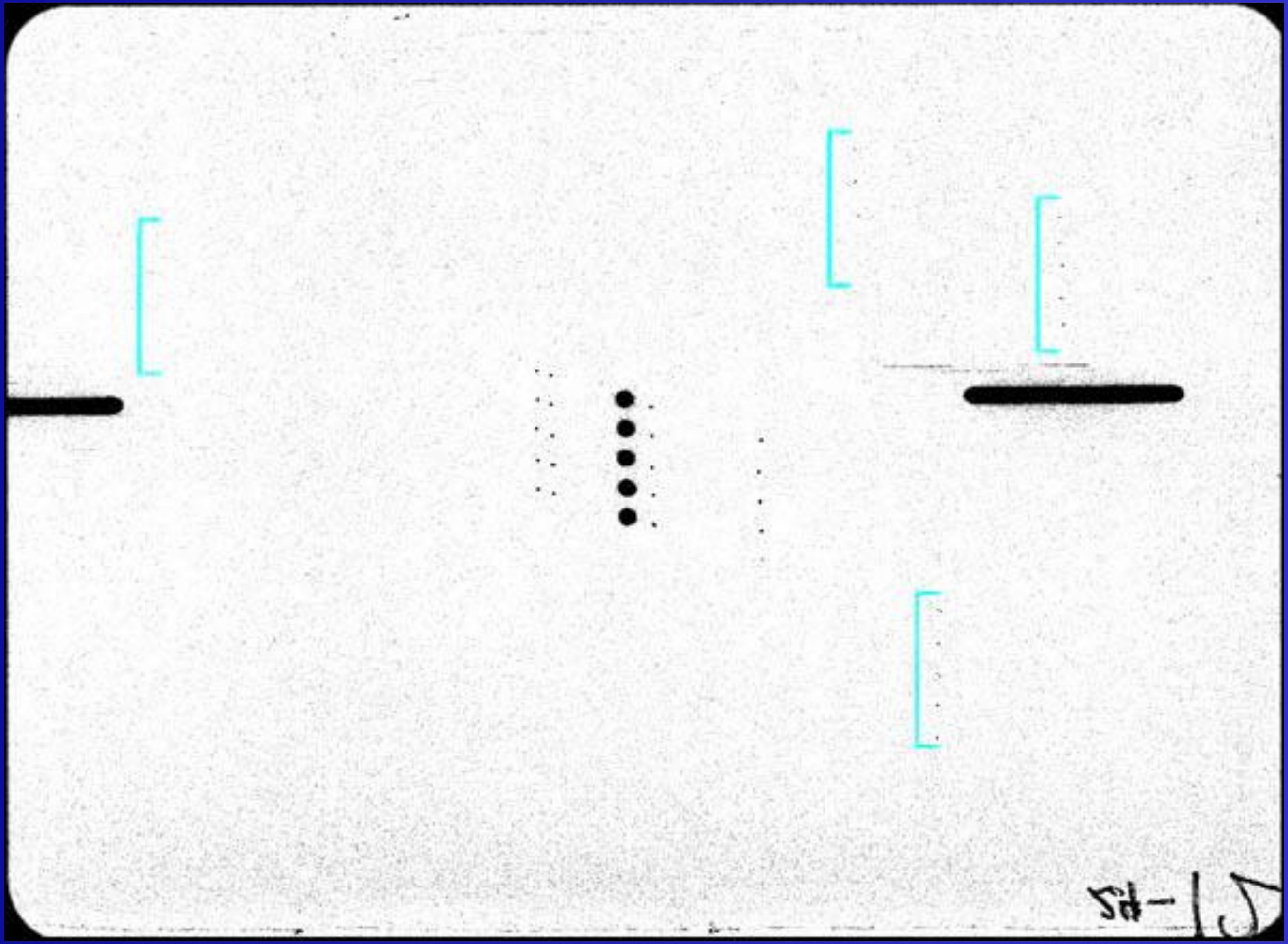
- Performing a new reduction
  - When the plates are available and in a good shape
  - For how old plates (20 years, 50 years, 100 years?)

What are old observations?

- Photographic plates
  - Raw measurements (have we all the needed information to re-reduce or improve these data?)
  - Numerical images by scanning of the plates
  - Too many data → choice of:
    - Objects
    - Period of time
- Where are the plates?
  Paris, USNO-Washington DC, ROB-Brussels, RGO-Greenwich, Pulkovo, Bucarest, Shanghai, ESO, Bordeaux, Kiev, Sofia, SAI-Moscow,…

Photographic plates from USNO

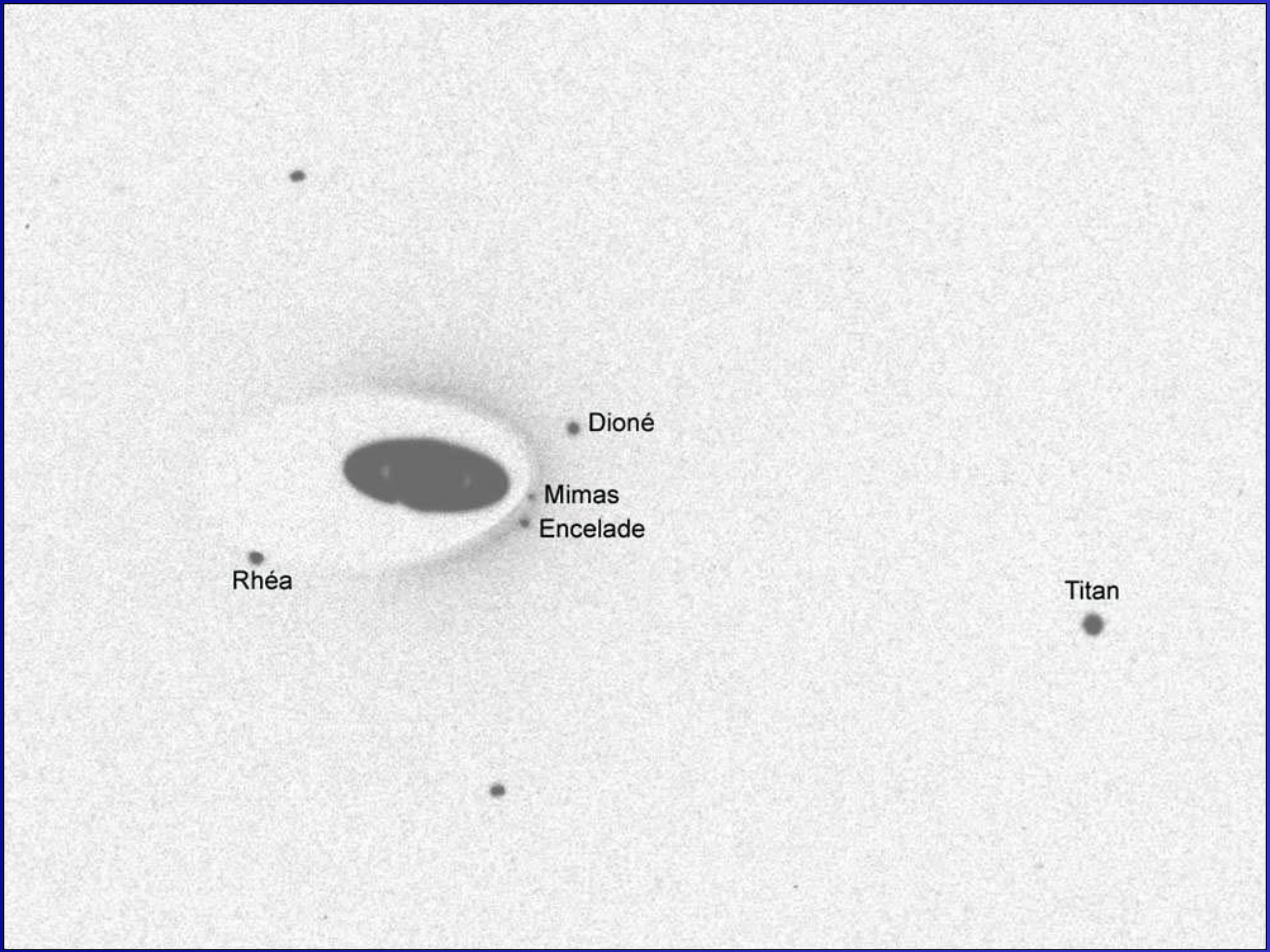
Galilean satellites



USNO photographic plates made in the 1970's:

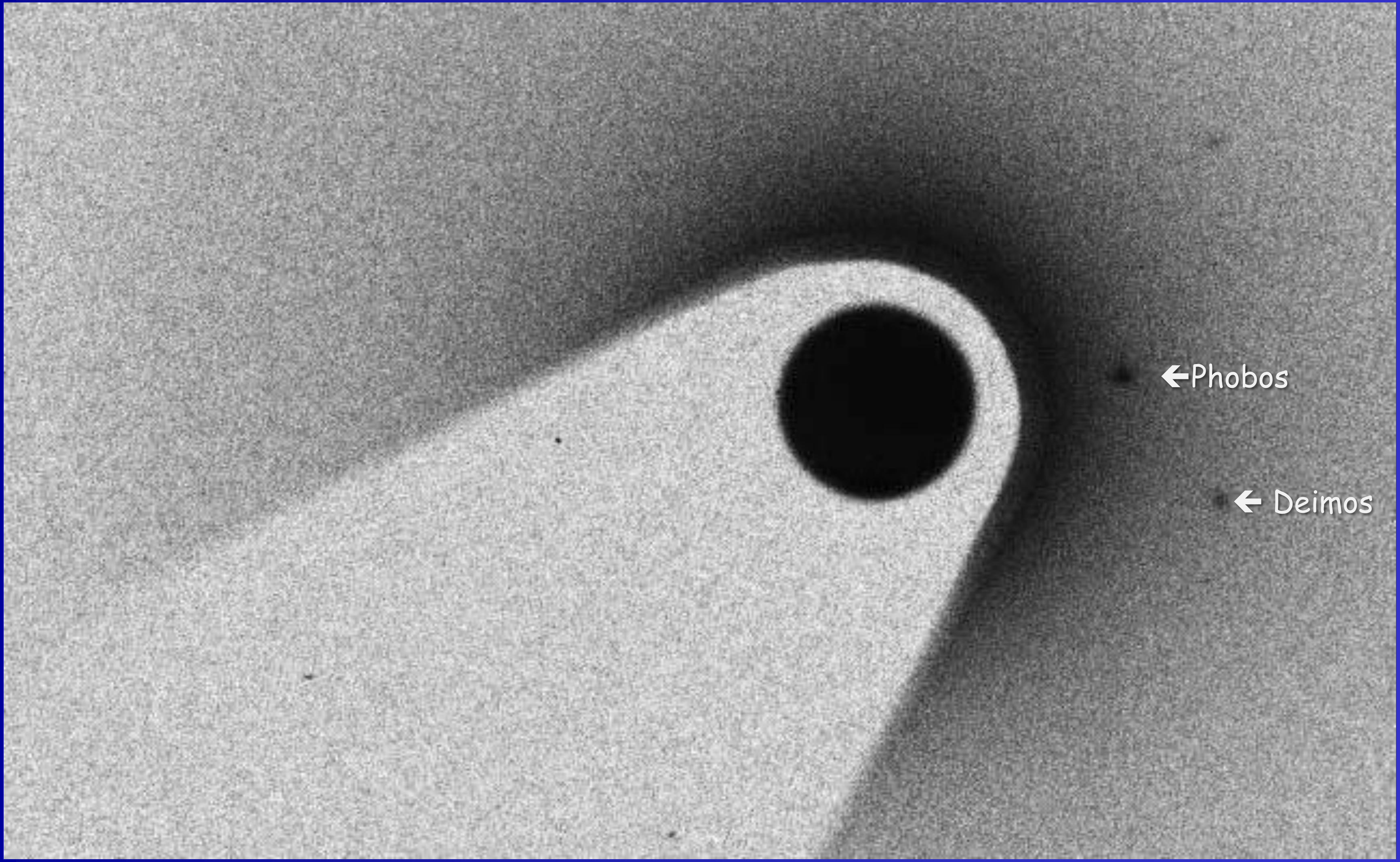
- from 5 to 17 stars per plate (more stars detected by the scanner)

The main Saturnian satellites



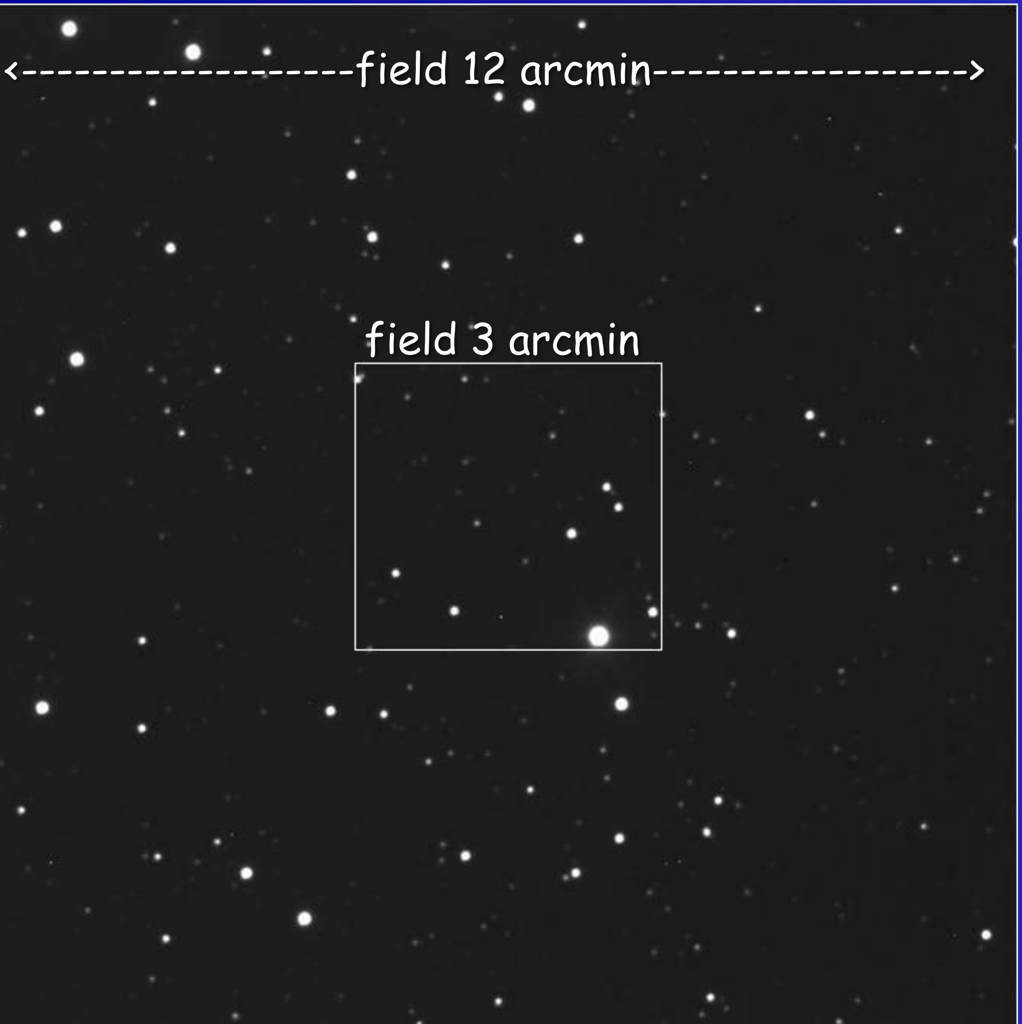
USNO photographic plate taken in the 1970's

Plates Mars, Phobos et Deimos



Ground based CCD observations made in the 1980's:

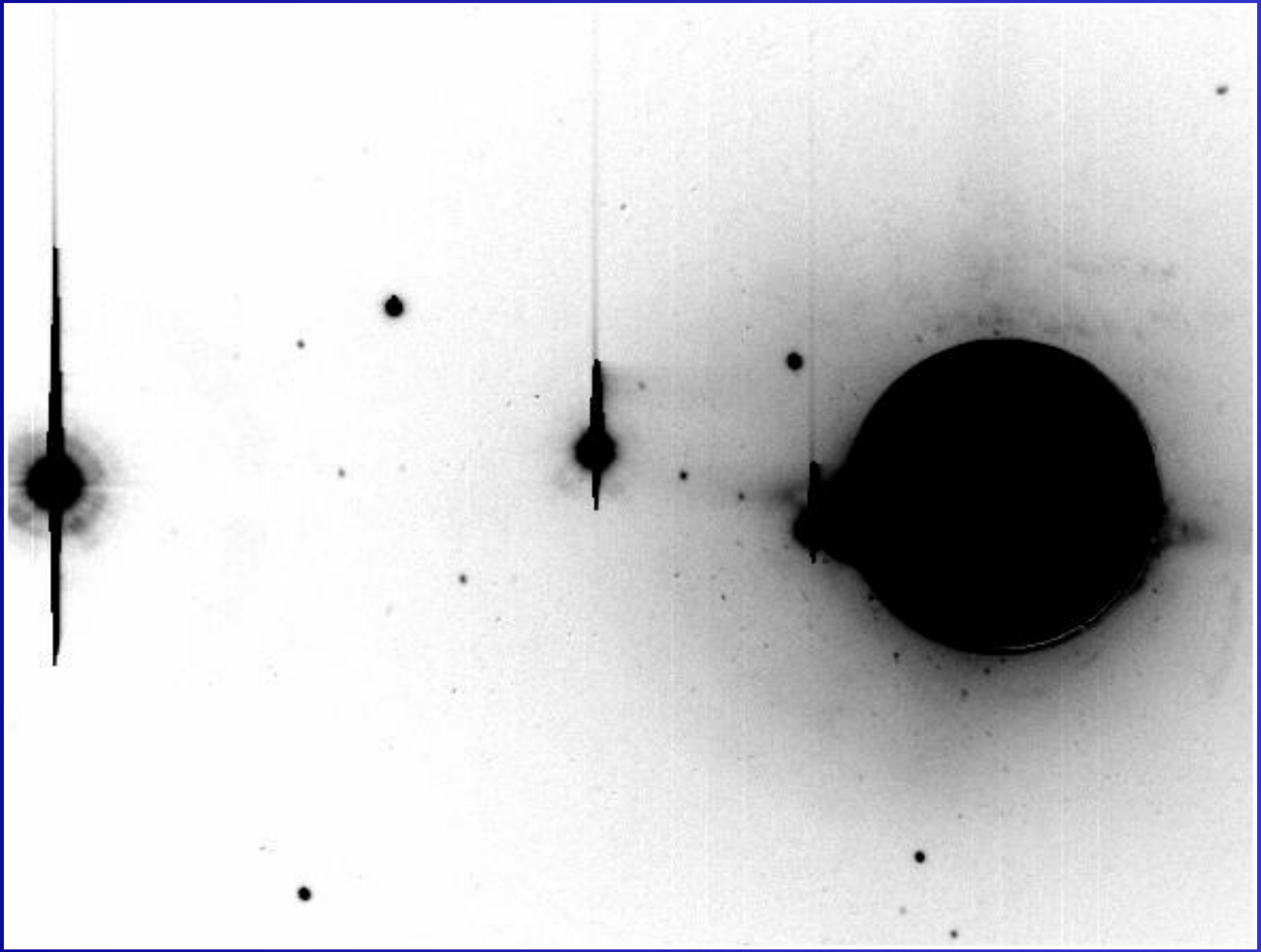
they are old observations!



Very small fields difficult to reduce with the star catalogue link method

The GAIA catalogue of stars will provide very accurate positions for many more stars than former catalogue

CCD observations are old observations…



CCD observations of Dione, Tethys and the Lagrange L4 librators Helene and Telesto with the Flagstaff 61-inch telescope

CCD observations

The large satellites: the Eight main satellites of Saturn

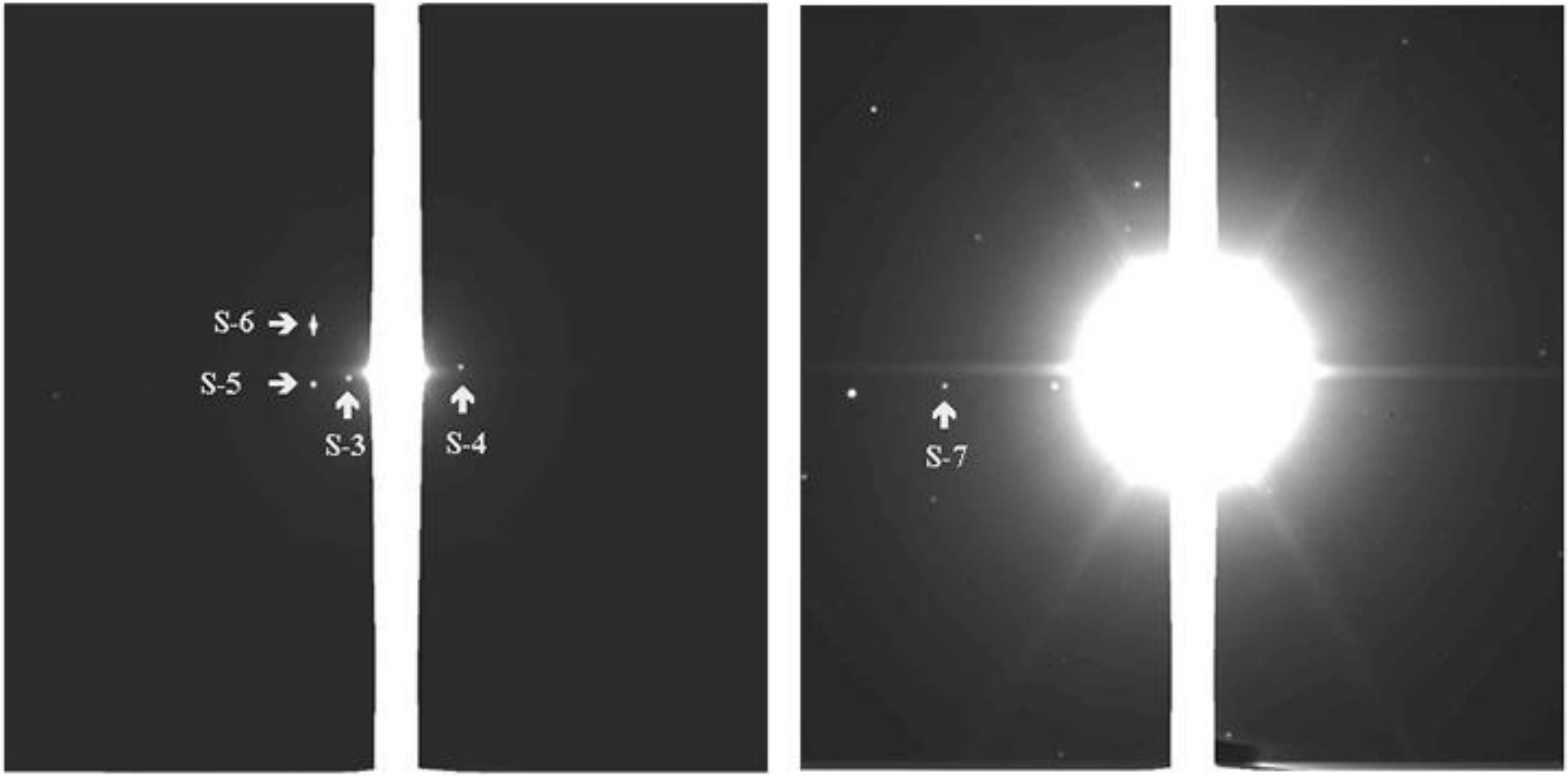


Image made at Observatoire de Haute Provence with the 1.2m telescope

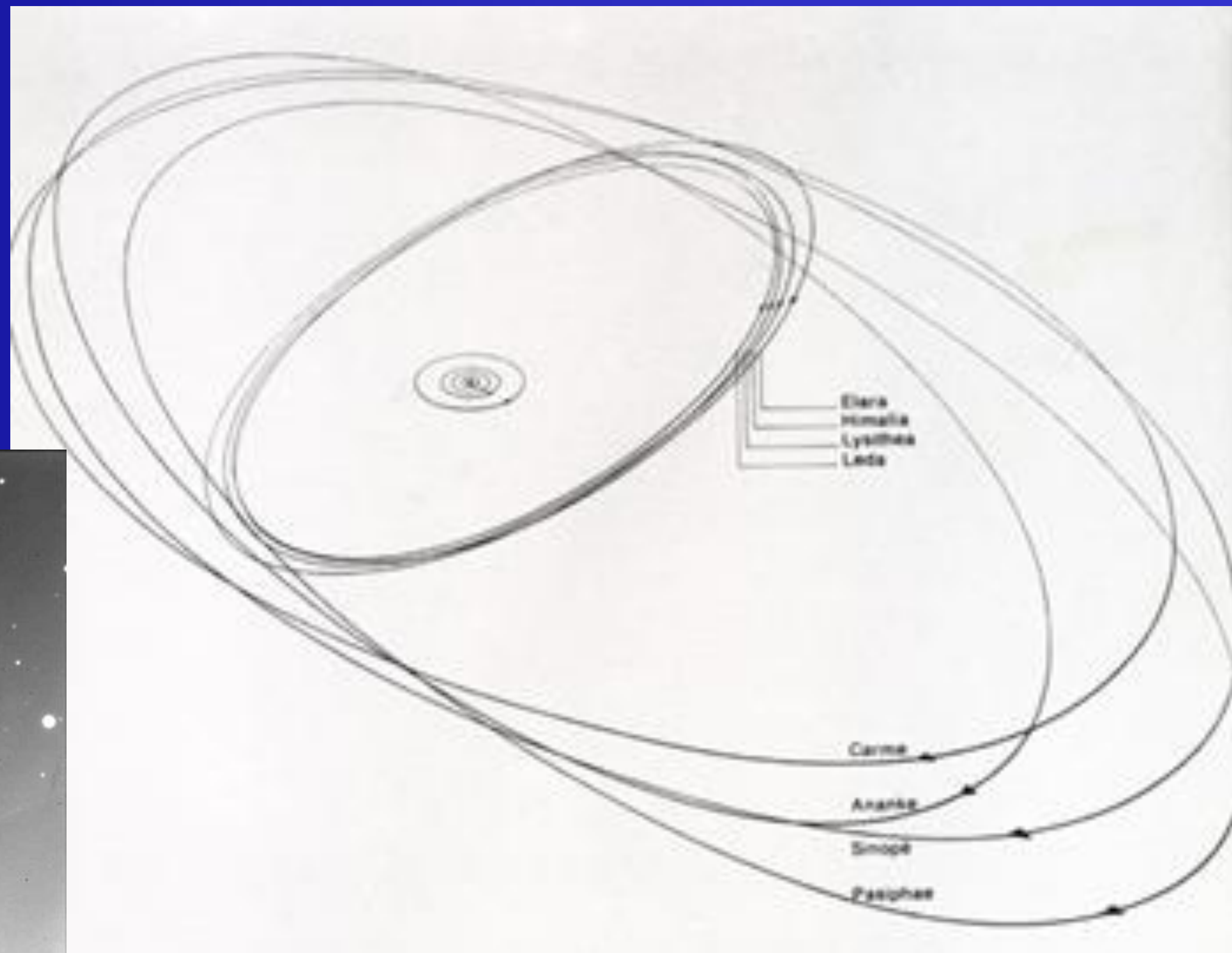
Not enough stars due to the short exposure because of the brightness of the satellites

CCD observations of the Uranian satellites

🡐 CCD observation (small field)

➔ For the Uranian system, the unknown precession is reachable through the observation of the satellites (very time dependant)

The irregular satellites

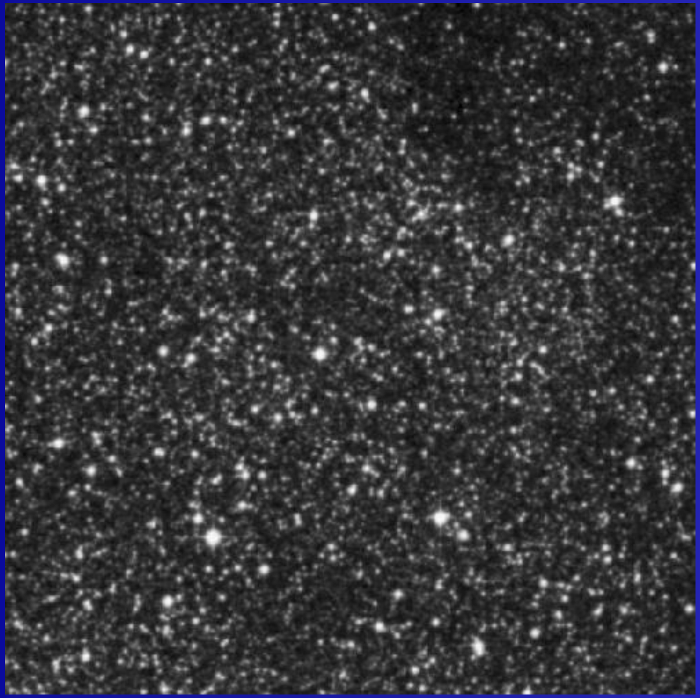


Outer satellites of Jupiter: two families

Some problems for the reduction

Satellites observed in the past with Schmidt plates:
how to re-reduce Schmidt plates?

Objects of the solar system are moving in either rich or poor field (here 10x10 arcmin):



Be careful when selecting old observations to be sure to be able to make a good reduction

Observations of the planets

- The giant planets are difficult to observe for astrometric purpose
- The satellites are easier to observe and their ephemerides provide the position of the center of mass of the planet

- In the past, the satellites were observed referred to their primary
- With a new reduction we are able to get RA and DEC of the satellites and then going back to the center of mass of the system ➔ new observations of the planets in the past

Space probes observations are old observations!

- The astrometric observations of solar system bodies used star catalogues

  ➔ they can be improved

Cassini Camera ISS

Field 0°.35 Dione (1120 km) and Enceladus (512 km)

Stars from UCAC2 (magnitude 9)

60 mas (UCAC2) = 3 km

1 mas (GAIA) = 50 m

In order to observe in the past, we must scan plates

Observing in the past

- the number of available plates makes necessary the coordination of this task
- selecting plates from scientific purpose
  - Objects
  - Period of time
- scanning the plates with adapted scanners and optimal criteria (pixel size, accuracy of positioning,…)
- reducing them starting with UCAC2 waiting for GAIA
- keeping images and distortion parameters for later re-reduction

The selection of old data to be re-reduced

Example: using the database of natural satellites to select the old data to be re-reduced

- Satellites of Mars:

3000 observations from 1877 to 1988 (14 per year per satellite)

Need to digitize plates from 1990's in order to avoid gaps

- Galilean satellites of Jupiter:

12000 observations from 1891 to 2001 (27 observations per year per satellite)

Need to digitize old plates from 1890's in order to improve old data and all un-reduced observations

Need to reduced data in intersatellites into RA and DEC

- Main satellites of Saturn

50641 observations from 1874 to 2003 (49 observations per year per satellite)

Need to digitize plates from 1920's to avoid gaps

Need to reduced data in intersatellites into RA and DEC

The NAROO project

Conclusions

- starting the « **N**ew **A**strometric **R**eduction of **O**ld **O**bservations » project

- making inventories of plate archives with objects, field, quality of plates, dates, …, all available through a common web site (Virtual Observatory?)

- selecting plates to be analyzed

- choosing criteria and parameters for digitization

- preparing reduction programs taking into account the increase in accuracy

- making a specific databases for files of digitized plates