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To cite this version:

Josselin Desmars, Alain Vienne, J. E. Arlot. A new catalogue of observations of the eight major satellites of Saturn (1874-2007). Astronomy & Astrophysics - A&A, 2009, 493 (3), pp.1183-1195. 10.1051/0004-6361:200810203 . hal-00588233

HAL Id: hal-00588233
https://hal.sorbonne-universite.fr/hal-00588233v1

Submitted on 22 Apr 2011

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A&A 493, 1183–1195 (2009)
DOI: 10.1051/0004-6361:200810203
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Astronomy & Astrophysics

A new catalogue of observations of the eight major satellites of Saturn (1874–2007)*

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Received 15 May 2008 / Accepted 2 September 2008

ABSTRACT

Context. The lastest catalogue of observations includes about 51 000 observations (over 3500 nights) of Saturn's satellites from 1874 to 1989. Since 1989, many observations have been published, often in different formats, based on the publication.
Aims. Our new catalogue of observations of the eight major satellites of Saturn includes the observations of the previous catalogues, newly published data and also old observations left out of the previous catalogue. The observations are tabulated in a consistent format.
Methods. We give, for each observation, the corrections applied for reduction such as refraction, aberration or phase effects. Furthermore, when it was possible, the instrument and catalogue are also indicated.
Results. The new catalogue presents more than 130 000 observations (over 6000 nights) of the eight major satellites of Saturn from 1874 to 2007.

Key words. catalogs – planets and satellites: individual: Saturn – astrometry

1. Introduction

The improvement of natural satellite ephemerides and the knowledge of their dynamical motion are required to fit dynamical models to observations.

Since the publication of the Strugnell & Taylor catalogue ST90 (1990) and the Harper & Taylor extension HT94 (1994) which tabulate in total about 67 000 observations of Saturn's satellites, many other observations have been realized and published. Our aim is to extend these catalogues by adding new and also old observations that previously have been ignored. We call the new catalogue COSS08 for Catalogue of Observations of Saturnian Satellites, and 08 because it is the 2008 version of the catalogue. We plan to update the catalogue with new observations in the future.

Although Saturn's satellites have been observed since the 17th century, the oldest observations of COSS08 come from USNO in 1874. The most recent ones come from Flagstaff in early 2007. During this long period (more than 130 years) many observations have been carried out by many different observers publishing their data in different formats. To compare observations with theoretical positions, all these observations have to be tabulated in a single and consistent format. The same format as the ST90 catalogue has been used as a basis, and other parameters have been added.

2. The observations

The first Saturnian satellites were discovered in the second part of the 17th century by Huygens (for Titan) and by Cassini (for Tethys, Dione, Rhea ans Iapetus). Mimas and Enceladus were discovered more than one century later by Herschel in 1789. Hyperion was discovered by Bond and Lassell in 1848. Since their discovery, Saturn's satellites have been observed to better understand their motion. Observations of satellites can be classified in seven different types:

- timing of elongation, opposition and conjunction;
- visual micrometer measures;
- photographic astrometric measures;
- automatic meridian transit circle measures;
- CCD image measures;
- photometry of mutual events;
- HST observations.

The first six ones (ground-based observations) are explained and detailed in HT94. In the last one, observations are from the Hubble Space Telescope (French et al. 2006). A first data-collection of observations was made by Pierce (1975) who tabulated observations of Saturn's satellites from 1789 to 1972. Consistent Harper & Taylor (1994), our catalogue does not deal with timings of elongation, opposition and conjunction made in the late 18th and in the 19th century, because they are few in number and low in accuracy. Furthermore, these observations are very specific, appearing to be specific events. So, their reduction in position is particular and will be the object of a forthcoming paper. The period of the catalogue stretches from 1874 to 2007.

COSS08 is a compilation of four different sources of observations. The first two are observations from ST90 and HT94.

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* The catalogue is available in electronic form at the CDS via anonymous ftp to `cdsarc.u-strasbg.fr (130.79.128.5)` or via
`http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/493/1183`

Article published by EDP Sciences

The large part of the added observations comes from the Natural Satellites Data Center NSDC (Emelianov & Arlot 2005). Some recent observations also have been tabulated in COSS08.

2.1. The Strugnell & Taylor catalogue (Ref. Code 1-61)

ST90 is made up of 51 000 observations (over 3500 nights) of the eight major satellites of Saturn. The observations from 1874 to 1989 are tabulated in a consistent format. We use the same format but we add new parameters (see Sect. 4). Moreover, the Reference Code used in ST90 has been kept. This code characterizes each bibliographic reference and each instrument used by giving reference. Thus, in a few cases, when different instruments have been used in a reference, this reference can present different Reference Code numbers.

A brief history and description of those observations of Saturn's satellites can be found in ST90.

As we will see (see Sect. 2.3), some observations of ST90 have been reduced again since the catalogue's publication. New reduced data have been favoured in COSS08 because of their better accuracy.

Among these observations, the Tolbin ones (Ref. Code 30 in ST90) have been reduced again (Tolbin 1991b). The new reduced positions replace the initial ones in COSS08 (Ref. Code 510). Likewise, the Tolbin observations (Ref. Code 33 in ST90) are replaced in COSS08 by the observations that have been reduced again (Tolbin 1991a) (Ref. Code 511).

In ST90, some groups of observations have not been published, for example, observations from Veillet and Dourneau, and from Pascu. The first ones have been published in Veillet & Dourneau (1992), but the Pascu ones still have not been published. Request for these data must be made to the author.

A longitude discrepancy due to phase effects has been detected by Aksnes et al. (1986) in mutual phenomena observations of the Galilean satellites of Jupiter in 1973 and of the Saturnian satellites in 1980. They proposed corrections to these observations (Aksnes et al. 1984) that we have taken into account in COSS08 for the Saturnian satellite observations.

2.2. The Harper & Taylor catalogue (Ref. Code 101-243)

Harper & Taylor (HT94) have compiled over 15 000 new ground-based observations of the major satellites of Saturn in order to fit analytical theory to the observations. They used an extended version of the Strugnell & Taylor catalogue. This includes observations made at the Lick, Yerkes and Leander McCormick observatories between 1894 and 1922. Most of those observations are visual micrometer measures.

2.3. The NSDC database (Ref. Code 420–552)

The Natural Satellites Data Center (Emelianov & Arlot 2005) provides data on natural planetary satellites (except the Moon). On the NSDC web site[1], each group of observations is published in its original format. A file gives information about time scale, reference system, reference frame, observation type, instrument used and sometimes catalogue reference and corrections (aberration, refraction, etc.) for reduction.

In the nomenclature of NSDC files, the rule for the Reference Code is as following: observations in the file called sm00XX on the NSDC web site will have Ref. Code 5XX in COSS08. For example, observations in Debehogne (1979) appear in file sm0004 on the NSDC web site. Then the Ref. Code of those observations is 504 in COSS08. Observations in Noyelles et al. (2003) are the single exception to the rule, because we kept the distinction between best observations (Ref. Code 420) and acceptable observations (Ref. Code 421).

When a CCD camera has been used, most observations are given in raw data. This means that the satellite positions are given in intersatellite coordinates and in pixels units. These data can be expressed in classical units (arcsec) with a scale factor and the orientation of the receptor (see Harper et al. 1997, for more details).

For observations in Harper et al. (1997, 1999), Vienne et al. (2001a), Peng et al. (2002) and Veiga et al. (2003), satellites were observed on the CCD images and their coordinates given in relation to an arbitrary origin, the CCD image center. To express the satellite positions, we make a choice between observed satellite and reference satellite. This choice for the reference satellite is in the order: Rhea, Titan, Dione, Tethys, Enceladus, Mimas, Hyperion, Iapetus. For example, if Enceladus, Dione, Titan and Iapetus were observed on the same CCD image, three observations are given in our catalogue: Iapetus-Titan, Enceladus-Titan and Dione-Titan[2]. This choice is related to the accuracy of the ephemerides of each satellite. For example, Titan and Rhea have better known orbits than Mimas, Iapetus or Hyperion. Also, Rhea has been more observed than Titan.

As we saw in Sect. 2.1, some observations of ST90 have been reduced again since the publication of the catalogue. Observations from the Nikolaev observatory published in ST90 were reduced again and published in Voronenko et al. (1991, sm0037 file on the NSDC web site), likewise for observations in Voronenko & Gorel (1988). Thus, observations from the Nikolaev observatory have been deleted and replaced by Voronenko et al. (1991) data (now with Ref. Code 537 in COSS08).

Some NSDC data are redundant, for example, observations in Izmailov (1998, sm0015) and ones in Kisseleva & Izmailov (2000) (sm0030). We keep only observations from Kisseleva & Izmailov (Ref. Code 530) because they have been reduced again compared to Izmailov ones.

Likewise, observations in Kisseleva & Chanturiya (2000) are given in absolute coordinates (α, δ) in file sm0025 and in intersatellite coordinates compared to Titan in sm0026. In that case, we favour observations in absolute coordinates because they allow us to have an additional coordinate of Titan (Ref. Code 525).

For files sm0027 (absolute coordinates) and sm0028 (intersatellite positions relative to Titan) which present observations of Hyperion only, we have preferred the absolute coordinates to the intersatellite positions. Indeed, the date of observations in sm0027 are the same in the sm0025 file. This is why we have kept observations in sm0027 but have allocated the Ref. Code 525.

In the particular case of the observations of Kiseleva et al. (1996, sm0013 and sm0014 files with positions relative to the planet and Titan) and in Kiseleva & Kalinitchenko (2000, sm0029 file), as several of them are redundant, we present in COSS08 the positions relative to the planet when more than two satellites were observed at the same time. If only one satellite was observed, we preferred the intersatellite positions relative to another satellite.

Finally, some observations in Vienne (2001a) are redundant. In that case, the CCD image with the largest number of satellites were favoured. If we have two CCD images with

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[1] Available at the adress `http://www.imcce.fr/nsdc`

[2] With the notation observed satellite-reference satellite.

the same number of satellites, the one with the best O–C was favoured. Likewise for some observations in Vass (1997) which are redundant.

2.4. The recent observations (Ref. Code 600–608)

Recent observations represent more than 9900 new data points. They have been obtained or published during the period 1994–2007.

Qiao et al. (1999) present 451 measurements of positions of Saturn's satellites made from 1994 to 1996 and Qiao et al. (2004) present 1167 new measurements. All these observations were made using a CCD detector attached to the 1.56 m reflector at the Sheshan Station in China.

The NOFS observations (USNO) from Flagstaff were obtained from 2000 to 2007 and have been usually updated. The last update was done on April 18th 2007. The first observations from 2000 to March 2001 were published in Stone (2001). So, those of NOFS have been excluded and those in Stone kept. All data are available on the web site of the FASTT Planetary Satellite Observations `http://www.nofs.navy.mil/data/plansat.html`.

French et al. (2006) published highly accurate astrometric positions of Saturn's satellites. Positions were obtained with Hubble Space Telescope between 1996 and 2005. Some satellite positions were measured in Planetary Camera frames (Ref. Code 605) and others in Wide Field (WF) frames (Ref. Code 606 for WF2, 607 for WF3 and 608 for WF4).

Rapaport et al. (2002) use CCD meridian circle observations for positions of Dione, Rhea, Titan, Hyperion and Iapetus. Those observations were made at the Bordeaux observatory from 1995 to 2001.

The same instrument was used for the observations of Dourneau et al. (2007). 216 observations of Titan, Hyperion and Iapetus were made between 1999 and 2007 (available at: `ftp://ftp.imcce.fr/pub/misc/bordeaux/1995-2007/`). Some of them were published in Rapaport et al. (2002) and so are excluded from this database.

2.5. Instrument and catalogue of stars

In Table 2, we indicate for each Reference Code the corresponding bibliographic reference, observatory and instrument used. Refractors with many different diameters are generally used. Nevertheless, reflectors, meridian circle and astrographs are also used.

For added observations (NSDC and recent observations) and when it was possible, the catalogue of reference stars (like PPM, ACT, AST, Tycho,...) used for the reduction is given. Several methods of astrometric reduction without reference stars have been developed. In such a case, calibration is made using a dynamical theory and well known satellites. For example, in Veiga et al. (2003), dynamical model TASS1.7 (Vienne & Duriez 1994) and satellites Tethys (S3), Dione (S4), Rhea (S5) and Titan (S6) were used to calibrate the CCD frame. So we note S3-S4-S5-S6 TASS1.7 as the reference star catalogue in Table 3. Qiao et al. (1999) used differents dynamical models for the calibration. In Table 3, HT93 refers to Harper & Taylor (1993), TS88 refers to Taylor & Shen (1988) and D87 refers to Dourneau (1987).

French et al. (2006) used the rings (especially the Encke division) for the calibration. Veillet & Dourneau (1992, Ref. Code 47) used the satellites S2-S3-S4-S5-S6 with the Dourneau theory (Dourneau 1987) for calibration.

3. Corrections of the reduction

One of the interests of an astrometric observation catalogue is the comparison between the dynamical model of satellite motions and observations. Thus, we have to apply some corrections like time scale, light-time, aberration, refraction and phase effects. Because some effects are not very important (less than 0.2″), these astrometric corrections were not automatically taken into account before now. While we present in this paper the main corrections, more details about effects can be found in Vienne et al. (2001a).

3.1. Time scale

To compute astrometrical residuals of observations, we need to have the same time scale. Usually, the time scale for dynamical models is the terrestrial time (TT) and observations are given in Universal Coordinate Time (UTC). The difference between TT and UTC (given by dt parameter in COSS08) can be determined since 1972 with the relation between UTC, TT and TAI (Temps Atomique International): TT = TAI + 32.184 and the difference TAI-UTC is an integer number of seconds, which follows the Earth's rotation, fixed by the International Earth rotation and Reference systems Service (IERS). Before 1972, UTC was approximated by UT1 and we use the relation between UT1 and TAI given in Stephenson and Morrison (1984).

For all observations, the sum of *utc* and dt parameters (UTC and TT-UTC respectively, see Sect. 4.1) gives the time of observation in TT. In Hatanaka (1995), Rapaport (2000), Izakevich (2001) and in Carlsberg (1999), observations were given in TT. So for those observations, the UTC time given in COSS08 is determined with the parameter dt with UTC = TT-dt.

Moreover, for one particular kind of observation (Kostinsky 1925), the time of observation is in a particular scale, MZ, corresponding to local time. In COSS08, this time is given in UTC from the relation between UTC and MZ for the Pulkovo observatory, UTC = MZ + 12 h – 2 h 01 m 26 s.

3.2. Light-time correction

The light-time is the difference between the time when the light leaves the observed object and the time when the light arrives at the observer. During the light-time (τ), the object moves on its orbit and then the observer measures the object's position not at time t but at time $t - \tau$. The observation time is that of the arrival of the light signal at the observer. Consequently, no light time correction is made for observations.

3.3. Refraction correction

The position of ground-observed objects is modified by the atmosphere. In general, the atmospheric model assumes horizontal layers with equal refractive index. Refraction is the angle between observed zenith distance z_0 and zenith distance without atmosphere z: $R = z - z_0$. Many models of refraction have been developed. To compute astrometric residual observations when refraction has not been corrected by the observer, the Laplace formula with parameters deduced from the refraction tables of

Pulkovo was used (Pulkovo 1985). With the Laplace formula, the refraction is a function of the observed zenith distance:

$$R = \mathcal{A} \tan z_0 - \mathcal{B} \tan^3 z_0$$

where $\mathcal{A}$ and $\mathcal{B}$ depend on temperature, pressure and wavelength. For standard atmospheric conditions (temperature of 0 °C, pressure of 1013 hPa and wavelength of 590 nm), the coefficients are $\mathcal{A} = 60.''236$ and $\mathcal{B} = 0.''0675$. Few observations (96 between 1875 and 1928) have been realized where the zenith distance was more than 70°. For such zenith distances the Laplace Formula is not very accurate. If the refraction has to be corrected, the parameter *refrac* is 2 or 3. If the refraction has already been corrected, the parameter is 0 or 1 (see Sects. 3.6 and 4.1).

3.4. Aberration correction

Aberration is the result of two facts: the light velocity is finite and the observer is in motion compared to stars. While the light is traveling from the object to the observer on the moving Earth, the observer moves away from the position occupied in space at the instant the light left the object (Woolard & Clemence 1966). To take into account aberration effects, we compute the position of the observer at time $t - \tau$ assuming that between $t - \tau$ and t, the Earth's motion is straight and uniform. In COSS08, if the parameter *aberr* indicates 0 or 1, it means that aberration has already been corrected. In the opposite case (*aberr* = 2 or 3), the aberration has not been corrected (see Sects. 3.6 and 4.1).

3.5. Phase effect correction

Phase effects produce a shift between the photocenter (which is observed) and center of mass (which is computed). For Saturn, the phase angle can reach 6 degrees. Lindegren (1977) estimates the shift between photocenter and center of mass for a spherical and homogeneous object in relation to its radius and the phase angle. The maximum value of this shift reaches 14 mas for Titan and 4 mas for Rhea. The impact of the phase effect can be debated for satellites like Mimas or Iapetus because of their inhomogeneous surfaces. Lindegren's method is only used to compute our own residuals presented in COSS08, when it appears necessary. If the phase effect has to be taken into account, the parameter *phase* indicates 2 or 3, and 0 or 1 in the opposite case (see Sects. 3.6 and 4.1).

3.6. Rules for corrections

The main problem when computing the O–C is to know if corrections have already been taken into account in the data publication. Sometimes, information about the reduction is given in a publication. But most of the time, this information is partially or totally missing, especially for observations before 1950. In this period, observations were not very accurate and the effects induced by refraction or aberration were smaller than the accuracy of those observations. However, information about corrections is also partially absent in recent publications.

Consistent with ST90, we correct refraction or aberration effects, if corrections are not explicilty stated, for observations before 1947 and we assume that observations after 1961 have already been corrected. This general rule nevertheless has many exceptions. To deal with suspicious observations, we compute O–C by correcting effects and without correcting effects and we choose those with the smallest O–C.

In the catalogue, three parameters inform about the corrections (see Sect. 4.1). We give information about that choice by distinguishing four cases for correction. The first one (0) is if the correction is clearly indicated in the publication. The second one (1) is when correction is presumedly made (either if the observation was made after 1961 or if the no-correction gives a better O–C). The third one (2) is when the correction is presumedly not made and the fourth one (3) is when no-correction is clearly indicated in the publication.

3.7. The case of tangential coordinates

With a photographic or CCD receptor, the satellites position are measured in the tangential plane of the celestial sphere at a point C (α_C, δ_C) which is generally the center of the frame. Local deformations induce a difference between the differential coordinates $(\Delta\alpha \cos(\delta_C), \Delta\delta)$ and tangential coordinates (X, Y) of a satellite's positions referred to C. If $\Delta\alpha$ and $\Delta\delta$ are small, the relation between these two types of coordinates is :

$$X = \Delta\alpha \cos\delta_C - \Delta\alpha\Delta\delta \sin\delta_C + ...$$

$$Y = \Delta\delta + \frac{1}{2}(\Delta\alpha)^2 \sin\delta_C \cos\delta_C + ...$$

In the past, the accuracy of the observations was not high enough to take this difference into account. Nowadays, many observers still consider that $X = \Delta\alpha \cos\delta_C$ and $Y = \Delta\delta$.

Vienne et al. (2001b) evaluate that the difference $(X - \Delta\alpha \cos\delta_C, Y - \Delta\delta)$ is about $s^2 \tan\delta_C$ (where s is the separation angle). They estimate the maximum value as 0.3″ for extreme conditions $s = 400''$ and $\delta_C = 23°$. Nevertheless, this value is rarely reached and for example, the difference reaches 0.022″ for observations of Harper et al. (1997) and 0.004″ for Vienne et al. (2001a) because Saturn is near the equator. Moreover, when the field is small, the difference is negligible.

To test this, we have computed residuals by considering that observations in differential coordinates (typ = 1) were given in tangential coordinates and we compared results. It appears that some observations (for example Kiseleva et al. 1996, Ref. Code 513) have better residuals if they are considered as tangential residuals. We have also verified that the difference is negligible when the field is small or when no reference stars are available (see Sect. 2.5).

Normally, the difference has to be taken into account but, because we do not know how the observers make the reduction, we can just use the type of coordinates they published even if they are incorrect. Moreover, to use the tangential coordinates, we need to give the position of the center of the frame which is rarely available. Consequently, in COSS08, there are no obervations in tangential coordinates. But we warn readers that some observations in differentials coordinates could be in tangential coordinates.

4. The catalogue

4.1. The format

The COSS08 observations are tabulated in chronological order and in a consistent format. An example extracted from COSS08 can be seen in Table 4. The full COSS08 catalogue is available in electronic form via anonymous ftp to `cdsarc.u-strasbg.fr` or via `http://cdsweb.u-strasbg.fr/` or on the web server of the IMCCE (see address in acknowledgements). In a

FORTRAN code, one line is read with the format:
`(i3,i5,i3,f11.7,f7.3,a4,i4,i2,i3,a1,i2,i1,2f14.7, 2i2,2f8.3,4i2)`
The meaning of each parameter is:

- *opp* (`i3`): number of opposition (1= 1610, 257 = 1874, 38 5= 2007)
- *anp* (`i5`): year of observation
- *moi* (`i3`): month of observation
- *utc* (`f11.7`): UTC time of observation in days (without light-time correction)
- d*t* (`f7.3`): TT-UTC in seconds
- *cob* (`a4`): observatory code (IAU) from Minor Planet Center[3]
- *crf* (`i4`): reference code (see Sect. 2.1 and Table 2)
- *typ* (`i2`): observation type
  - . 0 = α, δ
  - . 1 = $\Delta\alpha \cos(\delta), \Delta\delta$
  - . 2 = $\Delta\alpha, \Delta\delta$
  - . 3 = p, s (position angle, separation)
- *csob* (`i3`): observed satellite
- *csrf* (`a1`): reference object
  - . * = absolute coordinates
  - . 0 = Saturn
  - . 1 = Mimas
  - . 2 = Enceladus
  - . 3 = Tethys
  - . 4 = Dione
  - . 5 = Rhea
  - . 6 = Titan
  - . 7 = Hyperion
  - . 8 = Iapetus
- *fg1* (`i2`): presence flag for the first coordinate (0 = missing, 1 = present)
- *fg2* (`i1`): presence flag for the second coordinate (0 = missing, 1 = present)
- *ob1* (`f14.7`): first coordinate (0.0000000 if presence flag = 0)
- *ob2* (`f14.7`): second coordinate[4]
- *rfs* (`i2`): reference system
  - . 0 = mean equator and equinox of B1950
  - . 1 = true equator and equinox of date of the observation
  - . 2 = mean equator and equinox of J2000
  - . 3 = mean equator and equinox at the nearest beginning of a year
  - . 4 = mean equator and equinox at 1 January of the year of observation
- *rfr* (`i2`): reference frame
  - . 0 = topocentric
  - . 1 = geocentric
  - . 2 = heliocentric
- *oc1* (`f8.3`): (O–C) residual for the first coordinate (999.999 if missing)
- *oc2* (`f8.3`): (O–C) residual for the second coordinate (999.999 if missing)
- *refrac* (`i2`): refraction correction
  - . 0 = corrected
  - . 1 = presumedly corrected
  - . 2 = presumedly not corrected
  - . 3 = not corrected

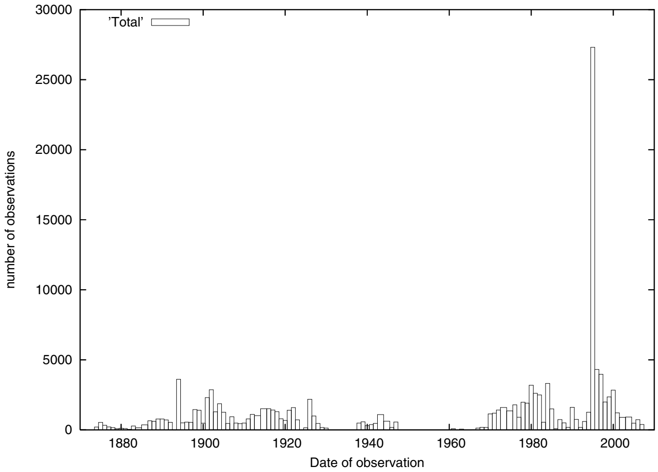

Fig. 1. Histogram of number of observations at each opposition.

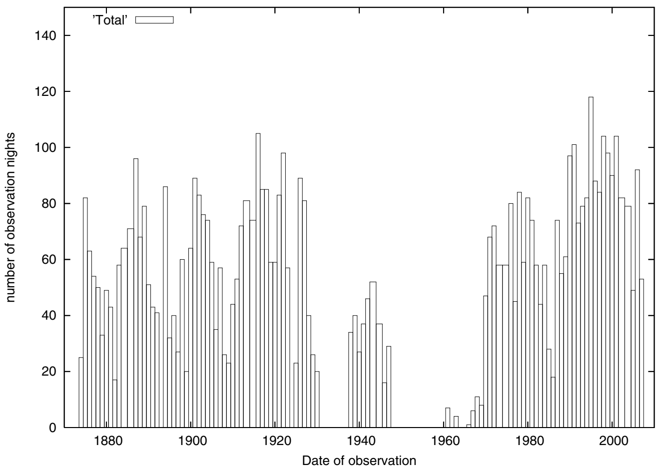

Fig. 2. Histogram of number of observation nights at each opposition.

Table 1. Number of observations, number of nights of observation and period covered for each satellite.

Satellite	Number	Nights	Covered period
Mimas	4410	714	1874–2005
Enceladus	11 529	1927	1874–2005
Tethys	24 034	3275	1874–2007
Dione	21 501	3265	1874–2007
Rhea	26 920	3976	1874–2007
Titan	22 788	4011	1874–2007
Hyperion	7321	1896	1874–2007
Iapetus	12 395	2760	1874–2007

- *aberr* (`i2`): aberration correction
  - . 0 = corrected
  - . 1 = presumedly corrected
  - . 2 = presumedly not corrected
  - . 3 = not corrected
- *phase* (`i2`): phase effects correction
  - . 0 = corrected
  - . 1 = presumedly corrected
  - . 2 = presumedly notcorrected
  - . 3 = not corrected
- *satref* (`i2`) (optional): reference satellite for O–C computation when a group of observations is given in absolute coordinates or compared to the planet at the same time.

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[3] Available at the adress:
`http://cfa-www.harvard.edu/iau/lists/ObsCodes.html`

[4] Units are for typ = 0: degrees, typ = 1: seconds of degrees, typ = 2: (seconds of hour, seconds de degrees), typ = 3: (degrees, seconds of degrees).

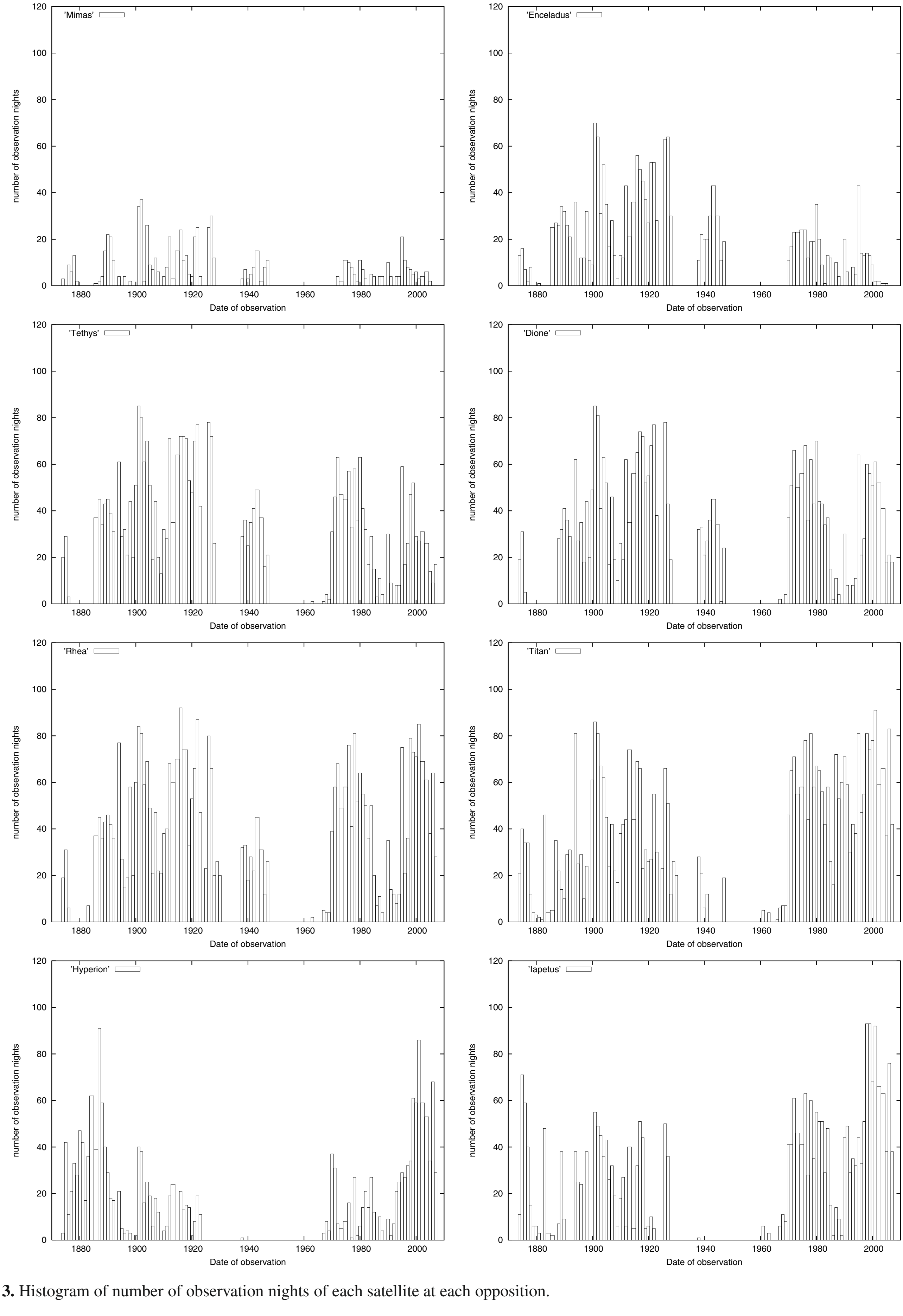

Fig. 3. Histogram of number of observation nights of each satellite at each opposition.

Table 2. List of the observations of the first eight Saturnian satellites presented in COSS08.

Ref. Code	Reference	Observatory	Instrument
		Strugnell & Taylor references	
1	USNO (1877–1887)	USNO Washington (before 1893)	Telescope – refrac., D = 26 inch
2	USNO (1887, 1889–1893)	USNO Washington (before 1893)	Telescope – refrac., D = 26 inch
3	USNO (1911)	USNO Washington (since 1893)	Telescope – refrac., D = 26 inch
4	USNO (1929)	USNO Washington (since 1893)	Telescope – refrac., D = 26 inch
5	USNO (1954)	USNO Washington (since 1893)	Telescope – refrac., D = 26 inch
6	Struve (1933)	Berlin-Babelsberg	Telescope – 65-cm refrac.
7	Struve (1933)	Johannesburg	Telescope – 65-cm refrac.
8	Struve (1933)	Yerkes Observatory	Telescope – 40-inch refrac.
9	Struve (1898)	Pulkovo	Telescopes: 30-inch refrac.
10	Alden & O'Connell (1928)	Yale-Columbia Station	Telescope: 26-inch photographic refrac.
11	Alden (1929)	Yale-Columbia Station	Telescope: 26-inch photographic refrac.
12	Soulie & Pourteau (1968)	Bordeaux-Floirac	Telescopes: 30 cm refrac.
13	Chernykh & Chernykh (1971)	Crimea-Simeis	Telescope – astrograph, D = 40 cm
14	Soulie (1972)	Bordeaux-Floirac	Telescope: 13-inch photographic refrac.
15	Soulie (1975)	Bordeaux-Floirac	Telescope: 33-cm refrac.
16	Peters (1973)	Table Mountain Observatory	Telescope: 24-inch reflec.
17	Soulie (1975)	Bordeaux-Floirac	Telescope: 38-cm refrac.
18	Kisseleva et al. (1977)	Pulkovo	Telescope: 26-inch refrac.
19	Kisseleva et al. (1977)	Pulkovo	Telescope: normal astrograph
20	Kisseleva et al. (1977)	Pulkovo	Telescopes: AKD (double short-focus astrograph)
21	Abbot et al. (1975)	McDonald Observatory	Telescopes: 2.1 m reflec., 76 cm reflec. Meas.machine: Mann measures
22	Abbot et al(1975)	McDonald Observatory	Telescopes: 2.1 m reflec., 76 cm reflec. Meas.machine: PDS measures
23	Kisseleva et al. (1975)	Pulkovo	Telescope: normal astrograph.
24	Soulie (1978)	Bordeaux-Floirac	Telescope: 33-cm refrac.
25	Sinclair (1974, 1977)	Herstmonceux	Telescope: 13-inch refrac.
26	Sinclair (1974, 1977)	Herstmonceux	Telescope: 26-inch refrac.
27	Mulholland et al. (1976)	McDonald Observatory	Telescope: 76-cm reflec.
28	Soulie (1978)	Bordeaux-Floirac	Telescope: 38-cm refrac.
29	Gorel (1977)	Nikolaev	Telescope: Zone astrograph
31	Pascu (1982) priv. comm.	USNO Washington (since 1893)	Telescope – 26 inch refrac.
32	Levitskaya (1979)	Ordubad	Telescope: lunar-planet telescope, $D = 700$ mm, $F = 10313$ mm
34	Mulholland & Shelus (1980)	McDonald Observatory	Telescope – reflec., D = 2.1 m
35	Soulie et al. (1981)	Bordeaux-Floirac	Telescope: 33 cm refrac.
37	Seitzer & Ianna (1980)	Leander McCormick Observatory	Telescope: 67- refrac.
38	Chugunov (1981)	Engelhardt Observatory	Telescope: 16-inch astrograph
39	Taylor & Sinclair (1985)	Herstmonceux	Telescope: 26-inch refrac.
40	Seitzer et al. (1979)	Leander McCormick Observatory	Telescope: 67 cm -refrac.
41	Chugunov & Nefed'ev (1980)	Engelhardt Observatory	Telescope: 16-inch astrograph
42	Aksnes et al. (1984)	Various	Telescope: 26″ refrac.
43	Rohde et al. (1982)	Leander McCormick Observatory	Telescope: 67- refrac.
45	Kitkin & Chugunov (1980)	Engelhardt Observatory	Telescope: 16″ astrograph
46	Dourneau et al. (1989)	Bordeaux-Floirac	Telescope: 38 cm refrac.
47	Veillet & Dourneau (1992)	Pic du Midi	Telescope: 1 m reflec.
48	Veillet & Dourneau (1992)	ESO, La Silla	Telescope: 1.5 m reflec.
49	Veillet & Dourneau (1992)	Mauna Kea	Telescope: 3.6 m reflec.
50	Debehogne (1981, 1982)	ESO, La Silla	Telescope: 40-cm refrac.
51	Kitkin & Chugunov (1982)	Engelhardt Observatory	Telescope: 16″ astrograph
52	Dourneau et al. (1986)	ESO, La Silla	Telescope: 1.5 m reflec.
53	Dourneau et al. (1985)	Bordeaux-Floirac	Telescope: 38 cm reflec.
54	Bowell (1982)	Lowell Observatory	Telescope: 13-inch refrac.
55	Debehogne (1984)	ESO, La Silla	Telescope: 40-cm equatorial
56	Kitkin (1985)	Engelhardt Observatory	Telescope: 16″ astrograph
57	Kitkin (1985)	Engelhardt Observatory	Telescope: Zeiss astrograph
58	Kisseleva et al. (1987)	Abastuman	Telescope: Zeiss Double Astrograph
59	Rapaport (pers communi)	Bordeaux-Floirac	Telescope: Meridian circle
60	CMC La Palma No4 (1989)	La Palma	Telescope: Carlsberg automatic meridian circle
61	Shen (pers communi)	Yunnan Observatory	Telescope: 1 m refrac.
		Harper & Taylor references	
101	Barnard (1913)	Yerkes Observatory	40-inch refrac.
102	Barnard (1915)	Yerkes Observatory	40-inch refrac.
103	Barnard (1916)	Yerkes Observatory	40-inch refrac.

Table 2. continued.

Ref. Code	Reference	Observatory	Instrument
104	Barnard (1918)	Yerkes Observatory	40-inch refrac.
105	Barnard (1927)	Yerkes Observatory	40-inch refrac.
131	Hussey (1902)	Lick Observatory	12-inch & 36-inch refrac.s
132	Hussey (1903)	Lick Observatory	12-inch & 36-inch refrac.s
133	Hussey (1905)	Lick Observatory	36-inch refrac.
144	Lovett (1898a)	Leander McCormick Obs	26-inch refrac.
145	Morgan (1898)	Leander McCormick Obs	26-inch refrac.
147	Stone (1898a)	Leander McCormick Obs	26-inch refrac.
148	Stone (1898b)	Leander McCormick Obs	26-inch refrac.
149	Stone (1898c)	Leander McCormick Obs	26-inch refrac.
150	Stone (1898d)	Leander McCormick Obs	26-inch refrac.
200	Barnard (1908)	Yerkes Observatory	40-inch, 24-inch, 10-inch refrac.s
202	Aitken (1909)	Lick Observatory	36-inch refrac.
203	Aitken (1905)	Lick Observatory	36-inch refrac.
206	Barnard (1910)	Yerkes Observatory	40-inch refrac. (presumedly)
211	Eastwood (1900)	Leander McCormick Obs	26-inch refrac.
222	Lovett (1895)	Leander McCormick Obs	26-inch refrac.
223	Lovett (1896)	Leander McCormick Obs	26-inch refrac.
224	Lovett (1898b)	Leander McCormick Obs	26-inch refrac.
225	Lovett (1897)	Leander McCormick Obs	26-inch refrac.
226	Lovett (1898c)	Leander McCormick Obs	26-inch refrac.
227	Lyon (1899a)	Leander McCormick Obs	26-inch refrac.
228	Lyon (1899b)	Leander McCormick Obs	26-inch refrac.
232	Morgan (1897)	Leander McCormick Obs	26-inch refrac.
233	Morgan (1900)	Leander McCormick Obs	26-inch refrac.
235	Paddock (1905)	Leander McCormick Obs	26-inch refrac.
240	Stone (1895a)	Leander McCormick Obs	26-inch refrac.
241	Stone (1895b)	Leander McCormick Obs	26-inch refrac.
242	Stone (1896a)	Leander McCormick Obs	26-inch refrac.
243	Stone (1896b)	Leander McCormick Obs	26-inch refrac.
		NSDC references	
420	Noyelles et al. (2003) best	Various	
421	Noyelles et al. (2003) acc	Various	
502	Kostinsky (1925)	Pulkovo	Normalastrograph
504	Debehogne (1979)	Uccle	Double astrograph, D = 40 cm
507	Kiseleva (1989)	Pulkovo	Double astrograph, F = 70 cm, D = 10 cm
509	Izhakevich (1991)	Golosseevo-Kiev	Double long-focus astrograph, D = 400 mm, F = 5500 mm and Double wide-field astrograph, D = 400 mm, F = 2000 mm
510	Tolbin (1991)	Pulkovo	Normal astrograph, D = 33 cm, F = 3.64 m
511	Tolbin (1991)	Pulkovo	
512	Tolbin (1991)	Pulkovo	refrac., F = 10.4 m, D = 62 cm
513	Kiseleva et al. (1996)	Pulkovo	refrac., F = 10.4 m, D = 62 cm
514	Kiseleva et al. (1996)	Pulkovo	refrac., F = 10.4 m, D = 62 cm
516	Kiseleva et al. (1998)	Pulkovo	refrac., F = 10.4 m, D = 62 cm
518	Vass (1997)	Bucharest	Astrograph, F = 6 m, D = 38 cm
519	Rapaport (2000) priv. comm.	Bordeaux-Floirac	Automatic photoelectric meridian cercle
520	Veiga et al. (1999)	Itajuba	1.6 m Ritchey-Chretien reflec.
521	Harper et al. (1997)	La Palma	1-metre Jacobus Kapteyn Telescope
522	Harper et al. (1999)	La Palma	1-metre Jacobus Kapteyn Telescope
523	Stone et al. (2000)	USNO, Flagstaff	Flagstaff Astrometric Transit Telescope (FASTT)
524	Stone et al. (2000)	USNO, Flagstaff	Flagstaff Astrometric Transit Telescope (FASTT)
525	Kisseleva & Chanturiya (2000)	Abastuman	Double wide-field astrograph, D = 40 cm, F = 302.4 cm
529	Kisseleva & Kalin. (2000)	Pulkovo	refrac., F = 10.4 m, D = 62 cm
530	Kisseleva & Izmailov (2000)	Pulkovo	refrac., F = 10.4 m, D = 62 cm
531	Filippov et al. (2001) priv.comm.	Golosseevo-Kiev	Double long focus astrograpf, D = 400 mm, F = 5500 mm
532	Izakevich (2001) priv.comm.	Golosseevo-Kiev	Double wide-field astrograpf, D = 400 mm, F = 2000 mm
533	Belizon et al. (2001) priv.comm.	El Leoncito	San Fernando Automatic Meridian Circle, D = 18 cm
537	Voronenko et al. (1991)	Nikolaev	Zonal astrograph, D = 120 mm, F = 2044 mm
538	Voronenko (2001) priv. comm.	Nikolaev	Zonal astrograph, D = 120 mm, F = 2044 mm

Table 2. continued.

Ref. Code	Reference	Observatory	Instrument
539	Vienne et al. (2001)	Itajuba	Ritchey-Chretien reflec., D = 1.6 m, F = 15.8 m
540	Kowalski (2001) priv. comm.	Zephyrhills	Maksutov, D = 0.18 m
541	Peng et al. (2002)	Yunnan Observatory	reflec., D = 1 m.
542	Kiseleva & Kalin. (2002)	Pulkovo	refrac., F = 10.4 m, D = 65 cm
543	Stone (2001)	USNO, Flagstaff	Flagstaff Astrometric Transit Telescope (FASTT)
545	Veiga et al. (2003)	Itajuba	1.6 m Ritchey-Chretien reflec., F = 15.8 m.
546	Hatanaka (1995)	Tokyo-Mitaka	refrac., D = 65 cm, F = 10 m
547	Abrahamian et al. (1993)	Byurakan	ZTA, D = 2.6 m, F = 10 m
548	Walker et al. (1978)	USNO Washington (since 1893)	Astrograph, D = 38 cm
552	Carlsberg (1999)	La Palma	Carlsberg Automatic Meridian Circle
		New references	
600	Rapaport (2002)	Bordeaux-Floirac	Bordeaux CCD meridian circle
601	Dourneau (1995-2007)	Bordeaux-Floirac	Bordeaux CCD meridian circle
602	USNO Flagstaff (1999–2006)	USNO, Flagstaff	Flagstaff Astrom. Transit Teles.
603	Qiao et al. (1999)	Zo-Se	1.56 m reflec.
604	Qiao et al. (2004)	Zo-Se	1.56 m reflec.
605	French (2006) HST PC	Hubble Space Telescope	HST Planetary Camera
606	French (2006) HST WF2	Hubble Space Telescope	HST Wide Field
607	French (2006) HST WF3	Hubble Space Telescope	HST Wide Field
608	French (2006) HST WF4	Hubble Space Telescope	HST Wide Field

Table 3. Catalogue used for the astrometric reduction of some references.

Ref. Code	Reference	Catalogue
12	Soulié & Pourteau (1968)	SAO
14	Soulié (1972)	SAO
17	Soulié (1975)	SAO
24, 28	Soulié (1978)	SAO
35	Soulié et al. (1981)	SAO
46	Dourneau et al. (1989)	SAO
47	Veillet & Dourneau (1992)	S2-S3-S4-S5-S6 D87
48	Veillet & Dourneau (1992)	SAO & Perth70
49	Veillet & Dourneau (1992)	AGK3 & SAO
52	Dourneau et al. (1986)	AGK3
53	Dourneau et al. (1985)	AGK3 (for 1981) & SAO (for 1982)
509	Izhakevich (1991)	Catalogue PPM
510	Tolbin (1991)	Catalogue FK5/FK4
512	Tolbin (1991)	Catalogue FK5/FK4
520	Veiga et al. (1999)	GSC corrected by PPM
521	Harper et al. (1997)	S3-S4-S5-S6 HT93
522	Harper et al. (1999)	S3-S4-S5-S6 HT93
523	Stone (2000)	Catalogue AST
524	Stone & Harris (2000)	Catalogue AST
525	Kisseleva & Chanturiya(2000)	Catalogue ACT
531	Filippov et al. (2001)	Catalogue ACT
532	Izakevich (2001)	Catalogue ACT
533	Belizon et al. (2001)	1976 IAU reference system
537	Voronenko et al.(1991)	Hipparcos/Tycho & ACTRC
538	Voronenko (2001)	Hipparcos/Tycho & ACTRC
539	Vienne et al. (2001)	S3-S4-S5-S6 TASS1.7
543	Stone (2001)	Catalogue – Tycho-2 (ICRF)
545	Veiga et al. (2003)	S3-S4-S5-S6 TASS1.7
547	Abrahamian et al. (1993)	Catalogue FOCAT-S (FK5,J2000)
548	Walker et al. (1978)	Catalogue – SAO
552	Carlsberg (1999)	1976 IAU reference system
601	Dourneau et al. (2007)	Catalogue – Tycho-2 (ICRF)
602	USNO Flagstaff (2000-2007)	Catalogue – Tycho-2 (ICRF)
603	Qiao et al. (1999)	S3-S4-S5-S6 HT93, TASS1.7, TS88, D87
604	Qiao et al. (2004)	S3-S4-S5-S6 TASS1.7
605	French et al. (2006) HST PC	Rings
606	French et al. (2006) HST WF2	Rings
607	French et al. (2006) HST WF3	Rings
608	French et al. (2006) HST WF4	Rings

Table 4. Extract from catalogue COSS08 with the first and the last observations.

257	1874	7	15.2570840	–2.881	787	1	3	70	01	0.0000000	98.8830000	1	0	999.999	–1.021	2	2	2	
257	1874	7	15.2640290	–2.881	787	1	3	70	10	132.2000000	0.0000000	1	0	0.719	999.999	2	2	2	
257	1874	8	30.1202790	–2.971	787	1	3	50	10	287.6000000	0.0000000	1	0	–0.375	999.999	2	2	2	
257	1874	8	30.1237510	–2.971	787	1	3	30	10	299.0000000	0.0000000	1	0	–0.213	999.999	2	2	2	
257	1874	8	30.1279180	–2.971	787	1	3	20	10	268.3000000	0.0000000	1	0	0.317	999.999	2	2	2	
257	1874	8	30.1327790	–2.971	787	1	3	40	10	107.3000000	0.0000000	1	0	0.290	999.999	2	2	2	
257	1874	8	30.1369460	–2.971	787	1	3	60	10	185.4000000	0.0000000	1	0	0.254	999.999	2	2	2	
257	1874	8	30.1438900	–2.971	787	1	3	50	01	0.0000000	66.7010000	1	0	999.999	–1.493	2	2	2	
257	1874	8	30.1494460	–2.971	787	1	3	30	01	0.0000000	25.4770000	1	0	999.999	–0.947	2	2	2	
257	1874	8	30.1550010	–2.971	787	1	3	20	01	0.0000000	33.2860000	1	0	999.999	–0.840	2	2	2	
	...		...		...					...				...					
385	2007	4	15.8272500	65.184	999	601	0	8*	11	140.7682387	16.6673253	2	0	0.005	0.048	1	1	2	
385	2007	4	15.8275220	65.184	999	601	0	7*	11	140.8665154	16.6499964	2	0	0.235	–0.280	1	1	2	
385	2007	4	15.8275930	65.184	999	601	0	6*	11	140.8923746	16.6512411	2	0	0.015	–0.066	1	1	2	
385	2007	4	18.1296759	65.184	689	602	0	4*	11	140.8983800	16.6686028	2	1	–0.093	–0.046	1	1	1	5
385	2007	4	18.1296759	65.184	689	602	0	5*	11	140.8896617	16.6663225	2	1	0.093	0.046	1	1	1	4
385	2007	4	18.1296759	65.184	689	602	0	7*	11	140.8891479	16.6496936	2	1	0.384	–0.173	1	1	1	5
385	2007	4	18.1296759	65.184	689	602	0	8*	11	140.7625637	16.6683714	2	1	–0.014	–0.055	1	1	1	5
385	2007	4	18.1312072	65.184	689	602	0	6*	11	140.9259692	16.6552381	2	1	–0.072	–0.225	1	1	1	

Note that the heliocentric reference frame ($rfr = 2$) is only used for mutual phenomena, especially for eclipse observations.

Oppositions have been numbered since 1610 (first observations of satellites by Galileo Galilei). So, observations of COSS08 are from opposition 257 in 1874 to opposition 385 in 2007.

The main modifications compared to the ST90 catalogue are the parameters added like refraction, aberration and phase effect corrections, and the unification of the time scale.

The O–C residuals have been computed with the TASS1.7 model (Duriez & Vienne 1997, for Hyperion motion and Vienne & Duriez 1994, for the seven others) according to the correction of refraction, aberration and phase effects. The position of Saturn is given by numerical ephemeris DE414, from JPL (Standish 2006). Residuals are purely indicative to measure the accuracy of observations in relation to the TASS model. When it was possible, residuals have been computed in intersatellite coordinates. For example, if satellites have been observed at the same moment and expressed in absolute coordinates or compared to the planet, O–C values were been computed in intersatellite coordinates compared to a reference satellite. In such a case, the reference satellite is indicated with the parameter *satref*.

4.2. Distribution of observations

In counting the observations, we adopt the same method as ST90. We have taken each coordinate for each observed or reference satellite. For example, if both coordinates of Encelade-Titan have been given, two observations for Encelade and two observations of Titan have been counted. This means that for one line of COSS08, we could have one, two or four observations. However if the same reference satellite appears several times in intersatellite measurements on a photographic plate, it is counted only once. Histograms of the number of observations at each opposition from 1874 to 2007 are represented in Fig. 1. The distribution is relatively inhomogeneous. There are significant gaps between 1930 and 1938 and between 1947 and 1961. Nevertheless there are also years with many observations. Indeed in 1995, there are more than 28 000 observations. In 1995, mutual phenomena of Saturn's satellites were observed with CCD cameras. Just before and after these phenomena, satellites were observed and their positions were reduced. Because of this inhomogeneity, we present histograms of the number of observation nights at each opposition in Fig. 2. The details of each satellite can be found in Fig. 3.

Table 1 gives the number of observations and the period covered for each satellite. Differences can be observed between satellites. Mimas and Enceladus are less observed because of their closeness to Saturn. Hyperion is a faint body and its observation was particulary difficult in the past. Iapetus is not much observed because with CCD images, the field of view is often small and the satellite is often out of this field. However, Rhea, Titan, Dione and Tethys are highly observed satellites. The total of observations represents 130 898 observations (over 6 023 nights).

4.3. Statistics of observations

We present in Table 5 the statistics of residuals for the ten references with numerous observations. First, the name and the Ref. Code of the reference, and the type of coordinates are indicated. Secondly, we give astrometric observation residuals for each type and each satellite[5]. μ_α, σ_α and N_α represent the mean, the standard deviation and the number of residuals of the first coordinate. μ_δ, σ_δ and N_δ are for the second coordinate. All the observations with O–C value larger than $2''$ were rejected for the residual computation.

5. Conclusion

The COSS08 catalogue is composed of more than 130 000 observations of the eight major satellites of Saturn. All observations are in the same consistent format. This catalogue can be very useful to fit a dynamical model by comparison to observations. Also, information about reduction is given and allows this comparison.

The large period covered by COSS08 from 1874 to 2007 allows the detection of long-term perturbations in the satellite motion. Thus, the tidal effects, measurable through a detection of an acceleration of the satellites, may be detected (Lainey et al. 2007).

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[5] S1 means Mimas, S2 Enceladus, S3 Tethys, S4 Dione, S5 Rhea, S6 Titan, S7 Hyperion and S8 Iapetus.

Table 5. Statistics for the ten most numerous observation references.

Reference	Satellite	μ_α	σ_α	μ_δ	σ_δ	N_α	N_δ
Vienne et al. (2001)	S1	–0.016	0.083	0.001	0.078	216	216
(539)	S2	0.014	0.092	–0.006	0.067	861	861
$(\Delta\alpha\cos\delta, \Delta\delta)$	S3	0.004	0.080	0.003	0.065	2048	2048
	S4	–0.007	0.062	0.000	0.055	1570	1570
	S5	0.014	0.084	–0.002	0.063	4739	4739
	S6	0.007	0.106	0.009	0.087	1484	1484
	S7	–0.084	0.118	–0.038	0.121	322	322
	S8	–0.107	0.090	0.010	0.068	524	524
USNO Flagstaff 1999–2006	S1	0.000	0.000	0.000	0.000	0	0
(602)	S2	0.000	0.000	0.000	0.000	0	0
(α, δ)	S3	–0.040	0.172	0.011	0.139	116	116
	S4	0.006	0.105	–0.011	0.130	203	203
	S5	0.016	0.090	0.004	0.117	364	364
	S6	0.068	0.115	–0.038	0.112	405	405
	S7	–0.005	0.259	0.050	0.321	300	300
	S8	–0.012	0.105	–0.010	0.137	353	353
Pascu (1982) priv. comm.	S1	–0.055	0.223	–0.017	0.157	57	57
(31)	S2	–0.009	0.125	–0.022	0.157	110	110
$(\Delta\alpha\cos\delta, \Delta\delta)$	S3	–0.003	0.074	–0.003	0.099	140	140
	S4	–0.012	0.066	0.003	0.108	166	167
	S5	0.013	0.064	–0.023	0.079	209	209
	S6	–0.011	0.066	0.024	0.081	228	228
	S7	0.050	0.236	–0.075	0.171	11	11
	S8	–0.028	0.146	0.033	0.145	217	216
USNO (1929)	S1	–0.002	0.198	–0.083	0.221	122	121
(4)	S2	–0.006	0.169	–0.080	0.167	129	127
(p, s)	S3	-0.008	0.169	–0.002	0.185	487	483
	S4	0.006	0.159	–0.006	0.166	280	281
	S5	0.008	0.154	–0.031	0.198	694	690
	S6	–0.002	0.214	0.025	0.274	581	575
	S7	–0.010	0.380	0.128	0.468	89	88
	S8	–0.004	0.210	0.158	0.169	120	117
Harper et al. (1999)	S1	0.172	0.234	–0.064	0.099	14	15
(522)	S2	–0.081	0.600	–0.056	0.241	118	119
$(\Delta\alpha\cos\delta, \Delta\delta)$	S3	–0.017	0.093	–0.003	0.099	277	277
	S4	0.015	0.087	–0.005	0.112	219	219
	S5	–0.004	0.238	–0.012	0.188	1068	1068
	S6	0.065	0.146	–0.030	0.112	336	336
	S7	0.103	0.222	0.056	0.326	189	187
	S8	–0.148	0.123	0.118	0.107	189	189
Qiao et al. 2004	S1	0.040	0.255	0.062	0.136	44	44
(604)	S2	–0.081	0.185	0.063	0.248	141	141
$(\Delta\alpha\cos\delta, \Delta\delta)$	S3	0.008	0.126	–0.002	0.154	236	236
	S4	–0.018	0.090	0.028	0.105	246	246
	S5	0.020	0.132	–0.003	0.148	862	862
	S6	0.002	0.099	–0.038	0.120	241	241
	S7	0.000	0.000	0.000	0.000	0	0
	S8	–0.090	0.075	–0.100	0.075	66	66
Harper et al. (1997)	S1	–0.160	0.213	0.050	0.213	73	73
(521)	S2	–0.022	0.109	–0.007	0.163	199	199
$(\Delta\alpha\cos\delta, \Delta\delta)$	S3	–0.011	0.079	–0.002	0.089	221	221
	S4	0.003	0.072	0.000	0.079	214	214
	S5	0.023	0.118	–0.006	0.129	852	852
	S6	–0.015	0.087	0.009	0.096	157	157
	S7	0.043	0.203	0.043	0.144	88	88
	S8	–0.066	0.072	–0.030	0.085	52	52
Struve (1898)	S1	0.030	0.181	0.012	0.163	119	105
(9)	S2	–0.032	0.121	0.003	0.126	233	222
(p, s)	S3	–0.005	0.124	0.034	0.131	549	532
	S4	–0.032	0.136	0.065	0.144	212	209
	S5	0.026	0.127	–0.073	0.143	490	475
	S6	–0.069	0.345	0.034	0.281	80	78
	S7	0.059	0.603	–0.038	0.336	232	234
	S8	–0.054	0.319	–0.027	0.209	22	22

Table 5. continued.

Reference	Satellite	μ_α	σ_α	μ_δ	σ_δ	N_α	N_δ
Veillet & Dourneau 1.5	S1	–0.205	0.156	–0.047	0.105	10	10
(48)	S2	–0.004	0.124	–0.025	0.120	57	57
($\Delta\alpha\cos\delta, \Delta\delta$)	S3	–0.003	0.139	0.012	0.093	78	78
	S4	0.008	0.083	0.003	0.082	155	155
	S5	–0.010	0.125	–0.007	0.098	884	884
	S6	–0.004	0.092	0.021	0.076	199	199
	S7	0.006	0.168	0.008	0.089	197	197
	S8	0.051	0.116	0.003	0.126	196	196
Peng et al. (2002)	S1	–0.023	0.054	–0.017	0.044	54	54
(541)	S2	–0.005	0.051	–0.021	0.054	136	136
($\Delta\alpha\cos\delta, \Delta\delta$)	S3	0.000	0.034	–0.002	0.043	120	120
	S4	–0.004	0.037	–0.002	0.038	136	136
	S5	0.029	0.066	0.023	0.047	336	336
	S6	0.006	0.051	–0.003	0.061	548	548
	S7	–0.022	0.066	0.037	0.095	96	96
	S8	–0.083	0.073	–0.050	0.043	102	102

Ground-based observations remain very useful for the improvement of the knowledge of satellite motion. We encourage future observers to publish their data in the COSS08 format and to indicate the frame center positions with their data, because it will allow us to use tangential coordinates in the astrometric reduction and consequently, in some cases it will improve the accuracy of the derived observed positions of satellites.

Acknowledgements. We would like to thank R. V. Martins for his participation in collecting data. We also thank N. Emelianov for his help and the update of NSDC observations. We are very grateful to V. Lainey for many helpful discussions. We wish to thank G. Dourneau for a careful reading of the manuscript and valuable comments that greatly helped to improve the present work. The catalogue is also available on the web server of the IMCCE at `ftp://ftp.imcce.fr/pub/databases/NSDC/saturn/raw_data/position/1874-2007_S1-8_COSS08.data.txt`

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