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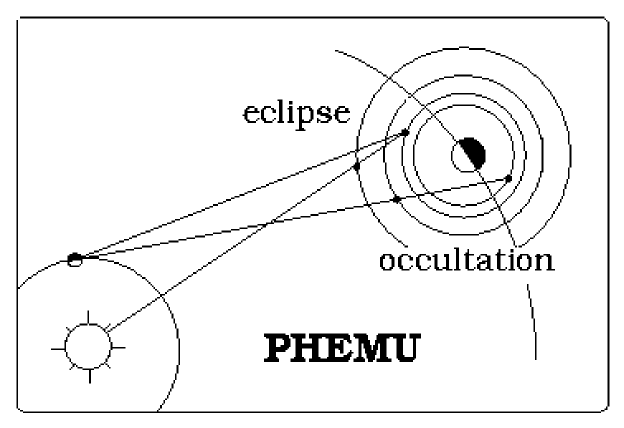

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BIBLIOGRAPHY ON VARIOUS WORKS RELATED TO THE MUTUAL EVENTS OF THE GALILEAN SATELLITES

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Introduction

The goal of this note is to give a description of the various works which have been done to observe the mutual events of the Galilean satellites,to analyse these observations and to make the interpretation of these data. This type of observation is recent, probably because of the difficulty to compute predictions of these events when electronic computers could not be used.The first observations have been made during the1973 period. Since these first observations, the observational techniques have been strongly improved furthermore since 1985 a great interest has been shown for these observations because they give access in some infrared bands to the measurements of the volcanic activity of Io where volcanoes and hot spots have been discovered in1979 by the Voyager space probes.Since 1985, when this note was first published many new articles related to the mutual events observations and analysis have been published. In the following pages, we give information and references of these publications gathered by period of observations. We also give in an Annex the list of the communications made during thedifferent workshops we organized on this topic.We then give a list of the PHEMU technical note which have been published during the previous campaigns of observations.

1. The mutual events observations madein 1973 and before

<u>a) Predictions</u>

Very few information is available on the predictions of the mutual events made before 1973. Bignell (1956) published a short list of the events observable in 1956 but no observation was made to our knowledge.
Brinkmann and Millis (1973) published the predictions for the 1973-1974 period, they announce they organize a campaign and they call for observations to be made either by astronomers as by amateurs.
Brinkmann (1973) showed the interest of these observations in order to get albedos maps of the Galilean satellites. He refers to the predictions of the Handbook of the British Astronomical Association (1973).

Arlot (1973) published predictions of events observable in France.
Aksnes (1974) published his own predictions for the 1973 period based upon the Andoyer's method and the Sampson's theory. He emphasizes the large discrepancies between these predictions and the ones made by Brinkmann and Millis (up to 30 minutes of time for J3 and J4).
There is a good agreement with the predictions of the Handbook of the British Astronomical Association (1973). Partial results had been already published in a IAU circular (Aksnes, 1973).
The 1973 period which was favorable to the observation of mutual events of the Galilean satellites induced numerous publications. Some of these publications gave mainly an astrometric reduction and measurements of the radii of the satellites. Other publications led to albedos maps of the Galilean satellites.

b) Astrometric analysis

Duxburry et al. (1974 and 1975) give lightcurves of seven phenomena observed, six mutual occultations of J2 by J1 and one occultation of J2 by J3. They deduced longitudinal corrections of the theory from them. These results agree well withthe Pioneer 10 results and with last observations of eclipses by Jupiter. These observations have been made with a photometer equiped with a S20cathod.
Arlot et al. (1974) give results obtained during the observation of an occultation and an eclipse ofJ1 by J2 on 1975 August 30th. The lightcurves obtained thanks to a photoelectric photometer dedicated to the planetary photometry at the1.07m telescope of the Pic du Midi observatory allowed them to compute corrections of longitudes and radii.
Blanco and Catalano (1974) published UBV lightcurves of three mutual eclipses.
Murphy and Aksnes (1973) published lightcurvesof two mutual occultations and made the assumption of a polar cap on Europa in order to explain differences between the observed light flux drops and the theoretical ones.
Wyckoff et al. (1974) published lightcurves of two mutual occultations and one mutual eclipse.They computed the shift in longitude and the difference in light flux drop between the observed value and the predicted one. They explain these disagreement thanks to the Murphy and Aksnes assumption.
Aksnes and Franklin (1975a) made an analysis of13 observations of nine occultations of J2 by J1.They deduced from it: a value of the radius of J2 and corrections of the longitudes in the Sampson's theory. They reanalyse the assumption of a polarcap on Europa and made a new assumption to explain the darkness of the South polar zone on J2. They adopted a theoretical latitudinal error in order to explain the disagreement observed.
Mosher et al. (1975) describes the observation of an eclipse of J2 by J3 made thanks to a Vidicon tube and reduced after that 54 images have been digitized. This technique allowed them to observe the satellites close to Jupiter (30 arcseconds).
Aksnes and Franklin (1976) give the final results of the campaign they organized during the 1973 campaign. 91 lightcurves have been collected.The radii of J2, J3 and J4 have been deduced with a precision of 27 km, 32 km and 75 km. They published corrections to the orbital elements of the Sampson's theory.
Wasserman et al. (1976) give results deduced from the analysis of seven lightcurves obtained during the observation of two occultations and two eclipses of J2, and three eclipses of J1. Observations have been made simultaneously in three wavelengths (0.35, 0.50 and 0.91 μm) with time constant of 0.1 sec. They give results concerning the limb darkening of J2. They used a model in order to study the influence of the albedo of the eclipsed satellite on the shape of the lightcurve.
Nakamura (1976) publishes lightcurves of four mutual occultations of J2 by J1 and two eclipses of J2 by J3. Longitudes corrections are obtained; they do not depend on the albedo model used. A radius of J2 is also obtained.
Williamon (1976) gives lightcurves of four mutual occultations and three mutual eclipses; he comments the discrepancy between observation and theory concerning the durations, the times of mid-event, and the magnitude drops. He used an uncooled photometer UBV adapted on a 91cm telescope, and used a time constant of 0.1 sec.Abraham and Strauss (1979) give the lightcurve and the reduction of a mutual eclipse of J2 by J1. Six mutual eclipses have also been observed and the comparison with the Aksnes predictions shows a good agreement. Large discrepancies exist with the Brinkman and Millis predictions (up to 20 min.) The photometer used was mounted on a 50cm telescope and was equiped with a S20 cathod. The time constant was 0.1 sec.

Lieske (1978, 1980) uses 85 mutual events in his development of new ephemerides based on theSampson's theory. He compares these observations with predictions and detects a bias in the residuals in right ascension for the mutual eclipses. This systematic effect will be explained later by Aksnes et al. (1986).

c) Study of the surface parameters of the Jovian satellites

Several papers are related to the study of albedos thanks to the observations of mutual events.
Vermilion et al. (1974) publish the analysis of three occultations of J2 by J1 which leads to the construction of a low resolution map of J2. They deduce a radius of J1. These results are then confirmed by using them for the reduction of a fourth observation of mutual event.
Herzog and Beebe (1975) used six mutual occultations of J2 by J1 in order to establish an albedo map of J2. Various models are used, the best result is obtained thanks to the assumption of a polar cap on J2. They comment the discrepancy between their results and the results published byVermilion et al. (1974).
Murdin (1975) uses an observation of an occultation of J2 by J1 simultaneously made in UBV in order to study the colour variation of the apparent disk of J2. He find a non uniformity of the brightness of J2 in UV.
Murray (1975) made visual observations of Io, Europa and Ganymede at the Pic du Midi observatory in France. He gave an estimate of their albedos and he observed a mutual occultation of Europa by Ganymede.
Greene et al. (1975) observed an occultation of Europa by Io in 30 wavelengths from 0.32 to 1.1 µm with the multi-wavelengths spectrophotometer at Hale telescope. The analysis gives the spectral reflectivity of seven areas on Europa and data on the north polar cap.
Brinkman (1976) study the possibility to inverse lightcurves of mutual events in order to produce albedos map. He applies his model to the lunar surface and deduces a good behaviour for observational defaults currently encountered: poor signal/noise ratio, non linear photometry.
Chen et al. (1978) analysed observations of two mutual occultations and four mutual eclipses. The receptor was a photoelectric photometer mounted on a 60 cm telescope with a GG11 filter. A model for the distribution of brightness has been used for the occulted satellite. The assumption of an eventual crater in the central area of the apparent disk of Europa is considered. Discrepancies between the observed and predicted values are discussed. A model of mutual eclipse is used to reduced three lightcurves. The radius of J2 is deduced.

2. The mutual events of the 1979 period

The maximum of phenomena during the 1979 period occurring when the jovicentric declinations of the Earth and the Sun became zero, was very close to the conjunction of Jupiter. So, very few phenomena were observed in spite of the two campaigns which were organized: one coordinated by Aksnes and Franklin, the other one by Bureau des longitudes.

a) Predictions

Predictions of the 1979 events were available in the Annuaire du Bureau des longitudes (1979) and in the Handbook of the British Astronomical Association (1979).
Aksnes and Franklin (1978) give predictions of these events for the 1979 period. They include phenomena of J5 Amalthea which were difficult to observe (and which have not been at our knowledge).
Arlot (1978) gives predictions of these mutual events based on the ephemerides done at Bureau des longitudes and based on Sampson's theory.

b) Campaigns of observation

Arlot et al. (1979) announce the beginning of a campaign of observations PHEMU79, they give the first results obtained and call for observers.
Arlot et al. (1982) publish results obtained during the observations made thanks to the PHEMU79 campaign. Nine phenomena have been observed, fourteen lightcurves have been obtained. Corrections of the most recent ephemerides are deduced.

Aksnes et al. (1984a, 1984b) publish some new observations and, including those from Arlot et al. (1982), compute theoretical corrections. They show two lightcurves obtained during the mutual events period of the Saturnian satellites.
Aksnes et al. (1986) make an analysis of the phase effect and of the reflection properties of the surfaces of the satellites. They deduce a significative influence of these effects on the astrometric measurements during the mutual events observations.They think that this can explain systematics effects detected in the residuals of the 1973 and1979 observations.

3. The mutual events of the 1985 period

The 1985 period of mutual events is favorable since the opposition of Jupiter is very close to the dates of equatorial plan crossing when the mutual events are numerous. The campaign PHEMU85 is organized by Bureau des longitudes with the support of the Centre National de la Recherche Scientifique.

a) Predictions

One can find predictions of the 1985 mutual events in the Annuaire du Bureau des longitudes (1985) and the Handbook of the British Astronomical Association (1985, 1986).
Arlot (1983) give predictions and local conditions of observation for the mutual events visible in France.
Aksnes and Franklin (1984a, 1984b, 1985a,1985b) give predictions for this new period and call for collaboration with observers. Arlot (1984, 1985) give predictions deduced from three different ephemerides.
Arlot and Rocher (1984) give conditions of visibility of several phenomena occuring when Jupiter is close to the Sun in the form of geographic maps.
Arlot et al. (1985a) and Ferrin (1985) invite amateurs to join the campaigns of observations and give information on the visual and photographic technique of observation which can be used.
Some other papers (Arlot, 1985b, Barufetti, 1985,1986) are published in order to give information to the amateur observers.
Sengoku (1984) describes the main theoretical characteristics of the Sampson and Lieske theories. He gives the predictions of the phenomena visible from Japan.

b) The PHEMU85 campaign

The PHEMU85 campaign organized by Bureau des longitudes has been closed by a workshop Journées PHEMU85 (Arlot, 1987b) which was held in Bagnères de Bigorre (France) (see Annex 1.), where different teams have communicated their results.
During this campaign several technical notes, the Notes Techniques PHEMU85, have been written (see Annex 3.) in order to give detailed ephemerides and to coordinate the observations.
Bergeal (1987) presents the contribution of amateurs to the PHEMU85 campaign and gives exemples of lightcurves obtained.
Arlot (1987a) and Arlot and Thuillot (1988) give the global description of the campaign and the results obtained.
Blanco (1988a, 1988b) gives lightcurves obtained at Catania (Italy) during the observation of thirty seven mutual events. He also gives the comparaison to the predictions.
Froeschlé et al. (1988) publish two occultations and four eclipses observed at CERGA observatory (France) thanks to their fast photometer TELOC.
Arlot et al. (1986, 1989b) give results obtained at ESO (Chile). Twenty one phenomena have been observed. A reduction and a comparaison of these observations with the results obtained in other sites allow to estimate the good precision.
Arlot et al. (1989a) give results obtained at the Haute-Provence Observatory in France. Eighteen phenomena have been observed and the results are compared with predictions and with results obtained by other observers.
Arlot et al. (1990a) have observed eight mutual phenomena in Brazil and they give a comparaison of their results with predictions and observations made by other observers.
Thuillot and Morando (1990) and Thuillot (1990) give an algorithm to model the lightcurves of the mutual events by taking into account the law of light scattering and phase effect. Two synthetic

lightcurves are given and compared with observations.
Thuillot et al. (1990) present two observations of mutual events observed in 1985 with video technique. They describe the method used. Arlot (1990b) gives information on the video technique applied to the mutual events observation. Ruatti (1990) give information on the reduction of the whole set of observations collected during the PHEMU85 campaign.
Vasundhara (1990) describes her analysis of thirty observations of mutual events made during the PHEMU85 campaign and shows five observations made in India. Her adjustment of a model shows the good agreement of the Lommel-Seeliger law of reflection of light with respect to the Lambert's one.
The whole set of observations made during the PHEMU85 campaign is published in a catalogue (Arlot et al. 1992). 65 phenomena observed have been observed and 168 lightcurves have been recorded. Photometric techniques, as well as photographic, visual or video techniques have been used. A comparaison with theoretical predictions is made and allows the estimate of the precision of each observation.

c) Other observations

Other papers concerning the mutual events observations have been published. New results are obtained concerning the volcanic activity of Io since the mutual events observations is revealed to be a powerful technique to detect and survey this activity.
Franklin and twenty two colleagues (GSO, 1991) give astrometric results deduced from their analysis of 198 lightcurves of 105 mutual events. Allen and Budding (1986) publish one observation of an occultation of Io by Ganymede. They give the results obtained by two ways: the uniformity of the light reflection or the linear limb darkening law of reflection.
Coulson (1986) publishes observations made during a campaign organized by the South African Astronomical Observatory. Eighteen lightcurves have been recorded and a table gives the comparaison with the predictions.
Grigorjeva et al. (1986a, 1986b) gives observations of fifteen phenomena made at Alma-Ata. Guhl (1986) gives a lightcurve of the visual observation of the total eclipse on 1985, September 4.
Marcialis (1986) give observations of mutual events for which the agreement with the Aksnes predictions is less than 30 secondes of time and 5p. cent of lightflux drop.
Mc Ewen et al. (1986) show the theoretical ability to observe the volcanic activity of Io thanks the observation of mutual occultations. They use a model of the thermic emission of the volcanoes based on the measurements made by the Voyager space probes.
Sengoku et al. (1987) publish twenty three lightcurves of fourteen mutual events observed in Japan Observaories Bisei, Simosato and Sir-ahama. A comparison with the predictions and longitudinal corrections are given for the three first satellites.
Goguen et al. (1988) publish seven infrared observations of occultations of Io by another Galilean satellite. Thanks to a model they verify that these observations allow to study the volcanic activity of this satellite. These observations show the effect of the occultation of Loki on the lightcurves observed at 3.8 µm, 4.8 µm or 8.7 µm. They get the spatial resolution of the thermic emission of the Loki area. Furthermore they detect a new hot spot.
Medina et al. (1989) publish three infrared observations of mutual events. They give an interpretation of the anomalies in the lightflux drop by means of occultation of hot spots on Io.Westfall (1989) publish thirty observations photometrically done by amateurs. Twenty five phenomena are concerned. Europa seems to show an advance of 26 seconds of time with respect to Io.

4. The mutual events of the 1991 period

a) Predictions

For the 1991 period predictions are available in several yearly ephemerides, for example in the Handbook of the British Astronomical Association (1990, 1991), the Annuaire du Bureau des longitudes (1991) or the Ephémérides Astronomiques de la Société Astronomique de France (1991).
On the other hand, Aksnes (1989) and Aksnes and Franklin (1990) publish their predictions of 200 phenomena observable from November 1990 to March 1992. They use the Lieske's ephemerides E-1.
Arlot (1988) publishes the predictions of selected mutual phenomena: the occultations of Io by the other

satellites. He also gives the conditions of observability for several observatories where infrared observations could be done.
Arlot and Rocher (1989) publish maps of the visibility of mutual occultations of Io for 1991. Arlot (1990a) publish his predictions of the phenomena for the 1990-1992 period based on theephemerides G-5.

b) The campaigns of observation

Goguen (1988) makes an analysis of different circumstances for the Io occultations during the 1991 period. He selects 53 occultations by Europa which lead to the best conditions for the infrared observations of the volcanic activity of Io.
Sinton (1988) describes the project to observe the occultations of Io by Europa during this new period coordinated by the International Jupiter Watch association. He recommends the infrared observation at 3.8 µm (or 3.5 µm), 4.8 µm and 8.7 µm.
Goguen and Howell (1989) publish predictions of radial velocities during occultations of the volcano Loki by Europa. These predictions show the possibility to get a spatial resolution of 10 km in the analysis of the observations. They intend to coordinate the observers and to give them informations.
Arlot et al. (1990b) announce they will coordinate a new campaign of observation, the PHEMU91 campaign. They invite infrared observers to join the campaign and to contact the Bureau des longitudes.
Goguen (1989) publish the proceedings of the Workshop The Io hot spots occultations organized in June 1989 by the Jet Propulsion Laboratory and International Jupiter Watch. The goal of this workshop was to organize the next observations of Io occultations during the very favorable period of 1991. New data on the volcanic activity of Io and the characteristics of its surface will result from them. Three working groups have written chapters of this report on the scientific goals, the observations and the instrumentation.
Allen et al. (1992) publish their analysis of five observations of mutual events, a mutual occultation and four eclipses. They study the penumbra effect thanks to a model for the mutual eclipses.Observations made during the PHEMU91 campaign are analysed (Arlot et al., 1992, Froeschlé et al., 1992, Le Campion et al., 1992, Mallama, 1992, Morando, 1992, Morando and Descamps, 1993,Oprescu et al., 1992 , Ruatti, 1992, Souchay et al., 1992, Thuillot et al., 1994, Vasundhara, 1990,1994).
The whole set of lightcurves recorded during the PHEMU91 campaign is gathered in a catalogue (Arlot et al., 1997). The 375 lightcurves of 111 mutual events of the PHEMU91 campaign and other data of the previous campaigns are available on the server of Bureau des longitudes (ftp://ftp.imcce.fr and http://www.imcce.fr). During the PHEMU91 campaign, one occultation of Io by Europa was observed in the infrared band and simultaneously in the visible one (Arlot et al., 1991, Descamps et al., 1992, Descamps et al.,1994). From this observation a precise astrometric measurement of the location of Loki could be deduced.
The results of the PHEMU91 campaign have been partialy used in order to get new constants of the theory of the motions of the Galilean satellites and to estimate the secular acceleration of Io (Vasundhara et al., 1996). Other observations are especialy made in order to study the volcanic activity of Io.
Spencer et al. (1994) give their results obtained during the observations of four occultations of Io by Europa in the 5.0 µm and 3.4 µm bands. A combination with infrared images of Io allows to reveal important variations of the activity of Loki.
Nelson et al. (1996) used simultaneous observations in four wavelengths of ten occultations of Io which allow them to get data on the surface composition.
Nasonova (1996) give a brief history of the international campaigns of observation of the mutual events.

5. The 1997 period of mutual events

a) The predictions

As for the previous periods, several authors made predictions of the circumstances of the 1997 mutual phenomena.
Emel'yanov (1996) presents his software MONS which gives the positions of the natural satellites and the dates of several phenomena.
Ephemerides have been computed by Meeus and are published in the Bulletin de la Société Astronomique de France (SAF, 1997).

Arlot (1996a, 1996b) gives his set of predictions of the mutual events for this new period and presents the organization of the PHEMU97 campaign. A part of these predictions are published in the Annuaire du Bureau des longitudes (1997).
Arlot et al. (1997) give a selection of occultations of Io well adapted to the observations of occultations of the volcanoes. They give the different parameters related to four main volcanoes of Io.

b) Campaigns of observation

A PHEMU97 campaign and other campaigns of observations are organized: different papers call observers to join the international effort in order to extend the network (Arlot and Wilds, 1997,Arlot and D'Ambrosio, 1997, Tanga, 1997). Various information, data and softwares ara available on Internet, for example on http://www.imcce.fr and on http://ringside.arc.nasa.gov/www/tools/tools.html.

Conclusion

This bibliography shows that works concerning the mutual phenomena of the Galilean satellites became numerous and diversified mainly because of the new techniques to observe and analyse these events. The applying of infrared techniques particularly allowed to get very new data on the volcanic behaviour of Io. Nevertheless observations in other wavelengths are still very useful, in particular to try to detect faint effects in the motions of the Galilean satellites such as the secular accelerations. We can expect results in this domain thanks to the use of the new techniques and to the cumulative data collected since the first campaign of observations. International campaigns of observations are essential for these goals.

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ANNEX 3. -- Technical notes PHEMU85.

N.T.n°1 : Périodes d'observation des phénomènes mutuels en 1985-86.
N.T.n°2 : Liste de tous les phénomènes mutuelsde la période 1985-86.
N.T.n°3 : Phénomènes mutuels prioritaires et conditions d'observabilité en France, en Italie, en Espagne et au Chili.
N.T.n°4 : Notice bibliographique sur les travaux divers effectués sur le sujet des phénomènes mutuels (1973-1984).
N.T.n°5 : La précision de la prédiction des phénomènes mutuels de 1985-86.
N.T.n°6 : Les astronomes amateurs et la campagne PHEMU85 (l'observation visuelle des phénomènes mutuels).
N.T.n°7 : Compte-rendu des journées préparatoires à la campagne PHEMU85 (28-29 septembre 1984

àParis).
N.T.n°8 : Comment observer les phénomènes mutuels avec un photomètre photoélectrique.
N.T.n°9 : Caractéristiques et données diverses pour chaque phénomène mutuel prioritaire.
N.T.n°10 : Calibrations (liste des étoiles standard de type spectral quasi-solaire et des étoiles doubles proches de Jupiter lors des phénomènes mutuels).
N.T.n°11 : Positionnement et suivi des satellites galiléens lors des phénomènes mutuels.
N.T.n°12 : Observation des phénomènes rasants et des conjonctions entre satellites.
N.T.n°13 : Ephémérides des satellites galiléens pour le deuxième semestre de 1985 (sous forme de coefficients de fonctions mixtes).
N.T.n°14 : Présentation des satellites galiléens de Jupiter, des phénomènes mutuels et de la campagne PHEMU85.
N.T.n°15 : Visibilité des phénomènes mutuels en1985-1986 (zone géographique de visibilité pour chaque phénomène).
N.T.n°16 : Les premiers phénomènes observables en France : configurations du système jovien (période mai-juin 1985).
N.T.n°17 : L'observation des phénomènes mutuels par la méthode photographique.
N.T.n°18 : Configurations du système jovien lors des occultations rasantes et des conjonctions.
N.T.n°19 : Configurations du système jovien lors des phénomènes mutuels visibles l'Observatoirede La Silla (Chili).
N.T.n°20 : Configurations du système jovien lors des phénomènes mutuels prioritaires observablesen Espagne et en Italie.
N.T.n°21 : Les phénomènes mutuels de juillet-août 1985 observables en France : configurations du système jovien.
N.T.n°22 : Configurations du système jovien lors des phénomènes mutuels prioritaires observables depuis le sud de l'Angleterre.
N.T.n°23 : Les phénomènes mutuels d'août-septembre 1985 observables en France : configurations du système jovien.
N.T.n°24 : Les premiers résultats de la campagne PHEMU85.
N.T.n°25 : Photométrie photoélectrique des phénomènes mutuels : problèmes liés au matériel utilisé pour l'observation et l'acquisition des données.
N.T.n°26 : Les phénomènes mutuels de septembre-octobre 1985 observables en France :configurations du système jovien.
N.T.n°27 : Deuxième bilan de la campagnePHEMU85.
N.T.n°28 : Les phénomènes mutuels d'octobre-novembre1985 observables en France.
N.T.n°29 : Modèle pour une éclipse d'un satellite galiléen par un autre.
N.T.n°30 : Les phénomènes mutuels de décembre 85 observables en France : configuration du système jovien.
N.T.n°31 : Les phénomènes mutuels de janvier 86 observables en France : configuration du système jovien.
N.T.n°32 : Réduction d'observations faites pourdes hauteurs faibles de Jupiter : obstruction par la coupole.