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308 Polyxo: ISO–SWS spectrum up to 26 micron⋆,⋆⋆

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Abstract. Infrared spectroscopic observations of the asteroid 308 Polyxo have been carried out by the Infrared Space Observatory (ISO) with the Short Wavelength Spectrometer (SWS) in the spectral region between 7 and 26 μm. The Standard Thermal Model and the Thermophysical Model have been applied to the obtained data in order to model the thermal continuum. Sub-solar and black-body temperatures also have been derived. The obtained spectrum has been compared with laboratory spectra of minerals and meteorites available in the literature. Moreover, we performed new measurements to obtain infrared spectra of the Tagish Lake meteorite, recognized as the best analog of primitive D-type asteroids. A tentative spectral similarity with the Ornans meteorite is suggested, while we cannot confirm, in the considered wavelength range, the analogy with the Tagish Lake meteorite.

Key words. minor planets, asteroids – radiation mechanisms: thermal – infrared: solar system – meteors, meteorites

1. Introduction

The asteroid 308 Polyxo is classified as belonging to the D2 class by Barucci et al. (1987) and as belonging to the T class by Tholen (1989) and Bus & Binzel (2002). Debehogne & Zappalà (1980) and Harris & Young (1983) carried out photometric observations of this asteroid and computed a synodic rotational period of 12.031 ± 0.009 h. The obtained lightcurves present an irregular two maxima and two minima trend, with a complex secondary maximum, indicating that Polyxo should have a very irregular shape. The largest amplitude was about 0.20 mag, giving a lower limit of the semimajor axis $a/b \geq 1.2$. Based on many different lightcurves, Lagerkvist & Magnusson (1990) derived an H-value of 8.19 ± 0.02 and a G-value of 0.25 ± 0.02. Later Piironen et al. (1997) computed $H = 8.15 \pm 0.05$ and $G = 0.17 \pm 0.05$ from observations covering a larger phase angle range.

Jones et al. (1990) detected a strong feature at about 3.0 μm, probably related to the presence of aqueous alteration products on the surface of Polyxo. Hiroi & Hasegawa (2003) found a strong similarity between the visible and near-infrared spectra of Polyxo and the Tagish lake meteorite: although the reflectances are quite different, about 2% at 0.55 μm for the meteorite and about 4.8% for Polyxo at the same wavelength, the obtained spectra show similar behaviours and features.

Several values of radiometric diameters and albedos have been published so far for Polyxo: D = 188 km, p_V = 0.027 (Hansen 1976); D = 162 km, p_V = 0.037 (Hansen 1977); D = 133 km, p_V = 0.040 (Morrison 1977); D = 140.69 ± 3.8 km, p_V = 0.0482 ± 0.003 (Tedesco et al. 2002); D = 151 ± 7 km, p_V = 0.043 ± 0.002 (Dotto et al. 2002). A stellar occultation event resulted in a modeled cross section ellipse of 172 by 134 km with an uncertainty in the long axis of ±16 km (Dunham 2001).

Dotto et al. (2002) published the first photometric and spectroscopic mid-infrared data of this object acquired with the Infrared Space Observatory (ISO) using two different instruments PHT-S and PHT-P. On the basis of these observations they derived the black-body temperature (232 K) and the subsolar temperature (265 K) and found a similarity with the CO3 meteorite Ornans in the spectral range 5.8–11.6 μm.

In this paper we present new observations of Polyxo obtained by ISO with the Short Wavelength Spectrometer (SWS) in the spectral range between 7 and 26 μm. Moreover, we report new laboratory spectra of the Tagish Lake meteorite, in order to check in this large wavelength range the suggested spectral analogy with Polyxo.

⋆ Table 1 is only available in electronic form at
http://www.edpsciences.org

⋆⋆ Based on observations with ISO, an ESA project with instruments funded by ESA Member States (especially the PI countries: France, Germany, The Netherlands and UK) and with the participation of ISAS and NASA.

2. ISO SWS observations

Our observations of Polyxo were part of the programme on "Dark, volatile rich asteroids: possible relation to comets" (Barucci et al. 1997). The measurements were taken with the ISO-SWS (de Graauw et al. 1996) on April 15, 1997 in the SWS06 observing mode (medium length grating scans to observe long wavelength regions at full resolution of 1000–2000). At the time of the observation Polyxo was at r = 2.645 AU, Δ = 2.633 AU and $\alpha = 21.9°$ and moved at about 42″/h on the sky in the satellite-centric frame. A detailed list of the individual measurements and epochs is summarized in Table 1.

The data reduction was first done interactively with OSIA[1]. Special care was taken in the analysis of the dark current subtraction and in removing the spikes and tails of high energy glitches. A recent tracking-correction tool (OSIA user Manual 3.0, p109ff) was used to account for the periodic flux losses due to the steep beam profiles in combination with the discrete tracking steps. In a second analysis, the software package ISAP[2] was used to take out bad detectors and to remove faint glitches. Then the up and down scans and the signals from different detectors were combined to produce one spectrum per sub-band. Spectral features were then checked for influences due to tracking, glitches, different up- and down-scan behaviour, detector outliers, rebinning and averaging effects, fringes and residuals of the relative spectral response function.

The data reduction resulted in the relatively smooth spectrum of Polyxo shown in Fig. 1. Minor jumps between band edges are probably still due to instrumental artefacts and calibration uncertainties. Some differences between adjacent bands might also be caused by the changing object cross section during the ~3 h observing time. The data below 7 μm and beyond 26 μm have not been considered since Polyxo was very faint at these wavelengths, and the obtained data suffer from low-gain settings and short integration time, yelding a low signal to noise ratio.

3. Models

To determine the black-body temperature of Polyxo we fitted the infrared data with a Planck function multiplied by the solid angle of the object. Both the solid angle and the black-body temperature were treated as free parameters. The computed black-body temperature is 230 K, in agreement with the result obtained by Dotto et al. (2002) on the basis of PHT-P and PHT-S observations.

By applying the Standard Thermal Model (STM) (Lebofsky & Spencer 1989), already used by Tedesco et al. (1992) in the IRAS asteroid survey, we obtained a sub-solar temperature of about 265 K, the same value as computed by Dotto et al. (2002). With STM we computed also a diameter of 145 ± 7 km and an albedo of 0.047 ± 0.004. These values are in agreement within the error bars with D = 151 ± 7 km and p_V = 0.043 ± 0.002 by Dotto et al. (2002).

To model the thermal continuum of Polyxo we applied also the ThermoPhysical Model (TPM), developed by Lagerros (1996, 1998). As input quantities we took H = 8.15, G = 0.17, $P_{\rm syn}$ = 12.031 h, a rotation axis perpendicular to the ecliptic plane and a spherical shape. We assumed also default thermal behaviour, with beaming, thermal inertia and emissivity as given in Müller & Lagerros (1998, 2002). This allowed us to derive thermophysical radiometric diameters and albedos for each band at the photometrically most reliable central wavelengths. The weighted mean values and standard deviations for diameter and albedo are: D = 142.1 ± 5.5 km and p_V = 0.049 ± 0.004 (the solid and dashed lines in Fig. 1). Considering the lightcurve amplitude and the fact that the shape of Polyxo might be irregular, our derived diameter and albedo agree well with previous values. A combination of all diameters would only be possible through a shape and spin vector model which currently does not exist.

TPM predictions match the observed continuum over the wavelength range from about 7 to 26 μm by better than about 10–15% at all band/scan key wavelengths. The STM predictions do not allow us to obtain such a close fit at wavelengths outside the N-band range. Since we used default thermal values (thermal inertia Γ = 15 Jm^{-2} s$^{-0.5}$ K^{-1}, beaming parameters ρ = 0.7 and f = 0.6, emissivity ϵ = 0.9) to describe the Polyxo behaviour, we can speculate that the surface is probably covered with a dust-rock regolith. A bare rock surface would show up as a significant mismatch between the TPM and observed continuum due to beaming and thermal inertia effects (see also Dotto et al. 2000; Müller 2002).

Using TPM we computed the expected flux of Polyxo at the time of ISO-SWS observations and we obtained the emissivity, by dividing the observed spectrum for the TPM expected flux (reported in the top of Fig. 2).

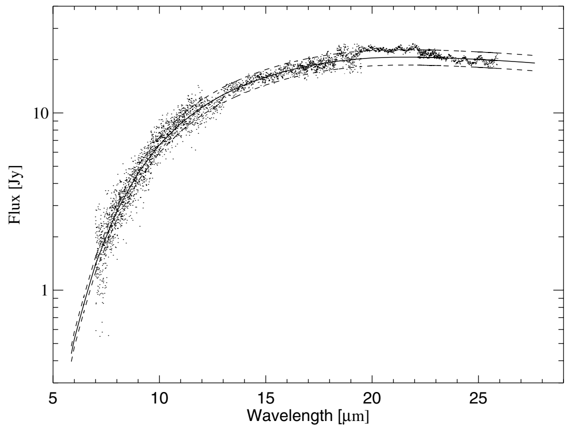

Fig. 1. The observed spectrum of Polyxo on April 15, 1997. The TPM expected flux for a diameter of D = 142.1 km (±5%) and an albedo of p_V = 0.049 is shown as solid line. Dashed lines correspond to the relative error bars.

[1] OSIA is a joint development of the SWS consortium. Contributing institutes are SRON, MPE, KUL and the ESA Astrophysics Division.

[2] The ISO Spectral Analysis Package (ISAP) is a joint development by the LWS and SWS Instrument Teams and Data Centers. Contributing institutes are CESR, IAS, IPAC, MPE, RAL and SRON.

4. Laboratory experiments

Since Hiroi & Hasegawa (2003) found a good similarity between the visible and near-infrared spectra of Polyxo and the Tagish Lake meteorite, we performed new laboratory experiments on particulate samples of this meteorite. The Tagish Lake meteorite (Hiroi & Hasegawa 2003) is an atypical carbonaceous chondrite, recording specific aqueous alteration conditions (Gounelle et al. 2001), and it is considered the only meteorite analog for primitive D-type asteroids (Hiroi et al. 2001).

Laboratory spectra were obtained in vacuum (1 mbar), using the Capodimonte Observatory Bruker IFS66v interferometer. Since asteroid spectra seem to be dominated by the effect of fine particles (Le Bertre & Zellner 1980), we considered two particulate samples at grain size smaller than 20 μm and larger than 100 μm and we performed our measurements using finely ground pure CsI powder as a reference. The diffuse reflectances of the sample (R_s) and the reference (R_r) were measured by using a biconical optical configuration. The diffuse reflectance of the particulates R was obtained as the ratio $R = R_s/R_r$, and the emissivity E was derived via Kirchhoff's law as $E = 1 - R$. The obtained laboratory spectra are shown in Fig. 2.

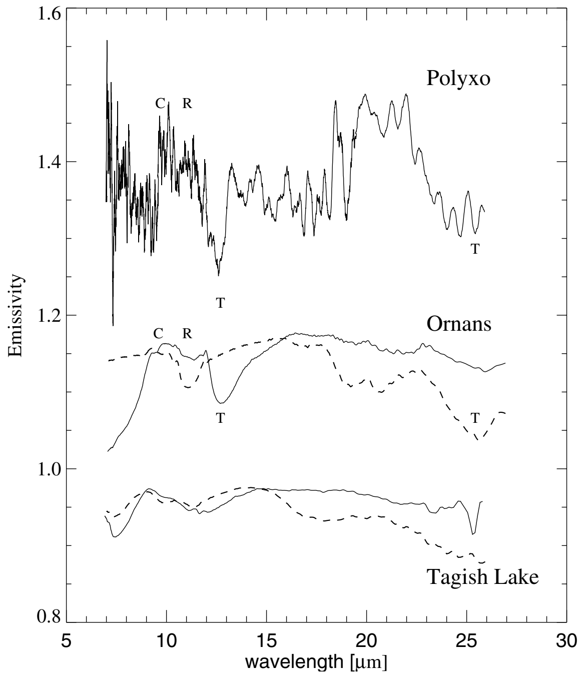

Fig. 2. The observed emissivity of Polyxo compared with the emissivities of 2 carbonaceous chondrite meteorites, as obtained in laboratory: two samples of Ornans at grain dimensions smaller than 20 μm (continuous line) and larger than 100 μm (dashed line) and two samples of the Tagish Lake meteorite at grain dimensions smaller than 20 μm (continuous line) and larger than 100 μm (dashed line). Christiansen, Reststrahlen and Transparency features are noted as C, R and T respectively (see the text).

5. Data interpretation

To analyse asteroid spectra we have to take into account the surface composition as well as several unknown physical parameters, such as density, mineralogy, particle size and packing. In the considered wavelength range the most diagnostic features are the Christiansen peak, reststrahlen, and transparency features. The Christiansen peak is associated with the principal molecular vibration band, where the refractive index changes rapidly, and occurs at a wavelength that for silicates is just short of the Si–O stretching vibration bands. This feature, directly related to the mineralogy and the grain size, appears generally as a peak between 7.5 and 9.5 μm. The reststrahlen features are due to the vibrational modes of molecular complexes. A plateau is visible between 9 and 12 μm in the spectrum of Polyxo shown in Fig. 2. In the spectral region where the absorption coefficient decreases, grains become more transparent. Usually, the transparency features occur at 11–13 μm between main reststrahlen bands and at longer wavelengths (>20 μm) (Mennella et al. 1998). If the grain size is small, volume scattering occurs and transparency features are observable due to a loss of photons crossing many grains.

In order to interpret the spectral features above the thermal continuum we compared the Polyxo emissivity with our laboratory spectra of the Tagish Lake meteorite. Moreover we considered all the laboratory spectra of minerals and meteorites already performed by our group and published by Dotto et al. (2000) and Barucci et al. (2002). We took also into account the whole sample of mineral and meteorite emissivities available in the literature (Salisbury et al. 1991a,b, ASTER spectral library on `http://speclib.jpl.nasa.gov`).

The Ornans sample at grain dimensions smaller than 20 μm represents the best similarity with the spectral behaviour of Polyxo: this analogy is supported by the Christiansen peak and reststrahlen features between 9 and 12 μm (noted as C and R in Fig. 2), as well as the transparency features around 13 μm and 26 μm (noted as T in Fig. 2). The presented ISO-SWS observations and laboratory experiments allow us to confirm what was found by Dotto et al. (2002) who claimed that the 5.8–11.6 μm spectrum of Polyxo was consistent with the laboratory spectrum of the Ornans meteorite particulate at grain size smaller than 20 μm. Nevertheless we cannot confirm 308 Polyxo as one of the best candidates of the parent body of the Tagish Lake meteorite, as suggested by Hiroi & Hasegawa (2003). None of the Tagish Lake particulate samples show in the considered wavelength range spectral features similar to those of Polyxo.

In Fig. 2 we have shown the comparison among the SWS emissivity spectrum of Polyxo and the emissivities of two samples of the Tagish lake meteorite at grain sizes smaller than 20 μm (continuous line) and larger than 100 μm (dashed line) and two samples of the Ornans meteorite at grain size smaller than 20 μm (continuous line) and larger than 100 μm (dashed line), as obtained by laboratory experiments.

6. Conclusions

In this paper we present a unique infrared spectrum obtained by ISO of 308 Polyxo.

In order to interpret this spectrum and to investigate the Polyxo surface composition we analysed the emissivities of several meteorites.

In the 7–26 μm wavelength range, Polyxo was consistent with the laboratory spectrum of an Ornans meteorite particulate with grains smaller than 20 μm. Since Ornans is a CO3 type aqueously altered carbonaceous chondrite meteorite, the similarity found with the Polyxo spectrum confirms the result by Jones et al. (1990) describing the presence of aqueous alteration products on the surface of this asteroid.

Nevertheless, we cannot confirm the analogy between Polyxo and the Tagish Lake meteorite found in the visible and near-infrared range by Hiroi & Hasewaga (2003). The SWS spectrum of Polyxo and the laboratory spectra of two samples of the Tagish Lake meteorite particulates are completely different: the spectral behaviour of Polyxo between 9 and 10 μm is not consistent with the Christiansen peak of the Tagish Lake meteorite which occurs at about 8.7 μm. Also the reststrahlen and transparency features occur at different wavelength ranges and with different trends in the two spectra.

Further observations in the mid- and far-infrared wavelength ranges of primitive dark asteroids are absolutely needed to check their spectral consistency with the Tagish Lake meteorite. The possibility that differences in the spectral analogy can be due to heterogeneity of the Polyxo surface observed at different rotational phases needs to be investigated.

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Online Material

Table 1. Summary of SWS06 observations of asteroid Polyxo on April 15, 1997. For each TDT (the number in the original data file names and FITS headers) the individual scans are sorted by wavelength.

		Time (UT)		Wavelength [μm]	
Band	Scan	Start	End	min.	max.
TDT 51600117					
3A	S06 Up	04:10:41	04:20:12	11.963	16.505
3A	S06 Down	04:20:55	04:30:26	11.963	16.505
TDT 51600118					
3C	S06 Up	06:12:11	06:18:50	16.466	19.506
3C	S06 Down	06:19:01	06:25:40	16.466	19.506
3C	S06 Up	06:12:11	06:18:50	16.591	19.641
3C	S06 Down	06:19:01	06:25:40	16.591	19.641
3D	S06 Up	05:06:41	05:21:54	19.427	23.255
3D	S06 Down	05:22:37	05:37:50	19.427	23.255
3D	S06 Up	05:06:41	05:21:54	19.701	23.568
3D	S06 Down	05:22:37	05:37:50	19.701	23.568
3D	S06 Up	04:50:45	05:05:58	22.123	25.909
3D	S06 Down	05:38:33	05:53:46	22.123	25.909
3D	S06 Up	04:50:45	05:05:58	22.394	26.216
3D	S06 Down	05:38:33	05:53:46	22.394	26.216
TDT 51600119					
2C	S06 Up	06:38:23	06:47:14	6.978	9.605
2C	S06 Down	06:47:57	06:56:48	6.978	9.605
2C	S06 Up	06:28:49	06:37:40	9.565	12.020
2C	S06 Down	06:57:31	07:06:22	9.565	12.020