ORBIT DETERMINATION FROM COMBINED RADAR AND OPTICAL TRACKS DURING XMM CONTINGENCY OPERATIONS

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ABSTRACT

On 18 October 2008 the operators of ESA's X-ray Multi-Mirror Mission (XMM-Newton) lost contact with the satellite. XMM is one of Europe's largest scientific satellites. It resides in a highly eccentric (21700 km x 99500 km) orbit with an inclination of 58 deg. The XMM operators asked to support the analysis of the contingency situation, in particular to acquire tracking data of the non-cooperative target via suitable tracking facilities, and to determine a precise orbit. Any information on orbital states and attitude was highly desirable in order to better understand the situation and to ensure proper follow-ups with the ground facilities during communication attempts. We present the fusion of radar and optical observations into a common orbit determination of a non-cooperative target using the predicted orbit as a-priori information. Three European sensors participated in the ad-hoc tracking campaign: the Tracking and Imaging Radar (TIRA) of the Forschungsgesellschaft für Angewandte Naturwissenschaften (FGAN) near Bonn, Germany, the ESA Space Debris telescope at Tenerife, Spain, and the telescopes ZIMLAT and ZimSMART at the Zimmerwald observatory of the Astronomical Institute of the University of Bern (AIUB) in Switzerland. All sensors were able to observe XMM close to the predicted positions. In the meantime the New Norcia ground station could establish a weak carrier-link. This finally led to re-establishing full radio contact. We validate the quality of the orbit determination through a comparison with the operational orbit. This work demonstrates the generation of orbit information for passive bodies by using European sensors only, even if the orbit is highly eccentric.

Key words: XMM; space debris; space surveillance; radar tracking; optical tracking; orbit improvement.

1. INTRODUCTION

ESAs X-ray Multi-Mirror Mission (XMM-Newton) [1] resides in a highly eccentric 21700 km x 99500 km orbit with an inclination of 58 deg. On 18 October 2008 the operators of XMM lost contact with the satellite (1999-066A, SSN 25989). The last uplinked command from the Santiago ground station was the request for an antenna switch at 15:27 UTC. At the scheduled time XMM was in the coverage gap between the Santiago and Villafranca ground stations. Villafranca ground station did not receive the expected telemetry at 15:37 UTC.

This paper concentrates on the orbit determination for XMM from combined radar and optical tracks during the XMM contingency operations. We start with an overview on the actions related to the ESA/ESOC Space Debris Office, before we introduce the utilised sensors and present an overview on the acquired data. We outline the orbit determination approach and then analyse and validate the determined orbits, which closes this work.

2. ACTIONS DURING THE XMM CONTINGENCY OPERATIONS AT THE SPACE DEBRIS OFFICE

The Space Debris Office was asked to support the analysis of the contingency situation. At that time several error scenarios were considered by the operators. One was the possibility of a fragmentation event involving XMM. With the help of the CRASS software, the Space Debris Office could exclude a collision with an object in the catalogue provided by USSTRATCOM. This was later confirmed by a conjunction event analysis of NASA that included all objects tracked by the US SSN. XMM operators asked the Space Debris Office to acquire tracking

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data using all available tracking facilities. Main concern was that XMM might have executed autonomous manoeuvres (ESAM) and/or could be in a tumbling state. Any information on orbital states and attitude was highly desirable in order to understand the situation better and to ensure proper tracking with the ground facilities during communication attempts.

An ad-hoc tracking campaign was set-up immediately by contacting the Tracking and Imaging Radar (TIRA) of the Research Establishment for Applied Science (FGAN) in Wachtberg, Germany, the ESA Space Debris Telescope (ESASDT), located at the Observatorio del Teide at Tenerife, Spain, and the Zimmerwald observatory of the Astronomical Institute of the University of Bern (AIUB), Switzerland. All three contacted European sensors rescheduled their ongoing observations to provide tracking capabilities in the evening hours of Monday, 20 October 2008, for which the next perigee pass of XMM was predicted. Around the apogee XMM was not accessible from central Europe.

As TIRA is frequently contacted to acquire tracking data of chaser objects involved in high-risk-events (see [2]), a well-rehearsed process exists, and the orbit determination of XMM from the TIRA orbit tracks could be performed soon after the data acquisition. Via phone conference Zimmerwald observers reported already around 17:30 UT that they have acquired XMM observations close to the predicted positions. They added that visual inspection of the acquired exposures does not show brightness variations for XMM, which indicates a stable (or slowly rotating) attitude. Also the ESA Space Debris telescope was able to acquire observations of XMM. In parallel to the described tracking campaign amateur astronomers of the Starckenburg observatory near Darmstadt in Germany informed the mission operators that they have observed XMM. They also did not observe brightness variations.

While the Space Debris Office started to fuse the radar observations into a common orbit determination with the astrometric observations from the Zimmerwald telescopes and ESA's Space Debris Telescope (ESASDT) on Tuesday morning (21 October 2008). ESA's New Norcia ground station could establish a weak carrier-link to XMM, suggesting a failure in the on-board RF switch. This finally led to re-established full radio contact on Wednesday, 22 October, around 16:00 UT. Support of the Space Debris Office was then no longer required by the XMM mission operators.

3. SENSOR OVERVIEW

In this section we briefly introduce the sensors that participated in the ad-hoc tracking campaign during the XMM contingency operations.

Figure 1. Photomontage of the FGAN radar system TIRA.

3.1. TIRA

TIRA (see Fig. 1) is one of the largest and most powerful radar systems for space observation. Its main subsystems are: a 34 m parabolic antenna, a narrow-band monopulse L-band tracking radar, and a high-resolution Ku-band imaging radar. The sophisticated, fully computer-controlled, 34 m parabolic Cassegrain-feed antenna is mounted on an elevation-over-azimuth pedestal. It is shielded from atmospheric influences by a rigid 49 m-diameter radome. The L-band radar is used primarily for the detection and tracking of space objects. Using a double-Klystron power stage, it generates high-frequency pulses of typically 1 to 2 MW peak power and 1 ms pulse length. The signal processing concept supports target tracking in angular direction as well as in range and range rate. In this operating mode, typically 30 statistically independent observation vectors per second are gained with the tracking filter. The main components of an observation vector are: time, azimuth and elevation angles, range, range rate, echo amplitude and phase, and the transmitted peak power.

3.2. OGS

The Optical Ground Station (OGS) is regularly used for high altitude space debris observations. The main instrument at OGS is a 1m optical telescope, the ESA Space Debris telescope (ESASDT). For space debris observations the ESASDT is equipped with 4 x 4 k mosaic CCD camera (Space Debris camera, SD). The SD camera is mounted to a modified Richey-Chretien focus. The focal length that configuration is 4.7 m and the image size is 0.7 deg x 0.7 deg. The field of view of one pixel is 0.6 arc seconds. The typical exposure times used during observations are 2-4 seconds. With those exposure times we can detect up to 21 magnitude objects. That corresponds to about 15 cm size objects at GEO (see [3] for details on the sensor design and on the observation strategy).

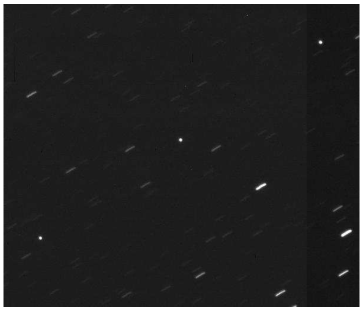

Figure 2. Composite of three exposures showing XMM (as dot-shaped image) acquired with the ESASDT. The figure shows only a small part of the entire field-of-view.

The weather conditions during the evening of 20 October were very bad and it was just amazing luck that less than 20 minutes before the end of XMM visibility from OGS the sky cleared and humidity dropped to acceptable limit. That allowed us to run 2 times our typical follow-up observations, which each lasts 6 minutes. Fig. 2 gives an example for astrometric observations of XMM as they result from the follow-up observation scenario.

3.3. Zimmerwald Telescopes

Two of the optical facilities at the Zimmerwald observatory were contacted to observe XMM, the Zimmerwald Laser and Astrometry Telescope (ZIMLAT), and the Zimmerwald Small Aperture Robotic Telescope (ZimSMART). Both usually perform optical observations every night if weather permits, and included XMM into their observation schedule for 20 October with the highest priority. They reported good weather conditions - unfortunatley with a rapid decrease forecasted soon after sunset. Zimmerwald observers tracked XMM for nearly one hour before clouds prevented further observation.

ZIMLAT is a 1-m multipurpose instrument - a Ritchey-Chrétien telescope on horizontal mount. It is unique in the world, as it allows to interleave - nearly in parallel - satellite laser ranging (SLR) observations with optical observations. The optical observations with ZIMLAT have their main focus on acquiring precise astrometric measurements and photometric light curves of Earth-orbiting satellites and objects in the solar system. As the telescope is equipped with a derotator platform, switching between up to 4 optical detectors is possible. Usually, a system with a focal length of about 4 m fitted with a backside-illuminated CCD Camera with an e2v 4240 Chip is used. The resulting effective field of view is about 21 arcmin, corresponding to a pixel scale of about 0.7 arcsec/pixel. Un-binned frames are read out in about 40 s. A filter wheel allows observations in different wavelengths reaching from blue to infrared. With the e2v camera the astrometric accuracy is about 0.1 arcsec, decreasing to about 0.5 arcsec at the limiting magnitude of the optical system at 20.5 mag. ZIMLAT is considered as being a quasi-operational system.

Figure 3. Optical facilities at the Zimmerwald observatory of AIUB, Switzerland, during the installtion of ZimSMART in Spring 2006.

When in 2006 a new annex to the observatory could be inaugurated, a robotic small aperture telescope was installed on the roof. ZimSMART, entirely built-up from commercially available components, is designed as test-bed for the development, test and validation of algorithms, survey techniques, and real-time follow-up procedures. As such it perfectly complements the optical observation capabilities of ZIMLAT. The telescope is a Takahashi Epsilon-180 (hyperbolic astrograph), mounted on a Paramount ME (German-equatorial) from Software-Bisque. The camera is a PL09000 camera from FLI with a front-illuminated Kodak KAP-09000 chip, which yields in a pixel scale of about 5 arcsec. In order to minimse the read-out noise ZimSMART is operated usually with a readout speed of 1MHz, which corresponds to a single frame readout within 12s. Observations acquired with ZimSMART give positions of reference stars usually better than 1 arcsec. The limiting magnitude is around 16 mag. Since 2008 ZimSMART is a operational sensor allowing to acquire and to process pre-planned observations automatically.

Detailed description of the two sensors installed at Zimmerwald observatory, together with an overview on the current optical observation program is given by [4]. See also Fig. 3.

4. DATA OVERVIEW

In this section we present and characterise the acquired data. We distinguish for the tracking of a non-cooperative target radar observations (range, azimuth and elevation, range rate in topocentric coordinates), and astrometric observations by optical telescopes (right ascension and declination in topocentric coordinates).

Tab. 1 shows that an arc of more than 4.5 hours after the perigee passing of XMM could be covered by European tracking sensors, not relying on transmissions from the satellite. Details to this data overview are provided in the subsequent paragraphs.

Table 1. Overview of the radar and optical tracking data acquired during the XMM contingency operations (Observed data: range r, azimuth a, elevation e, right ascension α, declination δ).

Sensor	#Obs	Start of arc	End of arc
TIRA	57	2008/10/20	2008/10/20
	(r, a, e)	17:28:43	18:07:06
ZimSMART/	93/19	2008/10/20	2008/10/20
ZIMLAT	(α, δ)	17:23:33	18:30:15
ESASDT	14	2008/10/20	2008/10/20
	(α, δ)	21:17:13	21:35:12

4.1. Radar observations

For TIRA, a matched filter processing of the received radar echos guarantees an optimum signal-to-noise ratio (SNR) of the output signal (assumed, that the echos are corrupted from Gaussian white noise only). To achieve sufficient range resolution, pulse compression is applied using binary phase shift keying (BPSK) with subpulse lengths of 4, 8, 16, 32, 64, 128, and 256 μs, providing a maximum compression ratio of 250. The tracking program automatically switches to the best possible compression ratio in each pulse based on the actual available SNR and by statistically analysing a certain history of received echos.

Analysis of the XMM observation situation revealed that for the range of involved target ranges in the observation window (23.200 km to >30.000 km) TIRA might be close to the edge of its sensitivity. Thus, prior to the observation of XMM, a rough estimation of the principal ability of the L-band radar to track XMM at the precalculated ranges was made, based on an adapted form of the radar range equation. The radar cross section (RCS), which the target at range R must show at reflection of a transmitted pulse, is given by the approximate relation RCS(R)=NRCS + SNR(τ_{sub}) + $40\log_{10}$(R[km]$/1000$), where NRCS is the noise-equivalent RCS at 1000 km range (for unmodulated pulses and transmit power of 1 MW). For the TIRA L-band radar NRCS is roughly -47 dBsm. SNR(τ_{sub}) is the signal-to-noise ratio, necessary for tracking the target with a given pulse compression ratio, i.e. with a desired principal range resolution. Values range from about 3 dB for unmodulated pulses (base range resolution 150 km) to about 15 dB for highest compression (base range resolution 600 m). Applying these values reveals that XMM must show a RCS of at least 23 dBsm (200 sm) for the minimum range of 23200 km to be tracked with the highest possible accuracy in range.

XMM acquisition successfully occurred at a range of 22195 km, and stable tracking could be performed until 30200 km range. The RCS varied between about 5 and 31 dBsm, with a mean value of about 20-22 dBsm. The number of pulses, in which full pulse compression could be applied decreased from the start to the end of the observation, becoming effectively 0 for the final 20 minutes. Even in the first part with the lowest ranges the number was not high enough to calculate an orbital element set from the data. It was thus decided to provide observation data only from the first 38 minutes of the observation and to extract only those echoes with the highest compression rates (>8).

We use in our analysis only the data set with maximum subpulse length of 32 μs, as the number of individual data points is still sufficient and we expect the highest internal precision from shortest sub-pulse samplings. In total 57 radar observation data sets (epoch, range, azimuth, and elevation) are available for XMM, covering the period 2008/10/20-17:28:43 until 2008/10/20-18:07:06. Fig. 4 and Fig. 5 give the distribution of the acquired data over time. Corrections for ionospheric and tropospheric refraction were applied during the orbit determination process.

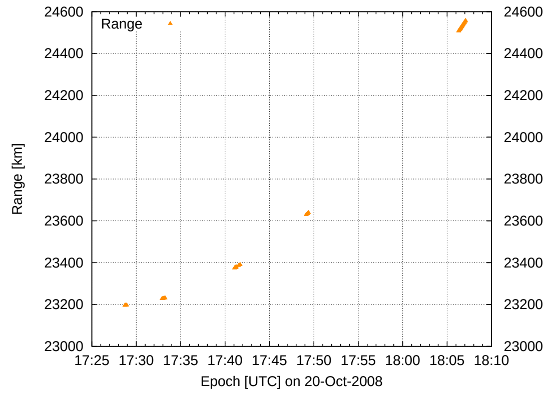

Figure 4. Observed Ranges to XMM by TIRA.

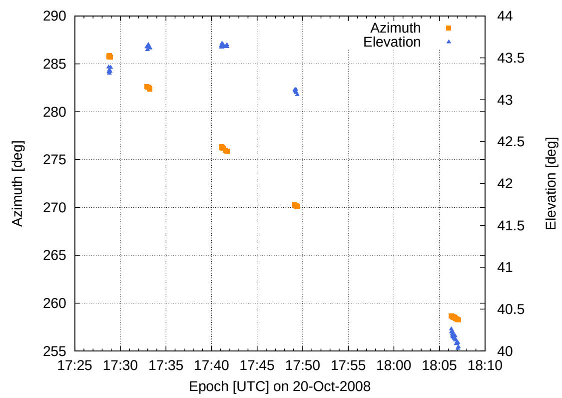

Figure 5. Tracking azimuth and elevation of XMM as observed by TIRA.

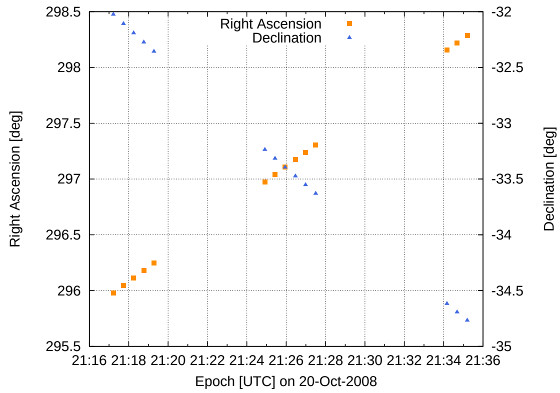

Figure 6. Right ascension and declination of XMM observed from the ESASDT.

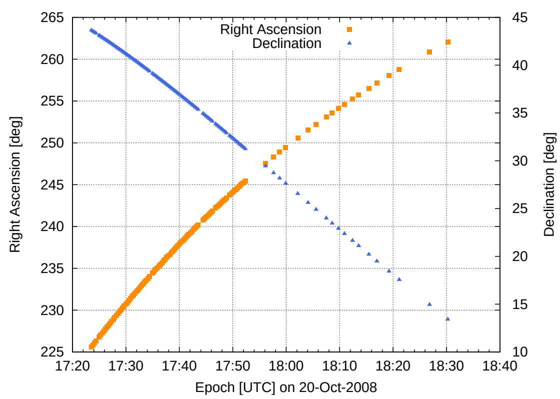

Figure 7. Right ascension and declination of XMM observed from the Zimmerwald observatory, Switzerland. The first 30 minutes are observations acquired by ZimSMART, the subsequent observations stem from ZIMLAT.

4.2. Astrometric observations

In total 126 astrometric observation data set (epoch, right ascension, declination) are available for XMM, covering the period 2008/10/20-17:28:43 until 2008/10/20-21:35:12. In chronological order ZimSMART provided 93 data sets, ZIMLAT 19 data sets, and the ESASDT 14 data sets. Fig. 6 and Fig. 7 give the acquired astrometric observations as a function of the observation epoch.

Corrections for tropospheric refraction are not applied during the orbit determination process, as observations are obtained from differential astrometry. The data is not corrected for parallactic refraction.

4.3. Light curve observations

A light curve (evolution of the apparent object brightness over time) was obtained from the XMM observations from ZIMLAT and ZimSMART. The data were corrected for varying range, i.e. normalised to range of first epoch, but phase angle corrections were not applied (Fig. 8). There is clearly no signature of any attitude motion (rotation or tumbling) with a period less than a few hours. The brightness decreasing by about 1 mag within 30 minutes is caused by phase angle variations and by the increasing range during the covered time frame. The stronger variations from 2500 s onwards are most likely due to high clouds that moved into the field of view.

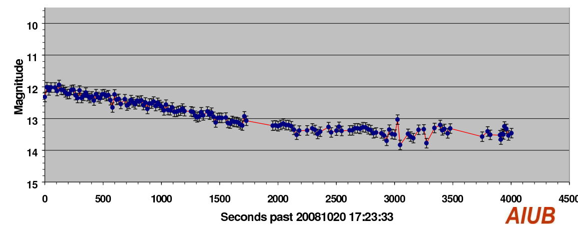

Figure 8. Range-normalised brightness of XMM observed from Zimmerwald (all epochs are in UTC).

5. ORBIT DETERMINATION APPROACH

We used the command line version of ODIN (Orbit Determination with Improved Normal equations) that is installed at the Space Debris Office for the data processing, supported by some external data conversion scripts (see [5] and [2] for a detailed description). The orbit determination approach was a Levenberg-Marquardt iteration with least-squares adjustment, terminating after the RMS changes less than 0.1% between consecutive iteration steps. As a-priori orbit we used the last known orbit of XMM in TLE format provided by ESOC's Flight Dynamics Division. ODINcl was used to propagate this TLE-set to J2000 ephemerides using the SGP4 propagator.

A-priori 1-sigma values of the tracking data were obtained from external sources. For the TIRA sensor, for which no experience in this altitude regime was available, we estimated the weights from an iterative manual adjustment. As we performed several orbit determination attempts using different combinations of the available tracking data, the internal consistency between the results of those attempts might indicate the applicability of the weighting criterion - assuming the observations to be free of biases.

6. RESULTS FROM ORBIT DETERMINATION

In this section we present the orbit determination results from different combinations of the available tracking data.

6.1. Determined orbits

Tab. 6.1 gives the determined orbits for various combinations of observations types, including also an orbit determined from Zimmerwald observations only, using AIUB's program system CelMech [6].

The results indicate for XMM that

- Telescope observations spanning several minutes in time may already fix the orientation of the orbital plane (i/Ω) quite well.
- The (overlapping) observations of the TIRA radar and the Zimmerwald telescopes already allow a very precise orbit determination with one hour of observations!
- The arc observed at the ESASDT seems to be underweighted (likely due to the short length and the low number of observations) and does mainly contribute to the orbit determination by extending the total covered arc, which in turn improves the determination of semimajor axis and eccentricity.
- There is no significant bias (within the orbit determination accuracy) between the radar and optical sensors participating in the tracking campaign.
- Comparison with the results from the orbit determination at AIUB indicates that some slight improvements might still be possible.

6.2. Comparison of obtained residuals (RMS)

Tab. 3 gives the resulting RMS values for various combinations of observations types. We will call the orbit determined from a combination of observations from TIRA, ZimSMART, ZIMLAT, and the ESASDT the 'best orbit'. For this orbit determination we plot the obtained residuals in Fig. 9, Fig. 10, and Fig. 11. The analysis of the residuals taking into account the according RMS values from Tab. 3 shows that due to the extreme ranges observed the precision of the observations of TIRA is by about one magnitude worse compared to the usually expected values. The residuals of the astrometric observations acquired with the ESASDT are larger than the residuals of the Zimmerwald observations by about a factor of 2. An already scheduled re-calibration of the epoch registration at the ESASDT might address this issue. Within the residuals of the Zimmerwald telescopes the observations acquired by ZimSMART and ZIMLAT system can be easily distinguished through the temporal density of observations. The epoch registration of ZimSMART was not fully calibrated, which might explain the small differences in the residuals in right ascension between ZimSMART and ZIMLAT.

Table 2. Comparison of the orbit determination results from different combinations of the available tracking data. Abbreviations for used observations: T (TIRA), Z (ZimSMART/ZIMLAT), E (ESASDT). For all determined orbits the epoch of the osculating elements is 2008/10/20-17:33:32.0. All results are in J2000.0.(*): independent orbit determination of AIUB.

T Z E	a [km]	e [-]	i [deg]	Ω [deg]
x	66849.6	0.5825812	57.7900	102.8368
	±198.4	±0.0011727	±0.0157	± 0.0196
x	66924.7	0.5830547	57.7797	102.8258
	± 97.7	±0.0005598	±0.0011	± 0.0007
x*	66914.3	0.5829934	57.7794	102.8261
	± 22.7	±0.0001305	±0.0001	± 0.0003
x x	66940.7	0.5831448	57.7794	102.8259
	± 4.8	±0.0000269	±0.0001	± 0.0002
x x	66926.7	0.5830662	57.7797	102.8258
	± 23.0	±0.0001321	±0.0002	± 0.0002
x x	66890.9	0.5828496	57.7760	102.8248
	± 24.0	±0.0001414	±0.0033	± 0.0013
x x x	66929.3	0.5830820	57.7794	102.8261
	± 2.8	±0.0000150	±0.0001	± 0.0001

Table 3. Comparison of the residuals from the orbit determination attempts using different combinations of the available tracking data. Abbreviations for used observations: T (TIRA), Z (ZimSMART/ZIMLAT), E (ESASDT).

T Z E	r [km]	a [deg]	e [deg]	α [deg]	δ [deg]
x	0.295	0.0239	0.0196	-	-
x	-	-	-	0.00015	0.00011
x*	RMS = 0.44 arcsec (=0.00012 deg)				
x x	-	-	-	0.00020	0.00013
x x	0.330	0.0322	0.0244	0.00015	0.00011
x x	0.308	0.0314	0.0267	0.00026	0.00023
x x x	0.334	0.0322	0.0244	0.00020	0.00014

6.3. Comparison of the determined orbit with XMM's operational orbit

As operational orbits for XMM are now available after the contact has been re-established, we are able to validate the quality of the orbit determination. The 'best' obtained orbit (considering the observations of TIRA, ZimSMART, ZIMLAT, and the ESASDT) was propagated by ODINcl, and compared to the ephemerides for XMM provided by ESOC's Flight Dynamics Division considering the given manoeuvre plan as of 18 October.

Fig. 12 shows how the propagated 'best orbit' fits with the operational orbit with a 1-sigma RMS of 0.446 km x 0.645 km x 0.284 km in radial, along-track, out-of-plane

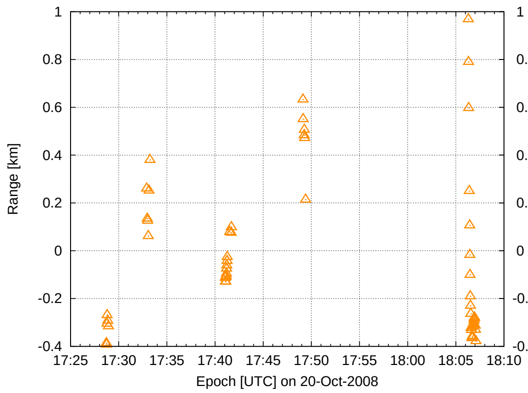

Figure 9. Residuals between observed ranges to XMM (by TIRA) and the 'best' determined orbit.

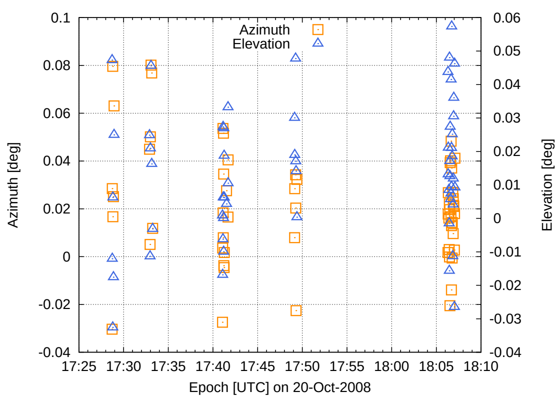

Figure 10. Residuals between observed azimuth and elevation angles to XMM (by TIRA) and the 'best' determined orbit.

components over an arc of 48h (i.e., one orbit of XMM).

Fig. 13 displays a comparison between the predictions of the Flight Dynamics Division and an orbit generated from the four optical and radar sensors and in addition including the Doppler information recorded at the New Norcia station. For the same orbit arc the resulting propagation fits with a 1-sigma RMS of 0.187 km x 0.300 km x 0.337 km in radial, along-track, and out-of-plane components over an arc of 48h. Around the periods covered by radar and optical observations the results are comparable. The Doppler data from New Norcia helps to cover a longer arc in time with observations and thus mainly improves the predictions of the along-track and radial components.

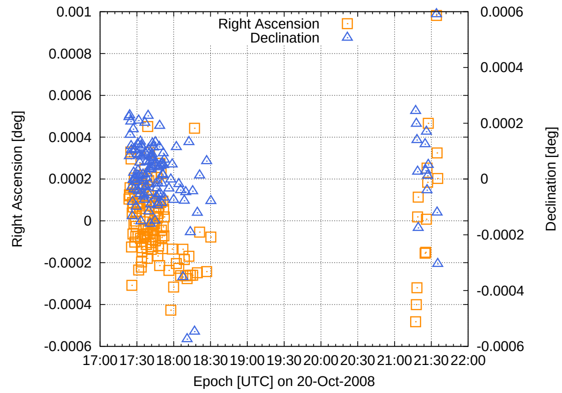

Figure 11. Residuals between observed right ascension and declination to XMM (ZimSMART, ZIMLAT, ESASDT) and the 'best' determined orbit.

7. SUMMARY

The Space Debris Office has supported the analysis of the XMM contingency of 18 October 2008 by conjunction assessments and by scheduling a tracking campaign involving the European sensors TIRA, the ESA Space Debris Telescope at Tenerife, Spain, and two telescopes at the Zimmerwald observatory in Switzerland. All tracking was carried out within extremely short notice on Monday, 20 October 2008, only a few hours after being requested. All sensor operators applied highest priority on the tracking of XMM.

With the help of the observations the latest orbit from the ESOC's Flight Dynamics Division could be improved utilising the ODINcl software installation. The combined orbit determination of XMM based on overlapping radar and optical tracking data is a unique achievement. In addition light curves were acquired and analysed by AIUB that indicated XMM being in a stable (or very slowly rotating) state.

The 'best' determined orbit derived from combining observations from TIRA, the ESASDT and the Zimmerwald telescopes was verified against the 'truth' of an operational orbit that is available after re-establishing the contact with XMM. We showed that combining data from the two telescopes with the data from the FGAN radar is sufficient to determine an orbit that comes close to the operational orbit. It fits by 0.446 km x 0.645 km x 0.284 km in radial, along-track, out-of-plane over an arc of 48h (one orbit revolution). Inclusion of the range rate data that was obtained from the first contact with XMM via New Norcia on Tuesday, 21 October 2008, into the orbit determination does only slightly improve the determined orbit further, indicating the high quality of the determined orbit. This is remarkable since the data used cover only an arc of 4 hours (17:30 - 21:35).

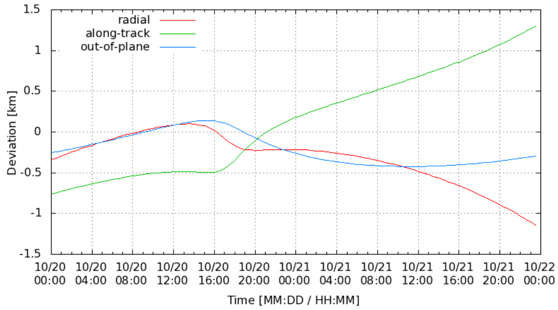

Figure 12. Deviation between the predictions from ESOC's Flight Dynamics Division after XMM's recovery and the orbit generated from ZIMLAT, ZIMSMART, ESASDT and TIRA tracking data.

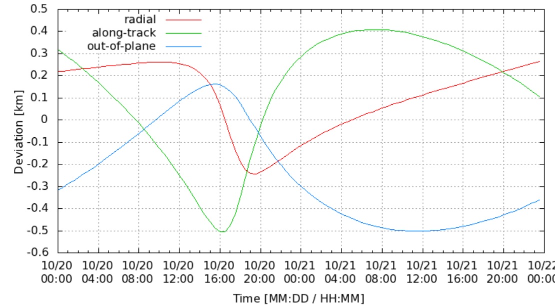

Figure 13. Deviation between the predictions from ESOC's Flight Dynamics Division after XMM's recovery and the orbit generated from ZIMLAT, ZIMSMART, OGS, and TIRA tracking data, and Doppler data from ESA's New Norcia ground station.

We presented that telescope observations spanning several minutes in time may already fix the orientation of the orbital plane (i/Ω) quite well, and that the (overlapping) observations of the TIRA radar and the Zimmerwald telescopes already allow a very precise orbit determination within one hour of observations only! The arc observed with the ESASDT later contributes to the orbit determination by extending the total covered arc, which in turn improves the determination of shape of the orbit (a/e) further.

This work demonstrates what can be achieved today by fusing data from European sensors. The combination of heterogeneous tracking data to determine the orbit of a passive, uncooperative object has proven to be possible within short time, on very short notice during contingency operations, even if the orbit is highly eccentric. It needs to be stressed that this has only been possible thanks to the commitment and flexibility of the sensor operators. The operators at FGAN, at Tenerife and at the Zimmerwald observatory acquired and made available XMM tracking data by re-scheduling their ongoing projects and by participating in the XMM ad-hoc tracking campaign instead.

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