UV COLOURS OF ASTEROIDS IN THE SERENDIPITOUS OBSERVATIONS OF THE XMM-NEWTON OPTICAL MONITOR CAMERA.

Universidad Internacional de Valencia

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1 Index

2 Resumen

(English version in section below)

El presente documento expone el trabajo realizado como parte del Trabajo Fin de Máster del Máster Universitario en Astronomía y Astrofísica de la Universidad Internacional de Valencia: "UV COLOURS OF ASTEROIDS IN THE SERENDIPITOUS OBSERVATIONS OF THE XMM-NEWTON OPTICAL MONITOR CAMERA" ("COLORES ULTRAVIOLETA DE ASTEROIDES EN OBSERVACIONES SERENDÍPICAS DEL OPTICAL MONITOR CAMERA DEL XMM-NEWTON").

El telescopio espacial de la Agencia Espacial Europea (ESA), XMM-Newton (X-ray Multi-Mirror Mission)[1], lanzado en 1999 ha realizado (y sigue realizando hasta la fecha) observaciones en longitudes de onda corta, centrándose sobre todo en rayos X y ultravioleta (UV). Éstas últimas llevadas a cabo por su telescopio óptico/UV: el XMM-OM (XMM-Newton Optical/UV Monitor Telescope). A lo largo de las últimas décadas, dicho instrumento se ha utilizado para la observación con carácter científico de objetivos específicos en el rango óptico y UV. No obstante, tal cantidad de observaciones a lo largo de los años abren la posibilidad a observaciones serendípicas (casuales, no intencionadas) de otros cuerpos celestes.

El objeto de este trabajo es el análisis de asteroides en dichas observaciones serendípicas. Está basado en el estudio previo realizado por la directora del TFM[2], donde se publicó un catálogo de observaciones que podrían haber capturado un asteroide en su campo de visión de forma inintencionada. En el presente trabajo se han analizado varias de estas posibles observaciones atendiendo al rango óptico/UV, procediendo a analizar fotométricamente aquellas que proporcionaban suficiente información.

En esta memoria se recogen no sólo los resultados del estudio, sino también la metodología seguida para llegar a ellos, tanto desde un punto de vista científico como

[1] *Technical Details - OM - XMM-Newton - Cosmos*. (2000, 01 01). cosmos.esa.int. https://www.cosmos.esa.int/web/xmm-newton/technical-details-om

[2] Racero, E. et al (2022). ESASky SSOSS: Solar System Object Search Service and the case of Psyche. *Astronomy & Astrophysics*, *659*, A38.

práctico, desglosando cada una de las herramientas desarrolladas para facilitar (e incluso automatizar) el proceso.

3 Summary

(Versión en español en la sección anterior)

The present document outlines the work done as part of the Master Thesis for the Máster Universitario en Astronomía y Astrofísica of Universidad Internacional de Valencia: “UV COLOURS OF ASTEROIDS IN THE SERENDIPITOUS OBSERVATIONS OF THE XMM-NEWTON OPTICAL MONITOR CAMERA”.

European Space Agency’s (ESA) space telescope, XMM-Newton (X-ray Multi-Mirror Mission)[3], launched in 1999 has been performing (and continues to do so) observations in short wavelengths, focusing primarily on X-Ray y ultraviolet (UV) ranges. The latter are carried out by its optical/UV telescope: the XMM-OM (XMM-Newton Optical/UV Monitor Telescope). In the past few decades, said instrument has been used for the scientific observation of targets within the optical and UV ranges. However such a large amount of observations throughout the years open up the possibility of serendipitous (i.e. random, unintended) observations of other celestial bodies.

The purpose of this work is the analysis of asteroids captured in the aforementioned serendipitous detections. It is based on the previous work done by the Master Thesis director[4], where a catalogue of observations that could unintentionally contain an asteroid within their field of view was published. The present work analyses several of these observations, focusing on the optical/UV range, and proceeding to photometrically analyse those that provide enough data.

This Thesis gathers not only the results but also the process that has been followed to reach them, from both a scientific point of view as well a pragmatic one, breaking down each of the tools developed to ease (and even automate) the process.

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[3] *Technical Details - OM - XMM-Newton - Cosmos*. (2000, 01 01). cosmos.esa.int. https://www.cosmos.esa.int/web/xmm-newton/technical-details-om

[4] Racero, E. et al (2022). ESASky SSOSS: Solar System Object Search Service and the case of Psyche. *Astronomy & Astrophysics*, *659*, A38.

4 List of Acronyms

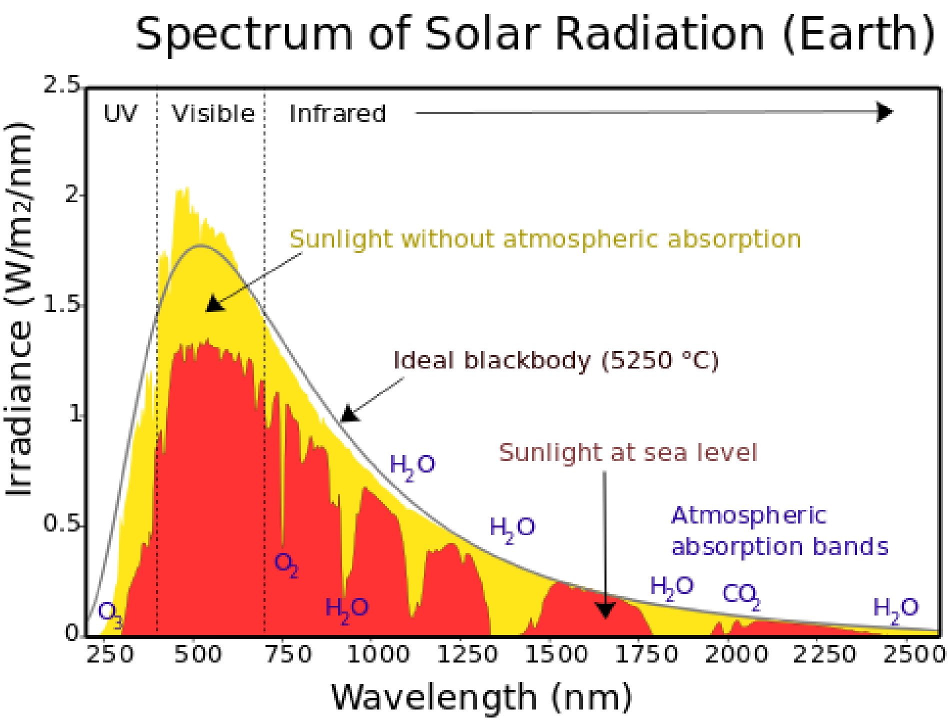
Acronym	
API	Application Programming Interface
DS9	SAOImageDS9 software
ESA	European Space Agency
FITS	Flexible Image Transport System
FoV	Field of View
HDU	Header Data Unit
HST	Hubble Space Telescope
HTTP	Hypertext Transfer Protocol
I/O	Input/Output
(XMM-Newton) OM	XMM-Newton Optical/UV Monitor Telescope
SSO	Solar System Object
(ESASky) SSOSS	(ESASky) Solar System Object Search Service
UV	Ultraviolet
(ESA) XMM-Newton	(ESA) X-ray Multi-Mirror Mission
XSA	XMM-Newton Science Archive

5 Introduction

5.1 Scientific background

In the past decades several asteroid classification systems have been published. These systems attempt at categorising asteroids based on their reflectance spectrum, that is, the spectrum of sunlight reflected off their surface. These classes and systems are important as they provide information regarding the composition of the asteroid's surface (and potentially their internal composition too).

However, the Sun's solar spectrum steeply drops at around 300 nm, making it very difficult for ultraviolet (UV) light reflected on the asteroid's surface to be detected:



Sun's solar spectrum from Earth[5].

[5] *Brune, W. H. (n.d.). 6.4 The Solar Spectrum* | *METEO 300: Fundamentals of Atmospheric Science. Dutton Institute. https://www.e-education.psu.edu/meteo300/node/683*

This, in addition to the atmospheric UV absorption, have burdened the possibility of a large demographic study of asteroids in the UV range. As of 2015, the largest study of asteroids in UV was carried out by the International Ultraviolet Explorer, which sampled 45 different asteroids between 1978 and 1992[6].

As of today, one could say that asteroid data in the UV range remains scarce.

5.2 Previous work

The present work leverages on ESASky Solar System Object Search Service (ESASky SSOSS)[7], a catalogue listing all potential detections of asteroids within estimated limiting magnitude or flux limit in Herschel, XMM-Newton (X-ray Multi-Mirror Mission) and HST (Hubble Space Telescope).

Observations for all three above-mentioned missions were geometrically cross-matched against ESASky 800,000 asteroids and 2,000 comets. Each one of the potential serendipitous observations was classified according to the likelihood of the Solar System Object (SSO) position (either at the start or end of the observation), being included in the field of view (FoV) footprint:

- Type 1: the position of the SSO does not lie within the FoV footprint, but its uncertainty overlaps with it.
- Type 2: the position of the SSO lies within the FoV footprint.
- Type 3: neither starting nor ending positions of the SSO lie within the FoV footprint, but the SSO path during the observation crosses the FoV footprint.

The catalogue was made available in 2021 and listed 909 serendipitous detections in Herschel images, 985 in XMM-Newton Optical Monitor camera images, and over 32,000 potential serendipitous detections in HST images.

[6] *Waszczak, A. et al (2015, 05 06). Asteroids in GALEX: Near-ultraviolet photometry of the major taxonomic groups.*

[7] Racero, E. et al (2022). ESASky SSOSS: Solar System Object Search Service and the case of Psyche. *Astronomy & Astrophysics*, *659*, A38.

For the purpose of this Master's Thesis objective, we are primarily interested in serendipitous observations of SSO in the Optical/UV range. The table below outlines the number of potential serendipitous observations by XMM-Newton Optical/UV Monitor Telescope (XMM-Newton OM), broken down for each one of its colour discriminating broad-band filters:

Instrument	Zero-Point[a]	N_{total}	N_{serend}
OM V	−0.0474	4038	216
OM B	−0.6028	3939	428
OM U	−0.7439	7792	431
OM UVW1	−1.4842	16501	294
OM UVM2	−4.0778	13112	9
OM UVW2	−3.6144	6605	3

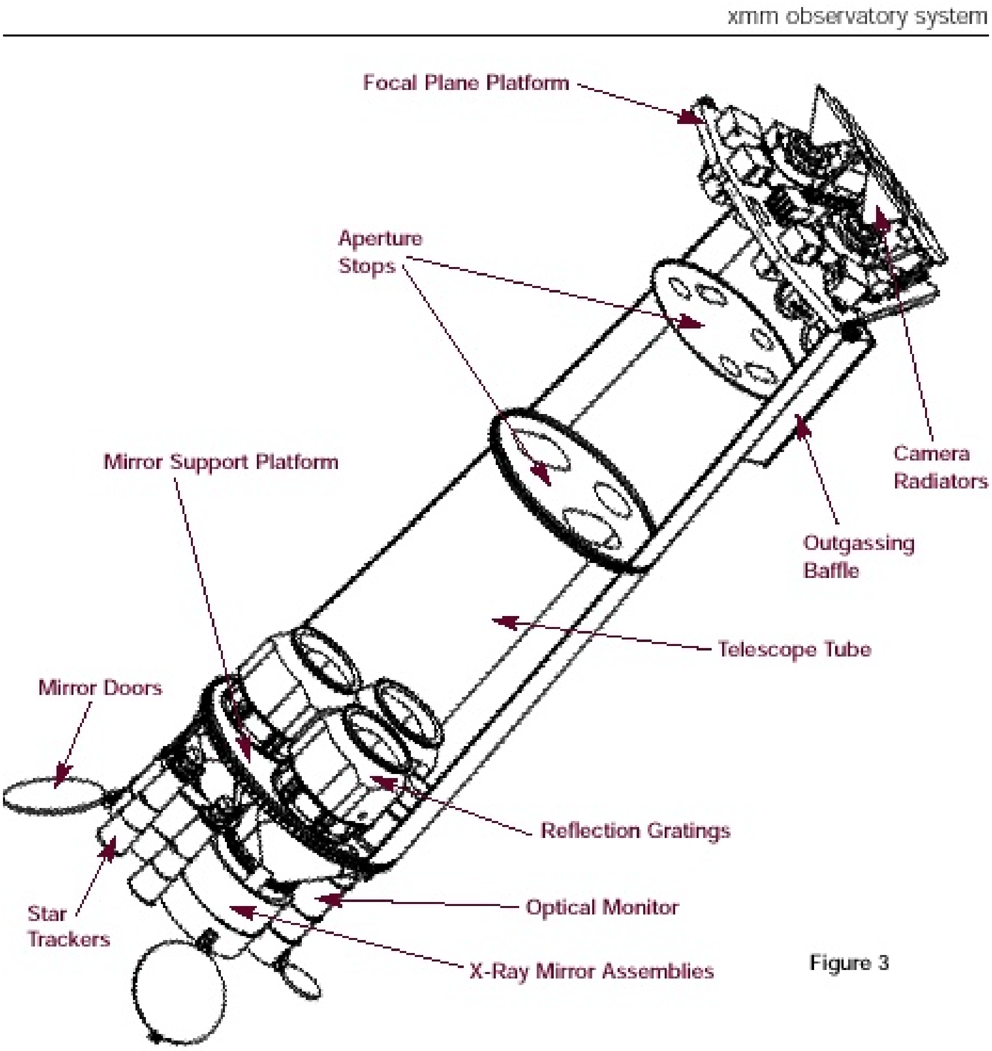
ESASKy SSOS number of potential XMM-OM (N_{serend}) serendipitous observations for each colour discriminating broad-band filter[8].

5.3 XMM Newton

The European Space Agency's (ESA) X-ray Multi-Mirror Mission (XMM-Newton) was launched on December 10th 1990. It constituted ESA's second cornerstone of the Horizon 2000 Science Programme[9].

At 4 tonnes, and 10 metres, the XMM-Newton spacecraft is the largest scientific satellite ever launched by the European Space Agency. It carries 3 high throughput X-ray telescopes, as well as an optical monitor.

[8] Racero, E. et al (2022). ESASky SSOSS: Solar System Object Search Service and the case of Psyche. *Astronomy & Astrophysics*, *659*, A38.
[9] *The Science Programme*. (n.d.). European Space Agency. https://www.esa.int/esapub/br/br114/br114sci.htm



XMM-Newton spacecraft[10].

Earth's atmosphere blocks out all X-rays, thus only a telescope in space can actually detect and observe celestial X-ray sources. As of May 2022, XMM-Newton sits at a tilted (~70 deg inclination) highly eccentric orbit, with a perigee around 26,000 km and an apogee around 100,000 km, resulting in an orbital period of approximately 48 hours[11]. Due to the radiation background from the radiation belts, XMM-Newton's instruments are limited to altitudes above 46,000 km, i.e. roughly 40 hours of operational time each orbit[12].

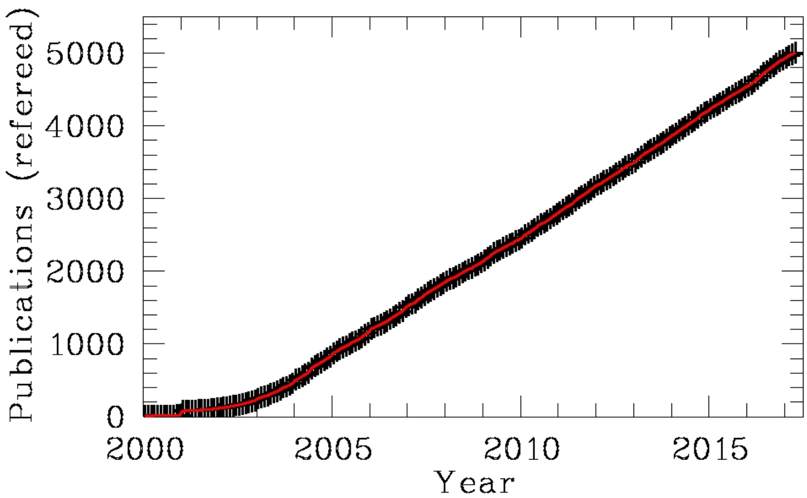
[10] *Technical Details - Spacecraft - XMM-Newton - Cosmos*. (n.d.). cosmos.esa.int. https://www.cosmos.esa.int/web/xmm-newton/technical-details-spacecraft

[11] *4.1 XMM-Newton orbit*. (n.d.). European Space Agency. https://xmm-tools.cosmos.esa.int/external/xmm_user_support/documentation/uhb/orbit.html

[12] *ESA Science & Technology - Orbit/Navigation*. (n.d.). ESA Science & Technology. https://sci.esa.int/web/xmm-newton/-/31349-orbit-navigation

XMM-Newton's mission is aiding the scientific community in solving a number of cosmic mysteries. Scientists can therefore apply for observing time on XMM-Newton, which are granted on a competitive basis.

Even today, more than 20 years after its launch, XMM-Newton keeps providing useful data for the scientific community. As of 2017 the XMM-Newton observatory had already reached 5,000 science papers in the referred literature[13].



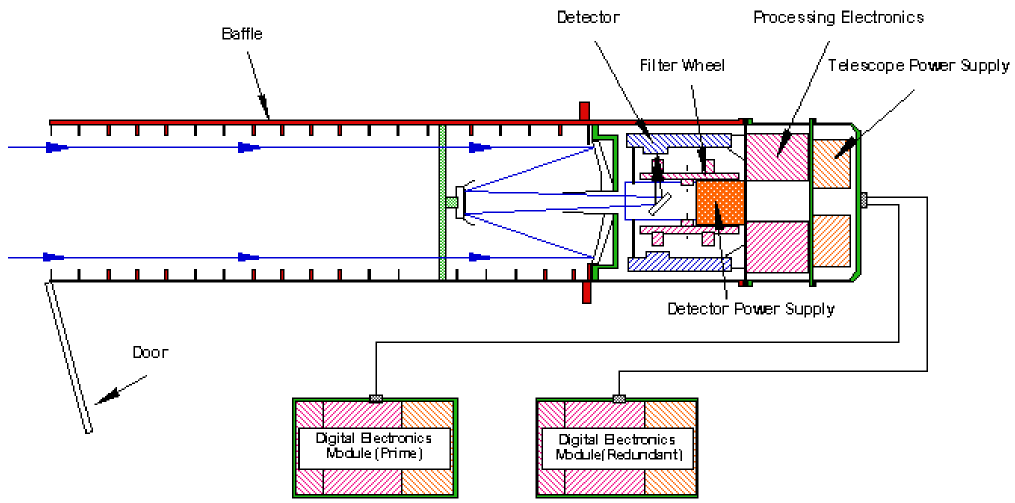
Number of XMM-Newton publications in refereed journals.

5.3.1 Optical/UV Monitor Telescope

The Optical/UV Monitor Telescope (XMM-OM or OM) provides coverage between 170 nm and 650 nm. It consists of a Telescope Module and a separate Digital Electronics Module. The former contains the optics and detectors, the latter houses the Instrument Control Unit (in charge of communication with the spacecraft and commanding of the instrument) as well as the Data Processing Unit (which carries out the pre-processing of the data before it is sent to the ground)[14].

[13] *5000 Papers - XMM-Newton*. (n.d.). cosmos.esa.int. https://www.cosmos.esa.int/web/xmm-newton/5000-papers

[14] *Technical Details - OM - XMM-Newton - Cosmos*. (n.d.). cosmos.esa.int. https://www.cosmos.esa.int/web/xmm-newton/technical-details-om



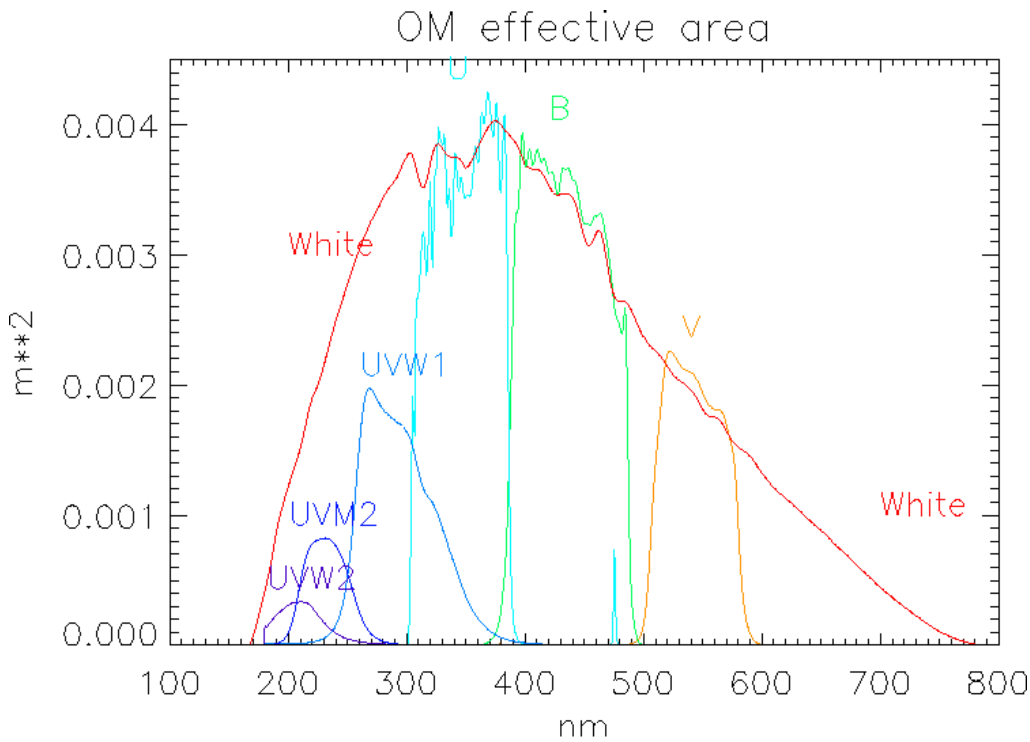
A schematic of the Optical/UV Monitor Telescope.

Some of OM's main characteristics:

- 2m long telescope tube.
- 30cm aperture Ritchey-Chretien telescope.
- f/12.7 focal ratio.
- 3.8m focal length.
- 6 broad band filters.

The 6 broad band filters for colour discrimination in the UV and optical, cover the wavelength range between 180 nm and 580 nm[15]:

[15] *Filter Wheel - XMM-Newton - Cosmos*. (n.d.). cosmos.esa.int. https://www.cosmos.esa.int/web/xmm-newton/om-filter



Throughput curves for the OM filters, folded with the detector sensitivity[16].

The following table outlines the 6 colour discrimination broad band filters as well as their alternative nomenclature used throughout the present document:

Filter	**Colour discrimination**	**Alternative name**
UVW2	UV	S
UVM2	UV	M
UVW1	UV	L
U	Optical	U
B	Optical	B
V	Optical	V

XMM-OM colour discrimination filters nomenclature.

[16] *Bands - XMM-Newton - Cosmos*. (n.d.). cosmos esa. https://www.cosmos.esa.int/web/xmm-newton/om-filter-bands

ESA provides the limiting magnitude for a 5-σ detection in 1000 seconds for its U,B,V and UVW1 (L) filters for different star spectral types:

Filter	Spectral type				
	B0	A0	G0	K0	WD
V	19.8	19.8	19.7	19.7	19.7
B	21.0	20.8	20.2	19.9	20.6
U	21.8	20.4	19.6	18.6	21.2
UVW1	21.1	19.2	17.6	15.4	20.5

Limiting magnitude for a 5-σ detection in 1000 seconds[17].

5.4 Objective

As XMM-Newton Optical/UV Monitor Telescope continues gathering information and serving specific observation requests from the scientific community, the chances of it unintentionally observing asteroids (i.e. 'by chance') increases. The objective of this Master's Thesis is to leverage previous work in the area to try and obtain Optical/UV colours for some of the asteroids observed serendipitously.

The process to achieve this objective can be outlined as:

1. Selection of candidate observations: during this step, we shortlist the observations provided by ESASky SSOSS that could contain data in line with our objective.
2. Screening: at this point the observations shortlist is shrinked further to exclude any instance with none or insufficient data.
3. Photometry: a calibrated magnitude in both optical and UV is obtained for the observations that passed the screening.

The next chapter ('Methodology') details each one of the above-mentioned steps.

[17] *3.5.5 OM sensitivity and detection limits. (n.d.). European Space Agency. https://xmm-tools.cosmos.esa.int/external/xmm_user_support/documentation/uhb/omlimits.html*

6 Methodology

This section describes the end-to-end process carried out. It's presented in a sequential manner:

- Candidate selection: describes which and how the candidate from serendipitous observations were filtered.
- Screening: describes how actual serendipitous observations are set apart from the non-promising candidates.
- Photometry: walks through the photometric process of said serendipitous observations.

6.1 Candidates selection

We refer to "candidates" as those observations that could potentially include a non-targeted Solar System Object (SSO) in their field of view (FoV), capturing data in wavelengths that might be of interest. The candidate selection leverages on previous work, the Solar System Object Search Service (SSOSS) catalogue for XMM-Newton OM, which provides up to 985 potential serendipitous detections[18]:

Instrument	Zero-Point[a]	N_{total}	N_{serend}
OM V	−0.0474	4038	216
OM B	−0.6028	3939	428
OM U	−0.7439	7792	431
OM UVW1	−1.4842	16501	294
OM UVM2	−4.0778	13112	9
OM UVW2	−3.6144	6605	3

ESASKy SSOS number of potential XMM-OM (N_{serend})serendipitous observations for each colour discriminating broad-band filter.

These 985 potential detections were filtered out considering:

- Geometrical constraints assessing whether the SSO could have been in the instrument FoV.

[18] Racero, E. (2022). ESASky SSOSS: Solar System Object Search Service and the case of Psyche. *Astronomy & Astrophysics*, *659*, A38.

- Instrumental constraints assessing whether the SSO apparent magnitude as seen from the instrument would be above its detection threshold.

The list of 985 observations is then trimmed further attending to the wavelengths (i.e. filters) of interest. We will consider observations that fulfil both of the following conditions:

- The observation used one or more of filters S, M and/or L (i.e. UVW2, UVM2 and-or UVW1).
- The observation used one or more of filters U, B and/or V.

After applying the above-mentioned constraints, the list is reduced down to 95 candidate observations (which can be found in the Annexes section). This will constitute the final list of candidates that will be subject to the screening process.

N	observation	sso_name	ra1	dec1	ra2	dec2	filters
1	0012440101	Lictoria	13.99603658	-1.415317889	14.07883767	-1.363111917	L;B
2	0081340801	Stepanov	183.3527003	2.7053835	183.433249	2.687358	L;U;B
3	0106660601	1994 UF2	333.6775958	-17.72910939	333.9756773	-17.53652372	L;U
4	0110980101	Lucubratio	170.061614	13.66864472	170.2531624	13.58085442	L;B
5	0110980601	1030 T-1	199.8925842	-14.85586353	200.1011217	-14.91287867	L;U;B
6	0111170101	Velichko	98.05291688	17.67519933	98.37874979	17.70504883	L;V

A subset of the final 95 candidate observations. The full table can be found in the Annexes section.

6.2 Screening

This section describes the work and process used to filter out candidates and see if they constitute actual detections. None of the shortlisted 95 are guaranteed to contain serendipitous detections so further analysis is needed.

A Python[19] script was written to help with the screening process by partially automating some of its stages.

[19] (n.d.). Welcome to Python.org. https://www.python.org/

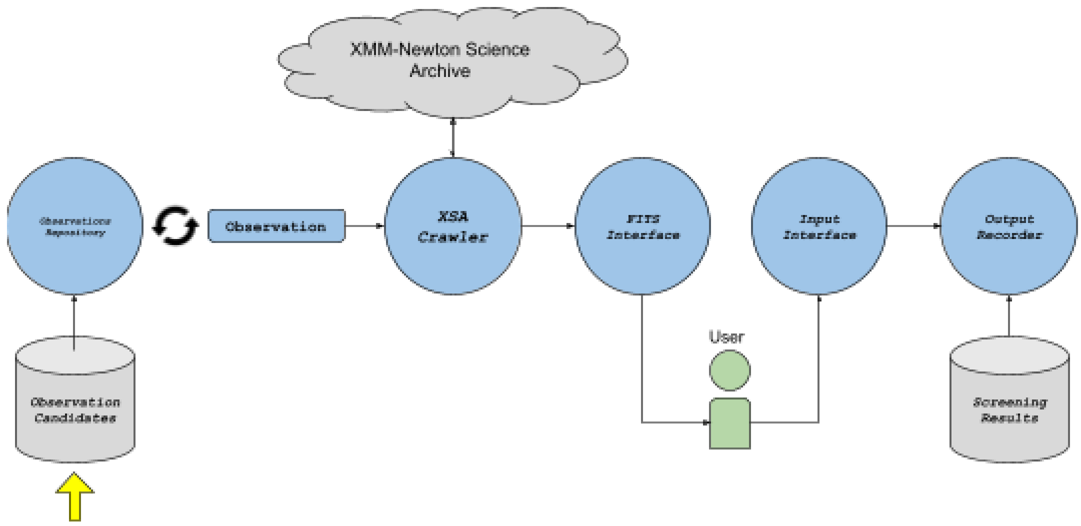


Diagram of the screening process.

The diagram above outlines the different software *entities* that take part in automating the screening process:

1. A starting list of *Observation Candidates* is made available by an *Observations Repository*.
2. The *Observations Repository* is iterated over, providing *Observation* instances. For each one of this instances:
    2.1. A XMM-Newton Science Archive Crawler (*XSA Crawler*) obtains the images related to the observation.
    2.2. The *FITS*[20] *(Flexible Image Transport System) Interface* displays the downloaded images to the user for them to analyse.
    2.3. The user's input is recorded by the *Input Interface* and sent over to the *Output Recorder*, which will update and persist the *Screening Results*.

Each one of the above-mentioned *entities* is abstracted, so that one can plug and play different implementations without breaking the entire process. For instance, the *FITS Interface* might have an implementation using a Python FITS library or it might be opening a process to call an external binary (e.g. DS9[21]).

[20] (2021, January 17). FITS Support Office. https://fits.gsfc.nasa.gov/fits_home.html
[21] (n.d.). SAOImageDS9. https://sites.google.com/cfa.harvard.edu/saoimageds9

6.2.1 Obtaining the observation data

The XMM-Newton Science Archive (XSA)[22] provides both a web-based user interface[23] as well as an HTTP-based (Hypertext Transfer Protocol) API[24] (Application Programming Interface) to obtain XMM-Newton data. XSA is used as the source to extract the candidate observations.

```python
class Crawler:
    """XMM-Newton Science Archive (XSA) crawler interface.
    """

    def crawl(self, observation: observation.Observation) -> Dict[str, List[str]]:
        """Obtains the images of the specified observation and filters.

        Args:
            observation (observation.Observation): observation to be obtained

        Returns:
            Dict[str, List[str]]: a key-value structure containing filter as keys and the list of corresponding
            file paths as a list. Filters with no files will not be included in the results (no key).
        """
        pass
```

XMM-Newton Science Archive Crawler.

An HTTP-based implementation of the *Crawler* interface was used to automate the process of downloading all the relevant data related to a given observation. The data is downloaded locally for it to be displayed and analysed on the next step of the process.

6.2.2 Displaying the data

Since the outlined process involves a user-in-the-loop, the data (images) are to be displayed for said user to analyse them.

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[22] *XMM-Newton Science Archive - XMM-Newton*. (n.d.). cosmos esa. https://www.cosmos.esa.int/web/xmm-newton/xsa

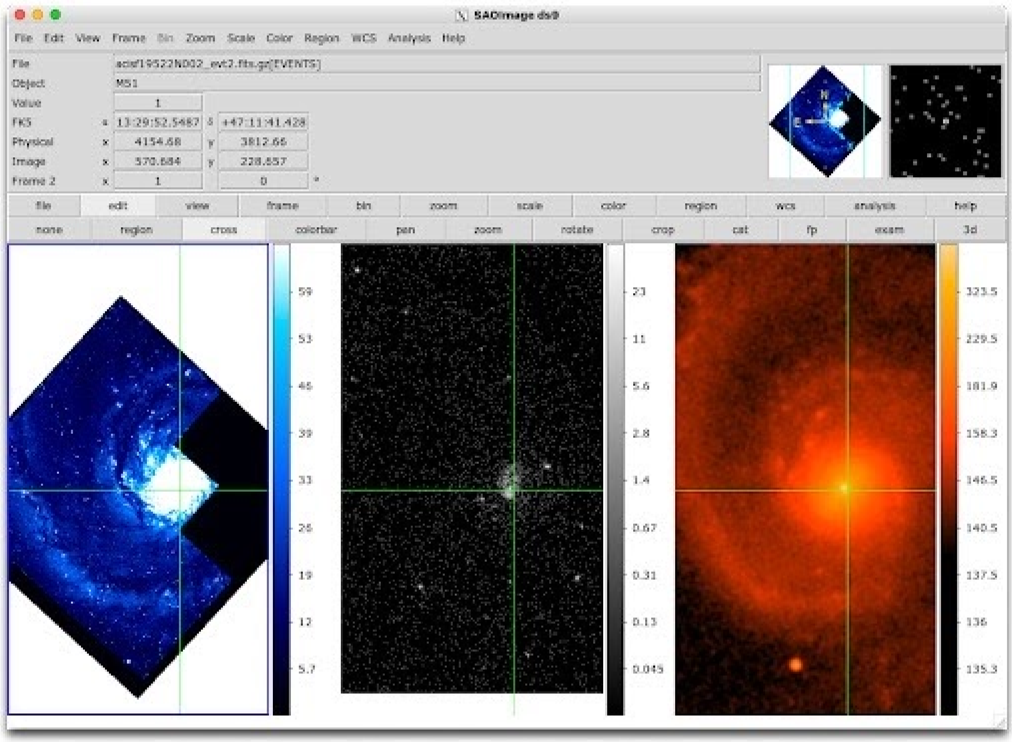
[23] Rodríguez, P. (n.d.). XMM-Newton Science Archive. http://nxsa.esac.esa.int/nxsa-web/#search

[24] Rodríguez, P. (n.d.). XMM-Newton Science Archive. http://nxsa.esac.esa.int/nxsa-web/#aio

```python
class Interface:
    """Flexible Image Transport System (FITS) user interface (UI)."""

    def display(self, fits_paths: List[str], observation: observation.Observation = None):
        """Displays the specified FITS corresponding to the specified observation.

        Args:
            fits_paths (List[str]): list of FITS paths
            observation (observation.Observation): the corresponding observation.
            Defaults to None.
        """
        pass

    def close_current_display(self):
        """Closes the current display."""
        pass
```

Flexible Image Transport System (FITS) Interface.

DS9[25] is an image display and visualisation tool for astronomical data. A DS9-based implementation was used during the screening due to the familiarity with the software and the capabilities it offers.



DS9 user interface.

[25] (n.d.). SAOImageDS9. https://sites.google.com/cfa.harvard.edu/saoimageds9

DS9 offers command line options[26] to interact with it programmatically. This allowed further automation of the overall screening process, opening DS9 with the relevant set of frames to be analysed with the desired set of parameters.

The one (and so far only) disadvantage of including DS9 as part of the automated screen process is its lack of interactiveness, i.e. once a DS9 instance has been opened via command line, there are no means to interact with it. In order to change any of its current state, (e.g. frames, zoom, etc.) one must close and reopen a new process. This, although saving time overall compared to a manual process, makes the screening a bit slower.

On the other hand, amongst the desired set of parameters above-mentioned, there were some that considerably improved the detection job:

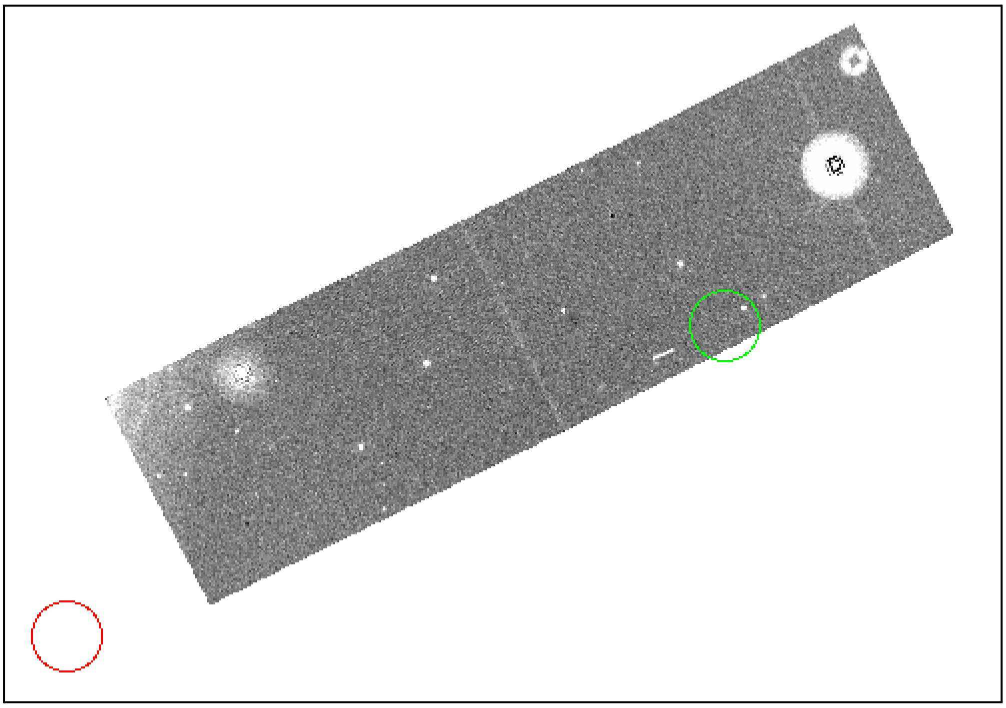
- Trajectory indicators
- Scale adjustment

6.2.2.1 Trajectory indicators

DS9 “Regions” package[27] offers means to overlay shapes on the image. This is used, together with the information from the survey regarding the likely starting and ending position of the object, to display the potential starting and ending point of the object’s trajectory.

The object, if present, is not necessarily likely to be found within the starting or ending area, but somewhere along the line that joins the. This greatly helps the user focus on the likely path of the object rather than on the entire field of view.

[26] (n.d.). Command Line Options. http://ds9.si.edu/doc/ref/command.html
[27] (n.d.). Regions. http://ds9.si.edu/doc/ref/region.html



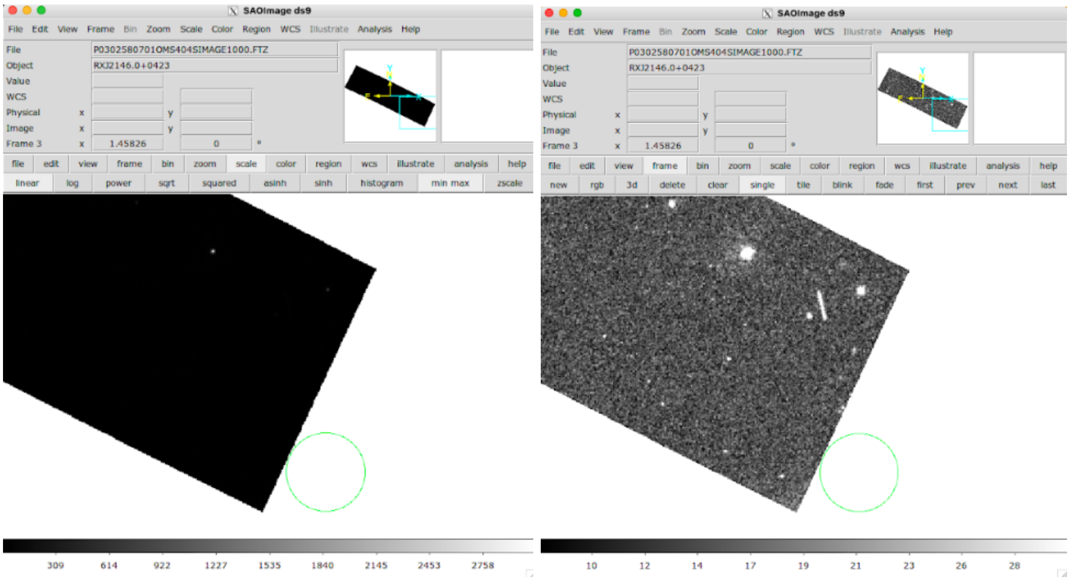
Trajectory indicators: start (green) and end (red).

The start and end trajectory indicators are built from the ESASky SSOSS catalogue of potential serendipitous observations.

6.2.2.2 Adjusting DS9 scale

DS9 provides means to modify its default display settings by means of its "scale" menu[28]. As per recommendation from the Thesis Director, the "zscale" command is used as it provides very good contrast to ease the object's detection.

[28] (n.d.). DS9 Scale Menu. http://spiff.rit.edu/tass/ds9/mscale.html



DS9 linear scale (left) vs zscale (right).

6.2.3 Recording the analysis outcome

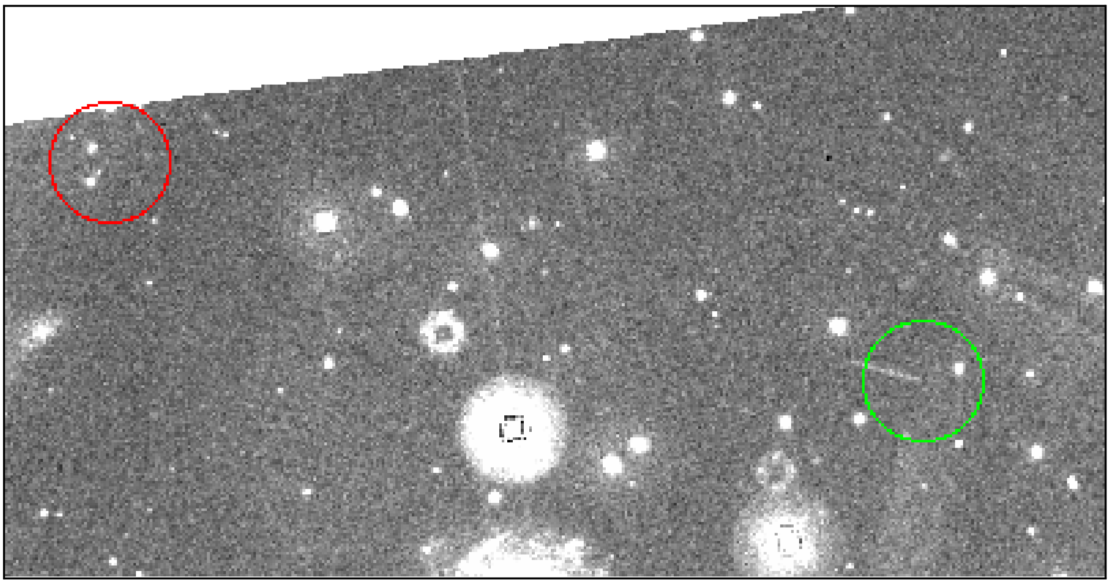
Once the user has analysed the data, the software collects their input.

```python
class Interface:
    """Analysis input interface."""

    def message(self, message: str):
        """Sends a message to the input interface.

        Args:
            message (str): message to be displayed
        """
        pass

    def listen(self) -> Input:
        """Waits and listens for inputs.

        Returns:
            Input: received input
        """
        pass
```

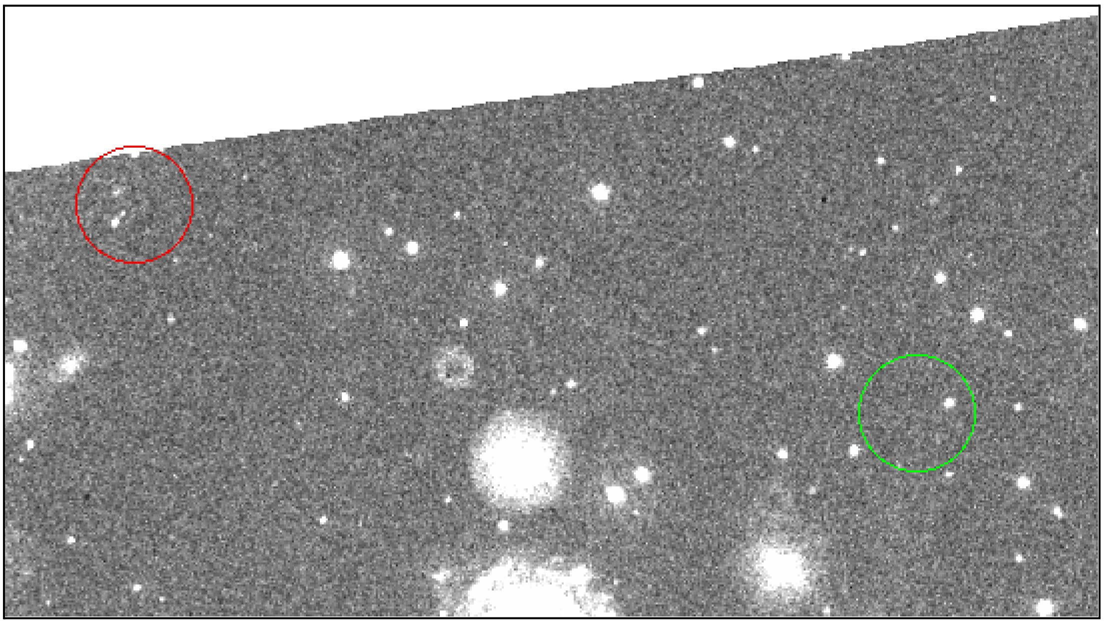
User input interface.

A standard input/output (I/O) implementation is used to gather the user's input. Said input is mostly limited to a shortlist of options:

- *DETECTED (Y)* Indicating that the object is distinctively observable in the image.
- *DUBIOUS (D)* Used for objects whose presence is not clearly identifiable nor outruled.
- *NOT_DETECTED (N)* Indicating that there is no indication of the object being present in the image.



An example of a clear detection (observation 0692330401 - Ivanka - L filter).



An example of a "dubious" detection (observation 0692330401 - Ivanka - U filter).

After each observation, the analysis outcome is recorded.

```python
class Recorder:
    """Analysis output recorder interface."""

    def prepare_observation_record(self, observation: observation.Observation):
        """Prepares the next observation record.

        Args:
            observation (observation.Observation): the observation instance
        """
        pass

    def record_filter_input(self, filter: str, input: input.Input):
        """Records the specified input for a specified filter.

        Args:
            filter (str): the filter (e.g. 'U')
            input (input.Input): the analysis input
        """
        pass

    def record_observation(self):
        """Records the current observation.

        Args:
            filters (List[str]): list of filters that have been considered.
        """
        pass
```

Analysis output recorder.

An implementation writing the analysis output to a comma-separated value file (CSV) was used.

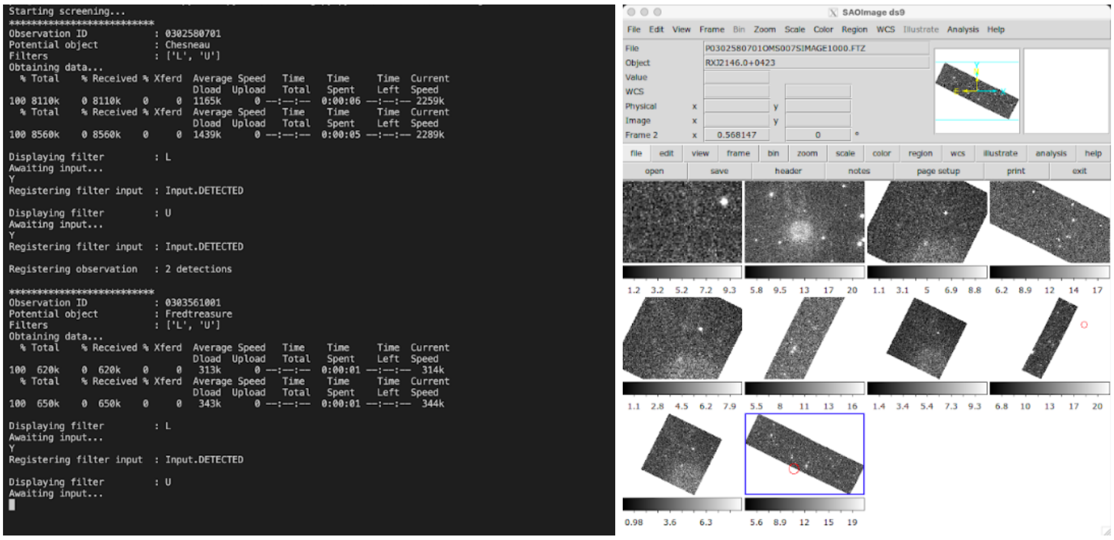
```
observation,object,S,M,L,U,B,V
0012440101,Lictoria,,,D,,D,
0081340801,Stepanov,,,N,N,D,
0106660601,1994 UF2,,,N,N,,
0110980101,Lucubratio,,,Y,,Y,
0110980601,1030 T-1,,,N,N,Y,
0111170101,Velichko,,,N,,,N
```

Sample of the CSV output file recorded during the process.

The output file can be imported as a table into other analysis tools. Below, the same output, in a table format:

N	observation	object	S	M	L	U	B	V
1	12440101	Lictoria			D		D	
2	81340801	Stepanov			N	N	D	
3	106660601	1994 UF2			N	N		
4	110980101	Lucubratio			Y		Y	
5	110980601	1030 T-1			N	N	Y	
6	111170101	Velichko			N			N

A subset of the screening results. The full table can be found in the Annexes section.



Screenshots of what the screening process looks like for the user.

6.3 Photometry

This section describes the work and process used to determine the magnitude(s) of the selected objects from the previously described screening process. A piece of Python code, leveraging the popular astronomy library Astropy[29], is written to carry out the following flow:

[29] (n.d.). Astropy. https://www.astropy.org/

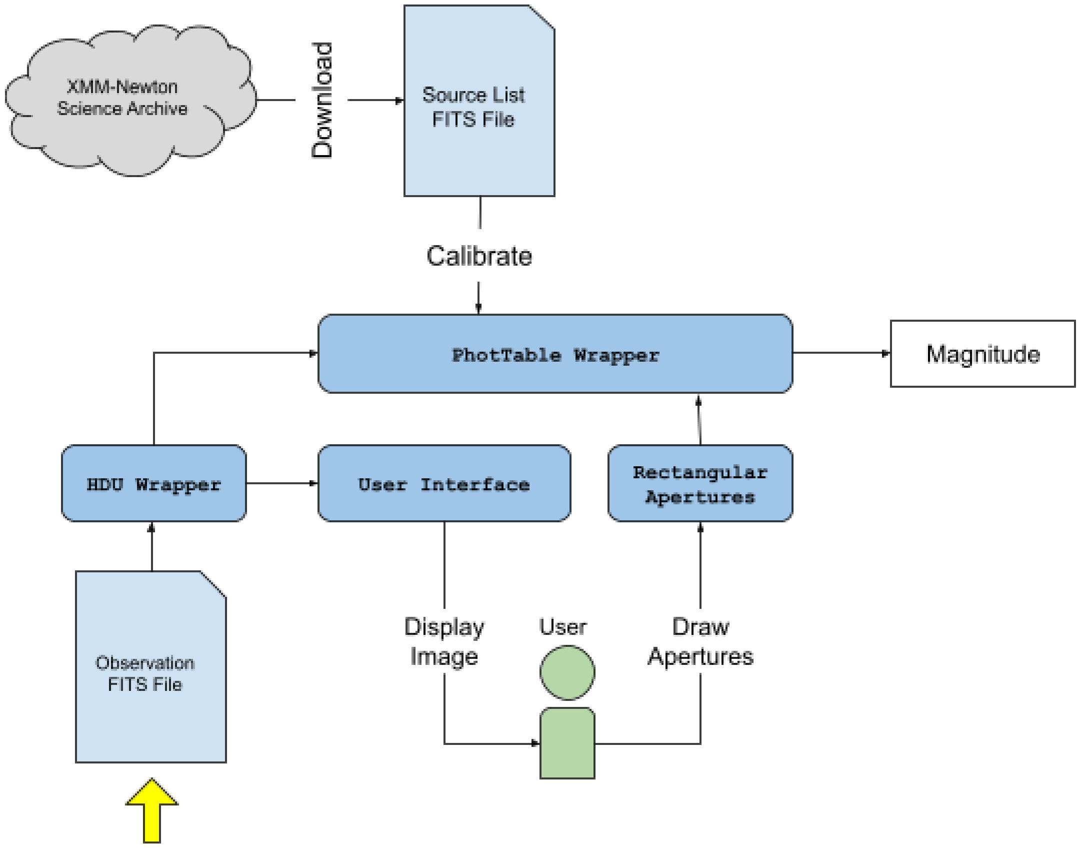


Diagram of the photometric process.

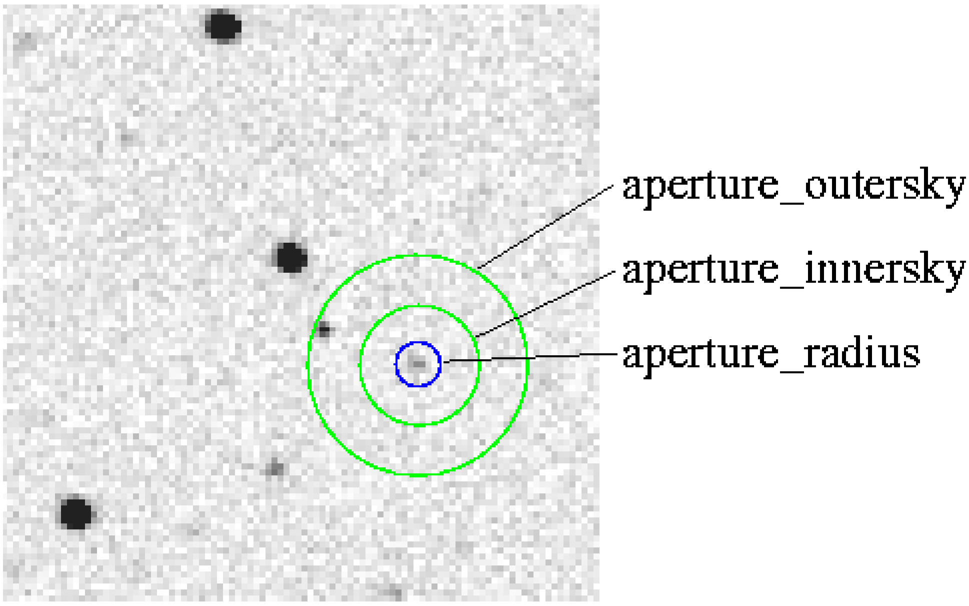
1. The process starts specifying the location of the observation FITS file, which is injected into an *HDU*[30] [31] *(Header Data Unit) Wrapper* instance.
2. A *PhotTable Wrapper* instance (an Astropy's *QTable*[32] utility wrapper) is created and fed with said *HDU Wrapper*. One can then:
    a. Download the corresponding "source list" (details of this specific product can be found in the following sections) FITS file from XMM-Newton Science Archive and
    b. obtain the coefficients of the linear model to be used to calibrate the actual observation file.

[30] *FITS Primer*. (2014, October 28). NASA FITS. https://fits.gsfc.nasa.gov/fits_primer.html
[31] *Header Data Unit — Astropy v5.2.1*. (n.d.). Astropy. https://docs.astropy.org/en/stable/io/fits/api/hdus.html
[32] *QTable — Astropy v5.2.1*. (n.d.). Astropy. https://docs.astropy.org/en/stable/api/astropy.table.QTable.html#astropy.table.QTable

3. A *User Interface* instance is created and launched, allowing the user to select the trail in the image. The user's input selection is translated into the two *Rectangular Aperture* instances.
4. The calibrated linear model of the *PhotTable Wrapper* is used together with the *Rectangular Apertures* to calculate the calibrated magnitude of the object.

6.3.1 Rectangular aperture (trail) photometry

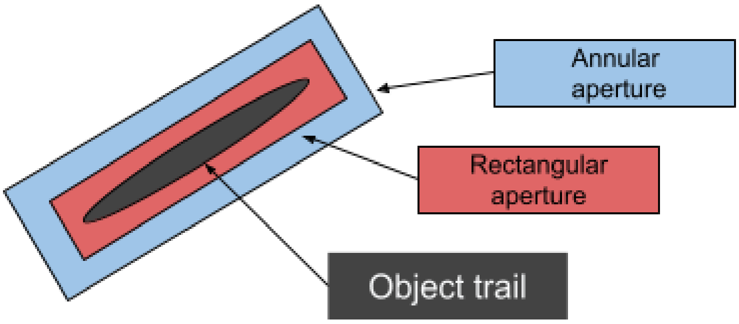
Aperture photometry is the process by which the light that falls inside a particular aperture is measured. The count rate of the object to be measured is obtained using an aperture containing the object and an annular aperture to measure the surrounding background count-rate. The surrounding background count-rate is subtracted from the first aperture count-rate to determine the actual light coming from the object of interest. Typically, this process is carried out using circular apertures.



Circular aperture photometry[33].

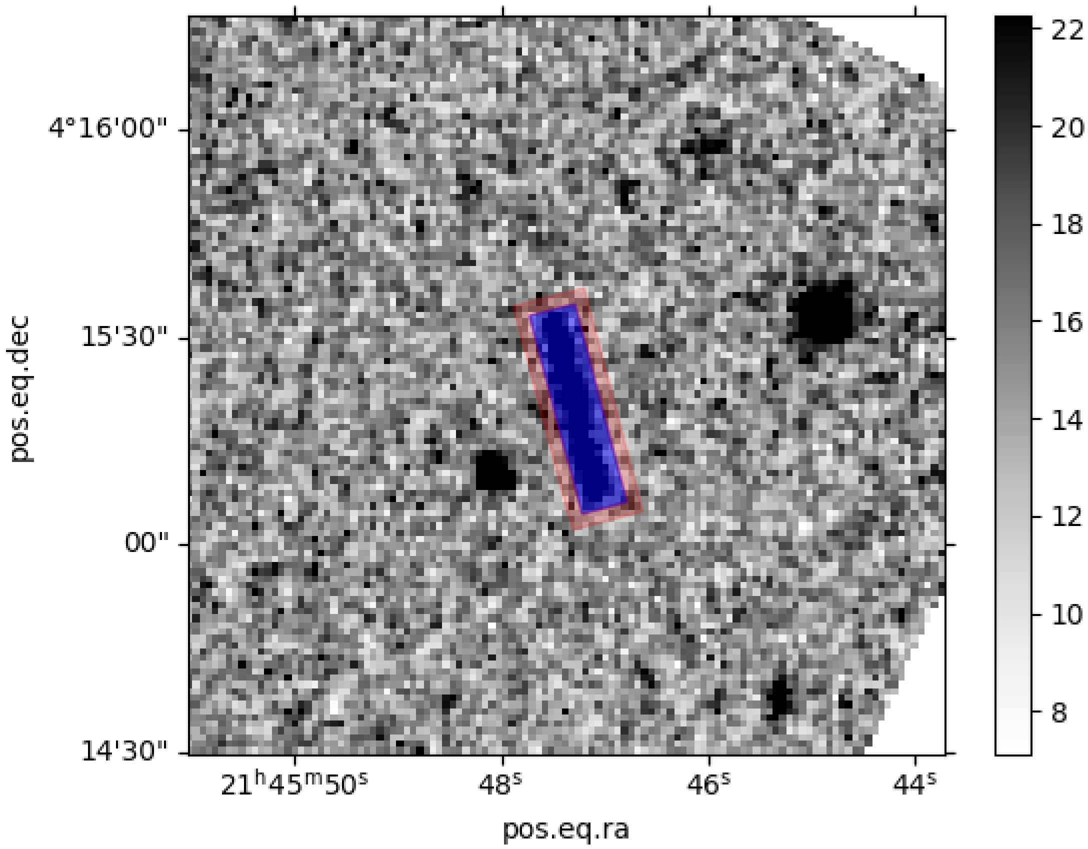
Given the nature of the object trail, rectangular aperture photometry was used instead, where a rectangle and an annular rectangle are used:

[33] *(n.d.). Simple Aperture Photometry by Hand. http://spiff.rit.edu/classes/phys445/lectures/photom/photom.html*



Rectangular aperture photometry.

Just like in standard circular photometry, where two concentric circles are used, the outer rectangle is used to subtract the background *noise*. In order to determine said rectangles, the user is presented with the observation image for them to select the edges of the trail. The two rectangles are then defined around the selected points with a width that can be programmatically defined.



User interface to define rectangular aperture and annulus.

The instrumental (measured) magnitude (m_{ins}) of the object:

$$m_{ins} = -2.5log_{10}(CR)$$

Where CR is the count rate of the objet:

$$CR = \frac{C_{obj} - \widehat{C}_{bkg}}{exp.time}$$

Where:

- C_{obj} is the count of the object aperture
- $\widehat{C}_{bkg}$ is the average count of the annular aperture (background count)
- $exp.\ time$ is the exposure time of the image

The Photutils package[34] was used to provide the different functionalities to compute the count of both the object aperture as well as the annular aperture. It was used in conjunction with the Matplotlib[35] to produce the user interface for aperture selection and magnitude computation.

6.3.2 Magnitude calibration

The aforementioned steps provide the instrumental magnitude of the object. This section describes how said magnitude is calibrated against a photometric system.

ESA has published several methods for XMM-Newton OM magnitude calibration and count rate to flux conversions[36]. Given its simplicity, method 3 “AB MAGNITUDE SYSTEM” was used. An AB magnitude system is a photometric system defined so that the zero-point flux for each filter is $3631\,Jy\ (Janskys;\ 1\,Jy = 10^{-26} W Hz^{-1} m^{-2})$[37].

[34] *(n.d.). Photutils — photutils 1.7.0. https://photutils.readthedocs.io/en/stable/*
[35] *(n.d.). Matplotlib — Visualization with Python. https://matplotlib.org/*
[36] *SAS Watchout - uvflux - XMM-Newton - Cosmos. (n.d.). Cosmos.esa.int. https://www.cosmos.esa.int/web/xmm-newton/sas-watchout-uvflux*
[37] *(n.d.). 16. Magnitude Systems. http://faraday.uwyo.edu/~admyers/ASTR5160/handouts/516016.pdf*

The zero-point values for each filter are published by ESA[38] but can be also programmatically obtained from the “source list” files (*SRCLIST* in XMM-Newton terminology). The header of this file contains the “zero-points and conversion factors[39].

⋮	⋮	⋮
x_AB_MAG	4-byte REAL	AB magnitude
x_AB_MAG_ERR	4-byte REAL	AB magnitude error
⋮	⋮	⋮

Subset of SRCLIST headers containing conversion factors.

These parameters are then leveraged to perform calibration of the object’s computed aperture photometry using the following expression:

$$m_{ab_i} = m_{ins_i} + ABM0_i$$

Where:

m_{ab_i} $is\ the\ calibrated\ magnitude\ in\ the\ aforementioned\ AB\ system\ for\ filter\ "i".$

m_{ins_i} $is\ the\ instrumental\ magnitude\ for\ filter\ "i".$

$ABM0_i$ $is\ the\ AB\ system\ zero\ -\ point\ for\ filter\ 'i'.$

[38] *SAS Watchout - uvflux - XMM-Newton - Cosmos. (n.d.). Cosmos.esa.int. https://www.cosmos.esa.int/web/xmm-newton/sas-watchout-uvflux*

[39] *XMM-Newton Specifications for Individual SSC Data Products & Science Survey Center Teams. (2021, 04 12). XMM-Newton Calibration Access and Data Handbook. (4.6), 29-30.*

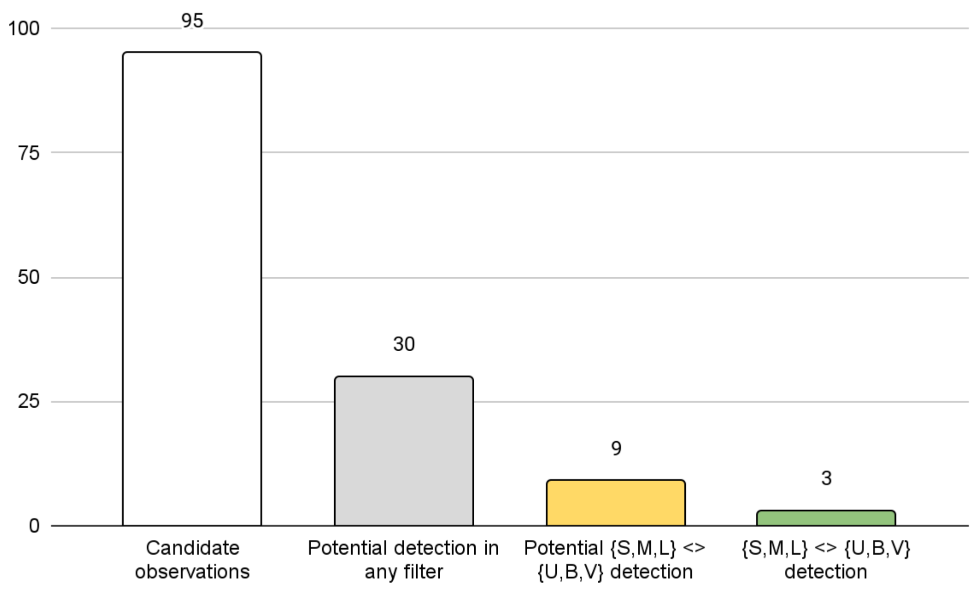
7 Results & analysis

This section breaks down in deeper detail the results obtained from each one of the steps described in the methodology section. It also includes a section outlining potential future work and improvements.

7.1 Screening

After completing the screening of all **95** candidate observations…

- …there are **30** observations where the object might have been detected (i.e. “dubious” or “clear” detection) in one or more of either the {S,M,L} filters or the {U,B,V} filters (i.e. not UV/optical overlap)...
- …out of which there are **9** observations where the object might have been detected (i.e. “dubious” or “clear” detection) in one or more of the {S,M,L} filters as well as in one or more of the {U,B,V} filters…
- …out of which there are **3** observations the object has been detected (i.e. “clear” detection) in one or more of the {S,M,L} filters as well as in one or more of the {U,B,V} filters.



Observations breakdown after the screening process.

The 3 observations where the object has been detected in both one or more {S,M,L} filters and one or more {U,B,V} filters are:

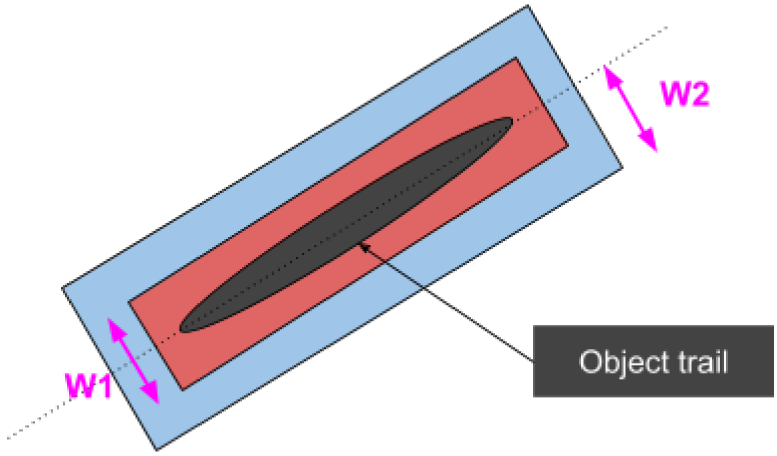
N	observation	object	S	M	L	U	B	V
4	110980101	Lucubratio			X		X	
25	302580701	Chesneau			X	X		
26	303561001	Fredtreasure			X	X		

Observations showing one or more clear detections in both {S,M,L} and {U,B,V} filters.

The actual images of the 3 above-mentioned objects can be found in the Annexes section.

7.2 Photometry

The 3 observations where detections in both UV {S,M,L} and optical {U,B,V} filters exist are photometrically analysed using the process described in the Methodology section. A series of captures and tables showcasing the photometric process and parameters are presented below for each one of the images for all 3 observations:



Where:

- W_1 is the width of the rectangular aperture in pixels.
- W_2 is the half-width of the annular aperture in pixels.

7.2.1 Obs. 110980101 - Lucubratio

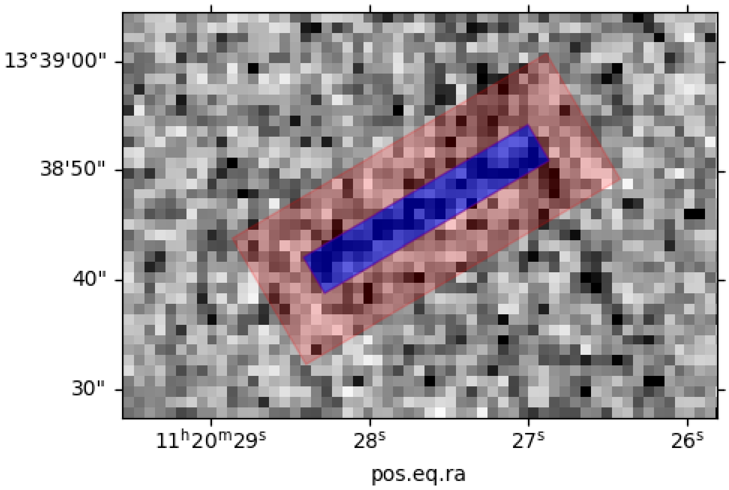


Image	Filter	W_1	W_2	m_{AB}
P0110980101OMS406SIMAGE1000	L	4	5	**20.82**

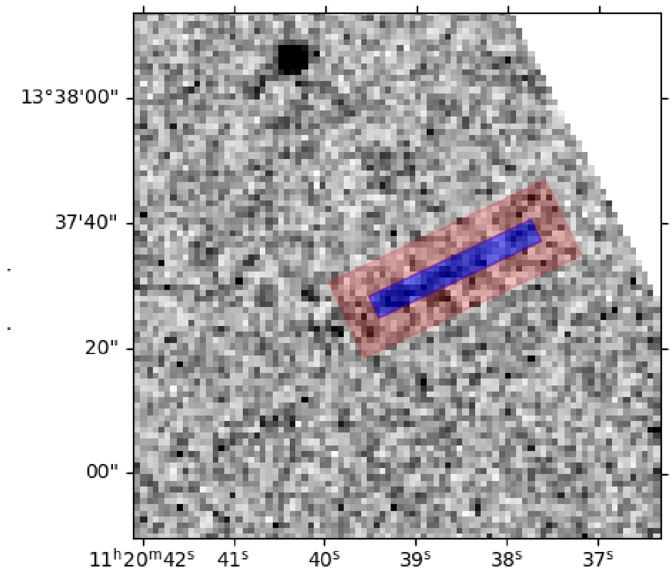


Image	Filter	W_1	W_2	m_{AB}
P0110980101OMS411SIMAGE1000	L	4	5	**20.70**

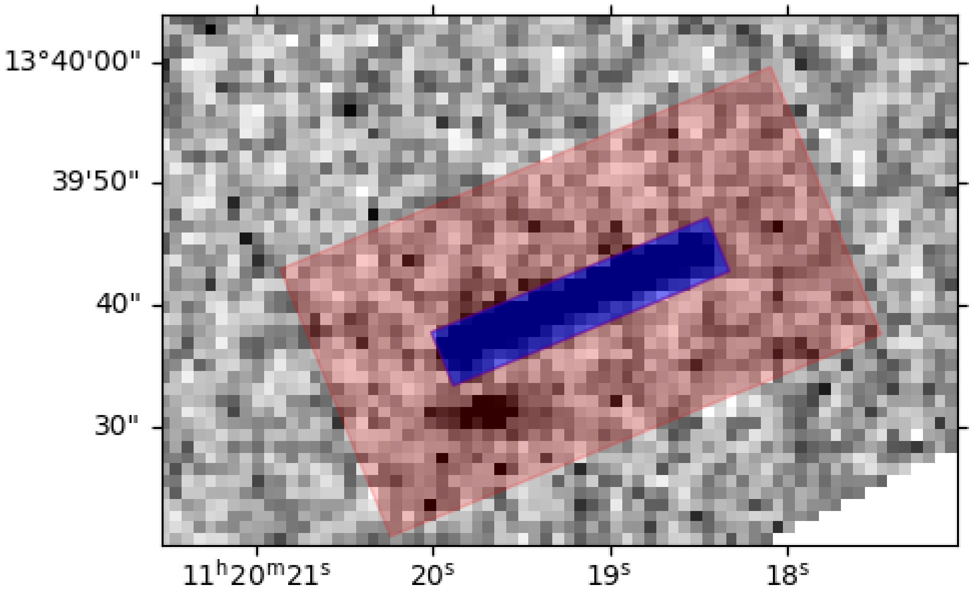


Image	Filter	W_1	W_2	m_{AB}
P0110980101OMS402SIMAGE1000	B	5	10	**18.25**

7.2.2 Obs. 0302580701 - Chesneau

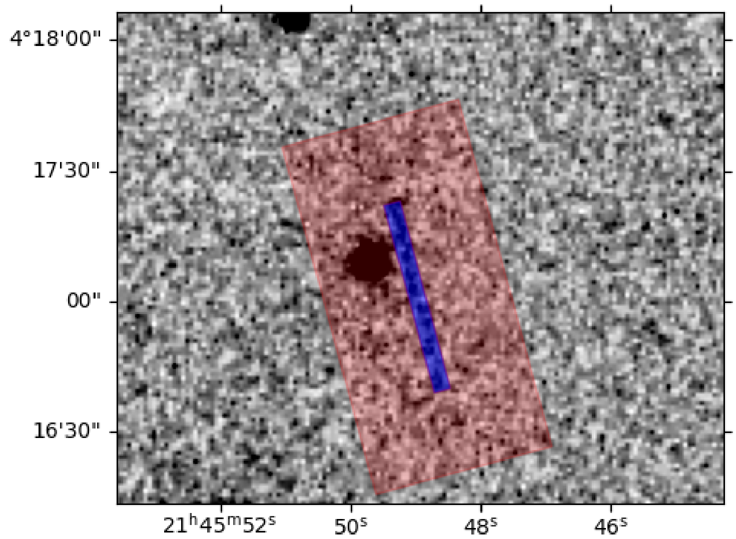


Image	Filter	W_1	W_2	m_{AB}
P0302580701OMS405SIMAGE1000	L	4	20	**20.57**

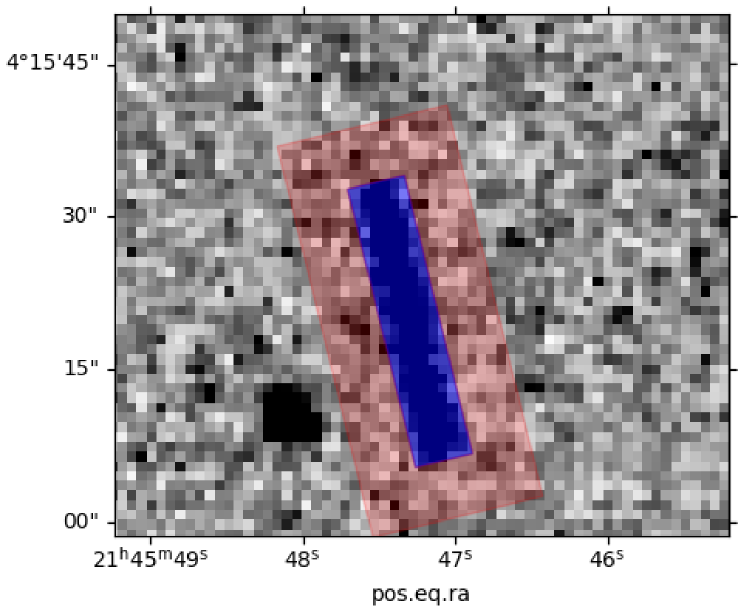


Image	Filter	W_1	W_2	m_{AB}
P0302580701OMS404SIMAGE1000	U	6	6	**18.82**

7.2.3 Obs. 0303561001 - Fredtreasure

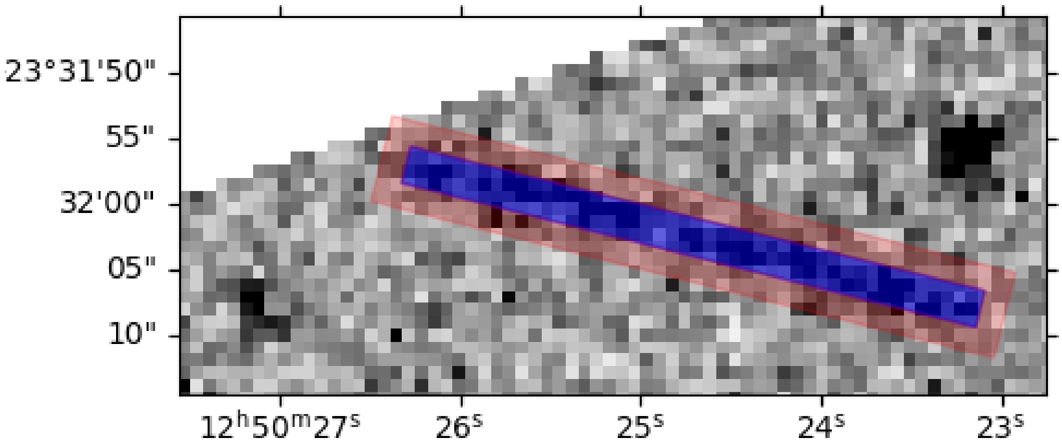


Image	Filter	W_1	W_2	m_{AB}
P0303561001OMS007SIMAGE0000	L	3	2	**20.40**

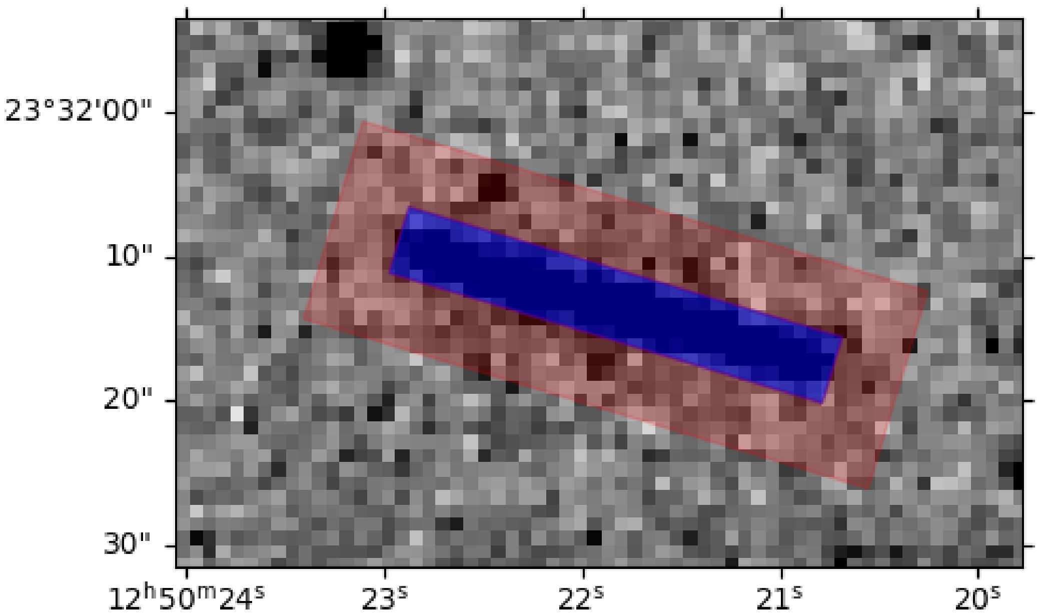


Image	Filter	W_1	W_2	m_{AB}
P0303561001OMS006SIMAGE0000	U	3	2	**18.93**

7.2.4 Magnitudes and colours

The following table summarises the magnitudes and UV-Optical colours in the AB system (the average figure has been provided if there were 2 or more measurements):

	UV Magnitude(s)			Optical Magnitude(s)			Colours	
Object	**S**	**M**	**L**	**U**	**B**	**V**	**L-U**	**L-B**
Lucubratio			20.76		18.25			2.51
Chesneau			20.57	18.82			1.75	
Fredtreasure			20.40	18.93			1.47	

Computed magnitudes and colours for the 3 observations showing one or more clear detections in both {S,M,L} and {U,B,V} filters.

7.3 Future work and improvements

Several improvements and potential future lines of work are discussed below:

- **Image-trajectory overlap**: currently all images of a possible observation are displayed during the screening process. In the *best* case scenario, there is only one, while in the *worst* case scenario there might be up to 30 images. Many of these images footprint do not overlap with the actual trajectory of the object, thus displaying many images for analysis where the chance of detecting the object is virtually impossible. This is quickly ruled out by the user thanks to the trajectory indicators, but one could optimise the process further by ruling them out programmatically before even presenting them for screening.
- Full **automation**: at the moment, the figure of a user is necessary ("human in the loop"), however, one could include a trail detection algorithm and fully automate both the screening and the photometric process.
- Re-running against an **updated catalogue** version: the present work is based on the ESASky SSOSS catalogue published towards the end of 2021, where all the starting 985 potential observations were made available. One could re-run the whole cross-matching process and provide another list of observations to analyse.
- Remove **DS9 dependency**: whilst DS9 is a powerful tool, it currently offers a few limitations when it comes to its programmatic usage. One could utilise a Python library for the display of FITS files. The current software pattern would allow for the implementation and easy "plug-in" of a Python-based FITS interface.

8 Bibliography

(n.d.). SAOImageDS9. https://sites.google.com/cfa.harvard.edu/saoimageds9

(n.d.). Command Line Options. http://ds9.si.edu/doc/ref/command.html

(n.d.). Regions. http://ds9.si.edu/doc/ref/region.html

(n.d.). DS9 Scale Menu. http://spiff.rit.edu/tass/ds9/mscale.html

(n.d.). Welcome to Python.org. https://www.python.org/

(n.d.). Astropy. https://www.astropy.org/

(n.d.). Simple Aperture Photometry by Hand. http://spiff.rit.edu/classes/phys445/lectures/photom/photom.html

(n.d.). Photutils — photutils 1.7.0. https://photutils.readthedocs.io/en/stable/

(n.d.). Matplotlib — Visualization with Python. https://matplotlib.org/

(n.d.). 16. Magnitude Systems. http://faraday.uwyo.edu/~admyers/ASTR5160/handouts/516016.pdf

(2021, January 17). FITS Support Office. https://fits.gsfc.nasa.gov/fits_home.html

Bands - XMM-Newton - Cosmos. (n.d.). cosmos esa. https://www.cosmos.esa.int/web/xmm-newton/om-filter-bands

Brune, W. H. (n.d.). *6.4 The Solar Spectrum | METEO 300: Fundamentals of Atmospheric Science*. Dutton Institute. https://www.e-education.psu.edu/meteo300/node/683

ESA Science & Technology - Orbit/Navigation. (n.d.). ESA Science & Technology. https://sci.esa.int/web/xmm-newton/-/31349-orbit-navigation

Filter Wheel - XMM-Newton - Cosmos. (n.d.). cosmos.esa.int. https://www.cosmos.esa.int/web/xmm-newton/om-filter

FITS Primer. (2014, October 28). NASA FITS. https://fits.gsfc.nasa.gov/fits_primer.html

5000 Papers - XMM-Newton. (n.d.). cosmos.esa.int. https://www.cosmos.esa.int/web/xmm-newton/5000-papers

4.1 XMM-Newton orbit. (n.d.). European Space Agency. https://xmm-tools.cosmos.esa.int/external/xmm_user_support/documentation/uhb/orbit.html

Header Data Unit — Astropy v5.2.1. (n.d.). Astropy. https://docs.astropy.org/en/stable/io/fits/api/hdus.html

QTable — Astropy v5.2.1. (n.d.). Astropy. https://docs.astropy.org/en/stable/api/astropy.table.QTable.html#astropy.table.QTable

Racero, E. (2022). ESASky SSOSS: Solar System Object Search Service and the case of Psyche. *Astronomy & Astrophysics*, *659*, A38.

Rodríguez, P. (n.d.). XMM-Newton Science Archive. http://nxsa.esac.esa.int/nxsa-web/#search

Rodríguez, P. (n.d.). XMM-Newton Science Archive. http://nxsa.esac.esa.int/nxsa-web/#aio

SAS Watchout - uvflux - XMM-Newton - Cosmos. (n.d.). Cosmos.esa.int. https://www.cosmos.esa.int/web/xmm-newton/sas-watchout-uvflux

The Science Programme. (n.d.). European Space Agency. https://www.esa.int/esapub/br/br114/br114sci.htm

Technical Details - OM - XMM-Newton - Cosmos. (n.d.). cosmos.esa.int. https://www.cosmos.esa.int/web/xmm-newton/technical-details-om

Technical Details - Spacecraft - XMM-Newton - Cosmos. (n.d.). cosmos.esa.int. https://www.cosmos.esa.int/web/xmm-newton/technical-details-spacecraft

3.5.5 OM sensitivity and detection limits. (n.d.). European Space Agency. https://xmm-tools.cosmos.esa.int/external/xmm_user_support/documentation/uhb/omlimits.html

Waszczak, A. (2015, 05 06). Asteroids in GALEX: Near-ultraviolet photometry of the major taxonomic groups.

XMM-Newton Science Archive - XMM-Newton. (n.d.). cosmos esa. https://www.cosmos.esa.int/web/xmm-newton/xsa

XMM-Newton Specifications for Individual SSC Data Products & Science Survey Center Teams. (2021, 04 12). XMM-Newton Calibration Access and Data Handbook. (4.6), 29-30.

9 Annexes

9.1 Candidate observations

The following table outlines all 95 potential XMM-Newton serendipitous observations of interest, where:

- N is the row ordinal.
- $observation$ is the observation ID (as per XMM-Newton's Science Archive).
- sso_name is the potential Solar System Object name in the XMM-Newton OM FoV.
- $\{ra1, dec1\}$ is the SSO's right ascension and declination at the start of the observation.
- $\{ra2, dec2\}$ is the SSO's right ascension and declination at the end of the observation.
- $filters$ indicates the potential filters used during the observation.

N	observation	sso_name	ra1	dec1	ra2	dec2	filters
1	0012440101	Lictoria	13.99603658	-1.415317889	14.07883767	-1.363111917	L;B
2	0081340801	Stepanov	183.3527003	2.7053835	183.433249	2.687358	L;U;B
3	0106660601	1994 UF2	333.6775958	-17.72910939	333.9756773	-17.53652372	L;U
4	0110980101	Lucubratio	170.061614	13.66864472	170.2531624	13.58085442	L;B
5	0110980601	1030 T-1	199.8925842	-14.85586353	200.1011217	-14.91287867	L;U;B
6	0111170101	Velichko	98.05291688	17.67519933	98.37874979	17.70504883	L;V
7	0137550501	Vermeer	83.65883033	21.96132228	83.72975342	21.95673122	L;U
8	0148090501	2000 VH57	268.6228585	-26.34105697	268.6597257	-26.33875756	L;B
9	0148560501	2000 OR6	157.6945887	5.506792639	157.9910666	5.444162528	L;V
10	0153450101	Coubertin	191.7900402	-5.714503389	192.0338537	-5.8043765	L;B
11	0153950901	2000 SG172	245.6509016	-15.71548278	245.687865	-15.72228931	L;U
12	0164570401	1998 QN30	229.0141158	-16.05640242	229.2929736	-16.14343586	L;U
13	0202680101	1992 AJ1	263.4018785	-26.09088186	263.940696	-26.11426953	L;U
14	0202680101	Puntel	263.1458409	-26.11714492	263.7103745	-26.16403192	L;U
15	0202730101	Kiyosato	155.414775	21.64732233	155.5115943	21.58226161	L;U;B
16	0203170301	1998 YB12	187.924908	0.3078198611	188.2312754	0.1890703333	L;U;B;V
17	0203450201	1941 UN	330.777767	-19.12108378	330.9844593	-19.069593	L;U
18	0203850201	1981 ET34	278.7704483	-7.654013611	278.8745769	-7.677327028	L;U
19	0206060101	1993 UB3	358.6213643	5.807185972	358.7399671	5.873919833	L;U

N	observation	sso_name	ra1	dec1	ra2	dec2	filters
20	0206060201	Vanavara	144.8699843	14.97476194	144.9659829	14.94839681	L;U
21	0206490301	Africa	337.1189521	-24.69079364	337.2161115	-24.68050169	L;U
22	0300240101	Mucha	139.650819	16.33086269	139.7237488	16.31634964	L;U;B
23	0300480301	1994 YO1	133.5344843	20.16909269	133.6593827	20.11736764	L;U;B;V
24	0300960631	Hermitage	204.3960185	-9.539437083	204.4068013	-9.540443056	L;B
25	0302580701	Chesneau	326.4374095	4.212535	326.5023323	4.446862	L;U
26	0303561001	Fredtreasure	192.5847993	-23.53889469	192.6238483	-23.529534	L;U
27	0312790101	1999 AD32	83.45220263	21.92756267	83.58099579	21.99086489	L;U
28	0402360101	2006 BQ6	27.57513963	32.19779597	20.13579171	33.51657169	M;L;U;B
29	0402430301	Masciarelli	266.332632	-28.93590631	266.5198225	-28.98743756	L;U
30	0402750301	Kazo	35.18939329	19.84358708	35.31994388	19.90695697	L;U
31	0500760101	1999 XN105	168.2132115	13.48386681	168.2961424	13.48310722	L;U
32	0501270301	The	98.40760025	17.72570306	98.44330771	17.72696461	L;U
33	0502091601	Kulibin	139.6860336	16.17447492	139.9306879	16.10896939	L;B
34	0502120101	Ibuki	184.5898656	5.767884056	185.0411175	5.664890611	L;U;V
35	0502430101	2000 BJ4	197.675828	-5.848601611	197.8108237	-5.93855275	L;U
36	0503490201	Naruke	340.5789013	-9.697185722	340.805813	-9.601553056	L;U
37	0503490201	2000 QP27	340.263912	-9.828102417	340.9032975	-9.58547225	L;U
38	0504780501	1999 XQ57	193.2852633	-9.254789083	193.5174435	-9.269204778	L;U
39	0552860101	Nantong	163.640493	-5.670915611	163.651515	-5.753722778	L;U
40	0556212301	Amenemhet	223.6749917	1.731918444	223.7060366	1.711334833	M;L;B
41	0601391001	Joan	311.1092784	-10.79975797	311.3062858	-10.78449478	S;M;L;U;B;V
42	0601670101	1986 RP5	19.7594455	3.550315778	19.94961175	3.669347333	M;L;U
43	0604740101	Lijiang	321.4909871	-12.20326347	321.776253	-12.12629567	M;L;U
44	0604740101	2000 NA6	321.2284947	-12.19873319	321.6523976	-12.00705717	M;L;U
45	0650510301	1999 SG12	23.21132146	30.93349644	23.55411408	31.11216489	M;L;U;B
46	0653840401	Grotius	24.86671587	6.247936944	24.93093133	6.264996833	S;M;L;U
47	0653950201	1993 SG1	82.50929946	10.55111419	82.71532771	10.47722242	L;U;B;V
48	0656200101	2000 WU93	137.2766764	14.62784539	137.3296748	14.61574197	M;L;U
49	0670120301	Chrisclark	343.5239665	-17.82484172	343.5560615	-17.647393	S;M;L;U;B;V
50	0670880401	1999 AN25	343.271595	11.46389467	343.5867534	11.57390897	S;M;L;U
51	0672990201	1994 CG2	318.0854782	-30.82999664	318.248346	-30.79596678	M;L;U
52	0673310101	2000 JZ79	186.3821592	13.11793753	186.443617	12.82925503	M;L;U
53	0673310101	2000 AV91	186.1031917	13.03456053	186.2139895	12.89814914	M;L;U
54	0673550201	1996 YP	265.897439	-29.70555036	266.1531568	-29.73510025	M;L;U
55	0674370201	Zurich	136.799451	14.87054631	137.150276	14.6254395	M;L;U
56	0674480401	Potomac	211.0622944	-1.794742861	211.0822733	-1.792068667	L;U

N	observation	sso_name	ra1	dec1	ra2	dec2	filters
57	0692330401	Ivanka	112.1893285	33.89455739	112.3496495	33.93021694	M;L;U
58	0692330501	1998 HF34	171.3479332	14.55508569	171.4278274	14.53439111	M;L;U
59	0692510201	Quaide	142.1817295	18.83117456	142.2683561	18.82097528	M;L;V
60	0693820201	2000 RX67	197.619011	-1.358278028	197.819275	-1.411782806	M;L;U
61	0694510101	Siegena	212.153216	-3.086574139	212.3203522	-3.078343194	M;L;U;B
62	0700182001	Landi	322.2720505	-7.793742944	322.3753971	-7.771863972	M;L;U
63	0721010501	1989 ST10	262.0557056	-14.185319	262.5758778	-14.32163672	S;M;L;U;B;V
64	0722310201	Auster	311.8667542	-10.03062875	312.1446029	-9.988439417	M;L;U
65	0723800701	1981 FT	181.0776443	1.763994861	181.4599945	1.556985611	S;M;L;U;B;V
66	0727771001	1988 XT1	329.8151669	-30.24738586	329.9649954	-30.22888356	S;M;L;B
67	0740920301	Tampere	189.9916692	-5.242599694	190.0440417	-5.266937222	S;L;U
68	0742570101	1990 QT9	130.4161485	19.43254819	130.512747	19.40390586	M;L;U
69	0743050301	2000 SL1	13.22112492	12.73247244	14.08068717	12.77018519	S;M;L;U;B;V
70	0743630501	2000 SG234	266.160831	-28.99608153	266.4460373	-29.01865606	M;L;U
71	0743950501	Aakashshah	146.3334294	10.01490692	146.5087875	9.944300806	S;M;L;B;V
72	0744420101	1988 RK	276.5005378	-12.98744389	277.1083537	-13.11541775	S;M;L;B
73	0744440301	Lipschutz	191.5872185	2.524155889	192.0992658	2.315665	S;M;L;U;V
74	0744440301	2001 FV5	191.3991292	2.555875667	191.8783471	2.321374083	S;M;L;U;V
75	0748190101	1999 WA3	28.89897346	5.562144528	29.00509067	5.689929778	M;L;U;B;V
76	0748391301	1998 EC9	266.4610222	-20.21344439	267.1787076	-20.26542956	S;M;L;U
77	0762520301	Boyan	135.95937	15.10115797	136.1865554	15.03699531	S;M;L;U;B;V
78	0763100101	Raissa	272.4010435	-26.10797106	272.7722155	-26.09434092	S;M;L;U
79	0763100101	Silentium	272.7717822	-26.24762669	273.2145032	-26.20041814	S;M;L;U
80	0782650101	1999 RU128	148.4771184	1.610909611	148.5702264	1.573129028	M;L;U
81	0793183501	Pluto	290.4538513	-21.19250028	290.4627145	-21.19216222	L;U;B;V
82	0793183801	Pluto	290.5976094	-21.20850228	290.5941724	-21.21058642	L;U;B;V
83	0800380101	Aimeemcarthy	334.2823285	-3.633520861	334.5500116	-3.628896917	M;L;U
84	0800400501	Sarpedon	137.5143637	-0.7671195	137.5362295	-0.744149	M;L;U
85	0800400601	2002 VU94	132.693046	-0.0530325	132.6390517	0.05990219444	M;L;U
86	0803161101	Asteropaios	159.304195	-2.555804833	159.3039392	-2.567429139	L;B
87	0803950801	Salazar	146.9090978	14.37213733	146.9327653	14.36387231	L;B
88	0803952201	Reseda	180.29188	1.151024972	180.3209618	1.136621639	L;B
89	0803952601	Joensuu	126.3411467	31.90827689	126.4194533	31.91556219	L;B
90	0804250301	Flagstaff	266.6556002	-29.83210128	266.7527539	-29.84931656	S;M;L;U;B
91	0810600201	2001 UY127	50.2470725	-1.158312056	50.30279604	-1.026853944	M;L;U
92	0811212701	1999 XT90	197.299954	-23.56913144	197.4071665	-23.70903806	M;L;U
93	0820460101	1999 FC32	177.9620883	3.972947472	178.0113729	3.942962222	L;V

N	observation	sso_name	ra1	dec1	ra2	dec2	filters
94	0821250601	2000 VR36	35.83477292	-3.512480722	36.04166496	-3.298254861	M;L;U
95	0830191001	2001 AG18	197.108645	-23.29220028	197.2994372	-23.30699	M;L;U

9.2 Screening results

The following table contains the screening results for all 95 potential XMM-Newton serendipitous observations of interest, where:

- N is the row ordinal.
- $observation$ is the observation ID (as per XMM-Newton's Science Archive).
- $object$ is the potential Solar System Object name in the XMM-Newton OM FoV.
- $\{S,\ M,\ L,\ U,\ B,\ V\}$ is the screening result for a particular filter, where:
    - Y indicates a clear detection.
    - D indicates a dubious detection.
    - N indicates no detection.

Rows have been colour-coded, where:

	The object has not been detected.
	The object might have been detected in one or more filters but either in the {S,M,L} filters or in the {U,B,V} filters.
	The object might have been detected (i.e. "dubious" or "clear" detection) in one or more of the {S,M,L} filters as well as in one or more of the {U,B,V} filters.
	The object has been detected (i.e. "clear" detection) in one of the {S,M,L} filters as well as in one of the {U,B,V} filters.

N	observation	object	S	M	L	U	B	V
1	12440101	Lictoria			D		D	
2	81340801	Stepanov			N	N	D	
3	106660601	1994 UF2			N	N		
4	110980101	Lucubratio			Y		Y	
5	110980601	1030 T-1			N	N	Y	
6	111170101	Velichko			N			N
7	137550501	Vermeer			N	N		
8	148090501	2000 VH57			N		Y	
9	148560501	2000 OR6			N			N
10	153450101	Coubertin			N		N	
11	153950901	2000 SG172			N	Y		

N	observation	object	S	M	L	U	B	V
12	164570401	1998 QN30			N	N		
13	202680101	1992 AJ1			N	N		
14	202680101	Puntel			N	N		
15	202730101	Kiyosato			N	N	N	
16	203170301	1998 YB12			N	N	N	N
17	203450201	1941 UN			N	Y		
18	203850201	1981 ET34			N	Y		
19	206060101	1993 UB3			N	N		
20	206060201	Vanavara			N	N		
21	206490301	Africa			N	N		
22	300240101	Mucha			N	N	N	
23	300480301	1994 YO1			N	N	N	N
24	300960631	Hermitage			N		D	
25	302580701	Chesneau			Y	Y		
26	303561001	Fredtreasure			Y	Y		
27	312790101	1999 AD32			N	N		
28	402360101	2006 BQ6		N	N	N	N	
29	402430301	Masciarelli			N	Y		
30	402750301	Kazo			N	N		
31	500760101	1999 XN105			N	N		
32	501270301	The			N	D		
33	502091601	Kulibin			N		N	
34	502120101	Ibuki			N	N		N
35	502430101	2000 BJ4			N	N		
36	503490201	Naruke			N	N		
37	503490201	2000 QP27			N	N		
38	504780501	1999 XQ57			N	N		
39	552860101	Nantong			N	N		
40	556212301	Amenemhet		N	N		N	
41	601391001	Joan	N	N	N	D	Y	Y
42	601670101	1986 RP5		N	N	N		
43	604740101	Lijiang		N	N	N		
44	604740101	2000 NA6		N	N	N		
45	650510301	1999 SG12		N	N	N	N	
46	653840401	Grotius	N	N	N	N		
47	653950201	1993 SG1			N	N	N	N
48	656200101	2000 WU93		N	N	N		

N	observation	object	S	M	L	U	B	V
49	670120301	Chrisclark	N	N	N	N	N	N
50	670880401	1999 AN25	N	N	N	N		
51	672990201	1994 CG2		N	N	N		
52	673310101	2000 JZ79		N	N	N		
53	673310101	2000 AV91		N	N	N		
54	673550201	1996 YP		N	N	N		
55	674370201	Zurich		N	N	N		
56	674480401	Potomac			N	N		
57	692330401	Ivanka		N	D	Y		
58	692330501	1998 HF34		N	N	D		
59	692510201	Quaide		N	N			Y
60	693820201	2000 RX67		N	N	N		
61	694510101	Siegena		N	N	N	N	
62	700182001	Landi		N	N	N		
63	721010501	1989 ST10	N	N	N	N	N	N
64	722310201	Auster		N	N	N		
65	723800701	1981 FT	N	N	N	N	N	N
66	727771001	1988 XT1	N	N	N		Y	
67	740920301	Tampere	N		Y	N		
68	742570101	1990 QT9		N	N	N		
69	743050301	2000 SL1	N	N	N	N	N	N
70	743630501	2000 SG234		N	N	N		
71	743950501	Aakashshah	N	N	N		N	N
72	744420101	1988 RK	N	N	N		N	
73	744440301	Lipschutz	N	N	N	N		Y
74	744440301	2001 FV5	N	N	N	N		N
75	748190101	1999 WA3		N	N	N	N	N
76	748391301	1998 EC9	N	N	N	N		
77	762520301	Boyan	N	N	Y	Y	Y	N
78	763100101	Raissa	N	N	N	N		
79	763100101	Silentium	N	N	N	N		
80	782650101	1999 RU128		N	N	N		
81	793183501	Pluto			Y	D	D	D
82	793183801	Pluto			D	D	D	D
83	800380101	Aimeemcarthy		N	N	N		
84	800400501	Sarpedon		N	D	D		
85	800400601	2002 VU94		N	N	Y		

N	observation	object	S	M	L	U	B	V
86	803161101	Asteropaios			D		D	
87	803950801	Salazar			D		N	
88	803952201	Reseda			N		N	
89	803952601	Joensuu			N		N	
90	804250301	Flagstaff	N	N	N	N	Y	
91	810600201	2001 UY127		N	N	Y		
92	811212701	1999 XT90		N	N	N		
93	820460101	1999 FC32			N			N
94	821250601	2000 VR36		N	N	D		
95	830191001	2001 AG18		N	N	N		

9.3 Detection images

This section contains the images used for the UV-Optical colours obtained in the Photometry section. The object has been highlighted inside a yellow box.

9.3.1 Obs. 11098010 - Lucubratio

9.3.1.1 L Filter

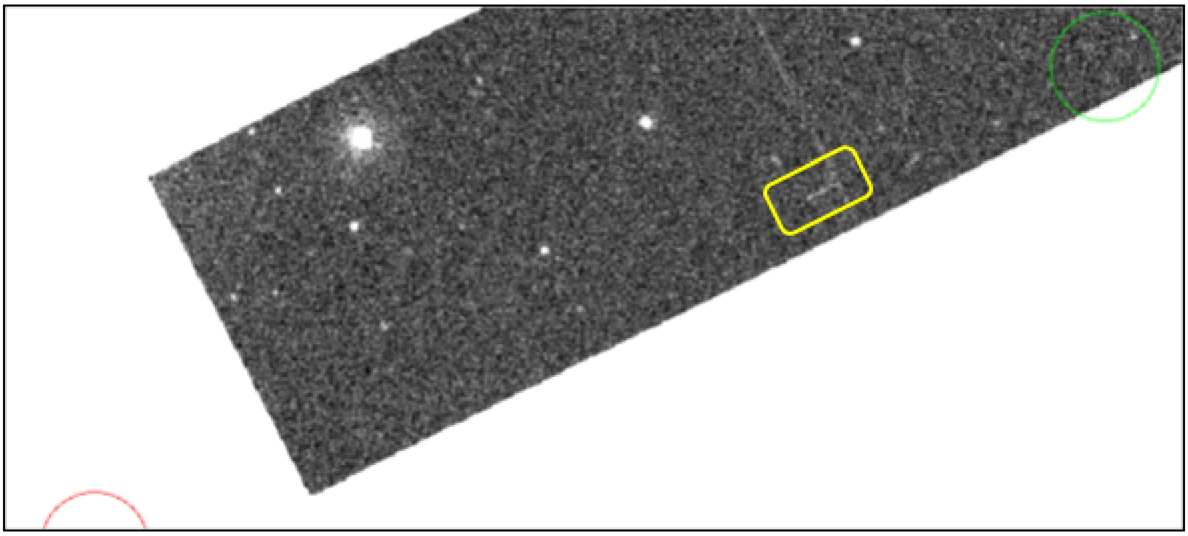


Image P0110980101OMS406SIMAGE1000

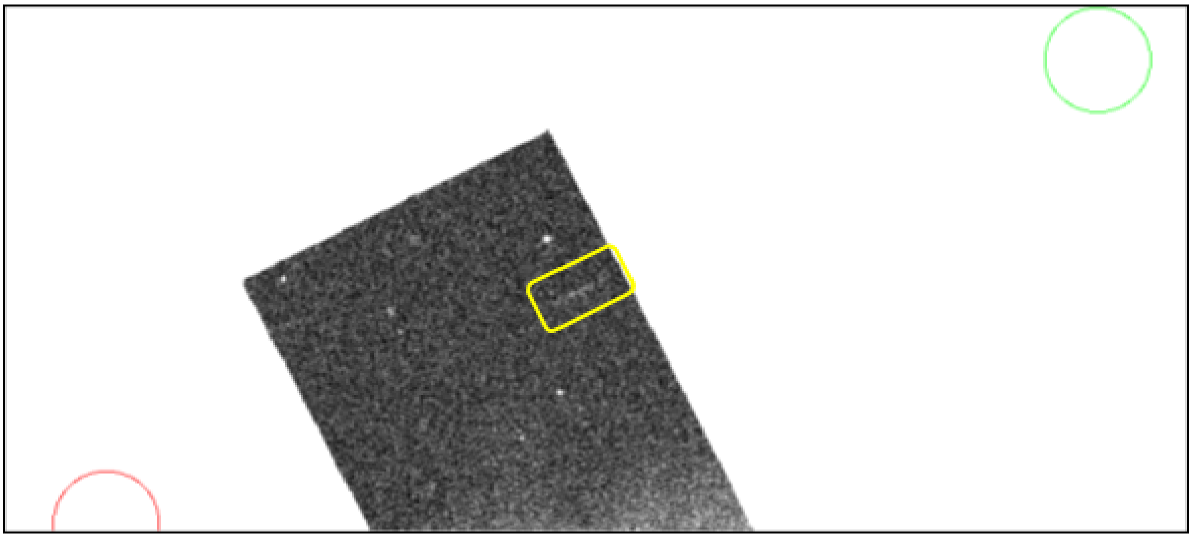


Image P0110980101OMS411SIMAGE1000

9.3.1.2 B Filter

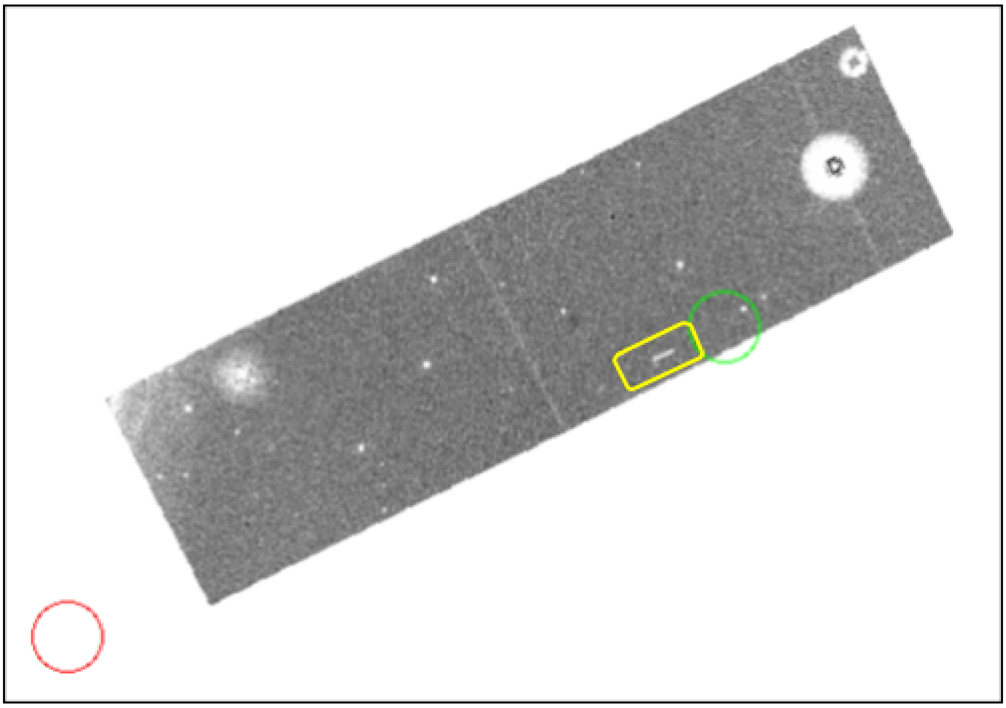


Image P0110980101OMS402SIMAGE1000

9.3.2 Obs. 0302580701 - Chesneau

9.3.2.1 L Filter

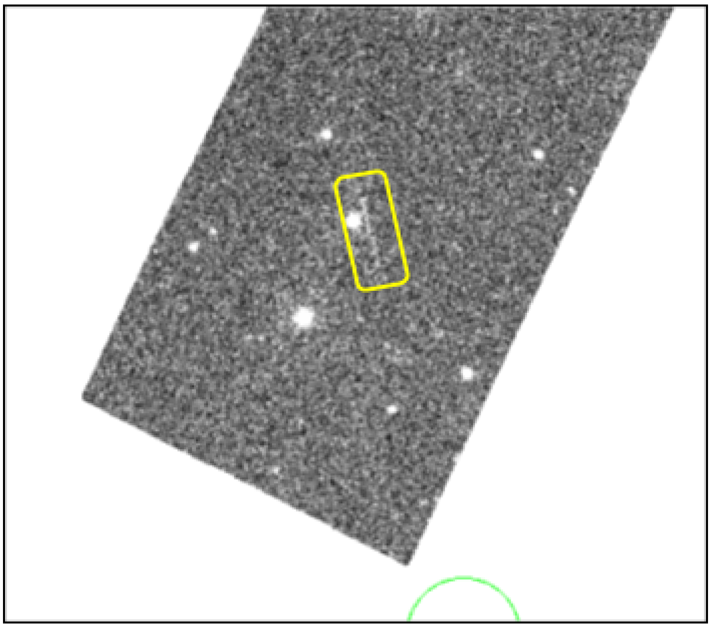


Image P0302580701OMS405SIMAGE1000

9.3.2.2 U Filter

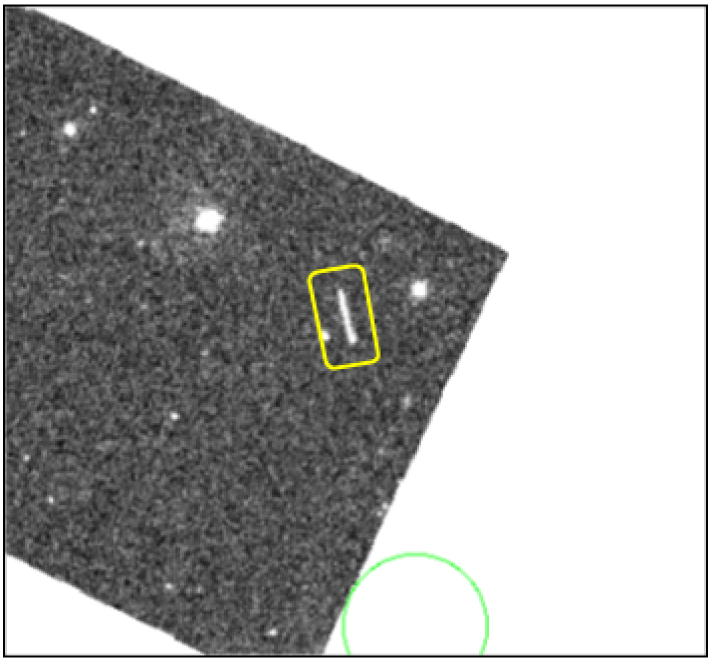


Image P0302580701OMS404SIMAGE1000

9.3.3 Obs. 0303561001 - Fredtreasure

9.3.3.1 L Filter

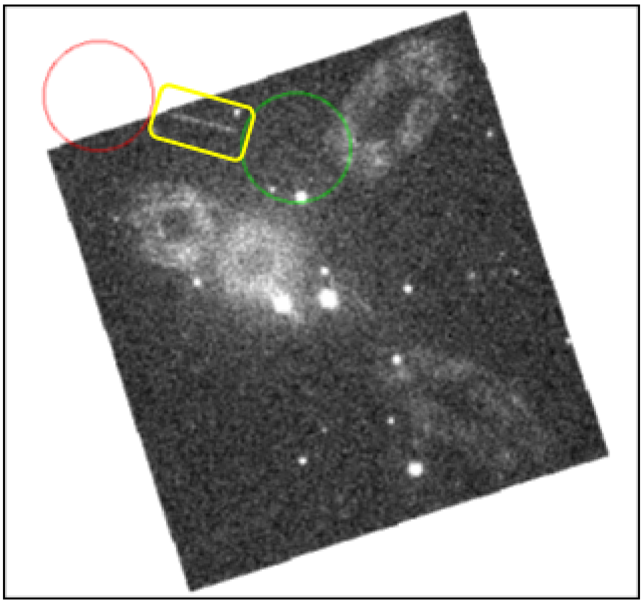


Image P0303561001OMS007SIMAGE0000

9.3.3.2 U Filter

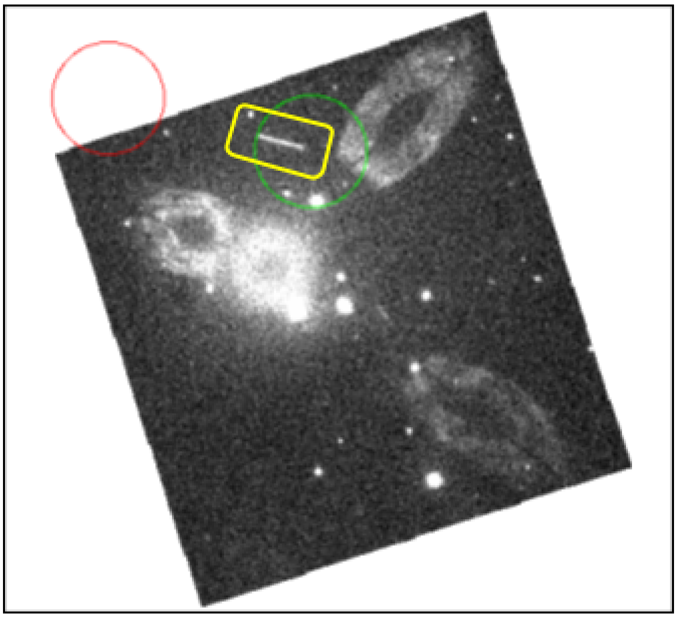


Image P0303561001OMS006SIMAGE0000