AIMING FOR APOPHIS:
How we did Asteroid Astrometry and Taught Others During COVID-19 Lockdowns?

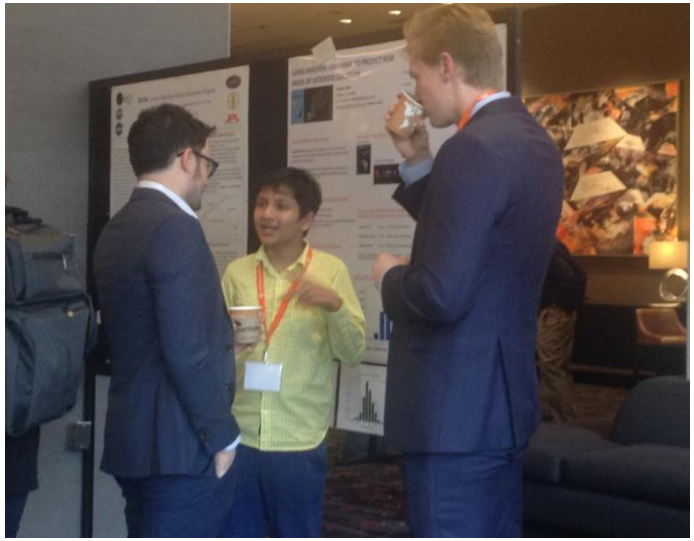
Arushi Nath (Grade 6)
Artash Nath (Grade 9)

7th IAA PDC Conference 2021
30 April 2021

Website: www.HotPopRobot.com
Twitter: @Wonrobot

How Apophis Entered Our Lives ?

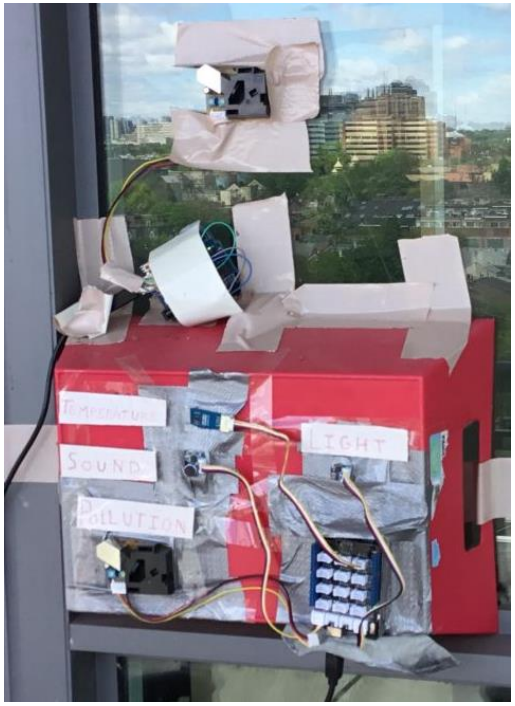
Artash: Participating and presenting in 6th IAA Planetary Defense Conference 2019, Maryland



Arushi: 3D printed models of Asteroid Apophis

COVID-19: Closed Schools, Open Minds

On Earth

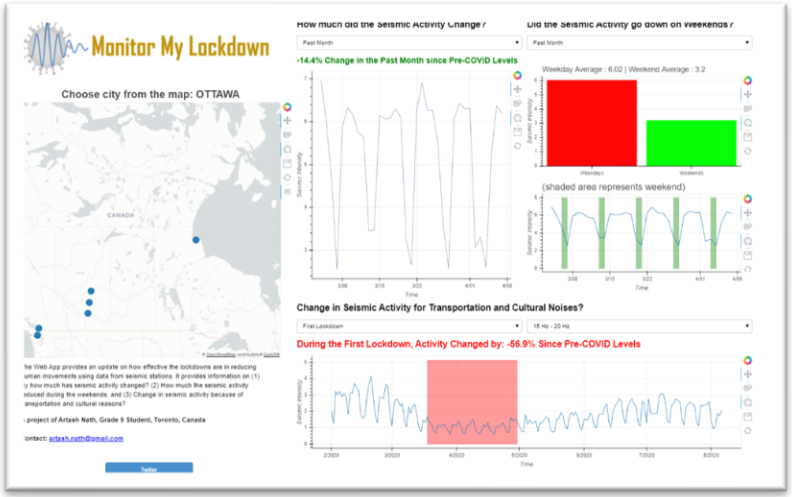


Measuring Impact of COVID-19 Lockdowns on Local Environment

Mar 2020 – Jul 2020

Subsurface

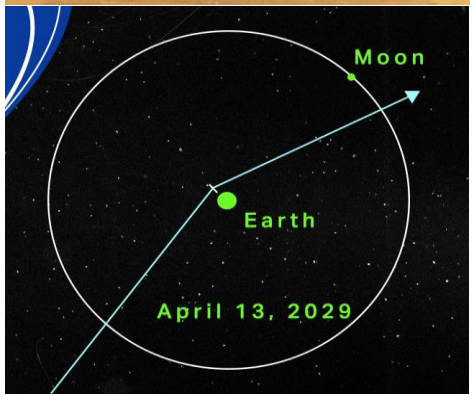
Monitor My Lockdown



Measuring Impact of COVID-19 Lockdowns on Seismic Vibrations

Jun 2020 – ongoing

Space

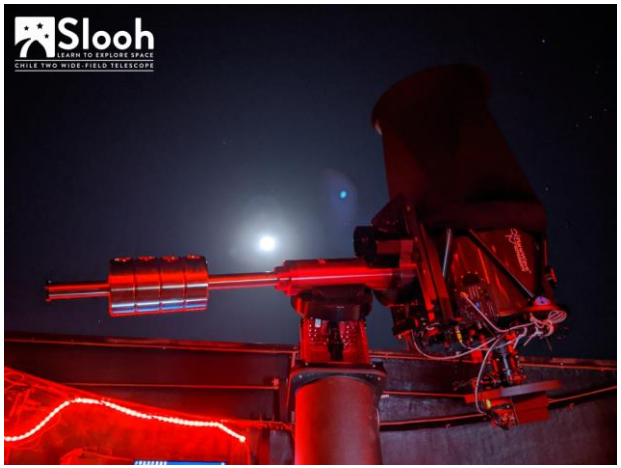


Finding APOPHIS!

Nov 2020 - Feb 2021

Imaging Apophis: Robotic Telescopes

Slooh
Chile Two Wide-Field Telescope



432mm Aperture
Field of View: 43 * 43 arcmin

iTelescope
T11 - Deep Space

510mm Aperture
Field of View: 54 * 35 arcmin

Faulkes Telescope Project /
Las Cumbres Observatory
Faulkes Telescope South (FTS)

2000mm Aperture
Field of View: 10 * 10 arcmin

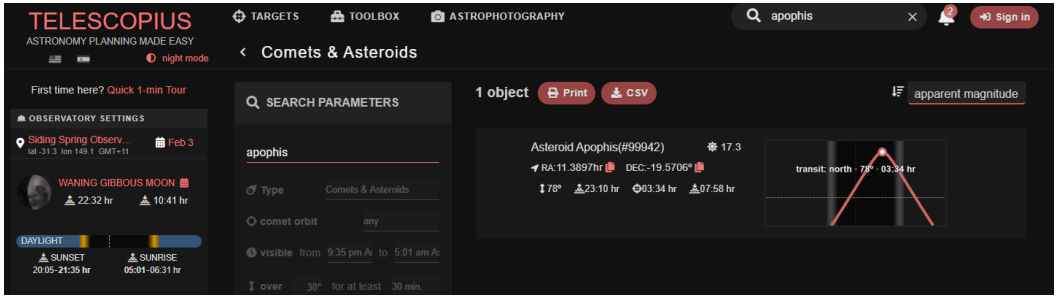
(Image Credit: Gronk Oz - Own work, CC BY-SA 4.0)

Pointing the Faulkes Telescope South to Apophis

Daily Right Ascension and Declination Values from NASA HORIZON project

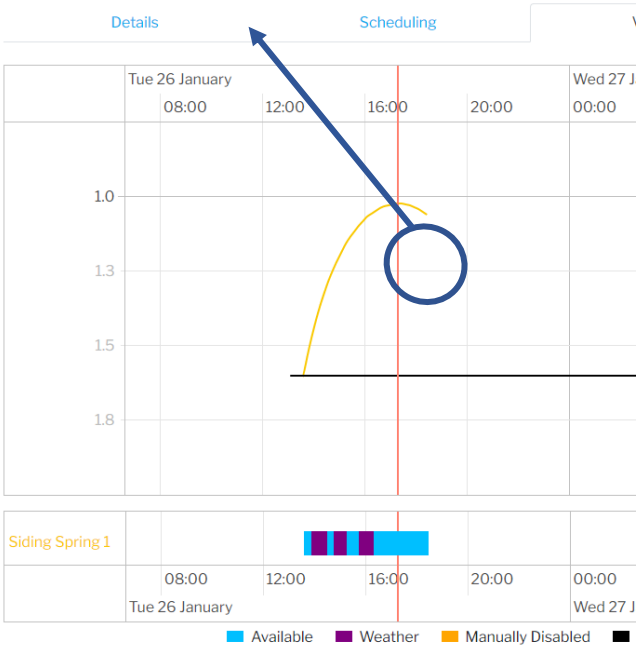
```
 Date__(UT)__HR:MN     R.A._____(ICRF)_____DEC    APmag
*******************************************************
$$SOE
 2021-Jan-10 00:00     11 43 51.55 -16 05 04.7   18.554
 2021-Jan-11 00:00     11 44 00.99 -16 18 09.7   18.515
 2021-Jan-12 00:00     11 44 06.86 -16 31 01.5   18.475
 2021-Jan-13 00:00     11 44 09.00 -16 43 38.9   18.435
 2021-Jan-14 00:00     11 44 07.26 -16 56 00.8   18.393
 2021-Jan-15 00:00     11 44 01.47 -17 08 06.2   18.351
 2021-Jan-16 00:00     11 43 51.49 -17 19 53.9   18.308
 2021-Jan-17 00:00     11 43 37.14 -17 31 22.7   18.264
 2021-Jan-18 00:00     11 43 18.28 -17 42 31.4   18.219
 2021-Jan-19 00:00     11 42 54.72 -17 53 18.7   18.174
```

Source: https://ssd.jpl.nasa.gov/horizons.cgi



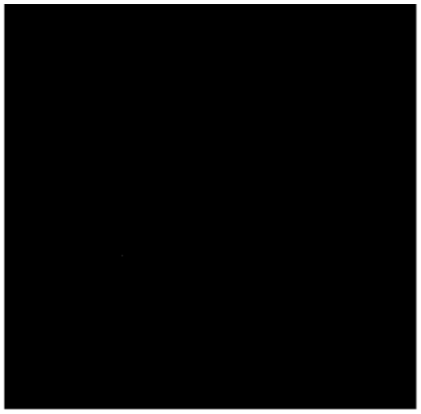
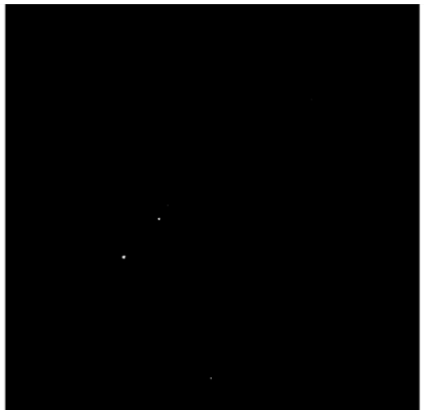
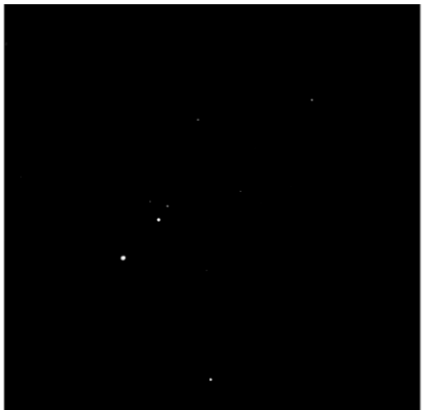
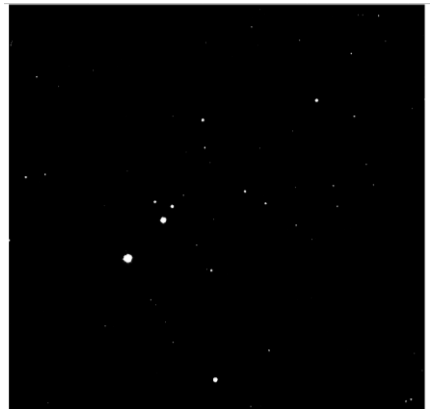
Source: Telescopius Website. https://telescopius.com/

Best Visibility and Time

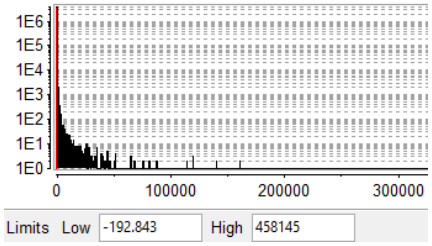


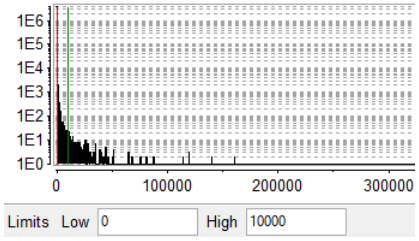
Scaling our Images taken from the Faulkes Telescope South

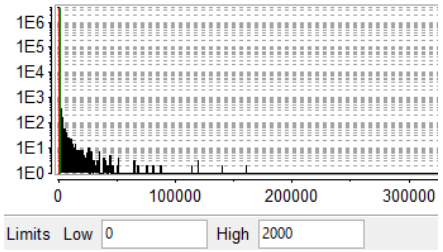
To see maximum possible objects: brighter and dimmer

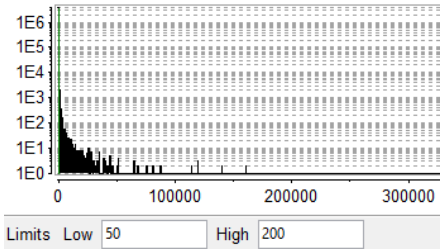





(Modifying Pixel Brightness Range using the Min/Max Function of SAOImage DS9 software, ds9.si.edu)



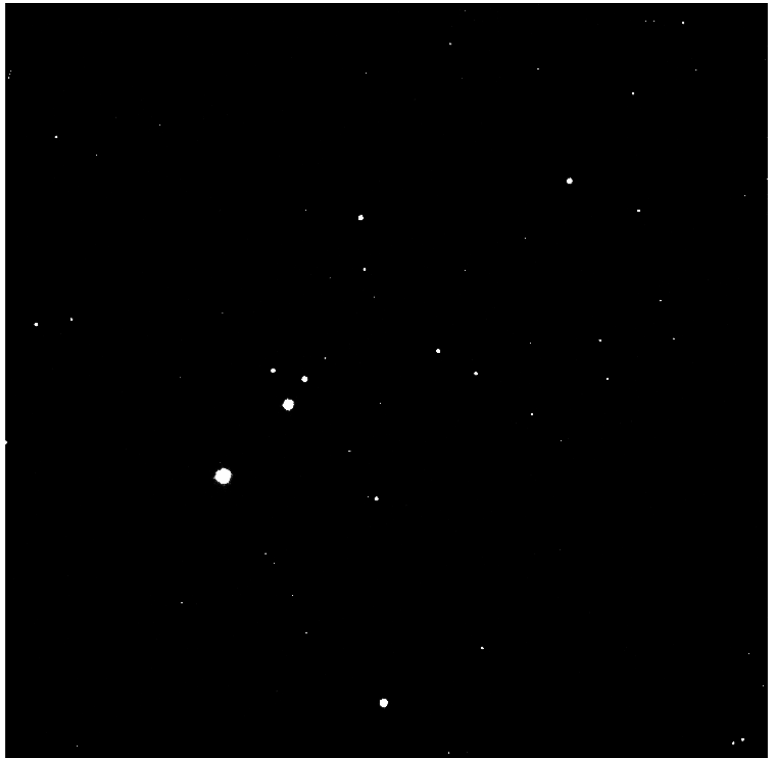






Comparing CCD Image with Celestial Field of View

Image could be rotated or flipped!



Taken with Faulkes Telescope South on 25th Jan 2021
(RA: 11h 38m 06.99s Dec: -18° 53' 59.4")

Matching of image using AAS WorldWide Telescope
http://worldwidetelescope.org/

Matching Stars in CCD Image with Stars in Celestial Field of View

Querying Star Catalogues Using Astrometrica software: www.astrometrica.at

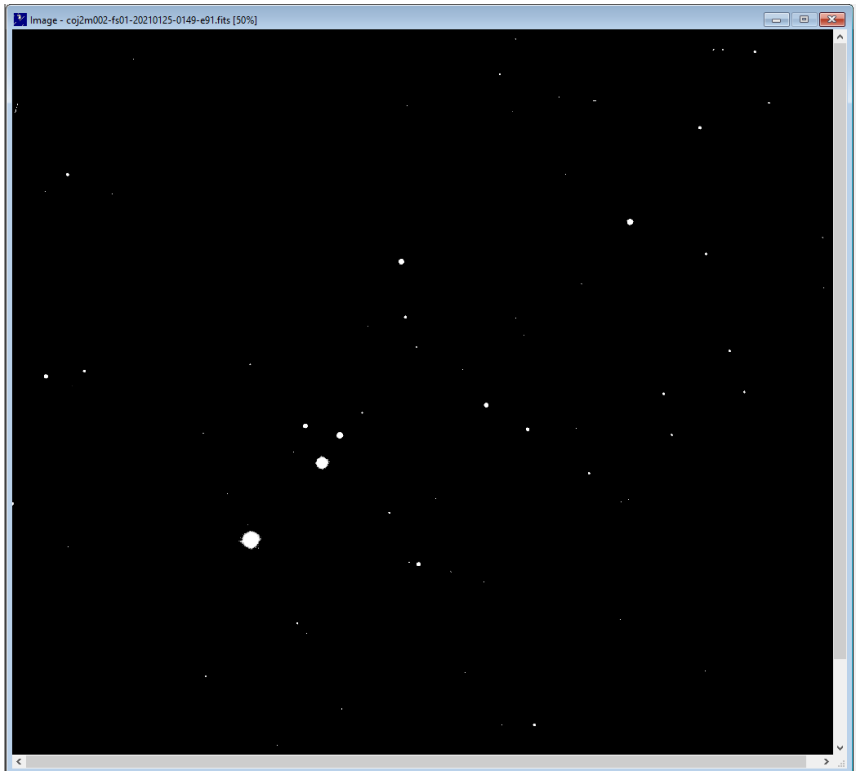
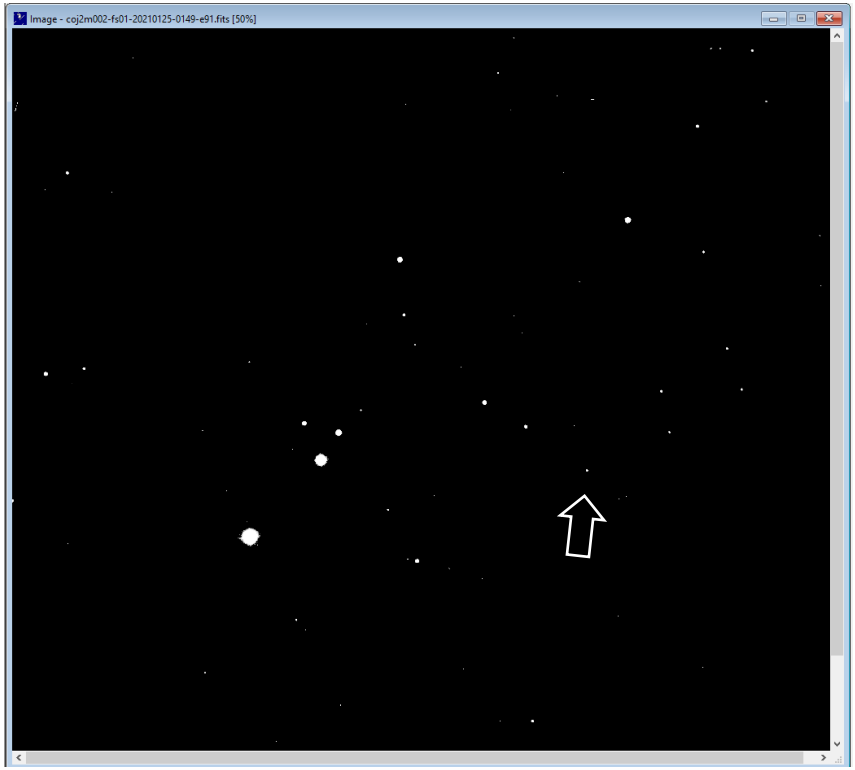


Image taken using the Faulkes Telescope South on 25th January 2021 (RA: 11h 38m 06.99s Dec: -18° 53' 59.4")

Finding Apophis!

Overlay the image from Minor Planet Centre (MPC) database using Astrometrica



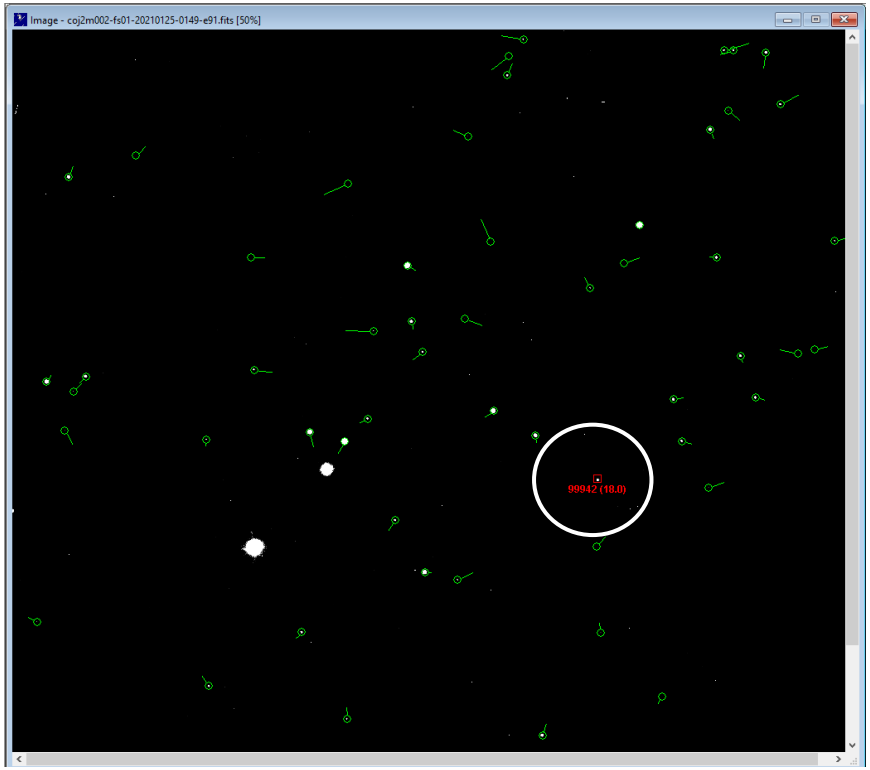
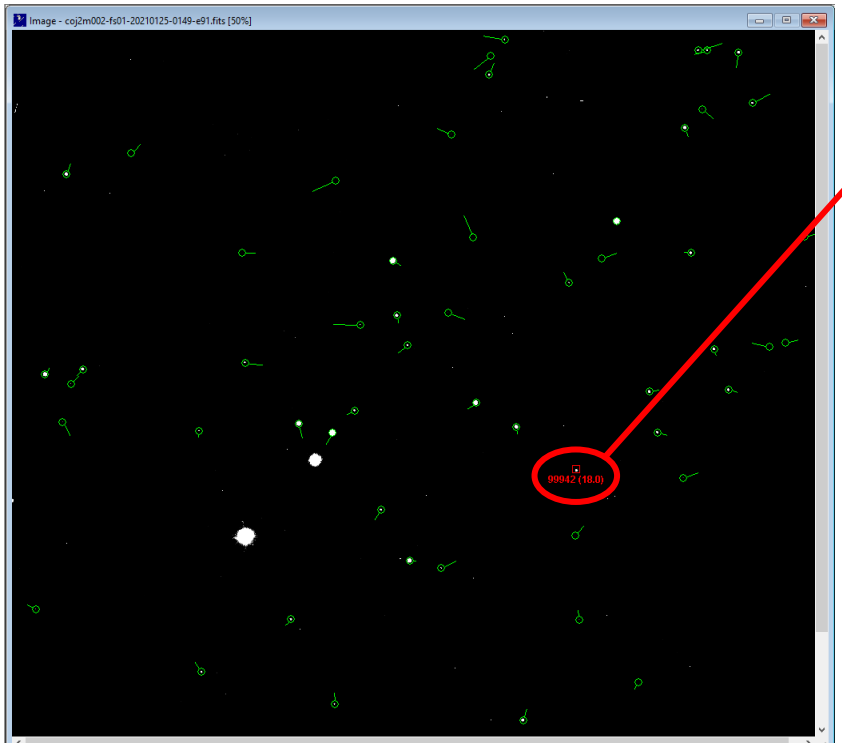


Image taken using the Faulkes Telescope South on 25th January 2021
(RA: 11h 38m 06.99s Dec: -18° 53’ 59.4”)

Locating Apophis Twice to Calculate Motion

25th January 2021. 18:07:33 UTC

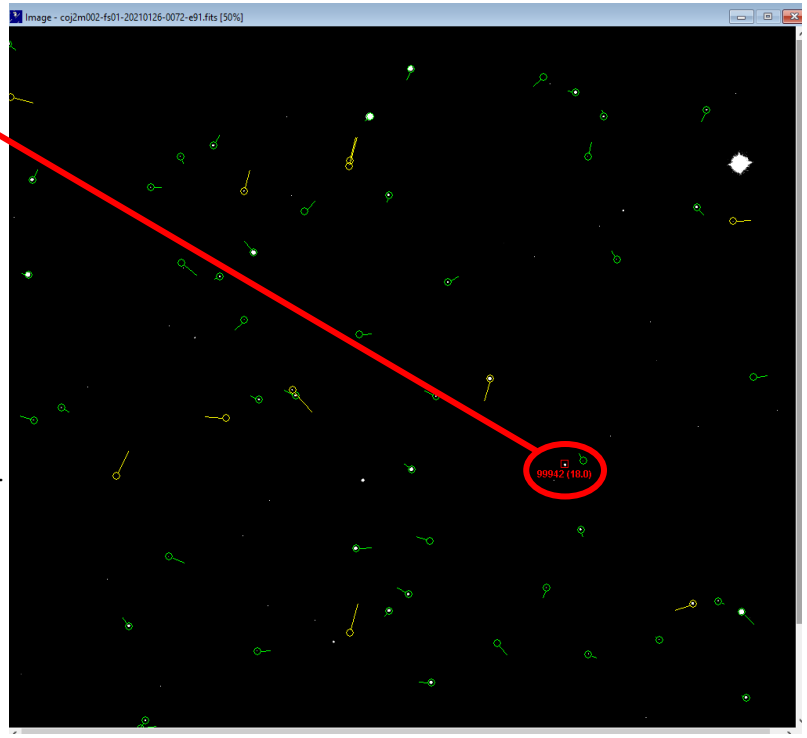


RA = 11h 37m 58.225s
Dec = -18 54’ 46.6”

99942 Apophis

Time Difference
23 hours 58 min 4 sec

26th January 2021 18:05:37 UTC

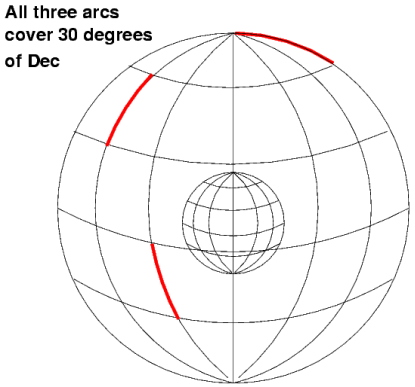


RA = 11h 36m 51.98s
Dec = -19 01’ 54.6”

Images taken using the Faulkes Telescope South

Calculating Proper Motion of Apophis

Apophis	Right Ascension	Declination
25 January 2021	11h 37m 58.225s (A)	-18 54’ 46.6” (A)
26 January 2021	11h 36m 51.98s (B)	-19 01’ 54.6” (B)

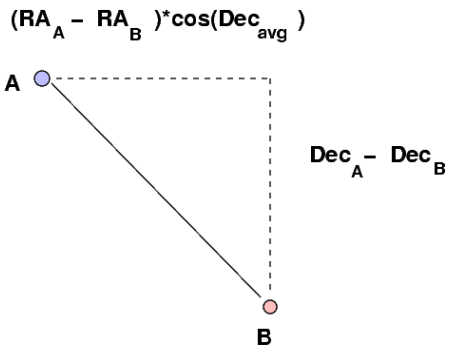


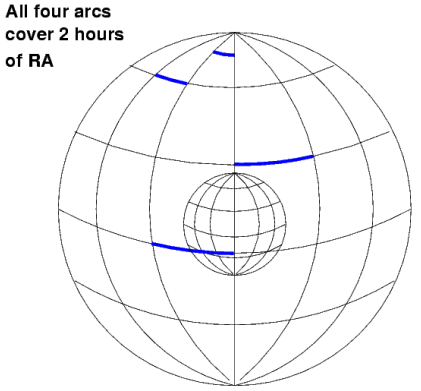
RA (A) – RA (B) = 174.4917 - 174.2167 = 0.275

Dec (A) – Dec (B) = (-18.9131)- (- 19.0319) = 0.1188

Average Declination (Dec avg) = -18.9725

Cos(Dec avg) = 0.95





Arc Length (AB) = 0.286 degrees

Time Taken = 23 hours 58 min 4 sec = 82800 + 3484 = 86284 s

Proper Motion of Apophis = 3.13 * 10^{-6} degrees /sec

= 0.011268 arcsec/sec

Source: http://spiff.rit.edu/classes/phys301/lectures/precession/precession.html

Doing Basic Asteroid Astrometry Using Python

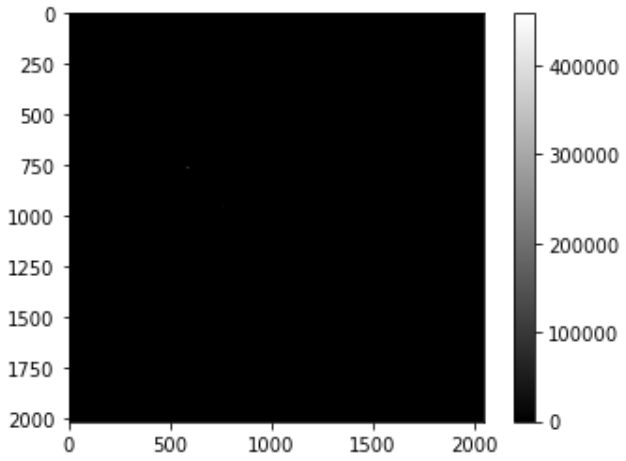
STEPS

1. Download libraries and open Flexible Image Transport System (**FITS**) files
2. Scale the images
3. Read FITS header files for RA and Dec, pixel scale, CCD size, and focal length
4. Query ‘Star Catalogues’
5. Match catalogue stars with stars in CCD images
6. Find the asteroid
7. *Plate Solving (arcmin/pixel) to calculate proper motion of asteroid*

Download Python Libraries and Open (FITS) Image Files

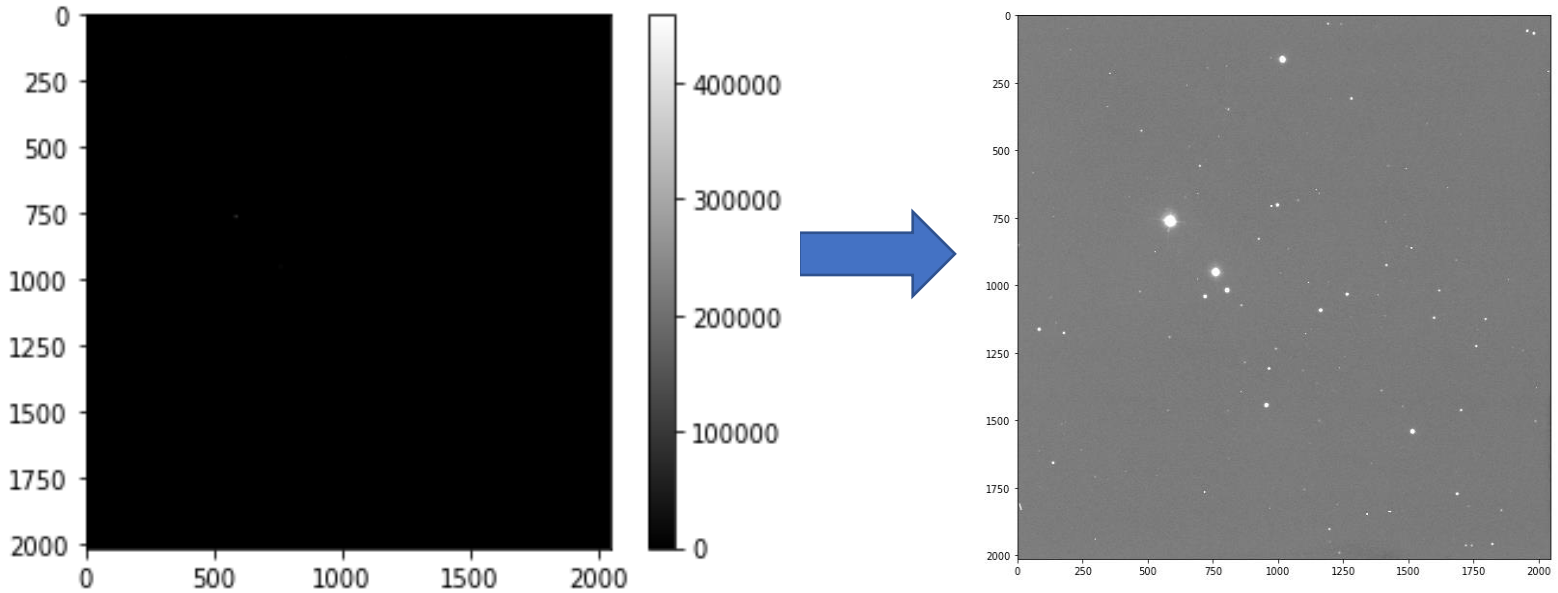
In [1]:
```
# Importing Required Libraries
import numpy as np
from astropy.io import fits
import urllib as url

import os
import matplotlib.pyplot as plt
```

In [ ]:
```
# Opening FITS Image Files
image_data = fits.getdata(r'\FILE PATH\xyz.fits')
plt.imshow(image_data, cmap = 'gray')
plt.colorbar()
```



Scaling of Images Using Python

```
# Scaling of Images using Standard Deviation Function

plt.figure(figsize=(10, 10))
plt.imshow(image_data, cmap='gray', vmin=image_data.mean()-0.2*image_data.std(), vmax=image_data.mean()+0.2*image_data.std())
```



Reading FITS header and Querying it for RA and Dec, Pixel Scale, CCD Size, and Focal Length

```
SCHEDSEE=            1.9225850 / [arcsec] Estimated seeing when group scheduled
SCHEDTRN= 'N/A     '           / [(0-1)] Estimated transparency when group sched
TRIGGER = 'N/A     '           / External trigger ID
OBRECIPE= 'N/A     '           / Observing Recipes required/used
PCRECIPE= 'N/A     '           / Processing Recipes required/used
PPRECIPE= 'N/A     '           / Post-Processing Recipes required/used
RA      = '11:38:06.4917'      / [HH:MM:SS.sss] RA where telescope is pointing
DEC     = '-18:54:22.377'      / [sDD:MM:SS.ss] Dec where telescope is pointing
RADESYS = 'ICRS    '           / [[FK5,ICRS]] Fundamental coord. system of the o
LST     = '12:24:53.68'        / [HH:MM:SS.ss] LST at start of current observati
CAT-RA  = '11:38:06.990'       / [HH:MM:SS.sss] Catalog RA of the object
CAT-DEC = '-18:53:59.40'       / [sDD:MM:SS.ss] Catalog Dec of the object
CAT-EPOC=         2000.0000000 / [Year] Catalog epoch of the coordinates
OFST-RA = '11:38:06.990'       / [HH:MM:SS.sss] Catalog RA plus pointing offsets
OFST-DEC= '-18:53:59.40'       / [sDD:MM:SS.ss] Catalog Dec plus pointing offset
TPT-RA  = '11:38:58.053'       / [HH:MM:SS.sss] Telescope demand RA
TPT-DEC = '-18:51:10.67'       / [sDD:MM:SS.ss] Telescope demand Dec
OBJECT  = 'Apophis '           / Object name
SRCTYPE = 'EXTRASOLAR'         / Source type
```

```python
#Querying FITS File for Information

#Camera
NAXIS1 = hdu.header['NAXIS1']
NAXIS2 = hdu.header['NAXIS2']
CCDXPIXE = hdu.header['CCDXPIXE']

#OBJECT
RA = hdu.header['RA']
DEC = hdu.header['DEC']
DATE = hdu.header['DATE-OBS']

#TELESCOPE
Aperture = 2000 #mm
Focal_Ratio = 10
Pixel_Scale = 0.0025 #arcmin/pixel
```

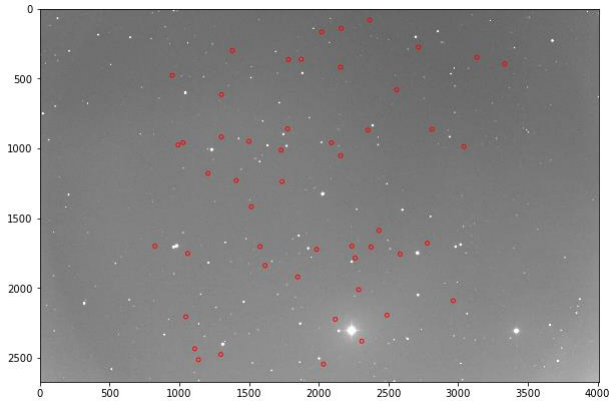
Query Star Catalogue USNO-B 1

```
#Querying Star Catalogue: United States Naval Observatory-B 1 (USNO-B 1)

def search_usno(ra_deg, dec_deg, fov_am):# RA/Dec in decimal degrees/J2000.0 FOV in arc min.

    #Request to open the USNO-B1 catalog from the internet
    str1 = 'http://webviz.u-strasbg.fr/viz-bin/asu-tsv/?-source=USNO-B1'
    str2 = '&-c.ra={:4.6f}&-c.dec={:4.6f}&-c.bm={:4.7f}/{:4.7f}&-out.max=unlimited'.format(ra_deg, dec_deg, fov_am, fov_am)
    f = url.request.urlopen(str1+str2)

    #   Read from the object, storing the page's contents in 's'.
    s = f.read()
    f.close()
    sl =s.splitlines()
    sl = sl[36:-1]    # get rid of header
```

The USNO-B1.0 Catalog

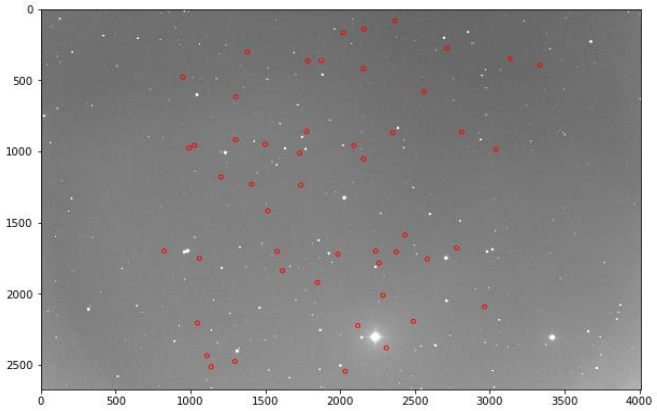
(Entry Format) (B1.0 at USNO)

http://tdc-www.harvard.edu/catalogs/ub1.html



Matching Catalogue Stars with CCD Stars

```python
#Rotating the USNO-B1 Catalog Stars to Match Stars in CCD Image

import math
def rotate(origin, point, angle):
    """
    Rotate a point counterclockwise by a given angle around a given origin.

    The angle should be given in radians.
    """
    ox, oy = origin
    px, py = point

    qx = ox + math.cos(angle) * (px - ox) - math.sin(angle) * (py - oy)
    qy = oy + math.sin(angle) * (px - ox) + math.cos(angle) * (py - oy)
    return qx, qy
```



Unmatched Image

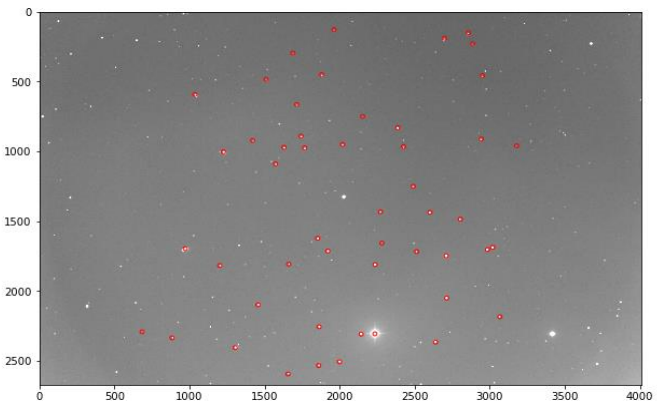
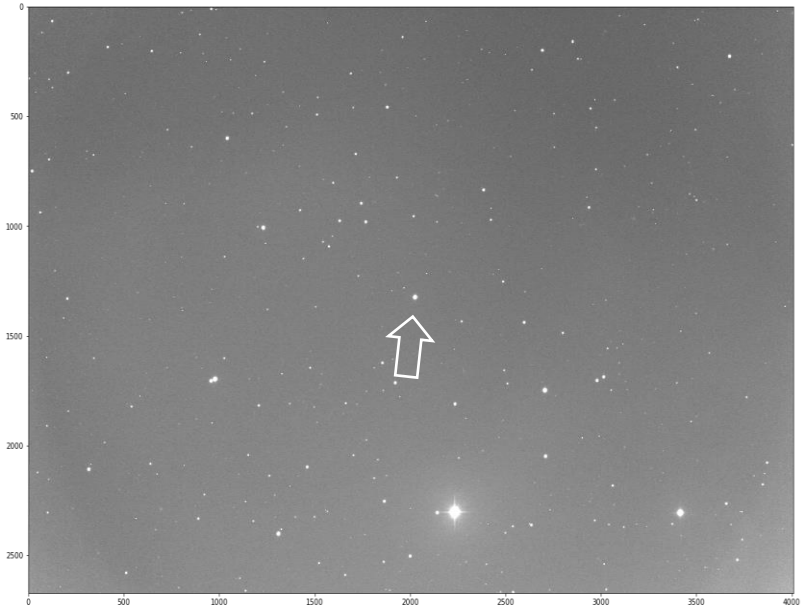
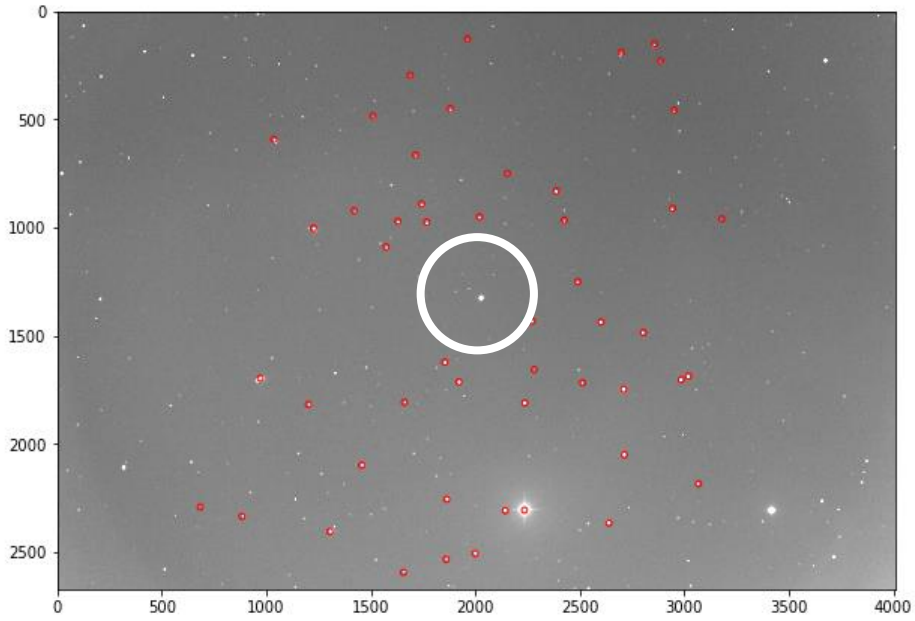


Image matched after rotating 180 degrees

Finding the Asteroid!



Original Image

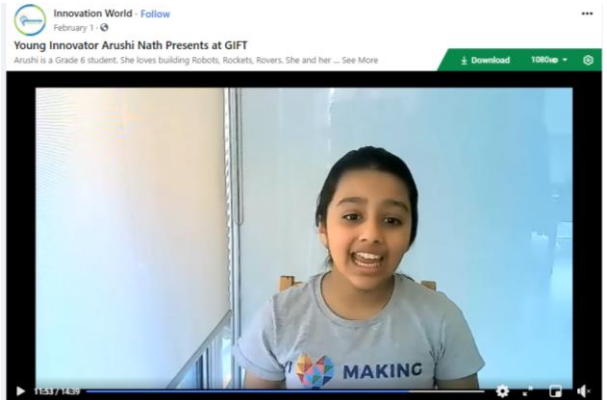


Data Reduced and Image Mapped Using Sky Catalogue using Python

Outreach: Reaching to Kids and Families

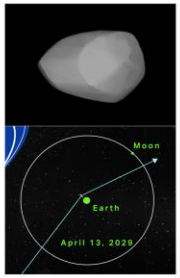
Royal Astronomical Society of Canada (RASC)

Global Innovation Field Trip (GIFT)



School Show and Tell (Français)

Viser à Apophis: Faites-le Vous-Même Astrométrie Astéroïde à l'Aide de Python



Arushi Nath (6e année)

8 février 2021

site: www.HotPopRobot.com

Conseil scolaire Viamonde

THE ROYAL ASTRONOMICAL SOCIETY OF CANADA · LA SOCIÉTÉ royale D'ASTRONOMIE DU CANADA

THE GLOBAL INNOVATION FIELD TRIP

Conseil scolaire Viamonde

tout est possible

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How we did Asteroid Astrometry and Taught Others During COVID-19 Lockdowns?

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7th IAA PDC Conference 2021
30 April 2021

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