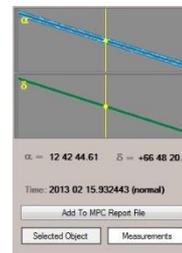


A Guide to Video Astrometry

Alex Pratt – MPC Z92



Introduction

Astrometry – the precise measurement of the position of a celestial body, e.g. an asteroid or a comet – is usually performed by taking one or more CCD images of the target object and determining its RA and Dec with reference to a field of stars whose positions are given in an astrometric-quality star catalogue.

This guide describes the technique of video astrometry using Tangra software, where an integrating video camera can be used to measure the positions of slow-moving and fast-moving bodies. Slow objects, such as main belt asteroids (motion $<2.0''/\text{min}$) are measured by taking the median value of hundreds of video frames. Faster objects, typically Near-Earth Asteroids, are measured by motion-fitting their movement in RA and Dec. For example, Tangra can produce O-C astrometric residuals $<1''$ for bodies with sky motions of $600''/\text{min}$.

These notes complement Hristo Pavlov's comprehensive description of the program and the sample tutorials on the Tangra website:- <http://www.hristopavlov.net/Tangra3/>

Hardware

A 10cm aperture f/6 refractor has been used to achieve good astrometry, but a larger instrument is recommended. A 20cm SCT with an f/3.3 focal reducer to give a brighter image and a wide flat field can be used on a range of objects to about magnitude 15. The telescope should be on a sturdy mount with an RA drive to enable videos up to 1 minute in duration to be recorded.

An **integrating video camera**, such as a Mintron or Watec, is required to record the field of view (FoV). This should be able to take exposures up to at least a couple of seconds for measuring faint objects. Colour cameras are not recommended because they generally have lower sensitivity than monochrome cameras.

A camcorder with DV tapes can be used to record the video, but the recommended method is to write video files directly to a computer with a USB video capture device or PC card. A modern laptop should suffice. These examples used an EZCap USB 2 video grabber.

Another essential is a **GPS video time-and-date inserter (VTI)**, to embed accurate time markers into the video recording. The inserter must be a GPS 1PPS (1 pulse per second) unit, like the IOTA-VTI which has an accuracy better than 1ms.

Software

Tangra is used for the calibration, reduction and measurement of the videos. These tasks are performed by its astrometry module. The current release of Tangra is version 3 <http://www.hristopavlov.net/Tangra3/> This guide includes examples of video astrometry using Tangra3 and its predecessor, version 1.4.

VirtualDub <http://virtualdub.org/> is recommended for writing AVI videos onto the computer, because some other software bundled with video grabbers dropped too many frames. VirtualDub buffers the video stream and reports any dropped frames.

OccuRec <http://www.hristopavlov.net/OccuRec/> is excellent multi-purpose video recording software. It produces small output files in AAV format (Astronomical Analogue Video) by processing all frames in real-time and saves a single averaged image from each integration period. Tangra supports AAV files.

Lagarith Lossless Codec <http://lags.leetcode.net/codec.html> compression can significantly reduce the MB/s written to the disk drive and it also creates smaller AVIs.

Tangra does not (currently) access online star catalogues, it needs a local copy on the computer. The Minor Planet Center (MPC) recommends **UCAC-4** (US Naval Observatory CCD Astrograph Catalogue 4)

<http://www.minorplanetcenter.net/iau/info/Astrometry.html#cats>

which can be downloaded from Vizier <http://cdsarc.u-strasbg.fr/viz-bin/Cat?cat=I%2F322A> alternatively it is free on request by e-mailing brenda.hicks@navy.mil with "UCAC4" as the subject and your full name and postal address in the body of the e-mail. (USNO dispatched my DVDs the day after receiving my request and then it took a month for the package to arrive.)

A planetarium program compatible with UCAC4 is required when calibrating the video star field in Tangra. **C2A** is excellent for this purpose <http://www.astrosurf.com/c2a/english/> It is integrated into **Occult Watcher** <http://www.occultwatcher.net/> and is useful for planning astrometry sessions.

Project Pluto's Guide software <http://www.projectpluto.com/> is also recommended.

Recording a video

After selecting a target object it is necessary to know its position at the time of the planned observation. The Minor Planet & Comet Ephemeris Service (MPES) webpage of the MPC provides this information:

<http://www.minorplanetcenter.net/iau/MPEph/MPEph.html>

Enter your site coordinates, observatory code, or a code of a nearby observatory. Note the RA, Dec and sky motion in "/min.

VirtualDub's Capture option has not dropped frames (*using Lagarith compression*) when recording AVIs on a 4-core Windows 7 laptop computer to a 2.5-inch format SATA 5400 rpm internal disk drive. From the 'Audio' tab, select 'No audio'. To avoid overwriting an AVI, tick the Capture option 'Autoincrement filename after capture'.

Power on the VTI and camera and check that the video signal is displayed on the computer or recorder. Set the camera to normal mode (25 fps) or a short integration interval, and then align the telescope on the given coordinates, referring to the planetarium program to confirm the star field. Depending on the motion of the asteroid or comet, its magnitude, sky brightness and f/ratio of the telescope, increase the camera's integration interval to maximise the number of field stars.

When a GPS VTI is switched on it might not initially display accurate UTC. The IOTA-VTI needs to fix on at least 4 satellites to determine UTC, which can involve updating its internal almanac. This could take several minutes. Cross-check the VTI against another source, such as a computer synchronised by Dimension4 software <http://www.thinkman.com/dimension4/> or other NTP systems, or against a radio-controlled clock.

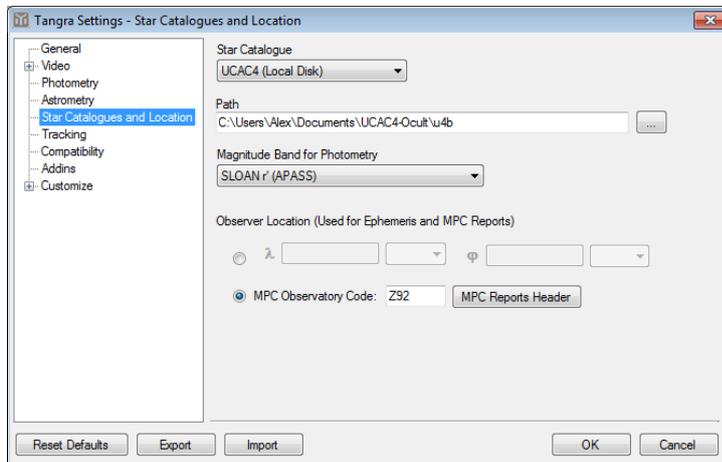
Record a 60s video of the target object(s) and note its integration setting in the filename, e.g. '32x'. The AVI file could be about 350 MB in size, depending on the compression used. Take further 60s videos at intervals of 30 minutes. Fast-moving Near-Earth Objects can be recorded at more frequent intervals. Remember that a recording isn't secure until at least one backup copy has been saved to another medium.

As with standard CCD imaging, Tangra supports bias and dark frames and flat fields, created from short videos. These can be taken at any time during the imaging session. For example, to make a dark frame video, cover the end of the telescope and disconnect or disable the VTI feed. Any hot pixels should be clearly displayed. Using exactly the same exposure and gain settings as the main astrometry video, save a 15s video and include 'dark'

in its filename. Remove the telescope cover. The dark frame is used to remove hot pixels during the video reduction and this can be sufficient for obtaining good astrometry. (Information on more extensive calibration is given in **Bias, Darks and Flats** on pages 17-18.)

Tangra configuration settings

Before using Tangra's astrometry module it is necessary to enter some configuration settings.



Click on 'Settings', click the 'Star Catalogues & Location' tab.

From the 'Star Catalogue' pick list, select 'UCAC4 (Local Disk)'.

In 'Path', enter its folder location on the computer.

From the 'Magnitude Band for Photometry' pick list, select 'SLOAN r (APASS)'. Tangra offers a comprehensive set of photometry options, including Johnson V. Hristo Pavlov recommends:

UCAC4: SLOAN r', then Model Fit Magnitude (fMag)

UCAC3: Cousins R - Computed from fMag, then Model Fit Magnitude (fMag)

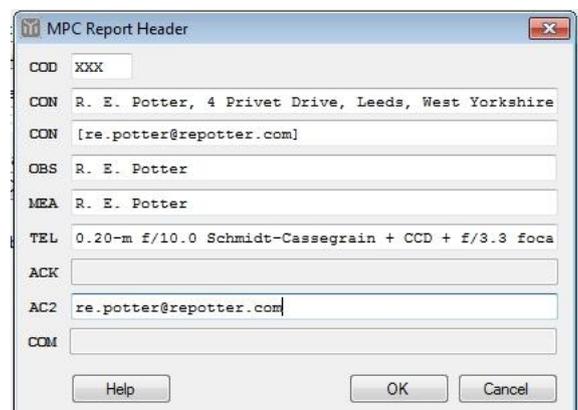
UCAC2: Internal UCAC magnitude (U2 Mag)

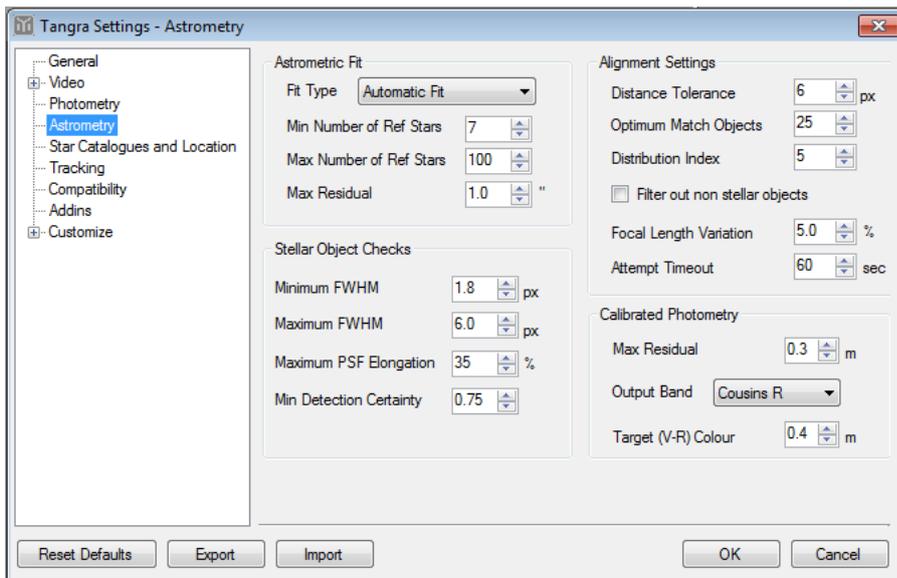
NOMAD: Cousins R from USNOB or UCAC2

Enter the longitude and latitude of your observing location, or preferably your MPC Observatory Code.

Click on the 'MPC Reports Header'.

Add details to the MPC Report Header as described in <http://www.minorplanetcenter.net/iau/info/ObsDetails.html>



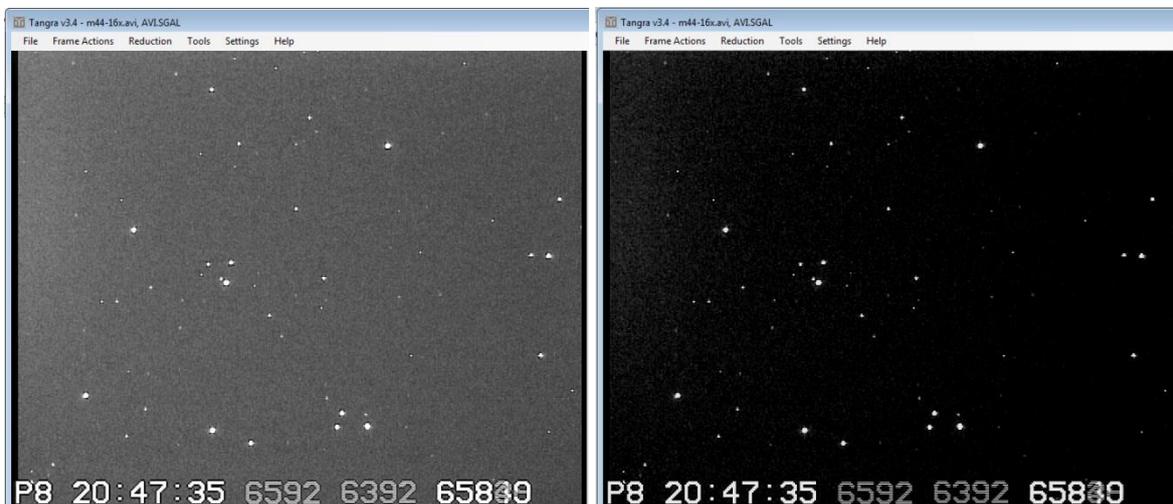


Click on the 'Astrometry' tab to display the default astrometry settings. Leave these unchanged for now.

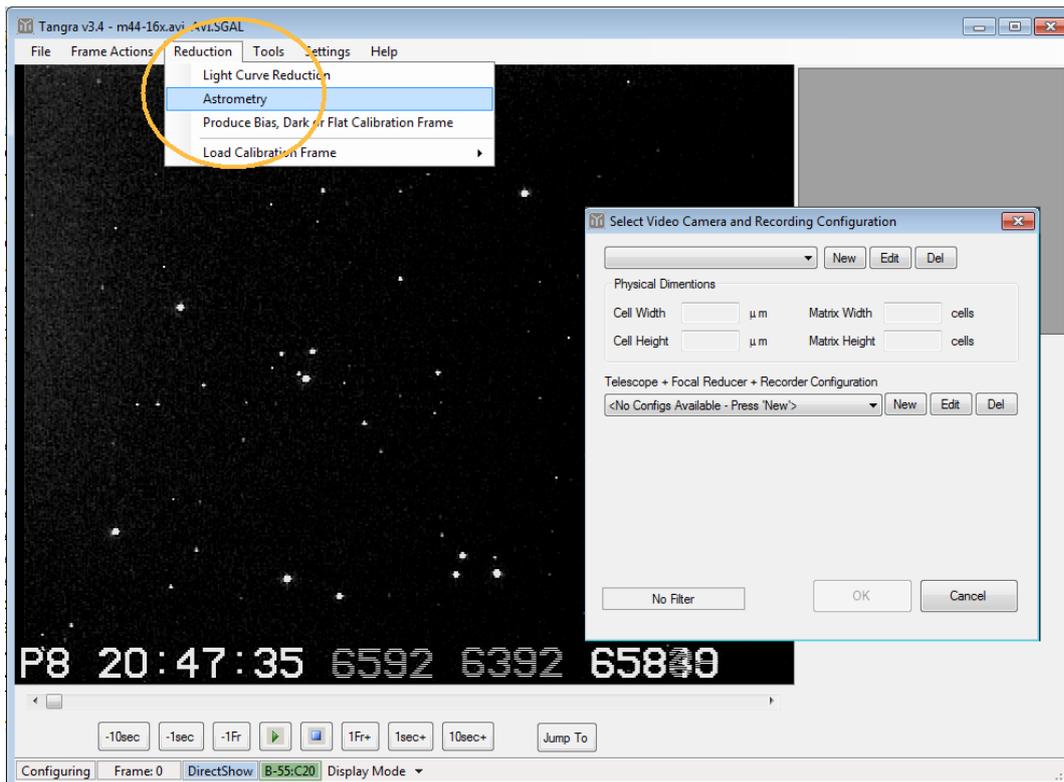
Calibrating a video

After recording a video using a specific combination of telescope, focal reducer, capture device and camera, Tangra needs to determine the pixel width and height with reference to the effective focal length, to be able to calibrate the star field and to perform precision astrometry on the target object.

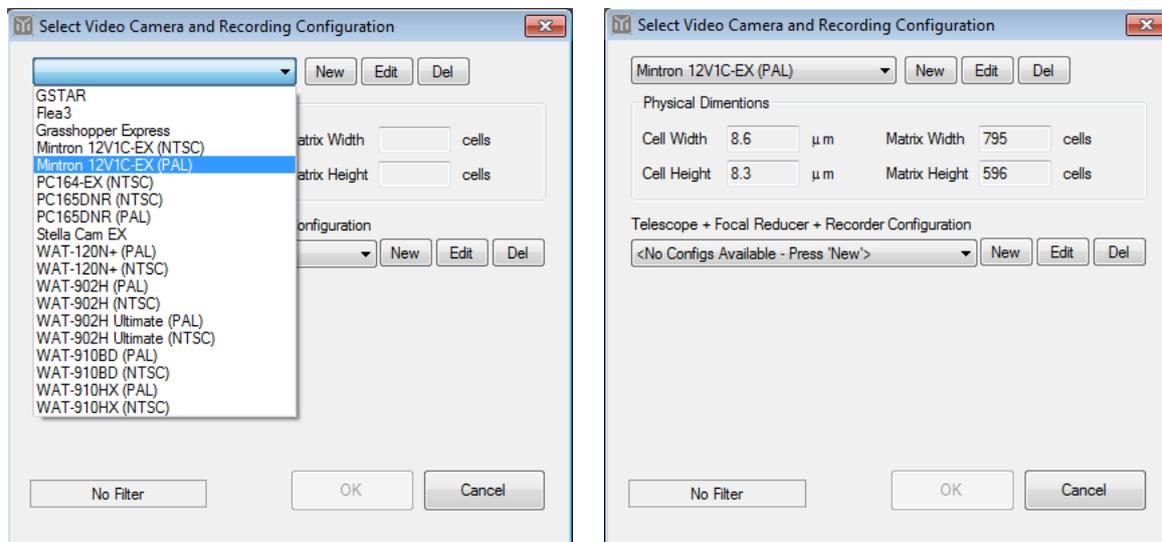
If a recording does not have a good spread of stars across the FoV it is recommended to record a 15s calibration video of a star field such as Messier 44 (Praesepe, the Beehive Cluster).



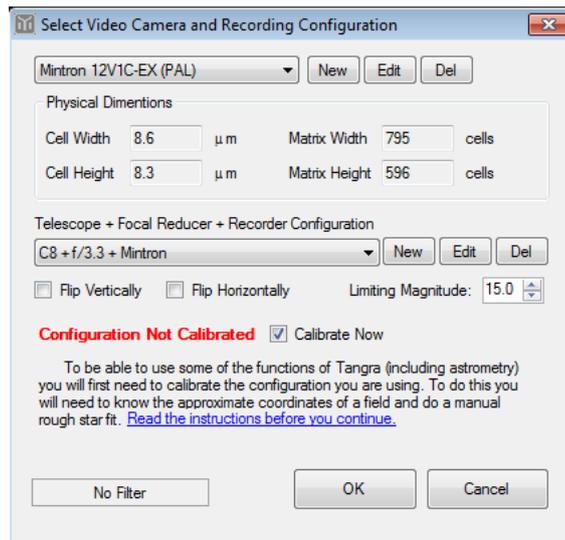
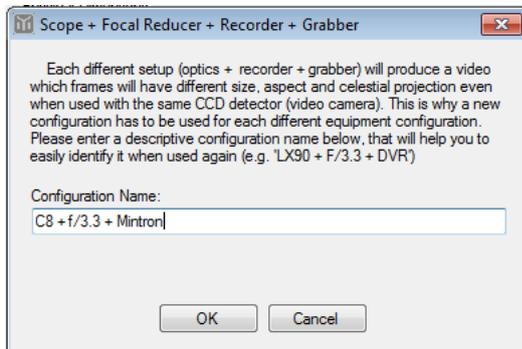
Open the calibration video, e.g. M44 recording. If required, select 'Reduction', 'Light Curve Reduction', 'Pre-Processing' to change the brightness and contrast.



Click on 'Reduction', 'Astrometry'. Tangra will open a 'Select Video Camera and Recording Configuration' window.

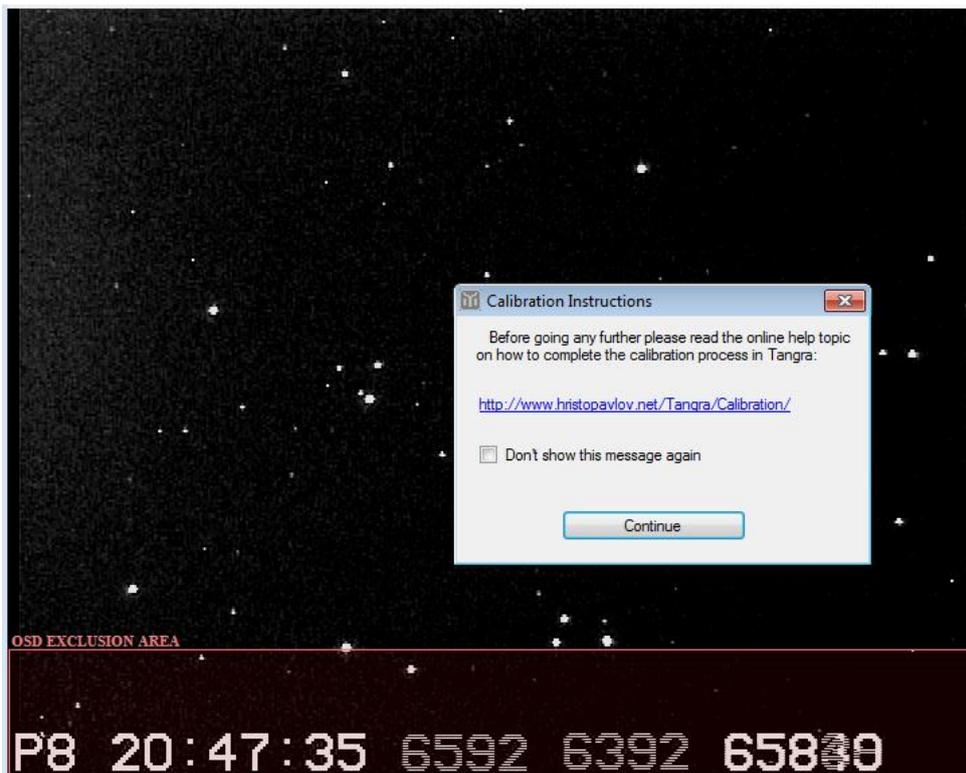


Select your camera (or a fully compatible model) from the pick list, e.g. Mintron 12V1C-EX(PAL). If it is not listed, click 'New', create a new Camera Name configuration entry and from the camera's technical specification documentation complete the Cell Width, Cell Height, Matrix Width and Matrix Height fields.

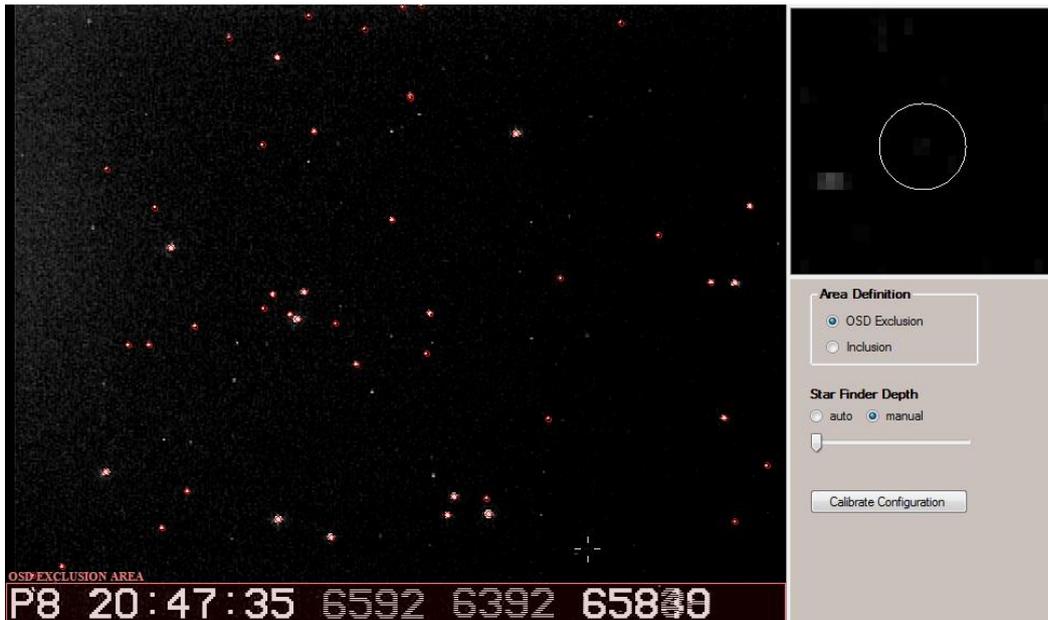


Under 'Telescope + Focal Reducer + Recorder Configuration' click 'New' and add a description, such as 'C8 + f/3.3 + Mintron'. Click 'OK'. Adjust the 'Limiting Magnitude' setting, if required.

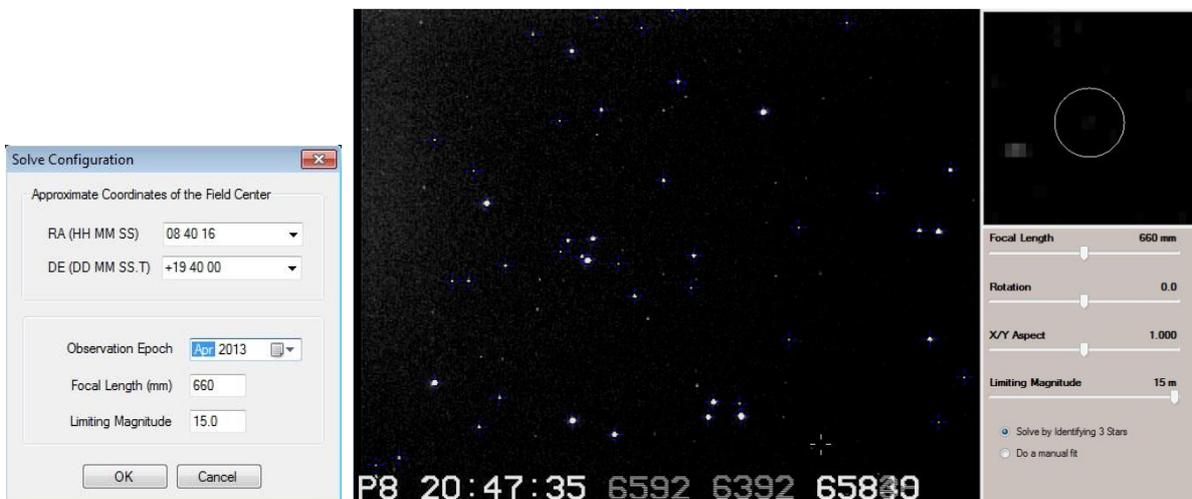
Tangra highlights **Configuration Not Calibrated**. Click 'OK' to proceed to the calibration screen.



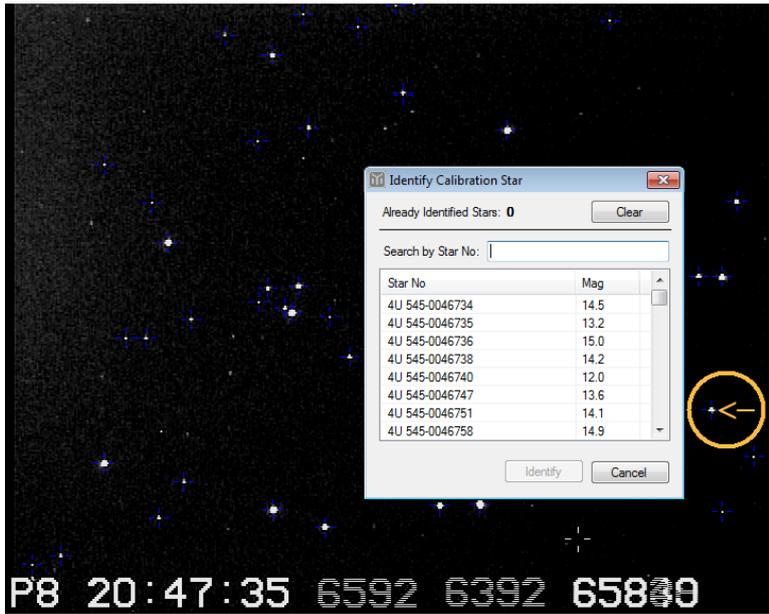
The VTI writes its information into the On Screen Display (OSD) area. Tangra needs to exclude this embedded timing data from its calibration process and subsequent astrometric measurements, but it will analyse any underlying stars. Click on 'Continue'.



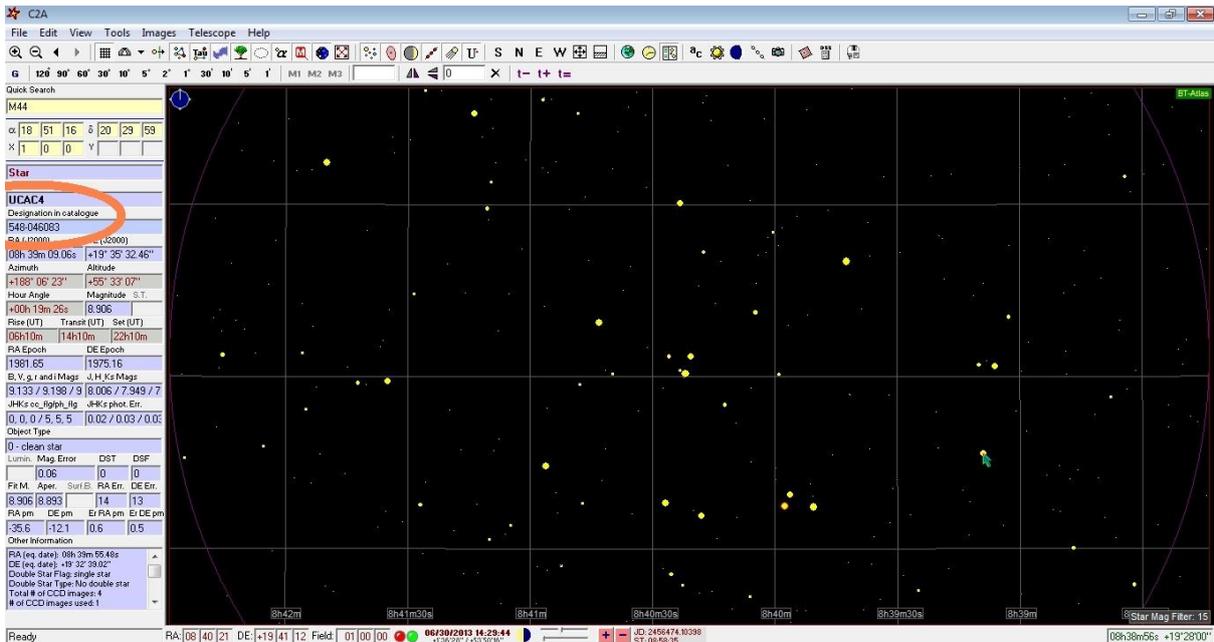
Tangra outlines the field stars for use in 3-star identification. Use the TouchPad or mouse to drag and delineate the 'OSD EXCLUSION AREA'. Click 'Calibrate Configuration'.



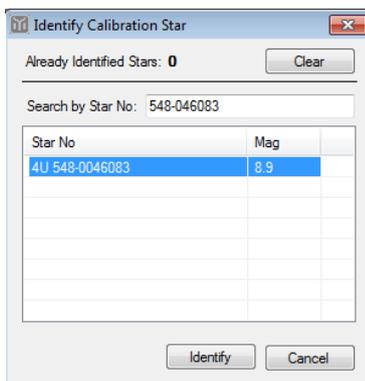
Refer to a planetarium program such as C2A or Guide and enter the approximate RA and Dec of the field centre, the month when the video was taken, the focal length (with reducer) and the approximate limiting magnitude. (It is recommended to select a faint magnitude, to allow Tangra to maximise its detection of field stars.) Click 'OK'. Tangra highlights crosshairs over the stars.



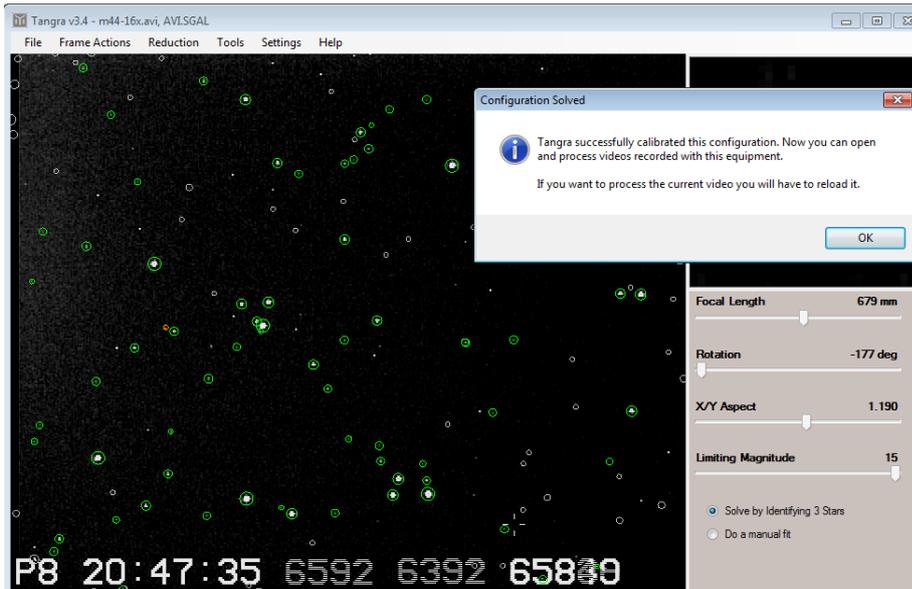
Clicking on a star brings up a list of possible candidates from UCAC4.



Clicking on the same star in C2A gives its UCAC4 data. Note its designation number.



If the UCAC4 entry says it is a 'clean' star click on its line in the candidate list displayed by Tangra and click 'Identify', then repeat the process for 2 other stars that are widely distributed across the FoV. If a chosen star is listed as 'poor astrometric result' or 'poor proper motion', select another calibration star with 'clean' status.

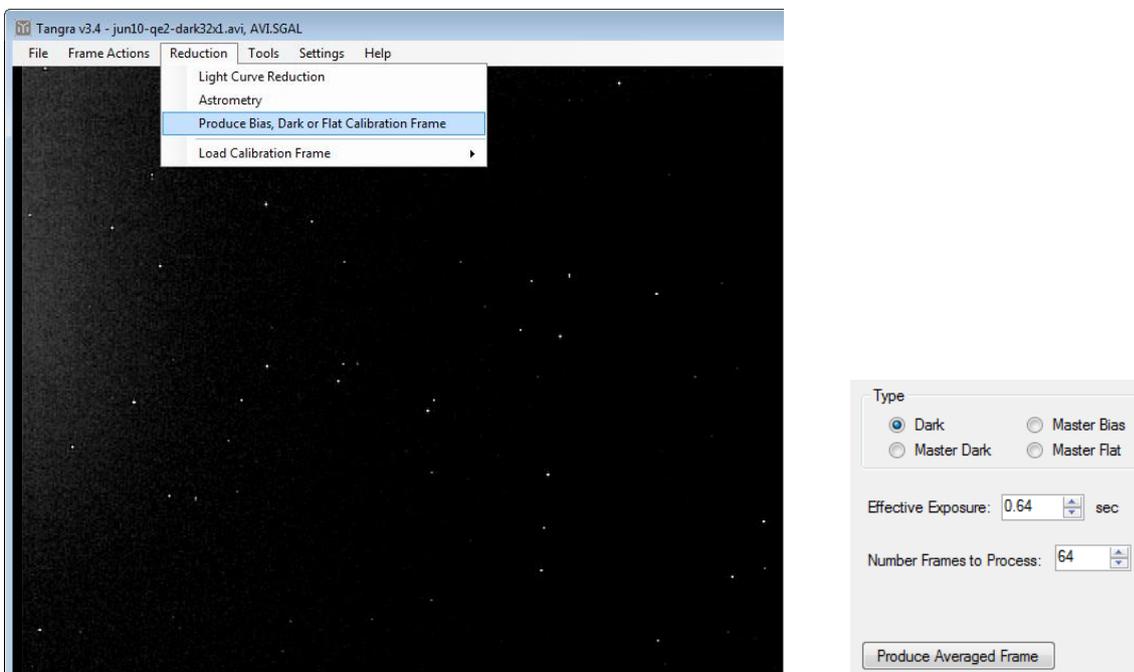


If Tangra successfully solves the field star registration and calibration it saves the new configuration for future use.

Reducing and measuring a video

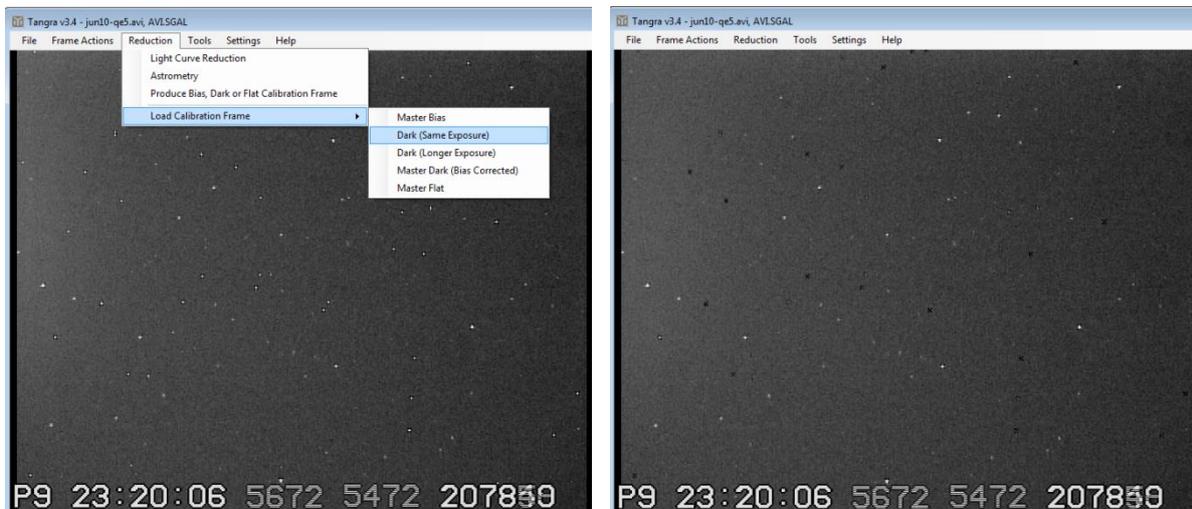
Once a specific configuration of telescope, optional focal reducer, capture device and camera has been calibrated and saved it can be used to analyse videos taken with the same setup.

The following steps describe the measurement of Near-Earth Asteroid (285263) 1998 QE₂ recorded during June 2013 with a 20cm f/10 SCT, f/3.3 focal reducer and Mintron video camera. Dark frame videos were also recorded each evening.



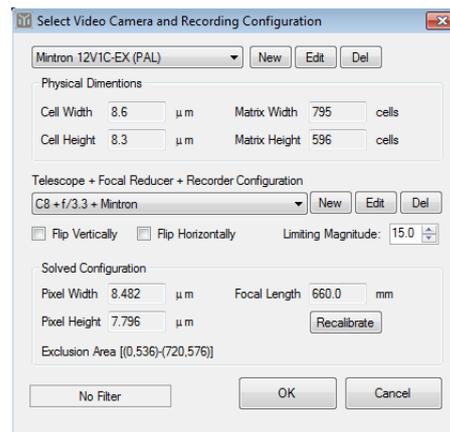
In Tangra, open the dark frame video. Click 'Reduction', 'Produce Bias, Dark or Flat Calibration Frame', 'Dark', enter the 'Effective Exposure' then click 'Produce Averaged Frame'. This creates a filename_Dark.fit file,

showing the hot pixels. (Note that when creating a 'Master Dark' it requires a bias frame). Repeat the process if a flat field video was recorded. (Not done for this example).



Open the video of 1998 QE₂. Click on 'Reduction', 'Load Calibration Frame', 'Dark (Same Exposure)', and select the 'dark frame' FIT file created previously. This will be subtracted from the video frames. If required, Select 'Reduction', 'Light Curve Reduction', 'Pre-Processing' to change the brightness and contrast, although this will affect the photometric calibration.

Click on 'Reduction', 'Astrometry'. Tangra opens the 'Select Video Camera and Recording Configuration' window.

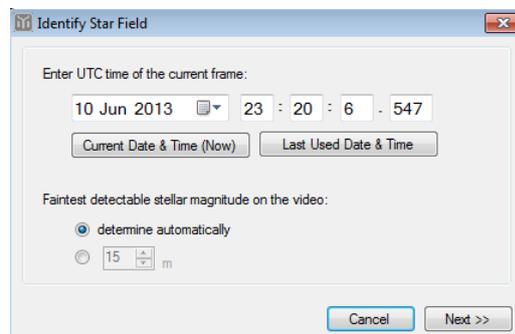


Select and confirm the camera configuration. In this case click 'OK' to use the 'C8 + f/3.3 + Mintron' saved configuration.

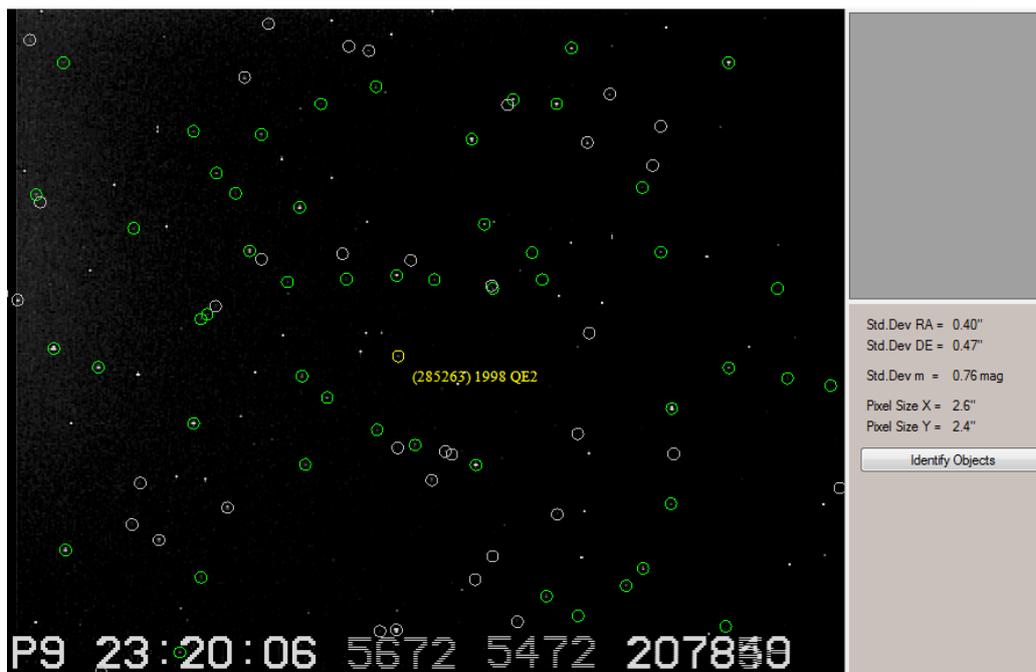
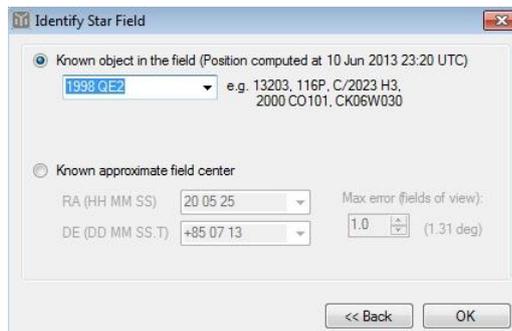
Enter the date and time of the current video frame.

Click 'Next >>'.

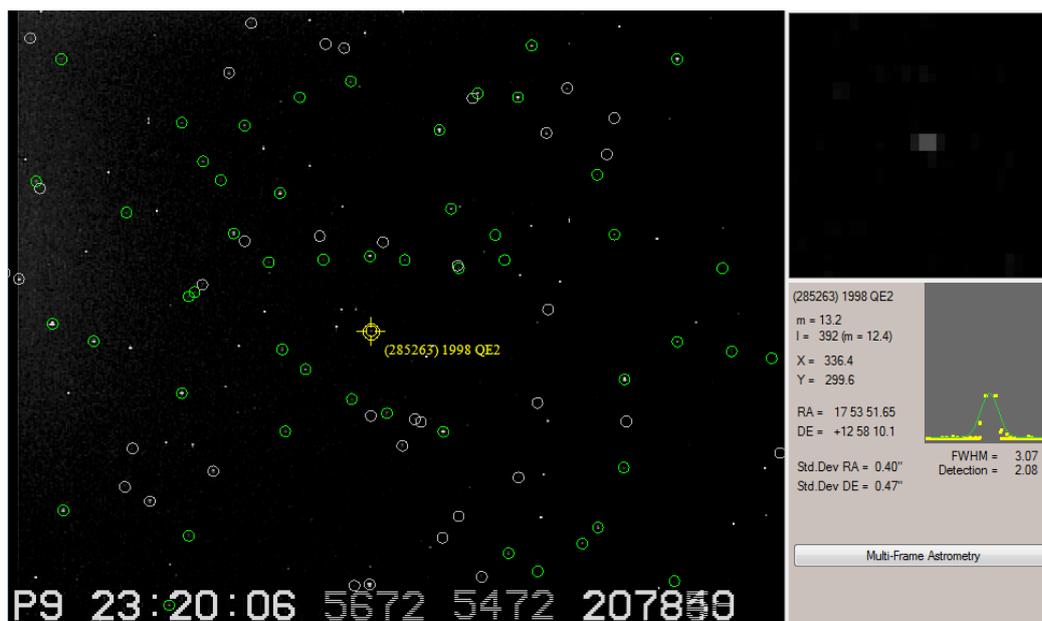
Note that the value of '547' ms was entered, taken from the VTI OSD data line '23:20:06 5672 5472'. The IOTA-VTI writes a timestamp at the end of each 'odd' and 'even' video field (PAL format of 50 per second). These are interlaced to form a video frame (25 per second). The timestamps of these fields are not always displayed in left to right order, so note the earlier of the times, which gives the end of the first video field, i.e. the mid-point of the video frame. (If a different model of VTI is used the owner must ascertain when it writes its timestamps.)



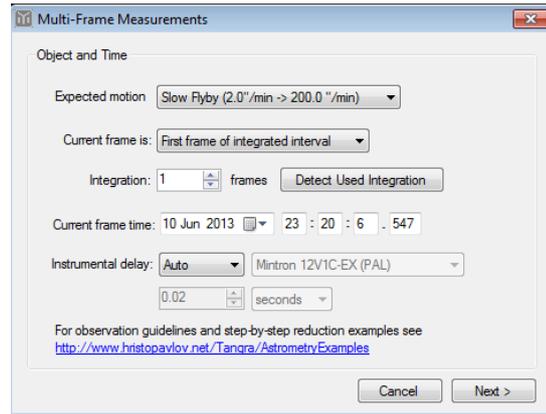
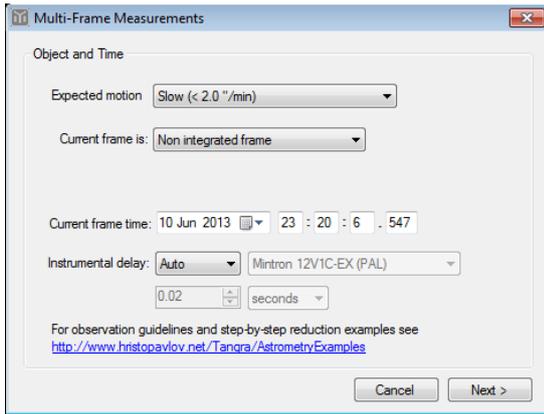
Identify the target object, either by its name or the RA and Dec of the field centre given by C2A or Guide. In this case enter '1998 QE2' and click 'OK'.



Tangra now links online to the MPC and checks for known objects in the FoV. If successful, it highlights the target object, i.e. '(285263) 1998 QE2'. (Tangra may also list other bodies, which can be analysed separately).

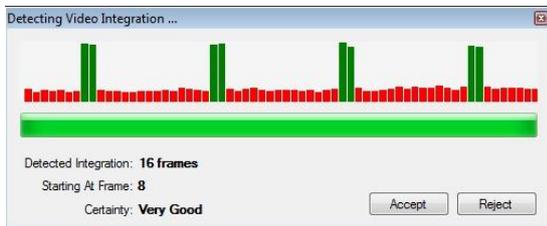


Click on the target object to be measured, then click 'Multi-Frame Astrometry'.

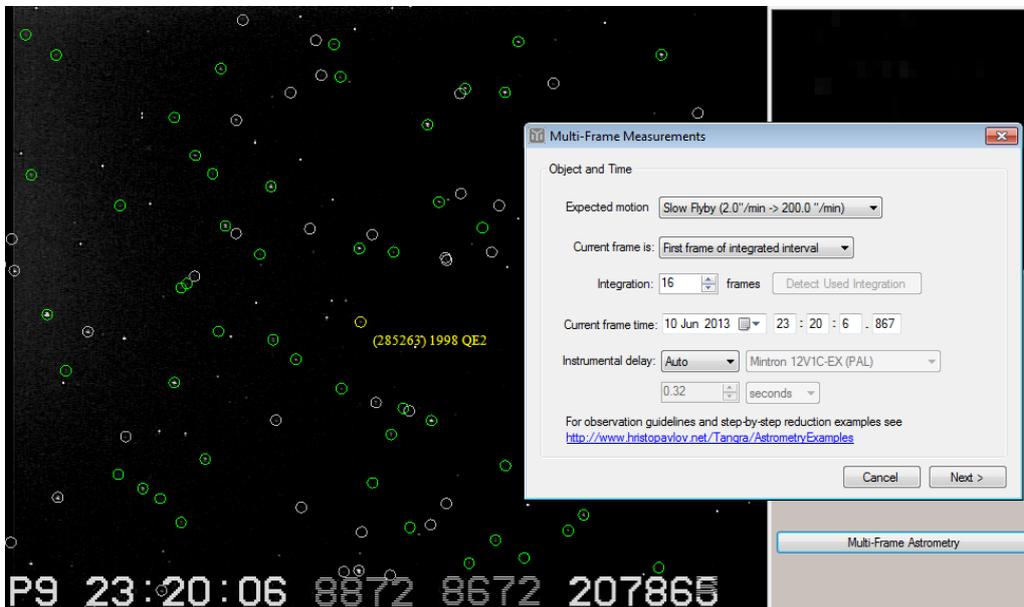


From the 'Expected motion' pick list select the range of sky motion of the object, as previously noted from the MPC MPES. In this case it is 5.9"/min, so select 'Slow Flyby (2.0"/min -> 200.0"/min)'.

From the 'Current frame is' pick list select 'First frame of integrated interval'. Click on 'Detect Used Integration'.



Tangra auto-detects the video integration. This should match the camera setting used, then click 'Accept'.

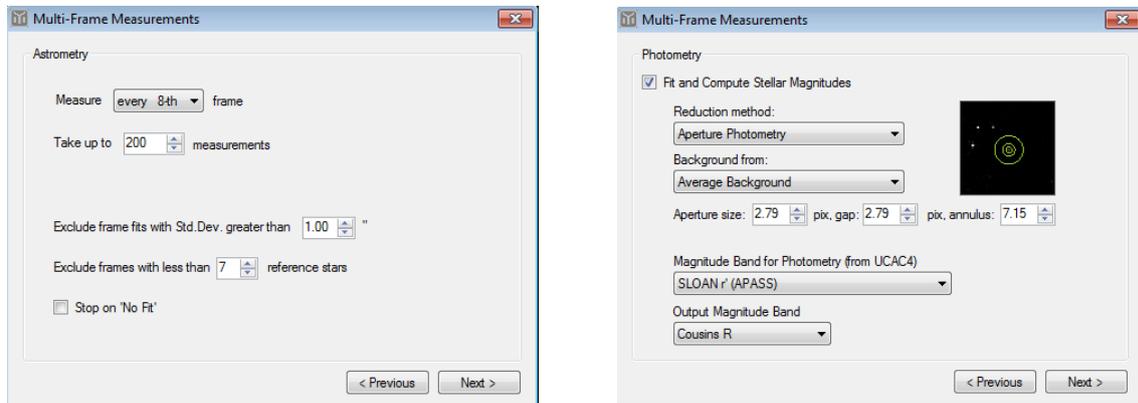


Tangra moves through the video to the start of the next integration interval. This is displayed on the 'Current frame time', now '867' ms (above) and on the main screen. Click 'Next >'.

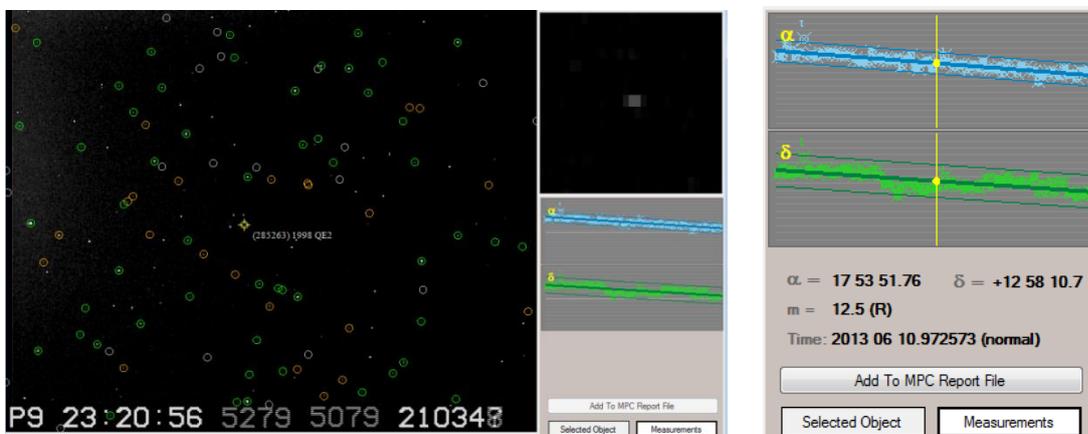
Note that the 'Instrumental delay' is set to 'Auto', which applies an automatic correction of 0.32s. Selecting 'Manual' offers options to change the camera model and the correction value. When integrating a number of frames it is necessary to correct for an Instrumental delay, so that the mid-integration time is used. Gerhard

Dangl has performed a thorough analysis of commonly used video cameras and he has provided tables of the instrumental delay measured at various integrations http://www.dangl.at/ausruest/vid_tim/vid_tim1.htm

The Mintron camera was set to integrate 16 PAL frames (0.64s), for which Gerhard gives an instrumental delay of 8 frames (0.32s). (This is exactly half the integration value *in this case*, but his work has shown that each specific instance of camera model and integration setting must be checked against his tables.) Tangra can apply these corrections automatically.



Select how often to measure frames, e.g. 'every 8th' and if desired change the Std. Dev. frame exclusion limit and reference stars lower limit. Click 'Next >'. As well as astrometric measurements Tangra can estimate the object's magnitude. This example uses Magnitude Band 'SLOAN r (APASS)' with Output 'Cousins R'. Click 'Next >' to proceed.



Tangra reads the video and 'plate solves' each selected frame. It plots the measurements of RA and Dec and fits lines through the data. (Motion in RA and Dec is assumed to be linear over the duration of the recording).

When clicking on a point on the graph Tangra locates the 'normal' time instant closest to the selected point and gives its time, its motion-fitted RA and Dec, and estimated magnitude (if photometry was selected). Normal positions are interpolated positions at integral micro-days - the time corresponding to a value in days with 6 significant decimal places followed by zeros. This provides extended precision for measurements obtained from GPS-tagged videos. The standard 6 decimal places time format - where the GPS time is truncated or rounded to the 6th decimal place - could introduce large errors for fast-moving objects.

Results can be added to an MPC Report File by clicking on that option. Up to 5 measurements were taken from each 60s video.

```

COD Z92
OBS A. R. Pratt
MEA A. R. Pratt
TEL 0.20-m f/10.0 Schmidt-Cassegrain + CCD + f/3.3 focal reducer
NET UCAC4
NUM 5
S5263      n2013 06 10.97227917 53 51.62 +12 58 08.8      12.7 R      Z92
S5263      n2013 06 10.97247617 53 51.71 +12 58 09.9      12.7 R      Z92
S5263      n2013 06 10.97267417 53 51.81 +12 58 11.1      12.7 R      Z92
S5263      n2013 06 10.97284917 53 51.89 +12 58 12.1      12.7 R      Z92
S5263      n2013 06 10.97301517 53 51.97 +12 58 13.0      12.7 R      Z92

```

Example from 'Add to MPC Report File'. (The line 'NUM 5' was added manually – this is not an MPC required line and so is optional).

```

20130610 Z92 0.2- 0.6-
20130610 Z92 0.3- 0.4-
20130610 Z92 0.2- 0.2-
20130610 Z92 0.2- 0.1-
20130610 Z92 0.2- 0.0

```

O-C residuals for the above observations, listed by the MPC MPES.

During 2013 June, 80 measurements of (285263) 1998 QE₂ were submitted to the MPC. From using the MPES options 'MPC 8-line' and 'Show residuals blocks' for Observatory Code Z92 the following average offset residuals and standard deviations in arcseconds were derived (2015 June):-

```

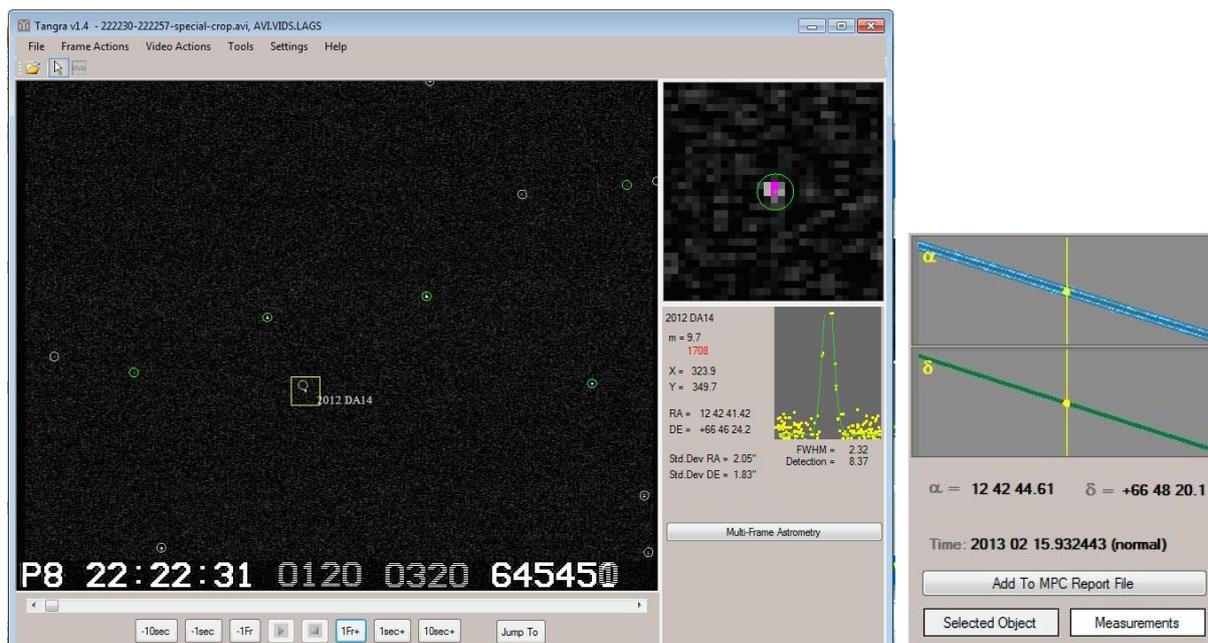
RA          Dec
-0.26 +/- 0.13  -0.25 +/- 0.19

```

The fast flyby of the Near-Earth Asteroid (367943) Duende = 2012 DA₁₄

On 2013 February 15 the 30-metre wide asteroid 2012 DA₁₄ made a record close approach to the Earth, passing much nearer to us than our Moon. Its path took it into evening skies as seen from the UK. It was then magnitude 8, with a sky motion >2000"/min, slowing as it moved north. Such rapid movement made the measuring of its position by standard CCD astrometry a difficult task.

The inclement weather hindered observations, but recordings of 2012 DA₁₄ were taken with a 102mm f/8 apochromatic refractor, f/6 focal reducer and Mintron video camera, working at X2 (25 fps) mode.



The video rate of 25 fps and lack of bright stars in the FoV resulted in few reference stars.

The videos were recorded, reduced and measured (with Tangra 1.4) as described above, except that an 'Expected motion' setting of 'Fast Flyby > 200.0" / min' was used because of the asteroid's rapid sky motion of 590"/min, almost exclusively in declination. This was equivalent to 10"/sec, i.e. 0.4"/video frame (PAL). The setting 'Non integrated frame' was selected, with an 'Instrumental delay' of 0.5 frames. The refractor gave sharp images and a flat FoV; good motion-fitting was achieved.

In total, 84 measurements of (367943) Duende were submitted to the MPC, with MPES (2015 June) giving the following average offset residuals and standard deviations in arcseconds:-

RA **Dec**
 -0.22 +/- 0.07 -0.29 +/- 0.28

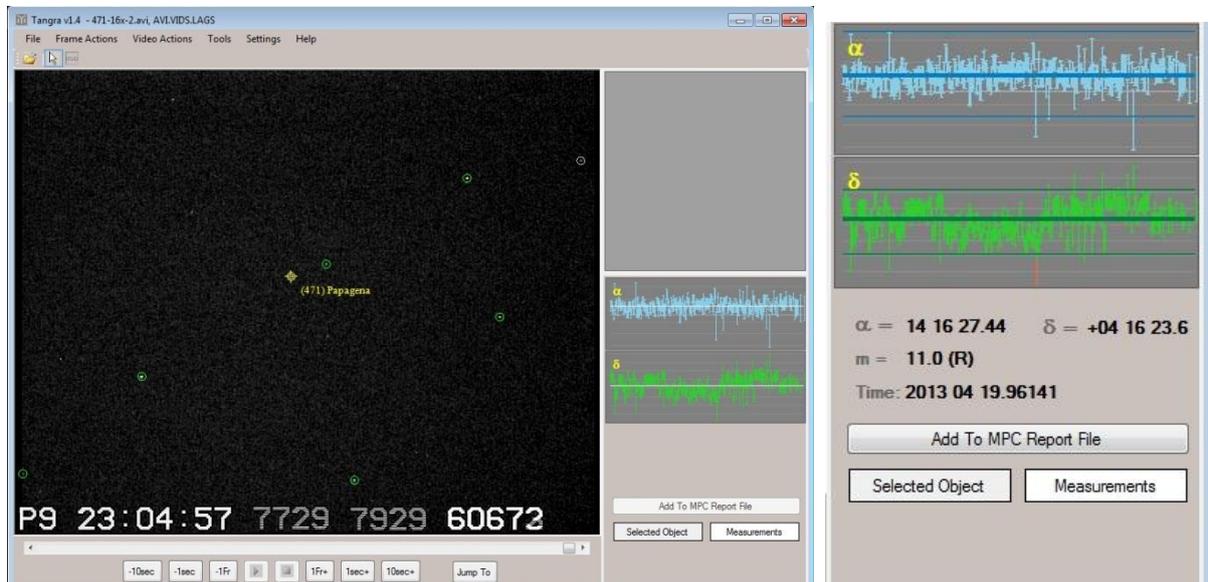
Video astrometry of slow-moving objects

Having successfully recorded and measured the fast flyby of (367943) Duende, the observations could not be immediately submitted to the MPC. Their Guide to Minor Body Astrometry:-

<http://www.minorplanetcenter.net/iau/info/Astrometry.html>

says that budding astrometrists should not start by observing fast-moving objects, especially without first obtaining an MPC Observatory Code. This is achieved by submitting good quality measurements of slow-moving main belt asteroids with O-C residuals consistently <1".

Using the 'What's observable' applet on the British Astronomical Association's Computing Section website, developed by Graham Relf http://britastro.org/computing/applets_planets.html a couple of main belt asteroids were selected that would be favourably placed over the next few months, i.e. (471) Papagena and (739) Mandeville. Due to the inclement UK weather it took a few weeks to capture the recordings.



The videos were recorded with a 20cm SCT, and analysed and measured with Tangra 1.4. An 'Expected motion' setting of 'Slow < 2.0" / min' was used, because the MPC MPES listed the asteroids' sky motions as 0.5"/min.

Unlike the previous examples, Tangra was now analysing slow moving objects and not applying motion-fitting. Clicking separately on the RA and Dec graphs selected the individual RA and Dec values most consistent with their median values from ~200+ measurements. Note that the time is given to 5 decimal places.

Each asteroid was measured on 3 nights, taking 2 measurements per night, 30 minutes apart. These were submitted as 'COD XXX'. A week later an e-mail was received from the MPC: **"Your site is now code Z92"**.

The MPES O-C residuals (2015 June) give the following average offsets and standard deviations in arcseconds:-

	RA	Dec
(471) Papagena	0.00 +/- 0.18	0.03 +/- 0.26
(739) Mandeville	-0.02 +/- 0.56	-0.33 +/- 0.60

Comet C/2014 E2 (Jacques)

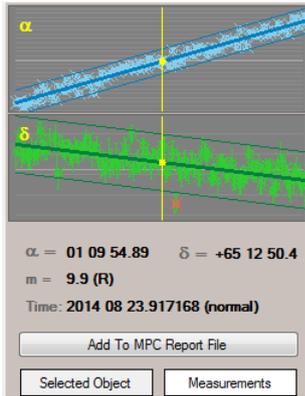
Tangra can also be used for astrometry of comets. For example, on the night of 2014 August 23 a series of 1-minute videos, recorded 30 minutes apart, were made of comet C/2014 E2 (Jacques).



The comet was well condensed, ideal for good astrometry.



C/2014 E2 had a sky motion of 8"/min so the measurements were performed using the 'Slow Flyby' setting.

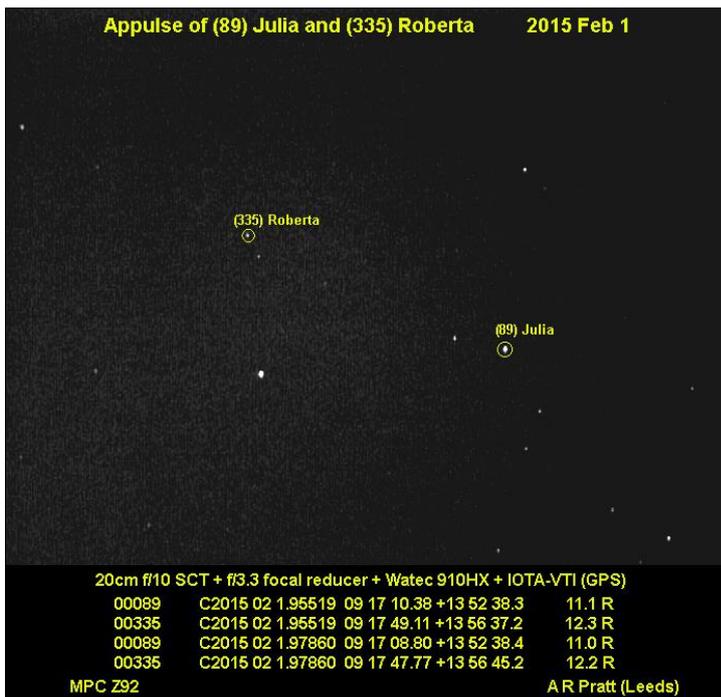


CK14E020	n2014	08	23.91716801	09	54.89	+65	12	50.4	9.9	R	Z92
CK14E020	n2014	08	23.93780501	09	17.43	+65	13	31.1	9.9	R	Z92
CK14E020	n2014	08	23.95848401	08	39.81	+65	14	10.9	9.9	R	Z92
CK14E020	n2014	08	23.97926301	08	01.94	+65	14	50.7	10.2	R	Z92

Model Fit Magnitude (fMag) was used for photometry. Because Tangra doesn't know it is processing a comet it is necessary to change column 71 to N (nuclear magnitude) before submitting the results to the MPC.

Asteroidal appulses

The BAA Computing Section website maintains a list of close appulses between asteroids brighter than magnitude 15 http://britastro.org/computing/charts_appulse.html This has been used to obtain astrometry of some asteroid pairings, e.g. (89) Julia and (335) Roberta on 2015 February 1.



The asteroids were analysed individually using the 'Slow < 2.0" / min' setting.

Bias, Darks and Flats

Tangra supports bias and dark frames and flat fields, created from short videos. Good astrometry can be achieved without dark frame and flat field calibration, although applying a dark frame is recommended because it removes hot pixels that could affect the 'plate solve' process.

Hristo Pavlov recommends the following guidelines:-

The dark-flat-bias calibration is important for accurate photometry but is not essential for astrometry. With 8-bit videos, incorrectly acquiring or applying the calibration frames could degrade the PSF of the stars and could make the measurements less accurate, because a good PSF shape profile is needed for good pin-pointing.

A bias video is not required if the dark has the same exposure as the main video. In that case, subtracting the "Dark (Same Exposure)" in Tangra will effectively correct for both dark current and bias at the same time.

When recording a flat field video, adjust the exposure and gain settings so that the background intensity is roughly half of the full well depth (i.e. it should not be too dark and not too bright).

Take a dark frame video for the flat field with the same gain and exposure as the flat. Subtract this dark from the flat to produce a master flat.

Don't forget to reset the exposure and gain back to their settings used for the astrometry video.

Using pre-processing such as brightness/contrast corrections will affect any photometric calibration done with dark/flat field corrections.

In summary

Given the relatively small size and sensitivity of CCD chips used in present-day video cameras - that are affordable to the amateur - it is recommended to use unfiltered fast focal ratio optics to achieve a good signal to noise ratio and to maximise the number of reference stars.

Video astrometry has advantages and disadvantages in comparison with standard CCD astrometry.

Pros

Slow-moving objects – astrometry from the median value of hundreds of frames

Fast-moving objects – astrometry from motion-fitting GPS-timestamped frames

Can produce O-C residuals $<1''$ in both cases

Cons

Photometry is limited to 8 bits (video camera output) for most cameras

Long video integrations and/or a large telescope are needed to record faint objects

Future developments

New high-sensitivity video cameras, such as the Watec 910, improve the video limiting magnitude, increasing the number of reference stars and the signal to noise ratio of the target object.

A video camera with a larger well depth, such as 12, 14 or 16-bits would give better photometry.

OccuRec <http://www.hristopavlov.net/OccuRec/> was not used for the examples in this guide, although the author is testing it with various USB frame grabbers. Hristo Pavlov has performed asteroidal astrometry using OccuRec.

Tangra Yahoo Group

Users of Tangra are recommended to join its Yahoo Group:- <http://tech.groups.yahoo.com/group/Tangra/>

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Alex R Pratt MPC Z92

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