Rappahannock Astronomy Club

March 14, 2012 Presentation

PHOTOMETRY AND ASTROMETRY FOR THE AMATEUR ASTRONOMER

PRESENTED BY JERRY HUBBELL

Introduction to Photometry and Astrometry

This presentation will be divided into two parts:

Part I: Photometry

Part II: Astrometry

In each Part we will discuss the history and origins of each, 20th century work in this area by professionals and amateurs, and processes amateur astronomers use in the 21st century.

Introduction to Photometry and Astrometry

Additionally, a demonstration will be done at the end:

The photometry demonstration will show how an instrumental magnitude is determined for a star, and how that is transformed into a relative V-band measurement as compared to catalog star magnitudes.

The astrometry demonstration will show how the position of a minor planet is determined based on the catalog positions of the stars in the field of view using the USNO UCAC3 star catalog. Also a live demonstration of the Astrometry.net website will be performed.

Photometry – History and Origins

From 147 to 127 BC Hipparchos, a Greek astronomer, made observations and created a catalog of stellar positions of at least 850 stars. He also created the first magnitude system which ranked the stars into 6 magnitude classes.

The stars were assigned a magnitude of 1 through 6 with 1 being the brightest. This system was found to define a linear brightness range of 1 to 100 on a logarithmic (exponential) scale by English astronomer Norman Pogson in 1856.

Photometry – History and Origins

Since the brightness scale of 1 to 6 magnitude defines a range of 5 magnitudes, and the range of brightness, or brightness ratio is equal to 100 on a logarithmic scale, the following relationship was defined as a standard. This is a relative brightness scale:

$$5 \text{ mag} = -x (\log(100/1))$$

the x value is negative since the scale is inverted in that the brighter objects are a lower magnitude value

Photometry – History and Origins

$5/\log(100/1) = -x$
$\log(100/1) = 2$
$-5/2 = x$
$x = -2.5$

So, the Δ magnitude is equal to:

$\Delta mag = -2.5 \log(\text{Brightness Ratio})$

FYI – the difference between each magnitude is the “fifth root of 100” or $100^{1/5}$ (100 to the 1/5th power). This is equal to 2.512. So each magnitude star is 2.512 times brighter than the next higher magnitude.

Photometry in the 20th Century

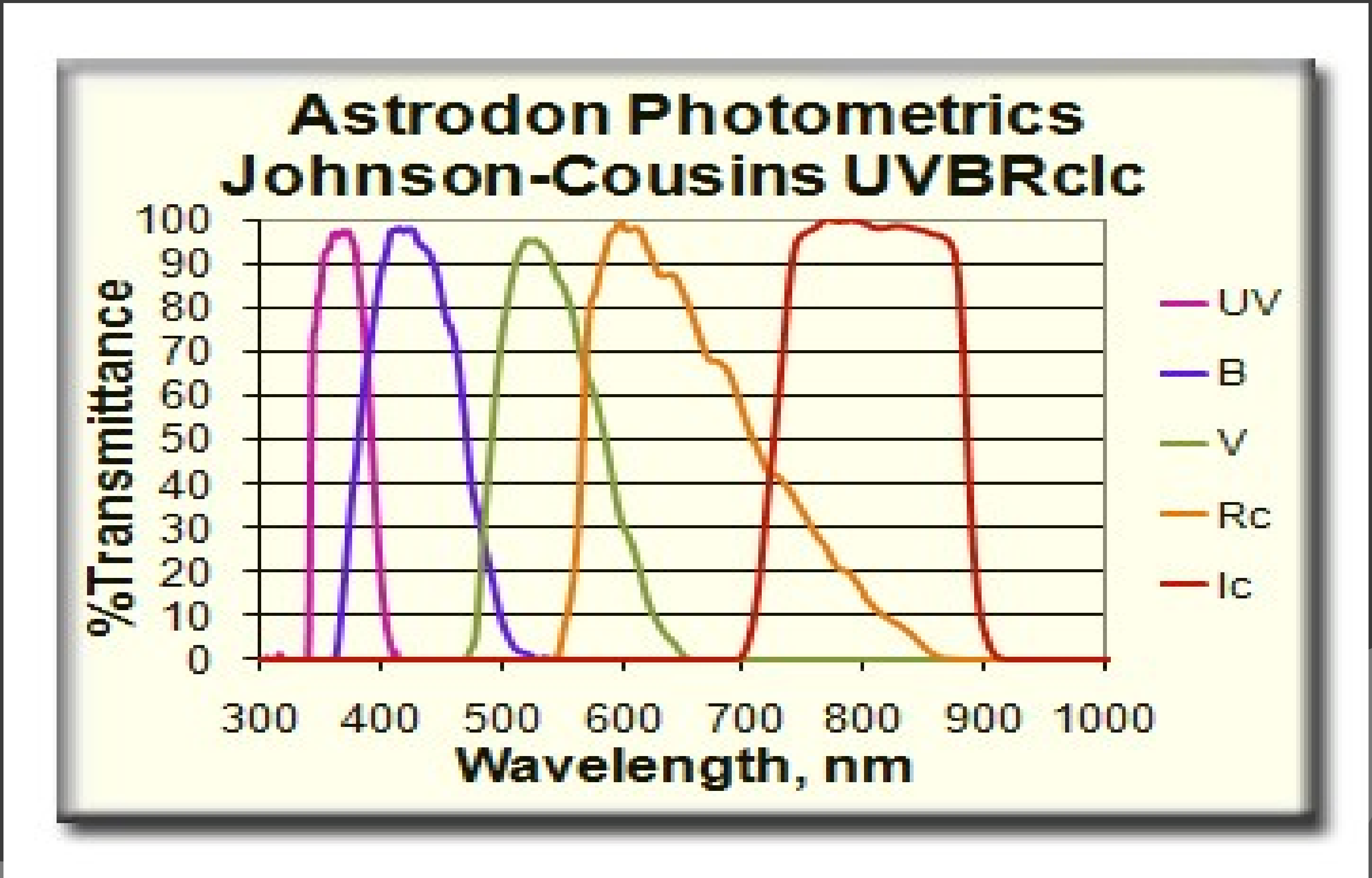
Definition:

Photometry is the relative measurement of the FLUX, or intensity of an astronomical object's electromagnetic radiation.

The FLUX measurements are done for various wavelength pass-bands using filters. The filters are designed to meet a given Standard called a Photometric System. Different Photometric Systems are available for use by the professional and amateur photometrist.

The most common Photometric System is the Johnson-Cousins UBVRcIc system developed in the 1970's.

Photometry in the 20th Century



Photometry in the 20th Century

In 1976 the Ultraviolet, Blue and Visual (UBV) photometric standard developed in 1953 by Johnson was extended by the work that astronomer Alan Cousins performed work in the Red and Infrared bands creating the RcIc standard and along with Johnson, created the UBVRcIc standard.

Photometry in the 20th Century

In 1992, astronomer Arlo Landolt published a list of photometric standard stars and their measured brightness in each of the UBVRcIc pass-bands for professionals and amateurs alike to use in calibrating their instruments. These are the standards used to make photometric measurements today.

Photometry in the 20th Century

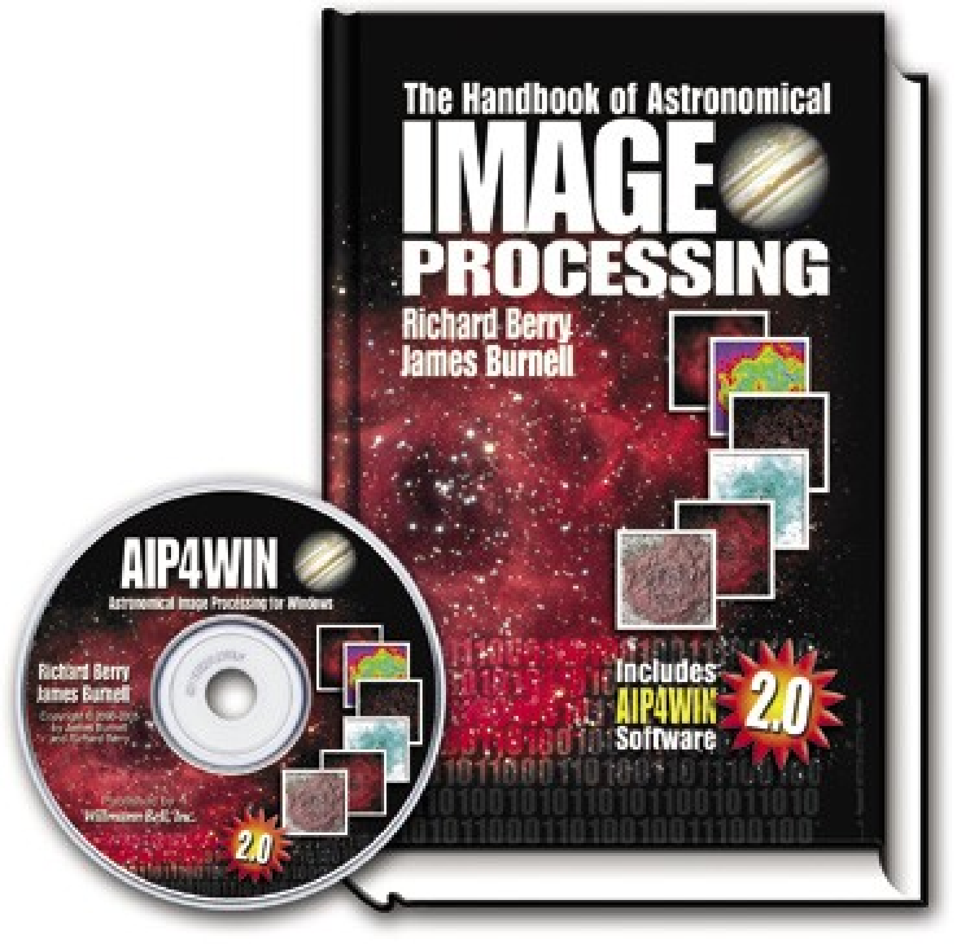
The most common pass-band used by amateur astronomers is the V-band. This band most closely matches the visual response of the eye and is used extensively by the members of the American Association of Variable Star Observers (AAVSO) when making comparisons of the visual observations of variable stars and the photometric measurements of these stars by instruments.

Photometry in the 20th Century

Amateur Photometry in the 21st Century

In the early 1990's, CCD photometric observations using small telescopes were pioneered by Richard Berry and James Burnell who eventually wrote a PC application (AIP4WIN) and a very successful book called "The Handbook of Astronomical Image Processing". This work introduced a large number of amateur astronomers to the world of photometry and astrometry.

Amateur Photometry in the 21st Century



Amateur Photometry in the 21st Century

In the past 10 years, amateur photometry has grown into a well developed process that practically anyone with a CCD camera a some basic software can learn to do. The basic photometry measurement process includes:

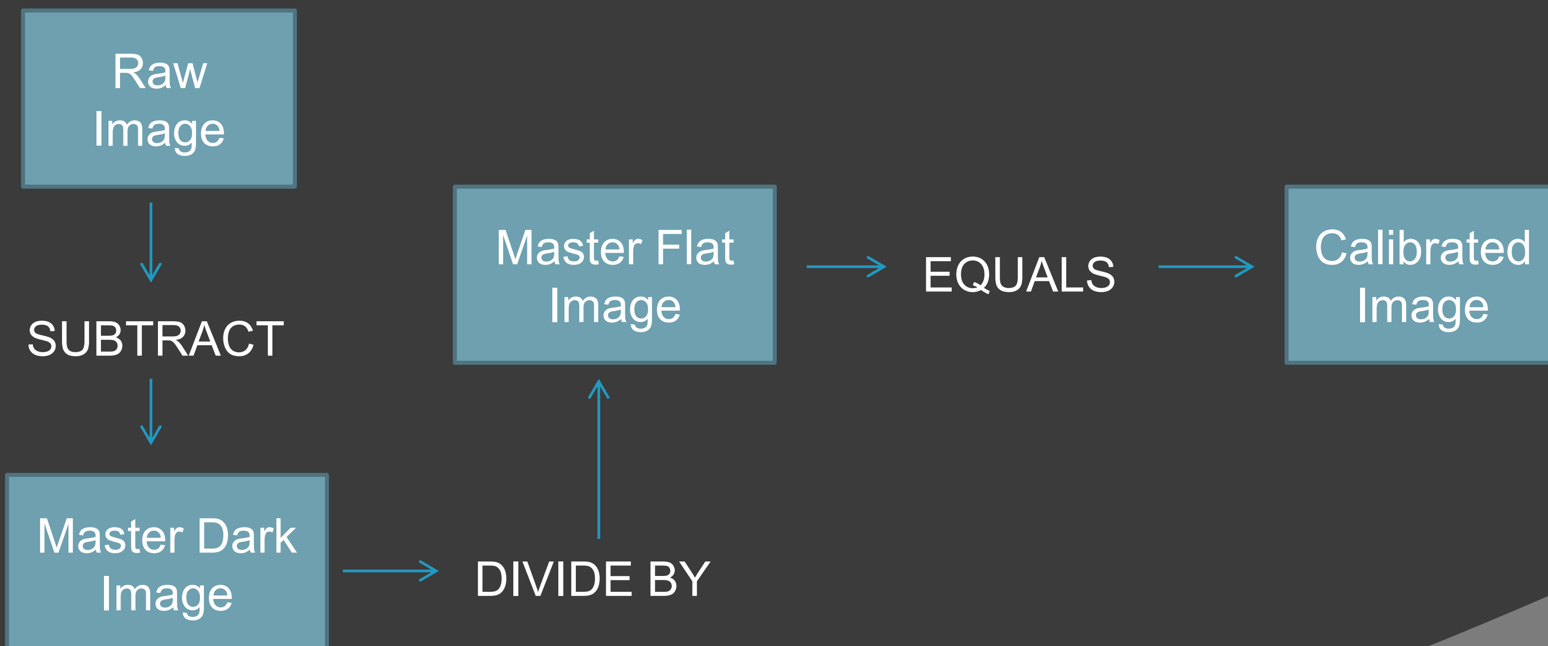
1. Acquire the raw CCD image data
2. Calibrate the raw image
3. Measure the brightness of each object under study
4. Calculate the instrumental magnitude and the relative magnitude of each object under study by comparing it to a reference object (star).

Amateur Photometry in the 21st Century

1. Acquire Raw Image Data (in V-band)

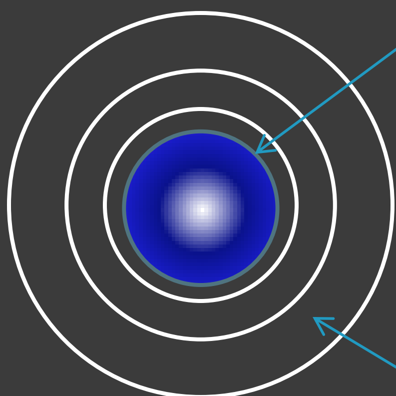
Amateur Photometry in the 21st Century

2. Calibrate the Raw Image



Amateur Photometry in the 21st Century

3. Measure the Brightness of the Object



Sum of Star Pixel values within Circle

SUBTRACT

Sum of Background Pixel values within Annulus

Sum of Only Star Pixels

Amateur Photometry in the 21st Century

4a. Calculate the Instrumental Magnitude of the Object under study

Using the sum of the values in Analog to Digital Units (ADUs) measured for each pixel in Step 3, calculate the Instrumental Magnitude:

Instrumental Mag = -2.5 log (ADU value)
= -2.5 log (3,348,326)
= -2.5 (6.525)
= -16.312 IMag

Amateur Photometry in the 21st Century

4b. Calculate the Relative Magnitude as compared to a Reference Star:

A Reference Star has been identified in the Field of View (FOV) of the object and its catalog magnitude is 12.41. A measurement was made and the sum of the values as determined by doing Step 3 was 4,682,394 ADUs.

First the magnitude difference between the reference star and the object star is determined:

$$\Delta m = -2.5 \log(\text{Reference} / \text{Object})$$
$$= -2.5 \log(4{,}682{,}394/3{,}348{,}326)$$
$$= -2.5 \log(1.39843)$$
$$= -0.364 \text{ mag}$$

Amateur Photometry in the 21st Century

4b (cont.)

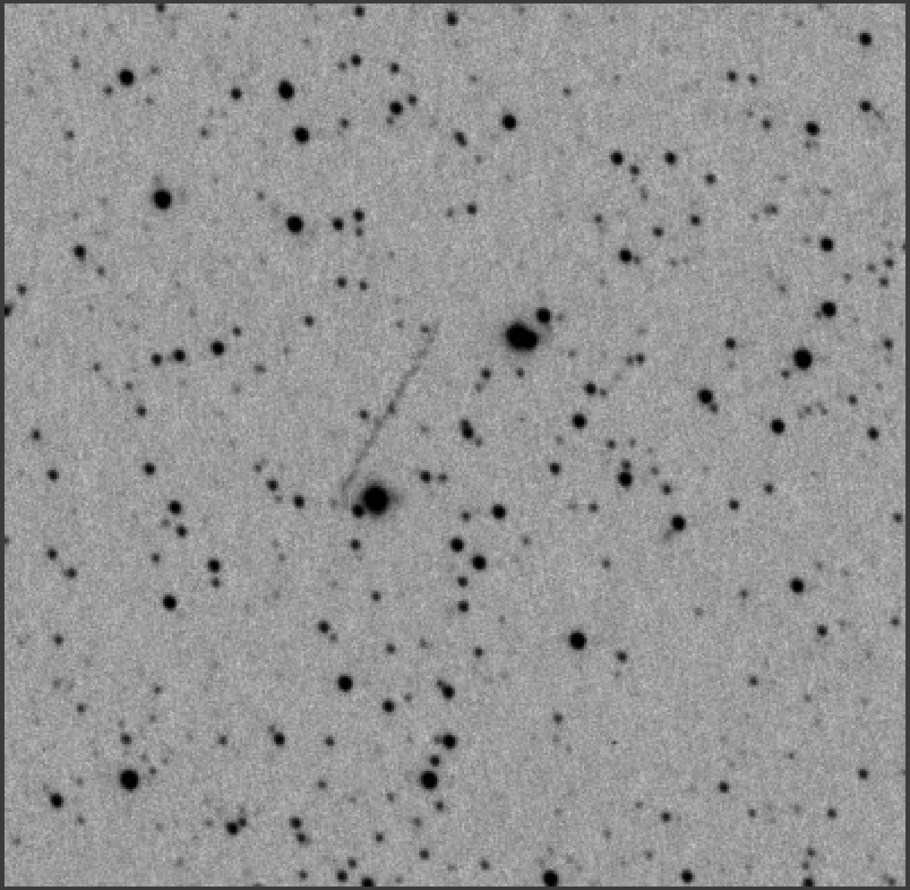
Then the relative magnitude is calculated:

The object under study magnitude is equal to the reference object magnitude minus the Δ magnitude difference:

Object mag = Ref mag – Δ mag
= 12.41 – (-0.364)
= 12.774 mag

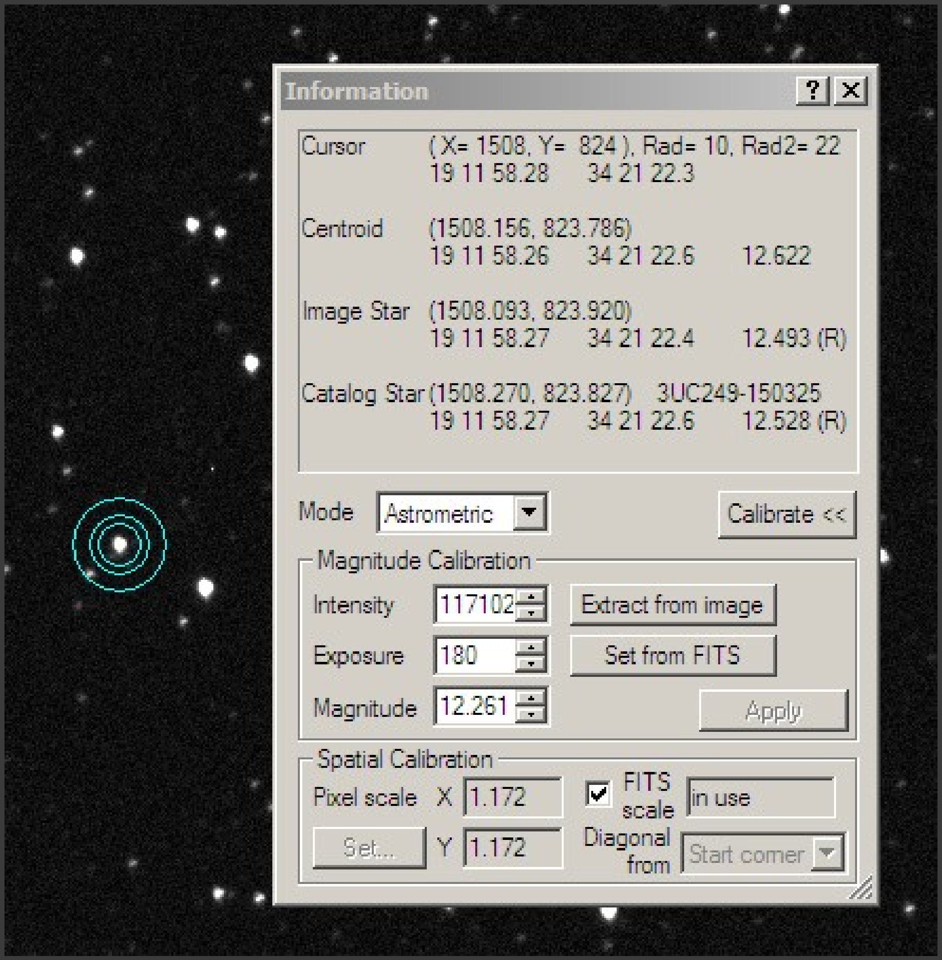
It is important to remember that the measurements for each star were taken from the SAME calibrated frame measured in the V photometric band. Also, this relative magnitude is NOT the same as the absolute magnitude because a Landolt Reference Star was NOT used.

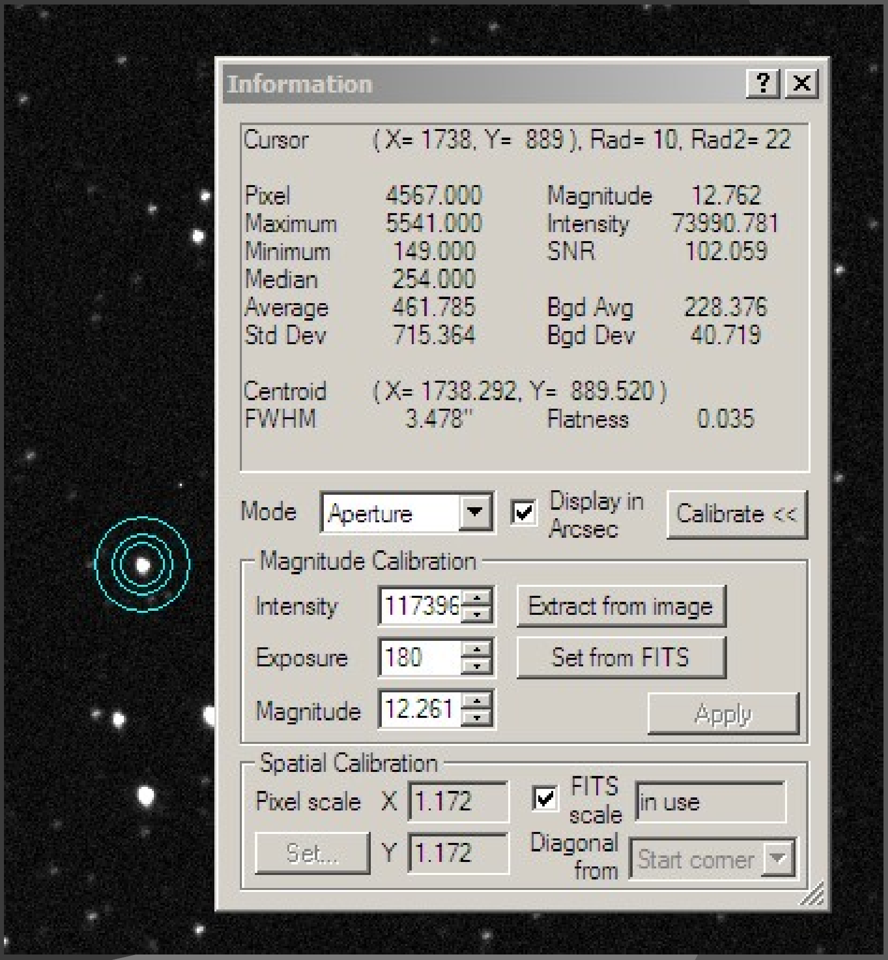
Amateur Photometry in the 21st Century



Minor Planet (68348) 2001 LO7

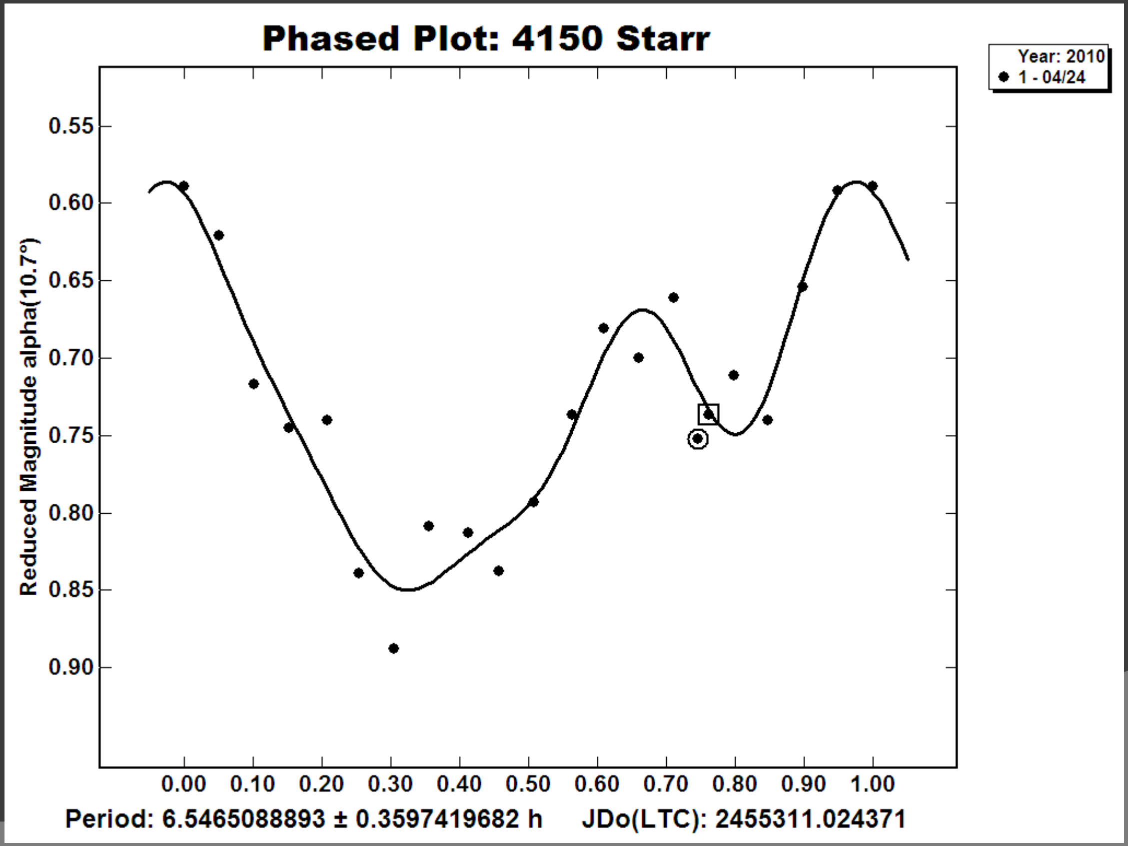
Amateur Photometry in the 21st Century





Amateur Photometry in the 21st Century

Differential Photometric Measurements of Minor Planet (4150) Starr using the Sierra Stars 0.61-m Astrograph 24 Apr 2010.



Astrometry – History and Origins

Around 190 BC Hipparchos used star catalogs created by his predecessors Timocharis and Aristillus giving him reference points in the sky. This was the first form of Astrometry or star position measurements. He used the stellar positions and his observations to discover the precession of the Earth's axis.

Astrometry – History and Origins

Astrometry is the precise measurement of the position and movement of stars and other bodies such as the Major, Dwarf, and Minor Planets. Several different types of information can be derived from the precise measurement of these celestial bodies. The position of these bodies is referenced to the Celestial Sphere based on a projection of the Earth’s coordinate system and rotational axis.

Astrometry – History and Origins

The celestial coordinate system is based on a projection of the Earth’s Longitude and Latitude coordinate system out into space. The Right Ascension is measured in Hours, Minutes, and Seconds and is a projection of the lines of Longitude. It is based on the rotation period of the Earth and is measured from 0 to 24 hours.

Astrometry – History and Origins

The Declination is measured in angular Degrees °, Minutes ‘, and Seconds “ and is a projection of the lines of Latitude. The Declination value is measured from the Celestial Equator at 0 degrees and goes North to 90 Degrees at the North Celestial Pole, and South to -90 Degrees at the South Celestial Pole.

Astrometry – History and Origins

Since all celestial bodies move, some just slower than others, the measurement of their position needs to be referenced to the time the measurement was taken. This time is called the Epoch.

For stars, the movement is called the Proper Motion. Knowing a stars celestial coordinates at a given Epoch and it’s proper motion allows you to calculate the stars celestial coordinates at any time in the future and past.

Astrometry – History and Origins

When star catalogs are created they are defined for a specific Epoch. Usually the standard Epoch for a catalog lasts for anywhere from 30 to 50 years. The star catalogs used today are referenced to and are calculated for the Epoch year 2000.0 (January 1, 2000 1200 hours UT, JD 2451545.0). The date chosen is usually used for a period both before and after the Epoch date. The current reference Epoch data is valid from 1975 to 2025.

Astrometry – History and Origins

So, there are different coordinates for the same object depending on the use. If you need to point a telescope at a star tonight, you need to calculate it’s coordinates for tonight. For example the brightest star in Ursa Major (α Uma) Dubhe, on 2012-03-13 01:16:03 UT has the coordinates:

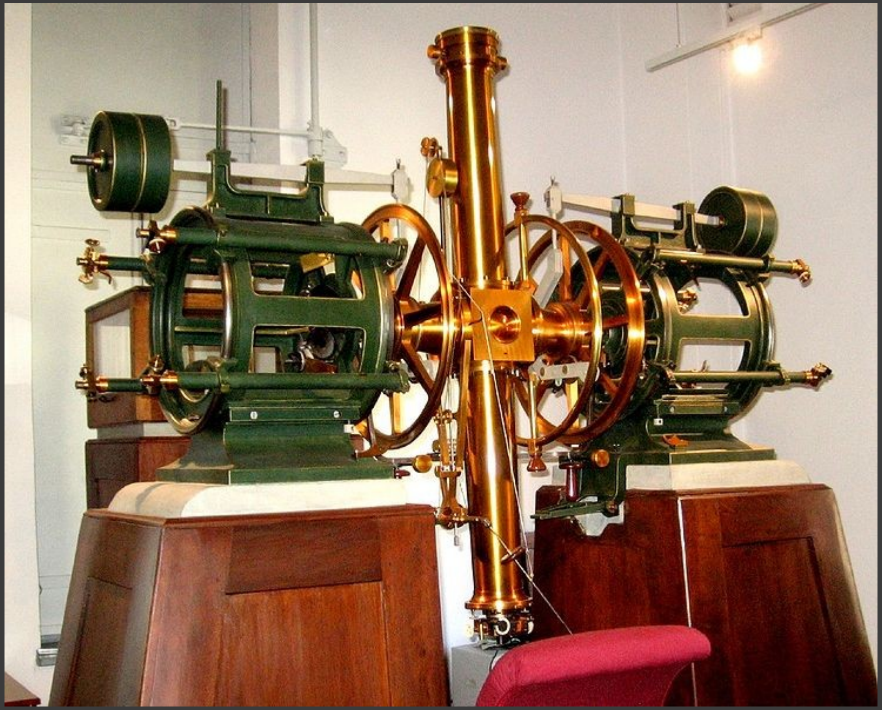
RA 11h 03m 31.846s, DE +61°41’04.97”.

The catalog coordinates for Epoch 2000.0 (used in astrometric measurements) is:

RA 11h 03m 43.494s, DE +61°45’02.17”

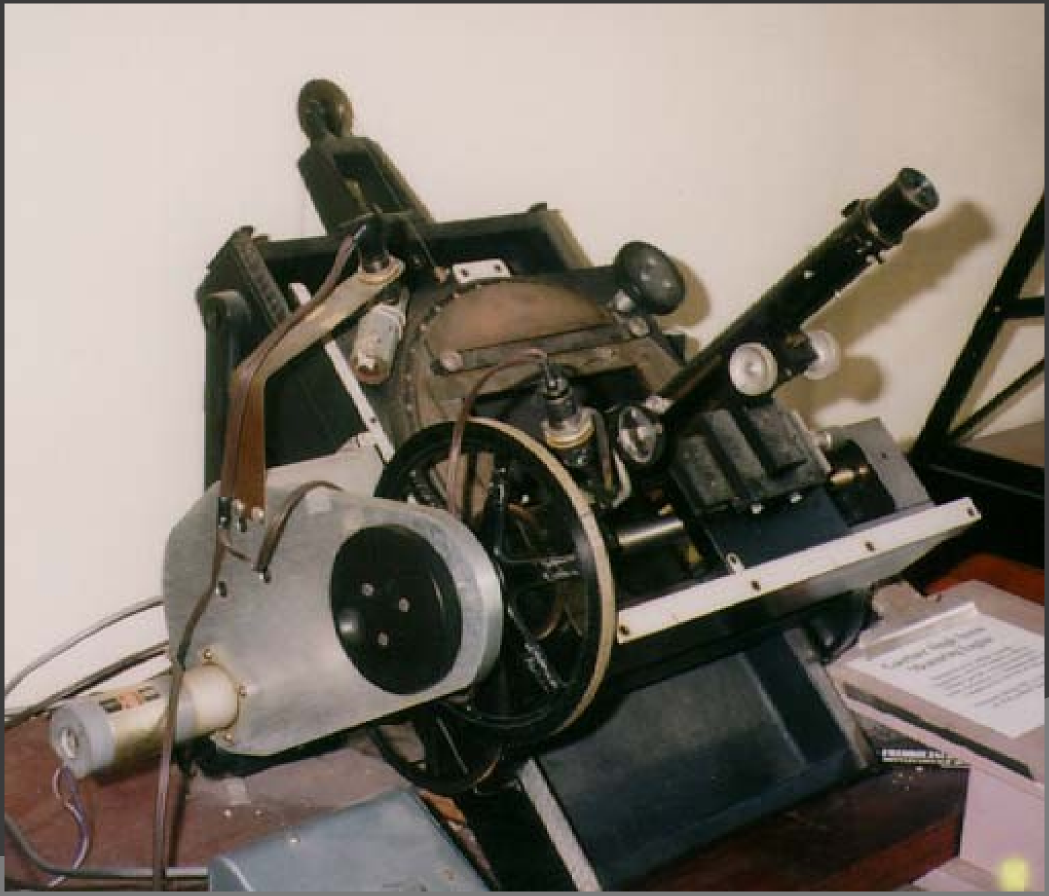
Astrometry in the 20th Century

In the pre-photography era, there were several methods used to measure star position. The main instrument used is called the meridian circle, transit circle, or transit telescope.(wikipedia.org)



Astrometry in the 20th Century

Measuring engines were used on glass photographic plates to measure the x, y position of the stellar objects appearing on the plate. (UVA Leander McCormick Observatory)

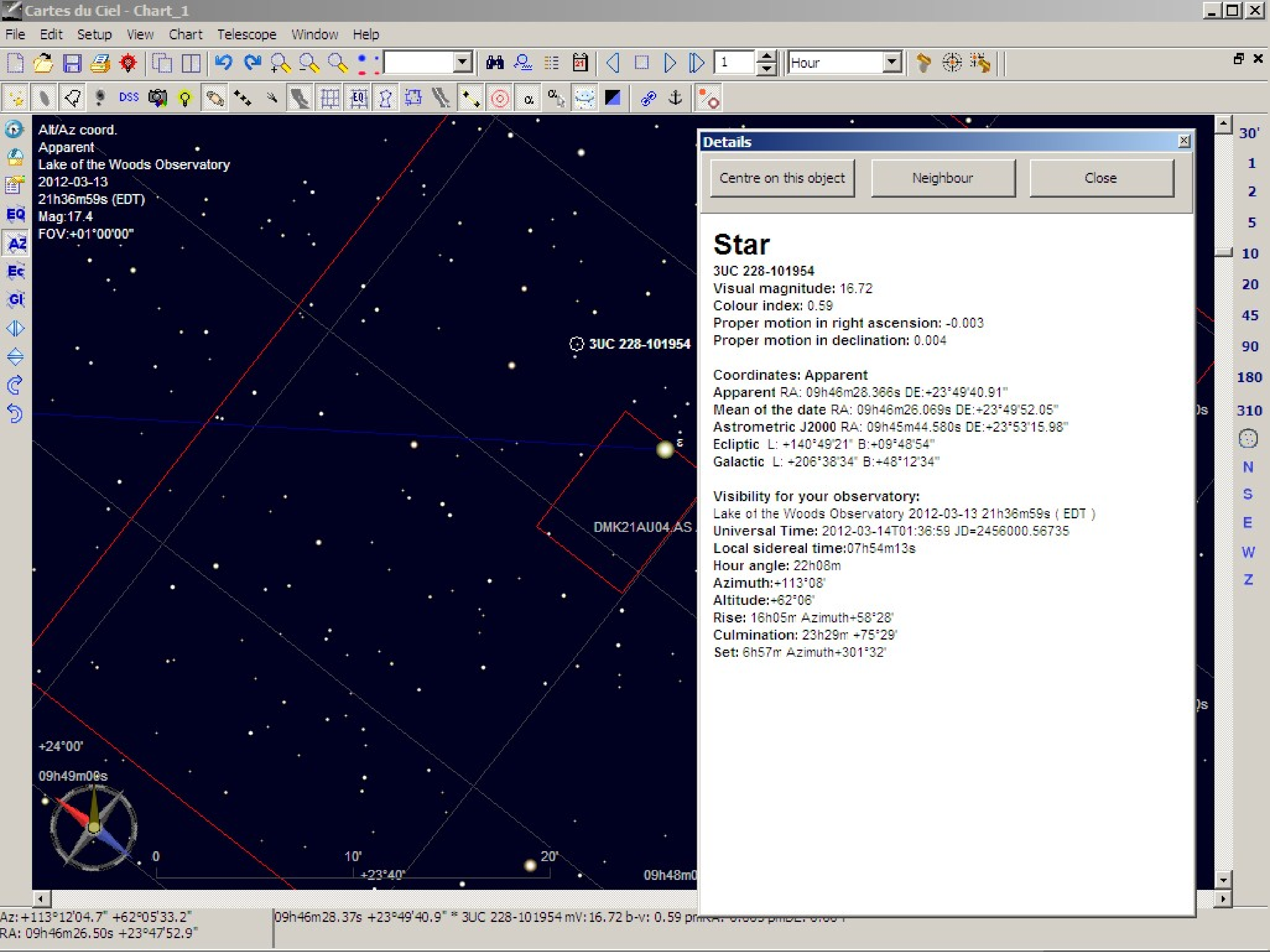


Amateur Astrometry in the 21st Century

Today amateur's use professional level star catalogs to provide reference positions for measuring their images. The United States Naval Observatory has issued several catalogs. One of the most accurate (to within 10's of milli-arcsec) which also provides very accurate proper motion data for each object is the UCAC (USNO CCD Astrograph Catalog) series of catalogs.

Amateur Astrometry in the 21st Century

The UCAC catalogs are available via DVD and are used by planetarium programs to plot stellar objects down to 18th magnitude. This catalog provides very accurate reference positions for astrometric measurements of minor planets, comets, and other moving bodies.


Cartes du Ciel - Chart_1
File Edit Setup View Chart Telescope Window Help
Hour
Alt/Az coord.
Apparent
Lake of the Woods Observatory
2012-03-13
21h36m59s (EDT)
Mag:17.4
FOV:+01°00'00"
3UC 228-101954
DMK21AU04.AS
+24°00'
09h49m00s
0
10'
20'
+23°40'
09h48m0
30'
1
2
5
10
20
45
90
180
310
N
S
E
W
Z
Details
Centre on this object
Neighbour
Close
Star
3UC 228-101954
Visual magnitude: 16.72
Colour index: 0.59
Proper motion in right ascension: -0.003
Proper motion in declination: 0.004
Coordinates: Apparent
Apparent RA: 09h46m28.366s DE:+23°49'40.91"
Mean of the date RA: 09h46m26.069s DE:+23°49'52.05"
Astrometric J2000 RA: 09h45m44.580s DE:+23°53'15.98"
Ecliptic L: +140°49'21" B:+09°48'54"
Galactic L: +206°38'34" B:+48°12'34"
Visibility for your observatory:
Lake of the Woods Observatory 2012-03-13 21h36m59s (EDT)
Universal Time: 2012-03-14T01:36:59 JD=2456000.56735
Local sidereal time:07h54m13s
Hour angle: 22h08m
Azimuth:+113°08'
Altitude:+62°06'
Rise: 16h05m Azimuth+58°28'
Culmination: 23h29m +75°29'
Set: 6h57m Azimuth+301°32'
Az:+113°12'04.7" +62°05'33.2"
RA: 09h46m26.50s +23°47'52.9"
09h46m28.37s +23°49'40.9" * 3UC 228-101954 mV:16.72 b-v: 0.59

Amateur Astrometry in the 21^{st} Century

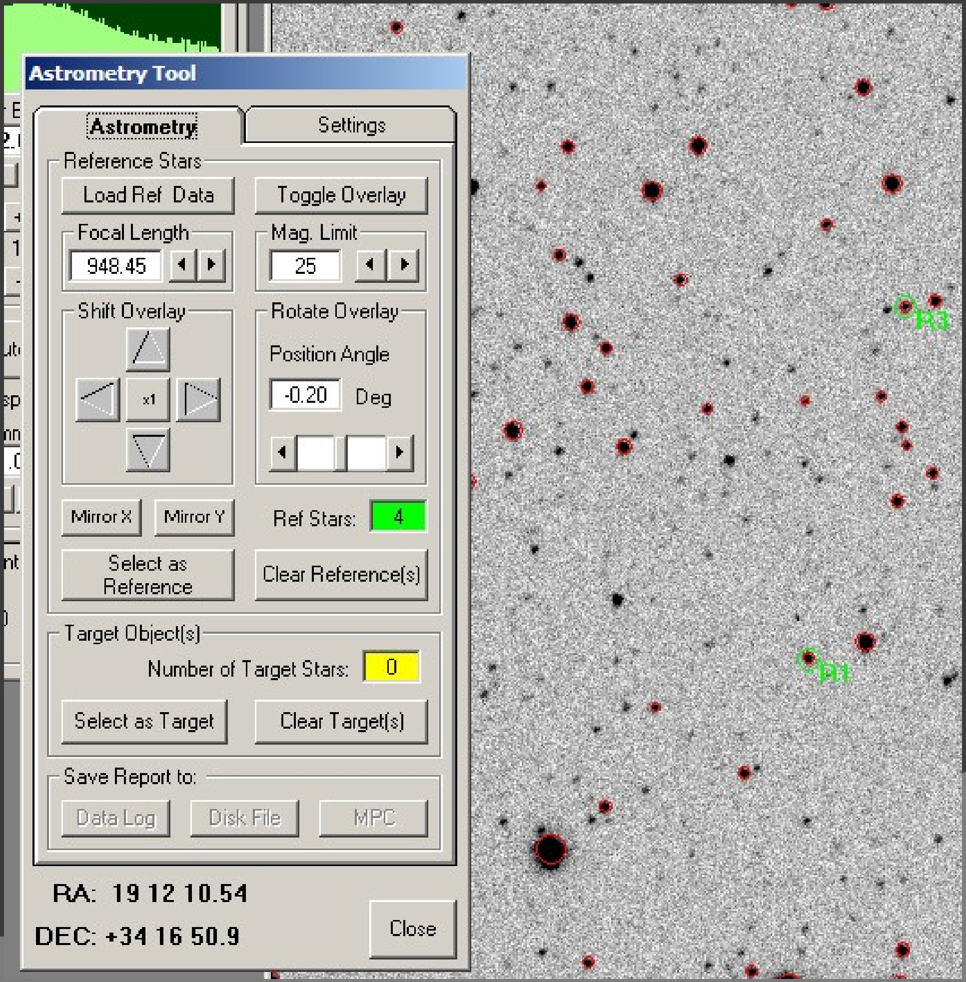
Images acquired by amateurs are astrometrically calibrated or measured by digitally overlaying the catalog stars onto the image and then scaling (sizing) the image and rotating it to match the configuration of stars. This rotation and scaling process when finished will provide a set of scaling constants used to relate the pixel location on the image to a Celestial Coordinate. This process is called Plate Solving. This term comes from the day when images were created on glass photographic plates and a measuring engine was used to measure the x, y position of the stellar objects.

Amateur Astrometry in the 21st Century

Today's amateur can use several different tools to do a plate solve. There is a manual method, a semi-automatic method, and a fully automatic method. The manual method uses a program to manually place, scale and rotate the catalog stars overlaying the image to figure out the best plate solve. The semi-automatic method uses an estimated plate center coordinate and image scale to then solve the plate. The third fully automatic method is called a "blind solve" in that the user does not have to provide any information at all to do the plate solve. The program does everything for you.

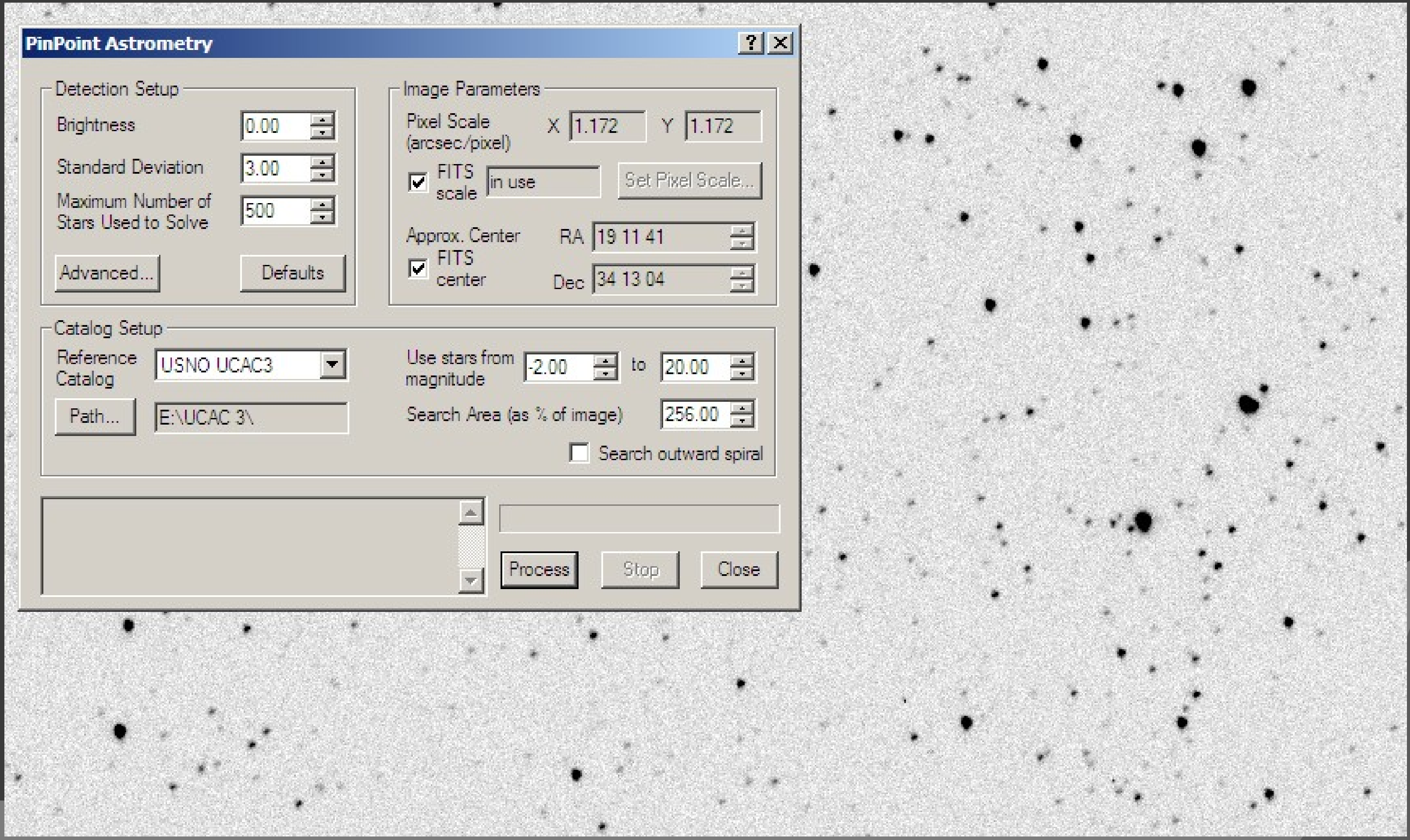
Amateur Astrometry in the 21st Century

Manual Method – AIP4Win



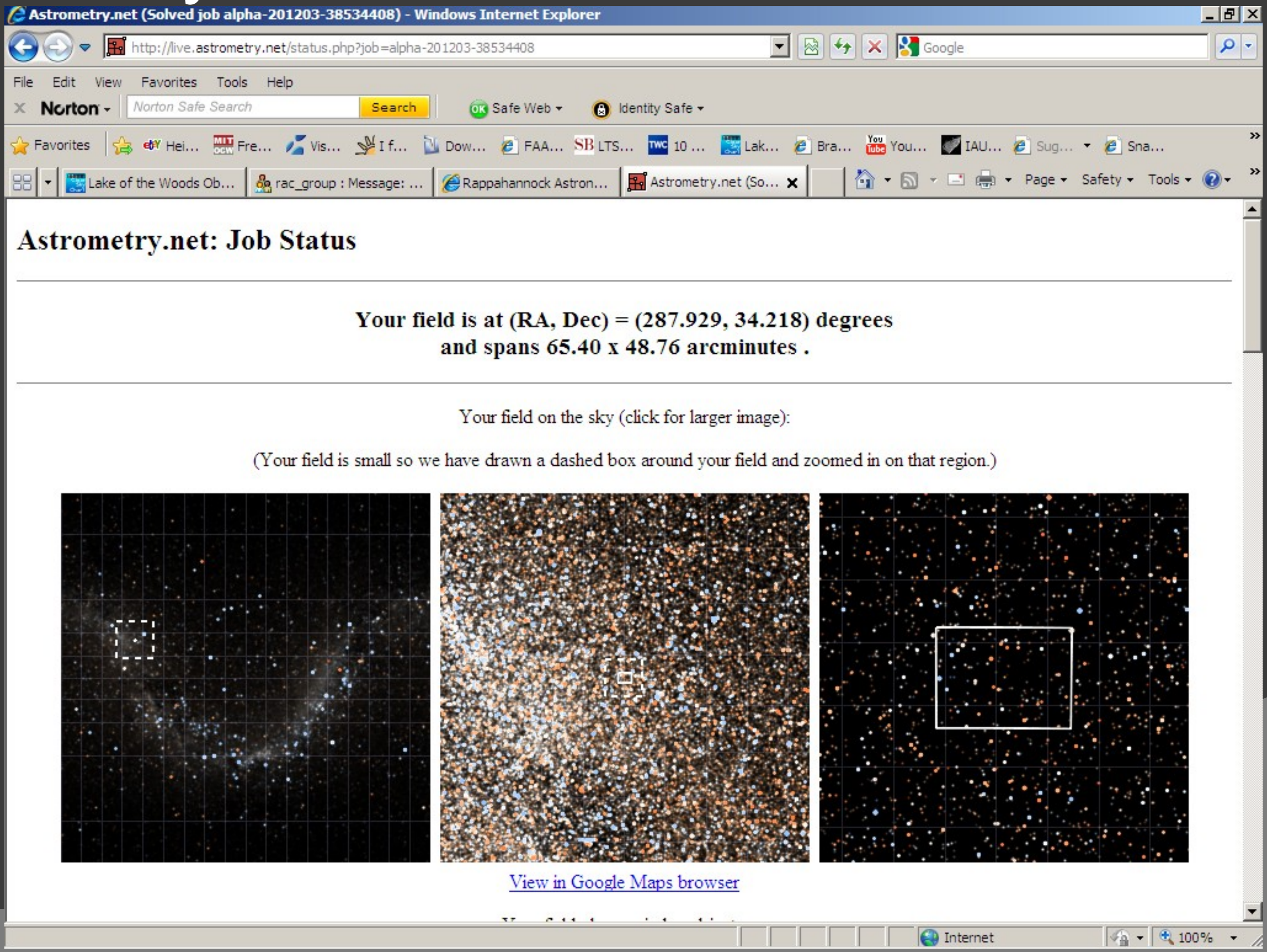
Amateur Astrometry in the 21st Century

Semi-Automatic – MaximDL + PinPoint



Amateur Astrometry in the 21st Century

Astrometry.net – Blind Solve



Amateur Astrometry in the 21st Century

DEMOs

Photometry and Astrometry for the Amateur Astronomer

Q&A