The Newsletter

of the

Orwell Astronomical Society (Ipswich)

Registered charity No 271313
www.oasi.org.uk

2009 DECEMBER No 447

I SEE NO SHIP
Side walk astronomy at the Levington Ship.

Society News (Roy Gooding)

1 2010 AGM Meeting Saturday 16th January

All members are invited to attend the 2010 AGM. The venue is at the Methodist Church Halls, in Blackhorse Lane. The meeting will start at 20:00.

2 Access into the School Grounds and Observatory Tower

Please use the third gate into the school grounds, this is the gate behind the Gym. If the Black door entrance at the base of the observatory tower is locked, you will have to phone someone in the observatory to let you in. My mobile number is [redacted]. (Roy Gooding) alternatively the Observatory mobile is [redacted] during meeting hours. The gate code is on the back of your membership card

3 Welcome to New Members

Frank Foster
Jonathan Marsden
Ray Larsen
Jon Childs

4 Society Events 2009

Meeting	Venue	Date
Geminid meteor watch	The "Dip" Felixstowe	Saturday 12th December To be confirmed
Christmas Meal	The Fountain Tuddenham	Wednesday 16th December 20:00

5 Observing events for 2010

Meeting	Venue	Date	1st Quarter date
Astronomy in the Park Star Party 1st option	Christchurch Park On top of the hill	Saturday 23rd January 18:00?	23rd January
Astronomy in the Park Star Party 2nd option	Christchurch Park On top of the hill	Saturday 20th February	22h February
Astronomy in the Park Star Party 3rd option	Christchurch Park On top of the hill	Saturday 27h February	22h February
Orwell Country Park Star Party Astronomy Evening	Orwell Country Park	Saturday 20th March 19:00	23rd March
Astronomy in the Park Observing the sun	Christchurch Park Reg Driver Centre	No date set yet	

After the success of holding a "Star Party" at Orwell Country Park and "Astronomy in the Park" in Christchurch Park, we have been asked to repeat these events in 2010. Taking astronomy to the public instead of asking them to visit us at Nacton, has now become a new and regular feature of our public outreach programme.

Astronomy in the Park "Star Party"

The first event is to arrange an evening in Christchurch Park. Three dates have been chosen, with the hope that one will be clear. If the 1st evening is clouded out the event will roll over to the next date. The event will be marshalled by the Park Rangers and will be by invitation only. Christchurch Park staff will be looking after these arrangements as well. We have been asked how many people we could look after and mentioned that about 100 could be easily accommodated.

The observation location will be on the flat area on top of the hill. Members with telescopes will be able to park on the track under the trees, at the top of the hill.

At present a start time has not been set, I will be contacting with Sam Pollard (Christchurch Park manager) and suggest a start time around 18:30. If members arrive at 18:00 it will give 30 minutes to set up our equipment. If about 100 visitors arrive we could do with a minimum of 4 telescopes, with other members giving tours of the night sky.

10:16	Moon rises
16:52	Mars rises
19:08	Jupiter sets
16:36	Sun sets

If you are able to help, please contact Roy Gooding for this event

Orwell County Park "Star Party"

The second event will be at the Orwell County Park . This is being co-ordinated by Paul Whiting.

15:40	Moon transits the meridian
18:08	Saturn rises
18:18	Sun sets
19:47	Venus sets
20:27	Mars transits the meridian

If you are able to help, especially if you can bring along a telescope please contact Paul

Night Sky (November)

All times GMT

Moon

Full Moon	3rd Quarter	New Moon	1st Quarter
2nd	9th	16th	24th

Object	Date	Times		Mag.	Notes
		Rise	Set		
Sun	1	07:51	15:56		
	31	08:13	16:02		
Mercury	1	09:20	16:30	-0.5 to 1.1	Mercury will be at greatest eastern elongation on the 20th
	31	08:40	16:56		
Venus	1	06:54	15:30	-4.1	Venus is very low down in the pre-dawn sky this month
	31	08:08	15:44		
Mars	1	21:02	12:28	-0.1 to -0.7	Mars has moved into Leo
	31	19:06	10:42		
Jupiter	1	12:16	21:37	-2.2	Jupiter is still well placed to observe this month
	31	10:28	20:10		
Saturn	1	01:31	13:45	1.1	At the star of the month Saturn is best seen after mid night
	31	23:37	11:50		
Uranus	1	13:12	00:44	5.8	Uranus is still well place to on observe this month.
	31	11:14	22:45		
Neptune	1	12:18	21:56	7.9	Neptune is also well placed to observe this month. It is near to Jupiter in the sky.
	31	10:22	20:02		

Meteor Showers

Shower	Limits	Maximum	ZHR
Geminids	December 7th to 16th	December 14th	100
Ursids	December 17th to 25th	December 22nd	10

Meteor source is the BAA Handbook

Autumn Open Weekend

After a successful series of public events during the spring for IYA, and being gluttons for punishment, we decided to repeat the whole process again for the Autumn season. The week commenced with our second public Open Weekend on the 24th and 25th October. The Saturday did not start out very promising, with continuous cloud cover during the day. The BBC weather site mentioned that the skies should clear by early evening. Surprisingly the cloud started breaking up before 17:00, everything was starting to look good for the evening.

On arriving at Nacton, a little after 18:30 the skies remained clear. Several members had already arrived, every one was now busy in setting up everything before the first visitors arrived: outside direction boards, reception table, the Tomline and balcony telescopes and telescopes on the school playing field. Setting up telescopes on the playing field is now a very popular addition to our Open weekend programme.

By 19:30 everything was setup in anticipation of a busy evening. Several early visitors had already arrived. However a large bank of cloud was approaching us from the west. It rapidly covered he whole sky, and much to our horror it started raining! A very quick action to get the telescopes under cover commenced. Much to everyone's amazement, within about 5 minutes the rain had stopped and the cloud dispersed, leaving the skies completely clear for the rest of the evening.

I decided to give both my small telescopes an outing. On the Saturday I had my 140mm Matsukov Cassegrain in use and on the Sunday my 120mm short focal length refractor made an appearance. I had recently purchase a RA drive, this proved an invaluable accusation. Having carefully aligning the equatorial mount I was able to track objects for more than half an hour with out any manual intervention. All I had to do was to point visitors towards the eyepiece, allowing free time to answer any question any of them cared to ask. I had my refractor pointing at M45 for most of Sunday evening. With a wide-angle eyepiece I had over a 2° field of view which gave a good view of the star cluster. I was told by some of the visitors, that the image of M45 through my telescope was better then the one they had seen from the balconies.

In previous years John Wainwright had his 200mm reflector in use. This year however, he arrived with a surprise. John's latest purchase was Meade 16" Dobsonian. He had also made the brave decision to have first light on the Saturday. Neil Morley also brought along his 80mm refractor.

The number of visitors on the Saturday was less than expected, only 49 came. This was put down to the bad weather during the earlier part of the day putting people off. Those that did arrive were able to have a very relaxed time with no queuing. Some visitors mentioned that they had been round all 3 observing locations several times.

Sunday evening gave us a 2nd clear sky, this encouraged about 100 visitors

Finally, I would like to thank all the members who were able to spare time to make this event another success.

2 Autumn Astronomy in the Park

Our final event for IYA was Astronomy in the Park scheduled for the 31st October and 1st November. The weather was against us on both days. Saturday remained cloudy to about 15:20 when the sun did appear for about 30 minutes. We quickly improvised an observing session outside the Reg. Drive centre, attracting a few passing members of the public. Prior, to this we had spend all afternoon round a table inside the centre, mostly having a lively discussion on food likes and dislikes

The Sunday session was cancelled.

OCCULTATIONS DURING DECEMBER

The table lists lunar occultations which occur during the month under favourable circumstances. The data relates to Orwell Park Observatory, but will be similar at nearby locations.

Date	Time (UT)	D R	Lunar Phase	Sun Alt (d)	Star Alt (d)	Mag	Star
01 Dec	19:54:29	D	1.00+	-37	43	5.5	36 Tau
04 Dec	20:56:41	D	0.90-	-46	23	3.5	delta Gem
	21:53:07	R		-53	31		
07 Dec	04:30:43	D	0.70-	-29	49	5.0	xi Leo
	05:35:32	R		-19	47		
19 Dec	16:56:49	D	0.09+	-10	11	5.3	sigma Cap
21 Dec	19:02:29	D	0.23+	-29	15	6.6	ZC 3208
	19:13:01	R		-30	14		
28 Dec	20:47:31	D	0.88+	-44	61	6.7	9 Tau
29 Dec	02:00:41	D	0.89+	-53	29	7.0	Hip 17684
29 Dec	02:09:57	D	0.90+	-52	28	7.0	ZC 550
29 Dec	02:29:21	D	0.90+	-49	25	5.4	ZC 556
29 Dec	02:55:16	D	0.90+	-46	21	6.5	26 Tau
29 Dec	02:58:28	D	0.90+	-45	21	6.2	ZC 564
29 Dec	03:15:39	D	0.90+	-43	18	6.7	ZC 567
30 Dec	04:54:12	D	0.96+	-28	14	5.8	98 Tau
31 Dec	18:52:30	R	1.00-	-26	26	7.2	Hip 32367
31 Dec	19:22:57	D	1.00-	-31	30	7.5	Hip 32614
31 Dec	19:24:54	R	1.00-	-31	31	6.5	ZC 1036
31 Dec	19:44:09	D	1.00-	-34	33	6.8	Hip 32688

Note that the occultation of ZC3208 will appear as close to a graze from Ipswich (unfortunately, the graze line itself runs far south of Ipswich).

James Appleton

Astronomy Workshop

Doors open at 7:30pm.
Workshops START at 7:45pm
Venue: NACTON VILLAGE HALL IP10 0EU

If you are a new OASI member, or haven't been to one of these workshops before – they are a mixture of events including beginners talks, interactive workshops, in-depth looks at one aspect of astronomy, hands-on observing sessions etc., suitable for all. Also a chance to chat with other members over a cup of tea!

Next workshop: 2nd December 2009
(Note – NOT the 9th – error in previous notice)

Collimating Your Own Telescope

I am going to partly recycle a previous workshop on collimating telescopes - but with the emphasis this time on getting people to bring their own telescope to the event and have a go at aligning it themselves. The society has various collimation tools ranging from a simple hole in a dummy eyepiece up to a laser collimator. You can try these out to check and adjust the alignment of your own telescope and decide if you need to buy a tool for your own use.

For beginners who might not know what collimating means – it is the process of aligning all the optical elements of your telescope to achieve the maximum sharpness with minimum distortions. This is particularly relevant to reflecting (mirror based) telescopes as the mirrors quite easily become misaligned, and have readily accessible adjustment screws to correct this – assuming you have an appropriate tool to show you when it is correctly aligned! Ideally you would collimate before every observing session – particularly if the telescope has been physically moved or reassembled. Anyone who attended the November workshop on using the 19" Millennium Telescope will have seen just how far out of collimation it can be when it is first assembled!

Refracting (purely lens based) telescopes are usually constructed to remain solidly aligned and do not require, or indeed cater for, adjustments.

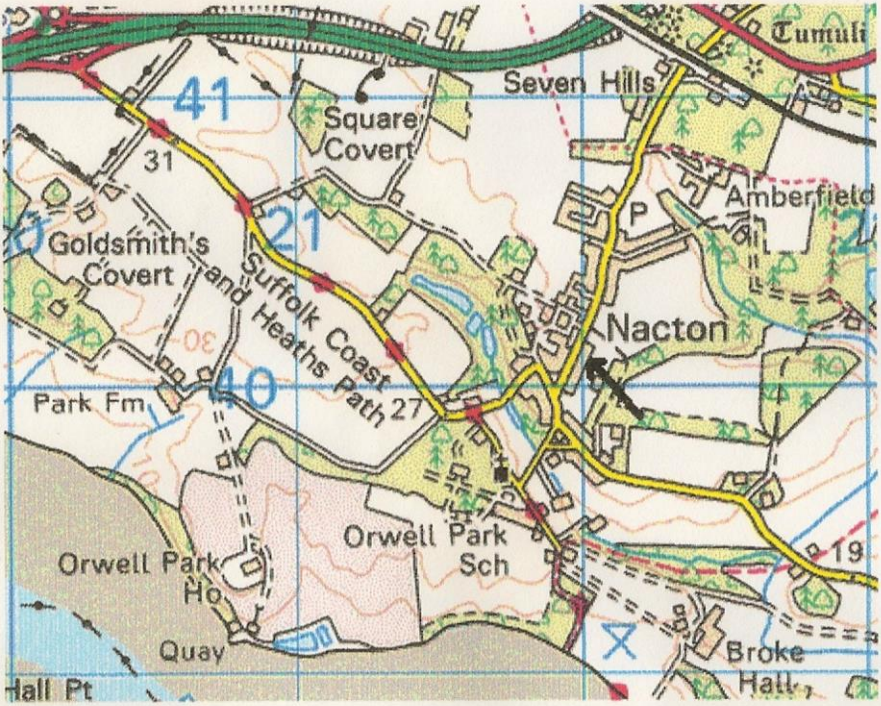
So – come along and learn about the theory but also the practice of telescope collimation – **and bring your own telescope.**

Future workshop (still being planned) are hoped to include something about the lifecycle of stars, and also about the Big Bang and theories about what happened before it (if there was a before!).

Mike Whybray

Map of Nacton. Workshops venue: NACTON VILLAGE HALL IP10 0EU (next to the small village school, just below and left of the N in Nacton on the map).

Please park on the same side of the road as the hall, but avoid parking on the white lines which mark clear spaces for various driveways and passing places.



Mike Whybray
Workshops organiser
[redacted] (Mobile)
[redacted] (Home)

Astronomy at St John's College, Cambridge

Exhibition open till 21st December, Weekdays 9am-5pm

Whilst visiting Cambridge recently, my father and I took the opportunity to drop in to the small exhibition currently in the Library at St John's College Cambridge, titled: The Way to the Stars – a history of College astronomy. This had been advertised in an email circulated on the OASI email group.

It was just a few minutes walk from Park Street multi-storey car to the ancient and impressive college entrance, where the porter let us in free to walk through to the exhibition (normally tourist entrance is £3). Proceeding through the First Court to the sound of organ music from St John's Chapel on the right, we entered the Second Court, at the far side of which stands the short Shrewsbury Tower upon the roof of which the college observatory once stood.

Turning right through a passage we entered the serene Chapel Court and on the left the library entrance, with a massive modern wooden door which pivots about its central vertical axis to let you in – once you've worked out where to push!

The exhibition is in a small area maybe only 5 by 5 metres, but being so small you feel you have time to read everything rather than just skim it. There are a few scientific instruments on display (clock, astrolabe, sextant, telescope) and several manuscripts, plus various photos and explanatory texts. A description of the observatory, by William Ludlam in 1769, is interesting as it describes some of the instruments it contained including a transit telescope, and the construction methods using wood and stone such that the observatory floor was mounted separately from the supports for instruments such as the transit telescope - to avoid vibrations being passed from one to the other. Our own observatory at Orwell Park used similar but improved ideas around 100 years later when it was being built, about the time the St John's College observatory was being removed from atop its tower.

In the picture below, the observatory is the squat wooden construction with a window, sitting immediately above the crenellations.

John Couch Adams, who deduced the existence of the planet Neptune from irregularities in the orbit of Uranus, was Keeper of the College Observatory in the 1840s and 1850s, and was appointed Lowndean Professor of Astronomy there in 1859, a post which meant he was also Director of the University of Cambridge Observatory on Madingley Road (now the Institute of Astronomy). The story is related of how he was pipped at the post for the visual discovery of the 8th planet by Urbain Le Verrier who got France's astronomers to actually search for the new planet using his calculations, whilst Adams' calculations were not taken seriously in England.

The telescope on display (made around 1816 by Dolland of London) was catalogued by Adams as follows: An achromatic refractor of 42 inches focal length and 2¾ clear aperture, with 3 Huygensian eyepieces (each with a dark glass), various other eyepieces, and a stand with polar axis, and two long handles with Hooke's joints.

The achromatic lens was invented by Dolland in 1758 and reduces chromatic aberration. A photograph of the telescope is below.

Other famous people at John's College were Sir John Herschel and Sir Fred Hoyle, and personal papers from these two are on display. Sir Fred is most popularly known as coining the name 'Big Bang' as a somewhat derisory term for the theory which challenged his own 'steady state' theory of the history of the universe. He also did fundamental work on how heavier elements are synthesised from lighter ones in the cores of stars.

Overall an interesting way to spend an hour – after which you can have a quick look round the rest of the marked 'tourist route' at John's College before the porter spots you've deviated from the Library!

~Mike Whybray~

OASI Committee Contacts & Responsibities

Neil Morley	**Chairman**	☎	[redacted]	
Roy Gooding	**Secretary**	☎	[redacted]	**MAIN POINT OF SOCIETY CONTACT** Press Publicity with Chairman. Observatory Decoration. Visits by potential new members.
Paul Whiting FRAS	**Treasurer**	☎	[redacted]	**Finance.** Supervision of Grant Applications. Visits by outside groups. **IYA 2009 Coordinator**
James Appleton	Committee	☎	[redacted]	Committee Meeting Minutes. Web Site.
Martin Cook	Committee	☎	[redacted]	Membership. Tomline Refractor Maintenance.
Peter Richards	Committee	☎	[redacted]	Lecture Meetings. Email Distribution Lists.
Eric Sims	Committee	☎	[redacted]	Newsletter.
Mike Whybray	Committee	☎	[redacted]	Librarian & Workshops.
Bill Barton FRAS	Committee	☎	[redacted]	Safety & Security.
John Wainwright	Committee	☎	[redacted]	Forward planning & Strategy Equipment Curator

DIARY For DECEMBER

Monday 7th - 21st From 8pm	**SMALL TELESCOPES OBSERVING NIGHTS AT THE OBSERVATORY** Main observational targets: Aries, Triangulum, Perseus, Mars & close by objects. ☎ Paddy O'Sullivan [redacted] ☎ Gerry Pilling [redacted]
Wednesdays **From 8PM** **The observatory will not be open on the 16th as this is the day of the christmas meal.**	**MAIN OBSERVATORY CLUB NIGHTS** Primary Observational targets: Nebulae and faint objects. ☎ Martin Cook [redacted] (mobile) [redacted] ☎ Roy Gooding [redacted] (mobile) [redacted]
Wednesday 2nd **Open 7.30 Start 7.45**	**OASI WORKSHOP** Collumating Your Own Telescope. Nacton village Hall ☎ Mike Whybray [redacted]
Thursday **3rd 8pm**	**OBSERVATORY VISITS BY LOCAL COMMUNITY GROUP** Personal group No taster evening this month ☎ Paul Whiting FRAS [redacted]
Saturday 16th January @ 8pm	**ANNUAL GENERAL MEETING** **Methodist Church Hall** **Blackhorse Lane Ipswich**

Society Primary Contacts

Chairman: Neil Morley ☎ [redacted]
Secretary: Roy Gooding ☎ [redacted] **(daytime)** [redacted] **(evenings)**
E-Mail queries: Ipswich@ast.cam.ac.uk

Society Trustees

Mr Roy Adams   Mr David Brown   Mr David Payne

Society Honorary President

Professor Allan Chapman D.Phil MA FRAS

Observatory Telephone Number

Meeting nights only [redacted]

IMAGE SCALING

Trefor Harries

When projecting an image onto a CCD for astrophotography one question that naturally arises is how big to make the image. It might seem desirable to make it as big as possible so as to minimise the subsequent enlargement required but there are some obvious snags to this. The maximum possible image size is that which would exactly fill the CCD sensor, but any drift in the image position would result in part of the image being lost off the frame which could not be recovered during the alignment and stacking stage of any post-processing. This problem will be compounded by the fact that a large image will also be a dim one since it requires a high magnification, which in turn means a long exposure time requiring more accurate tracking. Add to this the other drawbacks of high magnification, namely the extra demands put on the optics, and the effects of less-than-perfect seeing conditions. As the image size is reduced however, it occupies fewer photosites on the sensor array, limiting the ultimate resolution attainable, and requiring more enlargement. So how should the optimum image scale be determined ? This is the question addressed here. In order to answer it we must consider the capabilities of the telescope, the nature of the resulting image and the limitations of the detector. The effect of atmospheric turbulence is another influence.

First, let's define some of the parameters which will be used :

α_{airy}	Angular diameter of Airy disc (radians) to first dark diffraction ring	
d_{airy}	Linear diameter of Airy disc to first dark diffraction ring	
λ	Wavelength of light	(taken as 700 nm)
A	Aperture of telescope	
F	Focal length of telescope	
f	Focal ratio of telescope (= F/A)	
d	Diameter of image on CCD sensor	
W_{sens}	Width of sensor	
H_{sens}	Height of sensor	
W_{pix}	Width of sensor pixel	$= W_{sens} / N_{wpix}$
H_{pix}	Height of sensor pixel	$= H_{sens} / N_{hpix}$
N_{wpix}	Number of width pixels	
N_{hpix}	Number of height pixels	
α_o	Angular diameter of object	

α_{sens}	Angular field of view of sensor
α_{pix}	Angular field of view of sensor pixel
L_{sens}	Size of sensor
L_{pix}	Size of pixel
N_{pix}	Number of pixels across sensor (horizontal or vertical)

Next, we consider some useful preliminary aspects. These are to do with the image size at prime focus and the angular field of view at various levels. After this we will consider some characteristics of the image formed at the prime focus by the objective lens or mirror and see how this provides a criteria for establishing an optimum image scale on the sensor.

Image Size at Prime Focus

The first thing we will investigate is the image size at prime focus since this is first technique to consider when deciding how to obtain a photograph.

Fig. 1 : Image size at prime focus

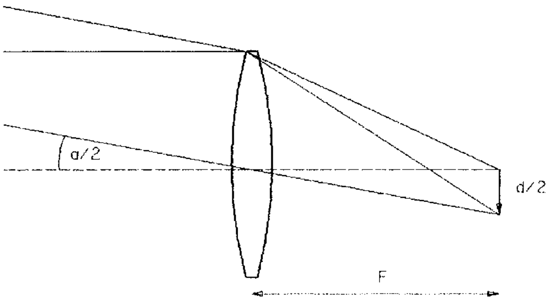


Fig. 1 shows a lens of focal length F projecting a prime focus image onto the focal plane.
The angular size of the object is a and the diameter of the image is d.

From Fig. 1 : $\tan(a/2) = (d/2)/F$

so $d = 2F\tan(a/2)$ .... (1)

For small angles this can be approximated to give a simpler expression :

$d = a F$ (a in rads) .... (2)

or : $d = a F / 57.3$ (a in degrees) .... (3)

Sensor Field Of View at Prime Focus

Another parameter that is sometimes used is the angular field of view of the CCD sensor at prime focus. Transposing equation (1) and substituting α_{sens} for a and L_{sens} for d :

$\alpha_{sens} = 2 \arctan [L_{sens} / (2F)]$ .... (4)

or, using equation (3) :

$\alpha_{sens} \doteq 57.3\ L_{sens} / F$ degrees .... (5)

Field Of View Of A Single Pixel

It will also be useful sometimes to consider the angular field of view of a single photosite (pixel) on the sensor.

Pixel size = Sensor size / Number of pixels (for horizontal or vertical dimensions)

$L_{pix} = L_{sens} / N_{pix}$

Putting this into equation (5) and substituting α_{pix} for α_{sens} :

$\alpha_{pix} = 57.3\ L_{sens} / (F\ N_{pix})$ or

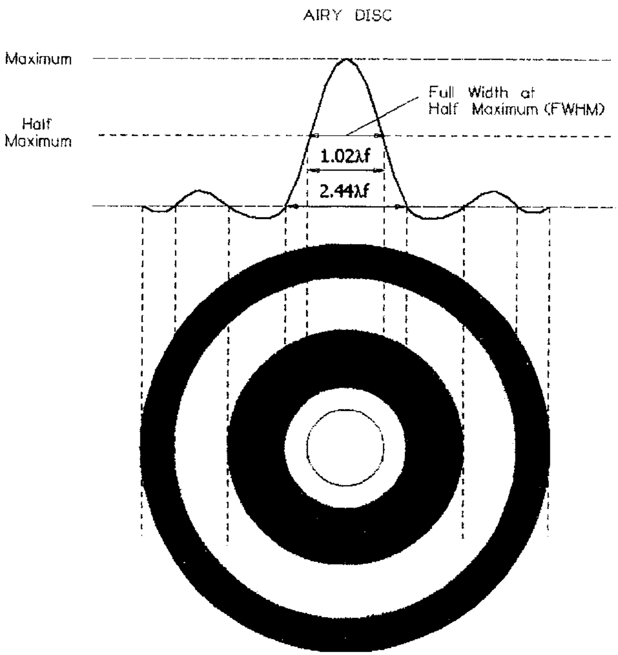
$\alpha_{pix} = 57.3\ L_{pix} / F$ .... (6)

Image Characteristics

Since we are interested in the quality of the final image, i.e. the resolution, we must investigate the limits to the smallest level of detail achievable. To pursue this lets consider the effects on an ideal point source of light such as might be represented by a very faint star.

Due to the wave aspect of the nature of light a point source of light can never be perfectly preserved in an optical system since the process of focusing rays from different light paths can never eliminate the inevitable phase differences. The end effect is that when a point source of light is imaged by a lens or mirror the result is not a pin-prick spot of illumination but a circular area of variable brightness known as an Airy disc. This has a well characterised distribution of brightness as shown in figure 1 :

Fig. 1 Airy Disc



Characteristics Of The Airy disc

$$\alpha_{airy} = \frac{2.44\,\lambda}{A} \text{ radians}$$

$$d_{airy} = \frac{2.44\,\lambda F}{A} = 2.44\lambda f \text{ metres}$$

$$\alpha_{FWHM} = \frac{1.02\lambda}{A} \text{ radians} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$d_{FWHM} = \frac{1.02\,\lambda F}{A} = 1.02\lambda f \text{ metres} \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

CCD Sampling And The Point Spread Function
(Focal length for critical sampling)

Some more parameters :

N_{phot}	Average number of photons captured
Φ	Photon flux (photons per area per second)
A_p	Collecting area of photosite
T	Integration time
Q	Quantum efficiency of photosite (electrons per photon)
N_e	Number of electrons
d_{PSF}	Diameter of Point Spread Function
d_{FWHM}	Diameter of Airy disc (full width at half maximum)
d_{pix}	Diameter of sensor pixel

The value of a photosite in the sensor depends upon the number of photons it has captured.

$$N_{phot} = \Phi A_p T$$
$$N_e = Q N_{phot}$$

So for a group of photosites that all receive the same illumination, N_e will be the average number of electrons released by each site. Since this is only an average and is subject to random fluctuation the standard variation will be $\sqrt{N_e}$. This random variation will represent a noise signal, and the signal to noise ratio SN will be :

$$SN = N_e / \sqrt{N_e} = \sqrt{N_e}$$

The Point Spread Function of the telescope image refers to size and shape of the actual image of a point source of illumination. Ideally this is equal to the Airy disc but, inevitably, there will be other factors to degrade this, e.g. optical aberrations, atmospheric turbulence, tracking errors etc. The CCD will also add the noise signal just mentioned. Hence we have :

$$d_{PSF} \geq d_{FWHM}$$

Electronics engineers are familiar with the Nyquist theorem for calculating the minimum frequency at which a signal must be sampled in order to preserve the information contained by it. This says that for the sampling to reveal the detail of the original with reasonable fidelity, the sampling frequency must be at least twice the highest frequency present in the original signal. If the sampling rate is lower than this the detected signal will not faithfully represent the original, as much of the detail will have been lost (and if it is much lower than this the detected signal will be a gross distortion of the original). This situation is referred to as undersampling. If the sample rate is exactly twice the highest frequency in the original then this is just adequate to preserve most of the detail in the original. This is called critical sampling. If the sampling rate is further increased the amount of detail detected will increase, but only marginally. This is called oversampling. This theorem is not restricted to any particular domain, and can be applied spatially as well as temporally, so we can legitimately consider the photosites in a CCD array to be sampling the image that is falling upon the sensor. Hence, we can approximate the Nyquist condition for critical sampling with :

$$d_{pix} = d_{PSF} / 2$$

And even for an ideal case where $d_{PSF} = d_{FWHM}$ we have from (8) :

$$d_{pix} = \frac{1.02\,\lambda F}{2A} = \frac{0.51\,\lambda F}{A} = 0.51\lambda f$$

The only parameter that we can usefully vary in this is f (i.e. F and/or A) which could be accomplished by introducing a Barlow lens into the optical system, or using eyepiece projection, or even substituting another telescope.

For a given telescope then we have :

$$F = \frac{A\, d_{pix}}{0.51\lambda} \quad \text{.......................................} \quad (9)$$

This represents the focal length required to provide critical sampling of the resulting image by the sensor array. A good way to summarise this is to consider the initial resolution of the prime focus image in terms of the point spread function. For simplicity we will disregard the degradation of the image due to optics, atmospherics etc., as this is a rather indeterminate contribution, and equate the point spread to the diameter of the Airy disc, i.e. $d_{PSF} = d_{FWHM}$. The number of point spread diameters (let's call them 'points'), N_p, contained in the image diameter, d_i, will be :

$N_p = d_i / d_{FWHM}$ which from (3) and (8) is :

$$N_p = \frac{\alpha_o F / 57.3}{1.02\,\lambda\, F/A} = \frac{\alpha_o A}{58.446\lambda} = \frac{\alpha_o A}{0.041} \quad \text{for } \lambda = 700 \text{ nm} \ ....(10)$$

Notice that this depends on only two factors; the angular size of the target object and the aperture of the telescope. This is the best resolution we can hope for ; there are many things that can degrade this but nothing that can improve it, although it may be possible to compensate for some of the degradations by subsequent image processing. We could adopt this as a measurement to describe this initial resolution. Let's call it PPI (points per image), a little analogous perhaps to the dpi (dots per inch) used to describe printing resolution. So, once we have established our PPI from (10), we are stuck with it. Increasing the image scale with greater magnification will not change this since the point spread will increase at least as fast as the image scale, as established by (8). What will change is the size of the sensor elements relative to the point spreads and it is this that can be used to gauge the degree of image sampling. When we have increased the image scale (and the point spread diameter !) to twice the diameter of a sensor element then we can consider the Nyquist criteria to have been met. Any further increase in image scale will result in a larger point image diameter which would be equivalent to going to an oversampling situation. Little would be achieved by this, i.e. little further detail would be revealed, and since the other consequence would be a dimmer image requiring longer exposure, greater tracking problems etc. there is little to be gained here. If the image scale is much less than this then the resolution is going to be limited by the size of the sensor elements. So, to make life as easy as possible we need to match the point spread function of our image to the dimensions of our sensor elements, which we can do by carefully selecting the focal length at which the image is made. A longer focal length will mean more difficult imaging, and a shorter focal length will mean that we will not fully reveal the detail in the original image. Hence we should use equation (9) to calculate our ideal focal length and provide for this by modifying the optical system with Barlow lenses, focal reducers, projection eyepieces etc. as needed.

Example 1
As an example lets assume a 150 mm Refractor at f8 and a Canon EOS 1000D Digital SLR camera which has a sensor size of 22.2 x 14.8 mm comprising 3888 x 2592 photosites.
We have :

λ = 700×10^{-6} mm
A = 150 mm
W_{sens} = 22.2 mm
H_{sens} = 14.8 mm
N_{wpix} = 3888
N_{hpix} = 2592
$W_{pix} = W_{sens} / N_{wpix}$ = 22.2 / 3888 = 5.71 microns
$H_{pix} = H_{sens} / N_{hpix}$ ≐ 14.8 / 2592 = 5.71 microns

So d_{pix} = 5.71 microns

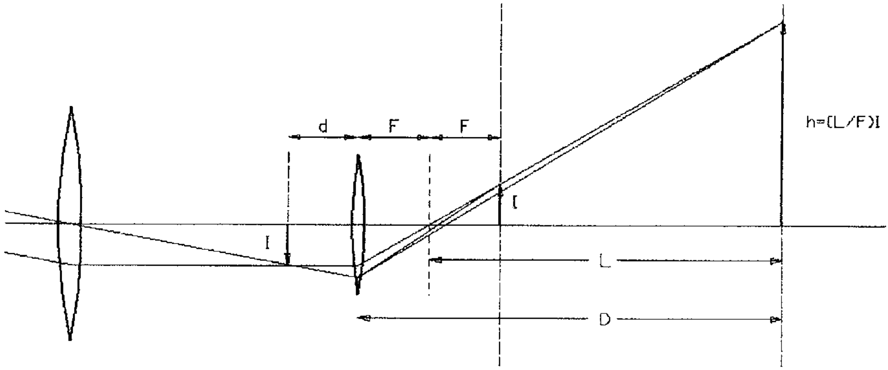
For critical sampling this requires from (9) a focal length of

$$F = \frac{150 \times 5.71 \times 10^{-3}}{0.51 \times 700 \times 10^{-6}} = 2400 \text{ mm}$$

The normal focal length is A x f = 150 mm x 8 = 1200 mm, so critical sampling can be achieved quite simply by incorporation of a x2 Barlow lens.

Equation (9) then provides a value of F which will give an appropriate image scale insofar as the characteristics of the camera and telescope will be matched for good image resolution. This is not the whole story however as no account has been taken of the actual image size which, of course, will depend upon the angular size of the target object. For small objects greater magnification may be desirable to reduce the need for subsequent enlargement, so the final image scale may be larger than equation (9) would suggest. A common way of achieving this is by eyepiece projection.

Eyepiece Projection   Fig. 2 : Projection Geometry



I   Prime focus image
d   Prime focus image to eyepiece distance
D   Projection distance (eyepiece to image plane)
F   Focal length of eyepiece
E   Image enlargement over prime focus

Fig. 2 shows an arrangement for eyepiece projection. Here, the projection distance D is determined by the distance, d, of the eyepiece relative to the prime focus image formed by the objective.
If d = F then light rays from any point on the image will be exiting the eyepiece in parallel, forming a virtual image at infinity to an eye placed behind the eyepiece and no real image projection will result. Another way of interpreting this is to say that a real image is produced, but at infinite distance, i.e. $D = \infty$.
If d > F then a real image will be projected as shown, and as d is further increased D will decrease. From Fig. 2 it can be seen that if D = 2F then the enlargement E = 1.

Generally : $D = L + F$

and $h = l\,(L/F)$

so $L = hF / l$

and $D = (hF / l) + F$

but $E = h / l$

so $D = (E + 1)\ F$ .... (11)

E.g. for an f6.3 telescope using a 25 mm eyepiece, to get an enlargement over a prime focus image of 4x, the distance of the CCD from the eyepiece must be set up from equation (11) :

$$D = (4 + 1) \times 25 = 125 \text{ mm}$$

This must be set and then the eyepiece-to-objective distance adjusted for focus.

Although eyepiece projection permits a large degree of magnification it has to be said that most eyepiece optics are not designed for projection and consequently will introduce some degradation to the image. An eyepiece has greater demands on its optics than an objective lens largely due to the greater angles it has to accommodate; an objective typically has a field of view of no greater than 1-2 degrees whereas an eyepiece may have 70-80 degrees or even more. However, for very small objects such as planets this may be the only option.

Angular Field Of View At Critical Sampling

As a gauge of the image quality to be expected, the image scale in terms of angular field of view per pixel is often a useful measure. This is usually expressed as arcseconds per pixel.

From (6) we can derive for the angular FOV per pixel :

$$\alpha_{pix} = 57.3\ d_{pix} / F$$

Also from (9) we have the focal length for critical spatial sampling of the image :

$$F = \frac{A\ d_{pix}}{0.51\lambda}$$

So we can say that critical sampling corresponds to an angular FOV per pixel of :

$$\alpha_{pix(crit)} = \frac{57.3 \times 0.51\lambda}{A} = \frac{0.020456}{A}\ ^\circ / \text{pixel}$$

$$\alpha_{pix(crit)} = \frac{0.020456 \times 3600}{A} = \frac{73.64}{A}\ \text{arcsecs / pixel} \ldots\ldots.(12)$$

Example 2

For A = 150 mm $\alpha_{pix(crit)} = 73.64 / 150 = 0.491$ arcsecs / pixel

This should agree with the situation in example 1 where

$\alpha_{pix} = (57.3 \times 5.71 \times 10^{-3} \times 3600) / 2400 = 0.491$ arcsecs / pixel

In practice the image scale that can be usefully used will be limited by the factors previously mentioned for oversampling. There are no hard-and fast rules for this but typical values in arcsecs / pixel for desirable image scales might be :

For views of constellations	: 30
For views of open clusters	: 5
For many deep sky objects	: 1-2
Planets	: < 1

Magnification v Subsequent Enlargement

Let's assume in example 2 that we capture an image of the Moon and another of Mars both at critical spatial sampling as determined by (9). The Moon presents an angular diameter of 29 minutes = 1740 arcsecs, while Mars at its nearest presents 25 arcsecs. At critical sampling :

For Moon : α_o / α_{pix} = 1740 / 0.491 = 3544 pixels
For Mars : α_o / α_{pix} = 25 / 0.491 = 51 pixels

For the previous example of a Canon EOS 1000D whose sensor has an array of 3888 x 2592 pixels, Mars would give an undersize image, while the Moon's image would be too large for the sensor if it is required to capture the whole disc. Obviously for the case of the Moon, we can simply use a lower value of F. For Mars, such an undersized image will require a large subsequent enlargement to provide a useable final image. This would look very 'blocky' from an initial image that was only 51 pixels wide so we would probably wish to increase the magnification when capturing the initial image. The detail in the magnified image will be subject to the same limits to the resolution but this will probably appear less obtrusive than the 'blockiness' in the unmagnified image, and a degree of sharpening may be achievable during image processing. If we provide more magnification by resorting to using eyepiece projection, the point spread function may be further degraded because of additional optical aberrations and sensitivity to atmospheric movements. All this means that to use a large degree of oversampling requires several conditions to be met as far as possible :

- Excellent seeing conditions
- Quality optics
- Accurate tracking

In summary, then, it seems that the image scale should initially be aimed at the value provided by equation (9) to get the optimum compromise between resolution and magnification. This should be achieved using prime focus, with the addition of a Barlow lens if necessary. If this results in too small an image then more magnification will have to be resorted to e.g. by employing eyepiece projection. This will require good optics, good seeing conditions and a good mount for tracking.