Proposed new guide-probe system and camera

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1 Introduction

It is proposed that the NOT autoguider system be upgraded due to the occasional problems of finding and seeing suitable guide stars, it can be difficult to see stars with visual magnitudes of 11 in moderate to poor seeing conditions. The cause of the problem is two fold, the sensitivity of the guide camera has deterioration over the years, and the size of the guide probe head and mirror vignette a significant amount of the field. This latter problem is enhanced with the arrival of FRED[1] with its 17 arcminute square field which actually means with the existing system there is no unvignetted guide-probe field available, so guiding would not be possible with this instrument.

Also in the near future it is planned to replace the whole of the existing telescope adapter with a new one which will allow for the possibility of completely changing the design of the guide system, if desired.

An additional feature desired from the guider system is for it to be completely automated, i.e. require no interaction from the observer. This means the current procedure of having to click on the guide star on the auto-guide screen should go and the auto-guider system automatically finds the position of the star and starts guiding.

2 Guide-probe alternatives

There are two alternative designs for a new guide probe, the first is to retain the existing x-y carriage but with a physically smaller head to reduce the vignetting of the probe and consequently increase its field of view, and replace the camera with a more sensitive one. The alternative is to place a fixed mirror in the guide probe field and use a large format CCD to view the whole area simultaneously.

2.1 X-Y carriage Head

A new guide probe head has been built at CUO using a pick off mirror only 41mm wide which significantly improves the available guide-probe area. For ALFOSC the field becomes approximately 200^2 arcminutes and roughly 17^2 arcminutes for FRED, see figure 1. A further improvement to this design would be to move the pick-off mirror and camera back [2] approximately 20mm, which would then include a second unvignetted area and will almost double the available guide field for FRED to 32^2 arcminutes, though will reduce the field for ALFOSC, but only by a few square arcminutes.

Even with the smaller guide probe head there is still a significant area that can not be accesses as illustrated in Figure 2. The estimated vignetted area is approximately 33.5mm wide centred on the probe. An assumption has been made that the distance behind the pickoff mirror is the same as the width of the mirror, this takes into account the thickness of the glass and mirror mount.

2.2 Mirror head

A different approach is to replace the x-y guide-probe carriage with a fixed mirror that is viewed by a large format CCD. This concept has been proposed by CUO for the IIAs 2m telescope [3] and is also shown in figure 1 using a KAF-6303E [4] 3072x2048 9μ pixels CCD with a pixel scale of 0.33 arcseconds/pixel.

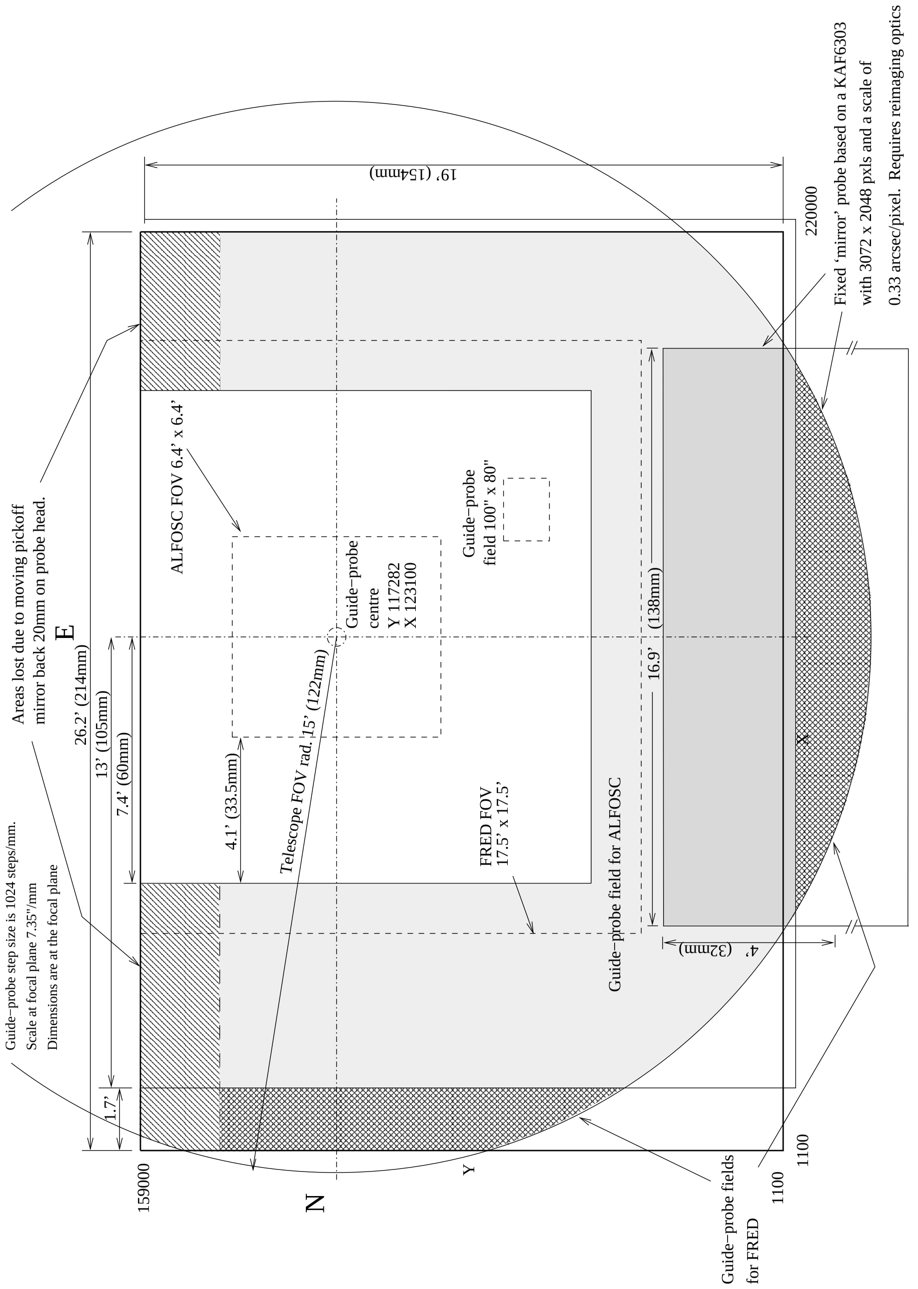

Figure 1: FOV for new guide-probe for ALFOSC and FRED. The light shaded area is the guide field for ALFOSC the hashed area is the available field for FRED. The dark area is the fixed mirror probe using a KAF-6303 3072 x 2048 CCD, but requires re-imaging optics.

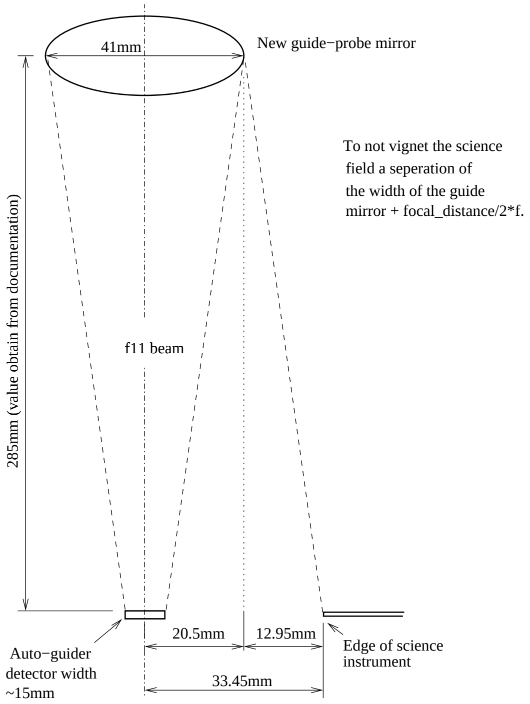

Figure 2: Vignetting of X-Y carriage guide-probe.

A Kodak CCD has been selected because of its very low dark current at room temperature of only 22 e^-/pxl/s and this particular device for its long edge of 3072 pixels, over two thirds of the width will not be in the FOV of the telescope so wasted. The position of the mirror is displaced from the edge of the FRED FOV by about 8mm to allow for its thickness. This idea has the elegant solution of fewer moving parts. It will give an identical field for all instruments of approximately 66^2 arcminutes. To be able to implement this system some re-imaging optics are required to convert the telescope scale form 7.35 arcsec/mm to 0.33 arcsec/pixel, this means a scale of 37 arcsec/mm for the KAF-6303E, or 48 arcsec/mm for the KAF-3200. A comparison of the two Kodak CCDs is given in appendix C.

Another possibility is to use two KAF-3200 CCDs with two sets of associated camera electronics and two mirrors. This will give the largest possible FOV for an autoguider and provide redundancy in the system making it more reliable. The biggest disadvantage with the one chip camera solution is that it gives us a single point failure, i.e. if the chip or camera dies no autoguiding will be available until it can be repaired or replaced.

The CUO design concept is based on the Audine [14] camera system which comes in kit form with a driver board and CCD board and is designed for the KAF-0400 CCD which is pin compatible with the KAF-3200. Unfortunately the KAF-6303E is not pin compatible so will require a new chip mounting PCB to be designed and made. If the smaller KAF-3200 2048x1024 6.8μ pixels CCD is used then a reduced field of about 45^2 arcminutes results..

If an identical system to the CUO proposal is followed through then a dedicated CPU will be necessary to control the readout of the CCD and do the image processing. To get the required readout rate it is expected that the guide star will always be found in an area no larger than 40 x 40 pixels or 13 x 13 arcsecs. This means the existing problems with the NOT guide system where the acquired star can not be relied on to land in a well defined area on the autoguider monitor, and sometimes even falling outside the approximate 80' x 80' field all together, needs to be fixed.

Another important consideration is how any new guide system will interface to TCS both hardware and software. The TCS runs under OS9 and is built around a Motorola M68x VME computer. The current auto-guider is an ICCD and the analogue CCIR video signal from this is captured by a frame-grabber ScanBeam card in the TCS VME rack.

2.3 Available Stars

Gemini Observatory have produce a technical note [5] that gives the average sky coverage of R-band field stars over the whole sky. Using this at the north galactic pole for the modified guide probe and the mirror probe, table 1 shows the average available R-band stars for given magnitudes. The probability of not finding a star has been found from $e^{-(Average\ number\ of stars)}$.

Table 1: Average number of R-Band field star at the North Galactic Pole for the two alternative FRED autoguider configurations.

R	Average number of stars and probability of no star			
(mag)	X-Y carriage (32')		Mirror (66')	
13.75	0.9	0.4	1.8	0.17
14.25	1.2	0.3	2.4	0.09
14.75	1.6	0.2	3.3	0.04
15.25	2.1	0.12	4.3	0.01
15.75	2.7	0.07	5.5	4x10^{-3}
16.25	3.5	0.03	6.9	10^{-3}
16.75	4.3	0.01	8.7	2x10^{-4}
17.25	5.4	4x10^{-3}	11	2x10^{-5}
17.75	6.8	10^{-3}	13	2x10^{-6}
18.25	8.4	2x10^{-4}	17	4x10^{-8}
18.75	11	2x10^{-5}	21	7x10^{-10}
19.25	13	2x10^{-6}	26	5x10^{-12}
19.75	16	1x10^{-7}	33	4x10^{-15}

3 SNR calculations for possible detectors

The criteria for identifying a star for any given detector is its sensitivity over the noise, i.e. signal-to-noise ratio. This ratio also affects the accuracy in calculating the star position. The centroid position is determined by doing a Gaussian fit in both the X and Y directions using the summed signal in the columns or rows.

Calculation of the signal-to-noise ratio for different detectors for an input image of a star and for a range of conditions has been simulated to identify the best detector for a new auto-guider. The detectors investigated were; a normal CCD, a L3CCD [6] and intensified CCDs (ICCD). From these results simulations the alternative camera system can be evaluated.

3.1 Procedure

Four detectors types were investigated to determine their signal-to-noise performance under several conditions. The detectors selected were a normal bare CCD, a L3CCD and second and third generation ICCDs.

One important parameter that is not known is the minimum autoguider frame rate such that adequate guiding can be maintained. If the guiding is too slow then the guide star could move significantly between corrections resulting in poor psf of the image. Contrary long integrations are preferred to detect fainter guide stars.

With these detectors the different operating conditions chosen to investigate were three exposure times of 0.5s, 1s and 2s with and without moon light, and for seeing of 0.88 arcsec and 2 arcsec. The assumed pixel scale is 0.33 pixel/arcsec and the SNR is calculated over a square aperture of five sigma, 6 pixels and 14 pixels square for 0.88 arcsec and 2 arcsec seeing respectively. From the NOT web page the median seeing for the period January 1991 to January 1998 was 0.88 arcsecs, this and the value of 2.0 arcsecs and the range of magnitudes from 15 to 22 were used.

The technique used to obtain the individual signal-to-noise values, was to integrate over a 2D Gaussian and determine the signal and noise in each pixel for all the conditions given above. The total signal is obtained from equation 1[7] which is the signal at the detector after taking into account atmospheric and telescope losses. The signal-to-noise ratio is then calculated for the appropriate square window size.

$$Photon/sec = 142 * 10^{\frac{(20-Mv)}{2.5}} \tag{1}$$

An IDL program was written to calculate the detected signal-to-noise ratio (SNR) for the different detectors, over a range of light levels. The affect of seeing, and moon illumination, and three exposure times have been investigated.

The method for obtaining the correct flux levels has been made by determining the actual flux level in each individual pixel over a specified area for given seeing conditions then the noise in each pixel calculated and the result of the total summed signal and noise calculated.

Table 2 shows all the parameters used for the signal-to-noise ratio calculations. From the ING web the background is 70 photons/arcsec^2/sec for no moon and 1000 photons/arcsec^2/sec for full moon assuming a 60% through put of the telescope. Therefore for 0.33 arcsec^2 pixels the background per pixel will be 5 ph/pixel/sec and 65 ph/pixel/sec for no moon and full moon respectively. The number have been verified using ING SIGNAL program giving the INT (2.5m) as the telescope.

Relative high RON of 15e for the normal CCD is taken from the KAF-6303 data sheet with its QE and typical dark current of 15 electrons/pixel/sec at 25^{o}C.

Table 2: Detector Parameters

Detector	QE(%)	MNF	RON
NCCD	60	1	15
L3CCD	40	0.5	0
ICCD Gen2-S25	12	0.4	0
ICCD Gen3-GaAs	30	0.4	0
Theoretical	100	1	0

Table 3: Percentage of signal within a given σ for a 2D Gaussian.

Width	percentage of signal
σ	11.750316
2σ	39.346951
2.35σ	49.858081
4σ	86.466485
6σ	98.889101
8σ	99.966451
10σ	99.999625

The low QE given for the L3CCD is typical of existing devices but it is hoped in the future the extra gain register can be added to thin back illuminated chips resulting in higher QEs.

Due to the dispersion in the gain in the multiplication stage of the L3CCD the signal-to-noise ratio of the output is reduced by a factor of $\sqrt{2}$, [8][13] which is the same as doubling the shot noise. The reduction in the signal-to-noise ratio of $\sqrt{2}$ is exactly equivalent to operating a normal device with half its quantum efficiency. This effect has been included in the signal-to-noise ratio calculation with the extra term *multiplication noise factor* (MNF). The gain of the normal CCD is given as one which is typical for CCD systems from Copenhagen.

Roper Scientific [8], manufactures of ICCDs quote these type of systems as having a MNF from 0.5 to 0.3. An additional noise source in ICCDs are thermally generated electrons, also known as equivalent background illumination (EBI), at the photo-cathode which are indistinguishable photo-electrons. The equivalent to these in a L3CCD can be virtually eliminated by cooling the detector where to cool a photo-cathode is much harder.

3.2 Results

Table 3 and figure 3 shows how much flux is contained within a give circular aperture with radii of multiple σ. An important thing to note is that only approximately half the signal falls inside the seeing disc, which is equivalent to 2.35σ.

Plots of signal-to-noise ratio against equivalent visual star magnitude for different seeing conditions and with and without the moon have been produced.

The equations for calculating the signal-to-noise ratio are given in appendix A with figures comparing performance against star magnitude.

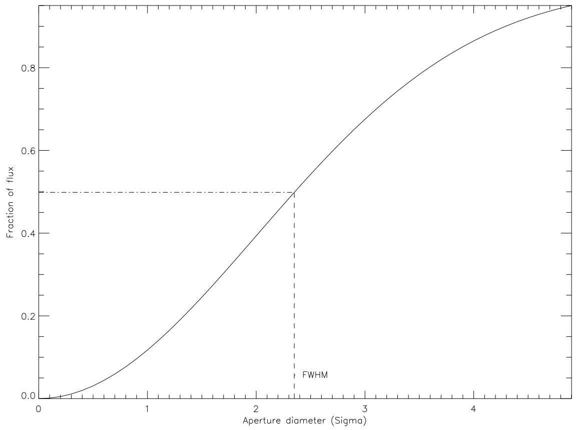

Figure 3: Fraction of flux contained in a circular aperture given as a multiple of σ.

Comparing the SNR performance between a L3CCD and a Kodak CCD for integration times up to 5 second and for different sky conditions and seeing values, it can be seen from figure 4 for two extreme cases that for a star of visual magnitude 17 and poor seeing the L3CCD consistently delivers a SNR of about 10 better than the normal CCD for integration time longer than about 1 second. On the other hand for good seeing the Kodak CCD gives a better SNR for integrating times longer than 1.5 seconds.

For bright stars (Mv $<$ 17) the performance of the bare CCD improves rapidly until at Mv $=$ 14 for a 1 second exposure it is better than the L3CCD even for the poor seeing and no moon situation and is significantly better with good seeing and a bright sky.

4 Guide Camera

The existing guide system consists of an old second generation EEV intensified TV camera with a CCIR video output that is captured by a frame grabber ScanBeam card in the TCS.

To replace the auto-guide camera several things have to be considered. It would be desirable to use a similar type of camera, i.e. with CCIR output so it can be easily interfaced to the ScanBeam frame grabber boards, though an extra desirable feature would be to be able to integrate with the camera. To have an output other than video will require a second CPU to do the image capture and processing since the TCS on its own does not have sufficient spare capacity to handle such a task.

Also the power dissipation of the camera head must be kept to a minimum, the existing camera's power consumptions is 3W and it would not be desirable to go above this. This would then make it difficult to use Peltier cooled detectors without some kind of plumbing, air or water, to remove the heat because these usually consume tens of watts .

A very important consideration regarding the selection of the camera is the

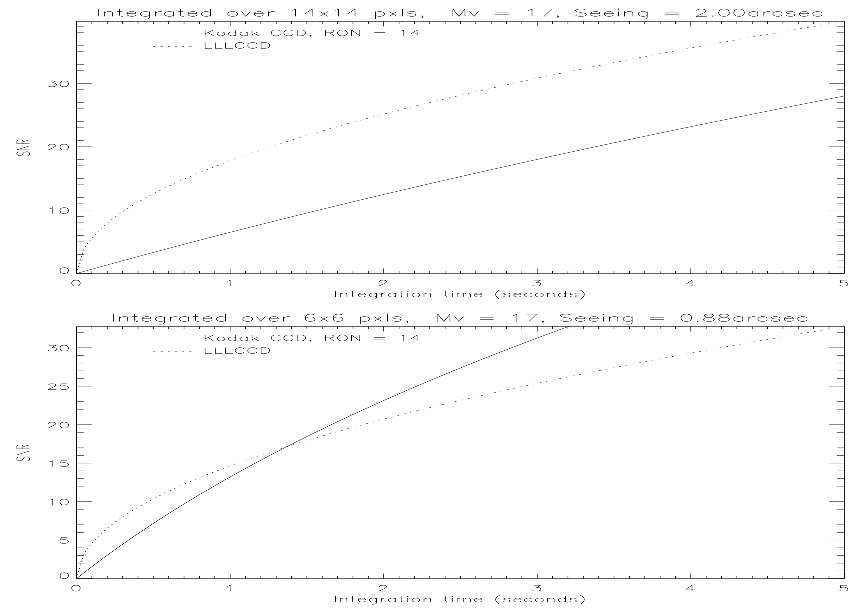

Figure 4: Signal-to-noise ratio comparison between a L3CCD and a Kodak CCD for integration times up to 5 second for different seeing conditions. The upper curves are for a dark sky and a seeing of 2 arcsec (the two curves cross at 48 s integration time), the lower for full moon and seeing of 0.88 arcsec.

integration time as already referred to in the section 3.2. A camera with CCIR video output by definition has an integration time of only 40ms (25Hz frame rate) where a custom built CCD system can be made to have any arbitrary exposure time set, for example 1 second, to match the guiding requirements. Figure 5 shows the significant difference between a L3CCD at video rates and a Kodak CCD with a 1 second exposure. The conditions for comparing the performance are the worst case for the bare CCD based on the measurements shown in figure 7 of seeing 2 arcsec and a dark sky.

An undesirable feature of traditional Gen2 and Gen3 intensifiers is they have a tendency to deteriorate (loose sensitivity) over time, are known to have limited life times of typically 10000 hours and have the drawback of been easily damaged by high light levels.

The Kodak CCDs are desirable because they are simple to operate and have a very low typical dark current of only 15 e^-/pixel/sec at 25^oC. To use a bare CCD there are two possibilities, the first is the fixed mirror probe where a large format CCD, such as the KAF-6303, images the whole field simultaneously and only a small region of the CCD is readout to obtain the fast readout times required. The second approach would be to mount a smaller bare CCD on the x-y carriage, though still only a small region of the chip can be read to keep the readout time down.

There are several alternatives for the small bare CCD, a KAF-0400 could be used with the Audine [14] kit or a commercial camera such as the SBIG [15] STV or ST-237. The Audine system is an amateur camera that is purchased in kit form, a similar electronic scheme to that proposed by CUO [3] can be used

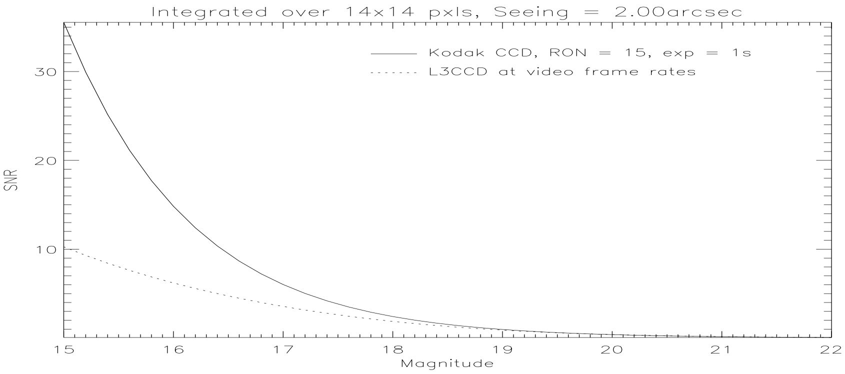

Figure 5: Signal-to-noise ratio comparison between a bare CCD with a 1 second exposure and a L3CCD run at TV rates (40ms exposure) for 2 arcsec seeing over a square aperture of 5 sigma, with no moon, over a range of magnitudes.

to operate it. The STV uses the Texas Instruments TC237 frame transfer CCD and has a video output that can be connected to our existing frame-grabber board. Unfortunately this device has a relatively high dark current at 21^{o}C of 214 e^{-}/pixel/sec, but can be cooled. The average dark signal can be remove by subtracting a dark frame. To read the chip in full frame it needs to bin 3x3 in so-called *Wide Mode*, if you request *Zoom Mode* you get unbinned pixels with only the centre 320x200 pixels read. A third mode called *Normal Mode* gives 2x2 binning and 640x400 pixels. The other SBIG camera, the ST-237 has digital output via the parallel port and a maximum data transfer rate for a quarter of the field of 1 second.

There is a large number of CCD cameras on the market typically interfacing using the parallel, USB or serial RS-232 ports. A few also include customised PCI boards that require proprietary software usually only running under Windows.

Another example of a guide system is the ING up-grade of the WHT autoguider [16] which has a E2V Technologies CCD47-20-1-A73 Peltier cooled frame transfer CCD, with an expected RON of 4e. They have built their own camera head and expect to use an obsolete SDSU controller to operate it. No performance details of this ING system are available to date on the web.

As mentioned above the use of a detector system that provides a digital unprocessed output requires the undesirable need of an extra computer to do the processing and to pass the resulting corrections to the TCS. To be able to use the existing frame grabber board it would be necessary to have a CCIR or NTSC analogue video signal.

Roper Scientific [8] produce two cameras based on L3CCD technology but require a Windows PC to operate them through a supplied PCI card. These camera systems consume a significant amount of power especially if cooled, total including PSU 96W, and have digital signal output, NTSC or CCIR is provided by the PCI card.

Andor Technology [10] supply similar L3CCD technology camera systems to Roper Scientific again requiring a Windows PC and a custom PCI control card. This company do claim to have a camera the iXonDV887-BIt0 which uses a

E2V CCD65 back illuminated L3CCD which has a QE of 90% but this device does not appear on the E2V Technologies web site and will probably never be manufactured.

E2V Technologies do a range of cameras using their own L3CCD devices. The Cam65-06 camera comes as a 2 board unhoused set with CCIR video output and consumes 5.5W. The L3C60 camera uses the CCD60 (128x128) CCD and comes in a back illuminated version and consumes 5.5W but has non-composite analogue video output. Finally there is the L3C65 which comes in two version, with and without Peltier cooling, and provides direct CCIR video.

Texas Instruments do a similar camera to E2V's using their own L3CCD, the MC681SPD-R0B0 with a NTSC video and digital LVDS output. This camera consists of the camera head with a thermal electric cooler (TEC) and a separate camera control unit (CCU), the head consumes 8W. The control of the chip gain is by a manual knob on front of the CCU, there is no remote control of this. This camera has the possibility of setting the integration time, with a shutter, remotely but only when using the digital LVDS output (with a frame grabber). Unfortunately the data sheet for this camera is very difficult to follow making it virtually impossible to evaluate its desirability.

Canadian Photonics Labs. (CPL) do a range of intensified cameras, both generation 2 and 3 (Gen2 and Gen3). The Gen3 CPL-22B is the most attractive, consumes less than 2.4W, has CCIR video output, an intensifier with a claimed peak quantum efficiency of 90% and is only 142mm long.

Photon Technology International produce three intensified CCD cameras of both Gen2 and Gen3 type. The Gen3 come in two varieties normal or with a blue enhanced sensitivity, IC-300 and IC-300B respectively. These have separate controllers and the camera head is slightly larger than the CPL cameras but are claimed to be affordable. The output is NTSC or CCIR video, no power consumption is given.

Lavision and Pulnix also produce ICCD cameras. Lavision cameras are designed mainly for very short exposures but will go up to 1 second. They interface to a PC by a PCI card. Pulnix do both Gen2 and 3 cameras as well as normal CCD imagers in a range of flavours with and without digital or video outputs.

5 Conclusions

From this study of the alternative options available for a new auto-guider system for the NOT the ideal solution, taking in to account the limited available field with FRED, would be to use a fixed mirror and a large format L3CCD detector. Unfortunately there is no such detector on the market at the moment (January 2004) so the compromises are either a L3CCD camera with the x-y carriage and the modified head or a large format CCD with the fixed mirror solution. A L3CCD will give better signal to noise for all observing conditions for identical integration times as a bare CCD but with approximately half the FOV the fixed mirror scheme provides for FRED. Another problem with intensified cameras is they either require custom PC interface cards which only come with proprietary Windows software or have video output, hence not integrating.

The simplest upgrade of the autoguider is to replace the existing intensified camera with an equivalent one using a L3CCD video camera. The L3CCD is not susceptible to the traditional problems associated with intensifier tubes of aging and over exposure damage. Retaining a TV type camera with analogue video output means the existing TCS ScanBeam frame-grabber card, for which we have a spare, can be used and no extra unknown CPU would be required. The frame-grabber would use the old TCS rack with one of the six liberated spare CPUs. The obvious drawback of this system is its lack of sensitivity compared to the bare CCD with integrating facility. Also it may be difficult to make this system fully automated, i.e. automatically find the guide star without observer intervention.

Using the KAF-6303 CCD with a pixel scale of 0.33 arcsec and a fixed mirror can give almost twice the field of 66 arcminutes for FRED compared to the modified guide probe, though for all other science instruments the field would be less. The 'mirror probe' will require some re-imaging optics to change the plate scale, but has the advantage of less moving mechanical parts over the x-y carriage. A complete new camera system needs to be built including a separate CPU to handle the camera control and image analysis. The camera head could be based on the Audine amateur camera but a new PCB would be required because the KAF6303 is not pin compatible with the Audine existing board design. This system could easily be made automatic with the extra computer, though the existing problem with the guide star positioning must be solved so the star falls within the small window this technique requires.

The SBIG STV camera with its bare integrating CCD and video output is an alternative choice with the x-y carriage, since with this you get the bare CCD performance and video so can be used with the existing ScanBeam hardware. Some problems with the STV is to get 1x1 binning you are only allowed to read a region of 320x200 pixels because it doesn't have the memory or video bandwidth to readout the whole chip at full resolution. This would give a FOV of 106x66 arcsec at 0.33 arcsec/pixel. The camera probably requires cooling by the internal TEC due to the relative high dark current and has a readout noise of 18e. This camera will still have the problem of making it none interactive in the future.

A Signal to Noise Calculations Details

The equation for calculating the signal-to-noise ratio per pixel:

$$SNR = \frac{QE.MNF.t_{int}.signal/pxl}{\sqrt{QE.MNF.t_{int}.(signal/pxl + BG) + t_{int}.DC + RON^2}} \tag{2}$$

Where QE is the quantum efficiency, t_{int} is the exposure time, MNF is the multiplication noise factor, gain is the CCD gain, BG is the sky background, DC is the dark current for the normal CCD, RON is the readout noise and signal/pix is the signal for each pixel.

For a normalized 2D Gaussian function, where u_x and u_y = mean and $\sigma_x = \sigma_y = \sigma$

$$G(x,y)dxdy = \frac{1}{2\pi\sigma^2} e^{\frac{-((x-u_x)^2+(y-u_y)^2)}{2\sigma^2}} \tag{3}$$

Given for a circle $x^2 + y^2 = r^2$, then $y = \sqrt{r^2 - x^2}$

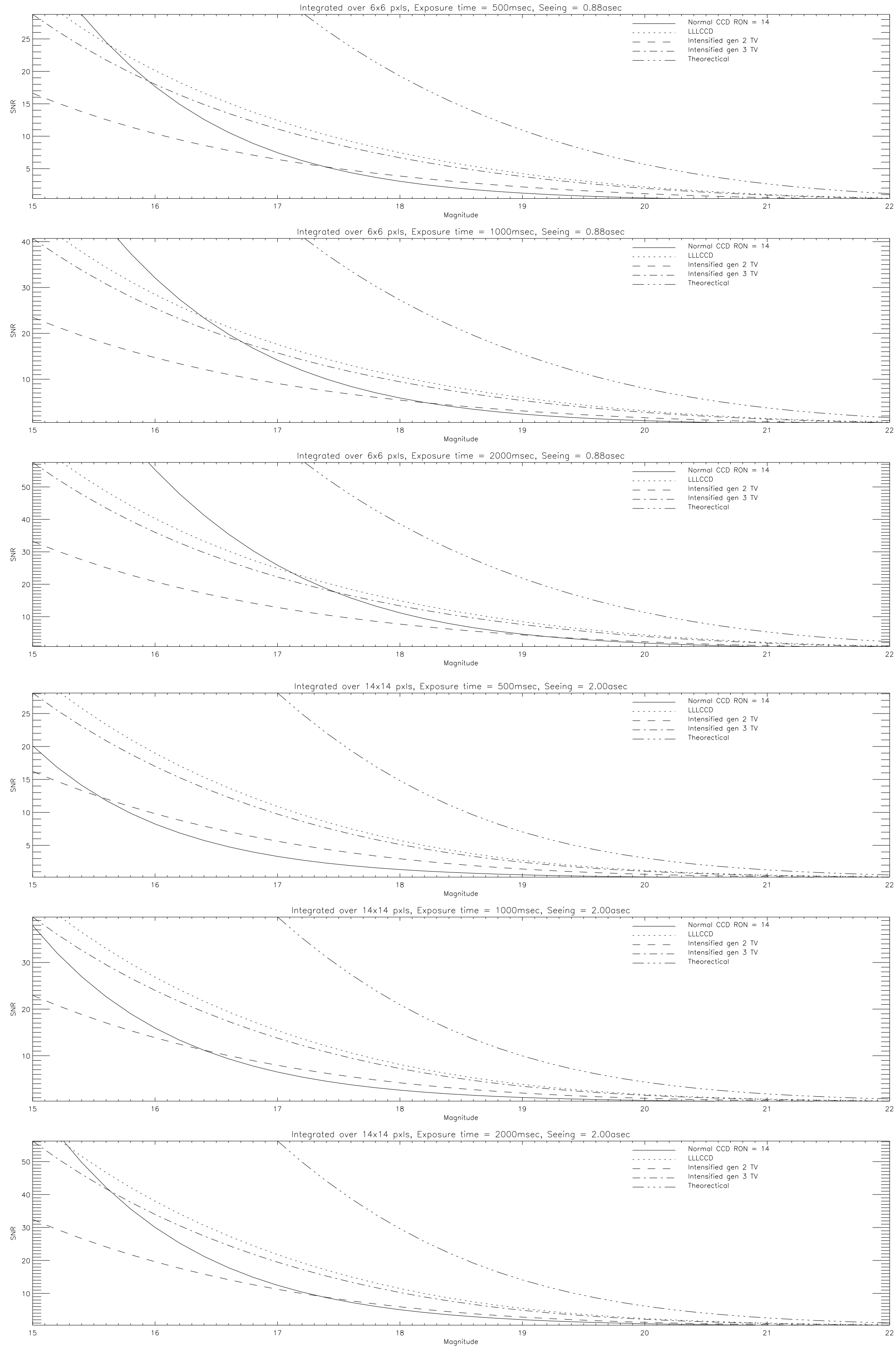

Figure 6: Signal-to-noise ratio comparisons for 0.88 arcsec seeing and 2 arcsec seeing over a square aperture of 5 sigma, for no moon and exposure times of 0.5s, 1s and 2s, over a range of magnitudes.

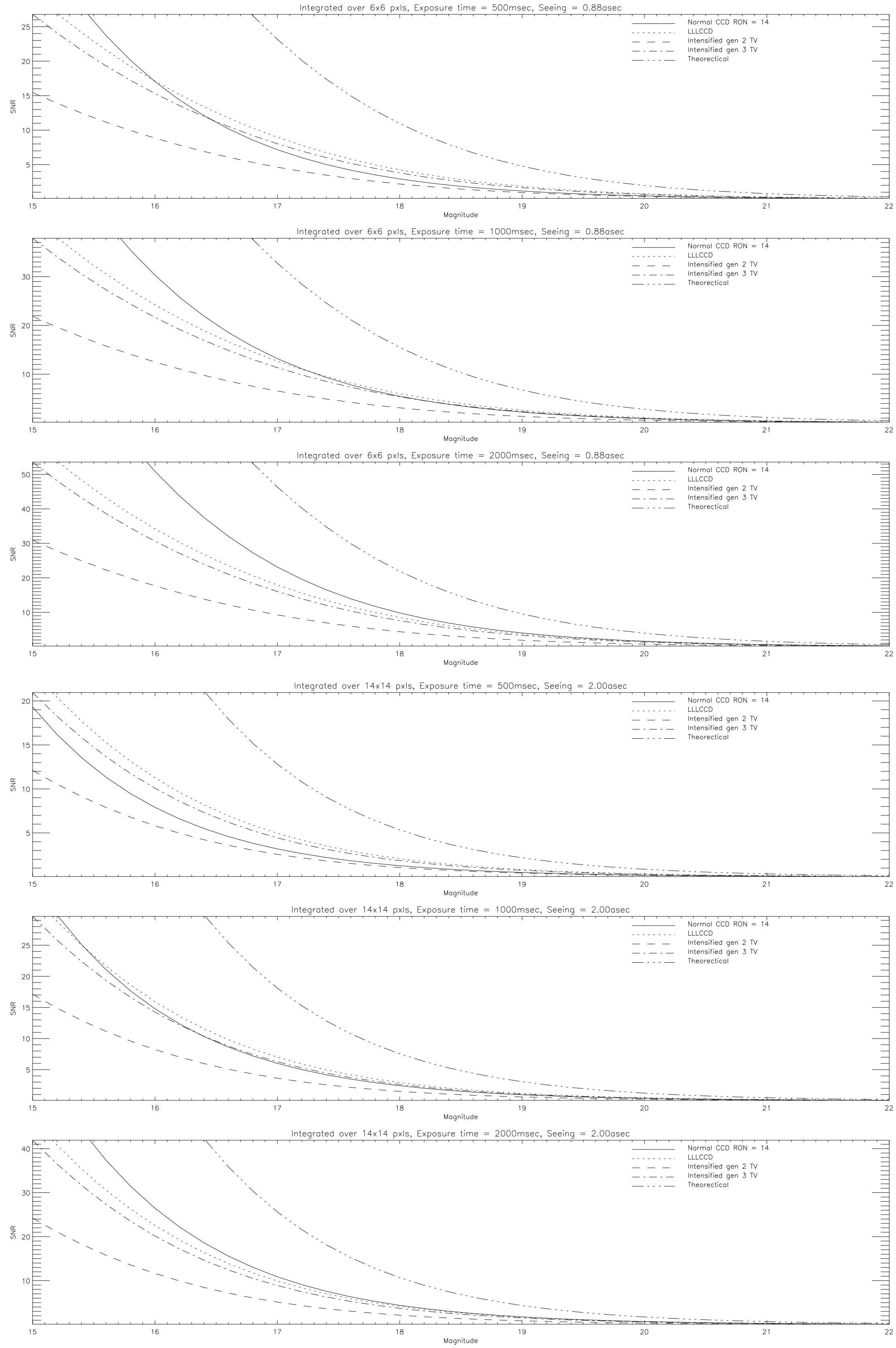

Figure 7: Signal-to-noise ratio comparisons for 0.88 arcsec seeing and 2 arcsec seeing over a square aperture of 5 sigma, with full moon, for exposure times of 0.5s, 1s and 2s, over a range of magnitudes.

Then the integral under a circular aperture of radius r of a 2D Gaussian is,

$$\int G(x,y)dxdy = \int_{x=-r}^{x=r} \int_{y=-\sqrt{r^2-x^2}}^{y=\sqrt{r^2-x^2}} \frac{1}{2\pi\sigma^2} e^{\frac{-((x-u_x)^2+(y-u_y)^2)}{2\sigma^2}} dxdy \qquad (4)$$

(Note: $fwhm = 2\sqrt{2\ln 2}\sigma \simeq 2.35\sigma$.)

The IDL function to calculate the volume under the 2D Gaussian for given radius is *INT_2D*. The INT_2D function computes the double integral of a bivariate function using iterated Gaussian quadrature.

A simplified listing of the IDL program is given here.

```
PRO int_2dgauss
  COMMON c_blk, radius
  radius = 1.175 ; = N*Sigma

  AB_limits = [-radius, radius]
 ; Volume contains the percentage of flux in the given radius about the
 ; centre of the 2D Gaussian.
  Volume = INT_2D('gauss2d', AB_limits, 'PQ_limits', 96, /DOUBLE)
END

FUNCTION gauss2d, x, y
 ; 2D Gaussian where SigmaX = SigmaY = s = 1 and Ux = Uy = 0
  s = 1.0
  RETURN, (EXP(-(x^2.0+y^2.0)/(2.0*s*s)))/(s*s*2.0*!PI)
END

FUNCTION PQ_limits, x
  COMMON c_blk, radius
  RETURN, [-sqrt(radius^2-x^2), sqrt(radius^2-x^2)]
END
```

To run the program, edit the files to have the desired data plotted then in IDL type '@run2dg4'.

Figure 6 show the signal to noise ratio for a normal bare CCD, L3CCD, generation 2 and generation 3 ICCDs and the theoretical response given as a reference for 0.88 arcsec and 2 arcsec seeing without the moon illumination, for three exposure times of 0.5s, 1s and 2s. Figure 7 is identical to 6 but with the moon. The value for sigma is related to the given seeing i.e. for 0.88 arcsec seeing five sigma is approximately 6 pixels and for 2 arcsec seeing it is approximately 14 pixels.

From the SNR curves 6 and 7 for the given conditions the bare CCD is always the best choice as a detector, though not necessarily the preferred option when it comes to interfacing it to the TCS since the TCS would require a second CPU to do the image processing. For the current system the extra processing power comes from the frame-grabber card.

B Intensified Camera manufactures

Listed here are examples of some manufactures of ICCD cameras of the L3CCD, Gen2 and Gen3 types.

Roper scientific (Photometrics) - www.roperscientific.com/cascade.html
Andor Technology - www.andor-tech.com
E2V Technologies - www.e2vtechnologies.com
Texas Instruments - www.tij.co.jp/jsc/docs/disp/eng/impact/mc681spd-e.htm
Canadian Photonics Labs - www.cplab.com
Photon Technology International - www.pti-nj.com/obb_10.html
Hamamatsu - www.hpk.co.jp/eng/main.htm
Lavision - www.lavision.de
Pulnix - www.pulnix.com

C Kodak CCDs Comparison

A comparison is given here of the parameters of two Kodak CCDs. The KAF-3200 is the device proposed for use with the NAGU system and the KAF-6303 is suggested for the NOT auto-guider system. Both devices use a 2-phase clocking scheme and have similar output structures. The main differences between the two are there size and consequently phase load capacitances and clock speeds, and the higher readout noise for the KAF-6303.

Table 4: Comparison of the Kodak KAF-3200 and KAF-6303 CCDs.

Parameter	**Units**	**KAF-3200**	**KAF-6303**
Pixels Row (H)		2184	2048
Pixels Column (V)		1472	3072
Pixel size	μm	6.8	9
Dark Current @25^{o}C	pA/cm^2	7	3.5
Dark Signal	e$^-$/pxl/s	15	15
Readout Noise Floor	e$^-$	7	15
Number of Clock phases		2	2
QE (λ=650nm)	%	65	65
O/P Amp. sensitivity	$\mu V/e^-$	20	10
Vertical clock, Low	V	-8.5	-10
Vertical clock, High	V	2.0	1.0
Horizontal Clock, Low	V	-3.0	-4.0
Horizontal Clock, High	V	7.0	6.0
Reset clock, Low	V	4.0	-3.0
Reset clock, High	V	11.0	4.0
ΦH Effective Capacitance	pF	150	400
ΦV Effective Capacitance	nF	5	82
ΦH Clock Frequency	MHz	10	4
ΦV Clock Frequency	KHz	$\sim$100	25
Line Time	μs	242.6	386

D Revised Calculations for FRED FOV

A revised estimate of the auto-guider FOV when used with FRED has been made and apparently there is more area available than originally believed. Figure 8 show the new auto-guider field which included an additional area along the X-axis. This area has been obtained because the assumed thickness of the auto-guider mirror, and hence the vignetted area behind the mirror, is less than expected. The resulting FOV of the guide-probe for FRED is then about 45^2 arcminutes. This does not include the additional area where a guide star can be seen but will not be in the centre of the guider field.

The difference between the apparent center of the auto-guider field and the instrument field centre is a result of the auto-guider mirror not been mount square on the head, hence the mirrors actual position does not correspond exactly to the guide-probe cordinants given by the TCS.

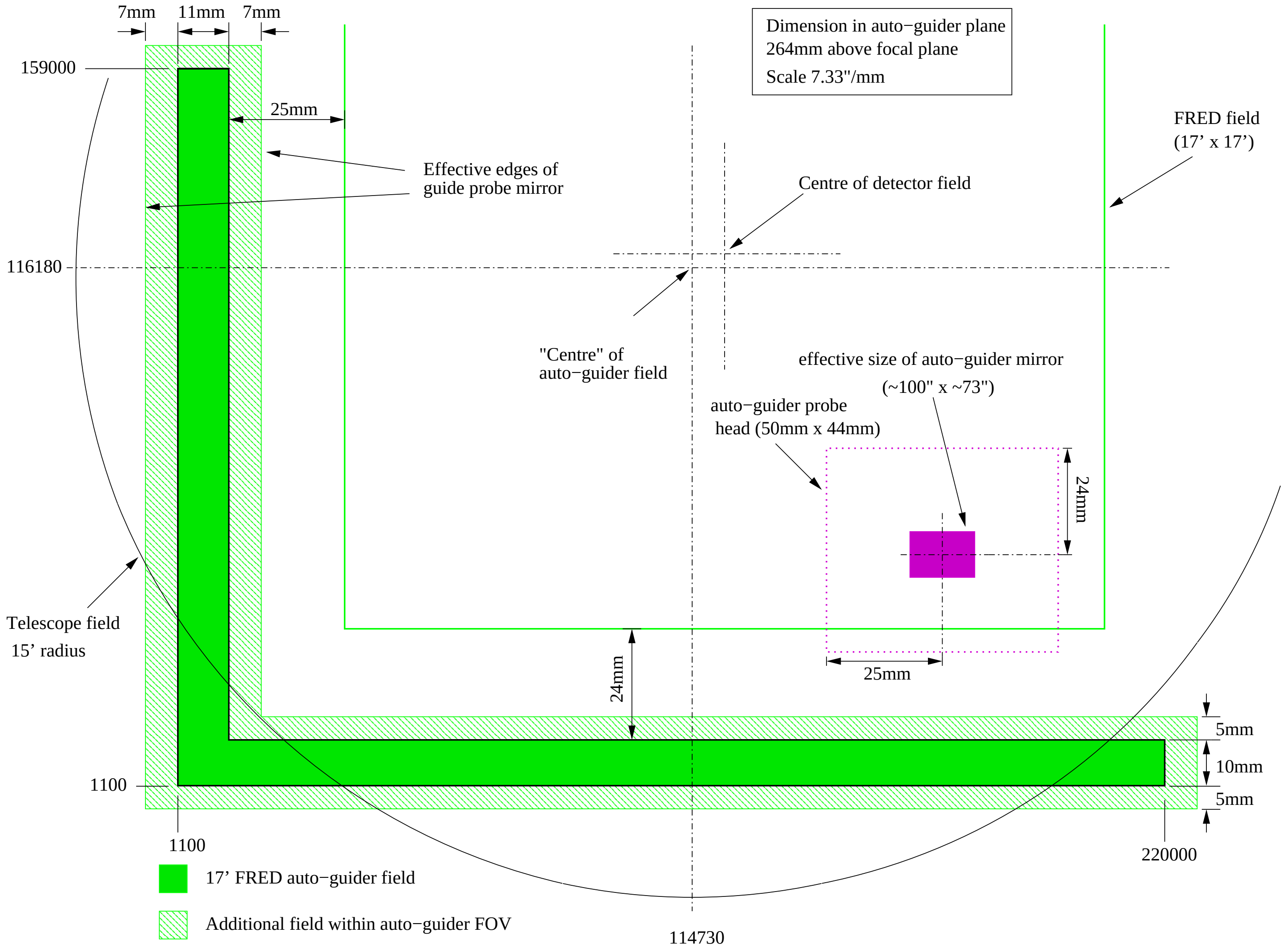

Figure 8: FOV for new guide-probe for the FRED field.

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