Drift Scanning (Time-Delay Integration)

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I. What is drift scanning

- how a CCD reads out
- drift scanning
- pros and cons of drift scanning
- drift scanning at high declinations

II. Drift scanning telescopes and cameras

- Spacewatch, Sloan, Palomar Quest
- world’s largest CCD cameras

III. The Palomar Quest camera

- design
- sample images

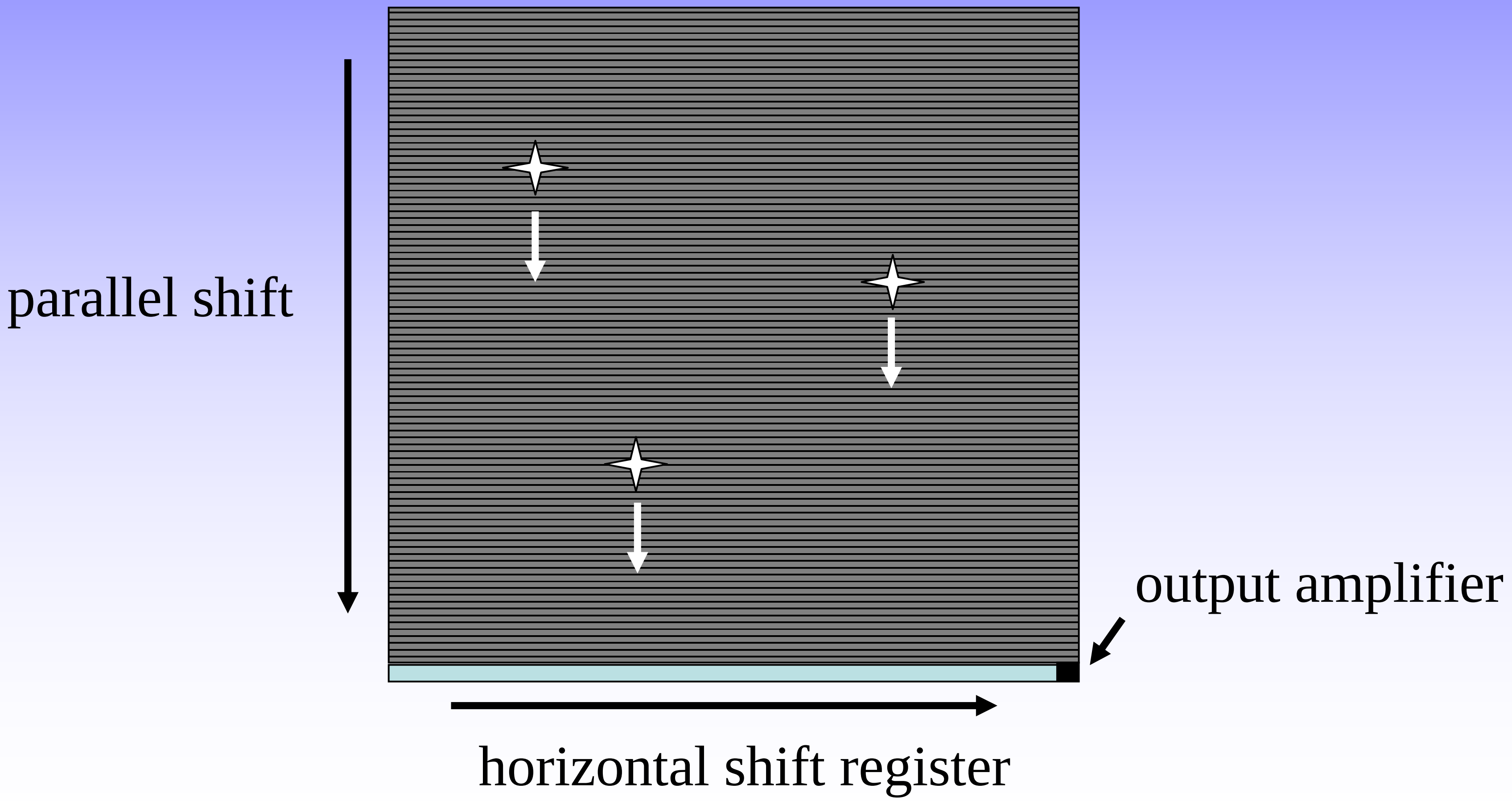
IV. Astrometry with Palomar-Quest drift scans

- method
- precision
- limits on precision

I. What is drift scanning ?

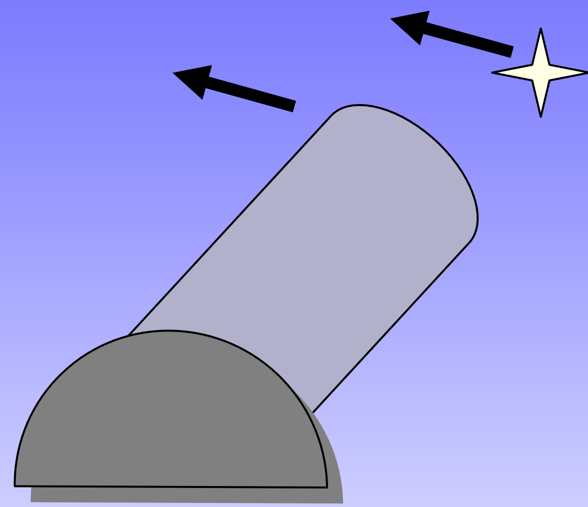
How a CCD reads out

(1)Parallel shift all rows down one row
(2) Shift out last row through horizontal register
(3) repeat



What is drift scanning ?

Point & Shoot:
telescope tracking
(1) open shutter
(2) close shutter
(3) readout CCD



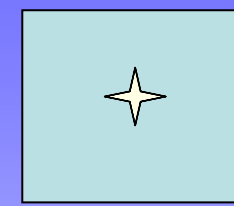
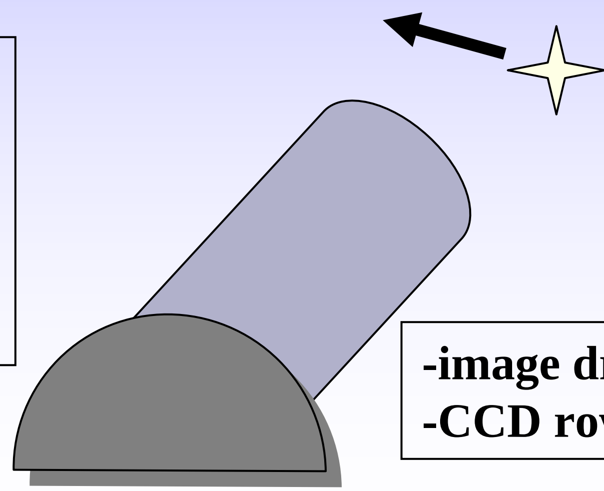
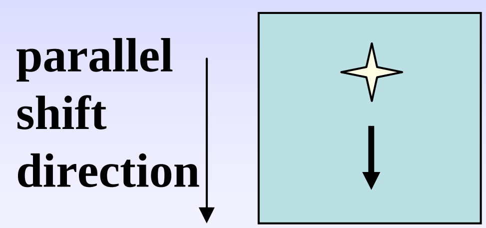


image is stationary in focal plane

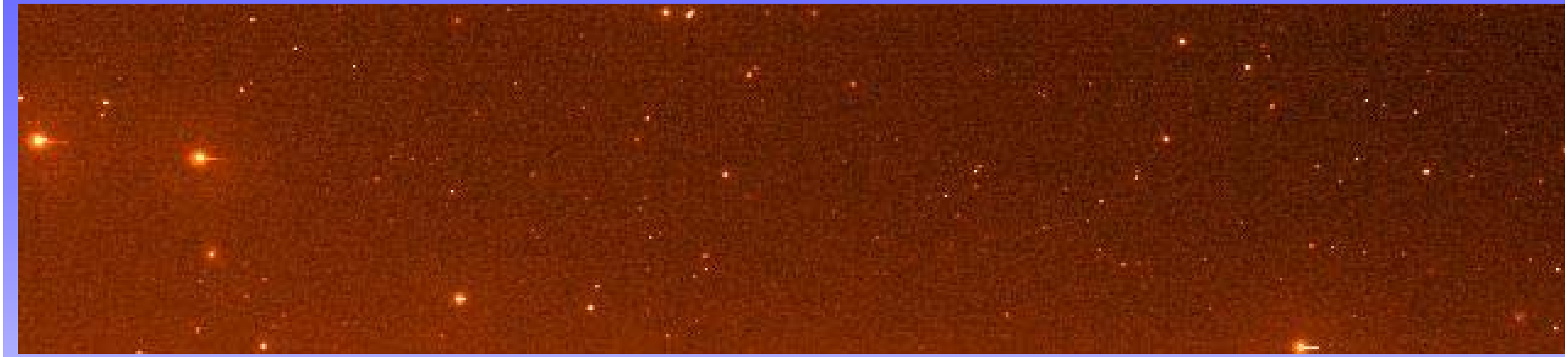
Drift Scanning:
-telescope stationary
-shutter stays open
-readout continuous





-image drifts in focal plane
-CCD rows shifted to match drift rate

Sample Drift Scan



RA

Why drift scan ?

(1) most efficient way to use a CCD camera

(2) consistent astrometry over widest possible field

(3) astrometric solution is linear in pixel coordinates

(4) precision unaffected by telescope tracking error

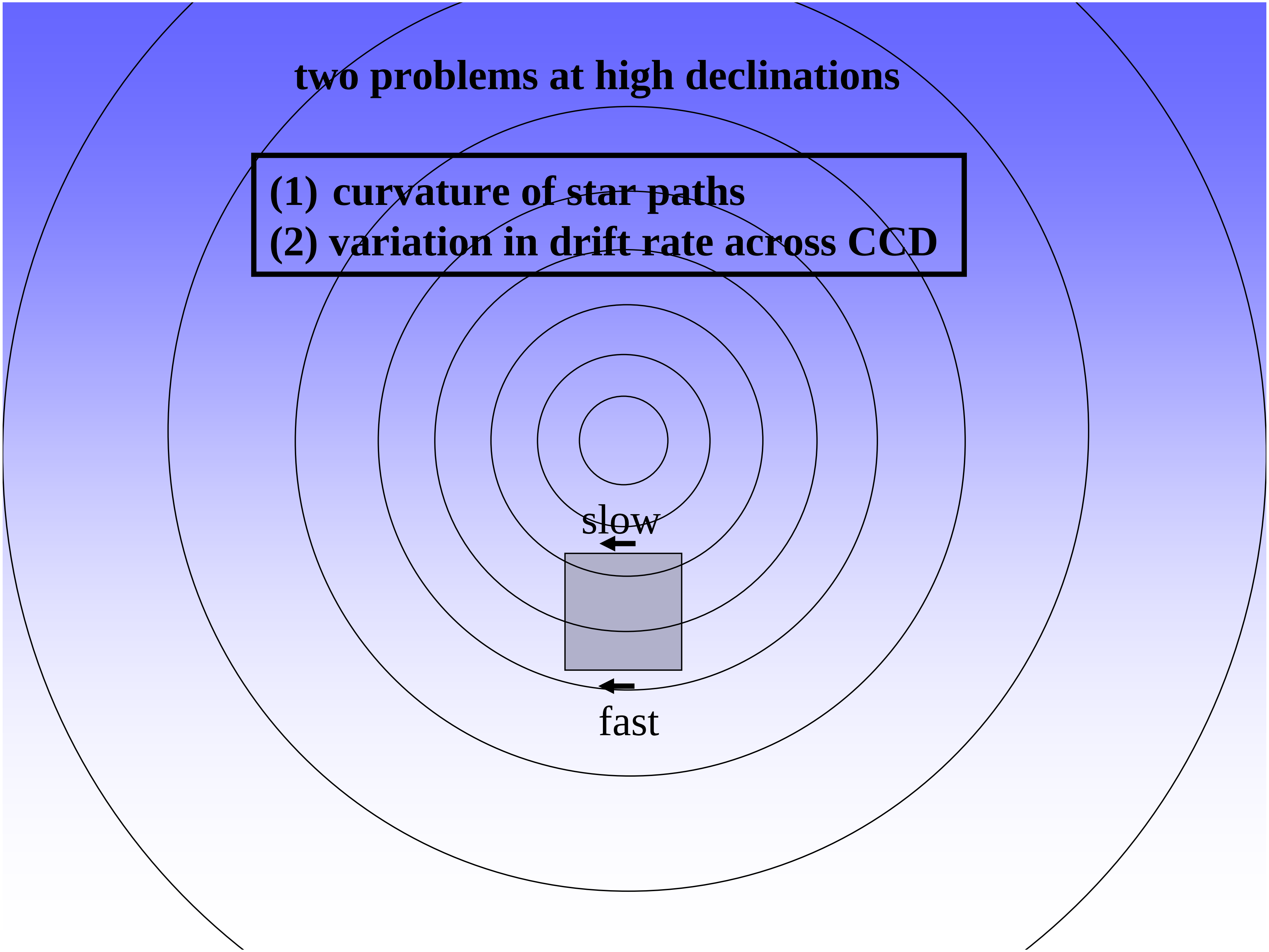
Why not to drift scan ?

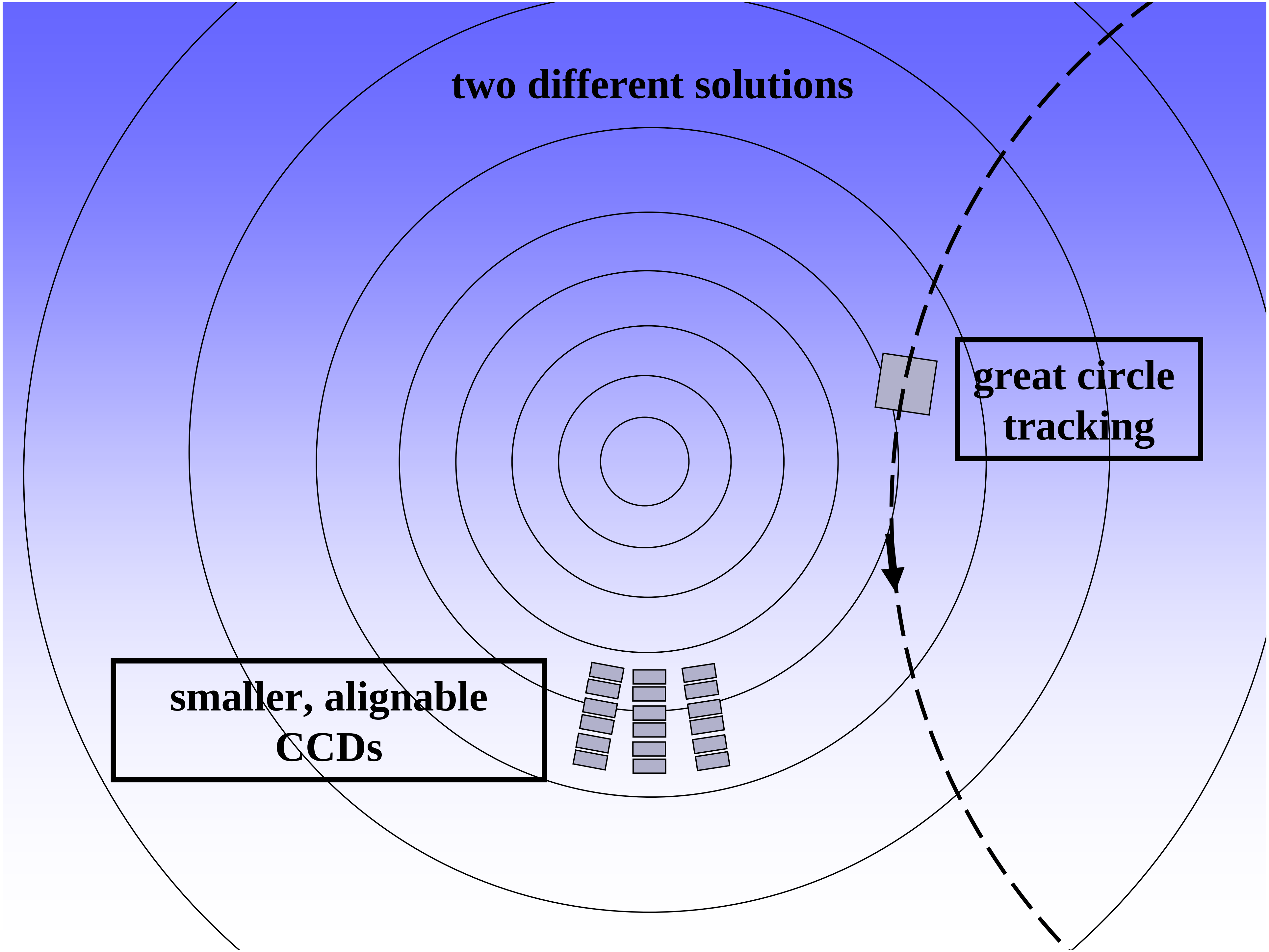
(1) difficult to drift scan far from equator

(2) scanning introduces some distortion to PSF

(3) images must be read and written at the same time

(4) variable sky conditions record spatially


two problems at high declinations
(1) curvature of star paths
(2) variation in drift rate across CCD
slow
fast


two different solutions
great circle tracking
smaller, alignable CCDs

II. Drift scanning telescopes and cameras

Drift scanning telescopes

0.9-m Spacewatch Telescope, Kitt Peak
1989 to 2003
(www.spacewatch.org)

2.5-m Sloan Digital Sky Survey Telescope, Apache Point
1999 to present
(www.sdss.org)

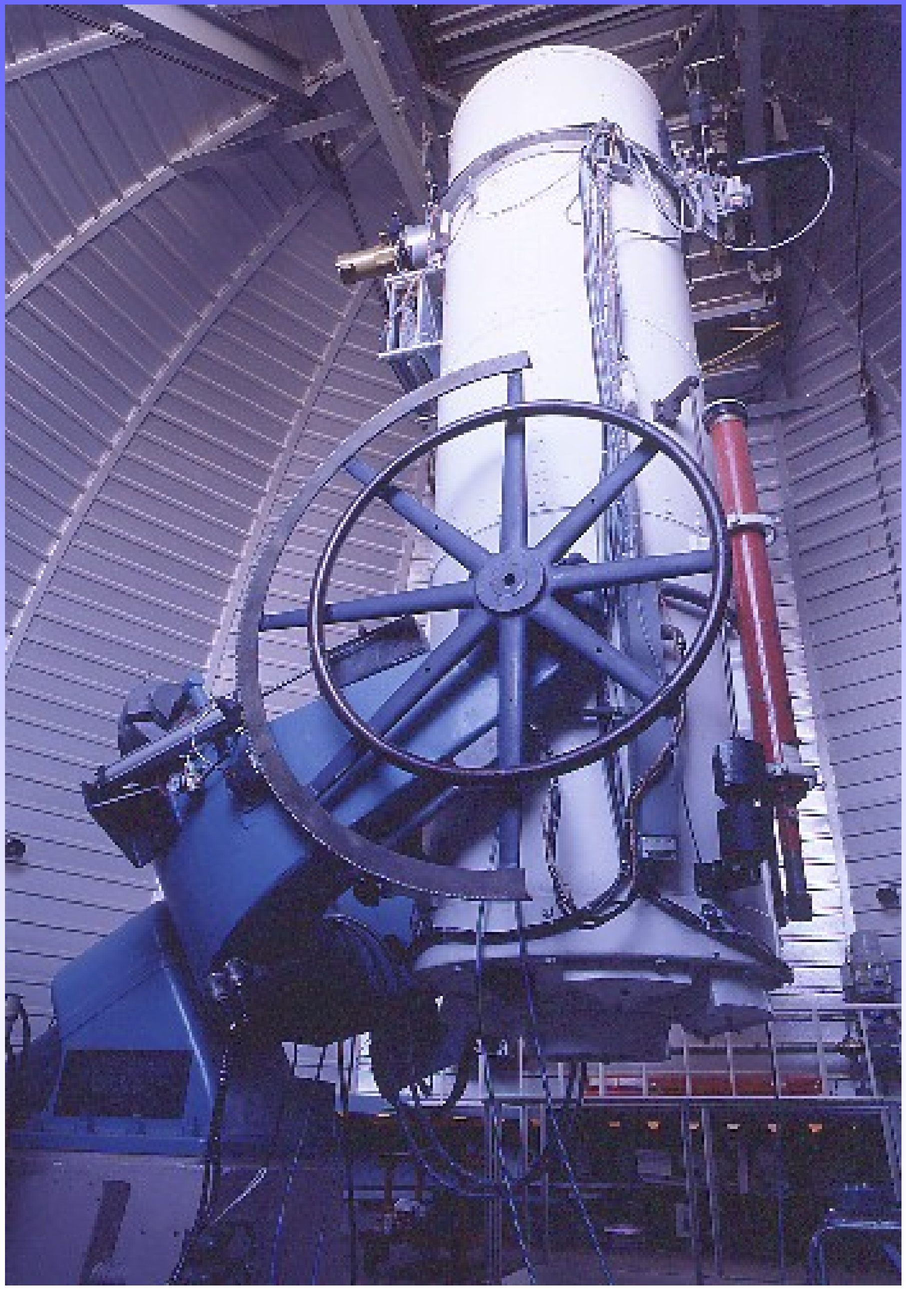
1.2-m Oschin Schmidt/Palomar-Quest camera, Palomar
2003 to present
(www.yale.edu/quest)

Spacewatch Telescope

optics:	Newtonian
aperture:	0.9m
focal ratio:	f/5.34
pixel scale:	1.05”
pixels:	1 x [2048x2048]
coverage:	0.3 deg^2

first telescope to automate discovery of asteroids

first drift-scan survey telescope



Sloan Survey Telescope

optics:	Ritchey-Chrétien
aperture:	2.5 m
focal ratio:	f/5.0
pixel scale:	0.44”
pixels:	30x[2048x2048]
coverage:	1.6 deg^2

First multi-color driftscan camera

scans on great circles

requires choreographed changes in RA, DEC tracking rates and image rotation

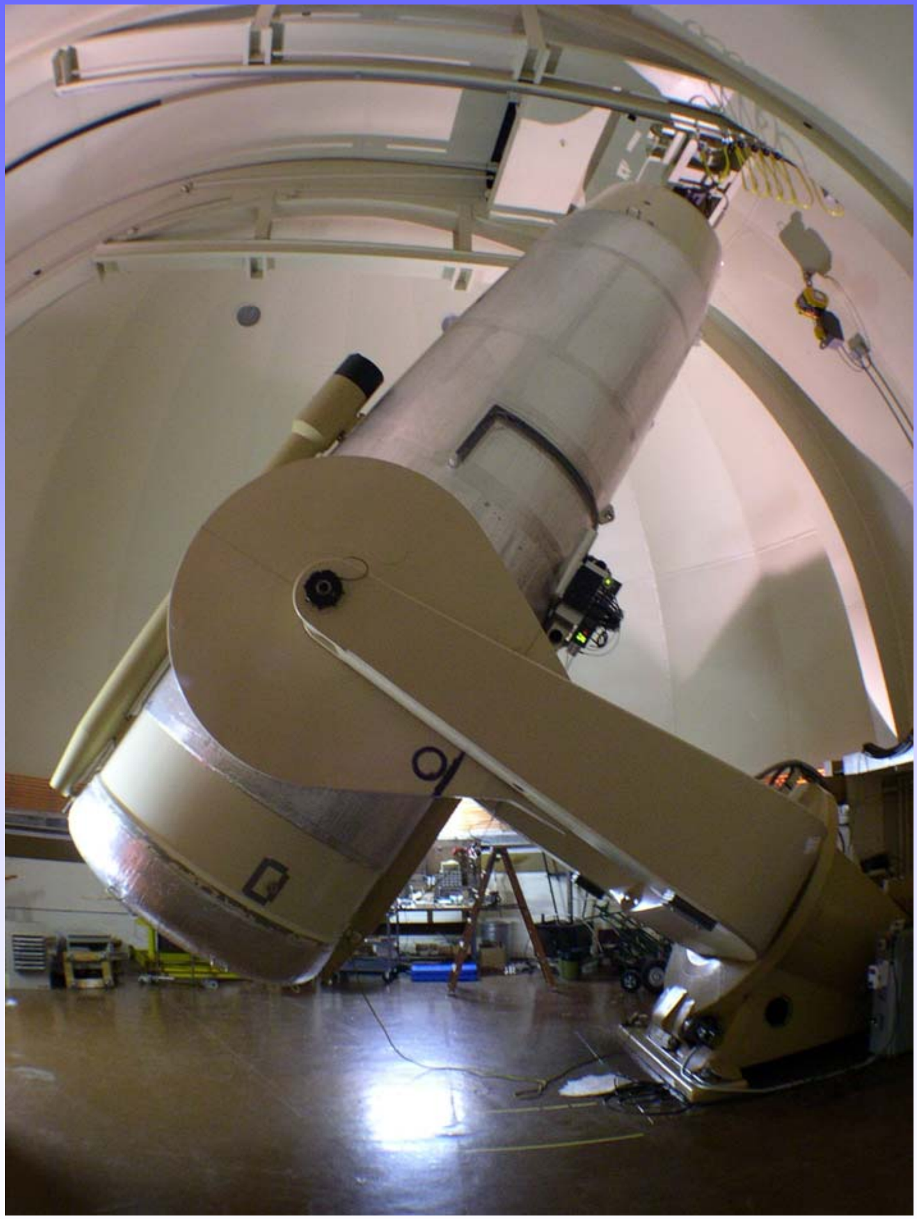
Palomar Quest Telescope

optics:	Schmidt
aperture:	1.3 m
focal ratio:	f/2.5
pixel scale:	0.88”
pixels:	112x[600x2400]
coverage:	9.6 deg^2

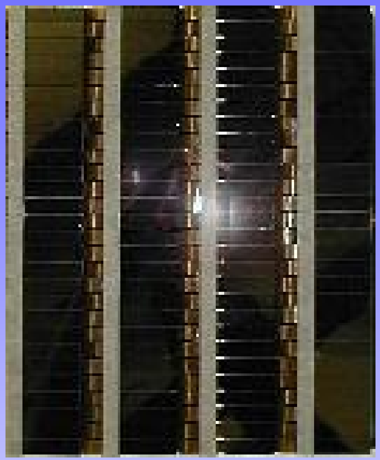
first wide-field survey for variable objects

covers 500 deg^2 per night in 4 colors

multiple coverage each year of Dec range -22.5 to +22.5



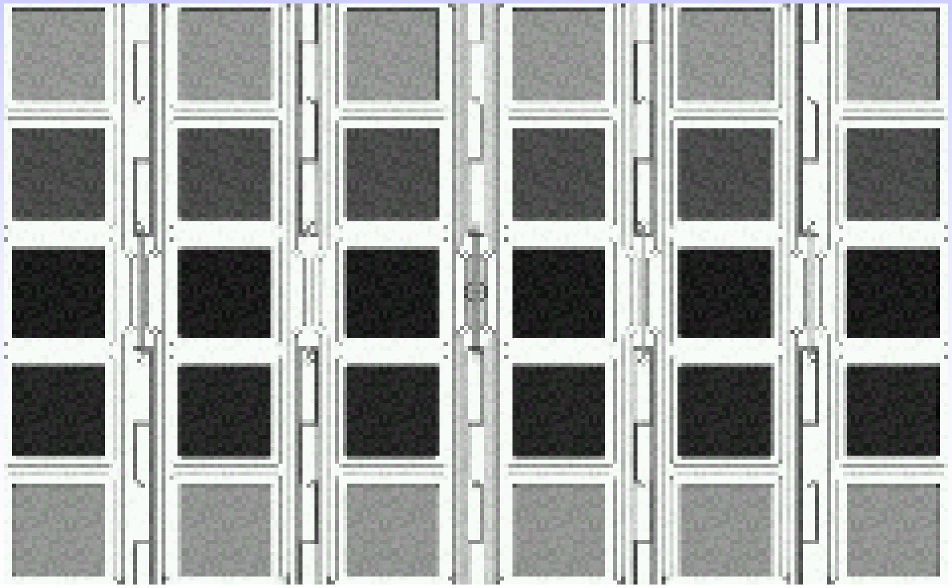
World's Largest CCD Cameras



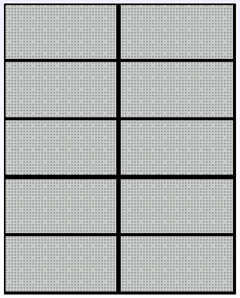
← 19 cm →

Palomar-Quest
112 600x2400

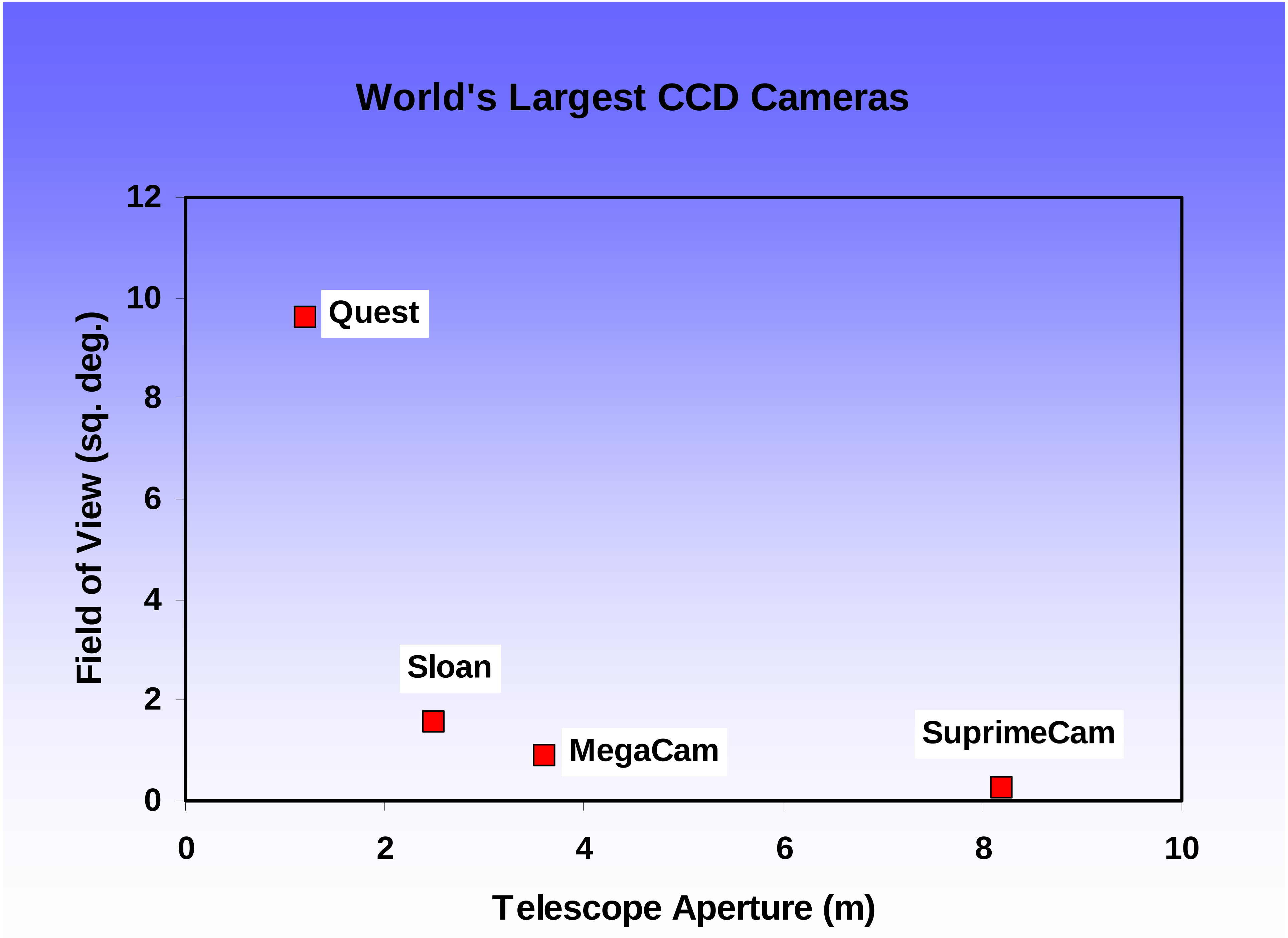
Megacam
36 2048x4612

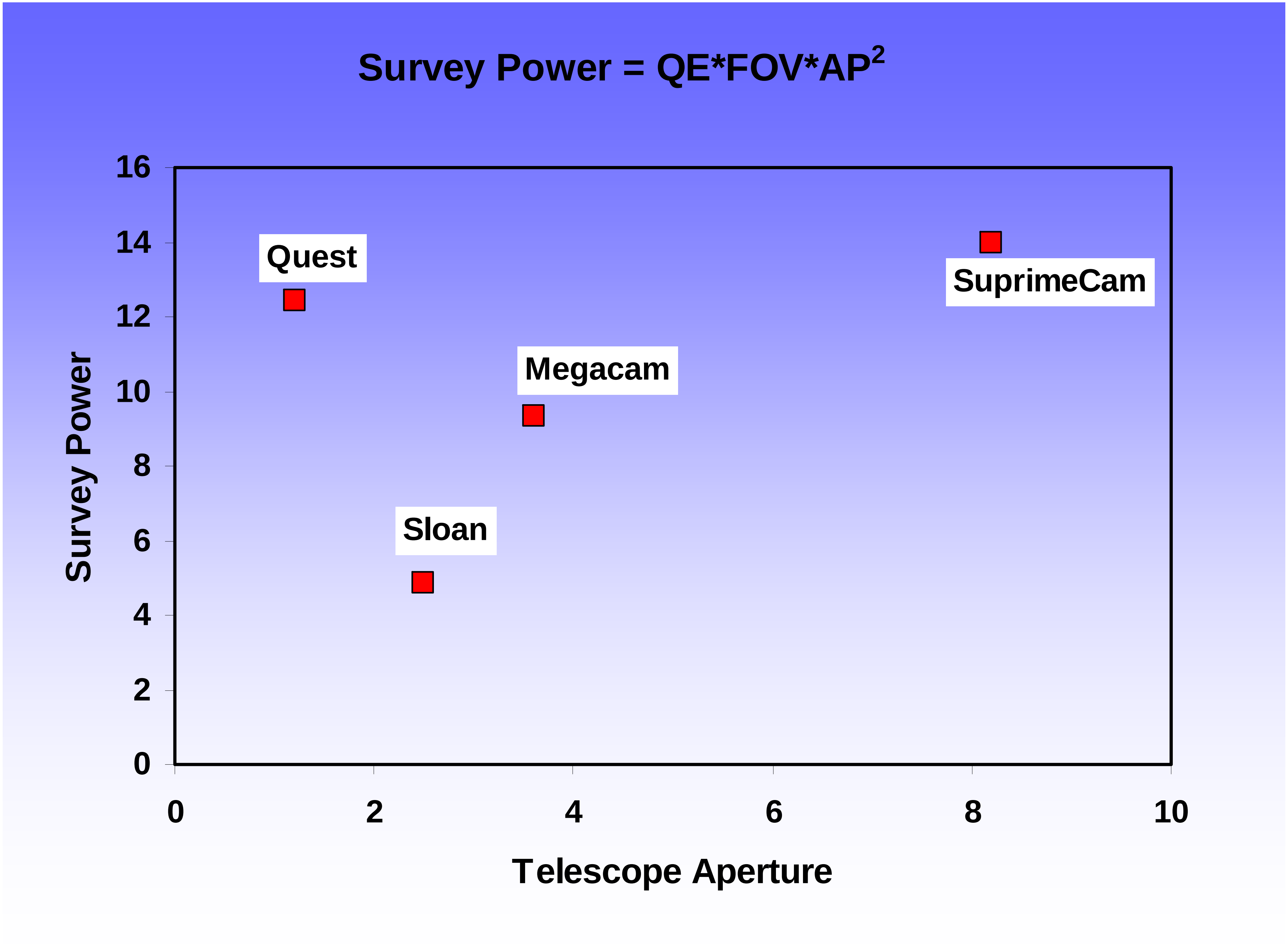


Sloan
30 2048x2048



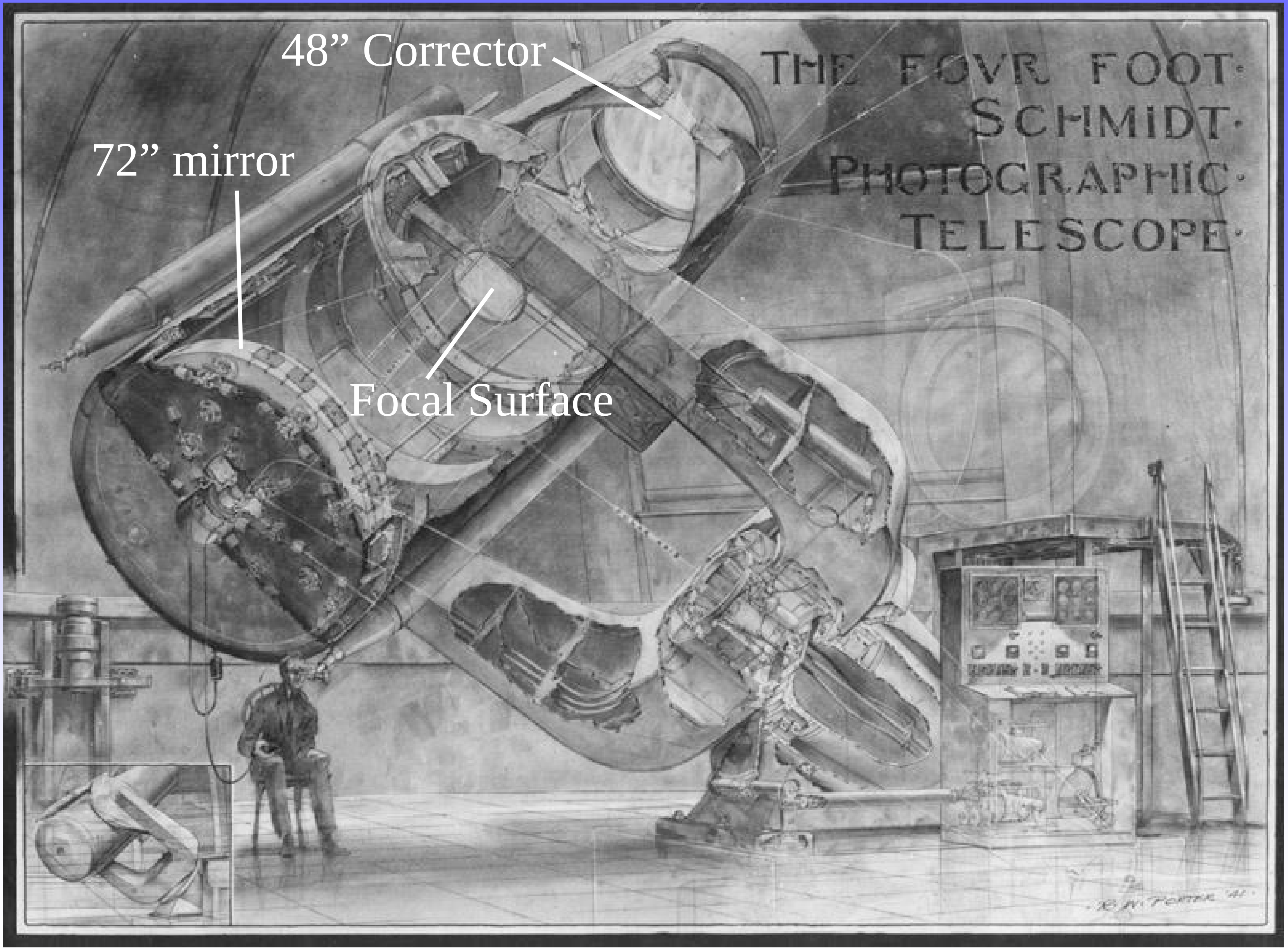
SuprimeCam
10 2048x4096


World's Largest CCD Cameras
Field of View (sq. deg.)
12
10
8
6
4
2
0
Quest
Sloan
MegaCam
SuprimeCam
0
2
4
6
8
10
Telescope Aperture (m)

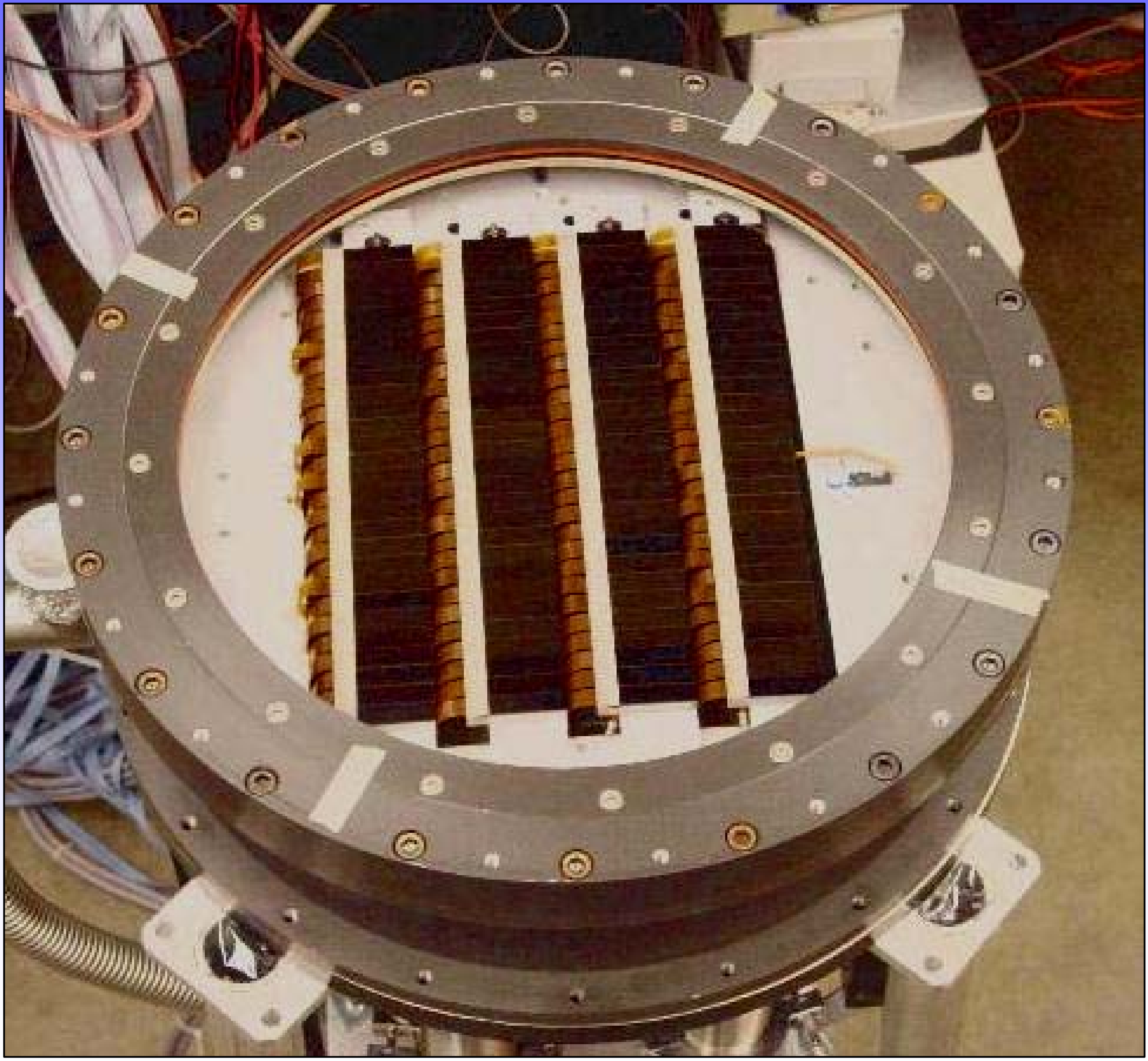

Survey Power = QE*FOV*AP2
Survey Power
Telescope Aperture
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
Quest
SuprimeCam
Megacam
Sloan

III. The Palomar Quest camera

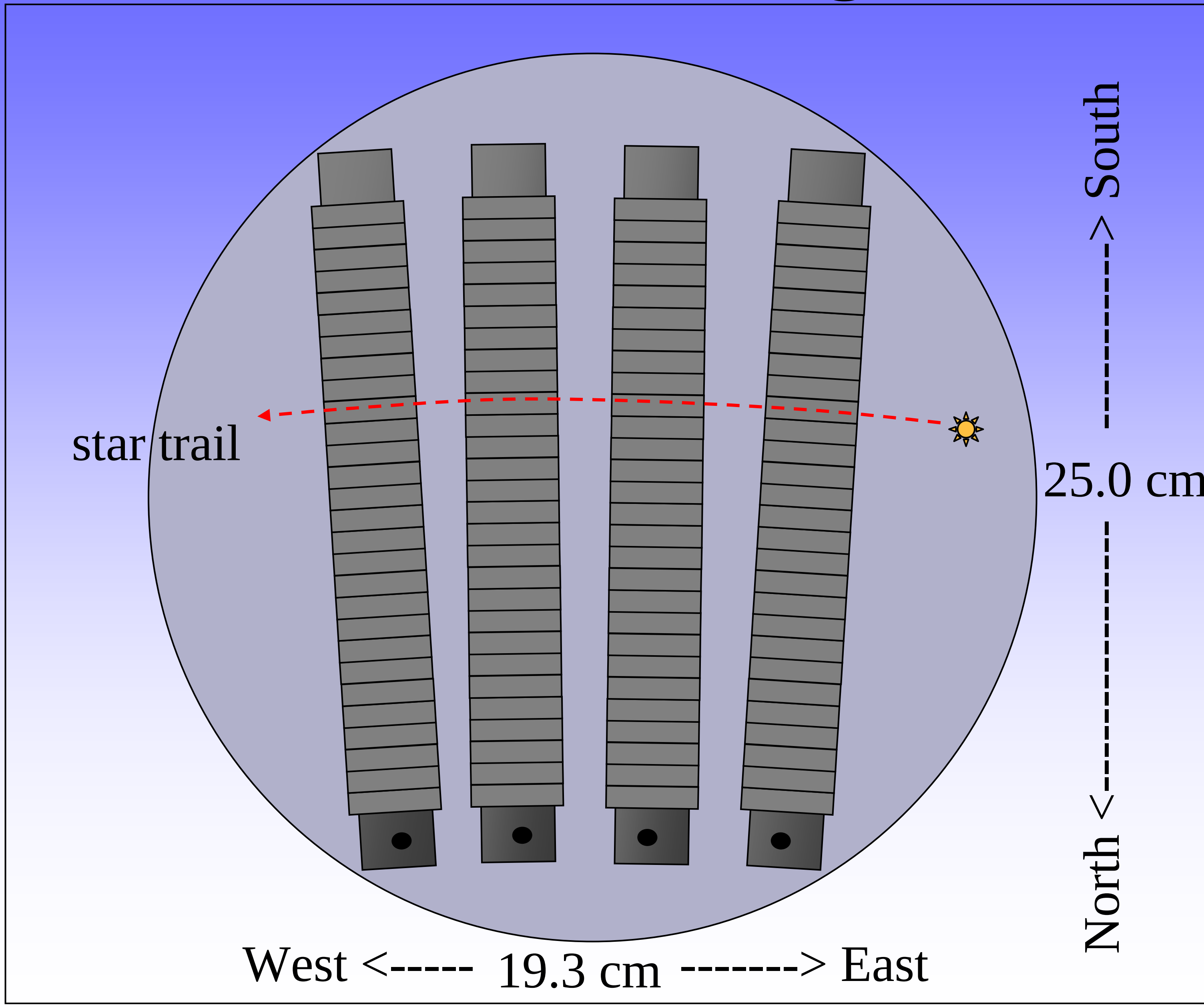
The 48” Oschin Schmidt at Palomar



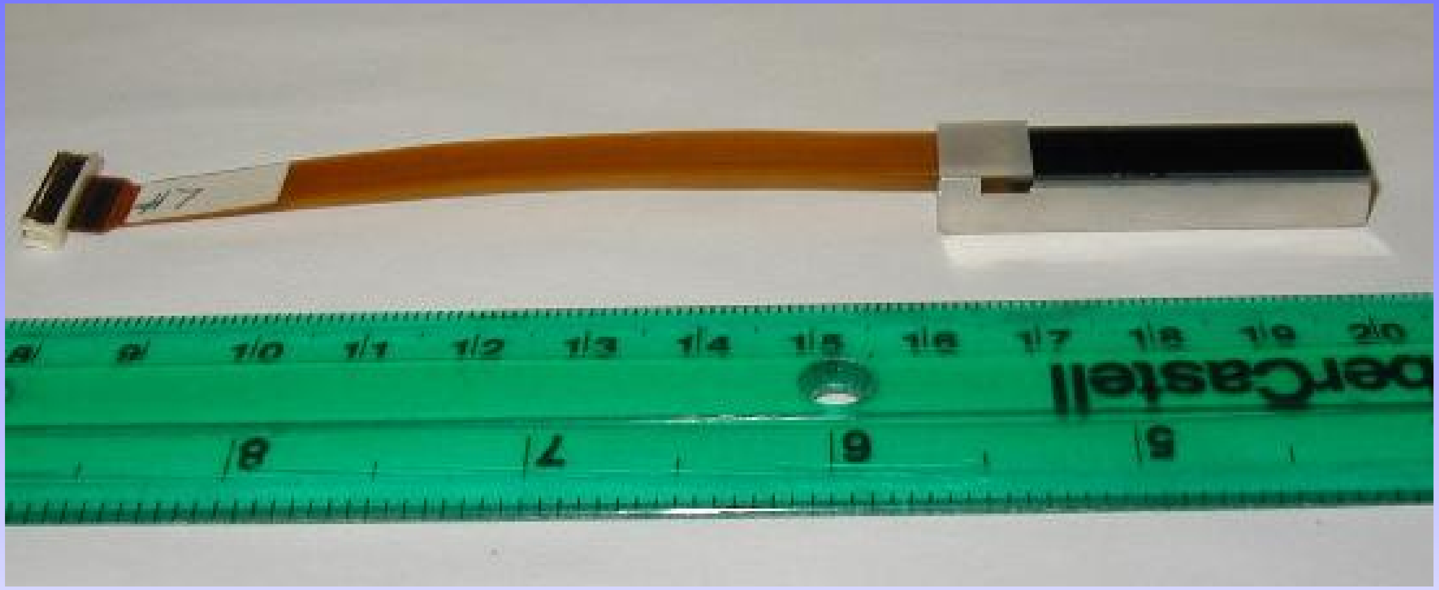
Palomar/Quest Camera



Drift-scanning

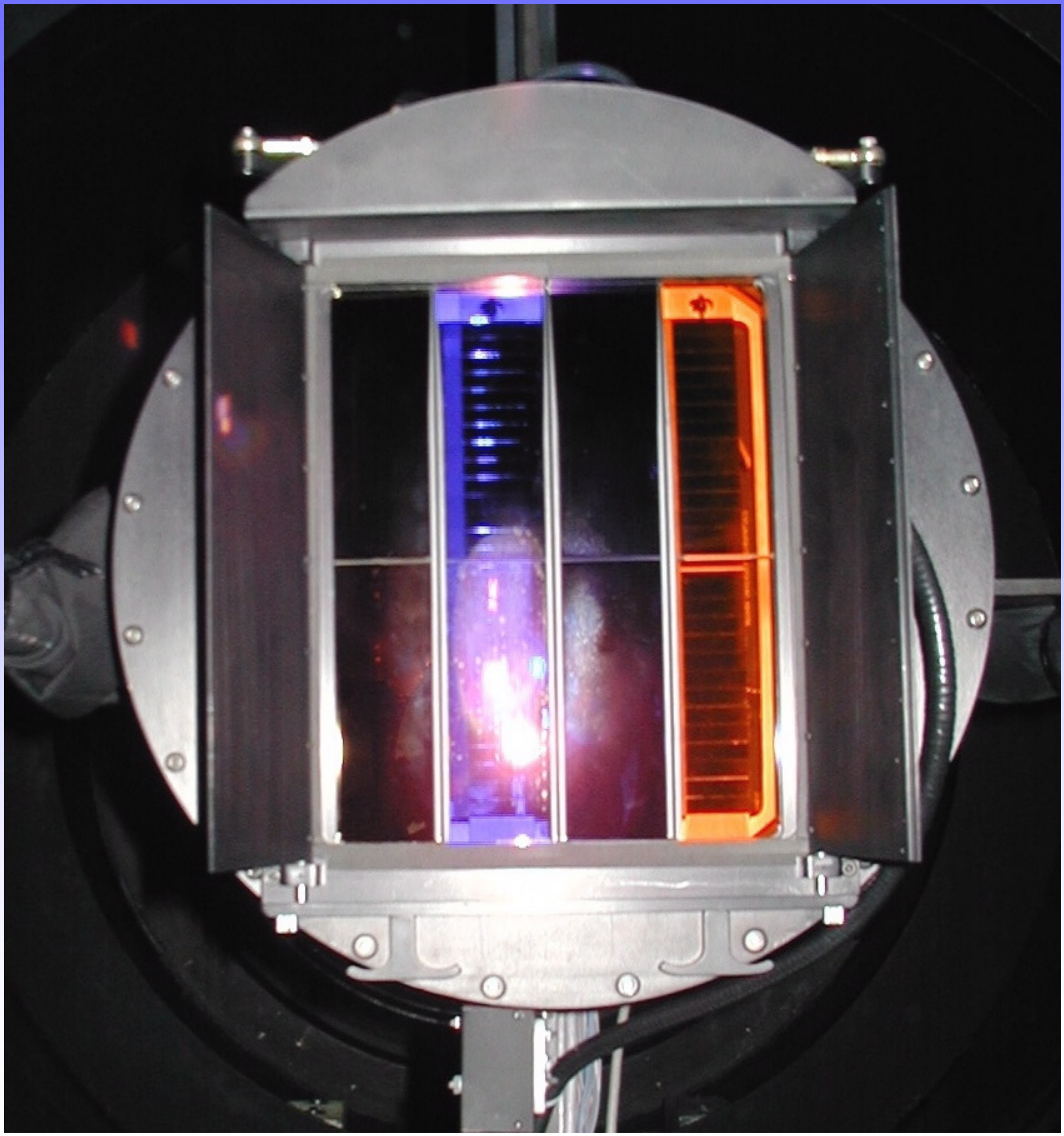


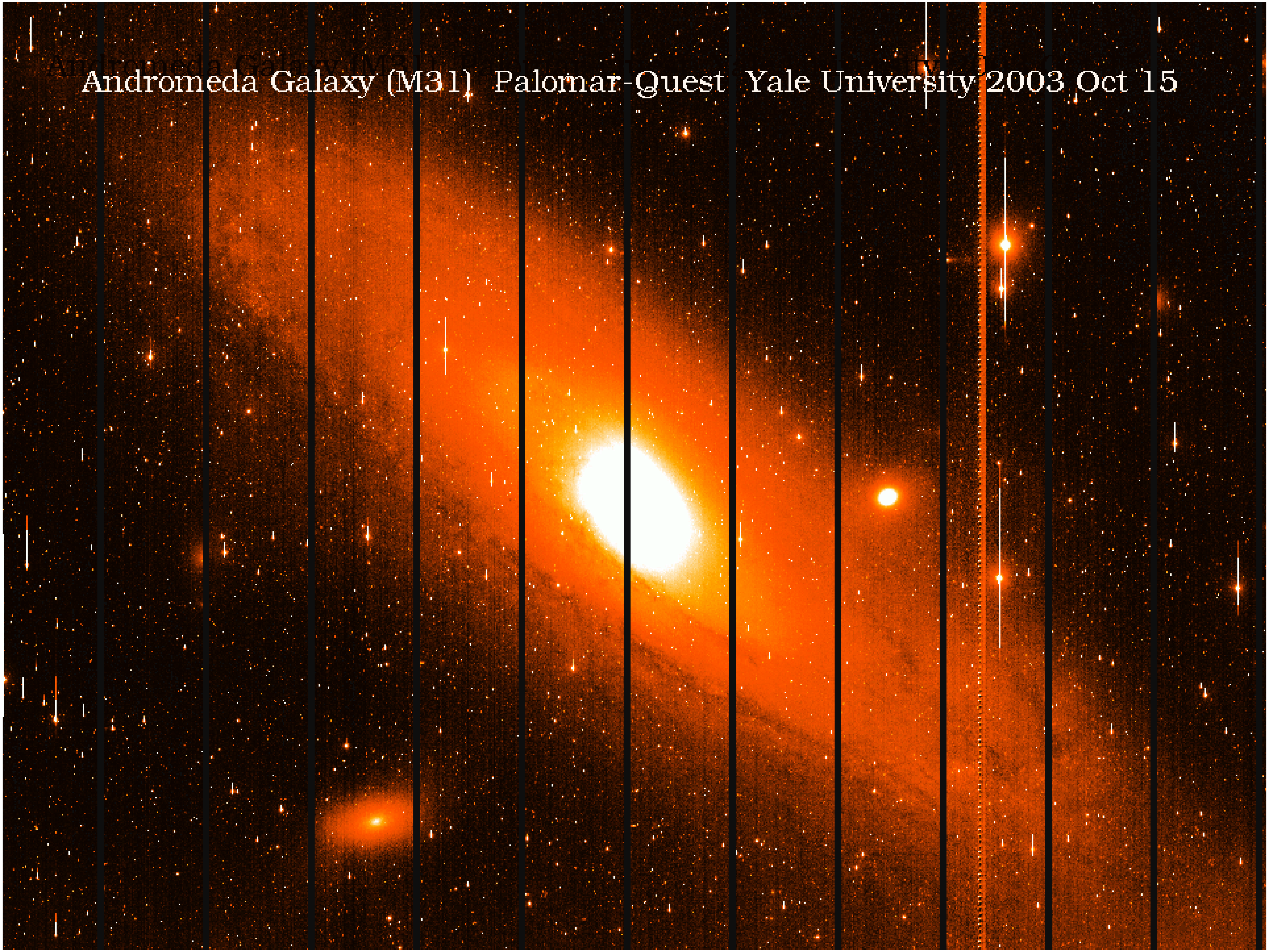
Palomar Quest CCD

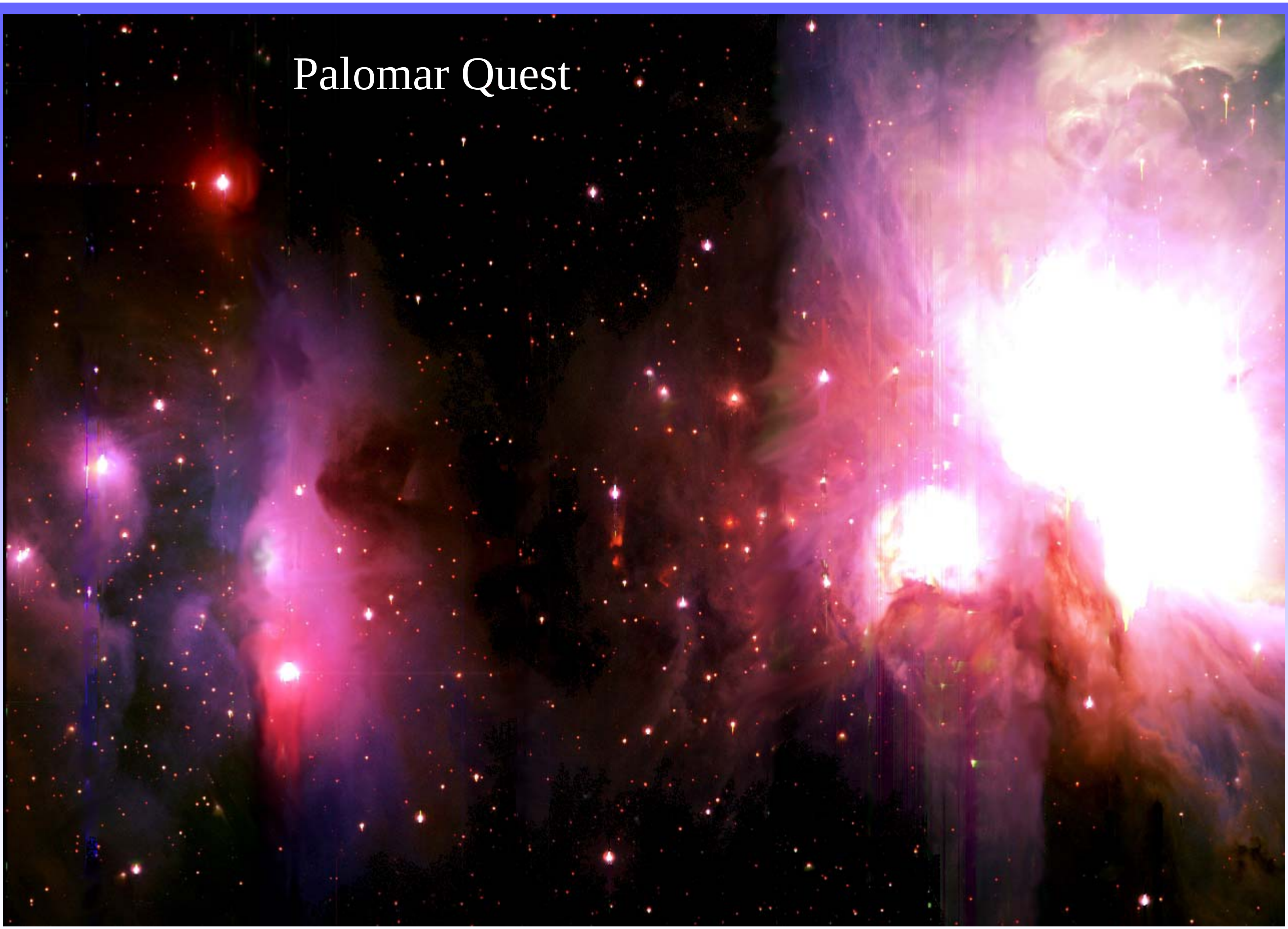


- thinned, back-illuminated
-fabricated for Yale by Sarnoff Corporation
- 2400 x 600 pixels (RA x Dec)
-optimal for scanning at |Dec| < 25°

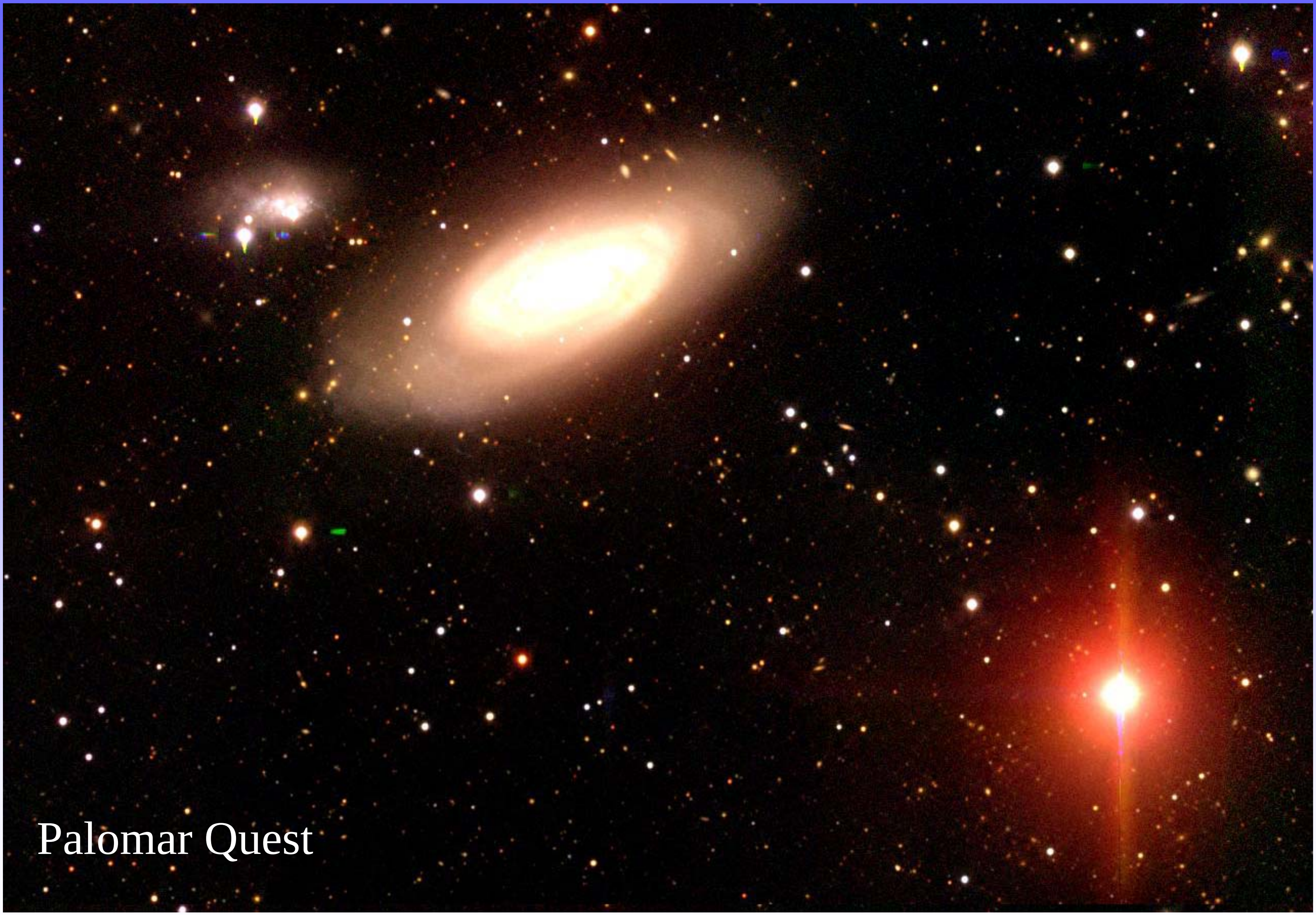
Color Photometry




Andromeda Galaxy (M31) Palomar-Quest Yale University 2003 Oct 15



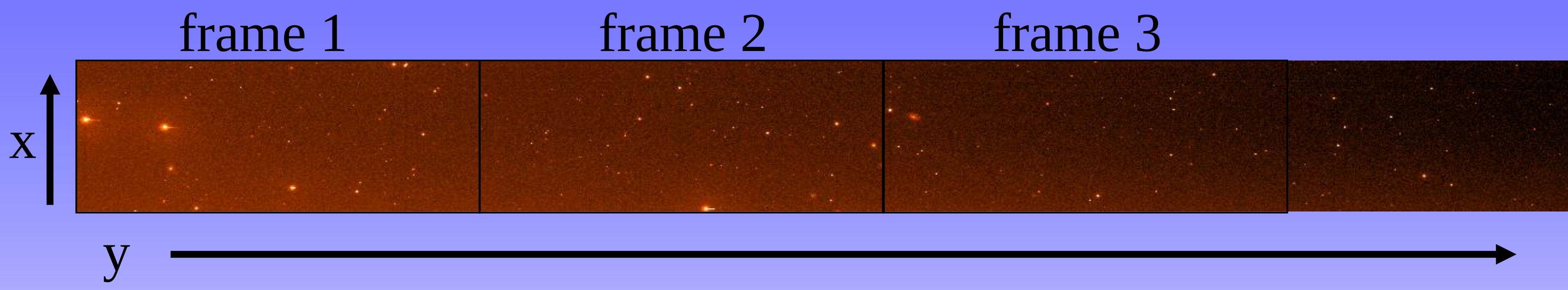
Orion Nebula Driftscan: BRI-composite, 140-sec exposure



M90, Virgo cluster: BRI-composite

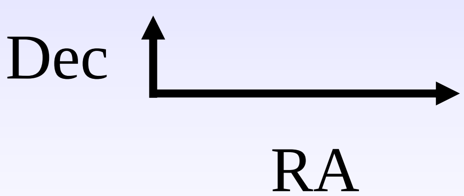
III. Astrometry with Palomar-Quest drift scans

drift scan astrometry



right ascension = $A_1 y + C_1$

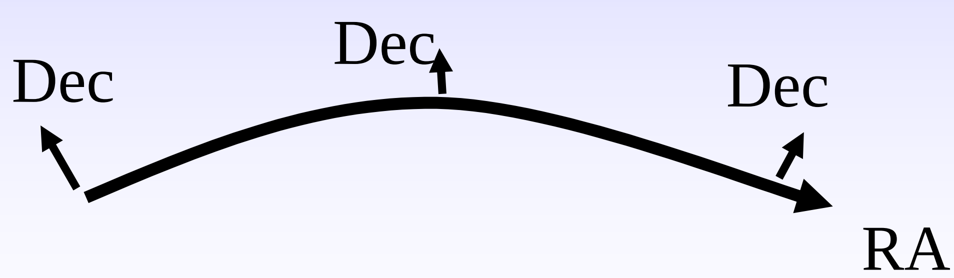
declination = $A_2 x + C_2$



of-date reference coordinates

right ascension = $A'_1 y + B'_1 x + C'_1$

declination = $A'_2 x + B'_2 y + C'_2$



catalog coordinate system

Palomar Quest astrometry

(1) find objects, measure their centers (pixel coords x,y)

(2) Precess catalog from J2000 to of-date reference frame

(3) match objects to catalog (triangle match)

(4) find transformation from x,y to of-date ra,dec

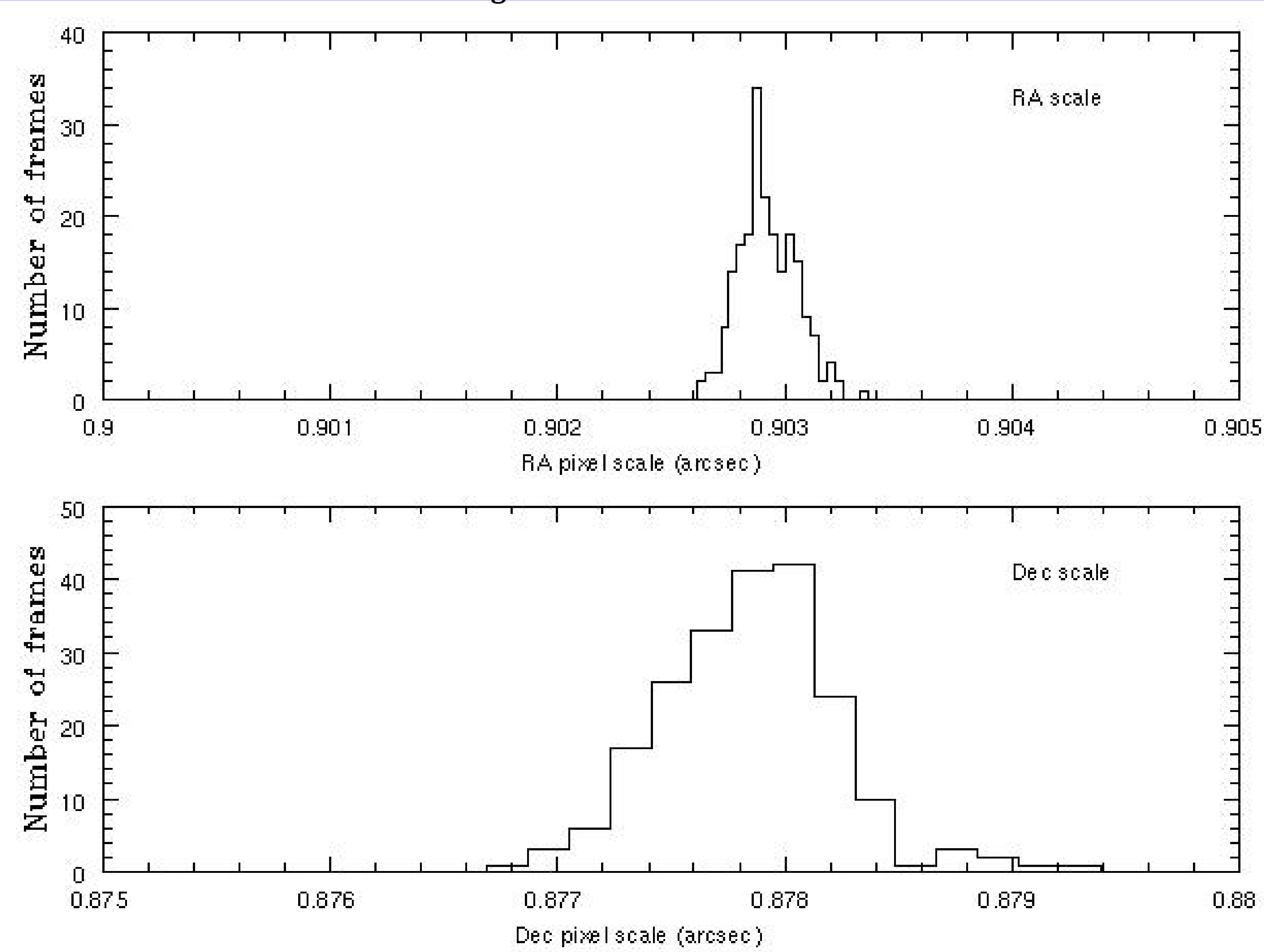
(5) Calculate of-date ra,dec for each object

(6) Precess objects positions from of-date to J2000

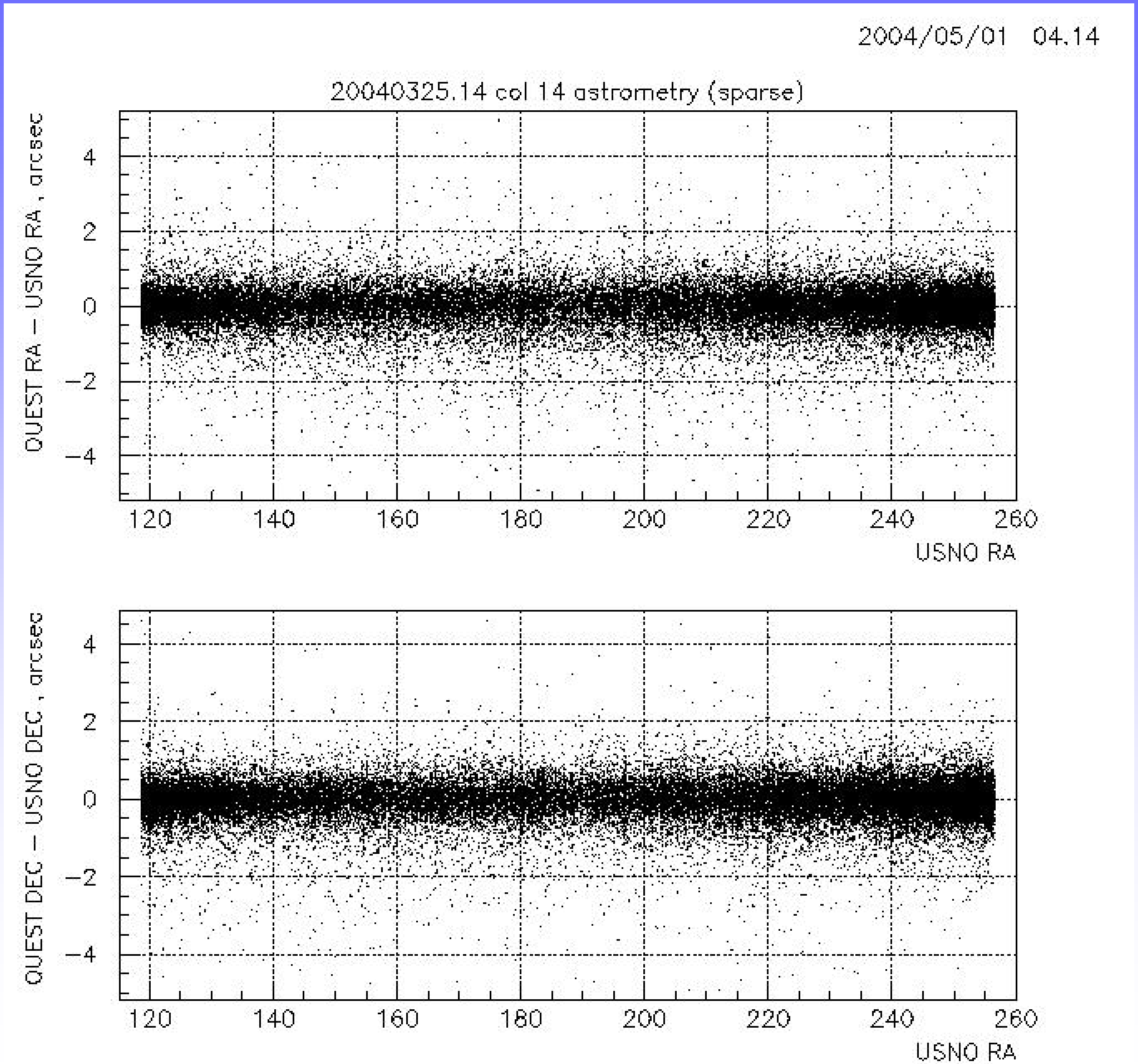
(7) Find transformation from x,y to J2000 ra,dec

Distribution of RA and Dec pixel scales

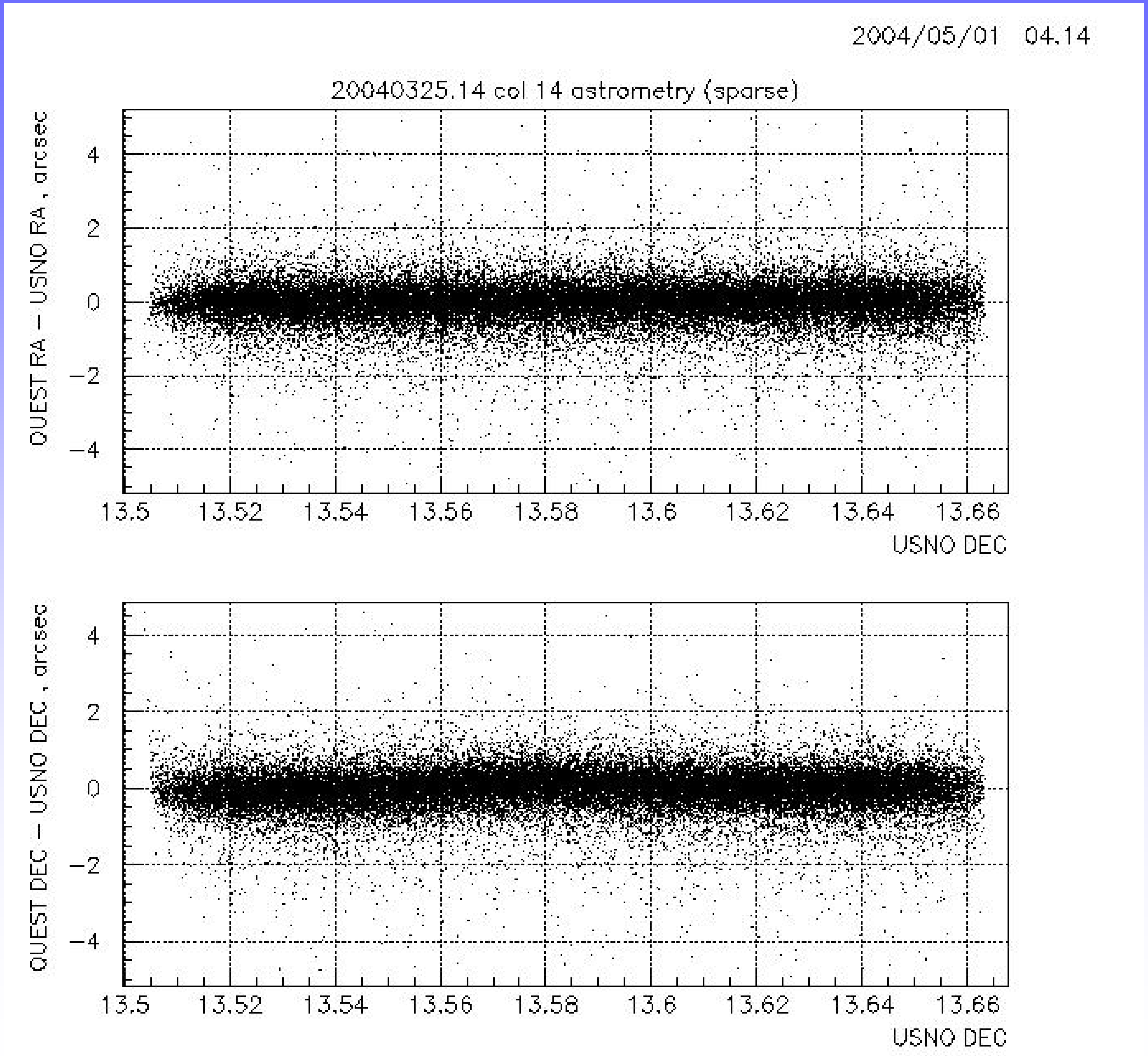
Single drift scan at Dec = 13.5°



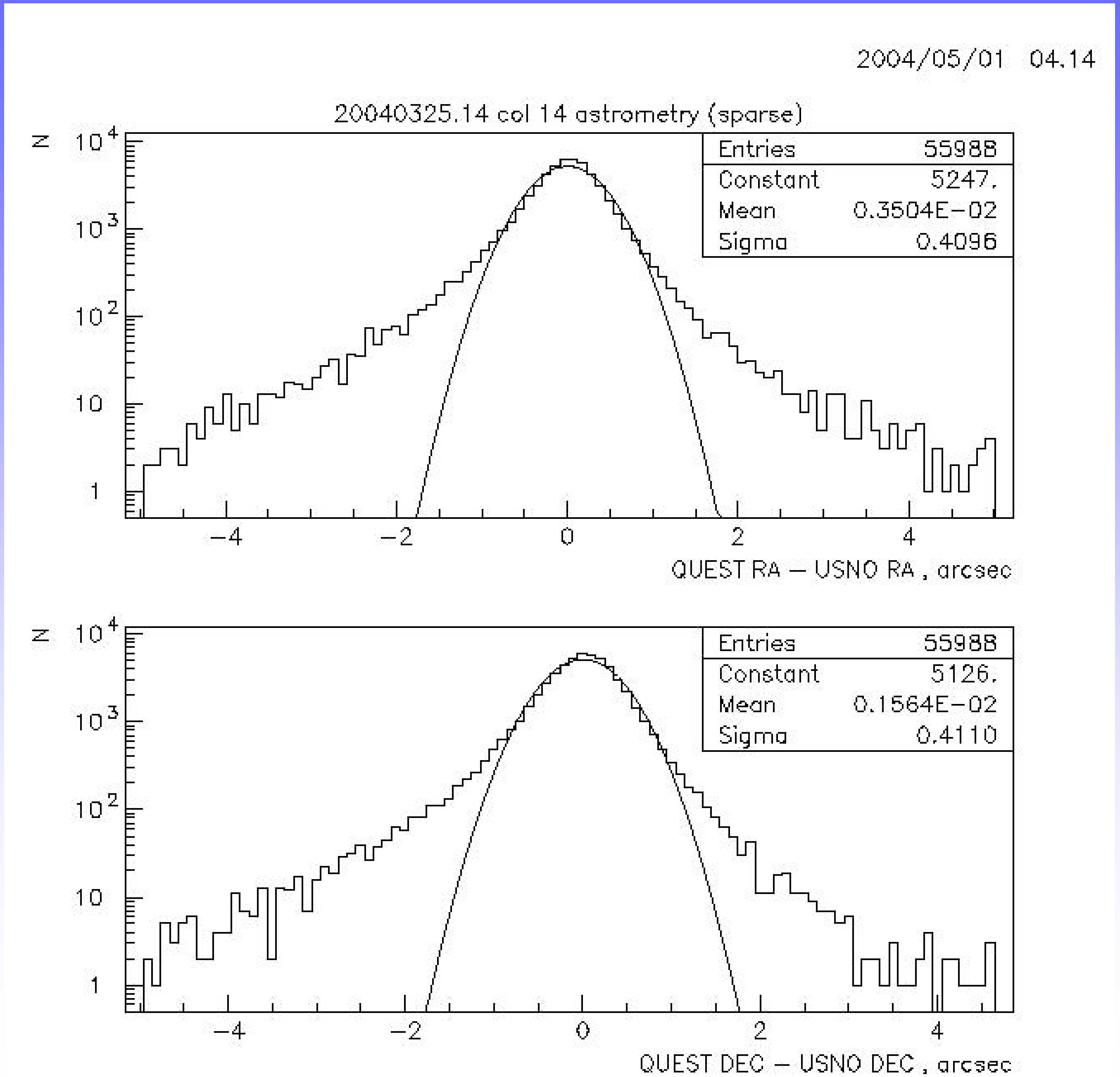
RA and Dec residuals vs RA



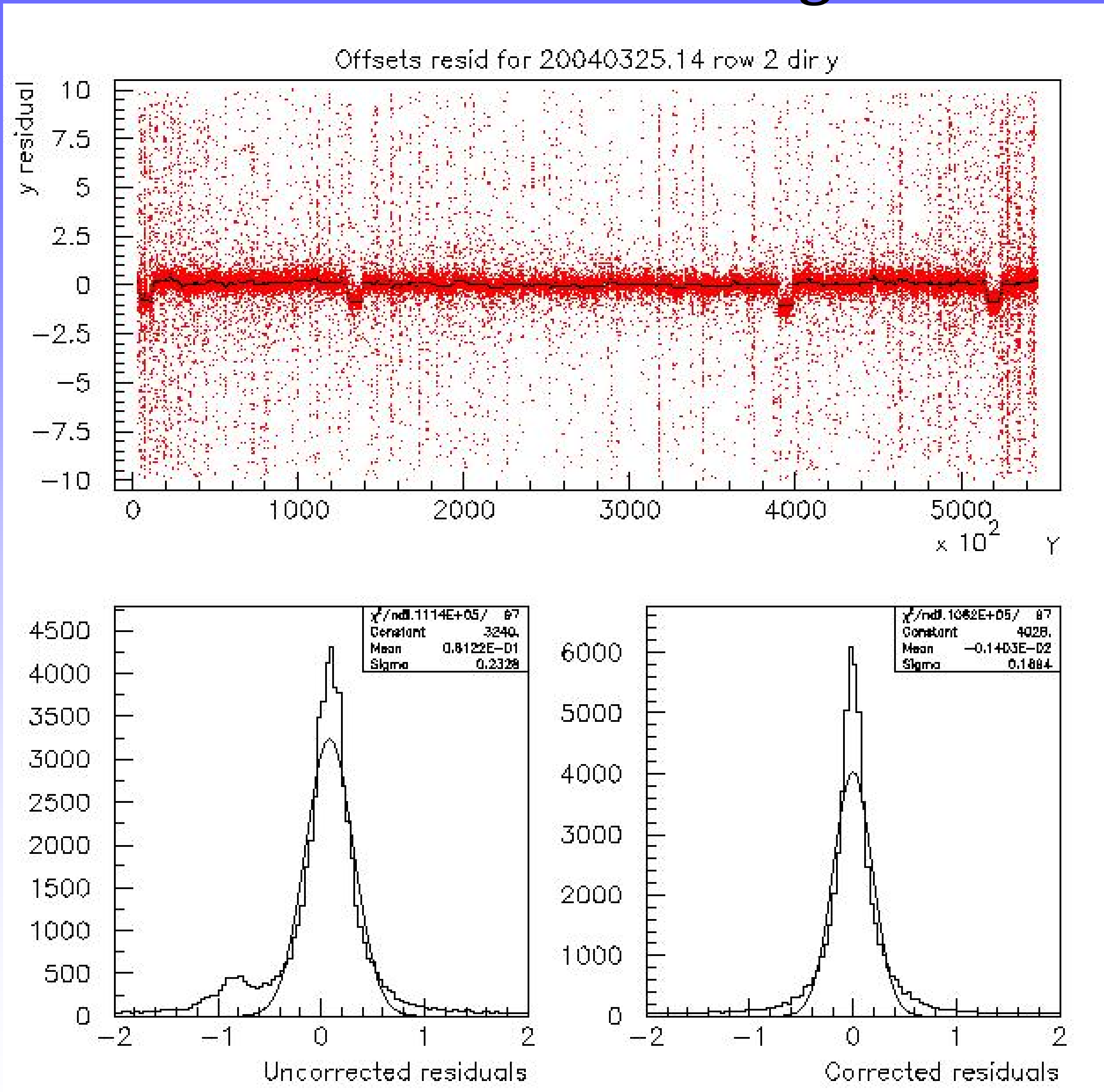
RA and Dec residuals vs Dec



Distribution of RA and Dec residuals



Precision of scan to scan registration



Conclusions

(1) hardware is complicated

(2) astrometry is easy

(3) millions of stars routinely catalogued over wide area to precision of reference catalog (~0.5”).

(4) Absolute precision limited to ~0.1” for Palomar Quest