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

parallel shift

horizontal shift register

output amplifier
What is drift scanning?

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

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

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

Parallel shift direction
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
two different solutions

smaller, alignable CCDs

great circle tracking
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**

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<th>Newtonian</th>
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<td>0.3 deg²</td>
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- first telescope to automate discovery of asteroids
- first drift-scan survey telescope
Sloan Survey Telescope

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
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<tbody>
<tr>
<td>optics</td>
<td>Ritchey-Chrétien</td>
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<tr>
<td>aperture</td>
<td>2.5 m</td>
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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 deg²

First wide-field survey for variable objects

Covers 500 deg² per night in 4 colors

Multiple coverage each year of Dec range -22.5 to +22.5
World’s Largest CCD Cameras

- Palomar-Quest
  - 112
  - 600x2400

- Megacam
  - 36
  - 2048x4612

- Sloan
  - 30
  - 2048x2048

- SuprimeCam
  - 10
  - 2048x4096
World's Largest CCD Cameras

![Graph showing the relationship between Telescope Aperture (m) and Field of View (sq. deg.). The graph compares different cameras: Quest, Sloan, MegaCam, and SuprimeCam.](image-url)
Survey Power = QE*FOV*AP^2

![Graph showing Telescope Aperture vs Survey Power for Quest, Sloan, and SuprimeCam.](image-url)
III. The Palomar Quest camera
The 48” Oschin Schmidt at Palomar

- 48” Corrector
- 72” mirror
- Focal Surface
Palomar/Quest Camera
Palomar Quest CCD

- thinned, back-illuminated
- fabricated for Yale by Sarnoff Corporation
- 2400 x 600 pixels (RA x Dec)
- optimal for scanning at $|\text{Dec}| < 25^\circ$
Color Photometry
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 = $A_1y + C_1$
declination = $A_2x + C_2$

right ascension = $A'_1y + B'_1x + C'_1$
declination = $A'_2x + B'_2y + C'_2$

of-date reference coordinates  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
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