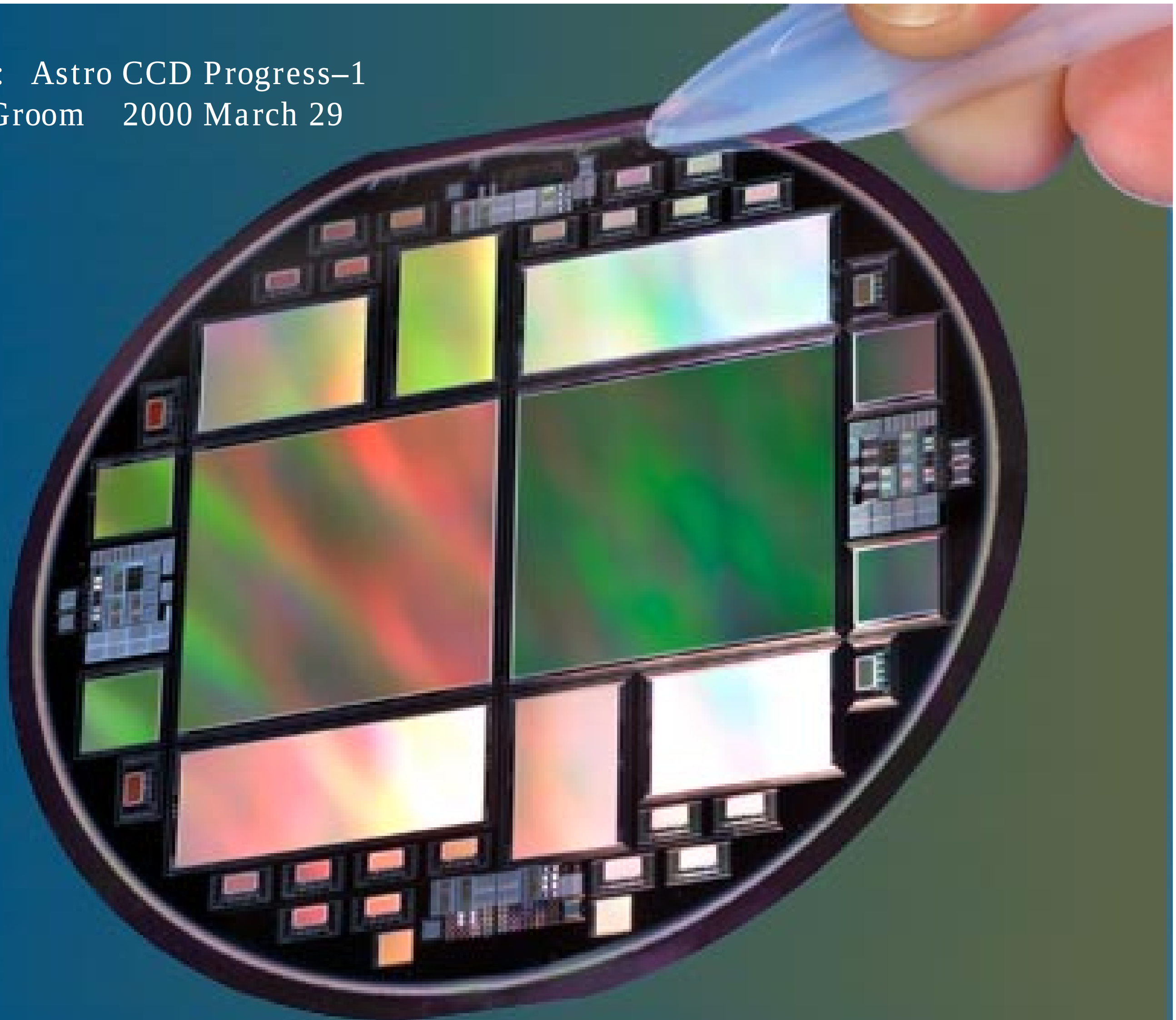
AS00: Astro CCD Progress–1
Don Groom 2000 March 29



Recent Progress in CCDs for Astronomical Imaging

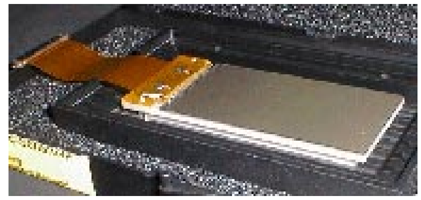
Don Groom
http://ccd.lbl.gov
Lawrence Berkeley National Laboratory

Presented on behalf of the rest of the UC/LBNL+UCO/Lick group

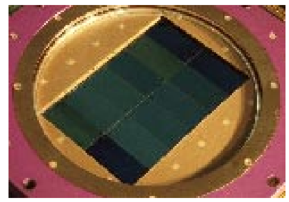
. . . Steve Holland, 2000 January

. . . and with thanks to many of you for your patience and help

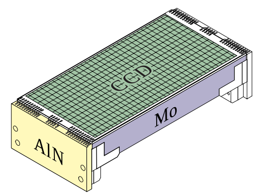
- Background



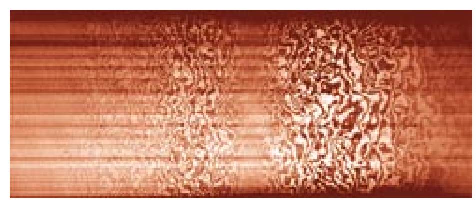
- Bigger CCDs



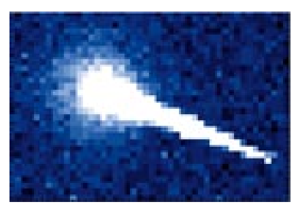
- Bigger arrays



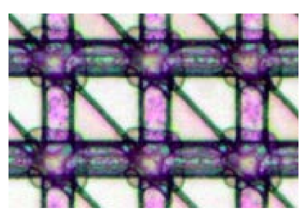
- 4-side abutment



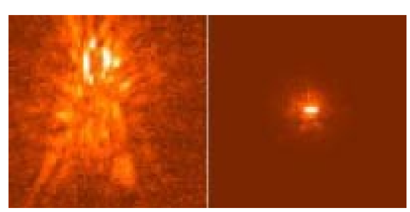
- Red response



- Transverse diffusion (MTF)

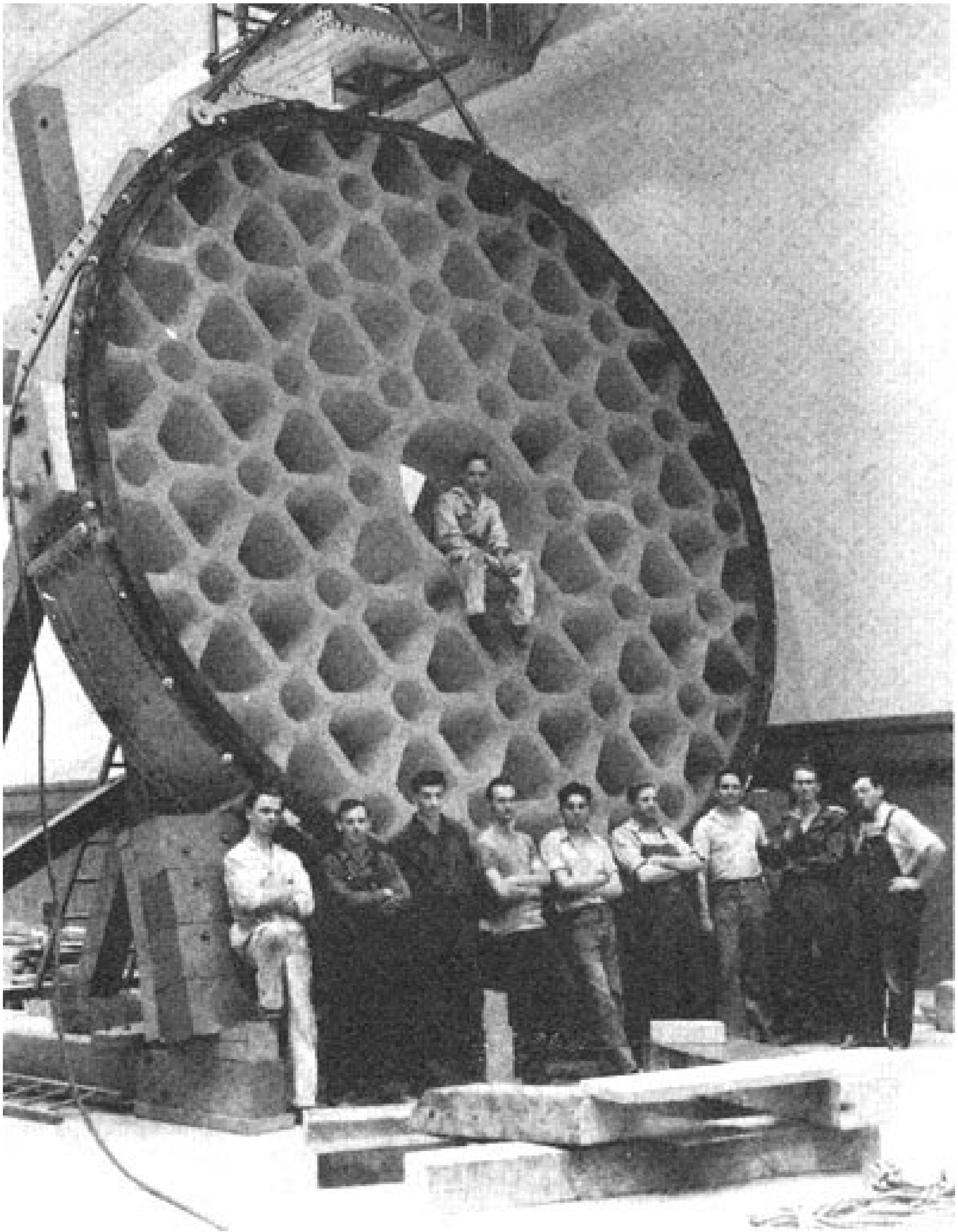


- Orthogonal transfer CCDs



- CCDs for adaptive optics

Public interest and publicity have always surrounded the construction of big telescopes. . .



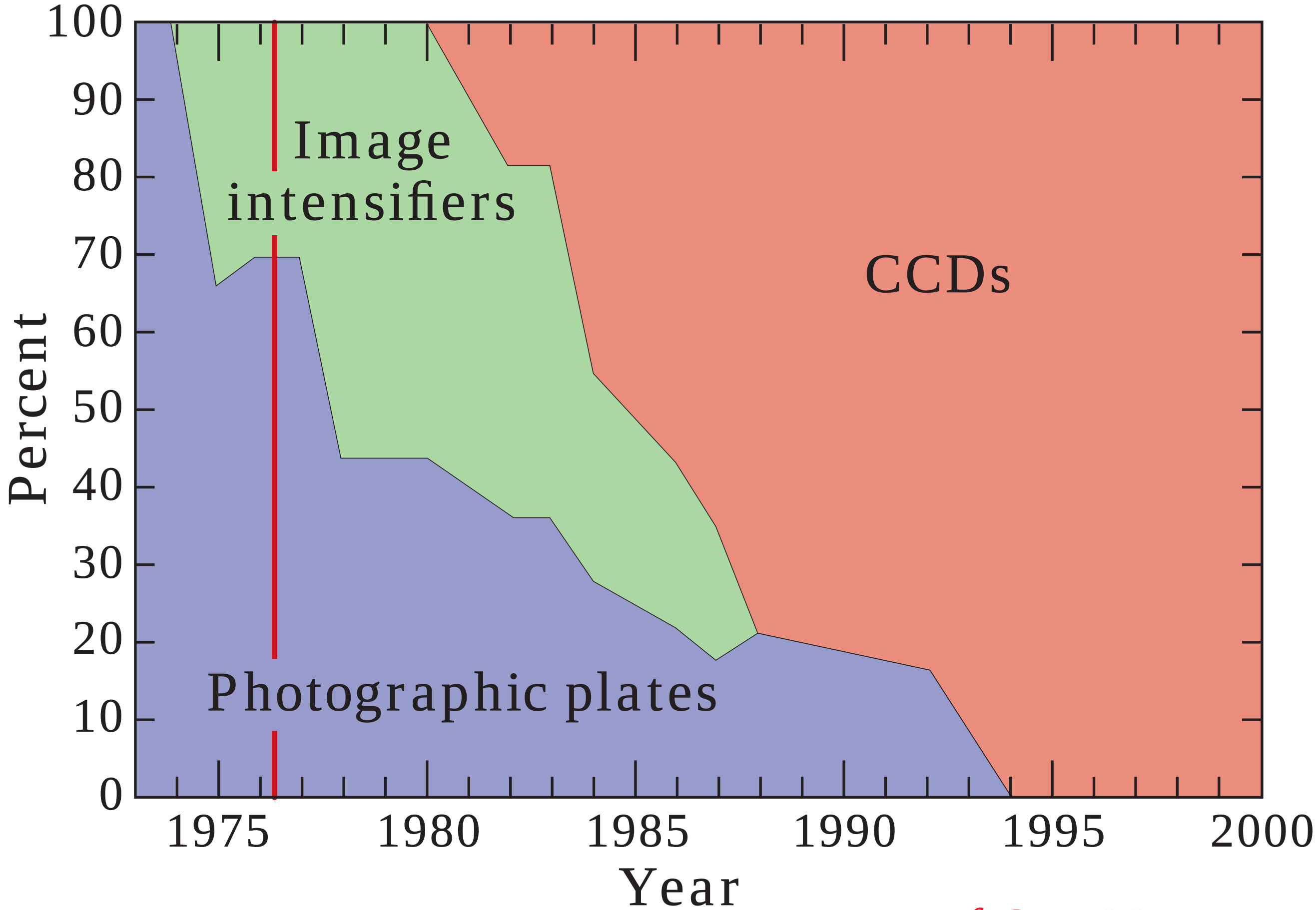
Pasadena, 1936 April

. . . but the real revolution came as a thief in the night

JPL Traveling CCD Camera System
1976, Mt. Lemon 1.5 m
(*Thinned* 400 × 400)

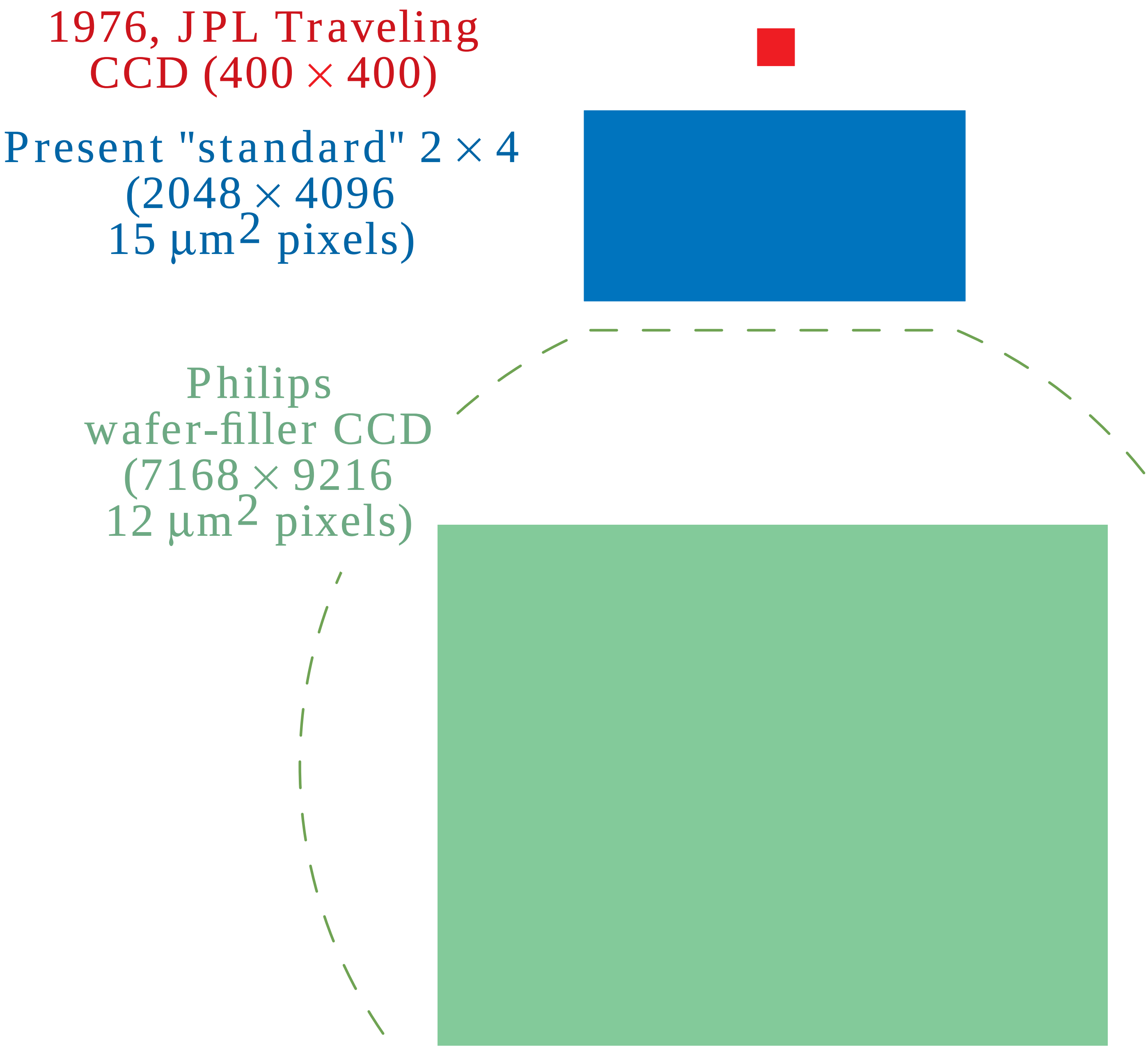
The takeover has been fairly complete.

ESO optical sensitive area demographics:



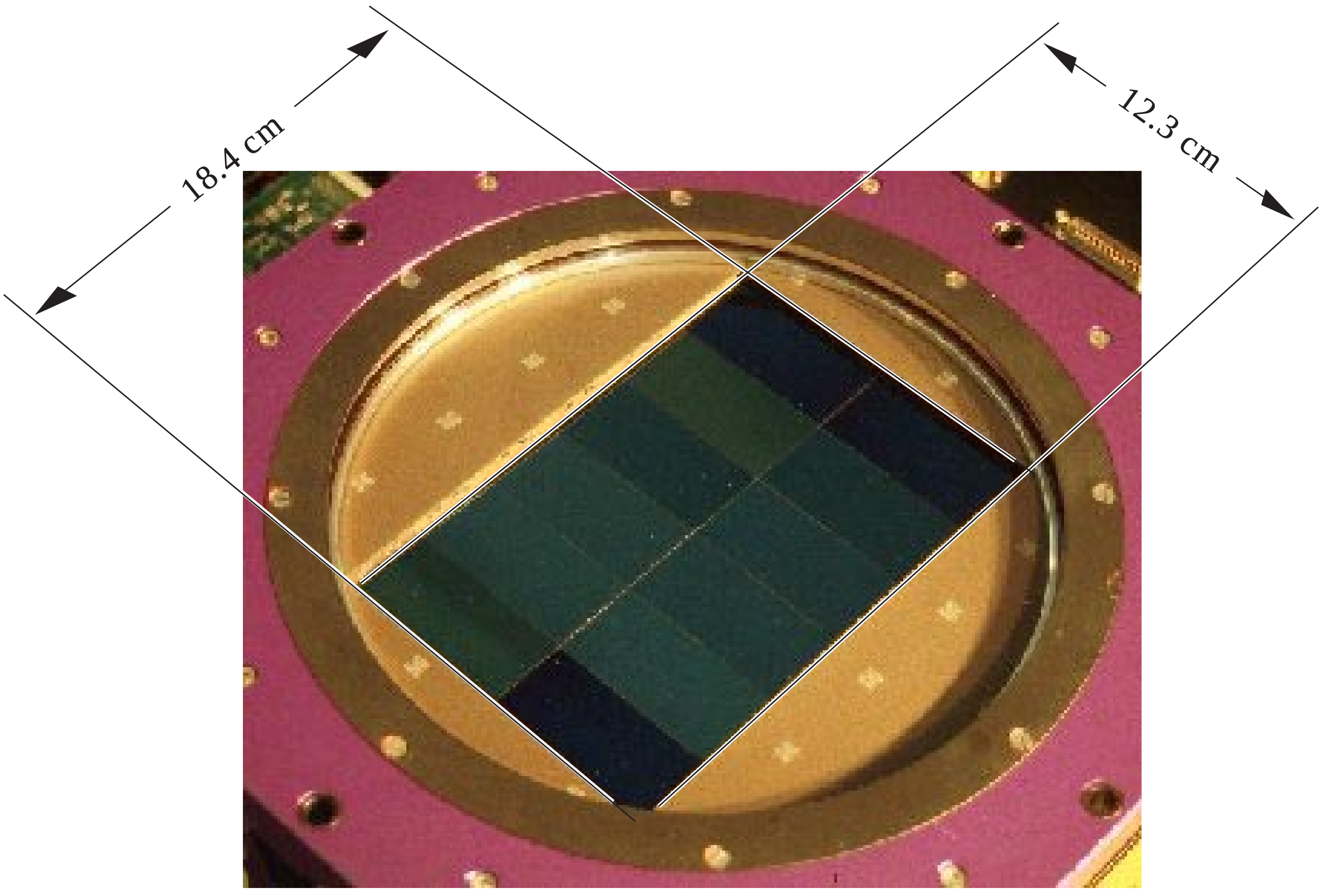
. . . courtesy of Guy Monnet

It's hard to make big CCDs which can be read out in a fairly short time, but progress continues—



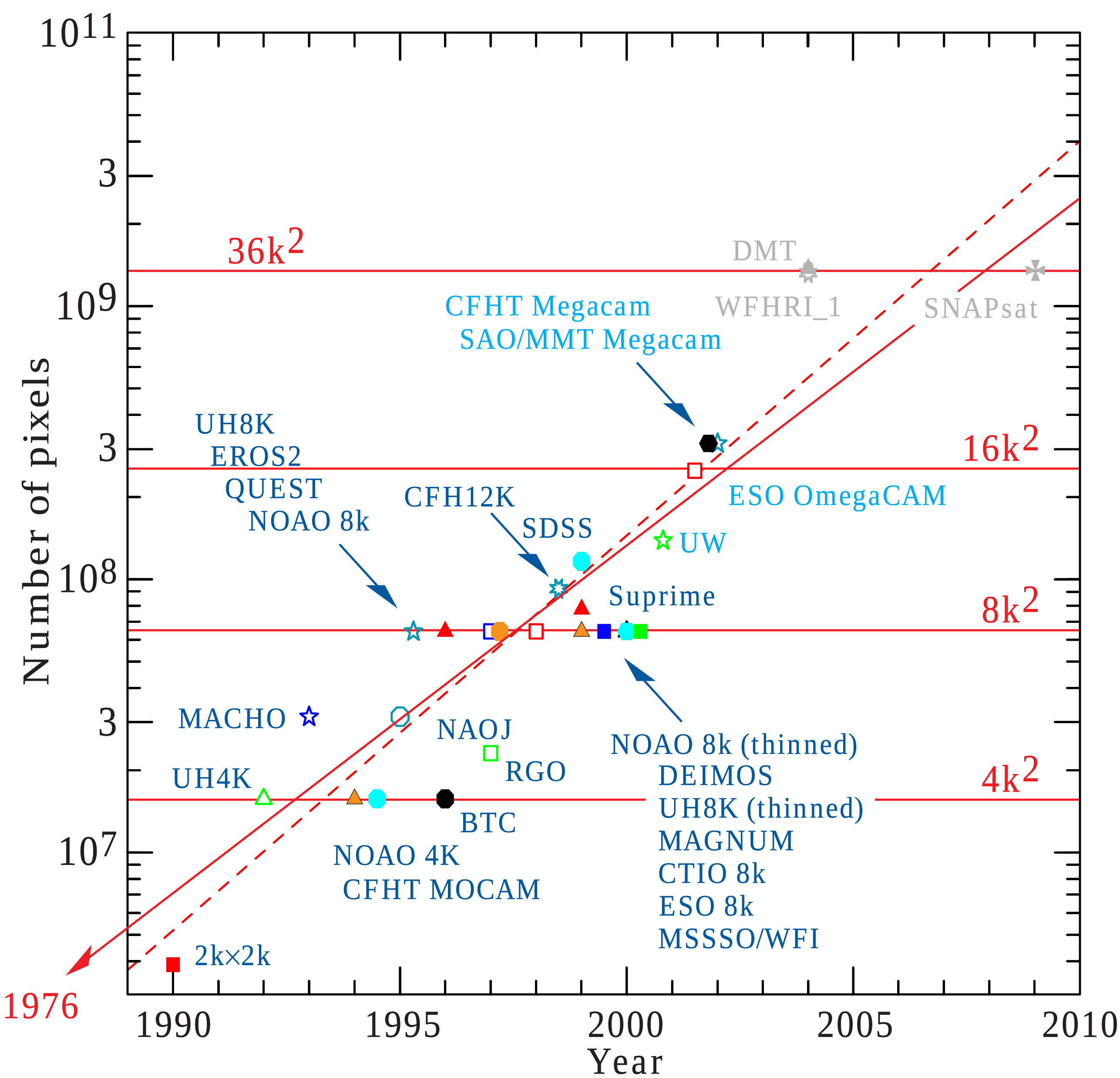
but, even so, CCDs are a long ways from the size of the photographic plates they replaced, and are likely to remain so.

The obvious solution is to build mosaics of CCDs

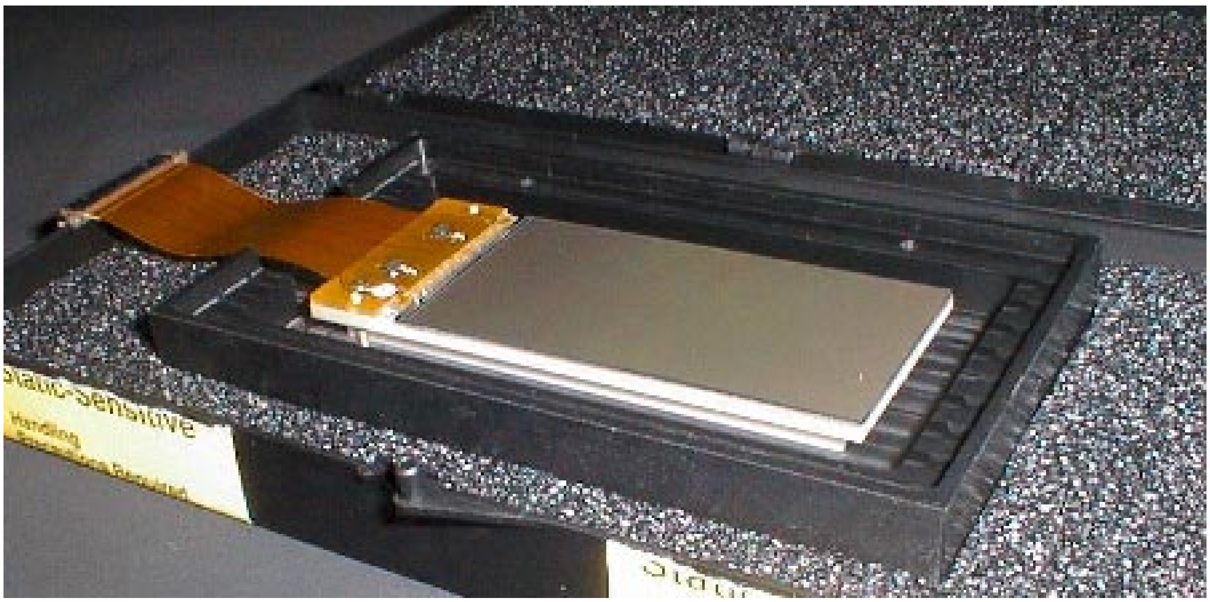


CFH12K

Gerry Luppino has made a nice summary of the progress (the "Luppino plot,") which shows an exponential rise in the number of pixels per detector, increasing by a factor of about 14 per decade



Electrical connections are the obvious limitation to making larger and larger CCD arrays—



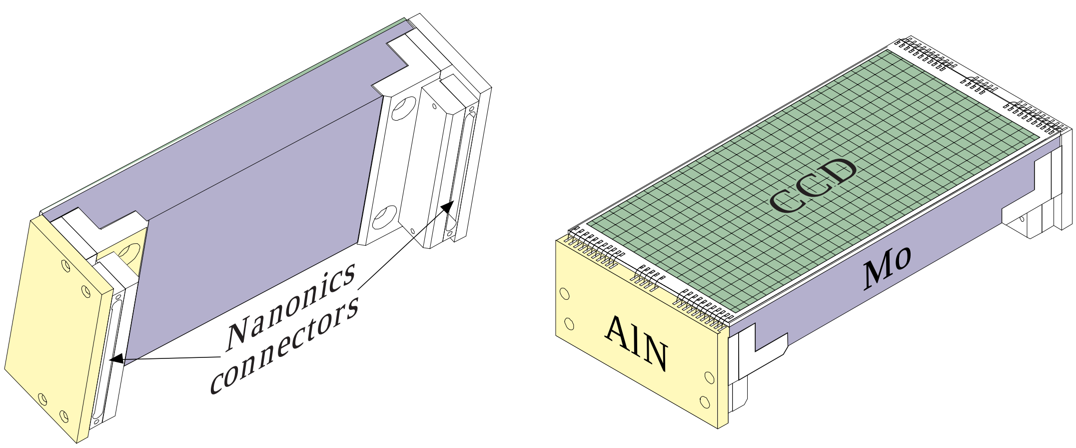
Hamamatsu 2k×4k

To maximize the packing fraction, *i.e.*, to minimize dead space between CCD active regions, Marconi, LL/MIT, UC/LBNL, Steward, and perhaps other places are developing "4-side abutable" packages

Marconi has demonstrated a "next-generation" 4-side abutable package (only they don't call it that)

from Paul Jorden, Marconi

and LL/MIT is developing an abutable package for their orthogonal transfer CCDs (OTCCDs), which will perhaps show up on their more conventional 2k×4k CCDs

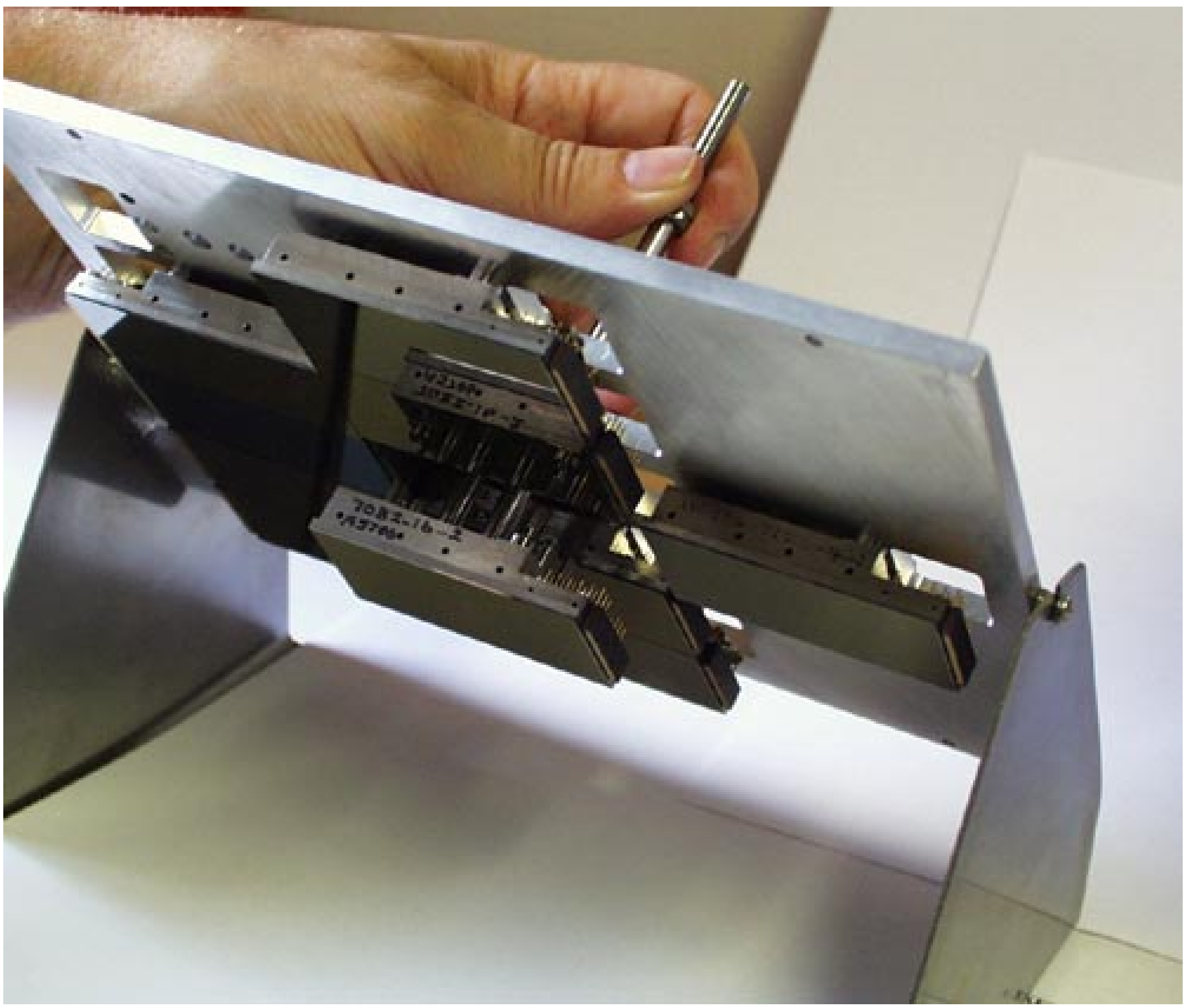


from Barry Burke, LL/MIT

The UC/LBNL thick CCD has pads on the front side, and is hence intrinsically 4-side abutable

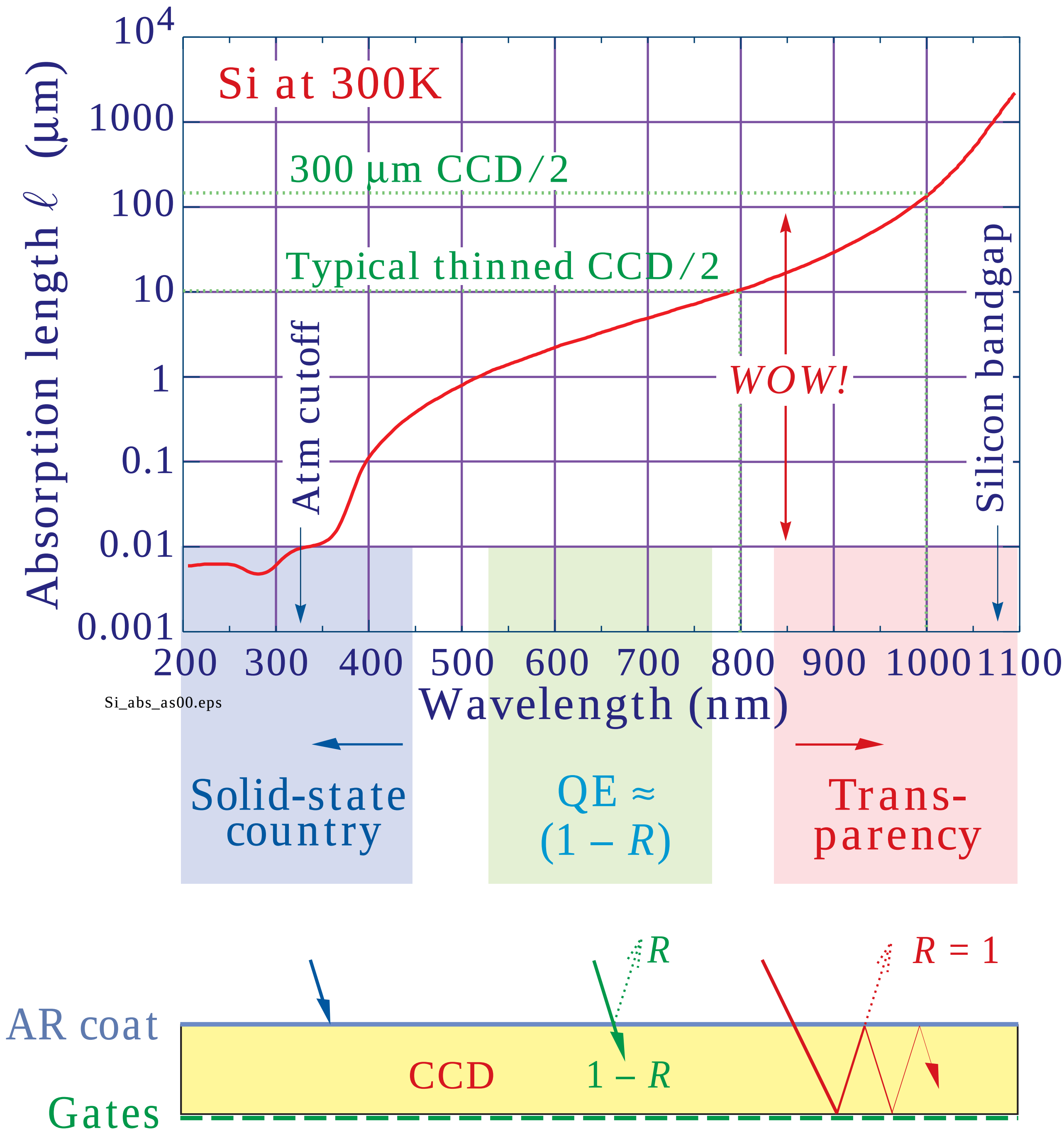
Any good abutable package has to come with a way to install it without hurting its neighbors—the more idiot-proof the better.

Marconi has come up with a really slick scheme, which I hope they will demonstrate during this conference. A shorter secondary guide rod prevents collisions; a CCD can be installed or removed between 4 neighbors with remarkable safety

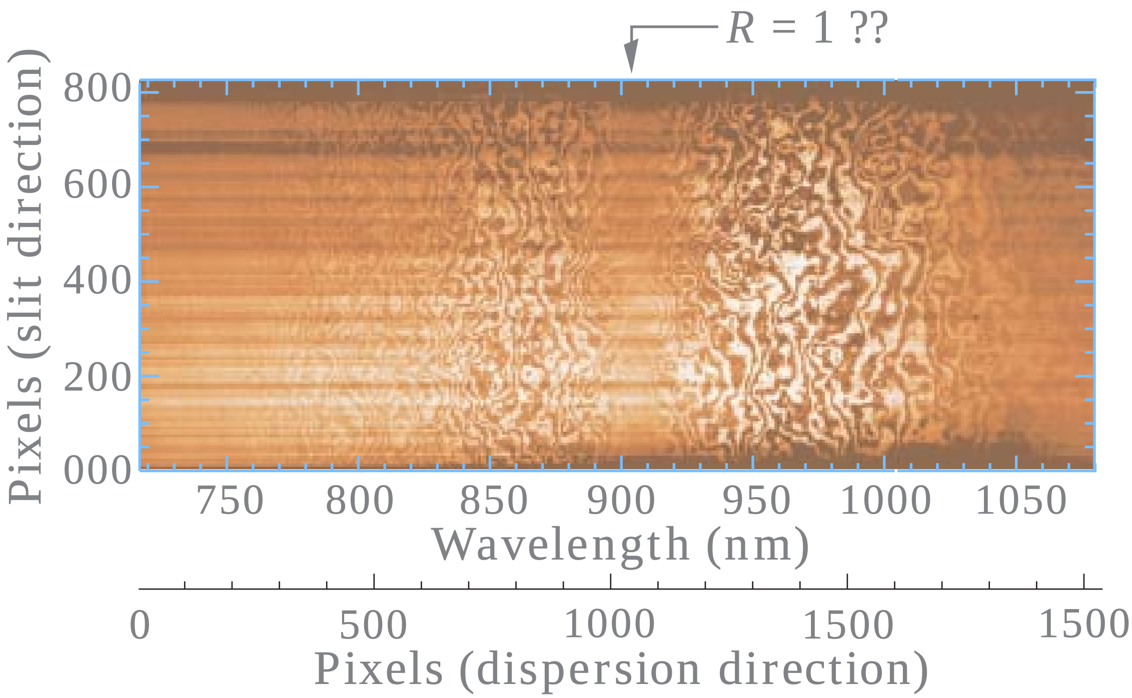


from Paul Jorden, Marconi

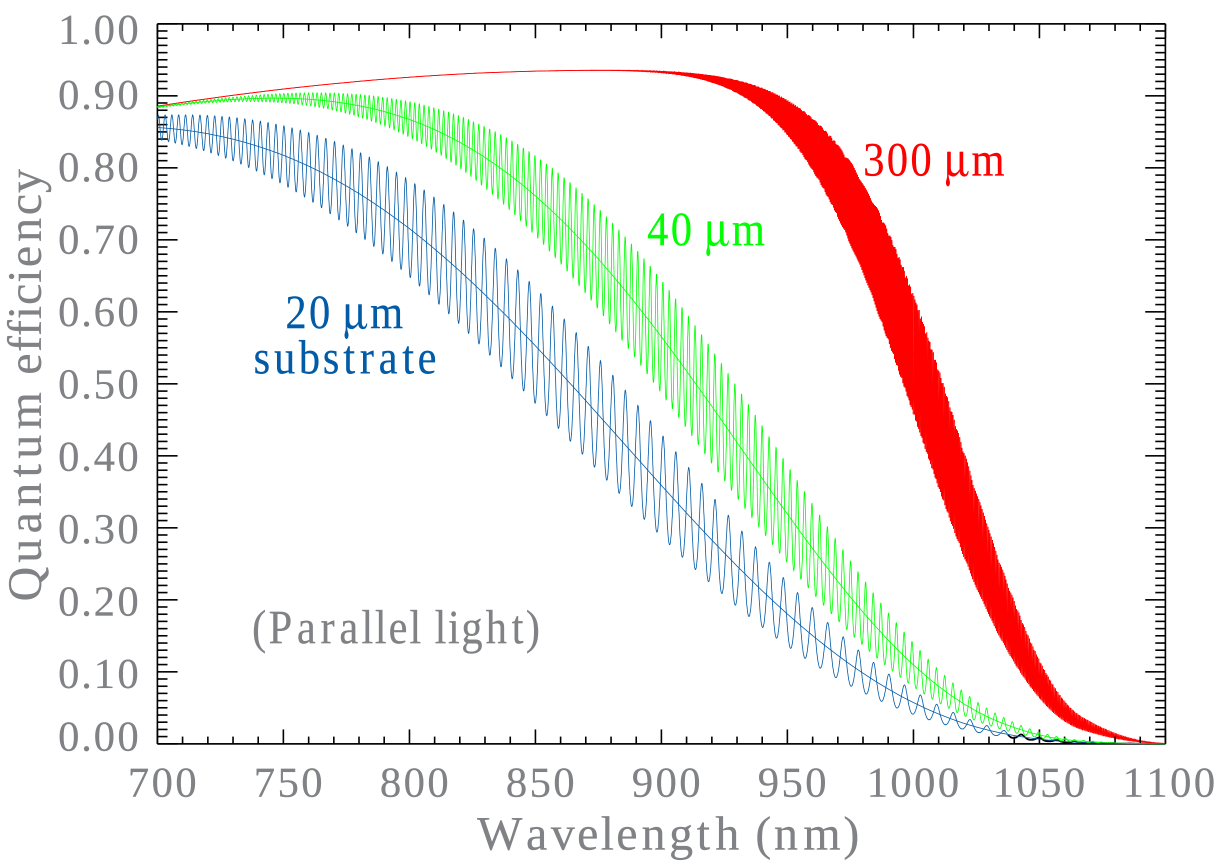
There are attempts to decrease fringing and improve QE in the red—



SITe CCD in Keck Low-Res imaging spect: Quartz flat

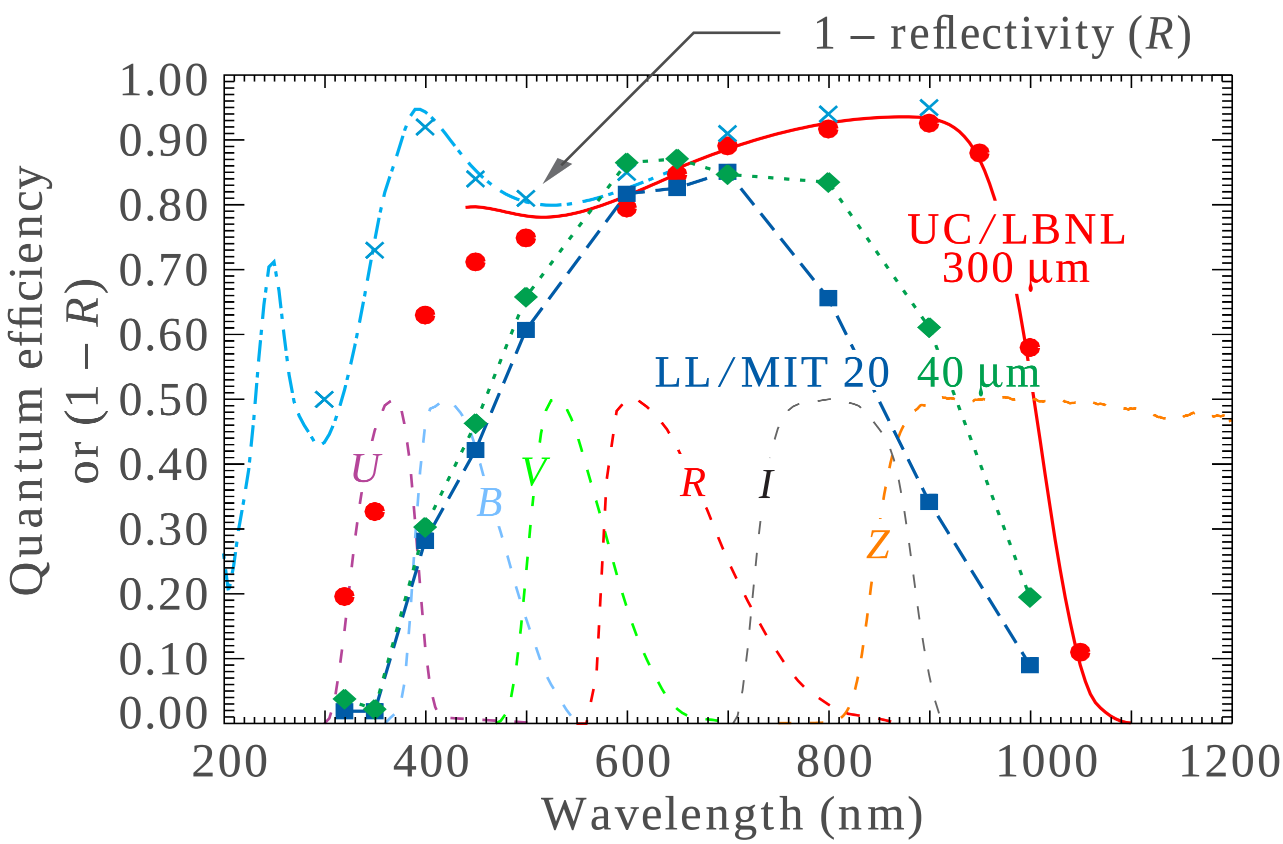


Calculated QE with the present UC/LBNL AR coating—



Pushing into the red—

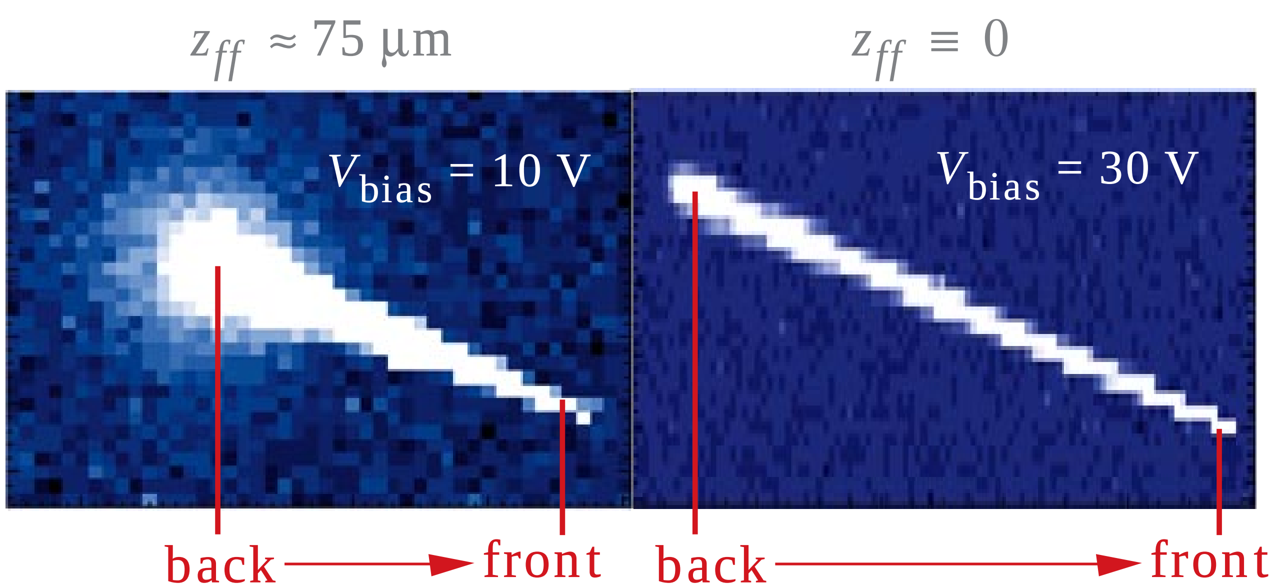
- LL/MIT: High-resistivity substrate with thicker epitaxial layer, thinned to 40 μm
- UC/LBNL: > 10 kΩ-cm substrate (300 μm), not thinned, depleted to back surface



—unnormalized broadband filter responses are shown for reference

Lateral diffusion (MTF) in the field-free region (thickness z_{ff}) *IS* an important issue; in most astro CCDs it makes the PSF much larger than a pixel

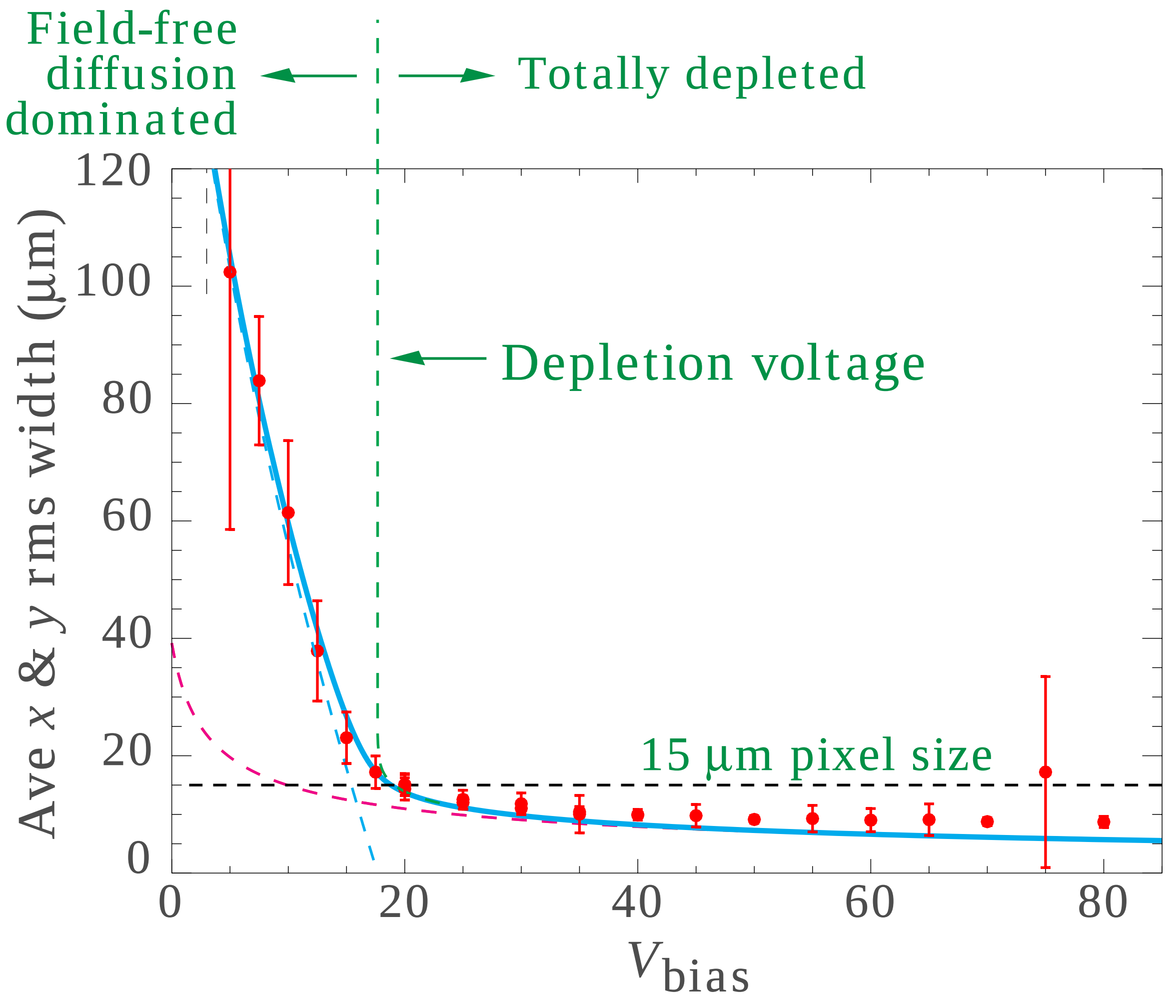
It's very easily seen in slanted cosmic ray muon tracks:



(Examples obtained with a UC/LBNL CCD with a 300 μm sensitive region)

In the UC/LBLNL CCDs we control z_{ff} by means of an external bias voltage

Measurements were made with a contact pinhole mask:



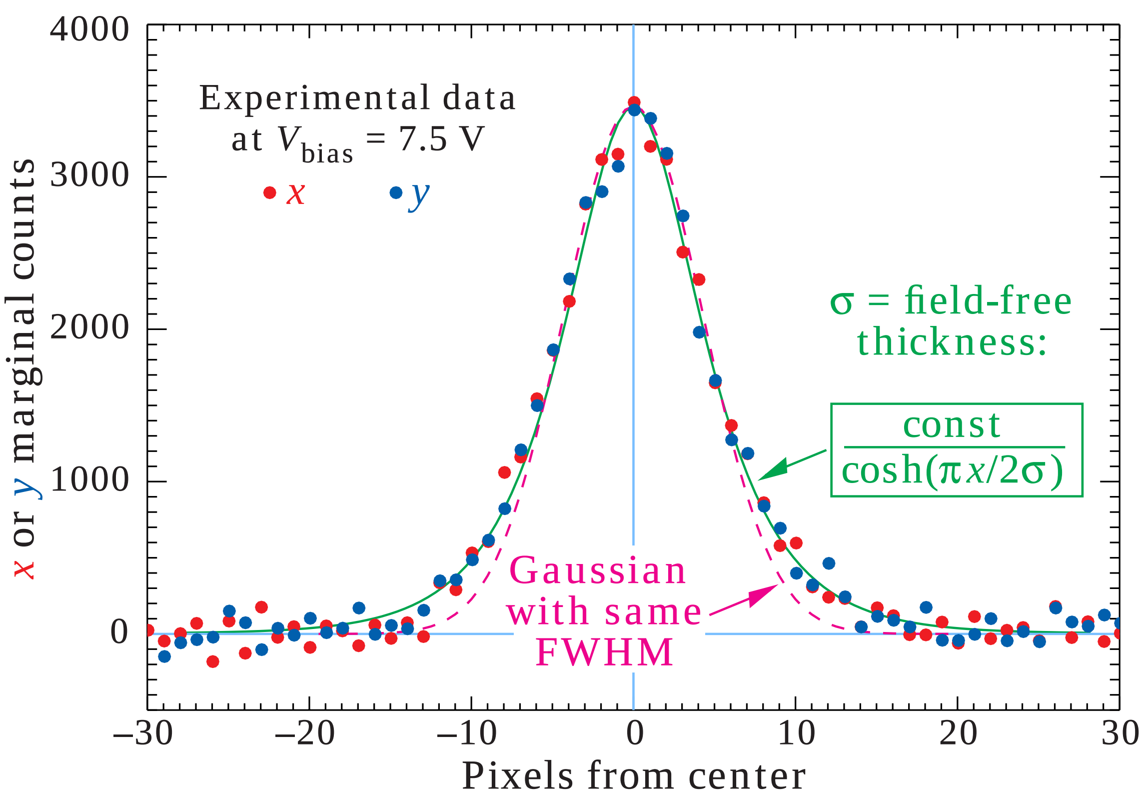
If the resolution is dominated by diffusion in the field-free region, then with the usual assumptions the x (or y) distribution at the front surface is given *analytically* by

$$q(x) = \frac{1}{2\sigma\cosh(\pi x/2\sigma)}$$

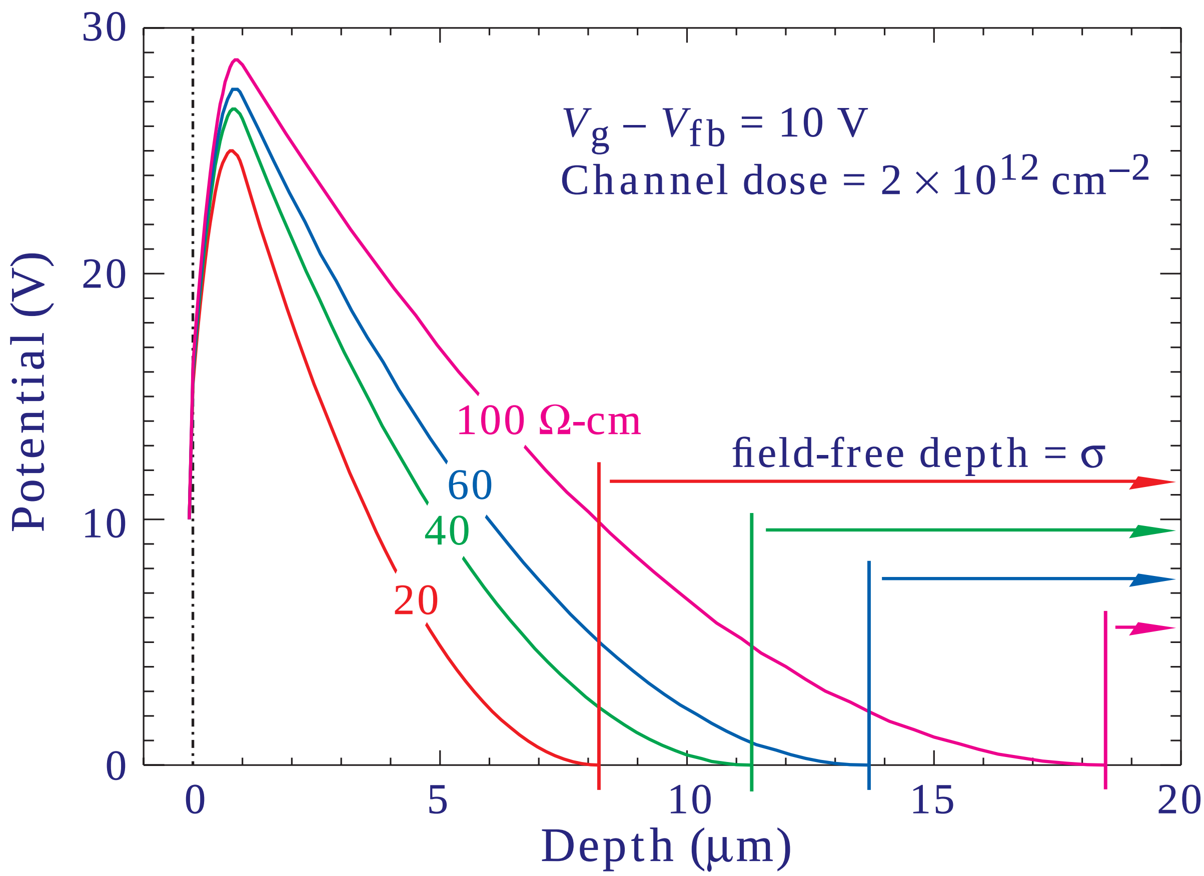
where

$$\sigma = z_{ff}$$

The modulation transfer function (MTF) is also 1/cosh, and can be combined with the pixel MTF to obtain the complete function for the CCD [Steve Holland]



How good is *YOUR* CCD?

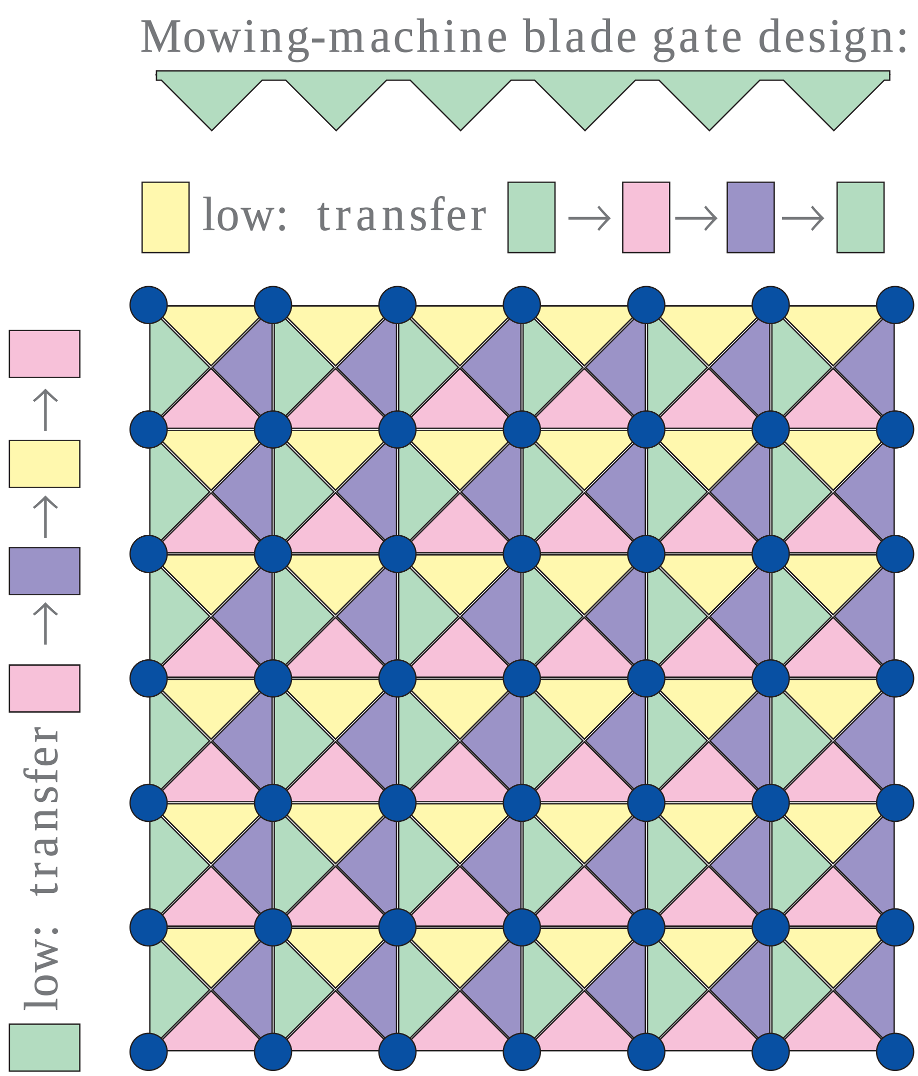


MORAL OF THE STORY: Unless the thickness of the field-free region can be *controlled* and *minimized*, there is absolutely no point in going to smaller pixels!

Orthogonal-transfer CCDs (OTCCDs) have come of age.

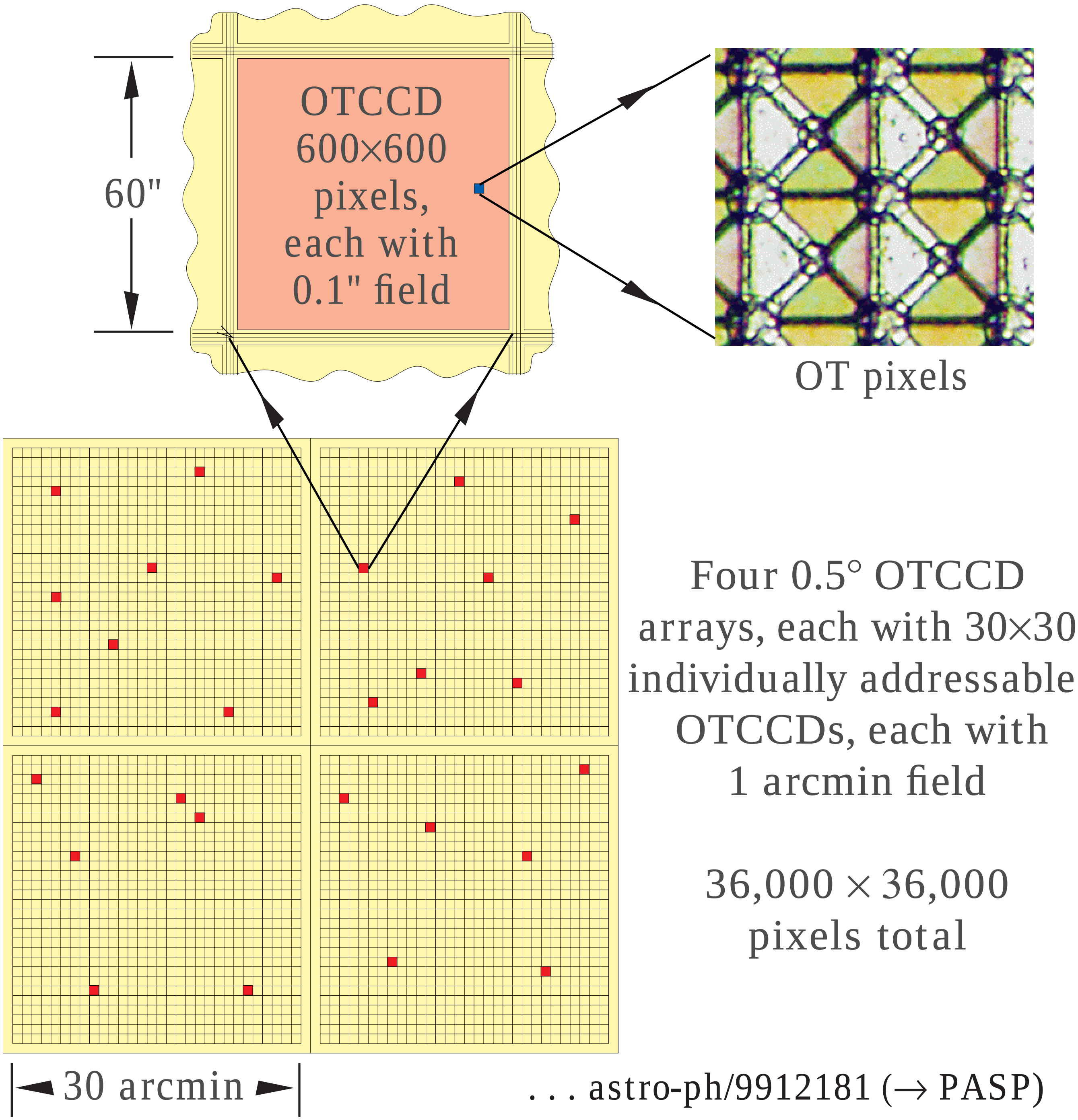
Replace linear channel stops with channel "spots," and transfer charge in either direction

$\Longrightarrow$ dance charge around to follow atmospheric turbulence effects



—early problems with charge traps seem to have been solved (Tonry, Burke, Schechter, *et al.*)

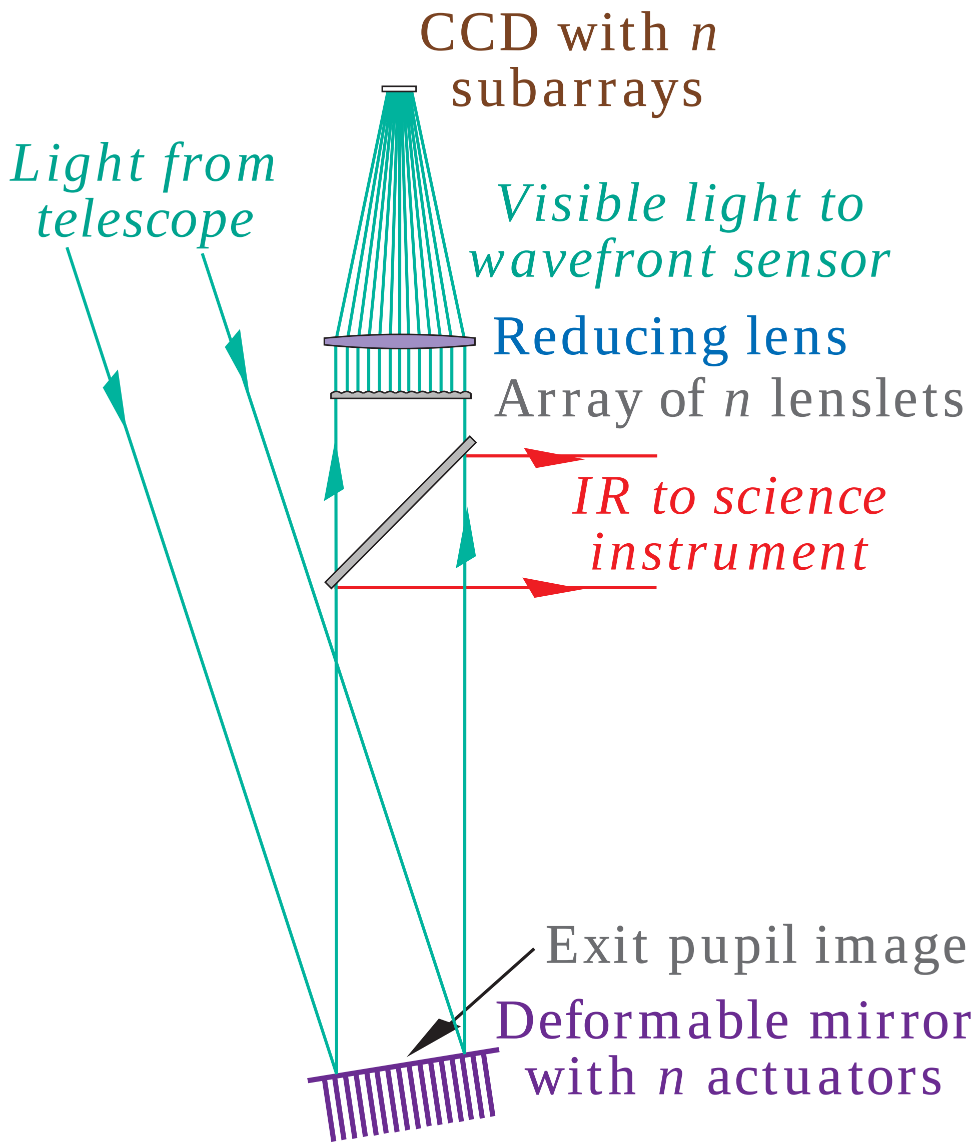
Kaiser, Tonry, and Luppino have a FAR more ambitious proposal (WFHRI) —

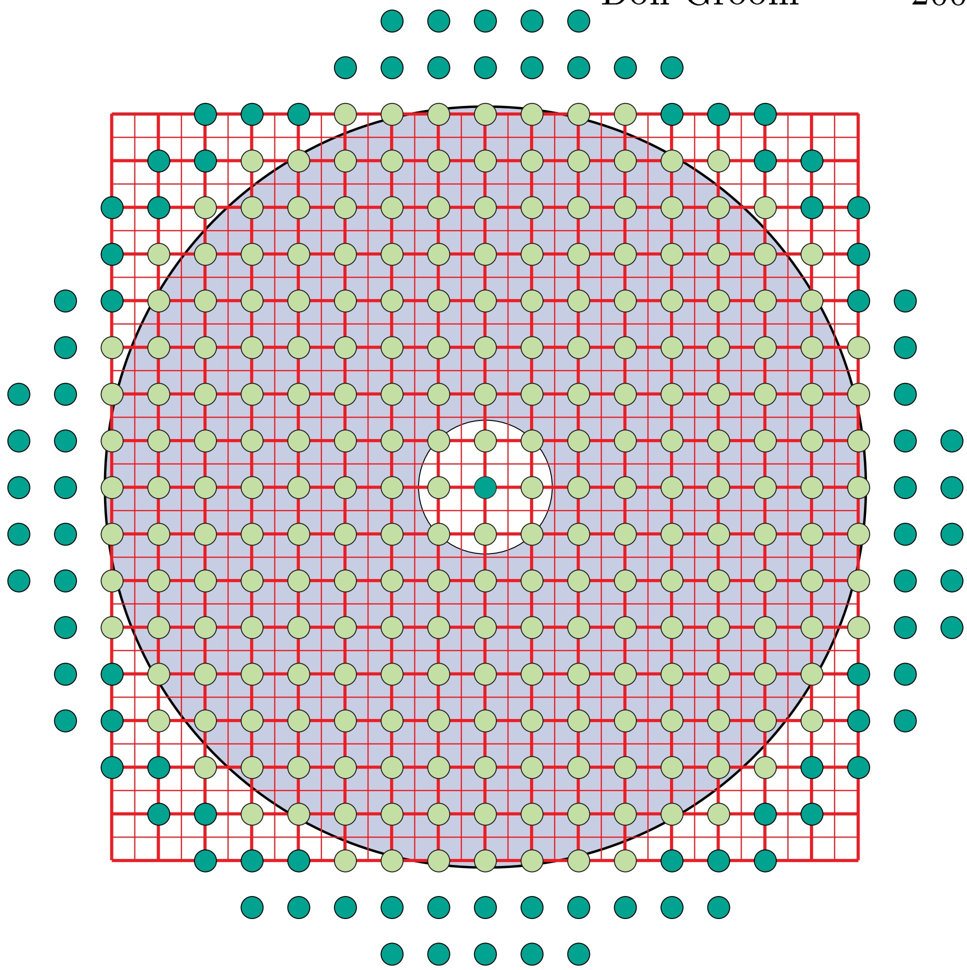


. . . astro-ph/9912181 (→ PASP)

Finally: Very little in astronomical instrumentation is moving so fast as adaptive optics (AO)

There are many ways to do it; this cartoon shows one way to define the CCD requirements

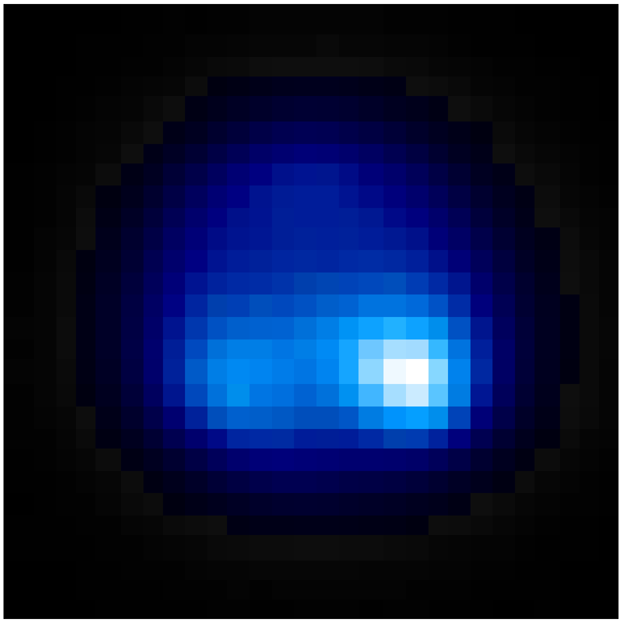




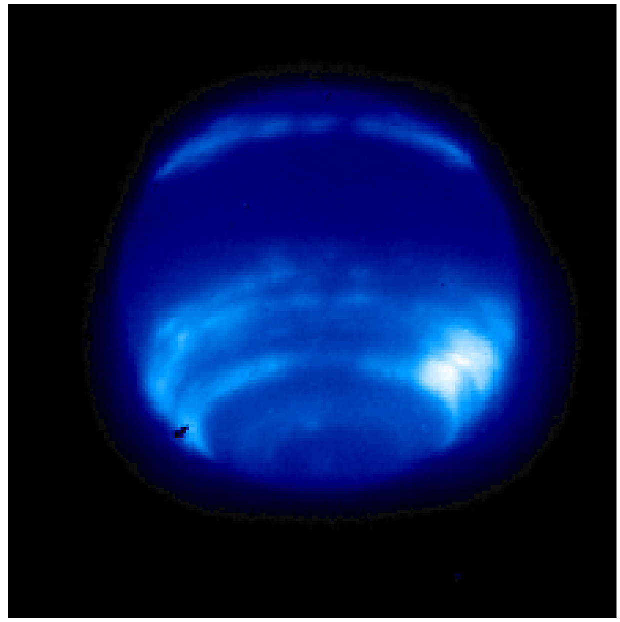
This defines the requirements:

- $\Longrightarrow$*FAST*$\Longleftarrow$readout
  (500 to 1000 frames/sec and rising toward 1500)
- $\Longrightarrow$*low noise* $\Longleftarrow$
- Only $\approx (4/\pi)n$ subarrays of perhaps 4 pixels each, for n actuators
  (n now a few hundred, but rising as fast as possible)
- Big pixels, if possible
- Marconi, PixelVision, LL/MIT, and others are actively developing the needed CCDs

Keck images of Uranus



—without AO



—with AO

In back of all of this—

Quality darkness at a modern big telescope is really, really hard to get and really, really expensive— $>$ \$1000/hr, and maybe $\gg$ \$1000/hr

So DO

- Cover the focal plane or whatever with as many pixels as you can
- Extend the QE(λ) as much as silicon allows
- Minimize lateral diffusion (MTF)

and DON'T

- Leave cracks
- Waste excessive time reading out
- Waste time focusing

"Don't let any photons fall onto the floor"