High QE, Thinned Backside-Illuminated, 3e- RoN, Fast 700fps, 1760x1760 Pixels Wave-Front Sensor Imager with Highly Parallel Readout

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Outline

- ESO and European Extremely Large Telescope E-ELT
- Wavefront Sensing and Adaptive Optics
- Specifications of the E-ELT WFS
- Results of the Technology Demonstrator, the TVP
- WFS Architecture and Design
- The massive parallel data problem
  - Solution - balanced clock tree of 88 LVDS channels

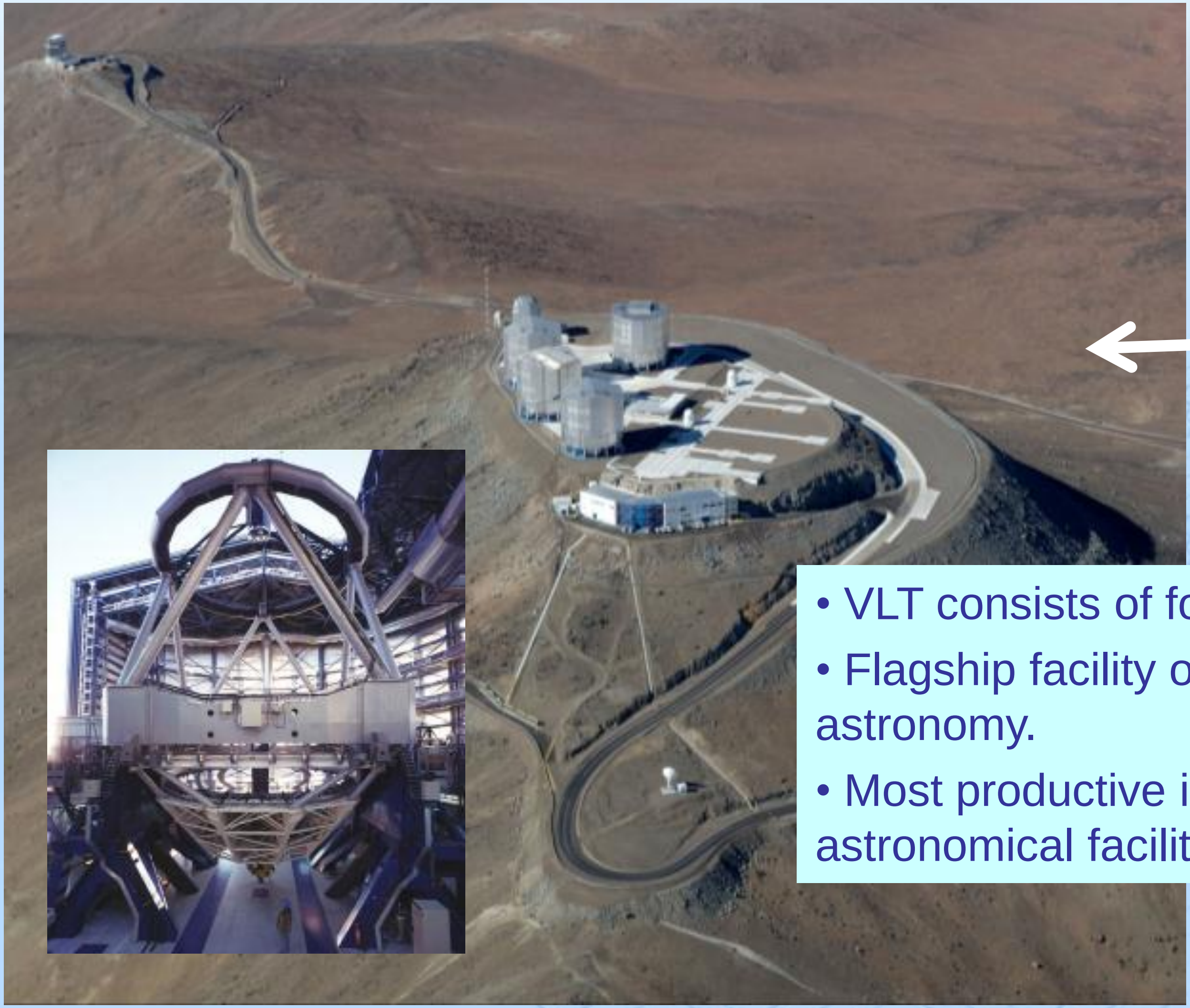
Who is ESO?

- European Organization
  - 15 member states: Germany, France, Italy, Switzerland, Netherlands, Belgium, Portugal, Denmark, Sweden, UK, Finland, Spain, and Czech Republic, Austria, Brazil
- <u>**Goal – to provide astronomers with state-of-the-art observational facilities**</u>

Operates 3 sites in Chile

- Two optical observatories
  - Paranal (2600m)
  - La Silla (2400m)
- One submillimeter
  - Chajnantor (5000m)

Paranal
→ Very Large Telescope



- VLT consists of four 8.2 m Telescopes
- Flagship facility of European ground-based astronomy.
- Most productive individual ground-based astronomical facility.

Our Next Challenge → European Extremely Large Telescope (E-ELT)

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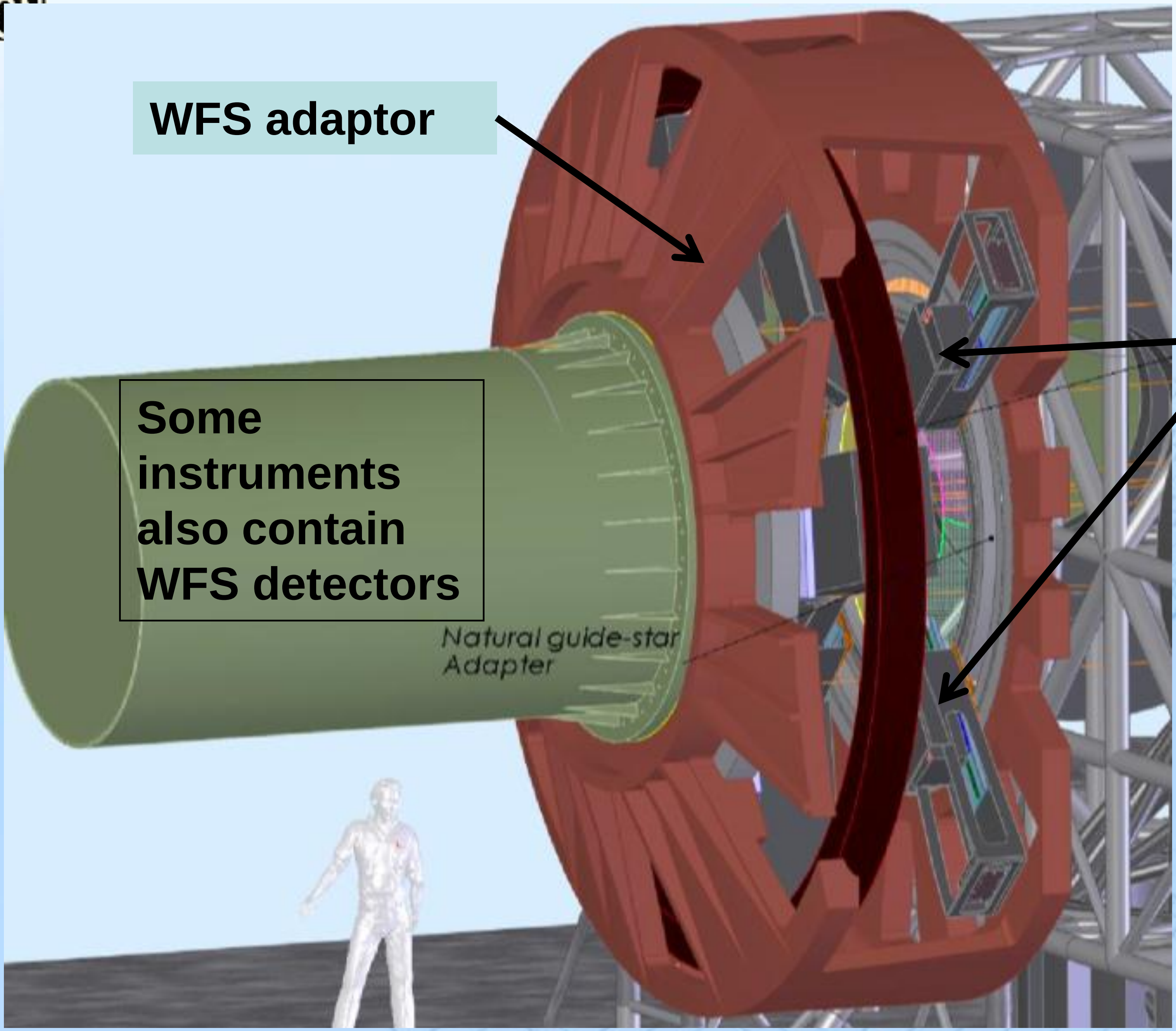
– E-ELT - a 39.5 m diameter, fully Adaptive Optics telescope.
– The E-ELT will be the largest optical/near-infrared telescope in the world (its mirror diameter will be almost half the length of a football field).
– Construction planned to begin next year; design complete and accepted

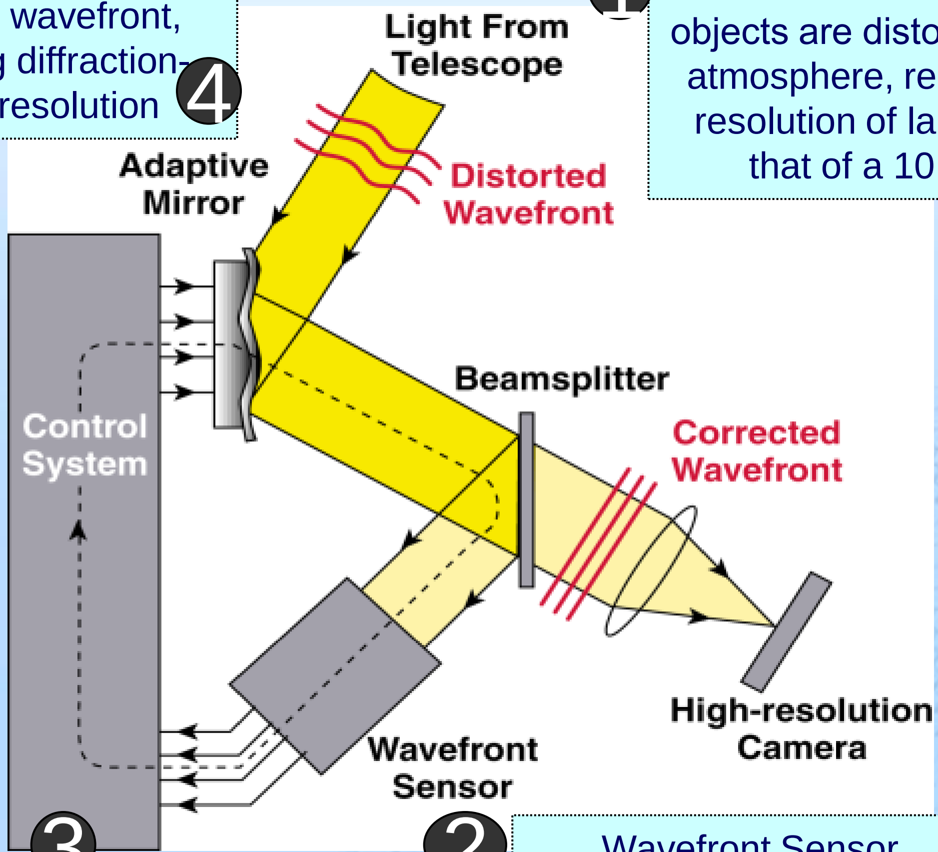
Wavefront sensors

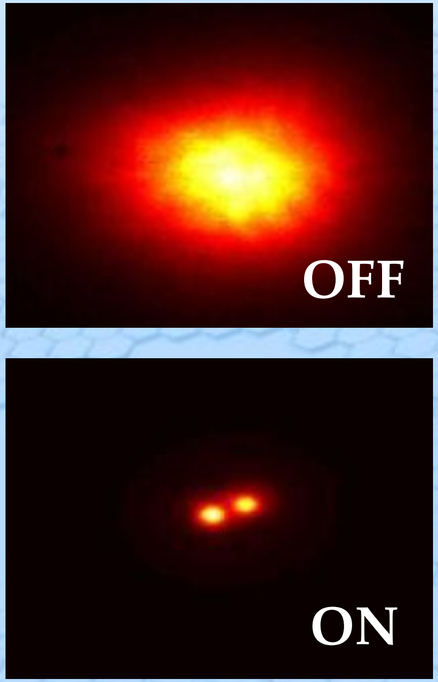


Adaptive Optics (AO)
- removing the twinkle of the stars

4 Deformable mirror compensates the distorted wavefront, achieving diffraction-limited resolution

1 Wavefronts from astronomical objects are distorted by the Earth's atmosphere, reducing the spatial resolution of large telescopes to that of a 10 cm telescope





2 Wavefront Sensor measures deviation of wavefront from a flat (undistorted) wave

3 Control System computes commands for the deformable mirror(s)

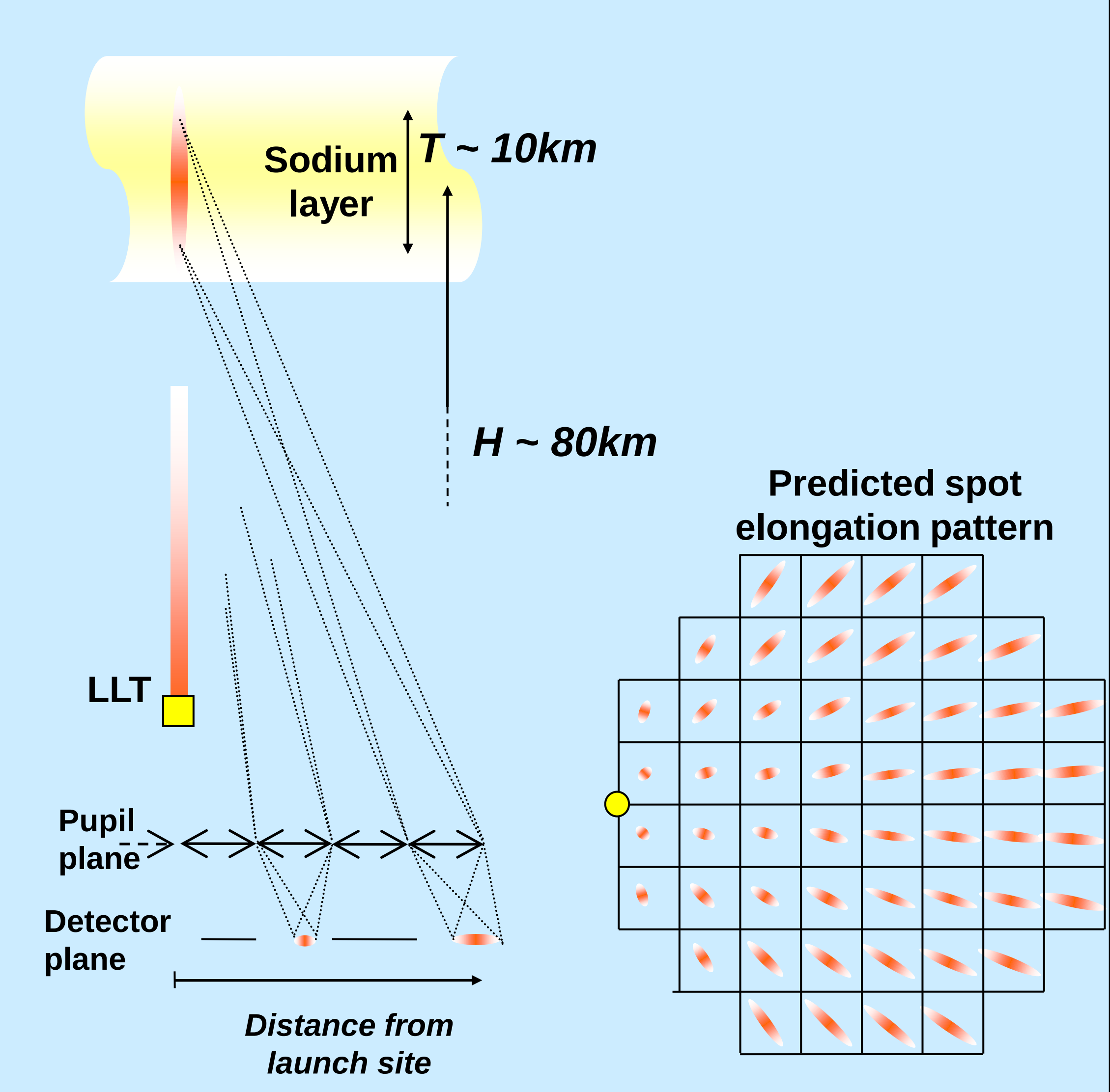
Large Visible AO WFS Detector needed to sample the spot elongation

Sodium Laser Guide Stars

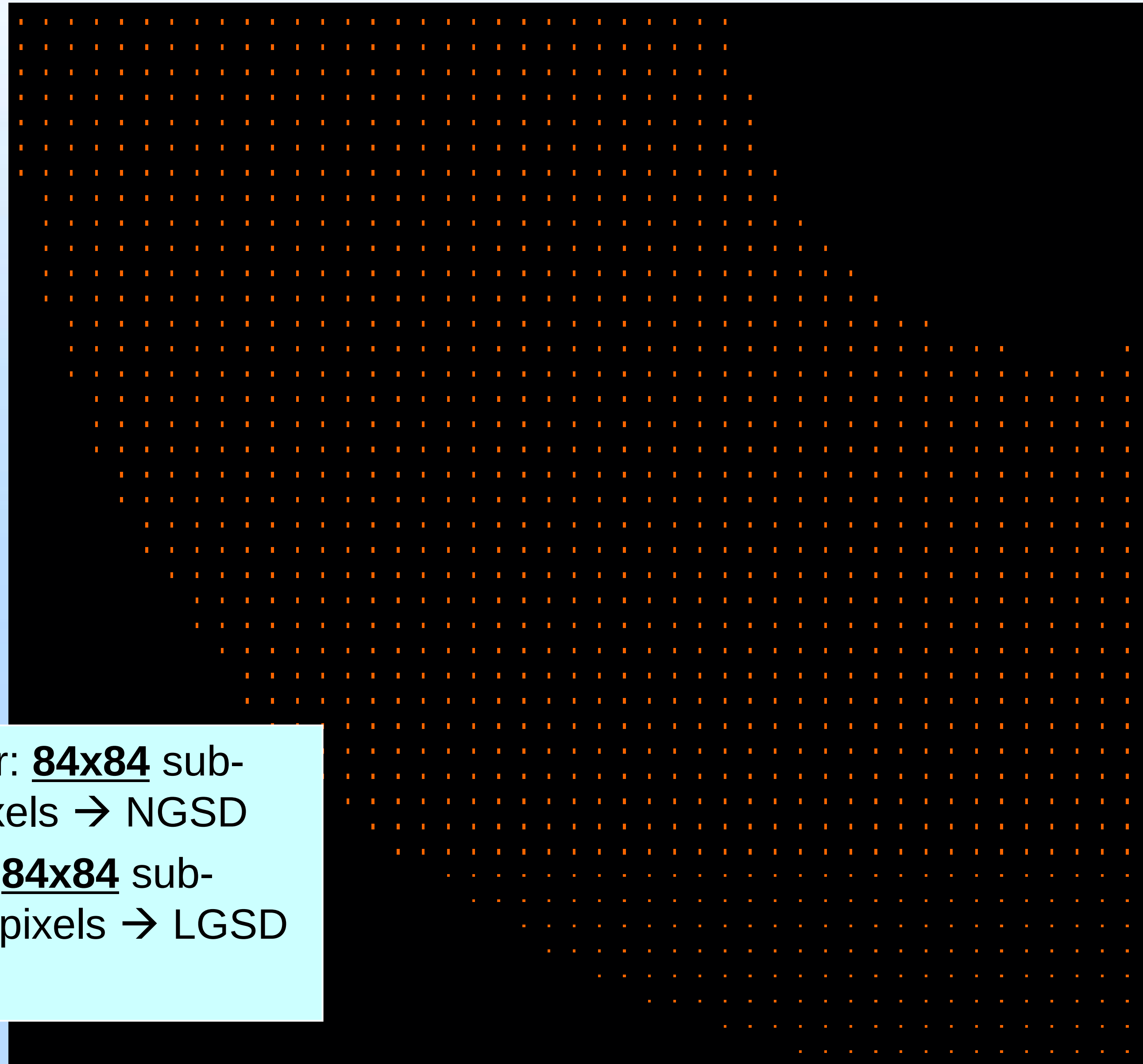
- Frame rate ~**1 kframe/sec**

→ require bright "guide stars"

- With natural guide stars only 1% of the sky is accessible
- Sodium layer at 80-90 km altitude can be stimulated by Laser to produce artificial guide stars anywhere on the sky



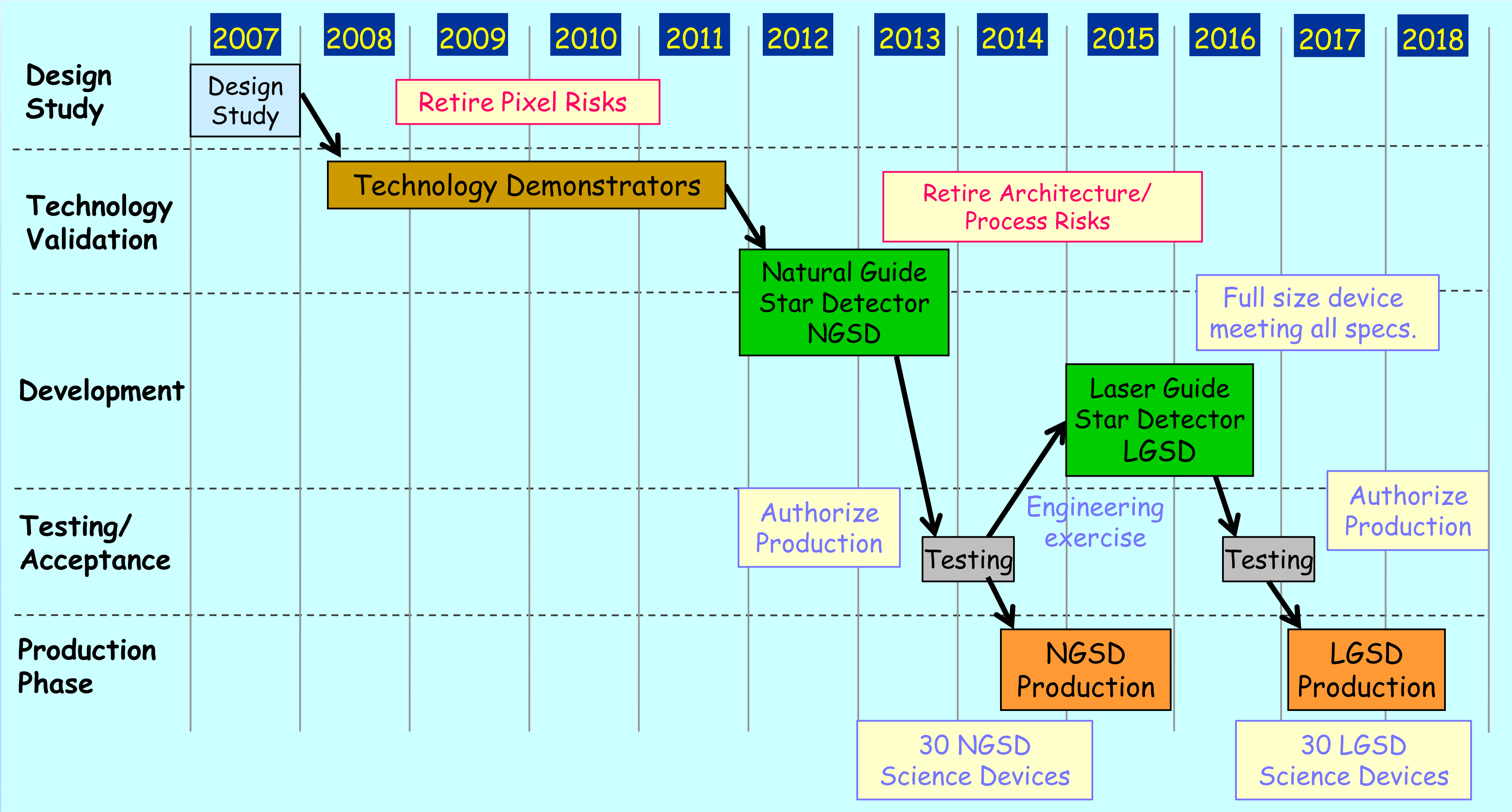
¼ WFS image



- Natural Guide Star: **<u>84x84</u>** sub-apertures of **<u>8x8</u>** pixels → NGSD
- Laser Guide Star: **<u>84x84</u>** sub-apertures of **<u>20x20</u>** pixels → LGSD

ELT WFS DETECTOR

Multi-phase plan to progressively retire risk



Specifications of the ELT WFS

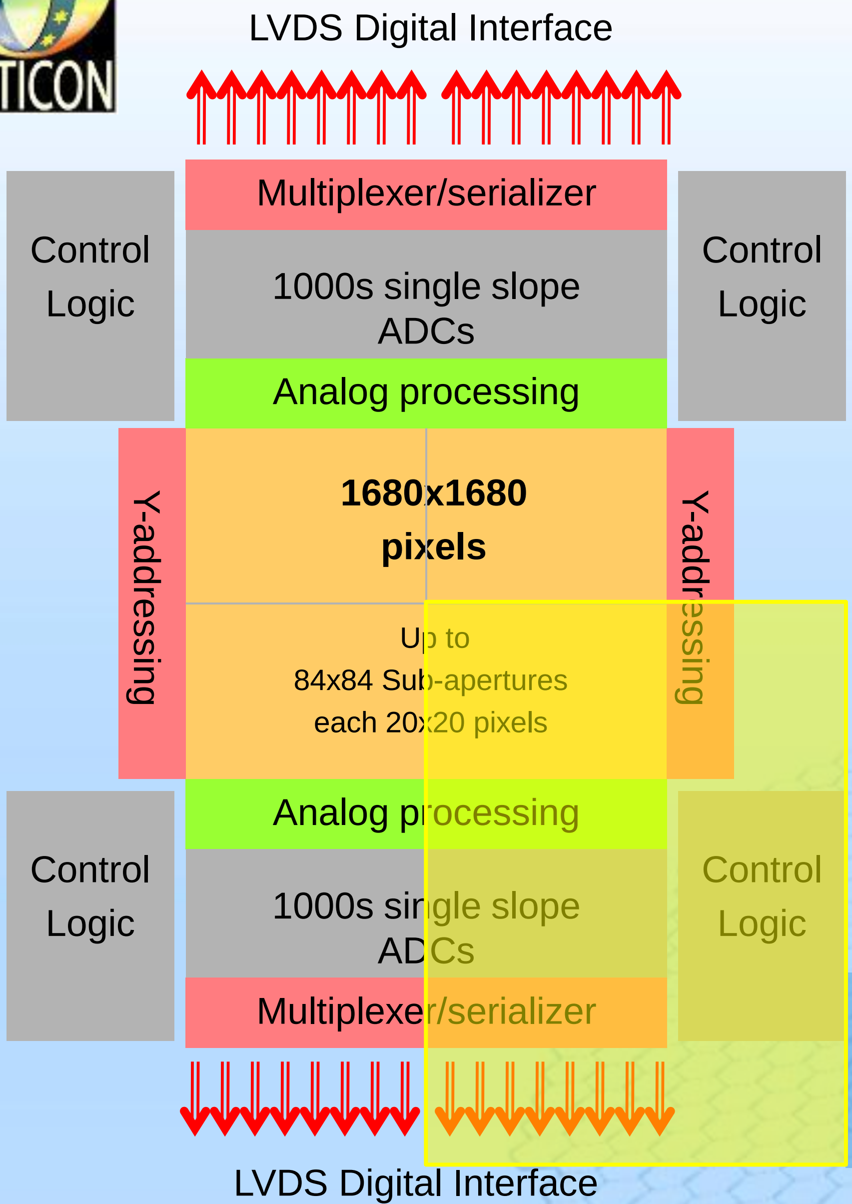
Physical characteristics

Pixel array (includes dark reference pixels)	Stitched design for two versions: “Natural Guide Star Detector” NGSD - 880x840 pixels then “Laser Guide Star Detector” LGSD - 1760x1760 pixels
Technology	Thinned backside illuminated CMOS 0.18µm
Pixel pitch	24µm
Pixel topology	4T pinned photodiode pixel
Array architecture	84x84 time coherent “sub arrays” of 20x20 pixels - LGSD image area size of 4x4cm
Shutter	Rolling shutter in chunks of 20 rows → synchronous detection within a sub-array.

Specifications of the ELT WFS
Performance

Responsivity	100 to 160 µV/electron
Pixel full well Q_{FW}	4000 e-
Read noise including ADC	< 3.0 e^{-}_{RMS}
QE	QE above 90% over the visible range → BackSide Illumination (BSI)
Image lag	< 0.1 %
MTF	ideal and symmetric in X and Y by design

Block Diagram of Full Size Device



Highly integrated

- All analog processing on-chip:
  - correlated double sampling (CDS),
  - programmable gain,
  - ADCs
- Many rows processed in parallel to slow the read out per pixel and beat down the noise.
  - trade study showed 20-40 to be the optimum number
- Fast digital serial interface to outside world
  - power consumption similar to high speed drivers to transport the analog signal off chip
  - better guarantee of achieving and maintaining low noise performance

Natural Guide Star Detector (NGSD)

scaled down demonstrator

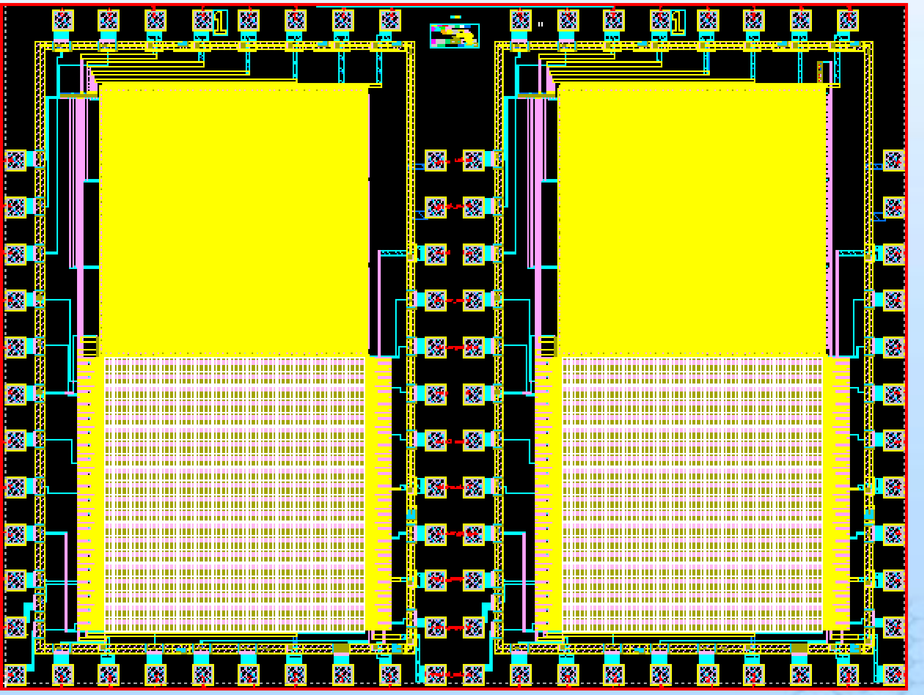
~ ¼ of full size → no stitching

Specifications of the ELT WFS

Read out

Number of rows read in parallel	40 (LGSD) or 20 (NGSD) rows in parallel
Number of ADC's	40x1760 (LGSD) or 20x880 (NGSD)
Number of parallel LVDS channels	22 (NGSD) or 88 (LGSD)
Serial LVDS channel bit rate	210 Mb/s baseline, up to 420 Mb/s (desired)
Frame rate	700 fps up to 1000 fps with degraded performance 2 to 3 Gpixel/s = 20 to 30 Gb/s over 88 parallel LVDS channels
Power dissipation (spec)	Maximum 5W , including the 88 LVDS drivers
Actual LVDS driver dissipation per channel	6.0 mW @ at maximum data rate. 4.5 mW in sub-LVDS

Demonstrated performance on Technology Validator - TVP



- In a nutshell
  - All features of NGSD/LGSD
  - 60x60 pixels,
  - Same pixel and ADC driving
  - 1200 (60x20) column ramp ADCs
  - > 700 frames/sec
- To optimize the pixel:
  - transfer gate and transistor geometries were varied in 12 pixel variants
  - threshold voltage of nmos transistors was varied
  - Implants to improve image lag were varied

Demonstrated performance on Technology Validator - TVP

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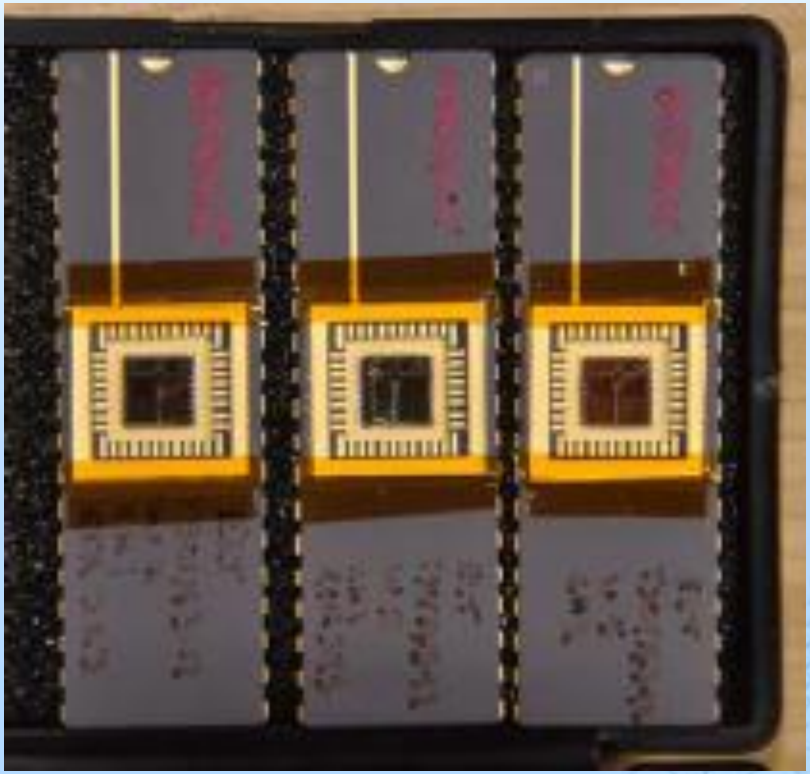
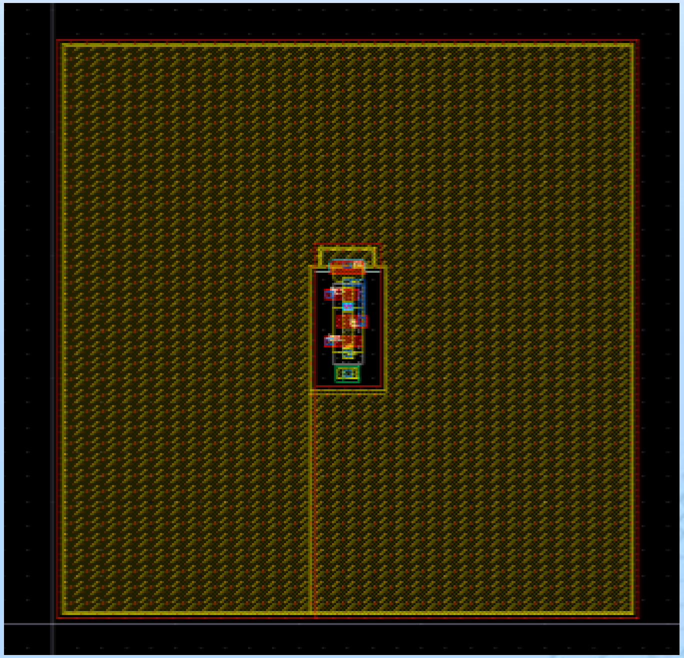
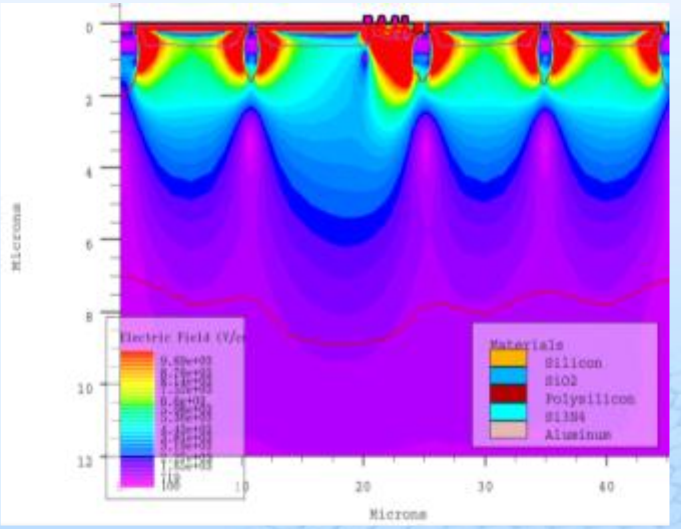


- Key performances have been validated
  - < 3.0e-$_{RMS}$
  - Full well 4000...8000 e-
  - Conversion gains 100...160 µV/e-
  - Image Lag < 0.1 %
  - Best pixel and implants found to go forward to next phase, NGSD
- Not tested in TVP:
  - Massive parallelism
  - Array of LVDS IO
  - Back Side Thinning & Back Side Illumination

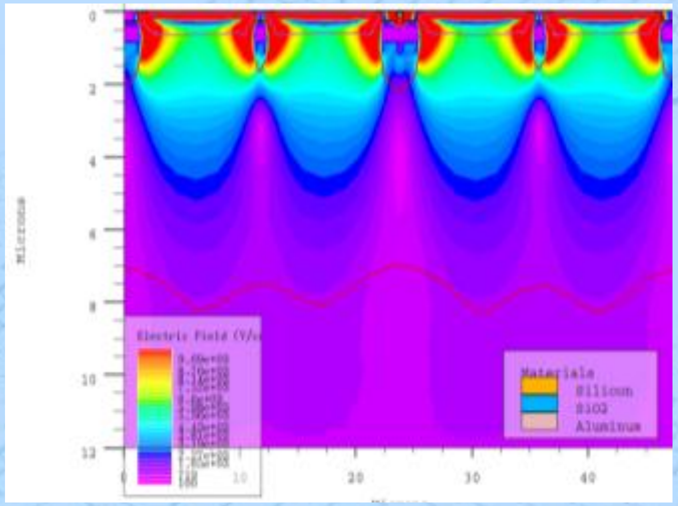
	Process, Pixel Architecture and Radiation Hardness		
14h15	JERRAM Paul	e2v technologies	Optimisation of performance of Backthinned CMOS devices

Pixel designed for best centroiding performances, TCAD simulations



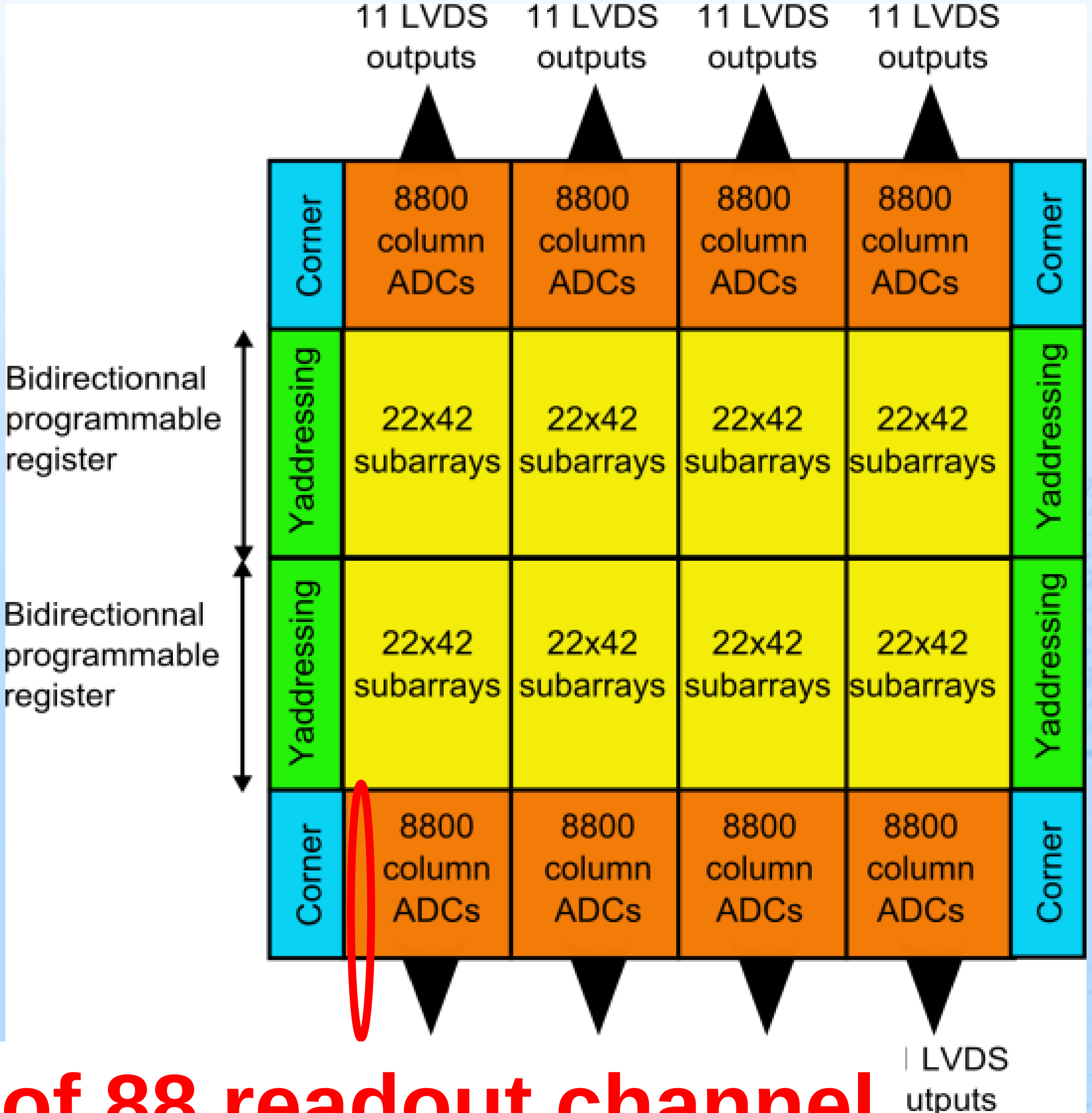


Y / center



X

LGSD/NGSD Stitching Plan



1 of 88 readout channel

One readout channel (of 88)

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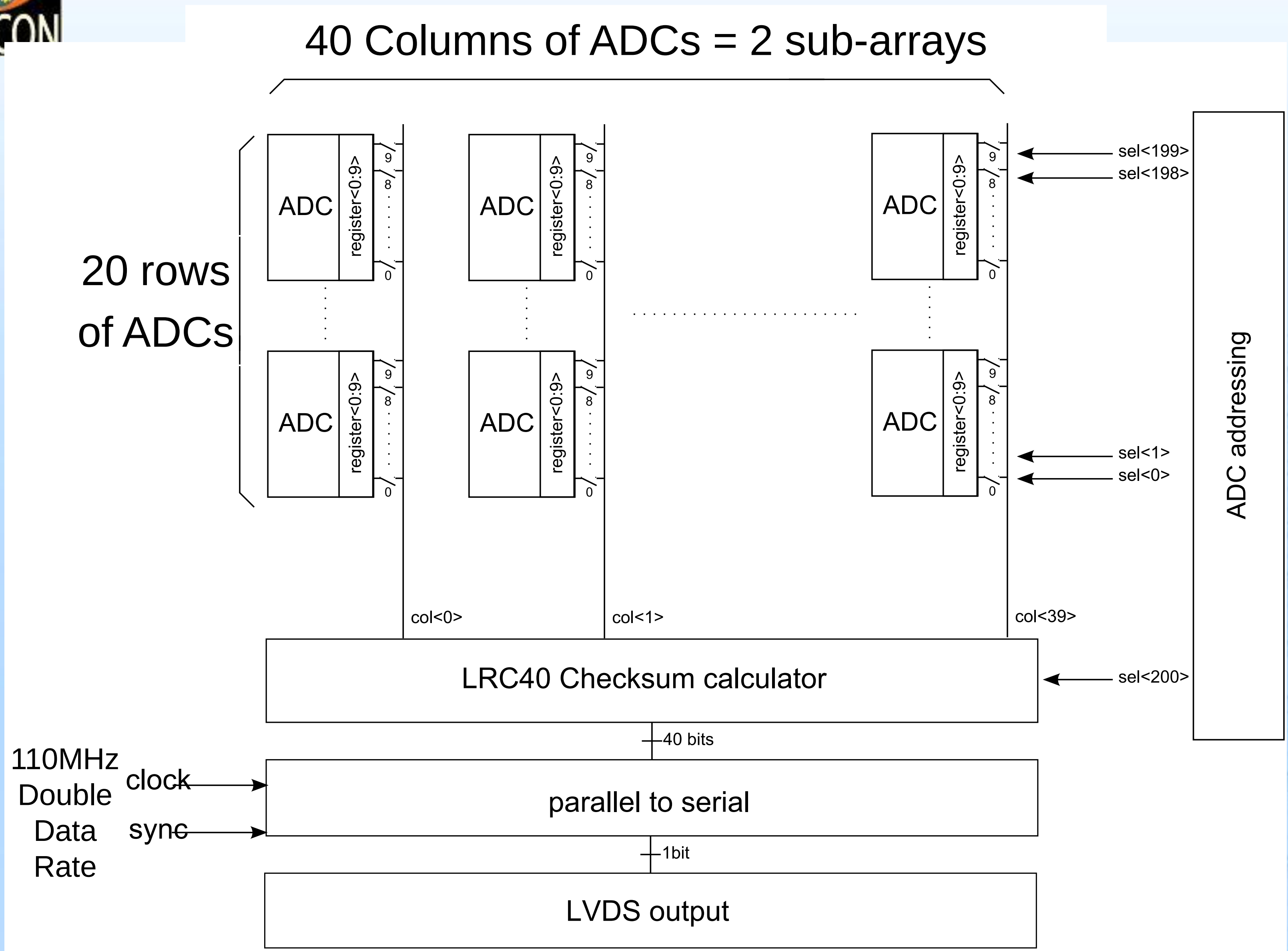
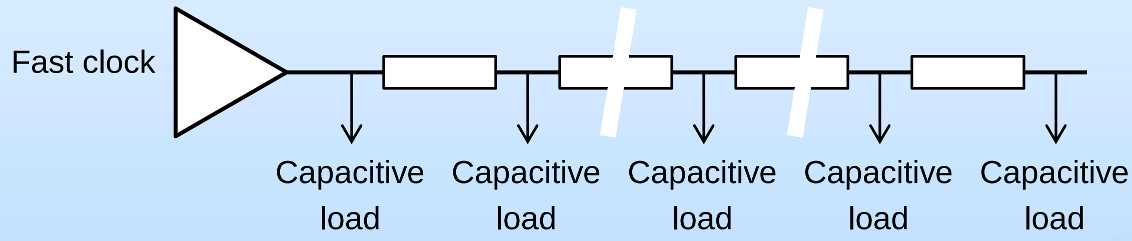
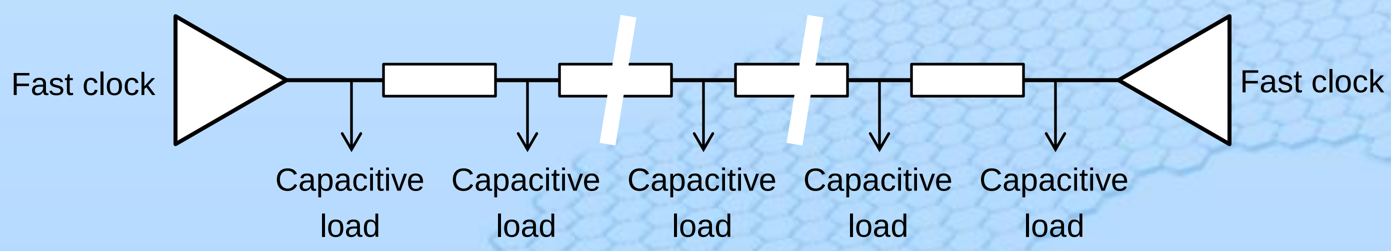


How to drive 210 MHz over 4cm?



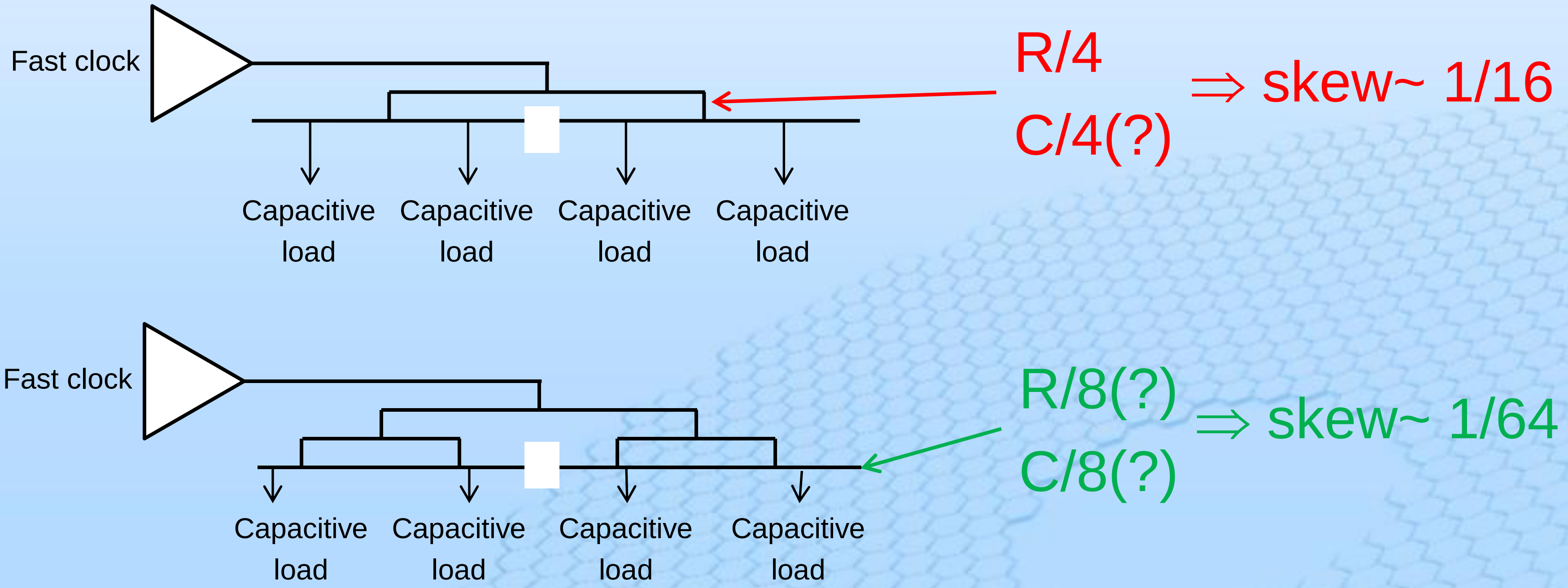
Reference case for speed and skew

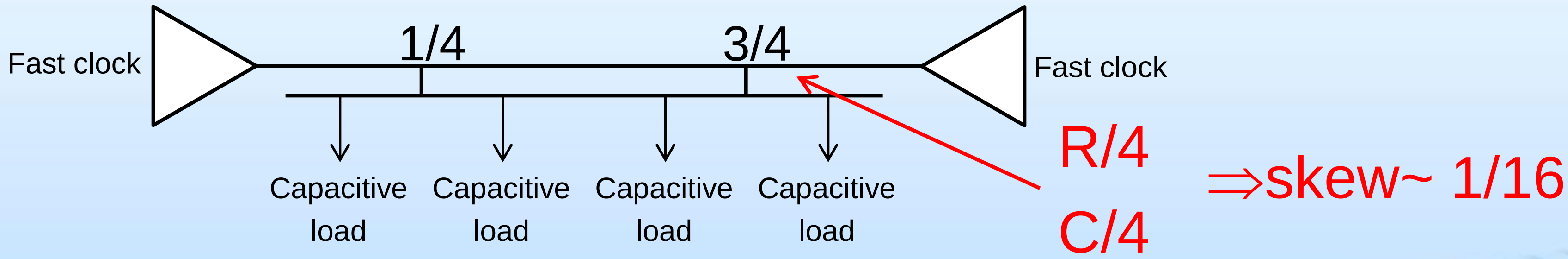
Skew>2ns

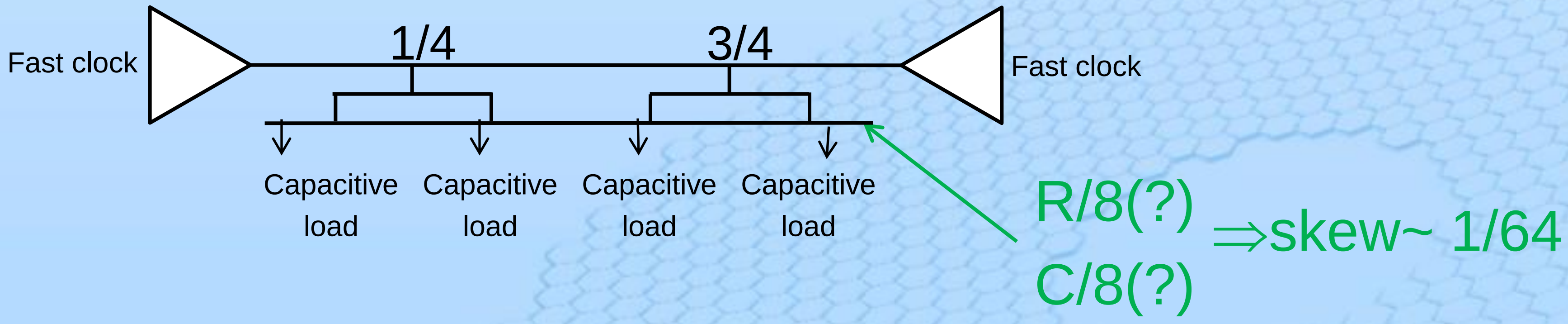


R/2 ⇒ Speed~ *4

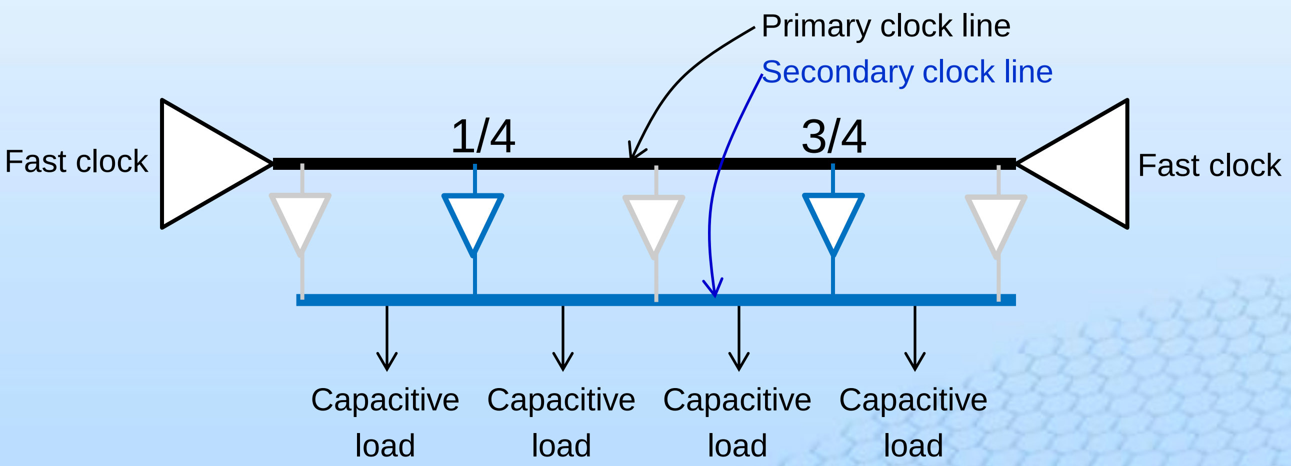
C/2 ⇒ Skew~ /4

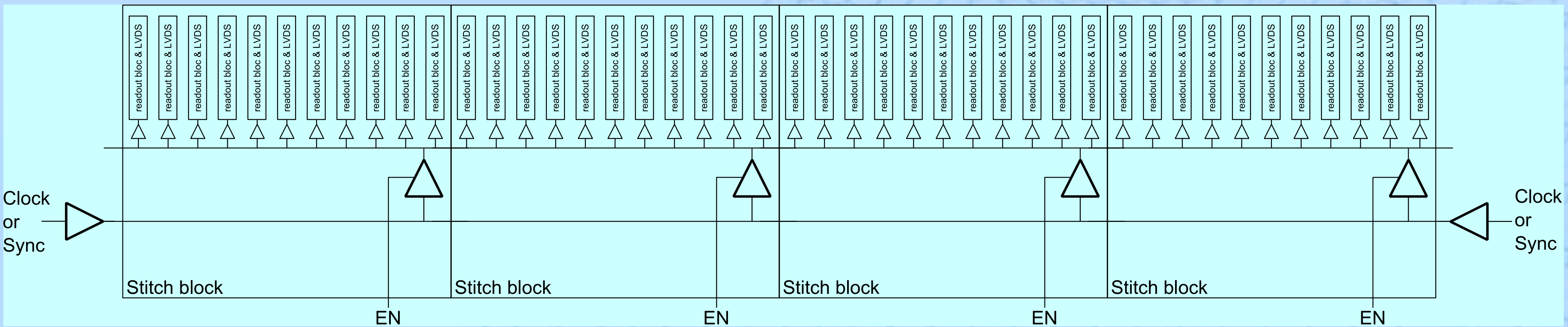

Fast clock
Capacitive load
Capacitive load
Capacitive load
Capacitive load
R/4
C/4(?)
⇒ skew~ 1/16
Fast clock
Capacitive load
Capacitive load
Capacitive load
Capacitive load
R/8(?)
C/8(?)
⇒ skew~ 1/64


Fast clock
1/4
3/4
Fast clock
Capacitive load
Capacitive load
Capacitive load
Capacitive load
R/4
C/4
⇒skew~ 1/16


Fast clock
1/4
3/4
Fast clock
Capacitive load
Capacitive load
Capacitive load
Capacitive load
R/8(?)
C/8(?)
⇒skew~ 1/64

How to implement this when stitching?





Summary

- Preparation work for our next challenge, the E-ELT, is well under way.
- ESO has formed a good partnership with e2v and Caeleste.
- Multi-phase, progressive risk reduction development plan should guarantee that devices are available on-time that meet specifications.
- Measured results from the TVP have clearly validated the CMOS imager approach.
- The best pixel design that meets the requirements has been found to go forward to the next phase, the NGSD.
- The next phase, the NGSD, starts in January 2012.

Thank You

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