Photogrammetry for Large Structures

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Antenna metrology is needed for:

Panel installation/setup

> Photogrammetry

Refined surface adjustment

> Holography

Surface changes (eg, elevation, time)

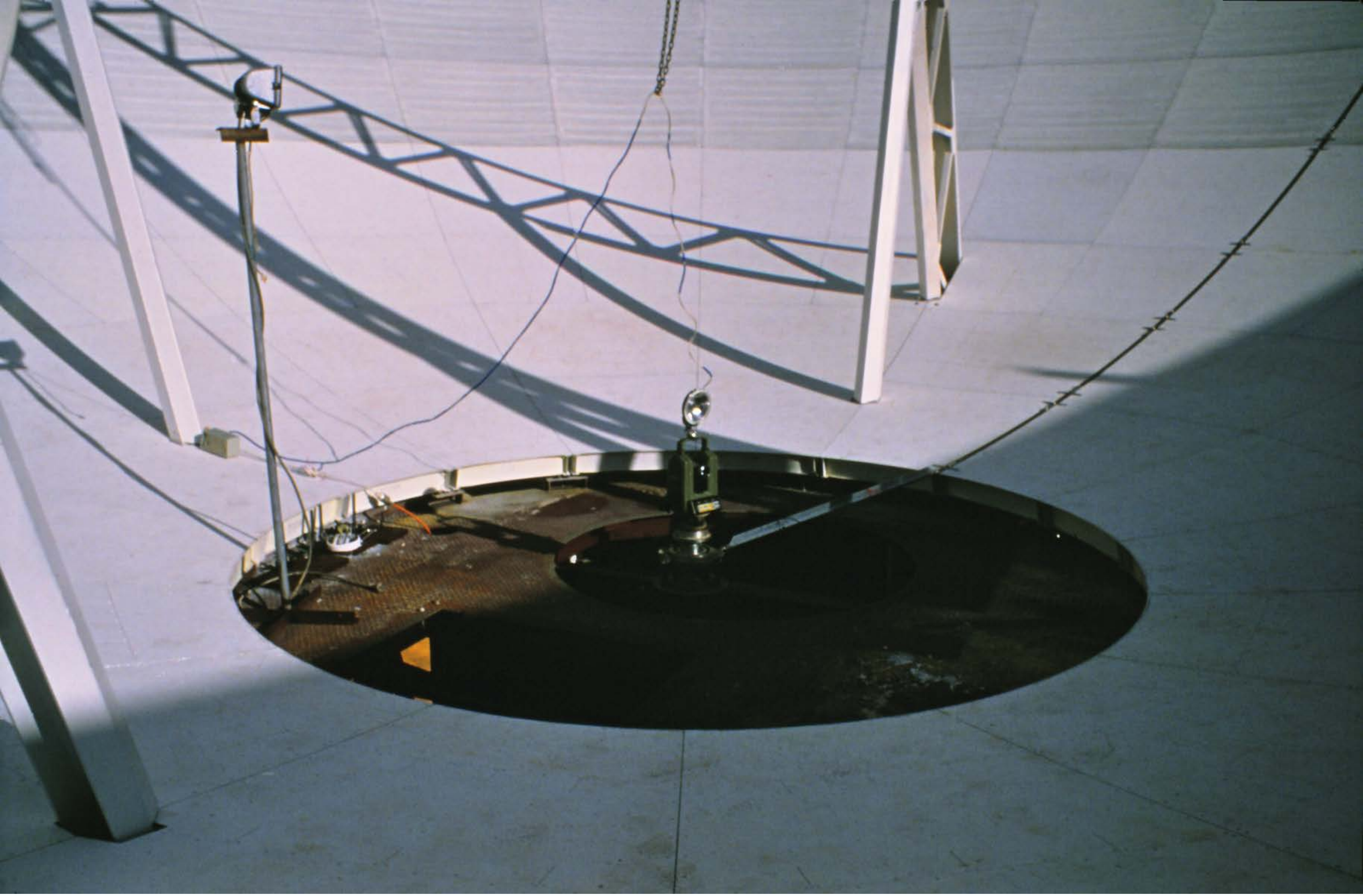
> Photogrammetry/Holography

Holography and Photogrammetry

Photogrammetry (generally) amounts to surveying relative to the design of the antenna optics.

Holography is surveying relative to the antenna beam criteria.

My feeling is that both are required – but holography is the final arbiter. Photogrammetry will expedite the process.



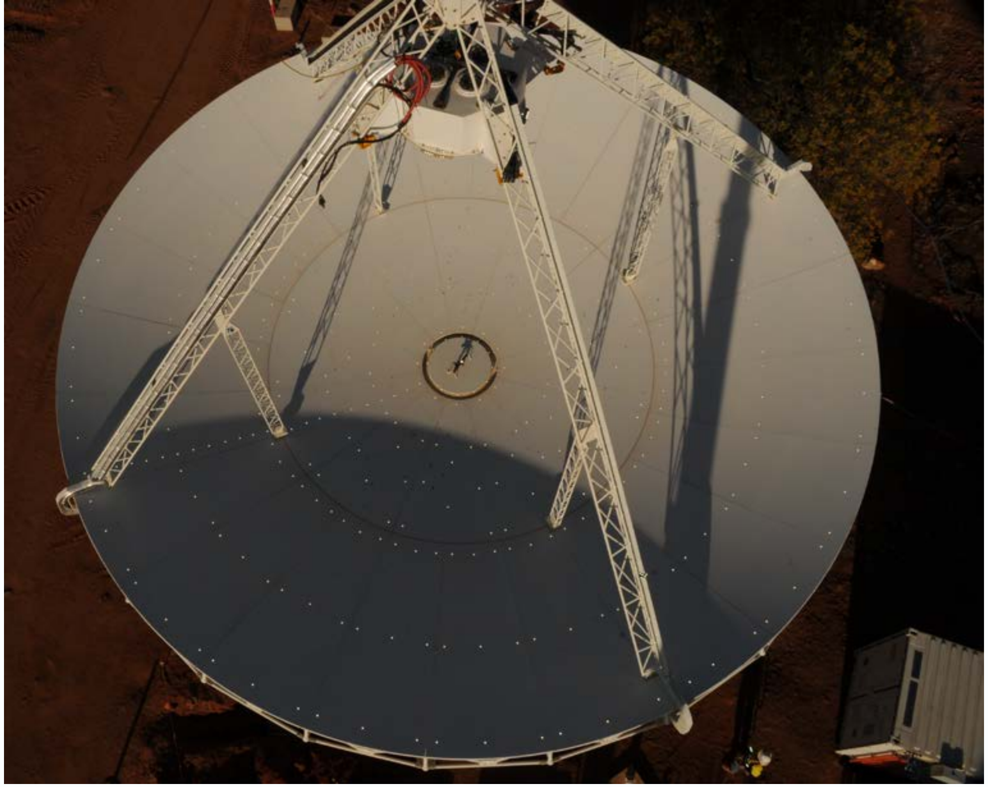
Circa 1986

Laser Tracker – an modern alternative option

OUTLINE :

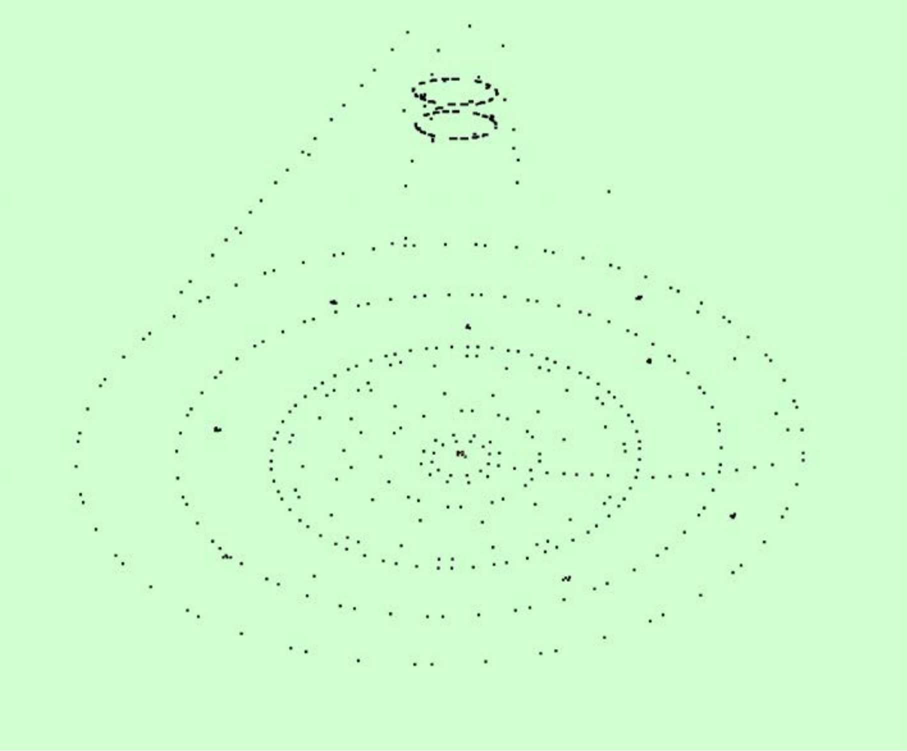
- **The photogrammetry process.**

- **Technical issues**
  - accuracy
  - limitations
  - antenna size
  - multiple reflectors



Photogrammetry in a nutshell

From many photographs of a targeted 3-D object

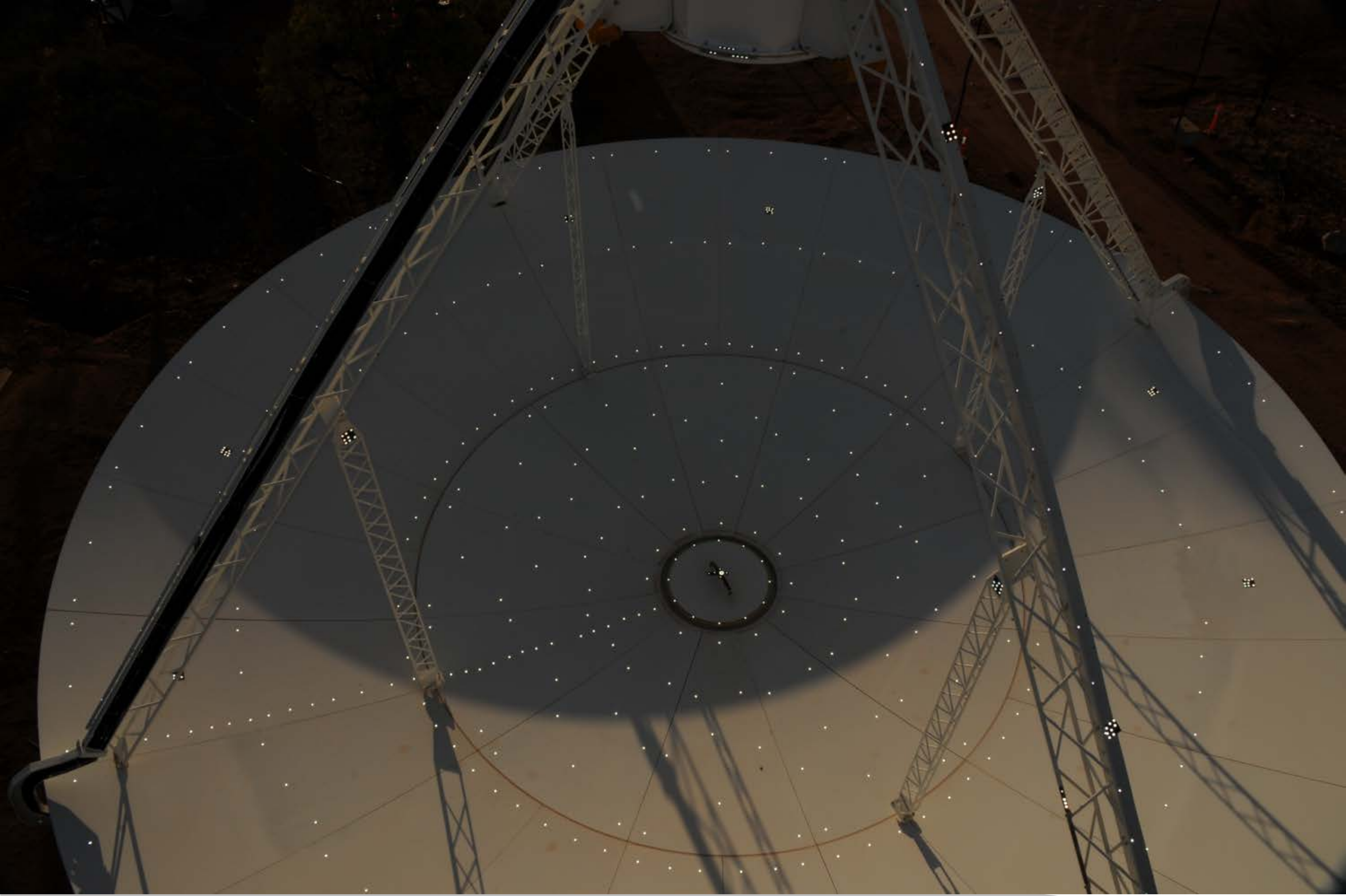


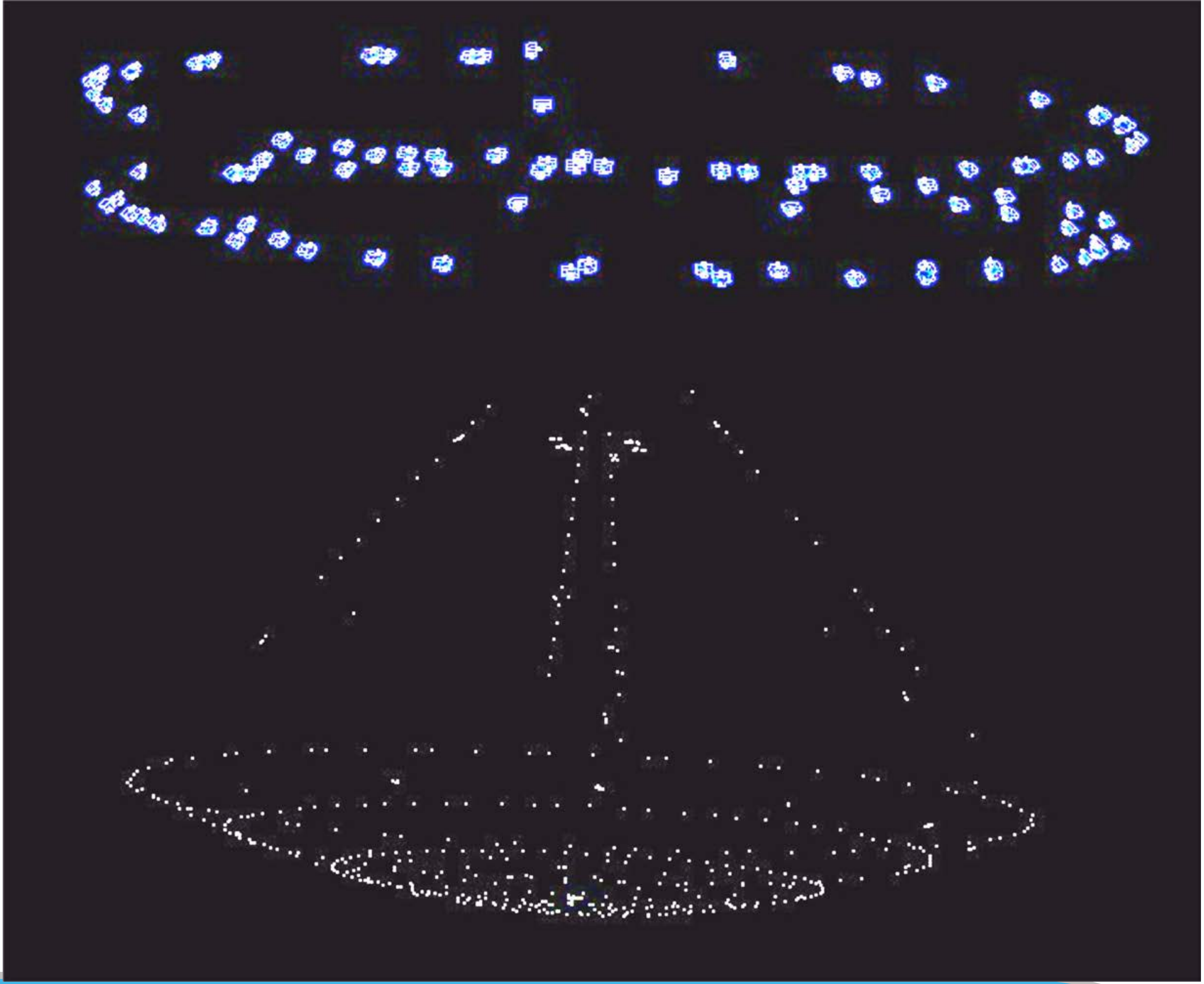
To a table of the (x,y,z) coordinates of every target

The photogrammetry sequence (1)

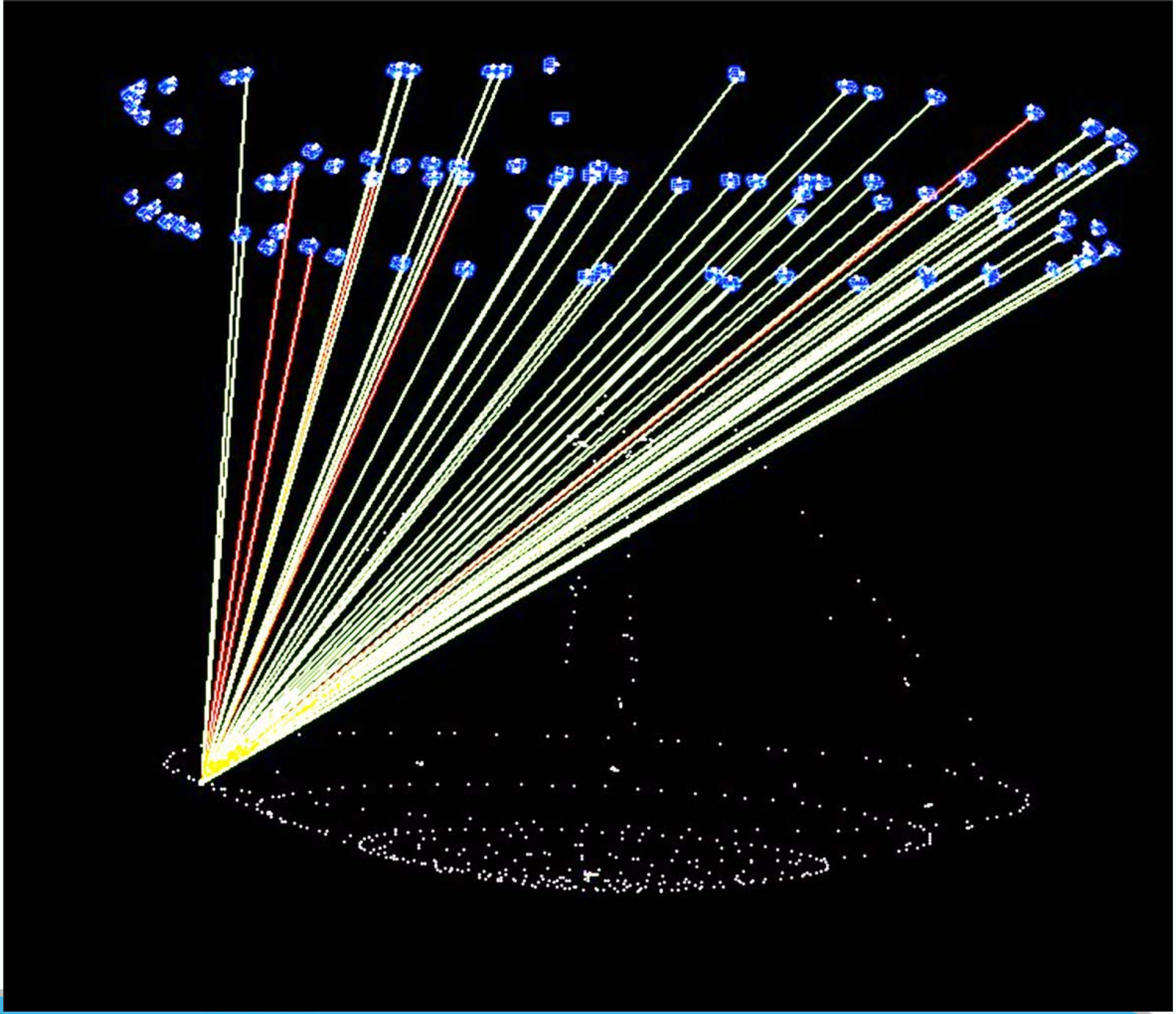
- Place retro-reflecting targets on the antenna.
  The targets come in a standard size set : 5/10/15 mm diameter

- Photograph the antenna from different positions. (The camera flash should be locked to the camera, coaxial with the lens – for the retro-reflection)





- The blue symbols show the camera locations.



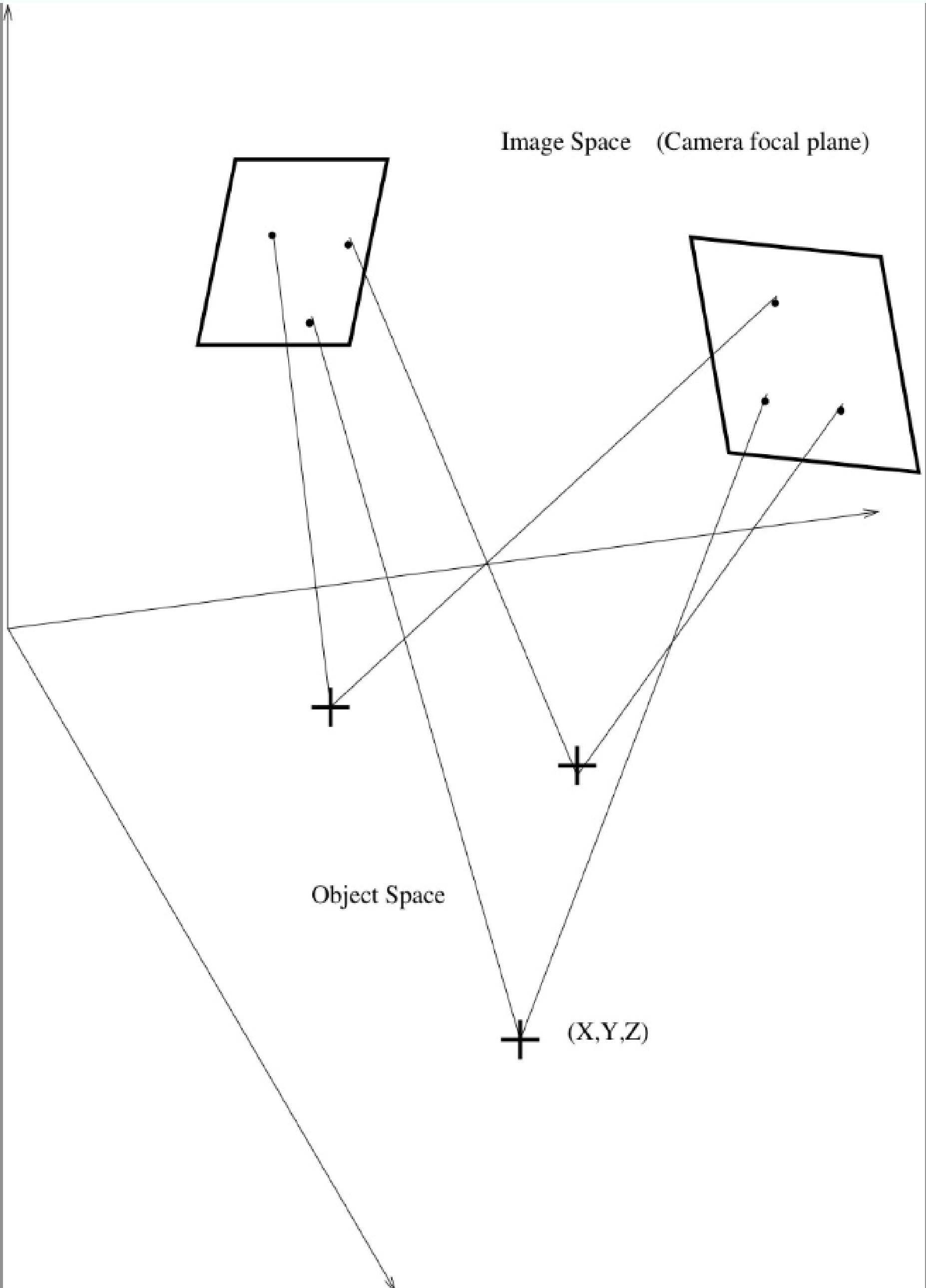
- The yellow rays show all the rays linked to one target

Photogrammetry (2)

A camera is a multi-target theodolite: every pixel in the image plane (the CCD) corresponds to a ray oriented relative to the camera body.

Basic surveying theory tells us that with pictures from a number of different camera locations we could reconstruct the shape of the object (the antenna).

The basic algorithm



Each object (reflecting target) will appear in a number of photos. Registration is the identification process – correctly labelling each detected target in all the photographs.

The processing then does an iterative loop to determine the location and orientation of the camera for each photograph, as well the location of every target.

The position error assigned to each target is set by the convergence of all the rays around the target. (In the ideal world all the rays for a given target would converge on the target; in the real world they converge around the target).

Photogrammetry (3)

- Scan each photograph for targets, and target patterns.

Determine the centroid, subject to quality criteria: (size, half-level width, in pixels)

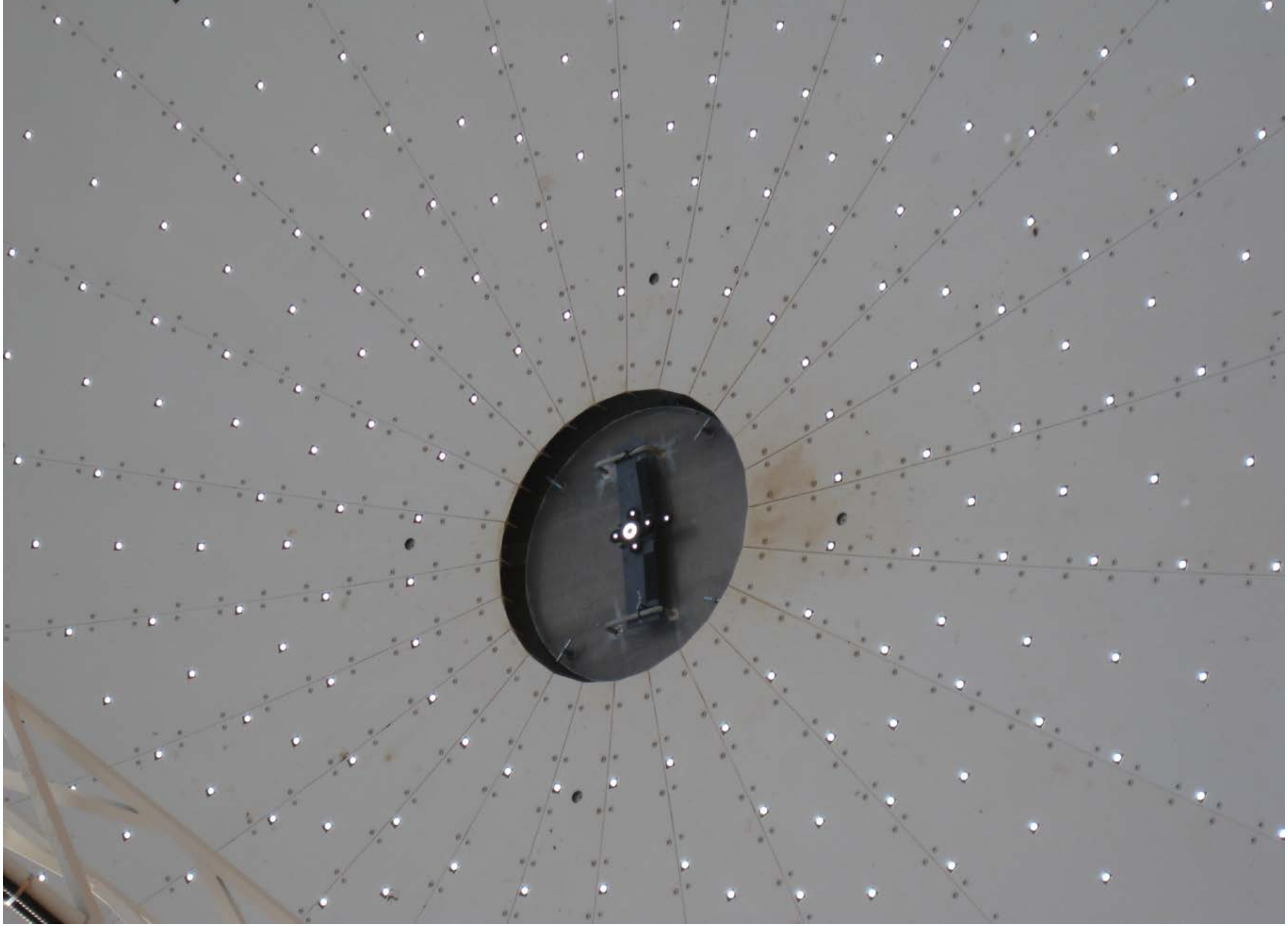
- Process the data to determine the target locations relative to a frame locked to the antenna.

Processing details - Solving for the scaling and camera locations

We need to place on the surface some objects of known size and shape -

1. A special reference object is often placed near the centre of the field (the “autobar”). Its size and shape is known, which means that we can determine the camera location (relative to the autobar) for each image (from this alone), to an accuracy of about 1 cm.

2. Self-identifying targets (“coded targets”) are also frequently used.



Autobar on the reflector

Option 2
Self-Identifying targets (Coded targets)

Two components :

-The “big dipper” pattern signals a code.

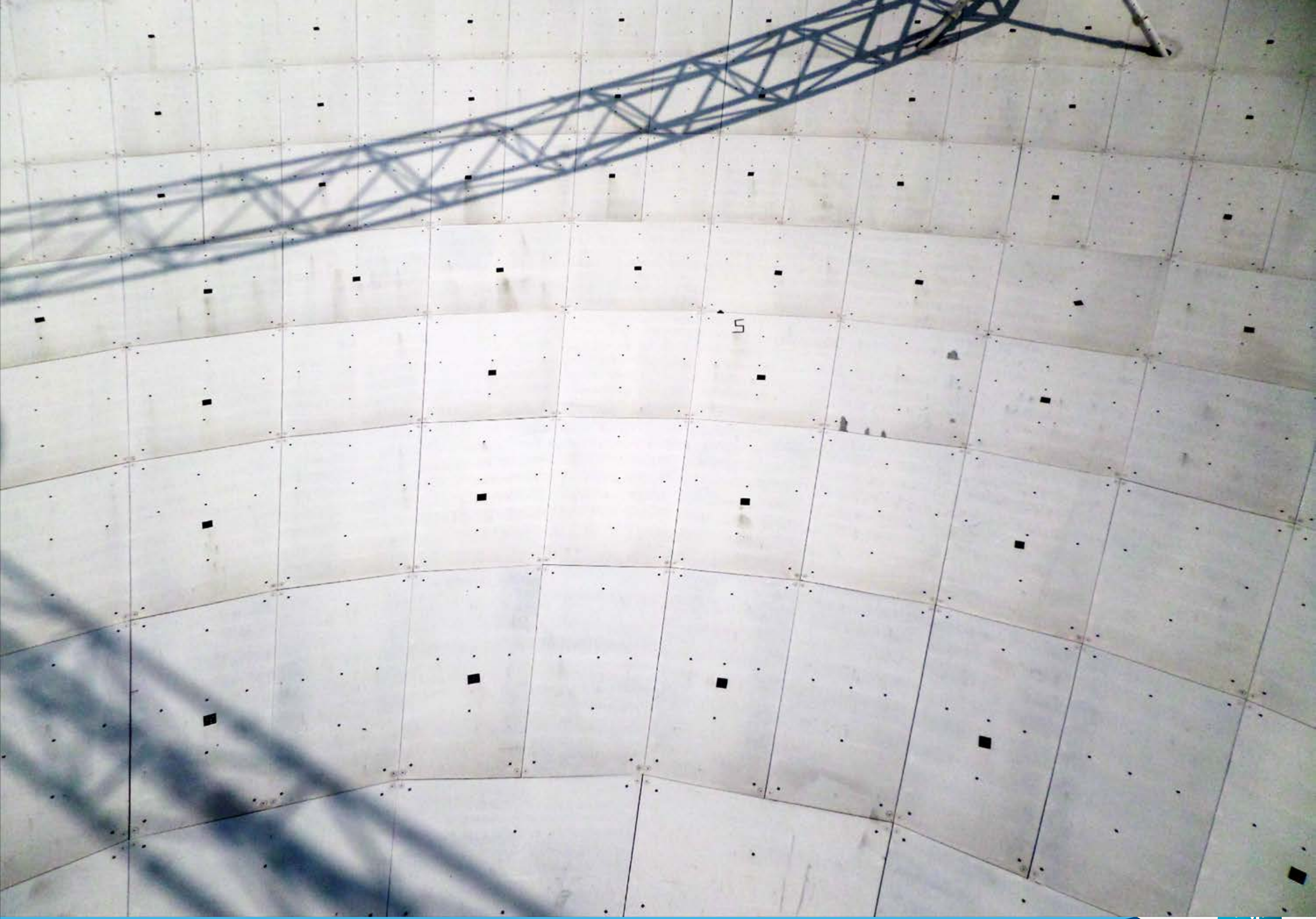
- The remaining three targets encode the target ID (0-255)

The central target provides the location (x,y,z) used in the processing.

Coded targets (2)

The measured proportions of the signature pattern of the coded target can be used to define the camera orientation relative to the plane of the coded target. The target size can set the scaling of the image.

Special scale bars might also be used to set the scaling of the data with increased accuracy.



The Shanghai 65m, with a generous set of coded targets, and with 9 standard targets/panel

Accuracy issues

An automatic estimate of the accuracy comes from the metric used in the iterative algorithm : we have, for each target, the rms perpendicular distance to each ray in its bundle.

We typically find σ ~ 0.03 mm for each axis, for the 12m ASKAP antennas. (This is the internal accuracy from the least squares operation. It is consistent with the FOV and the pixel size.)

-- a proportional accuracy of ~ 400,000 : 1

Accuracy issues (2)

The camera calibration is another contributor to this error.

This is the mapping from CCD pixel to an angle relative to the camera body. This calibration is refined as part of the iterative solution.

Accuracy issues (3)

- Camera :

  - Field of View : It is desirable that a substantial fraction of the object (antenna) be visible in each photo.

  - CCD array pixel count : the pixel spacing on the CCD array should be high enough that the uncertainty error associated with the centroid operation on each detected target.

Accuracy issues (4)

The distribution of rays at the target can be an issue – ideally the rays should be isotropic about each target. Some care is needed in taking the photos. Note that these retro-reflecting targets limit the reflection to a cone (normal to the plane of the target) of about 60° half-angle).

Our experience is that the system is remarkably simple and robust.

Multiple surfaces

Aligning Main and subreflector

(The Phased Array Feed in this instance)


P-5
P-6
PELTIER 5
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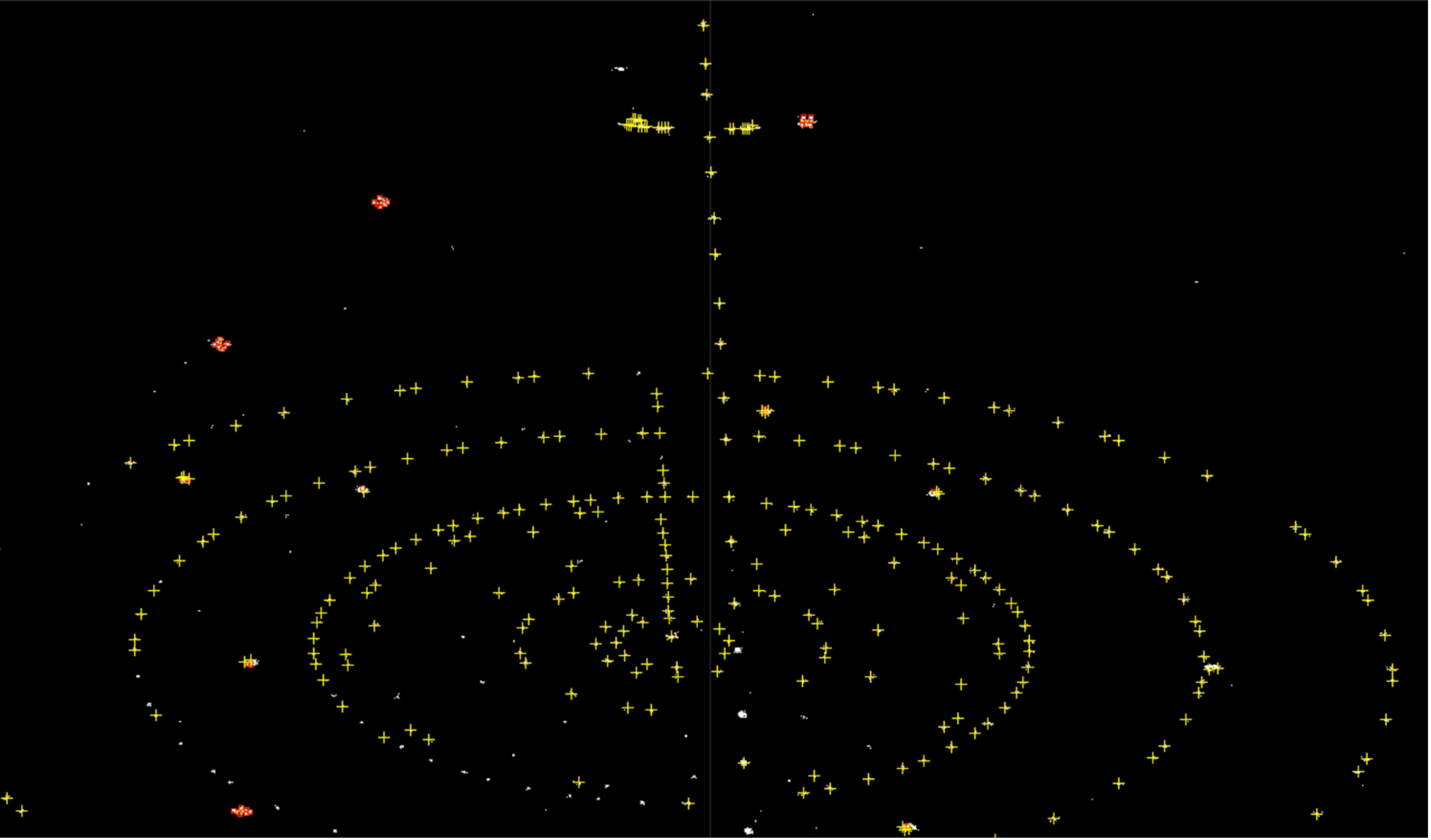
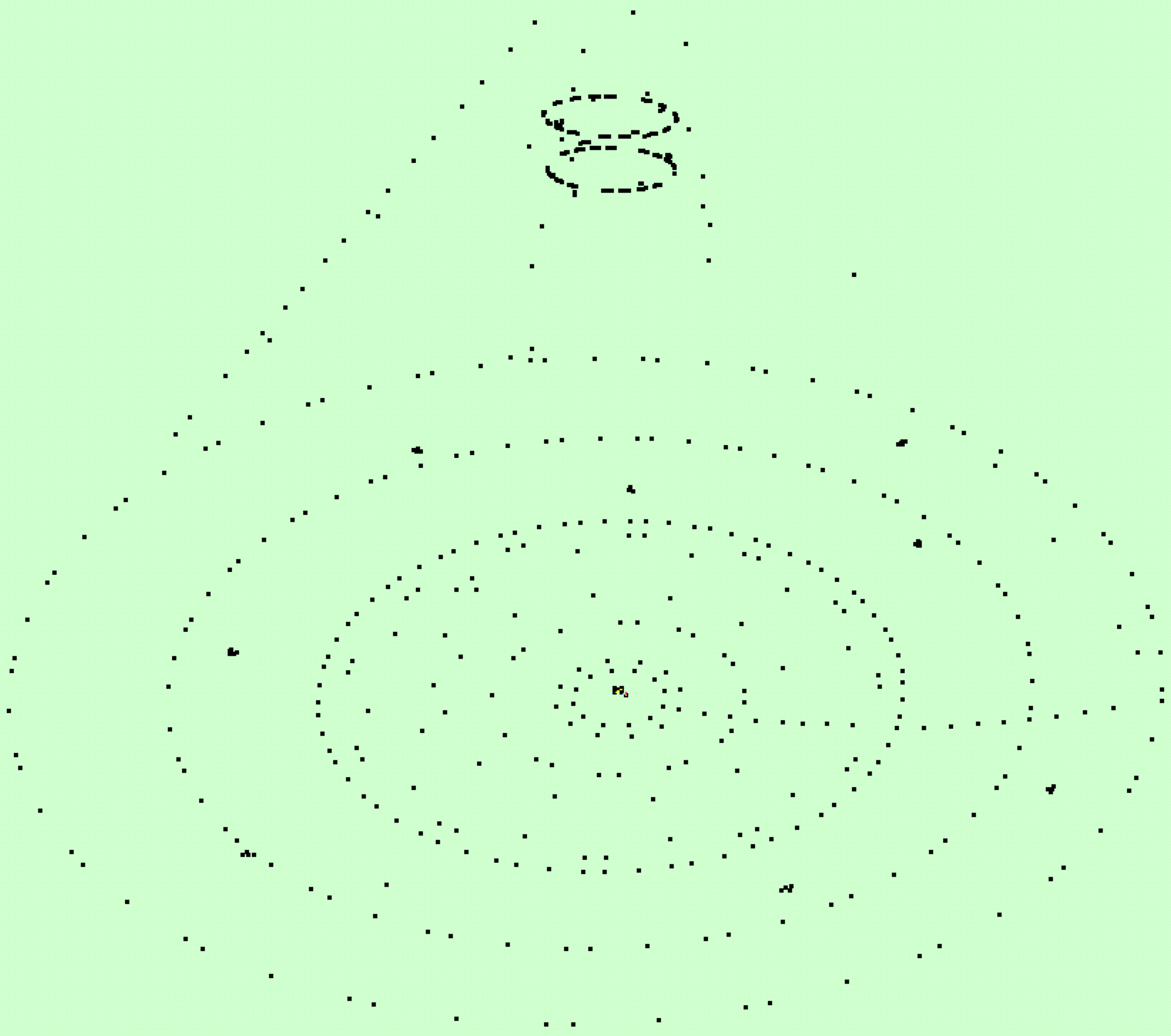


One photogrammetry image showing both the main reflector and the focal plane phased array feed



- The 3-D viewer image of the photogrammetry solution

Big Antennas

-TianMa (65m) and the SRT (64m) have both been measured photogrammetrically.   I imagine that the challenge is the photographer’s safety, rather than the photography itself.

-A camera on a drone might be a realistic option for large antennas. (As opposed to a difficult and challenging elevated work platform for the photographer).

ARECIBO and FAST

Arecibo (300m) (Edmundson and Baker, 2000)

This antenna's surface was adjusted under photogrammetry guidance :

- It used a large format camera, and a scanner to digitize the data.
- A small number of camera locations (on the towers which support the focus cabin).
- The surface adjustment concentrated sequentially on separate patches of the reflector (rather than the entire surface in one hit).

FAST (500m) photogrammetry

The FAST group have raised the standards to a new level, with a (real-time) photogrammetry-controlled surface adjustment.

Their approach is an interesting variant : use modern remote controlled cameras ("Super-high-accuracy stereo vision measurement system") mounted on the reflector rim. Measuring ~1000 targets on the 300m paraboloidal patch should take about 1 minute, and lead to a surface accuracy of 2mm.

Antenna Deformations

We can make separate photogrammetry runs at different antenna elevation to measure the deformation as a function of elevation. (Which we might then relate to the antenna gain-elevation function).

In our case (ATCA, csiro), with 22m (dia) antennas, the photography process was simple –

The photographer is installed in an elevated work platform a few metres above the edge of the antenna.

The antenna was driven in azimuth at a constant its fastest rate.

We took photos about every 5° .

Three different heights were used for each elevation setting.

Add a few images from Ravi's analysis

Epilogue – The analysis suggested a scheme that would exploit this analysis to cure the gain/elevation function. This will be described later (it was a complicated episode)

Alternative Technology

Laser Tracker

These are precision surveying instruments that are increasingly used on antenna construction and commissioning.

The Tracker is installed on a solid base (eg, a tripod, in the field).

It follows a retro-reflecting target.

Typical accuracies are $\pm 15\ \mu m + 6 \mu m/m$

Laser Tracker and Photogrammetry

These two techniques have identical surveying credentials.

They do differ somewhat on a few issues.

1. Measurements of the deformation as a function of the elevation angle might be a challenge for the tracker.

2. The photogrammetry targets are glued to the surface – this might be an advantage in the analysis of repeat measurements over extended periods of time.

3. The tracker will certainly win if a high density of measurement points is required.

Notes -

1. The process gives us the location of each target. Whether or not the target is representative of its immediate surroundings is a different matter. In effect, we require the scale size of panel defects to be larger than the target spacing.

2. Cautionary note: Multiple reflector systems (Cassegrain optics, for example) require a “matched set – main and subreflector”. It is possible that neither is the correct shape – but jointly, their errors can be cancelled.

A Cautionary Tale –

The case of the saddle-shaped subreflector

The Australia Telescope Array was commissioned in 1988

The antennas were upgraded, over the years following the commissioning, to support mm-class operations. This included a refining of the surface.

The surface was adjusted with holography – to achieve a surface rms ~ 0.2 mm.

In 2005, an extended photogrammetry program investigated the details of the reflector deformation as a function of elevation, and indicated that a better (gain-elevation) performance could be achieved if the subreflector was tilted gently as the elevation changed.

ATCA 22m antenna

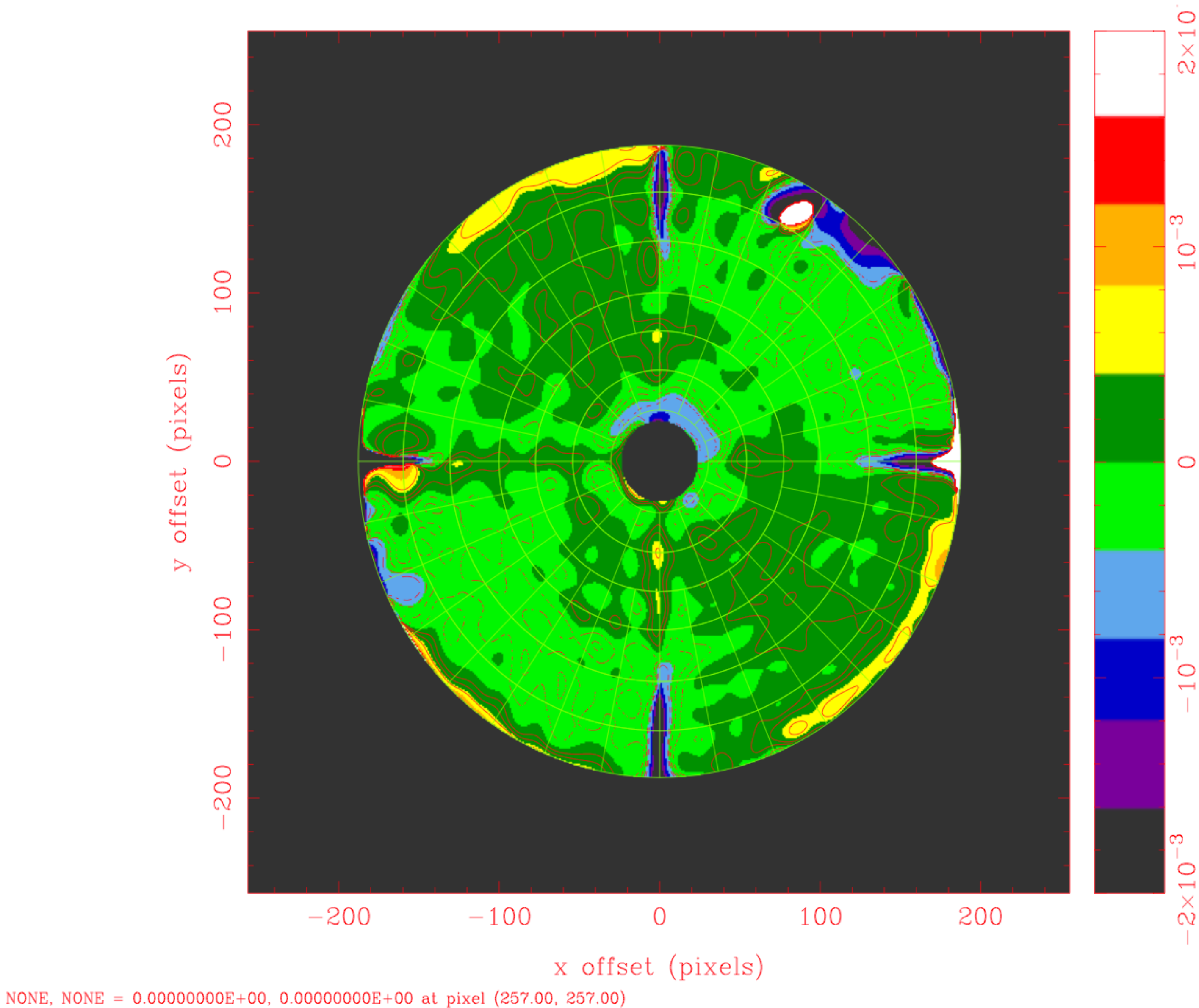
Analysis:

1. The main reflector changes shape as the elevation changes (from el=0 to el=15)
2. These deformations can account for the gain change.
3. The quadlegs bend (with elevation), imposing a small rotation on the subreflector.
4. It would be possible to recover most of the loss in gain by rotating the subreflector about an axis parallel to the elevation axis, as a function of elevation.

Unhappily, the outcome was a failure: the gain was down at all elevations.

No tilt nor refocussing could recover the gain.

The holography surface error map – measured after the installation of the tilt machinery



Diagnosis

We concluded that the subreflector had changed with the installation of the tilt machinery.

The subreflectors were precision surfaces, produced on a precision mill; but, apparently, the subreflector support structure was not made with the same accuracy.

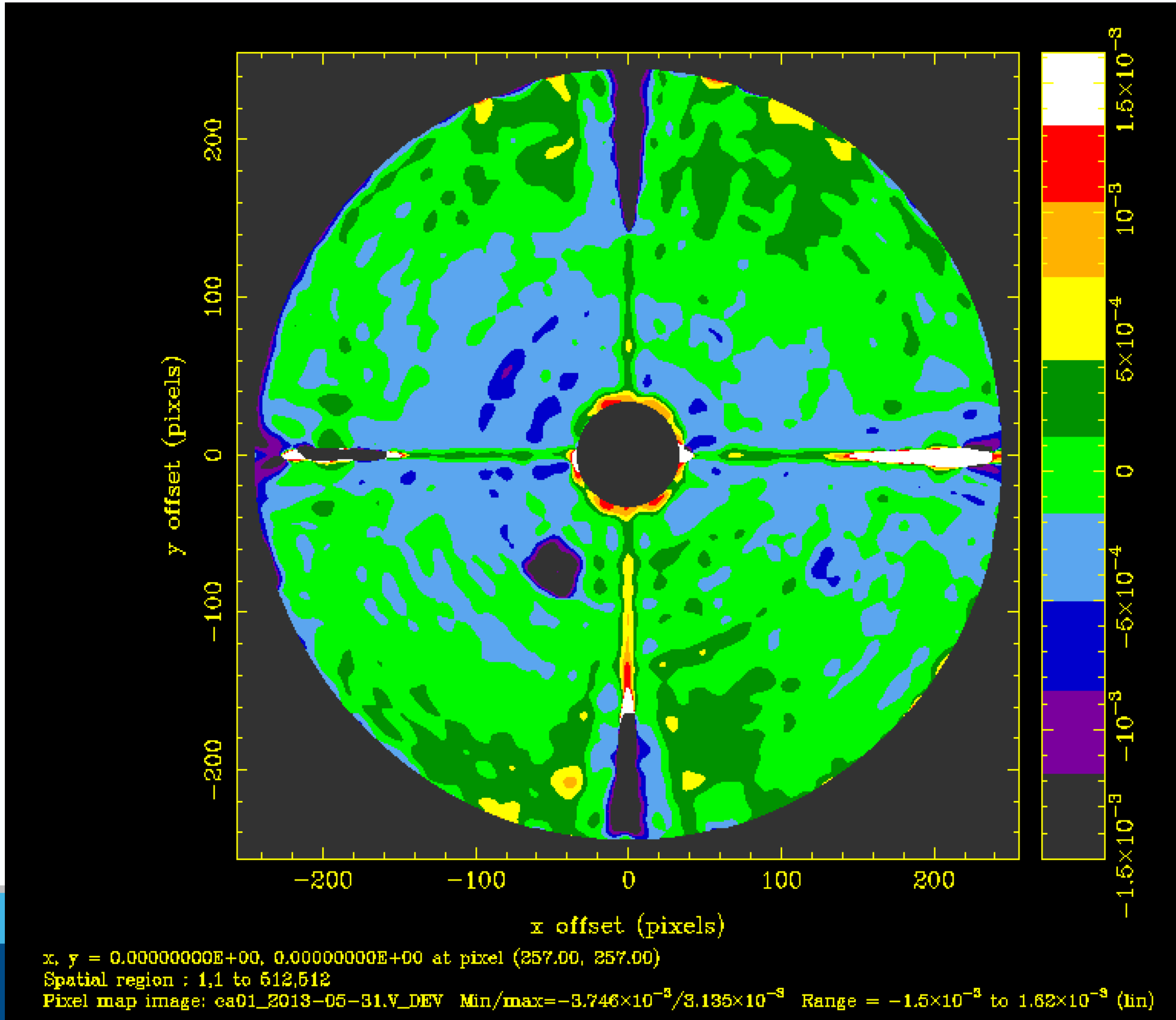
The subreflector was therefore deformed when it was installed on the antenna. The earlier antenna surface adjustment, guided by holography, had absorbed this deformation into the panel settings of the main reflector.

The upgrade tilt-machinery had released the stresses on the original subreflector installation, breaking the (main reflector/subreflector) joint match – thereby degrading the effective surface accuracy.

The holography had created a quality aperture plane, embedding a “negative subreflector error” on the main reflector.

We abandoned the trials, and restored the reflector support structure.

The holography surface – post re-adjustment.

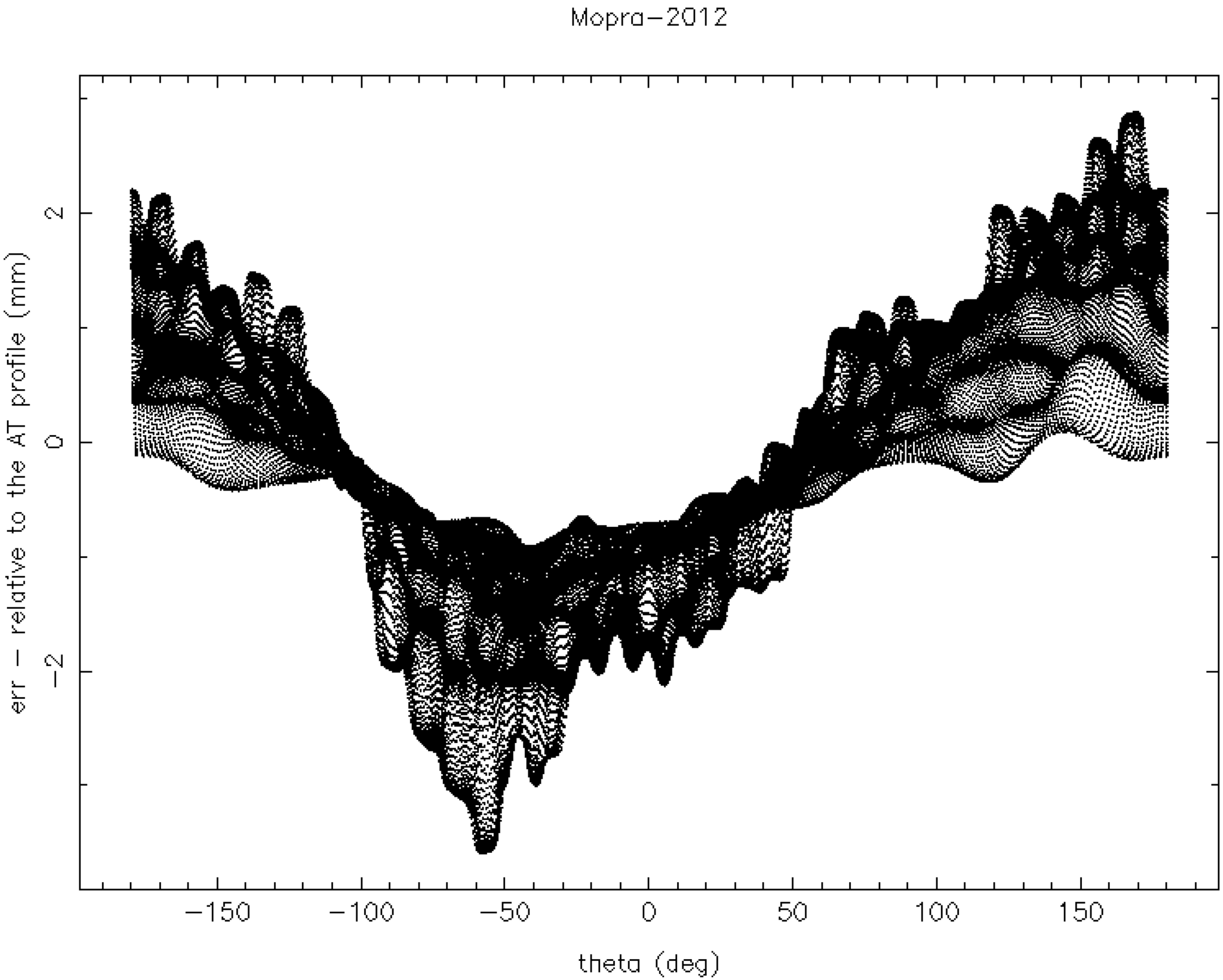


A test simple test looked at the offset between each target and the axial (z) position defined by the designed reflector radial profile.

The plot shows the error as a function of the orientation in the aperture plane.

It carries a clear error signature.

From the archives: the main reflector surface error – the offset from the design profile – the smoking gun



Thank you

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