Improvements to Stereo-SCIDAR turbulence profile estimation

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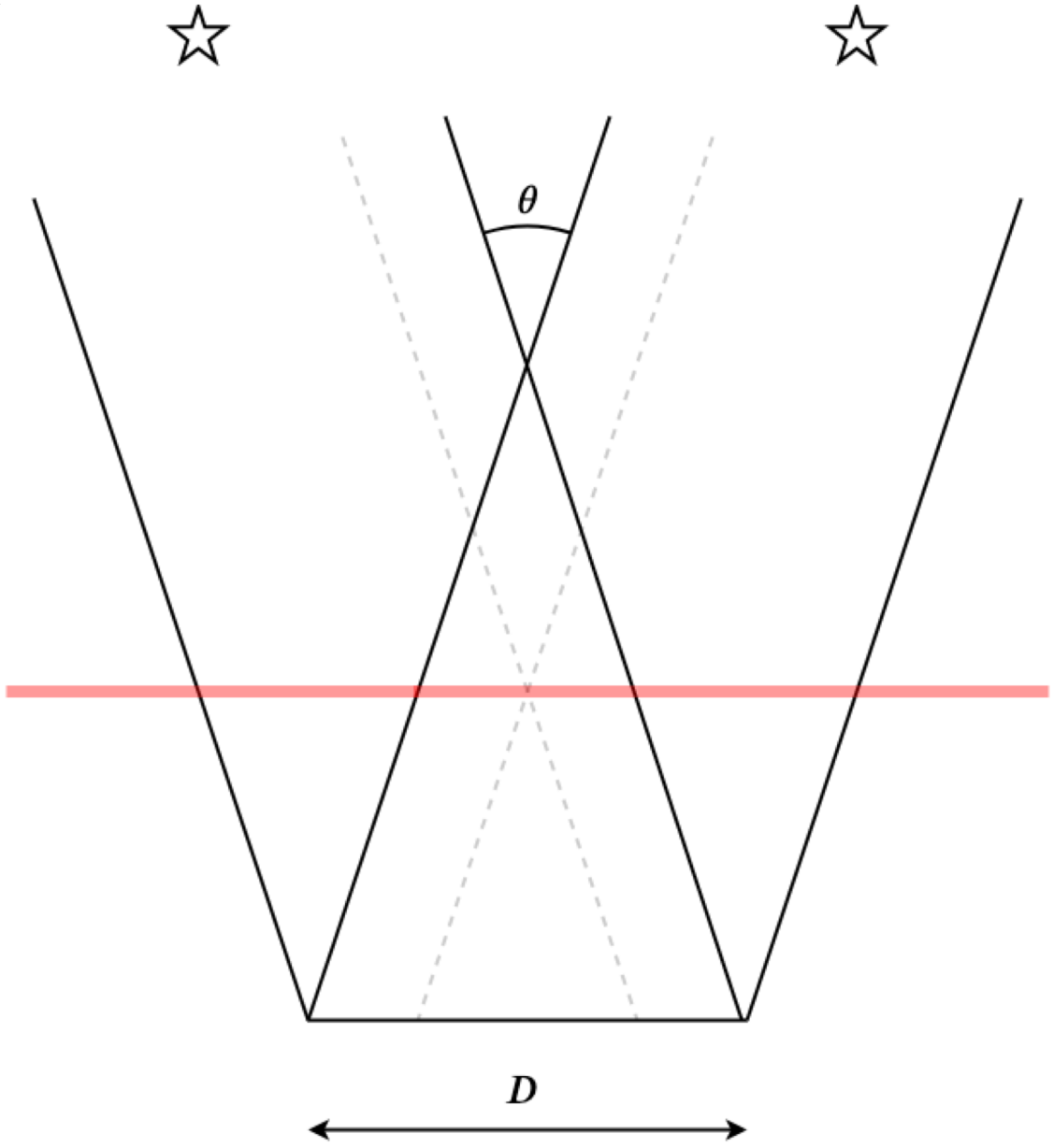
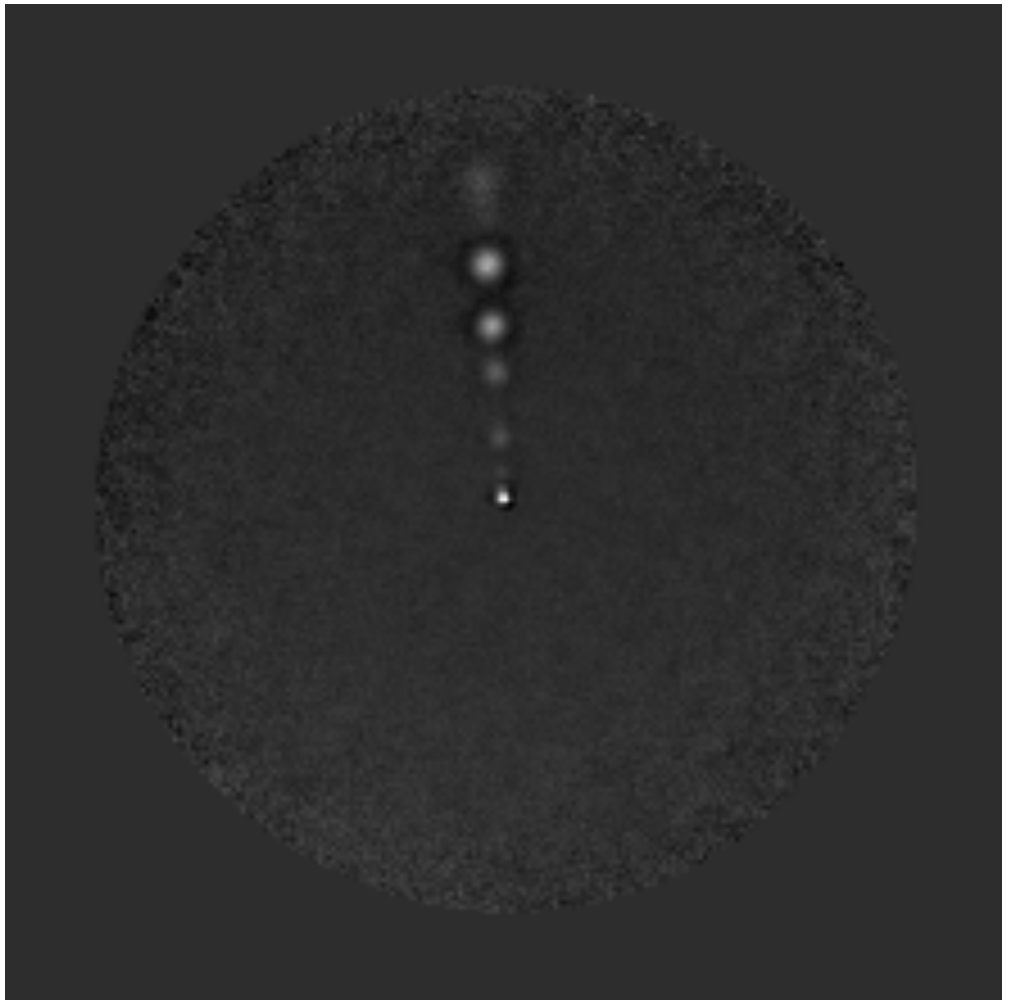
SCIDAR technique

- SCIDAR is short for “scintillation detection and ranging”.
- Optical turbulence profiling technique.
- Triangulation method: instrument observes pupil scintillation from 2 stars.
- Turbulence features from higher layers are projected onto the pupil with larger separations.



SCIDAR technique

- Turbulence profile is recovered from cross-covariance of scintillation (averaged over ~1 min).
- Each peak is a layer of turbulence:
  - Distance from centre is proportional to height above ground.
  - Width is a function of propagation distance from layer.
  - Peak height is proportional to layer strength.
- We fit a model to these peaks to recover the turbulence profile.



Example spatial cross-covariance from Stereo-SCIDAR (2019-02-15T02:30:53)

Paranal Stereo-SCIDAR

- “Stereo”: two cameras.
- Sampling: pixel size 1.8cm, exposure time 2ms.
- Generalised SCIDAR: cameras are conjugated below the ground to allow ground layer to be measured.
- Installed on 1.8m Auxiliary Telescope (AT).
- Output profiles are interpolated to fixed resolution of 250m.
- Profiles used for VLT and ELT AO modelling.
- More details: Osborn et al (2018), MNRAS 478, 825-834.

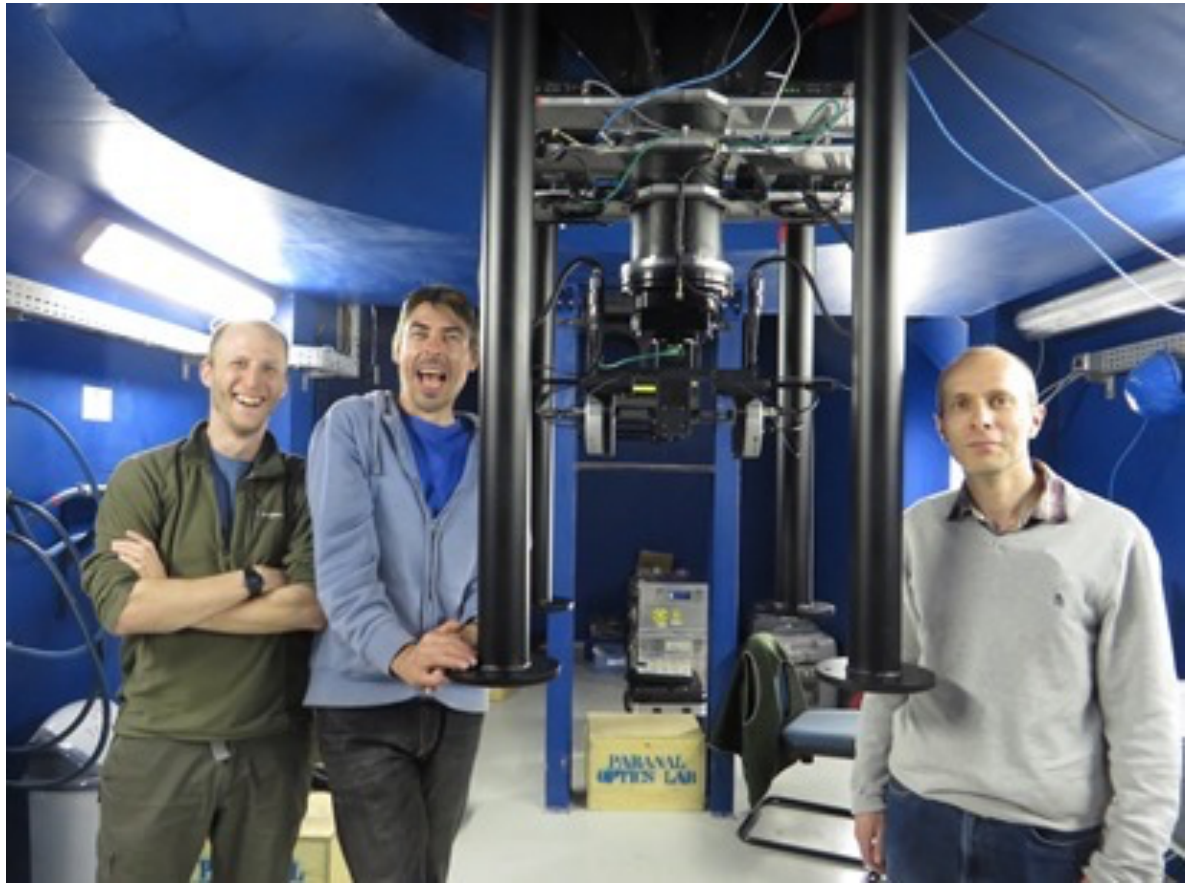


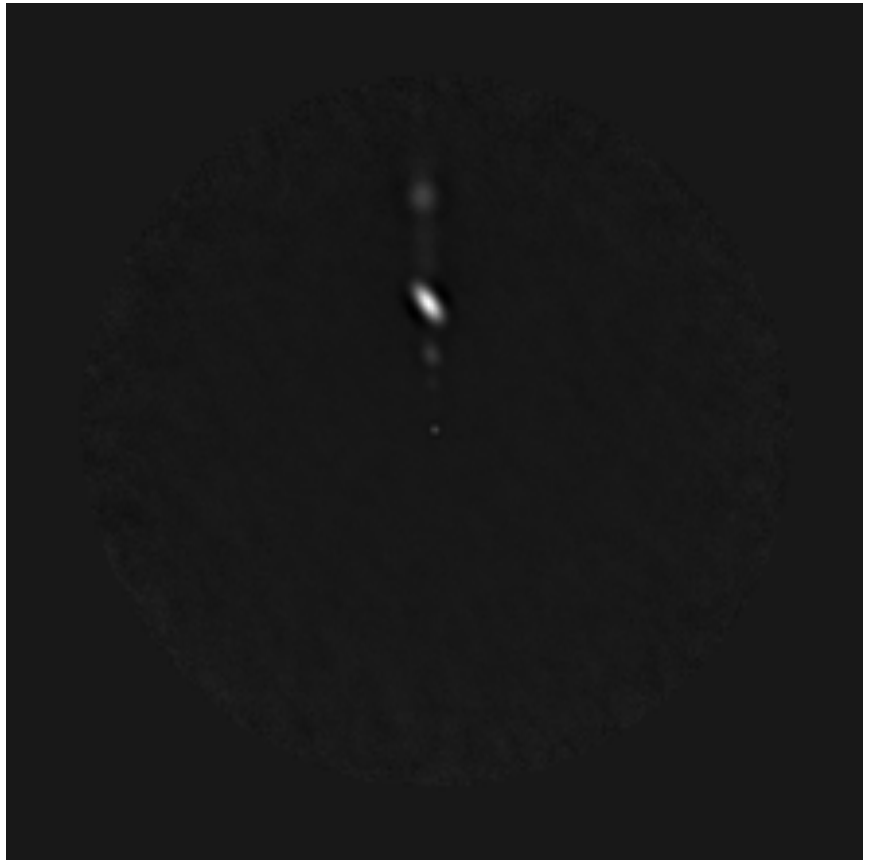
Image source: CfAI website

New pipeline

Model fitting refined to address 3 main error sources:

- 1.8cm pixels are not “small” (low altitude peaks are not Nyquist sampled).
- Scaling error in peaks of approx 1.9.
- 2ms exposure time is not short enough to “freeze” fast-moving turbulence. Wind speed can be > 50 m/s above Paranal – i.e. translation of 10cm within one exposure.

Existing data can be reprocessed with the new pipeline.

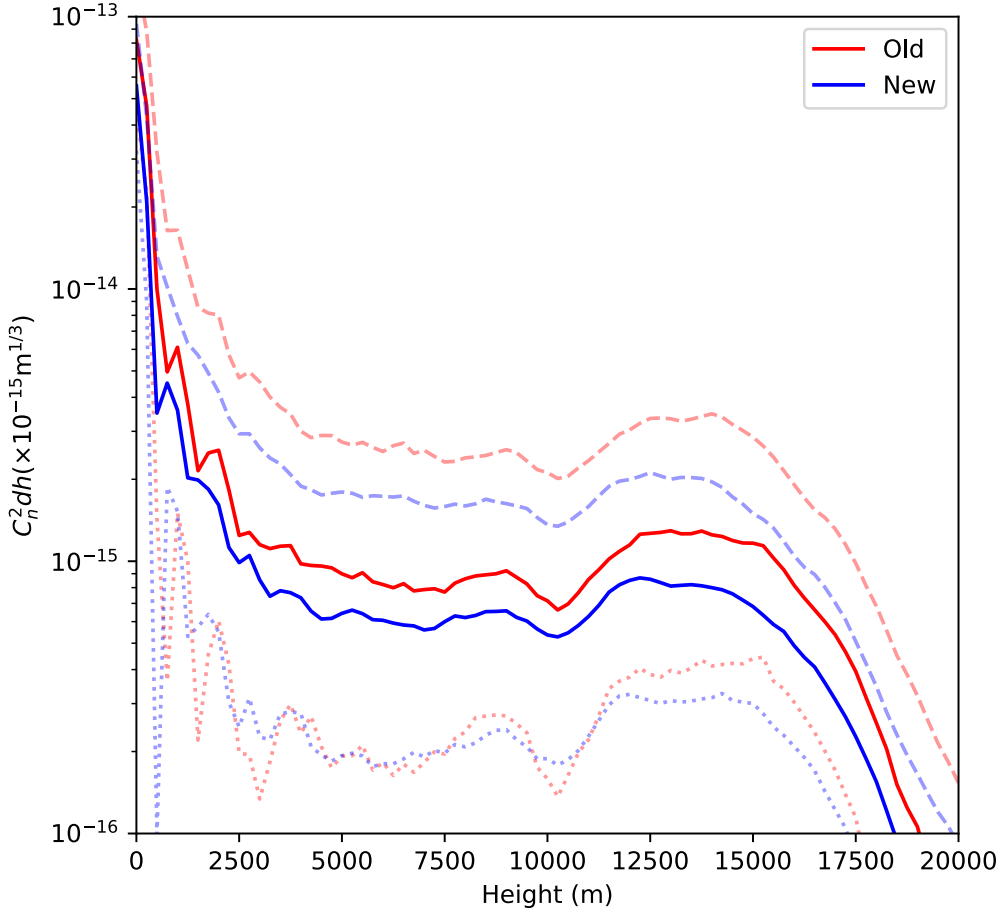


Example spatial cross-covariance (2019-10-05T01:12:53)

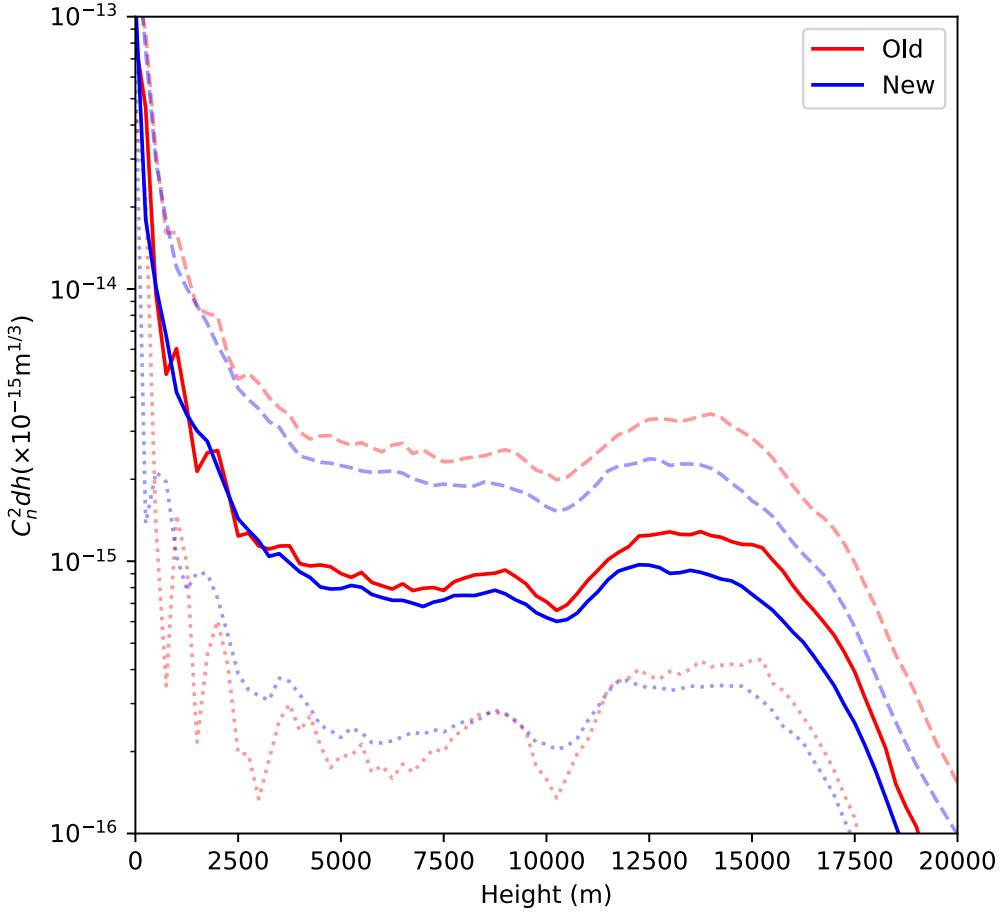
Conjugation altitude

- S-SCIDAR is a generalized SCIDAR i.e. it is conjugated below the ground.
- The design conjugation altitude was -3 km.
- The measured correlation peaks corresponding to the ground layer are too narrow, more consistent with a conjugation altitude of -2 km.
- Access to the instrument is required to verify the conjugation altitude – delayed by Covid-19.

Median profile

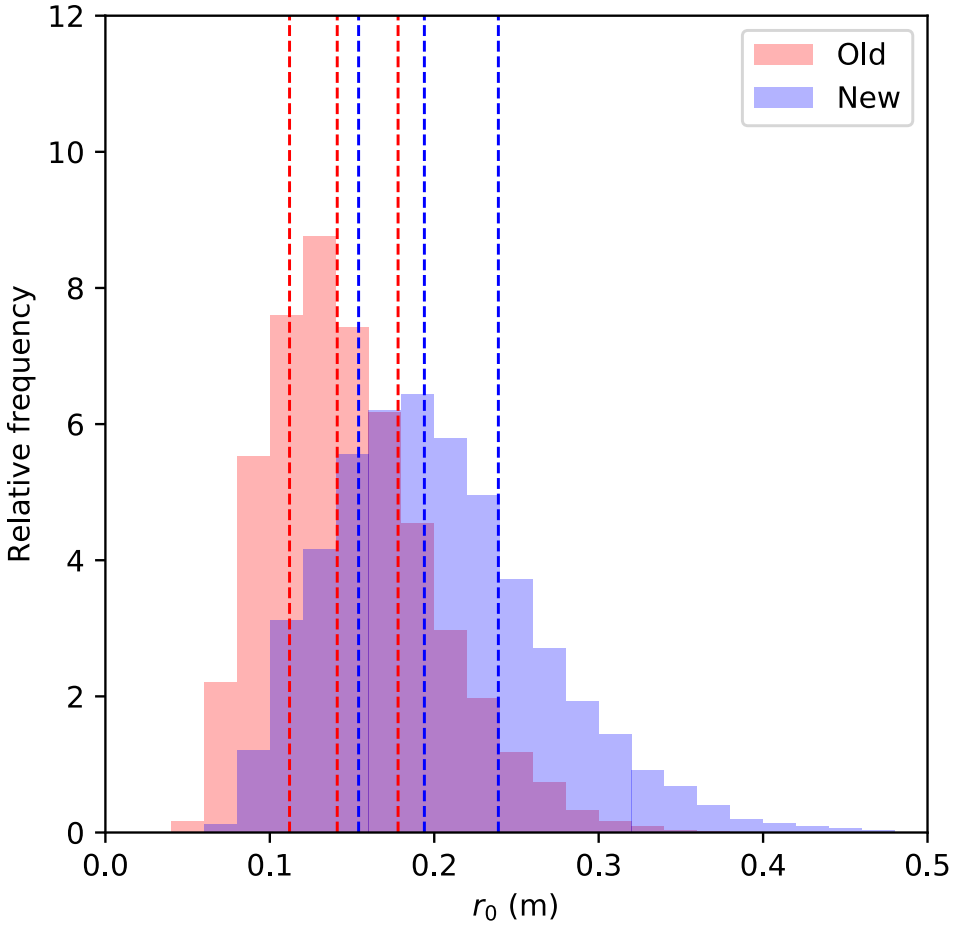


Assuming -3 km conjugation

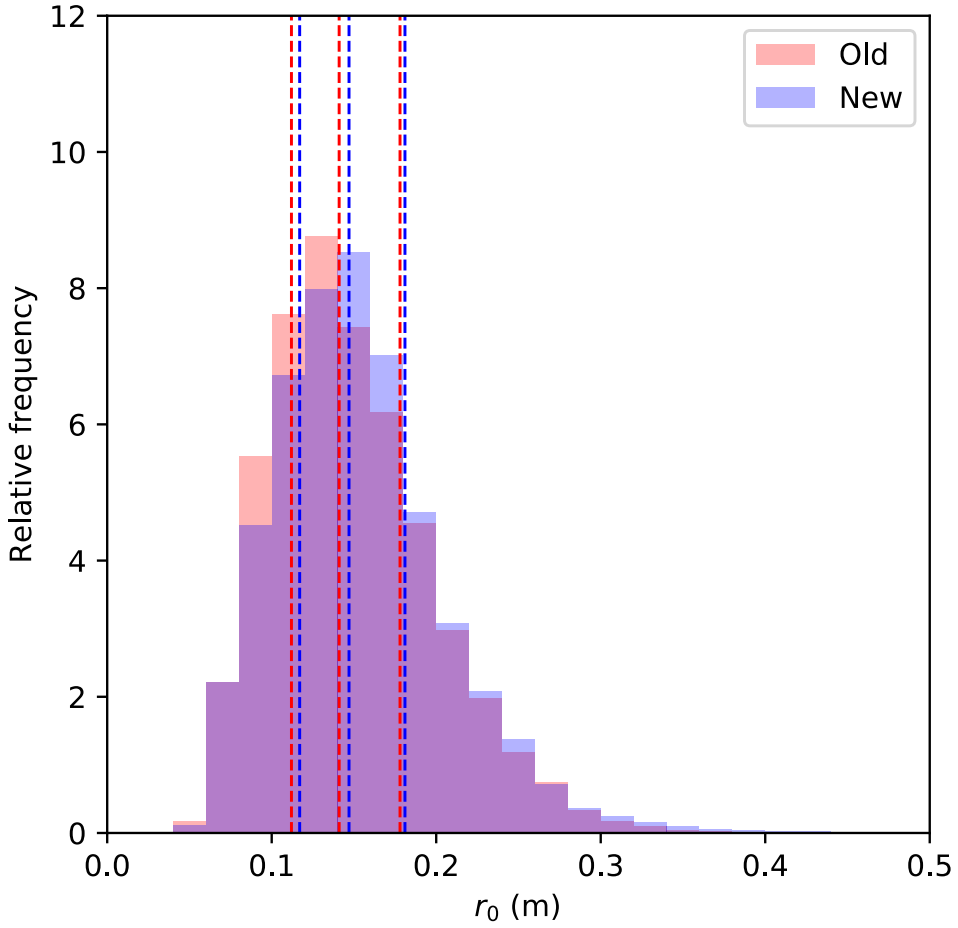


Assuming -2 km conjugation

Fried parameter

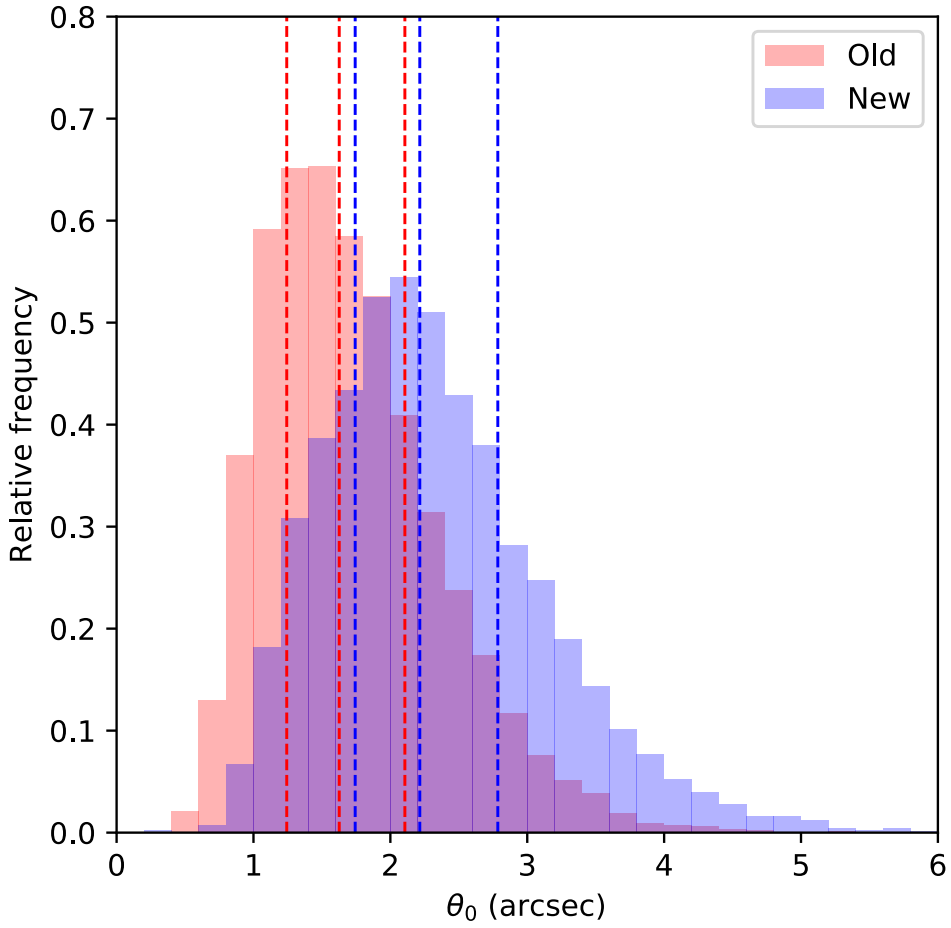


Assuming -3 km conjugation
Median 0.141 → 0.194 m

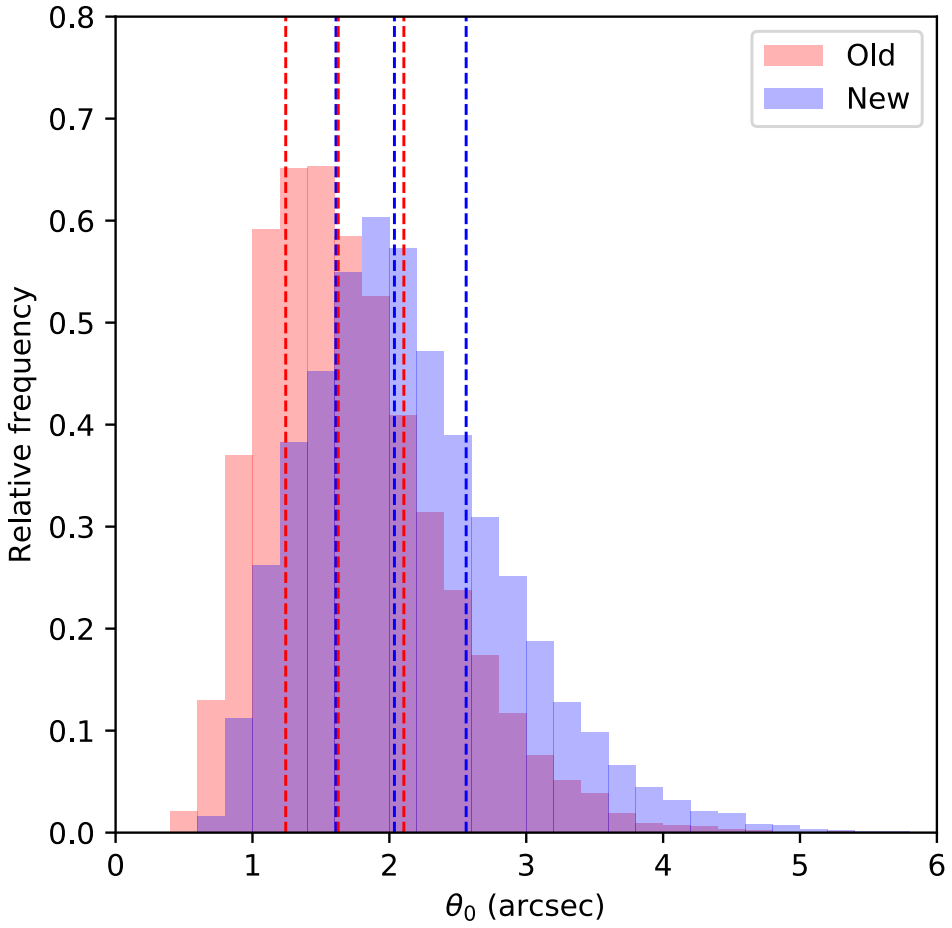


Assuming -2 km conjugation
Median 0.141 → 0.147 m

Isoplanatic angle

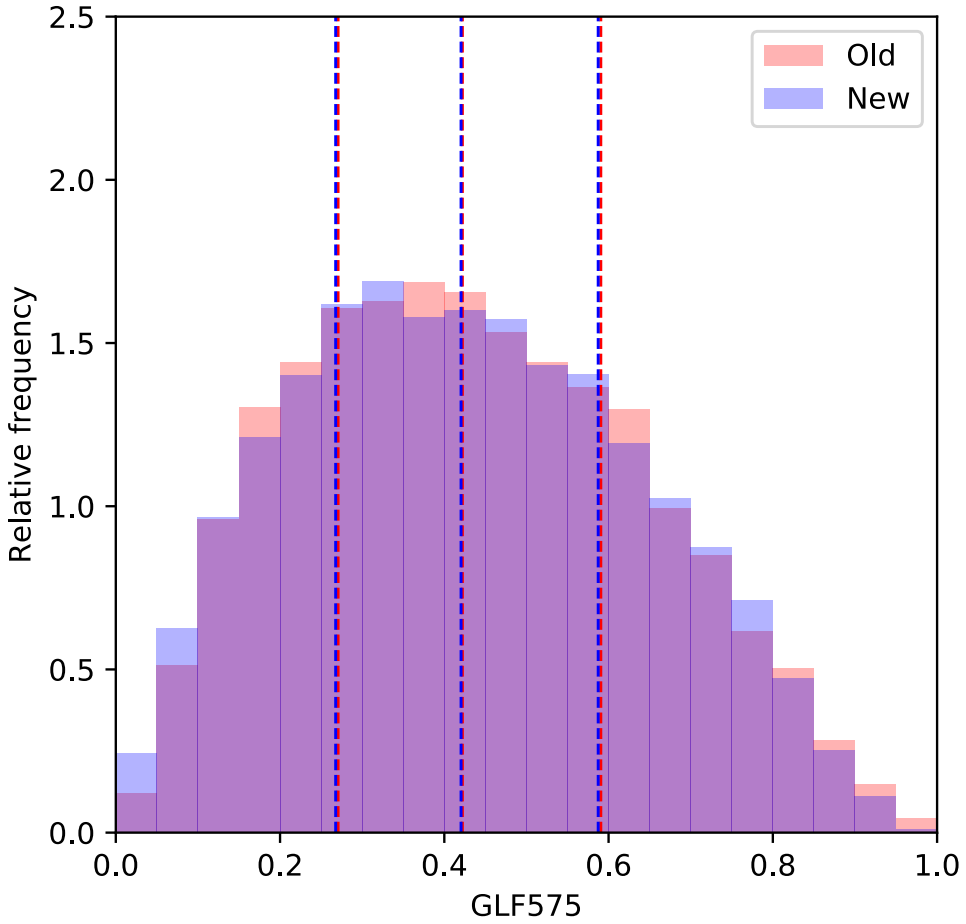


Assuming -3 km conjugation
Median 1.63 → 2.22 arcsec

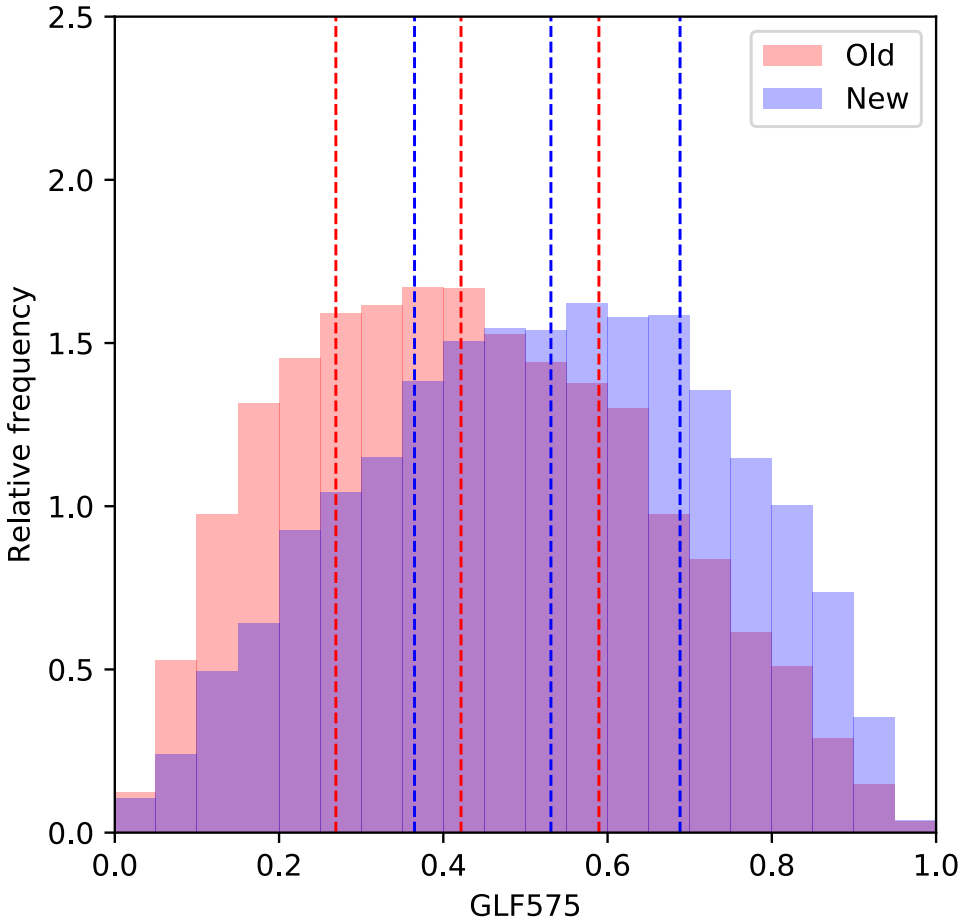


Assuming -2 km conjugation
Median 1.63 → 2.04 arcsec

Ground layer fraction (575m)



Assuming -3 km conjugation
Median 0.42 → 0.42



Assuming -2 km conjugation
Median 0.42 → 0.53

Conclusions

- S-SCIDAR data from Paranal has been reprocessed to correct error sources:
  - Corrected bug: factor of ~1.9
  - Accounted for finite pixel size.
  - Accounted for wind “smearing” of covariance peaks.
- Profile recovery (especially ground layer) depends on conjugation altitude.
- Conjugation altitude must be checked before the profiles can be finalized.

SPIE Astronomical Telescopes + Instrumentation, paper 11448-75