Fine tracking for laser flux stabilization on an optical detector for space-to-ground laser link communication

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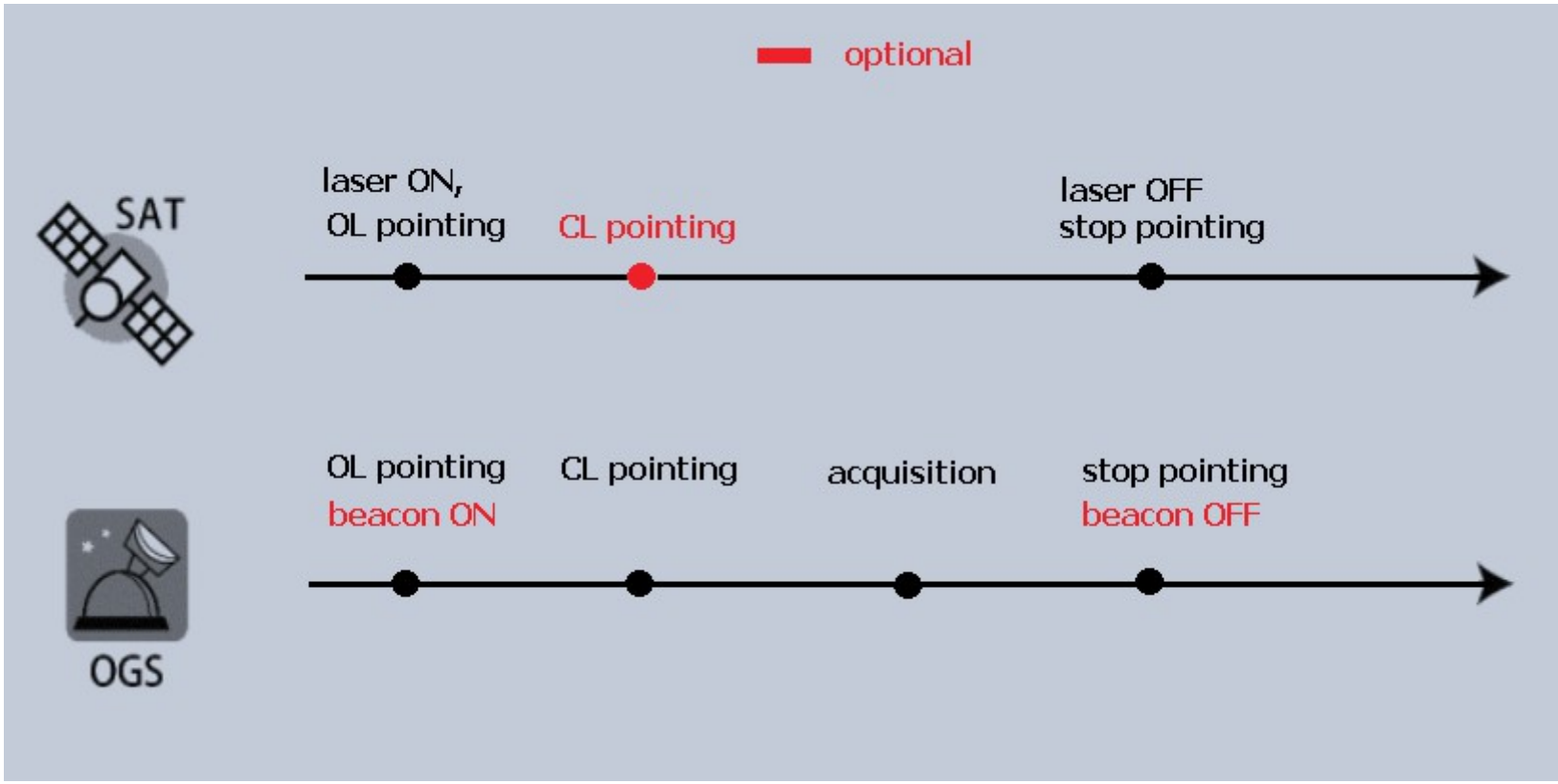
space-to-ground laser link : what for ?

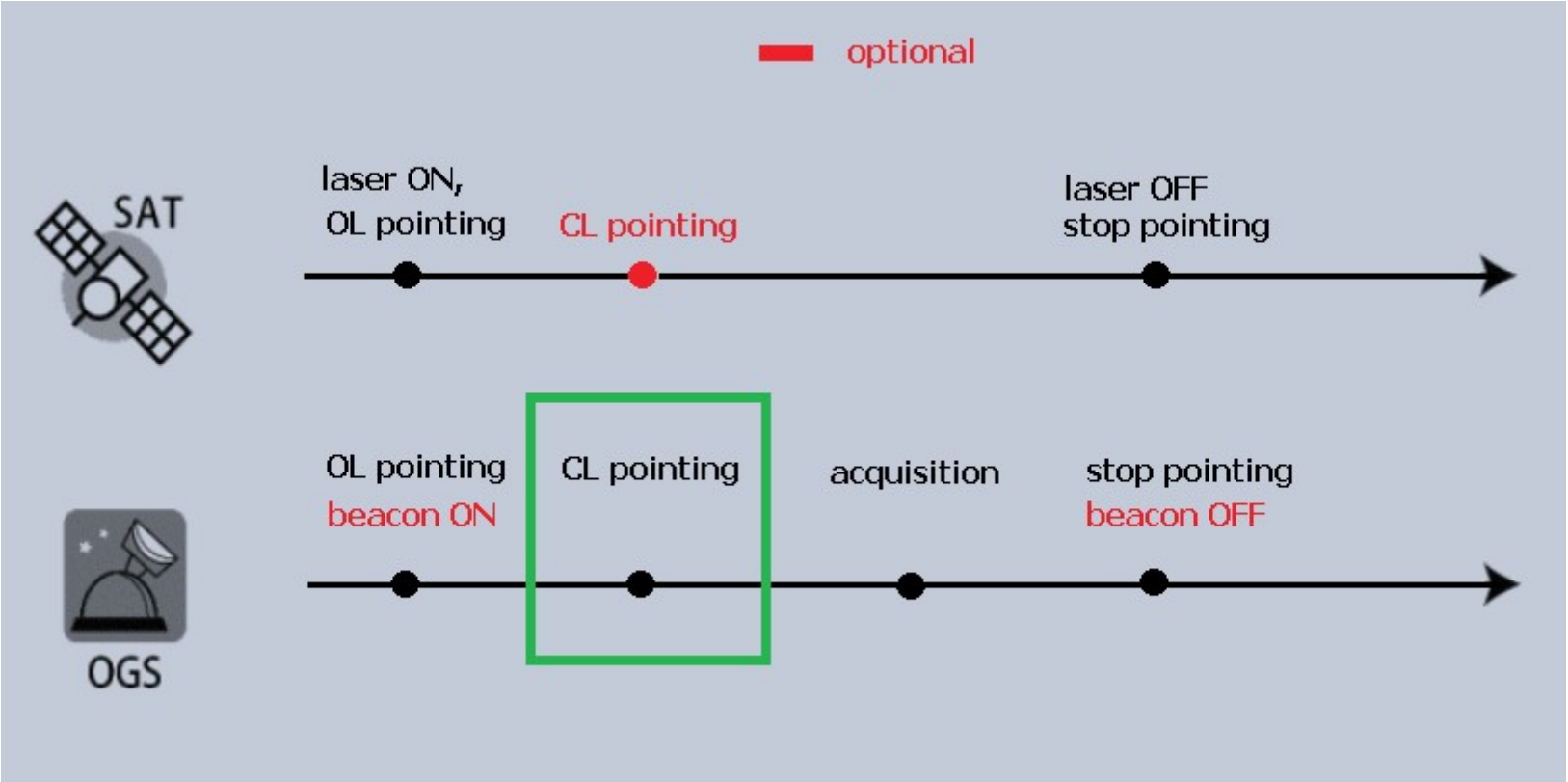
- secured link : laser is directional
- higher flux than RF link :

  >10 Gbps vs 500 Mbps

space-to-ground laser link : how it works



space-to-ground laser link : how it works



close loop pointing : a real challenge

constraints :

- size of the spot (telescope diffraction, seeing) : a few arcsec
- field of view of the optical detector : 30 arcsec
- low earth orbit satellite : high tracking speed

error sources :

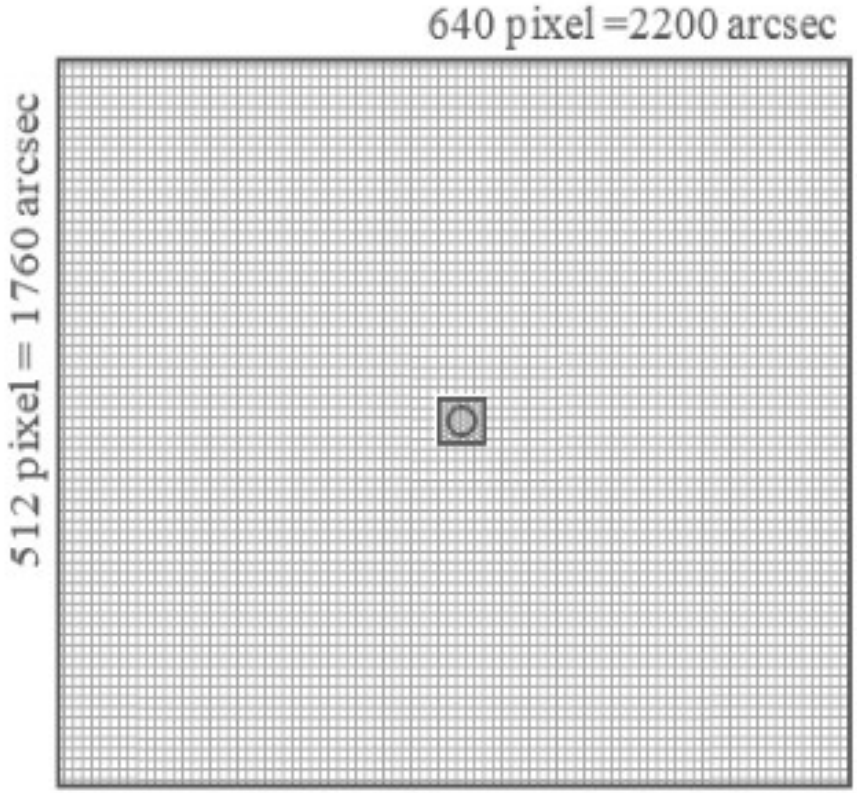
- prediction of the satellite (up to several arcmin)
- pointing of both telescopes (OGS and satellite)
- atmospheric turbulence

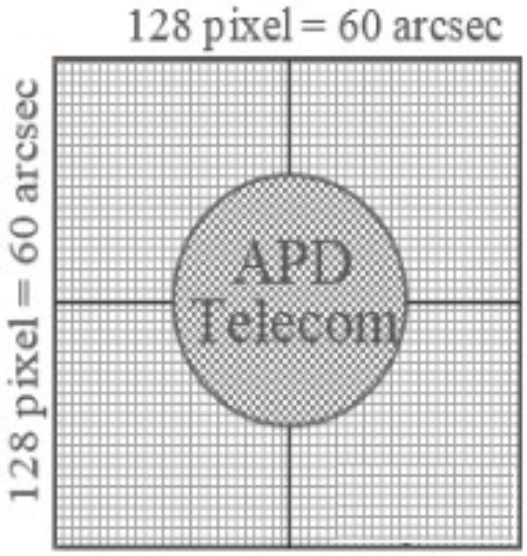
solution proposed : double visual servoing

- wide field camera : coarse tracking with the telescope
  → correct the low frequency errors (a few arcmin)

- small field camera : fine tracking with a tip-tilt mirror

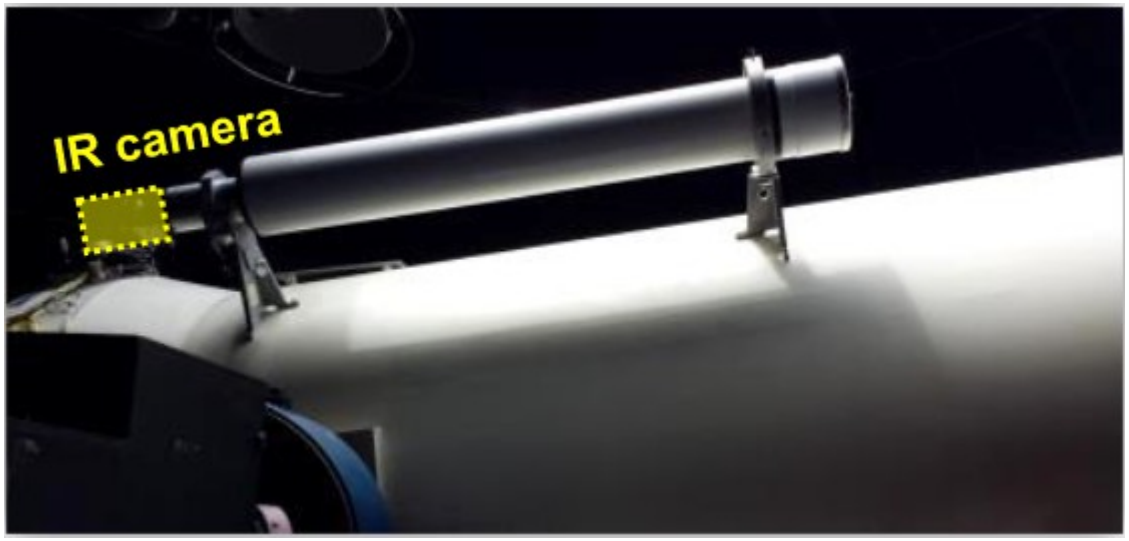
  → correct the higher frequency errors (a few arcsec)





APD telecom
30 arcsec

wide field camera : telescope control



IR camera to see the wavelenght of the descending laser

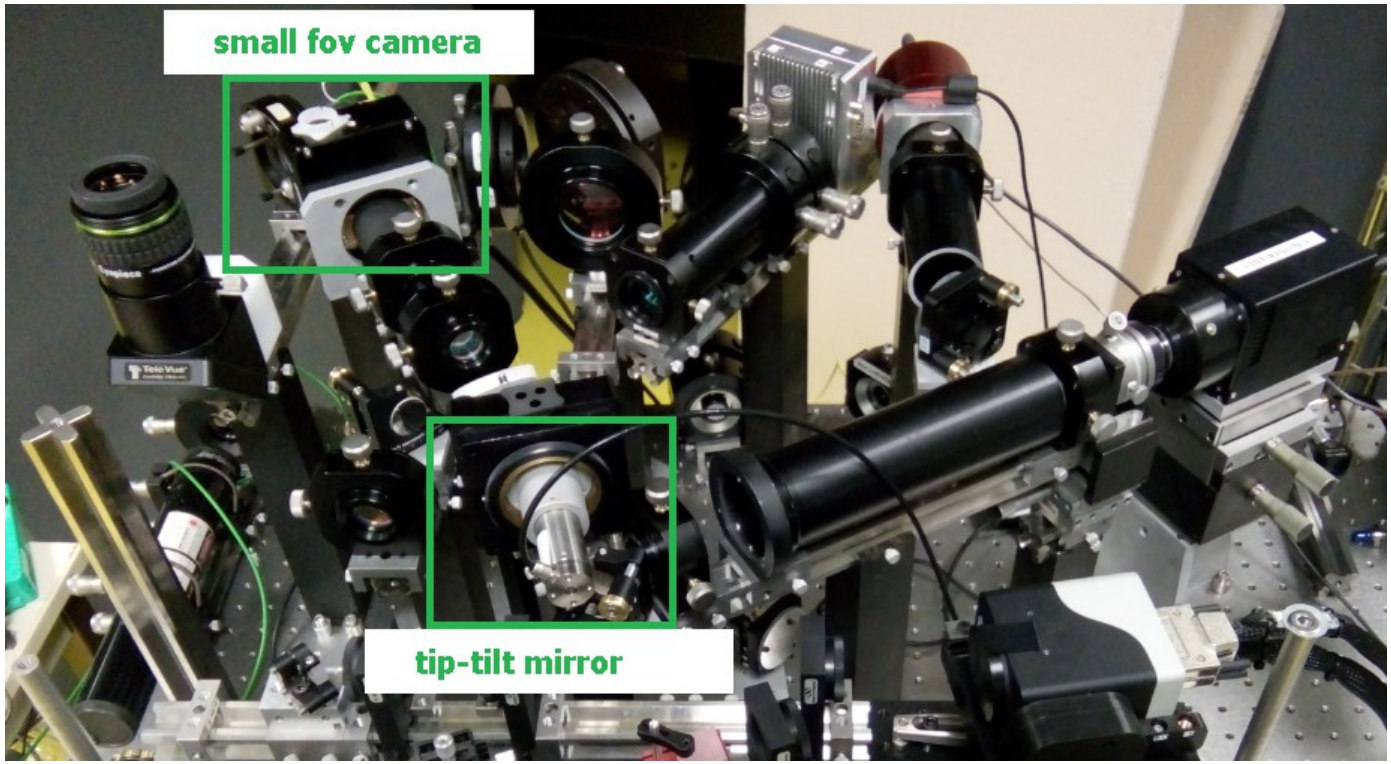
fixed on a 200 mm telescope mounted on the 1.5 m telescope

→ does not "steal" any flux for the optical bench

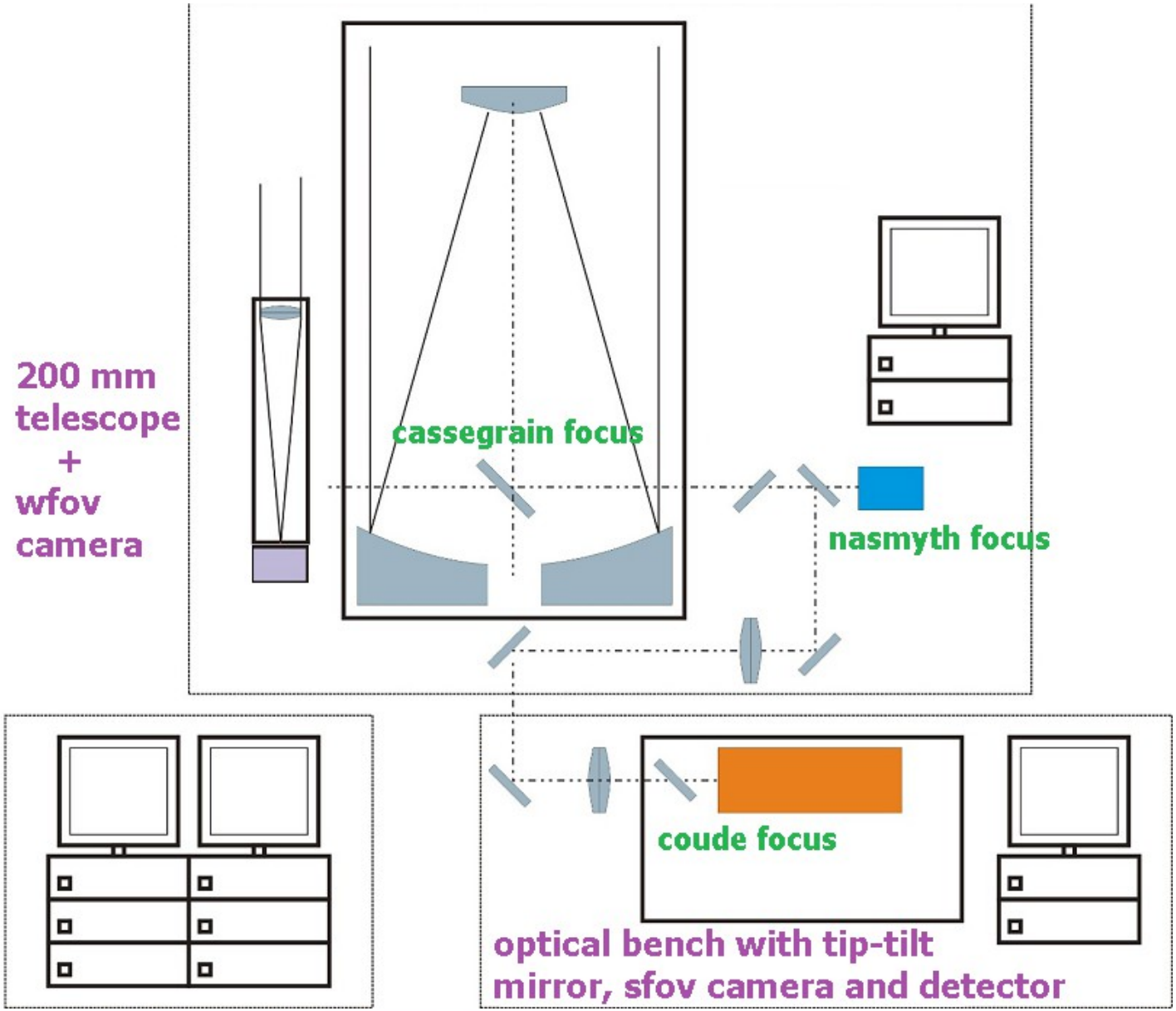
→ add a parallax error to be taken into account

small field camera : tip-tilt control

installed on an optical bench at the coude focus

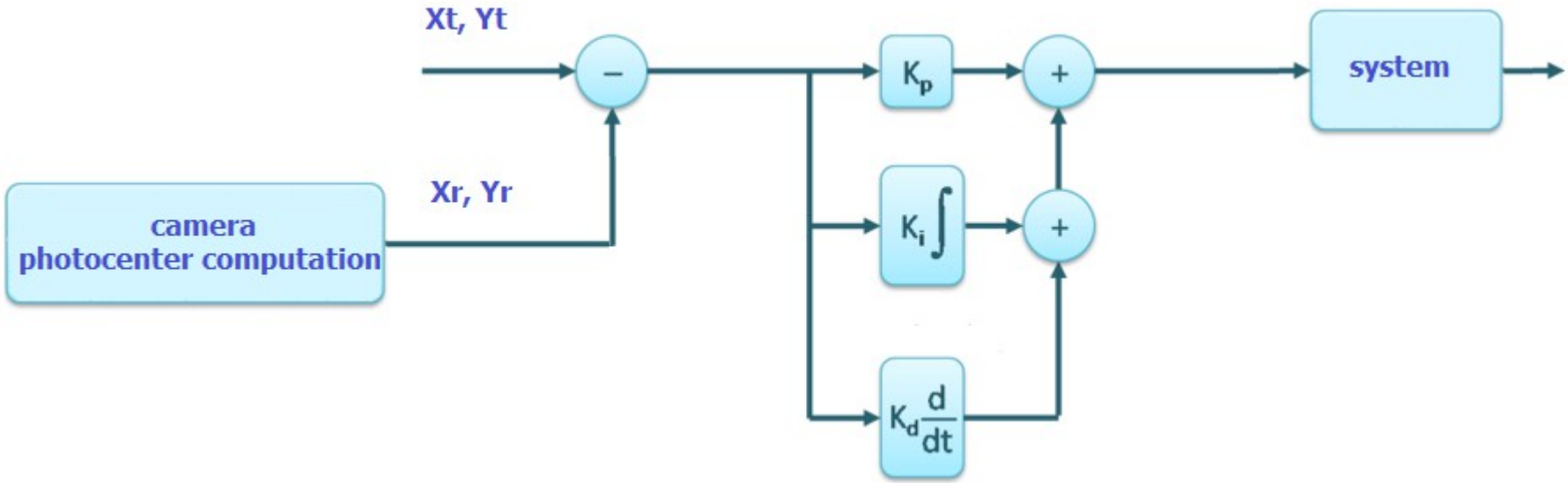


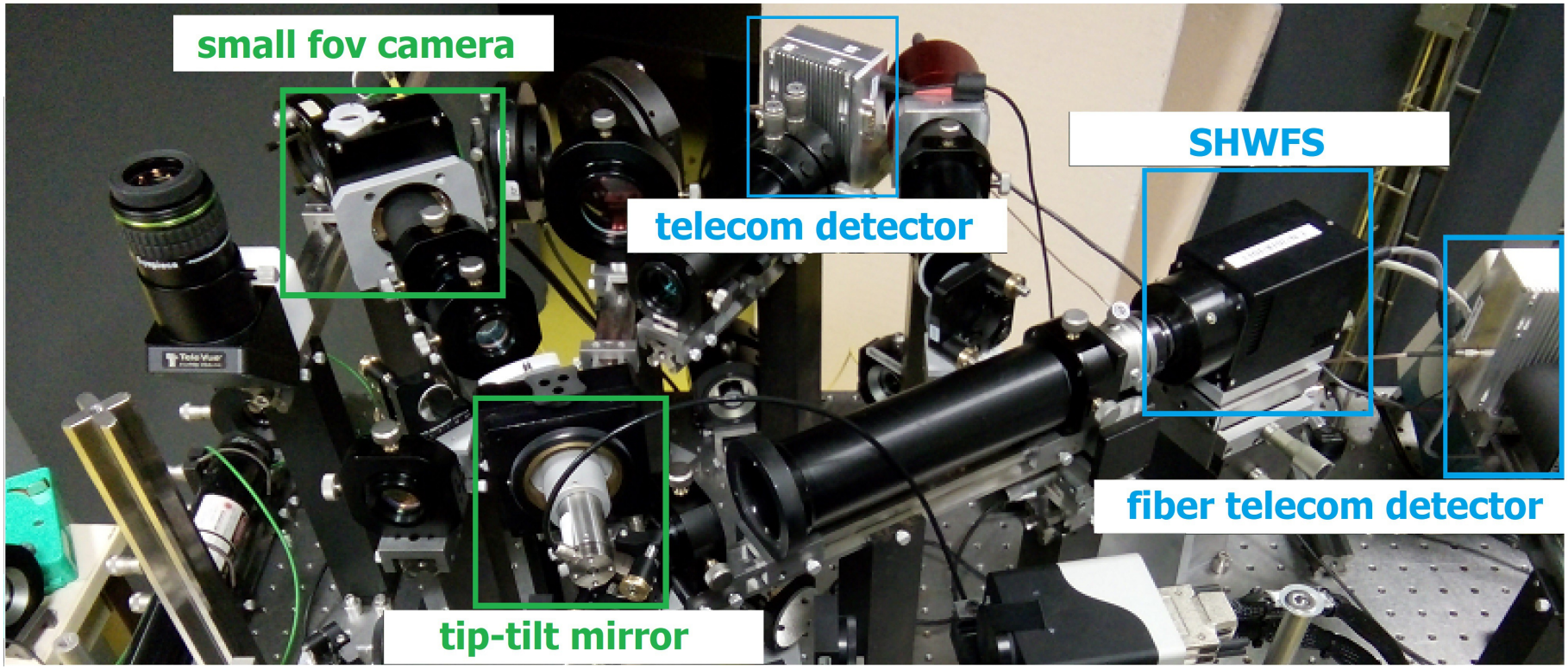
→ coude focus add a rotation transform to be taken into account

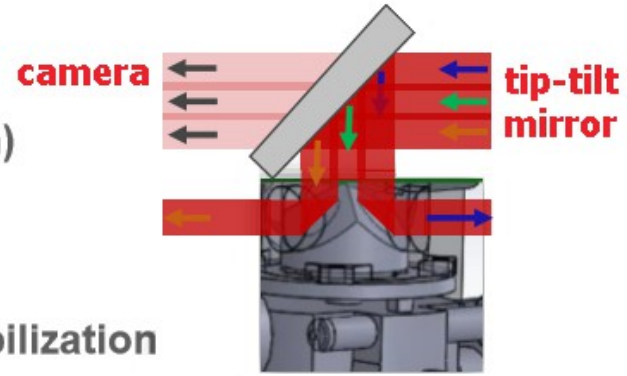

200 mm
telescope
+
wfov
camera
cassegrain focus
nasmyth focus
coude focus
optical bench with tip-tilt
mirror, sfov camera and detector

Servoing loop : numerical PID controller

- Telescope control : 10 Hz (volontary limited due to the low BW of the system)
- Tip-tilt control : 50 Hz (limitation = camera frame rate due to minimal exposure required)





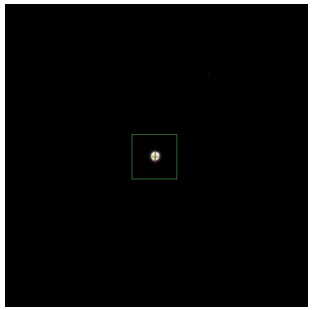


- 90% Triangle Beam splitter → 3 sub-aperture channels (40cm)
  - 1. Telecom APD detector
  - 2. WaveFront sensor (high speed IR camera)
  - 3. LISA ONERA (Adaptive Optic → fiber coupling)
- 10% Fine tracking by TipTilt mirror + camera → Pupil stabilization

Protocol :

Before the pass

correct the parallax error at a low elevation before the pass

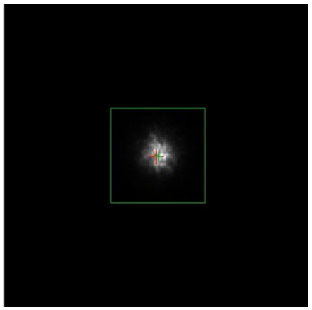


Beginning of the pass

search and center the spot on the wide fov camera

close the first servoing loop (wide fov camera + telescope)
→ correction of the prediction error (LF)

close the second servoing loop (small fov camera + tip-tilt)
→ correction of higher frequency errors (telescop vibration, atm., etc...)



what about the parallax ???

correcting the parallax error :

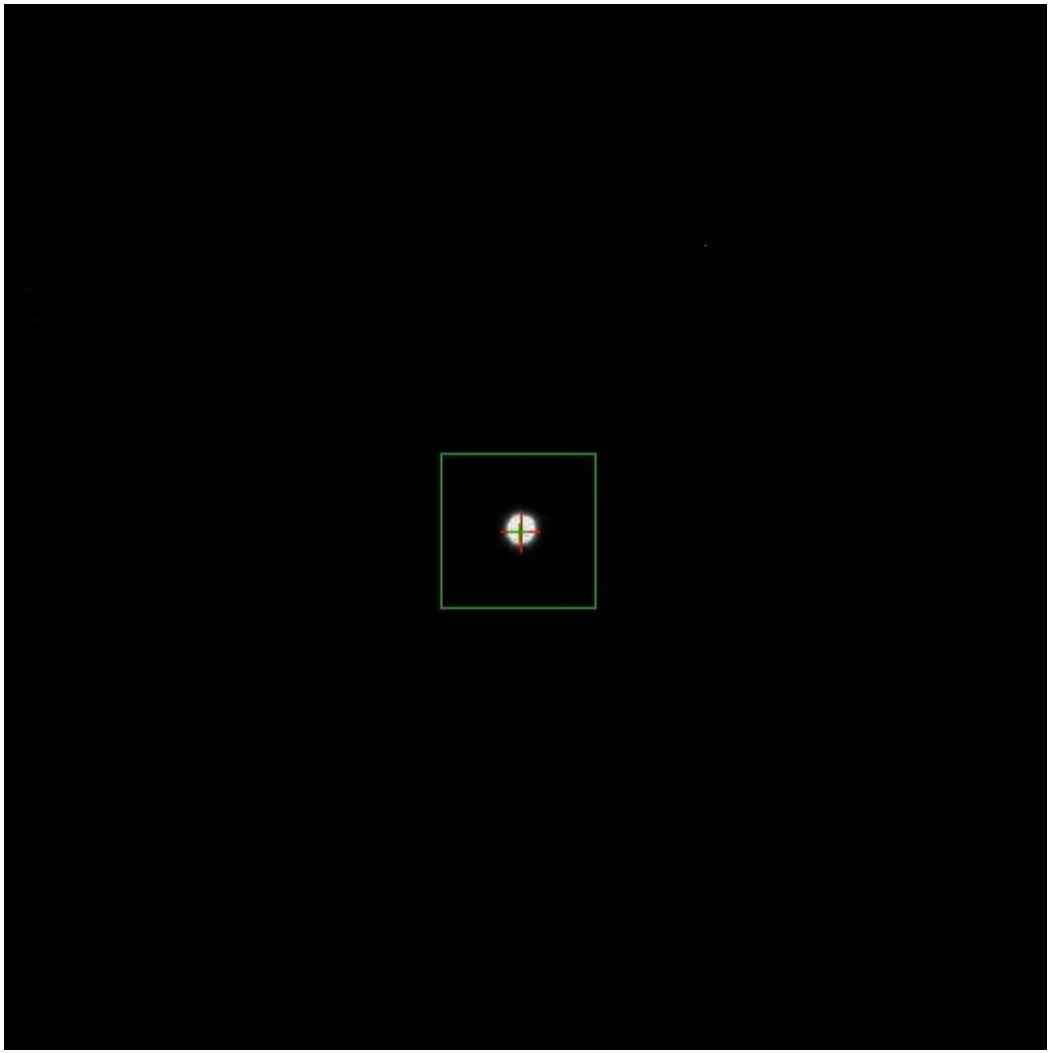
- *Modelization*

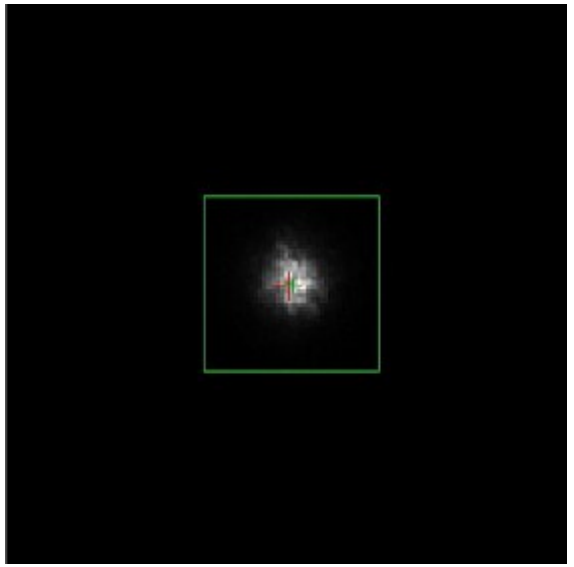
  - measurement report on stars, curve fitting (before the pass)

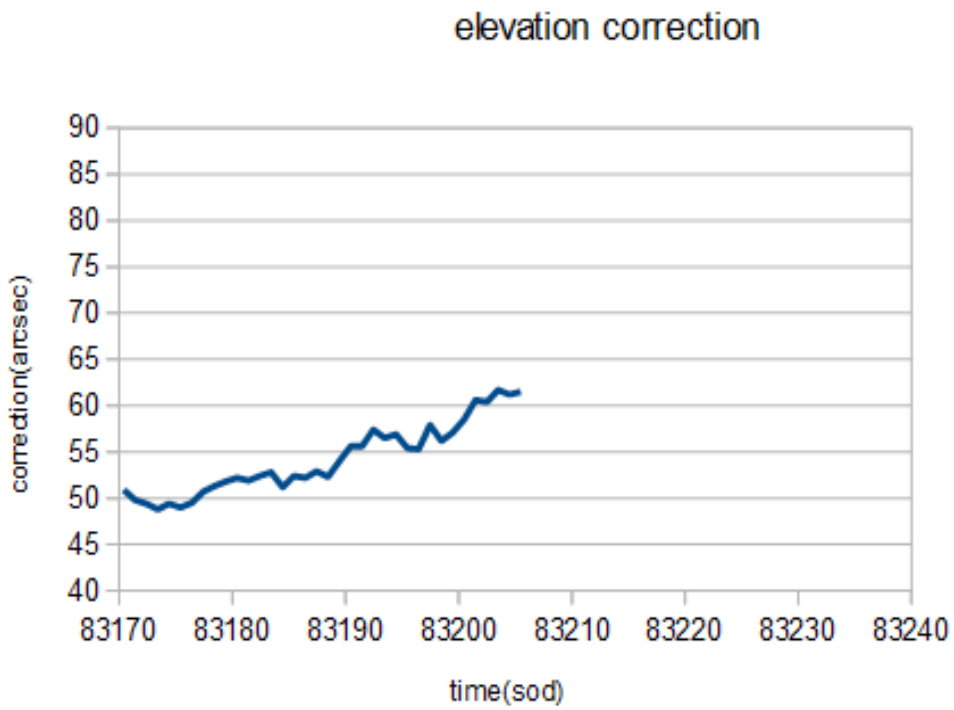
  - application of the law found on PID corrections (during the pass)

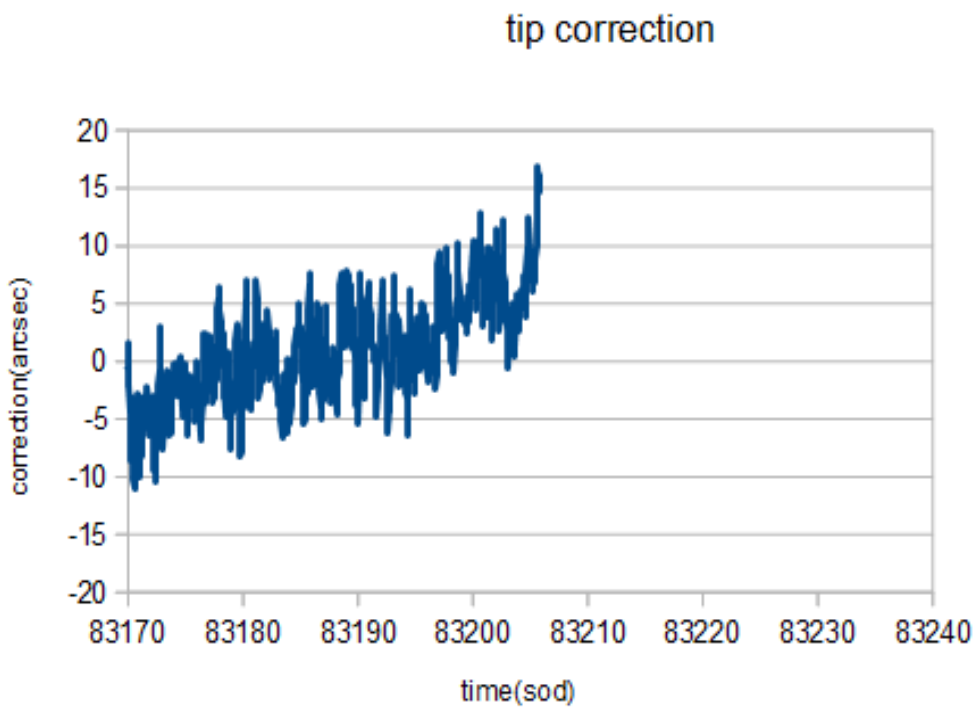
- *Real-time measurement and correction*

Both loops are closed, the spot is locked on the servoing reference (red cross)



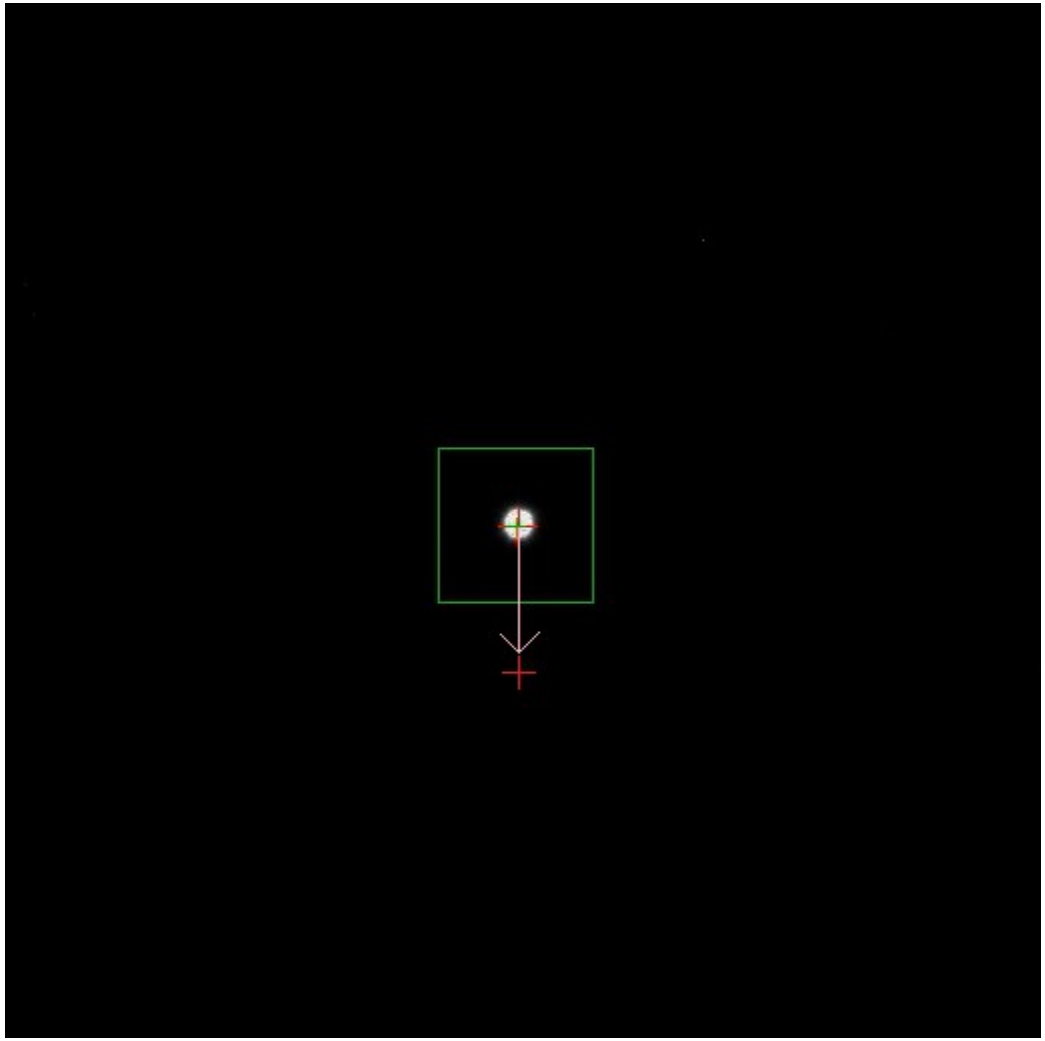


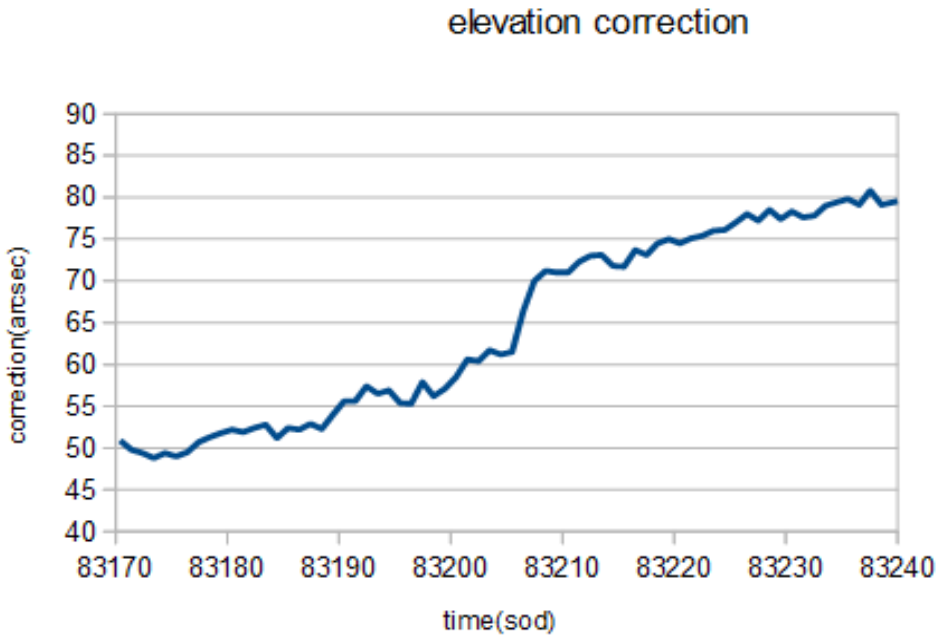


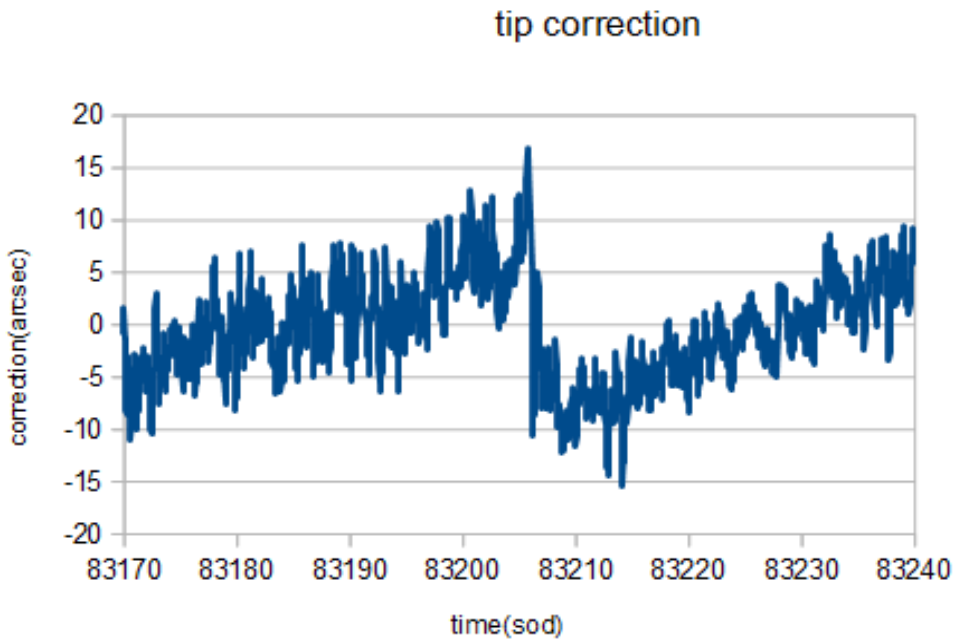


As the parallax angle varies, the corrections increase, and the tip-tilt mirror gets slowly closer to its mechanical limits...

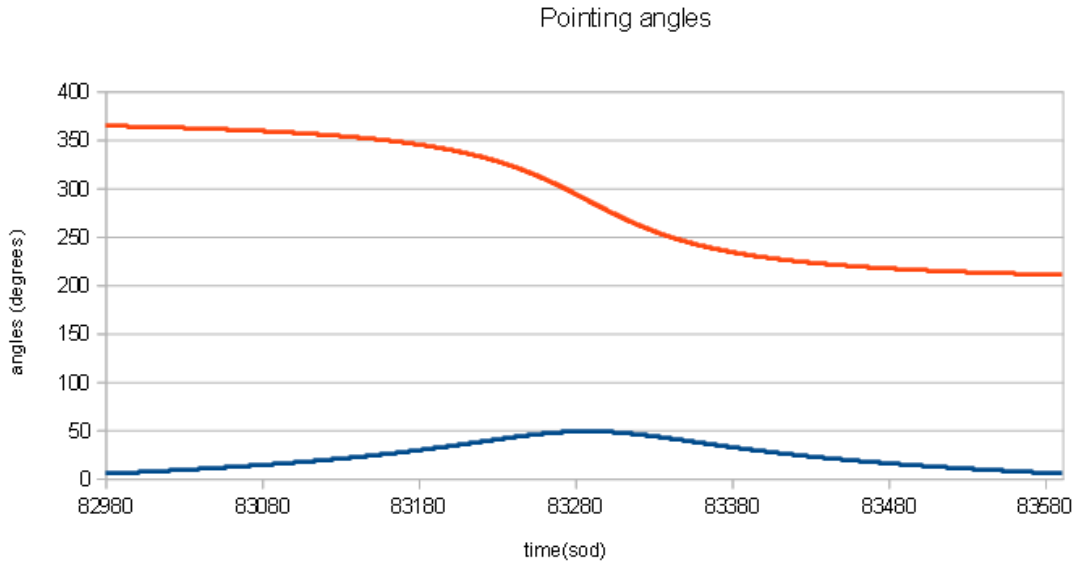
… it asks the telescope to move its servoing reference…

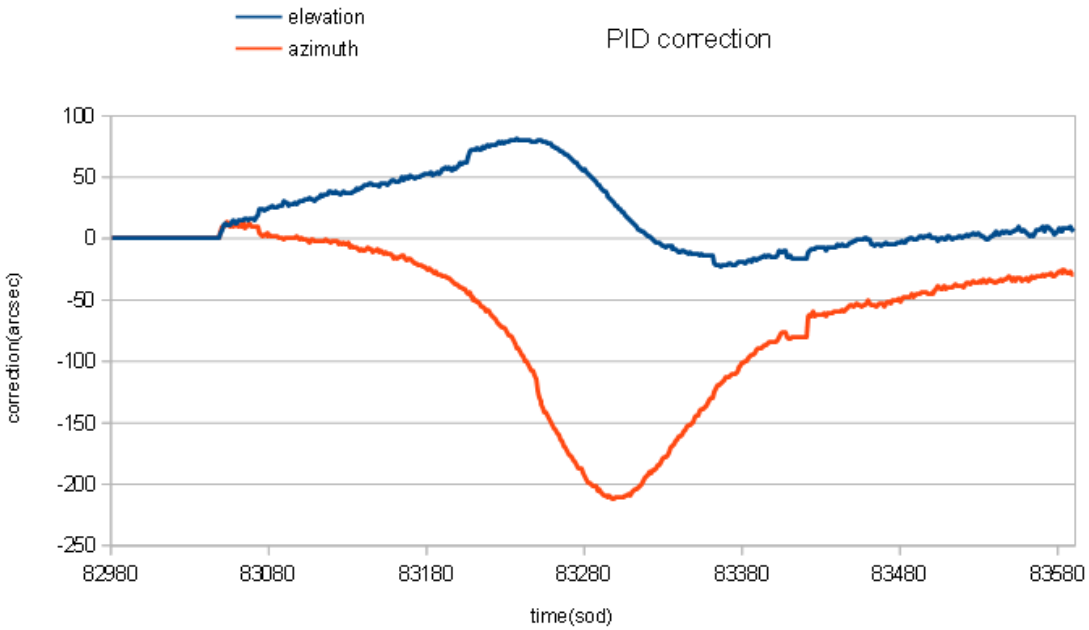






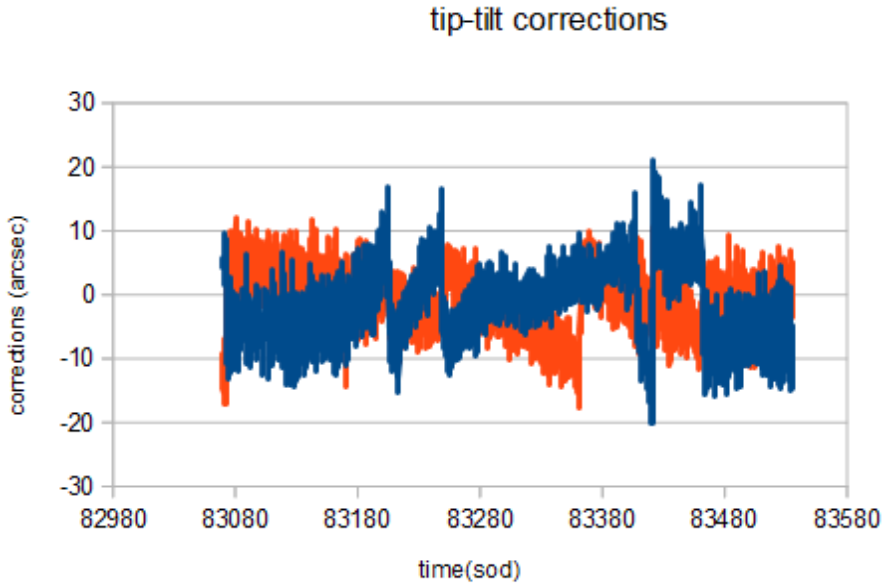
… so it can return to the middle of its range

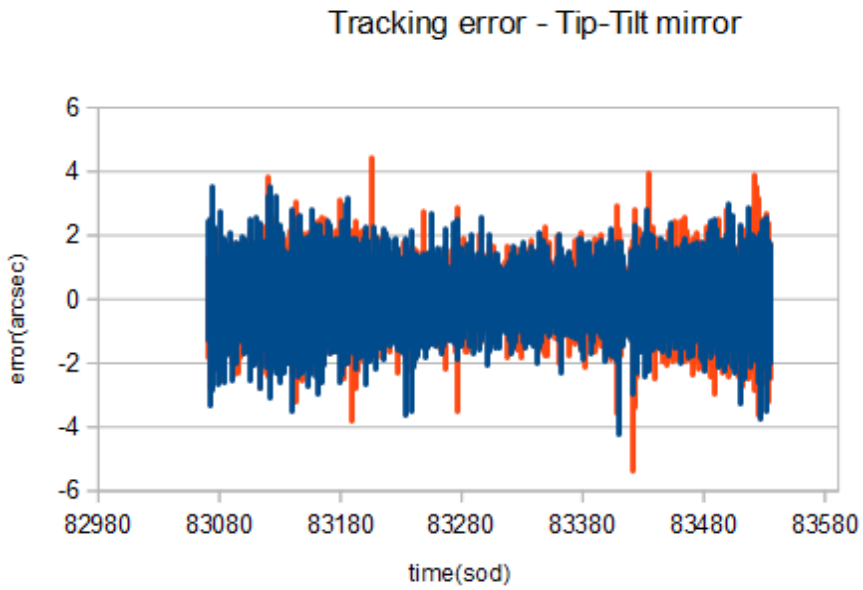




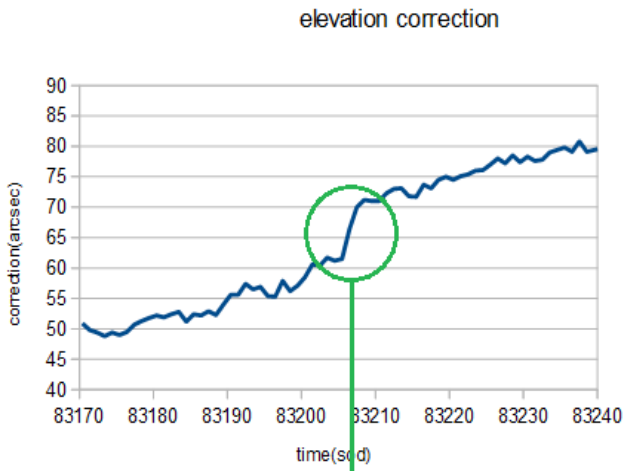
Satellite altitude :

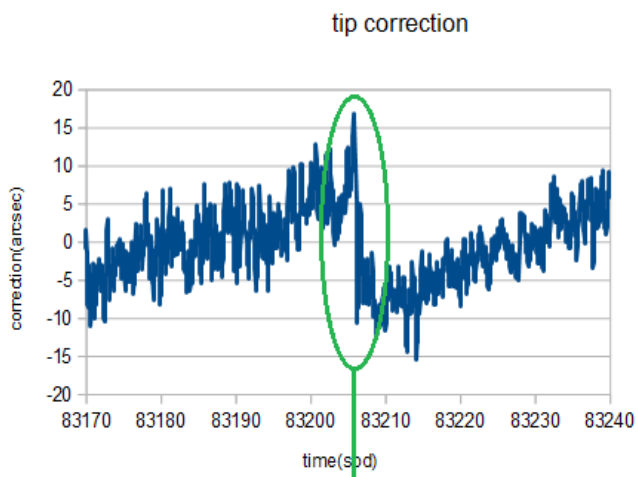
600 km

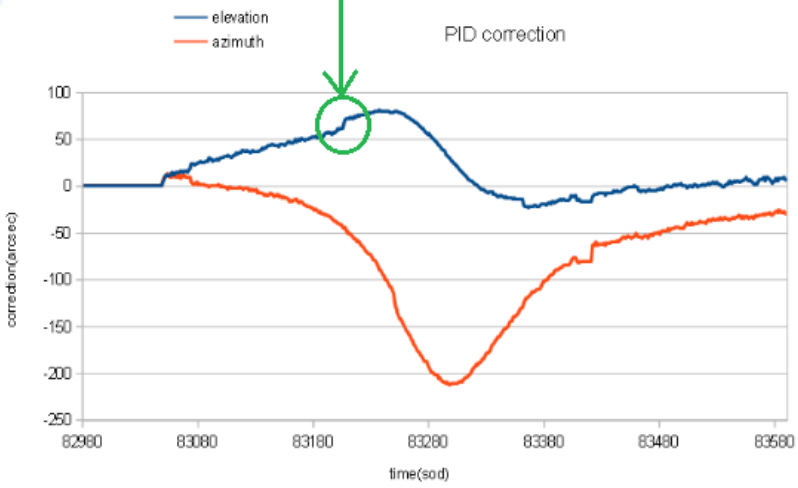


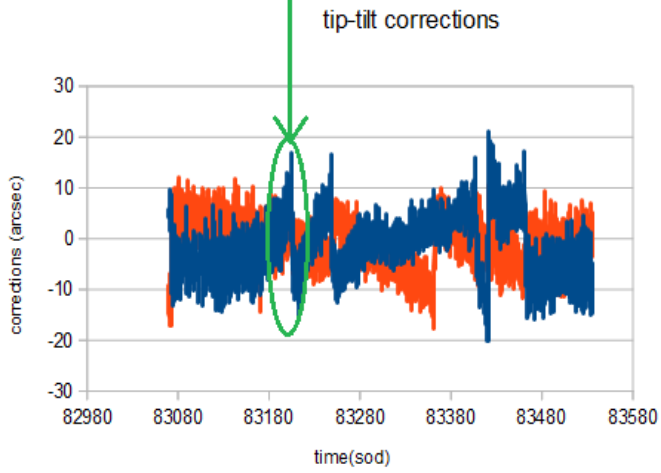


rms : 1.1 arcsec


elevation correction
correction(arcsec)
time(sod)


tip correction
correction(arcsec)
time(sod)


elevation
azimuth
PID correction
correction(arcsec)
time(sod)


tip-tilt corrections
corrections (arcsec)
time(sod)

Limitation :

very bad prediction → big errors to correct → the telescope cannot correct all (low bandwidth)

a drag appears getting stronger as the elevation angle increase

"smooth" drag

↓

move the servoing reference

↓

spot stays stable

too strong drag

↓

spot is lost

Possible solutions :

- Better prediction
- Estimation and correction of the time bias
- Adding an integrator in the servoing loop (hard to tune, instable !)
- Advanced control method such as H infinite (time-consuming)

Conclusion :

telescope coarse tracking (large fov, slow)

\+ tt mirror fine tracking (small fov, fast)

\+ tt mirror de-saturation by telescope

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enable to maintain the spot on the detector with an accuracy of 1.1 arcsec rms

Perspective :

improving SLR results on LEO satellites enlightened (sun or a rising beacon) by :

- maintaining return photons (reflected by the satellite) on the chronometry detector during the pass
- optimizing the focusing on the detector to avoid inhomogeneity of the sensitive surface
- using smaller detectors with higher bandwidths
- keeping a constant flux to :

  - stay in "single-photon"
  - homogenize the number of echoes/normal point