6th Chianti Topics – International Focus Workshop

Speckle interferometry at the Asiago Astrophysical Observatory

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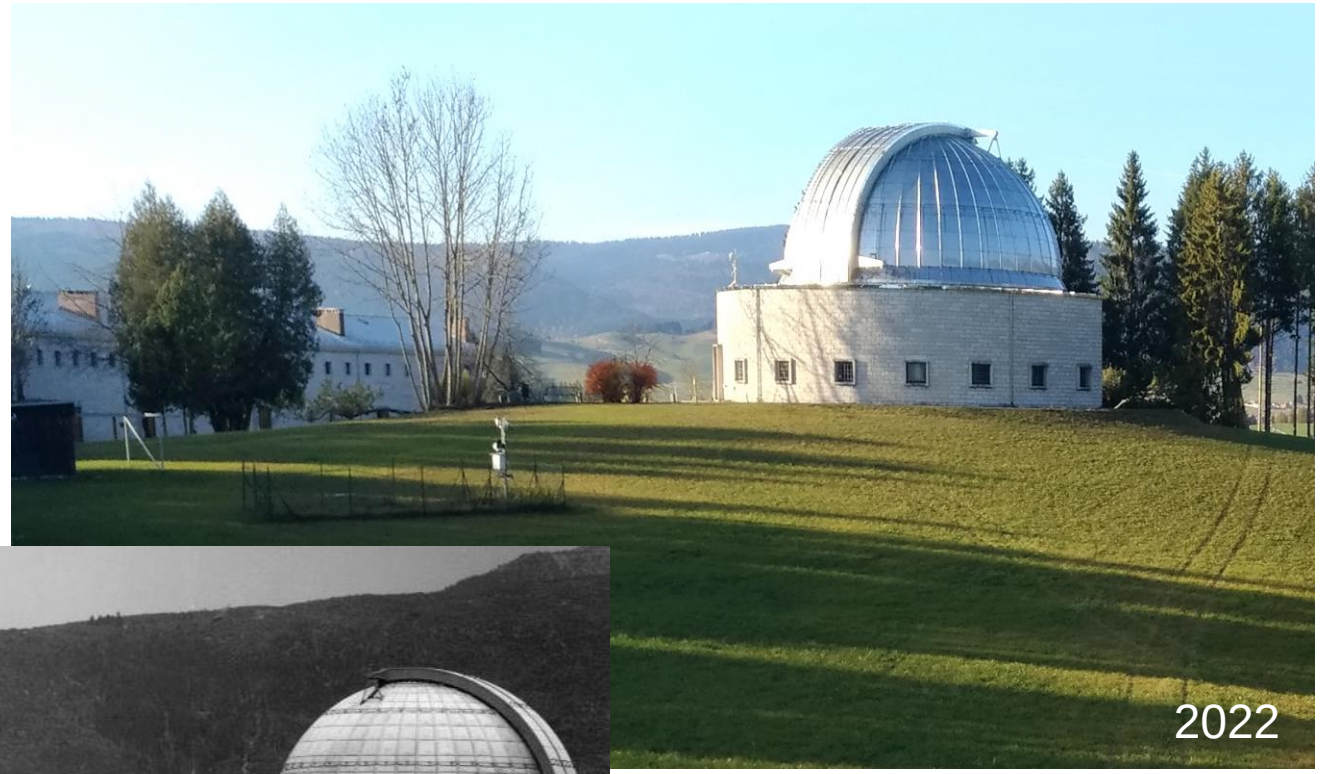
Asiago Astrophysical Observatory

Yesterday and today



Longitude : E11° 31' 35.138"
Latitude : +45° 51' 59.340"
Altitude : 1044.2 m

https://phaidra.cab.unipd.it/o:330172

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

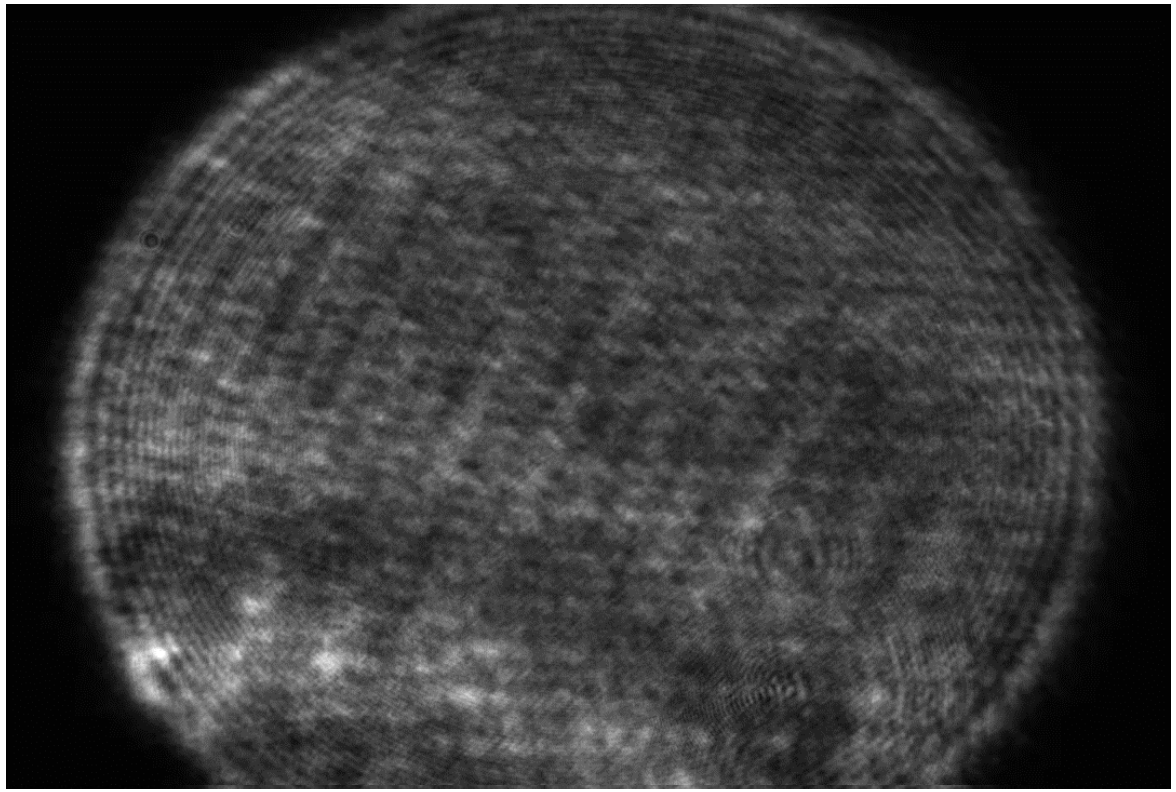
Galileo Telescope

Diameter of primary mirror (outer edge)	1237 mm
Effective diameter of primary mirror	1200 mm
Thickness of primary mirror (at edge)	208 mm
Weight of primary mirror	575 kg
Focal length of primary mirror	6000 mm
Focal ratio of primary mirror – Newton -	f/5.0
Diameter of secondary mirror	520 mm
Cassegrain Equivalent focal length	12100 mm
Cassegrain Focal ratio	f/10.1
Scale	17.05 arcsec/mm
Airy Disk diameter 400-700nm	**170 – 300 mas**
Typical seeing in Asiago	**1000 - 3500 mas**

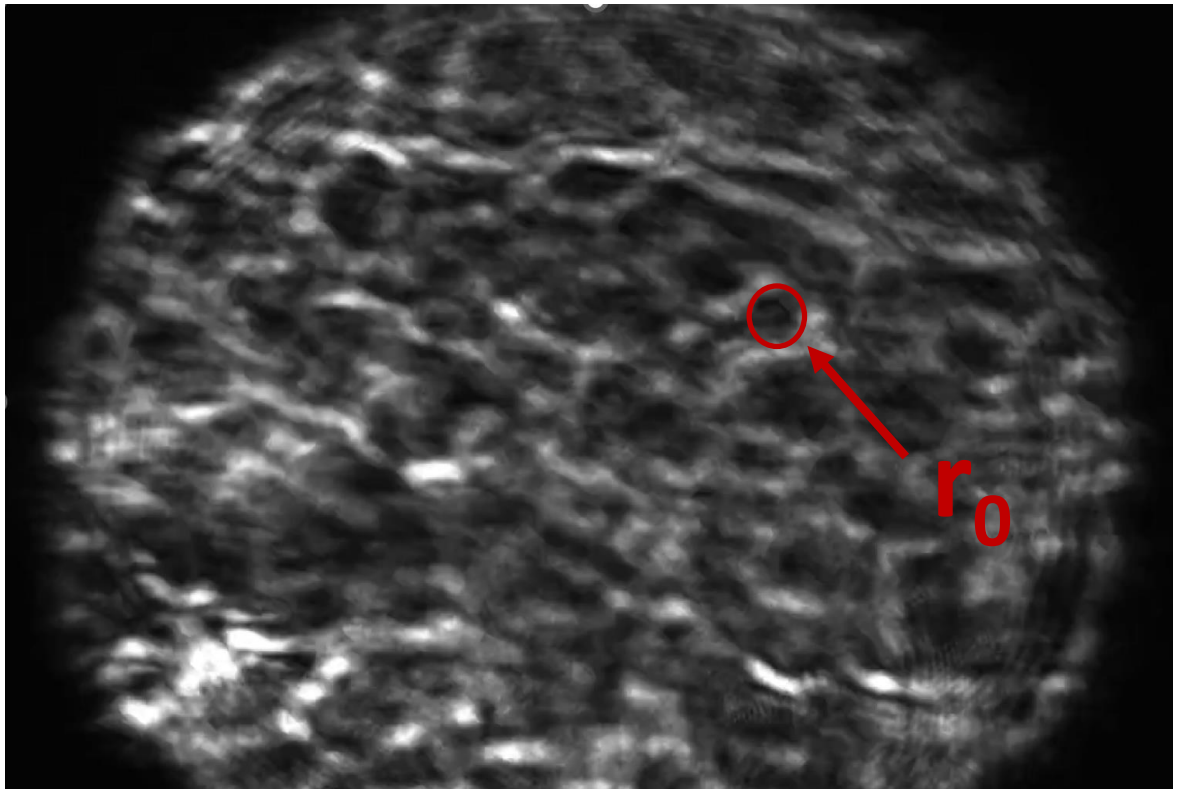
What is a speckle?

Pupil plane

Telescope Pupil without atmosphere atmosphere



Telescope pupil with atmosphere

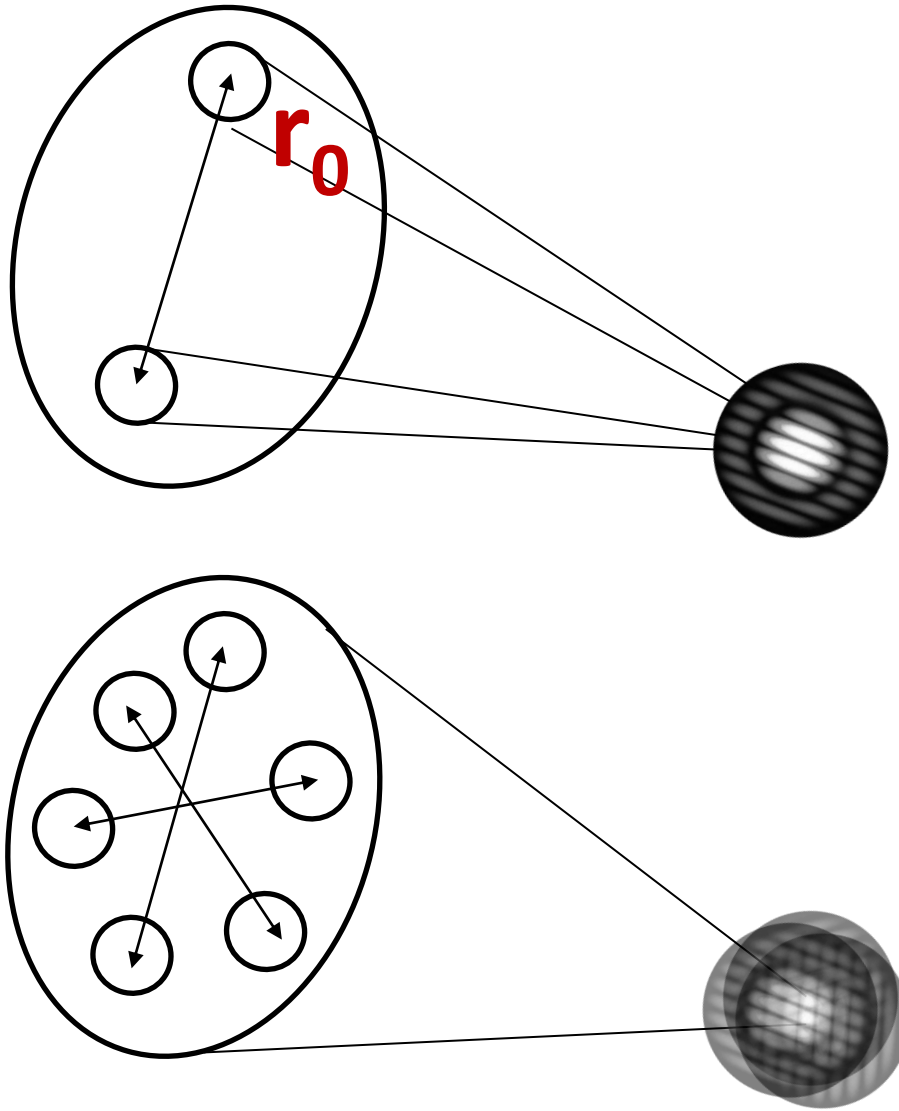


What is a speckle?

Fried parameter $r_0(\lambda^{-1/5}, Airmass^{3/5})$

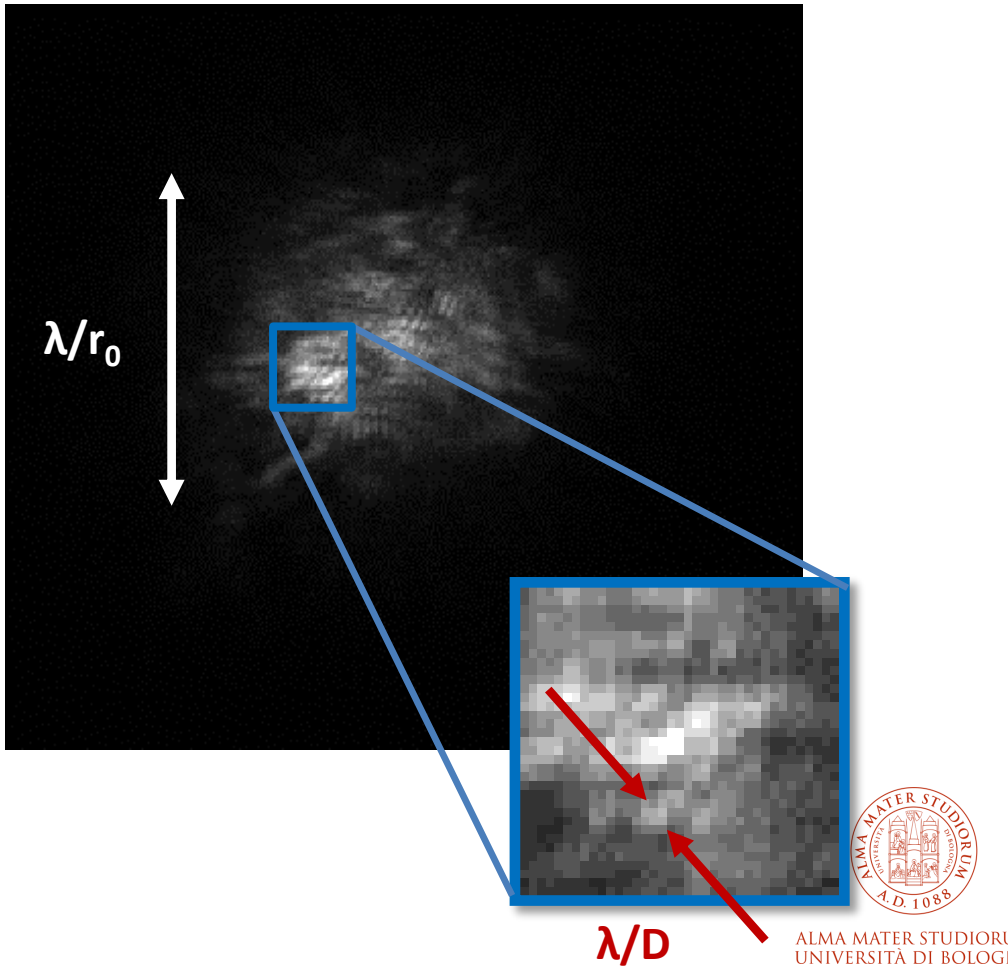
PSF size measured by the FWHM $(\lambda, 1/r_0)$

Numbers of speckle ~ $(D/r_0)^2$



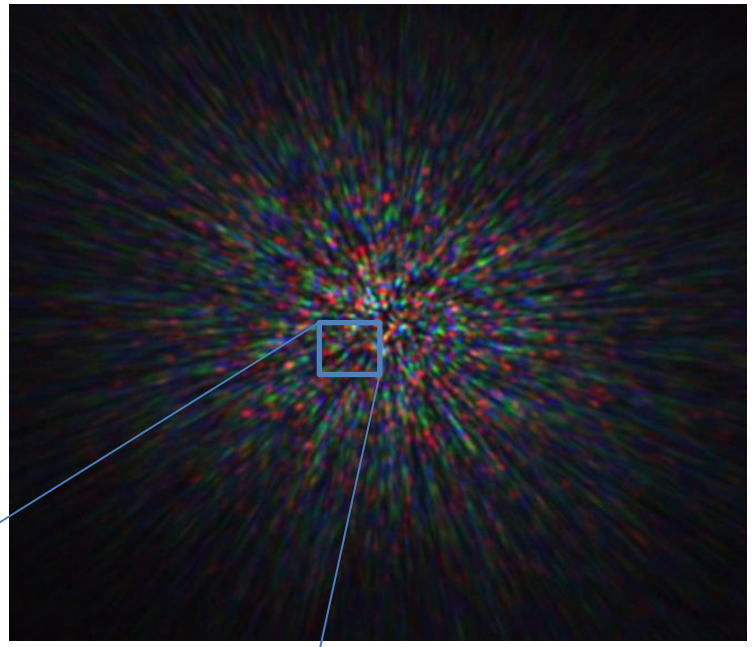
Focal plane

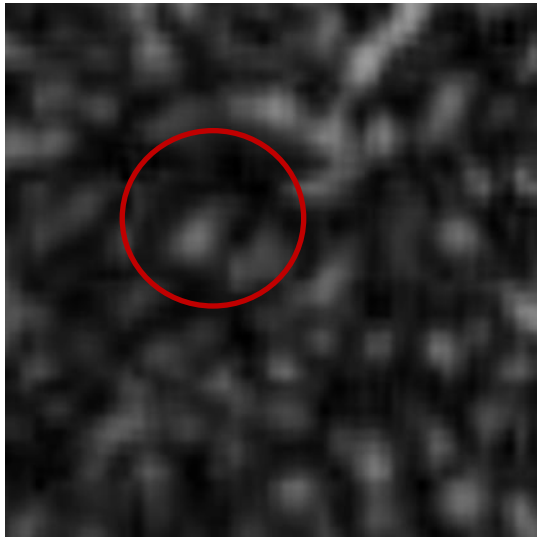
HD77327, double star exposure 10ms red



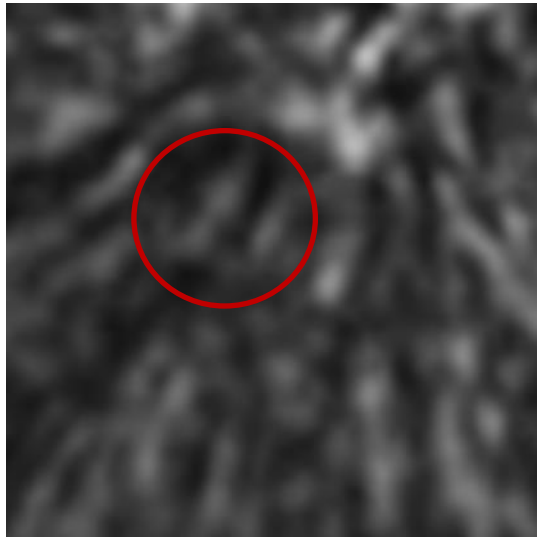
What is a speckle?

- Loss of resolution for large telescopes by atmospheric seeing
- Speckles are similar to a laser spot
- Only visible in very short exposure time
- Minimum grain size is equal to size of Airy Disk
- Colored speckles reduce the resolution
- Rapid changes in shape over time (ms)
- Numbers of speckle depent on telescope size and wavelength

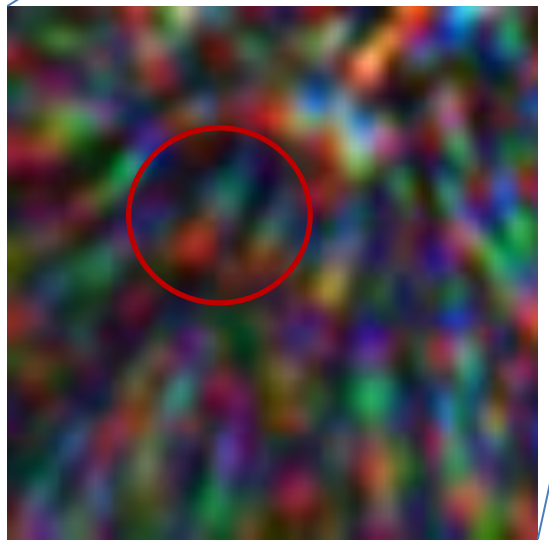




Red filter CMOS/BW

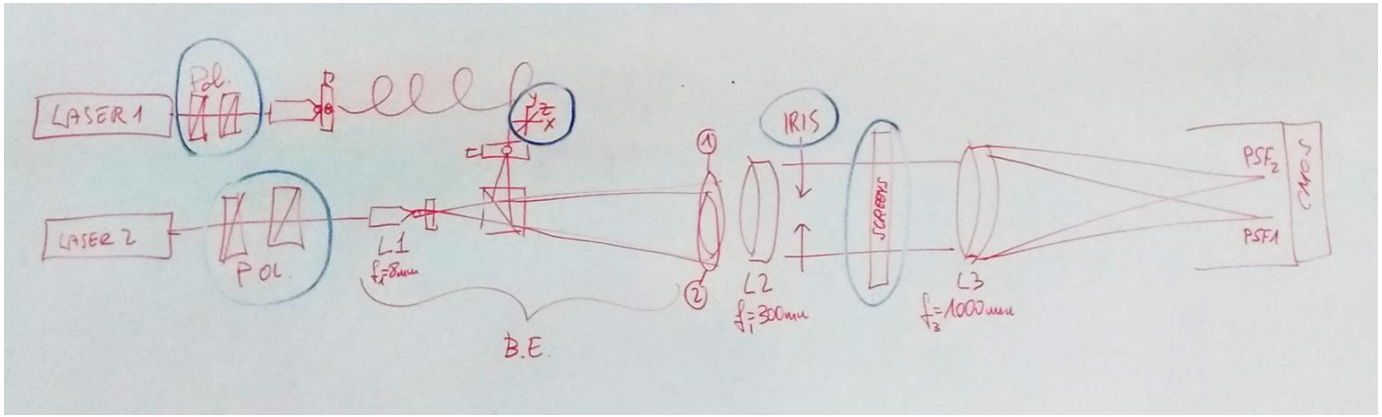


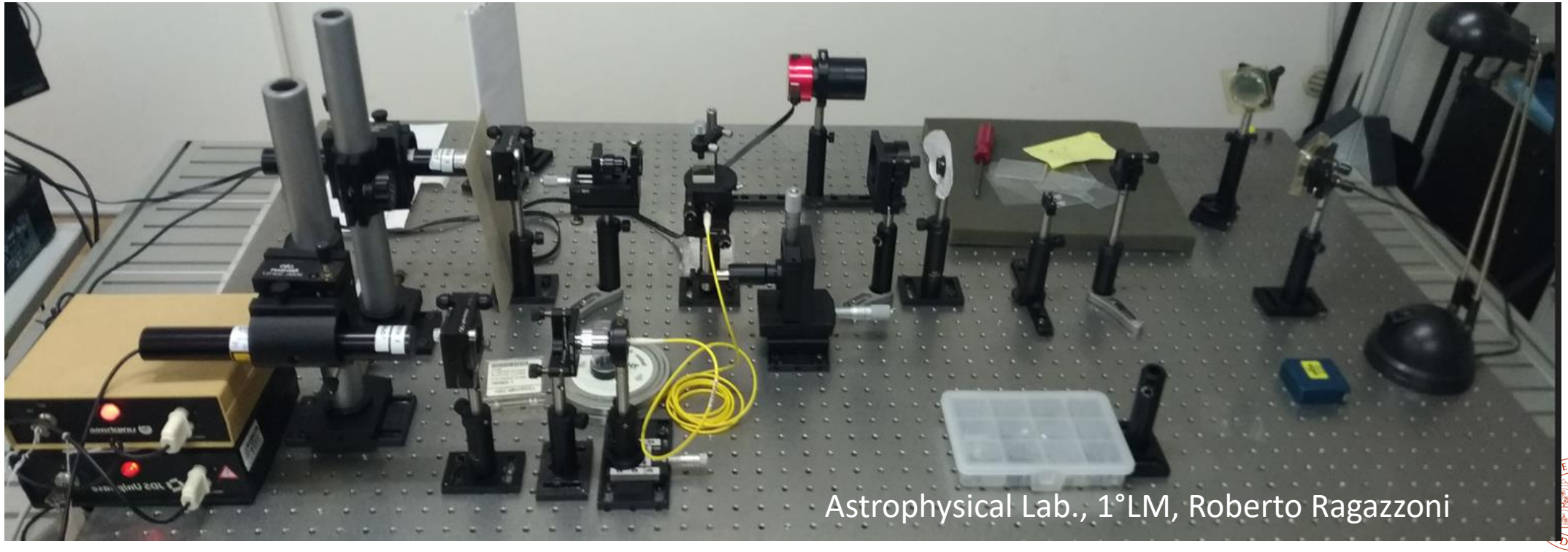
no filter CMOS/BW



no filter CMOS/COL

Binary star simulator





Astrophysical Lab., 1°LM, Roberto Ragazzoni

What is speckle interferometry?

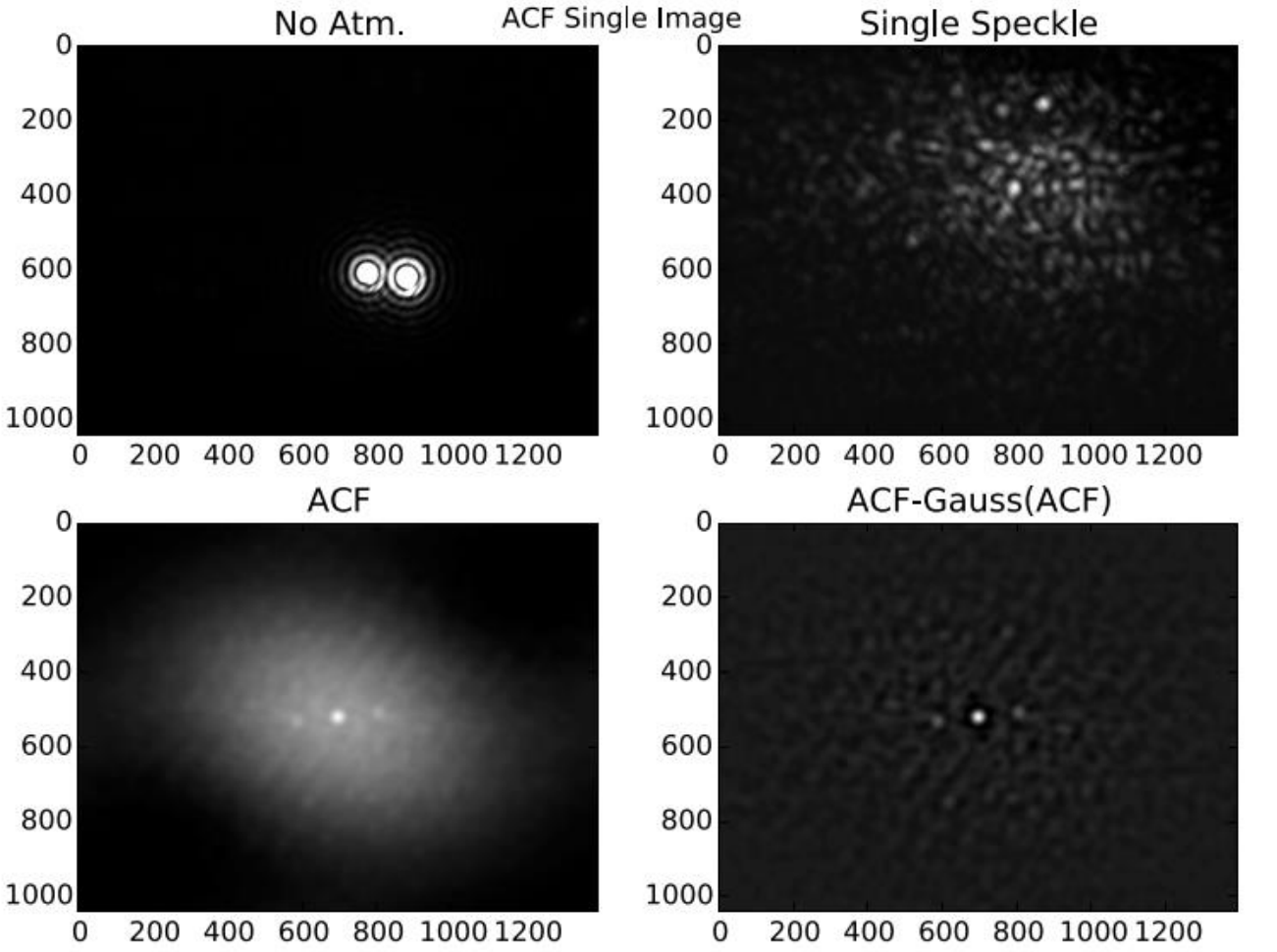
Fig. 2a and b. Fourier transform of simulated double star image, showing characteristic fringes. Turbulence noise, as well as photon noise, can be averaged by compositing a large number of such images. a) Star separation 0.03″, b) star separation 0.1″. Double stars were simulated by double-exposing plates, with a small displacement between exposures

Stand-alone interferometric technique by Antoine Labeyrie (1970 - thesis)

« Recherches sur les applications astronomiques et spectroscopiques de l'holographie »

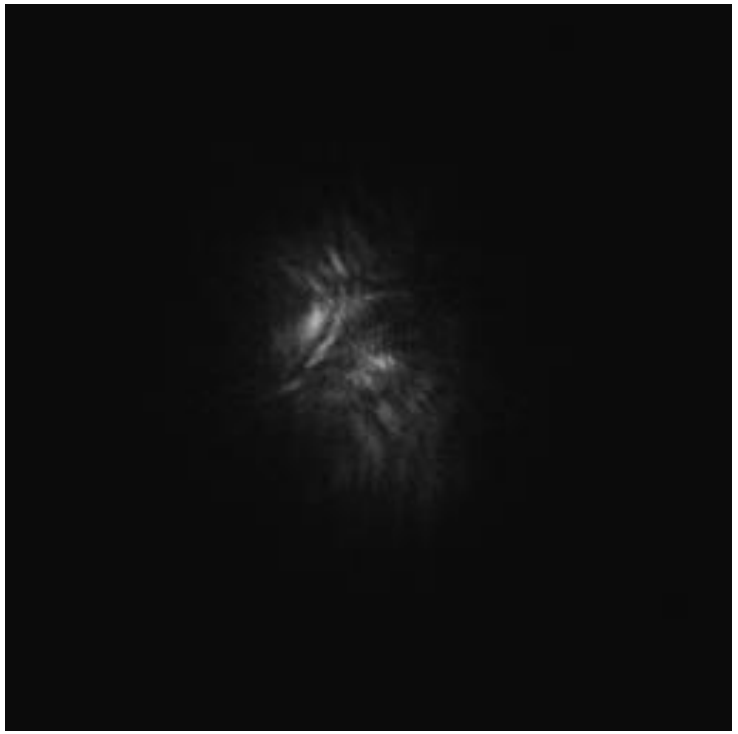
```
def autocor(mat): #autocorrelation function
    f1 = fftpack.fft2(mat)
    f1shift = fftpack.fftshift(f1)
    f1abs = np.abs(f1shift)**2
    f2 = fftpack.ifft2(f1abs)
    f2shift = fftpack.fftshift(f2)
    f2abs = np.abs(f2shift)
    return f2abs
```

autocorrelation function, simulated data on lab

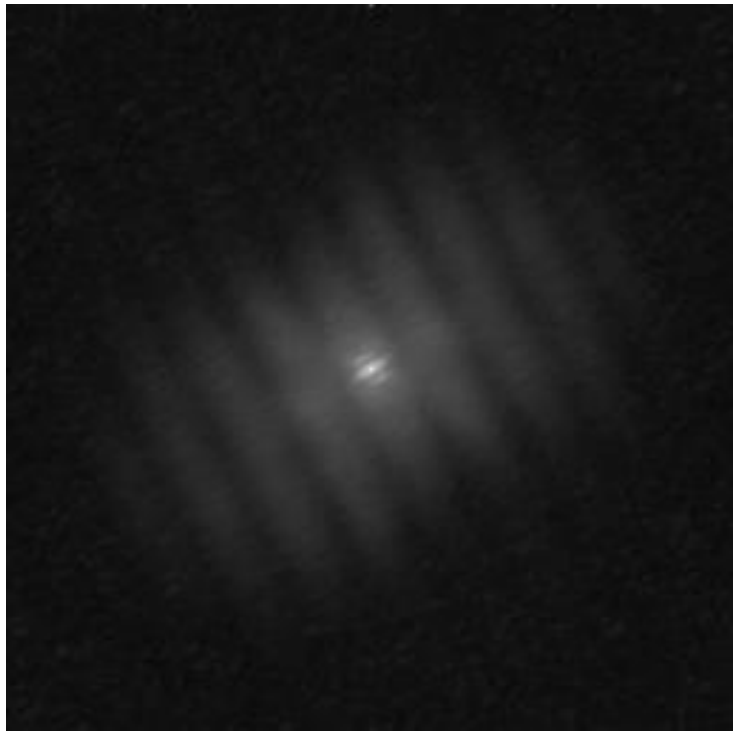


Autocorrelation on sky

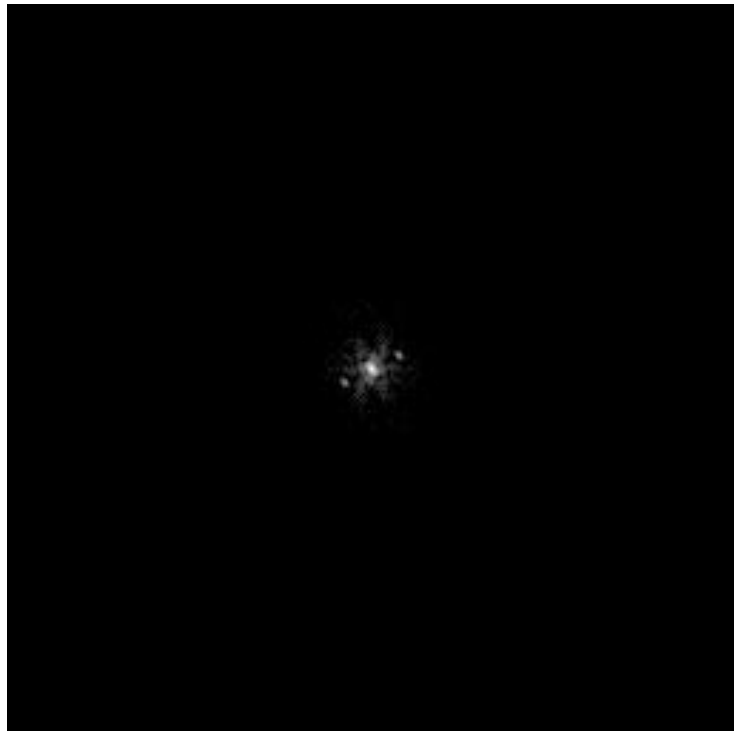
Single short exposure



Fourier Transform

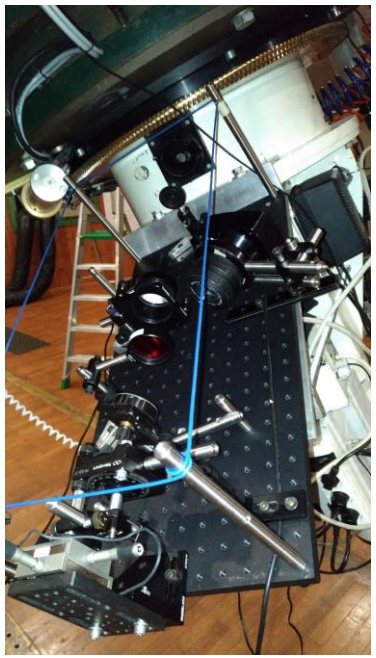


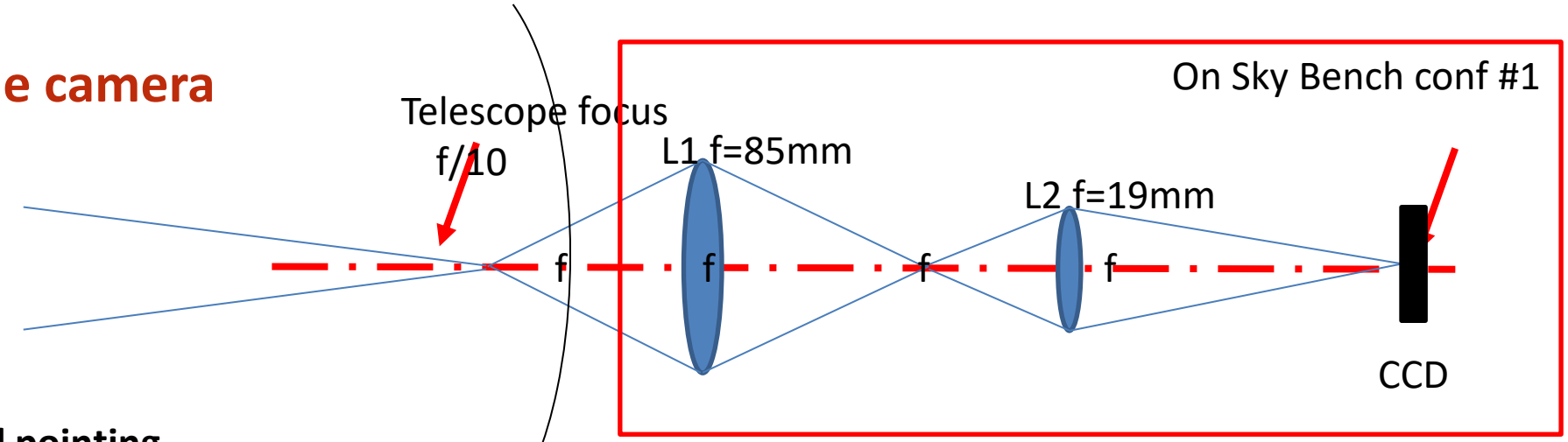
Autocorrelation

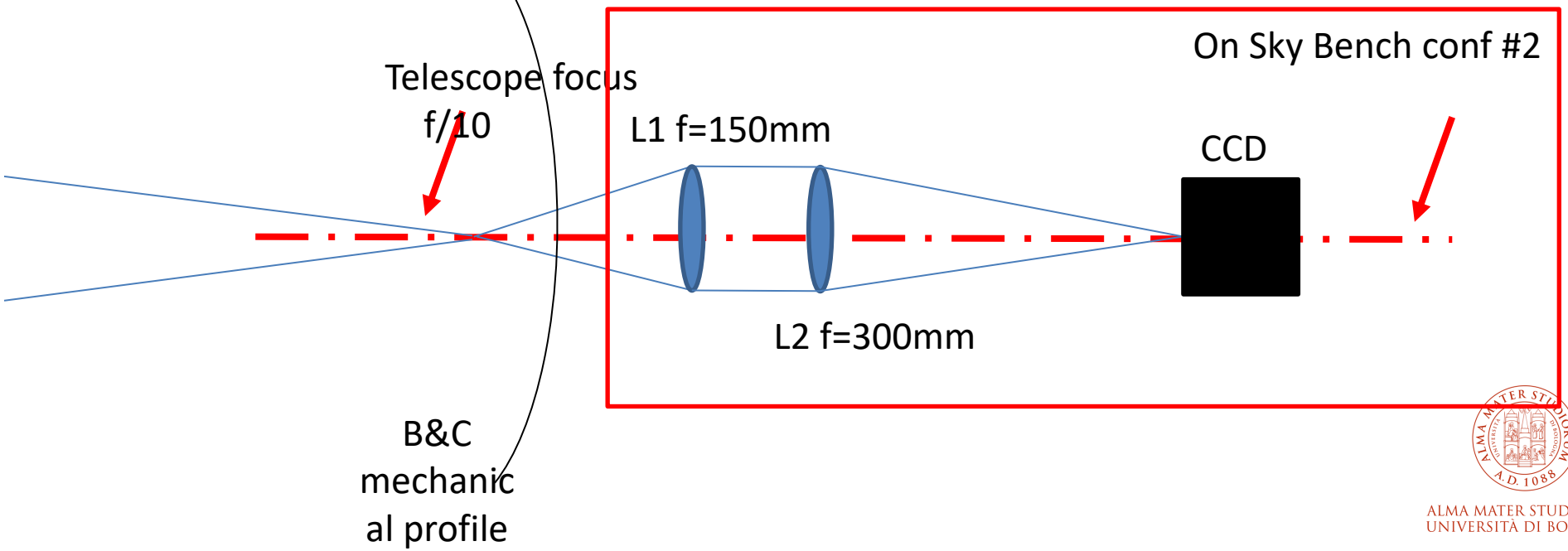


We need a speckle camera

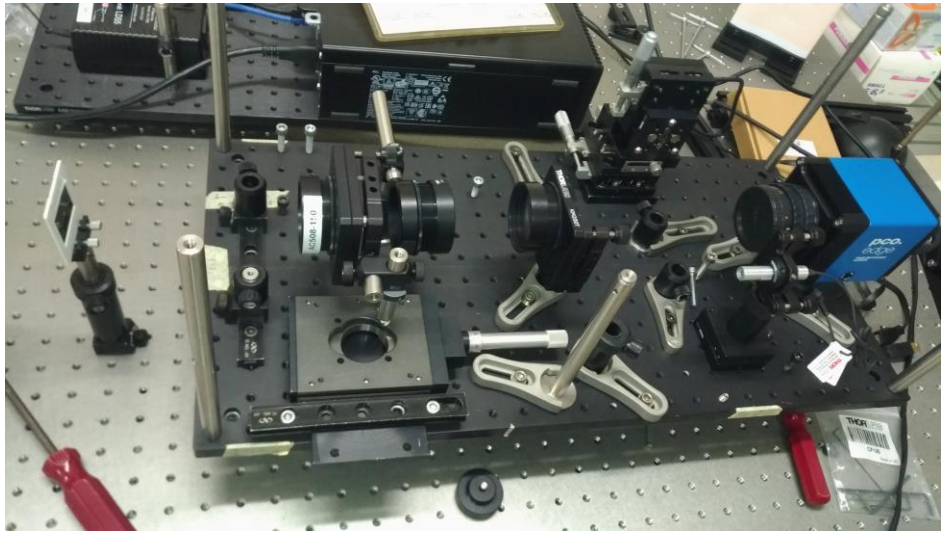
- **Fast camera**
- **High sensibility**
- **bandpass filter**
- **Telescope with good pointing**
- **Two configuration for Asiago**

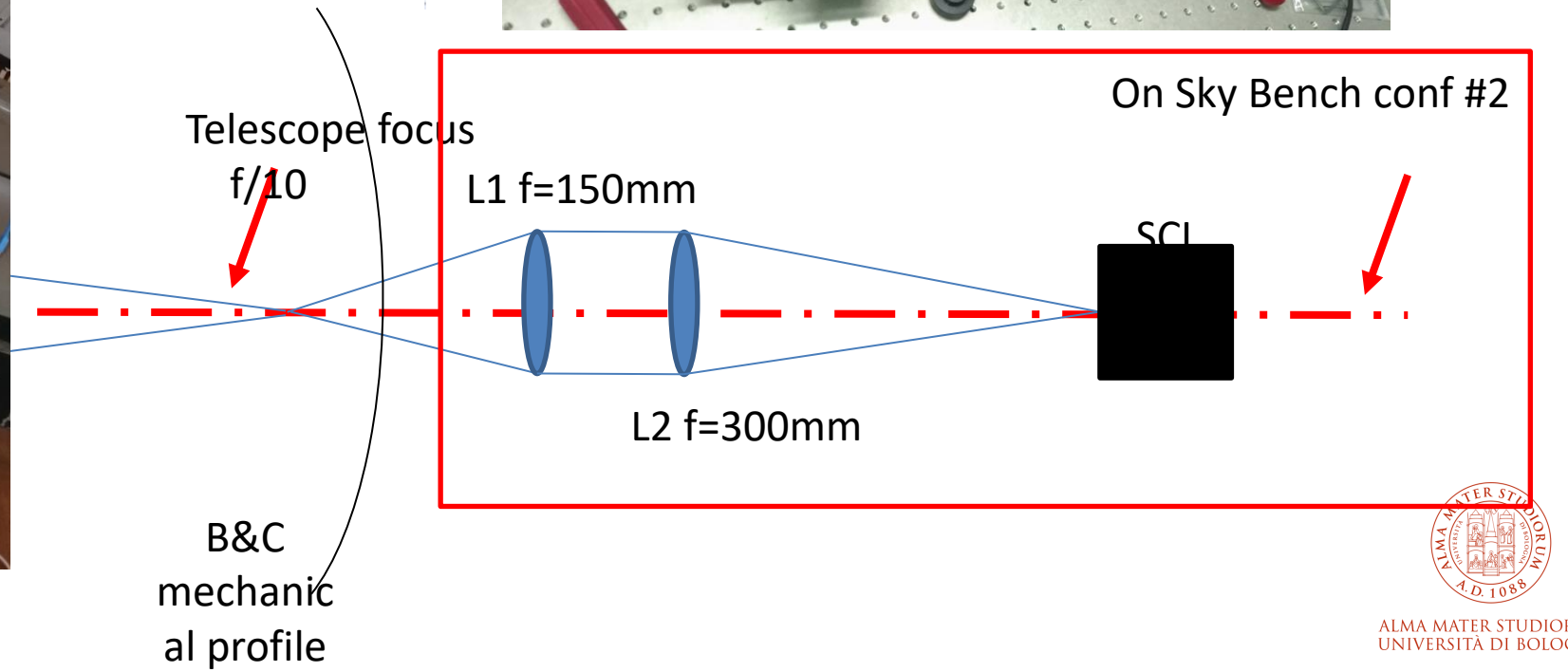




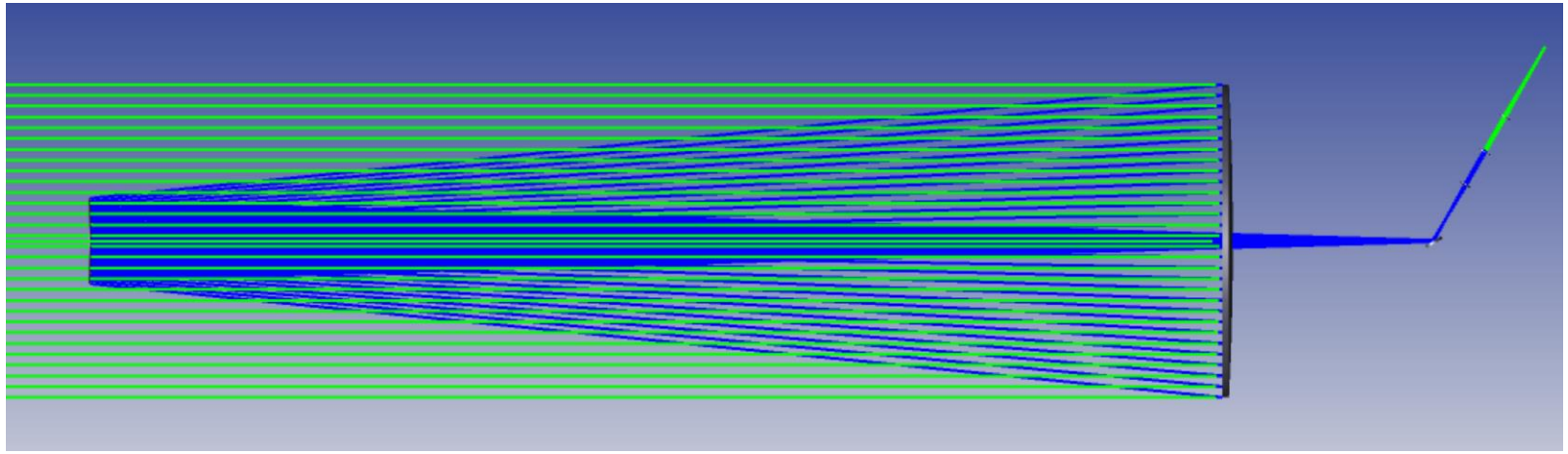


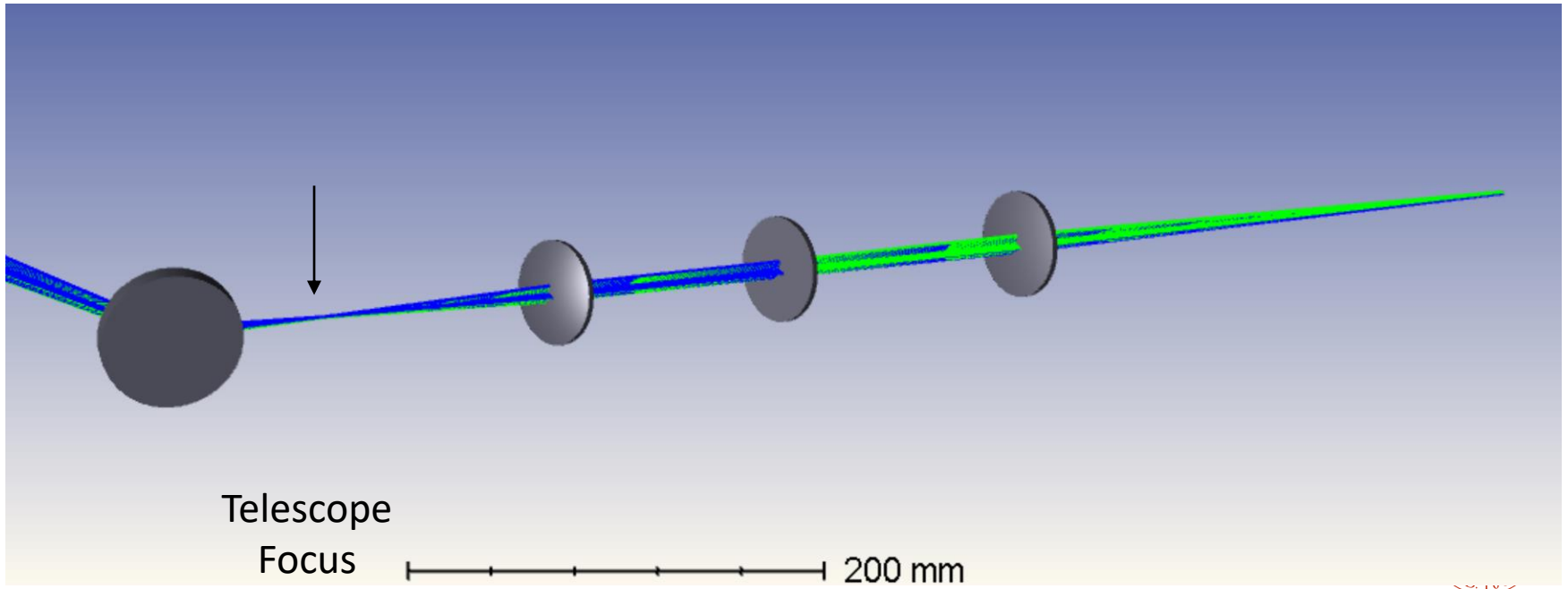
From lab to telescope



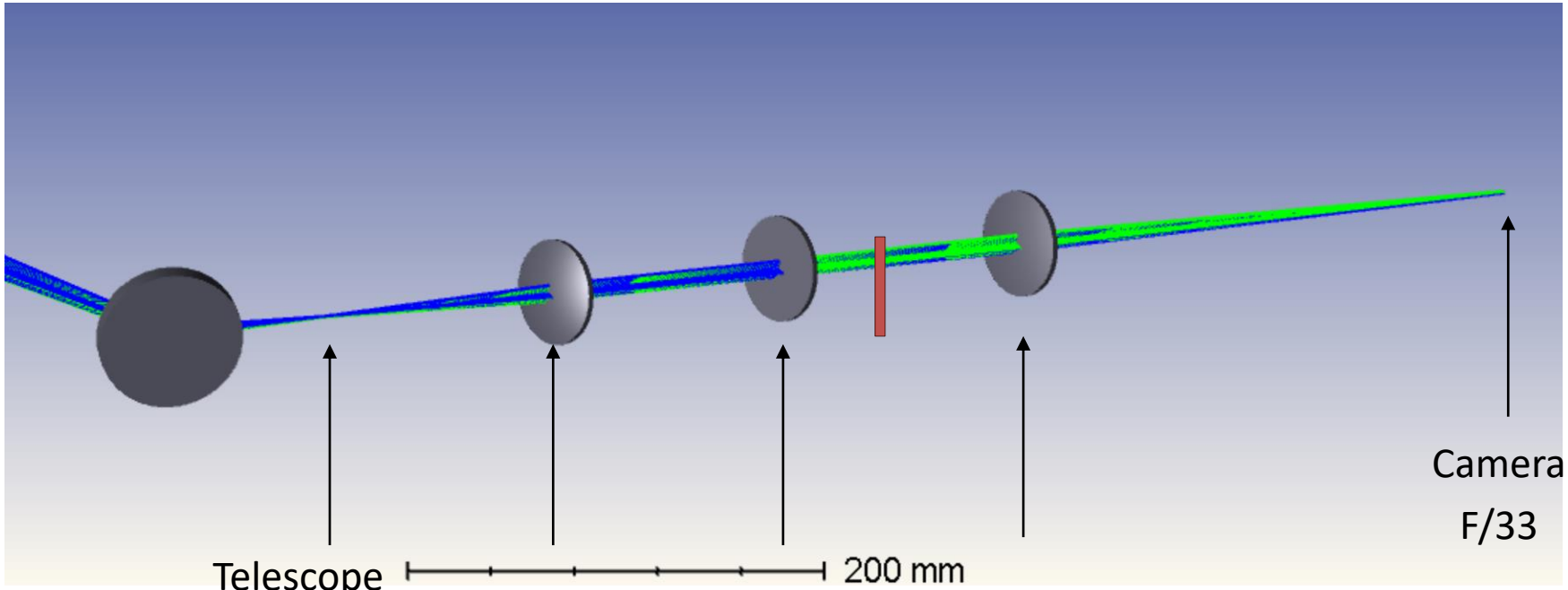


Optical layout conf #2





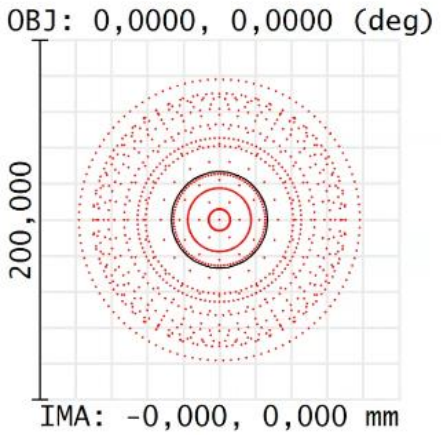
Optical layout conf #2

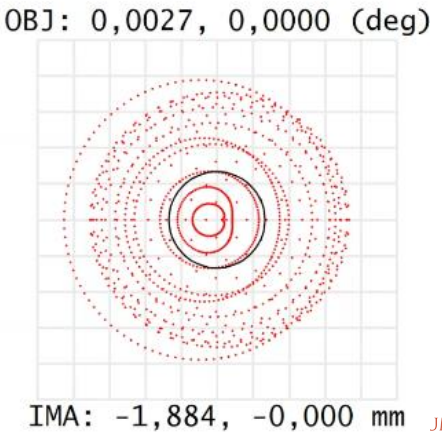


Airy disk 260 mas

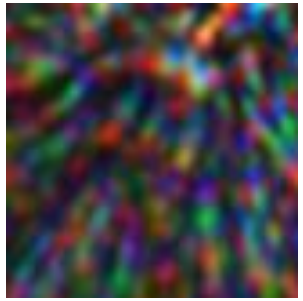
Units are µm. Airy Radius: 26,770µm. Legend items refer to Wavelengths

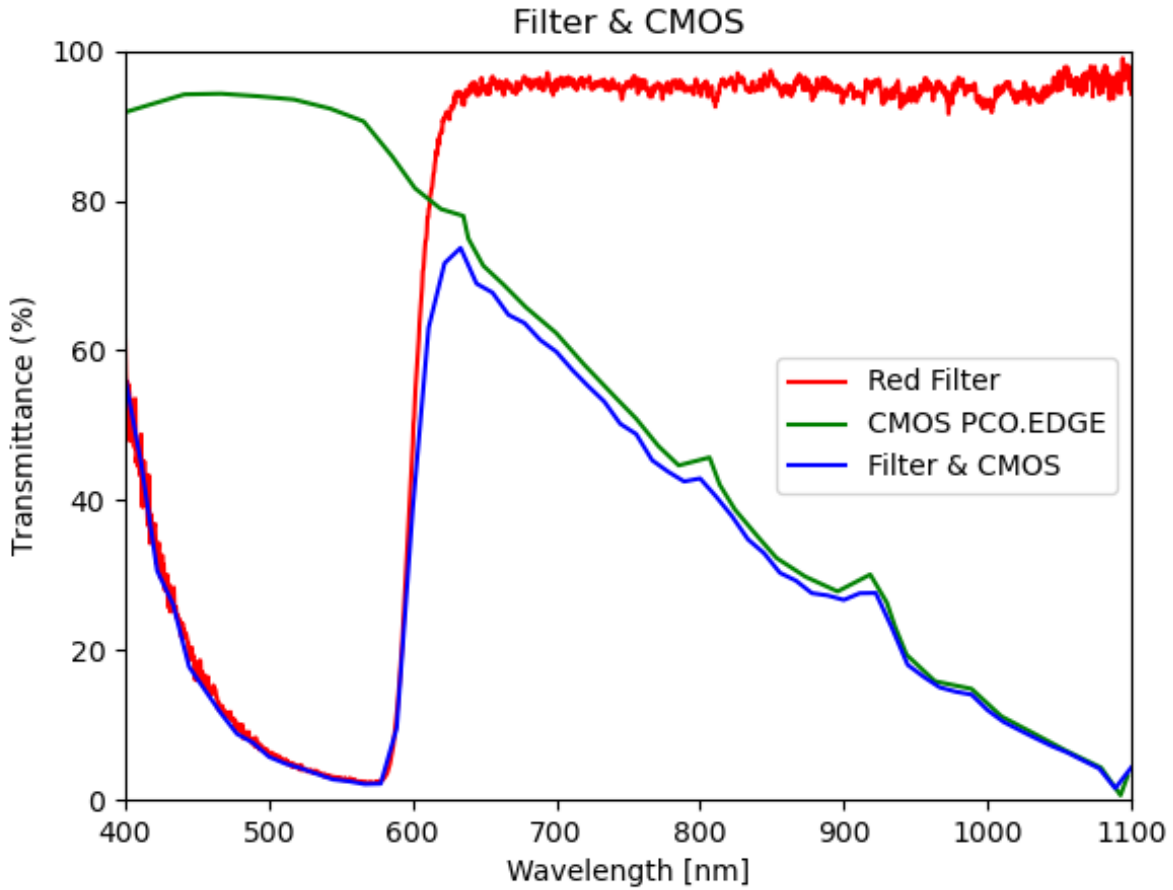
Field	:	1	2
RMS radius	:	52,856	53,217
GEO radius	:	78,244	85,160
Scale bar	:	200,000	Reference : Centroid

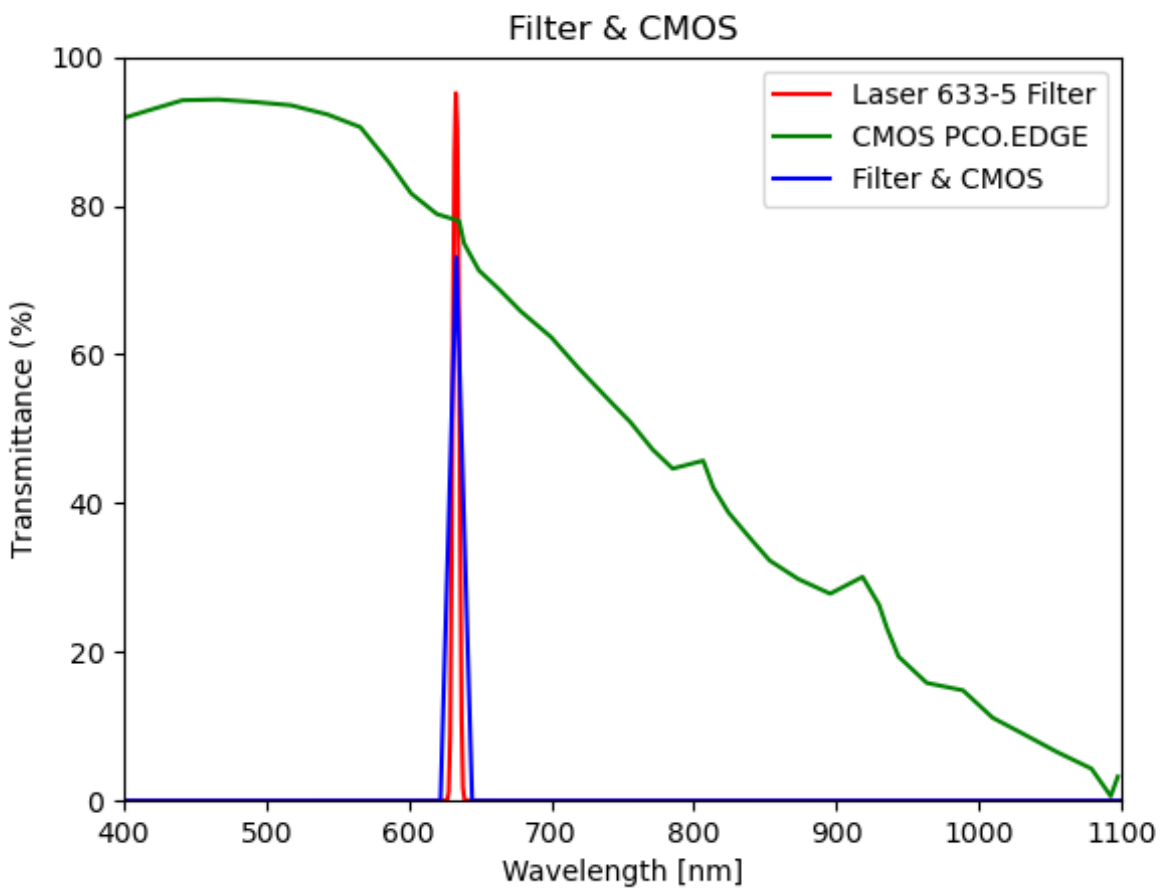




Filter wide or narrow







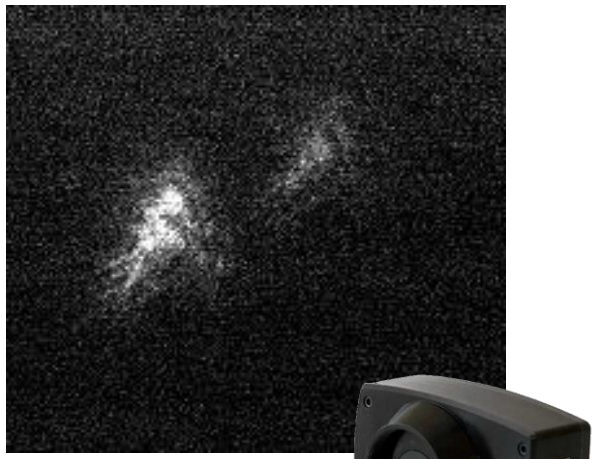
Difference btw camera used at 20ms ex ptime

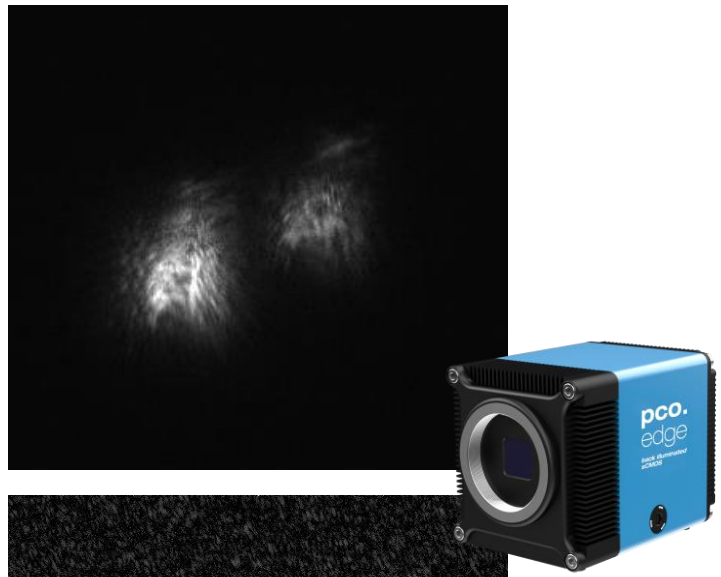
Skynix2.1 Sony ICX205 QE 35% @500nm
4.65 x 4.65 µm, depth 12-bit
Read Noise 12 e- rms
Dark Current Noise 2 e-/s 1K€

QHY183, Sony IMX183, QE 84%@
2.4 x 2.4 µm, depth 12-bit
Read Noise 1-2 e- rms
Dark Current Noise 0,002 e-/s 1K€

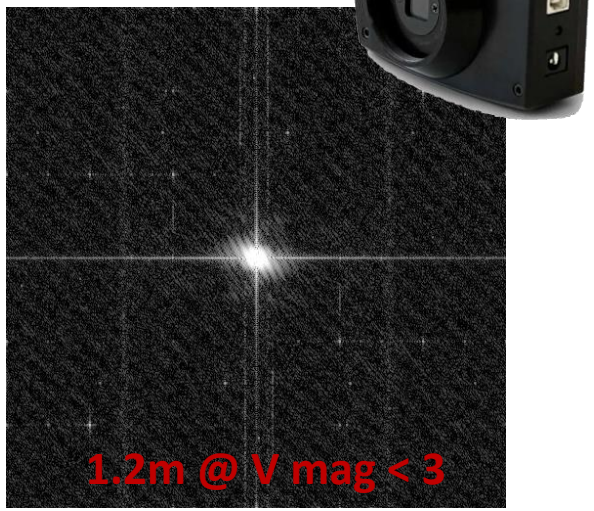
PCO Edge 4.2, (BI) sCMOS, QE 95%@580nm
6.5 x 6.5 µm, depth 15-bit
Read Noise 1 e- rms 100fps 2Kx2K
Dark Current Noise 0.2 e-/s 15K€

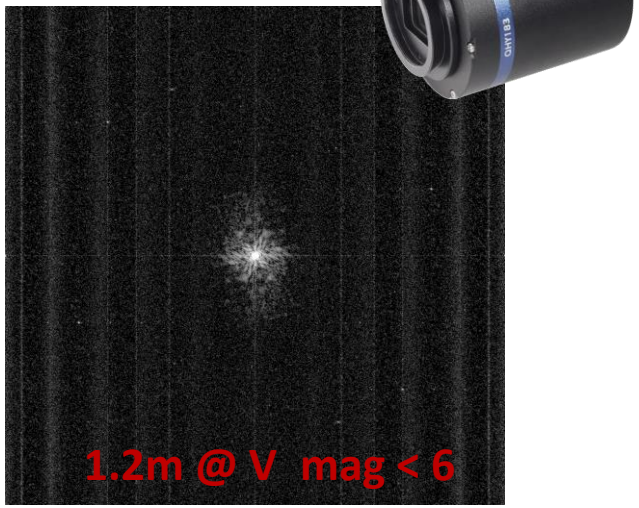
Image

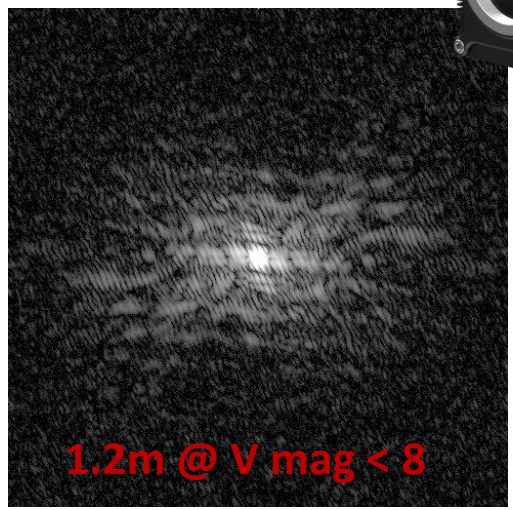




Power Spectrum





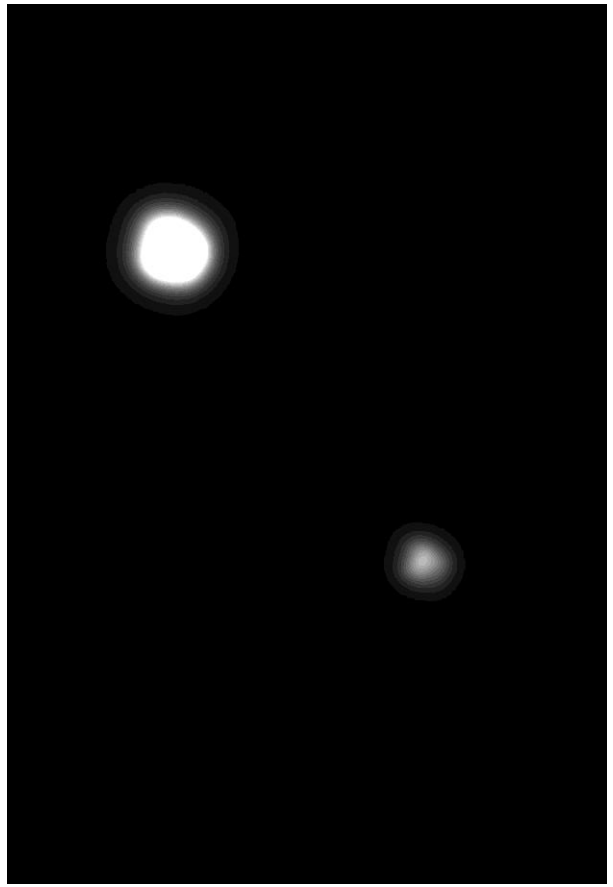


A short list of targets

Star	Cost.	Catalogo WDS	AR 2000	Dec 2000	sep. (")	mag. (V)
LAMBDA	CAS	00318+5431	00 31.8	+ 54 32	0.56	5.3 / 5.6
ETA	ORI	05245-0224	05 24.4	- 02 24	1.7	3.8 / 4.8
32	ORI	05308+0557	05 30.7	+ 05 56	1.06	4.5 / 5.8
33	ORI	05312+0318AB	05 31.2	+ 03 18	1.9	5.8 / 6.9
1	GEM	06041+2316AB	06 04.1	+ 23 16	0.27?	4.7 / 5.1
4	GEM	BU 1058	06 10.5	+ 23 00	0.2	7.3 / 7.6
54	AUR	STT 152	06 39.6	+ 28 16	0.9	6.0 / 7.8
ZETA	CNC	STF 1196	08 12.2	+ 17 40	0.88 / 5.7	5.6 / 6.0 / 6.2
KAPPA	UMA	A 1585	09 03.6	+ 47 09	0.09	4.3 / 4.5
OMEGA	LEO	STF 1356	09 28.5	+ 09 04	0.62	5.9 / 6.5
PHI	UMA	STT 208	09 52.1	+ 54 04	0.30	5.3 / 5.4
GAMMA	SEX	AC 5	09 52.5	- 08 06	0.61	5.6 / 6.1
55	LEO	BU 1076	10 55.7	+ 00 44	1.12	6.1 / 8.0
CSI	UMA	STF 1523	11 18.2	+ 31 33	1.80	4.3 / 4.8
GAMMA	VIR	STF 1670	12 41.7	- 01 27	1.20	3.5 / 3.5
48	VIR	BU 929	13 03.9	- 03 40	0.7	7.2 / 7.5
ALFA	COM	STF 1728	13 10.0	+ 17 31	0.11	5.1 / 5.1
25	CVN	STF 1768	13 37.5	+ 36 17	1.84	5.0 / 6.9
ZETA	BOO	STF 1865	14 41.1	+ 13 44	0.78	4.5 / 4.6
MI	LIB	BU 106	14 49.3	- 14 09	1.9	5.8 / 6.7
59	HYA	BU 239	14 58.7	- 27 39	0.35?	6.3 / 6.6
ETA	CRB	STF 1937	15 23.2	+ 30 18	0.70	5.6 / 5.9
GAMMA	CRB	STF 1967	15 42.8	+ 26 18	0.74	4.1 / 5.5
PI 2	UMI	STF 1989	15 39.7	+ 79 58	0.75	7.4 / 8.2
20	DRA	STF 2118	16 53.3	+ 65 02	1.27	7.1 / 7.3
PHI	DRA	STT 353	18 20.7	+ 71 20	0.42	4.4 / 6.1

Calibrate images: scale of the telescope and seeng r_0

NAME	SAO	COORD	WDS_NAME	LAST	OBS	PA	SEP	MAG1	MA
Lam Ari	75051	01 57 56 +23 35 46	H 5 12 AB	2020	94	48	37.3	4.80	6.



SAO 75051

sep 581,78 px

PA angle 308,76

120 imgs of 1 sec

Binning 1x1

PCO camera 6,5 um

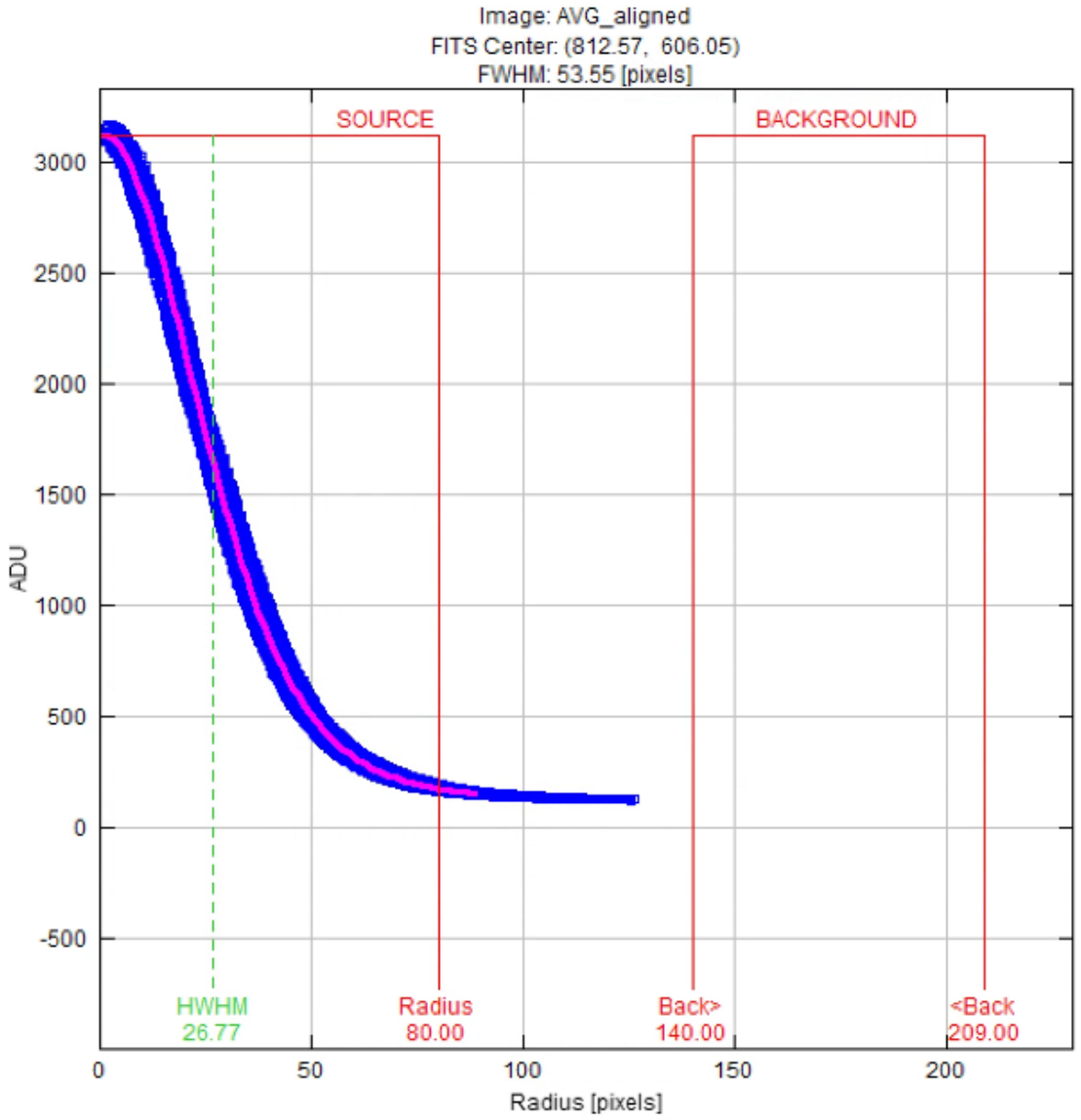
700 nm

r_0= 100 mm

Seeing = 3.5 arcsec

Scale 64 mas/px

Eq focal = 20.9m



Zeta Cnc 2022

NAME	CST	SAO	COORD	WDS NAME	LAST	OBS	PA	SEP	MAG1	MAG2	D MAG
Tegmine	Cnc	97645	08 12 13 +17 38 51	STF 1196 AB	2022	1230	359	1.1	5.30	6.25	0.95
Zet2 Cnc	Cnc	97646	08 12 13 +17 38 51	STF 1196 AB,C	2020	575	64	6.0	4.92	5.85	0.93

Zeta CNC AB

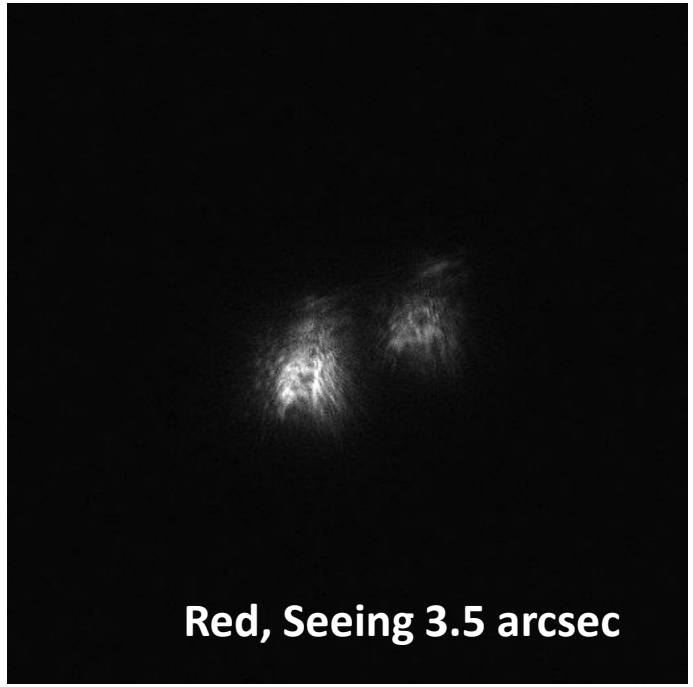
Sep : 1.101 arcsec [true 1.105], PA: 357 [true 357]

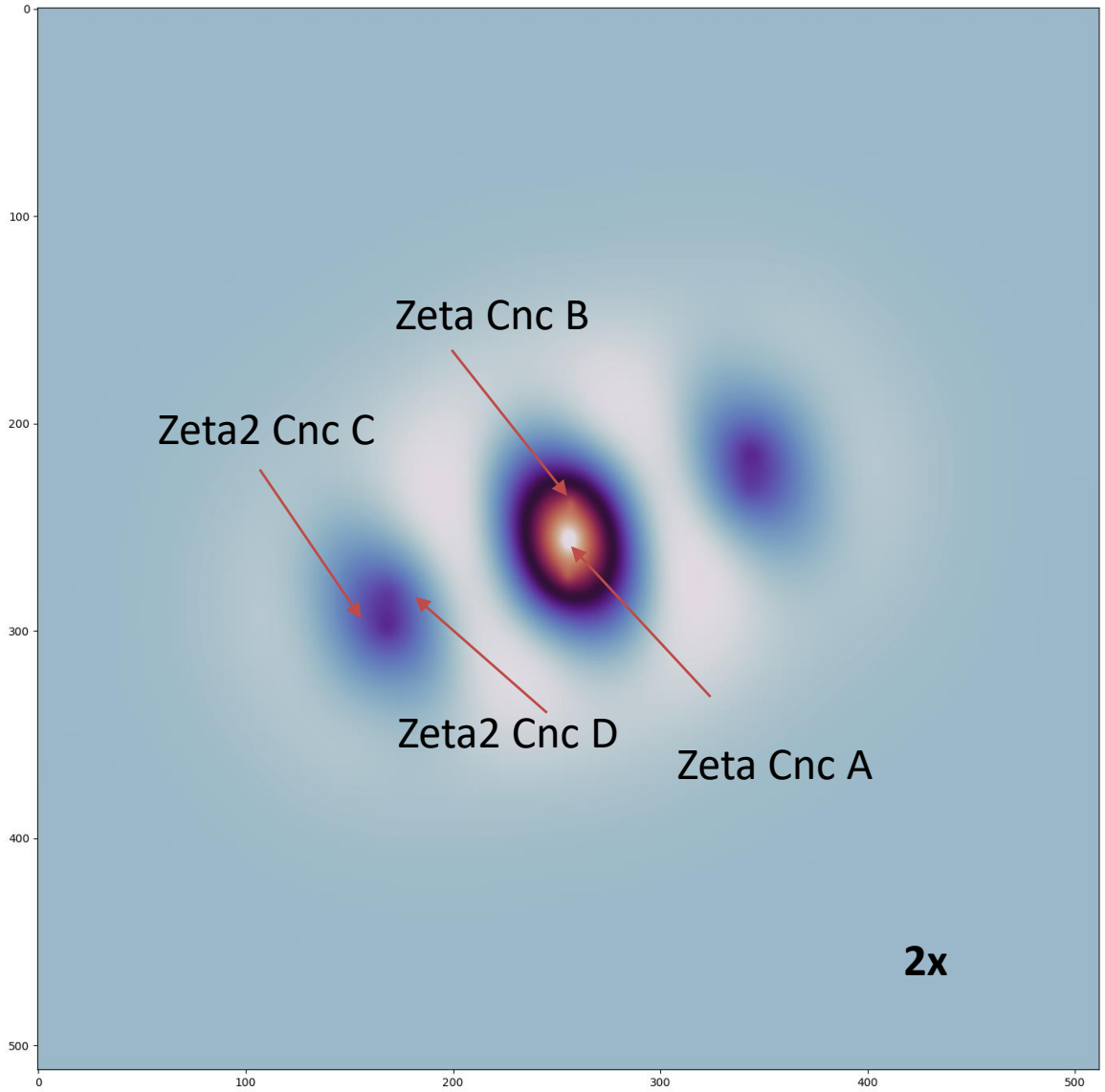
Zeta CNC AC

Sep : 6,263 arcsec [true 6.284], PA: 51 [true 63]

Zeta CNC CD

Sep : 0.766 arcsec [true ?], PA: 357 [true ?]

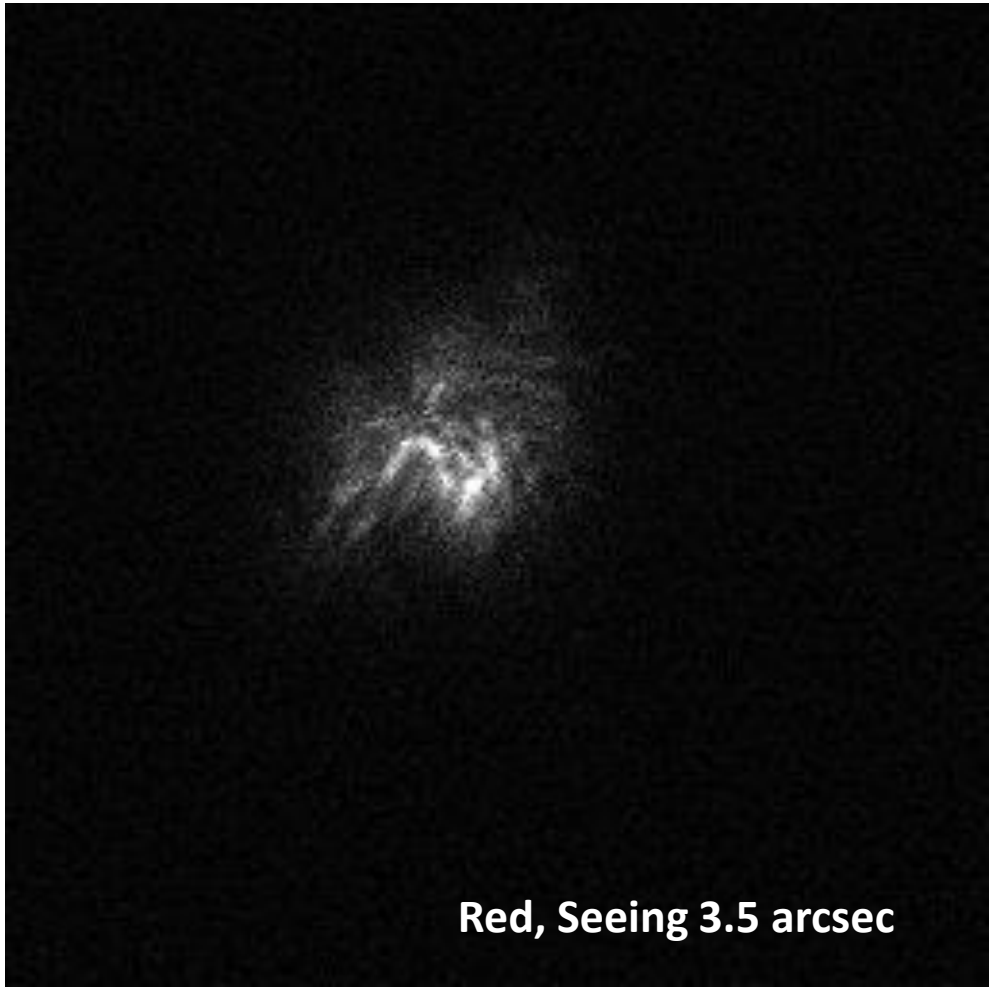


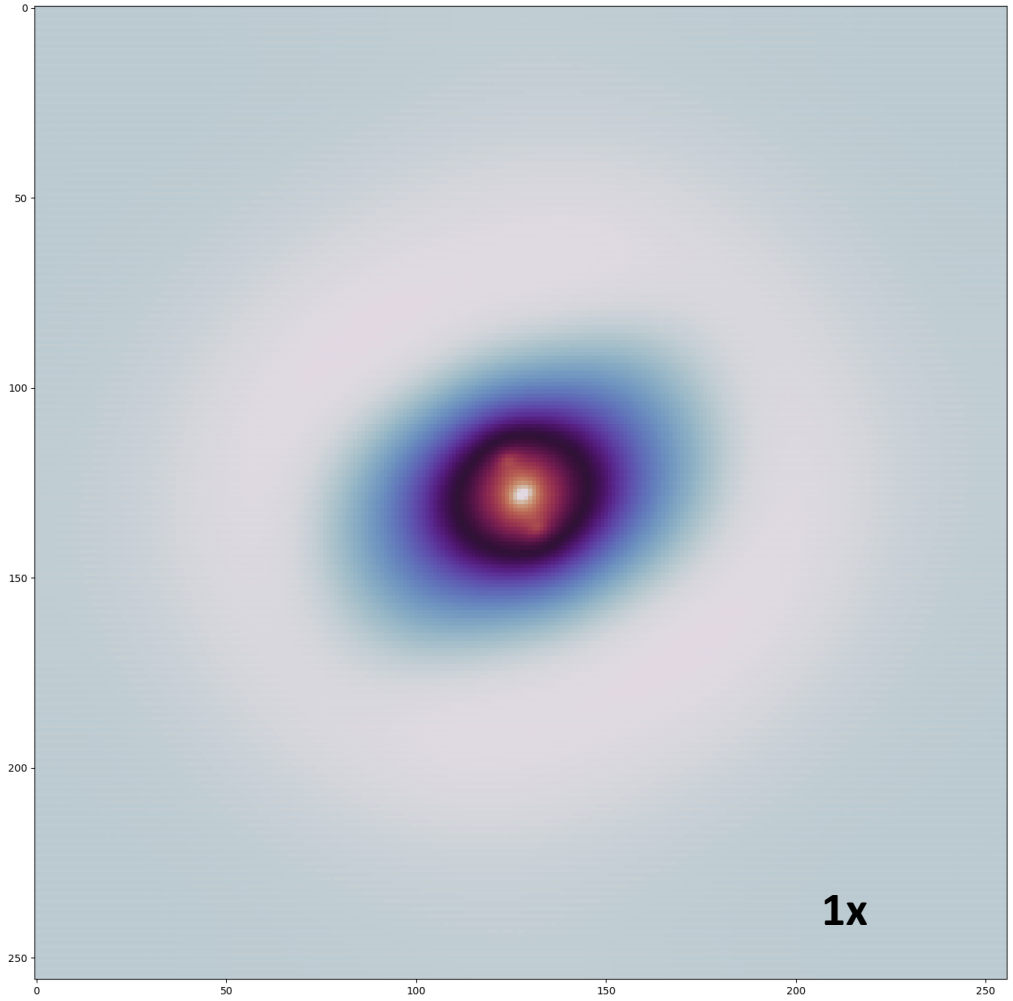


4 lyn 2022

SHOW	NAME	SAO	COORD	WDS_NAME	LAST	OBS	PA	SEP	MAG1	MAG2	D_MAG	ORB
Show	4 Lyn	25678	06 22 04 +59 22 20	STF 881 AB	2020	154	149	0.7	6.13	7.71	1.58	Y

Sep : 0,633 arcsec [true 0,620], PA: 147 [true 151]

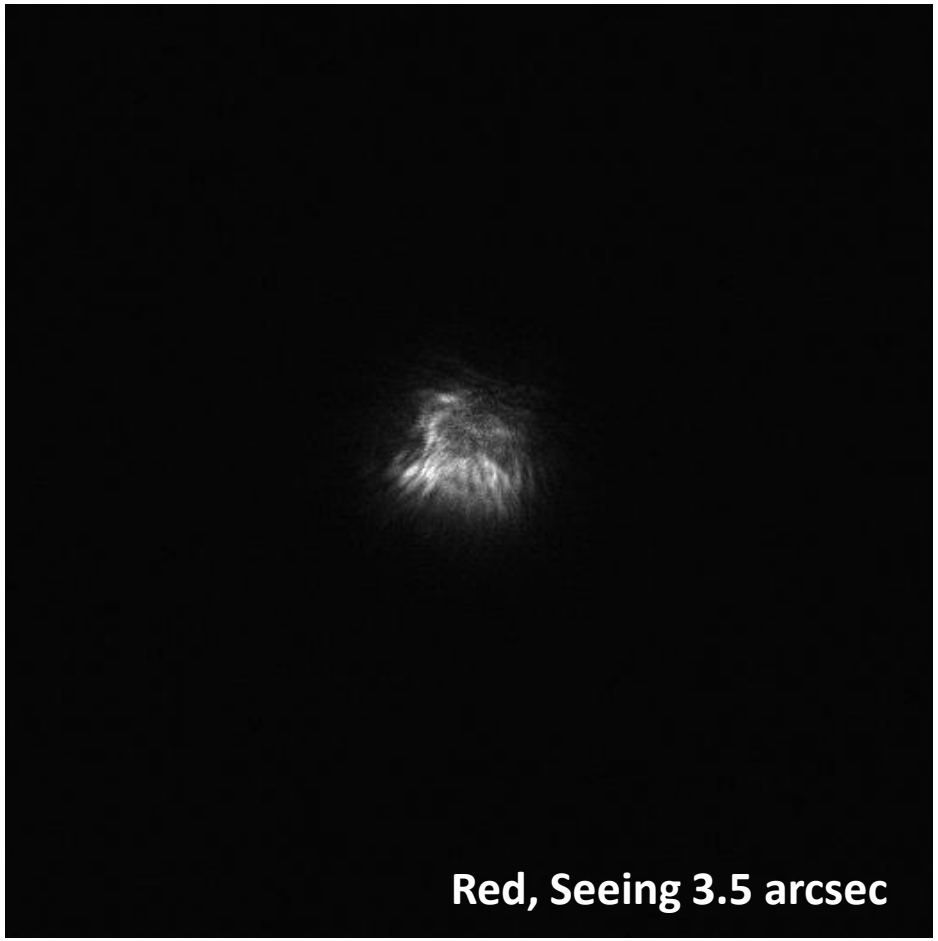


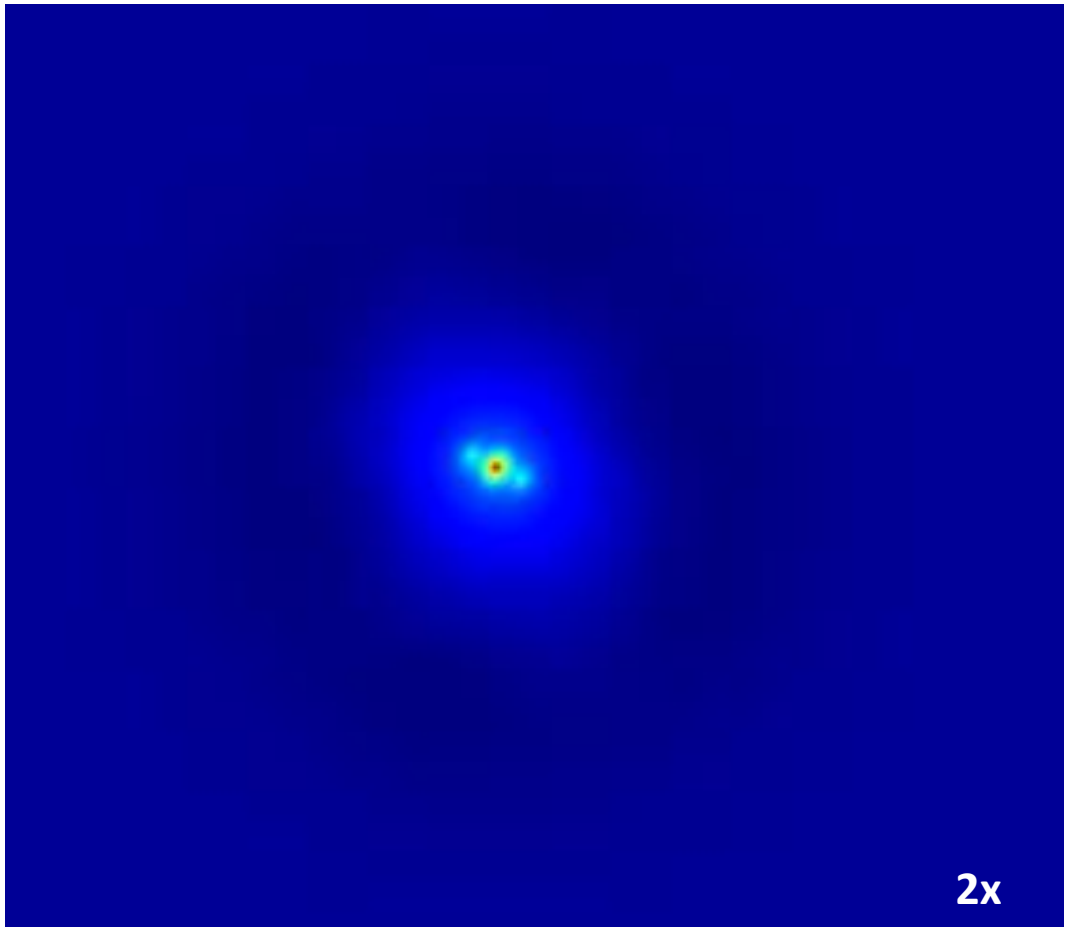


PHI AND 2022

NAME	CST	SAO	COORD	WDS NAME	LAST	OBS	PA	SEP	MAG1	MAG2	D MAG
Phi And	And	36972	01 09 30 +47 14 31	STT 515 AB	2021	232	114	0.5	4.59	5.61	1.02

Sep : 0,492 arcsec [true 0,525], PA:104 [true 113]





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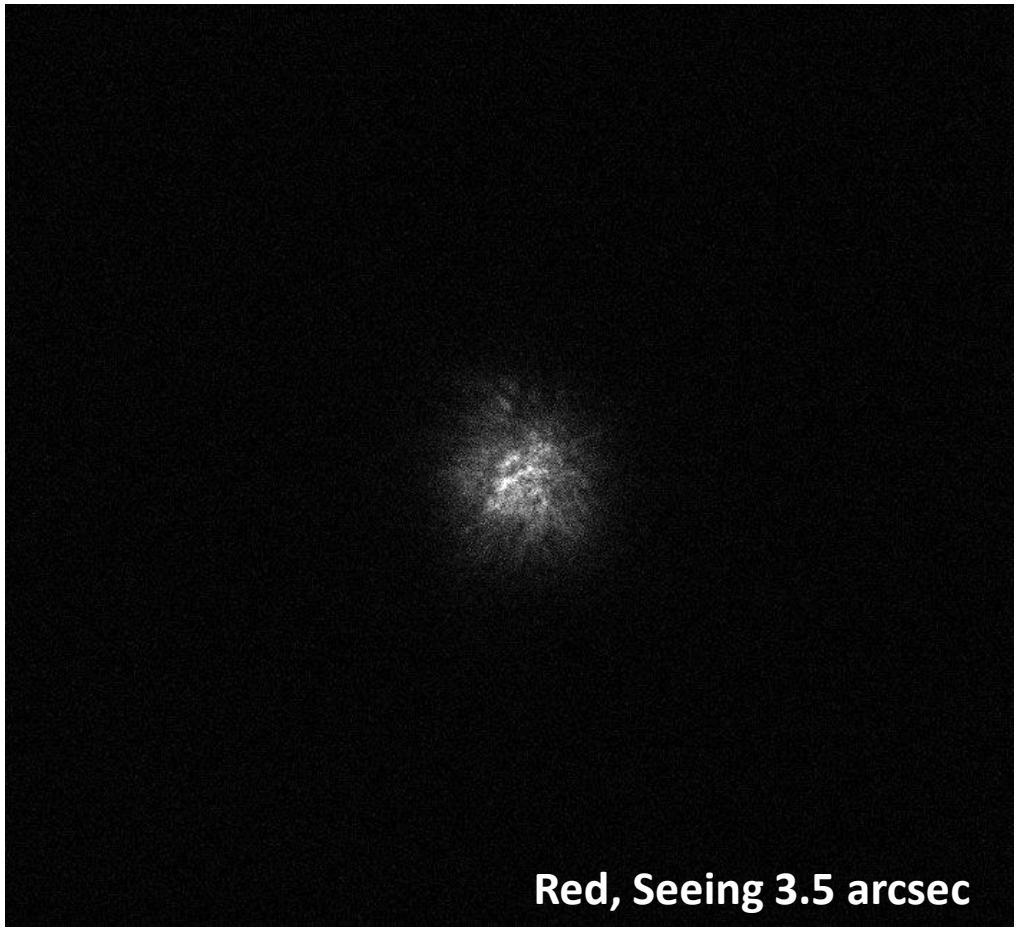
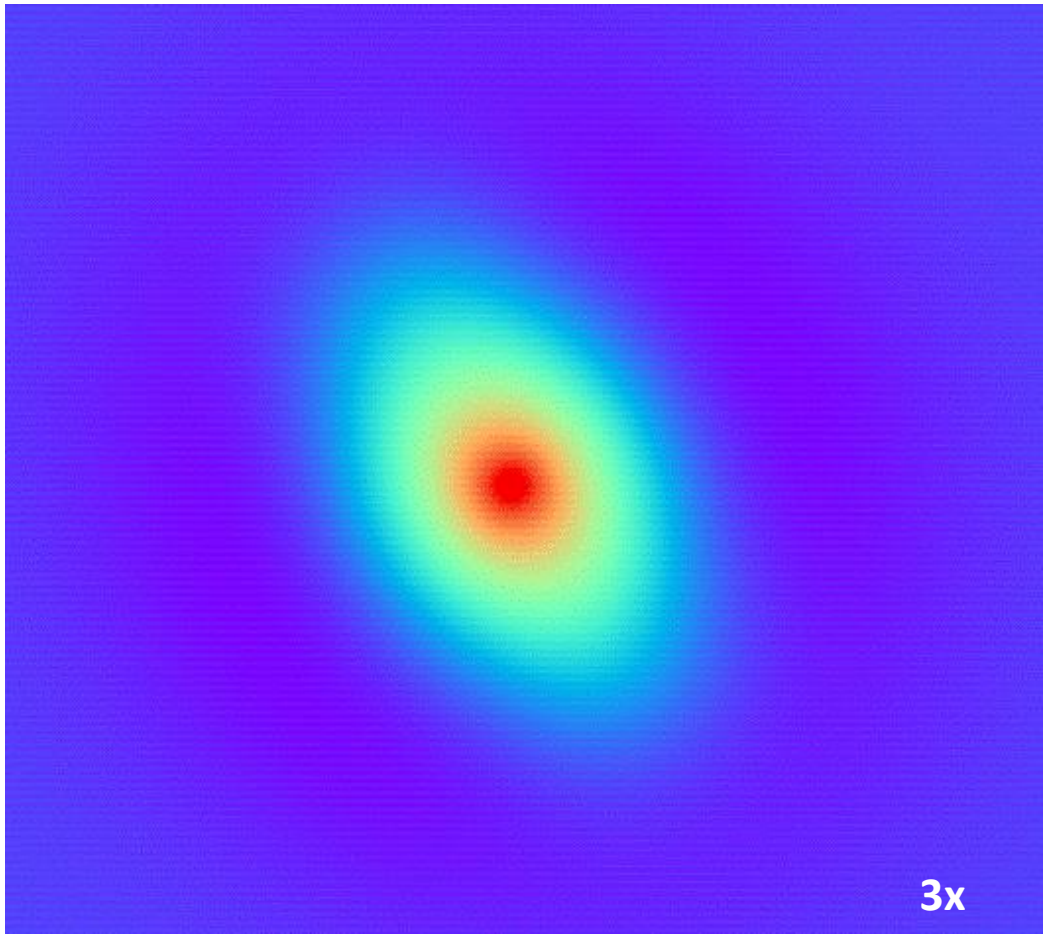
HD 17743 AB, 2022

CST	SAO	COORD	WDS NAME	LAST	OBS	PA	SEP	MAG1	MAG2	D MAG
Per	23674	02 52 52 +52 59 51	A 2906 AB	2018	24	115	0.3	7.26	8.78	1.52

Sep : invisible [true 0,230]

Airy disk 260 mas





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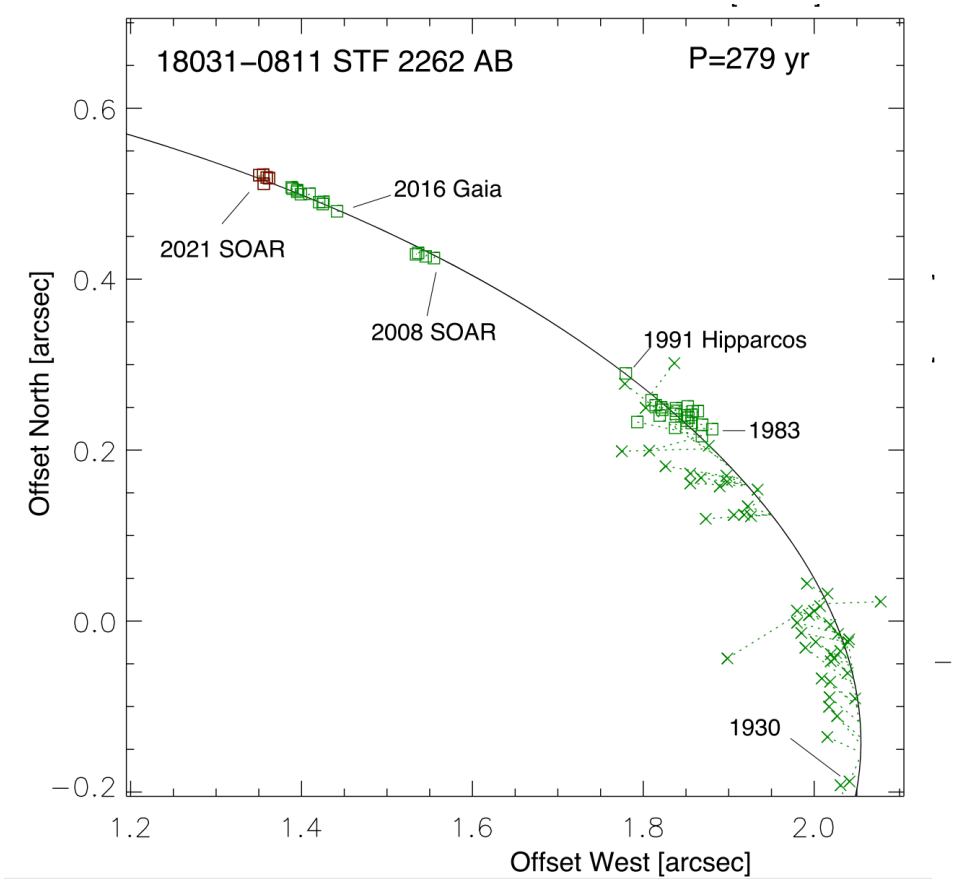
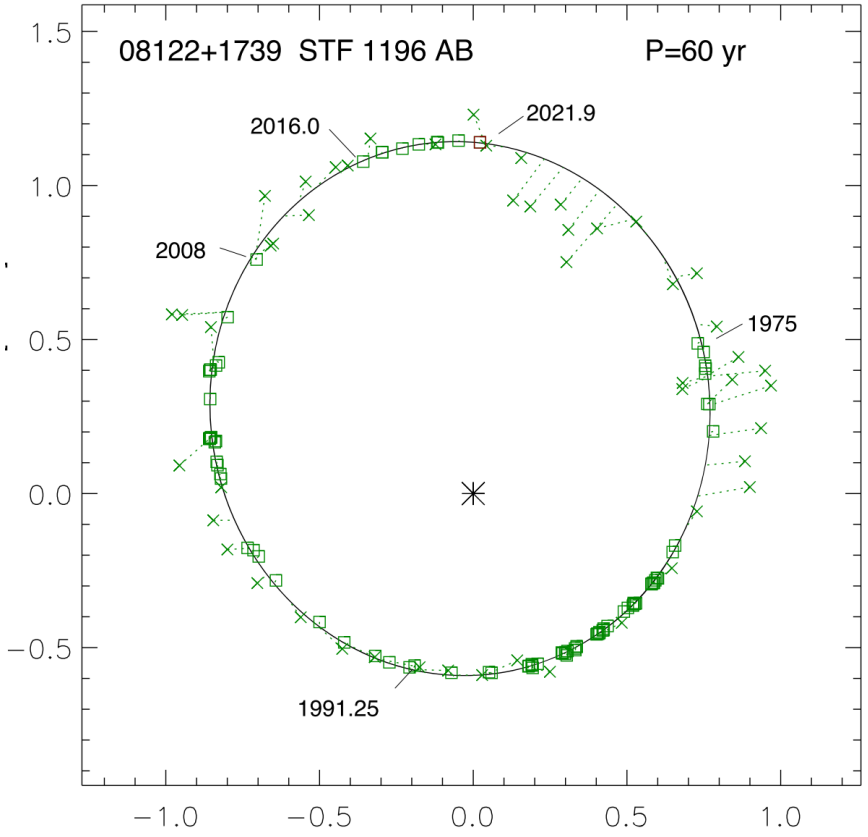
Science cases: orbital determination of binary stars

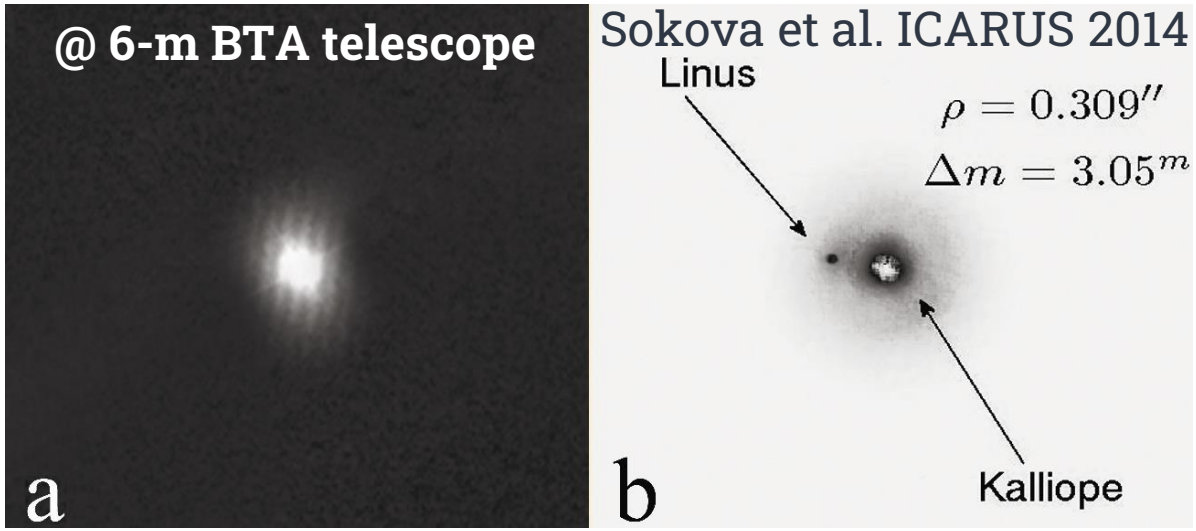


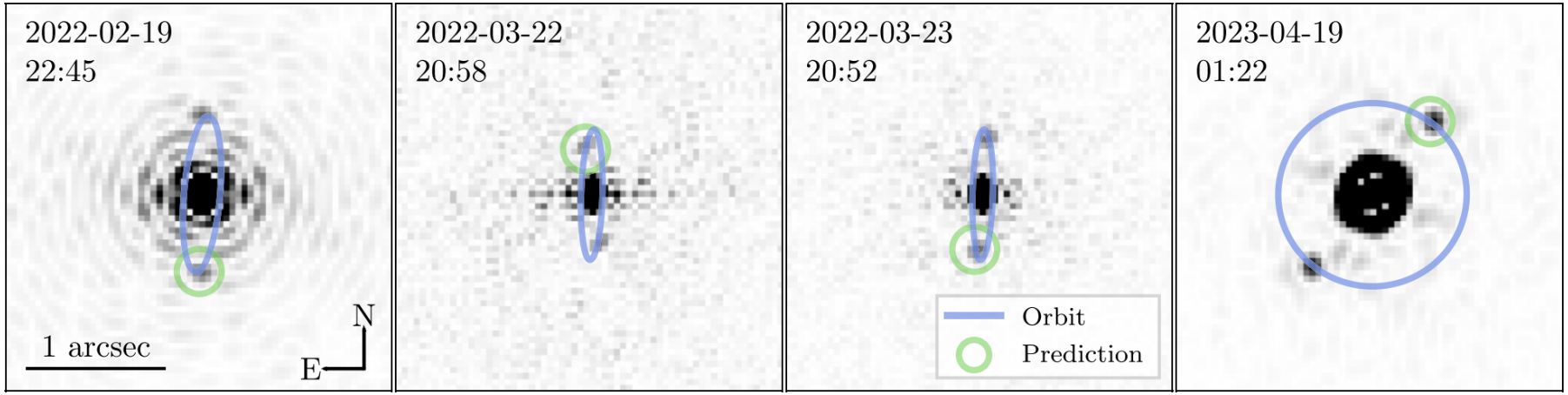


Tokovinin et al. AJ 2022

Science cases: investigating asteroid duplicity and size

The binary Asteroid 22 Kalliope





Aristidi et al. 2022 MNRAS @ Epsilon telescope 104 cm

Figure 1. Examples of 2D autocorrelations of Kalliope speckle images. The orbit of Linus and predicted position at the time of observation from Ferrais et al. (2022) are overplotted. Note the difference in the position angle between the two middle graphs, one day apart: the period of Linus is approximately 3.6 d, which imply a motion of ∼100° per day. Taking into account the inclination of the orbit, we observe a difference of almost 180° in the position angle.

ESA's Cosmic Vision - Plato Mission Science

Scientific goals: detect Earth-size exoplanets

- **3% accuracy on planets radius** (from photometric transits)
- **< 10% accuracy on planets masses** (ground-based RV)
- **< 10% accuracy on stellar masses, radii, and ages** (from asteroseismology)
- **identification of bright targets for atmospheric spectroscopy**

Observational concepts:
photometric monitoring in the visible band of very large samples of bright (m_V ≤11-13) stars.

- Ultra-high precision
- Long observation time (up to several years)
- Uninterrupted sequences

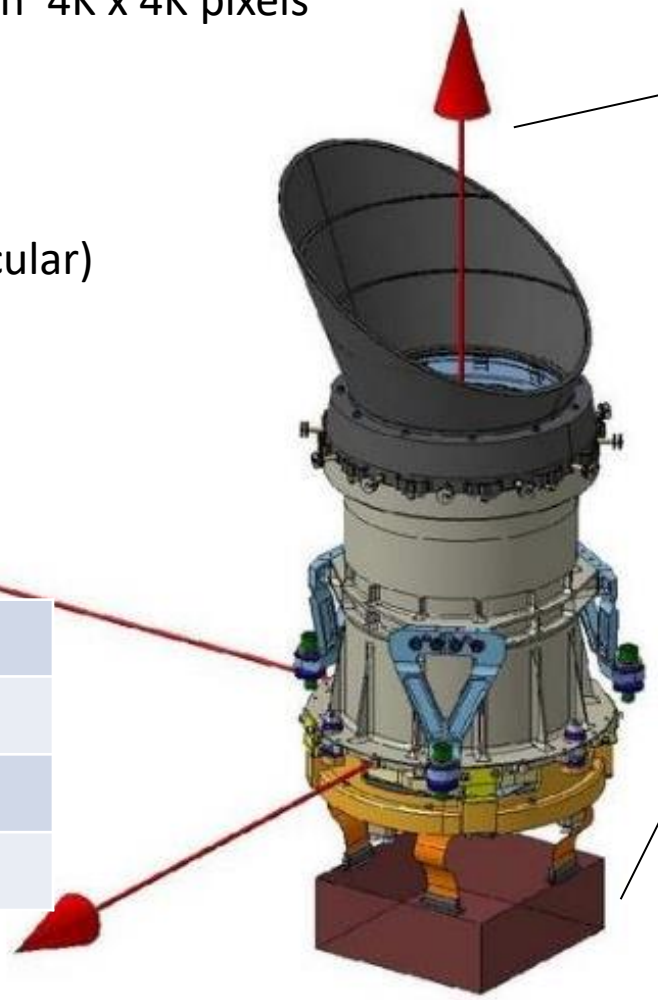
24

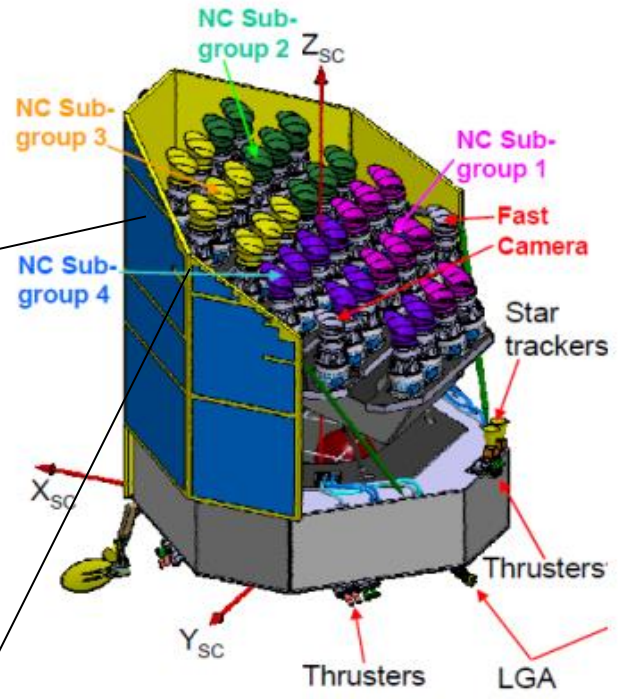
PLATO – payload concept

- Mosaic of 26 cameras arranged in sub-groups with same inclination
- Focal planes 104 CCDs (4 CCDs per camera) with 4K x 4K pixels

  → **2 Tera px image size!**
- Dynamic range: **4 ≤ Mv ≤ 16**
- Single TOU Field of View is 1037 deg² (37.7° circular)
- Total Field of View is **2232 deg² (48.5° × 48.5°)**
- focal plane size → 1 meter class telescope
- **Cadence 25 sec / 2.5 sec**

Image quality	**90% EE within 2x2 pixel²**
Plate Scale	**15 arcsec/pixel**
Pixel size	**18 micron**
Working Temperature	**-80°C**



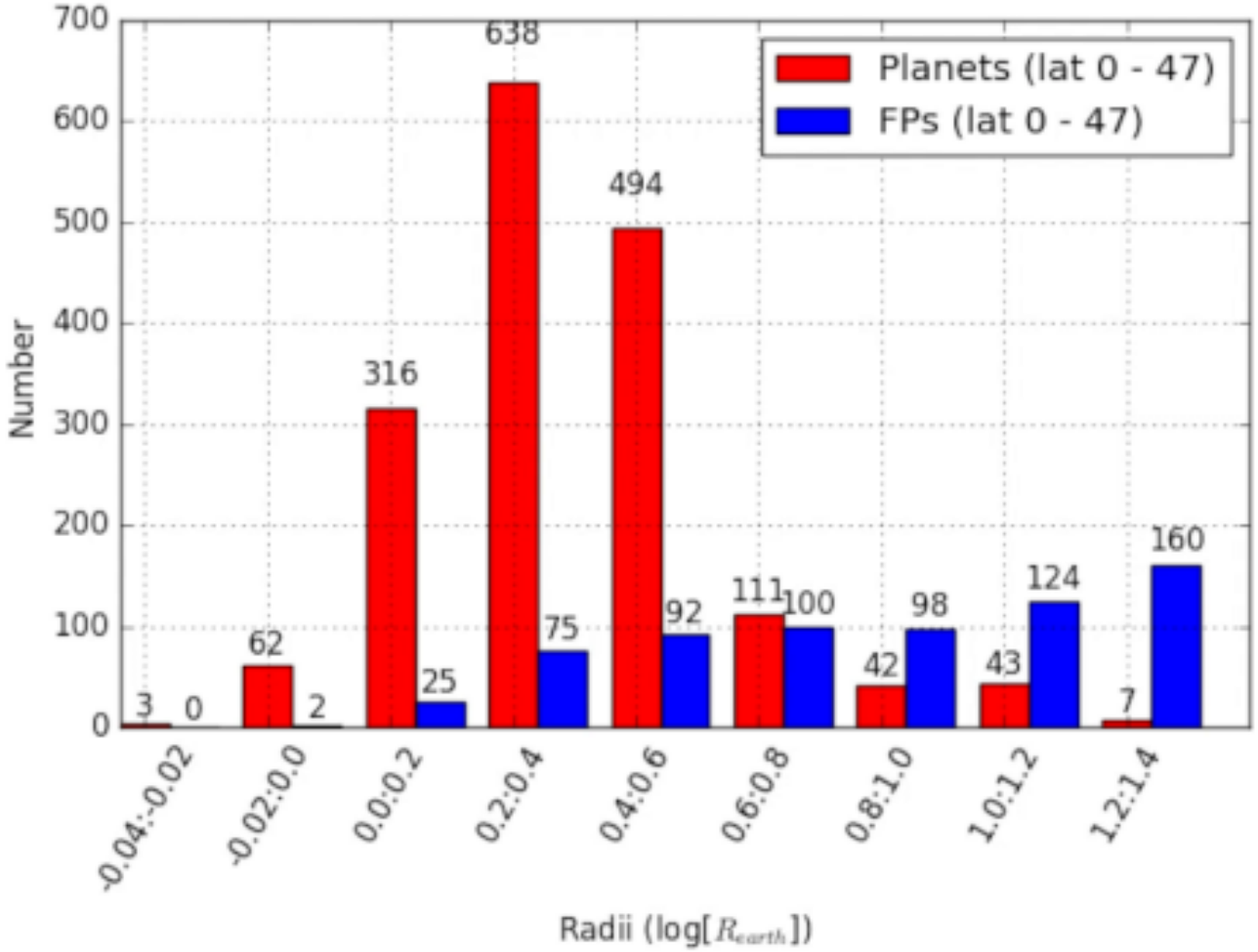


Launch is expected for 2026

Payload position on L2

25

Speckle interferometry to detect blended binaries and reduce false positive For PLATO MISSION



Bray, J C et. Al. MNRAS, 2022

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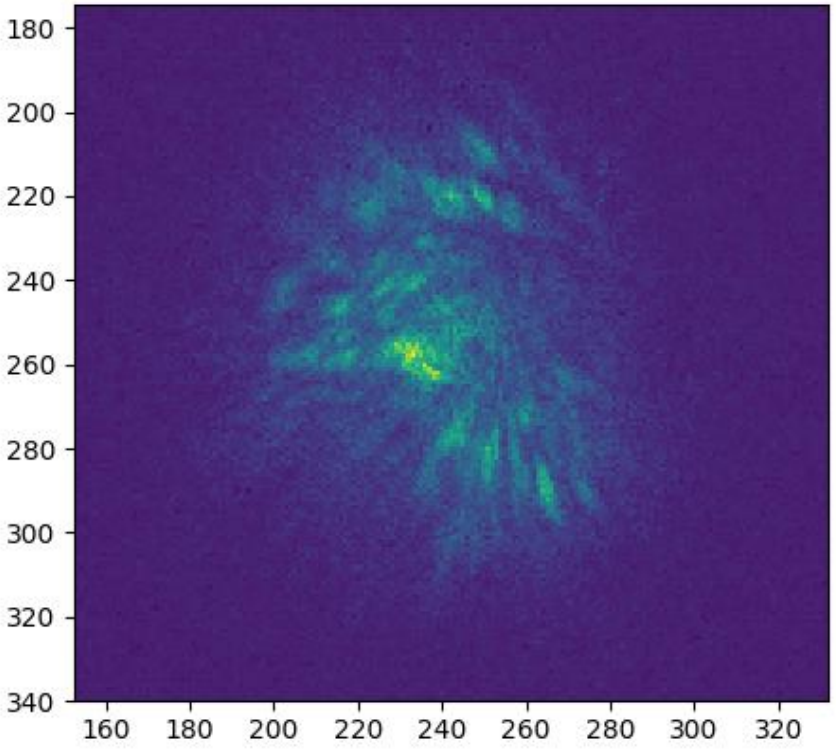
Go speckles interferometry!



seeing 3 arcsec
exp 20ms, red

54 Aur

Sep 0.7 arcsec

Mag pri	6.21
Mag sec	7.85