Faint IR Low Order Sensing: pushing the limiting magnitude of AOF's LTAO mode

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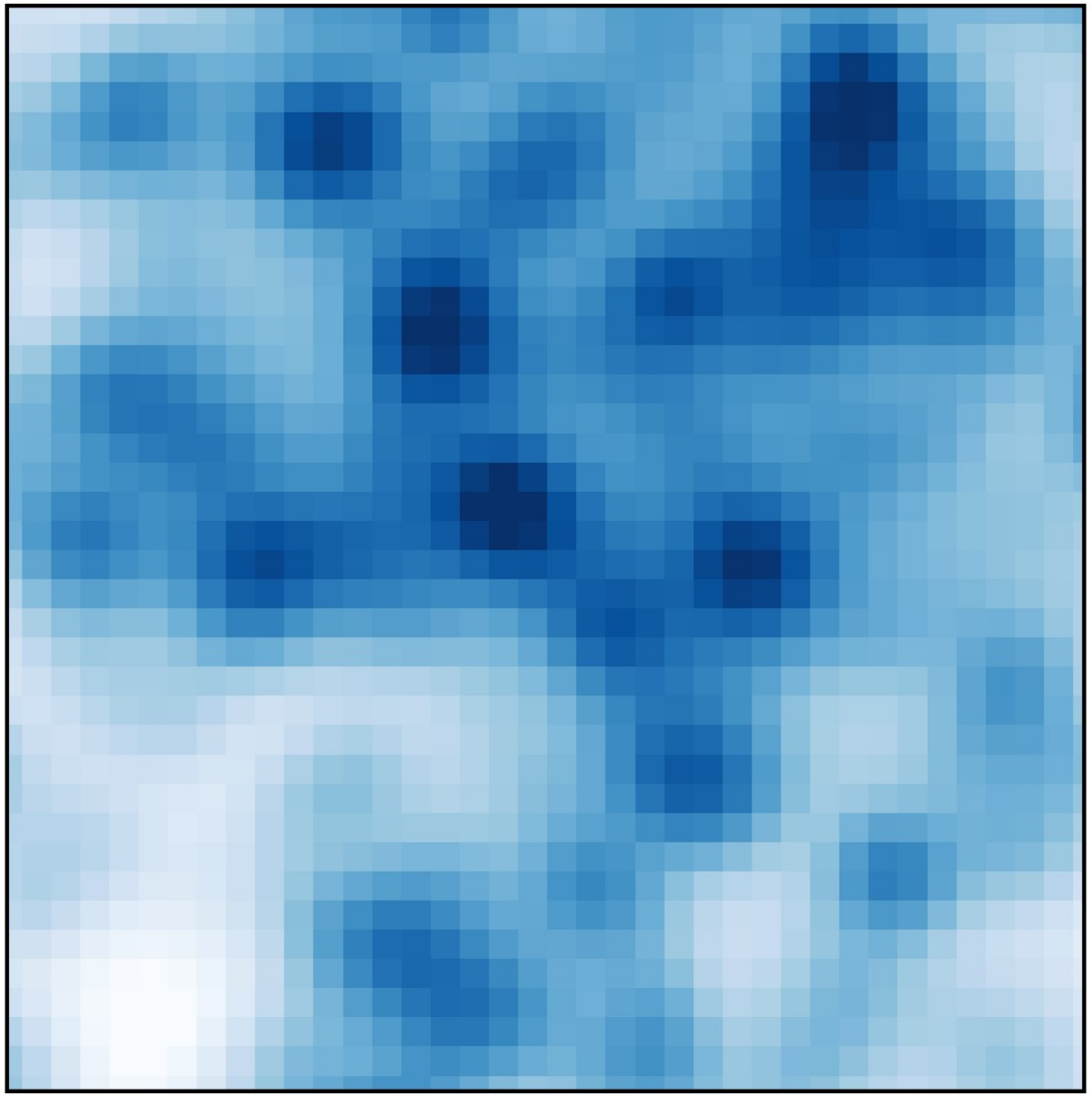
WFSing workshop

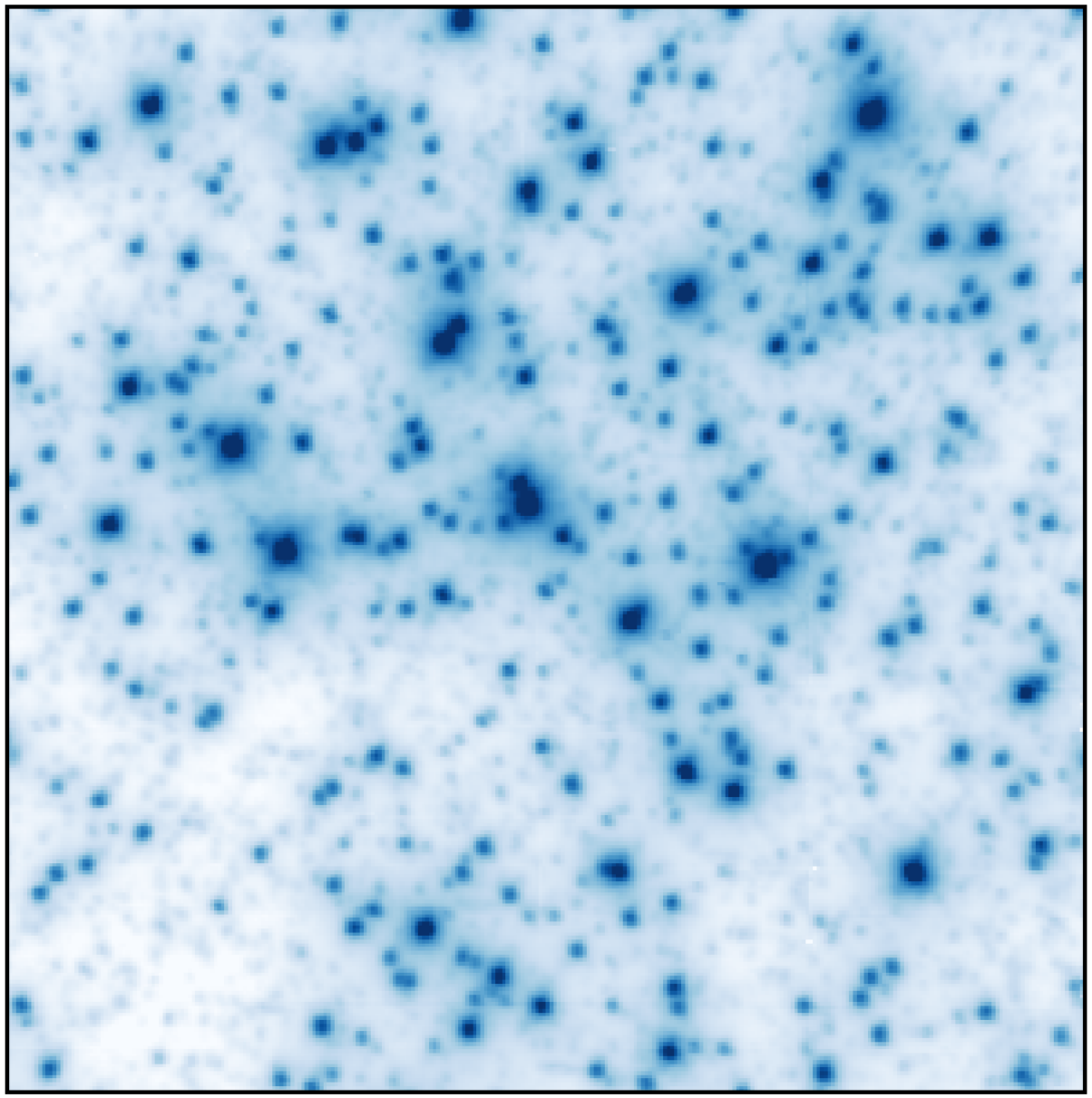
October 14th 2020

MUSE - NGC 6388: WFM GLAO in 7.5” FoV



MUSE WFM
SDSS R-band image
Spaxel scale= 200 mas
Wavelength: 550-700nm

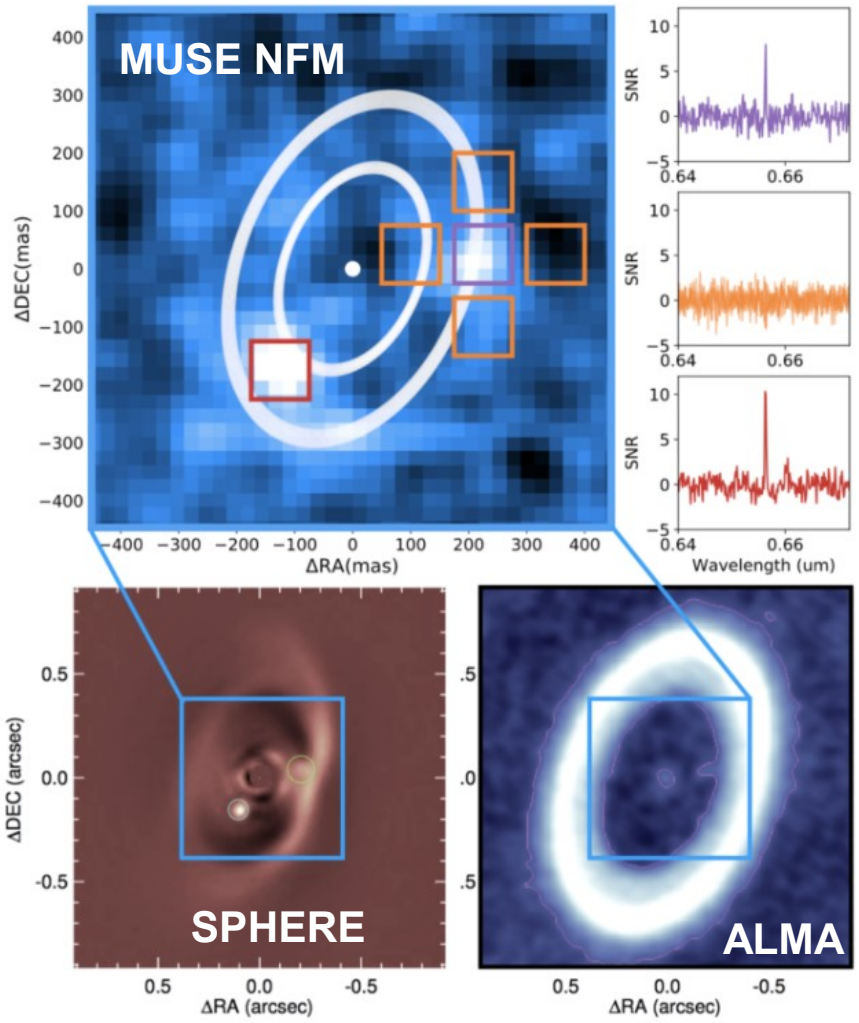
MUSE - NGC 6388: NFM LTAO in 7.5” FoV

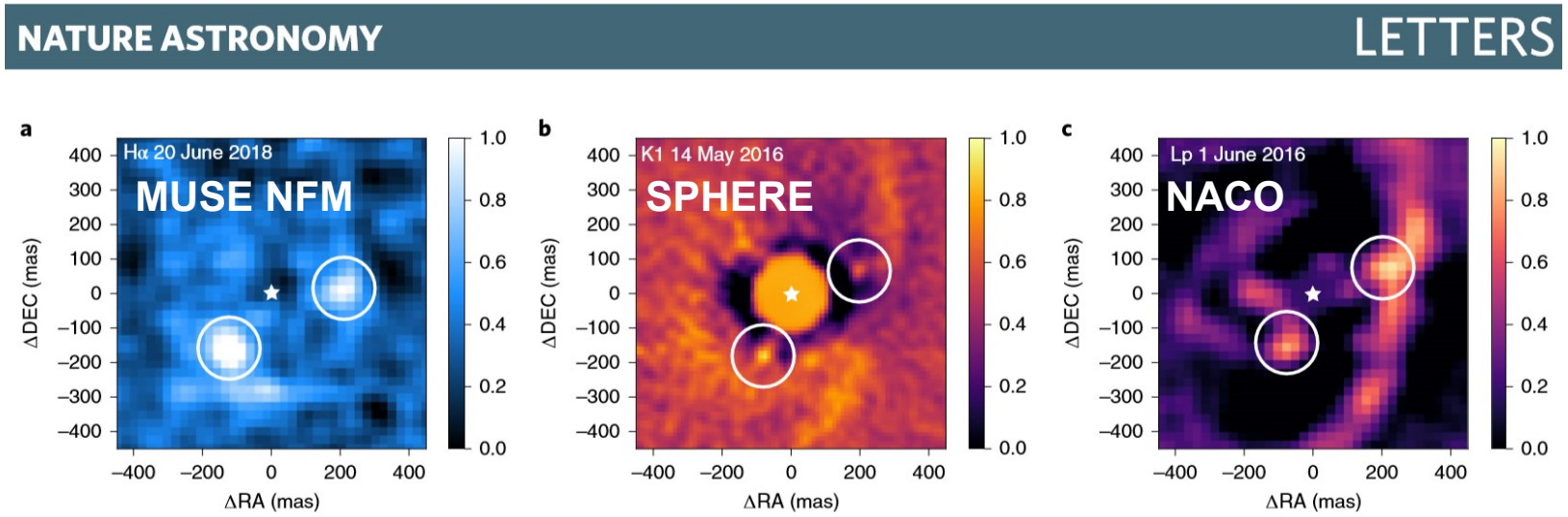


MUSE NFM
Spaxel scale= 25 mas
Wavelength: 480-930nm

Space spatial resolution in the visible achieved from the ground, combined with spectral resolution of ~3000 in each point of the field
> 10000 objects resolved in 7.5” square

Protoplanet Hα detection by MUSE NFM



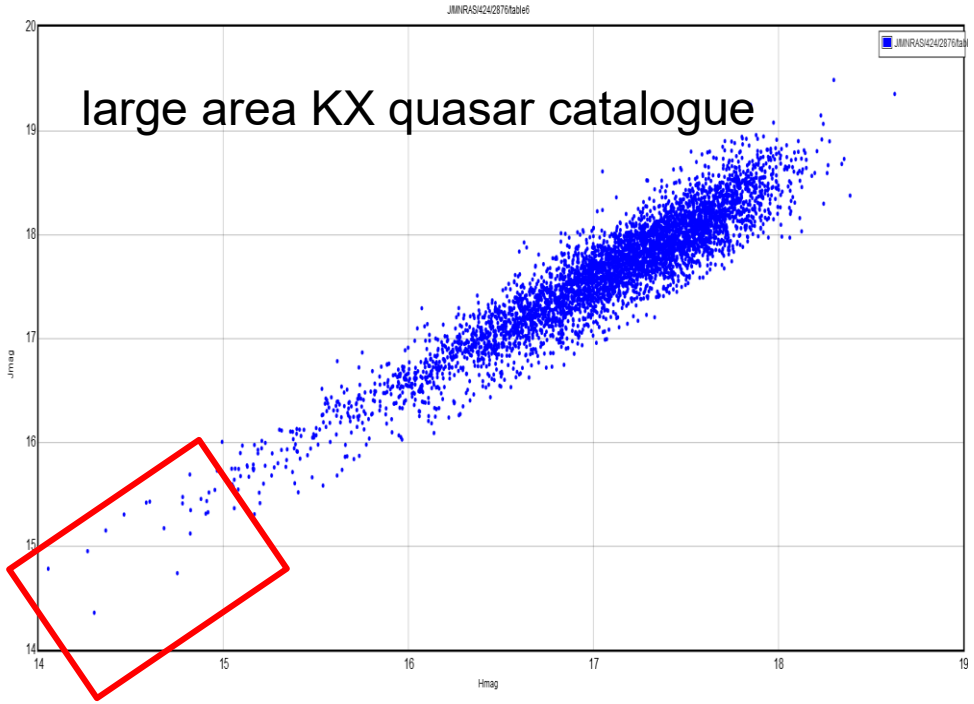


Two accreting protoplanets around the young star PDS 70

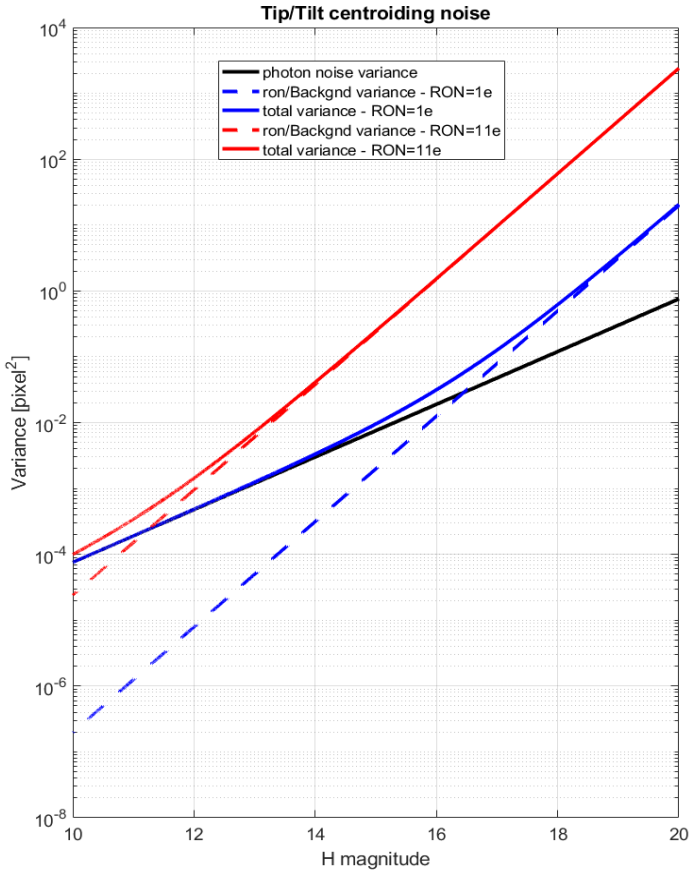
Haffert et al. June 2019 (Comm data - June 2018)

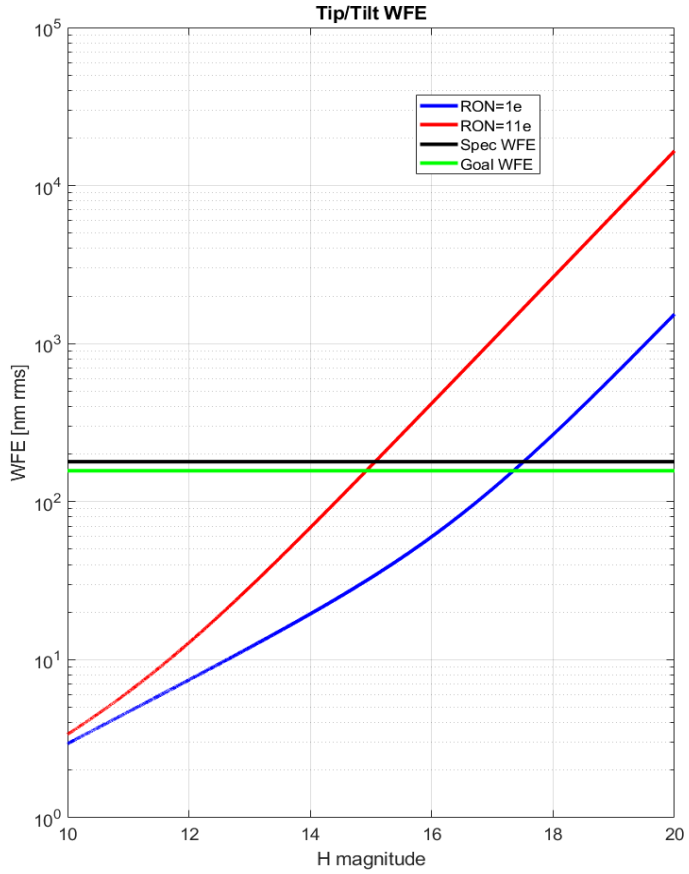
Today's LTAO limiting magnitude

- Limiting magnitude < magH = 14.5
- Loop closure until magH=15
- A handful of QSOs can be addressed



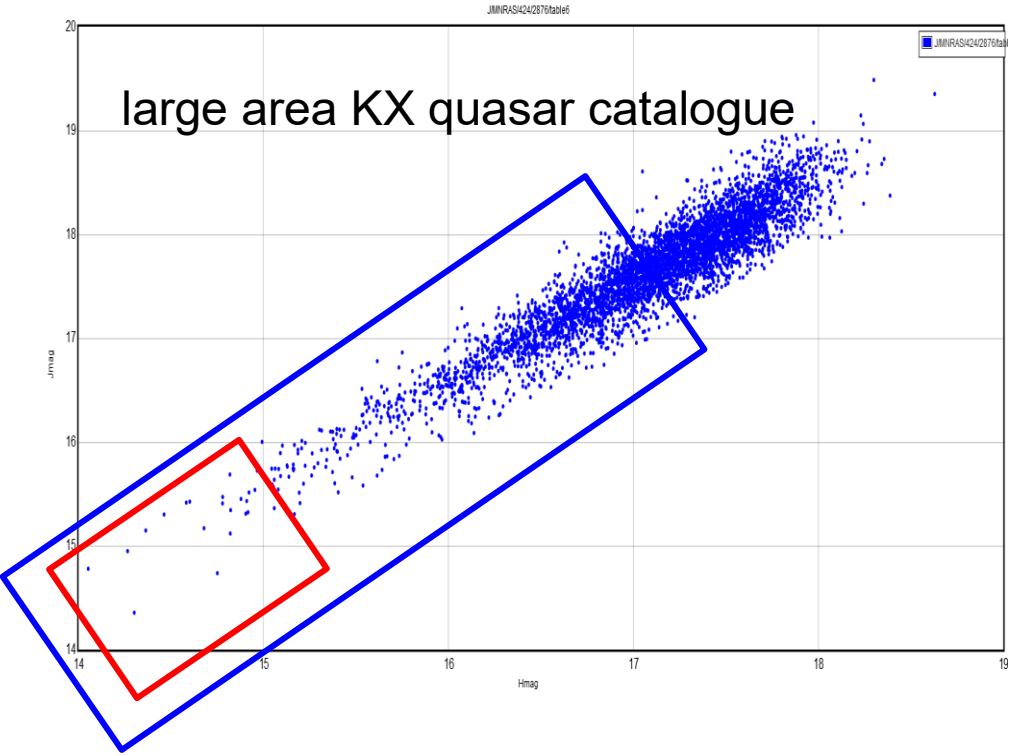
Analytical model

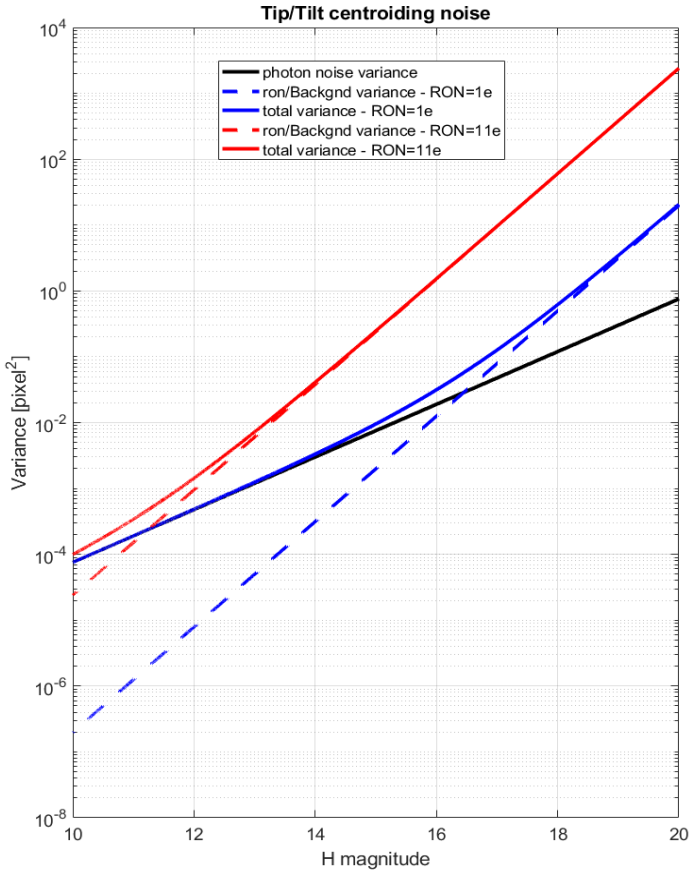


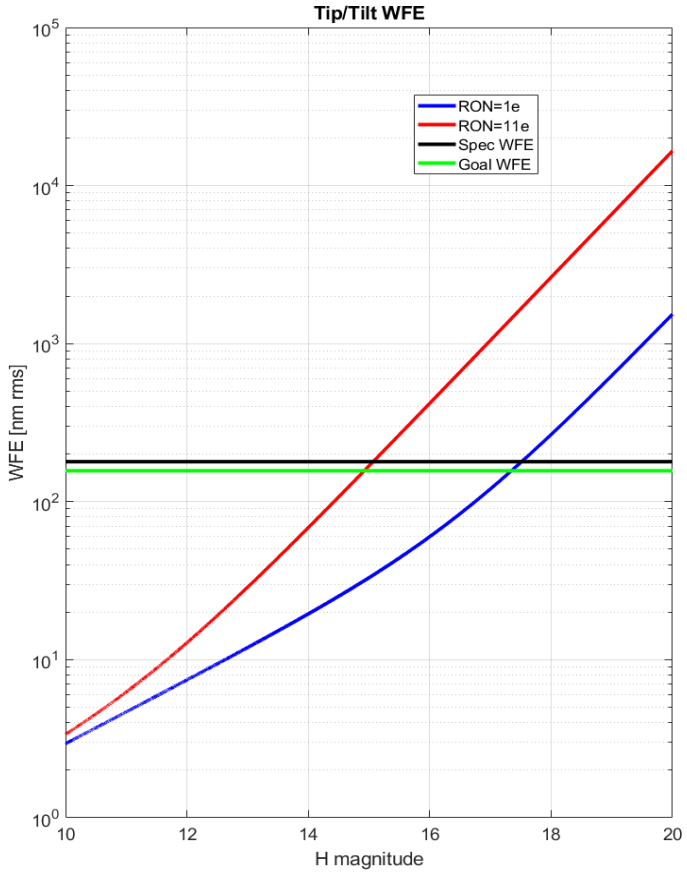


Expected performance gain in 2x2 with 1e- RON

- Analytical simulations show that:
  - + 2 mag can be gained
  - Difficult to go deeper than magH=17

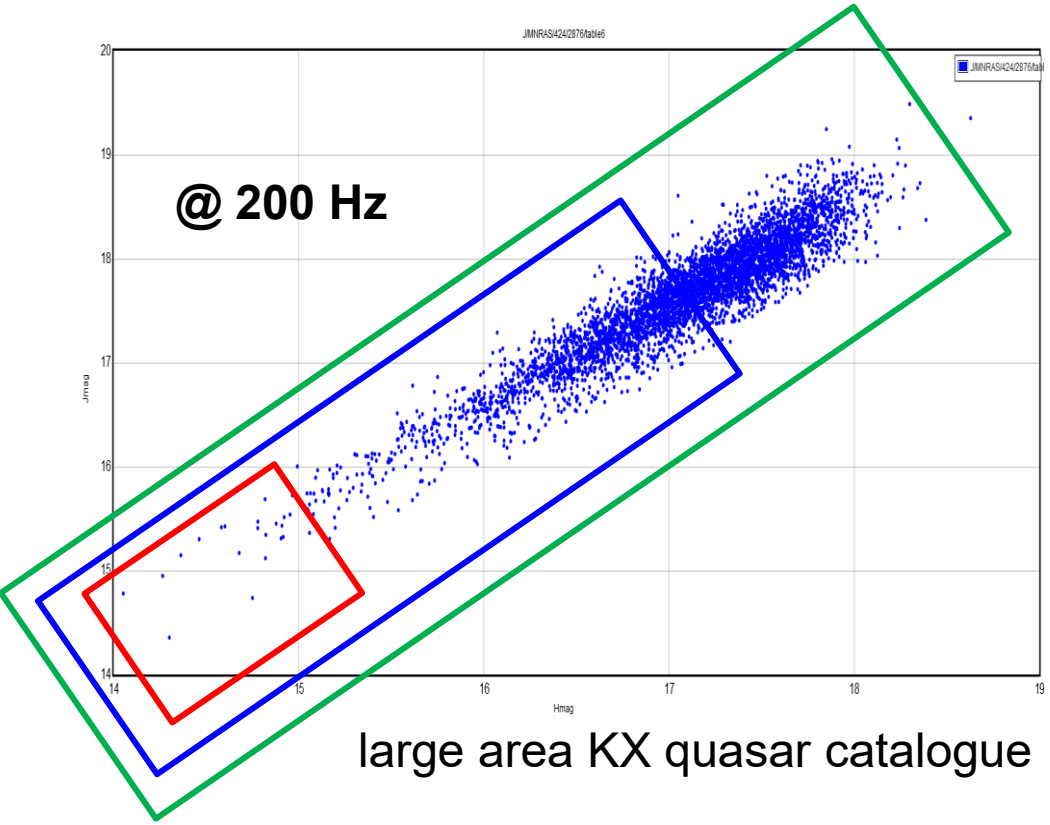




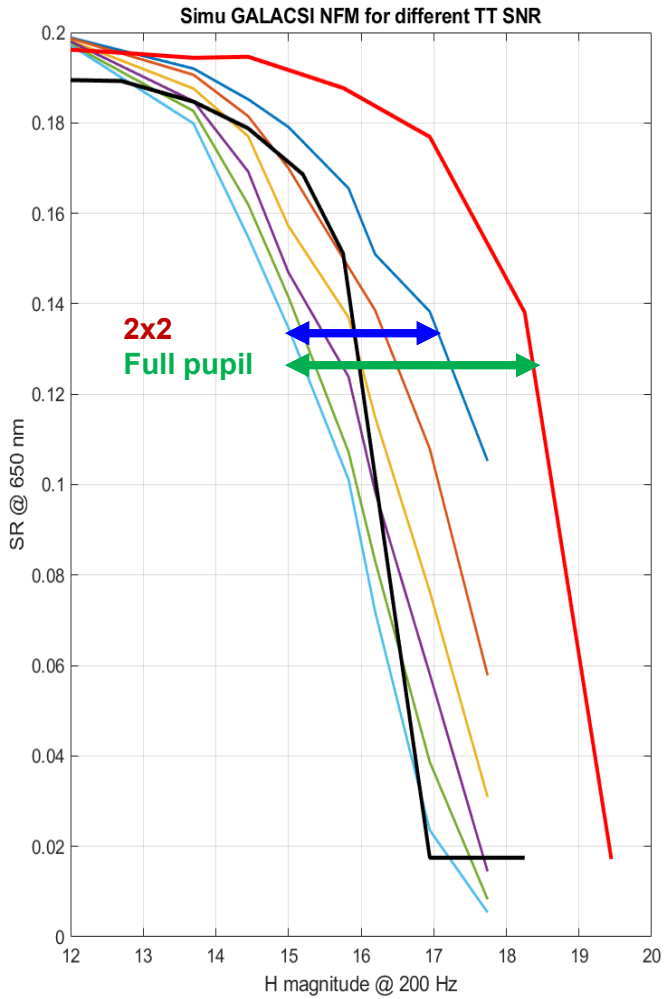


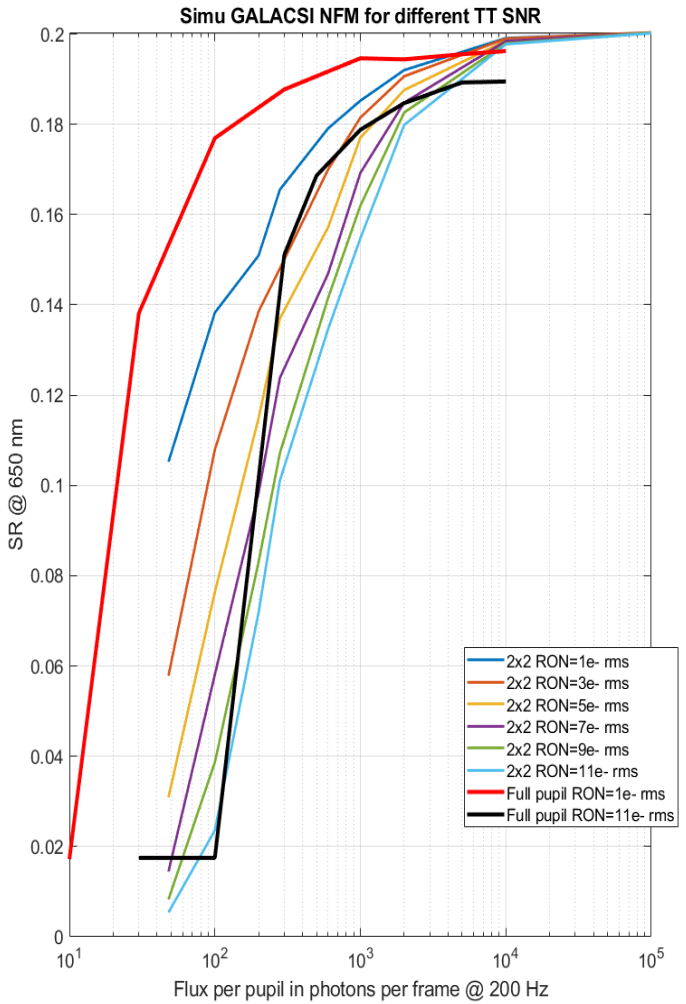
End-to-end: deep mode with full pupil

- E2E model confirms potential gain
- Full pupil mode seems very attractive
- **~ all QSO can be observed**

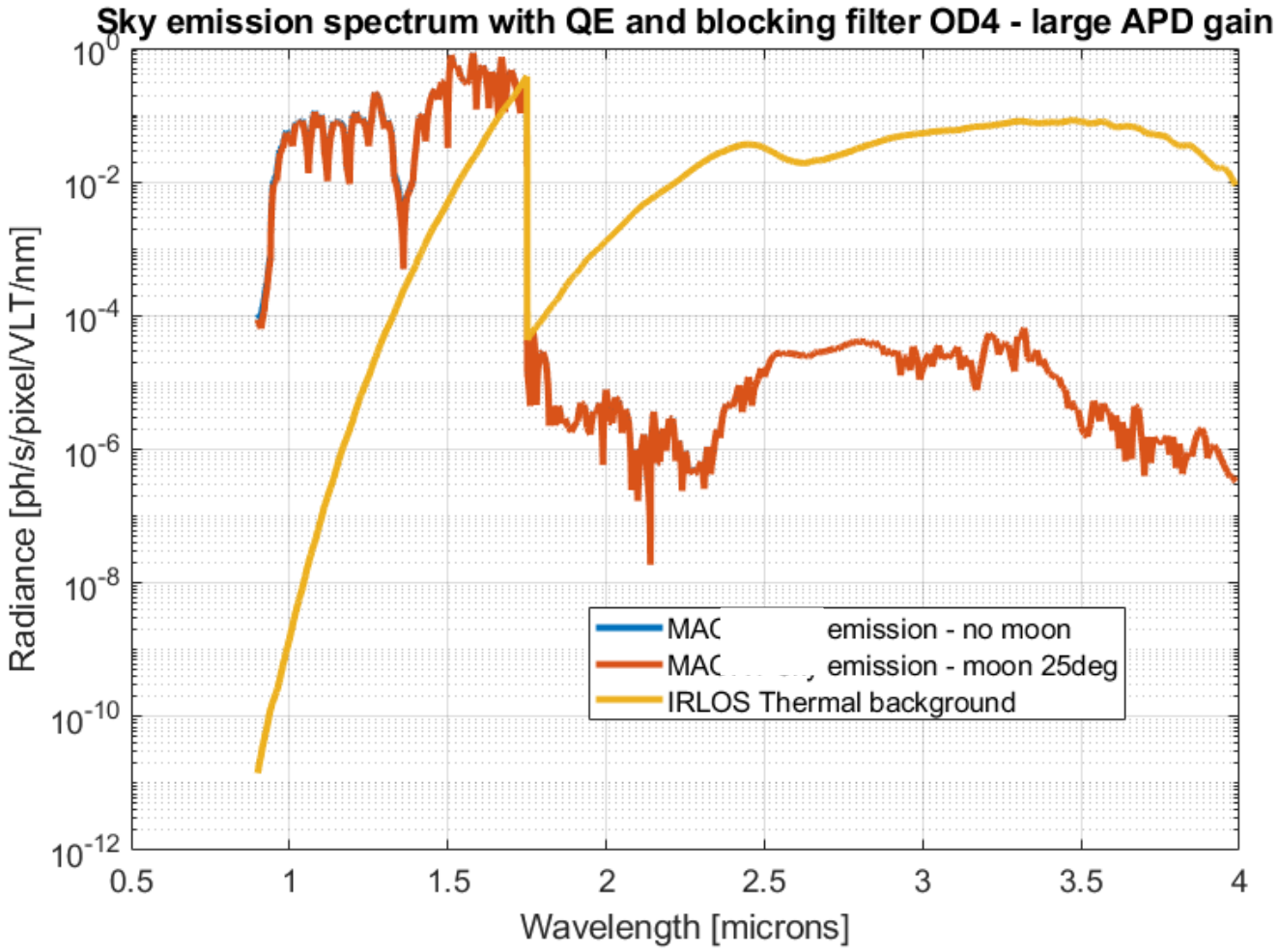


large area KX quasar catalogue

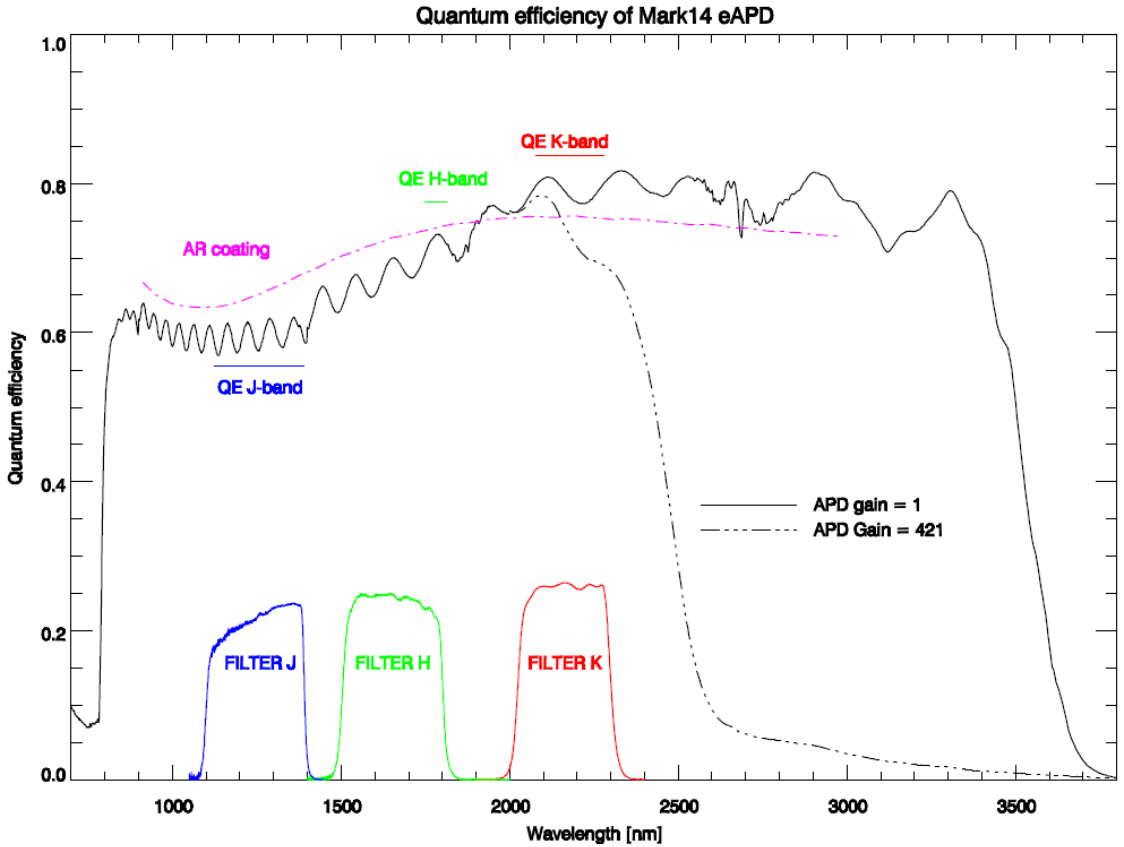




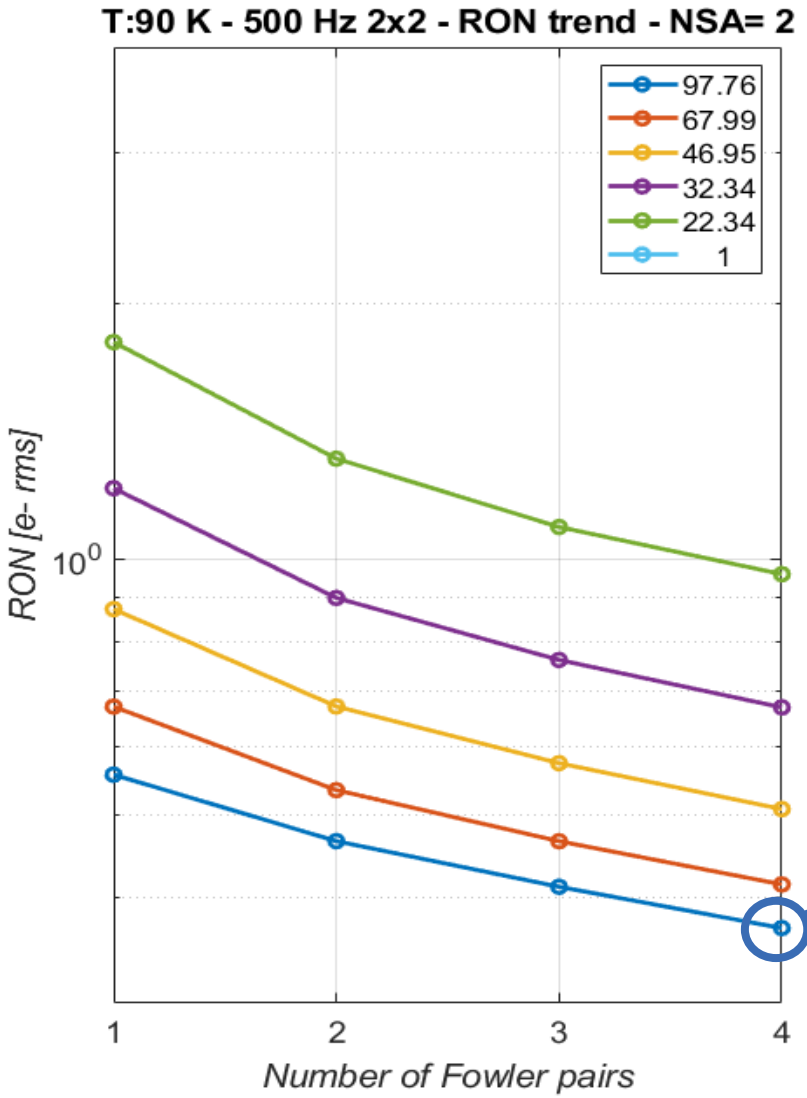
Sky + thermal background noise

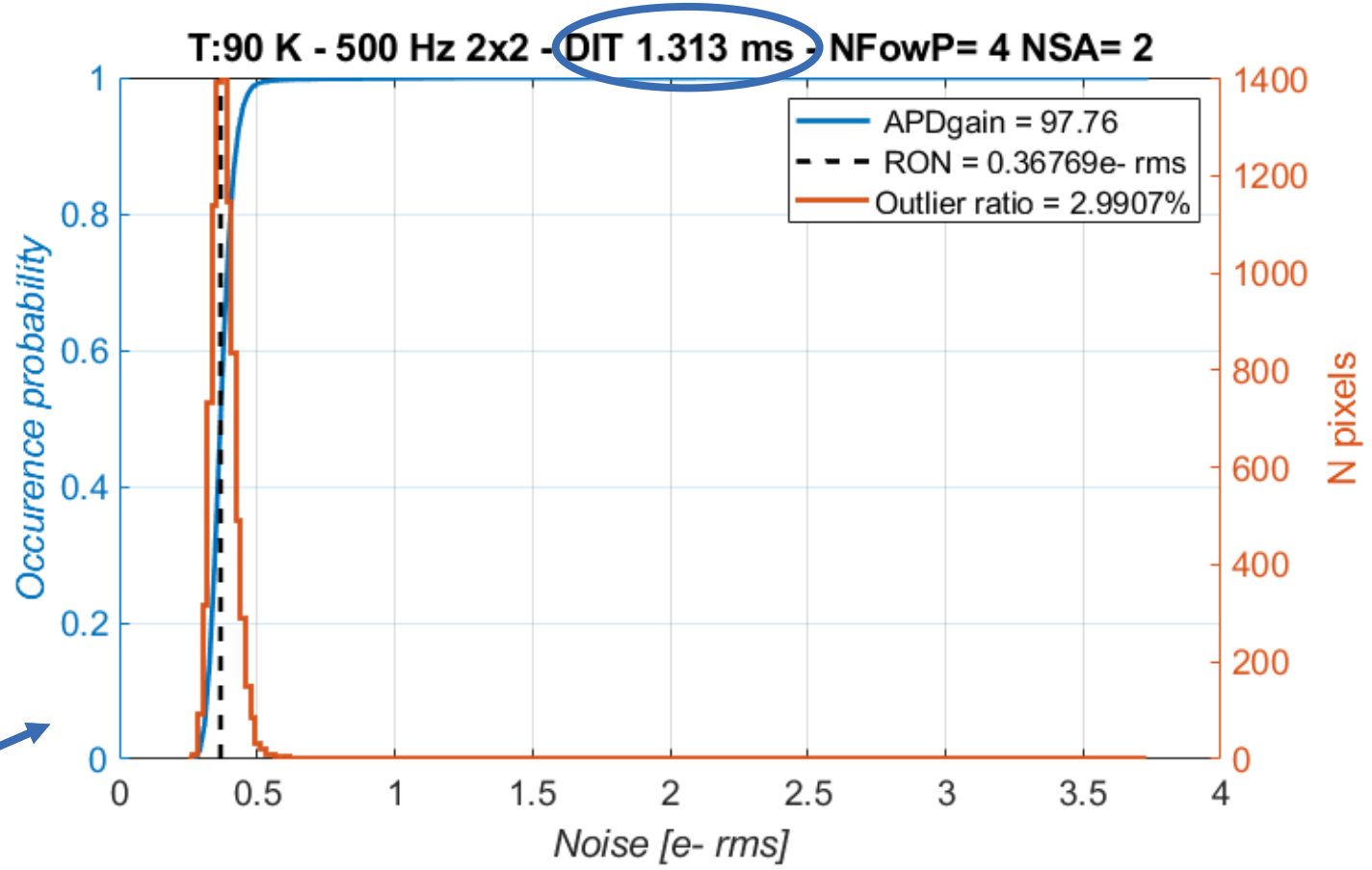


- Balanced budget for unresolved targets
  - Dark < 50 e-/s/pix
  - Thermal < 70 e-/s/pix
  - 14e-/s/pix <Sky<140 e-/s/pix vs. plate scale



Read-out optimization: low RON !





Read-out optimization: SNR matters !

FOWLER SAMPLING

SIGNAL:

$$S = F \cdot T_{eff} = F \cdot \left(T_{\text{int}} - N_p \cdot dt\right)$$

NOISE

RON LIMITED

$$\sigma_S^2 = \frac{2 \cdot \sigma_{ron}^2}{N_p}$$

POISSON LIMITED

$$\sigma_S^2 = F \cdot T_{\text{int}} + F \cdot dt \left(\frac{1}{3N_p} - \frac{4N_p}{3}\right)$$

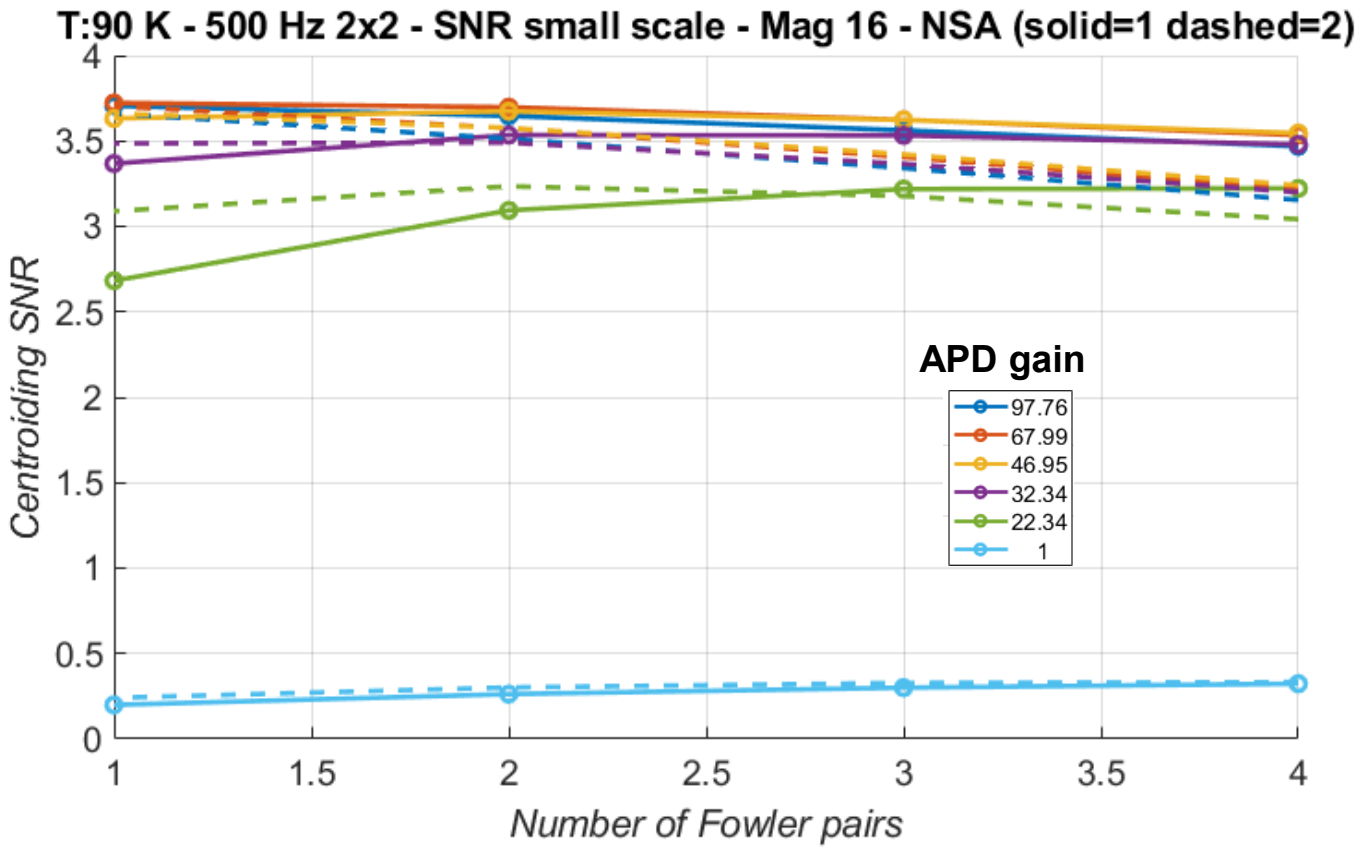
SIGNAL TO NOISE RATIO

$$SNR_{Fowler,RO} = SNR_{DCS}\sqrt{N_p}\left(1 - N_p \frac{dt}{T_{\text{int}}}\right)$$

$$SNR_{Fowler,Pois.} = SNR_{dcs,Pois.} \frac{1 - N_p \frac{dt}{T_{\text{int}}}}{\sqrt{1 + \frac{dt}{3T_{\text{int}}}\left(\frac{1}{N_p} - 4N_p\right)}}$$

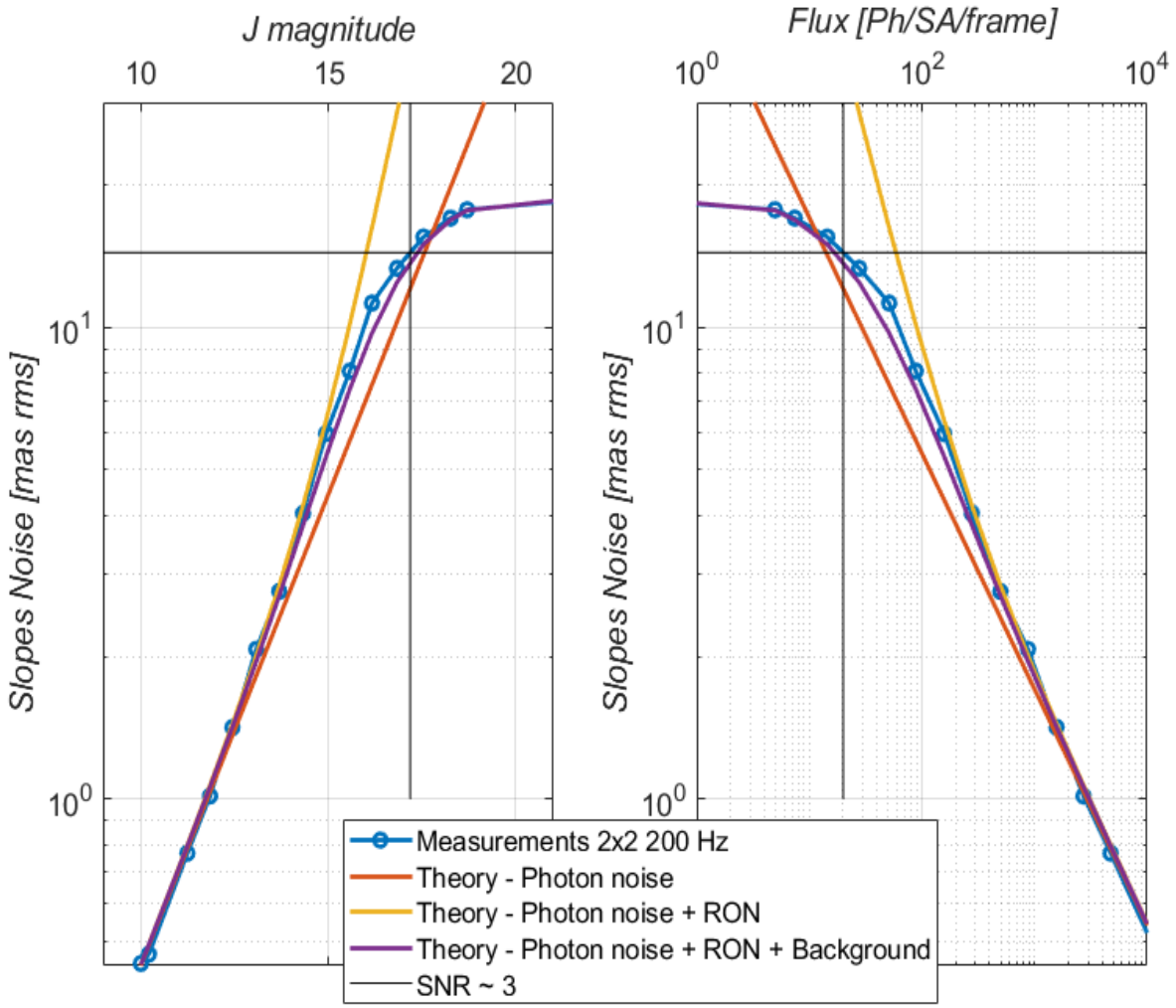
TOTAL SIGNAL TO NOISE RATIO

$$SNR_{Fowler} = \frac{F \cdot \left(T_{\text{int}} - n_p dt\right)}{\left[\frac{2 \cdot \sigma_{ron}^2}{n_p} + F \cdot T_{\text{int}} + F \cdot dt \left(\frac{1}{3n_p} - \frac{4n_p}{3}\right)\right]^{1/2}}$$

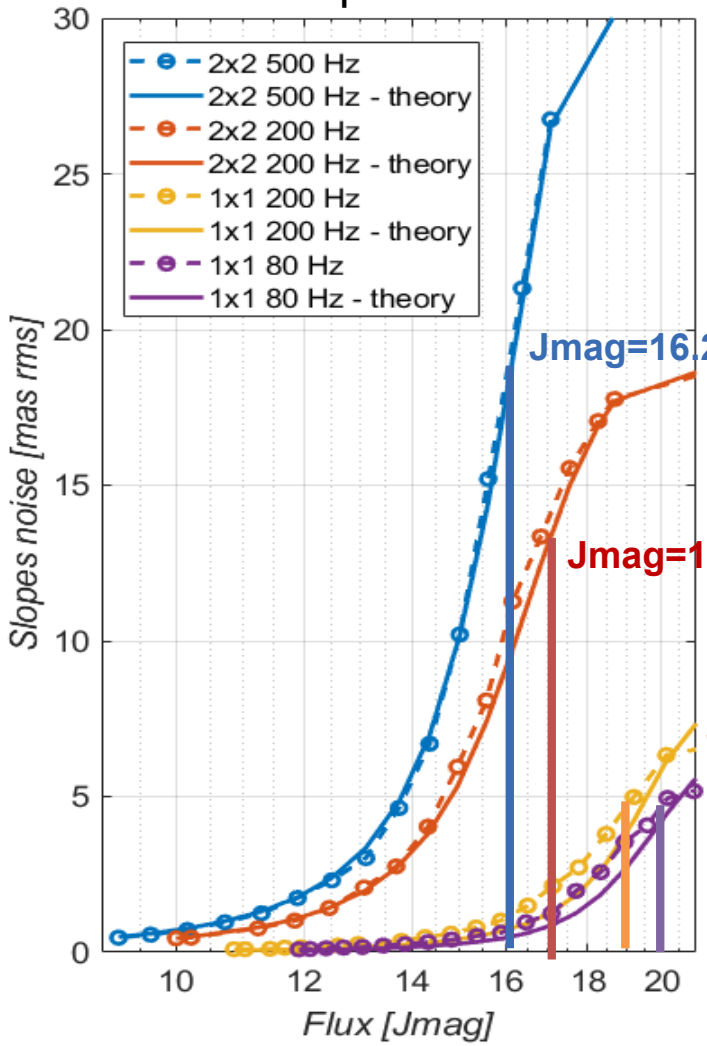


SNR including <u>background</u> and <u>excess noise</u> factor

Baseline limiting magnitude at low flux



Classical CoG 8x8 pixels – no noise propagation coefficient



Jmag=16.2 – High performance mode

Jmag=17.2 – covering a 1 mag gap

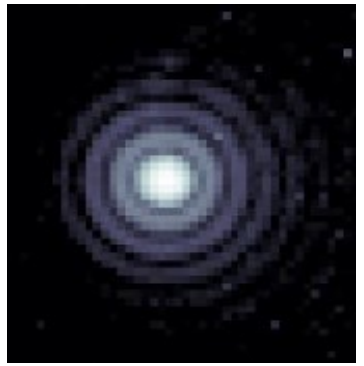
Jmag=18.7 – Deep mode

Jmag=19.7
High sky coverage mode

LTAO Upgrade Project status

- MUSE LTAO routinely used: NFM OBs > 30% of AO scientific Obs
- MAIT phase completed and concluded by the on-going PAE review
  - System is now fully baselined, configured and tested in all modes
  - High performance mode for targets with Jmag < 16
  - Full pupil mode will address fainter targets Jmag > 16 up to 18.5 +

12.3 mas plate scale
High SR > 80 % in H



- On-going: work on focal plane WFSing in simulation and lab
  - With new RTC cluster feature for average frames processing
  - Truth sensing of low order modes: LIFT etc …
  - Application to Low Wind Effect & possibly machine learning
- Next: AIV & commissioning and PAC in 2021 (if COVID-19 allows…)

Thank you for your attention! Any question?