Observing with DAG: Performance of Imaging (and Spectroscopy)

Adaptive Optics - *what else ?*

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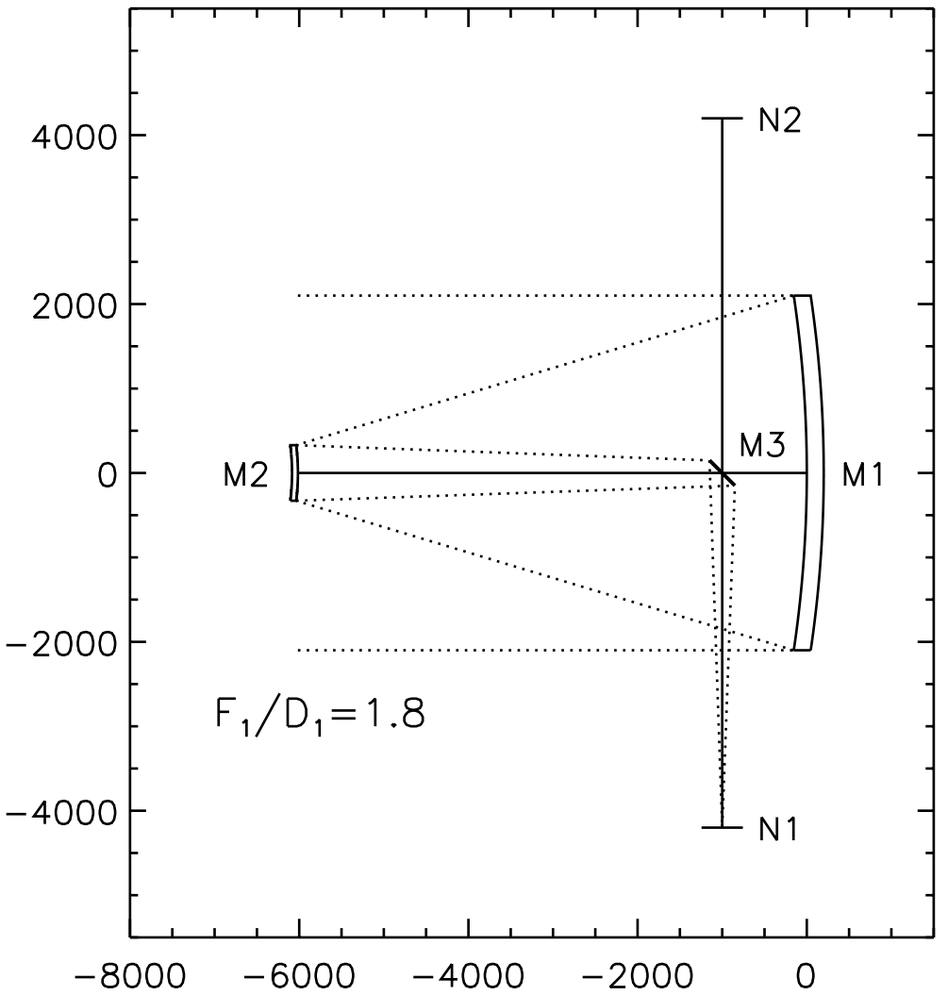
outline

- DAG telescope optics
- a bit of adaptive optics (AO)
- performance in wide & narrow field AO
- adaptive optics development plan for DAG

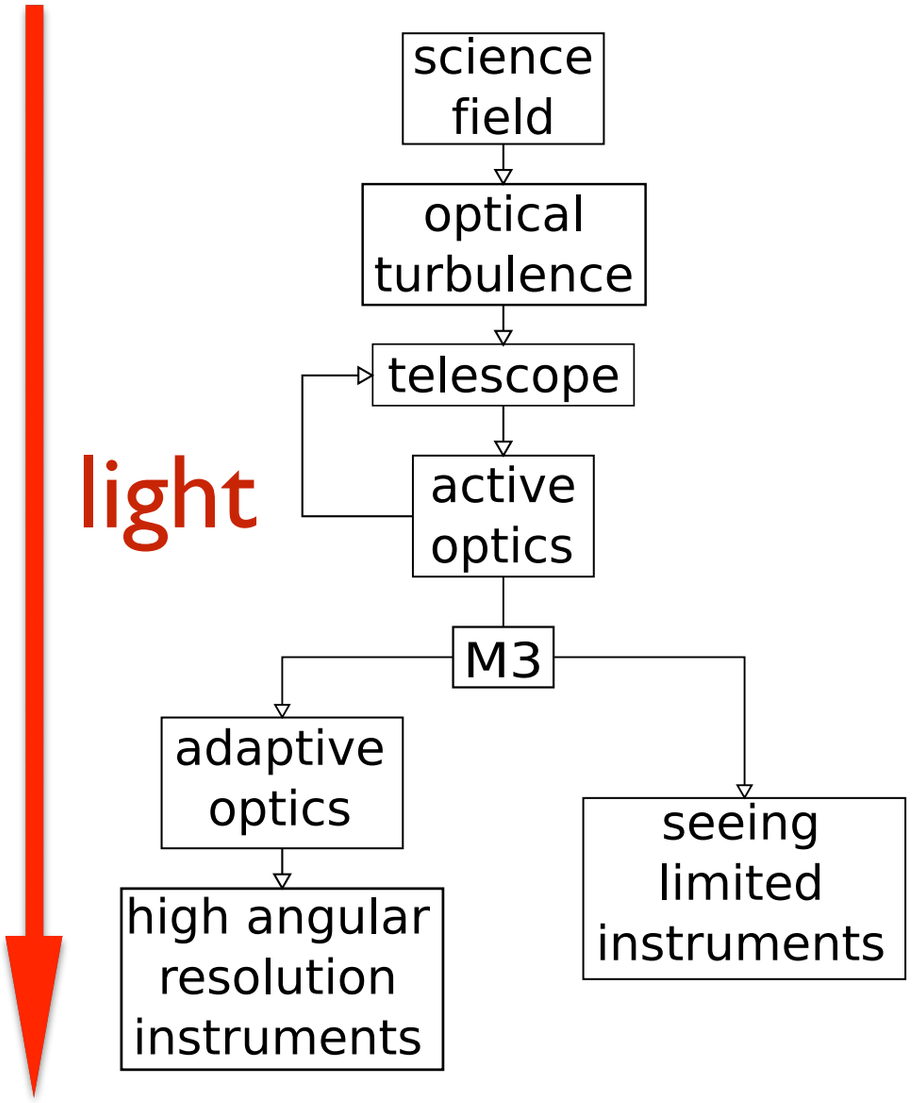
telescope optics

- 4 m in diameter, 56 m focal length
- diffraction limited
- 2 Nasmyth platforms
  - N-1 adaptive optics high resolution
  - N-2 seeing limited mode observations
- there can be 6 instruments (3 / platform)
- why Nasmyth only ?
  - main source of bad AO performance comes from vibrations in telescope and instrument
  - stable focal plane = minimize vibrations
- optical quality requirement set to **very high standard,** much higher than previous 4 m class telescopes
- if DAG 4-m mirror was Earth diameter, errors height = 20 cm



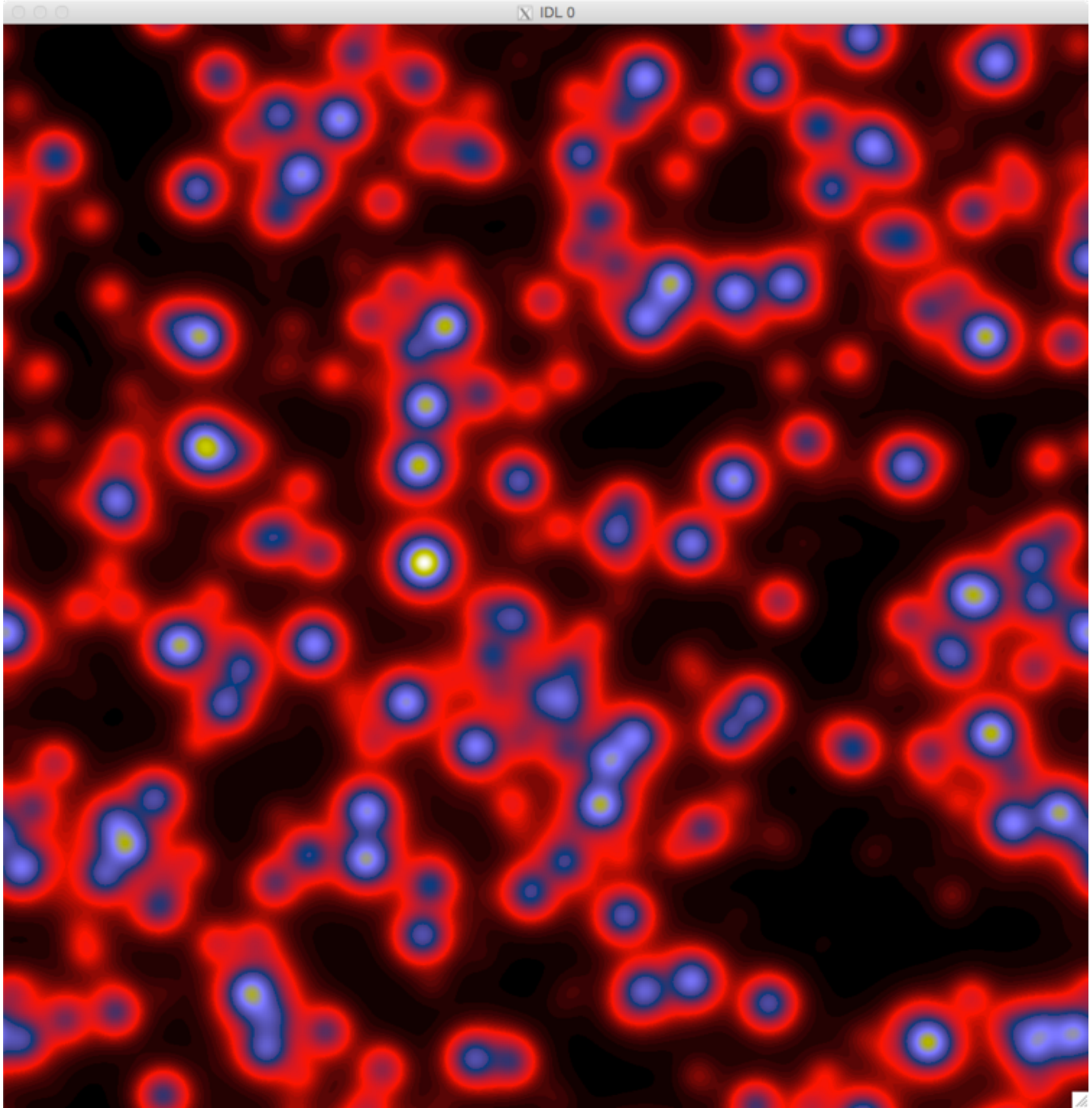
from the stars to the focal plane

- telescope optics is defined by
  - field of view (FoV)
  - image quality inside FoV
- FoV set by
  - off-axis aberrations
  - mechanical limits
- image quality set by
  - atmospheric turbulence (no AO)
  - in AO mode : diffraction limit
  - defined by star image (Point Spread Function) PSF
  - narrow PSF => lots of details
  - wide PSF => blurred image



synthetic
star field
1000 stars
Δm=15
FoV 15”

DAG with
0.7” seeing



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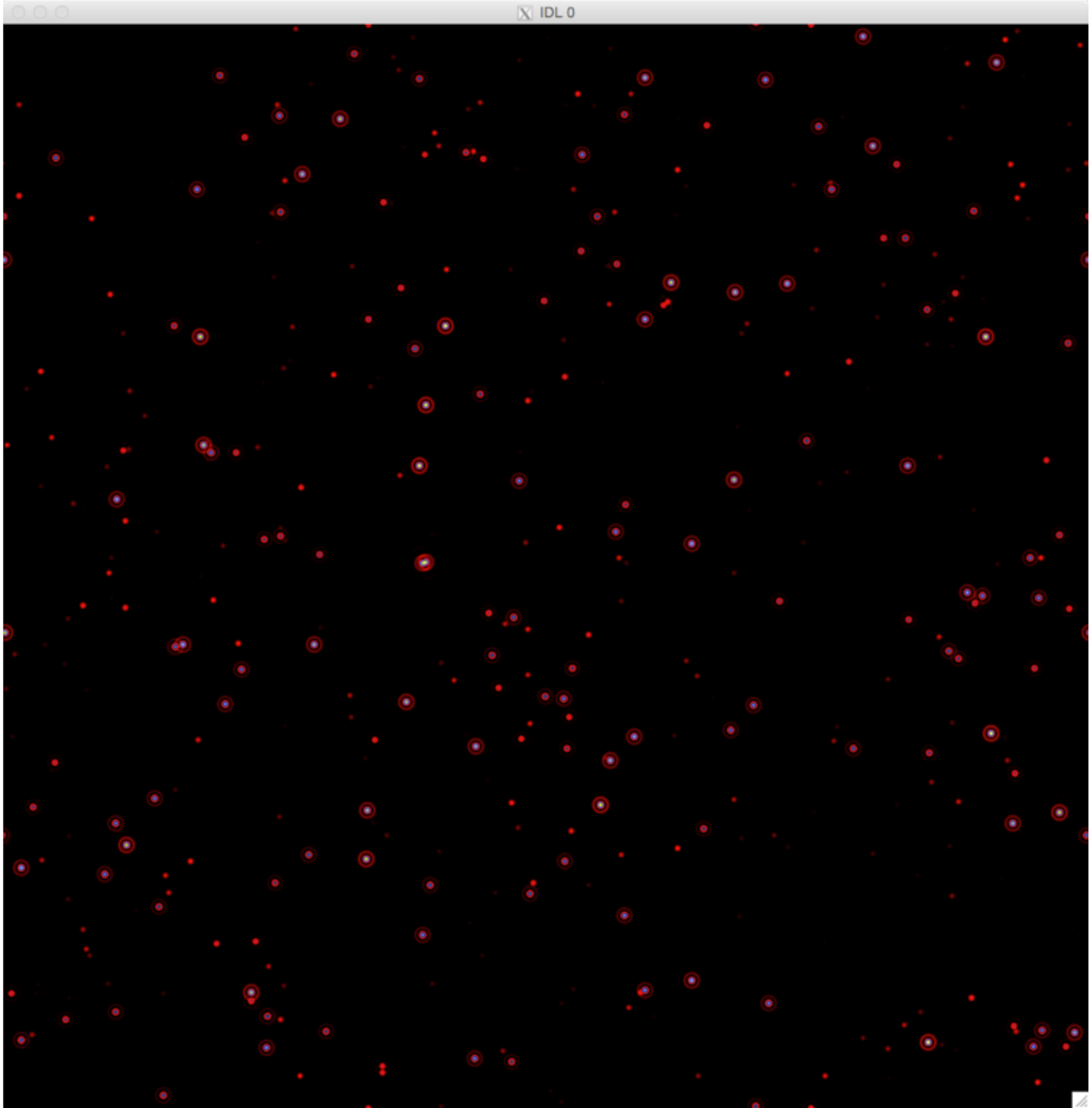
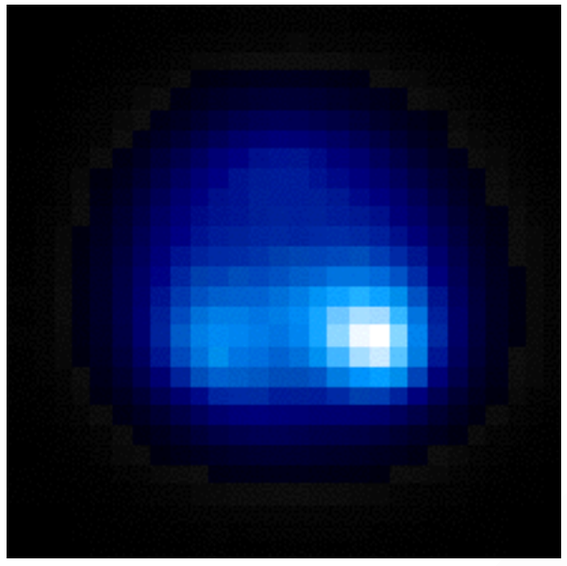
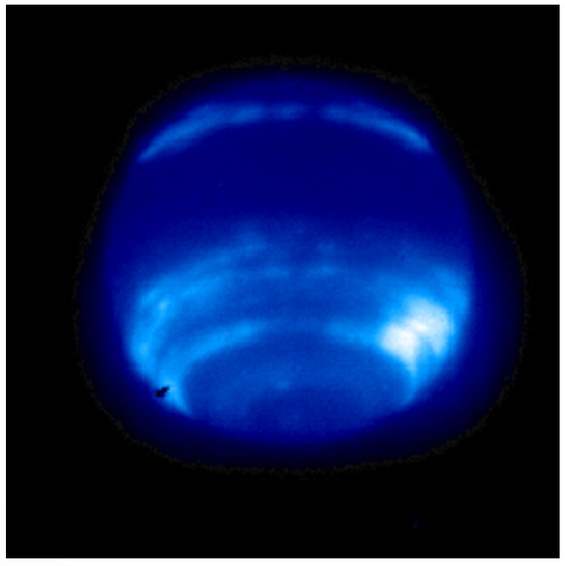


DAG without
turbulence

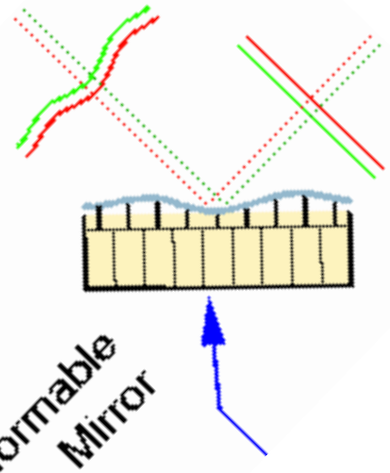
the magic of adaptive optics

- pick up bright stars in the FoV
- use these as measurement of optical turbulence
- send measurement to a deformable mirror
- correct the optical aberrations from the atmosphere
- do this 1000 times / second



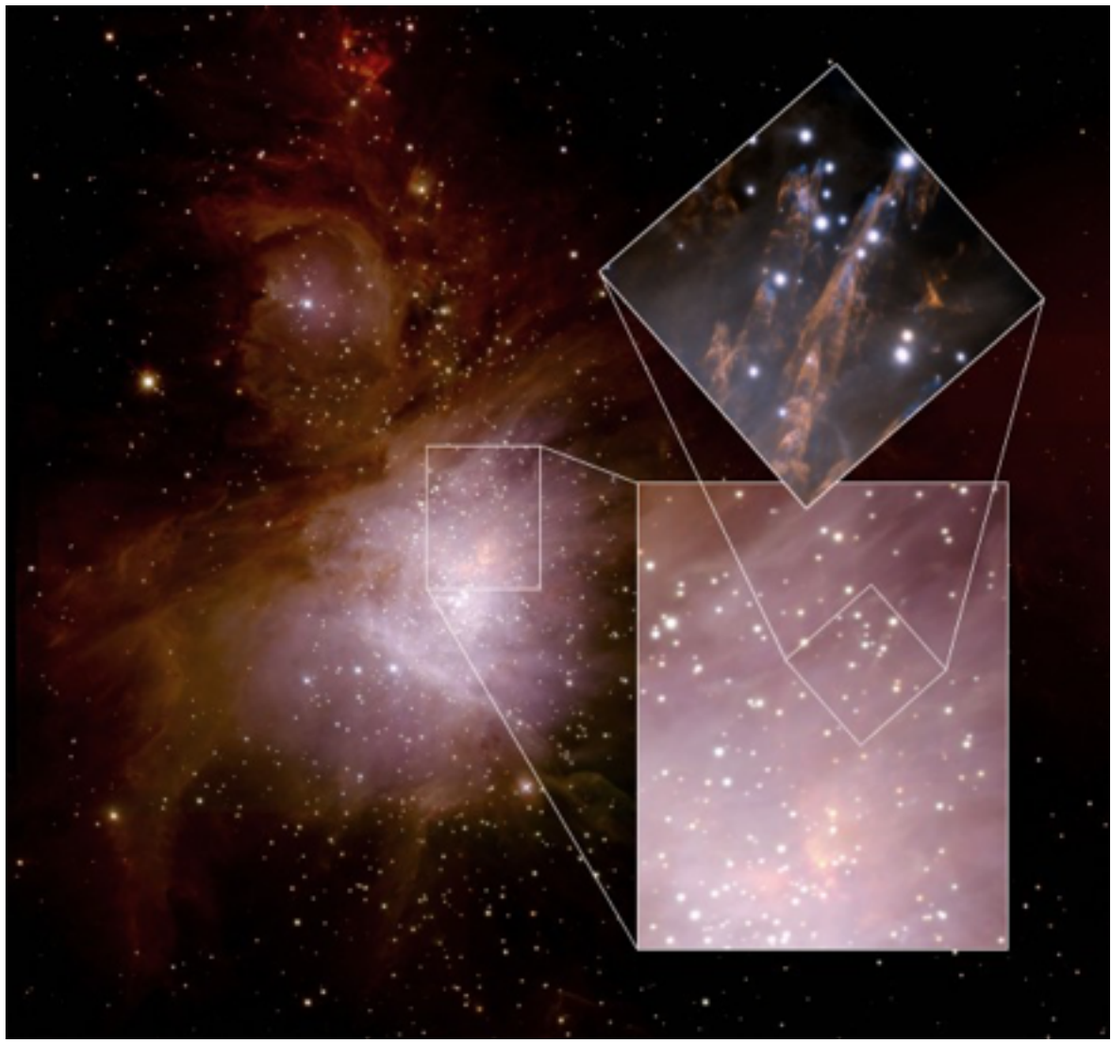


Neptune
Keck AO



- more guide stars, better correction over the field
- it actually requires several deformable mirrors
- add possibly artificial stars (laser guide stars) if not enough bright references
- this is called Multi-Conjugated AO (MCAO)

LGS at VLT



MCAO at GEMINI

adaptive optics modes

- depending on
  - the corrected FoV width
  - the quality of the correction
- AO comes in many modes
  - classical natural guide star AO (1st mode, 1989, France, Obs. Paris)
  - laser guide star AO (full sky coverage)
  - multi-conjugated AO (30” corrected FoV)
  - laser tomography AO (full sky, 10” FoV)
  - multi-object AO (correction in the direction of the objects-of-interest)
  - ground-layer only AO (very large FoV, improved seeing)
  - extreme AO - exoplanets (turbulence totally removed, FoV=0)
- see Dr Onur Keskin talk today

AO science today

- AO today is playing a major role in astrophysics research, everywhere
  - exoplanets science (Fomalhaut, Marois et al. Gemini AO system)
  - solar system studies (multiple asteroids, dwarf planets, … Trujillo et al.)
  - giant planets atmosphere (Neptune, Uranus, see Keck AO observations)
  - our Sun activity (1st MCAO system !)
  - galactic stars systems (clusters, stars forming regions, Bok's blobs in IR, T-Tauri, Eta Carina)
  - multiplicity detection (split down the false giant stars)
  - the Galactic Center dynamics and its BH, of course !!
  - extragalactic ? yes : clusters (MUSE IFS instrument at ESO AO facility, Bacon et al.)

DAG-AO development plan

- DAG diameter large enough to do same science than other international modern observatories
- therefore, it is not only useful, but mandatory to have an AO mode at DAG to make the maximum of the money spent to build this telescope
- because large telescope & AO both new for Turkey
- because we need to train the future Turkish AO scientists and engineers
- we will use a step-by-step approach
- but have **bold** and **ambitious** objectives on the long term, to attract the interest of the international AO community

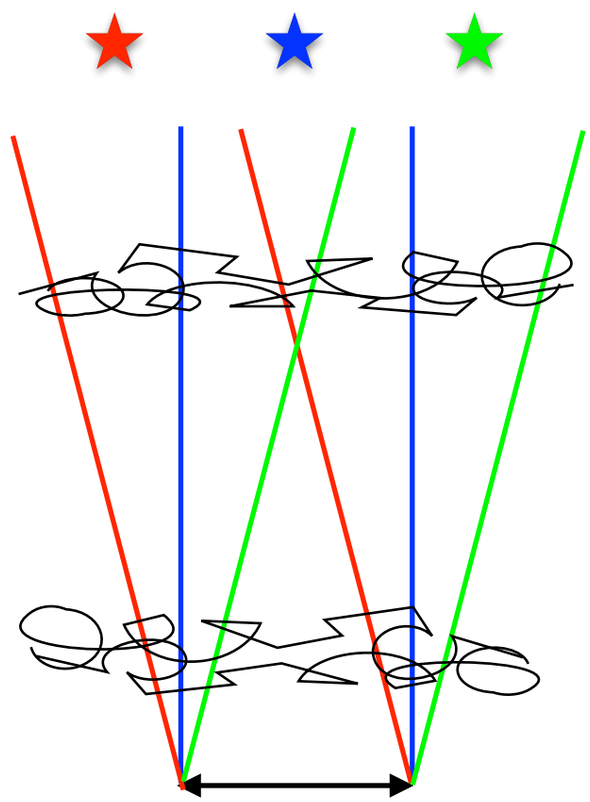
DAG-AO development plan

DAG without AO = a Ferrari without an engine

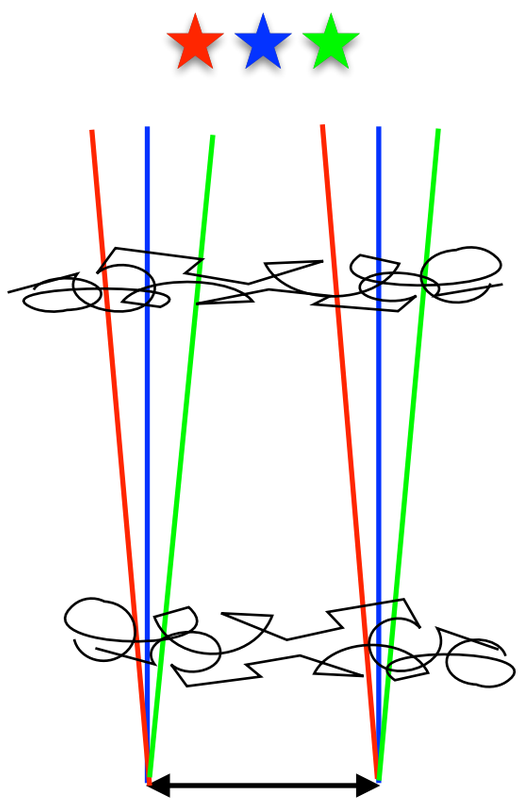
DAG-AO development plan

- 2019 (1st light) : a classical on-axis AO system, using natural guide stars
  - corrected FoV 10", diffraction limited
  - solar system, stars forming regions, multiple stars, galactic clusters, AGN …
- in parallel : develop a multi guide-stars approach for wide field AO correction
  - 5' to 10', improved seeing observations (0.2")
  - ready for 1st light for an IFS (surveys etc.) 4 years later ?
  - updated AO system : 1 GS = classical AO, >1 GS = wide field AO
- we will propose a versatile AO system for DAG, to serve both
  - the narrow field high angular resolution community
  - the wide field improved seeing (survey) community
- later : depends on astronomers' interests

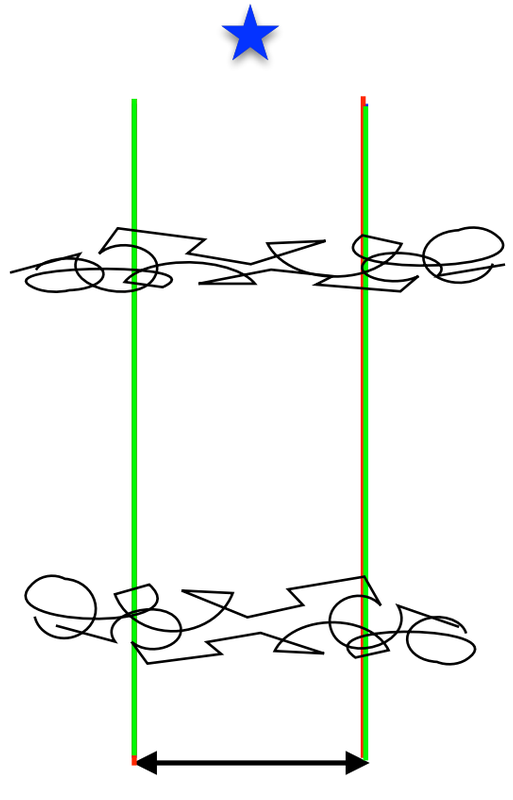
a versatile AO system for DAG - wide to narrow FoV



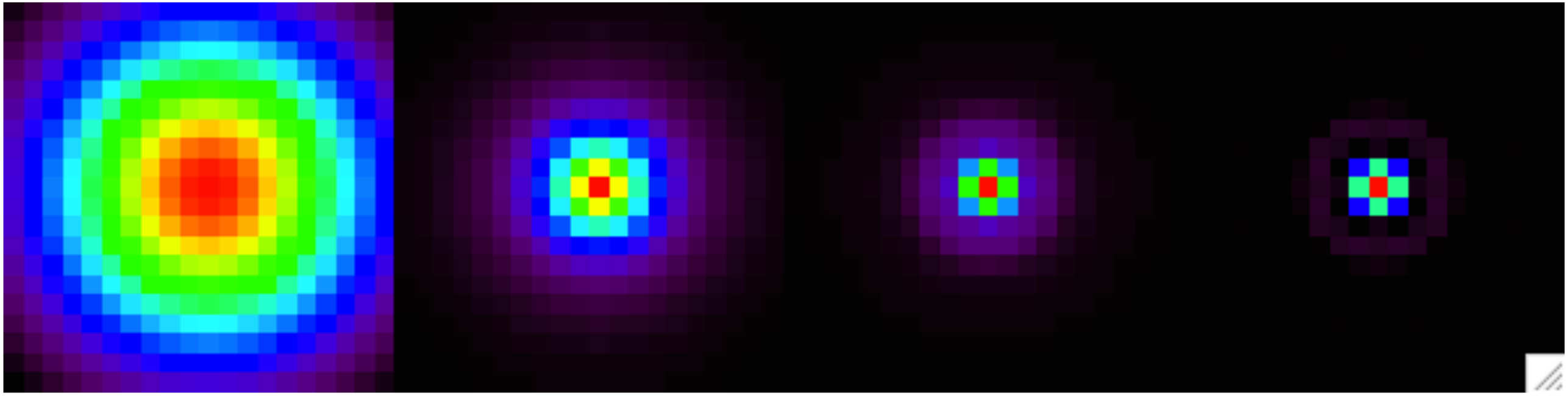
wide FoV
improved seeing



medium FoV
better PSF



narrow FoV
best PSF



a perfect candidate for wide AO mode

- guide star nearby
- Lynx GC (NGC 2419)
- 5’ diameter

simulation of an AO observation with DAG

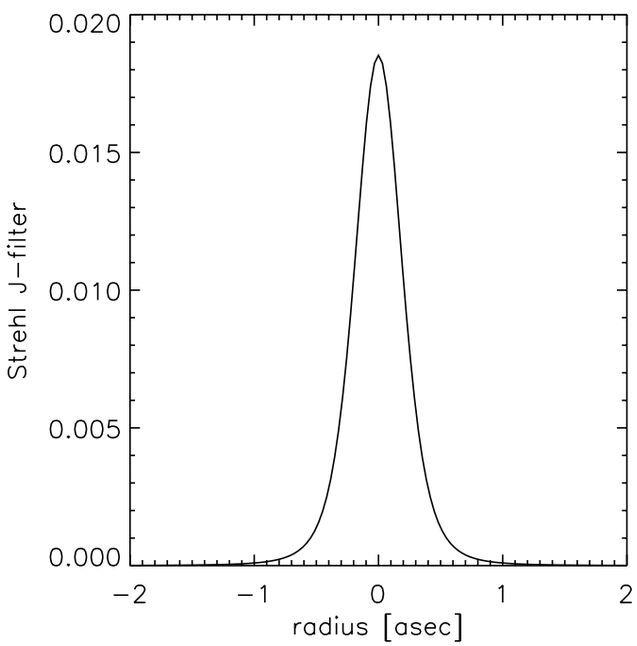
imaging a globular cluster

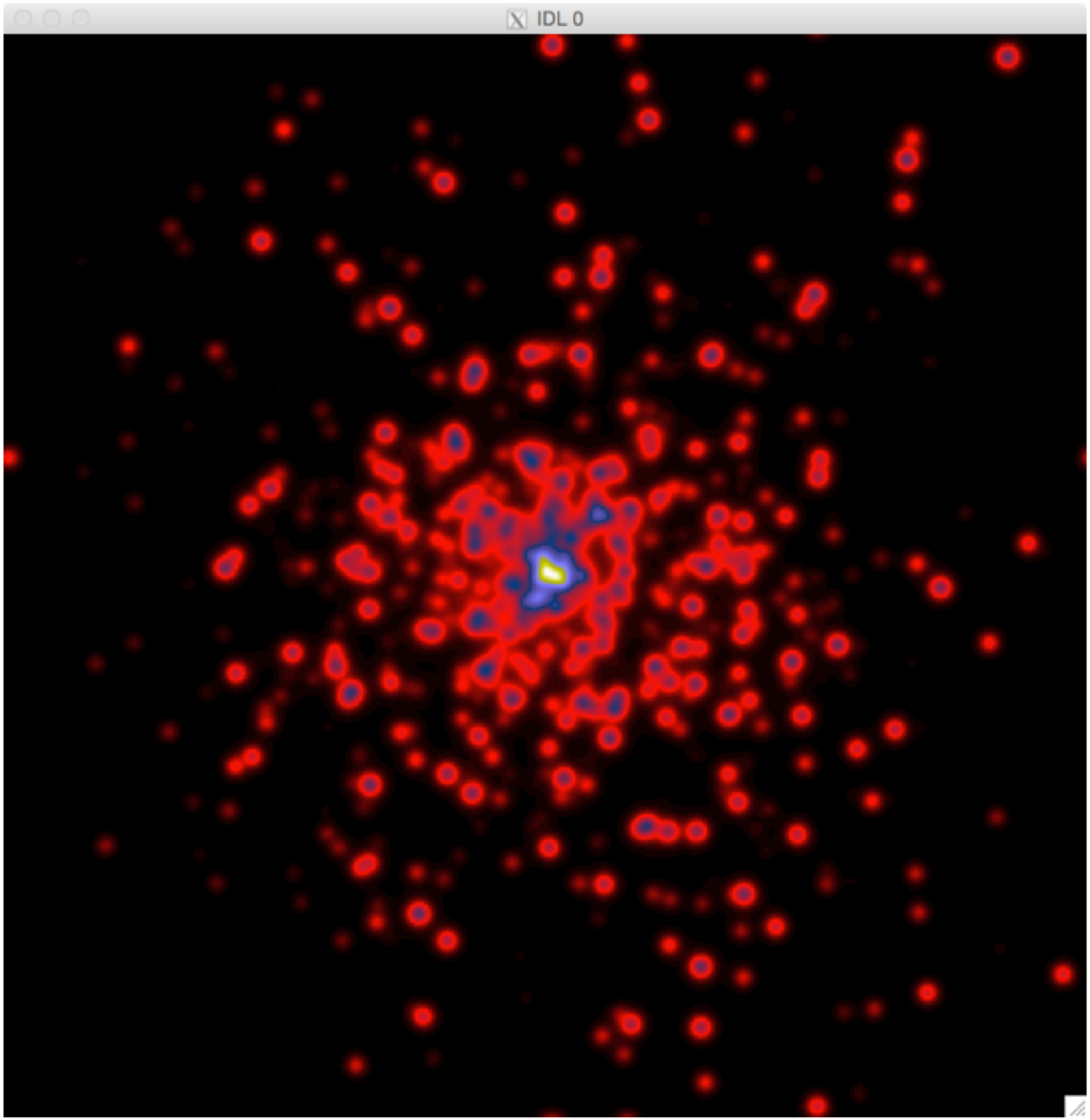
AO run simulation : a globular cluster

- synthetic GC
- surface density profile same as Lynx cluster
- 30” in diameter
- 3000 stars
- $\Delta m = 15$
- J-filter observations

seeing limited 0.7” (good conditions)

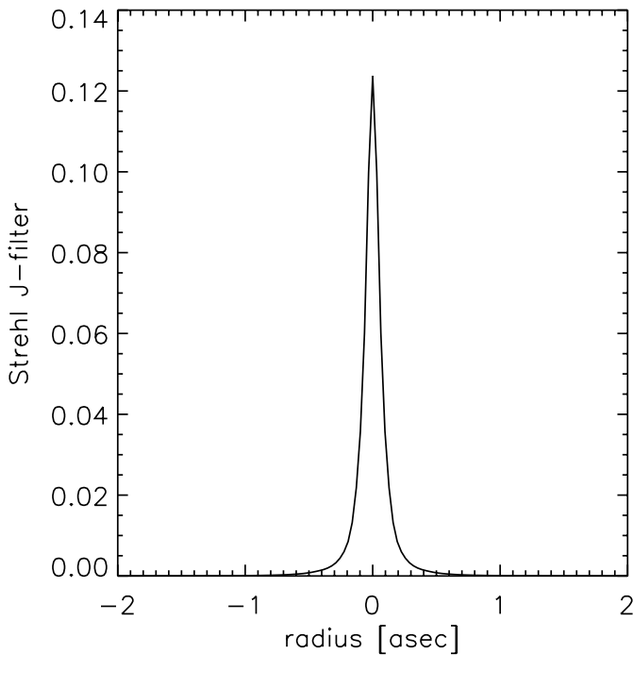
30”

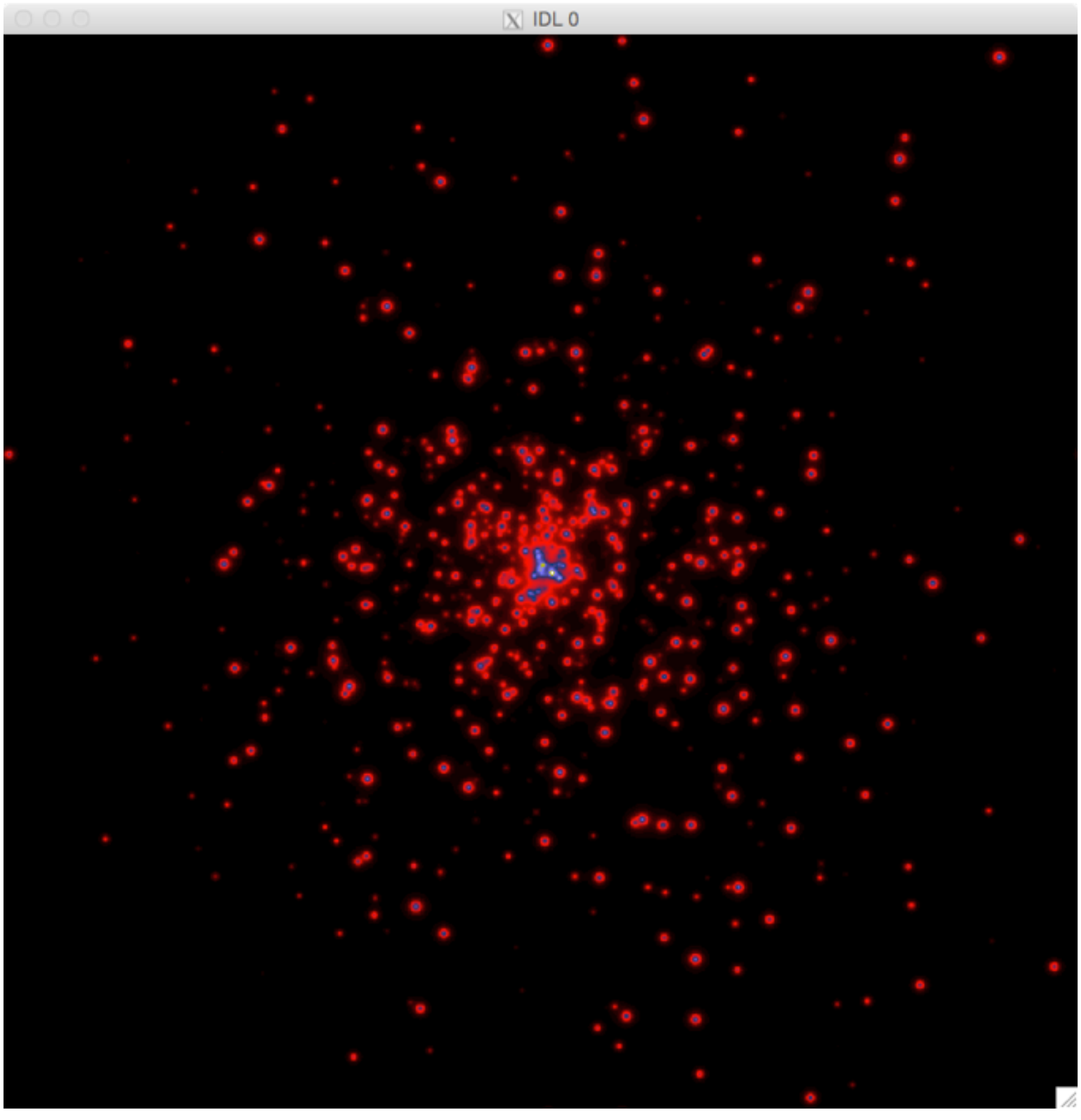




<u>wide</u> field
mode
2’ NGS
constellation

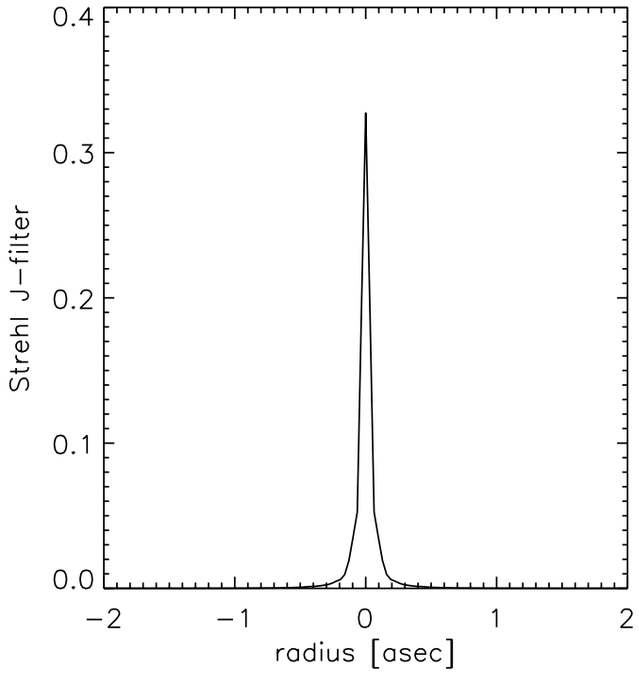
30”

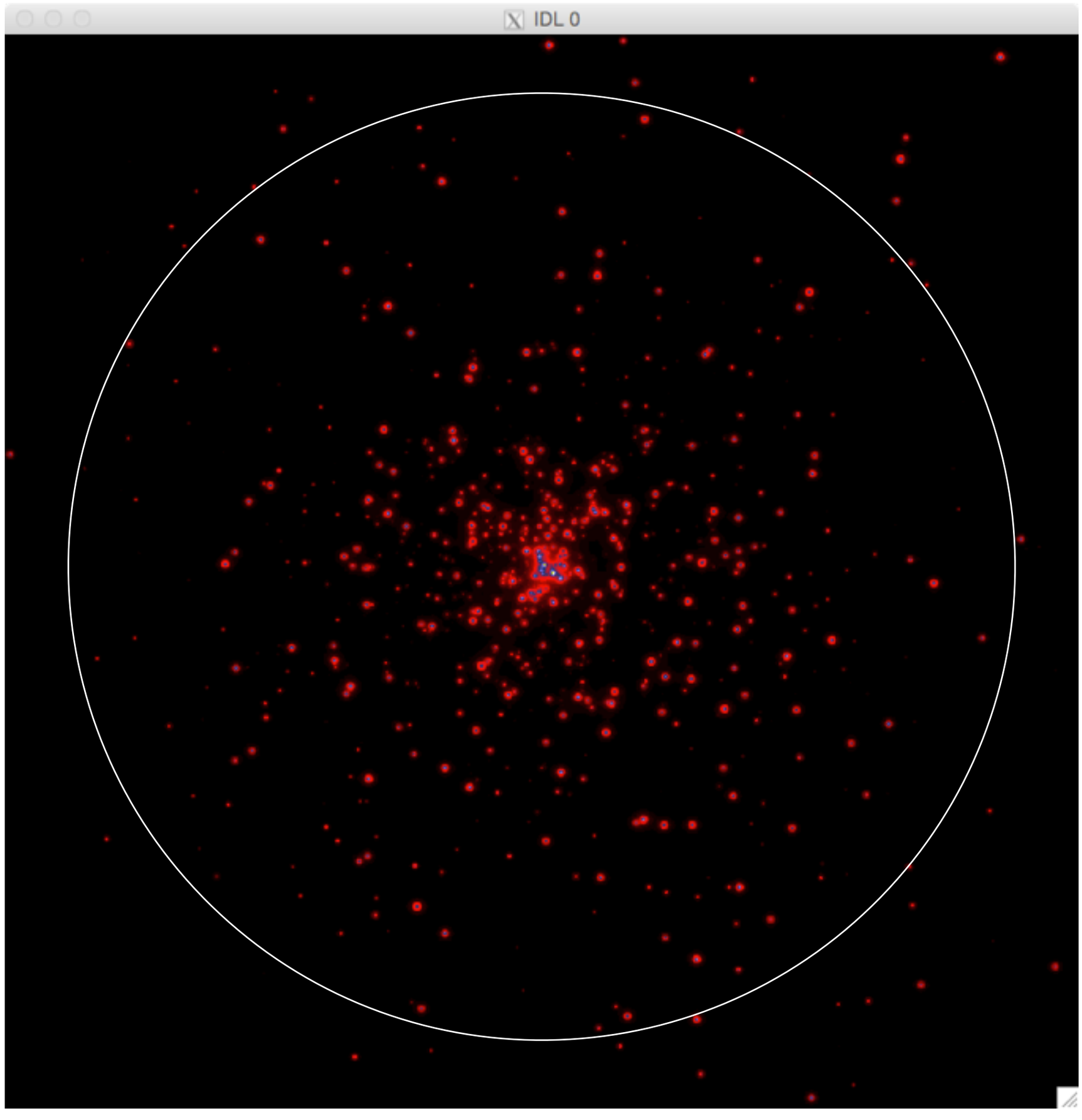




<u>medium</u> field
mode
40” NGS
constellation

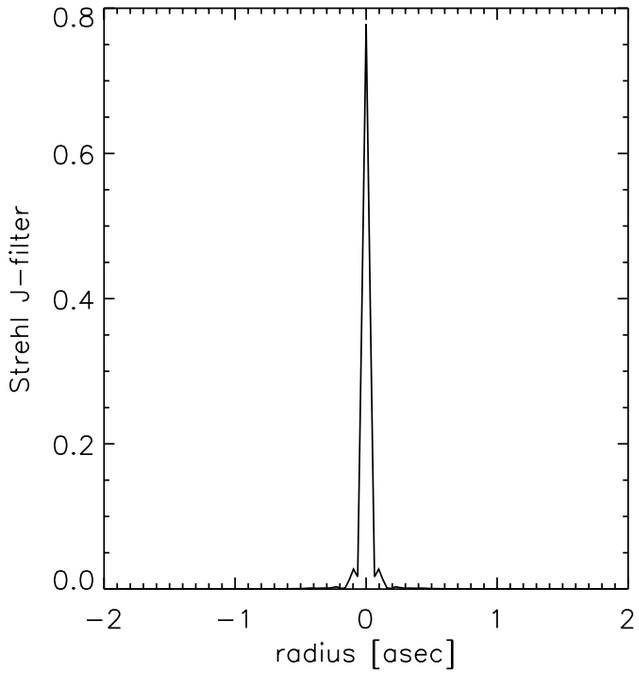
30”

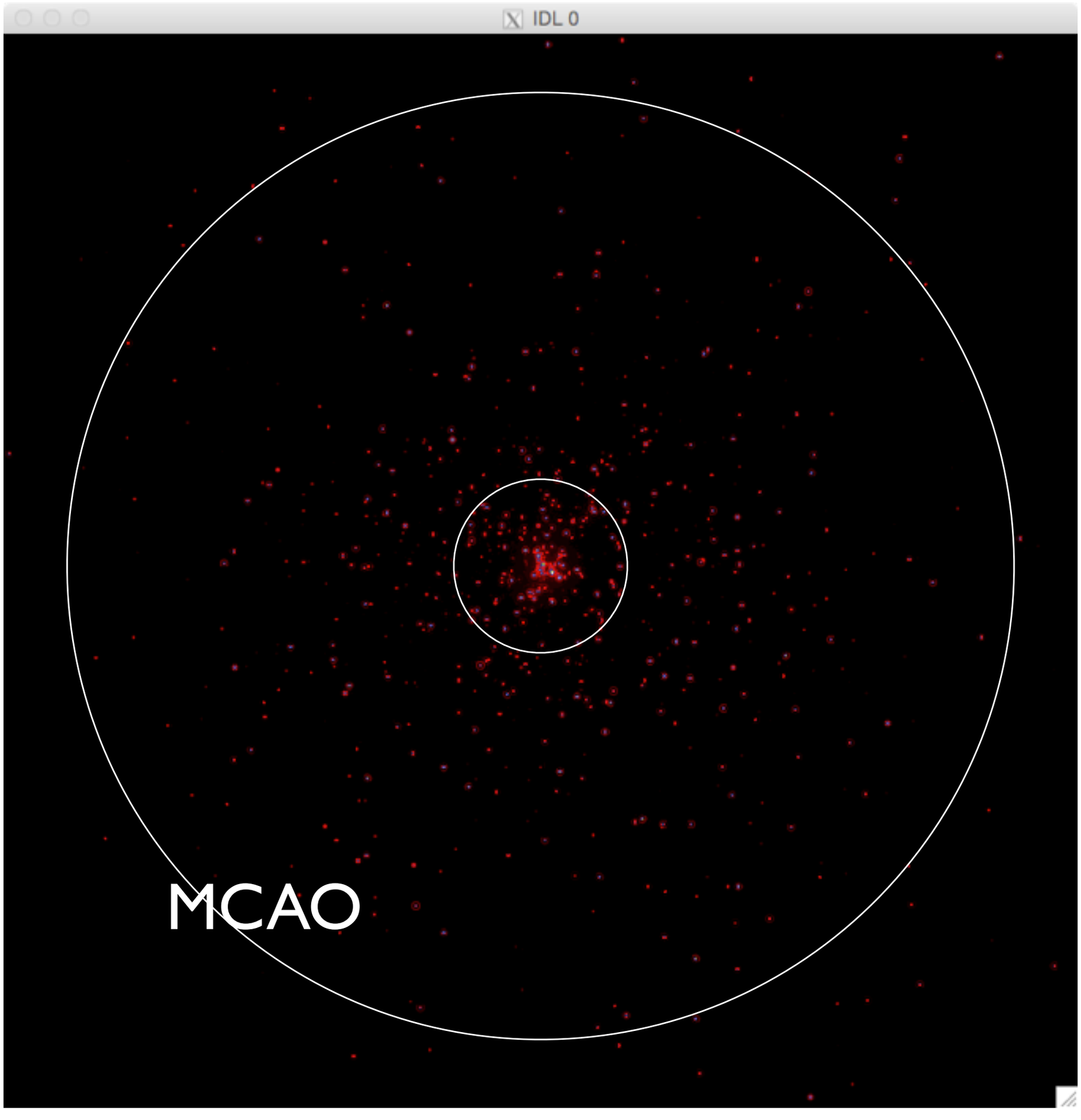




narrow field
mode
on-axis NGS

30”

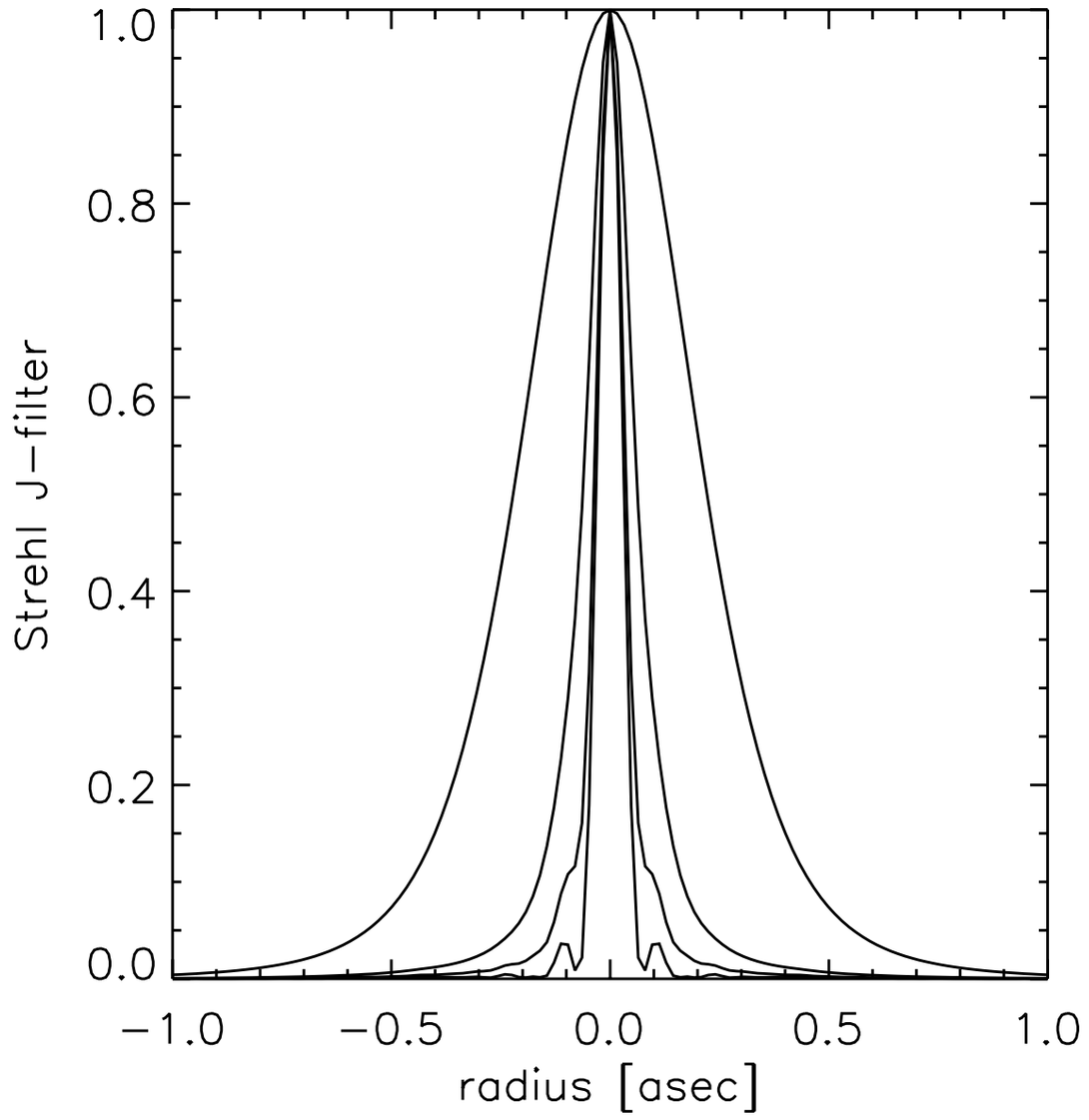




- obviously more stars are detected, better C-M diagrams over much longer distances
- astrophysics at higher-z, IMF etc.
- and yes, MORE useful photons because confusion is less and SNR higher
- so even single object observations (astrometry & photometry) is improved
- the actual gain depends on the residual of the AO correction
- PSF variable in time & across FoV : a difficulty

spectroscopy

- narrower PSF => narrower lines
- encircled energy diameter decreased



—-	diameter 50% EE	diameter 80% EE	FWHM
seeing	0.57” 100%	1.05” 100%	0.45” 100%
wide field AO	0.30” 53%	0.83” 79%	0.13” 29%
medium field AO	0.23” 40%	0.79” 75%	0.08” 18%
narrow field AO	0.10” 17%	0.72” 69%	0.07” 16%

seeing limited observations

- when AO not working, uncorrected beam goes through, AO instruments can be used
- second Nasmyth platform dedicated to seeing, full field observations (> 10’ - 20’)
- only in the far future AO will be everywhere
- 1st light FLAMINGOS - no AO

AO: the limits

- see Dr. Onur Keskin's talk this afternoon

to conclude

- DAG will be a beautiful telescope, ready for AO from start
- astronomers are smart, they can do without AO
- astronomers can be even smarter with AO
- caution: if you start with AO, you will not go back…
- see you in 2019 for 1st light !