香港中文大學
The Chinese University of Hong Kong

In a similar style to the Dragonfly Telephoto Array pictured here

Mapping the Milky Way and Nearby Galaxies with AMASE
利用AMASE对银河系和近邻星系作成像光谱巡天

Renbin Yan (CUHK) and the AMASE Team
严人斌（香港中文大学）

Image credit: John Corban

Current Instrument Team

- The Chinese University of Hong Kong:

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- South Africa Astronomical Observatory:

Sabyasachi Chattopadhyay, Egan Loubser, Mat

NRF National Research Foundation
SAAO South African Astronomical Observatory

- Univ. of Wisconsin:

WISCONSIN UNIVERSITY OF WISCONSIN-MADISON

Matthew Bershady, Micha Smith, Marsha Wolf

- Have benefited from the advice of Jim Gunn, Nicholas MacDonald, Kevin Bundy, Kyle Westfall, and Dmitry Bizyaev, and the work of a former RA and a few undergraduate students.

Affordable Multiple Aperture Spectroscopy Explorer (AMASE)

- A large array of cost-effective, fiber-based, high spectral resolution (R~15,000), integral field spectrographs paired with small telescopes (0.14m & 0.7m).

- Prototypes (AMASE-P) are funded by the Hong Kong Jockey Club Charities Trust and CUHK through the JC STEM Lab of Astronomical Instrumentation.

香港賽馬會慈善信託基金
The Hong Kong Jockey Club Charities Trust

香港中文大學
The Chinese University of Hong Kong

National Research Foundation

SAAO South African Astronomical Observatory

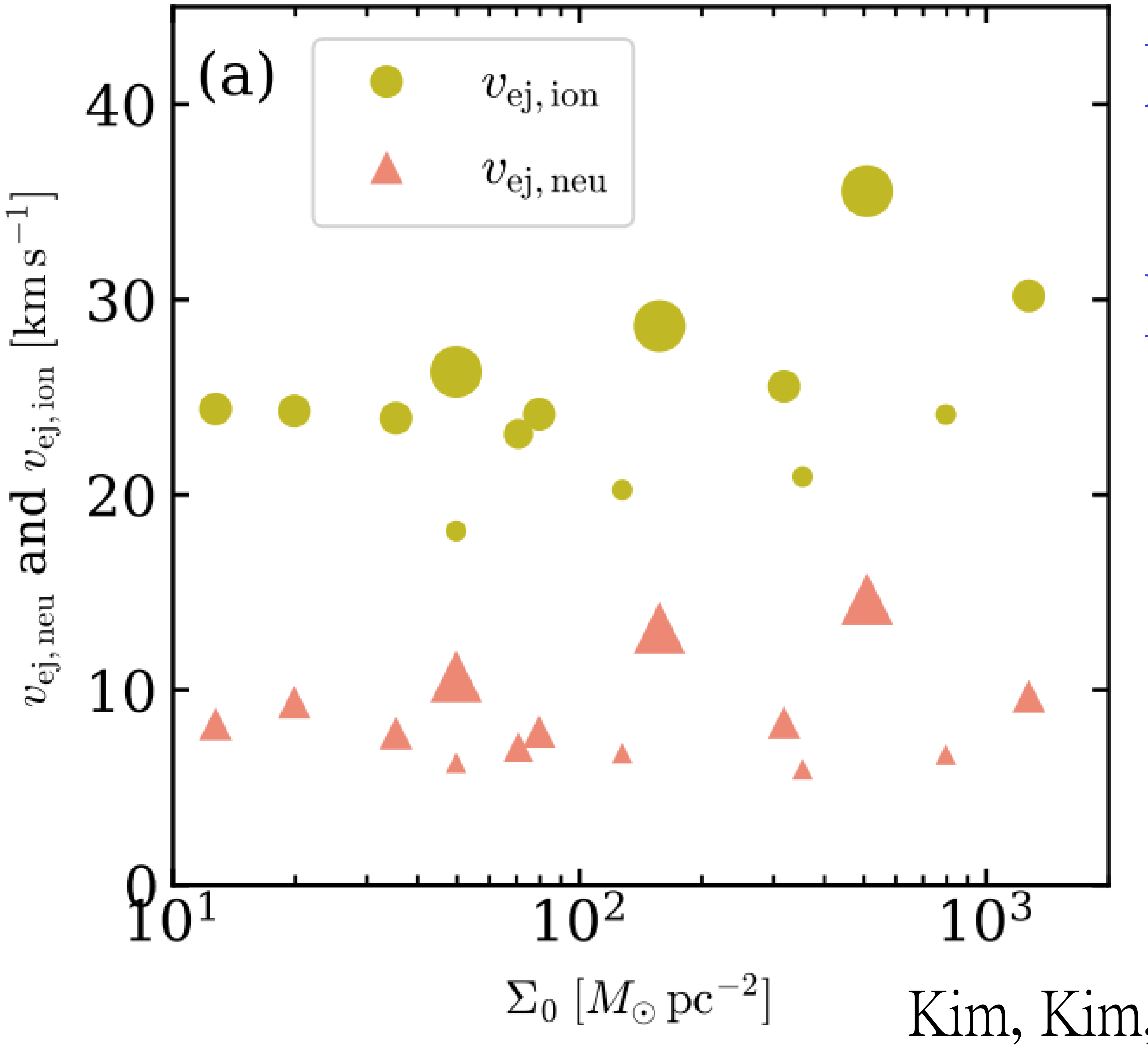
AMASE-P parameters summary

Telescope Aperture	0.13m (North+South)	0.7m (North)
Angular Resolution (FWHM)	26 arcsec	5 arcsec
Angular Diameter per bundle of 547 fibres	20 arcmin	3.7 arcmin
Wavelength coverage	4640-5092A (HeII, H β, [OIII]) 6250-6850A ([OI], H α, [NII], [SII])	
Spectral resolution	R~15,000 (σ ~8.5 km/s)	
Area covered in 2 years (w/ 6 fibre bundles feeding 6 prototype spectrographs)	~300 sq. degree (MW, M31, M33, IC1613, LMC, SMC, WLM, NGC6822)	
Planned Depth	S/N >10 for H α of 10 Rayleigh (5.7e-17 erg/s/cm^2/arcsec^2)	

1. Feedback from star formation

- Feedback from star formation is responsible for regulating star formation, distributing metal, and driving galactic wind.
- But how?

1.1 How fast is the ionised gas outflow?



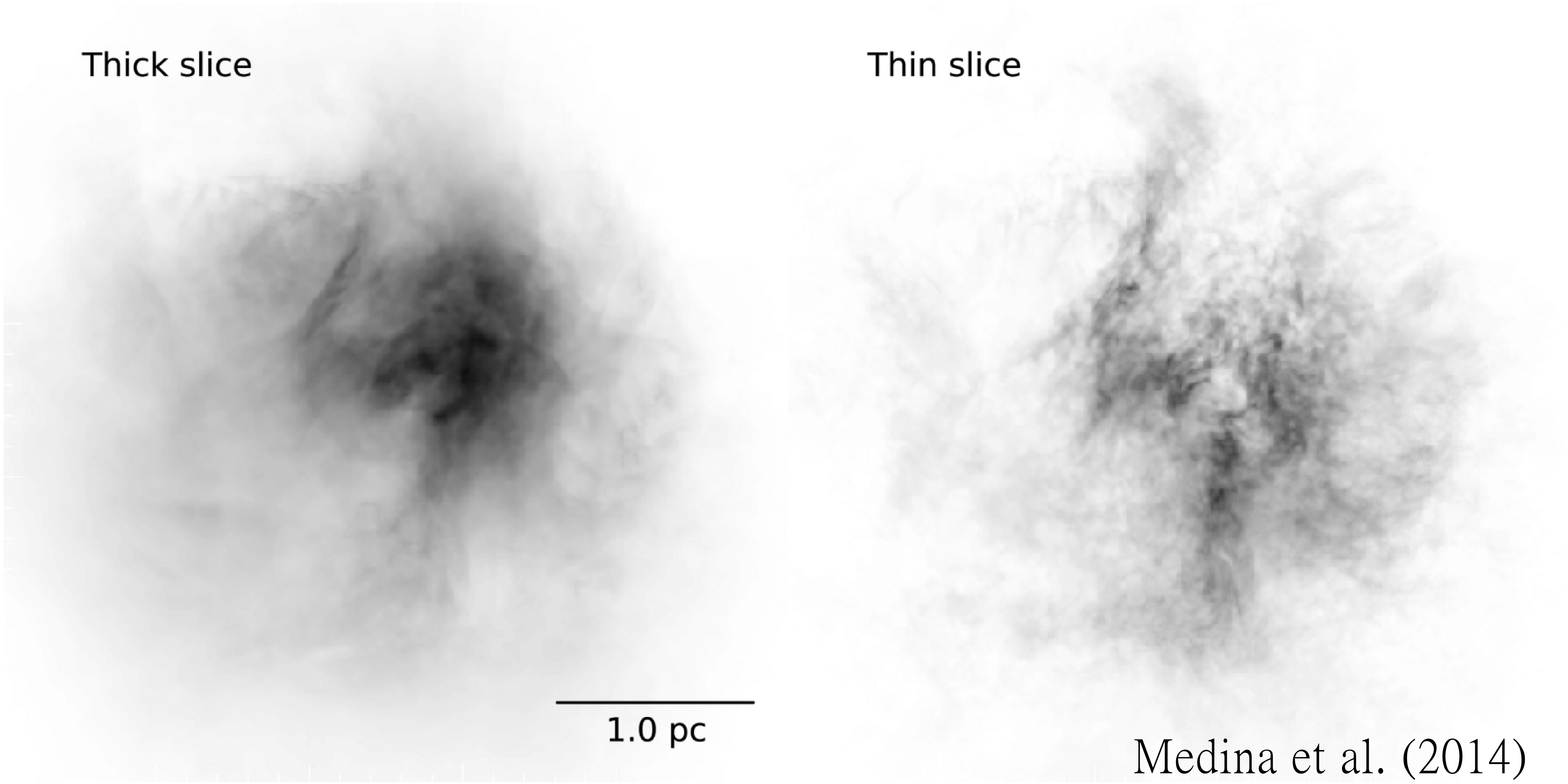
Kim, Kim, Ostriker (2018b)

Radiation pressure & photoionisation: > 20km/s
(Kim, Kim, & Ostriker 2018)

Radiation pressure only: ~ 10km/s
(Raskutii, Ostriker, Skinner 2017)

Need R >=15,000 to verify the model predictions.

1.2 How is the turbulence driven in ionised gas?



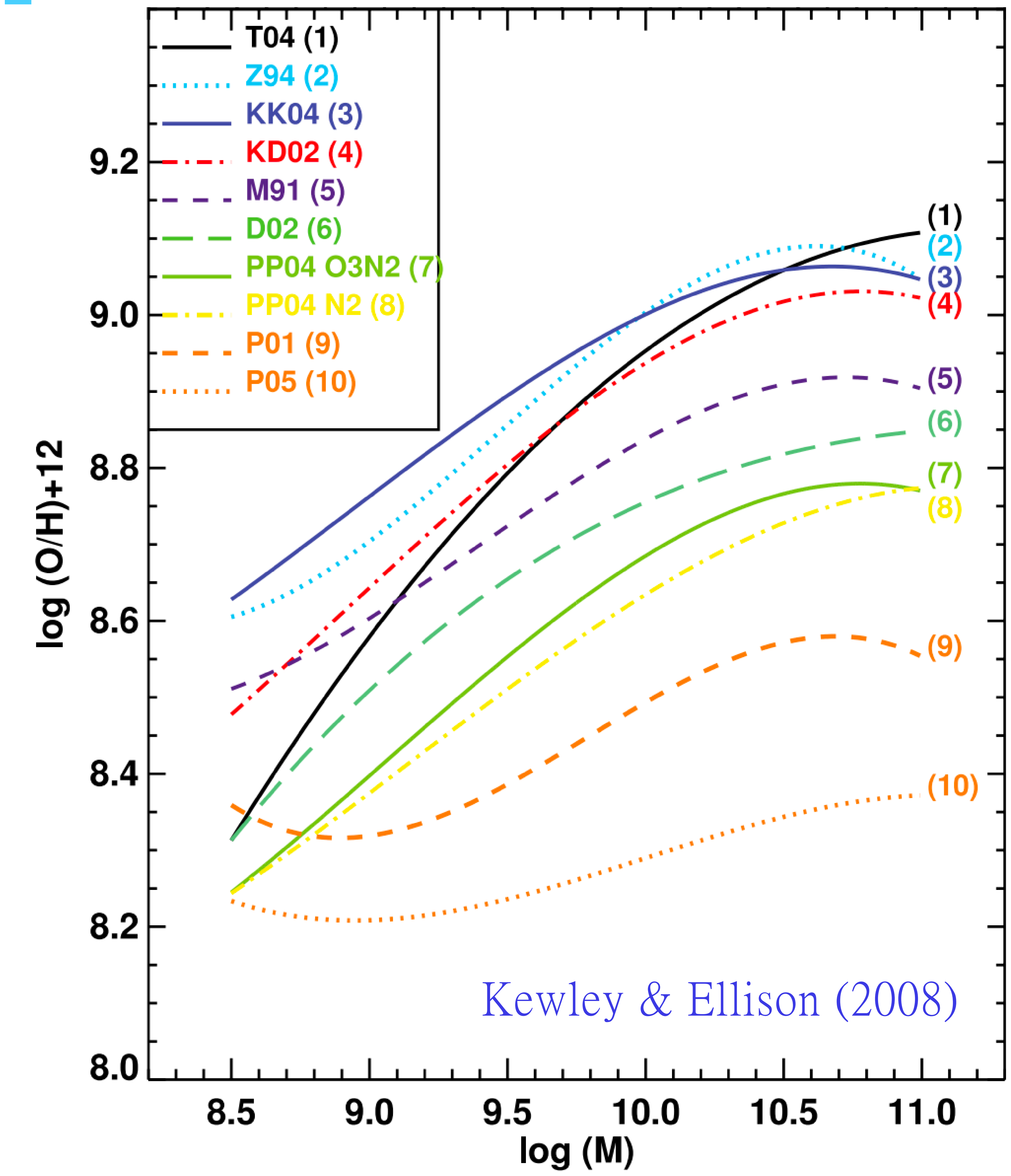
Medina et al. (2014)

Small-scale structure caused by velocity fluctuations can only be seen in thin velocity slices.

Need high spectral resolution

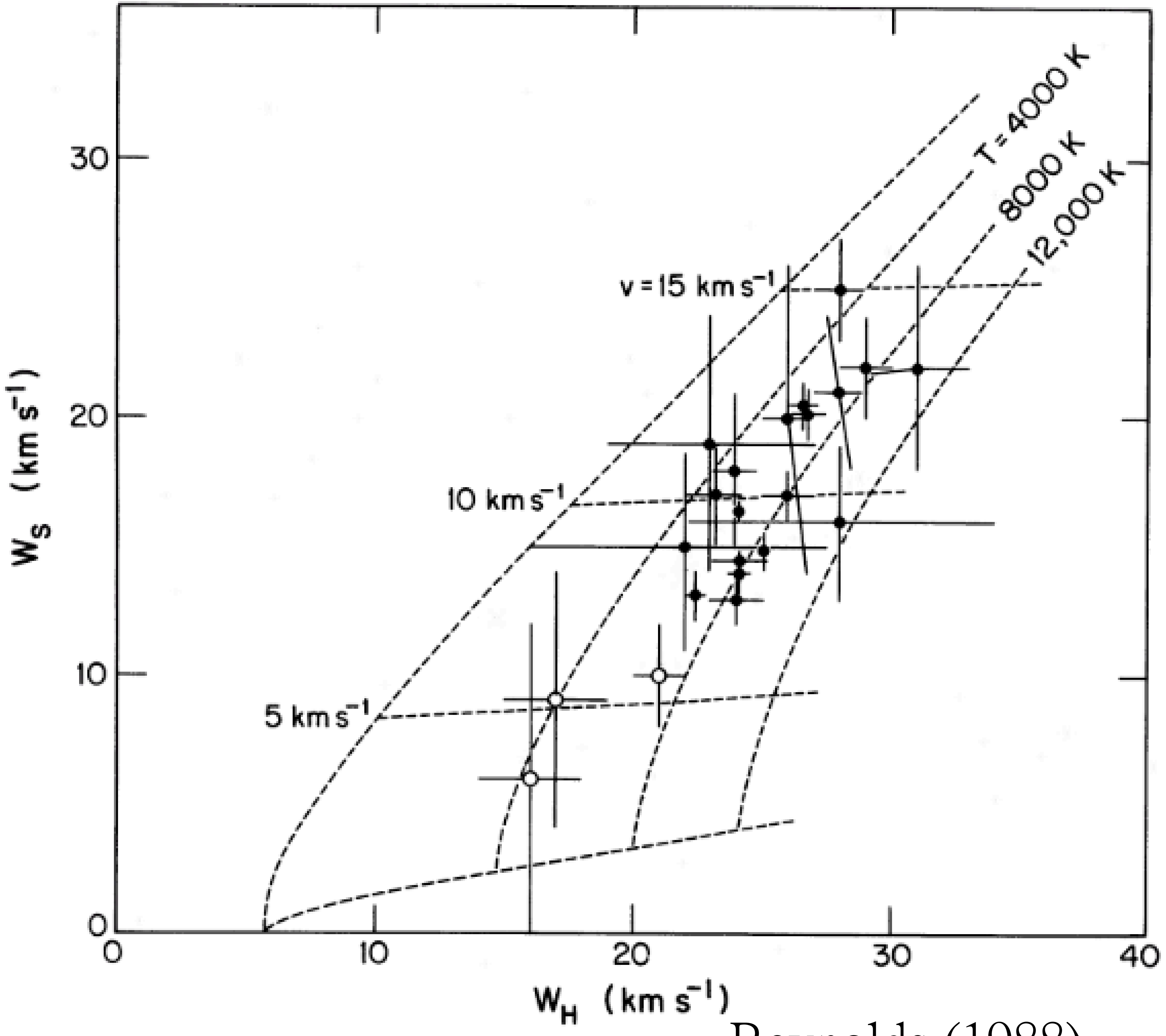
- Different turbulent energy injection scales will affect the index of the velocity power spectrum.
- Measuring the emissivity power spectrum in *thin* velocity slices (8km/s) for [OIII], [NII], [SII] will help constrain the velocity power spectrum index to an accuracy of +/-0.1 .

2. Calibrate metallicity indicators



With co-spatial density and temperature measurements throughout all zones of an HII region, we can much more accurately calibrate the metallicity indicators.

Temperature measurement from line width comparison



Reynolds (1988)

High spectral resolution can help separate thermal from non-thermal broadening

- Light atoms (H) has both thermal and non-thermal broadening
- Heavy atoms (like O, N, S) is dominated by non-thermal broadening

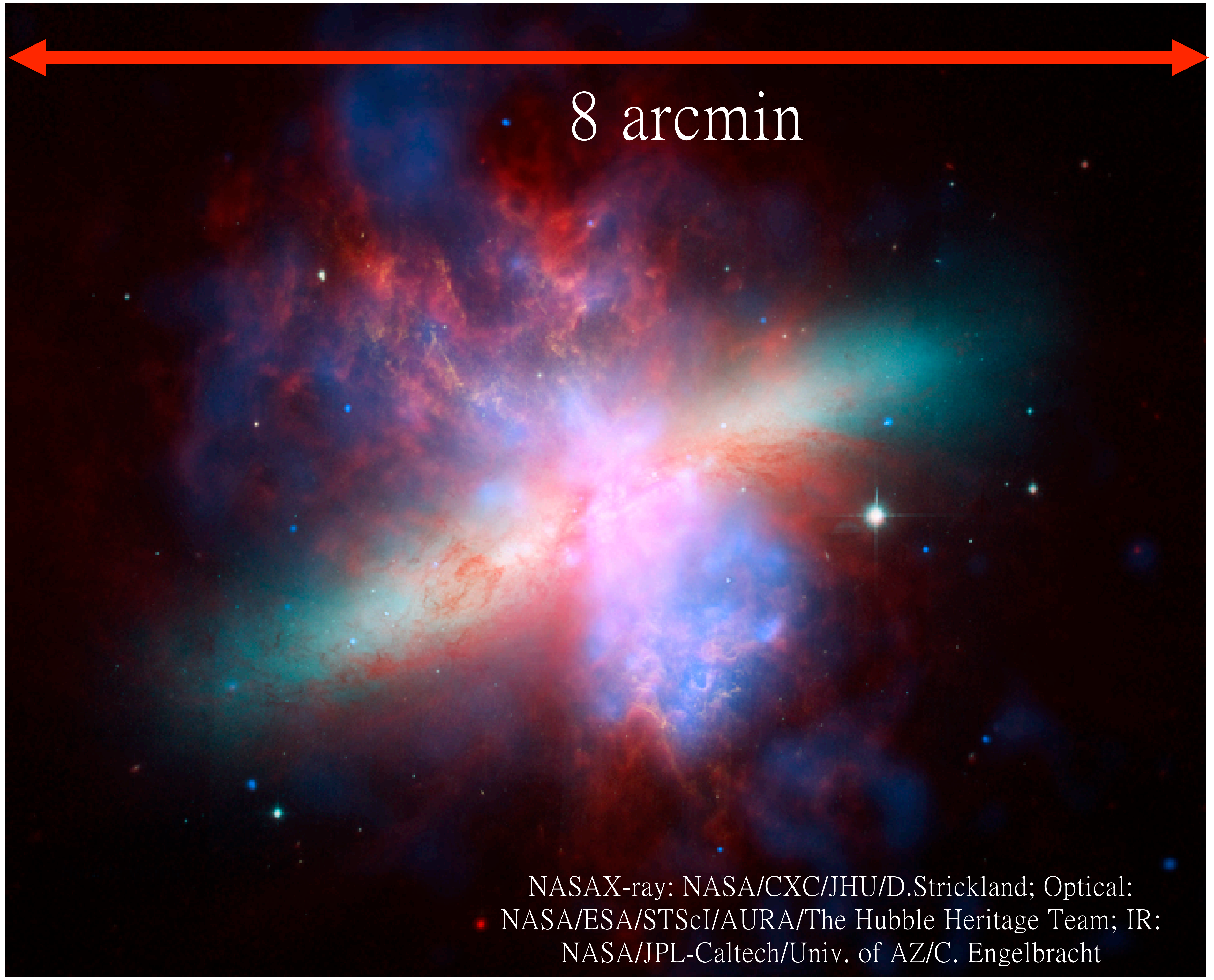
Temperature measurement helps calibrate metallicity measurement.

What kind of observation is needed?

- High spectral resolution (R>=15,000), integral field spectroscopy that can contiguously cover entire HII regions (many tens of pc) while resolving them at 0.1pc.
- Need to connect small and large scales
  - Scale at which RMS turbulence velocity equals to sound speed : ~0.03 pc
  - Sizes of self-gravitating cores: ~0.1 pc
  - Molecular cloud and HII regions (tens of pc)
  - MaNGA resolution ~ 1-2 kpc

The challenge to bridge the small and large scales!

1 arcsec = 0.002 pc



1 arcsec = 170 pc

CALIFA, MaNGA, SAMI resolution: 1-2 kpc

How to cover the intermediate scale: 0.1-100pc

To resolve 0.1pc

- In the Milky Way HII regions, this requires an angular resolution of 20-30" .
- A small telescope of 15-30 cm and fast focal ratio would suffice! No need for large telescopes.

To cover 100pc with 0.1pc resolution

- Dynamic range = angular coverage / angular resolution = 1000
- As a reference, VLT/MUSE has a dynamic range of ~120 (24 spectrographs)
- Cover a dynamic range of 1000 (0.1-100 pc) needs a dedicated survey instrument with lots of spectrographs! Therefore, we need to make spectrographs more cost-effective!

Apply same instrument on nearby galaxies to connect 10s of pc to kpc scales

S/N for extended sources

- For extended sources that are large enough, the signal-to-noise ratio does NOT depend on the aperture of the telescope.

$$\mathrm{Etendue}_{\mathrm{fiber}} = A_{\mathrm{telescope}} \times \Omega_{\mathrm{fiber}} = A_{\mathrm{fiber}} \times \Omega_{\mathrm{beam}}$$

- For a fixed fiber size and a fixed focal ratio, you get the same etendue on all telescopes.
- Telescope size (or focal length) only sets the plate scale.

Strategy to improve cost-effectiveness

- Generally, reduce beam width to enable the use of commercial off-the-shelf components, and take advantage of technology advances in CMOS sensors and lens coatings
- Thinner fibers

→ shorter collimator focal length (for fixed spectral resolution)

$$R = \frac{f_{\mathrm{coll}}}{d_{\mathrm{fiber}}} \frac{\lambda A}{r}$$

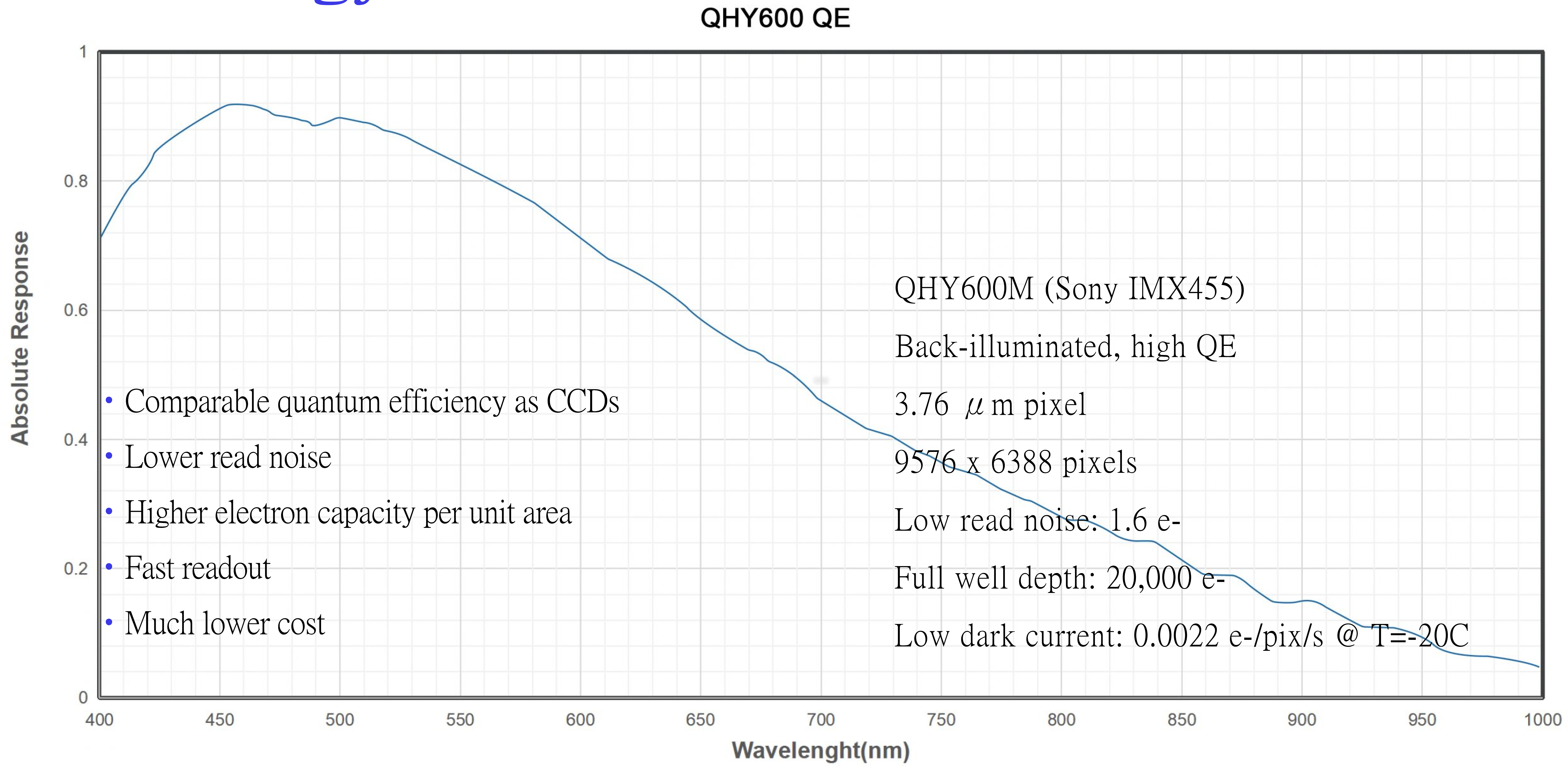
→ smaller beam width

→ smaller optics

- Thinner fibers

→ less demagnification in order to use small-pixel CMOS sensors

Technology advance in CMOS



- Comparable quantum efficiency as CCDs
- Lower read noise
- Higher electron capacity per unit area
- Fast readout
- Much lower cost

QHY600M (Sony IMX455)

Back-illuminated, high QE

3.76 μm pixel

9576 x 6388 pixels

Low read noise: 1.6 e-

Full well depth: 20,000 e-

Low dark current: 0.0022 e-/pix/s @ T=-20C

Commercial Photographic lenses with advanced coating technology

Canon

Nano-crystal coating used to improve throughput and reduce scattered light.

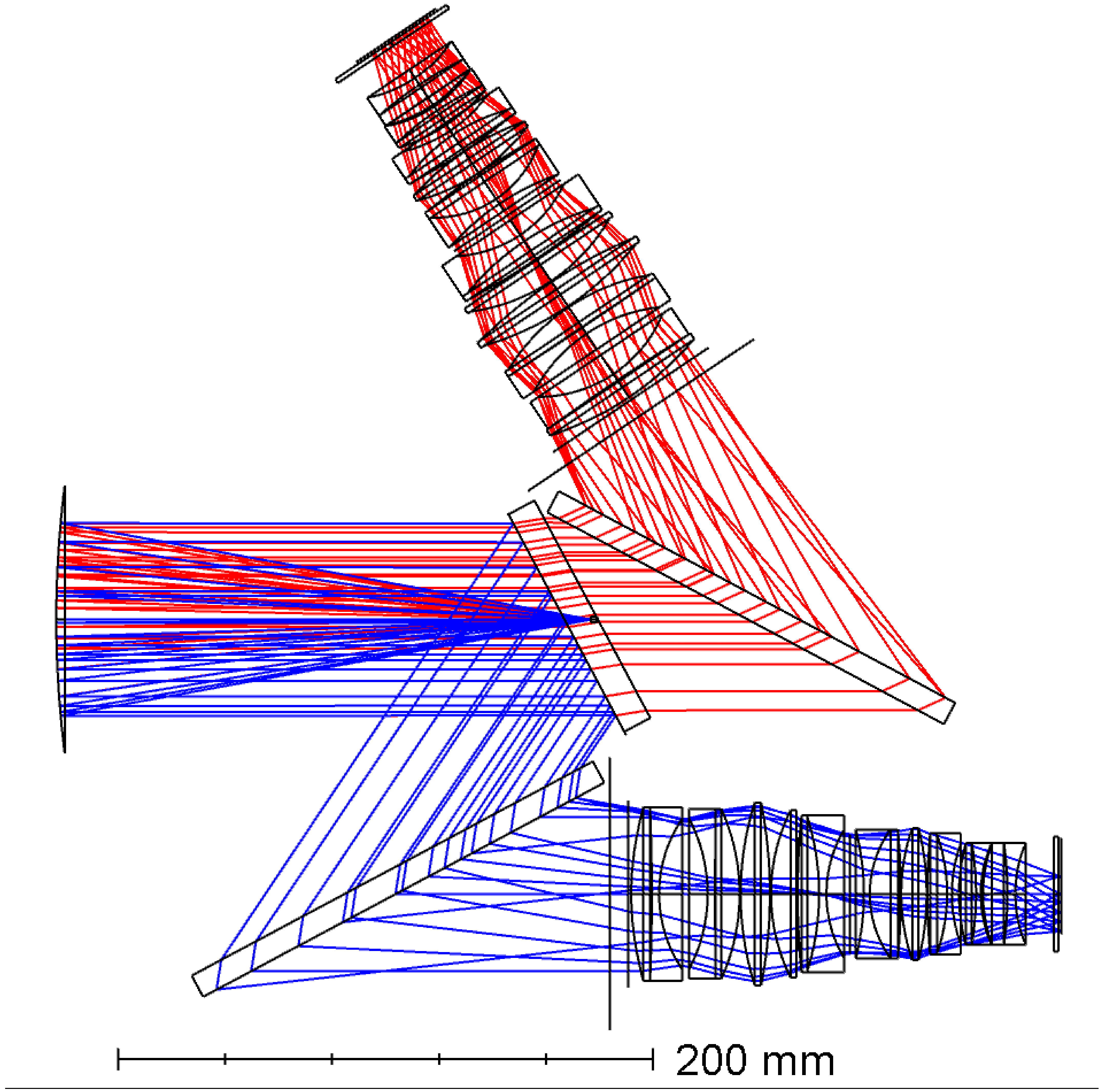
Nikon

Newly released super fast (f/0.95) Nikon lens designed for point sources in dark background!

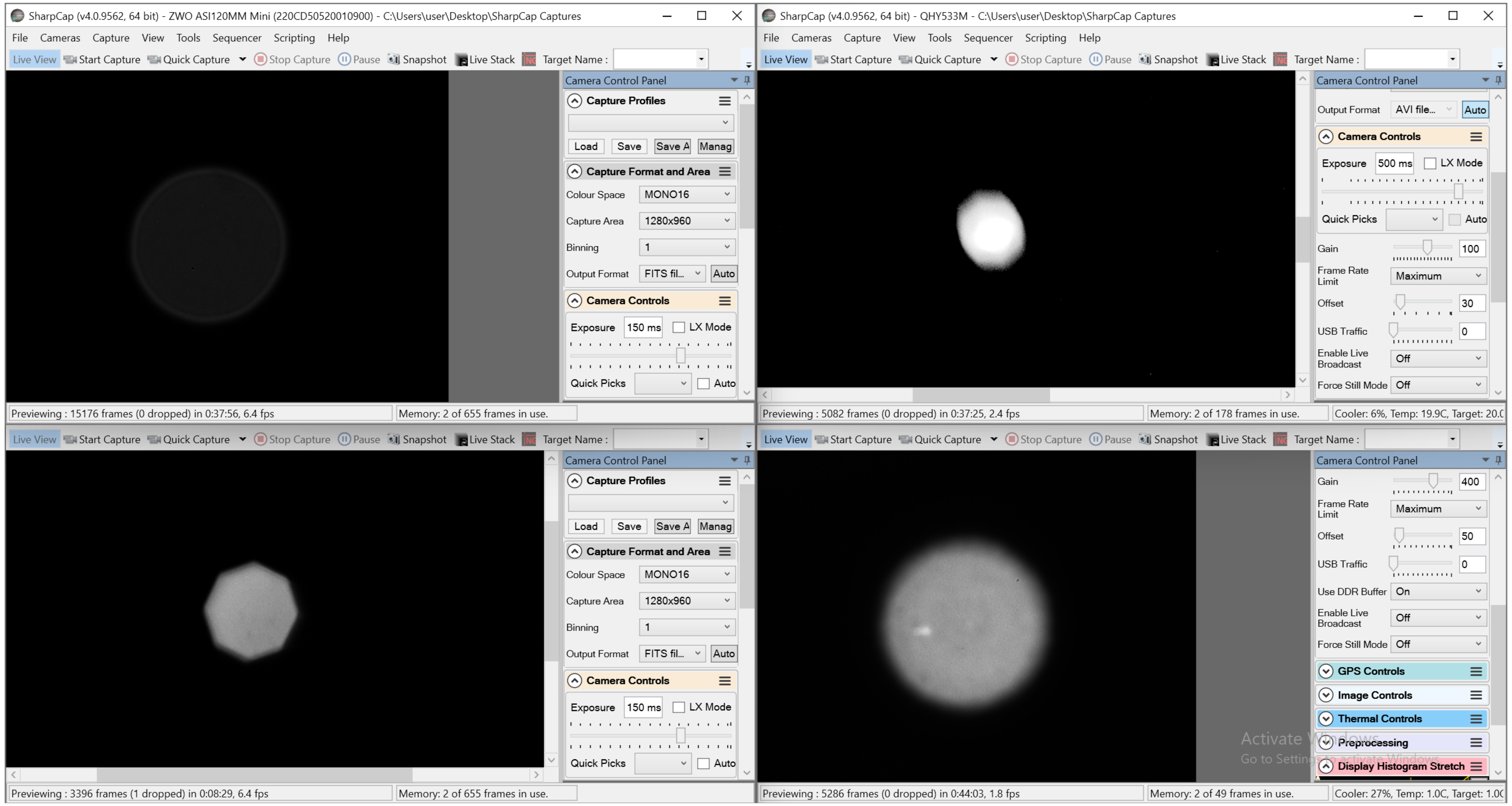
Ray tracing: 1-2 um RMS spot

Spectrograph design for AMASE-P

- 50 μ m-core **octagonal** fiber => 26" on the sky
- 547 fibers per spectrograph
- Blue channel: 4640-5092A (HeII, H β , [OIII])
  Red channel: 6250-6850A ([OI], H α , [NII], [SII])
- Spectral Resolution: R~15,000
- Custom dichroic and **fused-silica etched gratings**.
- Nikon 58mm f/0.95 lens as camera
- QHY600M CMOS detectors
- Telescope: Canon 400mm f/2.8 lens
- Total hardware cost: RMB ¥1M, and much cheaper if massively replicated.

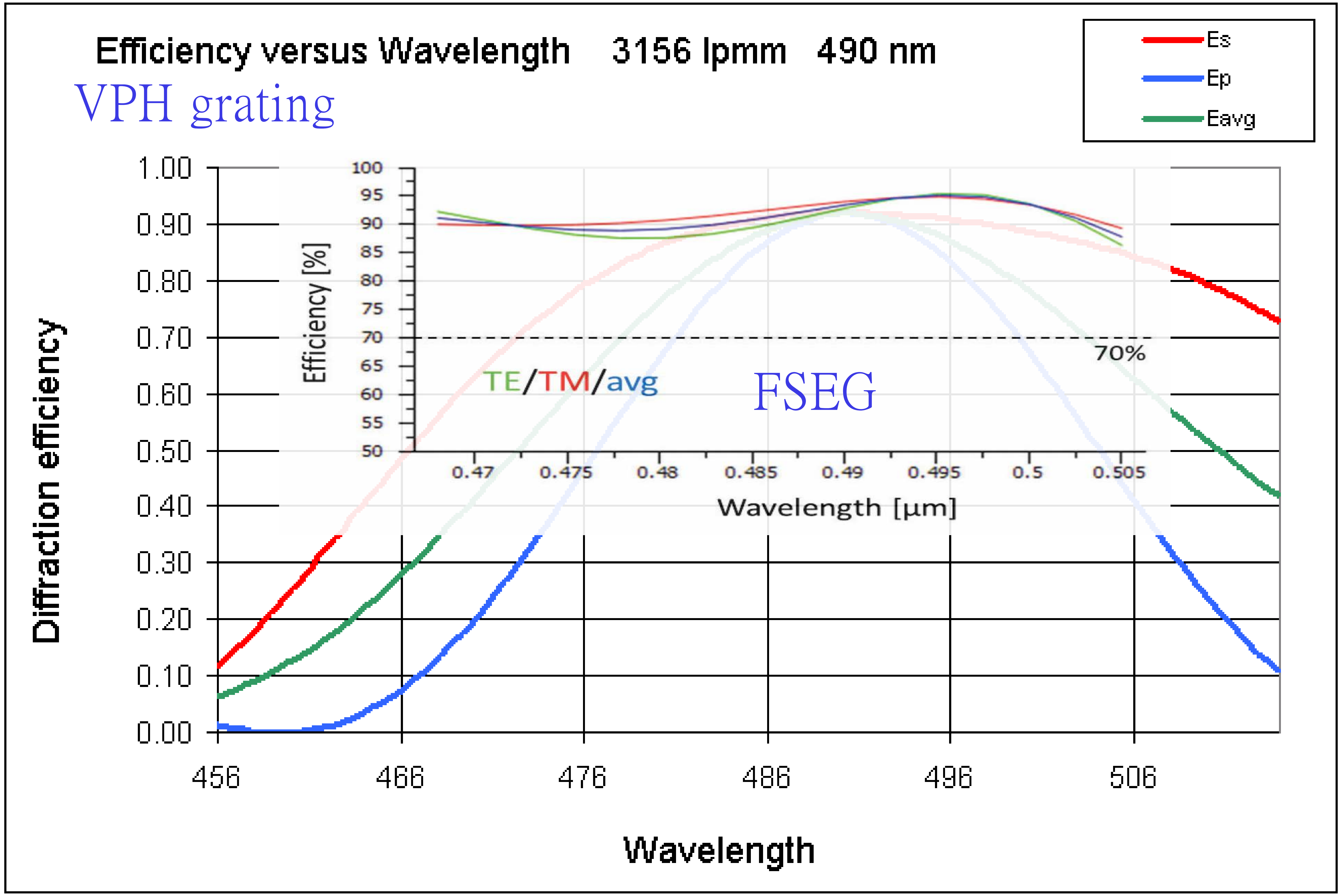


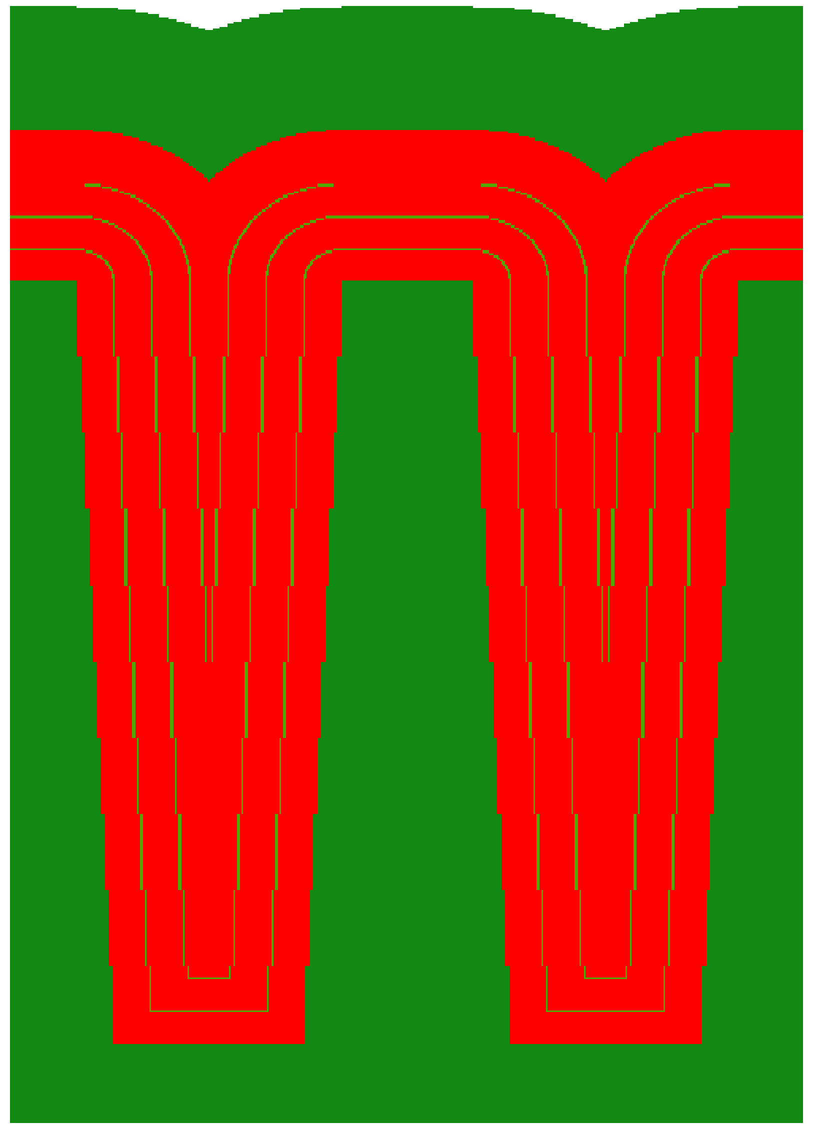
Why use octagonal-core fibers



- Octagonal-core fibers provide more uniform scrambling in both near-field and far-field than circular-core fibers. This will yield more stable line spread function.

Grating Choice: VPH vs. Fused silica etched grating

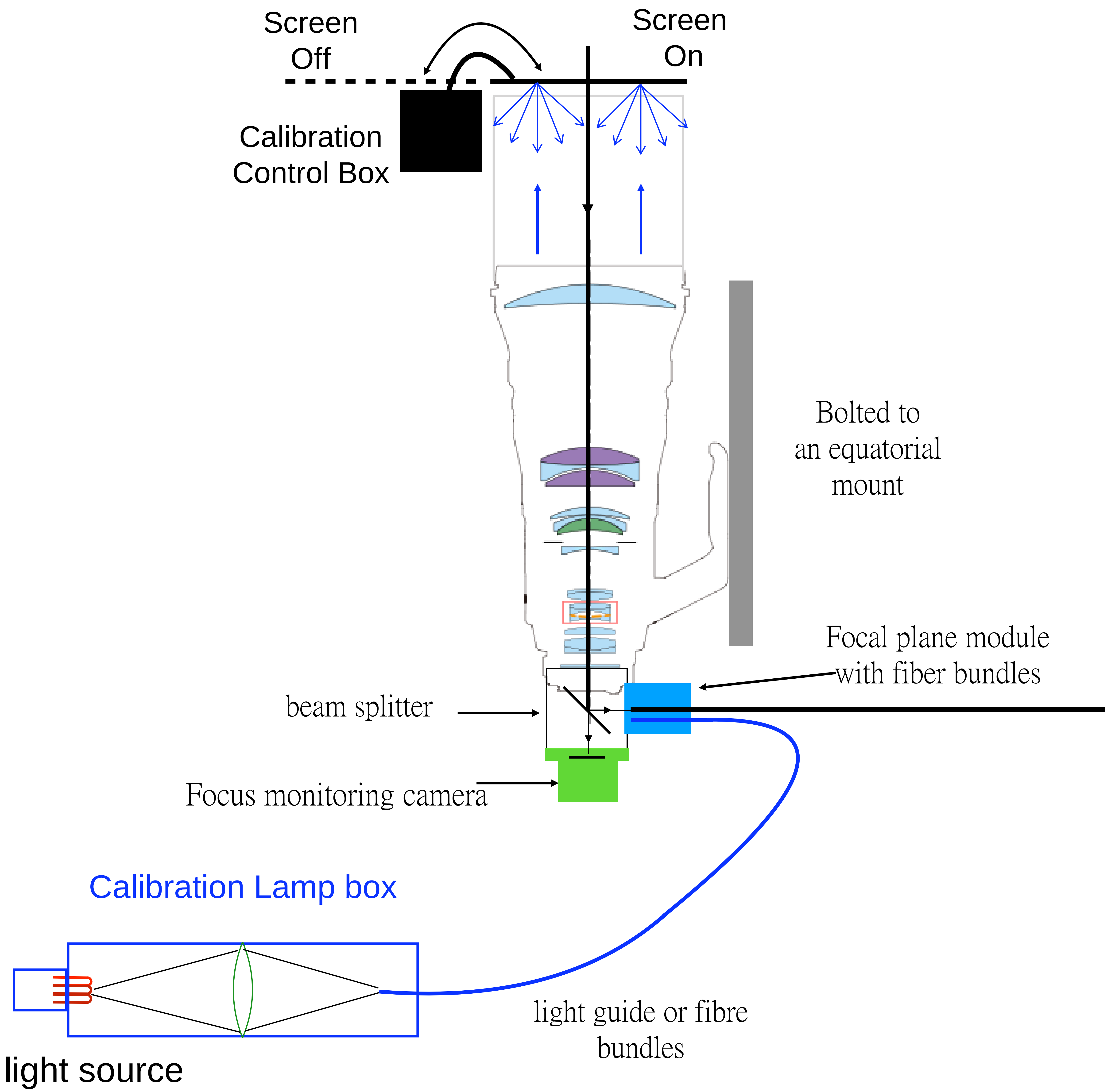




- FSEG has a much wider bandpass than VPH for high angular dispersion.

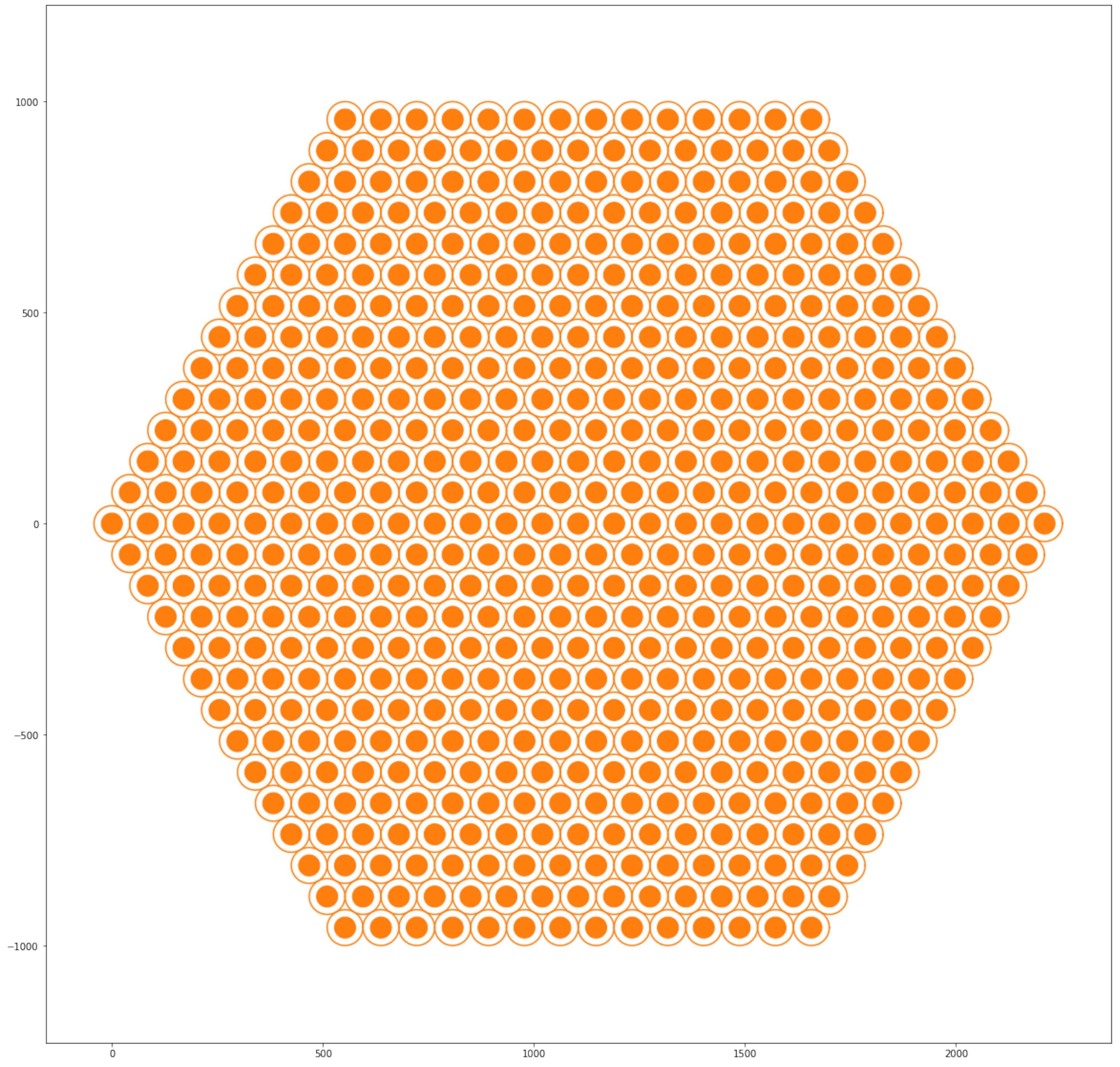
Telescope and Calibration System

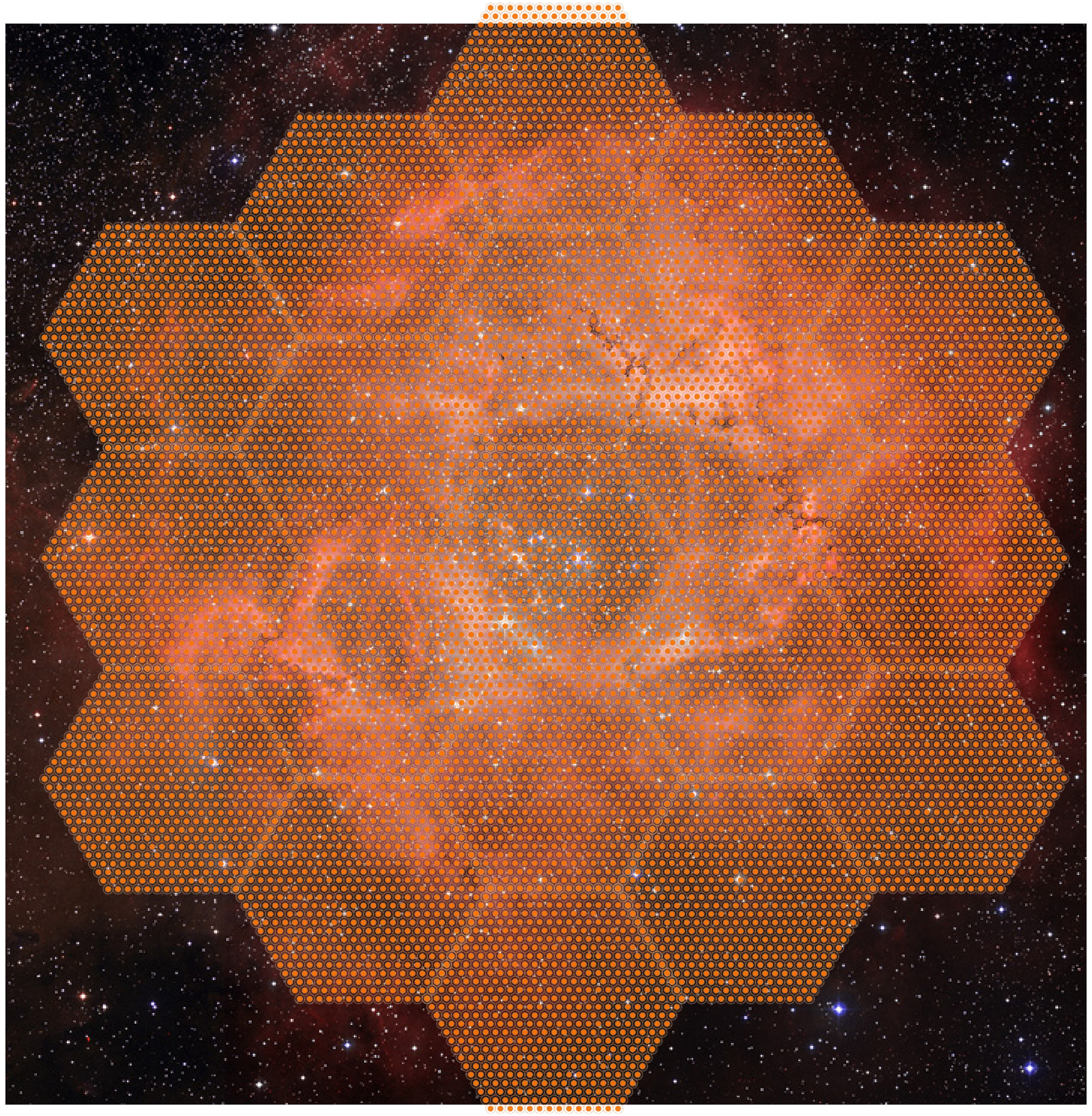
- Telescope: Canon 400mm f/2.8 lens
- 20 arcmin across, hexagonal fiber-bundle, fill factor 31%, covering 79 sq. arcmin at a time.
- Acquisition/Guiding/Focus-monitoring using on-axis guider using light between 530-620nm.
- Pre-set focus offset for bundle to smooth the near-field illumination within fibers (26”)
- Calibration screen for on-the-field calibration, illuminated from focal plane.



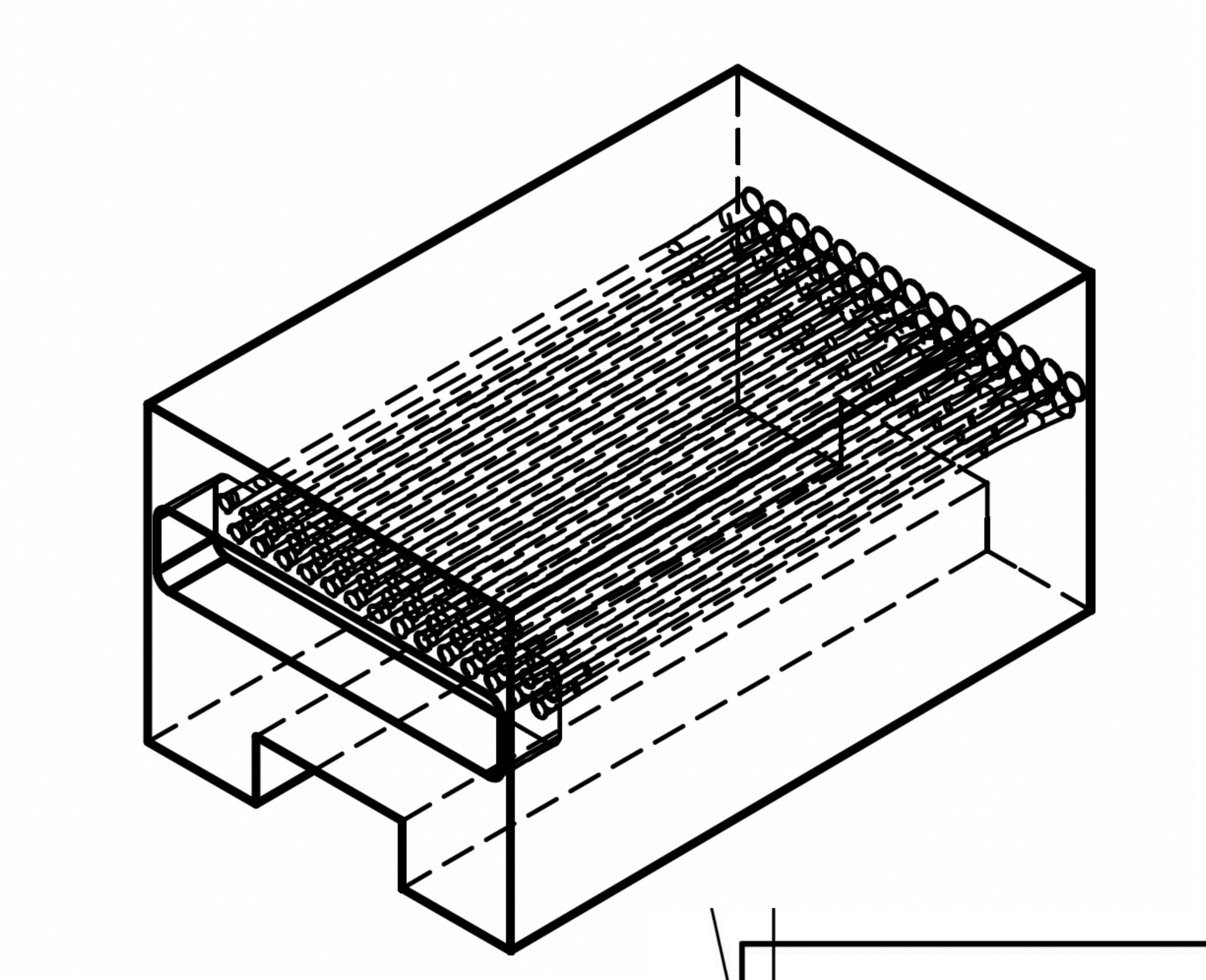
Hexagonal Fibre Bundle

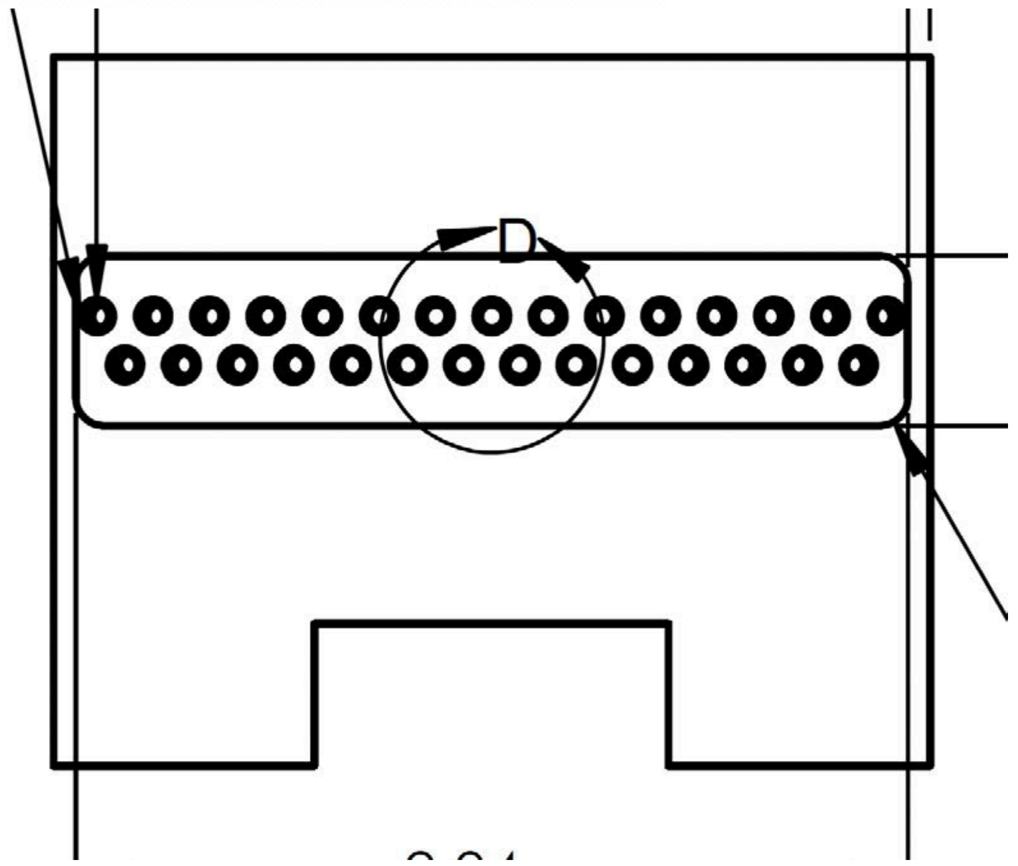
- A 547-fibre bundle per spectrograph

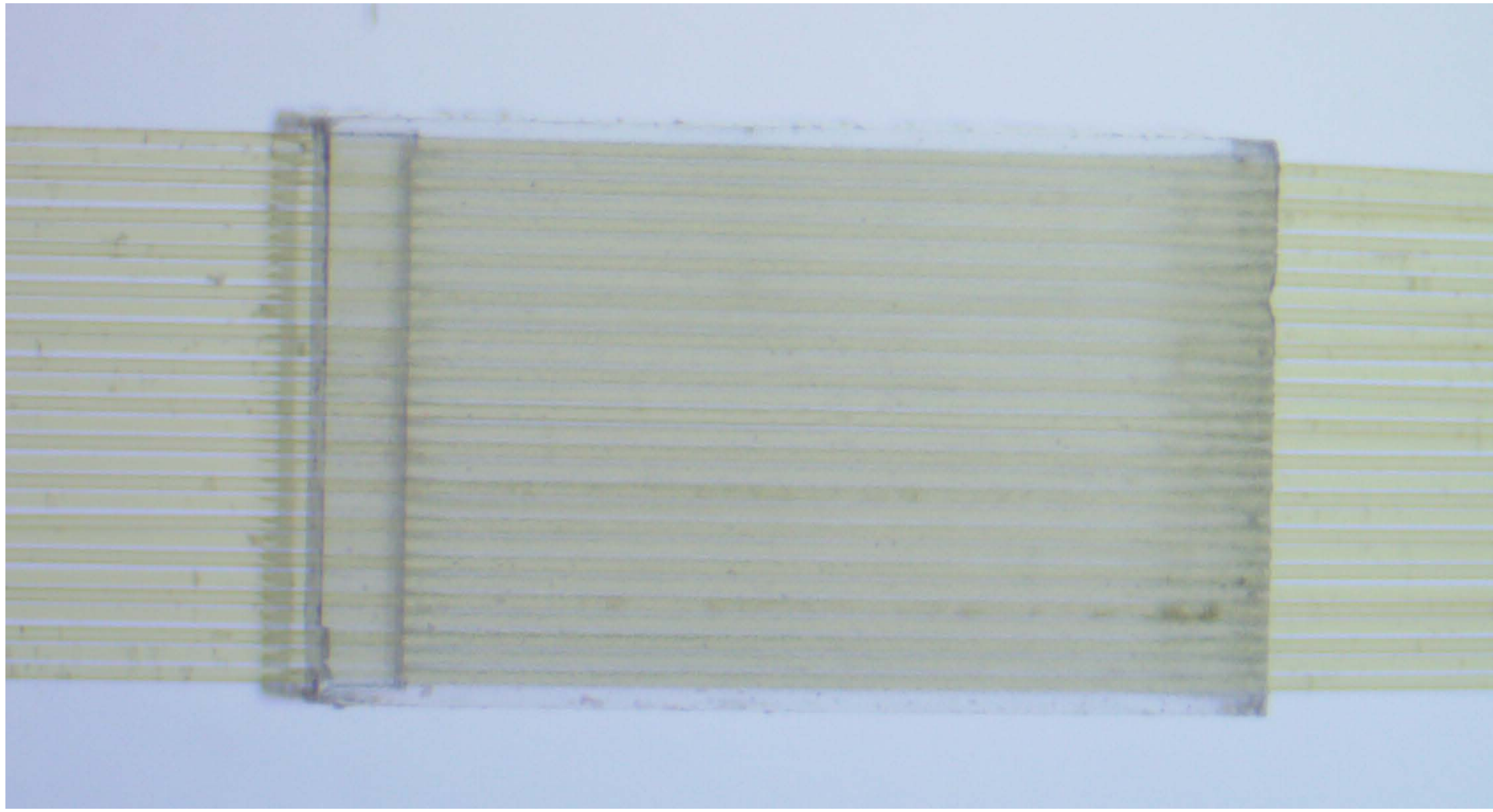




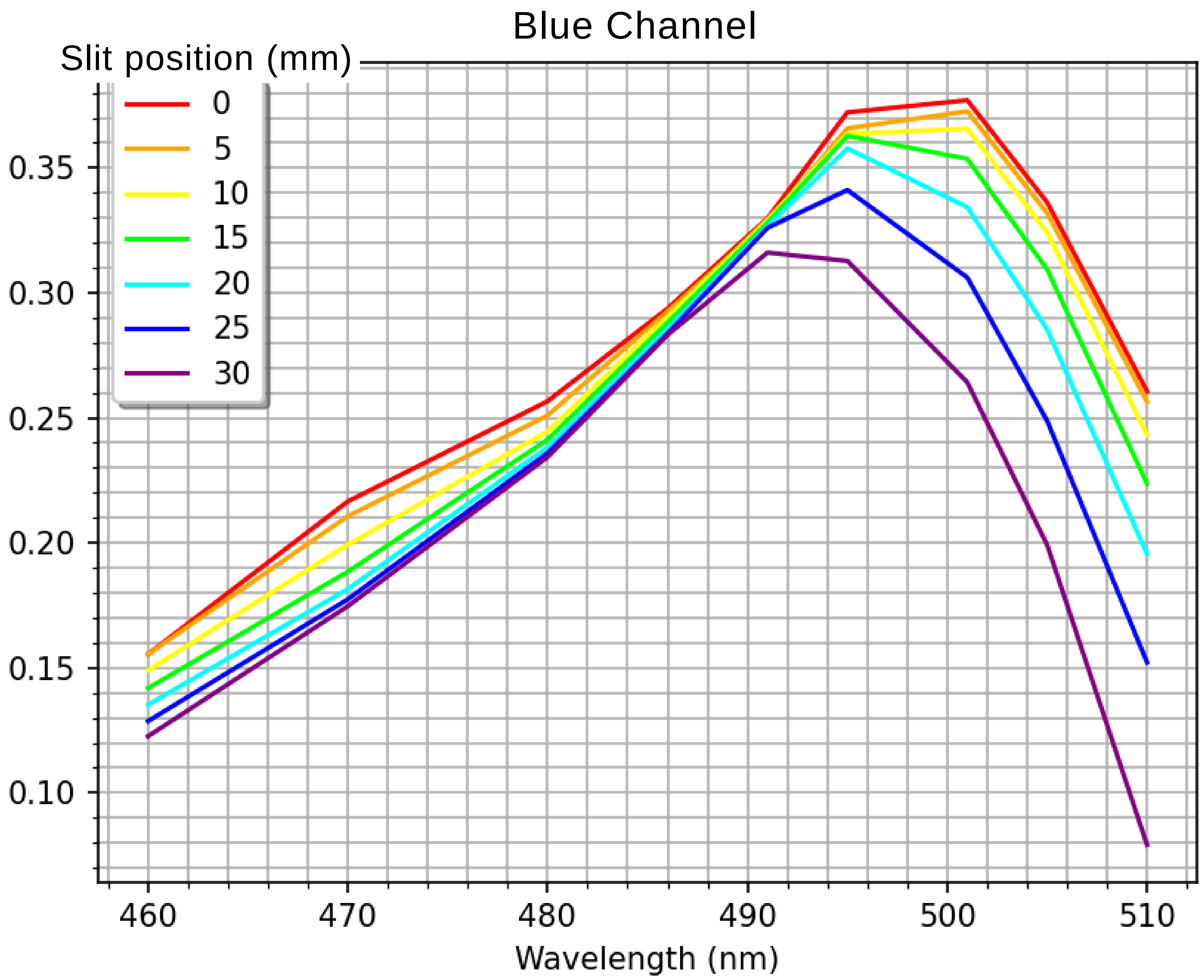
Fiber positioning blocks

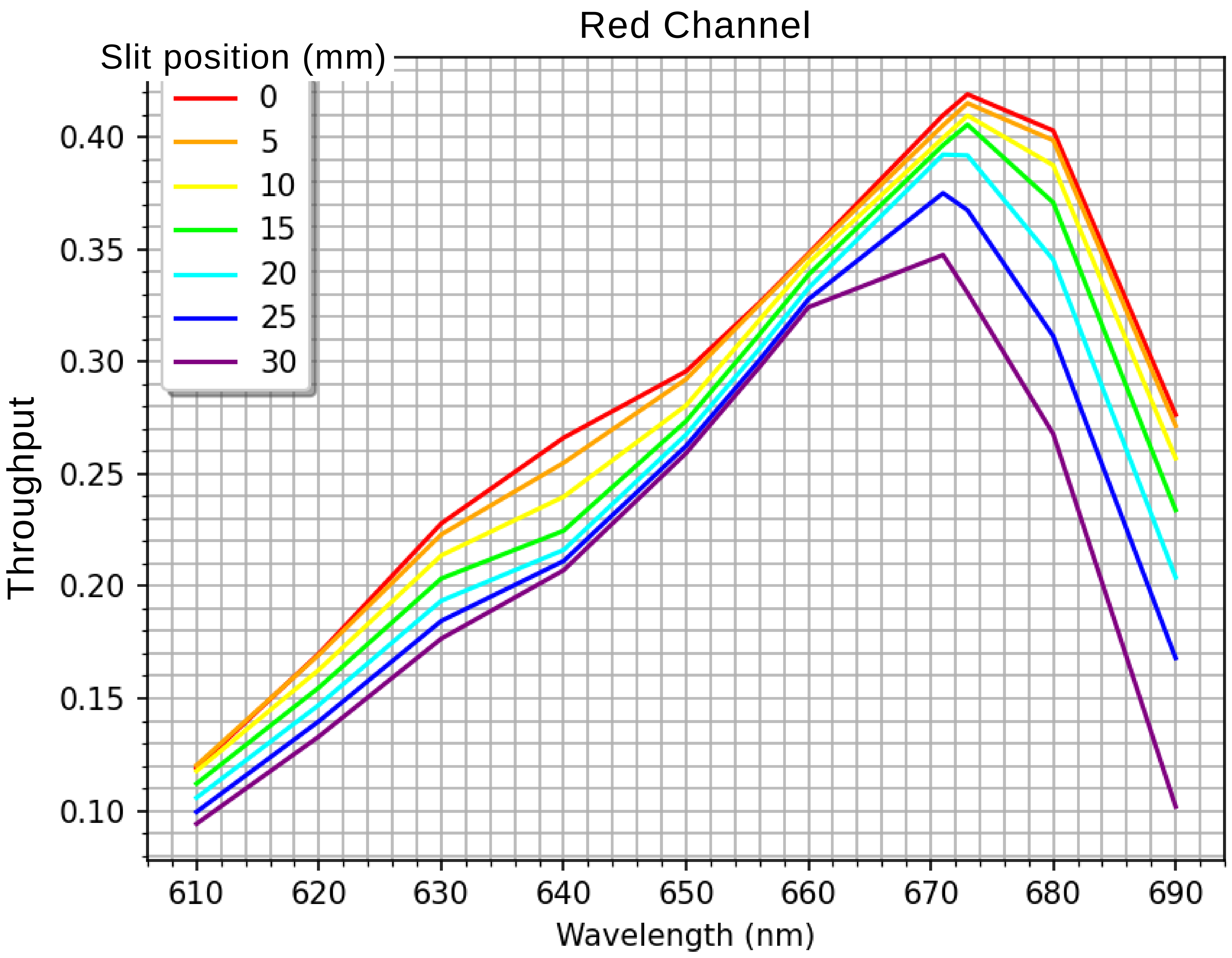




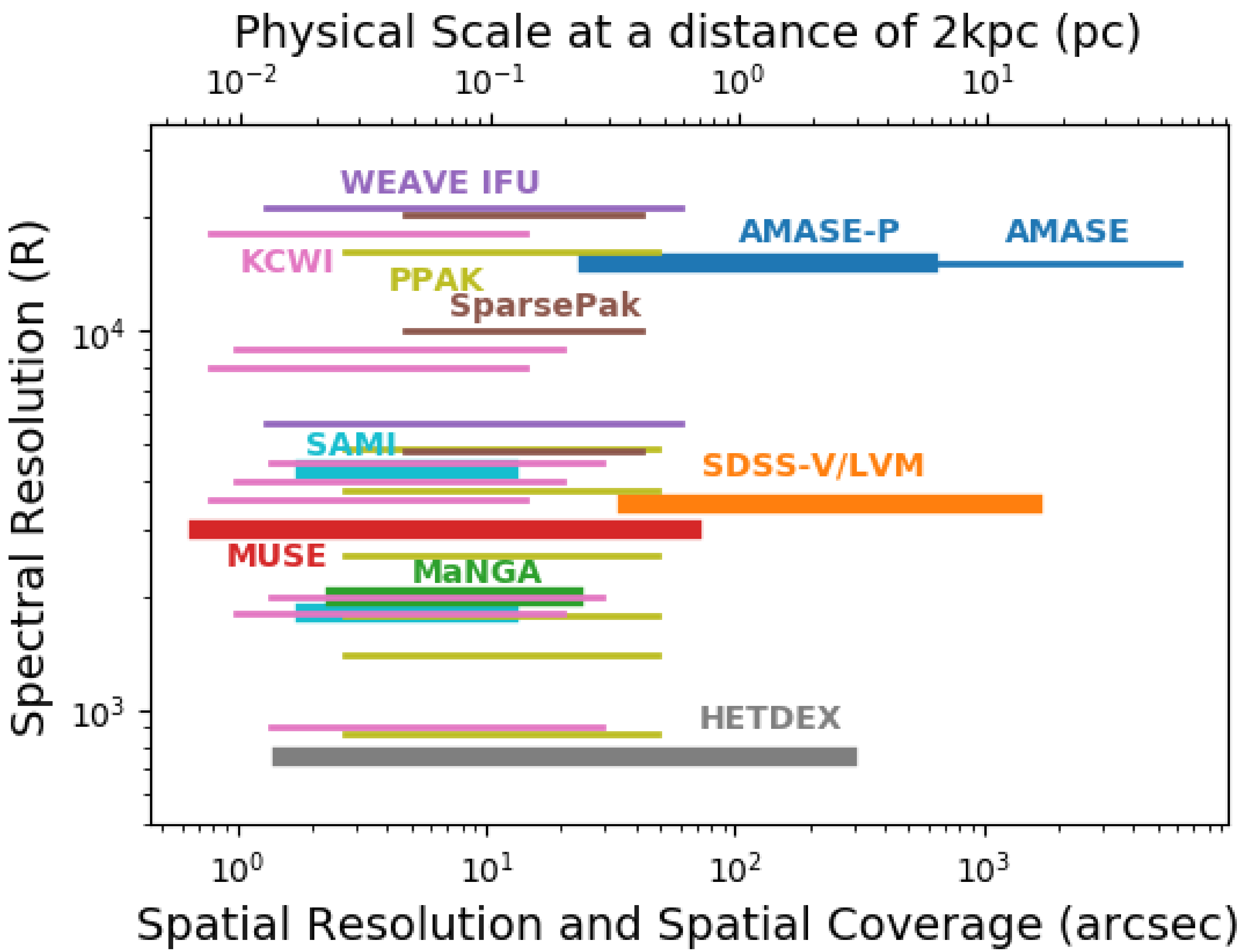


Throughput Prediction





Unprecedented Capabilities



- AMASE provides an unprecedented combination of spectral resolution and spatial scales it can cover.

Cost-effectiveness and Expected Sensitivity

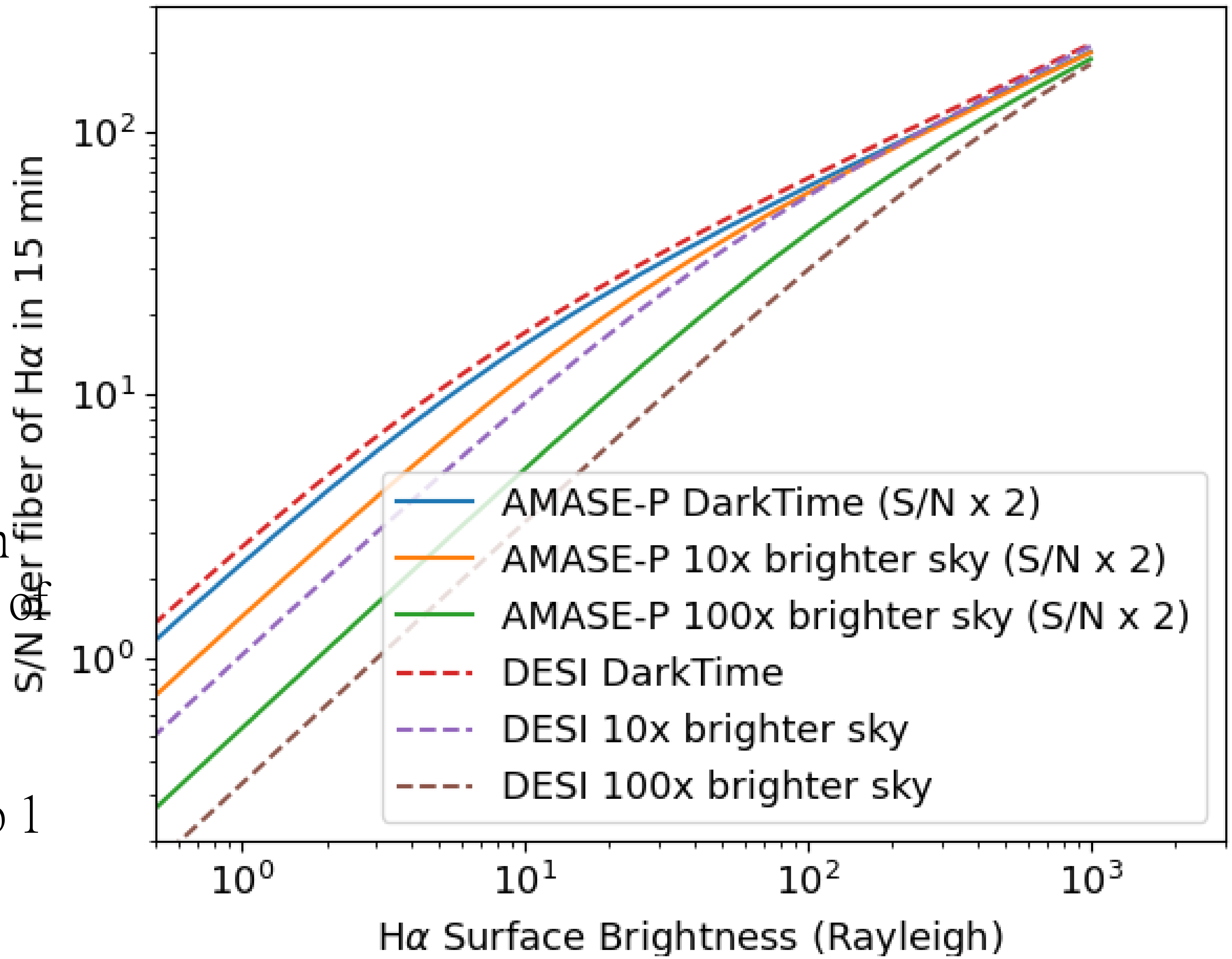
- Etendue = (input beam solid angle)
  x (fiber area) x(efficiency)
  $=A\times\Omega\times\varepsilon$

- Using DESI spectrograph as a reference

  Per-fiber etendue: AMASE-P = 18% DESI
  Per-fiber cost: AMASE-P = 9% DESI

- AMASE-P is twice as cost-effective as DESI, with 4-5 times higher spectral resolution, covering 18% of the bandpass as DESI.

- With an array of 100 spectrographs (¥100M), we can map 1/4 of the sky in 4 years, probing down to 1 Rayleigh.



Prototypes and the long term plan

- We have secured funding for six prototype spectrographs, which will be put at two sites, one in each hemisphere. Looking for potential sites in China and South Africa.
- The one in the north will also have a 0.7m telescope to map M31 & M33 with 20pc resolution.
- Expect to start observing with the prototypes in May of 2025.
- We plan to build a large international collaboration and to secure funding for a massive array of these spectrographs to cover 1/4 of the sky to map the Milky Way and nearby galaxies.

Hiring: Research Assistant Professor at CUHK in Astronomical Instrumentation

- https://jobregister.aas.org/ad/156e442c
- Suitable for people who have done 1 or 2 postdocs.
- Faculty position; can lead grant proposals and independent projects.
- With a good chance to obtain tenure-track position in the department.
- Salary minimum: > RMB ¥ 52000 per month