The Oxford SWIFT Integral Field Spectrograph

(commissioning & status update)

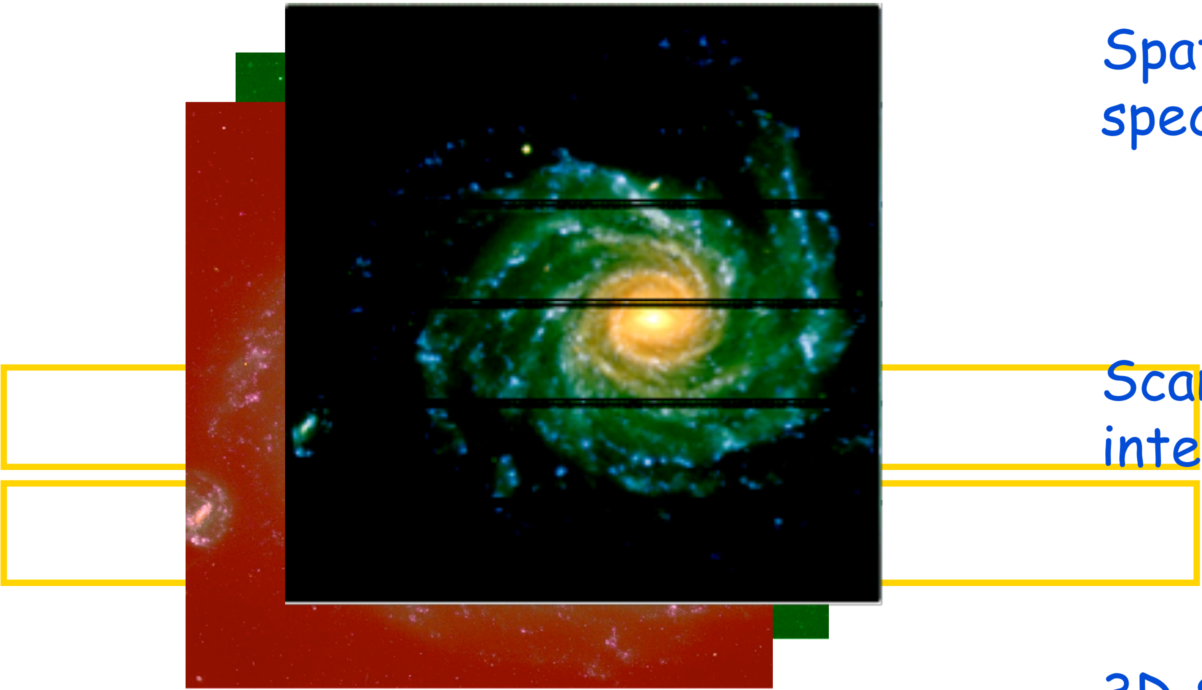
Niranjan Thatte (P.I.), Matthias Tecza, Fraser Clarke, Tim Goodsall, Lisa Fogarty, Ryan Houghton, James Lynn, Matthew Brock, Graeme Salter, Roger Davies, Susan Kassin

Outline

- IFS 101: integral field spectroscopy with slicers
- Capabilities of SWIFT
- Uniqueness of SWIFT
- Some key science cases
- Commissioning update and status
- The next few years?

Funded by a Marie Curie Excellence Grant from the European Commission, University of Oxford Physics dept, COO.

Integral Field Spectroscopy: Observing a data cube

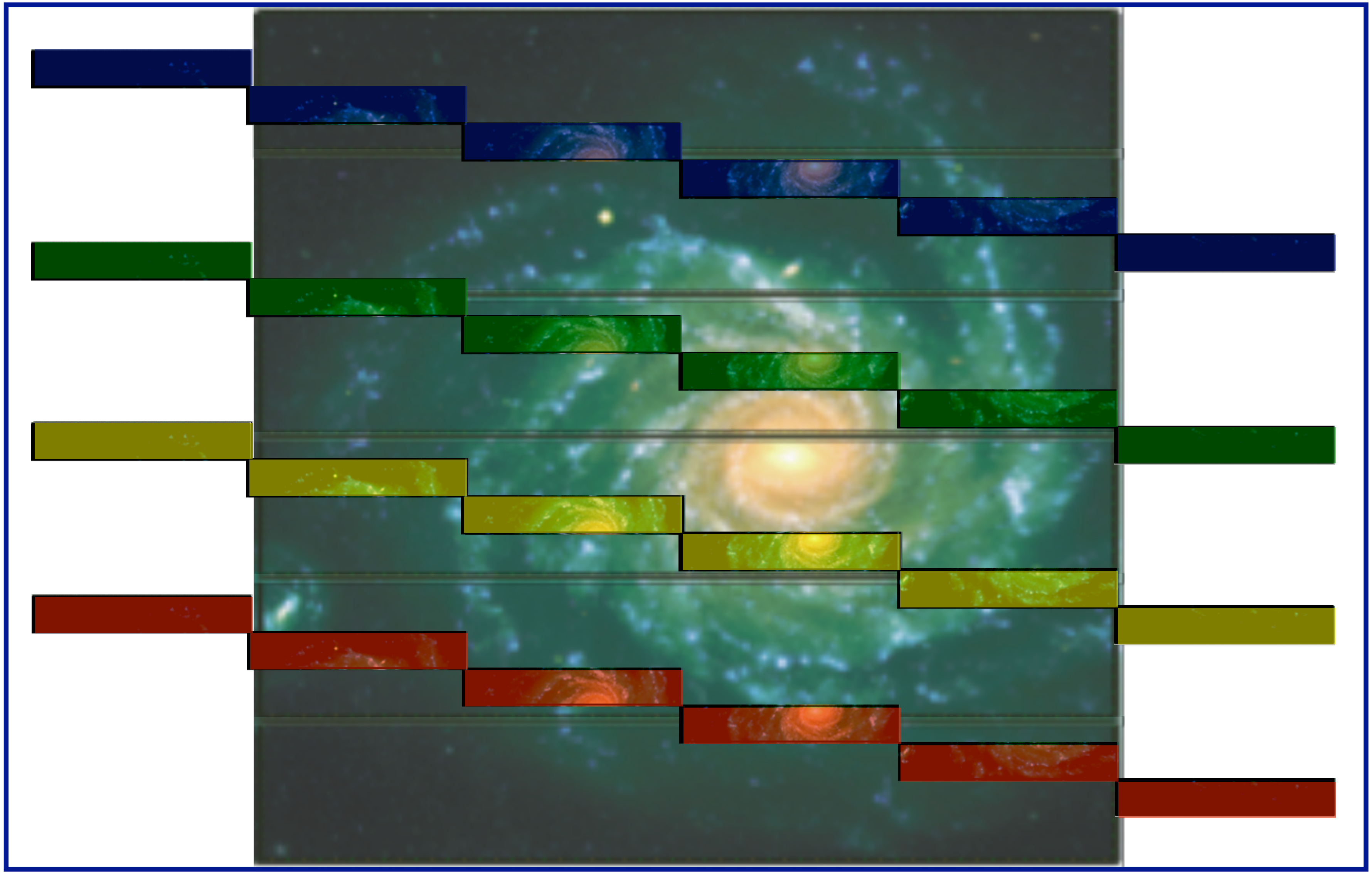


Spatially stepping a long slit spectrometer

Scanning with a Fabry-Perot interferometer

3D Spectroscopy: Data cube in a
single exposure

Slicing the Image



Principle of the Image Slicer

(used in MPE 3D, SINFONI)

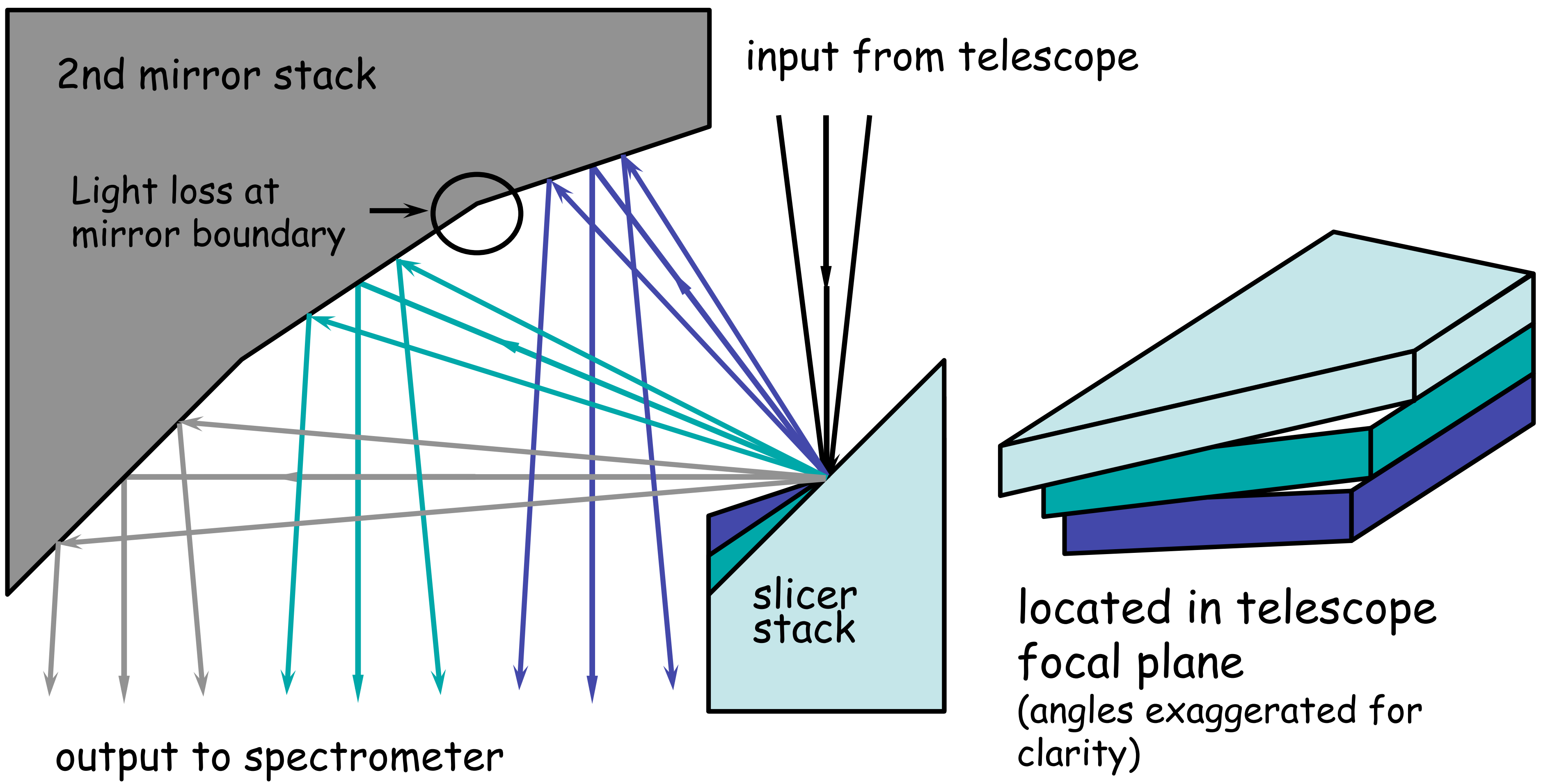
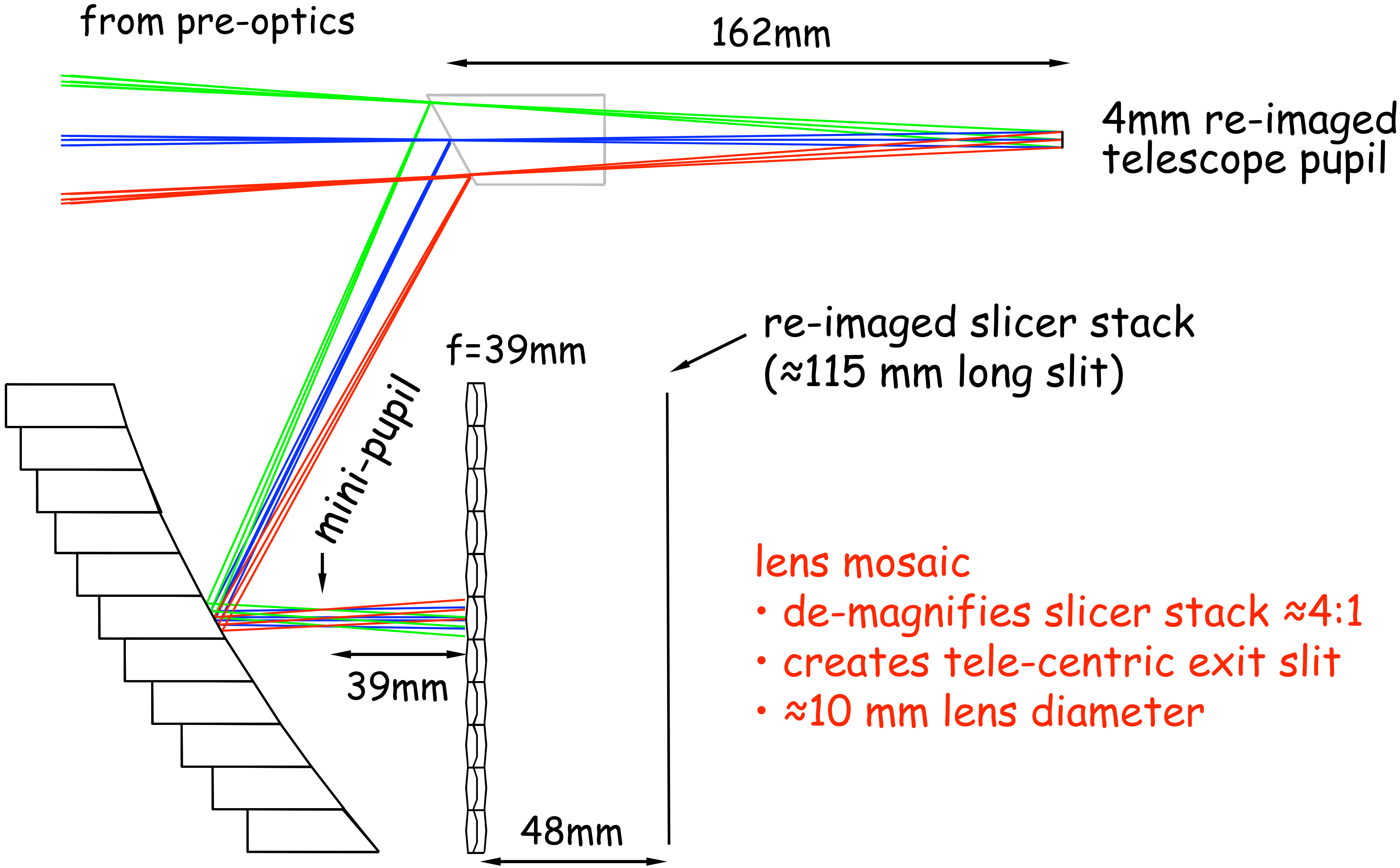


image slicer preserves the pupil of input beam

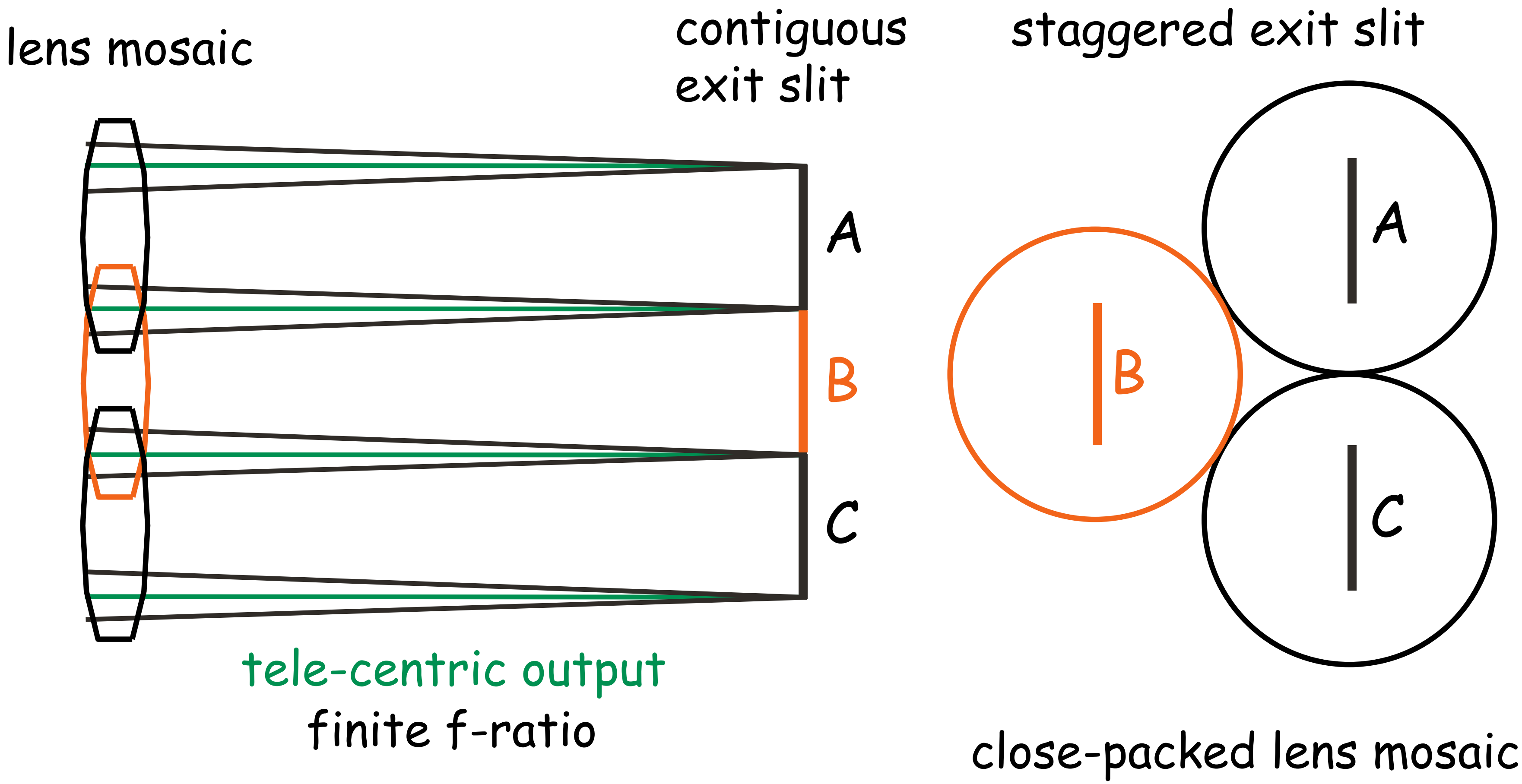
Image Slicer Demagnification



lens mosaic

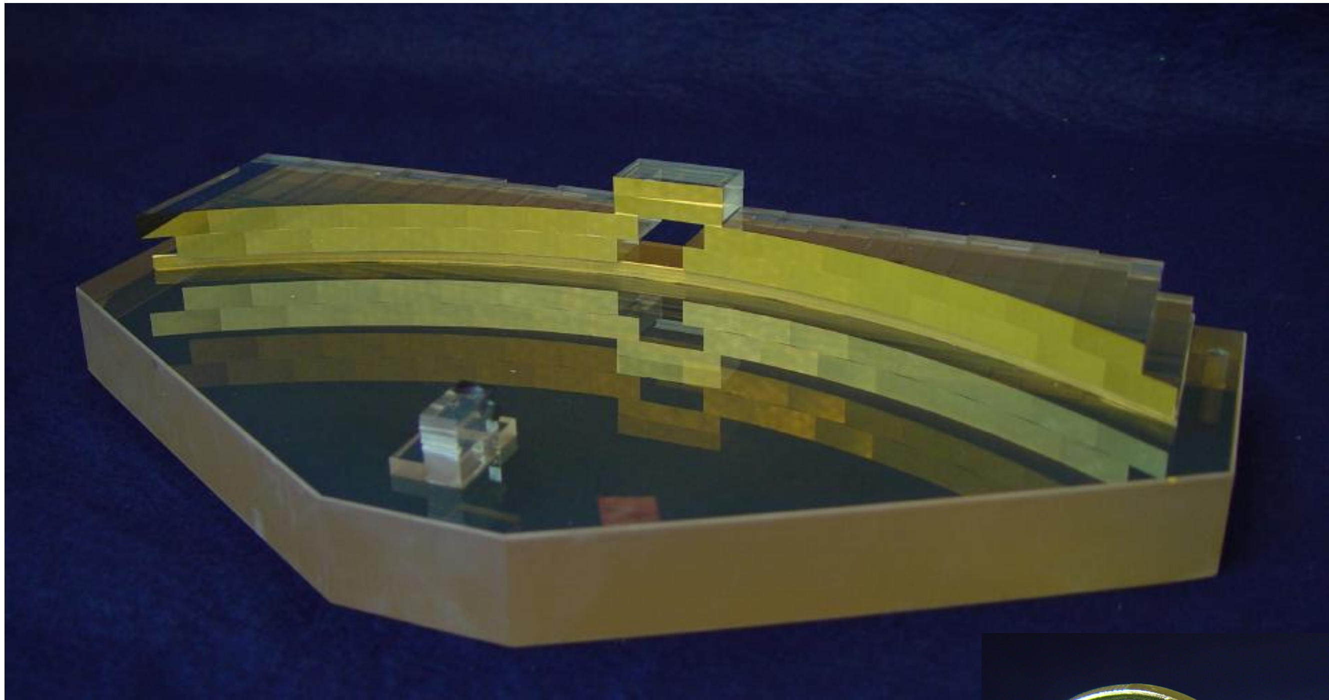
- de-magnifies slicer stack ≈4:1
- creates tele-centric exit slit
- ≈10 mm lens diameter

Principle of IFU: Brickwall pattern



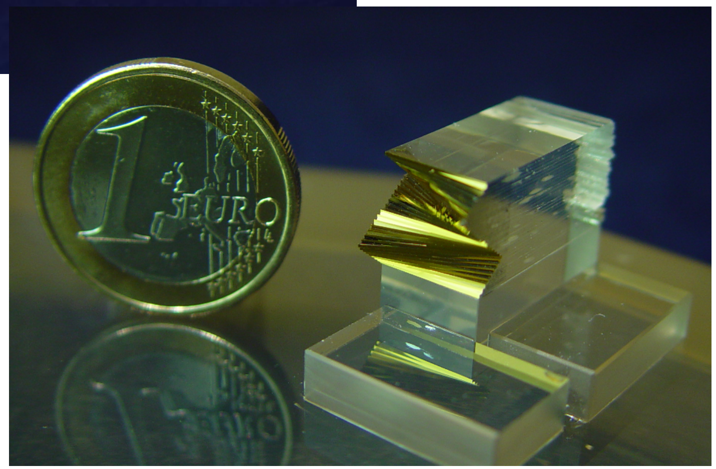
SPIFFI

Photos of the SPIFFI Slicer



SPIFFI is the integral field spectrograph that is a part of SINFONI

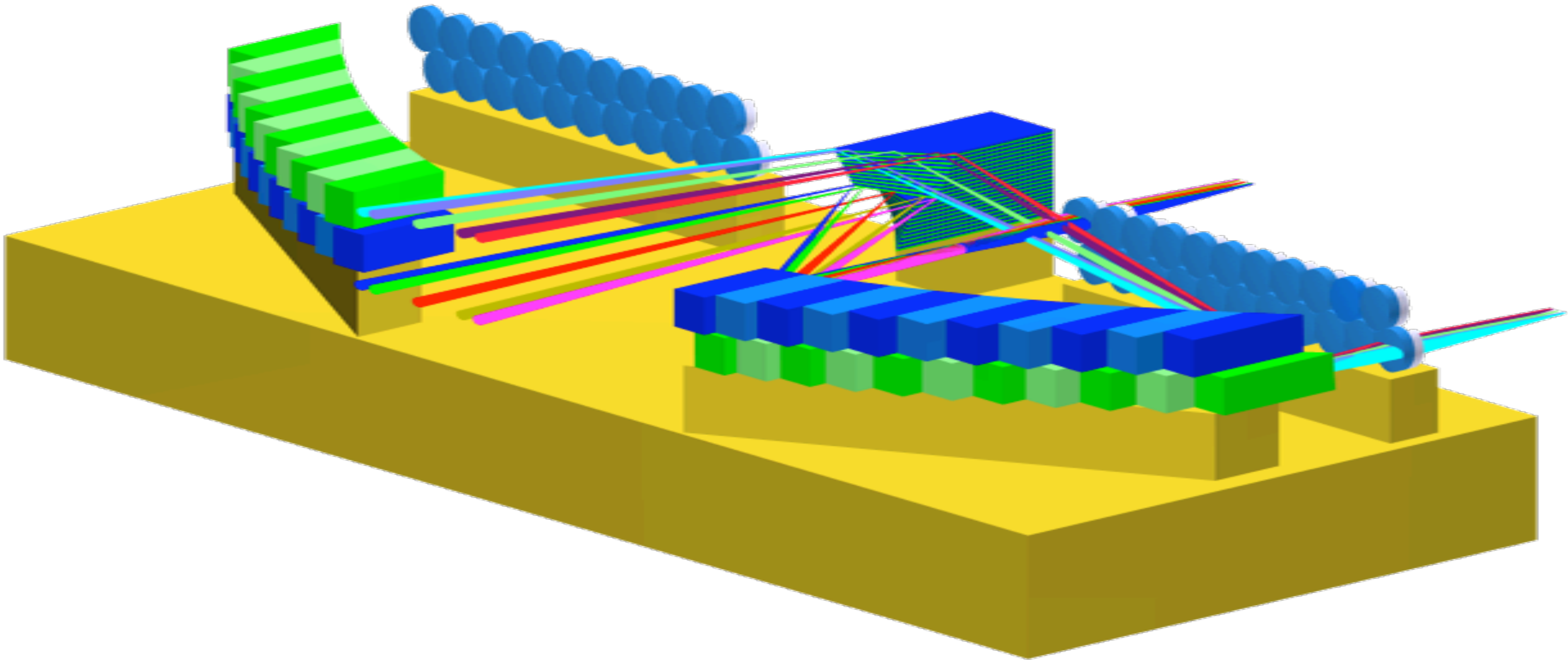
32 × 32 spaxels



>95% throughput!! (IFU), 30% overall

Tecza et al. 1998, Thatte et al. 1998

Perspective view of Slicer

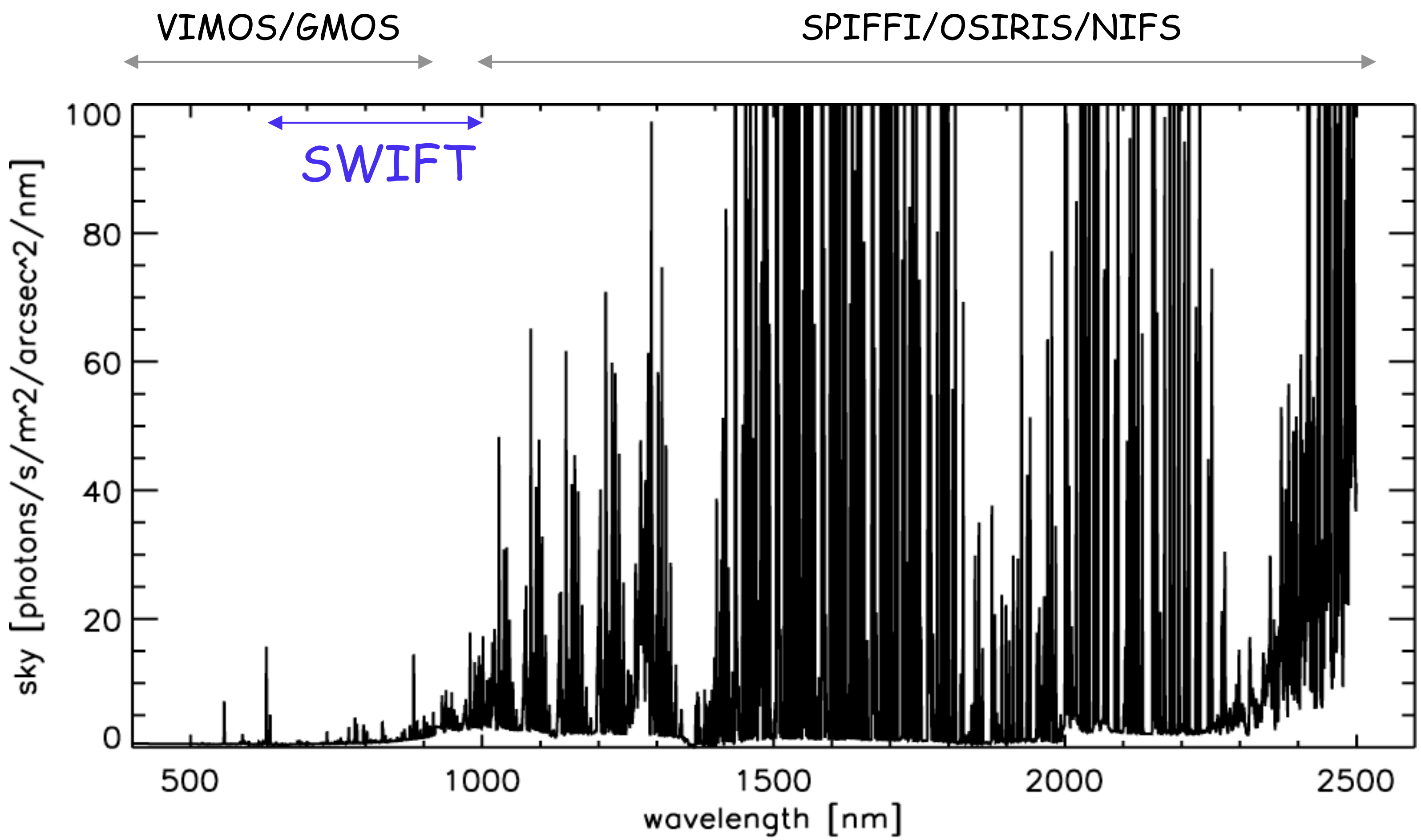


SWIFT's Uniqueness

- Conceived as a niche instrument that complements near-IR integral field spectrographs (SINFONI, OSIRIS, NIFS), but with lower sky background.

- Builds on three new developments
  1. The availability of a second generation A.O. system that provides good correction at wavelengths shortward of 1000 nm.
  2. Extremely red sensitive CCD detectors, available in large formats at a fraction of NIR detector cost.
  3. An all glass, classically polished, image slicer that provides high throughput even at visible wavelengths.

Sky background



» **SWIFT will occupy a niche between the NIR and the visible**

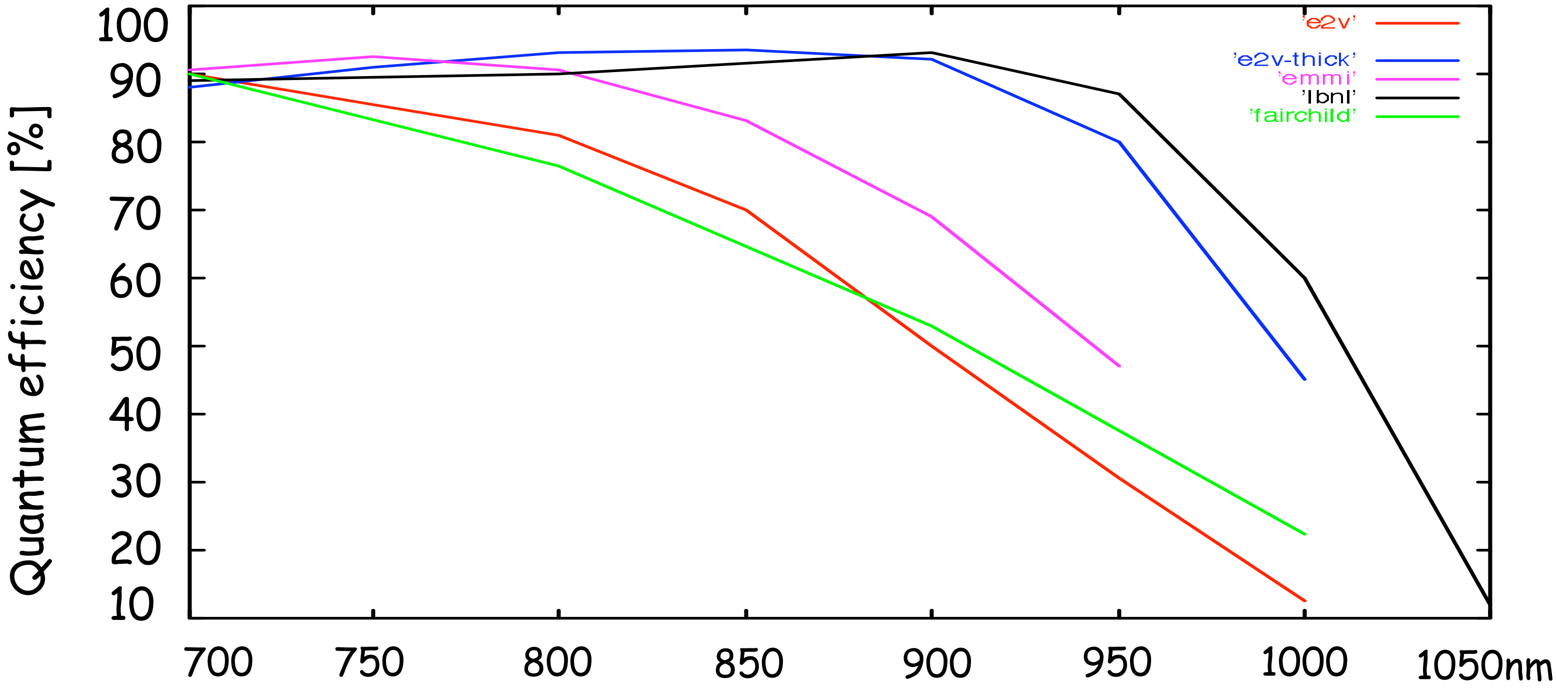
SWIFT's Uniqueness

- Conceived as a niche instrument that complements near-IR integral field spectrographs (SINFONI, OSIRIS, NIFS), but with lower sky background.
- Builds on three new developments
  1. The availability of a second generation A.O. system that provides good correction at wavelengths shortward of 1000 nm.
  2. Extremely red sensitive CCD detectors, available in large formats at a fraction of NIR detector cost.
  3. An all glass, classically polished, image slicer that provides high throughput even at visible wavelengths.

SWIFT's Uniqueness

- Conceived as a niche instrument that complements near-IR integral field spectrographs (SINFONI, OSIRIS, NIFS), but with lower sky background.
- Builds on three new developments
  1. The availability of a second generation A.O. system that provides good correction at wavelengths shortward of 1000 nm.
  2. Extremely red sensitive CCD detectors, available in large formats at a fraction of NIR detector cost.
  3. An all glass, classically polished, image slicer that provides high throughput even at visible wavelengths.

Red-sensitive CCD



- **E2V** & **Fairchild** available off-the-shelf
- **MIT/LL** chip has excellent Q.E. and low measured fringing
- **LBNL** develops SNAP chip with thick deep depletion technology
- **E2V** is developing thick deep depletion chips with Q.E. predicted to be similar to SNAP detectors

SWIFT's Uniqueness

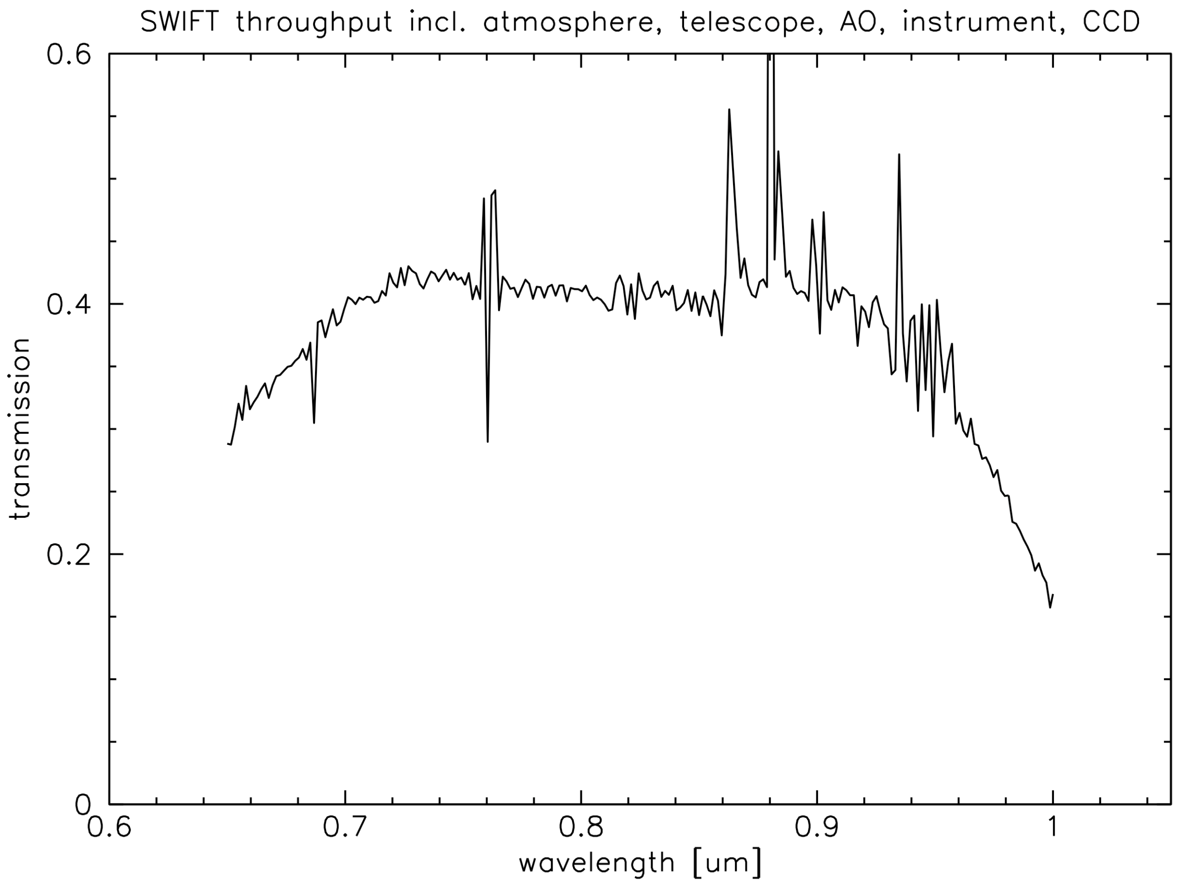
- Conceived as a niche instrument that complements near-IR integral field spectrographs (SINFONI, OSIRIS, NIFS), but with lower sky background.

- Builds on three new developments
  1. The availability of a second generation A.O. system that provides good correction at wavelengths shortward of 1000 nm.
  2. Extremely red sensitive CCD detectors, available in large formats at a fraction of NIR detector cost.
  3. An all glass, classically polished, image slicer that provides high throughput even at visible wavelengths.

Instrument overview

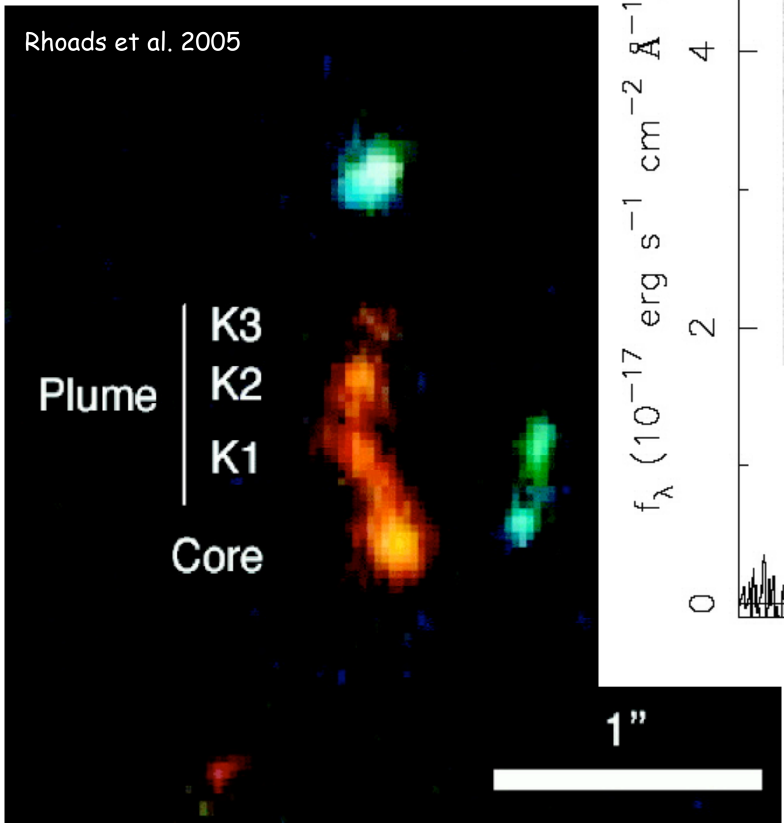
- I/z band integral field spectrograph mounted behind PALAO
  - Image slicer with 44x89 pixels (~4000 simultaneous spectra)
    - 0.235"/pixel giving 21" x 10" field of view
    - Also 0.160" and 0.080" pixel scales
  - Twin spectrographs after slicer
    - Fixed spectral formal, 650-1020nm at R~4000
    - Optional 750 nm dichroic for fainter guide stars
  - Thick LBNL CCDs (2k x 4k) with QE>80% at 950nm
  - Very high throughput, 50% excl. AO & detector (SINFONI 35%)

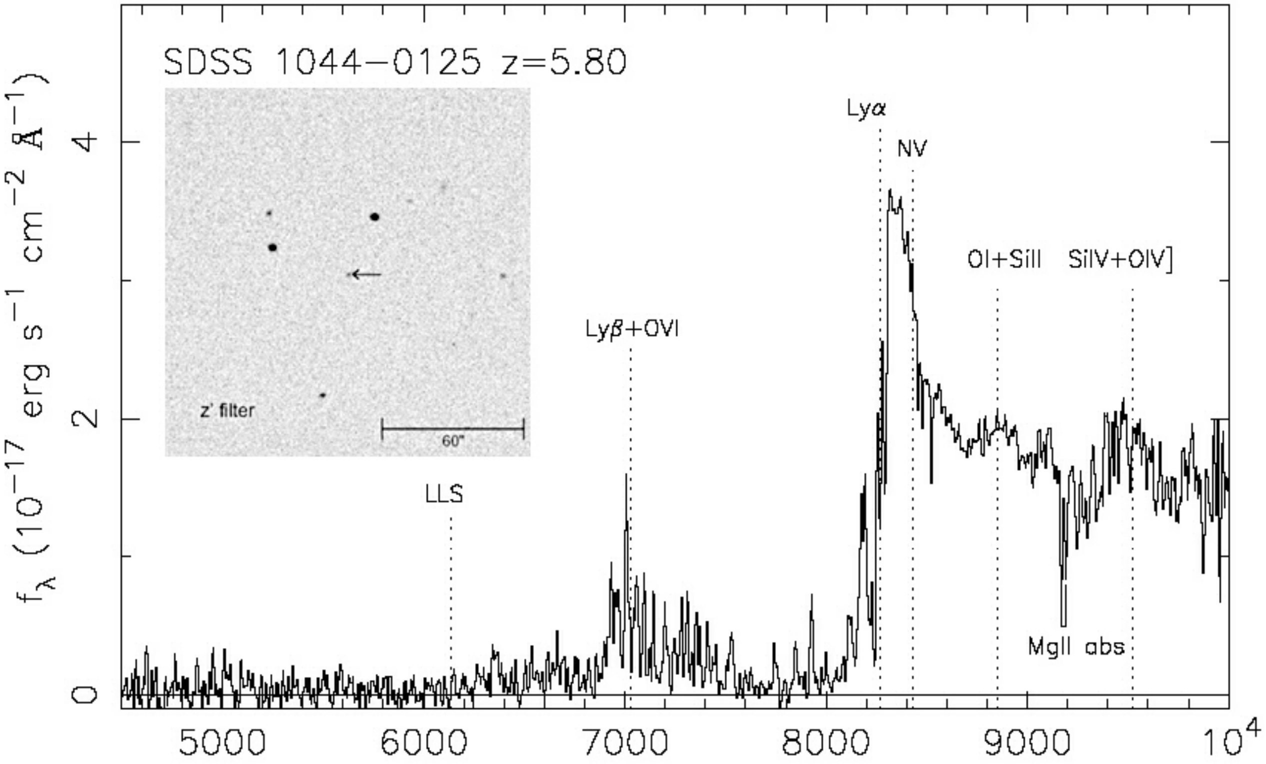
SWIFT Throughput measurement



Key Science Cases

Kinematics and dynamics of Ly-alpha emitters (SF & QSOs) at 5 < z < 7

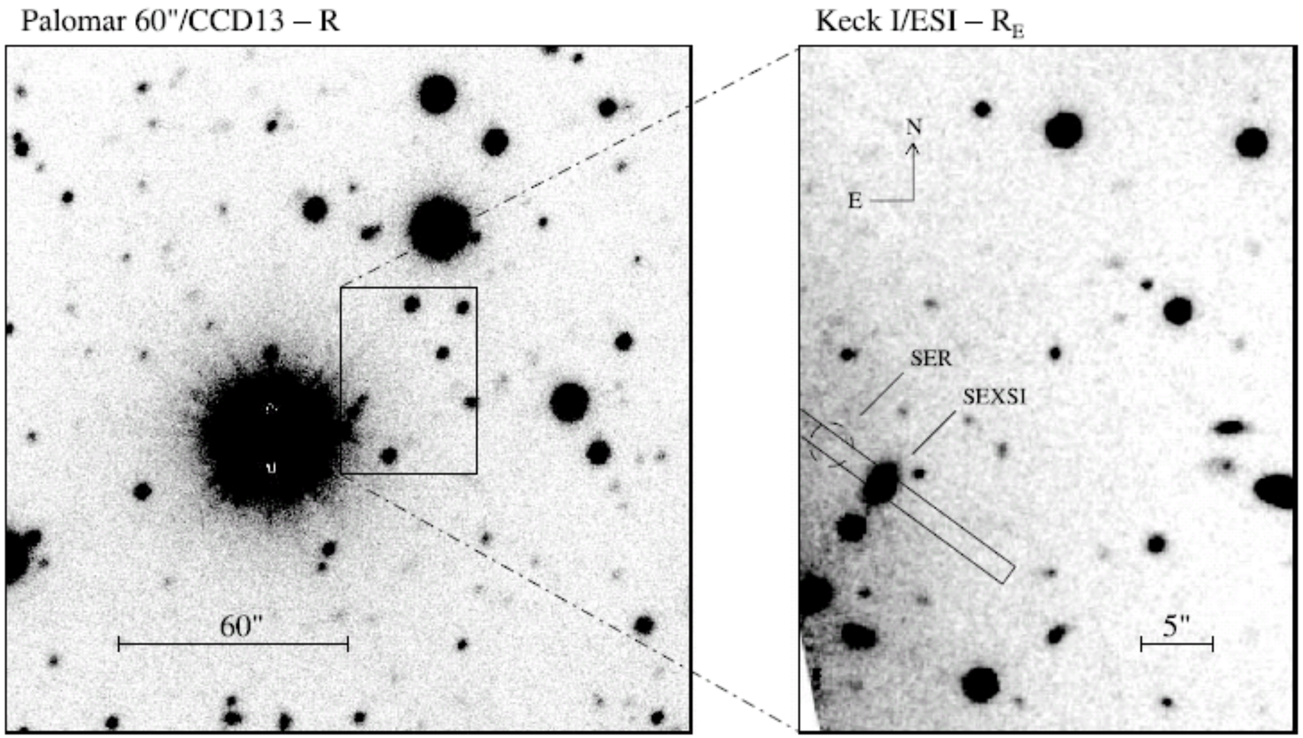




Fan et al. 2000

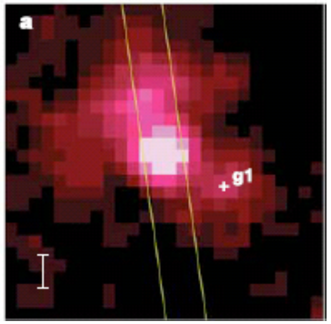
Ly alpha (contd) (4.34 < z < 7.2)

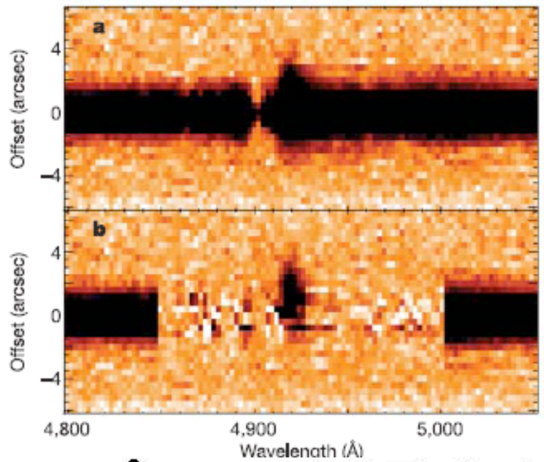
- A few Ly α emitters known to be spatially extended - e.g. Rhoads et al. 2005, LAE J1044-0130 (2.1" intrinsic size deduced by Ajiki et al. 2002), Stern et al. 2005 – target for NGS A.O



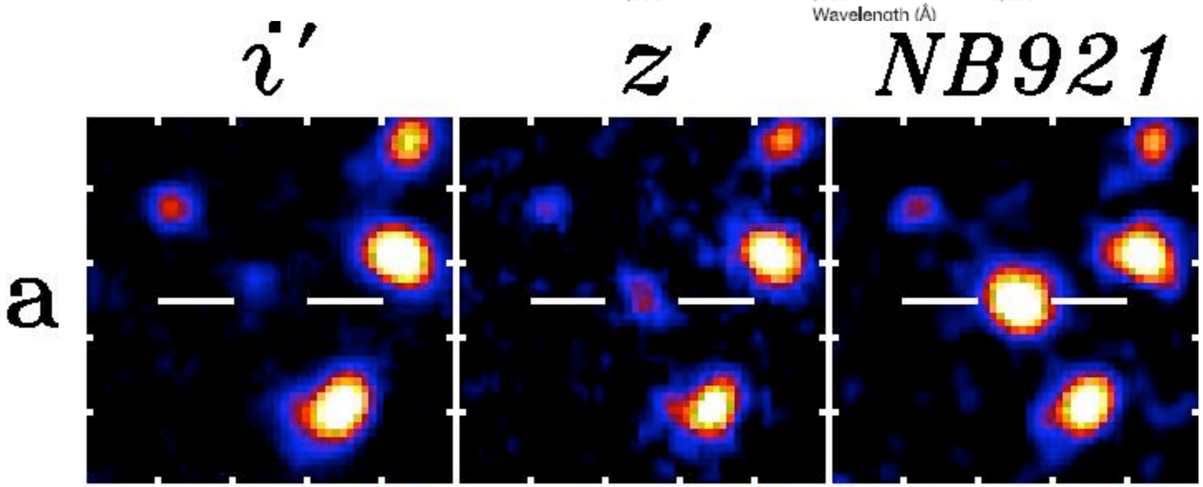
Ly alpha (contd) (4.34 < z < 7.2)

- Kinematics and dynamics to distinguish between infall in CDM halo and superwind in Ly α haloes





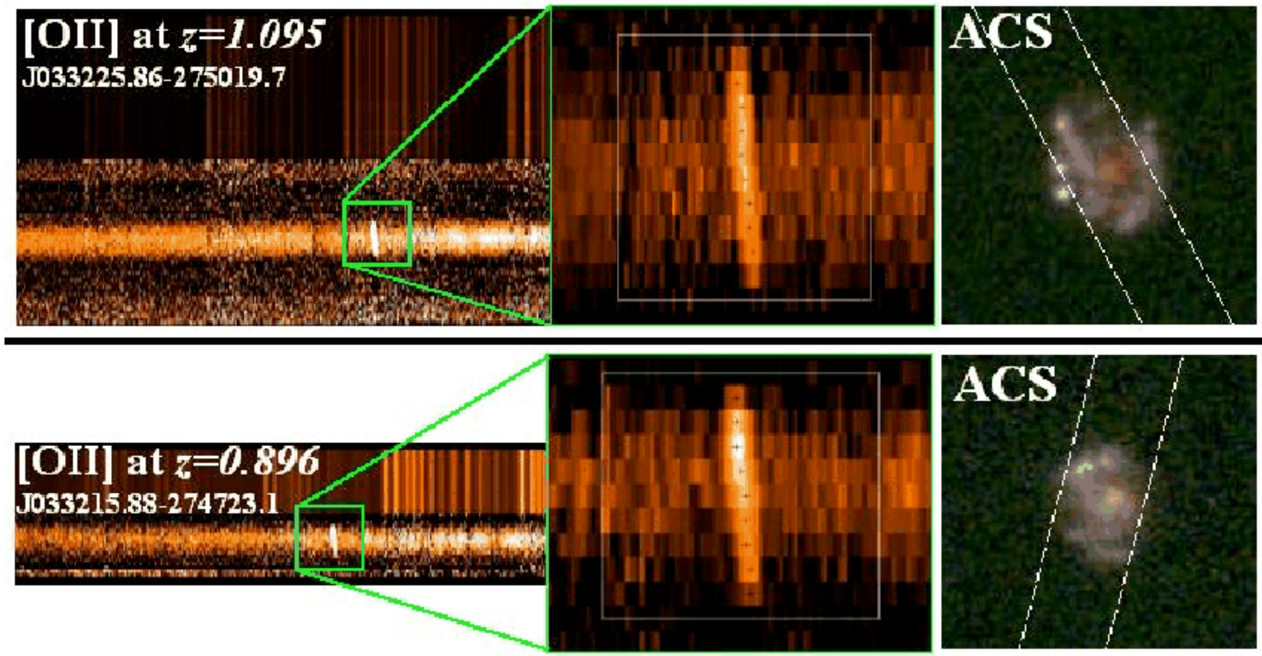
Weidinger et al. (2004)



Kodaira et al. (2005)
Target for 2009A

Probing the redshift desert

Project being pursued with PALAO, to be expanded with PALM3K



Rotation curves and dynamical masses out to z = 1.7 (probing the redshift desert)

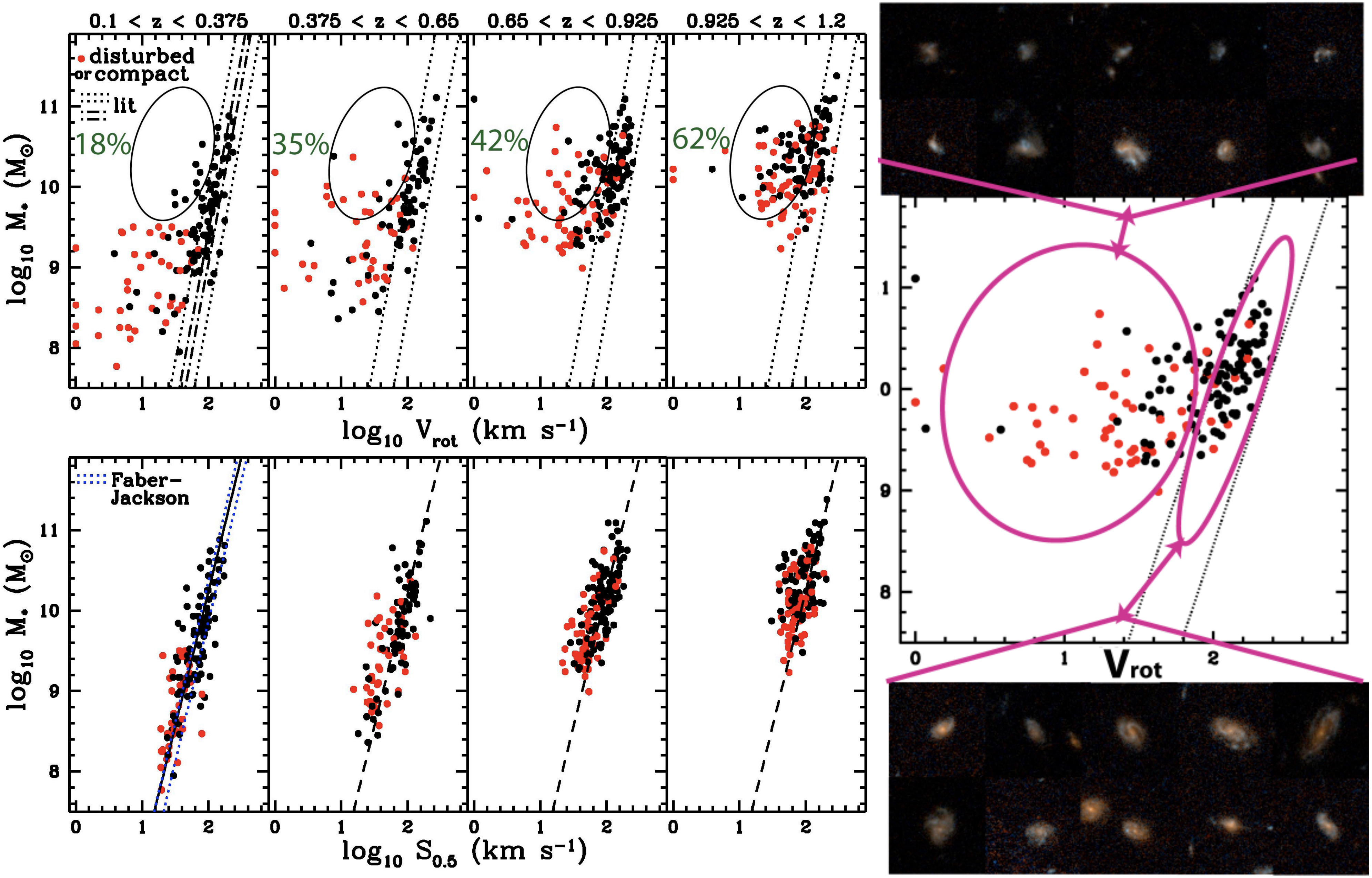
Vanzella et al. 2005

Small source size needs P3K to increase number of resolution elements across disk

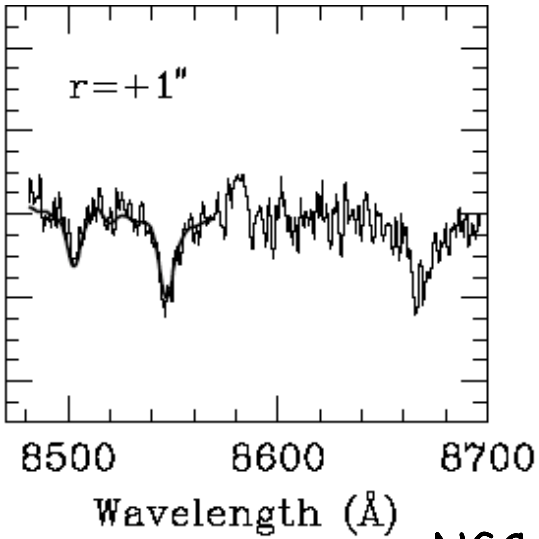
Advantages of using IFS

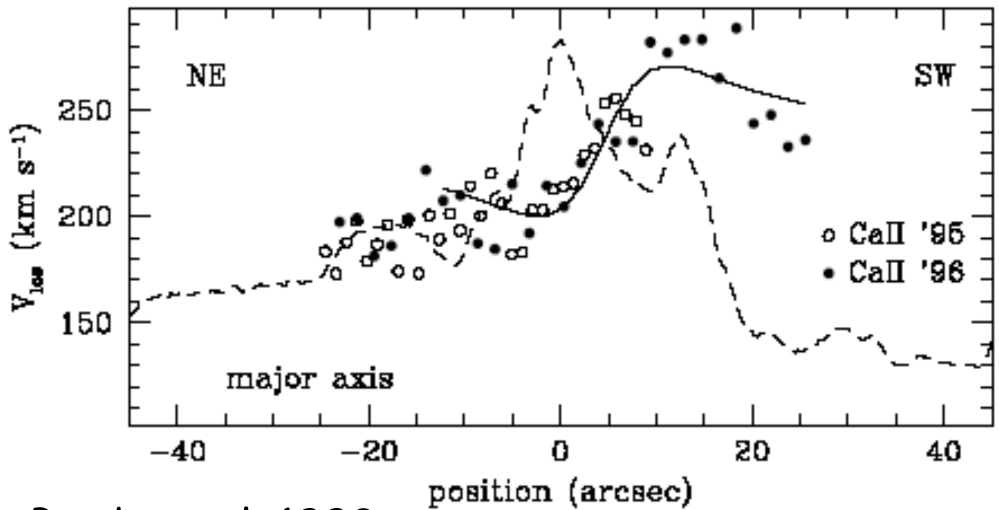
- No a-priori knowledge of kinematic major axis, inclination, etc. required
- Accurate slit positioning not required
- Azimuthal mean has high SNR and insensitive to HII regions

Probing the redshift desert



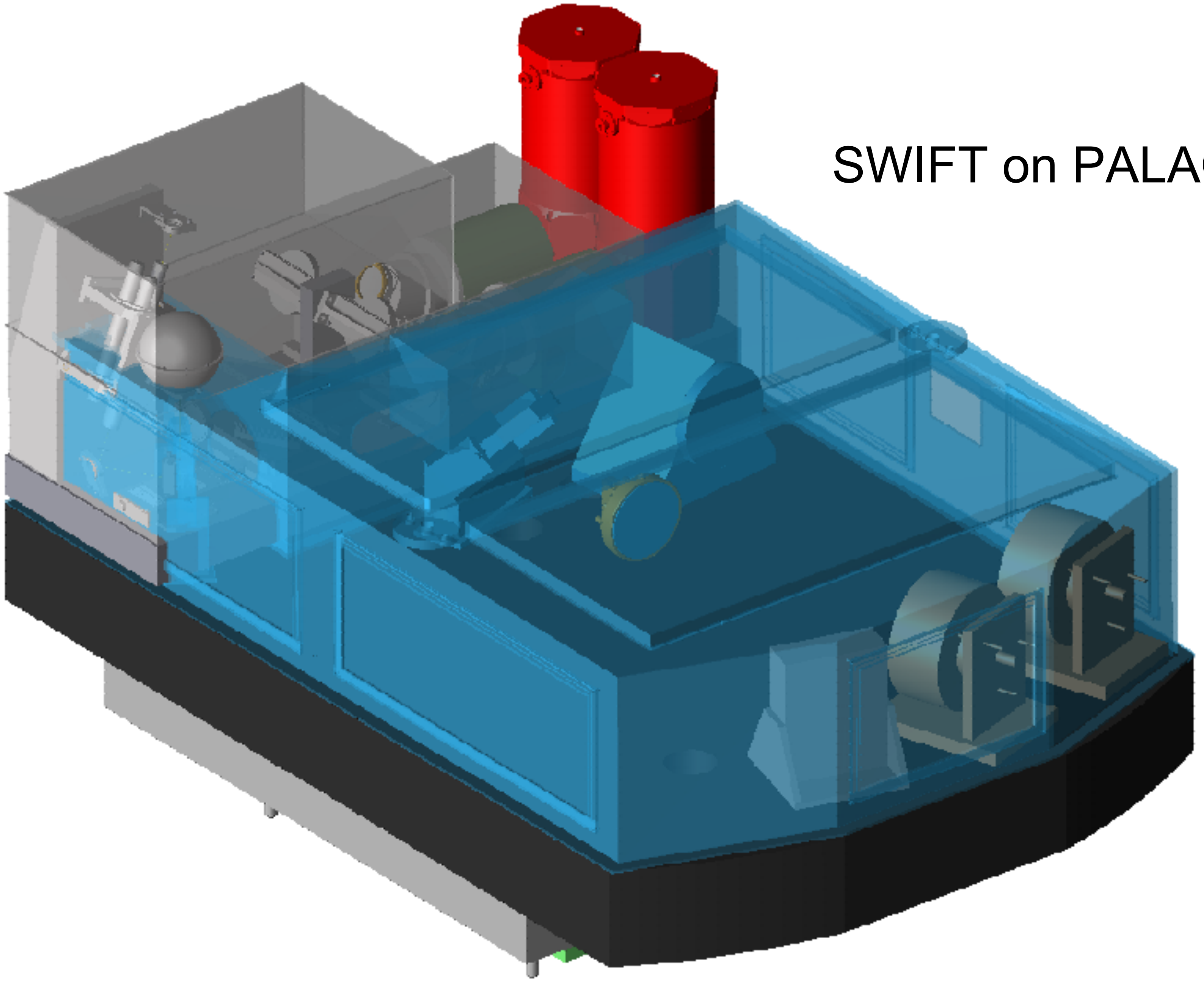
SMBH masses with Ca triplet





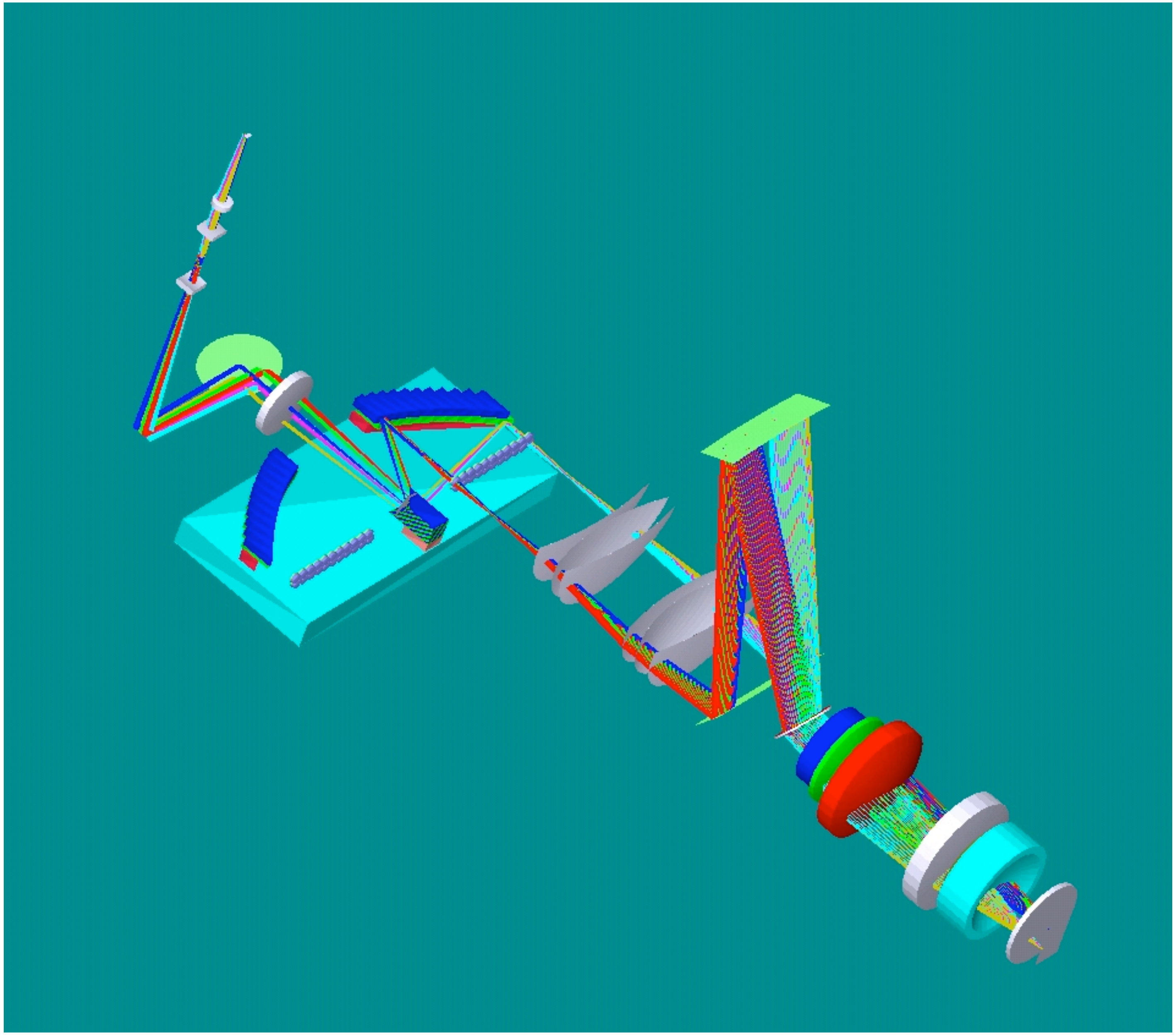
NGC 253: Prada et al. 1998

- Stellar dynamics in the innermost regions of nearby galaxies (Ca II triplet) ⇒ mass estimates for nuclear super-massive black holes
- Palomar 5 m at 0.87 μm ≡ 36 mas, compared with 59 mas for the ESO VLT (8 m) at 2.29 μm
- Can study objects out to z = 0.15

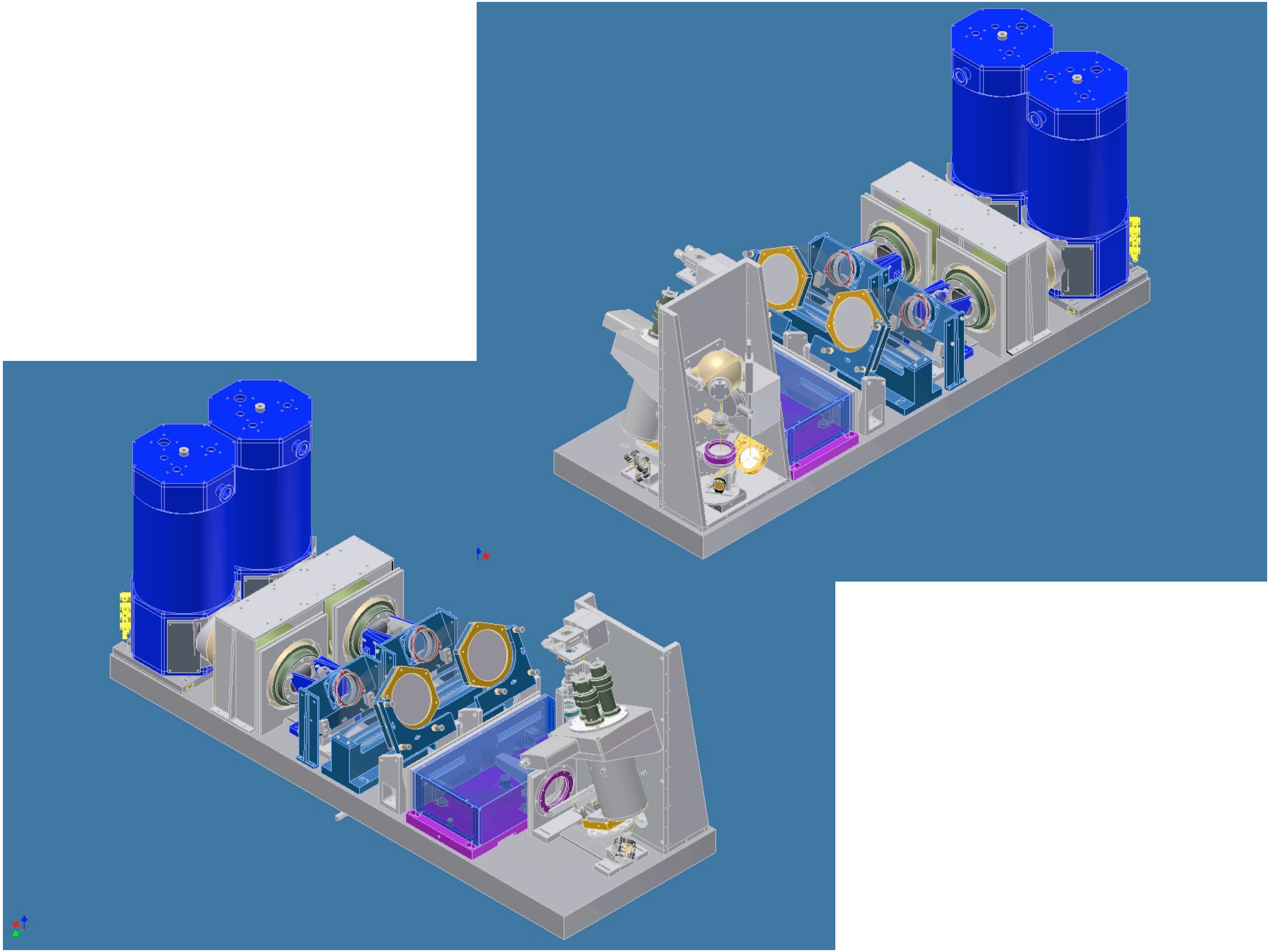


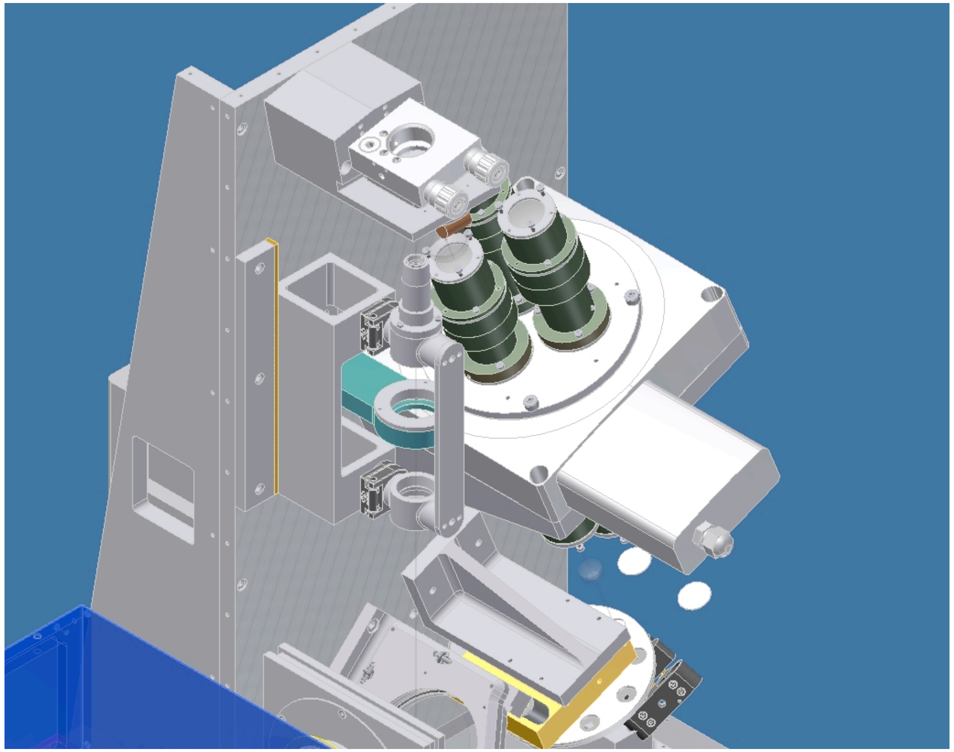
SWIFT on PALAO

Opto-mechanical Layout

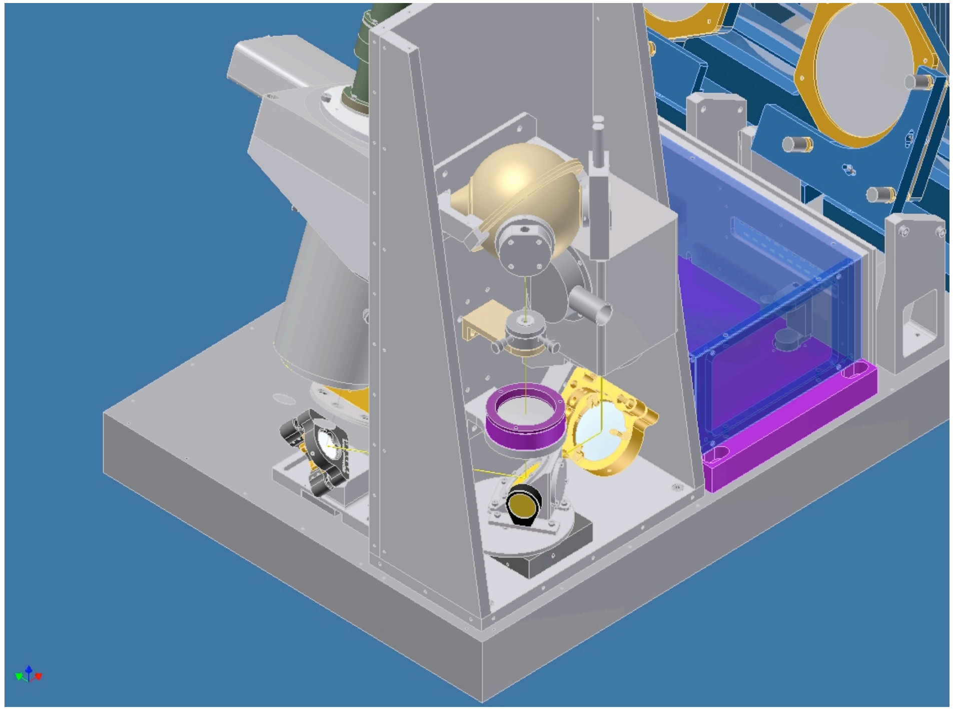


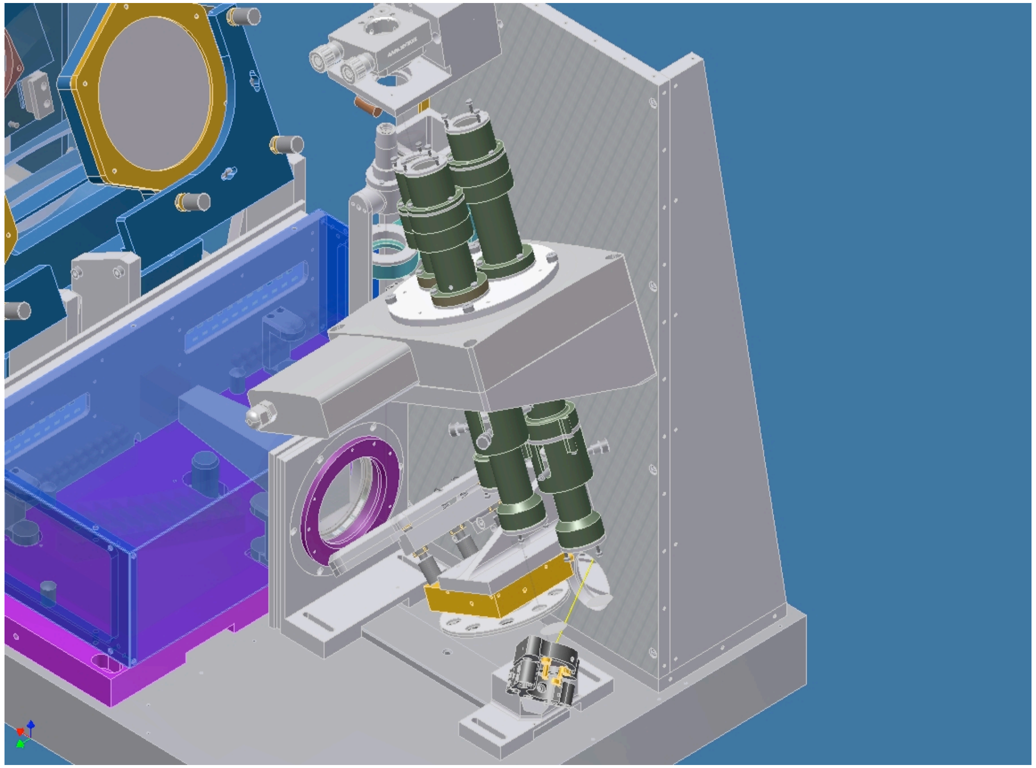
- Only one arm of twin channel spectrograph shown
- Each spectrograph disperses on to a 2048 × 4096 detector array

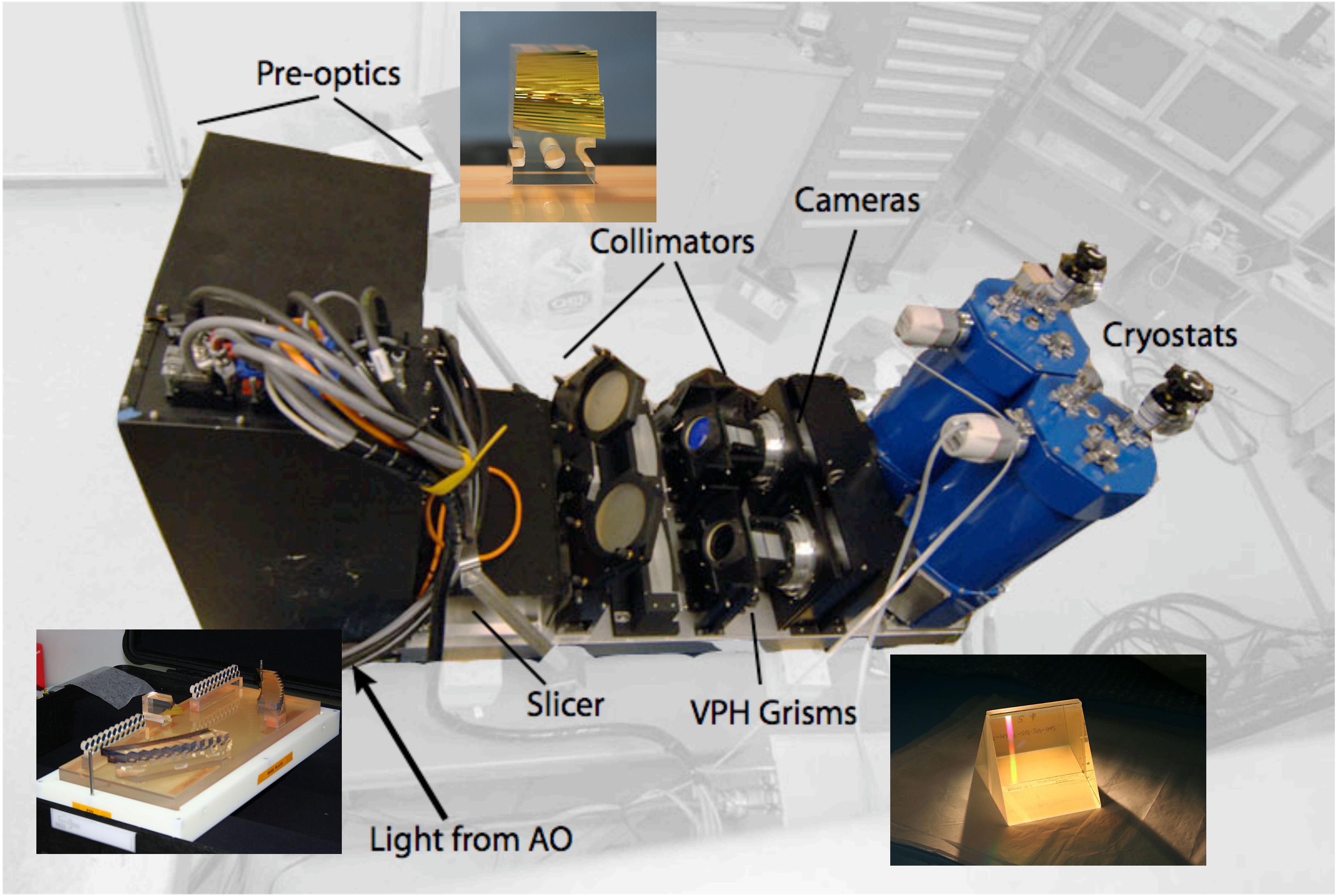




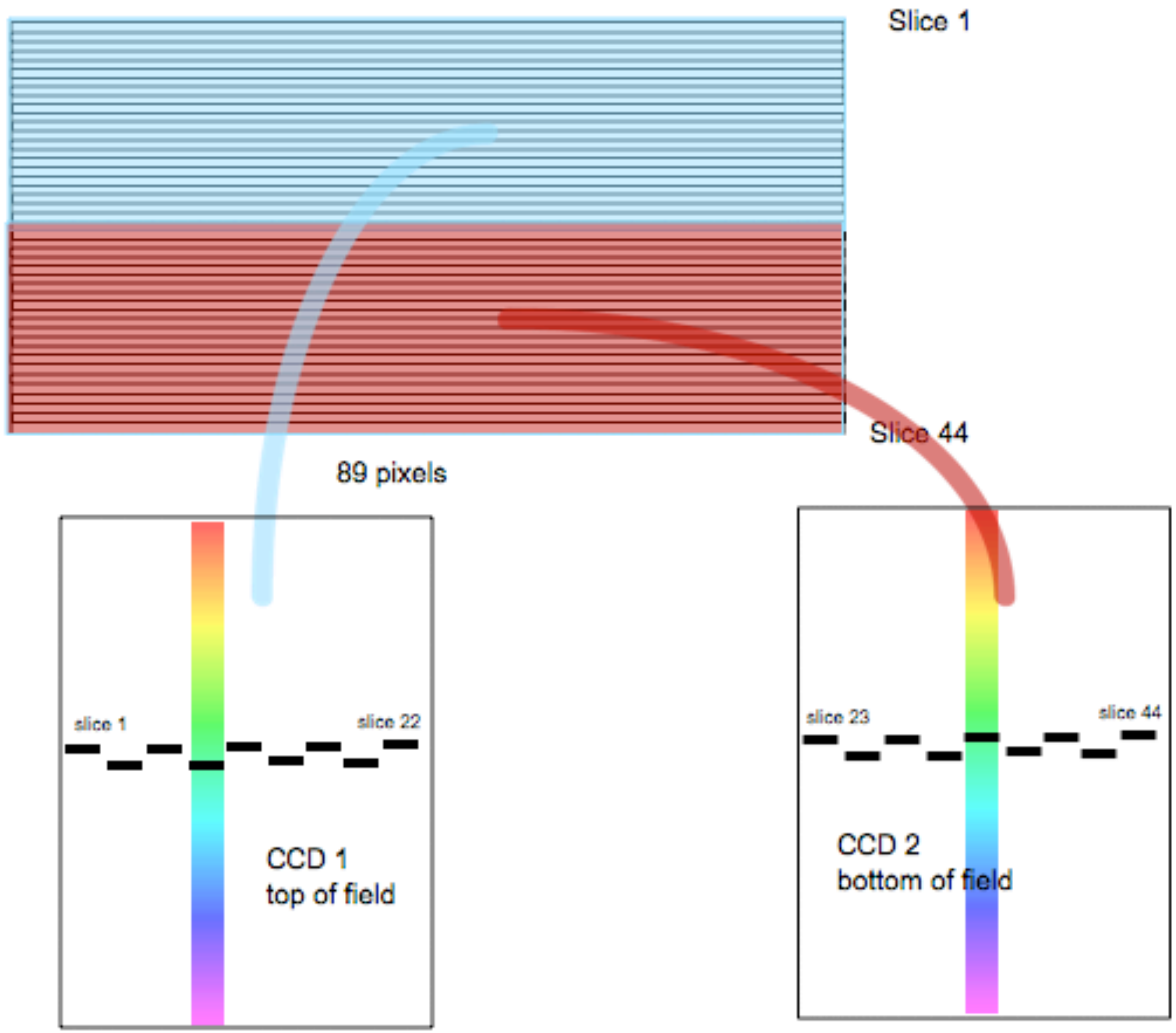
SWIFT Pre-optics and Calibration Unit

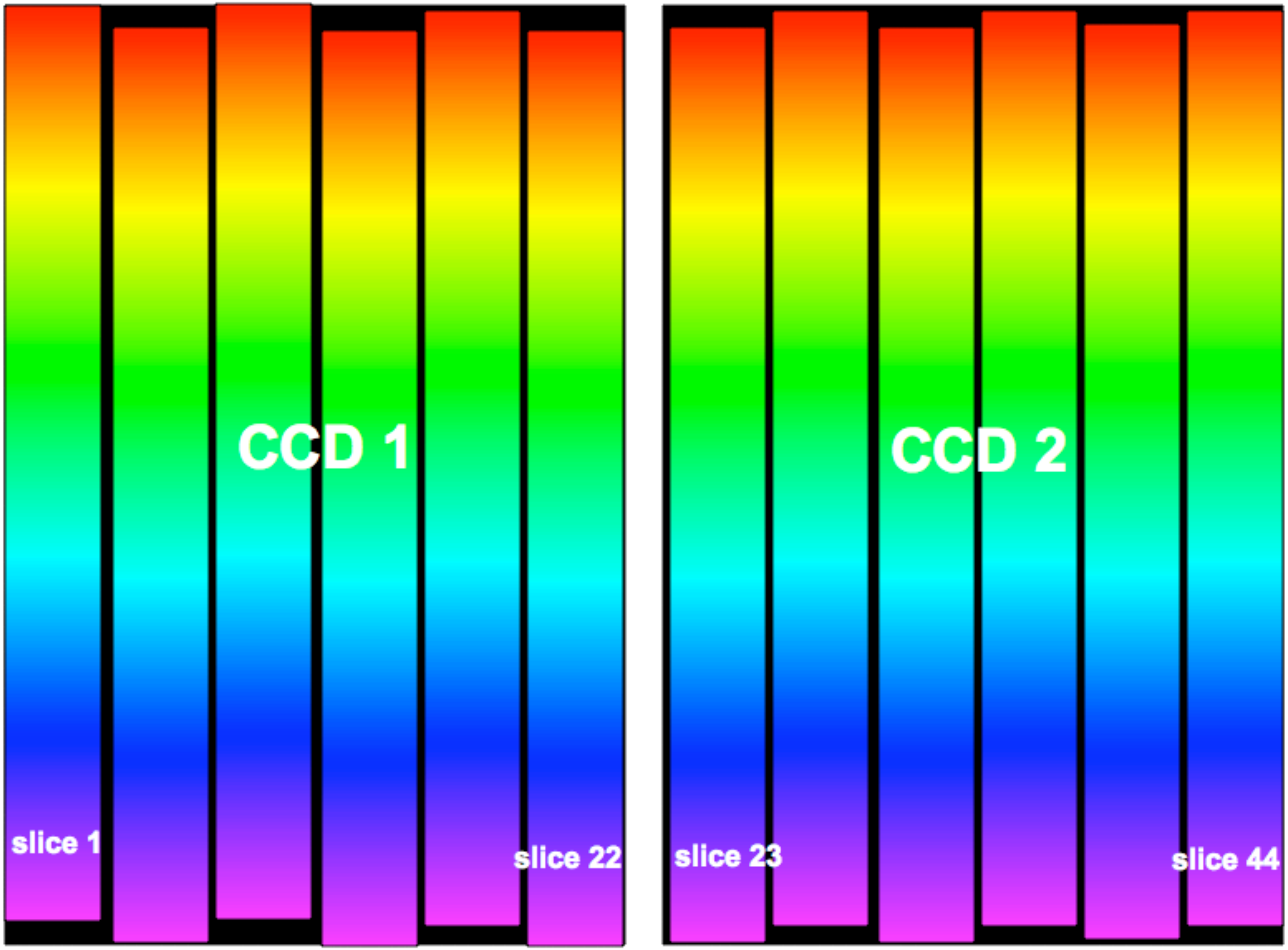





Pre-optics
Cameras
Collimators
Cryostats
Slicer
VPH Grisms
Light from AO

Spectral format on detector





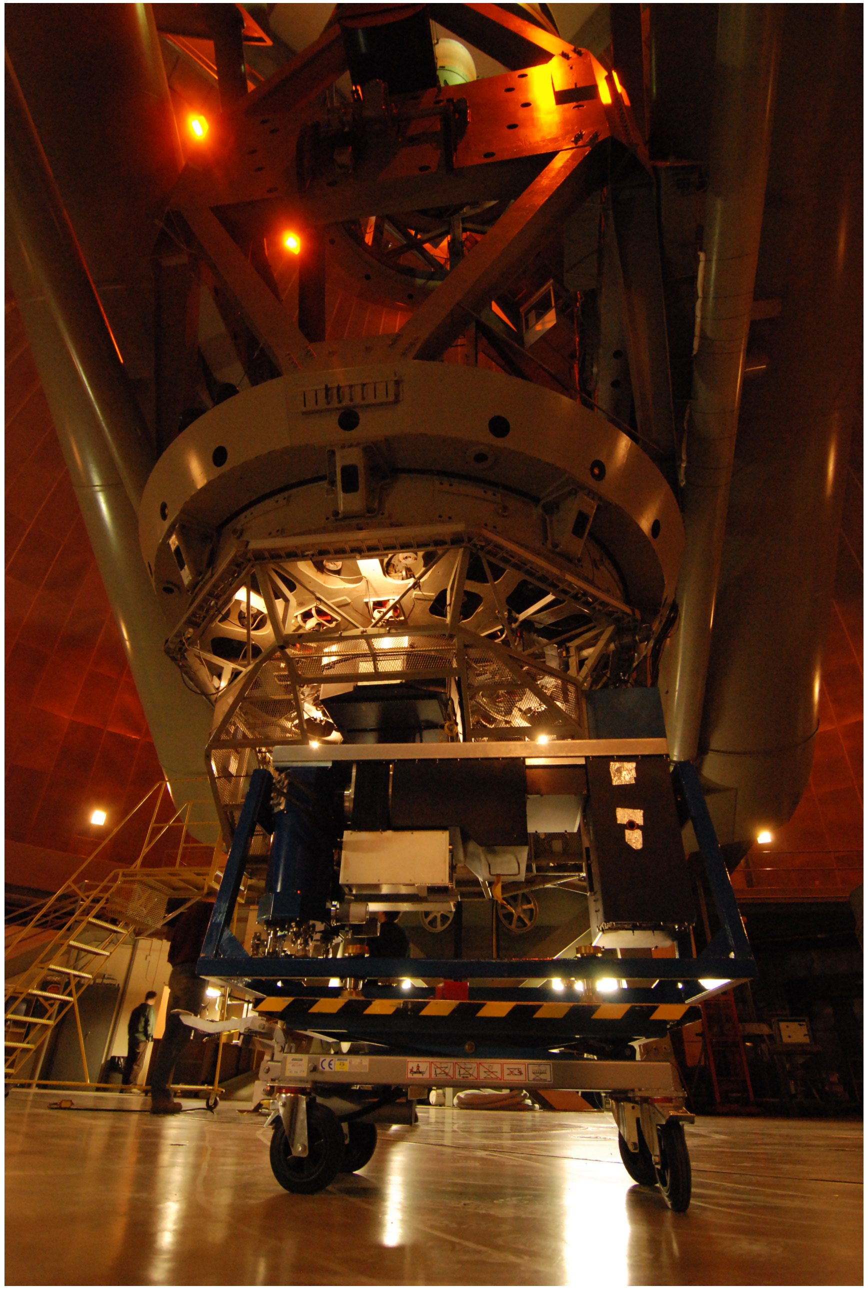
CCD 1
CCD 2
slice 1
slice 22
slice 23
slice 44

Installation and commissioning

- Instrument arrived at Palomar on 17th September
  - Team arrived 22--26th September
- 2 weeks of installation and testing in the AO lab at Palomar

- Commissioning on sky 10-14th October
  - Officially 2 commissioning nights and two science nights
- Four nights each scheduled in December and January for science observations

SWIFT @ 200 inch



SWIFT Weather Summary.

- Weather/Seeing Oct (10th-13th)
  - 4NGS 1/2LGS
  - 1st night, high winds, dome not opened.
  - 2nd night, open all night.
  - 3rd night, dome closed at 10UT due to dust.
  - 4th night, dome closed all night due to dust.
  - 5th (1/2) night (LGS). Dome open.
- Weather/Seeing Dec (10th-13th)
  - 2NGS and 2LGS nights
  - 1st night (NGS), very cloudy. Seeing ~2"
  - 2nd night (LGS but postponed), very thick cloud. Seeing ~2".
  - 3rd night (LGS but LOWFS trouble so only for 1st 1/2 night), closed in second 1/2. Seeing 4-5"(!)
  - 4th night (NGS) not open due to snow.
- Weather/Seeing Jan
  - 2NGS 2.5LGS
  - 1st 1/2 night (LGS) mostly tests.
  - 2nd night (LGS) seeing 2-4" so LGS not run. Light cloud for 1st 1/2 night.
  - 3rd night (LGS) Seeing 3.5" so no LGS.
  - 4th night (LGS but cancelled for FAA) seeing 1.6"-2.4".
  - 5th night (NGS) Seeing 1.6"-1.8". Closed for 4hrs due to dust.

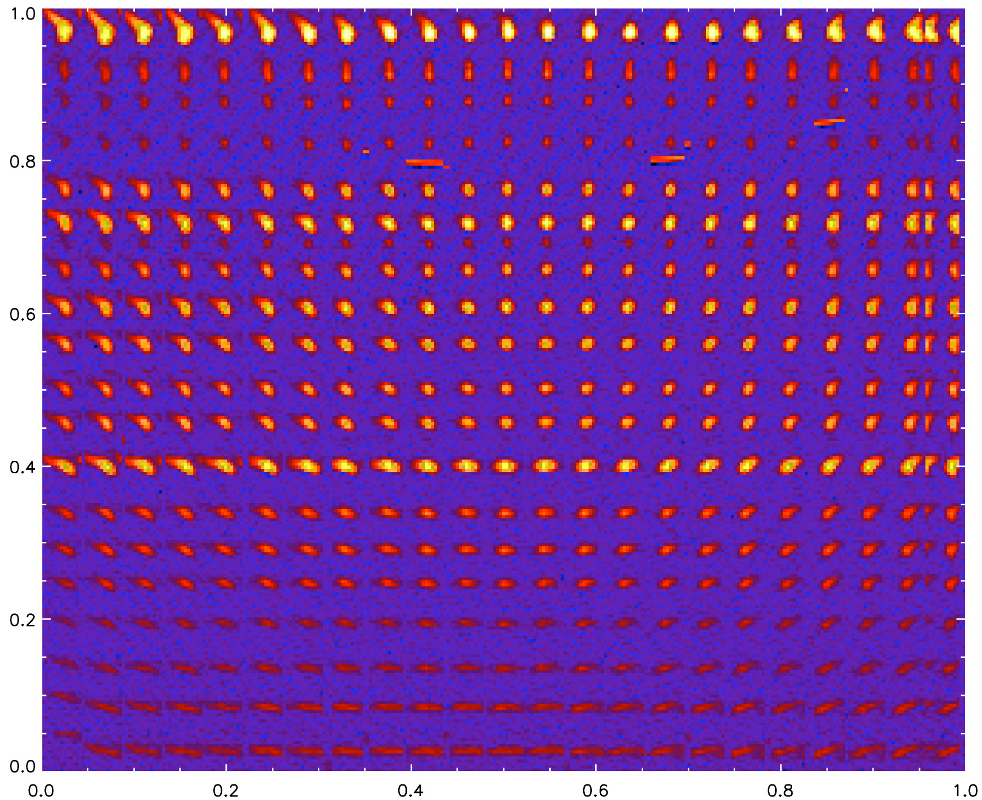
Key Issues after first run

- Detector noise
  - Detector read noise at commissioning run was 30e-, significantly higher than goal (5e-)
    - Limited science capability, but did not affect ability to commission instrument on sky
  - Tim Goodsall spent several weeks at Caltech after the commissioning run to work with Roger Smith/detector group on improving performance.
  - Read noise has now been reduced to 3-4e^-

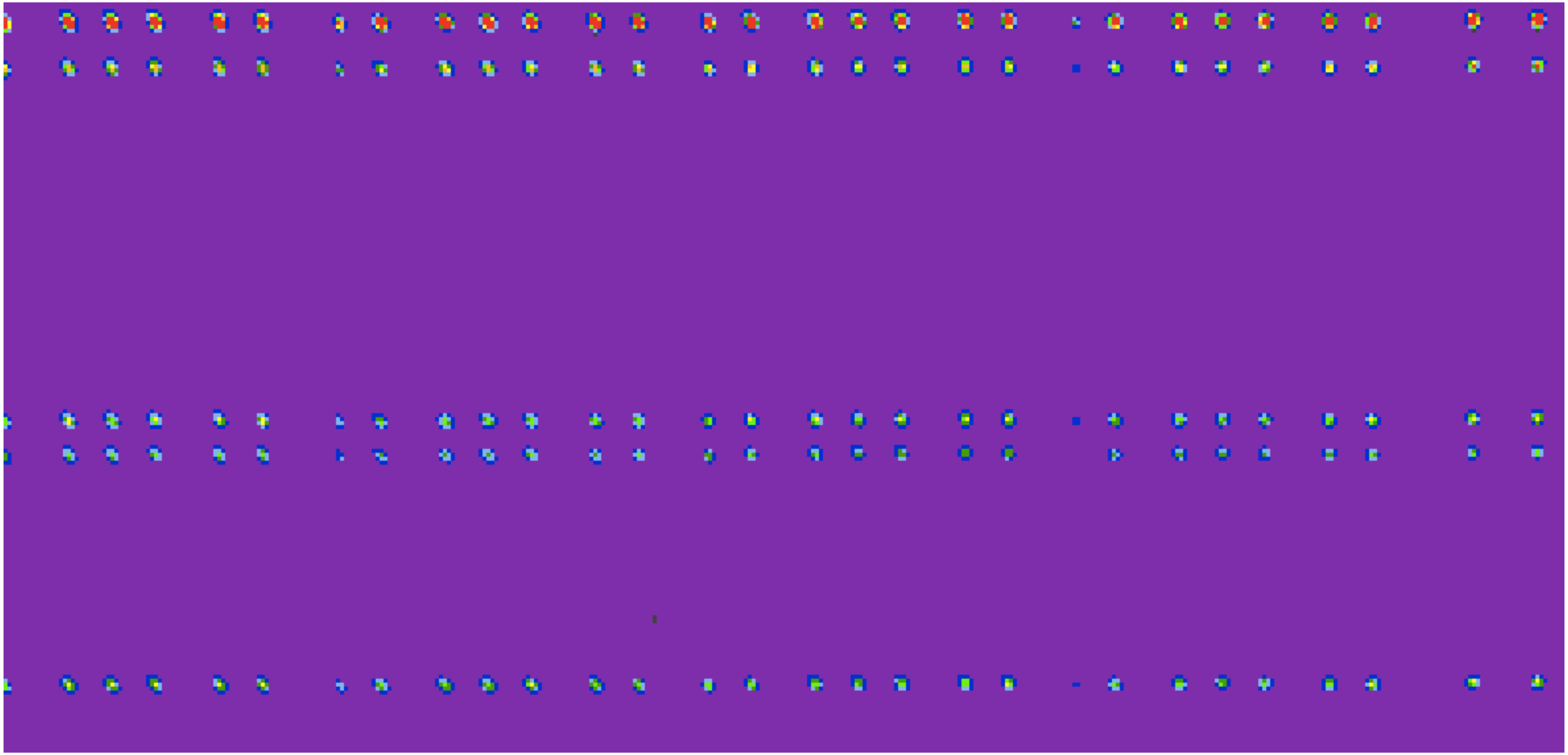
Key Issues

- Spectrograph PSF
  - PSF showing unacceptable amount of aberrations, esp. at corners of detector. Acceptable performance within central part, translates to a more limited wavelength range, and smaller FoV (1 strip on each channel)

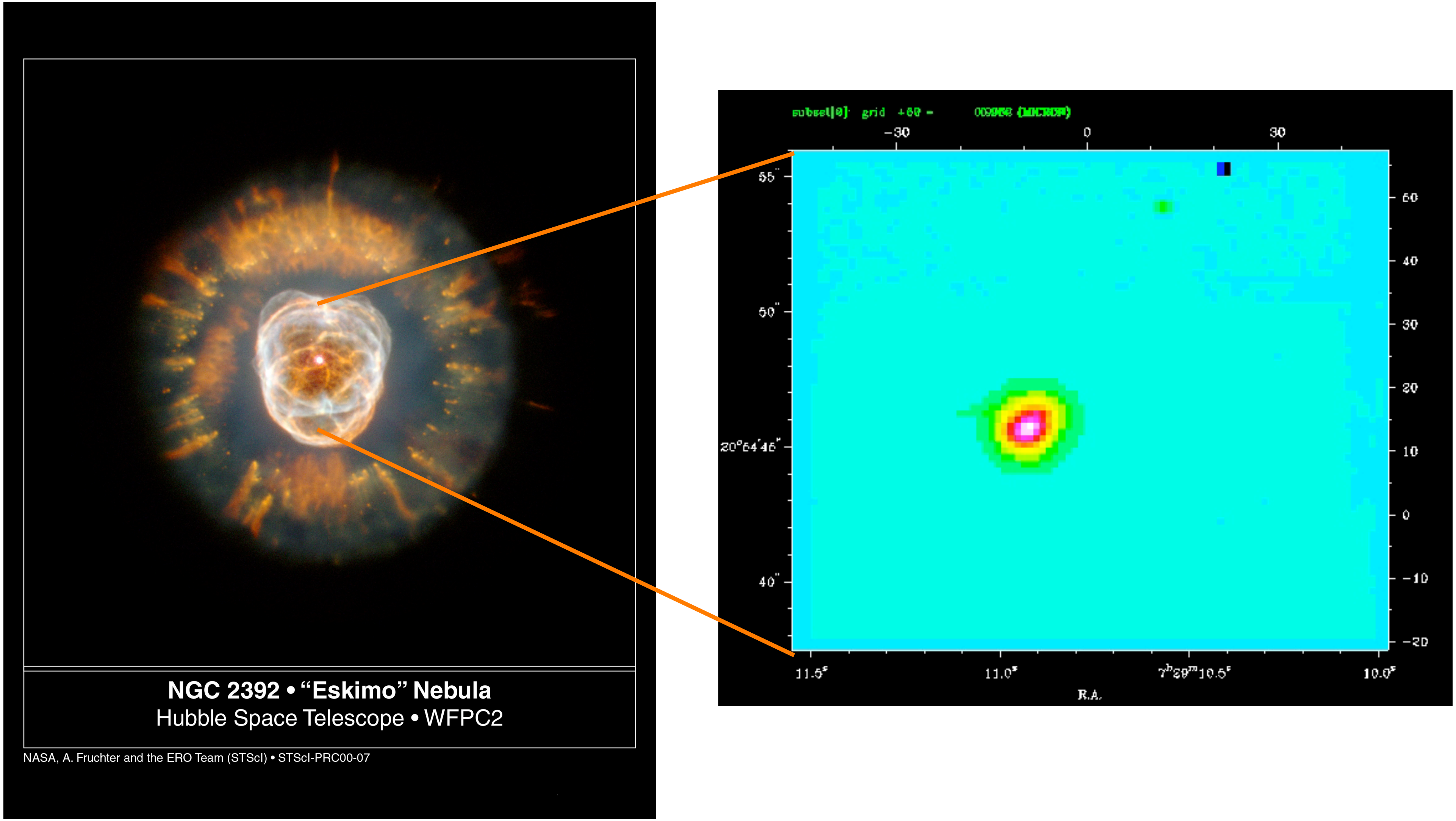
– cameras shipped back to Oxford, tested interferometrically, spacing between lenses fixed, and re-installed prior to the 09A observing run (ongoing) – hard work by M. Tecza to get cameras fixed.



Improved SWIFT camera PSF



First results, the Eskimo Nebula



Summary

- Commissioning progressed smoothly, but on-sky time in 08B mostly weathered out.
- Operation with LGS successfully demonstrated
- Few critical issues, all now closed.
  - Read out noise reduced to normal operating levels
  - Spectrograph PSF dramatically improved, no longer an issue.
  - High throughput and detector Q.E. demonstrated
  - Pipeline now running (thanks to R. Houghton)
- First regular science use in 09A (end-Apr to early-May)
- LGS operation crucial for PALM3K science.

The Future?

- Upgrade to PALM3K nominally planned to start in Apr 2010 – will lose 2010 summer observing season!
- No firm plans for continuing laser operations, and / or upgrading laser power, worries about post PALM3k operations?
- Extragalactic science VERY dependent on adequate laser power.

- PALM3K+OSWIFT is only AO+IFS capability at these wavelengths (< 1 micron). Unique scientific niche to exploit for a few years to come.