Oxford Astrophysics

High resolution in three dimensions with SWIFT and PALM3K

Fraser Clarke

Matthias Tecza, Niranjan Thatte, Kieran O'Brien, Ryan Houghton, Dane Tice, Leigh Fletcher, Pat Irwin, Aprajita Verma (Oxford)

Richard Dekany (Caltech), Rick Buruss, Jenny Roberts (JPL)

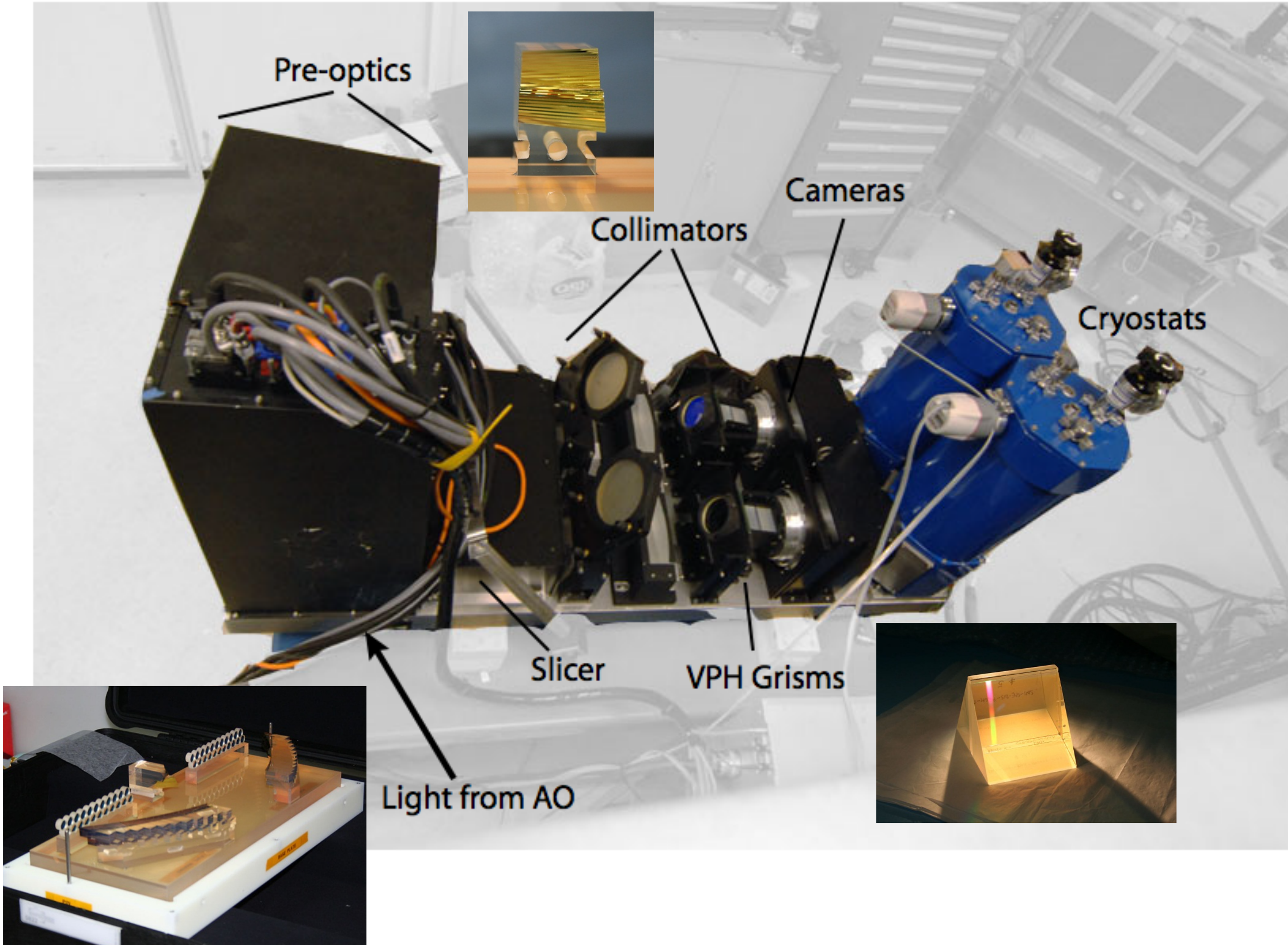
Palomar Operations Team

Oxford Astrophysics SWIFT Short-Wavelength Integral Field Spectrograph

SWIFT—PALMAO/LGS

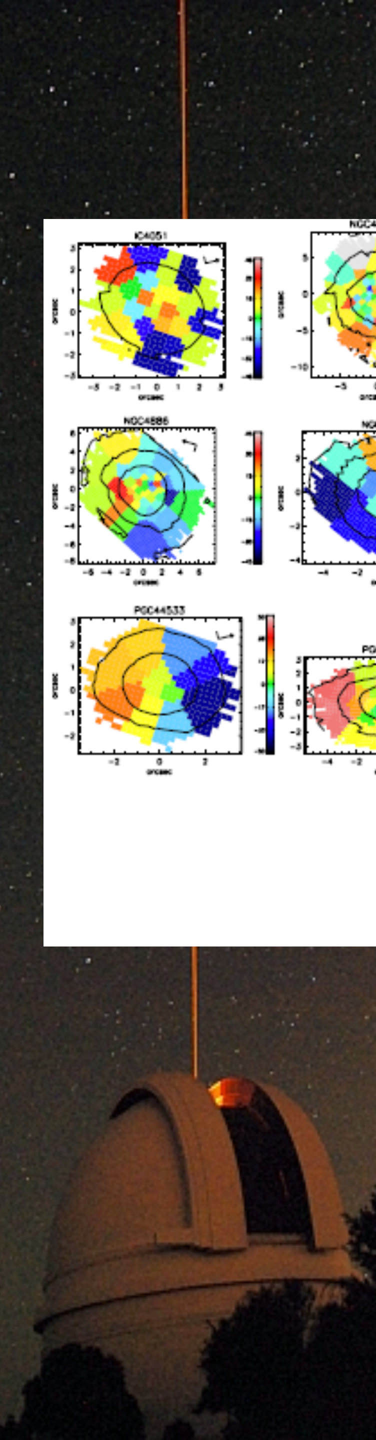
2008-2010

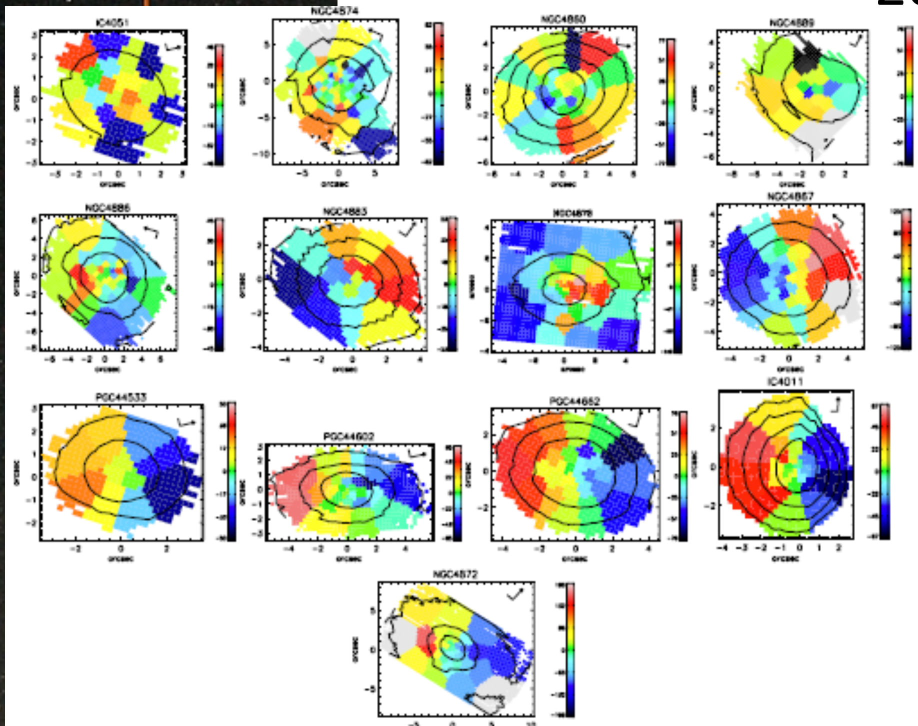
- I/z band integral field spectrograph
  - Palomar 200" + PALMAO/LGS adaptive optics
  - De-magnifying image slicer
    - 89×44 spaxels field-of-view
  - Fixed format spectrograph
    - Wavelength range 0.65—1.05μm
    - Spectral resolving power R≈4000
  - Interchangeable spaxel sizes
    - 235mas, 160mas, 80mas
  - Fully depleted very red-sensitive LBNL 4kx2k CCD
- Instrument designed to study galaxy dynamics/ composition
- Facility instrument available to whole Palomar community

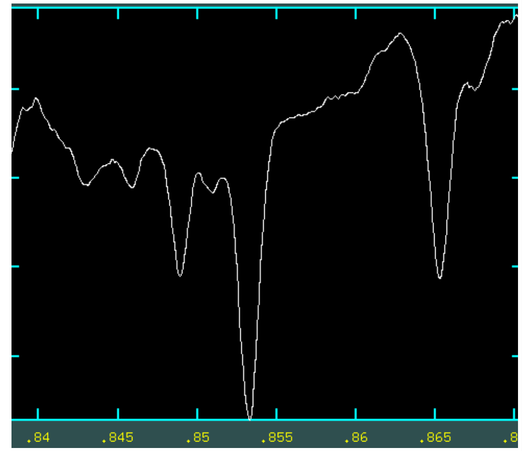

Pre-optics
Collimators
Cameras
Cryostats
Slicer
VPH Grisms
Light from AO

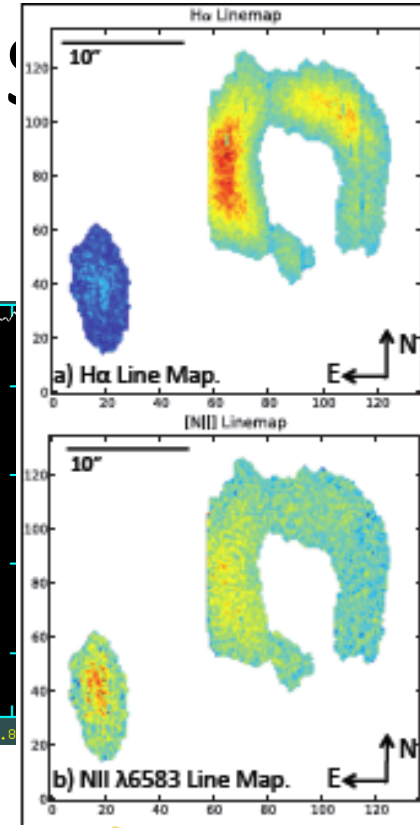
SWIFT—PALMAO/LGS

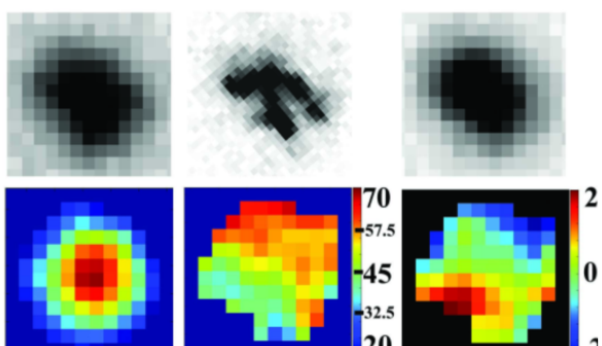
2008-2010

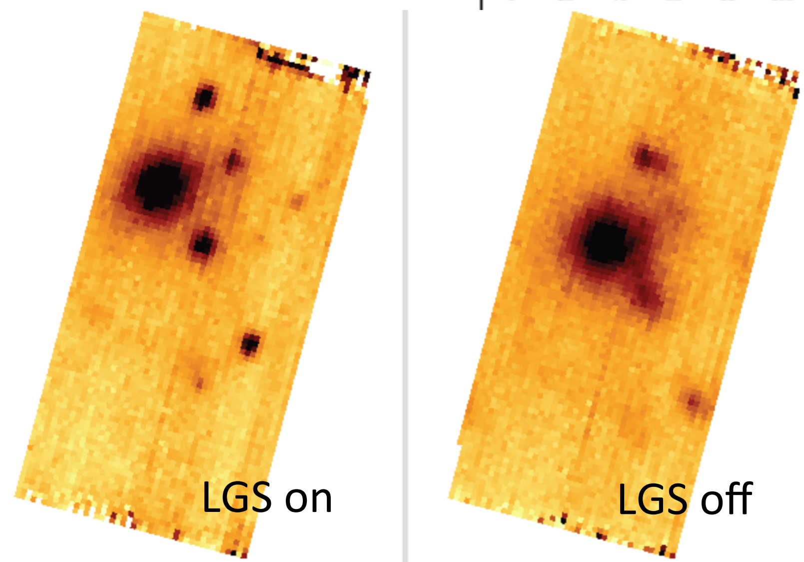






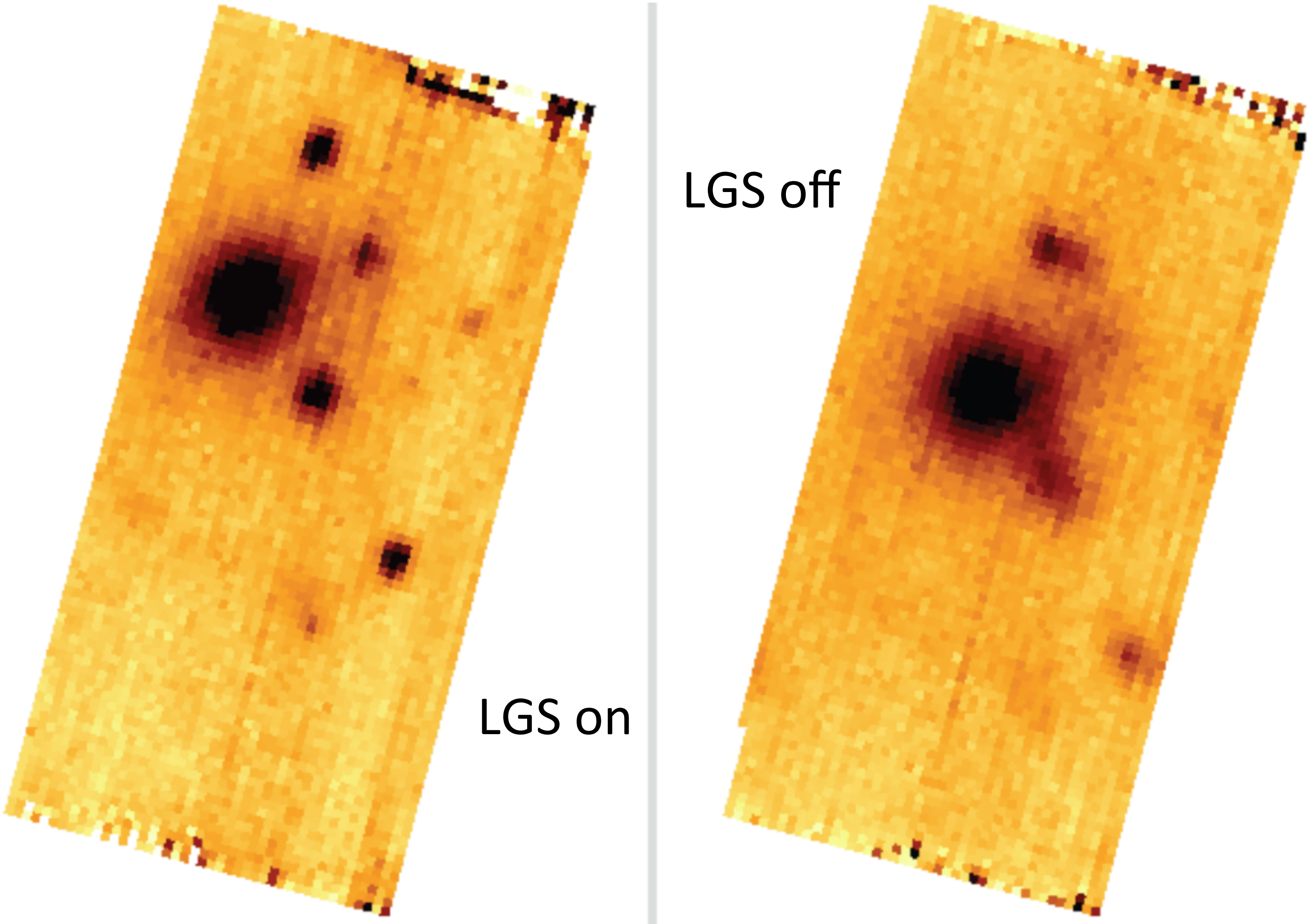






SWIFT—PALMAO/LGS

2008-2010



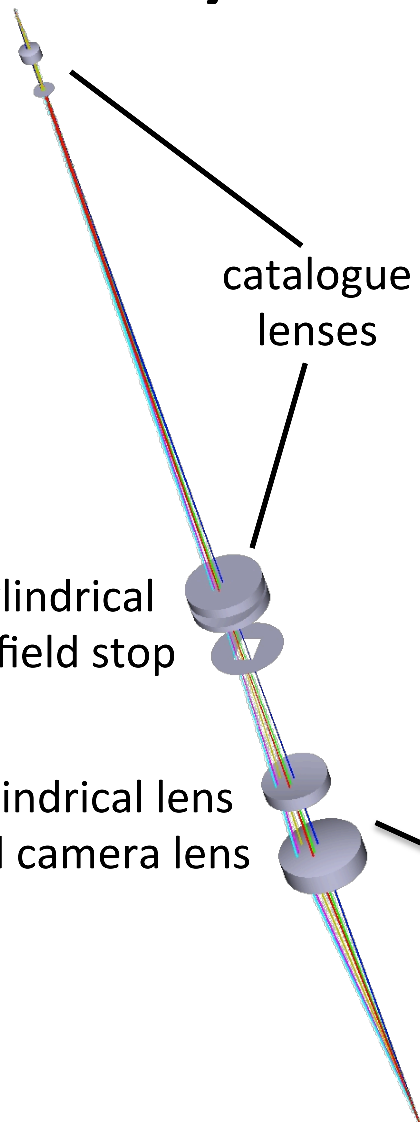
SWIFT – PALM3K/NGS/high-contrast

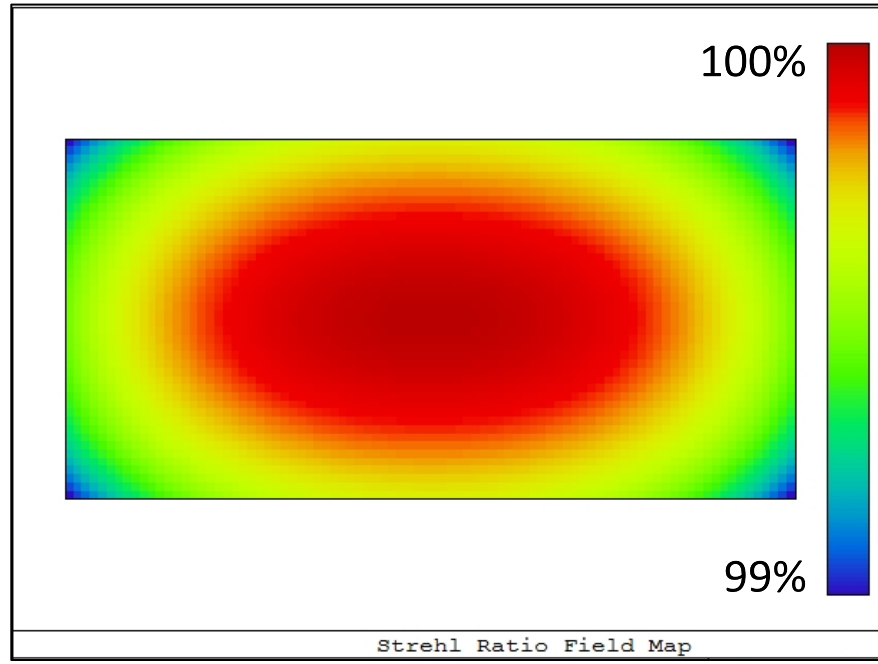
2011—…

- PALAO system decommissioned in mid 2010 to enable upgrade to PALM3K
  - Focus on high contrast AO
  - Laser indefinitely postponed
- SWIFT returned to Oxford for refurbish and upgrade to exploit PALM3K high contrast abilities;
  - Design of a new 16-milliarcsecond scale to sample diffraction limit at 800nm
  - Implement a 'blocking bar' to stop bright sources saturating detector
  - Modify calibration system accommodate 200x range in flux
- Commissioned back on-sky in late-2011 (bad seeing) and mid-2012 (good seeing)

Oxford Astrophysics
SWIFT
Short-Wavelength Integral Field Spectrograph

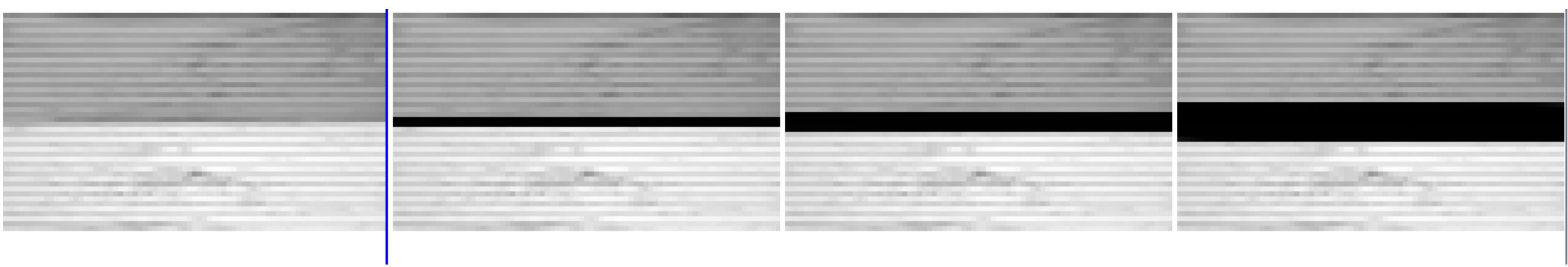
layout & strehl ratio





Supporting systems

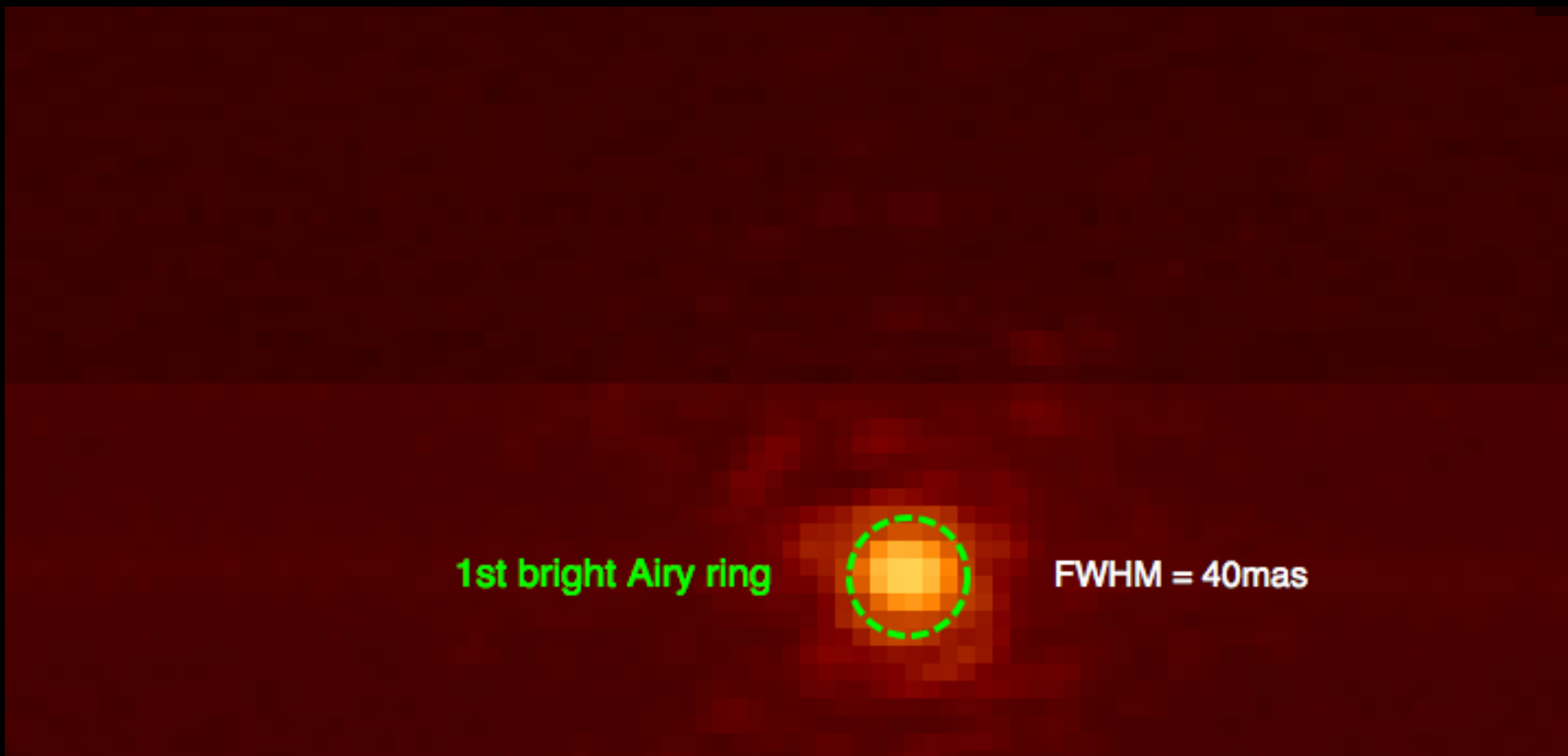
- Modified calibration system to have adaptable iris diaphragm to control arc flux
  - Factor of 15x in pixel scale is 225x in flux per pixel!
- Added a (very) poor man's occulting stop to avoid saturating on bright stars
  - Moveable blocking bar in the slicer exit focal plane
- Both achieved with <$100 off-the-shelf servo motors and controllers



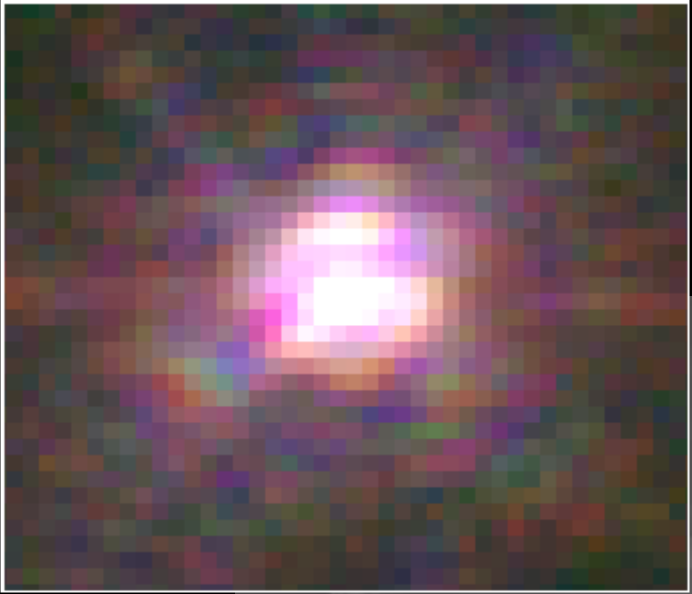
Full field | 2-slice block | 4-slice block | 8-slice block

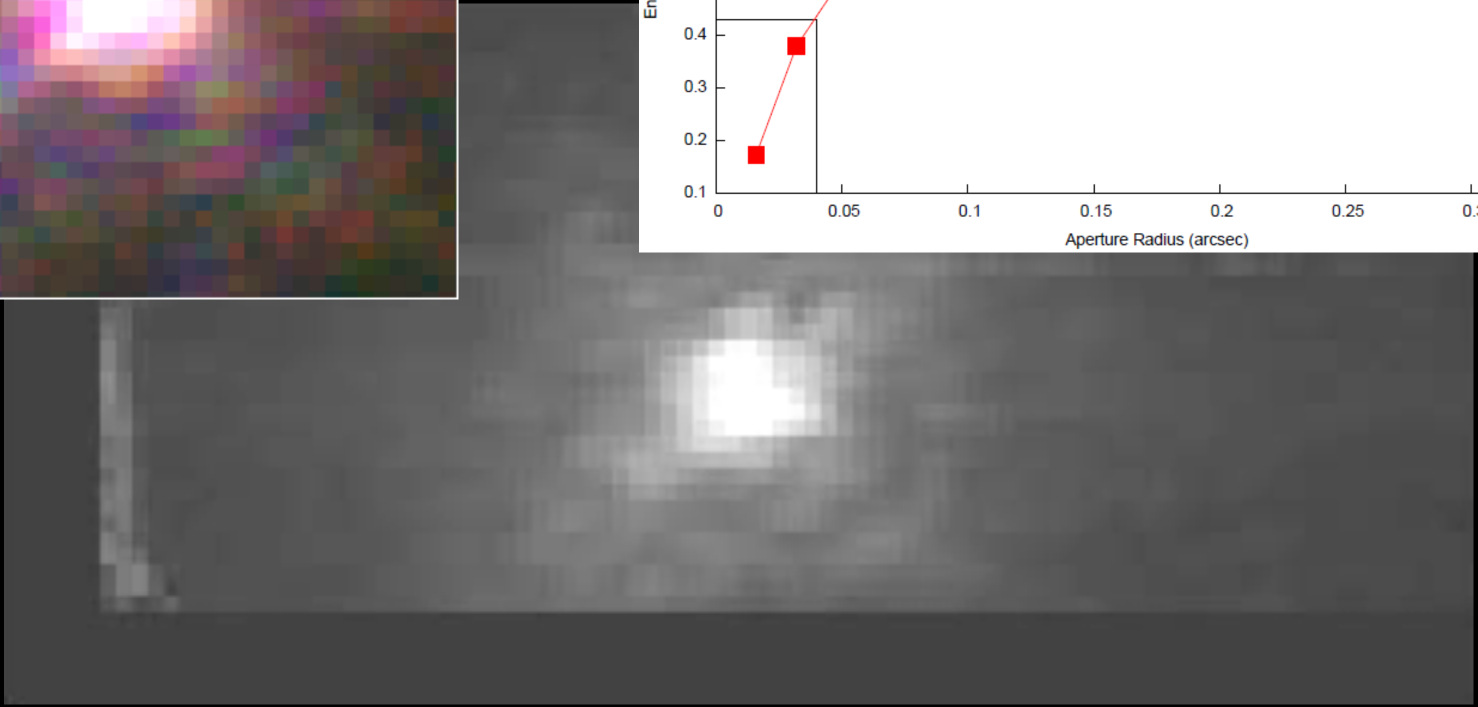
July 2012 — Internal PSF

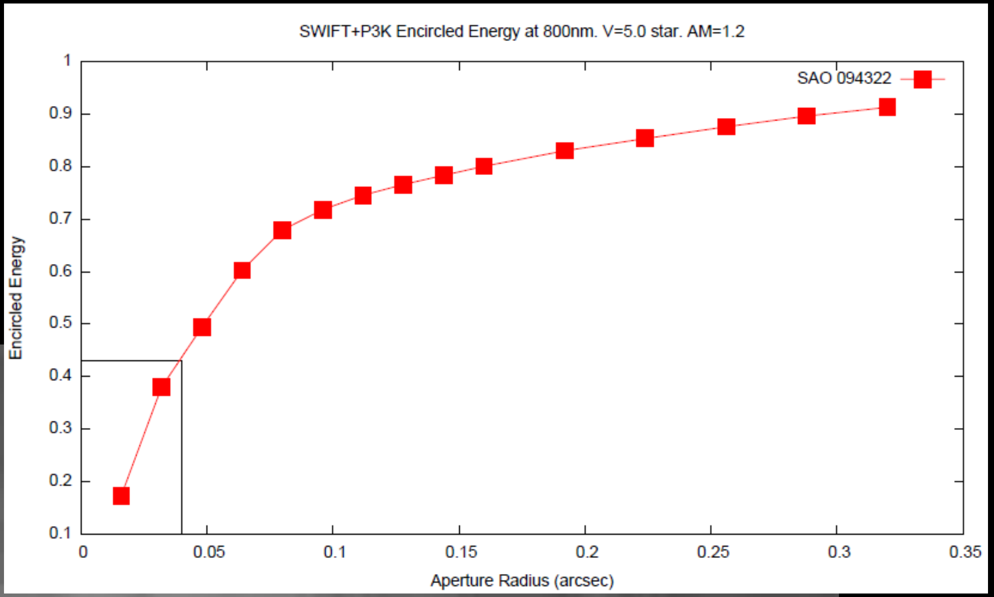
- Image of AO-stimulus after correction for non-common-path aberrations of SWIFT
  - 40mas FWHM vs 33mas limit



October 2012 – External PSF







Issues -- tuning

- Very hard to remove the non-common-path errors between AO and instrument
- Image slicer complicates image analysis
- Have to spend 1—2 hours per day tuning AO by hand
- Need to develop automated method (e.g. MGS) which works with slicers

Oxford Astrophysics
SWIFT
Short-Wavelength Integral Field Spectrograph

Raw data format

- IFU data needs some processing before it is easily interpretable
- Processing adds in extra problems, and time…

Why the Galilean Satellites?

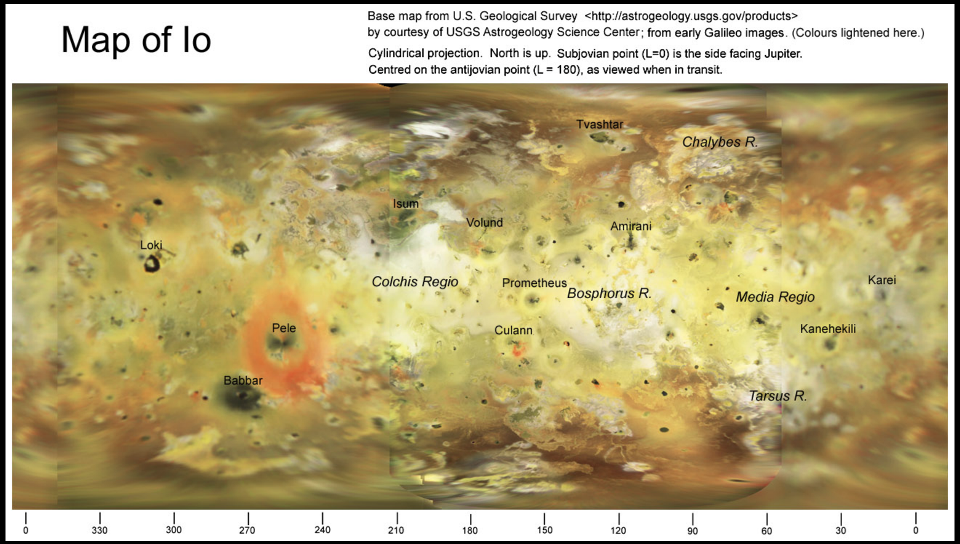
- Most accessible examples of a class of object prevalent throughout the Solar system – icy satellites.
- Miniature solar system in its own right.
- Subsurface oceans of potential astrobiological importance.
- Poorly studied in the past decade since Galileo due to the flood of new data from Cassini.
- Surface albedo contrasts are a good test of SWIFT capabilities for solar system targets.
- Soon to be explored by ESA's Jupiter Icy Moons Explorer (JUICE).

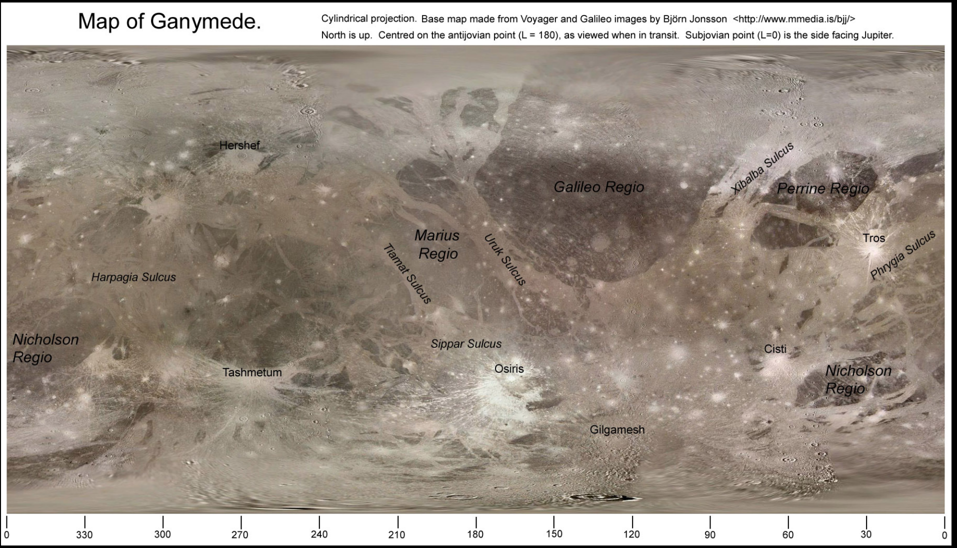
Courtesy of Leigh Fletcher

Why The Galilean Satellites?

- Use the powerful combination of SWIFT and the PALM3k AO to provide spatially resolved 0.63-1.04 µm spectroscopy of the Galilean satellites to provide spectral context for future imaging experiments.
- Science Aims:

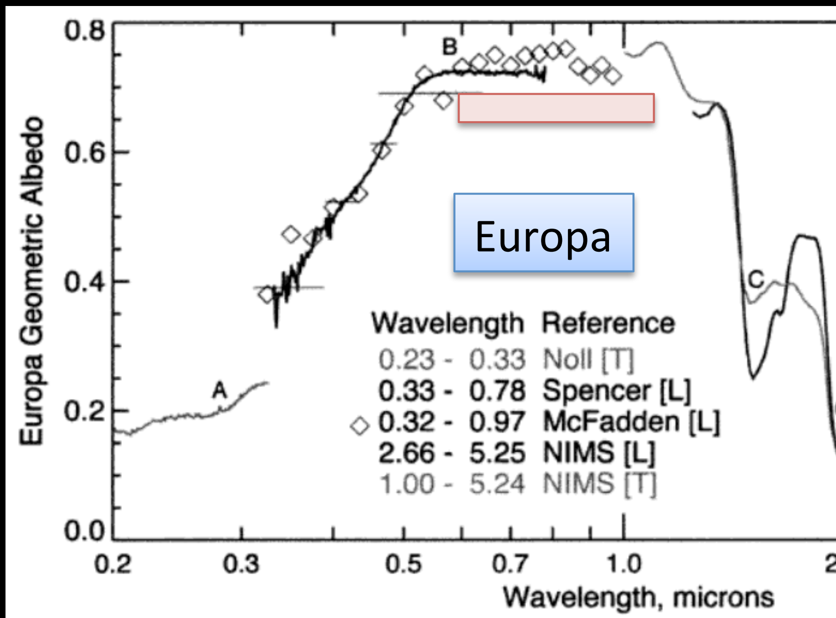
1. Compare the albedo characteristics of differing terrains across satellite surfaces.
2. Search for spectroscopic signatures of water ice and hydrated mineralogy.
3. Study asymmetries between the leading and trailing hemispheres of these satellites due to particulate deposition associated with Jupiter's powerful magnetic field.

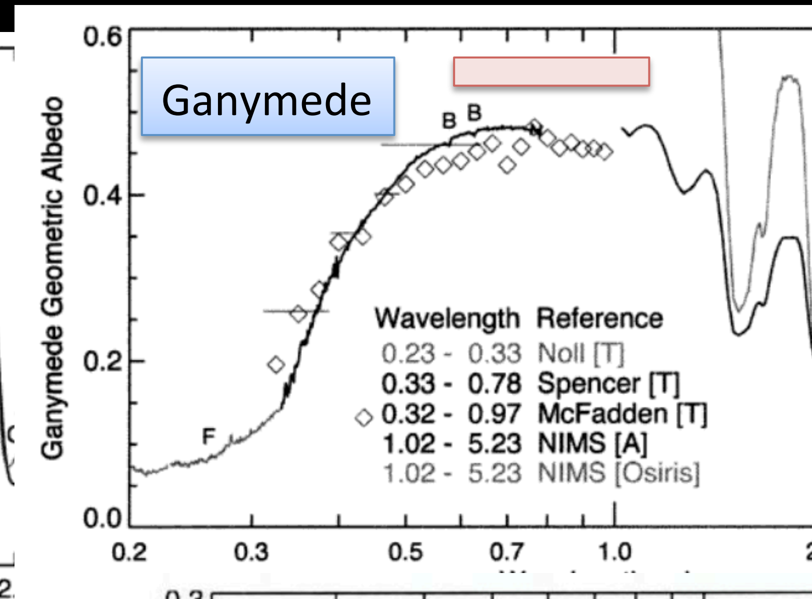


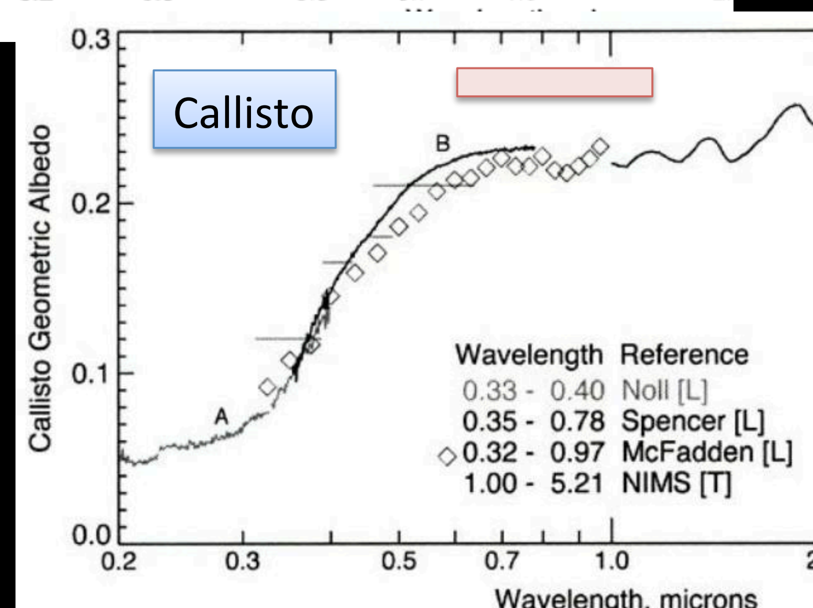


Courtesy of Leigh Fletcher

Observed Spectra (1990s)





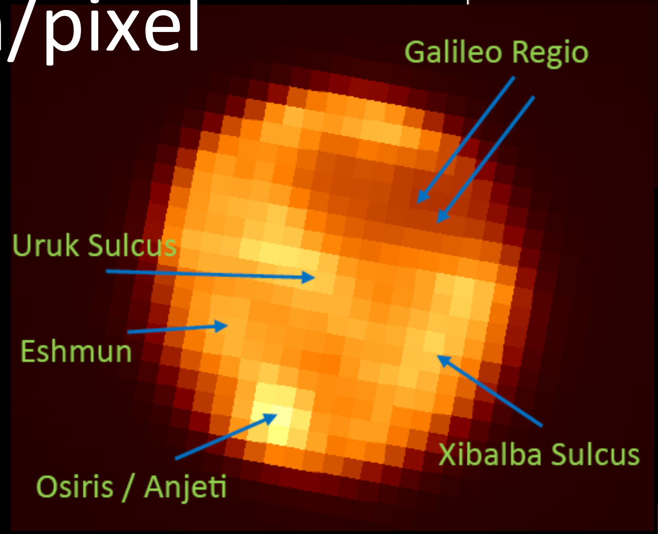


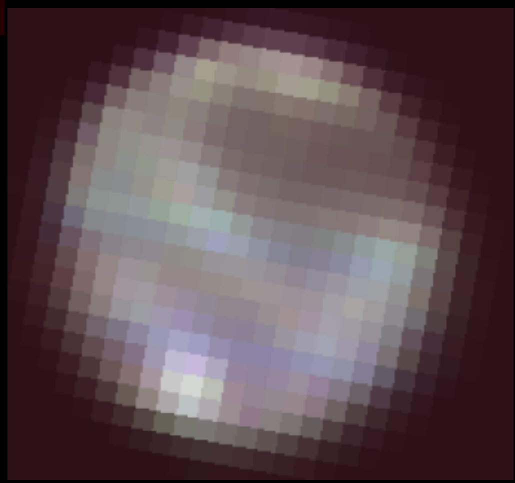
- SWIFT spectral range 0.6-1.05 µm relatively flat:
  - Dominant features of water ice (small kink near 1.04-µm).
  - O2 features denoted as ‘B’
  - Hydrated mineral bands all occur longward of 1 µm.
  - Possible olivine/pyroxene silicate signatures throughout this range?

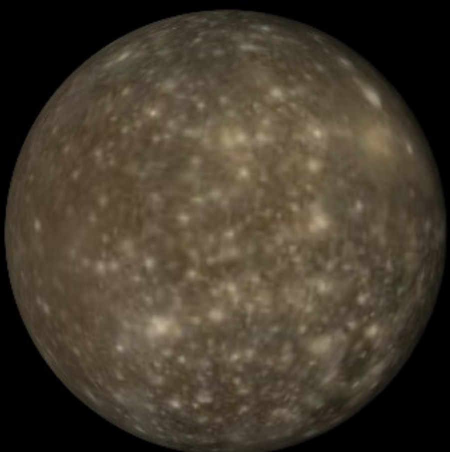
Courtesy of Leigh Fletcher

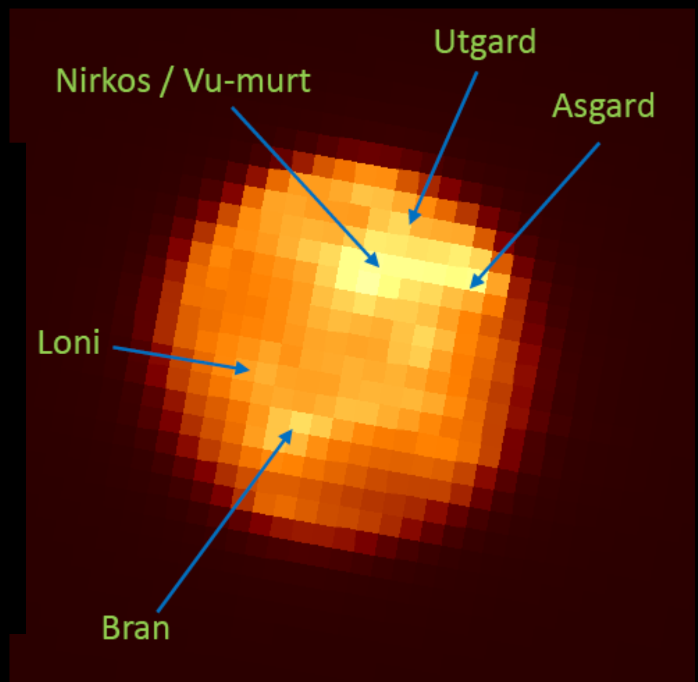
Ganymede & Callisto

80mas/250km/pixel



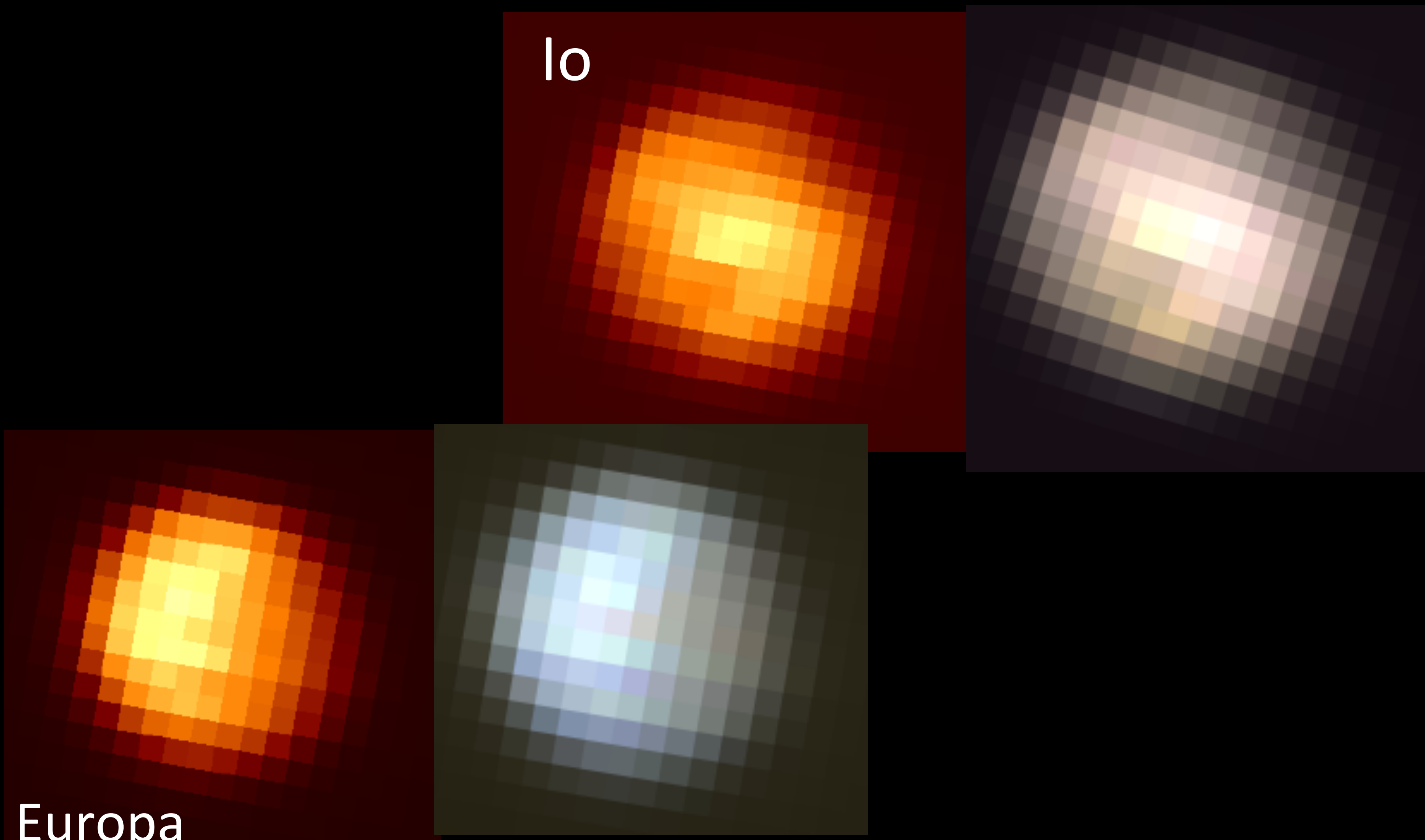






Io and Europa

80mas/pixel

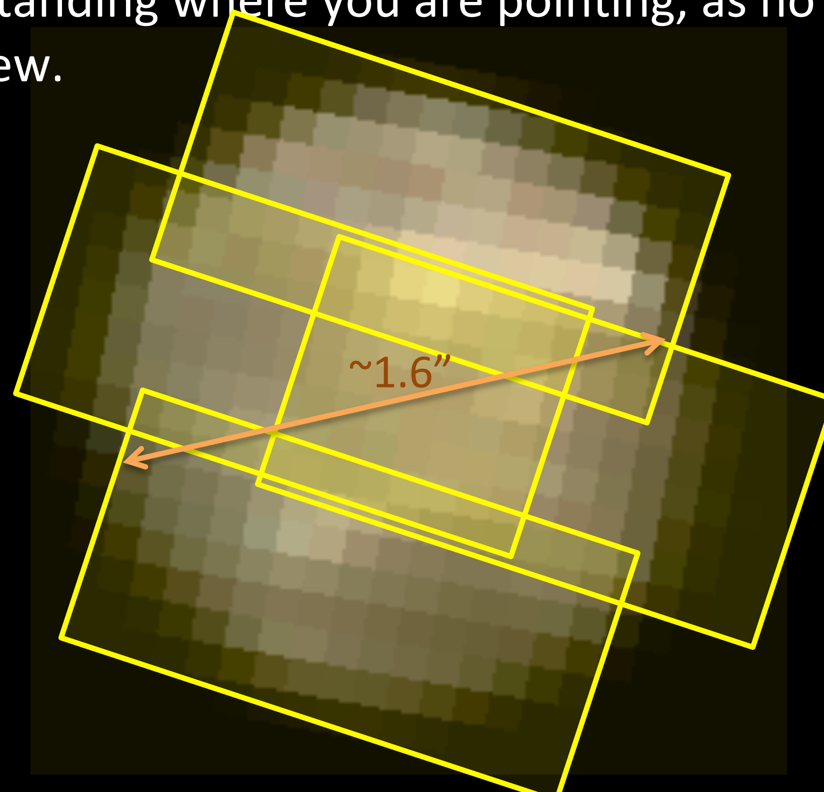


Zooming in

how many pixels can you afford?

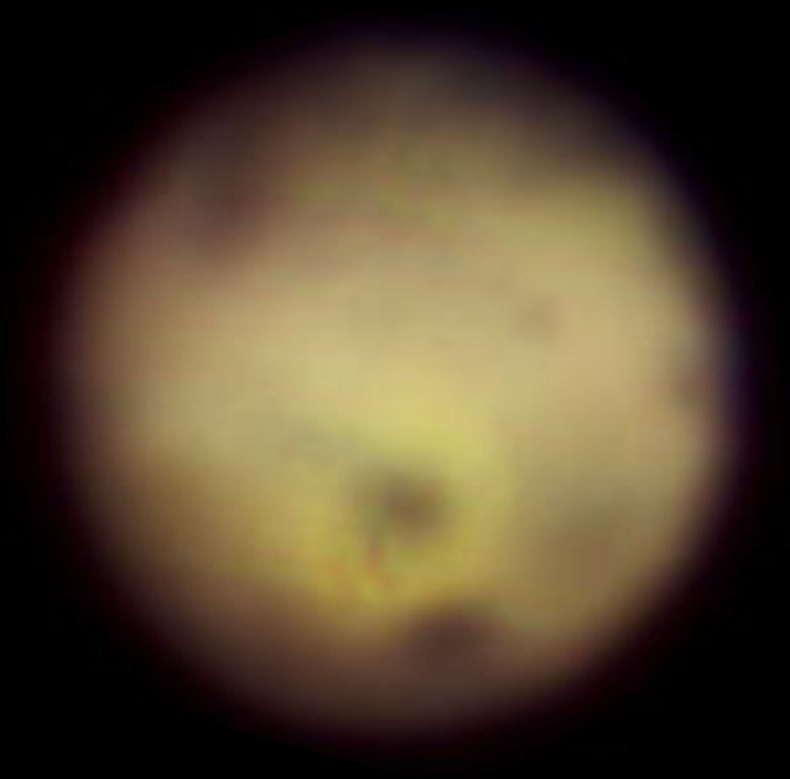
- Each spatial pixel (spaxel) needs 4000 detector pixels…
- 16mas scale on SWIFT only gives 1.4 x 0.7” field of view
- Need to mosaic even for Galilean moons!
- Puts strong requirements on understanding where you are pointing, as no good reference sources in field of view.
  - Haven’t got this sorted well enough yet!

Callisto/Ganymede need at least 4 pointings with 16mas scale to cover them

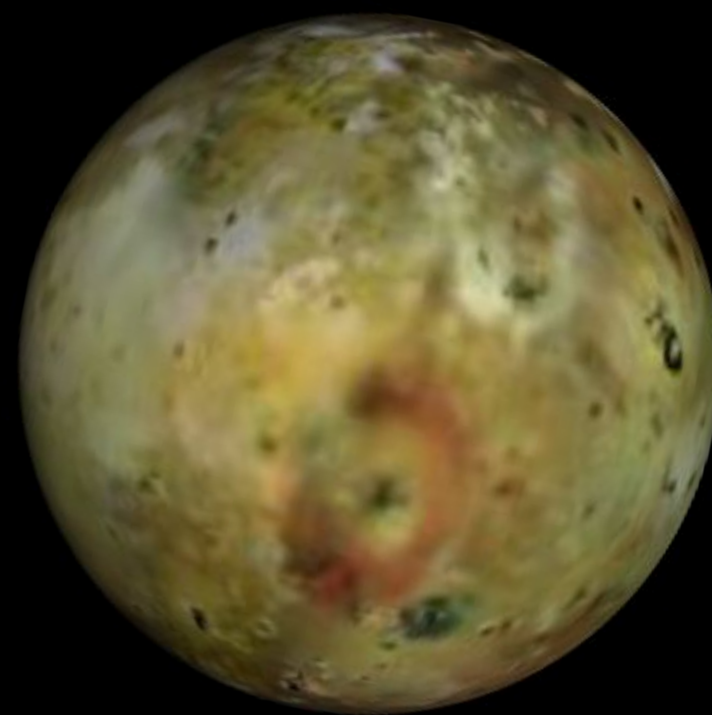


Io mosaic

16mas/pixel



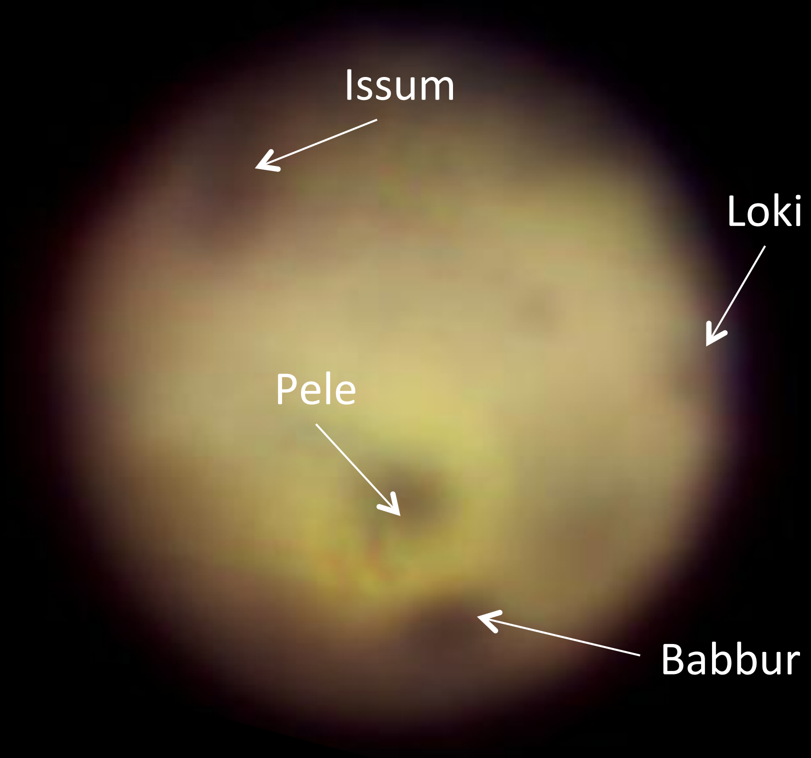
SWIFT+PALM3K
6 pointings in 2x1 mosaic
Approx 670nm, 800nm, 950nm
Smoothed for presentation!



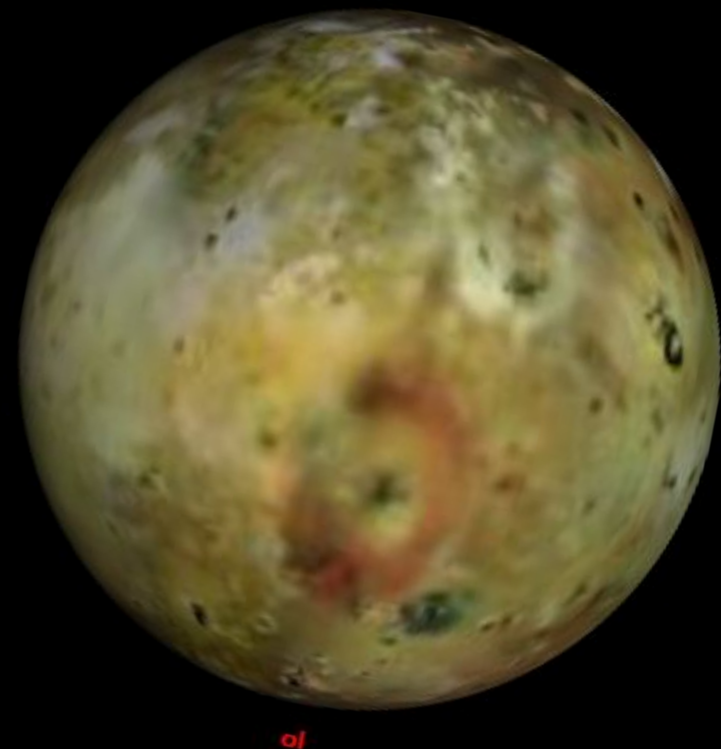
Galileo map projected to
time of observation

Io mosaic
16mas/pixel

Next steps:
Surface composition features
Signatures of ‘exosphere’ lines?
Compare to other data to look for evolution



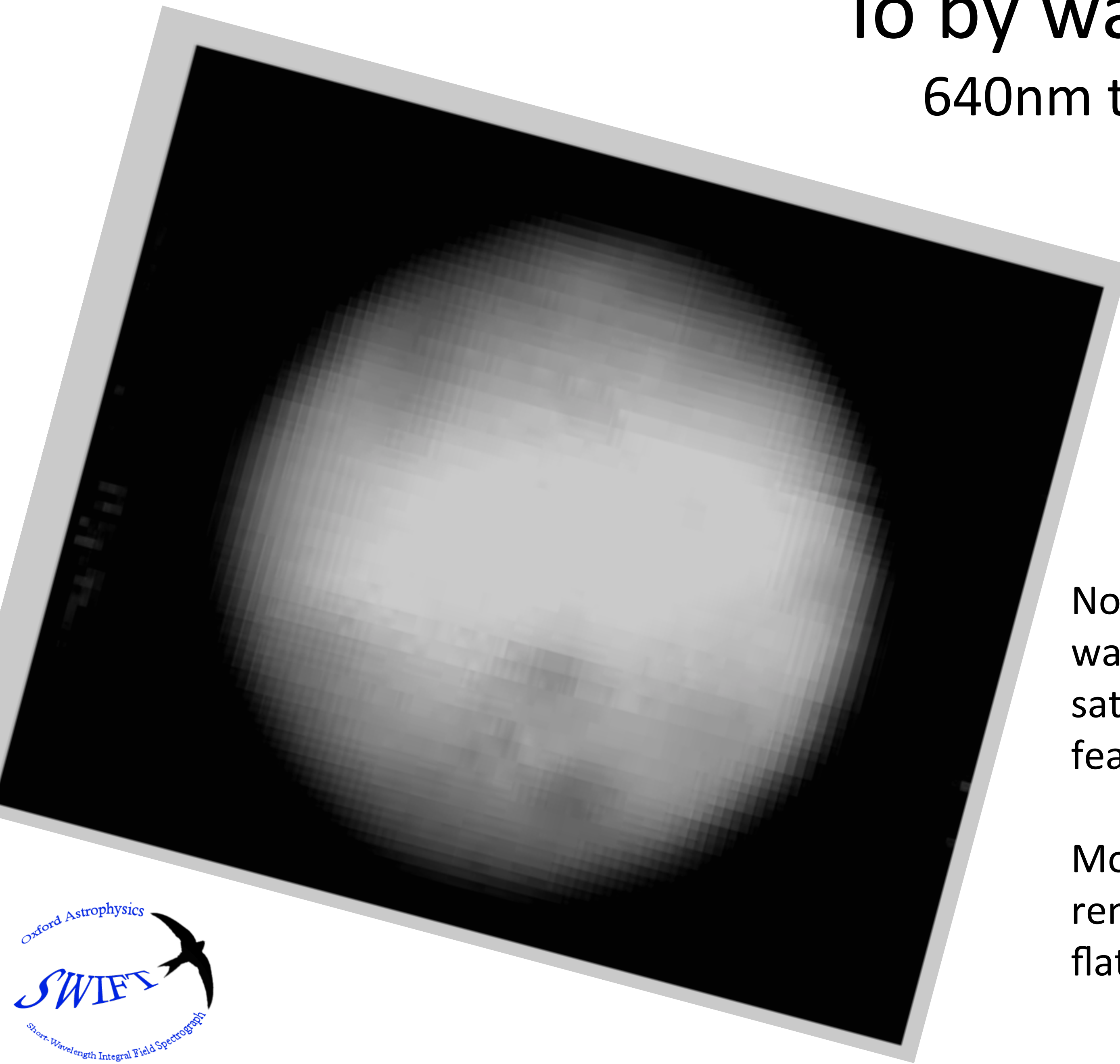
SWIFT+PALM3K
6 pointings in 2x1 mosaic
Approx 670nm, 800nm, 950nm
Smoothed for presentation!



Galileo map projected to
time of observation

Io by wavelength

640nm to 1040nm

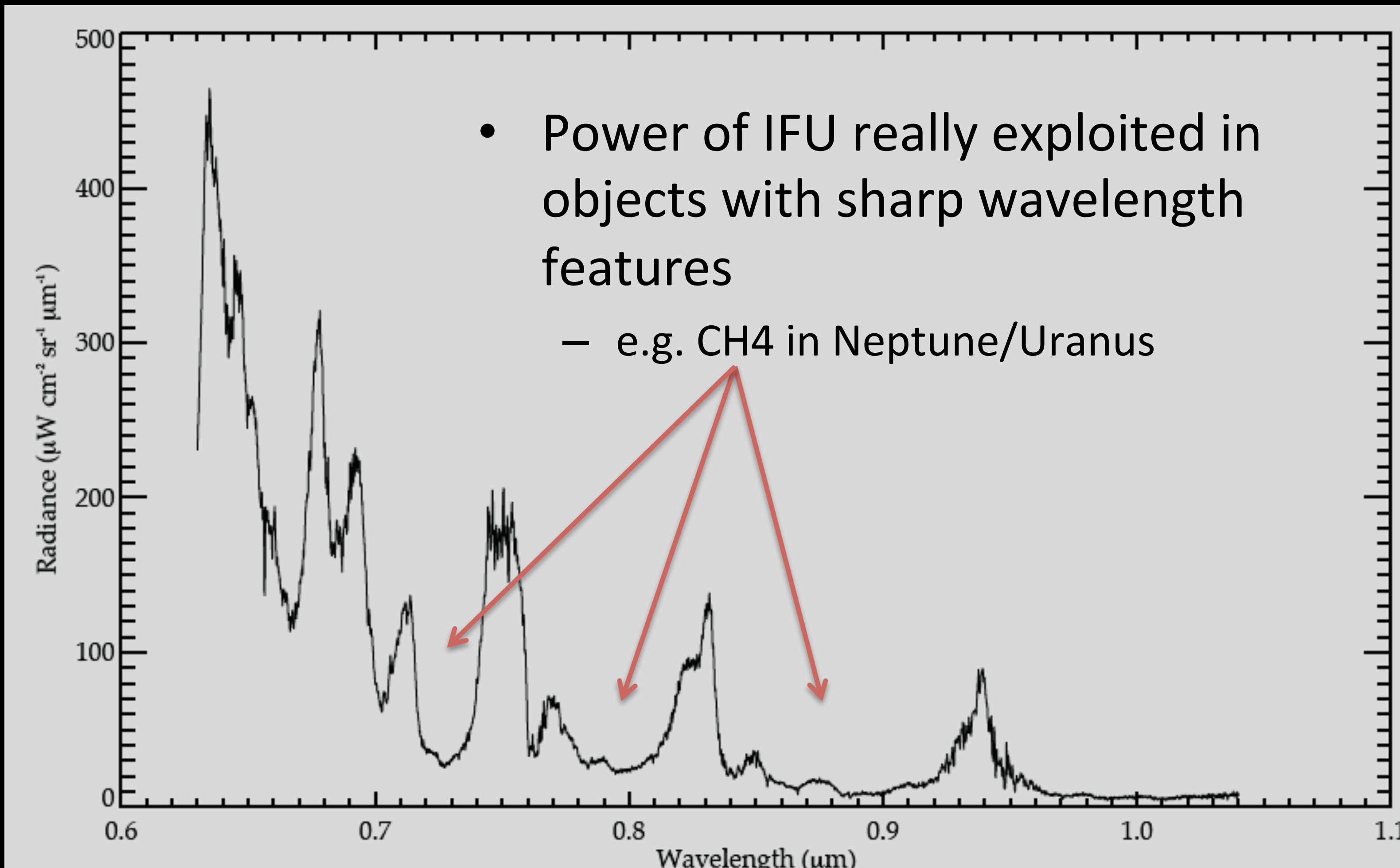


Not the most interesting wavelength for Galilean satellites, but some features visible

Movie shows some remaining issues with flat-fielding!

Gas giants

Probing Neptune's atmosphere

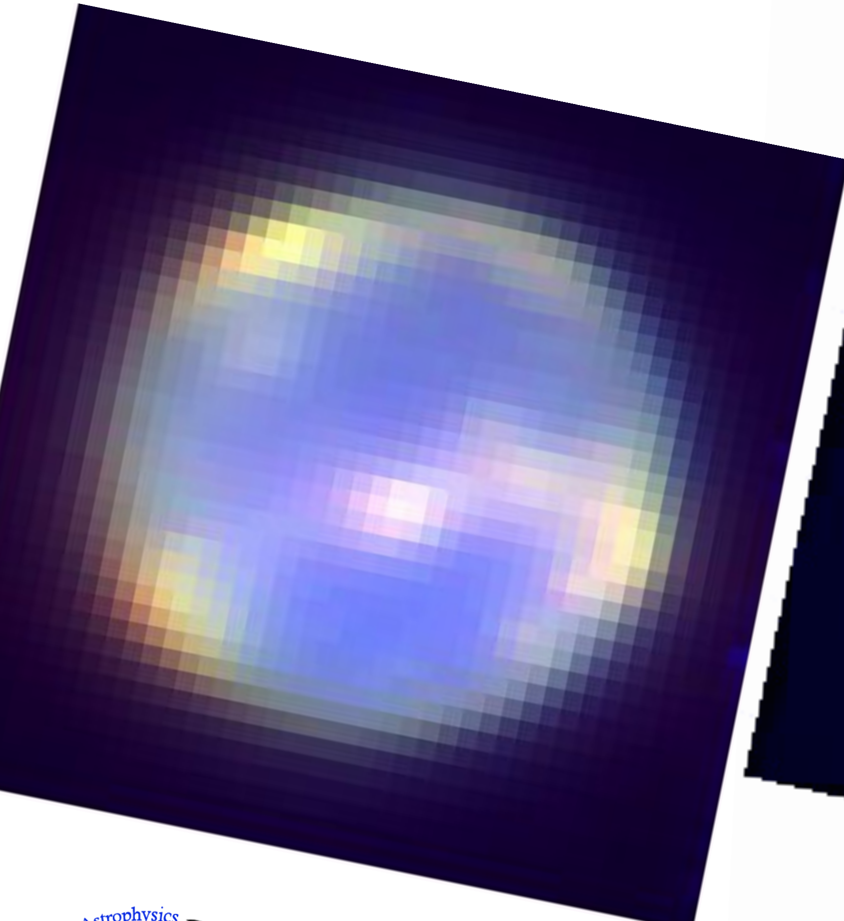


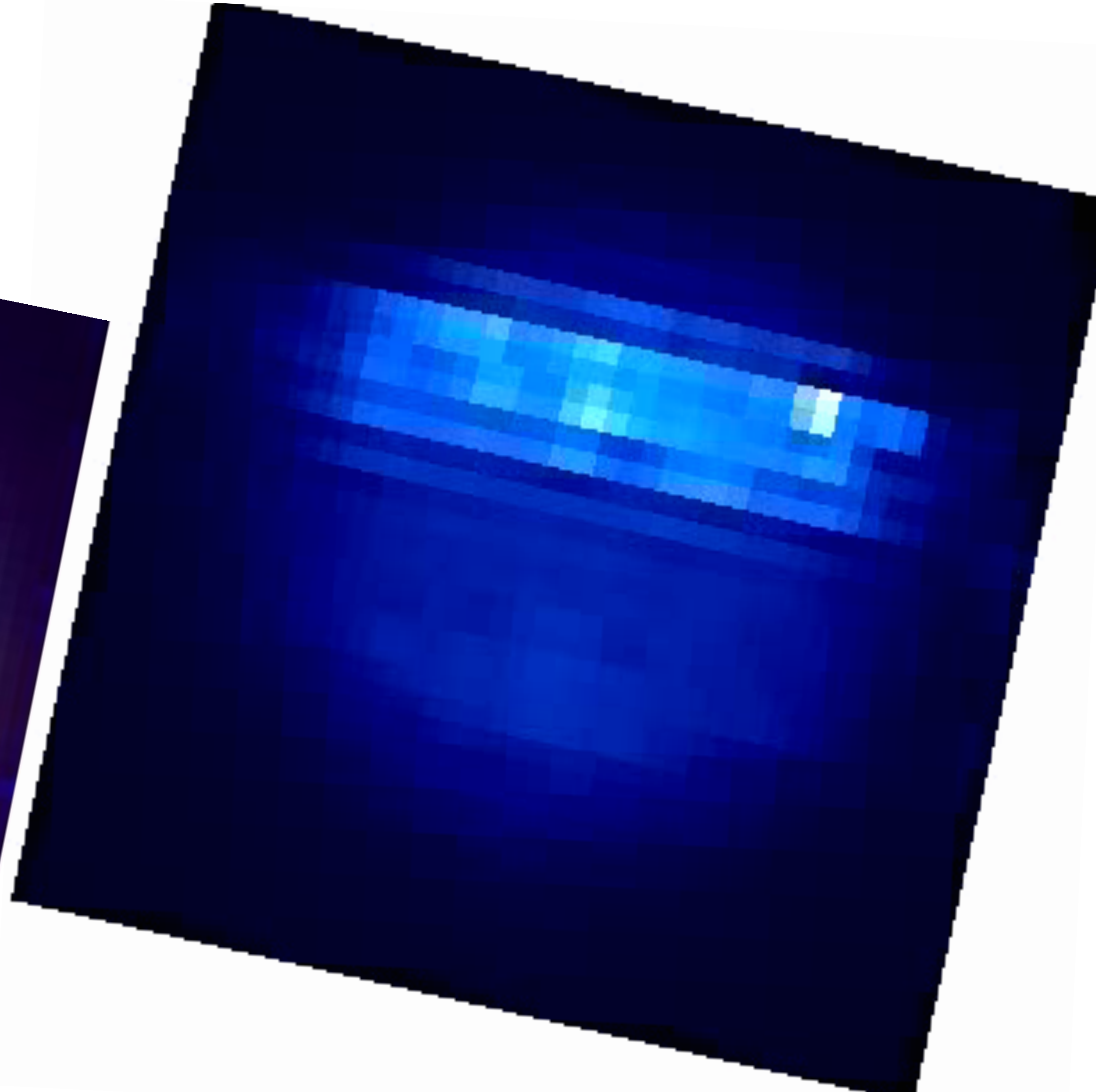
- Power of IFU really exploited in objects with sharp wavelength features
  - e.g. CH_4 in Neptune/Uranus

Courtesy of Dane Tice

Neptune

80mas/pixel



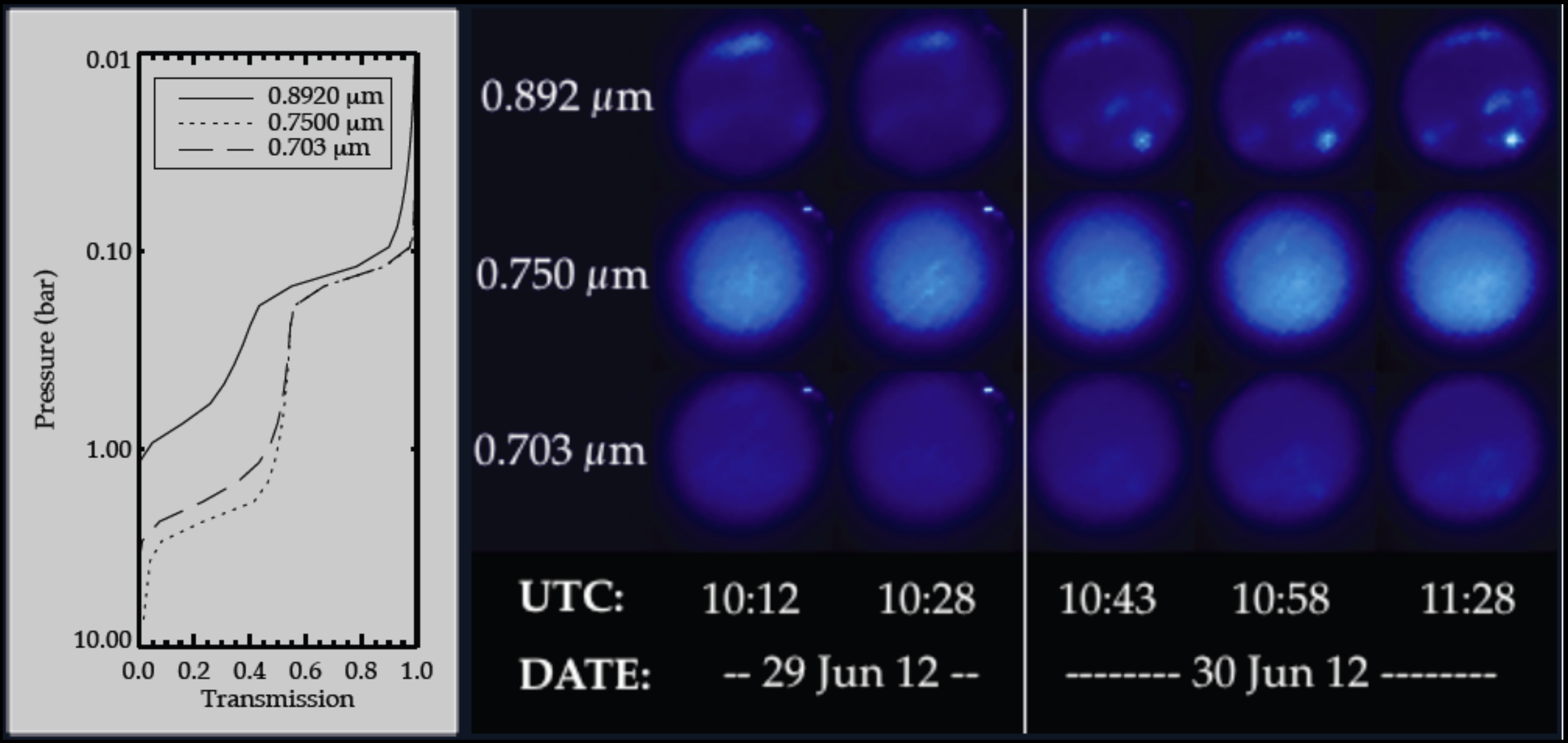


640nm to 1040nm in 10nm steps
80mas/spaxel

Oxford Astrophysics
SWIFT
Short-Wavelength Integral Field Spectrograph

Probing Neptune's atmosphere

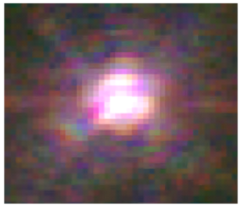
- Different wavelengths probe different depths in atmosphere
- Spatially resolved spectra allow us to probe for composition variations as a function of position
  - e.g. Monitor latitudinal CH4 variation previously seen in Neptune

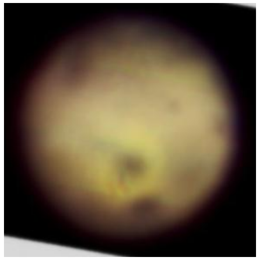


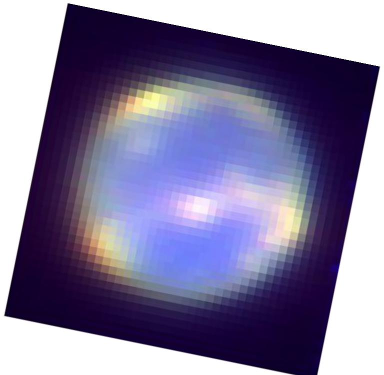
Courtesy of Dane Tice

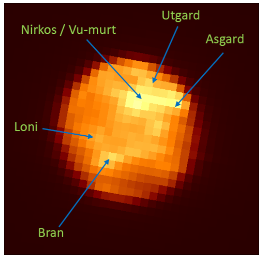
Exciting things for the future

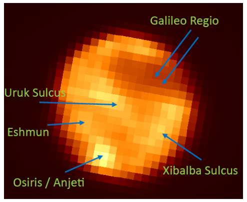
- High resolution in three dimensions enables unique science, e.g.
  - ***Gas giant atmospheres***; Composition and evolution
  - ***Galilean moons***; Surface composition, surface hydrology, atomic exospheres(?)
  - ***Titan…***; (coming in 2013 hopefully!)
  - ***Asteroids***; surface mineralogy, companion formation
  - ***Evolved stars***; e.g. P Cygni / Eta Car type nebulae, composition, shocks
  - ***Planetary nebulae***; ionisation/temperature, mixing, small scale dynamics
  - ***Young stars***; Circumstellar material, Inflow/Outflow dynamics, Jets
  - ***Binaries***; orbits in 3d!
  - ***High contrast***; Test-bed for SD routines with image slicers











Oxford Astrophysics SWIFT Short-Wavelength Integral Field Spectrograph

Oxford Astrophysics

Lessons learned and thoughts for the future

- Spectroscopic instruments and a great new dimension
  - *Both in capability and complexity!*
- Small field of view is challenging
  - Need very accurate referencing between frames to make best use of data
- Data format relies on good processing to make it easily usable
  - Can't relay on nice uniform square pixels!
- Imaging Spectrographs require calibrating as well as an imager, whilst including effects of a spectrographs!
  - Classical spectrographs just hide how tough the calibration is
- Close integration between the instrument and the AO system (and the telescope!) is critical for a good *and usable* system