HARMONI: An AO assisted, narrow field, integral-field spectrograph for the E-ELT

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What is HARMONI?

High
Angular
Resolution
Monolithic
Optical and
Near infrared
Integral field spectrograph

=

Single
Field
Wide
Band
Spectrograph

What is HARMONI/SFWBS?

- Instrument concept not studied (but envisaged) in context of OWL or FP6 even though it's proven to deliver high quality science
- Early spectroscopic follow up faint sources discovered in deep imaging surveys (e.g. JWST), which is only possible with an ELT
- Narrow field-of-view matched to early AO capabilities – near-diffraction limited over a small field
- Single object mode rather than survey mode (à la MUSE)
- Oxford pre-study of an instrument concept (Apr - Sep '07) with £70k award from STFC
- ESO call for proposal for SFWBS Phase A study

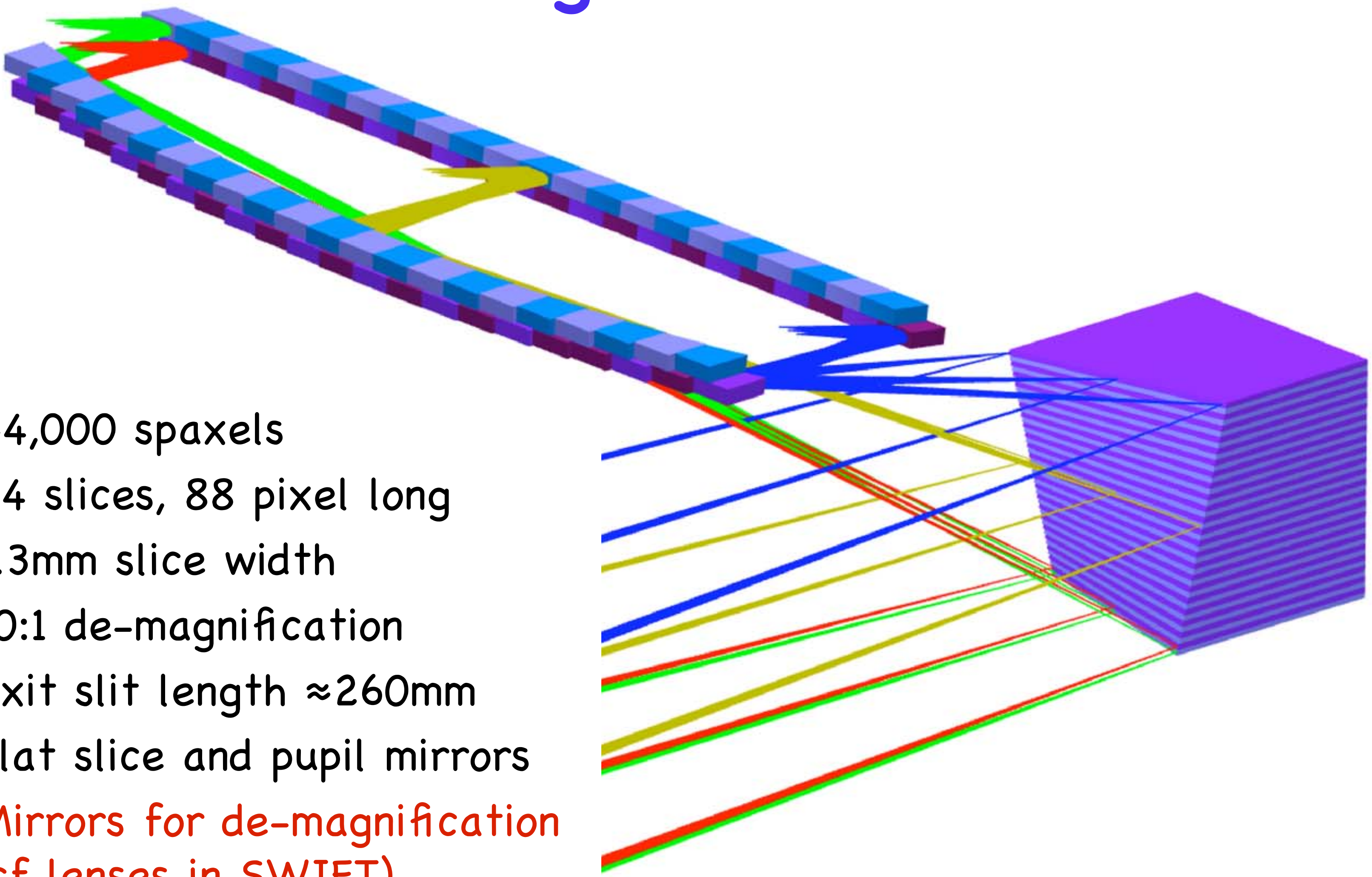
Initial Instrument Requirements

- Wavelength range
  - Near-infrared 1-2.5μm
  - Wide wave band favours slicer over lenslets à la Tiger
- Spectral resolving power
  - R ≈ 4000 for OH avoidance
  - one band (J, H, K) at a time
- Spaxel size and field-of-view
  - 5mas to 50mas spaxel size
  - ≈ 1″-5″ field-of-view
  - ≈ 16,000 spectra (or 8 HAWAII $2k^2$ detectors)
    - 88 x 176 2:1 rectangular field

Optional Instrument Requirements

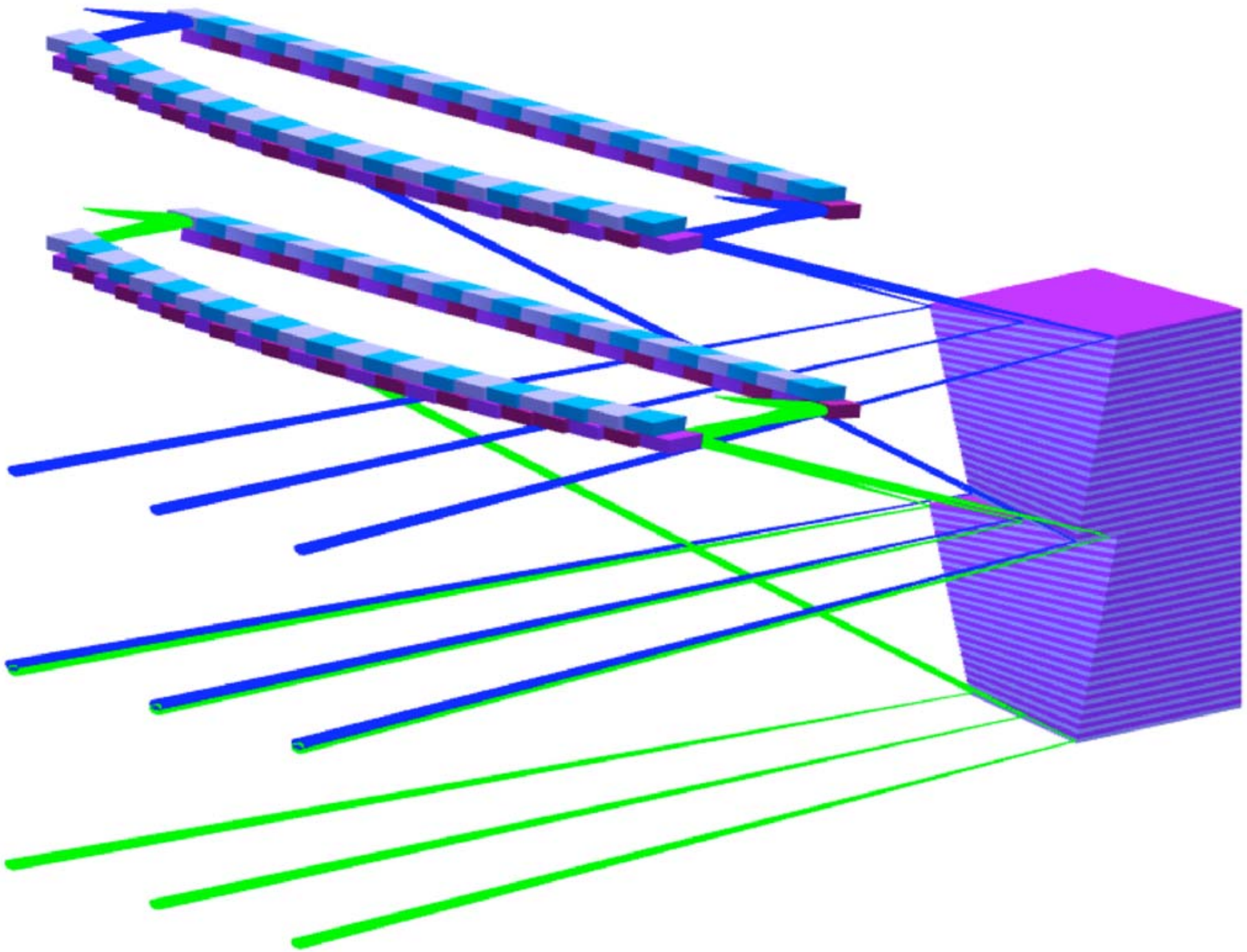
- Wavelength range
  - Optical & Near-infrared 0.8-2.4μm (0.6-2.5μm)
  - Wide wave band favours slicer over lenslets à la Tiger
- Spectral resolving power
  - R ≈ 4000, 20,000 for abundances, kinamatics: cf. science case
  - one band (J, H, K) at a time
- Spaxel size and field-of-view
  - 5mas to 50mas spaxel size
  - ≈ 1″-5″ field-of-view
  - ≈ 16,000 spectra (or 8 HAWAII $2k^2$ detectors)
    - 88 x 176 2:1 rectangular field
- Focus on slicer design
  - Initially based on SWIFT de-magnifying image slicer design

Single slicer



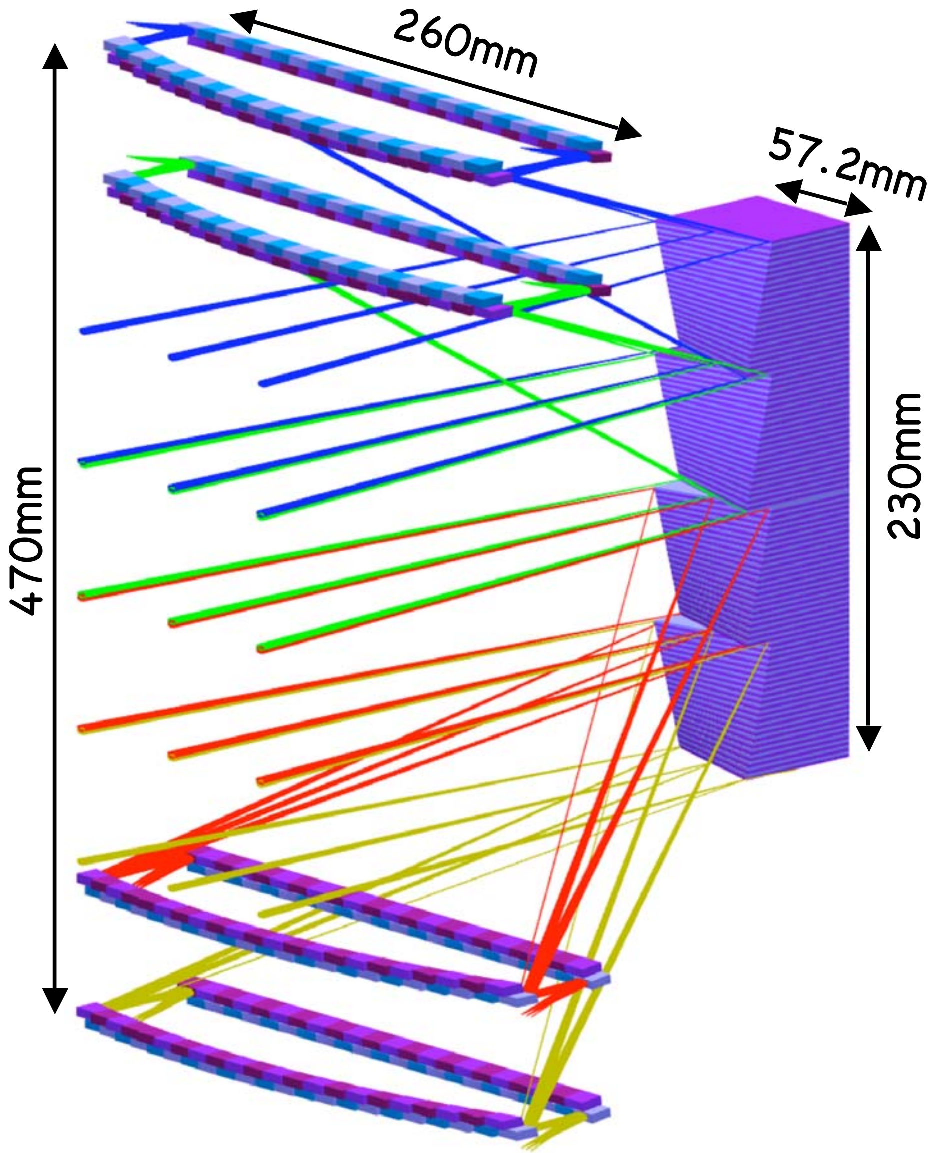
- ≈4,000 spaxels
- 44 slices, 88 pixel long
- 1.3mm slice width
- 10:1 de-magnification
- Exit slit length ≈260mm
- Flat slice and pupil mirrors
- Mirrors for de-magnification (cf lenses in SWIFT)

Two slicers: 8000 spectra



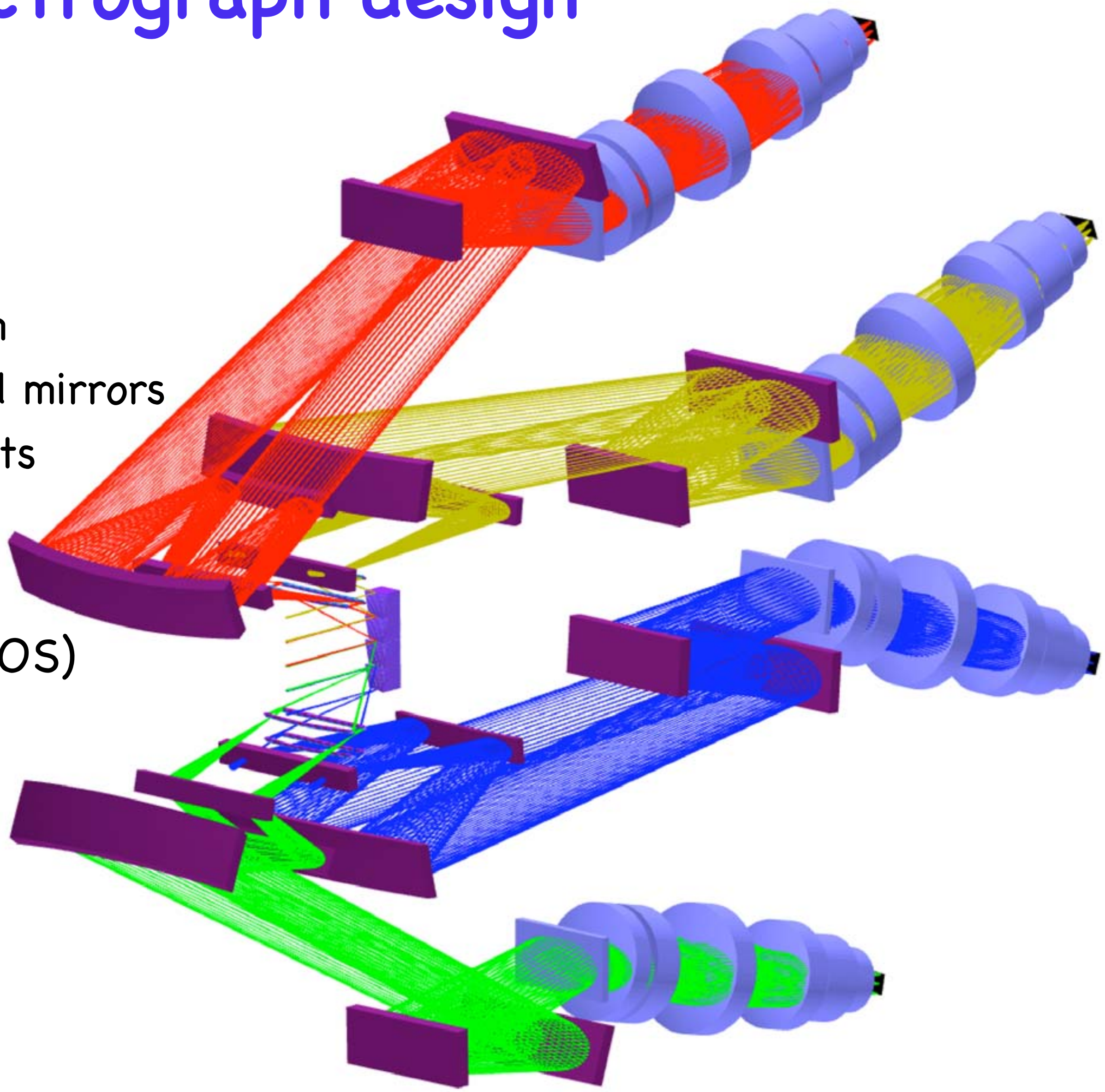
Full slicer

- Four exit slits
- 4:1 aspect ratio on slicer due to 2:1 anamorphic pre-optics
- 2:1 aspect ratio on sky
  - 176 x 88 pixels
- Maximum spaxel scale of 50mas
  - 8.8" x 4.4" FoV
- Smaller spaxel scales (eg. 5mas) through scale changing pre-optics



Conceptual spectrograph design

- f/6 Collimator
  - 1500mm focal length
  - 120mm x 240mm beam
  - 3 mirror design, 2 fold mirrors
  - 700mm mirror segments
- Grating (VPH)
  - 200mm x 250mm
- f/1.8 Camera (from KMOS)
  - 420mm focal length
  - ±5° field
  - 6 lens design
  - Ø 150-300mm lenses
  - 2 HAWAII2 detectors
- 3.5m x 2.5m x 1.0m



HARMONI slicer design advantages

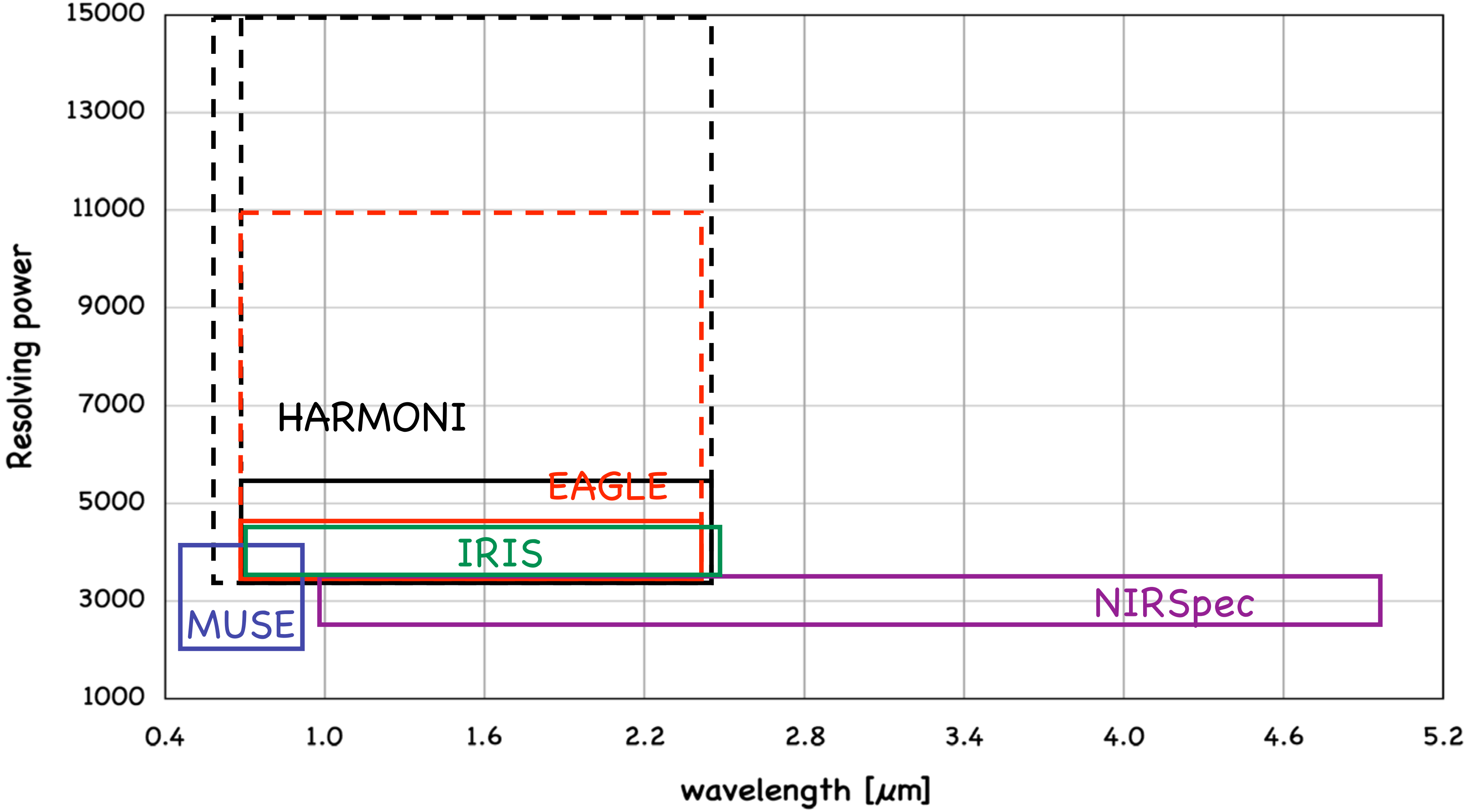
- No field splitting in pre-optics
  - No re-imaging like MUSE
  - High throughput
- Flat slicer and pupil mirrors
  - Aberrations are equal for all slices
- All mirror design
  - Fully achromatic for wide waveband coverage
- Very efficient use of detector real estate
  - ≈95% spectrum packing factor

HARMONI in context

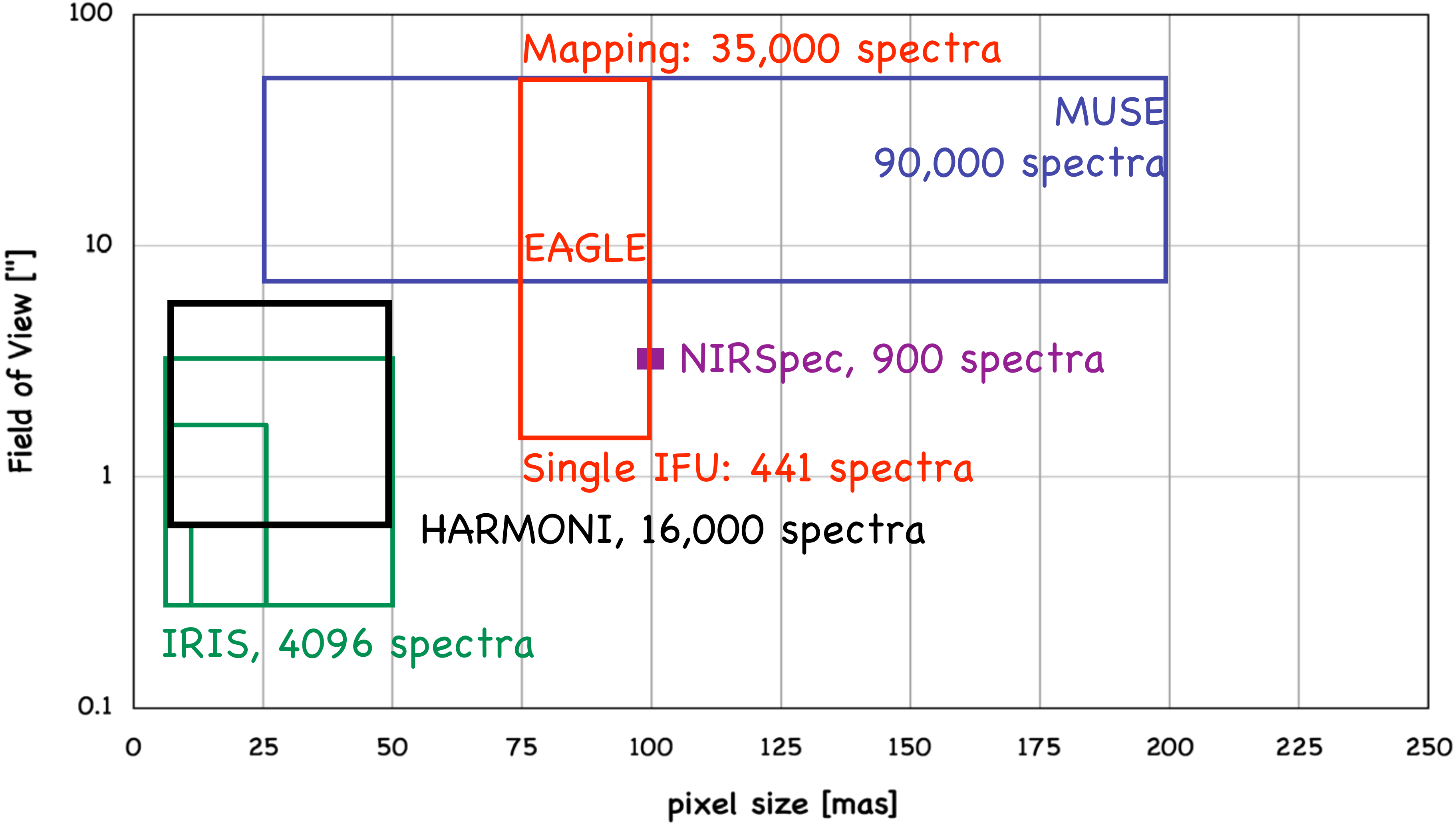
- No study of such an instrument for E-ELT carried out so far, although IRIS is part of TMT first-light suite

- Currently no other visible wavelength spectroscopic capability planned for E-ELT (except for CODEX)

Spectral Discovery Space



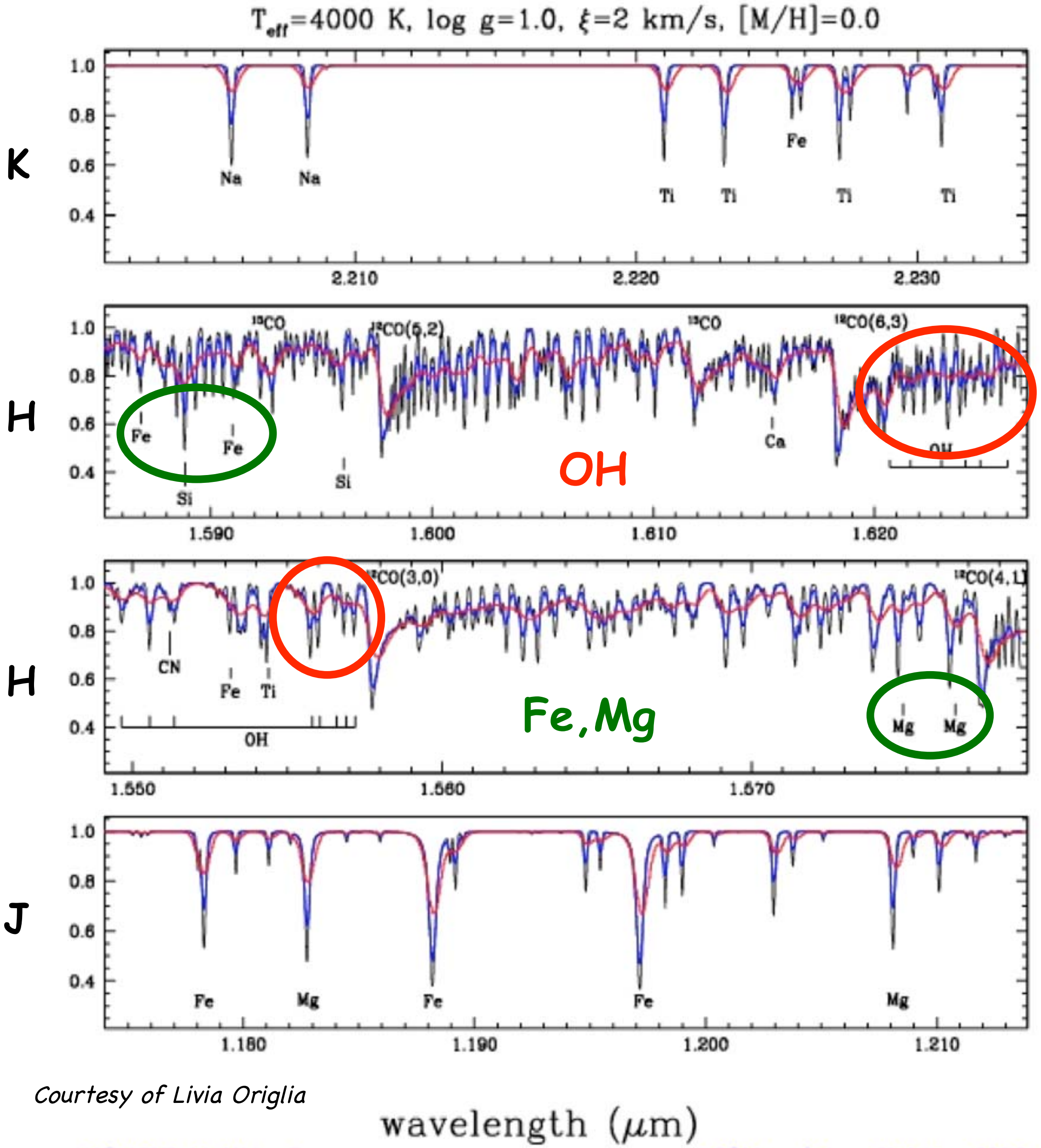
Spatial Discovery Space



What can HARMONI do?

- Prominent science areas
  - Planetary science
  - Circumstellar disks
  - Star forming regions
  - Stellar populations, IMF & Galactic archaeology
  - Black Holes and Galaxy Cores
  - GRBs
  - High redshift galaxies (1<z<10)

Stars, Star clusters & Galaxies with HARMONI in the NIR



Courtesy of Livia Origlia

Chemistry
(S/N≈30, [Fe/H]>-1.0)

- R≤10,000
  - » OH blends, Fe,Mg in J
- R>10,000
  - » OH progressively de-blended,
  - » J not needed for Fe,Mg in stars & star clusters
  - » J needed for Fe,Mg in galaxies due to velocity broadening

Kinematics

- R≈10,000
  - » σ=13 km/s » M≈$10^6 M_o$
- M∝σ^2
  - » R≥20,000 » SSCs, massive GGCs
  - » R≥50,000 » faint GGCs

Stars, Star clusters & Galaxies with HARMONI in the VIS

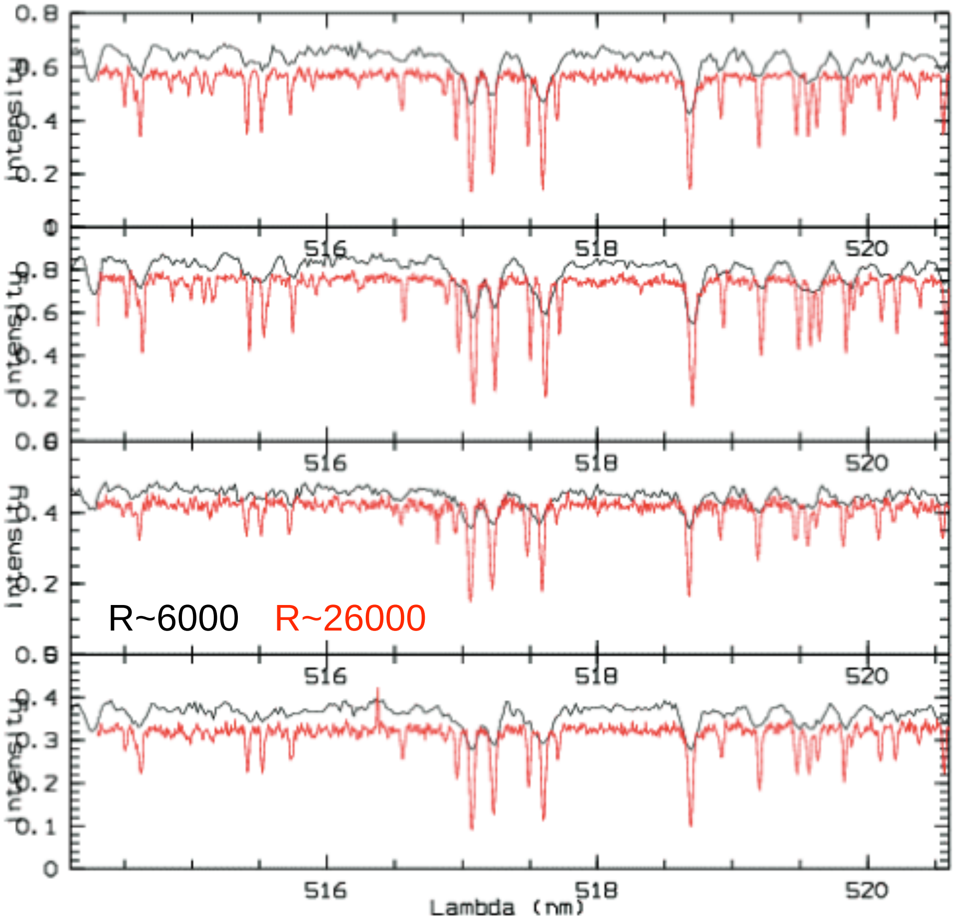


Figure15: GIRAFFE Low (L4, black lines) and High (H9, red lines) resolution spectra of 4 giants belonging to the Globular Cluster NGC 6809 *Pasquini et al. 2002 ESO Messenger, 110, 1*

R≈5,000 (≥0.8μm)

» Detailed abundances of B-A super-giants in spiral galaxies outside the Local Group

» Chemo-dynamical analyses

R≈20,000 (≥0.48μm)

» Lithium in old main-sequence stars in the most nearby galaxies

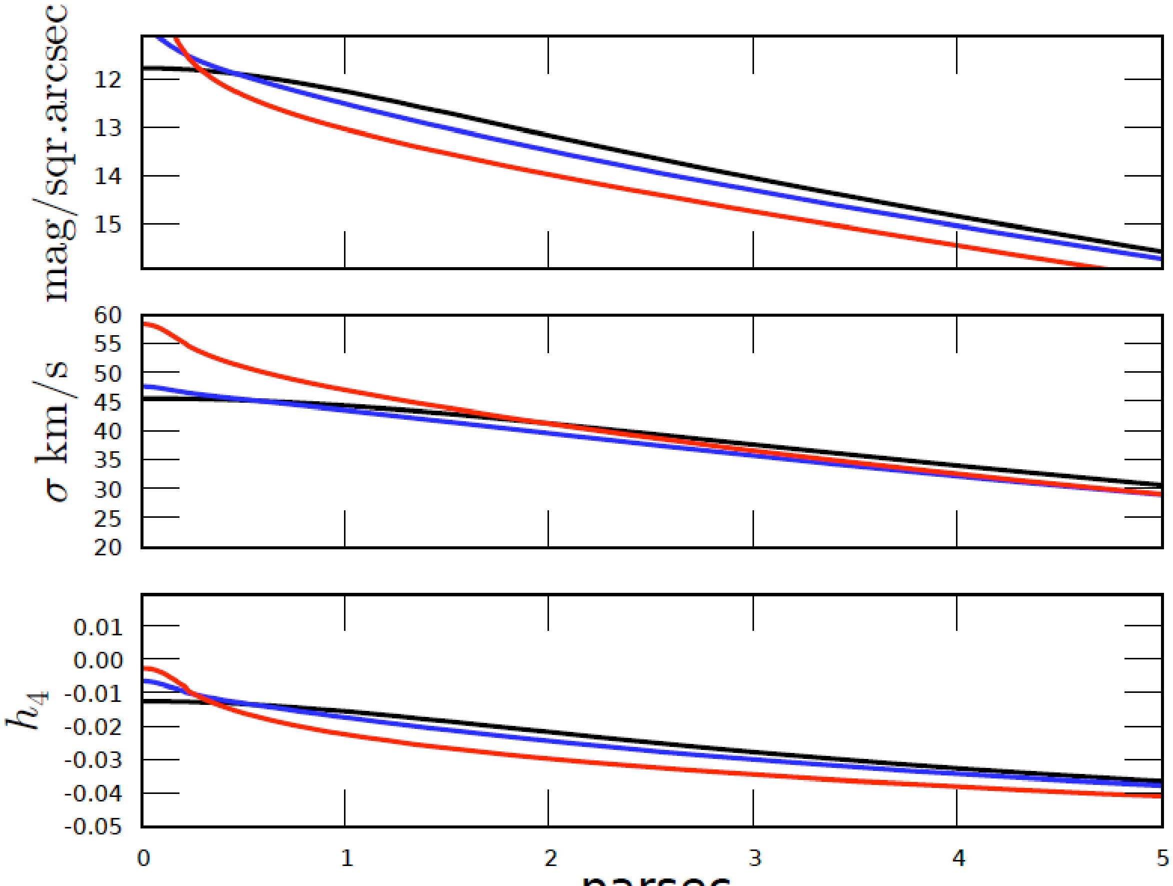
» Detailed abundances in old red giants at the edge of the Local-Group

» Detailed abundances of B-A super-giants in spiral galaxies outside the Local Group

Courtesy of Eline Tolstoy

Black holes & nuclear clusters

Simple cluster model (King DF like GC) but with optional BH



Courtesy of John Magorrian

$M_\bullet$ [$10^6 M_\odot$]	M_* [$10^6 M_\odot$]	R_h [pc]	σ_{av} [km/s]
0	8.2	3	36
0.17	7.1	3	35
0.3	5.8	3	37

R≈5,000 (≥0.8μm)

» metal abundances

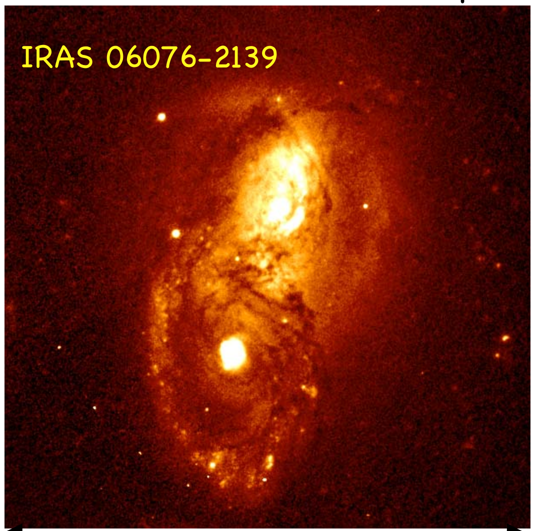
» stellar dynamics in galactic nuclei and nuclear clusters

R≈10,000 (≥0.8μm)

» Low mass black holes (< 10^6 $M_\odot$) & nuclear clusters

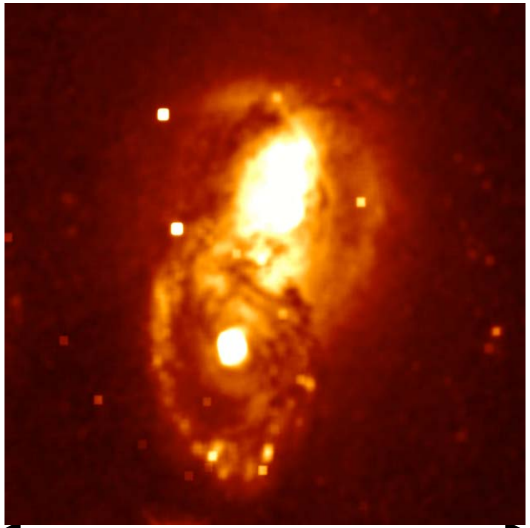
The power of HARMONI: spatially resolved galaxy properties and kinematics

HST/ACS at z=0.04 (160Mpc)



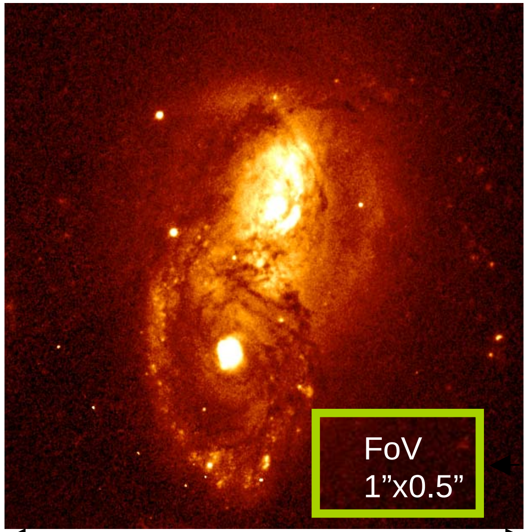
30 arcsec @ 50mas

ELT/GLAO/HARMONI at z=2



3 arcsec @ 50 mas

ELT/LTAO/HARMONI at z=2*



3 arcsec @ 5 mas

Courtesy of Santiago Arribas

R≈4,000

» 75 km/s (FWHM), σ = 33 km/s

$R_{hl} \approx$ 2 kpc => M = $4 \cdot 10^9$ M_o

$R_{hl} \approx$ 100 pc => M = $2 \cdot 10^8$ M_o

R≈20,000

» 15 km/s (FWHM), σ = 6.5 km/s

$R_{hl} \approx$ 2 kpc => M = $1.5 \cdot 10^8$ M_o

$R_{hl} \approx$ 100 pc => M = $8 \cdot 10^6$ M_o

Typical size of HII region ≈ 100pc

Typical masses of extranuclear knots 10^6–10^7 M_o

* z=2 (40pc/spaxel) worst case scenario. Any other z more favourable scale

High z galaxies at 100pc scales

- Metallicities
- Outflows and winds
- AGN/SF dominated regions
- Shocks
- Ionisation
- ISM enrichment
- Dynamical masses

- Fake velocity fields from HST/UDF H band images:
  i=60°, v=60km/s, r_p=3kpc