The FIREBALL project:

3D spectroscopy of 10^4 to 10^5 galaxies at z~0.2

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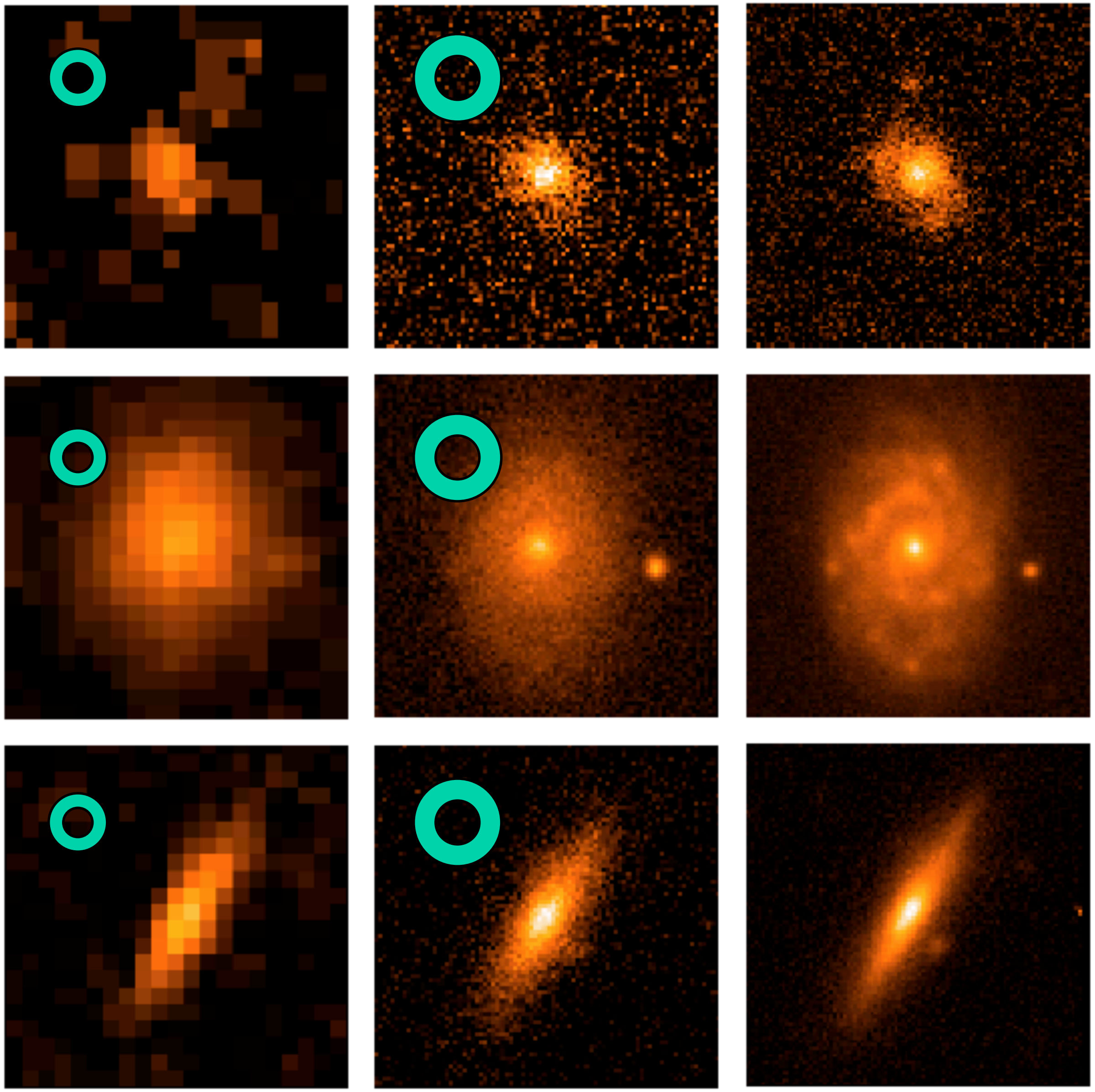
Ongoing and planned cosmological surveys at optical-IR have fundamental limitations…

Multi-slit, e.g. DEIMOS, VIMOS

Multi-fibre, e.g. 2dF, SDSS

IFU/Image slicer, e.g. SINFONI

But these are some of the most cited papers in astronomy…

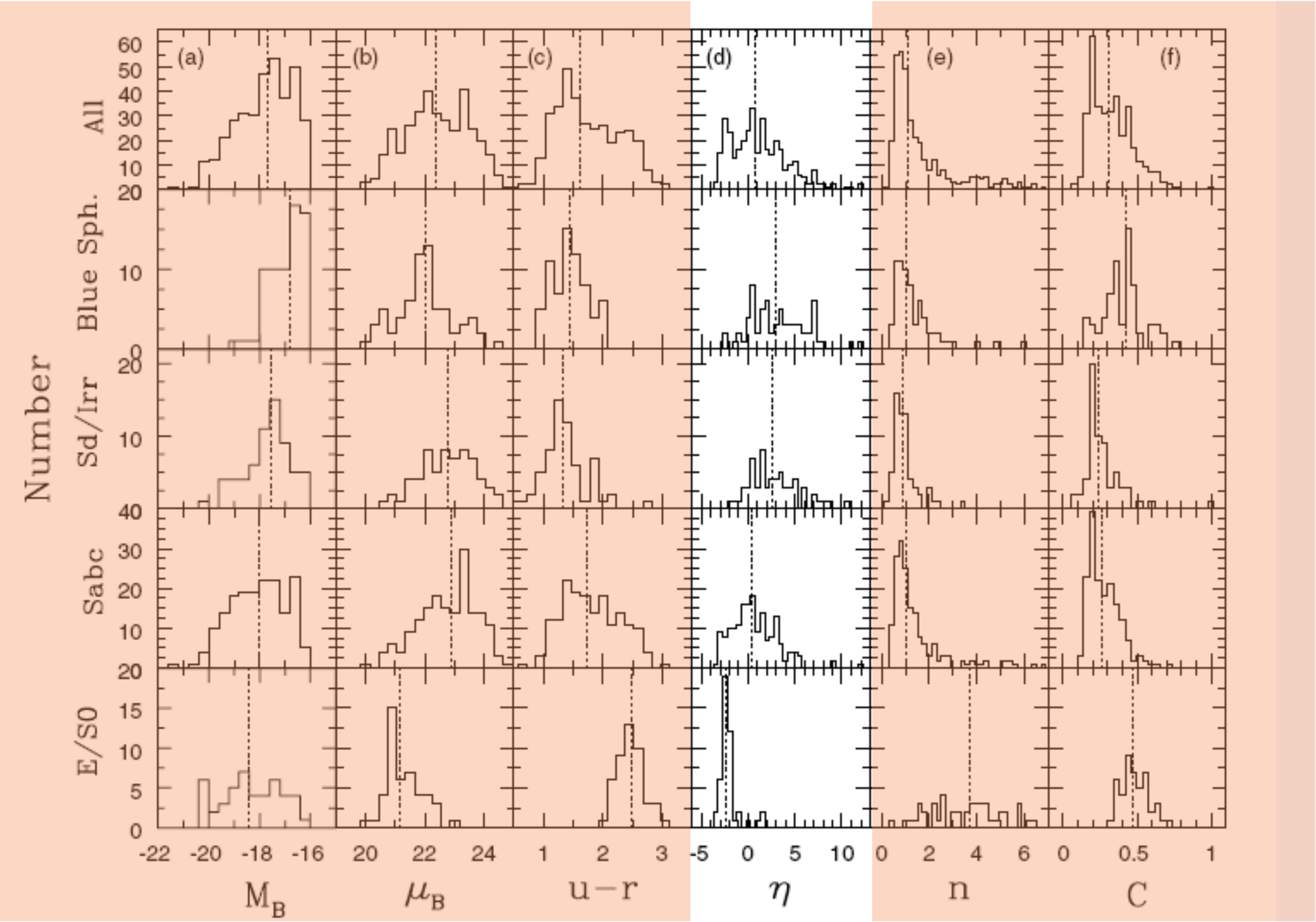


2dF SDSS MGC

One of several key flaws in existing surveys

S. Ellis+ 2005

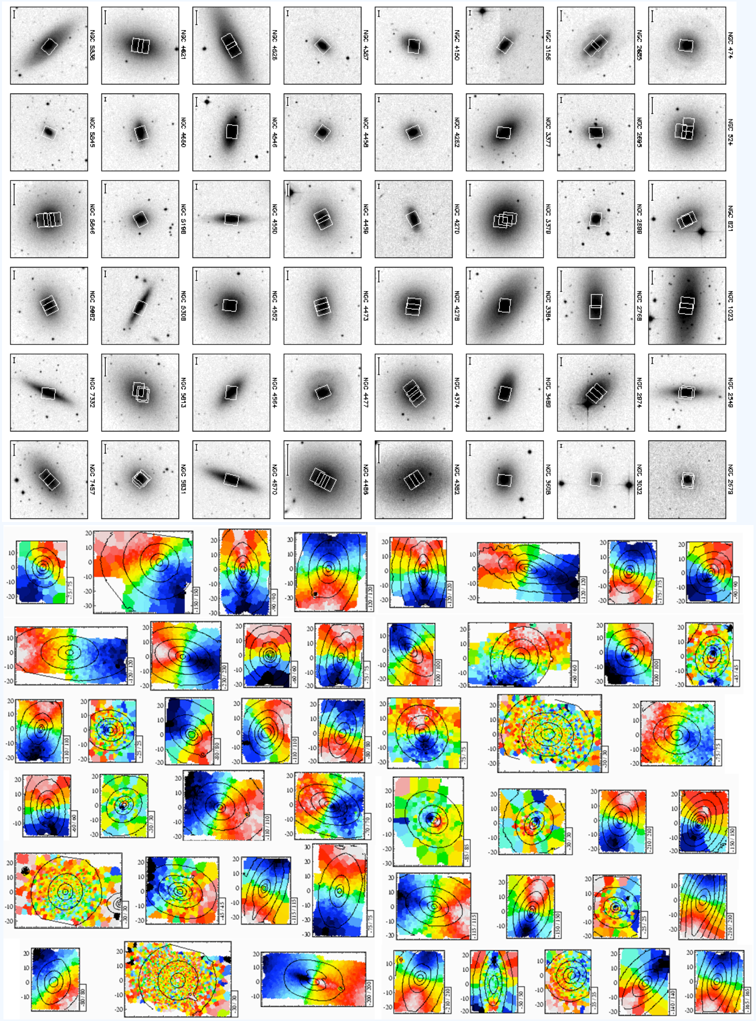
On the natural subdivision of galaxies



So why not combine the relative merits of MOS positioners and integral fields?

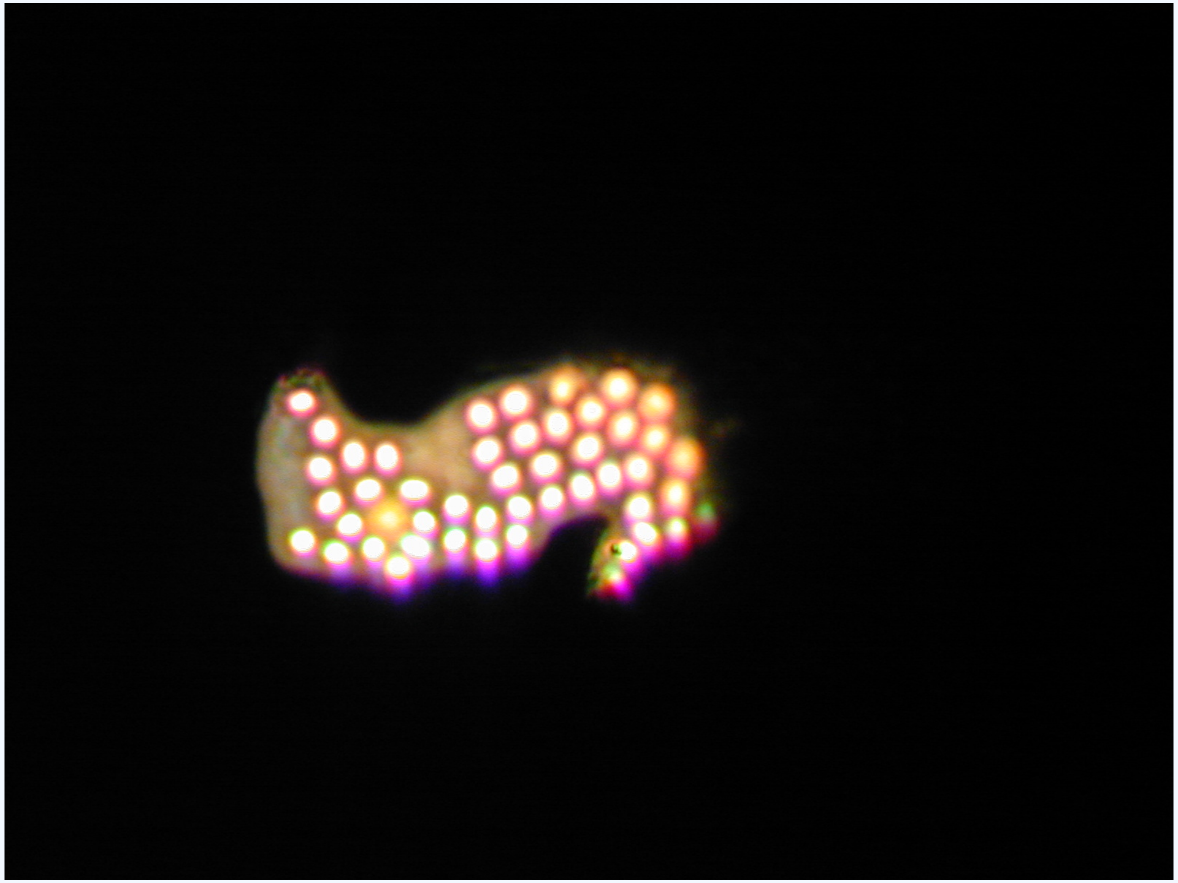
Hexabundles

i.e. fibres that can use existing MOS positioning technologies but multiply sample the object with independent multiple cores.



SAURON

Hexabundle: early attempt (2005)



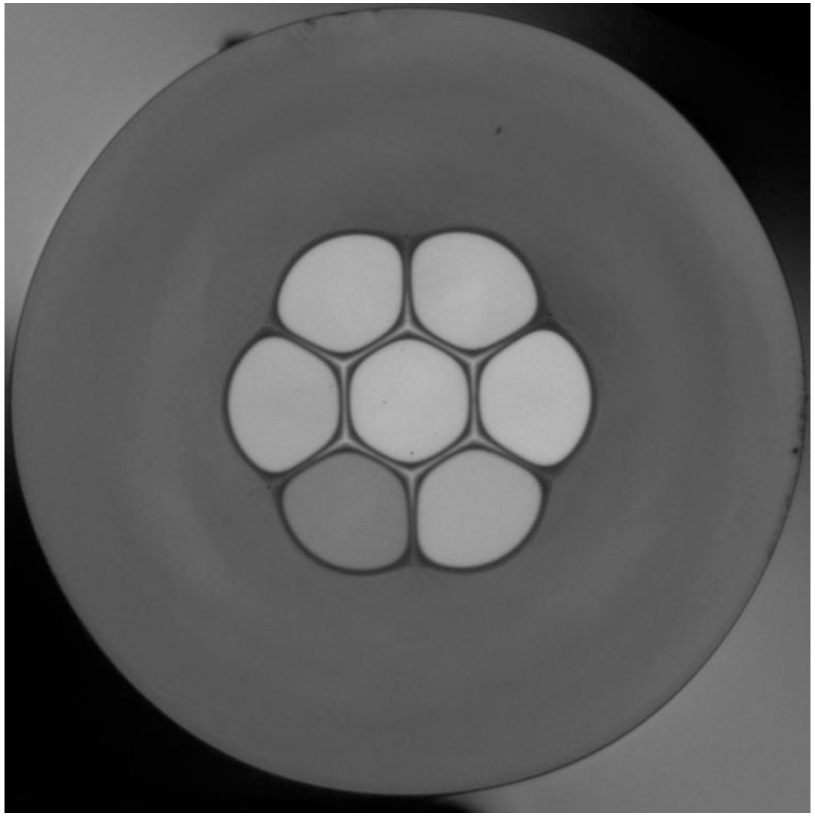
defunctus est!

astrophotonics

1x7 hexabundle (2007)

Conventional wisdom: cladding needs to be 10λ in thickness.

We find only 2λ cladding is needed over short fuse distances.



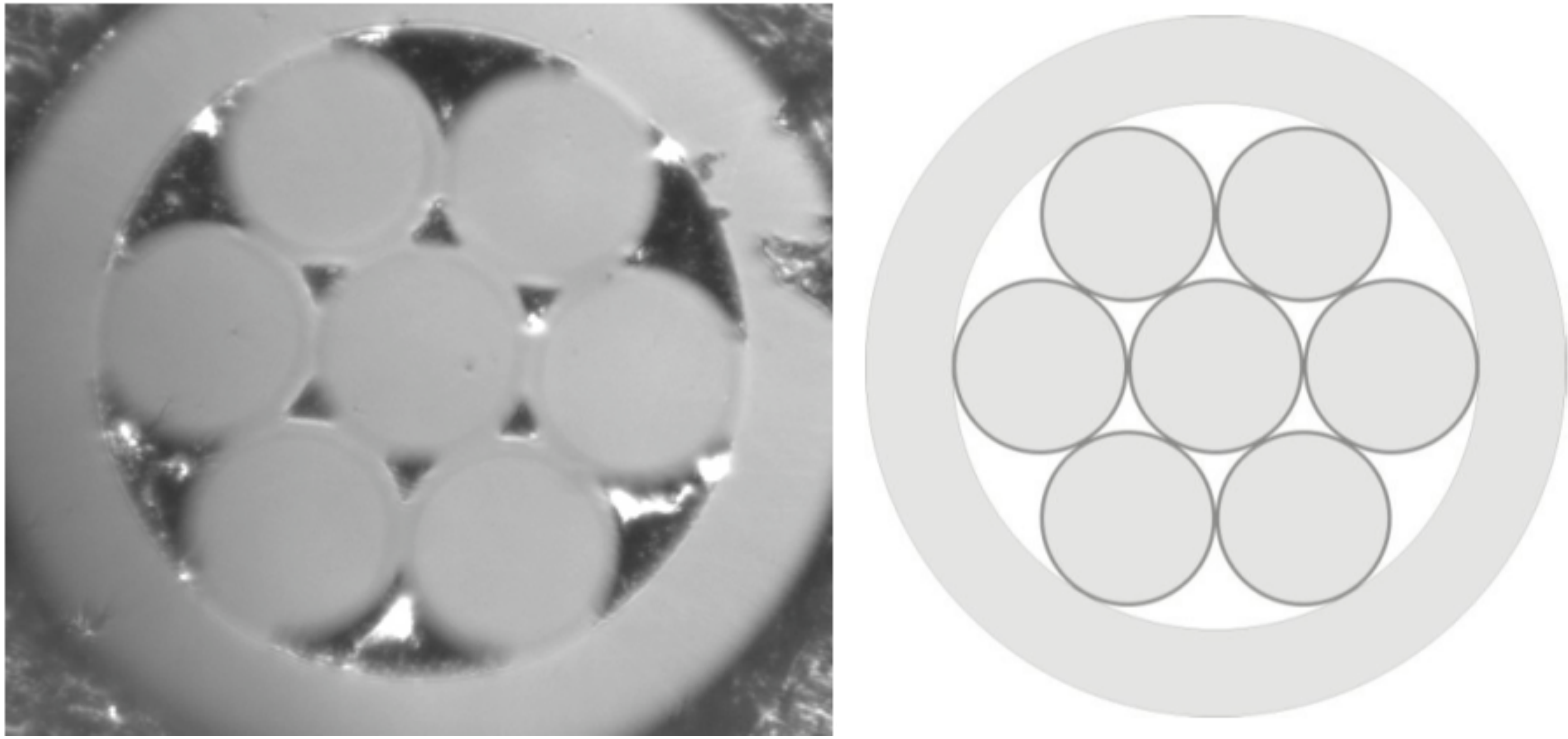
$$P = 1 - 2\frac{\delta r}{r}$$

Fully fused, 95% fill fraction (Bland-Hawthorn+ 2009)

astrophotonics

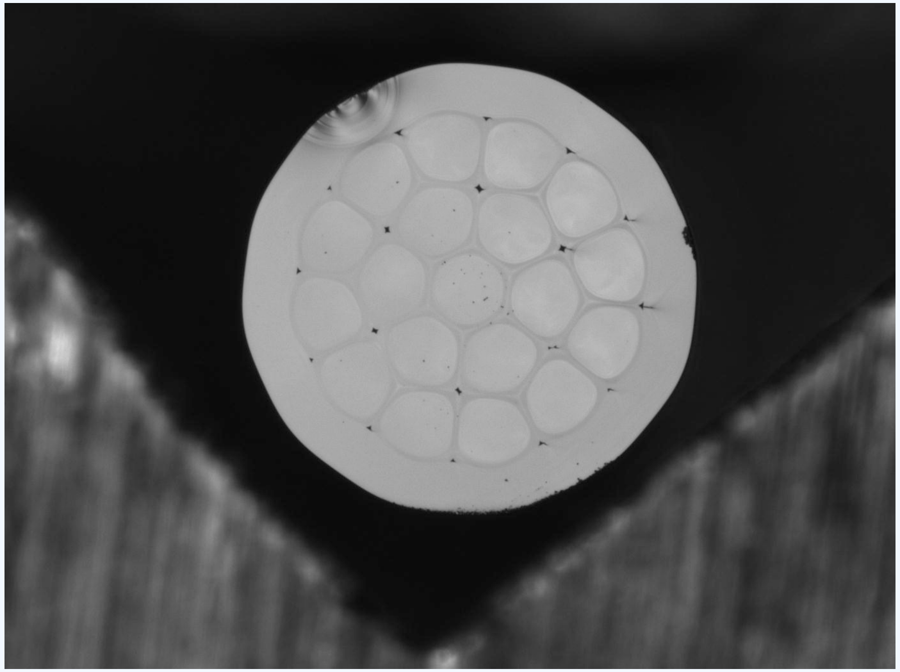
Hexabundles — unfused (2009)

$$P = \frac{\pi}{\sqrt{12}}\left(1 - 2\frac{\delta r}{r}\right)$$

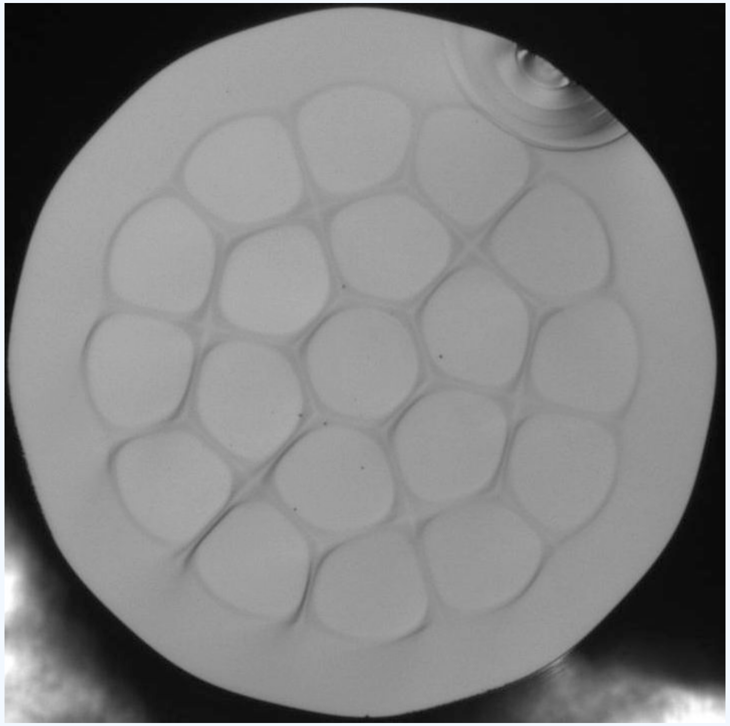


These may have better FRD performance, 90% fill fraction (Bland-Hawthorn+ 2009)

1x19 hexabundle (2008)



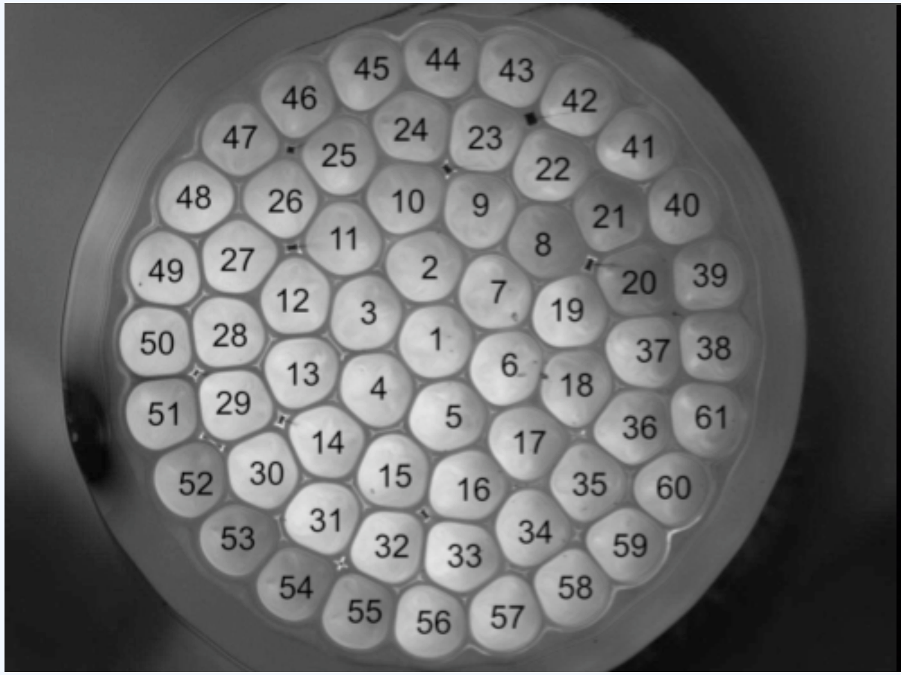
Not fully fused



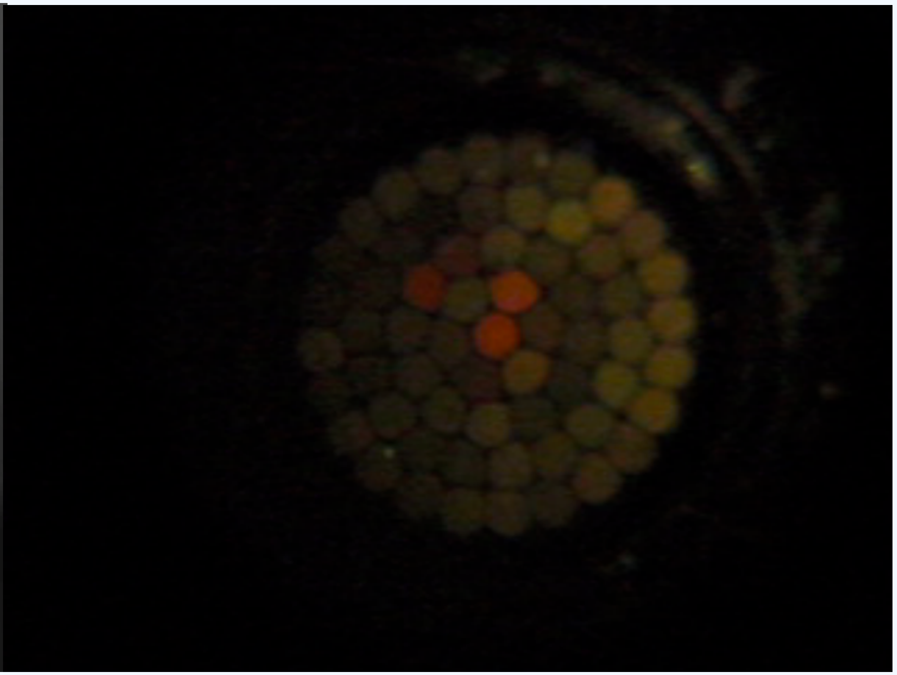
Fully fused - unpolished

astrophotonics

1x61 hexabundle (2008)



All cores have identical area



movie

Possible configurations – fused or unfused

No need for microlens array

Conventional fibre positioner (low tension)

If needed, macro lens to change plate scale

Fused region ~ 3 cm in length

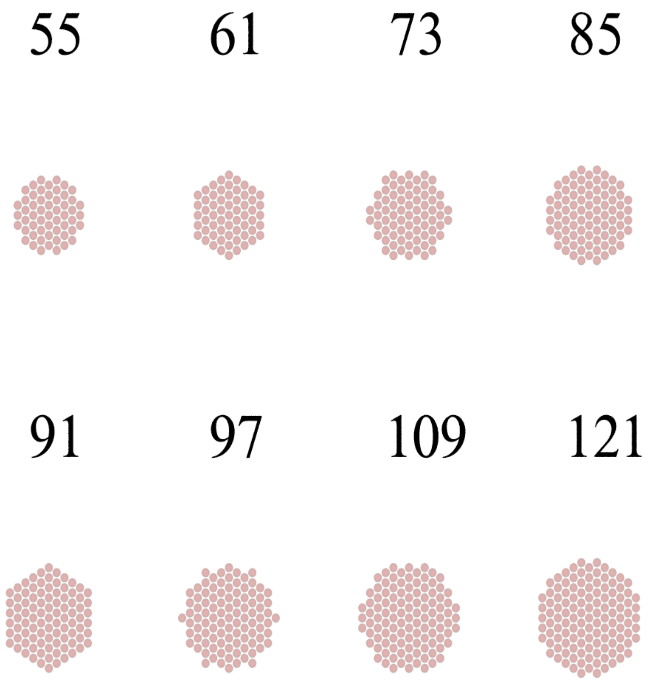
Core sizes ~ 50-150… microns

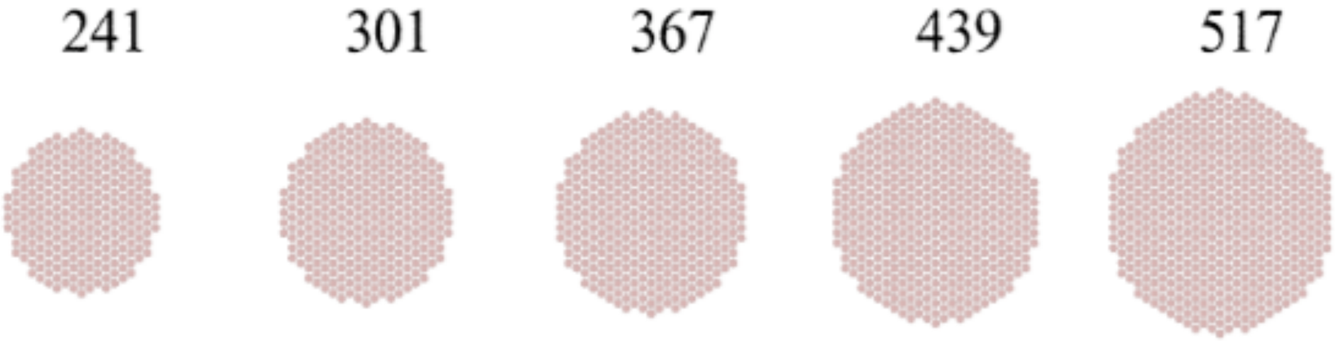
Cross talk < 0.1 dB (4%)

Fill fraction ~ 95% (fused), 90% (unfused)

NA ~ 0.05 to 0.25

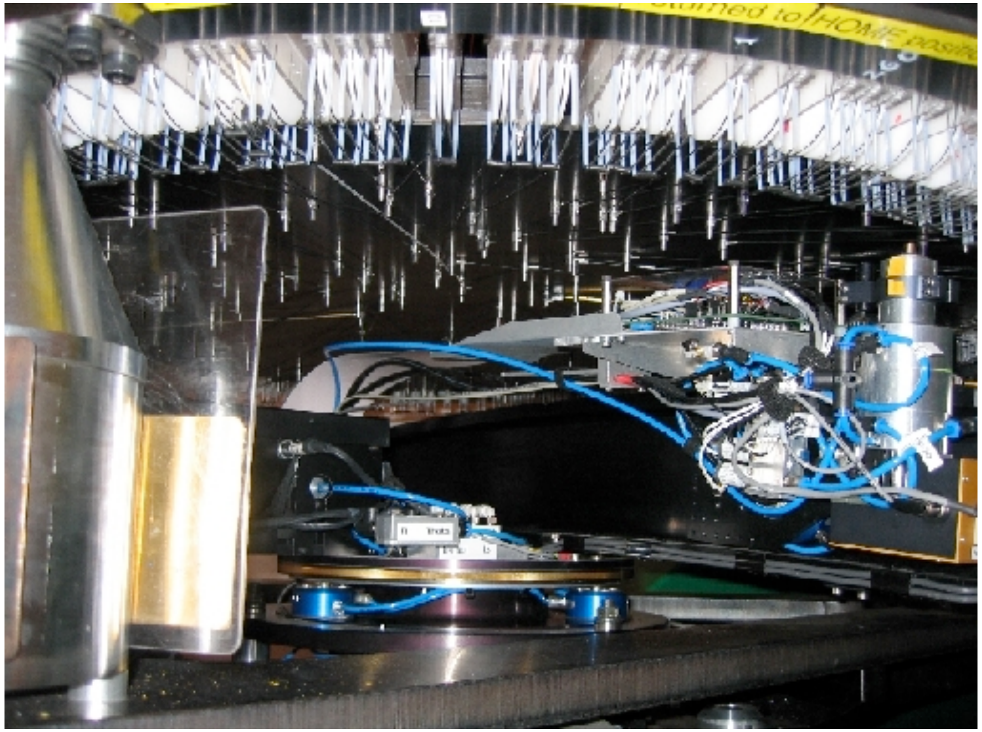
Format ~ up to 1x400 possible





FIREBALL (2012)

- FLAMES facility on VLT
- Operational since 2003
- OzPoz positioner by AAO
- **Now:** 132 fibers to GIRAFFE



Upgrade FLAMES, 26’ field

50 1x100 hexabundles, **5** MUSE-style spectrographs

R~1500-3600, λ=465-930nm

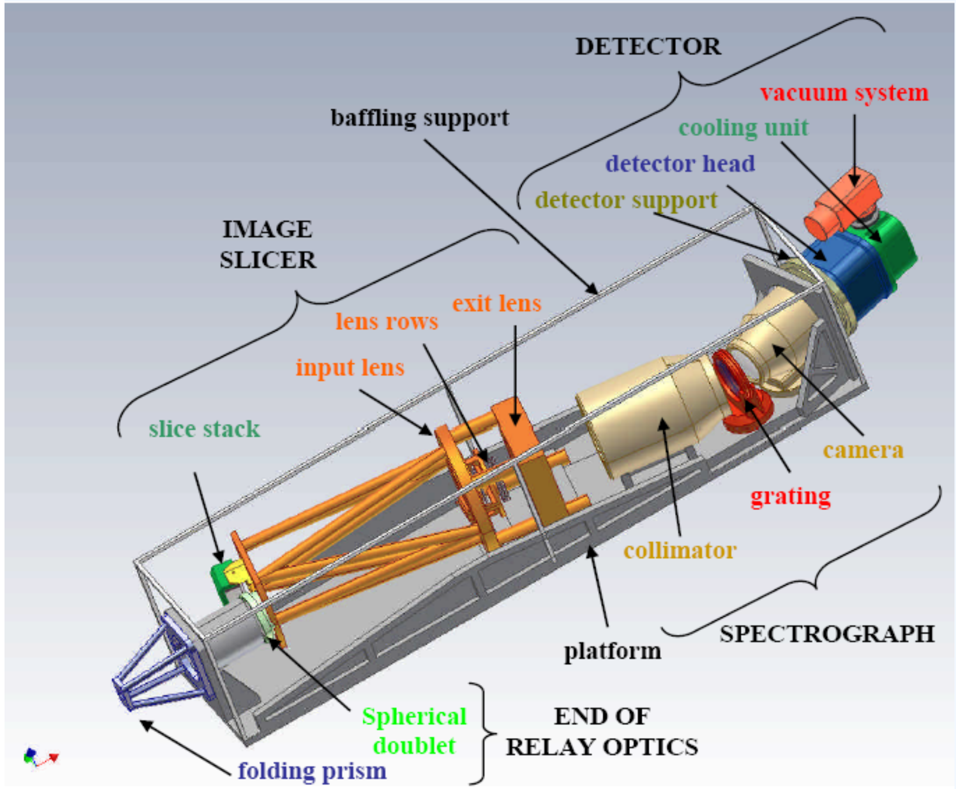
0.46” sampling, 4.6” ø f-o-v

Retain existing facility

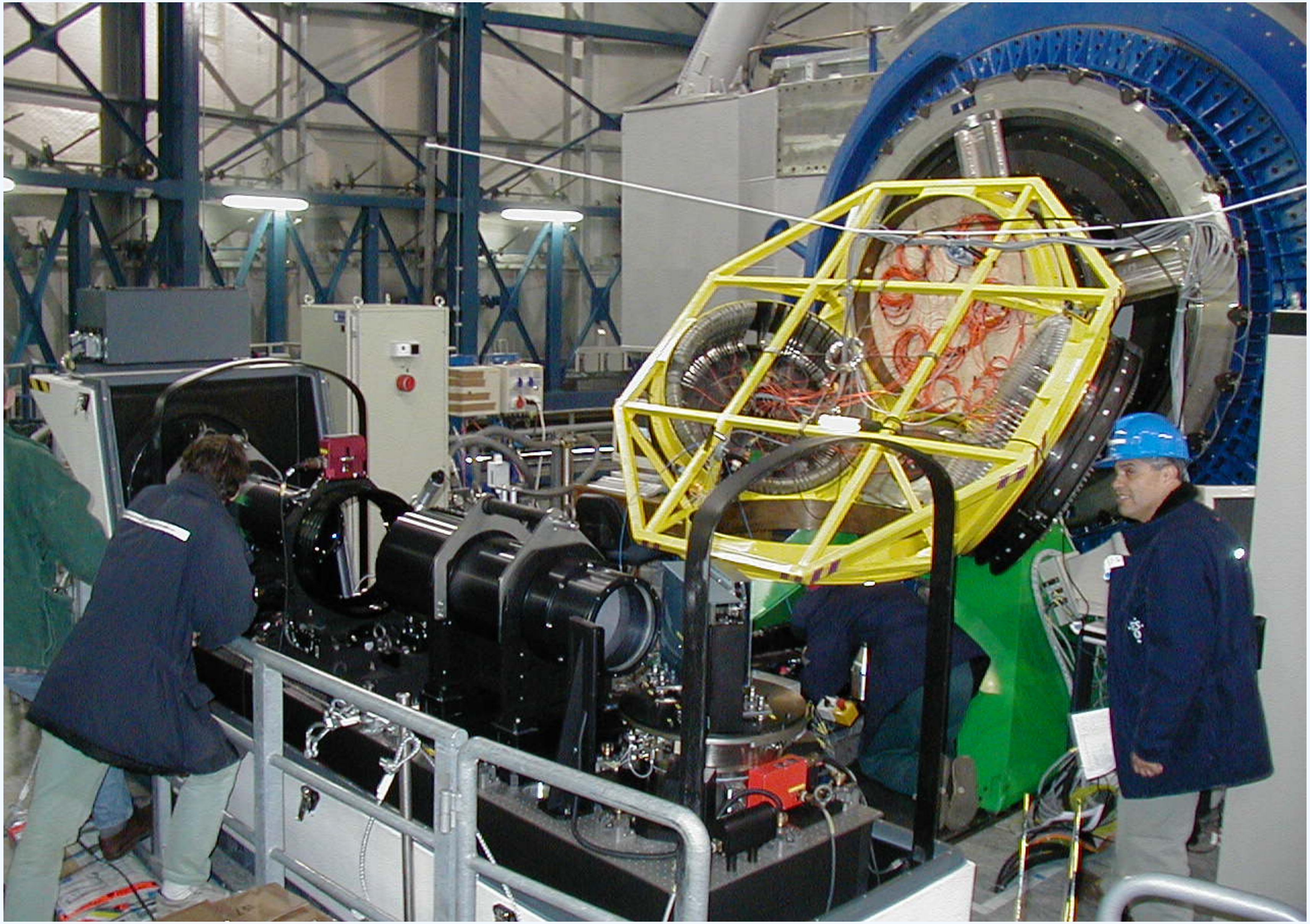
Cost: 1.12 M € (hardware)

OzPoz fibre positioner – field plate with fibre buttons

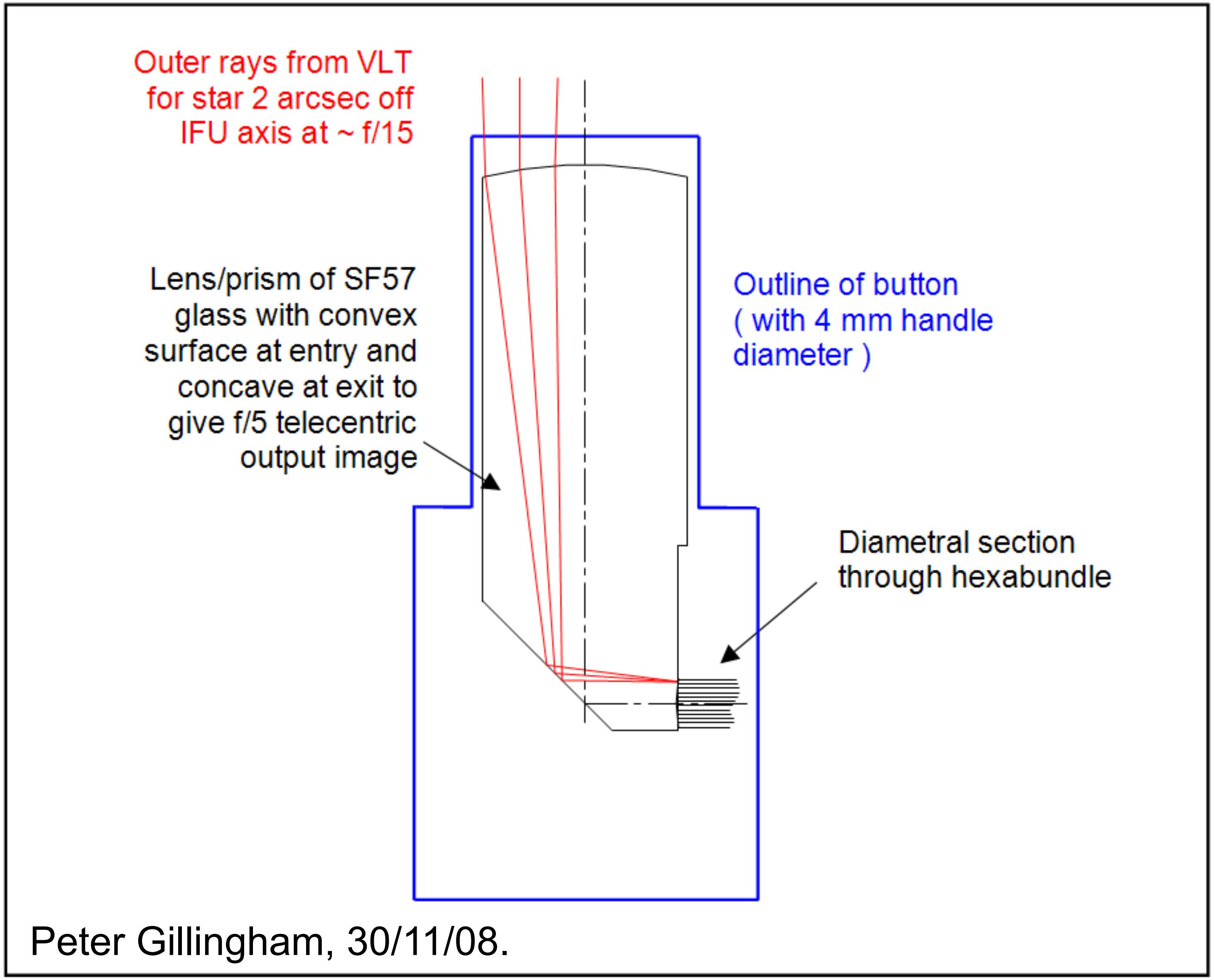
...feeding to MUSE spectrographs



FLAMES and the OzPoz fibre positioner at the VLT



OzPoz fibre button feeding a hexabundle – ray traced



Outer rays from VLT
for star 2 arcsec off
IFU axis at ~ f/15

Lens/prism of SF57
glass with convex
surface at entry and
concave at exit to
give f/5 telecentric
output image

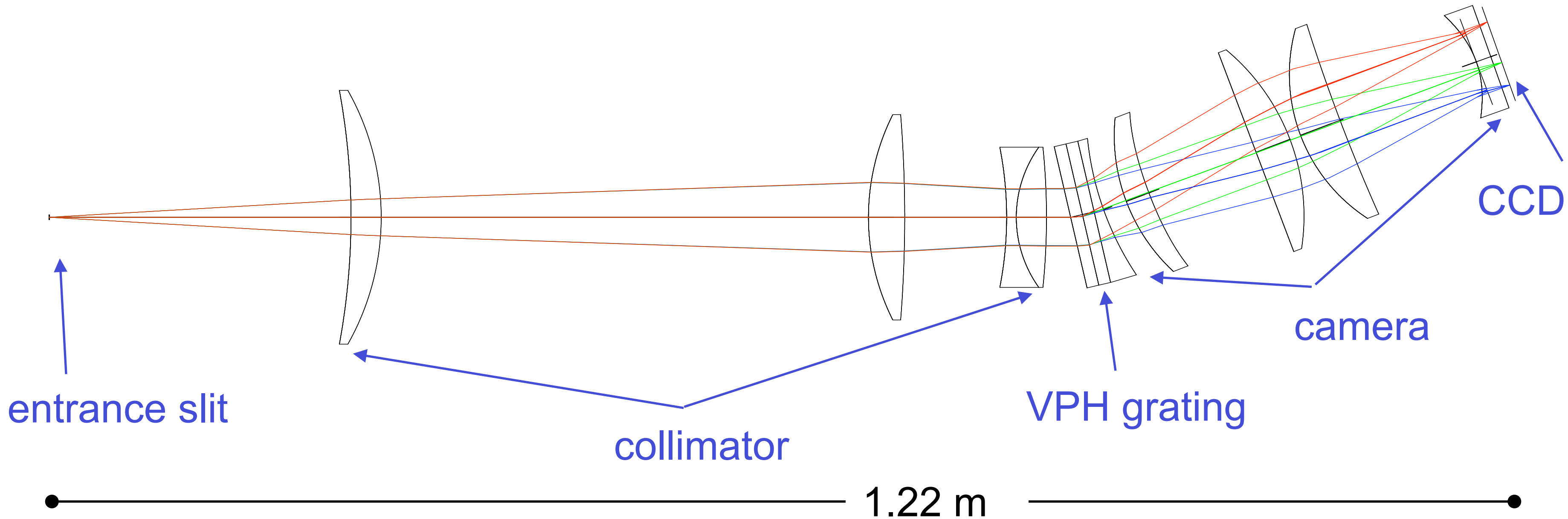
Outline of button
(with 4 mm handle
diameter)

Diametral section
through hexabundle

Peter Gillingham, 30/11/08.

Layout of lens/prism in standard OzPoz button envelope for acceptance of f/15 VLT beam, producing an f/5 telecentric focus onto a hexabundle.

MUSE spectrographs – ray traced



CCD

camera

entrance slit

collimator

VPH grating

1.22 m

Each of the 24 identical spectrographs has:

- Fixed format, using 639 l/mm Volume Phase Holographic grating
- **Wavelength coverage 465 – 930 nm**
- Spectral resolution Δλ = 0.25 nm

  Resolving power λ/Δλ 1750, 2440, 3750 at λ 465, 633, 930 nm
- Slit to detector magnification 0.45
- Image quality: ≥ 80% energy in 15 × 30 μm (spatial × spectral; λ ≥ 580 nm)
- Detectors 4096 × 4096 pixels, each 15 μm square

Science drivers

Fixing the biases in single fibre spectroscopy

Bolometric characterization of galaxies

Build up of mass and angular momentum in galaxies

Mergers and interacting galaxies

Where does star formation happen?

Winds and outflows

Abundance gradients

Mapping extinction and reddening

AGN fraction, triggering, connection to star formation

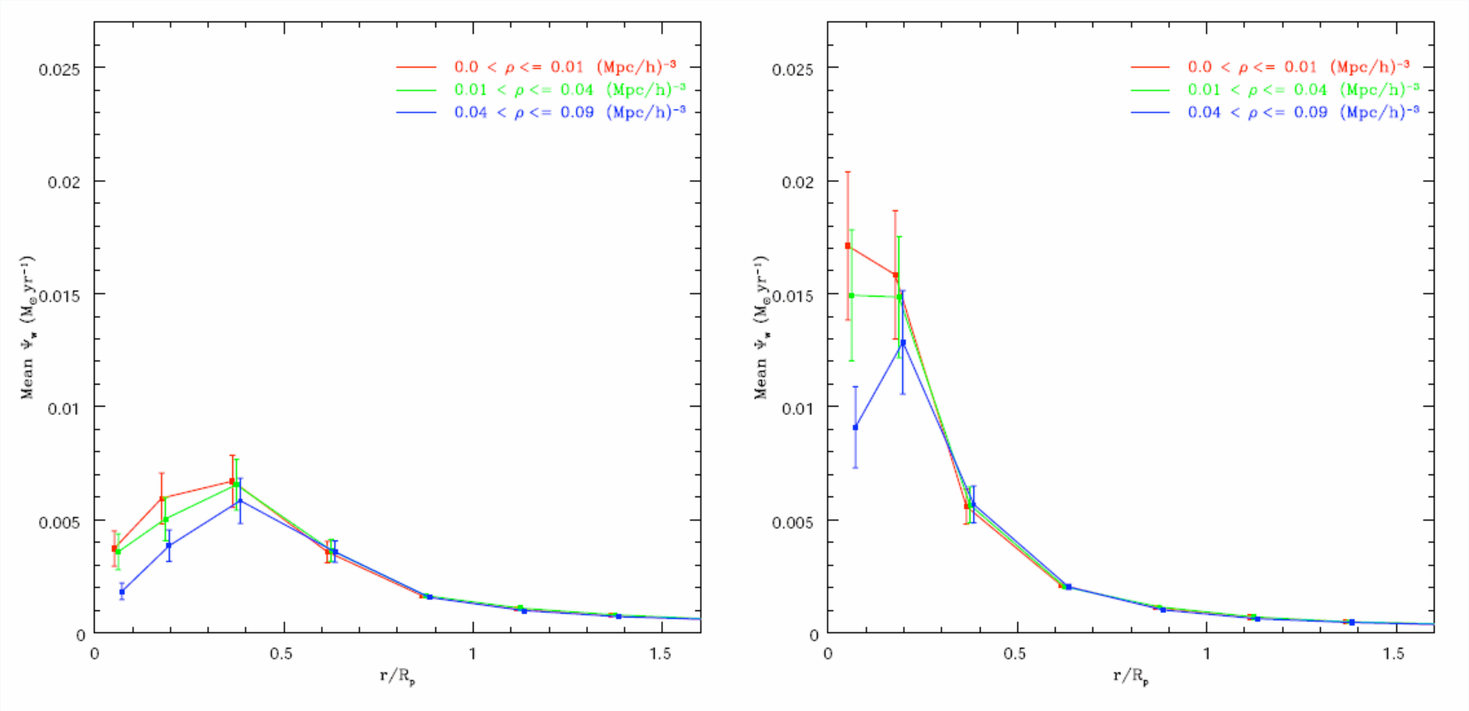
Reconstructing lensed galaxies

Planetary Nebulae in the bulge and LMC

HII regions in nearby galaxies

...∞

Resolved star formation



- Photometric analysis (pixel-z) suggests radial variations in SF are a function of environment (Welikala et al. 2009).
- Test the impact of harassment, ram pressure, feedback...

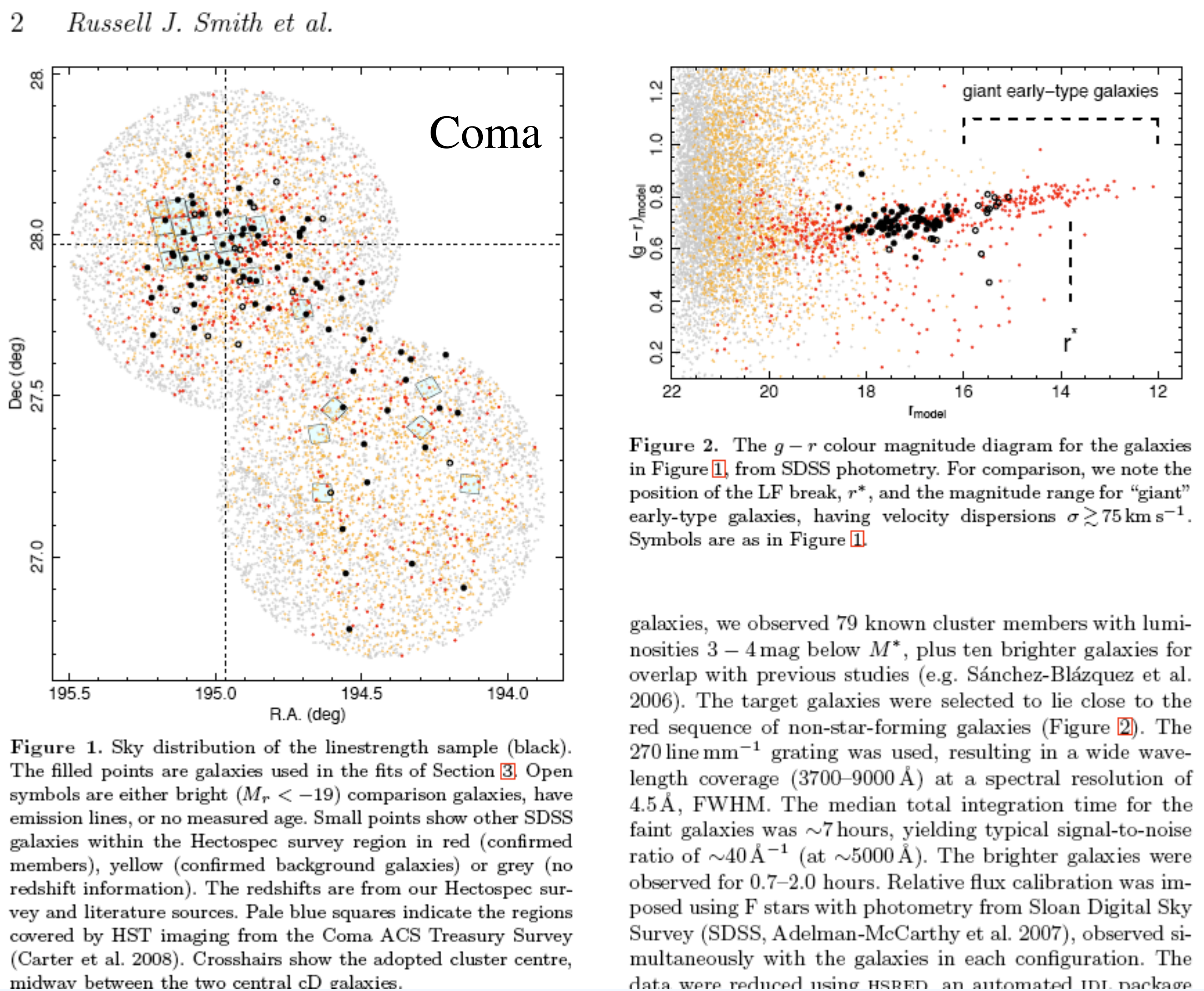


Figure 1. Sky distribution of the linestrength sample (black). The filled points are galaxies used in the fits of Section 3. Open symbols are either bright ($M_r < -19$) comparison galaxies, have emission lines, or no measured age. Small points show other SDSS galaxies within the Hectospec survey region in red (confirmed members), yellow (confirmed background galaxies) or grey (no redshift information). The redshifts are from our Hectospec survey and literature sources. Pale blue squares indicate the regions covered by HST imaging from the Coma ACS Treasury Survey (Carter et al. 2008). Crosshairs show the adopted cluster centre, midway between the two central cD galaxies.

Figure 2. The $g - r$ colour magnitude diagram for the galaxies in Figure 1, from SDSS photometry. For comparison, we note the position of the LF break, r^*, and the magnitude range for "giant" early-type galaxies, having velocity dispersions $\sigma \gtrsim 75\,\mathrm{km\,s^{-1}}$. Symbols are as in Figure 1.

galaxies, we observed 79 known cluster members with luminosities $3 - 4$ mag below M^*, plus ten brighter galaxies for overlap with previous studies (e.g. Sánchez-Blázquez et al. 2006). The target galaxies were selected to lie close to the red sequence of non-star-forming galaxies (Figure 2). The 270 line mm^{-1} grating was used, resulting in a wide wavelength coverage (3700–9000 Å) at a spectral resolution of 4.5 Å, FWHM. The median total integration time for the faint galaxies was ∼7 hours, yielding typical signal-to-noise ratio of ∼40 Å^{-1} (at ∼5000 Å). The brighter galaxies were observed for 0.7–2.0 hours. Relative flux calibration was imposed using F stars with photometry from Sloan Digital Sky Survey (SDSS, Adelman-McCarthy et al. 2007), observed simultaneously with the galaxies in each configuration. The data were reduced using HSRED, an automated IDL package

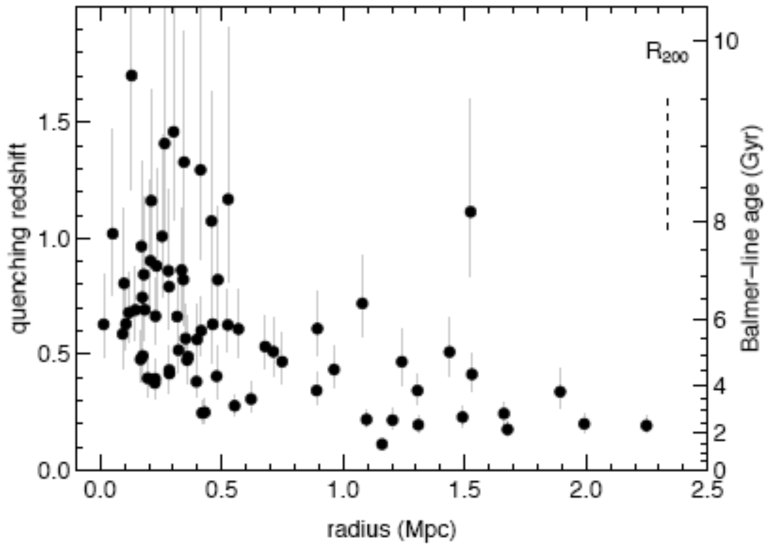


Figure 5. Quenching redshift, defined here as the redshift for which the look-back time is equal to the Balmer age, as a function of projected distance from the cluster centre. Although the most recent burst will generally be superposed on an older population, the Balmer age is strongly weighted toward the youngest stars present. If the mass-fraction of the most recent burst is very small, the quenching redshifts plotted here are upper limits. The assumed cosmology has parameters $(\Omega_M, \Omega_\Lambda, h) = (0.3, 0.7, 0.7)$.

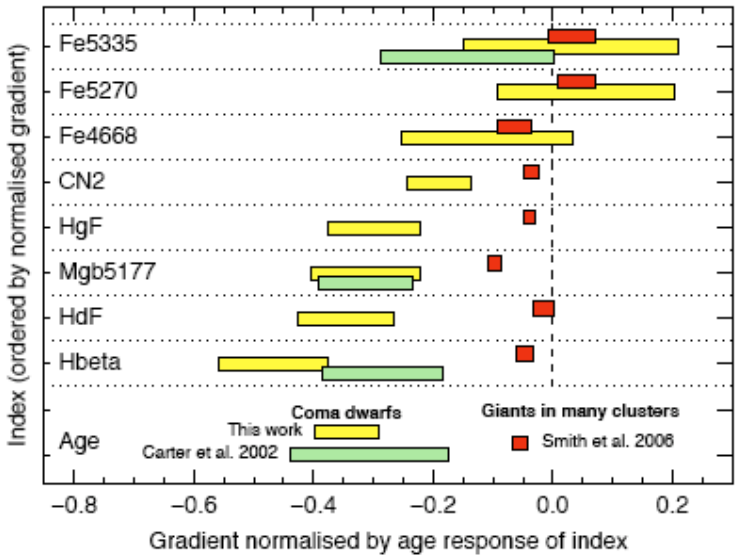


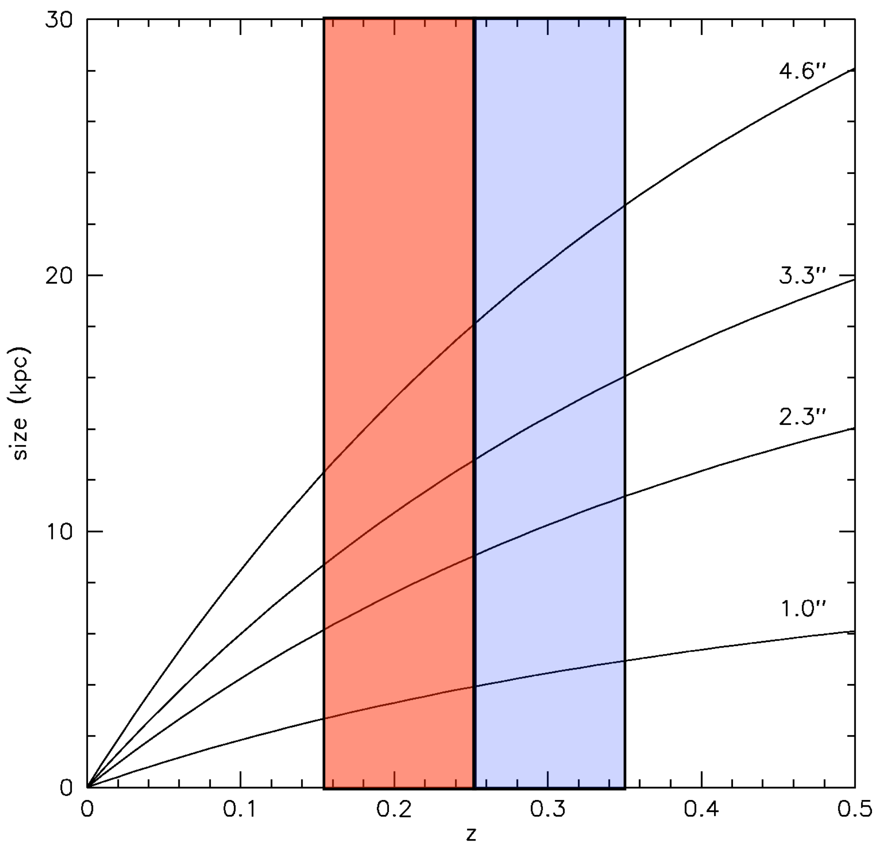
Figure 6. Comparison of our index gradient pattern (yellow) with previous work. For clarity, the results for each index have been normalised by its age response. Thus if age was the only variable changing with radius, all indices should give the same gradient. Yellow boxes show the 1σ range from this work. For Carter et al. (2002, green) we compare their $\langle \mathrm{Fe} \rangle$ with our Fe5335; their Mg2 gradient has been converted to an equivalent gradient in Mgb5177. For Smith et al. (2006, red), we have converted their gradients in R_{200} to degrees assuming $R_{200} \approx 80$ arcmin for Coma. The bottom row shows the age gradients derived for the three studies, including a new estimate for Carter et al., based on their published index gradients.

work in the south-west region, influencing the field placement of subsequent studies including the current one.

FIREBALL survey: z~0.2

- ~10,000 galaxies
- $r_{AB}<20$
- Targets in GAMA volume, say
- Hexabundle diameter of 15 kpc at z=0.2
- 1-2 hrs. per field
- 35-70 clear VLT nights

- Going to higher z: better area coverage but lower surface brightness



Big Science:

Going to 250 hexabundles + 25 MUSE spectrographs

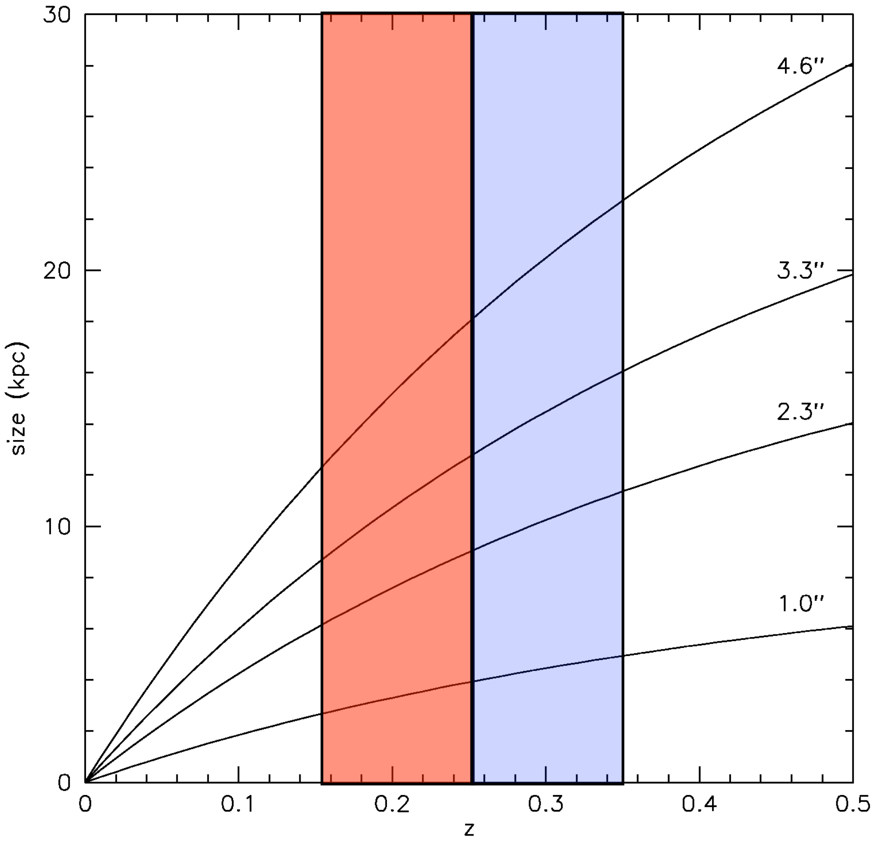
	all z	z > 0.1	z > 0.15
$r_{AB} < 20$	215	150	135
$r_{AB} < 20.5$	360	255	230

4000A break
matched to galaxy size

Cost: 5.6 M € (hardware)

FIREBALL survey: z~0.2

- ~100,000 galaxies
- $r_{AB}<20.5$
- Target galaxies in the GAMA volume, say
- Hexabundle diameter of 15 kpc at z=0.2
- 2-4 hrs. per field
- 140-280 clear VLT nights



Summary

- FIREBALL concept on the VLT:
  - 50 (250?) hexabundles with ~100 cores each using 5 (25?) MUSE spectrographs

- FIREBALL builds on existing infrastructure, is relatively cheap, low risk, and can be delivered by 2012.

- Excellent complementarity with:
  - MUSE (optical, 60" contiguous)
  - KMOS (infrared, 2.6" x 25 IFUs)
  - GIRAFFE (optical, 2.5" x 15 IFUs, high res. follow up)

- A major survey with FIREBALL would be **the** fundamental reference for galaxy formation models in the next decade.

Advantages

Instrumental

- Super-wide-field reformatting, AO or natural seeing, optical/IR
- Simplify design through smaller cores
- Less sensitive to seeing & seeing losses
- Less sensitive to positioning error

Scientific

- Less sensitive to object distance, size
- **Less sensitive to asymmetry, sub-structure**
- Measure radial, vertical, azimuthal trends (e.g. morphology)
- Better photometry, bolometric estimates
- Component decomposition now possible (e.g. nuc, bulge, disk)
- Differential binning to offset brightness variation

Key advantage over other imaging devices

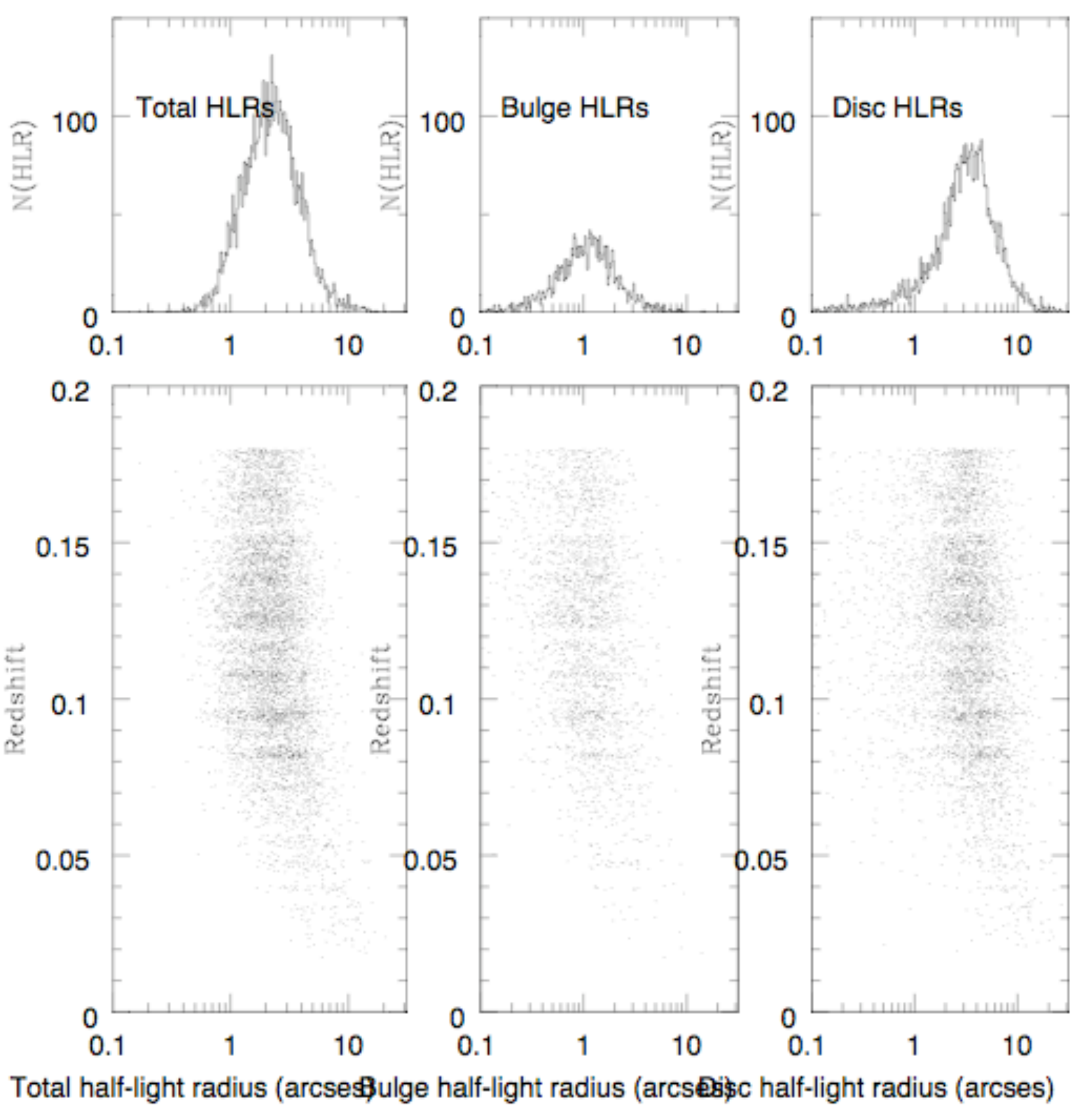
In image slicers, integral fields and densepak (glued fibre) arrangements, the wavefront is divided by hard optic boundaries.

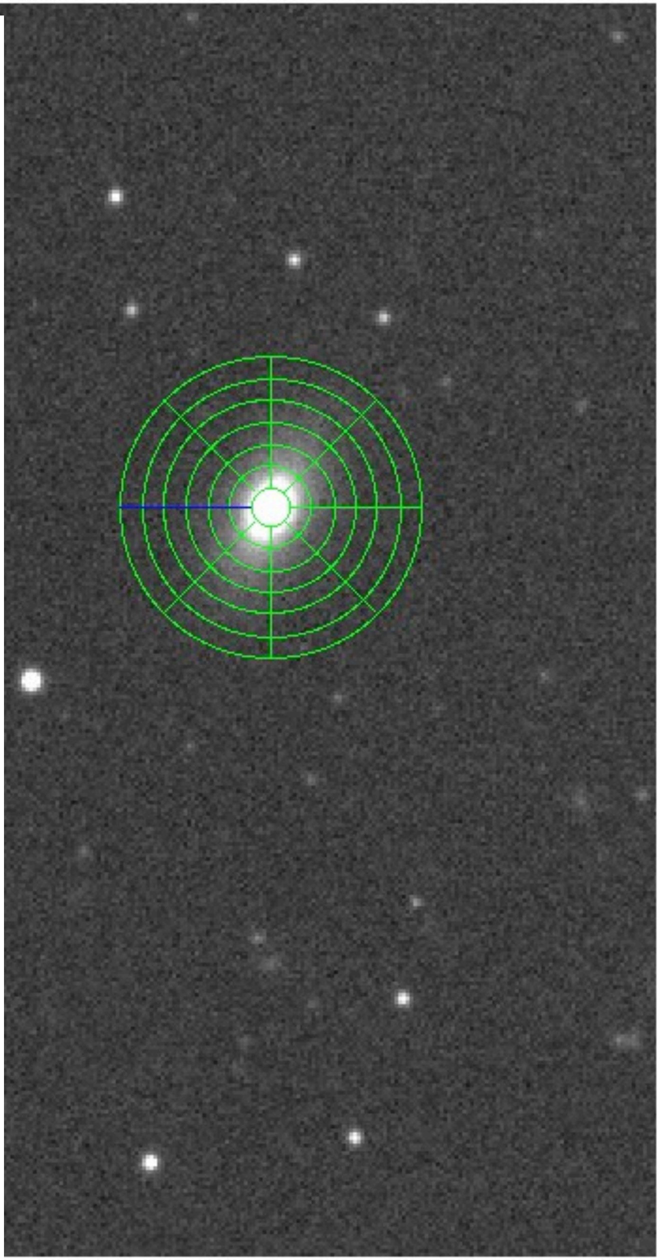
This is *not* the case in a hexabundle.

The wavefront is controlled by tiny refractive index variations, thereby minimizing optical losses, much like an interference filter.

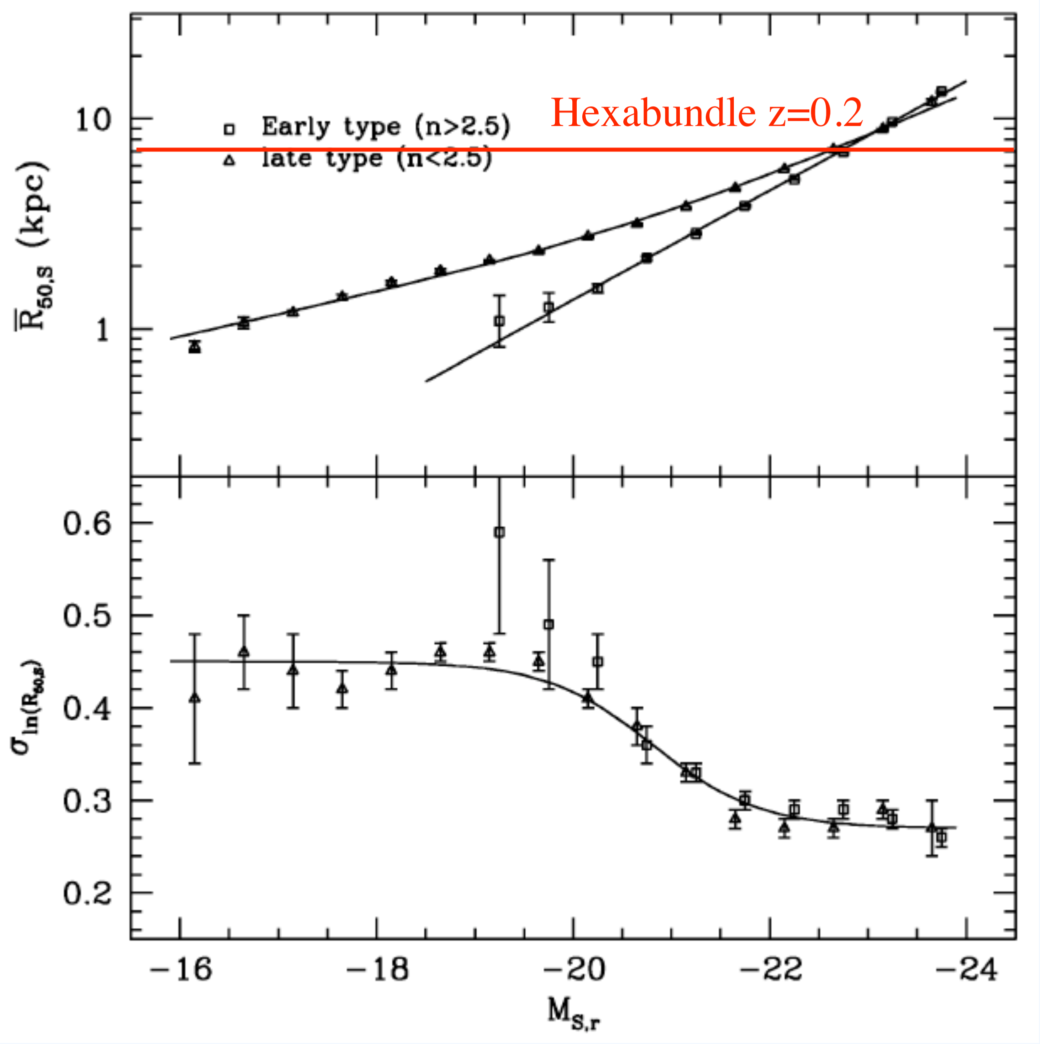
These should be *outstanding* photometric imaging devices.

Natural seeing (~0.6”), excellent site





Galaxy sizes



- Baseline hexabundle size can reach R_{50} for typical galaxies.
- But typical A/B~0.7
- Significant science gains from sampling past R_{50}.

SDSS galaxy sizes Shen et al. (2003)

Structure

90,000 element image-slicer IFU

Covers 60" × 60” at 0.2" × 0.2” sampling

Feeding 24 identical fixed format spectrographs

Detectors 4096 × 4096, with 15 μm pixels