Star formation and metal enrichment at z~1-2:

First multi-object near-infrared spectroscopy with large telescopes and the future with FMOS

Andy Bunker (Oxford)

Big Questions

1) What is the history for star formation - i.e. how rapidly is the Universe converting its gas into stars, and how does this evolve with time?

2) How is this star formation divided up among galaxies of different masses/environments as a function of cosmic time ("downsizing" etc).

3) Is the measured stellar mass density consistent with the integrated past cosmic star formation rate?

4) As heavy elements are made in stars, how does the metal enrichment of the gas & stars proceed?

Background

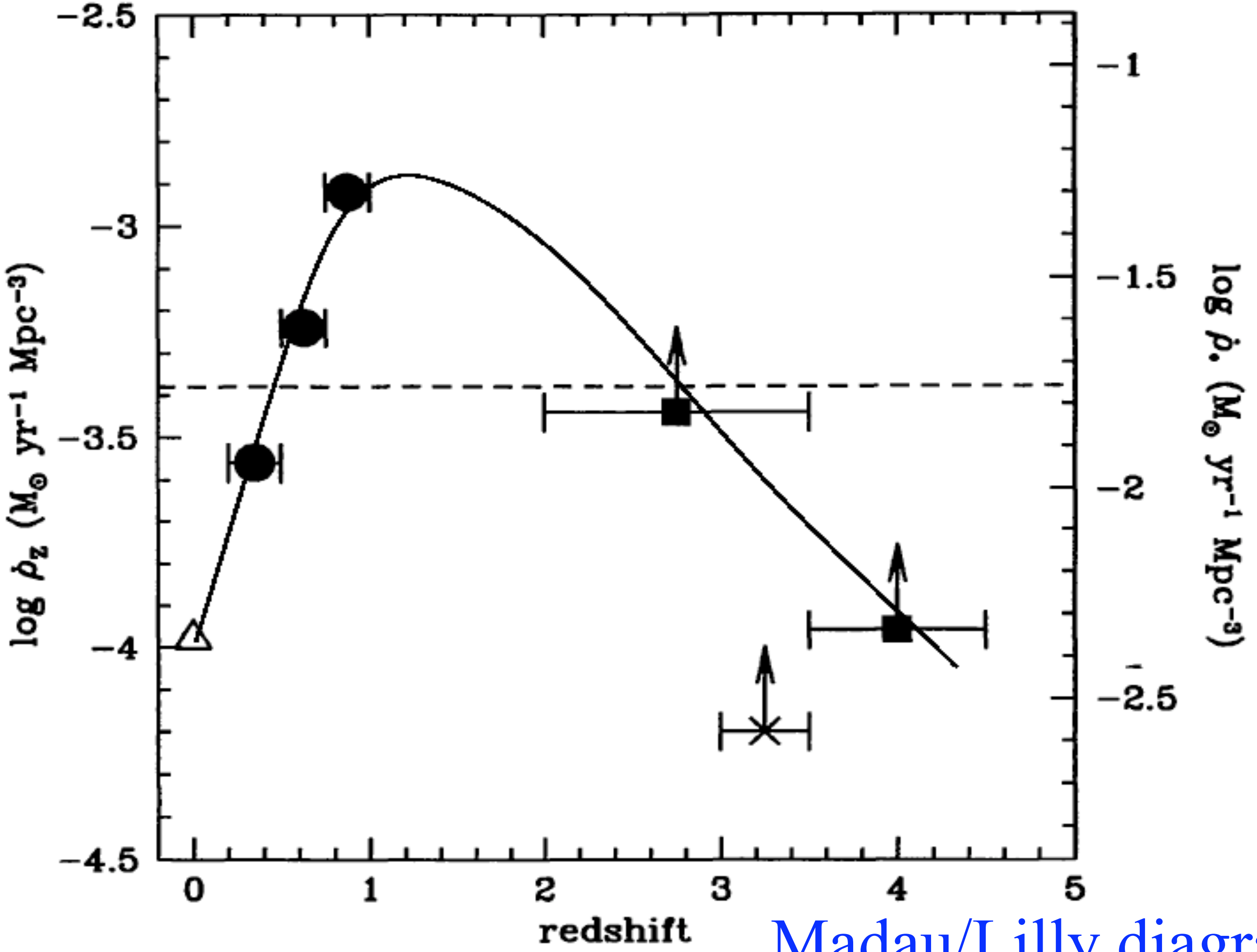
Key problem in observational cosmology:
At what epoch did majority of stars form?

- Star formation rate (SFR) higher in recent past, peaks around $z=1-2$?

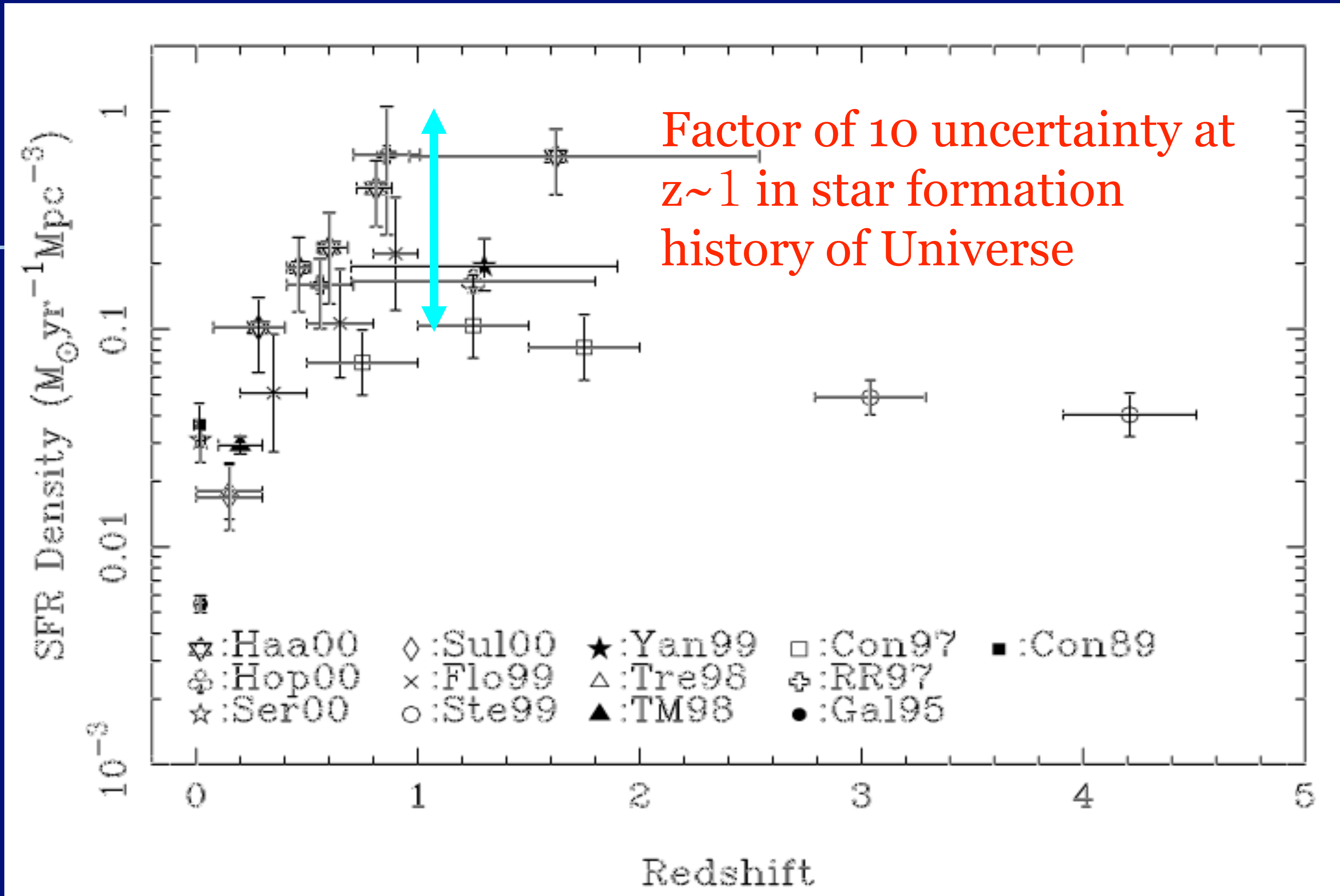
- Large discrepancies between SFR estimates obtained from different methods

Different indicators have uncertain relative calibration and are differently affected by dust extinction

The Star Formation History of the Univese



Madau/Lilly diagram



Madau-Lilly diagram (from Hopkins et al. 2001)

Hα as an SFR indicator

Hα luminosity proportional to ionising flux from massive stars (instantaneous SFR)

- Relatively immune to metallicity effects
- Less susceptible to extinction than rest-UV
- tracing Hα to early epochs forces a move to NIR at z>0.6♪

Hα in the Infrared

Previous Hα spectroscopy in NIR restricted to small samples

- long-slit spectroscopy (inefficient for surveys in terms of telescope time)

- e.g. Glazebrook et al. (1999), Tresse et al. (2002) @z~1 , Erb et al. (2003) @z~2

- Need a large sample (several hundred to a few thousand!) to address the issue properly. Spectroscopy is key
- Narrow-band searches, after years of trying (e.g. Bunker et al 1995) finally delivering a few hundred candidates (Geach et al. 2009, Villar et al 2008)

Cambridge InfraRed Panoramic Survey Spectrograph

CIRPASS

A near infrared fibre-fed spectrograph - prelude to FMOS

Built by the IoA with support of Sackler foundation & PPARC

Two modes

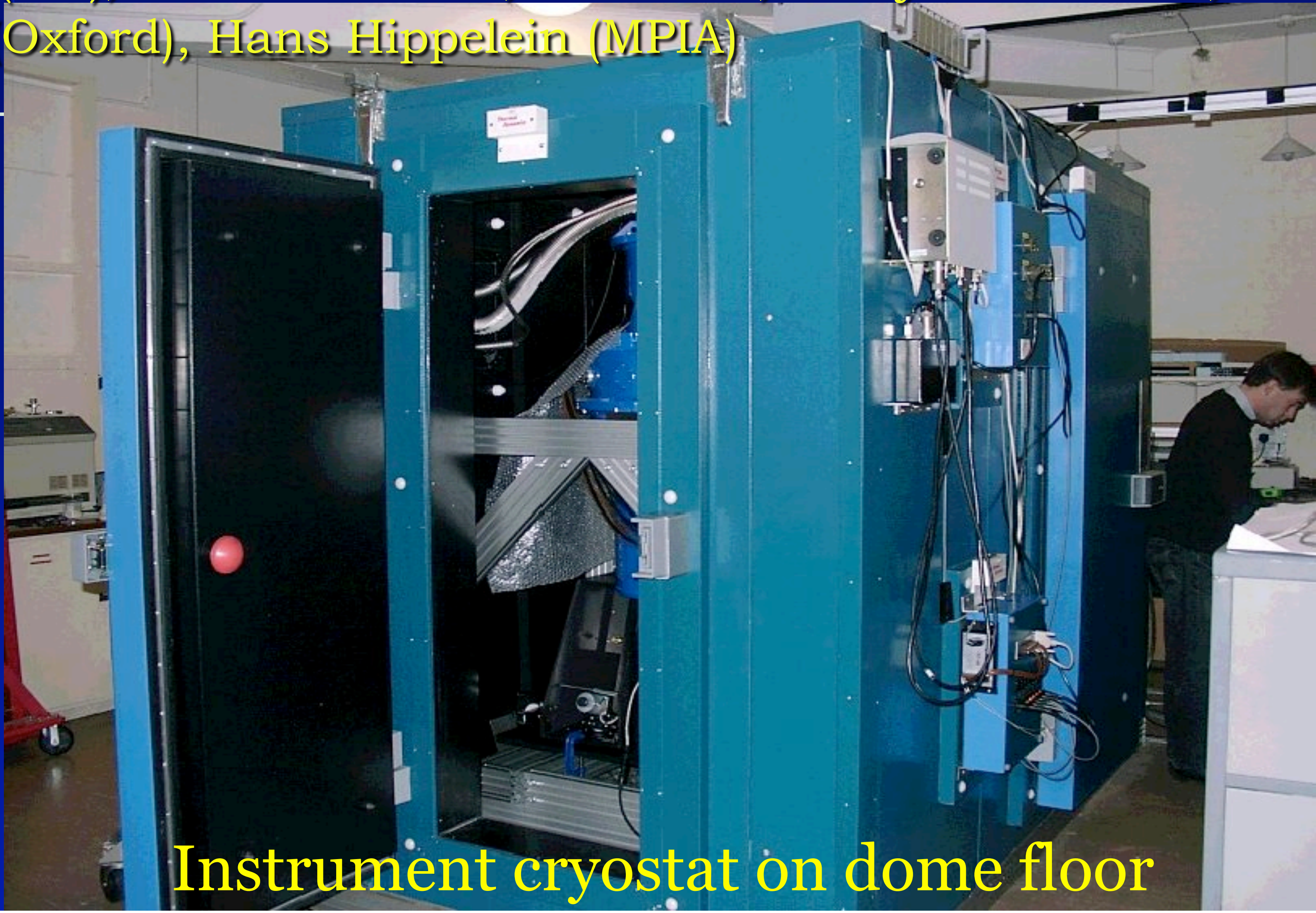
- Integral Field with 490 elements (commissioned Aug '02)
- Multi-object mode, 150 fibres (commissioned October '02)

Operates between 0.9-1.67 micron. Can survey galaxies over 40arcmin (AAT) or 17arcmin (WHT)

resolving power R~3000-5000, great sensitivity between skylines

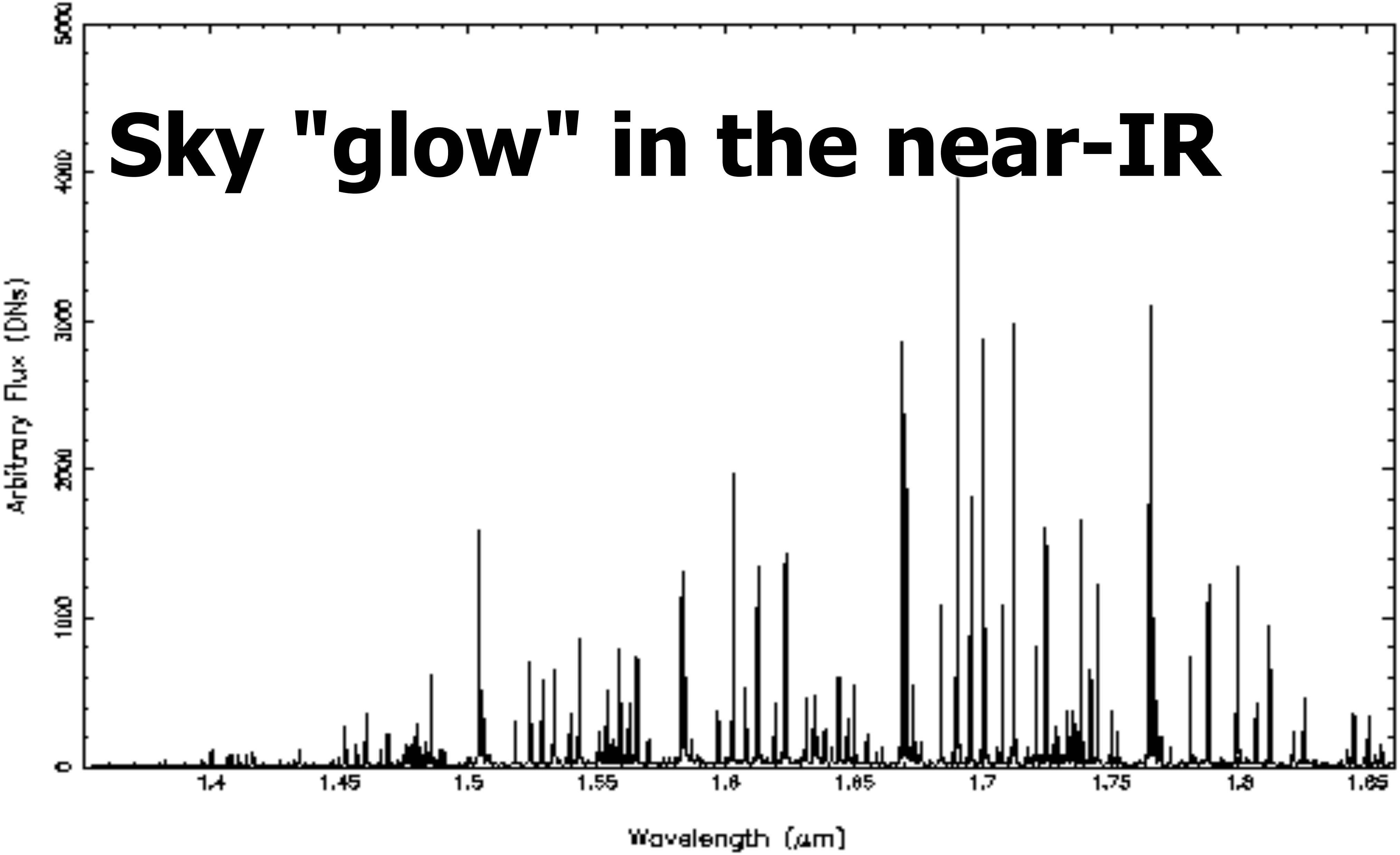
PhD of Michelle Doherty, IoA Cambridge (now ESO)

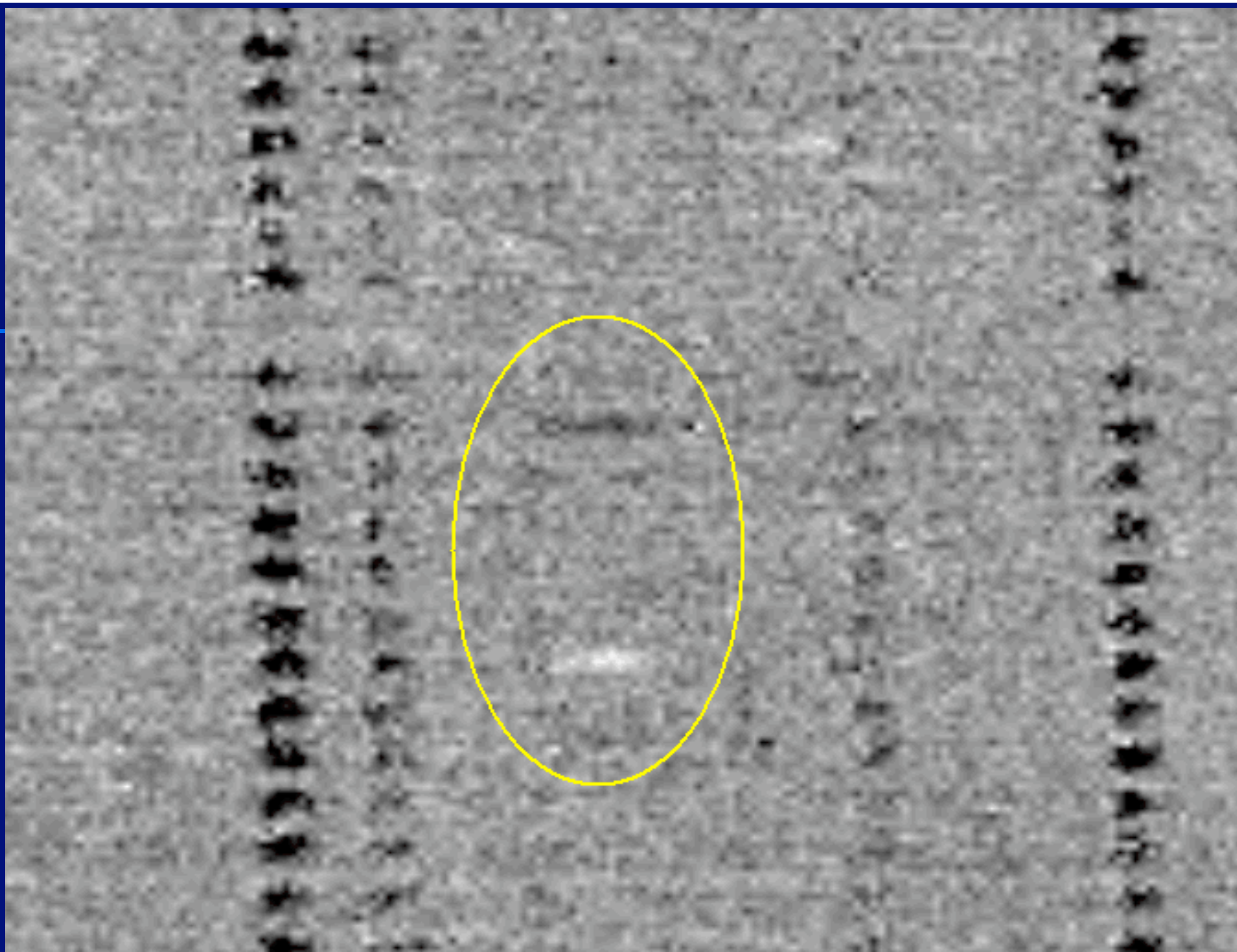
Collaborators: Andy Bunker, Rob Sharp (AAO), Ian Parry, Dave King (IoA), & Gavin Dalton, Ian Lewis, Emily MacDonald, Chris Wolf (Oxford), Hans Hippelein (MPIA)



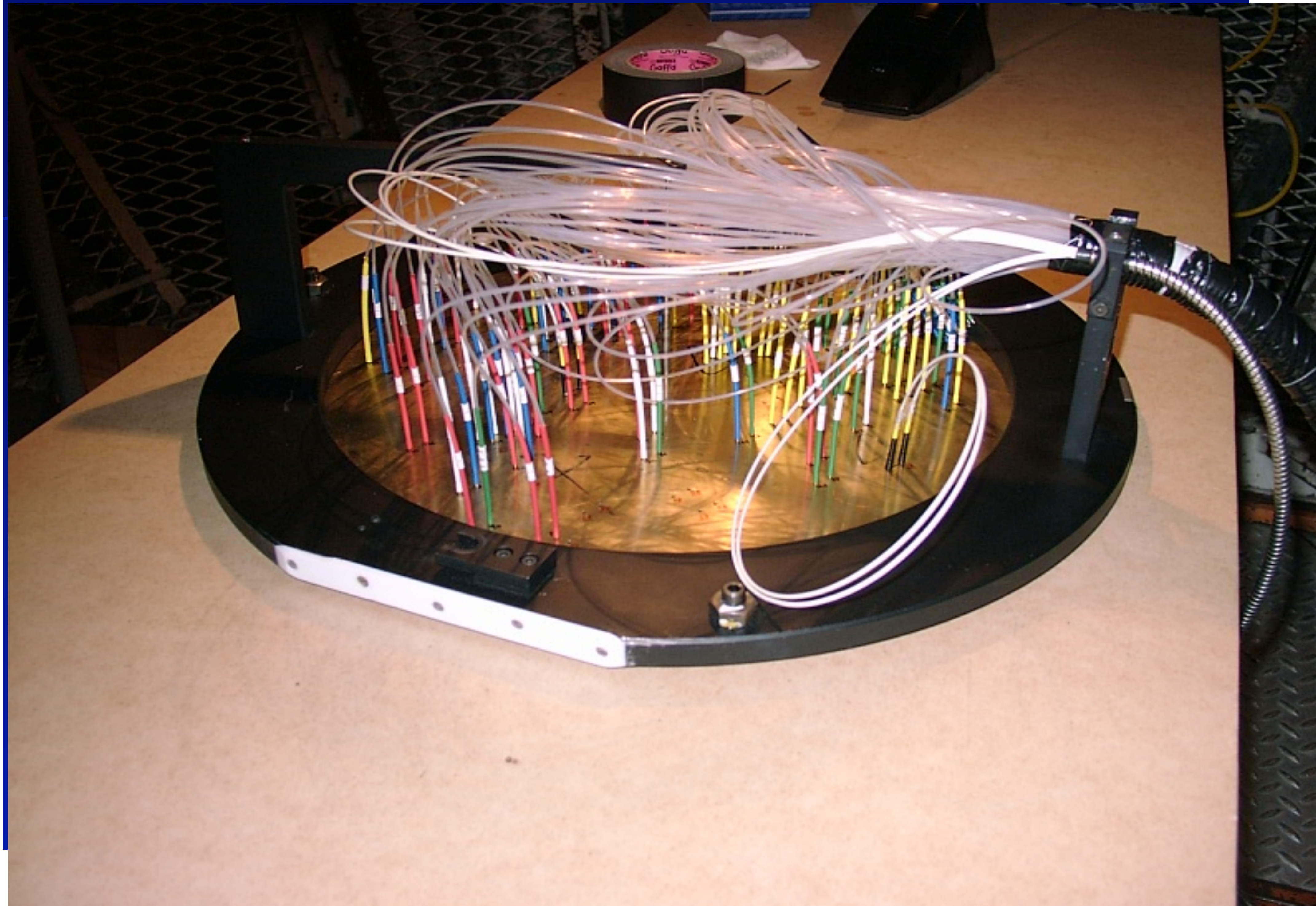
Instrument cryostat on dome floor

Sky "glow" in the near-IR





"Beam switching" between pairs of fibres. Sky lines burn only ~10% - no need for OH suppression at R~5000




Human fibre positioners with CIRPASS

Star Formation History

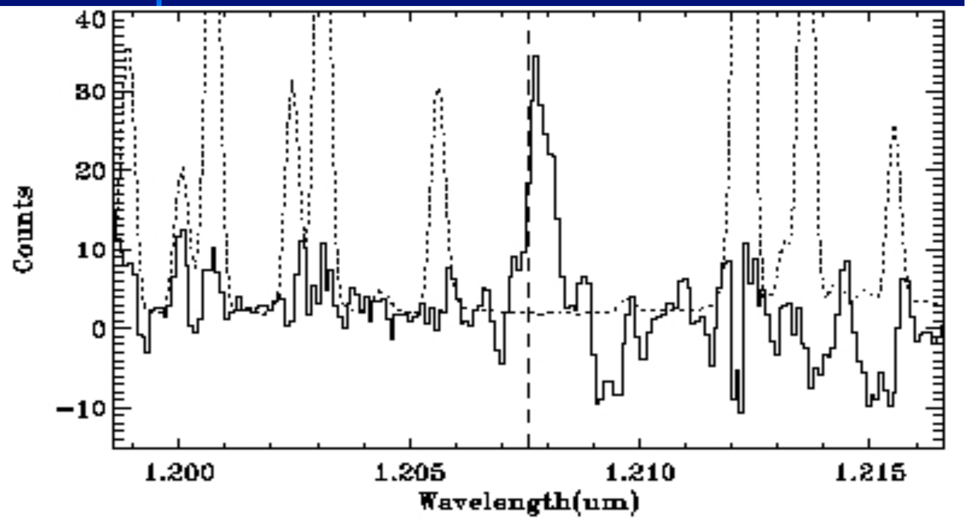
- Currently, different redshift bins use different indicators of star formation rate
- Uncertain relative calibration & susceptibility to dust
- At high-redshift, mostly relying on rest-UV
- By using IR spectrographs, can trace same reliable rest-optical tracers (Hβ, Hα etc.) over most of time
- Until recently, no multi-object capability, until CIRPASS
- Demonstrated on AAT & WHT with a few galaxies
- Want many thousand, and go fainter (FMOS/Subaru)

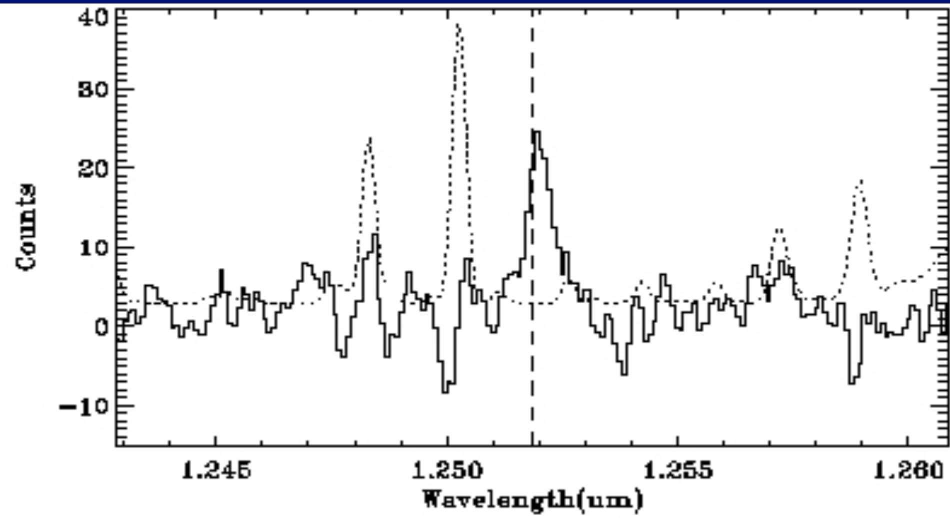
Hα Survey with FMOS

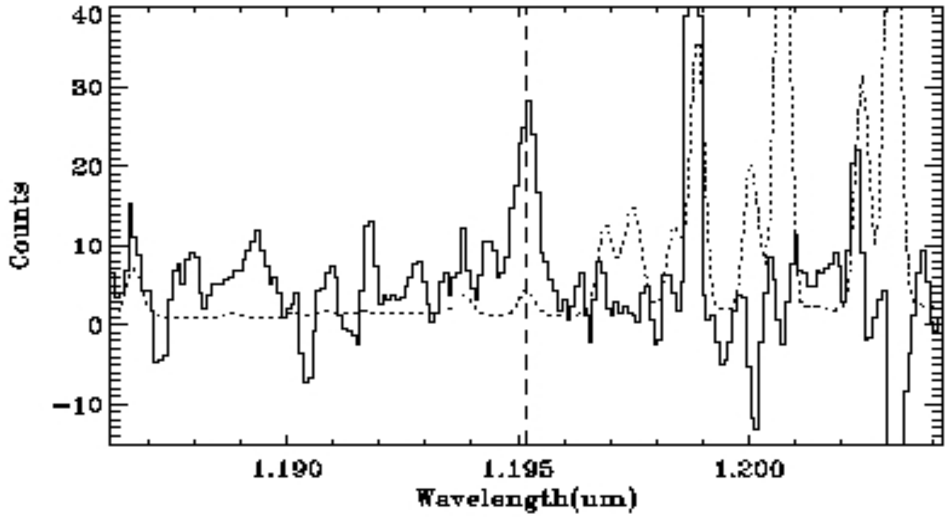
- huge multiplex advantage over any other IR spectrograph, making it ideal for surveys
- use the same robust star formation tracers used locally (e.g. Hα) at z>1 to study history of star formation.
- Pilot study with CIRPASS-MOS. Surveyed~200 galaxies at 0.7<z<1.5♪

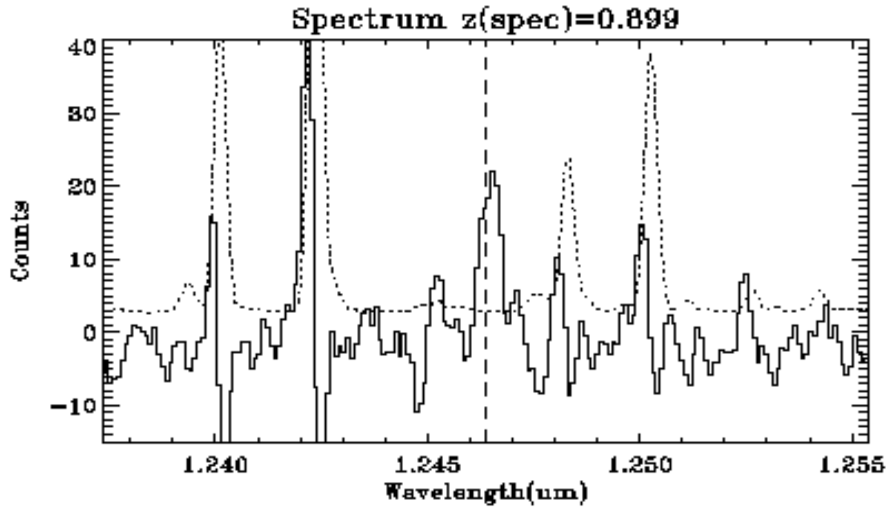
HDF-N galaxies, observed in Hα with CIRPASS on WHT

Doherty, Bunker, Sharp et al. *MNRAS 2004* 354, L7









Hubble Deep Field North

- Limiting flux 1.0×10^{-16}erg s^{-1} cm^{-2} with CIRPASS-MOS

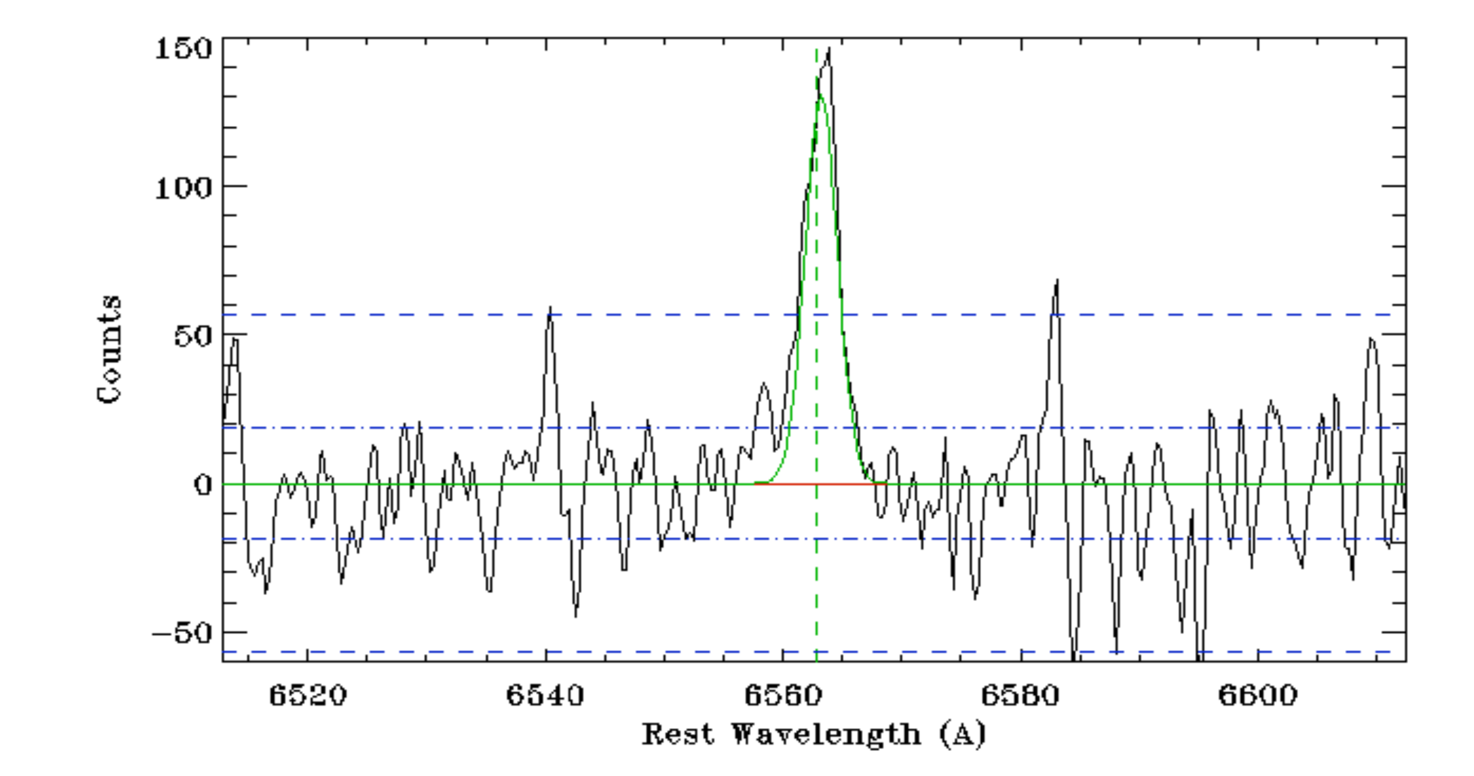
5σ in 3 hours = 5 M_{sun} /yr (Ω_M=0.3, Ω_Λ=0.7, Ho=70km/s/Mpc)

- Compare Hα to SFR from UV flux

=> photometry from GOODS HST/ACS images,

B band (4500Å) is rest-frame UV at this redshift

- Find $SFR_{H\alpha}/SFR_{UV}$ ratio of 2-3, consistent with results found by Glazebrook et al., Tresse et al., at similar *z*

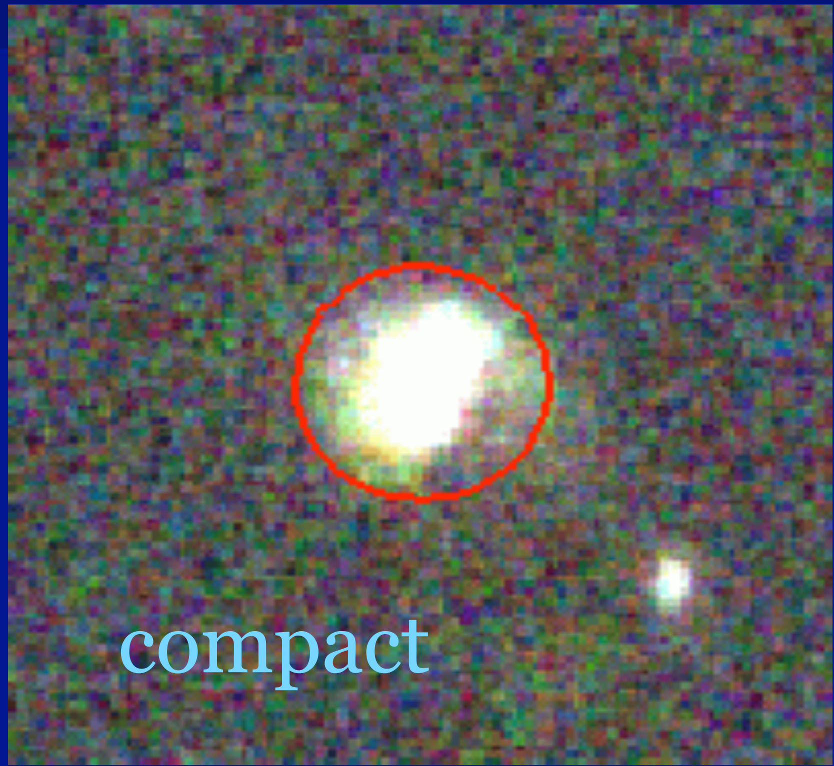


Stack of HDFN

Spectroscopic samples, complete to a mag limit (I~24m) - redshifts known from optical, want true star formation rates: can stack Hα lines (use e.g. Hubble Deep)

& photometric redshifts (e.g. Oxford ODT survey, GOODS) to preselect galaxies with Hα in near-IR. Less successful.

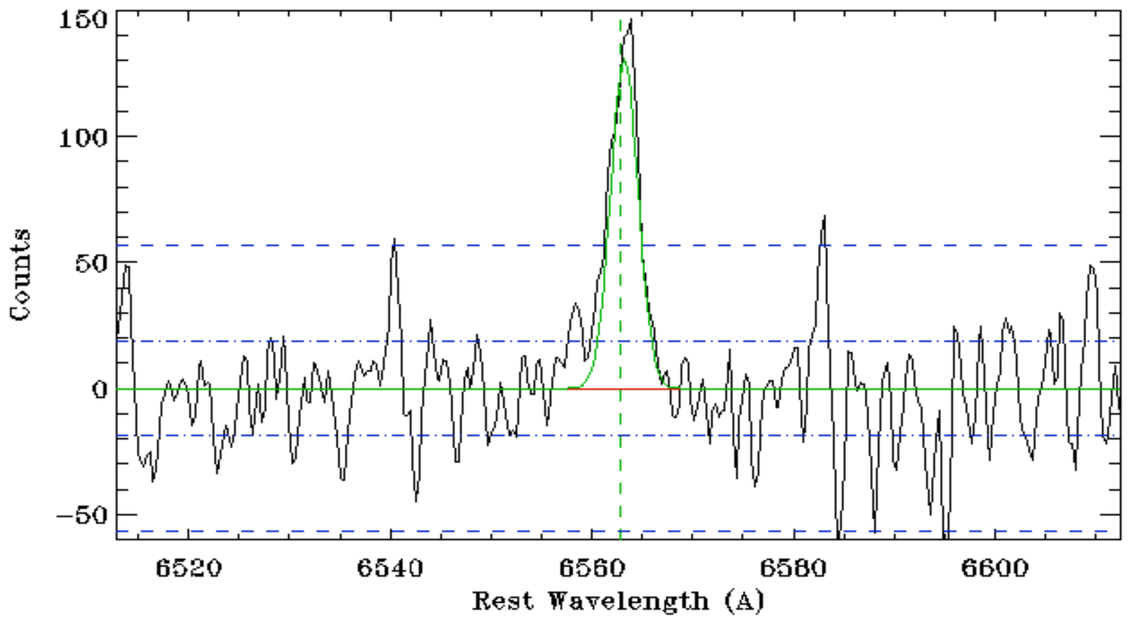
Hubble Deep Field North



1.1arcsec fibres : results heavily seeing dependant

affects different morphologies differently

Survey Science



We have a spectroscopic sample in HDFN, complete to a mag limit (I~24 mag) - redshifts known from optical, want true star formation rates: can stack Hα lines

- Next step at z~1-1.5 (Hα in J & H): move to an 8-m.

FMOS on Subaru based on CIRPASS design

Spectra with FMOS on 8-m Subaru;

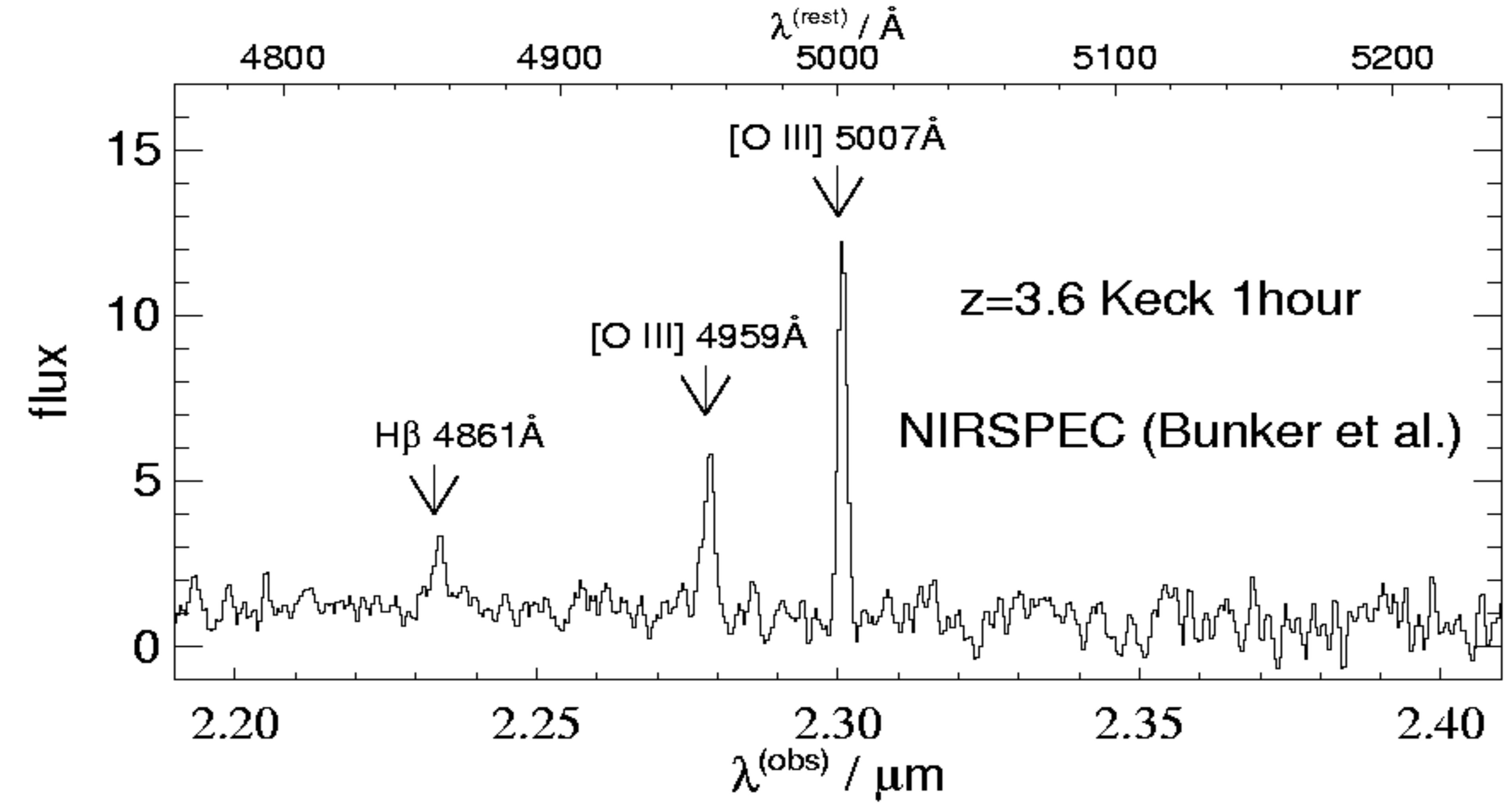
Evolution of Star-formation & Metallicity in the Universe at high Reshift with FMOS

Andrew Bunker, Scott Croom, Gavin Dalton, Michelle Doherty, Karl Glazebrook, Rob Kennicutt, Ian Lewis, Ian Parry, Rob Sharp, Chris Wolf et al.

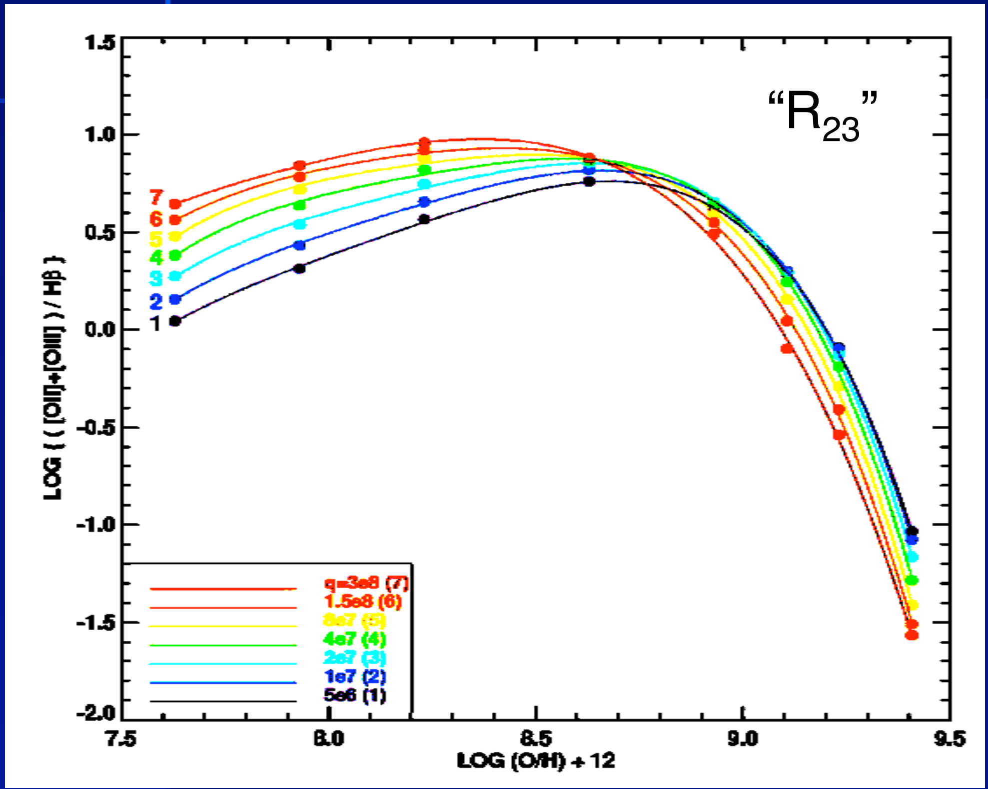
[YOUR NAME HERE…]

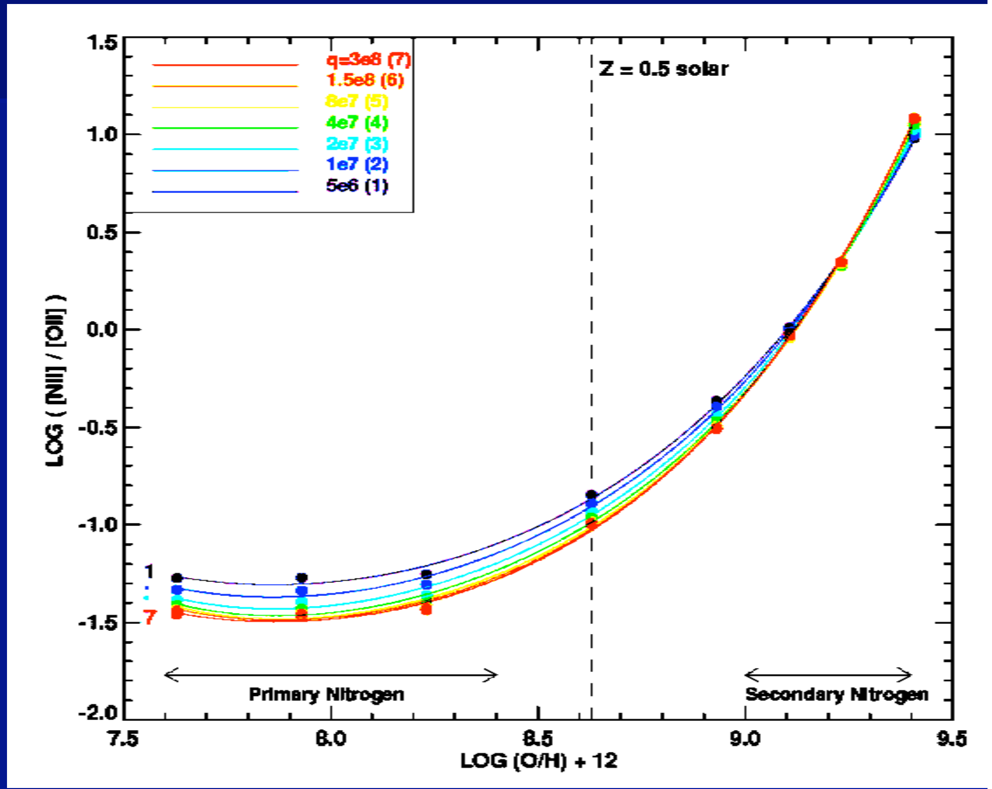
evol SMURF

Emission lines ⇒ Star formation rates, metallicity (oxygen, R_{23}), dust extinction Hα/Hβ line widths/rot curves ⇒ kinematics/masses



Metallicity Diagnostics





Kewley & Dopita (2002, ApJS, 142, 35)

Why ~>1sq deg? And why >>1000 galaxies?

Want not only luminosity function and clustering, but to split galaxies by:

- (stellar) mass
- Star formation rate
- Metallicity
- Environment
- Redshift slices

To test downsizing, feedback etc

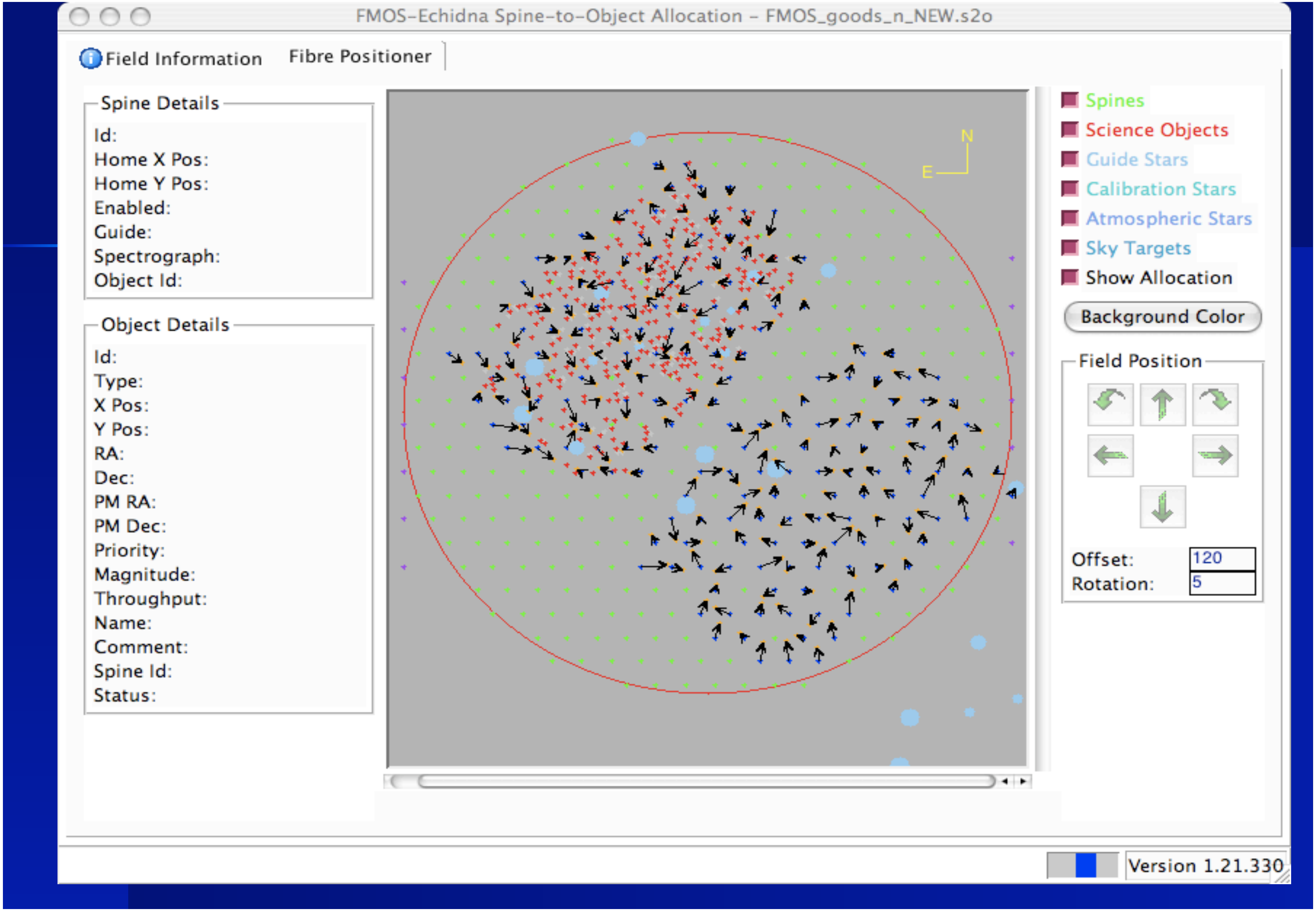
Want sufficient numbers, smooth over cosmic variance

Possible survey

- 10 luminosity bins with 400 galaxies per bin (5% Poisson error) at z=1, and perhaps 100 per bin at z=1.5 (10% error)
- Two redshift bins, z=1 (J-band), z=1.5 (H-band)
- 5000 galaxies in all (need multiple high-resolution settings)
- 30 arcmin field, surveys 30 x 30 Mpc^2 and 70 Mpc in redshift space
- Encompasses 2000 >0.3L* galaxies per field
- Well-matched to FMOS 400 fibres once crowding accounted for
- Do 2 repeats on 5 well-separated fields and 2 redshift bins
- Limiting flux 0.8×10^{-16}erg s^{-1} cm^{-2} with FMOS for FWHM~100km/s
- 5σ in 1 hours = 5 M_{sun} /yr (z=1, Ω_M=0.3, Ω_Λ=0.7, Ho=70km/s/Mpc)
- Aim for 7×10^{-16}erg s^{-1} cm^{-2} with FMOS 5σ in 5 hours = 2-4 M_{sun} /yr for z=1-1.5
- >100hours, 15+ nights (a useful trial in 4 nights, still world-beating)

Possible Fields

- Want good multi-waveband imaging (inc HST)
- Initially test on optical redshifts (e.g. DEEP2) so can do H-alpha "stacking"
- Extended Groth Strip (AEGIS), GOODS-North & GOODS-South (CDFS) have good spectroscopic redshifts, but smaller than 30arcmin FMOS field (can do "beam-switch")
- Mag-limited?
- Stellar mass selected? (photo-z ultimately?)
- Narrow-band follow-up? (e.g. UDS)


FMOS-Echidna Spine-to-Object Allocation – FMOS_goods_n_NEW.s2o
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Fibre Positioner
Spine Details
Id:
Home X Pos:
Home Y Pos:
Enabled:
Guide:
Spectrograph:
Object Id:
Object Details
Id:
Type:
X Pos:
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E
Spines
Science Objects
Guide Stars
Calibration Stars
Atmospheric Stars
Sky Targets
Show Allocation
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Field Position
Offset:
120
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5
Version 1.21.330

Conclusions

Have performed multi-object, near-infrared spectroscopy of z~1 galaxies in HDFN

- can detect star formation to 5 solar masses per year (5σ in 3 hours) on a 4m telescope
- We have ~200 galaxies (with at least upper limits to the SFR): already an improvement over previous work
- BUT: Want several thousand to pin down Ha luminosity function at z~1 . evolSMURF
- Very feasible with FMOS on subaru
- Use H-alpha/H-beta for dust, and with [OIII], [OII] and [NII] get metallicity (and weed out the AGN). Determine the mass-metallicity relation.
- Initally best to target surveys with known redshifts, and determine H-alpha SFR by stacking.

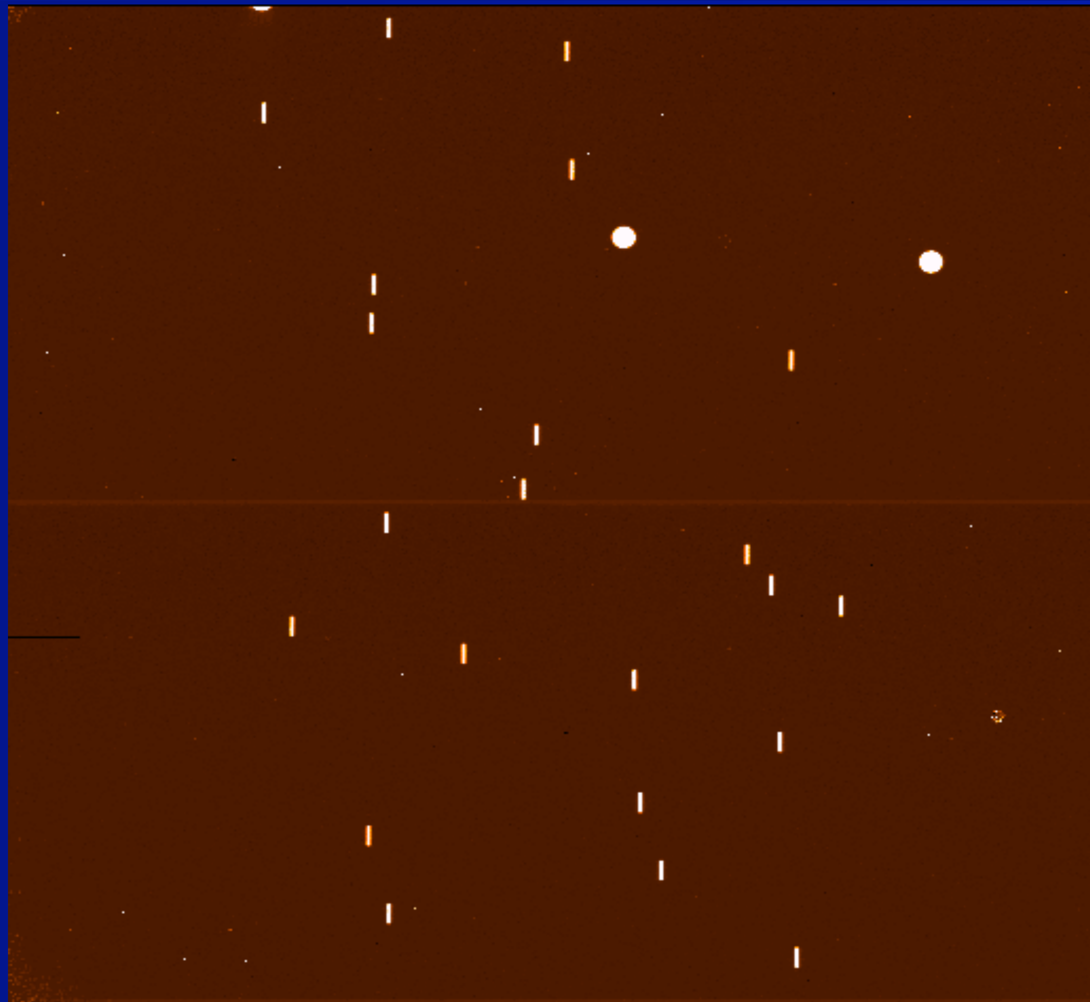
Pushing to Higher Redshifts

- CIRPASS and FMOS are fibre-fed, do not work well in thermal IR (wavelengths beyond 2microns, K-band)
- Rules out studying z>1.6 in Hα

=> Next step: cold slitmasks rather than fibres, to get K

late Sept 2005: used IRIS2 on AAT, 7arcmin field, to observe 100 galaxies in 3 fields at higher redshift

IRIS2 on AAT



Bunker, Sharp & Doherty (in prep)