Spectroscopy in Space

& the SPACE project

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Space Spectrographs

Low background - No sky emission line/absorption

- **Hubble**
  - *STIS Single slit - UV/Visible spectrograph*
  - ACS Grism - NICMOS Grism

  - *COS (UV spectrograph)*
  - WFC3 grism Visible+NIR

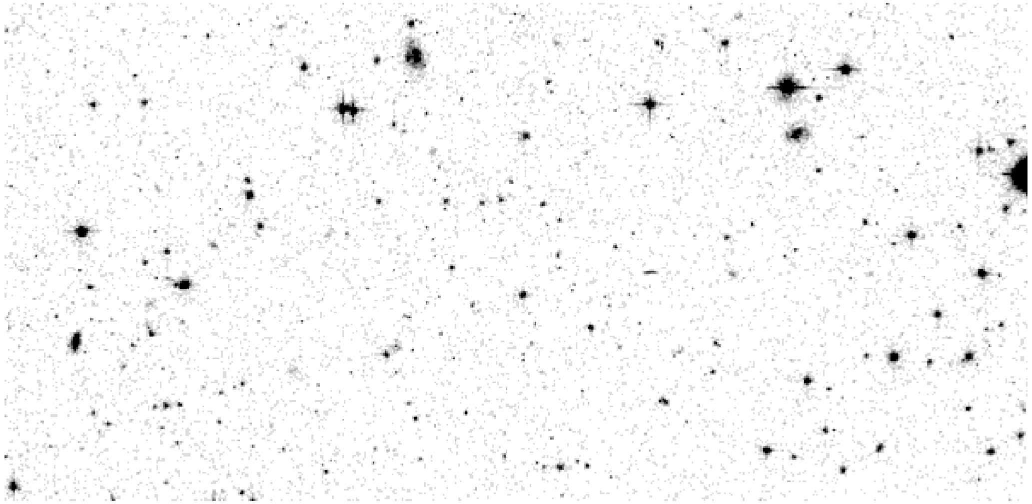
- **JWST**
  - NIRSPEC: Multi-Slit (micro-shutter) + Slicer

- **Future Dark Energy Mission**
  - SNAP, ADEPT, DESTINY, **SPACE**

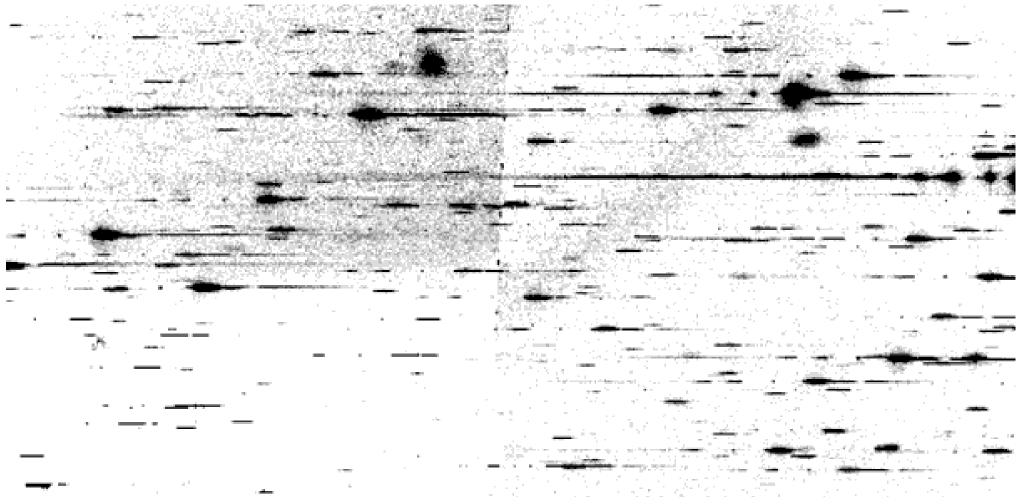
ACS Grism

- ACS WFC - G800L grism
- Resolution 70-130 from ~6500-9500 Angstrom
- Sensitivity AB~24 (7000A) in one orbit (~2000 sec)
- ACS grism parallel survey
- GRAPES

Direct image



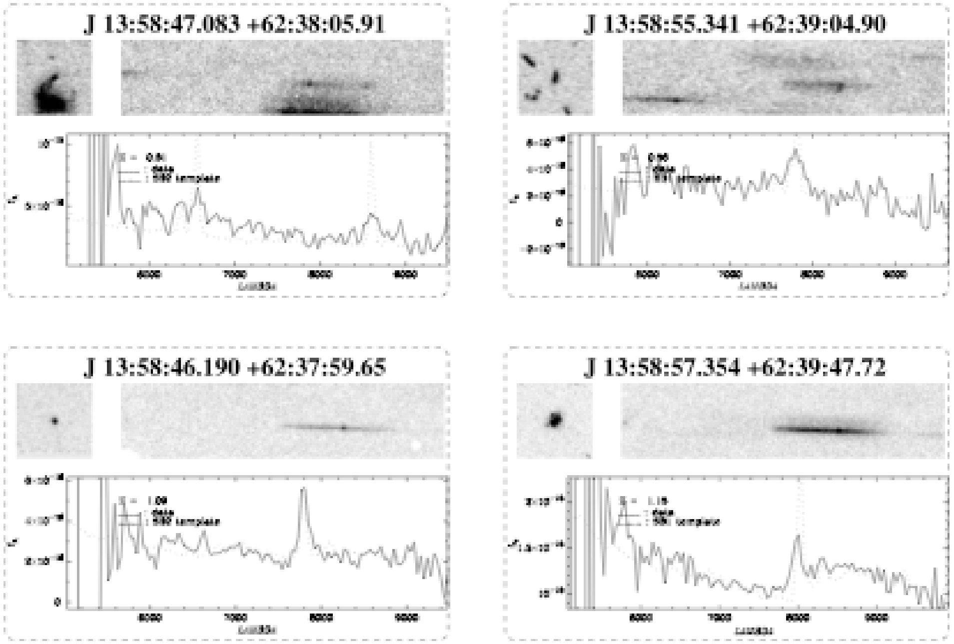
Grism

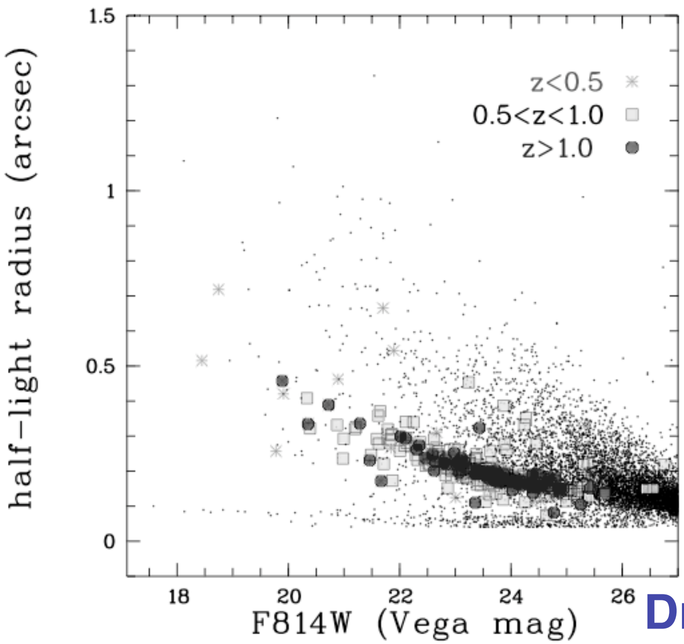


Advanced Camera for Surveys ACS

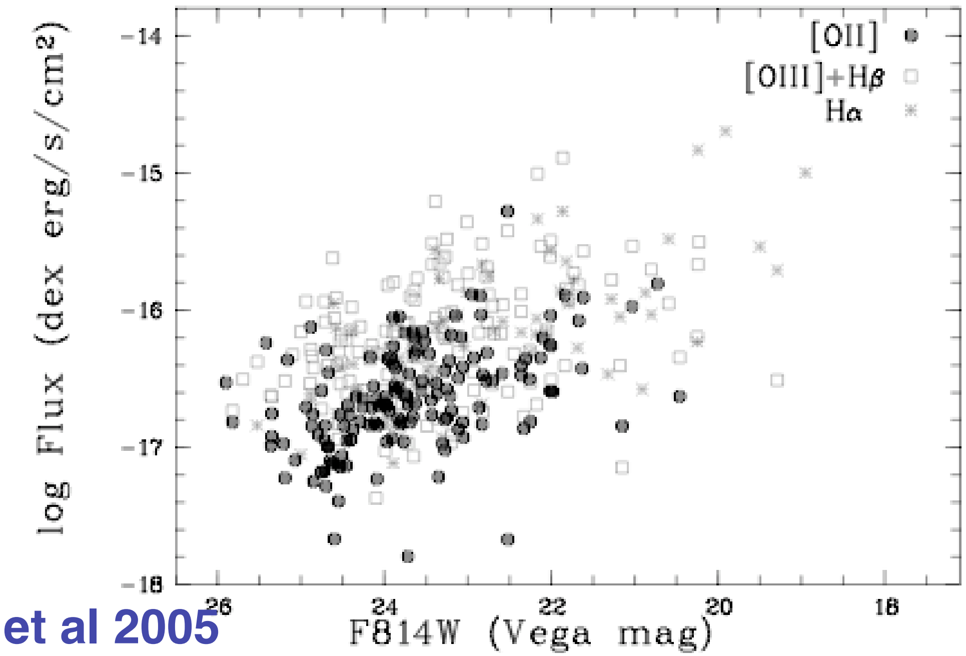
ACS Grism Parallel Survey

- 11 fields (~120 arcmin^2), exposure time larger than 12ksec
- 600 compact Emission Line Galaxies (ELG) [5 gal/arcmin^2] with z<1.6 and 3sigma flux limit >5e-18 cgs (iAB~26)
- Bias towards compact galaxies with strong emission lines.

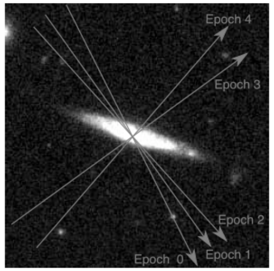




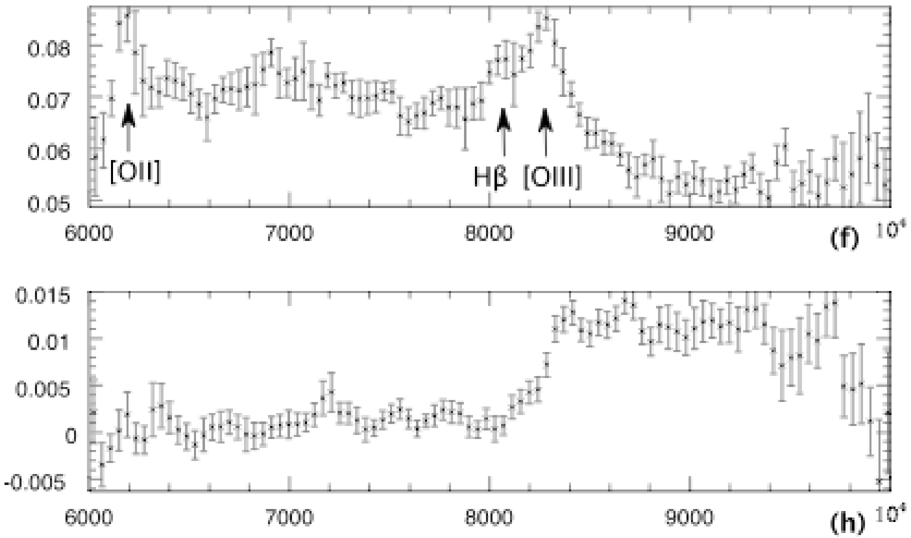
Drozdovsky et al 2005



GRAPES: ACS Grism on HUDF



- 1 ACS field (11arcmin^2)- 40 orbits (92 ksec) - aiming to get the deepest spectra
- 5 directions
- 5200 galaxies down to z(AB)~29
- 1600 spectra extracted with a significance of 10 down to z(AB)~27

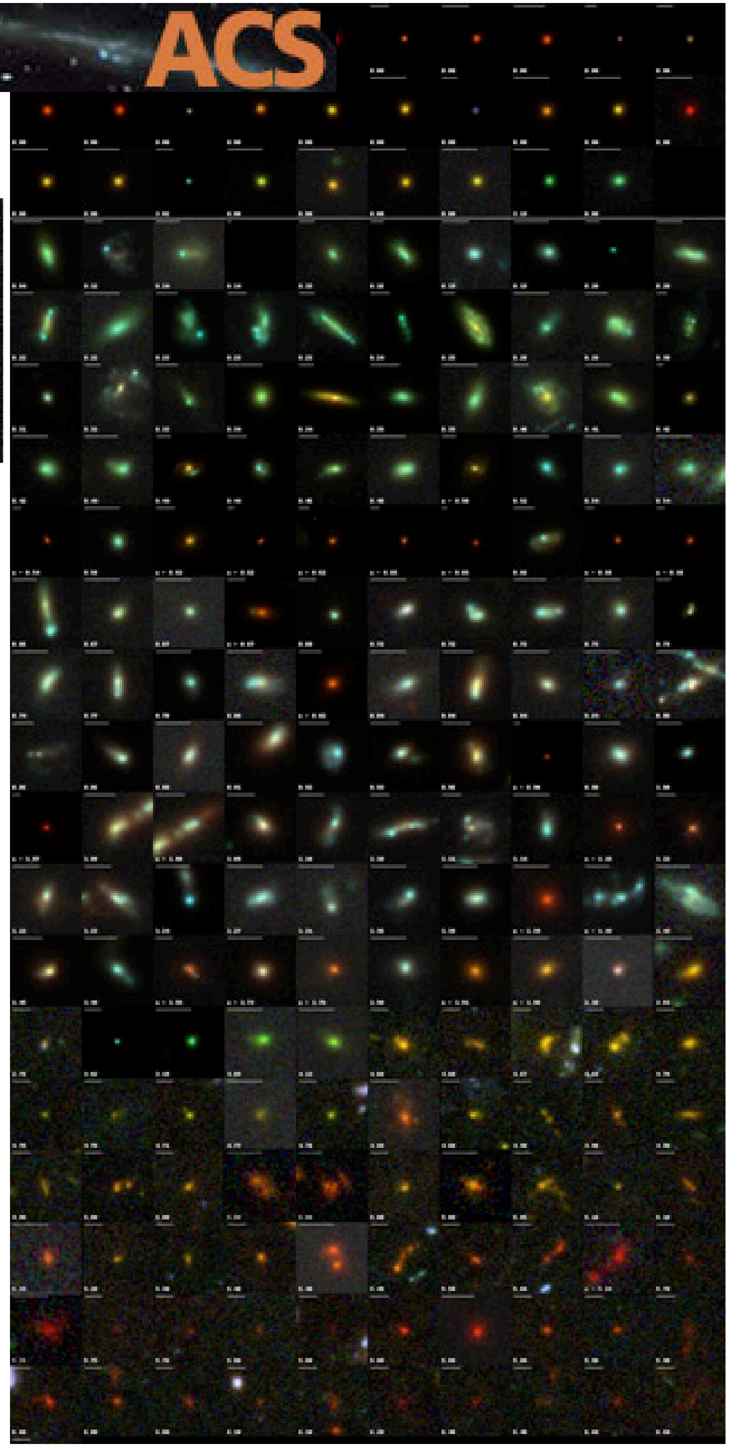


z=0.66

zAB=23.2

z=5.8

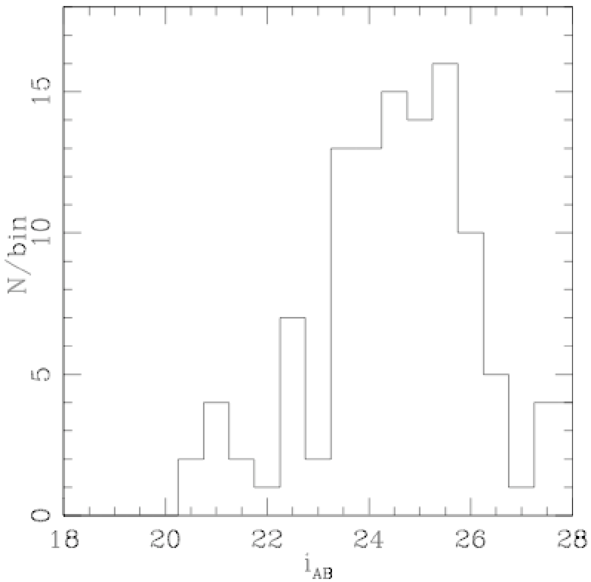
zAB=25.3

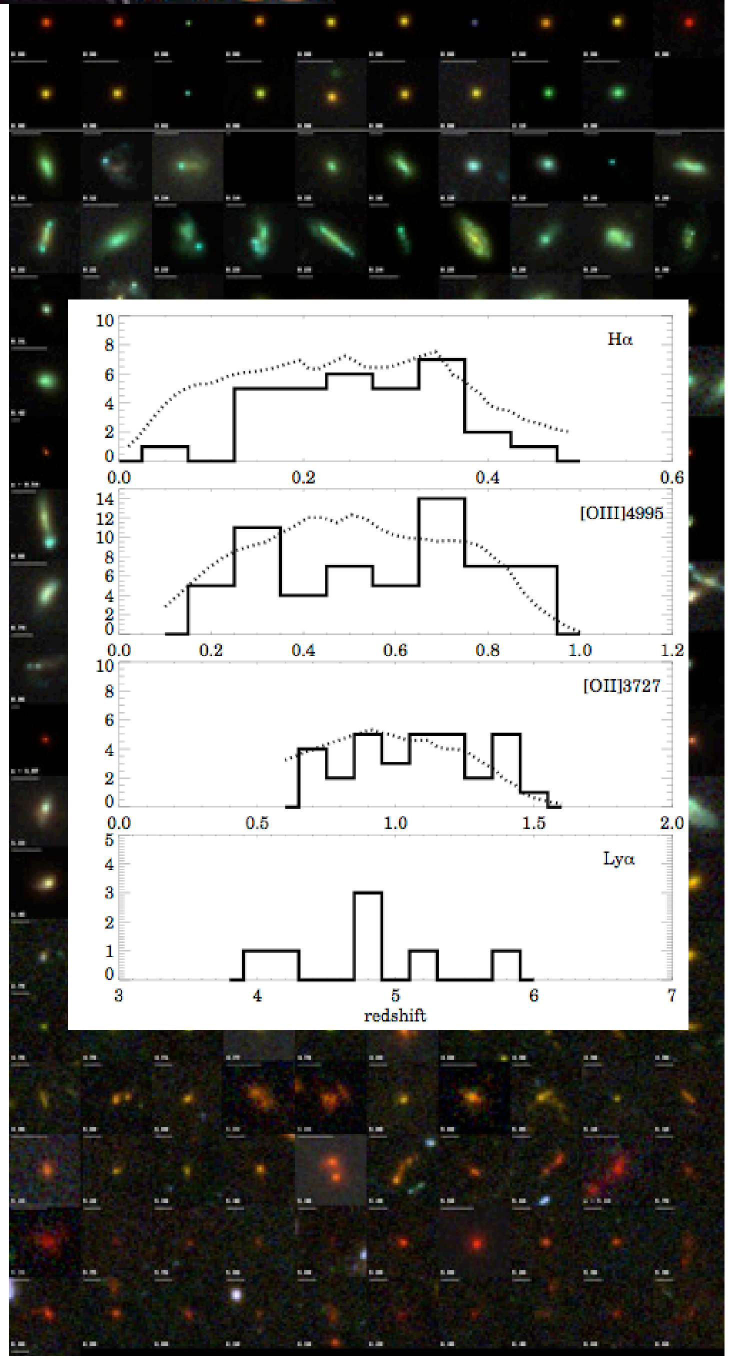


Pirzkal et al 2004

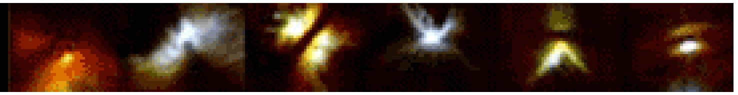
GRAPES: ACS Grism on HUDF

- In the ~90ksec data, 115 line emission objects are identified [~10 per arcmin^2]
- this correspond to typically 1 out of 10 galaxies down to iAB=26.5 *(not optimal wavelength range)*
- 40% are fainter than iAB=25 (ground based limit)
- Redshift are based on Halpha, OII, **OIII** or Ly-alpha



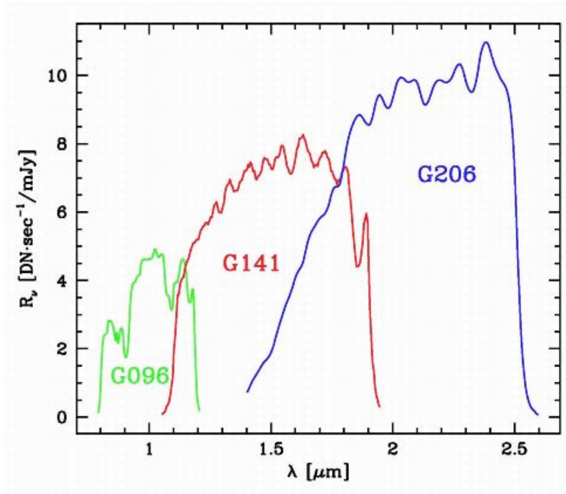


Xu et al 2007

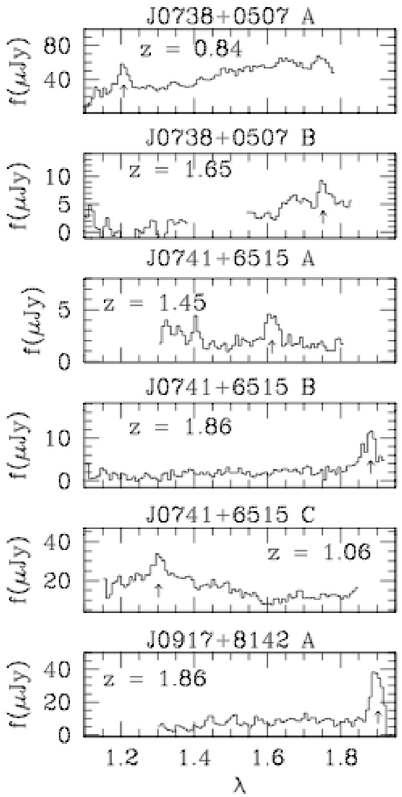


NICMOS

- 50x50 $arcsec^2$
- 3 grisms with resolution of ~100
- G141 covers 1.1 to 1.8 micron, throughput ~12%



- NICMOS grism Parallel (McCarty et al 1999)
  - 64 $arcmin^2$
  - ~1.8ksec exposure
  - 33 ELG mostly Halpha H_{AB}~22
  - Density of: 0.5 per $arcmin^2$



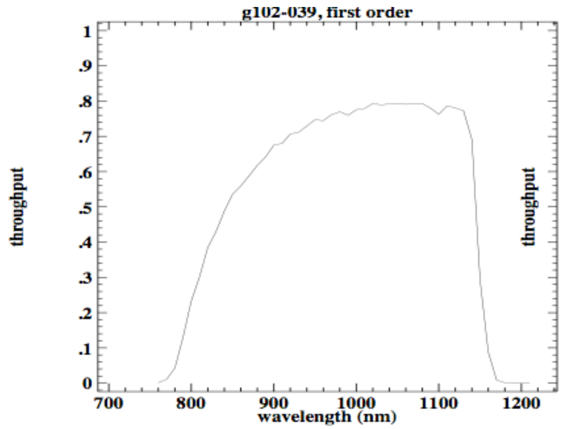
- Hubble-Legacy Archive of NICMOS G141 grism in progress

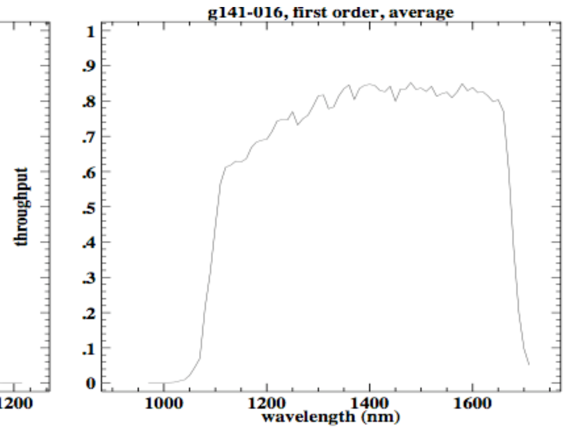
Wide Field Camera 3

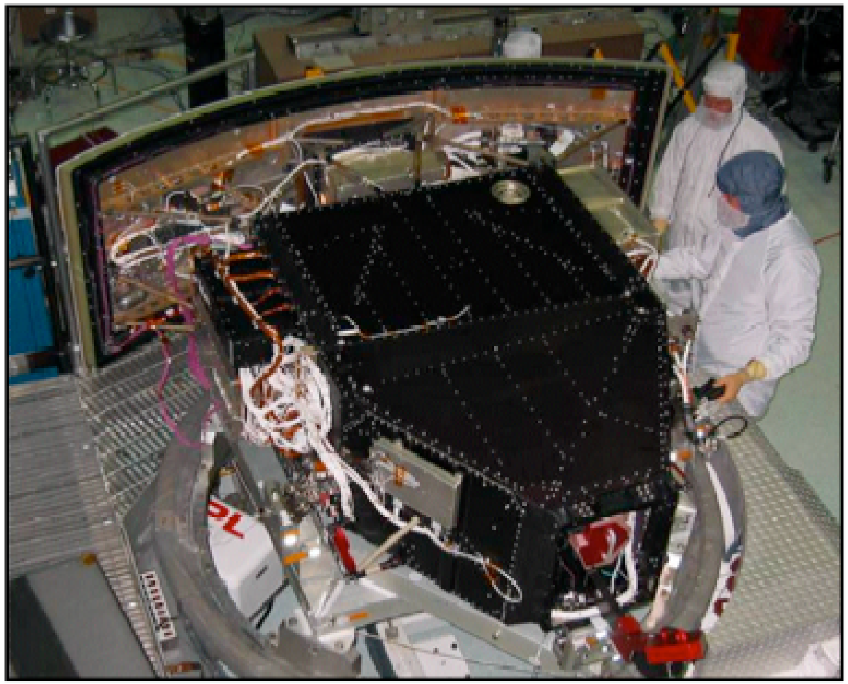
WFC3

- 2.5x2.5 $arcmin^2$ in NIR
- 3 grisms
  - 1 UV (R~70),
  - 2 NIR: R~210:800-1150nm & R~130: 1100-1700nm
- High performance NIR detectors => sensitivity much better than NICMOS
- Throughput ~30%
- ~30 more efficient than NICMOS grism

- Servicing mission August 2008 !!!

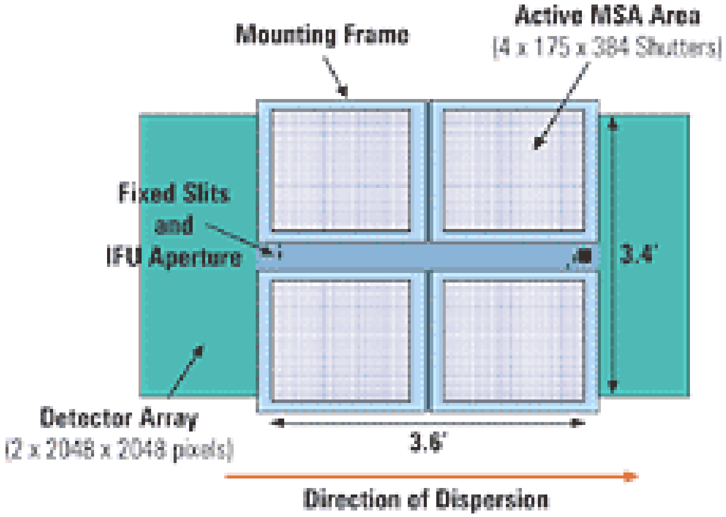


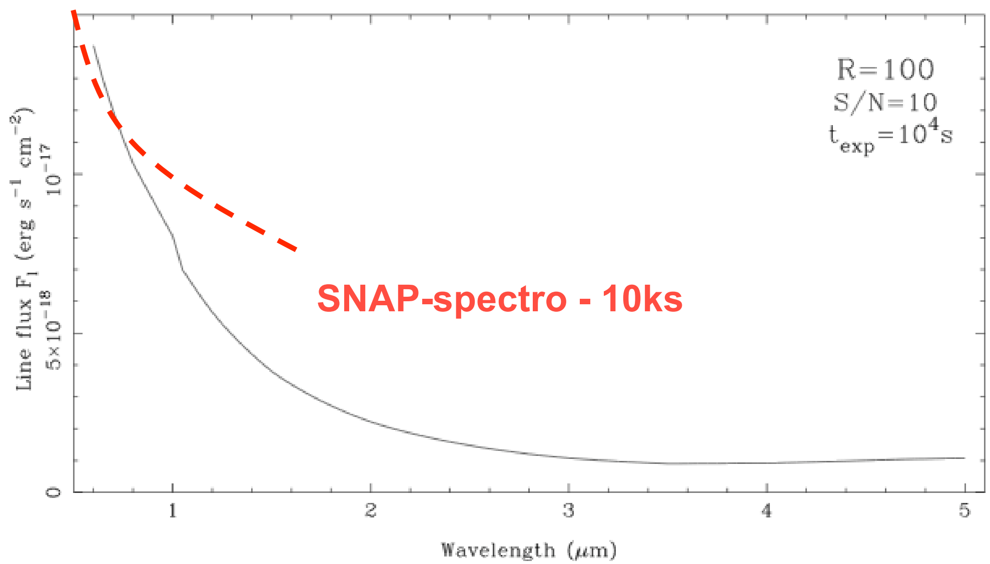


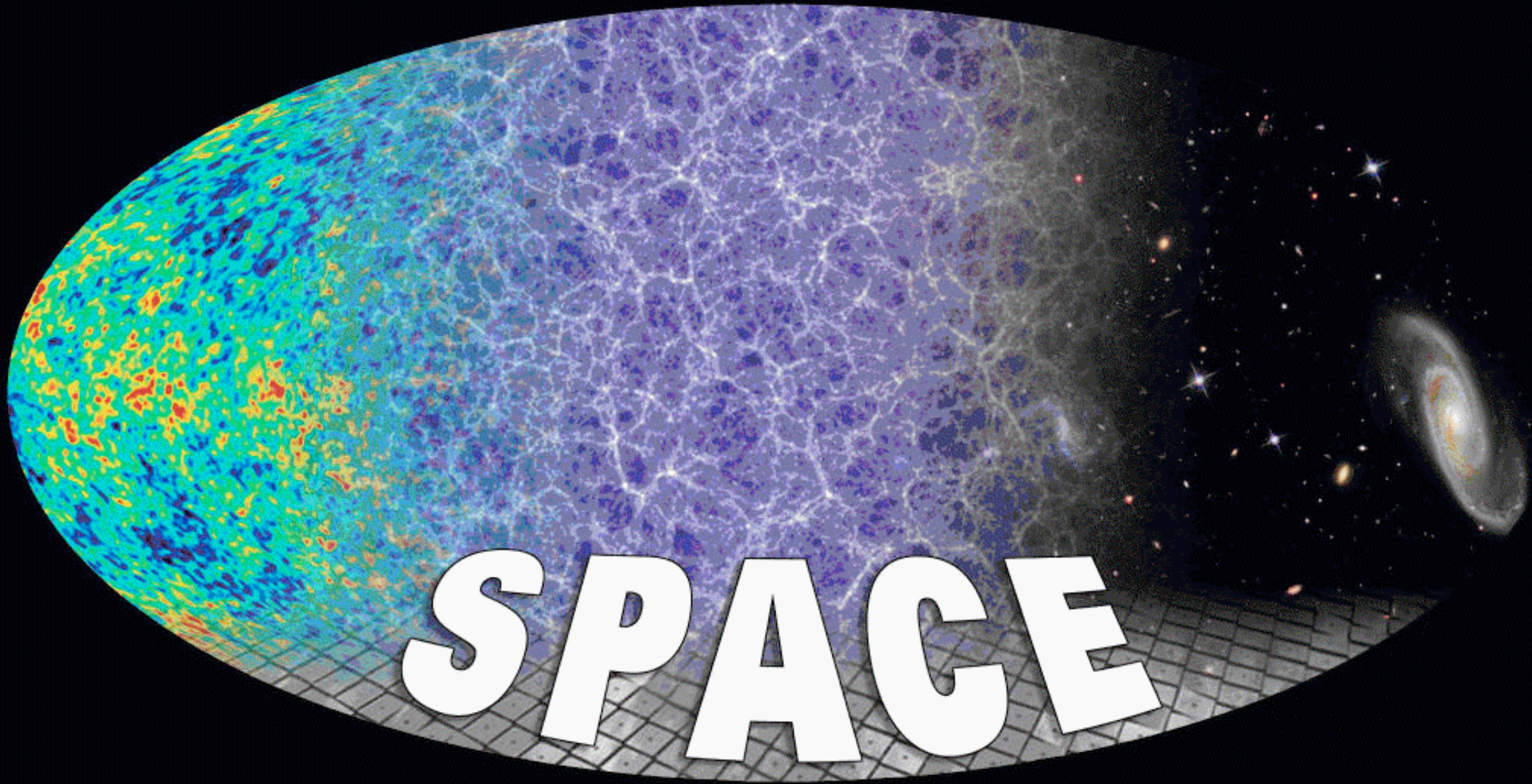


JWST/NIRSPEC

- 6.5m telescope
- NIRSpec design provides 3 modes:
  - R~100 resolving prism mode (0.6 to 5 microns)
  - R~1000 multi-object mode using micro-shutters (100 slits, 3 gratings from 1 to 5 micron)
  - R~2700 integral field unit (slicer) or long-slit spectroscopy mode.
- NIRSPEC field of view will be ~3.4x3.4 arcmin
- Comparison with SNAP spectrograph - note the high efficiency! (NIRSPEC has many mirrors)







SPectroscopic **A**ll-sky **C**osmic **E**xplorer

On behalf of Andrea Cimatti (UniBO), Massimo Robberto (STScI) & the ***SPACE*** Team

http://urania.bo.astro.it/cimatti/space/

Cosmic Vision Proposal (June 2007):

PI: A. Cimatti (University of Bologna, Italy) + **co-PI: M. Robberto** (STScI, USA)

Co-Is* (in boldface : coordinator of SPACE Working Groups):

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ThalesAlenia Space   OPSYS PROJECT CONSULTING   >invision   VISITECH creating images - together

Main Scientific Goal

To address the key questions of cosmology

3D evolutionary map of the Universe during the last 10 Gyr

High accuracy constraints on Dark Energy equation of state (BAO, growth of structure, clusters, SN, …)

Growth rate of cosmic structures

Accurate P(k) and its turnover (complementary to CMB)

Formation and co-evolution of galaxies/AGN in all environments

The end of Dark Ages : *luminous* galaxies and QSOs up to z ≈ 10+ (complementary to JWST)

Requirements for a 3D (spectro)mapping mission for Cosmology

Need to improve in survey size and depth compared to SDSS and other planned/foreseen spectroscopic projects (BOSS, WFMOS, etc …). HOW?

Observation of a huge volume of the Universe
($>>10^6$ spectra; $> 10{,}000$ deg^2, $0<z<3$)

Spectroscopic accuracy (not only redshift, but line width, and line ratios …) [better than photometric redshift]

- ➢Wide-field, high "multiplexing", high survey speed
- ➢High sensitivity : slit spectroscopy (more sensitive than slitless)

A space-based mission in the ***near-infrared***

- Sample selected in the near-IR to $m_{AB} \approx 23$: 0<z<3, weak k-corrections, all galaxy types (including E/S0), stellar mass–selected, less affected by dust extinction

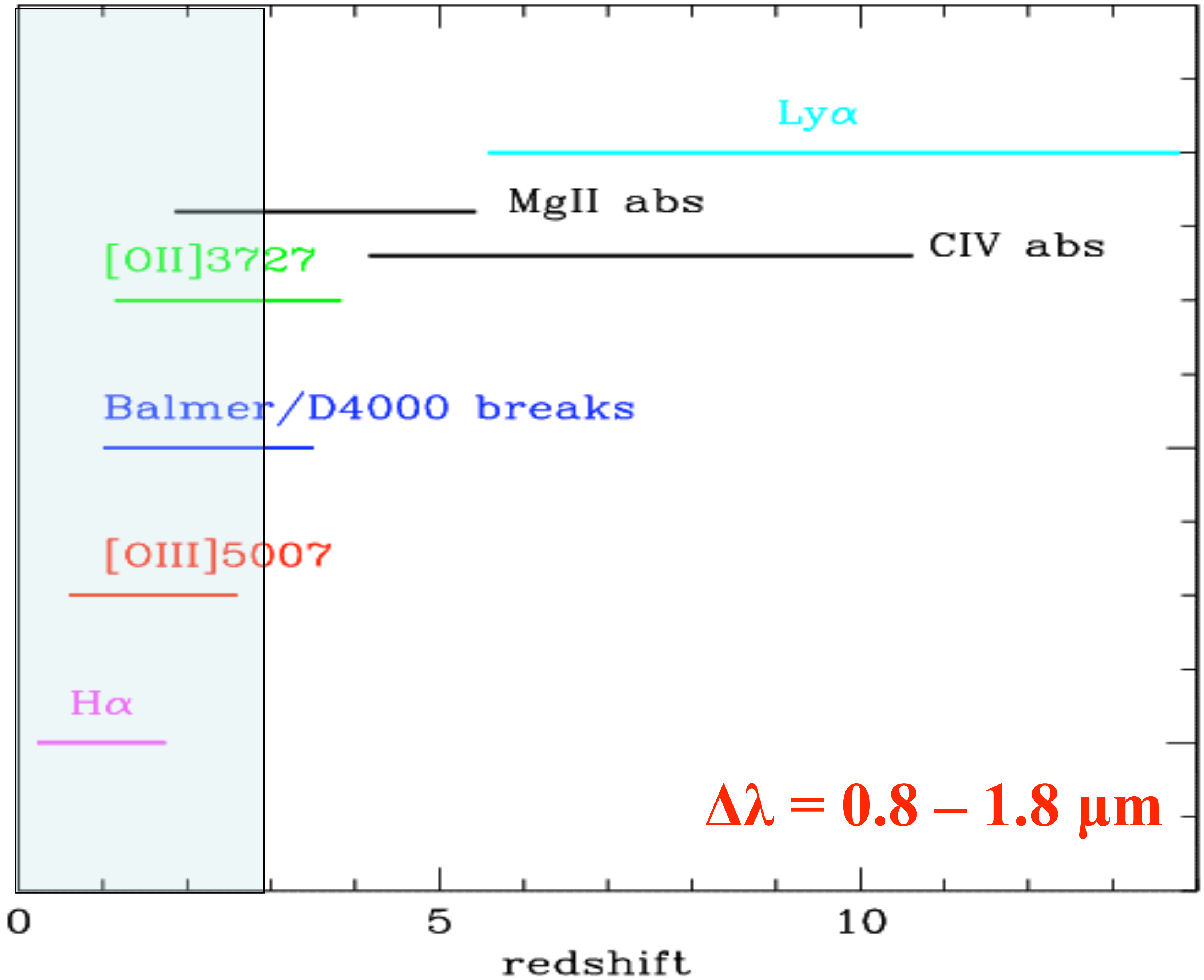
- near-IR Sky background is 500-1000 times lower in space

- No OH emission lines, no telluric absorptions

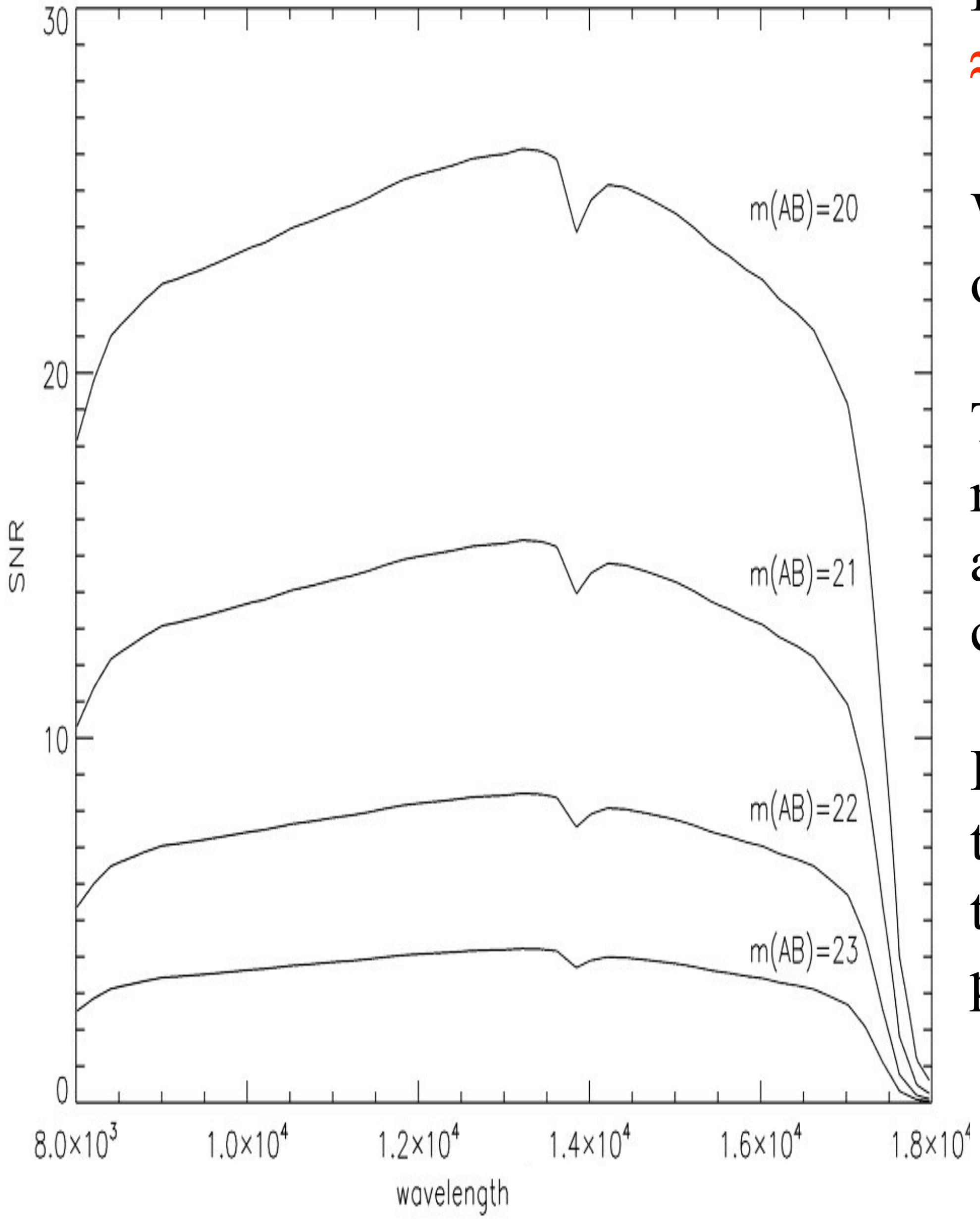
- Near-IR spectroscopy : rest-frame optical strongest features visible at all redshifts, E/S0 galaxies, Ly-α up to $z \approx 10+$

- Moderate spectral resolution (spec-z efficiency, aim to resolve Hα and [N II])

- SPACE concept: Digital Micro Mirrors (DMDs)


Lyα
MgII abs
CIV abs
[OII]3727
Balmer/D4000 breaks
[OIII]5007
Hα
Δλ = 0.8 – 1.8 μm
0
5
10
redshift

SPACE Sensitivity



Estimated SNR of SPACE spectra in **≈ 900s integration and R=400**.

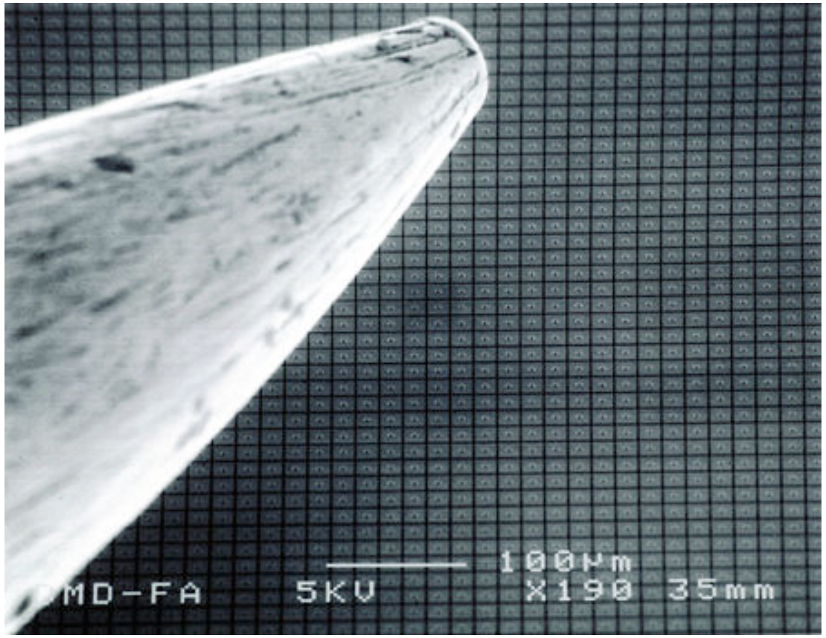
We used detector parameters typical of WFC3/IR flight candidates.

Transmission efficiencies of all reflective and refractive components are those of the WFC3/IR optical coating.

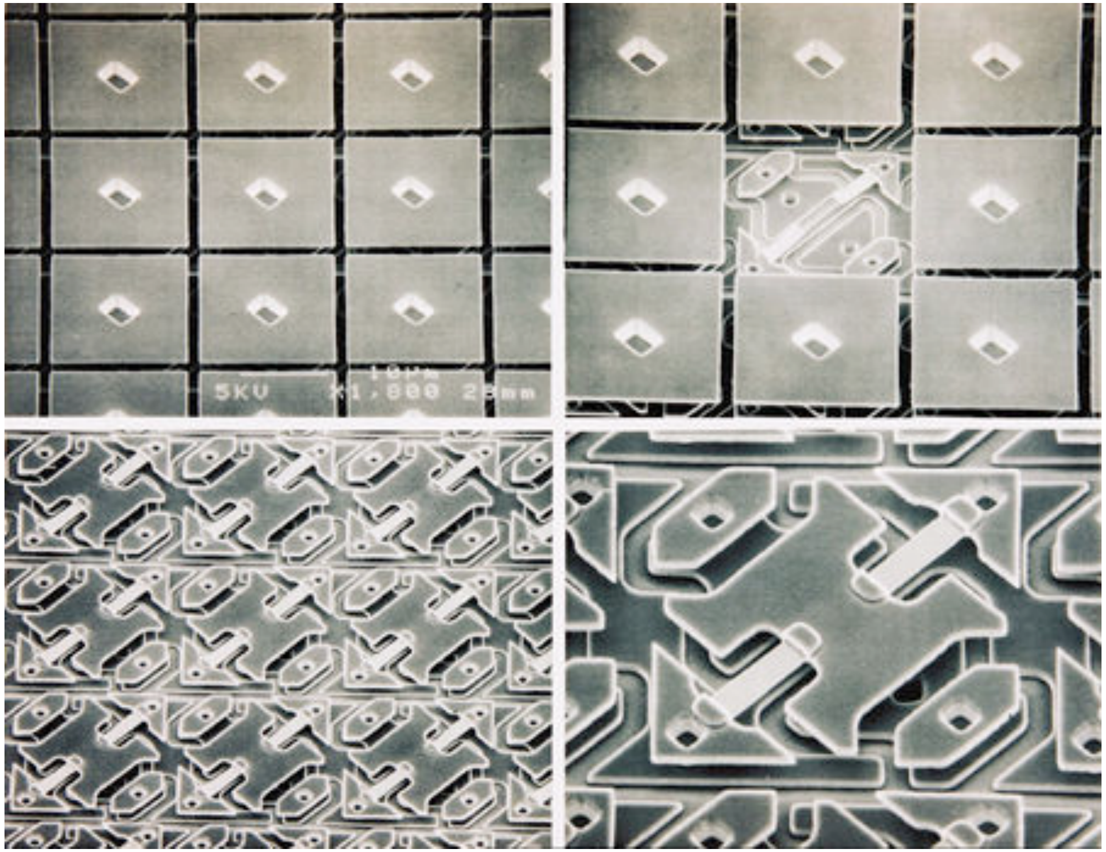
Light losses due to the prism thickness are included, together with the most recent zodiacal background prediction for SNAP (also at L2)

SNR ≈ 3 for AB ≈ 23

Digital Micromirror Devices (DMDs)



- Square mirrors, 14 x 14 μm
- Up to 2048×1080 elements
- Tilt angle ±12°

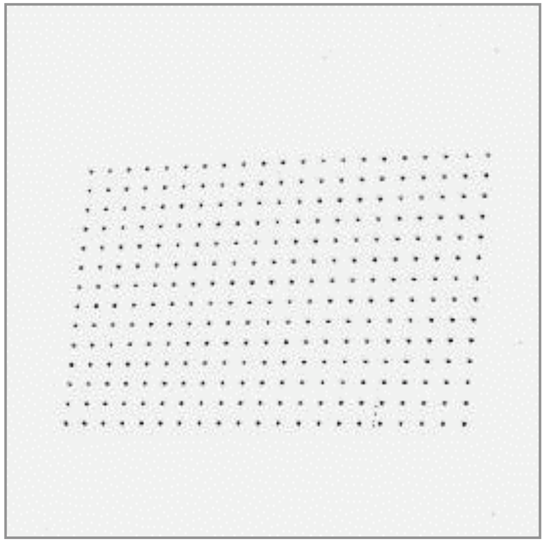


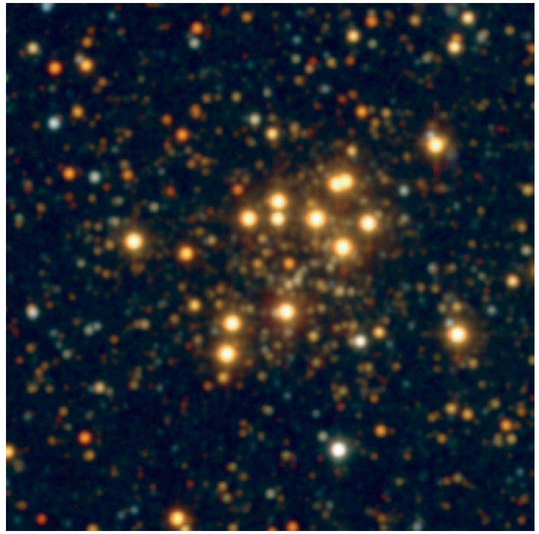
Transit time: 20μs
Frequency: ~7KHz
Contrast on/off ~400 on IRMOS
- 1 hr: 25 million cycles
-1 month: 1.8 billion cycles
-10 years: 2.2 trillion cycles

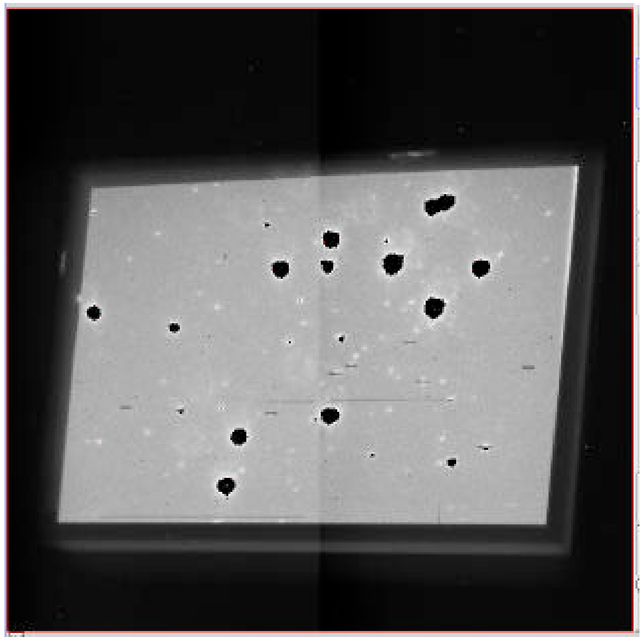
DMDs already work in Astronomy: IRMOS @KPNO

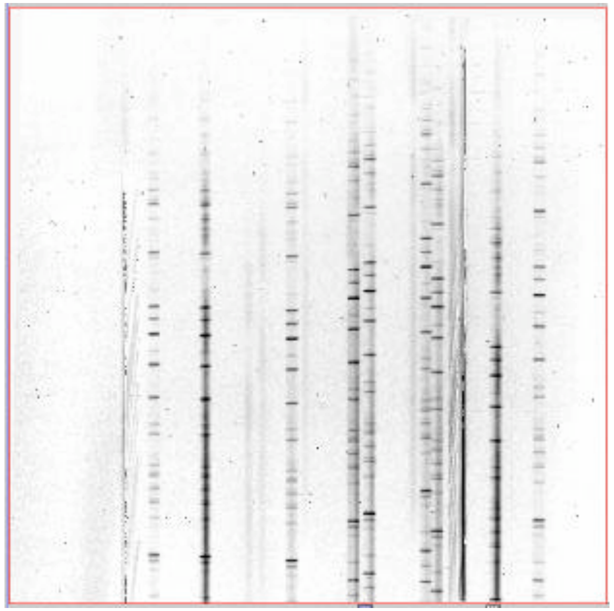
http://www.noao.edu/kpno/manuals/irmos/

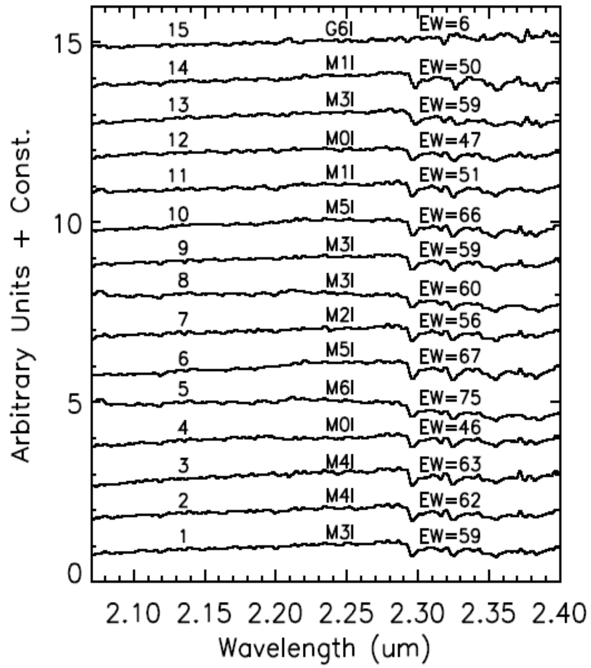

Figure 8: Texas Instruments DMD in test dewar operating at -50C in IRMOS custom socket (without baffle). Note Lakeshore thermal diode mounted at top.





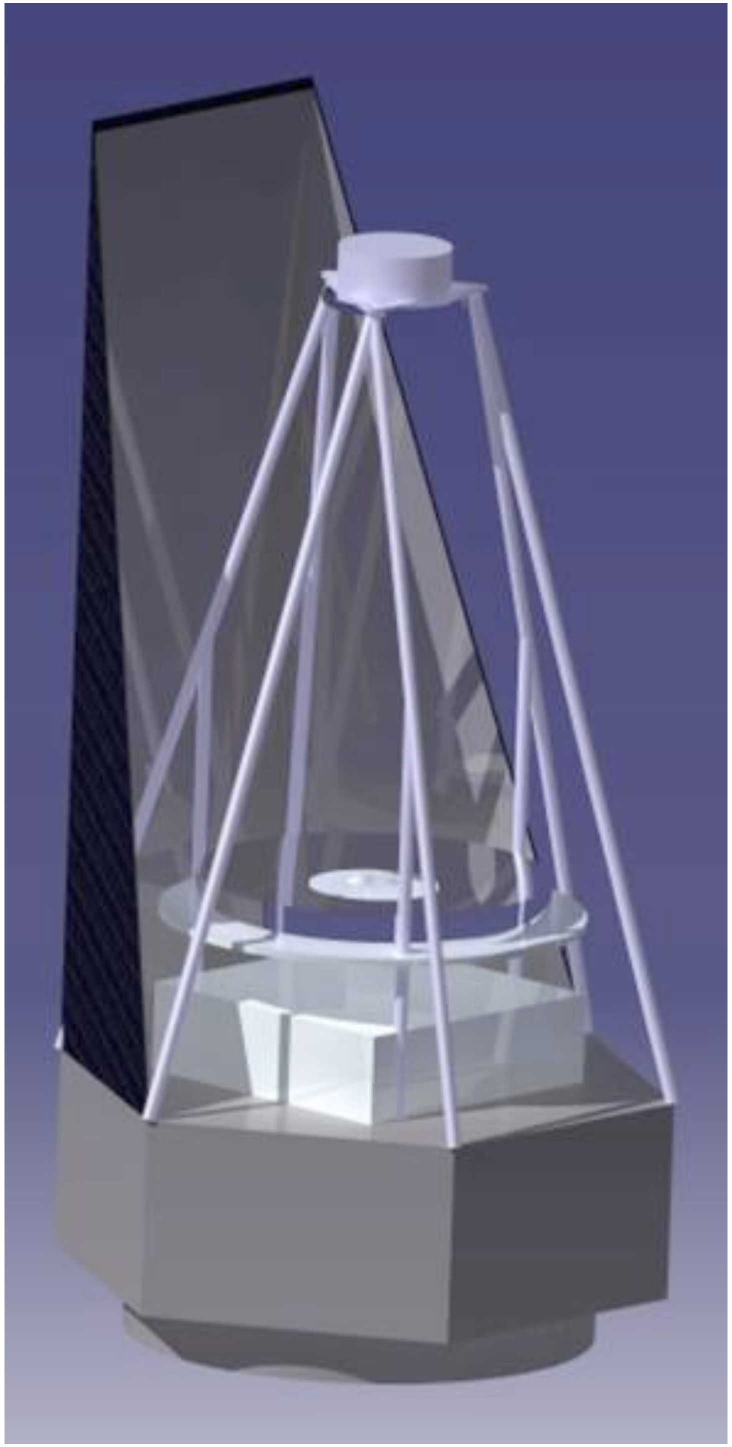






Spectroscopy simulations

- Realistic N(z) and galaxy sky distributions for H<23 (≈ 50,000 gal deg $^{-2}$)
- VVDS/zCOSMOS software (Bottini et al. 2005, PASP, 117, 996)
- Spectra are not allowed to overlap in wavelength by the software
- Spectra are separated by 2 pixels in spatial direction
- Best compromise for the instrumental parameters :
  0.375"/pix, 2 pix DMD^{-1} along λ (0.7'' slit width), 15Å/pix,
  R ≈ 400, spectrum length, width = 670 pixels, 2 pixels
- ≈ 6000 non-overlapping spectra over 51'x27' (0.4 deg^2),
  31% random sampling
- 85% – 95 % success rate in redshift measurements



SPACE MISSION SUMMARY

Telescope diameter	***1.5m***
Optical configuration	*Ritchey-Chrétien*
Wavelength range	***0.8 - 1.8 μm***
Optical quality	*Diffraction limited $\lambda > 0.65$ μm*
Pointing stability	*0.1” rms/ 30min*
Overall mass	*1486 kg*
Data rate	*1.5Mbit/s*
Orbit/Launcher	*L2/Soyuz*
Launch date	*Mid 2017*
Mission Duration	*5 years*
Partners	*ESA-NASA-* *European Agencies*

***SPACE* INSTRUMENT CHARACTERISTICS**	
Total field of view	***51' x 27'*** *(**0.4 sq. degrees**)*
Nr. and type of DMDs	*4 CINEMA chip (2048x1050)*
Total nr. of micromirrors	***8.8 million***
Mirror field of view	*0.75" x 0.75"*
Number of spectra	~ ***6,000 simultaneous***
Detector Pixel size	*0.375" x 0.375"*
Dispersing element	*Prism* ***R~400; 0.8-1.8 μm***
Imaging filters	***z, J, H, narrow band***
Detector	*HgCdTe 0.4-1.8μm, 2k x 2k, QE >75% average*
Nr. of detectors	*16 (4 mosaics of 2x2 chips)*
Detector Temperature	*~145 K*
Spectroscopy sensitivity	SNR $\approx$ 3 for AB $\approx$ 23 with t $\approx$ 900 s
Readout noise	*5e$^-$/multiple read*
Observing modes	***Broad- and narrow-band imaging, multi-slit spectroscopy***

SPACE survey programs

"All-sky" near-infrared **imaging** & **spectroscopic** survey of ¾ of the sky (**3π *sr***). Sample selected in *H*-band (**AB<23.0**). Random sampling rate of 1/3 ➔ ≈ Half-billion galaxies at **0 < z < 3** with spectroscopic redshifts, AND quasars **up to z ≈ 12**

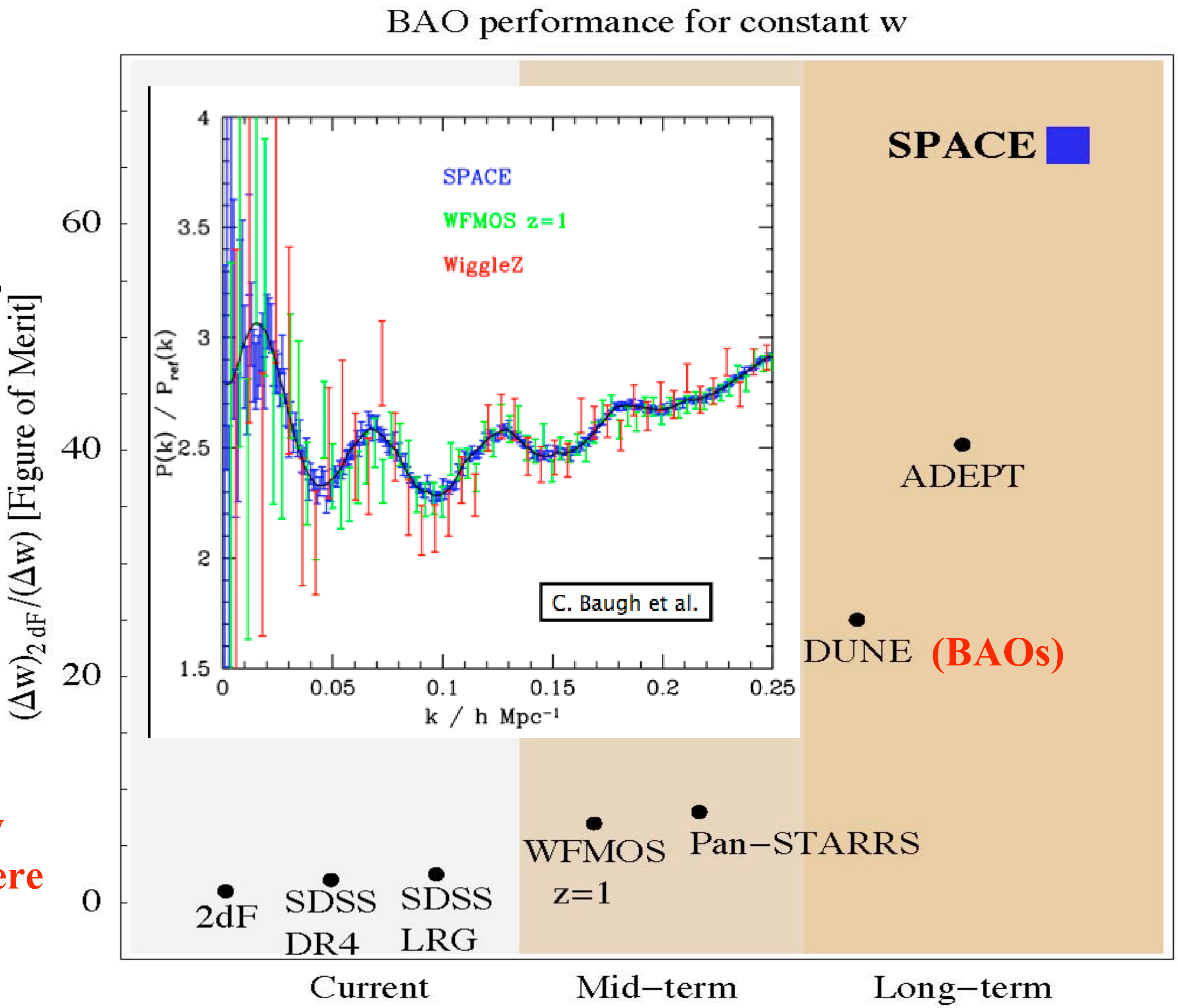
Deep near-infrared imaging and spectroscopy of **10 deg²** down to ***H*(AB) < 25**. About 2 million galaxies and AGN at **2 < z < 10**. (90% random sampling rate) + **Type Ia Supernovae to z ≈ 2**.

Galactic plane survey

Open time for Guest Observer programs

SPACE BAO alone is a Stage IV project (>10x improvement), even when survey is restricted to H=22 and 20,000 deg2

Y. Wang et al.



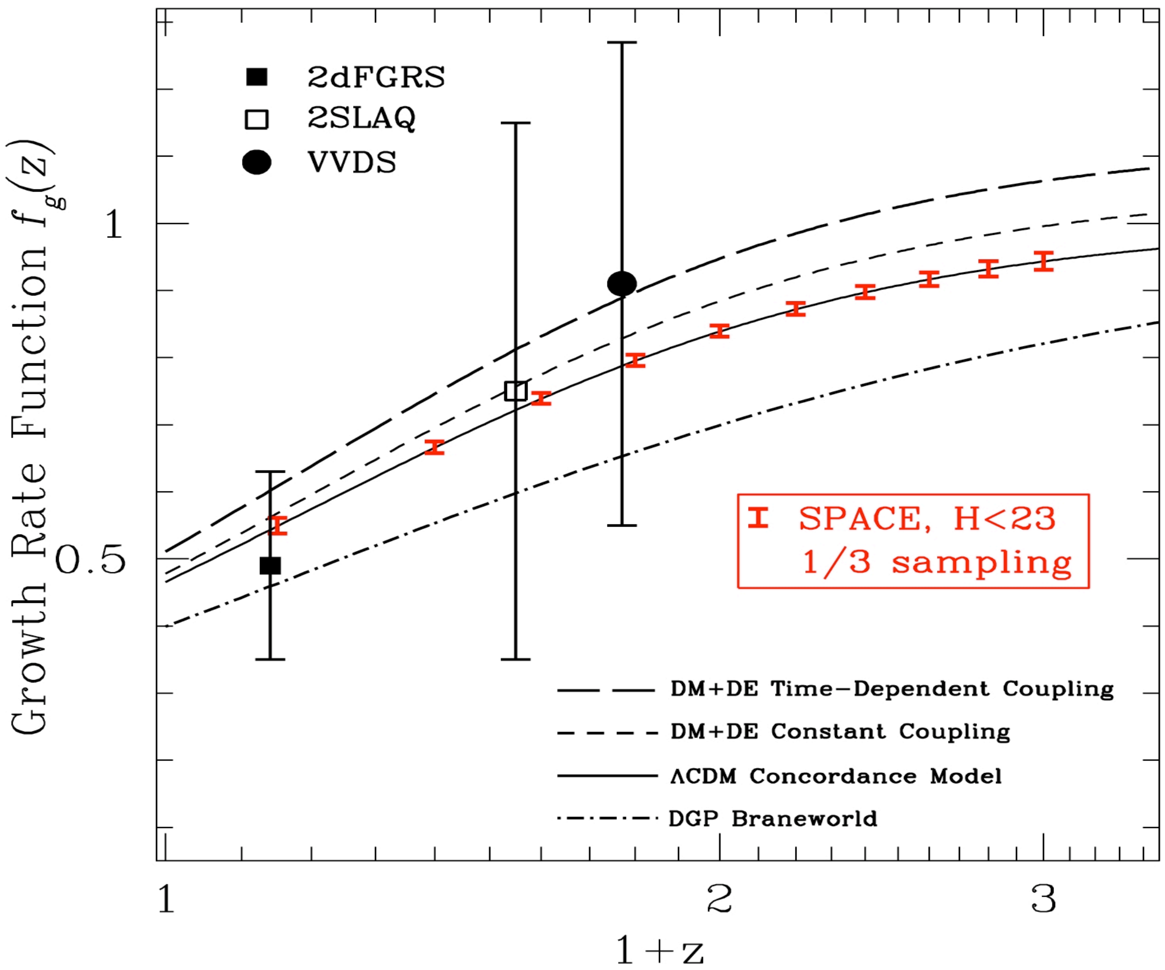
Constant w assumed here ($w_a = 0$) ➔ $\Delta w = \Delta w_0$

SPACE and the growth factor

- ~50 million galaxies per bin
- Accuracy <3% in each bin
- bias factor from CMB and/or higher-order clustering (unprecedented statistics)
- Growth rate from different classes of objects (LRG, groups, clusters?)

Guzzo et al. 2008
Nature (VVDS result)

$$f_g(z) = [\Omega_m(z)]^\gamma$$



Galaxy Clusters

•*SPACE* will provide spectroscopic confirmation for all clusters detected in the next generation SZ, X-ray large area surveys (SPT, eROSITA)

•**Near-IR selection:** *SPACE* alone will identify 10^5 clusters directly in 3D, and will provide *mass calibration* for complementary cluster surveys

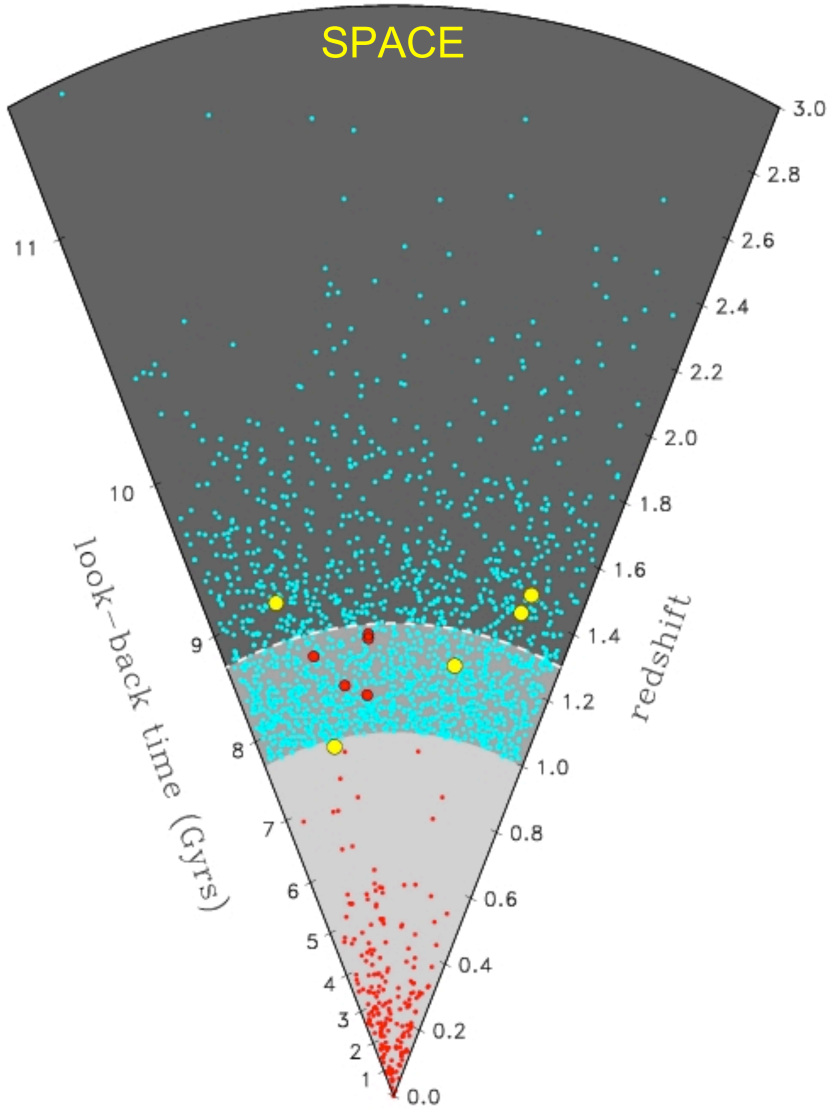
⇒**This will make next generation cluster surveys tools of precision cosmology**

•*SPACE* will unveil the first bona fide structures virializing at z≈2

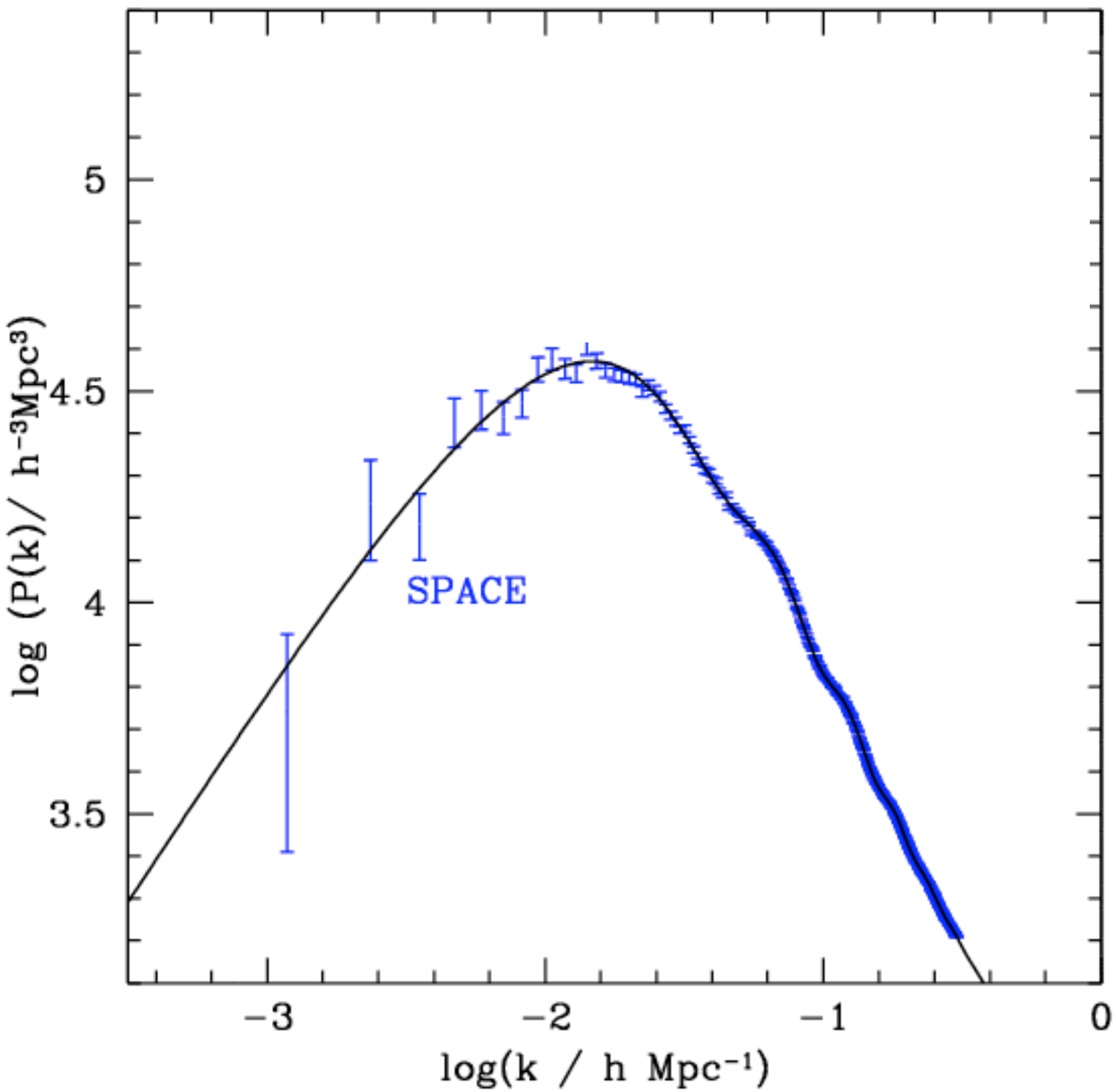
•Expected counts (H<23):
10-20 cluster/deg^2 ,
40-50% at z>1 ~5% at z>2

•Detection of all clusters at M>10^{14} $M_{\odot}$ at z>1 which carry a strong leverage on cosmology

•P(k) of clusters



SPACE and P(k)



Spectrum of CMB temperature fluctuations C_ℓ and matter P(k) subject to different parameter degeneracies ($\boldsymbol{\Omega_m h^2}$ and $\boldsymbol{\Omega_m h}$)

Combination of CMB (Planck) and P(k) (SPACE):
➔ break degeneracies

P(k) turnover :

- direct probe of primordial fluctuations
- position and shape depend on matter density, baryonic and neutrino fractions
- slope at $k < k_{turnover}$ constrains models of inflation

SPACE and galaxy evolution

(with spectroscopic redshift and spectra !)

SPACE All-Sky Survey :

- Co-evolution of galaxies and AGN at 0<z<2
- Rare QSOs at 7<z<10+

SPACE Deep Field (10 deg^2 to H<25) :

- Co-evolution of galaxies and AGN at 2<z<7+
- z,J,H color-selected galaxies at 7<z<10 to H<26 (N>1000)
- Narrow-band imaging : Lyα emitters at z>7 with very faint
- continuum (N>1000), luminous Pop III objects (HeII-1640)
- Spectroscopic follow-up of **Type Ia SNe**

P(k)

Dark Energy
[BAO + $f_g(z)$ + clusters (+Sne Ia?)]

SPACE

Formation and evolution of galaxies at $0.5 < z < 10$

Near-infrared imaging H-band deep atlas of ¾ of the sky

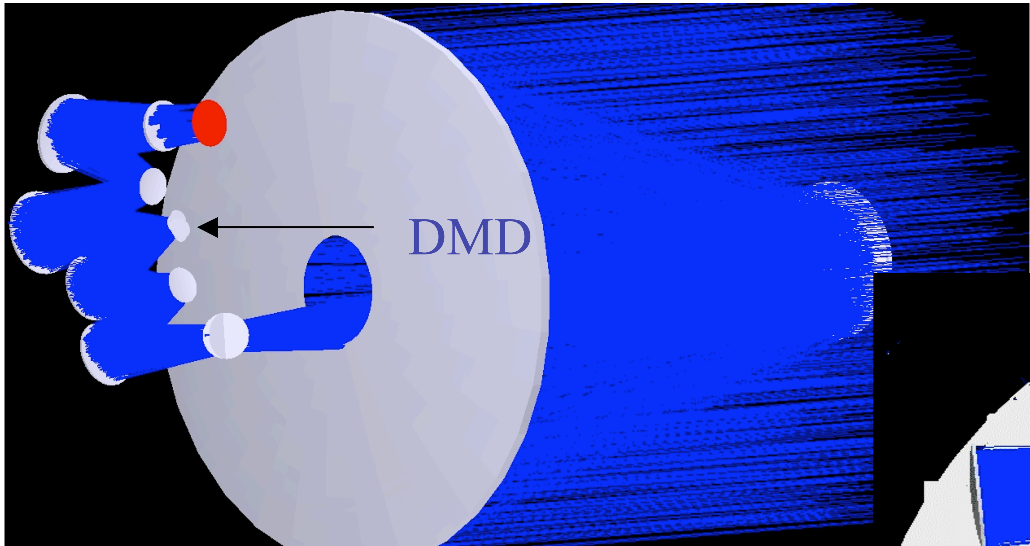
A <u>multi-aspect</u> cosmological mission

legacy value

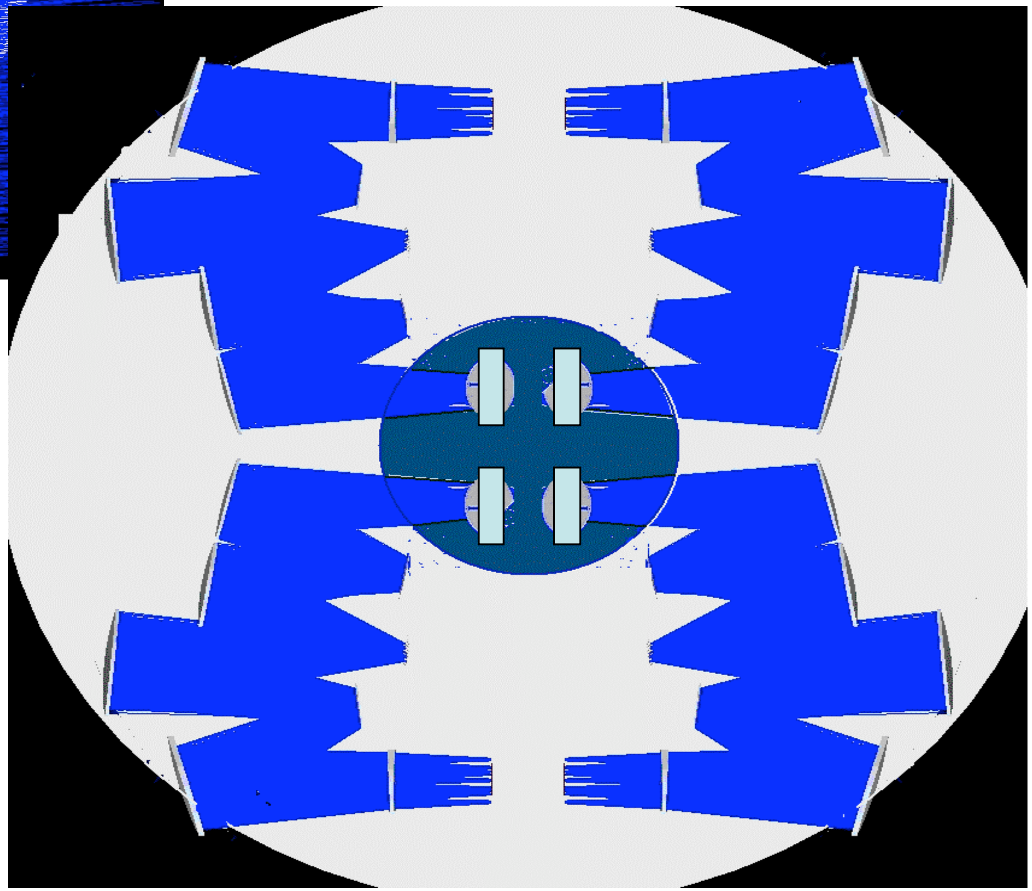
E-DEM-CAT Boundary Conditions

- M-Class, **ESA cost cap = 300 M€**
- Science case: Dark Energy/Cosmology: Weak-Lensing + BAO spectroscopy + others (SN, Clusters …)
- Mission duration: ideal = 4 years, maximum = 5 years
- Telescope : 1.2m diameter (smaller than SPACE: 1.5m)
- *IR focal plane : minimize the number of arrays (e.g. 60 for DUNE)*
- *Spectroscopy : reduce the 4-channel of SPACE to 1-channel ?*
- Metric: DETF FOM metric adopted (DUNE and SPACE had different metric in their proposals) in order to optimize the DEM mission concept

Merged optical concept with 4 spectrograph



Based on the DUNE design
0.1 deg^2 per channel for the spectrograph



Layout of the 4 spectrographs (LAM design)

Grange et al (LAM)