Exploring the (early) Universe requires large public surveys

43rd ESO’s UC meeting

@d_sobral_

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Reader in Astrophysics
Science path so far and why public surveys

- Surveys of emission-line galaxies across cosmic time (z~0-9)
- Detailed follow-up studies from X-rays to sub-mm/radio
- Resolved (IFU) and the roles of nature and nurture

Requirements: dedicated telescope time/own projects/experiments + relying on large public data/surveys in which they are based/built upon.

Own science: openness in discussing, allowing PhD students freedom to pursue their ideas, making products public, own codes
How do galaxies and their black holes form and evolve over the last 13 billion years?

Science path and the use of public surveys

IfA, Edinburgh (07-11)
Subaru: survey + follow-up

UKIRT: HiZELS survey
Leiden (11-18)

ESO/VLT + NTT: follow-up

Keck: follow-up

COSMOS UltraVISTA
UKIDSS UDS
CFHTLS SA22
Bootes

HST: follow-up

Survey science: public/archive

INT: survey/own filters

Lancaster 16-

ALMA: follow-up
Why Public Surveys are really worth it

- Blue (dark) skies research which can lead to unplanned discoveries/results
- Goes way beyond state-of-the-art: large investment + return
- Multiplication factor which is (typically) curiosity-driven
- Little to no political “feedback”/“quenching”
- Allows for entire ESO community to be engaged and not be left out: available to all. Even more important in the future?

Known unknowns + unknown unknowns

Large teams develop, small teams can make breakthroughs/“disrupt” (Wu et al. 2019, Nature, 566, 378). Public data essential for this in Astronomy

- **Requirement:** access to data to be fully explored - not just catalogues or high level products
Two complementary strategies to find distant galaxies

E.g.: Bouwens +2009; 2015; Oesch+2015a,b; Livermore +2016,2017; Atek+2018; Laporte+2017; Stark +2015,2016; Mainali+2018

Some science highlights using/relying on VISTA (and other) ESO public surveys

E.g.: Ouchi+2010; Matthee+2015; Bowler +2015; Hu+2016 Santos+2016; Sobral +2013,2017,2018a; Shibuya+2018;
A large Hα survey at $z = 2.23, 1.47, 0.84$ and $0.40$: the 11 Gyr evolution of star-forming galaxies from HiZELS*

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Sobral+2013a

• Citations to the Article (218)
What is so important in (VISTA) public surveys

- UltraVISTA: Y, J, H, K: rest-frame optical for higher redshift galaxies
- Photometric redshift estimates and colour-colour selections
- Contribute with deep NIR for SED fitting: stellar mass estimates
- Unique depth + area combination

- **Need**: actual images + catalogues (+value-added are always nice)
- Problems: pixel scale being so small (0.15” vs native 0.34””) means single images ~10 Gb, not easy to directly process for most purposes

- Extreme importance of other publicly available data-sets/surveys: zCOSMOS, LEGA-C, S-COSMOS, C-COSMOS, etc.
- **COSMOS is a role-model survey for galaxy evolution**: accessible, open, cut-out service, well-organised for multi-wavelength

VISTA public surveys (or any others) are only outstanding when combined with optical+MIR+others
[O\text{II}] + [O\text{III}] selected to $z \sim 5$

UltraVISTA + UKIDSS UDS allows to estimate good stellar masses, derive stellar mass functions (Khostovan+16)

Synergy is key: public surveys address that naturally

See also: Geach+08; Sobral+13a,14,15a; Karim+11; Madau & Dickinson14; Bouwens et al. 2015
SFRs & Stellar masses of emission line galaxies

The stellar mass function of star-forming galaxies and the mass-dependent SFR function since $z = 2.23$ from HiZELS

David Sobral, Philip N. Best, Ian Smail, Bahram Mobasher, John Stott and David Nisbet

\* Citations to the Article (95)
Determining and exploring the galaxy Density field + mass-complete samples
Based on public UltraVISTA data YJHK: photozs + stellar masses
Environment becomes relevant to determine quiescent fraction since z<1
Stellar mass always important at least since z~3

Darvish+15,16,17

Darvish, Mobasher, Sobral +2016
Surveys at higher redshift: $>10^6 \text{ Mpc}^3$ Ly$\alpha$ slices

- 18 narrow and medium-bands select redshifted Ly$\alpha$ emission from $z \sim 2$ to $z \sim 8$

- $z=2.2$  $z=3.1$  $z=4.8$  $z=5.7$  $z=6.6$  $z=7.7$

- **Fields**: COSMOS, UDS, SA22, Bootes, GOODS-N
- Down to $0.3L^*$ in Ly$\alpha$
- Galaxies as faint as $J \sim 25-26$

**Y-NBS (50 hrs VLT/HAWKI - PI: Sobral)**

At $z=2.2$ complemented with all major rest-frame optical lines
Slicing COSMOS with SC4K: the evolution of typical Lyα emitters and
the Lyα escape fraction from $z \sim 2$ to 6

David Sobral,1,2* Sérgio Santos,1 Jorryt Matthee,2 Ana Paulino-Afonso,1,3,4
Bruno Ribeiro,5 João Calhau1 and Ali A. Khostovan6

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2Leiden Observatory, Leiden University, PO Box 9513, NL-2300 RA Leiden, the Netherlands

Slicing COSMOS with SC4K: a low-cost “IFU”

16 narrow and medium filters on Subaru and the INT

On the full COSMOS UltraVISTA field:
ideal field!

All images needed

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16 different catalogues
Slicing COSMOS with SC4K: low-cost IFU from $z \sim 2$ to $z \sim 6$

16 narrow/medium bands $\Rightarrow \sim 4000$ Lyα emitters: $2 < z < 6$ in the COSMOS field

Complementary to MUSE: 2 deg$^2$

Publicly available

UltraVISTA DR4 crucial for stellar masses and SED fitting individually for first time. But requires all other bands!

All having HST + Chandra + Herschel + $\sim 30$ bands

The Lyα luminosity function from $z \sim 5.7$ to $z \sim 7.3$: UltraVISTA+

No evolution bright end: $L^*$ essentially fixed

Matthee, Sobral et al. 2015; Santos, Sobral & Matthee 2016

UltraVISTA + UKIDSS UDS + SA22

Steep faint end slope $\alpha = -2.3$

Patchy re-ionisation imprint?

Luminous Lyα: no evolution in number densities
**Discovery of the most luminous LAEs: CR7 + MASOSA**

EVIDENCE FOR PopIII-LIKE STELLAR POPULATIONS IN THE MOST LUMINOUS Ly\(\alpha\) EMITTERS AT THE EPOCH OF REIONIZATION: SPECTROSCOPIC CONFIRMATION*

David Sobral\(^{1,2,3,7}\), Jorryt Matthee\(^3\), Behnam Darvish\(^4\), Daniel Schaerer\(^5,6\), Bahram Mobasher\(^4\), Huub J. A. Röttgering\(^3\), Sérgio Santos\(^1,2,7\), and Shoubaneh Hemmati\(^4\)

**Citations to the Article (181)**

Sobral et al. (2015c)

Discovery of the most luminous z\(\sim\)7 Lyman-alpha emitters: CR7, MASOSA (Sobral et al. 2015c), COLA1 (Hu+16;Matthee+18) in UltraVISTA + UKIDSS UDS Himiko (Ouchi et al. 2010)

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MASOSA and VR7 (ALMA+HST): Matthee, Sobral+19; arXiv:1903.08171
Raw spectra ~15 minutes on Keck/DEIMOS & VLT/X-SHOOTER

*Not* quasars

Lyα line seen in the raw data at z~7

Matthee, Sobral+

VLT/XSHOOTER

High S/N spectra of z~7 Lyα emitters
Resolving the stellar and ISM components at z~7

- ALMA+HST follow-up and combining all facilities
- UltraVISTA DR4 now detects all luminous LAEs at z~7: SED fitting on-going

![Graph and Image Description]
Final remarks/thoughts on public surveys

- There should be incentives to make any significant amount of telescope time into a public data-set
- Science that is publicly funded should not (never) be “copyrighted”. Making it freely available benefits all
- Incentives and prizes to best practices should be considered
- **Recognition is needed:** fantastic individuals at ESO and in public survey teams who may not get credit they deserve!
- **Important to have data made available in a timely matter:** huge delays mean community may not be interested in it anymore - other data already better + jump fence (grass always greener on the other side [and in the future])
- Archive ESO proposals? Make more data into public surveys
- Direct high-relevance application: MUSE?