Euclid, JWST, ELT
Synergy with SKA

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What do we want to know?

Matter in the Universe
Dark matter/visible matter vs $z$

Dark energy:
Is it varying with time?

How is the Universe re-ionized?
End of the dark age: cosmic dawn, EoR

How do baryons assemble into the large-scale structures?
Galaxy formation and evolution (mergers, cold accretion)
Star formation history, quenching
Environment: groups and galaxy clusters

Strong-gravity with pulsars and black holes
1-What is dark energy: $w$
Equation of state and nature of DE, through expansion and growth rates, 5 tools: WL, BAO, RSD, CL, ISW

2-Gravity beyond Einstein: $\gamma$
Testing modified gravity, by measuring growth rate exponent $\gamma$

3-The nature of dark matter, $m_\nu$
Testing the CDM theory, and measuring neutrino mass

4- The seeds of cosmic structures
Improve by a factor 20, $n$, $\sigma_8$, $f_{NL}$
EUCLID Legacy

Wide survey $15\,000\,\text{deg}^2$
Deep survey $40\,\text{deg}^2\,(+2\text{mag})$

12 billion sources ($3\sigma$)

50 million redshifts

A reservoir of targets for JWST, GAIA, ELT, ALMA, Subaru, VLT, etc.

<table>
<thead>
<tr>
<th>Objects</th>
<th>Euclid</th>
<th>Before Euclid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galaxies at $1&lt;z&lt;3$ with precise mass measurement</td>
<td>$\sim 2\times 10^6$</td>
<td>$\sim 5\times 10^5$</td>
</tr>
<tr>
<td>Massive galaxies ($1&lt;z&lt;3$)</td>
<td>Few hundreds</td>
<td>Few tenss</td>
</tr>
<tr>
<td>Hα Emitters with metal abundance measurements at $z\sim2-3$</td>
<td>$\sim 4\times 10^7/10^4$</td>
<td>$\sim 10^4/\sim 10^2$ ?</td>
</tr>
<tr>
<td>Galaxies in clusters of galaxies at $z&gt;1$</td>
<td>$\sim 2\times 10^4$</td>
<td>$\sim 10^3$ ?</td>
</tr>
<tr>
<td>Active Galactic Nuclei galaxies ($0.7&lt;z&lt;2$)</td>
<td>$\sim 10^4$</td>
<td>$&lt;10^3$</td>
</tr>
<tr>
<td>Dwarf galaxies</td>
<td>$\sim 10^5$</td>
<td></td>
</tr>
<tr>
<td>$T_{\text{eff}} \sim 400,\text{K}$ Y dwarfs</td>
<td>$\sim \text{few} ,10^2$</td>
<td>$&lt;10$</td>
</tr>
<tr>
<td>Lensing galaxies with arc and rings</td>
<td>$\sim 300,000$</td>
<td>$\sim 10,-100$</td>
</tr>
<tr>
<td>Quasars at $z &gt; 8$</td>
<td>$\sim 30$</td>
<td>None</td>
</tr>
</tbody>
</table>
Strong Lensing

SLACS: The Sloan Lens ACS Survey

A. Bolton (U. Hawai‘i IFA), L. Koopmans (Kapteyn), T. Treu (UCSB), R. Gavazzi (IAP Paris), L. Moustakas (JPL/Caltech), S. Burles (MIT)

Images credit: D. Brito, for the SLACS team and INSTEARS
Will become an industry

Substructure study; high-z normal galaxies... **Dark matter studies**

Similar number per unit surface with SKA  100 000

Euclid Legacy: after 2 months
(66 months planned)
Ground spectroscopy in synergy

HI spectroscopy will provide spectro-z catalogs for Euclid
Ultimately 1 billion HI spectro-z (SKA2)
With SKA-1 ~ 10% of SKA2

MOONS is ideal to provide the control sample for Euclid
Euclid is ideal to provide deep near-IR photometry for MOONS

In addition to the ground photo-z Survey, with CFHT in the North
DES, LSST in the South

E-ELT: very small FOV
Will make follow-up of SKA and Euclid sources, with high resolution
Complementary in science goals
Overlap in space, redshift

SKA-Euclid projects: (mainly $<z>=1-2$)

- Euclid + SKA photometry + emission line galaxy analyses,
- Euclid + SKA redshifts,
- Euclid + SKA morphometry and astrometry

$Z_{\text{median}} \approx 1$
Different biases: HI surveys are not cluster biased
SKA: no bias from dust, stars..
Larger area covered in the sky (but less spatial resolution)
HI surveys for BAO with SKA-1

All sky survey: $4 \times 10^6$ gal $z=0.2$  $3\pi$ sr

Wide-field survey: $2 \times 10^6$ gal $z=0.6$  $5000$ deg$^2$

Deep-field survey: $4 \times 10^5$ gal $z=0.8$  $50$ deg$^2$

Euclid $10^8$ gal at $z\sim 1$

But photo-z, with $2 \times 10^5$ spectro-z
Pure sample, deep field

SKA will help to provide pure sample
WL, AGN -- Present status of radio surveys

HDF-N 5 x 5 arcmin area to I
≈29th magnitude


6 sources detected by VLA with $S_{8.4} > 12 \, \mu\text{Jy}$
(50 hour observation)
Deep radio sky
10’ size, @ 1.4GHz

1 \mu Jy top
100 nJy bottom

Left and Right
Cosmic variance

FRI: green, double
FRII: red, double

Beamed FRI: green dot
Beamed FRII: red dot

Star-forming: disk

Jackson 2004
In 2yrs achieve 2 $\mu$Jy rms would provide $\approx 4$ galaxies arcmin$^2$ ($>10\sigma$)

PSF is excellent quality circular Gaussian from about 0.6 – 100”
With almost uniform sky coverage of 3$\pi$ sr

Total of 0.5 billion radio sources, for All sky survey
for weak lensing and Integrated Sachs Wolfe

For wide-field (5000 deg$^2$) 2 $\mu$Jy rms $\approx 6$ galaxies arcmin$^2$ ($>10\sigma$)
For deep-field (50deg$^2$) 0.1 $\mu$Jy rms, $\approx 20$ galaxies arcmin$^2$ ($>10\sigma$)
Combining SKA1 (cont) & Euclid

$\Delta w$

$f_{NL}$ indicator of non-gaussian fluctuations

Bacon 2013
From ISW studies

$f_{NL}$ indicator of early-universe physics

Planck

Bacon 2013
Related main issues: JWST & ELT

**Galaxy formation and evolution, physics and dynamics**
- Surveys of galaxies at high and intermediate redshifts
- Mass assembly and star formation, mergers, cold accretion
- Quenching: supernovae and AGN feedback

**Epoch of reionization**
- Early galaxies and black holes $z=10-6$
- Absorption in front of QSO, GRB IGM

**AGN and super-massive BH**
- Symbiotic growth with galaxies
- Physics of accretion
## E-ELT, Euclid and SKA parameter space

<table>
<thead>
<tr>
<th>Parameter</th>
<th>E-ELT</th>
<th>Euclid</th>
<th>SKA</th>
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<tbody>
<tr>
<td>FOV</td>
<td>Single object to 10’ diameter patrol field</td>
<td>0.5 sq deg FOV ~full sky survey</td>
<td>1 deg(^2) or larger @ 1 GHz 100 deg(^2) @ 0.1 GHz</td>
</tr>
<tr>
<td>(\lambda) range</td>
<td>Optical to mid-IR</td>
<td>Optical and NIR</td>
<td>Radio 2cm–4 m (0.07 – 10+ GHz)</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>~Few mas (with AO) to seeing limited</td>
<td>0.2”(VIS) to 0.3” (NIR)</td>
<td>30 arcmin (0.5 km, 4m) to 1 mas (3000 km, 2cm)</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>Broadband imaging to R~100,000 (TBD)</td>
<td>Broadband imaging R=250 slitless spectroscopy</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>Dec ~ - 29 Fully steerable mount</td>
<td>Orbit around L2 – restricted pointing at any time</td>
<td>Australia + S. Africa, Beam formation anywhere in sky</td>
</tr>
</tbody>
</table>
Simulations of EoR

Only simulations for now!

Synergy Euclid /SKA

Discovery of the QSO in the EoR

Detection of the HII region around the QSO, at high redshift

Will be studied in detail and depth by JWST and ELT

Also absorption studies
Are galaxies at z=7-10 able to re-ionize?

Nbre of galaxies
mag$^{-1}$ Mpc$^{-3}$

Lyman Forest

Q1159+123
z=3.502

WAVELENGTH (ANGSTROM)
What is the first galaxy?

Candidates at $z=10$

Disappears at $\lambda=1.4$ microns

Difficult observations, at the limit of present telescopes

$\rightarrow$ JWST 6.5m, 2018

Detected in each sub-group of observations
Galaxy formation and evolution

How galaxies assemble their mass?
How much mass assembled in mergers?
How much through gas accretion and secular evolution?

Star formation modes; main sequence, Starburst, mergers?

Modes of Quenching
SF and AGN feedback
Atomic hydrogen HI-21cm
Simulated sky, $z=1, 3, 6$

Obreschkow et al 09

$z=3$ scale x10
$z=6$ scale x100

240 Mpc comoving depth
3 x 1 arcmin surface

HI line, and CO lines
AGN NLR, BLR

AGN-driven outflow in Mrk 231

AGN and starburst,
Outflow 700Mo/yr

IRAM Ferruglio et al 2010

JWST-ELT Census of black-holes
Spatial resolution (5mas)= sphere of influence
10^6 Mo BH at Virgo distance
10^9 Mo BH at z~0.2

In Virgo Kupcu-Yoldas

V

ΔV

BH 1.2E7Mo

Dasyra & Combes 2012
UFO Wagner et al 2012
Corresponding Time-scales

- **2018 – 2021**: construction of SKA1
- **2019/20**: early science begins
- **2022 – 2025**: construction of SKA2
- **SKA** operational for 50 years.

**Euclid**: 2020 - 2027

**LSST**: 2020-2022 Commissioning: 2022- Science!
**E-ELT**: 2023..  
**JWST**: 2018.. 2028
Telescope primary mirrors

- **Euclid**
  - Diameter: 1.2m

- **HST**
  - Diameter: 2.4m

- **JWST**
  - Diameter: 6.5m

- **GMT**
  - Diameter: 24m

- **VLT**
  - Diameter: 8m

**Collecting area = sensitivity**
**Diameter = resolution**
**Field of view = mapping speed**
SKA footprint to scale /100,000

3000 km