MESSIER
Unveiling galaxy formation

David Valls-Gabaud
on behalf of the MESSIER consortium

CAS-ESA First workshop
Chengdu - 2014 February 26
Science working group

Core team
Paris  Strasbourg  Heidelberg  Stockholm
Caltech  Arizona  Columbia

Technical team
Paris  Marseille  Shanghai

Interested parties: >100 researchers over 30 institutes
Standard cosmological model $\Lambda$CDM

... from initial conditions

.... to non-linear structures: filaments, clusters, galaxies
Hierarchical bottom-up accretion/merging of cold dark matter (sub)haloes

\[ M_{\text{BCG}} = 60.56 \times 10^{10} \text{ h}^{-1} M_{\odot} \]
\[ M_{\text{min}} = 1.0 \times 10^{10} \text{ h}^{-1} M_{\odot} \]
\[ \text{type} = 0 \]

Can we detect the fossil record of past accretion events in our Galaxy and beyond?
MESSIER’s two driving science cases

To critically test the ΛCDM paradigm on *non-linear* scales

- **How do galaxies form by accretion?**
  - Anisotropic accretion from filaments? Mergers?
  - Discs of satellites? Missing satellites? Halo profiles?

- **What are the properties of the cosmic web?**
  - Does it exist? Do baryons follow dark matter?
  - Reservoir of missing baryons? Shock heated? Ionisation?

*ESA Cosmic Vision:* 4.2 The universe taking shape
*NSF Decadal Survey:* How do cosmic structures form and evolve?
*Europe ASTRONET:* 3.2 Cosmic web 3.4 How were galaxies assembled?
Key prediction of the $\Lambda$CDM paradigm
(over?) abundance of dwarf satellites

Belokurov et al. (2008)
All newly-discovered satellites of the Galaxy and Andromeda are at the limit of surface brightness reachable by counting (resolved) stars.
Most predicted key structures lie at surface brightness levels below 30 mag arcsec$^{-2}$

Unreachable from the ground

Font et al. (2008)

500 kpc

Cooper et al. (2013)
Selection:
metal-poor RGB stars

PANDAS collaboration 2008-2014
[...] galaxies are like icebergs and what is seen above the sky background may be no reliable measure of what lies underneath.

M. Disney (1976)
The unprobed realm of the low surface brightness universe

$\mu(V) < 21.5$

Limited by systematics
- sky variability
- straylight
- flat field accuracy
- extended PSF wings

Mihos et al. (2005)
Current instrumentation is not adequate

Signal received by an *unresolved* source:

\[ F_{\text{point}} \propto A \epsilon t_{\text{exp}} 10^{-0.4 m_{\text{tot}}} \]

→ drives telescopes with large diameter and large focal length

Surface brightness received by a *extended* source:

\[ SB_{\text{extended}} \propto \left( \frac{D}{f} \right)^2 \epsilon t_{\text{exp}} s_{\text{pix}}^2 N_{\text{pix}} 10^{-0.4 \mu} \]

→ requires fast optics with minimal \((f/D)\) ratio
Driving science case #2

The Cosmic Web

Strongest in Lyman $\alpha$ by $\sim 1000$

Bertone + Schaye (2012)
Low surface brightness Lyman-α emitters

VLT
92 hours exposure

Rauch et al. (2010)
Extended Lyman-α emission from $z \sim 2.65$ star-forming galaxies

92 UV-selected galaxies with $<z>=2.65$

Extended haloes to $\sim 80$ kpc (when stacked)

SB $\sim 10^{-19}$ erg s$^{-1}$ cm$^{-2}$ arcsec$^{-2}$

900 hours integration at 8-10m class telescopes

Lyman-α cooling?
Fluorescence by ionising radiation?
Scattering from circumgalactic gas?

Steidel et al. (2011)
Fluorescent Lyα emission of the circum-galactic medium around a quasar at $z=2.4$

27 hours VLT

Cantalupo, Lilly & Haehnelt (2012)
The MESSIER satellite

Scientific and technical challenges
First catalogue of diffuse objects

Messier (1771)
Mem. Acad. Sci. Paris
Top-level design requirements

- **FOV**: $2^\circ \times 4^\circ$ (lifetime of satellite)
- **Focal ratio**: $f/2$ (200x better than HST)
- **Central obscuration**: none (minimal PSF wings)
- **Spatial resolution**: 1-2” per pixel
- **Roughness**: < 0.5 μm (UV to optical)
- **Flat field rms**: < 0.025% (TDI / drift scan)
- **Distortion**: < 0.5% in one direction
- **Diameter**: 40 cm (set by platform/design)
Obstruction by secondary mirrors yields very extended PSFs.

Zero obstruction is required.
Additional requirements

- flat(ish) focal plane
- no lenses (Čerenkov radiation)

Current solution

TMA
unobscured, off-axis
easy baffling
flat focal plane
f/2
4° x 2°
TRL 9 (optics/FP)
alignment issues TBD
No sky variability but many foregrounds:

- zodiacal light (variable)
- stray light contamination
- geocoronal/airglow emission
- optical/UV emission from Galactic dust (cirrus)

Minimise zodiacal contamination while keeping key information on stellar populations
Requirement for filters
AR coatings allow to reach a quantum efficiency of 80-90% 
Atomic Layer Deposition: multi-layer JPL/Columbia 
ITAR free (in principle, TBC)
Focal plane configuration

4 x 2 independent CCD controllers in drift-scan mode
QE of each detector optimised for each filter
No moving parts; no coolants

<table>
<thead>
<tr>
<th></th>
<th>r</th>
<th>g</th>
<th>u</th>
<th>Broad-band @200 nm Lyα</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra broad</td>
<td>i</td>
<td>z</td>
<td>Narrow band @200 nm Lyα</td>
<td></td>
</tr>
</tbody>
</table>
Simulated MESSIER images of a galaxy at 15 Mpc

Expected performances - I    Optical bands

10 ksec
5 kpc × 5 kpc

100 ksec
1 kpc × 1 kpc (14″ × 14″)
Expected performances - I Optical bands

Simulated MESSIER images of a galaxy at 15 Mpc

1 Msec
1 kpc × 1 kpc

10 Msec
1 kpc × 1 kpc
Expected performances - II  UV bands

Over $3 \times 10^6$ galaxies detected in Ly$\alpha$ with S/N>30
Expected performances - II  UV bands

Signal / Noise for simulated MESSIER images of the cosmic web
Secondary science cases (free by-products)

- The optical / UV cosmological background radiation
- Fluorescent emission from molecular hydrogen (Lyman-Werner bands)
- Surface brightness fluctuations and extragalactic distances
- Intracluster light and the accretion history in galaxy clusters
- Time domain astronomy: multi-wavelength variability
- Zodiacal dust + comet tails
- Mass loss from stars
- Synergies with GAIA and EUCLID

Sahai + Chronopoulos (2012)
Mission concept - I

Payload
- Off-axis TMA f/2 telescope, 40 cm diameter
  - flat focal plane, FOV: 8 square degrees
- Ultra-stable PSF with ultra-low wings
- No lenses (to avoid Čerenkov radiation)
- Extreme baffling to limit straylight contaminations
- 8 UV/ optical filters
- No moving parts, passive cooling, low power
- TRL 9 (but stability of FP TBD)

Detectors
- Optimised QE > 80% for each UV/optical band
- ITAR free (TBC)
- Time delay integration controllers + data flow to ground
Mission concept - II

- **Spacecraft**
  similar to ESA’s Proba-V (instrument: 40 kg, 43 W)
  platform: 40×60×80 cm; 95 kg
  MIDEX WISE (40 cm telescope, 200×285×173 cm, 660 kg, 300 W, 540 km)
  VESTA dual-payload adapter @ Vega rocket

- **Orbit**
  SSO 700-900 km, precession 360°/year
  pointing ⊥ Sun-Earth direction avoiding Earthshine
  great circle drift scan with centre at the Sun

- **Mission lifetime**
  3 to 5 years
  full sky coverage to SB > 32 (optical) - 37 (UV) mag arcsec$^{-2}$
Contributions by China to MESSIER

✔ Innovative optical design of the off-axis f/2 TMA telescope Marseille + Shanghai

✔ Large community working in cosmology / galaxy evolution ample scope for science and technology collaborations

✔ Expertise in UV instrumentation: Lunar-based UV Telescope NAOC: LUT @ Chang’e 3 150mm RC 245-340 nm
MESSIER
a backpacker trip to the extremely low surface brightness universe

Proposal for a Proba-like satellite 2020 horizon

The last unexplored niche in observational space

Legacy value: reference catalogue for multi-band optical/UV photometry

Further international partners welcome