Galactic Archaeology surveys

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& the WEAVE science team (incl. A. Helmi, S. Feltzing, N. Walton and teams in FR, NL, UK, ES, IT)
New survey frontiers from new survey instruments

- Gaia: Astrometry at microarcsecond precision
  - The history of the Milky Way
- SKA Pathfinders:
  - LOFAR:
    - The history of star formation
    - Precision cosmology
  - Apertif:
    - HI at cosmological distances
Kinematics + chemistry of stars enable to unravel the complex history of the MW assembly and internal evolution.

Learnt many things from SEGUE, RAVE, GES, APOGEE (Vr + chemistry + approx. ground-based Vt & isochrone D).

Now is time for Gaia’s harvest with exquisite geometrical D, Vt, in an unequalled volume. + Gaia’s ages.
Gaia’s reach: 1 billion stars
V<20

Astrometry:
- V<20 → Gaia distances, proper motions

Photometry (RP/BP):
- V<18-19 → Gaia stellar parameters

Spectroscopy (RVS):
- V<15 → radial velocity, parameters
- V<12 → Gaia chemical abundances

Gaia’s reach: 1 billion stars
V<20
Complementing Gaia:

• A survey to acquire accurate Vr (and stellar parameters, incl. metallicity) $15 < V < 20$
  ➢ Defined the LR mode of WEAVE:
  ➢ $R = 5,000$ in a wide range $[366 – 606] \text{ nm} + [579 – 959] \text{ nm}$

• A survey to determine accurate stellar parameters and detailed chemistry for $V > 12$
  ➢ Defined the HR mode of WEAVE:
  ➢ $R = 20,000$ in two windows $[404 – 465] \text{ nm}$ or $[473 – 545] \text{ nm} + [595 – 685] \text{ nm}$
WEAVE: a northern facility

WEAVE is the only HR Xwide field Xmultiplex optical facility in the north!
WEAVE LR surveys

Two main LR survey areas:
1. A high latitude survey mapping the assembly of the stellar halo
2. A galactic plane experiment to constrain the disc potential (spiral arms, bar, ...)

WEAVE can measure $V_r$ to $\sigma(v_r)<3$ km/s at $V=20$ in 1hr (dark time) or $V=19$ (bright time), i.e. closely matching the Gaia astrometric and photometric limits

Talk by B. Famaey
Mapping the stellar halo

Aquarius A @35kpc

SDSS

Helmi et al. 2011

Belokurov et al. 2006
Mapping the stellar halo

- # of streams increases towards the galactic centre (Gomez et al. 2013)
- Chemo-dynamical information for streams fundamental in the inner halo to identify accretions and characterize their
Galactic halo survey goals & means

1. Fraction of accretion/in situ formation? (LR&HR)
2. Total mass of the MW >100kpc; potential shape and lumpiness (LR)
3. Hunting and following-up metal-poor stars (LR&HR)
   - Known streams follow-up (incl. dSph) LR
   - « blind » halo survey LR (MSTO + giants)
   - « blind » halo survey HR of giants

- $\sim 1.5 \times 10^6$ stars over $\sim 9000\text{deg}^2$ selected SDSS + PanStars + Gaia-DR2(2017)
Disc dynamics survey: goals & means

Discriminate fundamental aspects of galactic dynamics in the MW: moving groups, velocity ellipsoid across the disc \( \rightarrow \) probe the axisymmetric potential + non-axisymmetric terms (bar, spiral arms). Implications for radial migration.

- Need \( V_r \) to a few km/s
- Reach across significant disc fraction

- LR in 100 well chosen los; MS+giants
- Several \( 10^6 \) stars selected Gaia-DR2 + gal plane phot surveys
WEAVE HR

Two main surveys concentrating on chemical tagging/labelling the oldest MW populations:

1. A high latitude survey searching for streams in the stellar halo
2. A intermediate latitude survey mapping the thick away from the solar vicinity

WEAVE can measure stellar parameters and individual abundances in all main nucleosynthetic channels to V=16, i.e. closely matching the Gaia’s most precise sphere (distances, ages).
Elemental abundances

dwarf

giant
WEAVE at R=20,000: chemical tagging/labelling

3 open clusters

Accreted stars?

Thick disc

Thin disc

These samples deal with 100 to 1000 stars, in a volume of <100pc around the Sun, at very high SNR and resolution.
Gaia ESO experience

R=20,000, smaller \( \lambda \) range, lowish S/N

Recio-Blanco et al. 2014

Mikolaitis et al. 2014
Gaia ESO experience

R=20,000, smaller $\lambda$ range, lowish S/N

Recio-Blanco et al. 2014

Guiglion et al. 2015 subm.

[Graphs and data showing differences in disc properties, with annotations on velocities and time scales.]
Gaia’s reach: best distances

$\sigma_\pi/\pi < 1\% \ (10^6*)$

$\sigma_\pi/\pi < 10\% \ (150.10^6*)$
Gaia’s reach: ages

Stellar type relevant for isochrone ages: MSTO and subgiants (FG stars)

### Gaia only

<table>
<thead>
<tr>
<th>Vmag</th>
<th>(\sigma_{\text{distance}})</th>
<th>(\sigma_{\text{teff (RVS)}})</th>
<th>(\sigma_{\text{teff (BPRP)}})</th>
<th>(\sigma_{\text{age}})</th>
<th>(\sigma_{[\alpha/Fe]})</th>
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<tbody>
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<td>13-14</td>
<td>1%</td>
<td>100 K</td>
<td>150 K</td>
<td>~5%</td>
<td>0.10 dex</td>
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<tr>
<td>16-17</td>
<td>10%</td>
<td>-</td>
<td>250 K</td>
<td>~25%</td>
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### Gaia + Ground-Spectro

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<td>50 K</td>
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<td>0.05 dex</td>
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<tr>
<td>16-17</td>
<td>10%</td>
<td>10%</td>
<td>50 K</td>
<td>~15%</td>
<td>0.05 dex</td>
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</table>
HR survey: goals & means

Probe the MW main populations history (mass assembly, internal evolution):
1. Chemical labelling of thin/thick disc and halo away from the Solar neighbourhood; emphasis on the outer disc
2. Complement Gaia in its extended « age-sphere » (D<3kpc)
3. Field/open cluster synergies
   - 12<V<16 survey at intermediate |b|, with special emphasis on old MSTO
   - « blind » halo survey HR of giants (V<16-18)
   - 25 old open clusters across the disc (+25 young)
   - ~0.5 10^6 stars selected Gaia-DR2(2017) (+SDSS)
WEAVE LR reach

All stars with $V < 20$

Halo stars with $V < 20$

Thick disc stars with $V < 20$
WEAVE LR reach

All stars with $V < 16$

Halo stars with $V < 16$

Thick disc stars with $V < 16$
WEAVE @ WHT (4m)

HR survey of $6 \times 10^5$ stars $V<16$ + LR survey of $6 \times 10^6$ stars $V<20$

Photometry and astrometry: $V<19$

Spectroscopy:
- $V<15$
- $V<12$

Distances, proper motions, Gaia stellar parameters
- radial velocity, parameters
- Gaia chemical abundances

WEAVE LR: radial velocities & parameters (incl. $[\alpha/Fe]$) $V<20$

WEAVE HR abundances $V<16$
+ WEAVE is the only HR very wide field facility for the North!

Photometry and astrometry: $V < 19$

Spectroscopy:
- $V < 15$
- $V < 12$

Distances, proper motions, Gaia stellar parameters
- radial velocity, parameters
- Gaia chemical abundances

Gaia-ESO HR survey
- $10^5$ stars $J < 18$

Gaia-ESO VHR survey
- $10^4$ stars $V < 14$

&

GALAH HR survey
- $10^6$ stars $V < 14$
## Nominal survey parameters

<table>
<thead>
<tr>
<th>Survey</th>
<th>Mode</th>
<th>No. Objects</th>
<th>Area (deg²)</th>
<th>Nights</th>
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<tr>
<td>GA halo LR</td>
<td>MOS/R=5000</td>
<td>$10^6$</td>
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<td>215</td>
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<tr>
<td>GA halo HR</td>
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<tr>
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<td>MOS/R=5000</td>
<td>$5 \times 10^6$</td>
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<tr>
<td>GA disk HR</td>
<td>MOS/R=20000</td>
<td>$5 \times 10^5$</td>
<td>2000</td>
<td>715</td>
</tr>
<tr>
<td>Clusters L1</td>
<td>MOS/R=5000</td>
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<td>25</td>
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<tr>
<td>Clusters L1</td>
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<td>$10^3$</td>
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<td>50</td>
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<tr>
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<tr>
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<td>Apertif-LIFU</td>
<td>LIFU/R=20000</td>
<td>60</td>
<td>0.025</td>
<td>60</td>
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</table>

N.B. Reduction in total time from the fact that the LOFAR and Halo surveys overlap…
Accuracy in Transverse Velocity

Distance in pc

σ(V_t) (km/s)

G0V
K0V
K5V
K5III
F0V
F5V
A0V

G < 12.5
WEAVE sky coverage
inner DISK
outer DISK
HALO
BULGE
inner DISK
WEAVE outer DISK
Galactic Center
Nominal survey parameters

<table>
<thead>
<tr>
<th>Survey</th>
<th>Mode</th>
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<th>Area (deg²)</th>
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</thead>
<tbody>
<tr>
<td>GA halo LR</td>
<td>MOS/R=5000</td>
<td>10⁶</td>
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<tr>
<td>GA halo HR</td>
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<td>5x10⁴</td>
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<td>115</td>
</tr>
<tr>
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<td>2000</td>
<td>715</td>
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<tr>
<td>Clusters L1</td>
<td>MOS/R=5000</td>
<td>3x10⁴</td>
<td>150</td>
<td>25</td>
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<tr>
<td>Clusters L1</td>
<td>mIFU/R=5000</td>
<td>10³</td>
<td>150</td>
<td>50</td>
</tr>
<tr>
<td>Clusters L2</td>
<td>MOS/R=5000</td>
<td>10⁴</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>Clusters L3</td>
<td>LIFU/R=5000</td>
<td>150</td>
<td>0.08</td>
<td>75</td>
</tr>
<tr>
<td>LOFAR</td>
<td>MOS/R=5000</td>
<td>4x10⁶</td>
<td>10000</td>
<td>575</td>
</tr>
<tr>
<td>Apertif-mIFU</td>
<td>mIFU/R=5000</td>
<td>10⁴</td>
<td>1000</td>
<td>290</td>
</tr>
<tr>
<td>Apertif-LIFU</td>
<td>LIFU/R=20000</td>
<td>60</td>
<td>0.025</td>
<td>60</td>
</tr>
</tbody>
</table>

N.B. Reduction in total time from the fact that the LOFAR and Halo surveys overlap…
Instrument consortium: UK/NL/ES/FR/IT

PI: Gavin Dalton (RAL, UK),
   National CoPI: S. Trager (RUG, NL)
   National CoPI: J.F. Lopez Aguerri (IAC, ES)
   National CoPI: P. Bonifacio (GEPI, FR)
   National CoPI: A. Vallenari (INAF-Padova, IT)
Background and progress

• Project started in 2010
• Developed from ING community meetings
• Stages:
  – Stage one: requirements capture (closed)
  – Stage two: preliminary design stage (closed)
  – Stage three: final design stage (current stage)
  – Stage four: MAIT and verification (Q1/15)
  – Stage five: closure (Q3/17)

• aiming for 1\textsuperscript{st} light in 2017, surveys starting Q1/18
• Surveys 2018-2022+ at >80% of telescope time
New survey frontiers from new survey instruments

- Gaia: Astrometry at microarcsecond precision
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  - LOFAR:
    - The history of star formation
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  - Apertif:
    - HI at cosmological distances
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- Apertif:
  - HI at cosmological distances
# Top level specifications

<table>
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<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Field of view</td>
<td>2° diameter</td>
</tr>
<tr>
<td>Multiplex in MOS mode</td>
<td>1000 ±10%</td>
</tr>
<tr>
<td>Input aperture size</td>
<td>1.3” (goal 1.5””)</td>
</tr>
<tr>
<td>Operational wavelength range</td>
<td>370nm—950nm (goal 370nm—1100nm)</td>
</tr>
<tr>
<td>Spectral resolution, $\lambda/d\lambda$ (full wavelength coverage)</td>
<td>5000 at band centre</td>
</tr>
<tr>
<td>Spectral resolution, $\lambda/d\lambda$ (high resolution mode)</td>
<td>20000 at band centre</td>
</tr>
<tr>
<td>High resolution wavelength ranges</td>
<td>410—460nm &amp; 600—678nm</td>
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<tr>
<td>Multiplex in small IFU mode</td>
<td>20—30</td>
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<td>Small IFU (MIFU) field of view</td>
<td>7”x7” (goal 9”x9””)</td>
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<tr>
<td>MIFU spatial sampling</td>
<td>1.3” (MOS fibre core size)</td>
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<tr>
<td>Large IFU (LIFU) field of view</td>
<td>60” (goal 80”)</td>
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<tr>
<td>LIFU spatial sampling</td>
<td>2.6”</td>
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<tr>
<td>Overhead/1 hour observation</td>
<td>&lt; 15 minutes (goal &lt; 5 minutes)</td>
</tr>
<tr>
<td>System throughput (excluding telescope, detector and atmosphere)</td>
<td>&gt;39% (blue), &gt;23% (red) (low resolution)</td>
</tr>
</tbody>
</table>
WEAVE throughput

Wavelength $(\text{nm})$

More photons/object than VLT FLAMES, with 10x multiplex
Surveys: Xgal

• Galaxy clusters *(Alfonso Lopez Aguerri)*:
  • Evolution of dwarf galaxies in 50 clusters (Xray+SDSS) MOS +mIFU
  • Infall regions, in 10 superstructures (clust, groups, filaments) MOS
  • Cluster evolution z=0.2-0.5 (cluster cores) LIFU

• Galaxy evolution (z<1) *(Bianca Poggianti)*:
  • Stellar populations at intermediate redshifts (z~0.2-0.8) MOS
  • Apertif-based surveys (on hold) mIFU + IFU

• Galaxy evolution (z>1) & Cosmology *(Chris Simpson)*:
  • LOFAR follow-up of ultra deep fields. MOS
  • Possibly also a shallower wide field, piggy back on halo LR survey) –under discussion vs eBOSS/DESI etc. MOS

• Cosmology with QSOs *(Matt Pieri)*:
Complementing Gaia for Galactic Archaeology

Low resolution WEAVE survey (\(\delta vr<2 \text{ km/s}\)) of 6-10.\(10^6\) stars 15<\(V<20\)
• Dynamical processes in the disc: resonances, radial migration, etc...
• Origin of the main galactic components: thick disc, thin disc, halo
• Galactic Halo: total mass, galactic potential, clumpiness (sub-structures, ...) and the dominant process for halo assembly

High resolution WEAVE survey (R\(\sim20,000\)) of 5.\(10^5\) stars 12<\(V<17\) in the volume where Gaia offers the best precision (distances to <10%, ages):
• Chemical tagging/labelling: origin of the galactic discs (vertical et radial properties, chemodynamical properties, and their variation with time through precise age determinations)
• Halo substructures identified in chemical, link to globular cluster formation, halo-thick disc and halo-bulge transitions.
• Open clusters
Gaia follow-up surveys:

<table>
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<tr>
<th></th>
<th>log(N)</th>
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<th>R</th>
<th>Depth</th>
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<td>Halo</td>
<td>6</td>
<td>1000</td>
<td>5000</td>
<td>V≤20</td>
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<tr>
<td>Disks</td>
<td>6.7</td>
<td>300</td>
<td>5000</td>
<td>V≤20</td>
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<tr>
<td>Chemical labeling</td>
<td>4.7 (disk)</td>
<td>2000</td>
<td>20000</td>
<td>V≤17</td>
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<tr>
<td></td>
<td>5.7 (halo)</td>
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<tr>
<td>Open clusters</td>
<td>4.7</td>
<td>150</td>
<td>20000</td>
<td>V≤17</td>
</tr>
</tbody>
</table>
Background and progress

• Project started in 2010
• Stages:
  • Stage one: requirements capture (closed)
  • Stage two: preliminary design stage (closed)
  • Stage three: final design stage (current stage)
  • Stage four: MAIT and verification (Q1/15)
  • Stage five: closure (Q3/17)
• aiming for 1st light in 2017, surveys starting Q1/18
• Surveys 2018-2022+ at >80% of telescope time
• Timely with Gaia launch 12/2013, DR2 mid-2016 (first PPM and parallaxes) and DR3 2017. Target selection will use DR2+
Project Schedule
## Total Project Costs

<table>
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<tr>
<th>System ID</th>
<th>Effort (mw)</th>
<th>Manpower (k€)</th>
<th>Indirect (k€)</th>
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<tr>
<td><strong>Totals</strong></td>
<td><strong>4731.68</strong></td>
<td><strong>8501.74</strong></td>
<td><strong>1022.70</strong></td>
<td><strong>8311.03</strong></td>
<td><strong>409.10</strong></td>
<td><strong>683.20</strong></td>
<td><strong>18927.78</strong></td>
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