WEAVE @WHT

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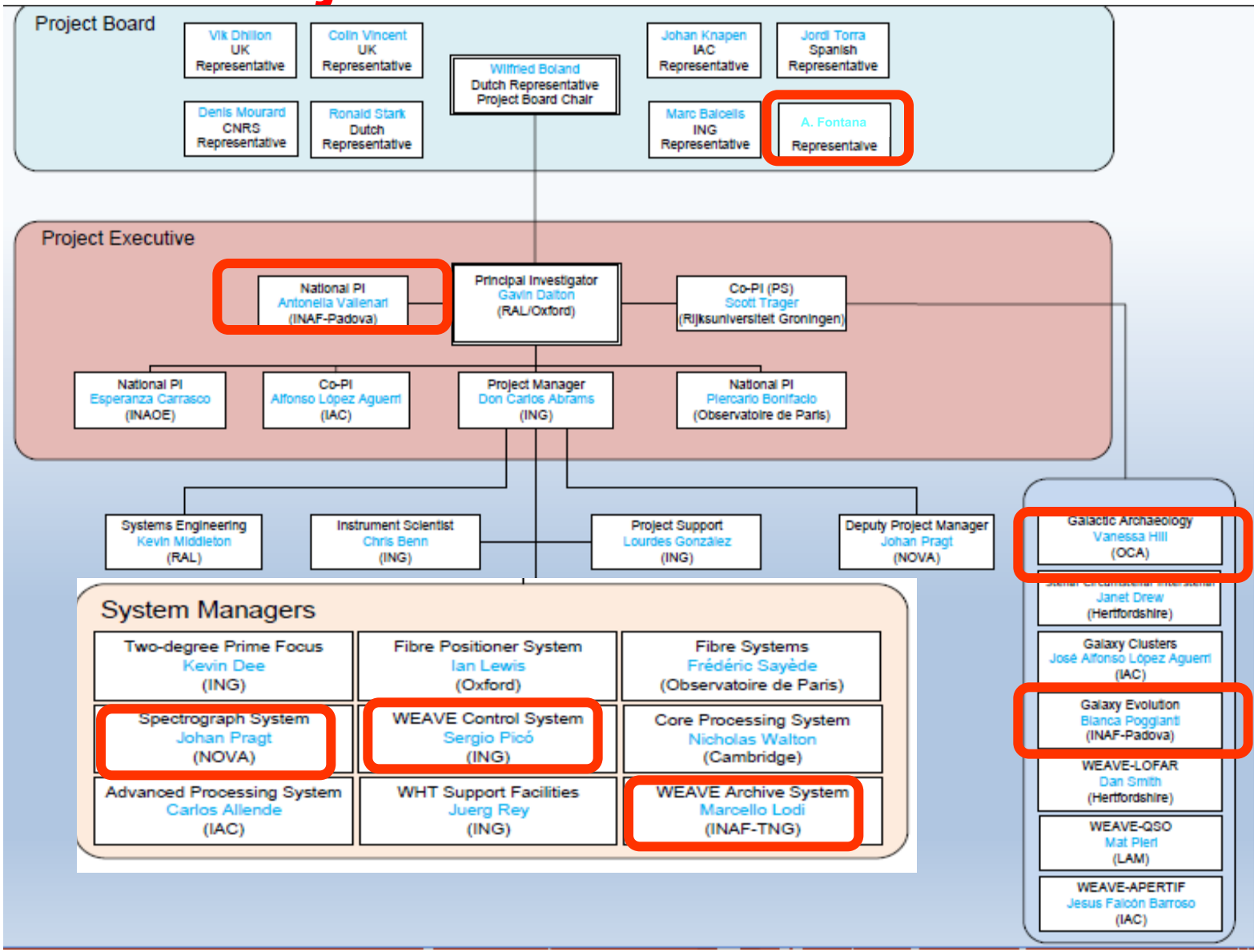
Overview

- WEAVE Science
- WEAVE Instrument
- WEAVE operations

WEAVE Consortium

- INAF joins the consortium in 2013
- 43 researchers in TNG, Padova, Bologna, Firenze, Catania, Torino, Brera, Napoli, Roma, Palermo

Project structure

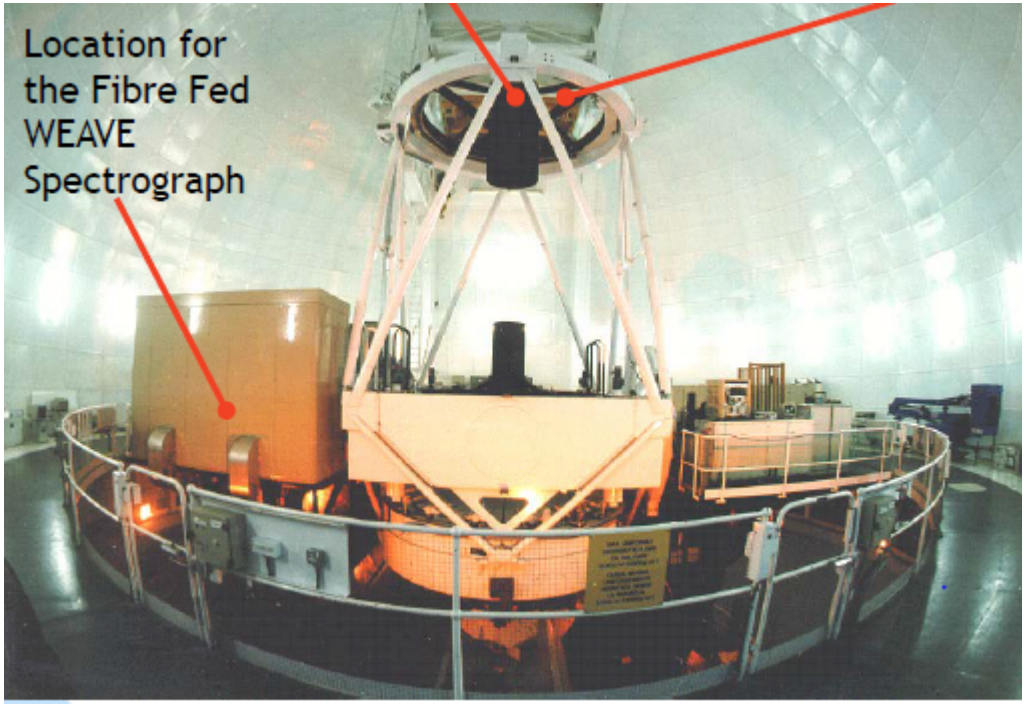


WEAVE Characteristics

Telescope, diameter	WHT, 4.2m
Field of view	2° ø
Number of fibers	960 (plate A)/940 (plate B)
Fiber size	1.3″
Number of small IFUs, size	20 x 11″x12″ (1.3″ spaxels)
LIFU size	1.3′x1.5′ (2.6″ spaxels)
Low-resolution mode resolution	5750 (3000–7500)
Low-resolution mode wavelength coverage (Å)	3660–9590
High-resolution mode resolution	21000 (13000–25000)
High-resolution mode wavelength coverage (Å)	4040–4650, 4730–5450 5950–6850

The WHT

Current Top End with Secondary Mirror Assembly.

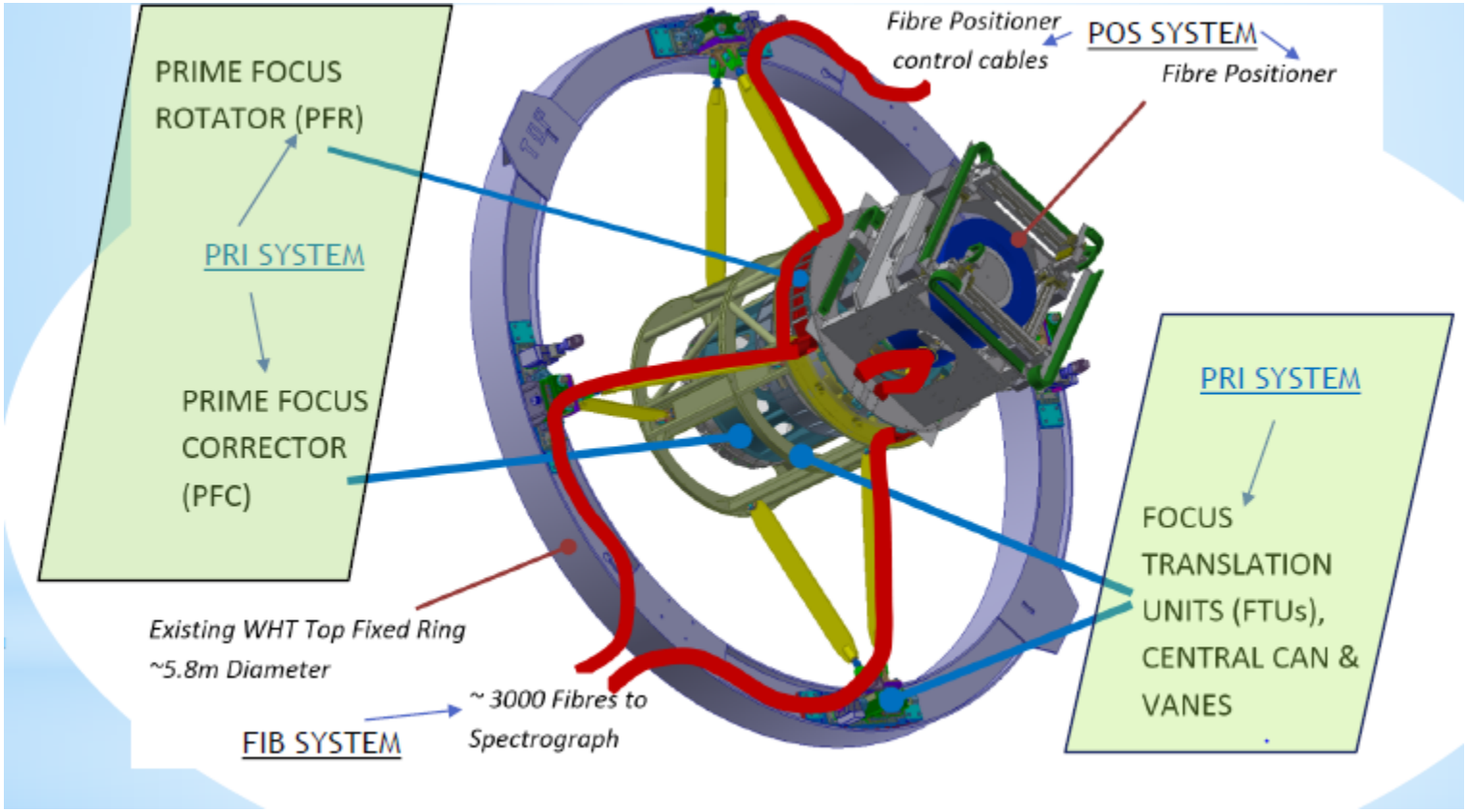


Courtesy: K.Dee

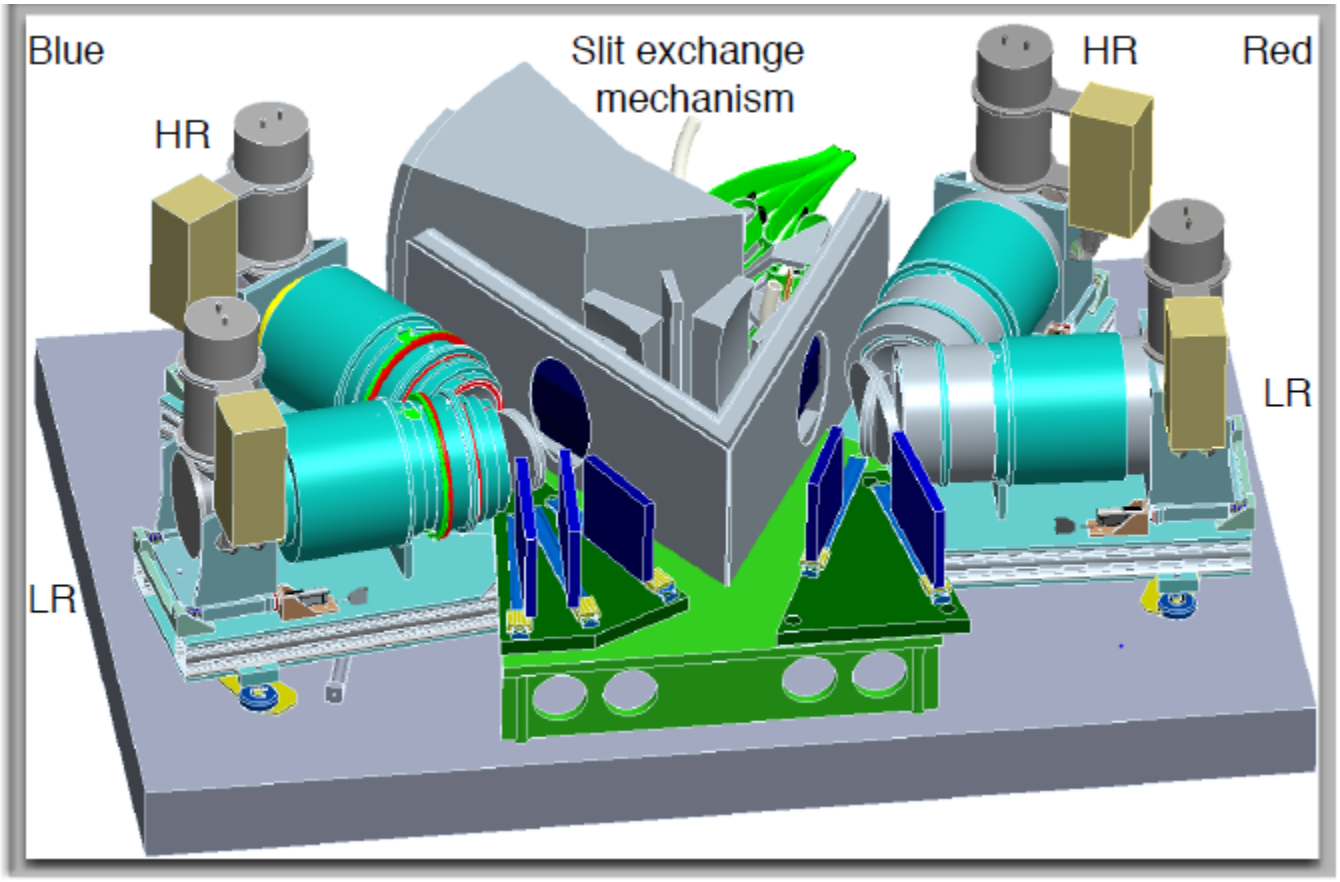
The WEAVE PRIME FOCUS ASSEMBLY will replace the current assembly

The Photo shows the Secondary Mirror Assembly mounted. In order to allow for the installation of the WEAVE Prime Focus Assembly it is necessary to remove the Secondary Mirror Assembly and Top End Flip Ring.

Prime Focus Assembly



The spectrograph

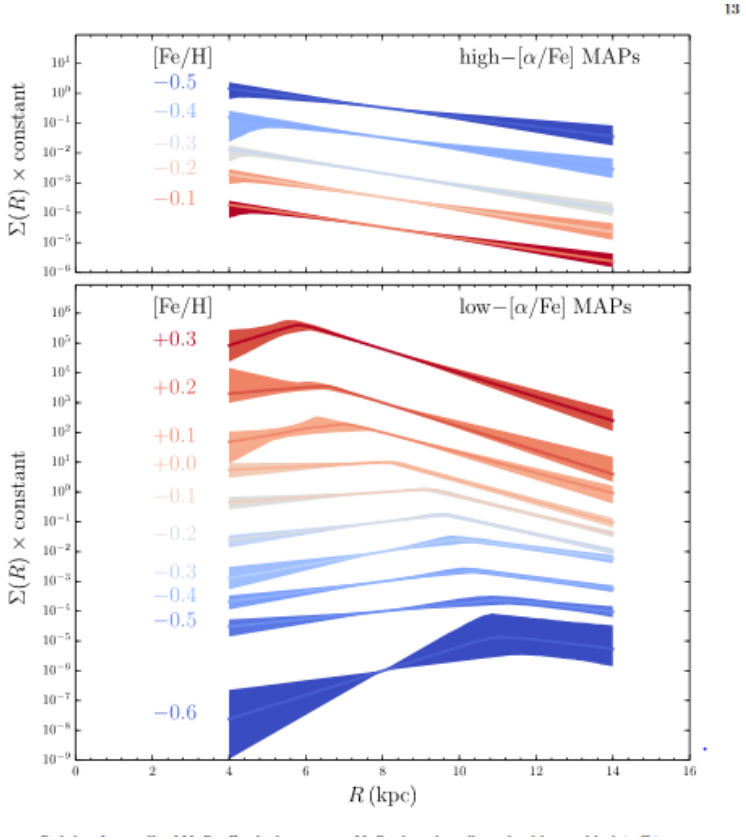


MOS and IFU cannot observe in parallel

The Galaxy view

- Unveiling the complex history of the MW assembly and internal evolution is still one of the main interest of astrophysics
- However the specific questions we ask have evolved substantially
- Diagnostics: Kinematics + chemistry of stars+ distance+ ages
- Metallicity from photometry
- Large amount of data requires ad-hoc modeling
- The selection function importance
- The presence of radial migration

in the disks has lead to a different way of describing stellar populations using chemical abundances as tag: → MAP



Bovy et al 2016

Primary Science Surveys

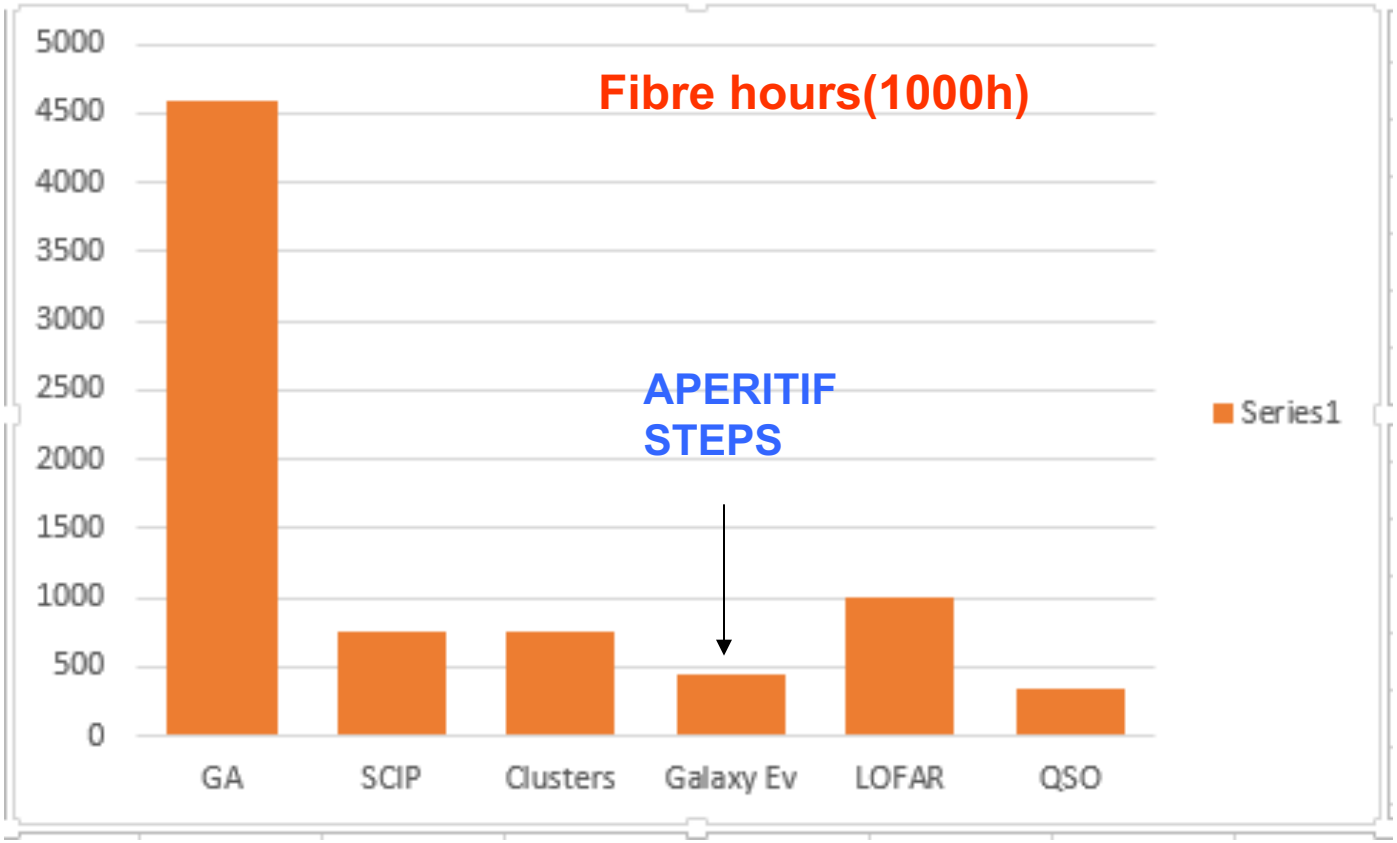
- WEAVE GA Goals:
  - To complement Gaia
  - To complement 4MOST , MOONS (in the North)
  - Bridge the gaps in APOGEE footprints
- GA Surveys:
  - LR Halo /LR disk
  - HR halo/HR disk/OC
- Stellar, Circumstellar, and Interstellar Physics (SCIP): 1200 sq deg on the disk (b<3-4 deg) to probe massive stars, ISM, YSO+ Great Cygn Rift star formation
- Characteristics:
  - Continuous sky coverage to sample global phenomena
  - High statistics

Extragalactic surveys

- WEAVE-Clusters
  - Evolution of dwarf galaxies in clusters : 10^4 Xray galaxies R=5000 +mIFU
  - infall regime: 10^4 galaxies in superstructures Z=0.1—0.2, LR, R<21 (WINGS)
  - Evolution of cluster galaxies at z<0.5 . LIFU+MOS
- WEAVE-APERTIF (21 cm camera @WSRT): gas content or activity
  - star formation quenching, dark matter, disk kinematics of a sample of galaxies, with LIFU and mIFU
- StePs
  - Archeological studies to probe massive galaxies evolutions at z=0.3—0.8 on 25 sq deg with MOS
- WEAVE-LOFAR: end of re-ionization era
  - LOFAR follow-up for 10^6 galaxies over 10^4 sq deg , V<21, z>6, LIFU+mIFU
- WEAVE QSO: 10,000 sq , g< 22, BAO constrain and IGM physics (LR+HR at g<20)

Preliminary fibre hours

Based on 5-year survey; 236 night/y, 7 h/night, 950 fibre/h



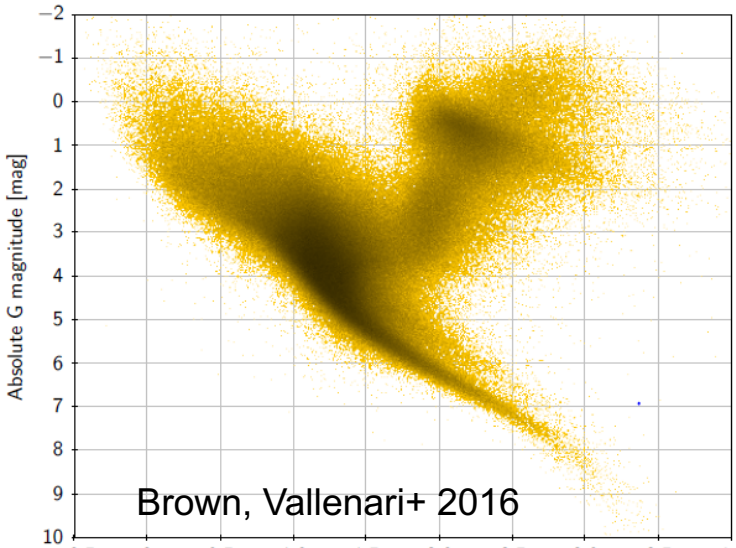
MW Surveys:key questions

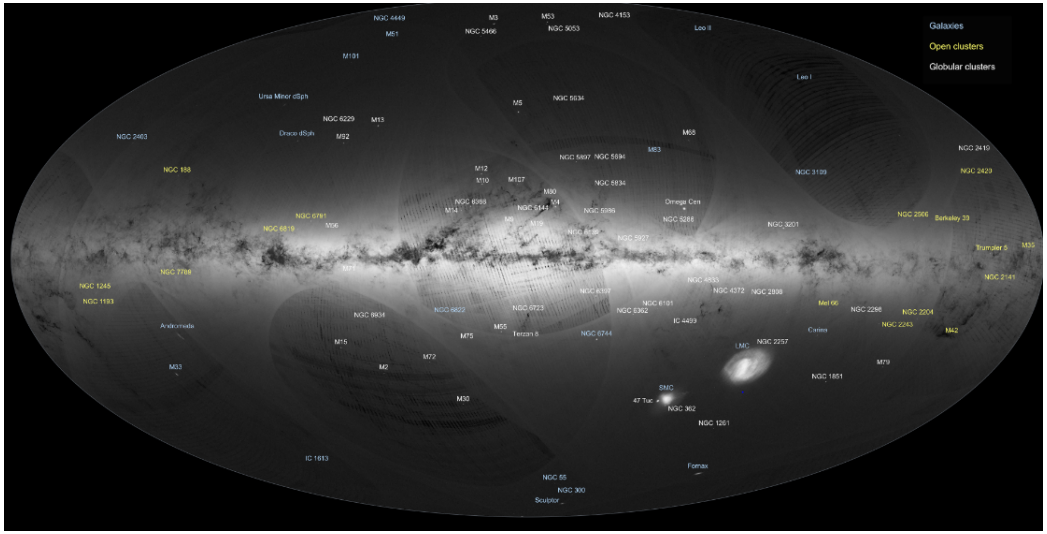
Structure formation on sub-galactic scale

- Halo: in situ vs accreted
  - What is the total mass of the Milky Way? What is the shape of the Galactic gravitational potential? (Battaglia + 2015, Koposov+ 2009)
  - Where are the most metal-poor stars in the Milky Way, what are their properties, and what do they tell us about the physics of the early Universe? (Caffau+2011)
  - dSph and UDFs : the role of disrupted dwarfs (Fabrizzio+2015, Tolstoy+2009)
- Dark matter
  - How much substructure does the Galactic dark matter distribution have within 20–50 kpc? How do they interact with cold streams? (Yoon + 2011)
- Disks respective roles of hierarchical formation and secular evolution in shaping the Galaxy?
  - what are the roles of spirals (+ number of arms, pitch angle, pattern speed?) and the bar (length, pattern speed?) (Helmi+2006, Schoenrich & Binney 2009, Minchev+2015)
  - What is the chemical evolution traced by the open clusters? (Magrini+ 2010, Jacobson+2016, Bragaglia+ 2006, Sestito + 2008, Cantat+2012, Donati+2012)

The Gaia Revolution

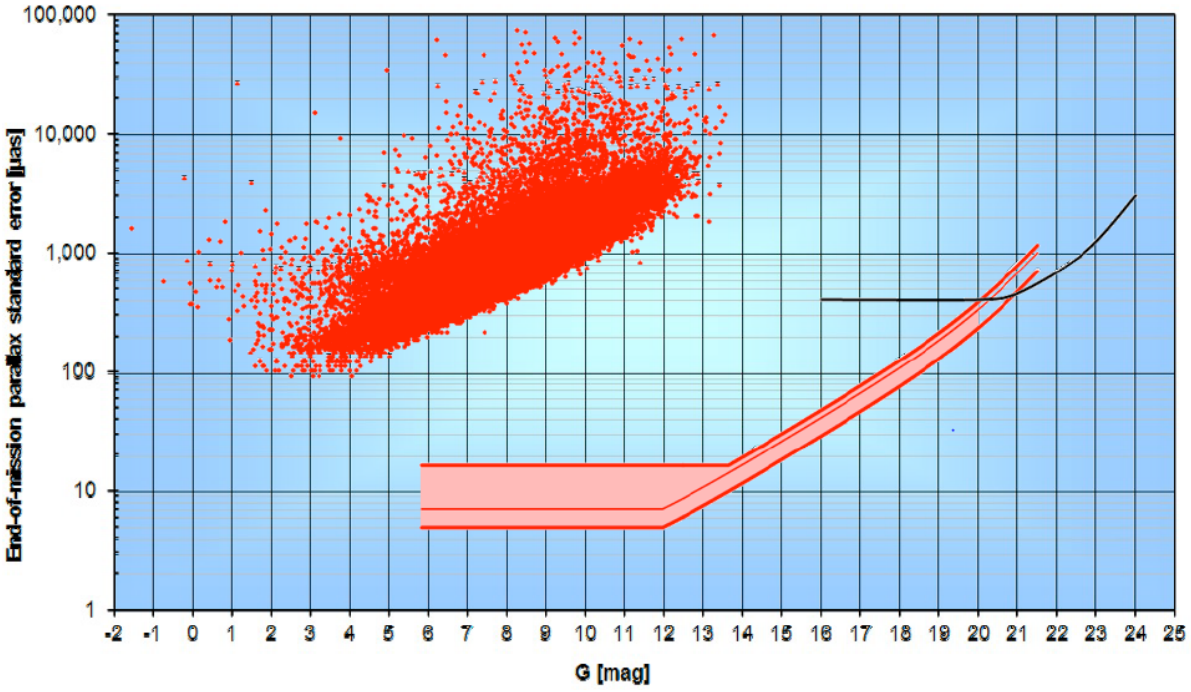
- Gaia DR1: positions, G; astrometry for TGAS stars (Brown, Vallenari+ 2016)
- Gaia DR1 dominated ESA Archive access
- From Sept 2016, 114 papers using Gaia data ; 1600 reads; a paper every 1.5 days
- DR2: all sky astrometry, G, BP, RP, variables, SSO→ April 2018
- Parallax accuracies of about 50 μas can be reached down to G ~ 15 mag, larger errors for fainter sources
- Proper motions of about 100 μas/ yr (comparable to the Hipparcos subset of TGAS) down to G ~ 15 mag
- DR2 for WEAVE GA target selection



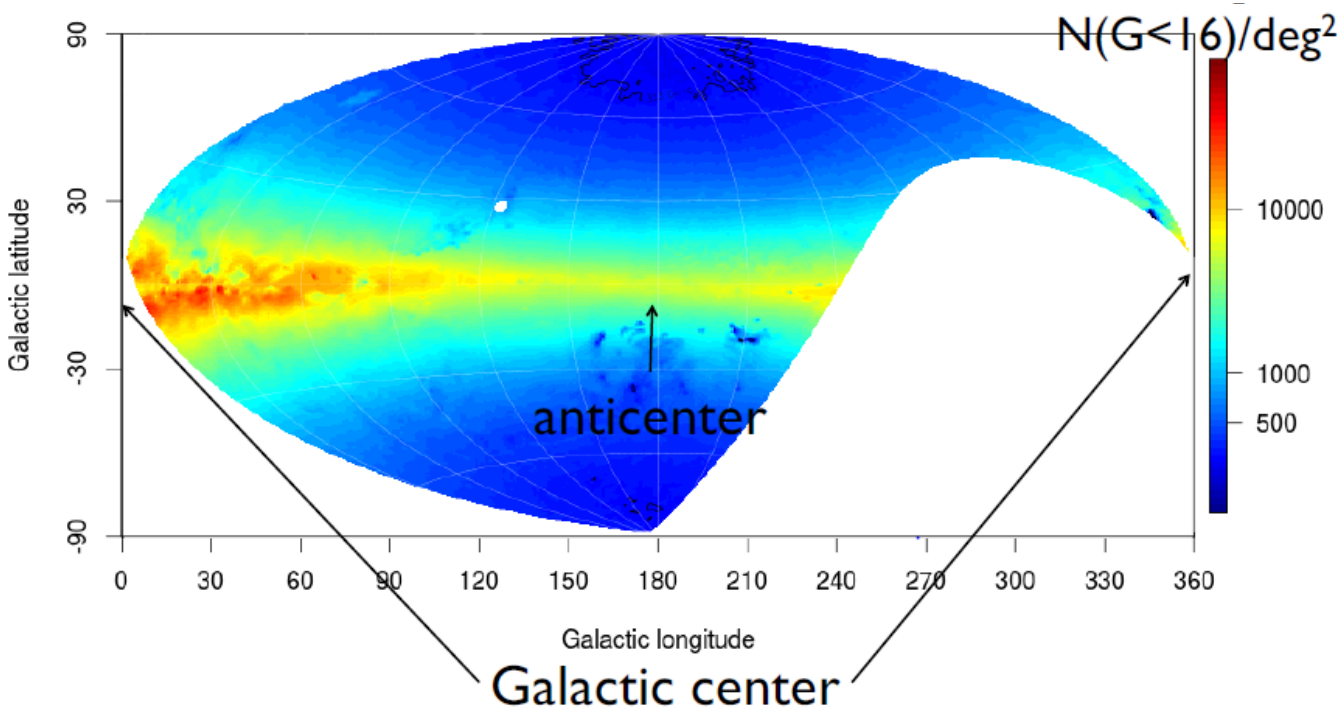


Galactic Archeology

- A wealth of information from ground and space based and surveys
  - **Pan-STARRS** (Kaiser+2010, δ>-30, no u filter), **Sky mapper**(Keller 2012)
  - **Gaia, LSST** (Ivezic+ 2014, 2022, r=24.5, 30,000sq deg), **PLATO**
- Spectroscopic surveys: GES, RAVE, APOGEE, 4MOST, MOONS...

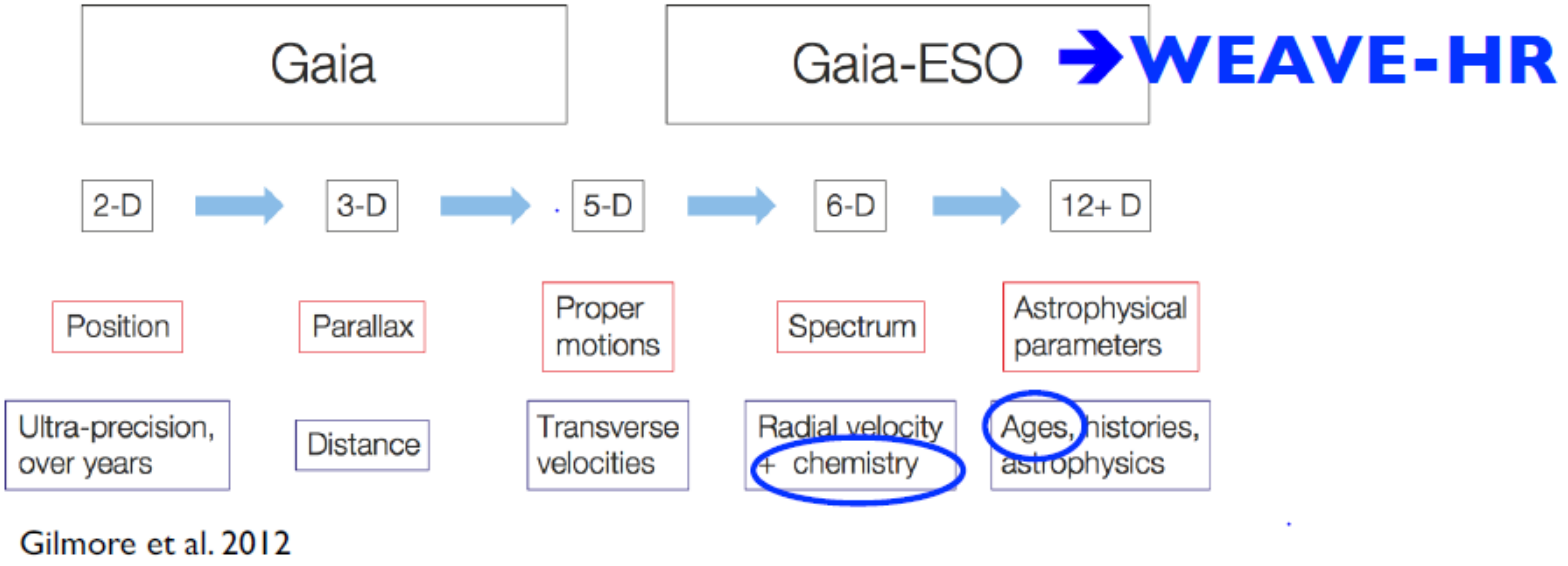


WEAVE Northern multiplex



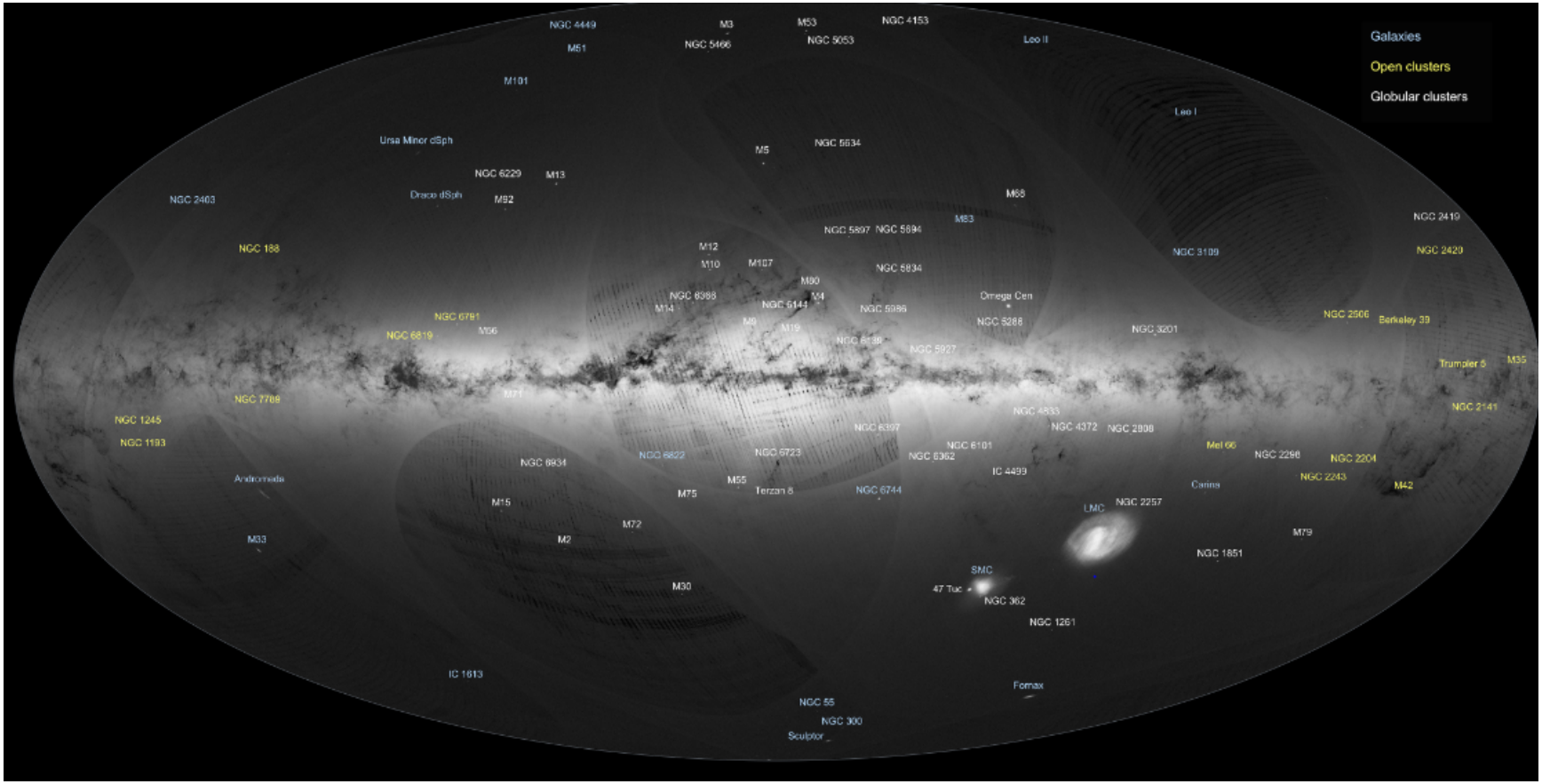
WEAVE is the only HR Xwide field Xmultiplex optical facility in the north !

WEAVE HR/LR Surveys



Gilmore et al. 2012

- GOALS
- Combine (spectroscopic) stellar parameters with Gaia distances, pm, radial velocities to constrain ages, to constrain the mass assembly of the MW disc(s) with time.
- Chemical labelling / tagging with all main nucleosynthetic channels, to deconstruct galactic stellar populations.


Galaxies
Open clusters
Globular clusters
NGC 4449
M3
M53
NGC 4153
M51
NGC 5466
NGC 5053
Leo II
M101
Leo I
Ursa Minor dSph
M5
NGC 5634
NGC 6229
M13
NGC 2403
Draco dSph
M92
M88
M83
NGC 2419
NGC 5897
NGC 5694
NGC 188
M12
NGC 3109
NGC 2420
M10
M107
NGC 6934
M80
NGC 6388
M4
Omega Cen
M14
NGC 5144
NGC 5986
NGC 6791
M9
NGC 5288
NGC 2506
Berkeley 39
NGC 6819
M19
NGC 3201
M56
NGC 6838
NGC 5927
Trumpler 5
M35
NGC 7789
M71
NGC 2141
NGC 1245
NGC 4833
NGC 6397
NGC 4372
NGC 2808
NGC 1193
NGC 6101
Mel 66
NGC 6934
NGC 6822
NGC 6723
NGC 6362
NGC 2298
NGC 2204
Andromeda
IC 4499
NGC 2243
M55
Terzan 8
Canis
M42
M75
NGC 6744
M15
LMC
NGC 2257
M72
M79
M33
M2
NGC 1851
SMC
M30
47 Tuc
NGC 362
NGC 1261
IC 1613
Fornax
NGC 55
NGC 300
Sculptor

WEAVE-Clusters survey strategy

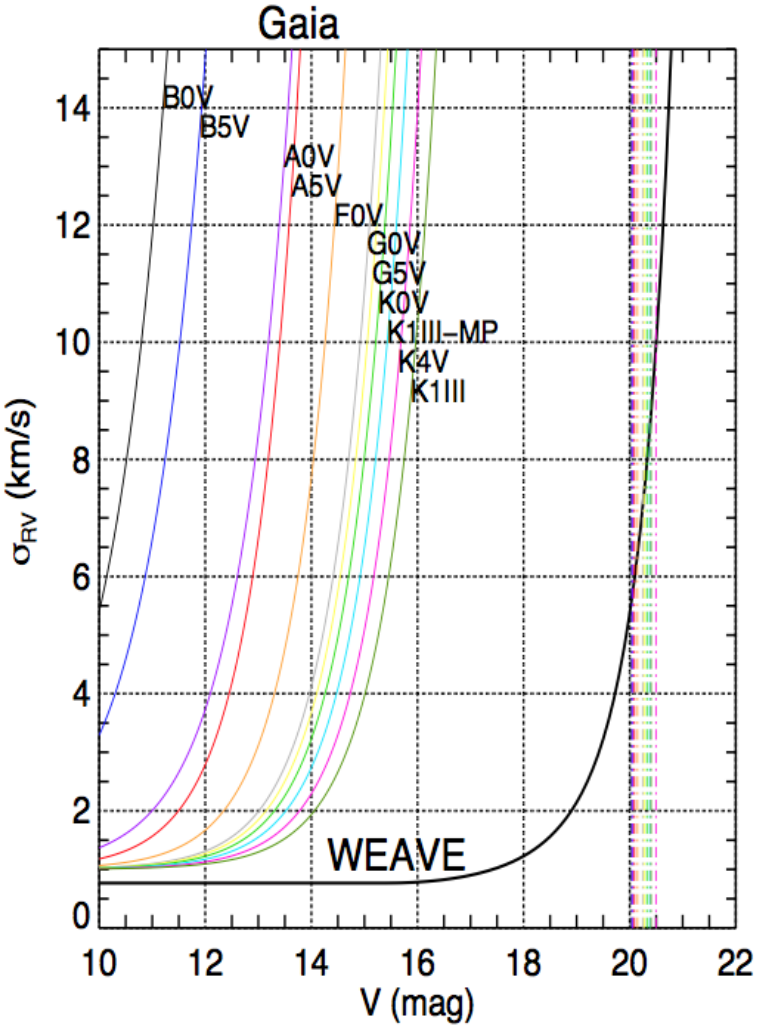
- **Layer 1**: Tracing the evolution of dwarf galaxies in clusters
  - $>10^4$ cluster dwarfs at R=5000 down to $M_r<-16$ with **MOS** mode + 10^3 cluster dwarfs with **mIFUs** to derive *spatially-resolved properties* in ~75 nearby clusters
- **Layer 2**: The infall regime
  - 10^4 galaxies in 10 large superstructures at z~0.1–0.2 at R=5000 to R<21 in **MOS** mode
- **Layer 3**: The evolution of cluster galaxies and cluster masses at $z<0.5$
  - 125 cluster cores at $z>0.3$ with **LIFU** mode, 35 clusters at $z<0.3$ in **MOS** mode to determine stellar populations and cluster masses to compare with Sunyaev–Zeldovich decrements

WEAVE performances

- Surveys to acquire accurate Vr (2 km/s) (and stellar parameters, incl. Metallicity at 0.2 dex)

  15<G<20 (bonus chemical abundances)

  - Defined the LR mode of WEAVE:
  - R = 5,000 in a wide range [366 – 606] nm + [579 – 959] nm
- Surveys to determine accurate stellar parameters and detailed chemistry(at 0.1 dex) for G>11-17
  - Defined the HR mode of WEAVE:
  - R = 20,000 in two windows [404 – 465] nm or [473 – 545] nm + [595 – 685] nm



R=5000

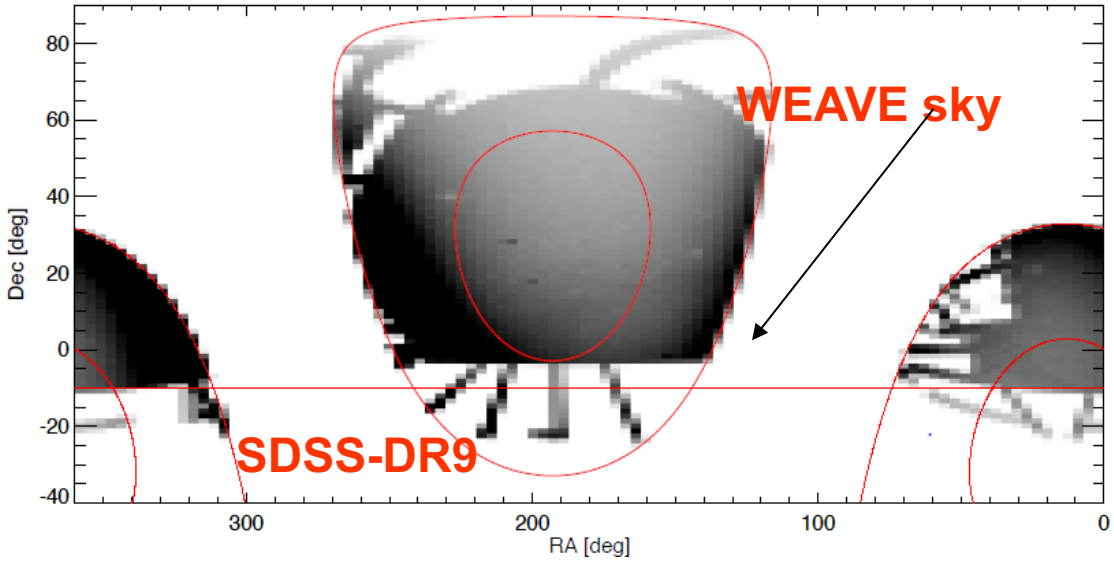
LR Halo wide survey: 10,000 deg ^{2}

- Constraining mass and scale radius of dark halo
- High galactic latitude survey (|b|>30°)
- Total number ~1–2×10^6 stars (nstream > 30 to break degeneracy, Helmi 2011)
- Tracers : MS (30Kpc)+RG (100 kpc)
- Selection on SDSS

- Pointed survey
- Northern dSphs

+ large streams + UFDs

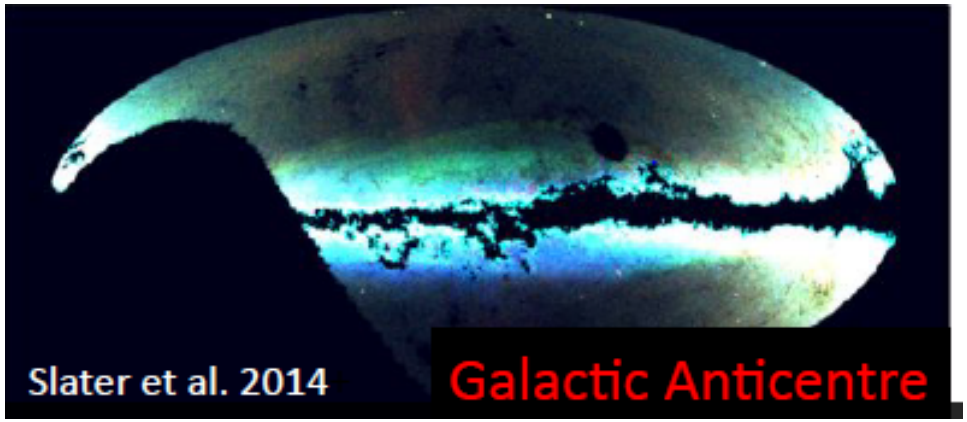
- 300 deg2
- V =21 (4 exposures)



LR disk survey

- A galactic plane experiment to constrain the disc potential, including departures from axisymetry (spiral arms, bar, …), moving groups. |b|< 6
  - Needs: Vr to 2Km/s to discriminate streams with 5-10 km/s
  - Tracers: red clumps
- WEAVE Privileged access to outer disk
  - How resilient to perturbations are disks? (Bovy et al 2011)
  - Anticenter:Stellar density & (average) extinction lower
  - Dynamical effects are the most visible (Kordopatis+2016)
  - Interactions with satellites: flaring of the stellar pops.
  - Accretions: ratio of accreted vs MW stars is the largest
  - Bar and spiral resonances (bar resonance at ~10 kpc, Bovy+2015)
  - Radial migration: kinematics do not allow to distinguish a in situ born star from one having migrated+ chemistry(DeBattista 2014)

Pan-STARR1



WEAVE HR Surveys

- **Goal: Chemical tagging : 5000deg ^{2}**
- High latitude Halo: searching for streams + first stars
- Assuming 500 streams cross the solar neighbourhood
- 100 members each needed to characterize them

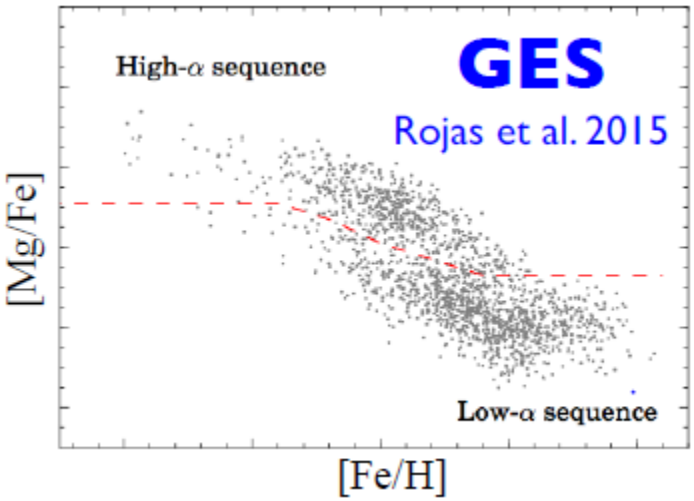
  → 5 x10 ^{4} halo star– target 5 x10 ^{5} stars
- Given the density of halo stars at magnitudes 12<V<16 (~10 / deg^2)

  → demands a high-latitude survey of 5000 deg2 (at |b|>30-40)
- Intermediate latitude survey mapping the thick disk
- MSTO stars selected from Gaia
- **1,800 deg^2 with 15<|b|<30°**

  to insure Rgc,Z coverage

→ minimum number of targets of 6x 10 ^{6} HR disk

- HR Globulars

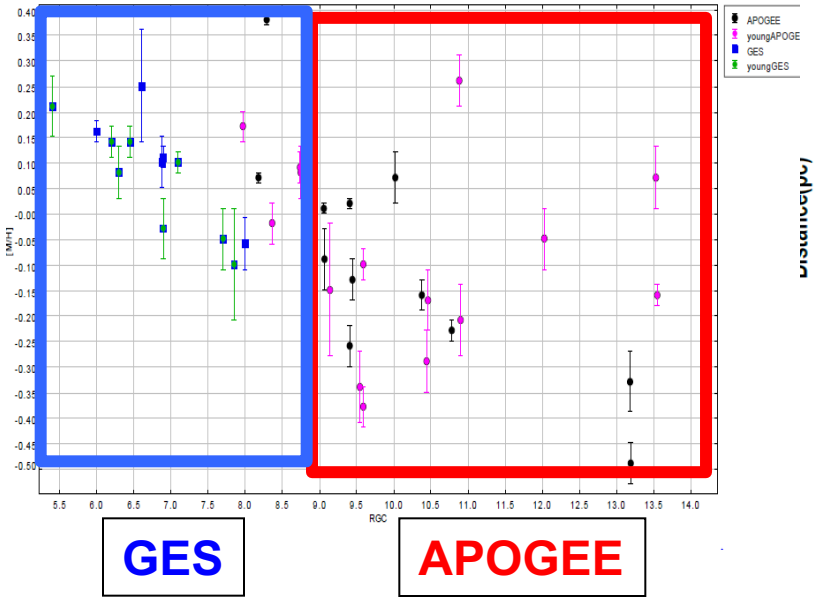


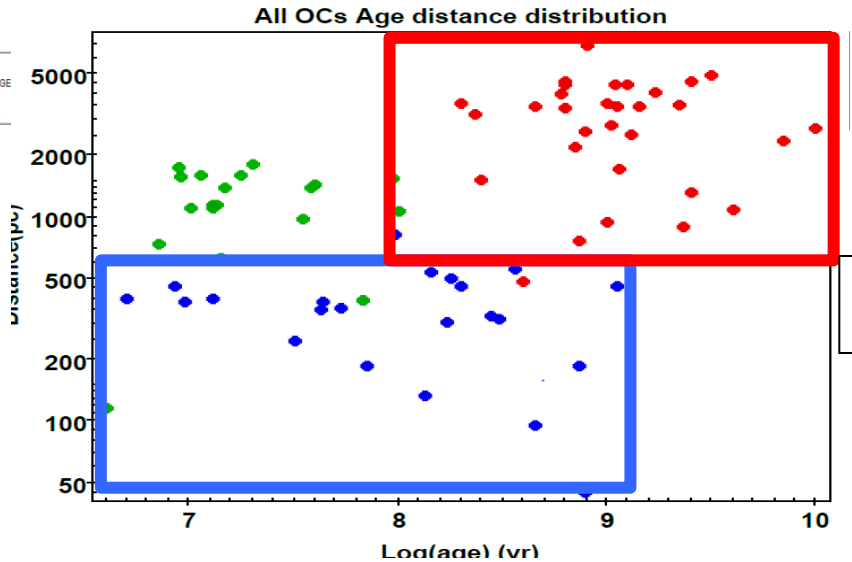
OC Survey

- Are all stars formed in clusters? How do clusters dissolve into the disc field?

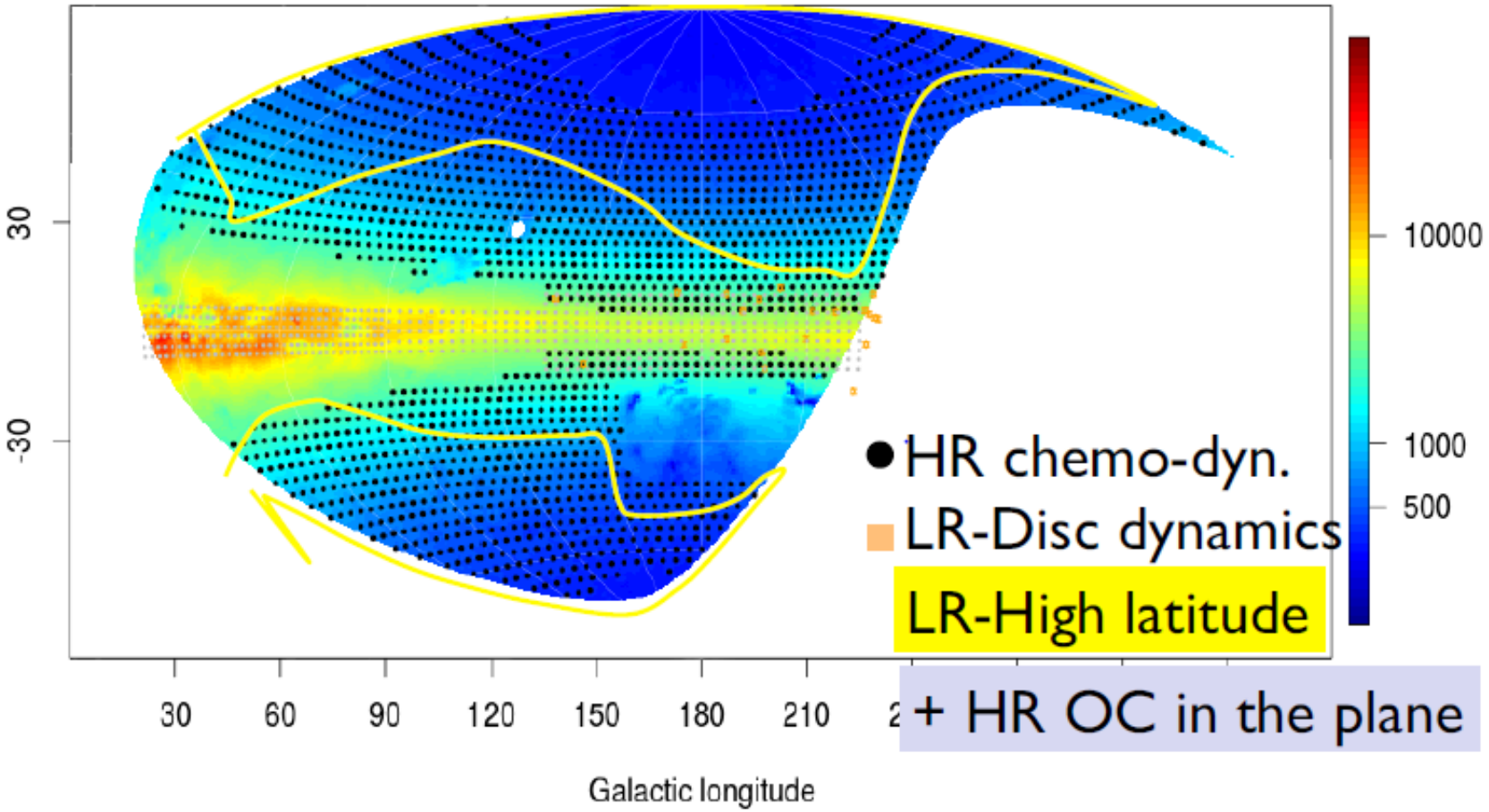
(Baumgardt& Kroupa 2007, Bressert+2010)

- What is the spatial distribution of the chemical elements in the Galactic disc? What is the effect of environment on star formation and the early stages of stellar evolution? (Mapelli+2014, Spina+2014)
- What is the impact of internal mixing, stellar rotation, and magnetic fields on stellar evolution?





WEAVE GA at glance



WEAVE - GA ~3-4 million stars to unravel the MW history !

LR disk: |b|<6
1.5x10^6 stars – on 210+405 LoS

HR disk: 1,800 deg2 with 15<|b|<30° to insure coverage of discs

GA Surveys

Survey	Essential
LR Halo 15<V<20-21 **LR Halo**	• 10,000 deg2 |b|>30-40°; • selected targets Giants (1st priority: all available) and MSTO (sampling among these candidates); • densities 600-700 per WEAVE fov
LR Disc Dynamics 16-17<V<20 **LR Disc**	• 210+405 line-of-sight towards the inner+outer galaxy • 5/1 pointings in each los respectively
HR Chemo-dynamics 12<V<16-18 **HR Chemo**	• 6,800 deg2; • selected targets Giants and MSTO; • densities 800-2000 targets.

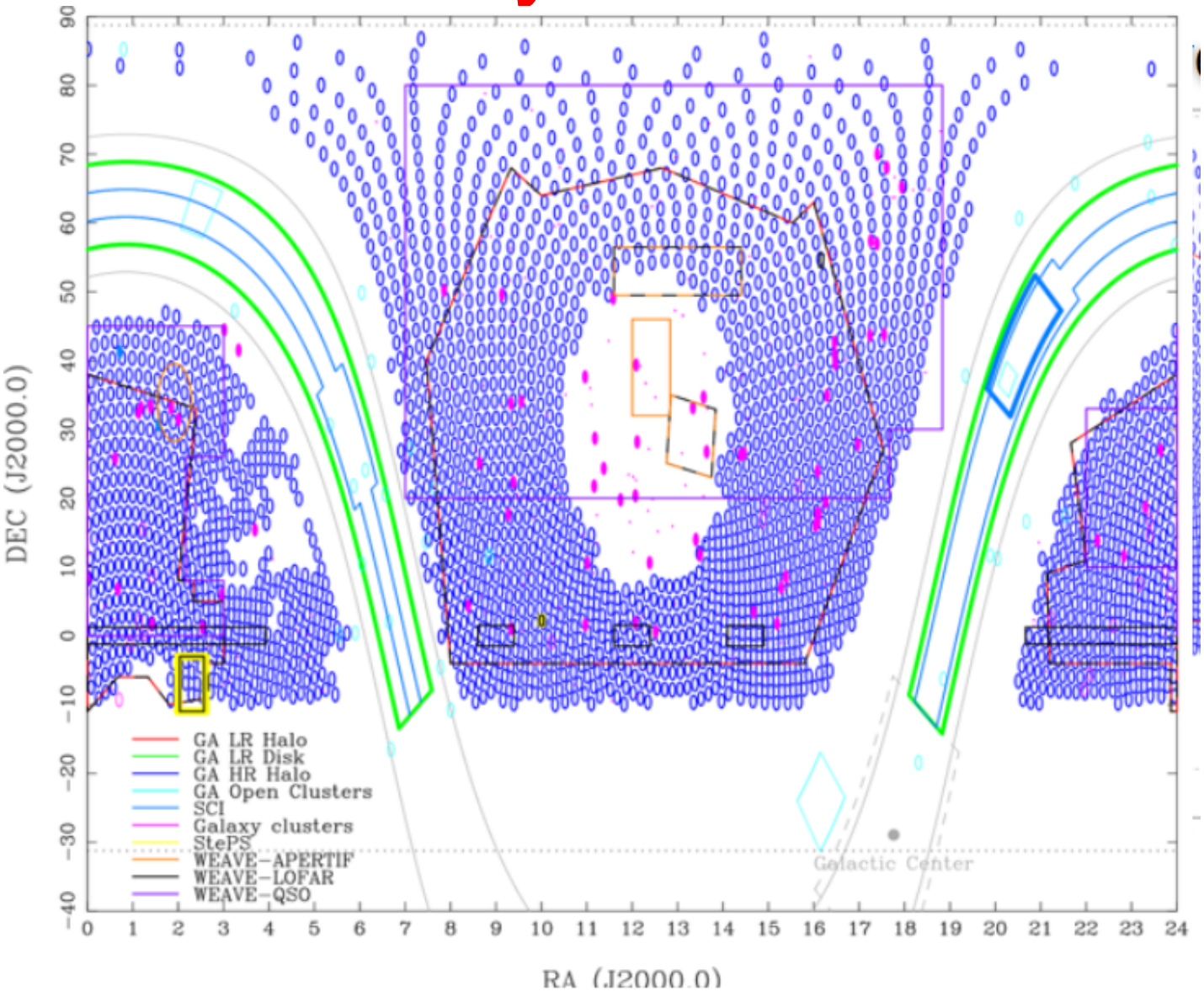
HR Ocs

4.10^5 halo giants out to ~100kpc and 5x 10^5 halo MSTO out to ~30kpc
Pointed survey : follow-up of known streams: 300 sq deg

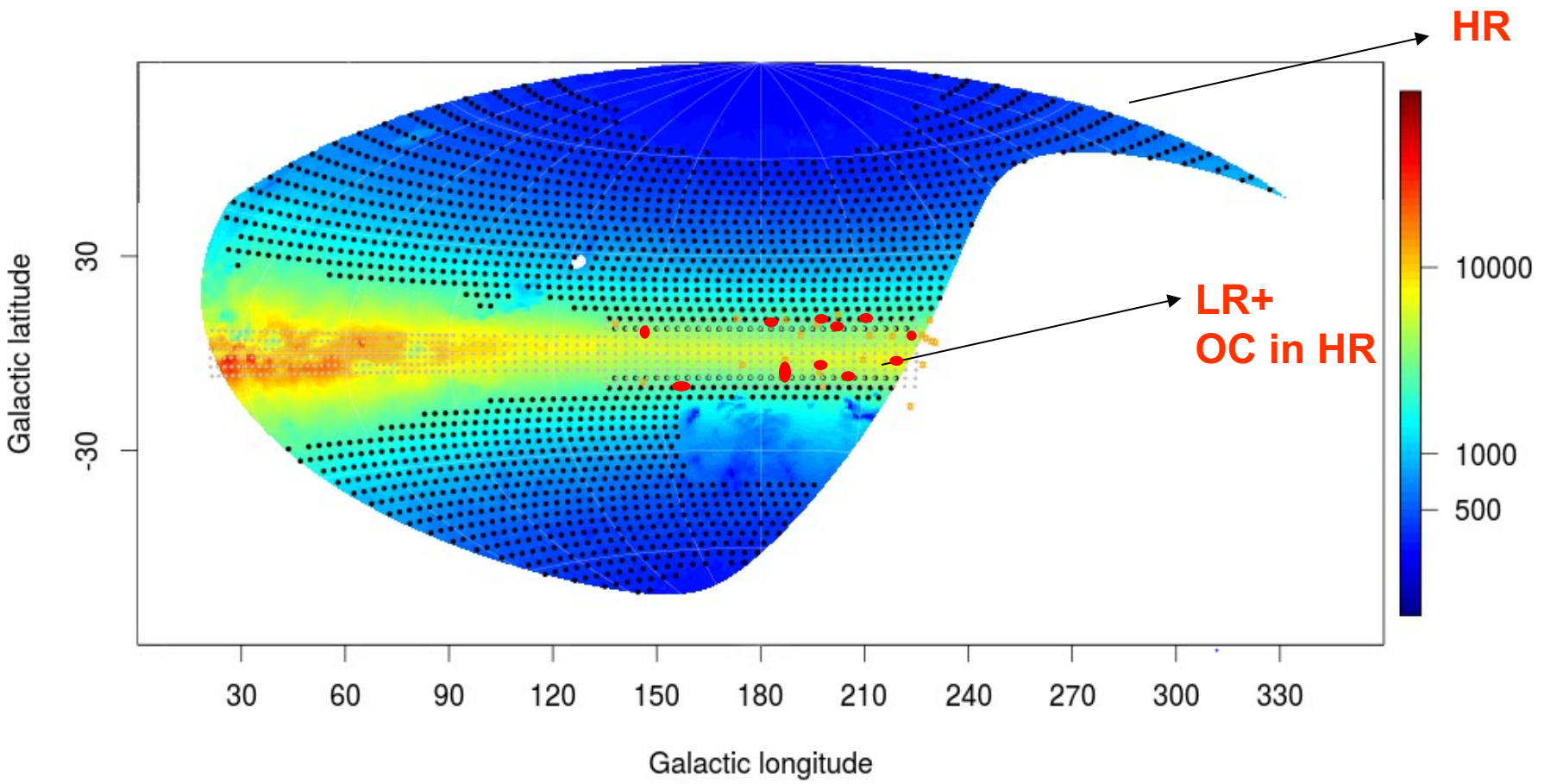
$1.5x10^6$ stars – one order of mag more than APOGEE

6,800 deg2, with 30<|b|~60° (halo, to reach 10^5 giants) +
1,800 deg2 with 15<|b|<30° to insure coverage of discs

Survey Overview



Survey Baseline

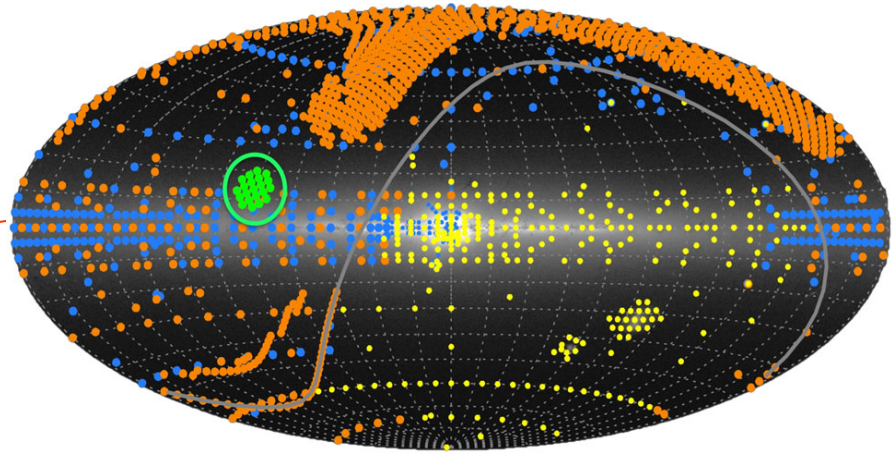


LR disk: |b|<6
1.5x10^6 stars – on 210+405 LoS

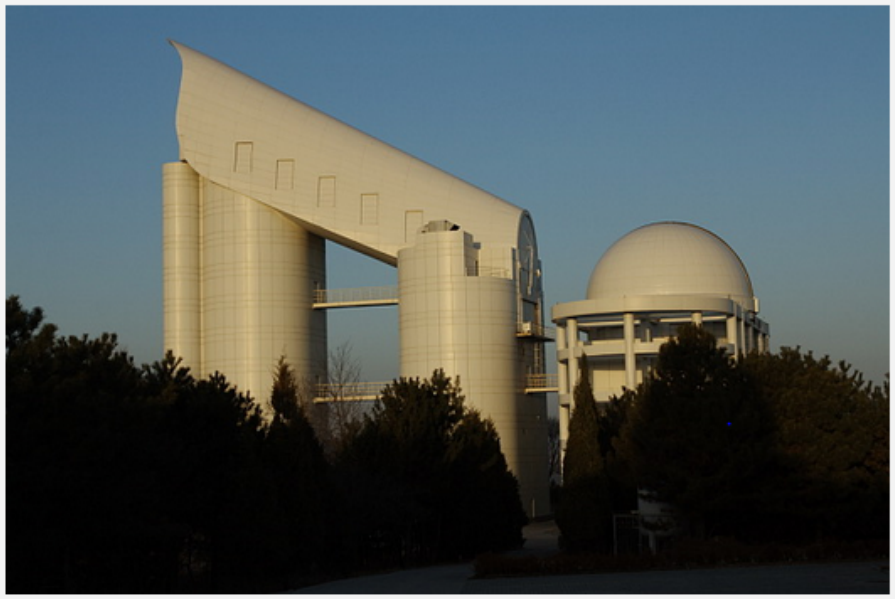
HR disk: 1,800 deg2 with 15<|b|<30° to insure coverage of discs

WEAVE in contest

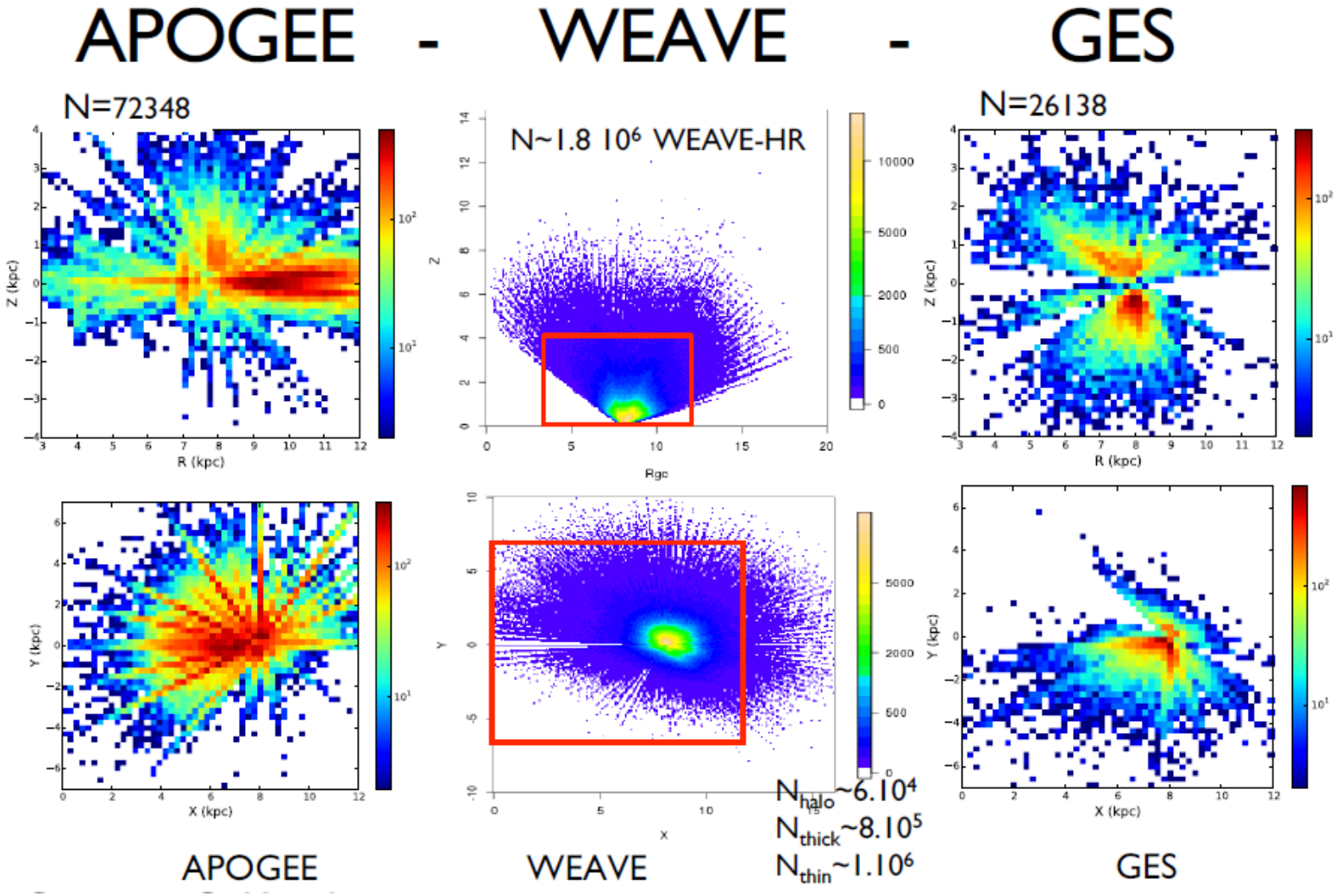
- APOGEE2: 300000 targets,
- R=22000 H=12.2



- Lamost:
- 4m telescope
- R=1800, r=19 mag
- Disk structure, 5 million spectra at the anti-center
- No chemical tagging

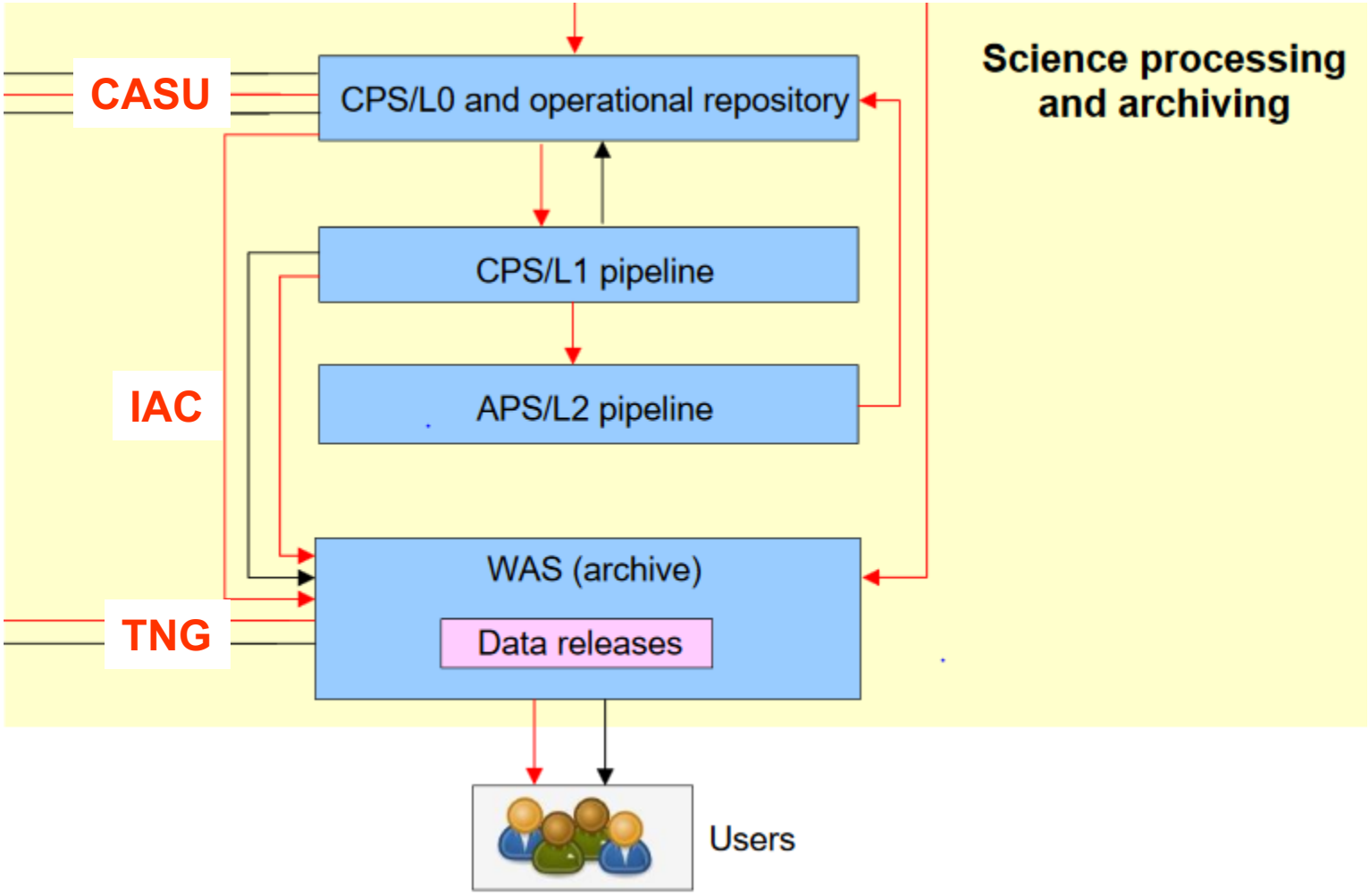


WEAVE HR in contest



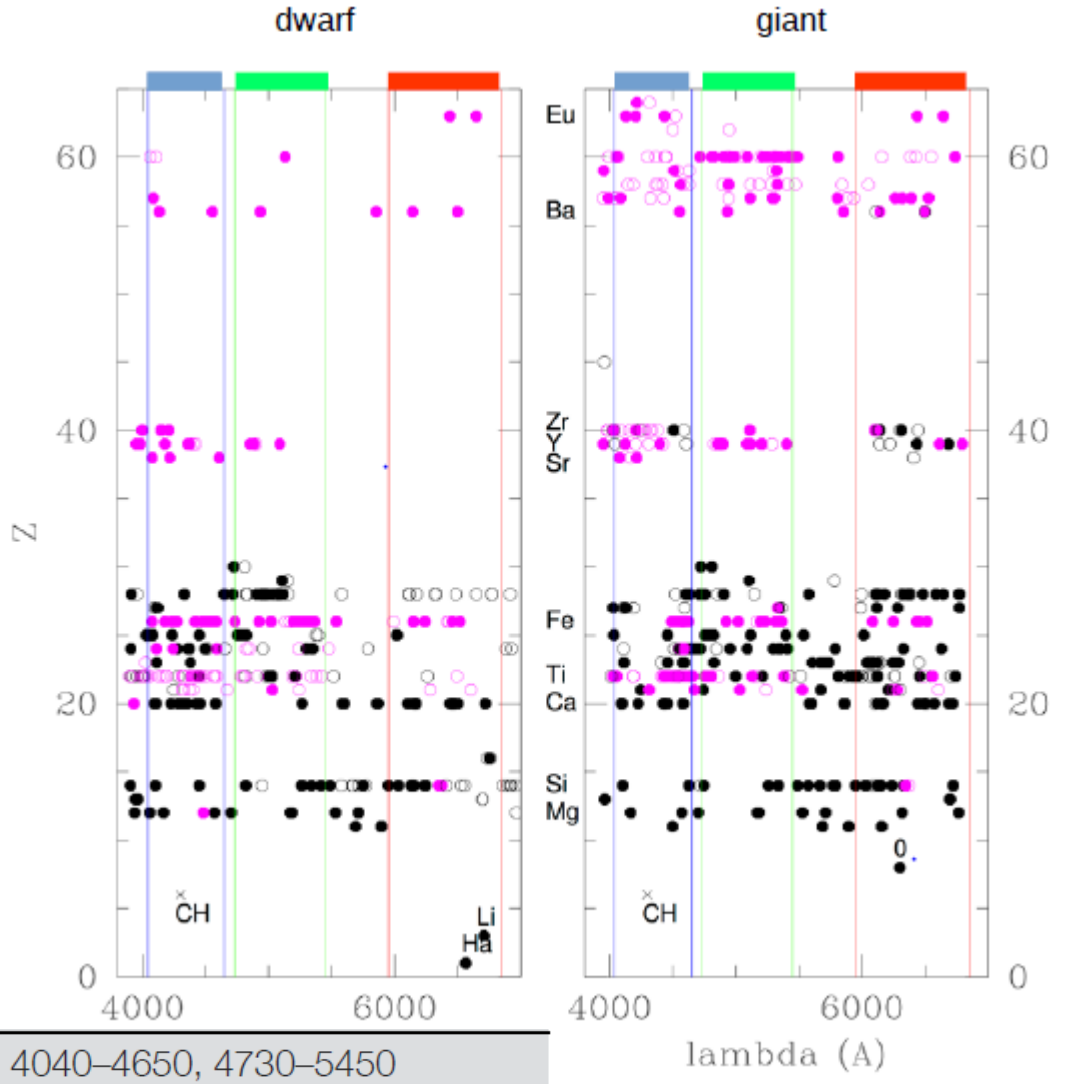
Kordopatis+ 2016

WEAVE Pipelines



WEAVE HR products

- 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)
- Teff, log(g), Vrad, Vsini
- Nucleosynthetic chanels :
  - Lithium → young objects
  - iron peak (Fe, Ni, Cr, Co, Zn),
  - alpha elements (C, Mg, Si, Ca, [OI]…),
  - neutron-capture slow and rapid elements (Zr, Y, Sr, Ba, La, Nd,Eu),
  - odd elements (Na, Al, Sc)



High-resolution mode wavelength coverage (Å)	4040–4650, 4730–5450 5950–6850

Data products

ALL	• Class (STAR, GALAXY, QSO) • Subclass • Redshift
STARS	• Velocity • Stellar atmospheric parameters GKM (3500-6000 K): T_{eff} ,logg, [Fe/H], [α/Fe],ξ, individual abundances AFG (5750 K-8000 K): T_{eff} ,logg, [Fe/H], [α/Fe],ξ, individual abundances A (7000-12000 K): T_{eff} ,logg, [Fe/H] OB (10000-30000 K): T_{eff} ,logg, [Fe/H] WD (7000-100000 K): T_{eff} ,logg
GALAXIES	• Galaxy category sub-classes • Stellar velocities, and velocity dispersions. • Amplitudes, centroids, and widths of emission lines. • A set of absorption strengths indices based on the standard **Lick system.**
IFU	• Maps of emission lines, color, velocity, and σ.

+ raw and reduced spectra

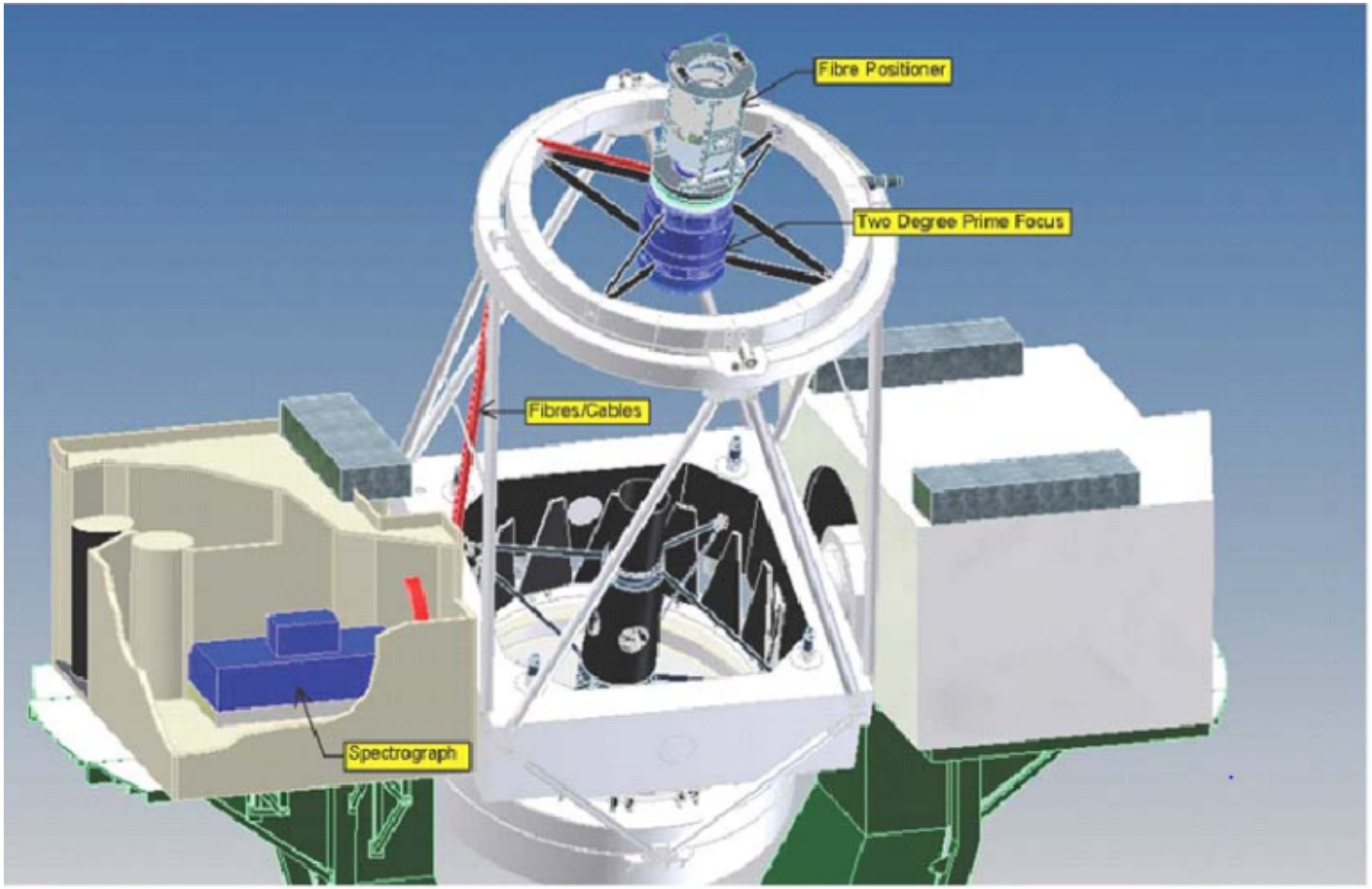
Courtesy: C. Allende & C: Zurita

WEAVE Timeline

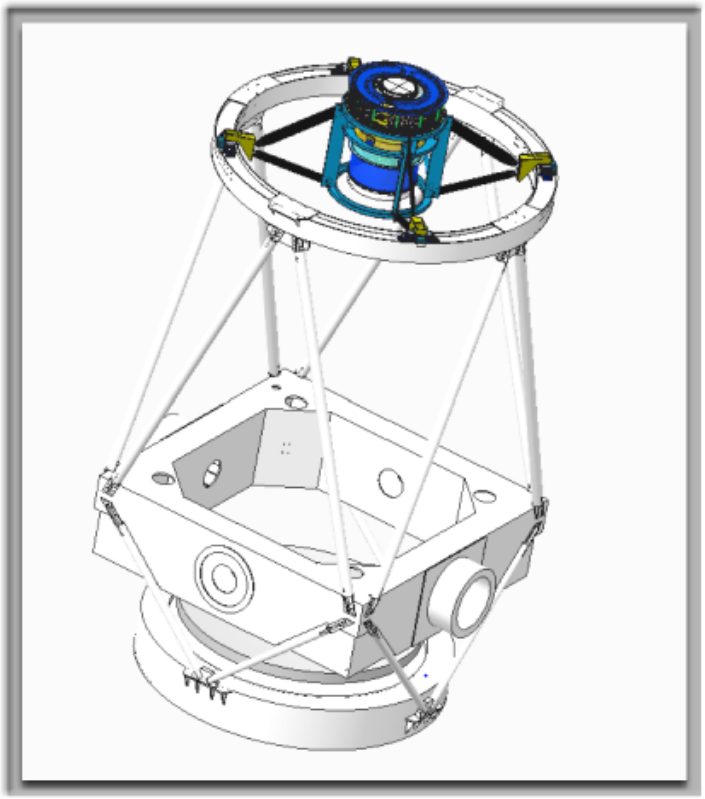
- Now Operation Rehearsal: March 2017
- First science light: 2018
- Surveys begin: T0+3 months
- WEAVE main instrument at WHT
- 5 years of WEAVE surveys (70% of available time), plus TAC time (30%) which may also include using WEAVE
- Open time PIs will have full access to WEAVE calibration data
- Post-2024: not defined, but likely continued use of WEAVE instrument (not necessarily current surveys)
- ING Board is starting to define post-2024 strategy

Data policy

- Goal: to maximise scientific return
- Open data access inside the Consortium for all «nominal» products
- Possibility for each Consortium member of re-analizing data
- Proprietary period of 1 year for additional data products
- First data release after 2 years from survey beginning (T0+12 months of data)
- Second+ DR every year
- Open time PI data??


Fibre Positioner
Two Degree Prime Focus
Fibres/Cables
Spectrograph

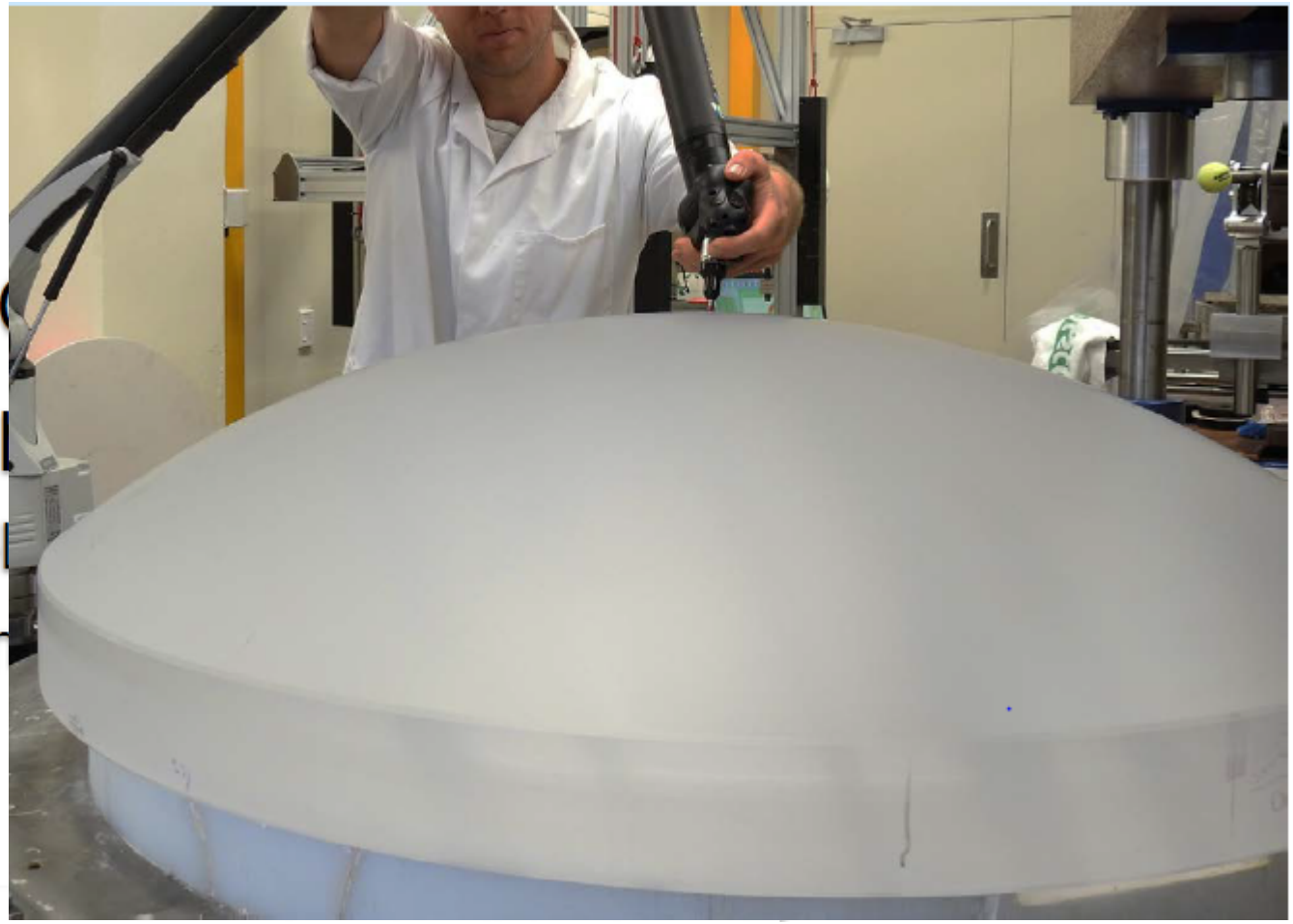
Top end flip ring test



Secondary mirror assembly and
top end flip ring removed in July 2016
to assess the feasibility

Prime Focus corrector

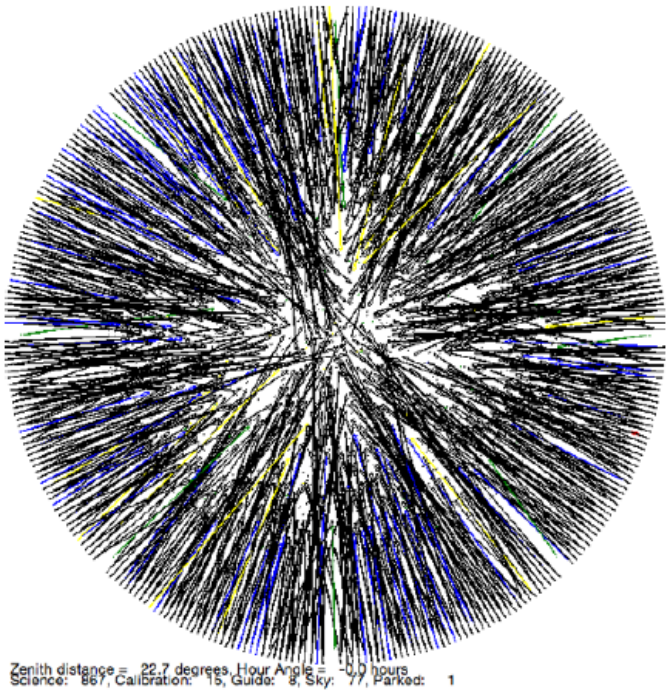
Prime fo
correcto
with ADC (L2–
L1 is 1100 mm

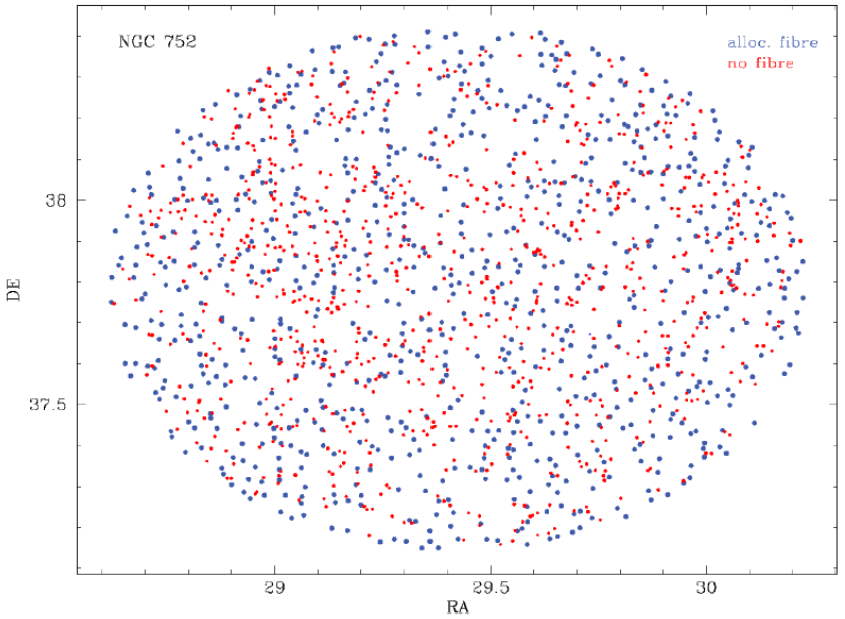


Lens 1 -- 1100mm by Kiwistar
New Zealand

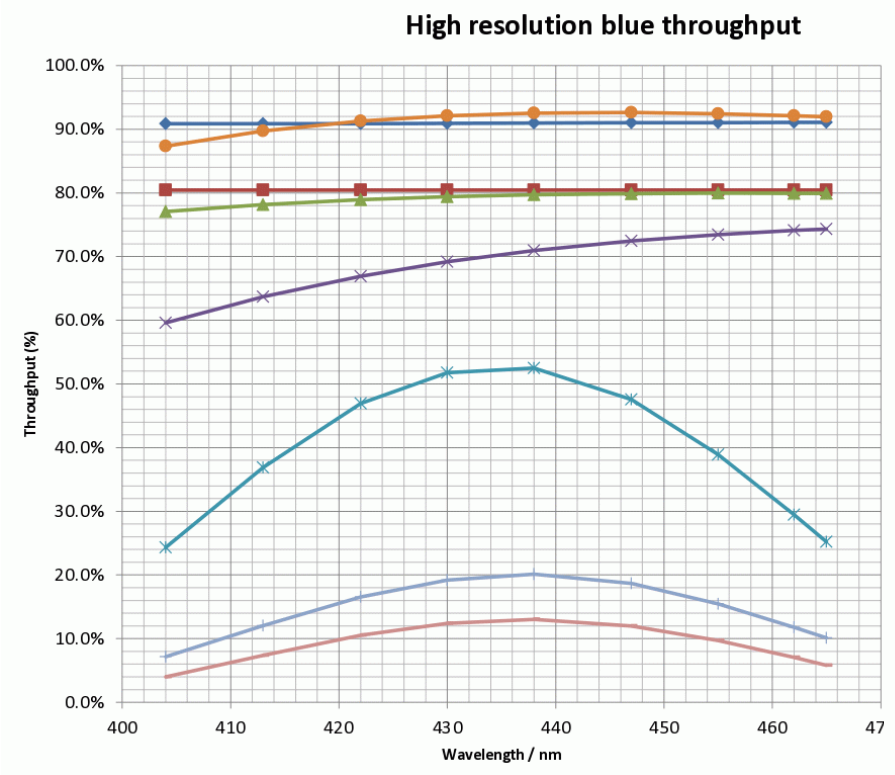
Fibre placement

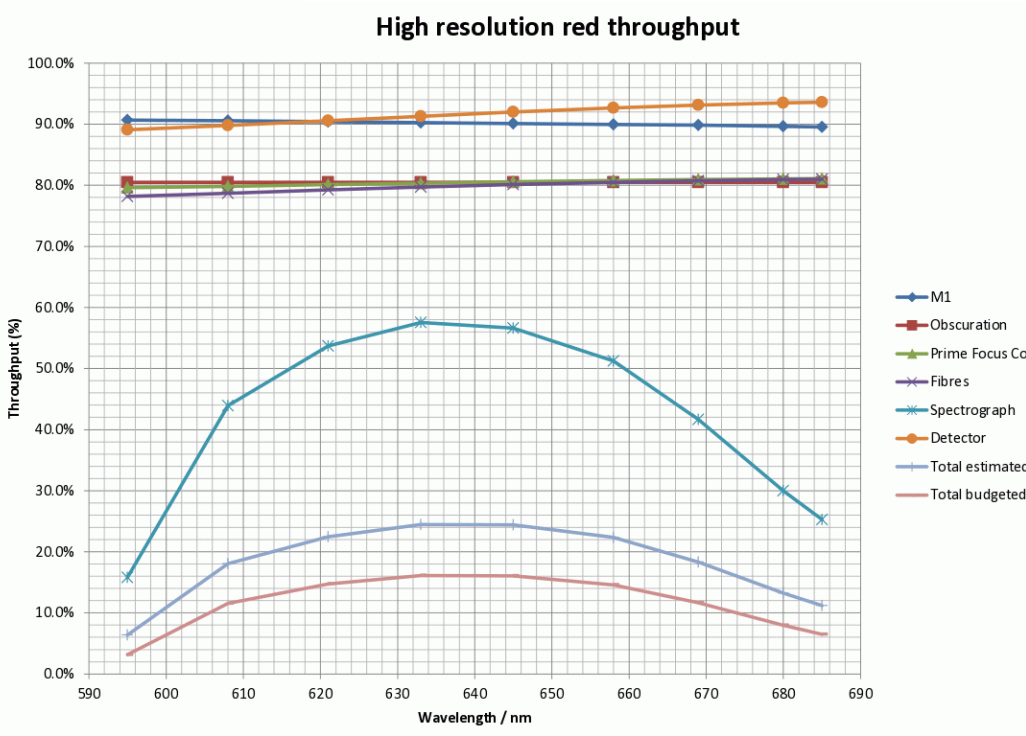
- 100 % fibres placed in a simulation of a cluster core
- about 8500 fibre crossing
- About 1800 moves in <55 minutes with two robots





HR throughput





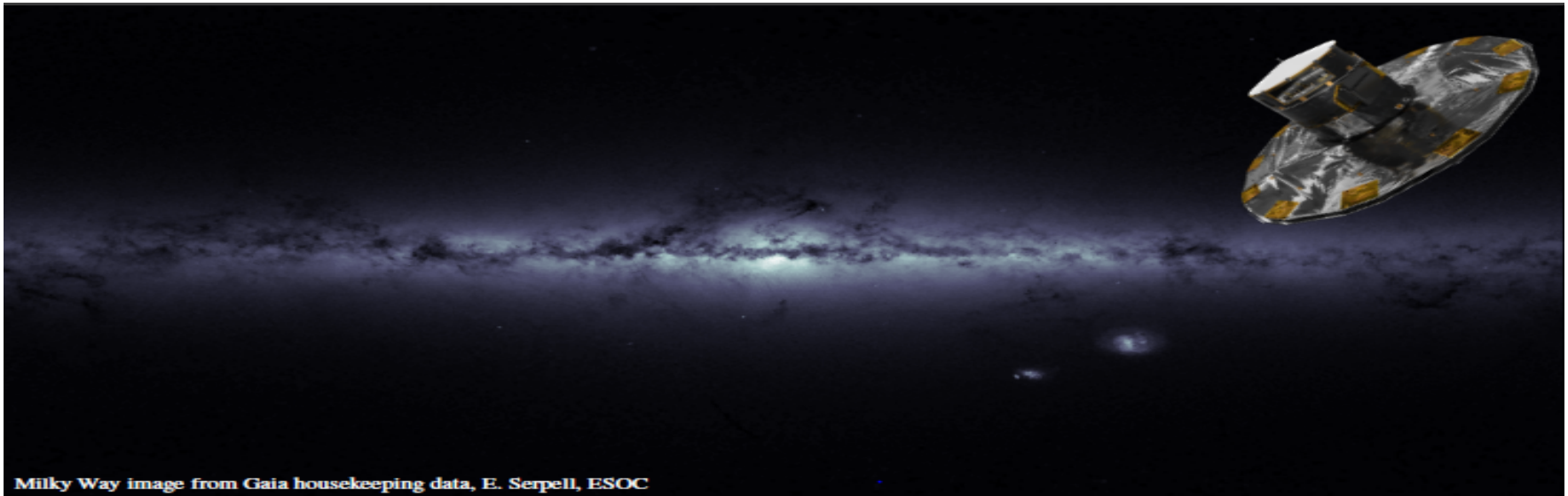
Conclusions

- WEAVE is an excellent example: focussed on very few things done very well, while discussing on big science questions
- The Gaia-related + LOFAR+ APERITIF follow-up projects are a superb example of optimal science use of a wide-field 4m telescope with data serving a huge range of science and a huge science community.
- WEAVE will maintain general-purpose 4m-class telescope in the Northern hemisphere for use by partner communities with competitive instrumentation, ensuring that telescope and instrumentation can deliver competitive science, even in an era of much larger telescopes
- Coordination with other facilities is fundamental
- Italian scientific community should organize itself to ensure the maximum scientific return
- Synergies with TNG (GIANO; HARPS..) are very important:
  - for detailed studies of specific objects (RGB, AGB, cool stars) → **Livia, Angela talks**
  - detailed chemical abundances
  - Chemical characterization of high reddening sources (stars, clusters)
  - MA1 science→ **Micol Talk**

Conclusions

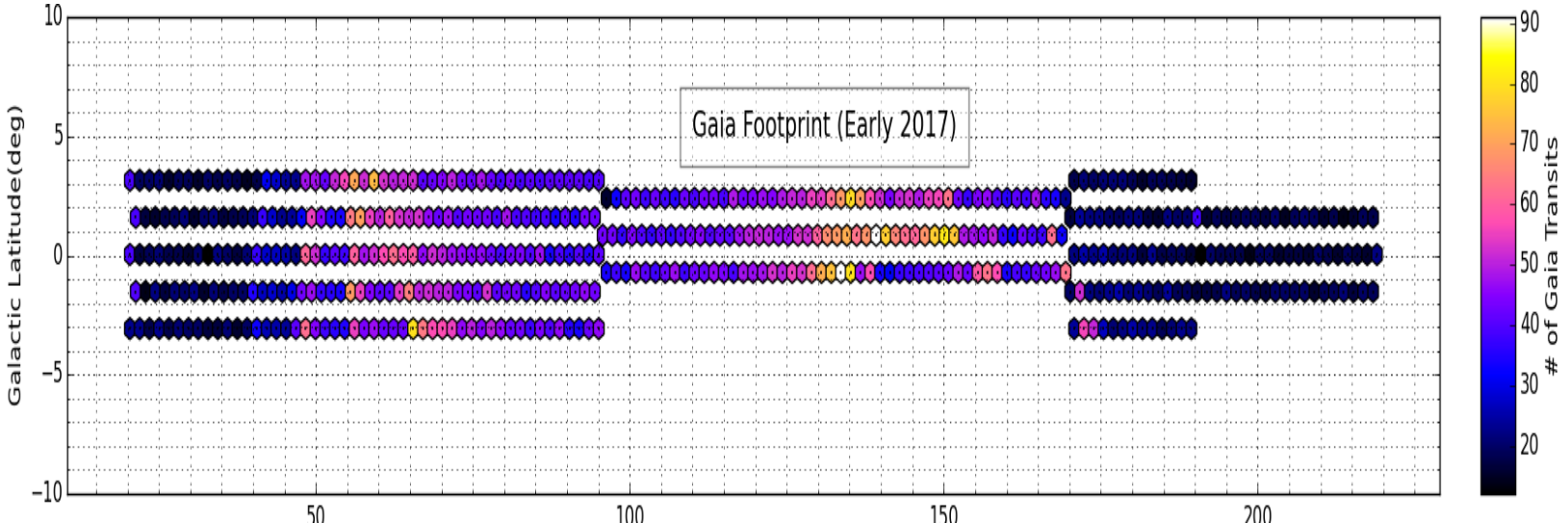
- WEAVE will complement present and upcoming surveys
- Italian scientific community should organize itself to ensure the maximum scientific return
- For more information see: www.ict.inaf.it/indico/event/428

  or *www.ing.iac.es/**weave**/*



Galactic Plane Stellar, Circumstellar and Interstellar Physics (SCIP)

- LR Surveys on GP selected from EGAPS over 1380 sq.deg
- Synergie with EGAPS: GP surveys
  - b<3 deg, ugri, Halpha , 20th mag VPHAS+ (u,g,r,i,Ha) ESO, UVEX (u,g,r, some HeI) North
  - IPHAS (r,i,Halpha) North
- Targets: *Young massive stars:* Comprehensive samples for improved modelling of massive-star evolution & Unbiased demographics: e.g. unclustered as well as clustered OB stars included
  - Targets: early B star with Av ~ 3, 10kpc away would have apparent mags B ~ 18.5, R ~ 17.5, I ~ 17 (S/N >30)



LR Halo Pointed Survey

- Dwarf Galaxies and UDFs
  - Northern dSphs + large streams and clouds + UFDs
  - 300 deg^2 down to V =21 (4 exposures per pointing)
  - A few exposures over 2 years for 3 dSphs (detection of 30% of binaries with |dv| > 2 km/s;

Catalogues: e.g. SDSS/PanSTARRS photometry or proprietary data