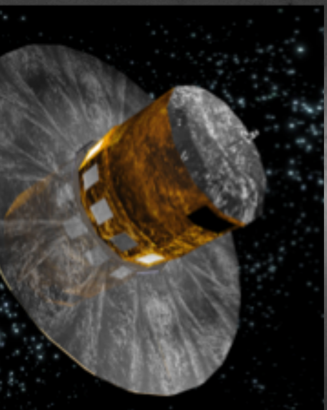
WEAVE and other Spectroscopic Surveys in the Gaia era



Vanessa Hill

Laboratoire Lagrange, UCA, Observatoire de la Côte d'azur, CNRS

Surveys in the Gaia era

1. Spectroscopic surveys: what for ?
2. Complementing Gaia: Galactic Archaeology
3. WEAVE as an example of new facility coming online
4. WEAVE Galactic Archaeology versus other spectroscopic surveys
5. A positive outlook ☺

pectroscopic surveys: what for

Many science cases call for large scale spectroscopic surveys, among which:

- ✓ Massive galaxy redshift surveys to map the structure of the Universe ar constrain cosmology (Baryonic Acoustic Oscillations, galaxy clustering)
- ✓ Massive galaxy surveys to probe galaxy evolution at different redshifts to reionization (and hence different λ);
- ✓ Large QSO surveys (line of sight absorbers) for cosmology, IGM tomography, …;
- ✓ Large stellar surveys to probe our Galaxy and stellar physics;
- ✓ Large samples of stars for planet searches

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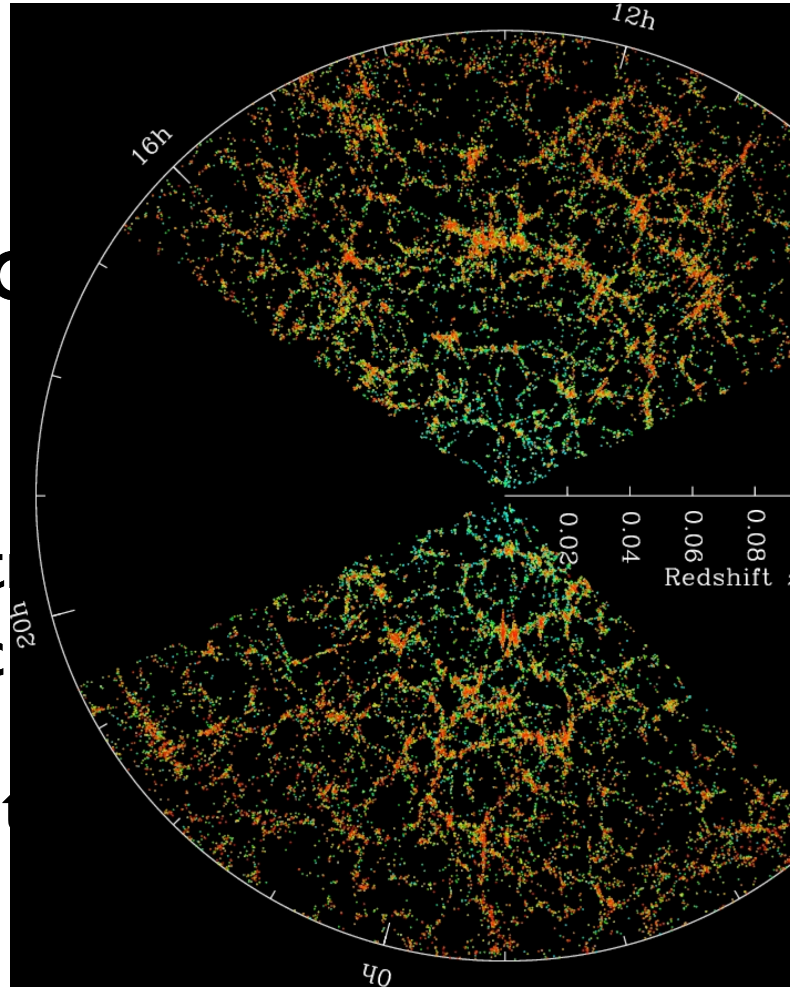

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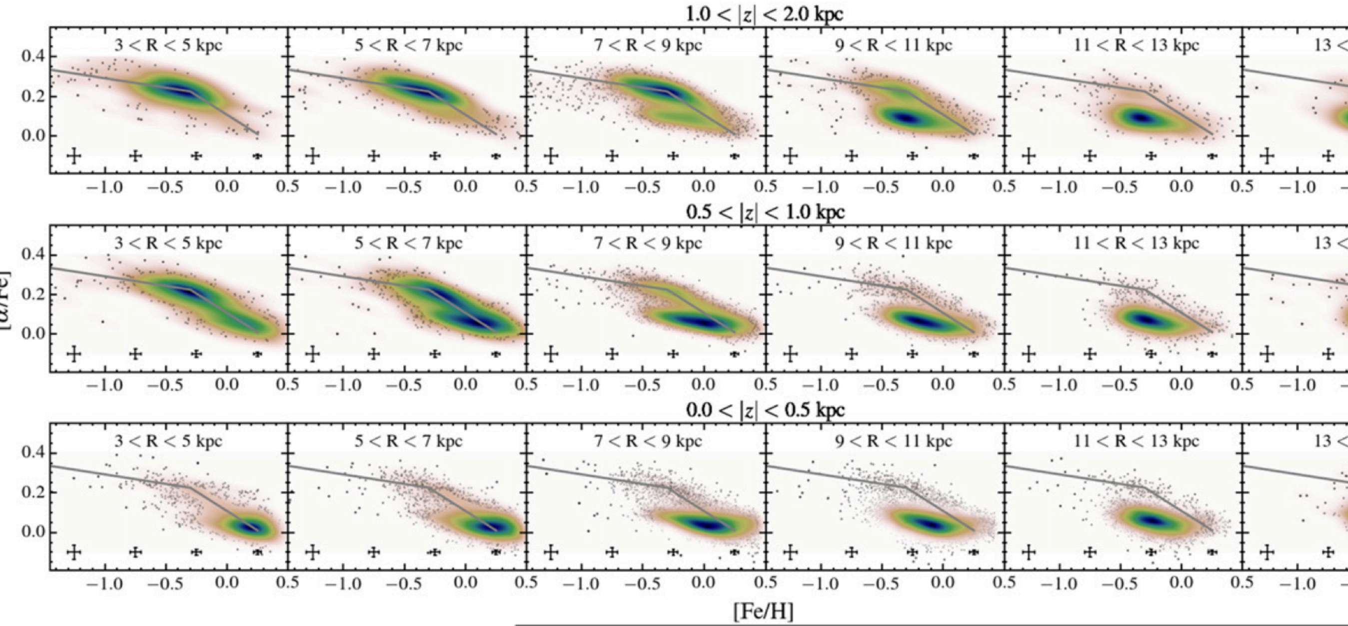

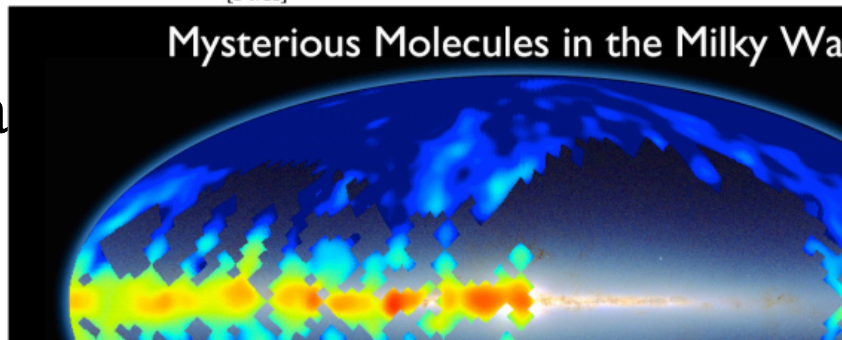

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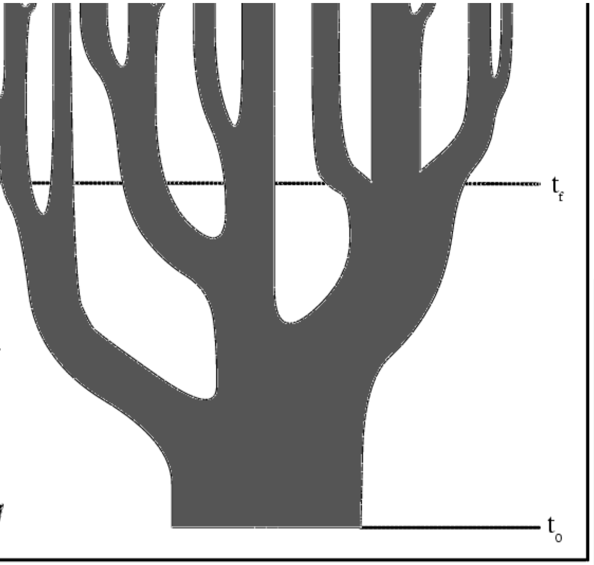
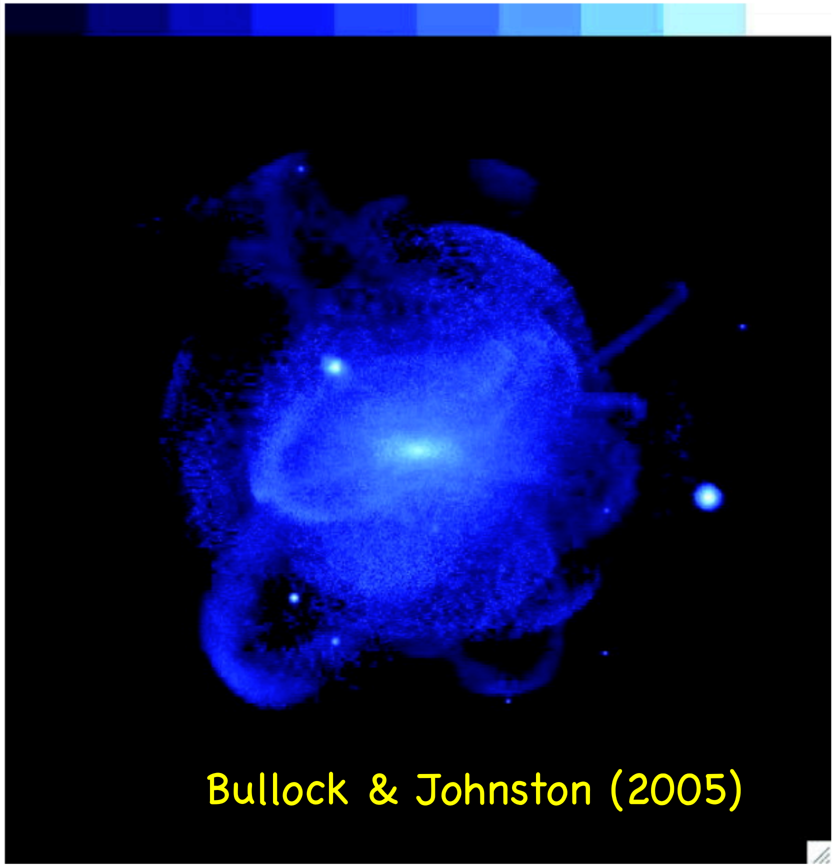
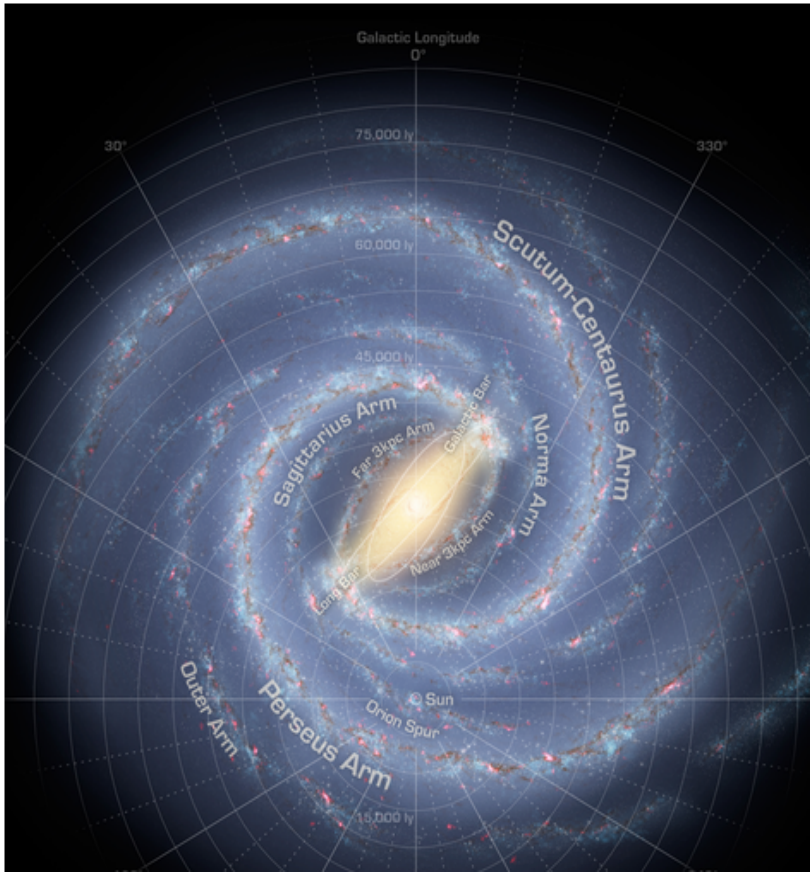
- ✓ Large QSO surveys (line of sight absorbers) for cosmology, IGM tomography, …;
- ✓ Large stellar surveys to probe our Galaxy and stellar physics;
- ✓ Large samples of stars for planet searches : not yet on multi-object

Milky-Way a
a prototype
for galaxy
evolution

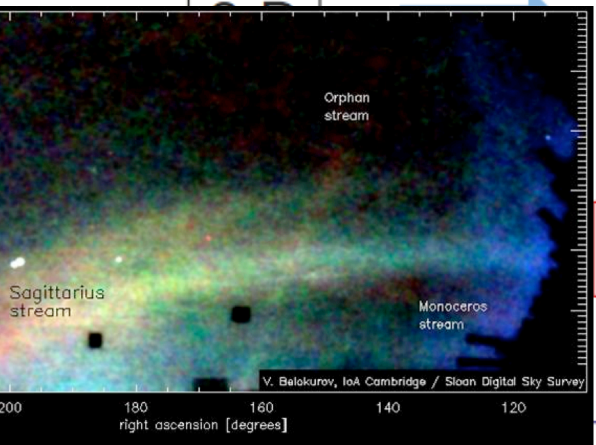






hen and how did the mass of the
V assemble ?
cretion-driven vs secular shaping
MW stellar populations ?

3-D → 5-D → 6-D → 12+ D



Parallax

Proper motions

Spectrum

Astrophysical parameters

over years

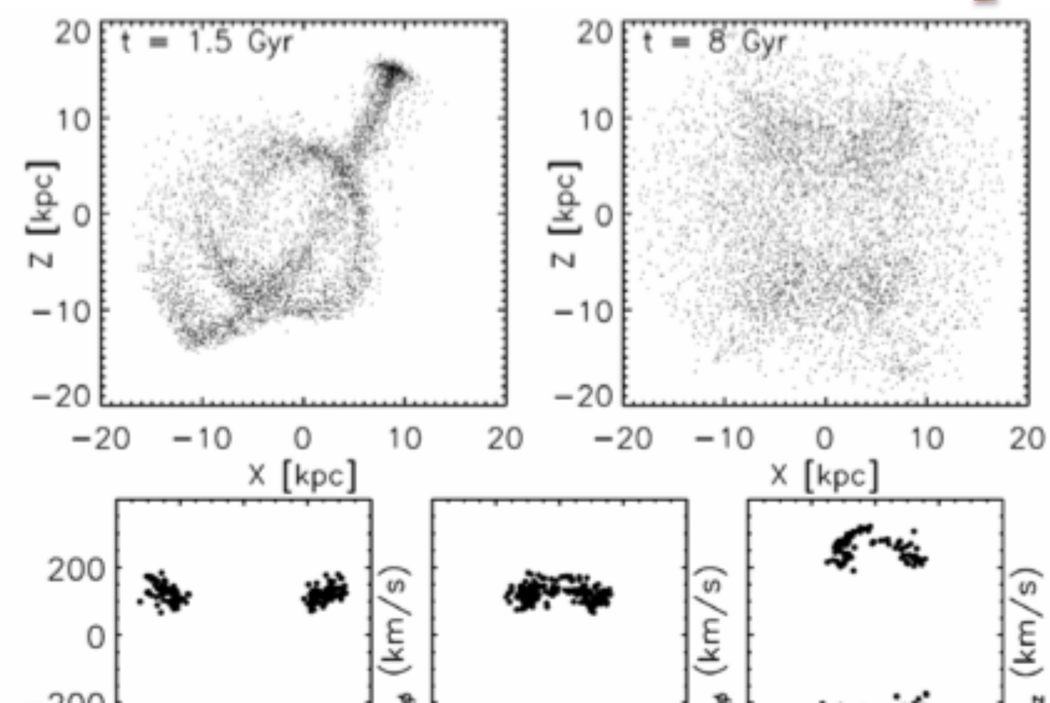
Distance

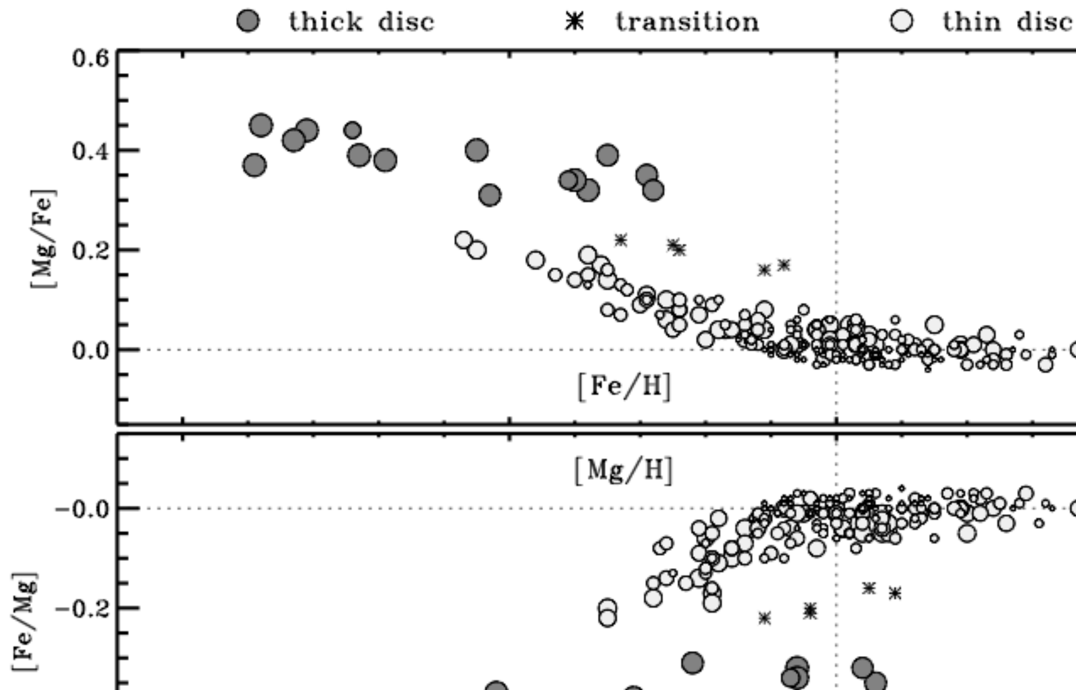
Transverse velocities

Radial velocity + chemistry

Ages, histories astrophysics

Gilmore et al. (2012)

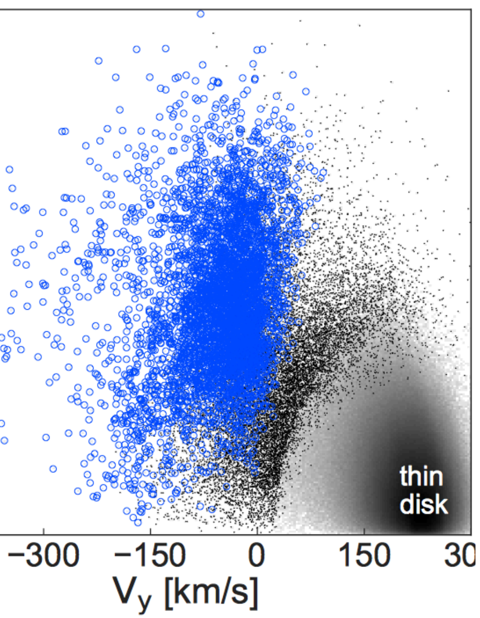




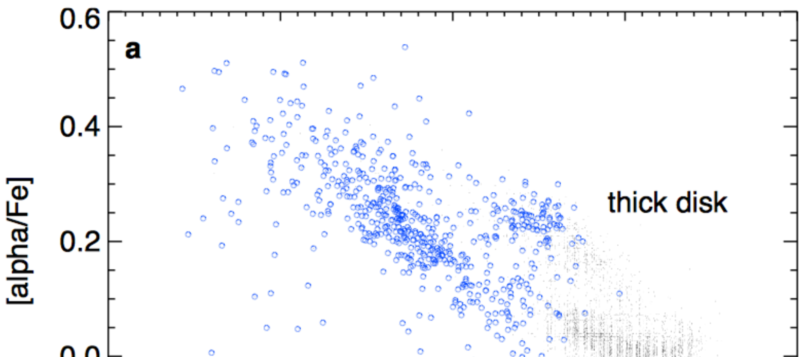
2-D → 3-D → 5-D → 6-D → 12+ D

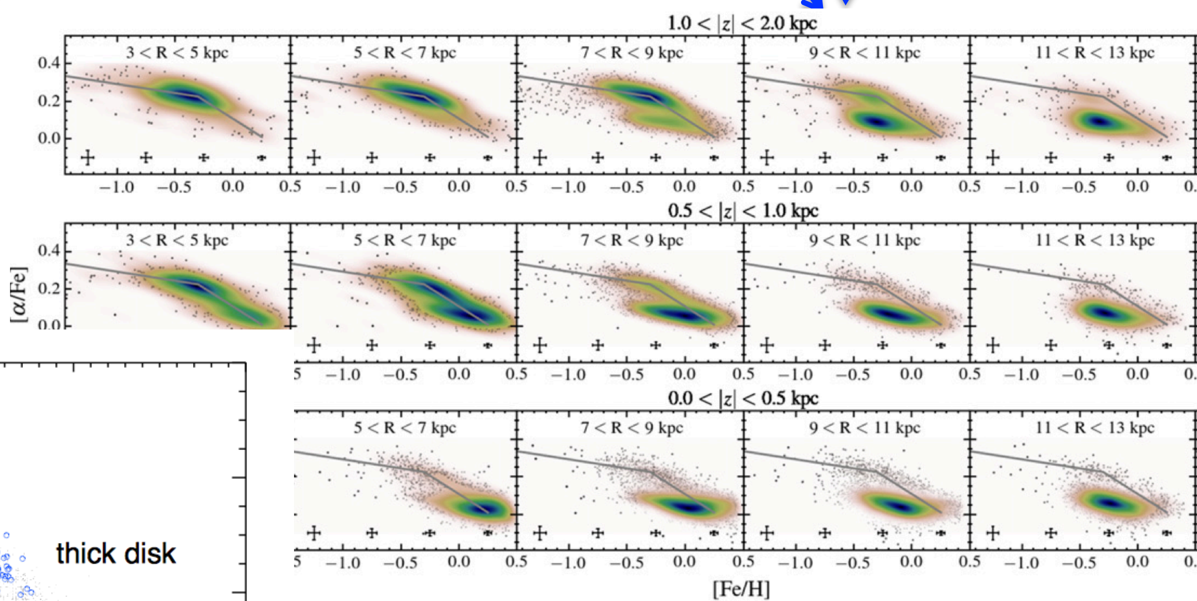
2-D	3-D	5-D	6-D	12+ D
Position	Parallax	Proper motions	Spectrum	Astrophysical parameters
Ultra-precision, over years	Distance	Transverse velocities	Radial velocity + chemistry	Ages, histories astrophysics

Gilmore et al. (2012)

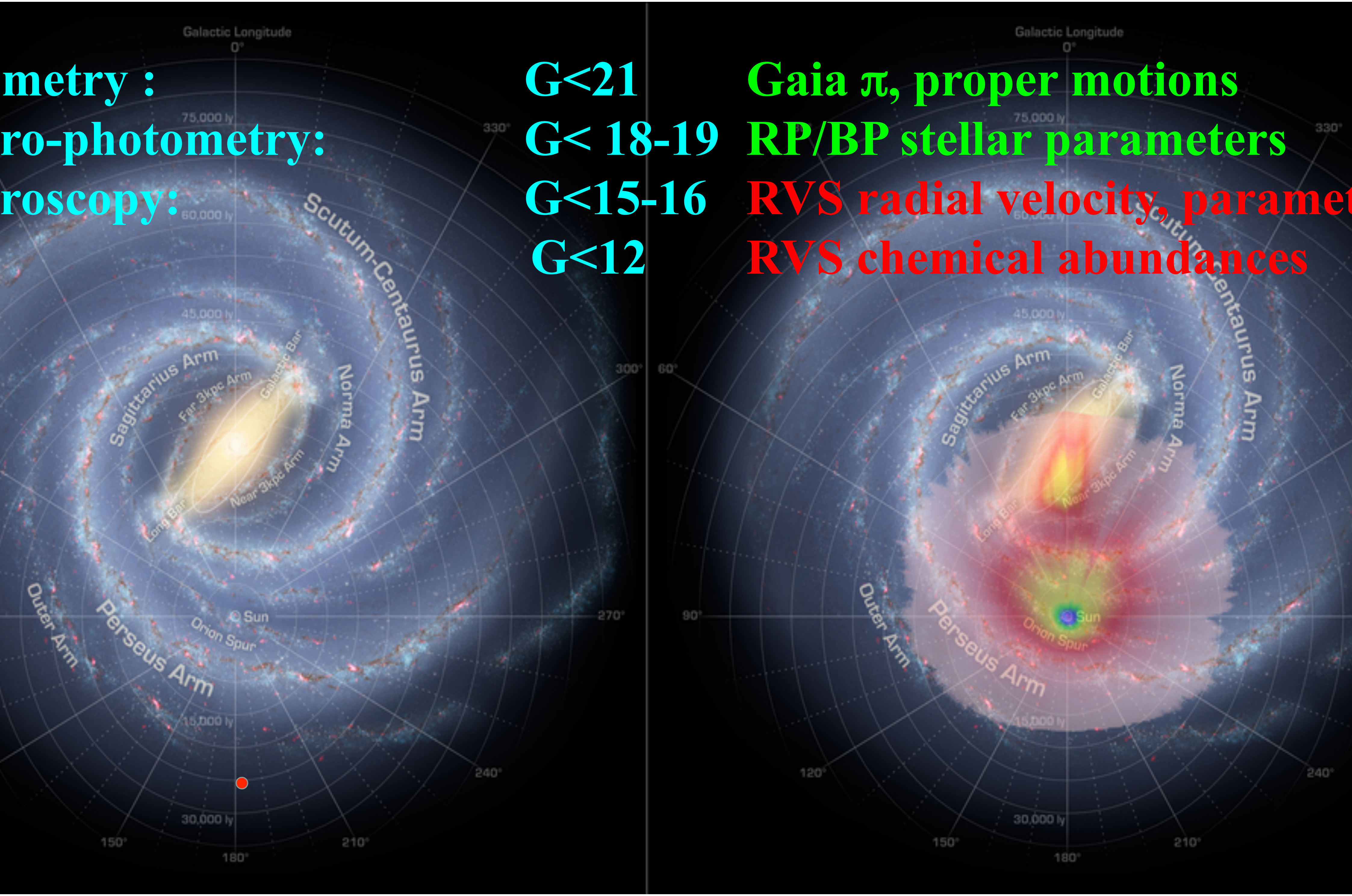


mi et al. 2018.





Hayden et al. 2015

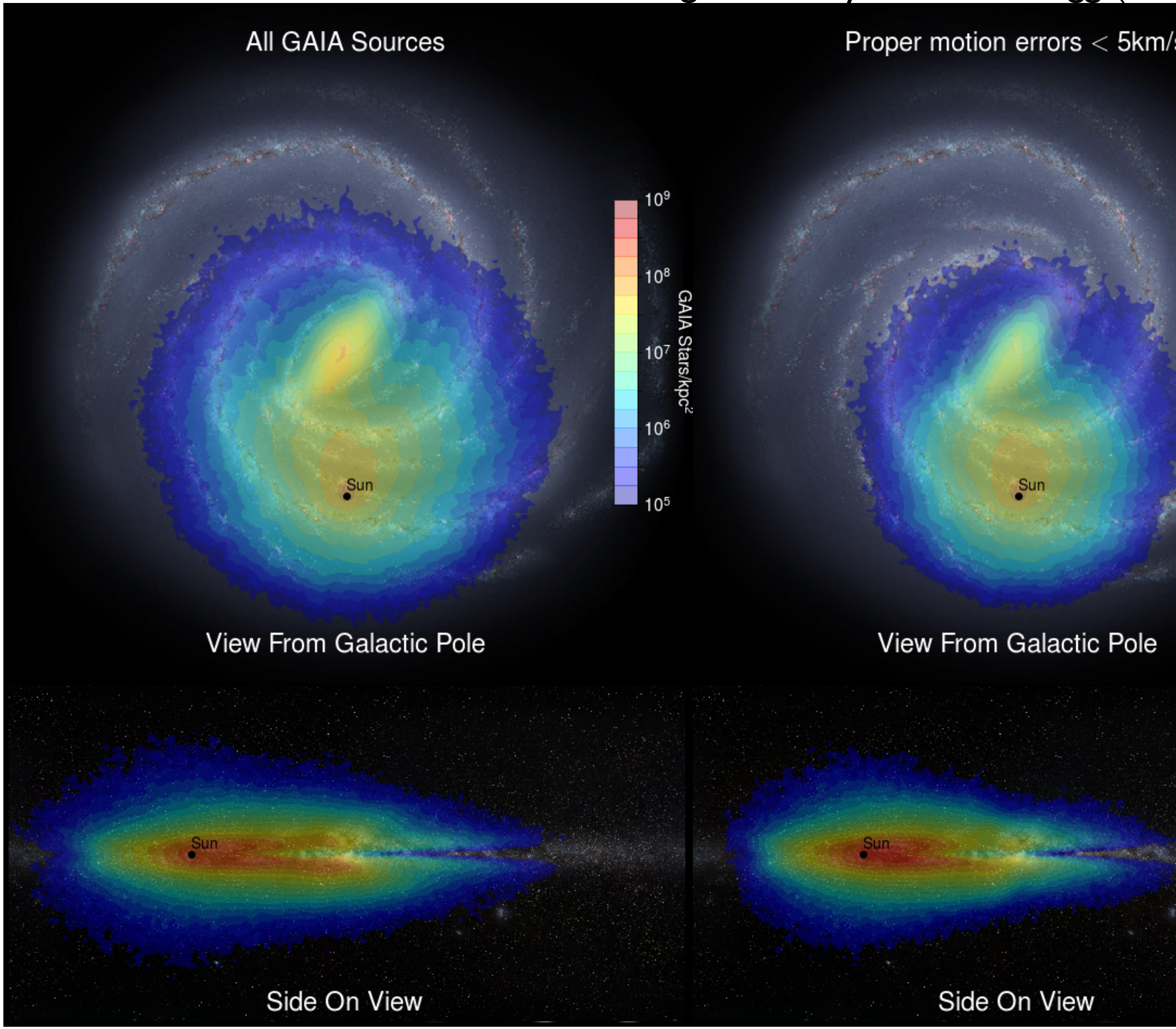

metry :
G<21
Gaia π, proper motions
ro-photometry:
G< 18-19
RP/BP stellar parameters
roscopy:
G<15-16
RVS radial velocity, paramet
G<12
RVS chemical abundances
Galactic Longitude
0°
75,000 ly
330°
60,000 ly
Scutum-Centaurus Arm
45,000 ly
Sagittarius Arm
Far 3kpc Arm
Galactic Bar
Norma Arm
Near 3kpc Arm
Long Bar
300°
60°
270°
90°
Sun
Orion Spur
Perseus Arm
Outer Arm
15,000 ly
30,000 ly
240°
120°
210°
150°
180°

Complement the Gaia catalogue with accurate Vr=Vlos (& metallicity) 15<G<20.-21.

Enrich the Gaia catalog with detailed chemistry fo 12<G<16

Enlarge the volume in which Gaia transverse motion are useful (i.e. where proper motions can be turned into velocities using distance): acquire precise stellar parameters (→ spectroscopic distances) of distant stars, where errors on $1/\pi$ kill geometrical distances.

Movie and images cortesy of Chris Wegg (mo



ctroscopic distances, turns proper motions in transverse

ynergies Gaia + ground based MO

2-D → 3-D → 5-D → 6-D → 12+

Proper motions

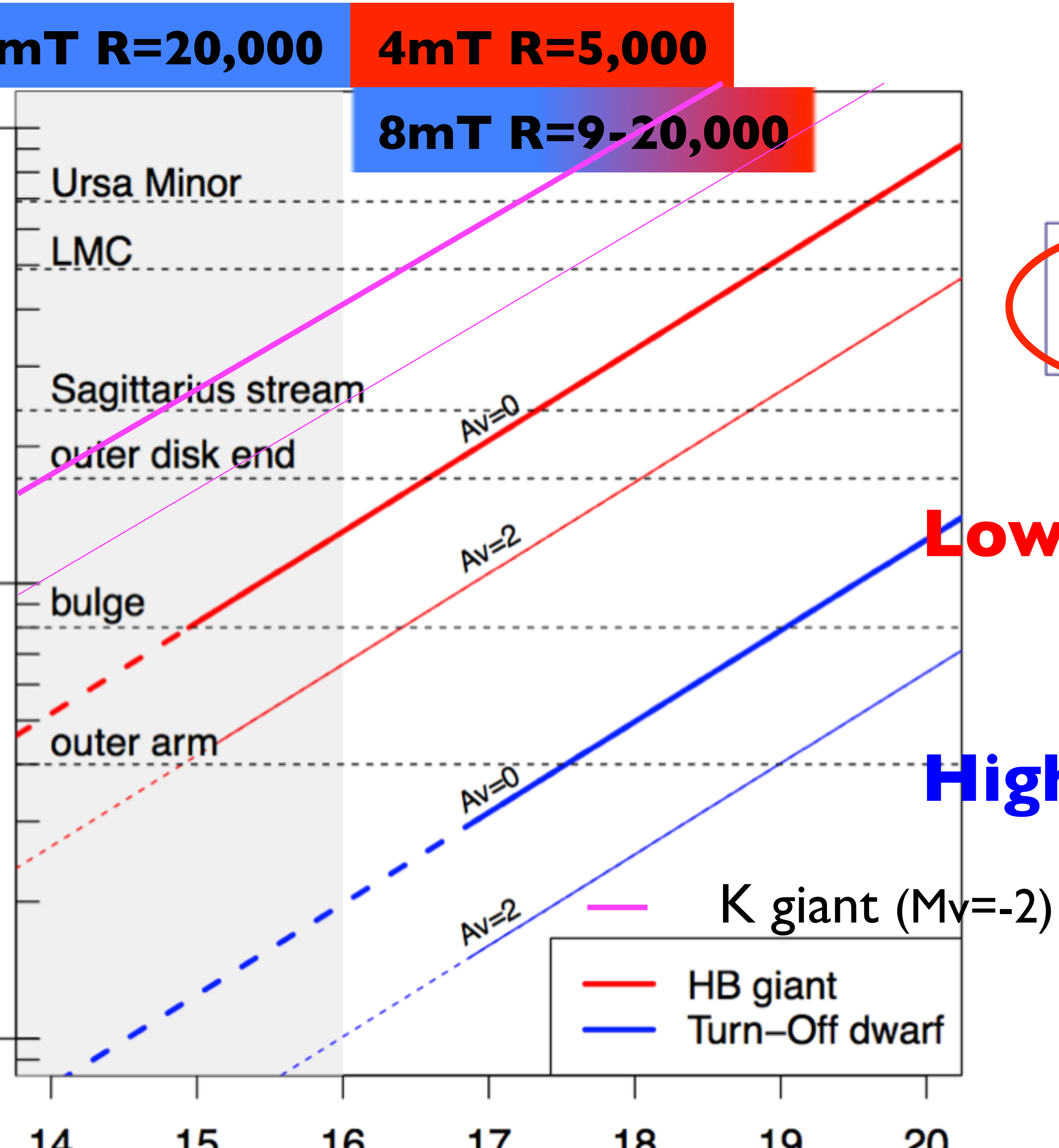
Spectrum

Astrophy parame

Transverse velocities

Radial velocity + chemistry

Ages, his astrophys



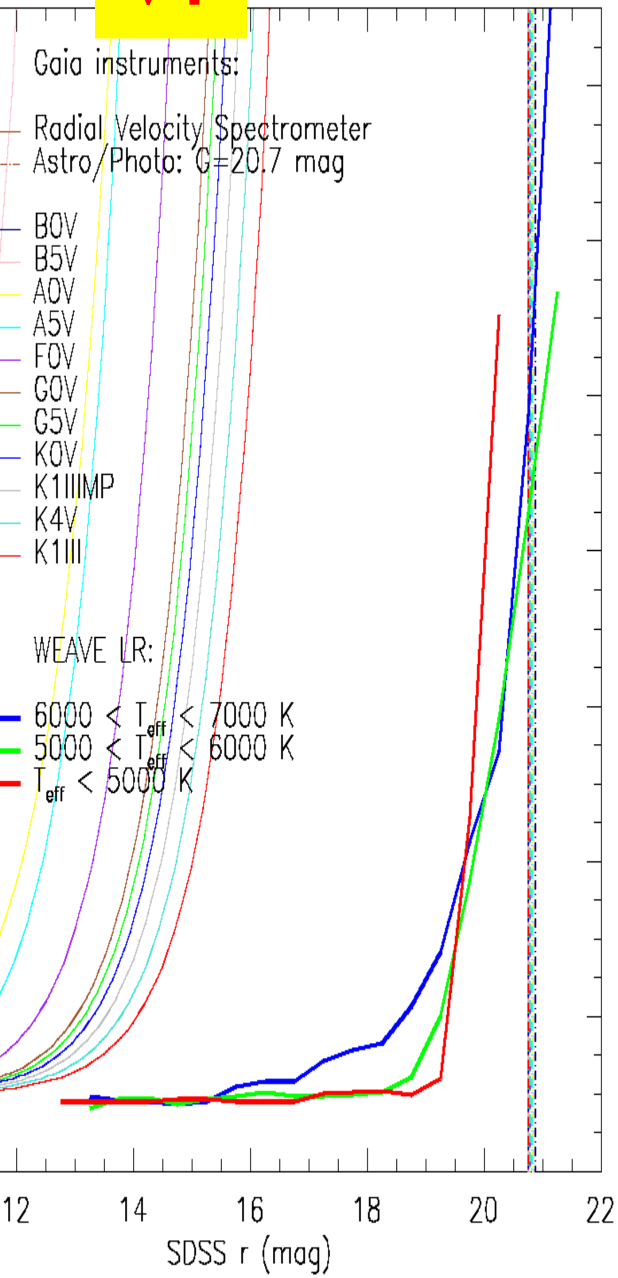
Low resolution spectra: R~5,000:

- **Vrad to 1-5 kms/s to Gaia**
- **stellar param & basic chem**

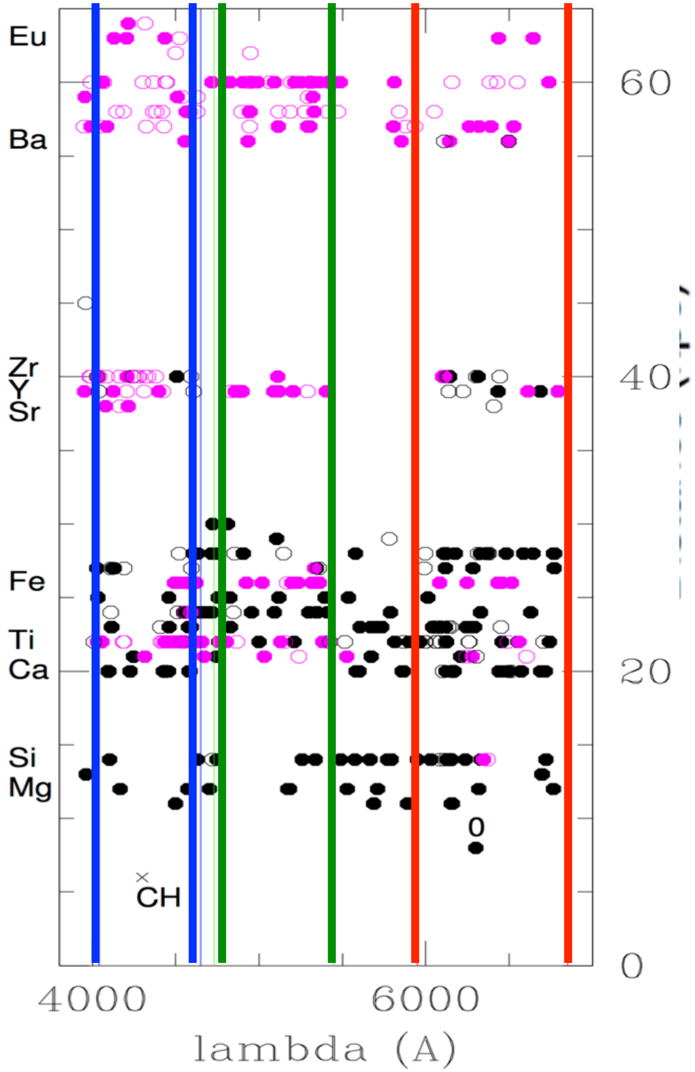
High resolution spectra: R~20,00

- Vrad to <1kms/s
- **precise stellar parameters**
- **detailed chemistry**
- **ages** (when combining π with pre

Vr



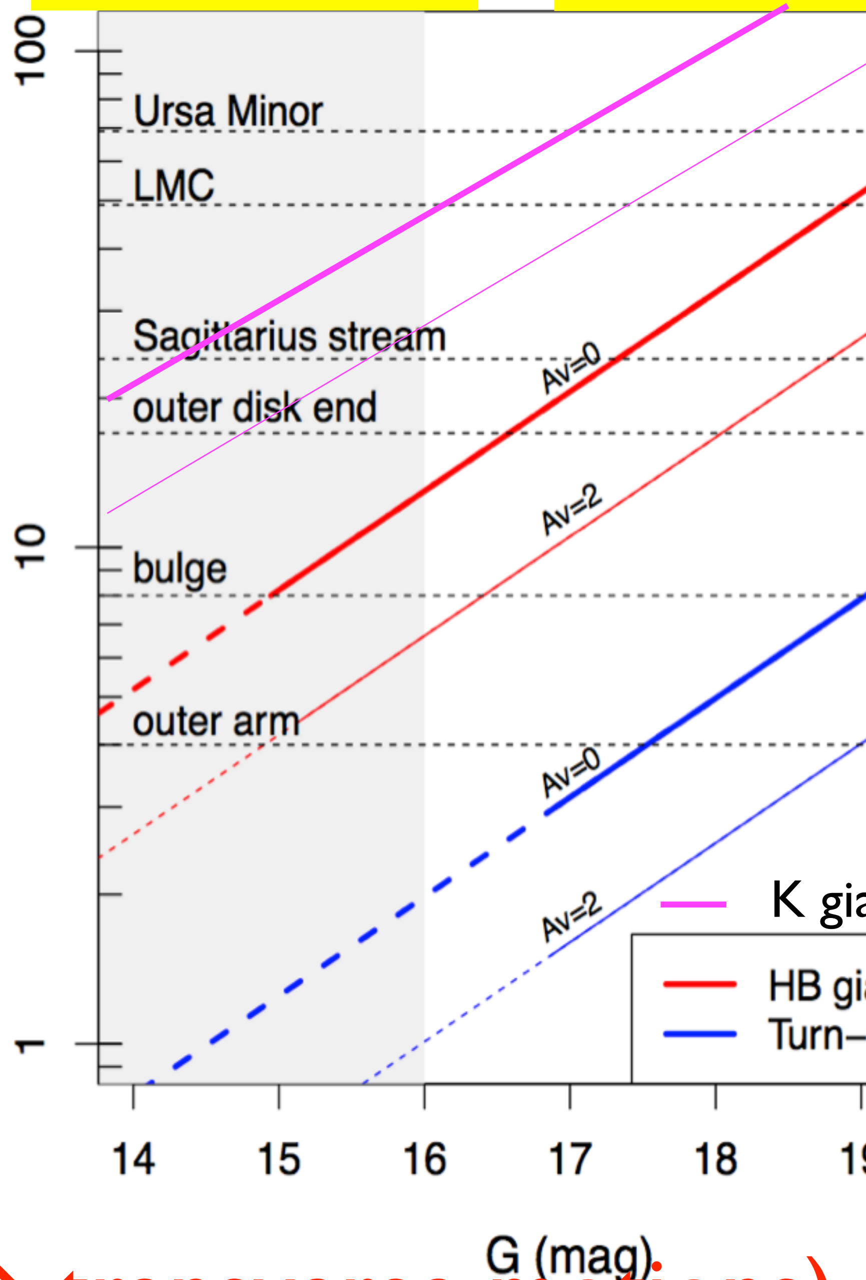
APs + abundances



On 4m-class telescop

R=20,000

R=5,00



urns 5D in 6D

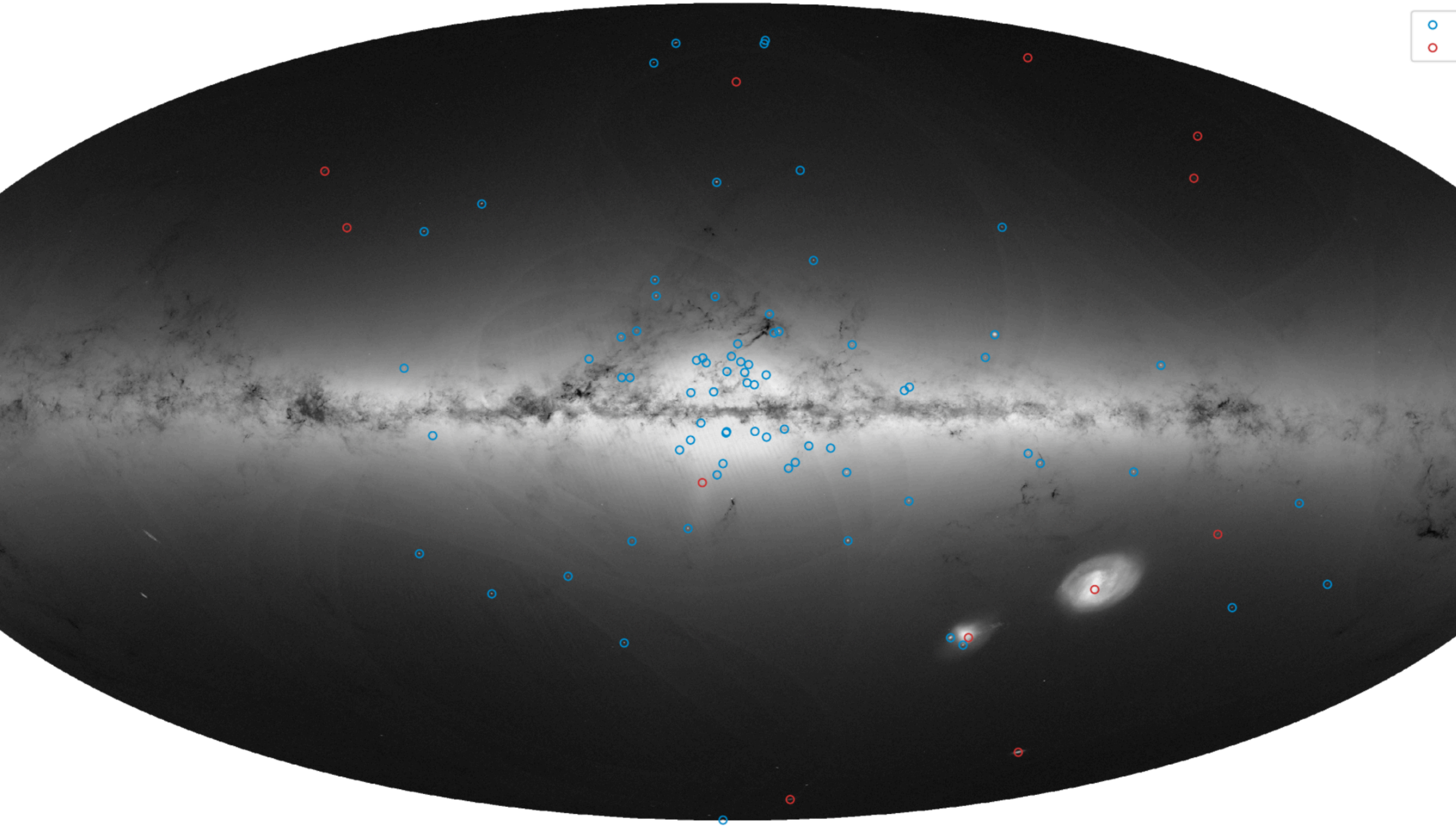
Complement the Gaia catalogue with accurate Vr=Vlos (& metallicity) 15<G<20

- Defined the LR mode of WEAVE:
- R = 5,000 in a wide range [366 – 606] nm + [579 – 959] nm

Enrich the Gaia catalog with detailed chemistry fo 12<G<16

- Defined the HR mode of WEAVE:
- R = 20,000 in two windows [404 – 465] nm || [473 – 545] nm [595 – 685] nm

Enlarge the volume in which Gaia transverse motion are useful: acquire precise stellar parameters (→ spectroscopi distances) of distant stars, where errors on 1/π kill geometrical



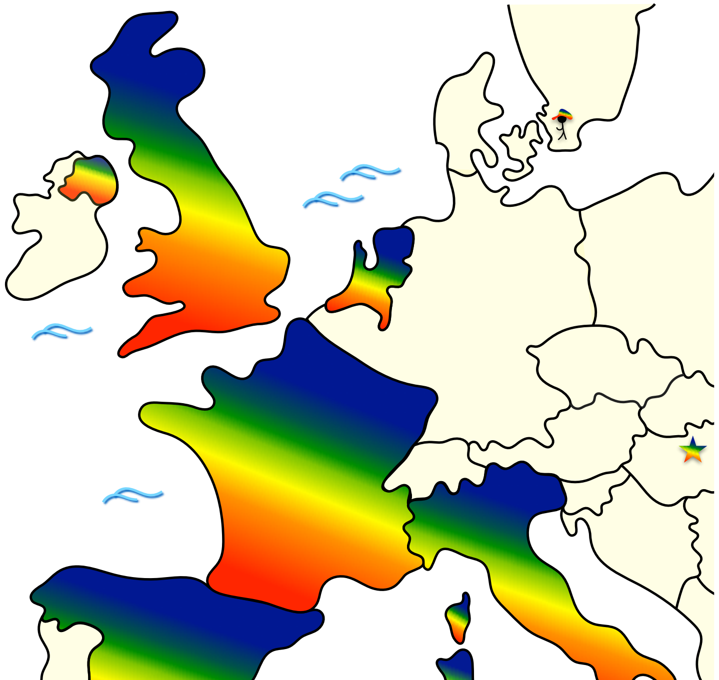
WEAVE is the first large spectroscpic survey

North to:

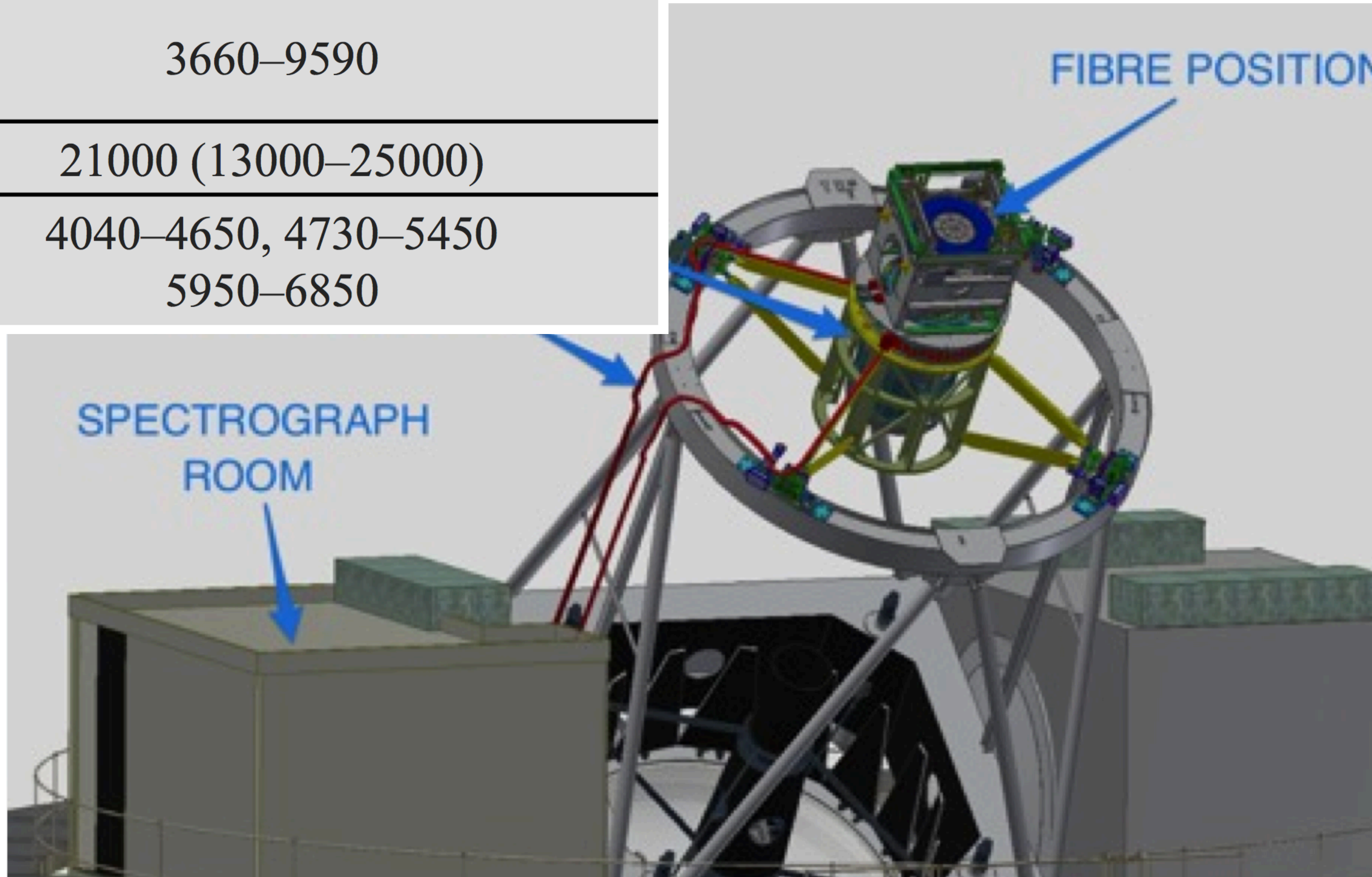
Complement Gaia (Galactic Archaeology)

Survey distant LOFAR galaxies (WEAVE-LOFAR)

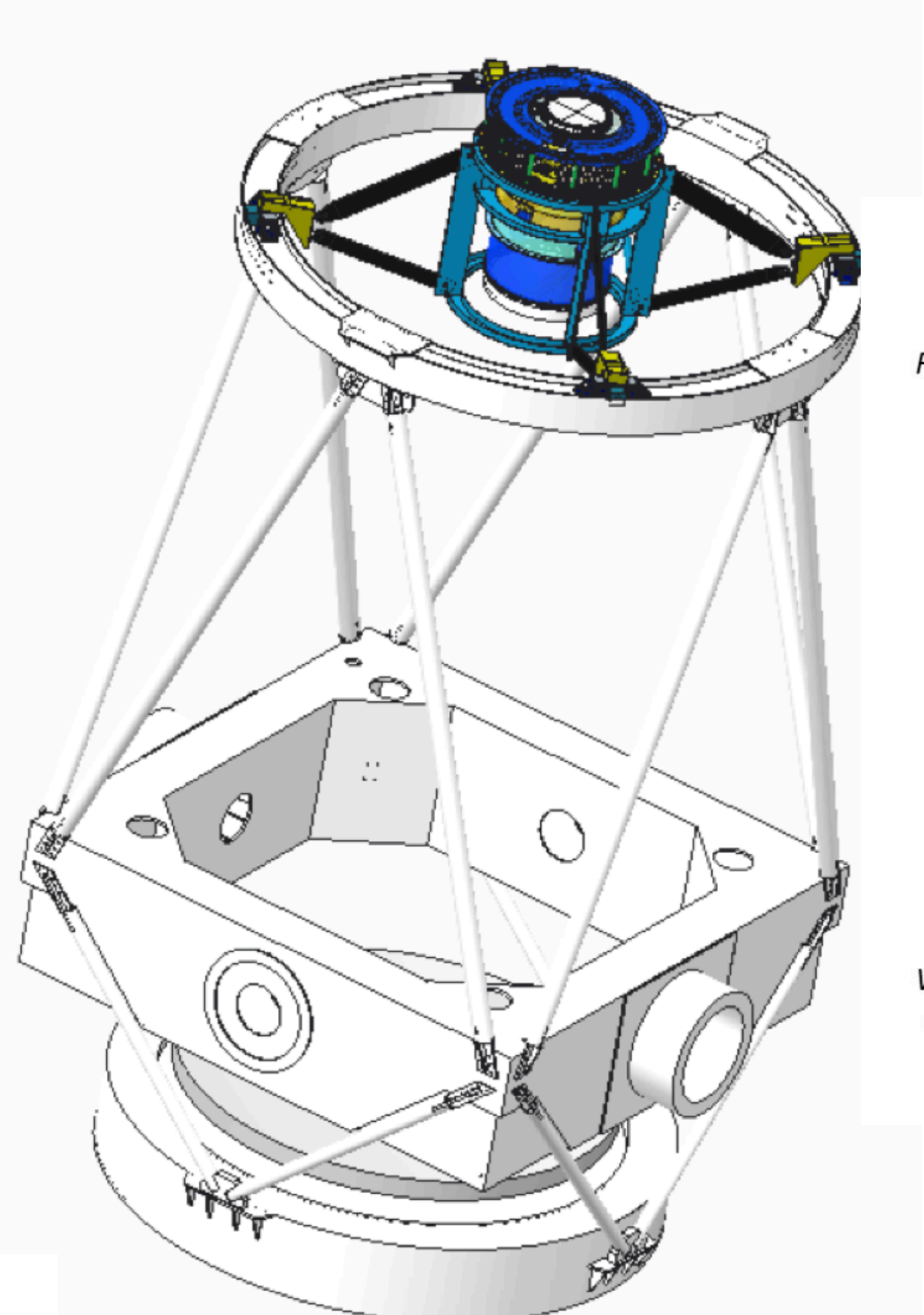
Serve many other science cases: Stellar, Circumstellar, and Interstellar Physics; Gaia White Dwarfs; WEAVE-APERTIF; Galaxy Clusters; Galaxy Evolution (STEPS); QSOs

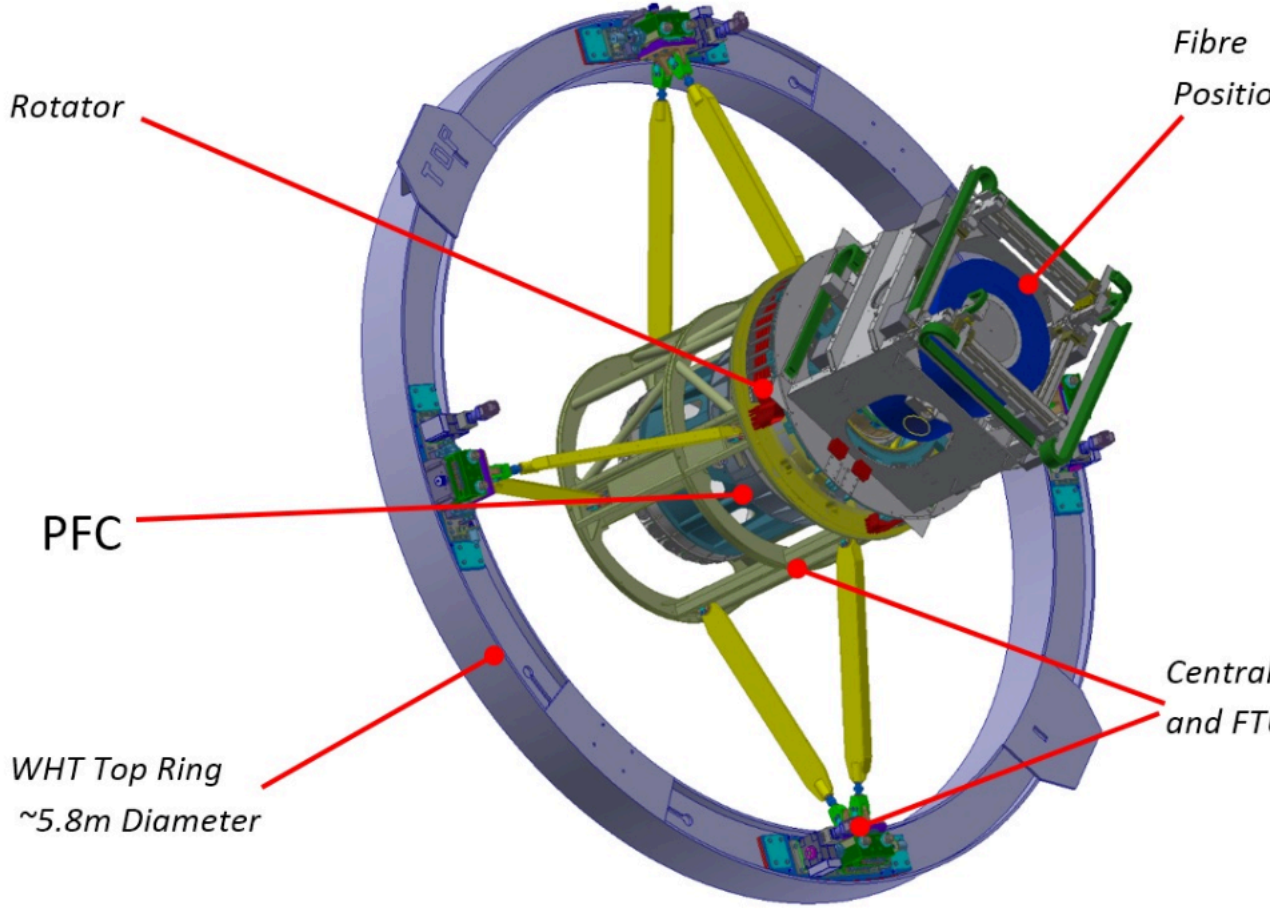


'elescope, diameter	WHT, 4.2m
Field of view	2º ⌀
Number of fibers	960 (plate A)/940 (plate B)
Fiber size	1.3″
ıber of small IFUs, size	20 x 11″x12″ (1.3″ spaxels)
LIFU size	1.3′x1.5′ (2.6″ spaxels)
esolution mode resolution	5750 (3000–7500)
solution mode wavelength coverage (Å)	3660–9590
esolution mode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



WEAVE @ WHT

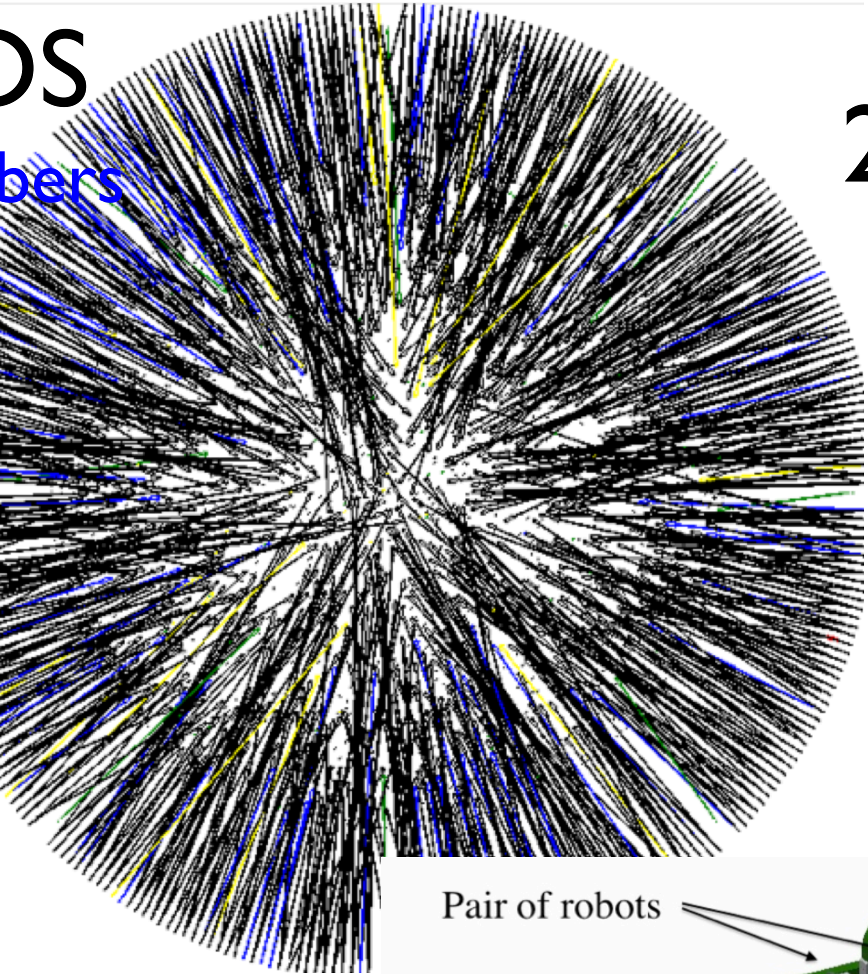




Rotator
PFC
WHT Top Ring
~5.8m Diameter
Fibre
Positio
Central
and FT

OS

bers



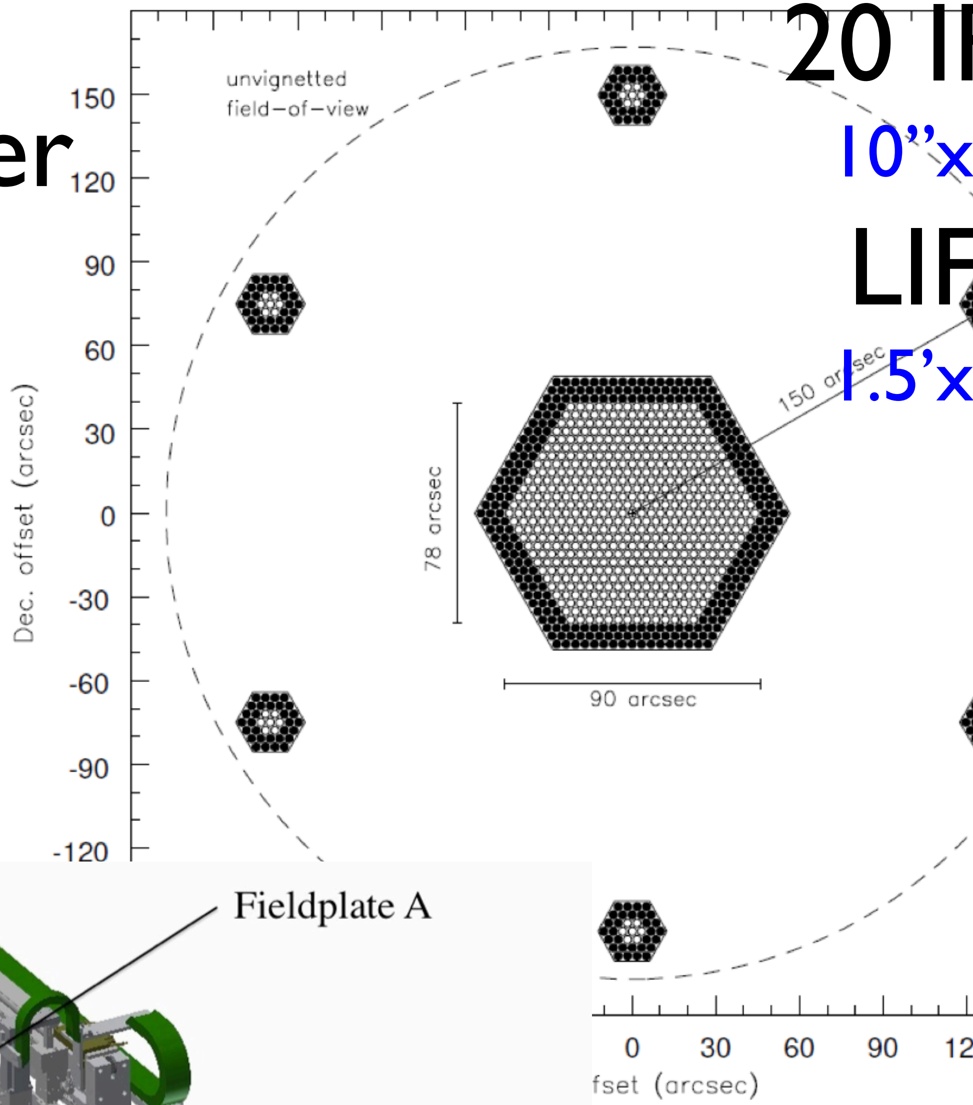
2°diameter
π deg^2

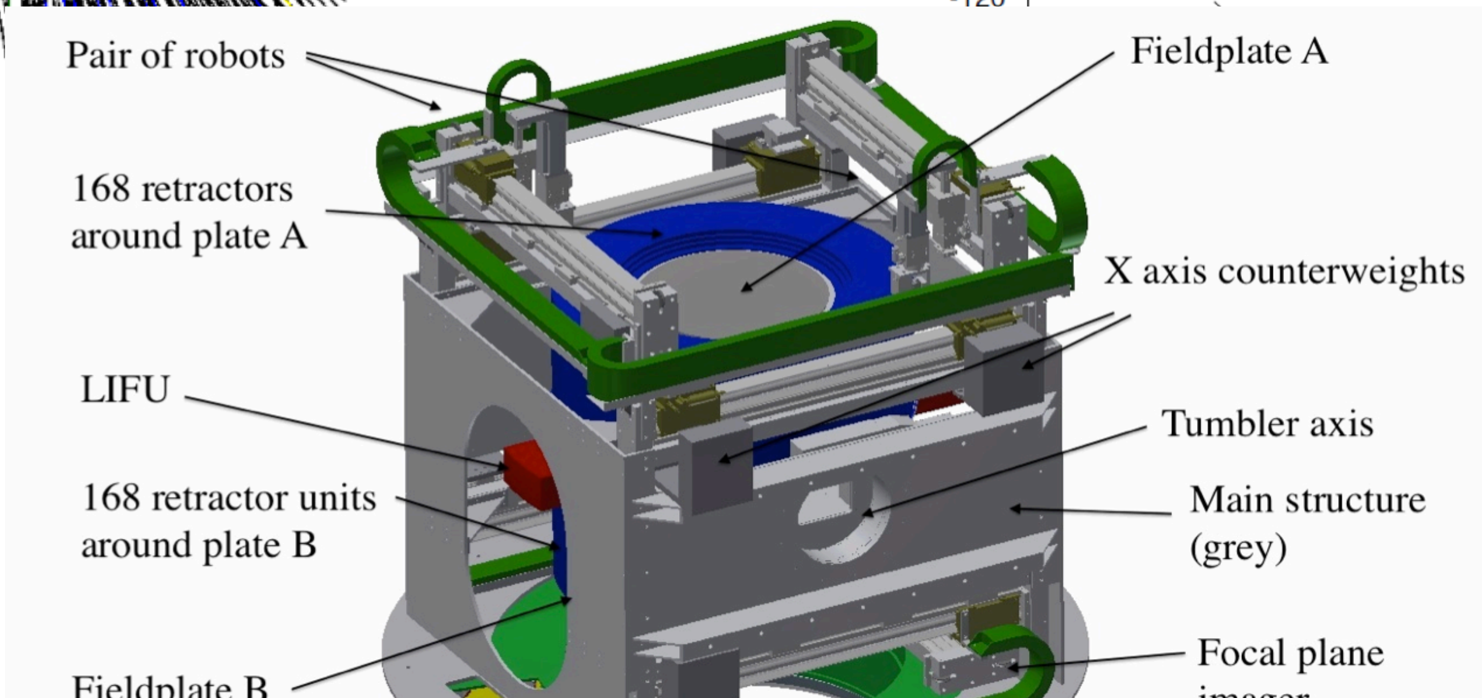
20 II

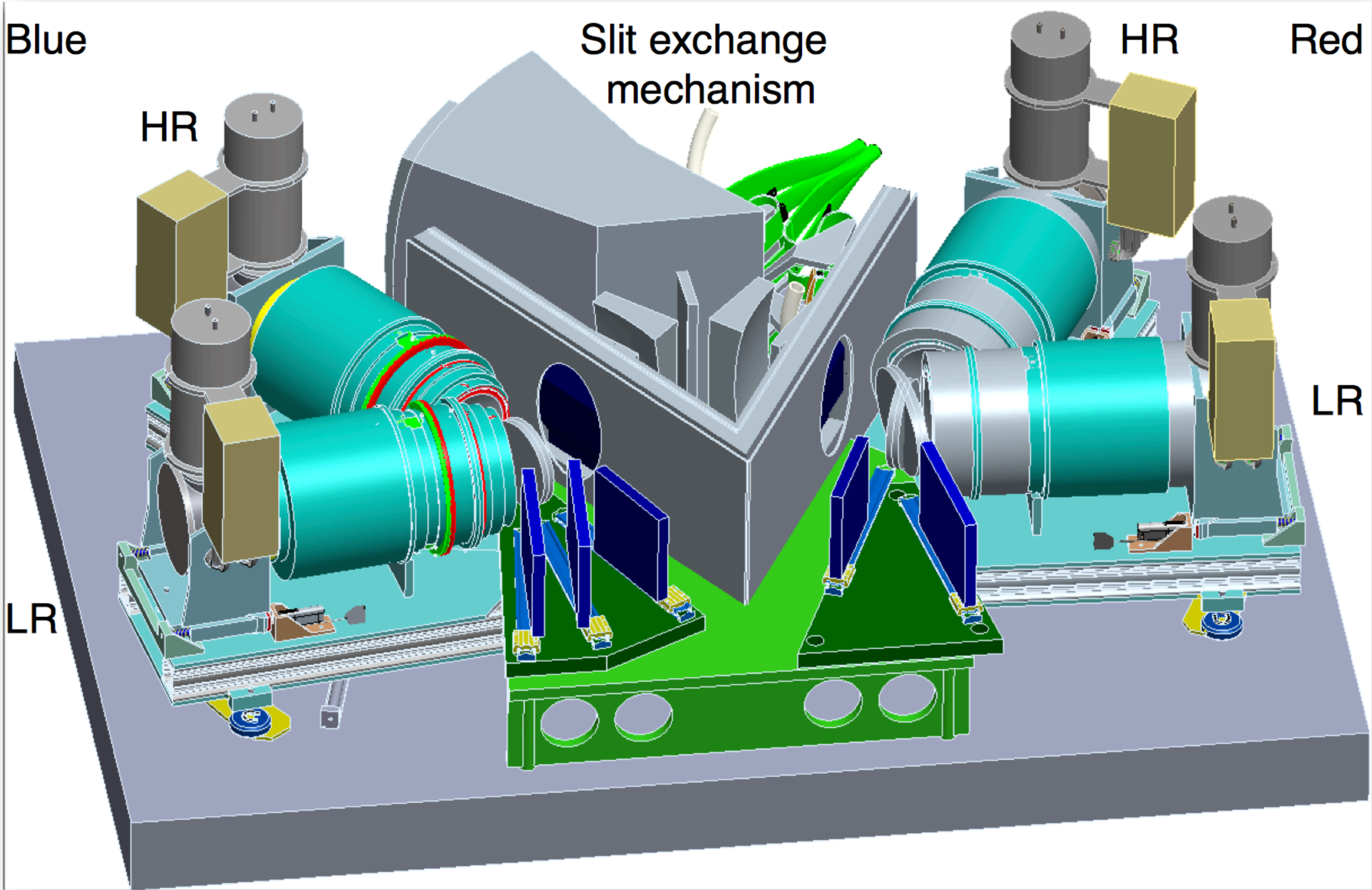
10"x

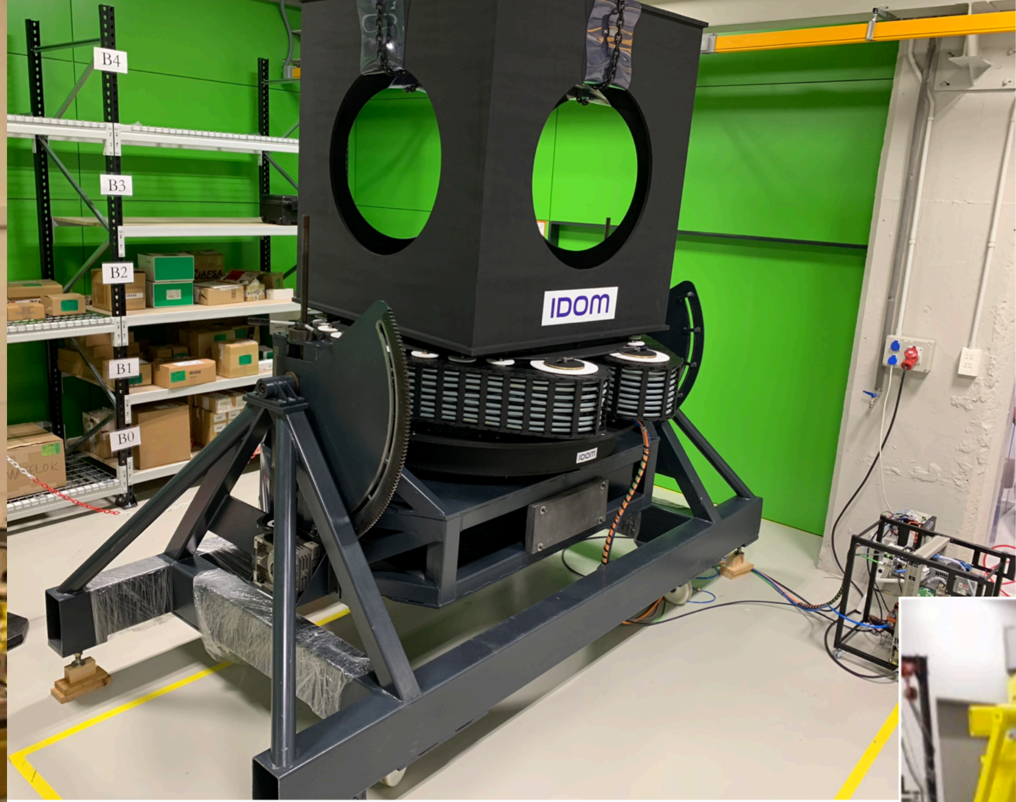
LIF

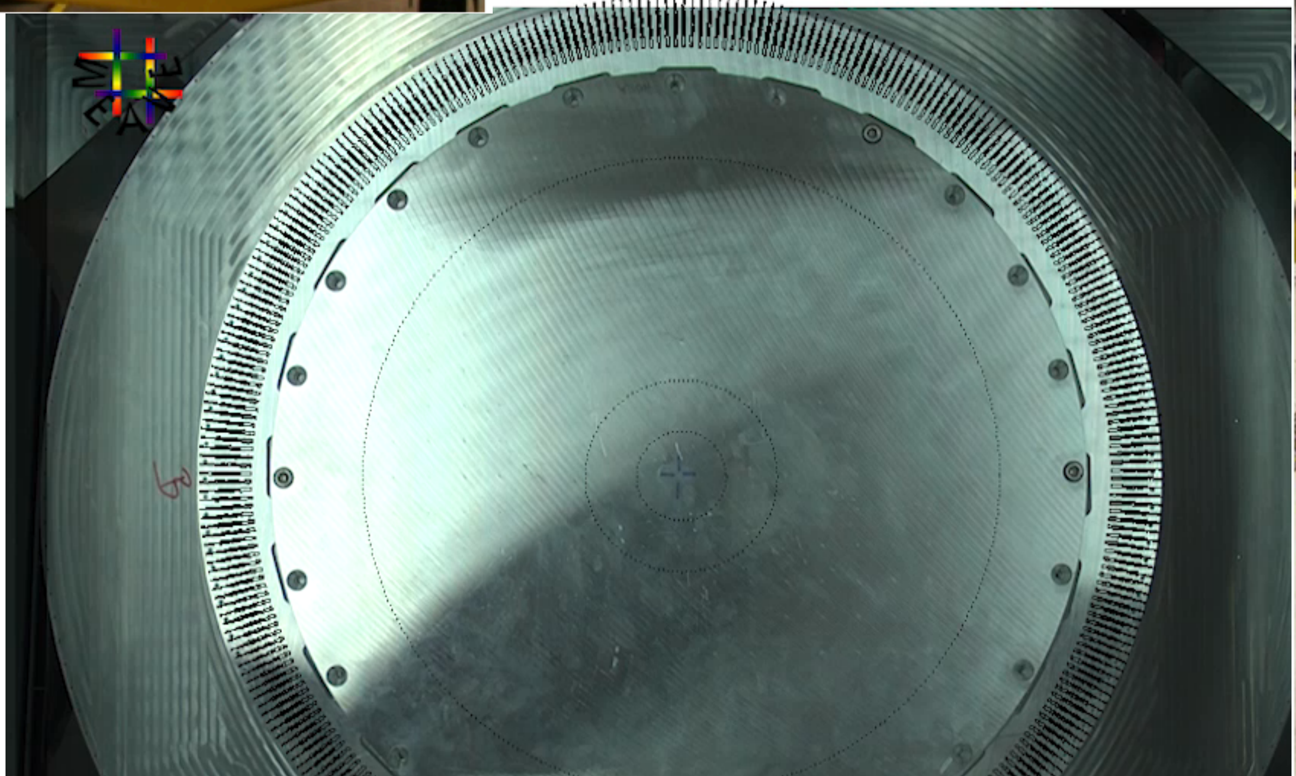
1.5'x



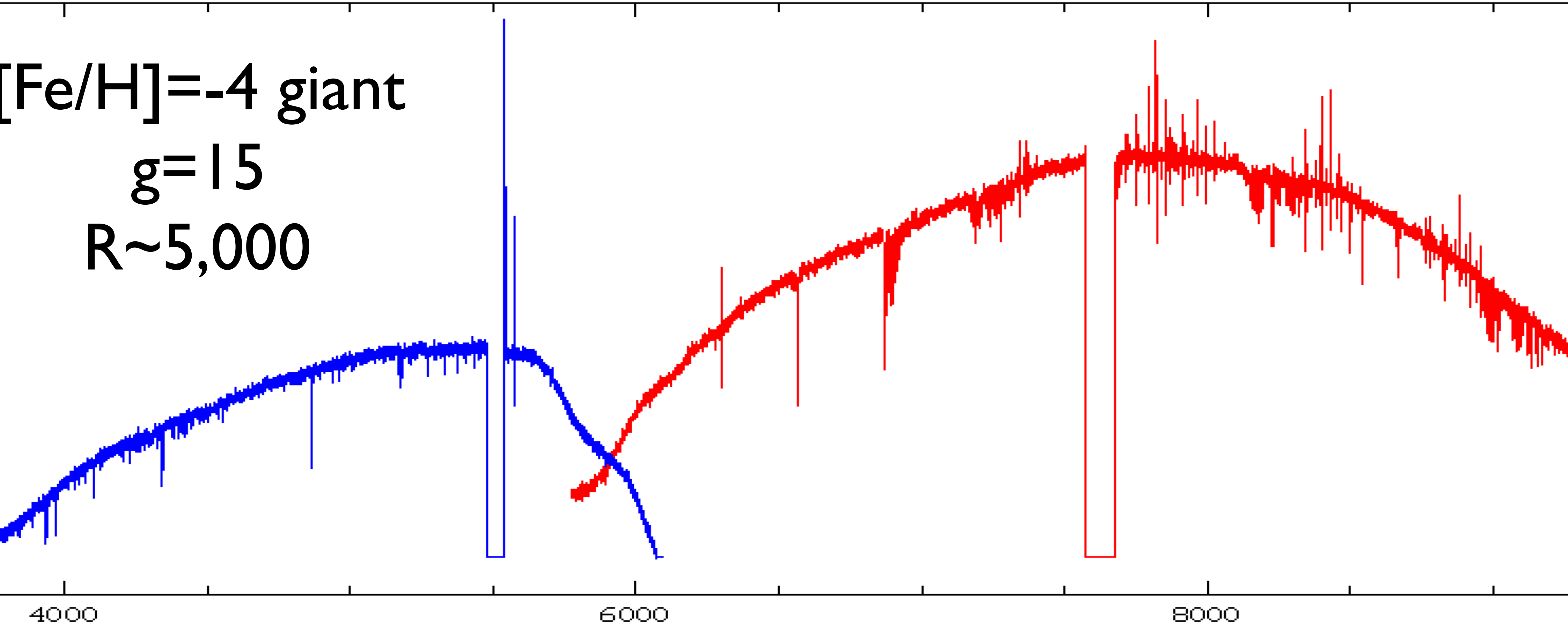


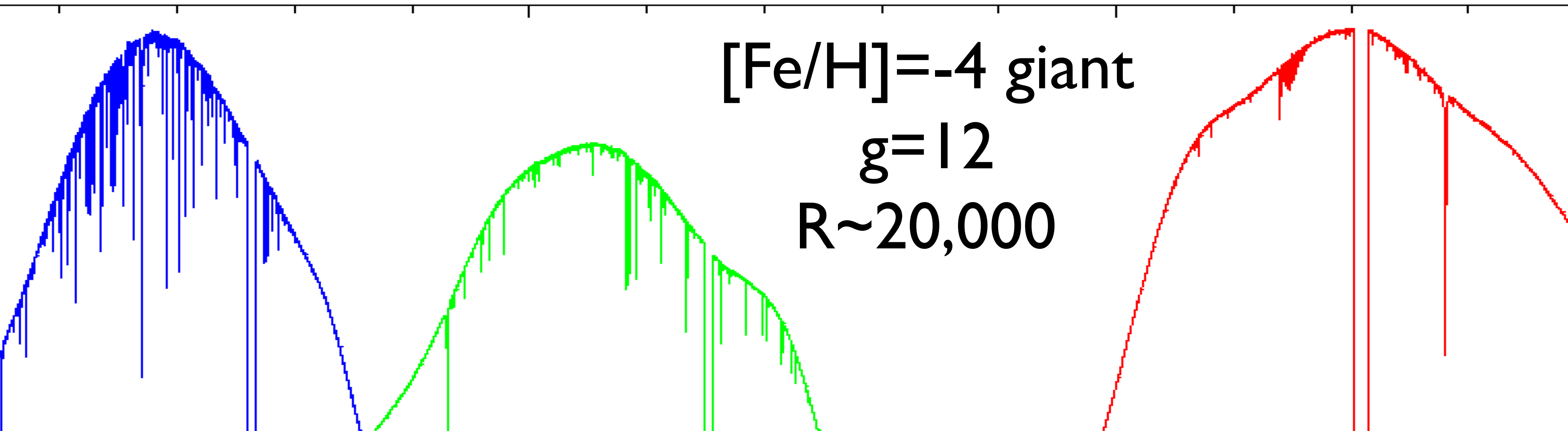

Blue
Slit exchange mechanism
HR
Red
HR
LR
LR





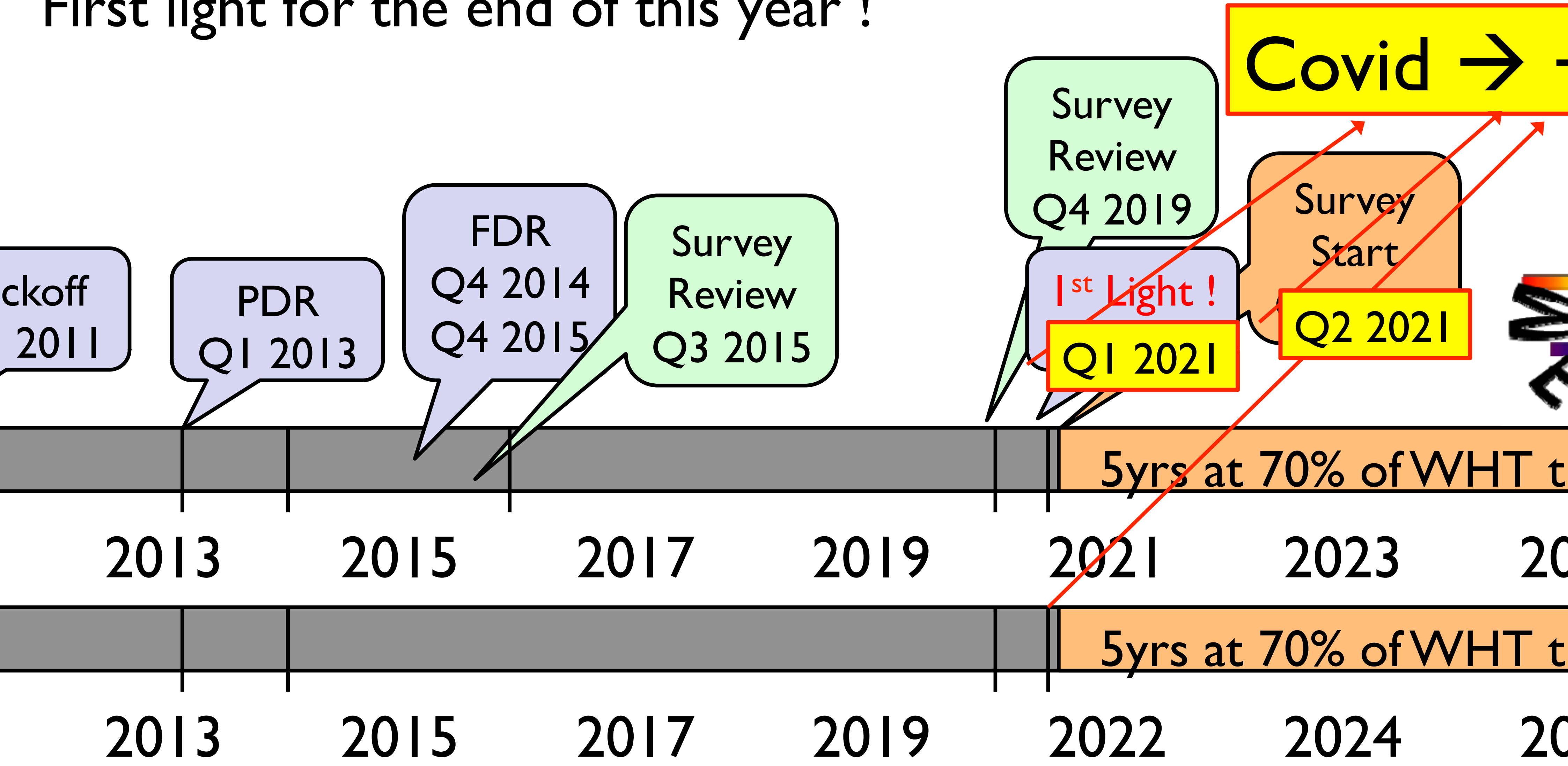
AVE will
at a field
r >=1h


[Fe/H]=-4 giant
g=15
R~5,000
4000
6000
8000


[Fe/H]=-4 giant
g=12
R~20,000

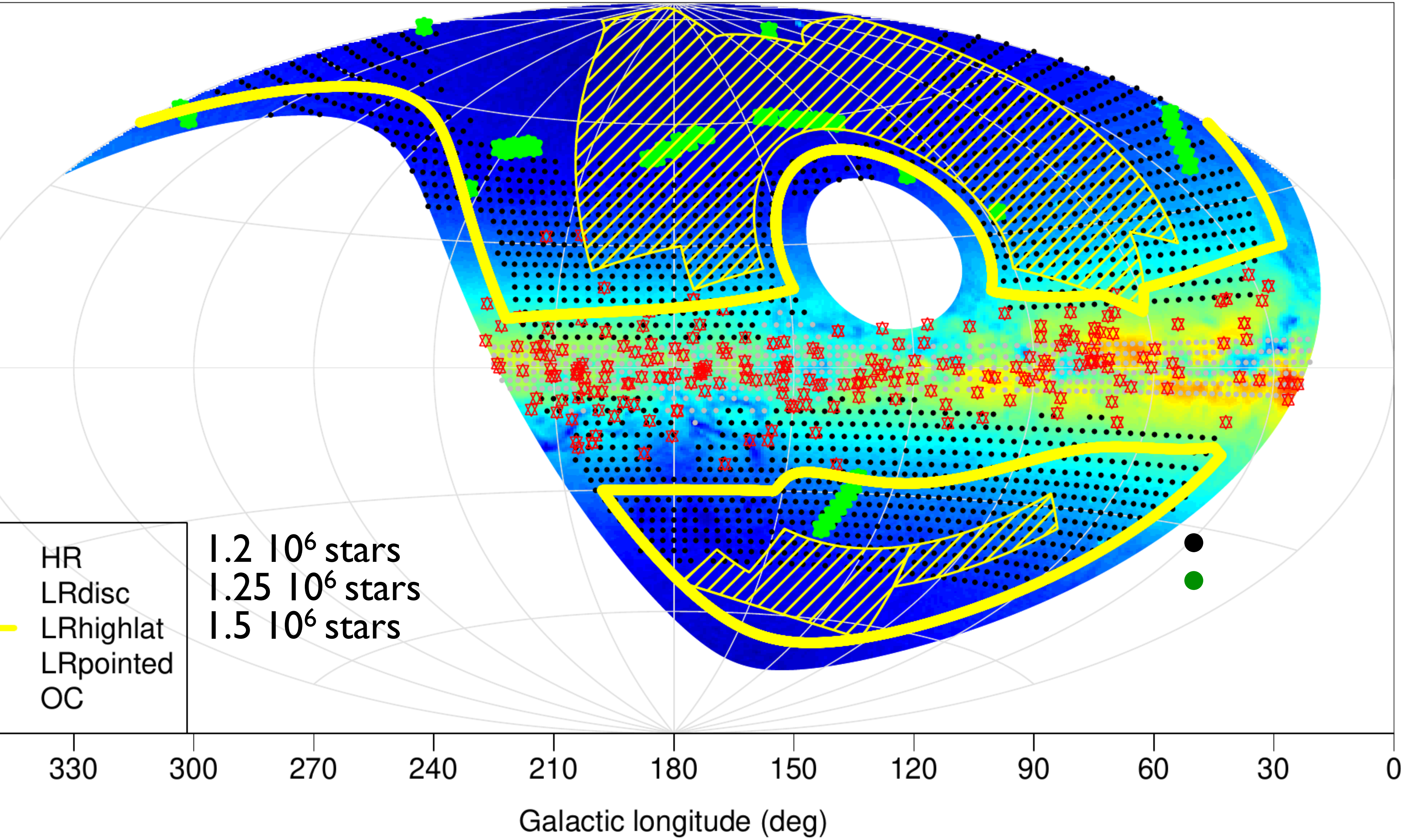
WEAVE timelines

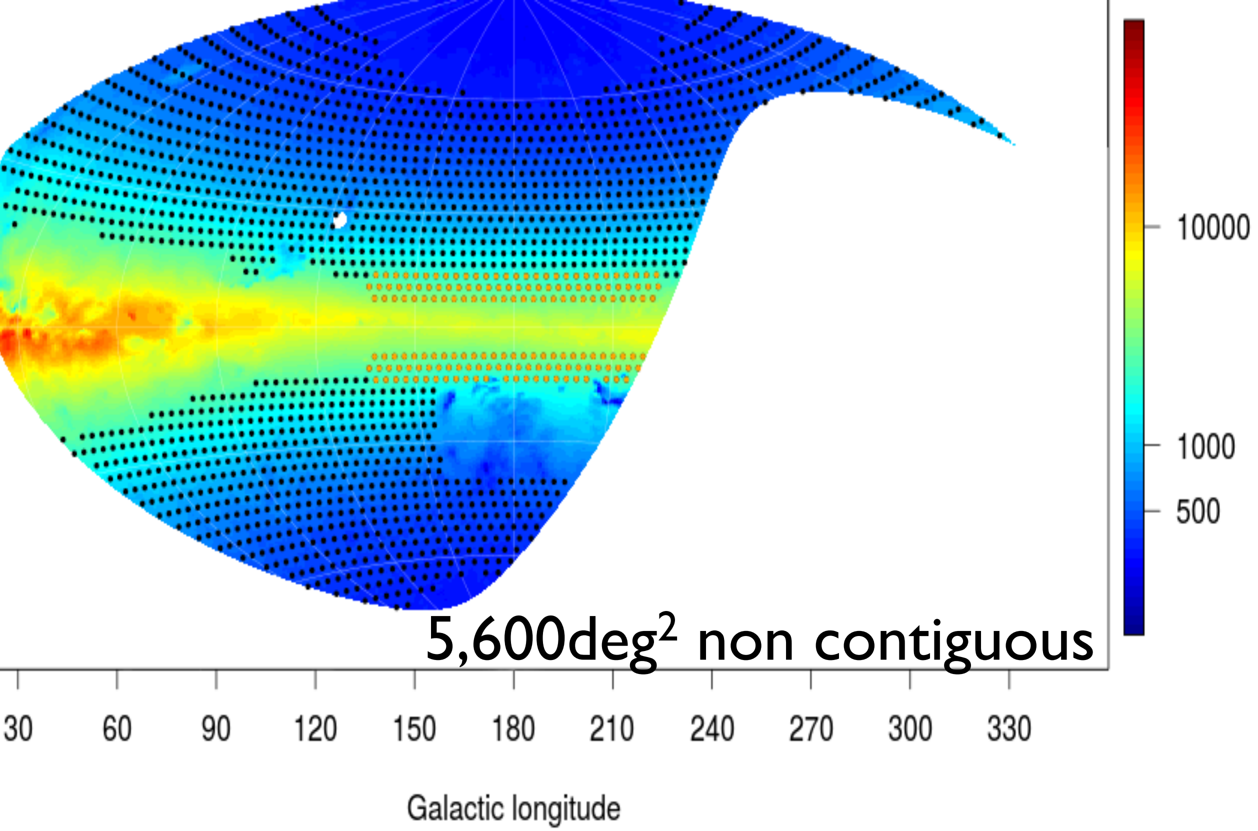
Currently in fabrication.
First light for the end of this year !

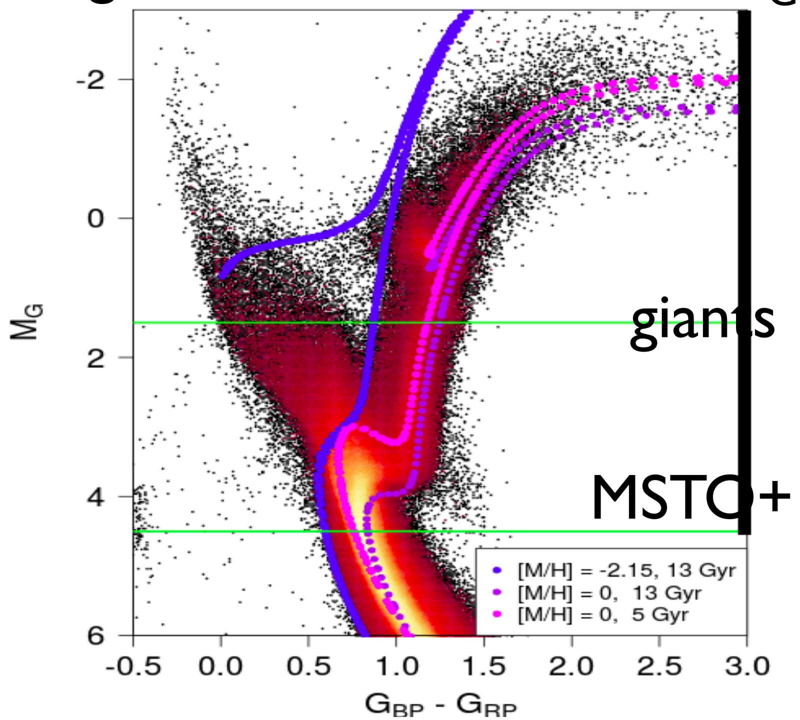


WEAVE is the last/ultimate pick & place MOS

WEAVE-GA surveys at glance

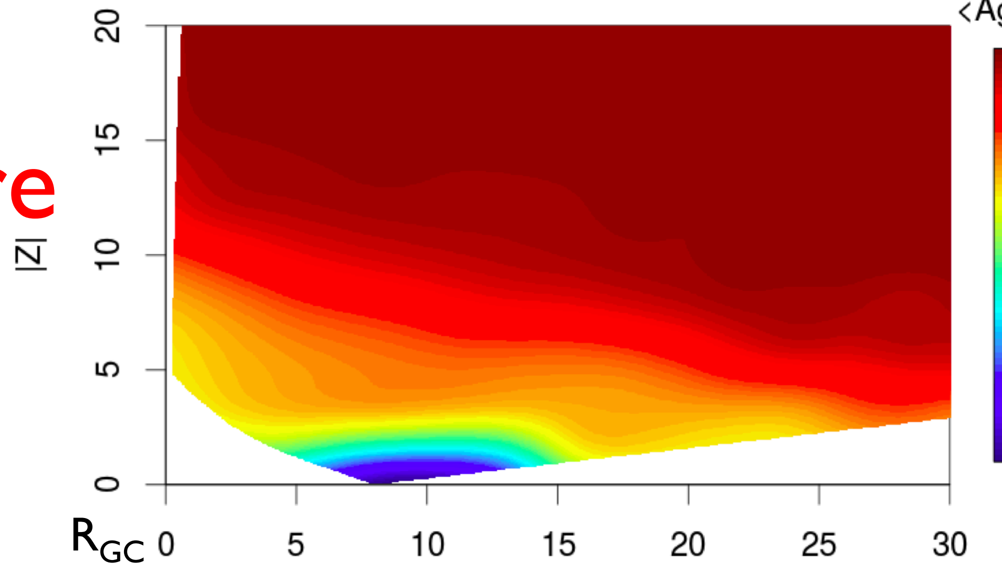






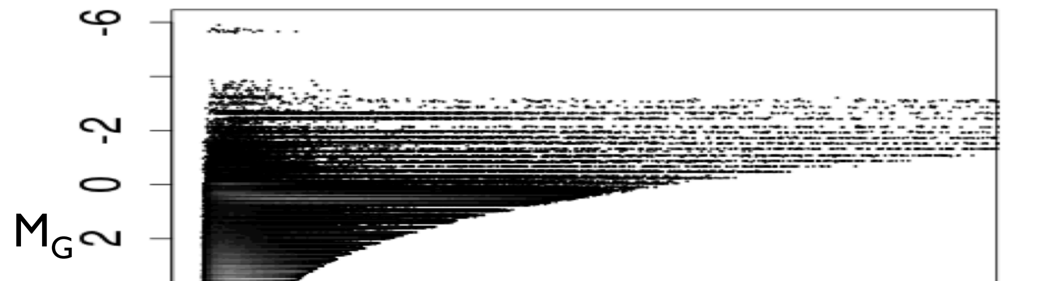
~10^6 stars in Gaia's age sphere

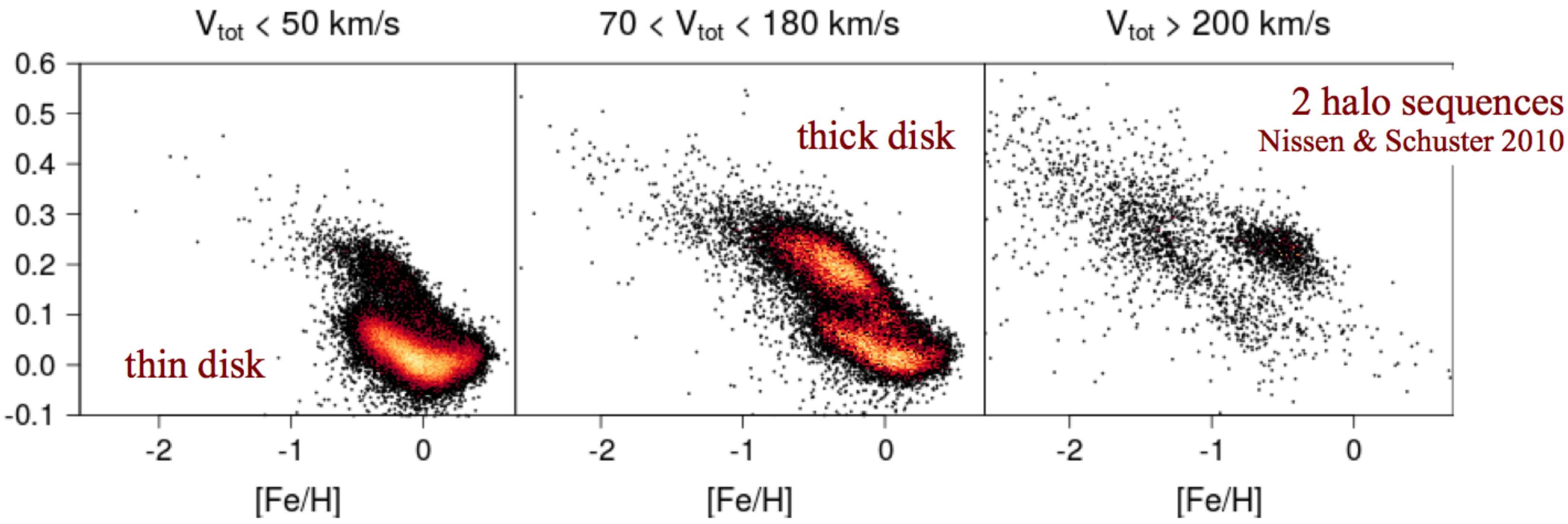
gnitude <M_G<4	σπ/π	Distance	%	Nb of stars
16	9%	2 kpc	28%	500,000
14	1%	0.8 kpc	11%	200,000



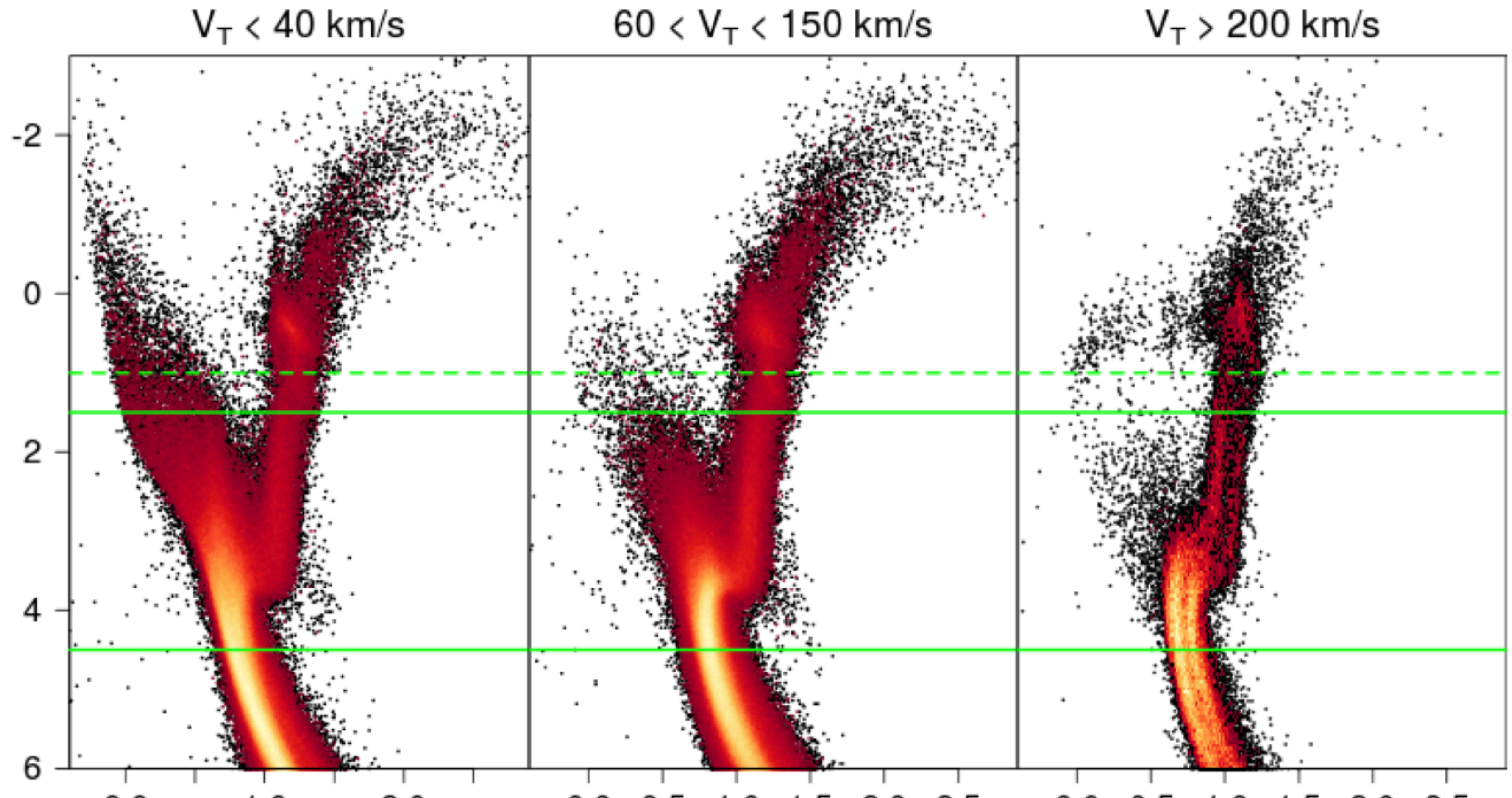
~2.10^5 stars reaching out

ough the thick disc (giants)



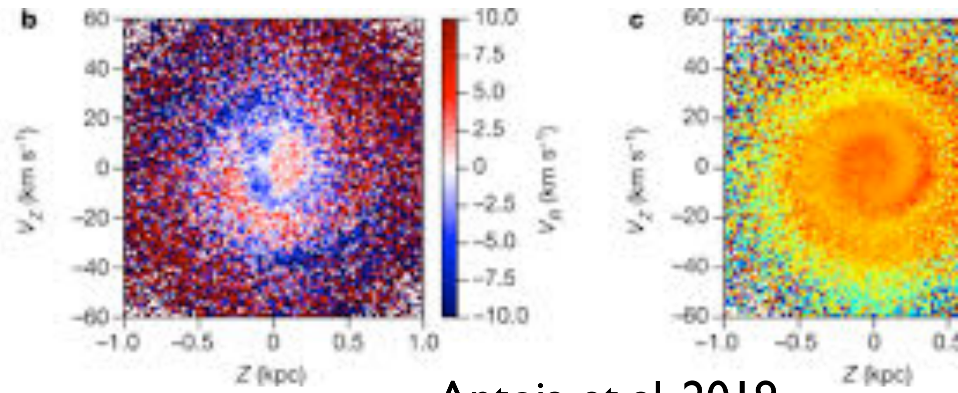


Cortesy C. Babusiaux

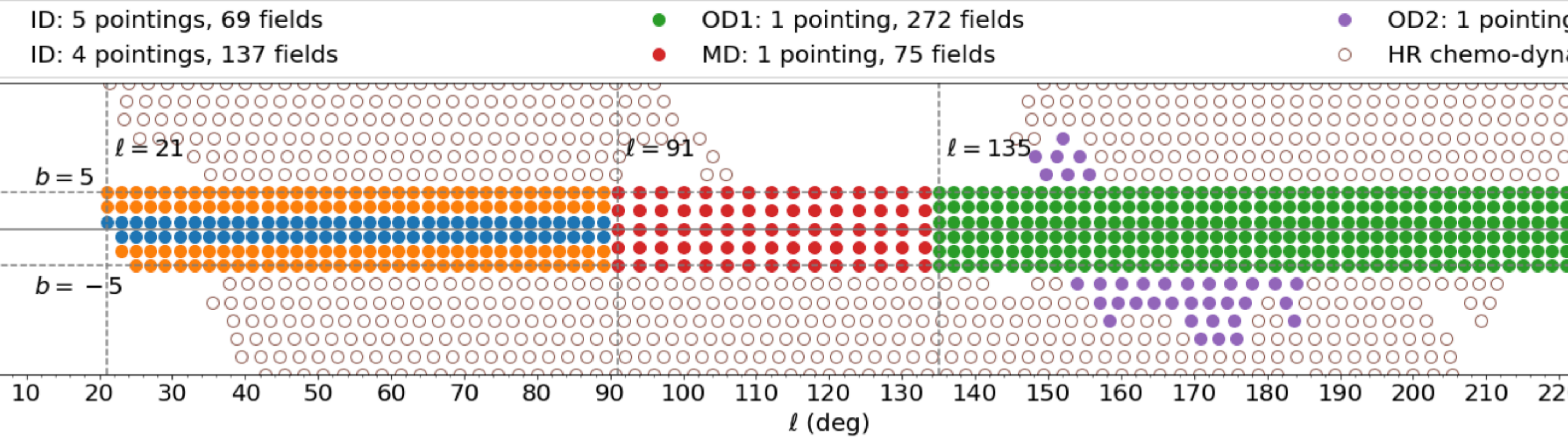


90% of WEAVE GA
have σ_π/π<20% (
DR2)

criminate fundamental aspects of
ctic disc dynamics: moving groups,
city elipsoid accross the disc ➔
e the axisymetric potential + non-
ymetric terms (bar, spiral arms).



Antoja et al. 2019

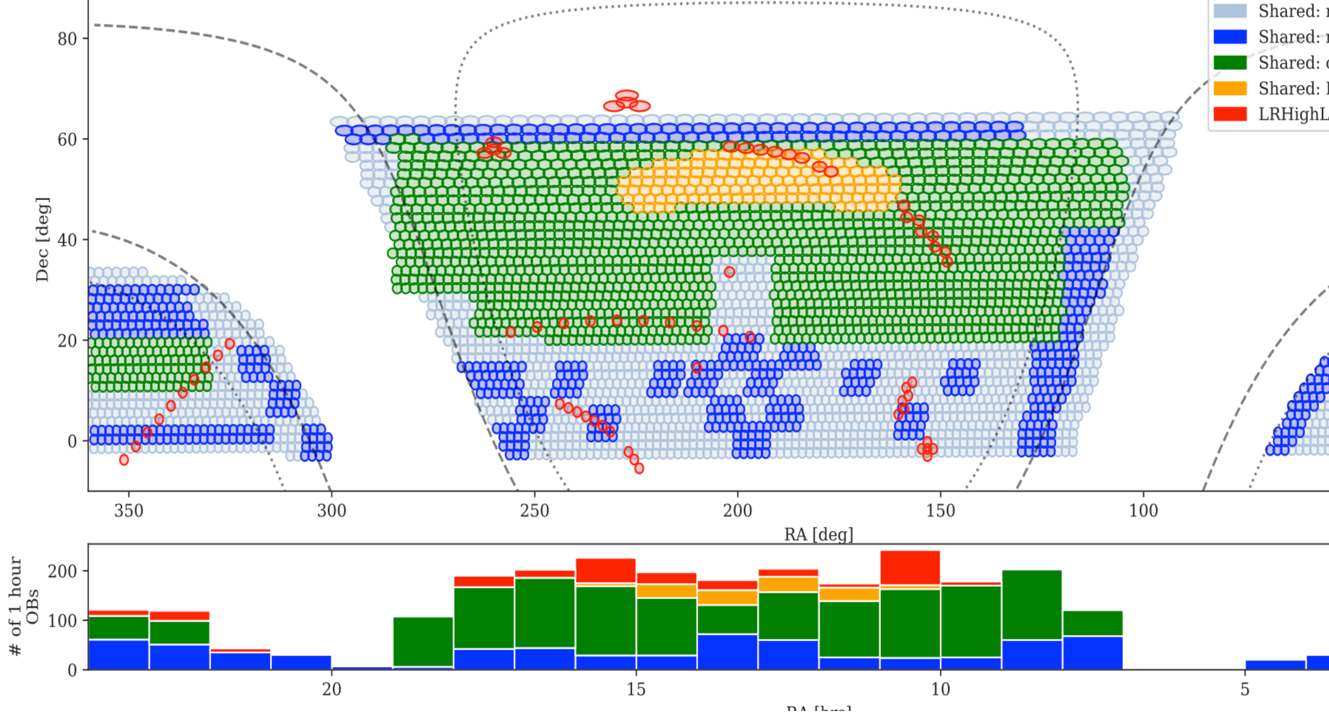


or a total of ~1.1 10^6 stars

➢Red Clump stars in the inner disc (ID and MD) (colour-magnitude select

down to r<=19; Giants in the outer disc (Gaia M_G selected) to G<=18

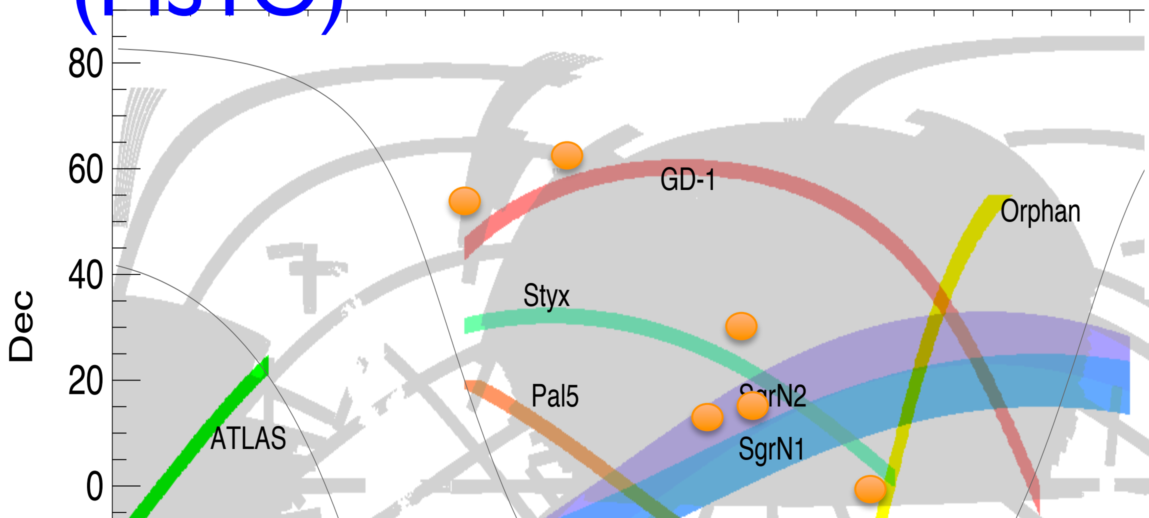
e-area survey =
red area survey”
deg^2, Down to r = 20-21
bined with cosmological
ys (LOFAR, QSOs)
rs: MSTO and giants + BHB/
and EMP stars (from Pristine)

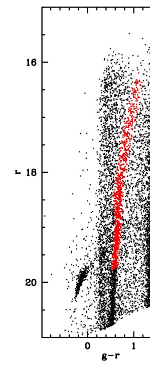


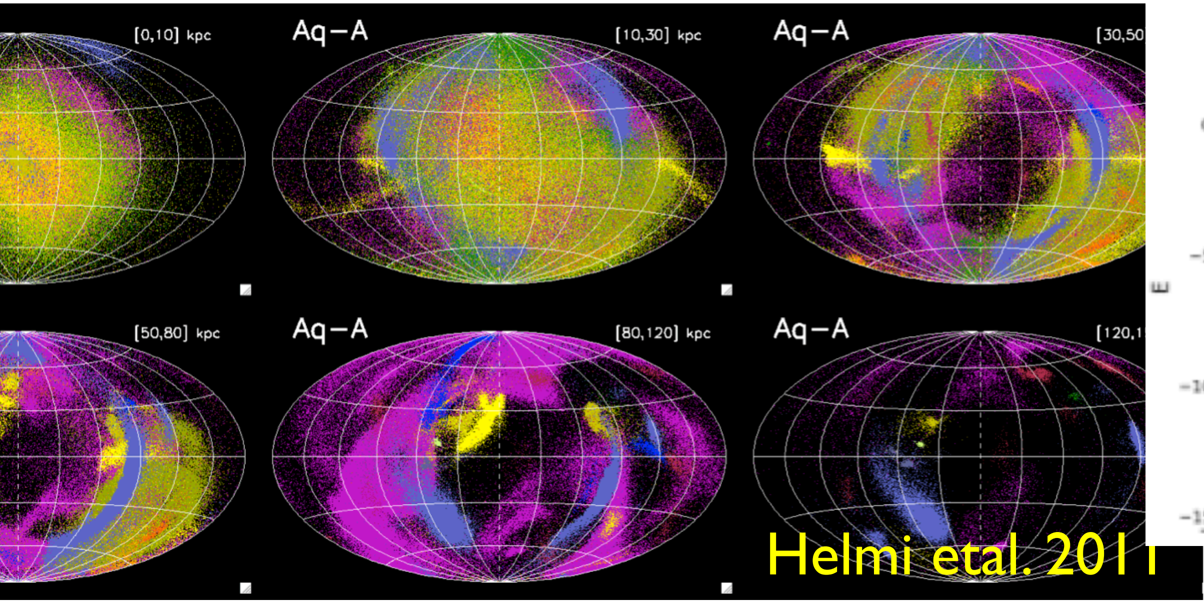
Expect:

Halo: ~1-2.10^5 halo giants out to ~100kpc; ~3.5.10^5 halo MSTO t
~30kpc; ~4.10^4 BHB and EMP candidates + Thick disc: ~6x10^5 sta
(MSTO)

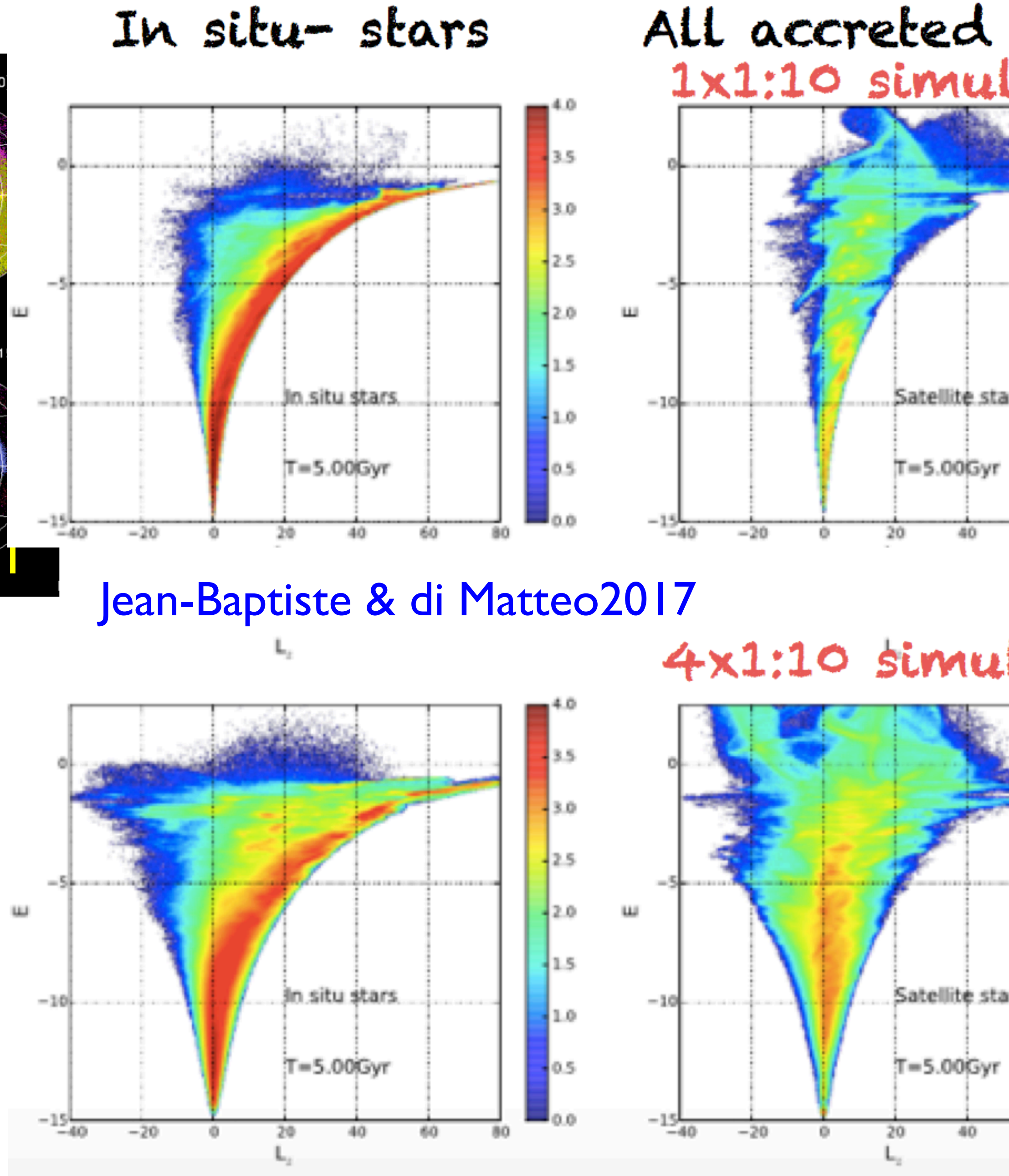
nted survey:
deg^2 w 4h/pointing
nown streams and
warf galaxies
nts down to r = 21, repeated







Helmi etal. 2011



Jean-Baptiste & di Matteo2017

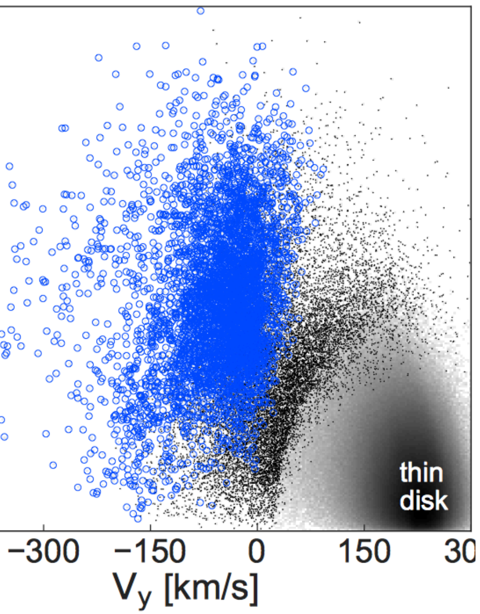
alaxy mass, potential; halo shape,
umpiness
our halo all built up from
ssembling small sub-systems? ;
ow much "in-situ" formed halo
nd from what origin (heated disc,
mooth gas accretion, …) ?
ost merger traces found D[10-30]kpc, but all mixed in "sky views

2-D → 3-D → 5-D → 6-D → 12+ D

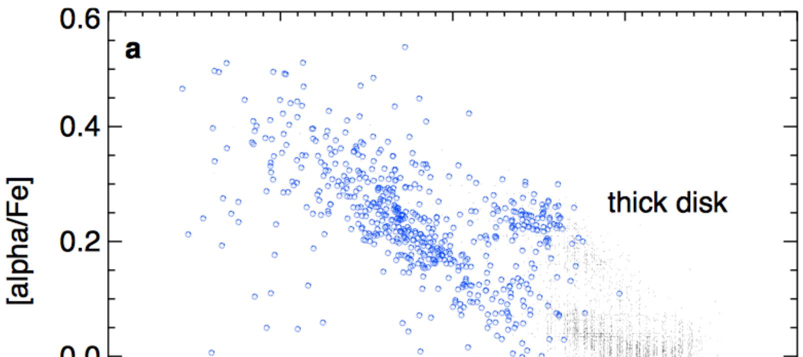
Position | Parallax | Proper motions | Spectrum | Astrophysical parameters

Ultra-precision, over years | Distance | Transverse velocities | Radial velocity + chemistry | Ages, histories astrophysics

Gilmore et al. (2012)



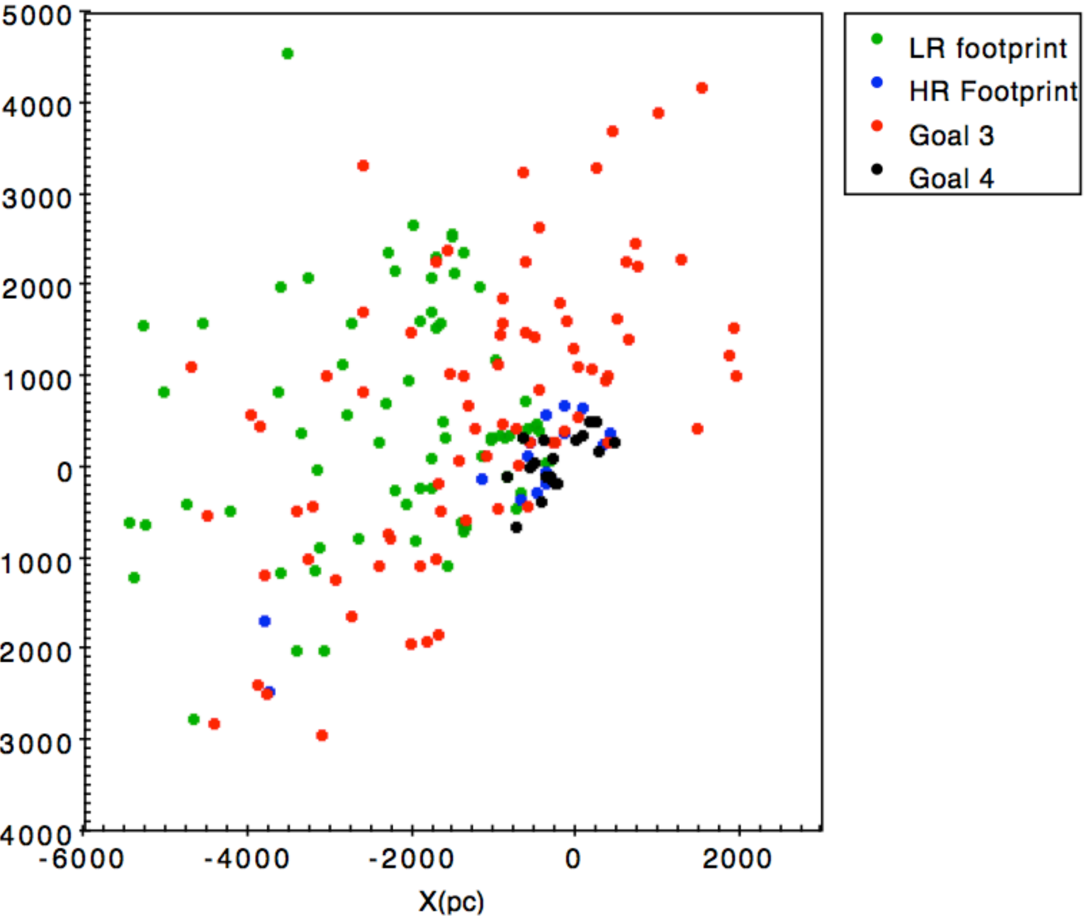
mi et al. 2018.

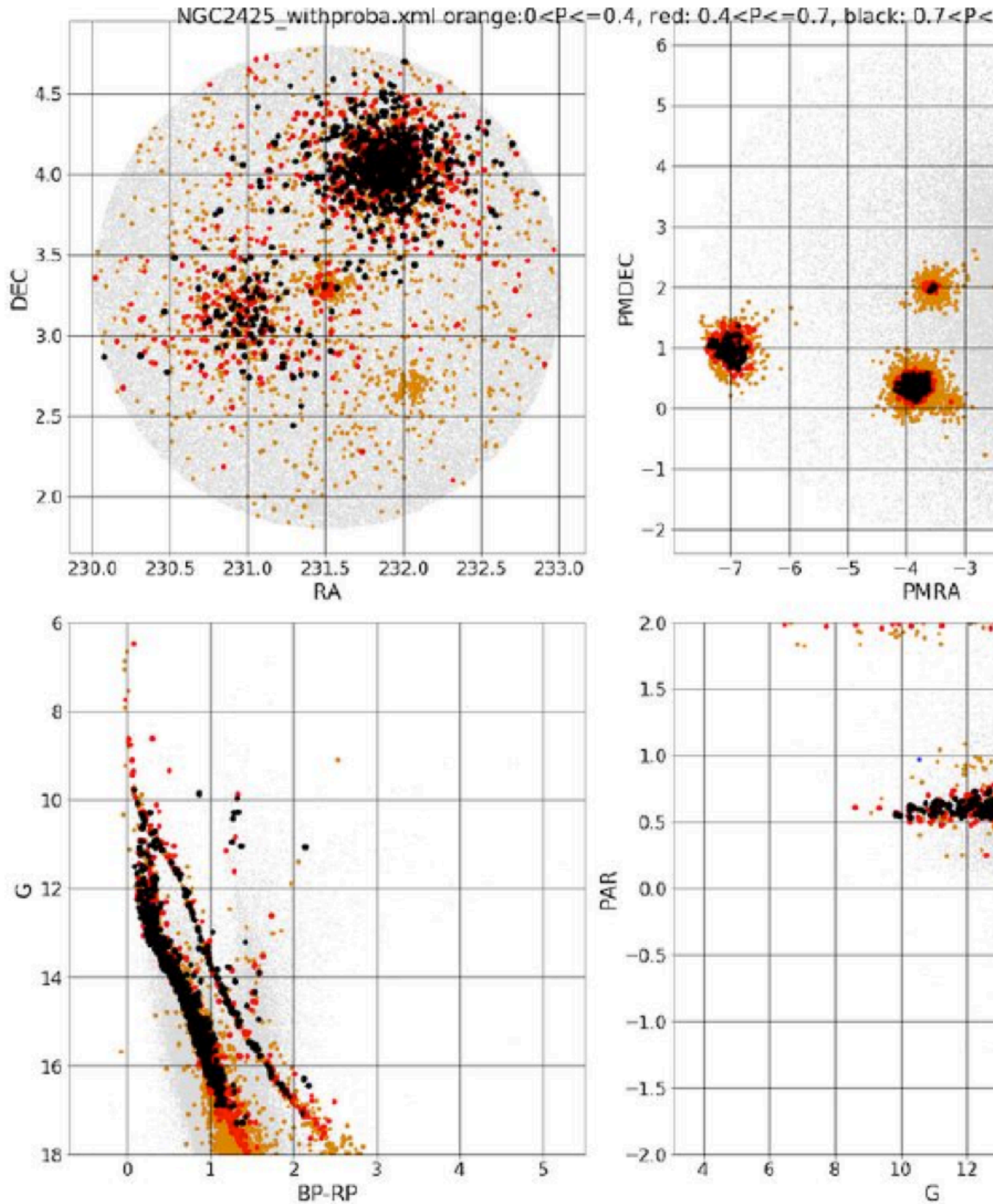


Hayden et al. 2015

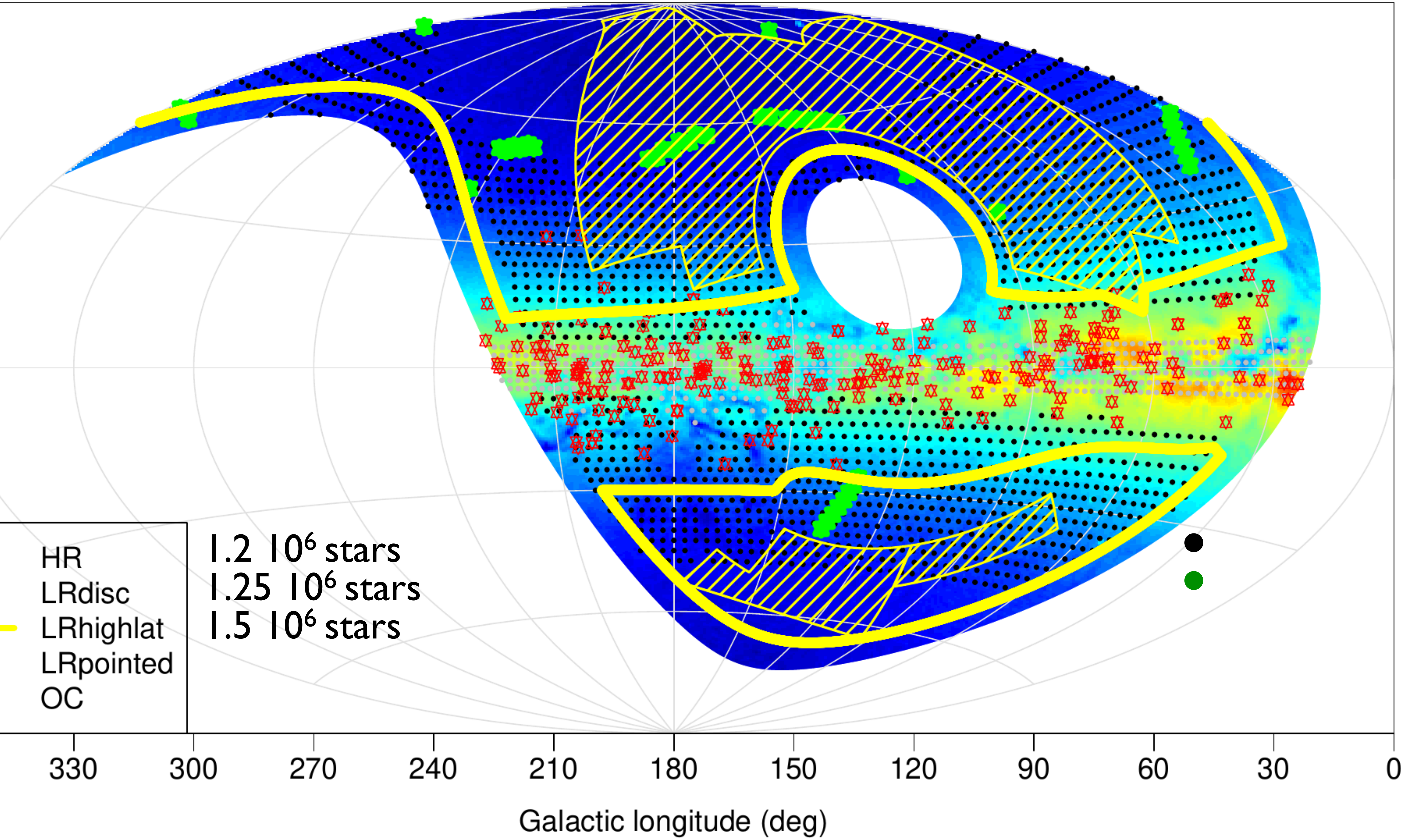
lusters as probes of the galactic disc (gradients at different ages, etc…), wi
pecial care about covering the parameter space (galactocentric radius, age,
etallicity)

ormation of clusters; Star formation





WEAVE-GA surveys at glance



Comparing survey facilities

Telescope	Diameter (m)	FoV (deg^2)	Etendue (m^2.deg^2)	
VLT – FLAMES / MOONS	8.0	0.136	6.63	Spectro VIS/NIR
Subaru - PFS	8.0	1.33	64.7	Spectro VIS
LSST	8.2	9.6	320	imaging
MSE	11.2	1.5	151	Spectro VIS
SDSS (SEGUE/BOSS/ eBOSS, APOGEE, SDSSV)	2.5	7.0	20.9	imaging+spectro VI NIR
PanSTARRS – 1	1.8	7.0	12.9	imaging
BlancoDECAM – DES	4.0	3.0	28.5	imaging
Mayall - DESI	3.8	8.0	77	Spectro VIS
WHT - WEAVE	4.2	3.14	38.3	Spectro VIS
VISTA – 4MOST	3.7	4.0	38.3	Spectro VIS
AAT - GALAH	3.9	3.14	13.9	Spectro VIS

Etendue (collecting surface x field of view) is one of the metrics to compare different facilities, tracing the efficiency of a survey to achieve a given depth on an area on the sky.

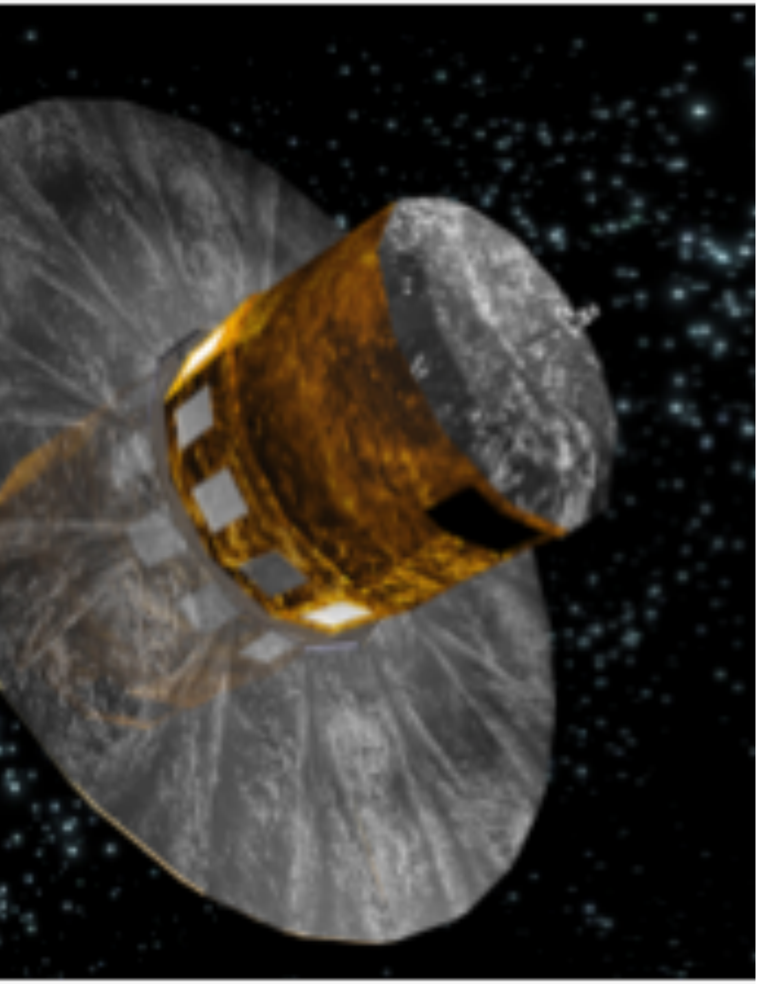
omparing spectroscopic survey faciliti

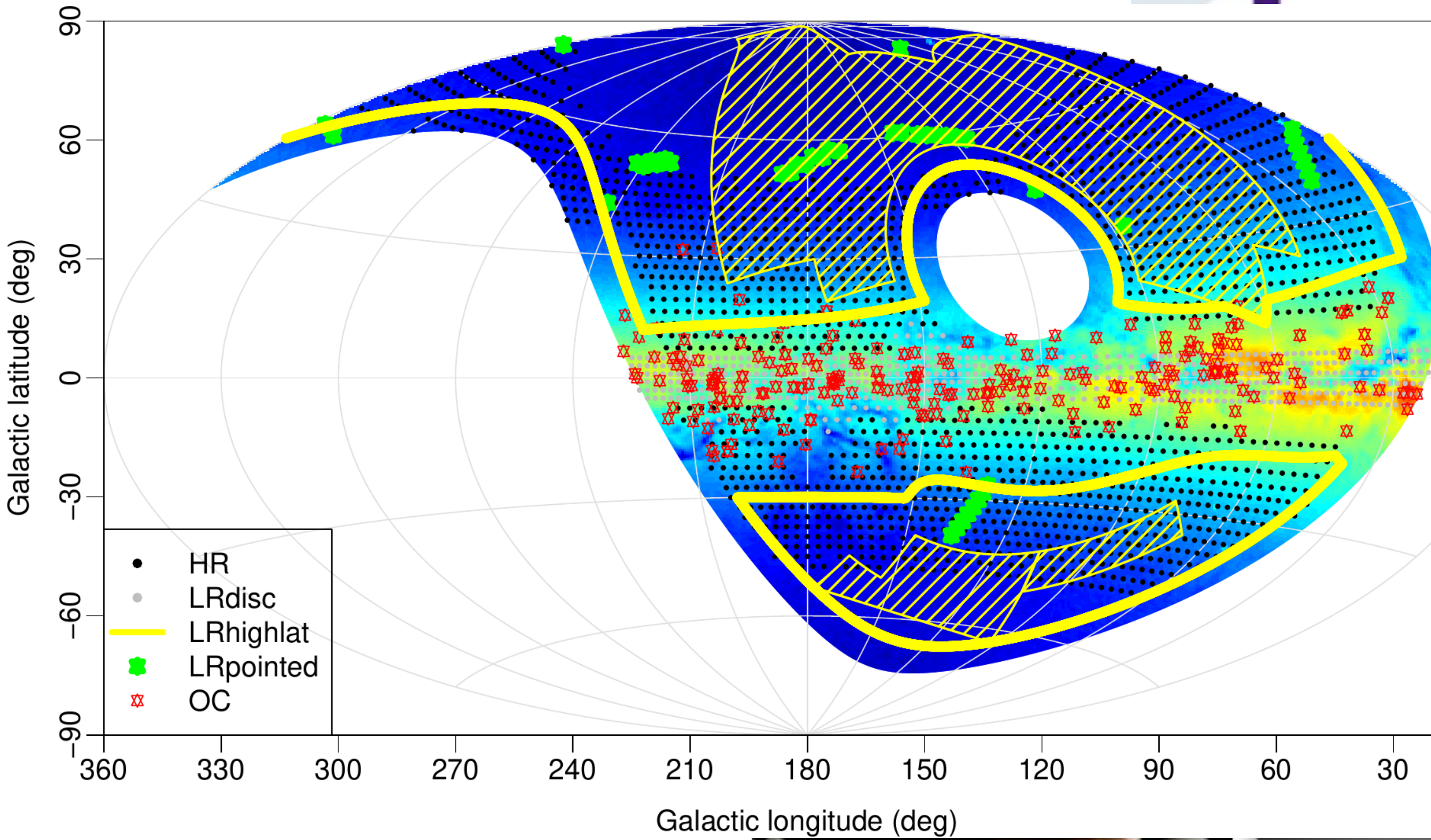
Telescope	Diameter (m)	FoV (deg^2)	Etendue ($m^2.deg^2$)	
VLT – FLAMES / MOONS (GES/ MOONS)	8.0	0.136	6.63	Spectro VIS/NIR
Subaru - PFS	8.0	1.33	64.7	Spectro VIS
MSE	11.2	1.5	151	Spectro VIS
SDSS (SEGUE/BOSS/ eBOSS, APOGEE, SDSSV)	2.5	7.0	20.9	spectro VIS/NIR
Mayall - DESI	3.8	8.0	77	Spectro VIS
WHT - WEAVE	4.2	3.14	38.3	Spectro VIS
VISTA – 4MOST	3.7	4.0	38.3	Spectro VIS
AAT - GALAH	3.9	3.14	13.9	Spectro VIS
LAMOST	4	5	<=30	Spectro VIS

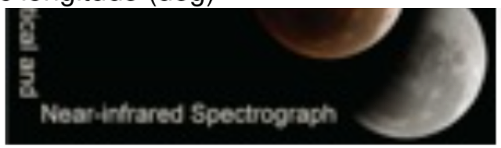
For spectrographs, also crux are :

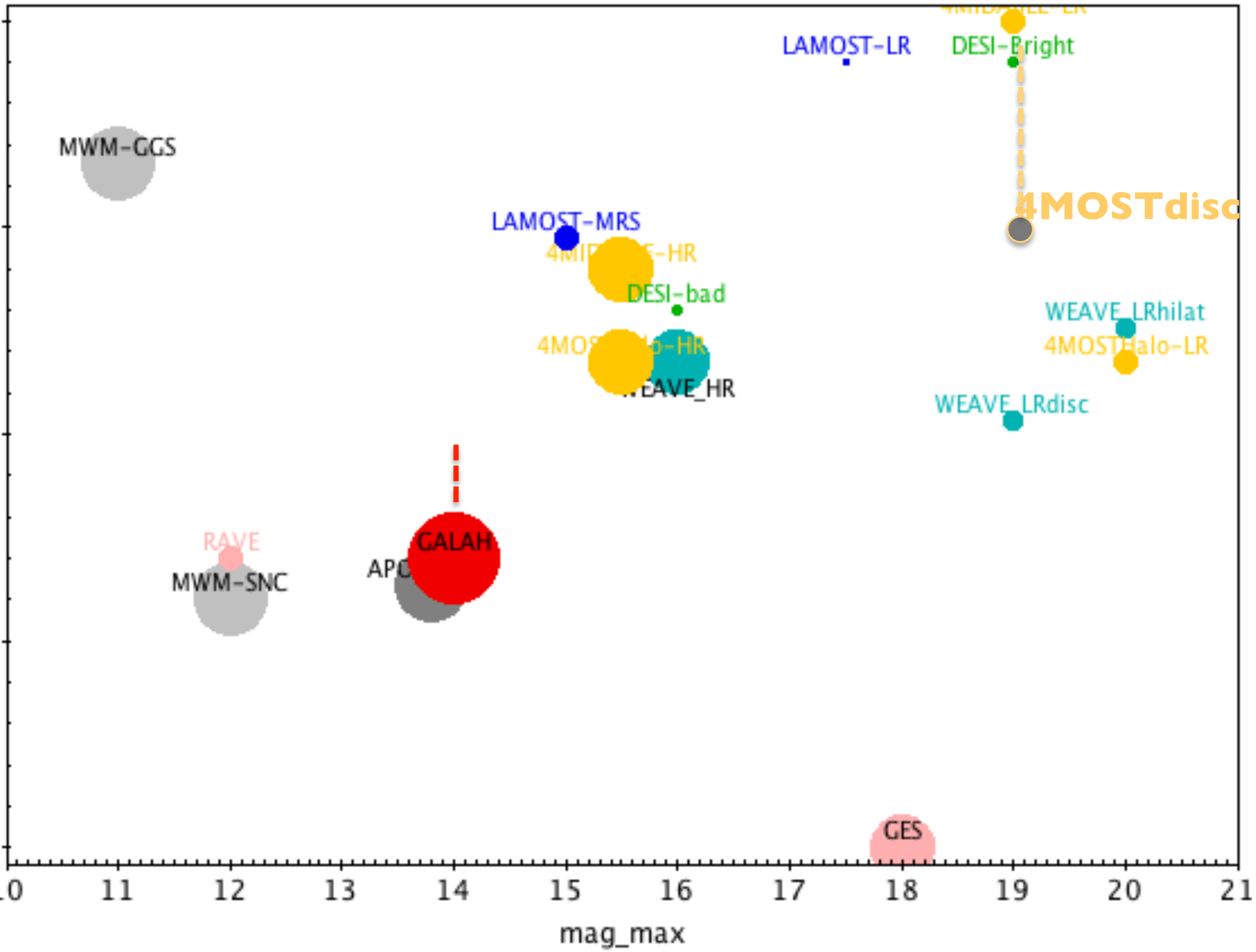
- *the nb of spectra obtained in each FoV*
- *spectral resolution that drive Vrad precision, and chemical information*
- *The spectral coverage (blue, visible, NIR), that drive chemical information*

the Milky-Way !





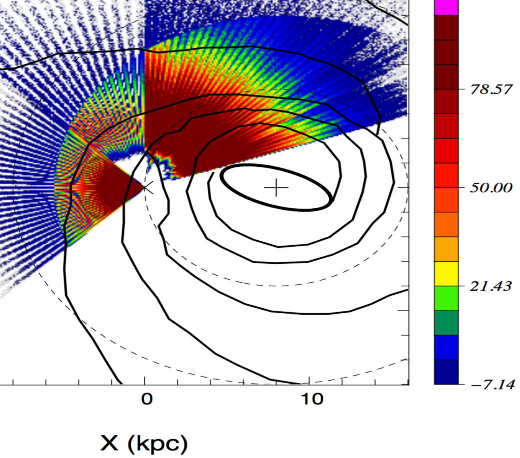


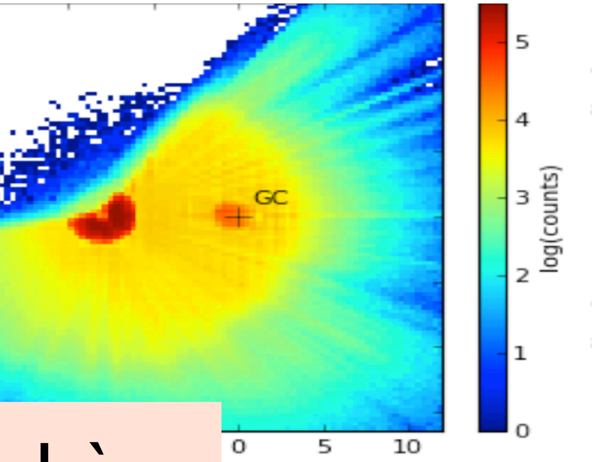


- North, visible: WEAV
  DESI, LAMOST
- South, visible: 4MOST
  GALAH, GES, RAVE
- Both hemispheres an
  NIR: APOGEE, SDSSV
  MWM
- Point size = Resoluti
  (1800 to 28,000)

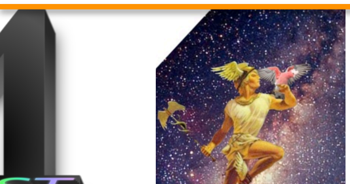
WEAVE-HR: complementary to GALAH and 4MOST-HR (hemisphere); APOGEE ver
different elemental abundances accessible and tracers

WEAVE-LRhighat: 4MOST complementary (hemisphere); DESI will have many more s
but shallower (>=1 mag)





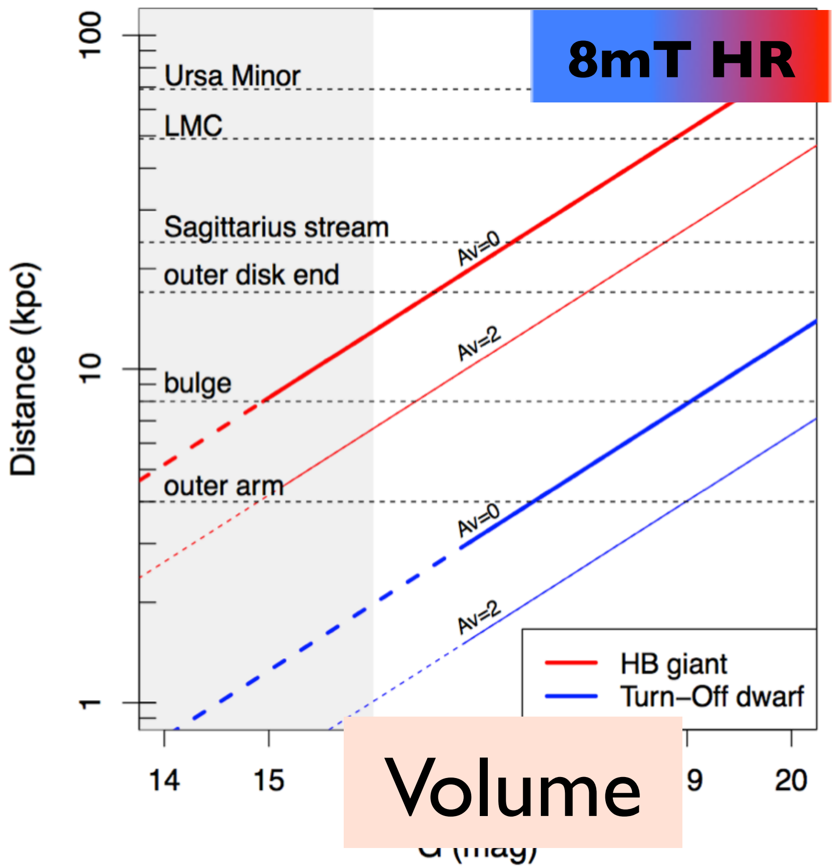
phère



4mT HR

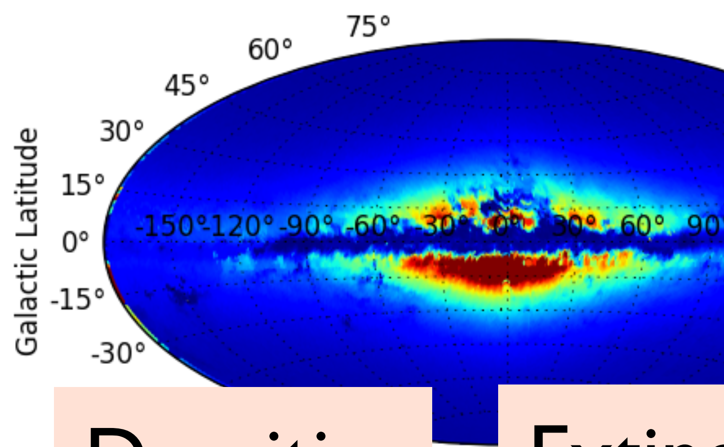
4mT LR

8mT HR



Volume

Thick disc stars with V <

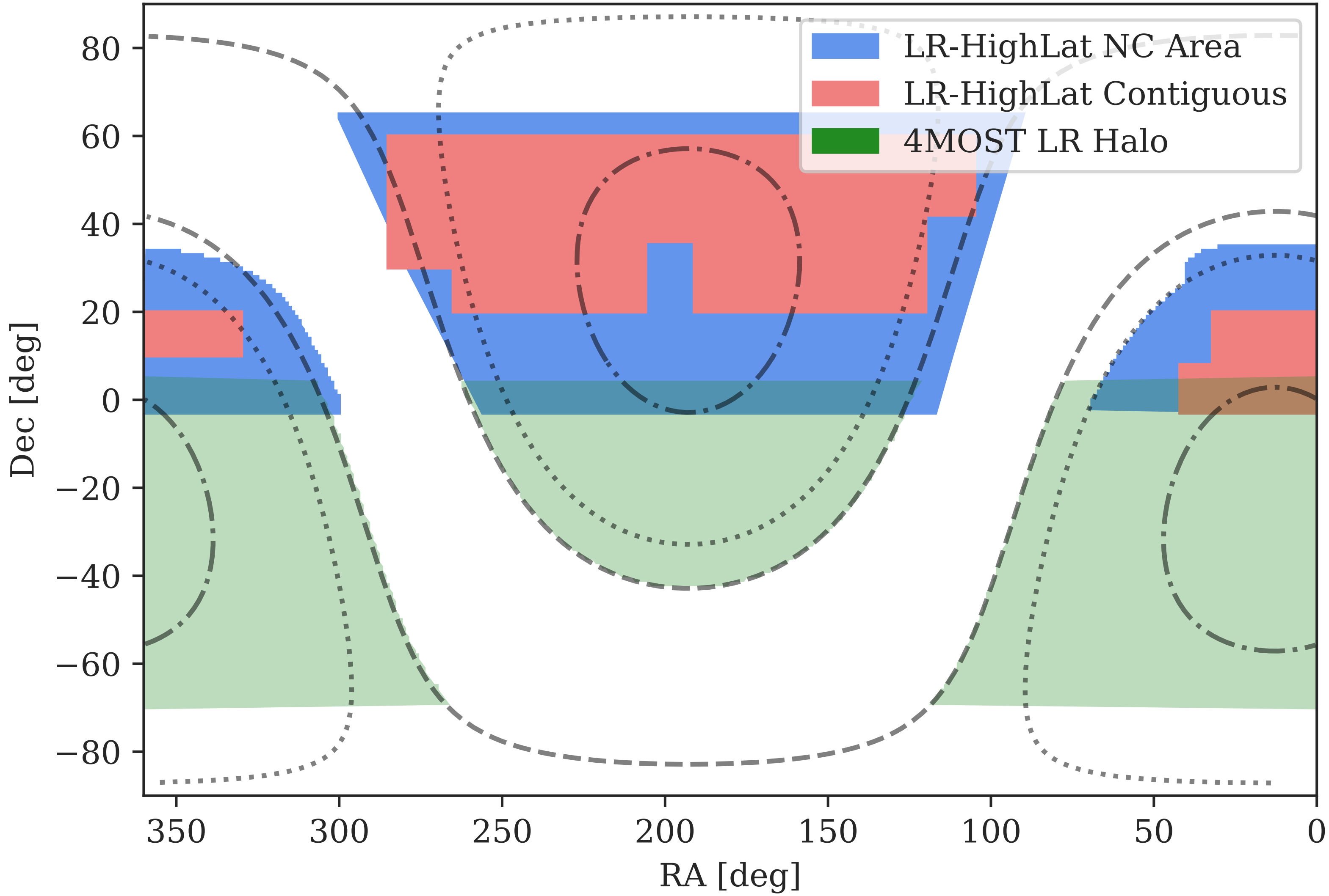


Densities

Extinc

- All MOS on 4m+ telescopes.
- European MOS go deeper (site + Res. for GALAH; exptime for DESI; telescope for APOGEE vs MOONS)

WEAVE LRhighlat vs 4MOST HaloL



- Complementarity: hemisphere.
- comparable area (4MOST 10,000deg^2 – WEAV

synergy with Gaia:

Ideally, we'd want to be able to use all together !! This implies:

Homogeneity / means to cross-calibrate:

- Most in the optical (SEGUE, RAVE, LAMOST, GALAH, WEAVE, DESI, 4MOST,PF MSE…) ; but also in the NIR (APOGEE, MOONS, …)
- Different resolution regimes: R<2,000; R~5,000; R~20,000
- Analysed independantly, with different methods
- Target selection need to be tractable in all surveys !

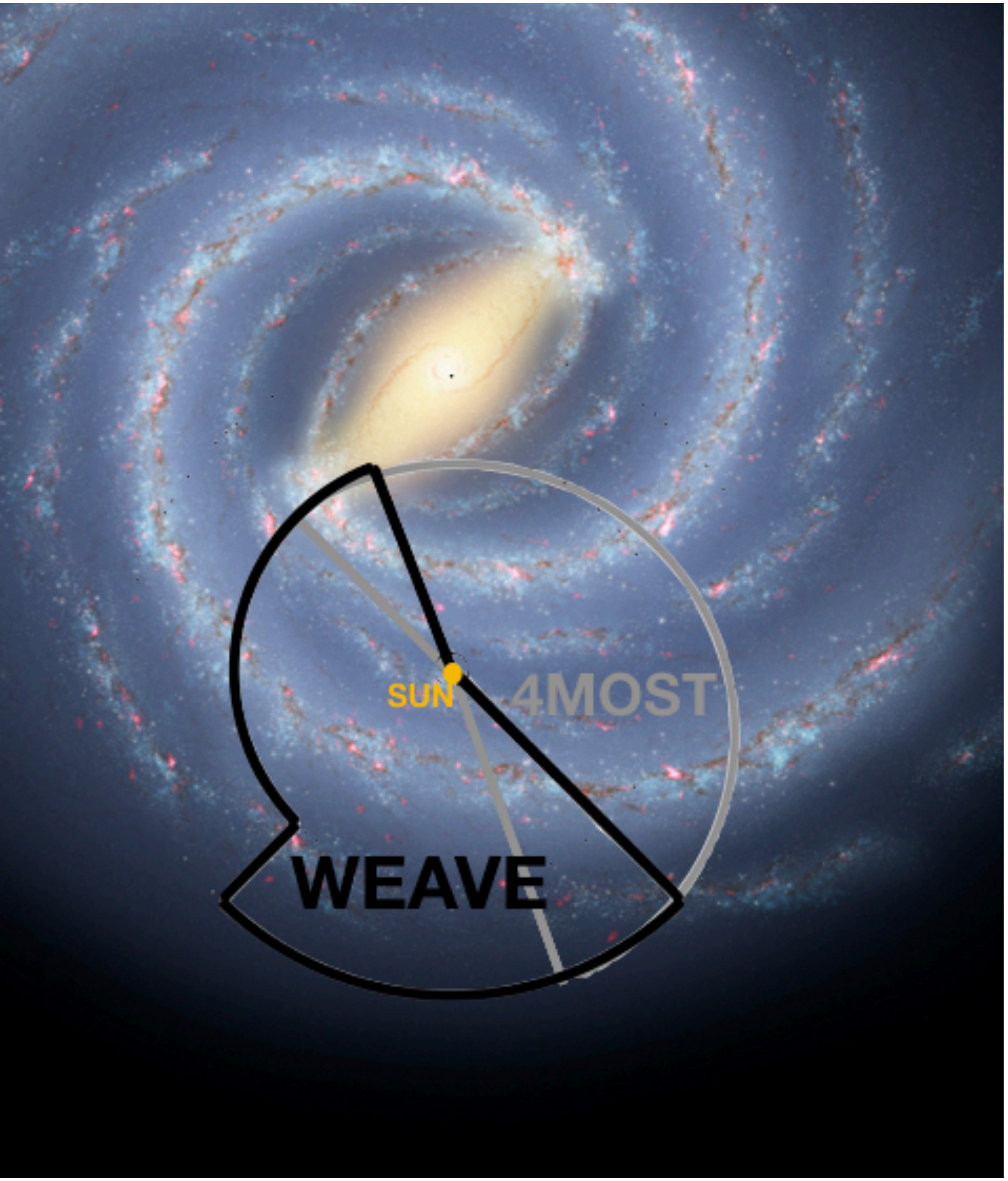
Survey overlap for cross-calibration

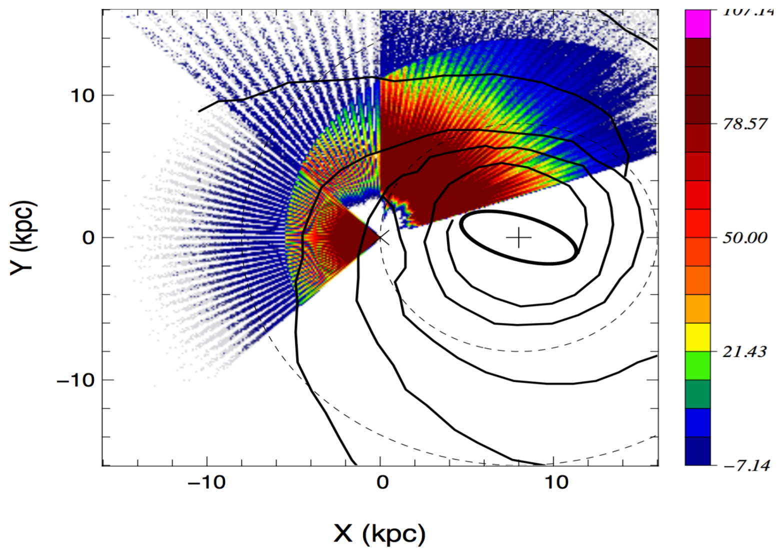
Spectro analysis methods

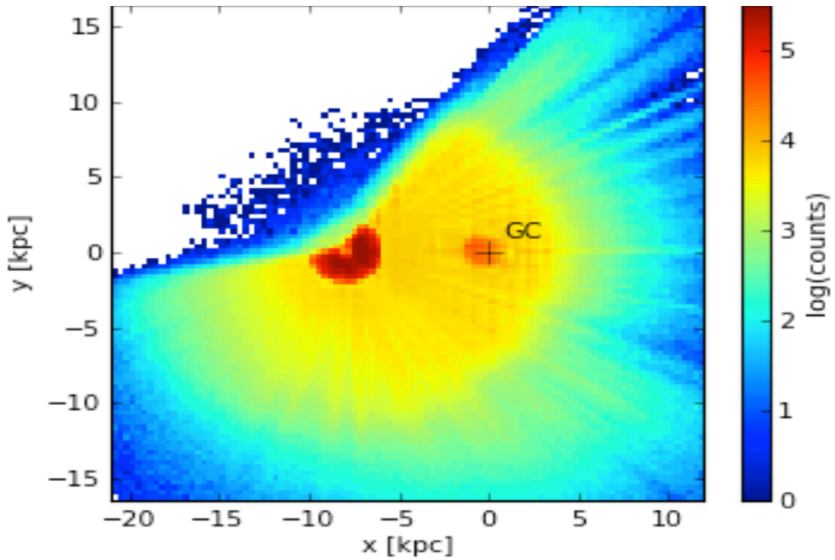
Astrophysical calibrations:
- Benchmarks (Gaia & al.)
- Asteroseismo (CoRoT, Kepler, K2)
- Clusters

Data mining methods

omplementarity North/South

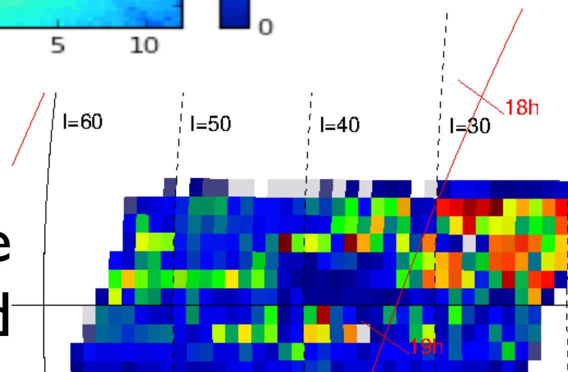






to access different regions of the disc

... making sure there are regions and



Outlook…

- Large spectroscopic surveys are a golden mine for a student starting a PhD or early-career researcher

✓ Large data sets, obtained in controlled way (target selection procedures, quality assurance on data products)

✓ Main-stream and niche science

✓ Lots of room for methodological developments (incl. machine learning, …) !

✓ Rich collaborative environments.

- For Galactic Archaeology, the combination of Gaia +