Leibniz-Institut für Astrophysik Potsdam

AIP

4MOST

Science & Performance

C. Chiappini

- Design Reference Surveys (DRSs)
- What is in our current DRS Mocks
- Simulation Results

Design Reference Surveys*

Doing Science in parallel !

- Science being designed for GOAL > 20 Million Objects

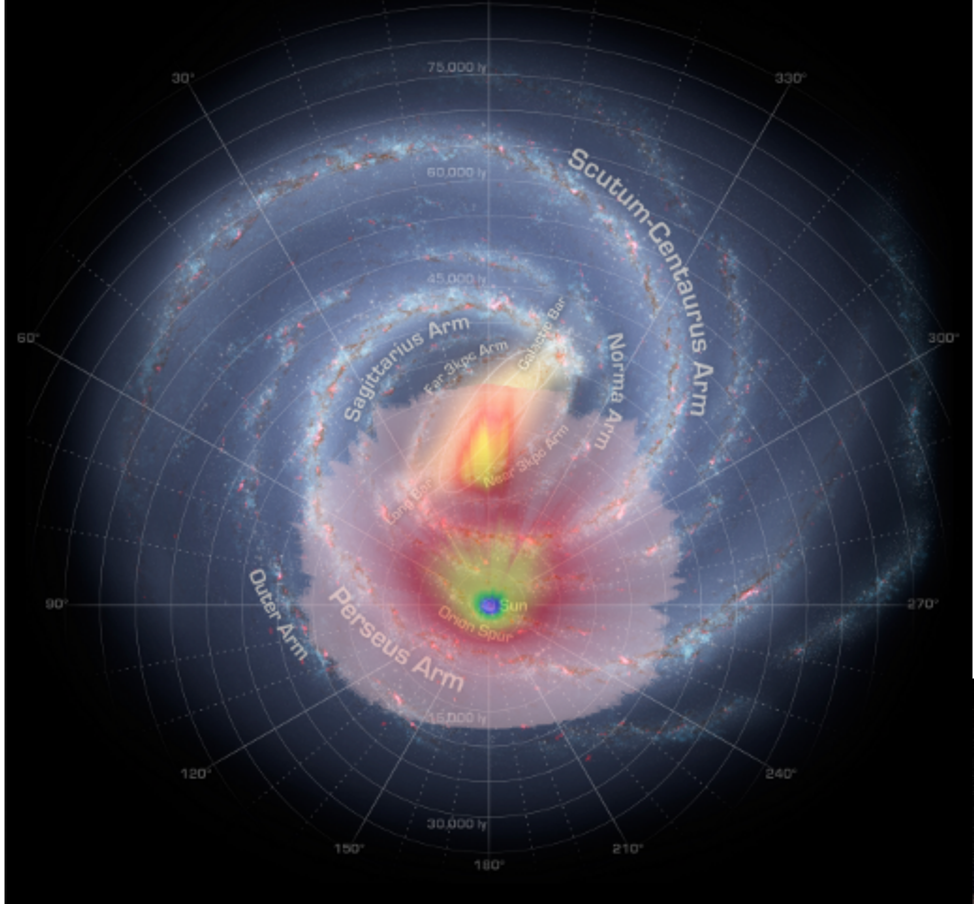
- Science Coordinator: C. Chiappini (deputy A. Schwope):

4MOST SWP represented at this meeting by names in red

- Halo – A. Helmi; M. Irwin (LR), N. Christlieb (HR) (Korn & Ludwig)
- Disk+Bulge – A. Koch; I. Minchev (LR), E. Caffau (HR)
- AGN – A. Merloni
- Galaxy Clusters – H. Boehringer
- Redshift Survey & BAO Science – F. Kitaura

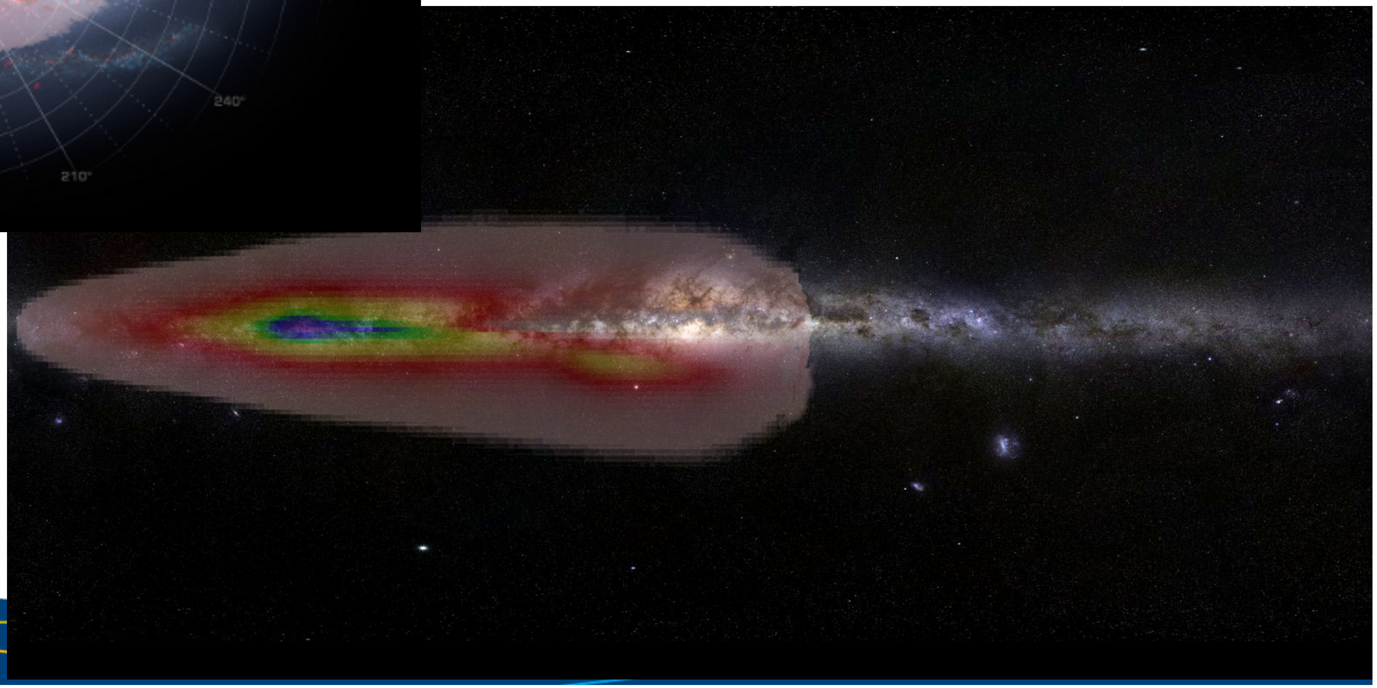
* Purpose of the DRSs: science cases that constrain the design the most.
We have made use of Galaxia model (Sharma et al. 2011 + Sharma priv. comm.)

Gaia astrometric mission



From 1 billion stars pick the best ~10 million!

Input catalog with Teff & log g and preliminar [Fe/H] info!



GREAT Chemo-dynamical Survey 2010, C. Babusiaux, A. Bragaglia, A. Brown, C. Chiappini, S. Feltzing, U. Heiter, A. Helmi, V. Hill, A. Lanzafame, A. Recio-Blanco, N. Walton, eds Feltzing & Walton

Gaia + spectroscopic follow-up to achieve its full potential

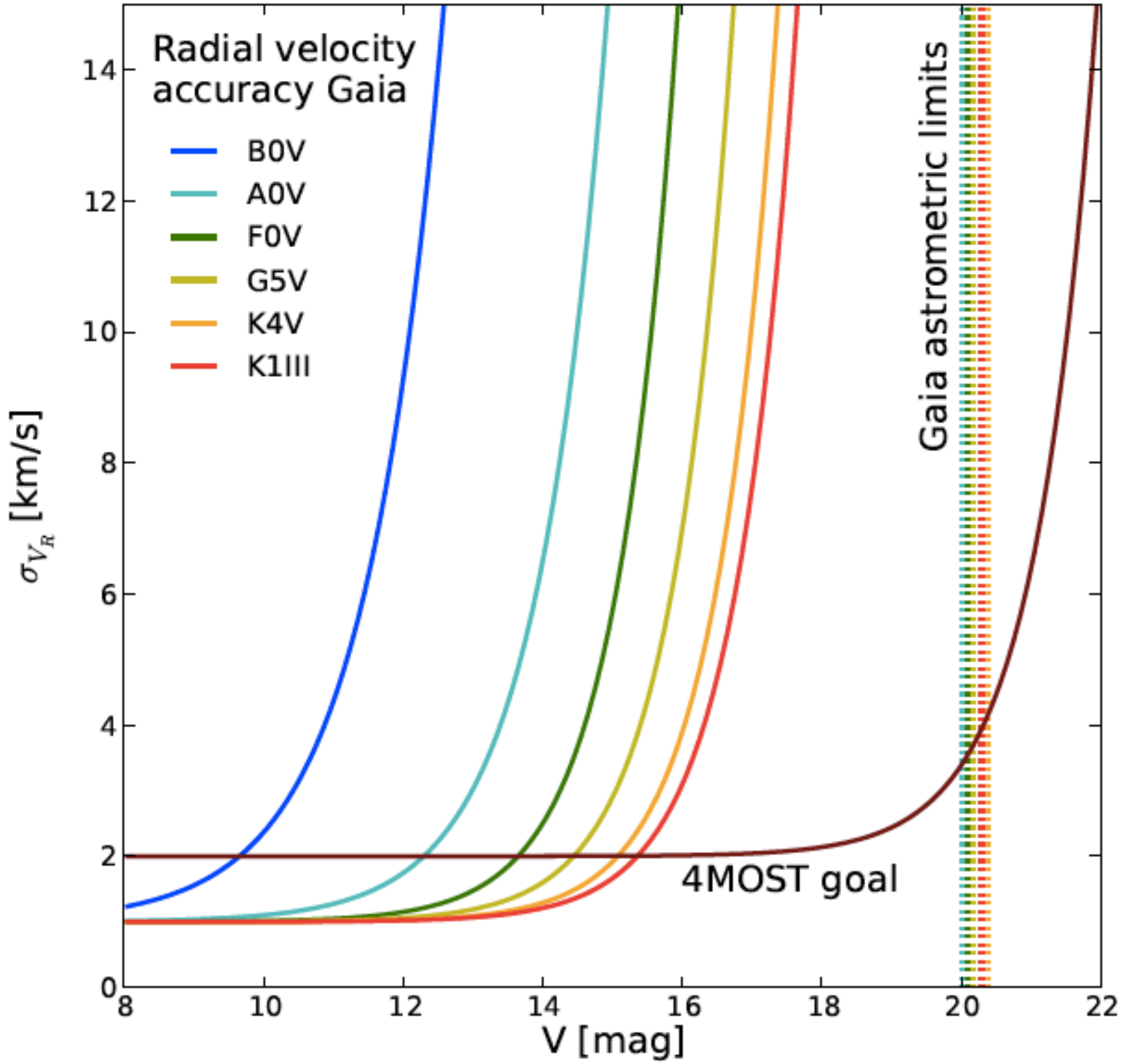
Gaia Launch 2013:

•parallaxes and proper motions for ~1 billion stars to m_G<20 mag

•spectra for radial velocities m_G<~15 mag

Gaia + 4MOST ~2019:

- Radial velocities 14< V <20
- Detailed Chemical Abundances ~14 < V < 16



Halo LR ~ 5000

Goal: to retrieve the history and dynamical evolution of our Galaxy by determining the mass, density, shape and substructure of the MW dark matter halo + the chemo-dynamical properties of its stars.

- Survey of ~10,000 deg^2 that will measure the radial velocities of halo stars (mostly K-giants) with a precision of 1-2 km/s as well as their metallicity distribution to 0.2 dex ([Fe/H]).

- FoM that requires a high completeness level *per field*, implying a high fraction of RGB stars with S/N > 10 at r = 19 for a survey of 10000 deg^2.

More details A. Korn talk

Halo HR ~ 20000

Goal: characterize the metallicity distribution function at low metallicities by increasing the number of objects known below [Fe/H] ~ -2.5 dex by a factor of 10; perform chemical tagging to identify substructures (streams etc.) associated with past merger events

- Observing all metal-poor giant stars brighter than V ~ 16, over 10000 deg^2 which will lead to a sample of 100,000 halo stars with HR spectra -> 100 times larger than any sample available to date.

- FoM that requires a minimum 50% of the total number of targets, with the specified quality per target.

Individual abundances of various species accessible in the 4MOST wavelength range at high resolution.

Parameter	[380; 450] nm domain Element	# lines (dwarf/giant)	[580; 680] nm domain Element (dwarf/giant)	# lines
T_{eff}	Fe I	73/70	FeI	96/107
			Hα	1
log g	Fe II	12/7	FeII	8/2
[α/Fe]	Ca I	8/8	CaI	14/14
	Mg I	2/1	MgI	1/2
	Si I	3/2	SiI	13/12
	Ti I	13/19	TiI	8/27
	Ti II	10/26	TiII	0/1
[X/Fe]			LiI	1
	Na I	1/0	NaI	4/3
	Al I	2/1	AlI	1/2
	Sc I	1/0	ScI	1/1
	Sc II	3/4	ScII	2/6
	V I	7/7	VI	9/27
	V II	1/1	VII	0/0
	Cr I	6/4	CrI	1/2
	Cr II	1/1	CrII	0/0
	Mn I	19/13	MnI	2/3
	Mn II	0/1	MnI	0/3
	Co I	9/11	CoI	0/11
	Ni I	3/3	NiI	18/19
	Sr II	1/1	SrII	0/0
	Y II	3/1	YII	1/1
	Zr II	2/2	ZrII	0/0
	Ba II	1/1	BaII	2/2
	La II	1/6	LaII	0/4
	Nd II	2/5	NdII	1/0
	Eu II	1/1	EuII	1/1
	CH	G-band		
	CN	X-A band		

More details A. Korn talk

(E. Caffau/N. Christlieb SWG)

Disk LR ~ 5000

Goal: Gaia proper motions and parallaxes + 4MOST radial velocities & metallicities

•Kinematical and chemical substructures -> map the position-metallicity-velocity space throught the disk

•Velocity field for an unprecedentedly large disk area -> quantify the bar and spiral structure dynamical parameters

➢Extended Solar vicinity: To study the changes of structure in velocity space of spatially localized samples (the U-V plane): we require σ(distance) < 200 pc and accuracy in U, V, W of ~2-5 km/s -> obtain accurate radial velocities for F/G dwarfs with 14 < V < 16.5 (d < 2kpc) – Requirement: millions of targets!

➢Extended disk sample: a) dynamical sample (SNR~10 but large number of targets) + b) chemo-dynamical sample (SNR >~30 but smaller number of targets) – using giants and dwarfs as tracers - Requirement: millions of targets!

More details I. Minchev's talk

- FoM   8.6 x 10^6 targets (2.6 ESN + ~5.5 disk + 0.5 bulge)

- We **must** understand *secular processes combined with accretion/merger & can **only*** calibrate them from million-star surveys (modified from Bland-Hawthorn)

- Obtaining individual abundances from low-resolution spectra by taking advantage of the combination of R ~ 5000 (similar to RAVE) and a very large spectral range (as in SDSS/SEGUE).

See Boeche's talk

Disk HR ~ 20000

Goal: Disk chemo-dynamics (Fe, α- and neutron-capture elements): trace abundance gradients with different chemical elements as well as gradients in the abundance ratios. Ages for brighter stars.

- ~14 < V < 16; criterion is complementary to other high-resolution surveys such as HERMES (V< 14) and also complements the Gaia's chemical information that will be available only for V < 12 - 13;

- Giants and dwarfs to cover large bins of (R, Z) in the Galaxy -> obtain [X/Fe] vs [Fe/H]; X = alphas, iron peak, n-capture elements …

- FoM : HR disk – N_{min} ~ 1M, N_{goal} ~1.5M on disk
  + High latitude sample ~0.5-1M (interface thick/halo)
  With quality requirements

More details I. Minchev's talk

Bulge LR & HR

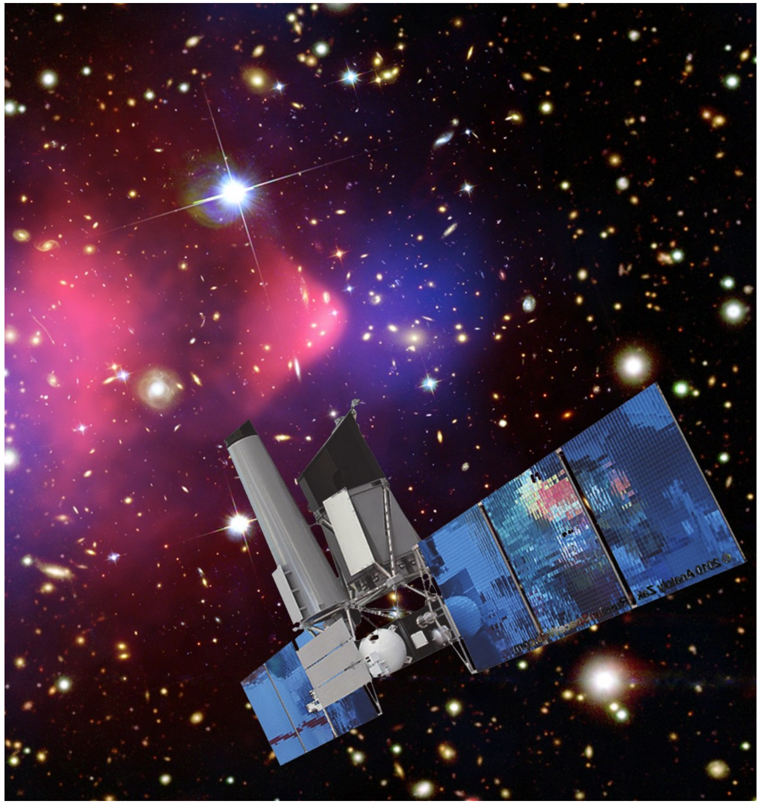
- **Bulge sample:** probe a large number of giants, in particular targeting the red-clump region in the HR-diagram. Search for multi-components & signatures of First Stars.

4MOST can deliver large bulge samples. Currently larger one is the ARGOS (Freeman & Collab.) sample (~28 000 objects) and FLAMES samples (Hill et al. 2011, Uttenthaler et al. 2012)

- LR: Find the most metal-poor stars in the Bulge – new candidates with APOGEE & ARGOS, but many more expected with 4MOST and APOGEE-South (AS3)
  -> 300 000 true bulge stars (~700 000 surveyed)

- HR: Full chemical analysis + 8m follow-up – First Stars abundance pattern? n-capture elements is key (Chiappini et al. Nature 2011)
  -> 120 000 min (goal 170 000)

eRosita Follow - up



- AGNs
- Cluster of Galaxies
- MW Compact objects

Cluster of Galaxies

Goal: 4MOST will provide redshifts for most of the eROSITA detected clusters and improve the cosmological constraints from the survey by about an order of magnitude compared to having only photometric redshifts.

- 2 – 3 Million possible target galaxies will be available in the survey area. We expect to reach our goals already with a fraction of targeted galaxies of 30 – 50%. targets, with the specified quality per target (the minimum fiber distance constraint)

- FoM: We define a positive cluster detection if we were able to identify 4 cluster members (BCG plus 3 further members) for clusters below redshift 0.9 and 1 member galaxy for clusters above z=0.9.

H. Boehringer's talk

AGNs

Goal: Follow-up all point-like extragalactic X-ray sources (mostly AGN) detected over an area of (at least) ~13,000 deg^2. The Xray flux limits expected to be reached by eROSITA are well matched by the spectroscopic capabilities of a 4-meter class telescope

- Reach completeness levels higher than 90% in both soft (0.5-2 keV) and hard (2-8 keV) X-ray bands.
- A wide wavelength coverage (380 - 1000 nm) will allow us to continuously map broad lines in the very wide redshift range $0 < z < 5$, thanks to the different emission lines (Hβ, MgII and CIV) redshifted into the 4MOST observed wavelength window.

- FoM: Function of completeness in number of targets, mag bin and redshift bin

A. Merloni's talk

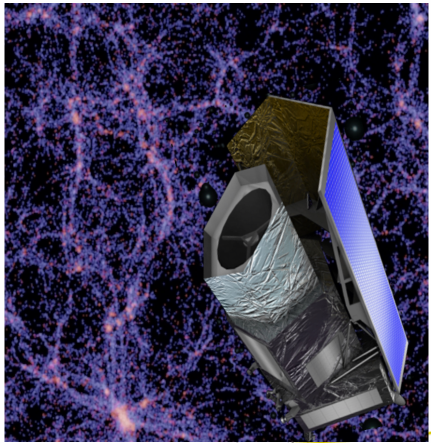
Galaxy Redshifts & BAO

Goal: Trace a *large* number of objects at different redshifts from z=0 to about 1.5. This will permit us to study the cosmic galaxy network, perform BAO reconstructions and deepen our understanding of structure formation.

- To perform an accurate estimation of the BAO signal we require homogeneous sky coverage . We expect about 3.8 Million BCG-like objects with $M>\sim10^{13}\ M_\odot$ in the surveyed volume. Additionally, we have also considered the counterpart of less massive tracers to fill the volume with ~7.6 Million objects.

- FoM: Completeness

F. Kitaura's talk



Euclid

Doing Science in Parallel

Finding best compromise between
FoV, number of fibers, ratio HR/LR

Need Survey Simulator

(next talk T. Dwelly)

New “systems concept”:

- Echidna + HR/LR = 1/3 + FoV ~ 4 deg^2

Mocks & “Figures of Merit”

how to condense a whole science case in one number
without avoiding over-simplifications?

4MOST Science Diversity -> Diversity in exposure times

Mocks Overview

(-70 < DEC < + 20)

4FS, TB and DW, 09.03.2012

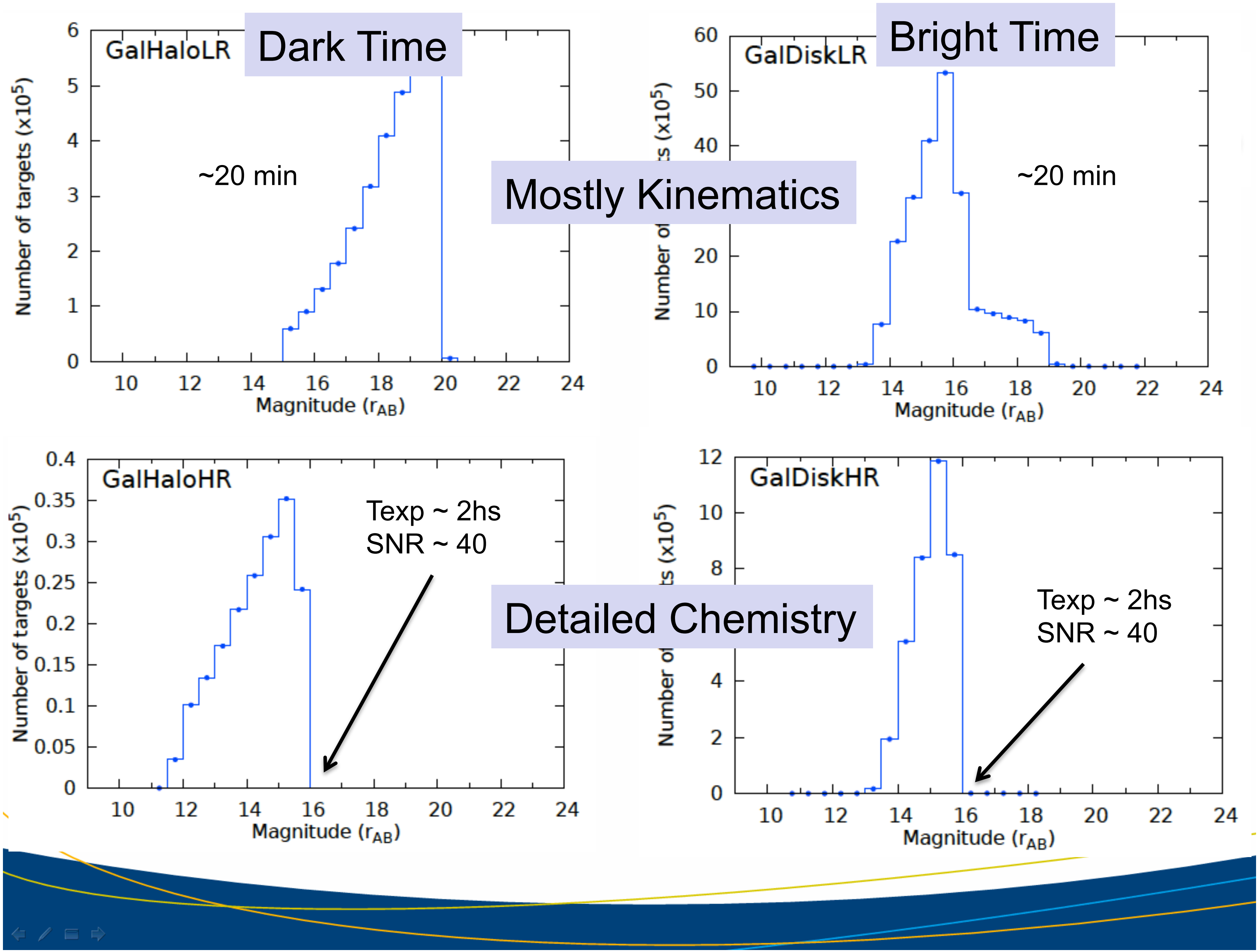
DRS	area [deg^2]	Objects	densities [deg^2]	[3 deg^2]	**[4.2 deg^2]**
AGN	26691	1.187.146	44.5	133.4	**~190**
BAO	20397	11.383.002	558.1	1674.2	**~2340**
GalHaloLR	18362	3.065.078	166.9	500.8	**~700**
Clusters	25177	2.945.325	117.0	351.0	**~490**
GalDiskLR	26715	23.081.666	864.0	2592.0	**~3630**
GalHaloHR	14423	182.951	12.7	38.1	**~50**
GalDiskHR	26692	2.215.660	83.0	249.0	**~350**
		HR (b>30)	~100	~300	**~420**

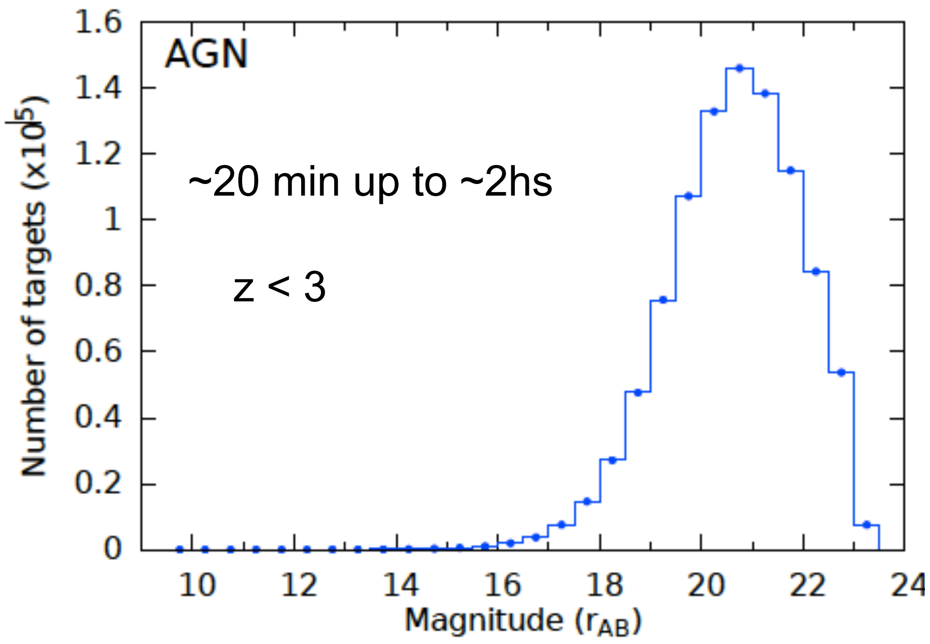
Diversity in Sky density distribution

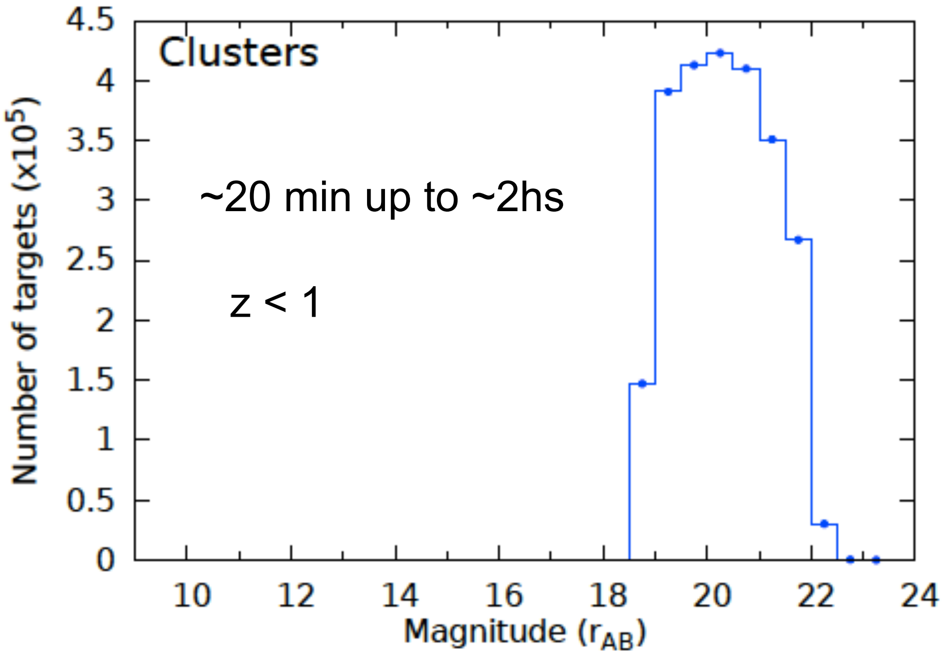
Diversity In required exposure times

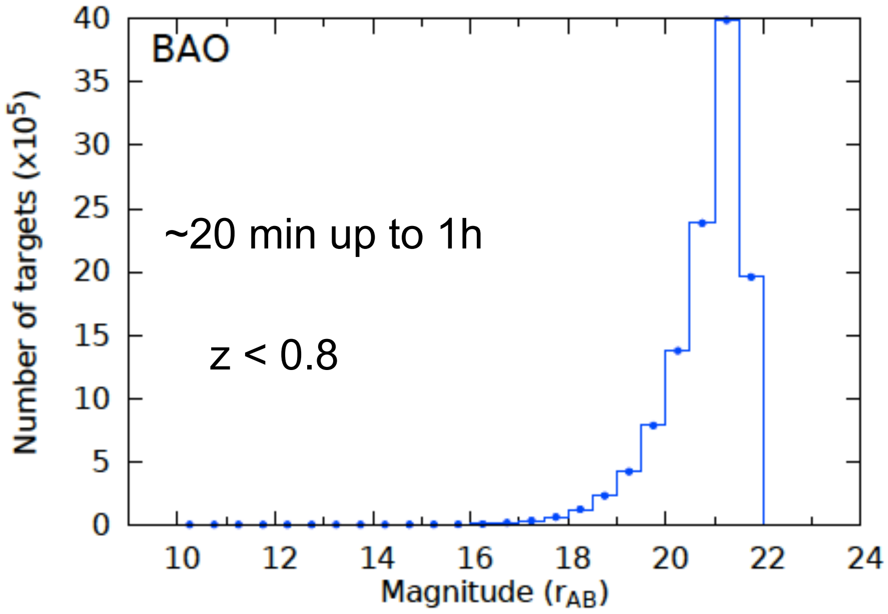
Required ~ 20 million objects (LR) ~ 2M (HR)

No room for back of the envelope calculations


Dark Time
GalHaloLR
~20 min
Bright Time
GalDiskLR
~20 min
Mostly Kinematics
GalHaloHR
Texp ~ 2hs
SNR ~ 40
GalDiskHR
Texp ~ 2hs
SNR ~ 40
Detailed Chemistry
Number of targets (x10^5)
Magnitude (r_AB)


AGN
~20 min up to ~2hs
z < 3
Number of targets (x10^5)
Magnitude (r_AB)


Clusters
~20 min up to ~2hs
z < 1
Number of targets (x10^5)
Magnitude (r_AB)


BAO
~20 min up to 1h
z < 0.8
Number of targets (x10^5)
Magnitude (r_AB)

Dark Time

Key point: Survey Strategy matters*

Dwelly's talk

*Results Round 5b + Round 5

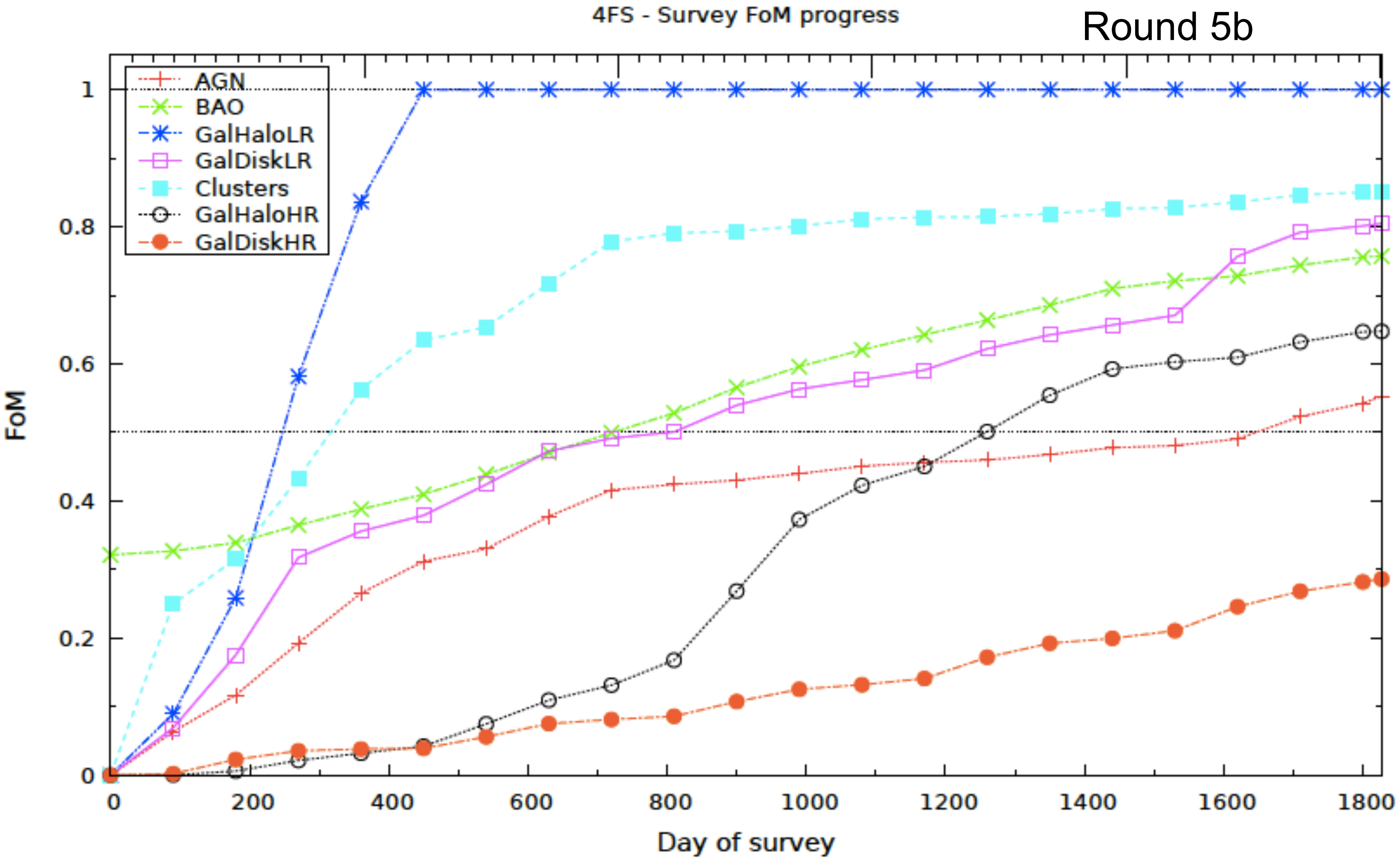
Round 5b*

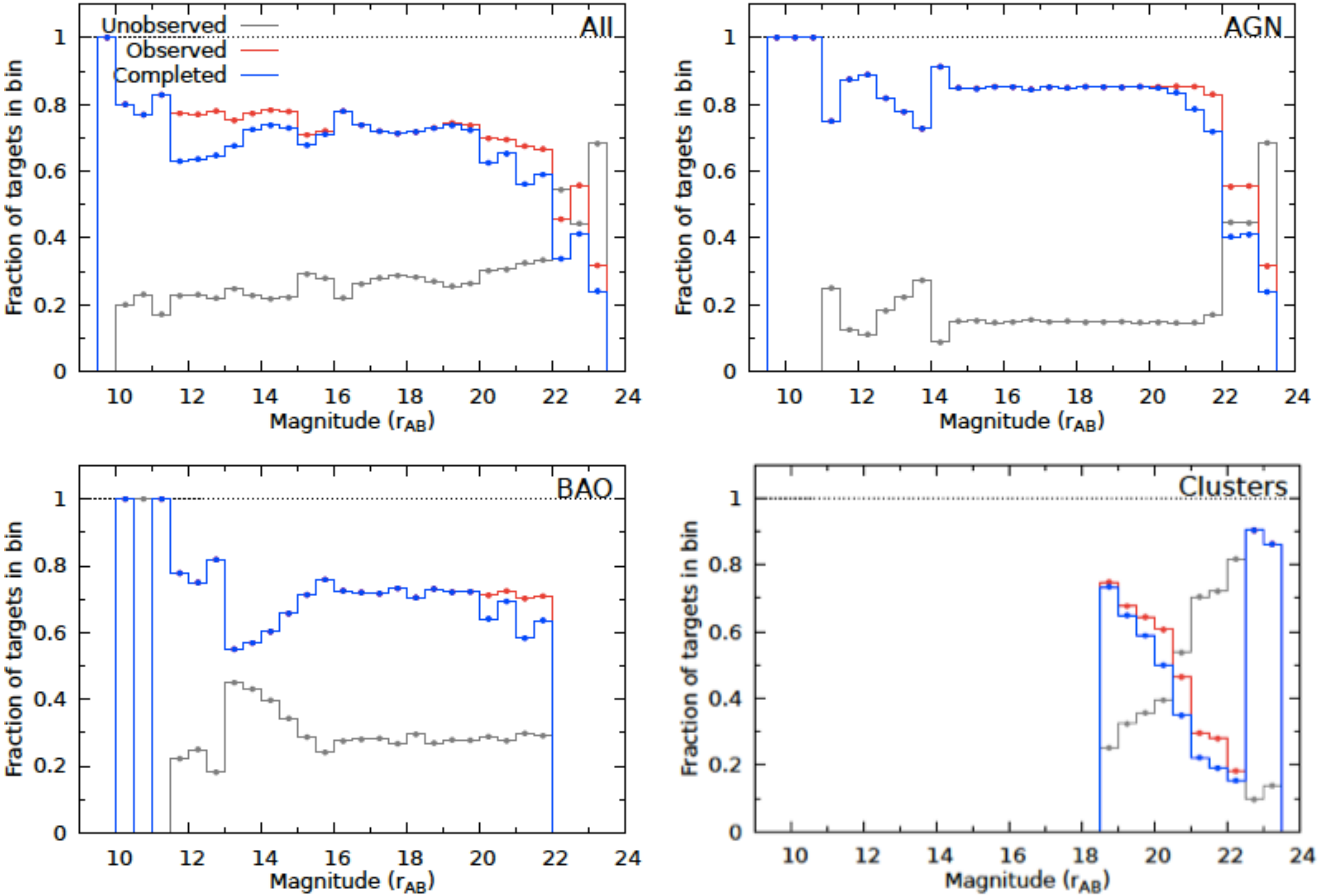
Loss due to sky reduction

Case	Nobs	Nsucc	Fsucc	Ffail	Nobs,red	Nsucc,red
AGN LR	775986	729310	0.94	0.06	0.9	0.9
BAO LR	8110110	7322074	0.9	0.1	0.85	0.9
Halo LR	2458023	2455358	1	0	0.85	0.85
Disk LR	17881260	17879892	1	0	0.99	0.99
Clusters LR	1270737	1092176	0.86	0.14	0.91	0.92
Halo HR	141622	117630	0.83	0.17	0.9	0.99
Disk HR	1789817	1204565	0.67	0.33	0.96	1.36
All	32427555	30801005	0.95	0.05	0.93	0.96

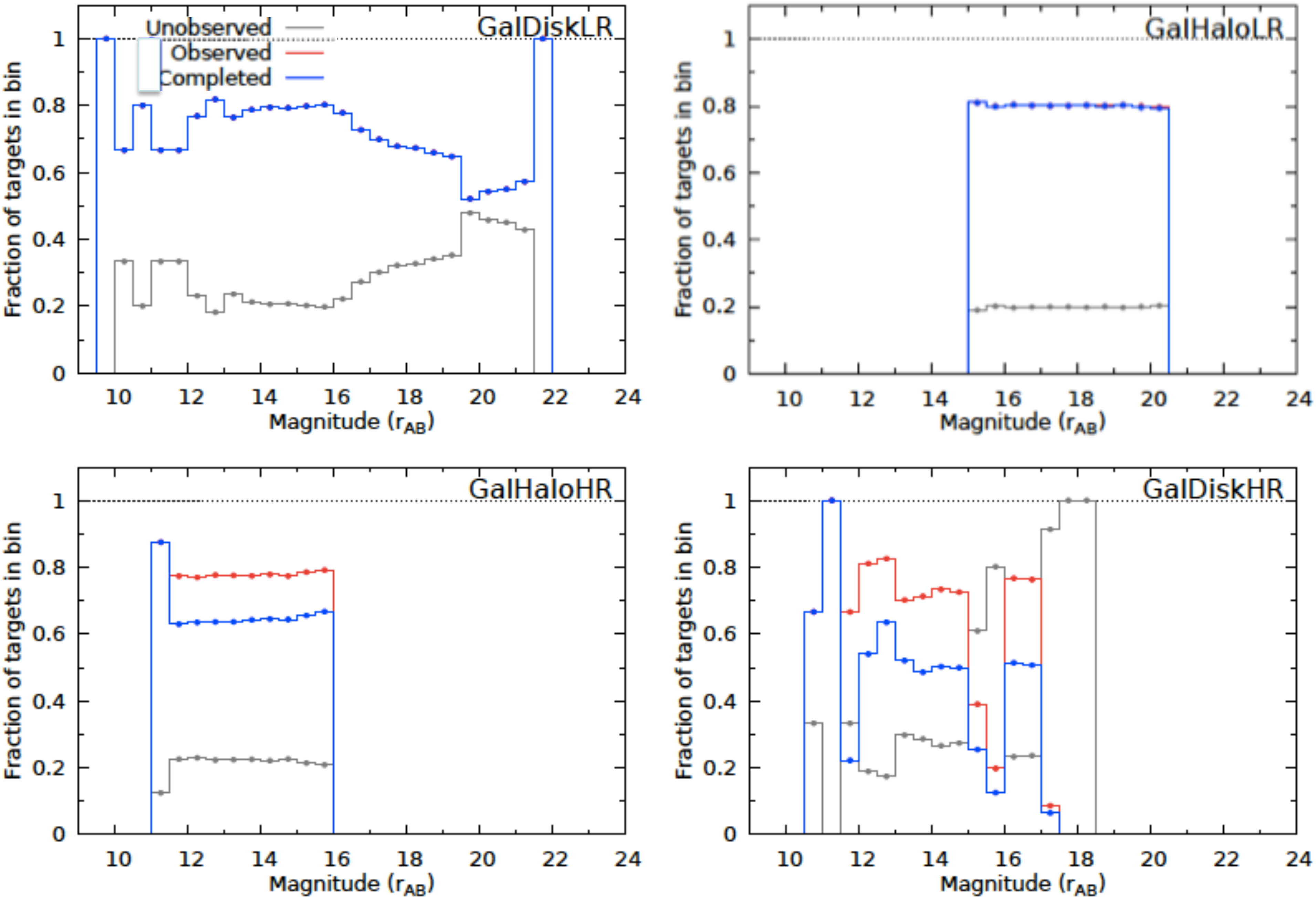
*(6 x 20 min, reduced sky, no dither), 1600 LR, 800 HR, FoV ~4 deg^2

Round 5b


4FS - Survey FoM progress
AGN
BAO
GalHaloLR
GalDiskLR
Clusters
GalHaloHR
GalDiskHR
FoM
0
0.2
0.4
0.6
0.8
1
0
200
400
600
800
1000
1200
1400
1600
1800
Day of survey

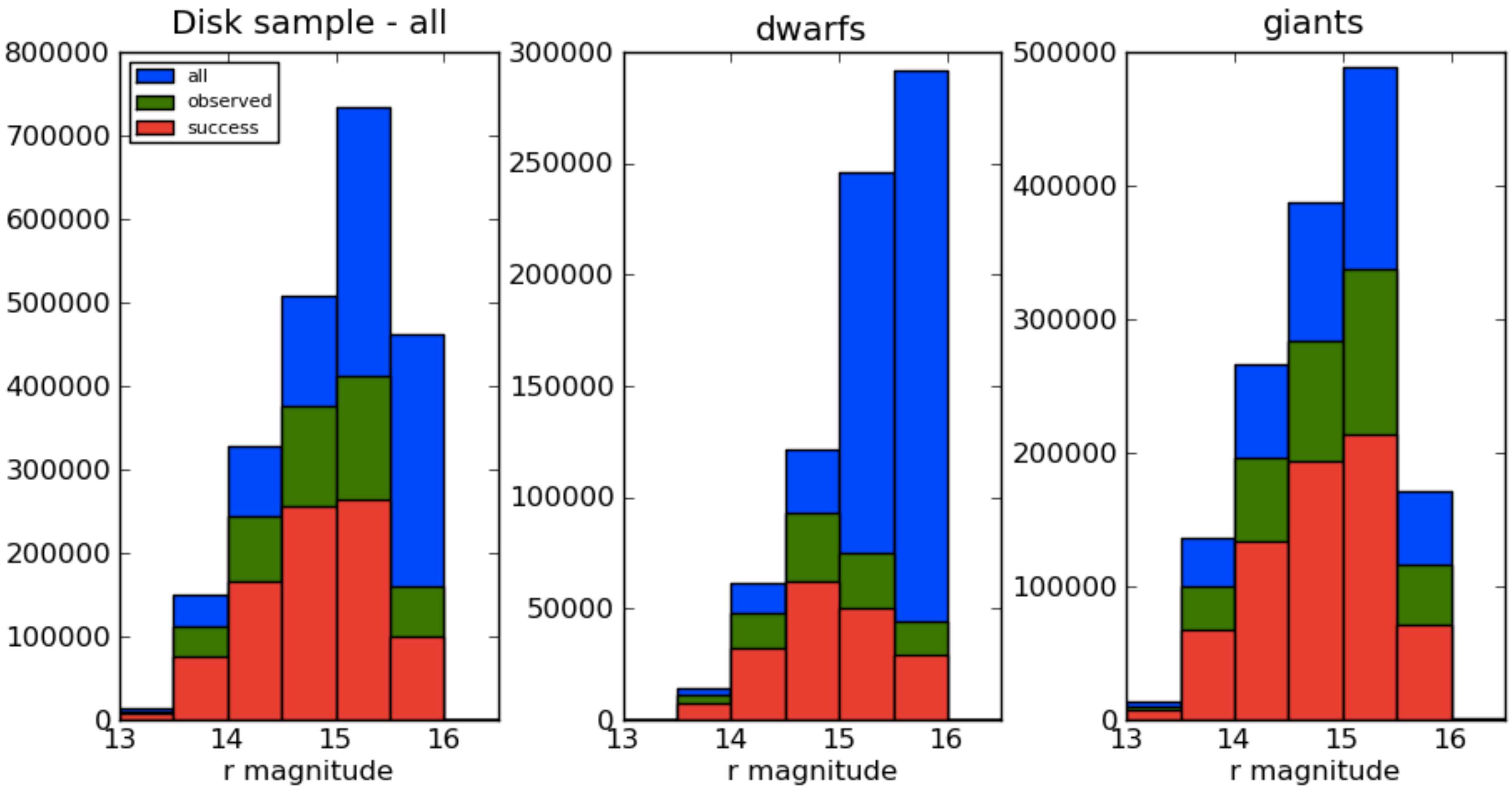


All
Unobserved
Observed
Completed
AGN
BAO
Clusters
Fraction of targets in bin
Magnitude (r_{AB})



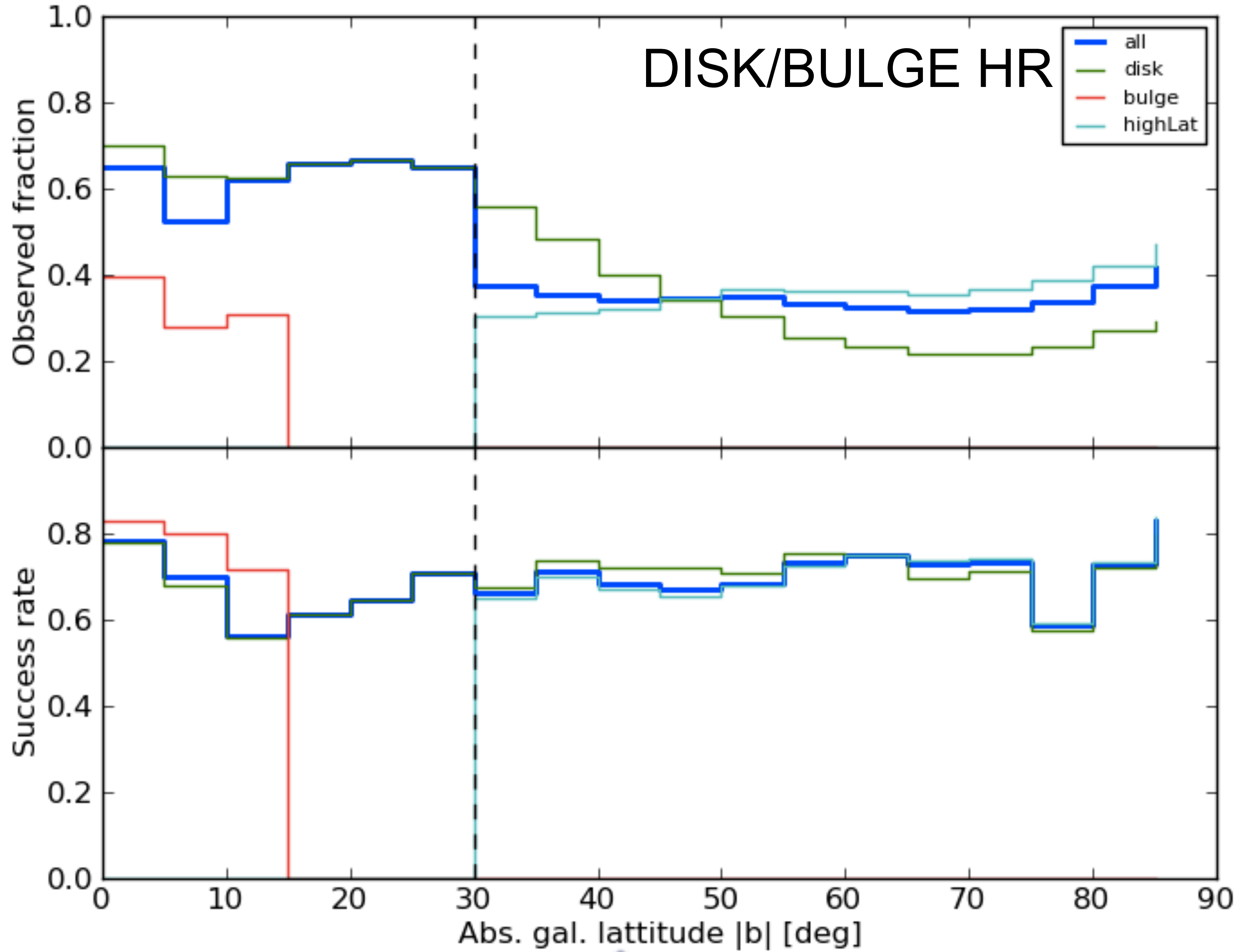
GalDiskLR
Unobserved
Observed
Completed
GalHaloLR
GalHaloHR
GalDiskHR
Fraction of targets in bin
Magnitude (r_{AB})

DISK HR Round 5b*



(figure by T. Piffl- AIP)

Round 5b*


DISK/BULGE HR
all
disk
bulge
highLat
Observed fraction
Success rate
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
90
Abs. gal. lattitude |b| [deg]

Overview Round 5 - Clusters

Clusters	Z_bin	N_clust_obs	N_clus_succ
	0.0 – 0.2	28 938	27 620
	0.2 – 0.4	27 014	25 925
	0.4 – 0.6	11 872	11 245
	0.6 – 0.8	4 035	3 733
	0.8 – 1.0	1 306	1 109
	1.0 – 1.2	359	319
Total			69 951

N_gal_succes = 1M

AGN

AGN	Zbin	Obs	Succ	Magbin	Obs	Succ
	0	511 003	409 850	16-17	5 706	5147
	1	369 694	293 135	17-18	22 061	19 950
	2	78 043	62 886	18-19	74 764	67 843
	3	6 389	4 902	19-20	183 016	165 810
	4	586	528	20-21	279 033	252 216
				21-22	253 510	213 968
				22-23	138 187	43 240

Ntot_obs = 750 291 – FoM_t = 0.6

Diversity of science cases

Diversity of exposure times

Strong requirements on:

- Keeping overheads to a minimum (CCDs readout & fiber positioning)
- Repositioning fibers each 20min *while* reading CCDs
- Throughput

But also opens opportunity for many other science cases (sub-catalogs of ~1000 – 10 000 Targets

What will 4MOST do that others cannot?

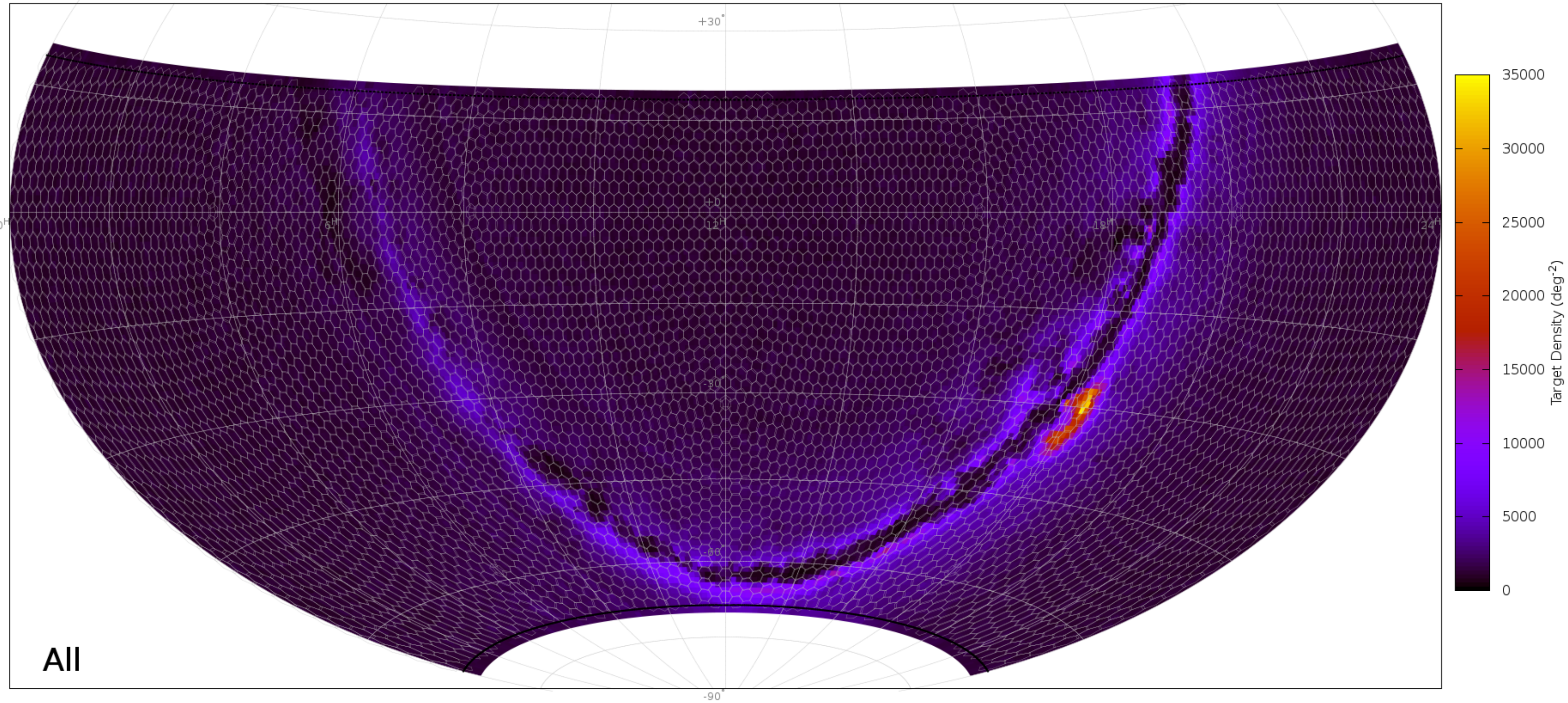
- All hemisphere coverage (with WEAVE, full sky)
- Permanent on telescope (enables time domain spectroscopy)
- Largest Gaia follow-up machine (> 10 Million Targets in LR and 2 Million in HR) -> only way to really understand secular processes in disk formation & map the chemo-dynamics of MW components
- Southern Location: Best Bulge & Inner-disk & LMC/SMC follow-ups
- Possibility to build large galaxy redshift catalog > 10 Million!

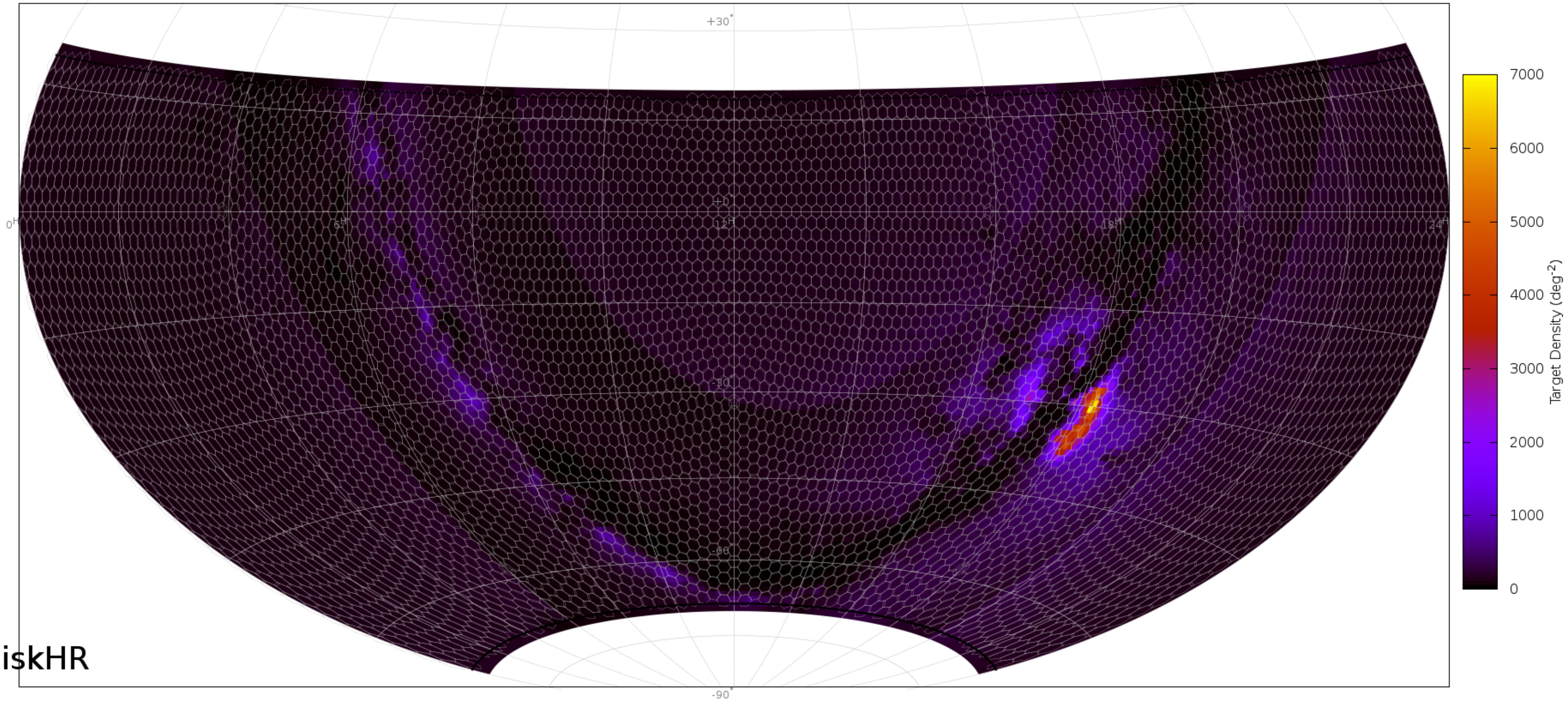
All this work done in 14 months !

Room for improvements

Room for many extra science cases

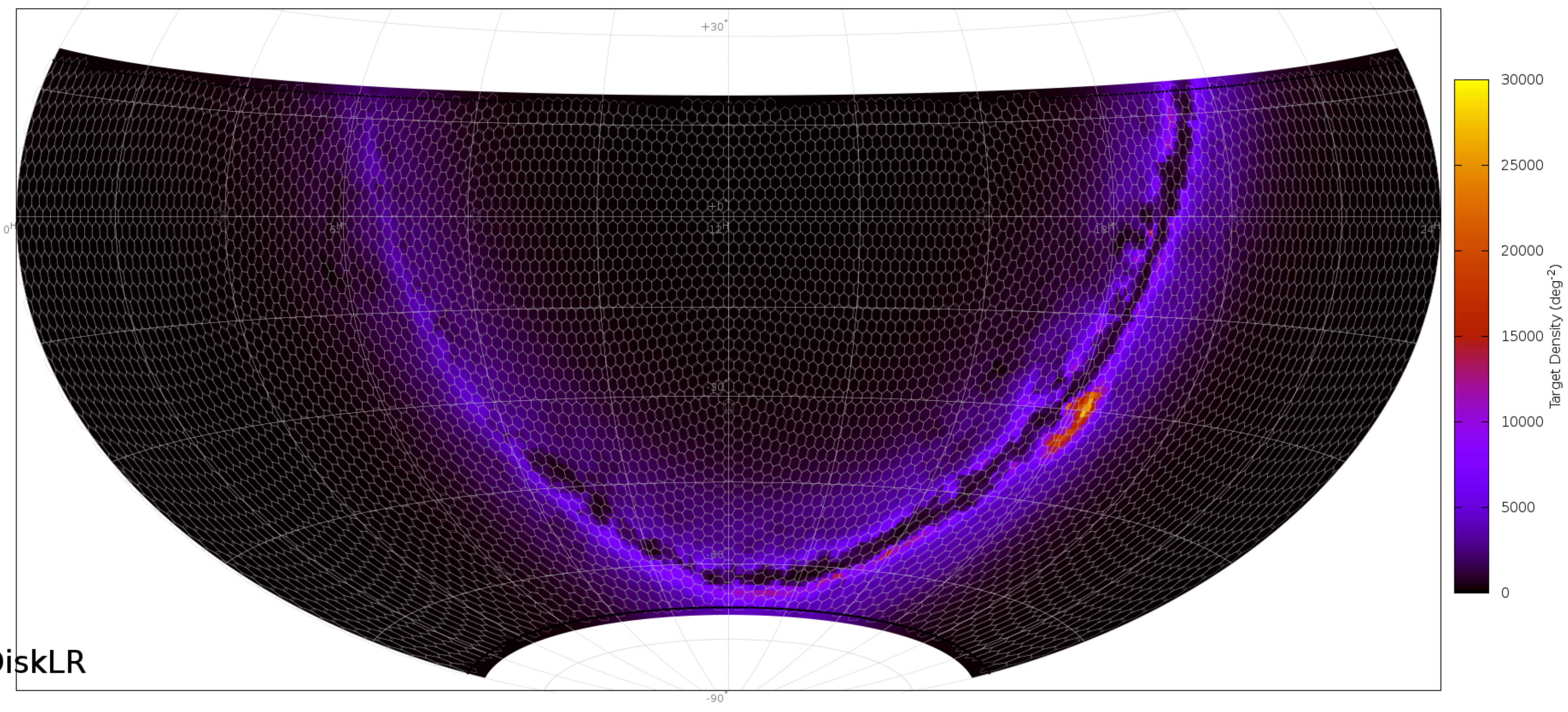
Extras


All
35000
30000
25000
20000
15000
10000
5000
0
Target Density (deg^{-2})
+30°
-90°



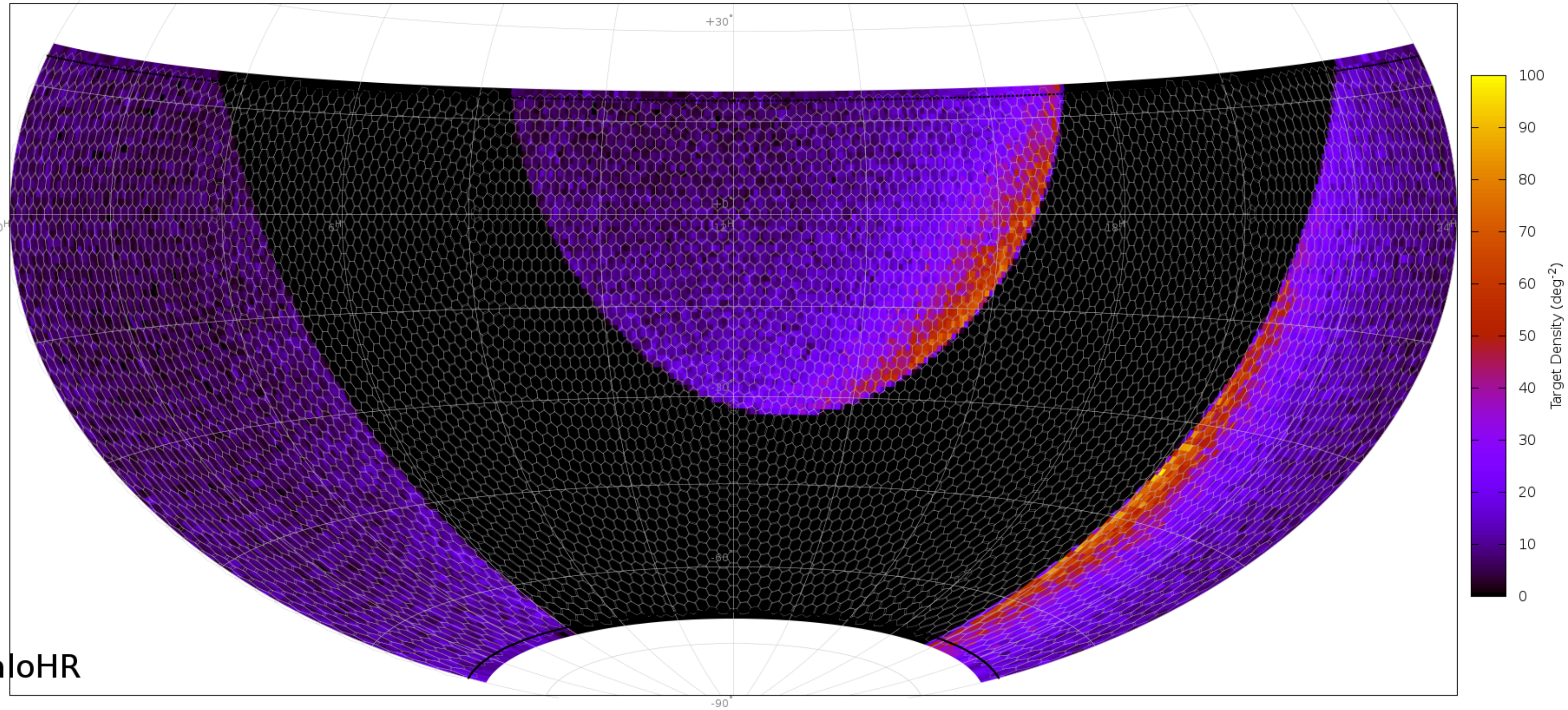
+30°
+0
-30
-60
-90°
0H
6H
12H
18H
24H
7000
6000
5000
4000
3000
2000
1000
0
Target Density (deg-2)

GalDiskHR

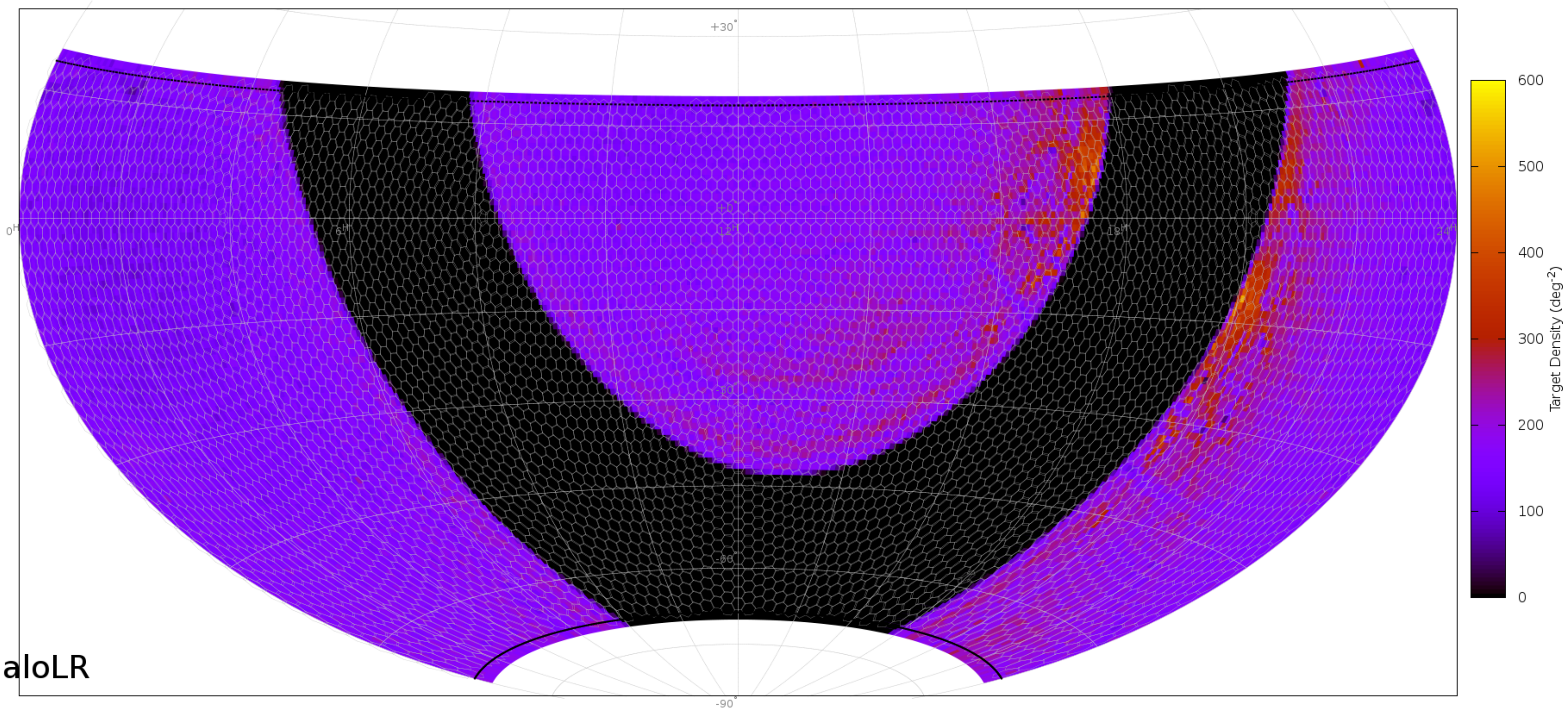


+30°
0h
6h
12h
18h
24h
-90°
30000
25000
20000
15000
10000
5000
0
Target Density (deg^{-2})

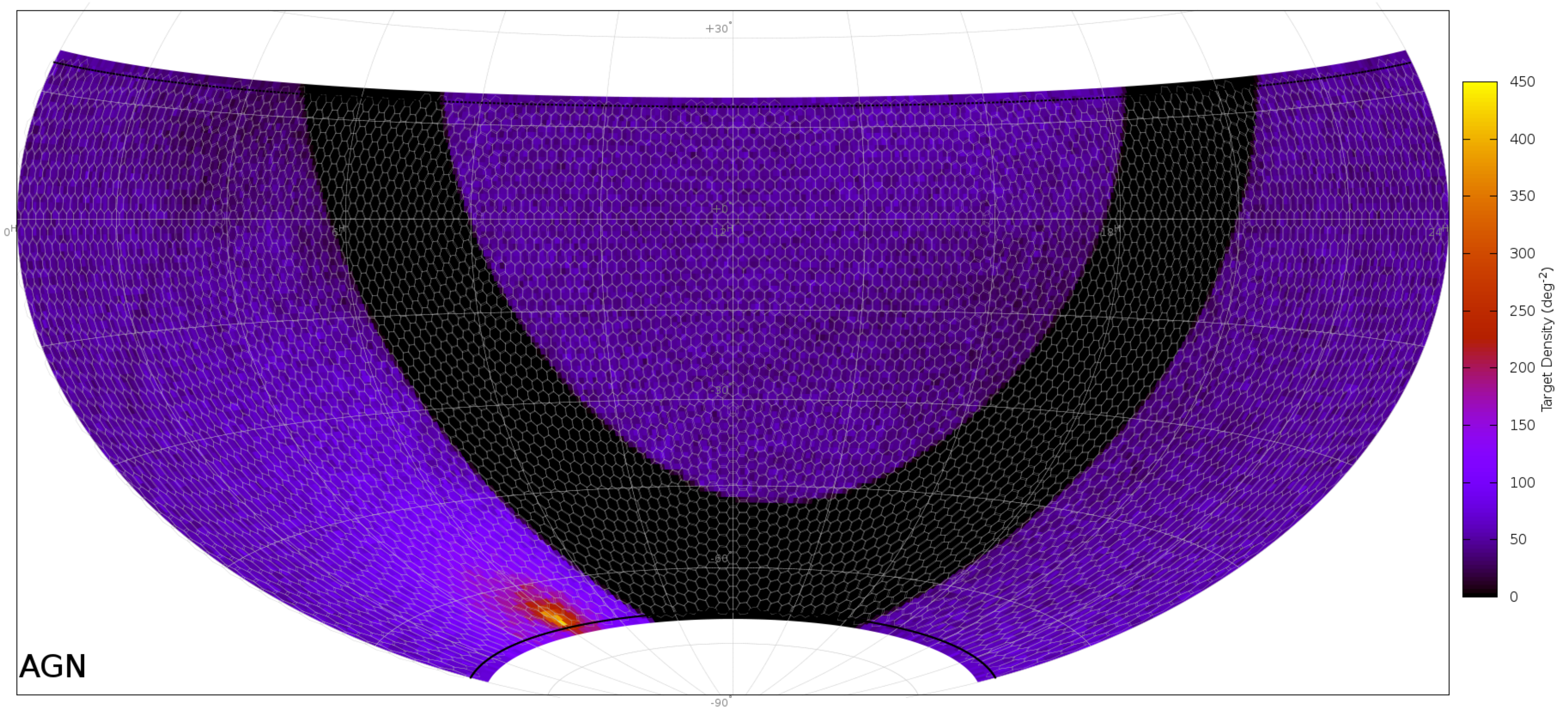
GalDiskLR

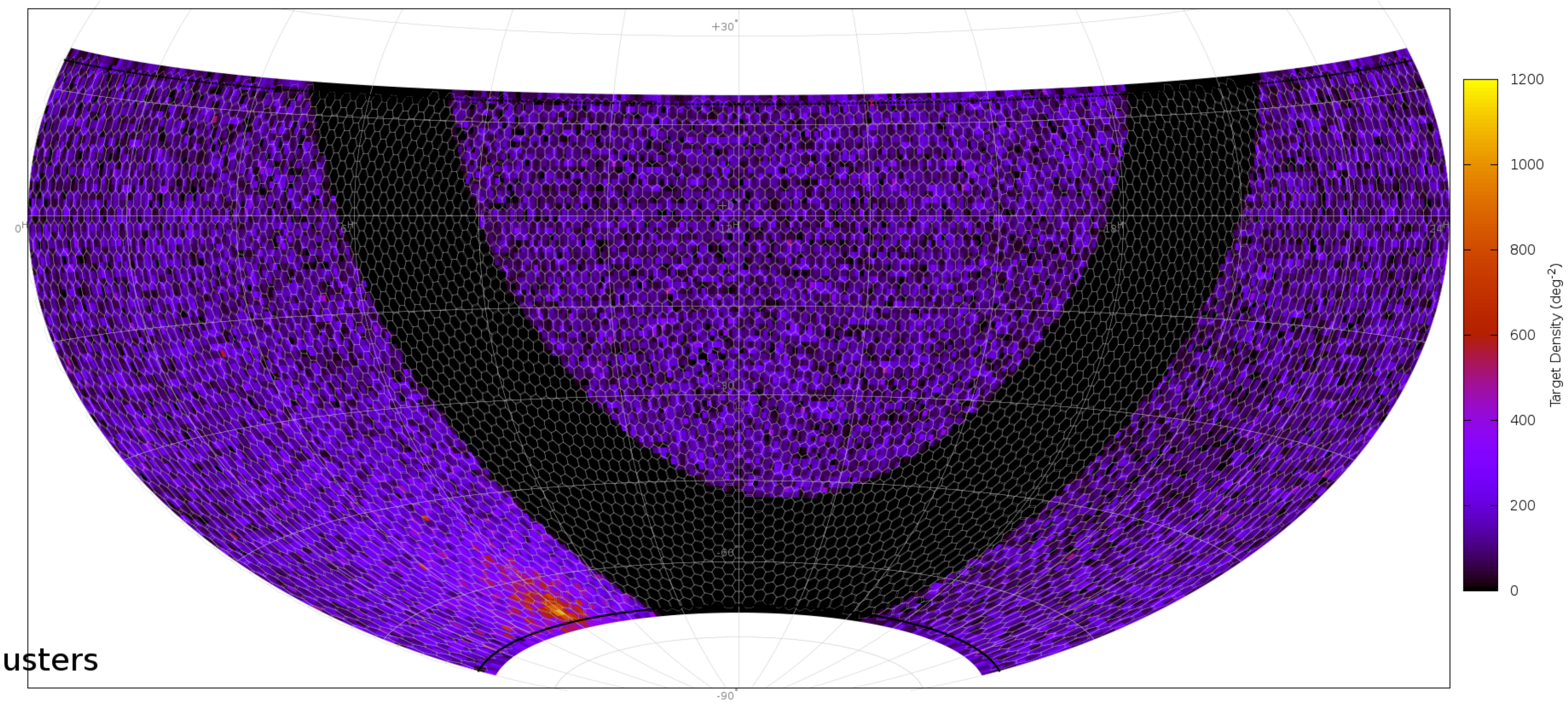


GalHaloHR



GalHaloLR


AGN
450
400
350
300
250
200
150
100
50
0
Target Density (deg⁻²)
+30°
-90°

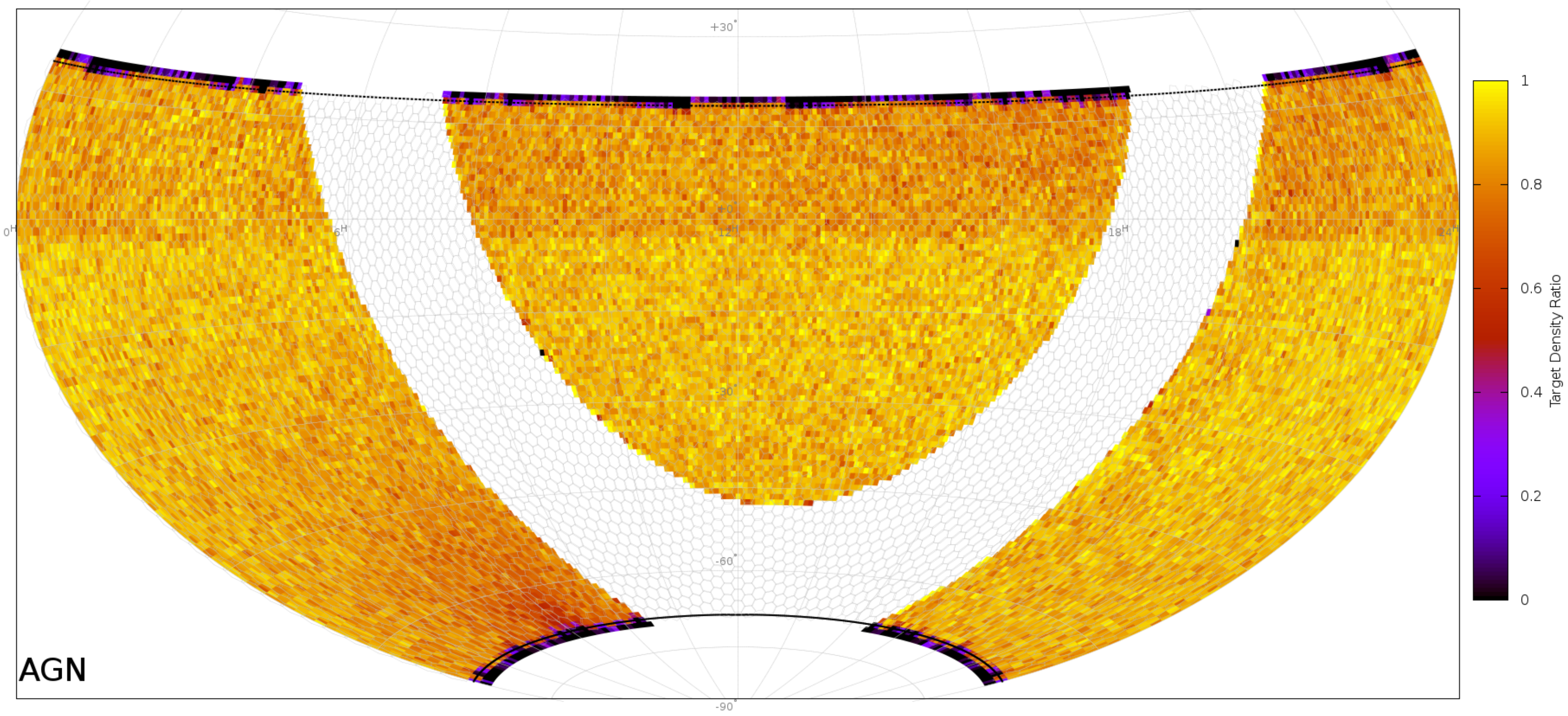


Clusters

Science requirement	HR halo	HR disk/ bulge	LR halo	LR disk/ bulge	Galaxy Cluster	AGN	BAO
Mag Range	13.5-15.5	15.5-15.5	15-20	14-18 (14-20)	17-22	16-22.5 (16-23)	16-23
Mean surface density [targets/deg^2]	10-30 - with contam.	50-800	180 (x 2 if contam.)	500 - 3000	200	90- 280	1500
Total # targets (10^6) Required (goal)	0.1 (0.2)	1.0 (1.5) d 0.12 (0.17)b 0.5 (1.1) hl	1.8 for 10k deg^2 3.1 for 17k deg^2	8.6 (13.8)	2 (3)	1.5	10 (15)
Total area of sky required (goal) [deg^2]	>10 000	15 000 (20 000)	10 000 (17 000)	16 000 (26 000)	15 000 (20 000)	13 000 (15 000)	10 000 (15 000)
Sky density [targets/deg^2]	18 [90%]	50-100 [90-30%]	160 [90%]	50-1000	100 (200) [>90%]	80-250 [>90%]	1000 [>50%]
Survey area (l, b) [-70 <DEC < +20]	|b| > 30	All sky	|b| > 20	All sky	|b| > 15	|b| > 20 (|b|> 15)	|b| > 25
Wavelength range	395-456.5 587-673	395-456.5 587-673	390-450 480-550 835-885	390-670 845-880	420-950 (390-1000	400-950 (390-1000)	420-950 (390-10^3)
Resolution	> 18 000	> 18 000	5000 (7000)	5000 (7000)	500 (>3000) @500nm	3000 (5000) @ 400-950	3000
S/N per Angstrom	150 [V=16]	140 [V=16]	10 [r=19]	10 [V >18] 30 [V <18]	4 (5) [r=20.5]	5 [r=21.5]	10 [r=20.5]

Round 5b

6 x 20 min all b



Round 5b

6 x 20 min all b