Spectroscopic survey of LAMOST

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On behalf of the LAMOST operation team

Outline

- LAMOST
- Spectroscopic Survey of LAMOST
- Spectra & stellar parameters
- LAMOST Sciences
- Summary

Innovations in LAMOST

- **a special reflecting Schmidt telescope**
  - **the Wang-Su type telescope which could get the largest aperture for wide field of view**

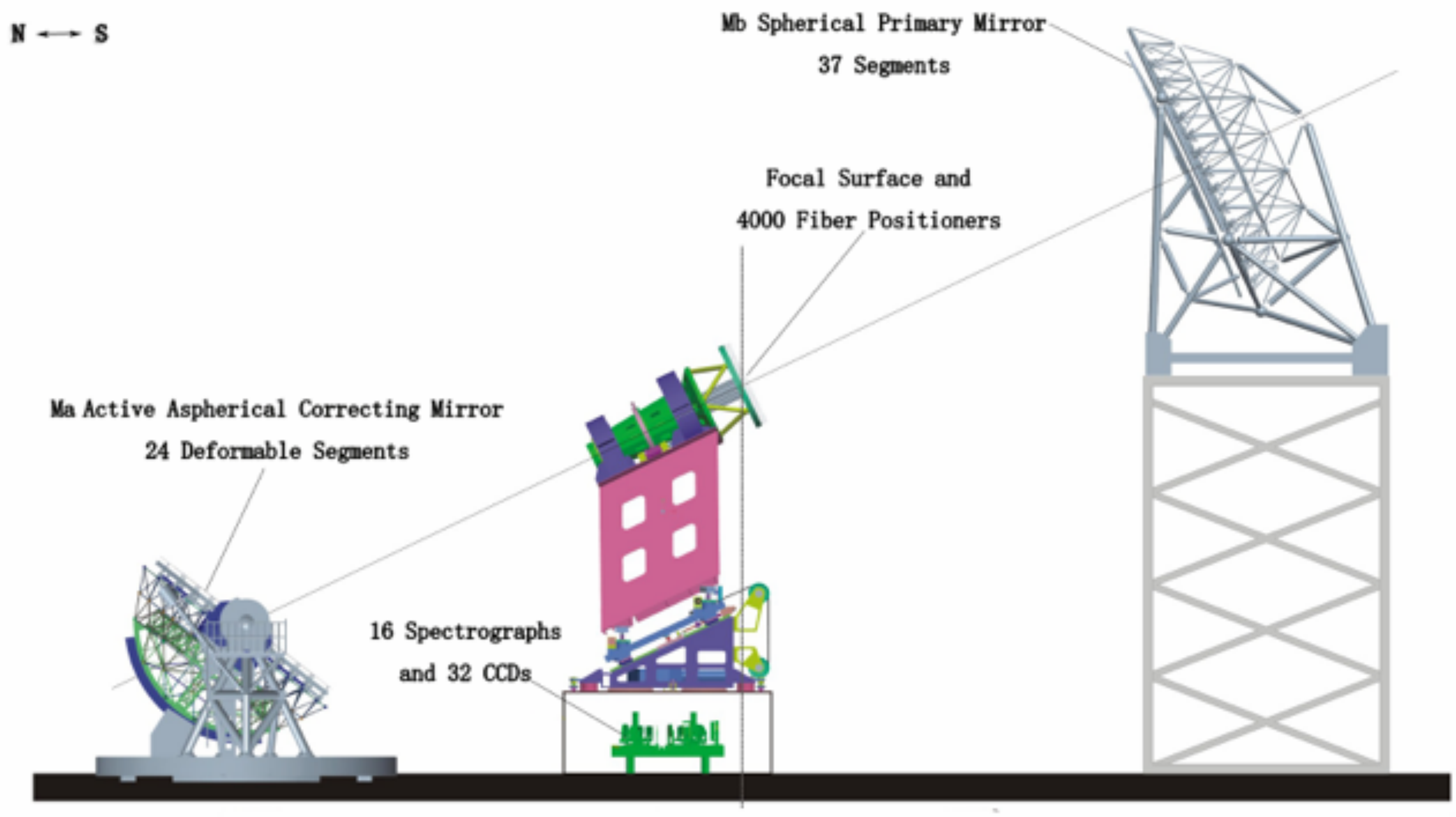
- **large field of view (5 deg) +large aperture (4m)**
  - **achieved by new type of active optics — thin deformable segmented mirrors active optics**

- **4000 optical fibers on focal surface**
  - **Parallel controllable fiber positioning opened the way to take thousands optical fibers observing in short time**

LAMOST timeline

- one of Chinese National Major Science Projects
  - Started in 1997
  - Finished in Aug. 2008
  - Checked and accepted by national government in June 2009
- Commissioning stage
  - June 2009 – Sept. 2011
- Pilot survey
  - Oct. 2011 - June 2012
- Regular survey
  - Sep. 2012 - present

Structure of LAMOST



LAMOST Survey

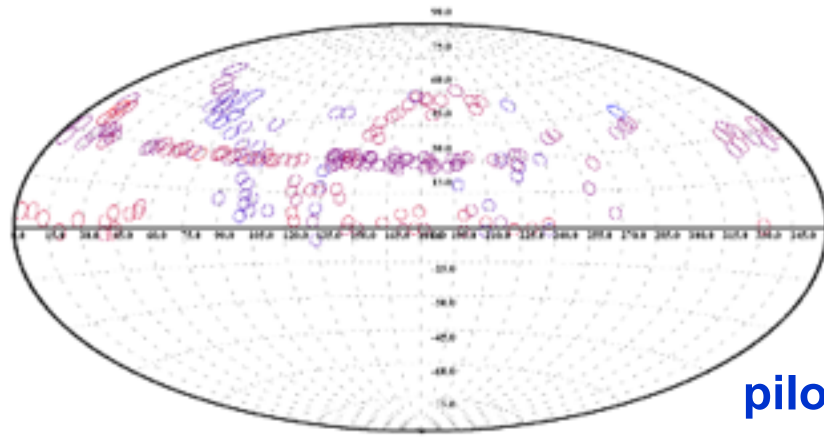
- **Pilot Survey**
  - **2011.10-2012.6**

  PDR: 2012.8

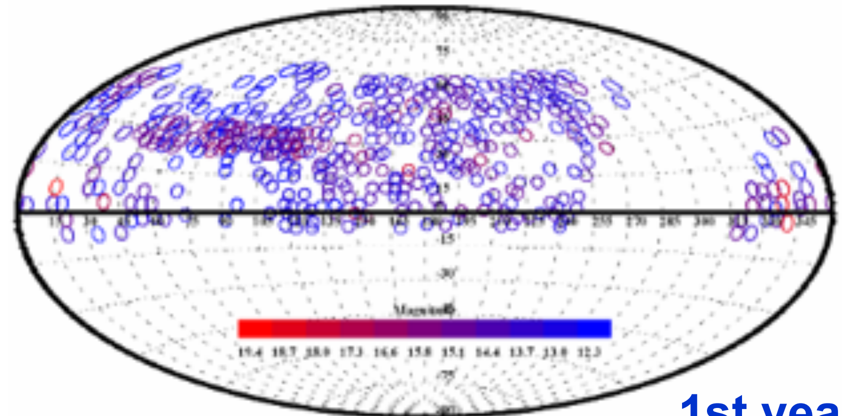
- **Regular survey**
  - **1st year: 2012.9-2013.6**

  DR1 (2013.9)
  - **2nd year: 2013.9-2014.6**

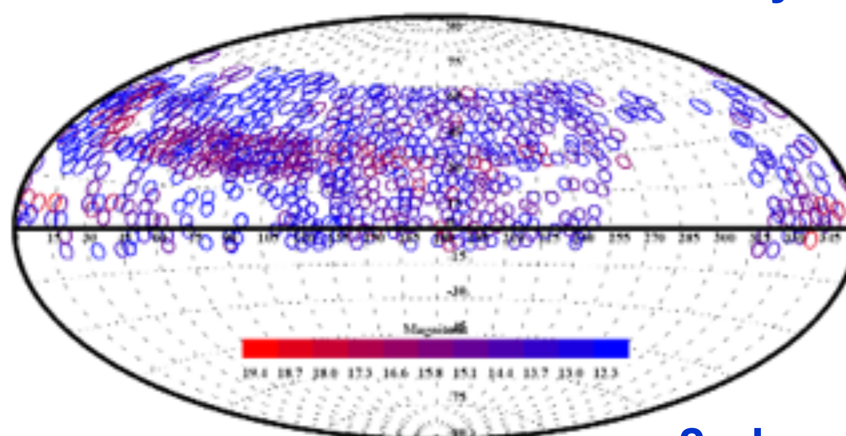
  DR2 (2014.12)
  - **3rd year: 2014.9-2015.6**



pilot

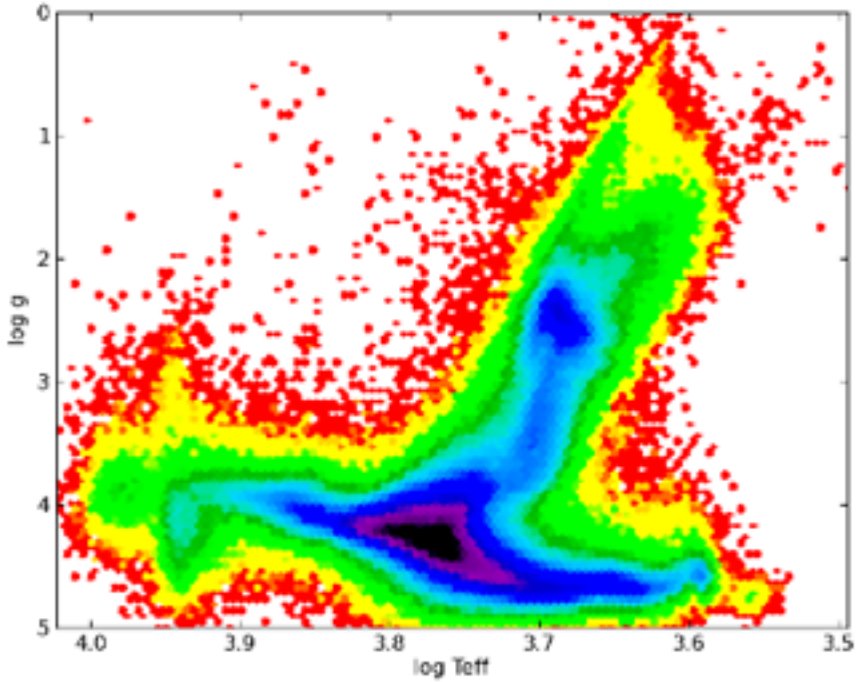


1st year

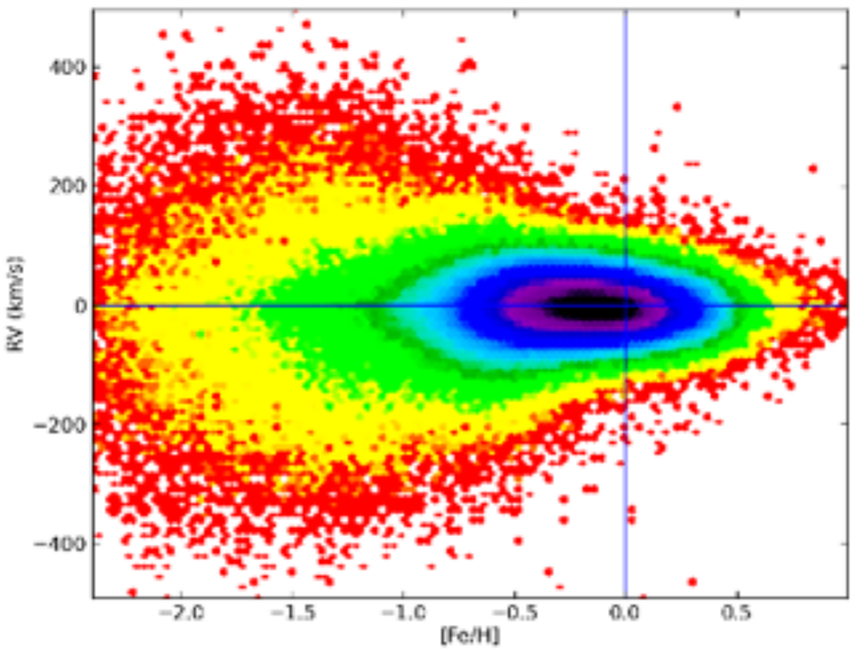


2nd year

Stellar parameters (1.0M spectra in DR1)



Teff, log g
[Fe/H], Vr

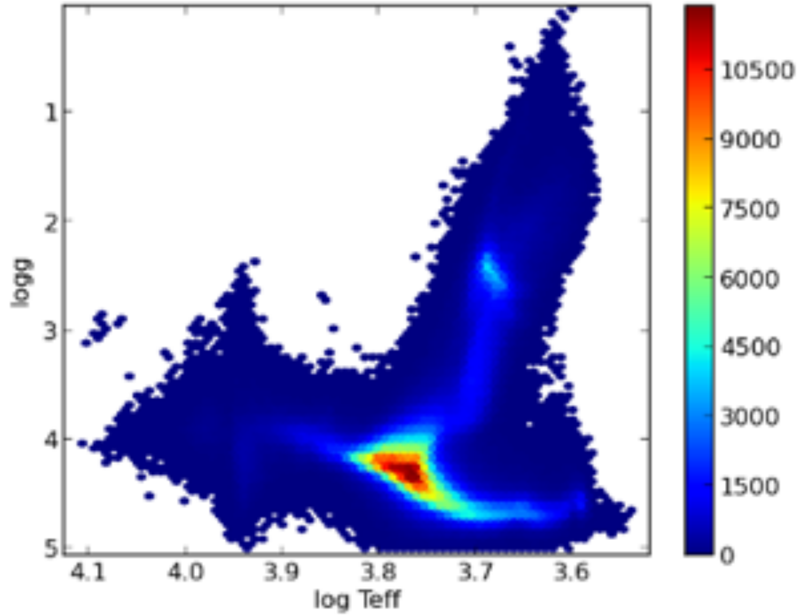


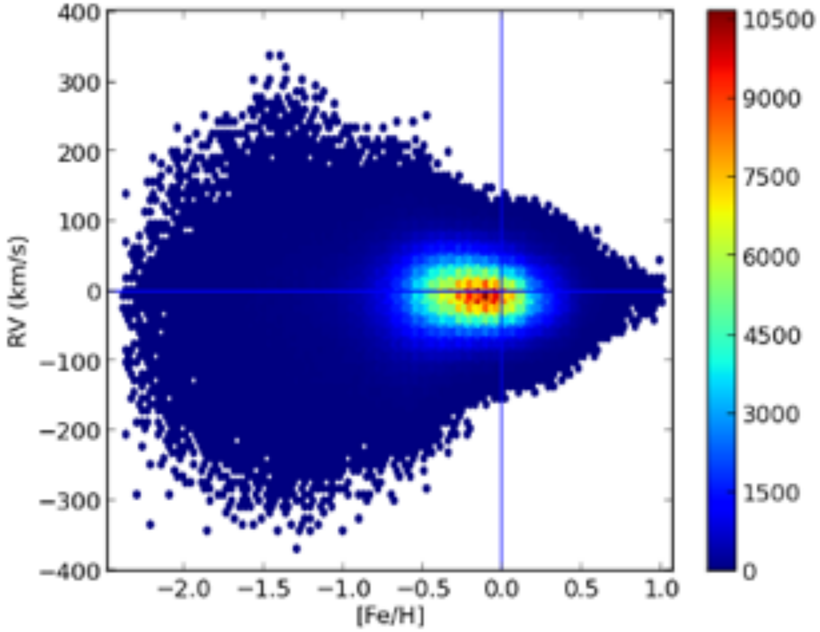
Spectral data

	PDR (1 yrs)	DR1 (2 yrs)	DR2 (3 yrs)
Spectra	717,660	2,204,860	4,158,038
stars	648,820	1,944,406	3,796,583
galaxies	2,723	12,082	37,849
quasars	621	5,017	9,495
Stars (S/N>10)	547,868	1,721,796	3,231,240
AFGK parameters	373,481	1,085,404	2,165,200

1 M spectra / year

Stellar parameters (2,165,200 spectra in DR2)





Exceeding the total number of currently known database;

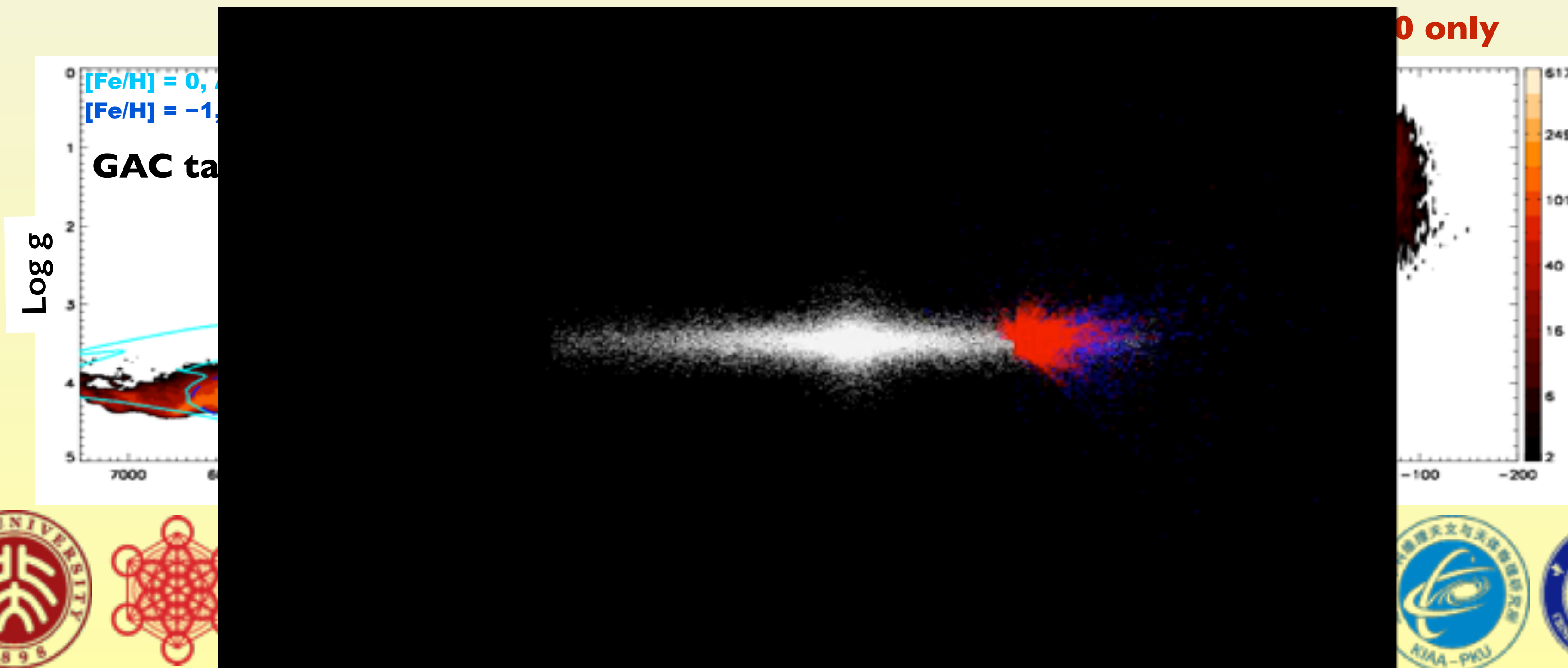
Largest stellar parameter catalogue so far

LSP3: LAMOST Stellar Parameter Pipeline at PKU

- **Flux calibration**: using an iterative approach to select suitable standard stars, ~12% accuracy (Xiang et al. 2015a, MN, 448, 90, arXiv:1412.6625)
- **Stellar atmospheric parameters**: template matching with the MILES library (Xiang et al. 2015b, MN, 448, 822; arXiv: 1412.6627)
- **Value-added catalogs DR1**: Stellar parameters, E(B−V), distances, proper motions, eccentricities, multi-band photometry for 0.75M stars (Yuan et al. 2015, MN, 448, 855; arXiv: 1412.6628)

225,000 GAC targets; 460,000 VB targets; 67,000 M31-M33 targets

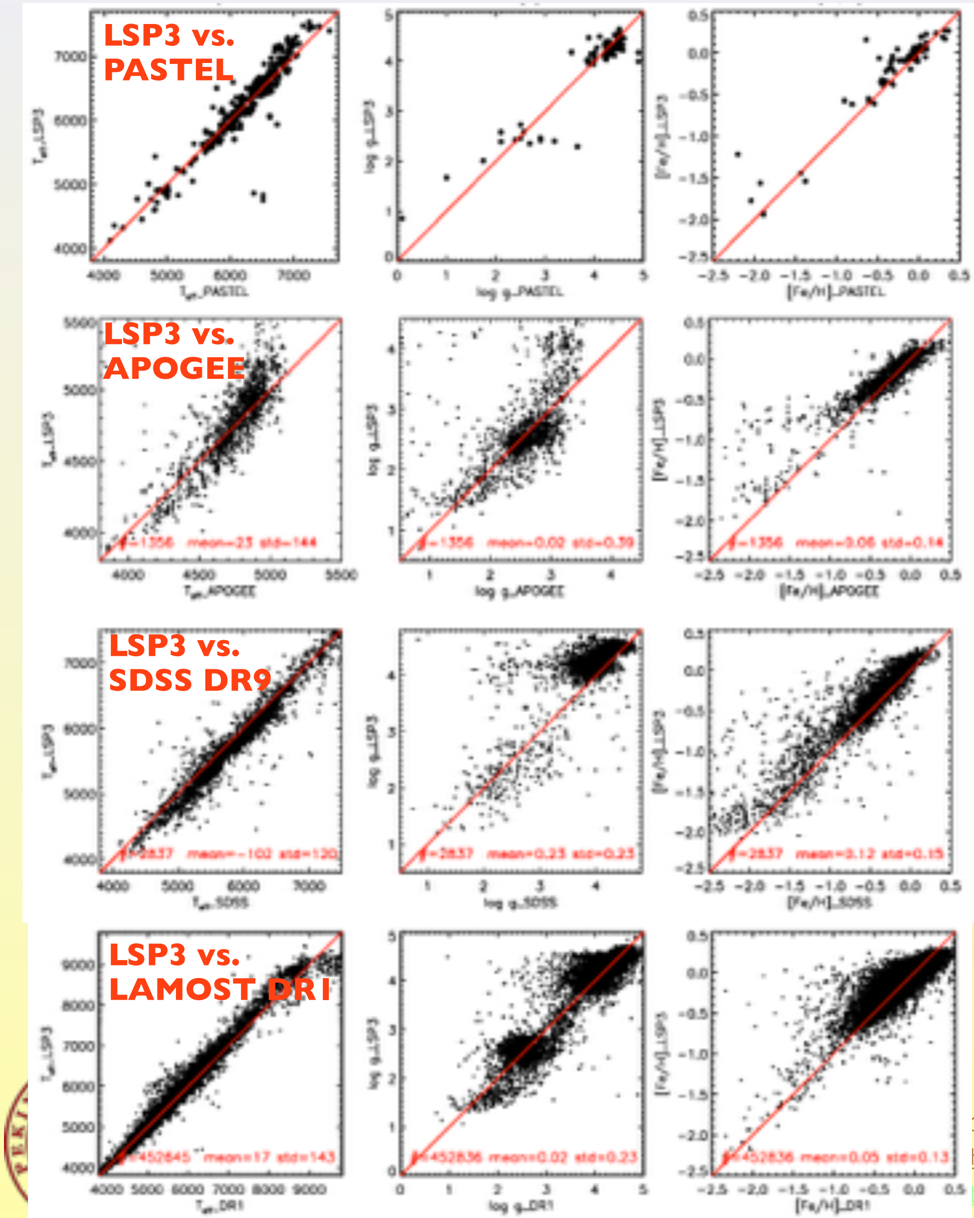
0 only



LSP3 parameters vs external data: Teff, Log g, [Fe/H]

Xiang et al. 2015b, MNRAS, 448, 822

Teff | Log g | [Fe/H]



LSP3 −	Teff (K)	log g (cm/s²)	[Fe/H] (dex)
PASTEL	23 ± 148	−0.03 ± 0.23	0.05 ± 0.12
APOGEE	23 ± 144	0.02 ± 0.39	0.06 ± 0.14
SDSS DR9	−102 ± 120	0.23 ±0.23	0.12 ± 0.15
LAMOST DR1	17 ± 143	0.02 ± 0.23	0.05 ± 0.13

LSP3 values agree well with those of PASTEL, APOGEE and LAMOST DR1.

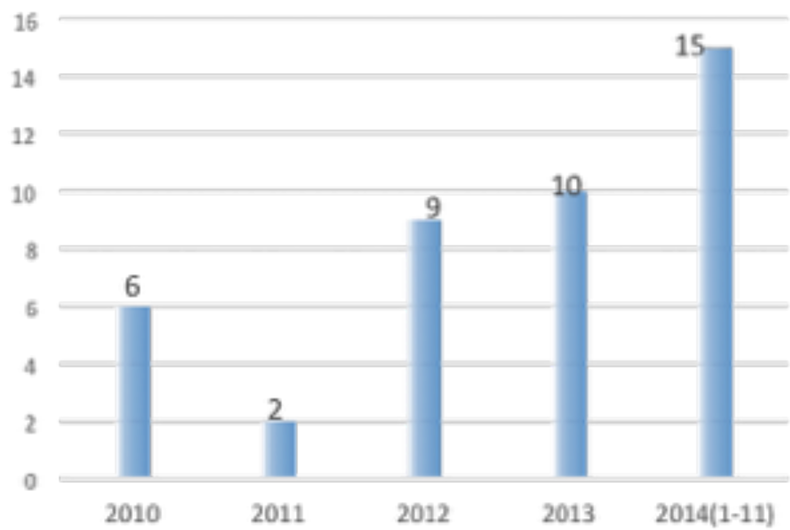
LSP3 Vr, Teff, Log g and [Fe/H] are accurate to ~ 5 km/s, 150 K, 0.25 dex, 0.15 dex for FGK stars, respectively.

The “adopted” values of SDSS DR9 show significant discrepancies with others.

Scientific papers

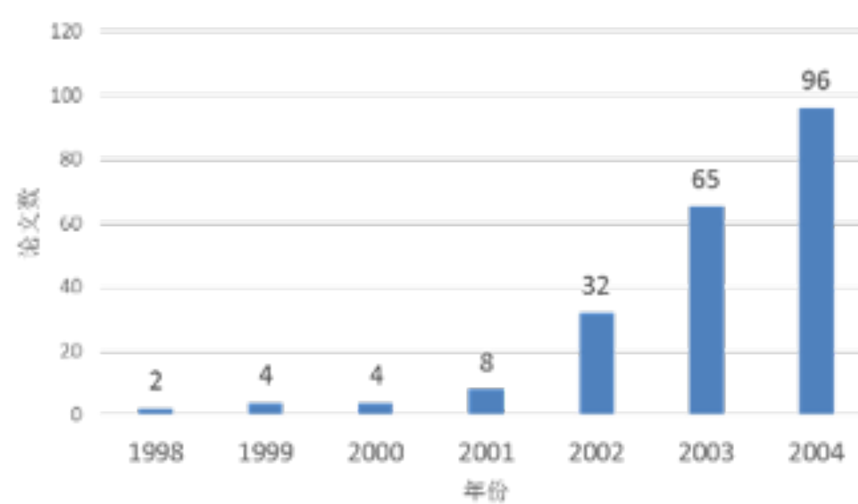
- 48 scientific papers published
  - 20 under processing

Papers with LAMOST data



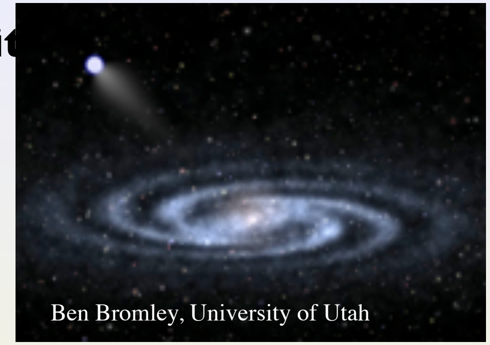
PDR DR1

Papers with SDSS spectral data



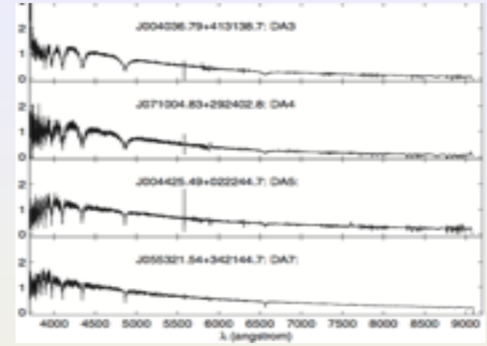
The first hyper-velocity star from LAMOST & nearest high-velocity stars

Zheng et al. 2014, ApJL
Zhong et al. 2014, ApJL



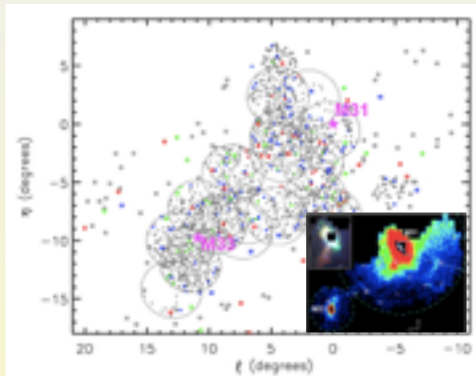
About 230 DA WDs found in the Pilot survey

Zhang et al. 2013, AJ
Zhao et al. 2013, AJ



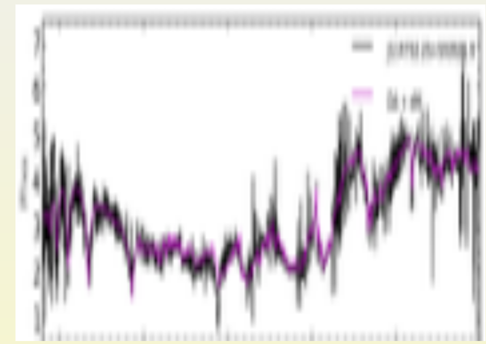
> 1900 background quasars in the vicinity of M31/M33

Huo et al. 2010, RAA
Huo et al. 2013, AJ
Huo et al. 2014, in prep.



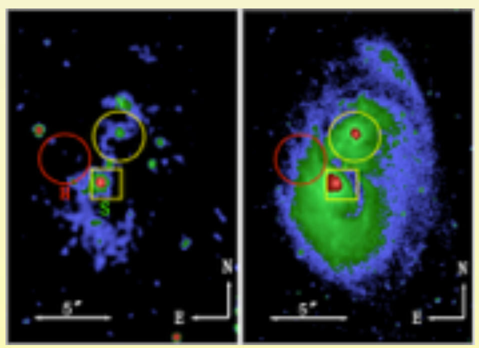
147 WD-MS binaries from the LAMOST DR1

Ren et al. 2013, AJ
Ren et al. 2014, A&A



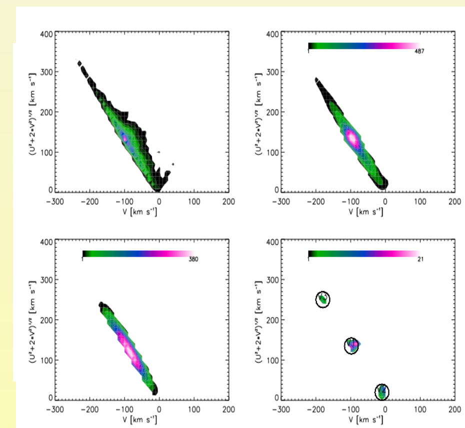
HST and LAMOST discover a dual AGN

Huang et al. 2014, MNRAS



Detect 3 moving groups in the thick disk and halo

Zhao et al. 2014, ApJ



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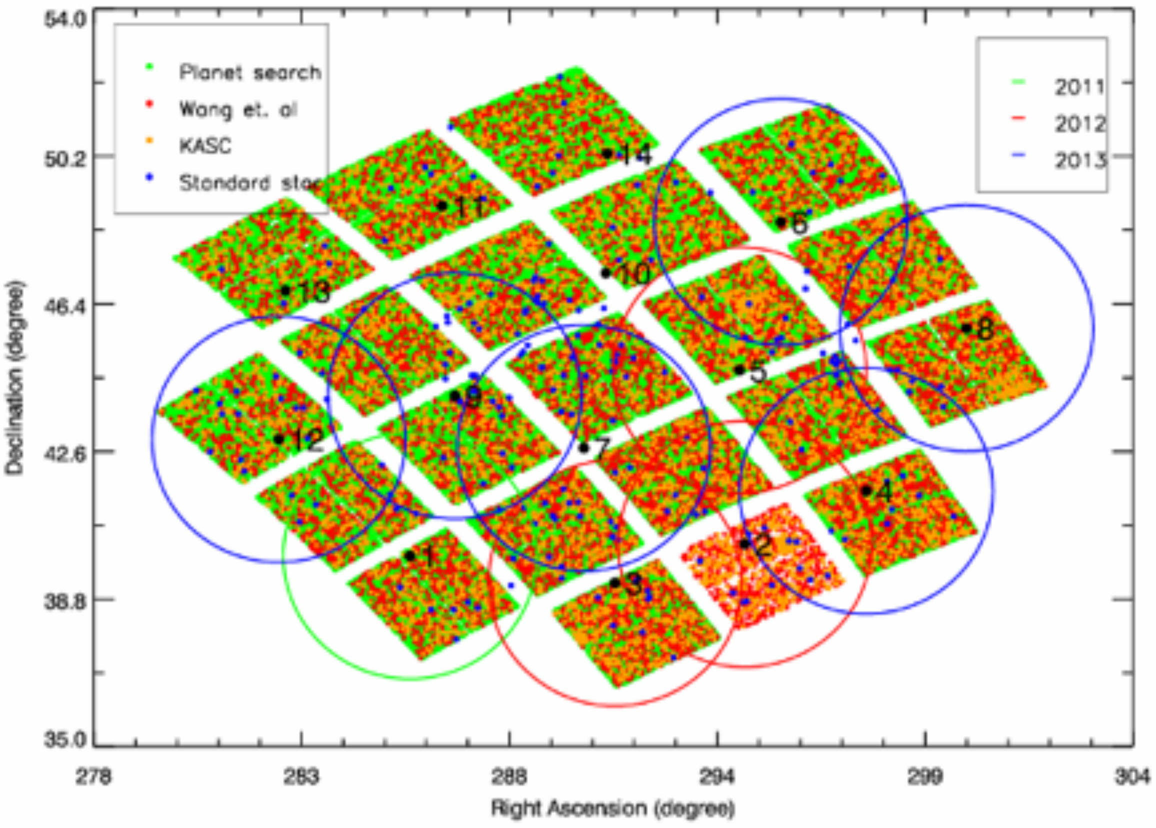
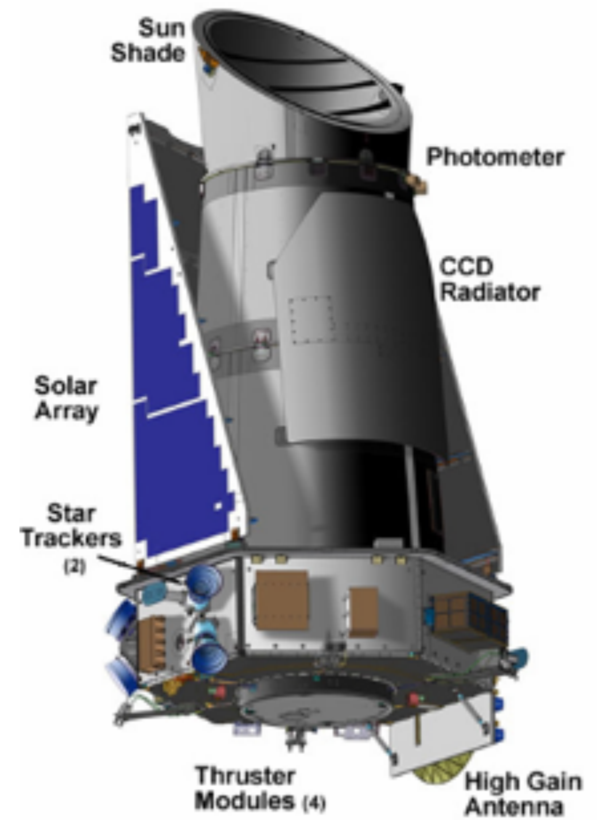
Collaboration with Kepler project

- 62,381 spectra observed ➔ 32,462 Kepler stars





LAMOST Sciences

- **Proposed**
  - p **Extra-galactic spectroscopic survey**
    - n Galaxy & QSO redshift survey
  - p **Stellar spectroscopic survey**
    - n Structure of the Galaxy & stellar physics
  - p **Cross identification of multi-waveband survey**
- **Present (2/3 slits：R = 1200 → 1800)**
  - p **Galactic survey**
    - ☑ Structure & evolution of the Galaxy
  - p **QSO & galaxy**
  - p **Cross identification of multi-waveband survey**

Spectroscopic surveys

Project	aper.	FoV	fibers	spectra	timeline
2dF	3.9m	2^{o}	400	250,000 G	1997-2002
6dF	1.2m	6^{o}	150	136,304 G	2002-2004
RAVE	1.2m	6^{o}	150	574,630 S	2006-2013
SDSS-I/II	2.5m	3^{o}	640	1,270,000 G	2000-2008
SDSS-III	2.5m	3^{o}	640	2,000,000 G	2008-2014
LAMOST	4m	5^{o}	4000	5,000,000 S	2012-2017
DESI	3.9m	3^{o}	5000	24,500,000 G	2018？-

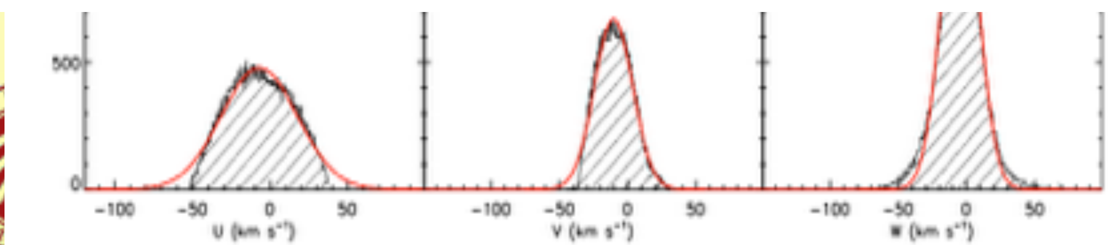
The Local Standard of Rest derived from the LSS-GAC

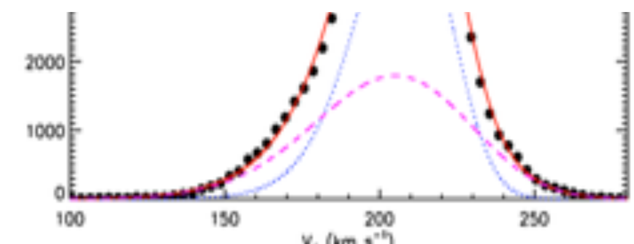
Huang et al., 2015, MNARS, in press (arXiv: 1501.07095)

- **Based on 94,332 FGK dwarfs within 600 pc**
- **A well relaxed local disk, $(U_{\odot}, V_{\odot}, W_{\odot})$=(7.01±0.20,10.13±0.12,4.95±0.09) km/s**

Table 1. Measurements of the LSR in the literatures and from the current work

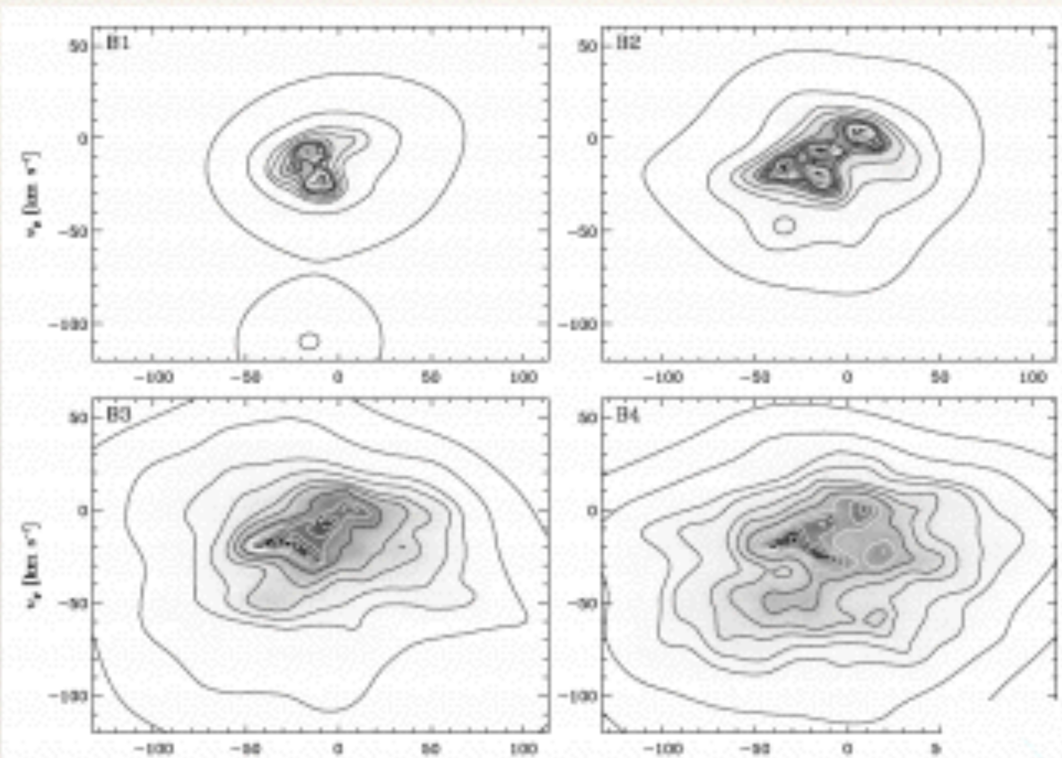
Source	Data	$U_{\odot}$ (km s^{-1})	$V_{\odot}$ (km s^{-1})	$W_{\odot}$ (km s^{-1})
This study (2014)	LSS-GAC DR1	7.01±0.20	10.13±0.12	4.95±0.09
Bobylev & Bajkova (2014)	Young objects	6.00±0.50	10.60±0.80	6.50±0.30
Coşkunoğlu et al. (2011)	RAVE DR3	8.50±0.29	13.38±0.43	6.49±0.26
Bobylev & Bajkova (2010)	Masers	5.50±2.2	11.00±1.70	8.50±1.20
Breddels et al. (2010)	RAVE DR2	12.00±0.60	20.40±0.50	7.80±0.30
Schönrich et al. (2010)	Hipparcos	$11.10^{+0.69}_{-0.75}$	$12.24^{+0.47}_{-0.47}$	$7.25^{+0.37}_{-0.36}$
Reid et al. (2009)	Masers	9.0	20	10
Francis & Anderson (2009)	Hipparcos	7.50±1.00	13.50±0.30	6.80±0.10
Bobylev & Bajkova (2007)	F & G dwarfs	8.70±0.50	6.20±2.22	7.20±0.80
Piskunov et al. (2006)	Open clusters	9.44±1.14	11.90±0.72	7.20±0.42
Mignard (2000)	K0-K5	9.88	14.19	7.76
Dehnen & Binney (1998)	Hipparcos	10.00 ±0.36	5.25±0.62	7.17±0.38
Binney et al. (1997)	Stars near South Celestial Pole	11.00±0.60	5.30±1.70	7.00±0.60
Mihalas & Binney (1981)	Galactic Astronomy (2nd Ed.)	9.00	12.00	7.0
Homann (1886)	Solar neighborhood stars	17.40±11.2	16.90±10.90	3.60±2.30



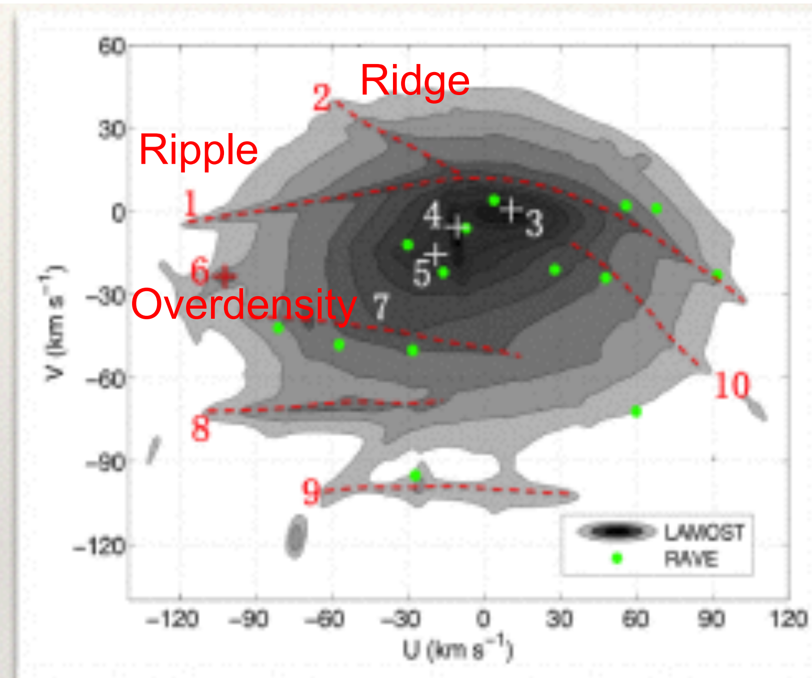


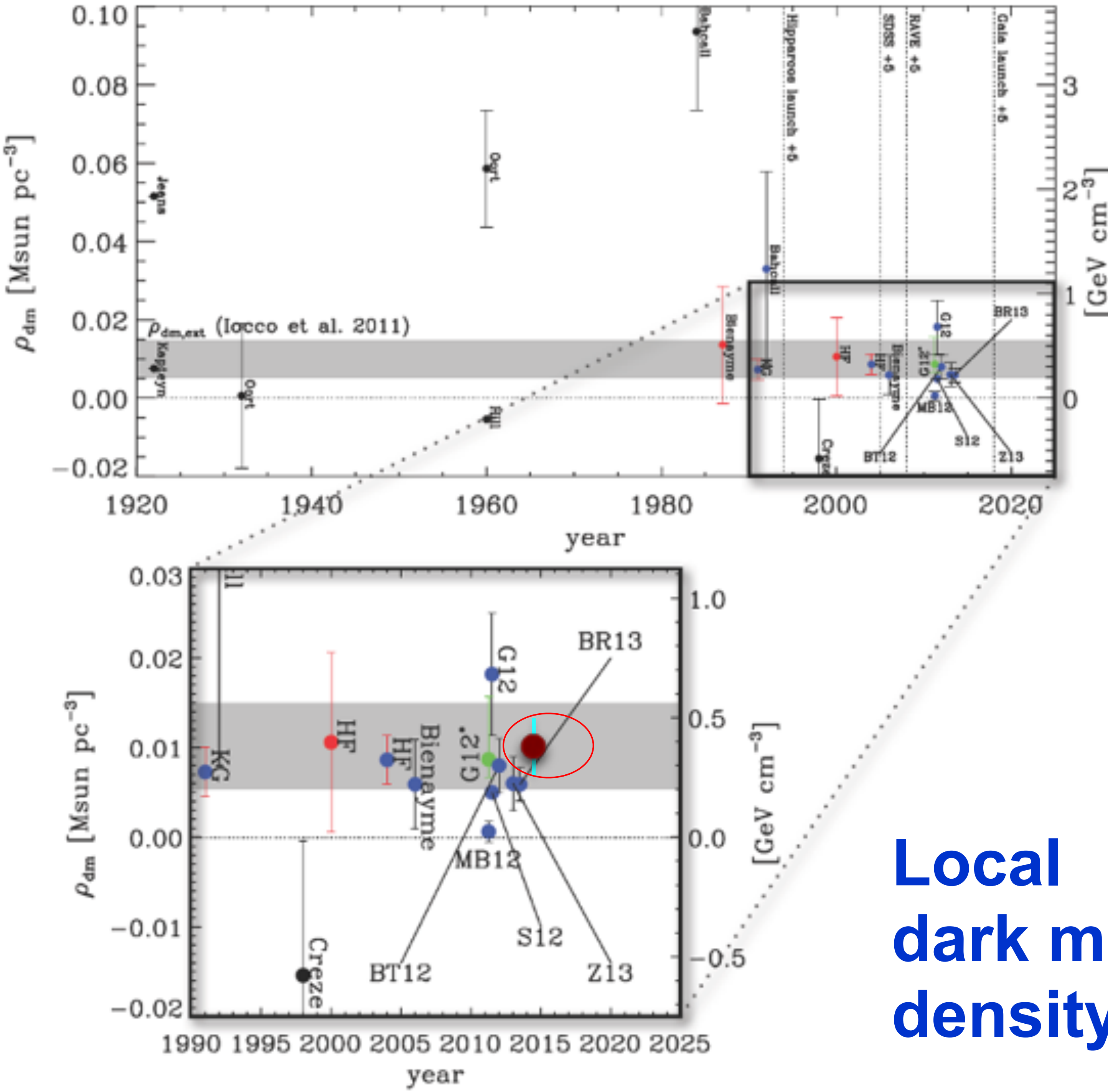
Stellar kinematics

Dehnen 1998



Xia et al. 2015, MN, 447, 2367



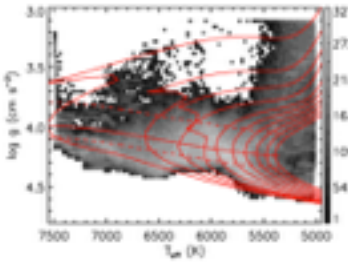


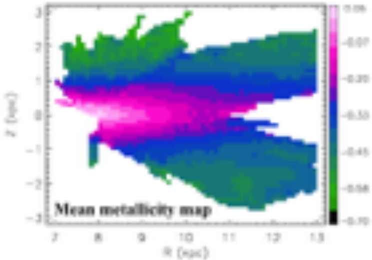
Local dark matter density

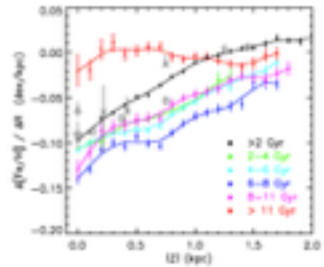
Age-dependent metallicity gradients

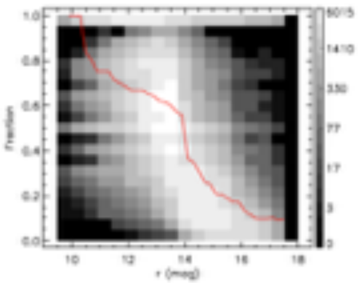
Xiang et al. in prep.

- 300,000 main sequence turn-off stars
  - 5400 < Teff < 7500 K, log g cut
- Stellar ages
  - YY isochrones
  - 30 per cent uncertainty
- Selection effects:
  - CMD weights —> Magnitude limited sample
  - Simulations: Used to characterize the bias of a magnitude limited sample

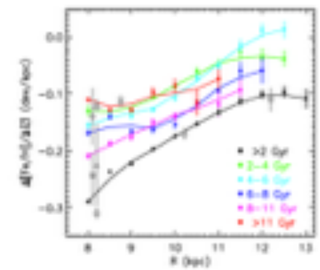




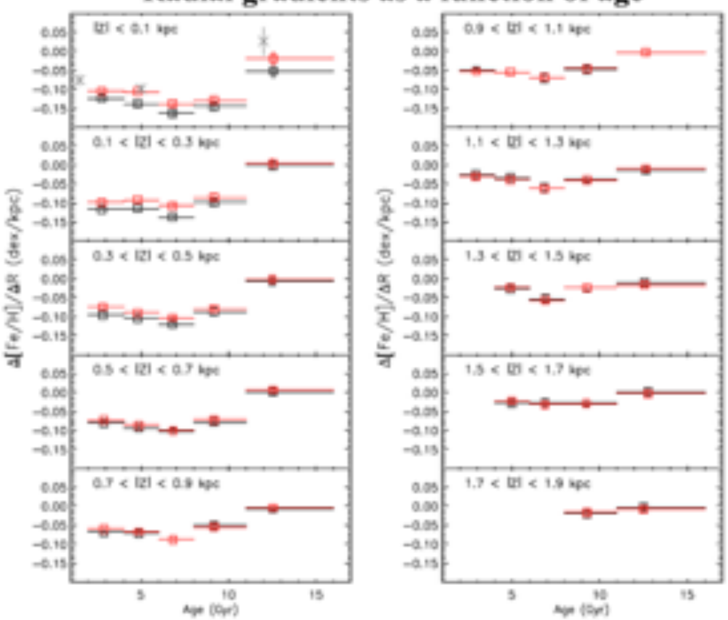




- Both radial and vertical gradients show significant temporal evolution
- Oldest stars: *zero* radial gradients; *negative* vertical gradients with weak-dependence on *R*
- Younger stars: negative radial and vertical gradients; Radial gradients flatten with |Z|; Vertical gradients flatten with *R*



Radial gradients as a function of age

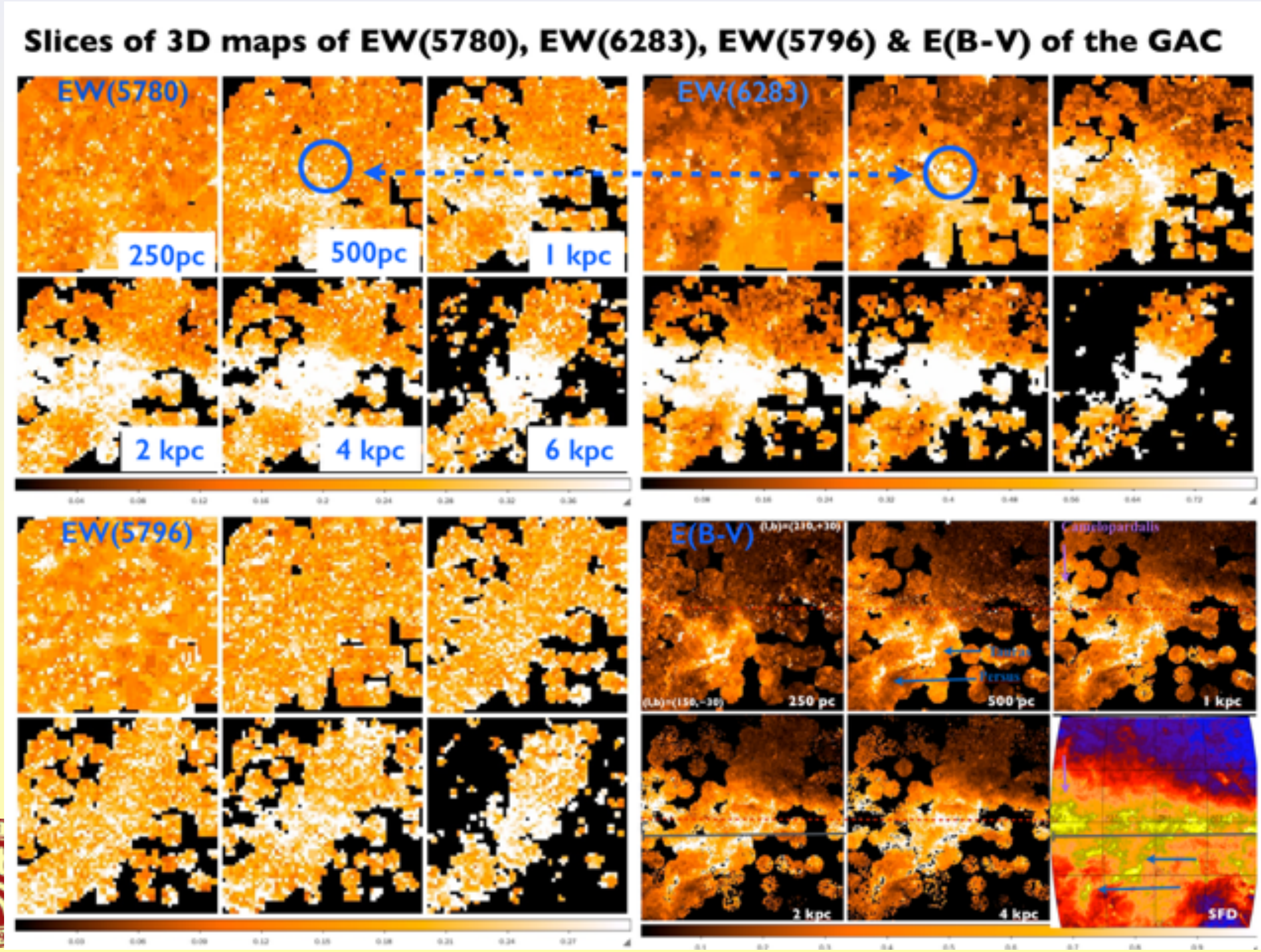


Red: CMD weight corrected

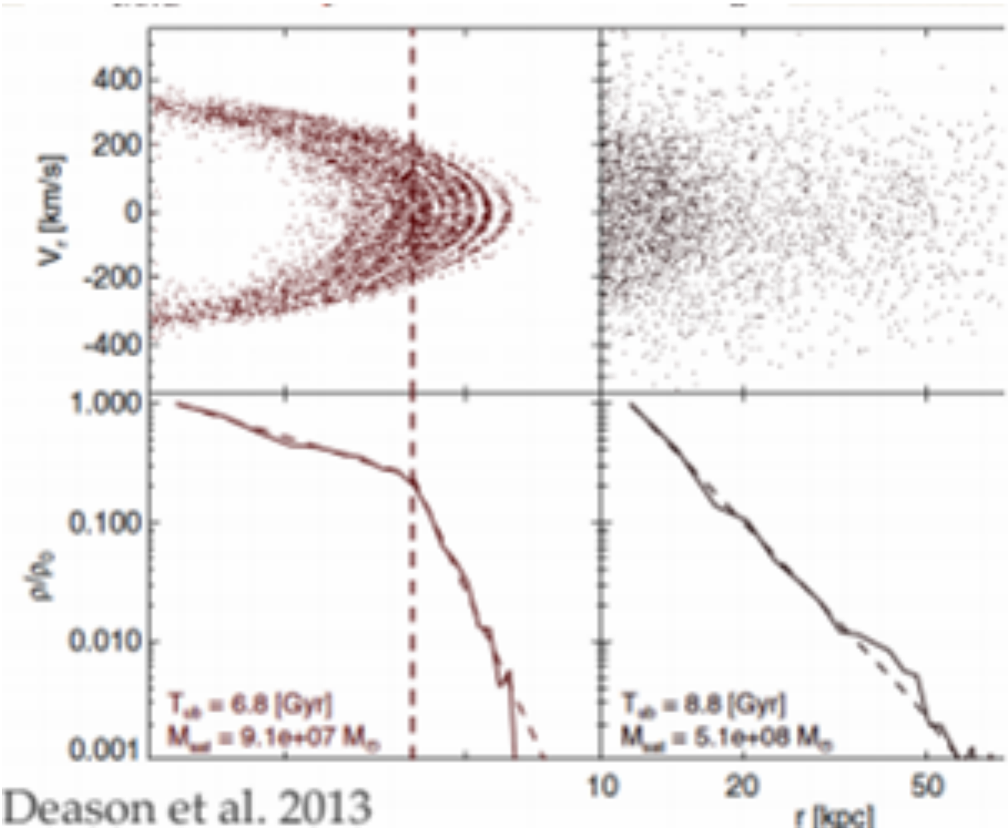
Implications

- A two-phase Galactic disk formation
- Age > 11 Gyr: A slow, pressure-supported collapse (radially well-mixed vertical gas flow) — thick disk formation
- Age < 11 Gyr: Gas accretion and radial flow — thin disk formation
- A phase transit between 8–11 Gyr

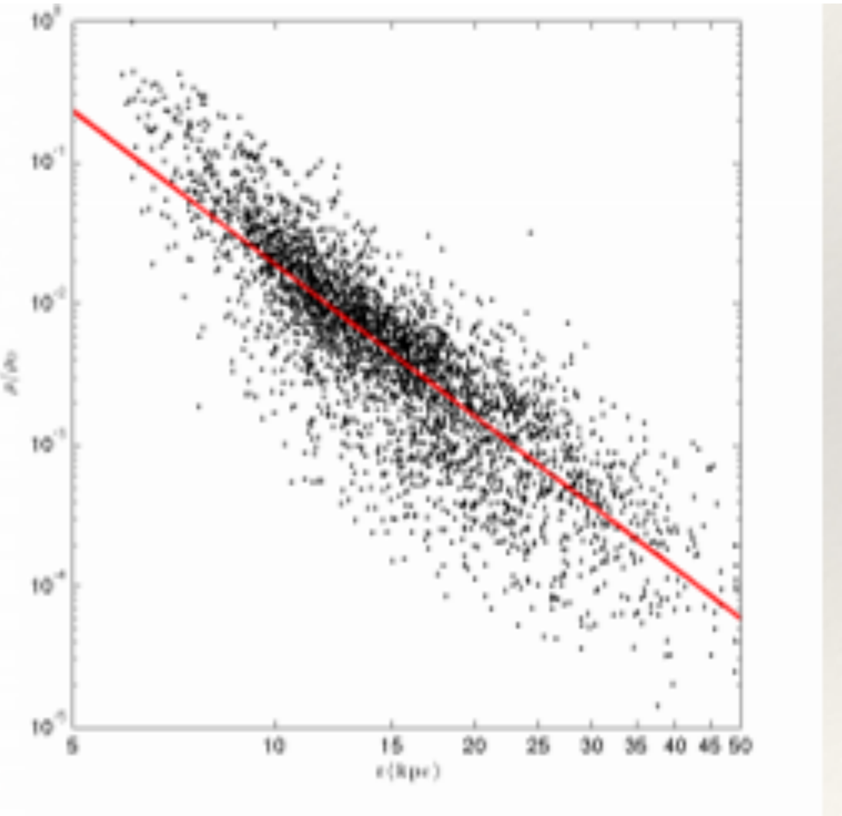
Demography of DIBs with millions of LAMOST spectra



Stellar halo profile

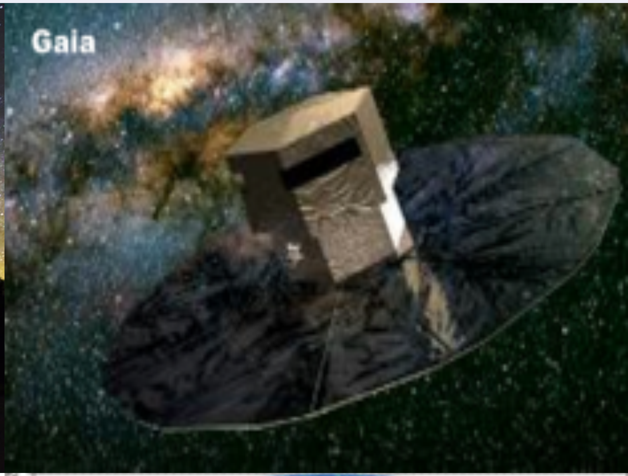


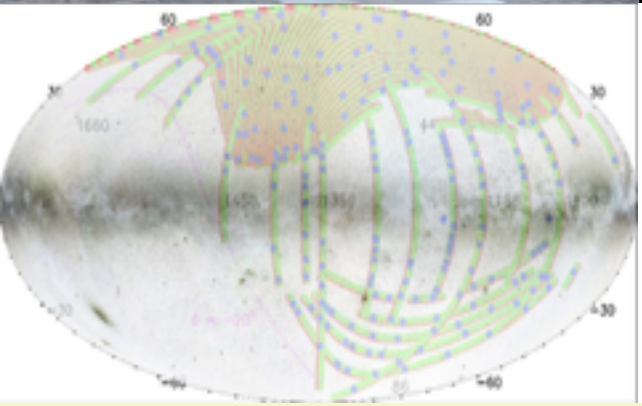
Deason et al. 2013

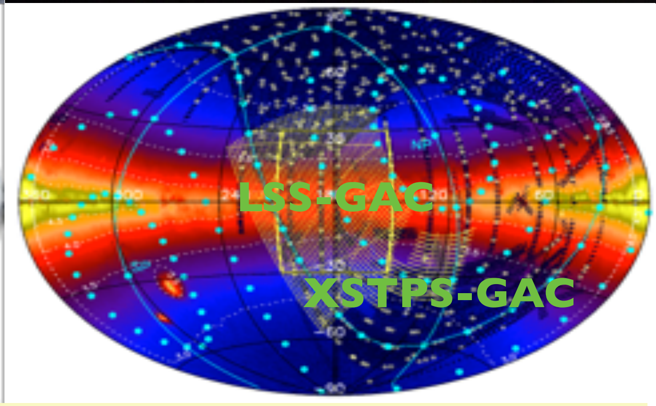


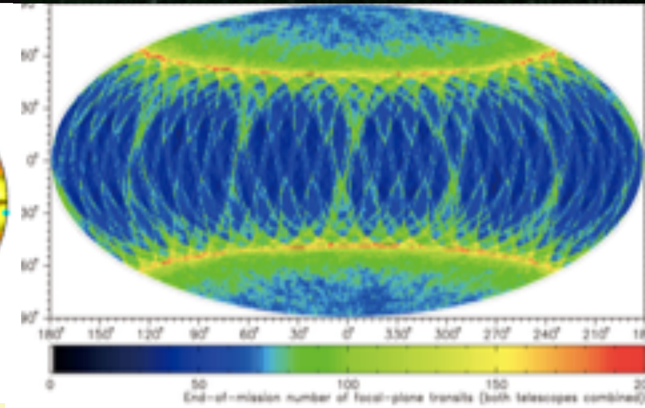
Xu et al. in prep.

Why Galactic (and anti-center)?







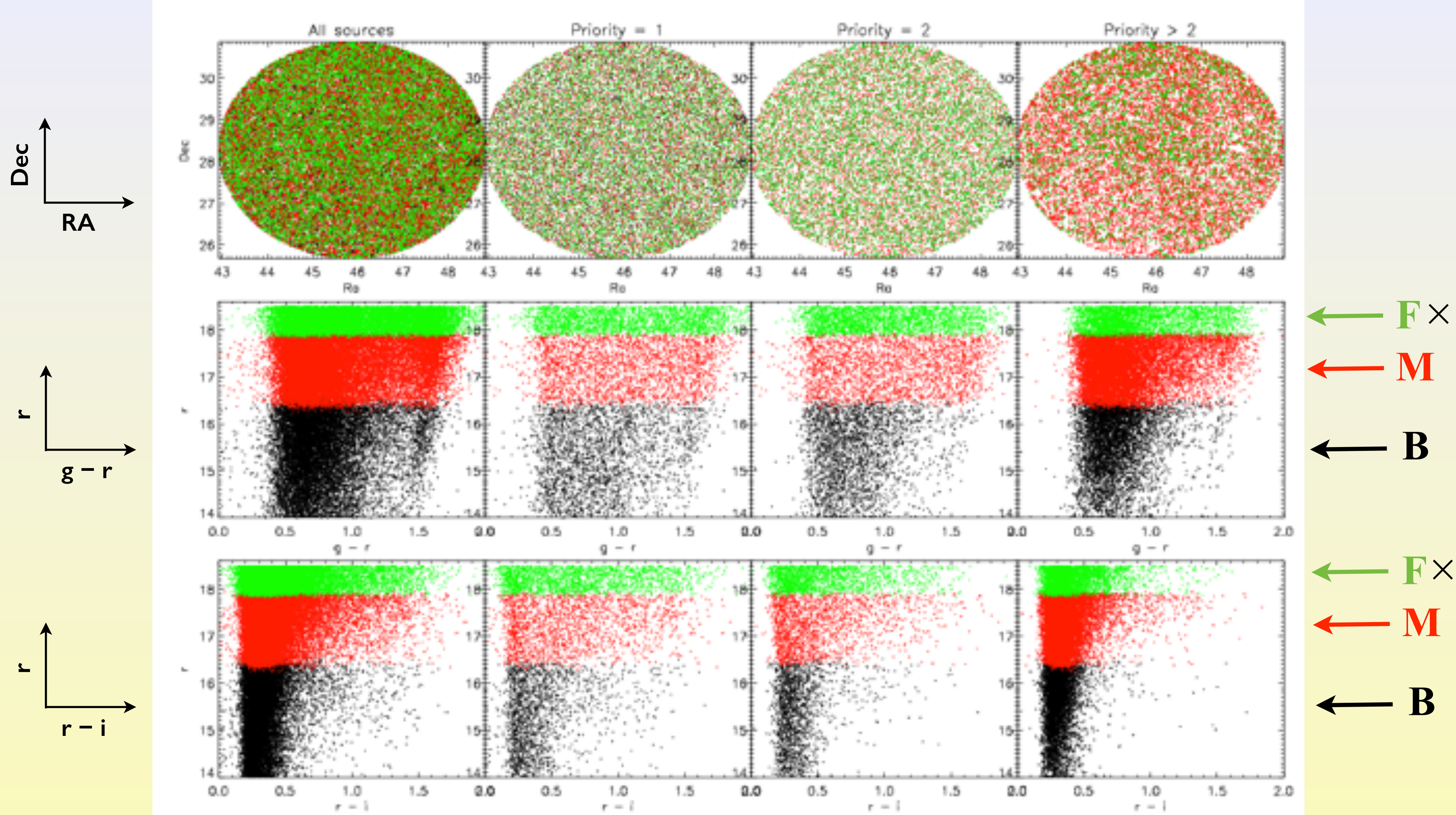


SDSS/SEGUE (footprint & depth) largely missed the (thin) disk, the MW's defining structure

With 4,000 in a 20 sq.deg. FoV, LAMOST opens up the possibility to (spectroscopically) survey a significant volume of the MW, in particular the disk in the anti-centre (site + weather).

Liu et al., in proceedings of the IAUS 298 Setting the scene for Gaia and LAMOST (arXiv:1306.5376v1)

Yuan et al., 2015, MNRAS, 448, 855 (arXiv: 1412.6628)



Bright plates: r ~ (14.0 — 16.3)   Medium plates: r ~ (16.3 — 17.8)   Faint plates: r ~ (17.8 — 18.5)

Targets are selected with an equal probability in the (g − r, r) and (r − i, r) space

- **A simple well-defined selection function**
- **Stars of all types selected by large numbers**
- **Rare objects of extreme colors are first selected**
- **A huge discovery space**

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Scientific goals of the galactic survey

- **The survey will deliver classification, Vr, Teff, log g, [Fe/H], [α/Fe] for ~5 millions of stars.**
  - A magnitude-limited and (statistically) complete sample of ~3 M stars
  - Distributed in a contiguous area
  - Sampling a significant volume of the thin/thick disks and halo
- **With GAIA data, yield a unique dataset to**
  - Study the stellar populations, chemical composition, kinematics and structure of the thin/thick disks and halo
  - Identify tidal streams & debris of disrupted dwarfs and clusters
  - Probe the gravitational potential and dark matter distribution
  - Map the interstellar extinction as a function of distance
  - Search for rare objects (e.g. stars of peculiar chemical composition or of hyper-velocities)
  - Ultimately advance our understanding of the assemblage history of the Milky Way, and of galaxies in general and their regularity and diversity.

Summary

- **LAMOST (Spectroscopy) + Gaia (Astrometry...) will yield a unique dataset to study our Galaxy.**
  - **stellar populations**
  - **kinematics**
  - **chemical composition**
  - **thin/thick disk, halo**
  - **assemblage history of the Milky Way**
- **LAMOST Regular Survey (2012 - 2017)**
  - **3 M spectra down to r = 17.8**
  - **5 M spectra in total**
- **LAMOST spectral data**
  - **DR1 (2013.09) : 1.8 M spectra / 1.0 M parameters**
  - **DR2 (2014.12): 3.0 M spectra / 2.1 M parameters**
- **LAMOST starts to produce scientific results, more results are expected**

Data policy of LAMOST

- **Internal release**
  - Chinese astronomers
  - International collaborators (with Chinese groups)
  - DR1 (2013.09) : 1.8 M spectra / 1.0 M parameters
  - DR2 (2014.12): <u>3.0 M spectra / 2.1 M parameters</u>

- **Public release （after 1.5 yrs)**
  - DR1 (2015.03) : 1.8 M spectra / 1.0 M parameters