(The 2nd LAMOST-*Kepler* workshop)

LAMOST as a ground-based support facility for the space missions

Dr. Prof. Jianning Fu

(*Beijing Normal University, China*)

Collaborators: Peter De Cat (Belgium), Martin C. Smith (China),

and the LAMOST-*Kepler* collaboration group

Brussels — August 1, 2017

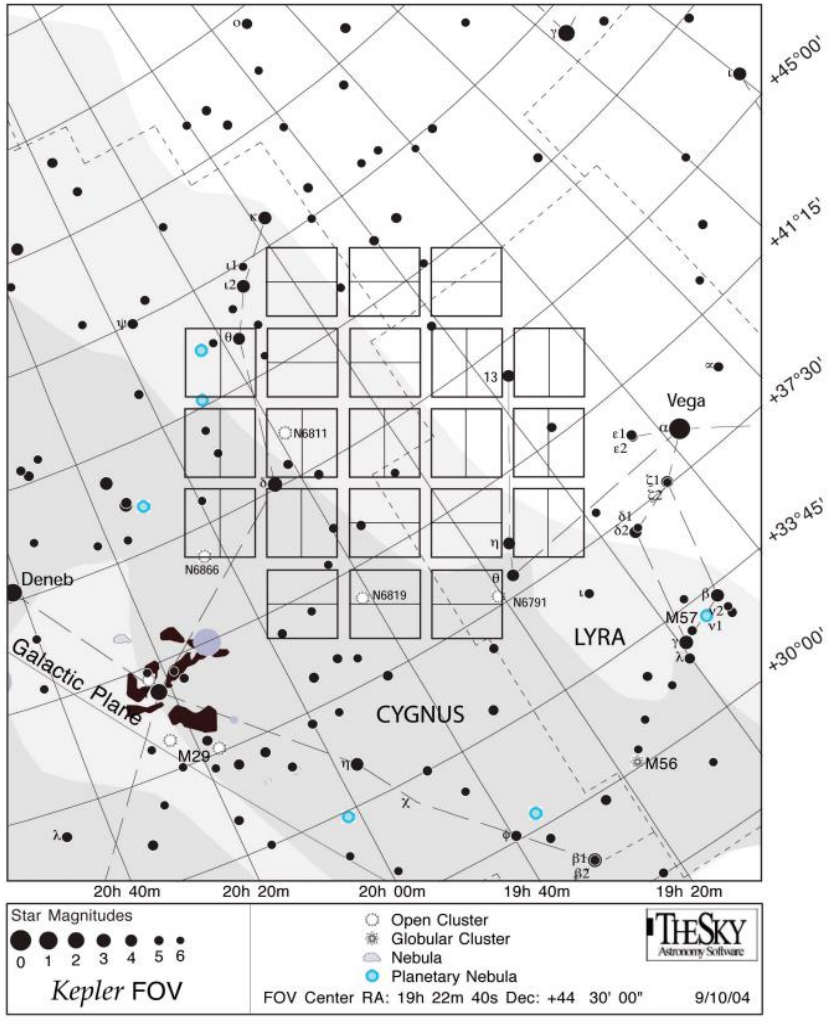
Outline

- Introduction
- LAMOST-*Kepler* Project
  - Observation progress
  - Existing scientific work
- LAMOST-*K*2 project
- Prospect of LAMOST for *TESS*
- Synergies between LAMOST and *GAIA*
- Summary

§1 Introduction

1.1 Support observations for the *Kepler* mission

- **Main scientific goals of the *Kepler* mission:**
  - **discover Earth-size planets by the transit method**
  - **characterize stars by asteroseismology**
- **Targets: ~160,000 stars in a 105 deg²**



Asteroseismology with the *Kepler* data

- ***Kepler* observations**
  - **Provide excellent light curves of a large number of stars of different populations**
  - **Asteroseismic study:**
    ages and evolutionary states for red giants, solar-like stars, etc.
  - **Stellar parameters are needed:**
    T_{eff}, ***log*** **g, [*Fe/H*], (v*sin i*)**

Exoplanet study with the *Kepler* data

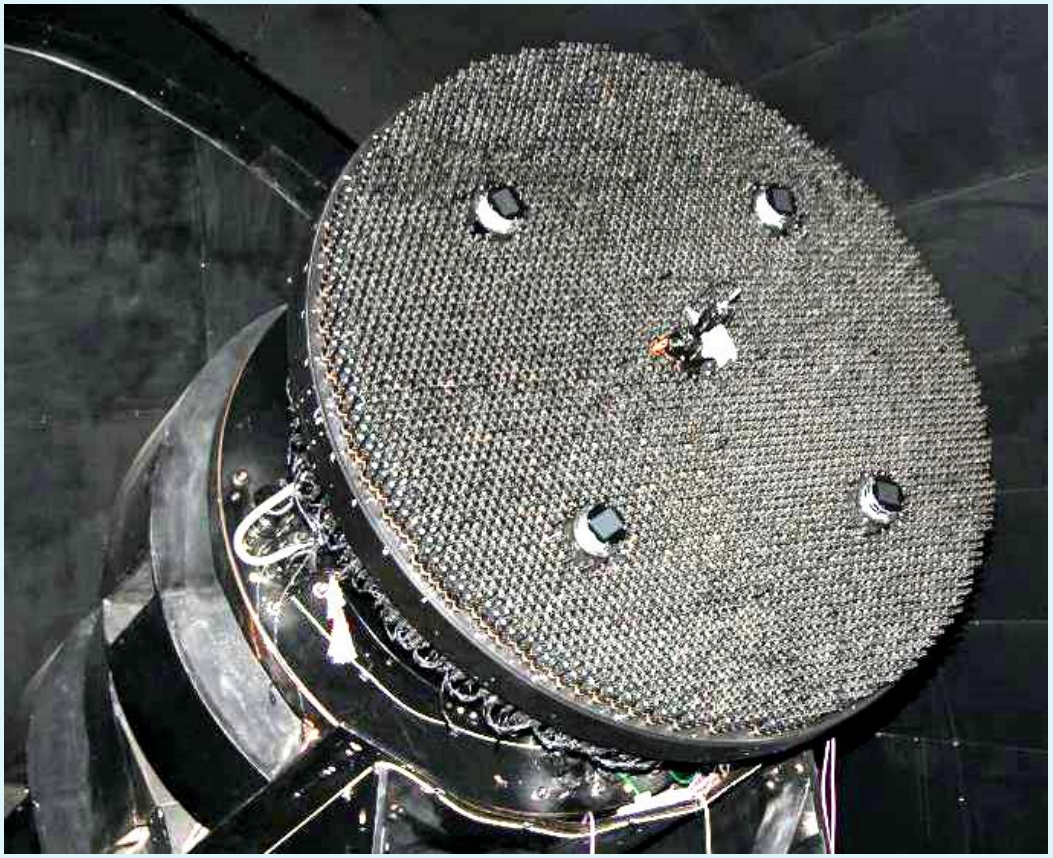
- ***Kepler* observations**
  - **Provide excellent light curves of a large number of stars with the transits of the planets**
  - **Exoplanet study: eccentricity distribution, exoplanet properties, exoplanet formation, etc.**
  - **Stellar parameters are needed: T_{eff}, *log* g, [*Fe/H*]**

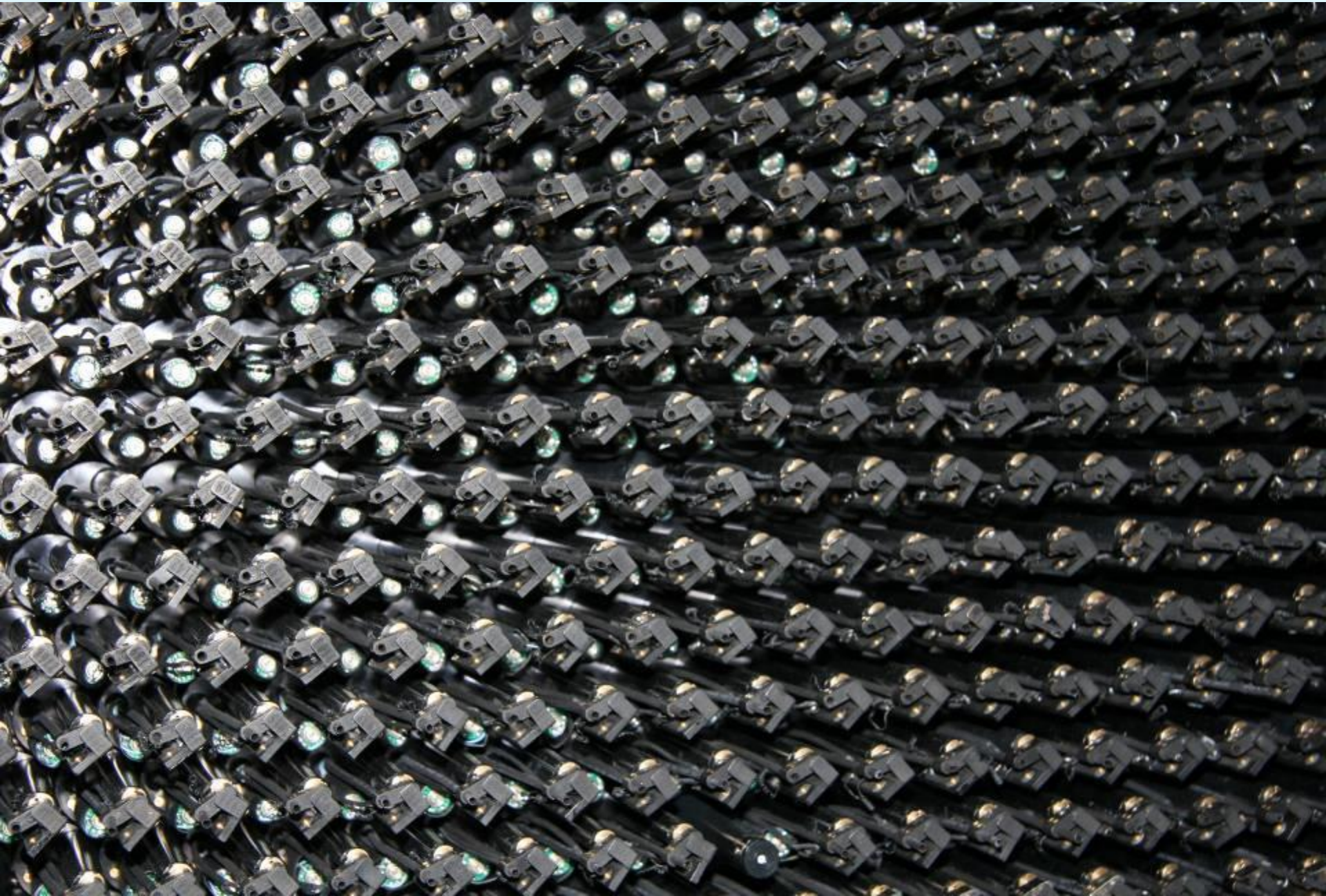
- **Existing stellar parameters: *KIC*10**
  - **Measurements based on multi-color photometry**
  - **T_{eff} and *log* g but the precision is low**
  - **No [Fe/H] and vsin *i***
- **Spectroscopic observations expected**
  - **Spectroscopy preferred above multi-colour photometry**
  - **Chemical composition, metallicity and rotation**
  - ***RV* for binaries and cluster members**
  - **Homogeneous measurements desired**

⇒ LAMOST!

1.2 LAMOST

Aperture: > 4 m
FOV: ϕ 5°
Fibers: 4000





§2 LAMOST-*Kepler* Project

2.1 First Round Observations

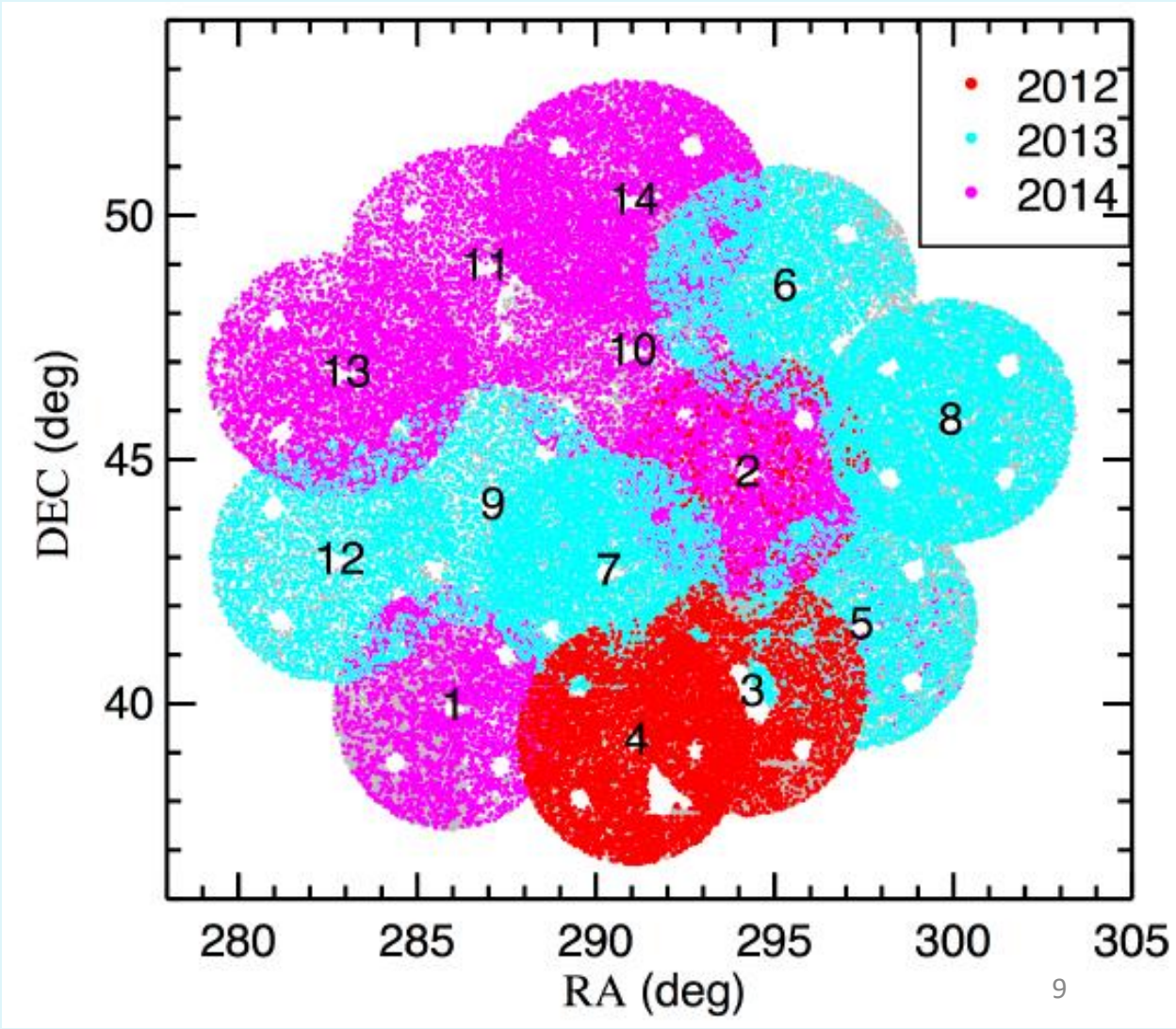
–Time:

June 4, 2012 —

Sept. 29, 2014

–S/N_i>20:

68,685



Stellar Parameters

Parameters measured with: LASP/ULySS, ROTFIT, MKCLASS

Filename/Object	Version	SNR_r	SpT	T_{eff} (K)	$\log g$ (dex)	$[Fe/H]$ (dex)	Method
spec-56094-kepler05B56094_2_sp13-034	v2.7.5	581	*A2 V*	9380(56)	3.65(11)	-0.35(5)	ULySS
KIC 373195	v2.4.3		*B9 IV*	9707(589)	3.83(11)	-0.16(14)	ROTFIT
*	v2.7.5		*A0 IV-V*				MKCLASS
spec-56096-kepler08B56096_1_sp07-250	v2.7.5	66	*A2 V*	11223(113)	3.79(18)	-0.18(8)	ULySS
KIC 313703	v2.4.3		*B9 III*	10839(342)	4.00(11)	-0.08(13)	ROTFIT
	v2.7.5		*B9 V*				MKCLASS
spec-56096-kepler08B56096_2_sp05-225	v2.7.5	23	A1 V	*10869(241)*	3.87(25)	-0.41(15)	ULySS
KIC 365421	v2.4.3		B9 IV	*10336(248)*	3.88(10)	-0.26(13)	ROTFIT
	v2.7.5		A1 IV				MKCLASS
spec-56094-kepler05B56094_2_sp09-061	v2.7.5	279	G0	*5619(12)*	*3.63(4)*	-0.15(3)	ULySS
KIC 518823	v2.4.3		G0 V	*5774(97)*	*4.13(13)*	-0.11(17)	ROTFIT
*	v2.7.5		G0 IV-V				MKCLASS
spec-56094-kepler05F56094_sp15-020	v2.7.5	50	G0	5741(41)	4.30(12)	-0.33(10)	ULySS
KIC 509591	v2.4.3		G0 V	5731(91)	4.22(14)	-0.41(16)	ROTFIT
	v2.7.5		G1 V				MKCLASS
spec-56096-kepler08B56096_1_sp05-091	v2.7.5	17	*F9*	5765(76)	3.88(26)	-0.18(16)	ULySS
KIC 365591	v2.4.3		*G0 V*	5647(216)	4.05(25)	-0.43(20)	ROTFIT
	v2.7.5		*G2 III-IV*				MKCLASS

For the details, please see the presentations of Anbing, Antonio and Richard & Chris

2.2 Second Round Observations

–Time:

May 29, 2015 —

June 15, 2017

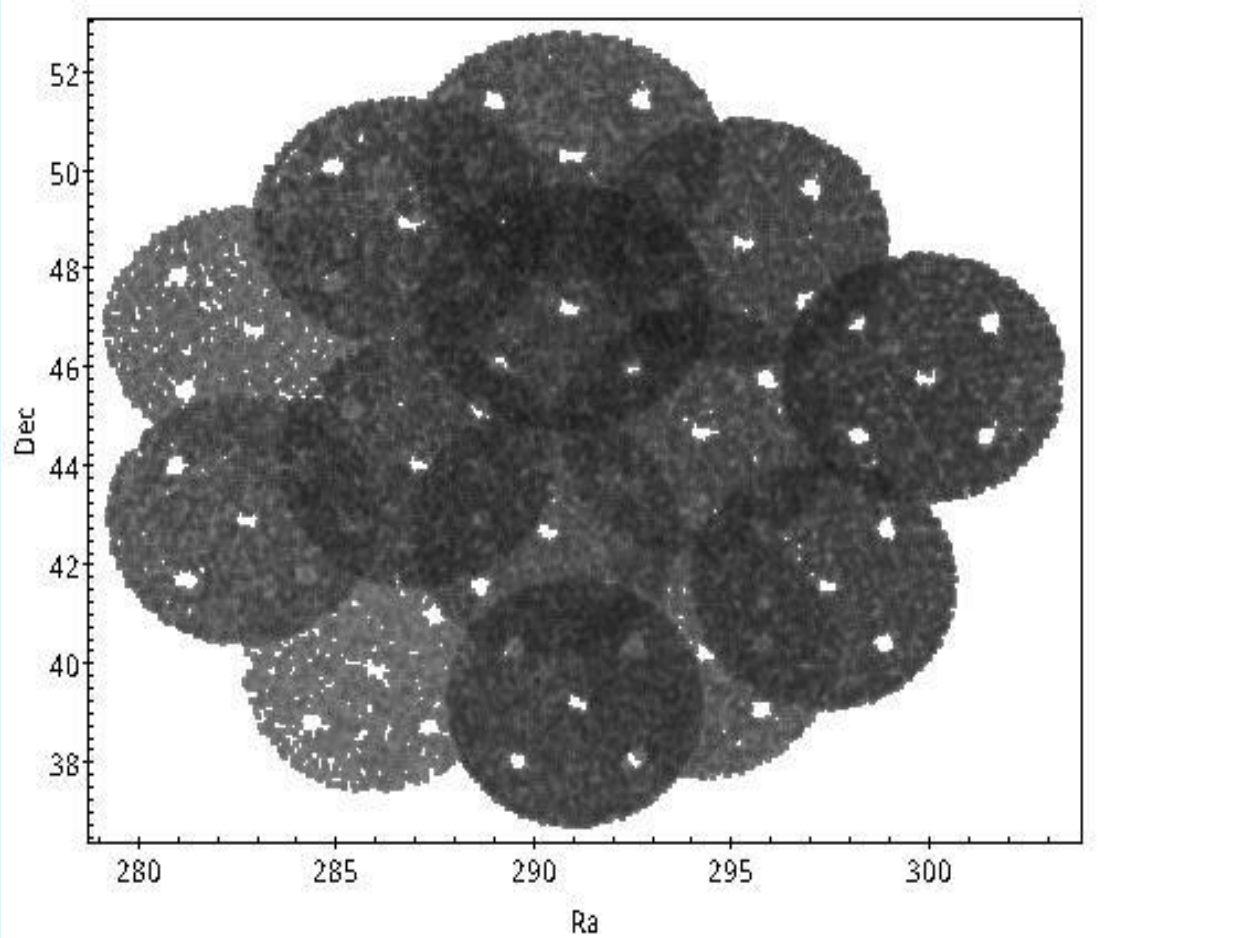
–Observations:

48 plates/24 nights

–Common stars

with *Kepler*:

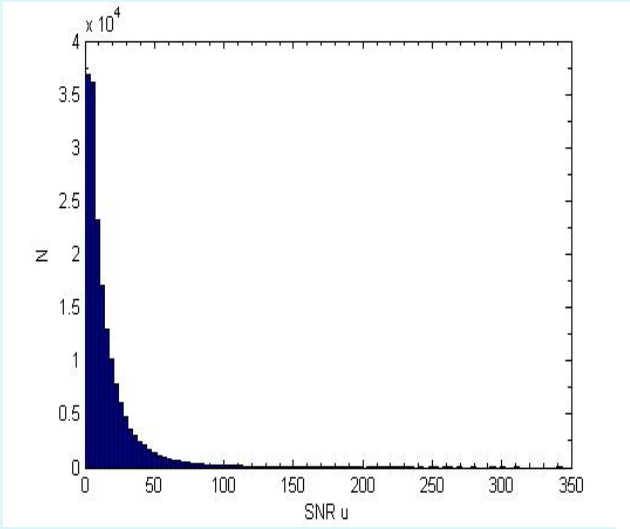
45,334

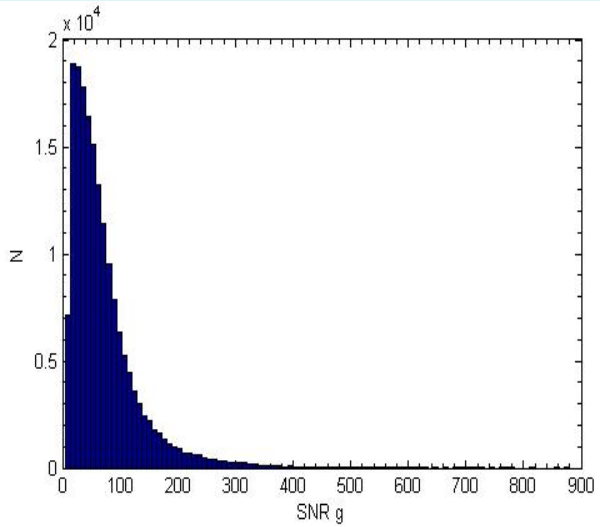


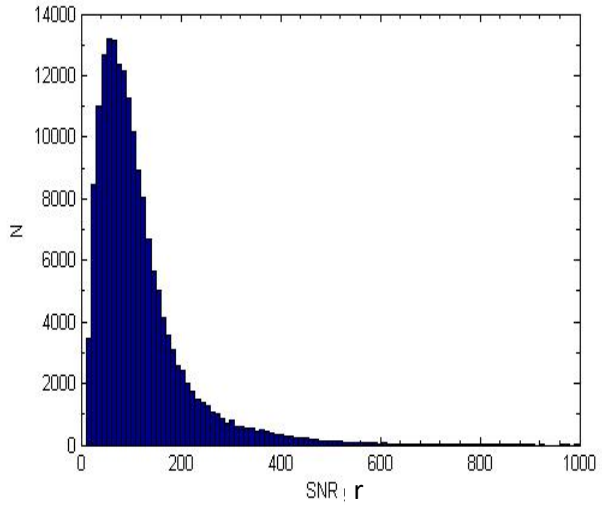
LAMOST-Kepler field	Ra	Dec	spectrum	parameters	Overlap targets	*	date
LK-01	18:50:31	42:54:43	10500	7398	2526	4	2015/10/04
							2017/06/07
LK-02	18:51:11	46:44:17	2947	2588	1225	1	2015/10/06
LK-03	19:03:39	39:54:39	5105	3327	2104	2	2017/06/03
LK-04	19:06:51	48:55:31	10944	7747	3290	4	2015/05/30
							2015/09/15
LK-05	19:08:08	44:02:10	13997	10278	1320	5	2015/09/25
							2017/06/15
LK-06	19:21:02	42:42:13	6228	5478	2677	2	2015/10/11
LK-07	19:23:14	47:11:44	16588	11983	5030	6	2015/09/14
							2015/10/02
							2017/06/14
LK-08	19:23:23	50:16:16	8689	6860	3083	3	2015/05/29
							2015/09/13
LK-09	19:24:09	39:12:42	14097	10370	4104	5	2015/10/12
							2017/06/13
LK-10	19:36:37	44:41:41	9164	6714	4170	3	2015/09/21
LK-11	19:37:08	40:12:49	9537	4463	2113	3	2015/10/18
							2017/06/12
LK-12	19:40:45	48:30:45	9451	8216	5530	3	2015/09/16
							2015/10/01
LK-13	19:49:18	41:34:56	9456	7930	3832	3	2015/10/08
LK-14	19:59:20	45:46:21	12726	9886	4332	4	2015/09/18
							2015/10/03

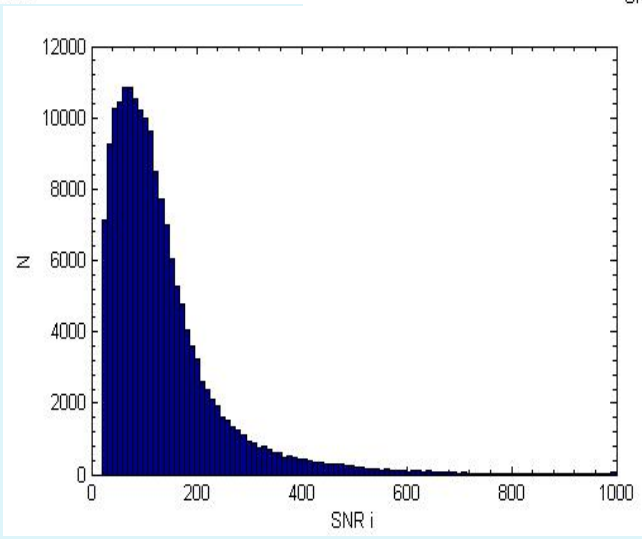
S/N distribution

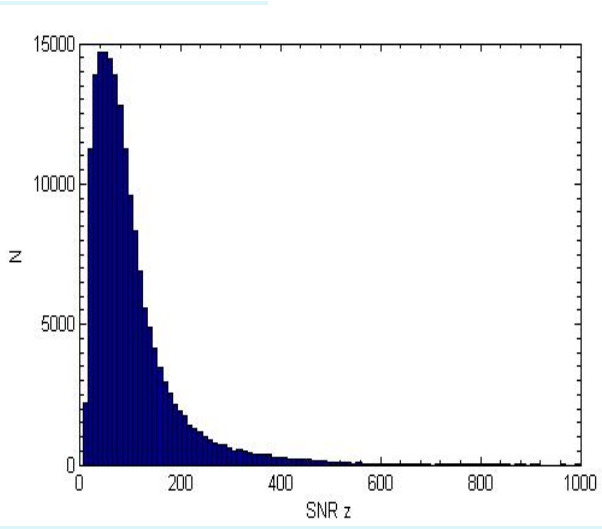
S/N_i>20: 113,227









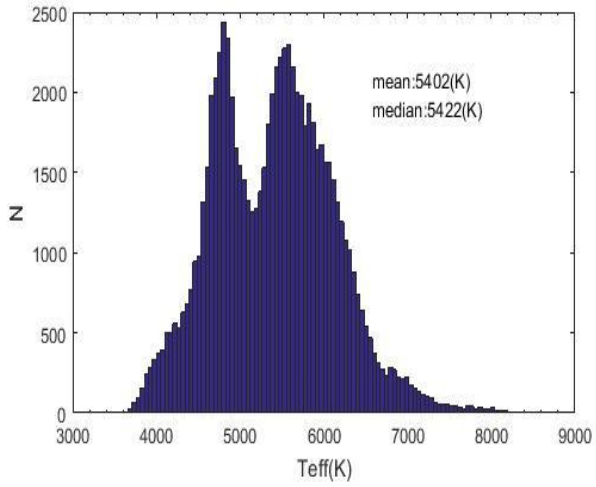


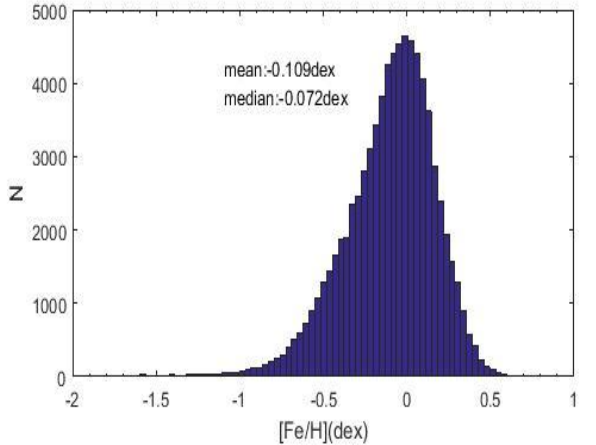
Stellar parameter distribution

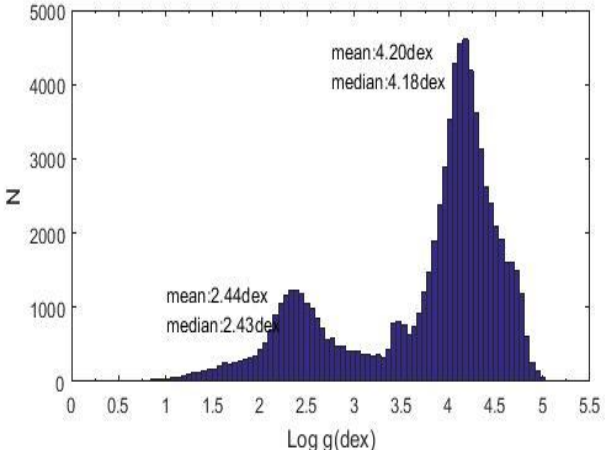
- **Stellar parameters： 103,238**

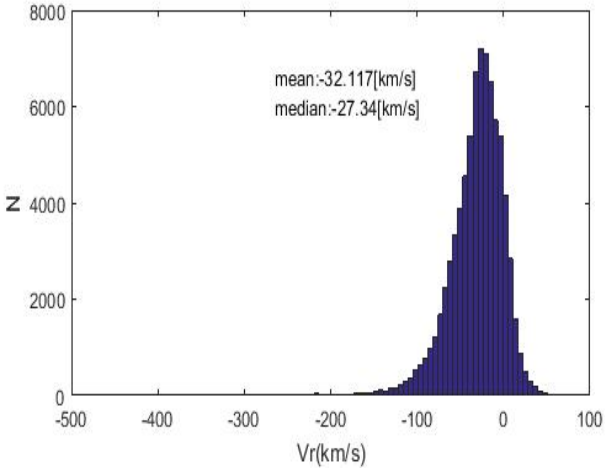
  Giants： 29,806; Dwarfs： 73,432

- **[*Fe*/*H*]<-1 dex: 500; <-2 dex: 42; $|V_r|$>300 km/s: 105**

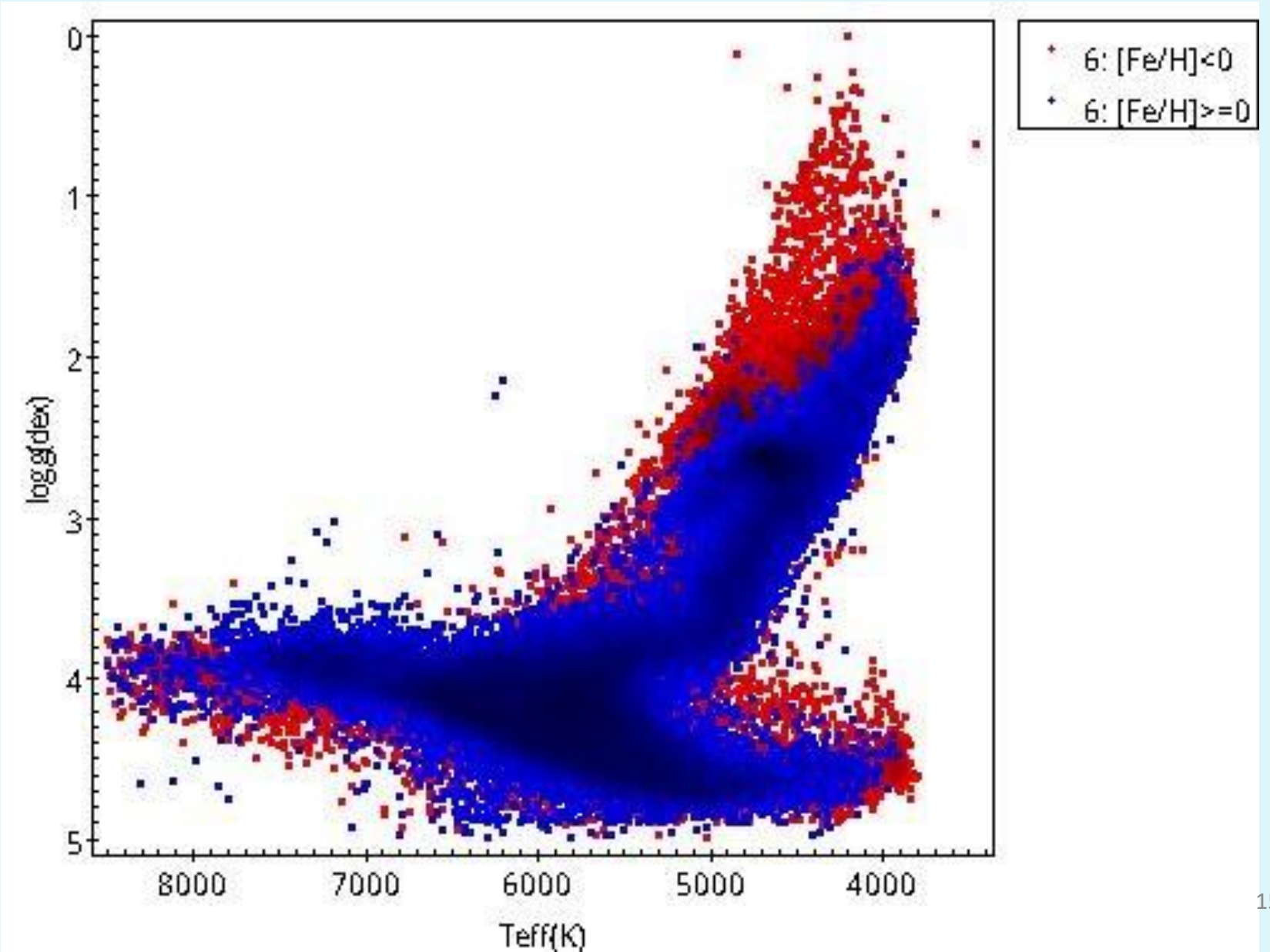








log *g* vs T_{eff}



2.3 Existing scientific work

—**De Cat, P.; Fu, J.N.; Ren, A.B.; et al. 2015, *ApJS*, 220, 19**

"LAMOST observations in the *Kepler* field. Database of low-resolution spectra"

—**Ren, A.B.; Fu, J.N.; De Cat, P.; et al. 2016, *ApJS*, 225, 28**

"LAMOST Observations in the *KEPLER* Field. Analysis of the Stellar Parameters Measured with the LASP Based on the Low-Resolution Spectra"

—**Gray, R.O.; Corbally,C.J.; De Cat,P.; et al. 2016, *AJ*, 151, 13**

"LAMOST Observations in the *KEPLER* Field: Spectral Classification with the MKCLASS Code"

—**Frasca, A.; Molenda-Żakowicz, J.; De Cat, P.; et al. 2016, *A&A*, 594, 39**

"Activity Indicators and Stellar Parameters of the *KEPLER* Targets. An Application of the ROTFIT Pipeline to LAMOST-*KEPLER* Stellar Spectra"

—**Dong, S.B.; et al. 2014, *ApJL*, 789, L3**
"On the Metallicities of *Kepler* Stars"
—**Deheuvels, S.; et al. 2014, *A&A*, 564, A27**
"Seismic Constraints on the Radial Dependence of the Internal Rotation Profiles of Six *Kepler* Subgiants and Young Red Giants"
—**Liu, C.; et al. 2015, *ApJ*, 807, 4**
"Asteroseismic based estimation of the surface gravity for the LAMOST giant stars"
—**Bostancı, Z.F.; et al. 2015, *MNRAS*, 453, 1095**
"A comprehensive study of the open cluster NGC 6866"
—**Ren, J.J.; et al. 2016, *RAA*, 16, 45**
"On the LSP3 estimates of surface gravity for LAMOST-*Kepler stars with* asteroseismic measurements"
—**Yu, J.; et al. 2016, *MNRAS*, 463, 1297**
"Asteroseismology of 1523 misclassified red giants using *Kepler* data*"*

—**Wang, L.; et al. 2016, *AJ*, 152, 6**
“Calibration of LAMOST Stellar Surface Gravities Using the KEPLER Asteroseismic Data”

—**Zhang, X.B.; et al. 2016, *ApJL*, 821, 32**
“Multi-period g-mode Pulsations of a Pre-He-WD Star in the Eclipsing Binary KIC 9164561”

—**Karoff, C.; et al. 2016, *Nature Communications,* 7, 11058**
“Observational Evidence for Enhanced Magnetic Activity of Superflare Stars”

—**Xie, J.W.; et al. 2016, *PNAS,* 113, 11431**
“Exoplanet Orbital Eccentricities Derived From LAMOST-*Kepler* Analysis”

—**Chang, H.-Y.; et al. 2017, *ApJ*, 834, 92**
“LAMOST Observations of Flaring M Dwarfs in the Kepler Field”

—**Wu, Y.Q.; et al. 2017, *RAA*, 17, 5**
“Stellar parameters of main sequence turn-off star candidates observed with LAMOST and Kepler”

Presentations at conferences

—**Molenda-Żakowicz, J.; De Cat,P.; Fu,J.N.; Yang,X.H.; 2014, *IAUS*, 301, 457**
"LAMOST observations in the Kepler field"

—**De Cat, P.; Fu, J.N.; et al. 2015, *EPJ Web Conf.,* 101, id.01011**
"LAMOST observations in the Kepler field"

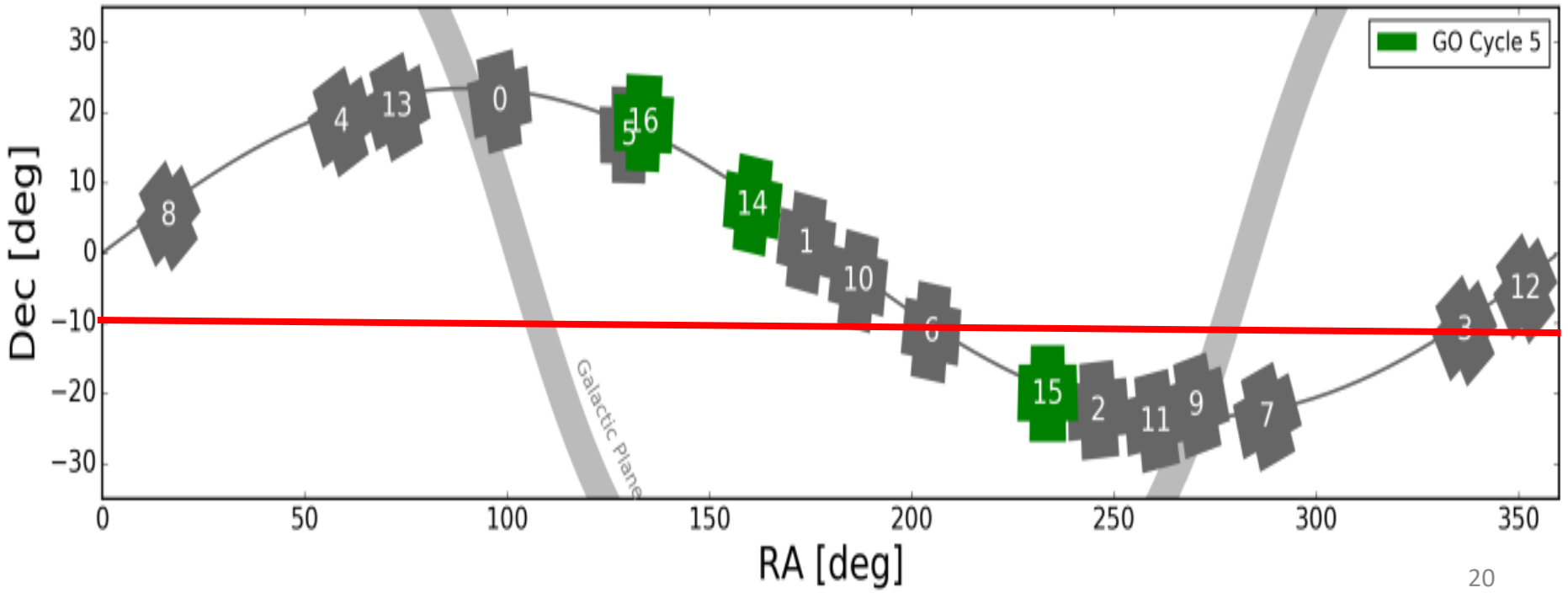
—**Molenda-Zakowicz, J.; De Cat, P.; Fu, J.N.; et al. 2015*, IAU GA XXIX, Meeting #29*, id.2250365**
"The Kepler Field of View Covered with the LAMOST Spectroscopic Observations"

—**Fu, J.N.; et al. 2015, *IAU GA XXIX, Meeting #29*, id.2255363**
"Synergies between spectroscopic and asteroseismic surveys"

—**Fu, J.N.; et al. 2017, *AAS229*, id.305.02**
"Synergies between spectroscopic and time-series photometric surveys—LAMOST observations for the *Kepler* field and *K*2 fields"

§3 LAMOST-*K*2 project

- ***K*2 mission**
  - **20 fields along the ecliptic (2014-2018)**
  - **~80 days for each campaign**
  - **Targets: exoplanets, stars, open clusters……**
- **LAMOST-*K*2: observe *K*2 fields with LAMOST**



*K*2 Observations

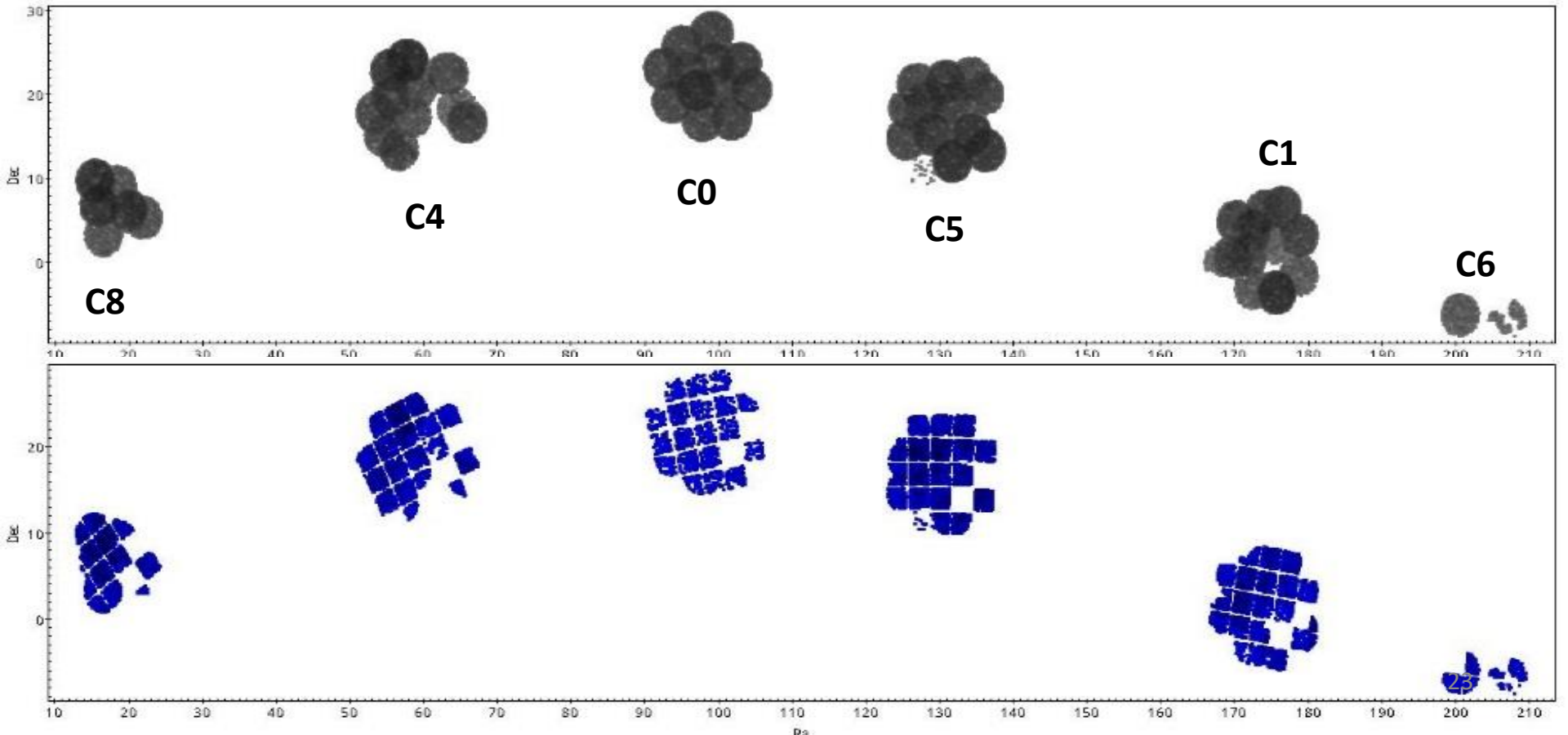
Field dates and positions

Field	Start	Stop	Data available	RA	Dec	Target list	Release notes	Comments
0	2014 Mar 08	2014 May 27	2014 Sep 08	06:33:11	+21:35:16	✔	✔	Near Galactic Anti-center, M35, NGC 2158
1	2014 May 30	2014 Aug 21	2014 Dec 23	11:35:46	+01:25:02	✔	✔	North Galactic Cap
2	2014 Aug 23	2014 Nov 13	2015 Mar 16	16:24:30	-22:26:50	✔	✔	Near Gal Center, M4, M80, M19, Upr Sco, ρ Oph
3	2014 Nov 14	2015 Feb 03	2015 Jul 17	22:26:40	-11:05:48	✔	✔	South Galactic Cap, Neptune
4	2015 Feb 07	2015 Apr 23	2015 Sep 04	03:56:18	+18:39:38	✔	✔	M45 (Pleiades), NGC1647, Hyades
5	2015 Apr 27	2015 Jul 10	2015 Oct 31	08:40:38	+16:49:47	✔	✔	M44 (Beehive), M67
6	2015 Jul 14	2015 Sep 30	2016 Feb 12	13:39:28	-11:17:43	✔	✔	North Galactic Cap
7	2015 Oct 04	2015 Dec 26	2016 Apr 20	19:11:19	-23:21:36	✔	✔	Near Galactic Center, NGC 6717, Pluto
8	2016 Jan 03	2016 Mar 23	2016 Jul 04	01:05:21	+05:15:44	✔	✔	Uranus, IC1613
9†	2016 Apr 21	2016 Jul 01	2016 Sep 30	18:01:25	-21:46:47	✔	✔	Gal Center, M21, M18, M25, M8, Earth, Mars
10	2016 Jul 06	2016 Sep 20	2016 Dec 20	12:27:07	-04:01:38	✔	✔	North Galactic Cap
11	2016 Sep 24	2016 Dec 08	2017 Jun 30	17:21:33	-23:58:33	✔	✔	Galactic Center, Saturn
12	2016 Dec 15	2017 Mar 04	2017 Aug 2	23:26:38	-05:06:08	✔		South Galactic Cap, Chiron, Mars
13	2017 Mar 08	2017 May 27	2017 Sep 5	04:51:11	+20:47:11	✔		Hyades, Taurus
14	2017 May 31	2017 Aug 19	2017 Nov-Jan	10:42:44	+06:51:06	✔		North Galactic Cap, Wolf 359, WASP-104

LAMOST-*K*2 Observations

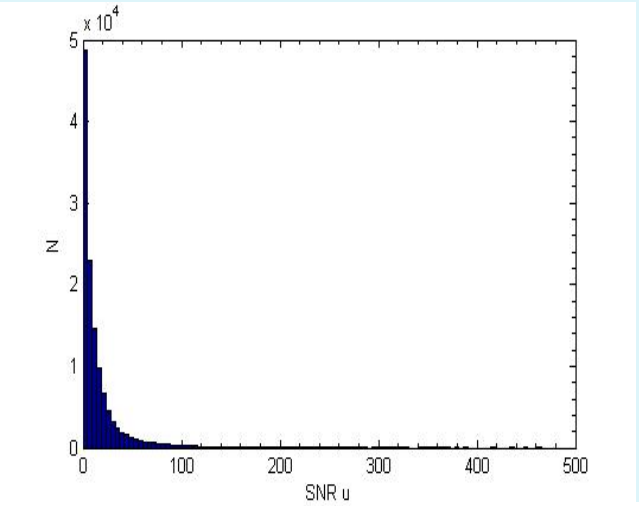
LAMOST-*K*2 field	RA (2000.0)	DEC (2000.0)	Spectrum Number	Parameter Number
C8	01:05:12	+05:15:44	22645	13579
C4	03:56:18	+18:39:38	29522	21760
C0	06:33:11	+21:35:16	36071	25498
C5	08:40:48	+16:49:47	41408	28259
C1	11:35:46	+01:25:02	34374	22569
C6	13:39:28	-11:17:43	2061	1169

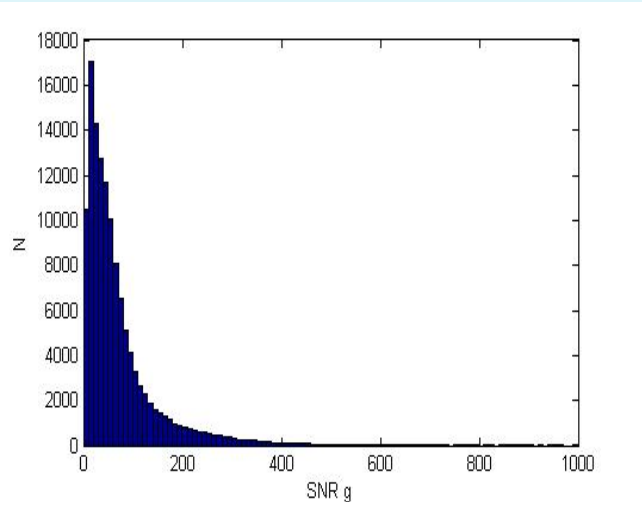
- **Observation Date: Dec. 30, 2015 – April 28, 2017**
- **86 plates observed during 53 nights**
- **Spectra: 168,081; Parameters: 112,843**
- **LAMOST-*K*2 cross-matching targets: 24,661**

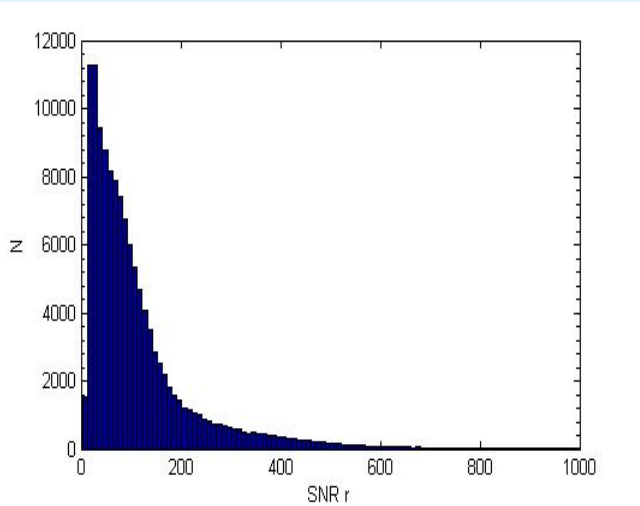


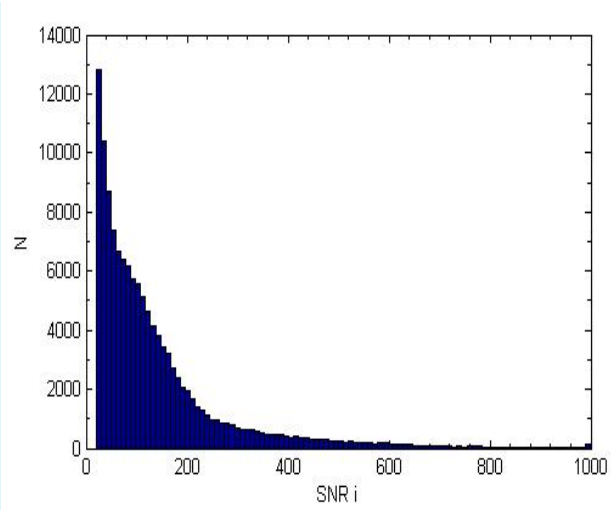
S/N distribution

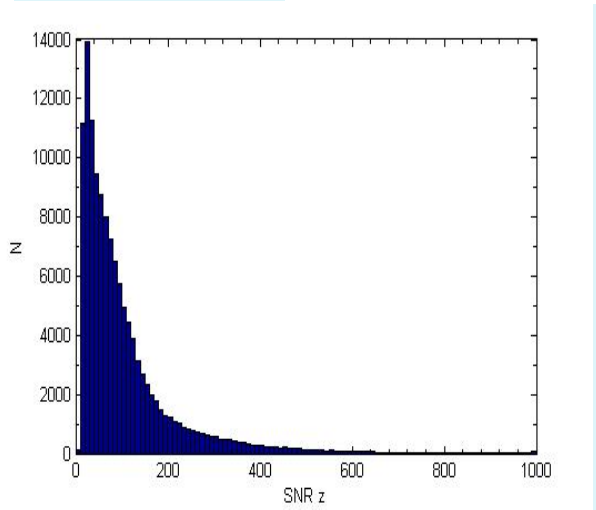
S/N_i>20: 126,675





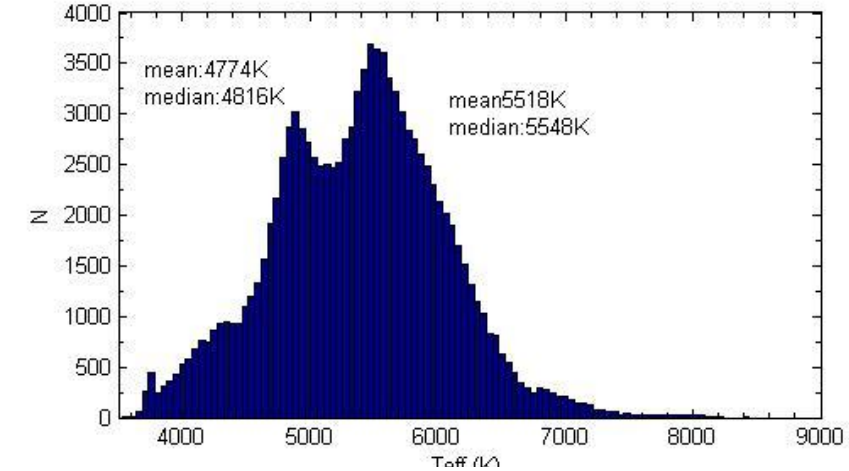


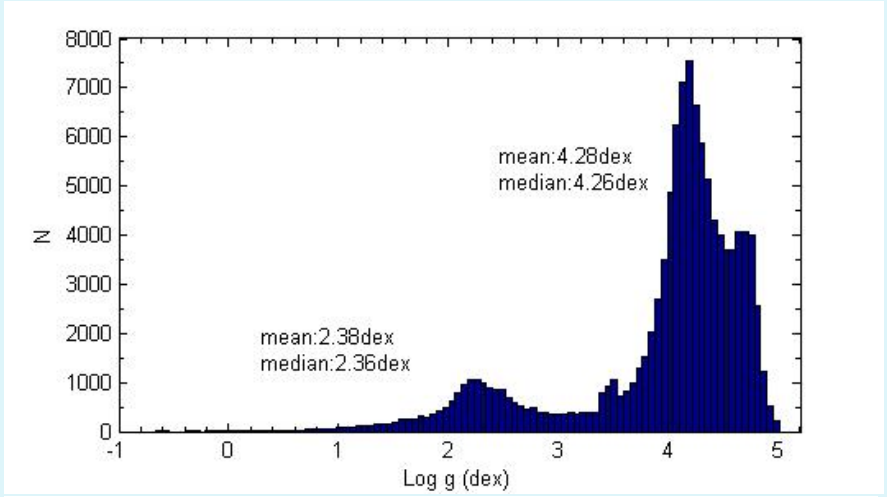


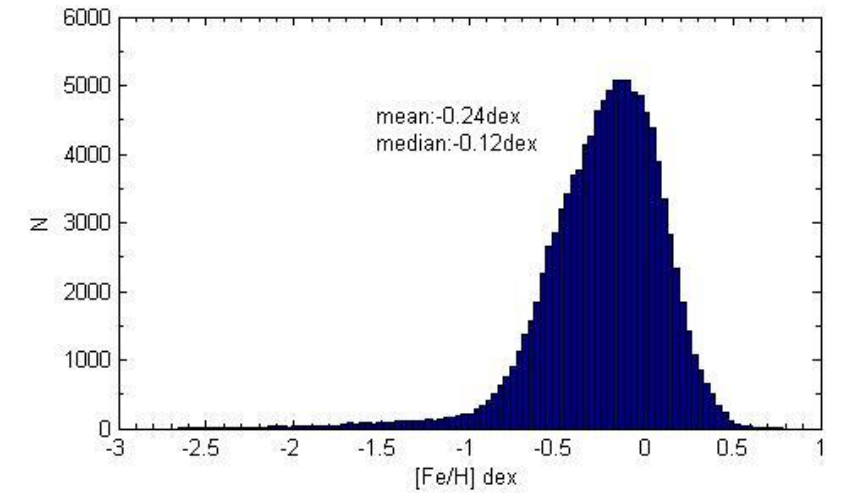


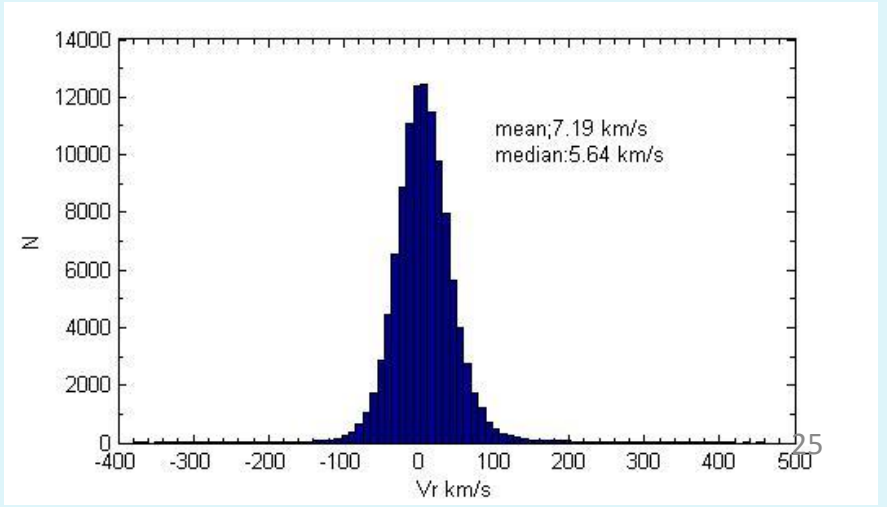
Stellar parameter distribution

- [*Fe/H*] <-1 dex： 3,104； <-2 dex： 272
  $|V_r|$>300 km/s： 92

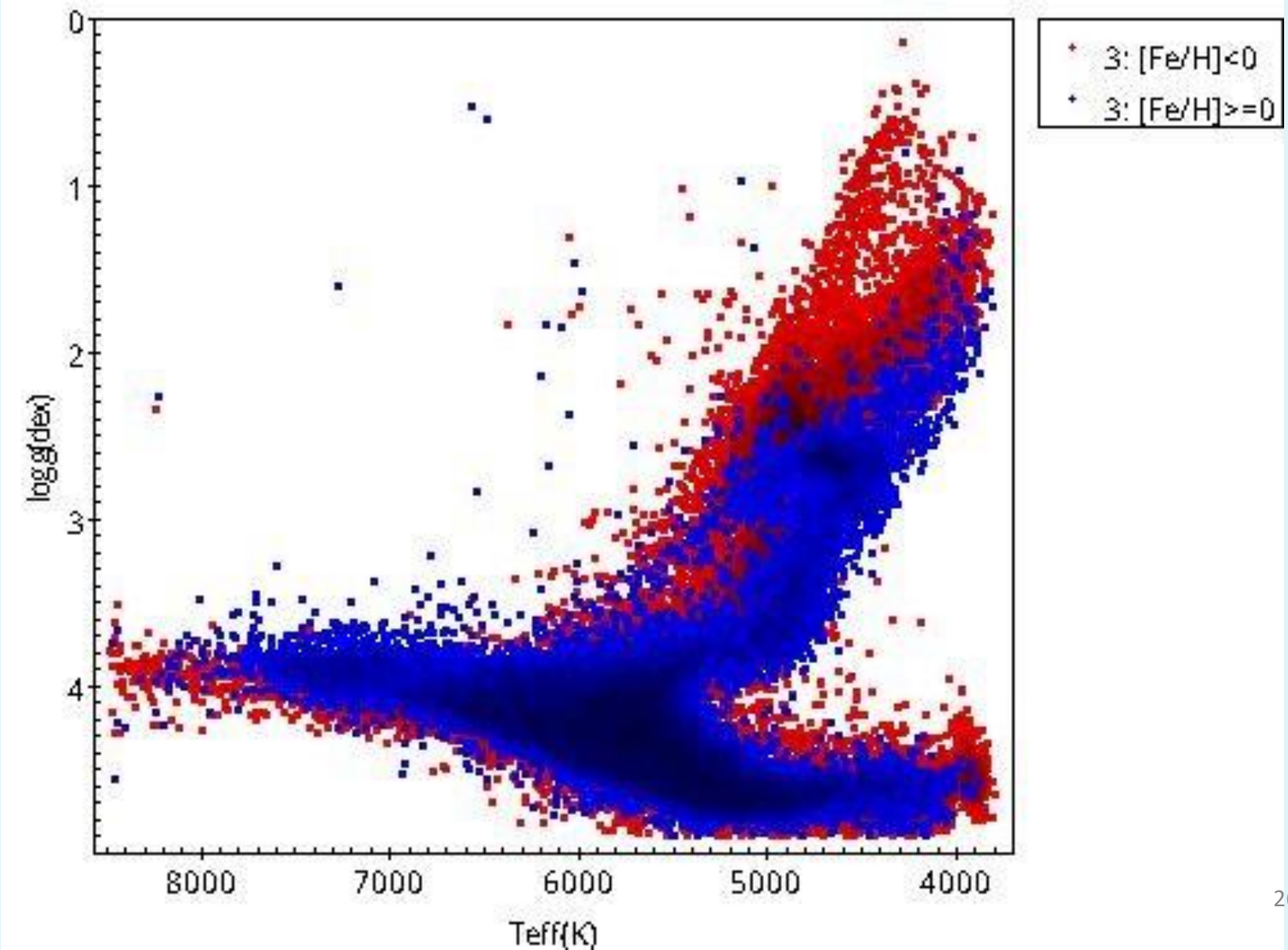








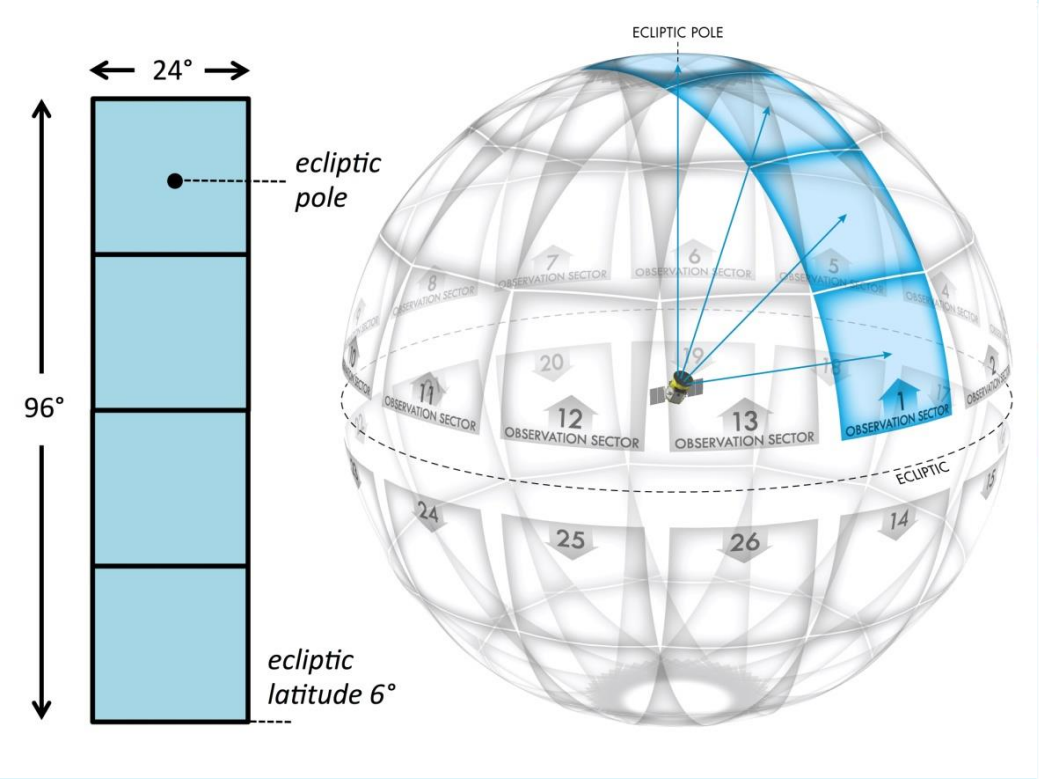
log g vs T_{eff}



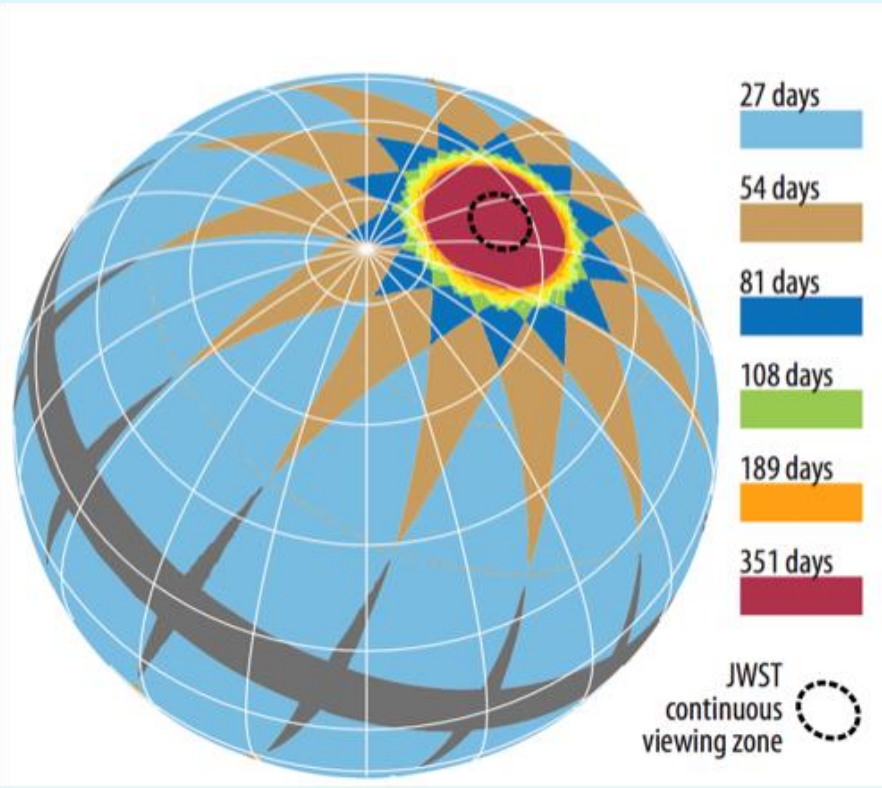
§4 Prospect of LAMOST for *TESS*

4.1 The NASA *TESS* mission

- –4 telescopes: aperture 10 cm
- –Field of view: 24°×24°/each
- –Wavelength range: 600-1000nm
- –Orbit: High Earth Orbit
- –Observation Plan: to be launched in 2018
  - 1 year for southern hemisphere sky
  - 1 year for northern hemisphere sky
- –Each field duration: ~27 days



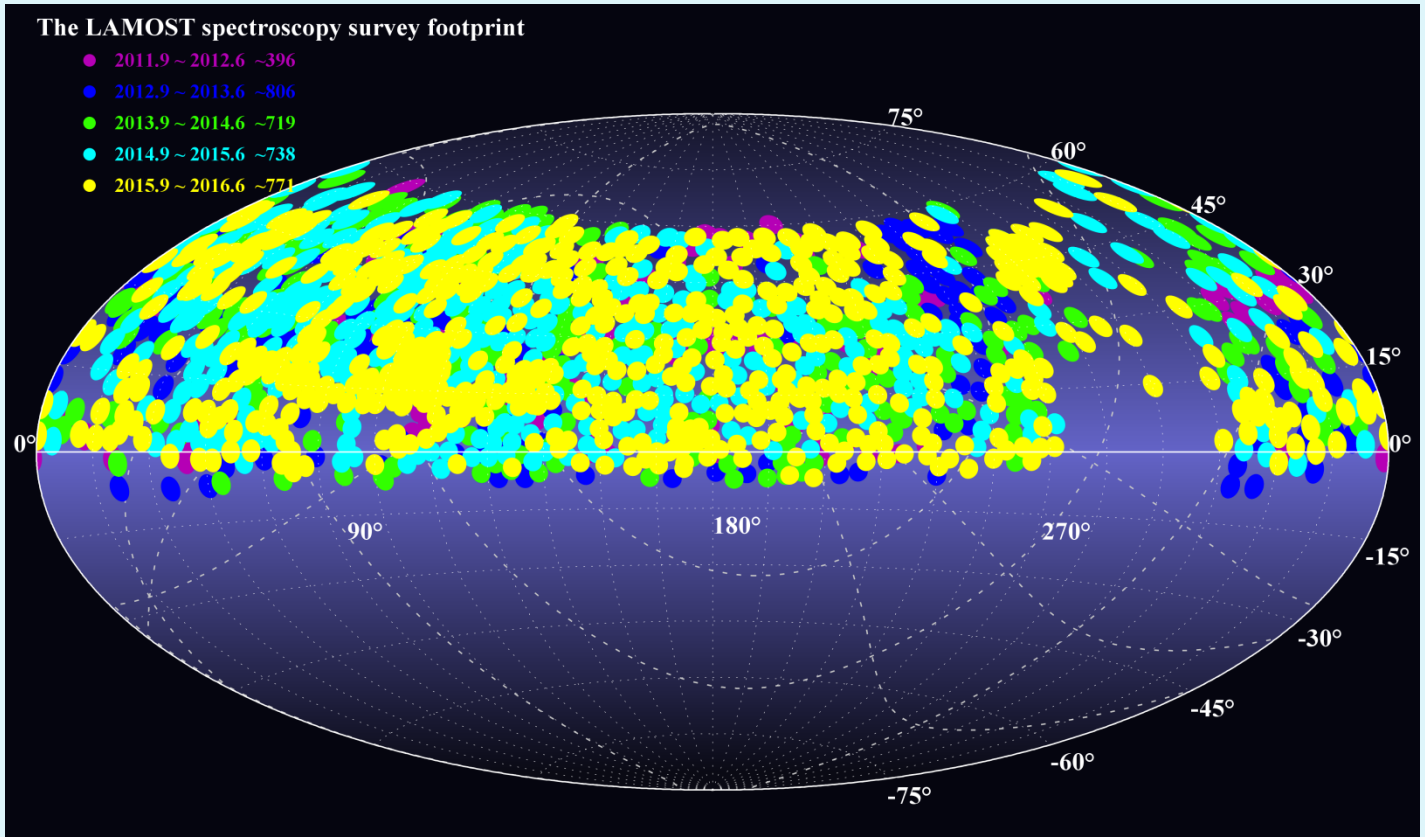
The celestial sphere with 26 observation sectors (13 per hemisphere)



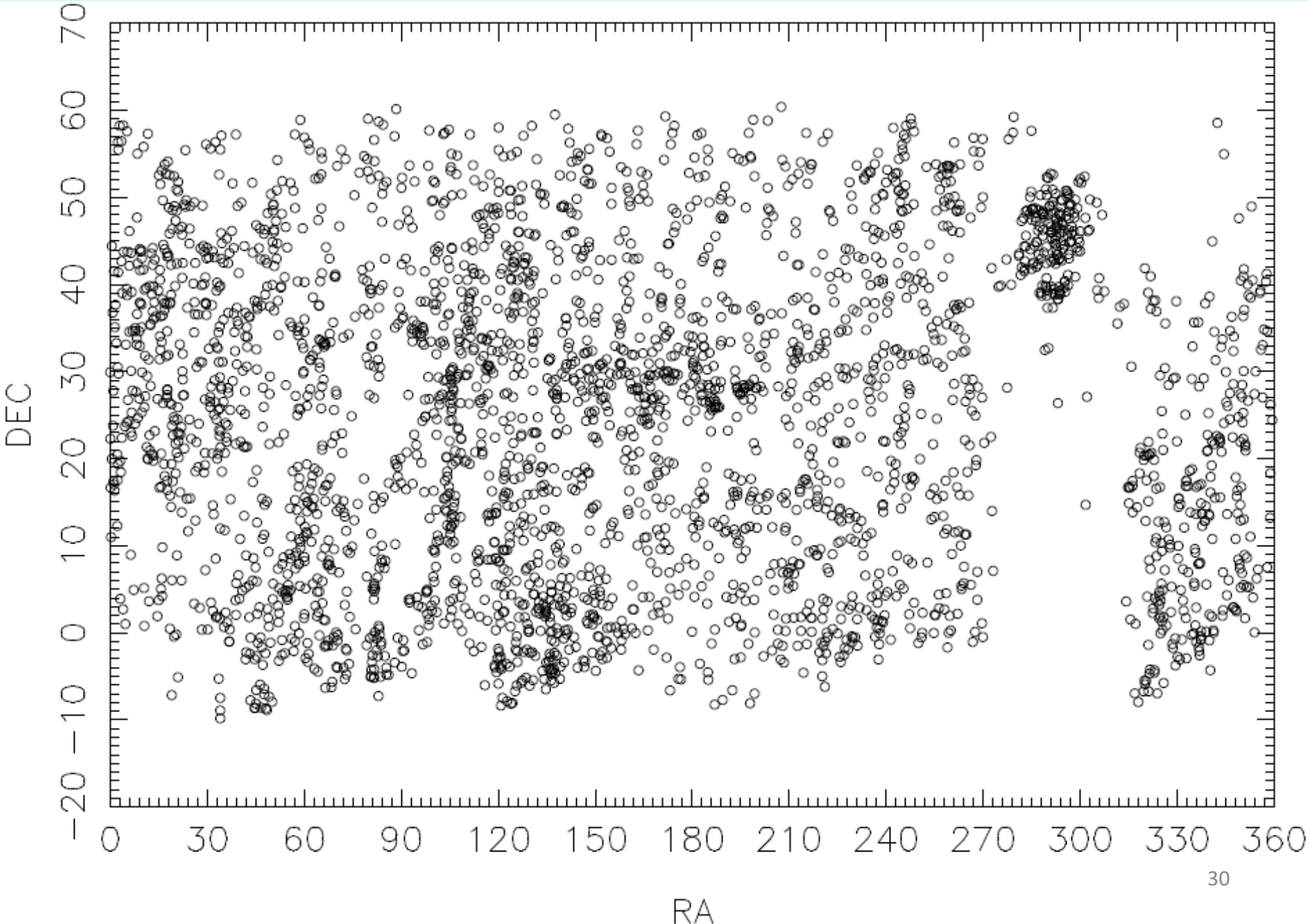
Duration of observations on the celestial sphere

4.2 TESS targets with LAMOST low-resolution Spectra

- many stars brighter than ~16 *mag* in *i* with DEC > -10° have been observed by LAMOST with low-resolution spectra (2011-2017)



Available LAMOST spectra of the *TESS* targets (3,062 stars, Peter)



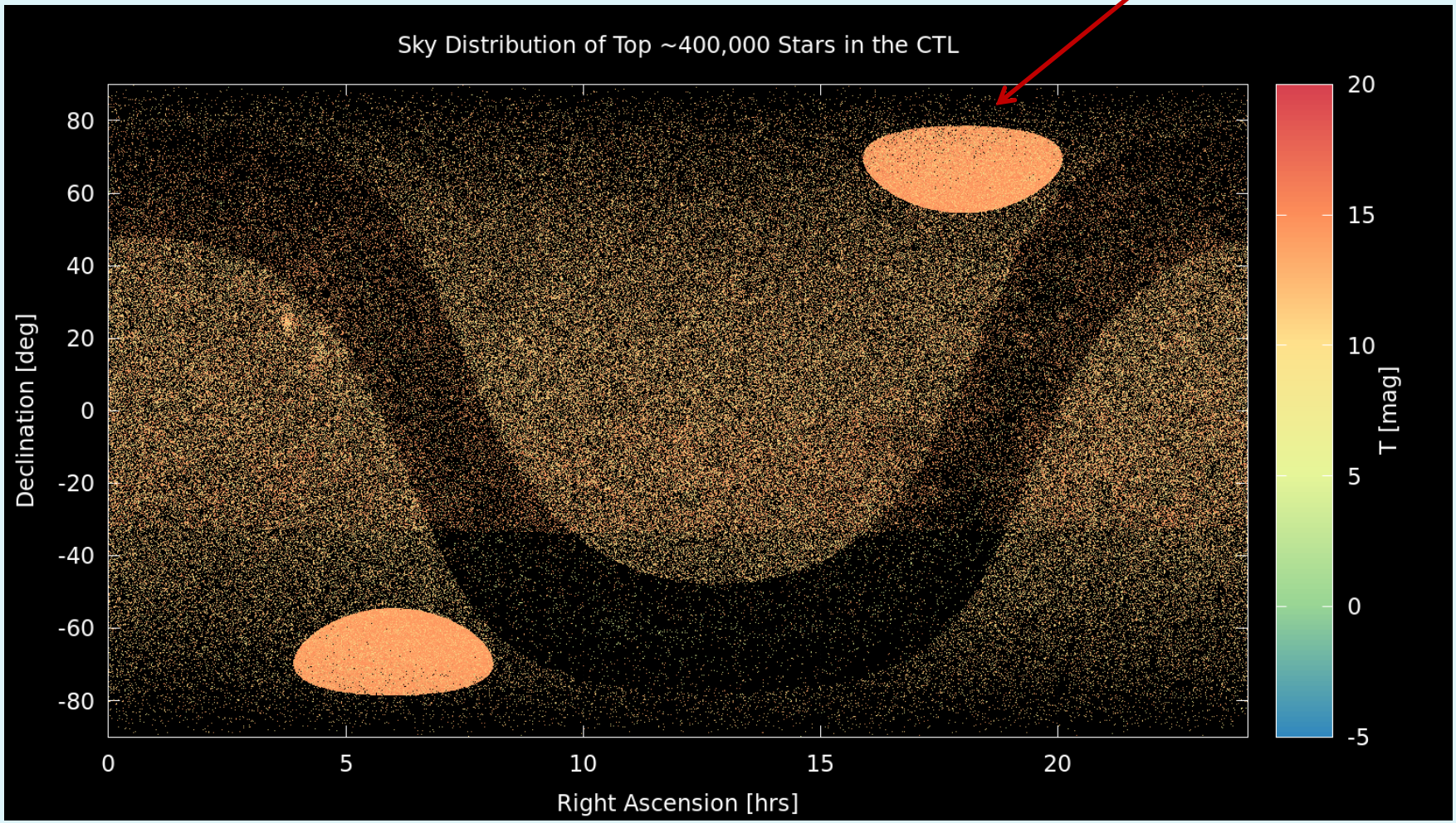
4.3 TESS targets with LAMOST mid-resolution Spectra

- 16 spectrographs with R=7500 since 2018
- Wavelength ranges:
  4950 – 5350 Å; 6300 – 6800 Å
- Target stars: < 15 *mag* in *i*
- Time-series spectra for some selected fields
  For variables: pulsators, binaries, etc
  Disk of the Galaxy
- Parameter measurement precisions expected:
  T_{eff}: 100 K; log g: 0.1 dex
  [Fe/H]: 0.1 dex; V_r: < 1 km/s
  [α/Fe]: 0.1 dex

Observation plan

Targets I: 82,000 stars in 440 deg^2 of Northern Ecliptic Pole (NEP)

***T*<15 *mag*, ~3700 stars/plate in average**



Targets II: ~1,000,000 stars on the whole sky, *T*<12 *mag* (Dong & Xie)

§5 Synergies between LAMOST with *GAIA*

5.1 The ESA *GAIA* mission

- –Targets: ~1 billion $V<20^m$ stars
- –Observations: astrometry, multi-color photometry, spectroscopy (*RV*)
- –Launched: 19/12/2013
- –Schedule: 5+1 years, ~70 times/the whole sky
- –DR1: Sept. 2016
  Full data release: 2021-2022

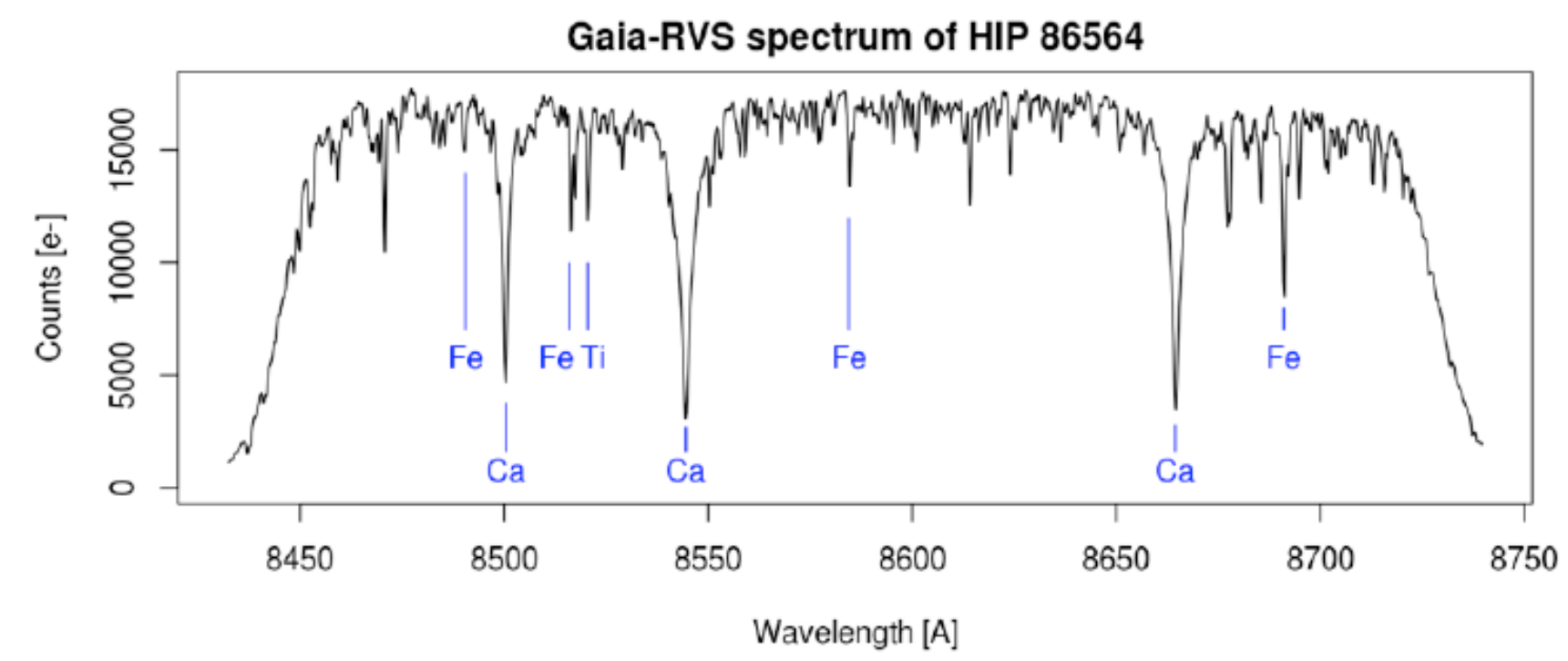
– **Spectrograph:**

847 - 874 nm (CaII triplets)

$\lambda/\Delta\lambda$=11,500

– ***RV* precision:**

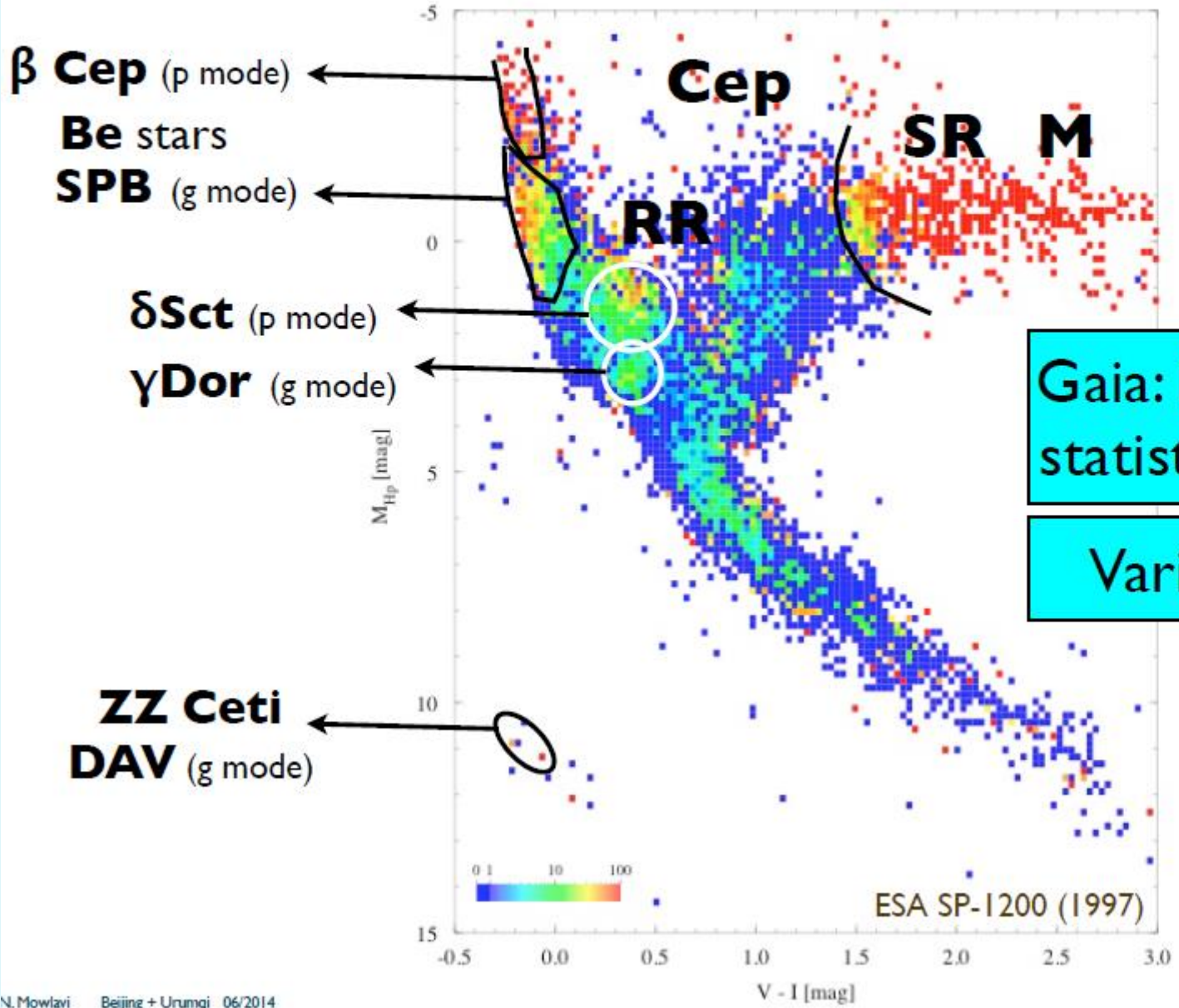
~1 km/s (G2V, 10-12 *mag*)



Variability processing

(From Dr. N. Mowlavi)

Fraction of variables (Hipparcos precision)



Gaia: Extremely good statistical description

Variability movie!

Limited to "good" parallaxes

Variability processing

~50-150 million variable objects for Gaia

- 0.5 or **4** or 7 million **Eclipsing Binaries**
  (Söderhjelm 2004, Eyer etal. 2013, Zwitter 2002)
- few 100s to few 1000s or 5,000-30,000 **Planetary transits**
  (Dzigan & Zucker 2012, Robichon 2002)
- 60,000-240,000 **δ Scuti stars** (Eyer&Cuypers 2000)
- 70,000 RR **Lyrae stars** (Eyer&Cuypers 2000)
- 2,000-8000 or 9,000 **Cepheids** (Eyer&Cuypers 2000, Windmark et al. 2011
- 6,000 **SuperNovae** to G=19 for alert system (Gilmore, Belokurov 2009)
- 1,000 **Micolensing events**
- 500,000 **Quasars**

5.2 Synergies between LAMOST and *GAIA*

- ***GAIA*:**
  - **astrometry precision ~10 μ *arcsec***
  - **parallax, proper motion**
  - **tangential velocity**
- **LAMOST:**
  - **T_{eff}, log *g*, [*Fe*/*H*], [α/*Fe*], *RV*, vsin *i***
- **Synergies:**
  - **structure of the Milky Way**
  - **archeology of the MW**
  - **pulsating variables**
  - **binaries**
  - **open clusters**
  - **…… (Talk of Chao)**

§6 Summary

- **LAMOST has made observations for a large amount of stars in the *Kepler* field and *K*2 fields**
- **For the *Kepler* field, 181,912 qualified low-resolution spectra are obtained with stellar parameters calculated**
- **For 6 *K*2 fields, 126,675 spectra are observed with stellar parameters measured**
- **Research has been made with the obtained data, leading to some scientifically interesting results**

- **Next Step I:**
  - **Continue observations of the two projects**
  - **Calibrate stellar parameters for the *K*2 fields, including using log *g* from asteroseismology and parameters from *APOGEE* (Talk of Ruyuan)**
  - **More research work with the LAMOST-*Kepler* and LAMOST-*K*2 data (e.g. Li-rich stars, Talk of Mengqi)**
- **Next Step II:**
  - **Mid-resolution spectra: *K*2 field C0 and *TESS*/NEP**
- **Future possibility:**
  - **LAMOST for the targets of the ESA/*PLATO* mission?**

Data Policy of LAMOST

- **Internal release**
  - **Chinese astronomers**
  - **International collaborators (with Chinese groups involved)**
  - **DR1: 2013.09**
  - **DR2: 2014.12**
  - **DR3: 2015.12**
  - **DR4: 2016.12**
  - **DR5: 2017.12 expected**
- **Public release (1.5 yrs later)**
  - **DR1 (2015.03) : 1.8 M spectra / 1.0 M parameters**
  - **DR2 (2016.06): 3.0 M spectra / 2.1 M parameters**
  - **DR3 (2017.06): 5.7 M spectra / 3.2 M parameters**

The First LAMOST-*Kepler* Workshop

August 18-22, 2014; Beijing

Website： http://202.112.85.102/meeting/kepler_lamost2014/

Wish The Second LAMOST-*Kepler* Workshop To Be Successful!

Thanks for your attention !