A new kinematic survey (from GSC-II and SDSS-DR7) to study the stellar populations of the Milky Way

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Outline

- **Combining wide field stellar surveys**

SDSS-DR7 (photometry, spectroscopy, 2° epoch positio ns)

GSC-II DB (multi-epoch positions)

- **Proper motions**

p.m. procedure, QSO accuracy test

- **GSC-II – SDSS catalogs**

p.m., photometry, APs, distances, velocities, kinematic sample (FGK dwarfs)

- **Thick disk: kinematics and chemical properties**

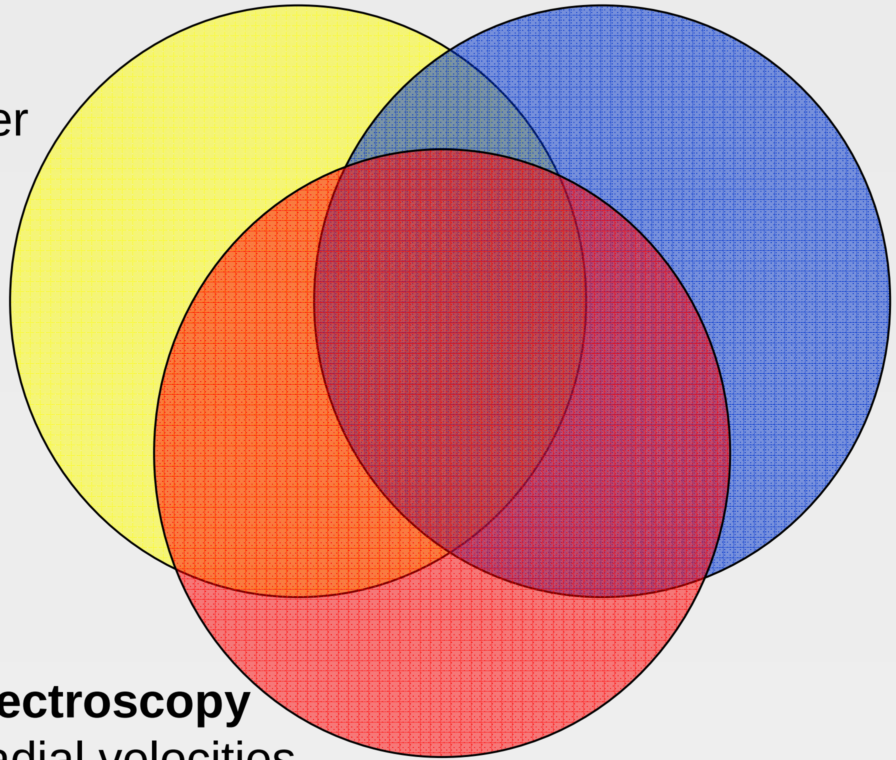
vertical rotation gradient – metallicity-rotation correlation

- **Halo: search for kinematic substructures**

search for fossil records in the Milky Way

Surveys of galactic stellar populations: basic ingredients

Astrometry
(positions, proper motions, Trigonometric parallaxes)



Photometry
(stellar classification, Photometric distances)

Spectroscopy
(Radial velocities, Chemical abundances)

SDSS DR7

Imaging

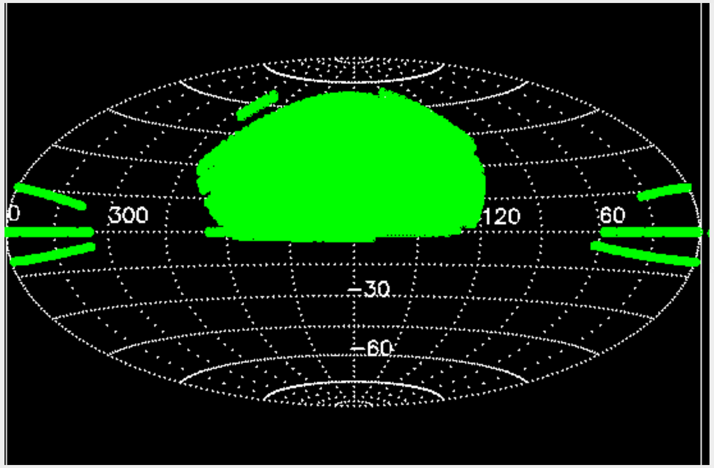
- **11,660 deg^2** of imaging data (1/4 of the sky)
- **357 million** objects
- Photometry *ugriz*, 14.0<g<22.2
- Object classification

Abazajian et al. 2009 ApJS, 182, 543

Spectroscopy

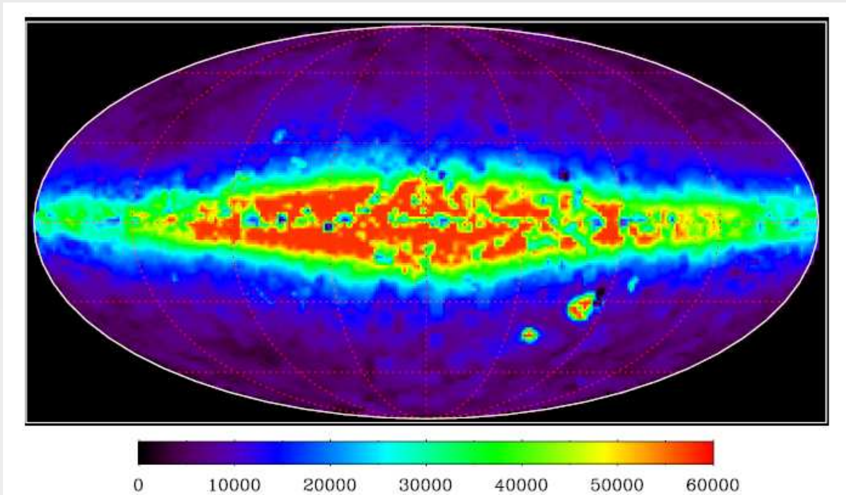
- **300,000** galactic stars
- 3850 < λ< 9000 A ,   R = 2000
- Astroph. parameters: Teff, log(g), [Fe/H]
- Radial velocities, **10 km/s** accuracy

Yanny et al. 2009 ApJ, 127, 4377



Guide Star Catalog II - Database

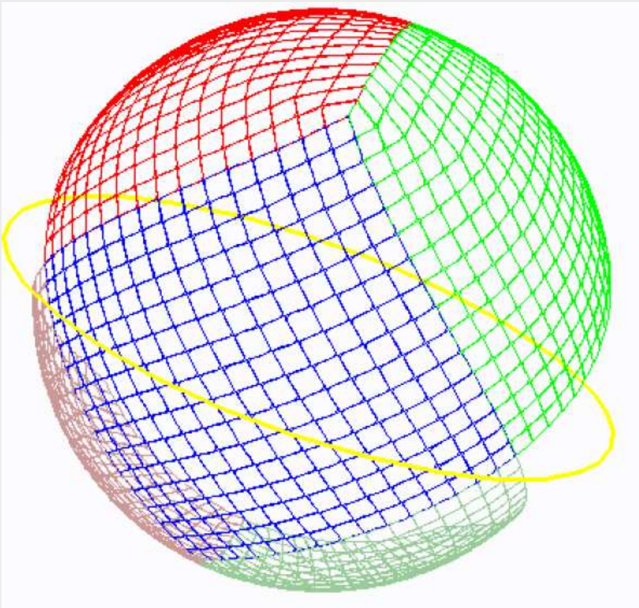
- All sky archive from the digitized Palomar and Anglo Australian Obs. Schmidt surveys
- 1 billion objects
- positions ICRF, classification (stellar/extended sources)
- Multi-epoch B_J V_{12} R_F I_N photographic photometry, B<22
- **Multi-epoch positions, 1950< Epoch < 2000**



GSC 2.3 counts: objects per deg^2 down to R_F=20.

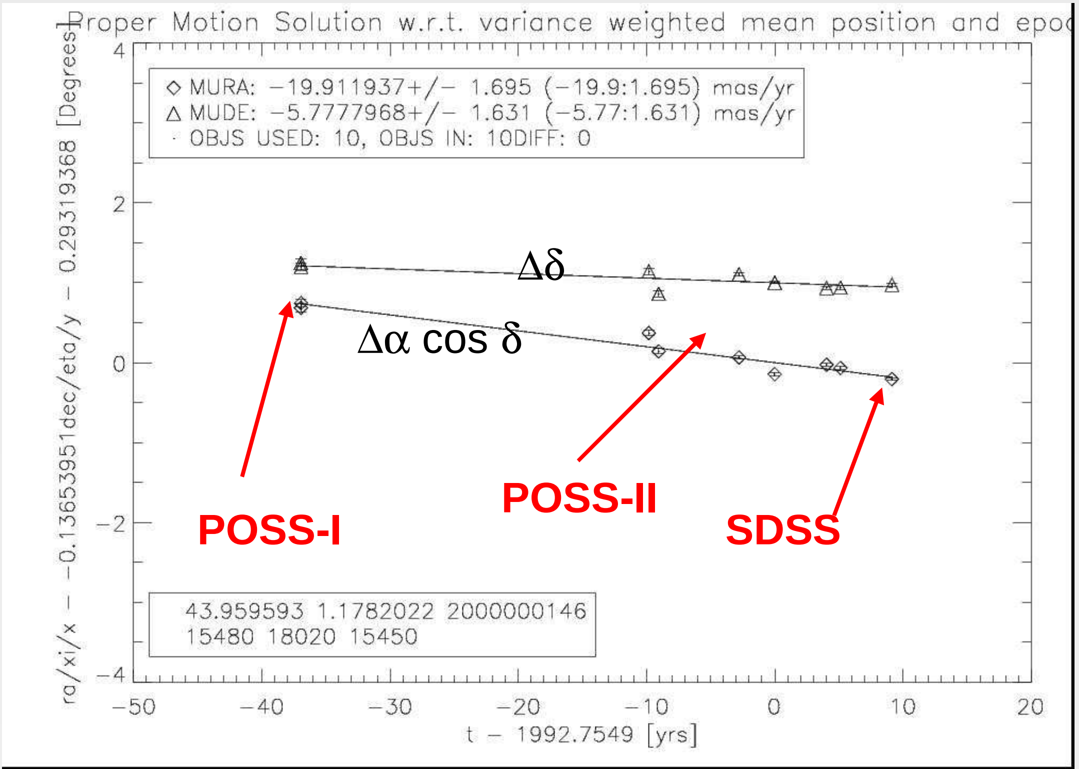
Lasker, Lattanzi, McLean et al, 2008, AJ, 136, 735

Proper motions



- Multi-epoch positions from SDSS *and* GSC-II (mainly POSS-I and POSS-II) available in the GSC-II DB mirror in Torino.
- Database structure: HEALPix tesselation level 7, i.e. 196,608 regions (0.46 deg^2)
- for each region:
  1. 2° order polynomial transformations from (X,Y) plate coordinates to SDSS standard coordinates (ξ, η)
  2. Relative proper motions
  3. Absolute p.m. computed with zero-point derived from extra-galactic sources (SDSS classification adopted)

Proper motions



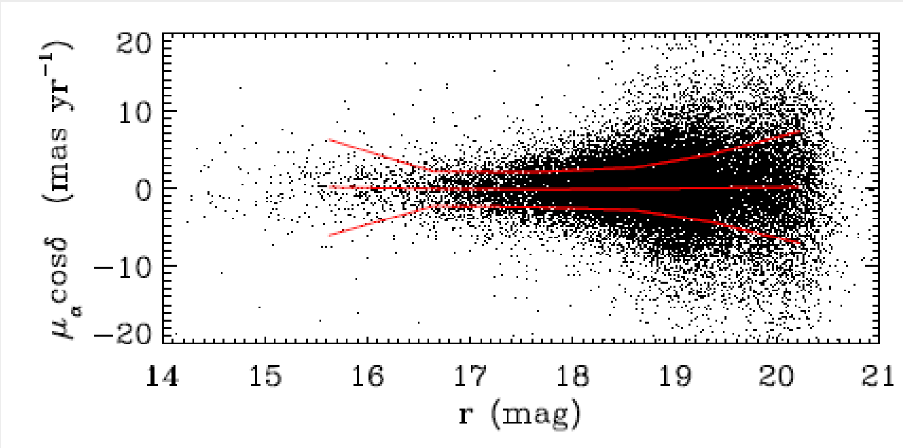
Δα cos δ, Δδ (arcsec) vs. Δt (yr)

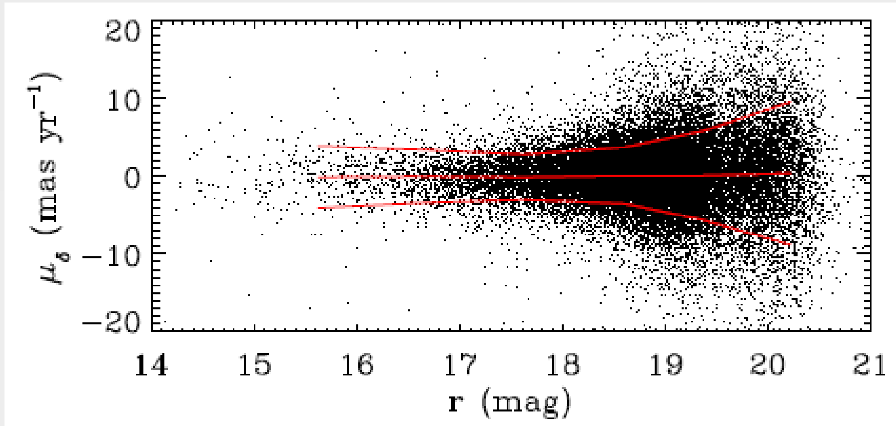
- **Typically, 5<n<10 observations available**
- **Δt ~ 50 yr**
- **Proper motion formal total errors:**

σ(μ) = 2-3 mas/yr

Proper motion accuracy – QSO catalog

Large Quasar Reference Frame (**LQRF**) assembled by Andrei et al. (2009). 77,000 QSOs matched with the GSC2-SDSS catalog.





QSO proper motion distribution as a function of magnitude:

$<\mu> = 0$, $\sigma(\mu) >$ pm. error

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Proper motion accuracy – QSO catalog

r (mag)	$\langle\mu_\alpha \cos\delta\rangle$ (mas yr^{-1})		σ_{μ_α} (mas yr^{-1})		$\langle\mu_\delta\rangle$ (mas yr^{-1})		σ_{μ_δ} (mas yr^{-1})	
14-15	0.20± 0.60	-1.90± 0.53	5.04	4.34	-0.30±0.57	-0.20±0.78	4.83	6.35
15-16	0.20± 0.19	-0.90± 0.25	3.28	4.33	-0.10±0.20	1.20±0.27	3.56	4.61
16-17	-0.20± 0.08	-0.20± 0.10	2.92	3.69	-0.30±0.08	0.50±0.10	2.95	3.60
17-18	-0.30± 0.04	0.20± 0.04	2.86	3.25	-0.30±0.04	0.20±0.04	2.96	3.23
18-19	-0.10± 0.02	0.30± 0.02	3.43	3.37	0.10±0.02	0.20±0.02	3.56	3.39
19-20	-0.10± 0.03	0.30± 0.03	4.83	4.36	0.00±0.03	0.00±0.03	4.90	4.43
20-21	-0.30± 0.08	0.00± 0.07	6.61	6.18	0.10±0.08	0.00±0.07	6.59	6.17
	GSC2	Munn	GSC2	Munn	GSC2	Munn	GSC2	Munn

QSO proper motion test. Comparison between the GSC2-SDSS catalog and the USNO-SDSS proper motions (Munn et al 2004).

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Proper motion accuracy – QSO catalog

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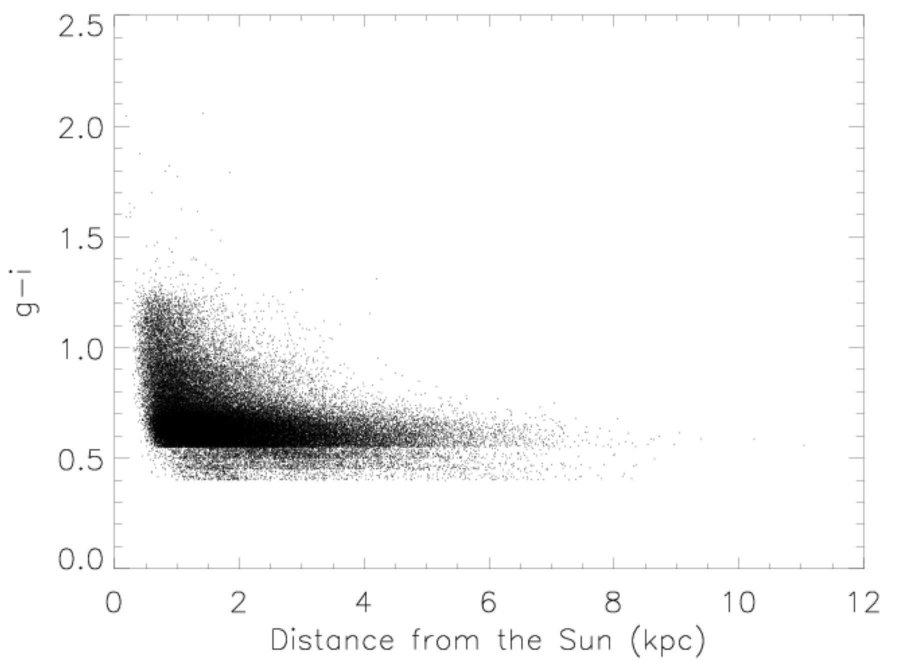
Photometric distances



Method:

1. Magnitude correction: extinction maps of *Schlegel et al. (1998).*
2. Photometric parallax: absolute magnitude from Eq. 1 of *Ivezic et al (2008),* calibrated for FGK (sub)dwarfs with [Fe/H]< -0.5.

$$M_r(g-i,\,[\mathrm{Fe/H}]) = M_r^0(g-i) + \Delta M_r([\mathrm{Fe/H}])$$

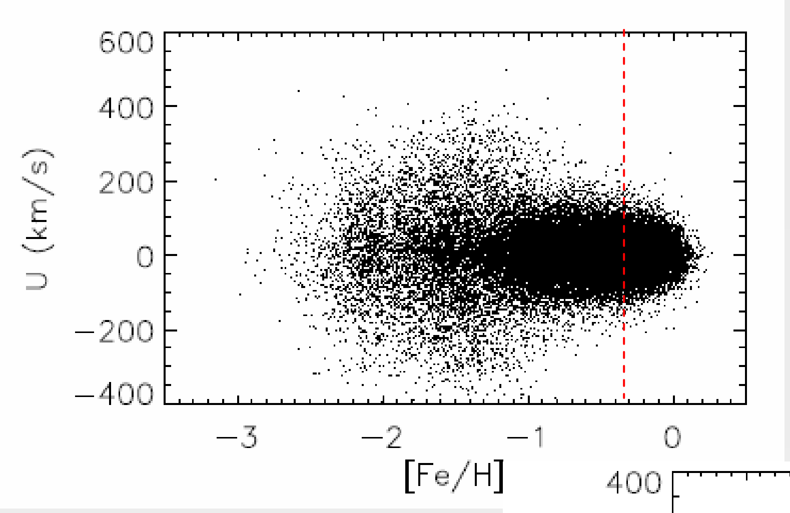
SDSS - GSC-II catalogs

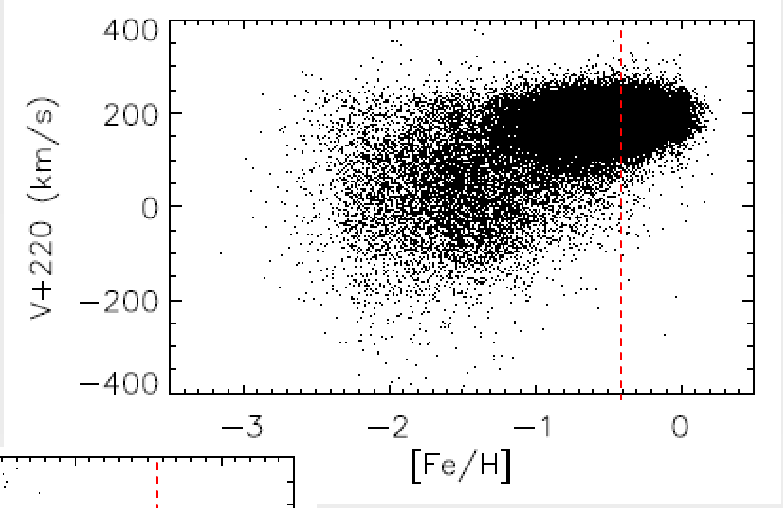
*Object Number**	*ugriz*	(μα,μδ)	Teff,	log *g*,	[Fe/H]	Vr	d	UVW
	mag	mas/yr	K	dex	dex	km/s	kpc	km/s
77 million sources	X	X						
150,000 stars	X	X	X	X	X	X		
27,000 FGK dwarfs**	X	X	X	X	X	X	X	X

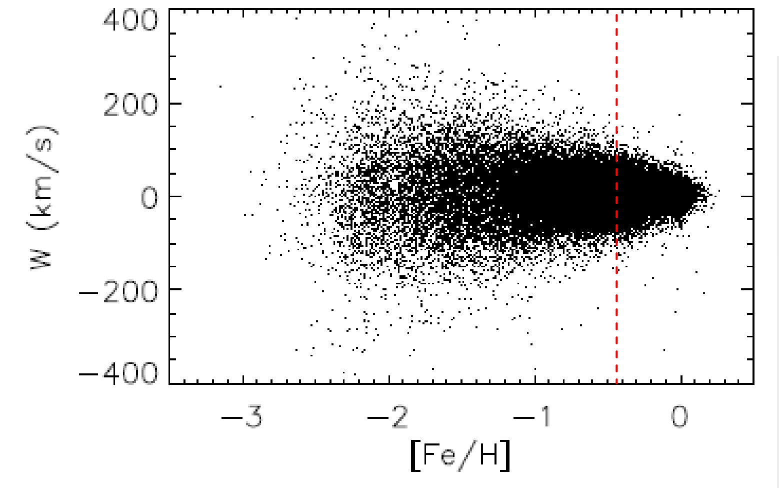
***** Area: **9000** deg2

** Kinematic sample: 4500<Teff<7500 K, log *g* >3.5, [Fe/H]< -0.5

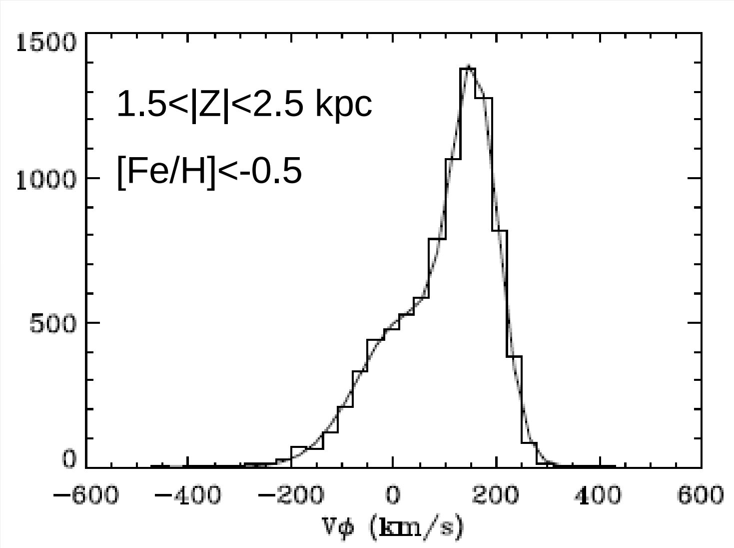
Kinematics & Chemical properties: overview







Kinematic properties



	Thick Disk		Halo	
Z (kpc)	V_ϕ (km s^{-1})	$\sigma_{V\phi}$	V_ϕ (km s^{-1})	$\sigma_{V\phi}$
1.0-1.5	169± 1	41± 1	28± 6	95± 3
1.5-2.5	159± 1	45± 1	26± 5	93± 2
2.5-3.0	146± 5	47± 5	34± 8	99± 8

Two-component (gaussian) best-fit (*thick disk* + *halo*) of the observed velocity distribution (*histogram*)

- **Vertical rotation gradient for the Thick Disk**, **-16 ± 1 km/s/kpc**, smaller than that measured by *Chiba&Beers* (2000), -30 km/s/kpc, and *Ivezic* et al (2008), but consistent with that of *Majewski* (1992), -12 km/s/kpc.
- **Small prograde rotation, ~30 km/s, of the Inner Halo**

Kinematics & Chemical properties

• **Rotation-metallicity correlation of the thick disk**

Median (Vϕ) vs. [Fe/H]

Z=1.0-1.2 kpc: **63 ± 7 km/s /dex**

Z=1.5-2.5 kpc: **43 ± 5 km/s /dex**

(-1.0 < [Fe/H] < -0.5)

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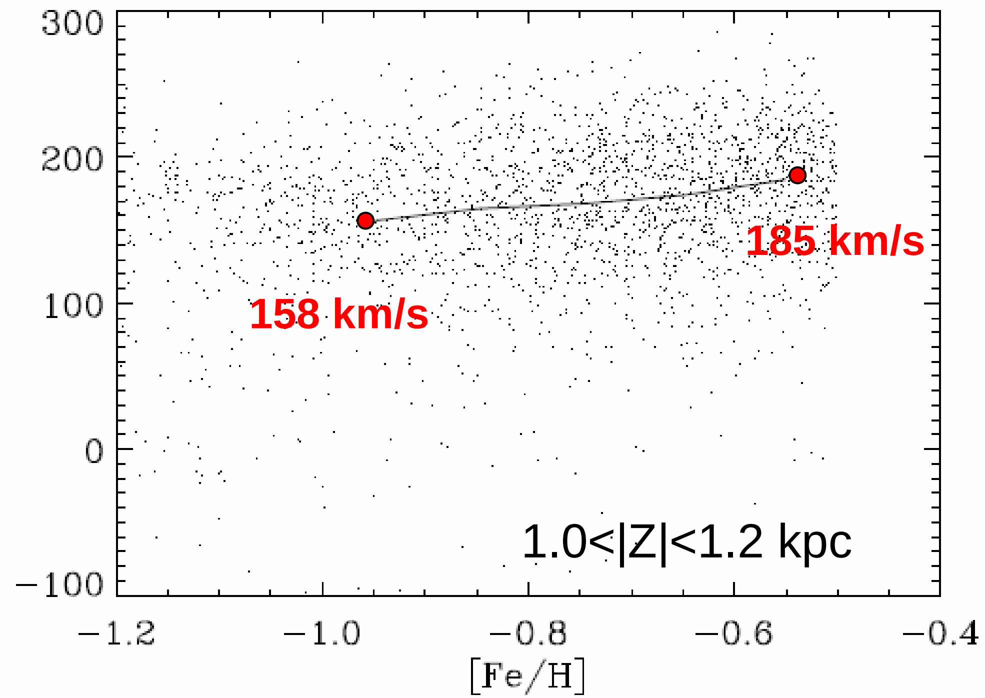
* Assuming that the metallicity bias of the spectroscopic sample does <u>not</u> affect the kinematic correlation.

**No correlation, i.e. less than 20 km/s/dex, according to Ivezic et al. (2008).



Kinematics & Chemical properties

- **Rotation-metallicity correlation for the thick disk**

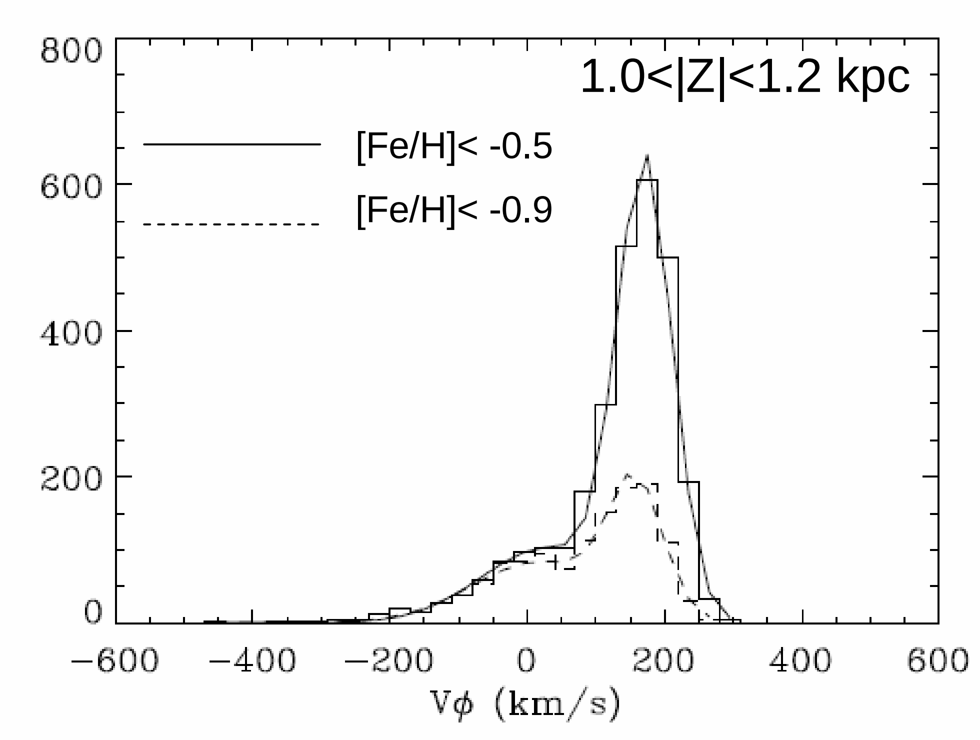
Fitted $V\phi$ (Thick disk)

Z=1.0-1.2 kpc:

[Fe/H]<-0.5 $V\phi$ =171±1 km/s
[Fe/H]<-0.9 $V\phi$ =158±3 km/s

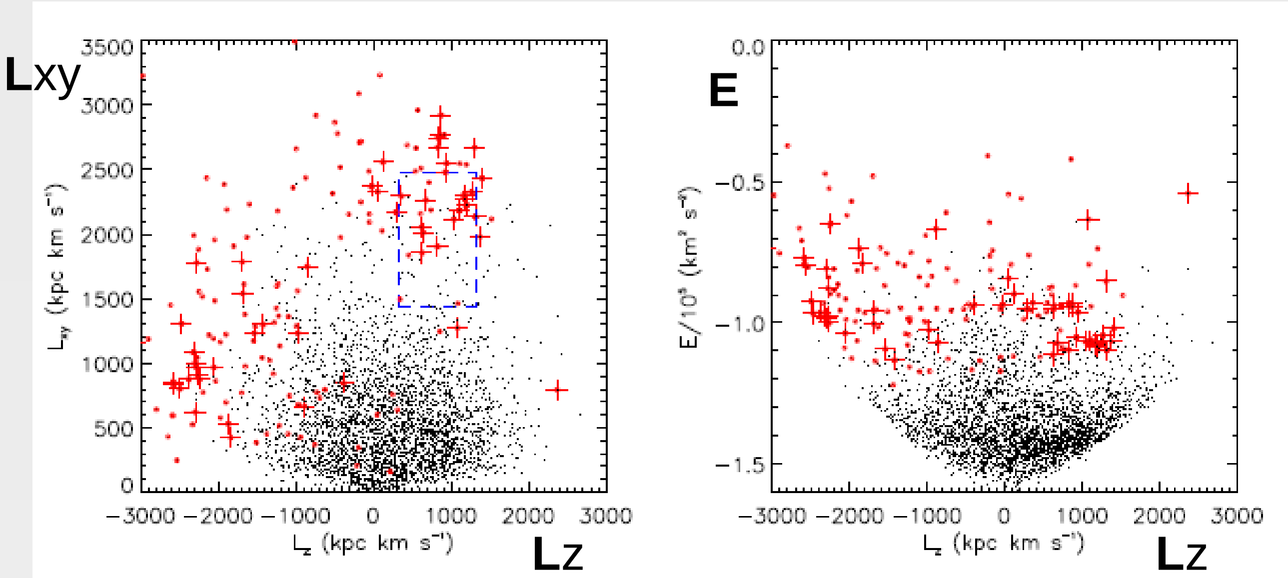
Z=1.2-1.4 kpc:
[Fe/H]<-0.5 $V\phi$ =169±1 km/s
[Fe/H]<-0.9 $V\phi$ =155±3 km/s

Z=1.5-2.5 kpc:
[Fe/H]<-0.5 $V\phi$ =159±1 km/s
[Fe/H]<-0.9 $V\phi$ =149±3 km/s



Two-gaussian best-fit (*thick disk* + *halo*) of the observed velocity distribution (*histogram*)

Kinematic substructures



Distribution of the halo subsample (3337 stars with [Fe/H]<-1.5 and d<3 kpc) in the space of the adiabatic invariants (Lz, Lxy, E).

Red dots indicate the 5% fastest stars and red crosses mark the pairs having a velocity difference within 42 km/s.

The blue box shows the locus of halo stream discovered by Helmi et al (1999).

(*from poster of Re Fiorentin et al.*)

CONCLUSIONS

- We have produced a new **proper motion survey** covering **9000 deg^2** based on the multi-epoch positions derived from SDSS – DR7 combined with the plate material from the GSC-II database.
- Accurate absolute **proper motions** ($\mu\alpha,\mu\delta$) have been computed for **77 million sources** down to magnitude *g*~22 (*r*~20). Proper motion errors attain **2-3 mas/yr**.
- Full *astrometric, photometric, and spectroscopic measurements* are available for **150,000 stars**.
- Photometric **distances** and **3D velocities** (UVW) have been computed for **27,000 FGK (sub)dwarfs** with [Fe/H]< -0.5, whose kinematic analysis shows:
    - A low rotation velocity gradient, $dV\phi/d|Z|$ = **-16 ± 1 km/s/kpc,** for the thick disk
    - Rotation-metallicity correlation, $dV\phi/d[Fe/H]$ = **43 ± 5 km/s/dex**, for the thick disk
    - Signature of kinematic substructures, related to known/new halo streams.