Mullard Space Science Laboratory

Galactic Archaeology at the Gaia era and follow-up survey

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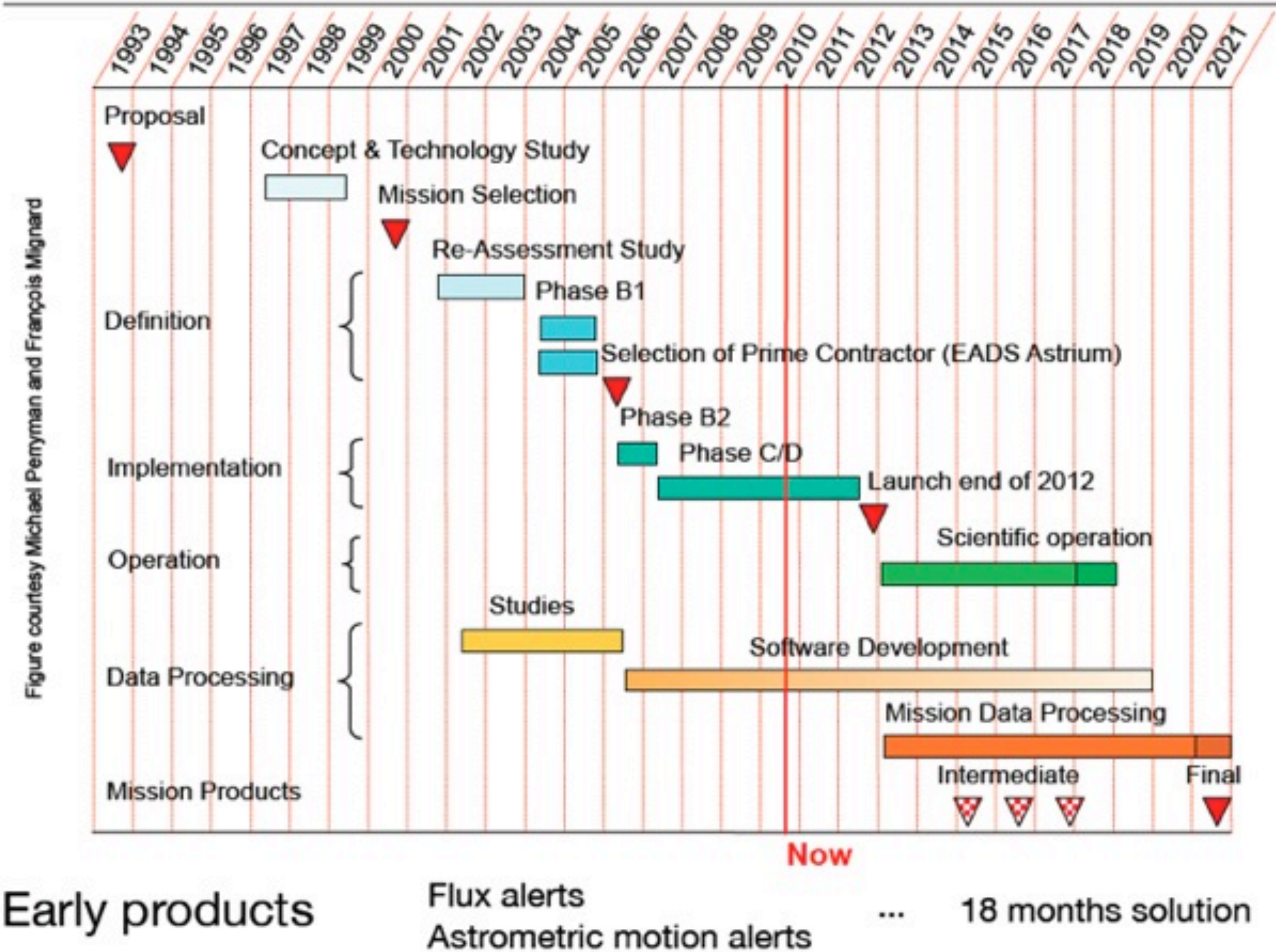
The Gaia mission

- Satellite of the European Space Agency
- Observations of all the objets brighter than V ~ 20
- astrometry, photometry, spectrophotometry, and low resolution spectroscopy (radial velocities)
- Length: 5 (+1) years (70 times all sky)
- Launch (Soyuz rocket, Kourou) 2012
- Final Results: 2021

Eyer's talk at KIAA, 2010

final data release 2010, everyone can equally access



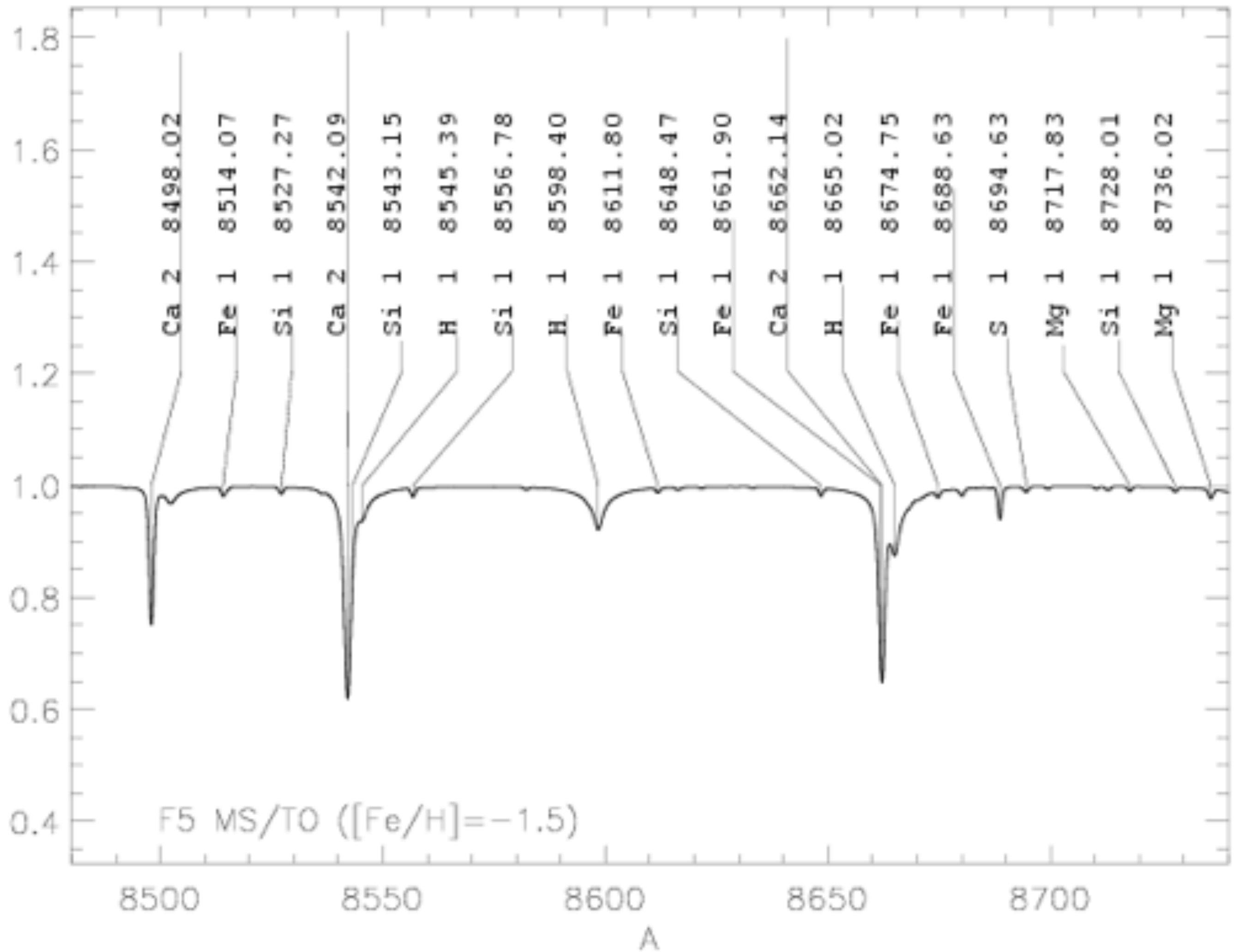
Eyer's talk at KIAA, 2010

	Hipparcos	Gaia
Magnitude limit	12	20 mag
Completeness	7.3 – 9.0	20 mag
Bright limit	0	6 mag
Number of objects	120 000	26 million to V = 15 250 million to V = 18 1000 million to V = 20
Effective distance	1 kpc	1 Mpc
Quasars	None	5×10^5
Galaxies	None	$10^6 - 10^7$
Accuracy	1 milliarcsec	7 μarcsec at V = 10 10-25 μarcsec at V = 15 300 μarcsec at V = 20
Photometry	2-colour (B and V)	Low-res. spectra to V = 20
Radial velocity	None	15 km/s to V = 16-17
Observing	Pre-selected	Complete and unbiased

Walton's talk at MSSL, 2010

RVS: Radial Velocity Spectrograph

Katz et al. (2004), Wilkinson et al. (2005)



Around Ca triplet: 847nm to 874nm

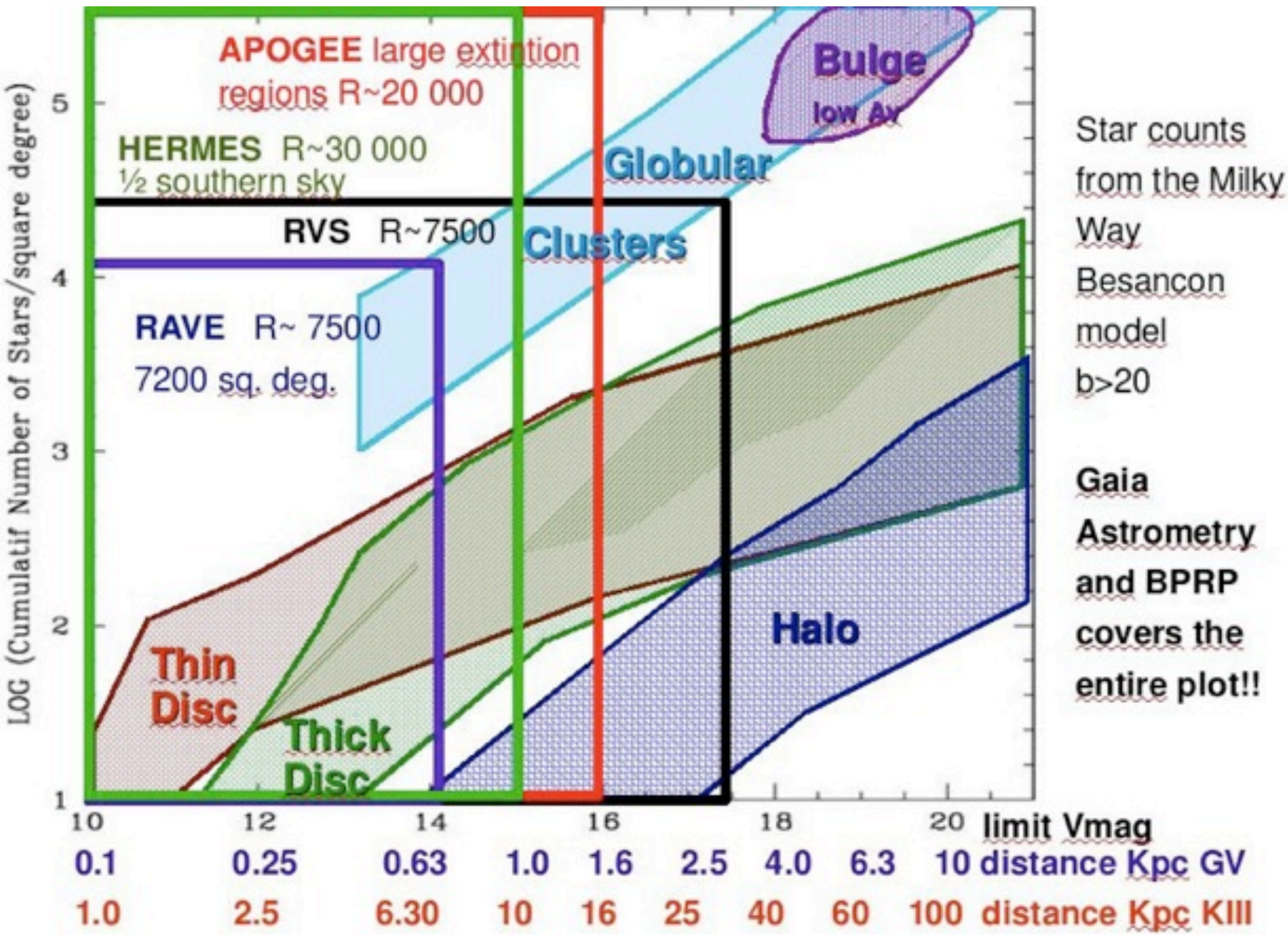
R=11,500

Katz's talk at ELSA, 2010

Spectroscopic survey

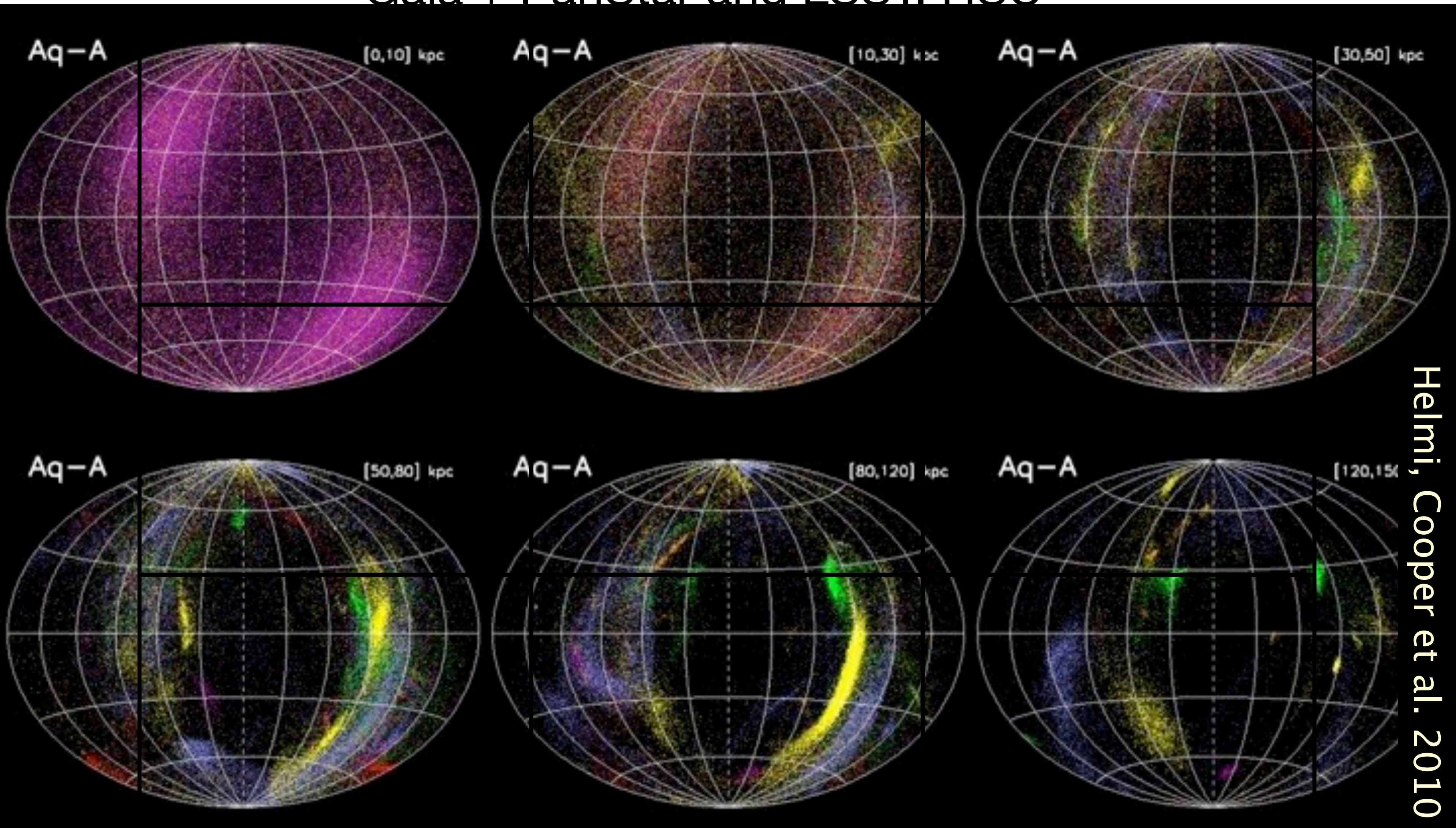
- **Stellar and interstellar parameters**
  - Radial velocities — $V \leq 17$ — $\sim 150\ 10^6$
  - Rotational velocities — $V \leq 13$ — $\sim 5\ 10^6$
  - Atmospheric param. — $V \leq 13$ — $\sim 5\ 10^6$
    and much fainter with spectro-photometer
  - Abundances — $V \leq 12$ — $\sim 2\ 10^6$
  - Interstellar reddening — $V \leq 13$ — **from 862 nm DIB**
- **Diagnostics**
  - Binarity/multiplicity, variability, …

Katz's talk at ELSA, 2010



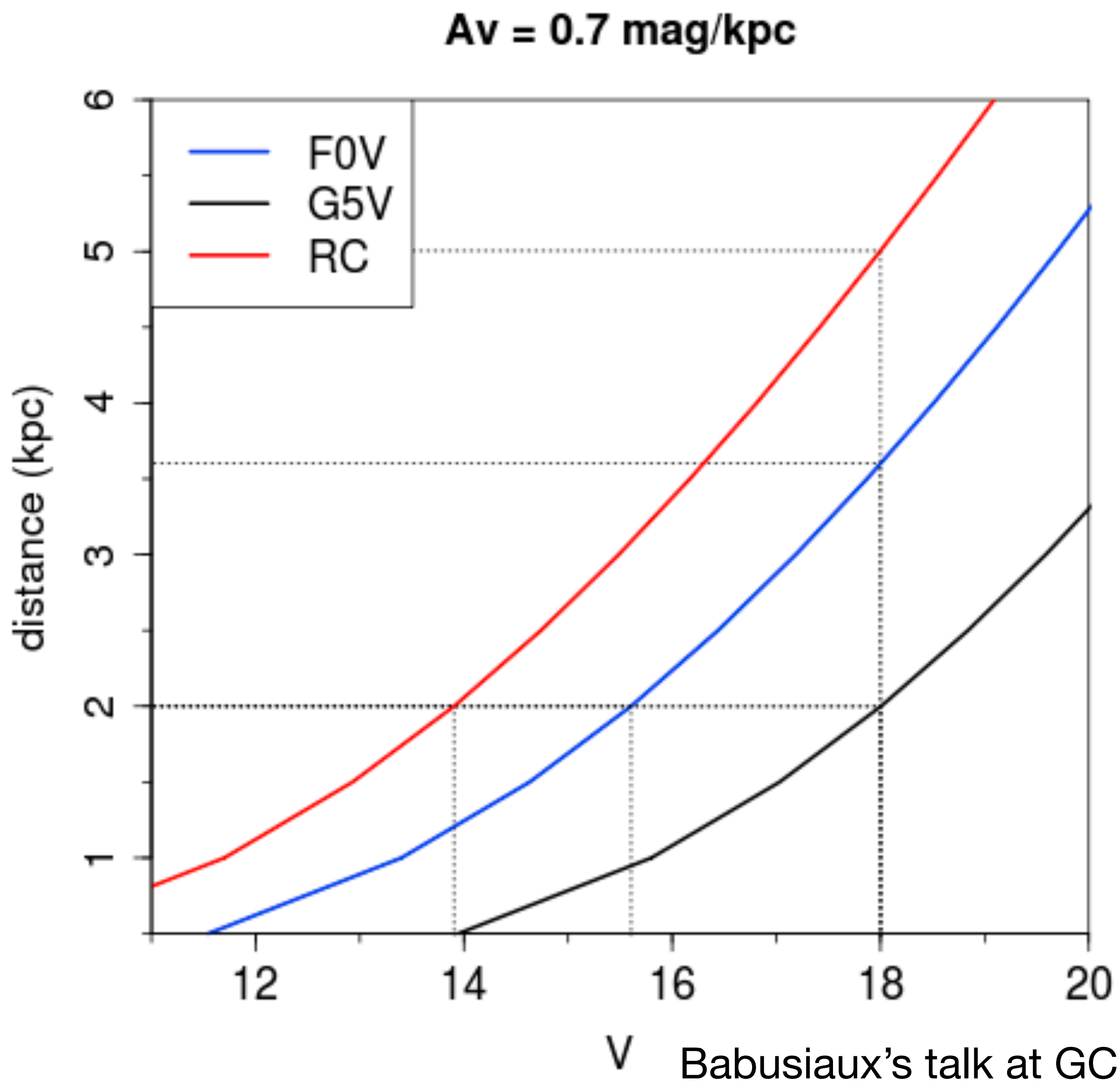
V. Hill's presentation at GCDS meeting

missing the outer halo kinematics and abundance
Gaia + PanStar and LSST, HSC

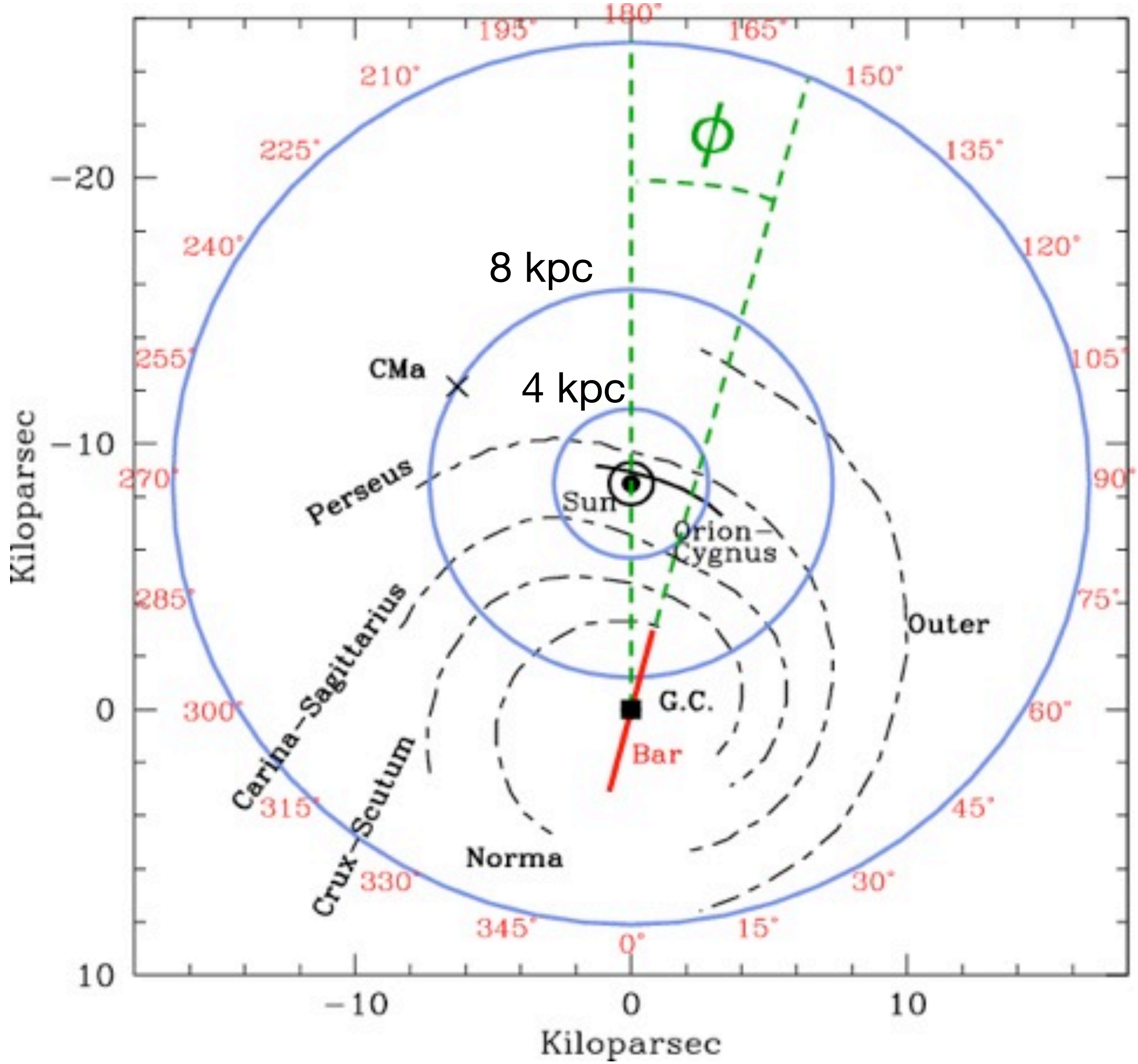


Inner halo (d < 10 kpc): very smooth (triaxial in shape)
Substructure apparent at d > 10 kpc and dominant at d > 30–50 kpc
Anisotropically distributed (coherent in dist): infall pattern!

disk plane + dust extinction



Babusiaux's talk at GCDS meeting



missing spiral kinematics, abundance gradient in the disk

Missing pieces

- radial velocity (V<17) and [al/Fe] (V<12) for faint stars
  ← R>5000 spectroscopy
  LAMOST (LR), SEGUE(LR), GCDS
- detailed abundance pattern, [X/Fe]
  ← high-resolution (R>20,000) spectroscopy
  HERMES, GYES, GCDS, APOGEE
- bulge/bar and inner disk - high extinction
  ← NIR astrometry and high-resolution(?) spectrograph
  APOGEE, JASMINE

The LAMOST Experiment for Galactic Understanding and Exploration (LEGUE)
LAMOST: 4000 fibers, 5 deg FoV

- Spheroid (|b|<20):
  2.5 M stars, g<20, S/N>10, R=2000
- Anticenter (|b|<30, 150<l<210):
  3M stars, g<18, S/N<20, R=2000
- Disk (OC &
  Selected star-forming region):
  3M stars, g<16, R=2000/5000

R=2000 ⇒ Vacc~10 km/s

SEGUE and SEGUE-II (R=2000)

Measured parameters:

σ RV: 5 km/s (med. S/N)

σ Teff: 157 K

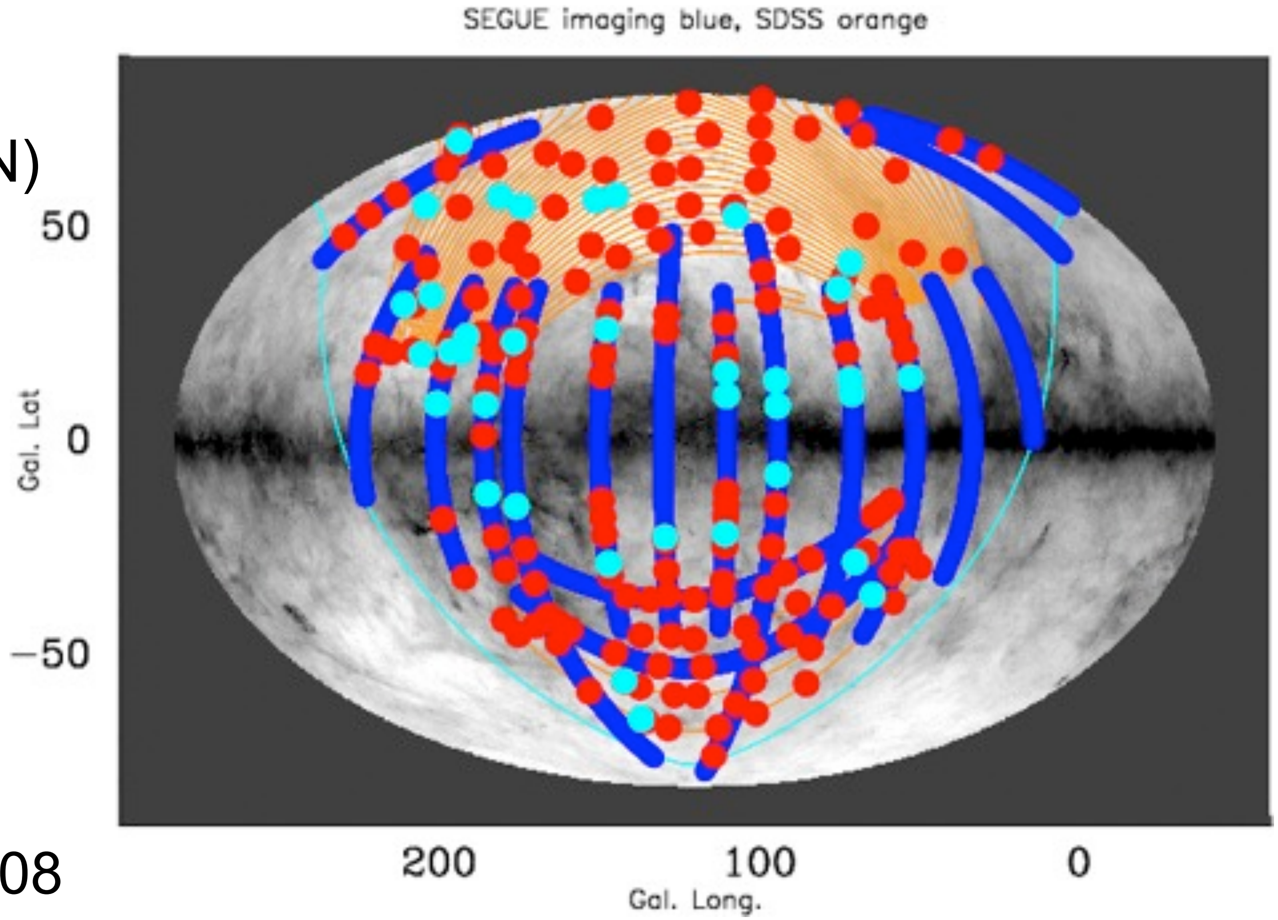
σ [Fe/H]: 0.23 dex

σ log(g): 0.3 dex

σ [α/Fe]:   0.1 dex

SEGUE pipelines:
Lee et al. 2008a,b,
Allende-Prieto et al. 2008

[α/Fe]: Lee et al. 2010, submitted



http://www.sdss.org/dr7

Yanny et al. 2009

DR8 Jan 2011

RAVE R~7500, typical RV error 2 km/s
8400-8800 Å (CaT)

S/N=100

[X/H]	offset	error (1σ)
O	-0.27	0.13
Mg	-0.11	0.07
Al	0.02	0.05
Si	-0.11	0.05
Ca	-0.01	0.13
Ti	-0.12	0.07
Fe	-0.04	0.08
Ni	-0.10	0.24

S/N=40

[X/H]	offset	error (1σ)
O	-0.33	0.15
Mg	-0.04	0.10
Al	0.02	0.10
Si	-0.08	0.09
Ca	-0.04	0.19
Ti	-0.15	0.16
Fe	-0.01	0.09
Ni	-0.22	0.25

HERMES: Galactic Archaeology

- Stellar survey, complete down to V = 14 (~fiber density), covering ~half the southern sky (|b| > 30) ➔~10,000 square degrees = 3000 pointings, spectra of 1.2 x 10^6 (!) stars
- For V ~ 14, R ~ 28,000, with SNR ~ 100 per resolution element in 1 hour, with ~ 8 fields per night ➔ can be done in ~ 400 clear nights (bright time)

HERMES: GA Survey

- In order to maximise chemical "resolution", select four wavelength regions to allow abundance measurements from a range of 7 independent

- Light elements (Na,Al)
- Mg
- Other alpha-elements (Ca, Si, Ti)
- Fe and Fe-peak elements
- Light s-process elements (Sr,Zr)
- Heavy s-process elements (Ba)
- r-process (Eu)

Channel	Wavelengths
Blue	4708 – 4893Å
Green	5649 – 5873Å
Red	6481 – 6739Å
IR	7590 – 7890Å

GREAT: Gaia Research for European Astronomy Training Chemo-Dynamics Survey (GCDS)

GCDS Survey Summary

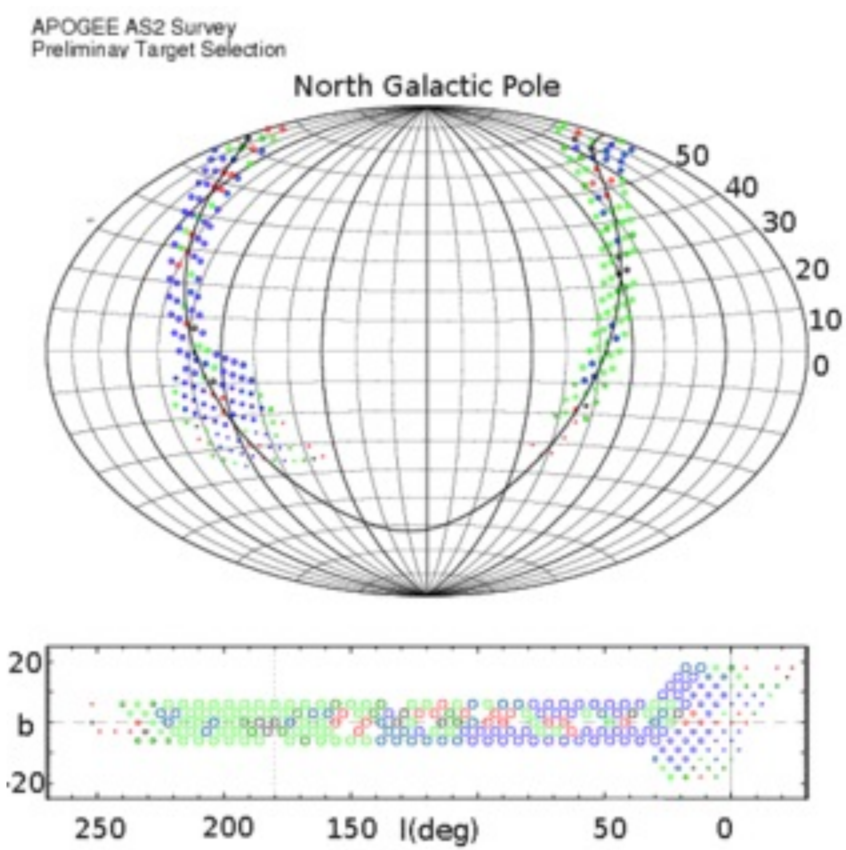
Science drivers outlined in following talk

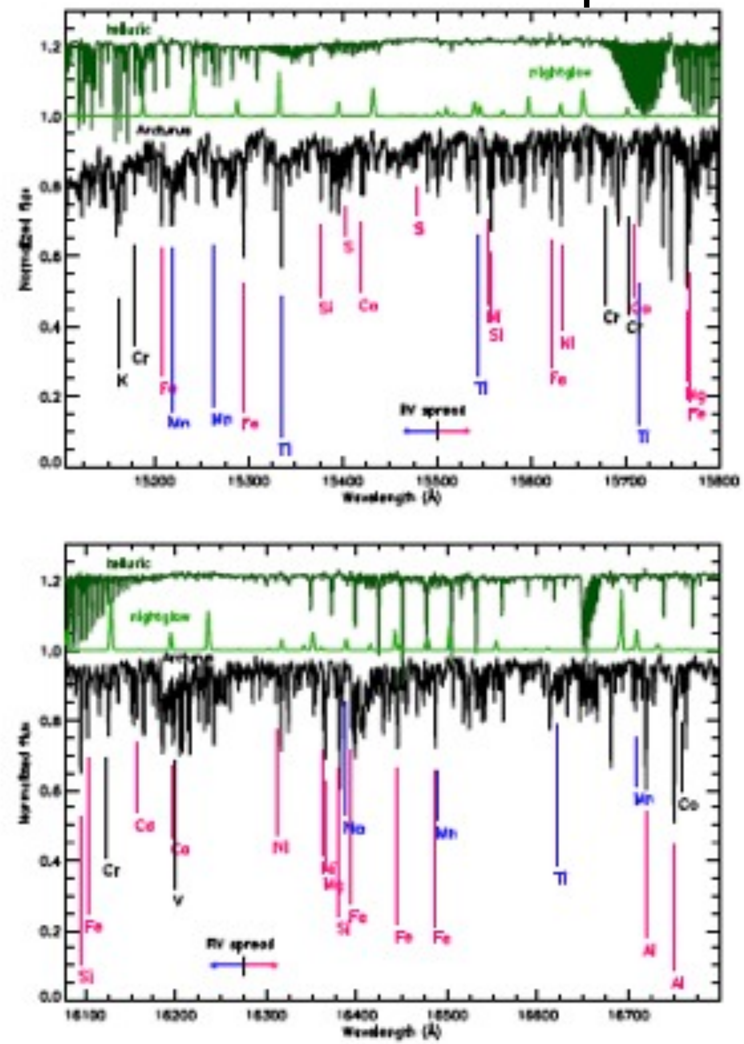
- Low Resolution Component
  - R=5000 – Chemo-Kinematics – 5 x 10^6
    - Disk / Halo / Bulge components — spiral arm, halo streams $\sigma < 5$ km/s
    - Radial velocities to ~2-3 kms^{-1} and [Fe/H] to 0.2 dex
- High Resolution: (< 1kms^{-1} and ~0.05 dex in [Fe/H])
  - good wavelength coverage, adjustable window(s) in ~3700-9500Å range, abundances: light elements, alpha-elements, r- s-process and heavy elements
  - R=20000 – Halo: 5 x 10^4 (Chemical-Labelling)
  - R=20000 – Bulge: 5 x 10^4
  - R=40000 – Disk: 2 x 10^5 (Chemical-Tagging)
    - Open clusters – x1000 at 100 per cluster

ESO VLT Public Survey

- up to 300 nights on any ESO telescope, including VLT
- start October 2011 (LoI, 15 October)
- Gaia community response:
  FLAMES survey
  LR8 (R~6500) or several HR mode (R~20,000)
  still in discussion
- Legacy value
- call for next generation ESO instruments

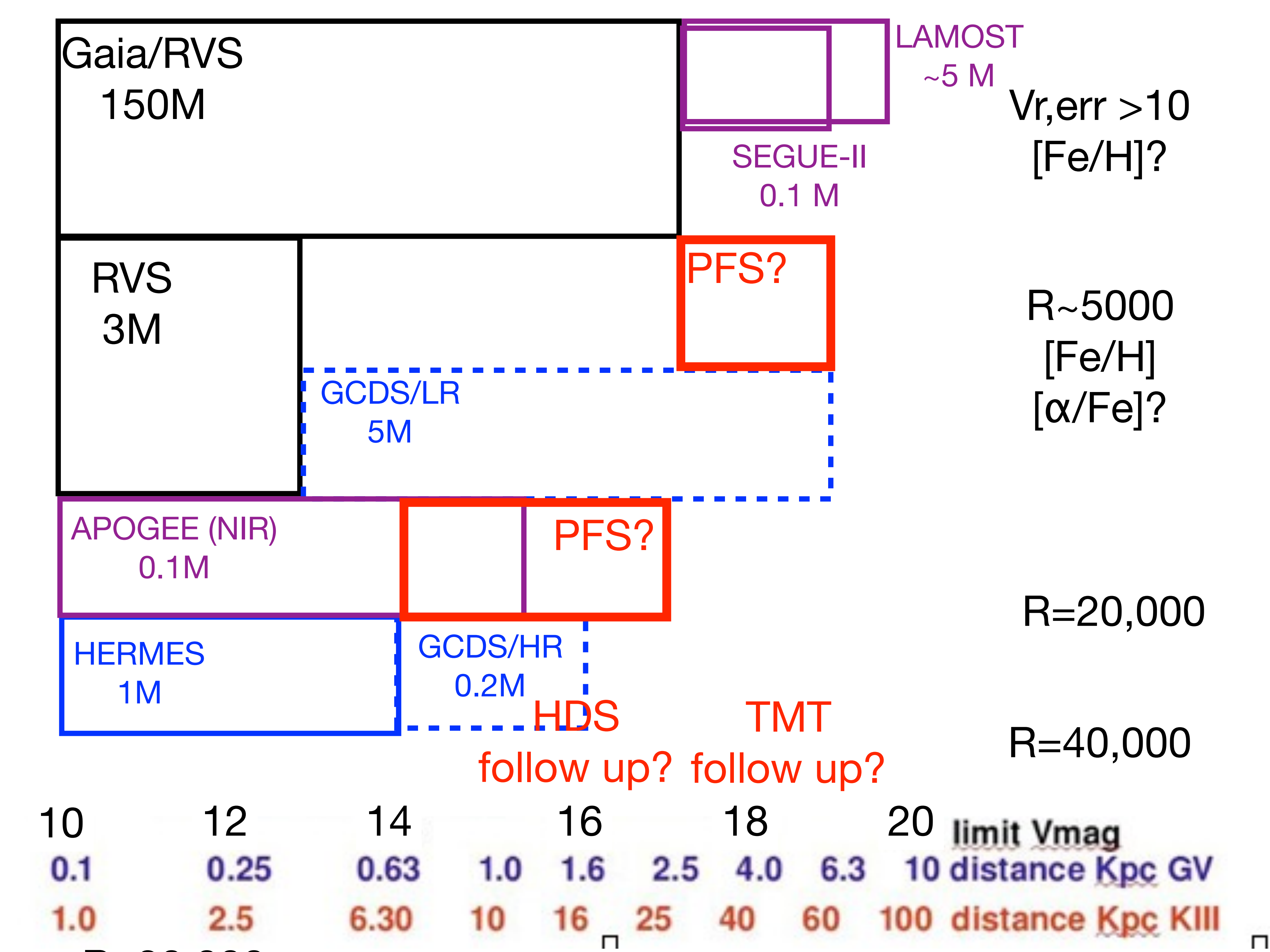
SDSS-III, APOGEE
The Apache Point Observatory Galactic Evolution Experiment





Allende Prieto et al. (2008)

R~20,000 IR spectra for 100,000 giant stars
in the disk and bulge (RV+C,N,O,Mg,Al,Si,Ca,Ti,Cr,Fe,Ni...)


Gaia/RVS
150M
LAMOST
~5 M
SEGUE-II
0.1 M
Vr,err >10
[Fe/H]?
RVS
3M
PFS?
R~5000
[Fe/H]
[α/Fe]?
GCDS/LR
5M
APOGEE (NIR)
0.1M
PFS?
R=20,000
HERMES
1M
GCDS/HR
0.2M
HDS
follow up?
TMT
follow up?
R=40,000
10 12 14 16 18 20 limit Vmag
0.1 0.25 0.63 1.0 1.6 2.5 4.0 6.3 10 distance Kpc GV
1.0 2.5 6.30 10 16 25 40 60 100 distance Kpc KIII

PFS at the Gaia era?

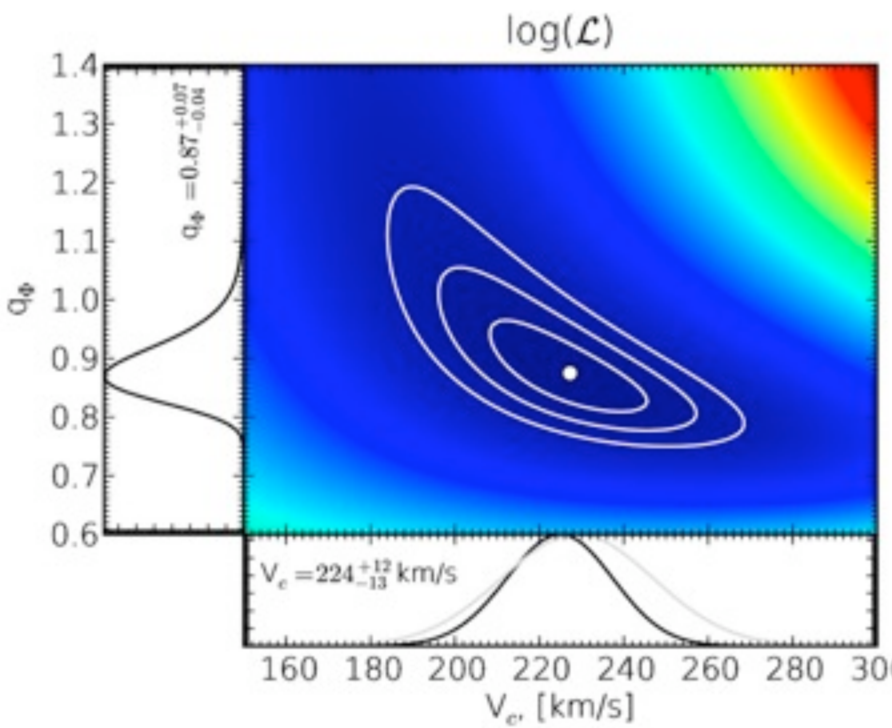
- R>5000 RV and [Fe/H] survey for V<19 stars:
  halo and disk kinematics and rough abundance, finding Pop III candidates
  large FoV: faint satellites, clusters even after Gaia
  complementary to SEGUE, LAMOST, GCDS

- R~20,000, V<16 mag survey for over million stars:
  3D abundance map (low Av region) of bar, thick and thin disk. Abundance of halo stream stars
  complementary to HERMES, GCDS

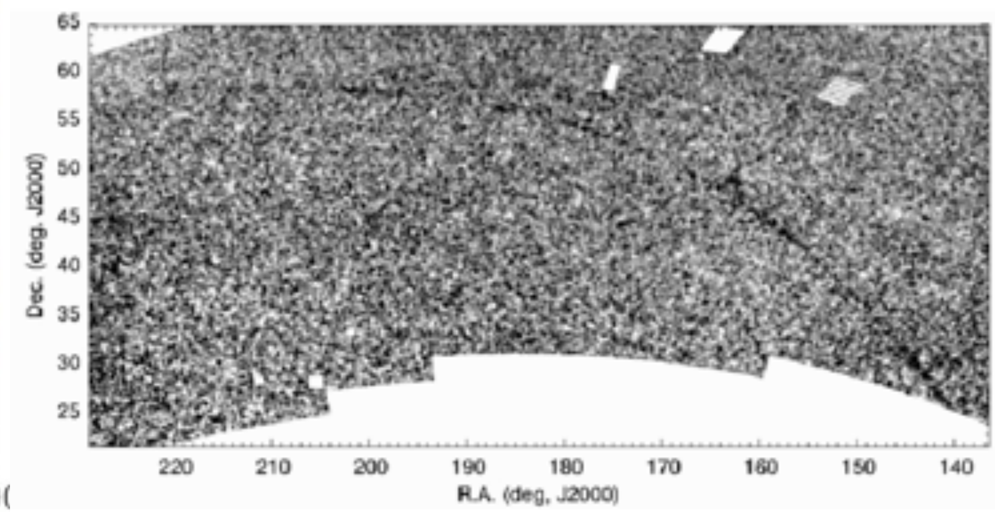
- R~20,000 (need HR?), NIR spectroscopic survey:
  bar and disk around b=0 ... huge interests on Galaxy modelling community.
  complementary to APOGEE, WINERED, JASMINE
  very unique on 8 m!

Mass distribution of the Milky Way: Streams

thin tidal stream → Milky Way potential shape, disk mass
more streams, further out, more constraints.

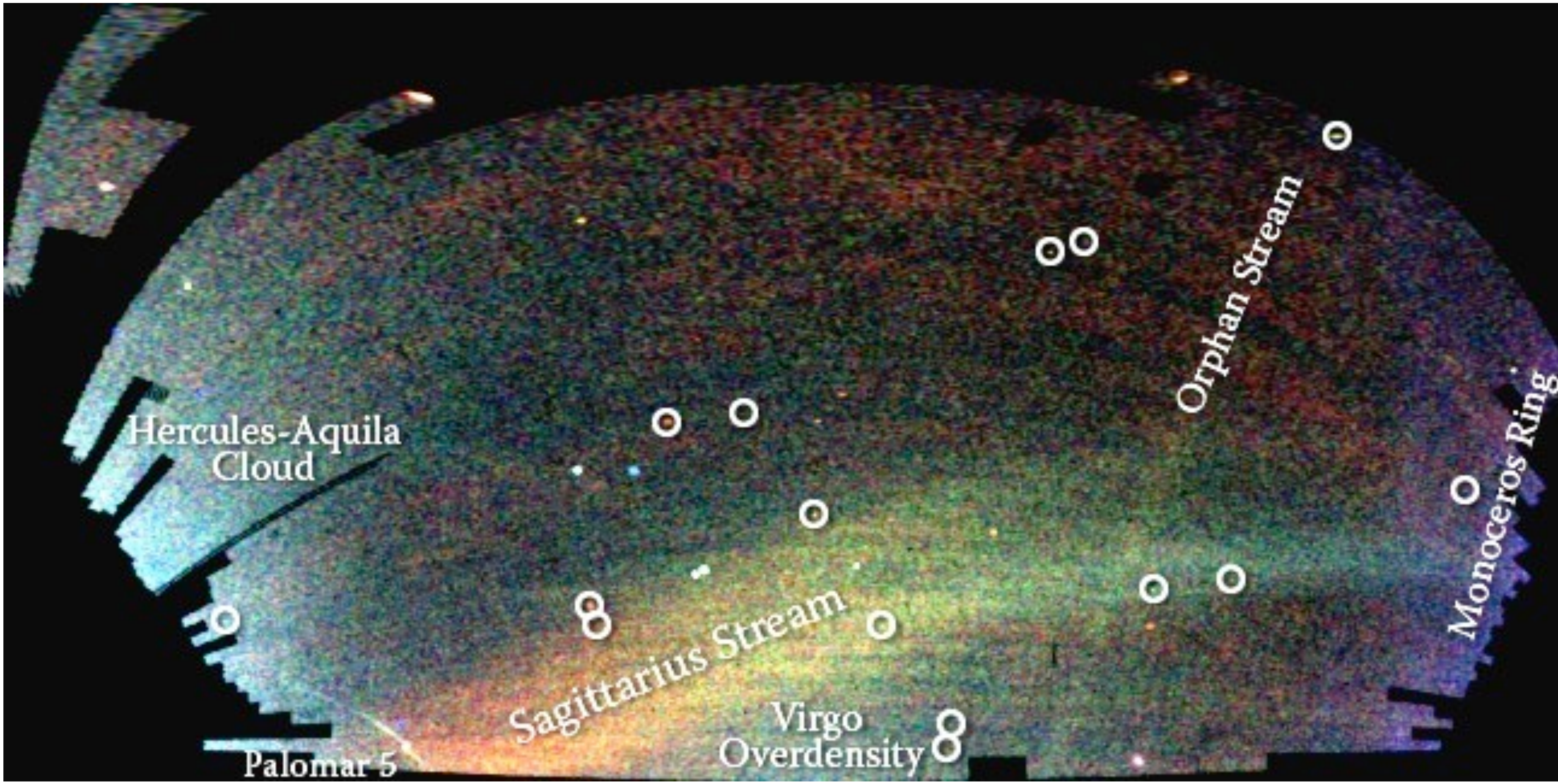


8-10 kpc



Koposov's talk: GD-1 stream case

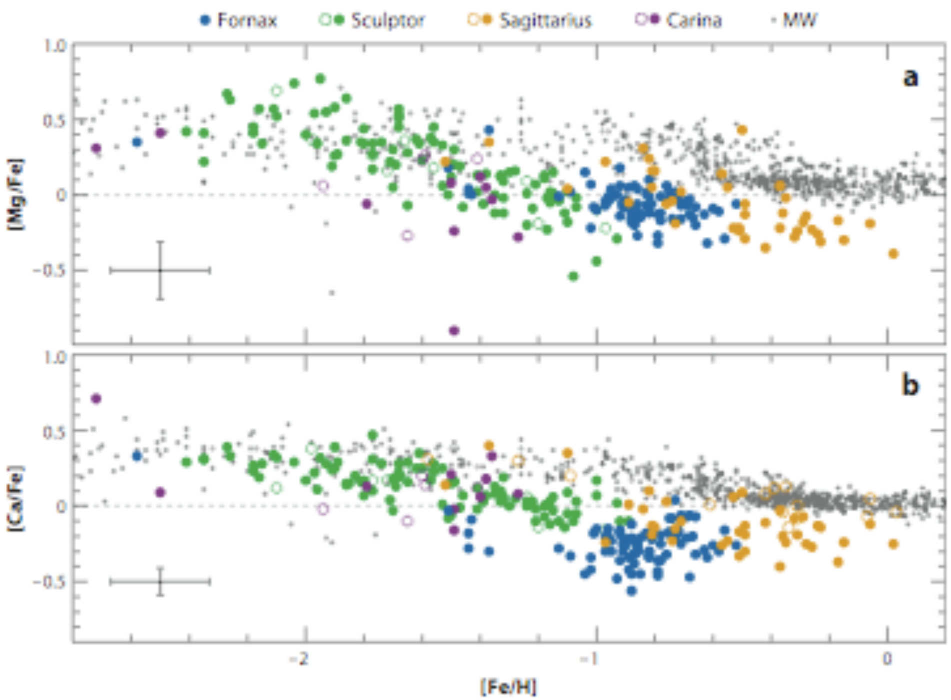
Assembly history
lots of streams and ultra faint dwarfs!



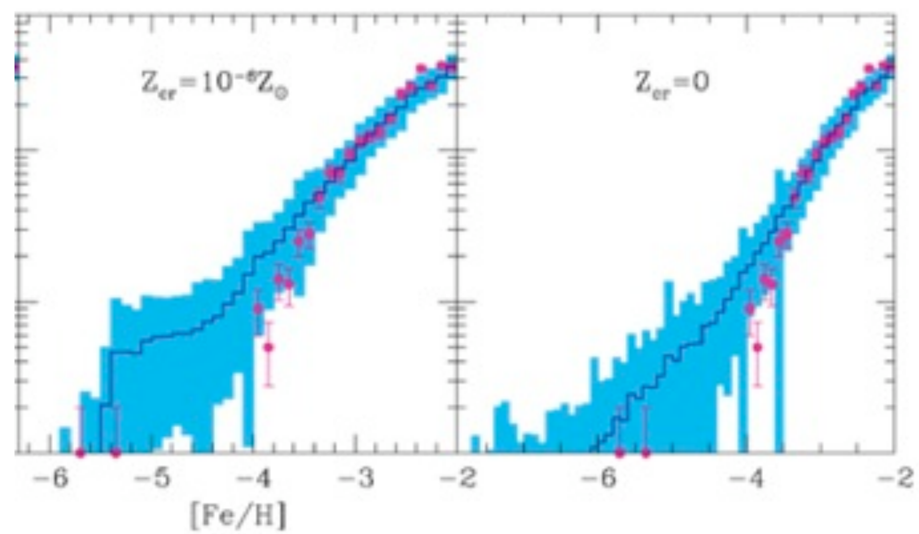
Chemical tagging (or trailing): stream and halo stars

chemical abundances (α+several elements)
→ star formation history of progenitor galaxies

Hunting extremely metal poor stars
→ chemical enrichment from first stars, IMF of first stars.

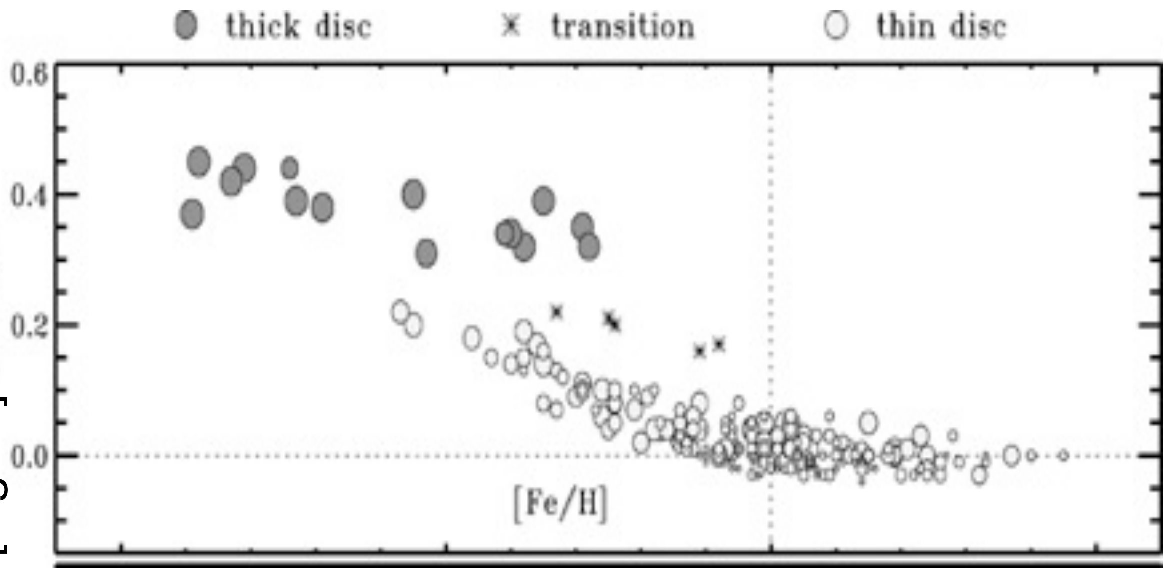


Tolstoy et al. (2009)



Salvadori et al. (2007)

[α/Fe] vs. [Fe/H] @ solar neighborhood (Brook, ..., DK 05)



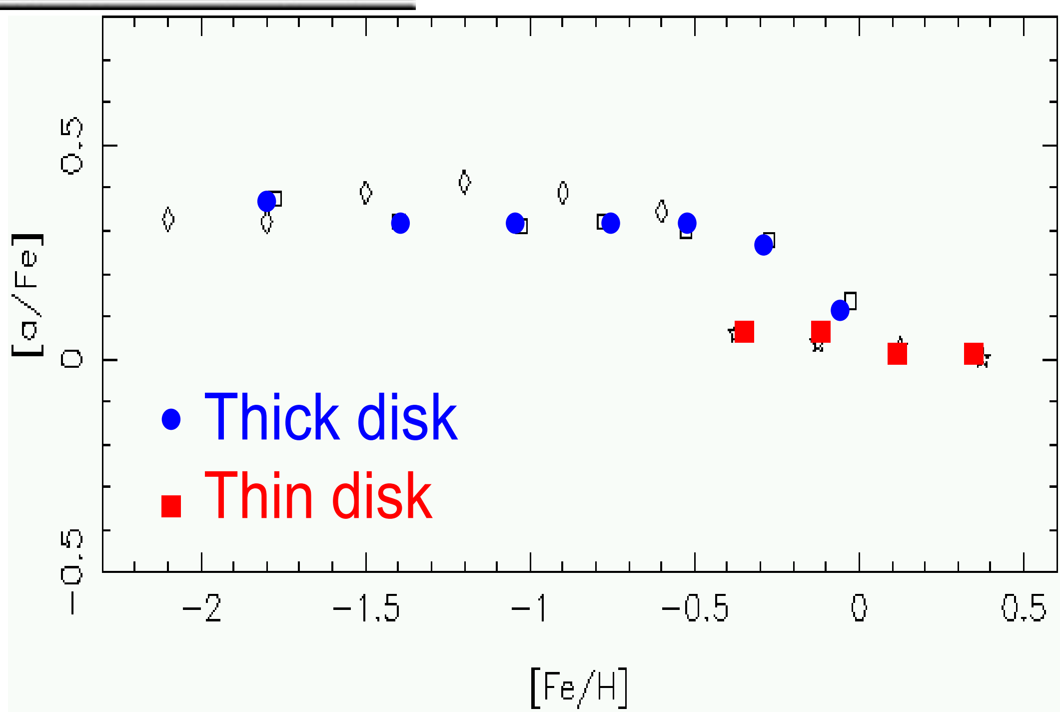
[Mg/Fe]

[Fe/H]

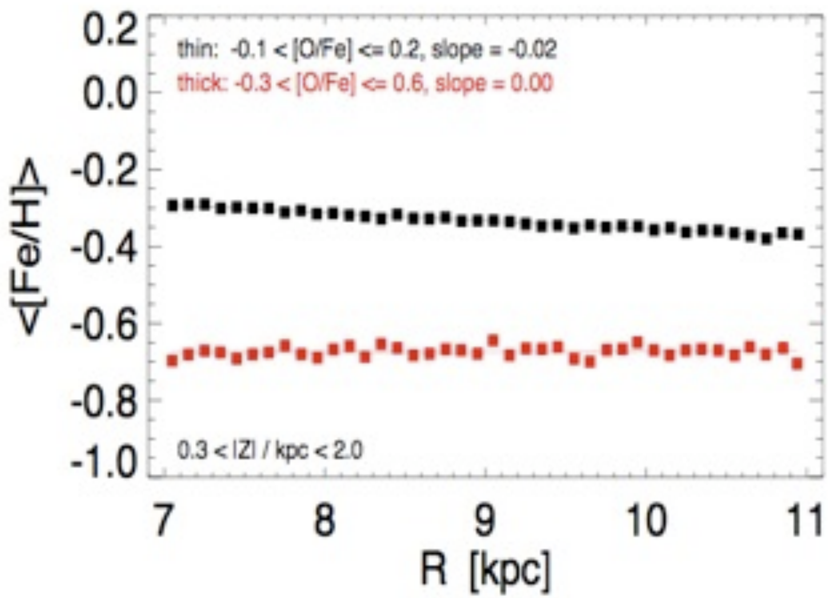
Observation

Fuhrmann (08)

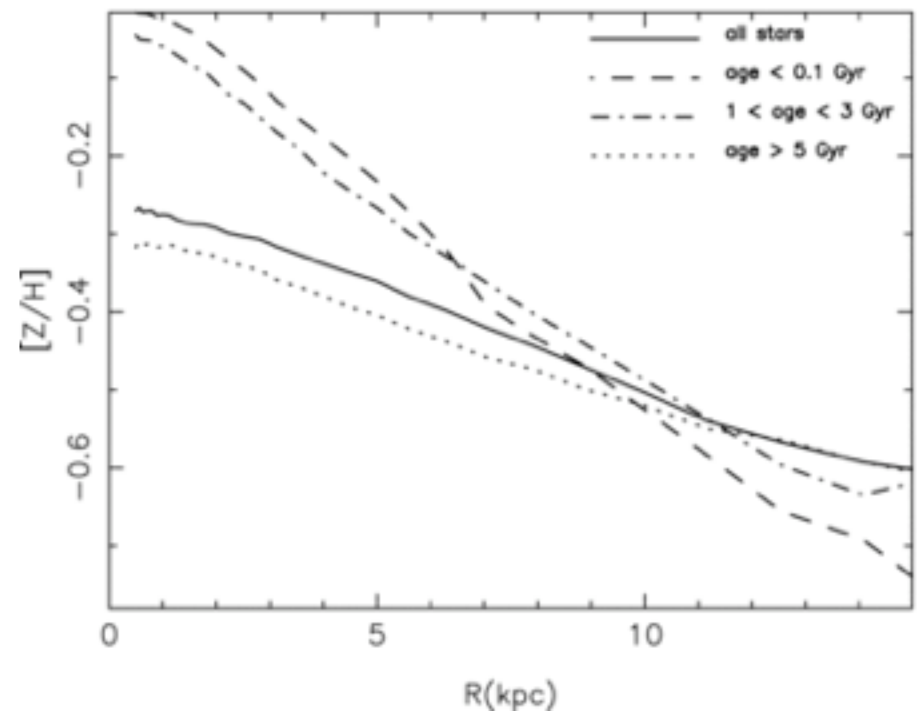
Simulation



Metallicity gradient could be a key?

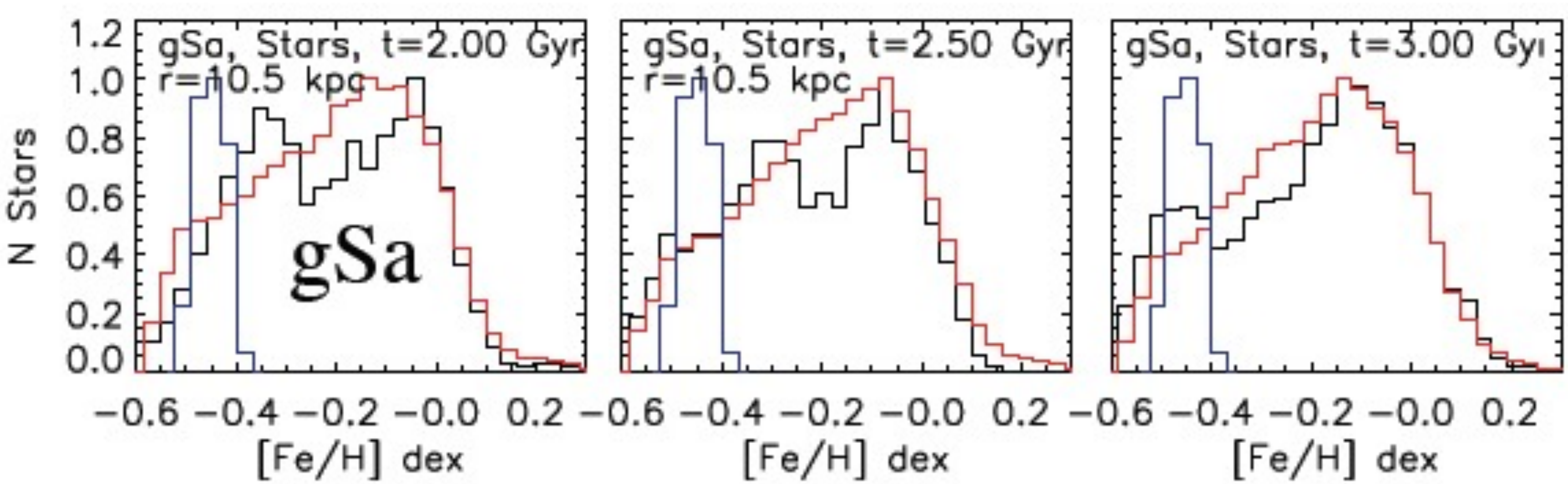


Debattista talk at
LAMOST meeting 2010



Sánchez-Blázquez et al. (2009)

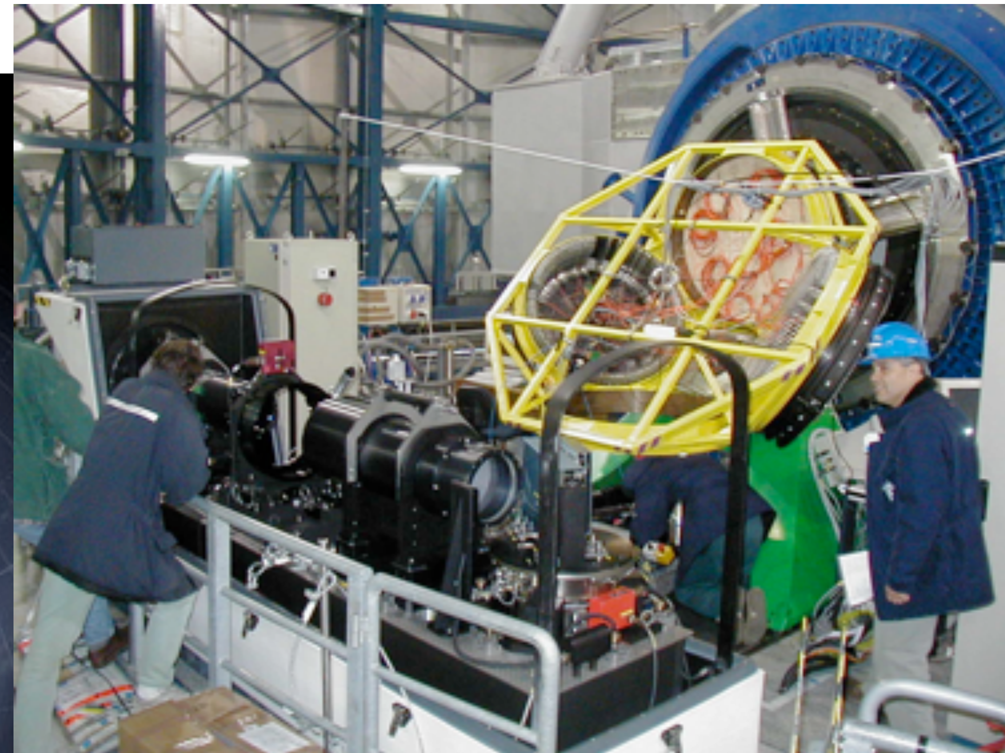
Metallicity distribution function at different radii for stars with different ages.



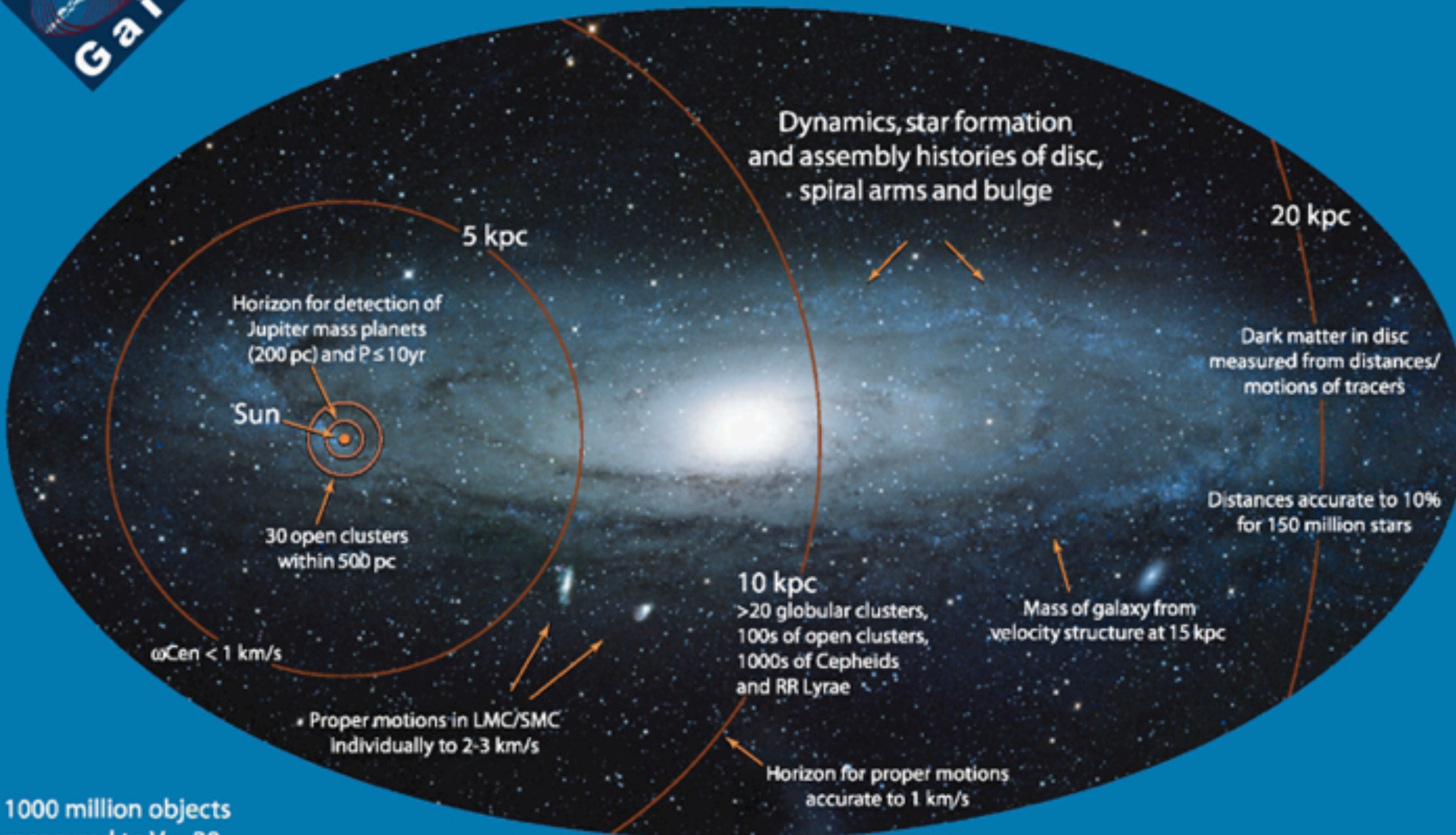
initial, cold orbit, hot orbit

Minchev's talk at
LAMOST meeting 2010

GREAT Chemo-Dynamics Survey (GCDS)
ESO VLT Public Survey
300 nights on FLAMES/VLT



A STEREOSCOPIC CENSUS OF OUR GALAXY



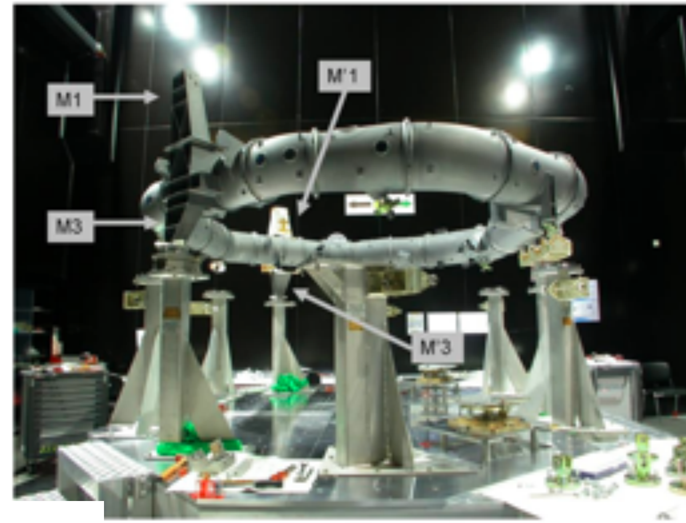
1000 million objects measured to V = 20

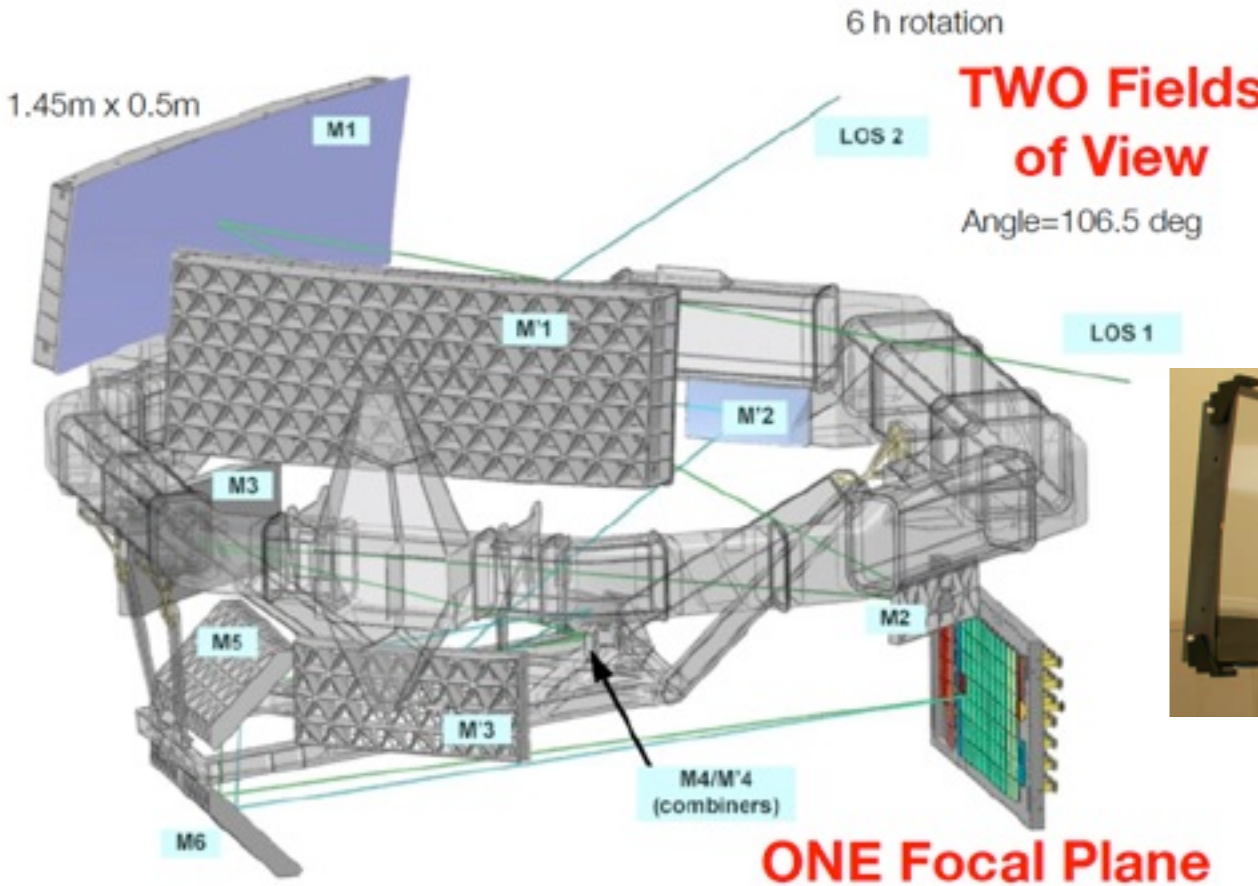
General relativistic light-bending determined to 1 part in 10^6

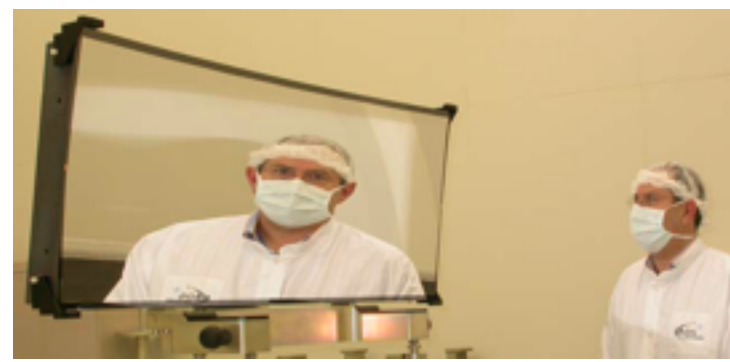
10 μas = 10% distances at 10 kpc
equiv 1AU at 100 kpc

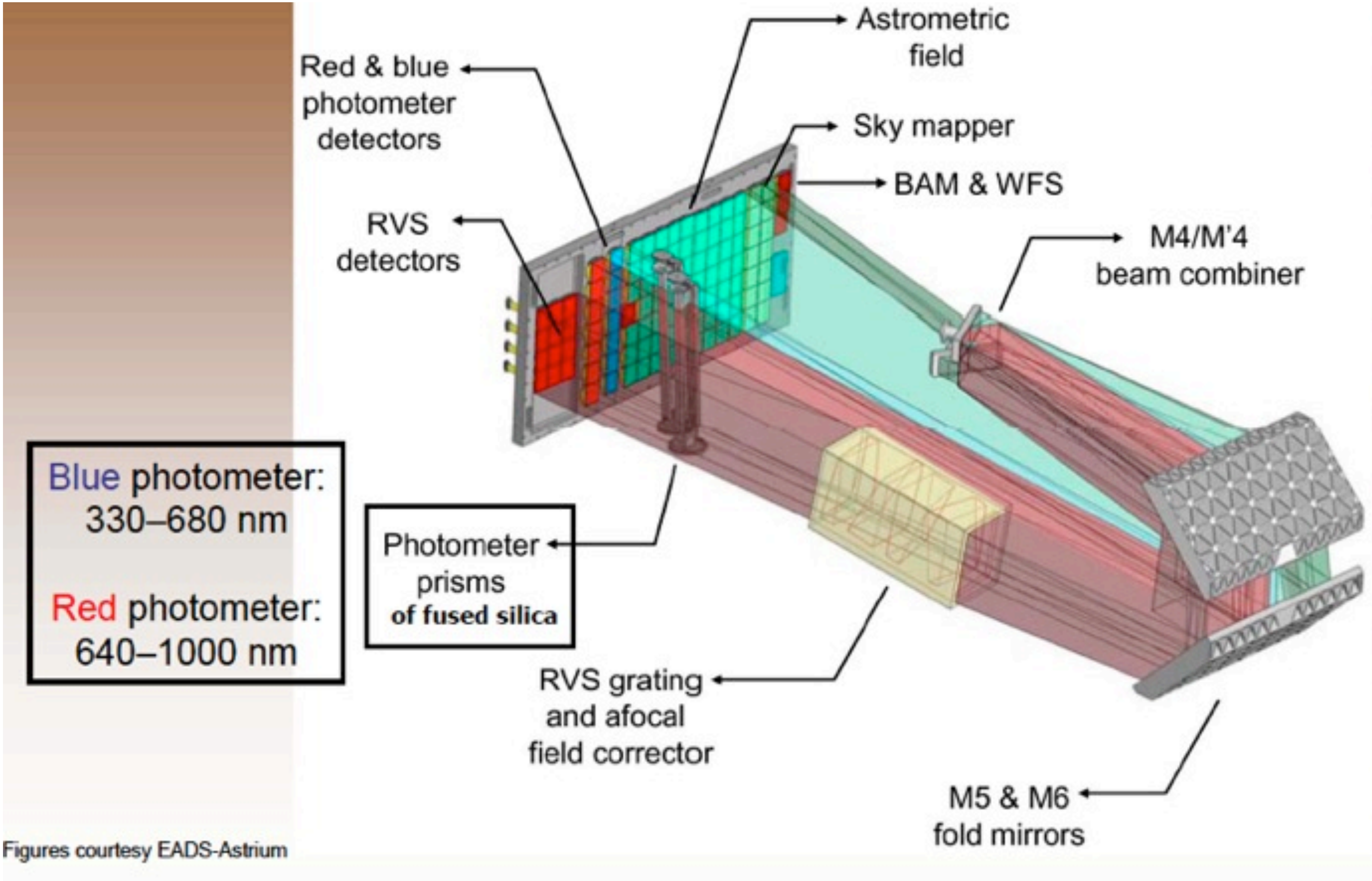
10 μas/yr = 1 km/sec at 20 kpc

The payloads and instruments









Jordi's talk at ELSA conference, 2010

Focal plane

106 CCDs , 938 million pixels, 2800 cm^2
pixel size= 59 mas, angular resolution=0.12"

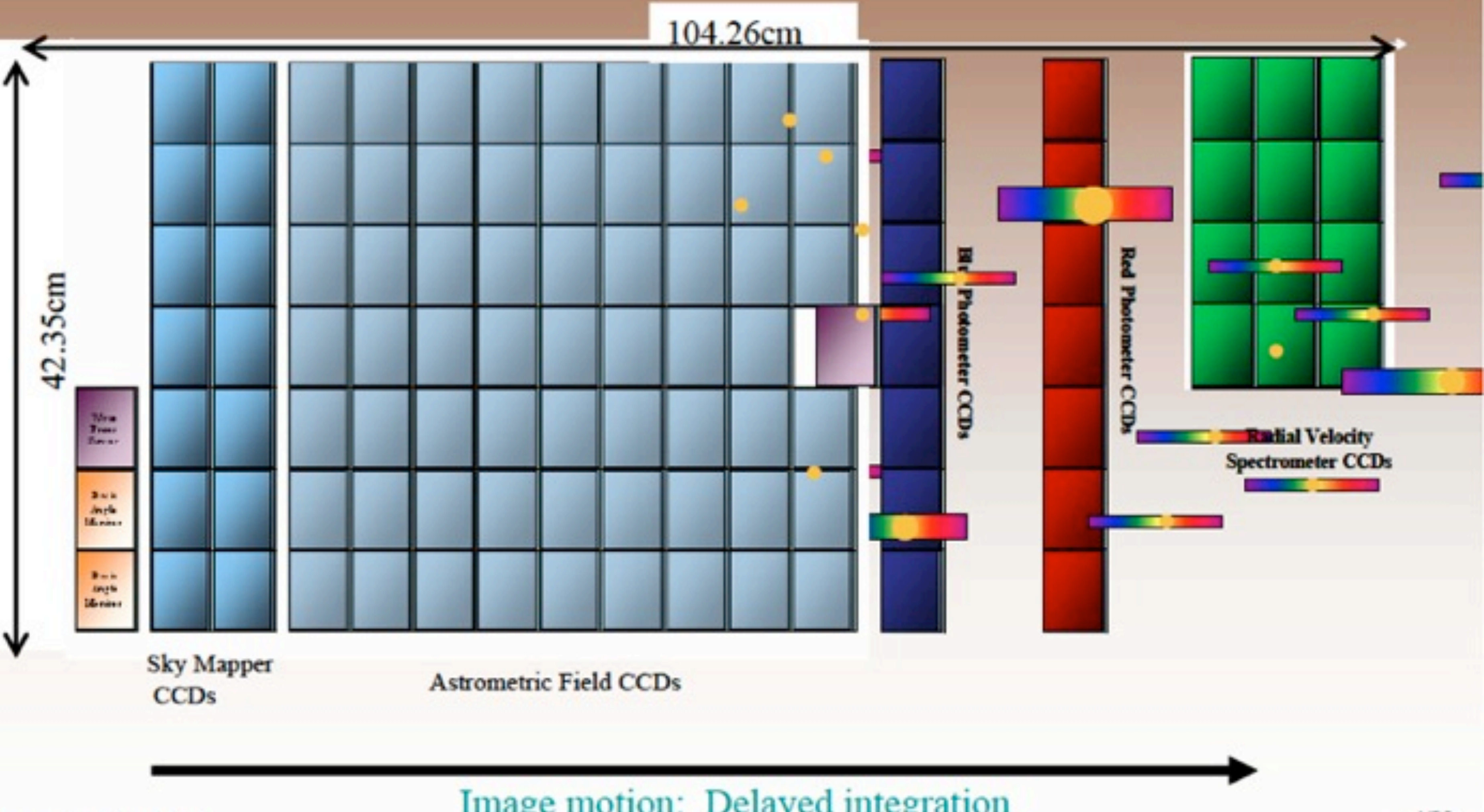
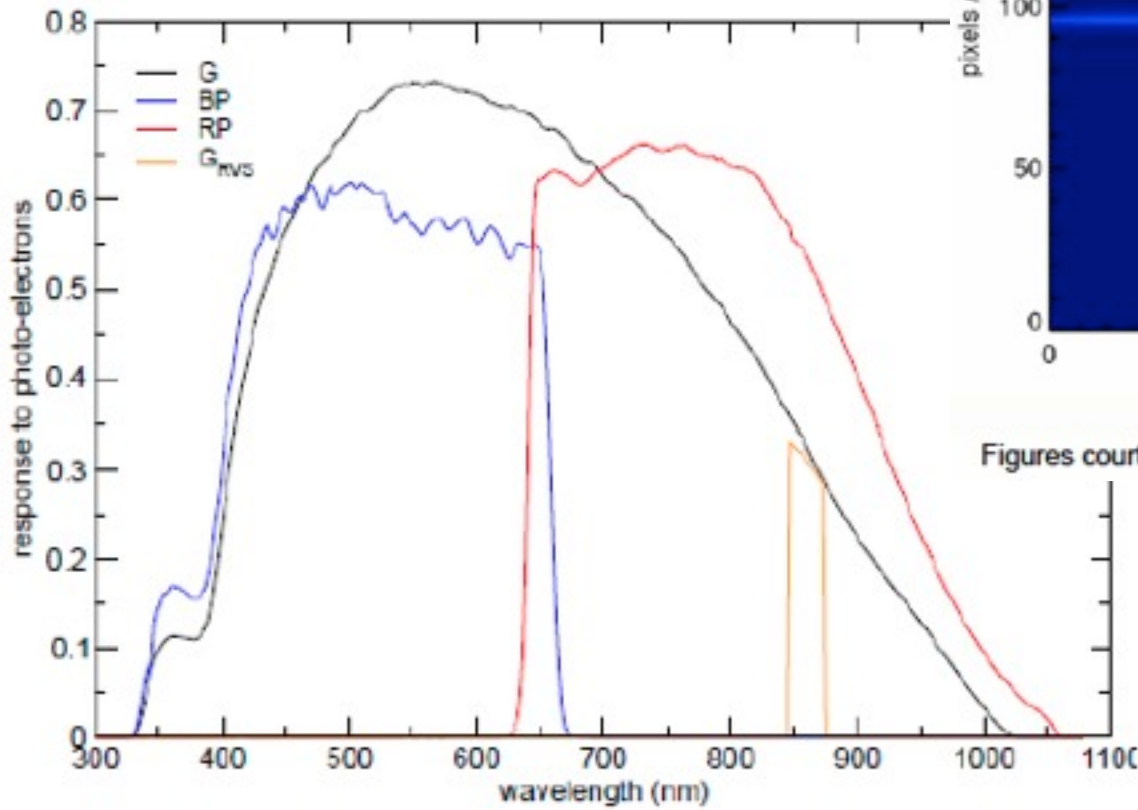


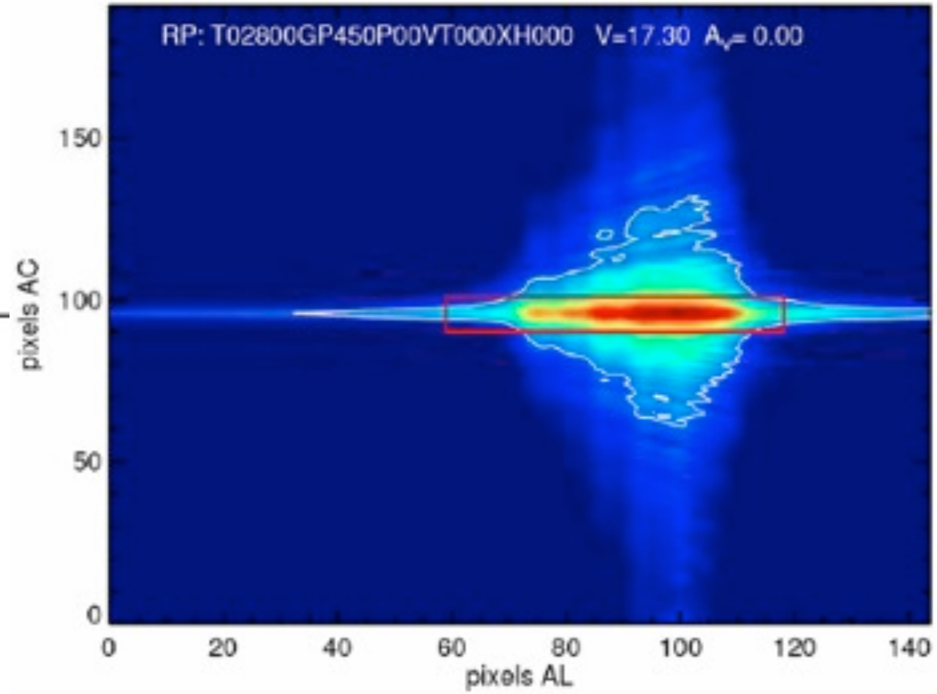
Figure courtesy Alex Short

Jordi's talk at ELSA conference, 2010

Gaia passband

(Jordi et al. 2010)

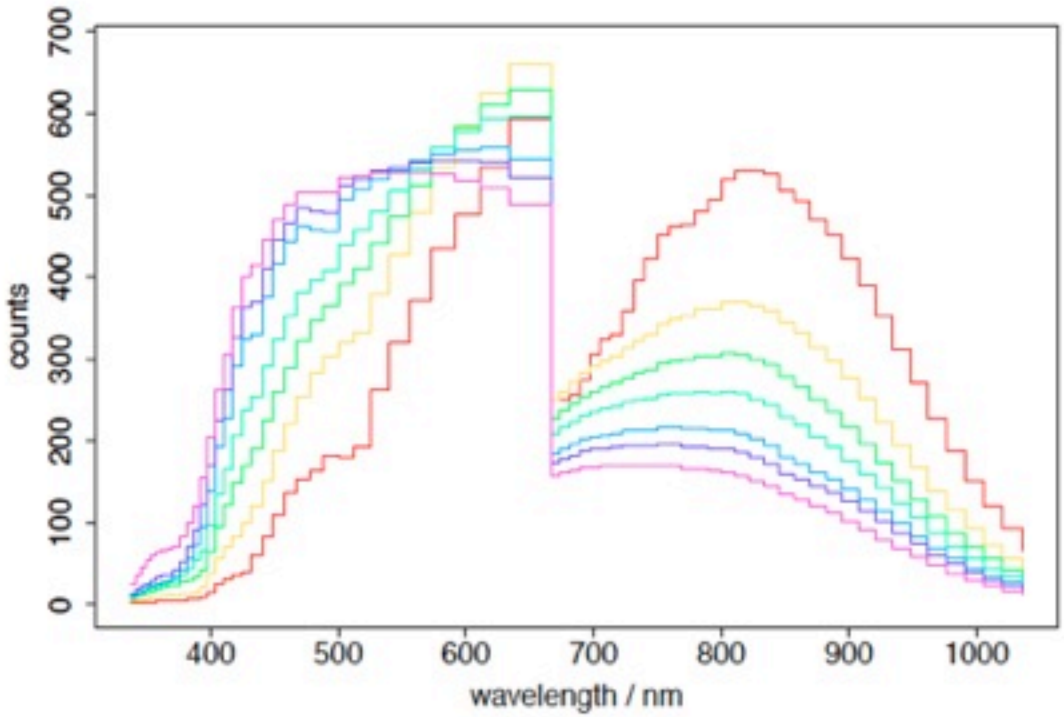




Figures courtesy Anthony Brown

spectrophotometer BP and RP: R~100
(also useful for galaxies and QSOs sciences)

Gaia BP/RP spectra (GOG simulations)



Av=0, [Fe/H]=0, [α/Fe]=0, logg=4

Teff / K = 4000, 5000, 6000, 7000, 8500, 10000, 15000

- Basel and Marcs stellar libraries
- 34 pixels in each of BP and RP retained
- Nominal sampling, LSF included, noise added, but no CTI etc.

Survey Strategy (A)

- 4-m spectrograph build:
  - 3+1 yr – 2014 on WHT (or CFHT) and/or VISTA
  - 5 yr survey – 1000 nights in N/ 1000 nights in S
  - Complete survey by 2019 – matched to release of Gaia
- 2000 night 4-m survey defines scope for disk/halo/bulge components
- Initiate 4-m programme now as pilot with current facilities
  - La Palma – autumn ITP programme (all spectroscopy)
  - GCDS consortium effort

Survey Strategy (B)

- 8-m component – via ESO large programme
- 500 nights over three years (1500 over 9 years)
- FLAMES/ GIRAFFE
  - 1-2 hr exposures – 1-2 sq deg/night – 1-2000 stars/ night
  - 1000 nights > 1-2x10^6 stars by 2018 (V~17/ R=20000)
  - 500 nights > for R=5000 = 1x10^6 stars (V~18/ R=5000)
- Thus – 3x very large programmes
  - Split 1:2 for R=5000:20/40000
  - Bulge/ Disk/ Halo components
- Combined with 4-m studies
  - … compulsive science

HERMES Basics

- 4 arms with VPH gratings and $4k^2$ CCDs
- R~28,000, 200-300 Å/ per arm (~1000Å total); higher res w/slitmask (R~50,000)
- For V~14, S/N ~ 100 in 1 hour
- Designed to work with 2dF top end on 3.9m