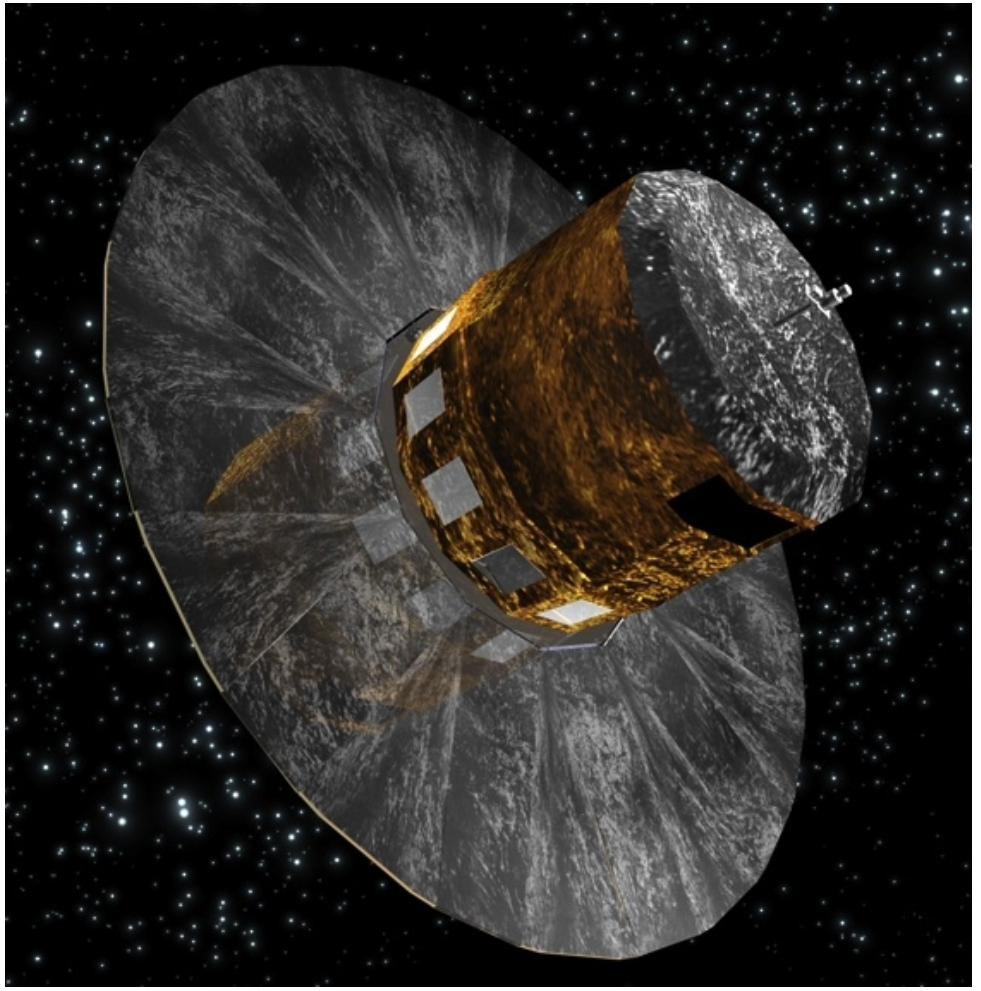
EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

Gaia, GREAT & Surveys

GREAT-ITN
MARIECURIE ACTIONS



GREAT: Gaia Research for European Astronomy Training

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(Institute of Astronomy)

UNIVERSITY OF CAMBRIDGE

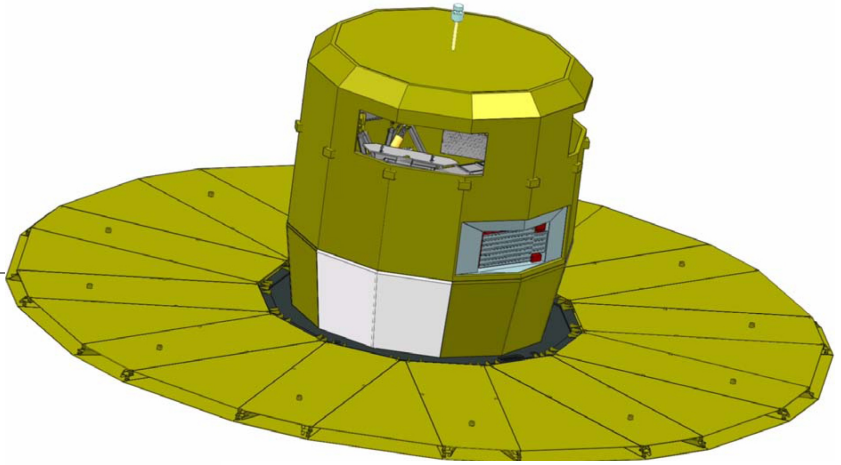
ioa

GREAT

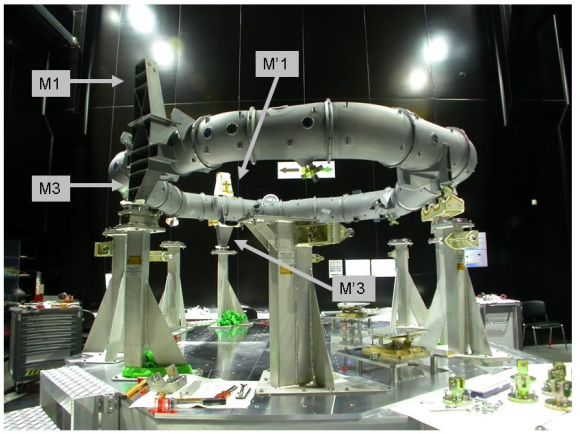
Gaia: mapping the Universe

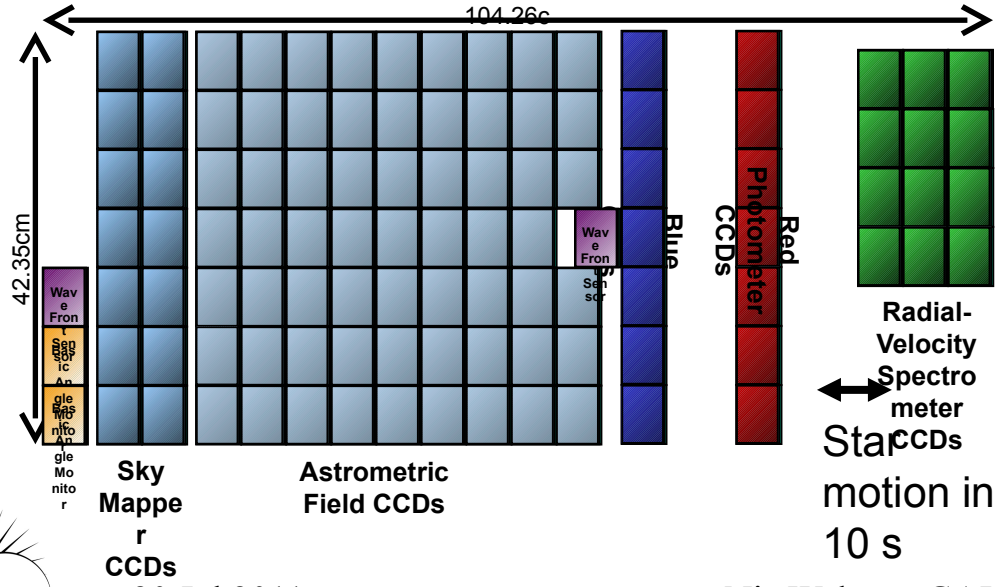
CDR complete: launches May 2013

	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

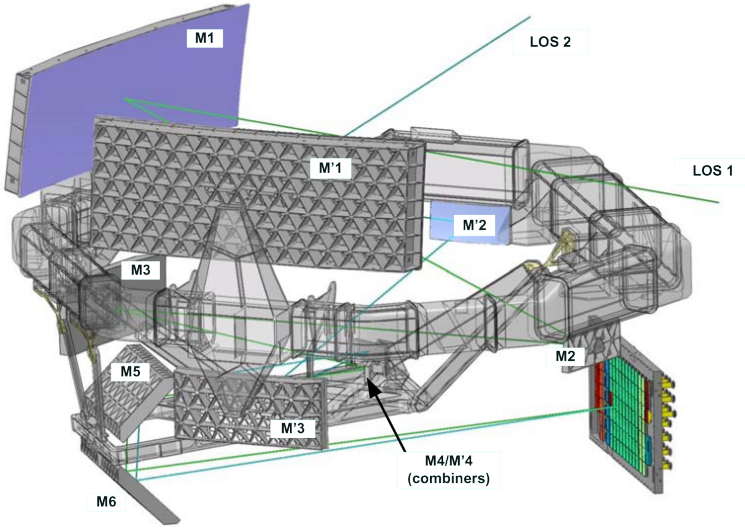


Images: ESA

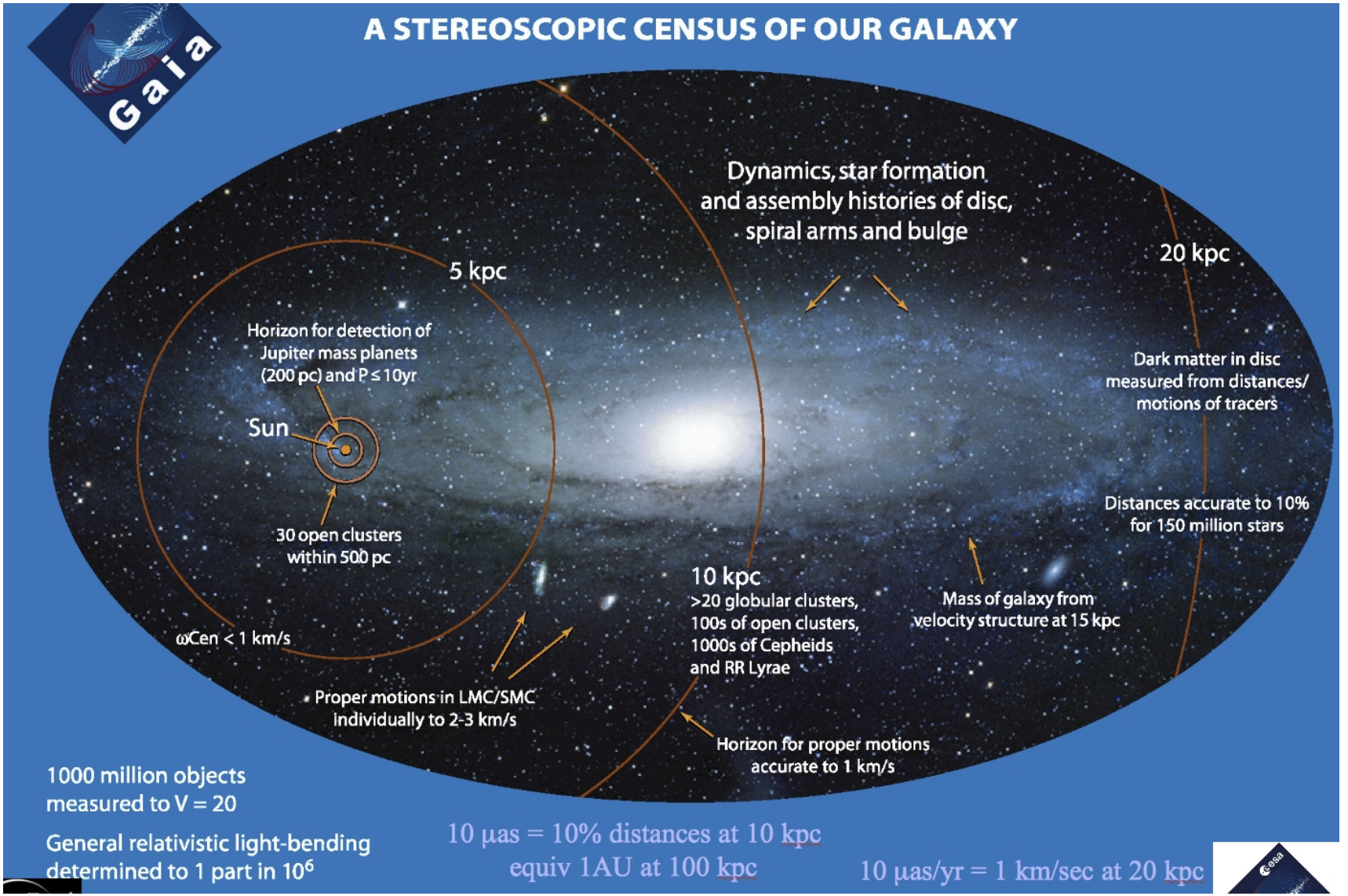




Star motion in 10 s



The Challenge of Gaia
transformational science



… not so far away now …

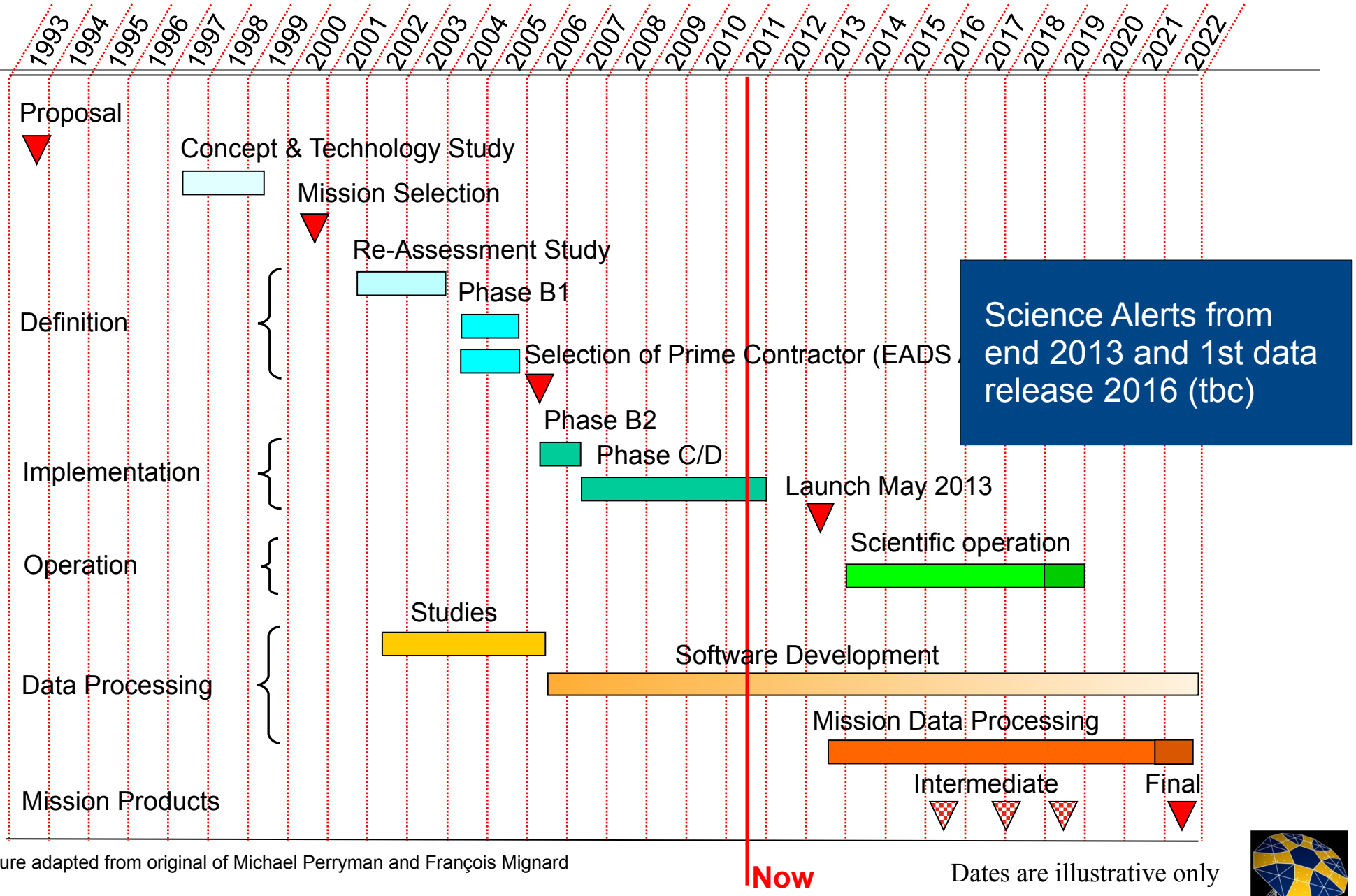


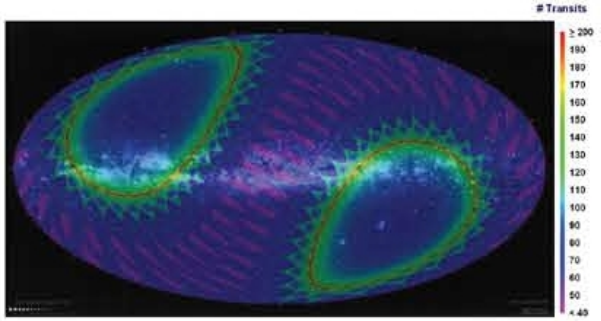
Figure adapted from original of Michael Perryman and François Mignard

Dates are illustrative only

Gaia Image Gallery

http://www.rssd.esa.int/index.php?project=GAIA&page=Image_gallery

© ESA-CNES/Illus D. Ducros - Mars 2010

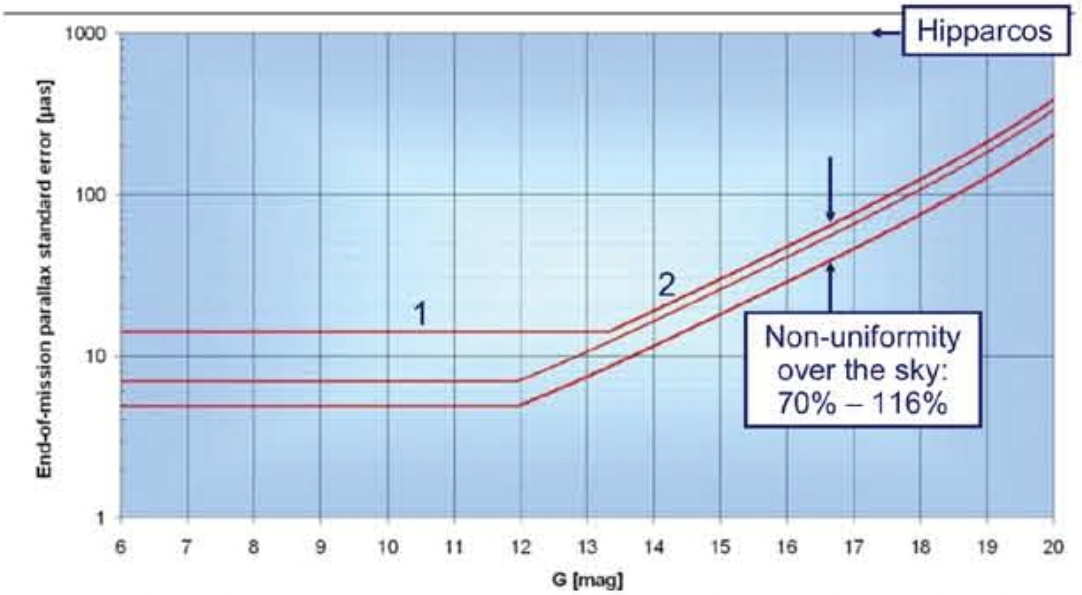


This shows the expected coverage for a 5 year mission. Each location of the sky will be observed in multiple blocks of four observations - these spaced a t_0, t_0 + 106 mins, t_0 + 6hrs, t_0 + 6hrs + 106 mins, with these then being repeated 10 to 30 days later. This temporal coverage of the sky leads to opportunities to discover an characterise various transient objects. Credit: A Brown / ESA.

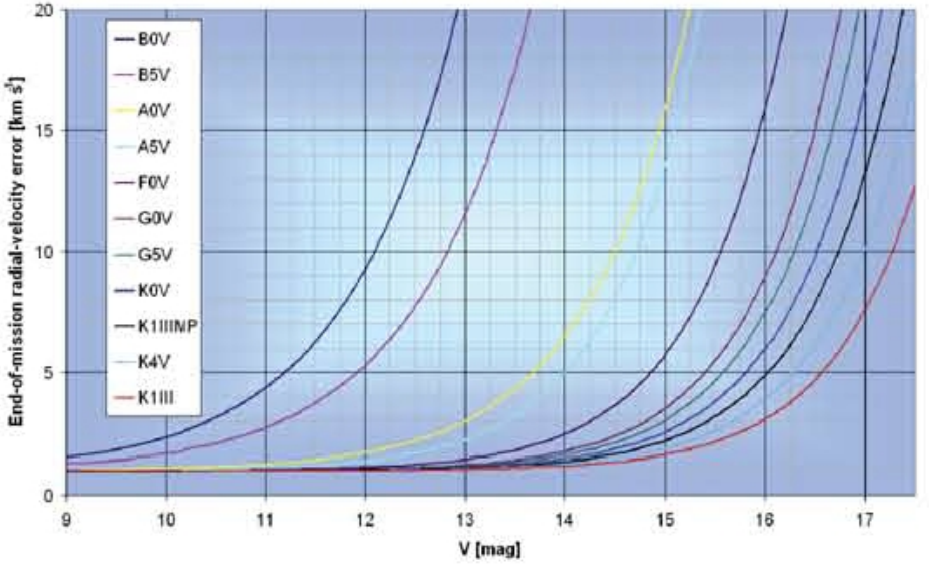
Summary of Gaia Science Products

- 10^9 stars
- 10^6 at V=12, $30x10^6$ at V=15, $250x10^6$ at V=18
- Sigma ~10μas V<12, 22μas V=15, 220μas V=20
- 25,000 stars/ deg^2 with max ~10^6 stars/ deg^2
- $150x10^6$ radial velocities
- Accurate stellar classification for all classes and types
- Recalibration of the distance scale
- Variability analysis for over 10^8 stars
- 10,000 stellar masses with $\sigma < 1\%$
- Extrasolar planets to 200pc
- $3x10^5$ minor bodies of the solar system
- ~$5x1^{05}$ QSOs + z + photometry, ICRF in the visible
- PPN gamma to ~ $2x10^{-6}$

End-of-life parallax errors



1. 6 < G < 12: bright-star regime (calibration errors, CCD saturation)
2. 12 < G < 20: photon-noise regime, with sky-background noise and electronic noise setting in around G ~ 20 mag



GREAT ESF RNP
Scientific Community Building

- Development led by team from GST and DPACE
  - Included science contributions from the respondees to the Sep 2008 expressions of interest call
- Funds conferences, workshops, exchanges, schools
- Key science remit inclusive across Gaia science
  - Origin, structure, evolution of the Milky Way
  - Stellar Astrophysics
  - Galactic Dynamics
  - Galactic Archaelogy
  - Star formation and evolution
  - Fundamental physics
  - Extrasolar planets and non single stars
  - Solar system
  - The IT data challenge

GREAT ESF Research Network Programme

- Provides funds for the GREAT research network:
  - Feb 2010 – Jan 2015 with a budget of ~€750K
- The Programme provides financial support for the following activities:
  - Science meetings (workshops, conferences or schools) organised either by the Programme Steering Committee or following an open call for proposals
  - Grants for short and exchange visits awarded following an open call for applications
  - Publication of information brochures and leaflets, scientific books and meeting proceedings etc

ESF RNP

- ESF networking programmes are 'Open'
  - Encouraged to involve the wider community
  - Ideal for the concept of including those that are not co-applicants in other network activities
- Period of call is science over 2010 – 2015
  - Thus, can factor in access to 'early' Gaia data releases
  - Access to Gaia science alert streams
  - Can also consider science programmes requiring preparatory work (theory, simulations, observational)
- Calls are published at http://www.great-esf.eu
  - Short visits can be proposed at any time, whilst for workshops/ conferences/ exchanges: two calls/year

GREAT-ESF Meetings 2011

range of topics to be covered

GREAT-ESF Workshop *Orbiting couples: "pas de deux" in the Solar System and the Milky Way*, 10 - 12 October 2011, Paris Observatory, Paris, France

GREAT-ESF Workshop *The Interstellar Medium in Three Dimensions with Gaia*, 11 - 14 July 2011, The Lorentz Centre, Leiden University, Leiden, The Netherlands (workshop website)

GREAT-ESF Workshop *Stellar Atmospheres in the Gaia Era: Quantitative Spectroscopy and Comparative Spectrum Modelling*, 23 - 24 June 2011, Free University Brussels (Vrije Universiteit Brussel - VUB), Campus Etterbeek, Brussels, Belgium (workshop website)

GREAT PLENARY *4th Great Plenary Meeting*, 21 - 23 Jun 2011, Brussels, Belgium (Plenary website)

GREAT-ESF Workshop *QSO Astrophysics, Fundamental physics, and Astrometric Cosmology in the Gaia era*, 6 - 9 June 2011, Faculty of Sciences, University of Porto, Porto, Portugal (workshop website)

GREAT-ESF Summer School and Workshop *Astrostatistics and Data Mining in Astronomical Databases*, 30 May - 3 June 2011, La Palma, (school website)

GREAT-ESF Workshop *Asteroid dynamic and physical studies during and after the Gaia mission*, 4 - 6 May 2011, Pisa, Italy (workshop website)

GREAT-ESF CONFERENCE *The Fundamental Cosmic Distance Scale: State of the Art and the Gaia Perspective*, 3 – 6 May 2011, Osservatorio Astronomico di Capodimonte, Naples, Italy (conference website)

GREAT-ESF CONFERENCE *Assembling the puzzle of the Milky Way*, 17 – 22 April 2011, Le Grand-Bornand, France (conference website)

GREAT-ESF Workshop *Gaia and the End States of Stellar Evolution*, 11 - 14 April 2011, The University of Leicester, UK (workshop website)

http://great.ast.cam.ac.uk/Greatwiki/GaiaScienceMeetings
See this link also for the final reports from each meeting

GREAT Initial Training Network

http://www.great-itn.eu

- FP7 Initial Training Network Proposal
  - 13 main nodes: IoA Cambridge, Leiden, Lund, Barcelona, Heidelberg, MPIA (Heidelberg), Leuven, Geneva, PKU (Beijing), CAUP (Porto), CNRS (Bordeau/Bescancon), INAF (Bologna, Padua), AMU (Poznan)
  - 19 Associate nodes (of which 4 are industrial partners)
  - €4.3M : Funds 17 Early Stage Researchers
  - **4 year duration**: 1 March 2011 – 28 February 2015
  - Much of the research relevant to GCDS and this meeting
- GREAT ITN complementary to GREAT ESF RNP
  - Opportunity for joint networking activities
- Kick-off meeting: 13-14 Apr 2011 in Cambridge

The GREAT ITN: Project Goals

- Science Theme: Unravelling the Milky Way – from the Galaxy to Asteroids
  - WP3: the origin and history of the milky way
  - WP4: the stellar constituents of the milky way
  - WP5: planetary systems, worlds near and far
  - WP6: grand challenges
- Increase the European potential in scientifically exploiting Gaia
- Develop multi-wavelength, multi-domain techniques incorporating information from Gaia
- Transfer best practice in the use of new IT techniques

GREAT and Gaia Data Access

- Community input into the data access design process
  - Via Great wiki: http://great.ast.cam.ac.uk/Greatwiki/GaiaDataAccess
- Opportunity to provide individual and GREAT WG input
  - Examples of science usage as to how the Gaia data might be used and how it will be accessed
- Input received will be used in the scoping and development of the Gaia data access and archive systems

  A chance for EGAPS / VVV / GPS etc requirements

GREAT Working Groups

http://great.ast.cam.ac.uk/Greatwiki/CategoryWorkgroups

Workgroup	co-facilitator	co-facilitator
WGA1GaiaModel	Céline Reylé	Daisuke Kawata
WGA2SurveyCensus	GeorgeSeabroke	ArnaudSiebert
WGA3ChemicalTagging	Sofia Feltzing	Nicholas Walton
WGA4LocalGroup	Vasily Belokurov	Michele Bellazzini
WGA5GaiaAlerts	Simon Hodgkin	Gerry Gilmore
WGA6GaiaExtragal	Mary Kontizas	tbd
WGA7NewStats	Will O'Mullane	NicholasWalton
WGA8DistanceScales	Gisella Clementini	Xavier Luri & Enzo Brocato
WGA9ISM	Rosine Lallement	U. Munari & T. Zwitter
WGB1OpenClusterYoungAssociation	AlessandroLanzafame	AntonellaVallenari
WGB2StellarVariability	Joris De Ridder	Laurent Eyer
WGB3BinariesAndMultipleSystems	Dimitri Pourbaix	Frederic Arenou
WGB4StellarAtmospheres	UlrikeHeiter	Alex Lobel
WGB5MassiveStars	Ronny Blomme	Janet Drew
WGB6EndStatesOfStellarEvolution	DuncanFyfe	Stefan Jordan
WGC1ExoPlanets	Alessandro Sozzetti	Don Pollacco
WGC2AstrometryReferenceFrame	Mariateresa Crosta	Géraldine Bourda
WGC3Quasars	Sonia Anton	Alexandre Andrei
WGC4SolarSystem	Paolo Tanga	Alberto Cellino

GREAT Chemo-Dynamical Survey
an example GREAT WG initiative

- GREAT Chemo-Dynamical Survey – concept
  - Outputs including theory and observational campaigns
  - GCDS Kick-off meeting held in Paris (Apr 2010)
    - http://great.ast.cam.ac.uk/Greatwiki/GreatCds/GcdsParisApr2010
- 8-m VLT/ FLAMES proposals: Gilmore & Randich
  - Gaia-ESO survey – see http://www.gaia-eso.eu
  - 300 nights over 5 years from Jan 2012
- 8-m & 4-m initiatives – instrumentation proposals
  - 4MOST – WF spectrograph on VISTA (de Jong)
  - WEAVE – WF spectrograph on WHT (Dalton)
  - MOONS – near IR MOS on the VLT (Cirasuolo)

GREAT Chemo Dynamical Survey
Background & Rationale

- March 2009 GREAT meeting
  - http://www.ast.cam.ac.uk/GREAT/events/cam-mar09/cam-mar09.html
- Chemical Tagging Working Group
  - http://great.ast.cam.ac.uk/Greatwiki/WGA3ChemicalTagging
- Discussion identified need for High Resolution Spectroscopy
  - In context of Gaia: amount and type of data required
  - Key science drivers
  - Routes to obtain data
  - Need for associated theory

GCDS: Galactic Science Drivers

the fossil record of galaxy assembly: 1st stars to now

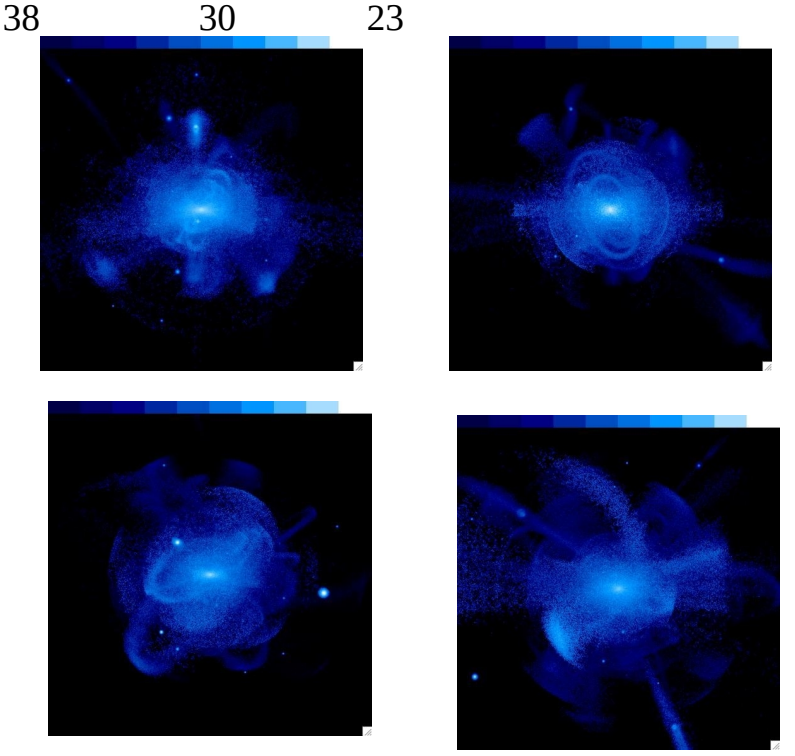
- relative importance of mergers and accretion in building the disk(s) and bulge
- chemo-dynamic structure of Galactic components
  - interface between disk, bulge/bar, halo
  - importance of radial mixing in the disk(s)
  - ancient dissolved and surviving substructures, streams
- fossil record of chemical evolution of stellar pops
  - chemical signature of ancient accretions
  - properties of metal-poor popIII stars
- evolutionary history of stellar components
  - IMF, SFH, tagging the chemical development
  - the role of star clusters
- detailed chemo-dynamics of surviving satellites

Milky Way Halo

- Studies of the inner and outer halos
  - How different are they (Corollo et al 2010 c.f Schronrich, Asplund, Casagrande 2010)?
  - Matching with models

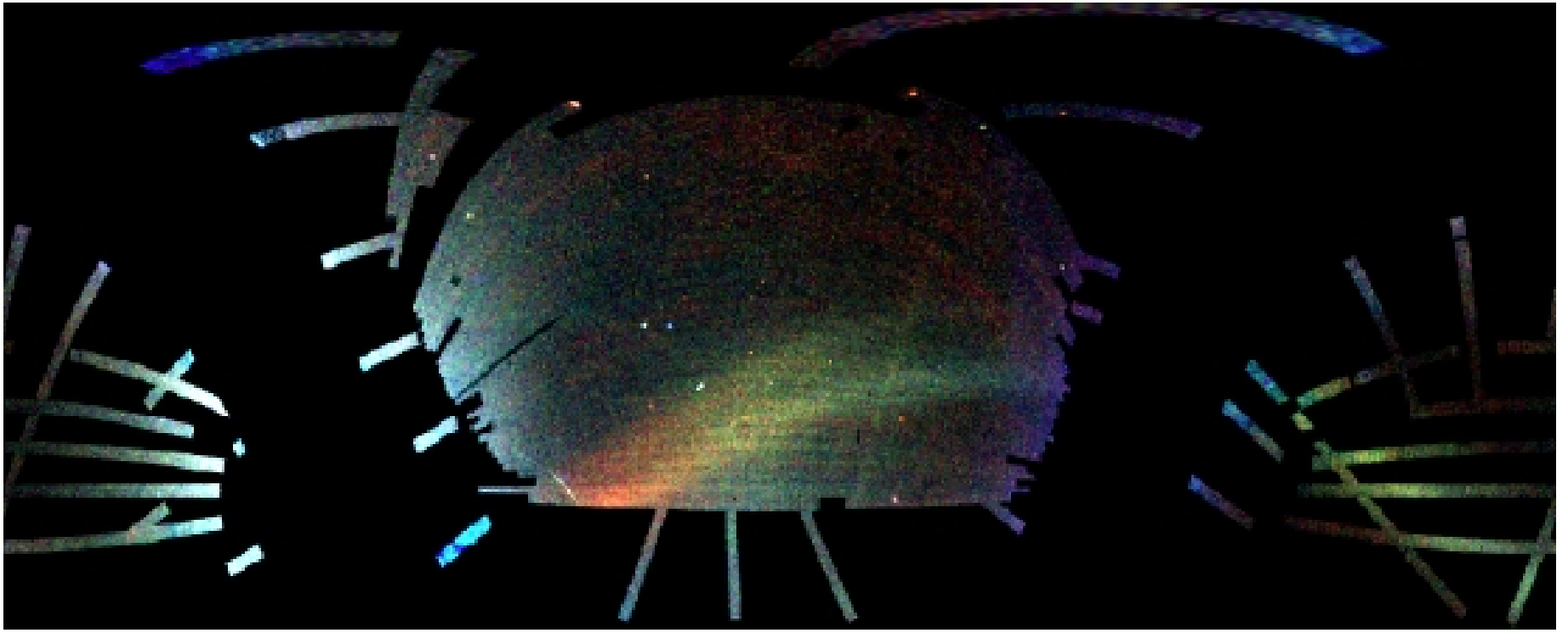
Lambda CDM models predict large-scale substructure in L_* galaxies like M31 and MW

Bullock & Johnston 2005



300 x 300 kpc

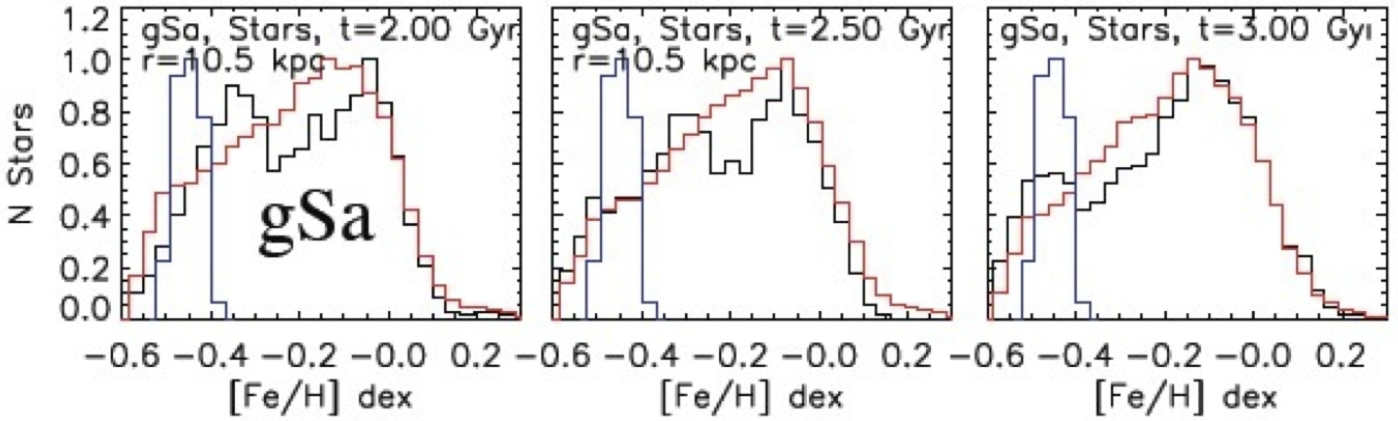
Galaxy substructure and satellite accretion



Belokurov et al (2006 etc) – this figure is the SDSS DR7 release. This shows turnoff stars (selected by colour) – where blue is closer, red further

The Galactic Disk

- Evidence for Mixing
  - Radial migration due to transient spiral arms, impact of bars
  - Metallicity variations, distributions
- Metallicity distribution function of young and old stars with R_{gal} → test of radial migration (c.f. Schönrich & Binney, 2009)

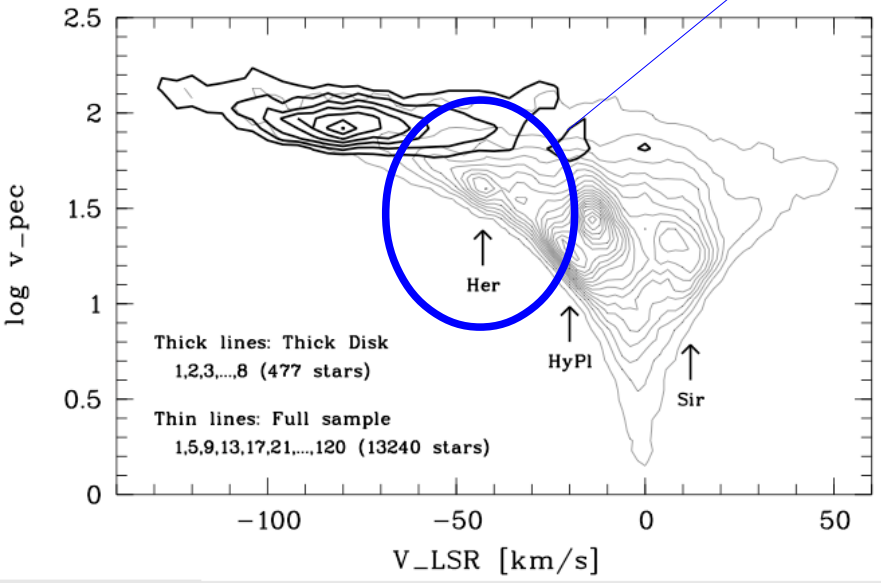


Bar + Spiral (Minchev et al 2010)

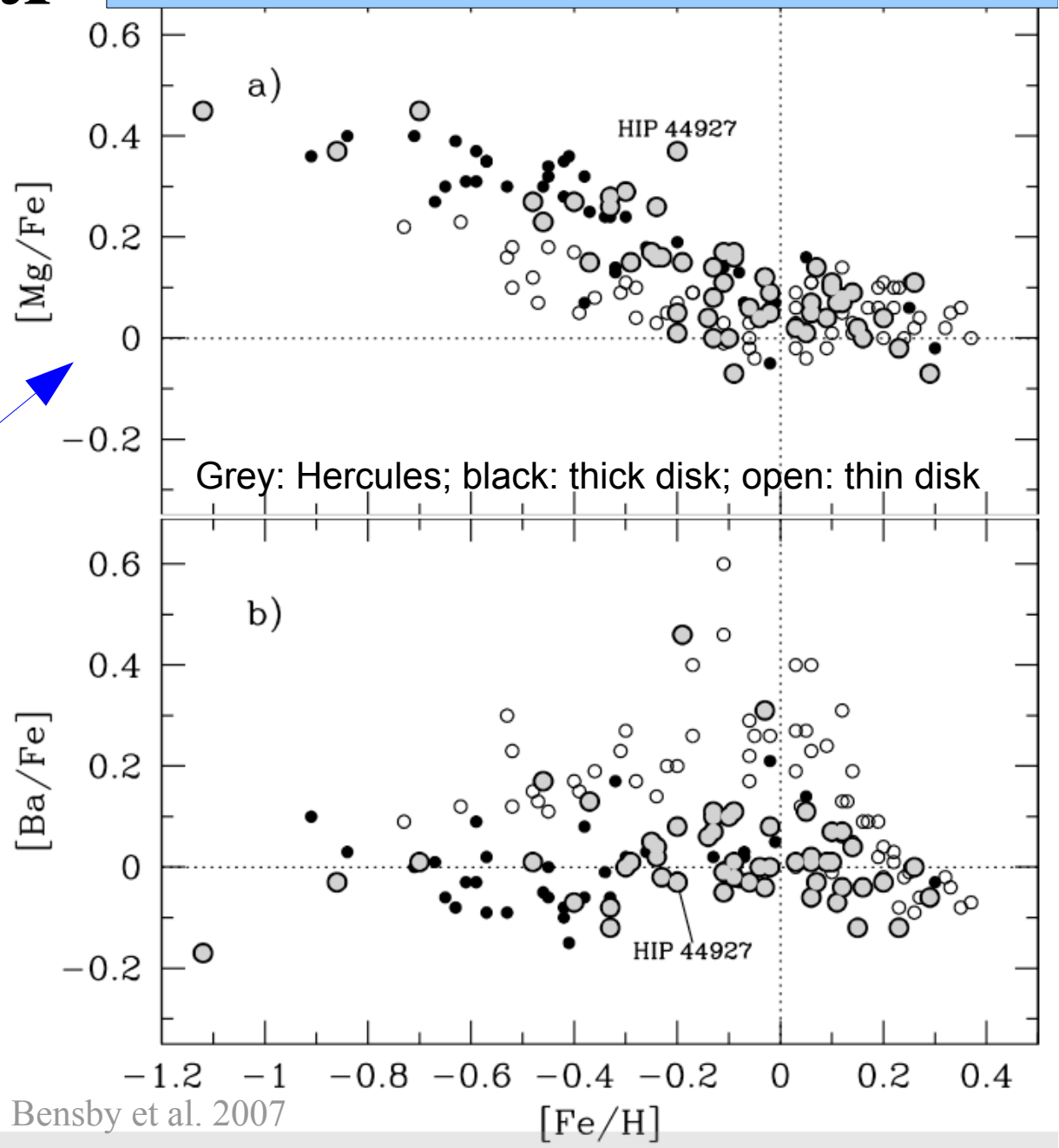
initial, cold orbit, hot orbit

Chemo-Dynamical Encoding

Hercules star chemistry similar to field stars thus a dynamical group, not a group with a common chemical birth site

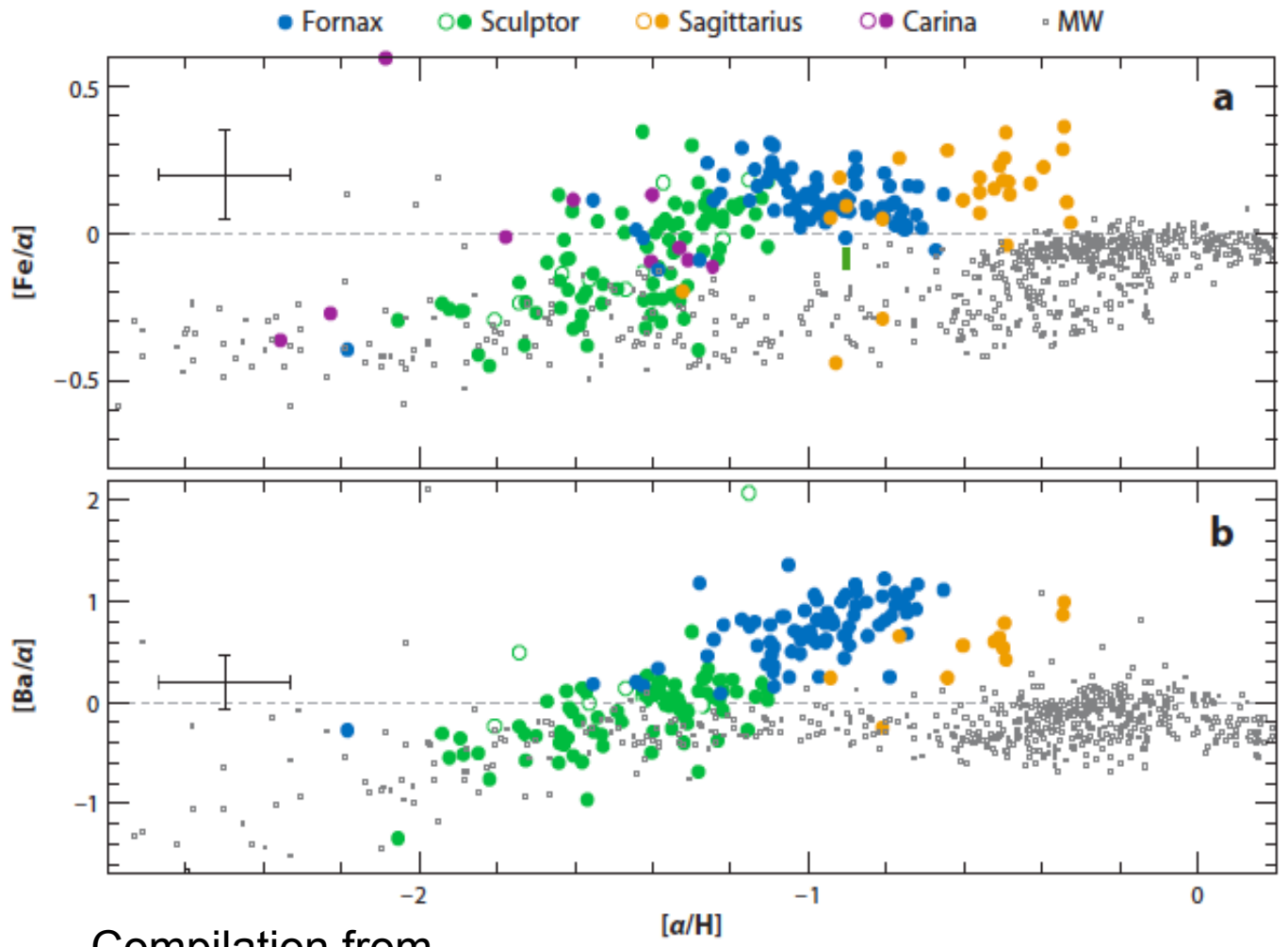


Famaey et al. 2005



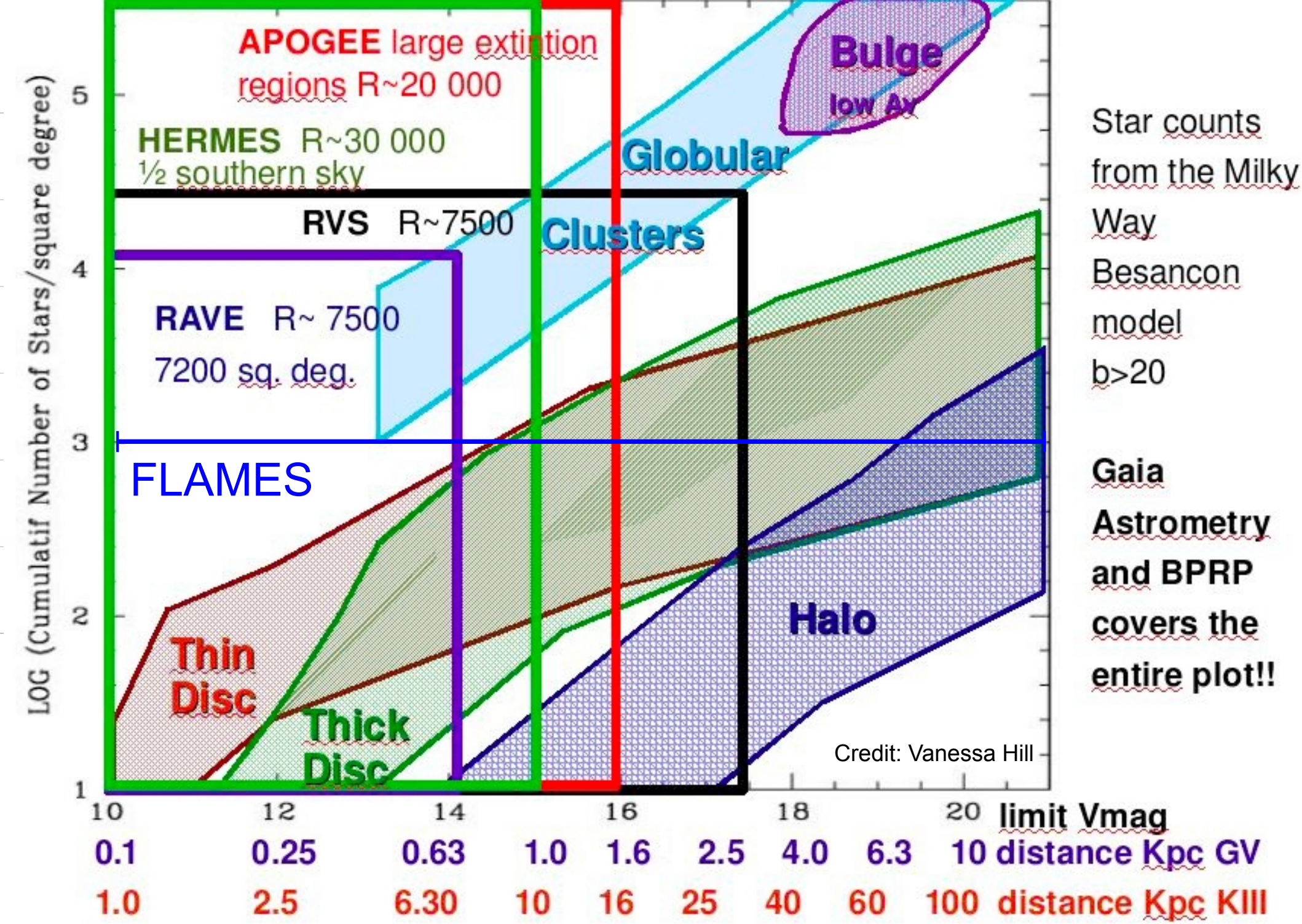
Bensby et al. 2007

Building (parts of) the Halo



Compilation from Tolstoy et al 2009

- Fossil record from chemistry
- 0.2 dex required
- R=20,000 and S/N ~50 required


APOGEE large extintion regions R~20 000
HERMES R~30 000
½ southern sky
RVS R~7500
RAVE R~ 7500
7200 sq. deg.
FLAMES
Bulge
low Av
Globular
Clusters
Halo
Thin Disc
Thick Disc
LOG (Cumulatif Number of Stars/square degree)
1
2
3
4
5
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
Star counts from the Milky Way Besancon model b>20
Gaia Astrometry and BPRP covers the entire plot!!
Credit: Vanessa Hill

The Initial GCDS Survey Concept

see http://great.ast.cam.ac.uk/Greatwiki/GreatCds

- Low Resolution Component
  - R=5000 – Chemo-Kinematics – 5 x 10^6 stars
    - Map the thick/thin Disk / Halo / Bulge components
    - Radial velocities to ~2 kms^{-1} and [Fe/H] to 0.2 dex
- High Resolution: (< 1kms^{-1} and ~0.05 dex in [Fe/H])
  - good wavelength coverage eg. 4800-6800A; 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)
    - Field Disk & Open clusters

AMBITIOUS SCALE

GREAT Chemo-Dynamical Survey

GCDS Kick-off meeting (27 Apr 2010)

http://great.ast.cam.ac.uk/Greatwiki/GreatCds/GcdsParisApr2010

- The Science Experiments
  - SE1: Mass Distribution of the Galaxy
  - SE2: Galaxies formation and evolution traced by chemistry
  - SE3: Clusters and star formation and evolution
  - SE4: Additional and Legacy Science
- Development of these proceeding – see
  - http://camd08.ast.cam.ac.uk/Greatwiki/GreatCds/GcdsSe1
  - http://camd08.ast.cam.ac.uk/Greatwiki/GreatCds/GcdsSe2
  - http://camd08.ast.cam.ac.uk/Greatwiki/GreatCds/GcdsSe3
  - http://camd08.ast.cam.ac.uk/Greatwiki/GreatCds/GcdsSe4

THE INCLUSIVE ELEMENT of GCDS

GCDS: status updates – to Dec 2010

- May 2010: WHT spectro upgrade development
- July 2010: ESO issued call for large (300 night) spectroscopic surveys (LoI deadline 15 Oct 2010)
- July 2010: ESO issued call for spectroscopic instrument upgrades
- The GREAT community involved in these
  - Response to the ESO VLT survey call (Gilmore & Randich)
  - 4-m MOS spectrographs for WHT (WEAVE: Dalton) and VISTA (4mMOSST: De Jong) (with associated surveys)
  - 8-m VLT (FLAMES-IR: includes Bonifacio)
- Nice GCDS Science Workshop (Nov 2010)
  - http://cassiopee.oca.eu/spip.php?article324/

GCDS-MW: Key Drivers

The Gaia-ESO survey: Galactic Astrophysics via VISTA Imaging, Gaia Astrometry, and Eso SpectrOscopy

- Combines key cases from:
  - SE1: Mass Distribution of the Galaxy
  - SE2: Galaxies formation and evolution traced by chemistry
- Key aims: kinematic studies of the halo, chemistry of the disk
  - Quantify thick disk and halo abundance and kinematic gradients
  - Distribution functions due to the inner bar and spiral arms
- Determine the relative importance of assembly and accretion
- Bulge-disk interface: (secular) origin of the thick disk
- Halo-disk interface: (merger) origin of the halo & thick disk
- Direct constraints on the disk and halo potential
- LoI submitted to ESO (Oct 2010) – PI: Gilmore

GCDS-OC: Key Drivers

Open Star Clusters: the path from molecular clouds to the MW disc population

- Key science from
  - SE3: Clusters and star formation and evolution
- Key aims: kinematic and chemical studies of a large sample of Open Clusters and cluster members – to:
  - understand how clusters form; evolve, dissolve, and populate the Milky Way
  - calibrate complex physics that affect stellar evolution;
  - measure the Galactic metallicity gradient at different ages with unprecedented accuracy, thereby setting constraints on models of disc formation
- LoI submitted to ESO (Sep 10): PI Randich

Gaia-ESO Survey

http://great.ast.cam.ac.uk/GESwiki

- ESO public survey
  - Public data products
- Co lead: Gilmore/ Randich
- 250 co-Is: pan-european
- 300 nights over 5 years
  - Starts Jan 2012
  - Overlaps: Gaia 1st releases
- 10^5 Giraffe (R~20K) spectra
- 10^4 UVES (R~47K) spectra

Co-PIs: Gerry Gilmore[1370], Sofia Randich[1335]
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Gaia-ESO Survey Components

- Bulge Survey: K giants/ Red Clump (I=15)
  - Fe-peak (Fe, Cr, Mn, Co, Ni) α (Mg, Si, Ca, Ti) p-capture (sc, V)
- Halo/ thick disk survey: r=17-18 F stars (thick disk/ halo) and K giants for outer disk/ halo streams
  - Probe gravitational potential of the galaxy
- Thin disk dynamics: rad vels to I-19: spiral arm/ bar dynamics
- Solar Neighbourhood: UVES obs of FG stars < 2kpc
- Open Clusters: young (velocity fields to <0.5 kms^{-1} for evolution history) to old (cluster destruction theories from kinematics, mass functions)

Survey design and strategy.
1. Field stars

Slide: Sofia Randich

Bulge survey targets – technically easy to do.

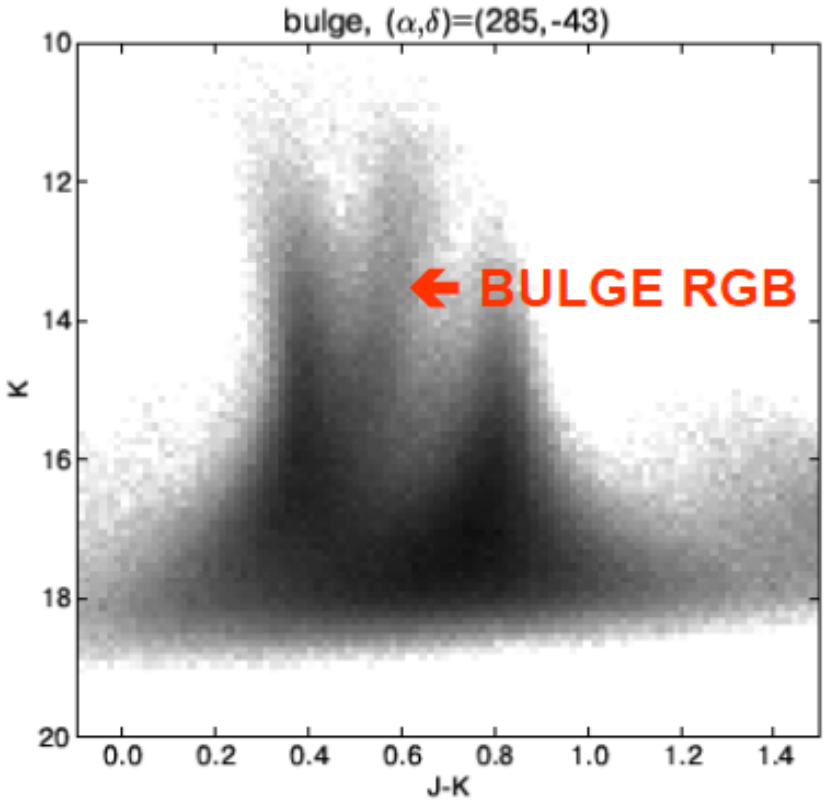
CHALLENGE: how to handle/model/select for the extreme biases due to red clump evolution?

Field target strategy:

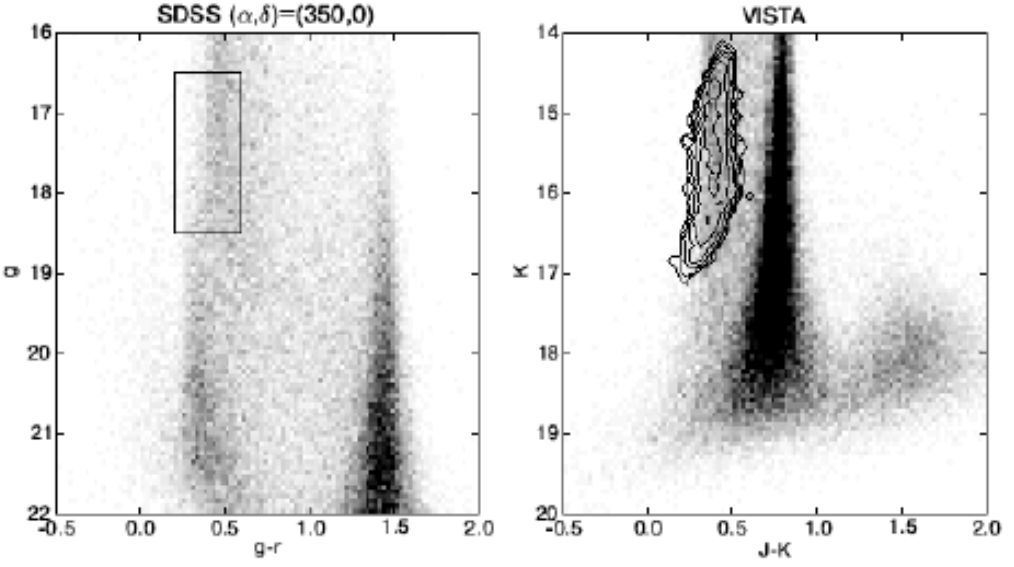
Fix a box in the CMD with thick disk & halo turnoff

Figures show sdss vs VHS

Select thick disk/halo locus (left), Implement in VHS (right)



VHS bulge data, b=40deg



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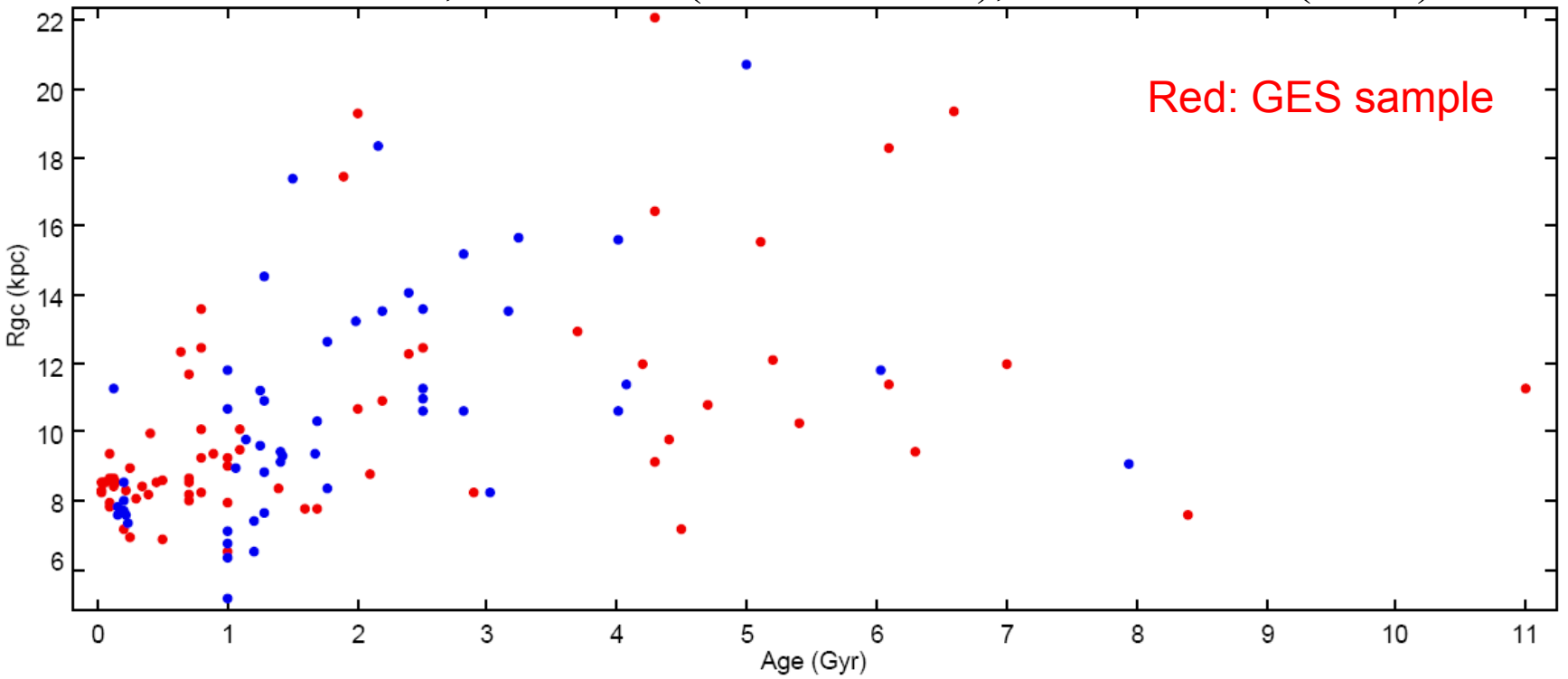
Survey design – open clusters

- Precise abundances and kinematics for a large samples of OCs – nearby (increased impact with Gaia) and far (for abundance gradients)
- 100 OCs in all phases of evolution (~1Myr to ~10 Gyr)
  from WEBDA database, Dias et al (2010 version), Kharchenko (2005)



Survey design and strategy.
Set-ups

Slide: Sofia Randich

- Limiting mag. (R): 16.5 (UVES), 19 (Giraffe)
- UVES: CD3 -520/580 (416-617/475-678 nm) for hot/cool stars; S/N > 60-70 → precise abundances
- Giraffe: *Cluster/field stars:* HR03/05A /06/14A (403-476, 631-670 nm) for hot stars; HR10/15N/21 (534-562; 647-679; 848.4-900) for cool stars: Teff/gravity indicators, Hα, Li, Fe I and II lines, Ca IR triplet, a few other el. lines;

  S/N>10-30; → RVs, stellar parameters/characteristics, [Fe/H], a few [X/Fe] (Ca, Ti, Mg at least)

Gaia-ESO survey accuracies

- Radial velocities: 0.1 – 1 kms^{-1} for cool stars, 5 kms^{-1} for hot stars
- Rotation: 10%
- T_{eff}: 50-200 K
- Log g: 0.15 – 0.3 dex
- [Fe/H], [X/Fe]: ~0.1 (UVES), ~0.2 (Giraffe)
- Average [Fe/H], [X/Fe] for the clusters to ~0.03 dex

Role of VPHAS/ IPHAS in Gaia-ESO

- Provision of supporting optical data: bulge and plane
  - Especially relevant for the open cluster, thin disk and bulge science themes
  - Possibility to accelerate VPHAS observations of OCs fields
- Added value science – combinations of imaging/ spectral data
- Involvement of people
  - e.g. Drew on Gaia-ESO Steering Group
  - Involvement of many others – plenty of work to do

http://www.gaia-eso.eu

http://great.ast.cam.ac.uk/GESwiki/GESHome

Plus email to Gerry Gilmore/ Sofia Randich for access

Conclusions

- Gaia set to revolutionise our understanding of the nearby Universe
  - ***ground based spectroscopy adds significant value***
- The European galactic astronomy community well organised through the GREAT network
- Ambitious survey programmes underway
  - Gaia-ESO survey
- New build instrumentation understudy
  - MOONS, 4MOST, WEAVE

More on the above in presentations at the GREAT Plenary – June 2011:
http://great.ast.cam.ac.uk/Greatwiki/GreatMeet-20110621