Spectral libraries in the Gaia context

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gaia

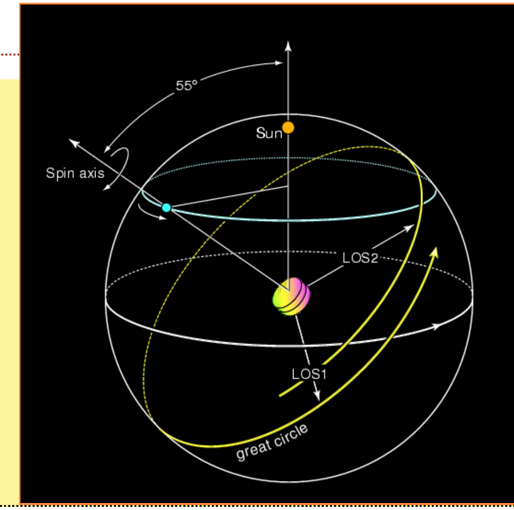
Summary

- Brief introduction on Gaia
- Gaia and galaxies:
  - How many?
  - What parameters?
  - A synthetic library of galaxy SEDs
- Gaia and stars:
  - Database of synthetic stellar libraries
  - Comparison
- SSP with the Gaia libraries
- Back to basis: calibration on real data

In collaboration with:

- Vallenari, A.; Tantalo, R.
- Gaia providers: Korn, A.; Allard, F.; Blomme, R.; Bouret, J.-C.; Brott, I.; de Laverny, P. ; Fremat, Y.; Martayan, C.; Damerdji, Y.; Edvardsson, B.; Josselin, E.; Plez, B.; Kochukhov, O.; .Munari, U.; .Zorec, Jean; Schweitzer, A.
- Athens group: Kontizas M., Kontizas E., Bellas-Velidis I., Dapergolas A.; Korakitis R.; Livanou E.; Karampelas A.; Belcheva M.; Nikolov G

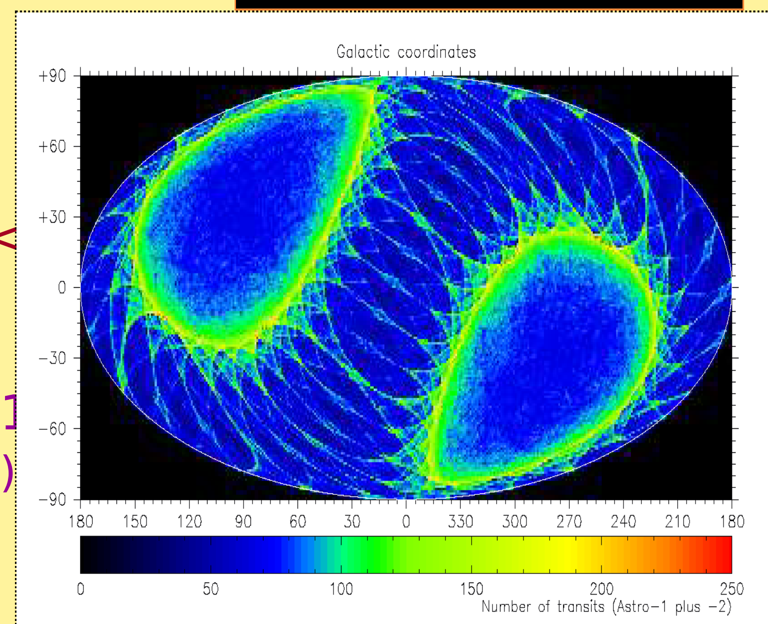
: the Galaxy and Local Cosmology



All sky survey, complete down to G=20.

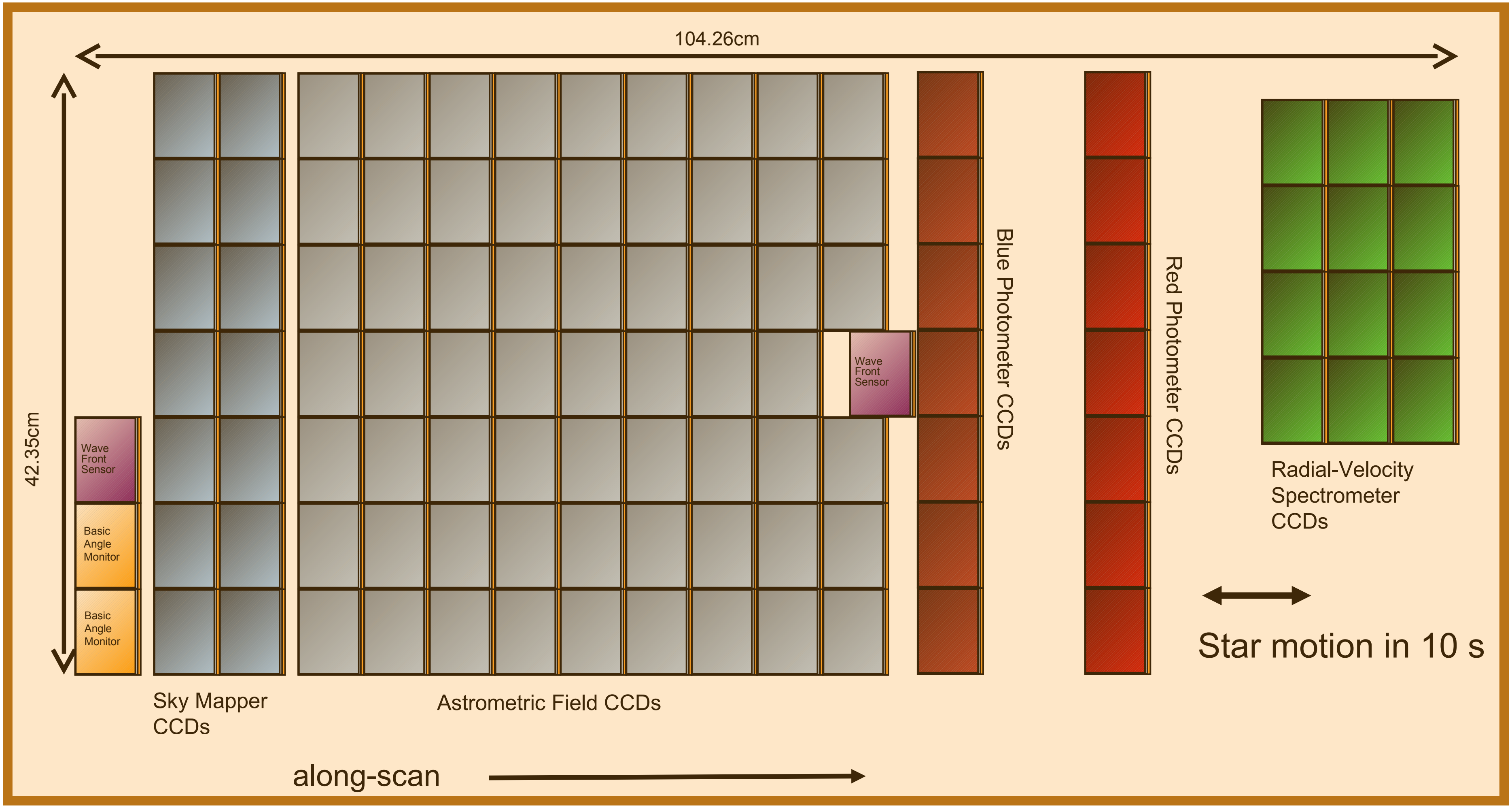
For 1 billion objects:

- µarcsec astrometry (parallax, proper motions)
  - Precision from 10 to 100µarcsec
- millimag precision photometry
  - In G band 0.001-0.004 mag
  - In color 0.003-0.05 mag
- low-resolution spectroscopy (BP/RP, G<
  - 300-1100 nm at Rp =3-30 nm/pix
  - For chromaticity correction, but…
- high resolution spectroscopy (RVS, G<1
  - Call triplet region survey at Rp~11,500)
  - For Radial Velocity (1-10 km/s), but…



Focal Plane

Figure courtesy Alex Short



Total field:

- active area: 0.75 deg^2
- CCDs: 14 + 62 + 14 + 12
- each CCD: 4500x1966 px (TDI)
- pixel size = 10 μm x 30 μm = 59 mas x 177 mas

Sky mapper:

- detects all objects to 20 mag
- rejects cosmic-ray events
- FoV discrimination

Astrometry:

- total detection noise: 6 e$^-$

Photometry:

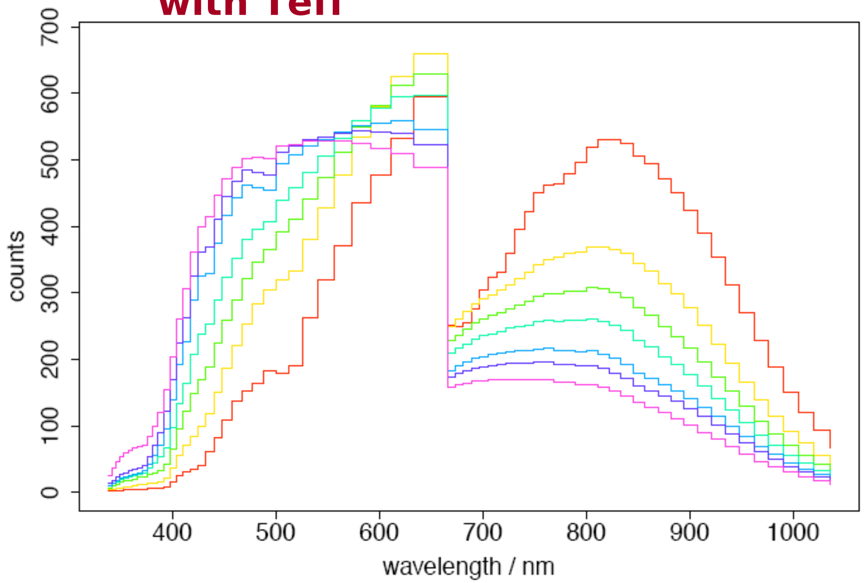
- spectro-photometer
- blue and red CCDs (BP/RP)

Spectroscopy:

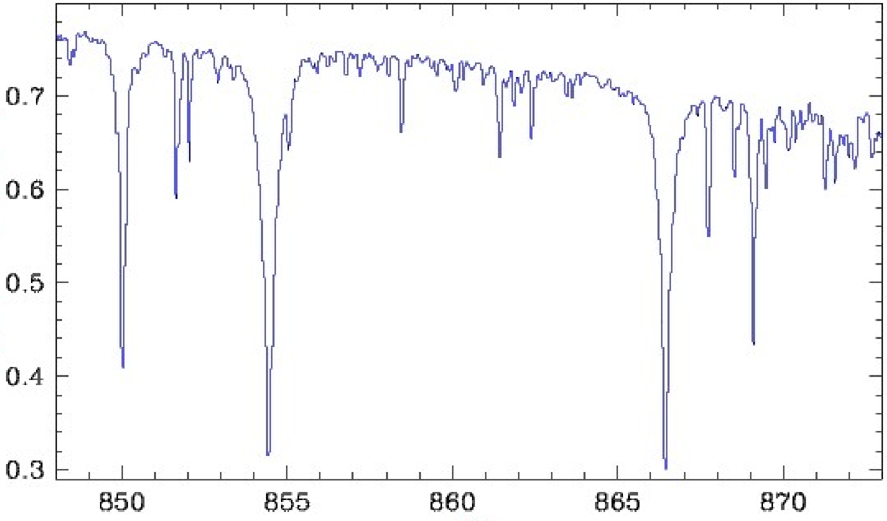
- high-resolution spectra (RVS)
- red CCDs

Gaia spectra

BP/RP spectral sequence with Teff

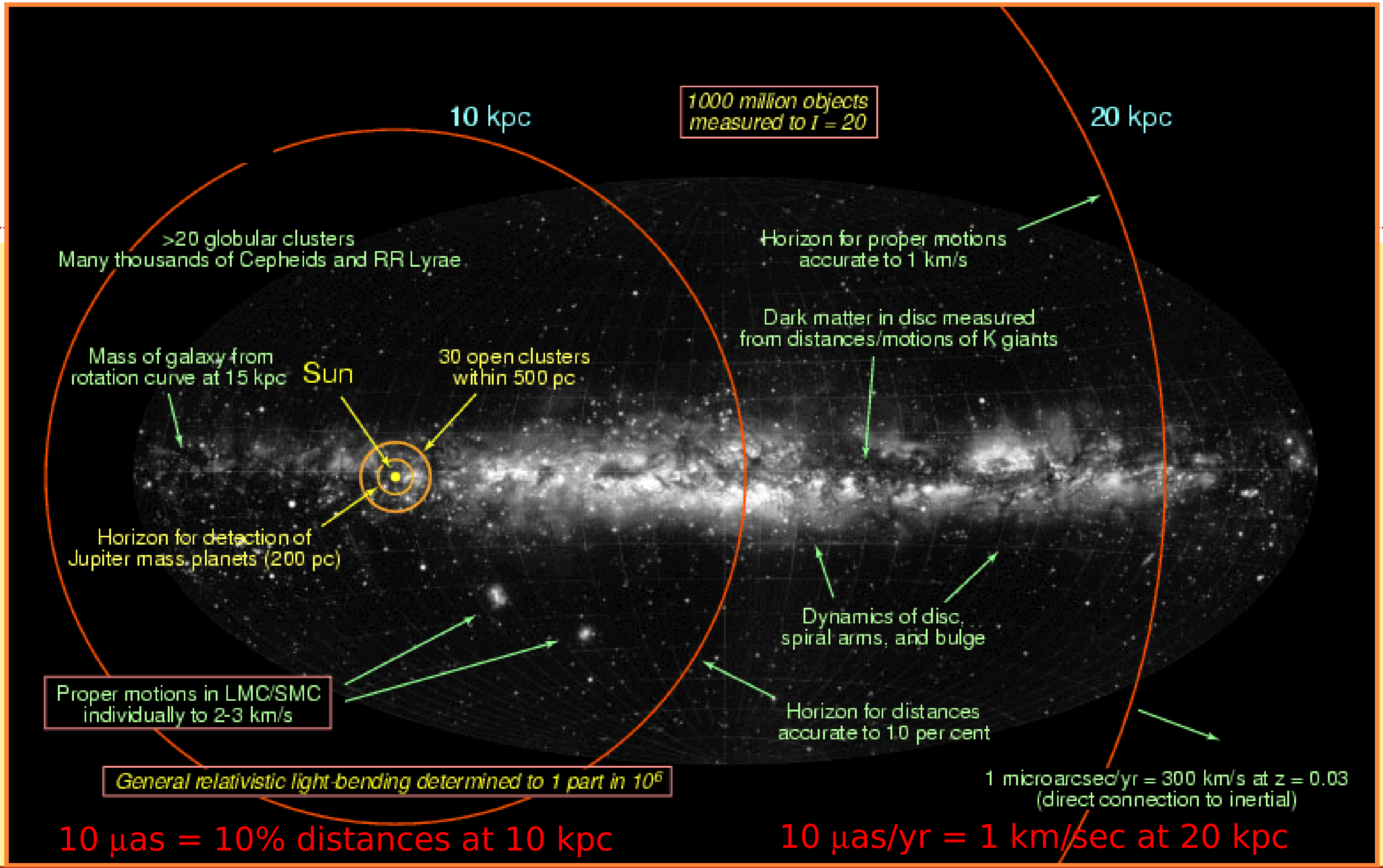


RVS spectrum of a cool dwarf



- Automated classification of sources is needed, first to classify them into broad categories (stars, galaxies…) and then to physically charachterize them
- Different algorithms for different object types

GAIA and our Galaxy



Extragalactic sources

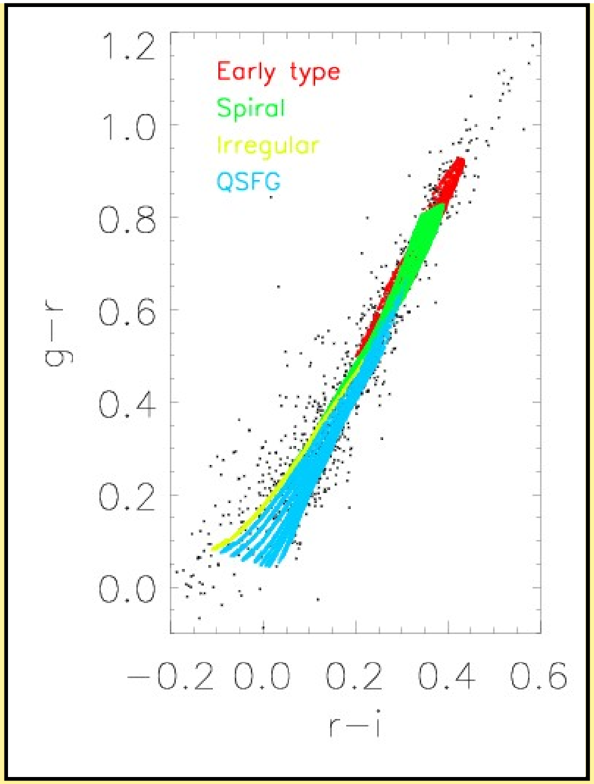
- Gaia will provide an all-sky survey of galaxies (10^6-10^7 are expected) :
  - A large homogeneous sample of spectra, up to z=0.4 (few having z>0.2)
  - Multiple observations
  - very large samples, but not resolve internal kinematics in most dSph
    - 20 muas/yr = 100 km/s a1 Mpc, i.e. a handful of very luminous stars in M31
    - 20 muas/yr = 5 km/s at 50 kpc (good kinematics for MCs)

In addition,

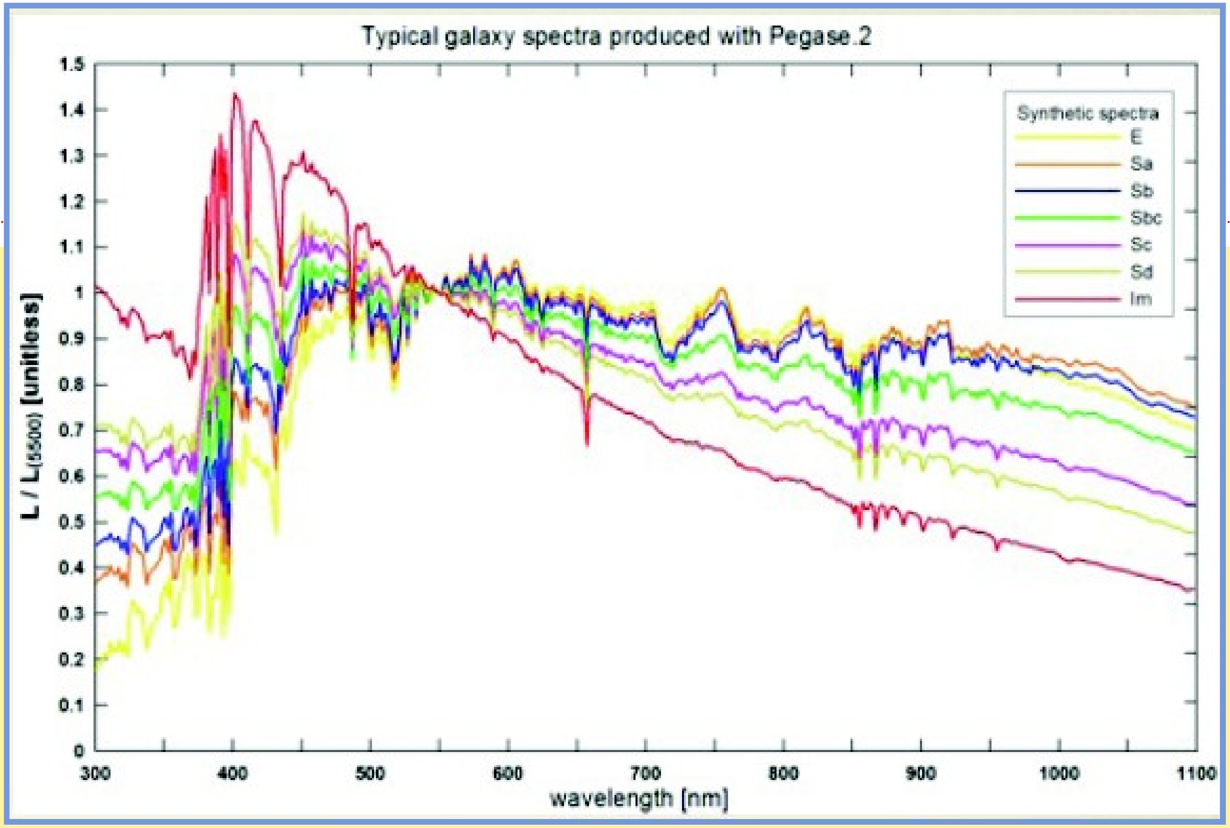
- ~100,000 supernovae
- ~500,000 quasars: kinematic and photometric detection (Reference Frame, to ~0.4 μas/yr)

The library of synthetic galaxy spectra

- The Gaia Universe Model simulator implements Tsalmantza et al (2009) library of synthetic galaxies:
  - 144,425 spectra produced using PEGASE.2 code- BASEL 2.2 stellar spectral library (Fioc & Rocca-Volmerange 1997, 1999;
  - 17 free parameters (4 for SFR) + inclination
  - 4 main spectral types (Early, Spiral, Irregular, QSFG)
  - Realistic colors, in comparison to SDSS
- The library is used by Athens group to automatically derive parameters from galaxy SEDs
- PEGASE-HR implementation for Gaia under developement (Le Borgne & Rocca-Volmerange 2009, using ELODIE)
  - but also implementing Munari, Sordo et al. (2005)



Work in progress: optimization of the parameter space to avoid degeneracies in the output SED



Inclination values:
0-22.5-45-67.5-90

Redshift:0-0.2

Type	SFR scenario	p1 (Myr)	p2 (Myr/Msol)	p3 (Myr)	infall (Myr)	Intrinsic extinction transfer
E2	p2*exp(-t/p1)/p1	89.17	1.1868	–	–	spheroidal geometry
E-SO		1.00	500.0	–	500	
Sa		1.00	1409.0	–	2800	Disk geometry: specific inclination: 0.0,22.5 45.0,67.5 and 90 deg
Sb		1.00	2500.0	–	3500	
Sbc	$Mgas^{p1}/p2$	1.00	5714.0	–	6000	
Sc		1.00	10000.0	–	8000	
Sd		1.00	14290.0	–	8000	
Im		1.50	15390.0	–	8000	
QSFG	$Mgas^{p1}/p2$, $t<t_f-p3$ 0, $t>t_f-p3$	2.61	5564.2	74.14	10560	

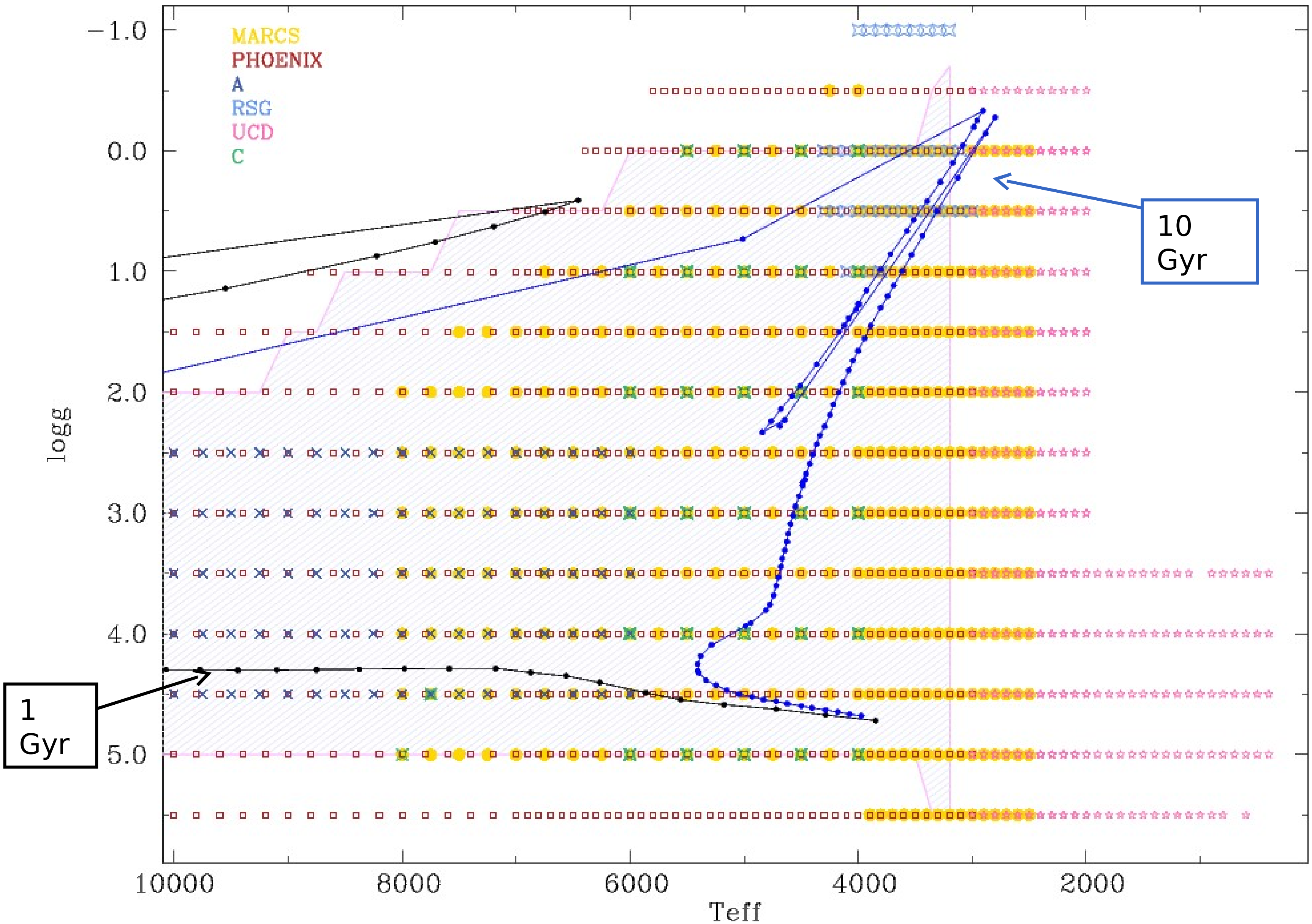
Gaia will mostly do stars...

- To be classified on-the-fly (which kind of source it is) and in more detail
  - Different algorithms are called, dealing with different stellar types
  - Using all measurements in sinergy
  - Ability to deal with “outliers”
- Final catalog will provide the Astrophysical Parameters (APs): Teff, logg, [Fe/H],[alpha/Fe],Av
- All algorithms need stellar spectra for training and testing:
  - Synthetic spectra are used now, to be able to “play” with parameters
  - Real spectra will be used later on

Synthetic stellar libraries for Gaia

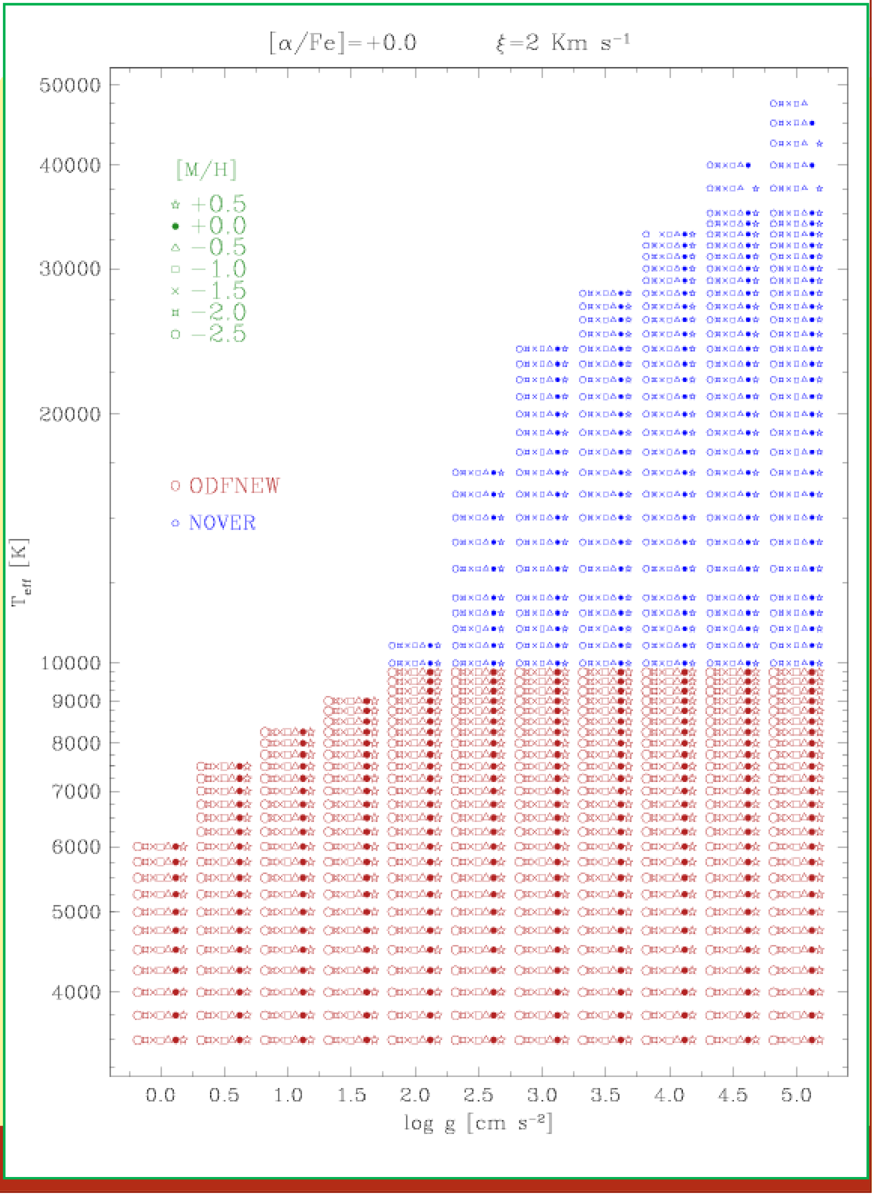
- Large effort to cover as much as possible the AP space, using state-of-the-art codes, with uniform and fine spacing (250 -1000 K according to Teff, 0.5 dex in logg and [Fe/H]) and avoiding gaps.
- ~100 Gb of synthetic spectra of stars have been produced for Gaia, covering the same wavelength range and with the same resolution
  - BP/RP: 300-1100 nm, 0.1 nm/pix
  - RVS: 840-870 nm, 0.001 nm/pix
- Calculated at the best of the current knowledge* on the dominant physical effects according to the stellar type: e.g. NLTE+rotation in early-type stars, atomic diffusion in late-B/A/early-F stars, molecular opacities in late type stars...
- The AP space is covered using different codes, optimized to the Teff range Different codes can be available for a given Teff range. No preferred choice is made and libraries overlap is encouraged, to avoid/map systematics.

Stellar type	T_{eff} [K]	logg	[Fe/H]	Provider/code
WD Stars	6,000-90,000	7 - 9		Koester/TMAP
sdOB Stars	26,000-100,000	4.8 - 6.4	+0.0	Heber
OB Stars	15,000-50,000	1 - 5	+0.0-+0.3	Ghost/Tlusty
BAF Stars	6,000-16,000	2.5 - 4.5	-1.5 - +1.0	Kochukhov/LL
Ap Stars	6,500-18,000	1 - 5		Kochukhov/LL
F-M Stars	4,000-8,000	-0.5 - 5.5	-5.0 - +1.0	Gustafsson/Marcs (BP/RP)
F-M Stars	2,800-8,000	-0.5 - 5.5	-5.0 - +1.0	deLaverny/Marcs (RVS)
A-M Stars	3,000-10,000	-0.5 - 5.5	-2.5 - +0.5	Hauschildt/Phoenix
NLTE Cool Stars	4,000-6,000	4.5 - 5.5	+0.0	Korn/Marcs+Multi (RVS)
C Stars	4,000-8,000	0 - 5	-5.0 - +0.0	Plez/Marcs
Emission line stars	25,000-50,000	3 - 5	--	Fremat,Blomme
Ultra Cool Dwarfs	100-4,000	2.5 - 5.5	+0.0	Allard/Phoenix
Fast Rotators	9,000-25,000	3.6-4.2	+0.0	Fremat/Zorec/Martayan
WR	25,000-100,000	3.0-5.2	+0.5	Blomme/CMFGEN
Red Super Giants	3,500-4,200	-1 – 1	+0.0	Josselin/MARCS
O-M stars	3,500-47,500	0 - 5	-2.5 - +1.0	Munari,Sordo /Kurucz


MARCS
PHOENIX
A
RSG
UCD
C
10
Gyr
1
Gyr
logg
Teff
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
10000
8000
6000
4000
2000

Munari, Sordo et al. (2005) library

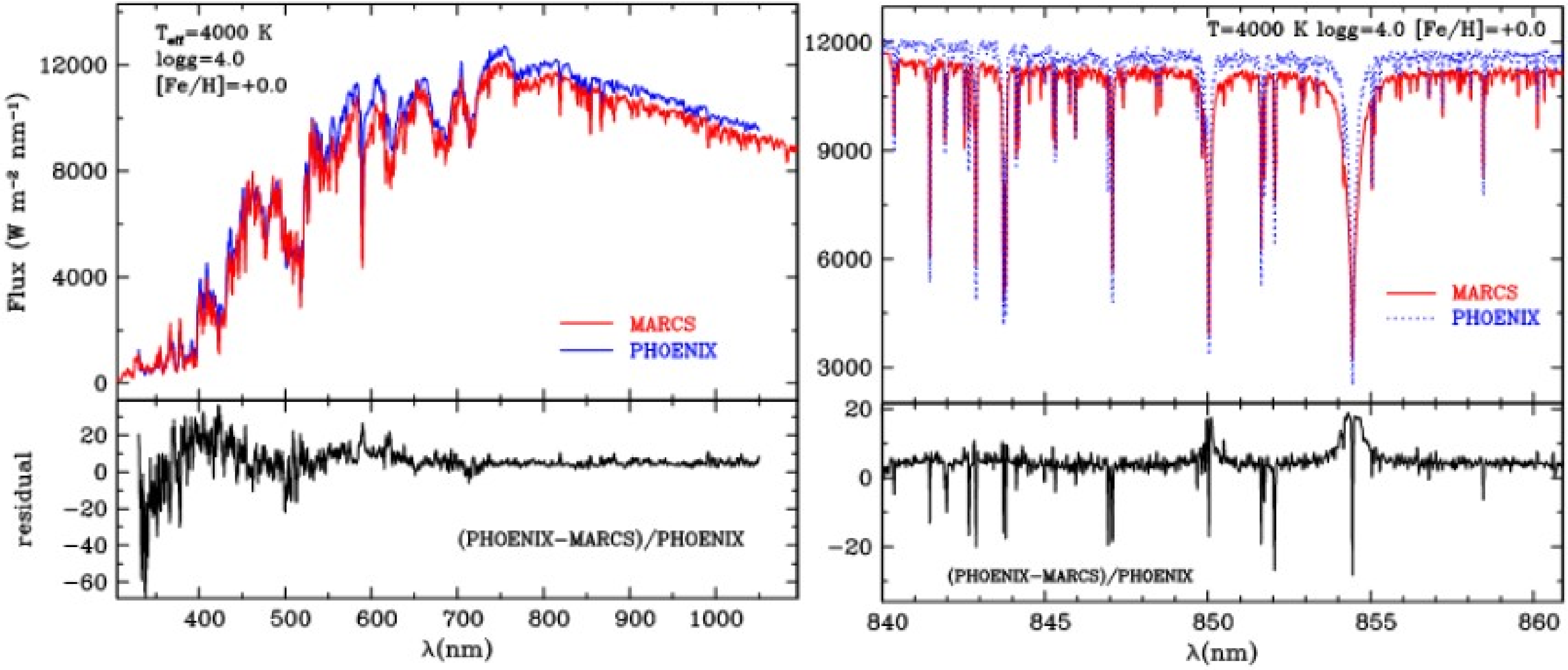
- A large high resolution library computed from Kurucz ATLAS9 NEWODF model atmospheres (Castelli et al 2002)
- Computed without predicted lines, to preserve from spurious features in the spectra (for radial velocity determination)
- Uniform coverage of the AP space, micro-turbulence and α-enhancement variations explored.
  - α-enhancement extended to high Teff (20,000 K), to properly model populations in external galaxies
- Applications in several fields:
  - Radial velocity measures (RAVE survey);
  - AP determination via automated fitting (RAVE);
  - Eclipsing binary stars solution (Tomasella et al 2008a,b, Siviero et al 2004);
  - SSPs computation (Percival et al. 2009);
- On-going implementation PEGASE-HR



Testing among different libraries

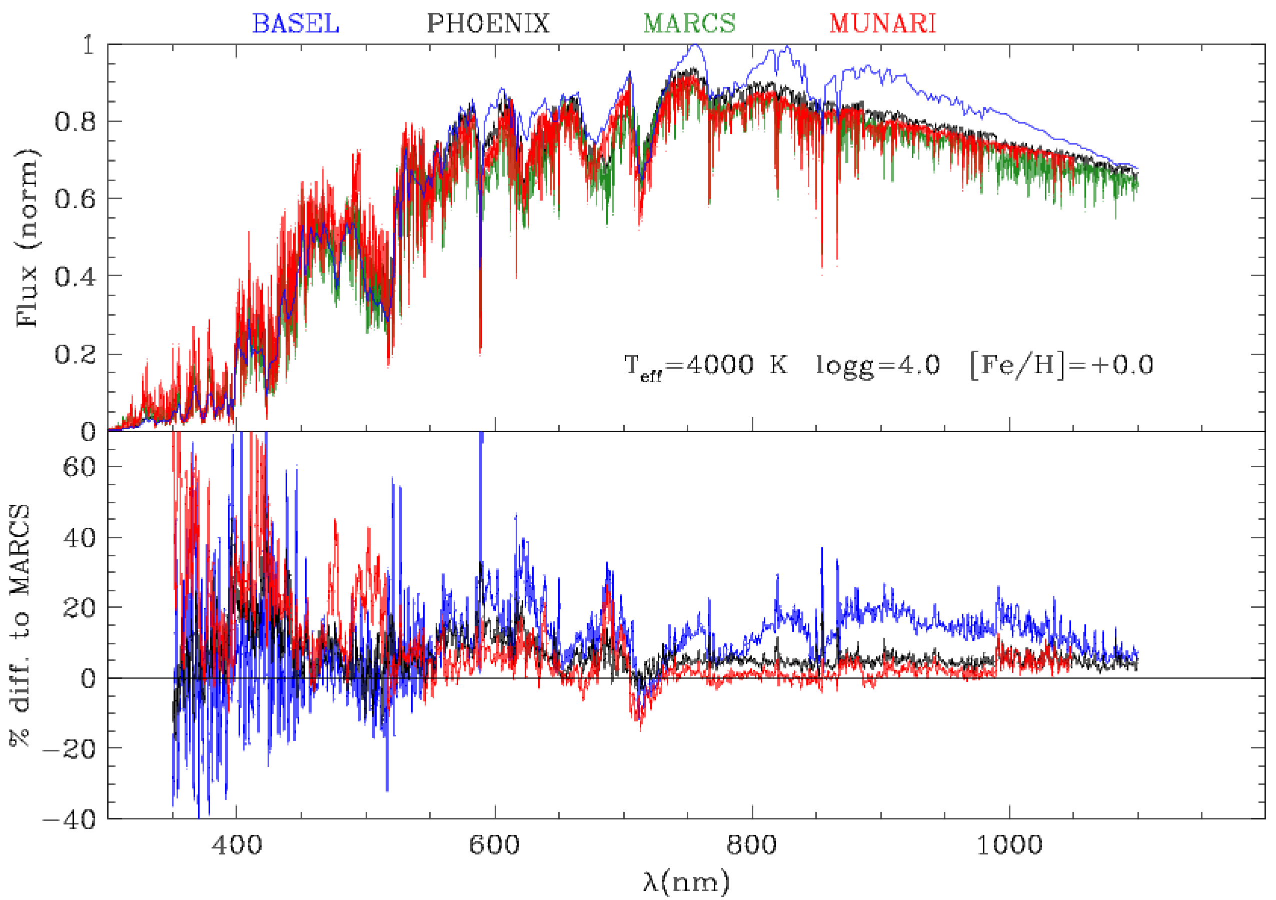
- Tests against spectra of single stars or with catalog of observed stars are available in literature for each of the Gaia libraries, as they are presented by providers themselves in dedicated publications.
- However the libraries **are** different, i.e. the SED correspondent to the same (Teff, logg, [Fe/H],...) can be different, in the continuum shape and/or in the lines detail.
- Several works in literature are dedicated to comparisons:
  - of spectral libraries in term of colors and of indices
  - of different families of SSP, in the same way.
  - (just to mention a few: Koleva et al. 2008, 2011, Bonifacio et al 2011, Bertone et al 2008, Coelho 2009, Martins&Coelho 2007, ...)
- No clear conclusion can be drawn...libraries perform quite well, some better in some regions, some problems are highlighted, etc...

Spectrum comparison -I

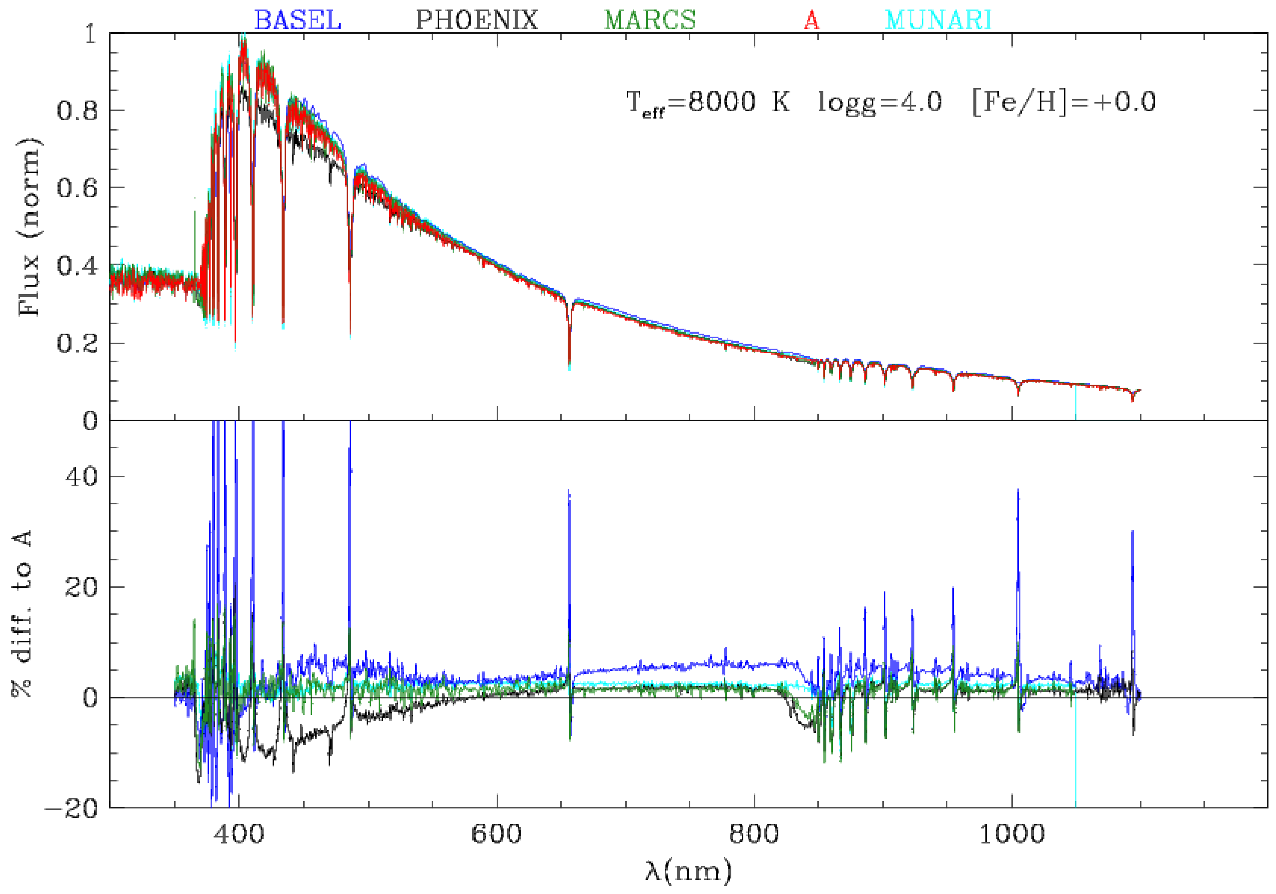


Sordo *et al.* 2009, MSAI 80, 103 (astro-ph/0812.0297)

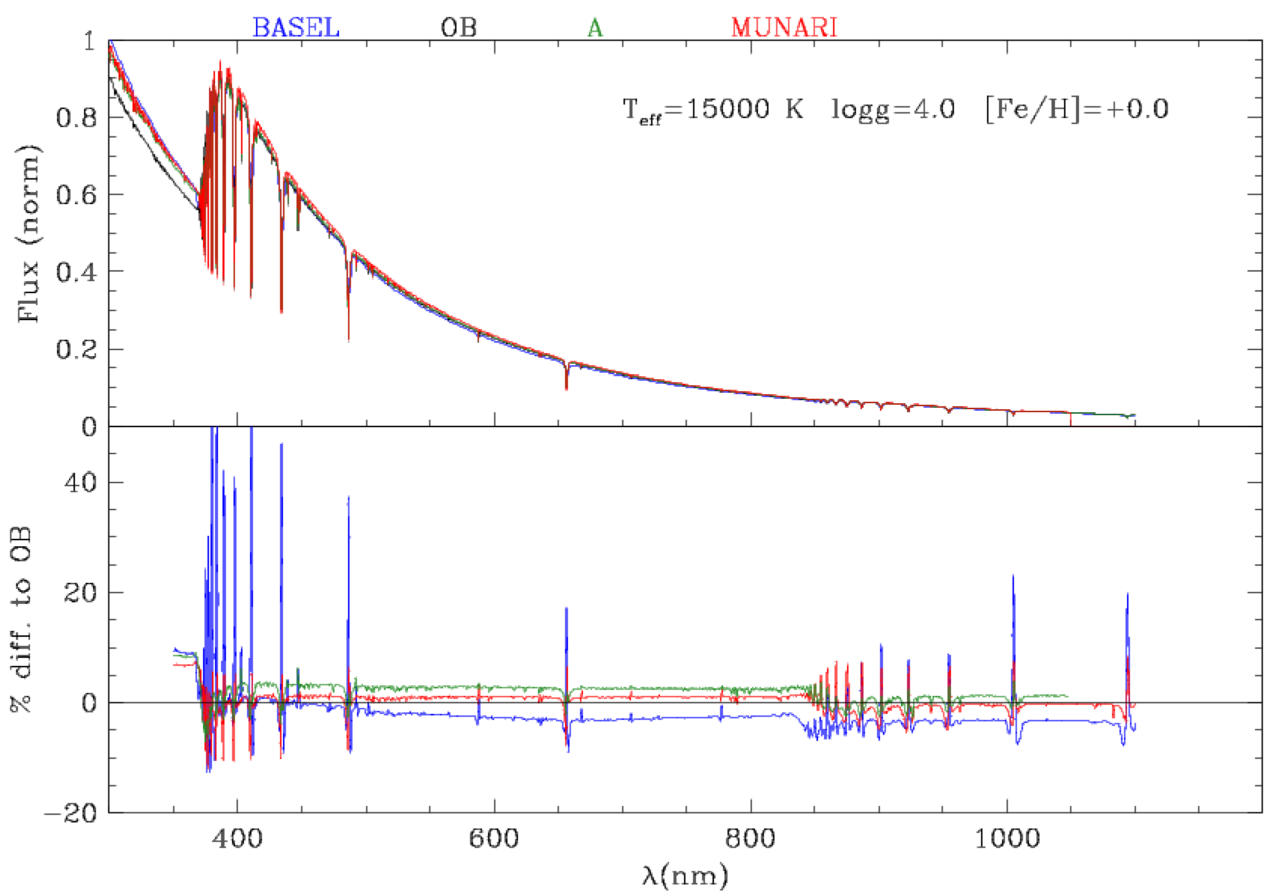
Spectrum comparison -II



Spectrum comparison -III

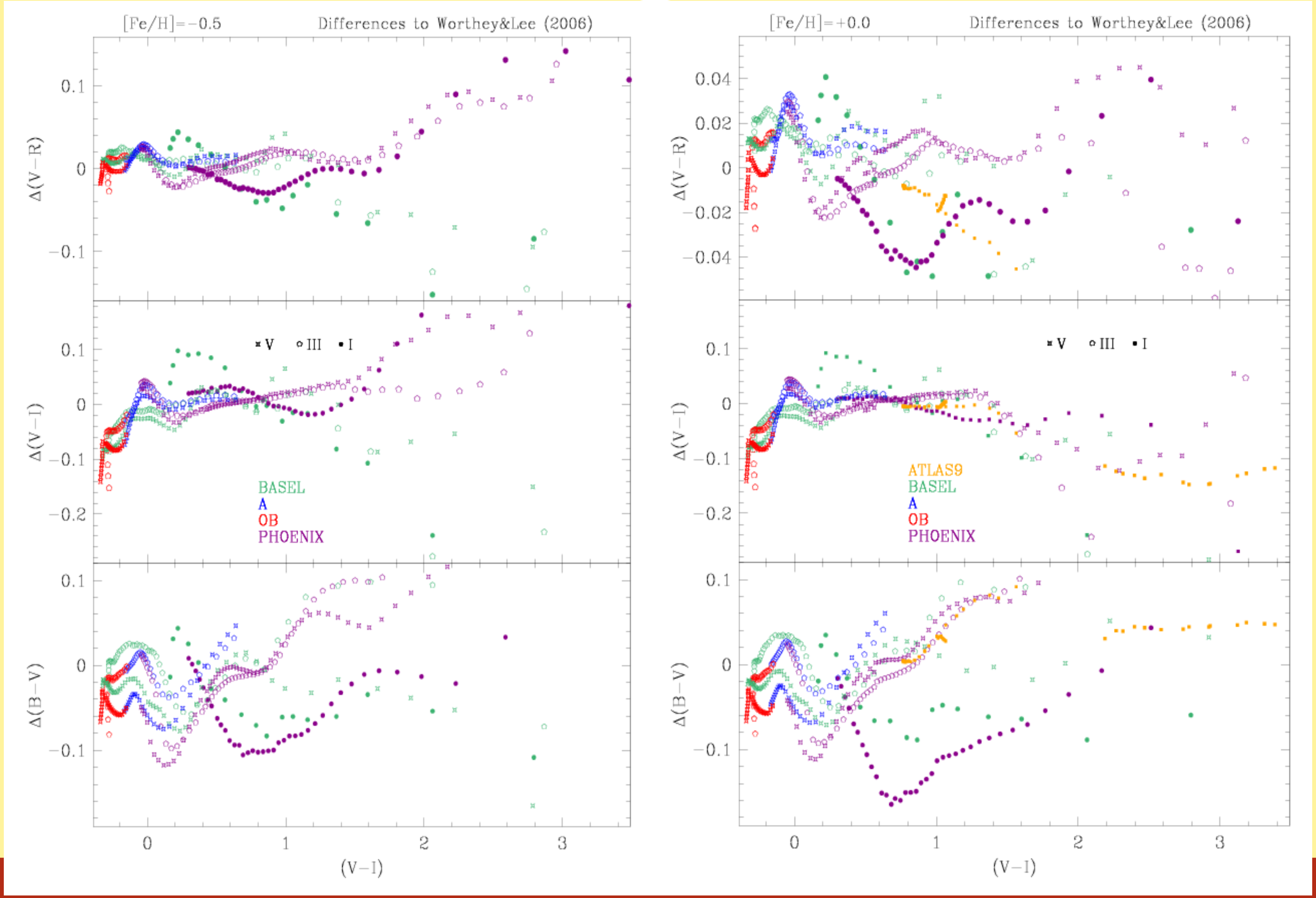


Spectrum comparison -IV



Color comparison

Sordo et al 2009
Sordo et al 2010



Testing among different libraries

- Given a spectrum synthesis code family and any observed spectrum, a fine tuning of the free parameters can be found allowing a wonderful fit… but the retrieved parameters can be very different!
- **Test case:** Workshop on *Comparative Stellar Spectrum Modelling* **(**Wien, Aug 2010). 14 different groups, with different analysis methods (codes and strategies) have studied the spectrum of 4 unknown giant stars (blind test).
  - The resulting parameters (Teff, Log g, [Fe/H]) cluster around the “true” values within (~200 K, ~0.5 dex, ~0.4 dex). No clear trends in the deviations.

Simple Stellar Populations

In an SSP, all stars are coeval and share the same initial chemical composition.

An SSP can be compared directly with cluster data (even in face of the

increasing evidence of multiple populations in many GCs), obtaining age

and chemical composition, also available via independent analysis (CMD...)

- Complex stellar systems (i.e. galaxies) can be modeled by a convolution of a suitable set of SSPs with a suitable SFH

Ingredients are:

- Isochrones: giving (L, Teff, M, Z) i.e. (Teff, logg, [Fe/H]...)
- IMF: number of stars along the isochronefor a fixed total mass
- libraries of stellar spectra: giving the SED correspondent to

Which spectral library?

Synthetic libraries:

- model dependency, different Teff, metallicity scales, some evolutionary stages difficult/impossible to model…
- But regularity in the grids, easy to interpolate, possibility to “play” with the parameters and explore effects on SSPs (assuming a local accuracy of the spectra)

Observed libraries (for instance MILES, STELIB…):

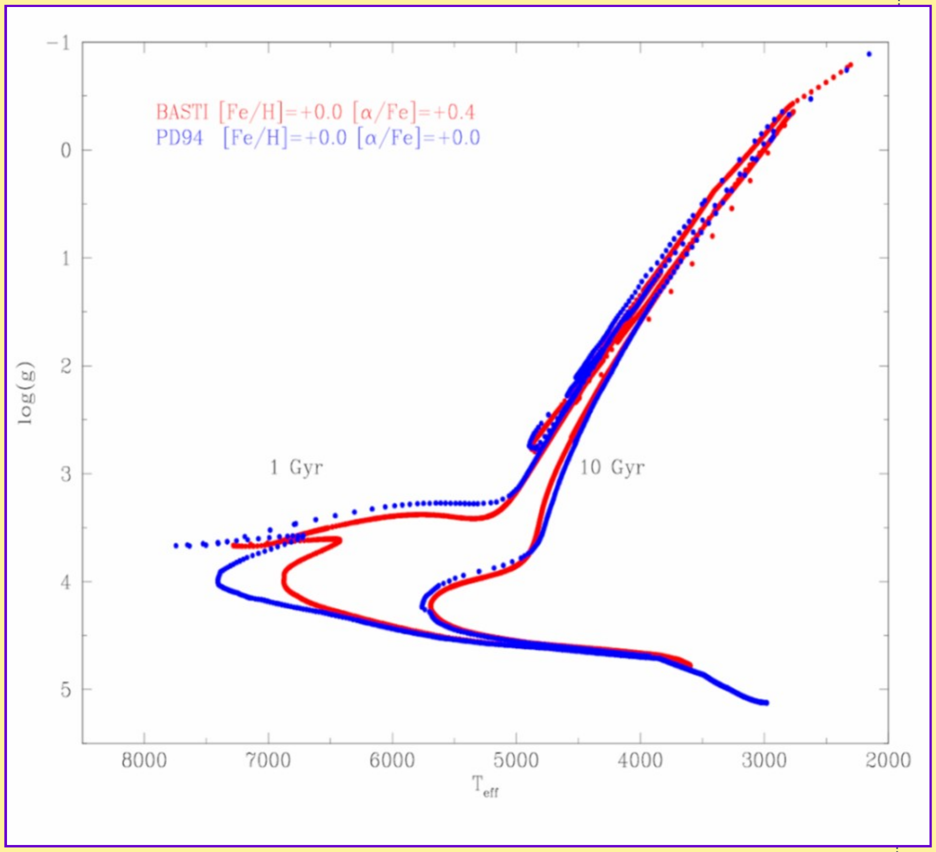
- Real stars!
- But… who decide the “true” value of the parameters? Models are often used for this, and model-free measurements are still sparse!
- local chemical evolution only, problems in analysis of different SFH
- difficulty in the observation of some stages and some metallicities.

We use...

SSPs are computed using a code from Tantalo (2005).

- Isochrones:
  - Padova set of isochrones (Bertelli et al. 1994, Girardi 2002) for solar scaled populations
  - Basti isochrones (Pietrinferni et al. 2006) for α-enhanced calculations.
- IMF: Salpeter initial mass function, but others explored.
- Spectral libraries:
  - Munari, Sordo et al. 2005,
  - Munari, Sordo et al. 2005 + UVBlue (Rodriguez et al. 2007),
  - Gaia Synthetic stellar spectral libraries, 0.1 nm resolution

Set of Isochrones



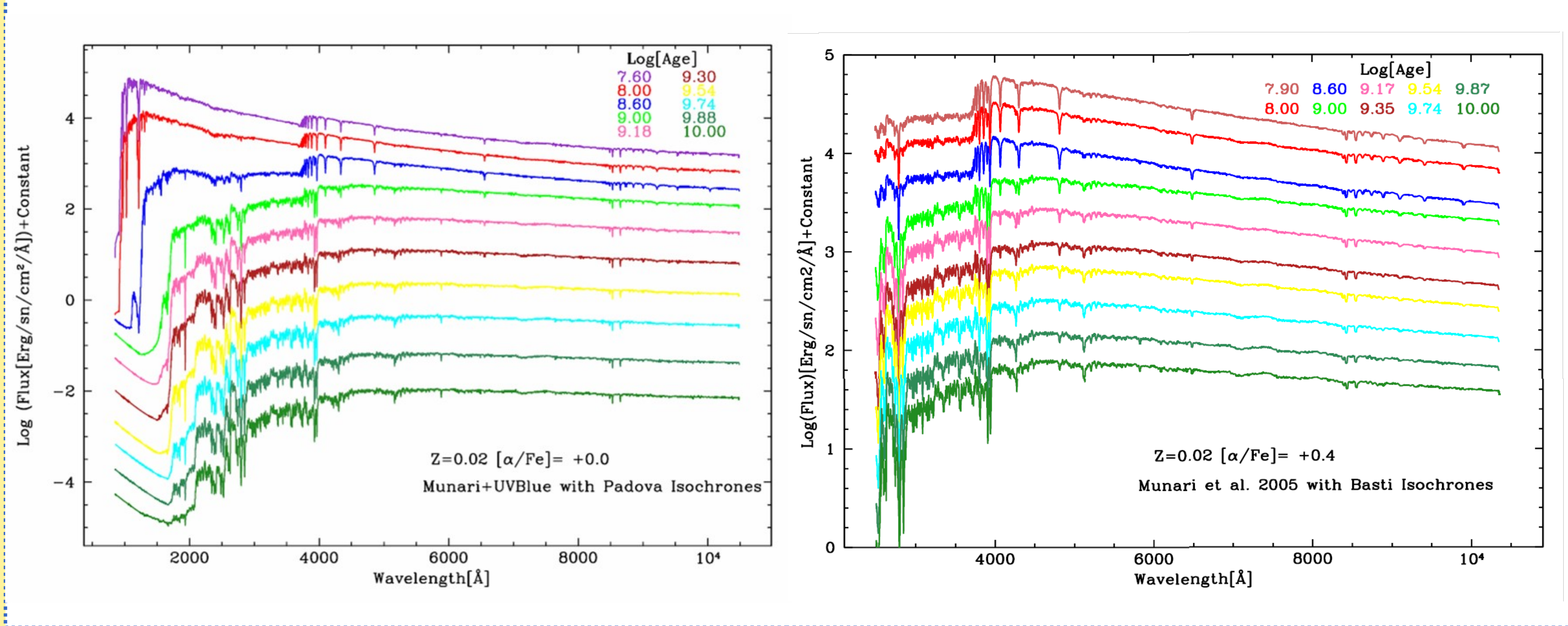
- Padova Isochrones [α/Fe]= +0.0 (Bertelli et al. 1994)
- Basti Isochrones [α/Fe]= +0.4 (Petrinferni et al. 2006)

SSPs using Gaia libraries

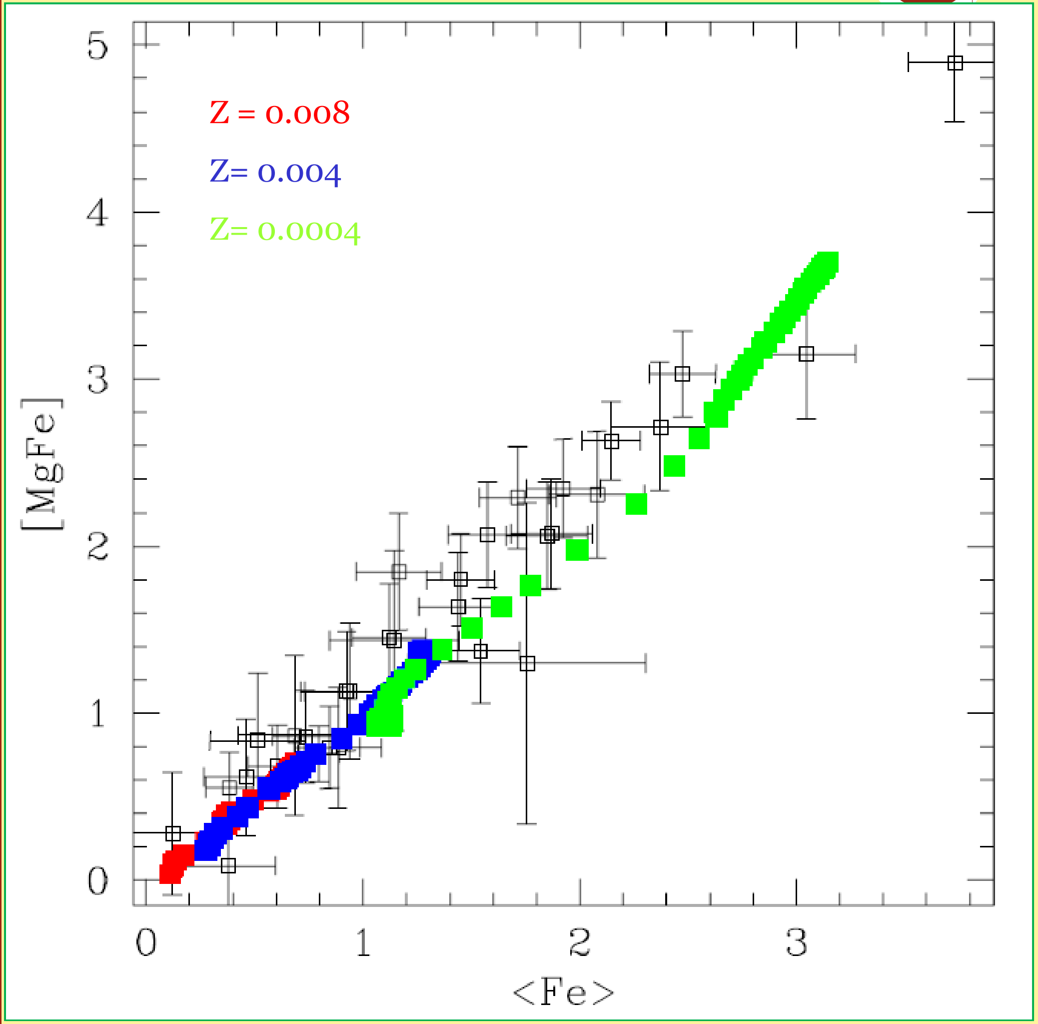
- Mixing of different libraries can introduce "boundary" effects
  - Comparisons shown in previous slides!
- Some evolutionary phases are missing :
  - No spectra available (cool supergiants, both M and C at logg < 0.5)
  - Evolutionary models have problems with AGB and post-AGB phases
- Given all this…
- We can match the isochrones chemistry with the correspondent spectra (no mixing solar scaled isochrones with alpha enhanced spectra). Using SSP with "local" chemistry to derive properties of external galaxies can lead to errors on age up to 20% (Koleva et al 2008).

SSP datasets

•Preliminary results in Sordo et al 2009, 2010. Series of papers in preparations



Comparison using GGC



Data from Trager et al. 1998

Indexes calculated from SSPs :

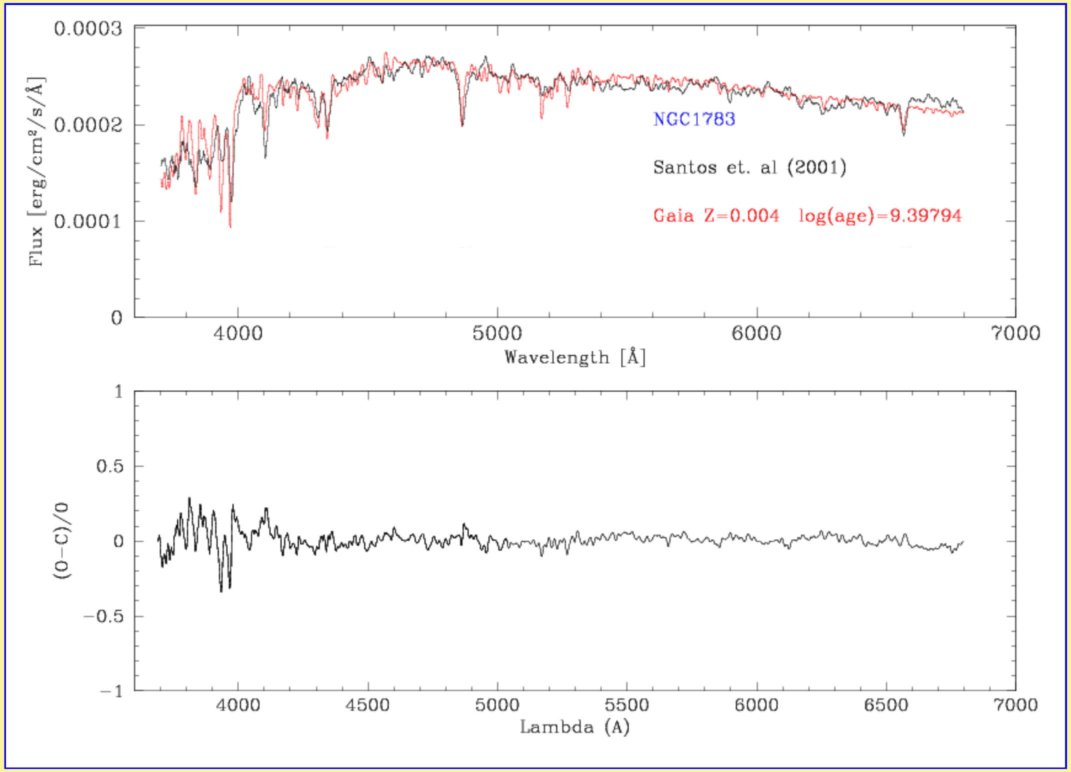
•Basti Isochrones

•Munari, Sordo et al. 2005

SSPs: full spectrum synthesis

Data sets:
- LMC clusters from Santos et al (2001), Rp=6-10 A
- GCC from Schiavon et al (2005), R= 3.1 A

Method :
- **Starlight v0.4** : Markov chain (El Cid Fernandez et al 2005, Asari et al 2007)



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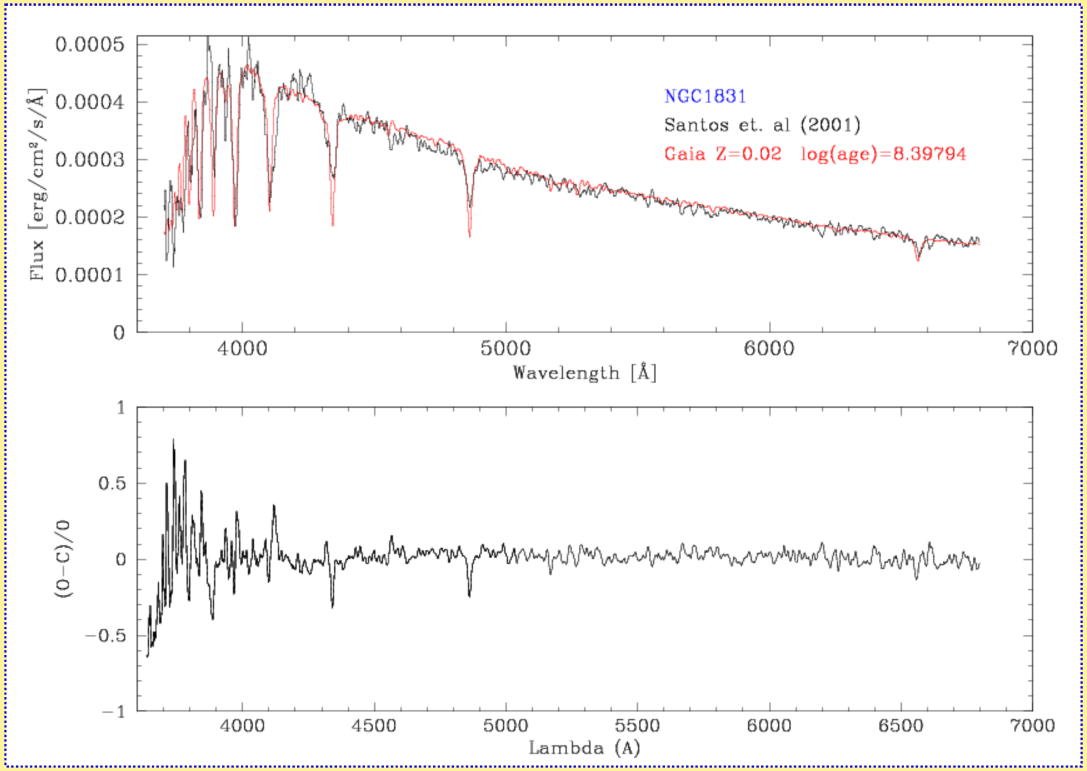
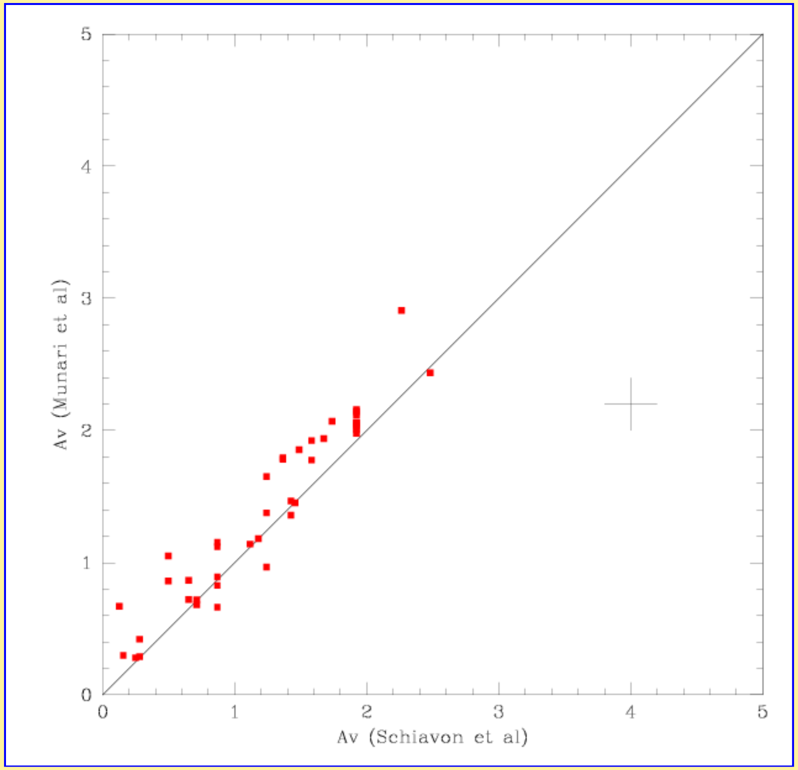
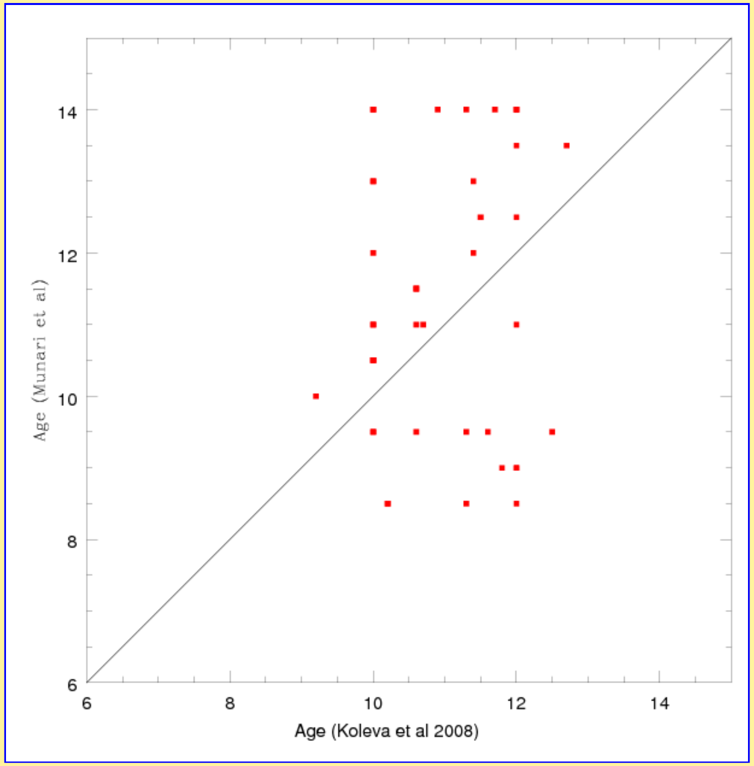


SSPs: full spectrum synthesis (global trends)





Problem of degeneracy: Av-Z-age

Calibration on real data

All Gaia (but not only) algorithms use synthetic data and derive model-dependent astrophysical parameters (APs).

- We can assume that synthetic spectra reproduce with accuracy small changes in APs (local accuracy), but possibly this does not hold for large AP variations (global accuracy).
- Nearly all the Gaia libraries are 1-D, while state-of-the-art 3D spectra can produce very different APs.

→Problem: calibration of models on real data!

- Possible solution: set of reference stars that will be observed by Gaia carefully chosen, to avoid systematics due to extrapolation or gaps.
- GBOG (Ground Based Observation for Gaia) aims to establish the AP scale for Gaia APs. This Gaia working group will provide to the community:
  - A small set of benchmark stars (too bright for Gaia), whose APs and basic parameters will be derived with great accuracy
  - A larger set of reference stars (primary and secondary) in the Gaia magnitude limits, to be calibrated on benchmark stars.

THANKS FOR YOUR ATTENTION!