Star formation history in the local group explored using the SAGA database for dwarf spheroidal galaxies

Takuma Suda (RESCEU, U-Tokyo)
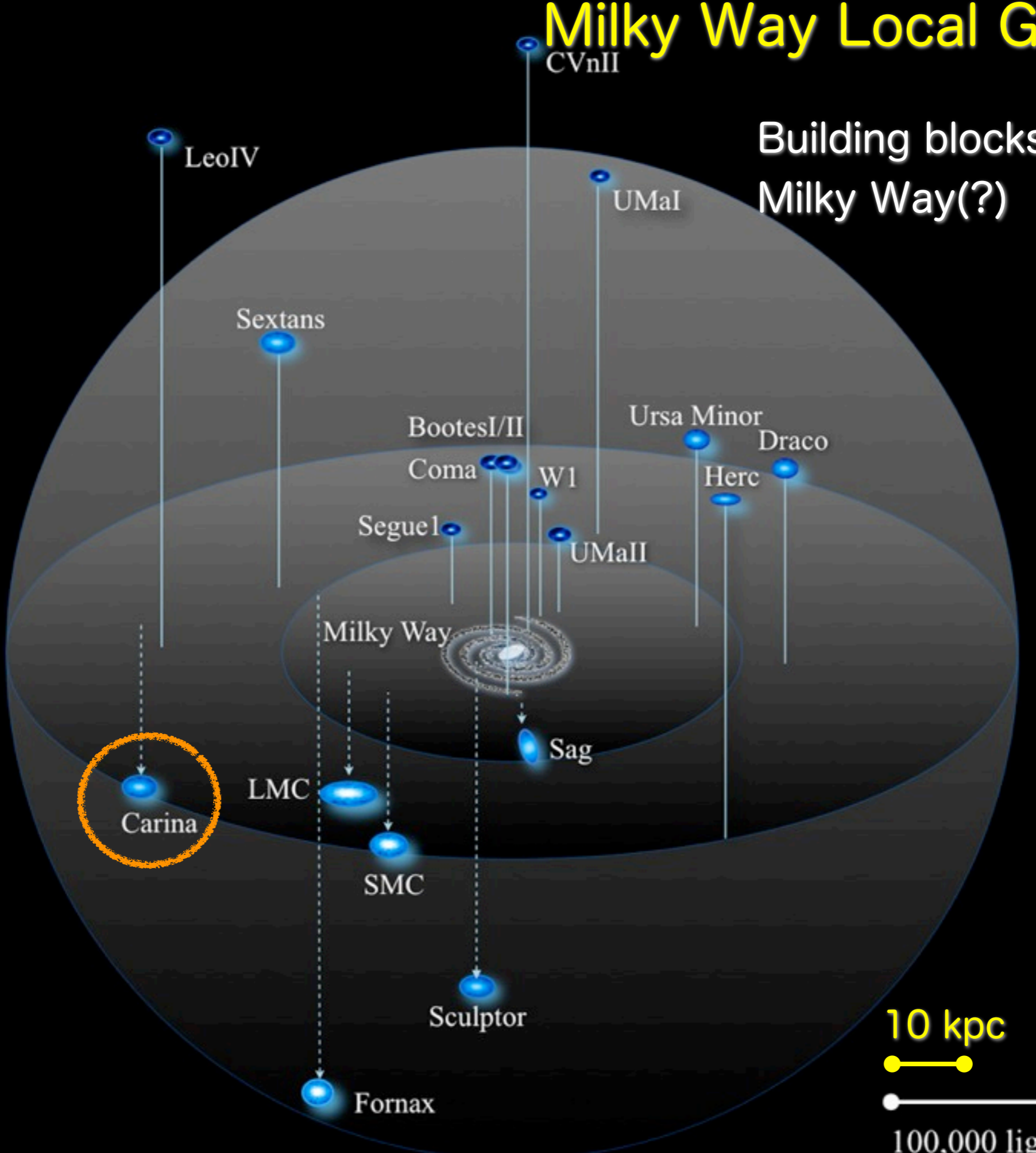
須田 拓馬（東大RESCEU）

Wako Aoki (NAOJ), Jun Hidaka (Housei-U), Yutaka Katsuta, Masayuki Y. Fujimoto (Hokkai Gakuen U)

青木 和光 (NAOJ), 日高 潤 (法政大学), 勝田 豊, 藤本 正行 (北海学園大)

Milky Way Local Group

CVnII

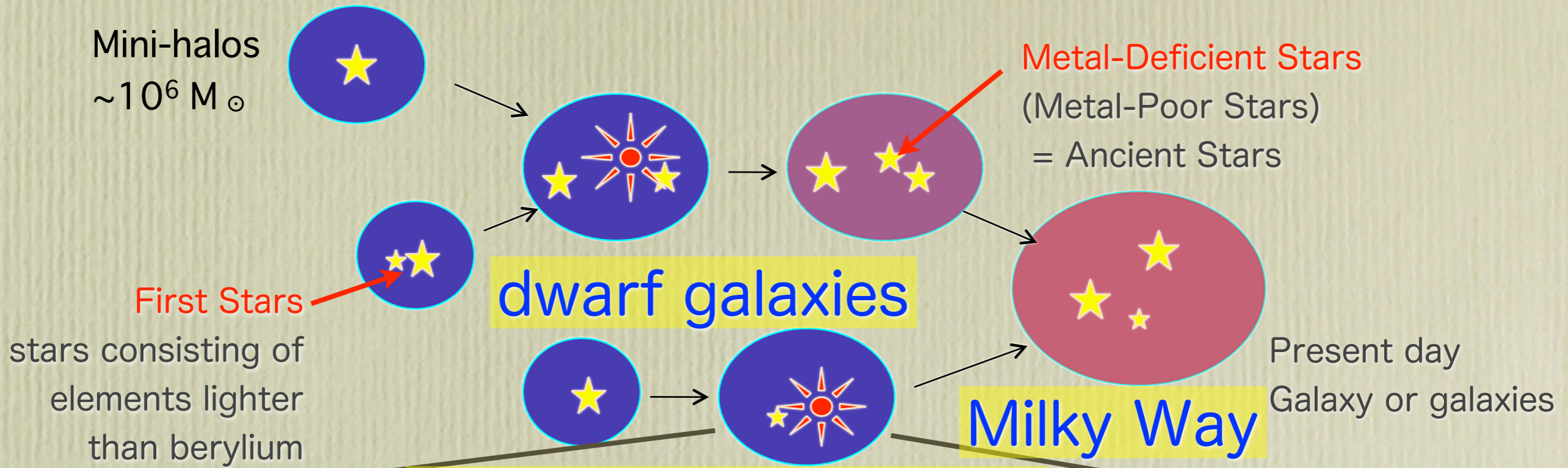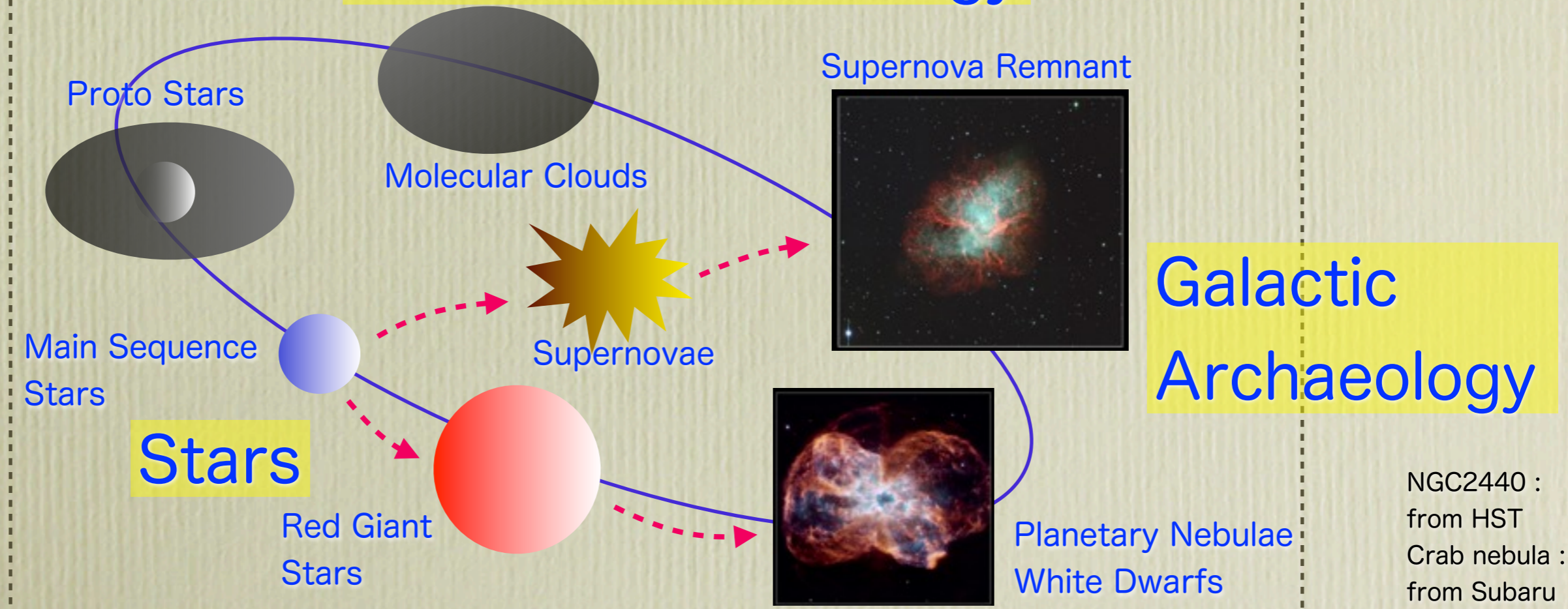LeoIV

UMaI

Building blocks of the
Milky Way(?)

Sextans

BootesI/II

Ursa Minor

Draco

Coma

W1

Herc

Segue1

UMaII

Milky Way

Sag

LMC

Carina

SMC

Sculptor

10 kpc

Fornax

100,000 light years

Formation and Evolution of Galaxies

Mini-halos
~10^6 M$_\odot$

Metal-Deficient Stars
(Metal-Poor Stars)
= Ancient Stars

First Stars

stars consisting of
elements lighter
than berylium

dwarf galaxies

Present day
Galaxy or galaxies

Milky Way

Near Field Cosmology

Proto Stars

Supernova Remnant

Molecular Clouds

Galactic
Archaeology

Main Sequence
Stars

Supernovae

Stars

Red Giant
Stars

Planetary Nebulae
White Dwarfs

NGC2440 :
from HST
Crab nebula :
from Subaru

HST Observations of Carina dSph

red: field stars
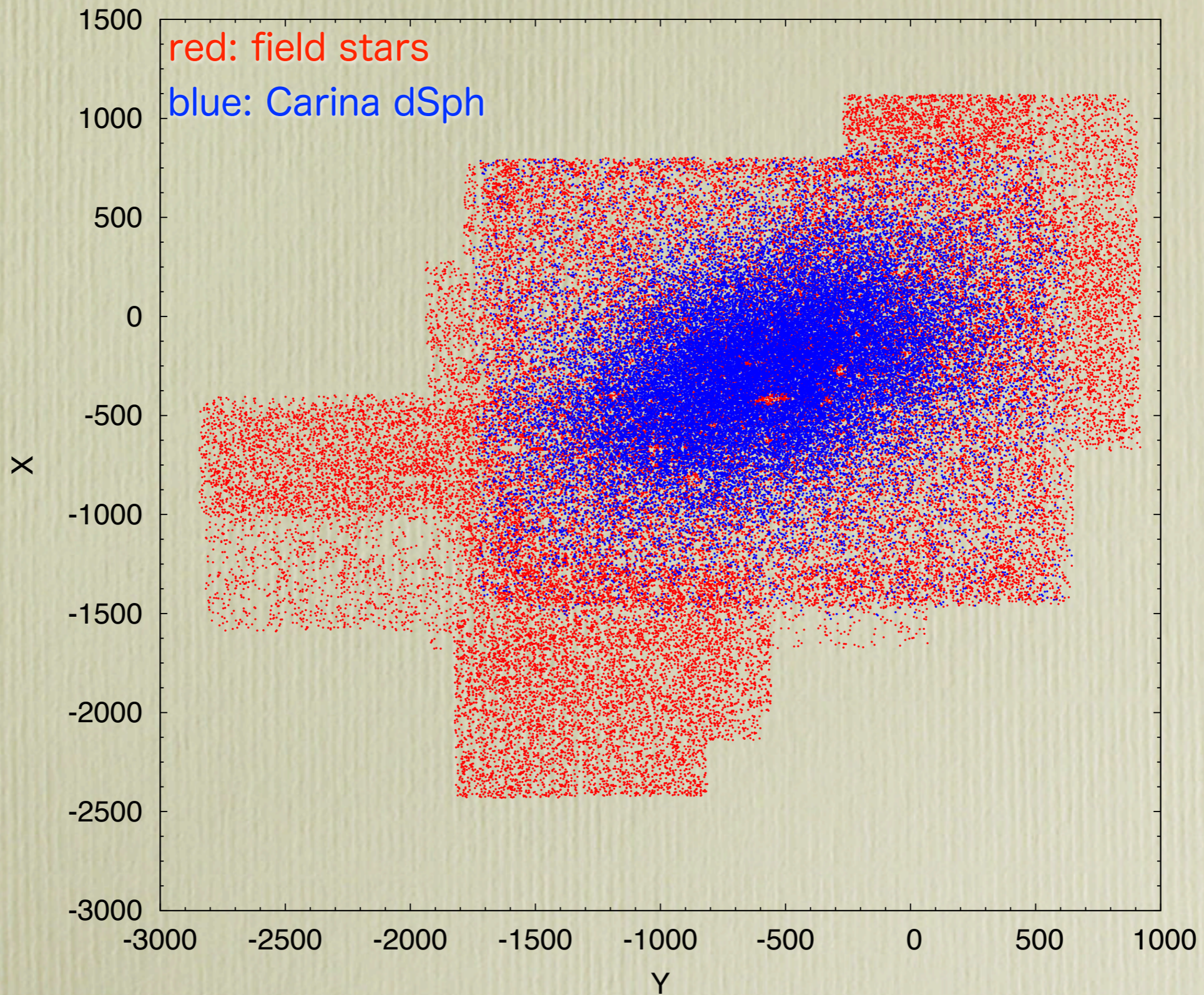
blue: Carina dSph

Photometric data kindly provided by Giuseppe Bono

Color-Magnitude Digram (CMD) of Carina dSph

red: field stars: 61745 stars

blue: Carina dSph: 38992 stars

Photometric data kindly provided by Giuseppe Bono
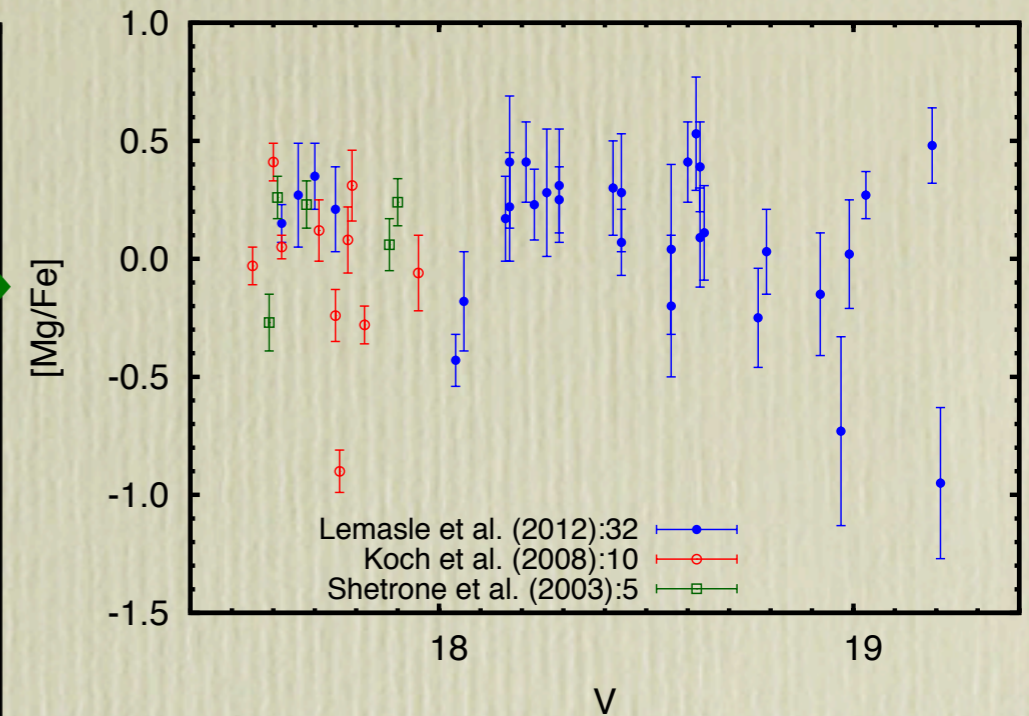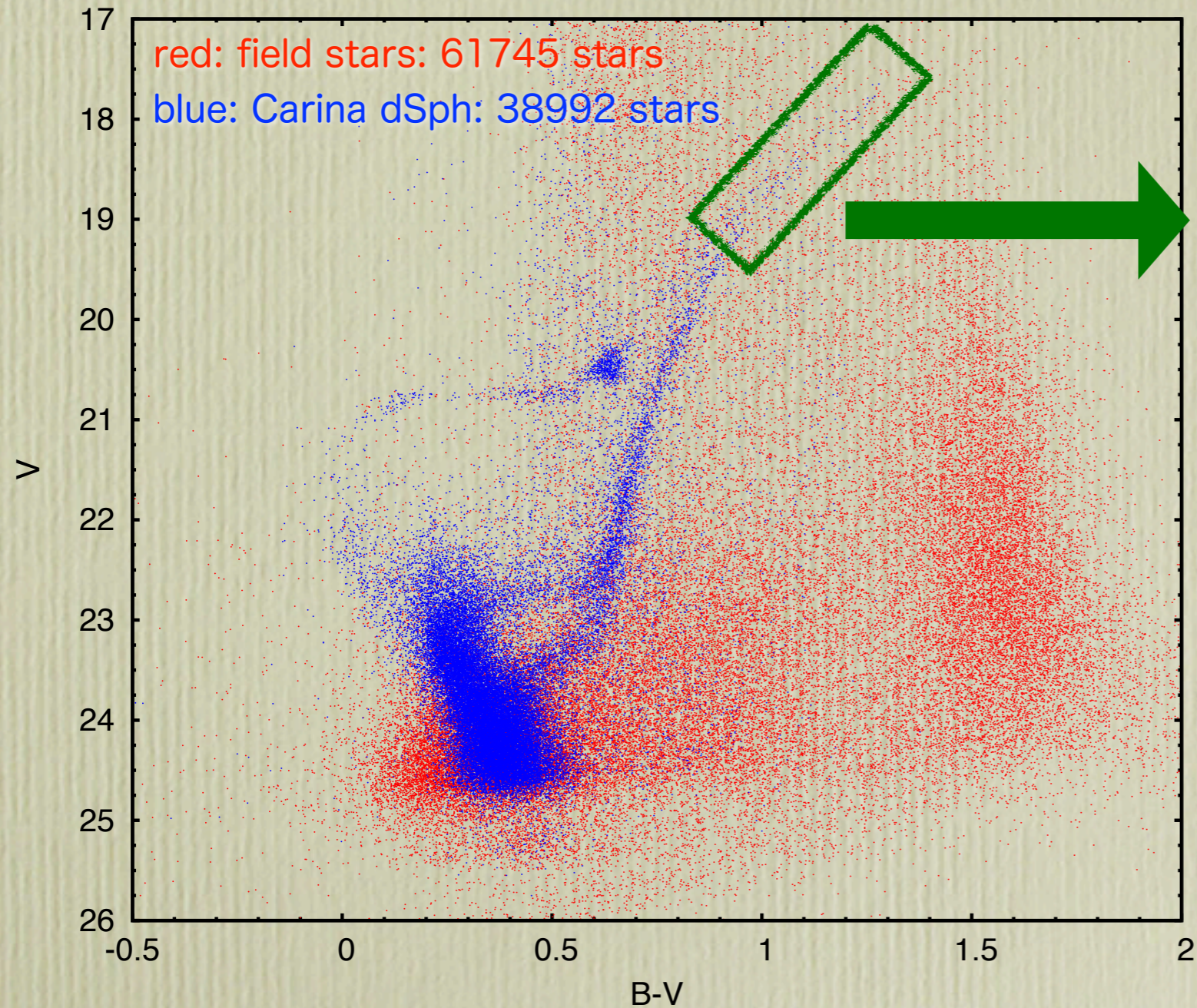
47 measurements for Mg

Abundances can be measured in stars at the tip of red giant branch!

Star Formation History of Carina

10 Gyr ■
11 Gyr ●
12 Gyr ✳
13 Gyr +
2 Gyr ×
3 Gyr +
4 Gyr △
5 Gyr ▲

$(m-M)_0$=20.06, E(B-V)=0.054

Superposition of isochrones

~300 stellar evolutionary tracks with [Fe/H]=-1.49 (average metallicity of Carina)

10 Gyr isochrone:
Evolution from zero-age main sequence to tip of red giant branch
0.300 - 0.900 $M_\odot$ in 0.002 $M_\odot$ steps
0.900 - 0.9134 $M_\odot$ in 0.0002 $M_\odot$ steps
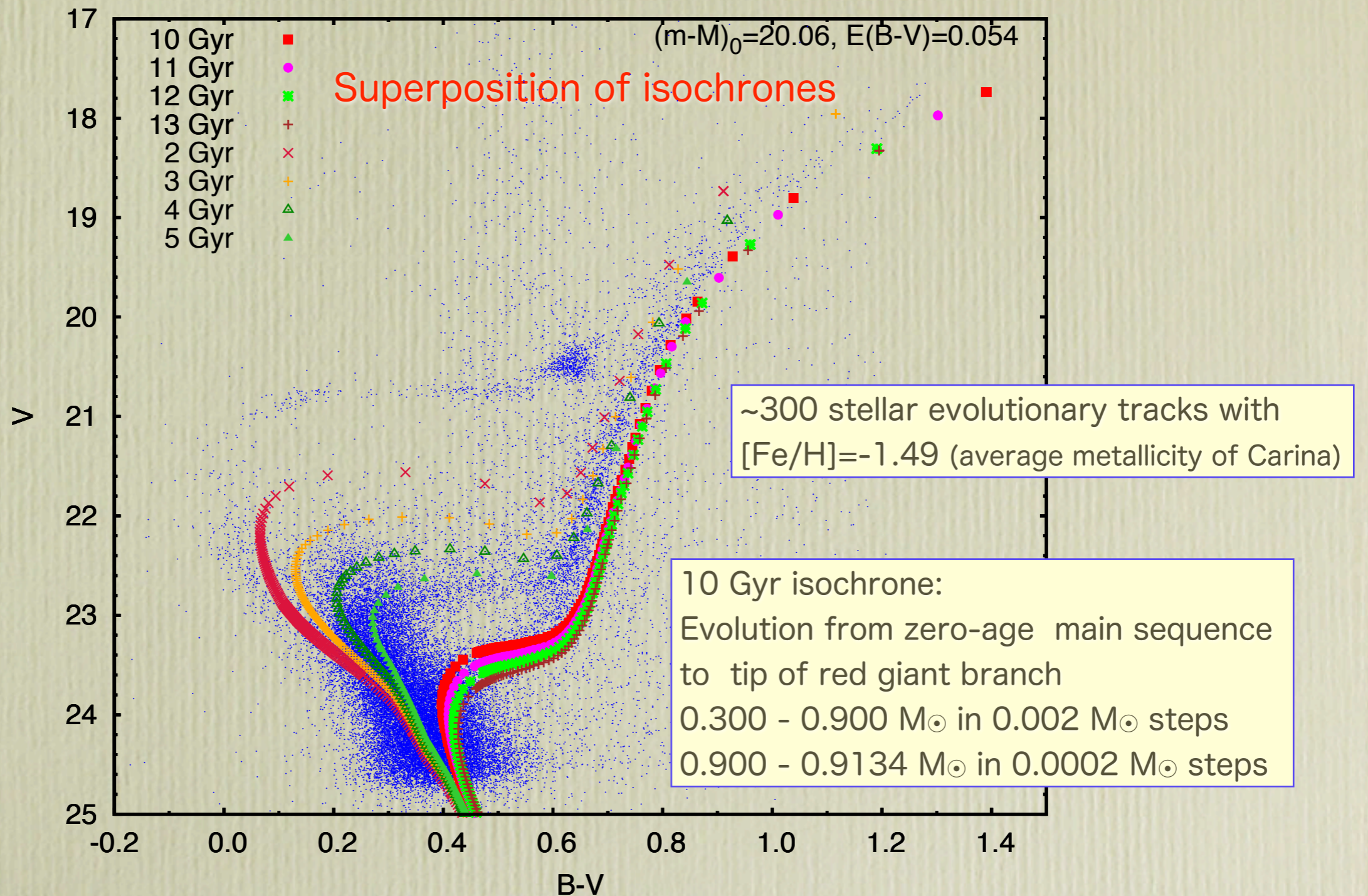
Isochrone fitting helps to:
⭐estimate distance to galaxies
⭐compare abundances and ages with observations

We are here!!

Star Formation History Explored Using SAGA (Stellar Abundances for Galactic Archaeology) Database

SAGA Database (Stellar Abundances for Galactic Archaeology)

Suda et al. (2008, PASJ, 60, 1159-1171)
http://saga.sci.hokudai.ac.jp → http://sagadatabase.jp
http://www.astro.keele.ac.uk/saga
Suda et al. (2011, MN, 60, 1159-1171)
Yamada et al (2013, MN, 436, 1362-1380)

科研費基盤(A) "宇宙黎明期の恒星の研究と宇宙開闢史の解明" (2003~2005)
科研費基盤(S) "宇宙黎明期の恒星の研究と宇宙開闢史の解明" (2006~2011)
科研費若手(B) "宇宙開闢史解読のためのデータベースの構築" (2007~2008)
科研費基盤(S) "宇宙初代星誕生から銀河系形成期における恒星進化と物質循環" (2011~2016)
研究成果公開促進費 "銀河考古学のための金属欠乏星データベース" (2014~2014
研究成果公開促進費 "銀河考古学のための金属欠乏星データベース" (2015~2017)

☆ Collection of observed data

　☆ Taken from the literature on the abundance analyses of stars

　☆ Papers including stars with [Fe/H]<-2.5 and some metal-rich disk stars

☆ Compilation of stellar parameters, derived abundance data, etc.

　☆ Data Registration System

☆ Use of compiled data

　☆ Search and Plot

DATA SAMPLE as of Aug., 2015
Papers: 241 (covering 2000-2011)
Stars: 9269 (4491 unique stars)
Data:
　[X/H]: 84,134
　V band mag.: 2,039
　Position data.: 1,522

SAGA

Register Login

Recent changes Media Manager Sitemap
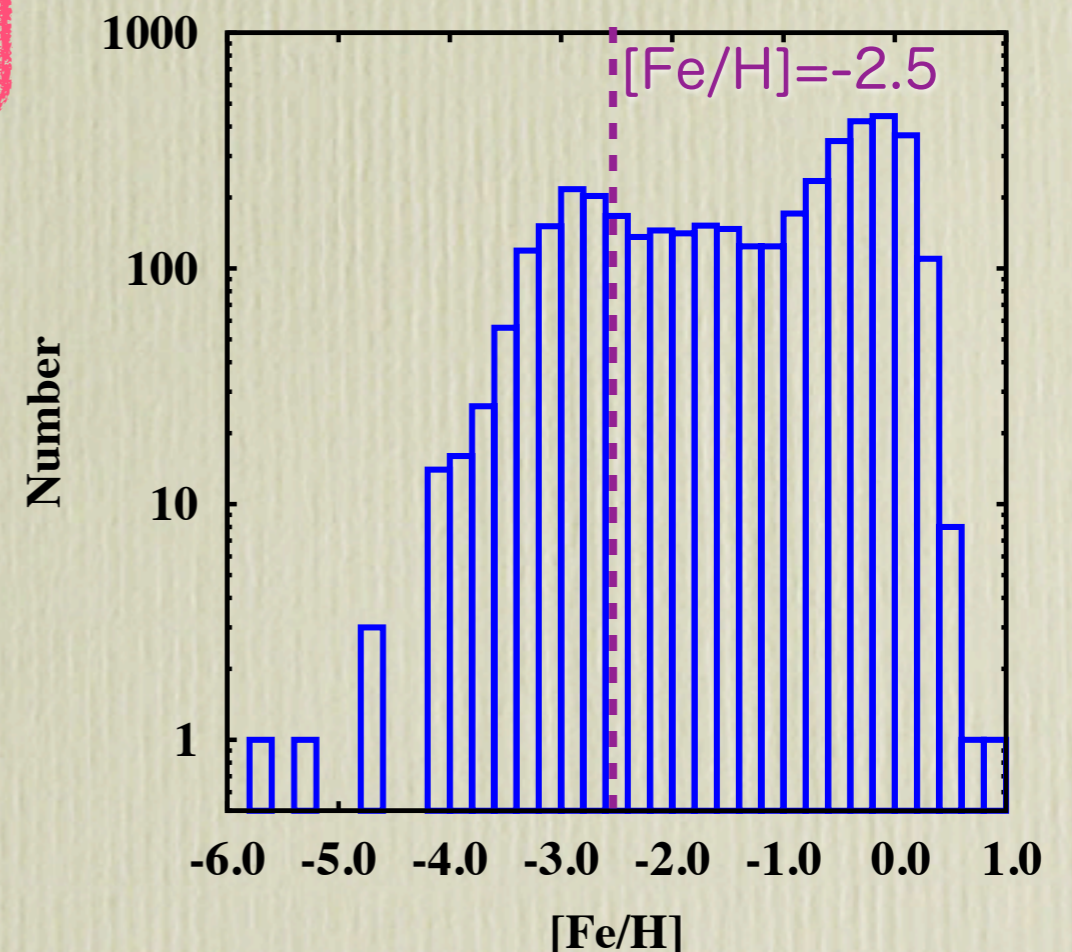
Trace: · **start**

start

SAGA -Stellar Abundances for Galactic Archeology Database-

This site is public since 24th of June, 2008 (go to ⊕ UK mirror site)

- ⊕ Retrieval – Last update of the retrieval system on **Oct. 31, 2010** and the database on **Aug. 6, 2012.** 😎 — *Data search and plot*
  - ⚠Important change!!! The definition of "CEMP" and "Crich" changed from [C/Fe] >= 0.5 to [C/Fe] >= 0.7. ⚠
  - Previous Versions – Last update on Oct. 31, 2010
- ⊕ SAGA viewer – easy comparison between stars, new release on Nov. 2, 2010 ⚠
- Readme–Important notes when using the SAGA database — *How to search the data*
- Information and News on update history (Database covers the paper published by Dec. 2011.)
  - Update history of the database — *News and Information*
  - Update history of the data retrieval system
- Tutorial–Tutorial for the data retrieval system
- ⊕ List of papers — *Links to the data of papers and objects*
- ⊕ List of objects
- FeedBacks–Please give us any questions, comments, and suggestions on data and database – not created yet 🙂
- Links–Links to related institute

SAGA Papers

Please cite the following paper if you think that the SAGA database is helpful in writing your paper.

"The Stellar Abundances for Galactic Archeology (SAGA) Database – Compilation of the Characteristics of Known Extremely Metal-Poor Stars"

T. Suda, Y. Katsuta, S. Yamada, T. Suwa, C. Ishizuka, Y. Komiya, K. Sorai, M. Aikawa, and M. Y. Fujimoto, **PASJ**, 2008, vol.60, 1159-1171

The paper is available at ⊕ PASJ web site for free until the end of 2008 (probably still now).

- "The Stellar Abundances for Galactic Archaeology (SAGA) Database II – Implications for Mixing and Nucleosynthesis in Extremely Metal-Poor Stars and Chemical Enrichment of the Galaxy"
  - T. Suda, S. Yamada, Y. Katsuta, Y. Komiya, C. Ishizuka, W. Aoki, and M. Y. Fujimoto, accepted by **MNRAS** on Oct. 28, 2010,
    ⊕ arXiv:1010.6272.
  - Five sets of database to produce figures in the paper are available here.

Data Retrieval System for SAGA Database

Last update of database: 2010-03-16 18:01:16

* not working

** Other options do not work.

Query

	search	example	*	reset

Graph Options

Xaxis	Category ▼	Li ▼	[Fe/H]	From :	To :	Include ▼ data with upper limit
	Category	Li				
	log-e	Li I				
Yaxis	[X/H]	Be		From :	To :	Include ▼ data with upper limit
	[X/Fe]	Be II				
Criterion +	Atmospheric Parameters	C	optional Criterion		Range	
	Photometric Parameters	C I				
Object	Binary Parameters	CH	0107-5240", "CS", "0107"			
	Position and Velocity	C2				
Binarity	Isotopic Ratio	N	m	To		
		CN				
Magnitude	Band ▼ : From	NH	mag			
		O				
Resolution	< R <	O I				
		OH				
		F	graphical Criterion			
		F				
Author		Na	hor ▼ ex) "Lastname"			
	⦿strict ◯forward agr	Na I	ward agreement ◯fuzzy			
		Mg				
Reference	ALL	Mg I ▼	▼			
Publication Year	From To					

Retrieval Options

Display / Page	10 ▼
Order by**	Object ▼
Output Option	single file ▼
	separated files
Histogram Option	single file Range (necessary for histgram)
	histgram
Cross Search	cross papers ▼

	search	example	*	reset

Specify X and Y axis

Additional criteria

Range

Search Result

plot | restart | reset | plot_all

Results : 420

#	○	Object	Reference	[Fe/H]	Teff	logg	[Fe/H]	log-e(Li)
1	☐	BD-09_4604	C.Charbonnel+,AAP, 442, 961, 2005	-1.38	5660	4	⊙-1.38	⊙2.121
2	☐	BD-10_155	C.Charbonnel+,AAP, 442, 961, 2005	-2.87	5008	3	⊙-2.87	⊙1.018
3	☐	BD-10_388	C.Charbonnel+,AAP, 442, 961, 2005	-2.51	6287	3.85	⊙-2.51	⊙2.257
4	☐	BD-12_3709	C.Charbonnel+,AAP, 442, 961, 2005	-1.34	5278	3	⊙-1.34	⊙1.268
5	☐	BD-14_5890	C.Charbonnel+,AAP, 442, 961, 2005	-2.07	4885	3	⊙-2.07	⊙1.025
			B.W.Carney+,AJ, 125, 293, 2003	-2.01	4840	2.1	○-2.01	
6	☐	BD-15_6355	C.Charbonnel+,AAP, 442, 961, 2005	-1.83	6349	4	⊙-1.83	⊙2.351
7	☐	BD-17_6692	C.Charbonnel+,AAP, 442, 961, 2005	-1.87	5065	3	⊙-1.87	⊙0.911
8	☐	BD-18_5550	M.Spite+,AAP, 430, 655, 2005	-3.06	4750	1.4	○-3.06	⊙0.75
			D.L.Burris+,ApJ, 544, 302, 2000	-3	4575	1.4	○-2.93	
			R.Cayrel+,AAP, 416, 1117, 2004	-3.06	4750	1.4	○-3.06	
			J.A.Johnson+,ApJS, 139, 219, 2002	-2.9	4600	0.95	⊙-3.03	
			A.McWilliam+,AJ, 109, 2757, 1995				○-2.91	
			J.Melendez+,ApJ, 575, 474, 2002	-2.87	4683	1.7	○-2.87	
			T.V.Mishenina+,AAP, 396, 189, 2002				○-3.01	
			T.V.Mishenina+,AAP, 370, 951, 2001	-3.01	4600	0.5	○-3.01	
			M.Spite+,AAP, 455, 291, 2006	-3.06	4750	1.4	○-3.06	
			S.M.Andrievsky+,AAP, 464, 1081, 2007	-3.06	4750	1.4	○-3.06	
			J.A.Johnson+,ApJ, 658, 1203, 2007	-2.89	4806	1.72	○-2.89	
			G.Bihain+,AAP, 423, 777, 2004	-3.01	4668	1.5	○-3.01	
			B.W.Carney+,AJ, 125, 293, 2003	-3.11	4820	1.8	○-3.11	
			S.M.Andrievsky+,AAP, 481, 481, 2008	-3.06	4750	1.4	○-3.06	
			J.A.Johnson+,ApJ, 579, 616, 2002				○-3.04	
			J.A.Johnson+,ApJ, 554, 888, 2001	-2.9	4600	0.95	○-3.05	
9	☐	BD-20_6718	C.Charbonnel+,AAP, 442, 961, 2005	-1.23	5064	3	⊙-1.23	⊙0.953
10	☐	BD-21_3420	R.Smiljanic+,ApJ, 644, L121, 2006	-1.04	5946	3.96	○-1.04	⊙1.95
			E.Caffau+,AAP, 441, 533, 2005	-1.04	5946	4.41	⊙-1.04	

previous | next

1 2 3 4 5 6 **7** 8 9 10 11 12 13 14 15 16 17 18 19 20
21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
41 42

PAGE : 7 / 42

Atmospheric parameters adopted for each object and reference

Retrieved values and available data. Choose one datum if two or more data are available.

Choose to plot this object

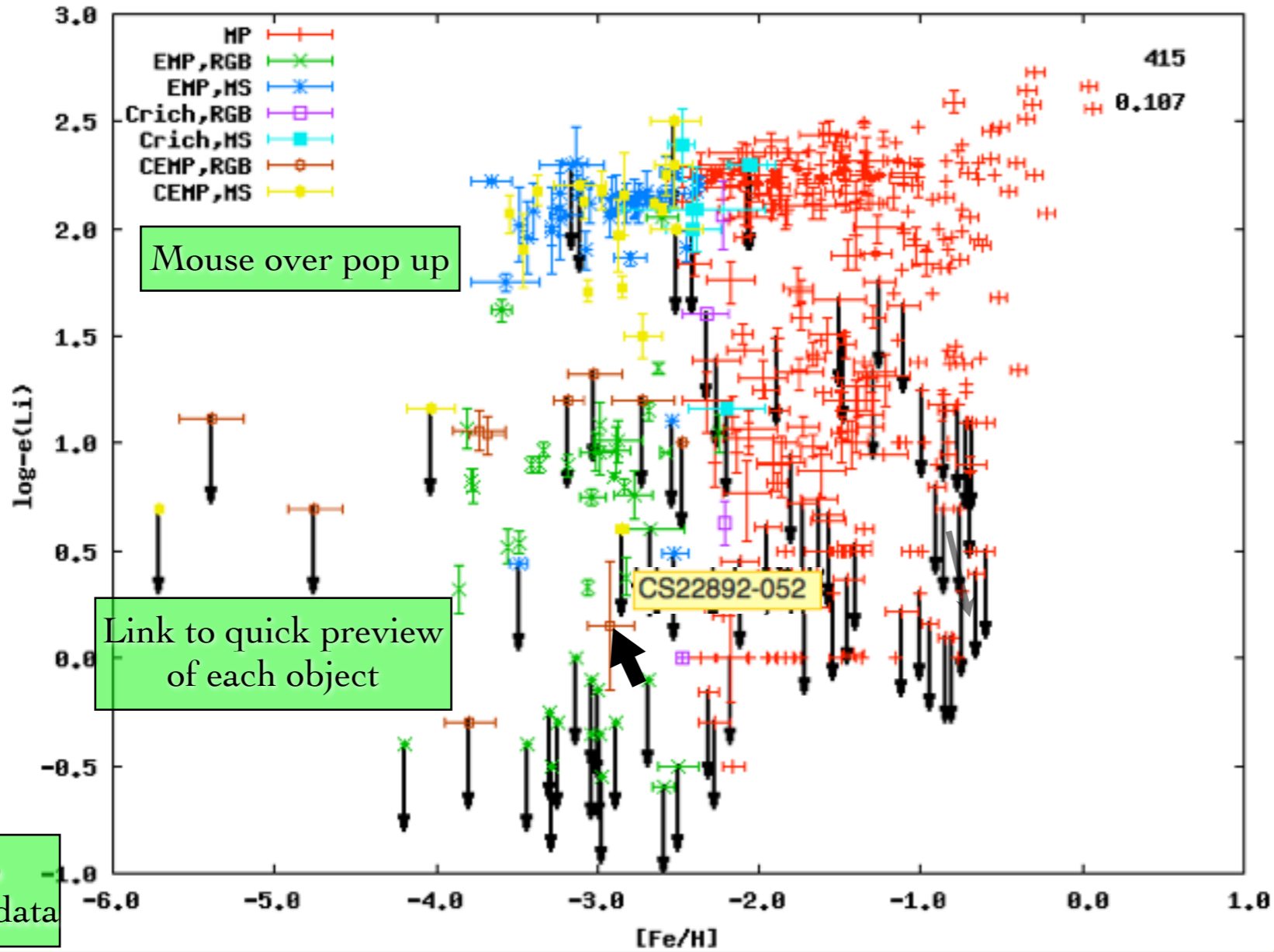Links to quick preview files in HTML format

Plot

Graph plot

Automatically generated clickable map

Mouse over pop up

Link to quick preview of each object

CS22892-052

Link to numerical data

Settings for figure

plot   reset

Title

LEGEND

⦿ Left Top   ○ Right Top
○ Left Bottom   ○ Right Bottom
○ No Key   ○ Outside

LABEL

X : [Fe/H]

Y : log−e(Li)

SCALE

X : ⦿ Linear ○ Logscale

Y : ⦿ Linear ○ Logscale

Range

X Low : *   High : *

Y Low : *   High : *

☑ > or < *   ☑

---

plot   reset   Delete all   restart

Control the list

Data		Legend	Size	Type*	Del*
1 :	☑	MP	1	1	☐
2 :	☑	EMP,RGB	1	2	☐
3 :	☑	EMP,MS	1	3	☐
4 :	☑	Crich,RGB	1	4	☐
5 :	☑	Crich,MS	1	5	☐
6 :	☑	CEMP,RGB	1	6	☐
7 :	☑	CEMP,MS	1	7	☐

Download data and script to reproduce figure

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☑ Color Figures
png ps eps pdf
Download Data
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▢ Load upload files

Upload Data*
UpLoad
**Input Data***   plot   reset

DATATYPE=

BPS CS22892-052: found in 18 paper(s).

Labels:

/C.Sneden et al.(2003)/ /R.Cayrel et al.(2004)/ /S.Honda et al.(2004)/ /N.Christlieb et al.(2004)/ /M.Spite et al.(2005)/ /A.McWilliam et al.(1995)/ /A.McWilliam et al.(1995)/ /J.E.Norris et al.(1997)/ /G.W.Preston and C. Sneden(2001)/ /P.S.Barklem et al.(2005)/ /C.Sneden et al.(2000)/ /W.Aoki et al.(2003)/ /J.J.Cowan et al.(2005)/ /S.Honda et al.(2004)/ /M.Spite et al.(2006)/ /S.M.Andrievsky et al.(2007)/ /J.A.Johnson et al.(2007)/ /D.K.Lai et al.(2007)/

Find this object in SIMBAD

Links to quick preview for this object

Link to SIMBAD

Abundance distribution of this object
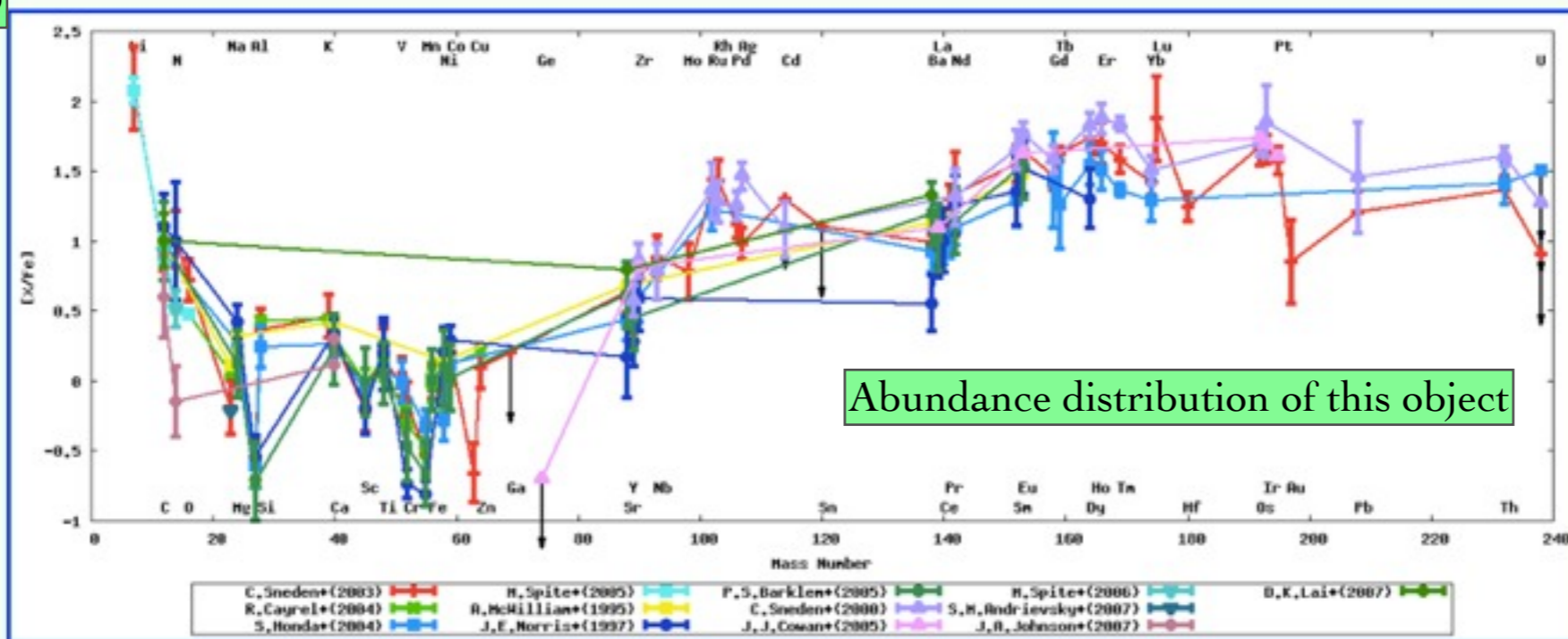
Link to ADS

C.Sneden et al.,ApJ, 591, 936, 2003 (A0003,ADS)

Link to quick preview for this reference

Atmospheric data

T_{eff} : 4800 log g : 1.50 v_{turb} : 1.95 Stellar atmosphere parameters

Chemical Abundances

☐ : Data presented in the paper
☐ : Data converted with the solar abundance from Grevesse et al. (1996)

Element	Nline	[X/H]	[X/Fe]	log-e
Li I	...	-1.01+-0.30	2.09+-0.30	+0.15+-0.30
CH	...	-2.22+-0.10	+0.88+-0.10	+6.30+-0.10
CN	...	-2.09+-0.20	+1.01+-0.20	+5.83+-0.20
O I	...	-2.38+-0.15	+0.72+-0.15	+6.45+-0.15
Na I	...	-3.29+-0.19	-0.19+-0.19	+3.04+-0.19
Mg I	...	-2.87+-0.08	+0.30+-0.08	+4.78+-0.08
Al I	...	-3.68+-0.15	-0.58+-0.15	+2.79+-0.15
Si I		-2.74+-0.15	+0.36+-0.15	+4.81+-0.15

Abundance data

and information on photometry, observing log, and binarity

特集　データベース天文学

金属欠乏星データベースの成果

須 田 拓 馬

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〒113-0013　東京都文京区本郷7-3-1〉
e-mail: suda@resceu.s.u-tokyo.ac.jp

　金属欠乏星データベース（SAGAデータベース）は恒星の元素組成データを収集したデータベースであり，2008年以来オンラインで常時公開している．元素組成データは恒星内部での元素合成を知る手がかりとなるだけでなく宇宙の物質進化，星形成史を理解するうえでも重要であり，その価値は普遍的である．本稿では，SAGAデータベースの概要を紹介するとともに，データ利用の現状について報告する．

1.　天文学の基礎情報としての元素組成データ

　宇宙に存在する元素の大部分は恒星内部での核融合反応によって合成される．宇宙において，元素がどのように分布するかという情報は元素合成過程だけでなく，星形成，恒星進化，銀河の形成と進化，ひいては宇宙の進化を理解するうえでも

AGB段階の質量放出によって輝く惑星状星雲の元素組成が，X線領域では超新星残骸の元素組成が測定できる．

　元素組成データは恒星だけでなく，他の天体の研究においても重要な役割を果たしている．星形成の現場である星間分子雲の電波観測では，星形成過程の段階を判定する指標として分子の輝線強度比が用いられる．元素の存在量は分子雲の構造

SAGA Database Extension to Stars in dSph

~20 dwarf spheroidal galaxies

Data registered(as of Aug. 2015)
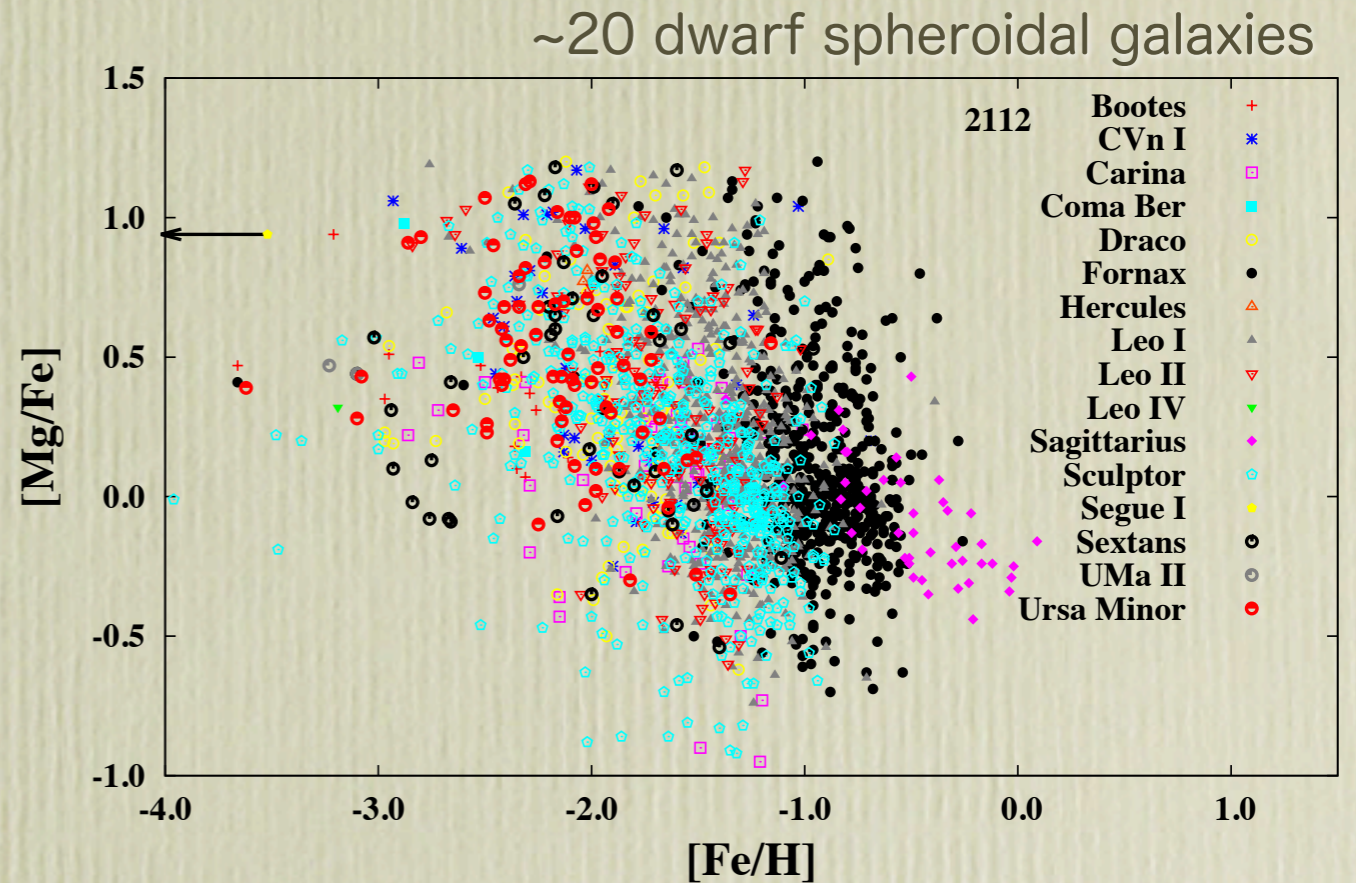# of papers: 57 (1998-2013)241
# of objects: 5925(5785)
# of data: 9269(4491)
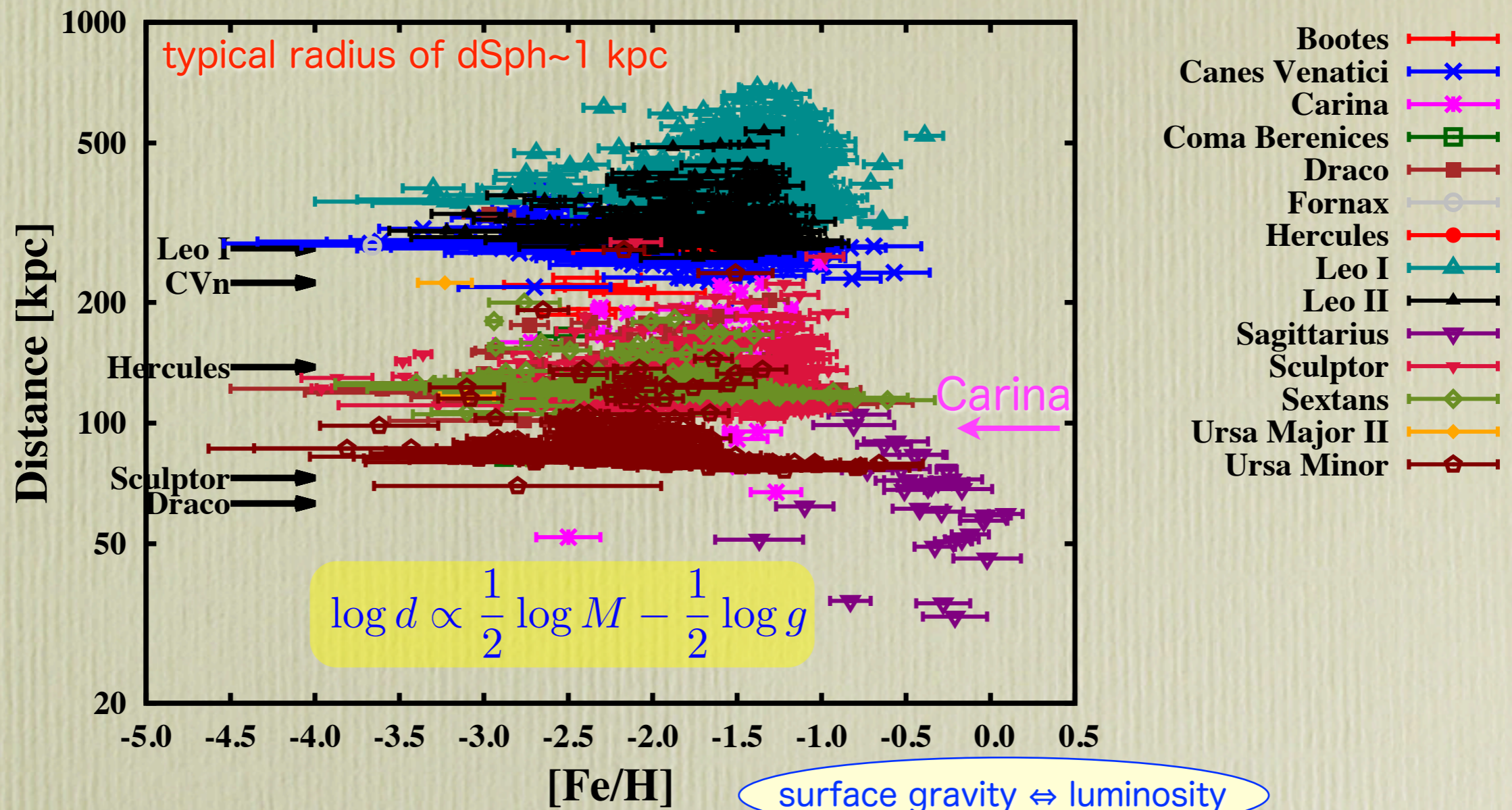 [X/H]: 18,992   84134   Galactic
  V mag.: 3,916   2039   stars
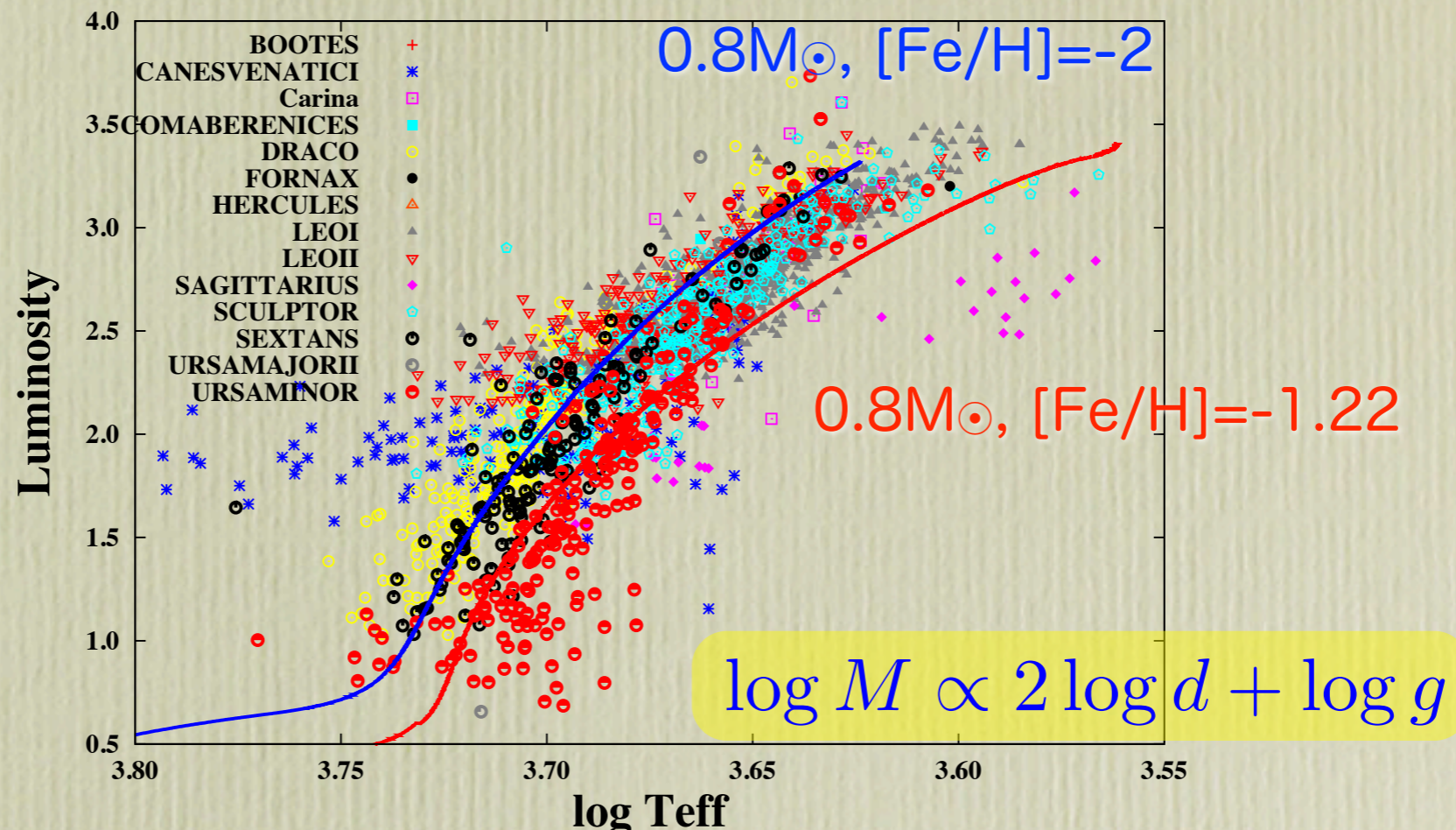 Position: 2,422   1522

cf) ~3,500 stars for Galactic stars

Distance Distribution of dSph (M=0.8 M⊙)

★ Distance is a function of V, log g, Teff, and M.

  ★ stellar mass is assumed to be constant (0.8M⊙).

★ Distance can be estimated photometrically.

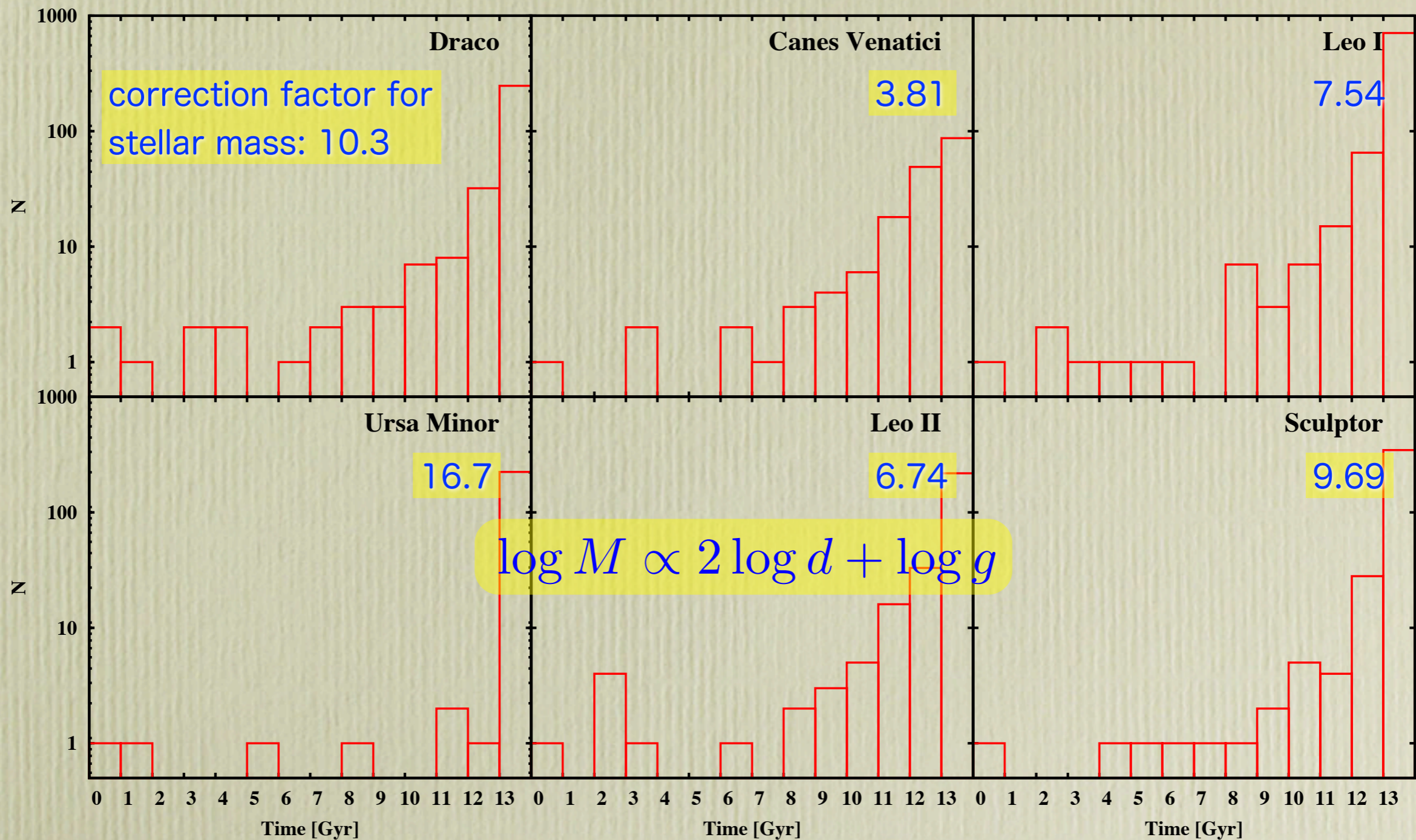 ★ Isochrone fitting on the CMD.

Comparisons on the CMD

Star formation history can be derived from the mass distribution by fixed distances and log g.

⭐ reasonable agreement with 0.8M☉ evolutionary tracks.
　⭐ consistent between model and observation on the CMD
⭐ problems in the estimates of distance or log g?
　⭐ 1 dex difference in log g still gives insignificant change of derived abundances.

## Star Formation History in dSph at Const. Distance

Draco — correction factor for stellar mass: 10.3

Canes Venatici — 3.81

Leo I — 7.54

Ursa Minor — 16.7

Leo II — 6.74

Sculptor — 9.69

$$\log M \propto 2\log d + \log g$$

Time [Gyr]

N

⭐Mass (lifetime) distribution at fixed distances.

⭐Distances at set at constant so that the maximum lifetime is 14 Gyr.
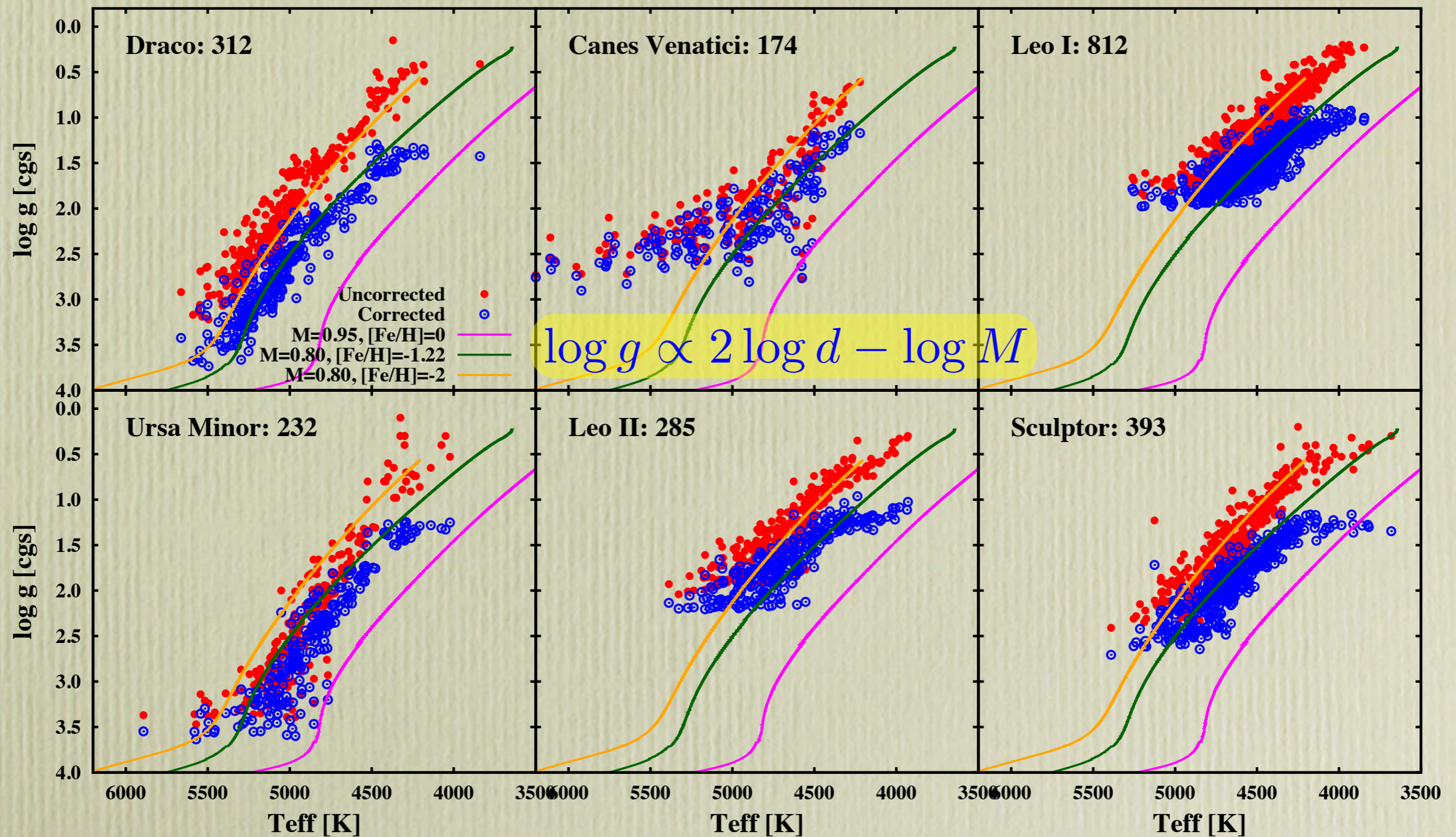
SFH of dSph (Comparisons on the CMD)

Cumulative Star Formation History

Draco

CVnI

LeoI

UrsaMin

LeoII

Sculptor-1

Lookback time [Gyr]

Weisz+14
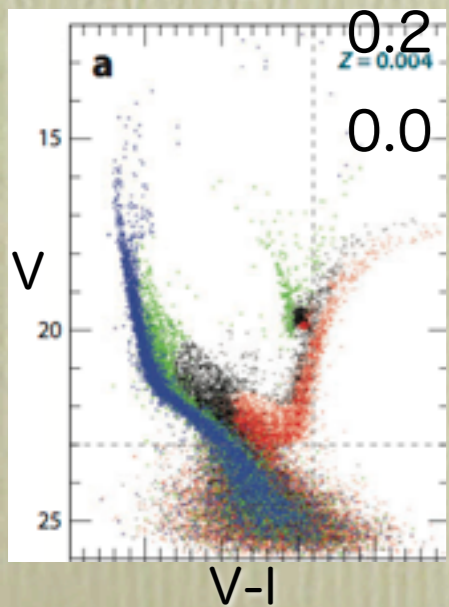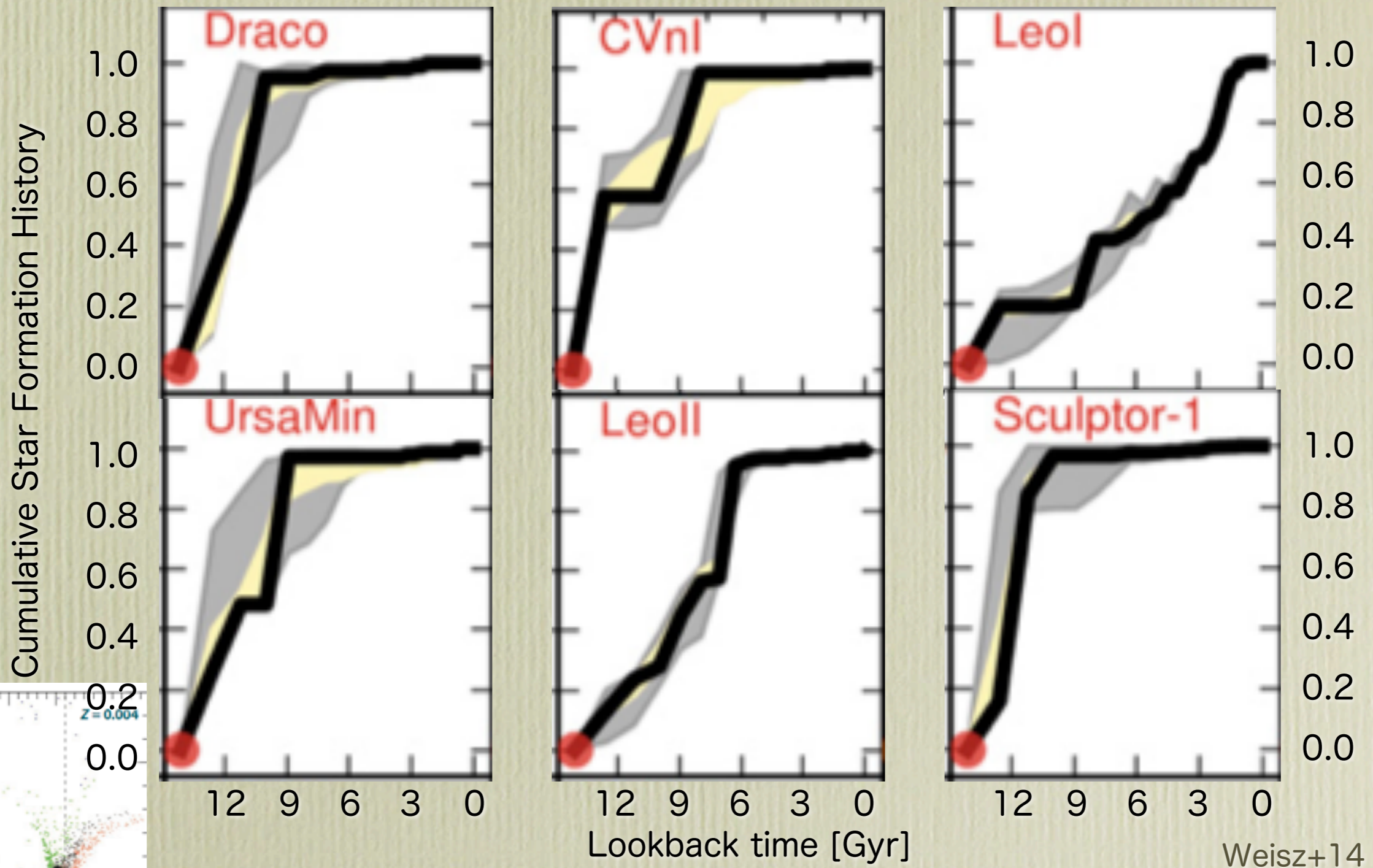
Tolstoy+09

⭐inconsistent with simple stellar population for Draco and Sculptor

Comparisons on CMD at Const. Mass and Distance

Uncorrected ● (red)
Corrected ○ (blue)
M=0.95, [Fe/H]=0
M=0.80, [Fe/H]=-1.22
M=0.80, [Fe/H]=-2

Draco: 312
Canes Venatici: 174
Leo I: 812
Ursa Minor: 232
Leo II: 285
Sculptor: 393

$$\log g \propto 2 \log d - \log M$$

☆corrected log g with constant mass and distance

☆not valid for galaxies with complex SFH (CVn, Leo I, Leo II).

☆Is corrected values of log g consistent with isochrone fitting?

Summary

- Star formation history (SFH) of dwarf spheroidal galaxies (dSph) are explored using the Color-Magnitude Diagram.
  - comparisons of isochrones with photometric data.
- There is a problem in distance estimate in the SAGA database for dSph.
  - Data with fixed mass and surface gravity (luminosity) gives a large scatter in the distance within the same galaxies.
- SFHs derived from spectroscopic RGB data are inconsistent with those with those from photometric CMD data.
- surface gravity is underestimated in most of galaxies.
  - SFHs should be checked again with the corrected surface gravity.