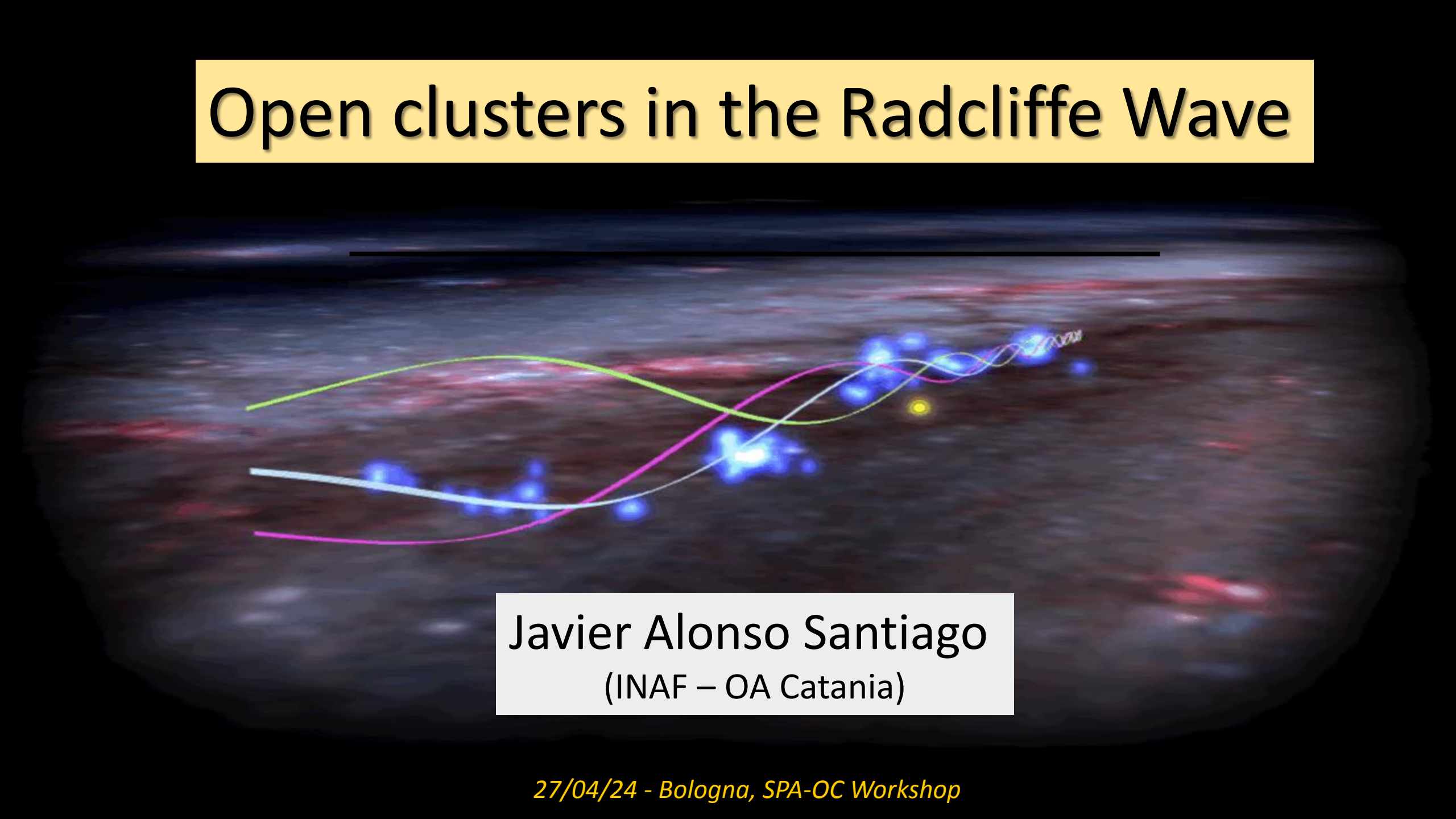
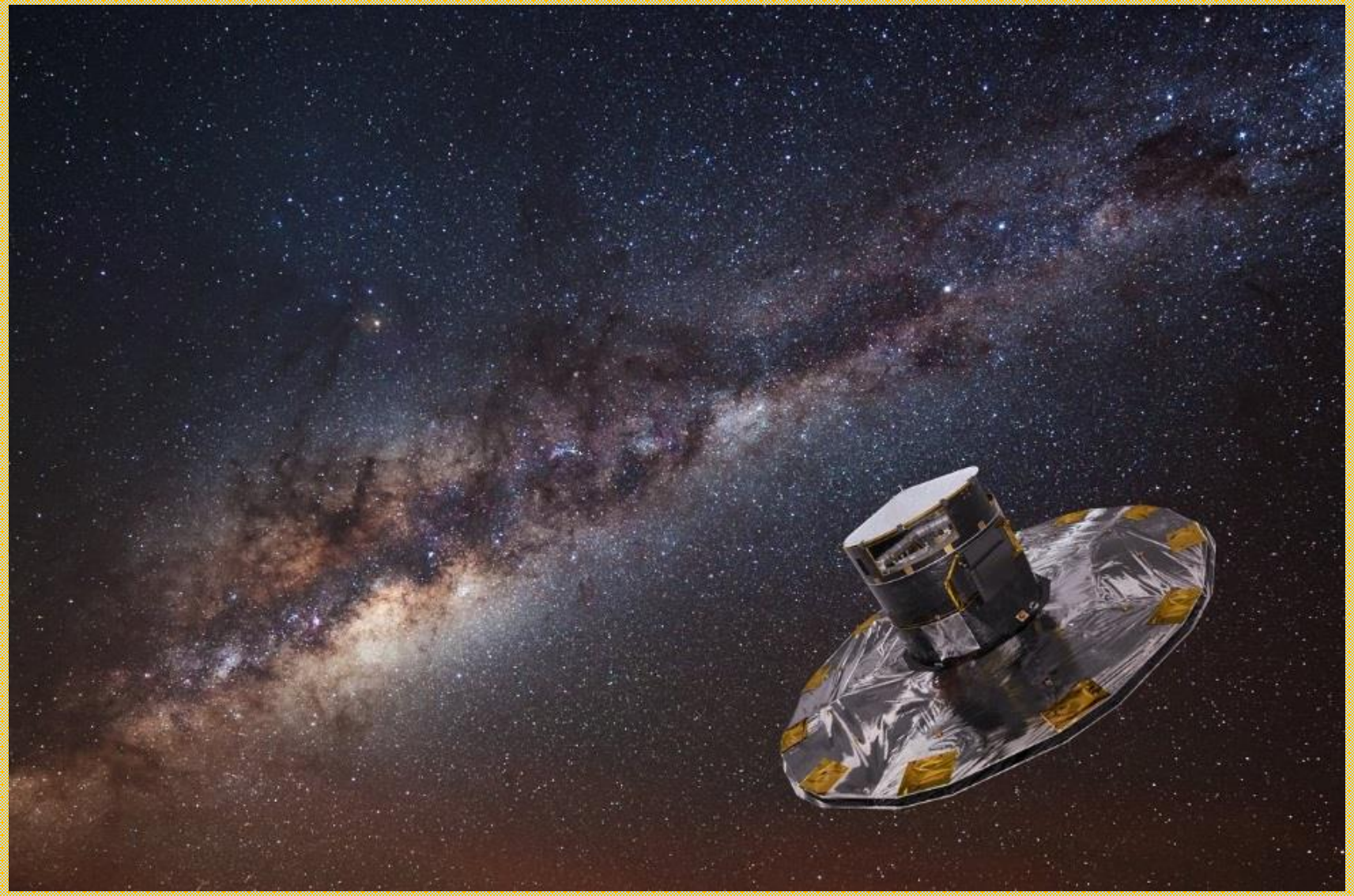
Open clusters in the Radcliffe Wave



Javier Alonso Santiago
(INAF – OA Catania)

27/04/24 - Bologna, SPA-OC Workshop

THE RADCLIFFE WAVE

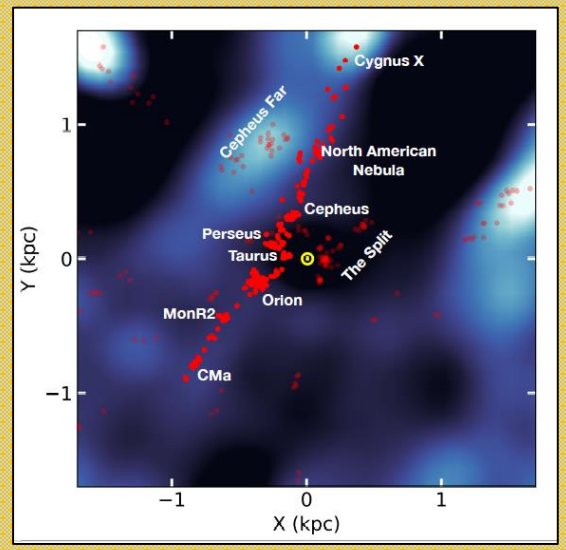


THE RADCLIFFE WAVE

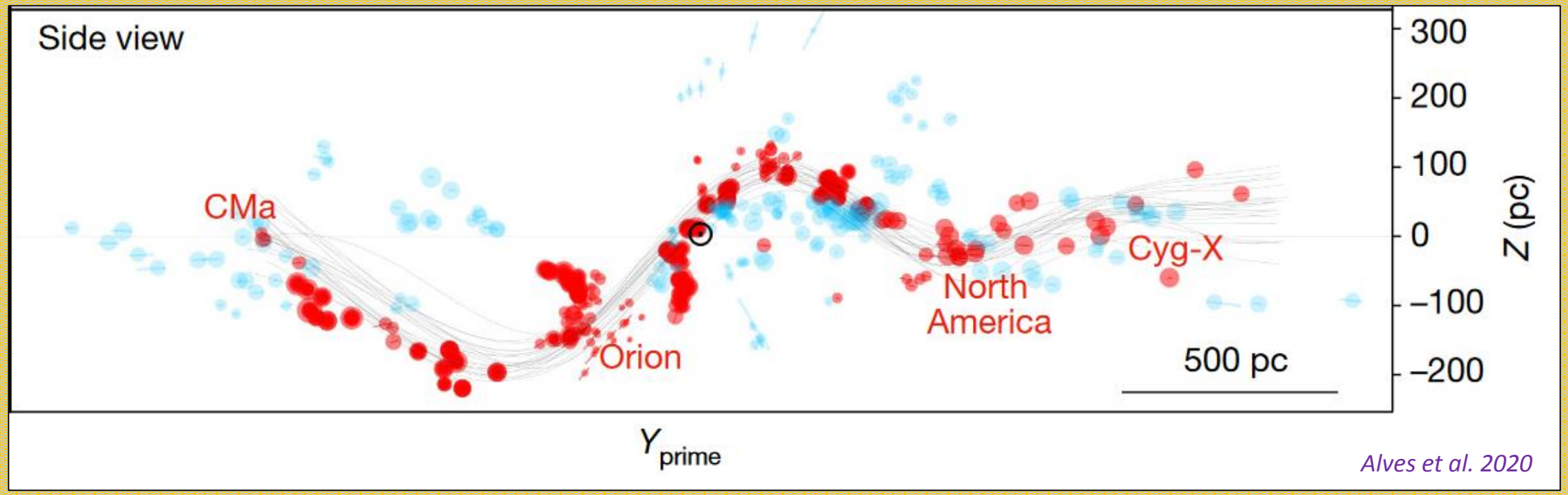
THE RADCLIFFE WAVE

"A Galactic-scale gas wave in the solar neighbourhood"

Alves et al. 2020



Swiggum et al. 2022

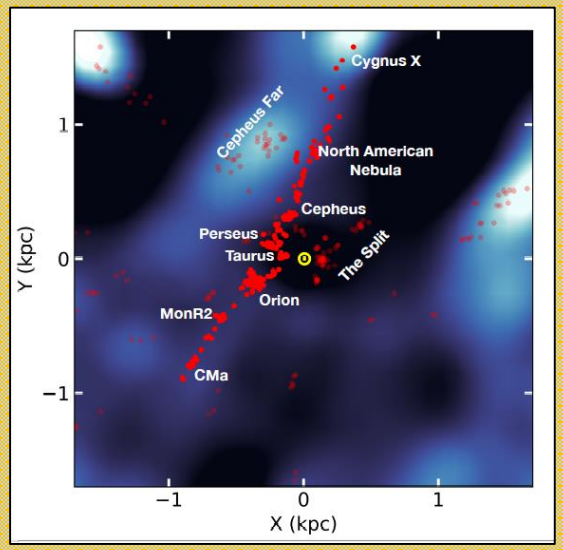


Alves et al. 2020

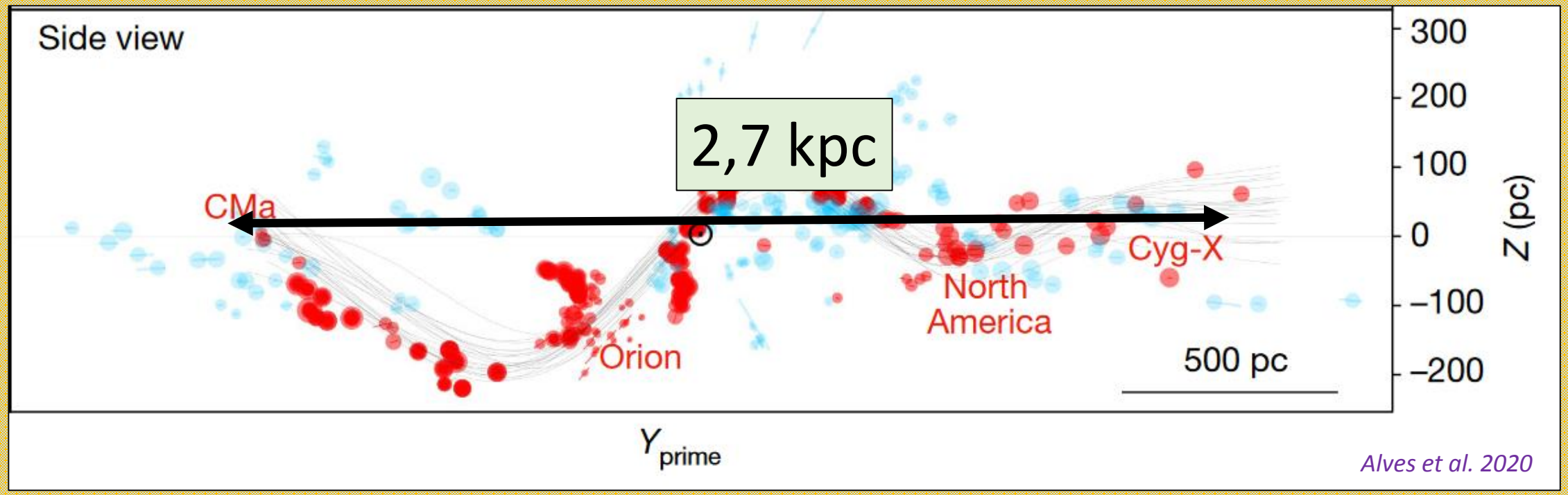
THE RADCLIFFE WAVE

"A Galactic-scale gas wave in the solar neighbourhood"

Alves et al. 2020



Swiggum et al. 2022

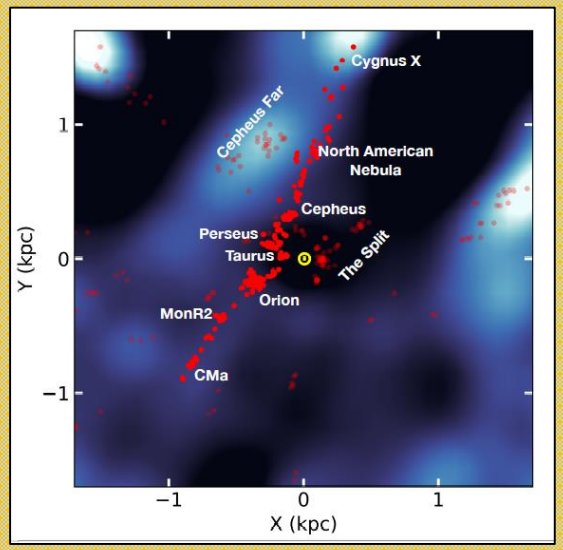


Alves et al. 2020

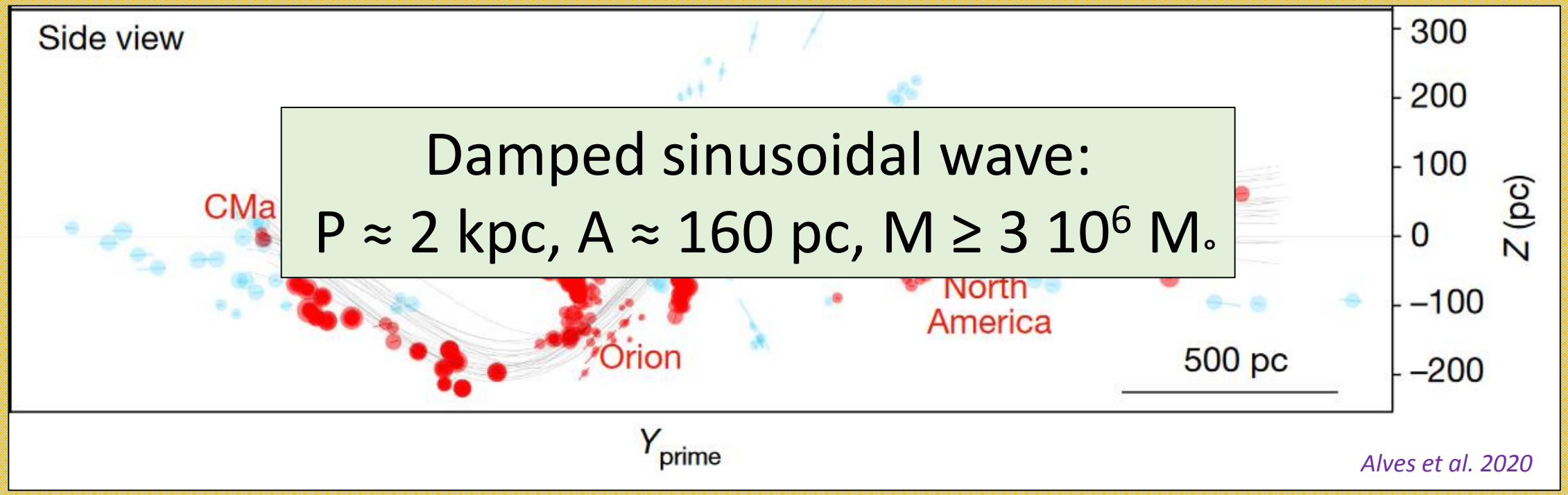
THE RADCLIFFE WAVE

"A Galactic-scale gas wave in the solar neighbourhood"

Alves et al. 2020



Swiggum et al. 2022



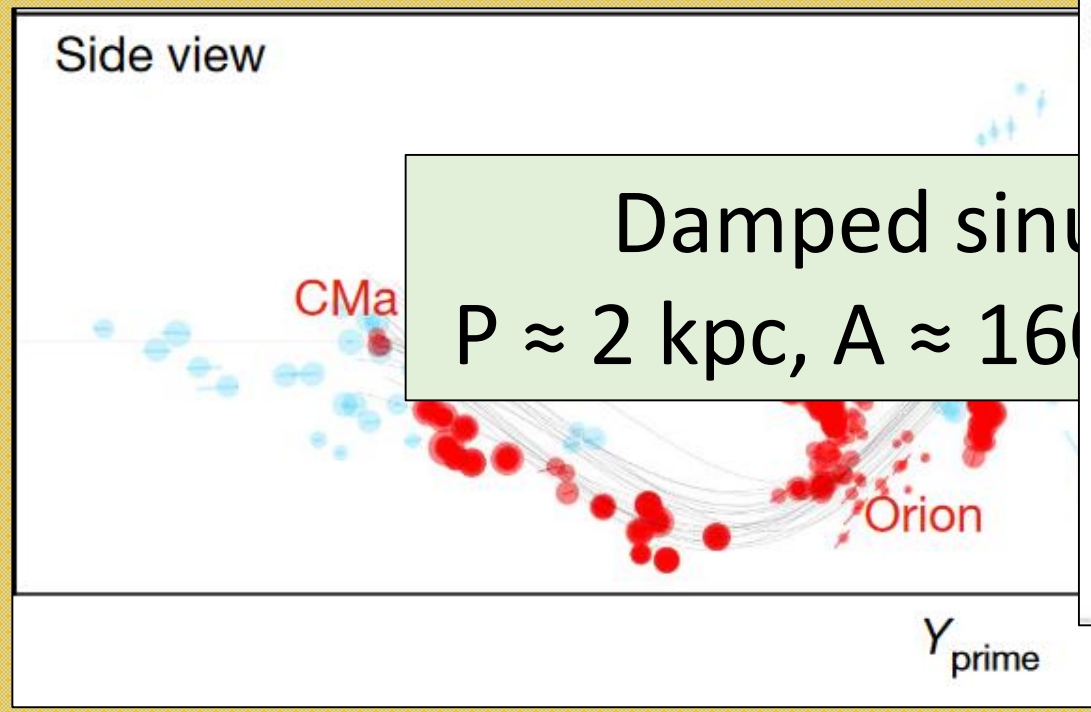
Damped sinusoidal wave:

$P \approx 2$ kpc, $A \approx 160$ pc, $M \geq 3\ 10^6\ M_\odot$

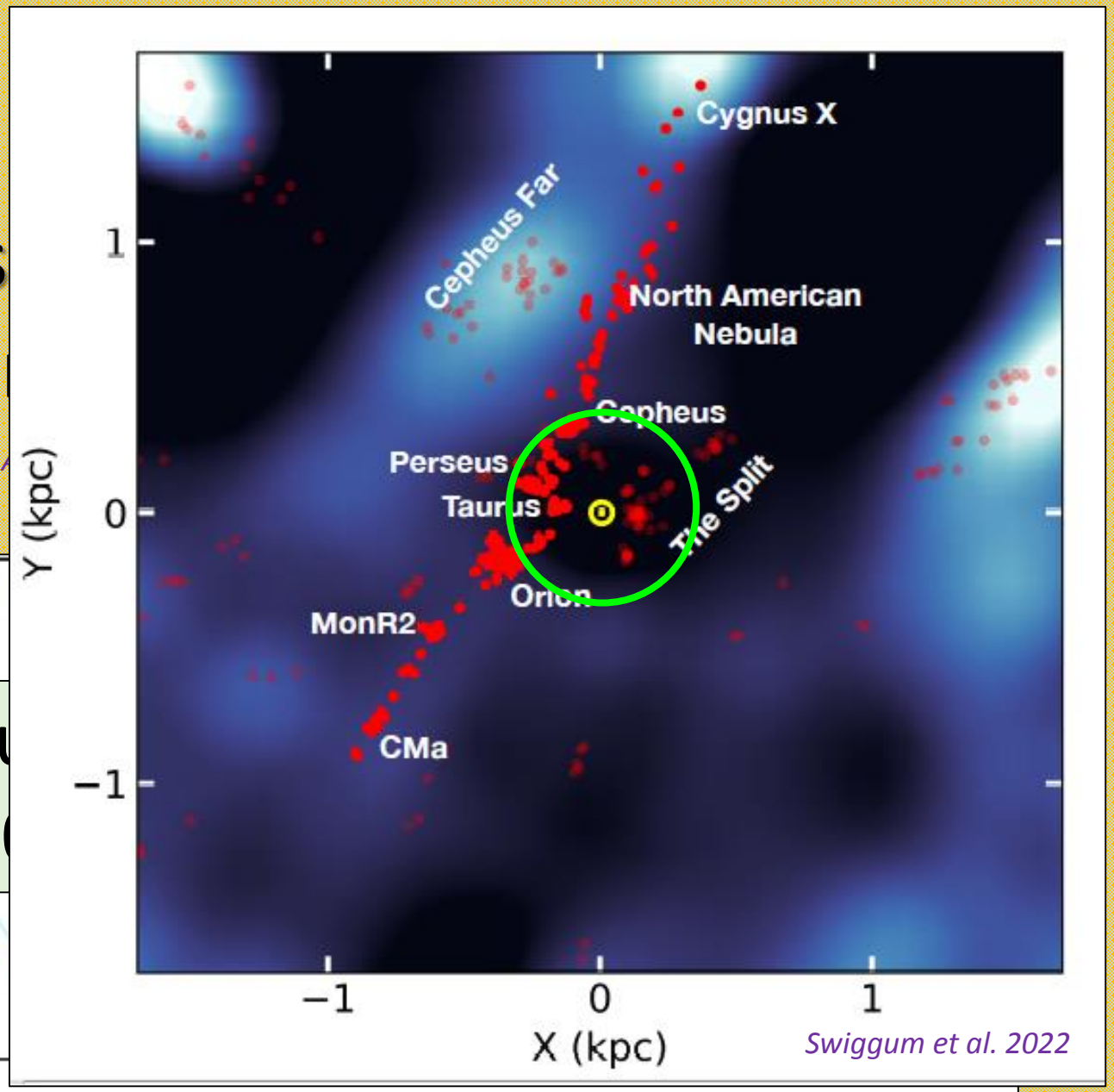
Alves et al. 2020

THE RADCLIFFE WAVE

"A Galactic-scale gas
the solar neighbou



Damped sinu
P ≈ 2 kpc, A ≈ 16

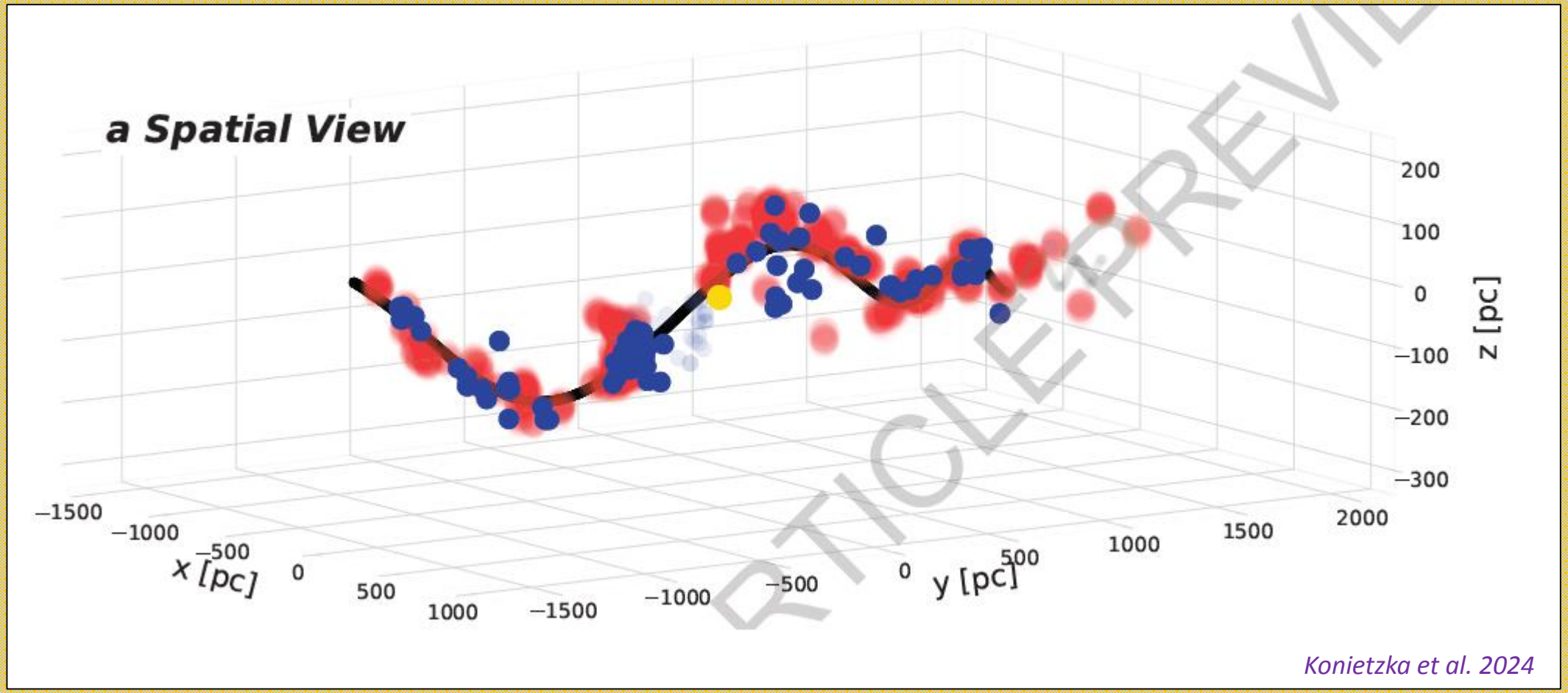


Swiggum et al. 2022

Alves et al. 2020

THE RADCLIFFE WAVE

"The Radcliffe Wave is Oscillating"

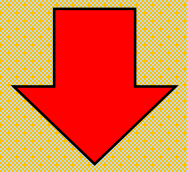


Konietzka et al. 2024

THE RADCLIFFE WAVE

What about its chemical composition?

The Wave and its individual complexes, a **natural laboratory**



Star formation in giant molecular clouds, metal mixing?

INAF – TIME ALLOCATION COMMITTEE

Application for observing time **Category: D**

Period AOT46 (October 2022 – March 2023) **Submit using: www.tng.iac.es/submit.html**

1. Title

Metal mixing in the Radcliffe Wave traced by young open clusters

2. Abstract

The Radcliffe Wave has only recently been recognised as a $\sim$ 3 kpc long coherent gas structure encompassing the majority of star forming regions in the solar vicinity. Also young (age $\leq$ 100 Myr) open clusters have been tentatively associated to the Radcliffe Wave. A dynamical connection between the regions along the Wave remains elusive and the nature and origin of this feature found in the dense gas are not well understood. Measuring stellar detailed chemical composition is in principle easier than determining information from the molecular gas. We propose to use GIARPS observations to derive detailed chemical abundances and radial velocities for 25 stars in five young clusters associated to the Wave to derive further insight about its history. By observing open clusters at different positions along the Radcliffe Wave we will provide useful constraints on the possible differences, which could be related to inhomogeneous mixing in the natal clouds. The chemical characterisation will mainly rest on HARPS-N spectra. GIANO spectra, besides providing more information for elements of interest (e.g., O, C, Zn), have the unique bonus of measurement of the helium abundance.

3a. Number of requested hours per telescope and instrument (must include overheads)

TNG						REM	
DOLORES	DOL.+MOS	NICS	HARPS-N	GIANO-B	SIFAP2	ROSS	REMIR
			31.3	31.3			

3b. Observing modes

TNG:	X	Visitor		Service		ToO
REM:		Rapid Response		Queuing		ToO

4a. Preferred months

first choice: October second choice: Sep, Nov

4b. Other scheduling constraints (use also box 14)

These observations will be performed in GIARPS mode.

5a. Past and future of the project

a) Hours already awarded to the project: 0

b) Hours foreseen to complete the project: 0
(not including this request)

6. Principal investigator

Name Angela Bragaglia

Institute INAF-OAS Bologna

Address via P. Gobetti 93/3, 40129 Bologna

e-mail angela.bragaglia@inaf.it

Phone +390516357332

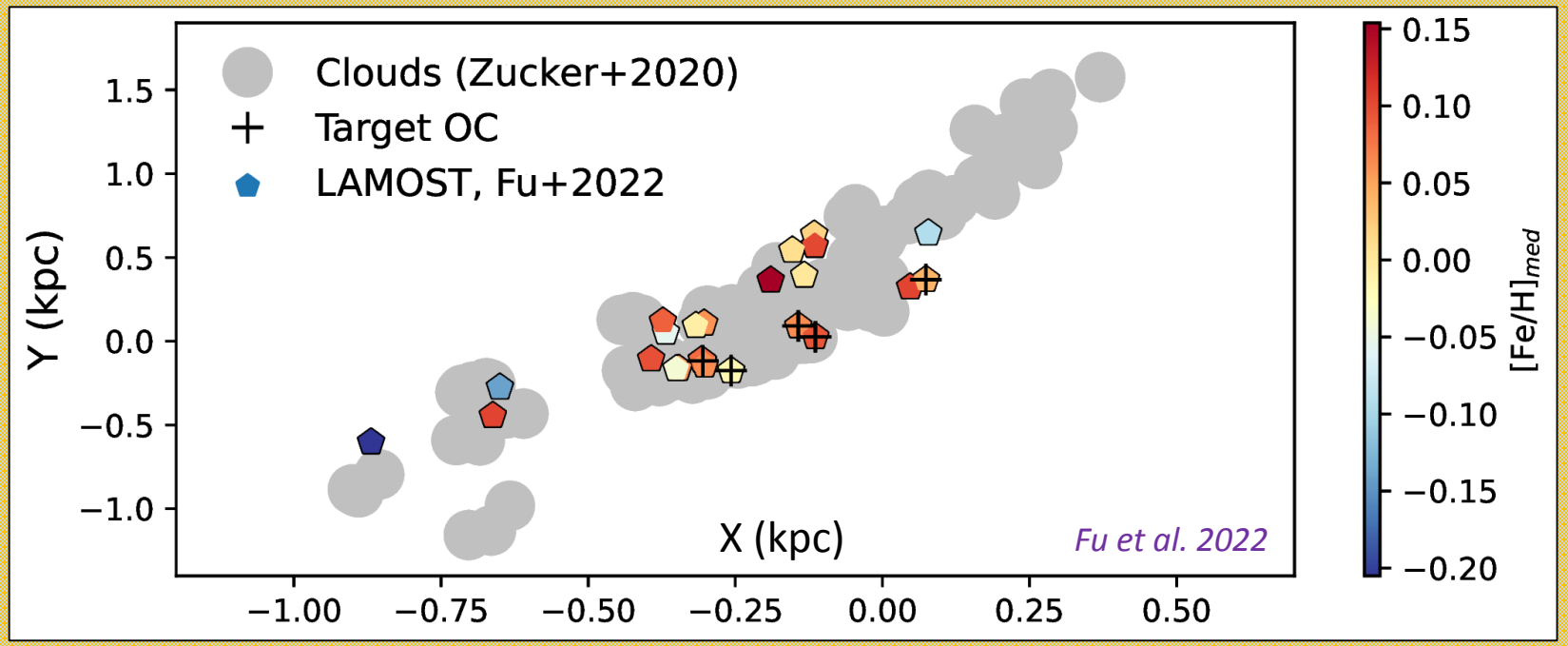
7. Co-investigators (name and institution)

-Javier Alonso-Santiago, Giovanni Catanzaro, Antonio Frasca: INAF-OA Catania, Italy
-Gloria Andreuzzi: INAF-OA Roma, Italy; Fundacion Galileo Galilei, Spain
-Ricardo Carrera, Valentina D'Orazi, Sara Lucatello, Lorenzo Spina, Antonella Vallenari: INAF-OA Padova, Italy
-Laura Magrini: INAF-OA Arcetri, Italy
-Xiaoting Fu: Peking University, China (& INAF-OAS Bologna associate)
-Mingjie Jian: Tokyo University, Japan

TARGET SELECTION

1 – SAMPLE OF **OPEN CLUSTERS** ASSOCIATED WITH THE RADCLIFFE WAVE

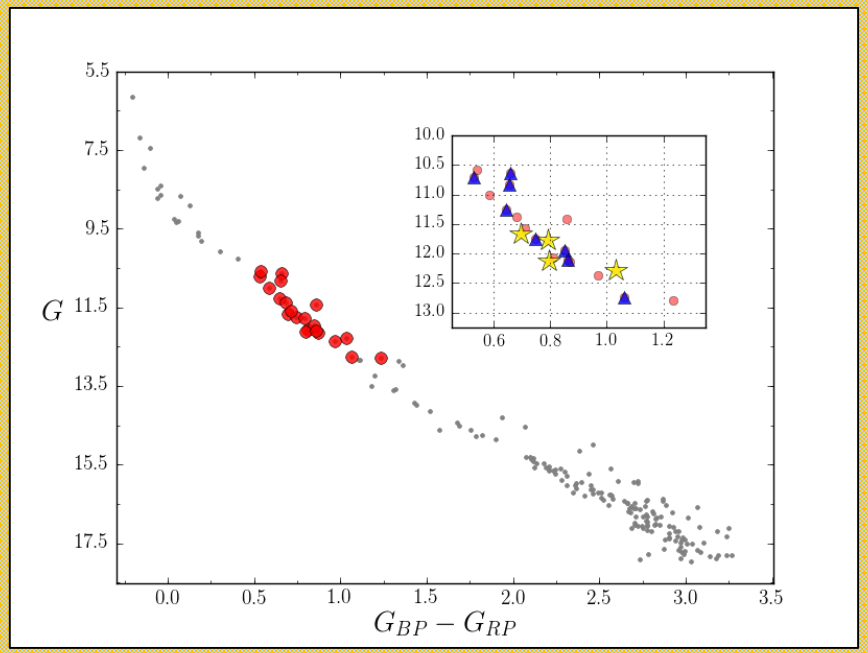
ASCC 16, NGC 2232, Roslund 6 + Pleiades, Melotte20



TARGET SELECTION

2 – SELECTION OF **INDIVIDUAL STARS** IN EACH CLUSTER

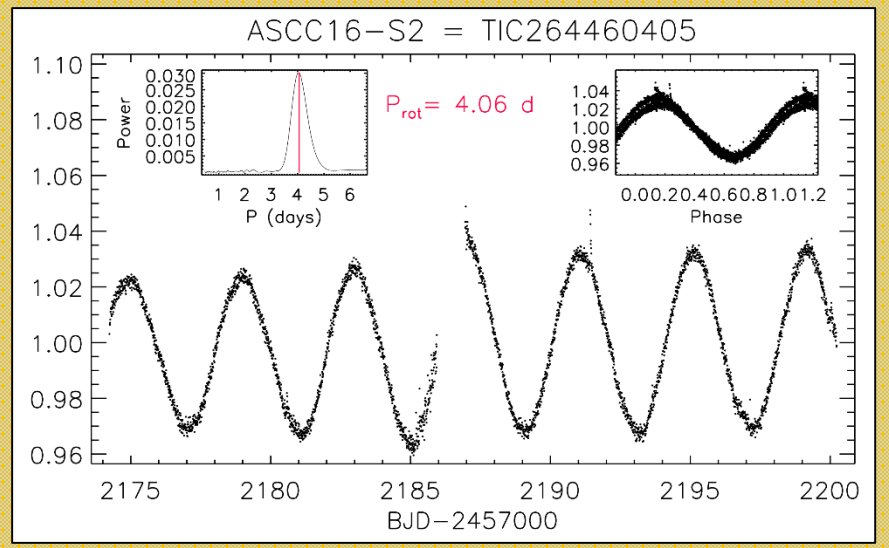
- Few representative stars per cluster ➡ Observation time optimization
- (Moderately) slow rotators ➡ Main Sequence G-type stars



Mamajeck calibration

V_{broad} < 40 km/s

Prot ≥ 3d (TESS)



DATA COLLECTION

26 – 28 October, 2022

3.6-m Telescopio Nazionale Galileo

GIARPS

Claudi et al. 2017

HARPS-N

Cosentino et al. 2014

R = 115 000
3900 – 6800 Å

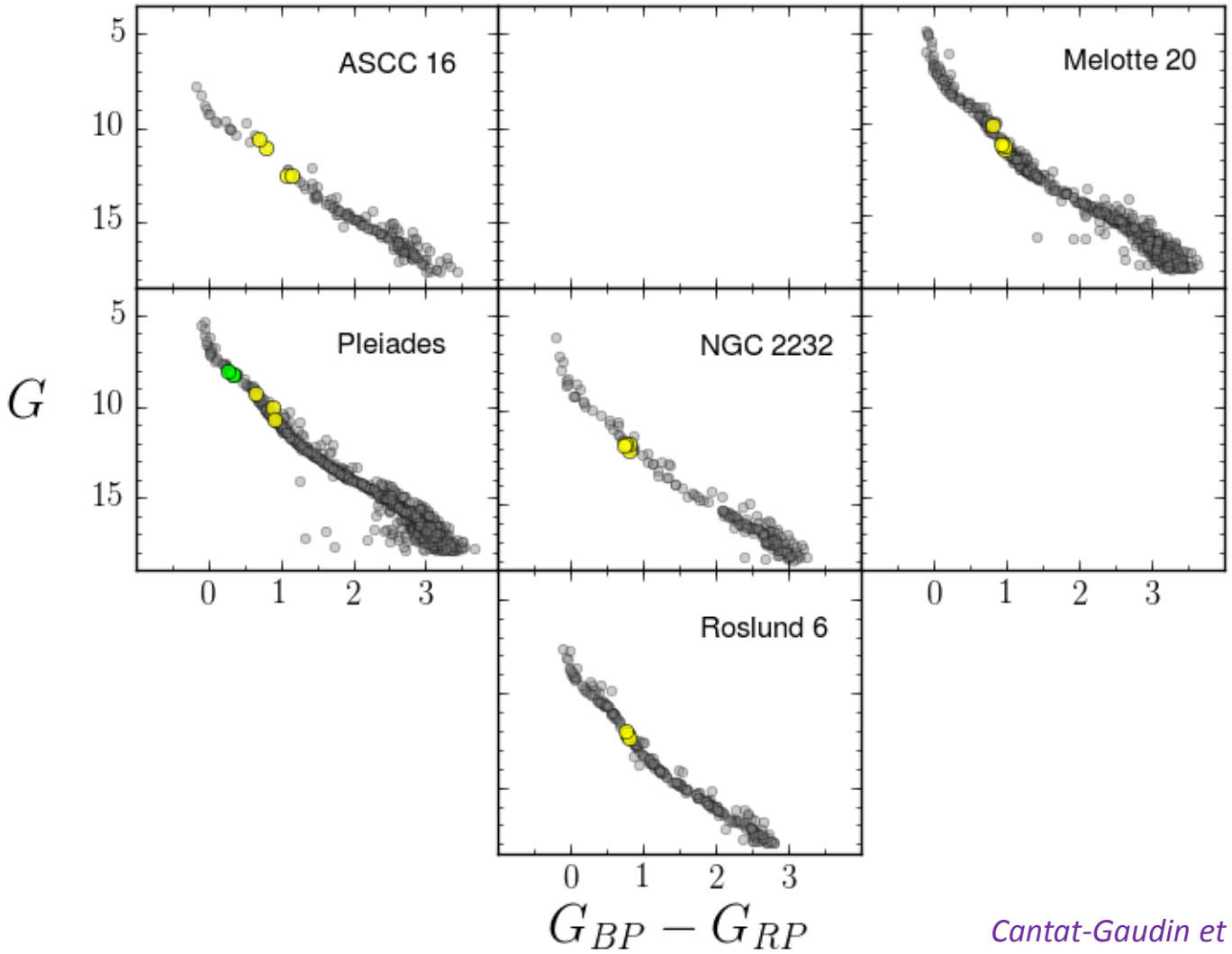
✚

GIANO-B

Oliva et al. 2012, Origlia et al 2014

R = 55 000
9700 – 24 500 Å

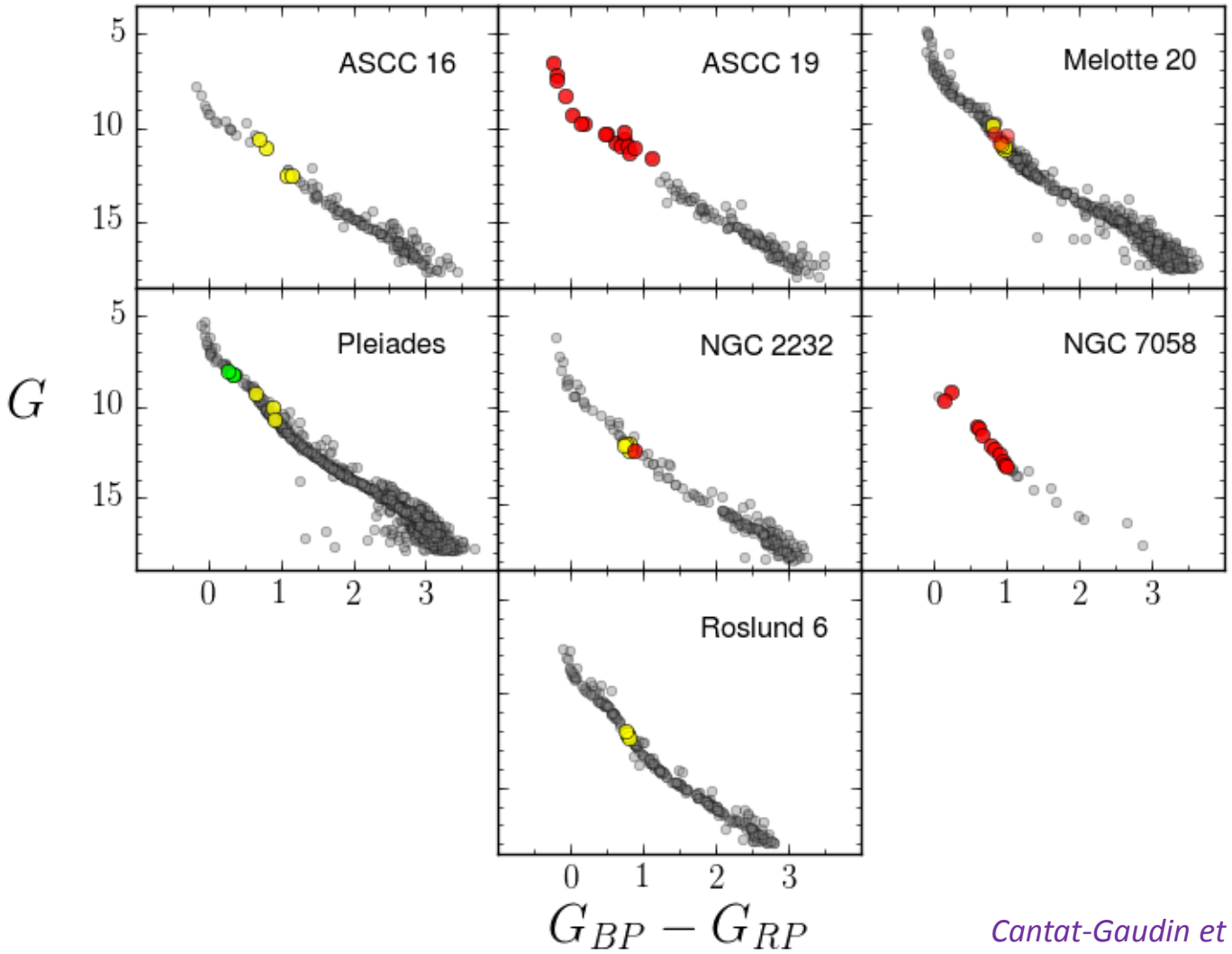
DATA COLLECTION



Cantat-Gaudin et al. 2020

Cluster	Obs
ASCC 16:	4
Melotte 20:	5
Pleiades:	3 (+3)
NGC 2232:	4
Roslund 6:	4

DATA COLLECTION



Cantat-Gaudin et al. 2020

Cluster	Obs	SPA
ASCC 16:	4	
ASCC 19:		17
Melotte 20:	5	3
Pleiades:	3 (+3)	
NGC 2232:	4	2
NGC 7058:		12
Roslund 6:	4	

DATA COLLECTION

Clusters main parameters

Cluster	$r50$ (°)	N	$\log\tau$	A_V	d (pc)	Stars observed
ASCC 16	0.376	175	7.13	0.20	344	4
ASCC 19	0.605	149	7.02	0.13	346	17
Melotte 20	2.027	747	7.71	0.30	171	8
Pleiades	1.274	952	7.89	0.18	128	6
NGC 2232	0.516	188	7.25	0.01	315	6
NGC 7058	0.109	26	7.61	0.18	350	12
Roslund 6	1.004	247	7.95	0.00	375	4

Cantat-Gaudin et al. 2020

Total number of stars in our sample (2019 – 2022)

57

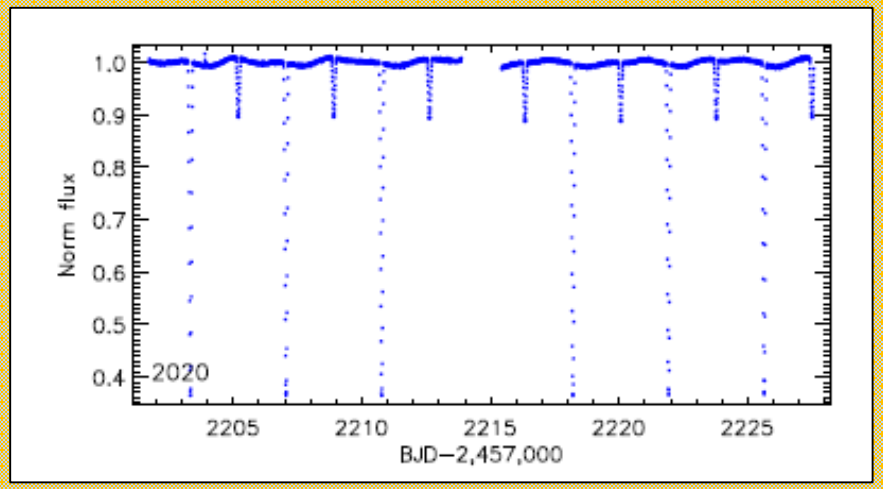
RESULTS

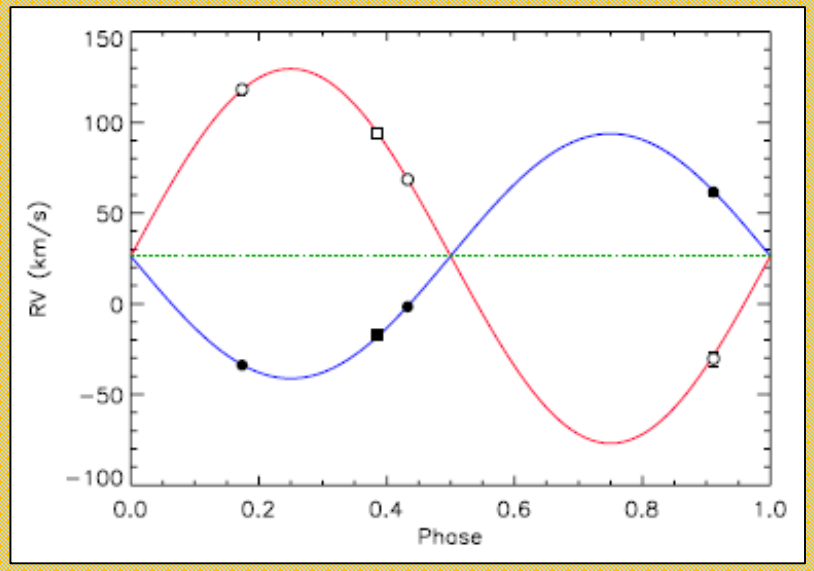
A&A 677, A154 (2023)
https://doi.org/10.1051/0004-6361/202347226

Astronomy & Astrophysics

TIC 43152097 The first eclipsing binary in NGC 2232★

A. Frasca[1], J. Alonso-Santiago[1], G. Catanzaro[1], A. Bragaglia[2], V. D'Orazi[3,4], X. Fu[5,2], A. Vallenari[4], and G. Andreuzzi[6,7]



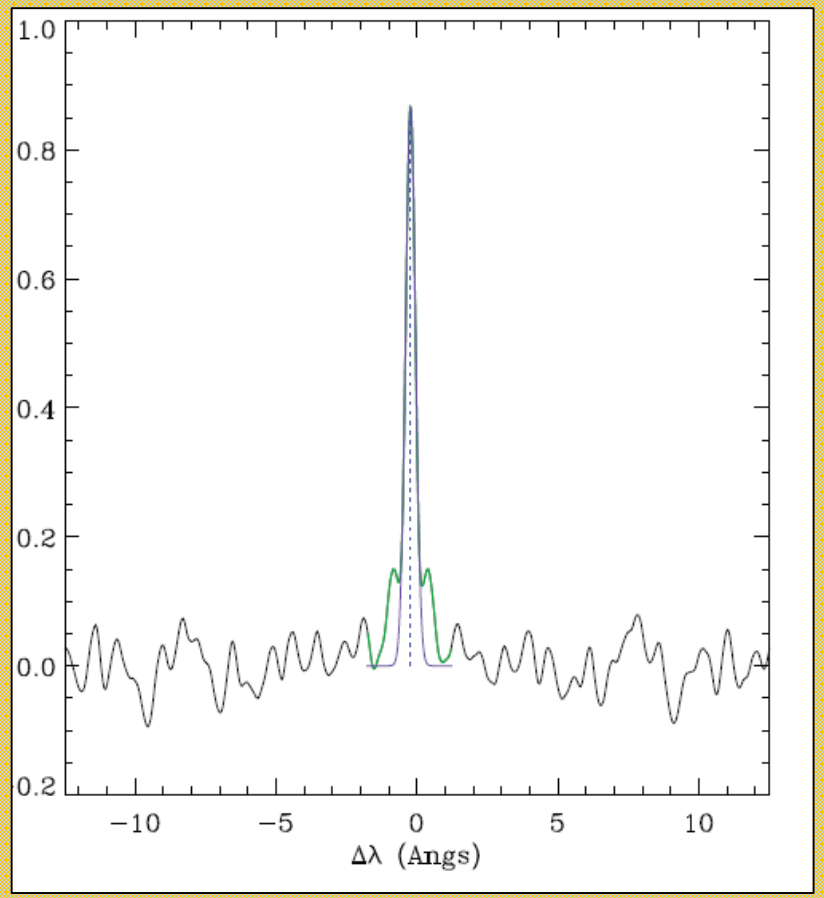


Orbital parameters	
BJD_0 [(a)]	2225.641 ± 0.001
P_{orb} (d)	3.718265 ± 0.000007
e	0
ω (°)	...
γ (km s^{-1})	26.27 ± 0.58
K_1 (km s^{-1})	67.48 ± 0.78
K_2 (km s^{-1})	103.28 ± 3.32
$M_1 \sin^3 i$ ($M_\odot$)	1.160 ± 0.083
$M_2 \sin^3 i$ ($M_\odot$)	0.758 ± 0.033
$q = M_2/M_1$	0.653 ± 0.022
$a \sin i$ ($R_\odot$)	12.54 ± 0.25
Stellar parameters	
M_1 ($M_\odot$)	1.160 ± 0.083
M_2 ($M_\odot$)	0.758 ± 0.033
R_1 ($R_\odot$)	1.121 ± 0.022
R_2 ($R_\odot$)	0.885 ± 0.021
$\log g_1$ (cgs)	4.423 ± 0.020
$\log g_2$ (cgs)	4.440 ± 0.016
T_1 (K)	6070 ± 70
T_2 (K)	4130 ± 60
L_1 ($L_\odot$)	1.531 ± 0.093
L_2 ($L_\odot$)	0.204 ± 0.015

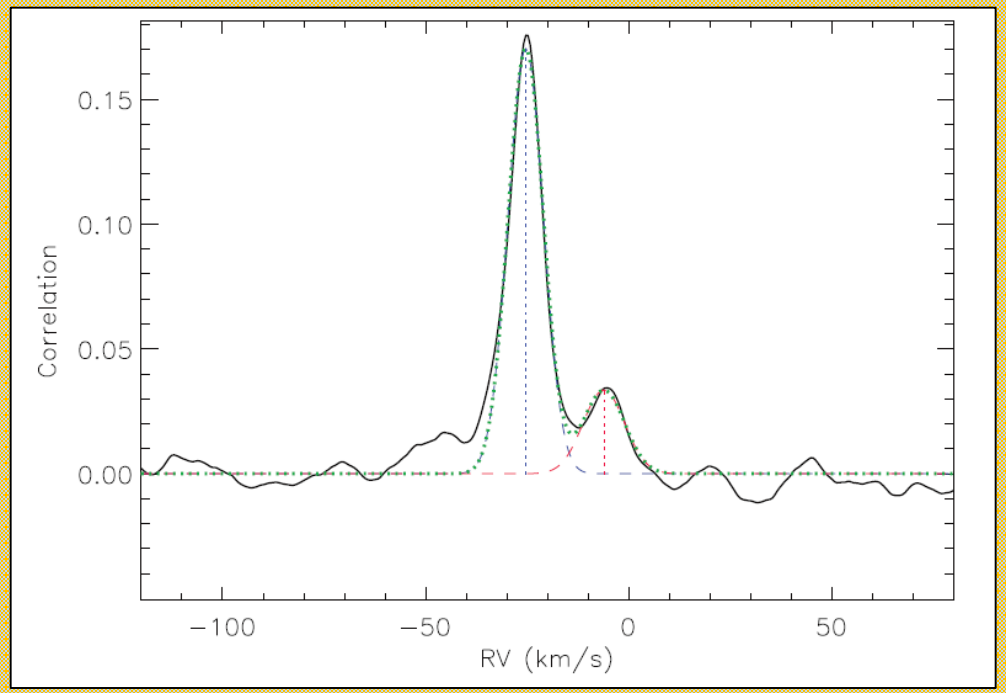
RESULTS

Radial velocity

Different CCFs



Single



SB2

RESULTS

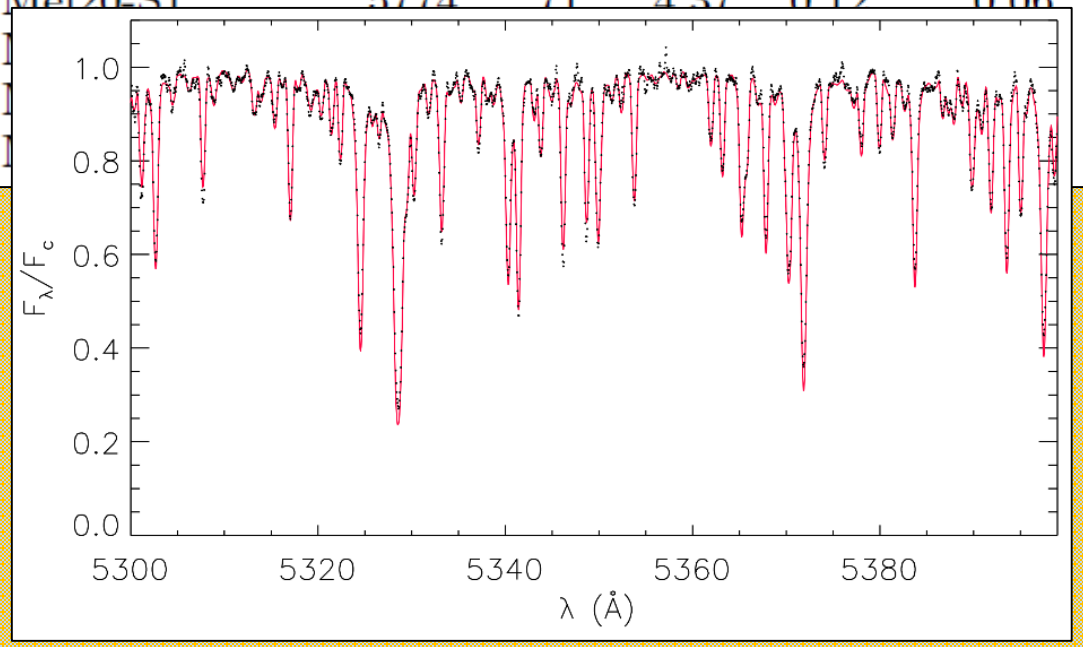
Stellar Parameters

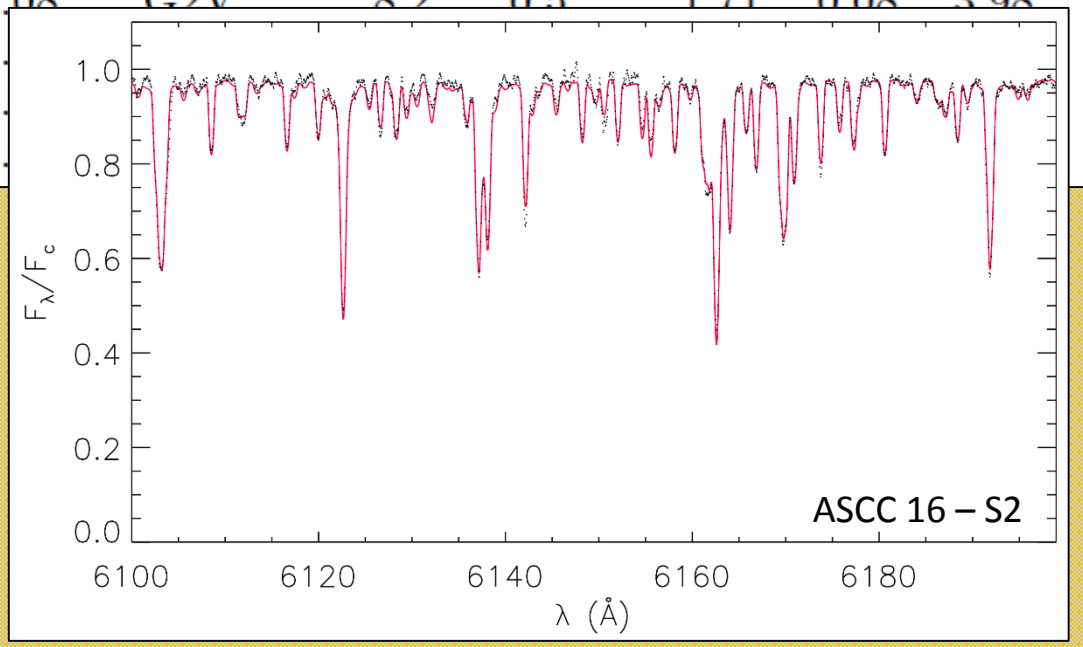
Single FGK stars (41)

ROTFIT

Frasca et al. 2021

ID	$T_{\rm eff}$ (K)	err	log g (dex)	err	[Fe/H] (dex)	err	SpT	$v \sin i$ (km s^{-1})	err	RV (km s^{-1})	err	$P^a_{\rm rot}$ (d)
Mel20-A1	5752	69	4.35	0.12	0.19	0.07	G2.5V	1.9	1.4	−5.98	0.07	...
Mel20-A2	5843	71	4.44	0.11	−0.03	0.10	G1V	11.6	0.4	−1.62	0.12	4.08
Mel20-A3	6101	70	4.20	0.10	0.09	0.08	F8V	4.4	0.8	−0.68	0.06	2.64
Mel20-S1	5774	71	4.37	0.12	0.06	0.08	G2V	8.2	0.5	1.71	0.08	3.98





RESULTS

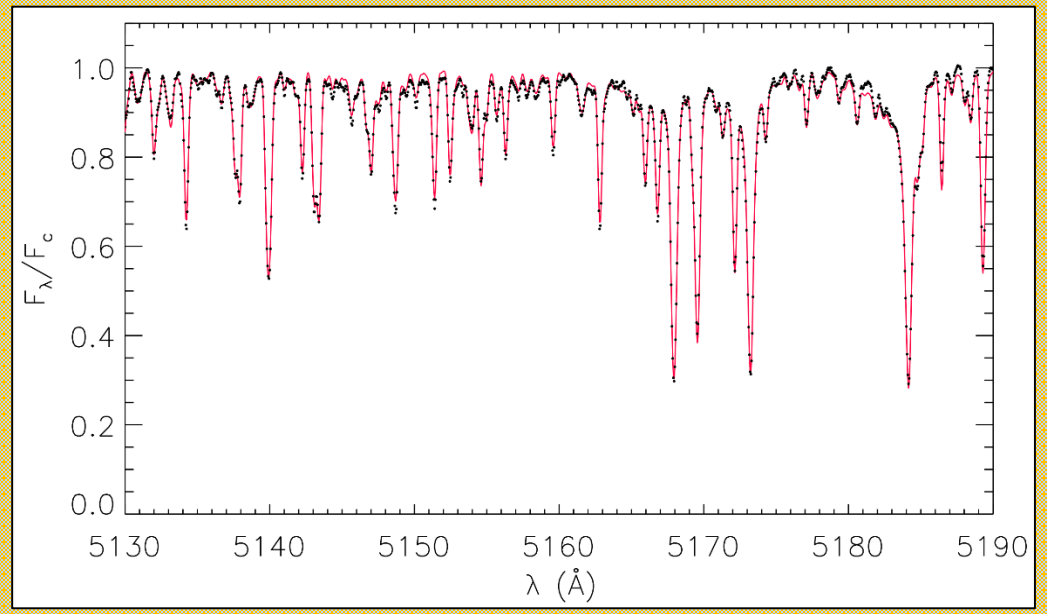
Stellar Parameters

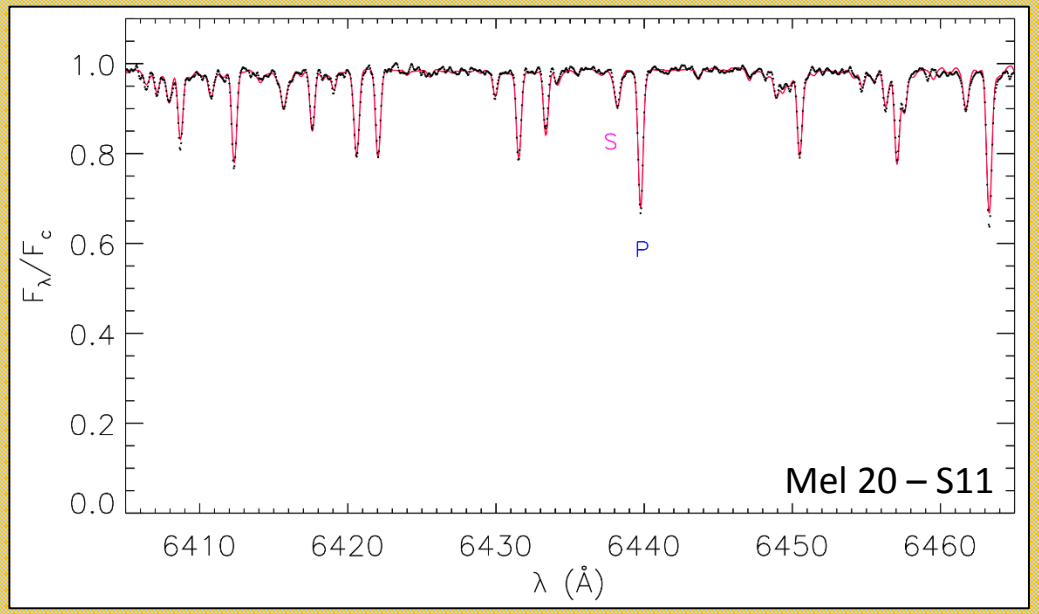
SB2 FGK stars (3)

COMPO2

Frasca et al. 2021

ID	$T_{\rm eff}$ (K) [P/S]	err (K) [P/S]	log g (dex) [P/S]	err (dex) [P/S]	RV (km s^{-1}) [P/S]	err [P/S]	γ (km s^{-1})	$w^{\rm P}_{4400}$	$w^{\rm P}_{5500}$	$w^{\rm P}_{6400}$	SpT [P/S]	$v \sin i$ (km s^{-1}) [P/S]
Mel20-S11	6119/5172	75/240	4.02/3.92	0.14/0.62	31.74/-41.46	0.15/2.39	4.2±1.2	0.91±0.02	0.89±0.02	0.90±0.03	F7IV/K1IV	8/8
Plei-S2	5674/5371	139/172	4.36/4.39	0.13/0.14	14.32/0.20	0.22/0.30	7.4±0.2[a]	0.56±0.03	0.55±0.03	0.53±0.03	G2V/G2V	4/3
ASCC19-S7	5376/4894	139/226	4.41/4.36	0.11/0.40	35.49/9.11	0.25/1.16	24.6±0.5	0.87±0.02	0.83±0.02	0.79±0.04	G8V/K4V	7/7





RESULTS

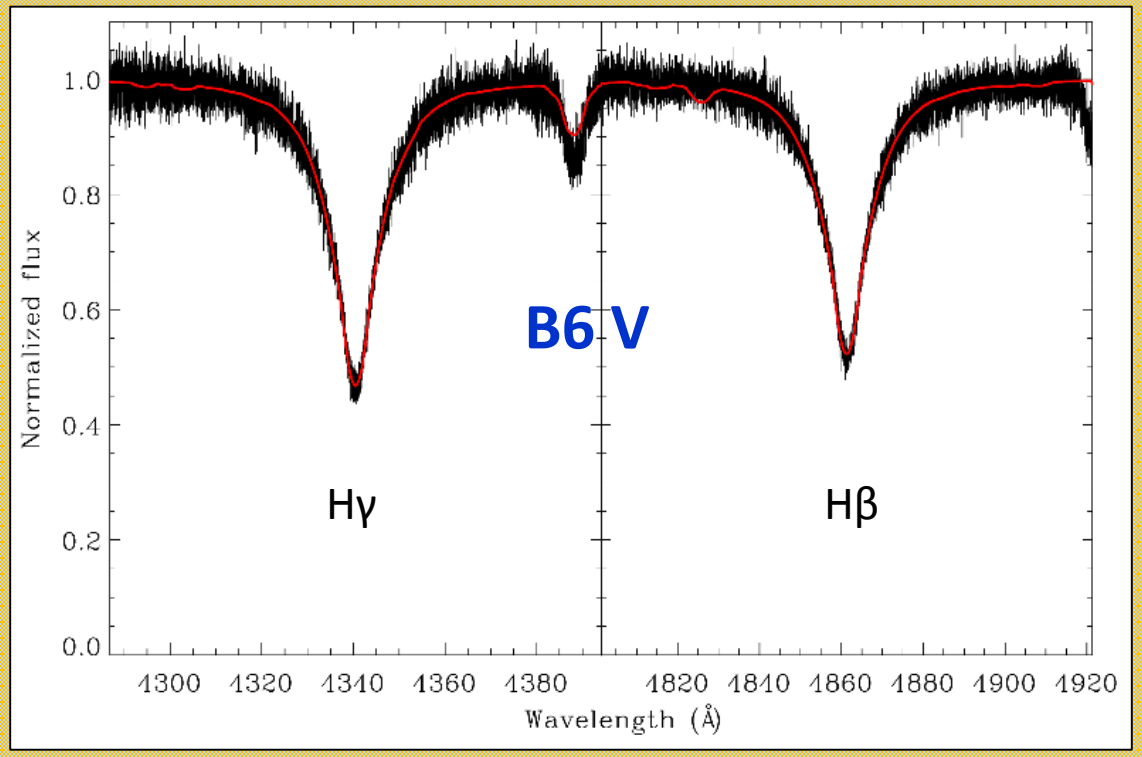
Stellar Parameters

Single hot stars (12)

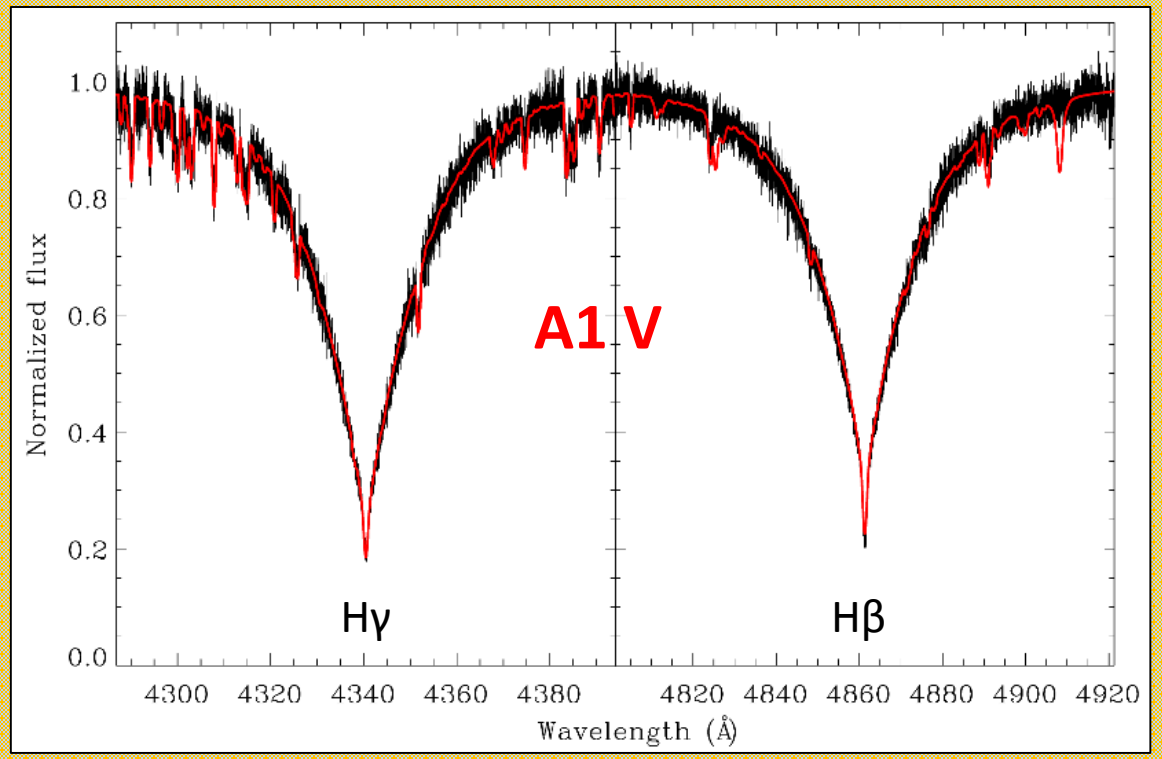
SYNTHE

Catanzaro et al. 2013

Spectral synthesis of the Balmer lines



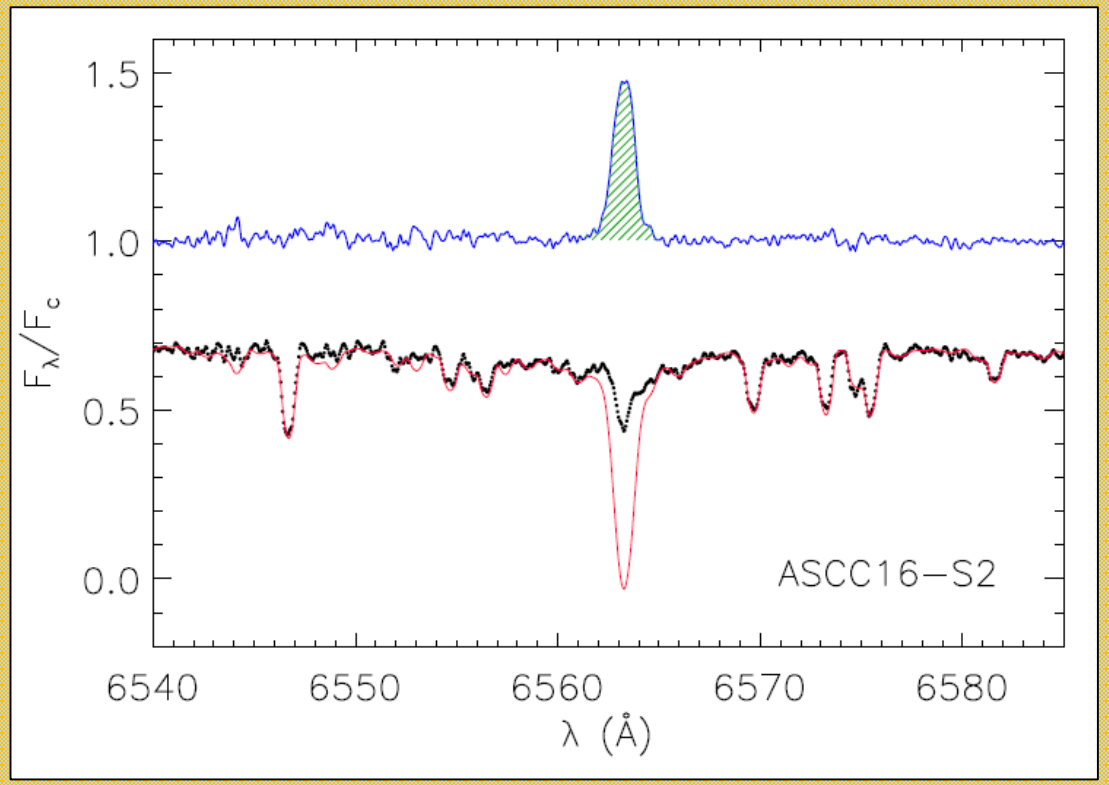
ASCC 19 – S19



ASCC 19 – S21

RESULTS

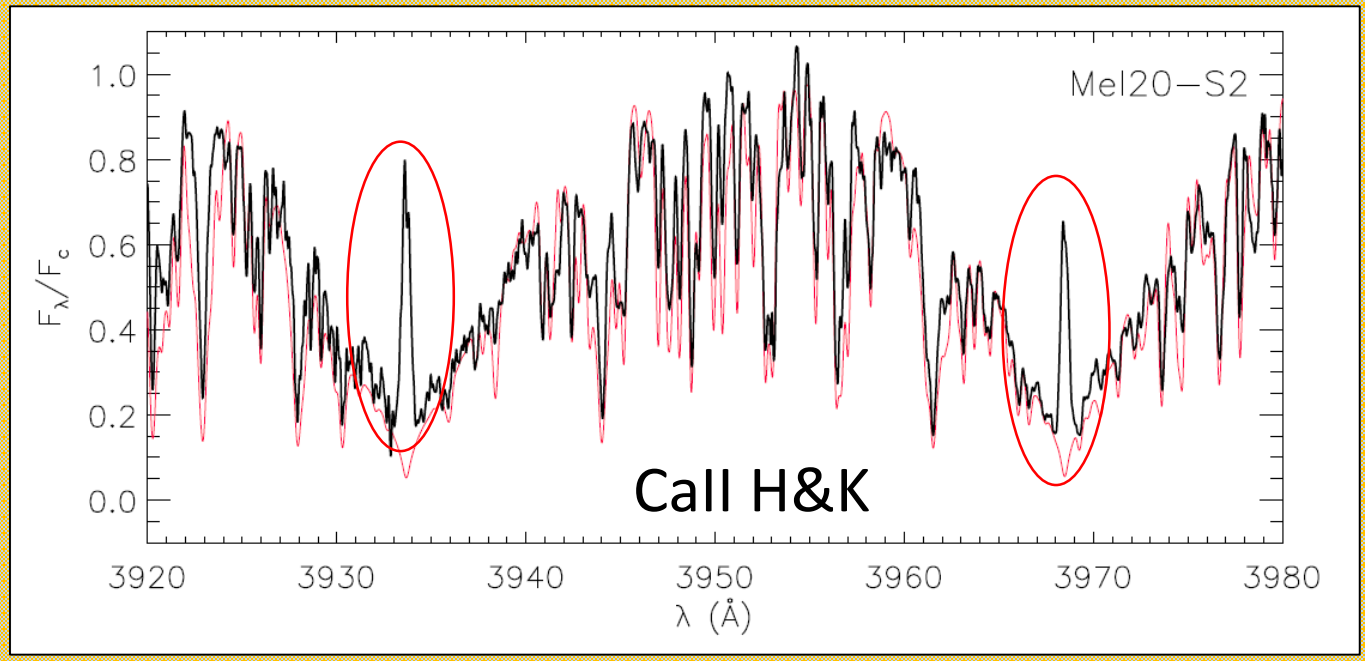
Chromospheric activity



Hα

$$F_{\mathrm{H}\alpha} = F_{6563} EW_{\mathrm{H}\alpha},$$

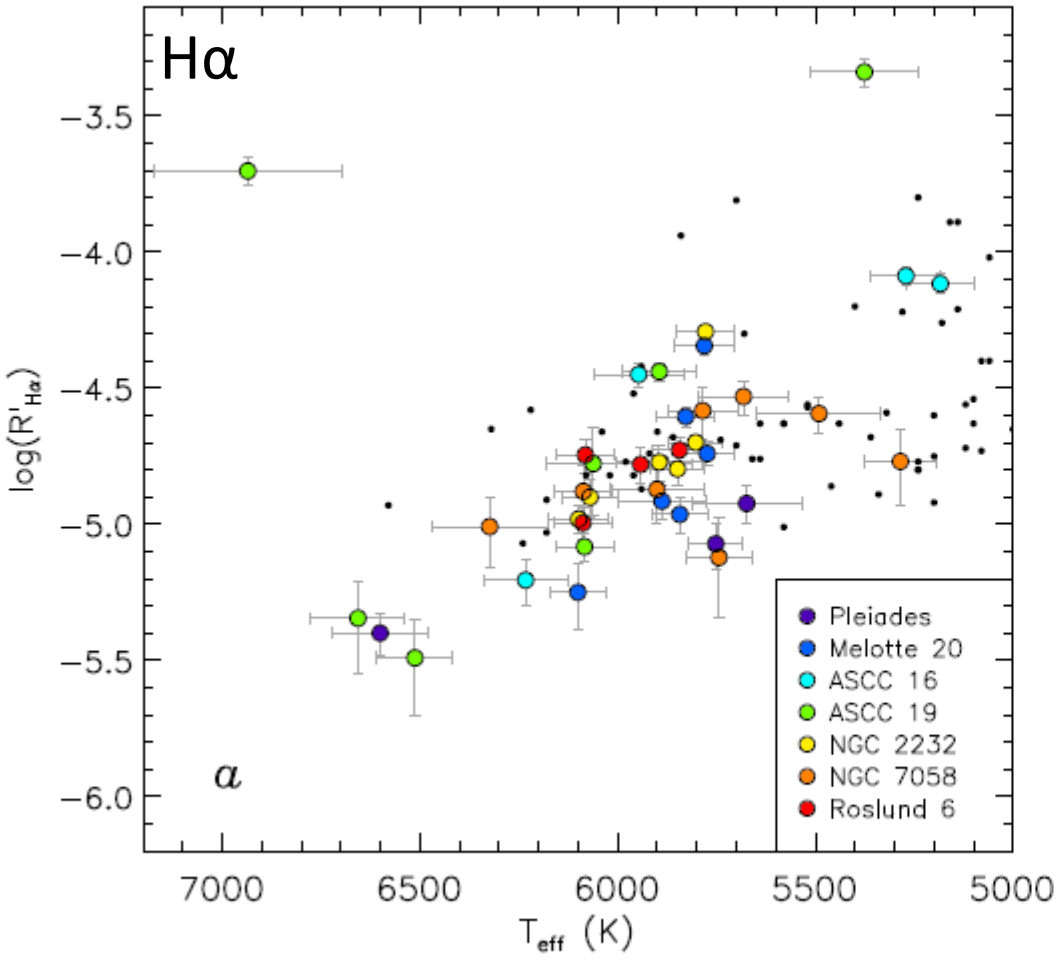
$$R'_{\mathrm{H}\alpha} = L_{\mathrm{H}\alpha}/L_{\mathrm{bol}} = F_{\mathrm{H}\alpha}/(\sigma T_{\mathrm{eff}}^4)$$

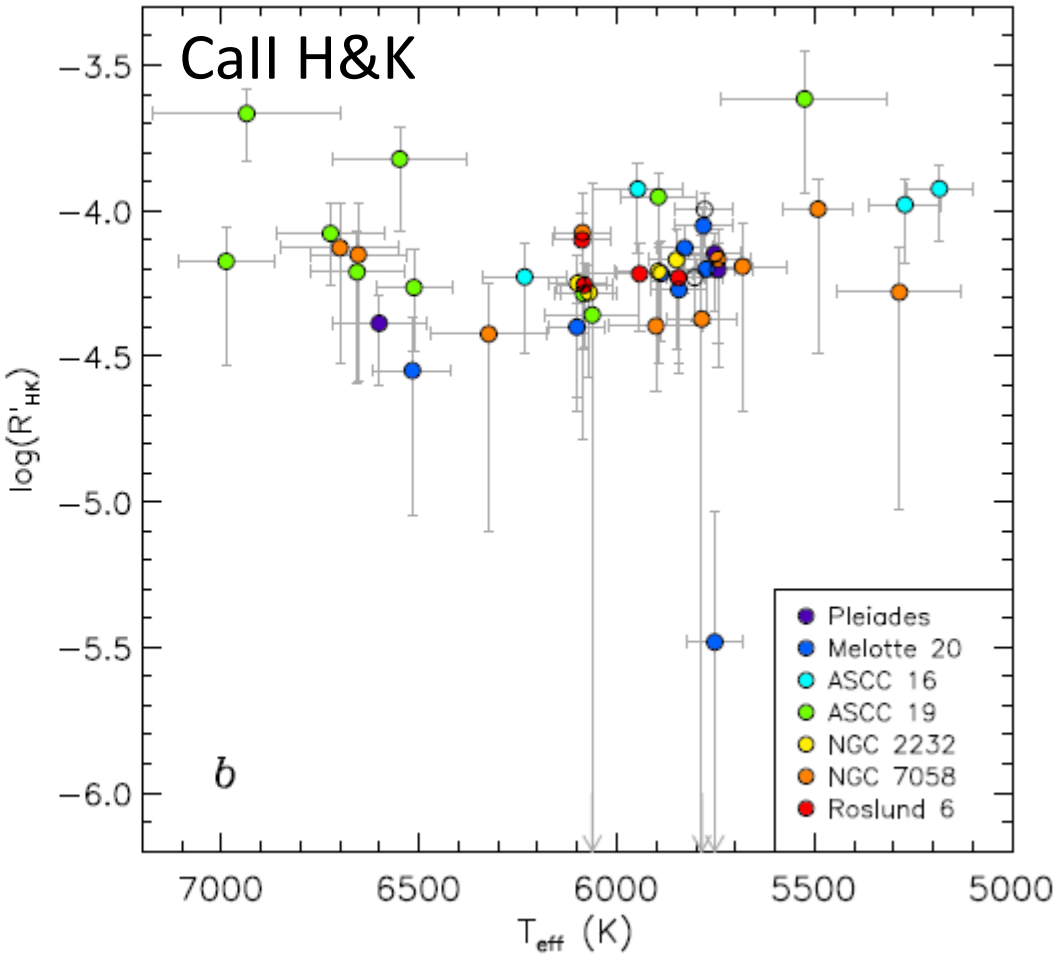


CaII H&K

RESULTS

Chromospheric activity





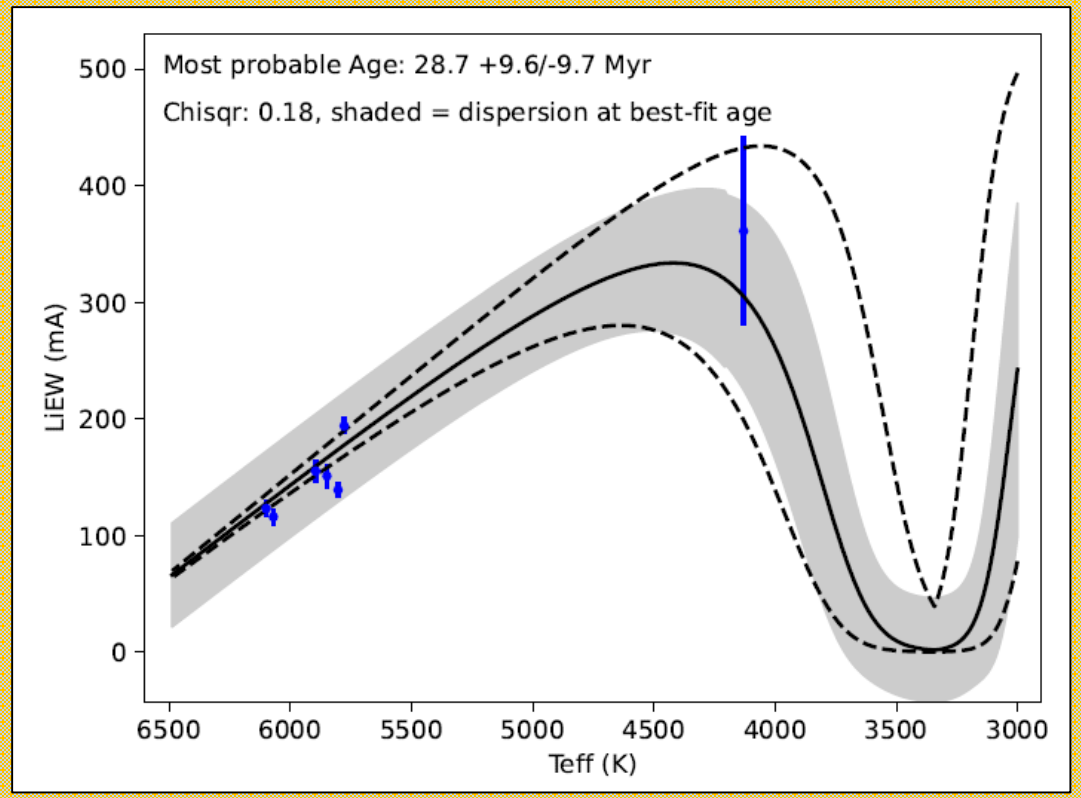
RESULTS

Li Abundance and Age

Cluster	CG20	This work
ASCC 16	13	14±10
ASCC 19	10	<20
Melotte 20	51	68±28
Pleiades	78	75±36
NGC 2232	18	29±10
NGC 7058	41	65±23
Roslund 6	89	108±66

Compatible results:
isochrone-fitting vs Li depletion

NGC 2232



EAGLES *Jeffries et al. 2023*

RESULTS

Chemical abundances

Spectral synthesis

1D LTE Models

ATLAS9

Kurucz 1993a,b

FGK Stars

Catanzaro 2011,2013

Synthetic spectra

Observed spectra

SYNTHE

Kurucz & Avrett 1981

Procedure overview

39 spectral segments of 50 Å
(4400 – 6800 Å)

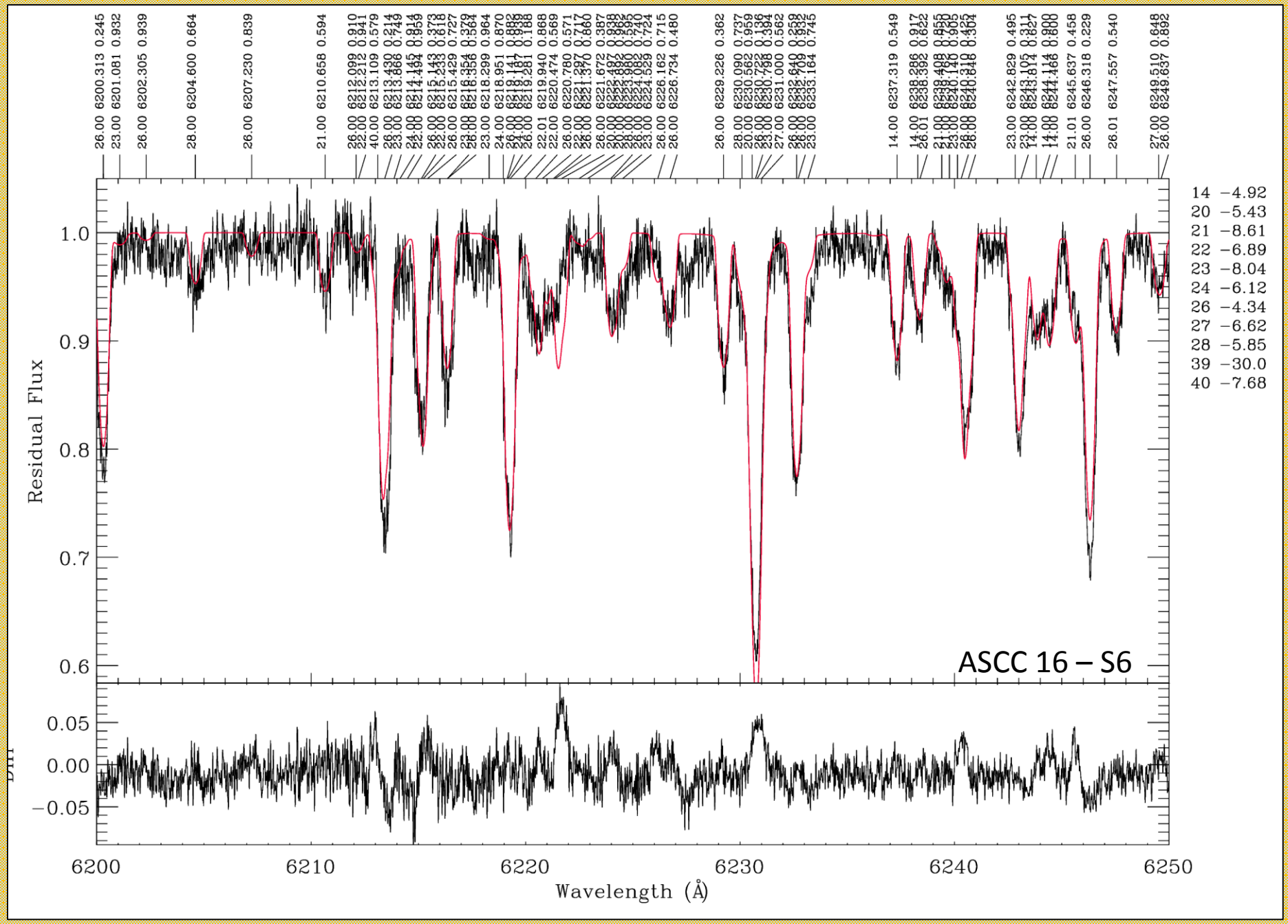
χ2 - minimization

A(X)

RESULTS

Chemical abundances

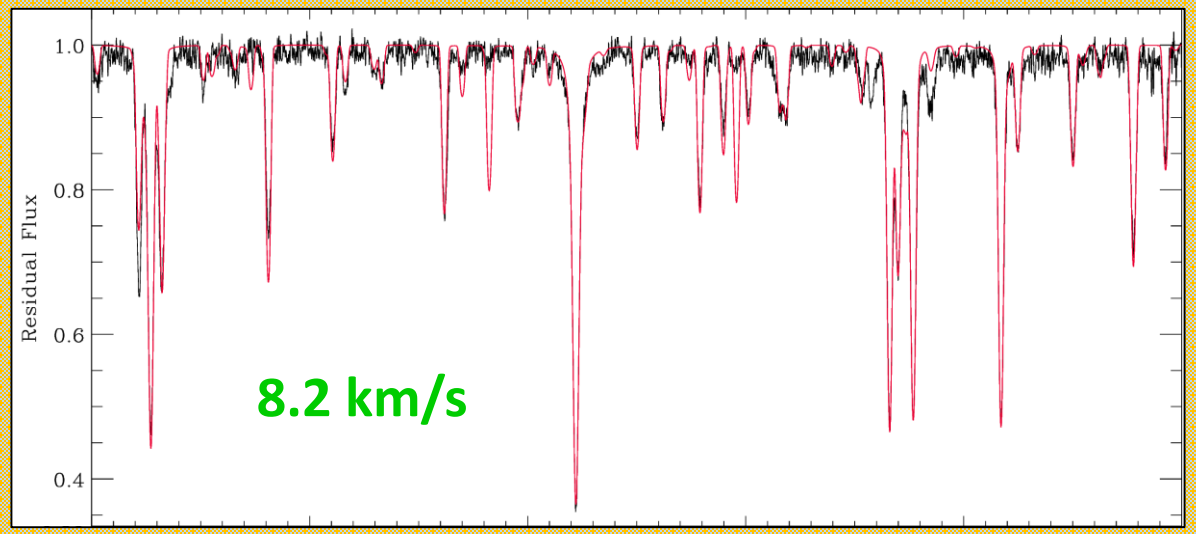
Example of fitting



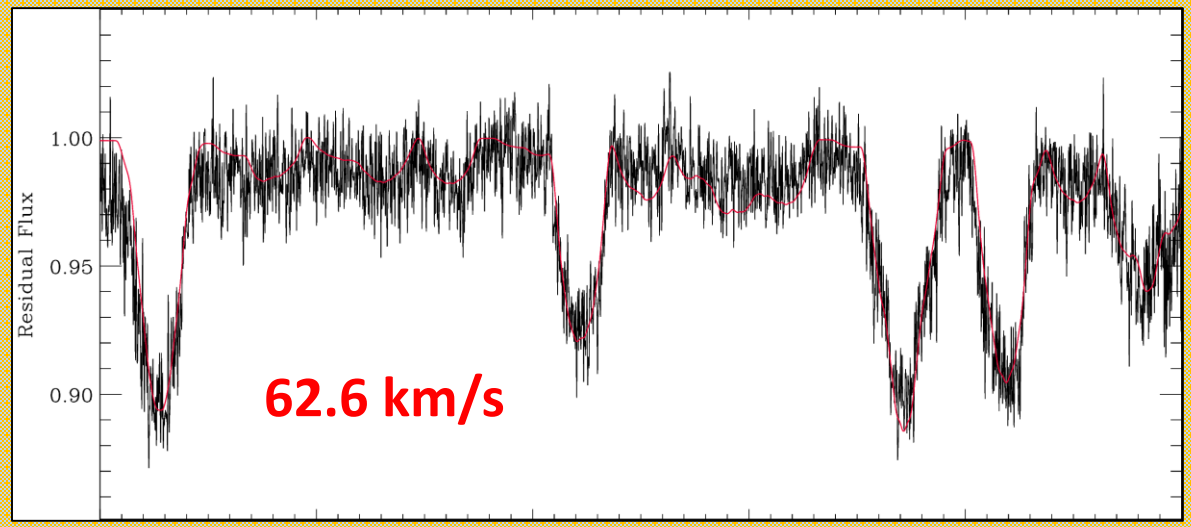
RESULTS

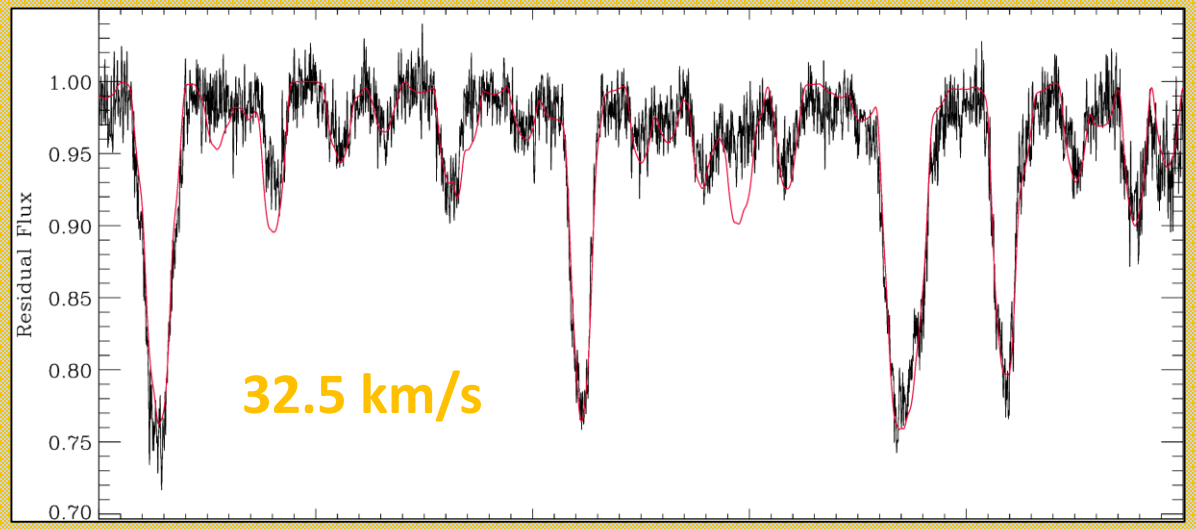
Effect of *v*sin*i* on the spectrum

Mel 20 – S1

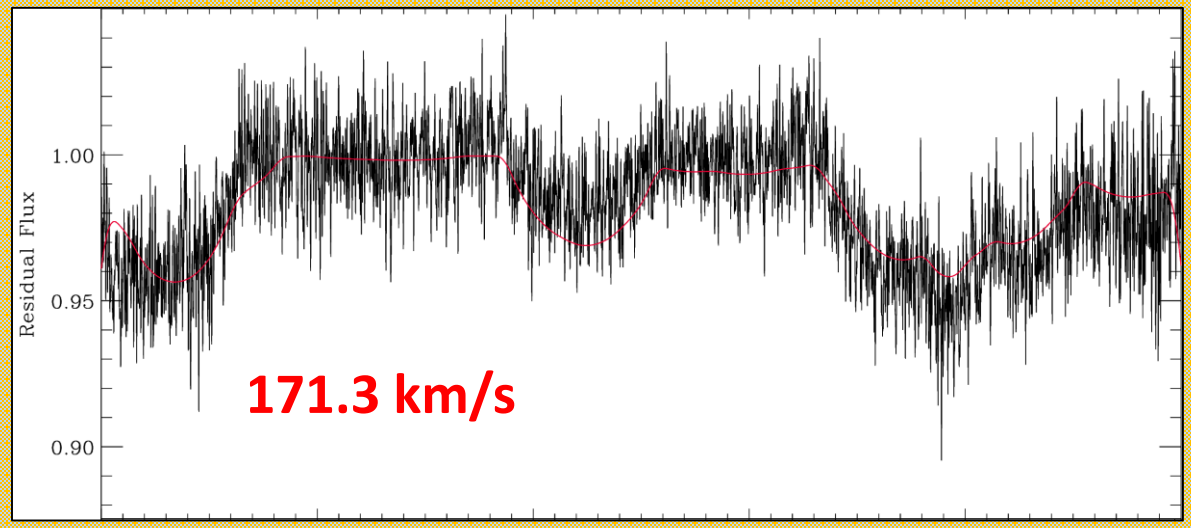


ASCC 19 – S15





ASCC 16 – S6



ASCC 19 – S2

RESULTS

Preliminary !!

Chemical abundances

[X/H]

Grevesse et al. 2007

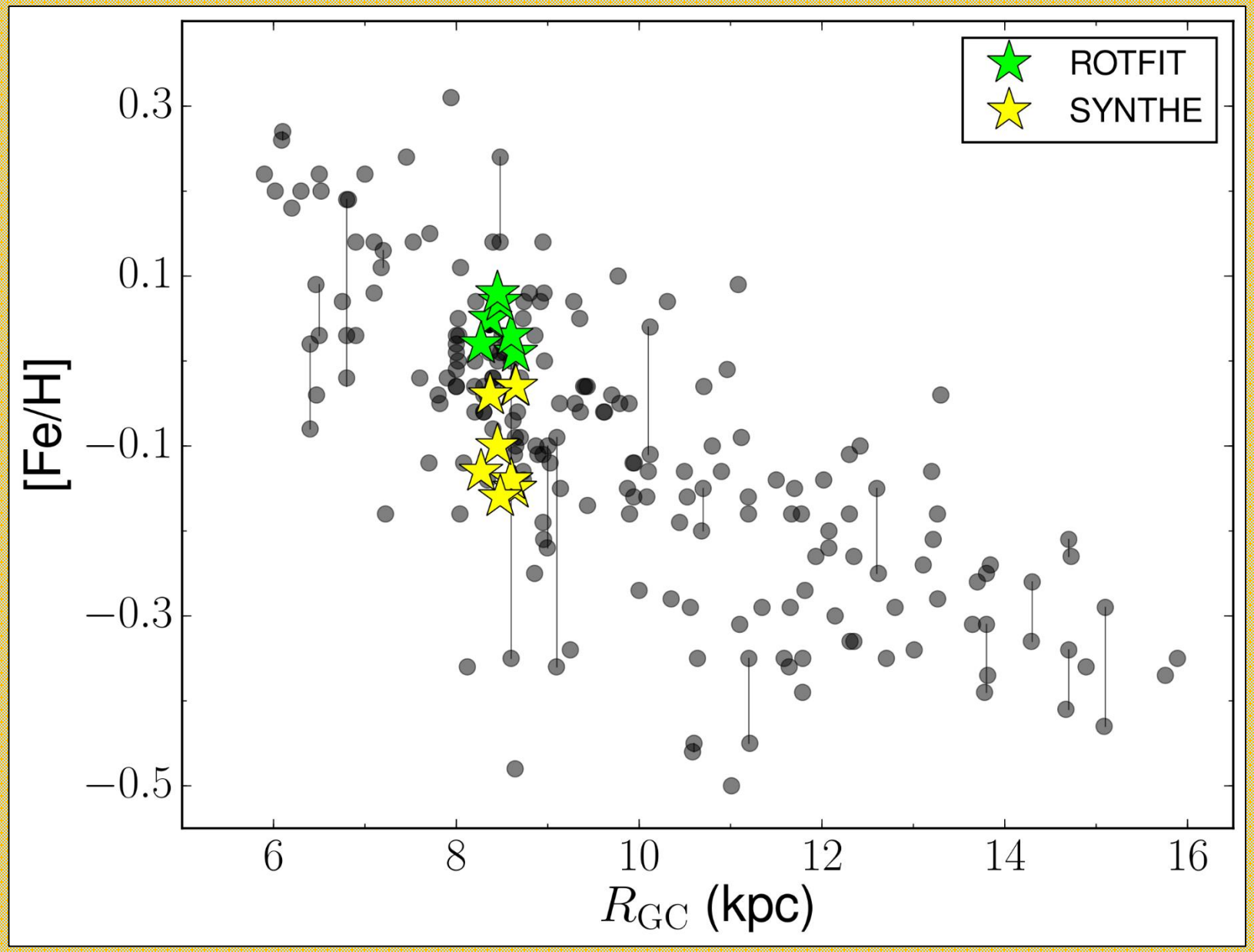
X	Melotte 20	Pleiades	ASCC 16	ASCC 19	NGC 2232	Roslund 6	NGC 7058
C	0.35±0.08	0.21±0.12	0.34±0.15	0.23±0.08	0.38±0.06	0.38±0.04	0.10±0.18
Na	0.06±0.14	0.07±0.07	0.06±0.09	0.03±0.18	−0.01±0.05	0.04±0.05	0.12±0.11
Mg	−0.04±0.07	0.06±0.06	0.02±0.06	−0.07±0.12	−0.01±0.01	0.00±0.04	0.04±0.16
Al	0.18±0.18	0.19±0.01	0.22±0.12	0.19±0.08	0.12±0.07	0.11±0.09	0.13±0.08
Si	−0.15±0.07	−0.05±0.14	−0.03±0.05	−0.01±0.10	−0.12±0.07	−0.08±0.09	−0.08±0.09
S	0.23±0.20	0.16±0.16	0.27±0.08	0.16±0.06	0.29±0.12	0.24±0.12	0.33±0.11
Ca	0.10±0.08	0.13±0.13	0.11±0.06	0.03±0.08	0.13±0.06	0.17±0.06	0.14±0.12
Sc	−0.05±0.07	0.01±0.08	0.19±0.06	−0.11±0.07	−0.03±0.10	−0.04±0.07	0.06±0.07
Ti	−0.05±0.10	0.08±0.11	0.13±0.09	−0.02±0.11	0.00±0.08	−0.04±0.06	0.06±0.10
V	0.10±0.06	0.20±0.11	0.19±0.10	0.21±0.05	0.16±0.04	0.13±0.04	0.14±0.07
Cr	0.01±0.10	0.09±0.14	0.11±0.11	0.05±0.11	0.05±0.09	0.05±0.08	0.08±0.11
Mn	0.08±0.09	0.15±0.14	0.13±0.09	−0.01±0.08	0.09±0.07	0.10±0.05	0.12±0.09
Fe	−0.16±0.16	-0.10±0.24	−0.03±0.12	−0.15±0.17	−0.14±0.12	−0.13±0.09	−0.04±0.12
Co	0.12±0.08	0.18±0.05	0.18±0.04	0.20±0.05	0.13±0.05	0.17±0.02	0.16±0.08
Ni	−0.10±0.07	−0.01±0.04	0.01±0.09	−0.07±0.12	−0.09±0.06	−0.06±0.09	0.02±0.05
Cu	−0.02±0.12	−0.10±0.23	0.01±0.15	−0.14±0.17	0.01±0.16	−0.13±0.08	−0.06±0.14
Zn	−0.26±0.10	−0.34±0.20	−0.23±0.12	−0.27±0.12	−0.26±0.07	−0.26±0.08	−0.21±0.14
Sr	0.20±0.09	0.07±0.11	0.26±0.15	0.15±0.14	0.08±0.07	0.17±0.07	0.17±0.13
Y	0.20±0.09	0.22±0.13	0.23±0.13	0.14±0.09	0.21±0.07	0.18±0.08	0.13±0.09
Zr	0.13±0.04	0.23±0.05	0.17±0.12	0.15±0.08	0.14±0.03	0.11±0.04	0.14±0.05
Ba	0.15±0.31	−0.03±0.06	0.08±0.18	0.24±0.12	0.45±0.07	0.36±0.07	0.34±0.13
La	0.26±0.10	0.32±0.07	0.22±0.11	0.27±0.10	0.27±0.05	0.28±0.06	0.25±0.11
Ce	0.14±0.09	0.17±0.02	0.15±0.13	0.12±0.08	0.19±0.04	0.12±0.06	0.23±0.15

RESULTS

Chemical abundances

Galactic gradient

HR spectroscopy of OCs
(APOGEE, SPA, GES)



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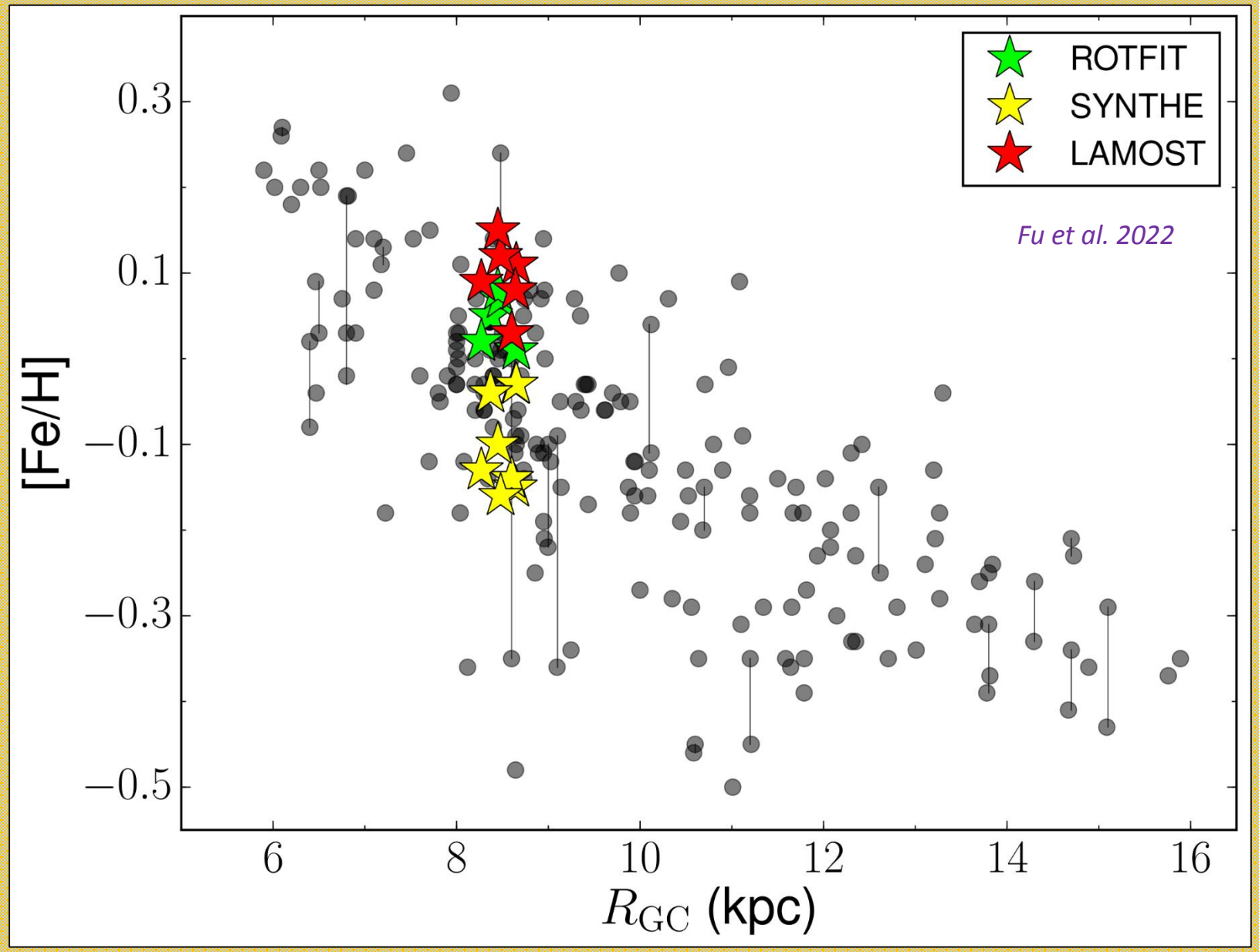

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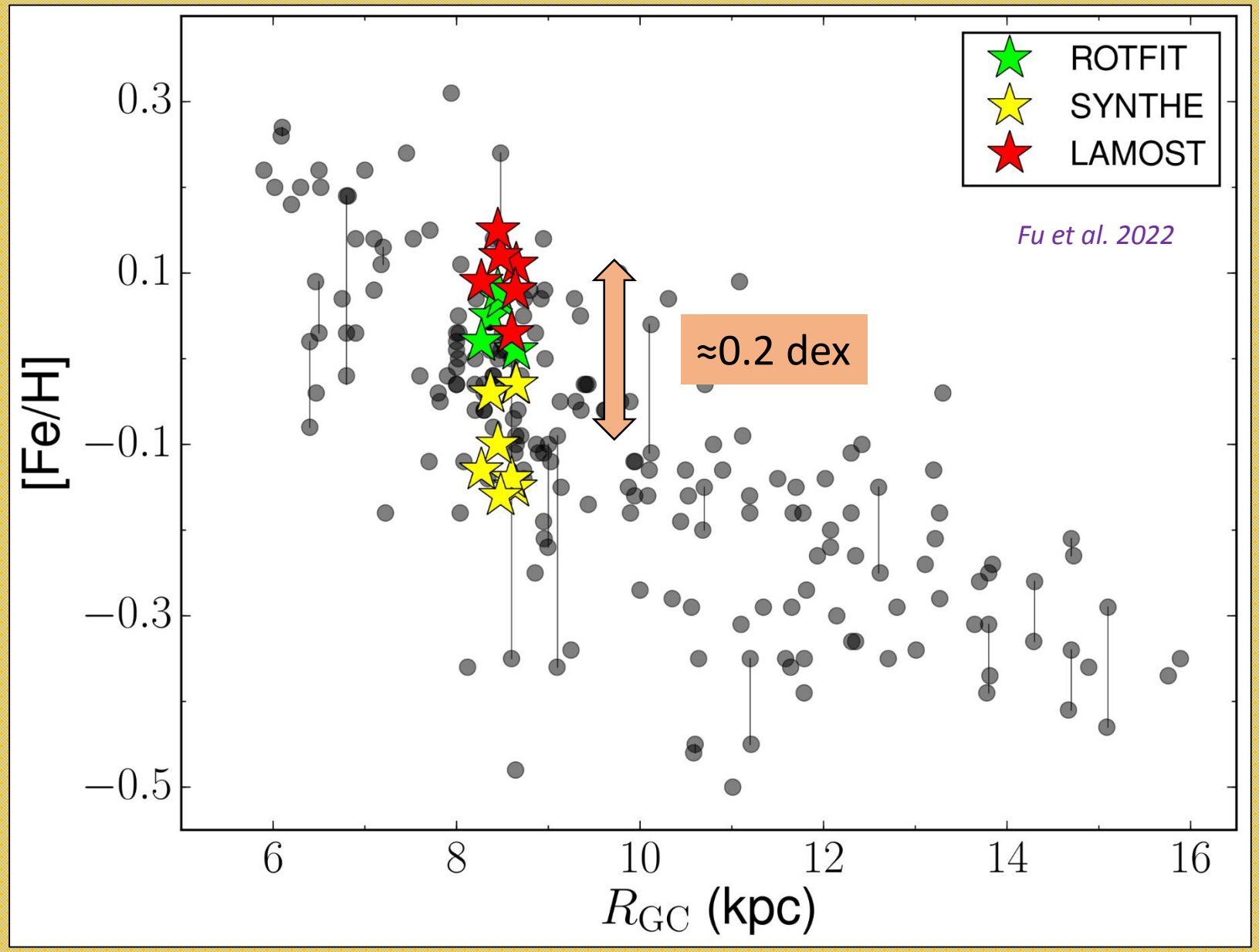

RESULTS

Chemical abundances

Grevesse et al. 2007

Galactic trends

HR spectroscopy of OCs
(APOGEE, SPA, GES)