Exploring Star Formation Histories in Local Group Galaxies:

A Deeper Perspective with the WST

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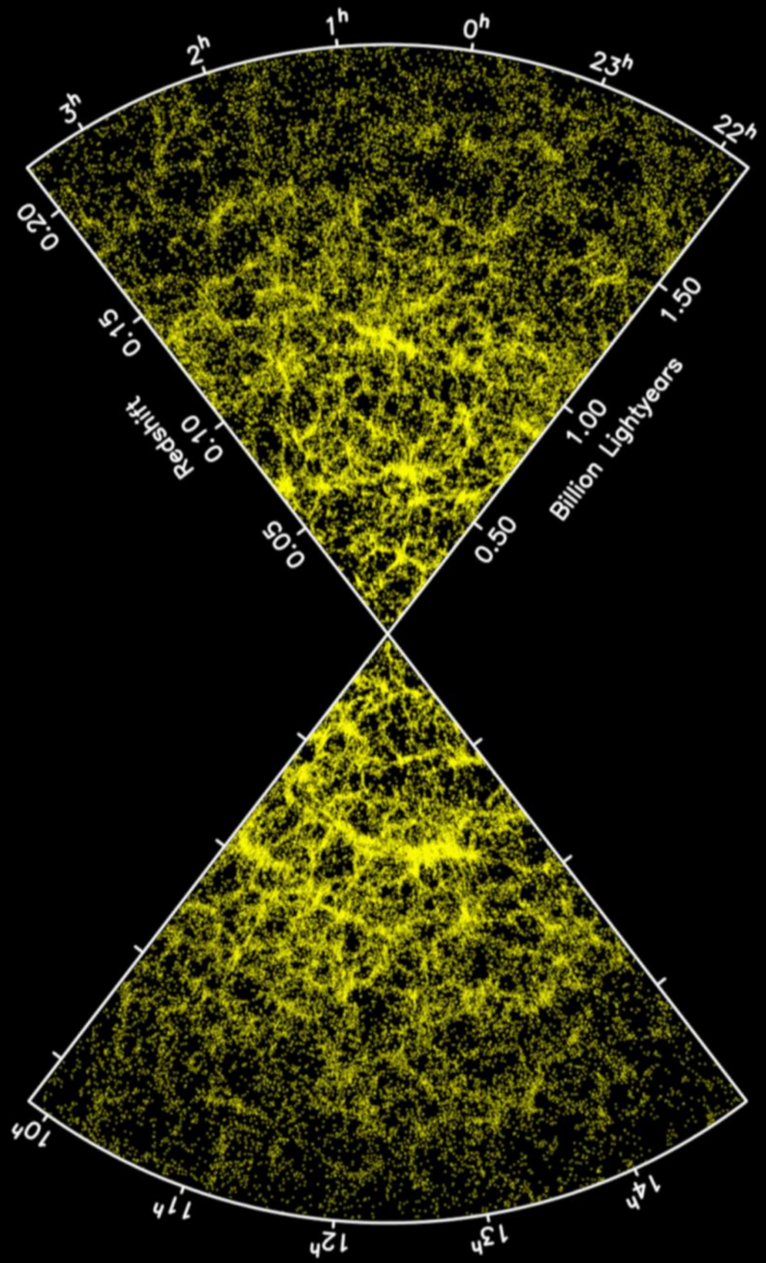
Why Dwarf galaxies?



Source: Mo, Van de Bosch, White – Galaxy formation and evolution

Bottom-up Scenario

Smaller protogalaxies formed first and became the 'building blocks' that formed galaxies, groups, clusters, etc.

Dwarfs Characteristics

$M_V > -17$

$10^6\, M_\odot < M_{dwarfs} < 10^9\, M_\odot$

$\sim$ 60 dwarf galaxies among the satellites of the Milky Way.

Small and Large Magellanic Cloud
Ctio/Noirlab/Nsf/Aura/Smash/D.Nidever

Fornax
ESO/Digitized Sky Survey 2

Sculptor
ESO

Sagittarius
NASA, ESA, and The Hubble Heritage Team STScI/AURA

Sextans I
SDSS

The synthetic CMD method

Building a synthetic CMD:

- **Isochrones**
- **IMF**
- **Binary fraction**
- Observational conditions
- Errors and incompleteness

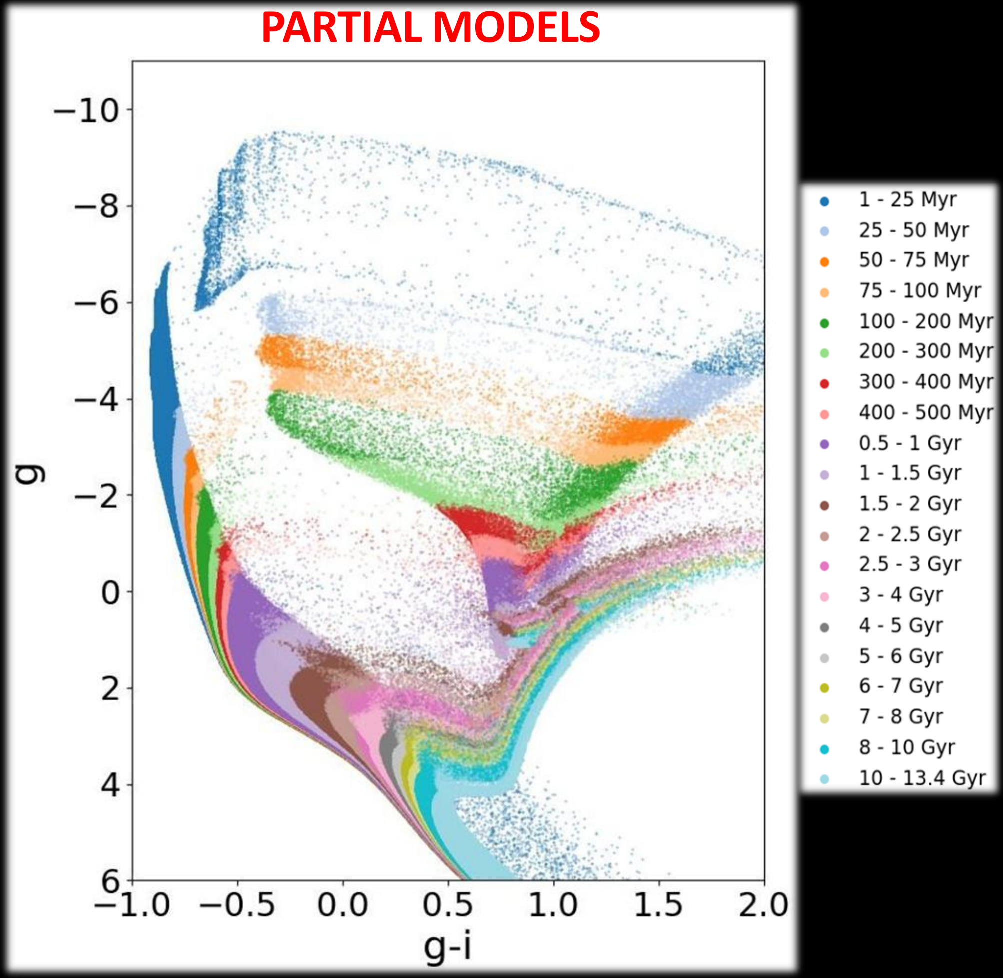
ISOCHRONES LIBRARY

+

IMF

+

BINARY FRACTION



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OBSERVATIONAL CONDITIONS

INTERSTELLAR EXTINCTION

DISTANCE MODULUS

ARTIFICIAL STARS TESTS

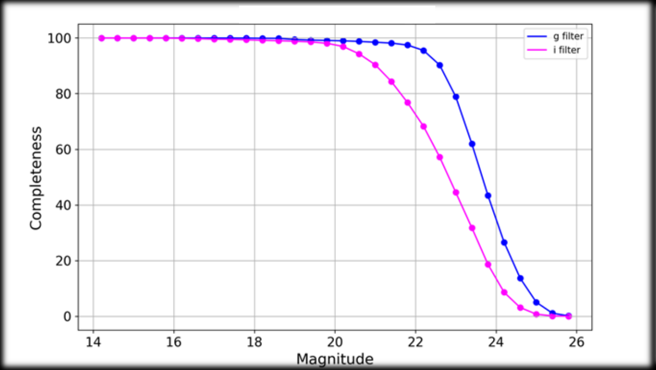
We inject at least $\sim 10^6$ artificial stars per analyzed CMD

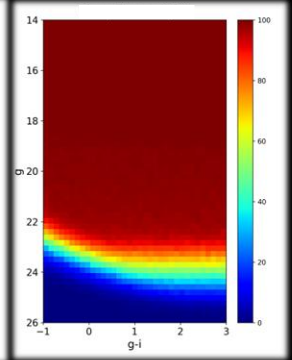
COMPLETENESS LIMIT

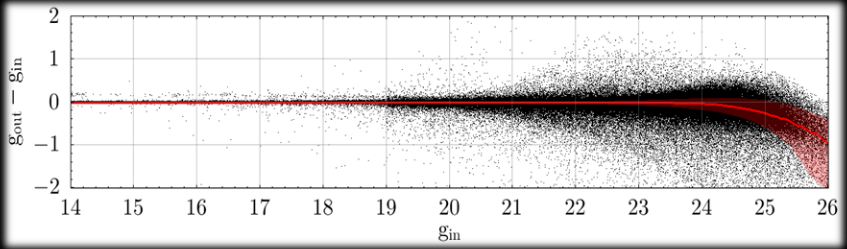
Faintest magnitude for confident object detection in the observed field.

PHOTOMETRIC ERROR

Difference between input and recovered magnitude of artificial stars.







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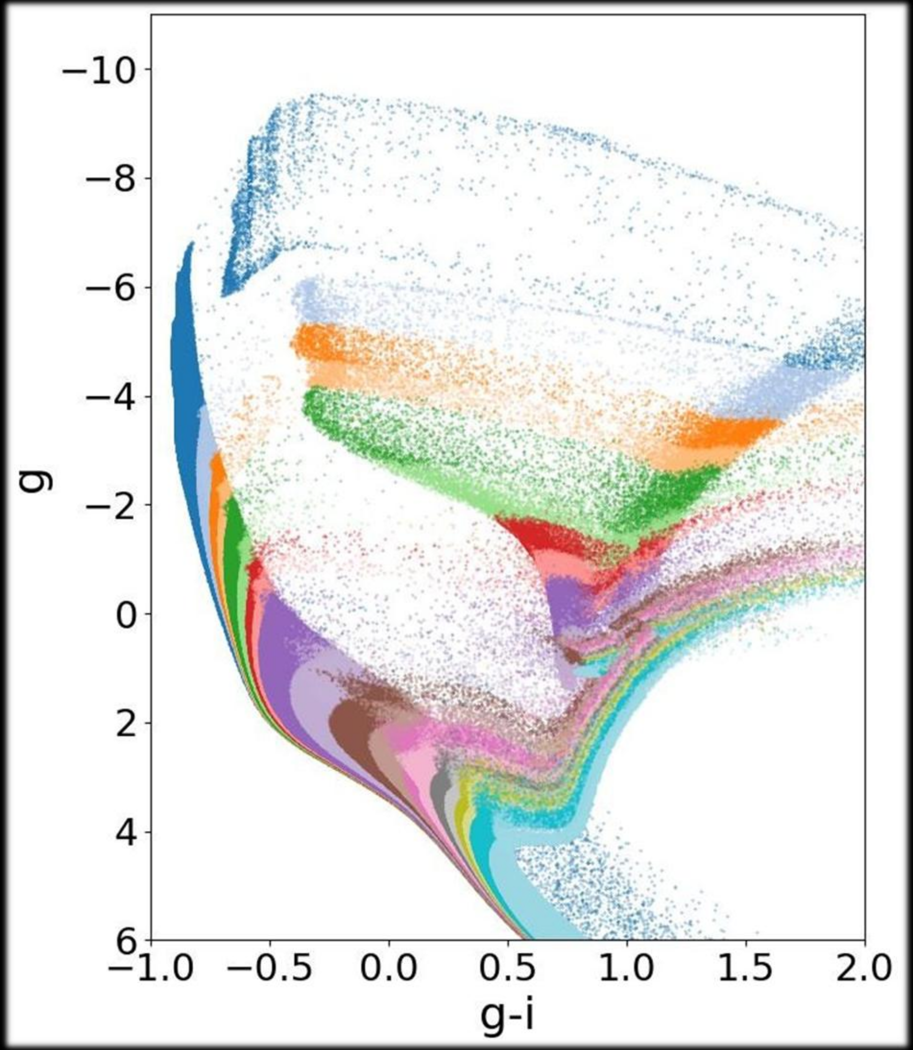
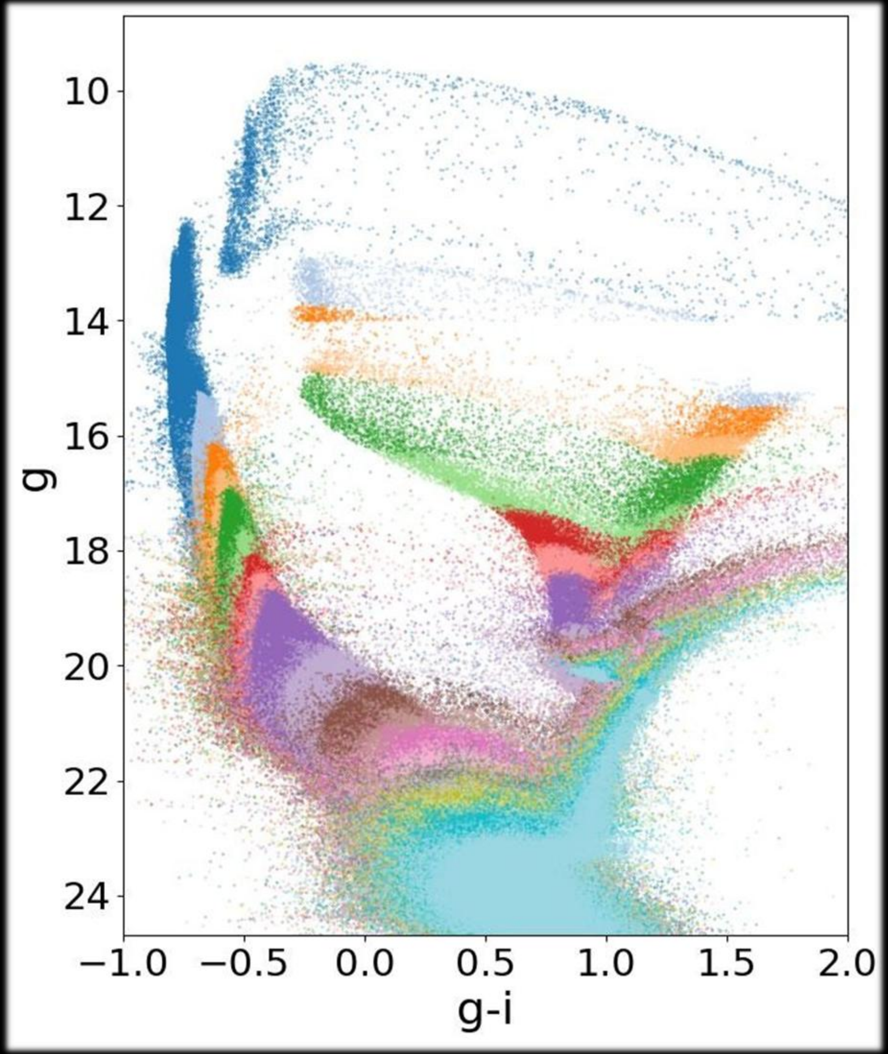
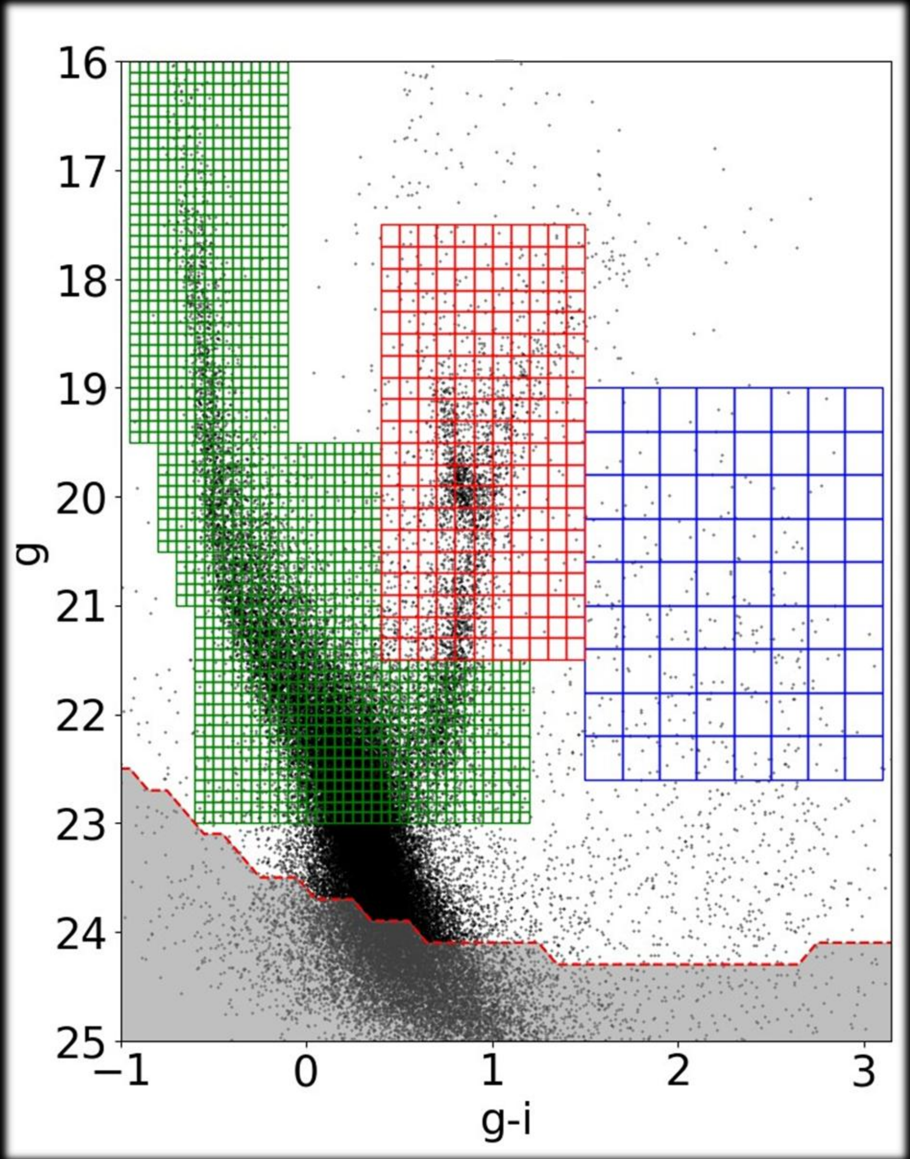
'Clean' Partial Models



'Dirty' Partial Models



The synthetic CMD method



Final library: $N \times M$ "dirty" partial CMDs $\begin{cases} \text{N metallicity steps} \\ \text{M age steps} \end{cases}$

Any synthetic model is built as a combination of these partial models

$$MOD_i = \sum_{j=1}^{N} \sum_{k=1}^{M} w(j,k) \times p_i(j,k) + w_{MW} \times f_i$$

Statistical similarity between the synthetic model and data is evaluated with a **Poisson** based **likelihood function** in selected regions of the CMD:

$$\chi_P = \sum_{i=1}^{N_{cells}} obs_i \, ln \frac{obs_i}{MOD_i} - obs_i + MOD_i$$

The best combination of partial models is found employing the **algorithm SFERA** (Cignoni et al. 2015).

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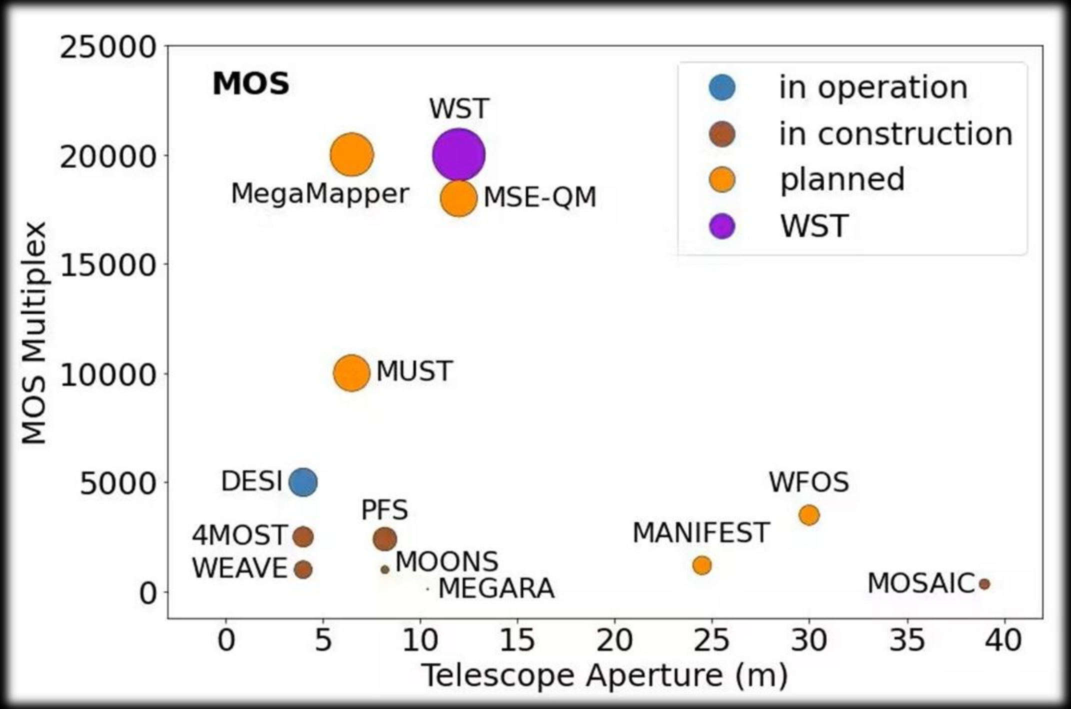
Star Formation Rate **SFR**	Age-Metallicity Relation **AMR**

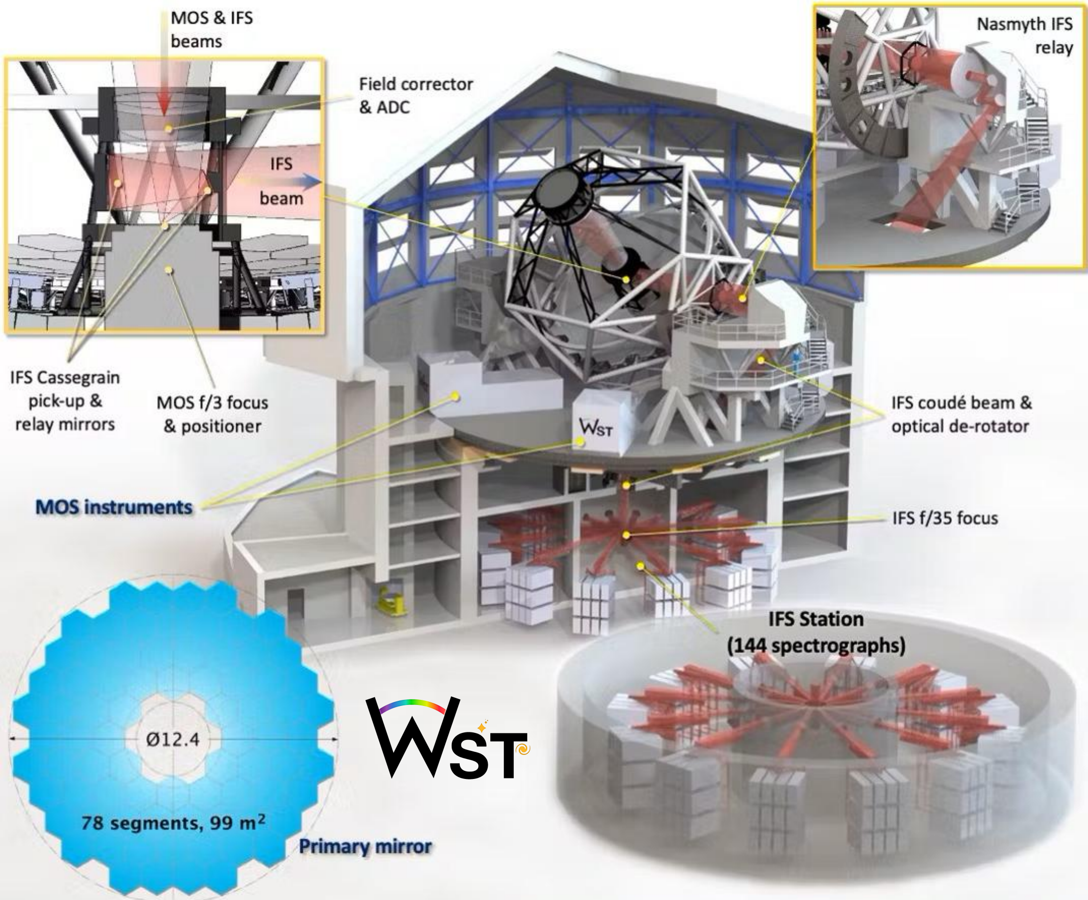
How can WST help with SFHs?

Binary Fraction

Metallicity
&
Metallicity dispersion

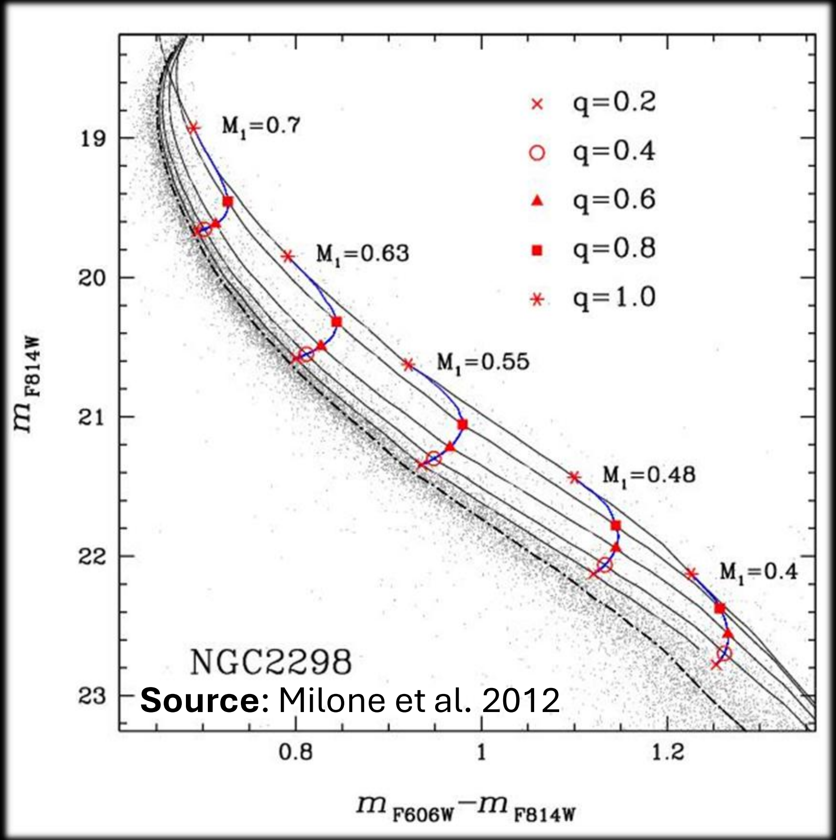


Source: WST website



Telescope aperture (M1)	12 m seeing limited		
Telescope FoV	3.1 deg^2		
Telescope Spec. range	0.35-1.6 µm		
Operations	MOS and IFS simultaneous operations ToO implemented at telescope and fibre level		
Modes	MOS-LR	MOS-HR	IFS
FoV	3.1 deg^2	3.1 deg^2	3x3 arcmin^2 (mosaic on 9x9 arcmin^2)
Spectral range (simultaneous)	0.37-0.97 µm	0.37-0.97 µm 3-4 windows	0.37-0.97 µm
Spectral resolution	4000	40000	3500
Multiplexing	20000	2000	

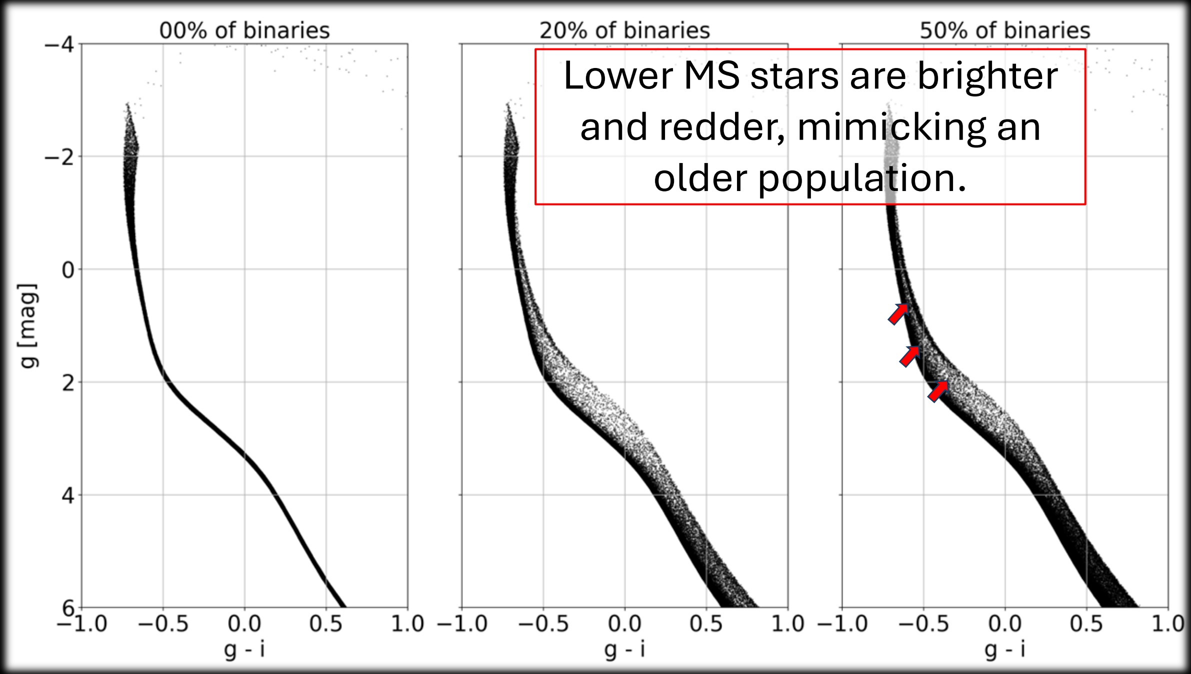
Non-resolved binary systems



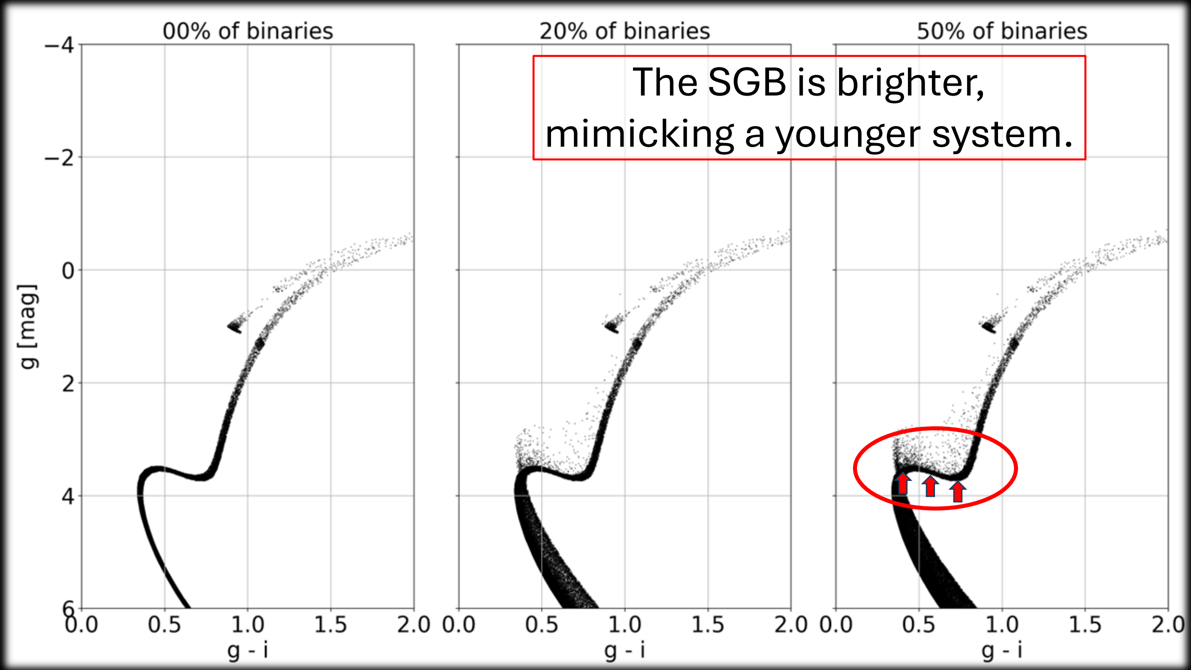
Source: Milone et al. 2012

The presence of not resolved binary systems affects the CMD morphology, shifting the system position position depending on the mass ratio of the stars **q**

100 Myr
Synthetic
population



7 Gyr
Synthetic
population

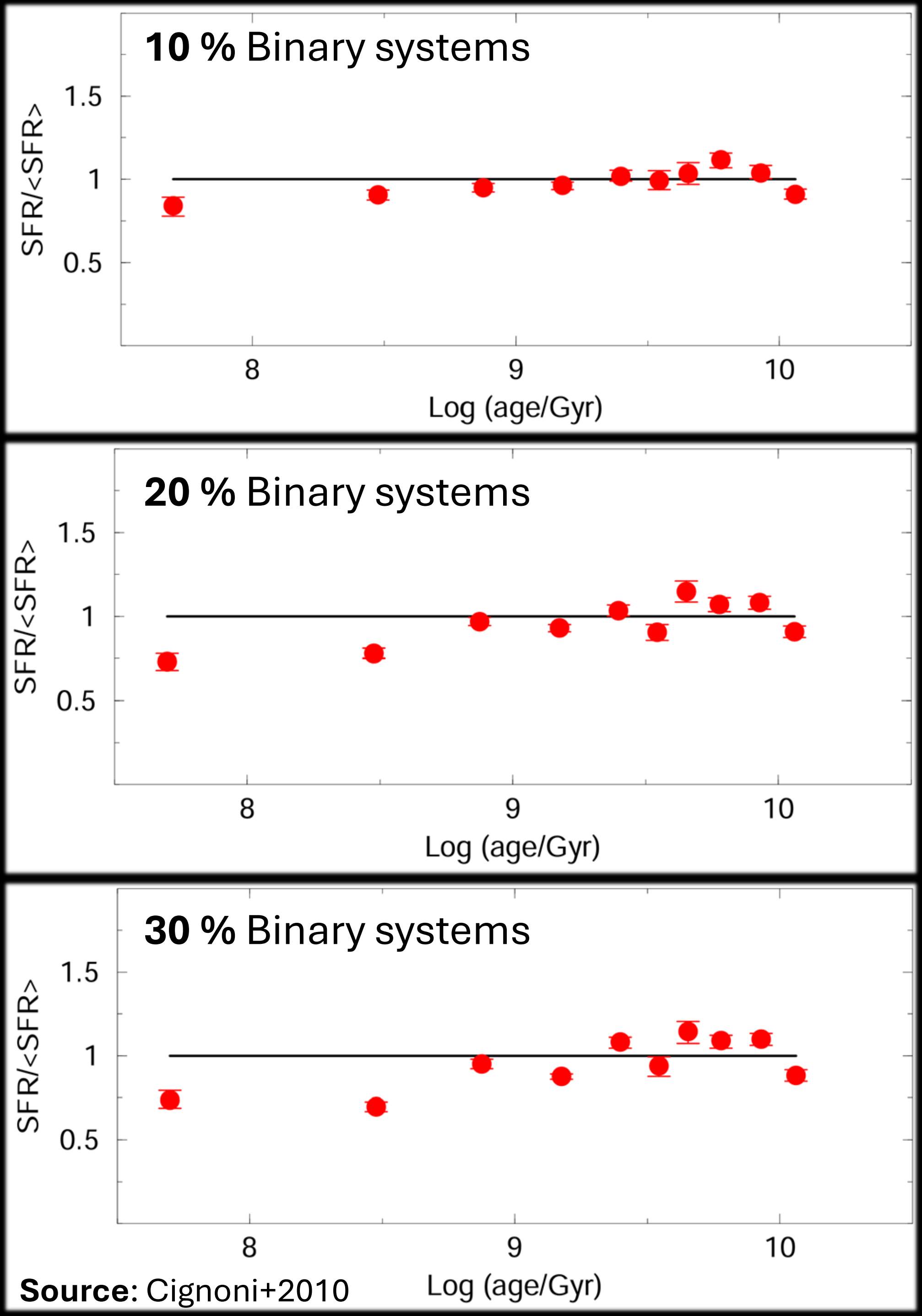


Non-resolved binary systems

Binary systems are brighter and redder than the average single star population

Effects on Star Formation History epochs

YOUNG	INTERMEDIATE	OLD
Lower MS stars shift to an older SFH step. The most recent star formation step is emptied of stars, mimicking a lower activity.	Progressively less affected, because some stars get in and some stars get out of these age bin.	Stars move towards younger bins. The SGB becomes brighter, mimicking a younger system.



Source: Cignoni+2010

WST MOS High-Res mode

The spectroscopic binary population may be studied with WST High-Res mode (R = 40000), with which we may be able to observe a minimum orbital velocity of ~ 7.5 km/s

$$t_{exp} = 1\ hr$$

V ~ 20 mag

S/N ~ 10-15

We will be able to reach Red Clump stars in the Magellanic Clouds and bright Red Giant Branch stars up to ~ 100 kpc.

With $t_{exp} = 3\ hr$ we may reach ~ 0.5 mag deeper, up to ~ 125 kpc

(purple solid line)	Gaia DR3 Spectroscopy	
(yellow dotted line)	4MOST MS Sun-like	1 kpc
(yellow solid line)	WST MS Sun-like	3 kpc
(red dotted line)	4MOST Red Giant	8 kpc
(red solid line)	WST Red Giant	20 kpc

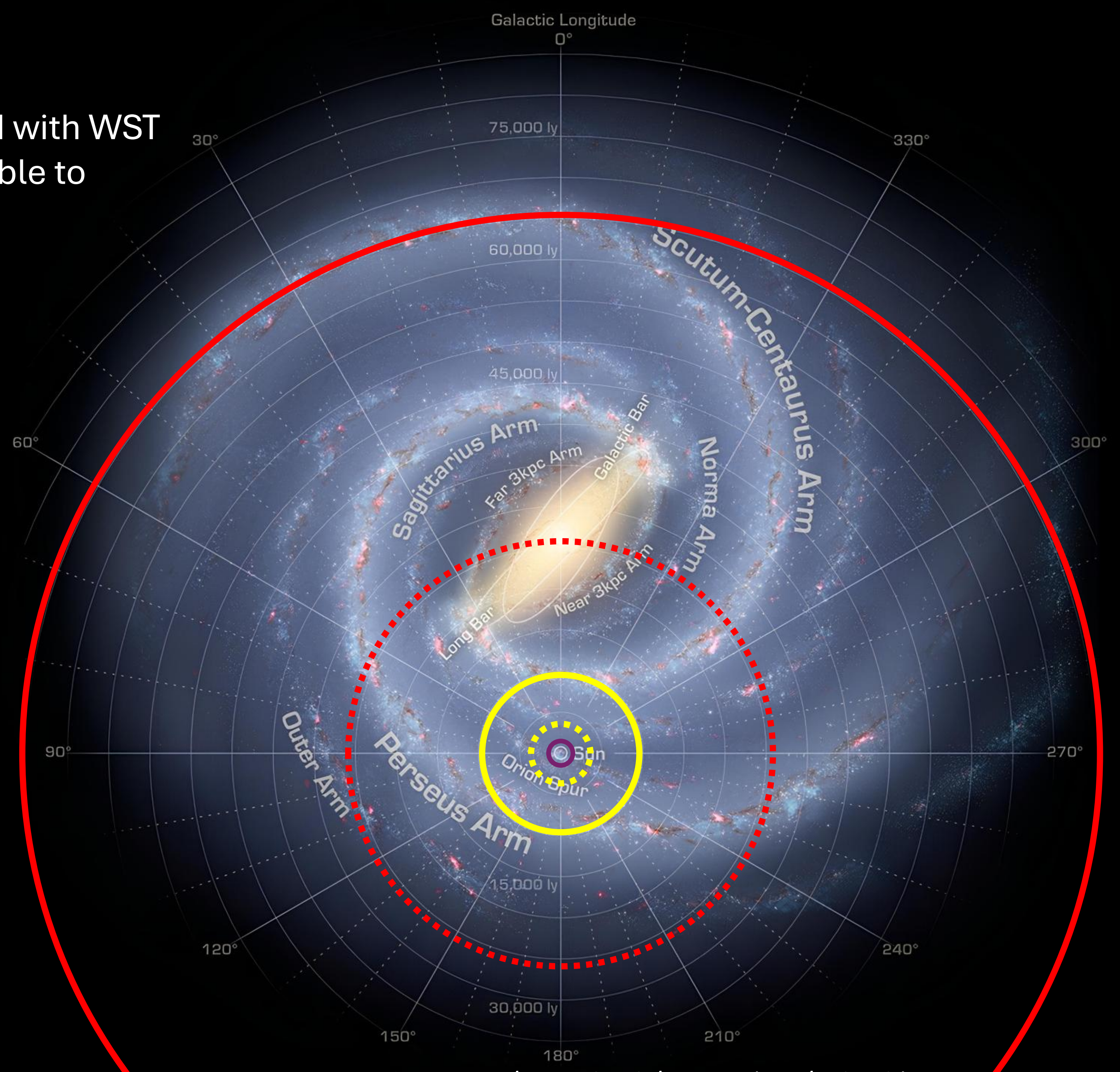


Image Credits: NASA/JPL-Caltech/R. Hurt (SSC/Caltech)

Metallicity and metallicity dispersion

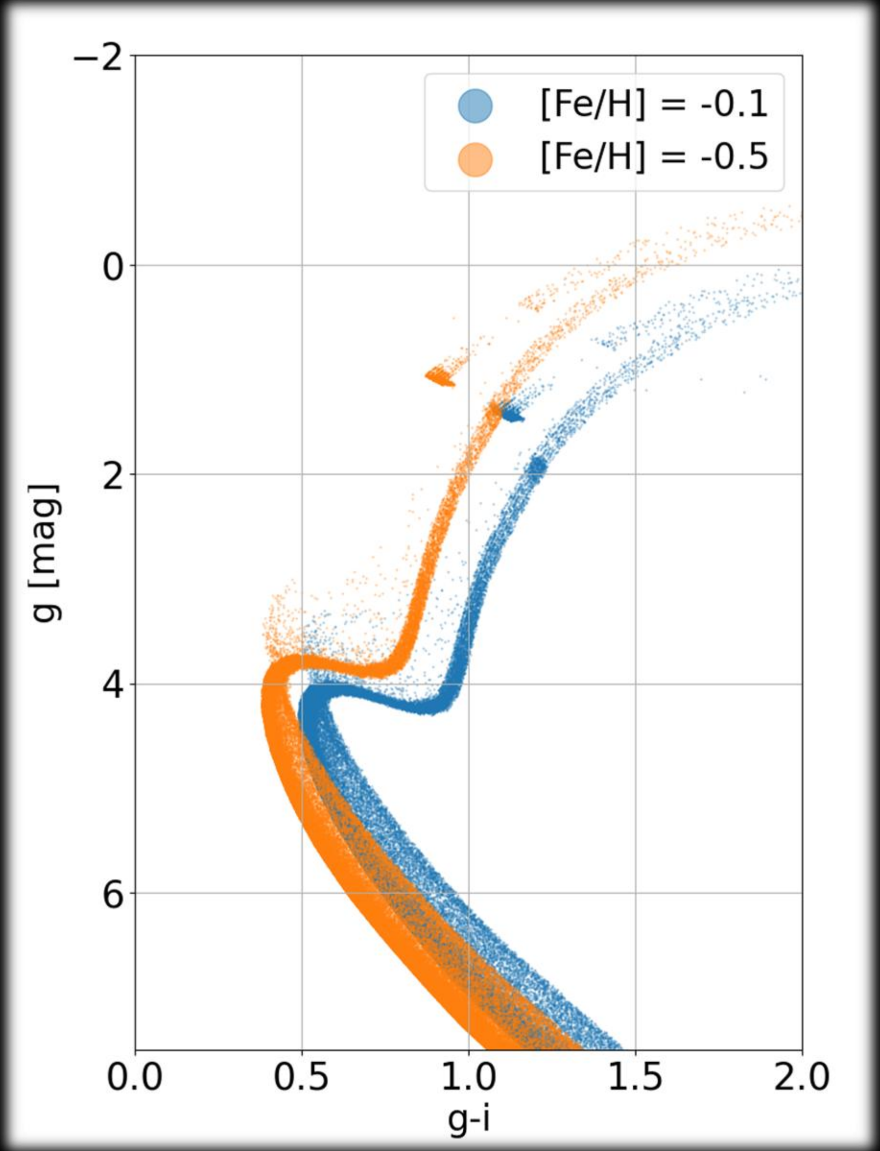
The Z content changes the radiative opacity and the CNO burning efficiency

The decrease of Z increase the surface T and L of the stars.

Metal poor stellar populations are **bluer**, but can be mistaken for a younger but metal-richer population.

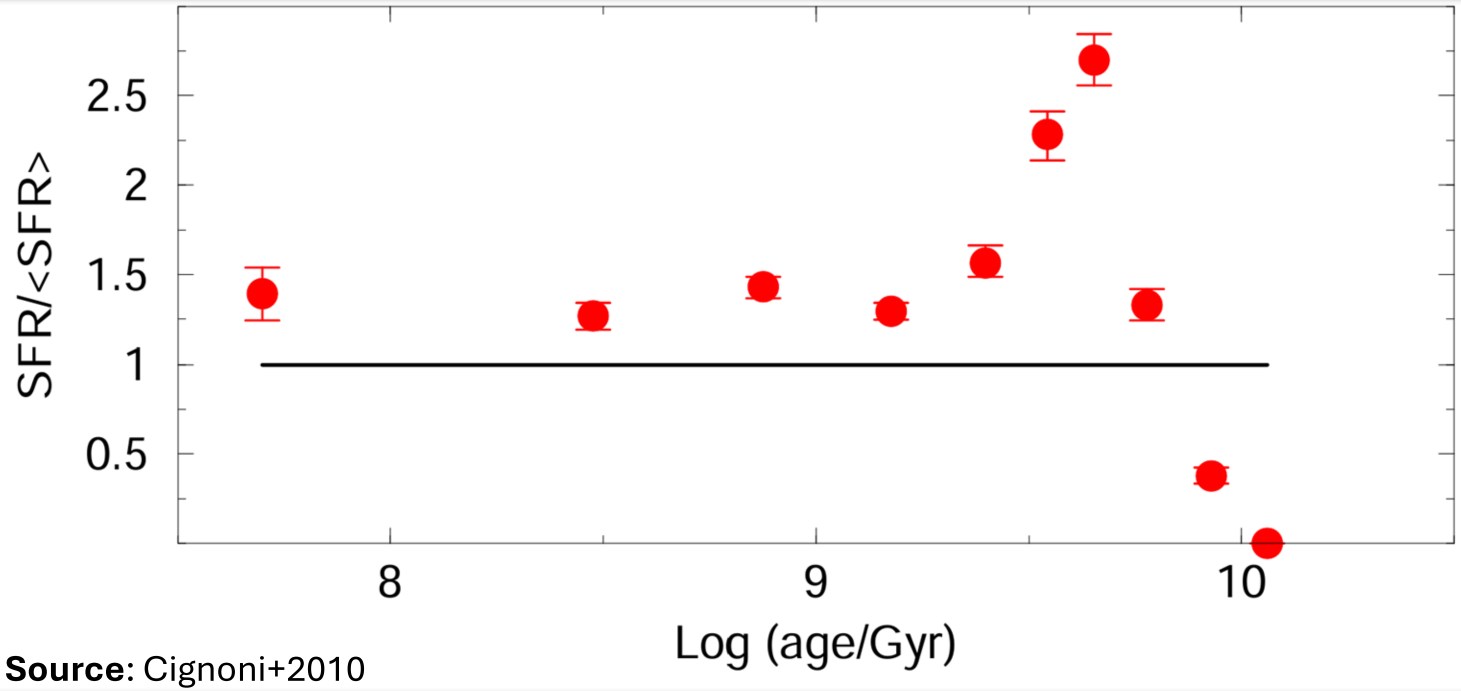
Metal poor stars have a **shorter lifetime** compared to the metal-rich ones (higher luminosity and temperature)

9 Gyr stellar population



Metallicity and metallicity dispersion

What happens if we recover the SFH by adopting models with the wrong metallicity?



Source: Cignoni+2010

In the analyzed mock population, stars with ages > 5 Gyr were built with a lower metallicity (Z = 0.002) respect to the younger objects (Z = 0.004)

AGE-METALLICITY DEGENERACY

To match the blue-shifted sequences of old metal poorer stars, the old SFH recovered assuming a wrong metallicity shift to younger age bins.

The **metallicity dispersion** can also be a **non negligible** factor

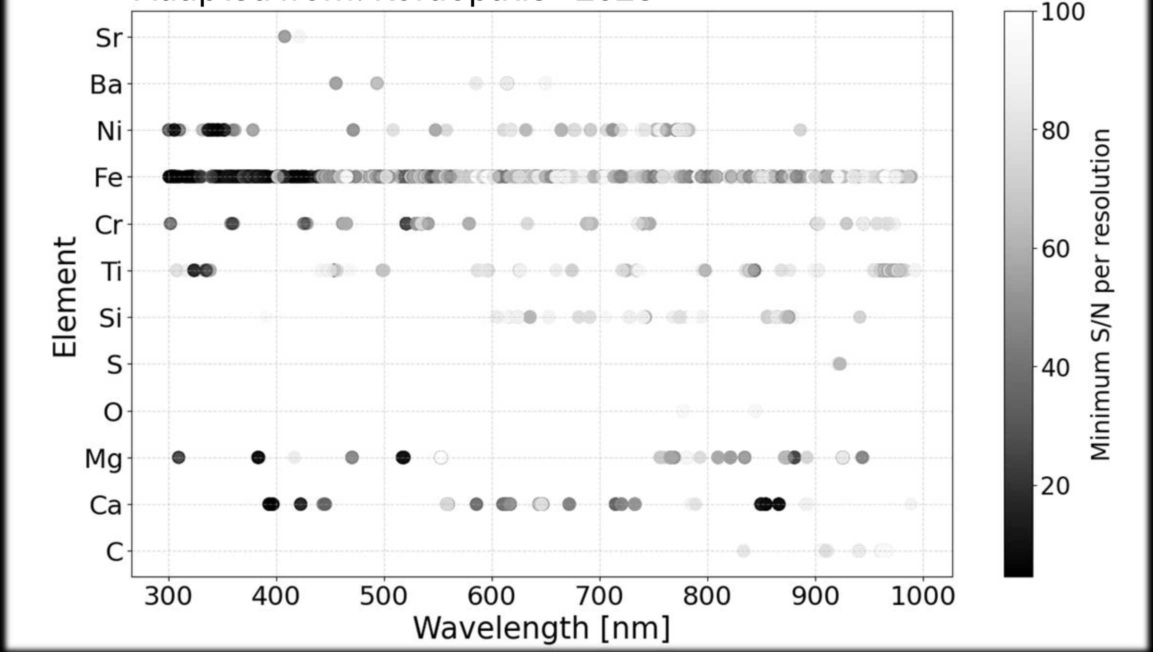
WST MOS Low-Res mode

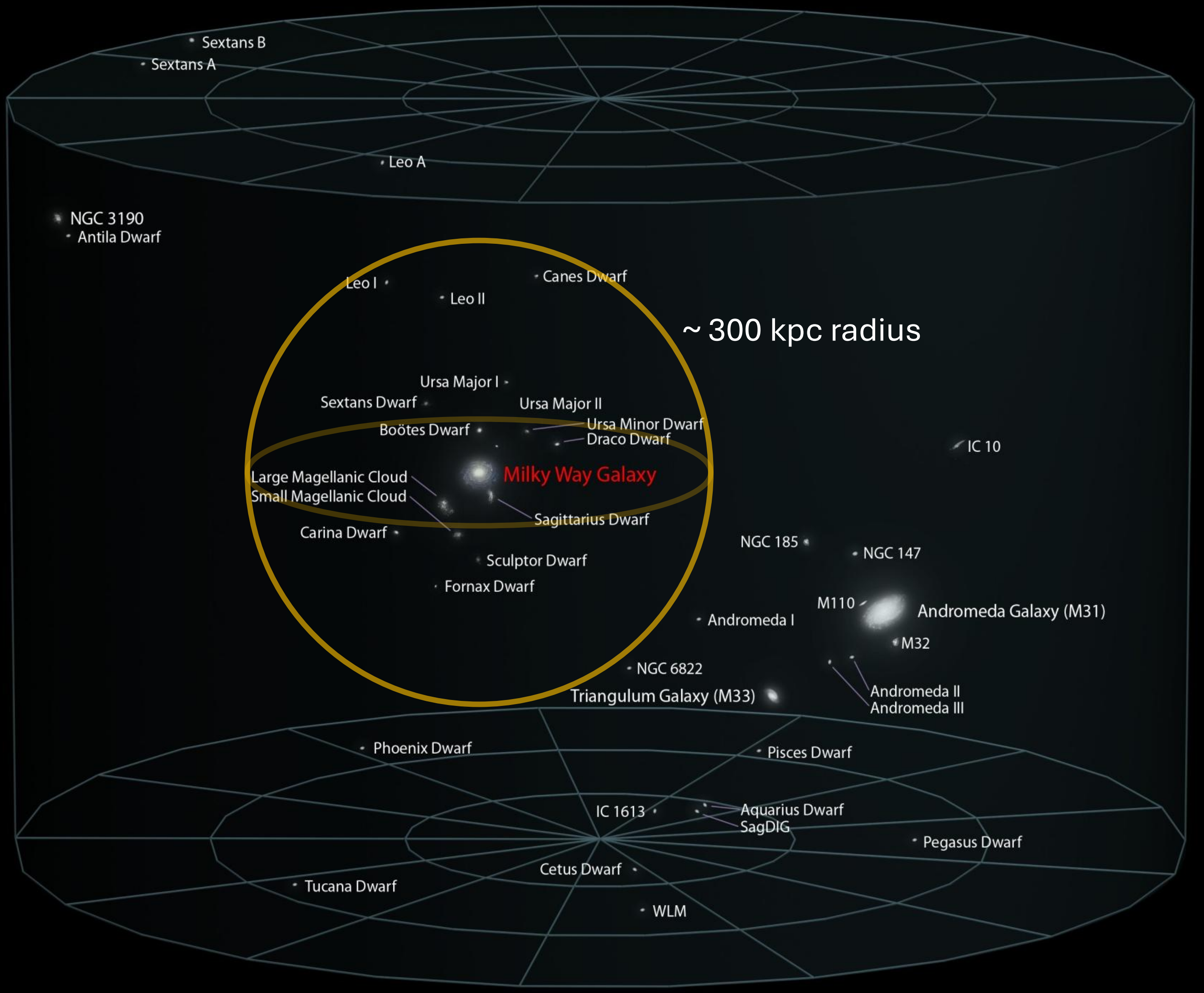
WST will estimate precise metallicities for millions of stars in Local Group galaxies.

- In Low-Res mode, it will reach 22.5 mag with $S/\mathrm{N} \sim 15/\text{Å}$ with exposure time of ~ 5 hr, sufficient for metallicity measurements.

- This allows probing solar-like stars in the up to a distance of ~ 300 kpc.

Adapted from: Kordopatis+ 2023





Summary

- **WST: A step ahead for Stellar Population Studies**

Thanks to its large field of view, high multiplexing capabilities, and large aperture, WST will enable spectroscopic observations of millions of stars within relatively short exposure times.

- **Breaking Degeneracies: Binaries and Metallicity**

WST will allow for a better determination of binary fractions and precise metallicity measurements will help break the age-metallicity degeneracy, refining our understanding of stellar population ages.

By delivering accurate stellar parameters on an unprecedented scale, WST will reduce the uncertainties in synthetic CMD modeling and SFH derivations.

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THANKS

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