

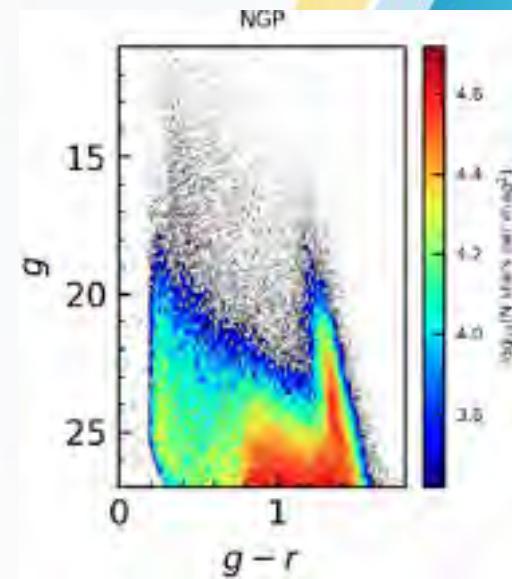
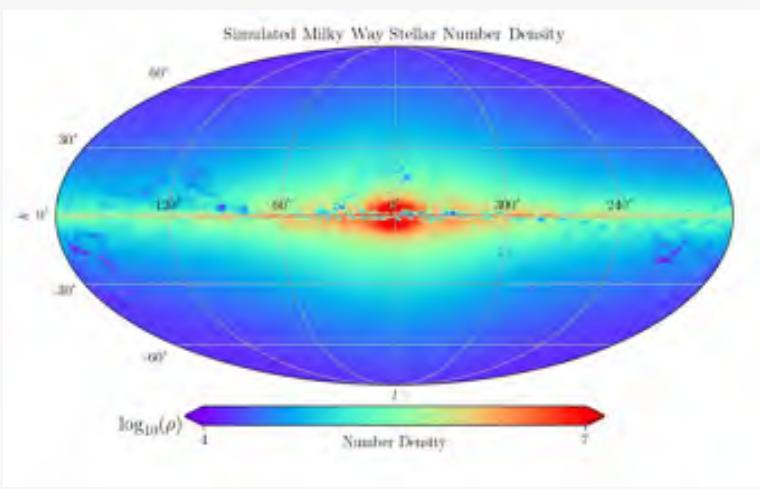
TRILEGAL Milky Way Stellar Mock Catalogue for the Chinese Station Space Telescope

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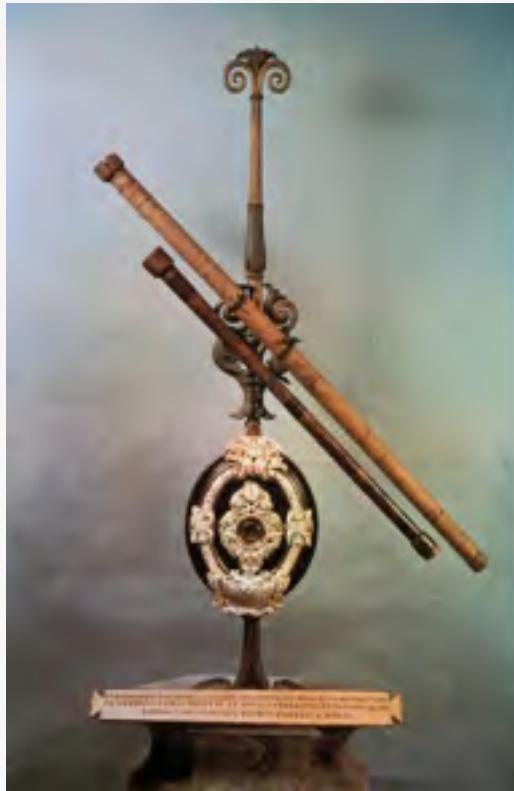
Outline :

- Brief history of understanding the Milky way
- Introduction of TRILEGAL:
 - Galactic models
 - Stellar models
- TRILEGAL MW simulation for CSST
- Concluding remarks and prospects

Brief history of understanding the Milky way

History: Galileo's obs. of the MW

- In 1610, Galileo Galilei: MW is composed by countless stars



Two telescopes built by Galileo, Museo Galileo, Florence
Image Source: www.mpg.de



Galileo's original sketch of the three stars in Orion's belt and the Orion Nebula

Hisotry: Kant's idea of MW

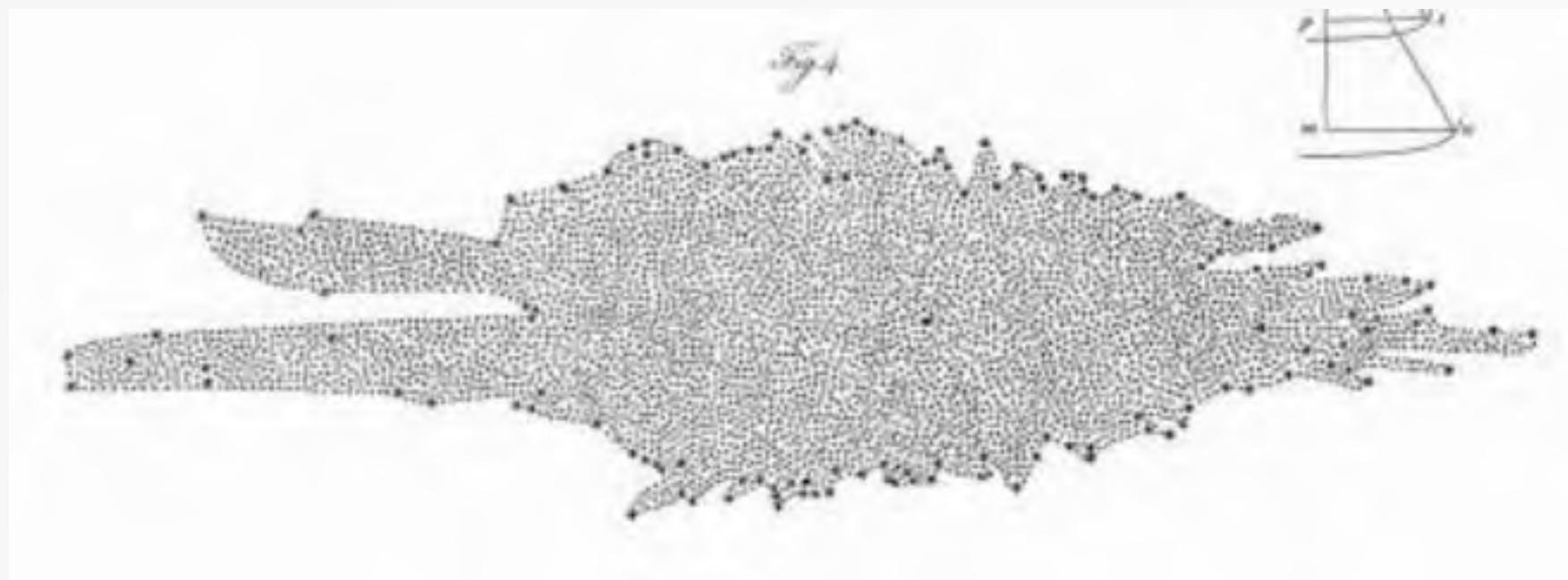
- 1750, Thomas Wright: Milky Way is a thin spherical shell of stars. The Sun is located inside the shell about midway between the inner and outer edges.
- In 1755, Immanuel Kant: MW is a large collection of stars gravitationally bound, rotating and flattened as a disk, with the Solar System embedded within the disk. Proposed “island universes” theory and sparked the “great debate”.



Wright's original woodcut

History: Herschel's MW

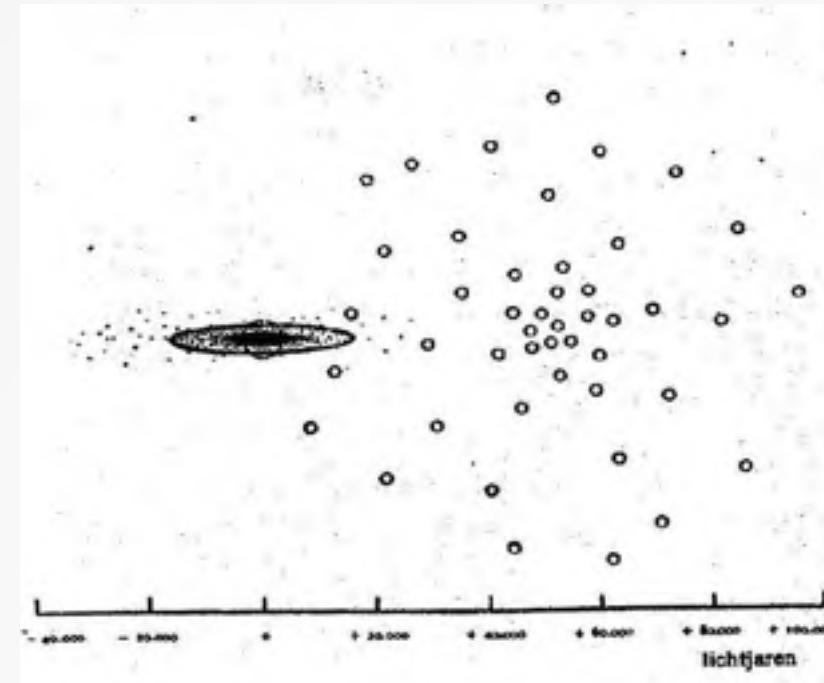
- In 1785, William Herschel: attempted to actually map out the shape of the Milky Way, based on the assumptions/neglections:
 - Stars uniformly distributed inside the MW boundary
 - Not realizing dust absorption



Shape of the MW by W. Herschel, 1785

History: Kapteyn & Shapley's MW

- Jacobus Kapteyn (1901~1922): used photographic star counting, estimated distances statistically based on parallax & proper motions of nearby stars.
- Harlow Shapley (1915~1921): estimated globular cluster distances from RR Lyrae stars.



Oort's illustration of the discrepancy of the Kapteyn Universe and Shapley's system of globular clusters. From de Sitter's book 'Kosmos'.

History: MW's position in the Universe by Hubble

- In 1923, Edwin Hubble: using Cepheids in M31, measured the distance M31 to be ~ 300 kpc (765 kpc nowadays' value), with the 100-inch Hooker telescope at Mount Wilson Observatory.



From New York Times, 1923

History: MW Stellar populations

- As early as 1926, Jan Oort has recognized two types of stellar populations.
- During 1944, Walter Baade, categorized groups of MW stars into
 - Population I: bluer stars associated with spiral arms
 - Population II: yellow stars dominated near the bulge and within GC

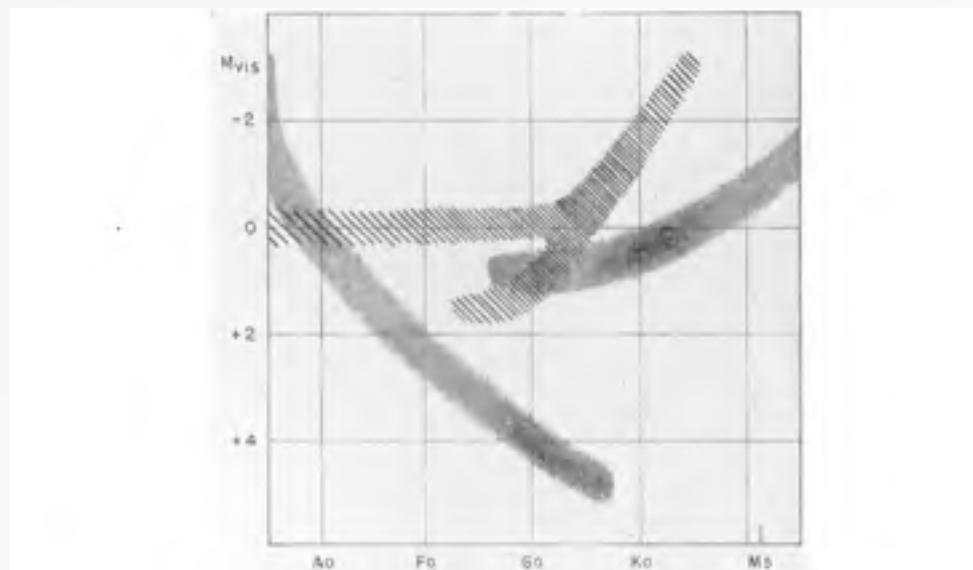
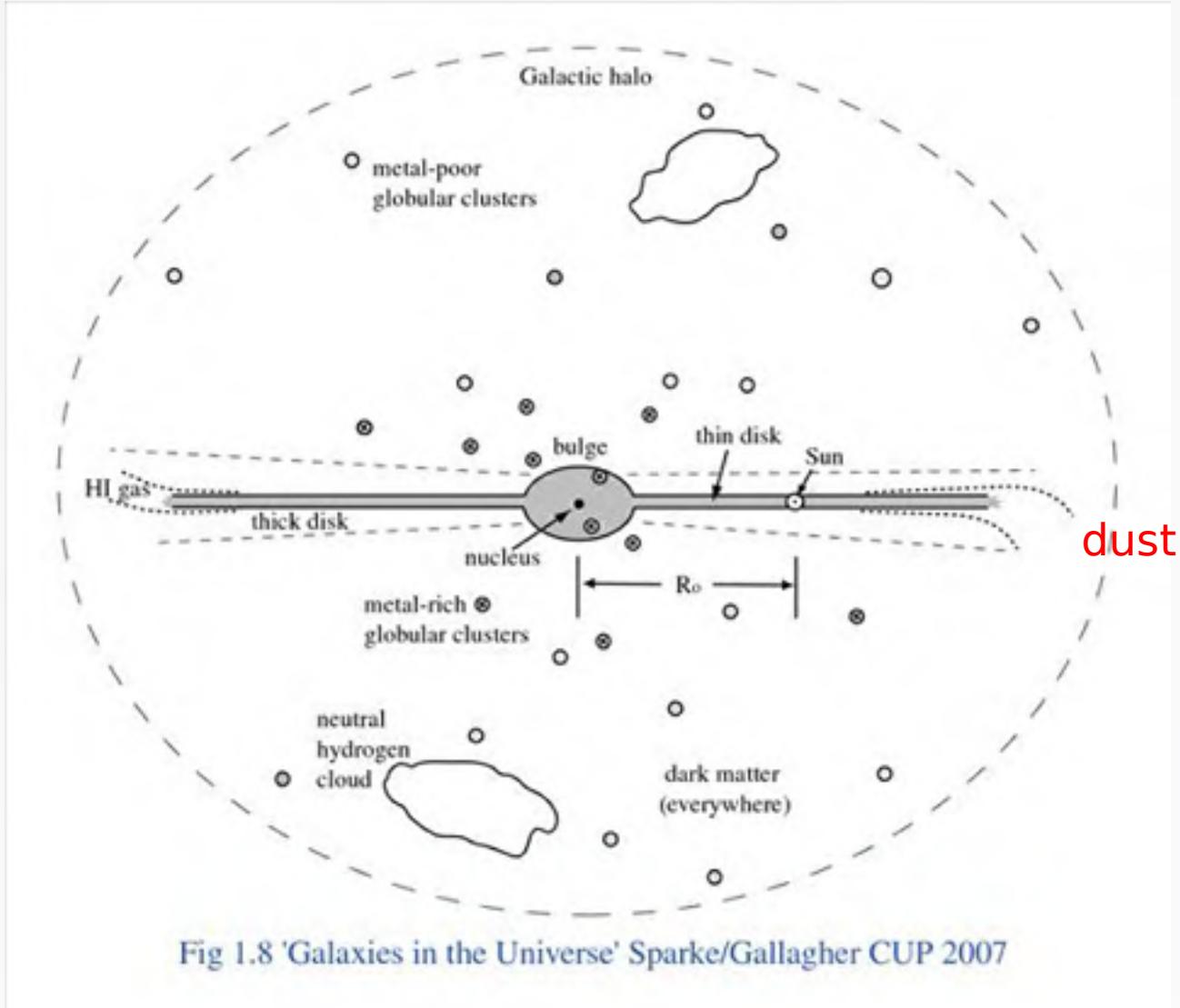


FIG. 1.—Shaded areas: ordinary H-R diagram (type I). Hatched area: H-R diagram of stars in globular clusters (type II).

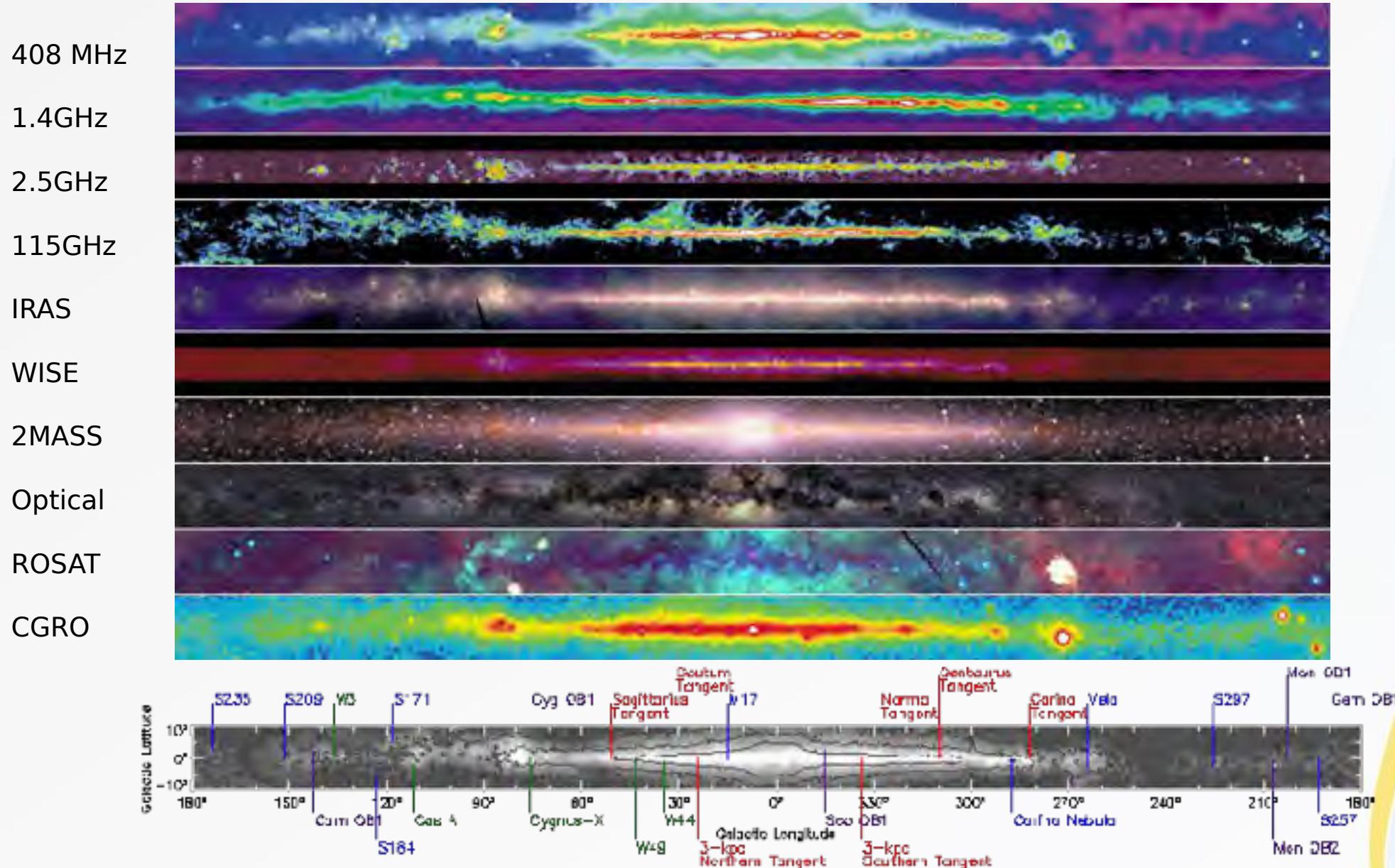
Figure 1 represents schematically the H-R diagrams of the stars in the neighborhood of the sun (*shaded*) and of those in globular clusters (*hatched*). To conform with the usual

by Baade, 1944

History: modern view of the MW

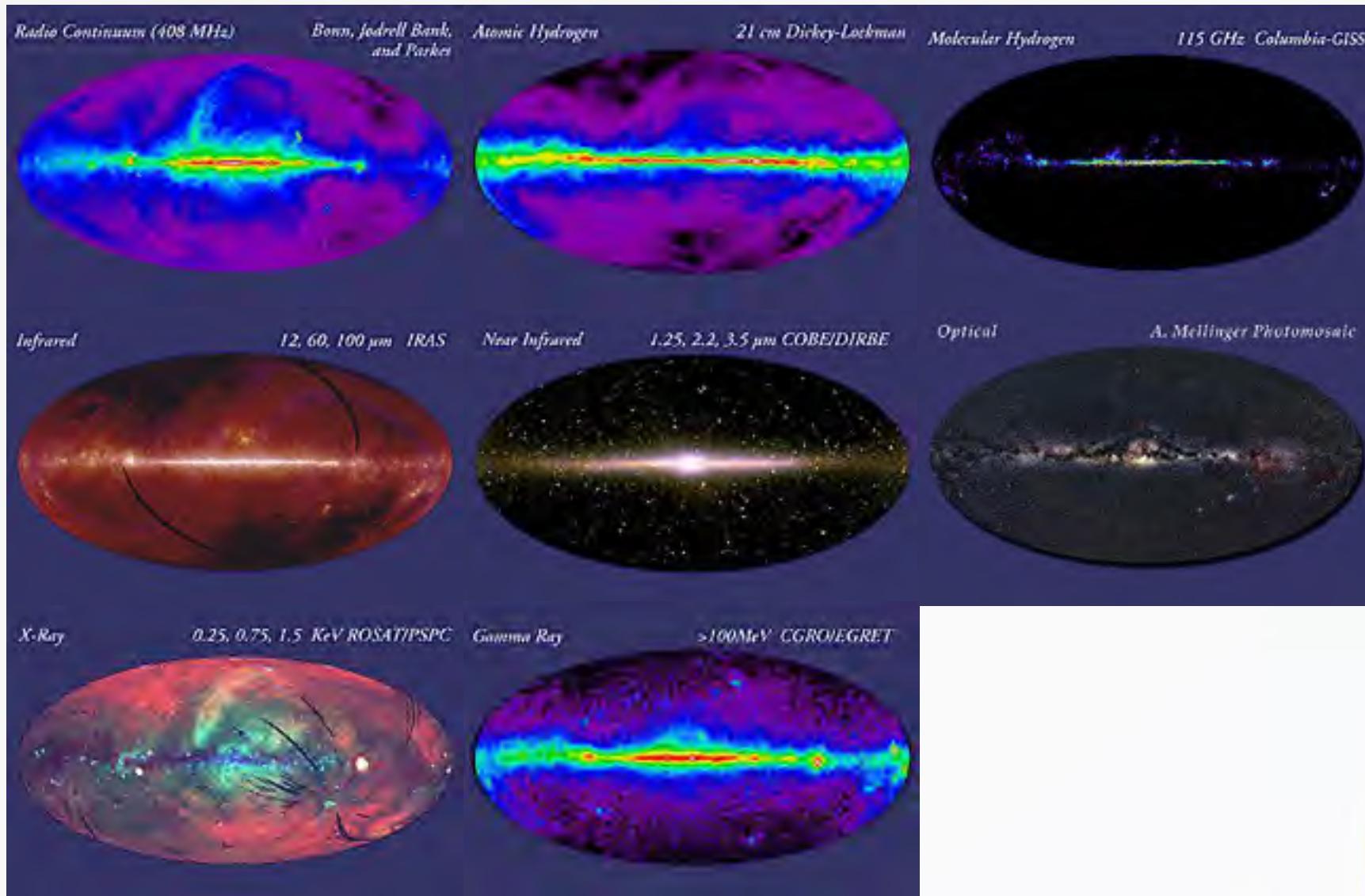


Multiwavelength Milky Way



From https://asd.gsfc.nasa.gov/archive/mwmw/mmw_images.html

Multiwavelength Milky Way



Introduction of TRILEGAL

Star counting Galactic model

Principle of star counting models based on stellar population synthesis :

$$N(m_\lambda, \hat{\mathbf{r}}) dm_\lambda = dm_\lambda \int_{r=0}^{r=\infty} \rho(\mathbf{r}) \phi(M_\lambda, \mathbf{r}) r^2 d\Omega dr$$

$$M_\lambda = m_\lambda - 5 \log r - A_\lambda(r) + 5$$

The goal of star counting models: to find the correct $\rho(\mathbf{r})$ and $\phi(M_\lambda, \mathbf{r})$

Density profile

Luminosity function

Galactic components & luminosity functions

$$\rho(\mathbf{r})$$

$$\rho = \rho_d + \rho_h + \rho_b$$

$$\rho_{\text{disk}}(r) \propto \exp[-z/H(M) - (x - r_0)/h]$$

$$\rho_{\text{spherical}}(r) \propto (r/r_0)^{-7/8} \exp[-10.1(r/r_0)^{1/4}]$$

and

$$\rho_{\text{massive halo}}(r) = \rho_H(r_0)[a^2 + r_0^2]/[a^2 + r^2]$$

May also be
the potential

$$\phi(M_\lambda, \mathbf{r})$$

$$\phi(M_\lambda, \mathbf{r}) = \phi(M_\lambda) \quad \text{for different components}$$

1. Empirical ones: derived from Solar Neighbourhood or globular clusters:

Bahcall & Soneira 80-83, GALFAST (Juric+08)

2. Theoretical ones: **Population synthesis star count models**

Requires: IMF, SFH, age-metallicity relation (AMR), **Stellar models**

e.g., Besançon (Robin+03), **TRILEGAL (Girardi+05)**, Just-Jahreiss+08,

Galaxia (Sharma+11), GalMod(Pasetto+18), etc.

Distance of Sun from the Galactic Center: as an example

Table 3 Recent measurements of distance R_0 to the Galactic Center

Label	Reference	Method	Location	T	R_0 (kpc)
Rd+09	Reid et al. (2009b)	Trig. parallaxes of Sgr B	GC	d	7.90 ± 0.75
Mo+12	Morris et al. (2012)	Orbit of S0-2 around Sgr A*	GC	d	7.70 ± 0.40
Gi+09	Gillessen et al. (2009b)	Stellar orbits around Sgr A*	GC	d	8.33 ± 0.15
Ch+15	Chamourelis et al. (2015)	NSC statistical parallax	GC	d	8.27 ± 0.13
Do+13	Do et al. (2013)	NSC statistical parallax	GC	d	8.92 ± 0.36
BB15	Bajkova & Bobylev (2015)	Trig. parallaxes of HMSCRs	DSN	m	8.03 ± 0.32
Rd+14	Reid et al. (2014)	Trig. parallaxes of HMSCRs	DSN	m	8.34 ± 0.19
Ho+12	Huang et al. (2012)	Trig. parallaxes of HMSCRs	DSN	m	8.05 ± 0.45
ZS13	Zhu & Shen (2013)	Near- R_0 rotation young tracers	DSN	m	8.08 ± 0.62
Bo13	Bobylev (2013)	Near- R_0 rotation SFR+Cephoids	DSN	m	7.45 ± 0.66
Sch12	Schönrich (2012)	Near- R_0 rotation SEGUE stars	DSN	m	8.27 ± 0.41
Ko+15	Kupper et al. (2015)	Tidal tails of Pal-5	III	m	8.30 ± 0.33
VH+09	Vanhaezebeek et al. (2009)	Bulge stellar population model	B	m	8.20 ± 0.50
Pi+15	Pietrukowicz et al. (2015)	Bulge RR Lyrae stars	B	s	8.27 ± 0.40
De+13	Dékány et al. (2013)	Bulge RR Lyrae stars	B	s	8.33 ± 0.17
Da09	Dambis (2009)	Disk/halo RR Lyrae stars	DSN	s	7.58 ± 0.57
Ma+13	Masunaga et al. (2013)	Nuclear bulge T-I Cephoids	B	s	7.30 ± 0.60
Ma+11	Masunaga et al. (2011)	Nuclear bulge Cephoids	B	s	7.90 ± 0.80
Gr+08	Groenewegen et al. (2008)	Bulge Cephoids	B	s	7.98 ± 0.51
Ma+09	Masunaga et al. (2009)	Bulge Mirac	B	s	8.24 ± 0.41
Gr05	Groenewegen & Blommaert (2005)	Bulge Mirac	B	s	8.60 ± 0.81
FA14	Francis & Anderson (2014)	Bulge red clump giants	B	s	7.80 ± 0.30
Ca+13	Cao et al. (2013)	Bulge red clump giants	B	s	8.20 ± 0.20
Fr+11	Fritz et al. (2011)	NSC red clump giants	GC	s	7.94 ± 0.76
FA14	Francis & Anderson (2014)	All globular clusters	B, III	s	7.40 ± 0.28
Bi+06	Bica et al. (2006)	Halo globular clusters	III	s	7.10 ± 0.54

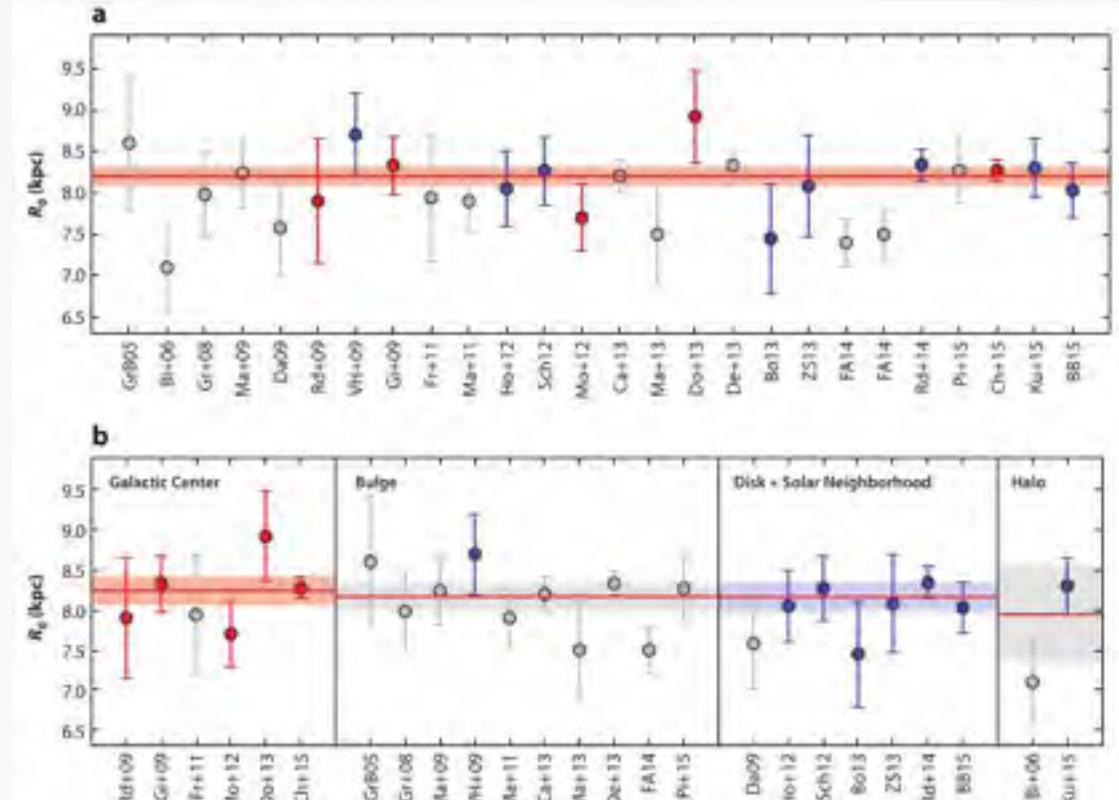


Figure 4

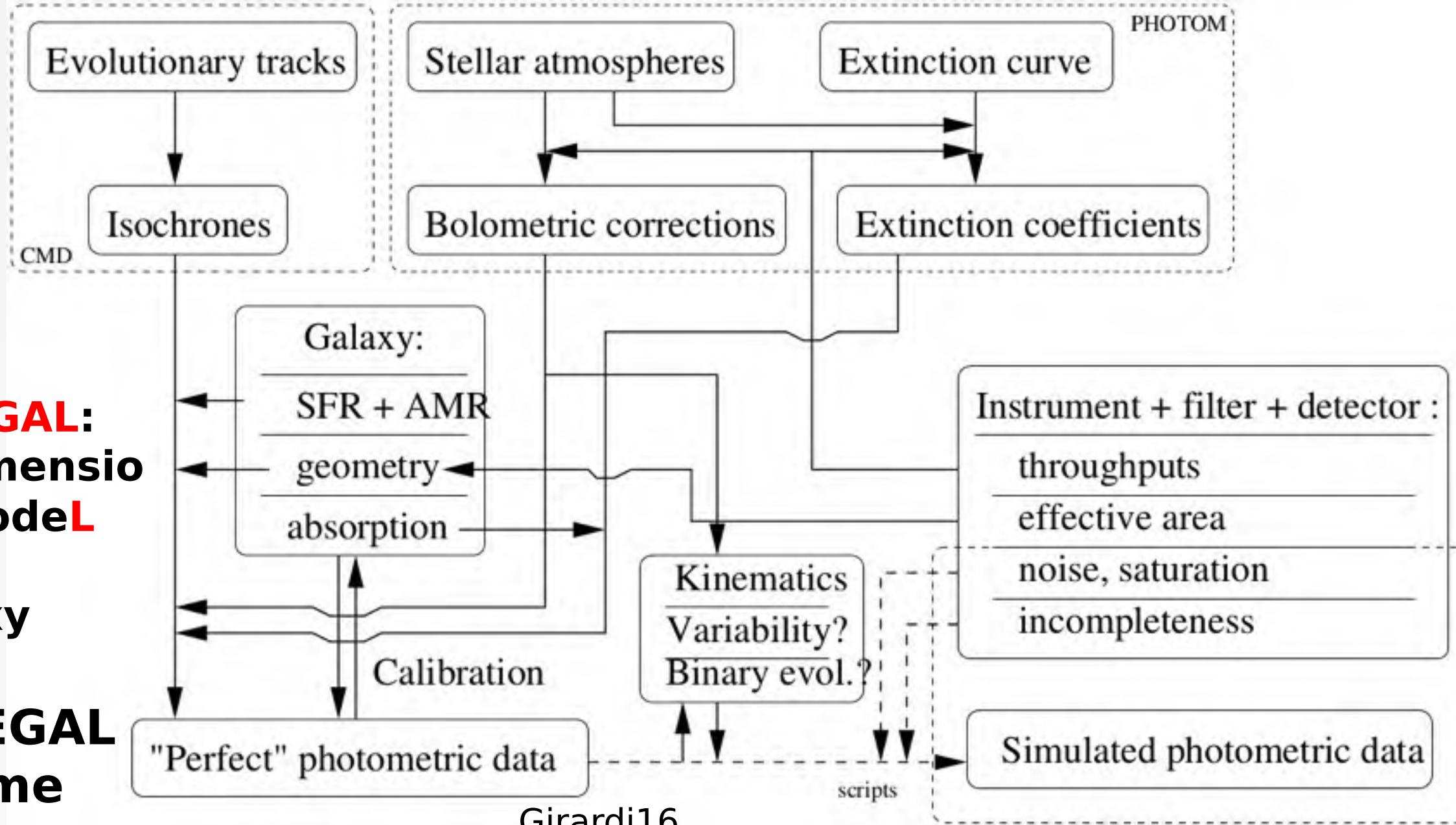
Recent measurements of R_0 [in Table 3], using different methods. Red, blue, and gray points denote direct, model-based, and secondary estimates, respectively. (a) Time sequence for all, with our adopted best estimate, $R_0 = 8.2 \pm 0.1$ kpc. (b) Separate time sequences for determinations in the Galactic Center, bulge, disk and Solar Neighborhood, and inner halo (not using the FA14 globular cluster value that includes the inner metal-rich clusters). The horizontal lines show weighted mean values for the respective components, and colored bands show 1σ UUE (uncorrelated unbiased standard errors).

Comparison of different star counting MW models

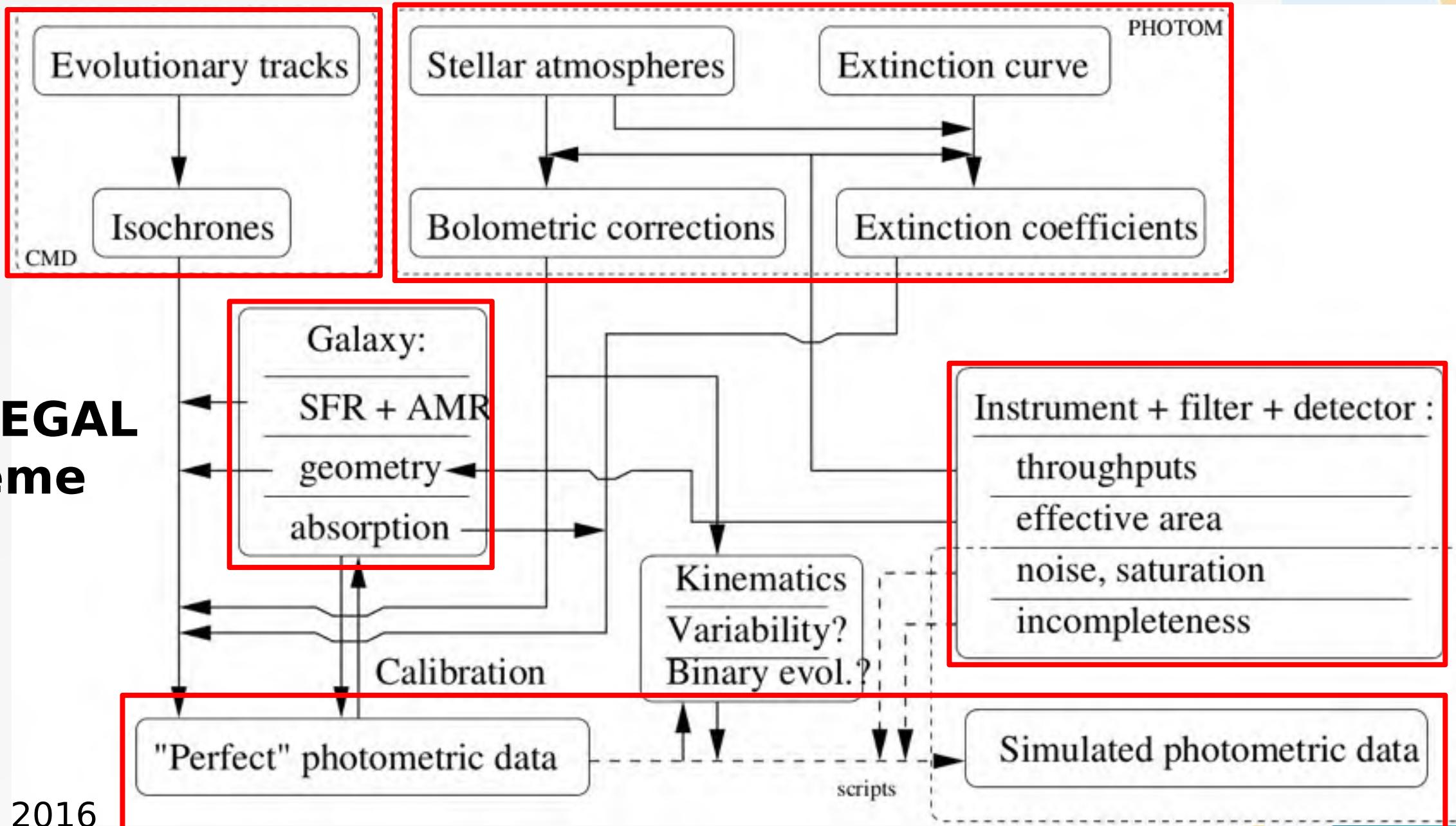
Model	Bulge	Thin disk	Thick disk	Halo	DM	Else	Stellar model	Dynamics	Kinematics	Comment
TRILEGAL (Girardi+05)	Triaxial	Exp.+ Sech ²	Exp.+ Sech ²	Power-law, axisymmetric	N	N	PARSEC	N	Y	
Besançon (Robin+03)	Exponential	Exponential	Exp.	Exp., spherical	Y	Warp, flare	Padova	Y	Y	
Galaxia (Sharma+11)	Similar to Besançon					Accept N-body sim.	Padova	Self-consistent	Y	
J-J (Just & Jahreiß, 10)	Disc shape					Y	Gas	PEGASE (with Padova models as default)	Y	Y
GalMod (Pasetto+18)	Spherical+density potential	Exp.+Sech ²		Solved from the potential	Y	Bar	PARSEC	Y	Y	

TRILEGAL:
TRIdimensional modeL
of the
GALaxy

TRILEGAL
scheme



TRILEGAL scheme



TRILEGAL's Galactic components

Geometry:

Thin disk exp. in R and sech^2 in z, scale height increasing with population age

Thick disk exp. in R and sech^2 in z, fixed scale height

Halo power-law oblate

Bulge triaxial cf. Binney+97

Dust layer exp. in z, extinction cf. SFD+98, SF+11, Abergel+14, Lallement+18, Green+19

External objects (e.g. SMC and LMC)

Galactic component	Mass distribution	Constants	
Thin disk	$\rho_d = C_d \frac{\exp(-R/h_{Rd})}{\cosh^2(0.5z/h_{zd})}$ $h_{zd}(t) = z_0(1+t/t_0)^{5/3}$	$h_{Rd} = 2913.36 \text{ pc}$	$z_0 = 94.69 \text{ pc}$
Thick disk	$\rho_D = C_D \frac{\exp(-R/h_{RD})}{\cosh^2(0.5z/h_{zD})}$	$h_{RD} = 2394.07 \text{ pc}$ $C_D = 0.00378 M_\odot/\text{pc}^3$	$h_{zD} = 800.0 \text{ pc}$
Bulge	$\rho_b = f_0 \frac{\exp(-a^2/a_m^2)}{(1+a/a_0)^{1.8}}$ $a = \sqrt{x^2 + (y/\eta)^2 + (z/\zeta)^2}$	$f_0 = 406.0 M_\odot/\text{pc}^3$ $a_0 = 95.0 \text{ pc}$	$a_m = 2500.0 \text{ pc}$ $\eta = 0.68$ $\zeta = 0.31$
Halo	$\rho_h = C_h \left(\frac{R_z}{\sqrt{R^2 + (z/q)^2}} \right)^{2.75}$	$q = 0.62 \text{ pc}$	$C_h = 10^{-4} M_\odot/\text{pc}^3$

Stellar populations:

Each component has its own IMF, SFH, AMR

IMF Chabrier+03 by default, Kroupa, Salpeter, etc.

Binary fraction default 30% for mass ratio 0.7-1

Bulge age~10Gyr, AMR cf. Zoccali+03

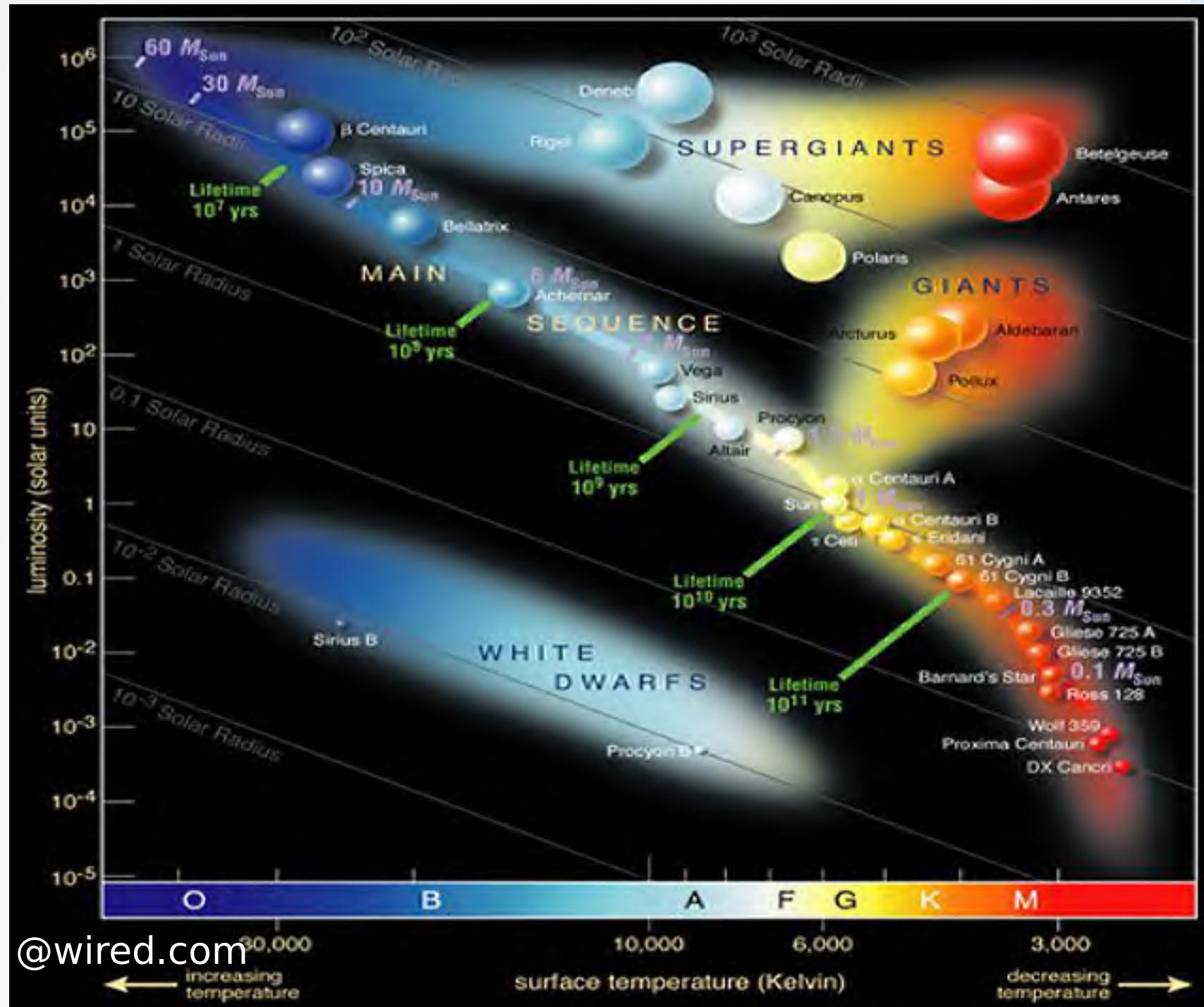
Thick disk age~10Gyr, AMR cf. Boeche+13

Halo constant SFR over the last 12-13 Gyr, AMR cf. Henry & Worthey 99

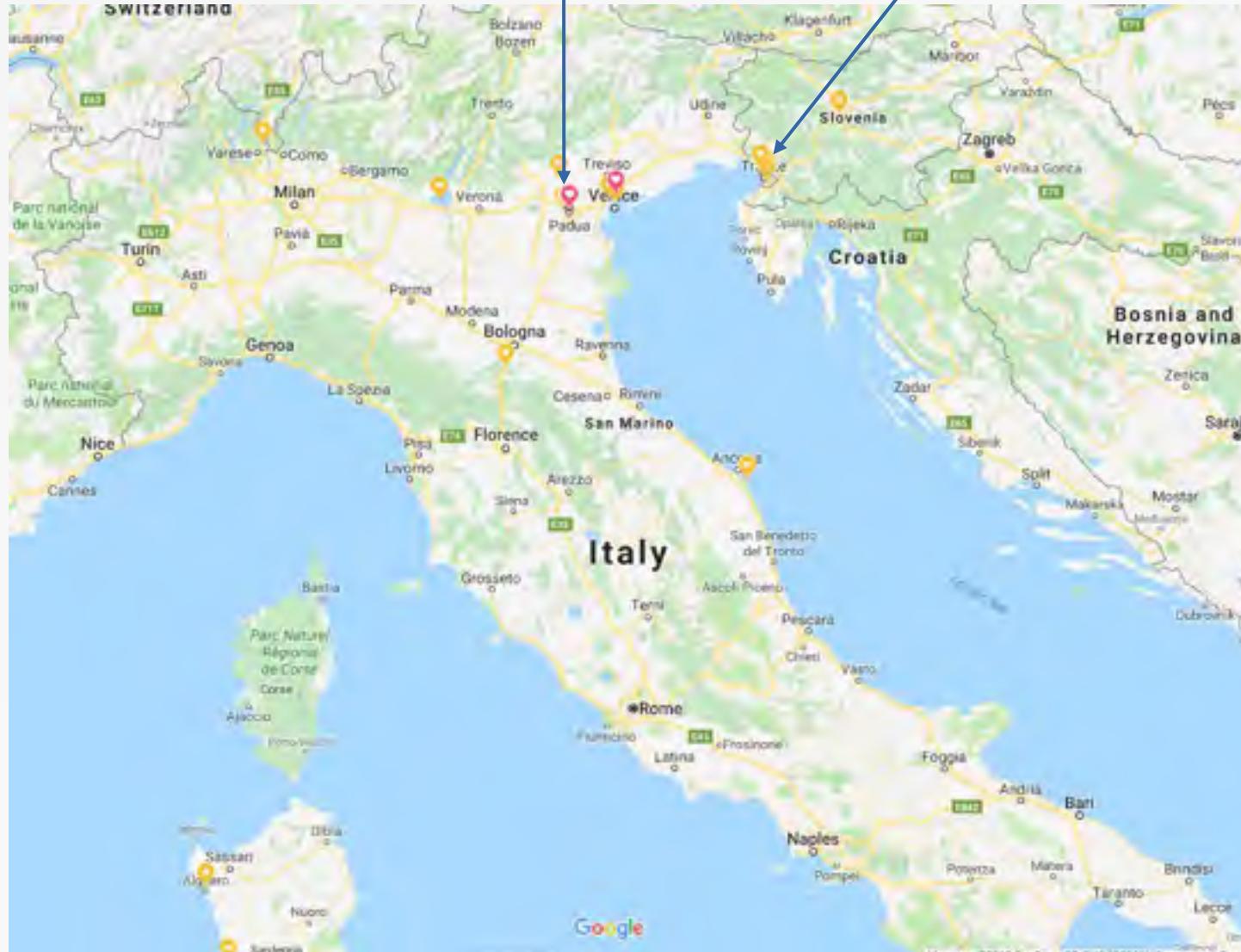
Thin disk constant SFR over the last 11 Gyr, AMR cf. Rocha-Pinto+00

External objects specific IMF, SFR and AMR

Check Girardi+05 for more details

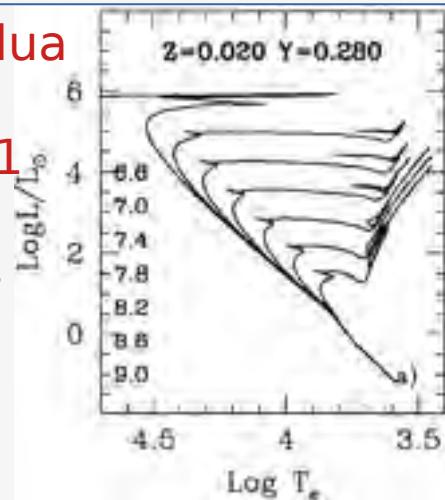


PARSEC: PAdova and tRieste Stellar Evolutionary Code

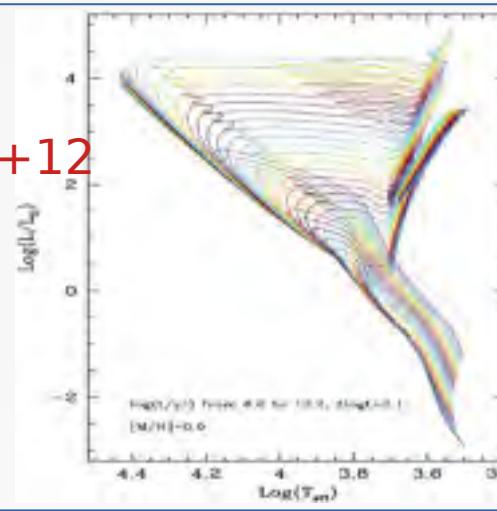


PARSEC Tracks/Isochrones

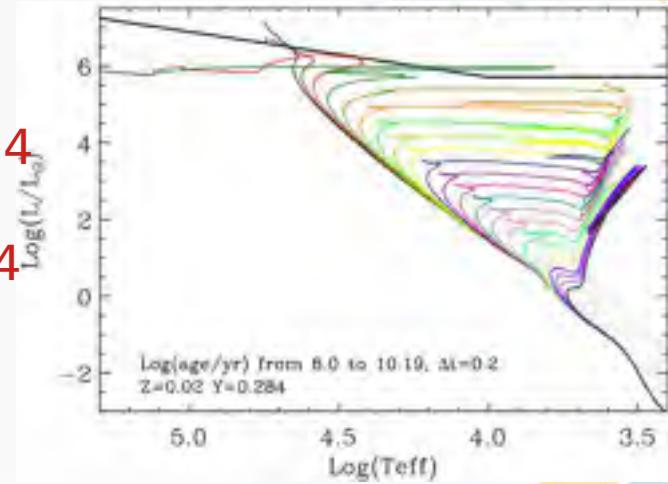
Padova/Padua
models:
Bressan+81
...
Bertelli+94
Girardi+00
Marigo+08
Girardi+10



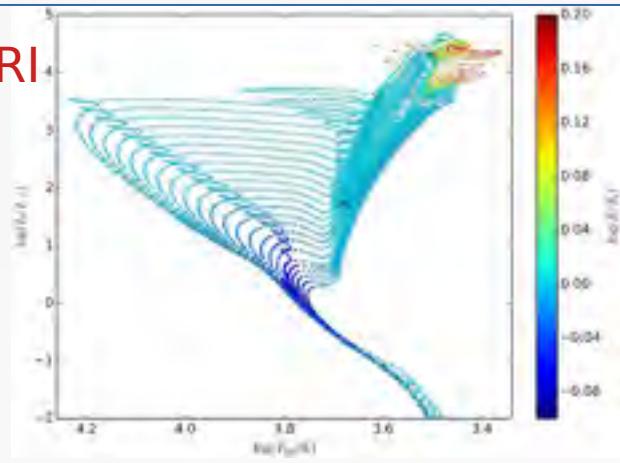
PARSEC
models:
Bressan+12



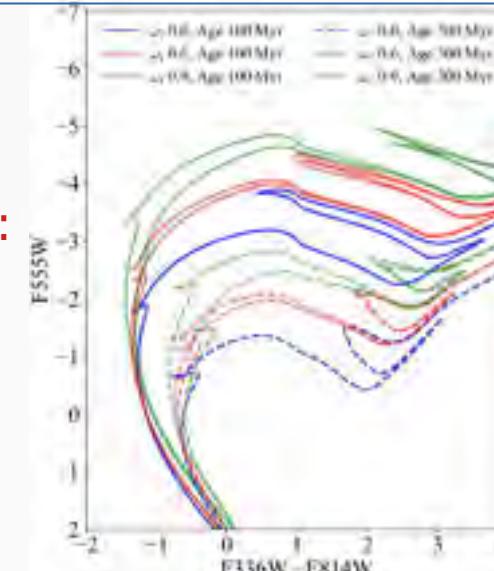
PARSEC
models:
Chen+14
+15
Tang+14
+16
Fu+15
+18



PARSEC-COLIBRI
models:
ERC/STARKEY
Marigo+17
Chen+18
Pastorelli+19
Pastorelli+20

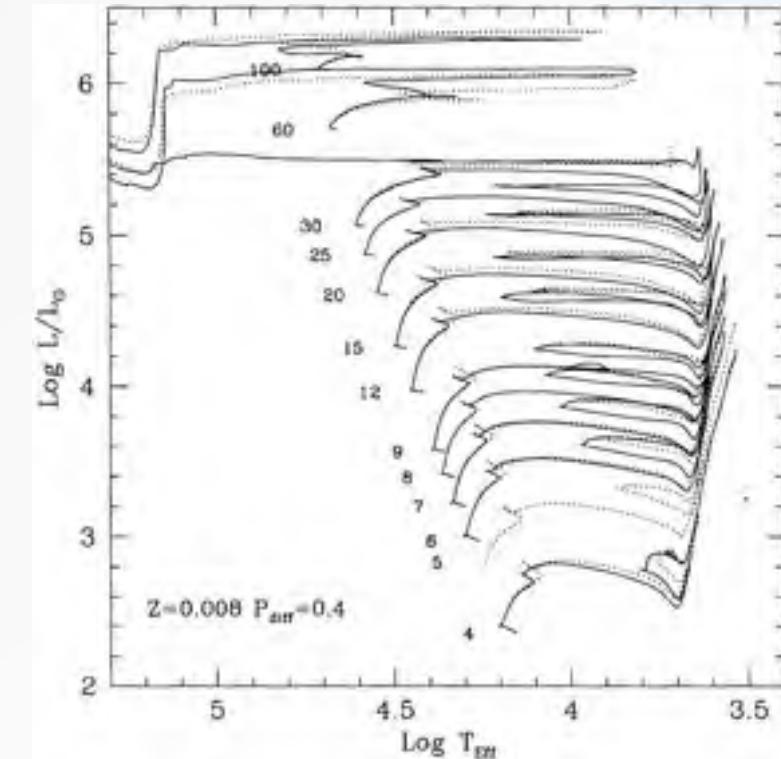
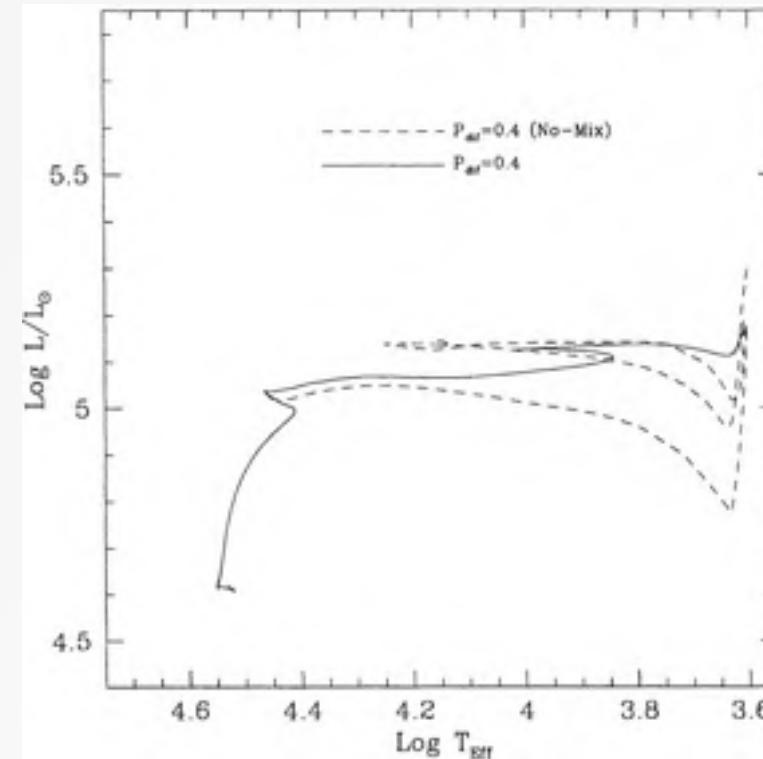


PARSEC
models
with rotation:
Costa+19
Costa+20



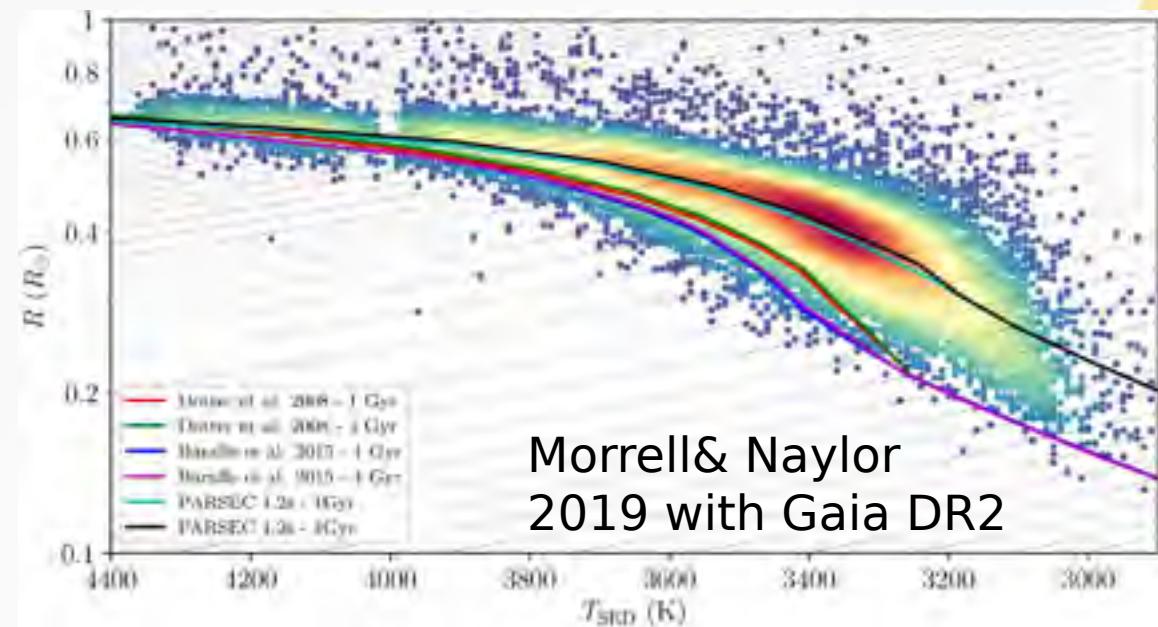
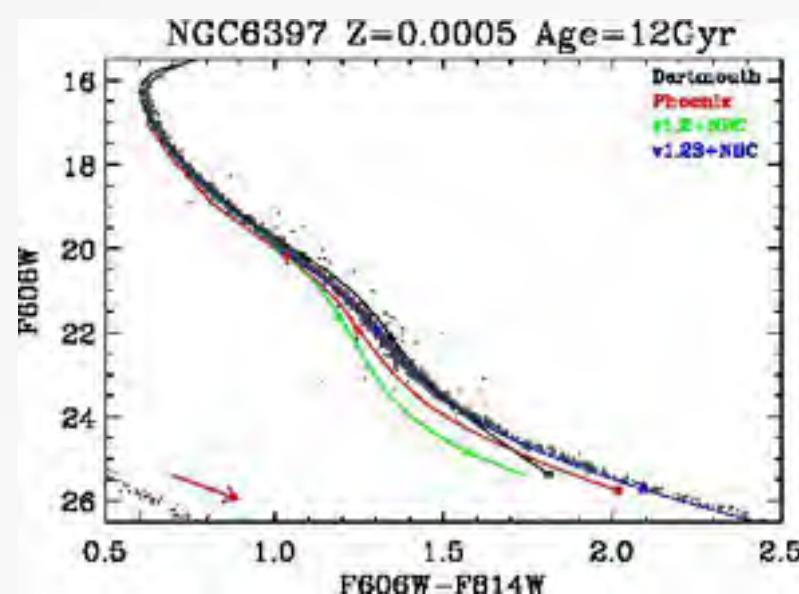
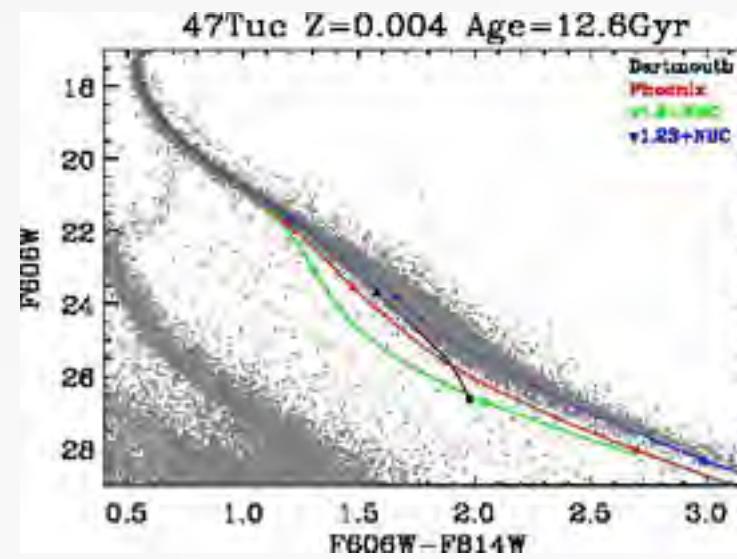
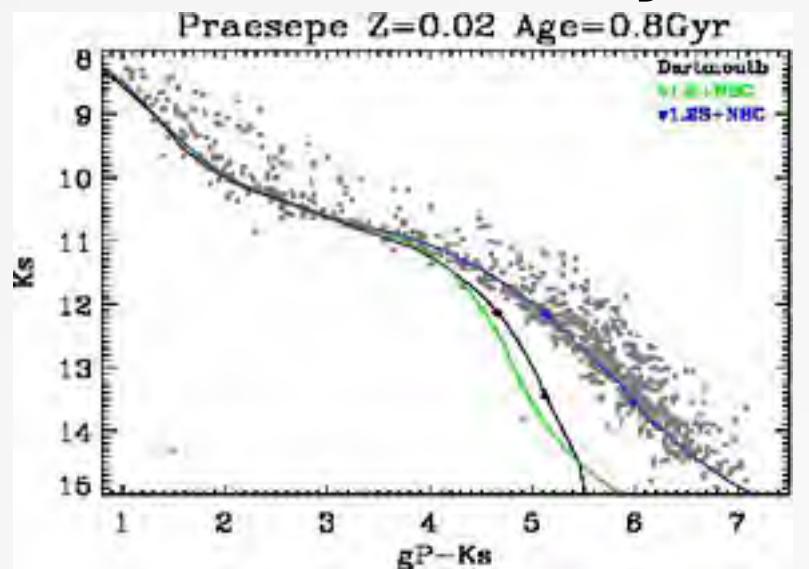
PARSEC-
TRILEGAL
models with
interacting
binaries, new
WD & NS
tracks: to do

Padova models: diffusion mixing by Deng+96a,b

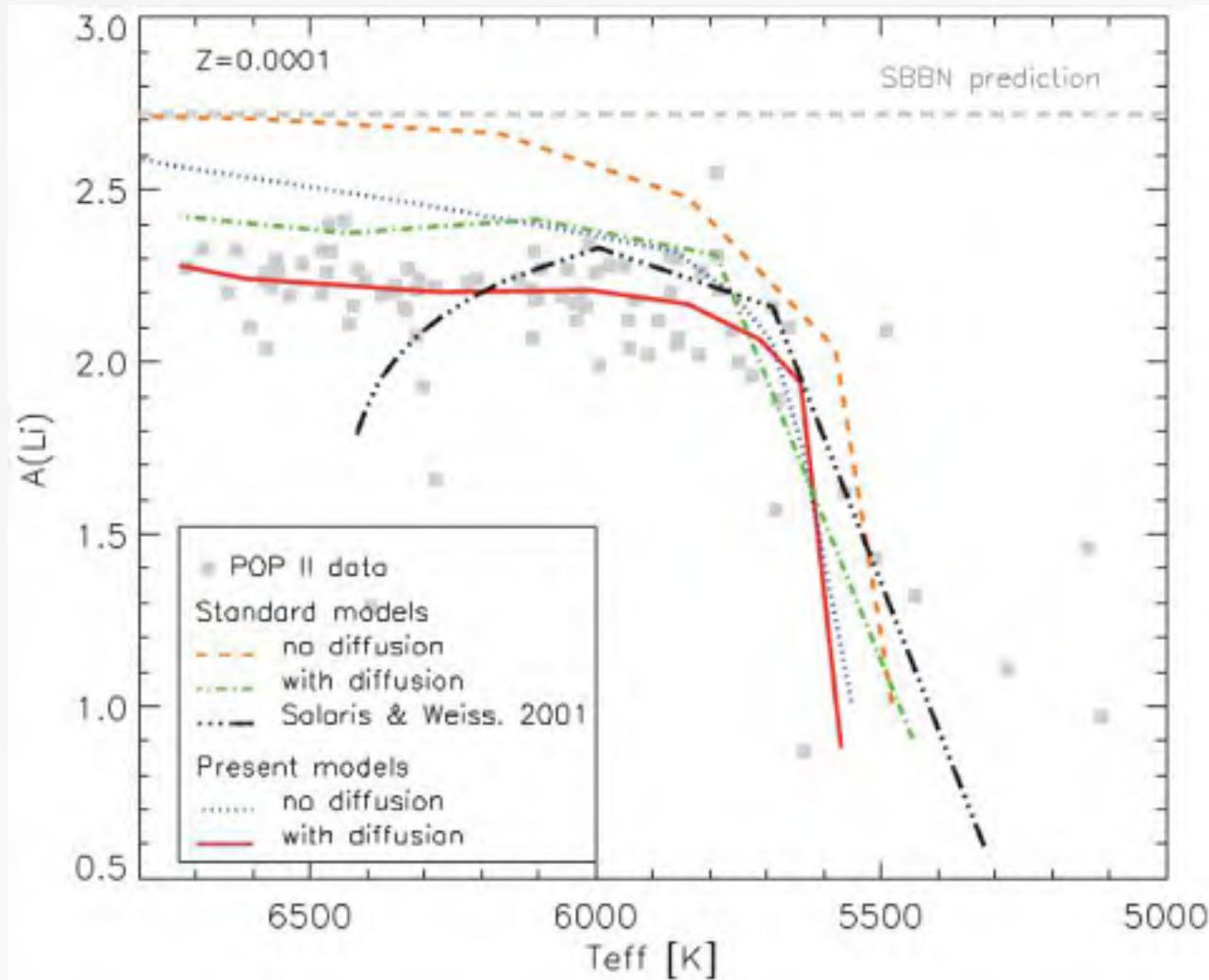


Stellar evolution with turbulent diffusion by **Licai Deng**,
A&A, 1996, v.313, p.145-158 & p.159-179

PARSEC very-low mass stars

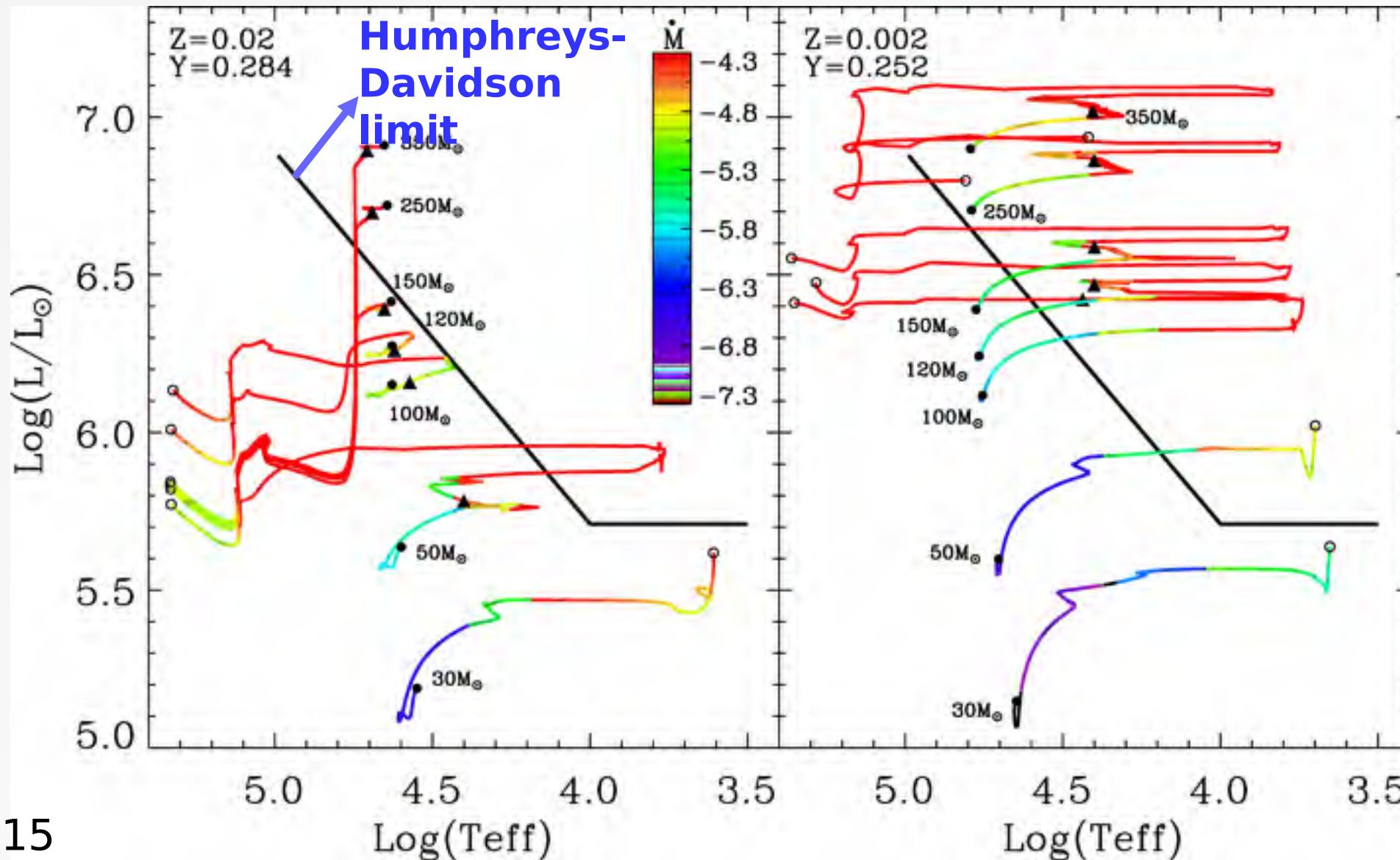


PARSEC Pre-Main Sequence models

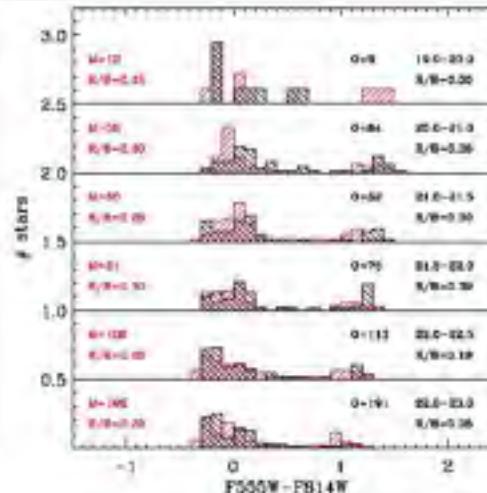
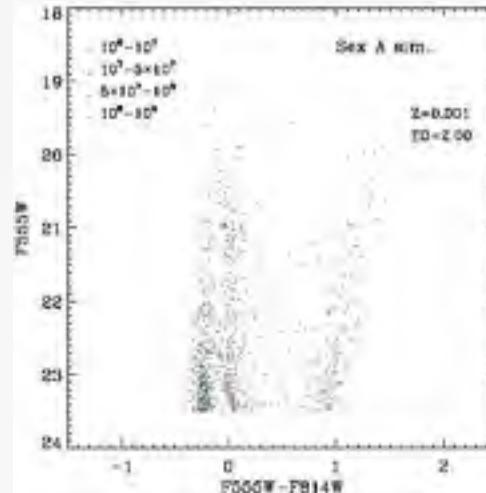
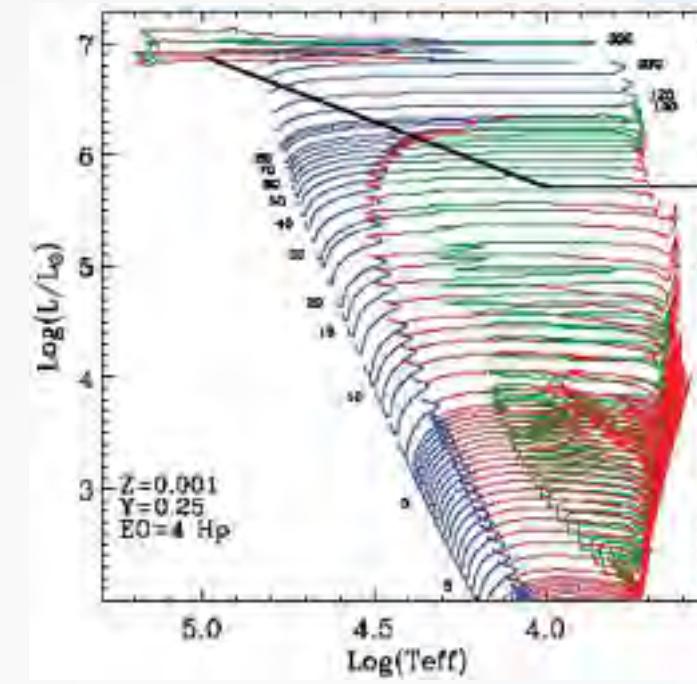
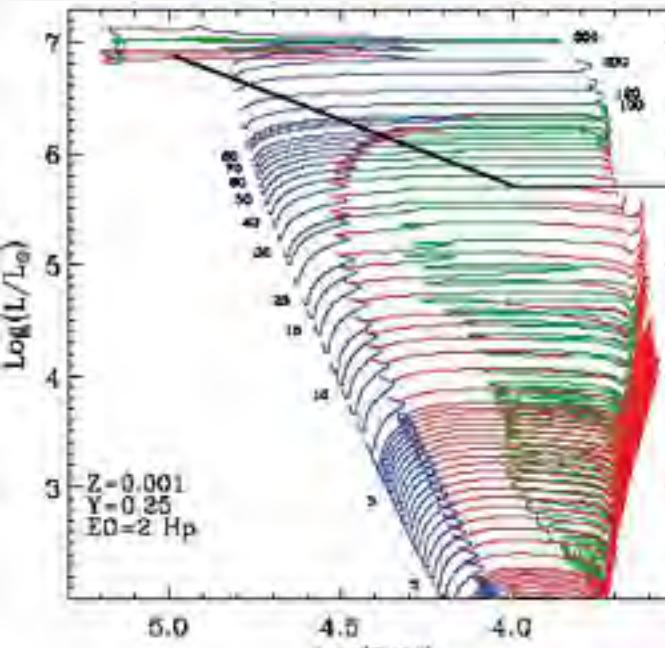
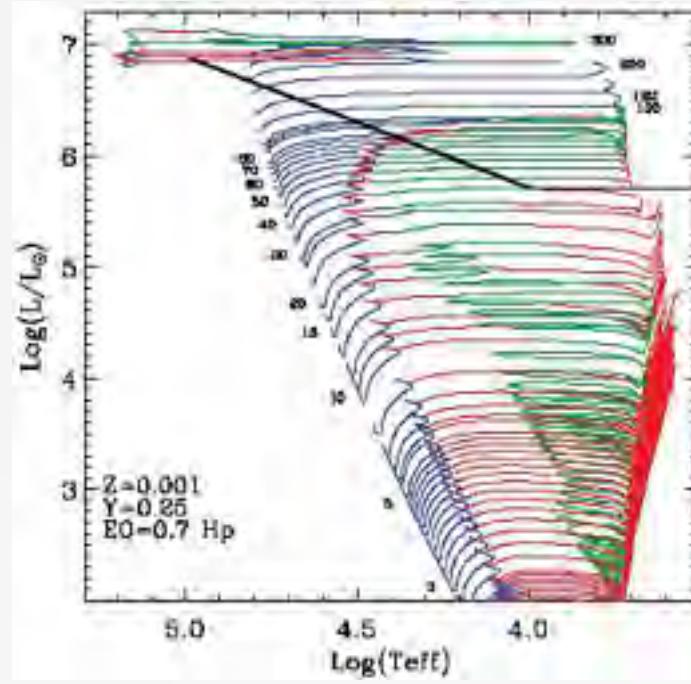


Fu+15: envelope OV + residual accreting reproduces the Spite-plateau

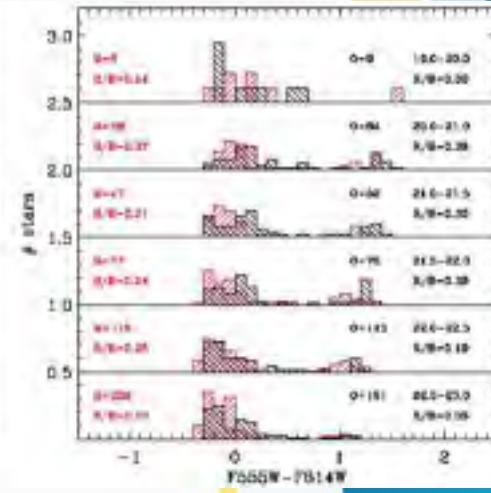
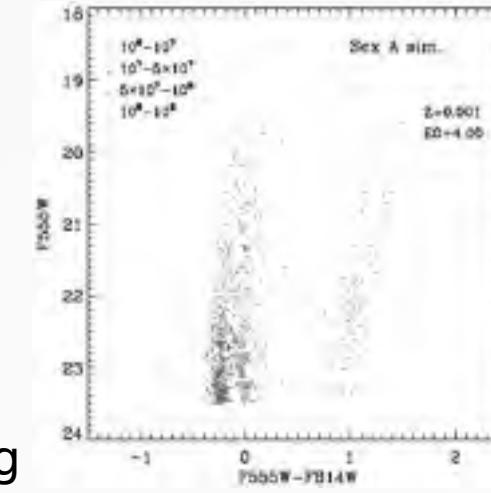
PARSEC models for very-massive stars



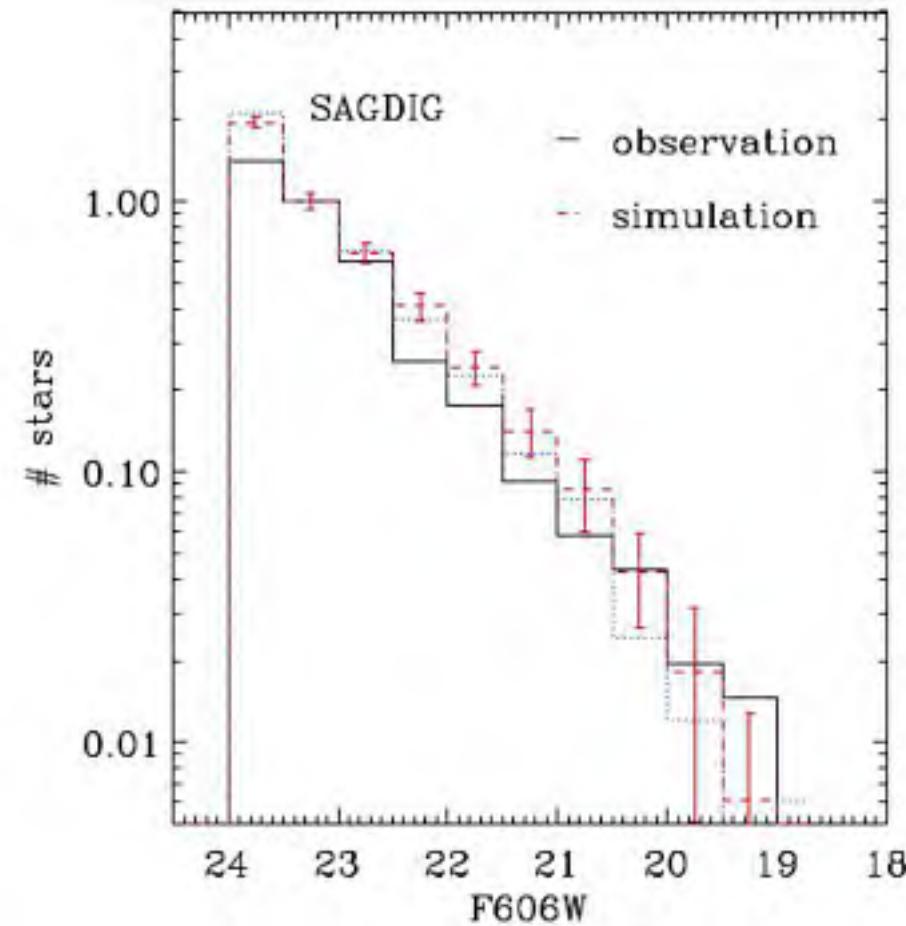
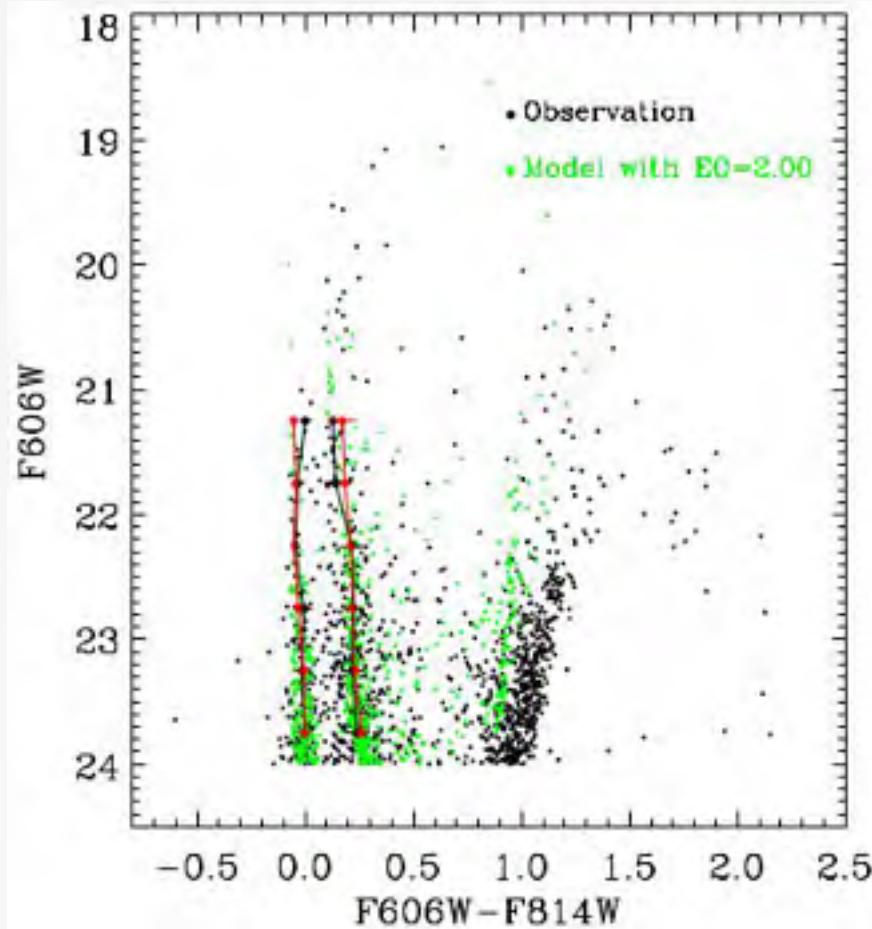
PARSEC models for very-massive stars



Tang+14:
calibrating
envelope
overshooting

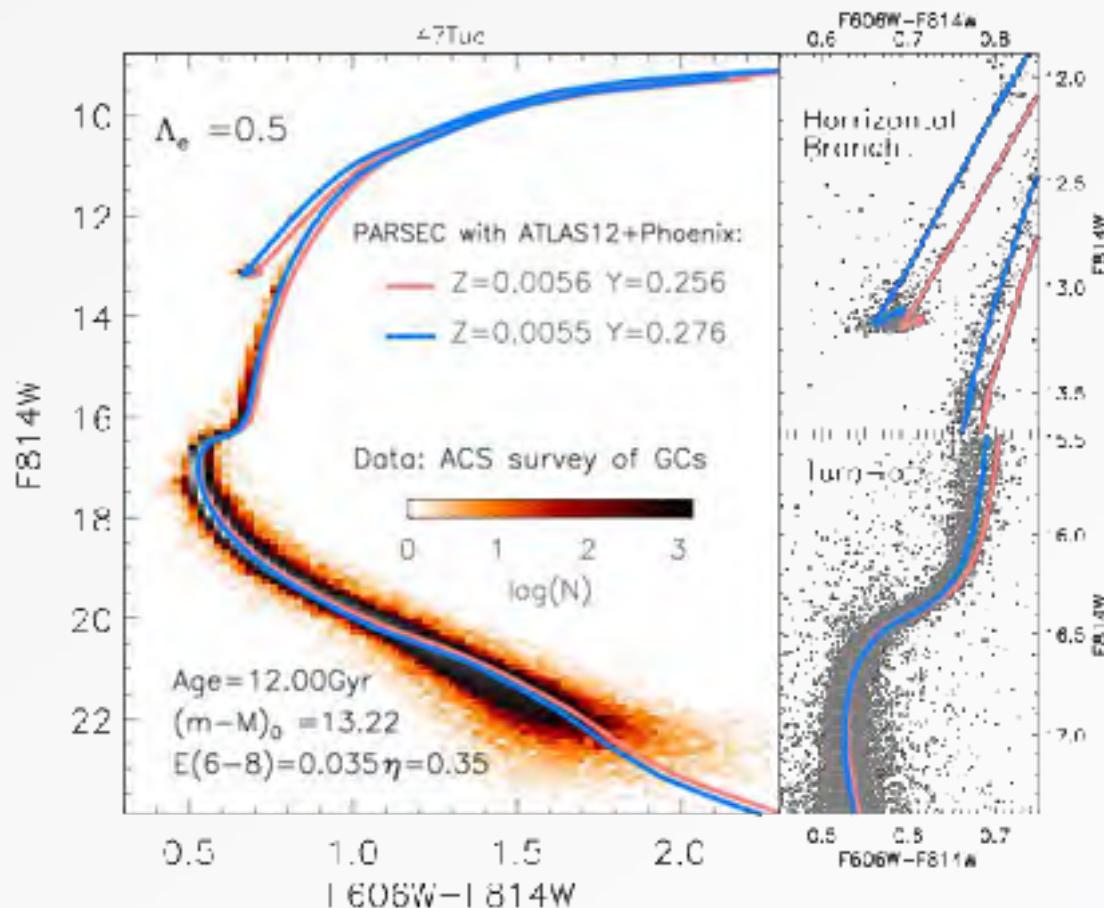


PARSEC models for very-massive stars



Tang+16: Contrary to what has been stated in the literature, we find that the Schwarzschild criterion, instead of the Ledoux criterion, favours the development of blue loops

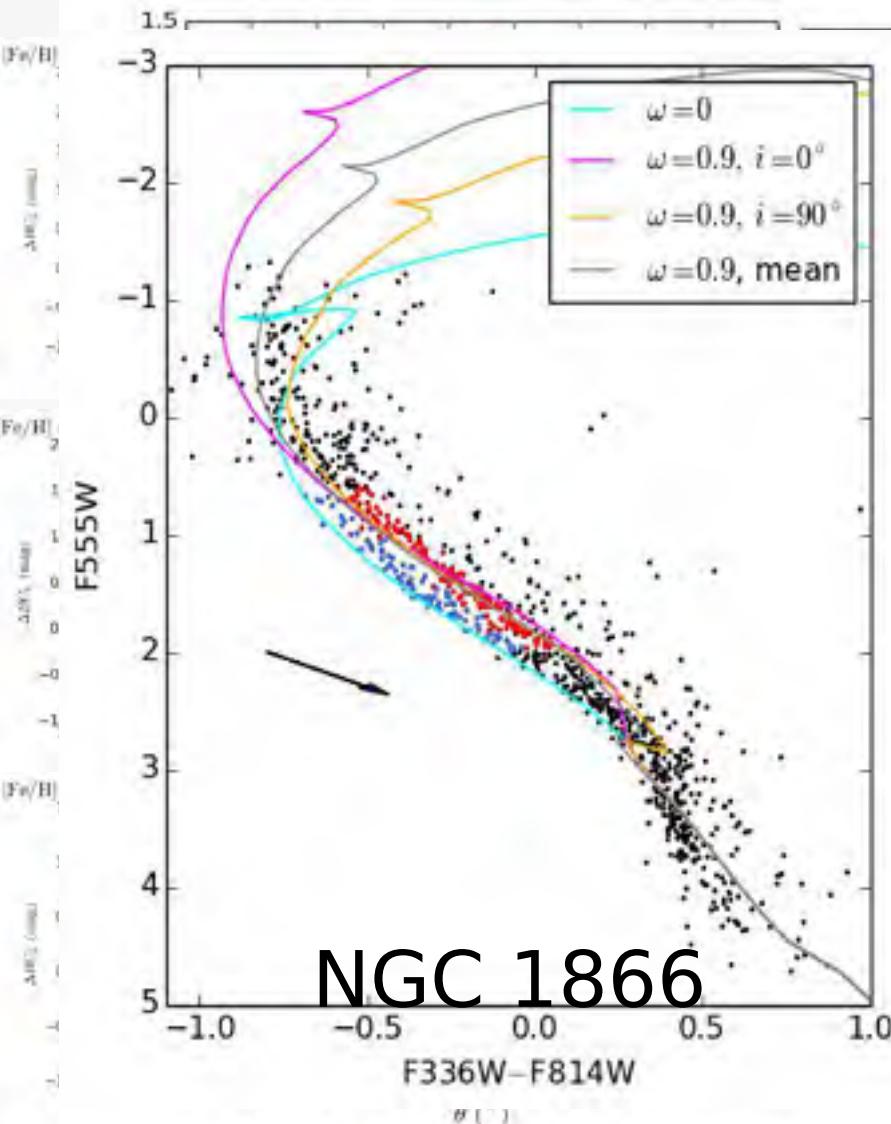
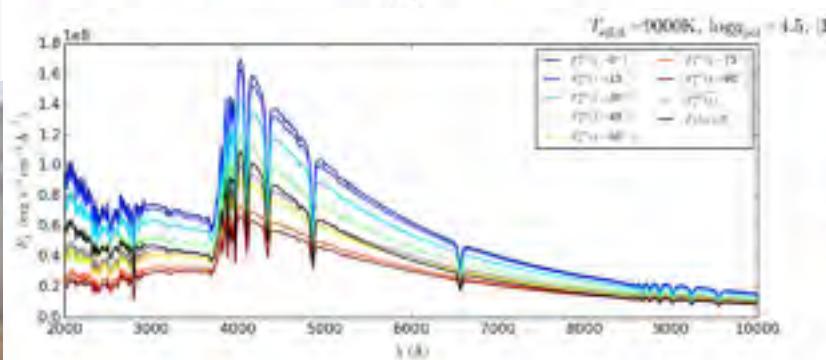
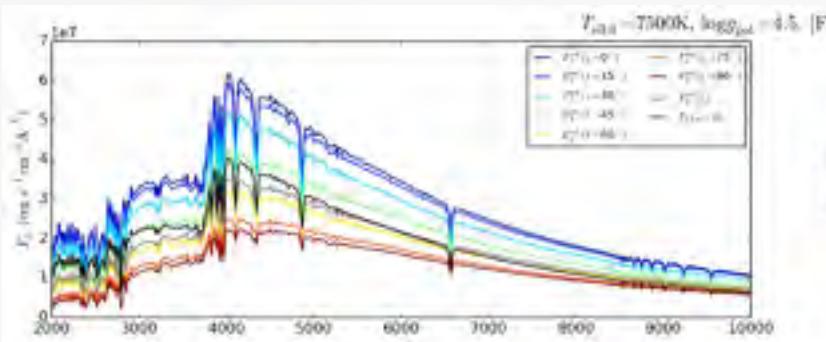
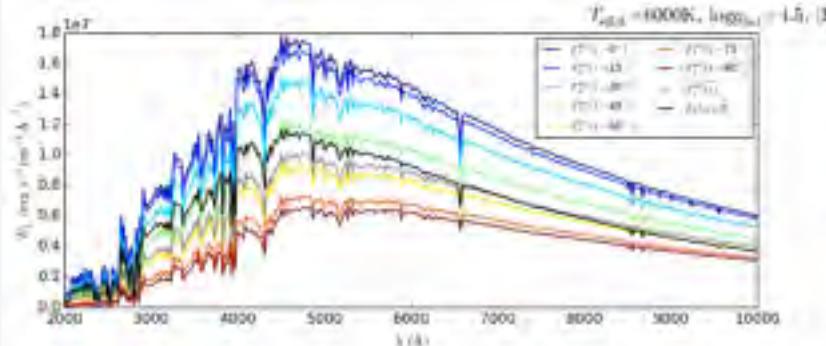
PARSEC models with alpha-enhancement



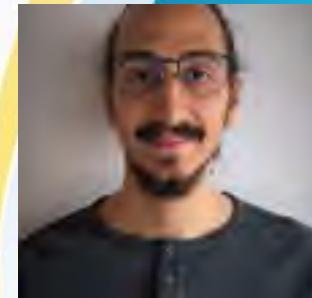
Fu+18: PARSEC alpha-enhanced model fitting to 47 Tuc

Important for elliptical galaxies, dSph, GC, thick disk, bulge, halo, ...

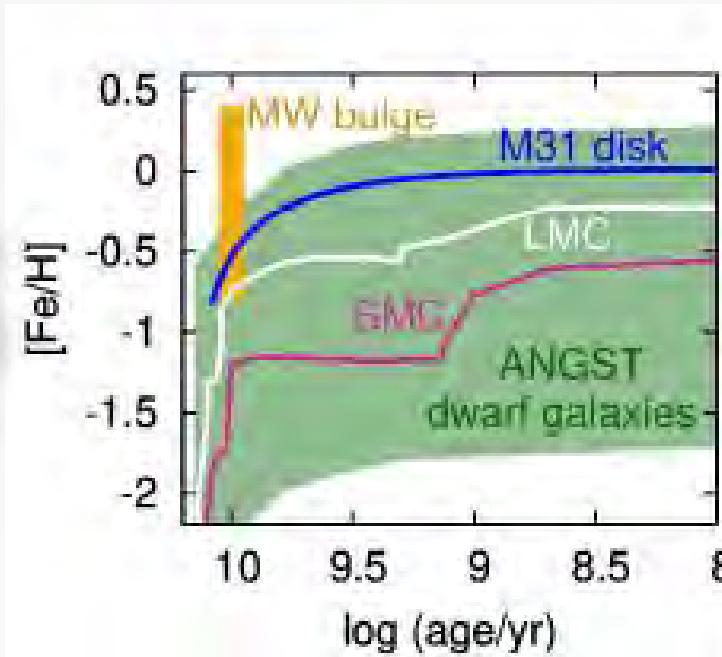
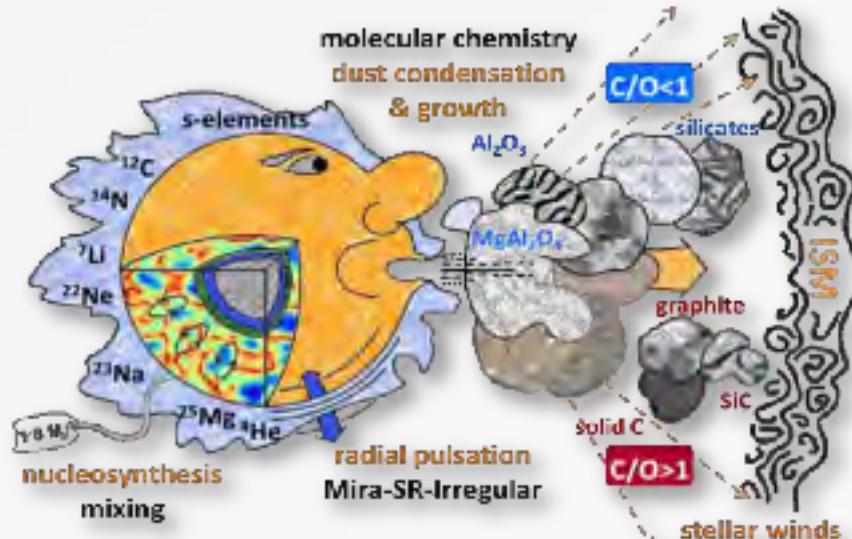
PARSEC model of rotating stars



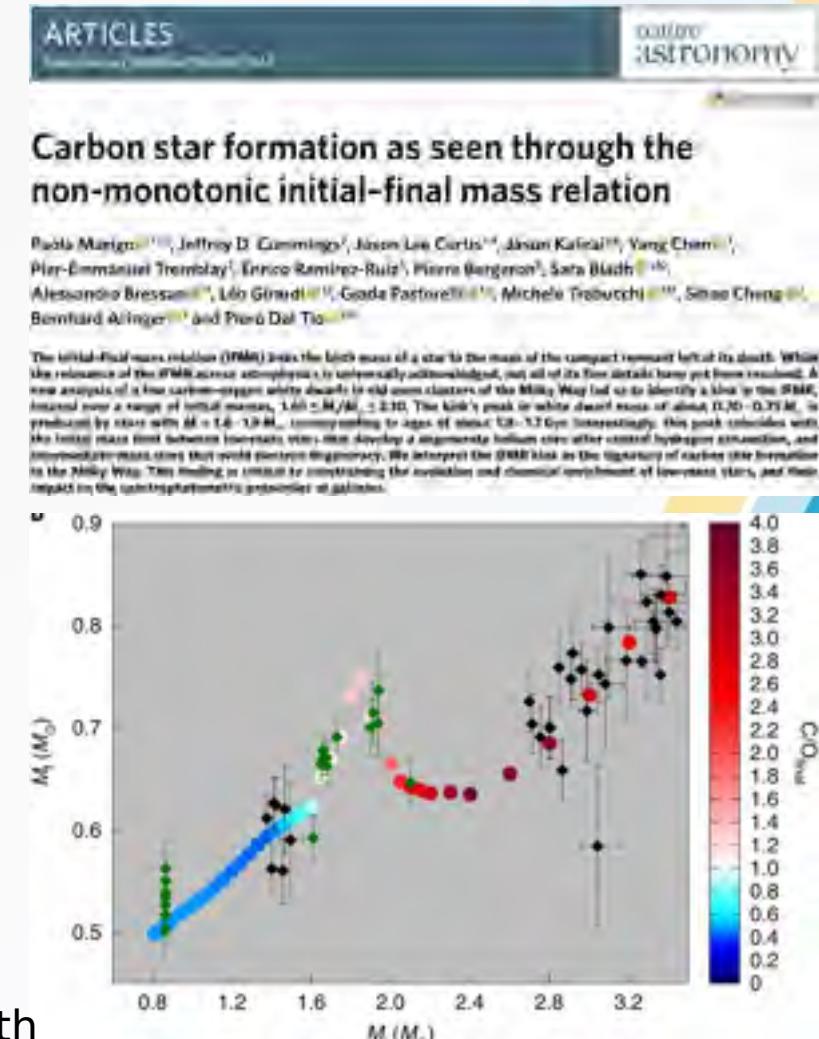
Girardi+19, Costa+19



TP-AGB models: ERC project *STARKEY*



Starkey results: Pastorelli+19,+20,
Chen+18, & in preps., Marigo+20



Marigo+20 :
reproduce the IFMR kink with
COLIBRI TP-AGB model

CMD 3.4 input form

A web interface dealing with stellar evolutionary and death theories

Latest news

- NEW! (13sep20) New COLIBRI tracks from [Pastorelli et al. \(2020\)](#) available.
- NEW! (13sep20) Look at the new LPV section, with LPV periods from [Trujillo-Gomez et al. \(2019\)](#). The cases Aver6 (with extensive computed star-by-star), and mixed ABB4 (with ABB4+ABBB4) are now available.
- NEW! (24jul20) Implementing post-AGB + WR mode, and LPV variability.
- (21jul20) Evolutionary histories and simulated populations are working, in version 0.1.
- (28jul20) YBC package for bolometric corrections, superposing and expanding the pre-

CMD: stev.oapd.inaf.it/cgi-bin/cmd

Step 1/3

Submit Reset

Evolutionary tracks

BARSEC tracks ([Bressan et al. \(2017\)](#)) are computed for a scaled-solar composition and following the $\text{Y} = \text{C}485 + 1.782$ relation. The present solar metal content is $2\% \pm 0.015$. [Tables of evolutionary tracks](#) are also available. COLIBRI tracks ([Manno et al. \(2013\)](#)) extend their evolution to the end of the TP-AGB phase, for several choices of mass loss and dredge up parameters.

PARSPEC

going from the PMS to either the 1st TE or C-ignition:

- BARSEC version 1.75

Available for 0.800 < Z < 0.010 (Z=0.001) for 0.000 < Z < 0.010 (Z=0.0001) for 0.0001 < Z < 0.001 (Z=0.00001) for 0.00001 < Z < 0.0001 (Z=0.000001). The mass range is 0.1 M_{sun} < M < 2.0 M_{sun}, and for Z > 0.01, 0.1 M_{sun} < M < 0.01 M_{sun}. [Bressan \(2014\)](#) for 1.000 < Z < 0.001, see [Chiosi & Piazzo \(2015\)](#) for other Z. With standard adiabatic outer boundary conditions for convective zones.

- BARSEC version 1.1

Available for 0.800 < Z < 0.010 (Z=0.001) for 0.000 < Z < 0.010 (Z=0.0001) for 0.0001 < Z < 0.001 (Z=0.00001).

- BARSEC version 1.0

ZAMS + Super-BPAC-MIPS + WISE

ZAMS + Super-BPAC-MIPS + WISE

Add post-AGB and WD evolution? Not yet.

You can also specify:

- the evolution of the thermal pulse cycles in I
- mass-loss on the RLB6 using the Kramers form

Warning:

Previous sets of tracks, described by [Chiosi et al. \(2014\)](#):

Photometric systems

Choose among the available photometric systems:

Available sets of tracks:

COLIBRI

and the TP-AGB evolution, from the 1st TP to the total loss of envelope:

- — COLIBRI S_37 ([Pastorelli et al. \(2020\)](#)) for $0.0005 \leq Z \leq 0.01$, + COLIBRI S_35 ([Pastorelli et al. \(2013\)](#)) for $0.0005 \leq Z \leq 0.006$ + COLIBRI PR16 ([Manno et al. \(2013\)](#), [Pastorelli et al. \(2016\)](#)) for $Z \geq 0.0062$ and $Z \leq 0.01$)
- — COLIBRI S_35 ([Pastorelli et al. \(2019\)](#)) dissolved in S_37 (Z > 0.01)
- — COLIBRI S_07 ([Pastorelli et al. \(2019\)](#)) dissolved in S_35 (Z < 0.01)
- — COLIBRI PR16 ([Manno et al. \(2013\)](#) and [Pastorelli et al. \(2016\)](#)) dissolved in S_35 (Z < 0.0001)
- No track selection

... are included in the CMD web interface v3.2+. They can be retrieved with previous versions (for instance, by [CMD v3.1](#)).

They are briefly described [here](#).

Available sets of bolometric corrections:

YBC (Chiosi et al. (in prep.))

This option expands and supersedes the NBC tables from [Carr et al. \(2014\)](#). All details in the YBC web interface, which provides more options with the stellar spectral libraries (e.g., X-ray only or Phoenix only).

Spectral libraries

for "normal stars"

An mix of ATLAS9 ODFNEW ([Carr et al. & Kurucz \(2008\)](#)) and PHOENIX RT-S ([Allende Prieto et al. \(2012\)](#))

for cool giants

O-rich and C-rich spectra from COMARCS, [Aigrain et al. \(2009\)](#) and [Aigrain et al. \(2015\)](#)

for very hot stars and WRs

from Chiosi et al. (2013), O, B star models computed with WM-code, WR star models from [Frost](#)

Comparison of different stellar models

Name	mass range	Z range	abundance	EOS	OP	NR	Rotation	stages	Else1	BC	UD
PARSEC (Bressan, SISSA)	0.1-350	5E4 to 0.07	solar,a	FREEEOS	OPAL+ÆSOP US	JINA REACLIB	0.002 to 0.02, omega=0 to 0.995, mi=1 to 5	Pre-MS to AGB0/CB0		Phoenix +Grey	19
MESA/ MIST (Paxton, UCSB)	0.1-300	[Fe/H] = -4 to 0.5	solar	OPAL+SCVH+McDonald	Ferguson05+ Freedman08 +OP+OPAL	JINA REACLIB	v/vcrit=0, 0.4	Pre-MS to WD	Planets, Oscillations	ATLAS12+Grey	16
Bastl (Cassisi, Teramo; Salaris, JMU)	0.1-15(new)	1E-5 to 0.05	solar,a,CNO	FREEEOS	OPAL	NACRE	N	Pre-MS to AGB0/CB0	WD, diff. Reimers etas	Vernazza+81	18
DESP (Dotter, Dartmouth)	0.1-4	[Fe/H] from -2.5 to +0.5	Solar,a	ideal gas+FREEEOS	OPAL + Ferguson05	Adelberger+98	N	Pre-MS to AGB0			08
FRANEC (Chieffi & Limongi)									link		
Genova (Meynet)									link		
STERN (Brott)									link		
STAREVOL (Decressin)									link		
Yale-Yonsei-Potsdam (Demarque)									link		
Pisa (Tognelli)									link		
Victoria-Regina (VandenBerg)									link		
Eggleton									link		
CESAM (Morel & Lebreton)									link		

incomplete

TRILEGAL Bolometric corrections

YBC (Chen+19)

Stellar spectral libraries:

ATLAS
PHOENIX
COMARCS
WM-basic
PoWR
Koester
TLUSTY

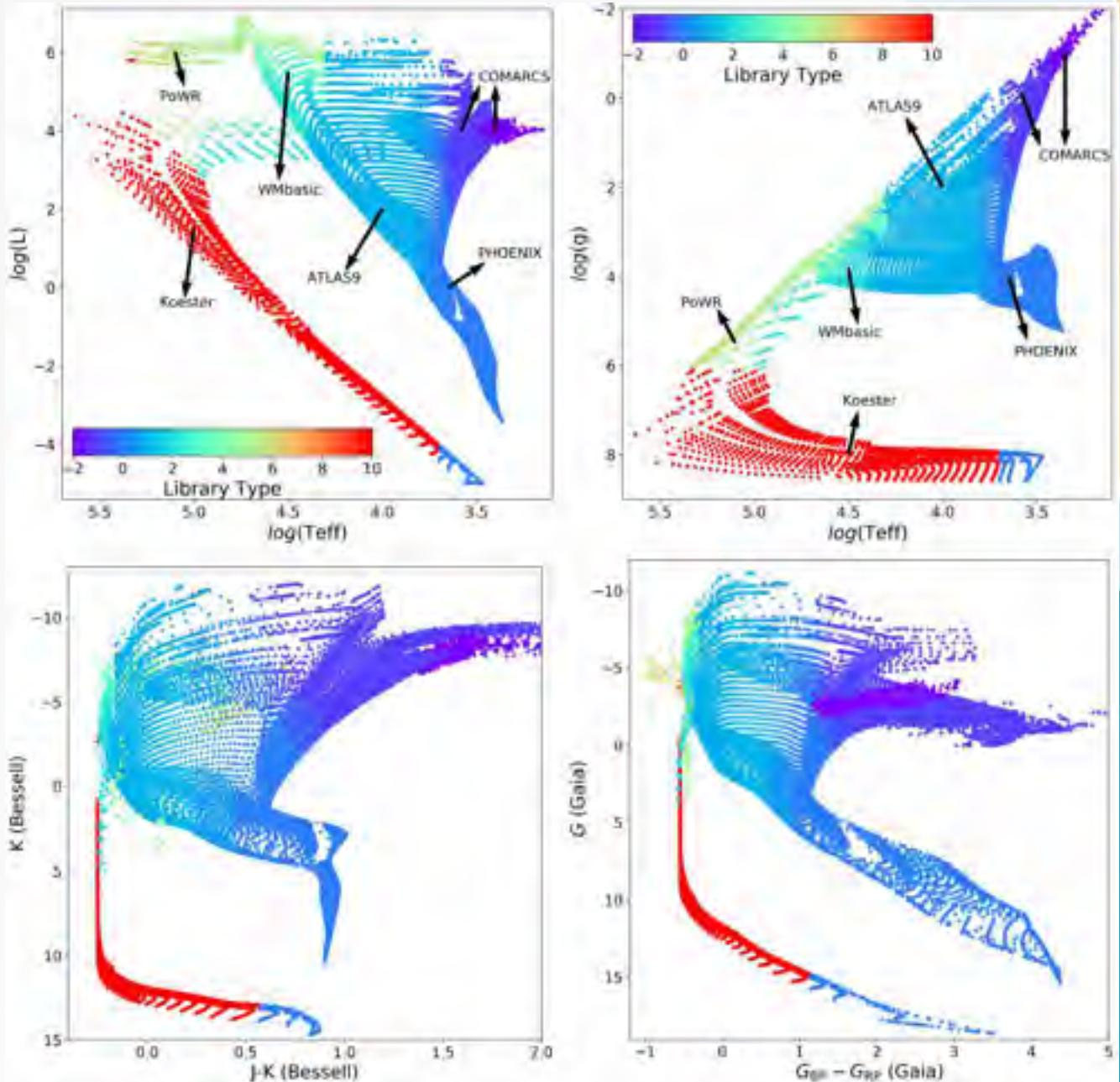
...

Extinction:

Circumsterllar dust: Marigo+
Interstellar dust: CCM+094, FM07, etc.

Supported photometric systems:

Basically all publicly available
UV-Opt.-NIR-MIR systems



TRILEGAL Bolometric corrections

YBC (Chen+19)

Stellar spectral lib

ATLAS
PHOENIX
COMARCS
WM-basic
PoWR
Koester
TLUSTY
...

Fiorella Castelli

Italy

1943-2019

Obituary:

Fiorella Caselli passed away on 2019 July 26, at the age of 76. Her work together with R. L. Kurucz on ATLAS9 model atmospheres is well-known and widely used by astronomers all over the world. Fiorella's synthetic spectral libraries for multiWavelength observations, from the UV to the near-infrared, for different types of stars are also famous and indispensable in studies of chemical abundances. We are losing not only an excellent highly valued scientist, but also a wonderful person always greatly helping colleagues in their work. Our thoughts are with her family.



Library Type

France Allard

France

1963-2020

Obituary:

<https://orai.univ-lyon1.fr/spp.php?article227&lang=en>



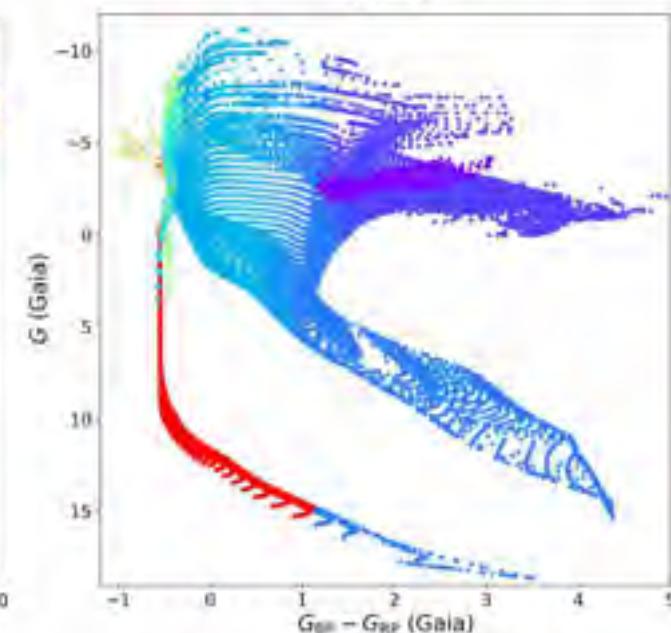
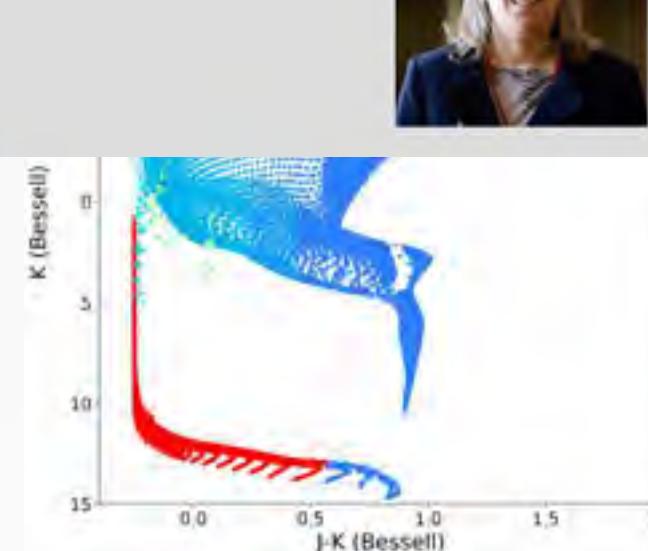
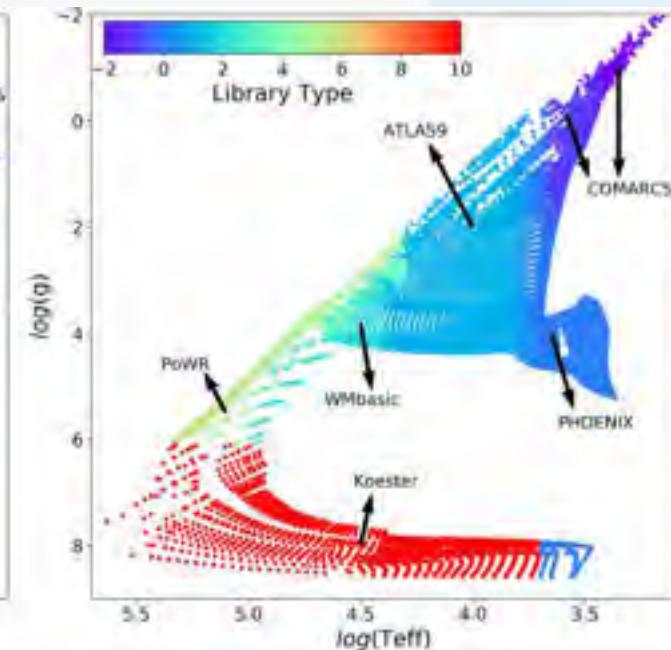
Extinction:

Circumstellar dust: Marigo+

Interstellar dust: CCM+094, FM07, etc.

Supported photometric systems:

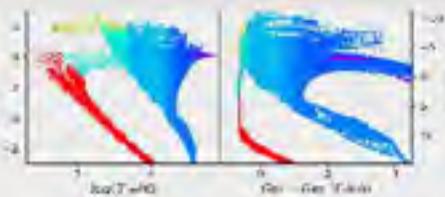
Basically all publicly available
UV-Opt.-NIR-MIR systems



PARSEC Bolometric Correction

by Yang Chen@Padova

TARSE, data set of bolometric corrections



Home Spectra libraries BC tables Source code Q&A

YBC: stev.oapd.inaf.it/YBC

<http://SEC.CENTER/YBC>

Five steps to obtain BCs for your stars:

1. Choose the filter sets

- 2MASS JHKs
- NGAO/CTIO/MOSAIC2 (Vegamags)
- VInuts
- CFHT Wircam
- CH-HI Naçaciam + Wircam (all ABmags)
- TESS + 2MASS (Vegamags)
- TESS + 2MASS (Vegamags) + Kepler + SUSS griz + DUOSI im (ABmags)
- Gaia's DR1 G, G_BP and G_RP (Vegamags)
- Gaia's DR2 G, G_BP and G_RP (Vegamags). Gaia passbands from Evans et al. 2018
- Gaia's DR2 G, G_BP and G_RP (Vegamags). Gaia passbands from Maiz-Apellaniz and Weiler 2018
- Gaia's DR2 G, G_BP and G_RP (Vegamags). Gaia passbands from Weiler 2018
- Gaia DR1 + Tycho2 + 2MASS (all Vegamags)
- Gaia DR2 + Tycho2 + 2MASS (all Vegamags). Gaia passbands from Evans et al. 2018
- Gaia DR2 + Tycho2 + 2MASS (all Vegamags). Gaia passbands from Weiler 2018
- LSST ugrizY, March 2012 total filter throughputs (all ABmags)
- S-PLUS (Vegamags), revised on Nov. 2017
- detgas (Paunzen) + UBV (Maiz-Apellaniz). in Vegamags
- UMT (all ABmags)
- Euclid/NISP (ABmags)
- SAGE vs band (Vegamags)
- CSS1 Trans (ABmags)

ATLAS12 models with $\log(47T\text{Fe})$ metal contents & Phoenix (and no TP-AGE) only

ATLAS12 models with non 47T Fe metal contents

Latest News

YBC paper on arXiv.org/astro-ph

October 22nd, 2019

The paper is available at arxiv.org/abs/1910.11037. It is accepted for publication in A&A.

Non-uniform extinction for stars

October 21st, 2019

Now you can supply different extinction value for different stars in your catalogue, by specifying the column number in section 4.

New extinction interpolation scheme and corrections

TRILEGAL output: synthetic stellar catalogues

Stellar parameters											LPVs periods				
Gc	muB	Av	comp	label	logAge	M/H	mini	Mass	logL	logTe	logg	McoteTP	Mloss		
1	11.75	0.684	0	1	8.55	-0.27	1.4118	1.412	0.716	3.8792	4.341	0.0	1.52E-13		
1							0.71	-0.25	0.33035	0.33	-1.642	3.5203	4.632	0.0	2.43E-15
1							0.71	-0.25	0.27569	0.275	-1.764	3.5088	4.628	0.0	2.03E-15
C,O	taulm	X	Y	Xc	Xn	Xo	Cexcess	Z	pnode	period0	period1				
0.537	0.0	0.7348	0.2572	0.001418	3.872E-4	0.003518		-1.0	0.008011	-1	0.0	0.0			
0.545	0.0	0.7273	0.2642	0.001539	4.15E-4	0.003764		-1.0	0.008555	-1	0.0	0.0			
0.545	0.0	0.7273	0.2642	0.001539	4.15E-4	0.003764		-1.0	0.008555	-1	0.0	0.0			
0.537	0.0	0.7325	0.2594	0.001479	3.8000E-4	0.003542		-1.0	0.008056	-1	0.0	0.0			
LSST + Gaia Photometry											Kinematics				
mbolmag	umag	gmag	rmag	imag	zmag	Ymag	Gmag	G_BPmag	G_RPmag	velU	velV	velW	Vrad	PMracosl	PMdec
14.731	16.758	15.561	15.315	15.261	15.244	15.219	15.243	15.503	14.875	-48.7	1.8	-3.7	29.6	2.89	-1.53
19.375	26.229	22.796	21.191	19.981	19.348	19.086	20.738	22.15	19.444	-35.8	-26.6	0.8	38.7	0.82	-2.36
19.679	26.822	23.289	21.66	20.344	19.866	19.361	21.121	22.628	19.79	-35.8	-26.6	0.8	38.7	0.82	-2.36
13.581	15.467	14.35	13.983	13.863	13.816	13.793	13.941	14.257	13.474	-37.7	-15.6	-2.9	29.8	2.95	-3.99

TRILEGAL calibrations

Photometric surveys:

Groenewegen+02:

Halo+disk

Girardi+05: Halo+disc

Vanhollebeke+09: Bulge

Pieres+20: Discs+Halo

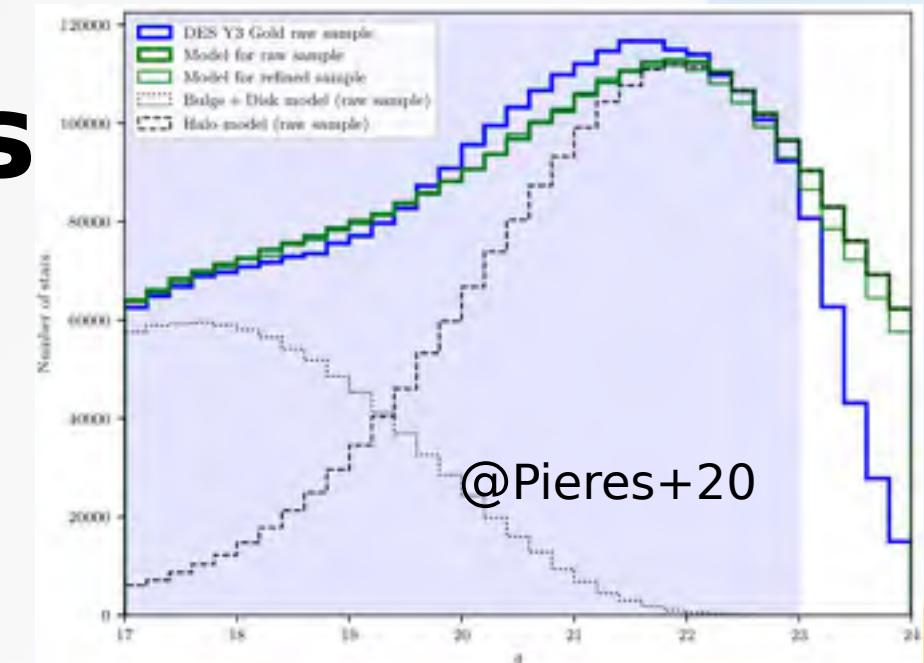
...

Spectroscopic surveys:

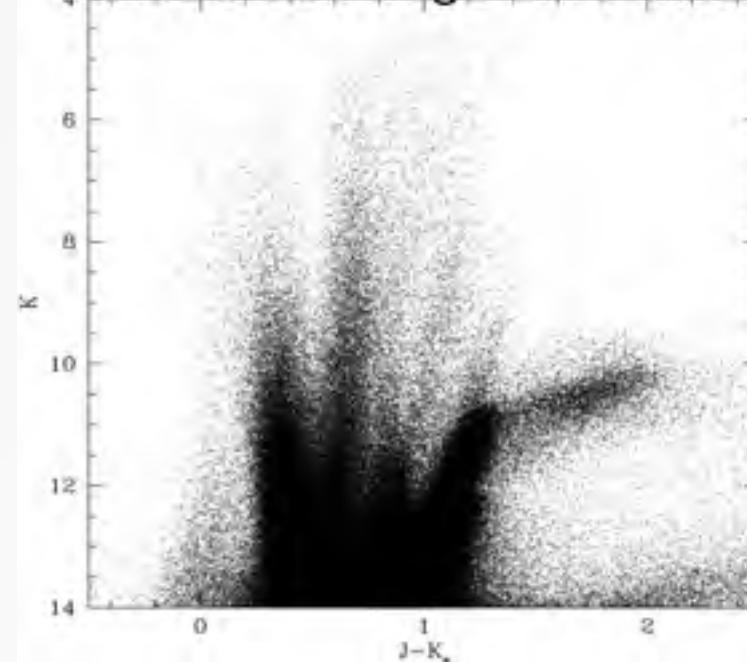
RAVE, SEGUE, etc.

Asteroseismic surveys:

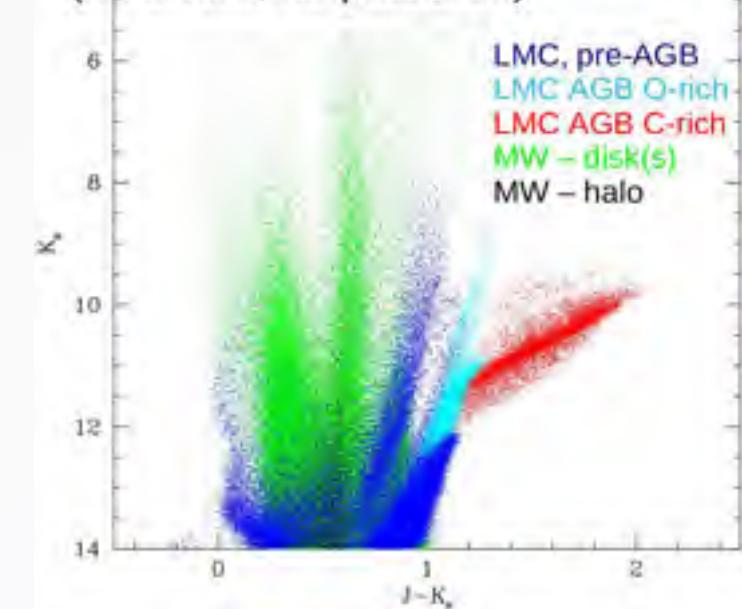
CoRoT, Kepler, etc.



2MASS 180 deg² LMC data



TRILEGAL simulation
(no errors, no pulsation)



Girardi

TRILEGAL 1.6 input form

Warning! (17mar13) We are forced to limit the maximum CPU time to 10 min. If this is too short, please split your simulation into smaller areas.

New version! (10Sep12) v1.6 becomes the default. It's the result of correcting some bugs in the central disk densities (for thin and thick disks), and then recalibrating their parameters. A provisional description of these changes is in [this paper](#). Changes are not dramatic but are in the sense of improving agreement with data. The previous version is still available in [v1.5](#).

[Help](#) [FAQ](#) [E-mail](#) [People](#) [History](#)

Pointing parameters

Using Epoch 2000, decimal numbers:

Galactic coordinates centered on $l =$ deg, $b =$ deg

Equatorial coordinates centered on $a =$ h, $\delta =$ deg

Total field area = deg 2 (max=10 deg 2)

Photometric system

Bolometric corrections are computed as in Giard et al. 2002.

Available systems: [UBVRIJHK](#) (cf. [Marz-Apuliauer 2006](#) + [Bessell 1990](#))

Limiting magnitude in $\text{A}_V^{(0)}$ filter is set to mag (max=32 mag)

Distance modulus resolution of Galaxy components is mag (min=0.05 mag)

IMF and binaries

IMF for single stars: [Chabrier lognormal](#) (see paper)

Turn binaries on off

Binary fraction = with mass ratios between and

Print binary components as a single entry separately

Extinction

No dust extinction or

Exponential disk $\exp(-|z|h_{z,\text{dust}})\exp(-R/h_{R,\text{dust}})$
with scale height $h_{z,\text{dust}} =$ pc and scale length $h_{R,\text{dust}} =$ pc

Local calibration: $dA_V/dr(\odot) =$ mag/pc

Calibration at infinity: $A_V(r) =$ mag

10 dispersion = times the total extinction (max=0.3)

Solar position

Sun's Galactocentric radius $R\odot =$ pc, height above disk $z\odot =$ pc

Thin disc

No thin disc or

Along z : Exponential: $\exp(-|z|h_{z,0})$ Squared hyperbolic secant: $\operatorname{sech}^2(0.5|z|h_{z,0})$

with scale height $h_{z,0}$ increasing with age t cf. $h_{z,0} = r_0(1+t/t_0)^{\alpha}$

$r_0 =$ pc, $t_0 =$ yr, $\alpha =$

Along R : Exponential disc: $\exp(-R/h_{R,0})$

with scale length $h_{R,0} =$ pc, and inner/outer cutoffs at $R =$ pc and pc.

Local calibration: $Z_\odot(\odot) =$ M \odot/pc^2

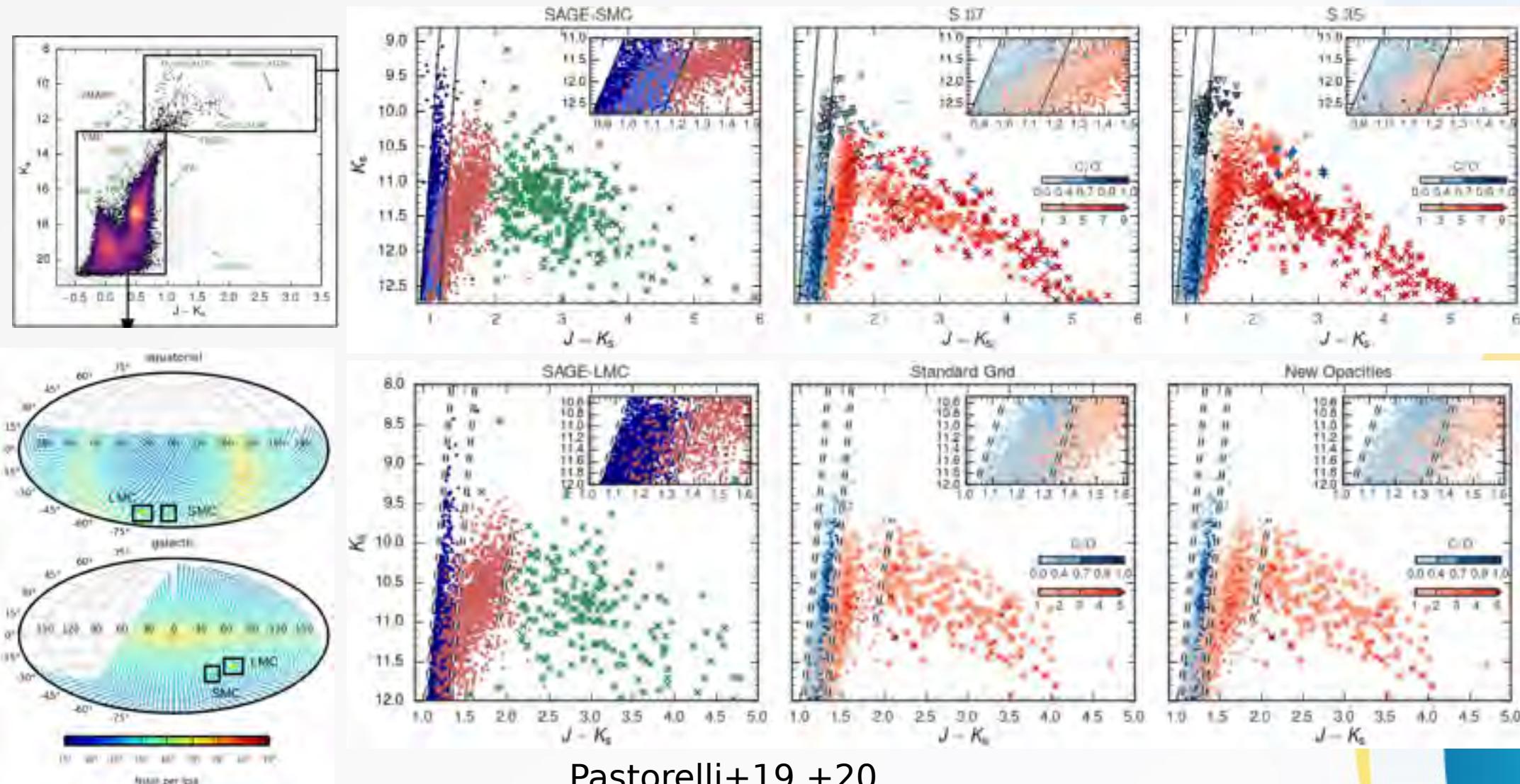
SFR and AMR given by [Zsun_SFR + Salpeter's AMR + a-corr. \(see paper\)](#) with age(tyr)= yr

stev.oapd.inaf.it/cgi-bin/trilegal

TRILEGAL DEMO 1: LSST sky survey sim.

Blank
intentionally

TRILEGAL DEMO 2: SMC & LMC sim.

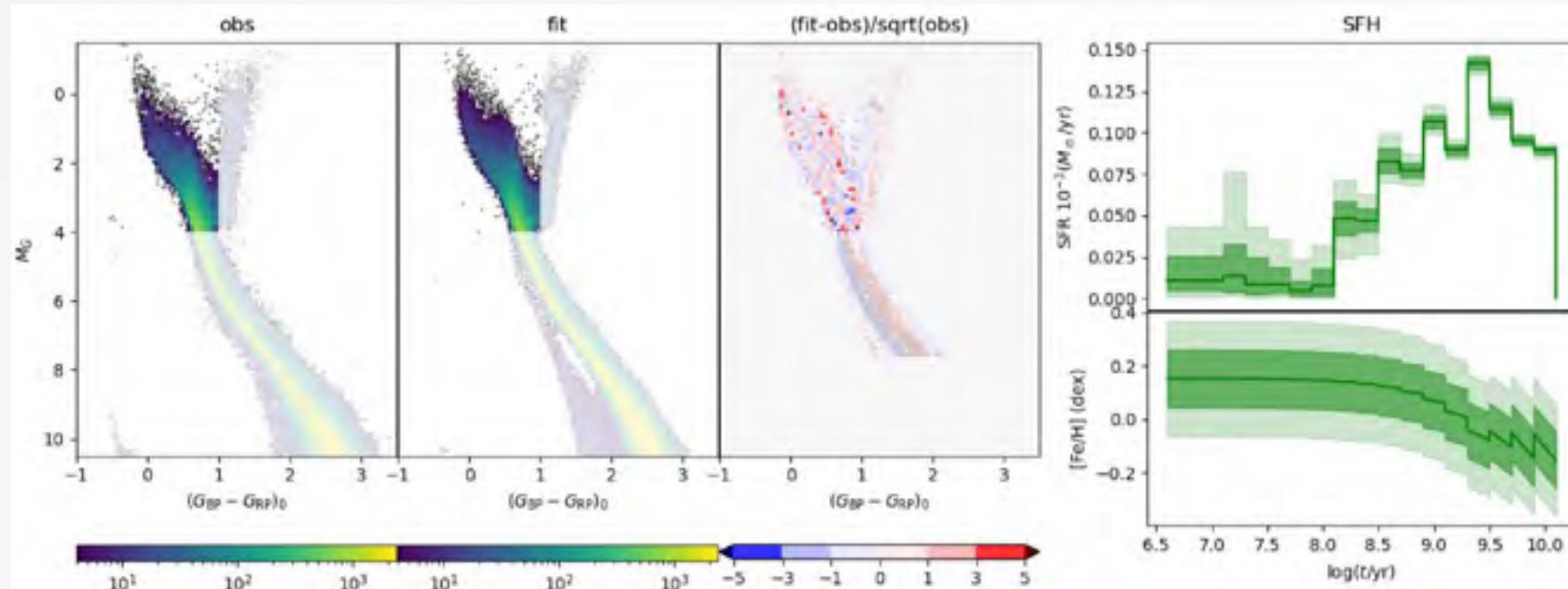


Pastorelli+19,+20

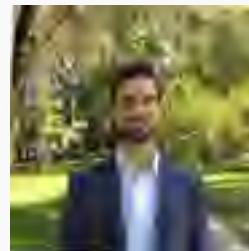
TRILEGAL DEMO 3: M31 sim.

Blank
intentionally

TRILEGAL DEMO 4: Binaries



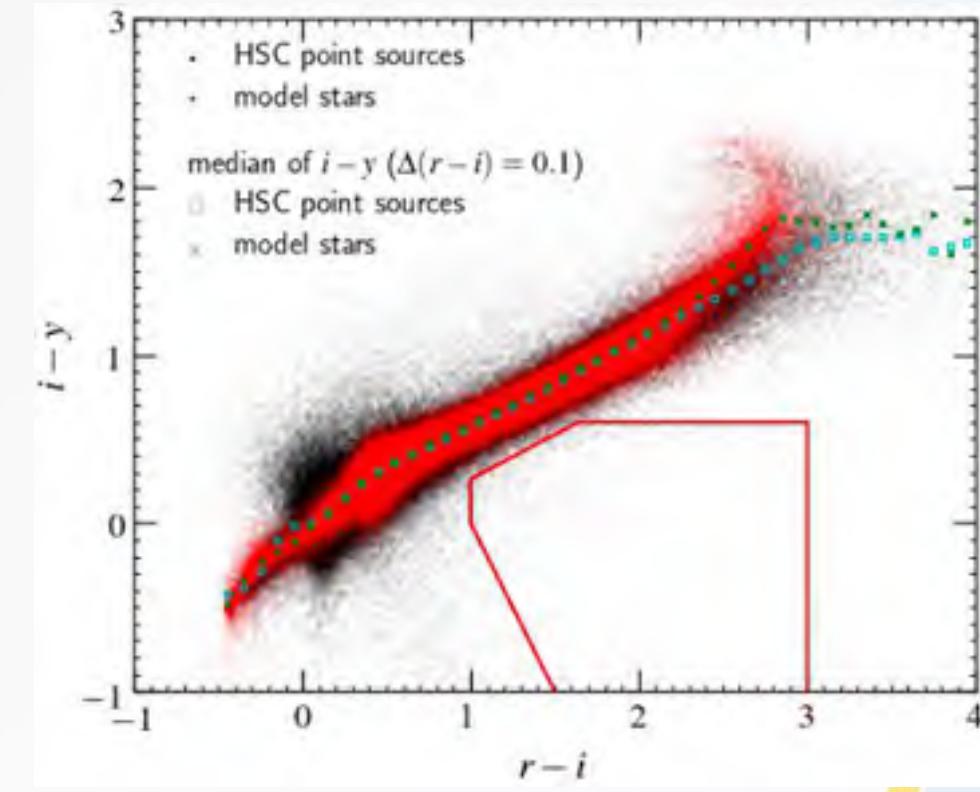
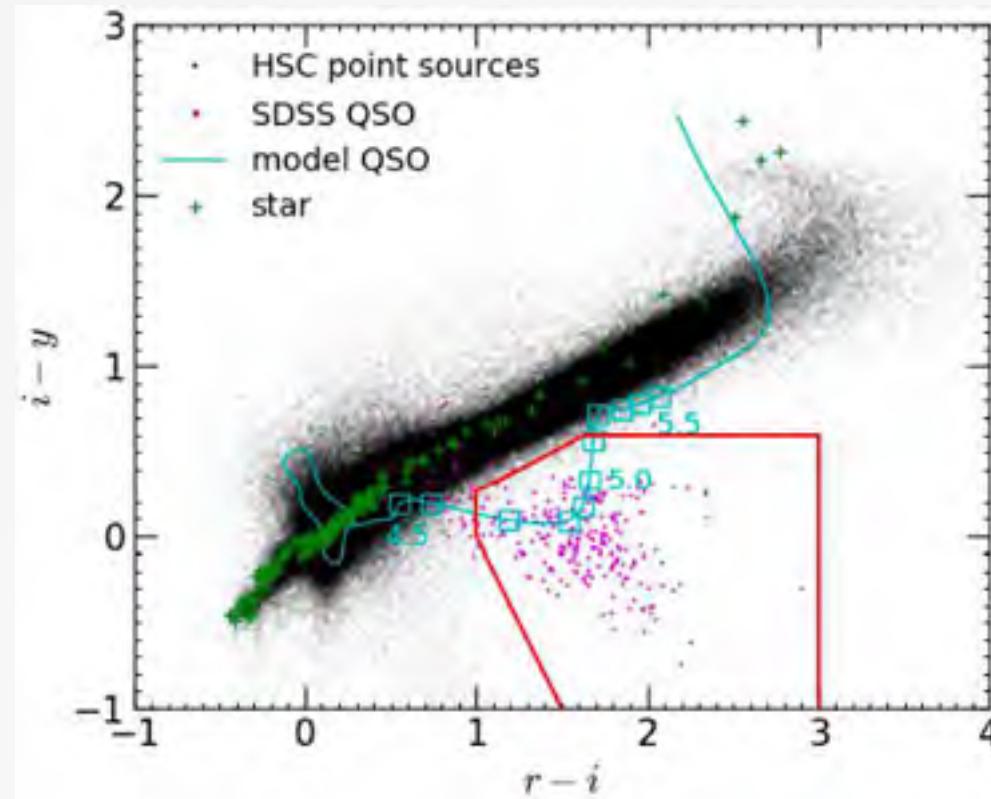
Dal Tio+19



TRILEGAL DEMO 5: Star Cluster sim.

Blank
intentionally

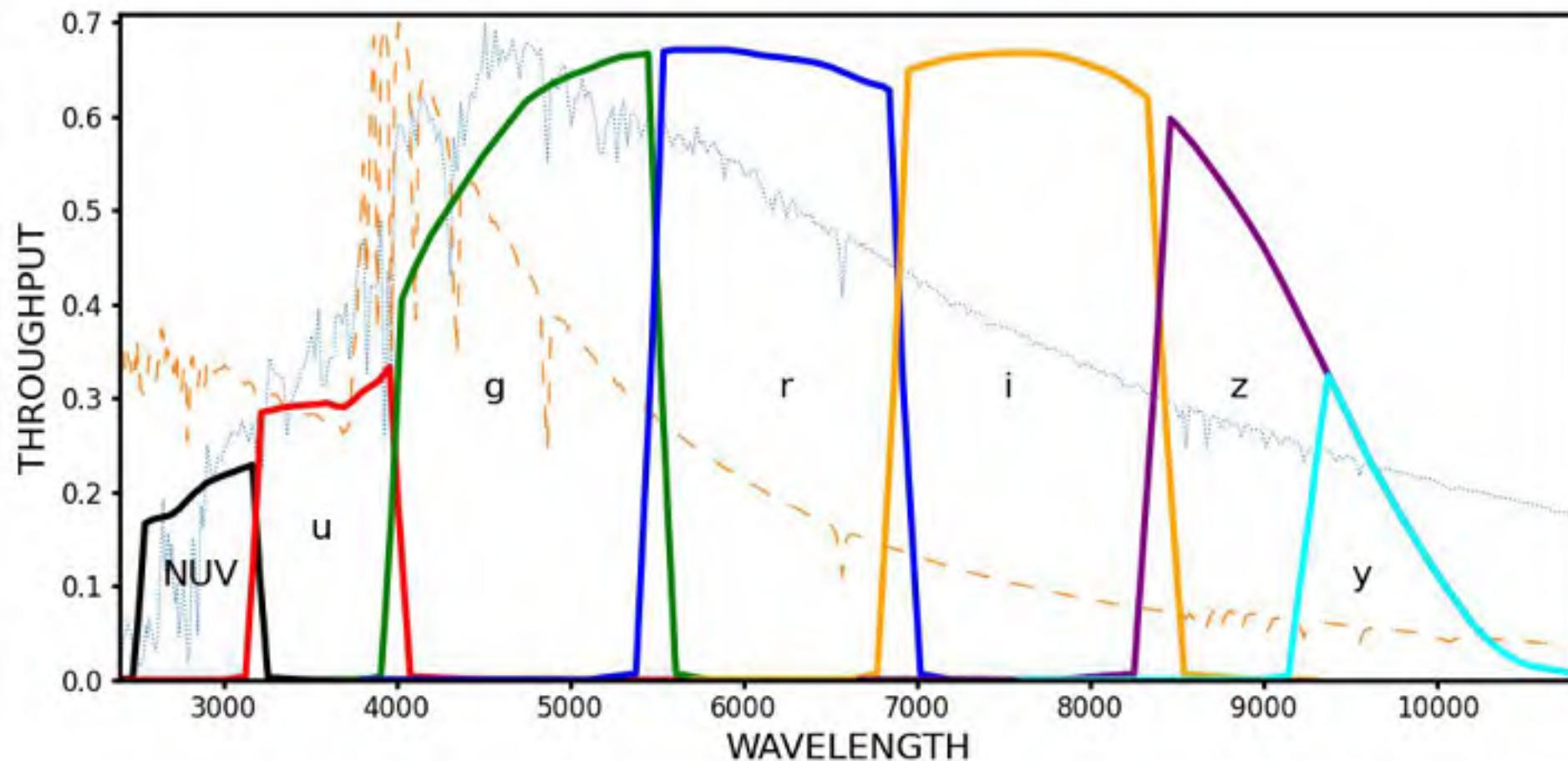
TRILEGAL DEMO 6: MW foreground stars for high-z objects



Niida+20: stellar contamination to the QSO sample

TRILEGAL MW simulation for CSST

CSST filters

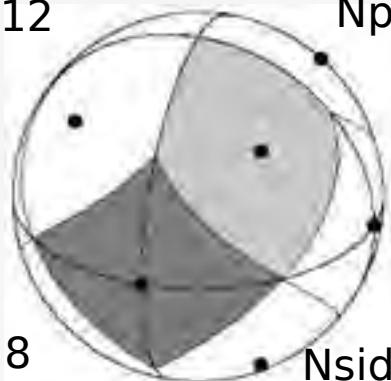


CSST filter transmission curves (from CSST group)
SEDs: CK03 ATLAS9 models of Teff=6000K and 10000K (logg=4,[M/H]=0)

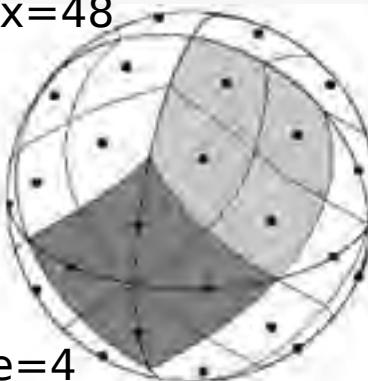
Skymap pixelization

HEALPix nested subdivision scheme:

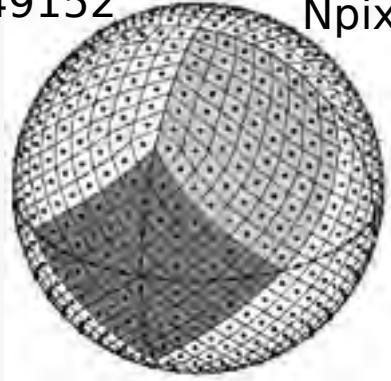
Nside=1
Npix=12



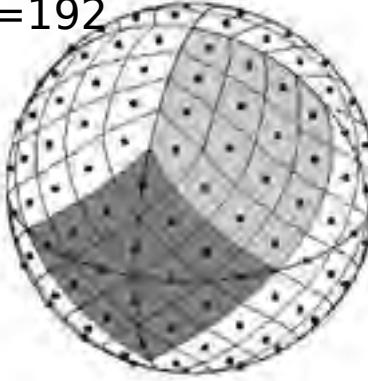
Nside=2
Npix=48



Nside=8
Npix=49152

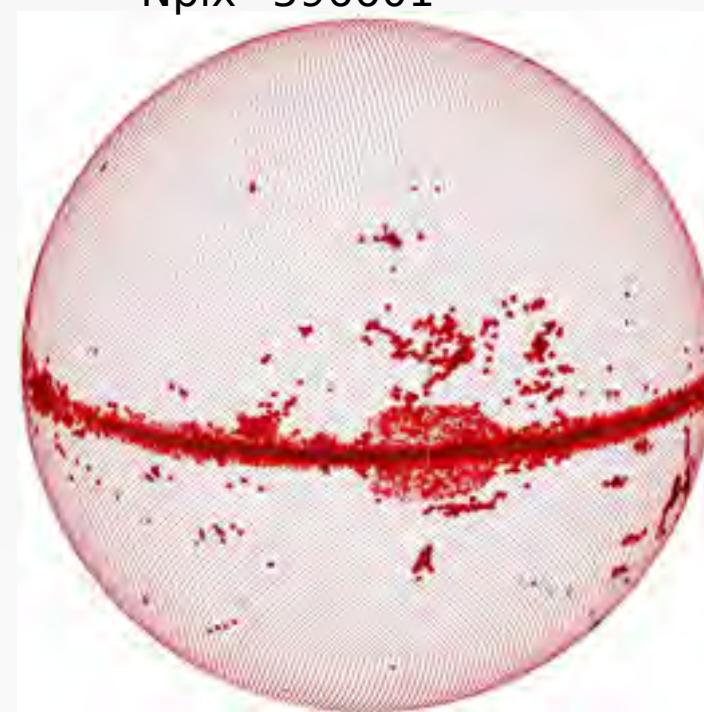


Nside=4
Npix=192

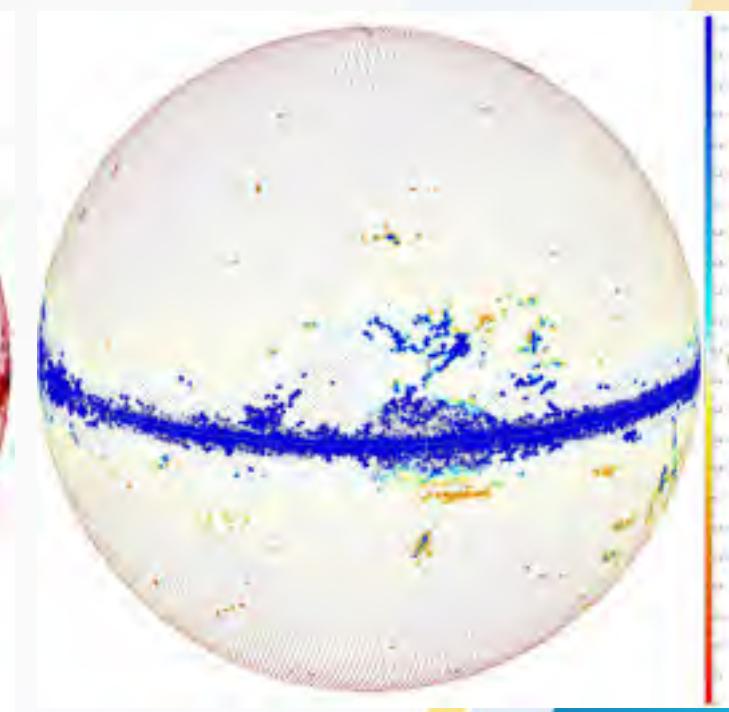


Gorski+05

Nside=64 to 2048 (1.72')
Npix=596601



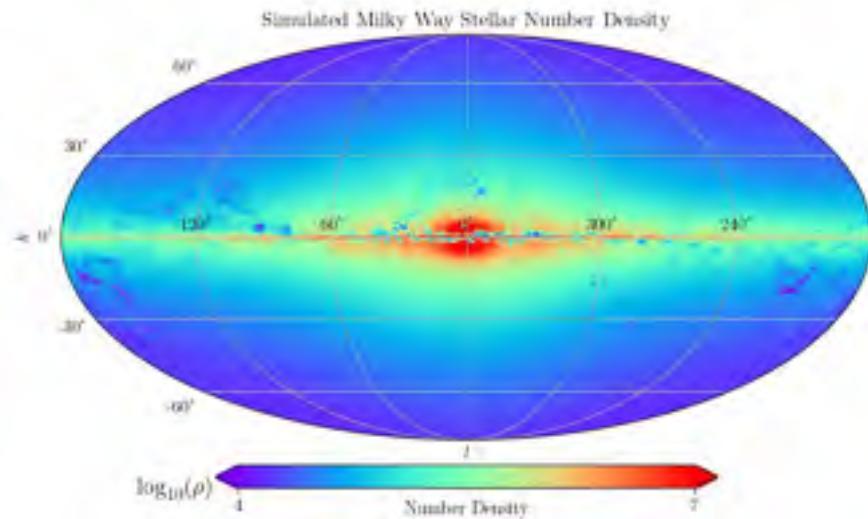
CSST sim. pixelization



Dust map

TRILEGAL simulation running

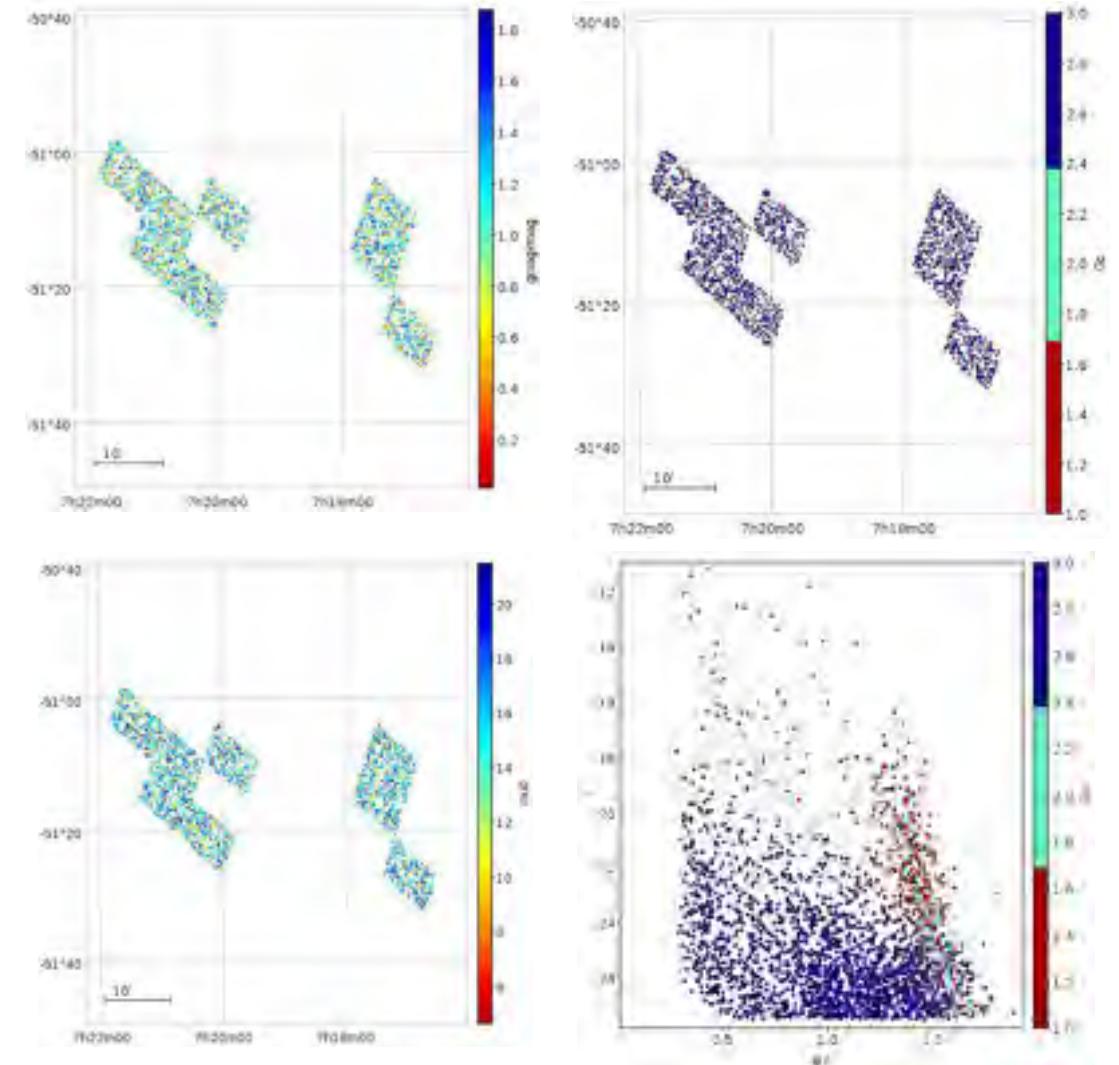
$g < 27.5$
~1.5TB fits data
12.6 Bilion stars



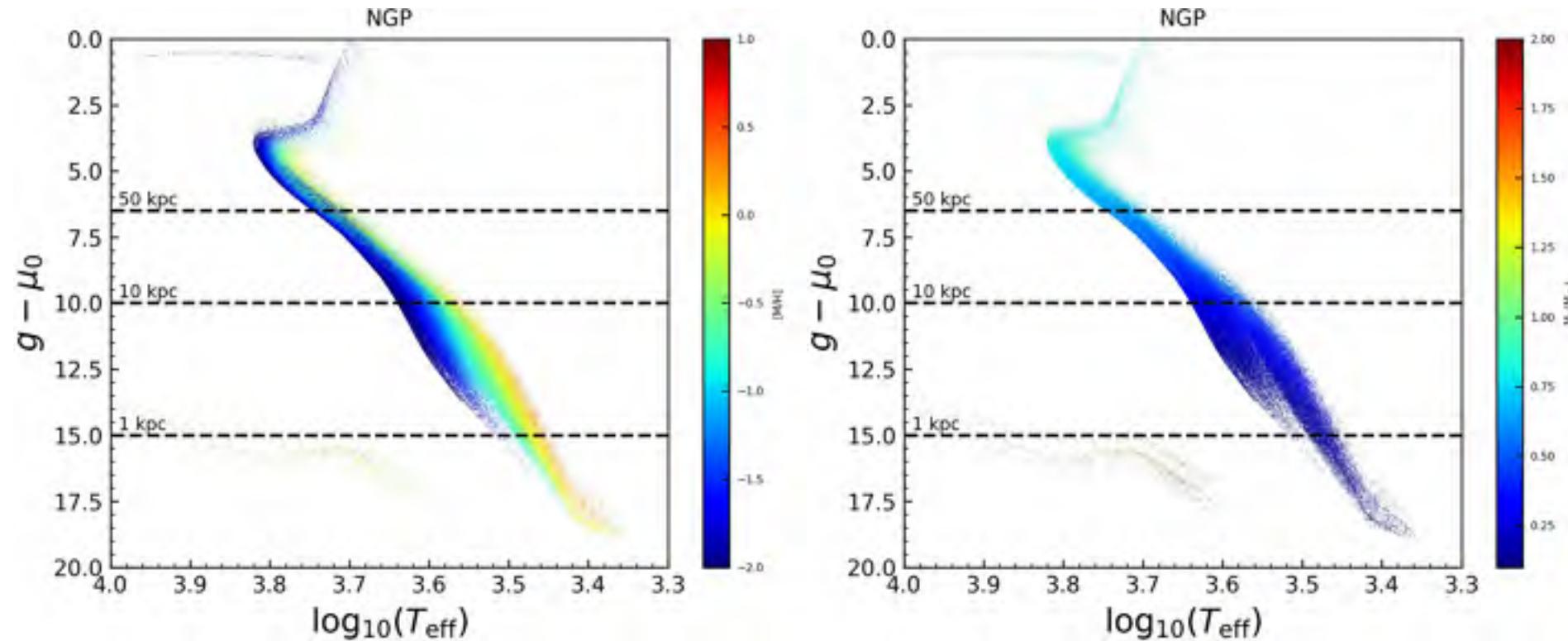
Soon on the
NAOC VO

TABLE 1 Example of the mock catalogue

Gr	logAge	M_HII	m_ini	mu0	Av	ratio	Mass	logL
1	8.91	-0.16514014	0.70204317549732	12.0	5.7288876	0.0	0.7020871	0.75758743
1	9.349999	-0.2096411	0.83383369445800	11.300001	5.6852345	0.0	0.83320236	-0.35524124
logTe	logg	label	MooreTP	C_O	period0	period1	pernode	Mloss
3.6680293	4.6660957	0	0.0	0.544593	0.0	0.0	-1	-1.21629594E-14
3.7332726	4.590082	1	0.0	0.53722	0.0	0.0	-1	-3.0392355E-14
X	V	Xe	Xn	Xo	Cexcess	Z	mbolmag	
0.72519267	0.26160725	0.0015283299	3.935209E-4	0.0044763405	-1.0	0.010200083	18.663069	
0.730663384	0.25433245	0.0015097563	4.370039E-4	0.003970457	-1.0	0.009033371	16.958103	
NUVmag	umag	gmag	rmag	imag	zmag	ymag	velU	velV
34.179413	30.573284	26.087975	23.63411	22.122843	20.99646	20.66116	-10.79798	-27.775371
30.68219	27.577374	23.878262	21.74874	20.387028	19.353289	19.050098	-12.106426	-5.577133
velW	Vrad	PMraeos	PMdec	gall	galb			
-11.022252	18.888453	0.17034815	-2.7342863	206.94619730114937	-16.770211787875738			
-10.877249	8.033585	-1.1146122	-1.9767536	206.930897081092842	-16.785654214628205			



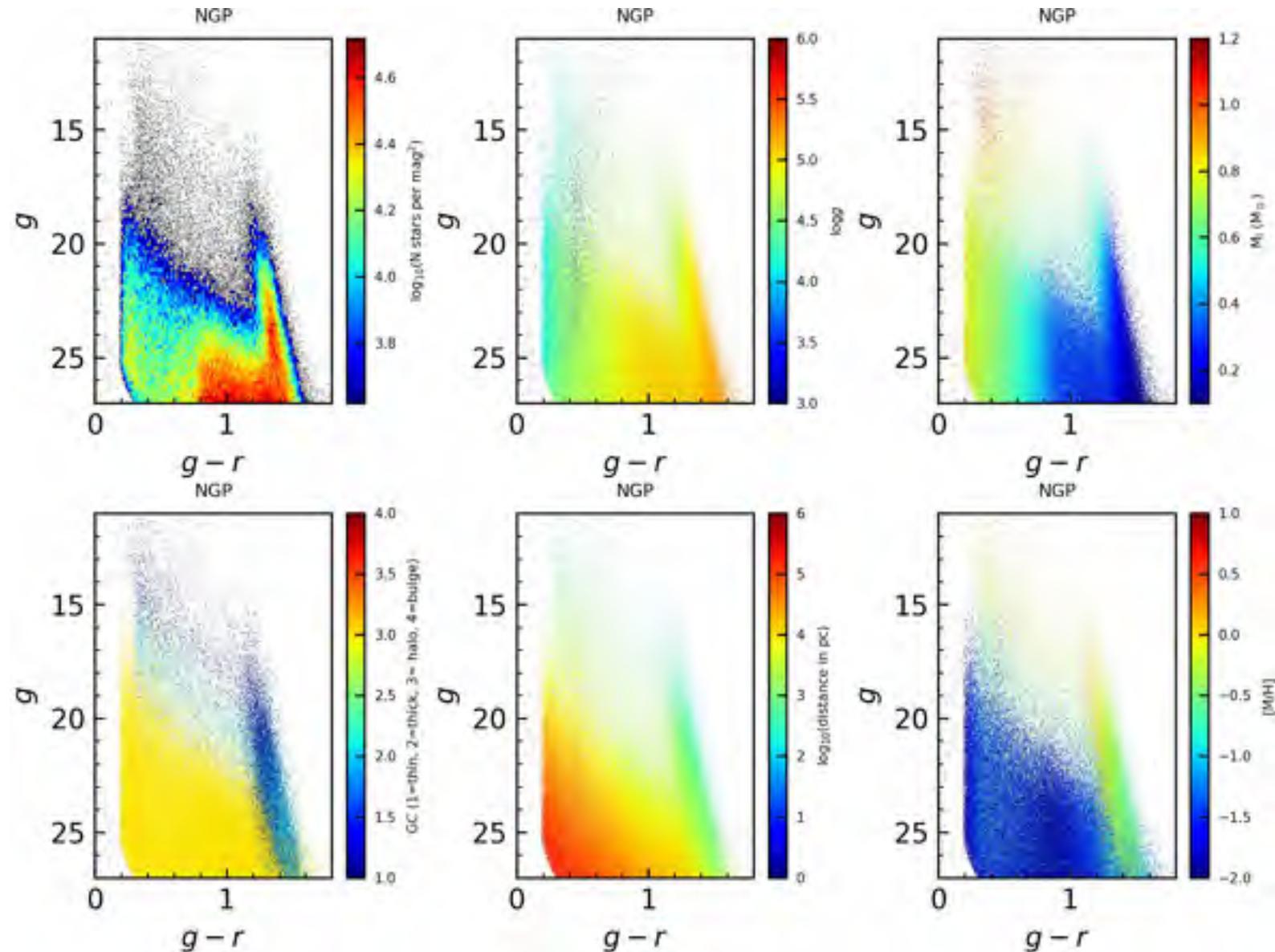
TRILEGAL sim. of the north galactic pole



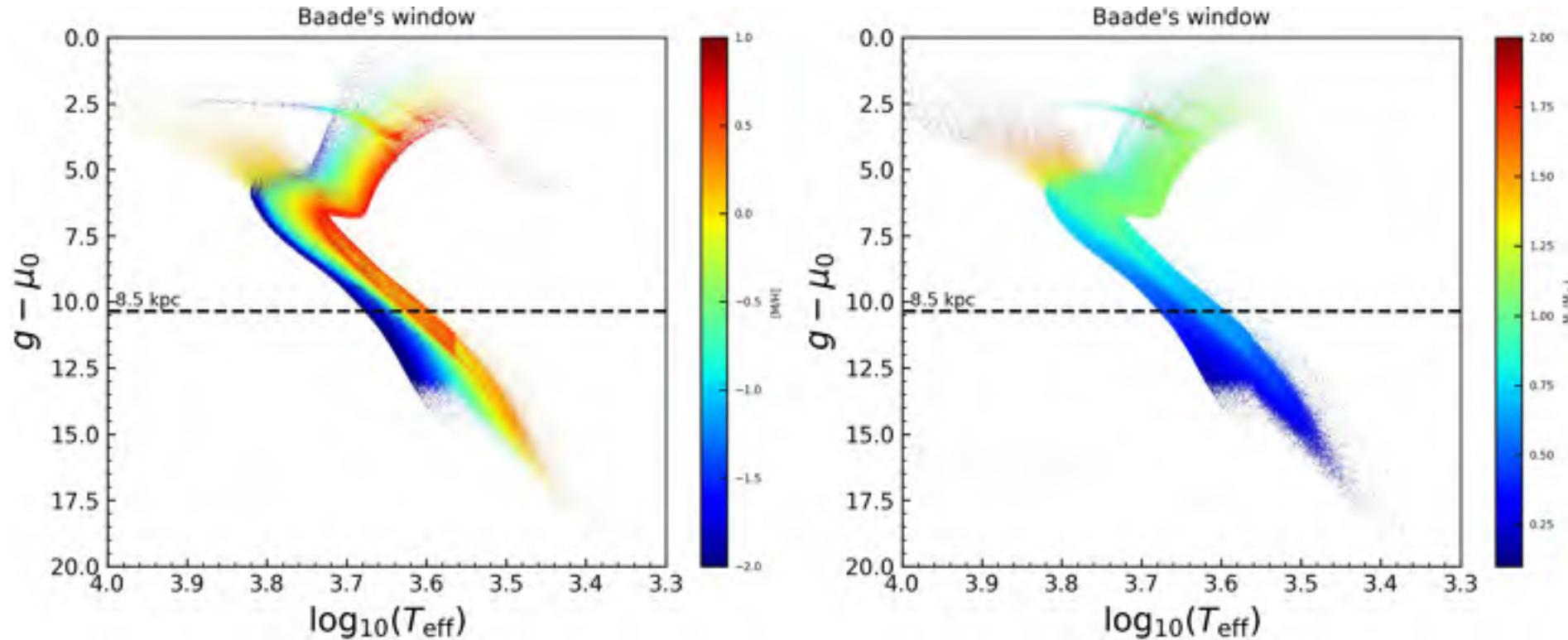
Absolute magnitude vs. effective temperature
CSST-OS will reach $g \sim 25.5$ (or 26.5) mag. A
star with $M(g) \sim 15$ mag, will have $g \sim 25$ mag
at 1 kpc, being above CSST-OS limit.

TRILEGAL sim. of the north galactic pole

Color-magnitude
diagram: $g-r$.vs. g



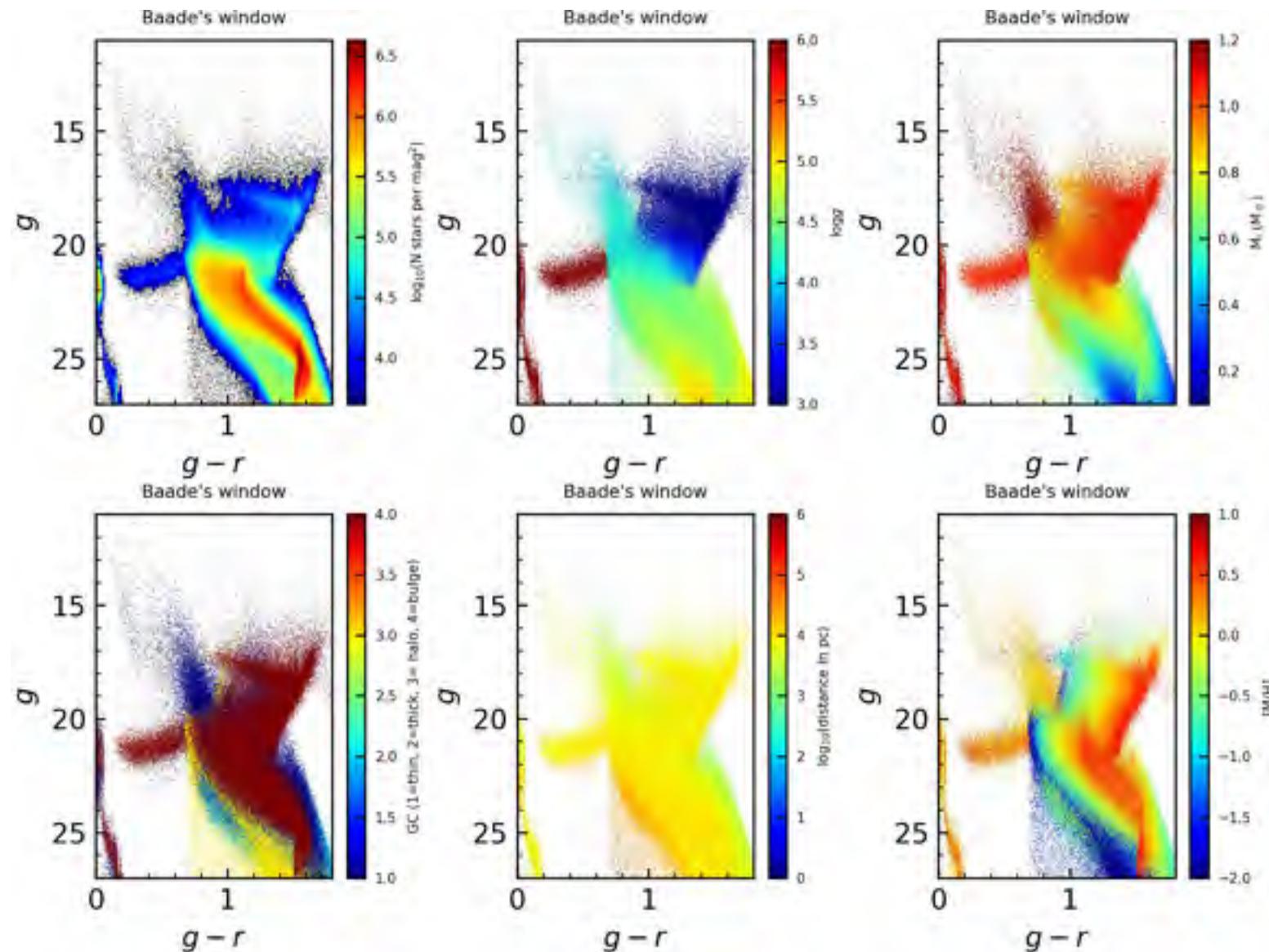
TRILEGAL sim. of the Baade's window



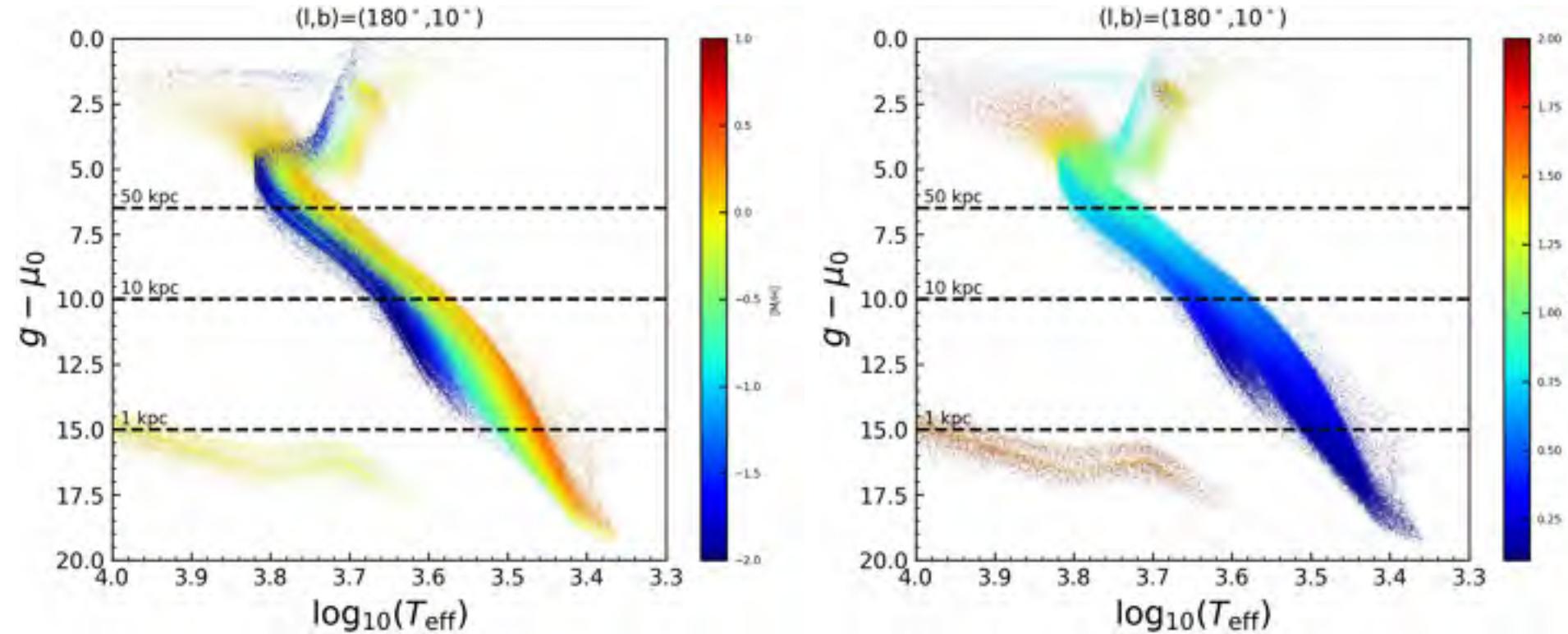
Absolute magnitude vs. effective temperature
CSST-OS will reach $g \sim 25.5$ (or 26.5) mag. A
star with $M(g) \sim 10.35$ mag, will have $g \sim 25$
mag at 8.5 kpc, being above CSST-OS limit.

TRILEGAL sim. of the Baade's window

Color-magnitude
diagram: $g-r$.vs. g



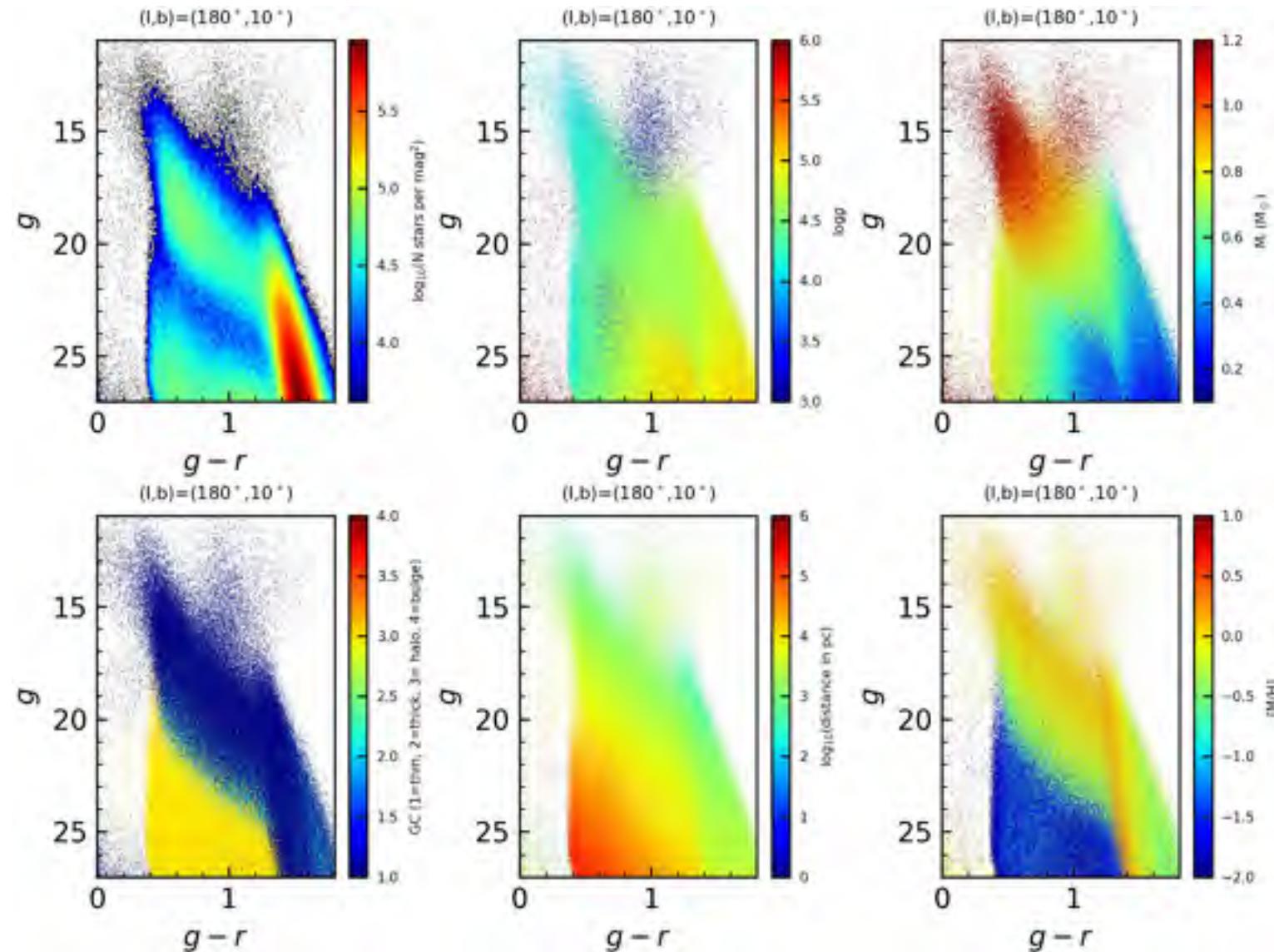
TRILEGAL sim. of the anti-Gal. direction



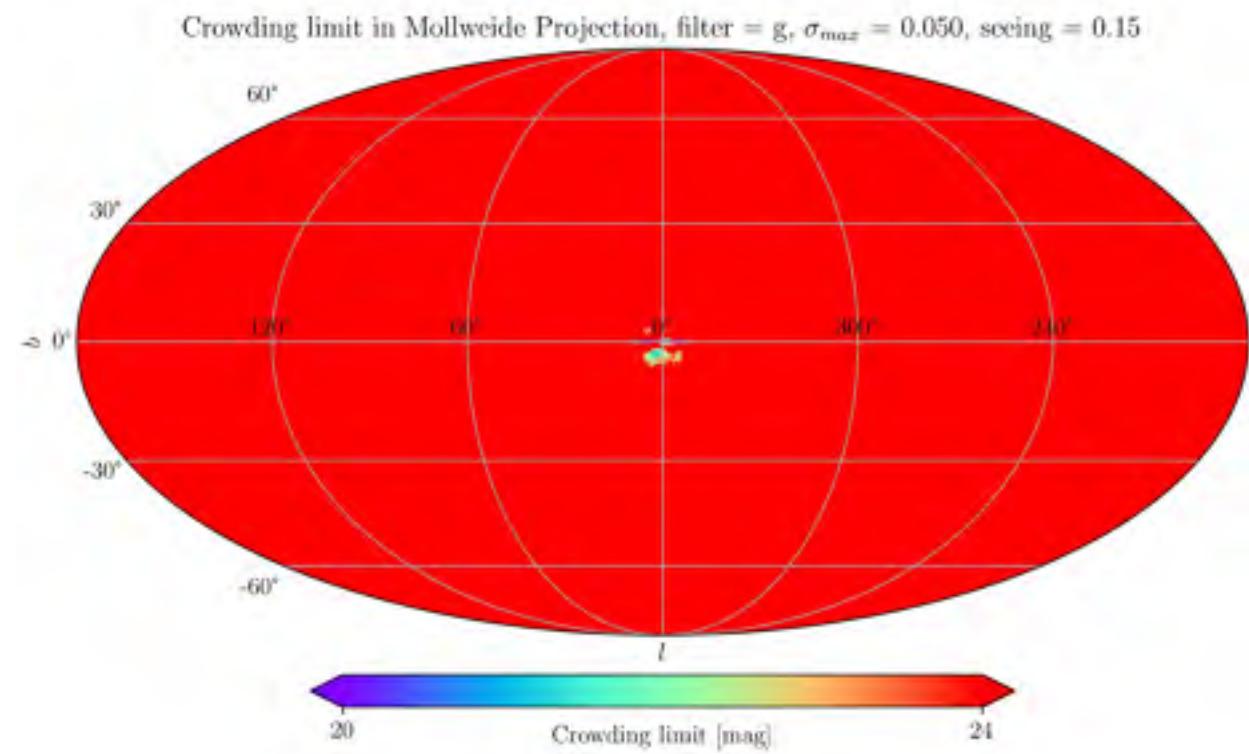
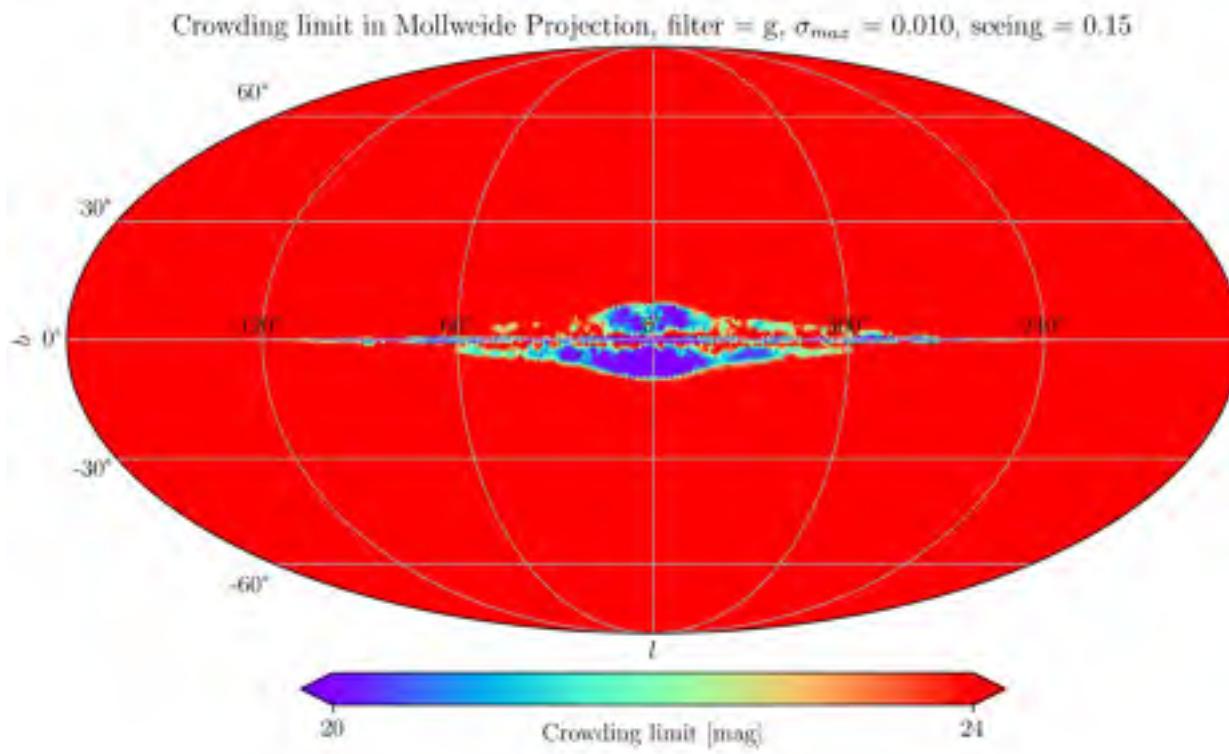
Absolute magnitude vs. effective temperature
CSST-OS will reach $g \sim 25.5$ (or 26.5) mag. A
star with $M(g) \sim 15$ mag, will have $g \sim 25$ mag
at 1 kpc, being above CSST-OS limit.

TRILEGAL sim. of the anti-Gal. direction

Color-magnitude
diagram: $g-r$.vs. g

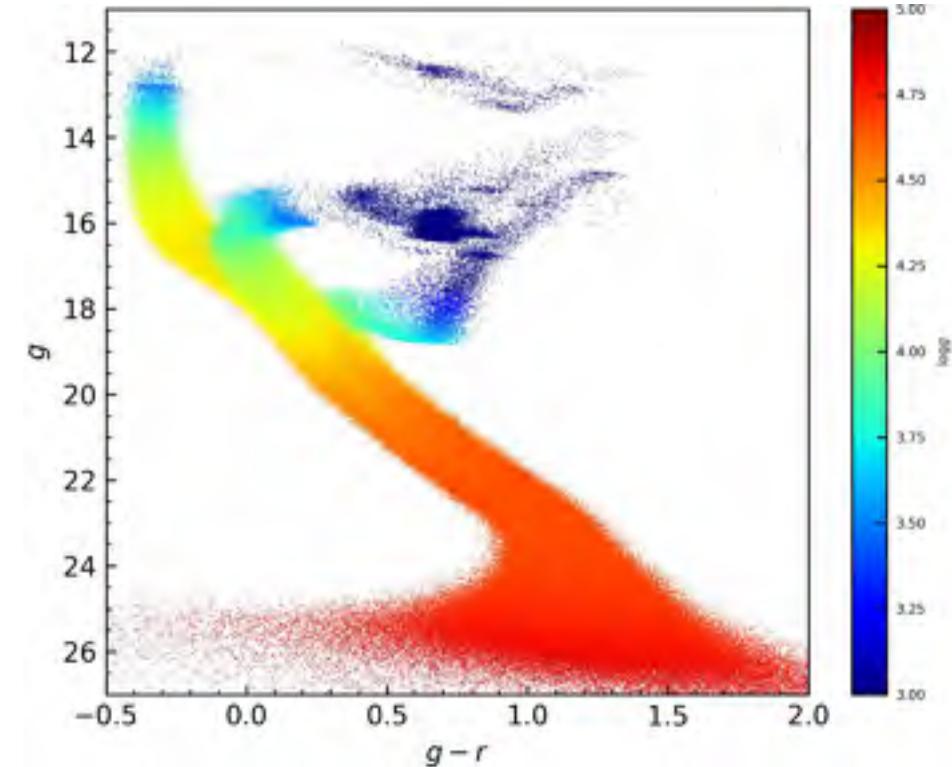
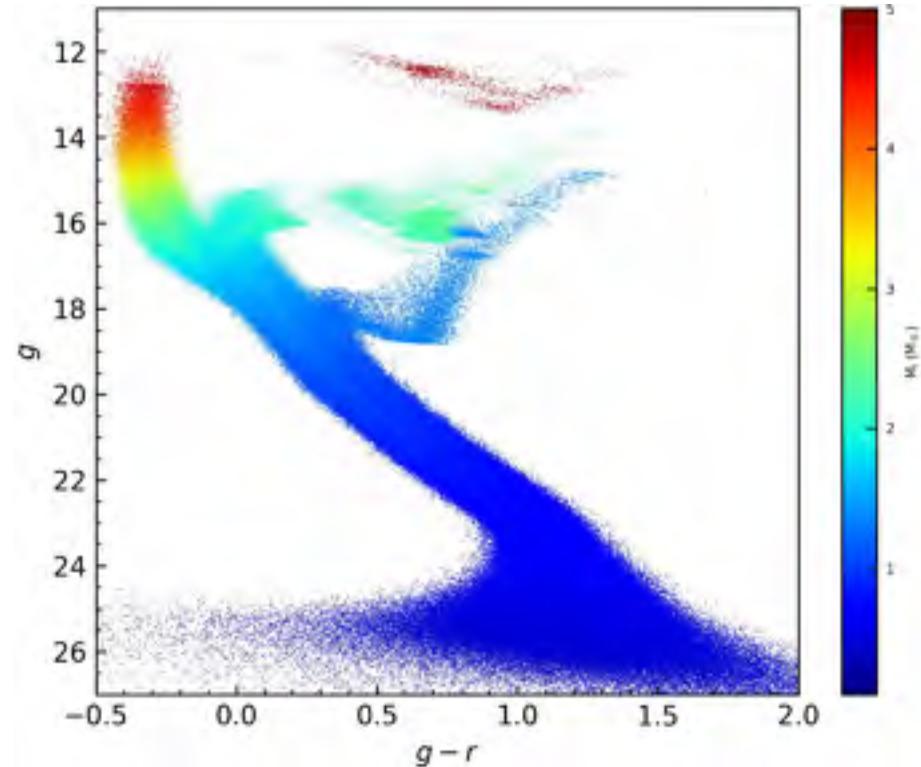


TRILEGAL sim.: crowding limit analysis



CSST-OS: PSF FWHM~0.15 arcsec,
photometric error ~ 0.2 mag at 25.5 mag, 0.01 mag at 29 mag.

TRILEGAL sim. of star clusters



Simulated star clusters of 0.12, 1 and 4.5 Gyr with errors included.

Concluding remarks prospects

- TRILEGAL is a powerful stellar population synthesis tool, can be used for broad applications, including for supporting the science of next generation telescopes
- We have generated a full sky MW mock stellar catalogue for CCST, and will do so for nearby galaxies. These catalogues will be publicly available
- We will refine PARSEC stellar models and TRILEGAL galactic models to provide better models

TRILEGAL: Active coding people

+



Léo Girardi



Yang Chen



Giada Pastorelli



Piero Dal Tio



Paola Marigo



Michele Trabucchi



Alessandro Mazzi

Collaborators: Bressan A., Xiaoting Fu, Costa G., etc.

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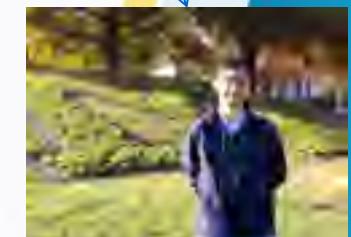
External collaborators: LSST, UW, STScI, SDSS, etc.

CSST MW TRILEGAL Sim.:

Initiates: Xiaoting Fu., Yang Chen, Chao Liu, etc.

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TRILEGAL people



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谢谢 !