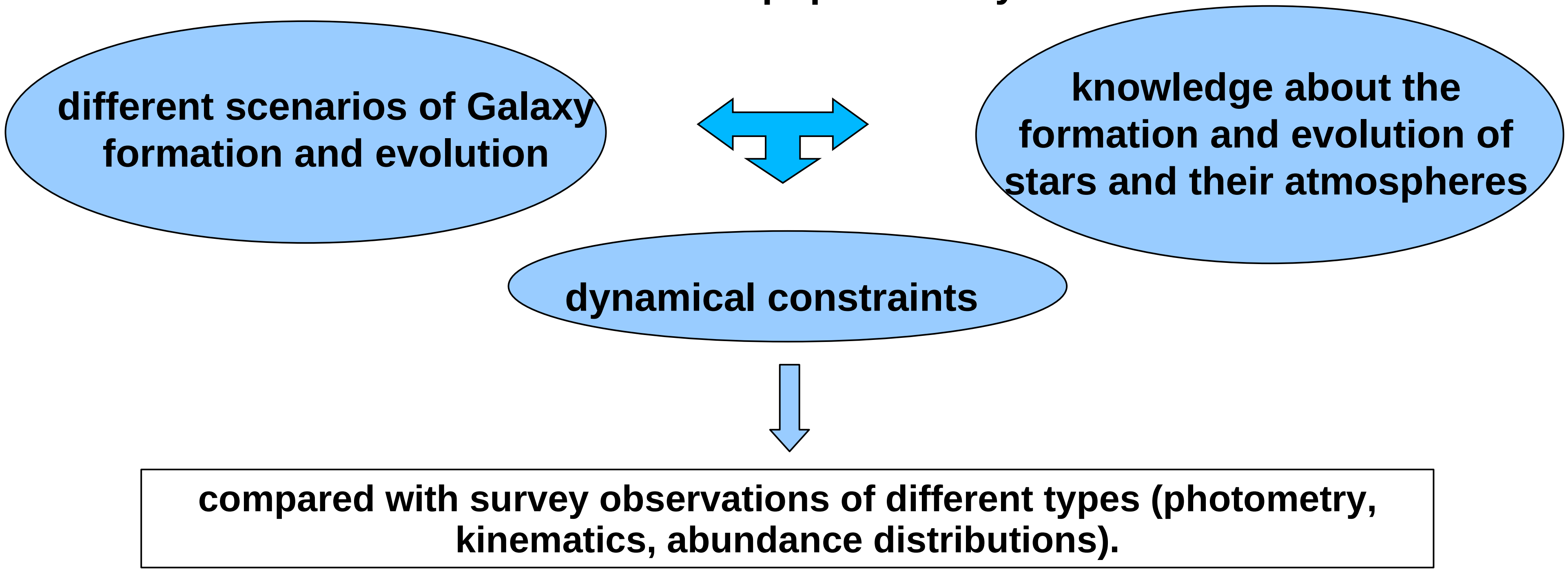
Besançon Galaxy Model

A model of stellar population synthesis



- **Links evolution with kinematics and dynamics by the stellar ages.**
- **Dynamical self-consistency**
- **Stars belong to 4 basic populations: the thin disk, the thick disk, the stellar halo and the bulge.**
- **Each group is characterized by its own SFR, IMF, evolutionary tracks, kinematics, and metallicity.**

A. Robin & M. Creze, 1986; Bienayme et al. 1986; M.Haywood et al. 1997; Robin et al. 2003;

Besançon Galaxy Model

Components of the model (Robin et al. 2003).
Chosen evolutionary parameters for each population –
since the last model release until now.

Table 1. Age, metallicity ($[\frac{Fe}{H}]$) (mean and dispersion about the mean), radial metallicity gradient (dex/kpc), initial mass function (IMF), and star formation rate (SFR) of the stellar components.

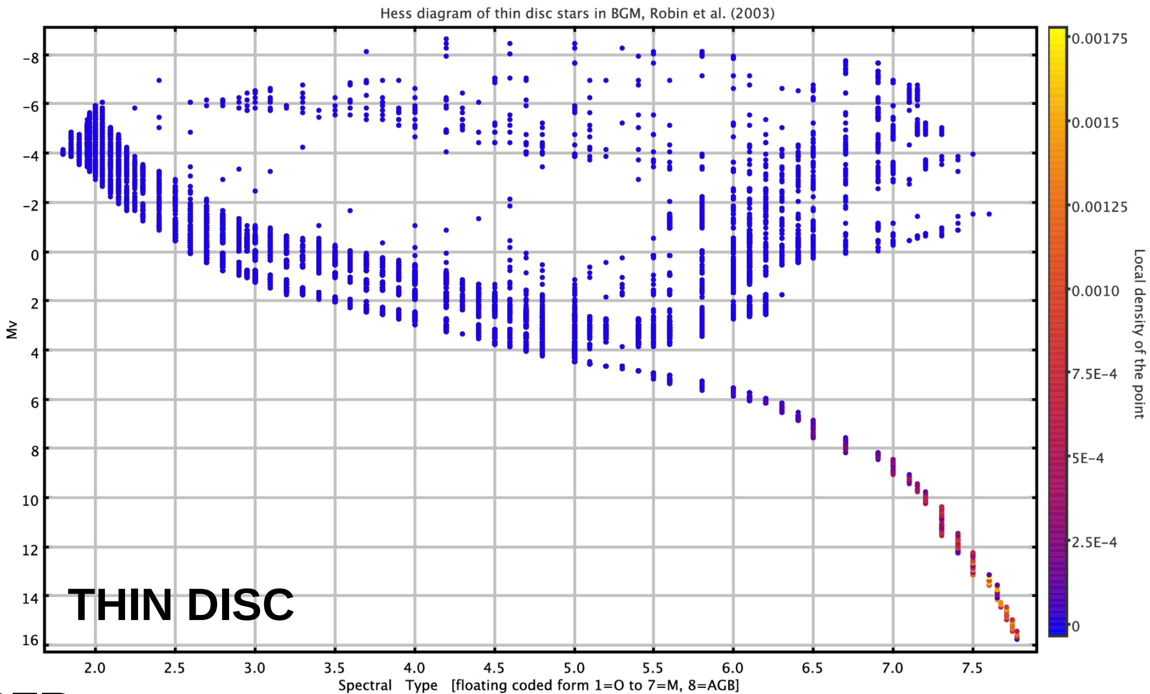
	Age (Gyr)	$[\frac{Fe}{H}]$ (dex)	$\frac{d[Fe/H]}{dR}$	IMF	SFR
Disc	0-0.15	0.01 ± 0.12	-0.07	$dn/dm \propto m^{-\alpha}$ $\alpha = 1.6$ for $m < 1M_\odot$ $\alpha = 3.0$ for $m > 1M_\odot$	constant
	0.15-1	0.03 ± 0.12			
	1-2	0.03 ± 0.10			
	2-3	0.01 ± 0.11			
	3-5	-0.07 ± 0.18			
	5-7	-0.14 ± 0.17			
	7-10	-0.37 ± 0.20			
Thick disc	11	-0.78 ± 0.30	0.00	$dn/dm \propto m^{-0.5}$	one burst
Stellar halo	14	-1.78 ± 0.50	0.00	$dn/dm \propto m^{-0.5}$	one burst
Bulge	10	0.00 ± 0.40	0.00	$dn/dm \propto m^{-2.35}$ for $m > 0.7M_\odot$	one burst

Density laws:

- Disc : Einasto (in between exp and sech2)
- Thick disc : double exponential (Reylé et al, 2002)
- Spheroid (stellar halo): power law (Robin et al 2000)
- Bulge : Old bulge (fitted to DENIS data, Picaud & Robin, 2004); a new model being prepared

Chosen kinematic parameters for each population, see Tab. 4 (Robin et al. 2003).

BGM version released in 2003 (previous to the PhD of M.Czekaj)



Hess diagrams for each model population were calculated assuming a given IMF, SFR and using particular set of evolutionary tracks.

It is like a t**hree dimensional HR diagram**, where every point (Mv; Spectral type) is associated with a density of stars existing there (stars/pc^3) and also with the age distribution (7 factors corresponding to 7 subcomponents).

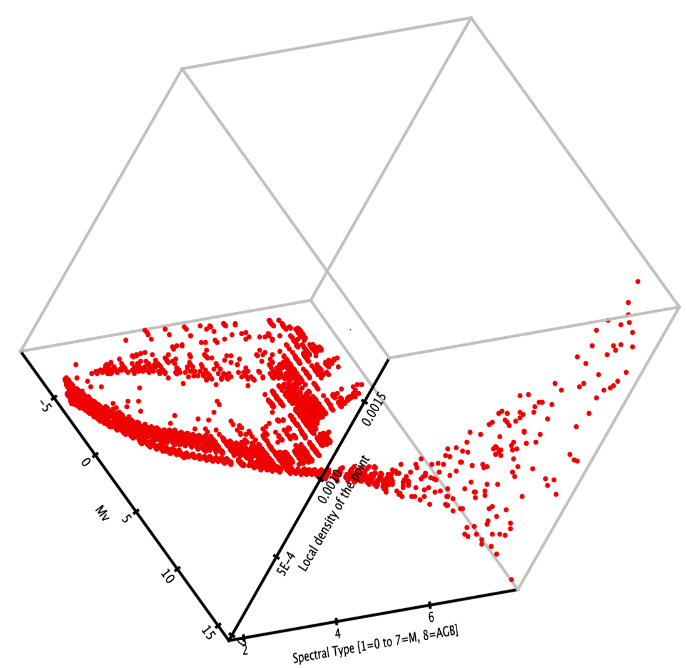
SFR – constant

IMF – power-law with 3 different slopes on 3 mass intervals: x = 0.6 (0.11; 0.2 Msun), 0.6 (0.2; 1 Msun), 2 (>1Msun)

Tracks: Masses >1 Msun Schaller et al. (1992), Low masses from Vandenberg (private comunication), Helium-burning stars at masses between 1 and 1.7M from Castellani et al. (1992)

Integration time: 10 Gyr

M. Haywood et al. 1996



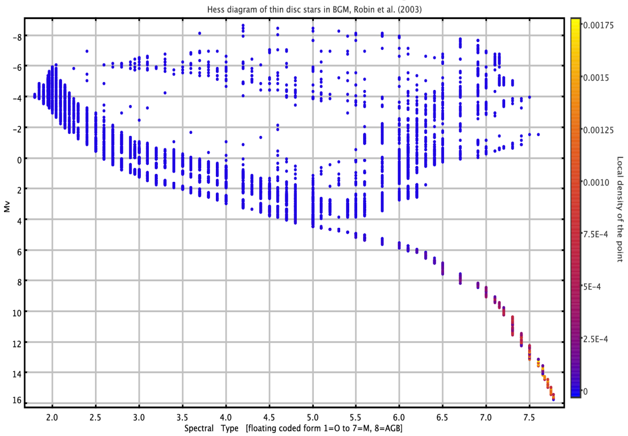
Besançon Galaxy Model (PhD M. Czekaj)

– turning the **IMF**, **SFR** and **evolutionary tracks** into **free user specified parameters.**

This coding task was an important change in star production philosophy.

BEFORE the stars production

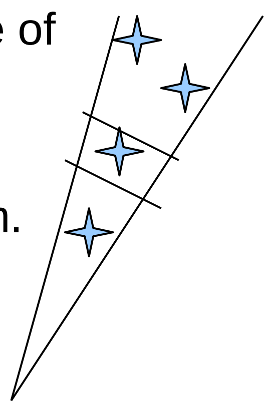
fixed Hess diagram



For all volume elements on the line of sight,

for each population separately,

summation on whole Hess diagram.



NOW, the SFR, IMF and evolutionary tracks are being read as an input in the run time of the program

In a volume element:

- calculate **the total mass reservoir** according to the density laws (parameters + gradients) +**SFR**
- generate star by star until there is **mass available, mass reservoir > 0**
- The mass of each individual star is being drawn according to the shape of **IMF**
- when age, mass and metallicity of a star are known we find its position (Teff, log(g), Luminosity) on HR diagram from **evolutionary tracks.**

Now, we can run the model with several different ingredients:

Evolutionary track sets:

1) The set of Padova tracks: from Bressan et al. 1993 to Girardi et al. 1996

2) masses > 0.7 Msol Bertelli (2008, 2009) + horizontal branch
masses < 0.7 Msol Baraffe (1997)

IMF

Kroupa 2008, Vallenari 2006, Just & Jahreiss 2010, Haywood & Robin 2003, **Kroupa+Haywood**

SFR

1) constant
2)several decreasing scenarios, (Aumer&Binney 2009) exp(0.12*tau).

Atmosphere models

1) BaSeL2 library
2) BaSeL3 library

Age-metallicity relation

1) Twarog (1980) (Tab. 1 Robin et al. 2003)
2) **Haywood (2006)**

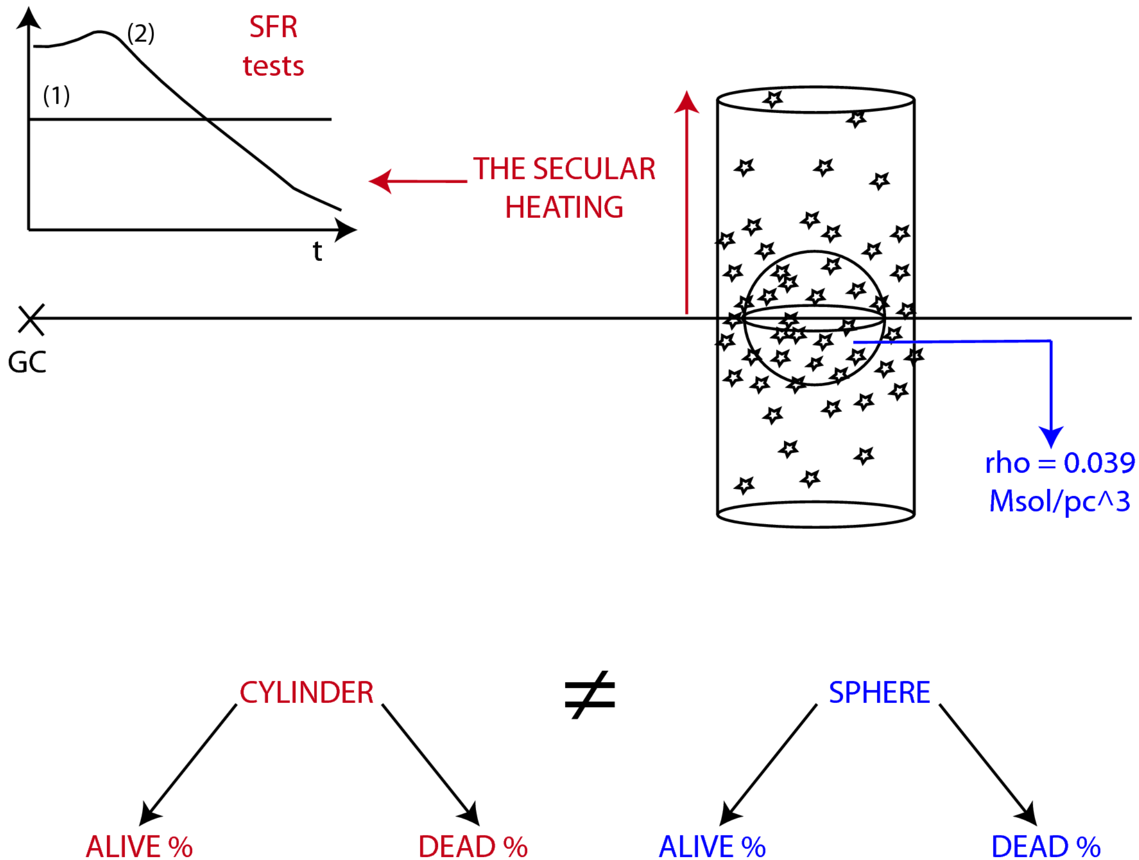
dynamical mass

1) M. Crézé (1998)
2) **F. van Leeuwen** (2007)

age-velocity dispersion σ_W relation

1) Gomez (1997)
2) Holmberg (2009)

Simulations for specific studies. A sphere and cylinder modes.



THIS IS A FACT AND IT IS CORRECT

When studying the SFR scenarios in the SN one must account for the fact that scale heights of young and old object are very different.

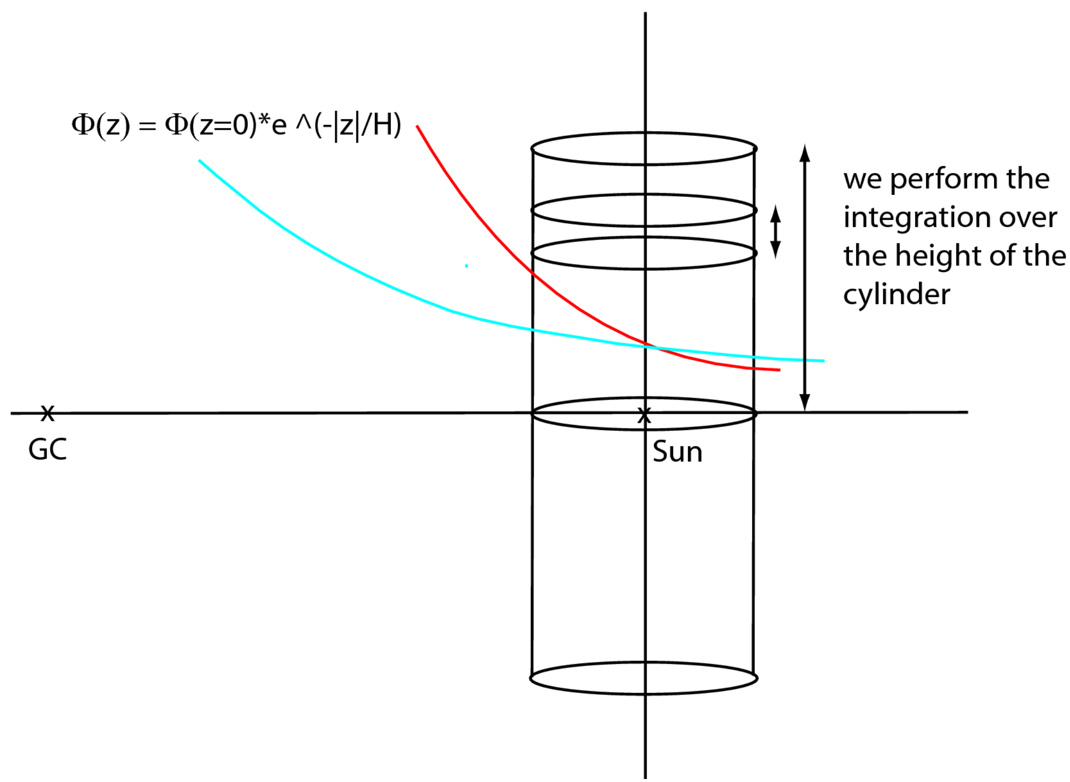
Consequently one should consider a cylindrical volume perpendicular to the Galactic plane and with its axis passing through the Sun.

Simulations provided until now:

- 19 July 2011, cylinder Rcyl=100pc, z_max=2.5kpc, Mv=[3.5, 6.5], IMF (Kroupa + Haywood), SFR=const, Evolutionary models (Lyon 1997, Padova '93-'96), Basel 3.1 atmosphere model, Haywood (1996) age-metallicity relation

- 21 July 2011, changing BaseL3.1 for BaseL2.1
- 29 July 2011,
  a) same as simulations of 21th July but including all Mv (2 milion stars)
  b) same as simulations of 21th July but using a cylinder of radius=200pc (500000 stars)
  c) same as simulations of 21th July but using a cylinder of radius=200pc and without adding dispersion to the age-metallicity relationship (500000 stars).

Below additional slides in case of questions.



Φ(z) = Φ(z=0)*e ^(-|z|/H)
we perform the integration over the height of the cylinder
GC
Sun

Table 3. Density laws and associated parameter of the stellar components. $a^2 = R^2 + \frac{z^2}{\epsilon^2}$ where R is the galactocentric distance, z is the height above the Galactic plane, and ϵ is the axis ratio. Values of ϵ are given in table 2. The disc density law is given here without the warp and flare. The corrections for these structures are given in the text (sect. 2.1.3). $\mathrm{d_0}$ are normalization constants. For the bulge, x,y and z are in the bulge reference frame and values of N, x_0, y_0, z_0 and R_c are given in the text (sect. 2.4).

	density law	
Disc	$\rho_0/d_0 \times \{\exp(-(a/h_{R_+})^2) - \exp(-(a/h_{R\_})^2)\}$	if age $\leq$ 0.15 Gyr
	with h_{R_+} = 5000 pc, $h_{R\_}$ = 3000 pc	
	$\rho_0/d_0 \times \{\exp(-(0.5^2 + a^2/h^2_{R_+})^{1/2}) - \exp(-(0.5^2 + a^2/h^2_{R\_})^{1/2})\}$	if age > 0.15 Gyr
	with h_{R_+} = 2530 pc, $h_{R\_}$ = 1320 pc	
Thick disc	$\rho_0/d_0 \times \exp\,(-\frac{R-R_\odot}{h_R}) \times (1 - \frac{1/h_z}{x_l \times (2.+x_l/h_z)} \times z^2)$	if $\|z\| \leq x_l$, x_l=400 pc
	$\rho_0 \times \exp\,(-\frac{R-R_\odot}{h_R}) \times \frac{\exp(x_l/h_z)}{1+x_l/2h_z} \exp(-\frac{\|z\|}{h_z})$	if $\|z\| > x_l$
	with h_R = 2500 pc, h_z = 800 pc	
Spheroid	$\rho_0/d_0 \times (\frac{a_c}{R_\odot})^{-2.44}$	if $a \leq a_c$, a_c = 500 pc
	$\rho_0 \times (\frac{a}{R_\odot})^{-2.44}$	if $a > a_c$
Bulge	$N \times \exp(-0.5 \times r_s^2)$	$\sqrt{x^2 + y^2} < R_c$
	$N \times \exp(-0.5 \times r_s^2) \times \exp(-0.5(\frac{\sqrt{x^2+y^2}-R_c}{0.5})^2)$	$\sqrt{x^2 + y^2} > R_c$
	with $r_s^2 = \sqrt{[(\frac{x}{x_0})^2 + (\frac{y}{y_0})^2]^2 + (\frac{z}{z_0})^4}$	
ISM	$\rho_0 \times exp(-\frac{R-R_\odot}{h_R}) \times exp(-\frac{\|z\|}{h_z})$	
	with h_R = 4500 pc, h_z = 140 pc	
Dark halo	$\frac{\rho_c}{(1.+(a/R_c)^2)}$ with R_c = 2697 pc and ρ_c = 0.1079	

Chosen kinematic parameters for each population.

Table 4. Velocity dispersions ($\sigma_U, \sigma_V, \sigma_W$), asymmetric drift V_{ad} at the solar position (see section 2.1.4) and velocity dispersion gradient $\frac{d\ln(\sigma_U^2)}{dR}$, where σ_U is expressed in km s^{-1} and R in kpc.

	Age (Gyr)	σ_U (km s^{-1})	σ_V (km s^{-1})	σ_W (km s^{-1})	V_{ad} (km s^{-1})	$\frac{d\ln(\sigma_U^2)}{dR}$
Disc	0-0.15	16.7	10.8	6	3.5	
	0.15-1	19.8	12.8	8	3.1	
	1-2	27.2	17.6	10	5.8	
	2-3	30.2	19.5	13.2	7.3	-2×10^{-1}
	3-5	36.7	23.7	15.8	10.8	
	5-7	43.1	27.8	17.4	14.8	
	7-10	43.1	27.8	17.5	14.8	
Thick disc		67	51	42	53	0
Spheroid		131	106	85	226	0
Bulge		113	115	100	79	0