Chemical evolution models in the Era of Galactic surveys: new 2D model for the Milky Way disc

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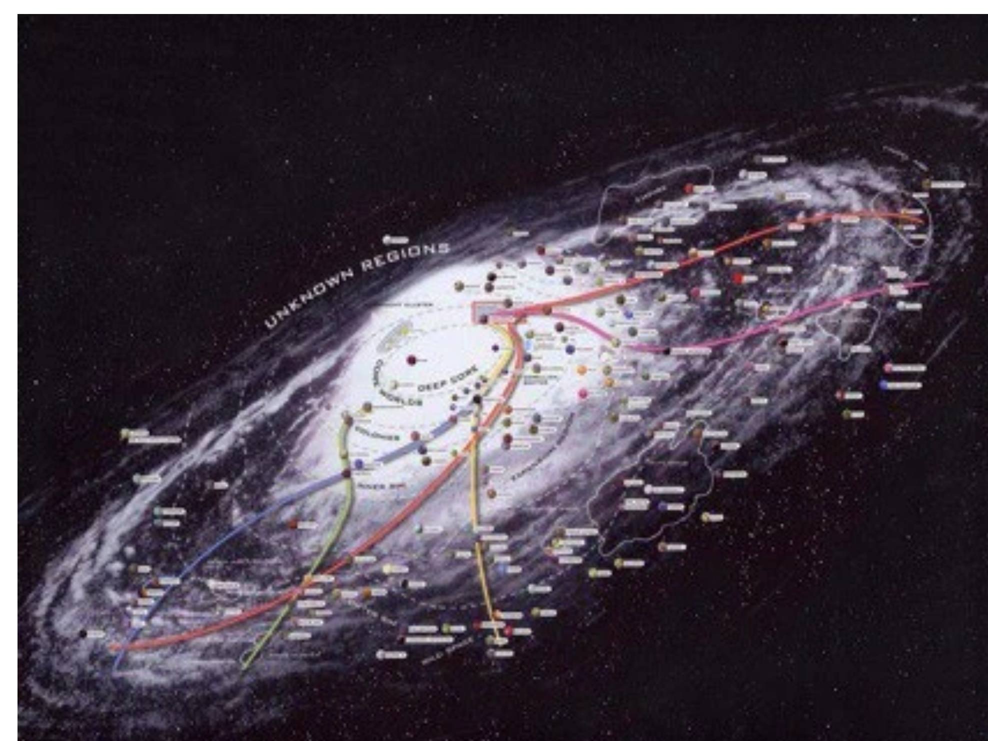


Standard Chemical evolution model for the disc

Matteucci&Francois '89

The galactic disc is modelled as different rings.
Each ring has a different evolution,
due to SF law

$$\Psi(R,t) = \nu(R,t)G^k(R,t)$$

And the time scale of the infall

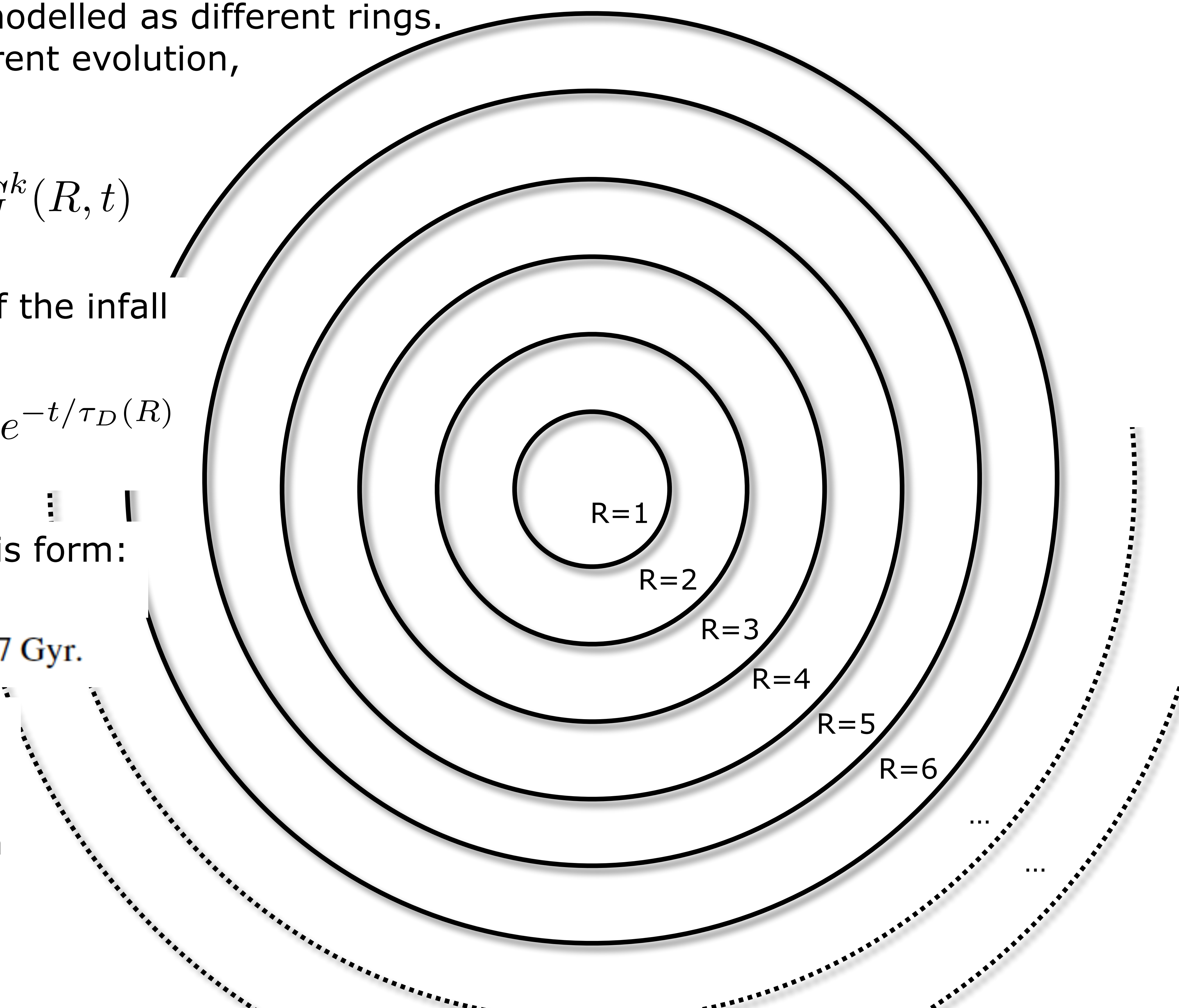
$$\dot{G}(R,t)_{inf} = A(R)e^{-t/\tau_D(R)}$$

where tau was on this form:

$$\tau_D = 1.033r(\,\mathrm{kpc}) - 1.267\ \mathrm{Gyr}.$$

so longer timescale
in the outskirt

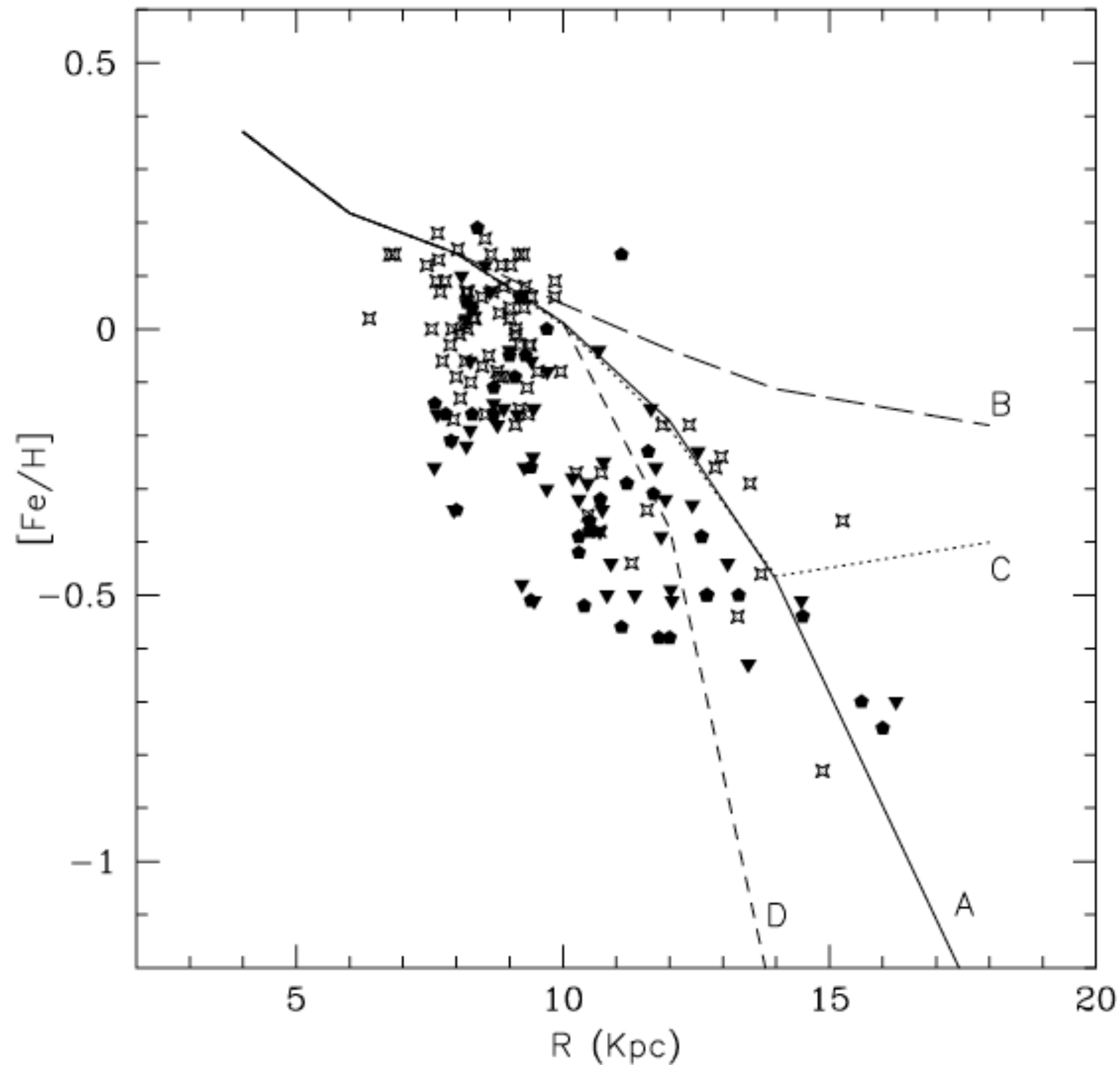
inside-out formation



Chiappini+01

Based on the two infall model.

The impact of how the disc is pre-enriched, in particular for the outskirt of the Galaxy.



Data from HII regions and B stars

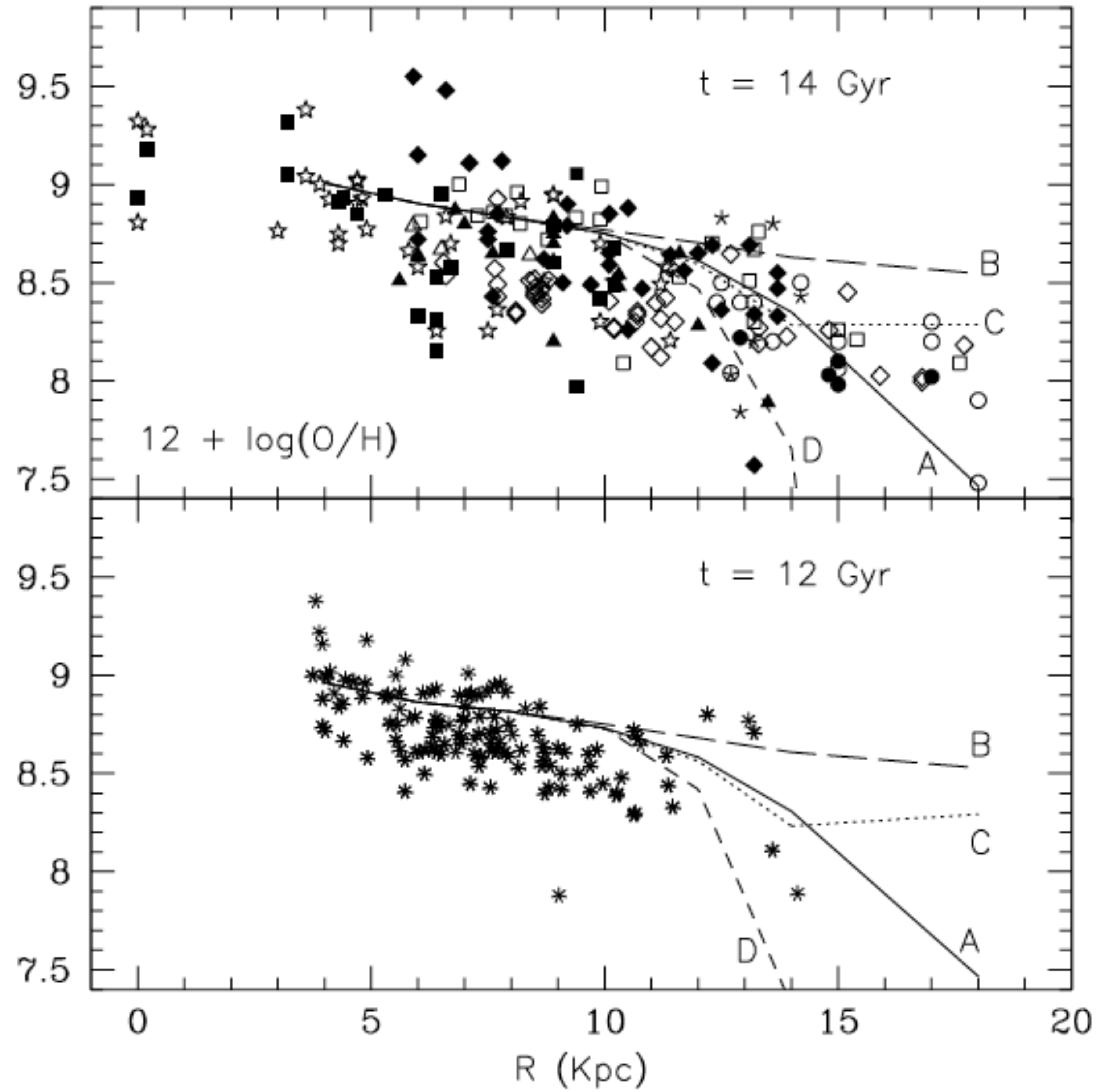
MODEL PARAMETERS

Model	$\Sigma_H(R, t_{Gal})$	Σ_{thr}^H	τ_H
A	17 $M_\odot$ pc^{-2} for $R \leq 8$ kpc $\propto R^{-1}$ for $R > 8$ kpc	4 $M_\odot$ pc^{-2}	0.8 Gyr for $4 \leq R \leq 18$ kpc
B	17 $M_\odot$ pc^{-2} for $4 \leq R \leq 18$ kpc	4 $M_\odot$ pc^{-2}	0.8 Gyr for $4 \leq R \leq 18$ kpc
C	17 $M_\odot$ pc^{-2} for $R \leq 8$ kpc $\propto R^{-1}$for $R > 8$ kpc	No threshold In the halo phase	0.8 Gyr for $4 \leq R \leq 18$ kpc
D	17 $M_\odot$ pc^{-2} for $R \leq 8$ kpc $\propto R^{-1}$for $R > 8$ kpc	4 $M_\odot$ pc^{-2}	0.8 Gyr for $R \leq 10$ kpc 2 Gyr for $R > 10$ kpc

Chiappini+01

Here we see the difference at 2 different time

Data: HII regions and B stars

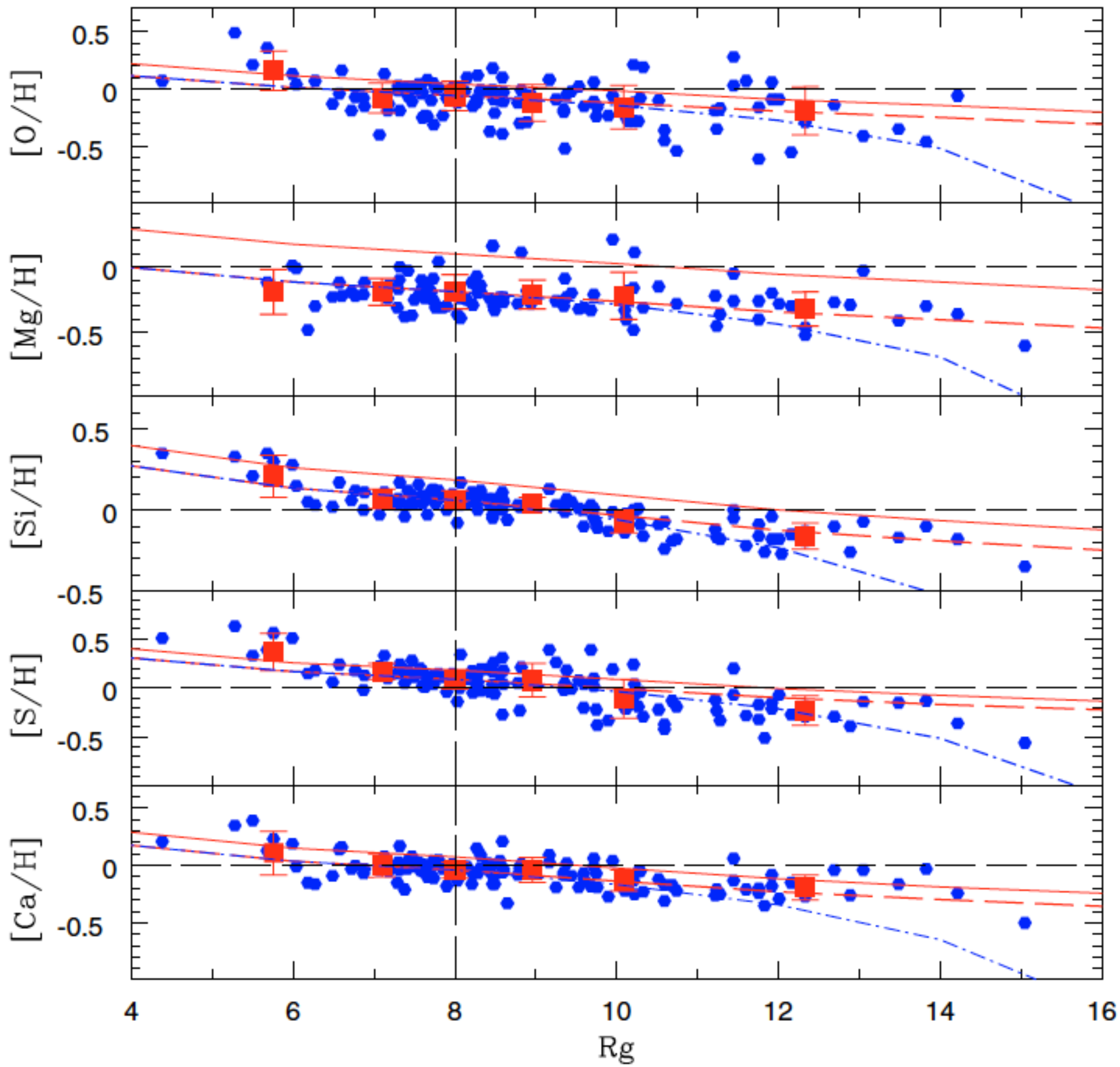


Data: PNe

Cescutti+07

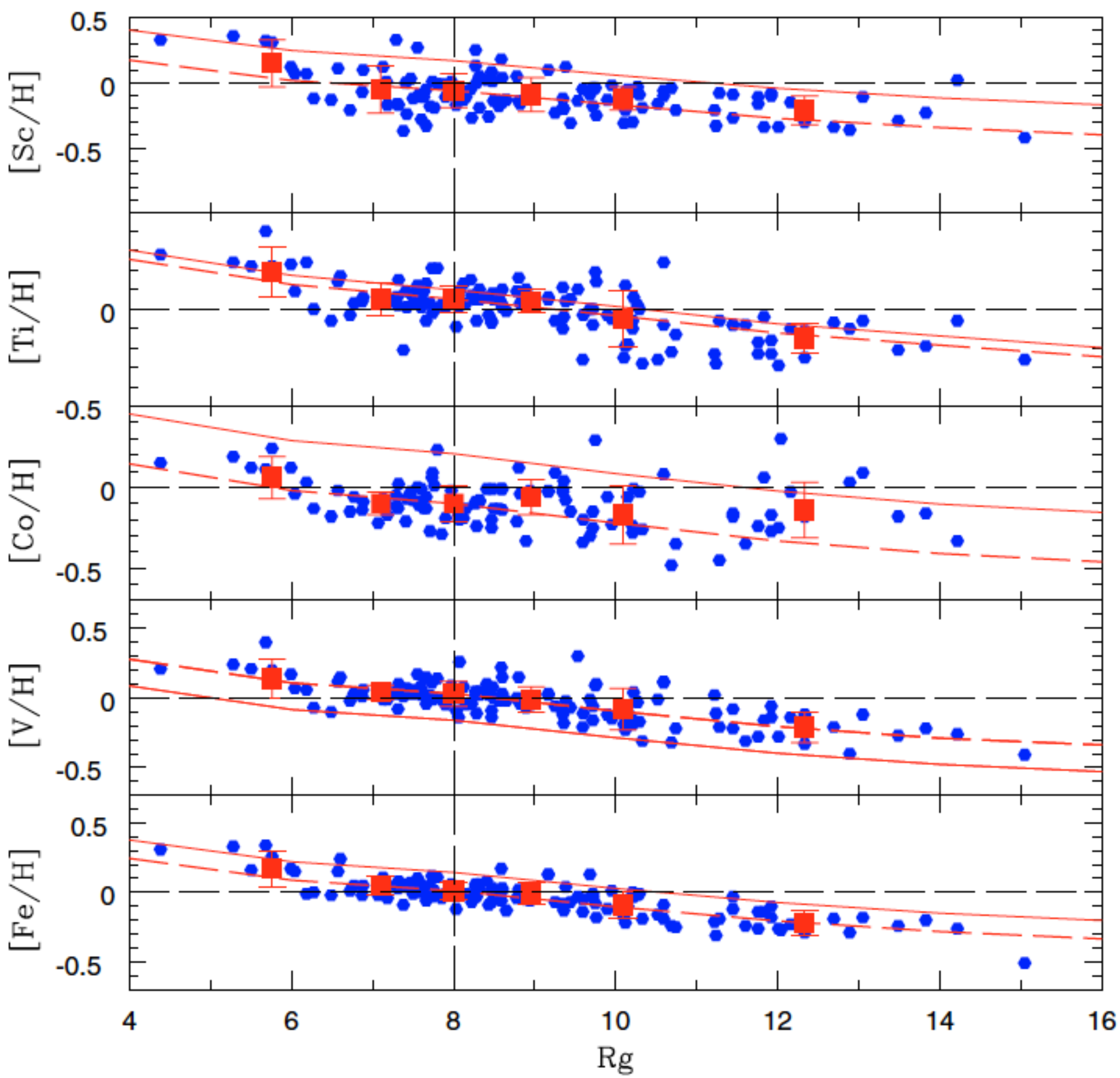
Gradients for an increased number of chemical elements including neutron capture elements.

An important novelty was that the comparison was made only with Cepheids measured by the same group (Andrievsky+02 +04, Luck+03) that provided a valuable data set.



Cescutti+07

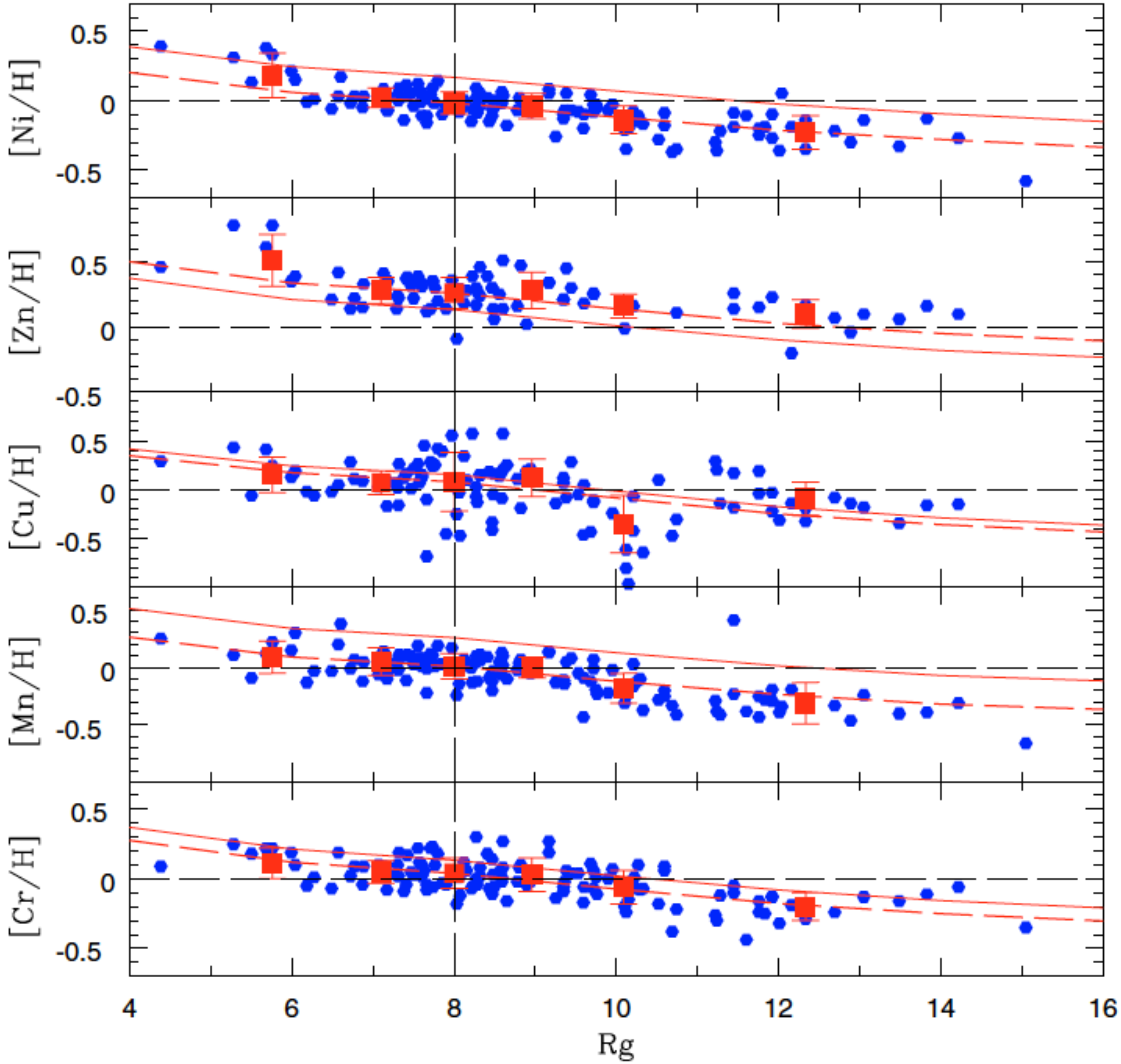
Iron peak elements
note that Fe gradient is steeper compared to O



Cescutti+07

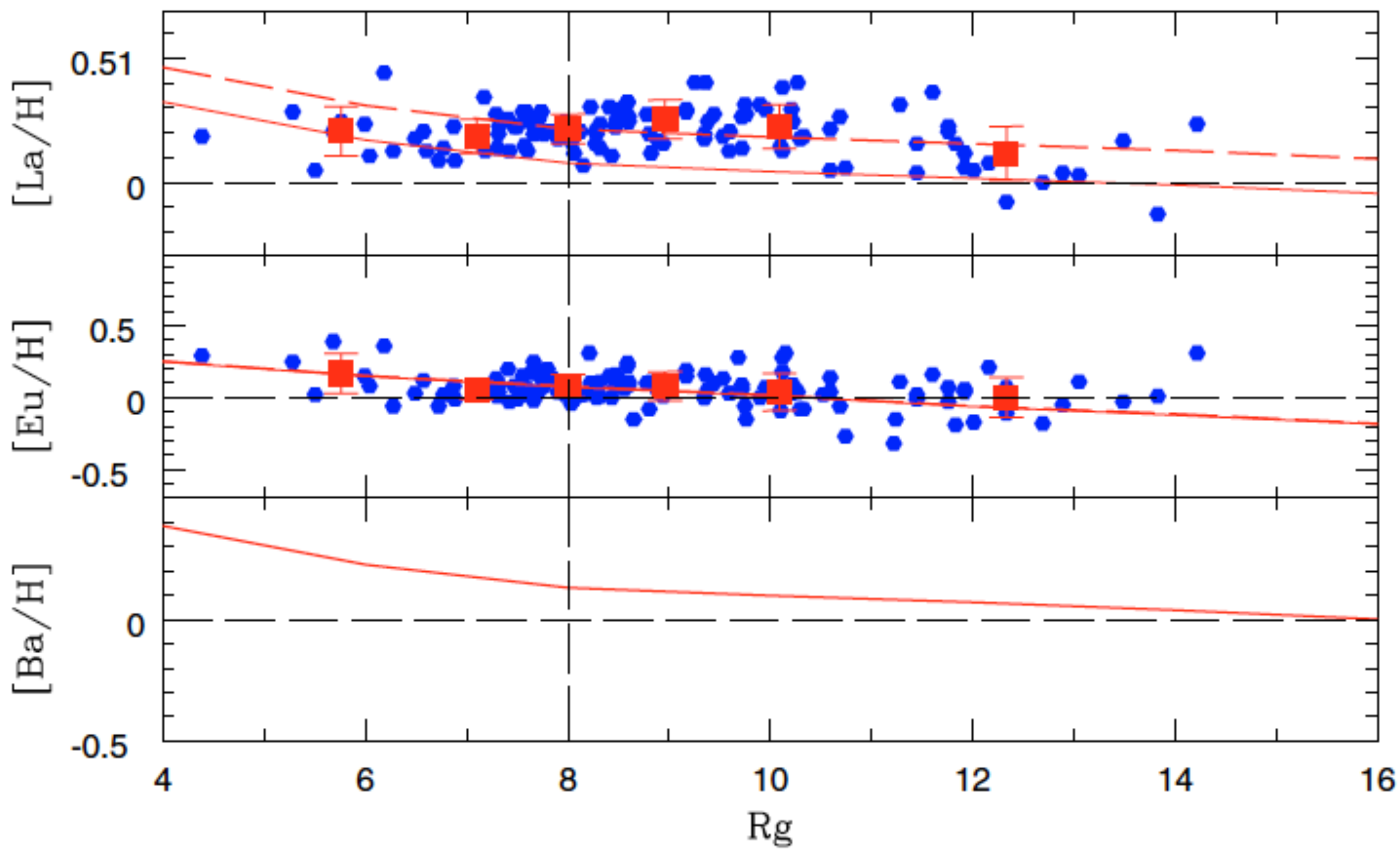
Iron peak elements 2

Scatter in Cu, probably due to observational problems



Cescutti+07

neutron capture elements
We did not have data for Ba, but we predicted that Ba has the flattest gradient, similar to La, whereas the Eu has a gradient similar to alpha elements.



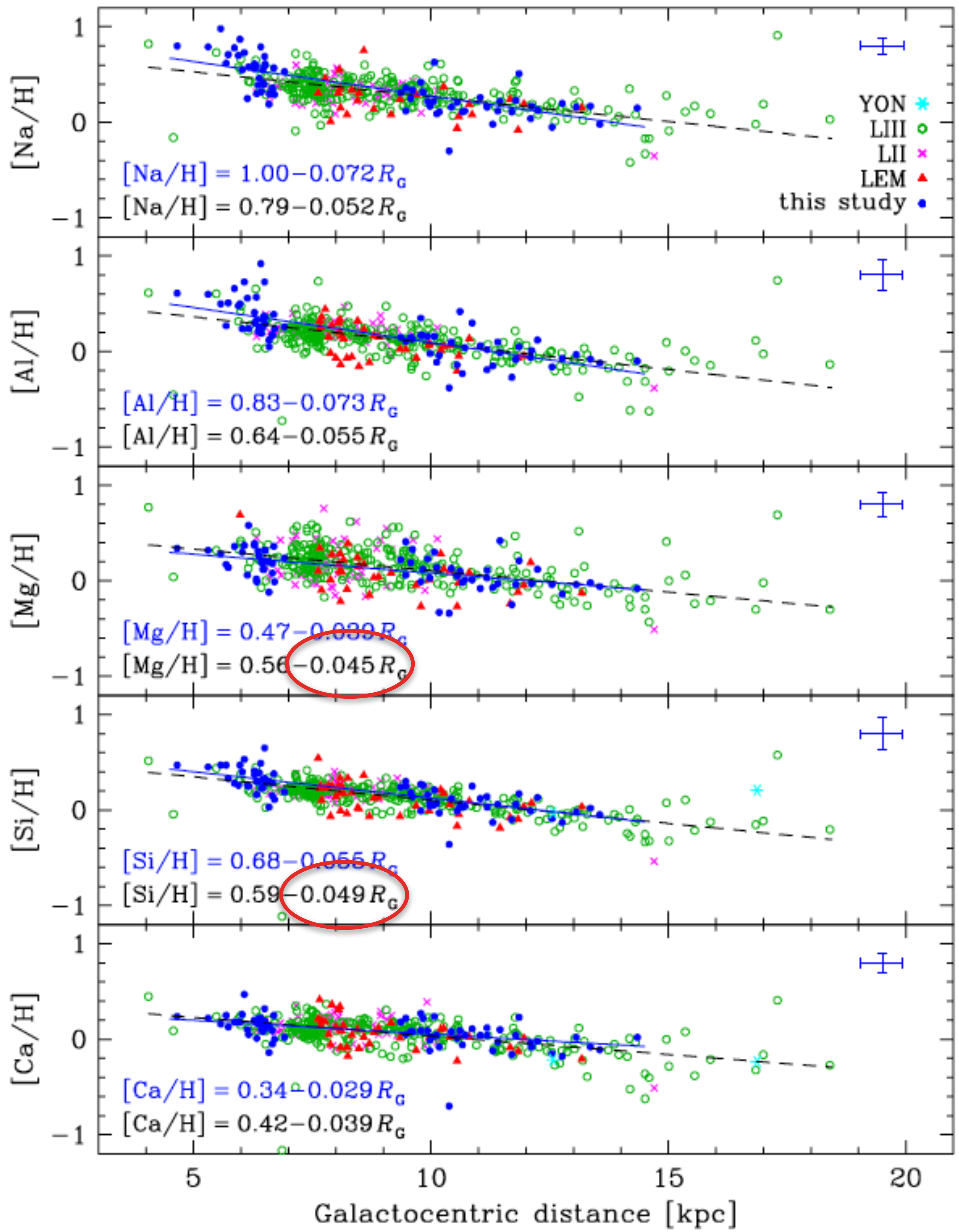
	Fe	O	Mg	Si	S	Ca	Cu	Zn	Ni
$\frac{\Delta[el/H]}{\Delta R}$(dex/kpc) from 4 to 22 kpc	−0.036	−0.028	−0.031	−0.033	−0.034	−0.034	−0.050	−0.038	−0.034
$\frac{\Delta[el/H]}{\Delta R}$(dex/kpc) from 4 to 14 kpc	−0.052	−0.035	−0.039	−0.045	−0.047	−0.047	−0.070	−0.054	−0.047
$\frac{\Delta[el/H]}{\Delta R}$(dex/kpc) from 16 to 22 kpc	−0.012	−0.011	−0.012	−0.012	−0.012	−0.012	−0.014	−0.012	−0.012

	Sc	Ti	V	Cr	Mn	Co	Ba	Eu	La
$\frac{\Delta[el/H]}{\Delta R}$(dex/kpc) from 4 to 22 kpc	−0.036	−0.032	−0.038	−0.036	−0.038	−0.037	−0.021	−0.030	−0.021
$\frac{\Delta[el/H]}{\Delta R}$(dex/kpc) from 4 to 14 kpc	−0.051	−0.043	−0.056	−0.052	−0.057	−0.055	−0.032	−0.036	−0.032
$\frac{\Delta[el/H]}{\Delta R}$(dex/kpc) from 16 to 22 kpc	−0.012	−0.012	−0.011	−0.012	−0.011	−0.011	−0.009	−0.013	−0.008

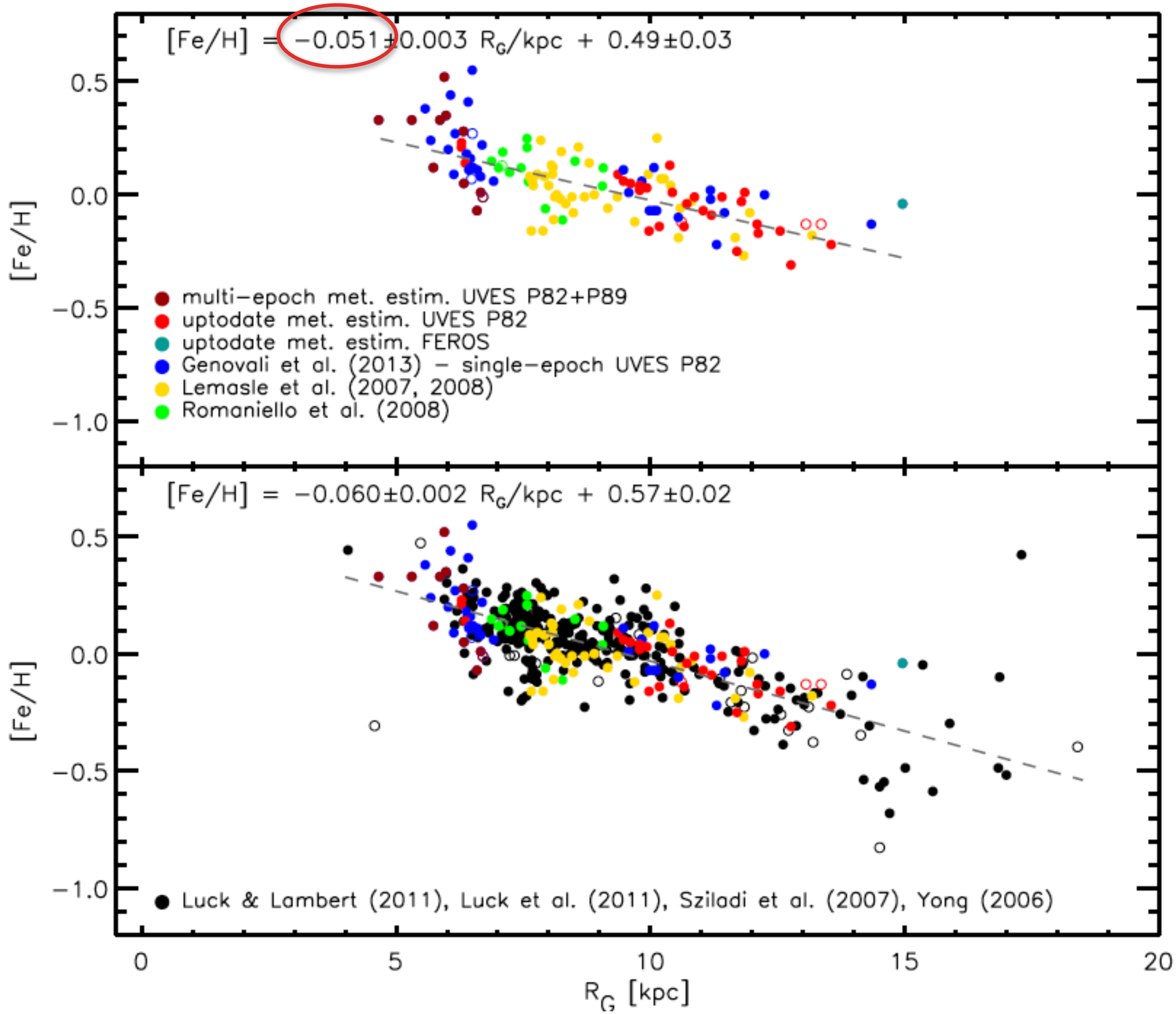
New data from Cepheids - Genovali+15

Light elements.

A larger sample has been collected and measured.
The new data confirm a relative flat gradient for these young objects



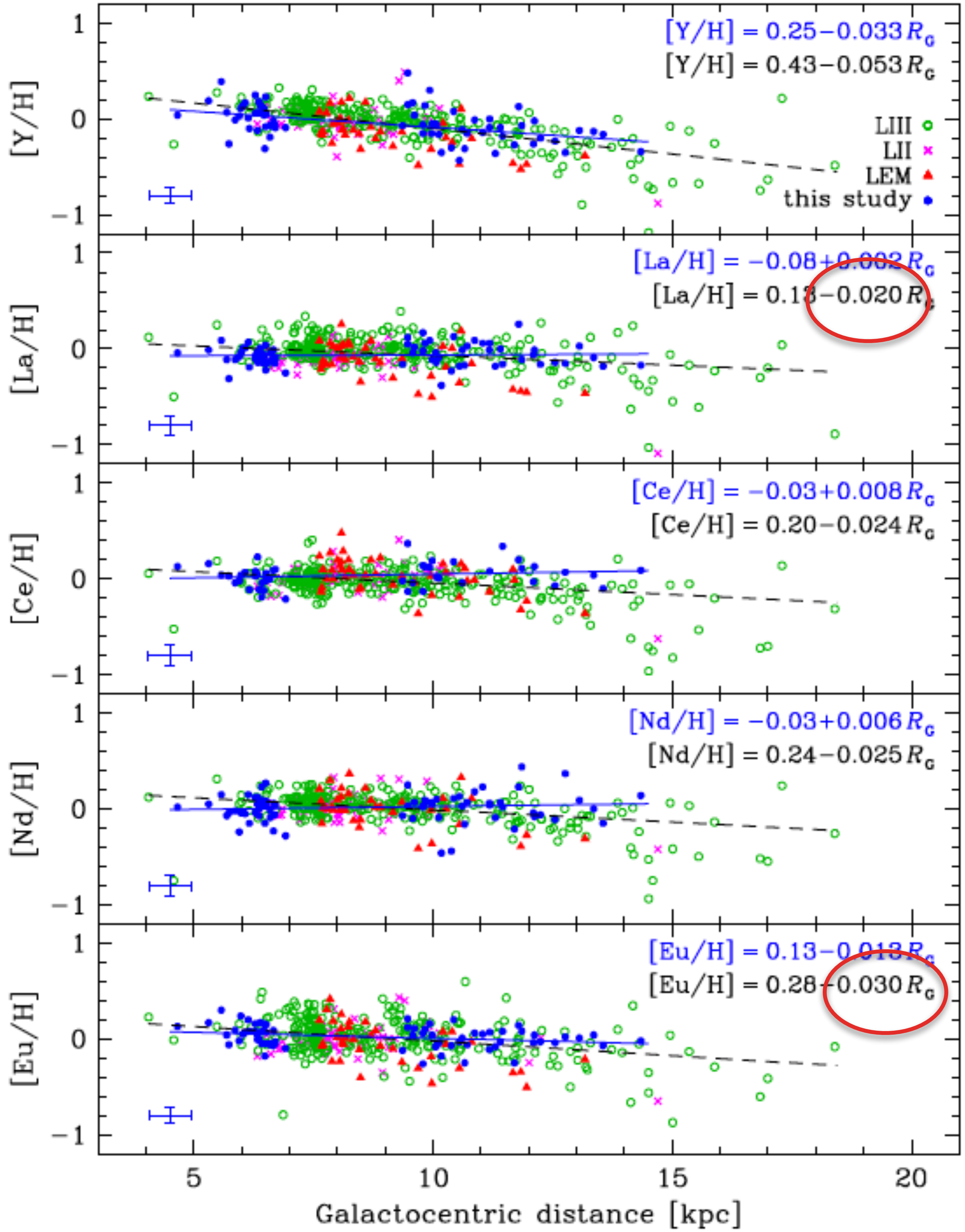
New data from Cepheids - Genovali+15



New data from Cepheids - Da Silva+15

Heavy elements.

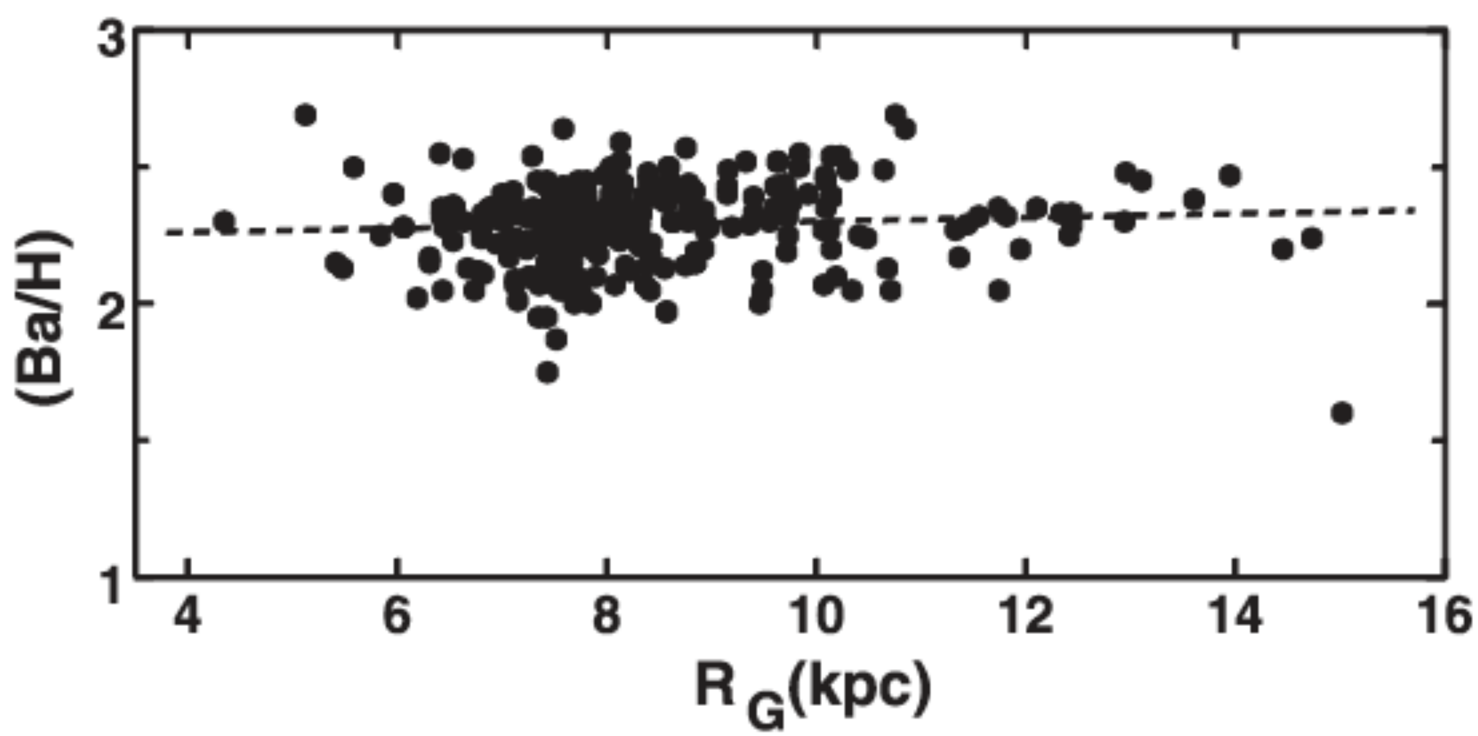
La and Eu exactly as predicted in Cescutti+07 and …
regarding Ba



da Silva+15

Andrievsky+13

“As a result, we conclude that the Ba abundance distribution can be characterized by a zero gradient. This result is compared with derived gradients for other elements, and some reasons are briefly discussed for the independence of the barium abundances from Galactocentric distances.”

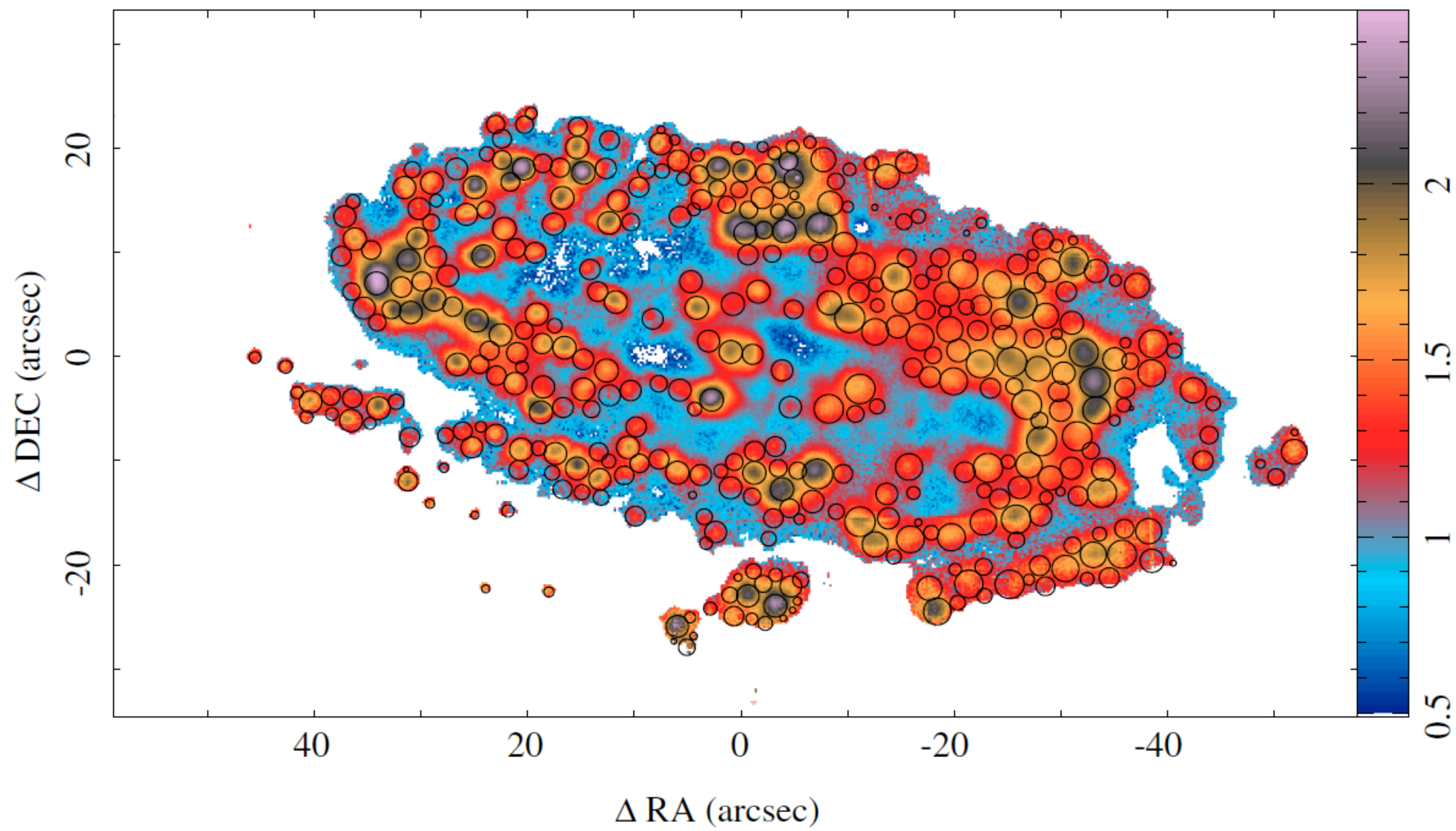


However ...

a galaxy is not formed by homogeneous rings

A real Galaxy looks like this, with a patchy Star formation

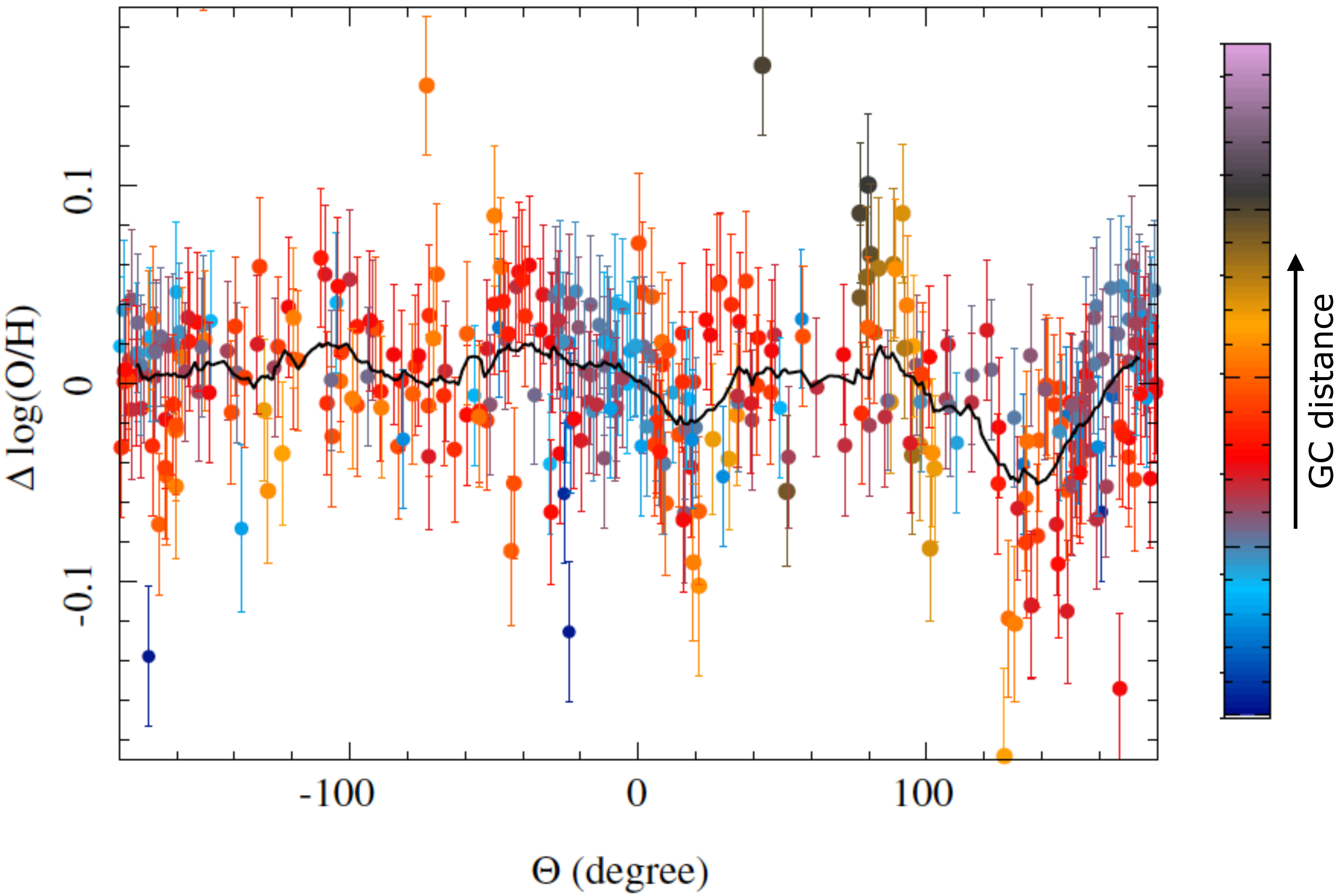
Sánchez+15
Muse data NGC 6754



Equivalent width of Hα in logarithmic scale.
Circles represent the detected HII regions

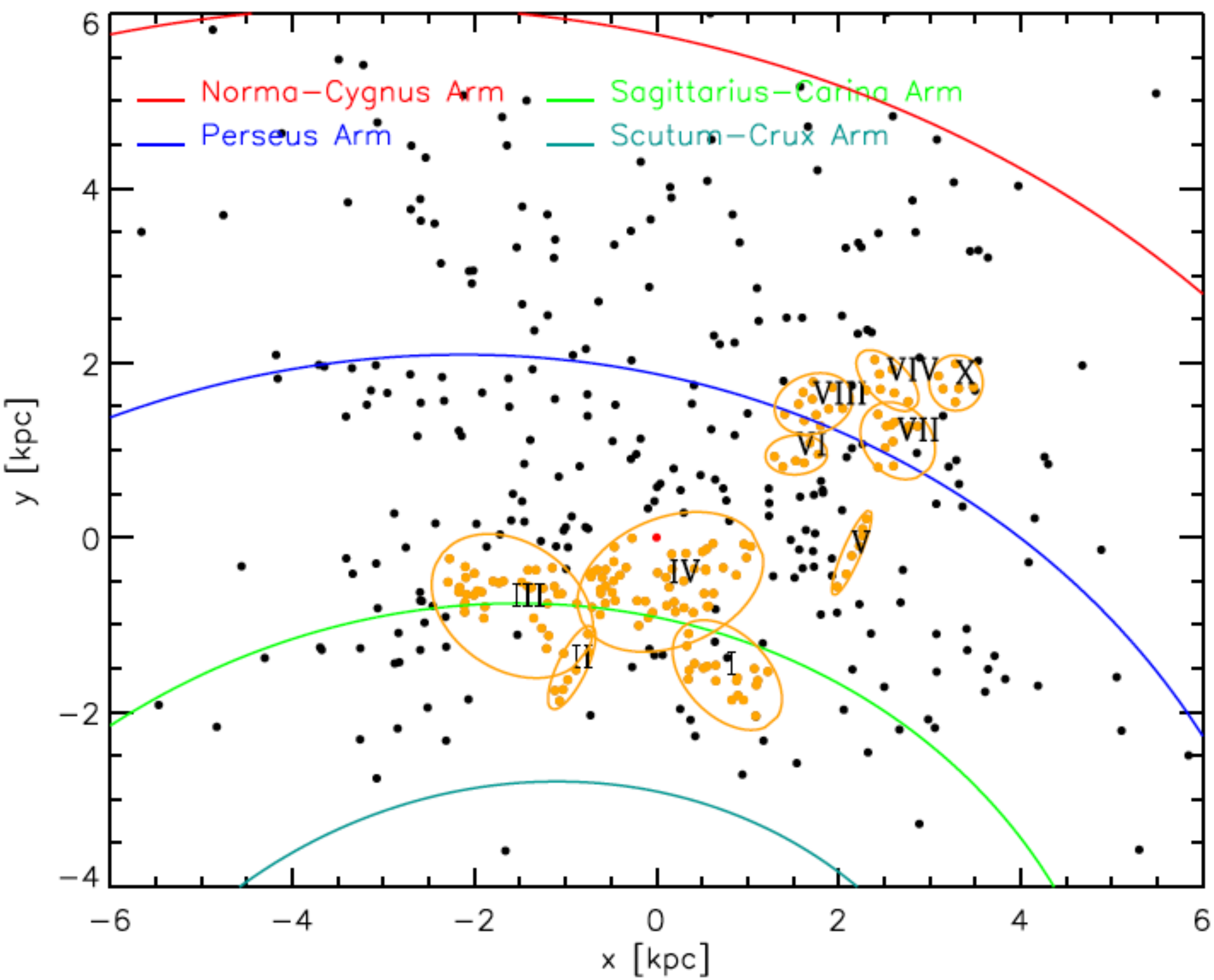
Azimuthal variation - [O/H]

Sánchez+15
Muse data NGC 6754



Azimuthal distribution of the residual of the oxygen abundance
for the individual HII regions after subtracting the average radial gradient.

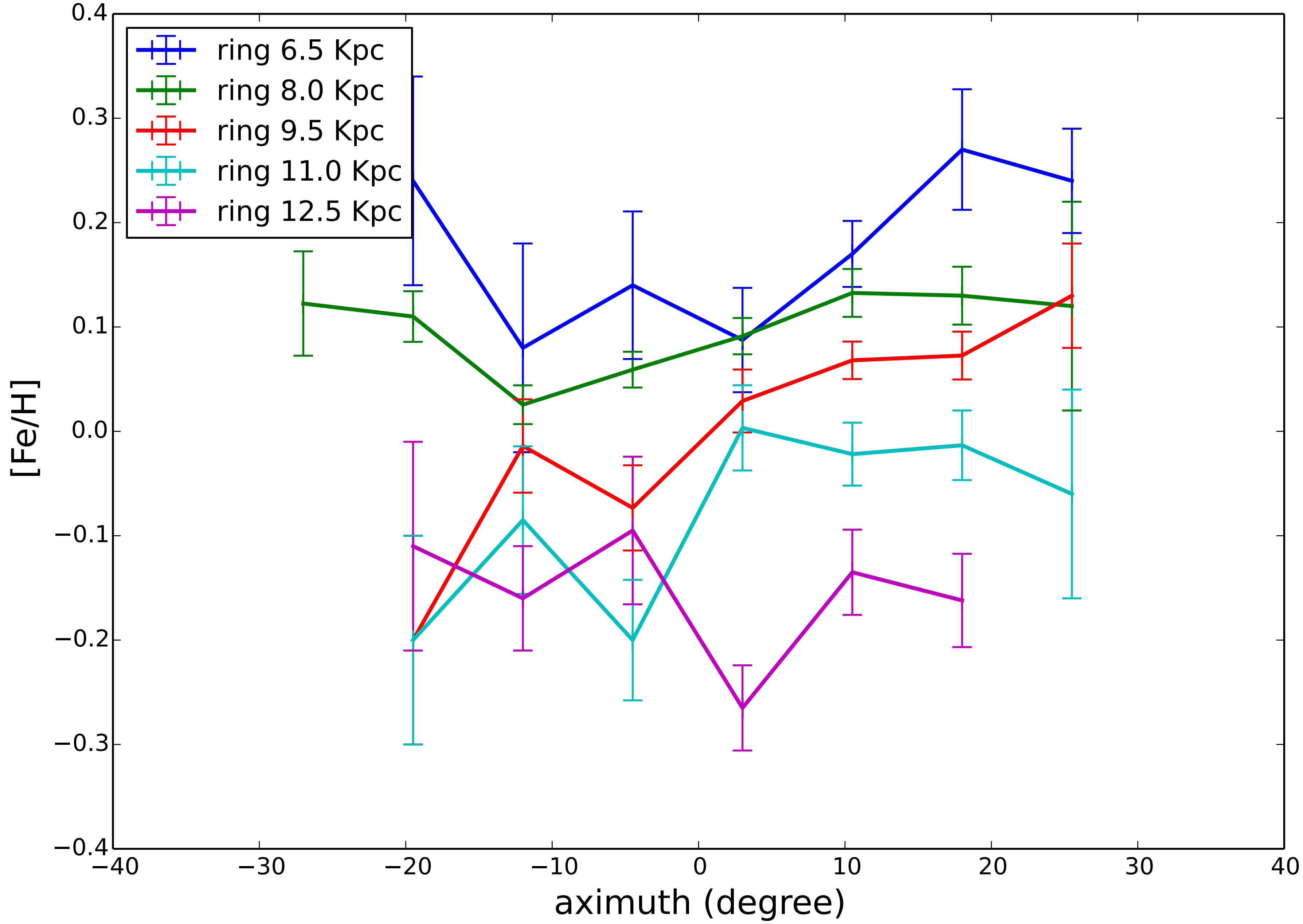
The data for the MW disc



Genovali+14

Azimuthal variation - [Fe/H]

Using the previous data from Genovali+14



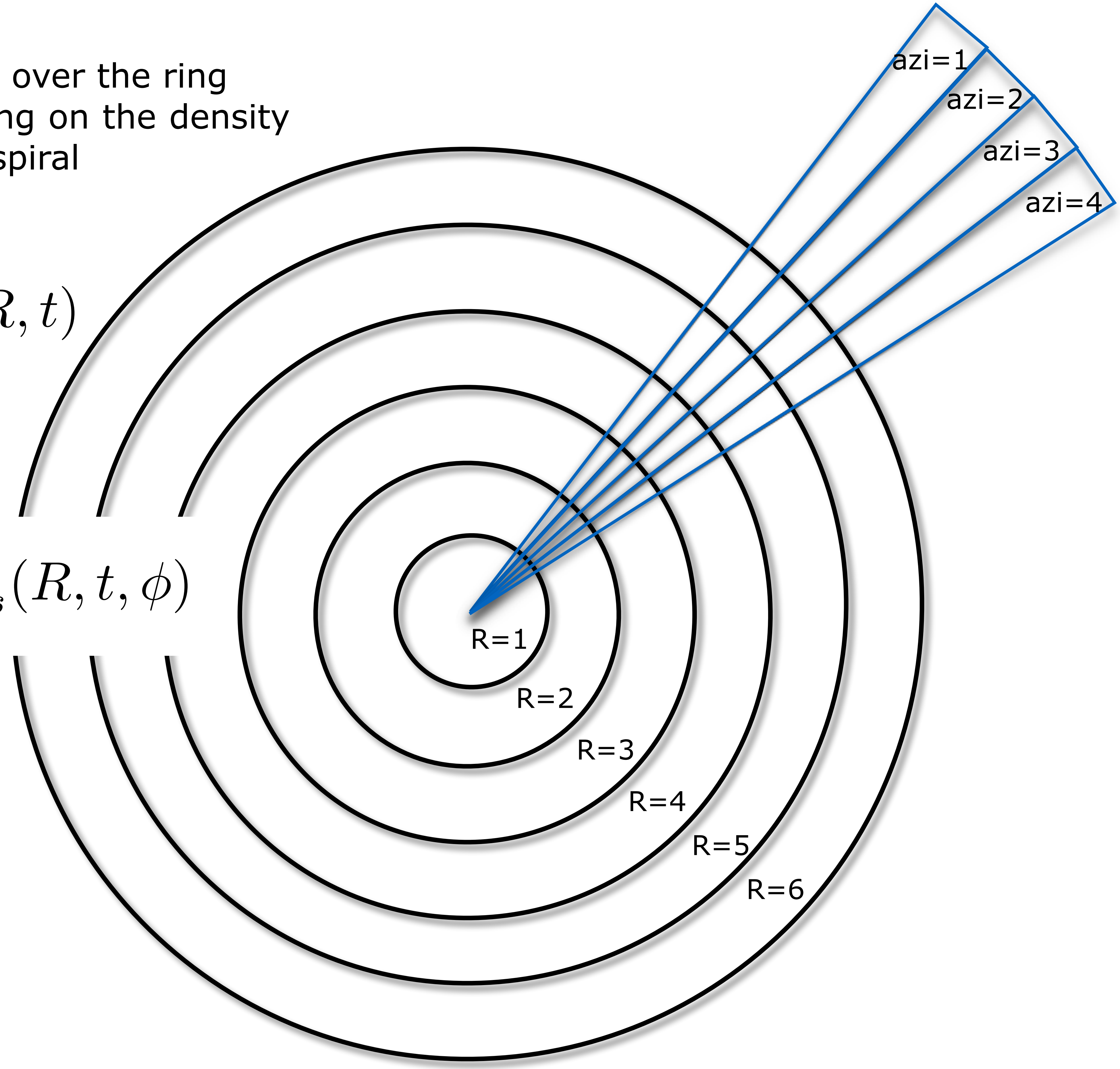
The new 2D model for the disc

The SFR is not constant over the ring but it can vary depending on the density perturbation driven by spiral arms or bars.

$$\Psi(R,t) \propto \sigma^{k}_{gas}(R,t)$$

↓

$$\Psi(R,t,\phi) \propto \sigma^{k}_{gas}(R,t,\phi)$$



The new 2D model for the disc

The previous model is quite successful, therefore we intend to preserve its general trend. For this reason we impose:

$$\sum_{i}^{N} \frac{\sigma(R,t,\phi_i)}{N} = \sigma(R,t)$$

if we define

Density contrast function

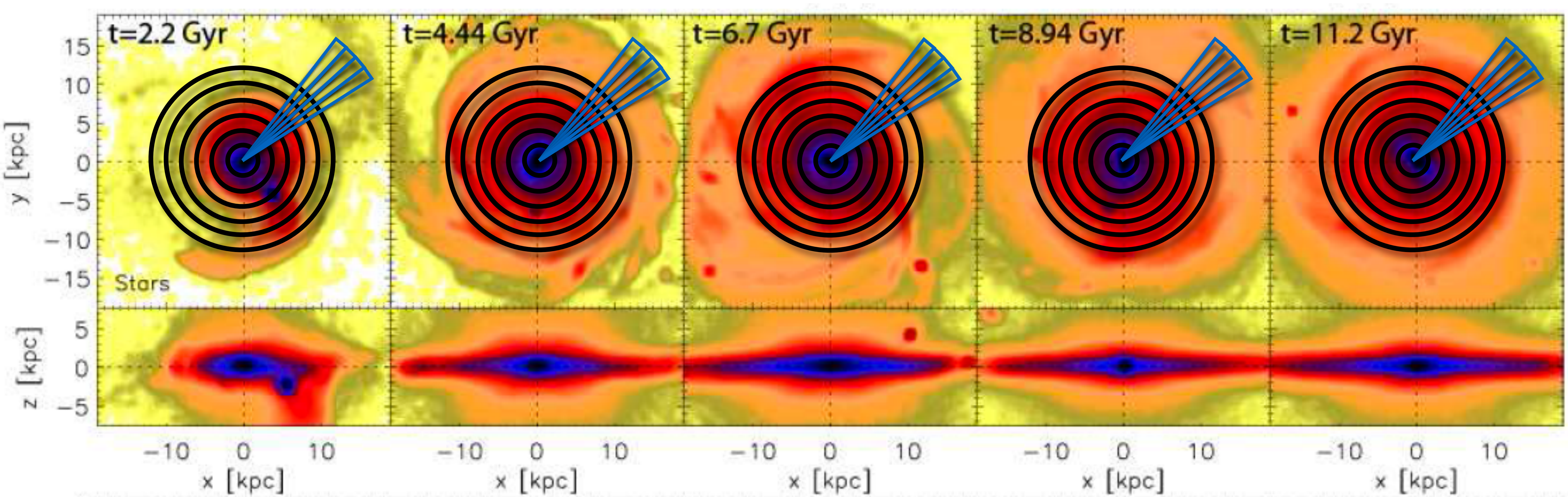
$$\sigma(R,t,\phi_i) = \sigma(R,t) f(\phi_i,R,t)$$

what we need is a function such as:

$$\sum_{i=1}^{N} \frac{f(\phi_i,R,t)}{N} = 1$$

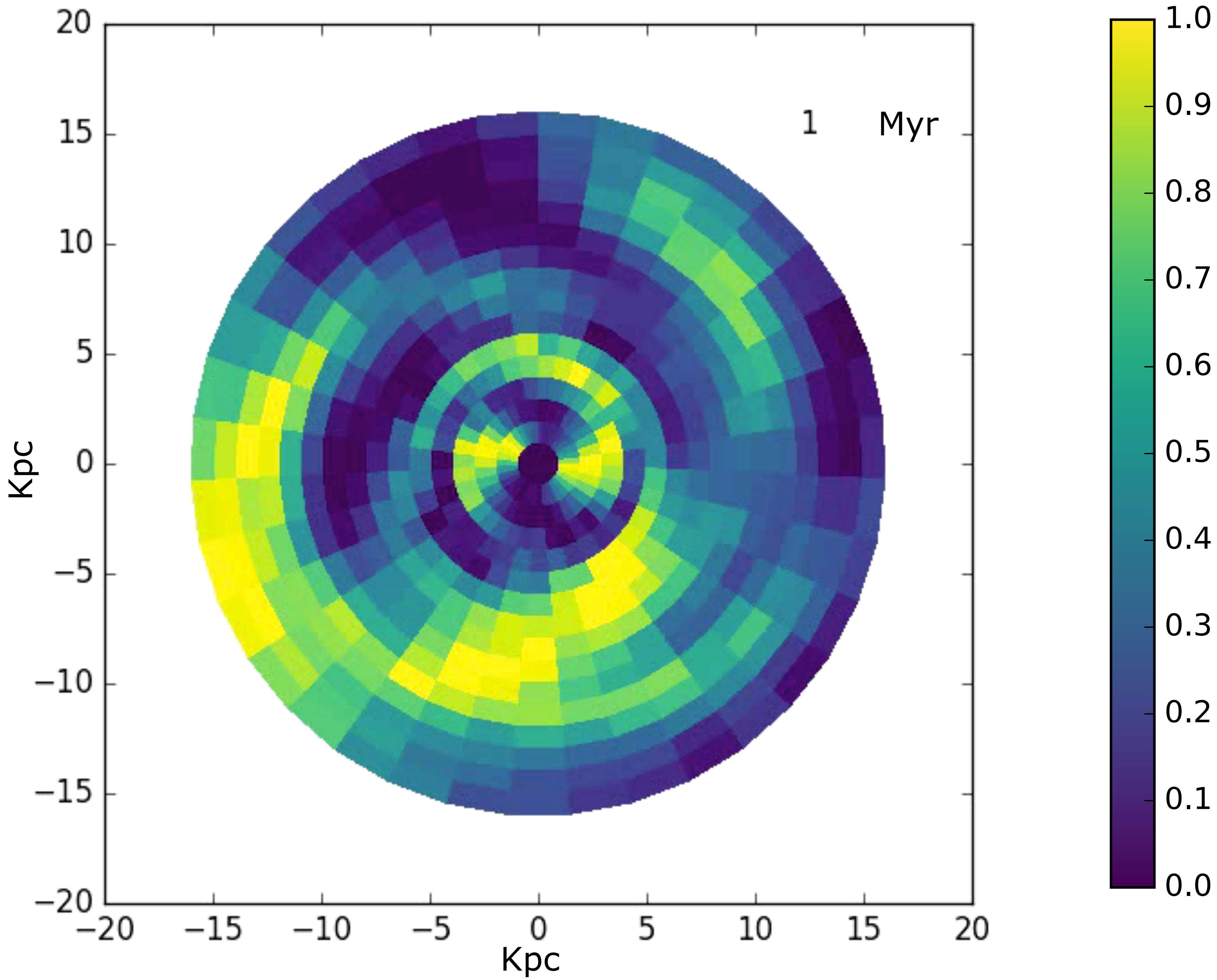
The new 2D model for the disc

We consider the density fluctuations present in the MilkyWay like simulation obtained by Martig+12 and chosen in Minchev+13 for their chemodynamical model. Basically we average at each time-step the gas density in each ring and we compute the density fluctuation in bin of 10deg on the azimuth.



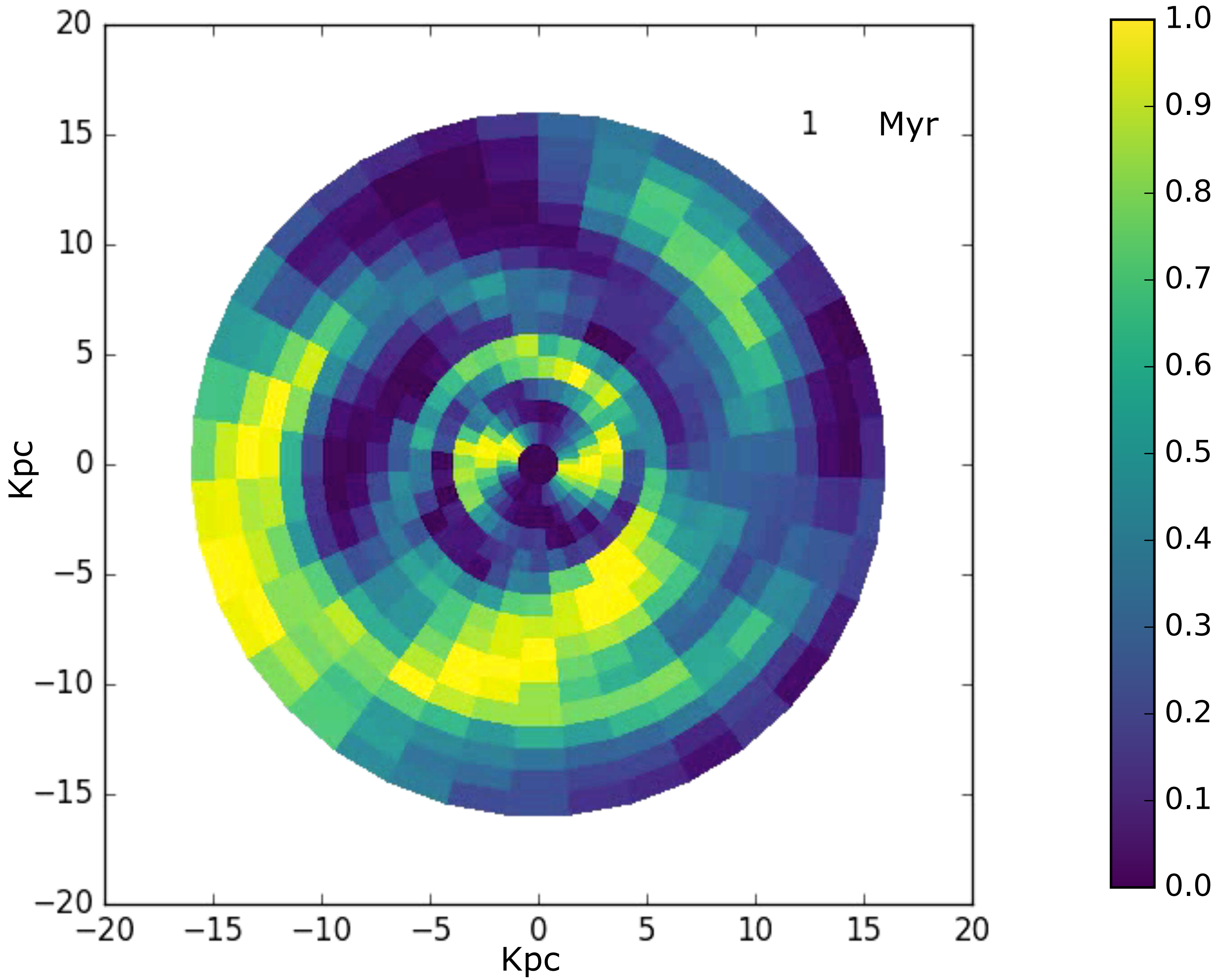
We adopt these values in our 2D chemical evolution model.

Results new model: SFR



Linear scale normalised between [0:1] at each ring

Results new model: stars

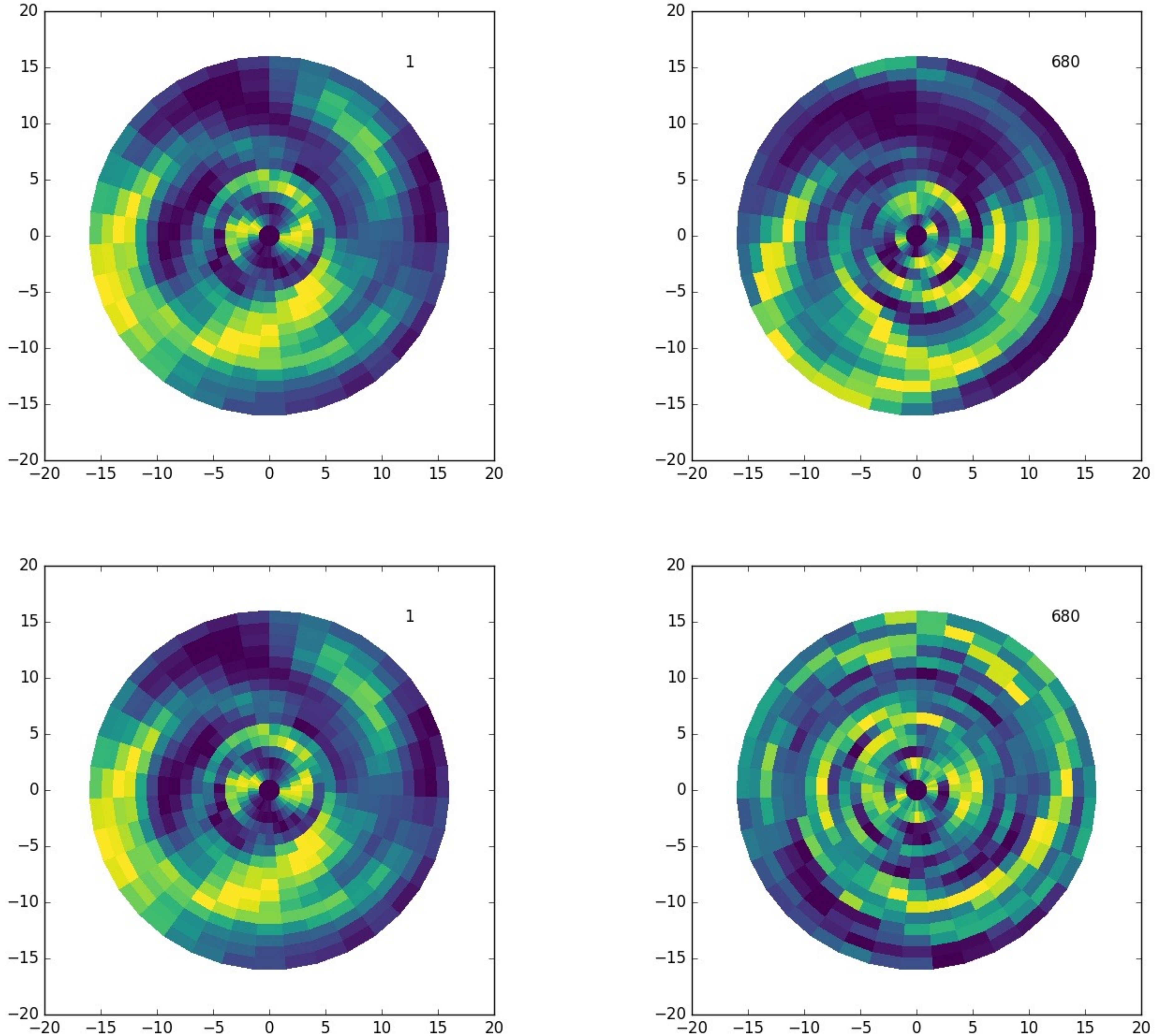


Linear scale normalised between [0:1] at each ring

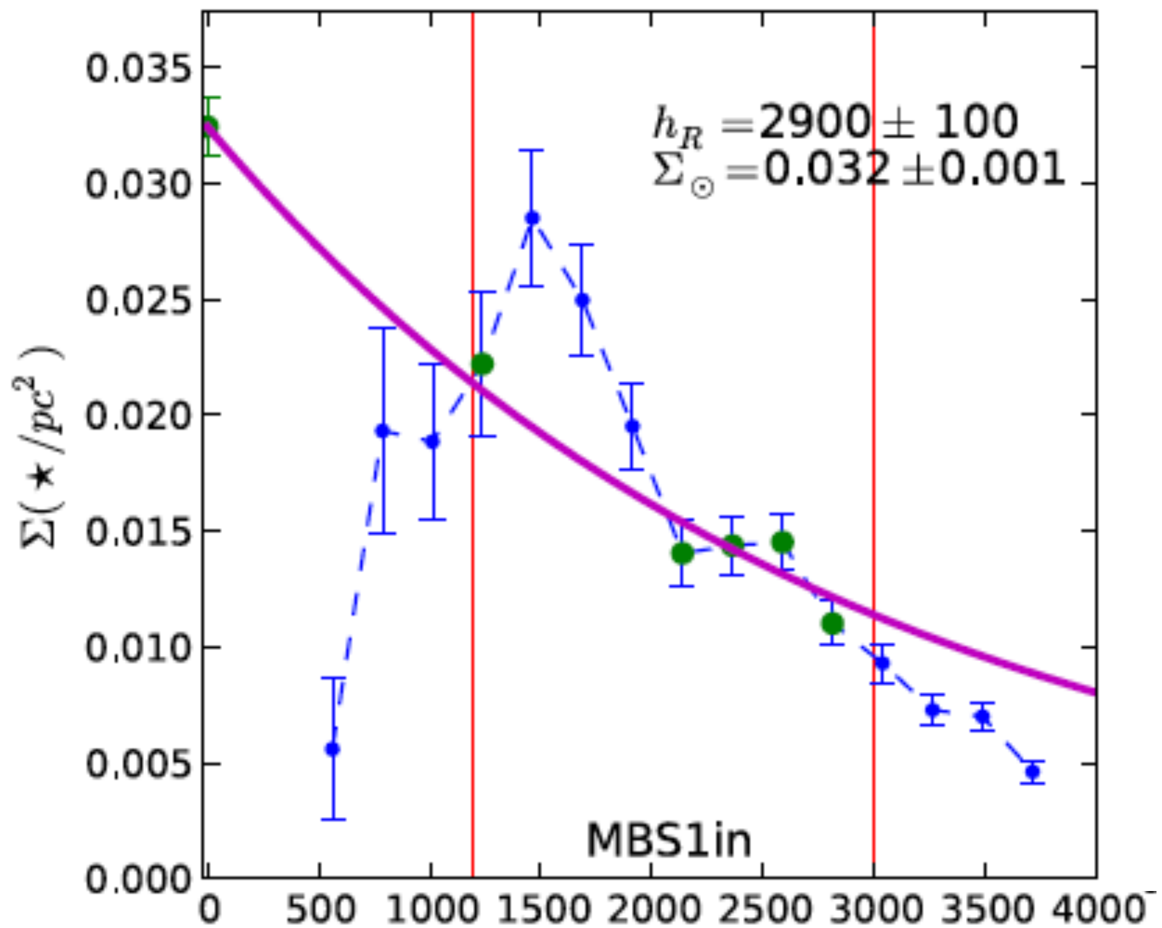
Results new model: comparison between stars and SFR

SFR

Stars

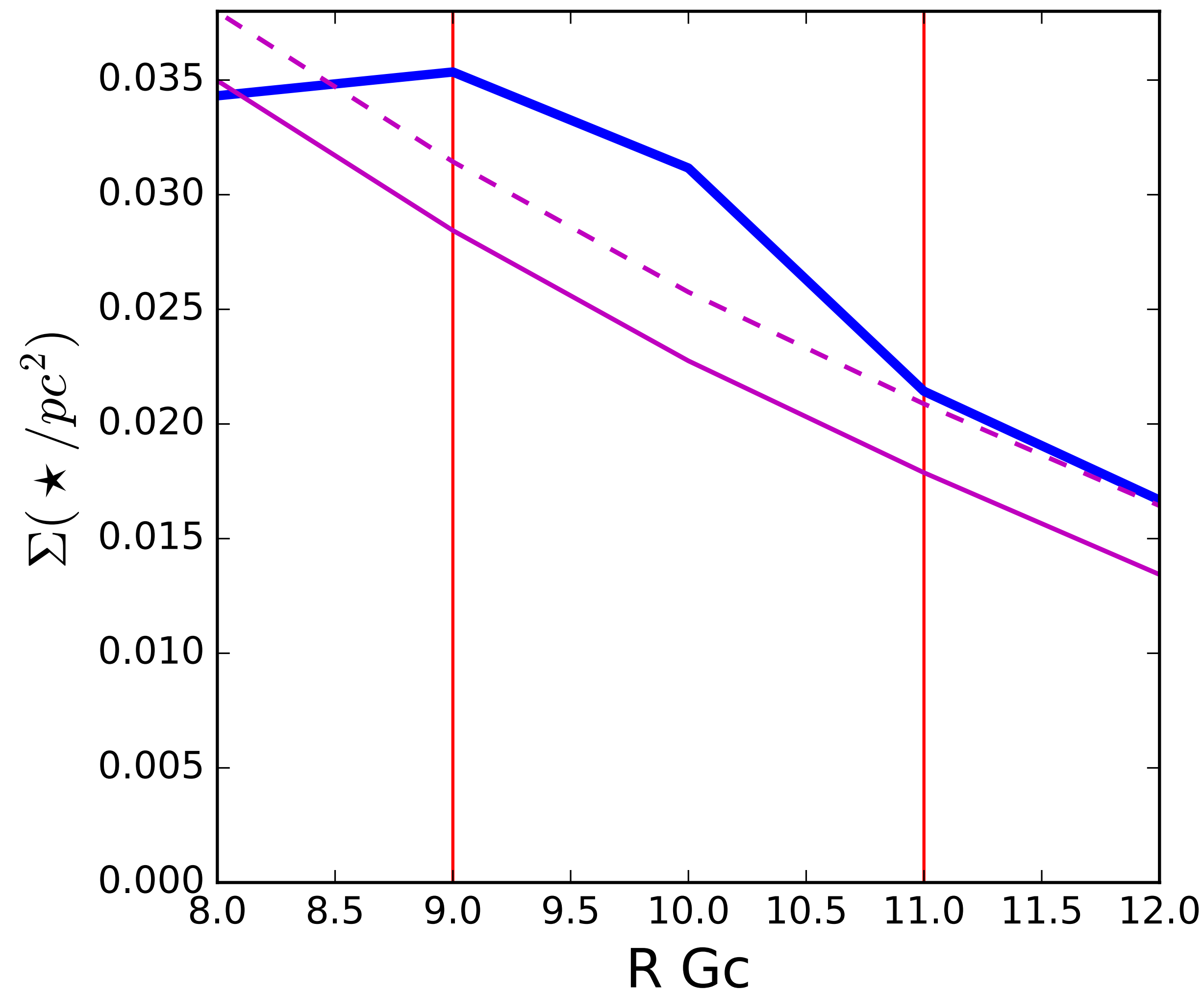


Results new model:
comparison with observational data



Stellar overdensity observed in "A" stars in the direction of the Perseus arm (beam in ~ 5 deg)

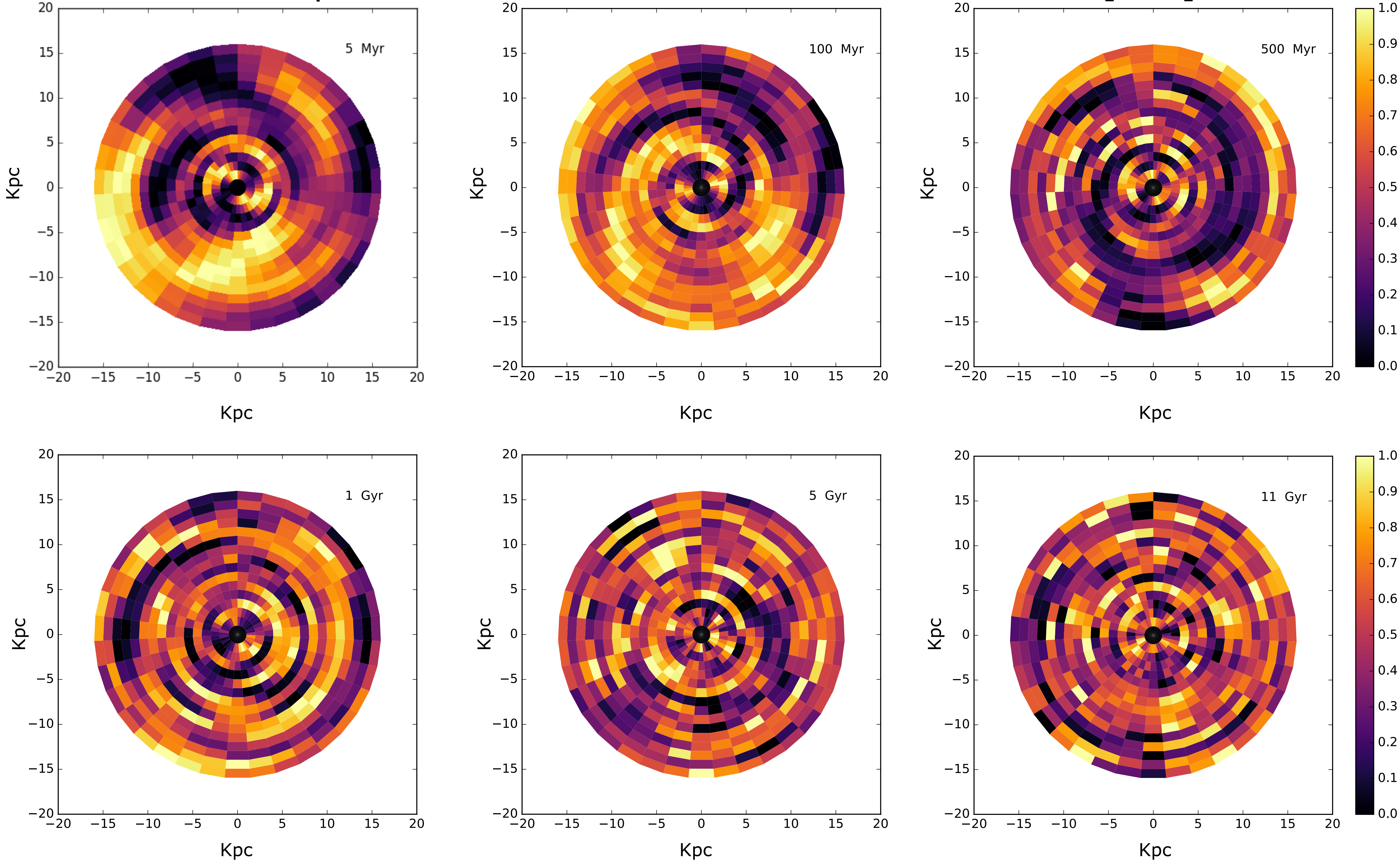
Moguio+15



Model results:
Stars formed in the last 600Myr (lifetime of A star) in a single azimuth bin (10deg)

Results new model: [O/H]

Comparison at different time of the evolution of the [O/H]



The [O/H] is normalised between [0:1] at each ring

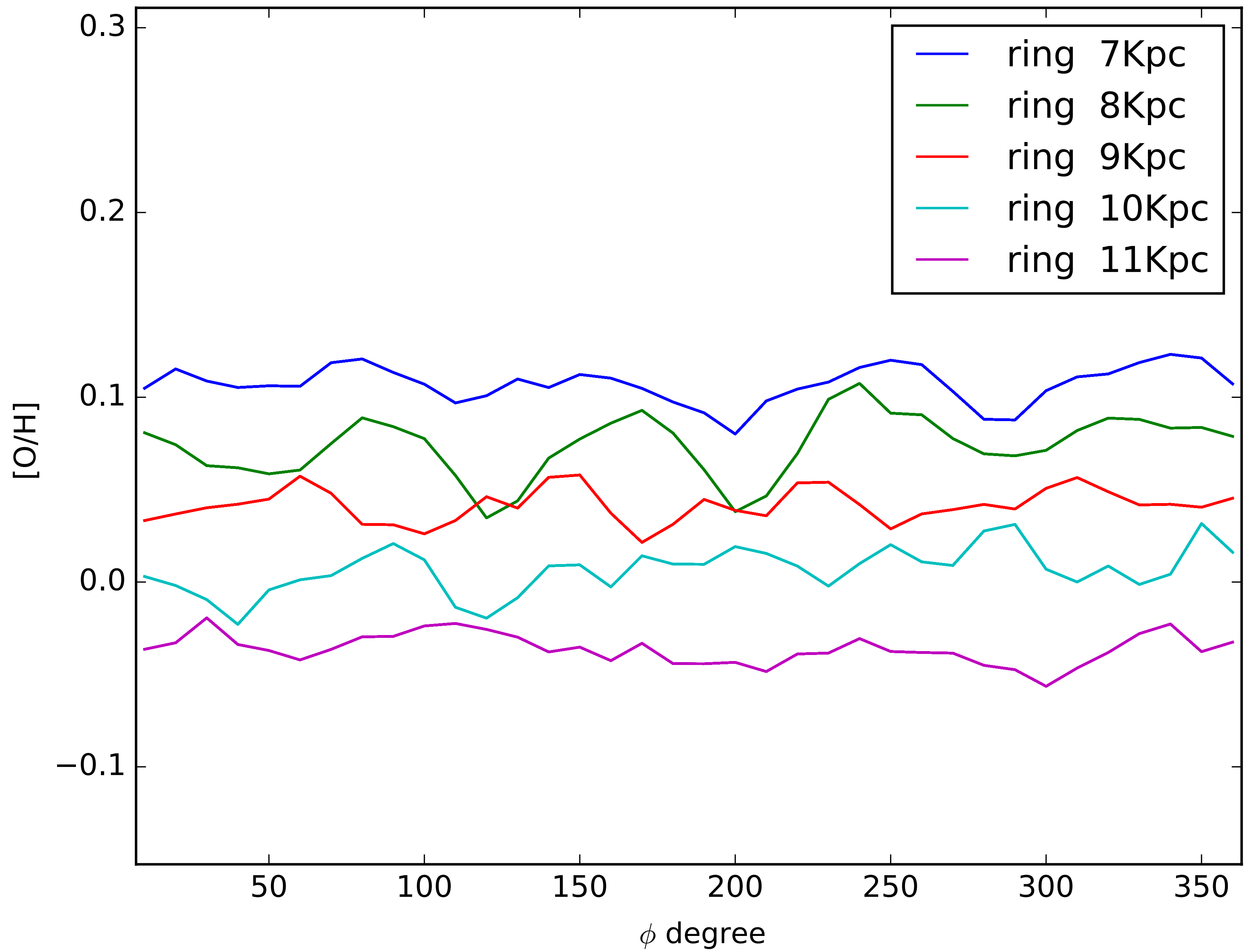
Results new model:

Azimuthal variations for a single time-step

Each line shows the model results at the present time depending to different azimuth angle.

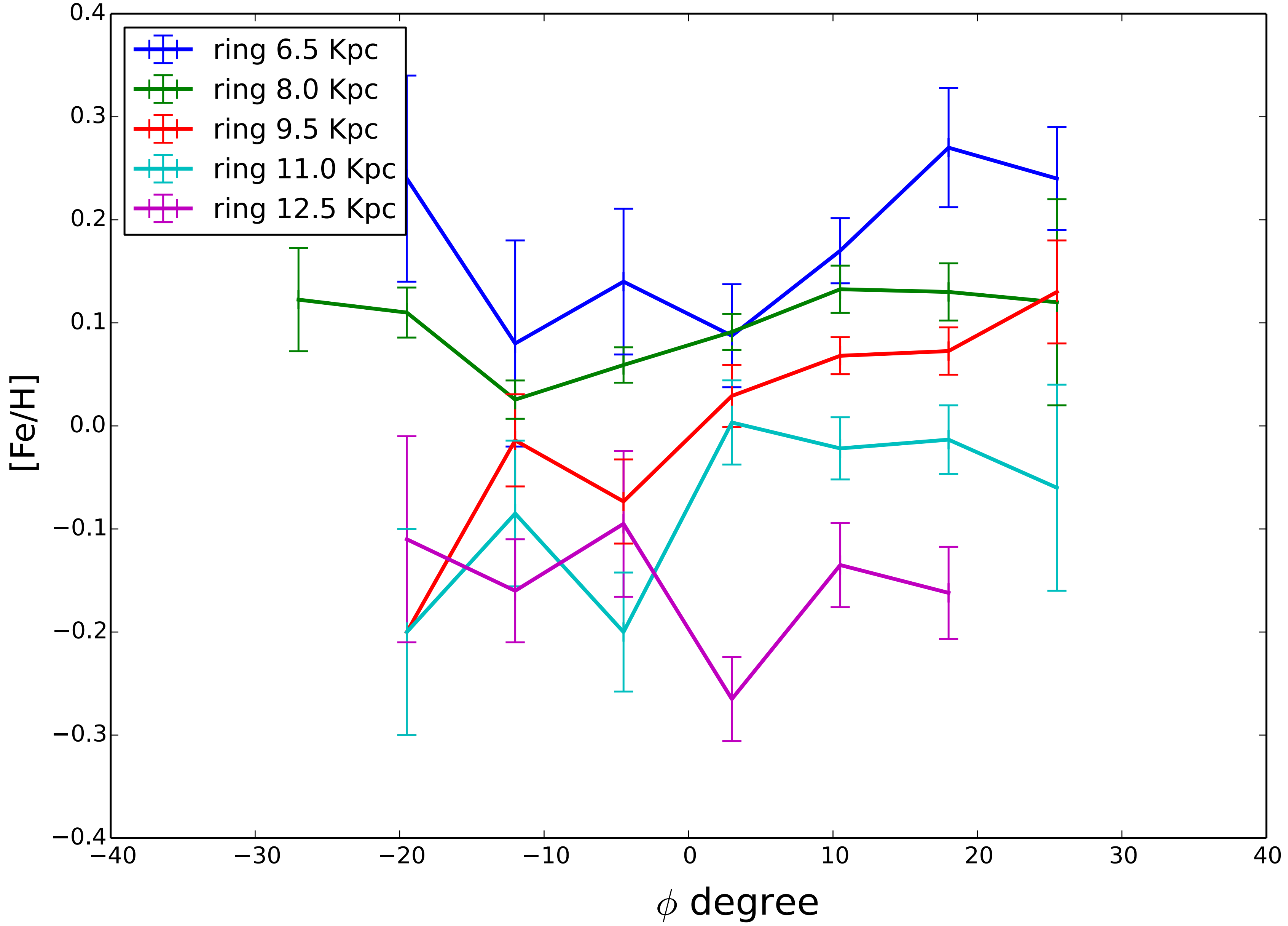
From the results of this model, we cannot associate to a GC radius a single value of [O/H].
Stars born 2 Kpc away at the present time can share the same [O/H].

They can also have larger difference greater than 0.1 dex



Results new model:

Comparison with the data

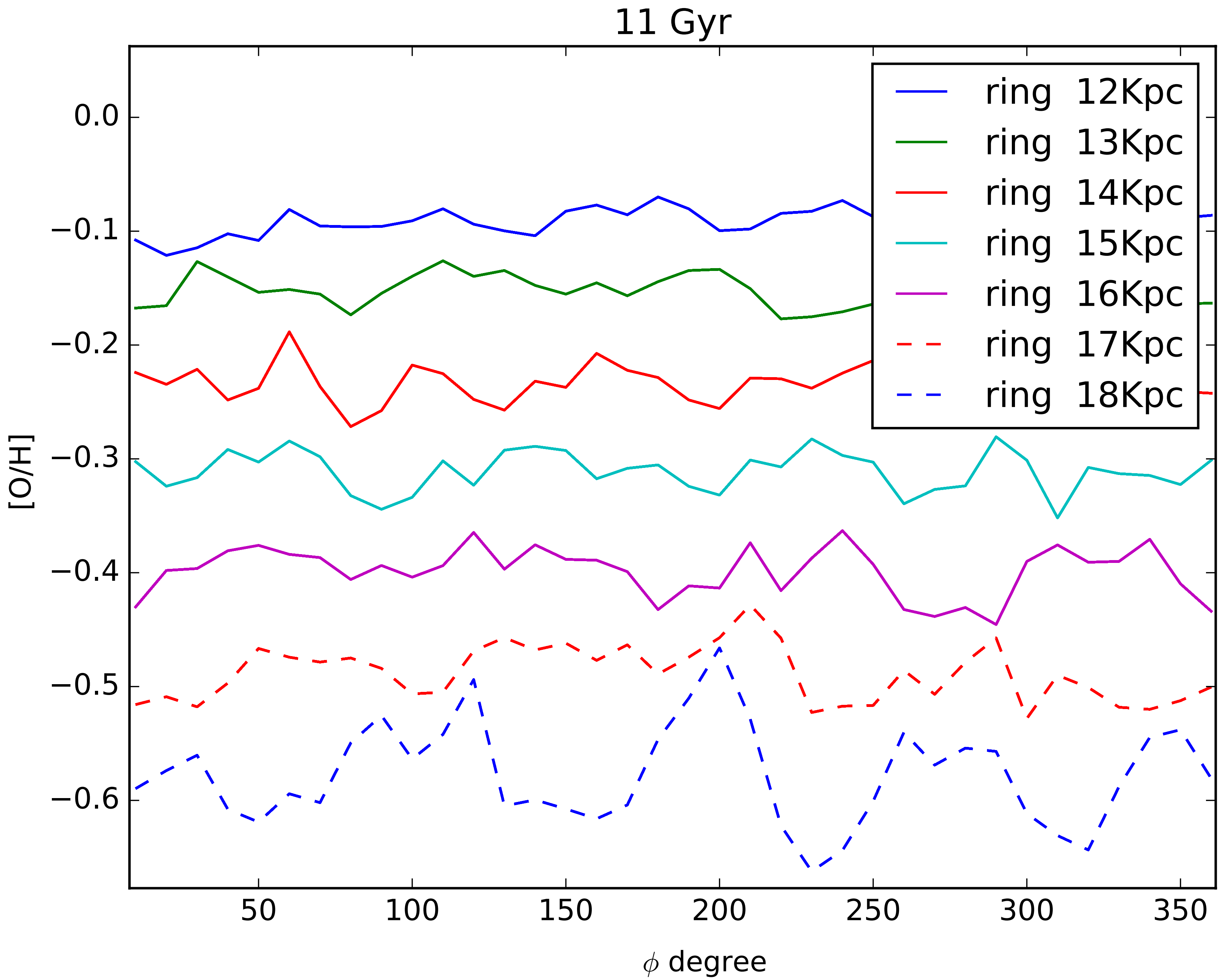


Results new model:

Azimuthal variations in the outskirt of the Galaxy

Each line shows the mode
results a 11 Gyr dependin
to different azimuth angle.

The model predict large
variation in [O/H] in th
outskirt of the Galaxy.

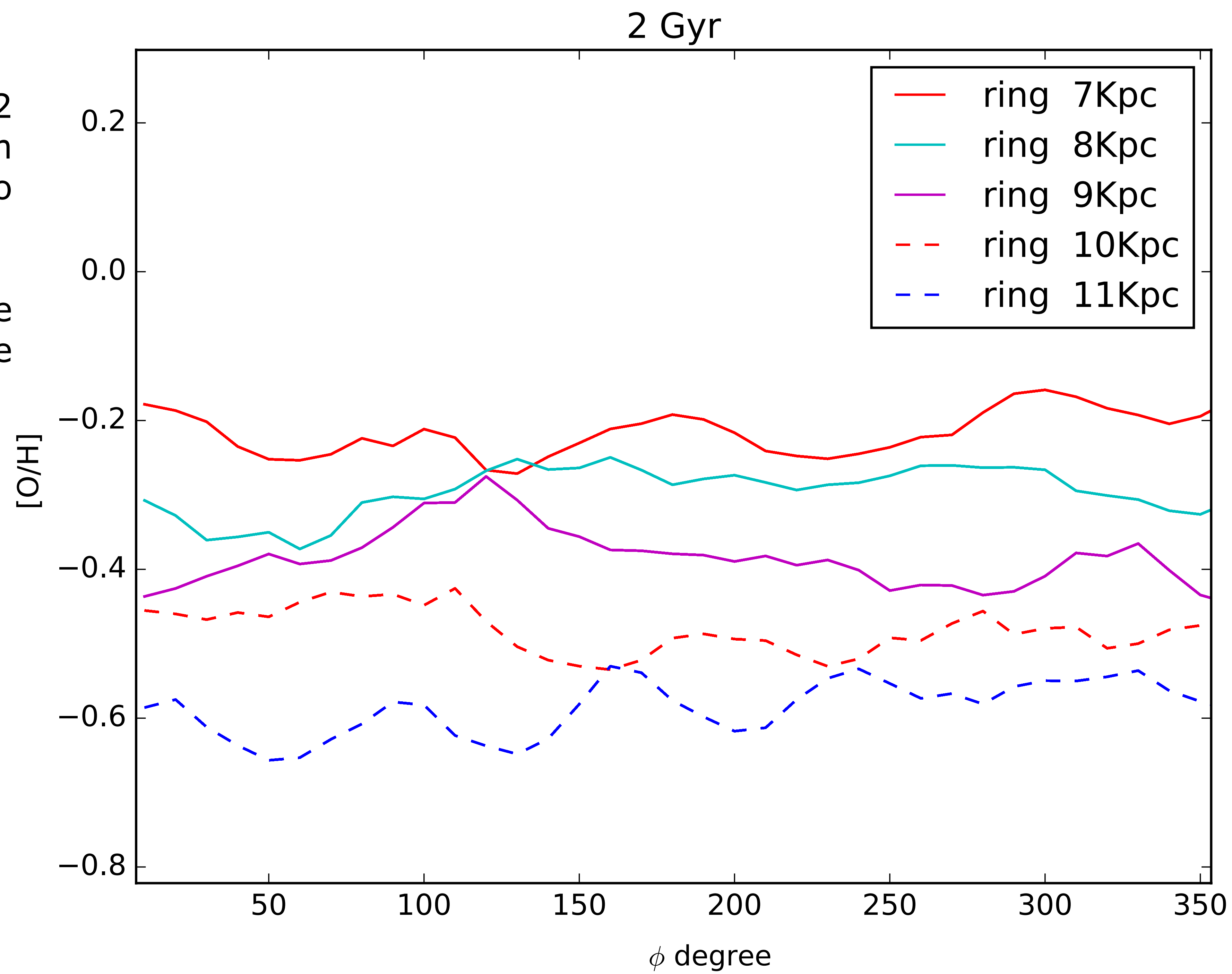


Results new model:

Azimuthal variations 10 Gyr ago

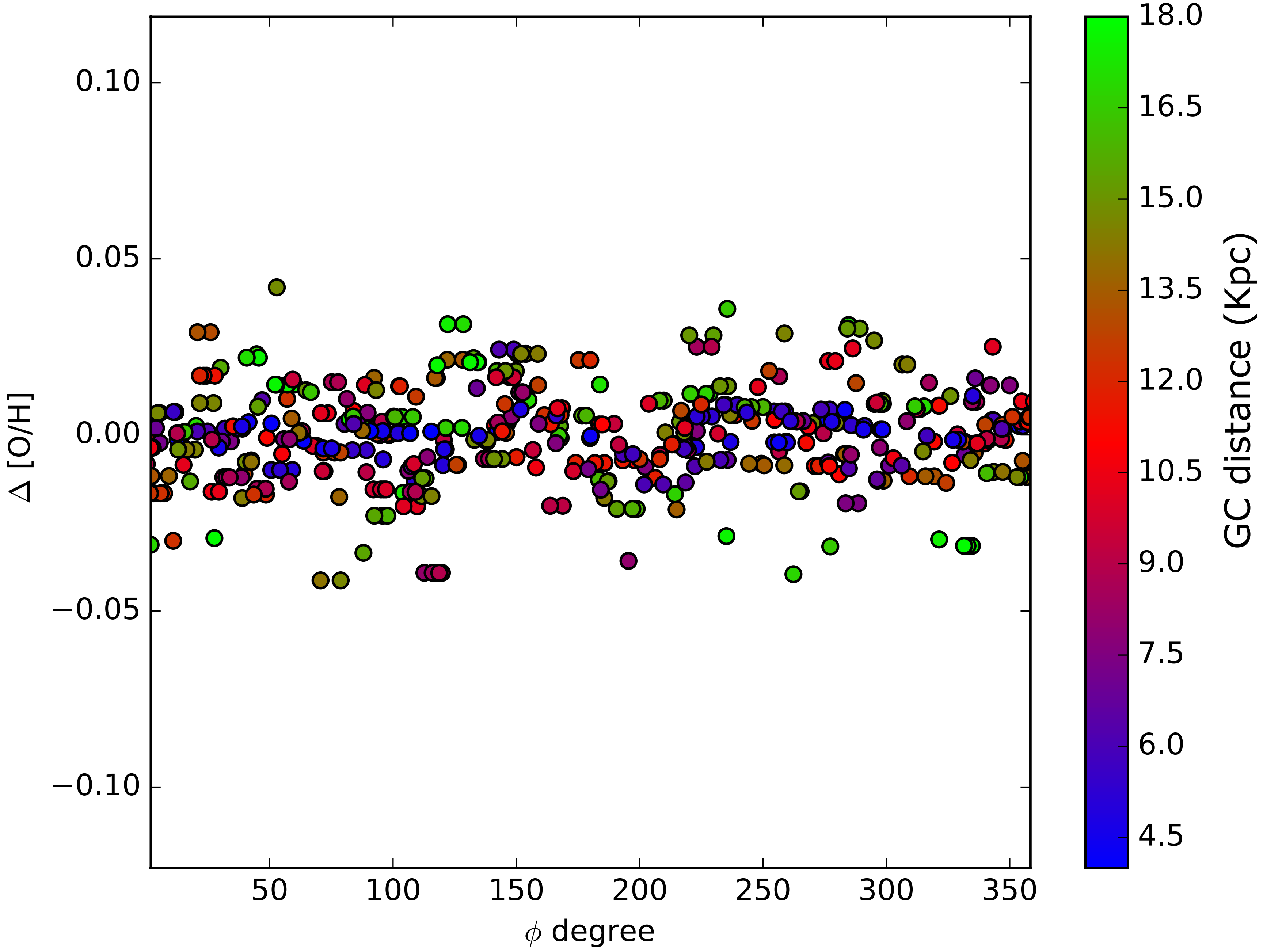
Dispersion of the order of 0.2 - 0.3 dex is expected from this model and possibly up to 4 Kpc of uncertainty.

Note that as expected the dispersion is larger in the outskirt of the Galaxy.



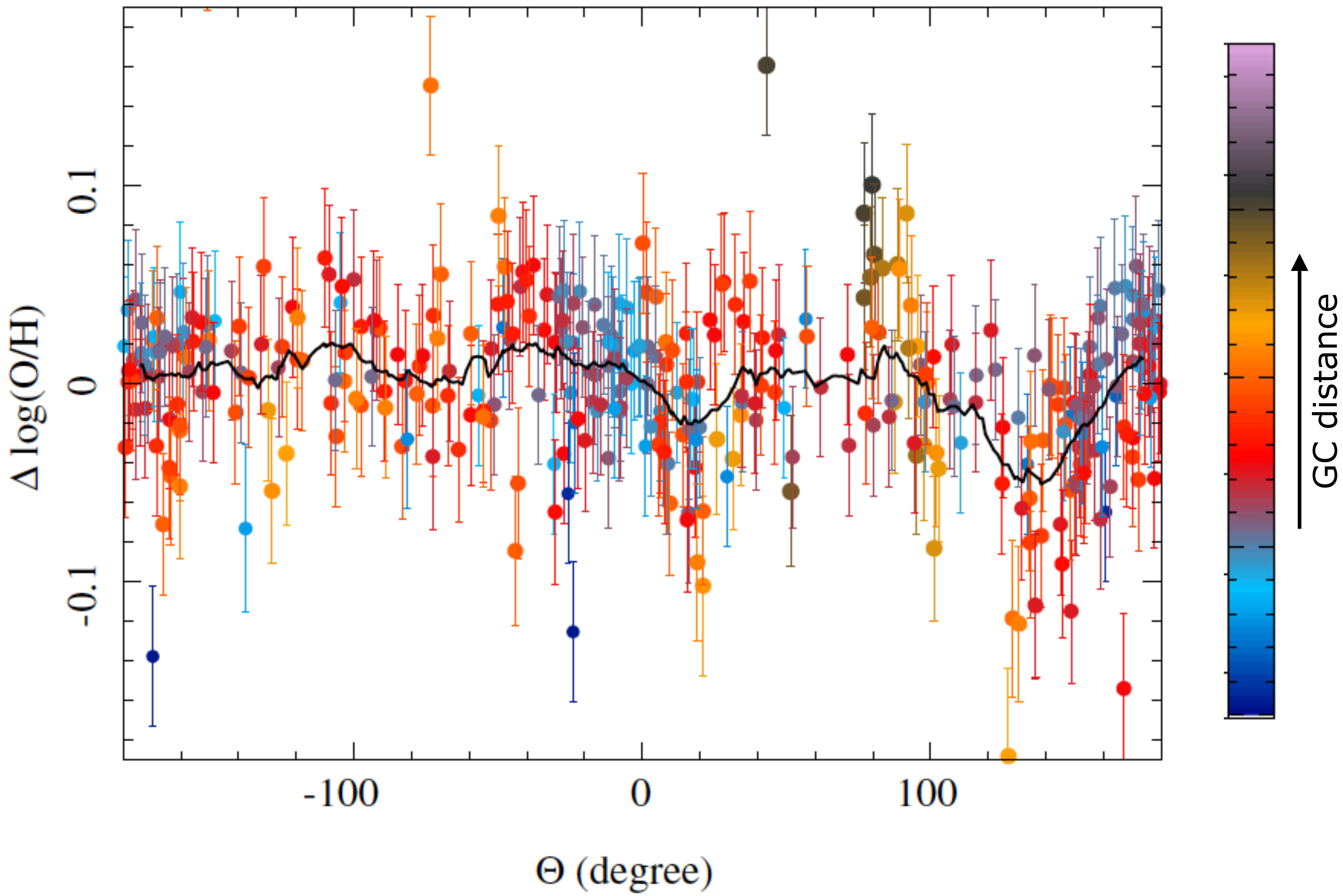
Results new model:

Azimuthal distribution of the residual of the oxygen abundance after subtracting the average radial gradient.



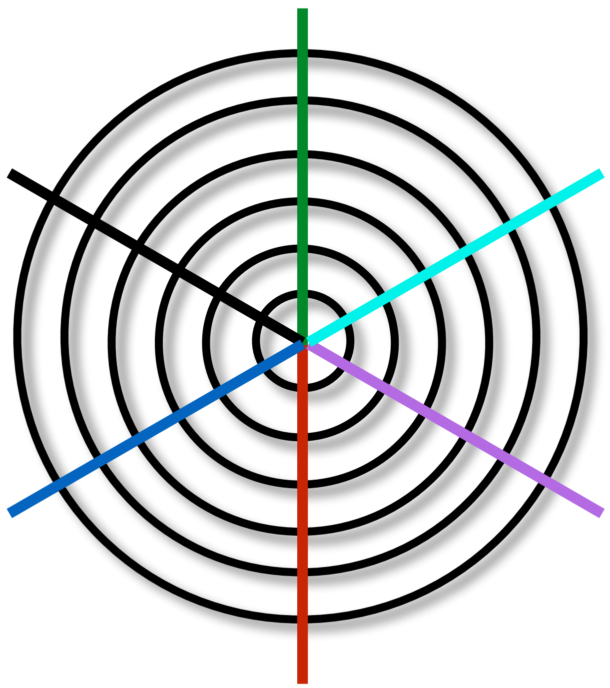
Azimuthal variation - [O/H]

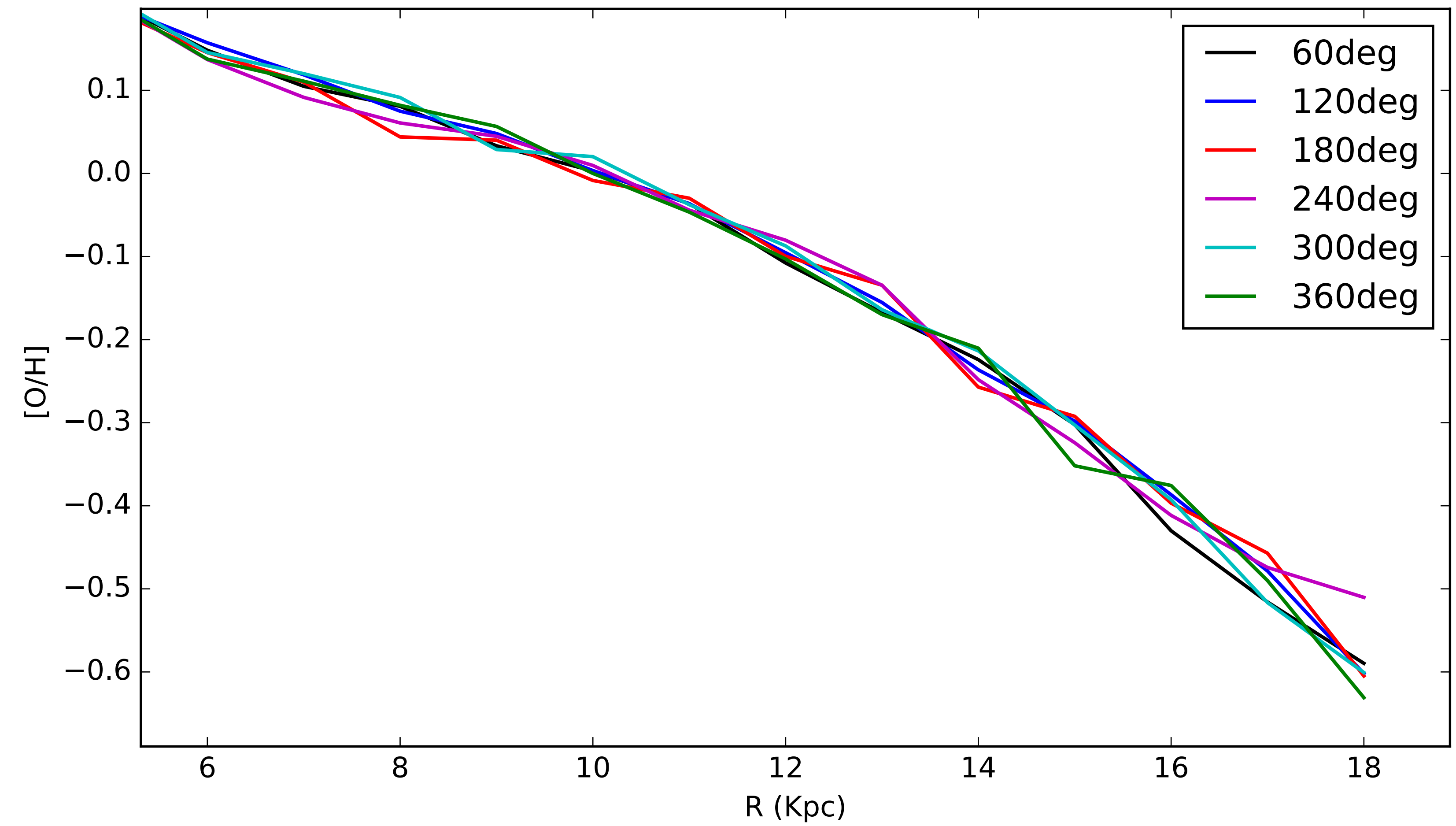
Sánchez+15
Muse data NGC 6754

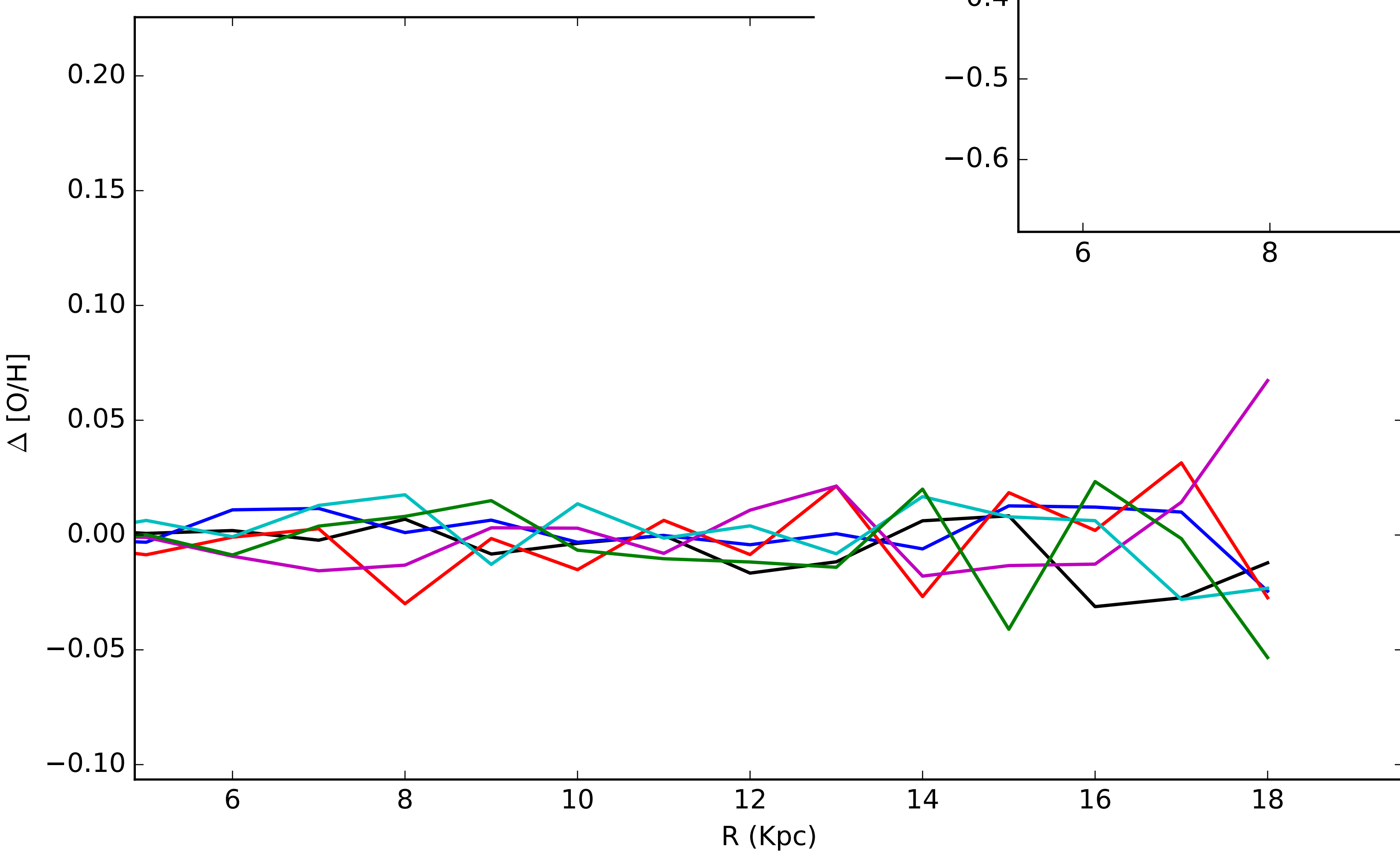


Azimuthal distribution of the residual of the oxygen abundance
for the individual HII regions after subtracting the average radial gradient.

Gradient of O/H vs R for different azimuth





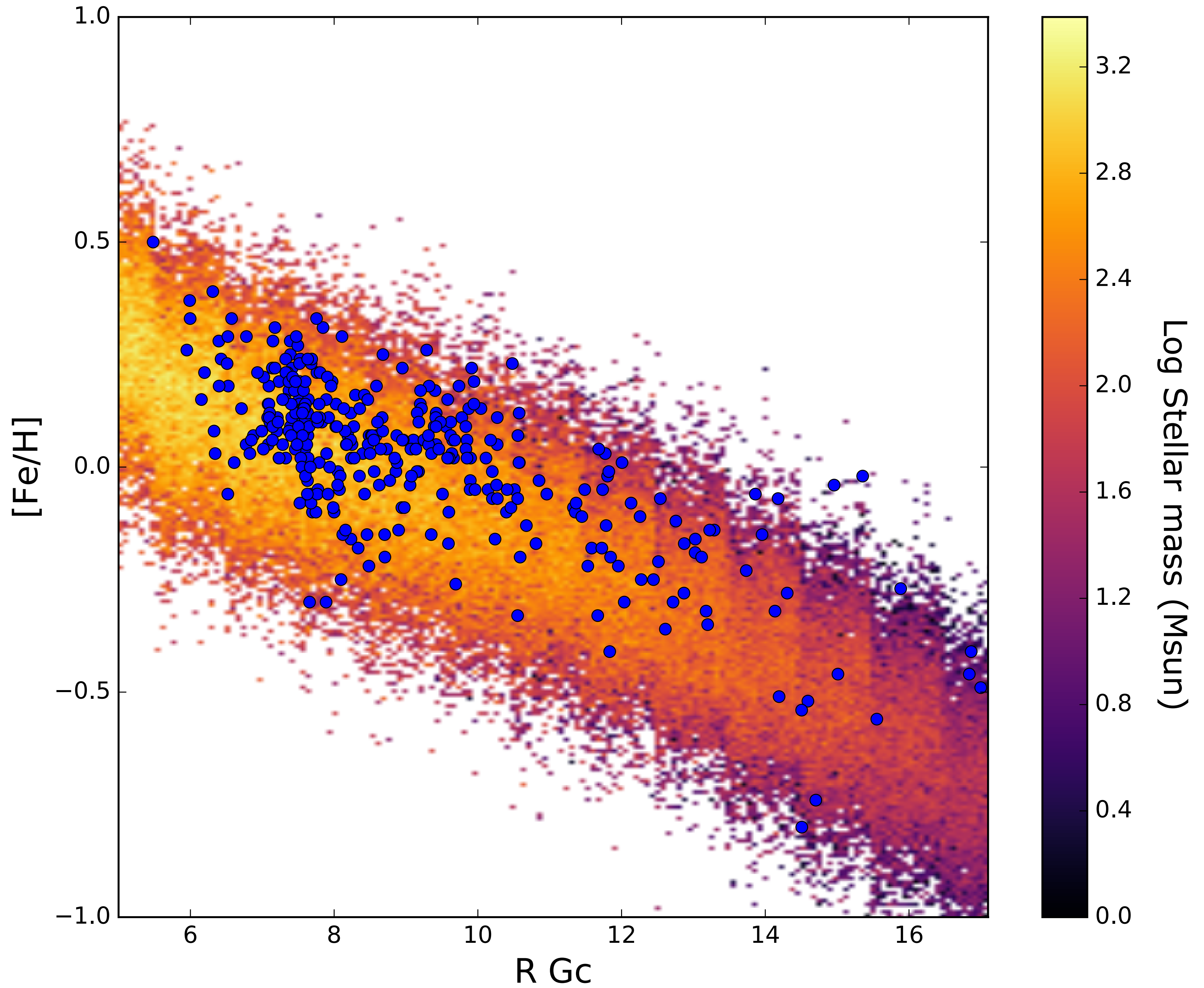


residual of the oxygen abundance after subtracting the average radial gradient

Gradient of Fe/H vs R now

The prediction of our model for iron gradient at the present time.

We consider the variation in the last 200 Myr and we add to the variation due to the azimuthal perturbation an observational error of 0.1 dex.



● Cepheids from Genovali+14

Conclusions

The model enable us to predict the variation in the chemical abundances due to patchy star formation, induced by density fluctuations.
The model produces promising results compared to the data:

- Variations in the stellar density vs GC distance
- [O/H] vs azimuth at different GC distance
- Azimuthal distribution of the residual of the oxygen abundance

and have some predictions as:

- Larger azimuthal fluctuations in the outskirt of the Galaxy
- Variation in the radial gradient for different azimuth

The predictions show a general agreement with the data, however the amplitude of the variations seems to be smaller. Possible solution/steps forward:

- Gas inflows/outflows
- Different dependence of the SF law to the fluctuations