MAPPING THE GALACTIC HABITABILE ZONE

G. Murante – INAF Ts
G. Vladilo – INAF Ts
L. Silva – INAF Ts
F. Matteucci – Univ Ts
P. Monaco – Univ Ts
E. Spitoni – Univ. Ts
…and many others….

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Aim: identify galactic regions where complex life could dwell

- Currently: academic interest. SETI?
- In the future: help to identify suitable objects promising for biomarker searches?
- Why complex: …even "life as we know it" can be found in very unsuspected places…. spoiling our starting guesses…

The Galactic Habitable Zone

Question: are there specific places where rocky planets with complex life can be found in the Galaxy? … this is nothing but the Drake equation!!

Probability of surviving to dangerous astrophysical events P_{surv}

$$N = R^* \cdot f_p \cdot N_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

- N: Number of extraterrestrial civilizations
- R^*: Star formation
- f_p: Fraction of stars with planets
- N_e: Average number of habitable planets per stellar system
- f_l: Fraction of inhabited planets
- f_i: Inhabited planets with intelligent life
- f_c: Civilizations able to communicate
- L: Duration of civilizations

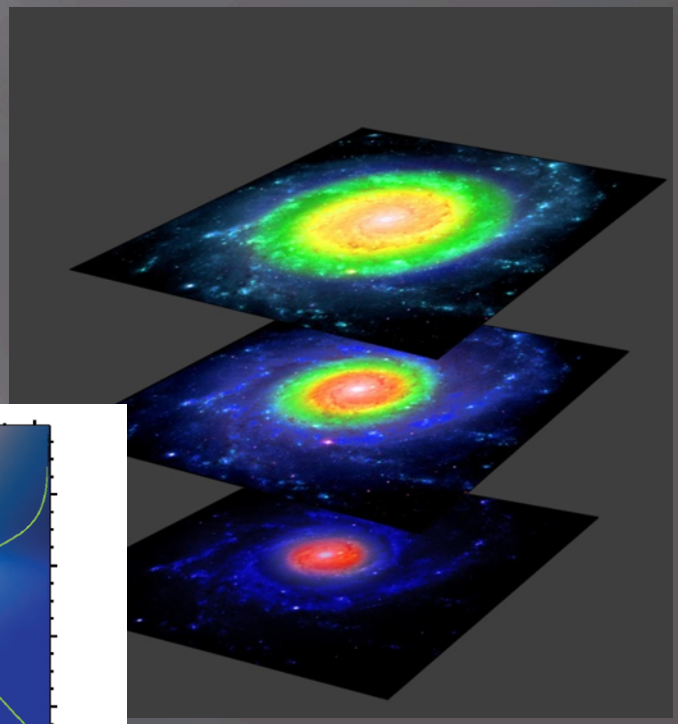
Planet probability P_{plan}

Evolution probability P_{evo}

The Galactic Habitable Zone – "classical computation"

Gonzalez+ 2001, Lineweaver+ 2004: $P_{life} = P_{plan} \cdot P_{evo} \cdot P_{surv}$

- P_{plan}: simple hypotesis on **metallicity dependance** for planets
- P_{evo}: simple hypothesis on **stellar ages** and **time needed** for the evolution
- P_{surv}: simple hypothesis on **stellar density** and **Supernovae danger factor**



From simple to sophisticated chemical evolution models of the Galaxy used

See talk by Emanuele Spitoni for details!

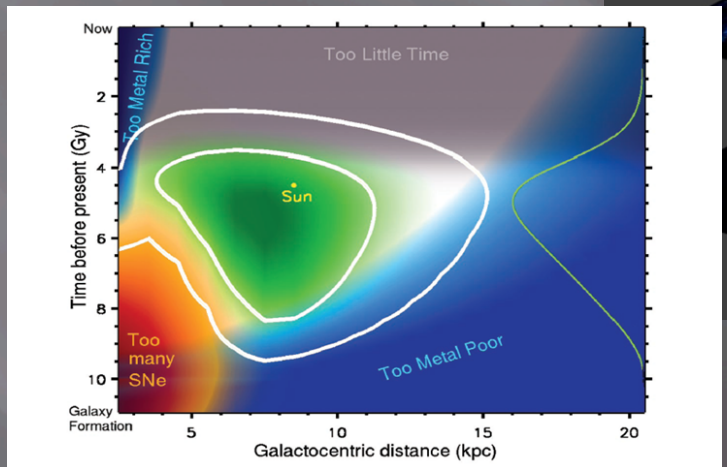


Fig. 3. The GHZ in the disk of the Milky Way based on the star formation rate, metallicity (blue), sufficient time for evolution (gray), and freedom from life-extinguishing supernova explosions (red). The white contours encompass 68% (inner) and 95% (outer) of the origins of stars with the highest potential to be harboring complex life today. The green line on the right is the age distribution of complex life and is obtained by integrating $P_{GHZ}(r, t)$ over r.

The Galactic Habitable Zone …now mapping it……

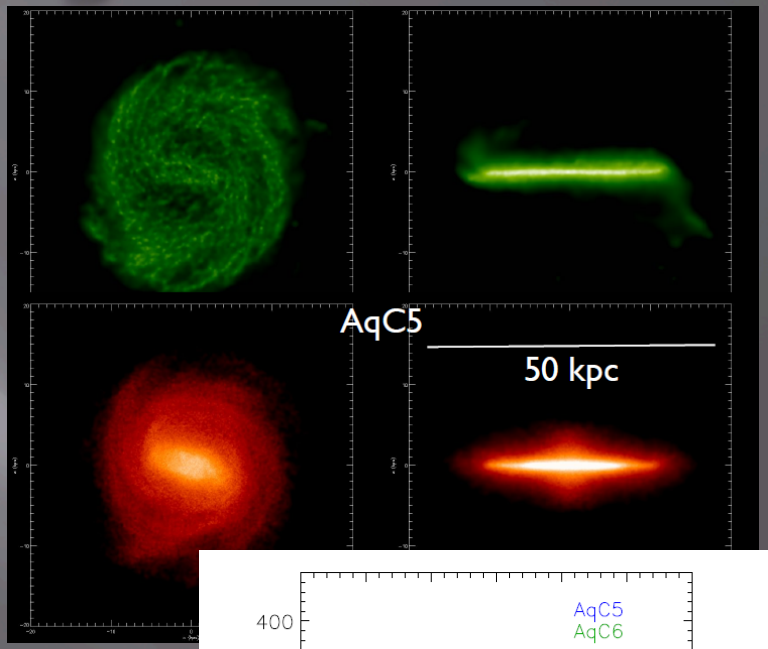
We now have realistic numerical simulations of disk galaxies (NOT OF THE MILKY WAY…..)

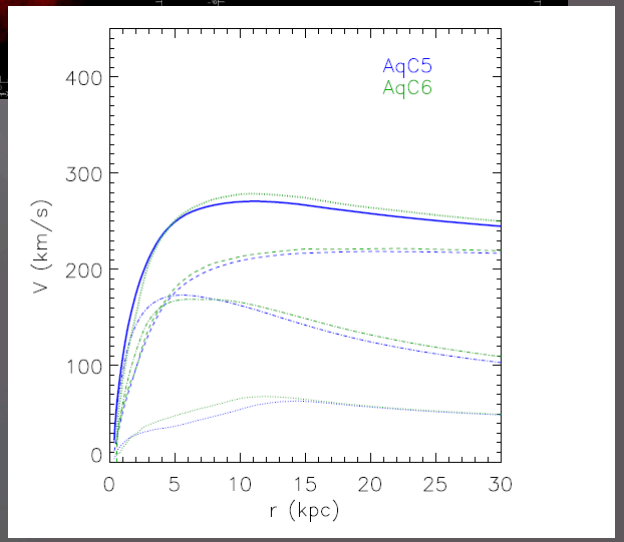
Details long complicated and boring – ask me if you want….

We produced spatial maps of the Galactic Habitable Zone, using the kinematic information we have in the simulation on the stellar particles (now and in the past)

Note that a stellar particle is a Single Stellar Population (10^5 solar masses)

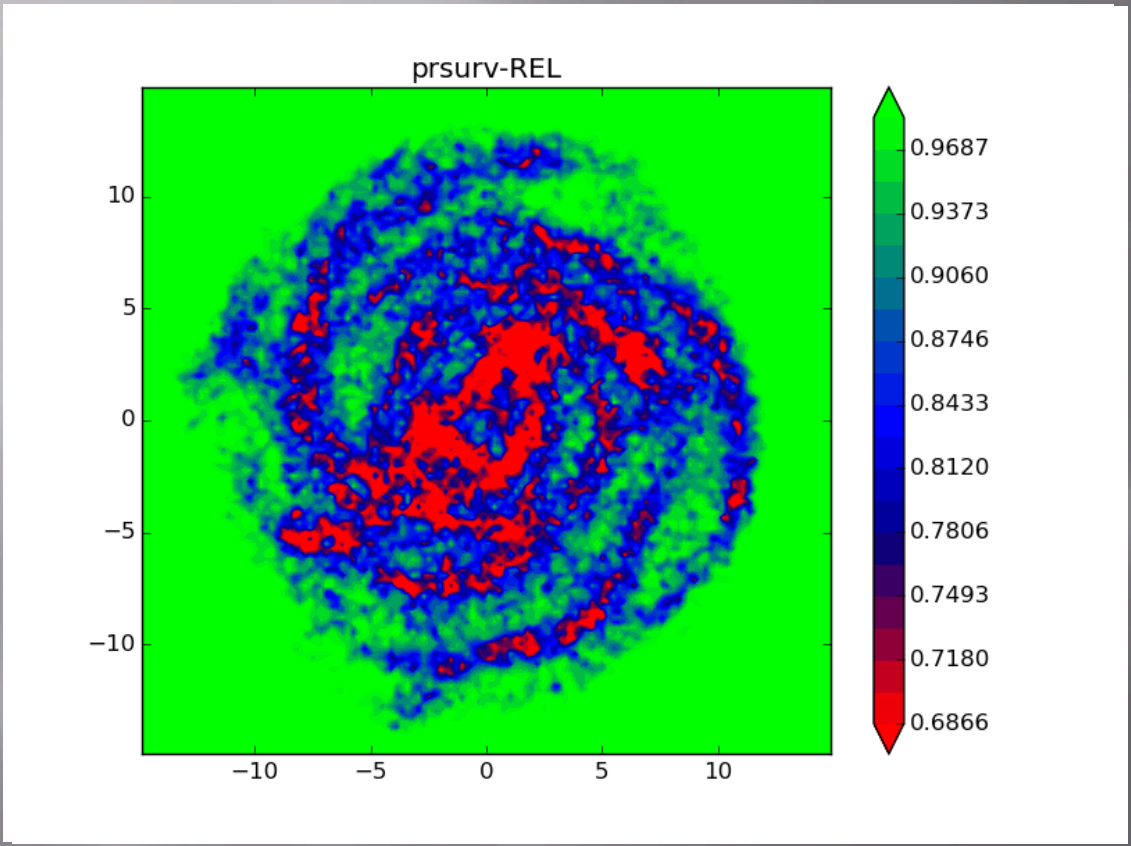
Focus on Supernovae Danger Factor (P_{evo}, P_{plan} unchanged)





Murante+ 2015

Reproducing Lineweaver 2004



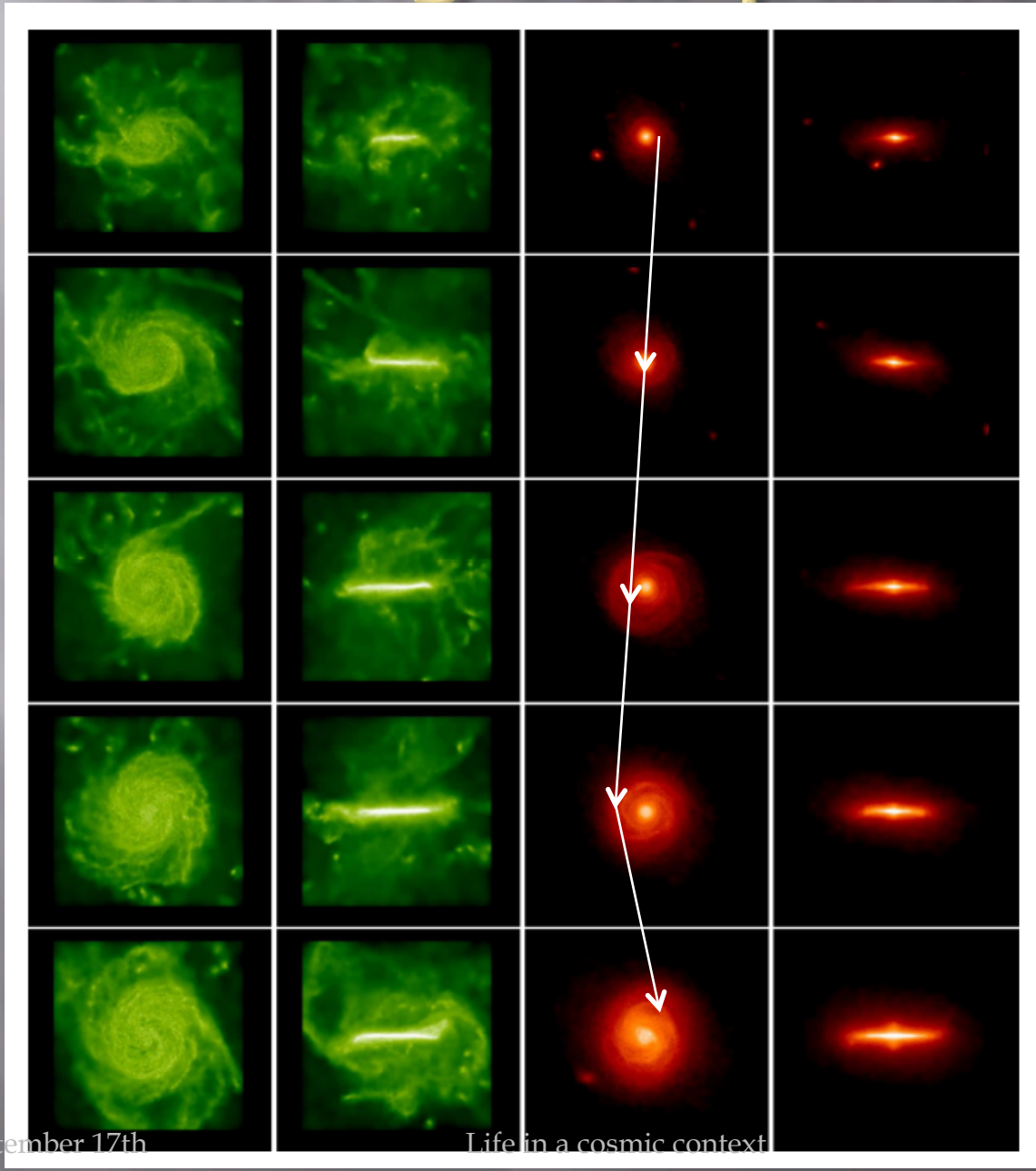
From the simulation:
metallicity and stellar age maps

…we can apply exactly the same prescription of L04..

…but we need to
FOLLOW BACK the
stellar particles in the history!!

(from the bachelor work of M. Facco)

Chasing star particles

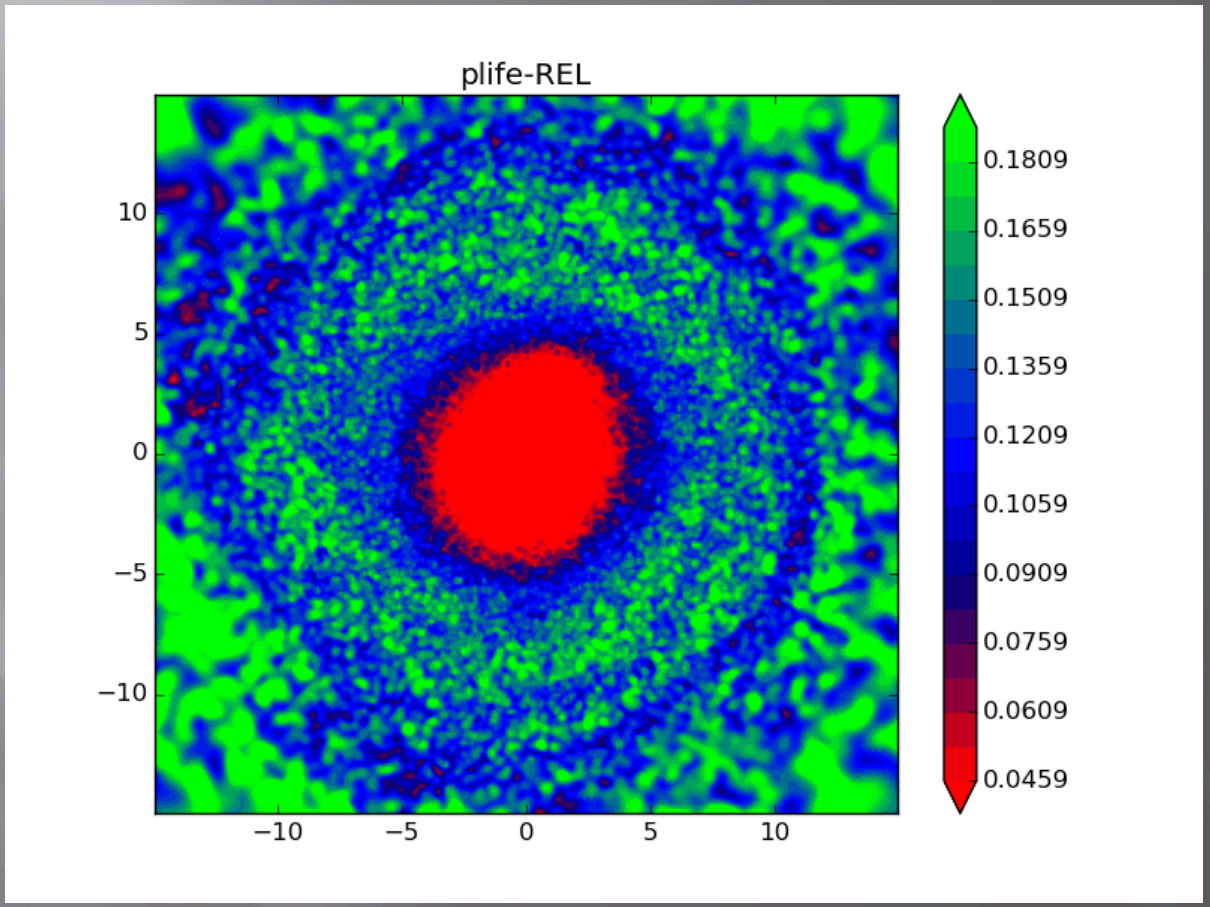


At each epoch, we have stellar density, gas density, instantaneous SFR, etc…

Setting the epoch till which to chase back the stars means setting the maximum sterilization epoch

Reproducing Lineweaver 2004

"solar" density from simulation



Improving the Supernovae danger factor

Having the age and IMF of each SSP, and the instantaneous SFR of the gas, we can calculate directly how many SNe explode in a ΔT

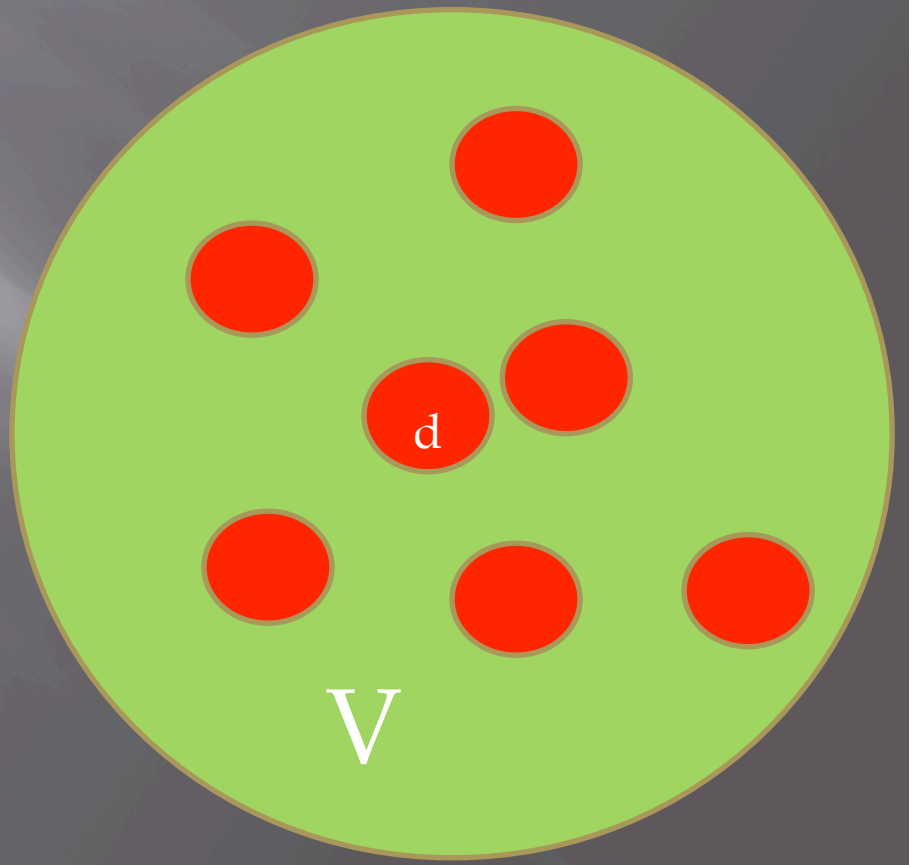
(SnII: IMF;
SnIa: Matteucci & Recchi 2001)

Assigning a volume V to each SSP, the danger factor will be: $DF = \sum \frac{d}{V}$

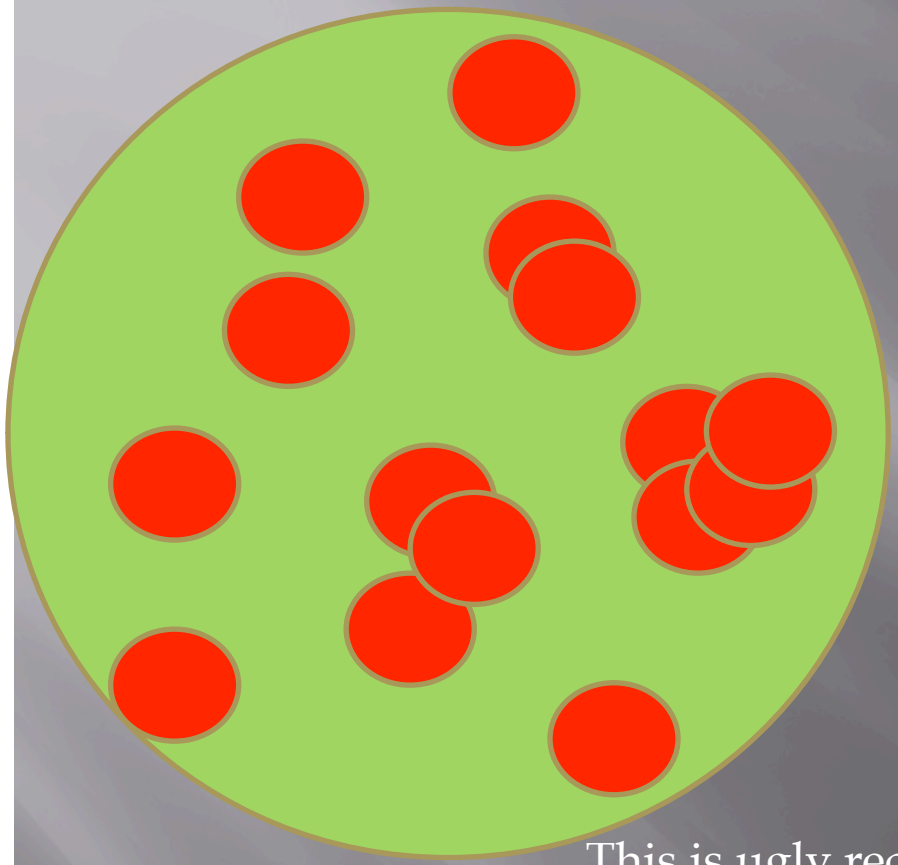
d is the volume sterilized by ONE SN

From literature: a sphere with radius 4-10 pc?

Set V, vary d….



But they can overlap…!



Important at high danger factor!

First SN has a voume V: $DF_1=d/V$

2nd has a probability to hit the first:

$DF_2 = (d/V)\,[(V-d)/V)]$

$= (d/V)(1-d/V)$

3rd, a probability to hit the first two:

$DF_3 = (d/V)\{(d/V)[1-(1-d/V)]\}$….

That is:

$$DF_n = \sum_{i=1}^{n} f(1)[1 - f(i-1)]$$

with $f(1)=x=d/V$, $f(0)=0$

This is ugly recursive (>10,000 Sne in one dense particle….]

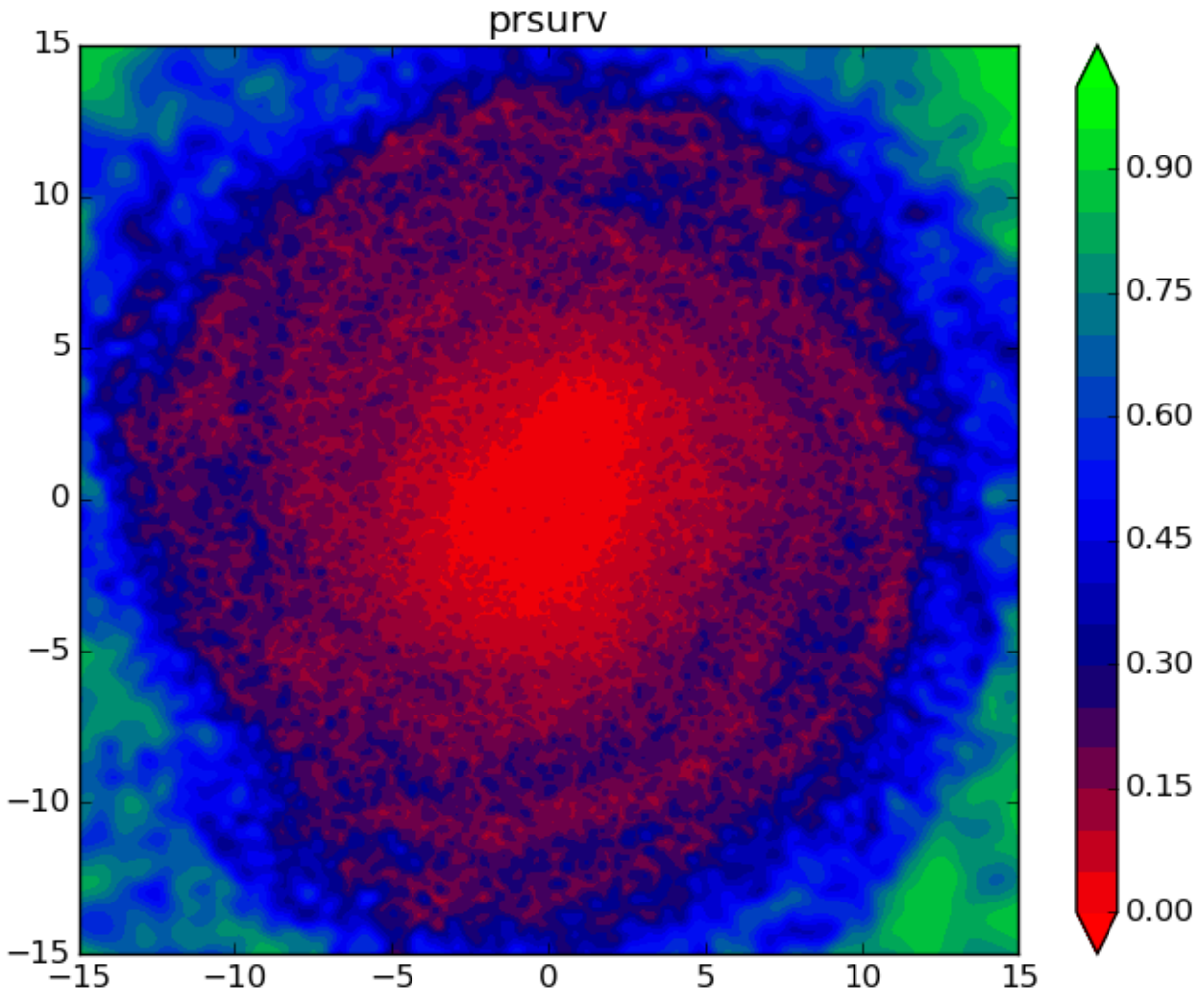
making some calculations: $DF_3 = 3x - 2x^2 + x^3$; $DF_4=4x - 3x^2 + 2x^3 - x^4$….

$$DF_n = \sum_{i=1}^{n}(n-i+1)(-1)^{i+1}x^i$$

…we are using this.

SNe survival probabilities maps

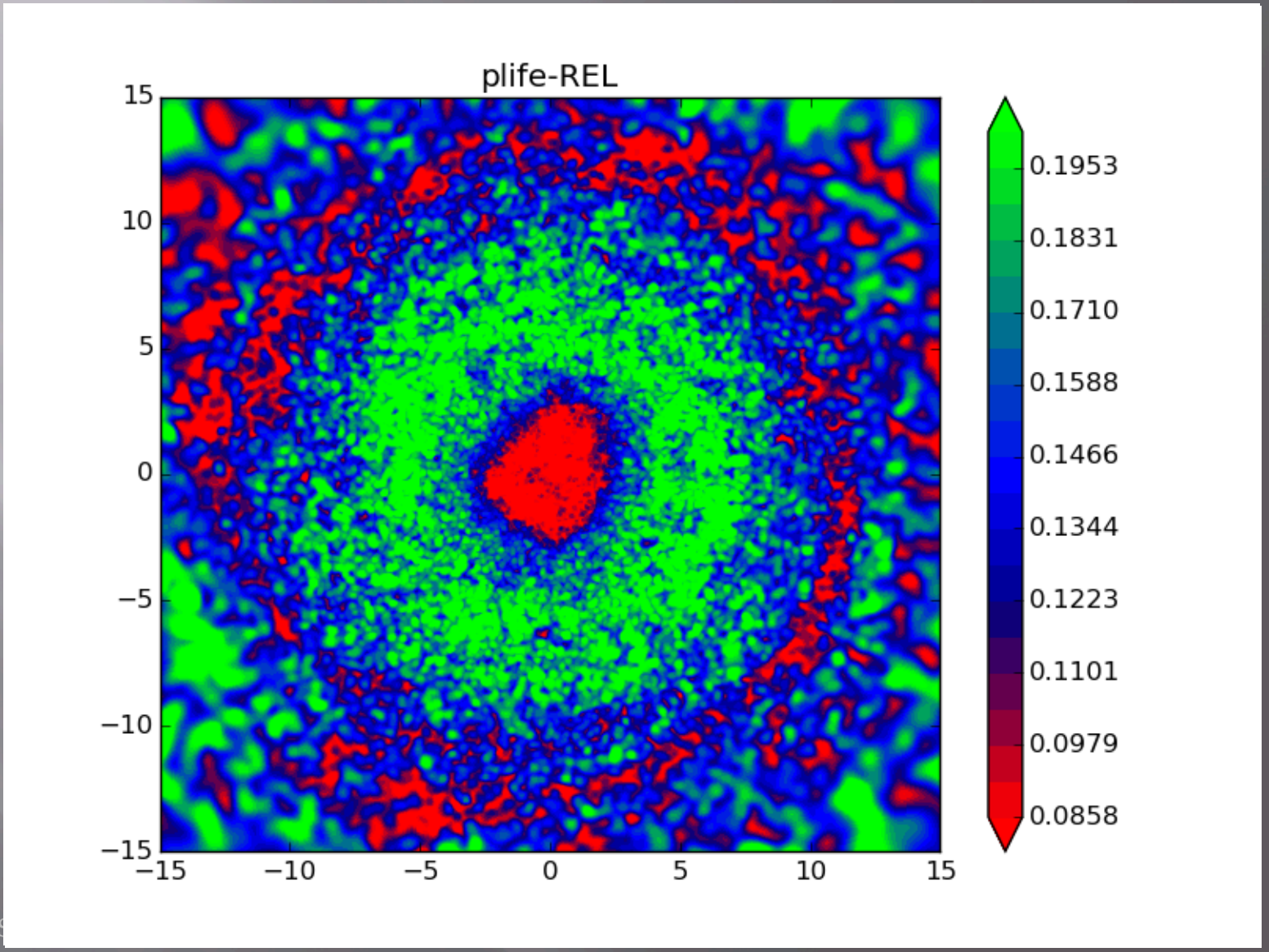
Varying d from 4pc to 12pc…



The map of the Galactic Habitable Zone

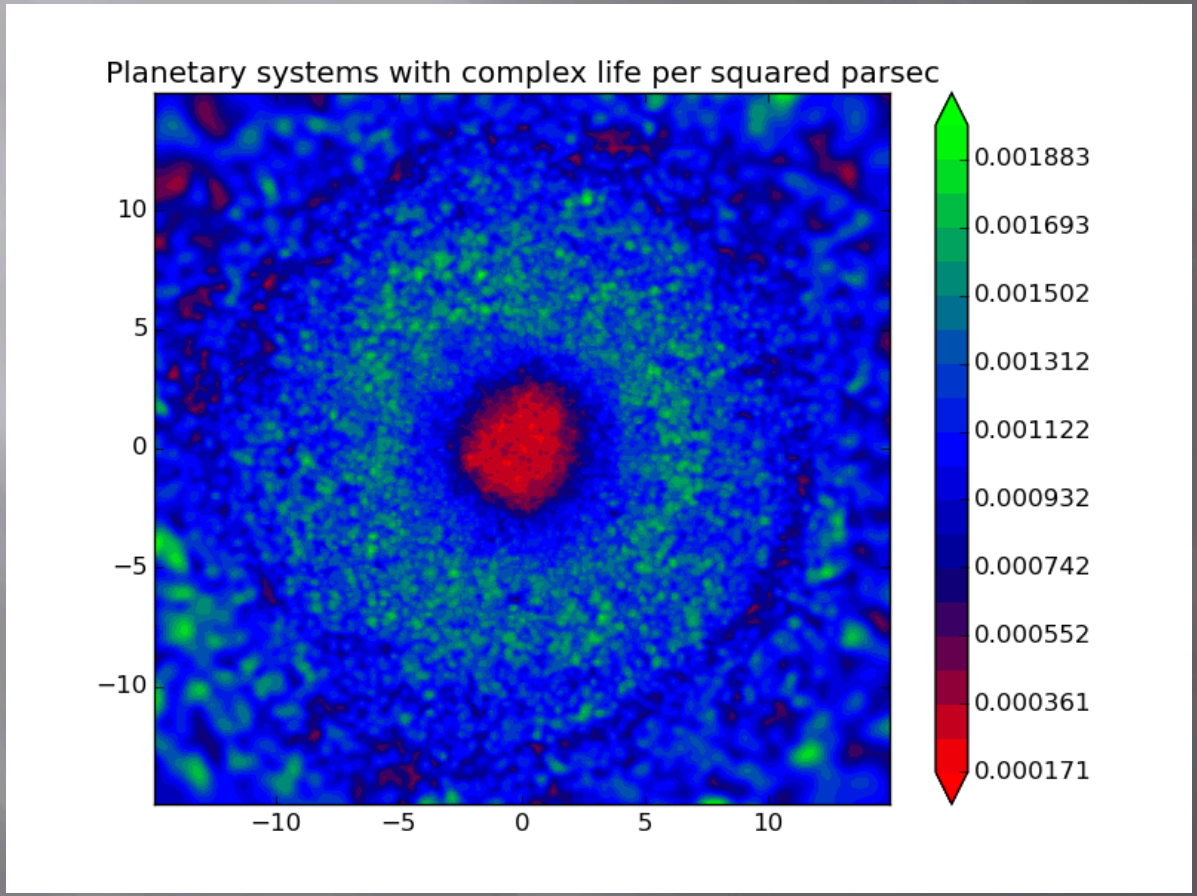
Evolutionary probability (I-04)

(d=8pc)



Number of stellar systems

Having the IMF, we can compute how many stellar system there are for each spectral class O, B, A… K, M and estimate the number of stellar systems per squared pc (binaries not accounted for, here!)

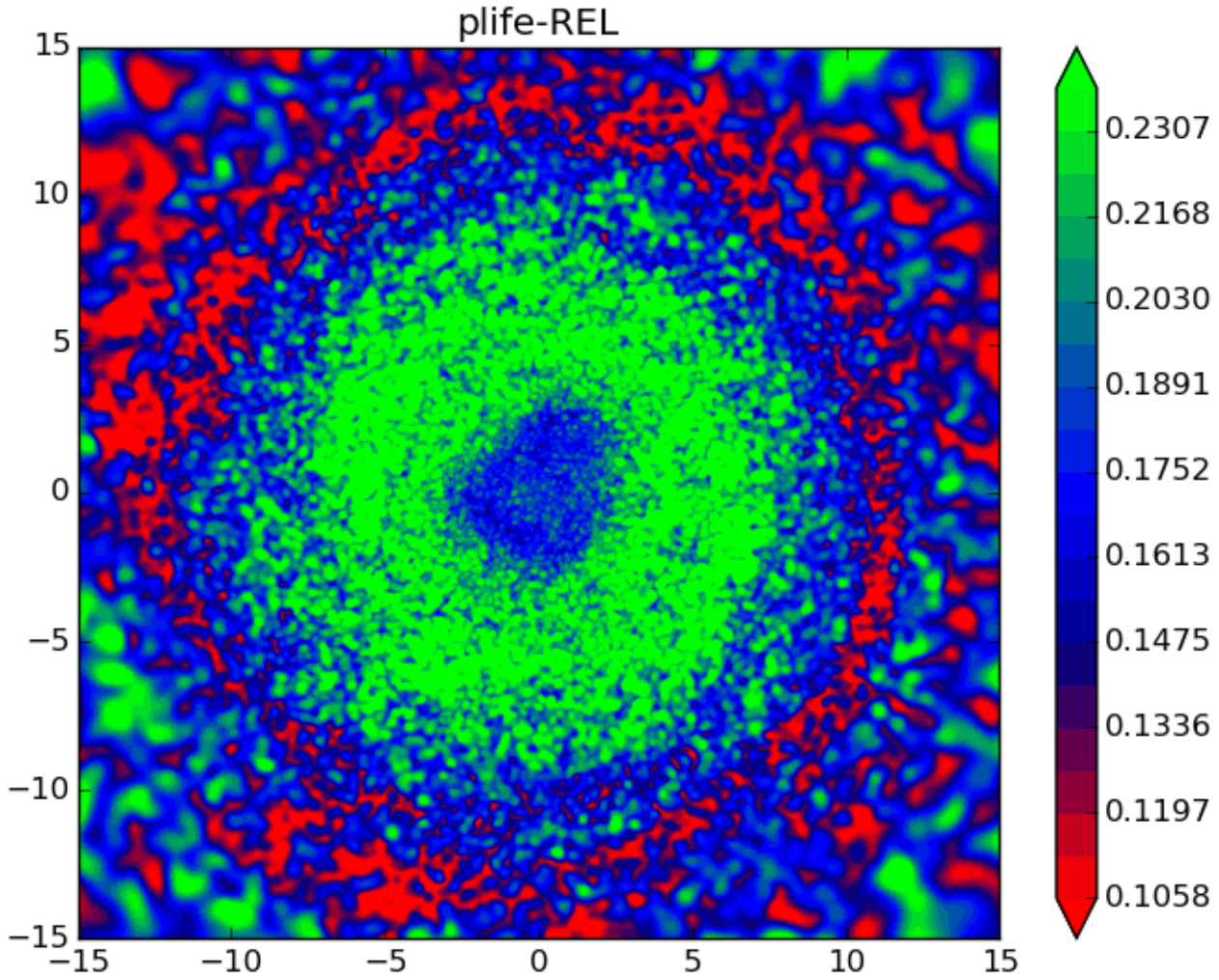


All stars, but O,B,A

Also M stars excluded

Only G stars

IMF!


plife-REL
15
10
5
0
−5
−10
−15
−15
−10
−5
0
5
10
15
0.2307
0.2168
0.2030
0.1891
0.1752
0.1613
0.1475
0.1336
0.1197
0.1058

Conclusions

- The study of the GHZ with **numerical simulation** of galaxy formation is now becoming **feasible**
- *Simulations can help in investigate details that are not accessible using chemical evolution models (effect of the sterilization radius of SNe, maps of the effect of the IMF…)*
- …but simulations currently do not produce "the MW", but only generic disc galaxies: both approaches should be used and their results compared
- ***We need to improve the terms P_{plan} (using modern statistics, from recent observations) and P_{evo} (..suggestions from evolution studies welcome!)***
- If the general behaviour of the GHZ is (approx…) estabilished, its **details do depend on many parameters!!**

Thank you.