Alone on a wide wide sea. The origin of SECCO 1, an isolated star-forming gas cloud in the Virgo cluster*†‡

M. Bellazzini[1]§, L. Armillotta[2] S. Perina[3], L. Magrini[4], G. Cresci[4], G.Beccari[5], G. Battaglia[6,14], F. Fraternali[7,15], P.T. de Zeeuw[8,9], N.F. Martin[10,11], F. Calura[1], R. Ibata[10], L. Coccato[5], V. Testa[12], M. Correnti[13]

[1] *INAF - Osservatorio di Astrofisica e Scienza dello Spazio di Bologna, Via Gobetti 93/3, 40129 Bologna, Italy*
[2] *Research School of Astronomy and Astrophysics - The Australian National University, Canberra, ACT, 2611, Australia*
[3] *INAF - Osservatorio Astronomico di Torino, Via Osservatorio 30, 10025 Pino Torinese, Italy*
[4] *INAF - Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125 Firenze, Italy*
[5] *European Southern Observatory, Karl-Schwarzschild-Strasse 2, 85748 Garching bei München, Germany*
[6] *Instituto de Astrofisica de Canarias, 38205 La Laguna, Tenerife, Spain*
[7] *Kapteyn Astronomical Institute, University of Groningen, Postbus 800, 9700 AV, Groningen, The Netherlands*
[8] *Leiden Observatory, Leiden University, Postbus 9513, 2300 RA, Leiden, The Netherlands*
[9] *Max Planck Institut für extraterrestrische Physik, Giessenbachstrasse, 85748 Garching, Germany*
[10] *Université de Strasbourg, CNRS, UMR 7550, F-67000 Strasbourg, France*
[11] *Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany*
[12] *INAF - Osservatorio Astronomico di Roma, via Frascati 33, 00040 Monteporzio, Italy*
[13] *Space Telescope Science Institute, Baltimore, MD 21218*
[14] *Universidad de La Laguna, Dpto. Astrofisica, E-38206 La Laguna, Tenerife, Spain*
[15] *Dipartimento di Fisica & Astronomia, Università degli Studi di Bologna, Viale Berti Pichat, 6/2, I - 40127 Bologna, Italy*

Accepted for publication on February 15, 2018

ABSTRACT

SECCO 1 is an extremely dark, low-mass ($M_\star \simeq 10^5$ M$_\odot$), star-forming stellar system lying in the Low Velocity Cloud (LVC) substructure of the Virgo cluster of galaxies, and hosting several HII regions. Here we review our knowledge of this remarkable system, and present the results of (a) additional analysis of our panoramic spectroscopic observations with MUSE, (b) the combined analysis of Hubble Space Telescope and MUSE data, and (c) new narrow-band observations obtained with OSIRIS@GTC to search for additional HII regions in the surroundings of the system. We provide new evidence supporting an age as young as $\lesssim 4$ Myr for the stars that are currently ionising the gas in SECCO 1. We identify only one new promising candidate HII region possibly associated with SECCO 1, thus confirming the extreme isolation of the system. We also identify three additional candidate pressure-supported dark clouds in Virgo among the targets of the SECCO survey. Various possible hypotheses for the nature and origin of SECCO 1 are considered and discussed, also with the help of dedicated hydrodynamical simulations showing that a hydrogen cloud with the characteristics of SECCO 1 can likely survive for $\gtrsim 1$ Gyr while traveling within the LVC Intra Cluster Medium.

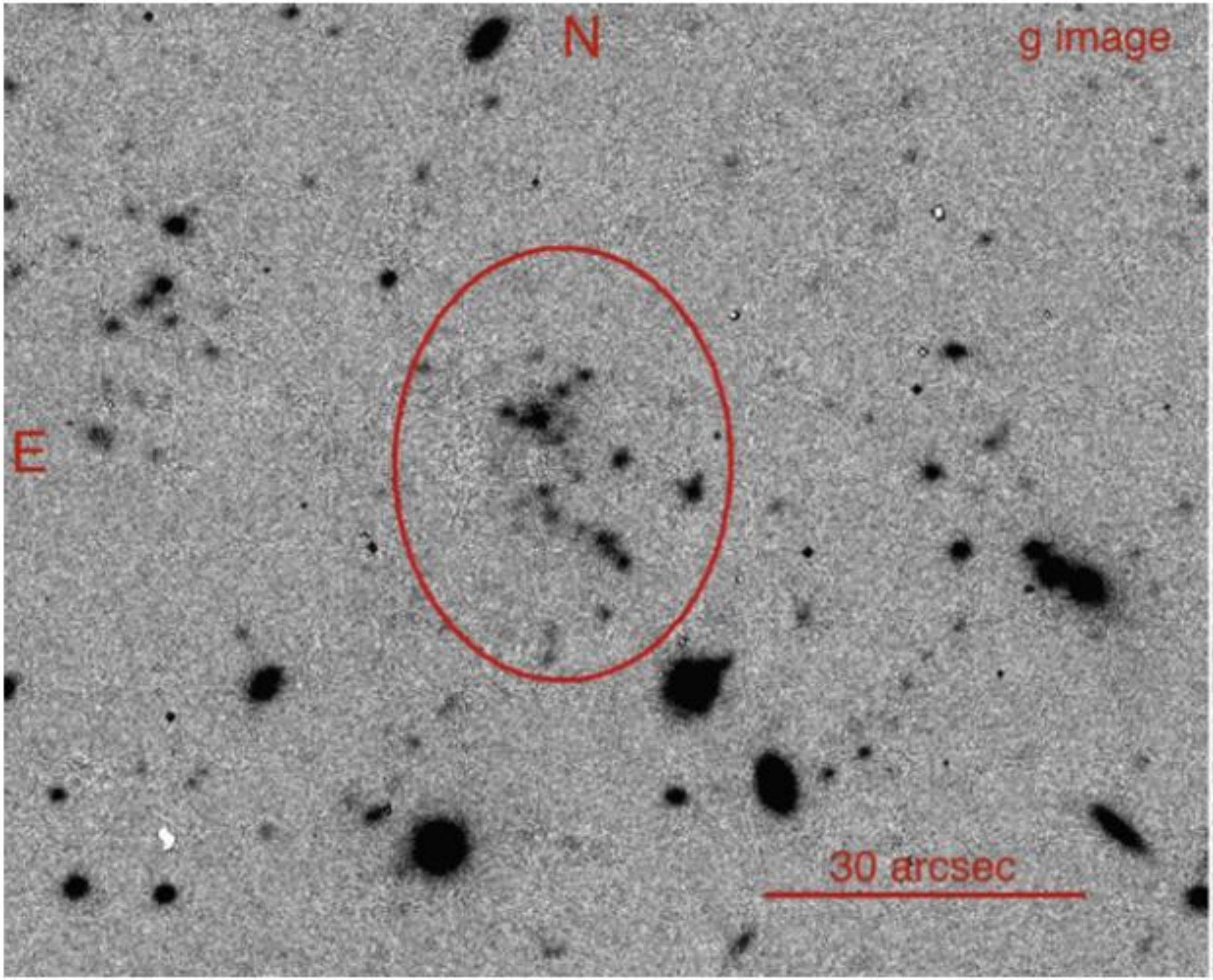
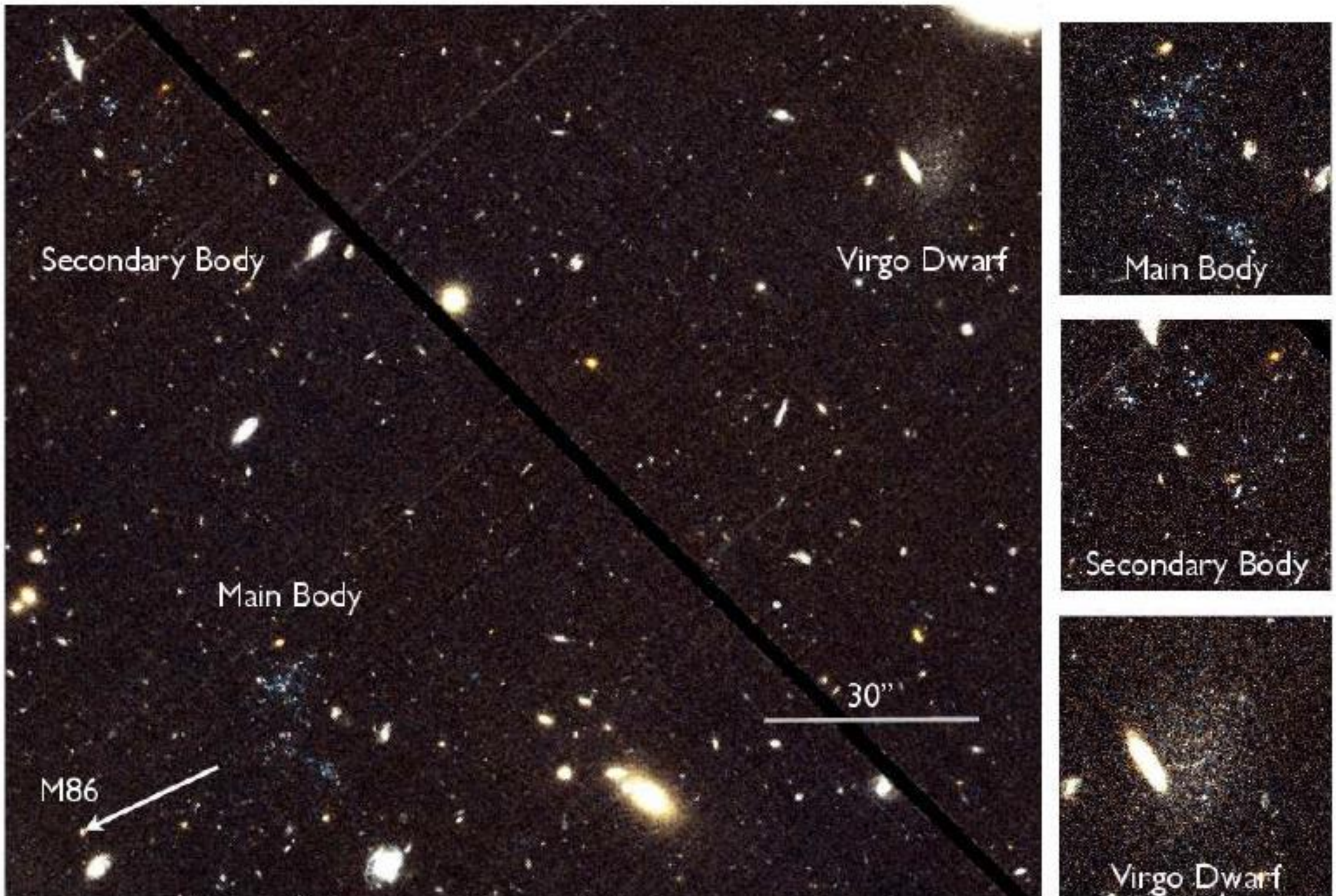


Figure 1. Deep *g* (left panel) and *r* (right panel) images zoomed on candidate D1. T

HUBBLE SPACE TELESCOPE IMAGING OF THE ULTRA-COMPACT HIGH VELOCITY CLOUD AGC 226067: A STRIPPED REMNANT IN THE VIRGO CLUSTER

Sand et al 2017

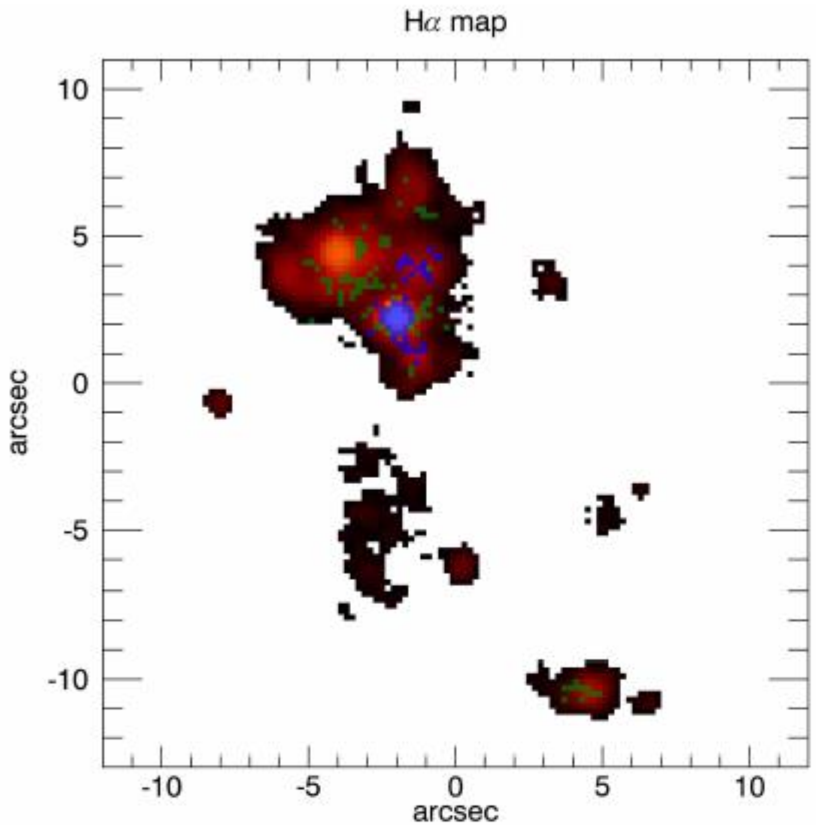


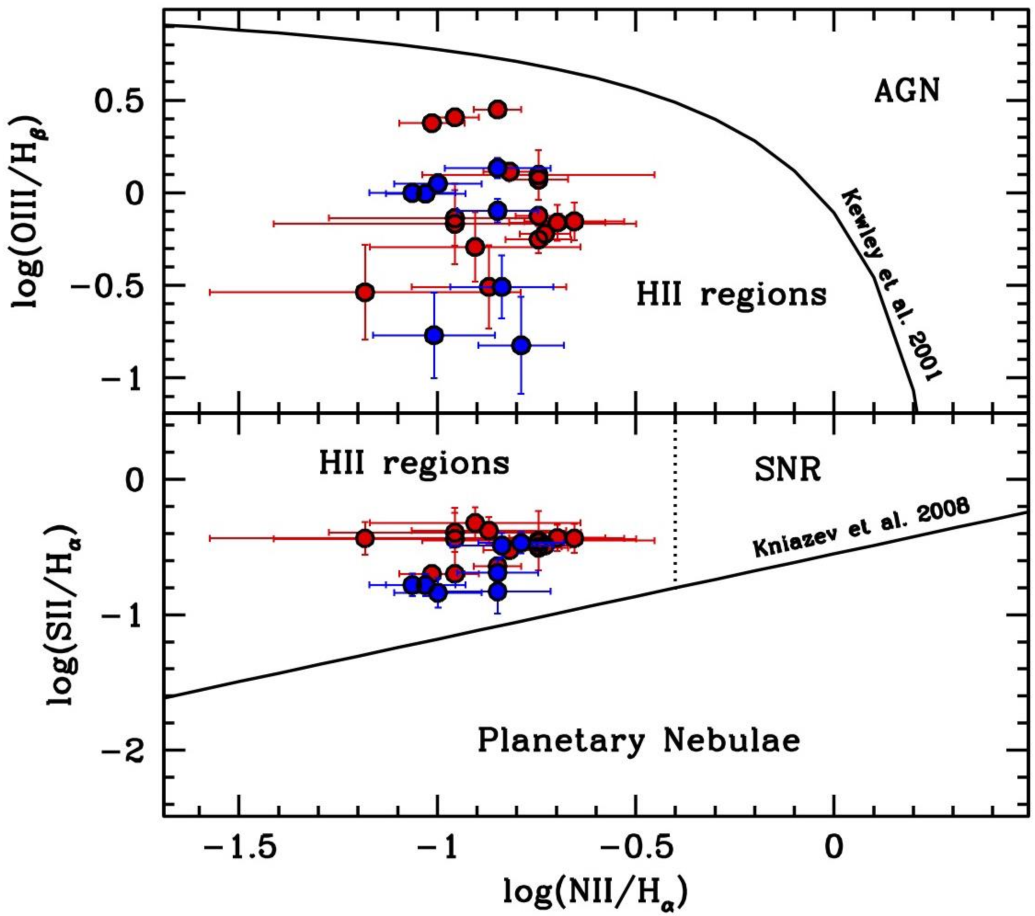
- Secco-1 открыт **Bellazzini et al,2015** в Virgo cluster.
- Отождествлён с Ultra Compact High Velocity Hi cloud (UCHVC). Два компонента.
- $MHI = 2x10^7 M_c$, $M_* < 1.6x10^5 M_c$
- Отсутствие красных гигантов (Sand et al, 2017).
- Информация о кинематике – для основного компонента см. **Adams et al 2015 (VLA):**

<<For AGC 226067, we adopt a rotational velocity of 15 km s−1 , a velocity dispersion of 9 km s−1, and a radius of 4.1 kpc, to find a dynamical mass of 4.5 × 108 Mc>>.

- **We presented a thorough analysis and discussion of the available data on the almost-dark stellar system SECCO 1, with additional results from the MUSE observations shown in [Be17a,b] and an analysis of the stellar content of the system, based on coupling the stellar photometry from HST-ACS data and MUSE spectroscopic data.**

- We reduced and analyzed independently the Sand 2017 dataset to have a deeper insight on the stellar populations in SECCO 1 by combining the HST-ACS and MUSE data.





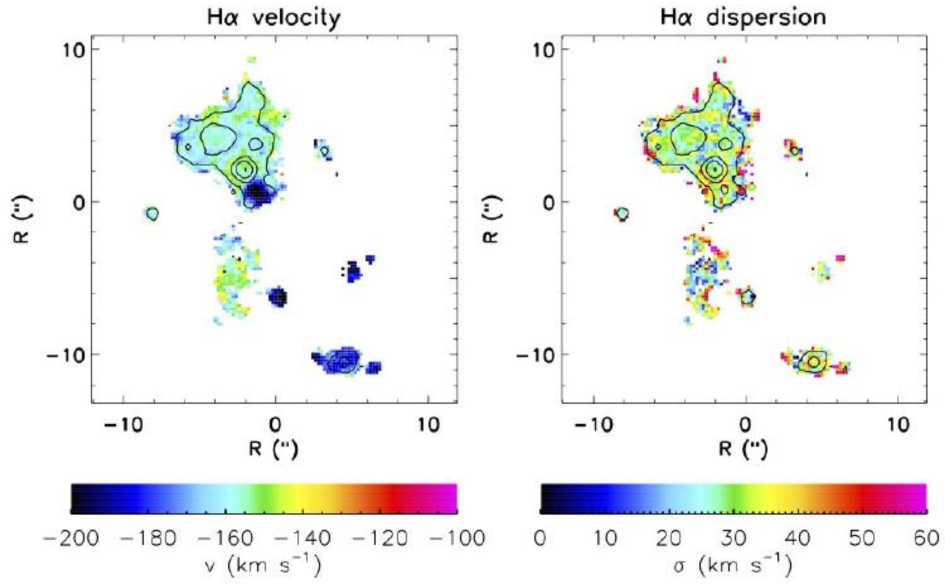


Figure 2. Kinematic maps for the Main Body. The Hα velocity (left panel) and velocity dispersion (right panel) are shown for all the spaxels with $S/N > 3$ after a Gaussian kernel smoothing of 3 pixels (0.6″). Hα contours are overplotted for reference, corresponding to 0.3, 0.8, 2, 6 erg s^{-1} cm^{-2} Å^{-1} respectively.

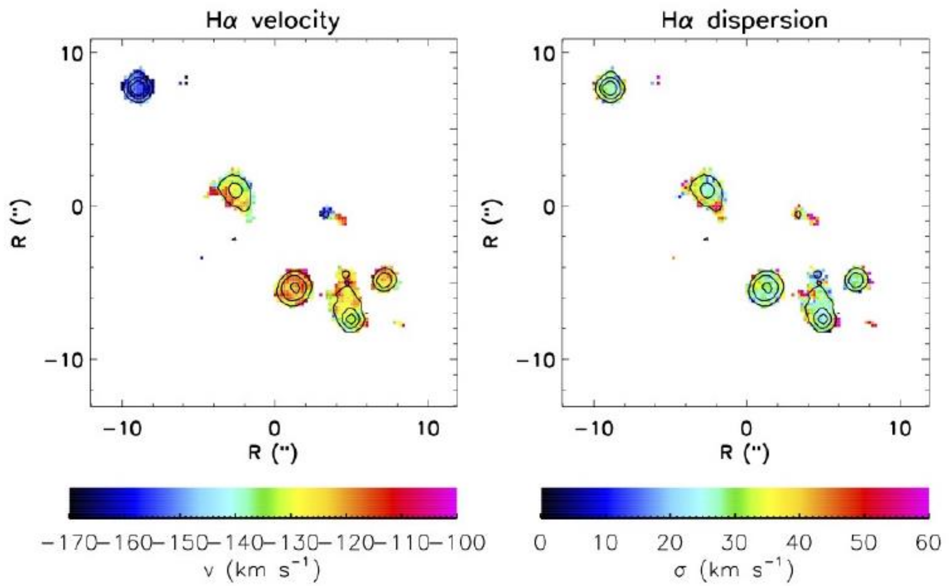


Figure 3. Kinematic maps and Hα contours for the Secondary Body. The arrangement and the meaning of the symbols are the same as in Fig. 2.

По измеренным потокам H\beta и He I:

T_{eff} О-звёзд > 35 тыс.К , т.е. T < 4 Myr.

SF продолжается!

- We confirm the conclusion by Be16, Be17a and S17 that no trace of excess RGB population is seen around SECCO 1.

Blue circles are sources cross-identied in the list of Hii regions in B17a;

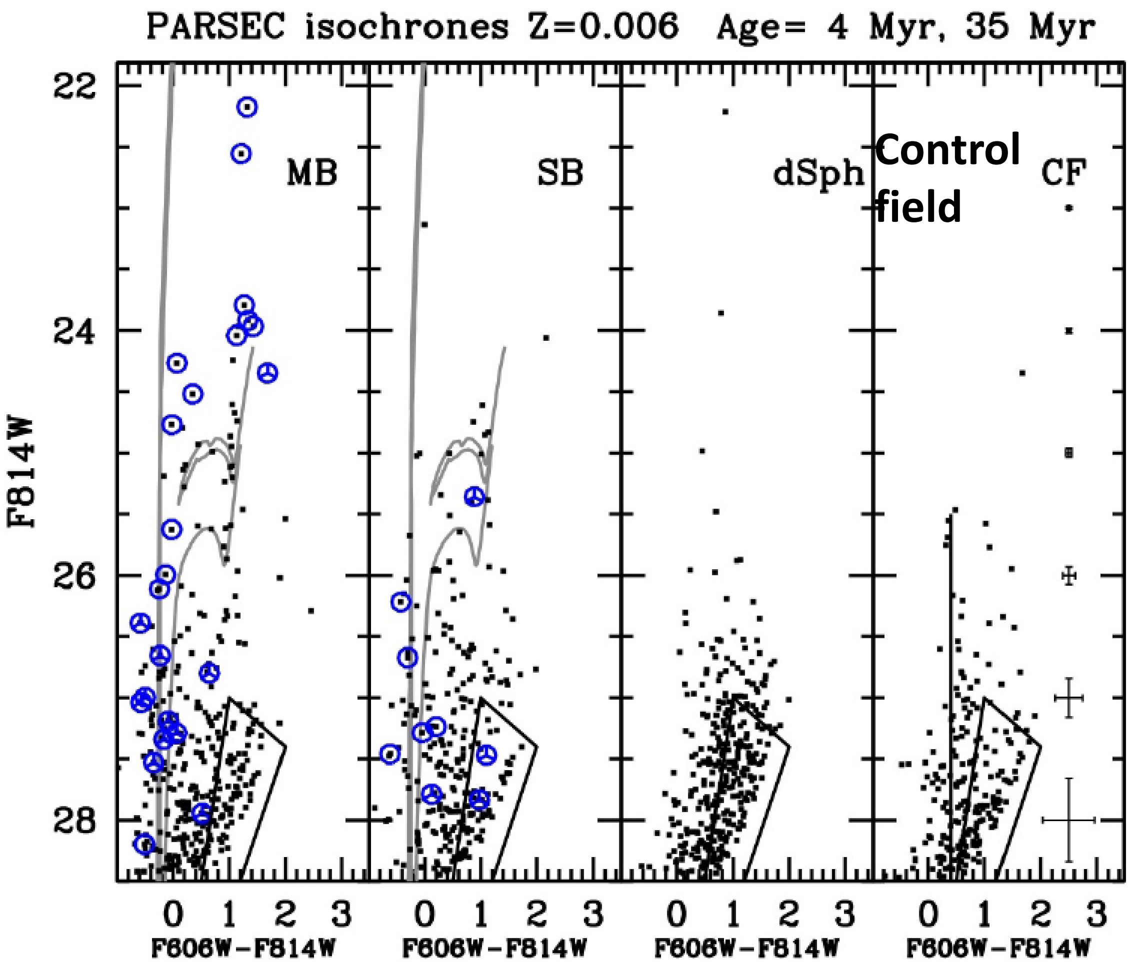


Figure 6. Color magnitude diagrams from HST/ACS photometry of circular regions of radius=20″ centered, from left to right, on the center of the main body of SECCO 1, on the center of the secondary body of SECCO 1, on the center of the Virgo dwarf spheroidal Dw J122147+132853, and on a region devoid of resolved stellar systems (Control Field). The polygonal contour at F814W≤ 27.0 and F606W-F814W≃ 1.0 approximately encloses the intra cluster population of RGB stars as sampled by Williams et al. (2007), the thick

The mean metallicity of the dSph is lower than that of the old IC population in this specific line of sight.

The structural and dynamical properties of SECCO 1 are in the range of those expected for a dwarf galaxy of the same baryonic mass.

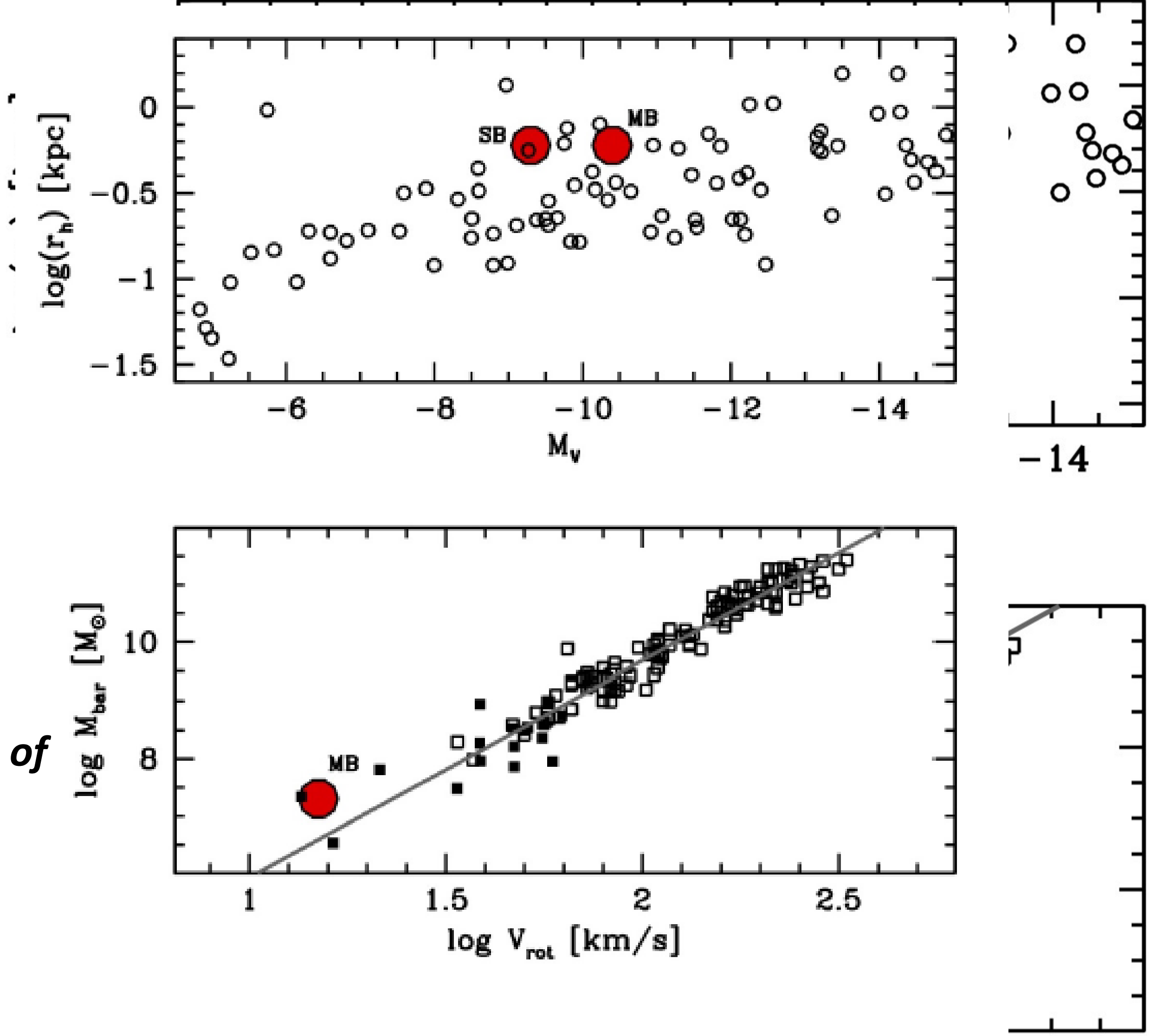


Figure 9. Upper panel: SECCO 1 MB and SB (large red filled circles) in the integrated absolute V magnitude vs. log of the half-light radius diagram. Small empty circles are dwarf galaxies in the Local Group from McConnachie (2012). As a proxy for the half-light radius for MB and SB we adopted half of the radial size reported (and defined) in Tab. 1. Lower panel: baryonic Tully-Fisher relation. Open squares are from Lelli et al. (2016) and

On the other hand, the velocity field of the overall system (gas + stars), and the offset in position between SB and AGC 229490 suggest that it is unlikely that the system is in dynamical equilibrium. If confirmed, also the lack of an underlying old population would argue against the hypothesis that SECCO 1 is an ordinary, albeit very dark, dwarf galaxy .

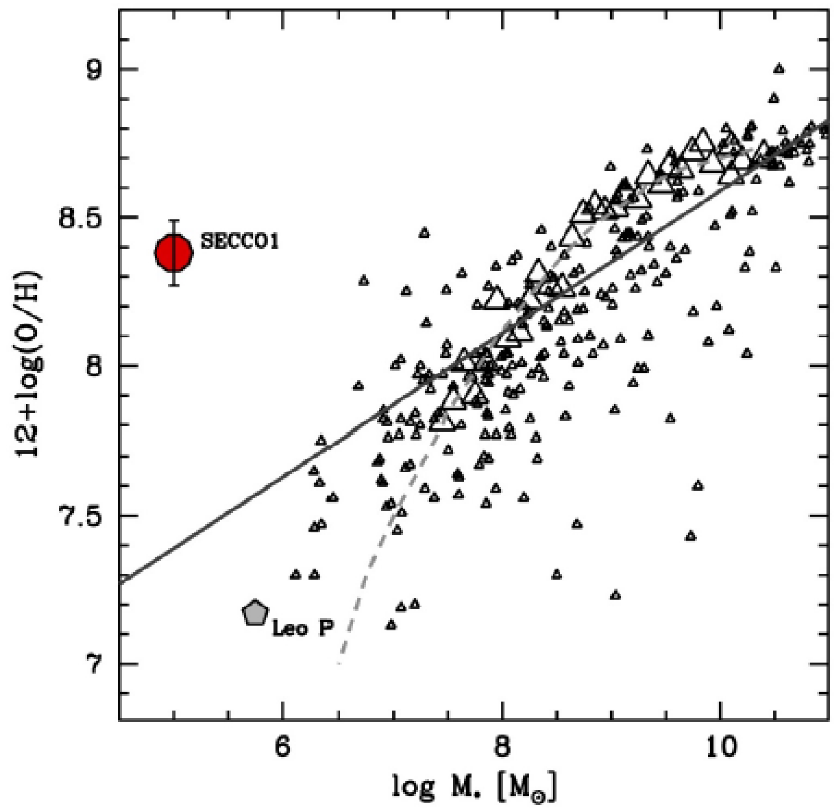
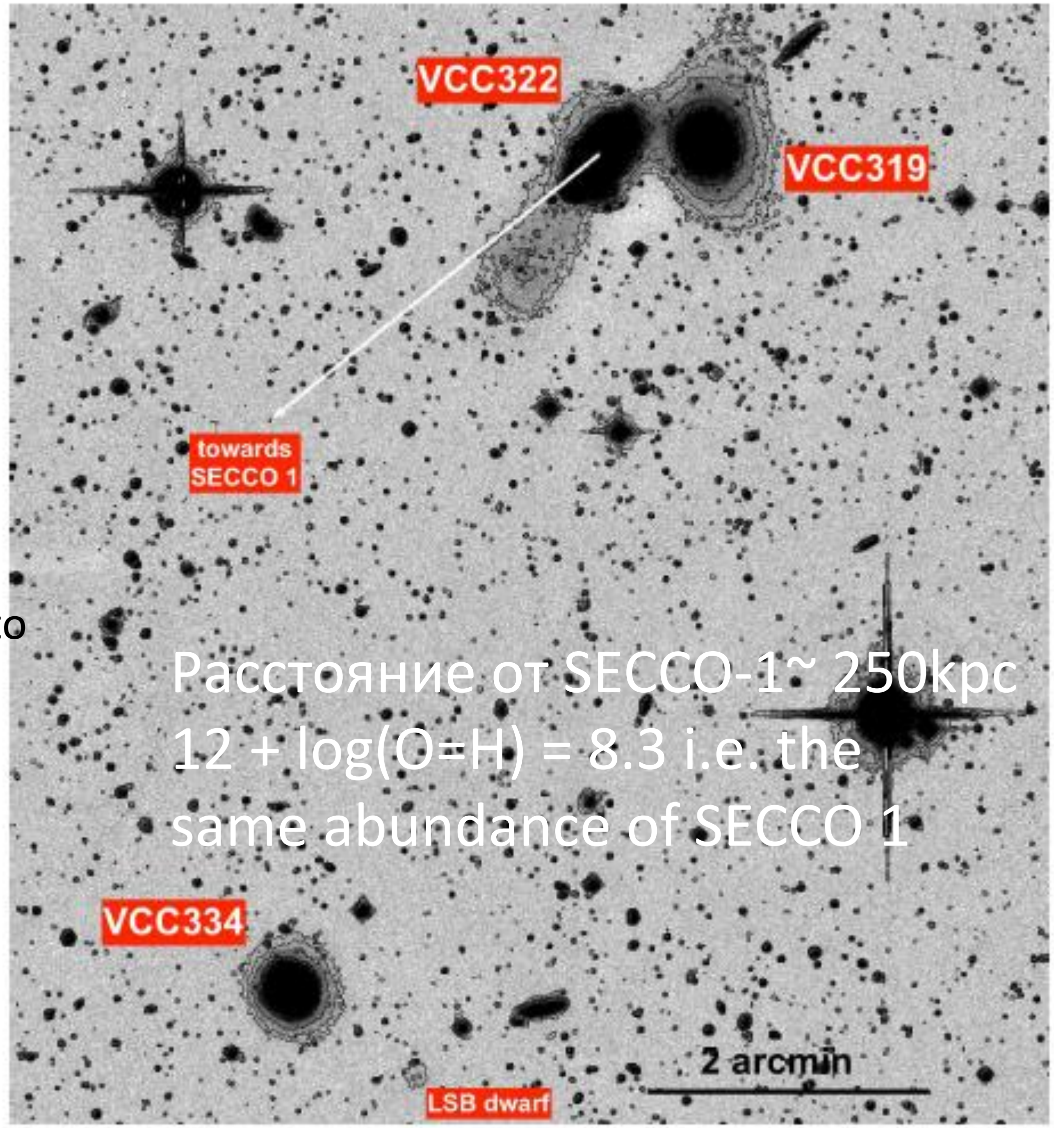


Figure 10. SECCO 1 as a whole into the stellar mass - metallicity relation. Small triangles are the z≃ 0 sample of Hunt et l. (2016), large triangles are from Andrews & Martini (2013), the light grey long-dashed curve is the best-fit to the same data (from direct-

Are such kind of clouds expected to have lifetimes longer than 1 Gyr?



Расстояние от SECCO-1~ 250kpc
12 + log(O=H) = 8.3 i.e. the same abundance of SECCO 1

Figure 11. Deep g-band image of the interacting group of dwarfs suggested as candidate site of origin of SECCO 1, from the Next Generation Virgo cluster Survey (Ferrarese et al. 2012). North is up and East is to the left. Density contours at arbitrary intensity levels have been drawn to put in evidence low surface brightness

2D

Table 4. Initial parameters of the simulation: hot gas temperature T_{hot}, hot gas density n_{hot}, hot gas metallicity Z_{hot}, cloud temperature T_{cl}, cloud density n_{cl}, cloud metallicity Z_{cl}, cloud radius R_{cl}, cloud velocity v_{cl}.

T_{hot} (K)	n_{hot} (cm^{-3})	Z_{hot} ($Z_\odot$)	T_{cl} (K)	n_{cl} (cm^{-3})	Z_{cl} ($Z_\odot$)	R_{cl} (kpc)	M_{cl} ($M_\odot$)	v_{cl} ($km\,s^{-1}$)
5×10^6	2.5×10^{-5}	0.1	5×10^3	2.6×10^{-2}	0.5	3.7	9.4×10^7	200

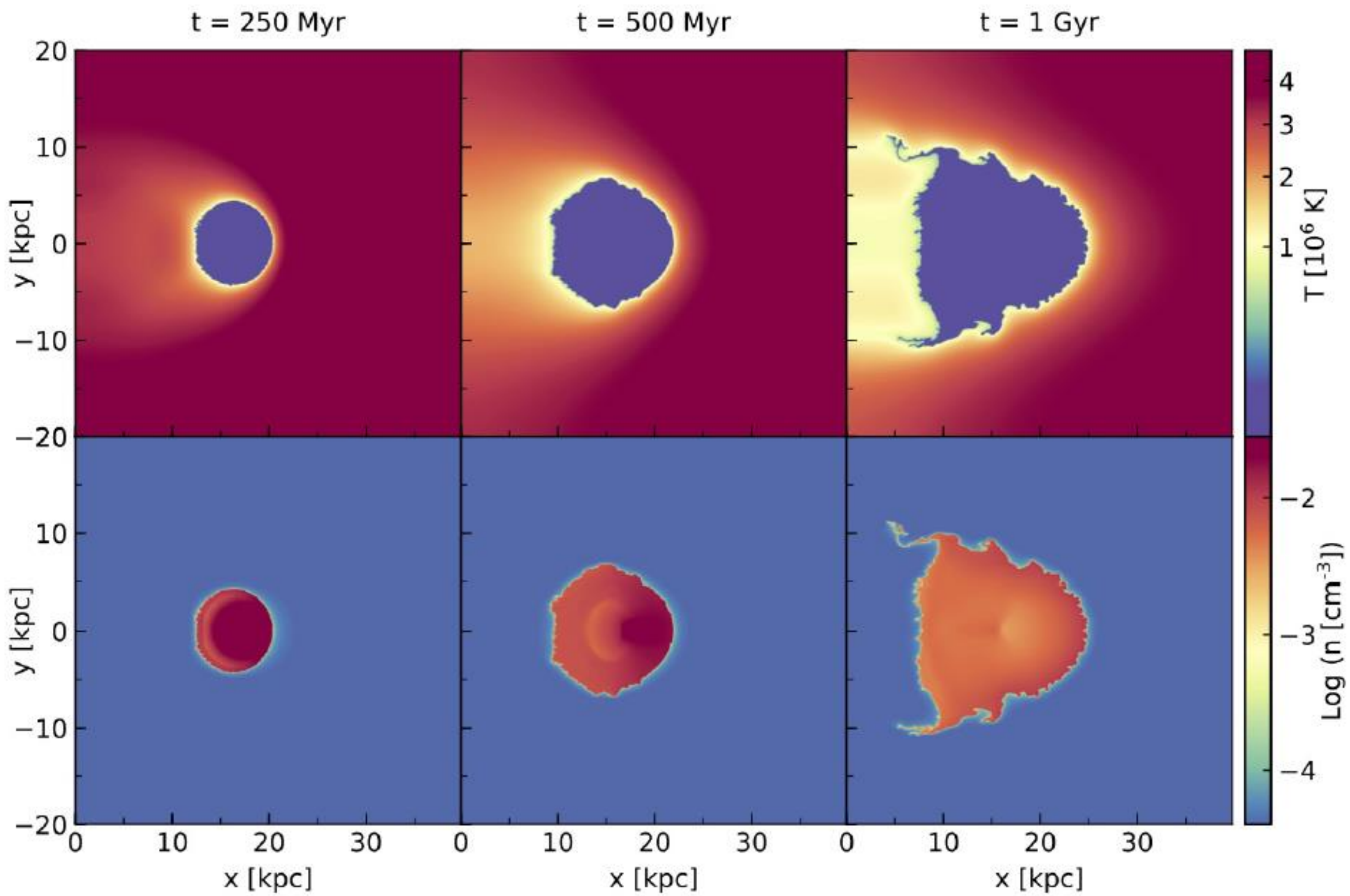


Figure 12. Temperature (top panels) and number density (bottom panels) snapshots of the simulation at t=250 Myr (left panels), t=500 Myr (middle panels) and t=1 Gyr (right panels) for the 2D simulation.

3D

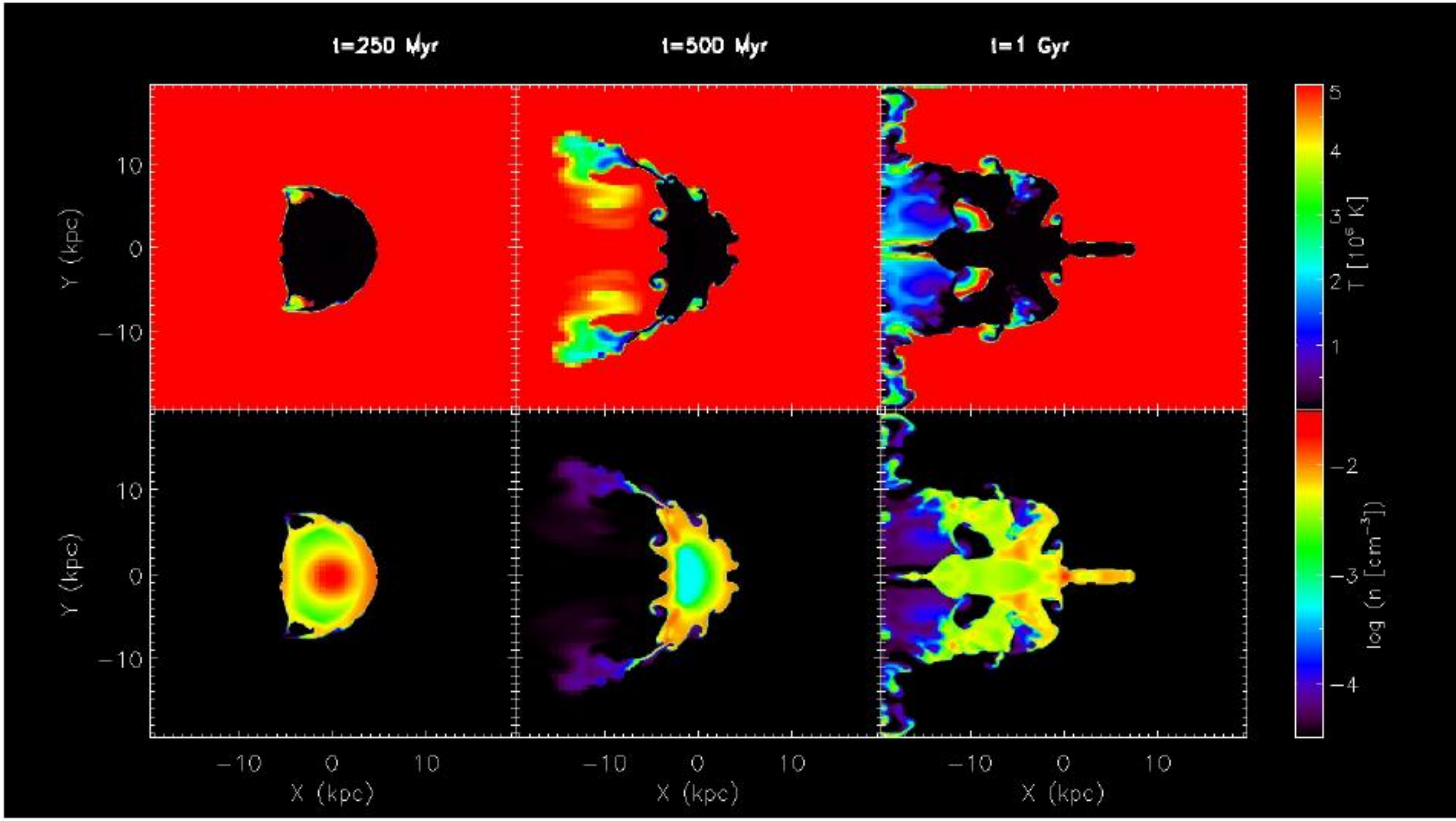


Figure 14. Temperature (top panels) and number density (bottom panels) snapshots of the simulation at t=250 Myr (left panels), t=500 Myr (middle panels) and t=1 Gyr (right panels) for the 3-D simulation.

We note that SECCO 1 MB and SB are not far from the other dark or almost-dark Hi clouds but lie below the generally accepted critical density lines. However this may be due to the smearing effect of the VLA beam

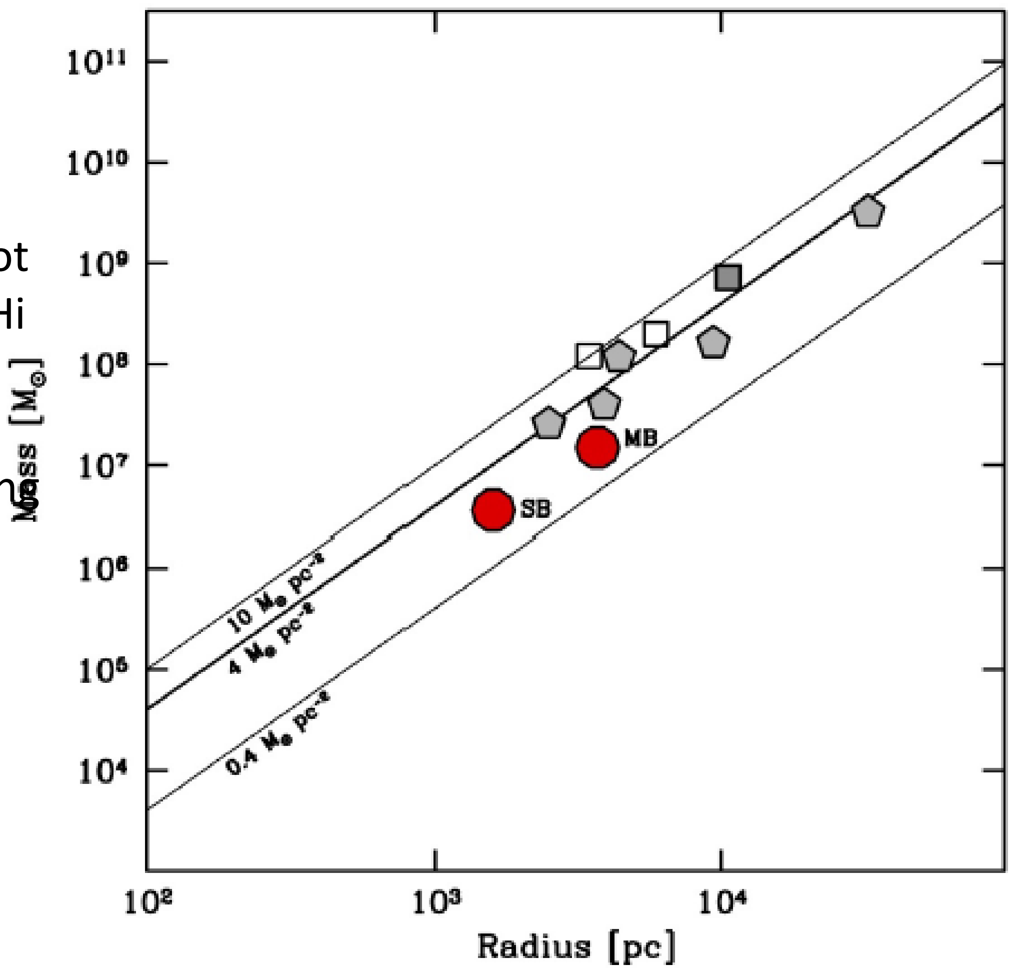


Figure 16. Size vs. mass relationship for starless or nearly starless HI clumps, following Burkhart & Loeb (2016). Squares are from Janowiecki et al. (2015), pentagons from Cannon et al.

Основные выводы

- Most of the star formation in SECCO 1 likely occurred within the last 35 Myr, with no sign of old or intermediate-age populations associated to the system.
- Its oxygen abundance is a factor of >10 larger than the typical galaxy of the same stellar mass. This implies that the system most likely originated from a ram pressure or tidal stripping event that removed a pre-enriched gas cloud from a galaxy with M>108 Mc.
- The virial ratio of the gas cloud indicates that it is not gravitationally bound but it is confined by the external pressure.
- Independently of the actual site of origin, the stripped gas cloud that formed SECCO 1 should have travelled for > 1 Gyr within the ICM before the onset of the currently ongoing star formation episode.
- The process that lead the cloud to cross the critical density to ignite
- star formation is unclear.