Происхождение кальция и химическая эволюция галактик ранних типов

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ГАИШ МГУ

В диске нашей Галактики:

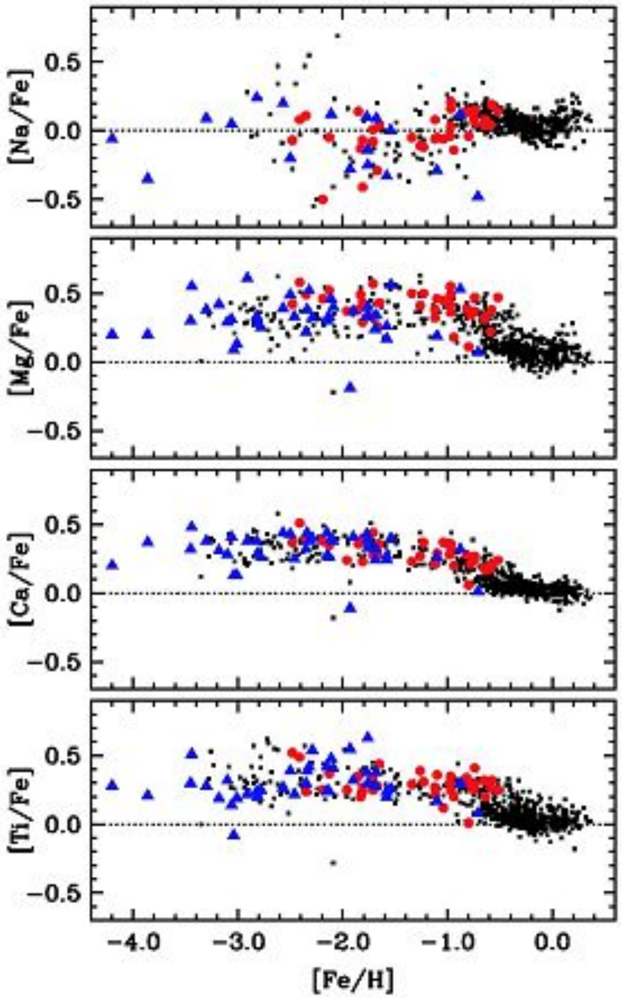
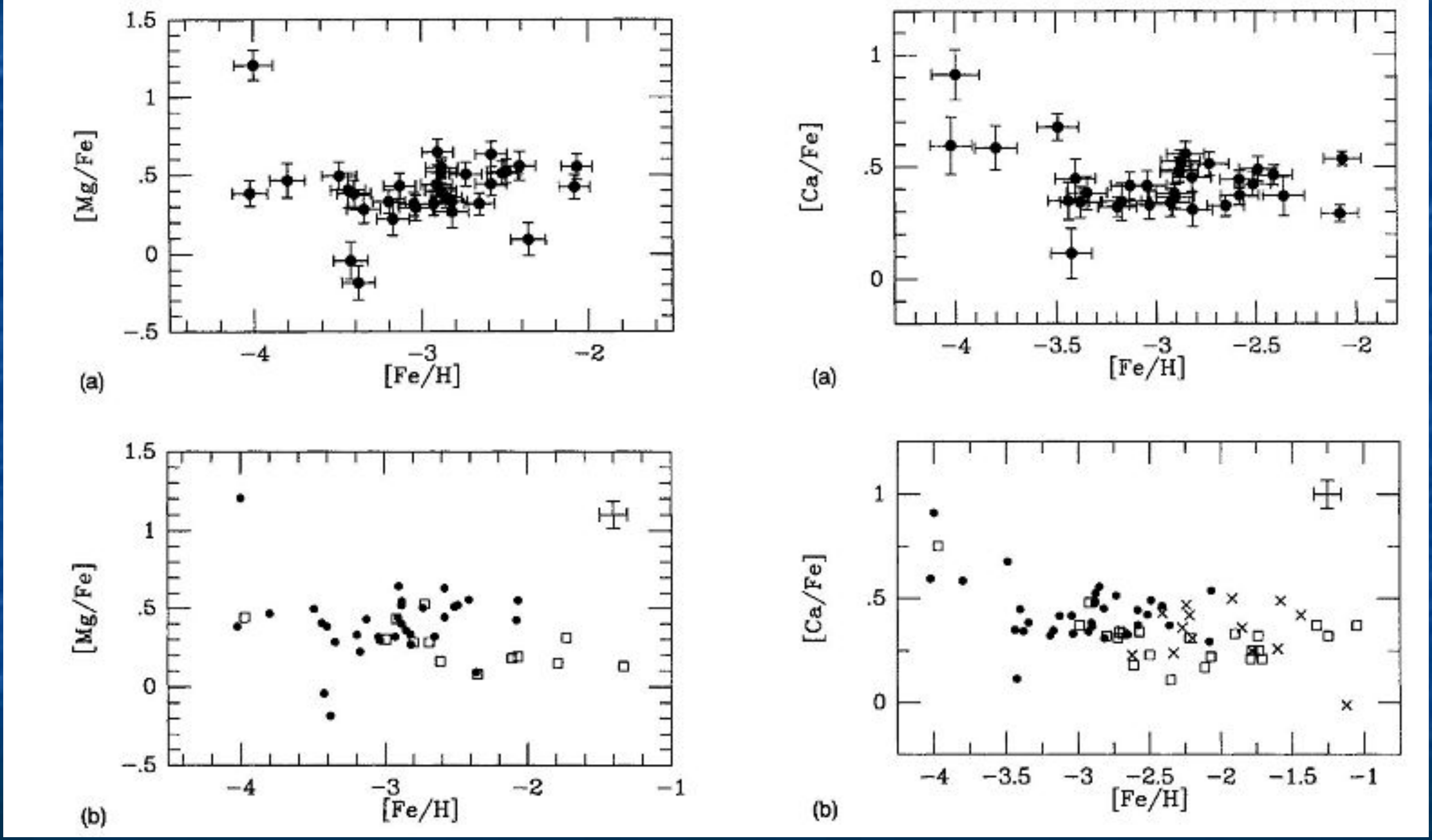


Figure 8. [Na/Fe], [Mg/Fe], [Ca/Fe], and [Ti/Fe] abundance ratios for our inner (dark gray circles, red in the online edition) and outer (black triangles, blue in the online edition) halo populations. Stars that did not meet the kinematic criteria for these two populations are shown as small dots.

(A color version of this figure is available in the online journal.)

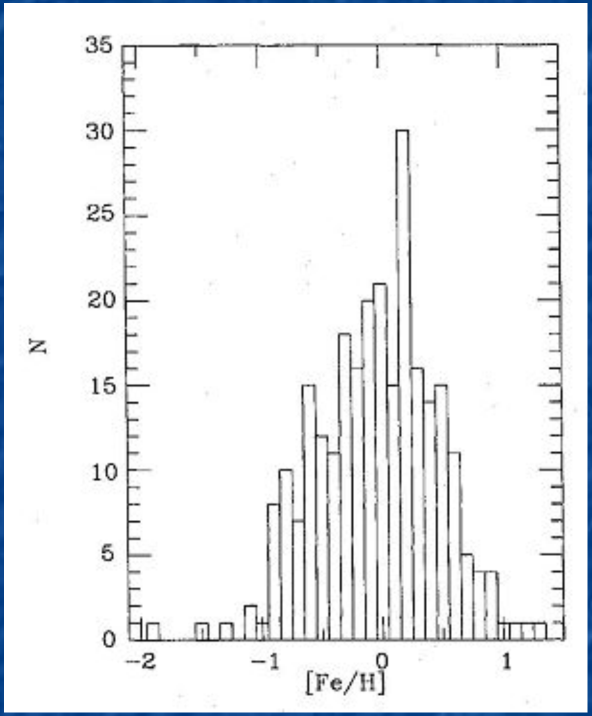
Roederer 2009

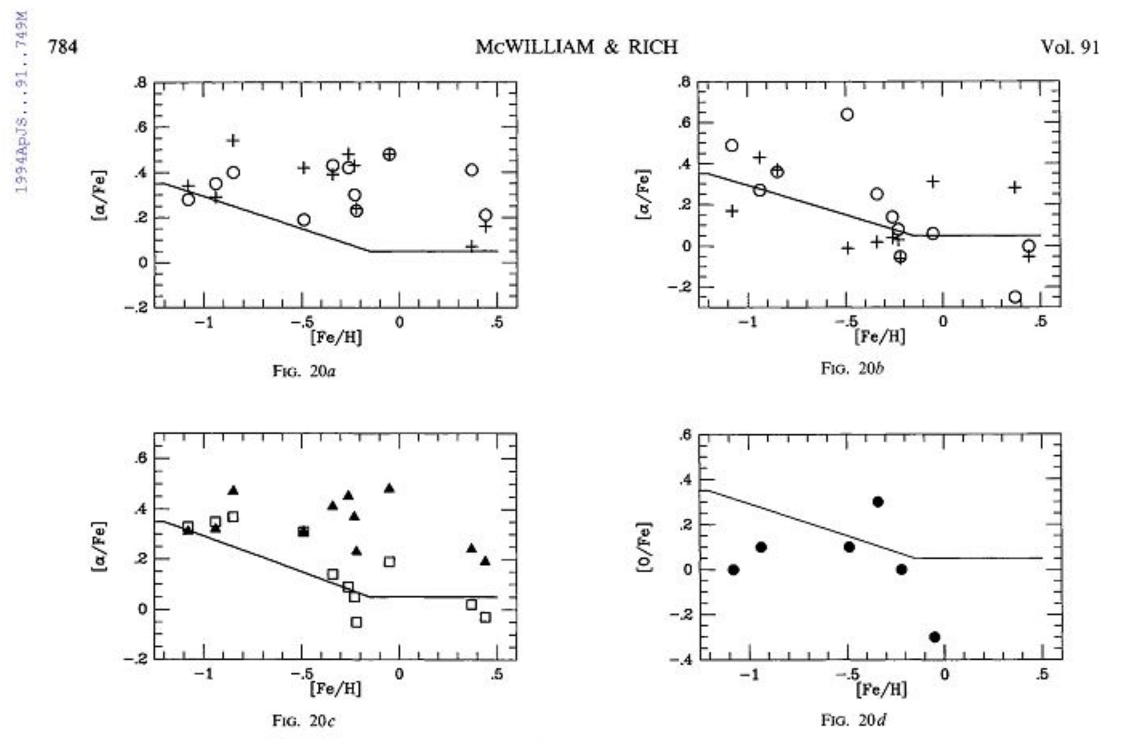
Наблюдения: гало нашей Галактики



McWilliam et al. 1995

НО!: в балдже Галактики





784 McWILLIAM & RICH Vol. 91

FIG. 20a

FIG. 20b

FIG. 20c

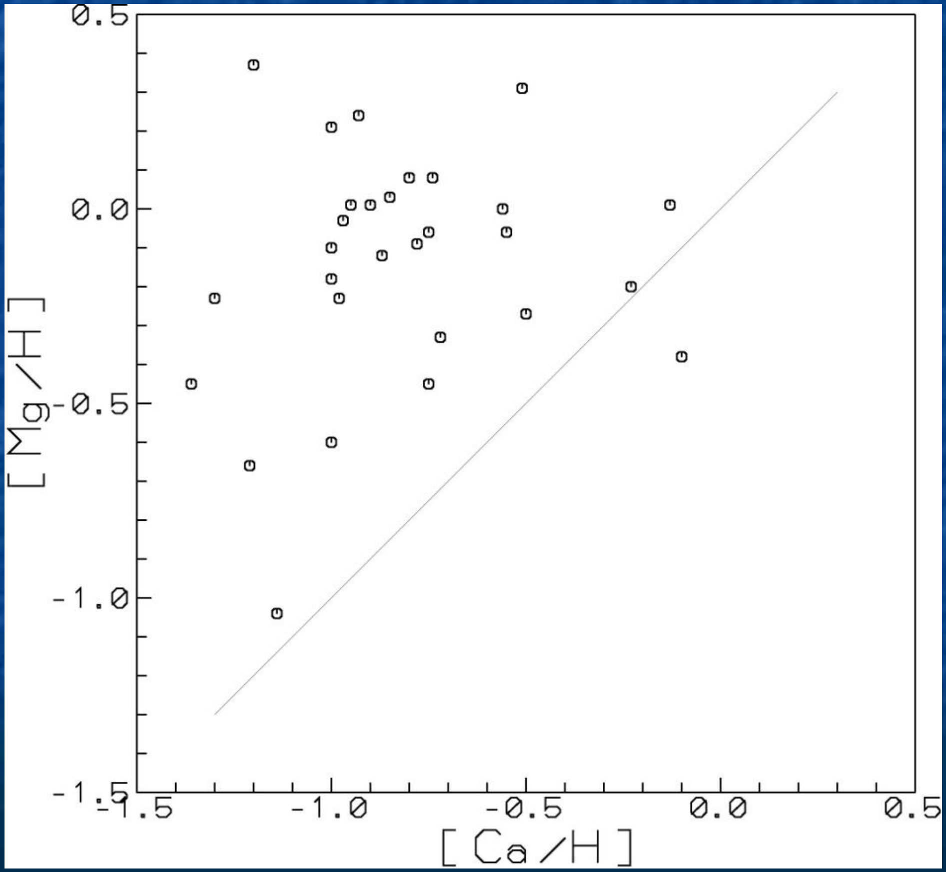
FIG. 20d

FIG. 20.—(a) Plot of [α/Fe] against [Fe/H] for our sample of 11 bulge giants. Open circles represent [Ti/Fe], and plus signs represent [Mg/Fe]. The solid line is the disk/halo relation found by Lambert (1987). (b) Plot of [α/Fe] against [Fe/H] for our sample of 11 bulge giants. Open circles represent [Si/Fe], and plus signs represent [Ca/Fe]. The solid line is the disk/halo relation found by Lambert (1987). (c) Plot of [α/Fe] against [Fe/H] for our sample of 11 bulge giants. Filled triangles represent an average of [(Mg + Ti)/Fe], while open squares indicate the average [(Si + Ca)/Fe]. The solid line is the disk/halo relation found by Lambert (1987). (d) Plot of [O/Fe] against [Fe/H] for six bulge giants with measurable [O I] features. The solid line is the disk/halo relation found by Lambert (1987). Note that the sample can be accurately described with [O/Fe] = 0.0.

Sadler et al.1996

McWilliam & Rich 1994

В эллиптических галактиках и балджах S0-Sa металличность по магнию и кальцию расходится…



Сильченко 1994:

Линии CaIIH и K и MgIb

В эллиптических галактиках металличность по магнию и кальцию расходится…

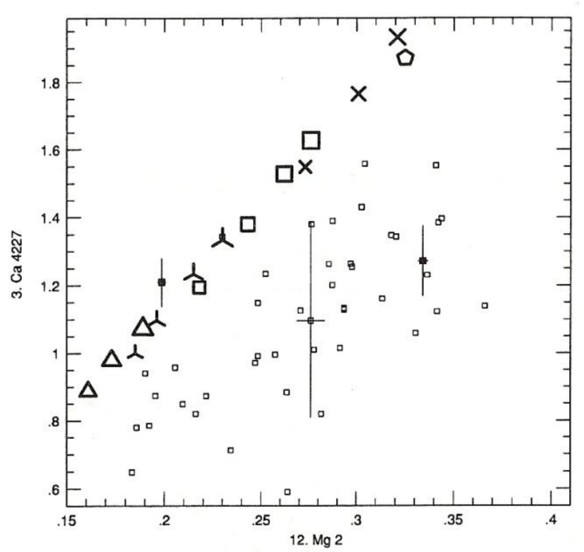


Fig. 5.4 — IDS nuclear Ca4227 index versus Mg_2. See Figure 5.3 for explanation of symbols. Note the large, real scatter and comparatively shallow global slope compared to the models.

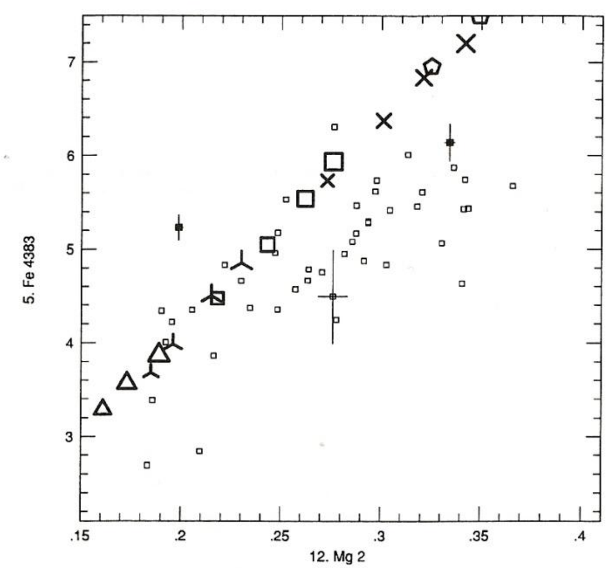


Fig. 5.6 — IDS nuclear Fe4383 index versus Mg_2. See Figure 5.3 for explanation of symbols. Note the large, real scatter and comparatively shallow global slope compared to the models.

Worthey 1994

Модели звездных населений подтверждают недостаток кальция

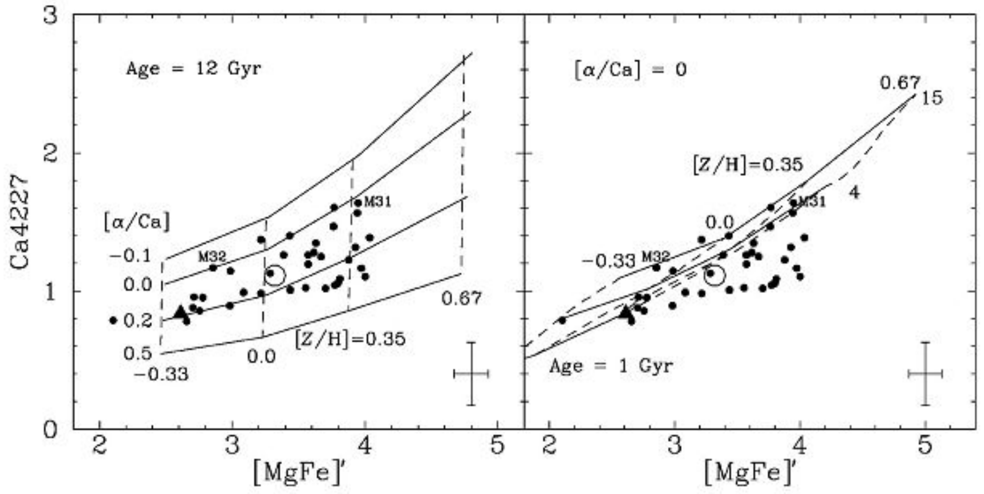


Figure 1. Early-type galaxies in the [MgFe]′–Ca4227 plane. Galaxy data (filled circles) are from Trager et al. (1998). The open circle is their median. The filled triangle is the integrated Galactic bulge light from Puzia et al. (2002). Lines are stellar population models from Thomas et al. (2003). Left-hand panel: models for constant α/Ca ratios [α/Ca] = −0.1, 0.0, 0.2 and 0.5 (solid lines) and constant metallicities [Z/H] = −0.33, 0.0, 0.35 and 0.67 (dashed lines) at a fixed age of t = 12 Gyr. Right-hand panel: models for constant ages of 1, 4, and 15 Gyr (solid lines), and the constant metallicities [Z/H] = −0.33, 0.0, 0.35 and 0.67 (dashed lines) at a fixed solar α/Ca element ratio ([α/Ca] = 0).

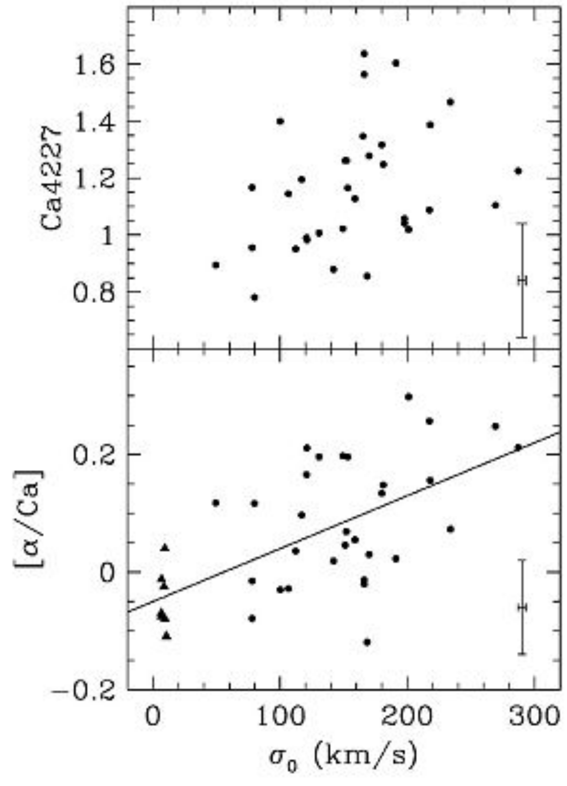
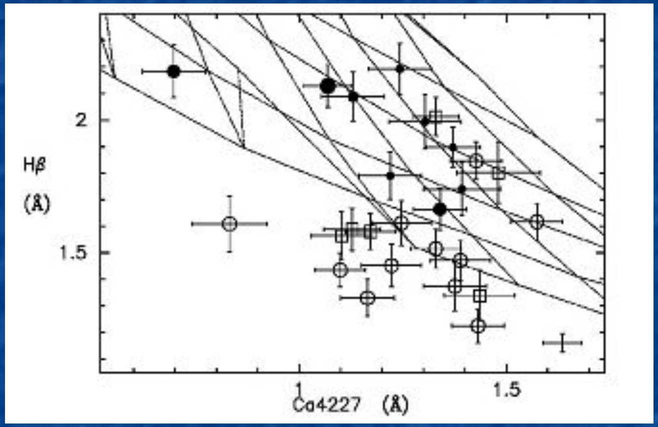
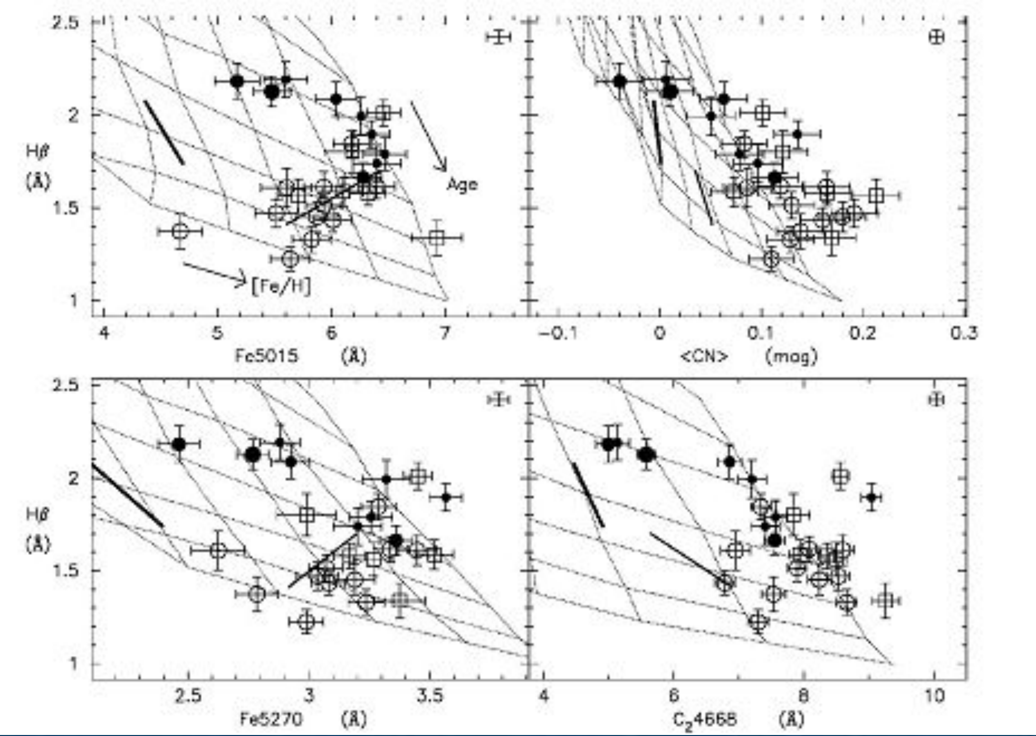


Figure 2. Ca4227 index (top panel) and α/Ca ratio (bottom panel) of early-type galaxies as functions of central velocity dispersion. Ca4227 data (circles) are from Trager et al. (1998). α/Ca ratios are derived from Fig. 1. Triangles are Local Group dwarf spheroidal galaxies for which α/Ca ratios are measured in individual stars (Shetrone et al. 2001, 2003). Central velocity dispersions are from Whitmore et al. (1985), Faber et al. (1989), Bender et al. (1992), González (1993) and Mateo (1998). The solid line is a linear least-squares fit to the giant galaxy data (circles).

Thomas et al. 2003

Модели звездных населений подтверждают недостаток кальция, а также избыток C и N





Proctor & Sansom 2002

Тяжелые элементы в звездах эллиптических галактик

Table 7. Mass of individual elements as a fraction of total metals $(X_i/Z)_\odot$ in the Sun. Data are from Cox (2000). The total mass fraction of metals in the Sun ($Z_\odot$) is assumed to be 0.0189. Elements enhanced in low-metallicity, solar-neighbourhood stars and in galaxy populations are identified by a +. These are the elements which are included in the enhanced group (E) in each case. The final column indicates (with Y) the elements modelled by TB95. The last row in the second column shows the total fraction of all tabulated elements in the Sun. For the other three columns, totals indicate solar proportions of elements identified by + or Y.

Element	$(X_i/Z)_\odot$	Low [Fe/H] stars	Galaxy populations	Modelled by TB95
C	0.1619		+	Y
N	0.0583		+	Y
O	0.5054	+	+	Y
Ne	0.0921	+	+	
Na	0.0018	+	+	Y
Mg	0.0343	+	+	Y
Al	0.0030	+	+	
Si	0.0370	+	+	Y
S	0.0193	+	+	
Ar	0.0054	+	+	
Ca	0.0034	+		Y
Cr	0.0009			Y
Fe	0.0719			Y
Ni	0.0039			
Total	0.9986	0.7017	0.9185	0.8749

Proctor & Sansom 2002

Нуклеосинтез в массивных звездах

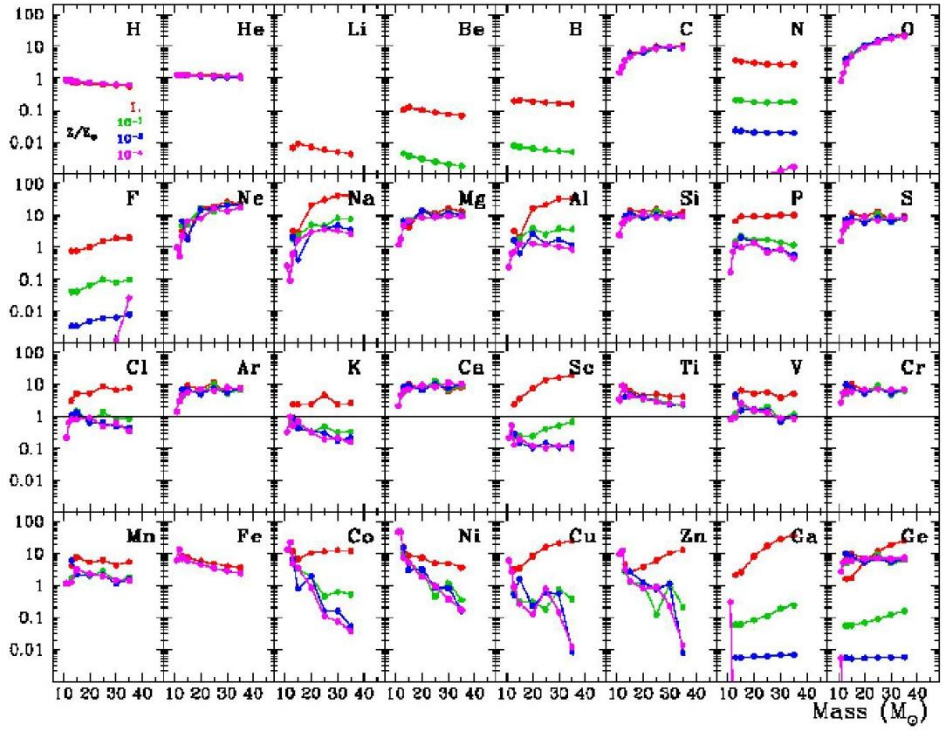


Fig. 4. Production factors $f_i(M) = \frac{Y_i(M)}{X_{\odot,i}(M - C_M)}$ for elements up to Ge in the ejecta of stars with no mass loss, of initial metallicity $Z/Z_\odot$=1, 0.1, 0.01 and 0.0001 (upper left panel) in the mass range 12-35 $M_\odot$ (data from Chieffi and Limongi 2004). Primary elements (C, O, Ne, Mg, Si, S, Ar, Ca, Ti, Cr, Fe) have metallicity independent f. N is produced only as secondary in massive stars with no rotational mixing. The odd-even effect is clearly seen for Na, Al, P, Cl, K, Sc, V, Mn,while Li, Be and B are depleted to various degrees. A horizontal dotted line at f=1 in all panels indicates ejection of material with solar abundance.

Prantzos 2007

Нуклеосинтез в сверхновых типа Ia

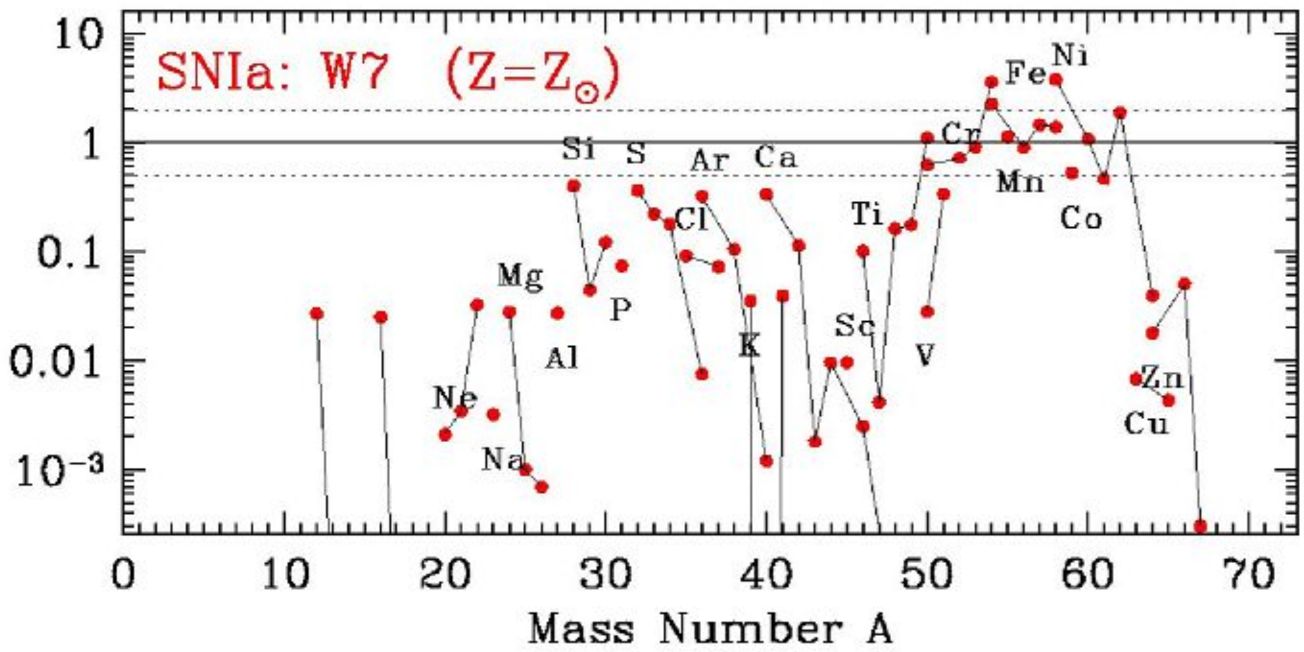


Fig. 6. Production factors f for isotopes from C to Cu in the "canonical" model W7 of SNIa (from Iwamoto et al. 1999). They are normalized to f_{Fe56}=1.

Prantzos 2007

Независимое происхождение кальция: третий вид сверхновых

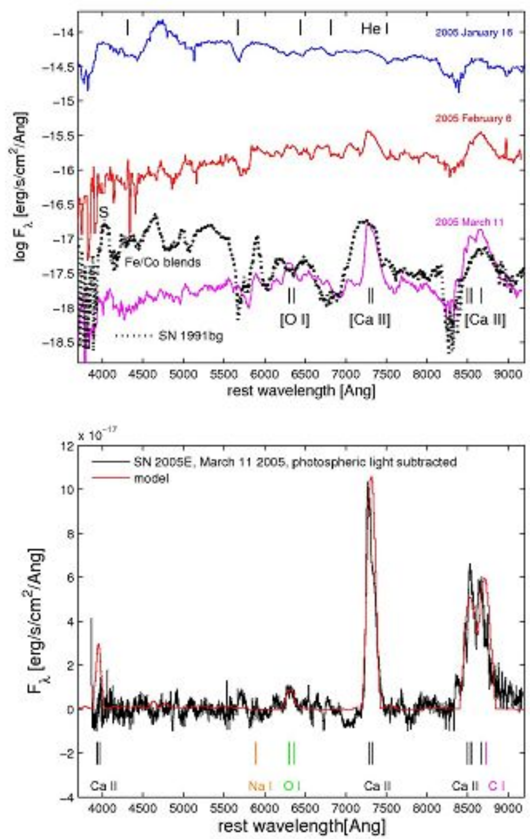


Figure 2. The mass and composition of the SN 2005E ejecta (technical details of observations can be found in SI Section 1). Upper panel: Photospheric spectra of SN 2005E. The top spectrum is obviously photospheric and shows absorption lines of the He I series (marked with black ticks after application of an 11,000 km s^{-1} blueshift, at the top). Nebular lines of intermediate-mass elements, most notably oxygen and calcium, begin to emerge in the middle spectrum, and dominate the latest nebular spectrum at the bottom. Also note that the typical Si lines of SNe Ia are absent in all spectra, while the nebular

Perets et al. 2009

Независимое происхождение кальция: из старых звезд

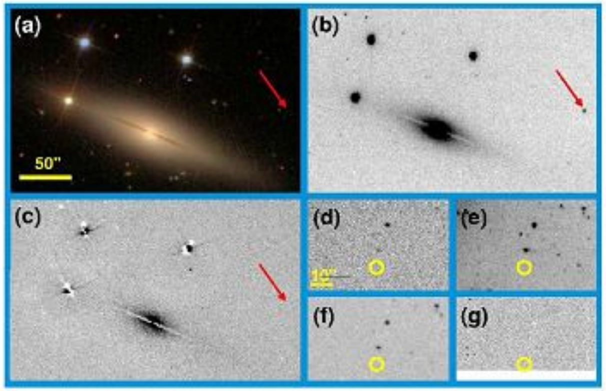


Figure 1. The environment of SN 2005E (technical details about the observations can be found in SI Section 1). **(a)** NGC 1032, the host galaxy of SN 2005E, as observed by the Sloan Digital Sky Survey (SDSS), prior to the SN explosion. The galaxy is an isolated, edge-on, early-type spiral galaxy, showing no signs of star-formation activity, warping, or interaction. Its luminosity is dominated by the cumulative contribution of a multitude of low-mass old stars (yellow light in this image). Panels **(a)**-**(c)** are $275'' \times 175''$; a scale bar is provided, north is up, and east due left. **(b)** The LOSS[10] discovery of SN 2005E on Jan. 13, 2005 (shown in negative). Note the remote location of the SN (marked with a red arrow) with respect to its host, 22.9 kpc (projected) from the galaxy nucleus and 11.3 kpc above the disk, whose edge-on orientation is well determined (panel **(a)**). **(c)** An image of NGC 1032 in the light of the Hα emission line, emitted by interstellar gas ionized by ultraviolet (UV) radiation, and a good tracer of recent star formation. There are no traces of recent star-formation activity (usually appearing as irregular, compact emission sources) near the SN location or anywhere else in the host.

Perets et al. 2009

Баланс производства элементов

Элемент	Выход из SNII, Mo	Выход из SNIa, Mo	Выход из SNx, Mo
Ca	0.0058	0.012	0.06
Fe	0.084	0.63	0.003
O	1.8	0.143	0.02

Iwamoto et al. 1999

Баланс сверхновых

- Если считать химсостав звезд гало продуктом только нуклеосинтеза массивных звезд, то чтобы довести отношение элементов до солнечного, необходимо стационарное отношение числа сверхновых SNII:SNIa:SNx=2.5:1:0.05
- Оценки современных частот вспышек по полной выборке ограниченного объема LickOSS (Perets et al. 2009): SNIa:SNx=0.07+/-0.05

Галактики ранних типов: необходимость новой модели

- Идея с короткой шкалой звездообразования больше не проходит – иначе кальций соответствовал бы обилию других α-элементов;
- Теперь проще «получить» эллиптическую галактику из обычной спиральной – добавлением магния, азота и углерода.

Вспышка звездообразования при мержинге? Т.к. корреляция с массой…

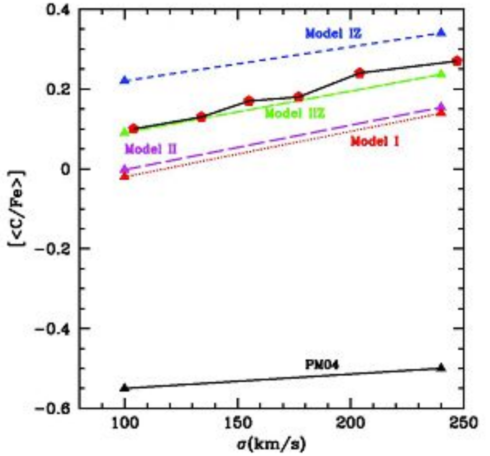
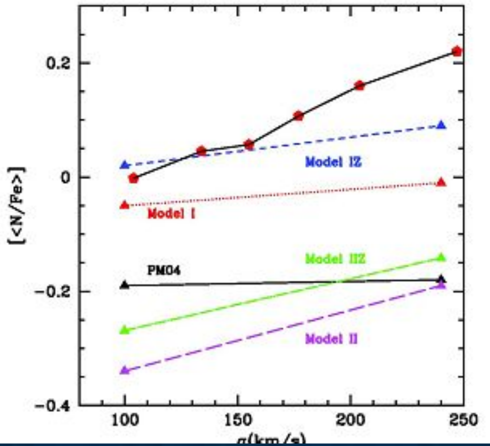
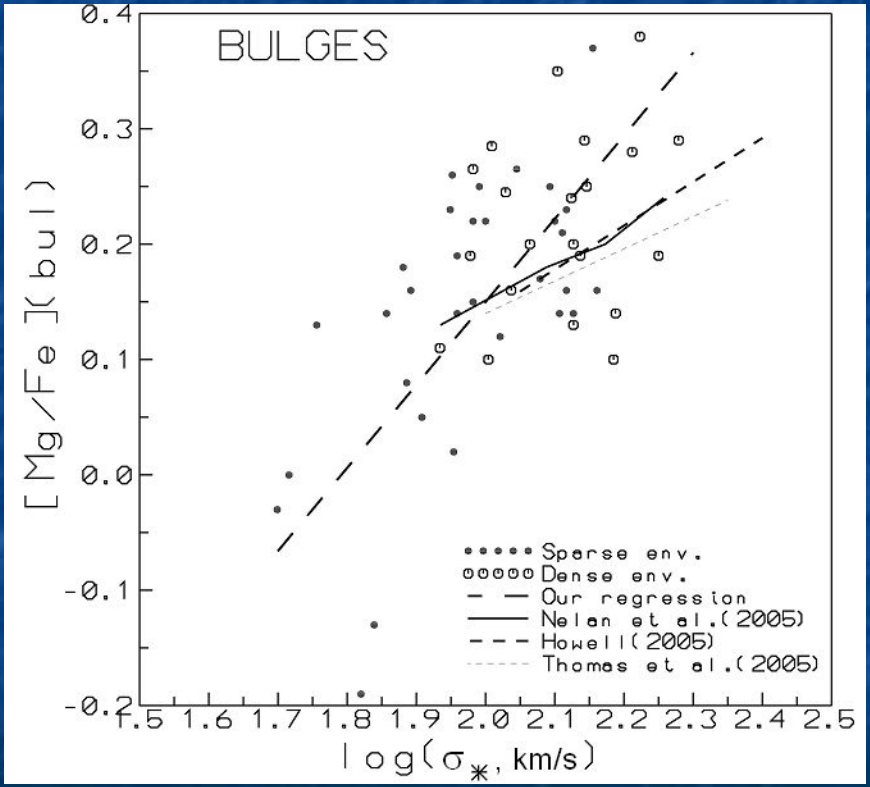


Figure 1. Mass-weighted [⟨C/Fe⟩] as a function of galactic velocity dispersion predicted by PM04 (triangles linked by a solid line) and models I (dotted line), IZ (short-dashed line), II (long-dashed line) and IIZ (short-dash–dotted line) compared to the observed relation found by Graves et al. (2007, pentagons linked by a solid line).





Pipino et al. 2009

Sil'chenko 2008