

COMMISSION 28

GALAXIES

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TRIENNIAL REPORT 2006 - 2009

1. Highlights in extragalactic research 2005 - 2008

This short report describes some highlights in extragalactic research over the past three years, and lists the main symposia and meetings in the domain.

1.1. *Star formation in galaxies with Spitzer and GALEX*

The combination of results from the two satellites, infrared and ultraviolet, has given a new and more complete view of star formation in nearby galaxies. In particular, the *Spitzer* Infrared Nearby Galaxies Survey (SINGS) has obtained a comprehensive set of imaging and spectroscopy for 75 nearby galaxies. By comparison with optical and ultraviolet SFR tracers, robust extinction-corrected star formation rate indices have been developed. They have been applied to measure the form of the spatially-resolved SFR vs gas density Schmidt law (Kennicutt *et al.* 2007). Among the various observed tracers, the flux at $24\ \mu\text{m}$ has been found a good tracer of star formation, while $8\ \mu\text{m}$ depends more on dust and metallicity (Calzetti *et al.* 2007).

Combined with *HST* optical and *XMM* X-ray results, infrared and UV trace star formation as a function of environment. This gives insight into galaxy interactions and ram pressure triggering mechanisms. Star formation histories have been obtained. While the average SFR increases as z increases, the fluctuations in SFR is not large, and most galaxies spend their time within a factor 2 of the average SFR since $z = 1$ (Noeske *et al.* 2007). The dominant mode of the evolution of SF since $z \simeq 1$ is more a gradual decline of the average SFR than a decreasing frequency of starburst episodes, or a decreasing starburst efficiency. The gradual decline is suggesting gas exhaustion, as a slow quenching of star formation. Poggianti *et al.* (2006) have determined the influence of environment on star formation history. At high z , the star formation in clusters is decreasing with the cluster mass. Galaxy clusters had more star forming galaxies in the past than now, and the quenching occurs earlier for higher masses.

1.2. *Extended UV (XUV) disks*

GALEX has unveiled the existence in UV emission of extended disks of spiral galaxies. While the $H\alpha$ emission is truncated at the optical disk radius, the UV, which is a tracer of older star formation, extends almost as far as the $H\text{I}21\text{cm}$ emission, and correlates with it. Gil de Paz *et al.* (2007) show through abundance measurements, that the outer disks are not made of pristine material, but are enriched like young spiral disks 1 Gyr after these first stars would have formed. The amount of gas in the XUV disks allows maintaining the current level of star formation for at least a few Gyr.

A large survey of UV disks has shown that extended disks are frequent, beyond the threshold of traditional star formation and beyond the limits of old stellar disks (Thilker *et al.* 2007). The star formation in these outer disks could be episodic; these disks are gas rich, and the phenomenon could be due to significant, continued gas accretion from the intergalactic medium or neighboring objects.

1.3. *Bimodality in galaxy colour and classification*

Bimodality has been found in large galaxy surveys, in colour-magnitude diagrams, and many properties follow this feature, like the Sersic index, or the surface brightness (Driver *et al.* 2006). It has been recently found that the number of red galaxies has almost doubled since $z = 1$, while the blue sequence was stationary. Galaxies appear to enter the red sequence via different quenching modes, which vary with time. The red sequence builds up in different ways (merging, external accretion, environment harassment), and the concept of a single process to explain ‘downsizing’ is not likely (Faber *et al.* 2007).

The theory of downsizing however has gained some further support (Cimatti *et al.* 2008). Old, passive galaxies at $z > 1.4$ have been followed in the GOODS fields, and it was shown that major star formation and assembly processes for these galaxies occurred at $z > 2$.

A population of heavily-obscured and distant AGN has been found via mid-infrared excess. About 30% of $z \simeq 2$ galaxies detected at $24\mu\text{m}$ with *Spitzer* show an excess mid-IR emission, with respect to the SED expected from star formation. When their X-ray spectra are stacked, X-ray emission is detected, revealing Compton-thick AGN. The density of these objects on the sky is twice that of X-ray detected AGN, and their fraction increases with galaxy mass, up to 60% at $10^{11} M_{\odot}$ (Daddi *et al.* 2007). These AGN were expected from the observed mass ratio of black holes to stars in local spheroids, and confirms the concurrent growth of both in distant massive galaxies.

An interpretation of the bimodality has been proposed in terms of halo mass categories, and external gas accretion. The latter is cold, under a certain mass threshold, and hot above, since accretion shocks are induced by the depth of the potential well. In halos below a critical shock-heating mass of $\sim 10^{12} M_{\odot}$, discs are built by cold streams, not heated by a virial shock, yielding efficient early star formation (Dekel & Birnboim 2006).

1.4. *Evolution and high- z galaxies*

Large scale structures and galaxy evolution have been studied with deep and wide surveys, such as COSMOS at $z < 1.1$ (Scoville *et al.* 2007), or GOODS (Vanzella *et al.* 2008). The comparison with the large-scale CDM simulations reveal higher overdensities in the observed distribution. The downsizing phenomenon is evident, and galaxies in dense environments tend to be older.

The molecular clouds have been mapped with interferometers (Tacconi *et al.* 2006), and it has been possible to obtain, the first gas rotation curve at high redshifts

(Förster-Schreiber *et al.* 2006). Galaxies reveal disk rotation quite similar to the analogs at low redshifts.

Very deep near-infrared and optical imaging have searched for galaxies at $z \simeq 7-8$, about 700 Myr after the Big Bang (Boowens & Illingworth 2006). Only one candidate galaxy at $z \simeq 7-8$ was found, where ten would be expected if there were no evolution in the galaxy population between $z \simeq 7-8$ and $z \simeq 6$. This demonstrates that very luminous galaxies are quite rare 700 Myr after the Big Bang, which can be explained since the Universe is just too young to have built up many luminous galaxies at $z \simeq 7-8$ by the hierarchical merging of small galaxies.

1.5. *Scaling laws and time evolution*

The Tully-Fisher relation has been observed not to evolve strongly up to $z \simeq 1$, except for a brightening of B-magnitudes, due to star formation. This result is obtained by only taking into account the third of disks that are rotating, and excluding the perturbed ones (Flores *et al.* 2006).

Sheth *et al.* (2008) determine in the COSMOS field that the bar fraction decreases with redshift, refining the previous GEMS survey (Jogee *et al.* 2004).

The SAURON project has studied the kinematics of a large sample of early-type galaxies, and deduced scaling relations and their M/L ratio. The comparison of the dynamical M/L with that inferred from the stellar population, indicates a median dark matter fraction in early-type galaxies of 30% of the total mass inside the characteristic radius R_e . There appears to be a variation in the total to stellar mass ratio, linked to the galaxy dynamics: fast-rotating galaxies have lower dark matter fractions than the slow-rotating and generally more-massive ones (Cappellari *et al.* 2006).

1.6. *Numerical simulations*

There has been remarkable advance in numerical simulations, in particular in the baryonic physics, to probe galaxy formation scenarios. The standard Λ CDM theory encounters difficulties at the galaxy scale, to form disks without bulges, or sufficiently large spiral galaxies, with enough angular momentum. The complex baryon processes, including gas cooling, star formation, the effects of a uniform ultraviolet background and feedback from supernovae or supermassive black holes have been studied (e.g., Bower *et al.* 2006; Cox *et al.* 2006; Governato *et al.* 2007).

The black hole formation has been studied through empirical recipes, and their concurrent formation with bulges has been found compatible with what is expected from the $M(\text{BH}) - \sigma$, or $M(\text{BH}) - M(\text{stars})$ relation. The BH accretion rate density peaks at lower redshift and evolves more strongly at high redshift than the star formation rate density, while the ratio of black hole to stellar mass density shows only a moderate evolution at low redshifts (Di Matteo *et al.* 2008).

Attempts have been made to solve the missing satellite problem, in adapting the cooling and feedback during the hierarchical scenario of structure formation. Suppression of cooling into lower sigma peaks suppresses efficiently satellite galaxies. Re-ionization at $z = 12$ is a way to wash out the formation of these small systems (Moore *et al.* 2006).

The ‘Via Lactea’ N -body simulation, one of the biggest dark matter simulation for a single spiral galaxy, shows that the mass function of CDM subhalos is steeply rising below $10^8 M_\odot$. But the dark to stellar mass ratio is not likely to be constant over the satellite distributions. To reproduce the observations, the brightest satellites must correspond to the earliest forming subhalos (Strigari *et al.* 2007).

2. Conferences

2.1. IAU Symposia and Joint Discussions

The following lists IAU meetings where Commission 28 was widely involved:

- IAU Symposium No. 230 *Populations of High Energy Sources in Galaxies*, 15-19 2005, Dublin, Ireland
- *11th Latin-American Regional IAU Meeting (LARIM-2005)*, 12-16 December 2005, Pucon, Chile
- IAU Symposium No. 235 *Galaxy Evolution across the Hubble Time*, 14-17 August 2006, Prague, Czech Republic
- IAU XXVI General Assembly Joint Discussion 07 *The Universe at $z > 6$* , 17-18 August 2006, Prague, Czech Republic
- IAU Symposium No. 238 *Black Holes – from Stars to Galaxies*, 21-25 August 2006, Prague, Czech Republic
- IAU Symposium No. 241 *Stellar Populations as Building Blocks of Galaxies*, 10-16 December 2006, La Palma, Canary Islands, Spain
- IAU Symposium No. 244: *Dark Galaxies and Lost Baryons*, 25-29 June 2007, Cardiff, UK
- IAU Symposium No. 245 *Formation and Evolution of Galaxy Bulges*, 16-20 July 2007, Oxford, UK
- IAU Symposium No. 254 *The Galaxy Disk in Cosmological Context*, 9-13 June 2008, Copenhagen, Denmark
- IAU Symposium No. 255 *Low-Metallicity Star Formation: From the First Stars to Dwarf Galaxies*, 16-20 June 2008, Rapallo, Liguria, Italy

2.2. Other meetings

There were a long list of international meetings, during the last three years, and we have selected those related to the research domain of Commission 28, from July 2005 to June 2008. The list is not complete, but gives an idea of the wealth of the domain. The list compiled by Liz Bryson at CADC has been extremely useful to build such a summary. See <www1.cadc-ccda.hia-ihp.nrc-cnrc.gc.ca/meetings/>.

- *Island Universes: the Structure and Evolution of Disk Galaxies*, 3-8 July 2005, Terschelling, Netherlands
- *Mass Profiles and Shapes of Cosmological Structures*, 4-9 July 2005, Paris, France
- *Stellar Populations, a Rosetta Stone for Galaxy Formation*, 4-8 July 2005, Ringberg, Germany
- *Mass and Mystery in the Local Group*, 17-22 July 2005, Cambridge, UK
- *Nearly Normal Galaxies 2005*, 7-13 August 2005, Santa Cruz, CA, USA
- *Extreme Starbursts: Near and Far*, 14-20 August 2005, Lijiang, China
- *Stellar Evolution at Low Metallicity: Mass Loss, Explosions, Cosmology*, 15-19 August 2005, Tartu, Estonia
- *QSO Host Galaxies : Evolution and Environment*, 22-26 August 2005, Leiden, Netherlands
- *Outer Edges of Disk Galaxies: A Truncated Perspective*, 4-8 October 2005, Leiden, Netherlands
- *Galactic and Extragalactic ISM Modelling in an ALMA Perspective*, 13-15 October 2005, Onsala, Sweden
- *Origin of Matter and Evolution of Galaxies (OMEG05)*, 8-11 November 2005, Tokyo, Japan

- *The Spitzer Science Center 2005 Conference: Infrared Diagnostics of Galaxy Evolution*, 14-16 November 2005, Pasadena, CA, USA
- *Groups of Galaxies in the Nearby Universe*, 5-9 December 2005, Santiago, Chile
- *From Z-Machines to ALMA: (Sub)millimeter Spectroscopy of Galaxies*, 13-14 January 2006, Charlottesville, VA, USA
- *Galactic Bulges*, 25-26 January 2006, Padova, Italy
- *Aspen Center for Physics: Local Group Cosmology*, 5-11 February 2006, Aspen, CO, USA
- *Globular Clusters - Guides to Galaxies*, 6-10 March 2006, Concepcion, Chile
- *Dwarf Galaxies as Astrophysical and Cosmological Probes*, 12-17 March 2006, Ringberg, Germany
- XXVI Astrophysics Rencontre de Moriond: *From Dark Halos to Light*, 12-18 March 2006, La Thuile, Italy
- *Galaxies and Structures Through Cosmic Times*, 26-31 March 2006, Venezia, Italy
- 36th Advanced Course Swiss Society for Astrophysics and Astronomy, *First Light in the Universe*, 3-8 April 2006, Les Diablerets, Switzerland
- *Cosmology, Galaxy Formation and Astro-particle Physics on the Pathway to the SKA*, 10-12 April 2006, Oxford, UK
- Galactic Center Workshop 2006 *From the Center of the Milky Way to Nearby Low-Luminosity Galactic Nuclei*, 18-22 April 2006, Bad Honnef, Germany
- *Galaxies in the Cosmic Web*, 15-19 May 2006, New Mexico, USA
- Fourth Harvard-Smithsonian Conference on Theoretical Astrophysics *The History of Nuclear Black Holes in Galaxies*, 15-18 May 2006, Cambridge, MA, USA
- *Making the most of the Great Observatories*, 22-24 May 2006, Pasadena, CA, USA
- *Studying Galaxy Evolution with Spitzer and Herschel*, 28 May - 2 June 2006, Agios Nikolaos, Crete, Greece
- *Galaxy Evolution from Large Surveys*, 29 May - 18 June 2006, Aspen, CO, USA
- *Deconstructing the Local Group: Dissecting Galaxy Formation in our own Backyard*, 12 June - 2 July 2006, Aspen, CO, USA
- *The Metal Rich Universe*, Monday, 12 June 2006 - Friday, 16 June 2006, Los Cancijos, La Palma, Canary Islands, Spain
- *Blazars: Disk-jet Connection. Observations and theories*, 12-17 June 2006, Nauchny, Crimea, Ukraine
- *The First Stars and Evolution of the Early Universe*, 19-21 June 2006, Seattle, WA, USA
- *Fine-Tuning Stellar Population Models*, 26-30 June 2006, Leiden, Netherlands
- *Mapping the Galaxy and Nearby Galaxies*, 26-30 June 2006, Ishigaki, Okinawa, Japan
- *Physics and Astrophysics of Supermassive Black Holes*, 9-14 July 2006, Santa Fe, NM, USA
- CRAL Conference Series. I. *Chemodynamics: from First Stars to Local Galaxies*, 10-14 July 2006, Lyon, France
- *Galaxy Redshift Surveys of the Future*, 20 July 2006, Portsmouth, UK
- *Gravitational Lensing*, 31 July - 5 August 2006, Leiden, Netherlands
- *Heating vs. Cooling in Galaxies and Clusters of Galaxies*, 6-11 August 2006, Garching, Germany
- *The Role of Black Holes in Galaxy Formation and Evolution*, 10-13 September 2006, Potsdam, Germany
- EARA Workshop 2006 *Supernovae and their host galaxies*, 2-3 October 2006, Paris, France

- *Applications Of Gravitational Lensing: Unique Insights Into Galaxy Formation And Evolution*, 3-6 October 2006, Santa Barbara, CA, USA
- *Galaxy Mergers: From the Local Universe to the Red Sequence*, 4-6 October 2006, Baltimore, MD, USA
- *Radiation Backgrounds from the First Stars, Galaxies and Black Holes*, 9-11 October 2006, College Park, MD, USA
- *The Central Engine of Active Galactic Nuclei*, 16-21 October 2006, Xi'an, China
- *From Stars to Galaxies: Building the Pieces to Build up the Universe*, 16-20 October 2006, Venice, Italy
- *Massive Galaxies over Cosmic Time. II*, 1-3 November 2006, Tucson, AZ, USA
- *Extragalactic Surveys: A Chandra Science Workshop*, 6-8 November 2006, Cambridge, MA, USA
- 37th Saas-Fee Advanced Course *The Origin of the Galaxy and Local Group*, 4-10 March 2007, Murren, Switzerland
- *Extragalactic surveys with LOFAR*, 6-8 March 2007, Leiden, Netherlands
- *The Origin of Galaxies: Exploring Galaxy Evolution with the New Generation of Infrared-Millimetre Facilities*, 24-29 March 2007, Obergurgl, Austria
- *A New Zeal for Old Galaxies*, 25-30 March 2007, Rotorua, New Zealand
- *ANGLES School on Gravitational Lens Modelling*, 27-30 March 2007, Valencia, Spain
- *New Quests in Stellar Astrophysics. II. The Ultraviolet Properties of Evolved Stellar Populations*, 16-20 April 2007, Puerto Vallarta, Mexico
- *The Nuclear Region, Host Galaxy and Environment of Active Galaxies*, 18-20 April 2007, Huatulco, Oax., Mexico
- *Black Holes*, 23-26 April 2007, Baltimore, MD, USA
- *Pathways Through an Eclectic Universe*, 23-27 April 2007, Playa de La Arena, Tenerife, Spain
- *Black Holes VI*, 12-15 May 2007, White Point, Nova Scotia, Canada
- *Structure Formation in the Universe: Galaxies, Stars, Planets*, 27 May - 1 June 2007, Chamonix, France
- *Obscured AGN across Cosmic Time*, 5-7 June 2007, Bavaria, Germany
- *HI Survival through Cosmic Times*, 11-15 June 2007, Sarteano (Siena), Italy
- *Searching for Strong Lenses in Large Imaging Surveys*, 14-15 June 2007, Batavia, IL, USA
- *Tracing Cosmic Evolution with Clusters of Galaxies: Six Years Later*, 25-29 June 2007, Sesto Pusteria, Italy
- *Galaxy Interactions and Mergers*, 4-5 July 2007, Nottingham, UK
- *Galaxies in the Local Volume*, 8-13 July 2007, Sydney, Australia
- *From IRAS to HERSCHEL/PLANCK: cosmology with infrared and submillimetre surveys*, 9-11 July 2007, London, UK
- *Galaxy Growth in a Dark Universe*, 16-20 July 2007, Heidelberg, Germany
- *Dynamics of Galaxies*, 6-10 August 2007, Saint Petersburg, Russia
- *Star Formation, Then and Now*, 13-17 August 2007, Santa Barbara, CA, USA
- *The Globular Clusters - Dwarf Galaxies Connection*, 27-29 August 2007, Ann Arbor, MI, USA
- *X-rays from Nearby Galaxies*, 5-7 September 2007, Madrid, Spain
- MPA/ESO/MPE/USM 2007 Joint Astronomy Conference *Gas Accretion and Star Formation in Galaxies*, 10-14 September 2007, Garching, Germany
- *Next Generation of Computational Models of Baryonic Physics in Galaxy Formation: From Protostellar Cores to Disk Galaxy Formation*, 17-21 September 2007, Zurich, Switzerland

- *Formation and Evolution of Galaxy Disks*, 1-5 October 2007, Rome, Italy
- *Spectroscopy in Cosmology and Galaxy Evolution 2005-2015*, 3-5 October 2007, Granada, Spain
- *Indian Conference on Cosmology and Galaxy Formation*, 3-5 November 2007, Allahabad, India
- *ELSA school on the Science of Gaia*, 19-28 November 2007, Leiden, Netherlands
- *Galaxy and Black Hole Evolution: Towards a Unified View*, 28-30 November 2007, Tucson, AZ, USA
- *The Evolving Interstellar Medium in the Milky Way and Nearby Galaxies*, 2-5 December 2007, Pasadena, CA, USA
- 1st Subaru International Conference *Panoramic Views of Galaxy Formation and Evolution*, 11-15 December 2007, Hayama, Japan
- *Surveys and Simulations of Large-Scale Structure: A Celebration of Marc Davis' 60th Birthday*, 16-18 January 2008, Berkeley, CA, USA
- *Galaxy Evolution from Mass-Selected Samples*, 28 January - 1 February 2008, Leiden, Netherlands
- *The Evolution of Galaxies through the Neutral Hydrogen Window*, 1-3 February 2008, Arecibo, Puerto Rico
- *The Dark Side of the Universe through Extragalactic Gravitational Lensing*, 4-8 February 2008, Leiden, Netherlands
- *Observational Evidence for Black Holes in the Universe*, 10-15 February 2008, Kolkata, India
- *The First Two Billion Years of Galaxy Formation: The Reionization Epoch and Beyond*, 11-15 February 2008, Aspen, CO, USA
- *EARA Workshop: Herschel Promises for Galaxy Evolution Studies*, Monday, 18 February 2008 - Tuesday, 19 February 2008, Paris, France
- *Galactic & Stellar Dynamics in the Era of High Resolution Surveys*, 16-20 March 2008, Strasbourg, France
- *Galactic Structure and the Structure of Galaxies*, 17-21 March 2008, Ensenada, Baja California, Mexico
- *Deep Surveys of the Radio Universe with SKA Pathfinders*, 31 March - 4 April 2008, Perth, Australia
- *An XXL Extragalactic Survey: Prospects for the XMM Next Decade*, 14-16 April 2008, Paris, France
- *Galaxy Formation and Evolution as Revealed by Cosmic Gas*, 17-19 April 2008, Irvine, CA, USA
- *Blazars Variability across the Electromagnetic Spectrum*, 22-25 April 2008, Paris, France
- *Cosmic Web: Galaxies and the Large-Scale Structure*, 16-17 May 2008, Socorro, NM, USA
- OXFORD-COSMOCT Workshop on *The Interface between Galaxy Formation and AGN*, 19-22 May 2008, Island of Vulcano, Messina, Italy
- *The Central Kiloparsec: Active Galactic Nuclei and Their Hosts*, 4-6 June 2008, Ierapetra, Crete, Greece
- *Gas and Stars in Galaxies: A Multi-Wavelength 3D Perspective*, 10-13 June 2008, Garching, Germany
- *Tidal Dwarf Galaxies: Ghosts from Structure Formation*, 15-20 June 2008, Bad Honnef, Germany
- *Merging Black Holes in Galaxies: Galaxy Evolution, AGN and Gravitational Waves*, 15-20 June 2008, Sydney, Australia

3. Review articles

- Athanassoula, E. 2008, in: M. Bureau, E. Athanassoula & B. Barbuy (eds.), *Formation and Evolution of Galactic Bulges*, Proc. IAU Symposium No. 245 (Cambridge: CUP), p. 93, *Boxy/Peanut and Discy Bulges: Formation, Evolution and Properties*
- Bregman, J. 2007, *ARAA*, 45, 221, *The Search for the Missing Baryons at Low Redshift*
- Brodie, J. P., & Strader, J. 2006, *ARAA*, 44, 193, *Extragalactic Globular Clusters and Galaxy Formation*
- Combes, F. 2008, in: M. Bureau, E. Athanassoula & B. Barbuy (eds.), *Formation and Evolution of Galactic Bulges*, Proc. IAU Symposium No. 245 (Cambridge: CUP), p. 151, *Gaseous Flows in Galaxies*
- Fabbiano, G. 2006, *ARAA* 44, 323, *Populations of X-Ray Sources in Galaxies*
- Gadotti, D. A. 2008, in: G. Contopoulos, & P. A. Patsis (eds.) *Chaos in Astronomy*, in press [arXiv:0802.0495], *Barred Galaxies: An Observer's Perspective*
- Li, A. 2007, in: L. C. Ho & J.-M. Wang (eds.), *The Central Engine of Active Galactic Nuclei*, *ASP-CS* 373, 561, *Dust in Active Galactic Nuclei*
- Mayer, L., Governato, F., & Kaufmann, T. 2008, *Advanced Science Letters*, in press [arXiv:0801.3845], *The Formation of Disk Galaxies in Computer Simulations*
- McNamara, B. R., & Nulsen, P. E. J. 2007, *ARAA*, 45, 117, *Heating Hot Atmospheres with Active Galactic Nuclei*
- Omont, A. 2007, *Rep. Prog. Phys.*, 70, 1099, *Molecules in Galaxies*
- Renzini, A. 2006, *ARAA*, 44, 141, *Stellar Population Diagnostics of Elliptical Galaxy Formation*

4. Closing remarks

Commission 28 is more lively than ever. The era of large galaxy surveys, such as the SDSS, and the search for statistical samples at higher and higher redshifts, have triggered wide modelisation efforts and numerical simulations, to tackle galaxy formation and evolution. At the IAU XXVI General Assembly in Prague, 2006, the Symposia organised by Commission 28 had by far the widest attendance. Out of the 40 IAU Commissions, Commission 28 has about 850 members, i.e. nearly 10% of all members.

With the prospective of future space or ground instruments, such as ALMA, ELTs or SKA, the progress in the domain is expected to grow at even higher rate, ensuring an exciting future.

Françoise Combes
president of the Commission

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