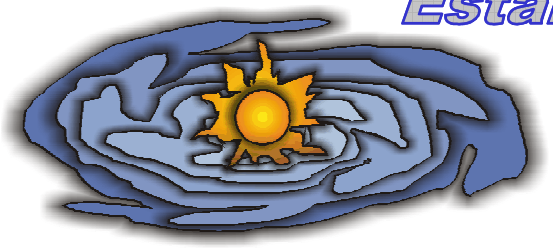
Estallidos de formación estelar en galaxias

Puerto de la Cruz, 12-14 December 2007

Massive Compact Nuclear Star Clusters (MCNSC) in Normal Galaxies and their relation with Supermassive Black Holes (SMBH)

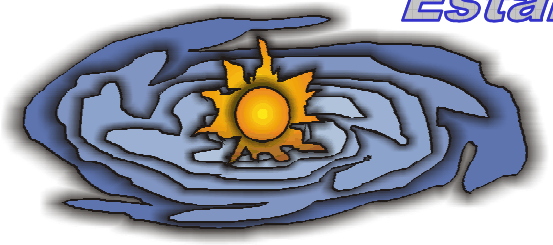
Roberto Terlevich et al. (INAOE,UAM,IoA)



Summary

- We propose a medium/long term project to investigate the properties of MCNSC, their relation with SMBH, with the circmnuclear regions of starformation and with disk star formation.

- For the first observational stage we propose high spatial resolution imaging of a volume limited sample of nearby normal galaxies (D<15Mpc), the results of this imaging will be useful for a wide range of studies.



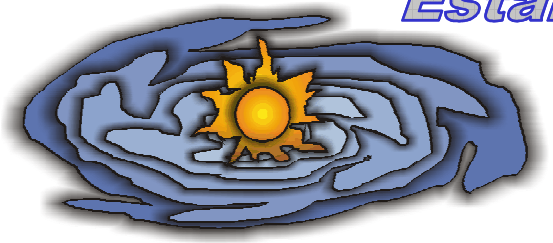
SCIENCE CASE

Section 1 - SMBH in Normal Galaxies

Several star and gas dynamical studies have concluded thatmany luminous galaxies contain central SMBHs. Following the discovery that the SMBH masses correlate with various properties of the host galaxy such as bulge luminosity (Kormendy & Richstone 1995), mass (Haring & Rix 2004), velocity dispersion (Ferrarese & Merritt 2000; Gebhardt et al. 2000a), light concentration (Graham et al. 2001), and halo circular velocity (Ferrarese 2002), it has become widely accepted that SMBH and galaxy formation are somehow related.

Unfortunately, the physical mechanisms supporting the star/galaxy formation-SMBH connection are not known (e.g. Silk & Rees 1998; Portegies Zwart et al. 2004; Shapiro 2005). Despite a huge observational effort, only about 30 galaxies have "safe" SMBH detections (see the recent review by Ferrarese & Ford 2005), the great majority of which are luminous galaxies with magnitudes in the range -22<MB<-18.

It is not clear if fainter and less massive galaxies also contain SMBH and, if so, whether such objects would obey extrapolations of the SMBH scaling relations defined by the bright galaxies. Searches for SMBHs in low-luminosity members of the Local Group have so far produced ambiguous results. There is no evidence for a SMBH in either M33 (Merritt et al. 2001; Gebhardt et al. 2001) or NGC 205 (Valluri et al. 2003), yet M32 does appear to contain a SMBH with mass ~ 2.5 x 10^6 Msun (Verolme et al. 2002). Although they have very different morphologies, M33 (Sc II-III) and NGC 205 (S0/E5pec) share one interesting similarity: their centers are both dominated by a compact stellar cluster (with half-light radius rh . 2-4 pc) that is ~20 times brighter than a typical globular cluster (e.g., Kormendy & McClure 1993; Butler & Martinez-Delgado 2005). While ground-based surveys of the Virgo and Fornax clusters have shown that\~ 25\% of dE galaxies contain such nuclei (e.g. Binggeli, Tammann & Sandage 1985; Ferguson 1989; Binggeli & Cameron 1991), recent observations with the HST have revealed them to be far more common.

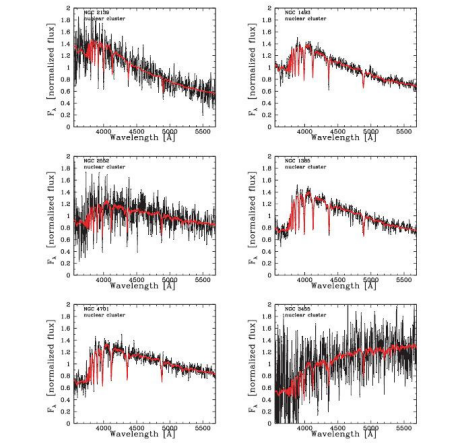


Section 2 - Massive Compact Nuclear Clusters in normal galaxies

The centres of normal galaxies have been studied for decades using ground-based observations. However, only with the advent of high spatial resolution observations from the HST it became clear that there is still much to be learned. As mentioned above, a particularly exciting finding has been the fact that most spiral galaxies have a massive and compact star cluster in their very center (MCNSC).

In fact, about 50-70% of late-type galaxies observed by HST contain a nuclear cluster (Carollo, Stiavelli & Mack 1998; Matthews et al 1999; B¨oker et al. 2002, 2004; Balcells et al. 2003). A recent HST survey of 100 galaxies in the Virgo Cluster has detected nuclei in a comparable fraction (66$(G!9(B82%) of early-type galaxies (Cot´e et al. 2006; see also Lotz et al. 2004; Graham & Guzman 2003; Grant et al. 2005). The agreement between the positions of these nuclear clusters and the isophotal centers of the galaxies is generally better than 1arcsec and consistent with zero displacement (Bo¨ker et al. 2002). These objects have now been studied in detail for large samples using broadband imaging with HST -F¢s Wide Field Planetary Camera (WFPC; Phillips et al. 1996),-A Wide Field Planetary Camera 2 (WFPC2; Carollo et al. 1997, 1998; Matthews et al. 1999; Bo¨ker et al. 2002, 2004), and Near-Infrared Imaging Camera and Multi- Object Spectrometer (NICMOS) (Carollo et al. 2001, 2002). These projects have shown that at least 50% of early-type and 75% of late-type spirals host a massive nuclear cluster.

This relatively recent area of research has already provided some unexpected and potentially important new results summarized in what follows.



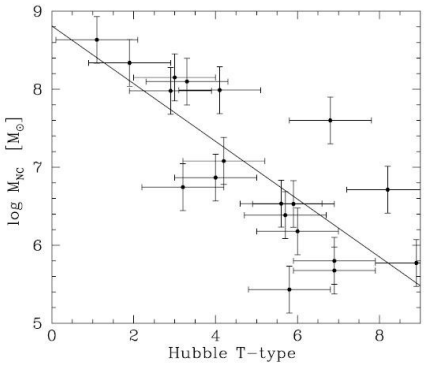


FIG. 9.—Relation between the NC mass M listed in Table 4 and the Hubble T-type of the host galaxy (Tables 1 and 2). Masses were assigned a measurement uncertainty of 0.3 dex, based on the discussion in § 6.3. Hubble T-types were, somewhat arbitrarily, assigned an uncertainty of 1.0. Early-type spirals tend to have more massive NCs. The solid line indicates the best linear fit, the parameters of which are listed in Table 6.

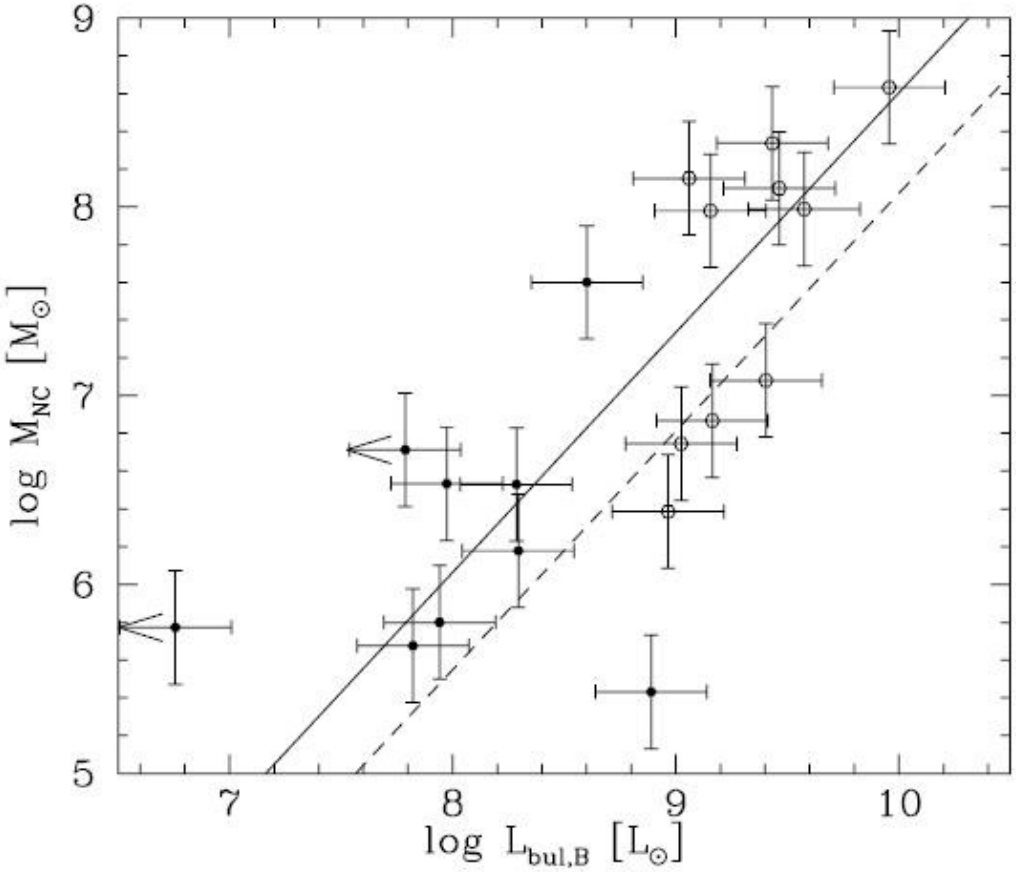


FIG. 15.—Relation between the NC mass M (listed in Table 4) and the B-band luminosity $L_{bul,B}$ of the host galaxy bulge. Masses were assigned a measurement uncertainty of 0.3 dex, based on the discussion in § 6.3. The measurement uncertainties in $L_{bul,B}$ are dominated by variations in disk-to-bulge ratios among galaxies and were somewhat arbitrarily assigned a value of 0.25 dex. There is a strong correlation in the sense that galaxies with more luminous bulges

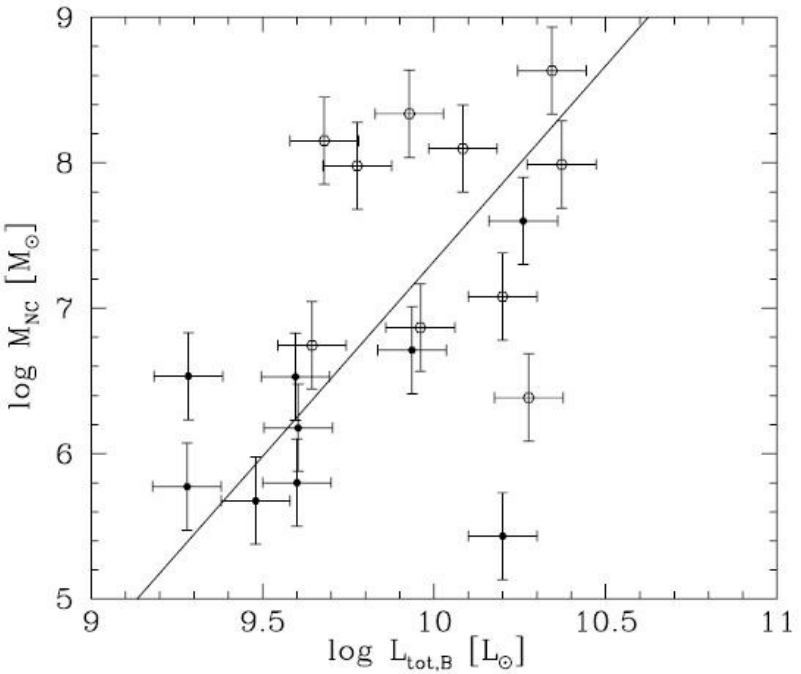


FIG. 14.—Relation between the NC mass M listed in Table 4 and the total B-band luminosity L_B of the host galaxy. Masses were assigned a measurement uncertainty of 0.3 dex, based on the discussion in § 6.3. The measurement uncertainties in L_B are not well known and were somewhat arbitrarily assigned a value of 0.1 dex. There is a weak correlation in the sense that more luminous galaxies have more massive NCs. Open symbols denote early-type spirals, and filled symbols denote late-type spirals. The solid line indicates the best linear fit, the parameters of which are listed in Table 6.

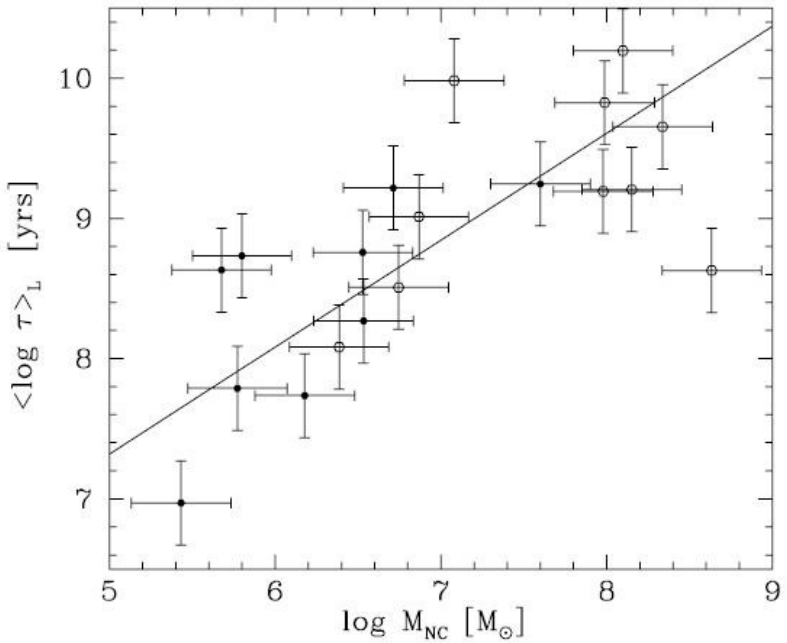


FIG. 16.—Correlation between the NC mass M and the luminosity-weighted age $\langle \log \tau \rangle_L$ (listed in Table 4). Both quantities were assigned a measurement uncertainty of 0.3 dex, based on the discussions in §§ 4.3 and 6.3. More massive clusters tend to have older stellar populations (and tend to reside in earlier-type spirals) than less massive clusters. Open symbols denote NCs in early-type spirals, and filled symbols denote NCs in late-type spirals. The solid line indicates the best linear fit, the parameters of which are listed in Table 6.

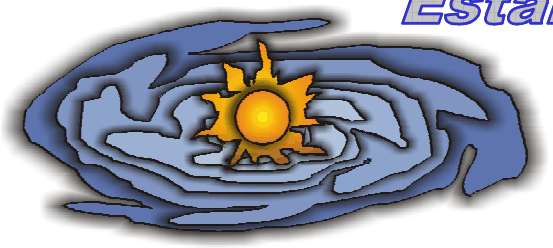
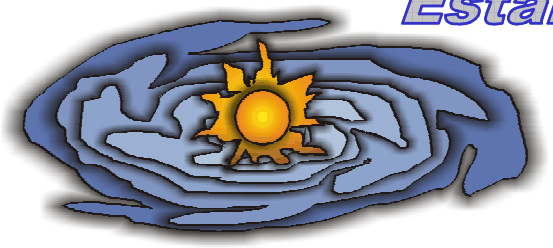


TABLE 4

NC Properties from Spectral Population Fits and Derived Masses

Galaxy (1)	Z (2)	A_V (3)	$\langle \log \tau \rangle_L$ (4)	$\langle \log \tau \rangle_M$ (5)	M/L_B ($M_\odot\ L_{B,\odot}^{-1}$) (6)	$\chi^2_{\rm red}$ (7)	$\log M$ ($M_\odot$) (8)	σ (Km/s)
Early-Type Spiral Galaxies								
NGC 1325	0.008	0.3	9.98	10.13	3.65	2.19	7.08	4.4
NGC 1385	0.008	0.3	8.08	9.01	0.12	3.02	6.39	1.8
NGC 3177	0.05	0.3	9.21	10.05	2.72	9.37	8.15	4.3
NGC 3277	0.05	0.0	9.65	10.24	8.18	5.89	8.34	9.0
NGC 3455	0.02	1.4	8.51	9.48	0.57	2.26	6.75	2.9
NGC 4030	0.05	0.0	9.83	10.28	8.96	3.66	7.99	4.6
NGC 5377	0.02	0.2	8.63	10.13	1.39	3.28	8.63	18.1
NGC 5806	0.02	0.6	10.20	10.30	7.97	2.42	8.11	7.3
NGC 7421	0.05	0.0	9.01	9.14	0.74	2.80	6.87	5.6
NGC 7690	0.02	0.1	9.19	10.13	2.12	2.58	7.98	5.7
Late-Type Spiral Galaxies								
NGC 300	0.004	0.4	8.63	9.62	0.51	3.46	5.68	
NGC 428	0.02	0.1	9.22	9.65	1.18	2.42	6.71	
NGC 1493	0.02	0.0	7.74	8.72	0.12	2.95	6.18	
NGC 2139	0.02	0.1	6.97	7.74	0.02	3.03	5.43	
NGC 2552	0.02	0.5	7.79	8.87	0.17	2.84	5.77	
NGC 4411B	0.05	0.8	8.76	8.85	0.36	2.35	6.53	
NGC 4701	0.008	0.4	8.27	9.00	0.17	3.49	6.53	
NGC 4775	0.02	0.5	9.25	10.04	1.87	3.56	7.60	
NGC 5585	0.004	0.7	8.73	9.14	0.26	3.06	5.80	

Note—Col. (1): Galaxy name. Cols. (2) and (3): Metallicity and extinction that give the best fit to the observed spectrum. Cols. (4) and (5): Luminosity-weighted and mass-weighted average value of log τ for the best spectral population fit, where τ is the population age in years. Col. (6): B-band mass-to-light ratio for the NCs in solar units. Col. (7): χ^2 per degree of freedom of

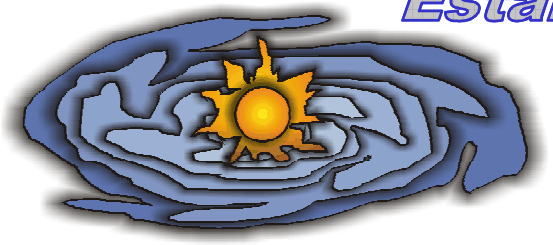


NUCLEAR CLUSTERS ARE MASSIVE AND EXTREMELY COMPACT!

- Typical masses are about 10^7 - 10^9 Msun (between 10^2 and 10^4 times the mass of a Globular Cluster),

- Typical Radii are between 2 and 20 pc (Rossa etal 2006 AJ 132,1074) (similar to that of a globular cluster),

- From their masses and radii it is possible to estimate their velocity dispersions. They are typically about 80-130Km/s for the most massive and compact subset of Rossa et al sample.



The properties of the MCNSC correlate with the host galaxy properties.

- 1- There is a good relation between the mass of the MCNSC and the Hubble type,
- 2- There is a loose relation between the mass of the MCNSC and the Total blue luminosity of the galaxy,
- 3- There is a good relation between the mass of the MCNSC and the bulge luminosity
- 4- Relations 2 and 3 are similar to those holding for SMBH!!!!
- 5- The ``age'' of the MCNSC seems related to the Hubble type of the galaxy Late type galaxies tend to harbour younger MCNSC.

Surprisingly, according to Ferrarese etal 2006, there is continuity in all the observed properties among Compact Nuclear Objects (CNO): (CNO = MCNSC + SMBH candidates) suggesting a common origin or even a common underlying physics.

The main difference being that while SMBH candidates populate massive bulges/galaxies, MCSNC are found preferentially in low mass bulges/galaxies.

This is an important result given that the properties of the SMBH are mainly derived from the properties of the nuclear stellar population (kinematics and brightness profiles) of the host galaxy i.e. similar information to that used for the MCNSC.

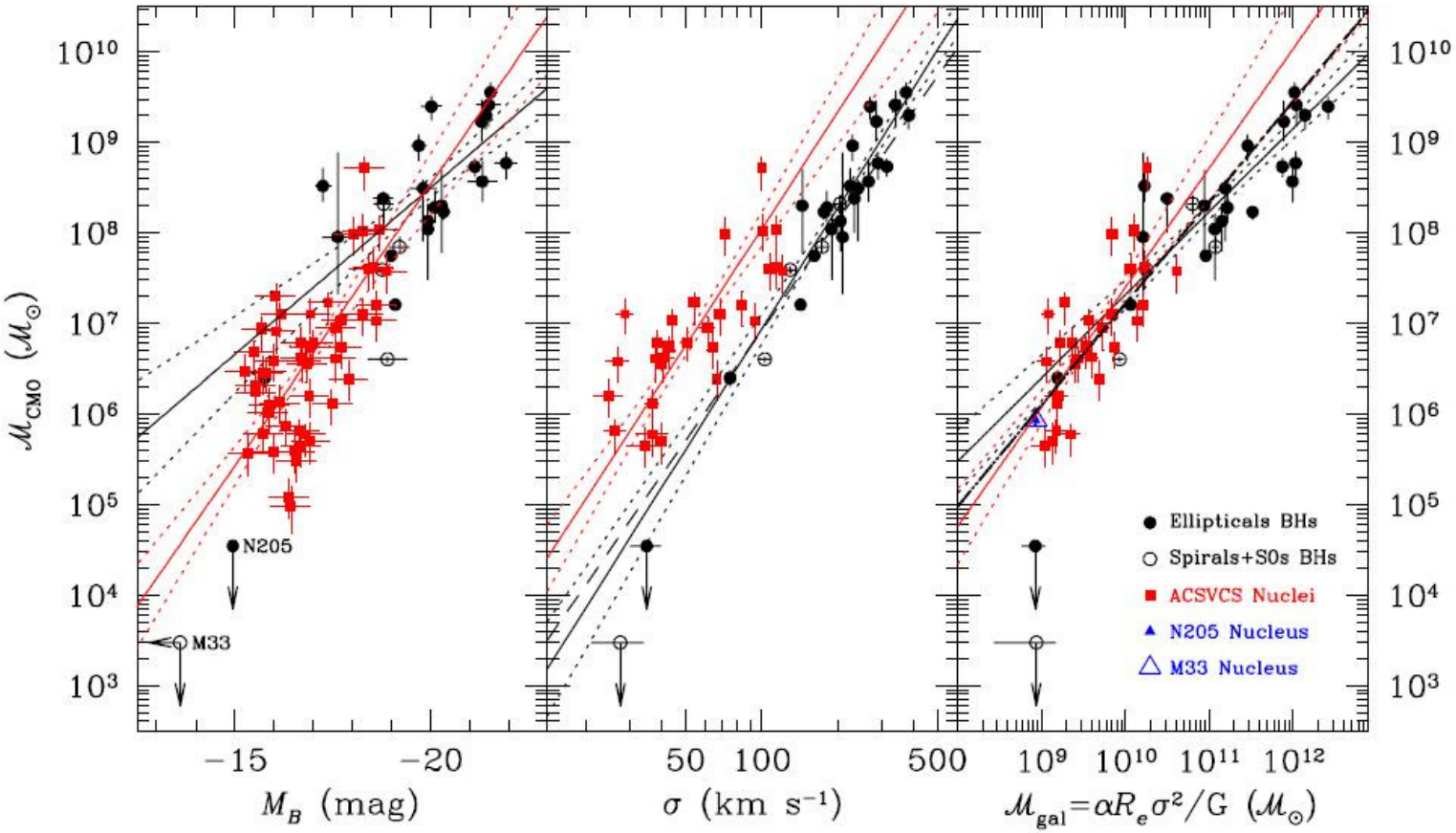
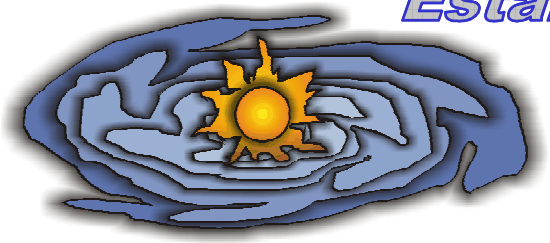


FIG. 2.— *(Left Panel)* Mass of the Central Massive Object (CMO) plotted against absolute blue magnitude of the host galaxy (or bulge for spiral galaxies). Nuclei from the ACSVCS are shown as red squares. The supermassive black holes (SBHs) in early-type and spiral galaxies are shown as filled and open circles respectively. *(Middle Panel)* CMO mass as a function of velocity dispersion of the host galaxy, measured within R_e. *(Right Panel)* CMO mass plotted against galaxy mass, defined as $\mathcal{M}_{\rm gal} \equiv \alpha R_e \sigma^2/G$ with $\alpha = 5$. In all panels, the solid red and black lines show the best fits to the nuclei and early-type SBH samples respectively, with 1σ confidence levels shown by the dotted lines. In the middle panel, the dashed line is the best fit $\mathcal{M}_{\rm SBH}$-σ relation of Tremaine et al. (2002). In the right panel, the dashed line is the fit obtained for the combined nuclei+SBH sample. Coefficients for all fits are listed in Table 1.

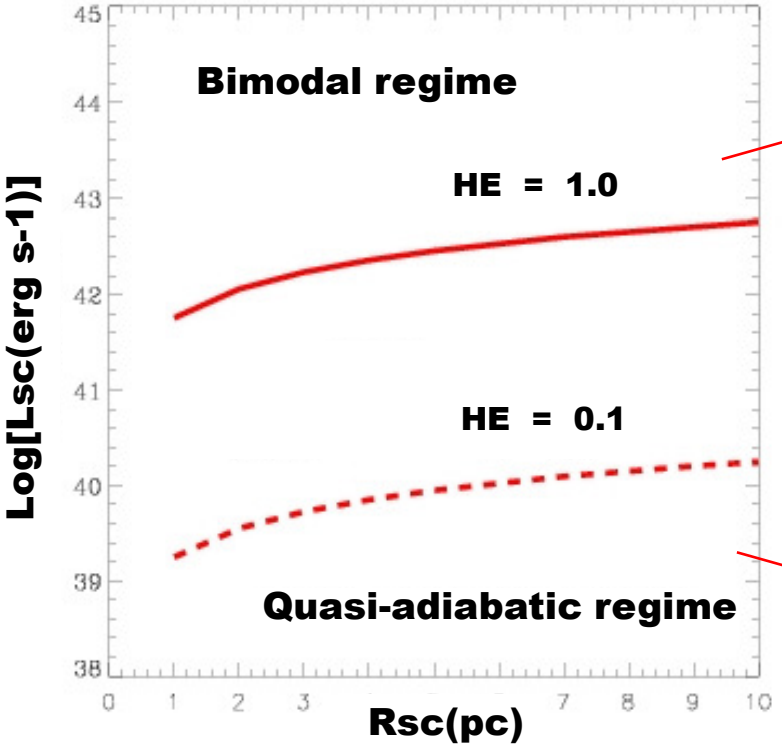


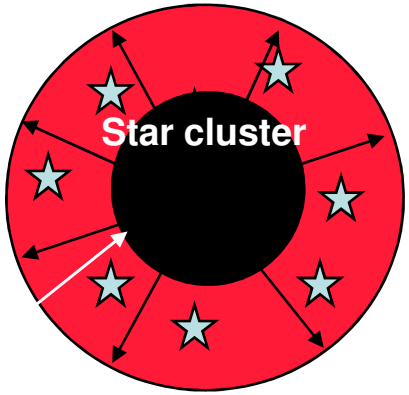
BIMODAL MODE??

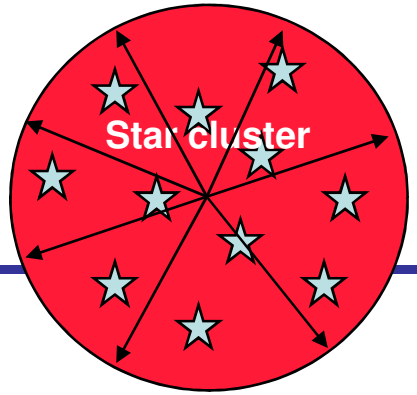
From the theoretical point of view, MCNSC lay close to the "critical line" of models for massive star clusters in the Size vs Mass diagram (Silich et al 2004 ApJ,610,226; Tenorio-Tagle et al 2007 ApJ, 658,1196; Wunsch et al.~2007 astr-ph/0706.1889). This implies that the behaviour of ejecta from massive stars and SN is in the transition region between the quasi-adiabatic regime and the bimodal or high accretion rate mode. For clusters that populate this region of the diagram, a substantial fraction of their ejecta will be retained instead of expelled as occurs in clusters with either lower mass or larger radii.

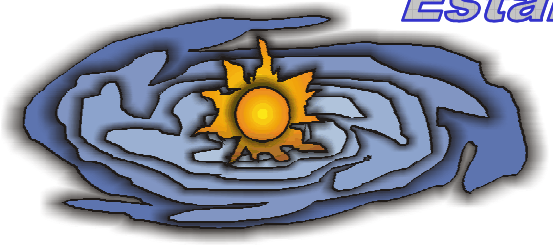
This will lead in MCNSC to either further self-enriched star formation or to the fuelling of an hypothetical central BH.

In the bimodal regime, radiative cooling moves the stagnation radius out of the cluster center. All matter reinserted within this volume losses its pressure and cannot participate in the cluster wind, what leads to mass accumulation and to positive feedback. Matter deposited in the outer zone still develops a wind.



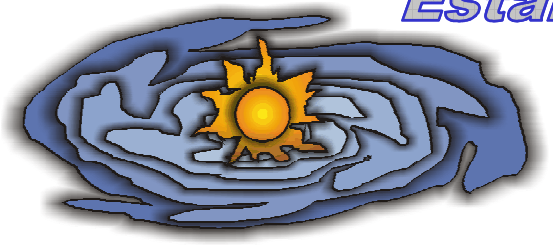






There are several important questions

- How are these MCNSC formed?
- What are their evolution and final state?
- What is their relation with a central SMBH?
- What causes the continuity of observables between MCNSC and SMBH?
- What is the relation between MCNSC and CNSFR?
- What is the relation between MCNSC and "normal" disk or spiral arm regions of massive star formation (MSC)?
- What is the IMF of MCNSC?
- **Is the IMF the same in MCNSC, CNSFR and disk GHIIR?**
- Are current models of stellar evolution valid for MCNSC?
- What are the gas and stellar kinematics like?
- Is the gas kinematics the same in all emission lines at all frequencies?
- How is the chemical evolution of these MCNSC? Are they self-enriched?

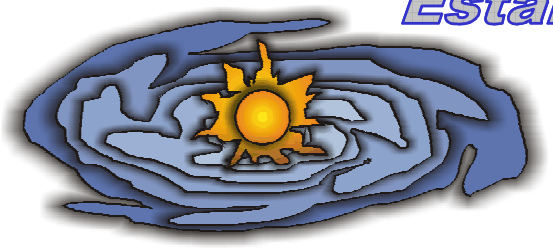


PROJECT STRATEGY

1-SAMPLE SELECTION

- The first step is to produce a VOLUME limited sample of nearby (Distance $<$ 16Mpc), "equatorial" (Dec \pm 30, so it will be accessible both from southern and northern large telescopes) (e.g. from B.Tully sample). At 16Mpc OSIRIS scale is ~10pc/pixel (9.8pc/px).
- From Tully's catalogue of nearby galaxies NBGC we obtain a sample of 291 galaxies closer than 16Mpc (using Tully's distance parameter with Ho=75 Km/s Mpc) and inside the equatorial band.
- In the sample there are:
-
- 19 Ellipticals
- 2 E/S0
- 14 S0
- 8 S0/a
- 8 Sa
- 7 Sab
- 21 Sb
- 18 Sbc
- 41 Sc
- 23 Scd
- 13 Sd
- 13 Sdm
- 35 Sm
- 49 Ir
- 6 S Spiral/Irregular (classification uncertain)
- 15 P Peculiar

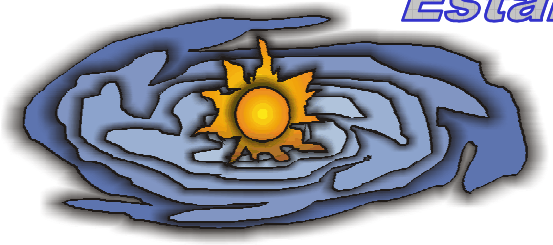
Inside a volume of 8Mpc radius there are 155 galaxies (4.8pc/px)
Inside a volume of 4Mpc radius there are 59 galaxies (2.4pc/px)
Inside a volume of 2Mpc radius there are 20 galaxies (1.2pc/px)



TASKS

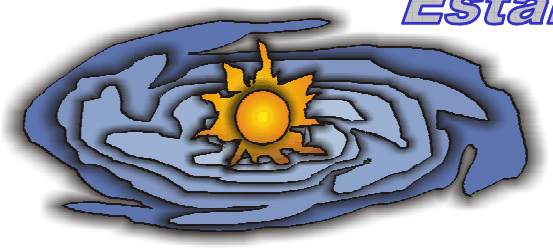
Rapid growth of information on the sample will be achieved by cross-comparison with all available databases (observations and literature) Clearly the HST database is of the greatest importance.

The time scale for this archival stage should be less than 3 months to be ready in time for end of march dead-lines for telescope time.

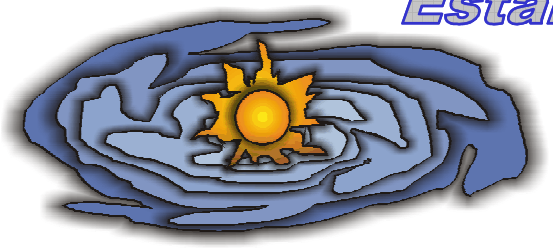


2-DATA ACQUISITION

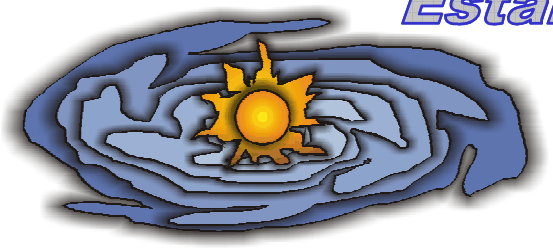
- CENTRAL SCOPE: Deep images with high spatial resolution (<~ 10pc) in continuum (narrow u,b,v,r,i) and lines, both emission and absorption, in narrow filters of a volume limited sample of nearby (D<8Mpc) equatorial galaxies.
- These will provide a unique high spatial resolution high S/N database for galaxy research and, among other things, emission line corrected colours and in particular for this project a complete sample of nuclear, circumnuclear and disk clusters with good estimates of its mass, age and metal content of their stars and ionized gas. These colour images will be spectacular!
- Being an equatorial sample allows access from most facilities.
- Many of the galaxies of the sample have already been or will be soon mapped in several other wavelengths from UV to radio.

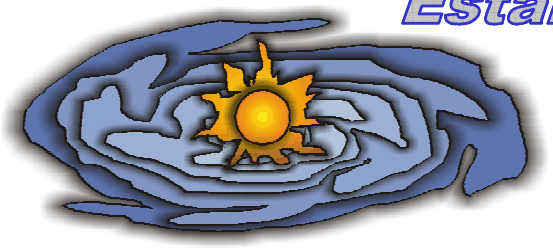


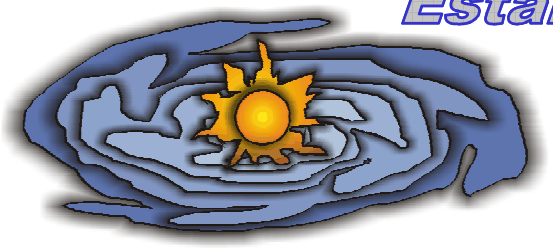
- Cluster Masses will be derived from sizes and velocity dispersions => sigma ~ 10 Km/s (> 30 Km/s for nuclear ones) S/N ~ 20 R~20000 observations (UVES, SUBARU ECHELLE)
- Stellar populations determination and precise abundances, => wide wavelength coverage, resolution ~50 Km/s R~5000 (X-SHOOTER ESO)
- Canaricam with its field of 25 x 20 arcsec should provide sharp FIR images of individual selected regions.

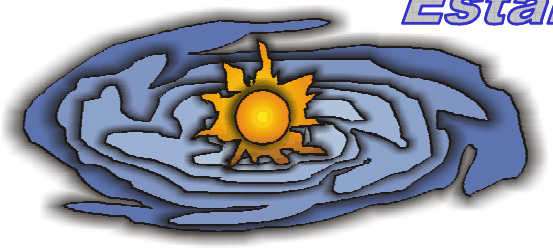


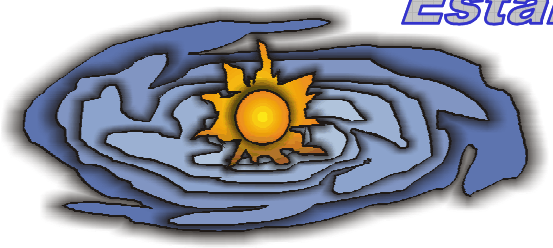
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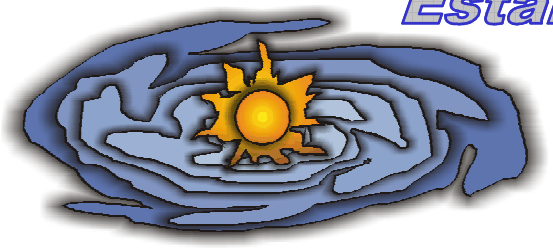


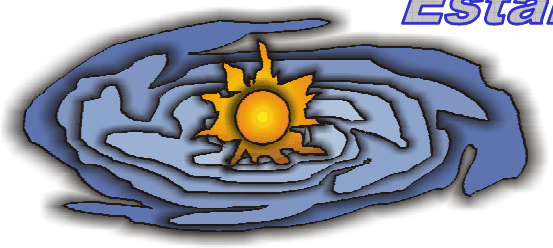


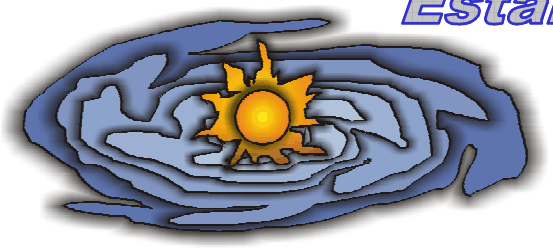


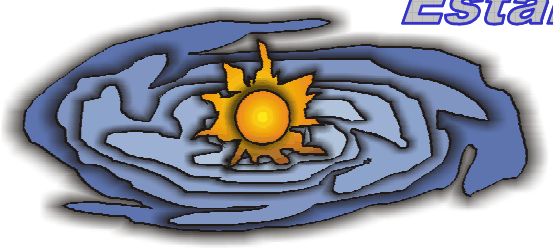


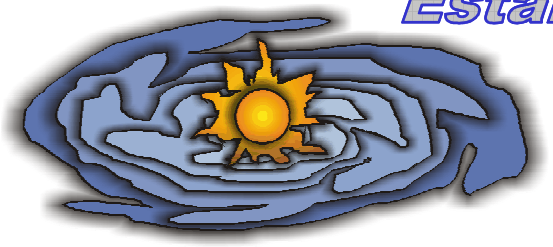










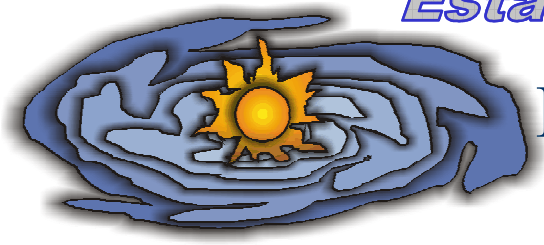


Supercumulos Estelares y su impacto.

- Evolución e impacto de un Supercúmulo- el feeback.
  - Cuanta masa se usa y re-usa?
  - Impacto en el halo?, regiones HII....cascarones (kpcs)-El DIG, el froth...

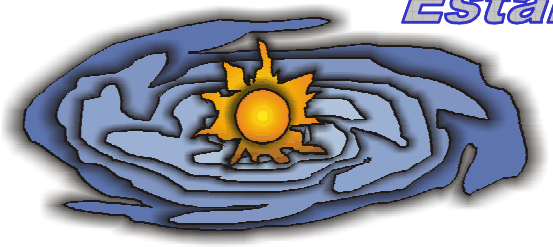
- Evolución e impacto de Supercúmulos compactos.
  - Supervientos, superburbujas o mas estrellas?? El feedback.

- Muestra 1 (TBD): cúmulos y SSCs compactos (hasta decenas pcs); y con masas diversas (10^4- 10^6-7)
- Muestra 2: galaxias con la población de SSCs ya caracterizada (con el HST); casos de alta (tipo M82 o NGC 3079) y baja (e.g. NGC 1569) densidad de fuentes (SSCs).
- Observaciones: OSIRIS (TF)-para estructuras extendidas. Espectroscopia multiobjeto (osiris) caracterizar cúmulos.



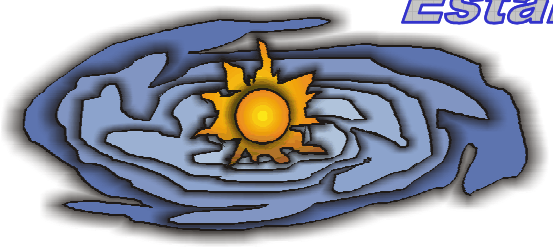
Los aglomerados de las Clumpy Galaxies... el caso de retroalimentación positiva?

- Galaxias(?) descubiertas en el UHDF..
- Dos o más aglomerados (kpc) de estrellas jóvenes...supermasive, young cluster (?)
- Existen desde cerca hasta cerca de z=5...
- No sabemos si tienen líneas de emision.
- “Dicen” que son galaxias (objeto del equipo SINK)...
- Ya estamos intentándolo en el sur...SINFONI-VLT



Los aglomerados de las Clumpy Galaxies... el caso de retroalimentación positiva?

- Buscar muestra de posibles candidatos para el norte- candidatos GTC (usando archivos) Supervientos, superburbujas o mas estrellas?? El feedback.
- Observaciones: OSIRIS (TF)-para estructuras extendidas. Espectroscopia rendija larga (osiris) e imagen Canarican para caracterizar aglomerados.



Formación estelar y feedback: de SSCs a Galaxias Clumpy

TEAM:

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