Neutral gas in Blue Compact Dwarf Galaxies

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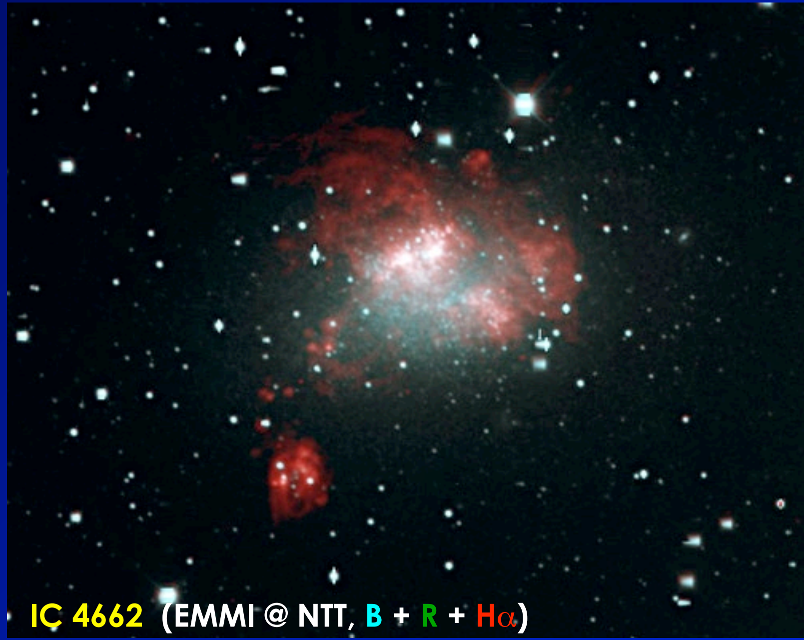
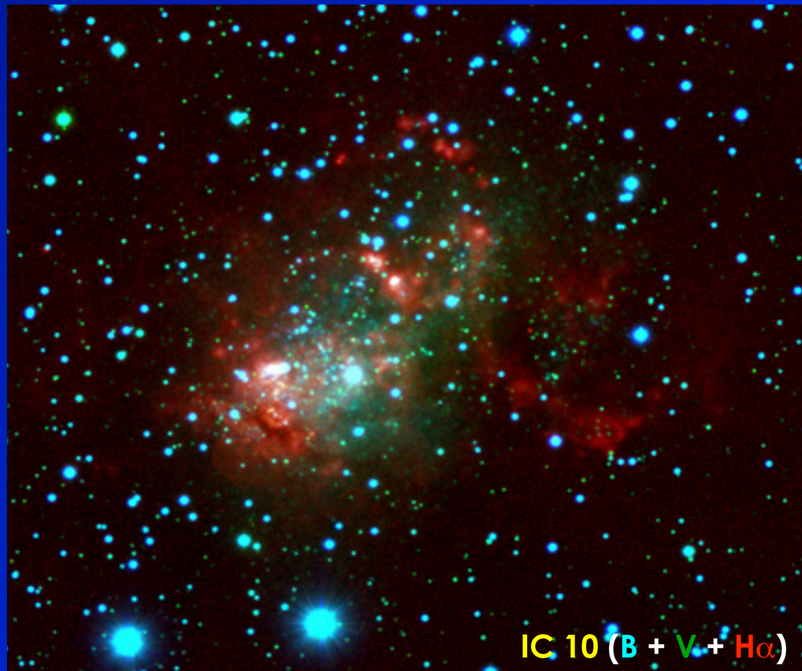
***Evolution Paths in Galaxy Morphology* – Sydney – Australia – 26 September 2013**

Blue Compact Dwarf Galaxies (BCDG)

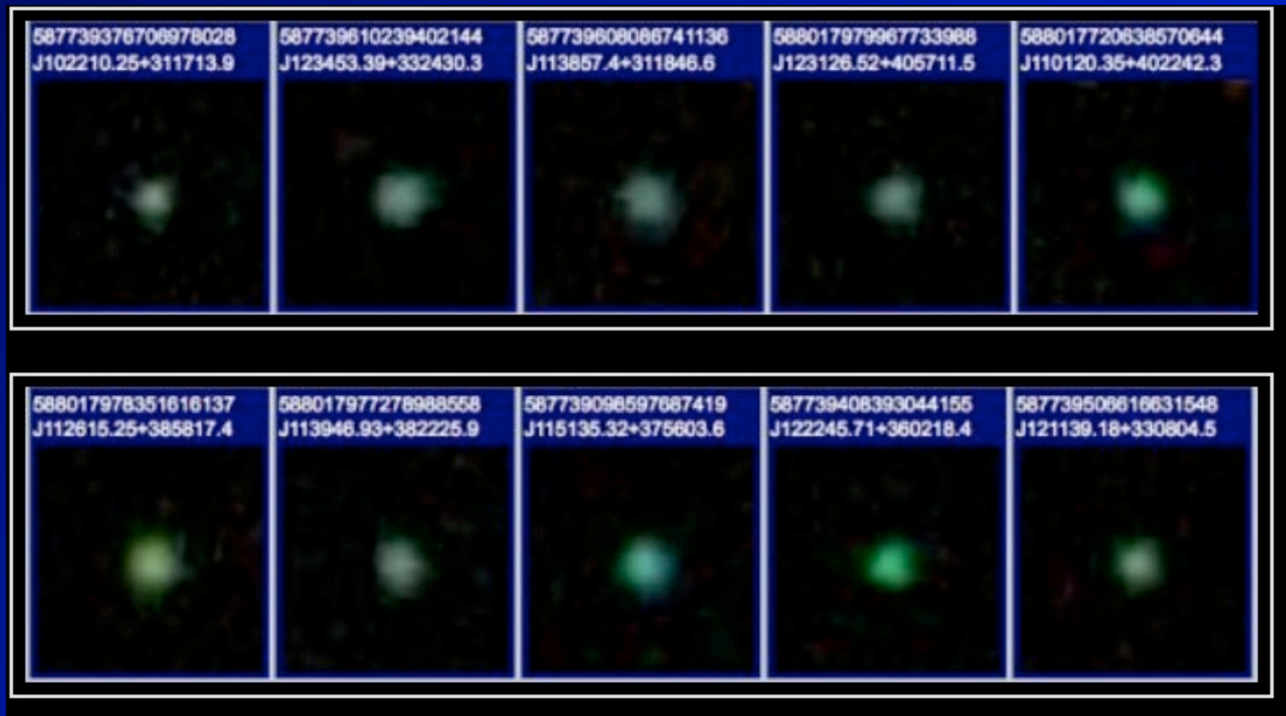
- **Subset of low-luminosity** ($M_B \geq -18$) and **low metallicity** (~10% solar) galaxies undergoing a **strong** and **short-lived** episode of **star formation.**
- Quickly gas consumption.
- **Compact**, **irregular** morphologies
- Intense **narrow emission lines** superposed on a **blue continuum**.
- The **starbust** and a **very young stellar population** dominate the optical light (Cairós et al. 2001), very often **masking** all evidence of the **underlying older stellar population**(Noeske et al. 2003).
- What is the **origin** and **nature** of their starburt activity?





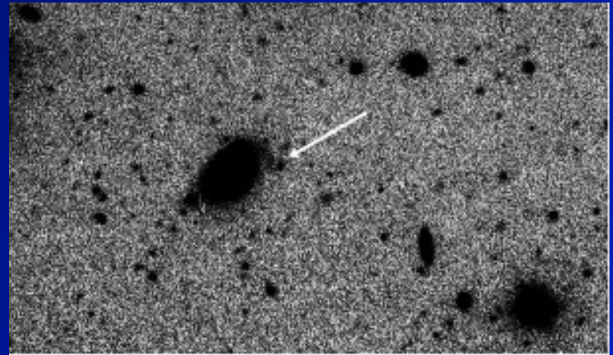
Green Pea Galaxies: Luminous BCDG at intermediate redshift

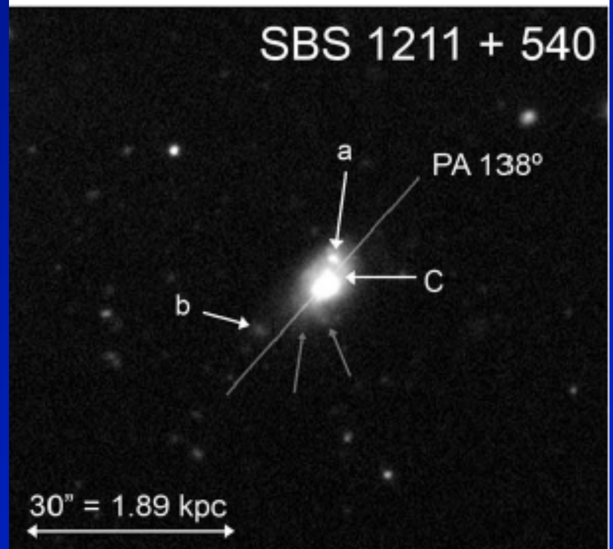
- Discovered by Galazy Zoo participants (Cardamone et al. 2009).
  - Low mass ($M_* < 10^{10.5}\ M_\odot$) galaxies showing strong starbursts
  - High SFR (up to 60 $M_\odot$ yr $^{-1}$) and sSFR (10^{-7} to 10^{-9} yr $^{-1}$)
  - Low intrinsic reddening, E(B-V) < 0.25 mag
- GPs are a subset of luminous blue compact galaxies showing chemical abundances (including a high N/O ratio!) similar to local BCDG (Izotov et al. 2011, Amorín et al. 2012).
  - 7.6 < 12 + log (O/H) < 8.4 (average ~ 1/5 solar) but carefull with empirical calibrations!

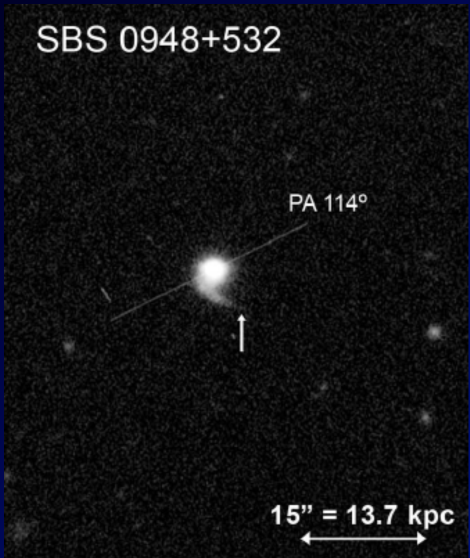


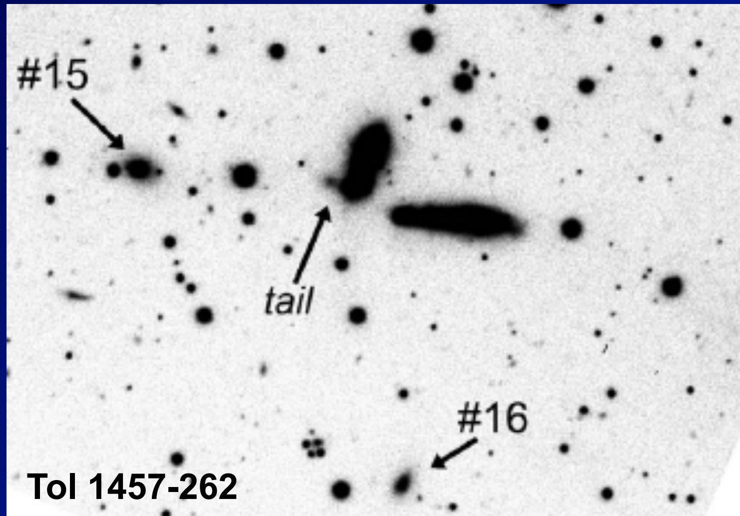
Morphologies of BCDG: Faint stellar plumes

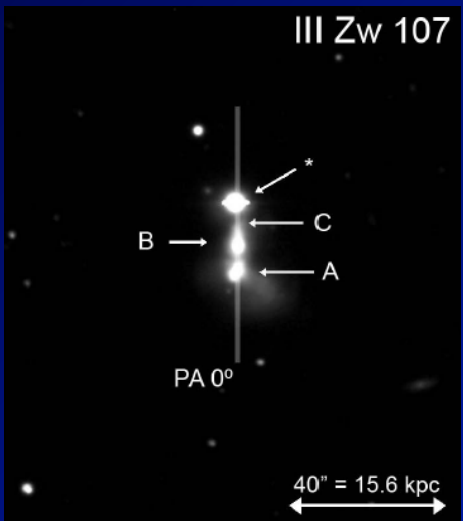
- López-Sánchez & Esteban 2008, A&A, 491, 131
  - Deep optical images: interactions between dwarf galaxies and low-luminosity dwarf objects

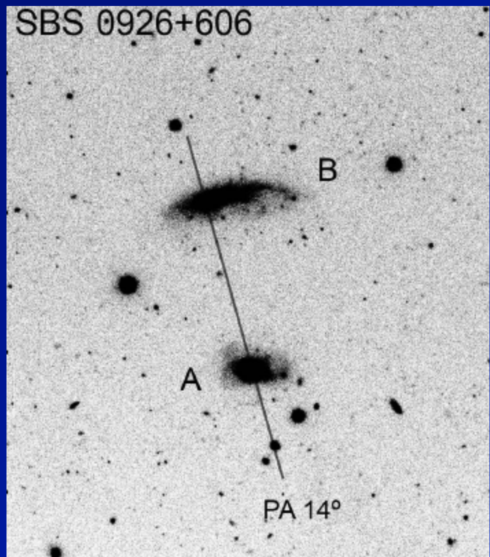


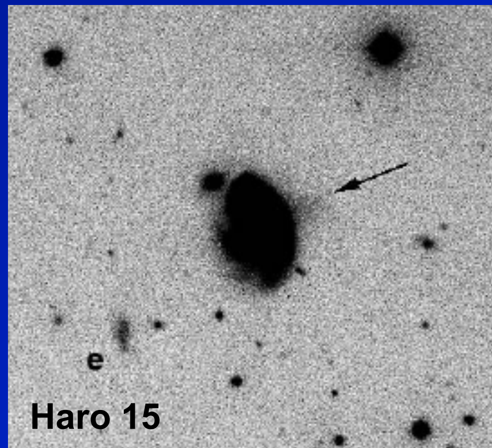


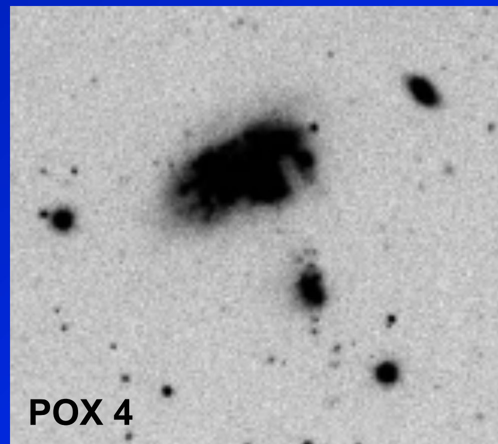












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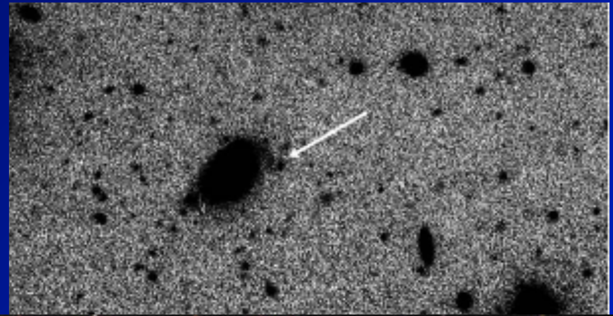
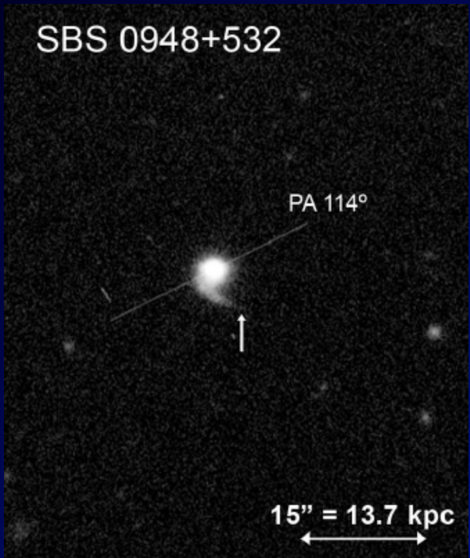
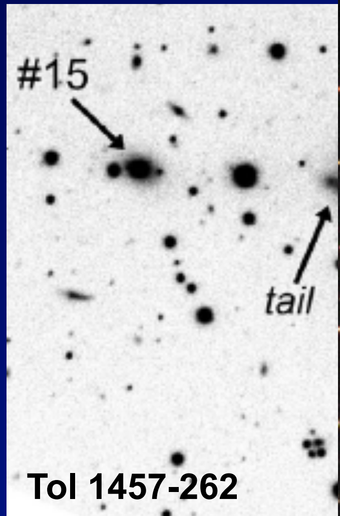
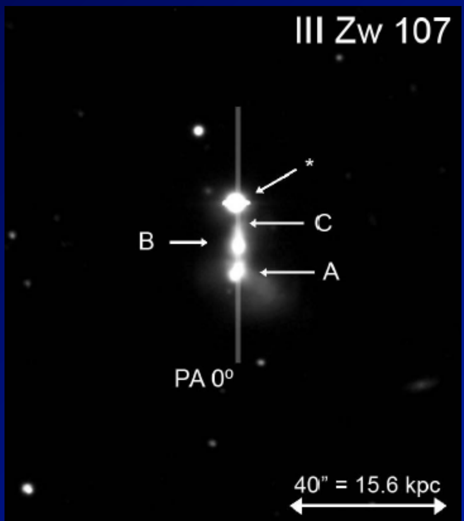
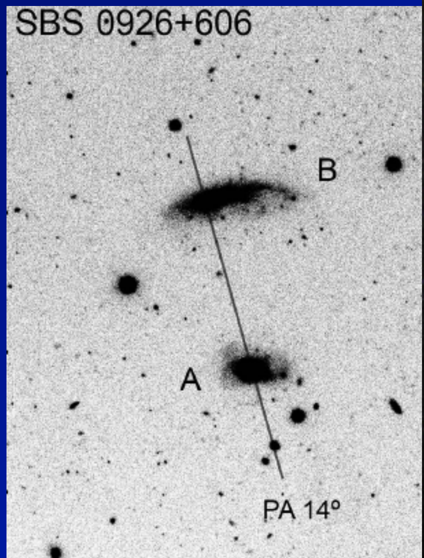
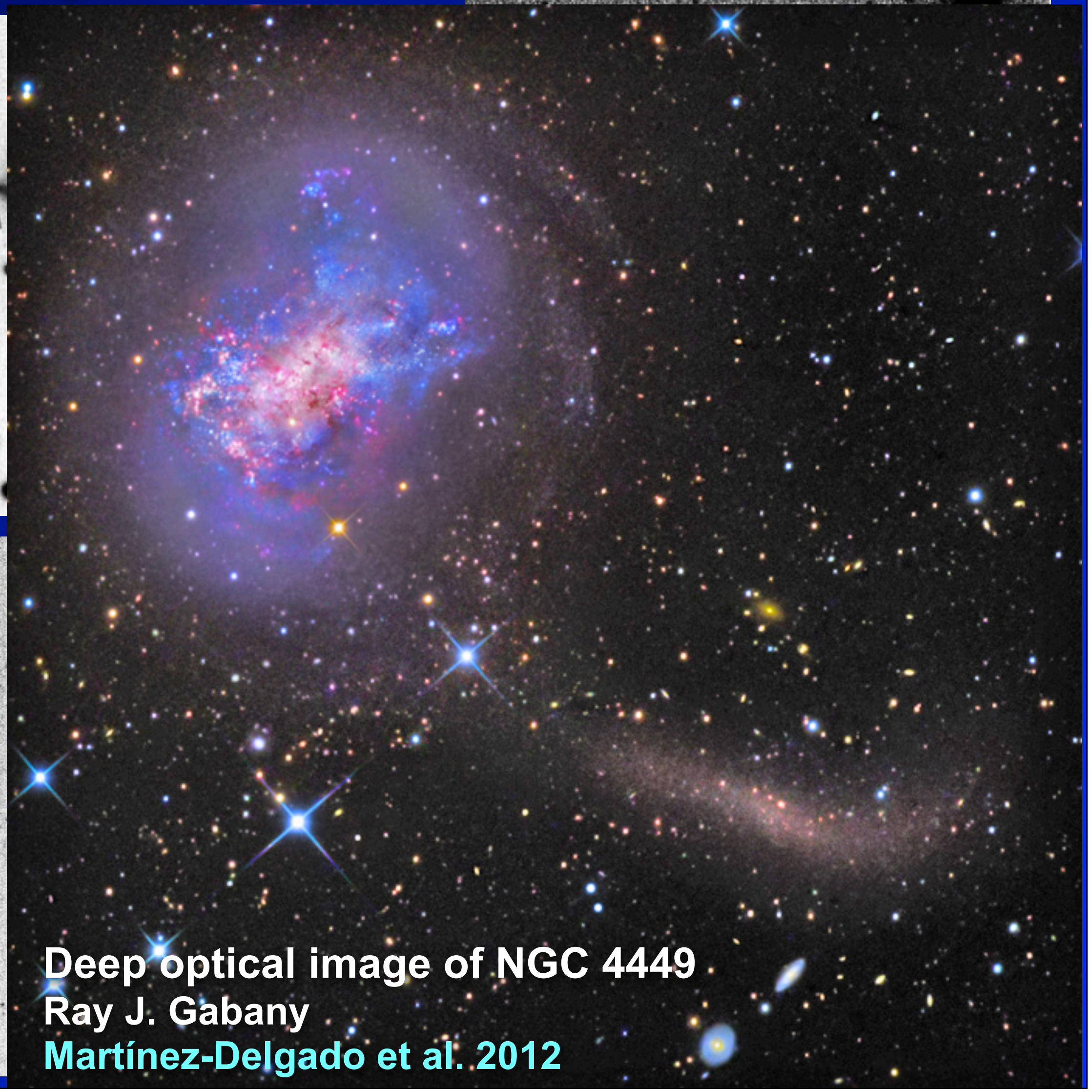






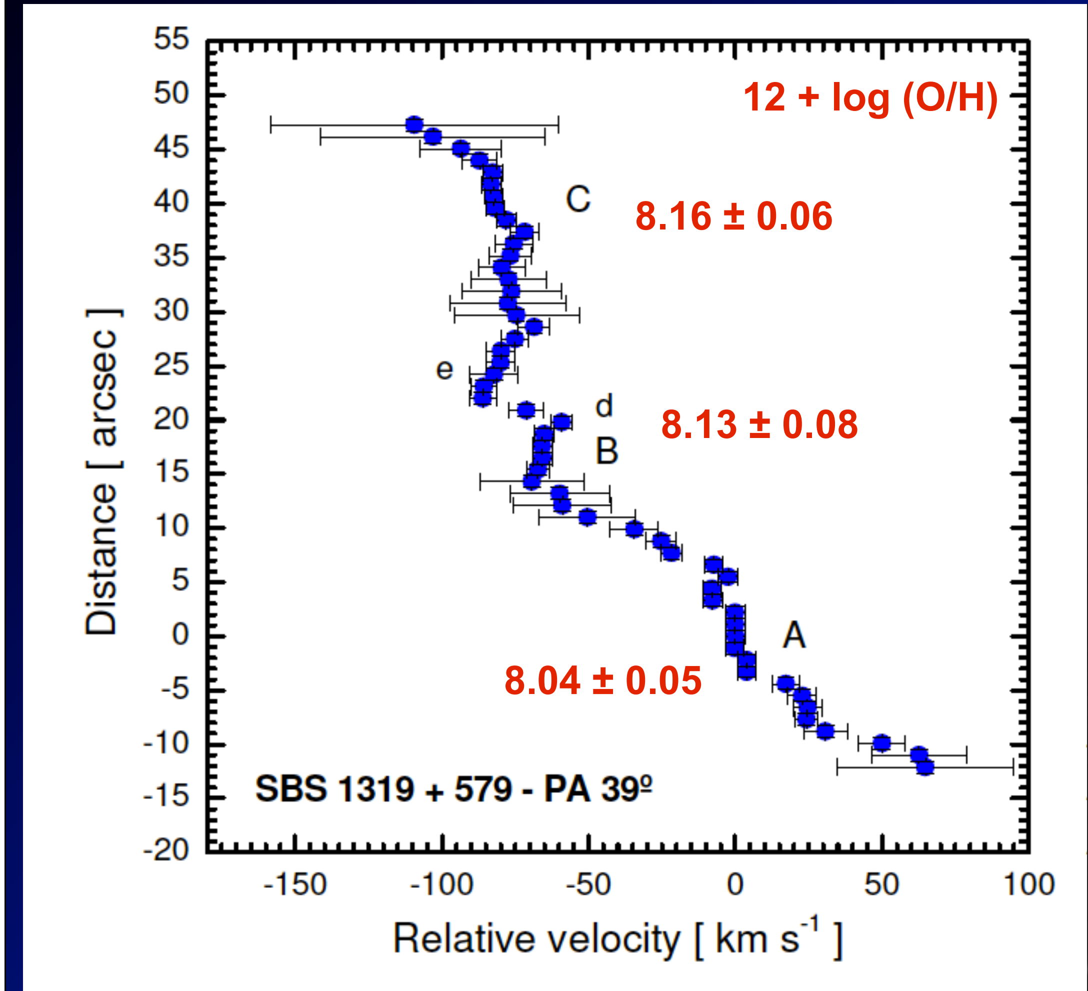


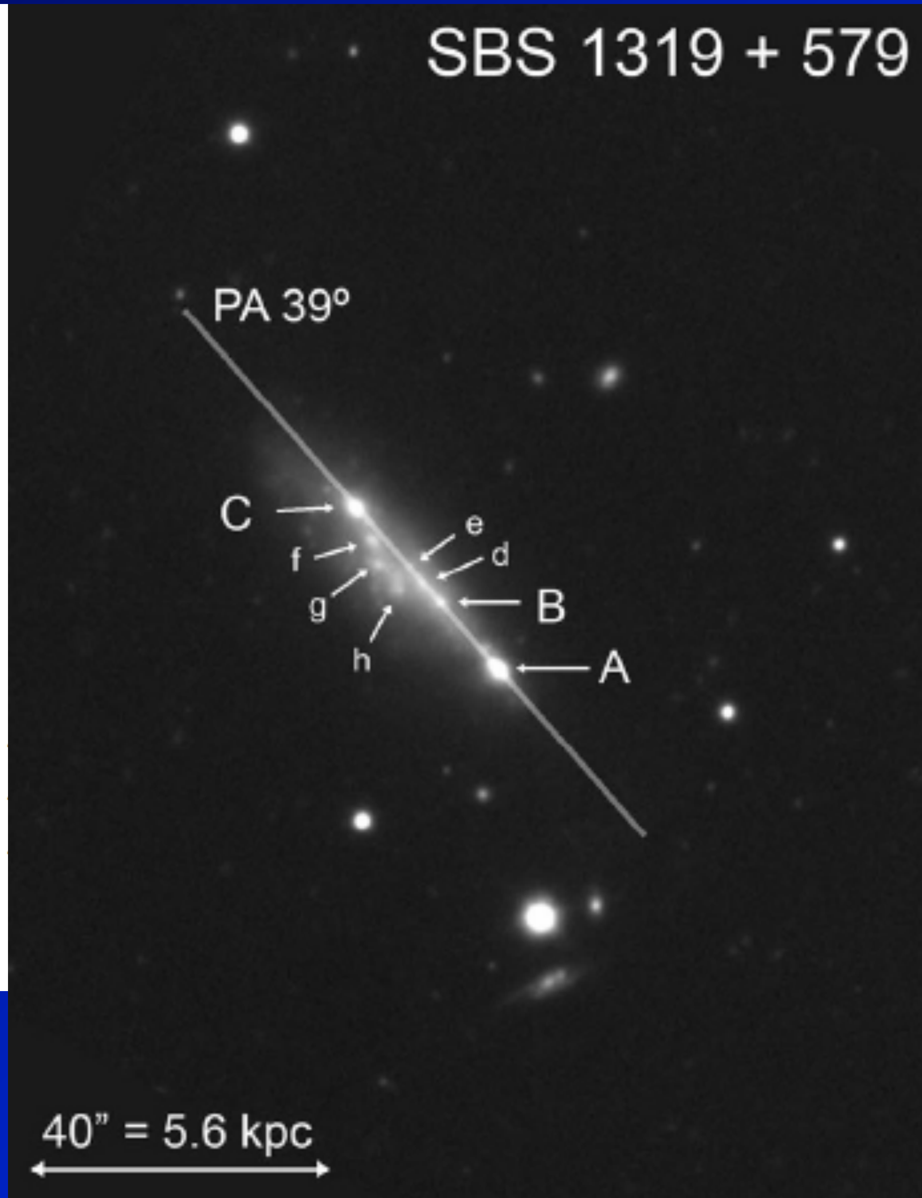




Deep optical image of NGC 4449
Ray J. Gabany
Martínez-Delgado et al. 2012

Kinematic features of interactions in BCDG



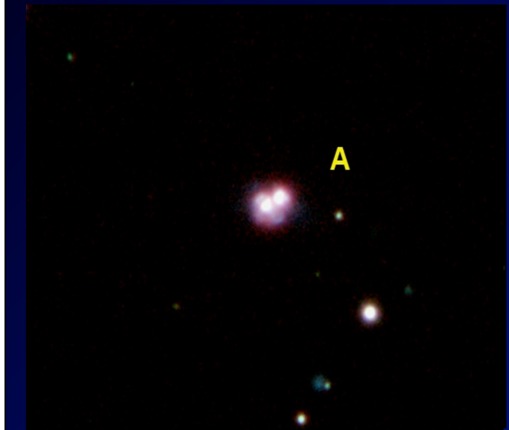


López-Sánchez & Esteban, 2009, A&A, 508, 615

Star Formation in BCDG

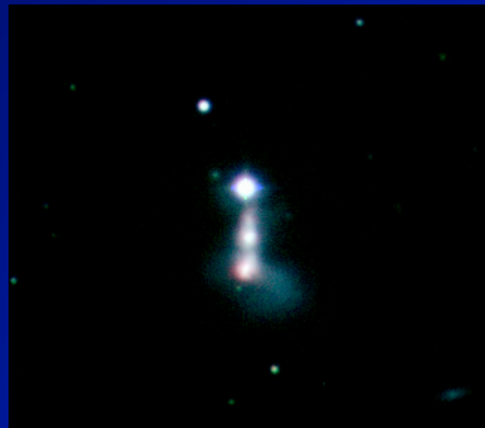
- Individual and detailed analyses of BCDG using deep observations are fundamental to derive their properties and understand their evolution.

López-Sánchez & Esteban 2008, 2009, 2010b, López-Sánchez 2010

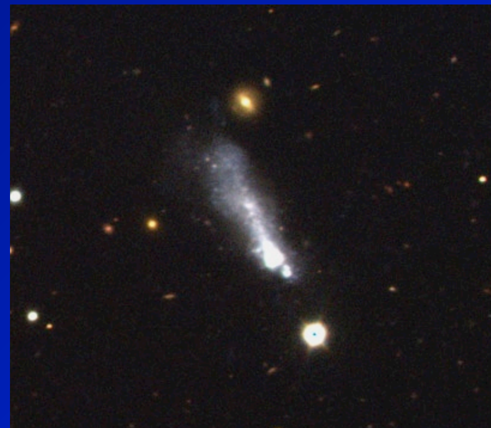


SBS 0926+606 A
(ALFOSC @ NOT, B + R + Hα)

IRAS 08208+2816
(ALFOSC @ NOT, B + V + R)

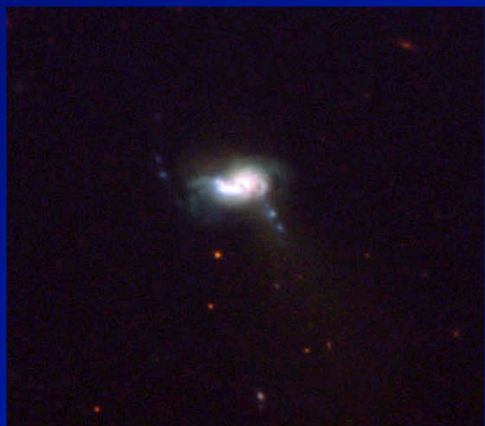


III Zw 107
(CAFOS @ 2.2m CAHA, B + R + Hα)



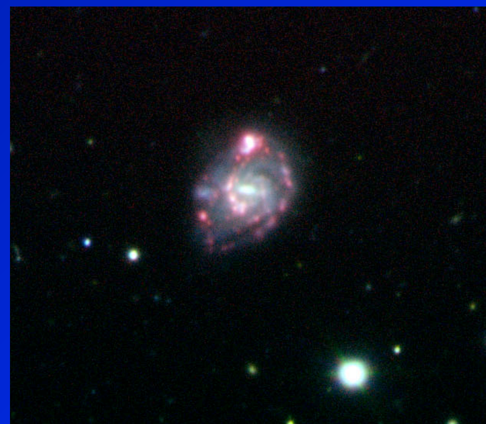
SBS 1415+437
(ALFOSC @ NOT, B + V + R)

Mkn 309
(ALFOSC @ NOT, B + R + Hα)



UM 448
(ALFOSC @ NOT, U + B + R)

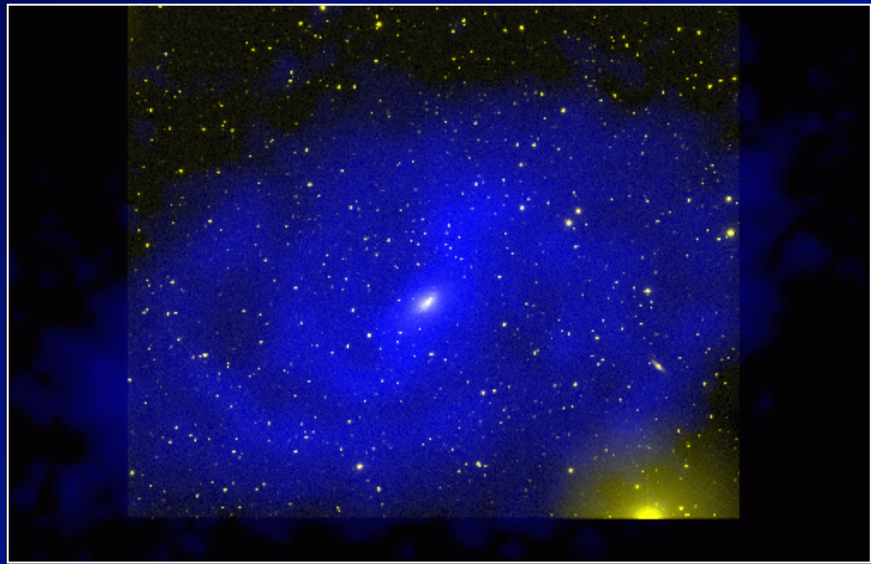
UM 420
(CAFOS @ 2.2m CAHA, U + B + R)



UM 159
(ALFOSC @ NOT, B + R + Hα)

Star formation in BCDG: The importance of HI observations

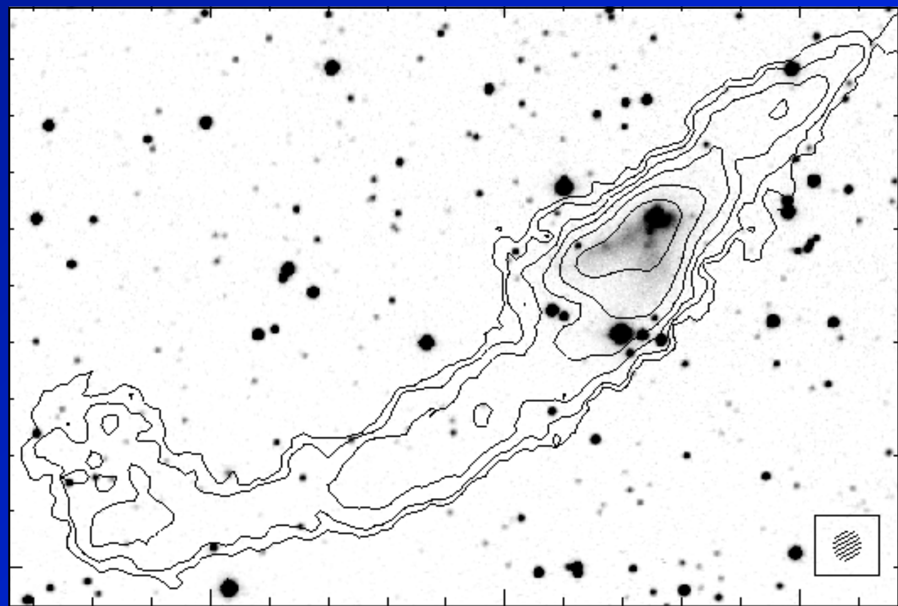
- "HI studies can trace feedback and feeding in a variety of ways"
  Thijs van der Hulst
  - BCDGs have large amount of neutral gas
  - Analysis of the H I kinematics (total mass and dark matter)
  - HI gas is the best tracer of galaxy-galaxy interactions !
  - Infall / Outflows



NGC 2915
HI (blue)
+ B (green)
+ R (red)

HI is 5 times the Holmberg radius and M_{Dyn}/L_B=76

Meurer et al. (1996)



II Zw 40
B (grayscale)
+ HI contours

Long HI tidal tail

van Zee et al. (1998)

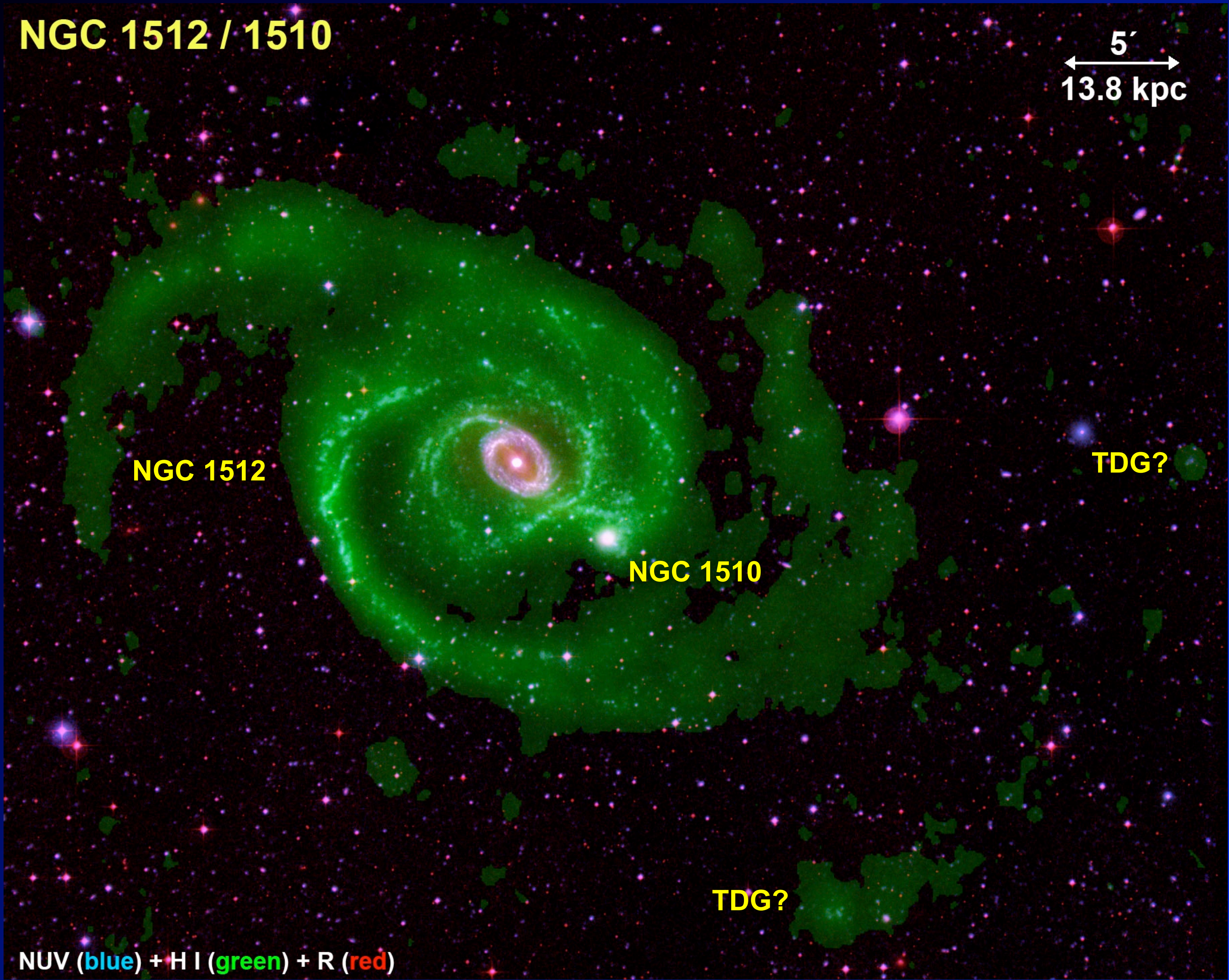
H I Observations of BCDG using the ATCA

- Australia Telescope Compact Array, 6 x 22m dishes, Narrabri, NSW, Australia
- Deep H I line & 20 cm radio continuum observations for a sample of BCDGs
  - NGC 1510*
  - NGC 5253*
  - Tol 9
  - Tol 30
  - POX 4
  - He 2-10
  - IC 4662*
  - IC 4870
  - Tol 1924-416
  - ESO 108-G017

- Full 12h x 4 arrays:
EW 367m, 750m, 1.5km, 6 km
  - Velocity resolution of 4 km/s
  - HI column density:
    ~ 5 x 10^{19} cm^{-2} (for 40” beam)
  - Angular resolution of ~20”
- Complementary optical / NIR observations (AAT, INT, NOT, 2.3m ANU, WHT, VLT)
+ UV / IR data if available

* Belonging to the *Local Volume HI Survey* (LVHIS) project, PI B. Koribalski

Galaxy pair NGC 1512 and BCDG NCG 1510

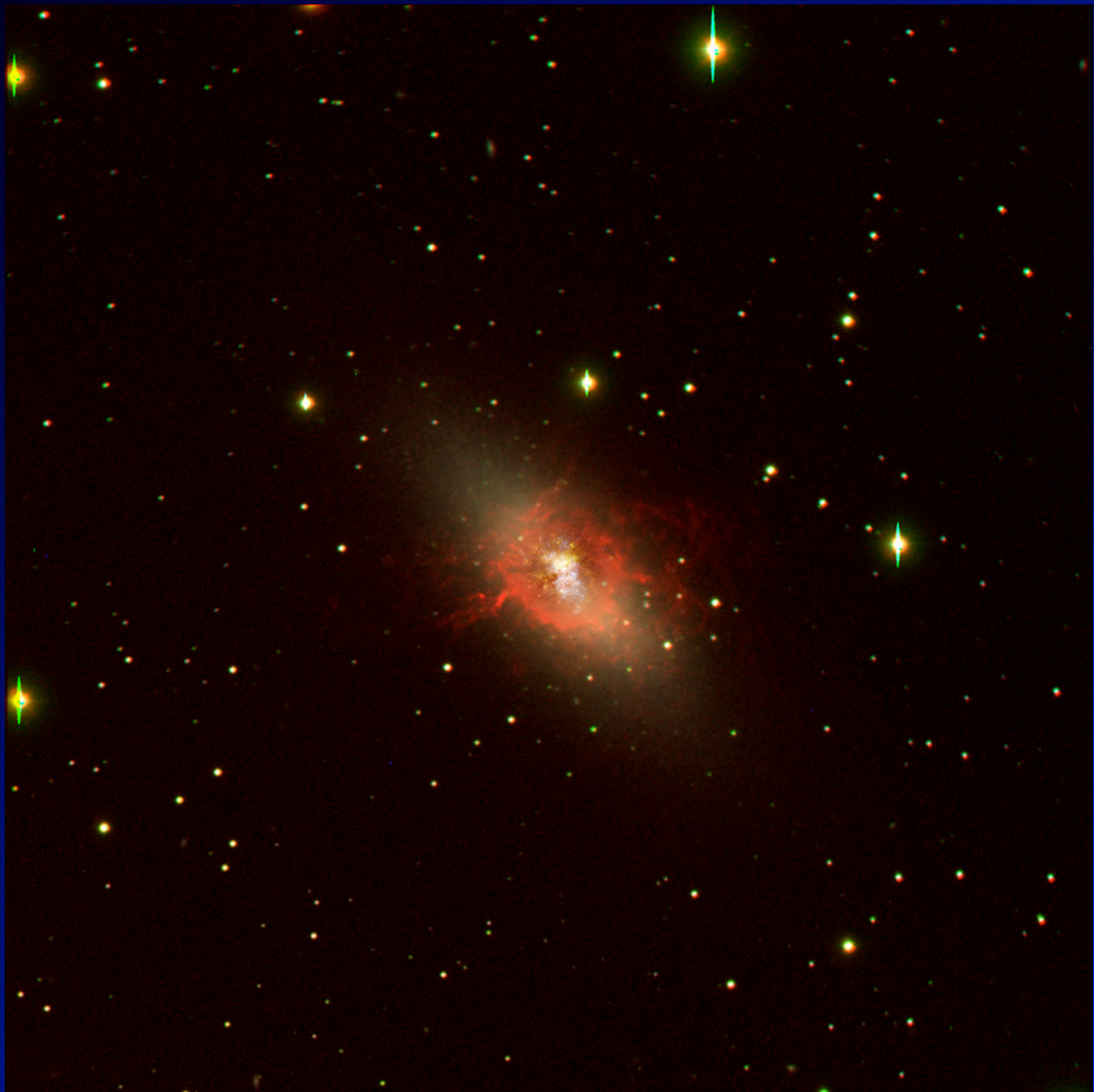


- ATCA observ. using 7 arrays
- Mosaic using 4 pointings
- Total int. time: 3.11 days
- Huge amount of neutral gas!
- Two extended spiral arms
- Two TDG candidates
- NGC 1512:
  - $M_{HI} = 5.7\times10^{9}\ M_{\odot}$
  - $M_{Dyn} \sim 4 \times 10^{11}\ M_{\odot}$
  - $M_{HI}/L_B = 1$
- NGC 1510:
  - $M_{HI} \sim 4\times10^{7}\ M_{\odot}$
  - $M_{HI}/L_B \sim 0.07$

Koribalski & López-Sánchez (2009, MNRAS)

The BCDG NGC 5253

8.8’

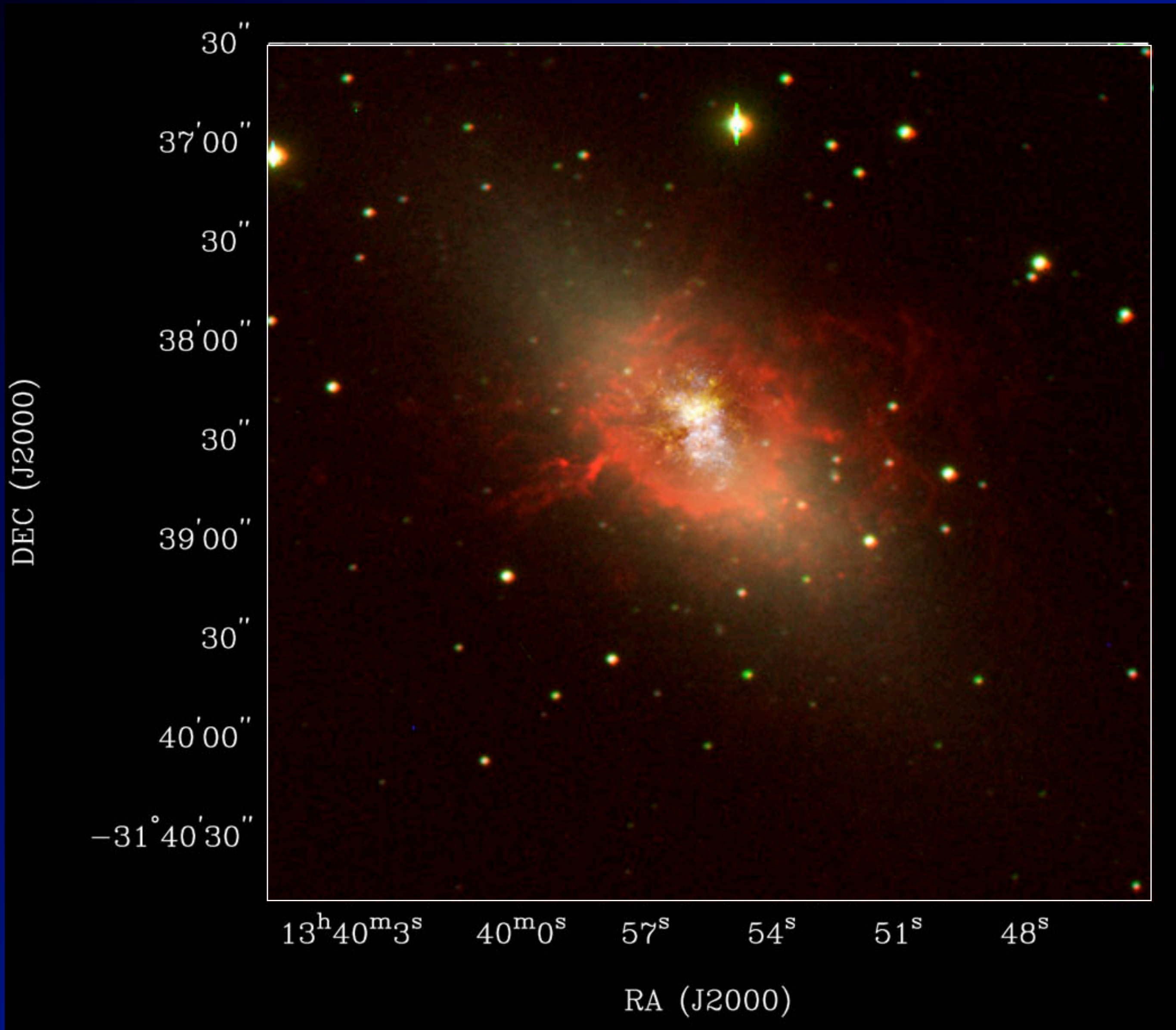


- D_{Hel}= 4.0 **Mpc** (Karachentsev et al. 2004)
- Scale: **19 pc / arcsec**
- Optical size: **5.0’ × 1.9’**

  (5.7 kpc × 2.2 kpc)
- One of the **closest starbursts**, observed at all wavelengths
- Filamentary ionized gas (Calzetti et al. 1994)
- Deep analysis of the **ionized gas** of its center using UVES@VLT by López-Sánchez et al. (2007)
- 2D spec. observations FLAMES @ VLT by Monreal-Ibero et al. (2010, 2012) suggesting **outflows** from the massive HII regions

NGC 5253 – V (blue) + I (green) + Hα (red)
2.5m du Pont telescope, LCO (V, I) + 1.5m CTIO (Hα)
combined by Á.R. López-Sánchez

NGC 5253: H I radio data - High resolution map

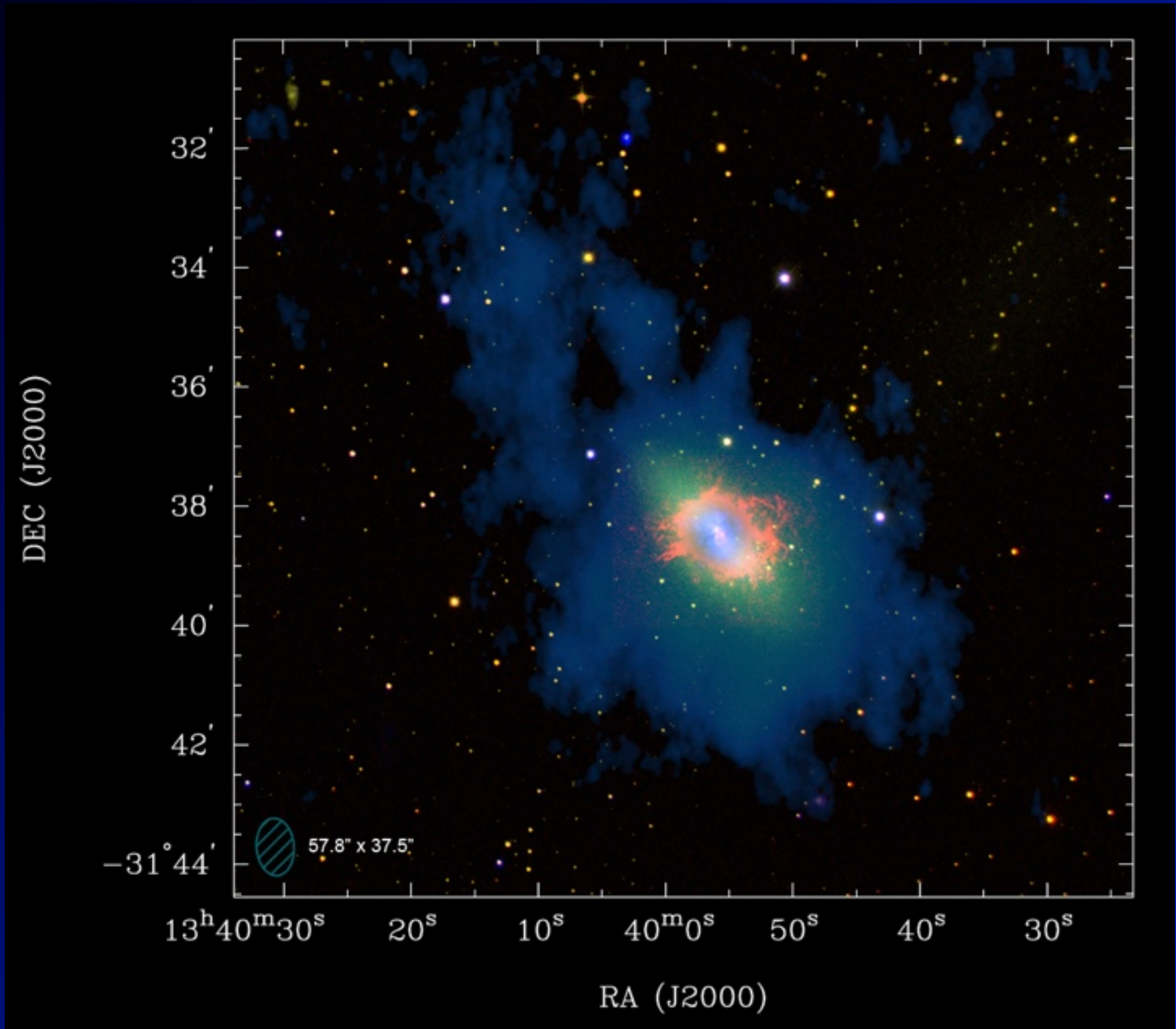


López-Sánchez et al. (2012)

In very good agreement with the results found by Kobulnicky & Skillman (2008) using VLA data.

NGC 5253 – High resolution H I map (dark blue + contours) + R (green) + Hα (red) + UV HST (light blue)

NGC 5253: H I radio data
Low resolution map



NGC 5253 – Low resolution map (blue) + UV (blue) R (green) + Hα (red) + J (orange)

Radio data of NGC 5253 from the LVHIS (*Local Volume HI Survey*) project using four different ATCA arrays

Properties:

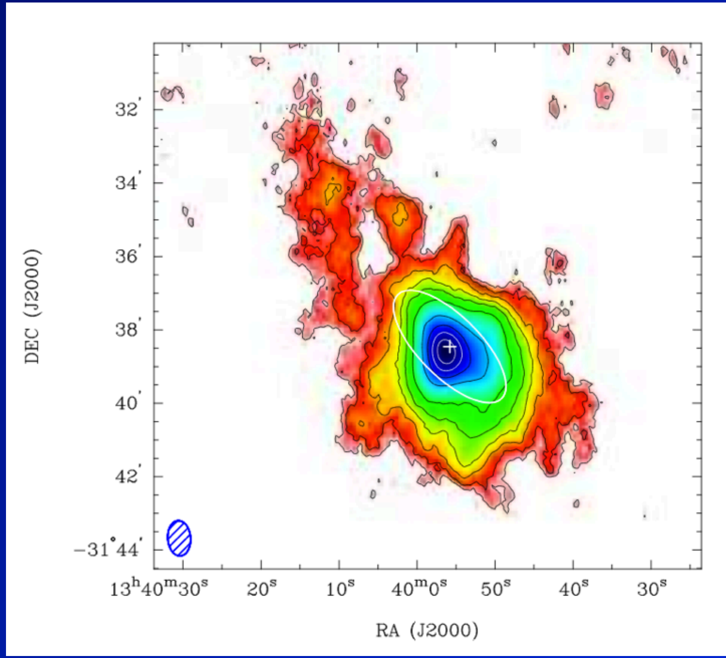
- ✓ **H I mass: (1.7 ± 0.2) × 10^8 $M_\odot$**
- ✓ **H I / L_B = 0.069 $M_\odot$ / $L_{B\odot}$**
- ✓ **Dynamical mass: ~10^8 $M_\odot$?**

López-Sánchez, Koribalski & Esteban 2007

López-Sánchez et al. (2012)

NGC 5253: H I radio data

ESO 154-G023 ATCA H I velocity field



H I velocity field:

Rotating about the optical MAJOR axis?

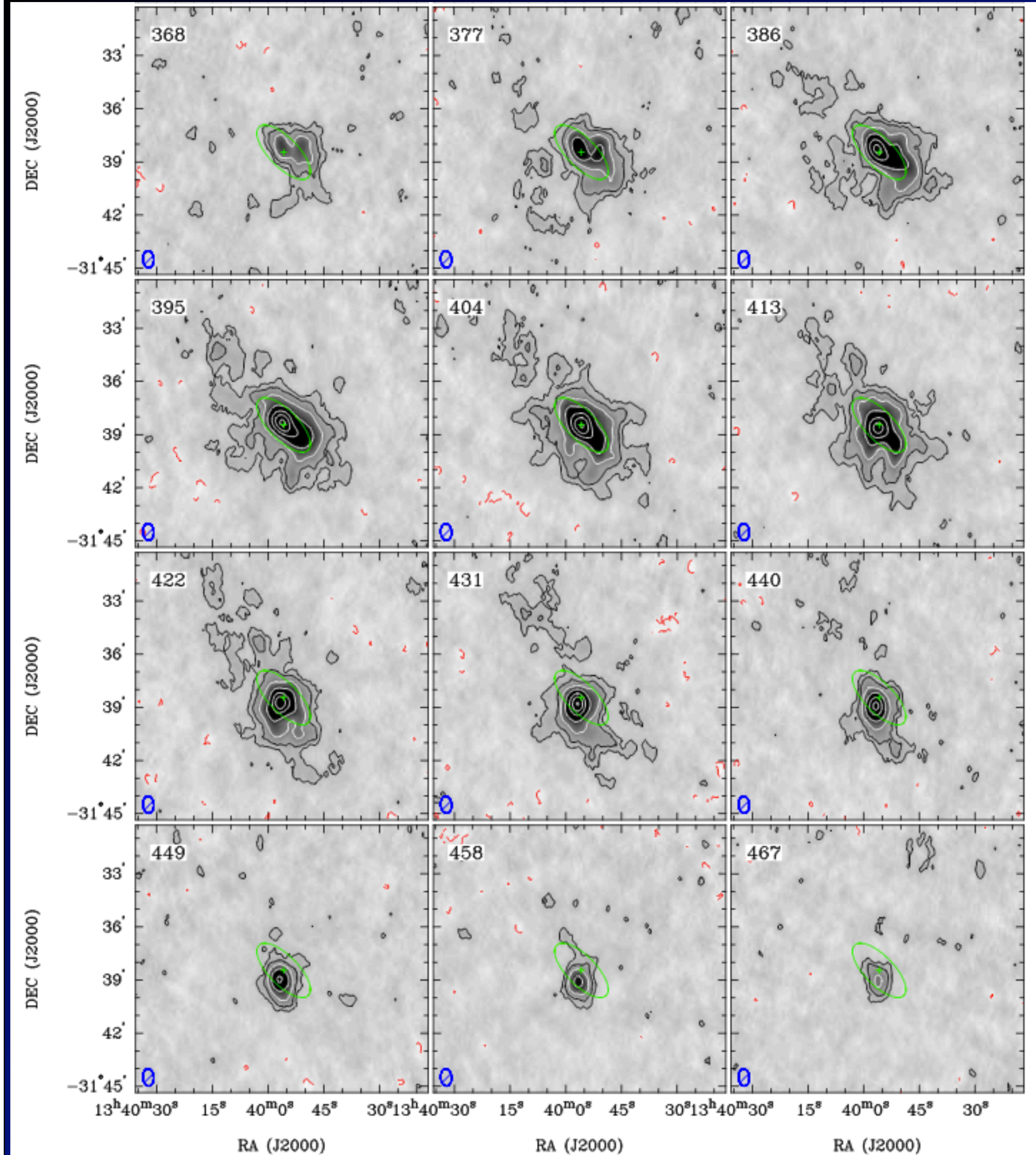
- ✓ Any kind of outflow?
- ✓ Formation of a polar ring?
- ✓ Interaction with M83 ~1 Gyr ago?
- ✓ Disruption/accretion of a gas-rich companion ←

Kinematics of the ionized gas decopled from kinematics of stars?

NGC 5253 ATCA H I velocity field

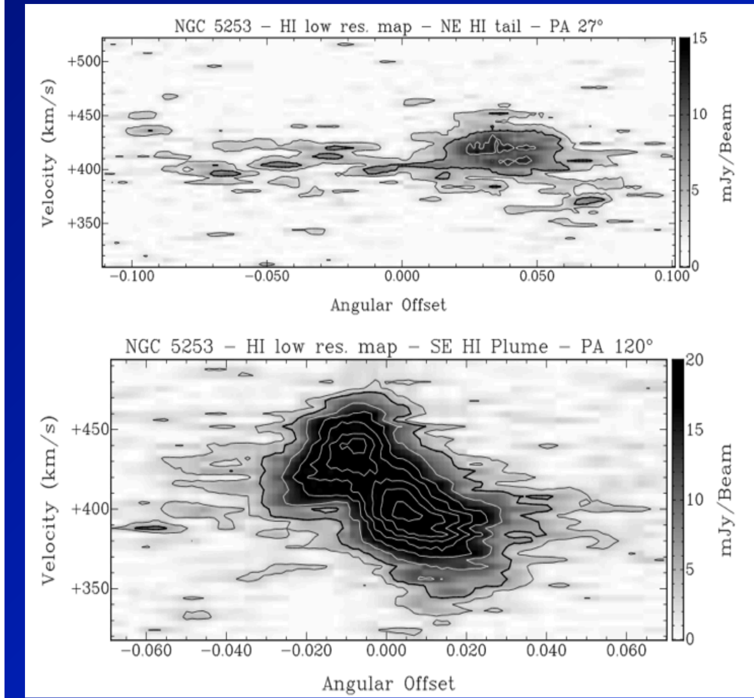
López-Sánchez, Koribalski & Esteban 2007, Kobulnicky & Skillman 2008
López-Sánchez et al. 2012

NGC 5253: H I radio data



NGC 5253 ATCA H I channel maps

NGC 5253 Pos-vel diagrams



- ✓ Infall of a gas-rich companion
- ✓ In agreement with CO observations (Turner et al. 1997)
- ✓ NGC 5253 is far from other BCDG properties

López-Sánchez et al. (2012)

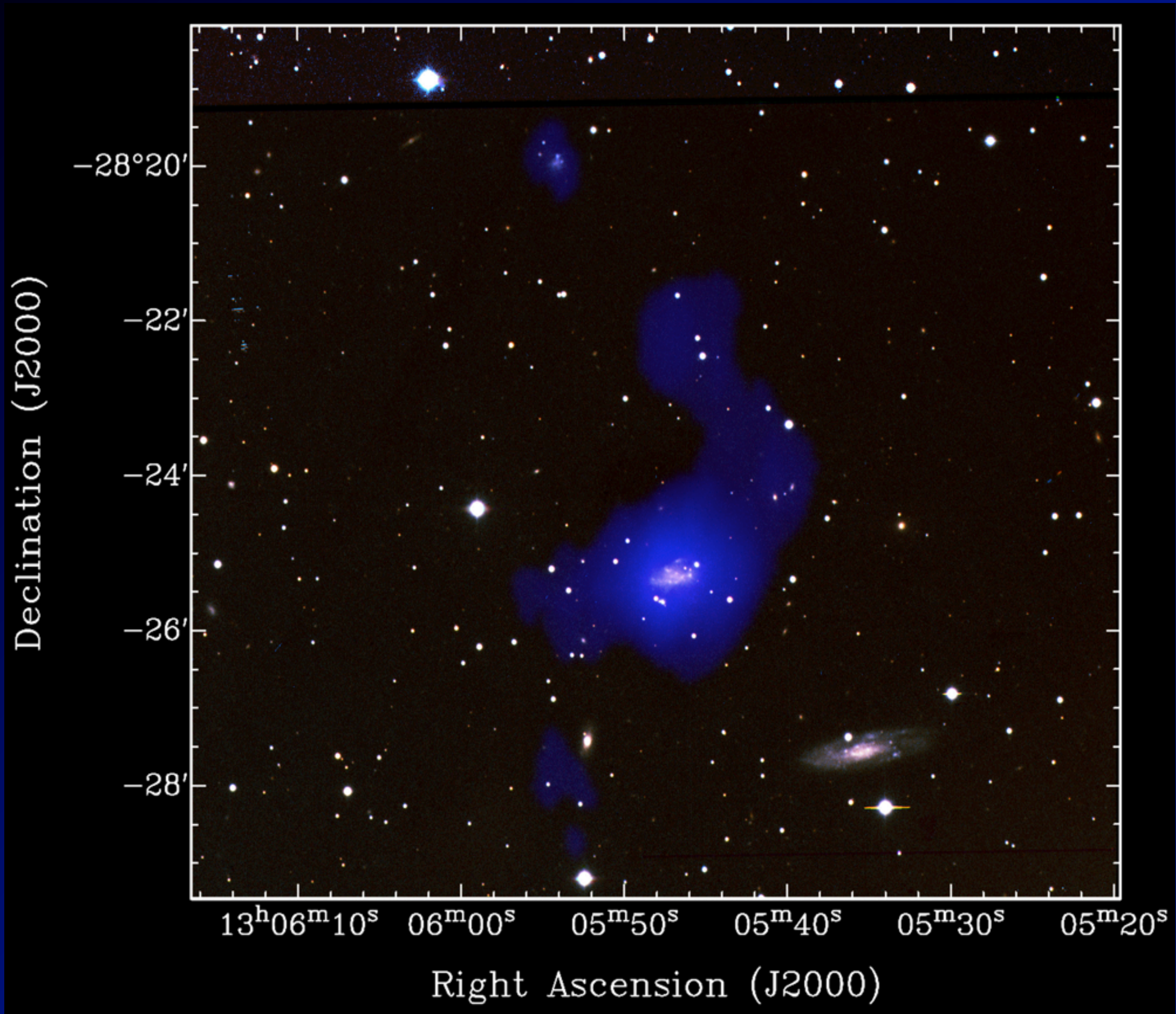
BCDG Tol 30

Tol 30 – B (blue) + R (green) + Hα (red) ALFOSC @ 2.6m NOT

- D = 29.3 **Mpc**
- **1' = 8.5 kpc**
- Optical size: **1.2' × 1'**
- Optical imagery and ionized gas analysis using 2.56m NOT:
- **Two intense star-forming** regions in opposite places within the galaxy
- Knot A:
  - **WR features**
  - **12+log O/H = 8.11 ± 0.09**
  - **log N/O = – 1.55 ± 0.12**
- Knot B:
  - **12+log O/H = 8.25 ± 0.07**
  - **log N/O = – 1.44 ± 0.12**
- Deep optical imagery using WFC @ 2.5m INT
  - **Detection of nearby and diffuse non-stellar objects**

López-Sánchez et al. in prep.

BCDG Tol 30



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  - **log N/O = – 1.44 ± 0.12**
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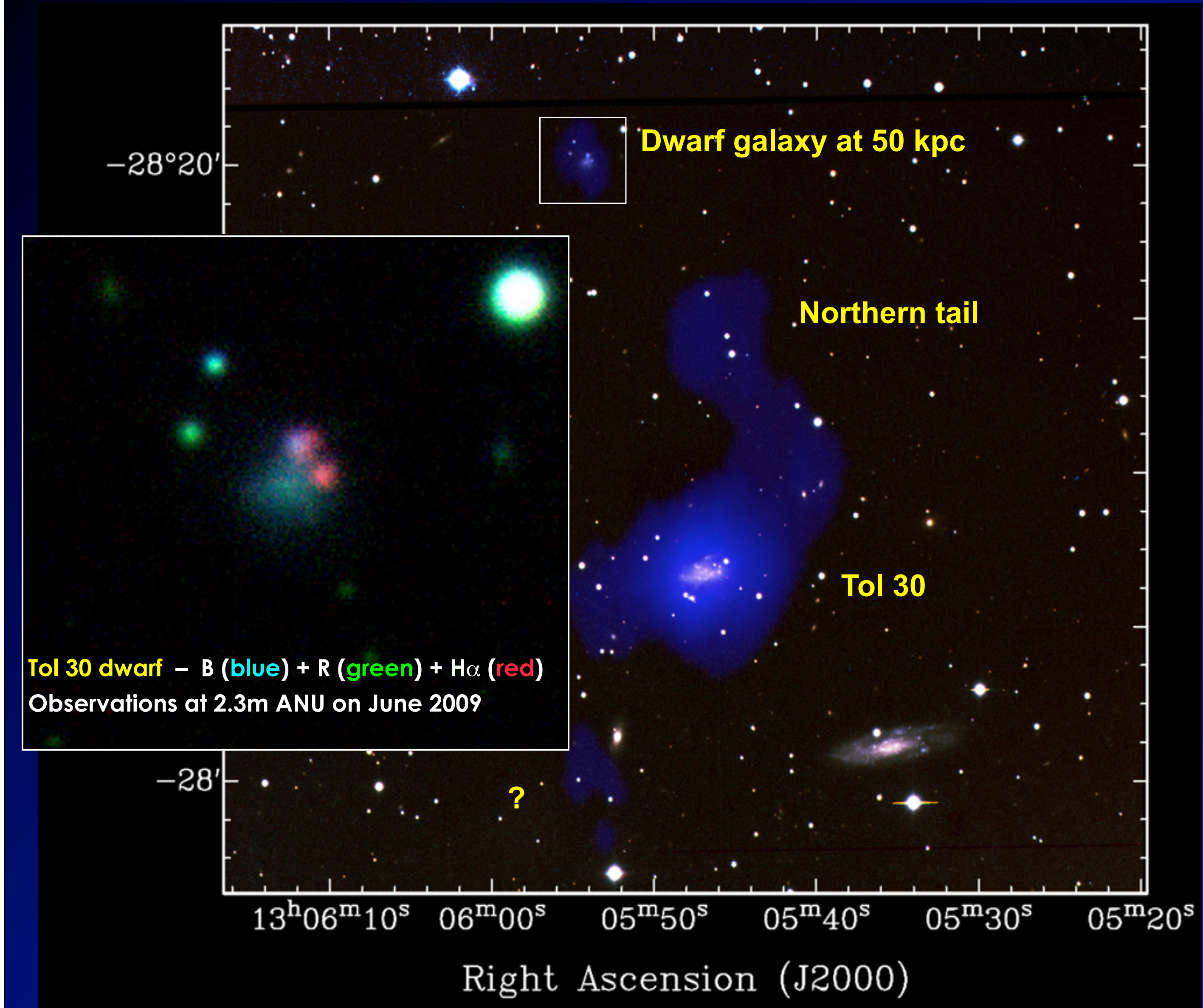
Tol 30 – B (blue) + V (green) + R (red) WFC @ 2.5m INT

López-Sánchez et al. In prep.

BCDG Tol 30



Tol 30 – H I map (blue) + B (green) + R (red)

H I distribution

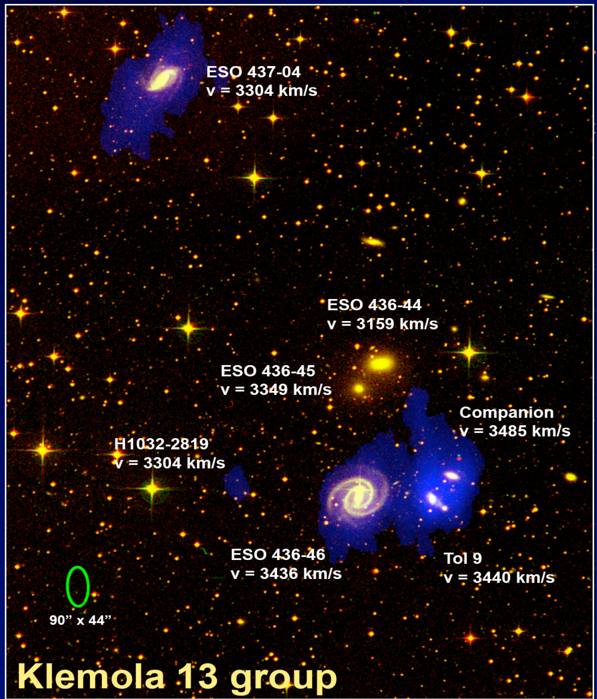
- Total HI mass:
  - M_{HI}: $1.4 \times 10^9\ M_\odot$
- Tol 30:
  - M_{HI}: $1.1 \times 10^9\ M_\odot$
  - $M_{HI}/L_B = 1.2$
  - $M_{Dyn}/L_B = 17.1$
- Northern tail:
  - M_{HI}: $2.1 \times 10^8\ M_\odot$
  - 15% total HI mass
- Eastern tail:
  - M_{HI}: $9.1 \times 10^7\ M_\odot$
  - 7% total HI mass
- TDG or dwarf obj?:
  - M_{HI}: $2.3 \times 10^7\ M_\odot$
  - $M_{HI}/L_B = 0.12$
  - It shows rotation!
  - $M_{Dyn}/L_B = 7.3$

López-Sánchez et al. In prep.

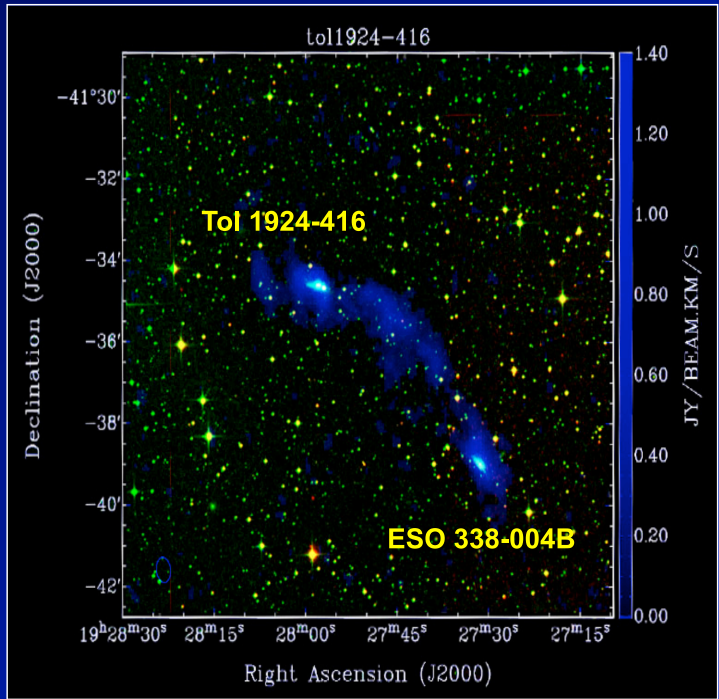
BCDG in different environments

- In galaxy groups:
  - Tol 9
  - Tol 30
  - NGC 5253
- In galaxy pairs:
  - Tol 1924-416
  - NGC 1510
- Apparently isolated
  - IC 4662
  - IC 4870
  - ESO 108-G017
  - He 2-10
  - POX 4

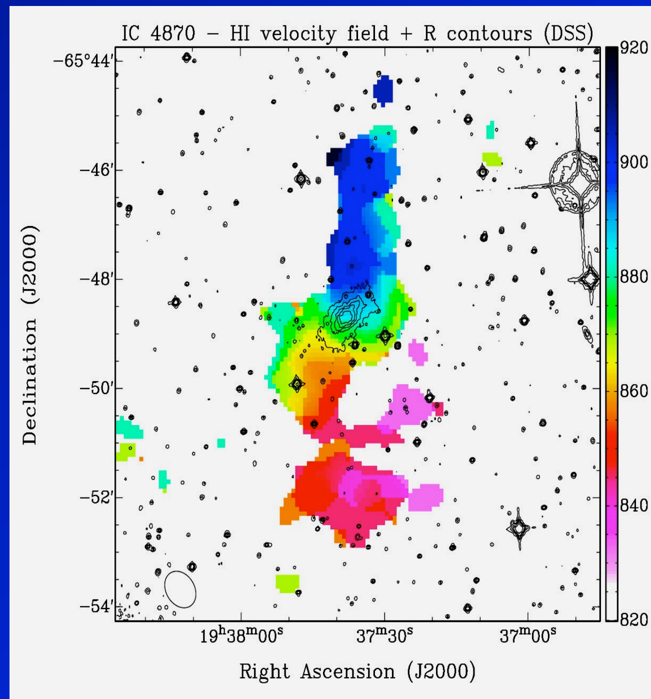
- **Despite the environment, ALL studied BCDG** show **interactions features**, very evident in the majority of them.



Tol 9 within Klemola 13 group



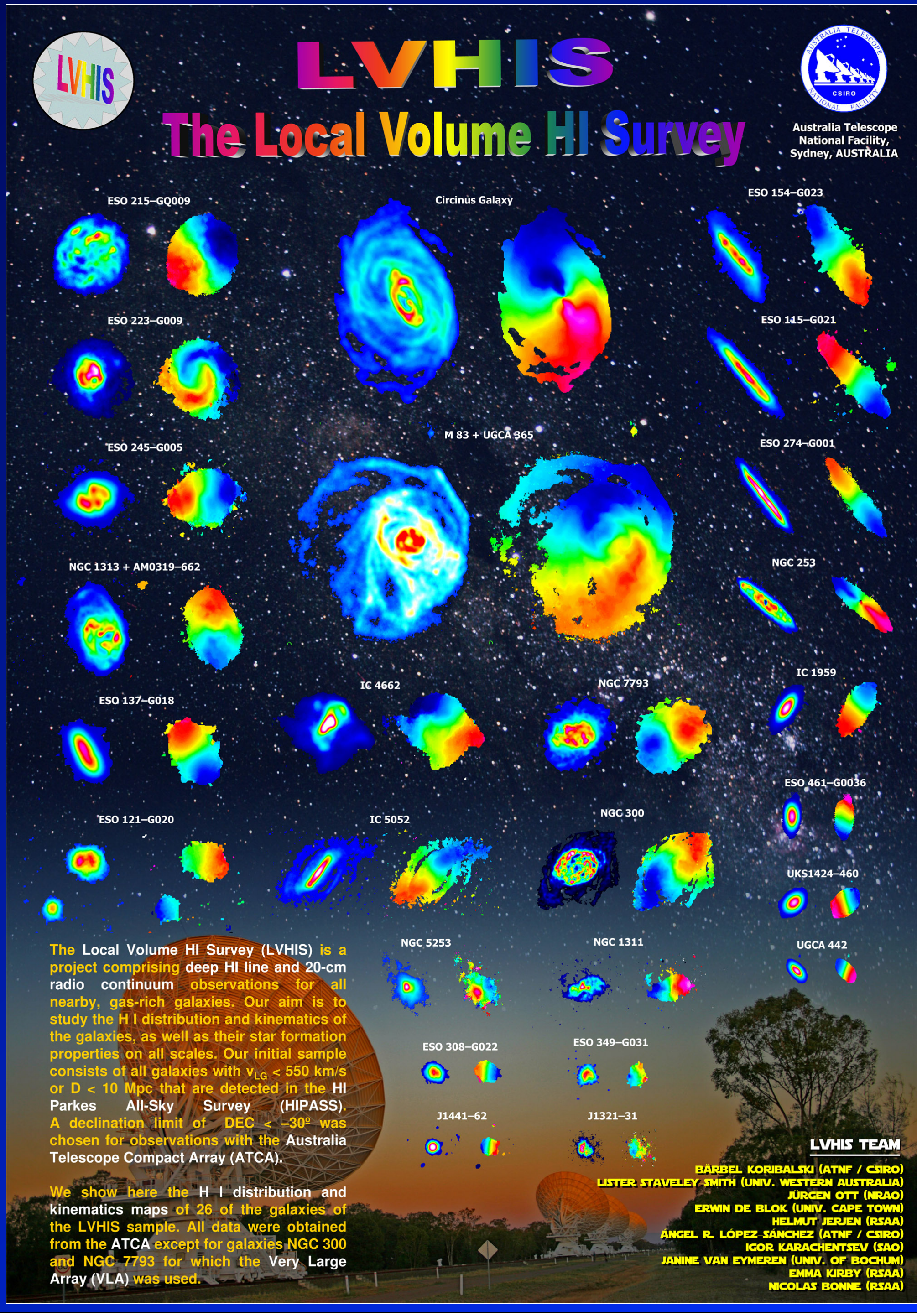
Galaxy pair Tol 1924-416 & ESO 338-004B



IC 4870

What is the HI morphology of "normal" dwarf galaxies?

- LVHIS: "Local Volume HI Survey"
  - PI: B.S. Koribalski (CSIRO)
  - Deep H I line & 20 cm radio continuum observations for all nearby (v_{LG} < 550 km/s, D < 10 Mpc) gas-rich galaxies (HIPASS) with δ < -30° using the ATCA
  - The majority dwarf galaxies!
- Little-THINGS
  - PI: D. Hunter (Lowell Obs.)
  - VLA observations of dwarf galaxies
- Few disturbed morphologies in HI



What is happening in "normal" dwarf galaxies?

- **Deep NIR (H-band) observations of LV dwarf galaxies using AAT:**
  - Regular stellar/gas morphologies, low SFR, old stellar populations
  - **Tye Young (PhD, ANU, SEE POSTER), López-Sánchez, Jerjen, Koribalski, Ryder**
- **See also Kirby et al. (2008, 2012)**
- **Ivy Wong: progenitors of post-starburst galaxies show distortions in HI !!**
- **Smirti Mahajan: Starburst galaxies on the outskirts of clusters result from galaxy-galaxy harassment**

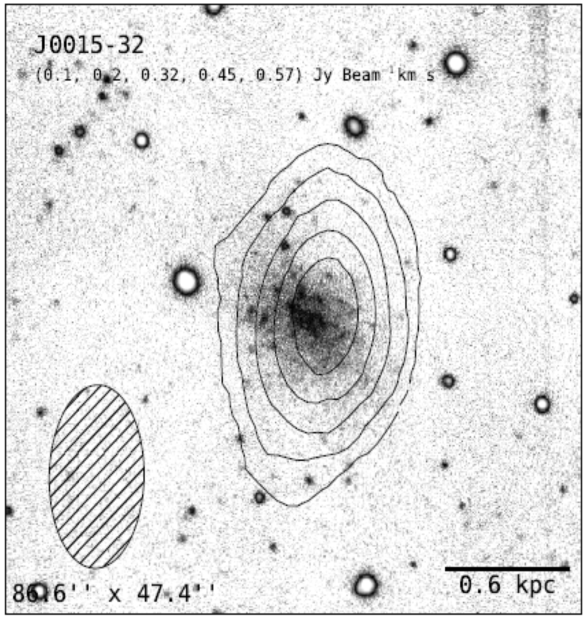
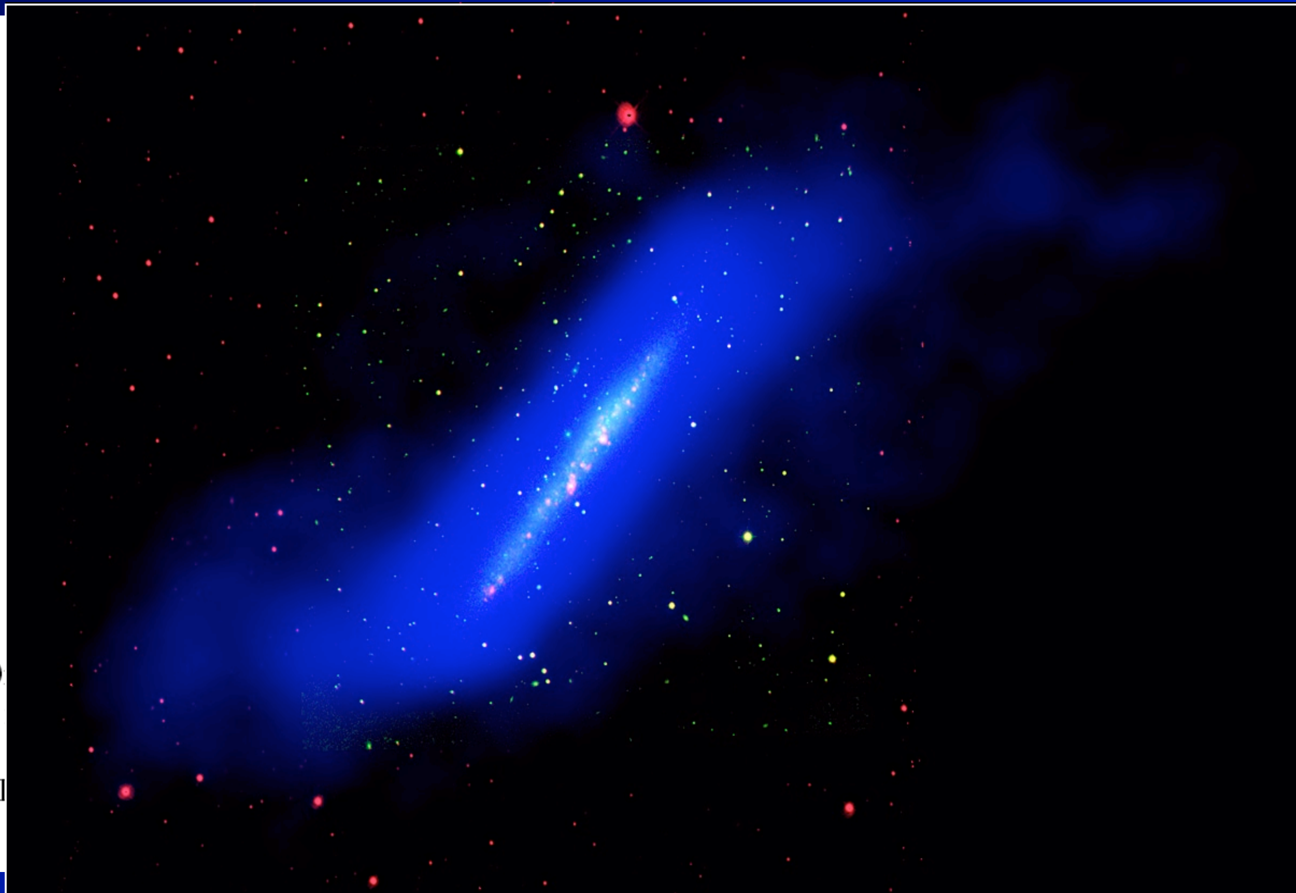


Figure 4. Deep H-band images from the 3.9
linear distance scale is displayed. The image
by a divergent greyscale, which begins with
white (high intensity). Where available, the
left portion of the image panel.



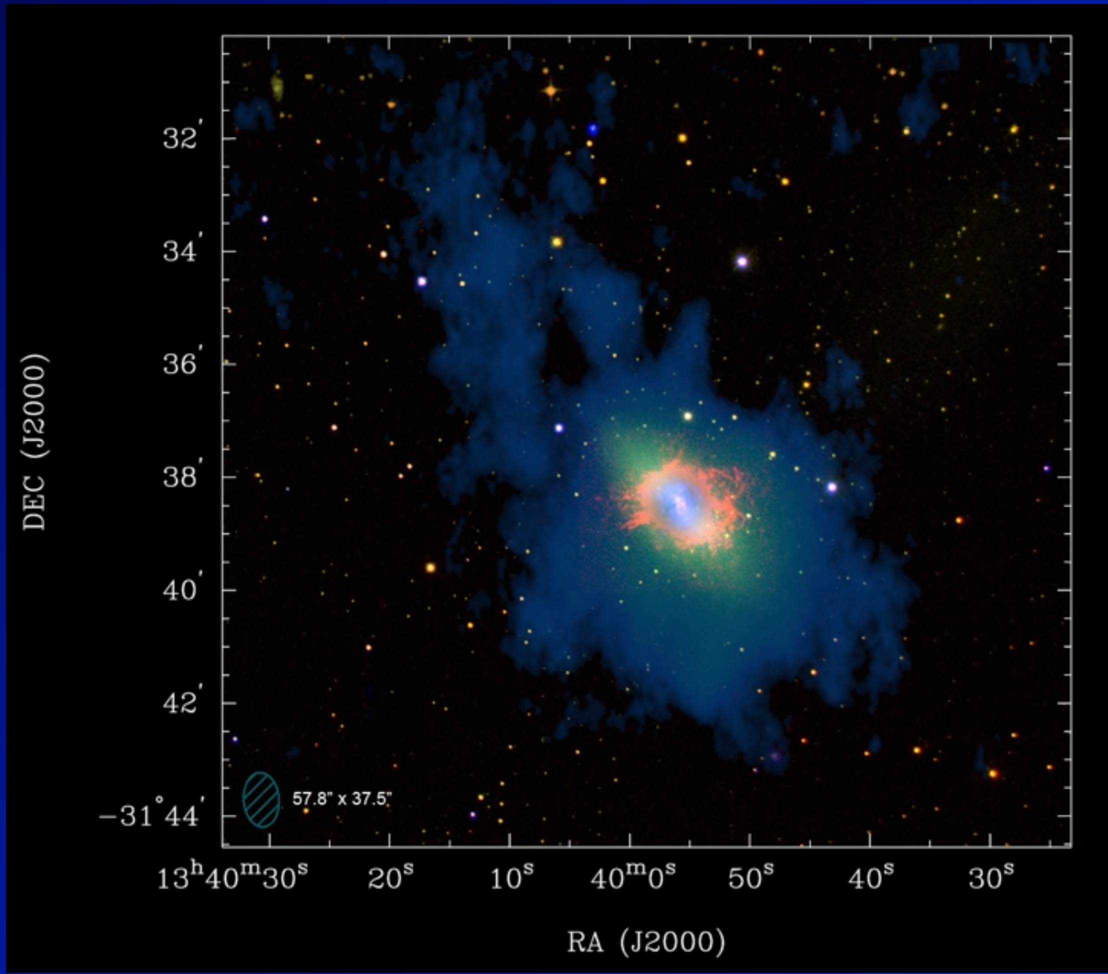
IC 5052 H I map (blue) + H (green) + Hα (red) (Kirby et al. 2008)

Conclusions

- **Detailed multiwavelength analysis of BCDGs**
  - **Optical / NIR imagery**
  - **Hα imagery**
  - **2D optical spectroscopy**
  - **H I and 20cm observations**
  - **UV / IR data when available**

- **H I** data are **fundamental** to understand the **dynamical evolution** of these objects.

- **Despite the environment, FIREWORKS are produced by INTERACTIONS (FEEDING) of diffuse, HI-rich objects in ALL studied BCDGs. The FEEDBACK is fundamental to understand the evolution of dwarf galaxies.**

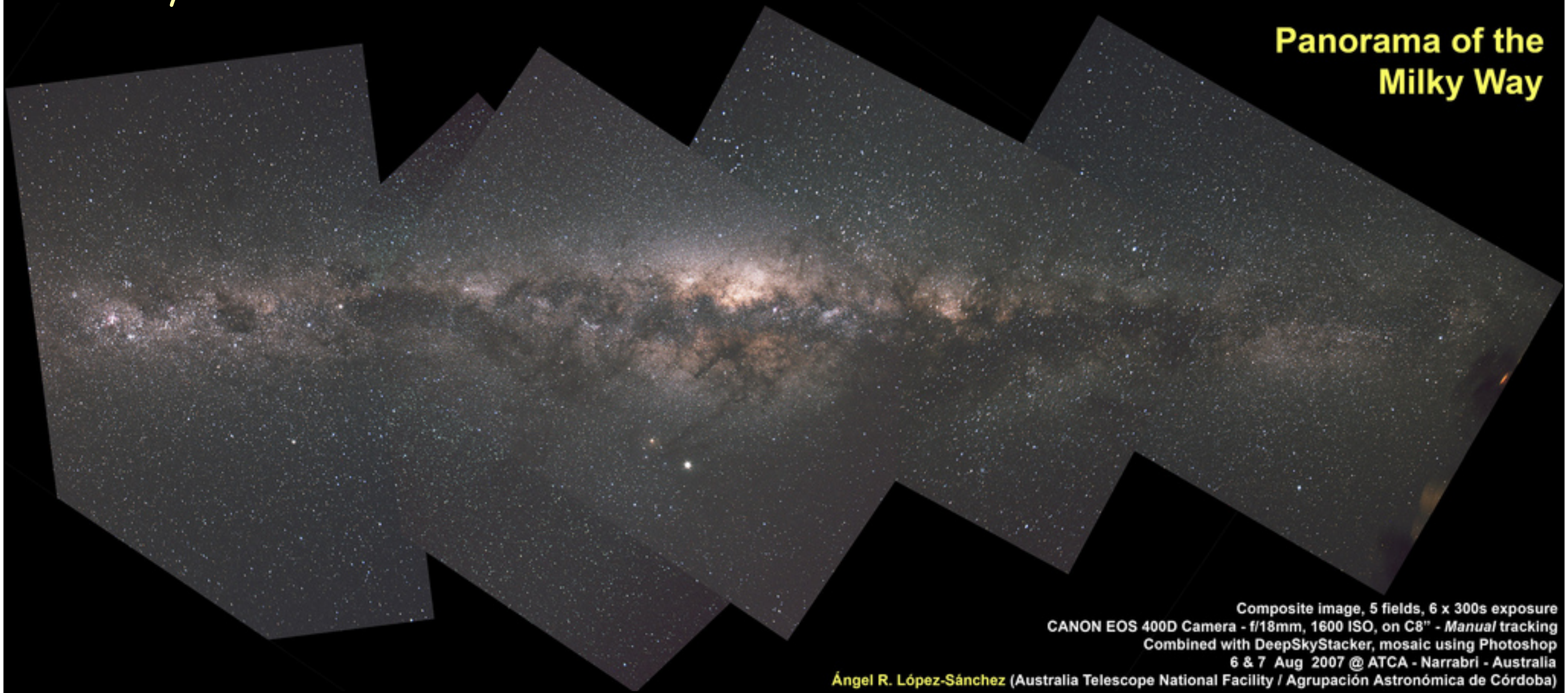


- **López-Sánchez & Esteban 2008, 2009, 2010a,b, 2011, 2012, López-Sánchez 2010**

Many surprises will come from HI surveys (i.e. MeerKAT, ASKAP, APERTIF)

Thanks for your time!

Panorama of the Milky Way



Composite image, 5 fields, 6 x 300s exposure
CANON EOS 400D Camera - f/18mm, 1600 ISO, on C8" - *Manual* tracking
Combined with DeepSkyStacker, mosaic using Photoshop
6 & 7 Aug 2007 @ ATCA - Narrabri - Australia
Ángel R. López-Sánchez (Australia Telescope National Facility / Agrupación Astronómica de Córdoba)