Ionized and neutral gas in the XUV discs of nearby spiral galaxies

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#EWASS2015 *Sp16 "Outskirts of galaxies"*
La Laguna – Tenerife – Spain – 24 Jun 2015

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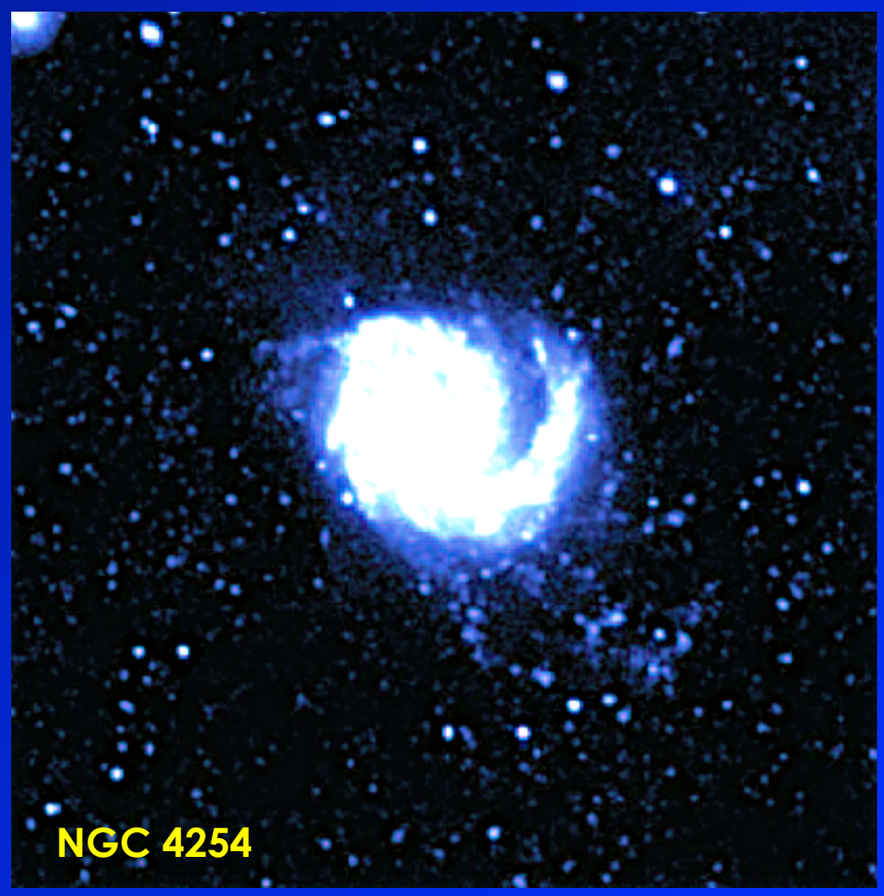
Extended UV-emission (XUV) in galaxies

- **Discovered using GALEX data.**
  - UV-bright complexes in the outskirsts of nearby spirals
  - Well beyond their B_{25} or Hα radius
  - Thilker et al. 2005, 2007
    Gil de Paz et al. 2005, 2007
- **XUV discs seems to exists in 20 - 30 % of the local disc galaxy population.**
  - Zaritsky & Christlein 2007; Thilker et al. 2007; Lemonias et al. 2011.
- **Even found around E/S0 galaxies.**
  - Thilker et al. 2010; Salim & Rich 2010; Moffett et al. 2012; Salim et al 2012; Bresolin 2013.
- **UV-bright complexes are young stellar clusters associated with recent or still on-going star formation.**
  - Gil de Paz 2007, Bresolin et al. 2009, 2012
- **XUV-discs should be embedded in larger HI envelopes, 2X-HI,** (Koribalsky & L-S 2009).

Thilker et al. 2007



The galaxy pair NGC 1512 / 1510

- **NGC 1512:**
  - SB(r)ab, Z ~0.7 Zo
  - D = 9.5 Mpc
  - Bar ~ 3’ = 8.3 kpc
  - Ring ~ 3’ x 2’ = 8.3 x 5.5 kpc
  - Nuclear ring ~ 16” x 12” (740 x 550 pc)
- **NGC 1510:**
  - S0, BCDG, WR, Z~0.2 Zo
  - N enrichment ?
  - 5’ = 13.8 kpc from NGC 1512
- Hα images (Meurer et al. 2006) reveal many star forming regions
  - Sizes 2”–5” (90–230 pc)
  - Dozens in the ring
  - NGC 1510
  - But also in external regions with no evident continuum emission!

NGC 1512 / 1510 , B + R + Hα , CTIO data combined by Á.R. L-S.

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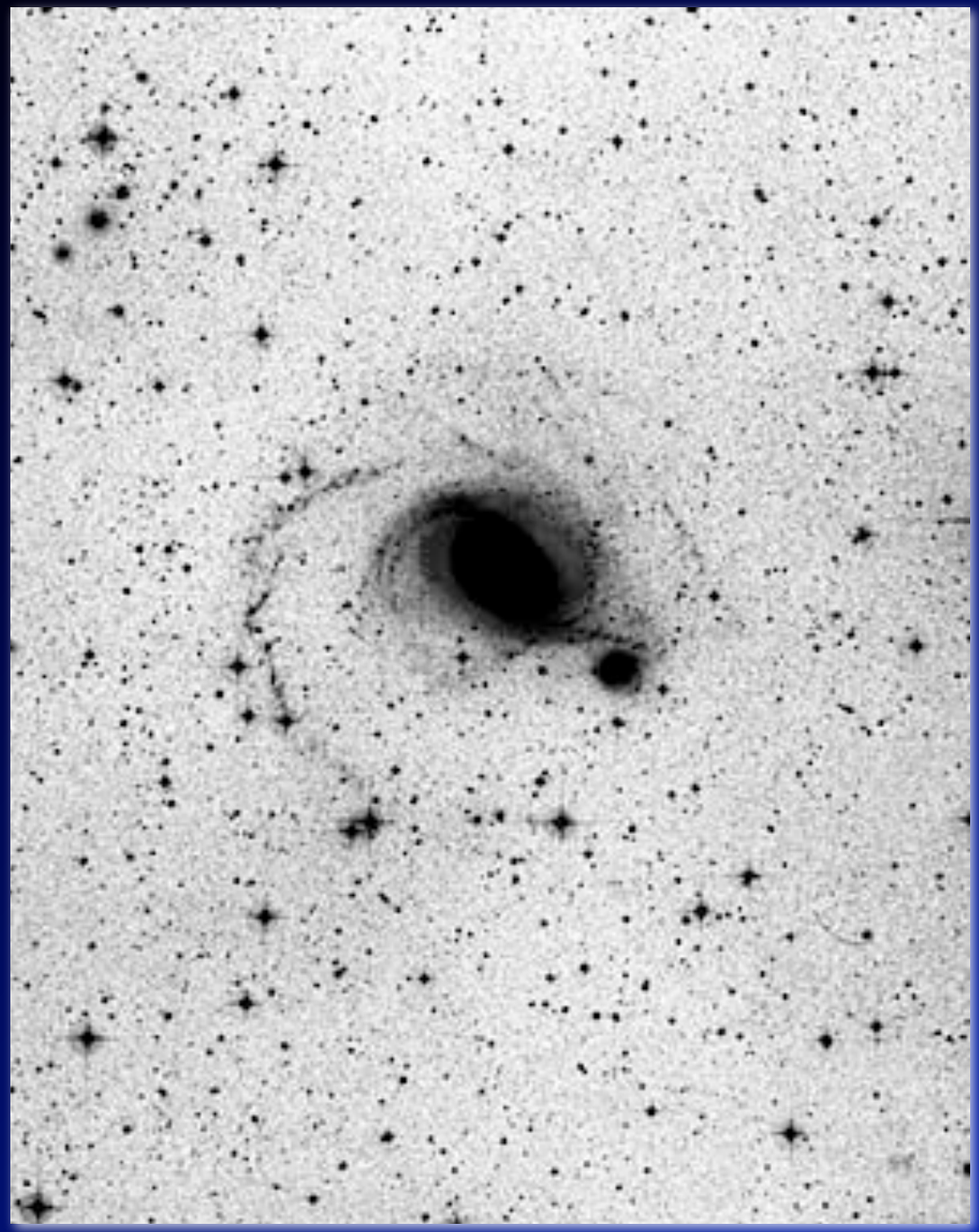
NGC 1512/1510 deep optical / UV images



Deep optical image
(1.2 UKST, David Malin, priv. com.)

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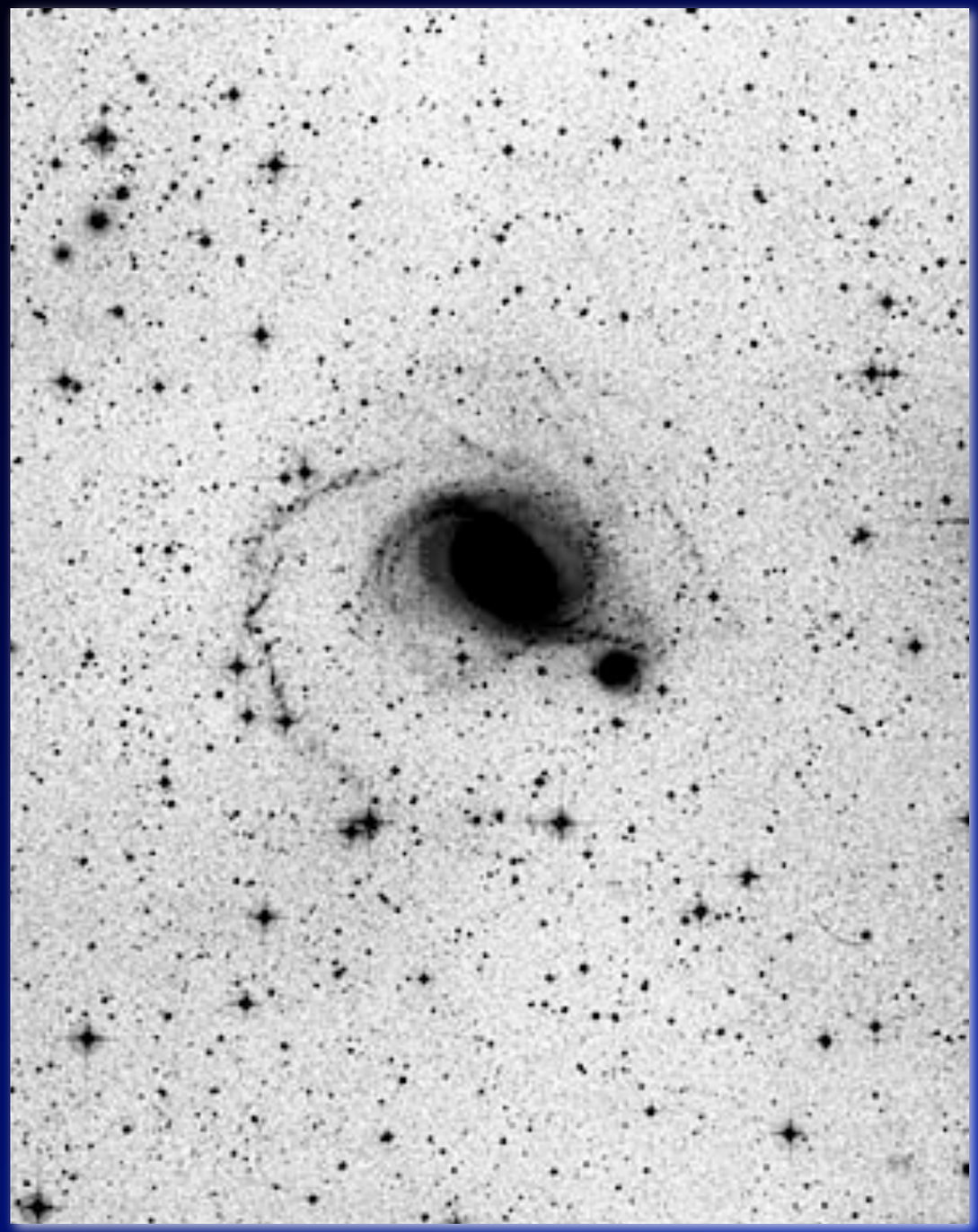

Deep optical image
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The Huntsman Array (AAO/MQ) and the Dragonfly Array, see also Martínez-Delgado+ 2010,2013, Lewis+13, Duc+2014
Extended stellar features also observed in dwarf starburst galaxies, see López-Sánchez et al. 2006, López-Sánchez & Esteban 2008

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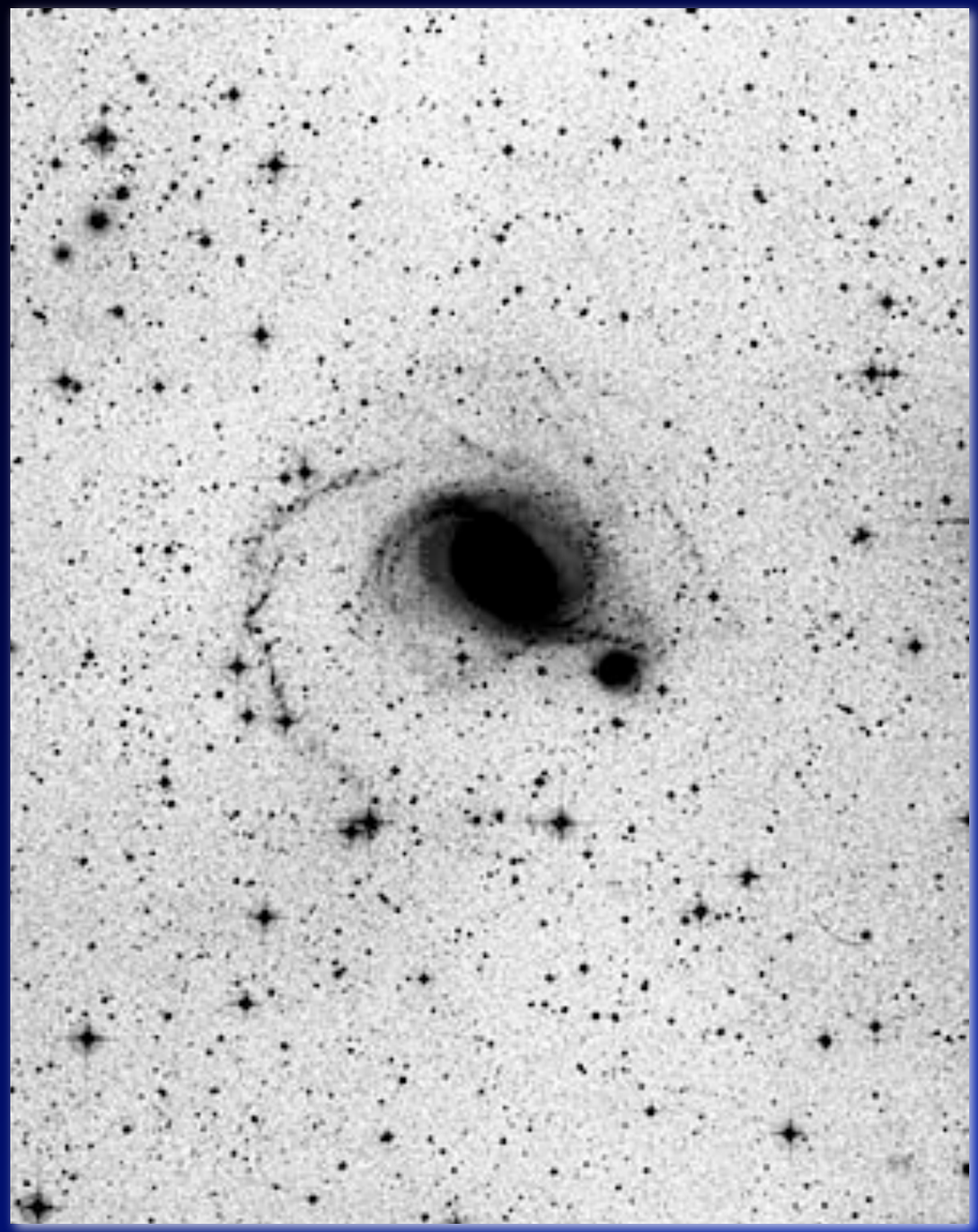

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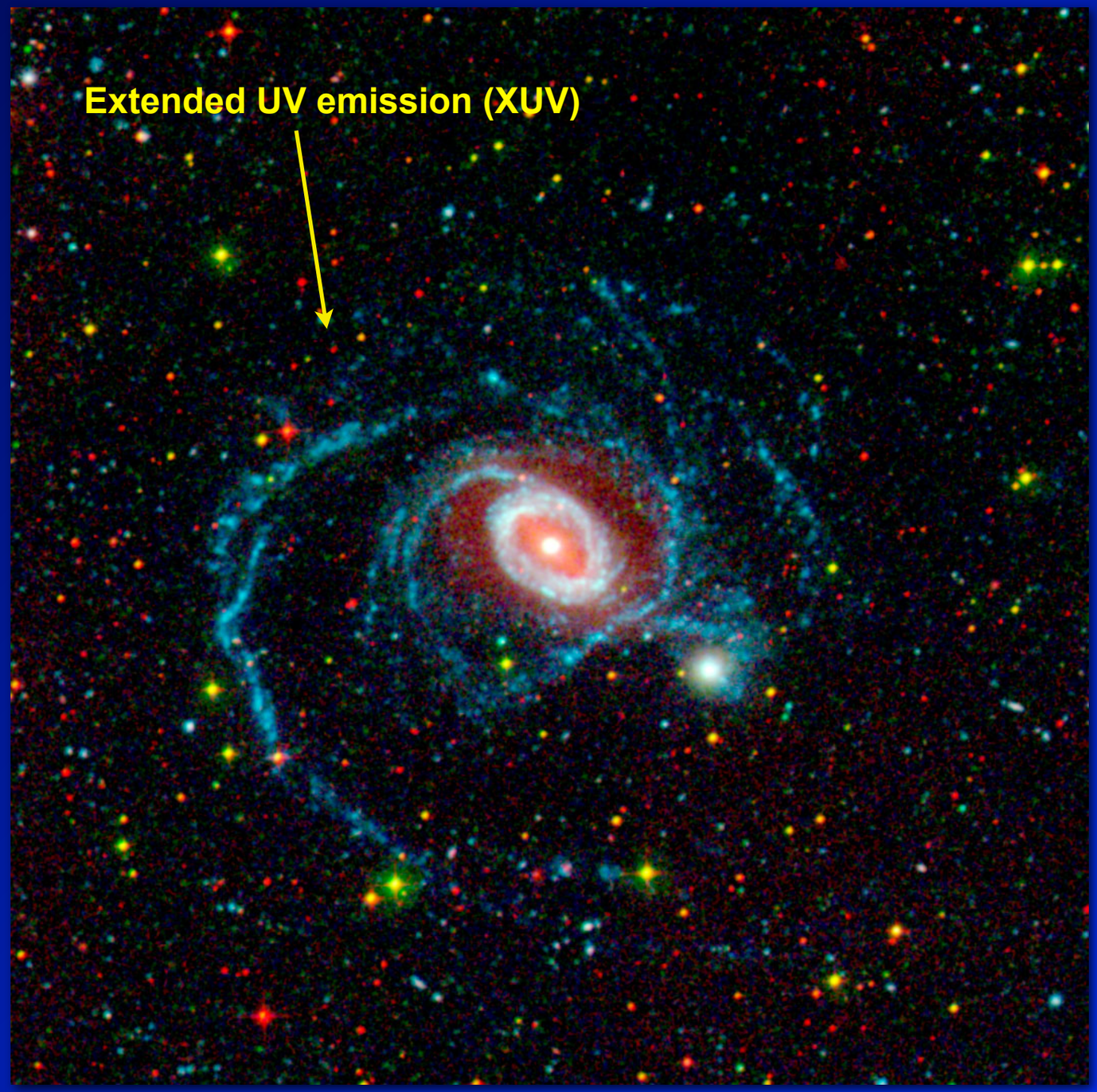

Deep UV image
(FUV + NUV, GALEX, Gil de Paz et al. 2007)

The Huntsman Array (AAO/MQ) and the Dragonfly Array, see also Martínez-Delgado+ 2010,2013, Lewis+13, Duc+2014
Extended stellar features also observed in dwarf starburst galaxies, see López-Sánchez et al. 2006, López-Sánchez & Esteban 2008

Observations of XUV using ATCA + AAT

- **HI data from LVHIS, the *Local Volume HI Survey*, P.I. B.S. Koribalski,**
  - **Koribalski 2008, Koribalski et al. in prep.**
  - **Australia Telescope Compact Array**
  - **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 < -30º .**

- **http://www.atnf.csiro.au/research/LVHIS**

- **Optical data using the 2dF/AAOmega instrument at the 3.9m Anglo-Australian Telescope**
  - **Use NUV image to select UV-bright regions**
  - **AAOmega: blue (3700λ - 5500λ) + red spectra (6200λ - 7200λ) simultaneously**
  - **Main objective: chemical abundances and kinematics of ionized gas**

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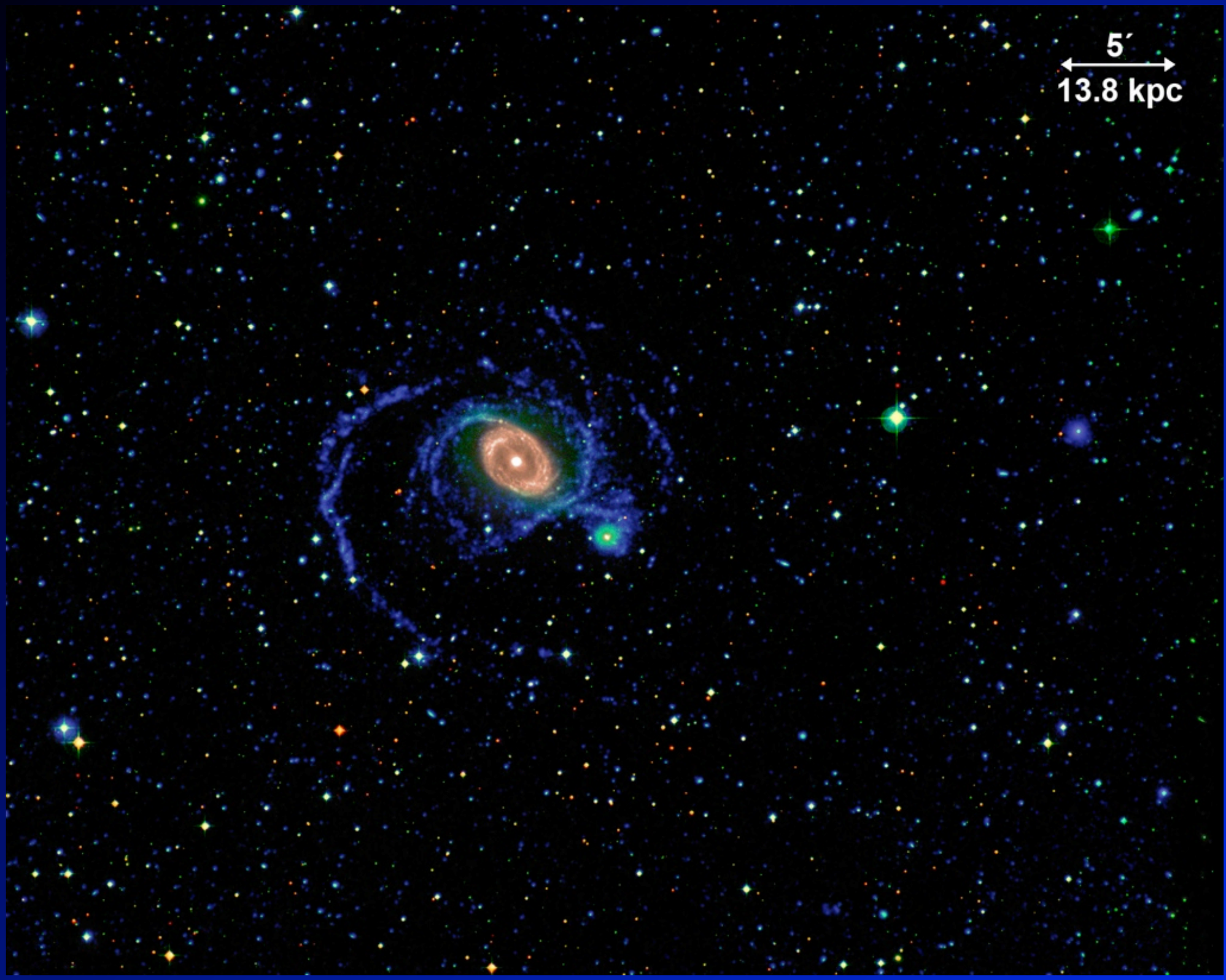
The HI distribution in the galaxy pair NGC 1512 / 1510



FUV+NUV (blue) + R (green) + J (red) + MIR (NGC 1512, luminosity)

Koribalski & López-Sánchez (2009, MNRAS)

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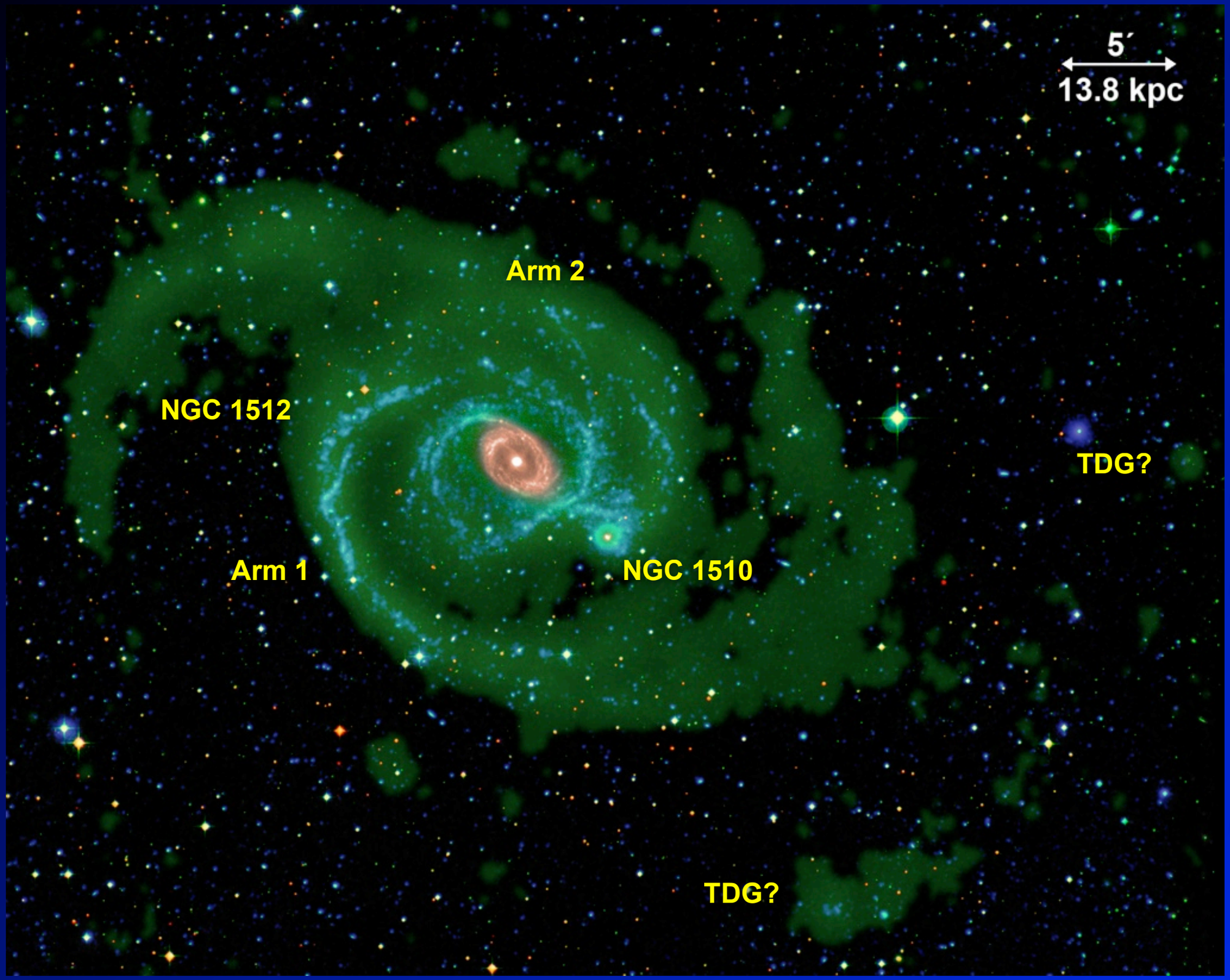

- ATCA observ. using 7 arrays
- Mosaic using 4 pointings
- Total int. time: 3.11 days
- Huge amount of neutral gas!
- Two extended spiral arms
- Two TDG candidates
- NGC 1512:
  - $M_{HI} = 5.7 \times 10^9\ M_\odot$
  - $M_{Dyn} \sim 4 \times 10^{11}\ M_\odot$
  - $M_{HI}/L_B = 1$
- NGC 1510:
  - $M_{HI}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

FUV+NUV (blue) + H I map (green) + R (green) + J (red) + MIR (NGC 1512, luminosity)

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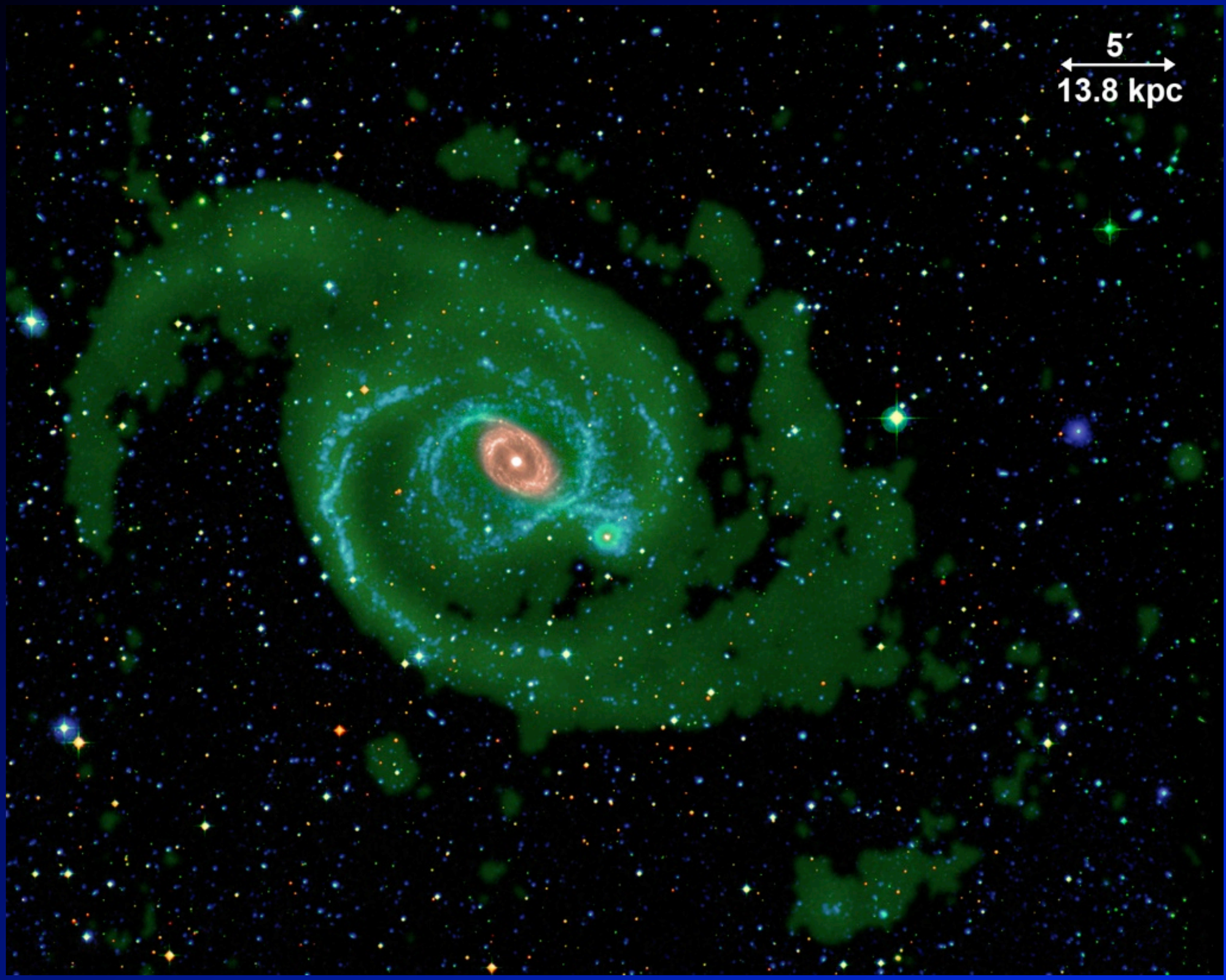
H I / UV comparison in NGC 1512/1510



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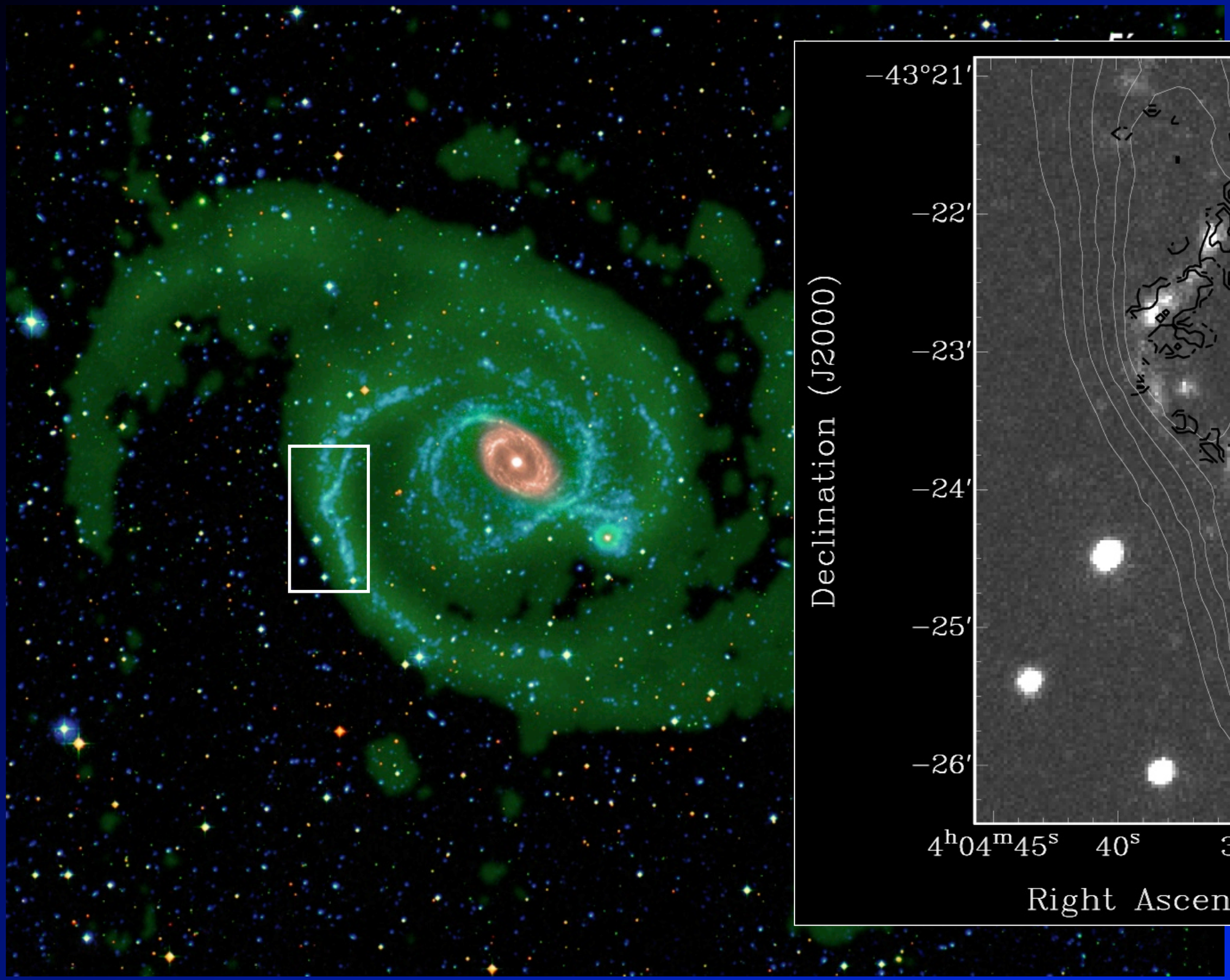

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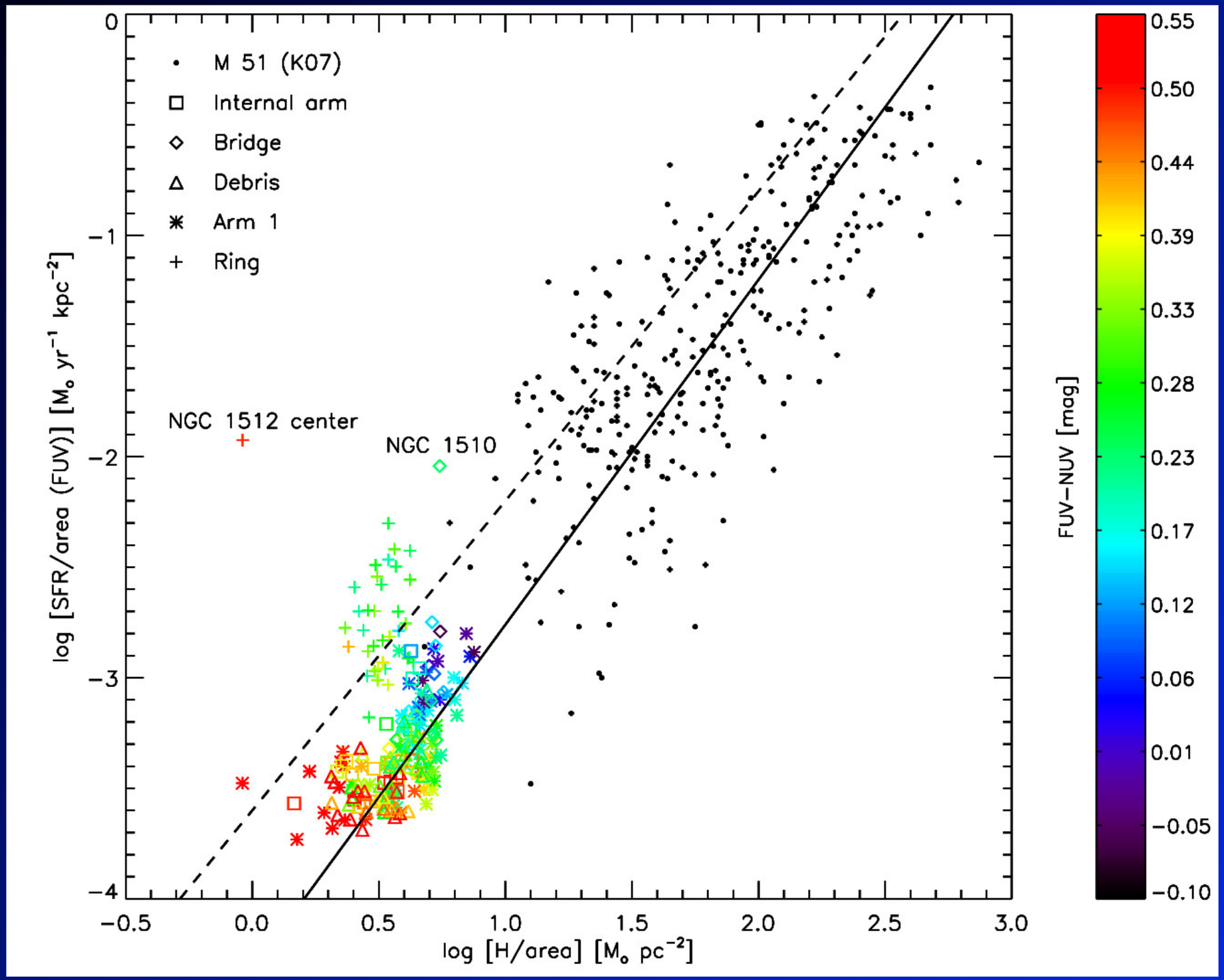
Star-formation law in NGC 1512/1510



Star-forming regions in NGC 1512/1510 follow the Schmidt-Kennicutt relation.

Comparison of star-forming regions within different areas with regions in M 51 (Kennicutt et al. 2007, continous line) and relation for dwarf and spiral star-forming galaxies (Kennicutt et al. 1998, dashed line).

Same results that Bigiel et al. (2008, 2010a,b), and models by Lagos et al (2013)

But see Schruba et al. (2011, 2012), Lada et al. (2013)

Koribalski & López-Sánchez (2009, MNRAS)

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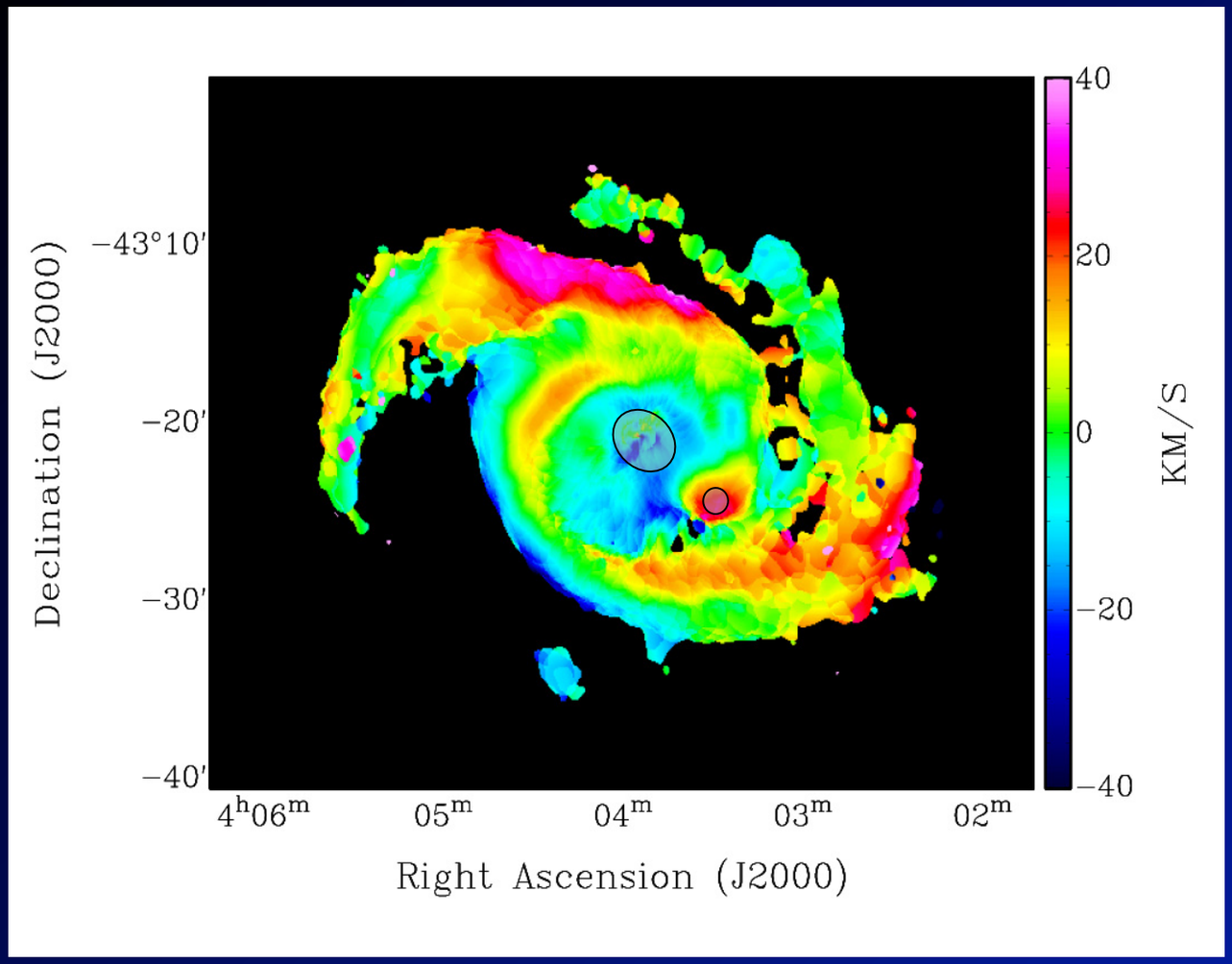
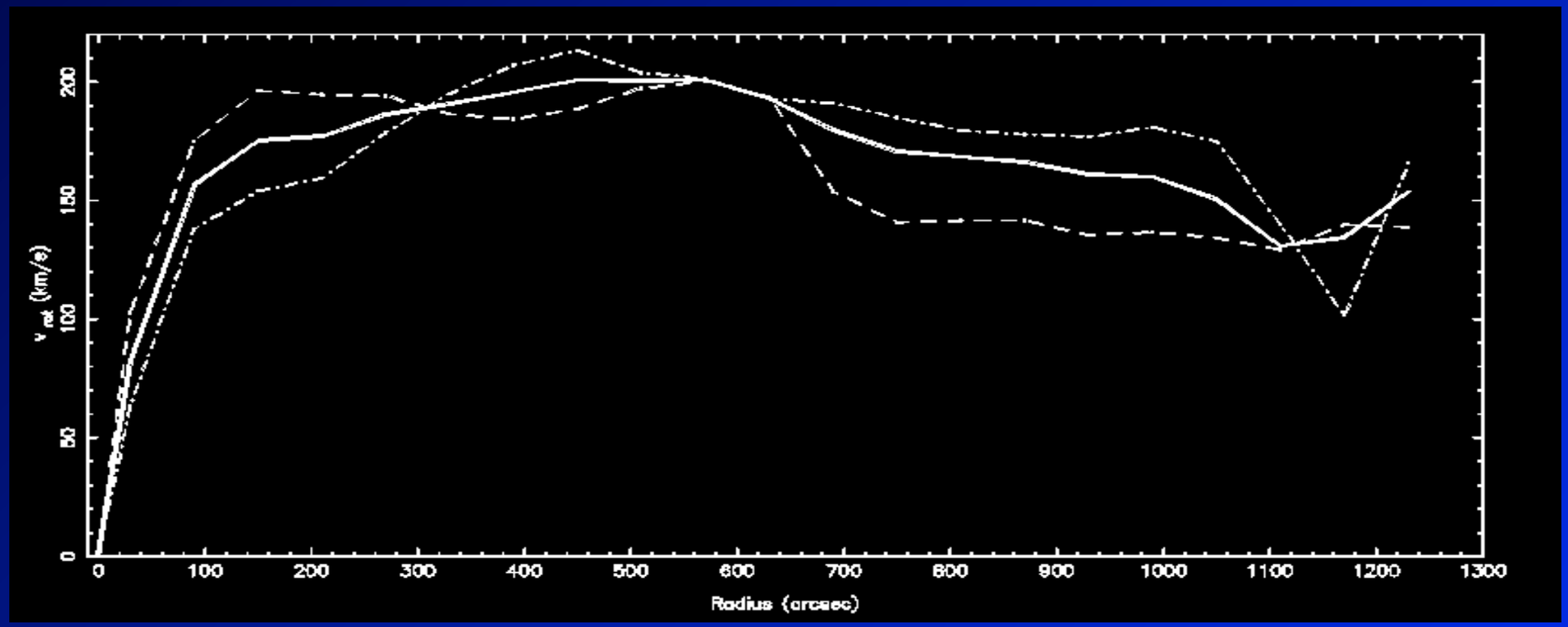


NGC 1512 / 1510
Rotation fit and residues

- The velocity field is mainly **rotation**,
- But we found some **discrepances** in the most **external regions** and in the position of **NGC 1510**.
- **Star formation activity** and the external **HI structures** seem to be consequence of the **interaction** that **NGC 1512** and **NGC 1510** are experiencing. **Minor merger ~ 400 Myr**



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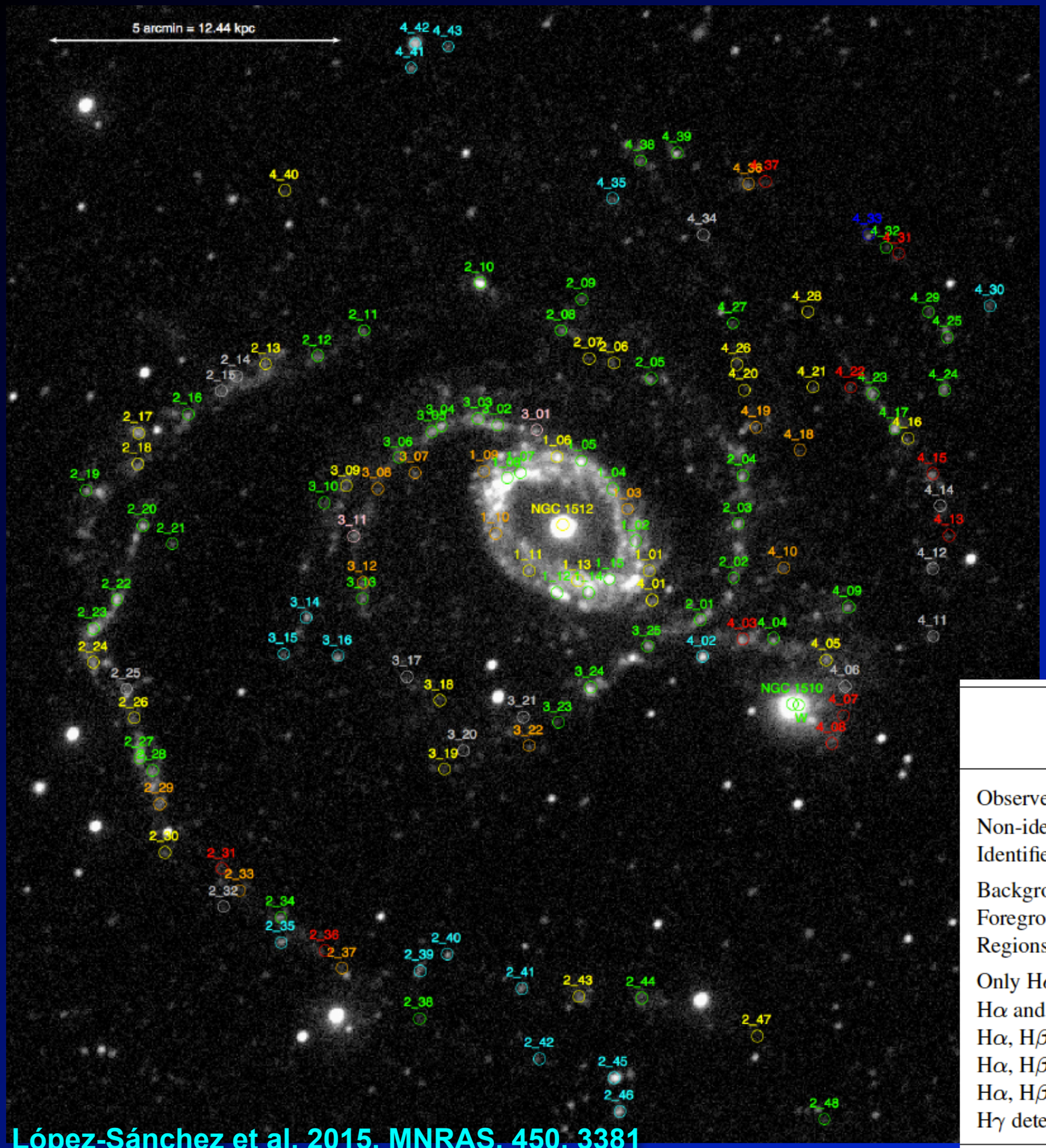

López-Sánchez et al. 2015, MNRAS, 450, 3381

Ionized gas in the XUV disc of NGC 1512

- **10%** of the identified targets are **background galaxies**
- **88%** of the UV-bright regions observed in NGC 1512 / NGC 1510 **have ionized gas**!
- Almost **half** of those regions show **Hα, Hβ, [O II], [O III] and [N II] emission.**
- **[O III] λ4363** detected in 4 regions (2 are in NGC 1510)

	Fibre number	% Total	% Class	Color in Fig. 1
Observed	164	100.0	...	...
Non-identified	11	6.7	...	red
Identified	153	93.3	...	...
Background galaxies	17	10.4	11.1	cyan
Foreground stars	1	0.6	0.7	blue
Regions in NGC 1512/1510	135	82.3	88.2	...
Only Hα detected	15	9.1	11.1	grey
Hα and [N II]	30	18.3	22.2	yellow
Hα, Hβ, and [N II]	6	3.7	4.5	pink
Hα, Hβ, [N II], and [O III]	20	12.2	18.8	orange
Hα, Hβ, [N II], [O III], and [O II]	64	39.0	47.4	green
Hγ detected	51	31.1	37.8	...

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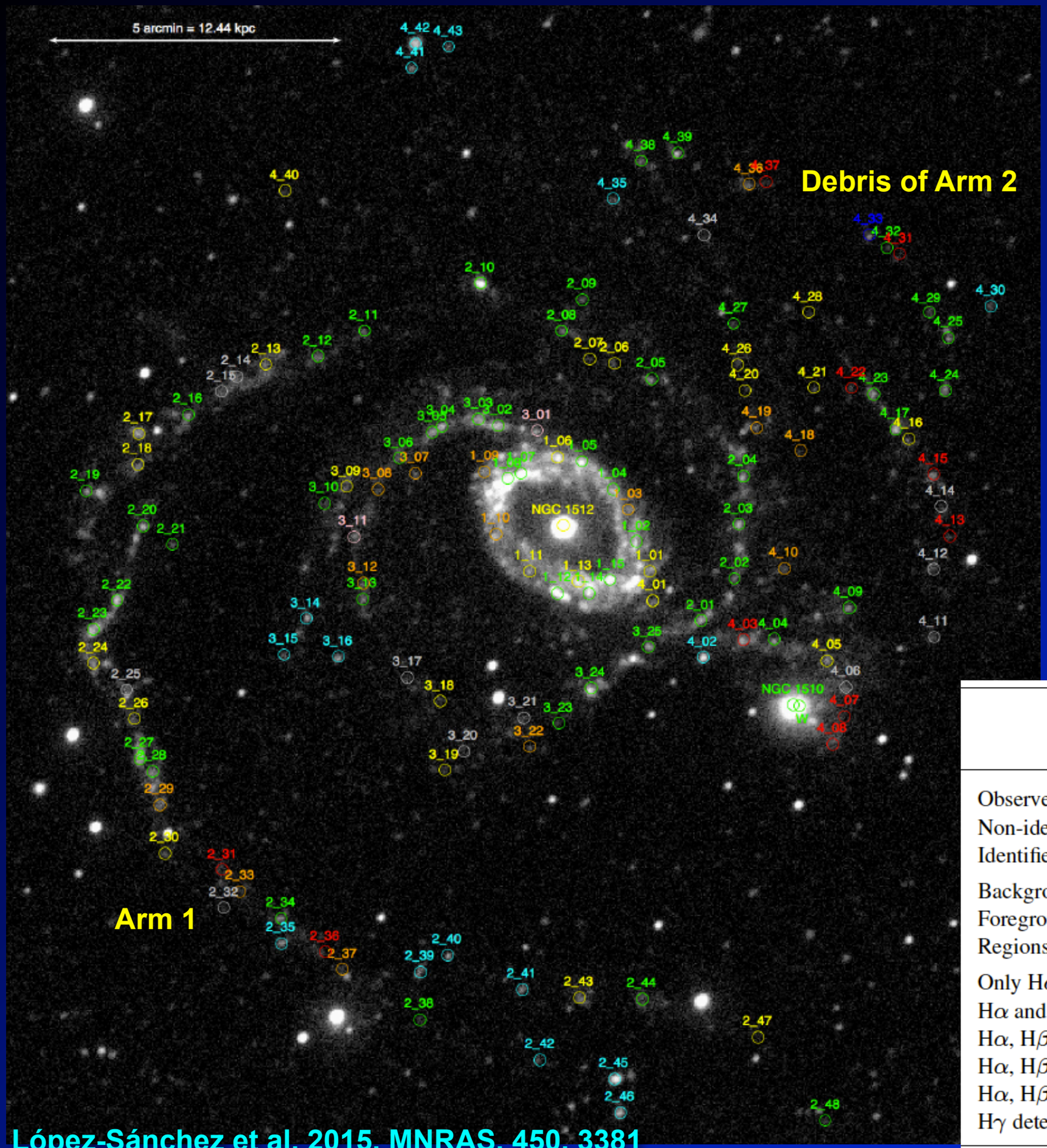

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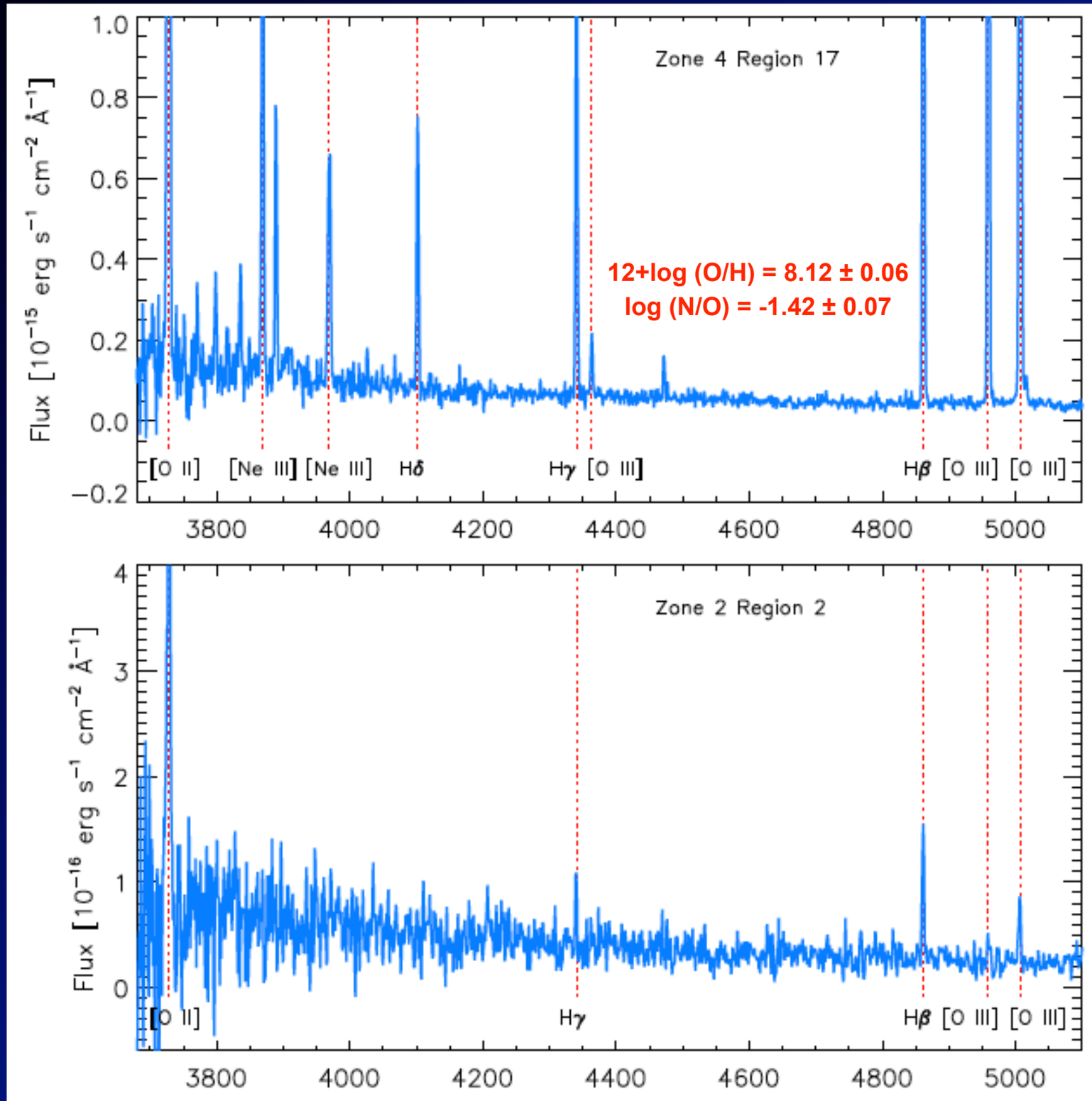
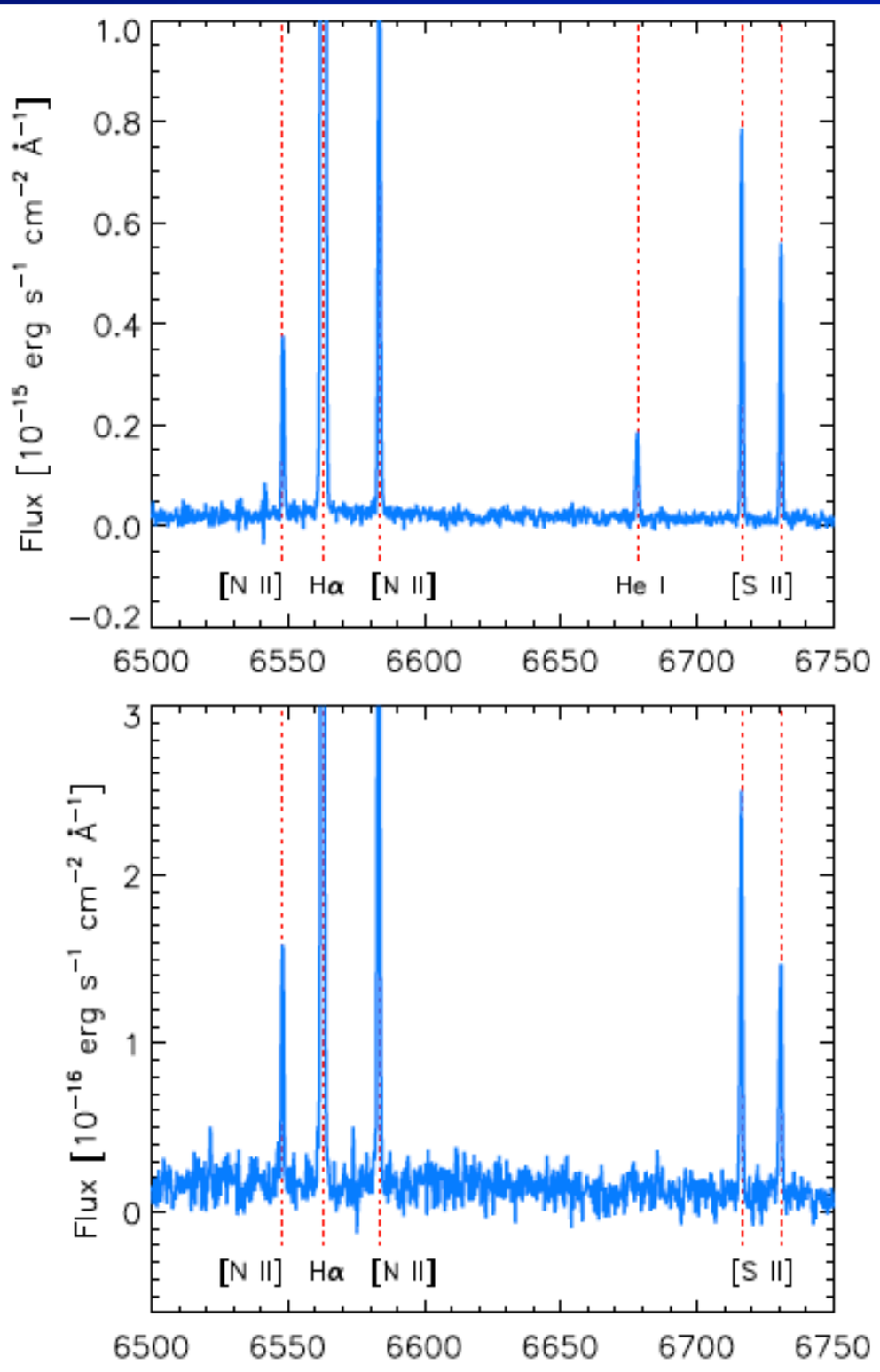
Examples of the optical spectra of UV-bright regions in NGC 1512





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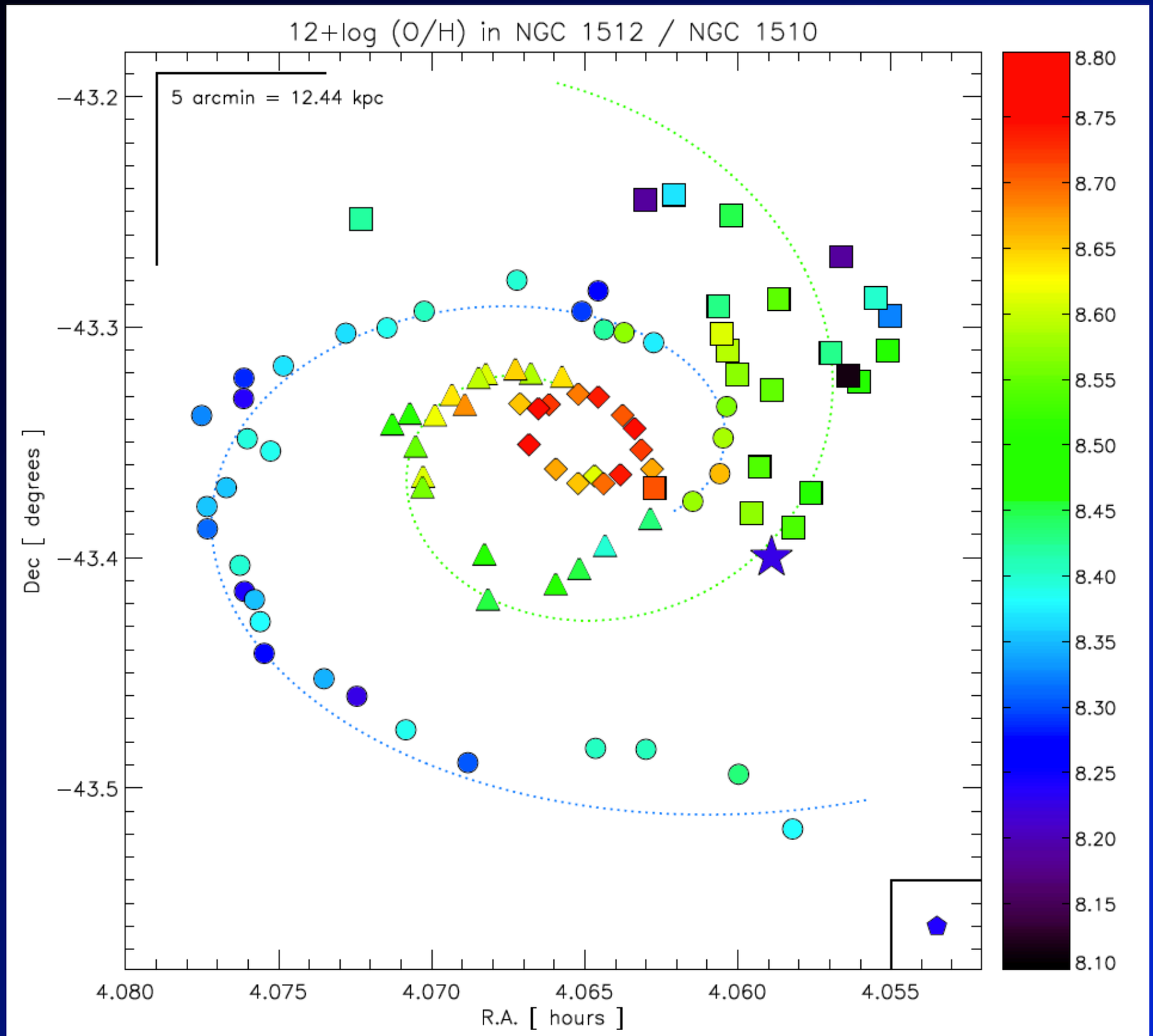
NGC 1512 / 1510 oxygen abundance map



12+log (O/H) map in NGC 1512 / 1510 (López-Sánchez et al. 2015, MNRAS, 450, 3381)

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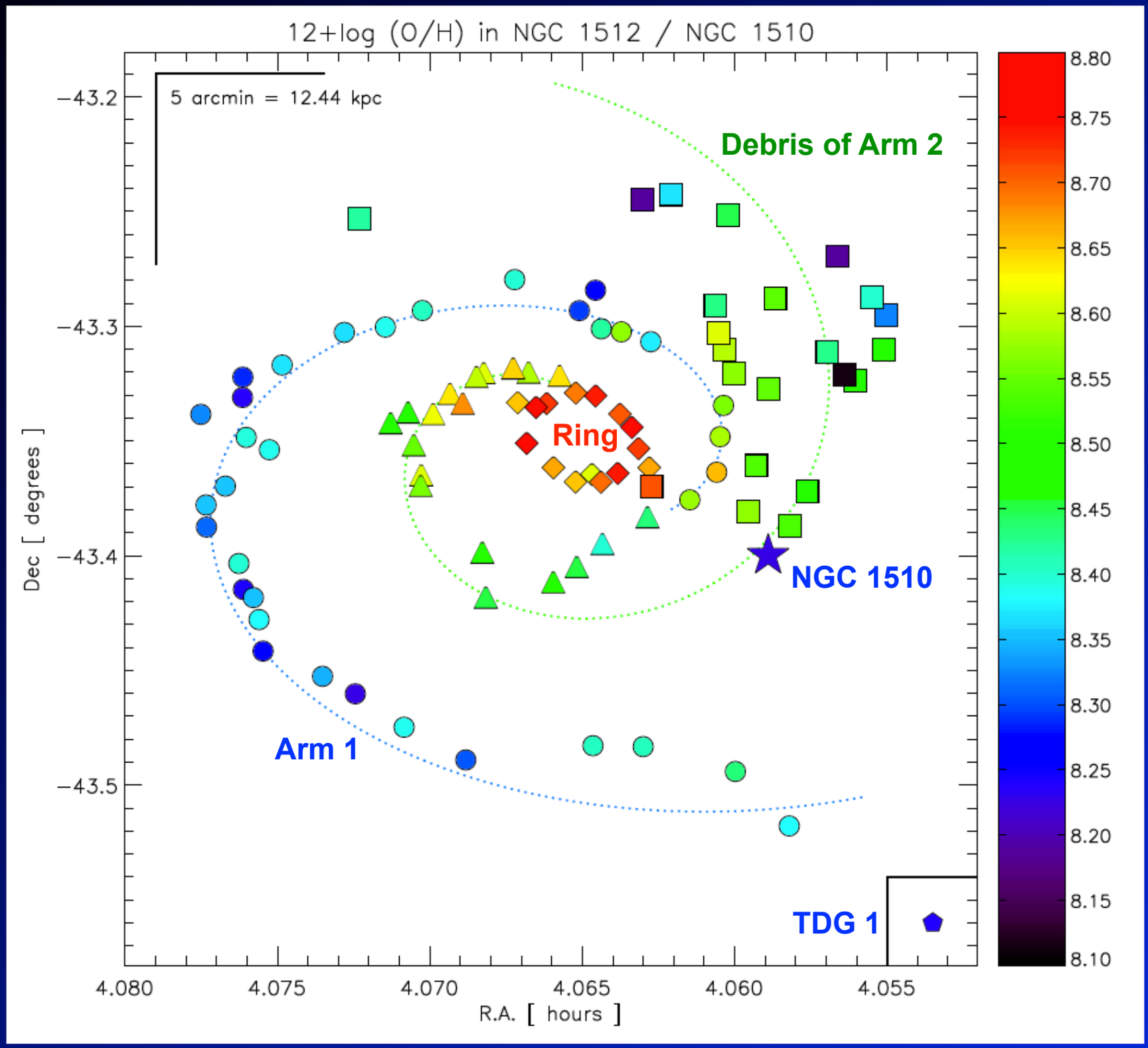

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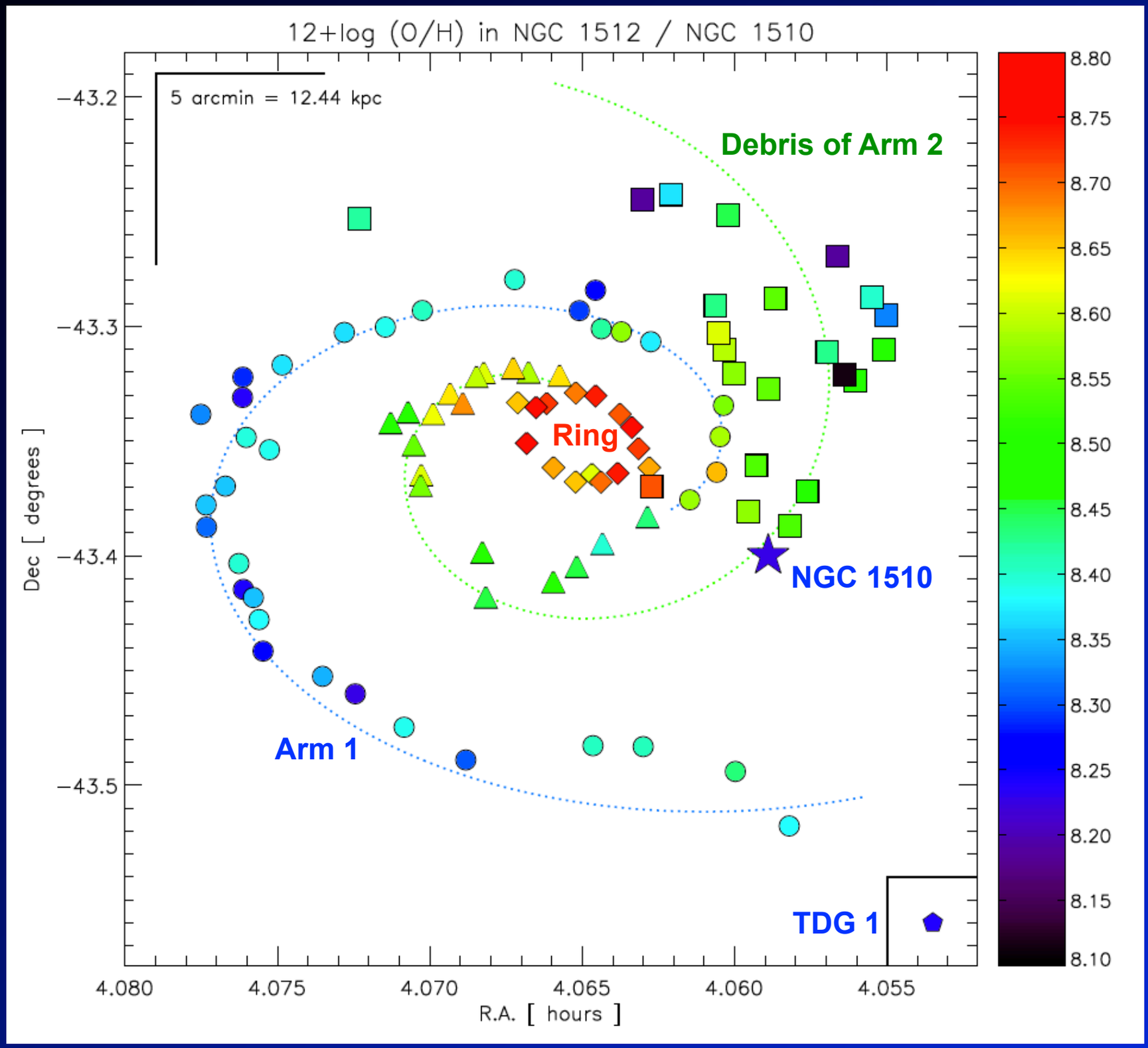

- Ring: 12+log(O/H) ~ 8.71

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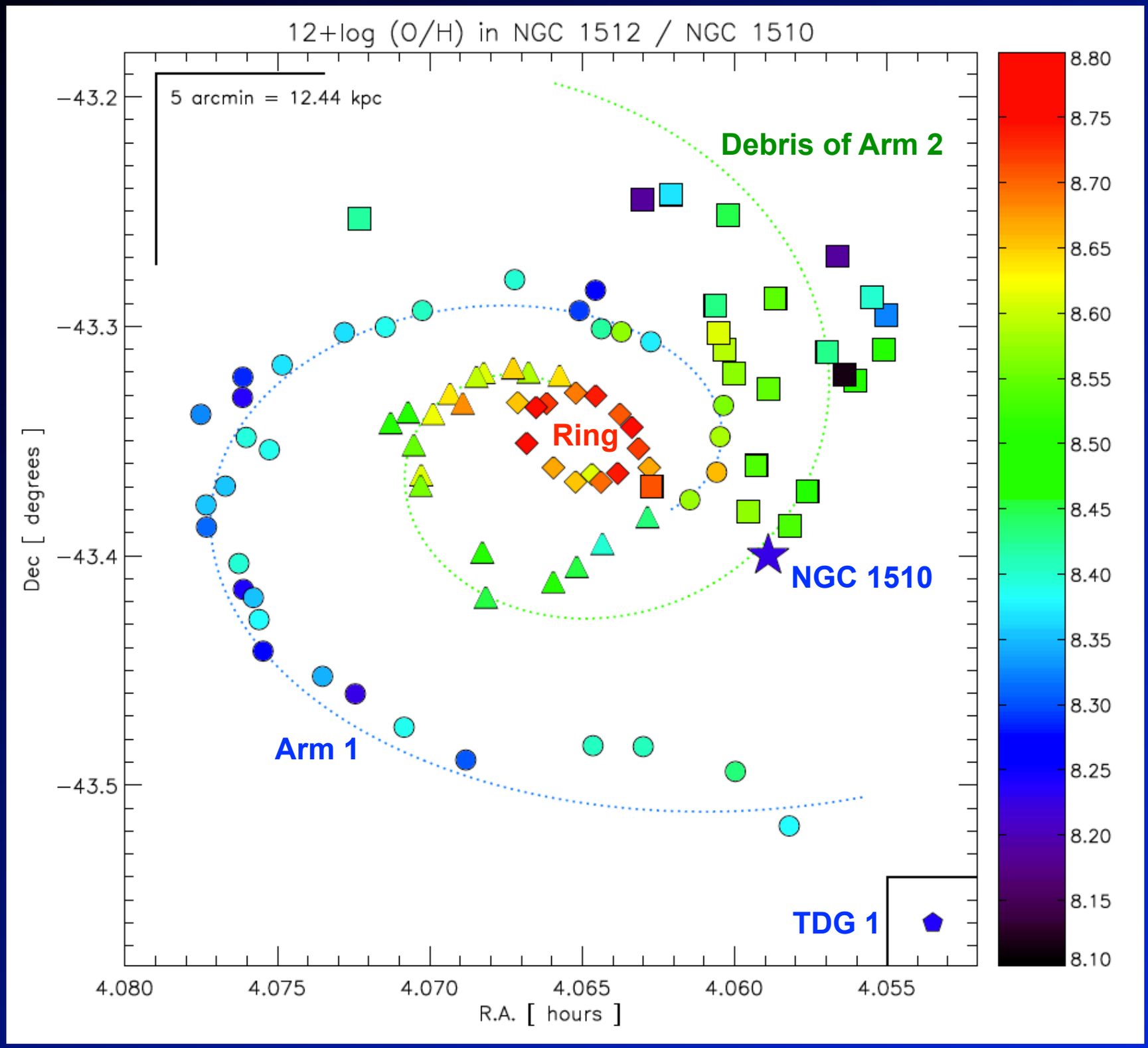

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- Long almost flat abundance gradient through Arm 1, average value ~ 8.35.
  - *Star-formation activity seems to be not important in their recent past.*

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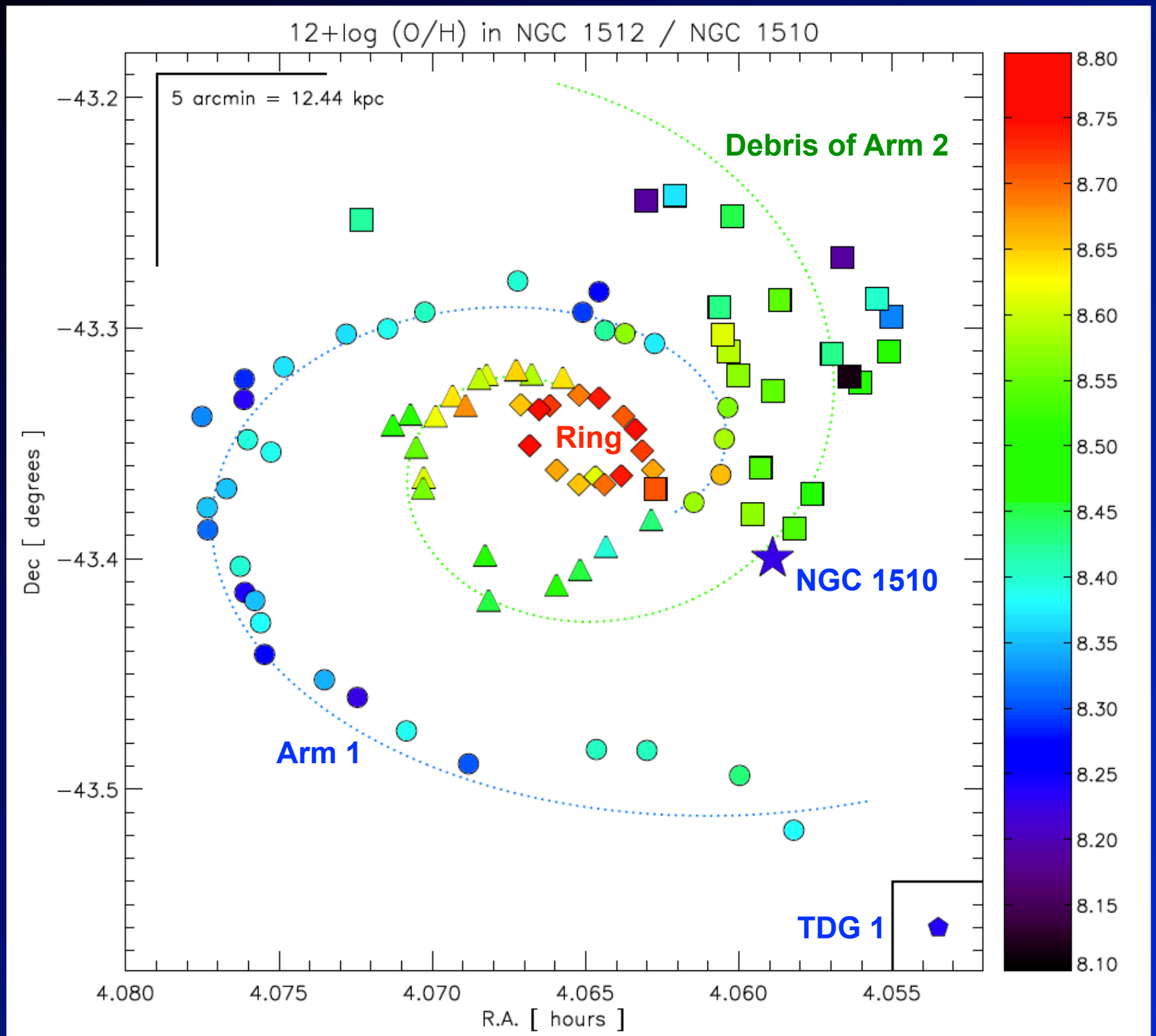

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- Assymetric O/H distribution throughout debris of Arm 2, average value ~ 8.44, but high dispersion (8.71 - 8.12).
  - Interaction processes with NGC 1510 enhanced SF!
  - This confirms results by Kewley et al. (2010) , Rupke et al. (2010) and Werk et al. (2010, 2011) that galaxy interactions flattens the metallicity gradients in galaxies.

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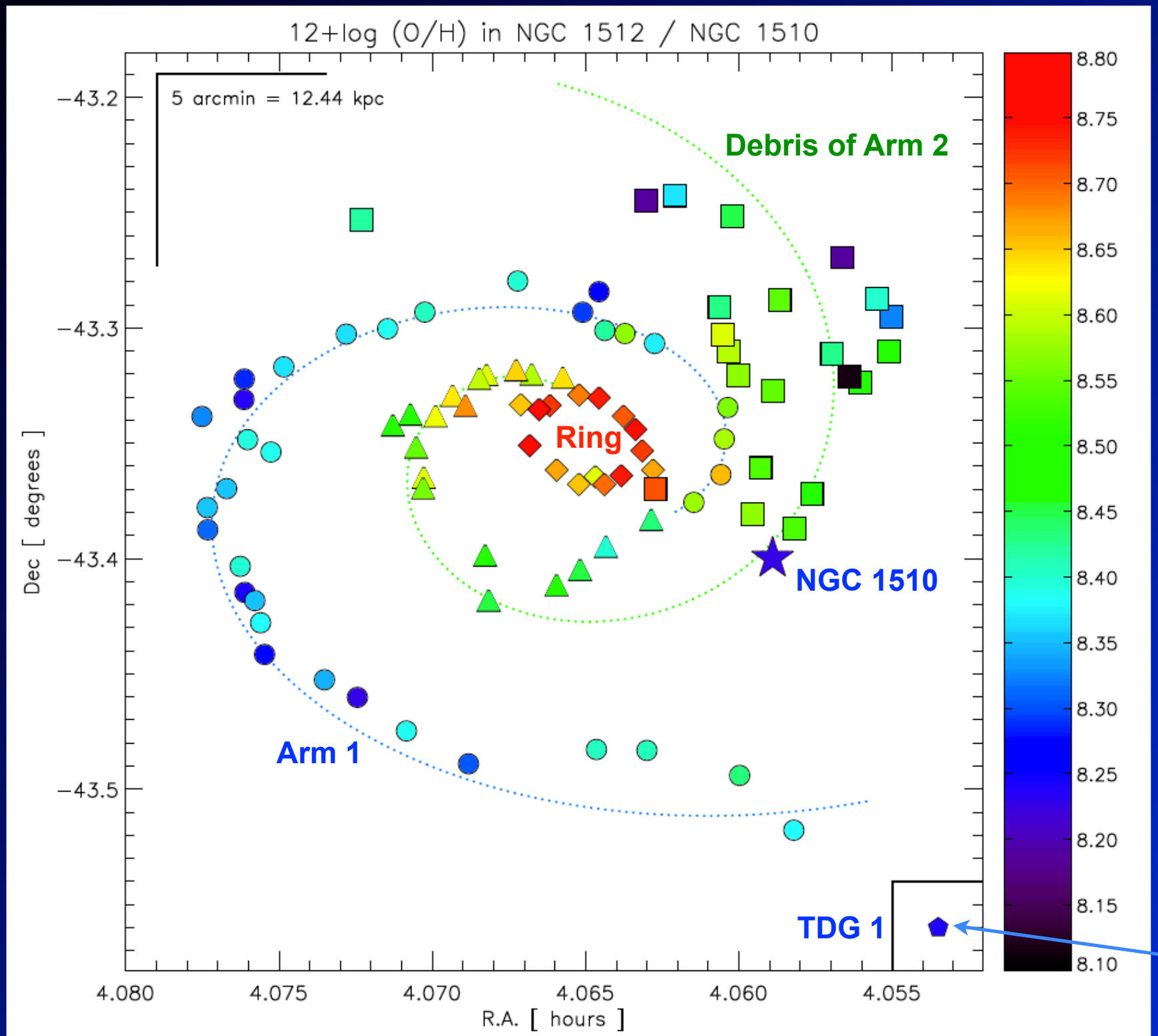

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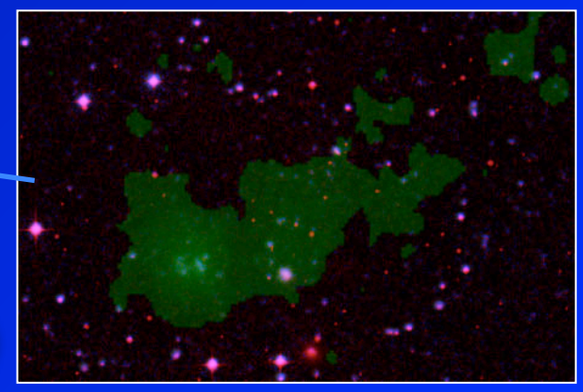
- TDG1 has 12+log(O/H) = 8.24
  - Is it actually a TDG?



12+log (O/H) map in NGC 1512 / 1510 (López-Sánchez et al. 2015, MNRAS, 450, 3381)

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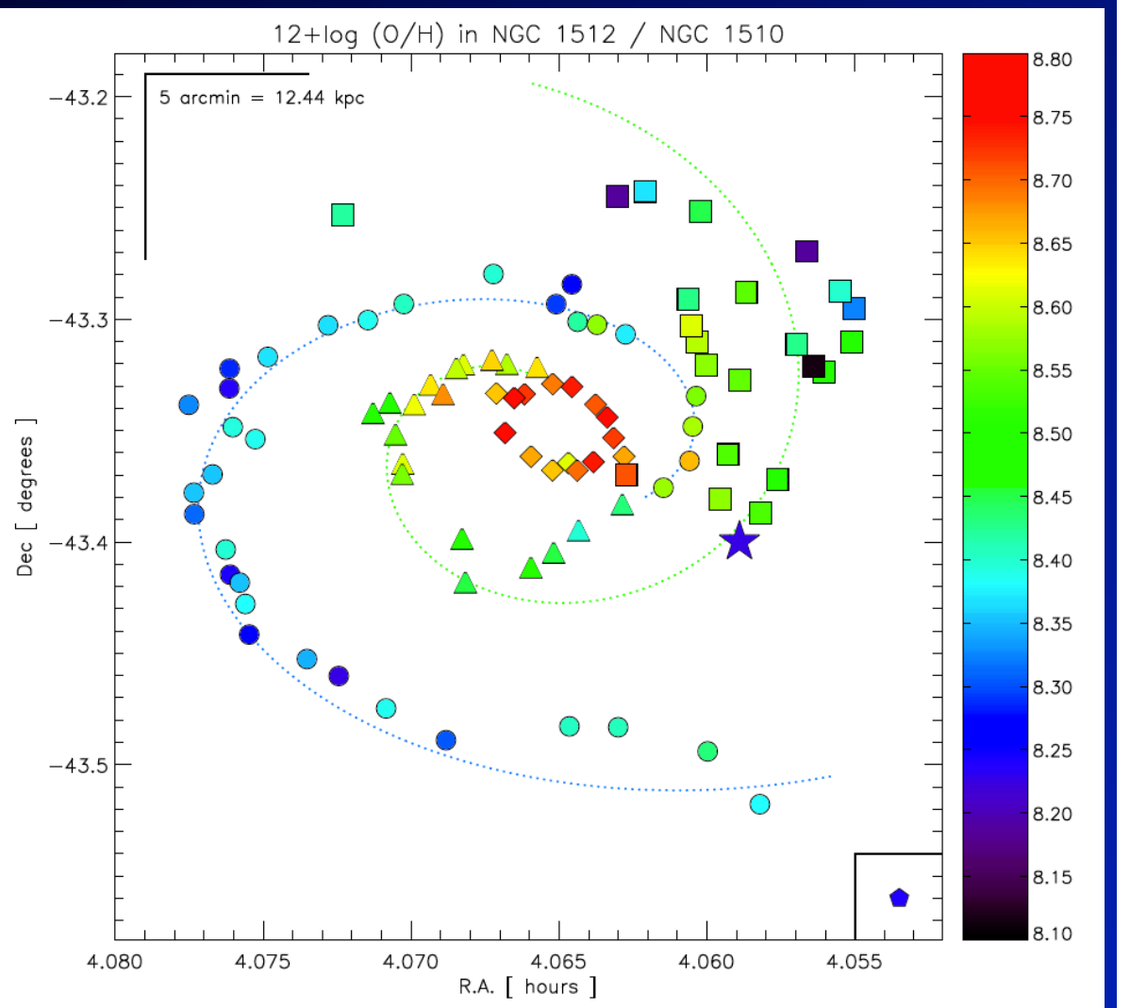
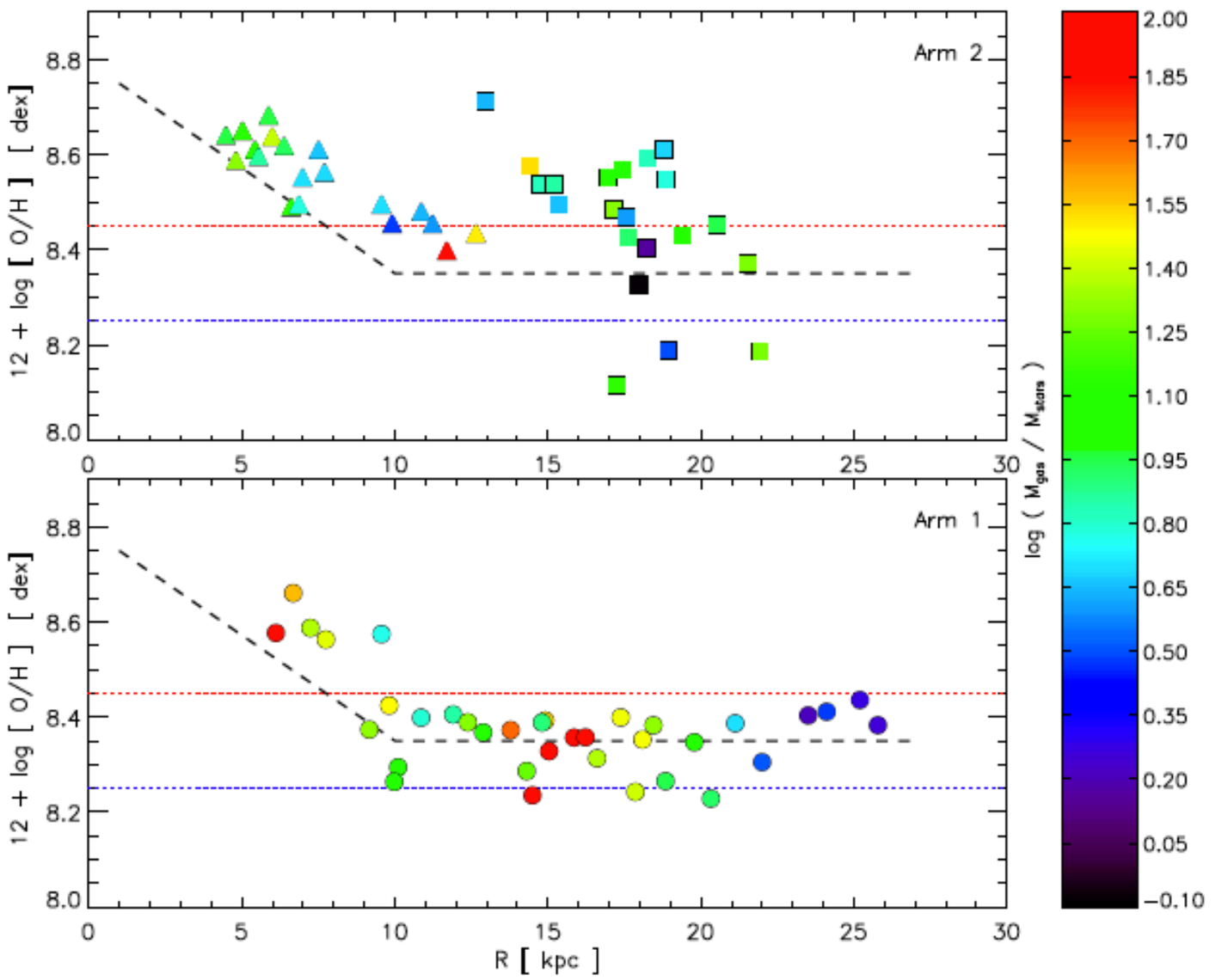
Metallicity gradients

- Assuming a **radial + azimuthal gradient** along **spiral arms,** the almost undisturbed Arm 1 and the very disturbed Arm 2 are easily identified.
- Similar result plotting the N/O ratio
- The flattening of the metallicity gradient in external regions of spiral galaxies was already detected (e.g. Bresolin et al. 2009, 2012; Kewley et al. 2010; Werk et al. 2010, 2011; Sánchez et al. 2014), as it is seen even in the Milky Way (Esteban et al. 2013).





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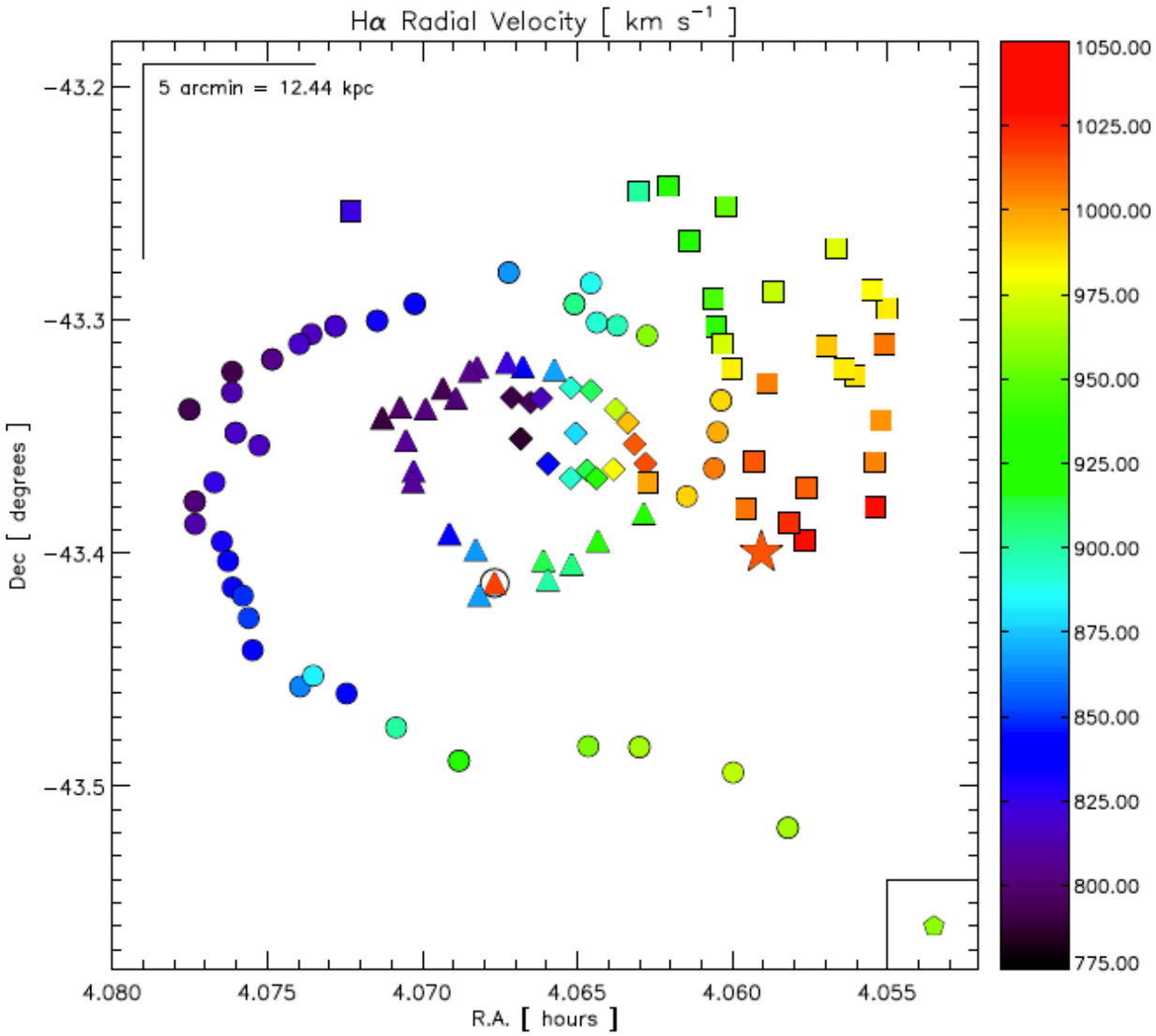
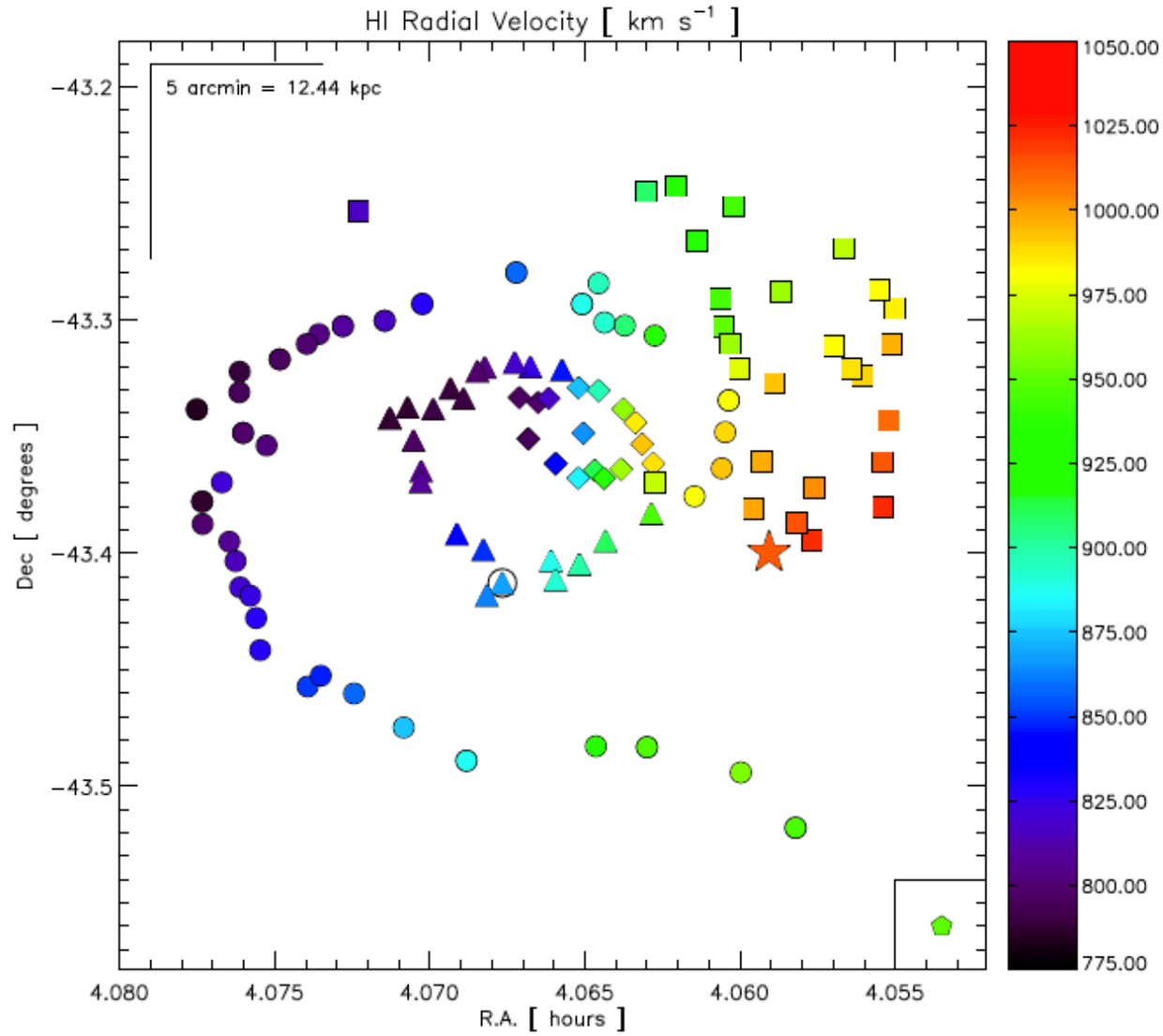
Kinematics of the ionized gas vs kinematics of the neutral gas





- In general, **excellent agreement between H I and Hα kinematics**
  - This maps traces the kinematics of the system using ionized gas up to 2.8 Re !!!

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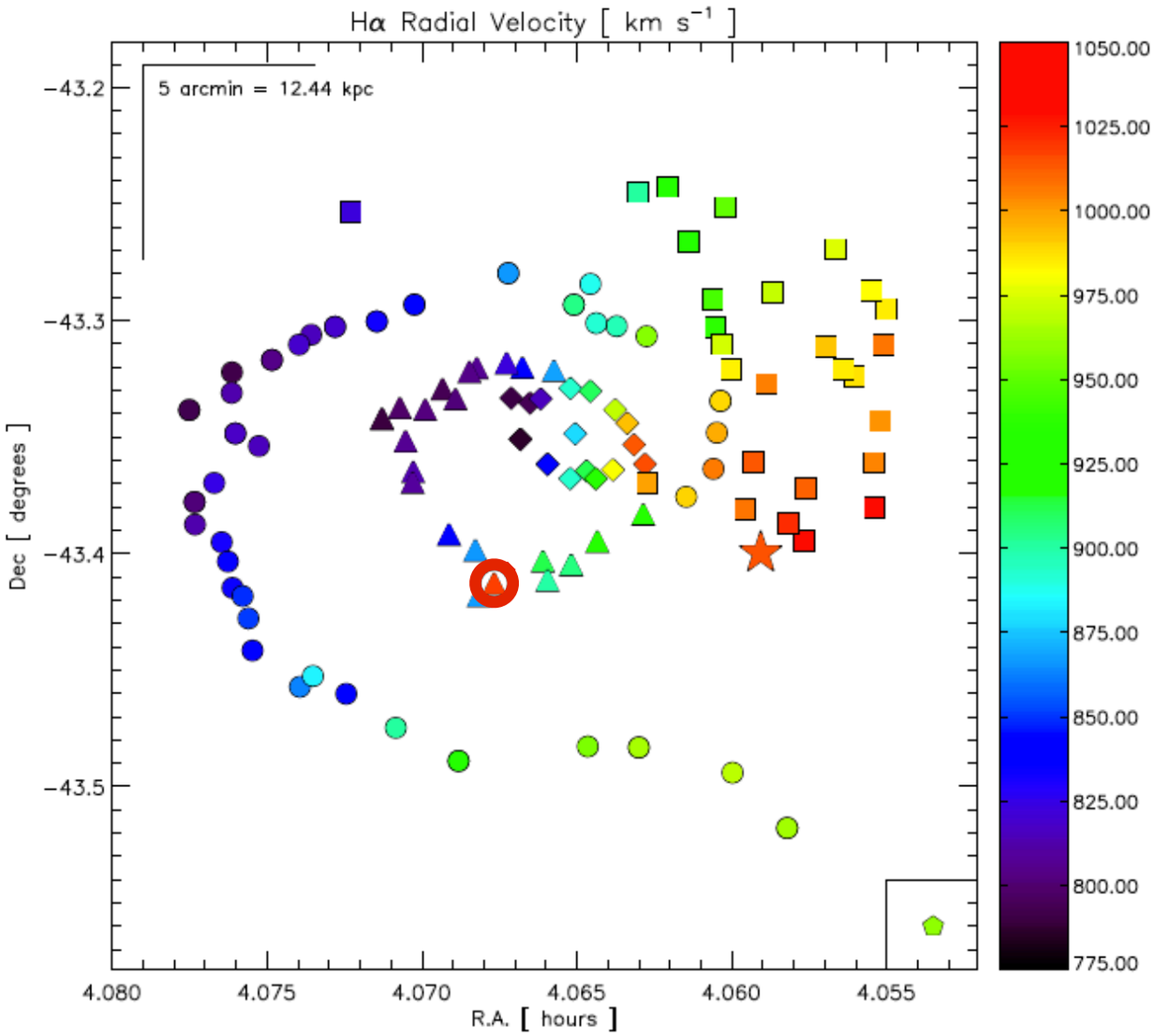

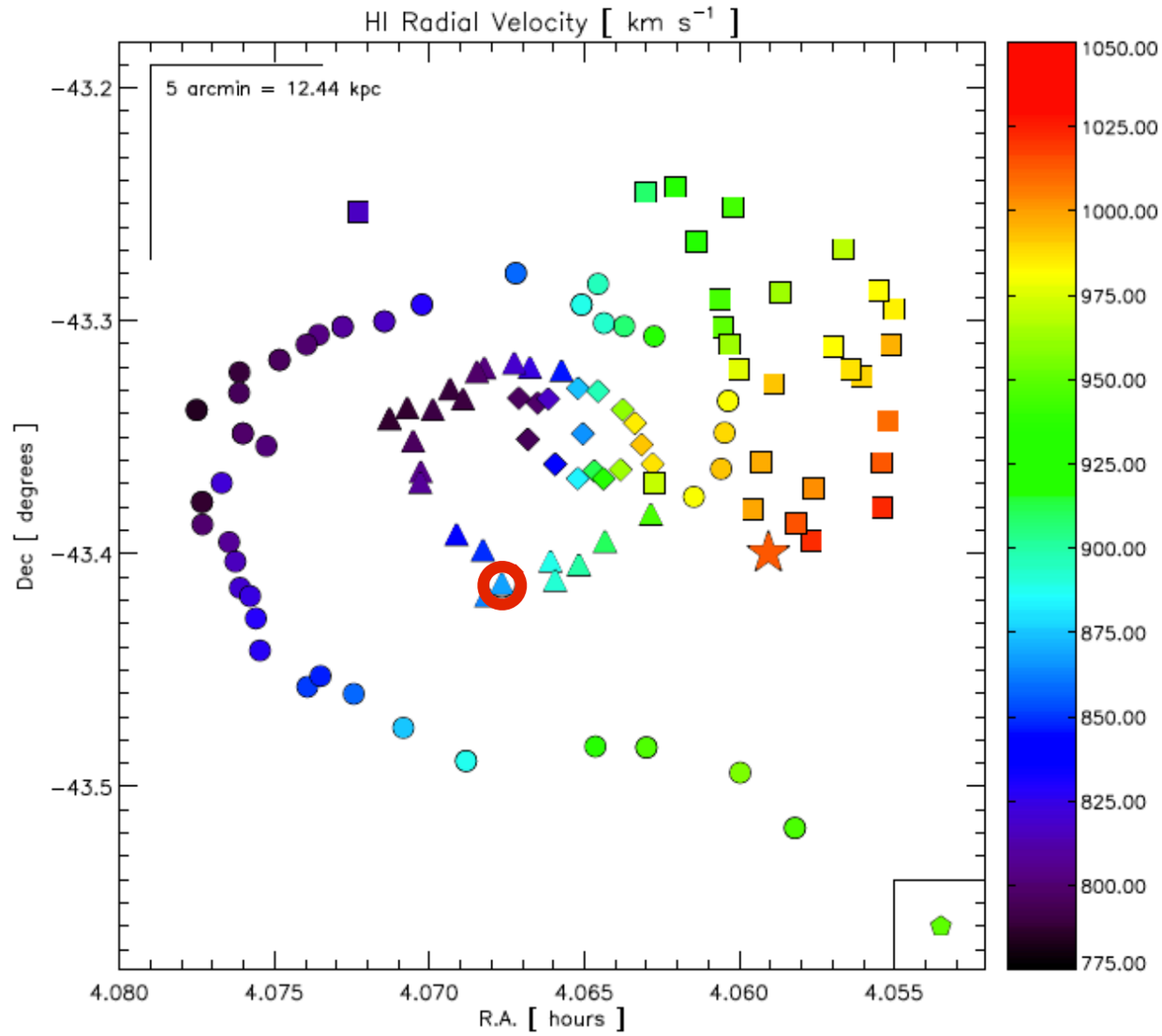

- In general, **excellent agreement between H I and Hα kinematics**
  - This maps traces the kinematics of the system using ionized gas up to 2.8 Re !!!
- But knot **3_20** shows a difference of **136 km/s** between **H I and Hα velocities** !
  - A careful inspection reveals **high Hα dispersion** and **12+log (O/H) < 8.1** (8.5 nearby knots) !!
  - Is it an **independent dwarf galaxy**?

López-Sánchez et al. 2015, MNRAS, 450, 3381

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Where are the metals coming from?

How much enrichment in oxygen ?

$$\Delta\left(\frac{\mathrm{O}}{\mathrm{H}}\right) = \frac{y_{\mathrm{O}} \times \Delta t}{f} \times \frac{\mathrm{SFR}}{M_{\mathrm{H\,I}}},$$

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- ***yo*** *: effective yield*
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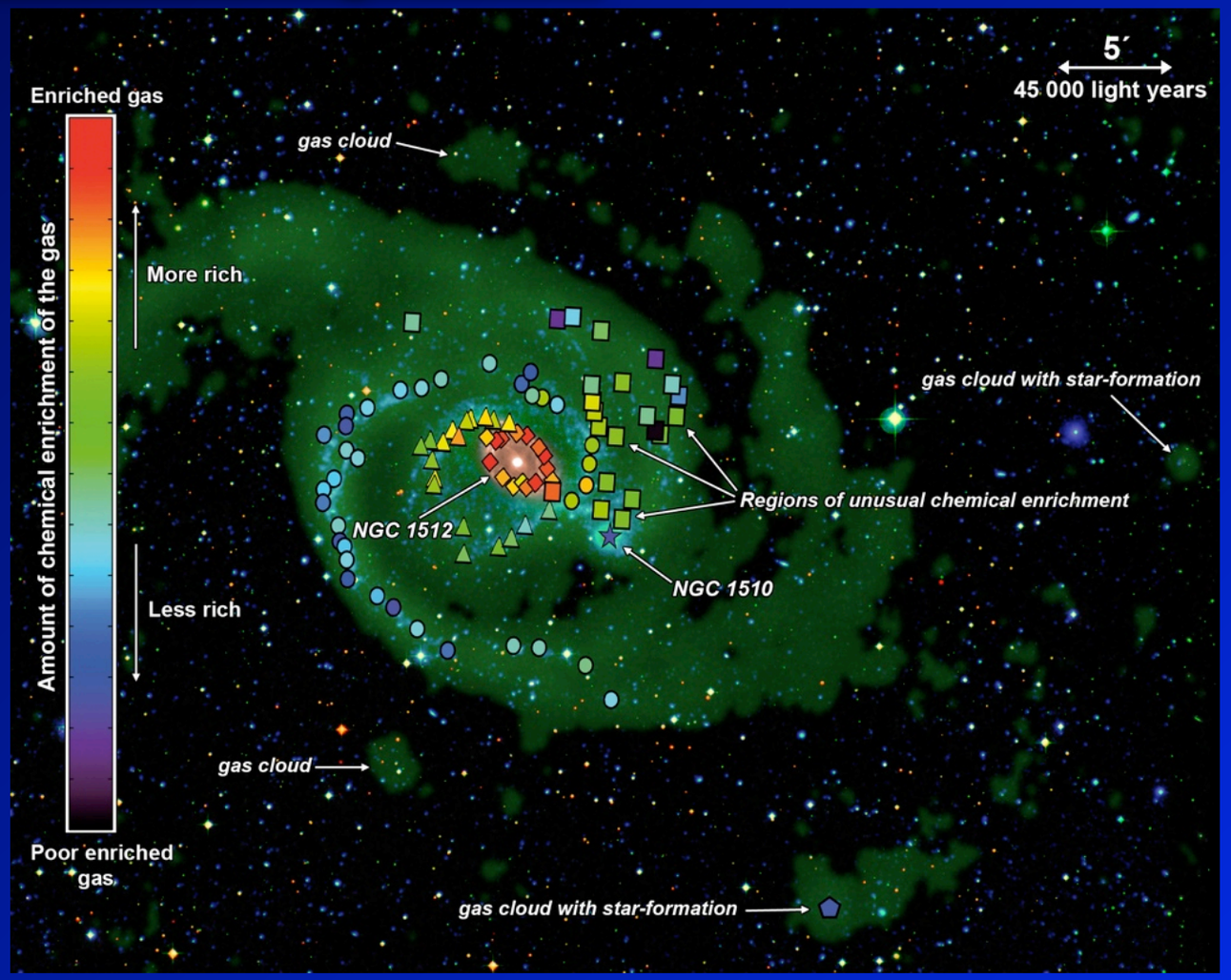

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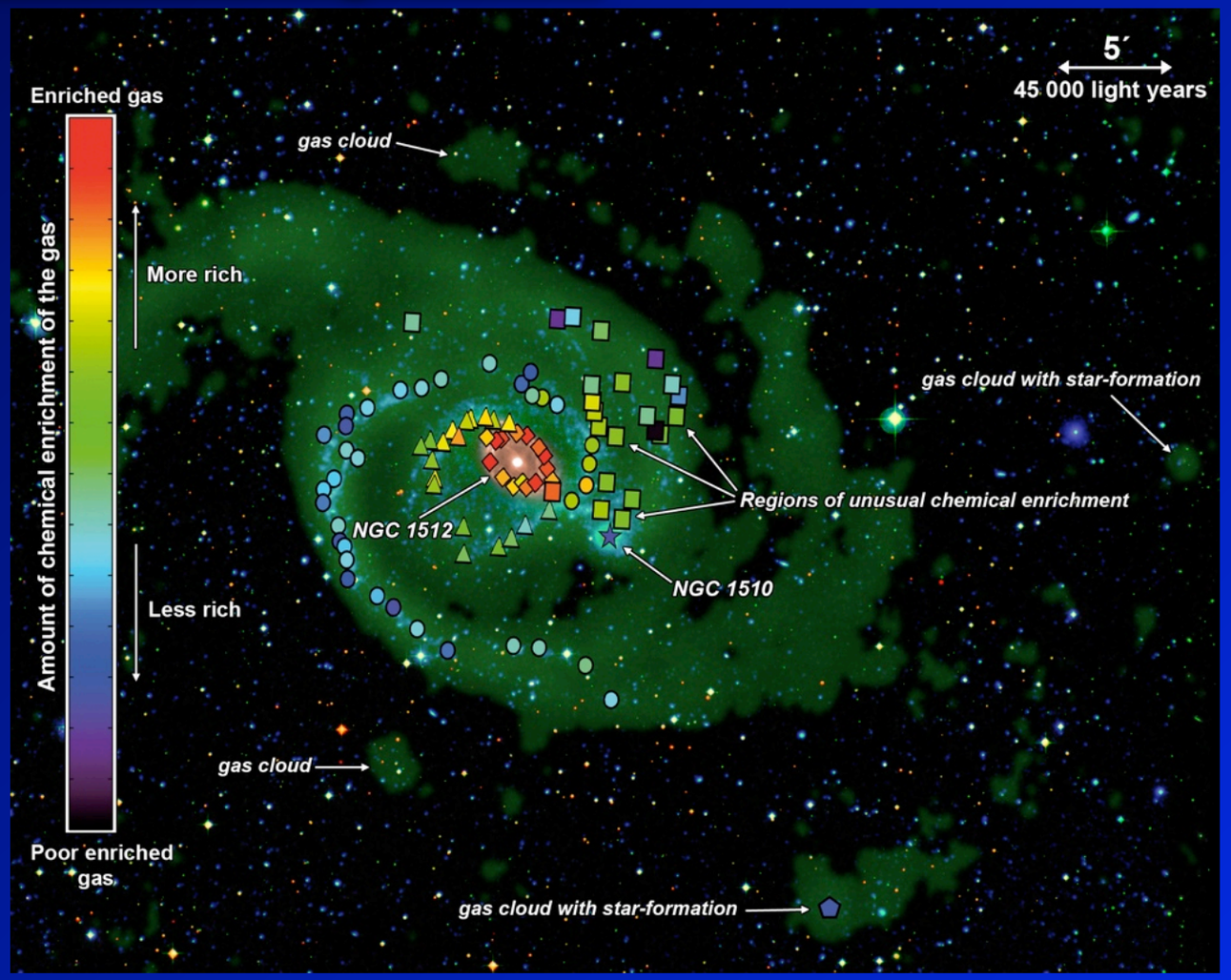

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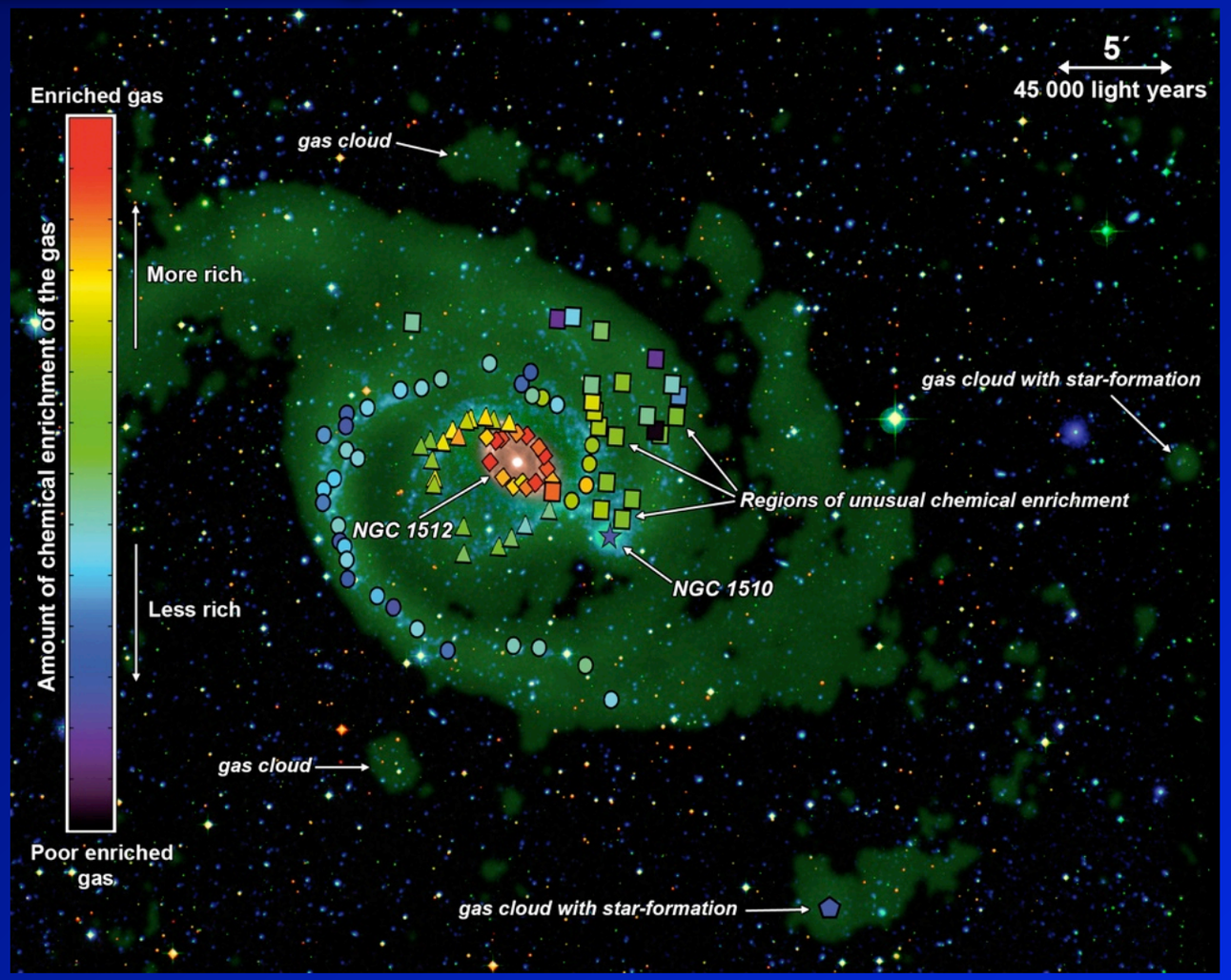

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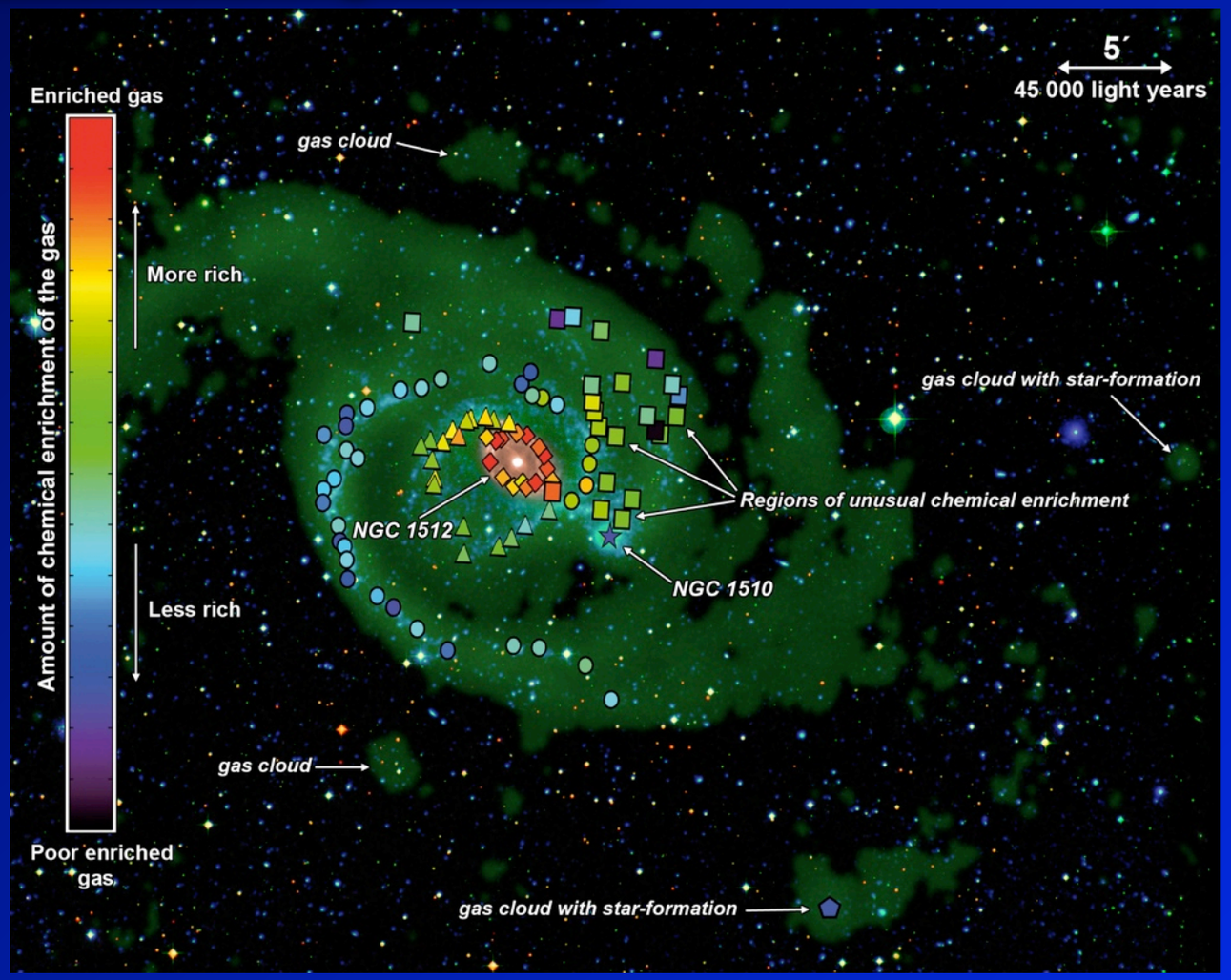

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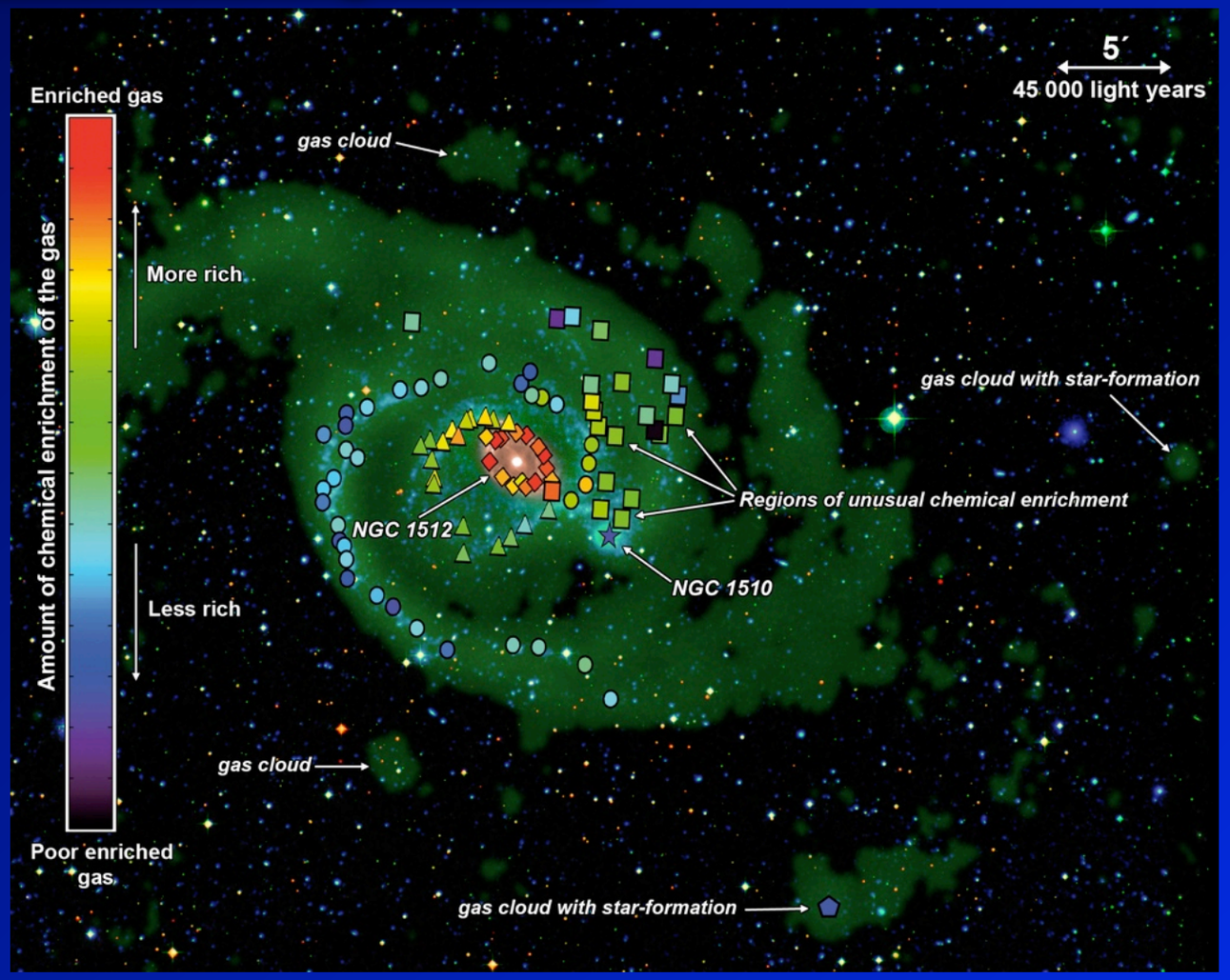

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➡ **Metals are probably coming from dwarf, low-luminosity, gas-rich galaxies which have been slowly accreted and destroyed into the system.**

Gas and XUV disk in ETGs consequence of accretion of gas-rich dwarf galaxies (Silchenko et al. 2012, in prep)

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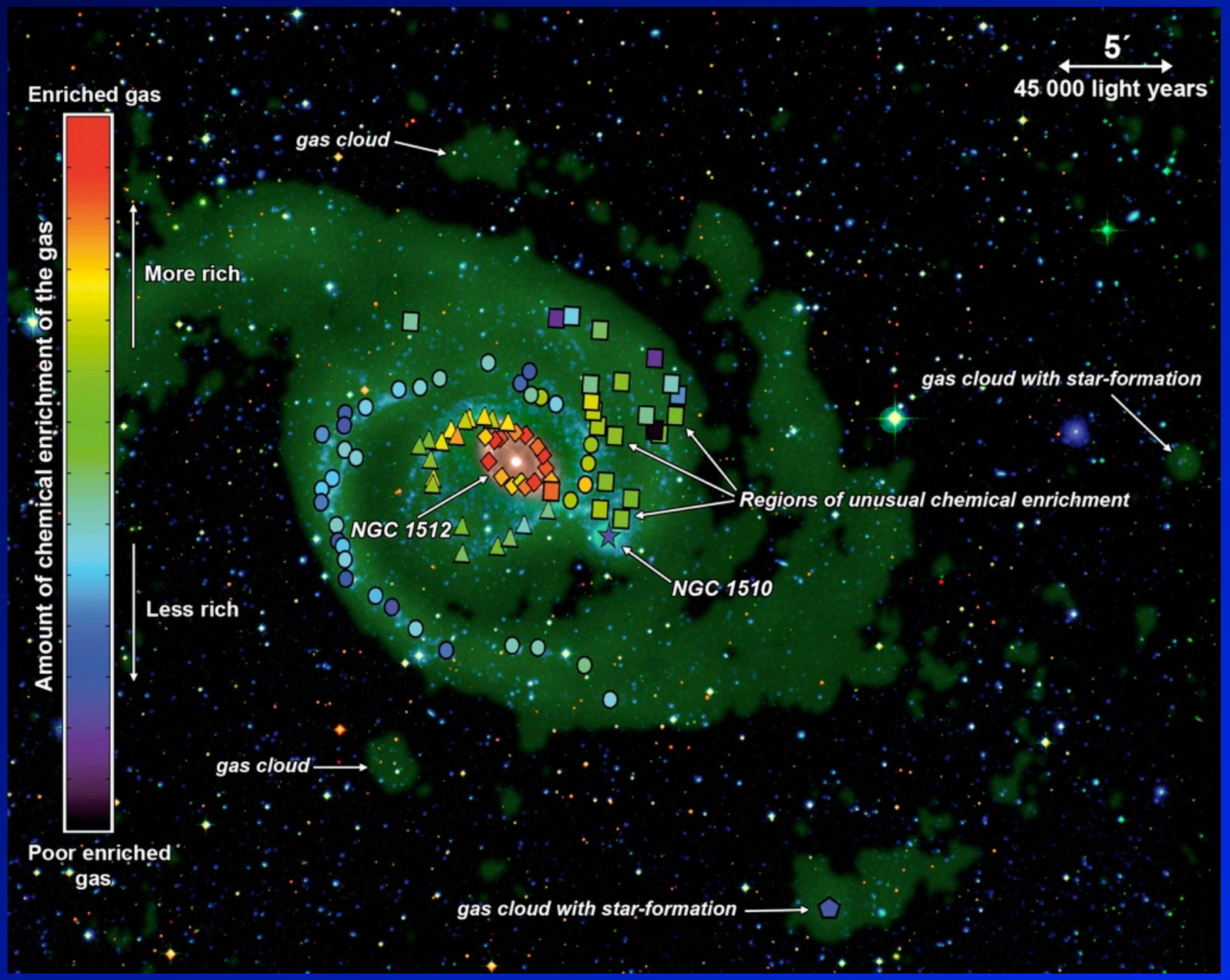
Summary

- Analyses of local SF processes and ISM / IGM interaction in nearby galaxies using HI / UV / optical / MIR data.
  - Multiwavelength data needed to get the complete picture!
  - Metallicity provides important clues about nature of the gas



- There are many things happening in the outskirsts of spiral galaxies.
  - The huge reservour of diffuse gas in the outskirsts of spiral galaxies may be coming from the accretion and destruction of gas-rich low-luminosity, low-metallicity dwarf galaxies.
  - Allows us to understand galaxy evolution and test ΛCDM scenarios.

Koribalski & López-Sánchez 2009, MNRAS, 400, 1749
López-Sánchez et al. 2015, MNRAS, 450, 3381