The MUSE view of Henize 2-10:
no accreting Black Hole but a sparkling starburst

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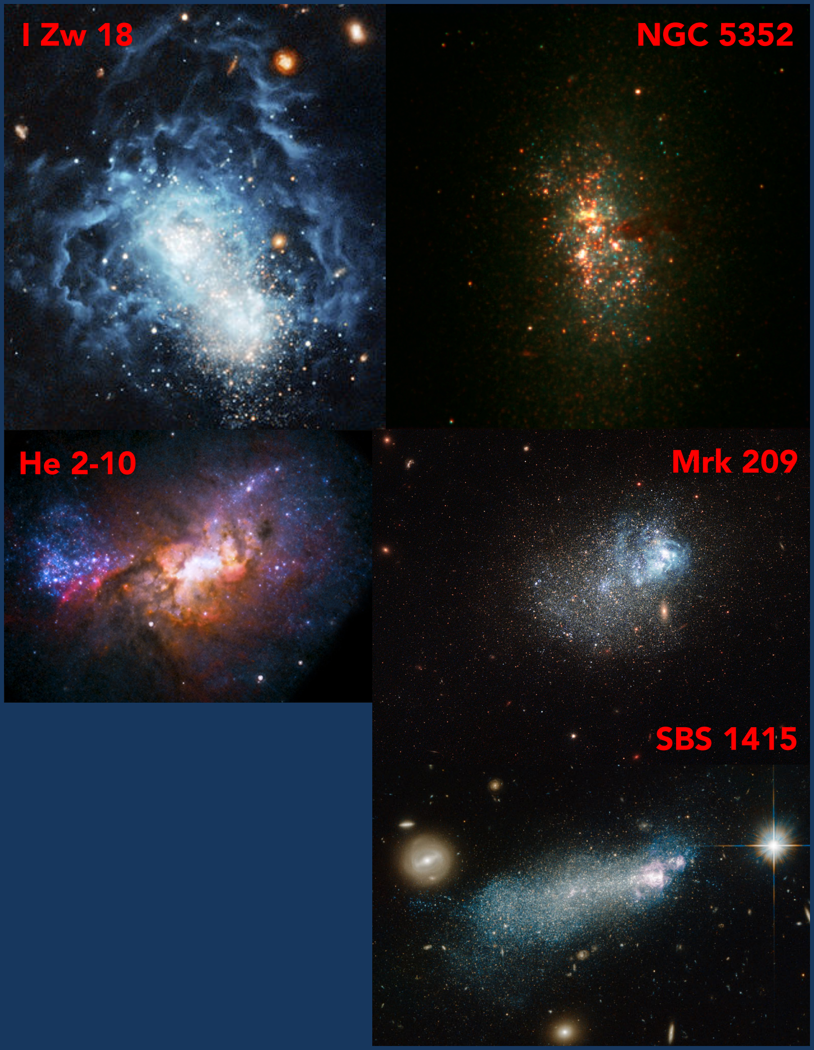
BCD and HII Galaxies as labs

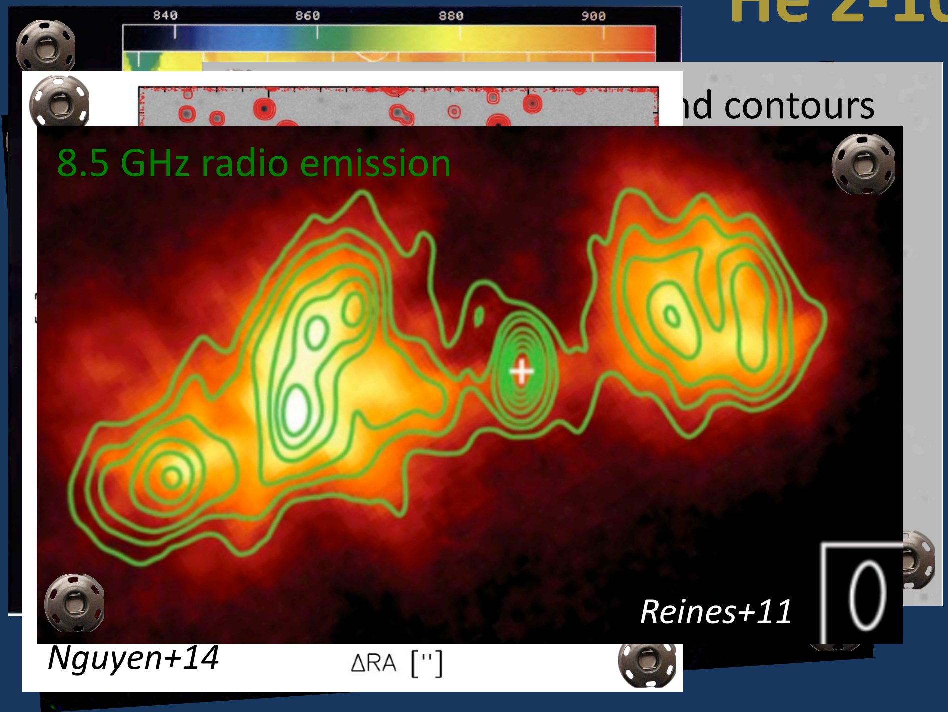
Nearby Blue Compact Dwarf and HII galaxies represent an unique nearly pristine environment, resembling those in high-z galaxies but accessible with much larger details:

- High current sSFR, on scales <1 kpc
- Large gas content
- Typically low metallicities
- Compact size (Re ~ 0.1-0.6 kpc)
- Presence of Super Star Clusters
- Sometimes underlying evolved low surface brightness host



- ➢ *What are the triggers and conditions required for Star Formation?*
- ➢ *What is the impact of SF on the structure of the ISM?*
- ➢ *Which are the effects and properties of infalls and outflows?*
- ➢ *….*

He 2-10 ID card



Name: Henize 2-10

Category: prototypical HII galaxy

Distance: 8.23 Mpc (40 pc/arcsec)

Stellar Mass: ~4 x 10^9 $M_\odot$

$M_{gas}(H_2)$: 1.6 x 10^8 $M_\odot$

$M_{gas}(HI)$: 1.9 x 10^8 $M_\odot$

f_{gas}: ~10%

Star Formation Rate: 1.9 $M_\odot$/yr

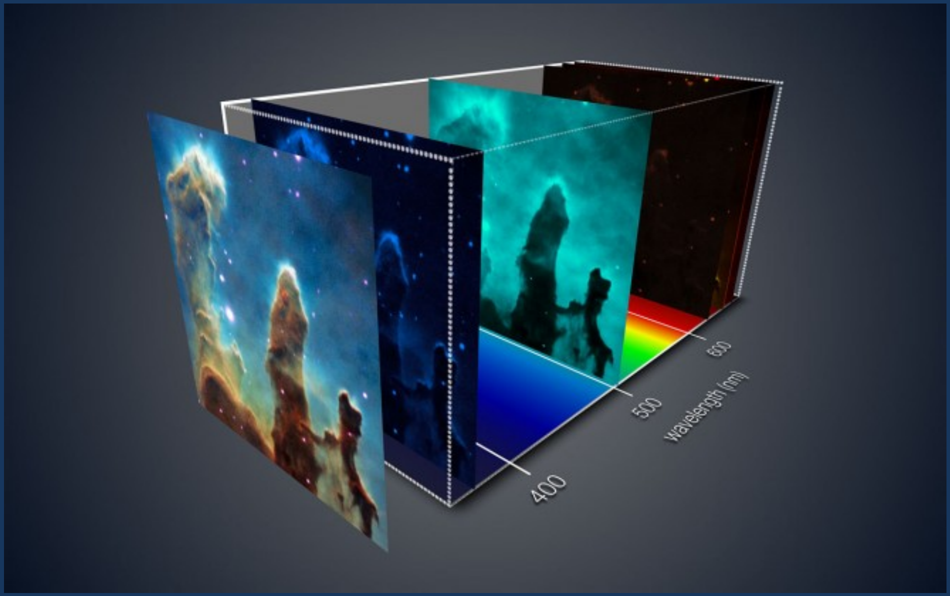
Distinguishing marks:

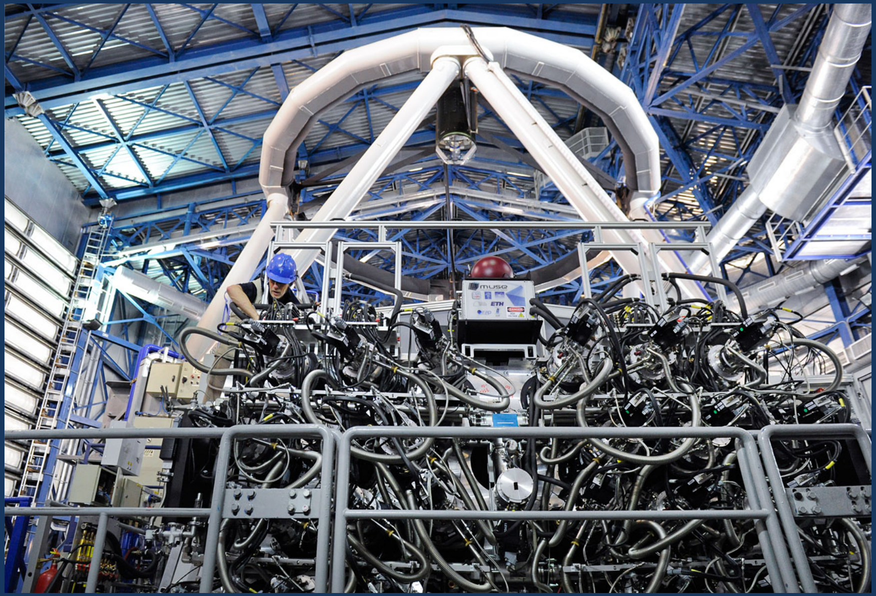
- Rotating HI disk (M_{dyn}~7x10^9 $M_\odot$) and tidal tail in CO (Kobulnicky+95; Vanzi+09; Santangelo+09)
- Strong central (R~3”) starburst, from optical, IR lines, Wolf-Rayet features, mid-IR emission, far-IR continuum (e.g. Vacca & Conti 92; Schaerer+99; Sauvage+97; Vacca+02; Johanson+87; Cresci+10, etc…)
- Underlying older stellar population dispersion supported (Nguyen+14)
- Non thermal compact radio source identified as an accreting BH (Johnson & Kobulnicky 03; Reines+11, Nature)

The MUSE instrument at VLT

Integral field spectrometer in the optical range:

- fov 1x1 arcmin^2, advanced slicer design feeding 24 identical spectrographs
- $4650 < \lambda < 9300$ A @ $1500 < R < 3500$
- 90,000 0.2”×0.2” spaxels
- image quality limited by atmosphere or GALACSI seeing enhancer
- High stability (no moving parts) and high throughput (0.35 end-to-end)
- 400 Mpixels (!!) in total





MUSE view of He 2-10

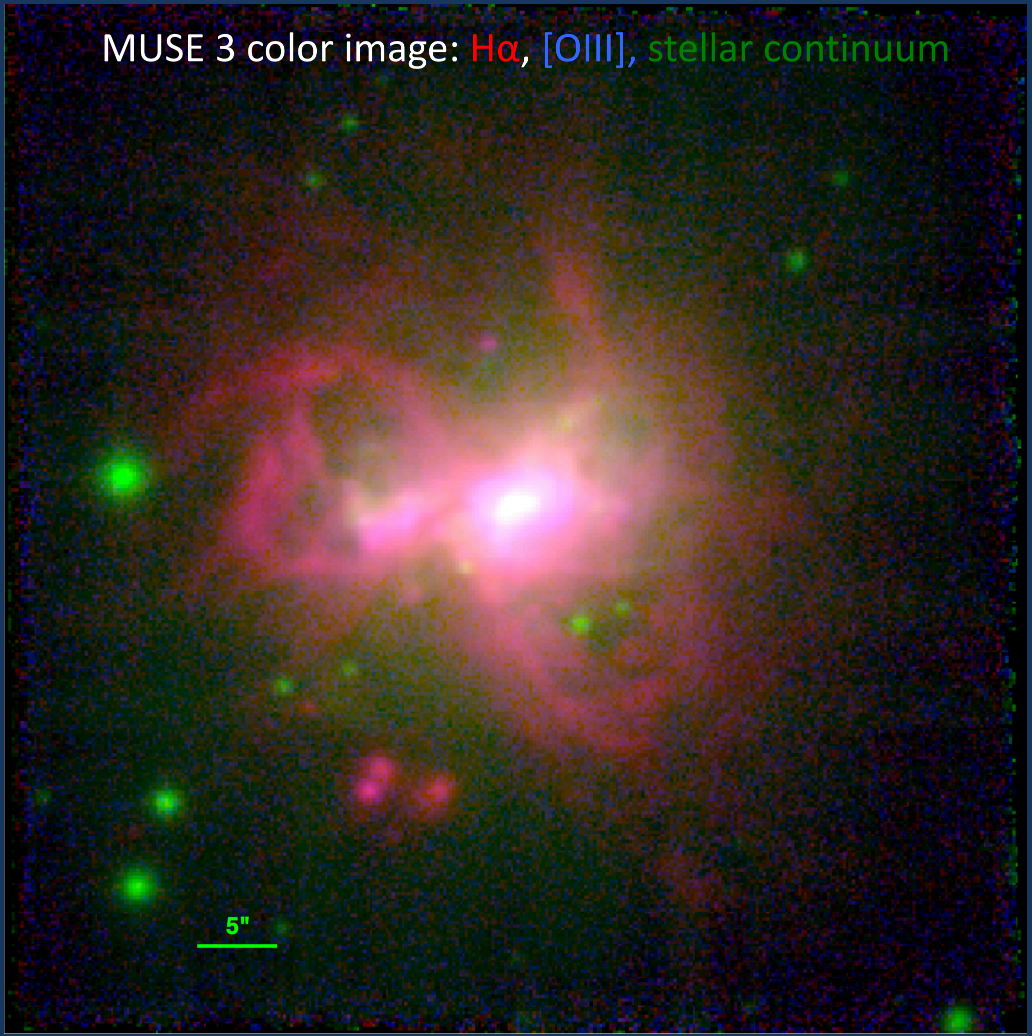
He 2-10 was observed with MUSE in May 2015

Total exposure time on source was just 2'!

Final seeing in the datacube FWHM ~ 0.68"

Stellar Continuum subtracted using a combination of MILES templates

Emission lines fitted using multiple Gaussian functions when required

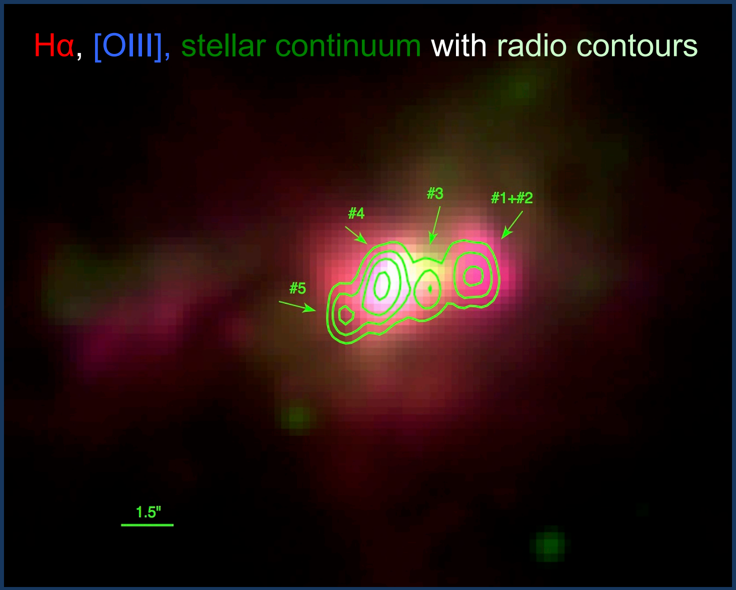


Cresci et al. 2017, A&A, 604, 101

Extreme conditions in He 2-10 central regions

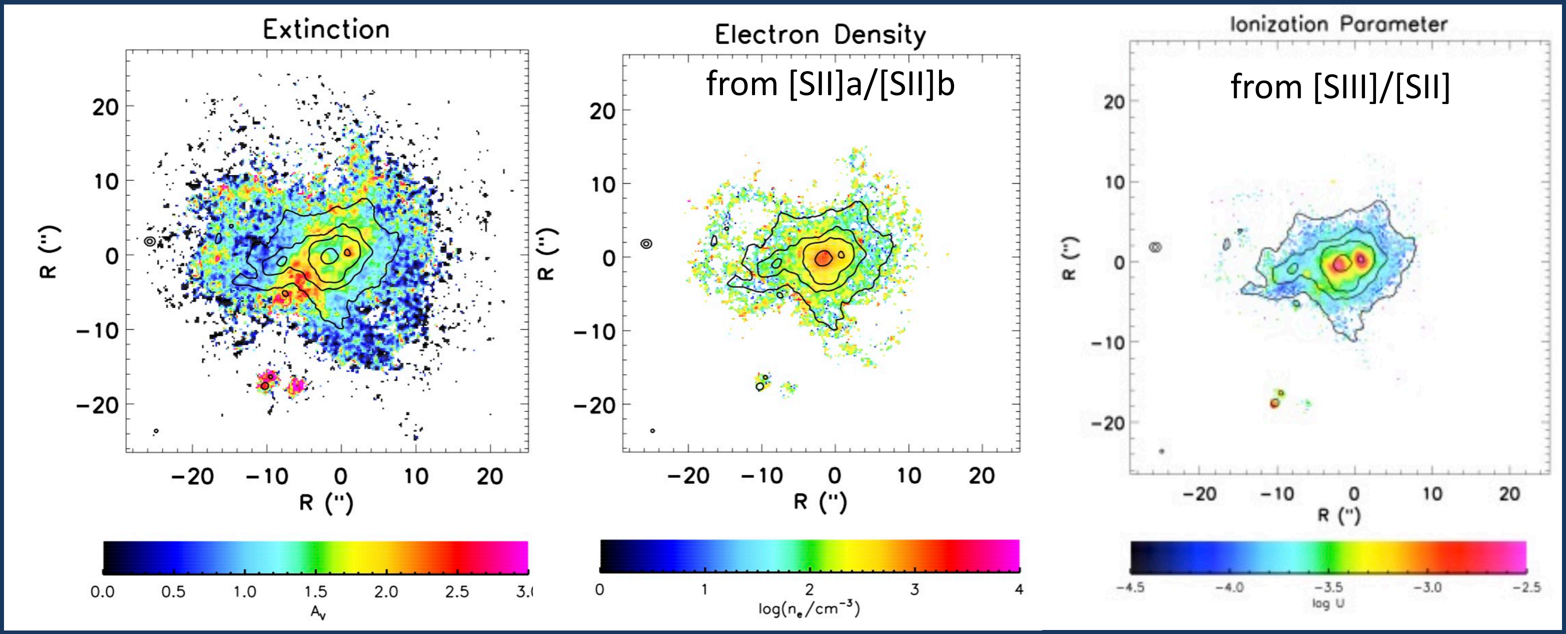
Extinction as high as A_V~8 in the central star forming regions from NIR spectroscopy (e.g. Cresci+10)
In MUSE we do not penetrate the dust:

- lower extinctions at the center
- high A_V at the location of the CO accreting cloud



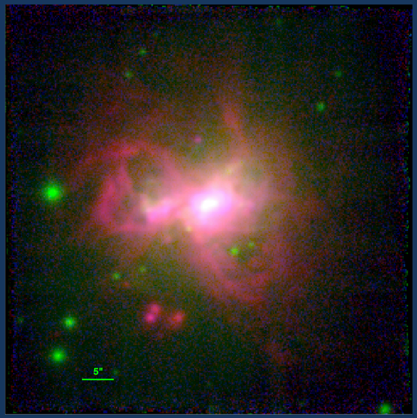
Central SF regions show the highest values of:

- SFR density: Σ_{SFR}=70 $M_\odot$ yr^{-1} kpc^{-2}
- electron density: n_e ~ 1500 cm^{-3}
- ionization parameter: logU = −2.5



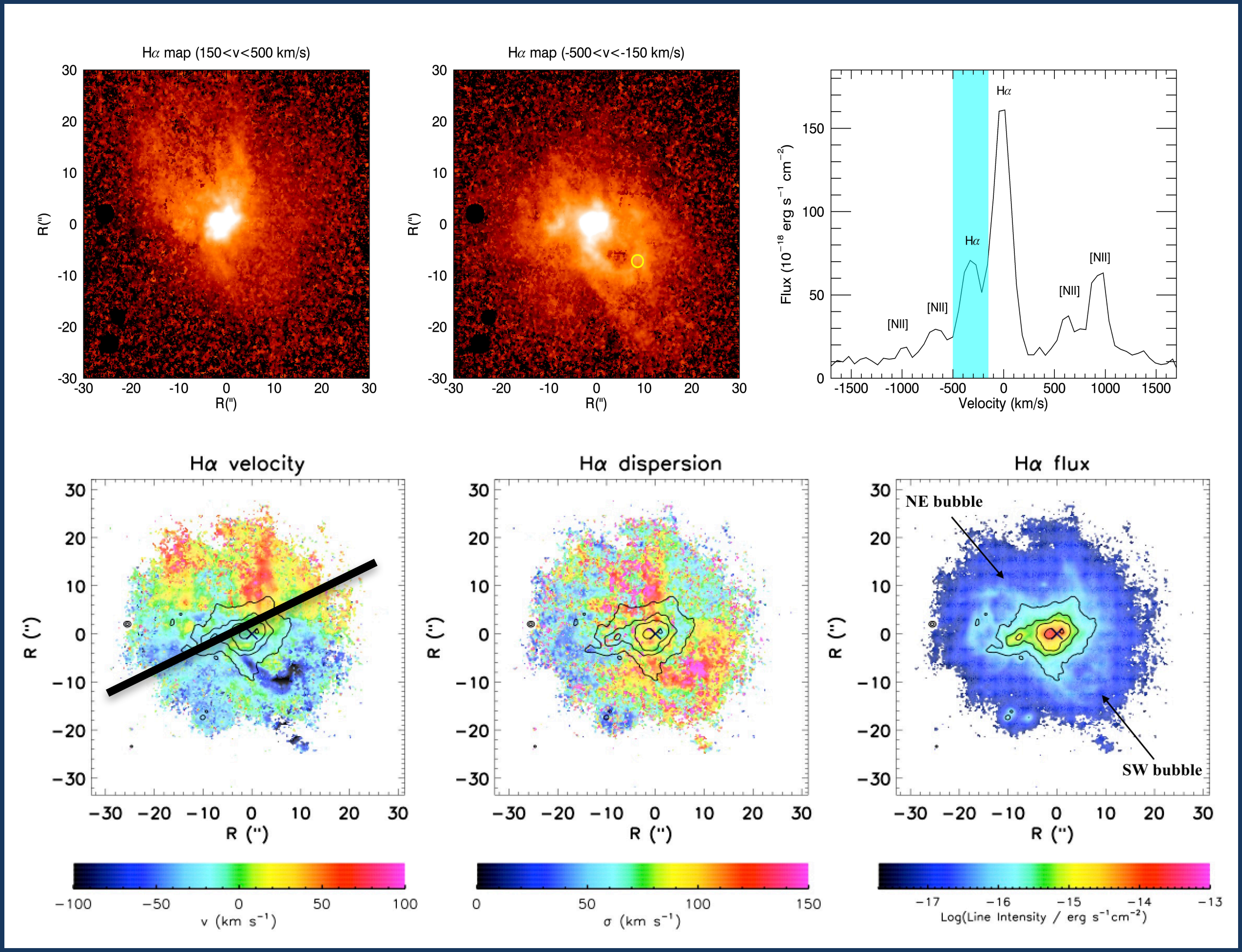
Extreme conditions in the central SF region!

Gas dynamics



The gas dynamic is dominated by a complex expanding bubbles system:

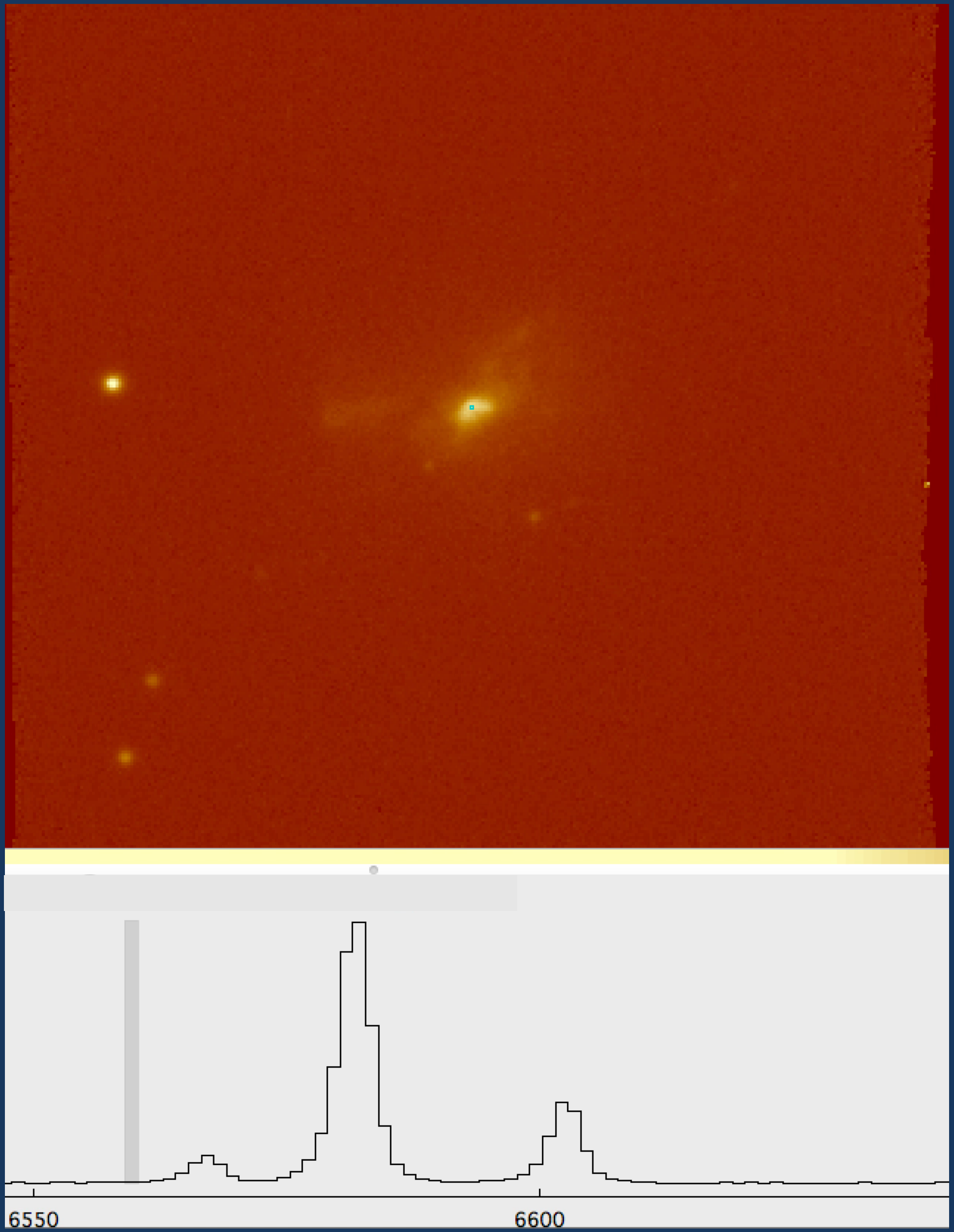
- high velocities: blue/red-shifted gas velocities v_{max} > 500 km/s, higher than the galaxy escape velocity (v_{esc}~200 km/s, Johnson+2000)
- extended up to 720 pc projected from the central SF region



Young bubbles?
$t_d \sim R_{out}/v_{out}$ = 2.3 Myr

Hint of rotation with Δv_{rot}~75, consistent with HI data

A galactic superwind in He 2-10



Mass outflow rate $\dot{M}_{out} \sim 0.30\ M_{\odot}\ yr^{-1}$ corresponding to mass loading factor

$$\eta = \dot{M}_{out}/SFR \sim 0.4$$

in range with similar measurements in local starburst LIRGs/ULIRGs (e.g. Arribas+14) and lensed high-z starburst (e.g. Perna+18)

Kinetic energy in the outflow:

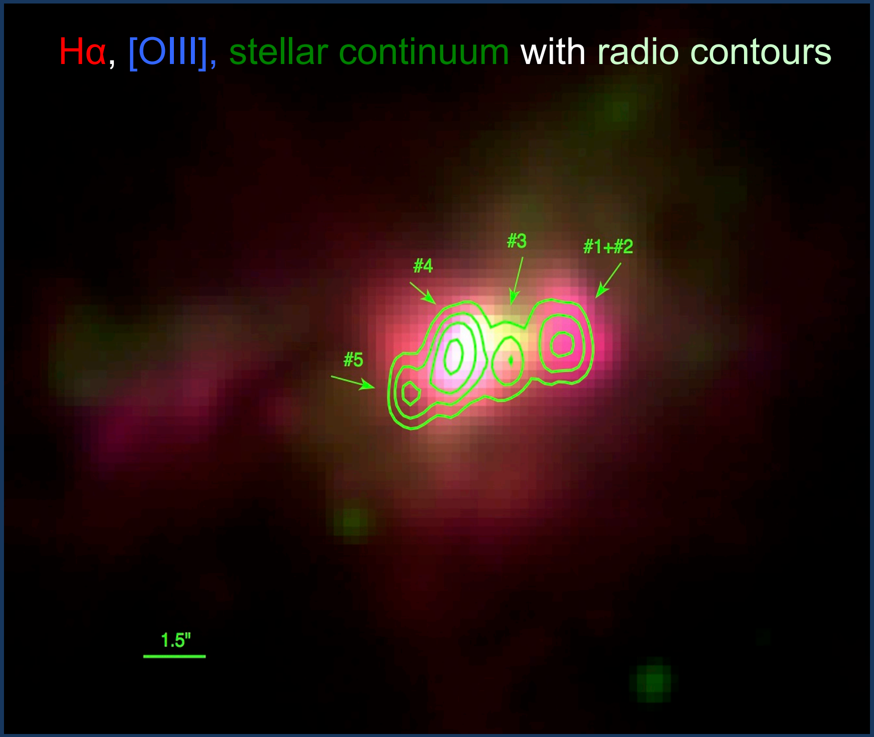
$$E_{out}(kin) \sim 2.2 \times 10^{53}\ erg$$

Assuming ~3750 SNR from radio obs in He2-10 (Mendez+99), this is an order of magnitude lower than their injected energy of ~3.5 × 10^{54} erg

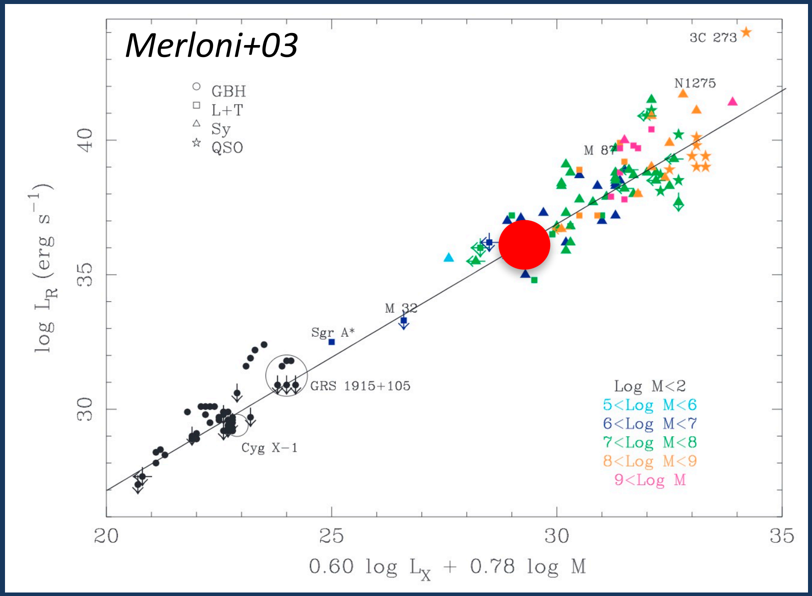
$$\varepsilon \approx 5\%$$

An accreting Black Hole in He 2-10?

Reines+11 (Nature) identified a compact (R< 3x1 pc, Reines+12), non thermal radio source in the central region of He2-10 with an X-ray source from deep (20 ks) Chandra observation



$$R_X = \nu L_\nu(5\ \mathrm{GHz}) / L_X(2 - 10\ \mathrm{keV}) = -3.6$$



Radio to X ray

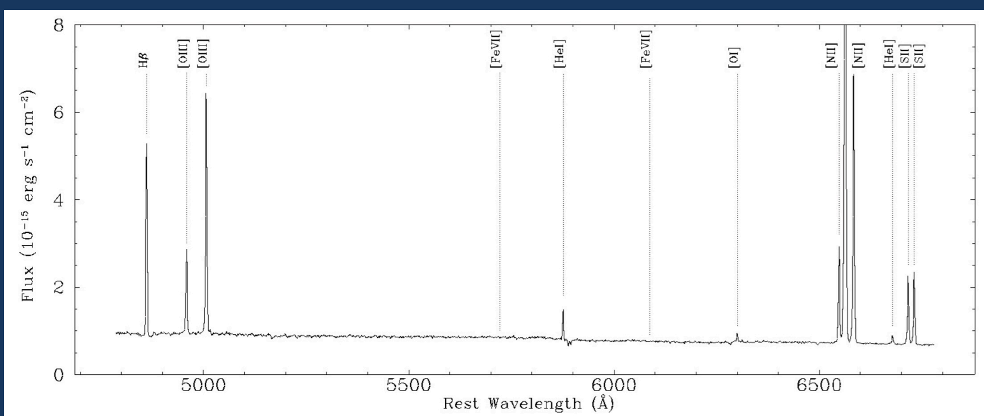
- too high for an X-Ray binary (R_X<-5.3)
- too low for a SNR (R_X>-2.7)
- in range with LLAGN (R_X~-2.8 ÷-3.8)

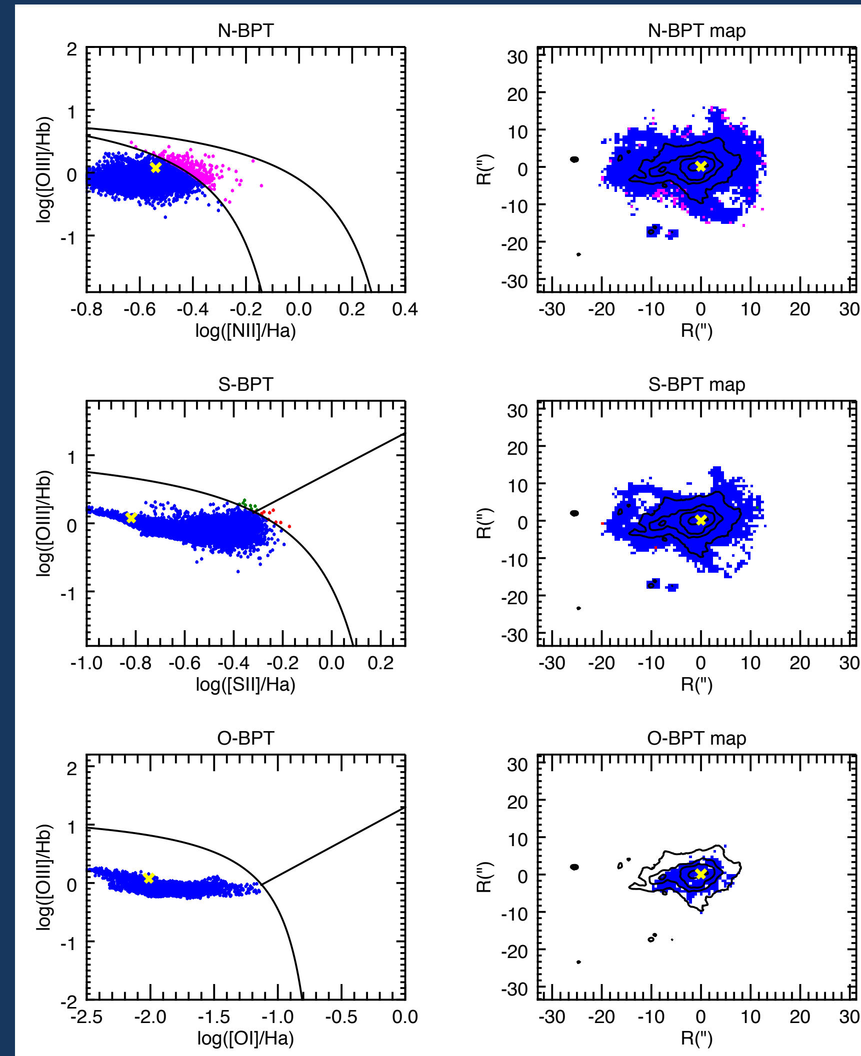
They concluded that there is a SMBH in He2-10, with $\log(M_{BH}/M_\odot)=6.3$

Gas ionization in He 2-10

Despite the claimed presence of an accreting SMBH in He2-10, the BPT diagrams show ionization dominated by Star formation all across the galaxy

No evidence of high ionization lines typical of AGNs (e.g. FeVII/Hβ<7×10^{-3})





Is there really an active BH in He 2-10?

An alternative origin for the compact radio source?

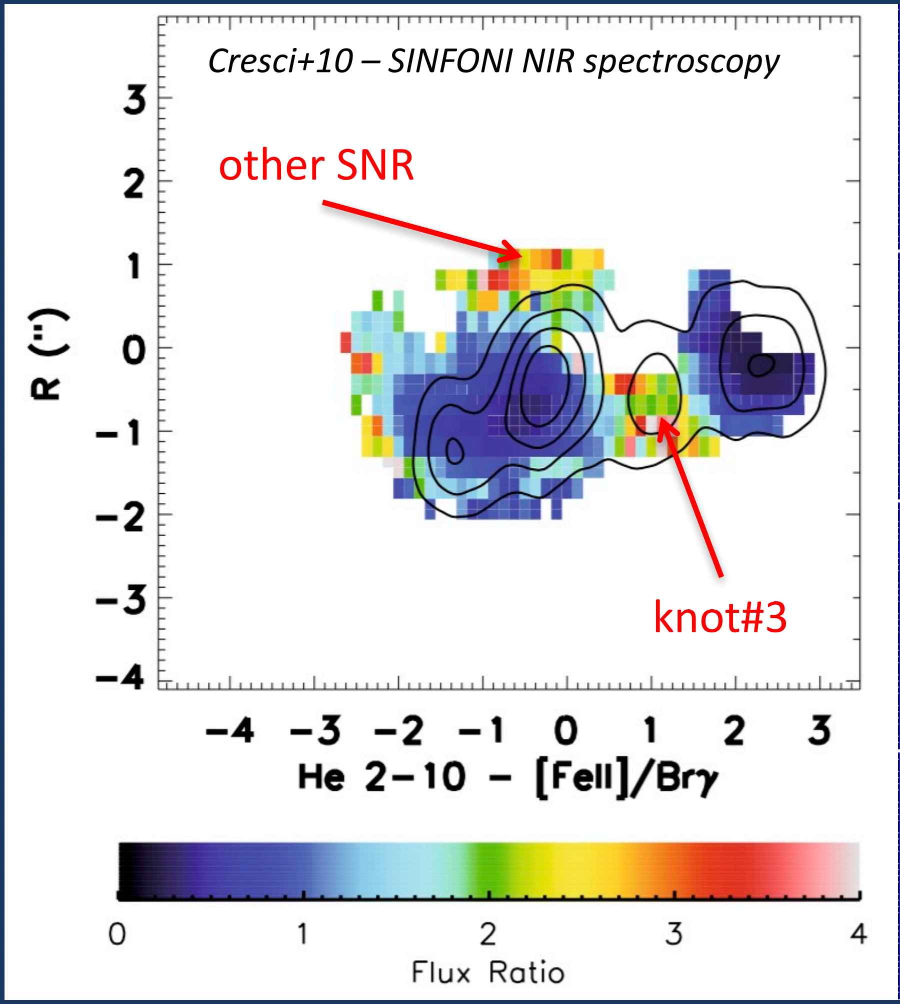
Reines+16 revised the X-ray flux of knot#3 → most of the flux in the previous data from a variable source ~30 pc away.

Using new X-ray and deeper Radio data:

$R_X > -2.4$

- The new value is compatible with SNR
- X-ray flux and radio diameter in the range of young SNR in M82
- Radio spectral index α=-0.5 typical of SNR
- High [FeII]/Brγ~2 compatible with excitation in SN shock

Knot #3 probably associated with a young SNR



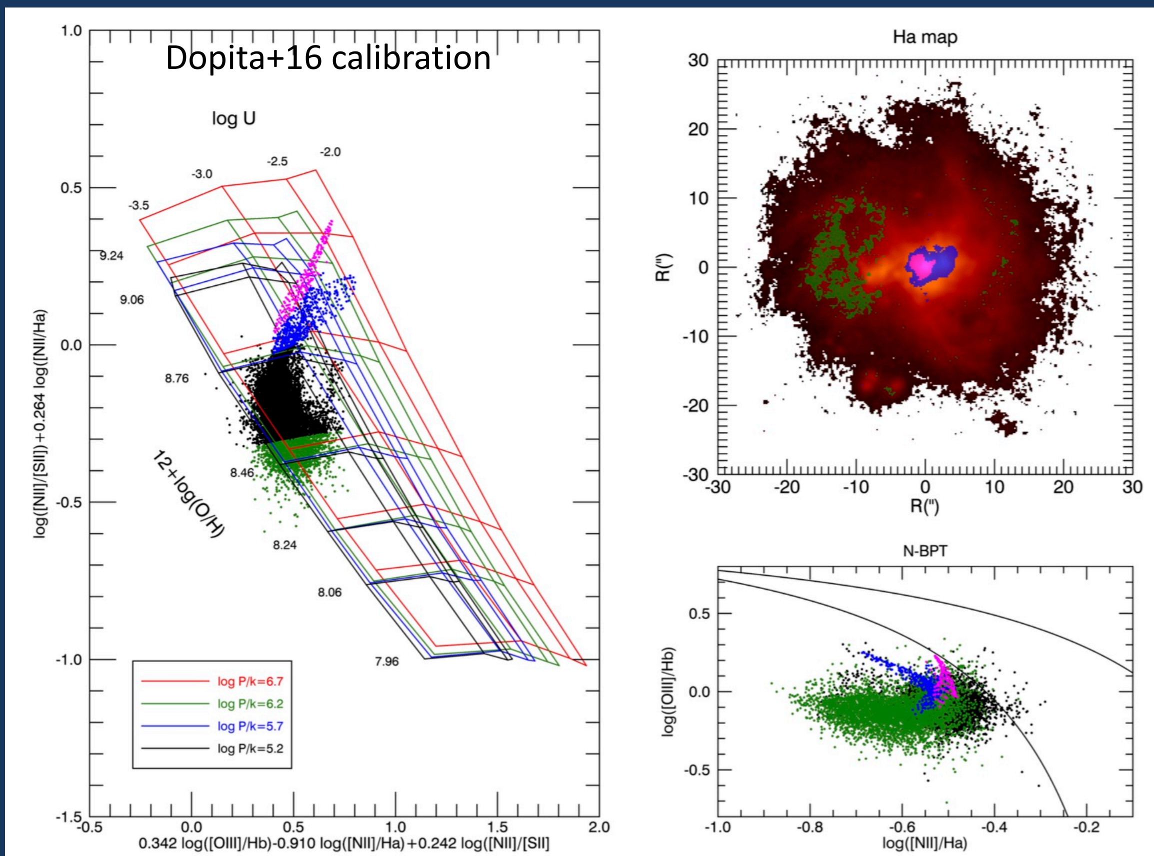
For a SMBH, the new fluxes would suggest:

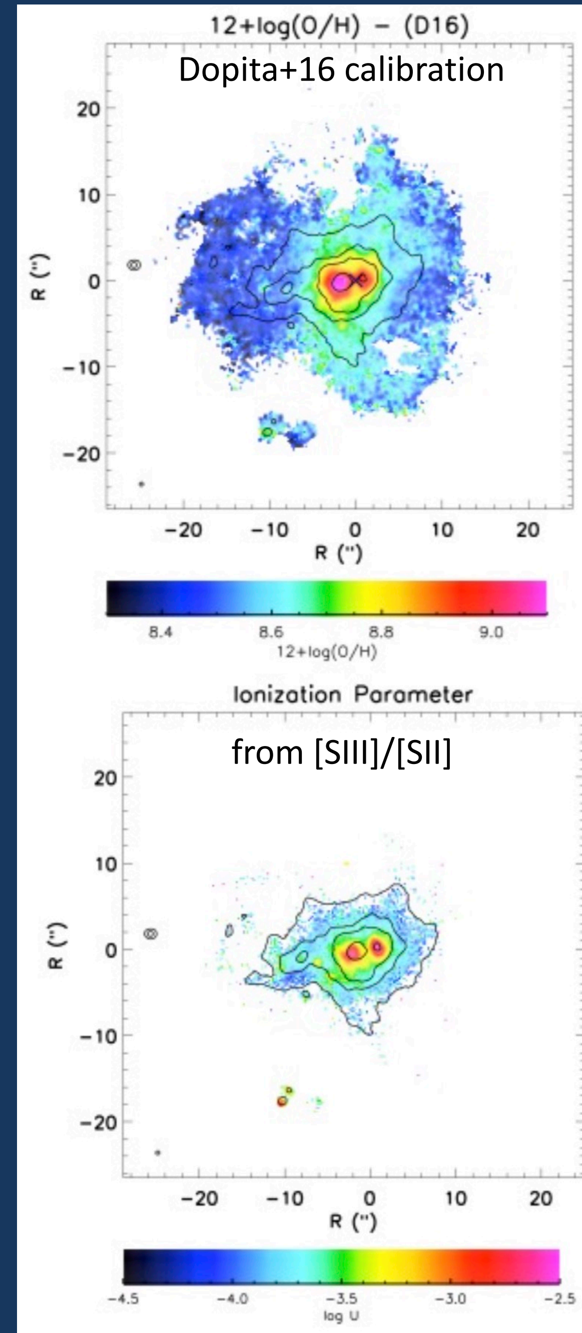
- $\log(M_{BH}/M_\odot) \sim 7.6$, excluded from AO assisted dynamical observations (Nguyen+14, $\log(M_{BH}/M_\odot) < 7$)
- $L_{bol}/L_{Edd} < 1\times10^{-6}$, two orders of magnitude lower than "active" AGNs

Gas metallicity in He 2-10

Single line ratio should not be used to measure metallicities in extreme environments…
"Inverted" metallicity gradient if the differences in U are neglected (see also Krühler+17)

Large gradient between central enriched clusters and external regions (~0.5 dex)





The MUSE view of HE 2-10: Summary

He 2-10 was observed with MUSE for a total of just 2' on source, providing unique view of this prototypical HII galaxy:

- Extreme conditions in the central star forming regions (SFR density, ionization, extinction, density, metal enrichment…)
- Complex system of outflowing bubbles with v>500 km/s, sustainable by the star formation in the central region, carrying $M_{out} \sim 0.30\ M_{\odot}\ yr^{-1}$, corresponding to a mass loading factor $\eta \sim 0.4$
- No evidences of the claimed SMBH in the core of the galaxy. Data compatible with a young SNR
- Beware single line ratio metallicities in extreme environments, as line ratio variation due to ionization conditions may dominate