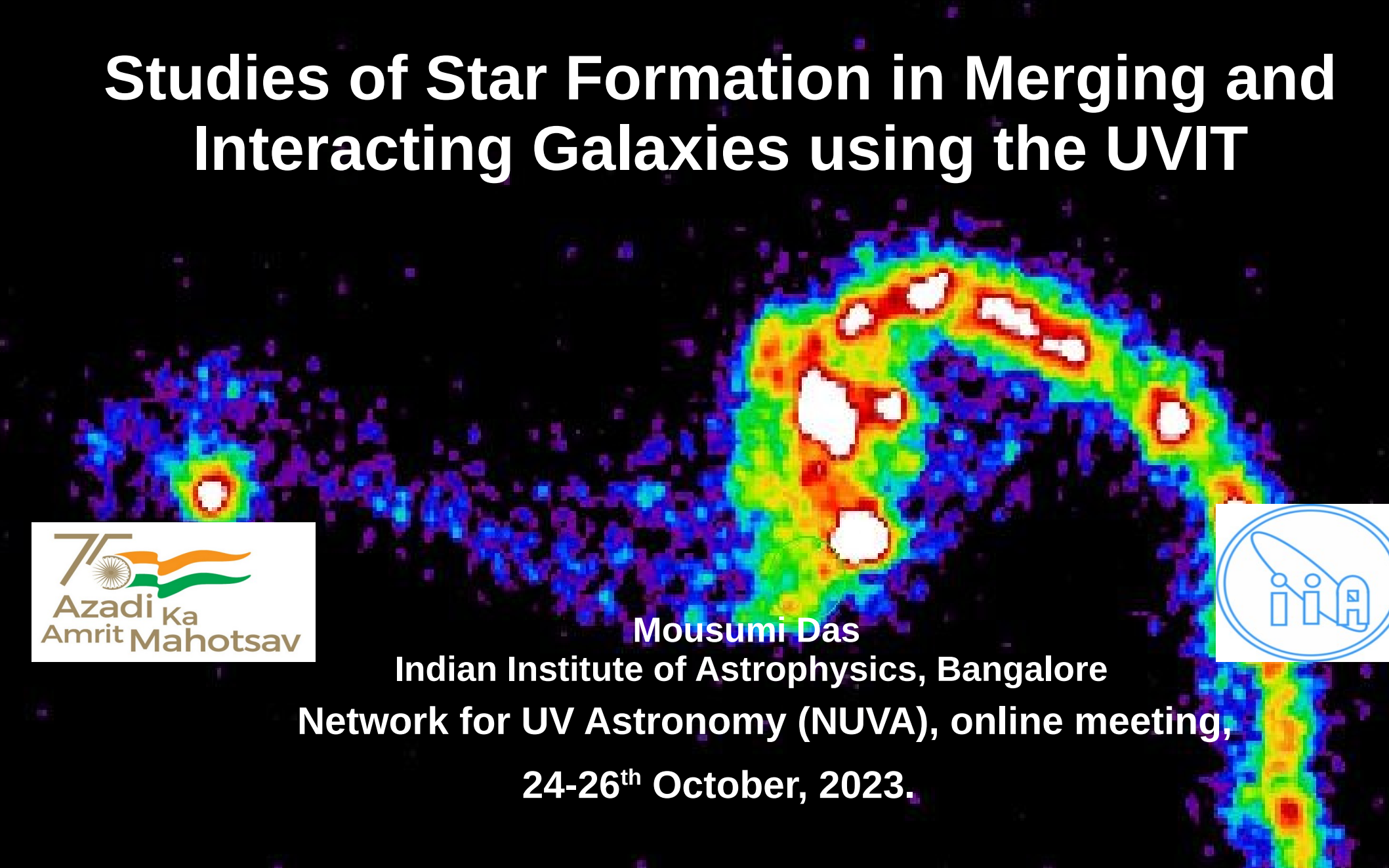
Studies of Star Formation in Merging and Interacting Galaxies using the UVIT



Mousumi Das
Indian Institute of Astrophysics, Bangalore

Network for UV Astronomy (NUVA), online meeting,

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Main Contributors :

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Broad Outline :

- Galaxy mergers – star formation and AGN activity.
- Different types of nuclei in merging galaxies– starburst, AGN and dual AGN.
- What does UV emission trace in mergers?
- The UV emission from dual AGN : MRK212
- Close mergers : the triple AGN in NGC7733-7734
- Detection of a Diffuse Galaxy in an Interacting Pair

Galaxy Mergers : drivers of galaxy evolution

- Most galaxies are not isolated but have smaller satellite galaxies. They undergo interactions/mergers and sometime merge with other large galaxies.
- Galaxy interactions and mergers cause enormous changes in the gravitational potential of galaxies, even in distant interactions.
- If even one of the galaxies has gas, there will be star formation and this makes the merger remnants very bright (e.g. ultraluminous galaxies or ULIRGs).
- As the galaxies come closer, their nuclei often become brighter – due to gas infall, nuclear star formation and the triggering of AGN activity.

Koss et al. 2007

Two Nuclei in galaxy mergers :

- As the galaxies come closer, their bulges or nuclei come closer as well. Finally the galaxies become embedded in a common envelope, this is usually called the merger remnant. The result is a galaxy with two nuclei.
- The nuclei can starburst or AGN in nature. Or just a quiescent nuclei. If there is gas there will be associated star formation in the disks, rings and tidal arms.

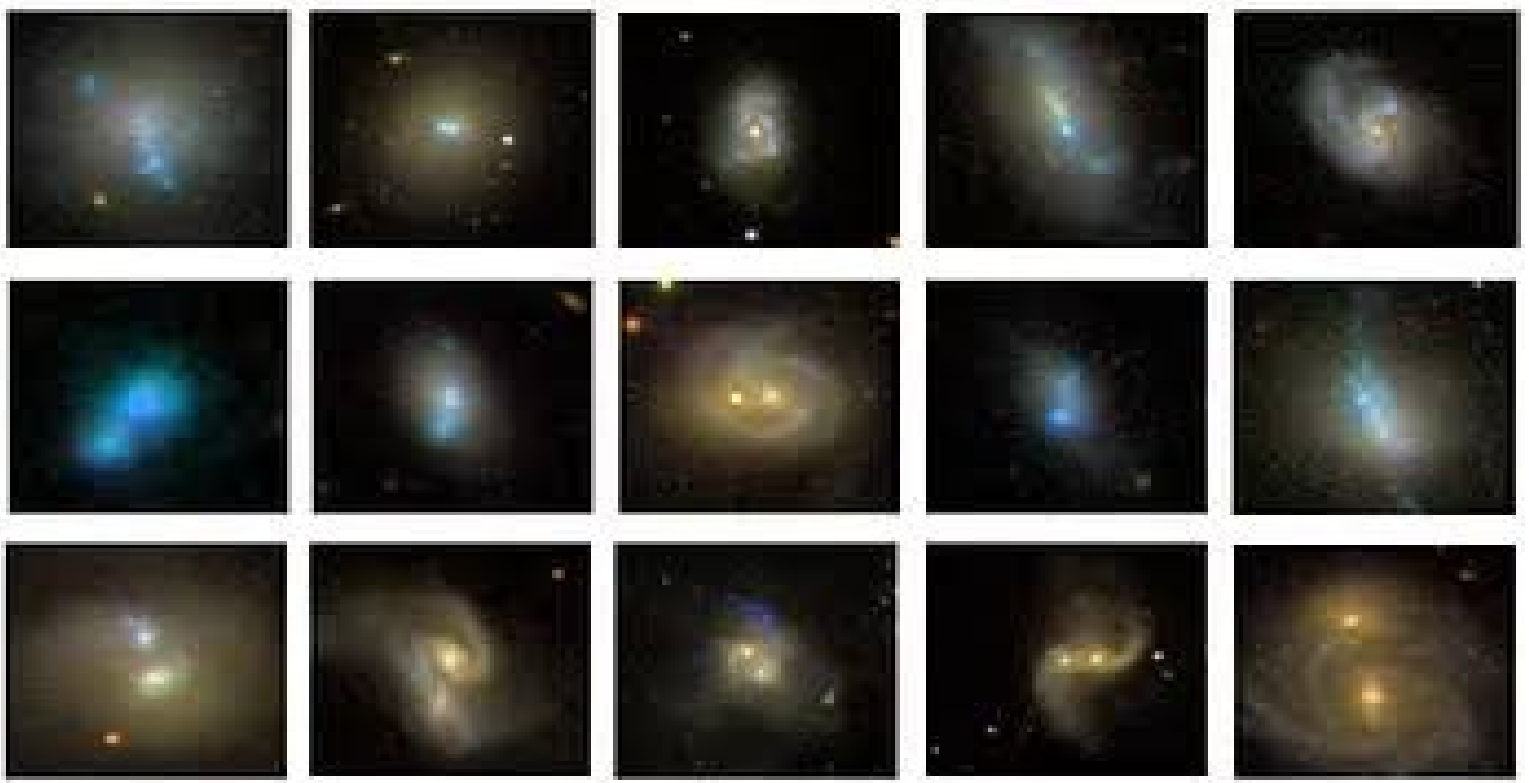
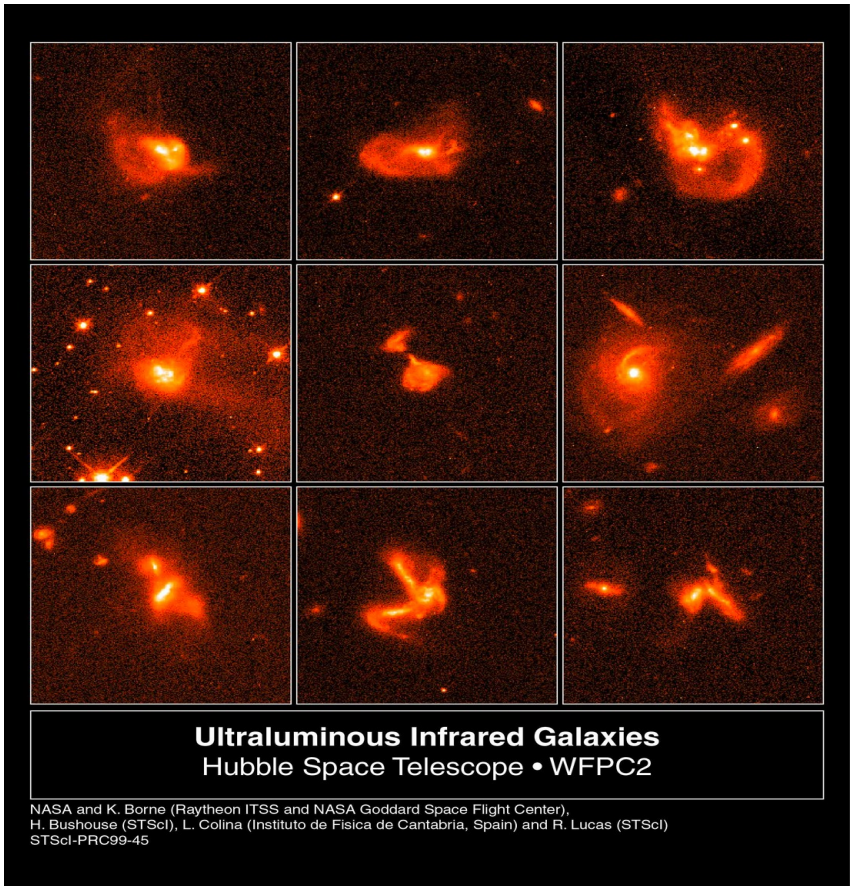


Image credit : Mezcua et al. (2014)

Major Merger remnants ==> luminous ellipticals ?

- The major merger of large galaxies usually leads to the formation of a large elliptical galaxy. Mergers are more common in dense environments. This clear because there is an increasing number density of ellipticals and S0 galaxies towards the centers of clusters (Dressler1980).
- If the galaxies are gas rich, large spirals, then the merger remnant has large amounts of star formation. These galaxies are also called ultraluminous infrared galaxies (ULIRGs). They finally transform into an elliptical galaxy (Genzel et al. 2001).
- High resolution radio studies suggest that some ULIRGs have small radio jets (Norris et al. 2012, Nandi et al. 2021).



So we see a sequence :

galaxy mergers ==> star formation ==> Starburst/AGN activity ==> formation of a massive galaxy (elliptical) ==> radio jets.

Where does UV emission come from in galaxy mergers/interactions :

The UV emission comes from the following sources

1. Star formation ==> due to massive O, B type stars formed in the compressed gas.

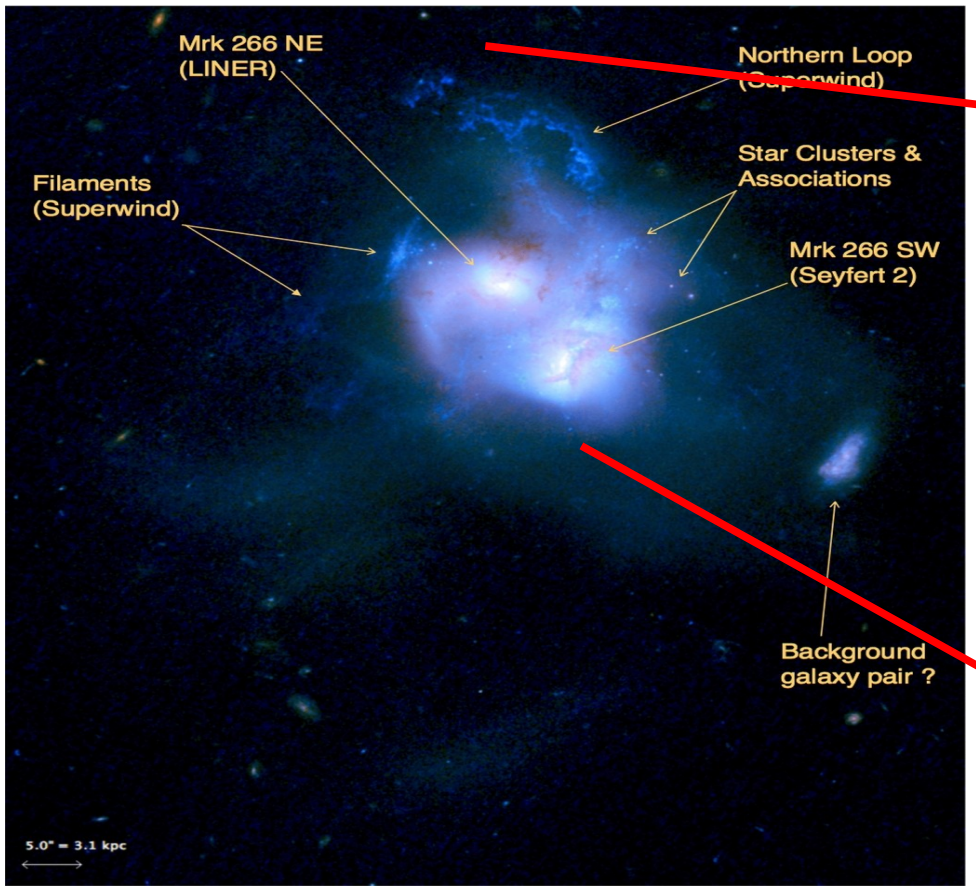
2. AGN in the nuclei ==> the SMBH(s) star accreting and become Active Galactic Nuclei (AGN). The UV arises from accretion disk near SMBH.

3. Evolved population : the HB and EHB stars. Their emission may come from the outer stripped parts , e.g. tidal tails, rings.

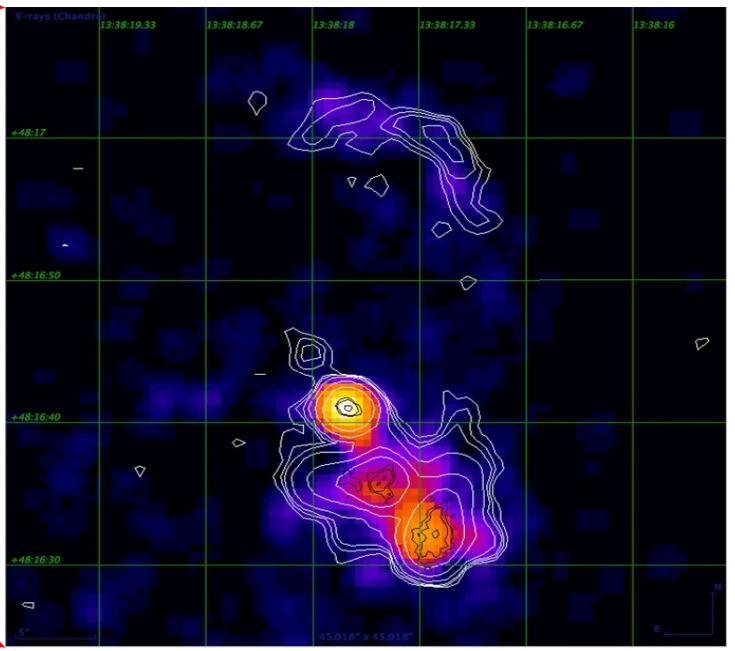
4. AGN feedback : strong AGN/stellar outflows can trigger star formation around the merger remnant.

An example of a dual AGN : SF and feedback

- The associated winds can drive gas outwards and trigger star formation in the gas thrown out. The AGN appear as bright compact sources.



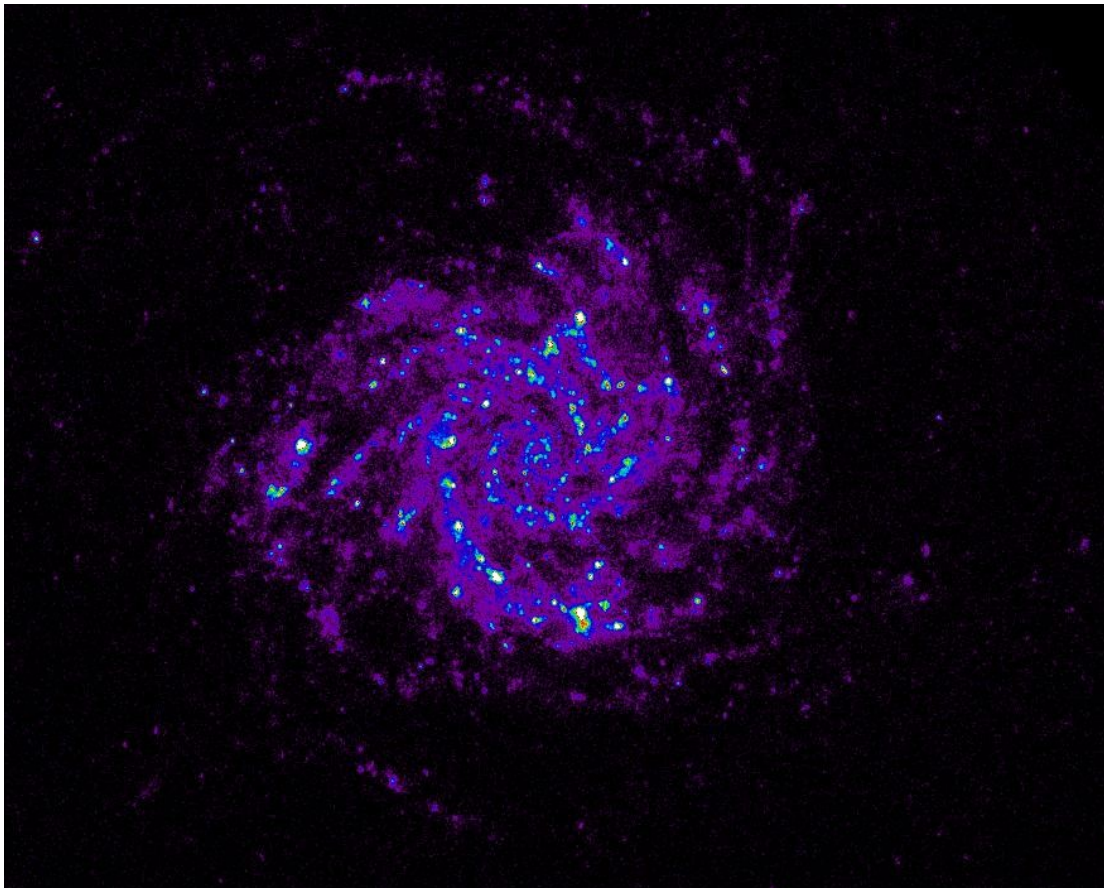
X-ray (blue), radio (contours)



Mrk266 : Mazzarella et al. 2012

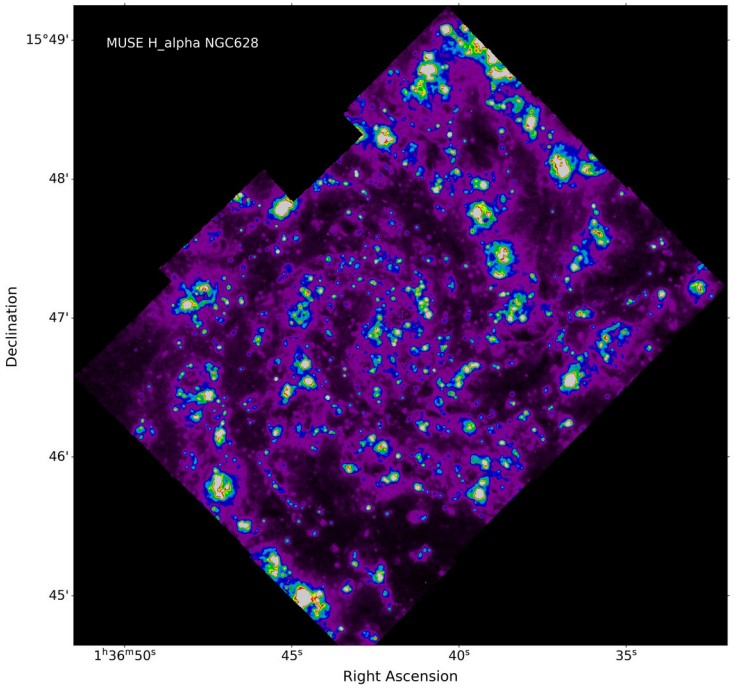
Why UV Observations?

- The FUV and NUV emission are mainly due to star formation and AGN activity in galaxies.
- FUV and NUV trace star formation for up to 10^8 yrs whereas Hα traces for 10^6 to 10^7 years only. So UV can detect star formation for longer duration.
- The UV can detect individual star forming clusters in regions well beyond the central star forming disk.
- The UV from the AGN comes from the accretion disk and gives the compact nucleus an intense bright appearance.

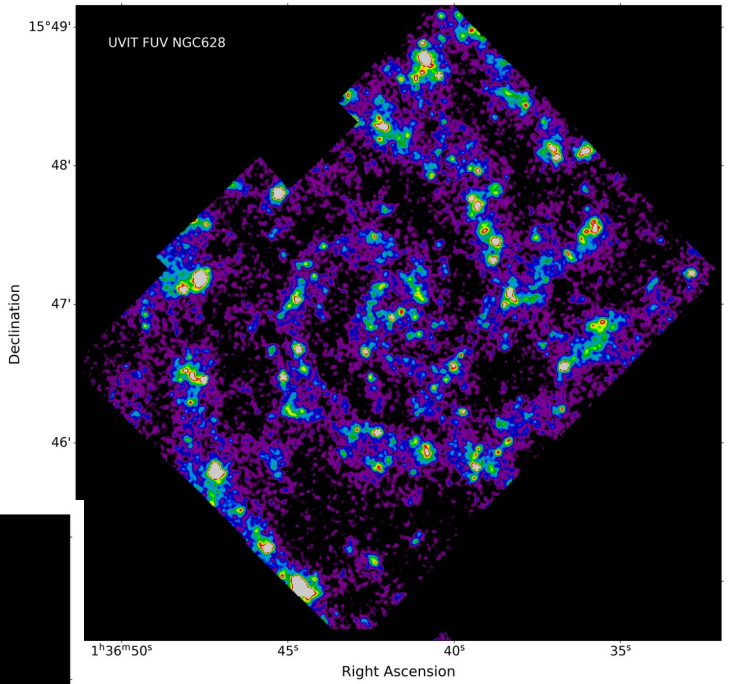


UVIT FUV image of NGC628

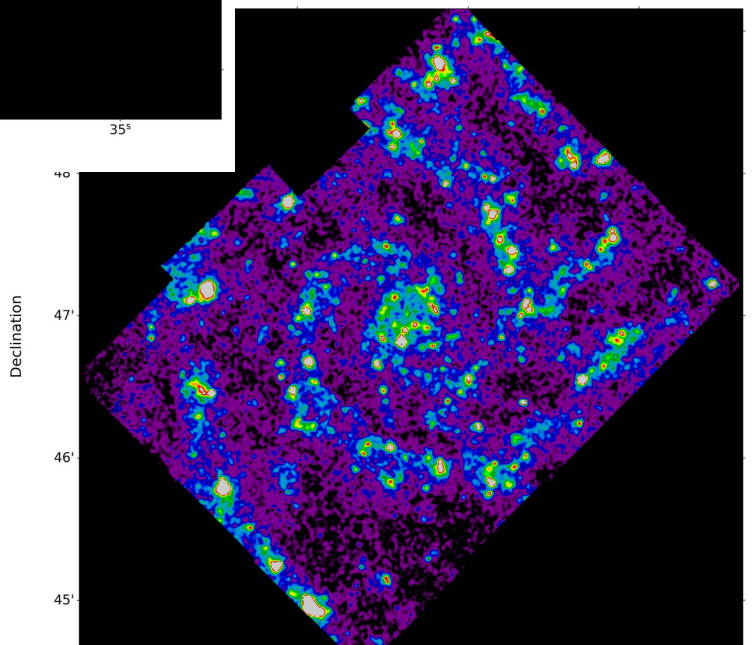
UV and Hα Observations : comparison in NGC 628



MUSE Halpha



UVIT FUV



UVIT NUV

Image credit :
Amrutha

ASTROSAT UVIT

UV observations cannot be done using ground based telescopes, since most of the UV radiation is absorbed by the atmosphere. Only balloons and space based observations can be used for UV observations.

The ultraviolet imaging telescope (UVIT) is part of the ASTROSAT telescope. It has a resolution of ~1.5". This is much better than GALEX which has 5" resolution.

The field of view (FOV) is ~28 arcmin, which means that even nearby galaxies such as NGC628 (D~6Mpc) can be imaged easily.

UVIT has the resolution to study compact regions in the very outer disks of galaxies as well as in the disks of nearby galaxies. So it can detect the kpc-size star forming clusters (SFCs) in merging galaxies. It is also important for AGN related studies of outflows and nuclear star formation in nearby galaxies.

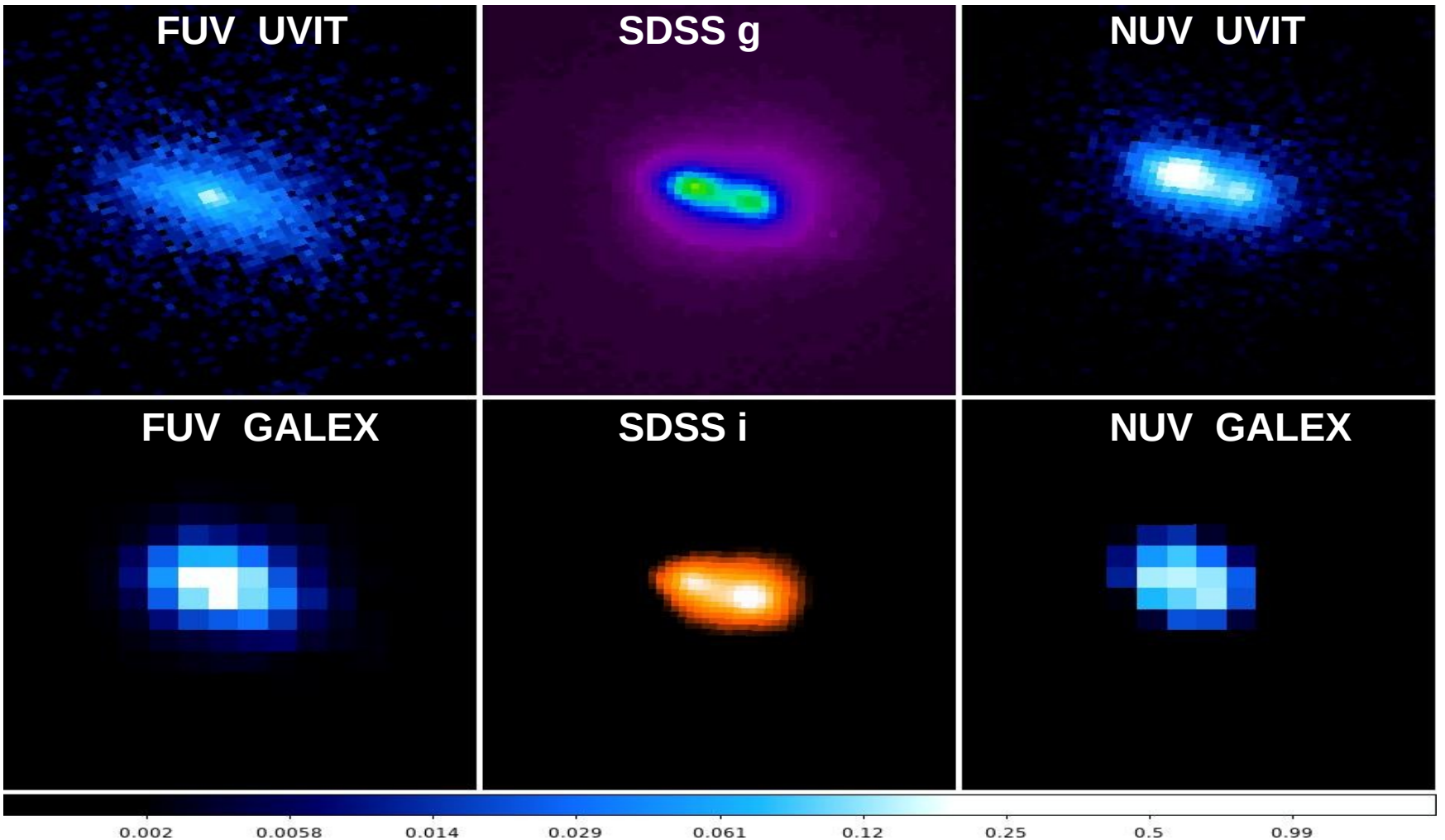
UV and optical studies of Dual AGN

We have done FUV and NUV observations of several dual nuclei galaxies using the UVIT. Preliminary observations were done for 1 to 2 Ks for each source.

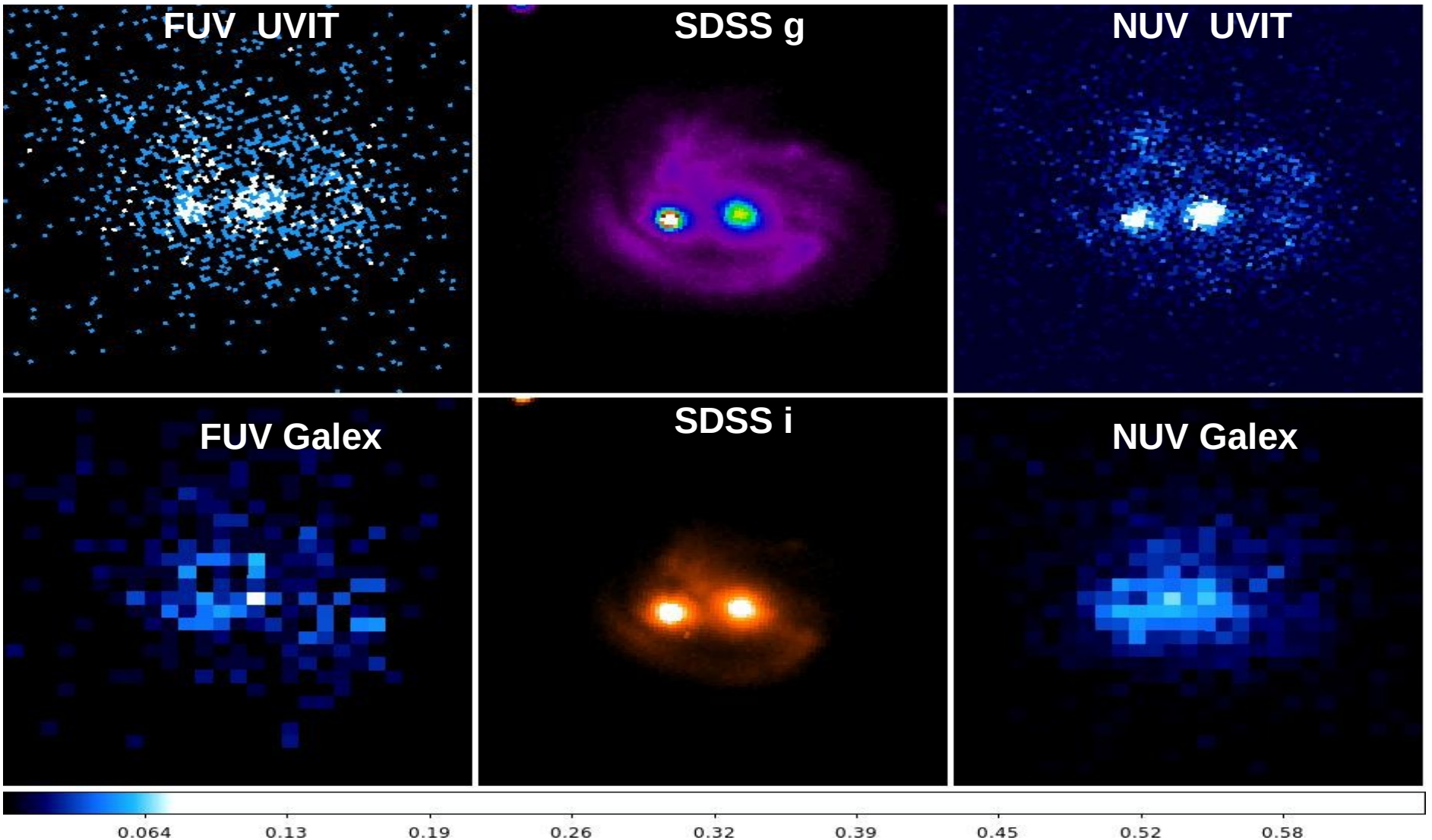
Some have dual AGN whereas others have star forming nuclei or mixed nuclei pairs.

The nuclei have bright cores and sometimes star forming tidal arms associated with them.

UVIT observations of dual nuclei : NGC3773 (z=0.003, Sy1-Sbrst nuclei pair, Rubinur et al.)

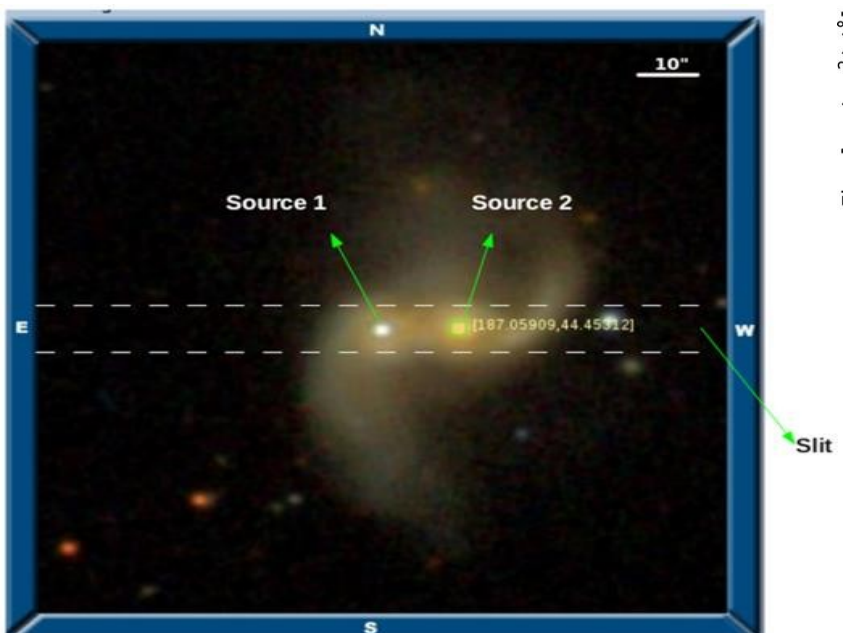


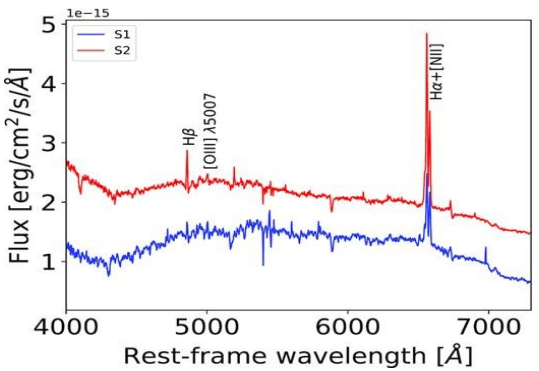
UVIT observations of NGC3758 (MRK 739) Sy1-Sy2 pair

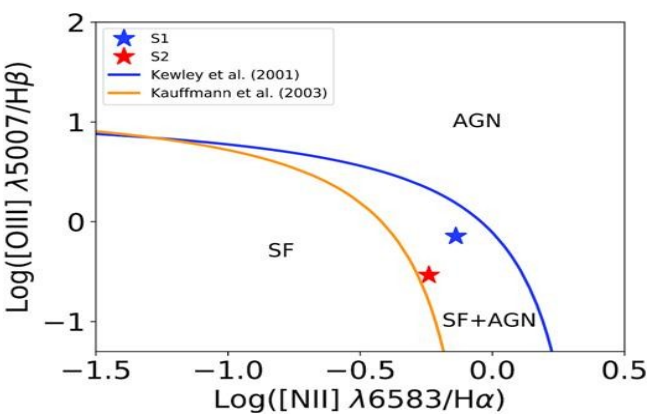


The Dual AGN in MRK212 : confirmed via multiwavelength observations

We studied the dual nuclei galaxy MRK212 using radio (EVLA and uGMRT), FUV (UVIT), optical spectroscopy (HCT). The galaxy is a major merger and nearly face-on. Both nuclei are bright in FIRST radio images. The HCT spectra of the 2 nuclei confirmed that they fall in the star forming + AGN class in the BPT plot.

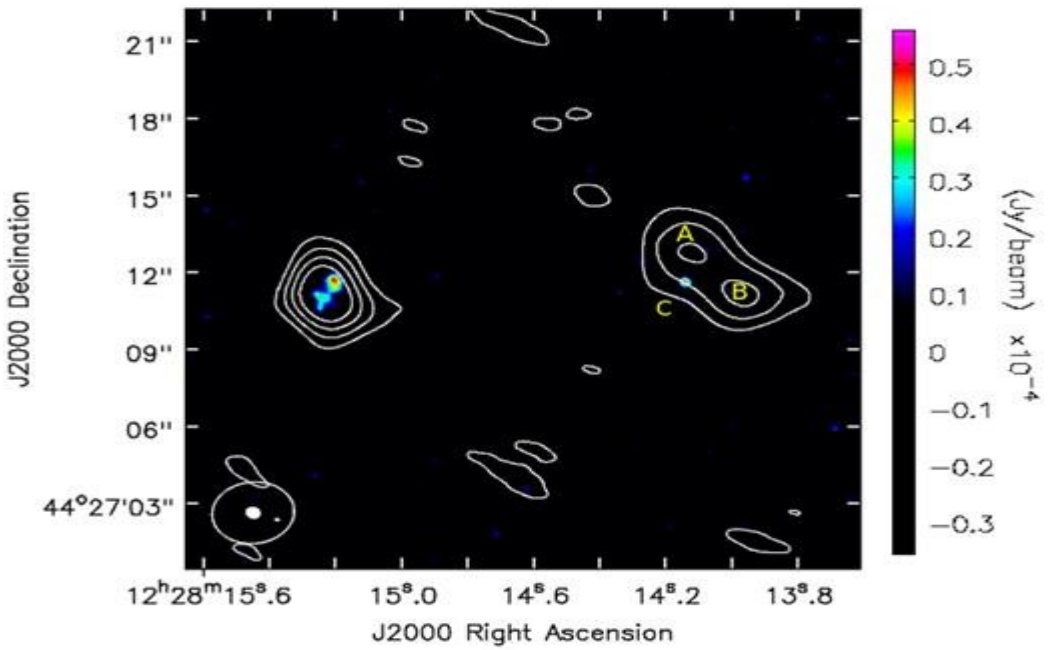




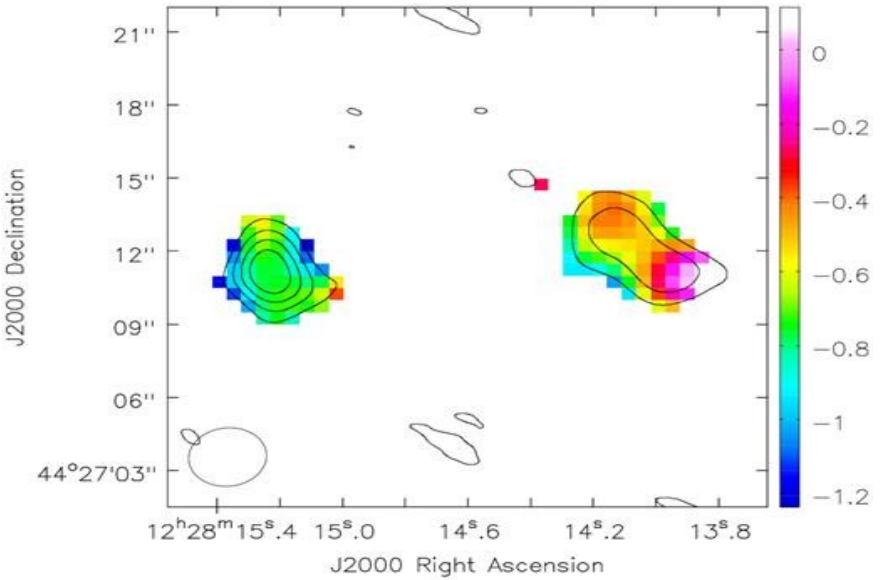


(Left is the SDSS color composite image of MRK212. Top right is the HCT spectra of the 2 nuclei and below is the BPT plot **(Rubinur et al. 2021, MNRAS)**.

Dual AGN in MRK212 : radio observations

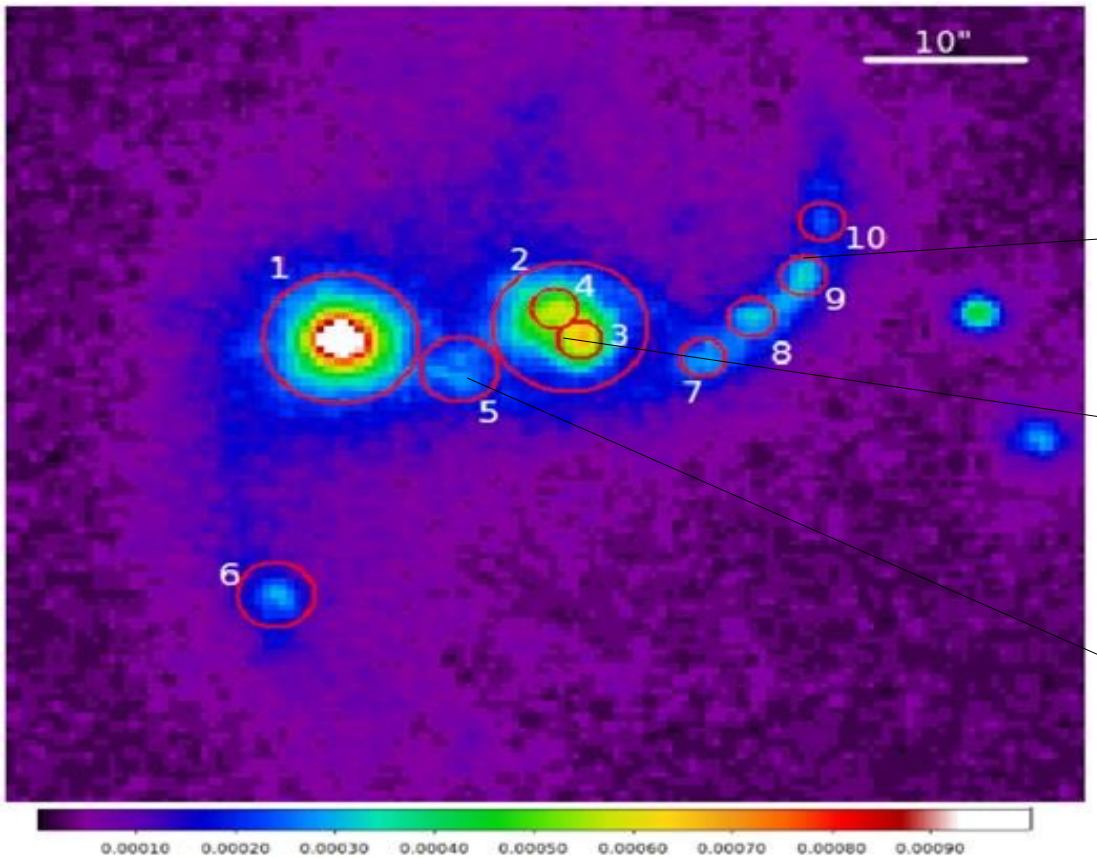


The 8.5-GHz VLA contours image showing radio emission associated with S1 and S2. The 15-GHz EVLA image is superimposed in color. The S2 nucleus shows an offset extended structure, marked with features A and B. The C marks the position of the point source associated with S2.



The spectral index image from the VLA 8.5-GHz and uGMRT 1.4GHz images. The 8.5-GHz contours are overlaid. The contour levels are 20, 40, 60, and 80 per cent of the peak flux density value.

MRK212 : UVIT FUV deep 15 ks observations



Star forming knots associated with the spiral arms.

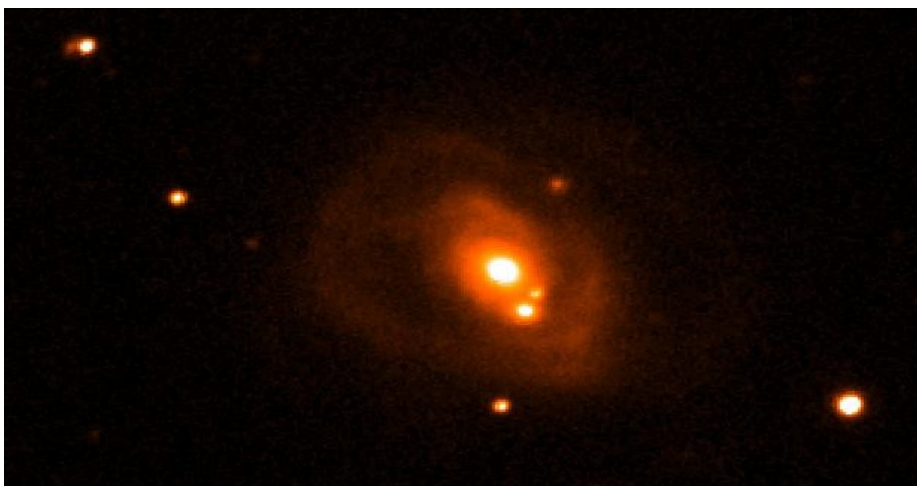
FUV from star forming regions that coincide with the 8.5GHz radio lobes. Possible sign of AGN feedback.

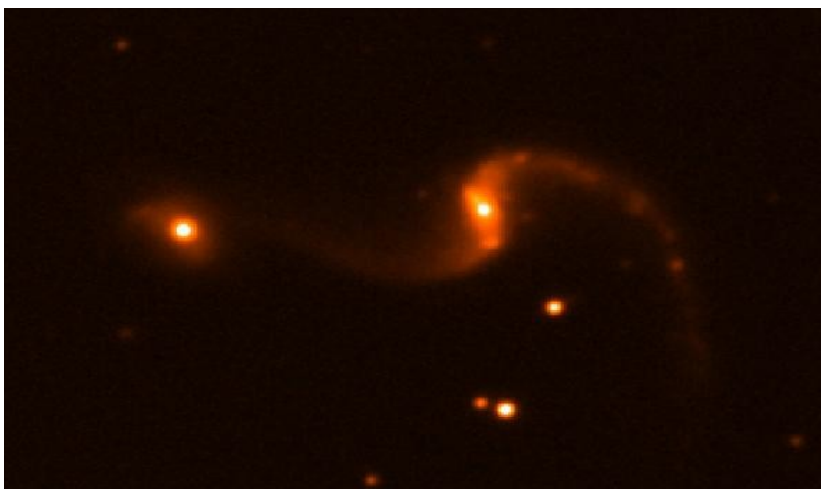
Star formation between the nuclei.

The FUV image of MRK212 had 15Ks of observing time. The star forming knots are clearly detected. The S2 nucleus has 2 knots of star formation that coincide with the 2 radio lobes detected at 8.5 GHz. The outflows from the AGN in S2 could have triggered the star formation. This could be a signature of AGN feedback on kpc scales.

A Study of Close Mergers using UVIT, SAAO and MUSE

Multiple Nuclei can be traced using NIR (J,H,K) observations. We did NIR observations of a sample of 10 southern interacting galaxies with the 1.5m IRSF telescope at SAAO (S.Africa).

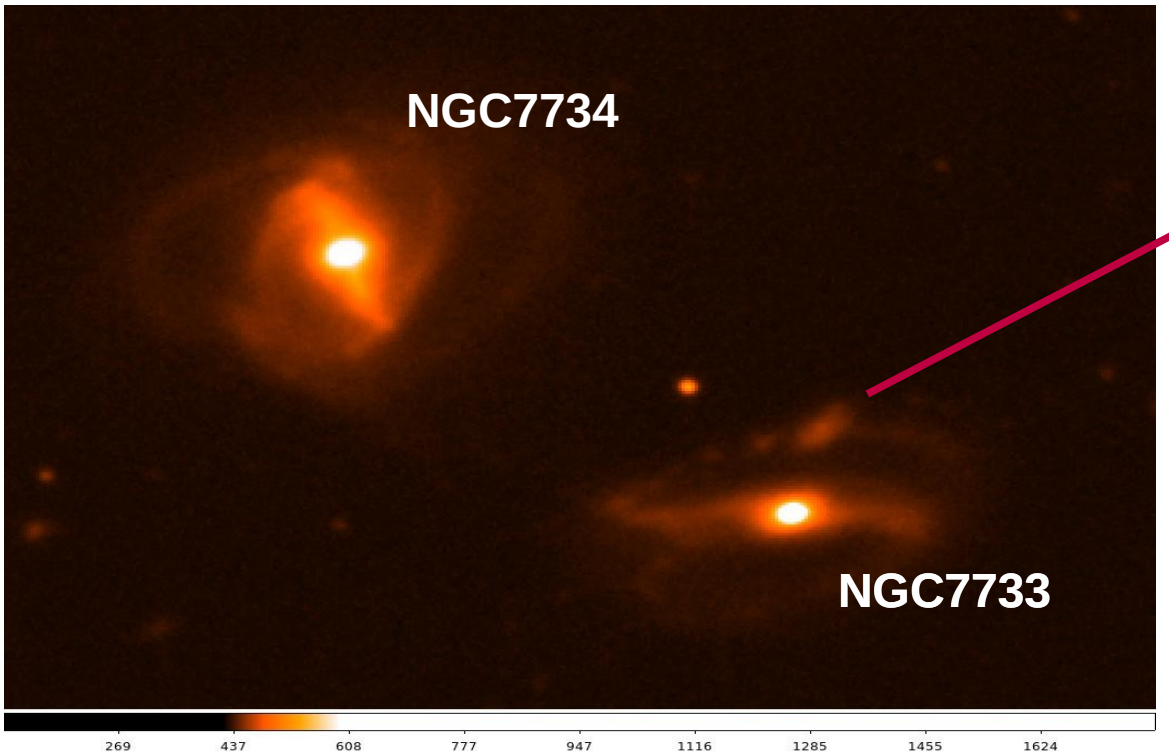




(SAAO NIR K band images of southern interacting galaxies, UVIT images also obtained, Jyoti Yadav+2023, MNRAS).

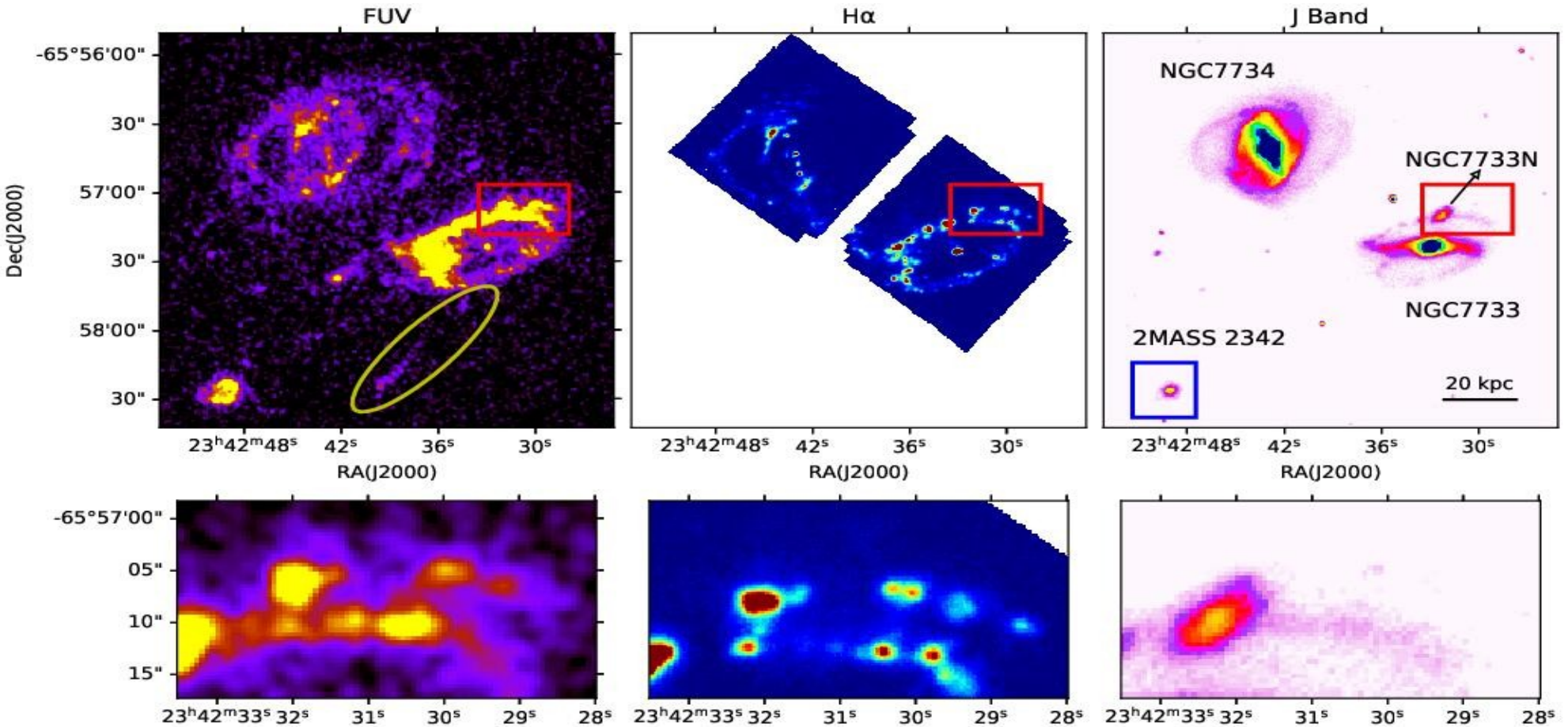
NIR observations of the interacting pair NGC7733 and NGC7734 with SAAO-IRSF

J Band Image



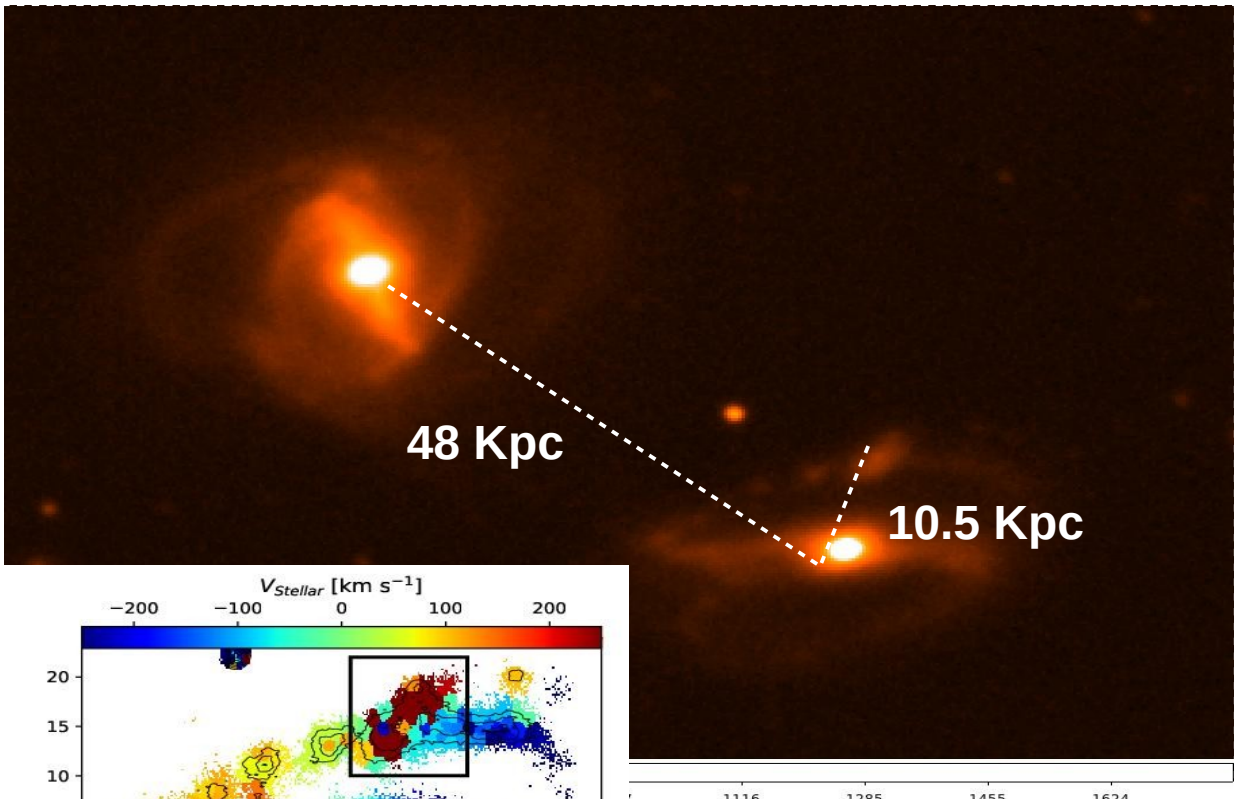
- As part of a study of interacting galaxies, we observed the southern pair NGC7733 and NGC7734 in the JHK band using the near infrared 1.5m telescope IRSF in SAAO.
- The northern knot in NGC773 was previously identified as a star forming region, but is clearly a bulge in the NIR images.

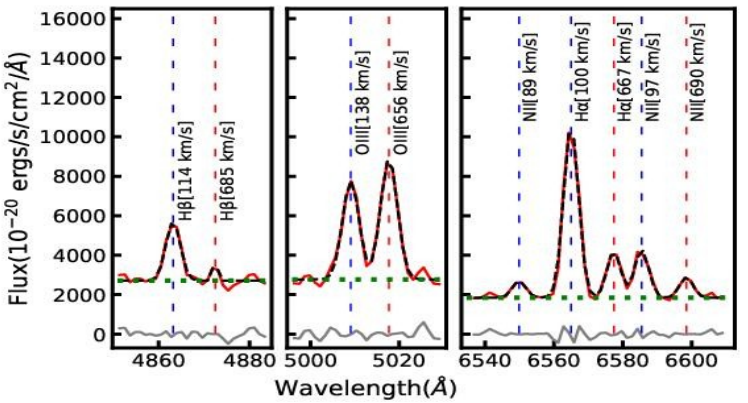
NGC7733-7734 : UVIT-FUV, MUSE (archival) and IRSF-NIR



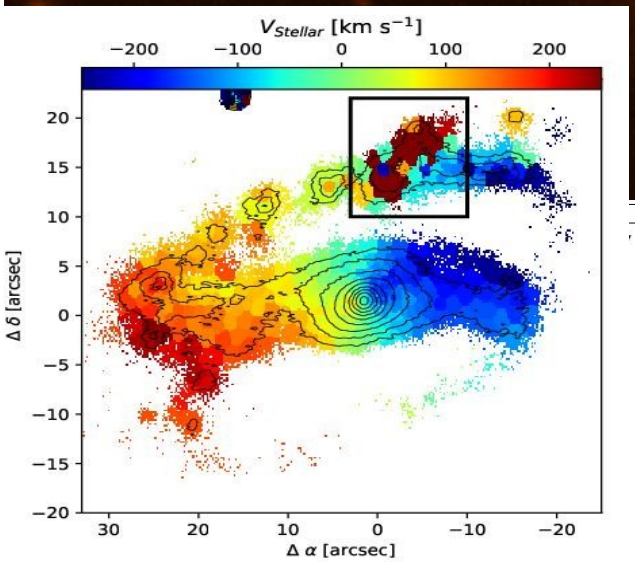
Observing times : UVIT-FUV – 2.57 Ks, MUSE – 1.05 Ks, IRSF-SAAO – 120 mins

The velocity determination from MUSE Hα lines



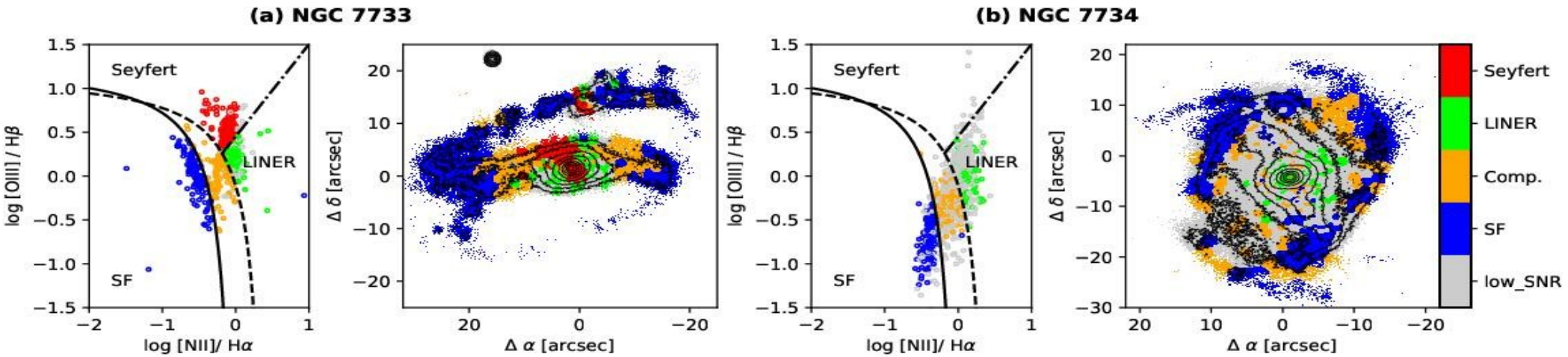


- The Hα emission lines from the MUSE data cube was essential to determine the systemic velocity of NGC7733N. It has a <v>~600 km/s wrt NGC7733. Hence it is not part of the galaxy but could be in a tidal arm.



- The Hα velocity field from the MUSE data cube also clearly shows that the velocity field of NGC7733N is very different from NGC7733.

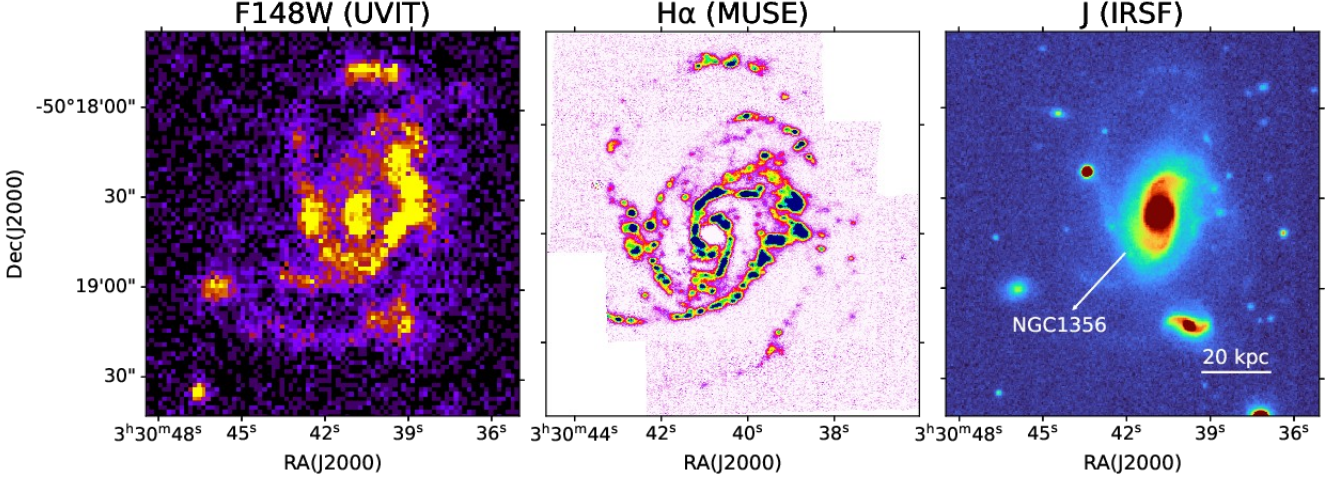
The nature of the 3 nuclei : star forming or AGN?

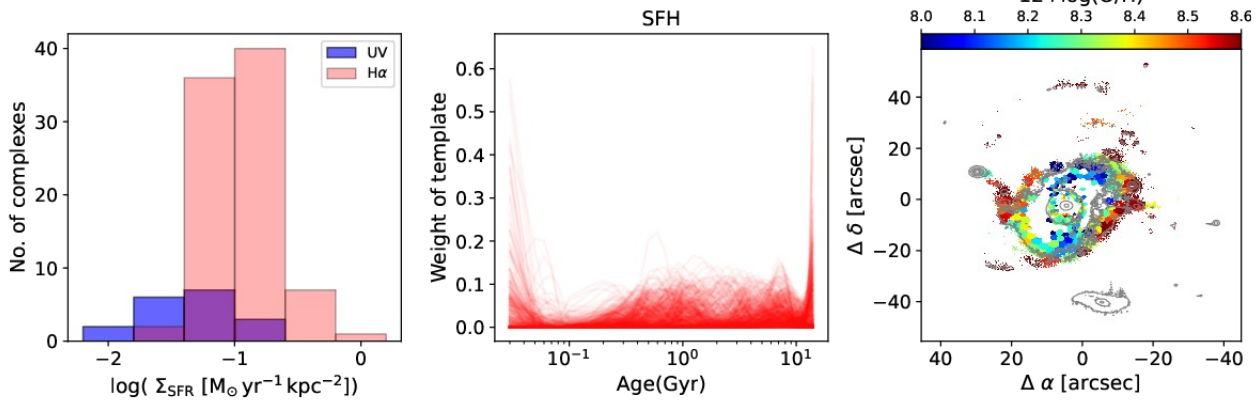


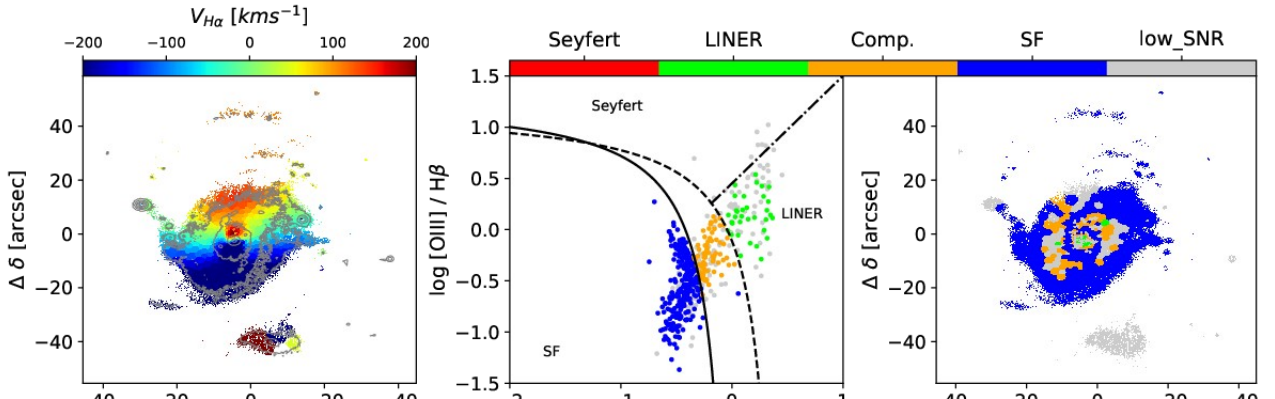
- The nature of the nuclei can be determined using the empirical plot called the BPT plot, which is based on the ratio of the emission lines [OIII], [NII], Hα and Hβ. MUSE give the spectra of spaxels and so the BPT position of the individual pixels can be determined.
- It is clear that NGC7733 nucleus and NGC7733N are both Seyfert type whereas NGC7734 is LINER. Both galaxies show extensive star formation in the spiral arms, but it is stronger in NGC7733.
- So the small group can be considered as **a triple AGN system,** although all 3 nuclei are not really within a common envelope.

NGC 1356

- We find several tightly wound tidal rings, similar to resonance rings in galaxy disks.
- The rings are clearer in FUV as the range of stellar type and ages are broader.







Jyoti Yadav+2023, MNRAS

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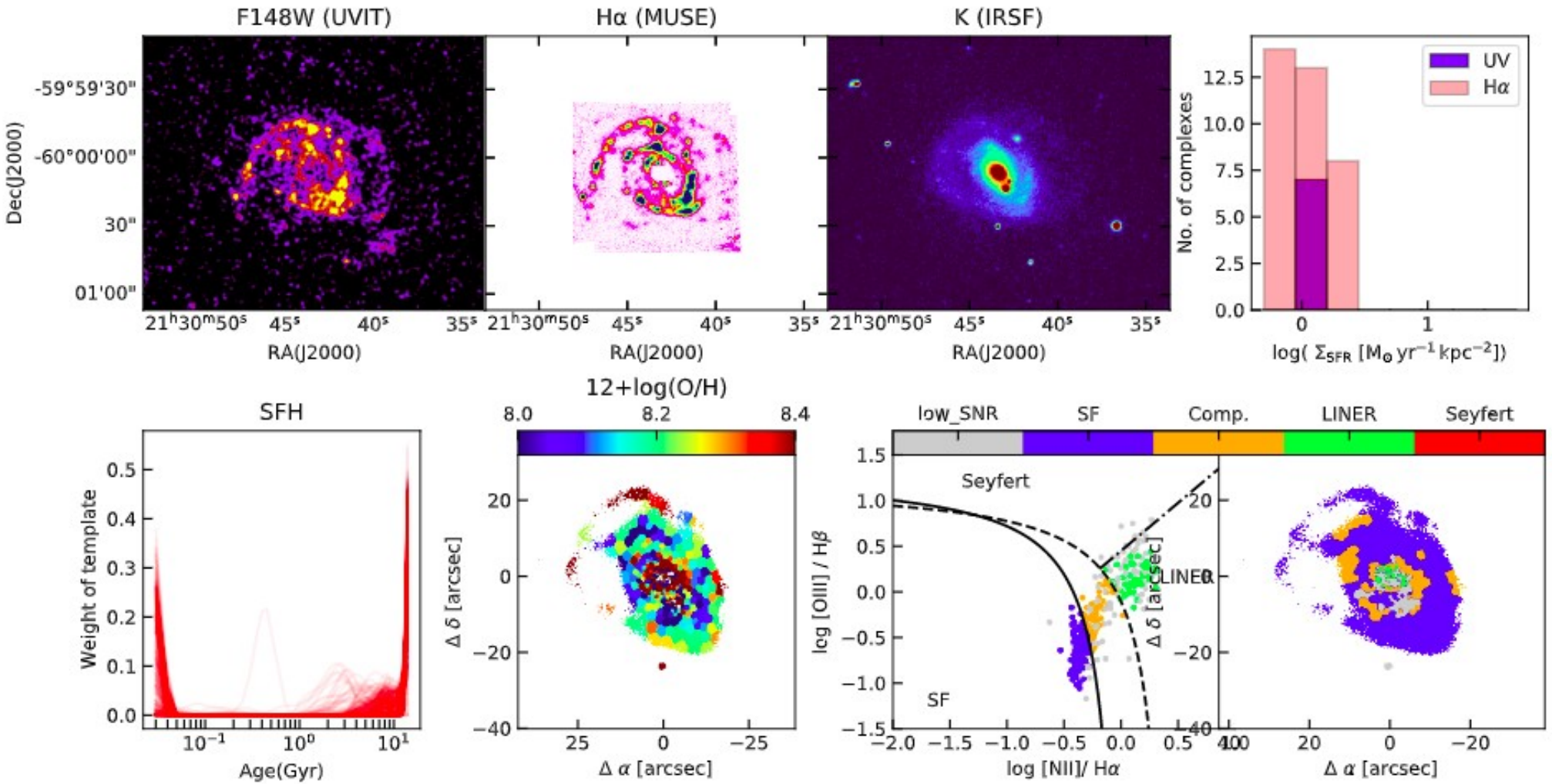
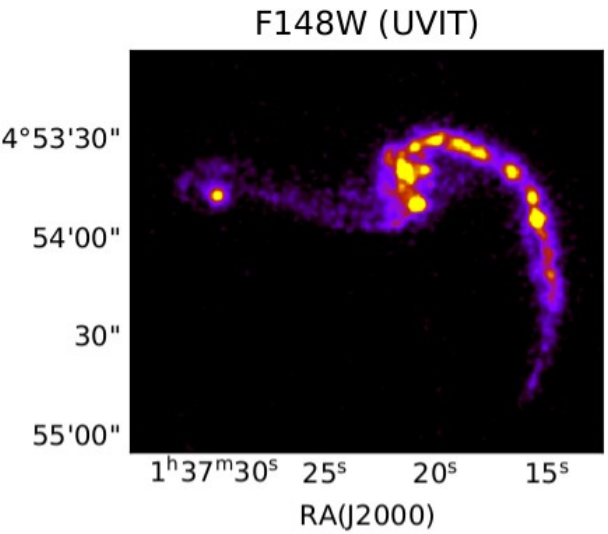
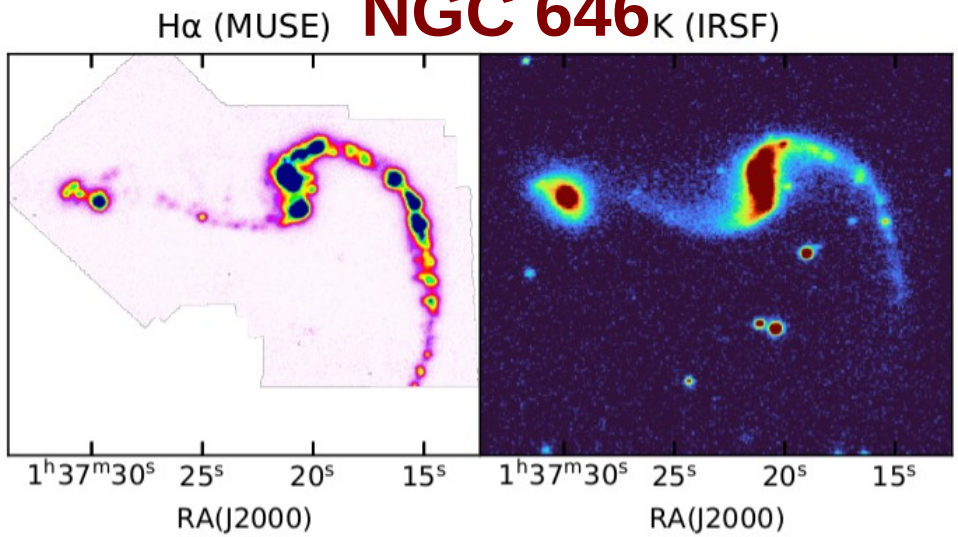
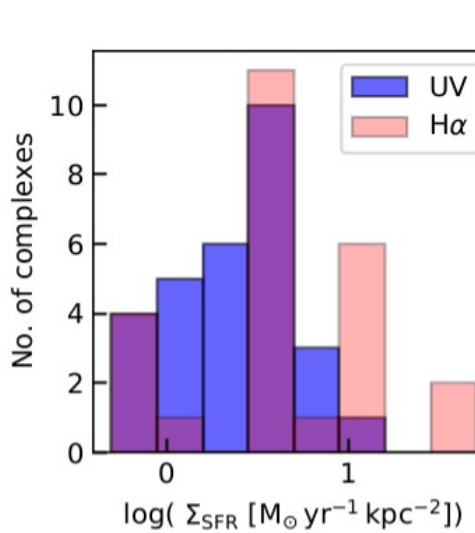


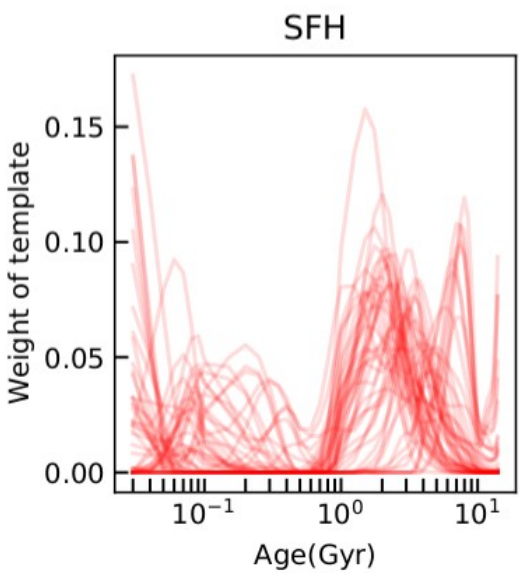
Jyoti Yadav+ 2023, MNRAS

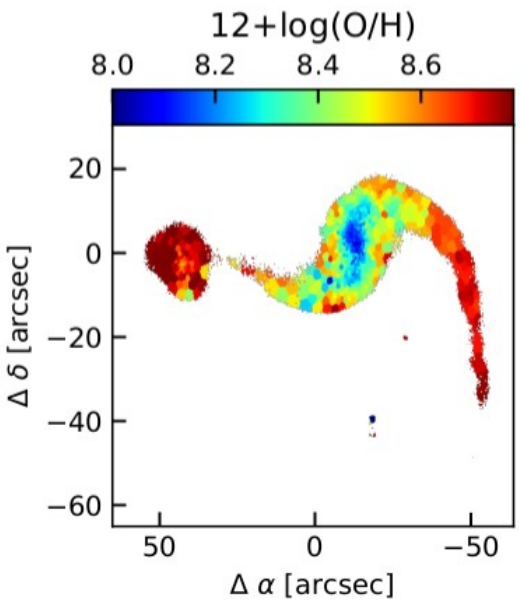
NGC 646

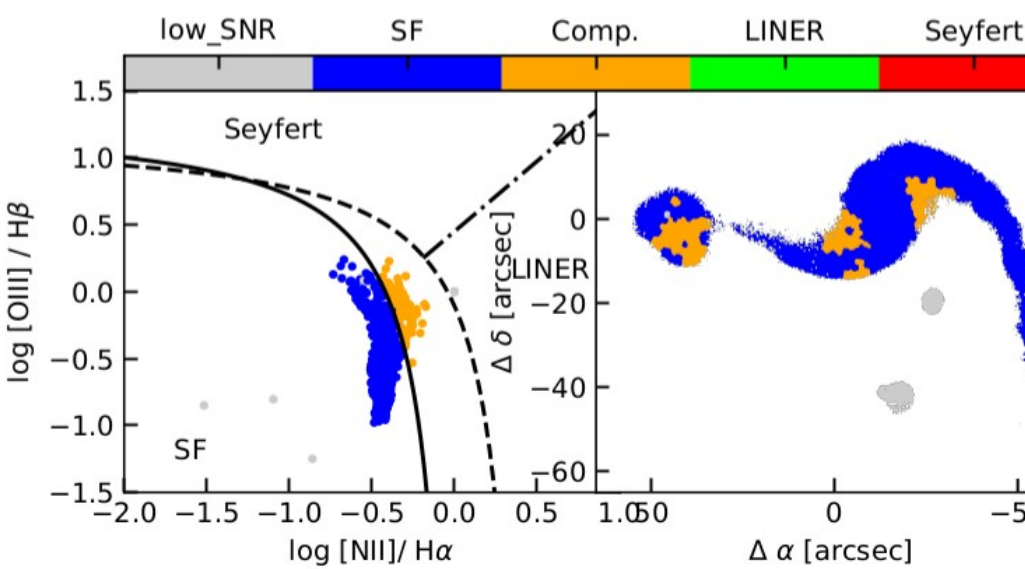












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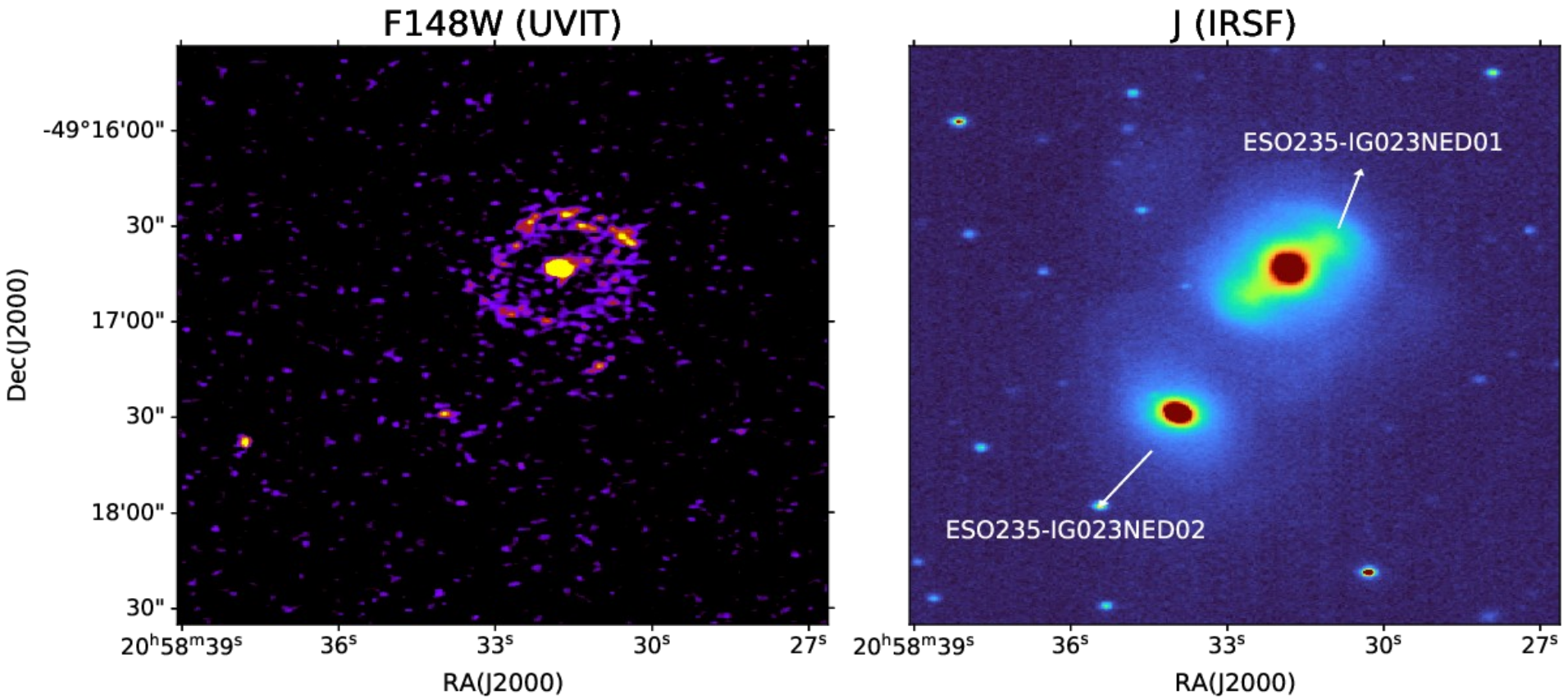

Jyoti Yadav+2023, MNRAS

The accidental discovery of a new galaxy in an interacting pair

Astronomy & Astrophysics manuscript no, output
December 10, 2021

LETTER TO THE EDITOR

Hidden in Plain Sight: UVIT and MUSE discovery of a Large, Diffuse Star Forming Galaxy

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December 10, 2021

ABSTRACT

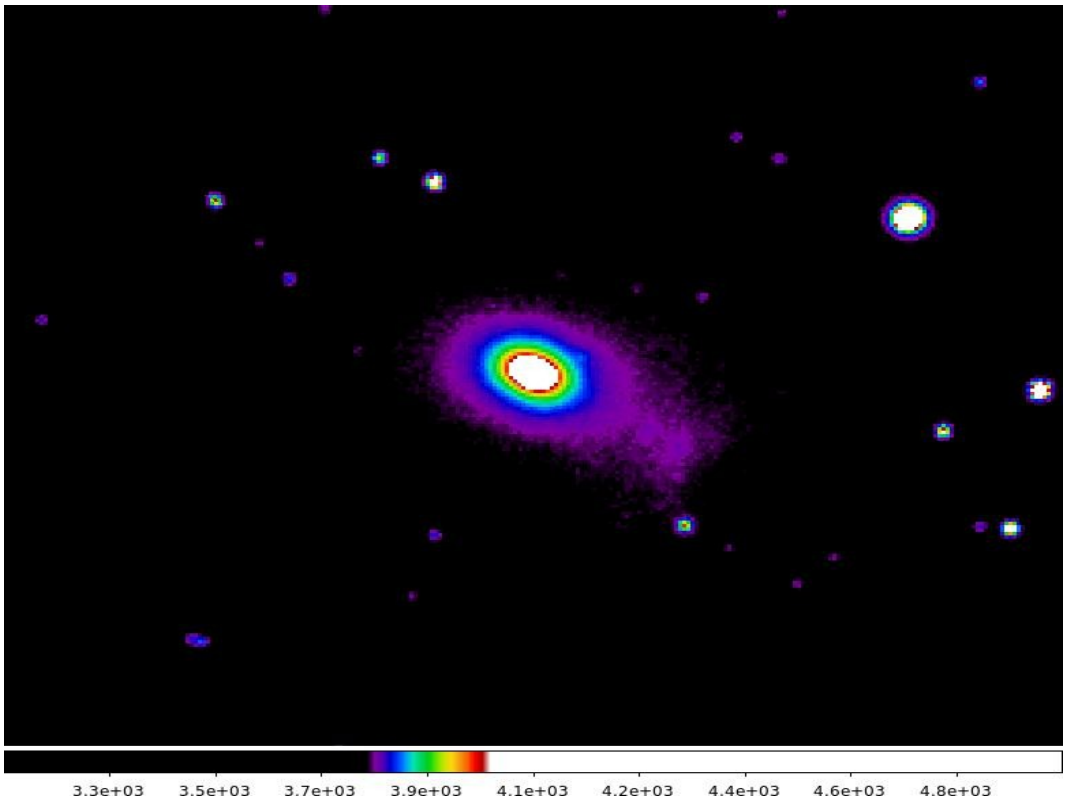
We report the discovery of a nearby large, diffuse galaxy that shows star formation, using UVIT FUV observations, archival optical data from MUSE and DECaLS, and IRSF near-infrared observations. The galaxy was not detected earlier due to its superposition with the background galaxy NGC 6902A. They were together mistakenly classified as an interacting system. NGC 6902A is at a redshift of 0.05554, but MUSE observations indicate that the interacting tail is a separate star-forming, foreground galaxy at a redshift of 0.00980. We refer to the new galaxy as UVIT J202258.73-441623.8 (UVIT J2022). The near-infrared observations show that UVIT J2022 has a stellar mass of $8.7\times10^{8}M_{\odot}$. Its inner disk (R<4 kpc) shows UV and Hα emission from ongoing massive star formation. The rest of the disk is extremely low luminosity, has a low stellar surface density, and extends out to a radius of R~9 kpc. The velocity and metallicity distribution maps and the star formation history indicate that UVIT J2022 has undergone three bursts of star formation, and the latest episode is ongoing, which is supported by the presence of widespread Hα and UV emission in its inner disk. The galaxy also shows patchy spiral arms in FUV, and there is a metallicity enhancement along a bar-like feature. UVIT J2022 is thus a unique example of triggered star formation in a diffuse galaxy, resulting in the growth of its inner stellar disk. Our study raises the intriguing possibility that (i) there could be similar diffuse galaxies that have been mistakenly interpreted as interacting galaxies due to their superposition, and (ii) UV or Hα could be a way to detect such diffuse galaxies in our local universe.

Key words. Galaxies: individual: NGC 6902A, UVIT J202258.73-441623.8 – Galaxies: interactions – Galaxies: star formation – Techniques: imaging spectroscopy

The interacting galaxy NGC6902A

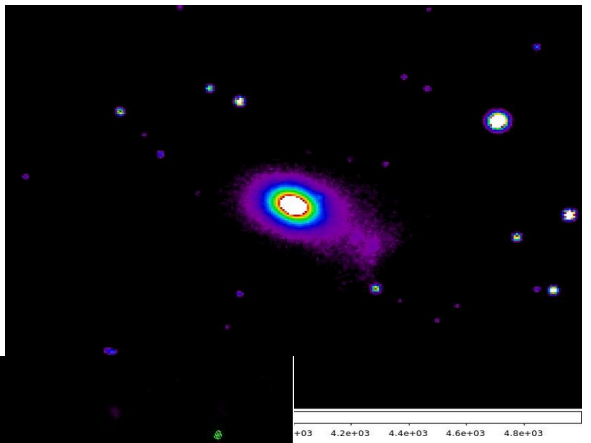
- We observed NGC6902A in near-infrared with the SAAO. It appeared to be interacting with a companion.
- Maybe a minor merger taking place?

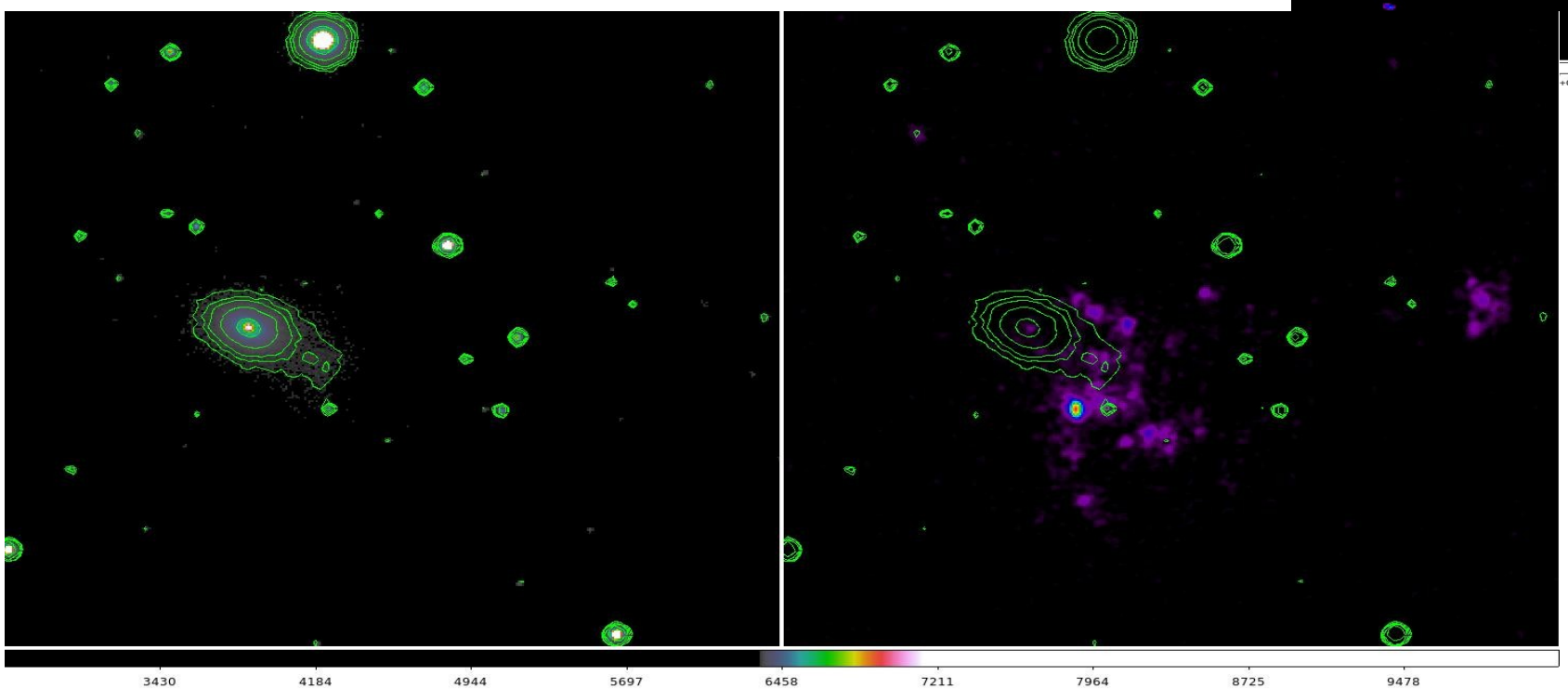
Image in K band (NIR) =========>



The interacting galaxy NGC6902A ==> tidal tail is UV bright!!

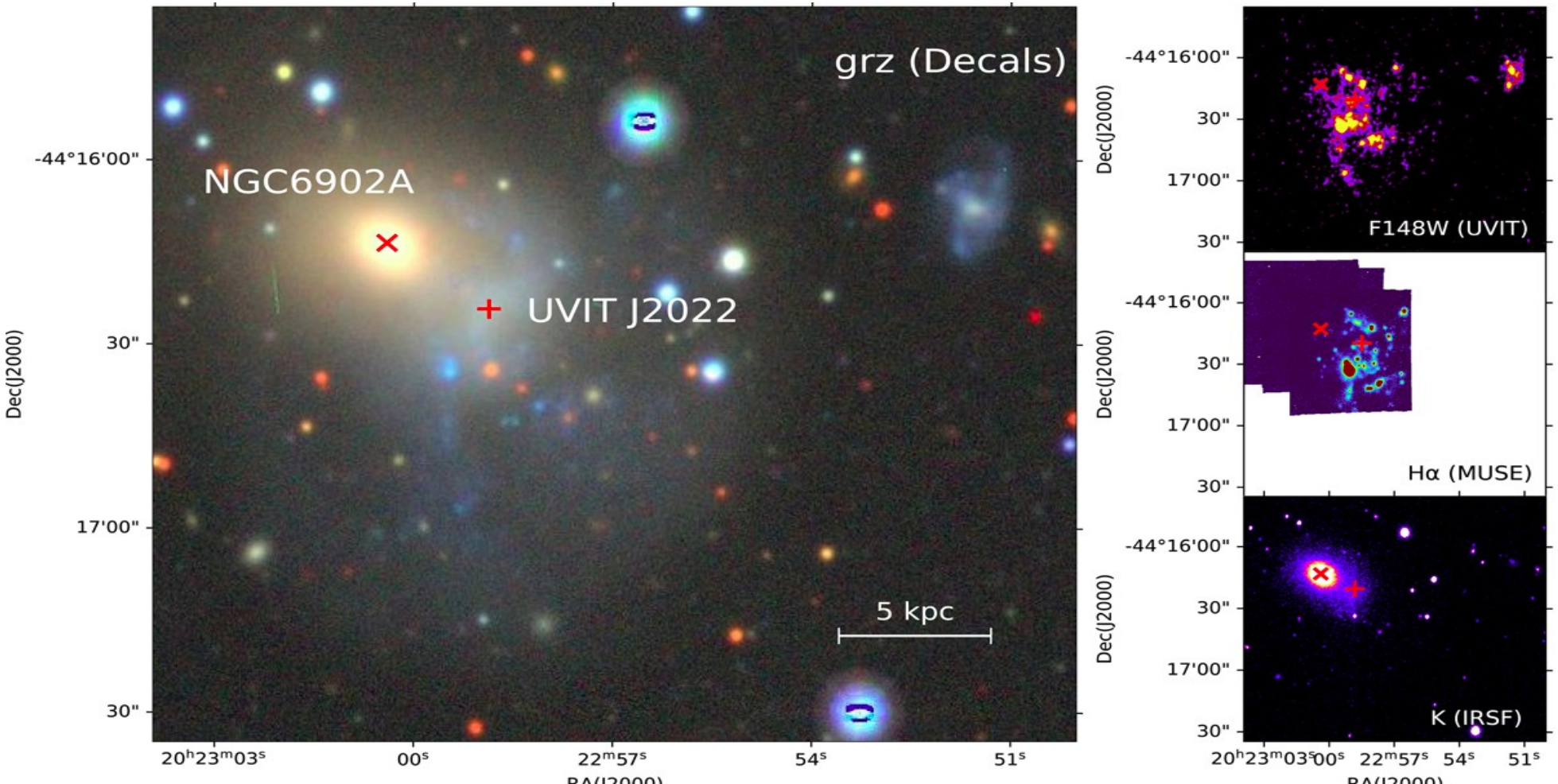
- The tidal tail in NGC6902A had a peculiar UV morphology!!





Discovery of the diffuse galaxy UVITJ2022

- We can see the diffuse galaxy in UV and Hα emission. But it appears like a “ghost” in optical images (the DECALS survey image).



The diffuse galaxy UVITJ2022

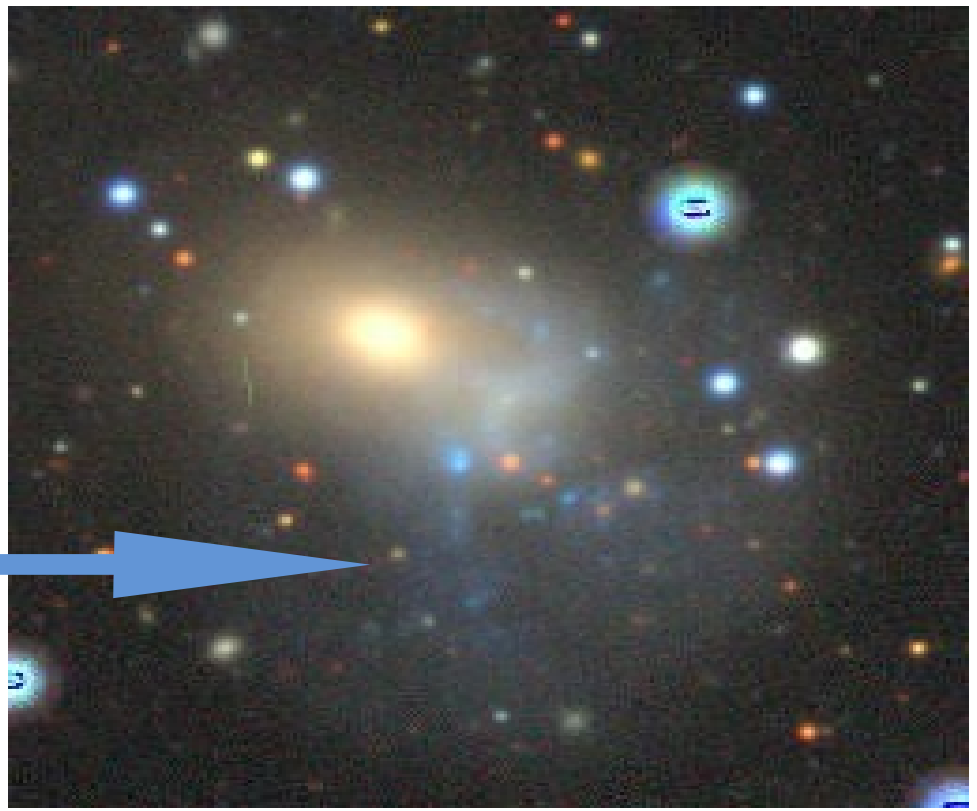
NGC 6902A is actually a superposition of a background galaxy at a redshift of 0.05554, but MUSE observations indicate that the interacting tail is a separate star-forming foreground galaxy at a redshift of 0.00980.

Thus checking the redshift of the interacting pair or nuclei is very important!!

This detection is very important for the field of diffuse galaxies ==> UDGs and LSB galaxies.

Indicates that we maybe missing many diffuse galaxies in the low redshift universe.

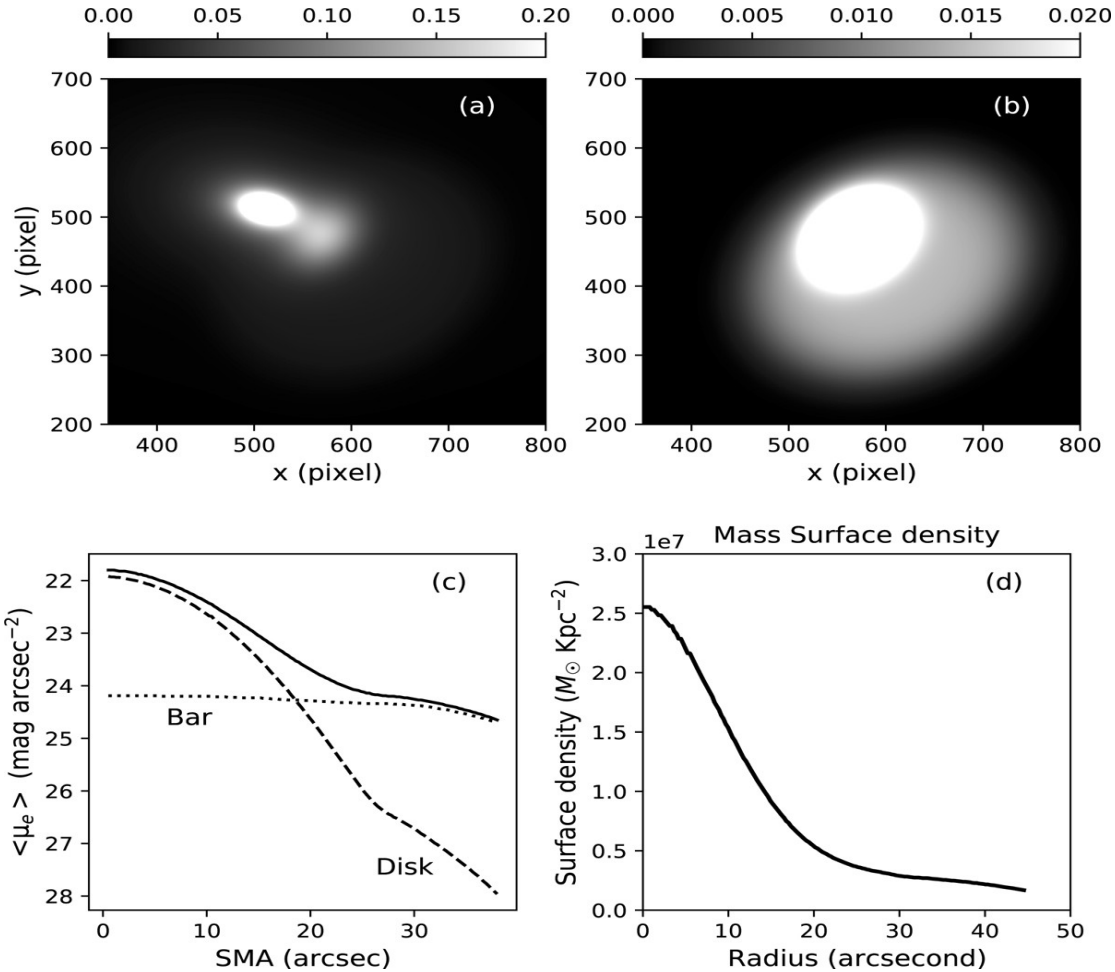
UVIT 2022



The decomposition of the galaxies NGC6902A and UVITJ2022 using GALFIT

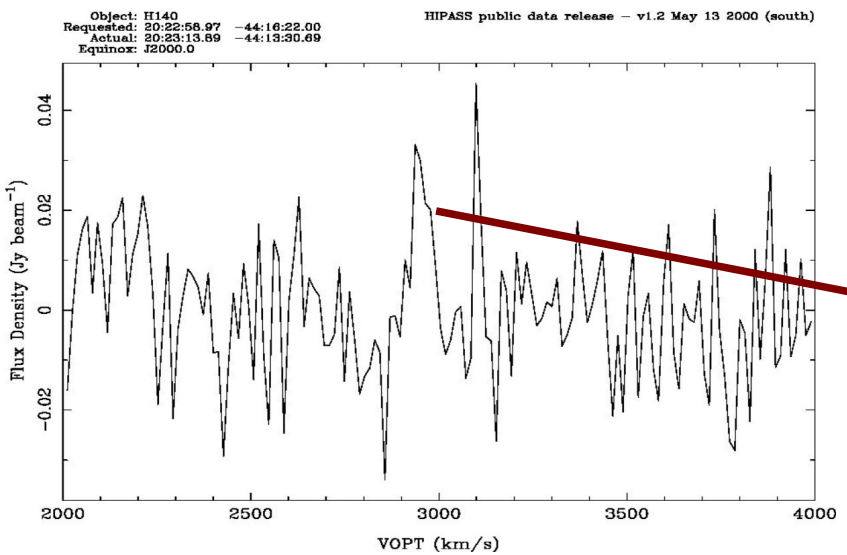
A model was obtained from the fitting of NGC 6902A and UVIT J2022 with the 3+2 Sersic component in the r band. Panel and b: model image of UVIT J2022. The size scale is the same in panels a and b but the grayscale in panel b is different to show the extent of UVIT J2022.

Below is the total model average surface brightness profile of UVIT J2022 in the r band, obtained from GALFIT (solid curve). The dotted and dashed curves show the Sersic profiles for the inner central bar-like structure and disk component, respectively.

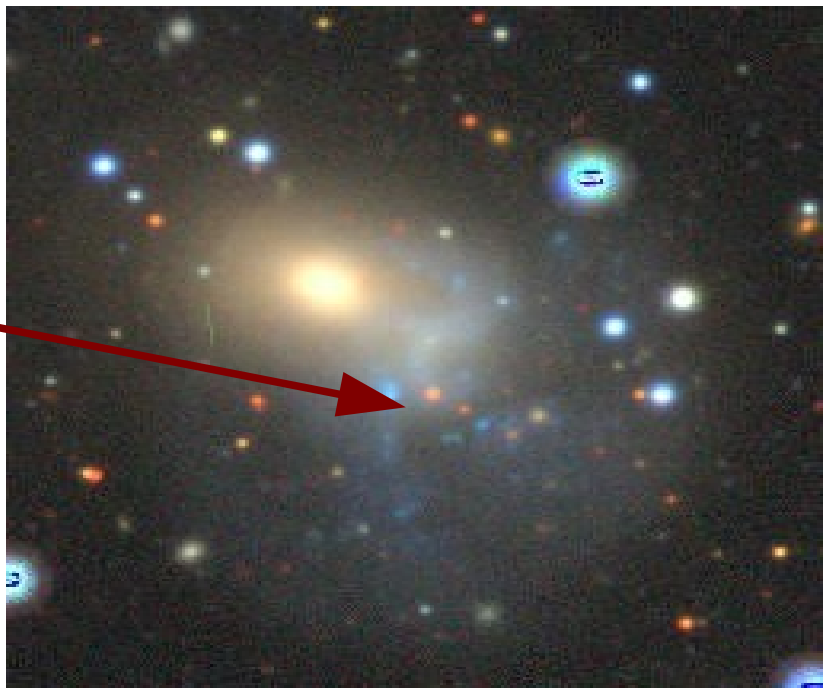


The neutral gas content of UVITJ2022

- We looked at HIPASS for HI gas in the direction of NGC 6902A. We found that there is HI at the redshift of 0.00980. The flux yielded an HI mass of approximately 10^9 Msun

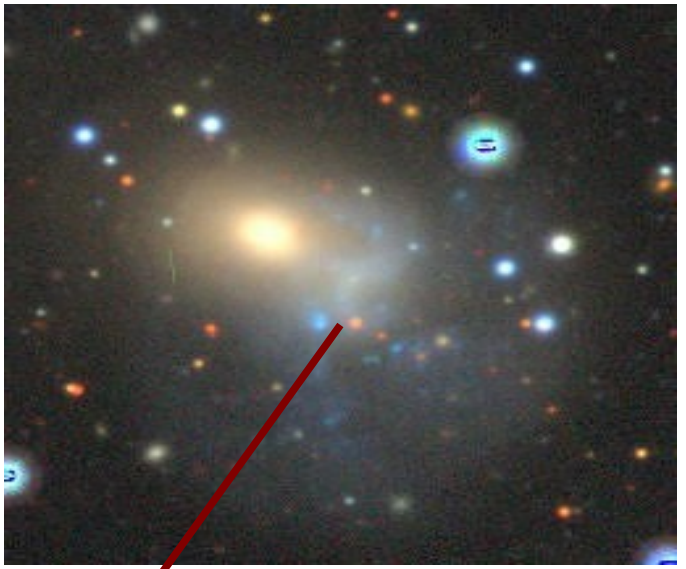


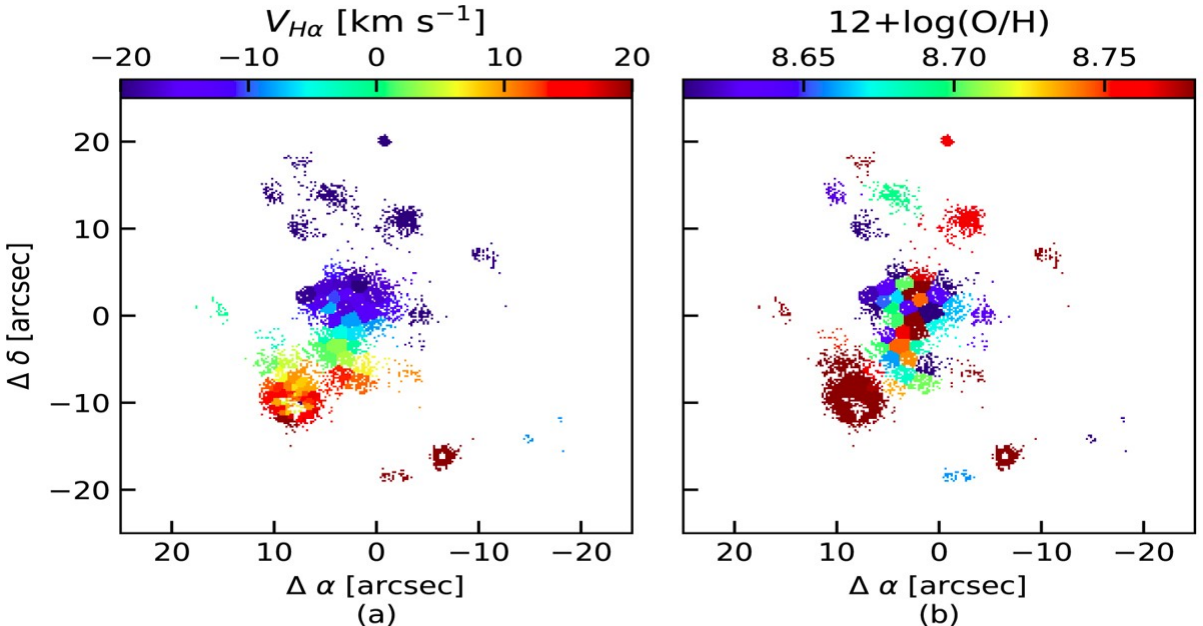
The HIPASS HI spectrum of UVIT 2022



The metalllicity of UVITJ2022 :

- The foreground galaxy UVITJ2022 has a velocity distribution which is distinct from background galaxy.
- There is signature of disk rotation in UVITJ2022, of the order of 20km/s.
- There is a metallicity distribution across the galaxy. There is a bar like distribution in the metallicity.





So UVITJ2022 appears to be a diffuse galaxy which has been triggered into star formation in the central parts. But the outer disk is diffuse.

Summary

- UV studies can offer us new insights into the star formation and nuclear activity in nearby galaxy mergers. **This is mainly because UV traces star formation for longer timescales compared to Hα. So it can detect fainter star formation e.g. in tidal arms, in diffuse disks and in extended tidal tails.**
- When the UV is combined with optical integral field spectroscopy (IFS) data such as MUSE or SDSS-MANGA it can reveal hidden nuclear activity and star formation in our nearby universe. So UVIT images combined with such optical data can reveal a host of interesting processes.
- Multiwavelength observations such as radio continuum studies are also important to understand the nuclear activity.