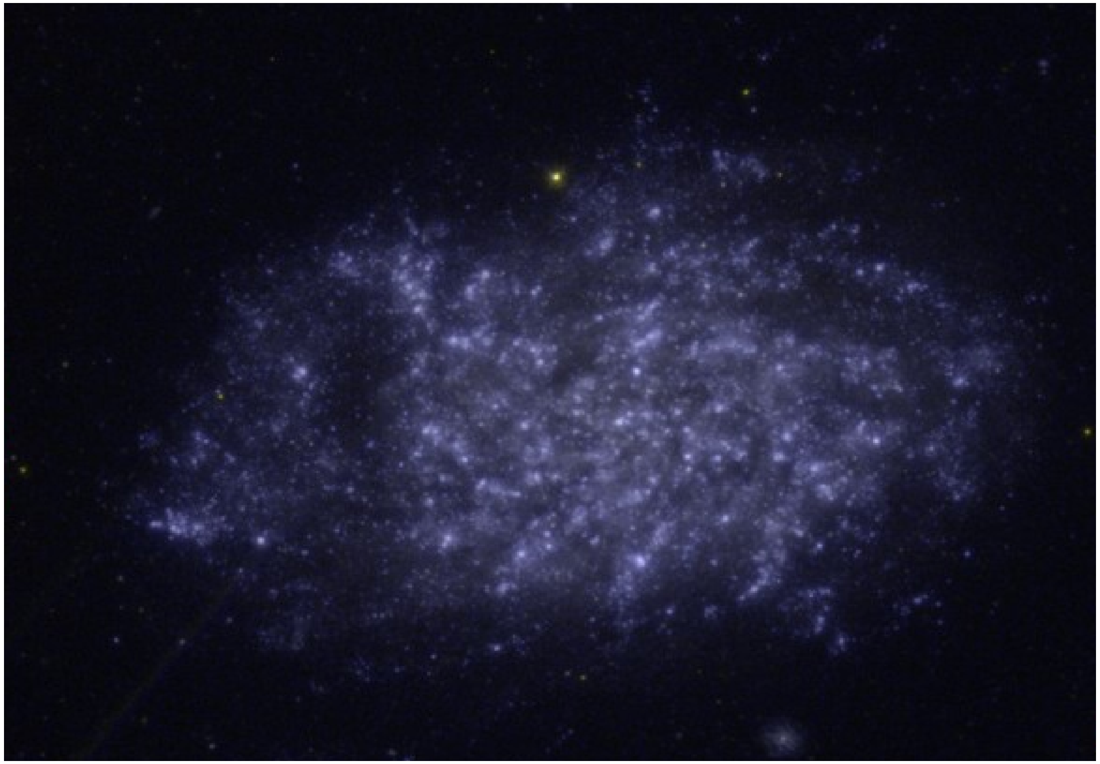
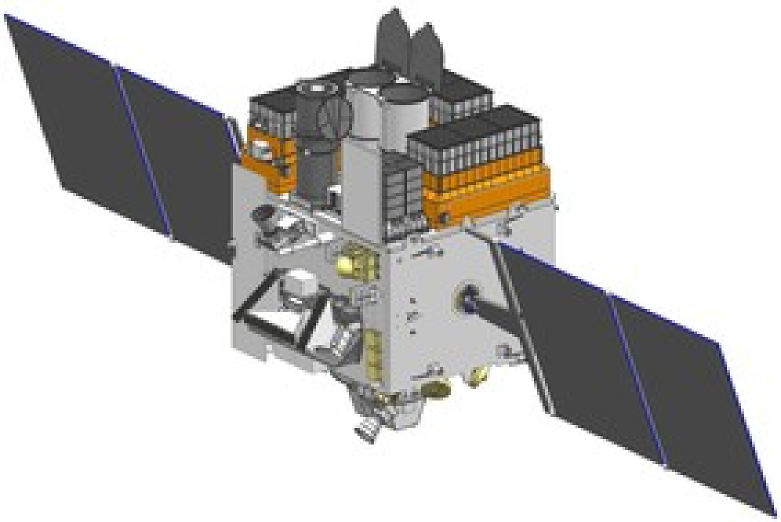
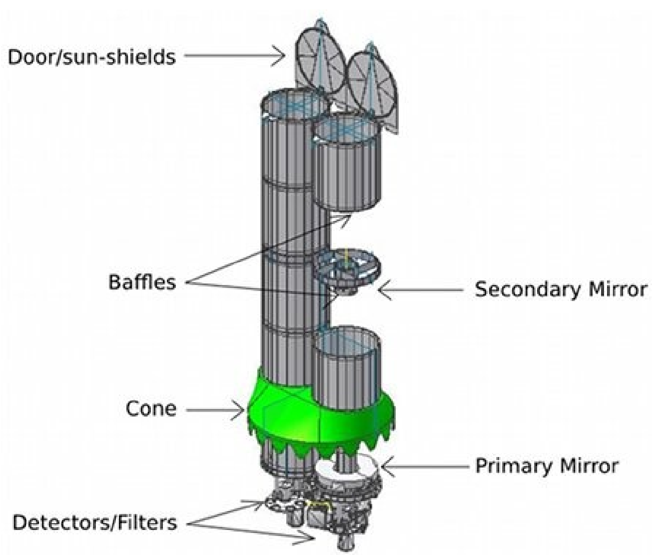
Understanding Star formation in galaxies using UVIT - A new UV eye in the sky







Chayan Mondal

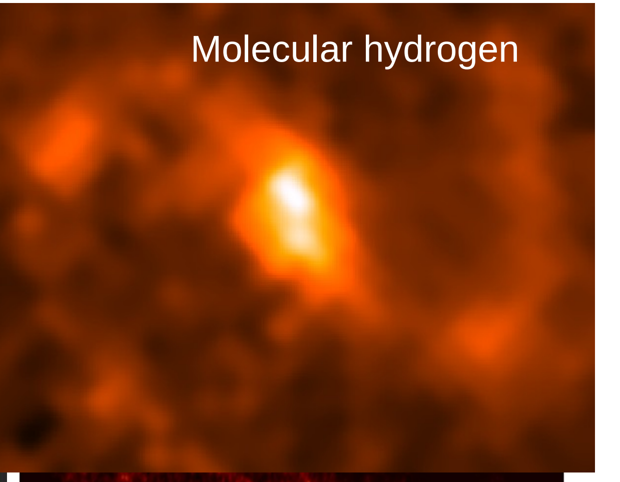
Post Doctoral Fellow
Inter-University Centre for Astronomy and Astrophysics, Pune
June, 2021
ASSC workshop

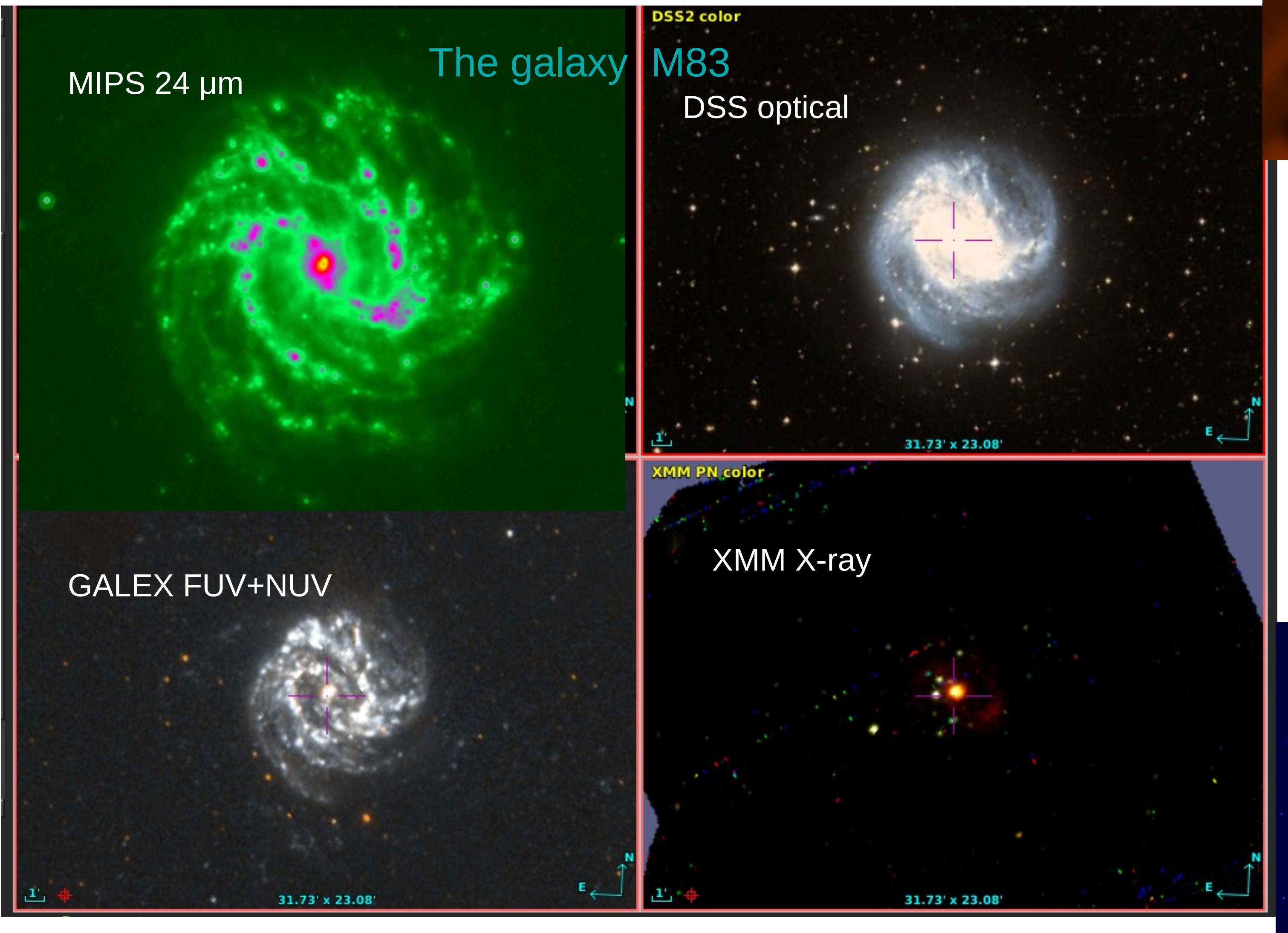
What we aim to learn?

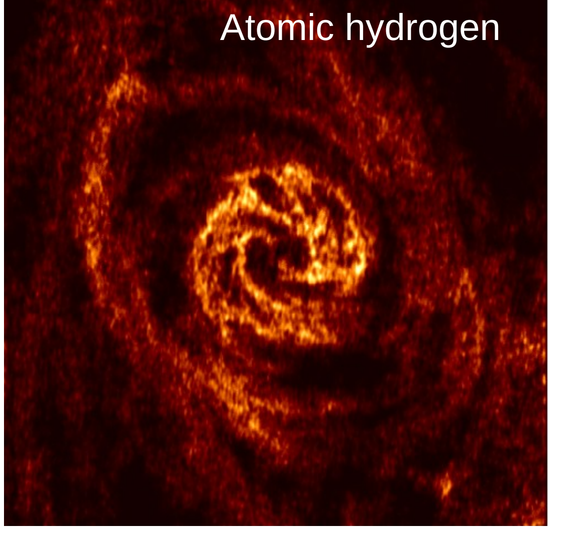
- Ultra-Violet Imaging Telescope (UVIT) – Observation and data
- Role of UVIT in studying star formation in nearby galaxies
- Techniques to identify star-forming clumps in galaxies
- Perform custom aperture photometry and characterize the clumps
- UVIT study of the nearby galaxy NGC 7793

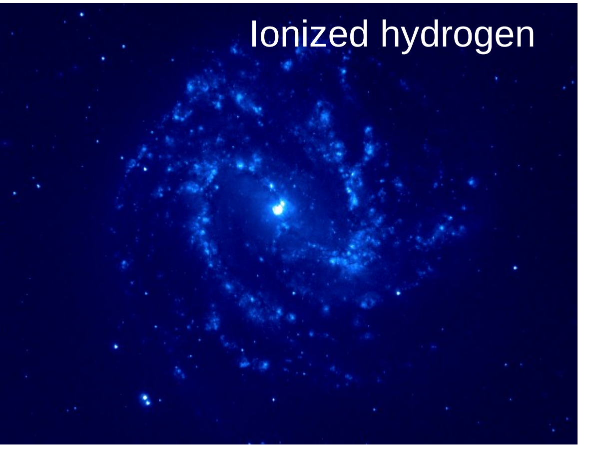
What is a ‘Galaxy’ made of – A Multi-wavelength view

Galaxy : A gravitationally bound system of dark matter and baryonic matter.
Baryonic components of a galaxy :
Star (of different age and metallicity)
Gas (atomic, molecular, ionized)
Dust (carbon, silicate and graphite grains and other complex molecules)









Images are obtained from NED

How to trace star-forming regions ?

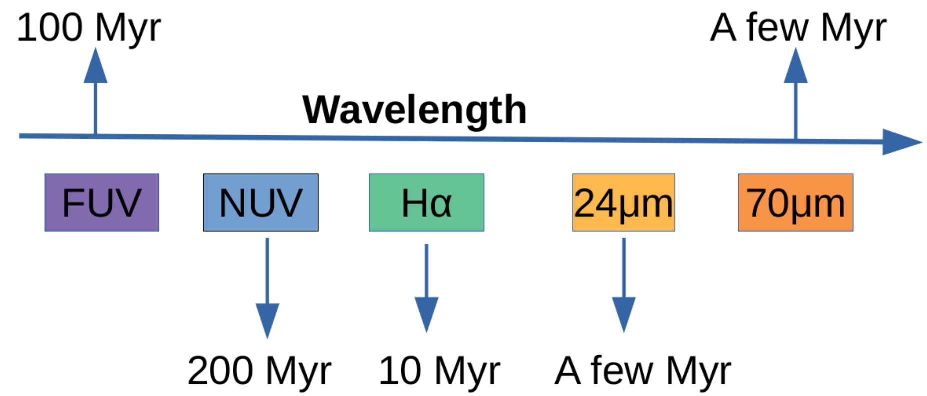
Importance of FUV

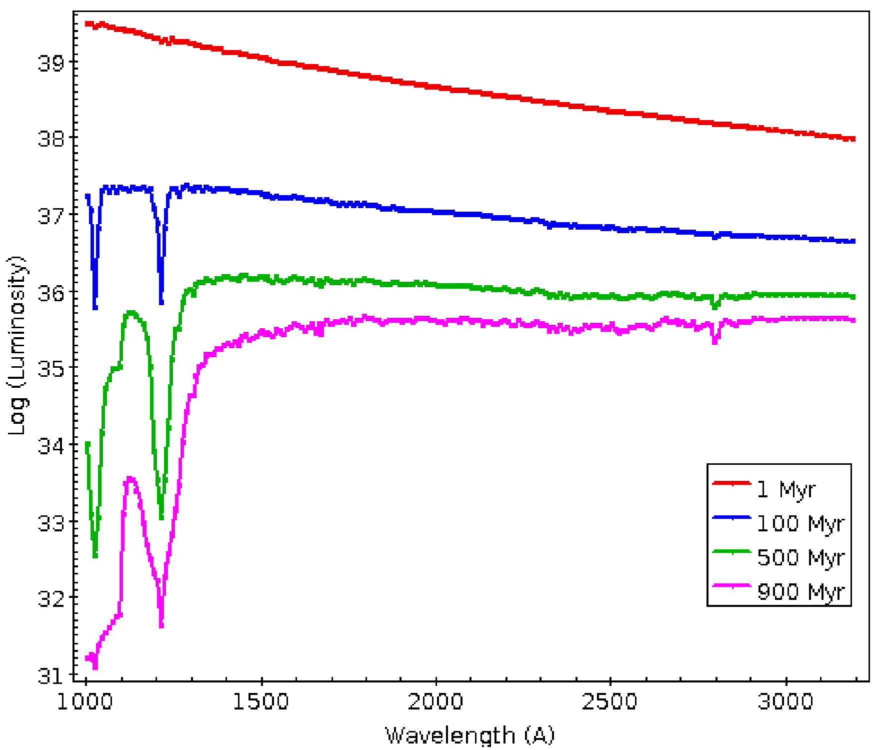
Molecular gas – Points to potential location of star formation

H alpha emission – Star formation up to ~ 10 Myr

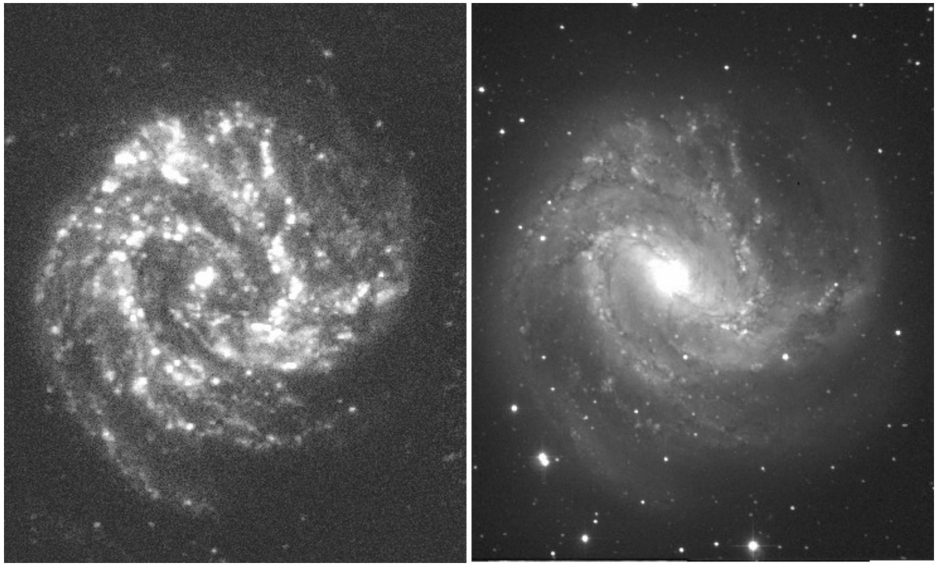
FUV emission – stellar populations up to ~100 Myr

Far-Infrared emission – Traces dust obscured youngest star formation





Starburst99 SSP spectra of different ages



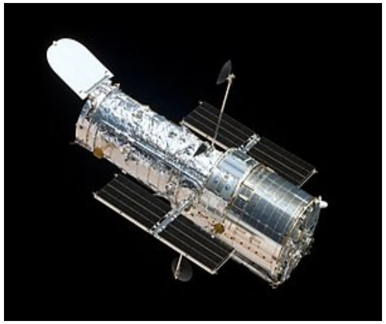
M83 galaxy – FUV and optical
(source : NED)

Ultra-violet Telescopes

International Ultraviolet Explorer (IUE) : 1978-1996

Far Ultraviolet Spectroscopic Explorer : (1999-2007)

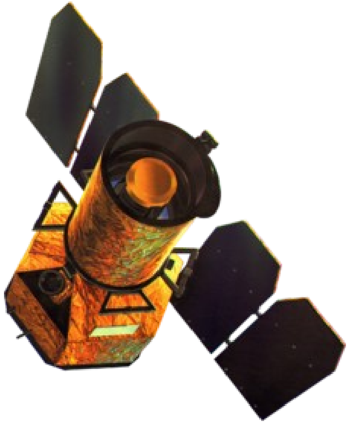
Swift : 2004-



Hubble Space Telescope : 1990-

UV surveys of nearby galaxies: TrImS, PHAT, LEGUS

A Telescope dedicated for UV sky survey was needed

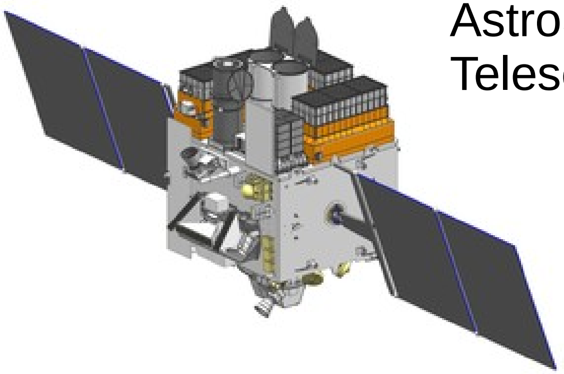


Galaxy Evolution Explorer (GALEX) : 2003-2013

Covered 2/3 of the sky in UV

Survey: AIS, MIS, NGS

Need : A UV telescope with superior spatial resolution, large FOV and multiple imaging bands within FUV and NUV channel

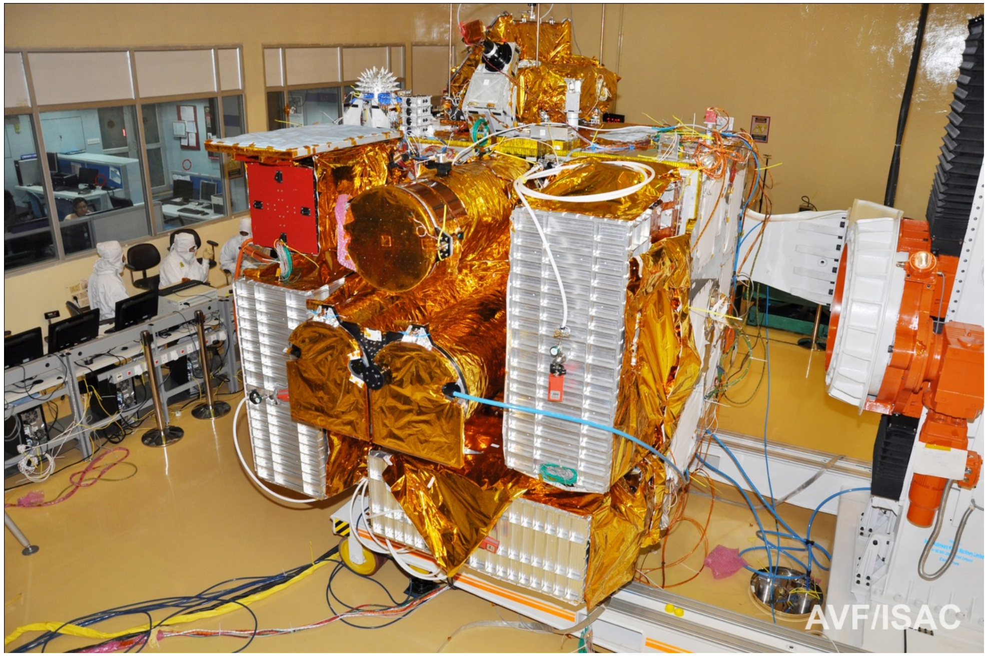


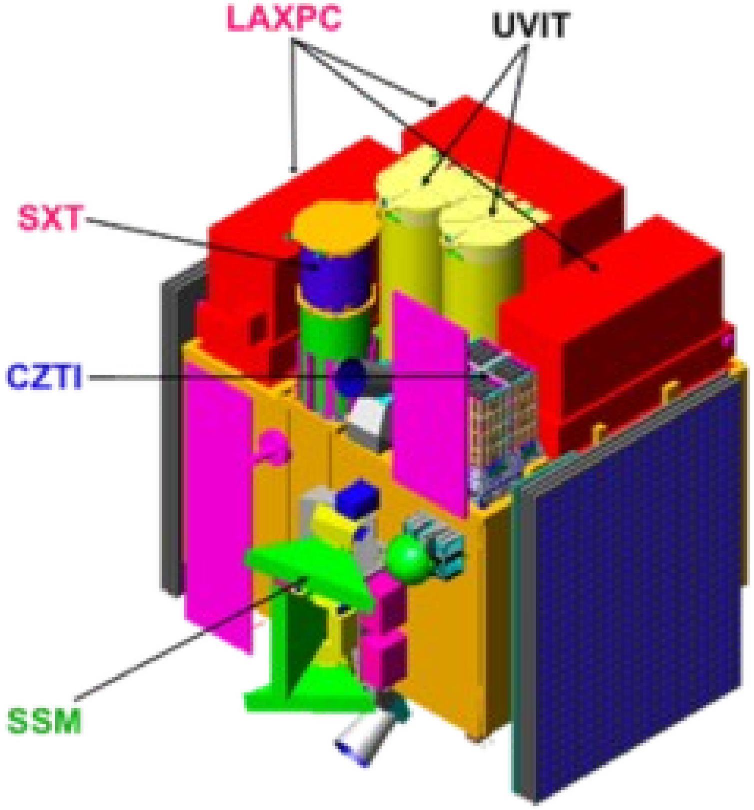
AstroSat – Ultra-violet Imaging Telescope (UVIT)

AstroSat

- AstroSat is India's first dedicated multi-wavelength space observatory.

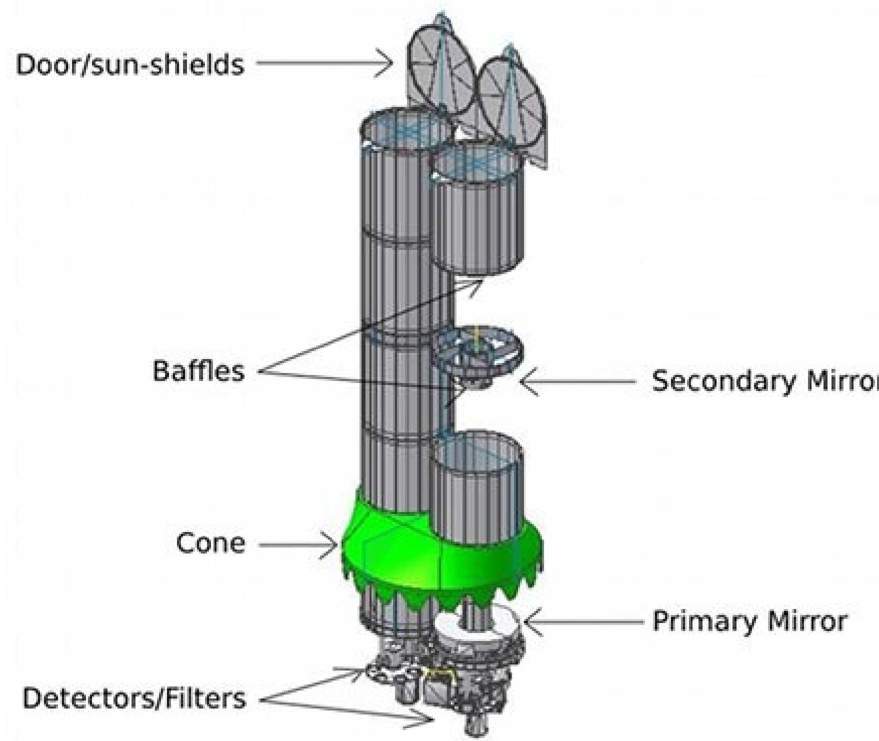
Equiped with X-ray, UV and optical telescopes





It was launched on September 28, 2015 into a 650 km orbit inclined at an angle of 6 deg to the equator from Satish Dhawan Space Centre, Sriharikota, India.

Ultra-Violet Imaging Telescope (UVIT)



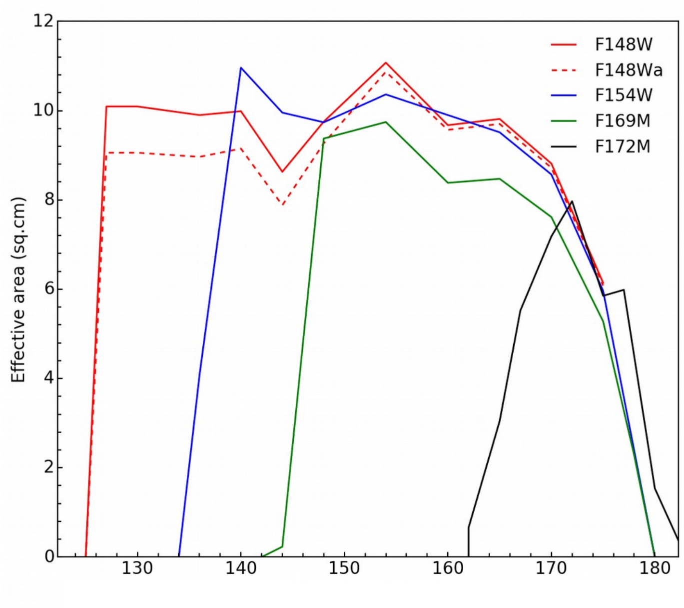
Multiple filters in each of FUV and NUV channels for imaging observation

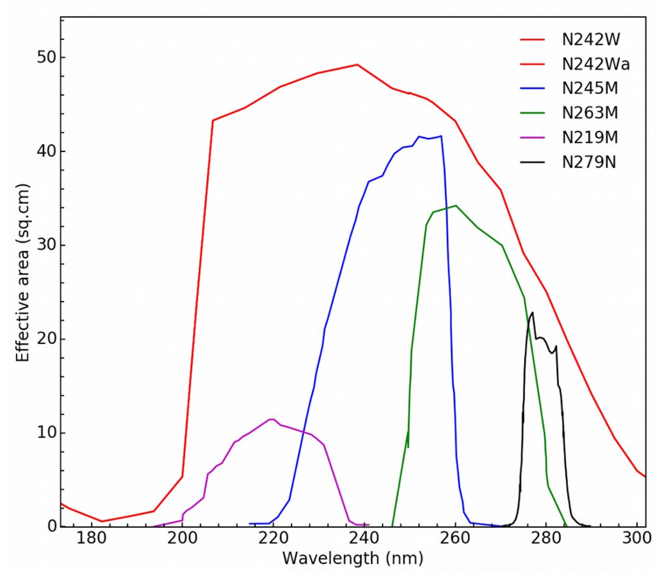
Visible channel is used for tracking sources during observation

Equiped with two telescopes.
One observes in FUV
Another one in NUV and Optical

It also has two FUV grating (resolution ~ 17 Angstrom) and one NUV grating (~ 33 Angstrom).

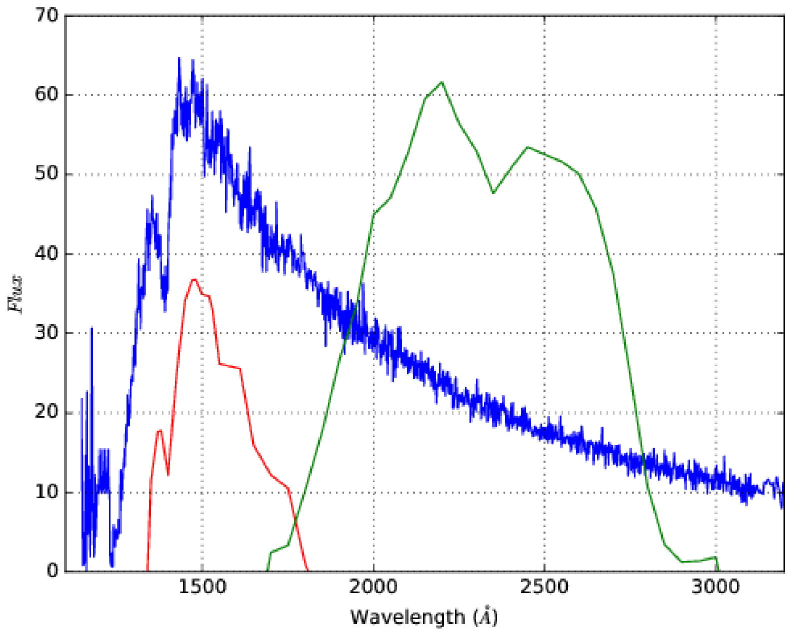
How UVIT can improve the present scenario

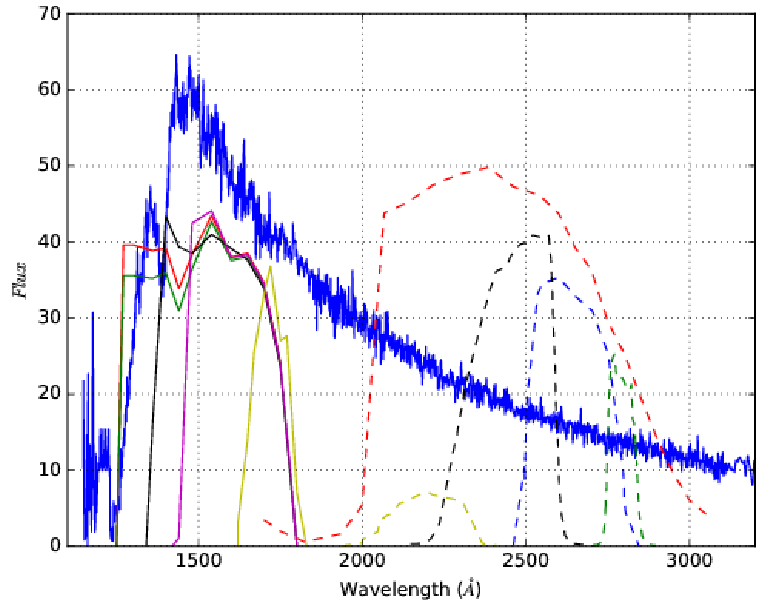




Multiple filters

Better sampling of the UV continuum

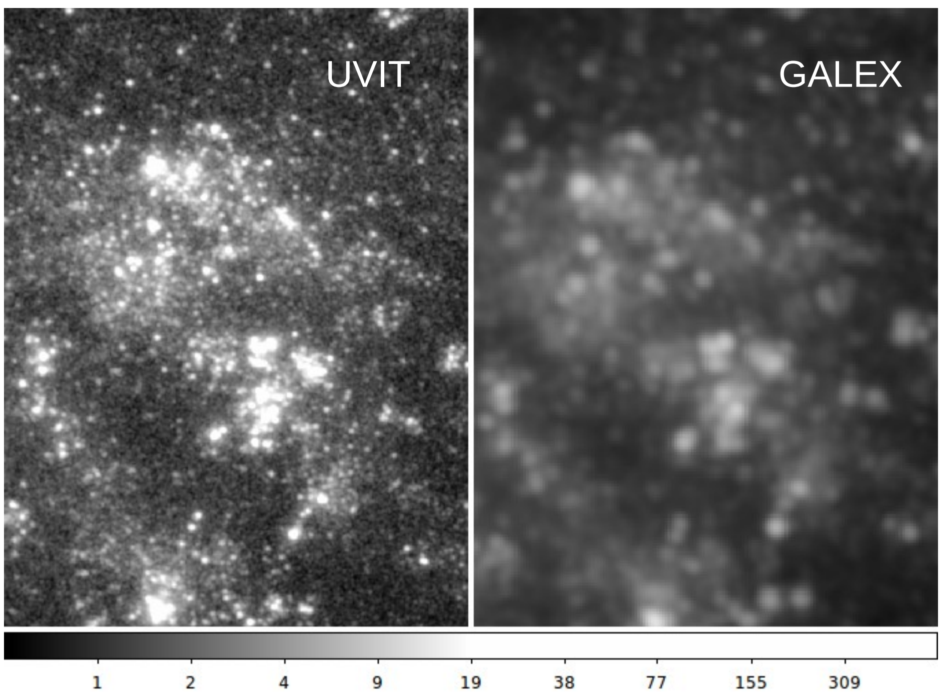




Tandon et al. 2017

How UVIT can improve the present scenario

A star-forming region in the galaxy NGC 300

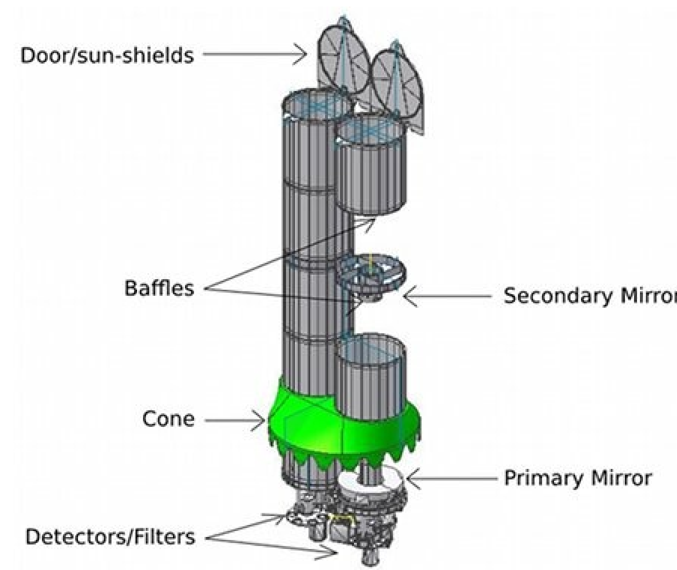


Spatial sampling ~0.4 arcsec/pixel

Observation – John hutchings

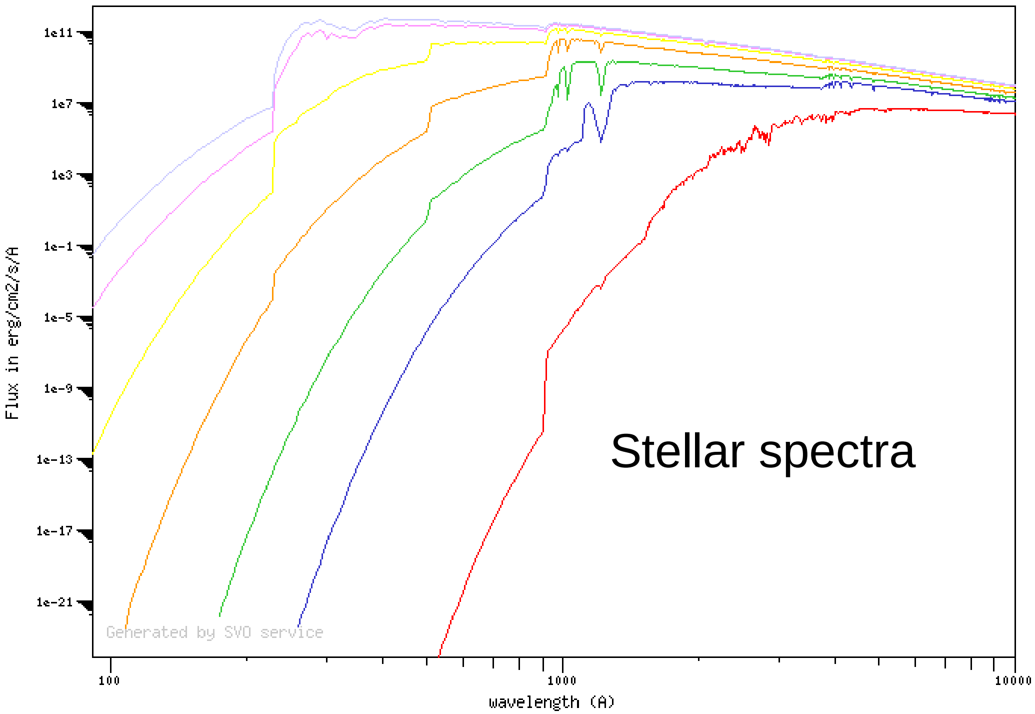
Superior Spatial resolution in UV

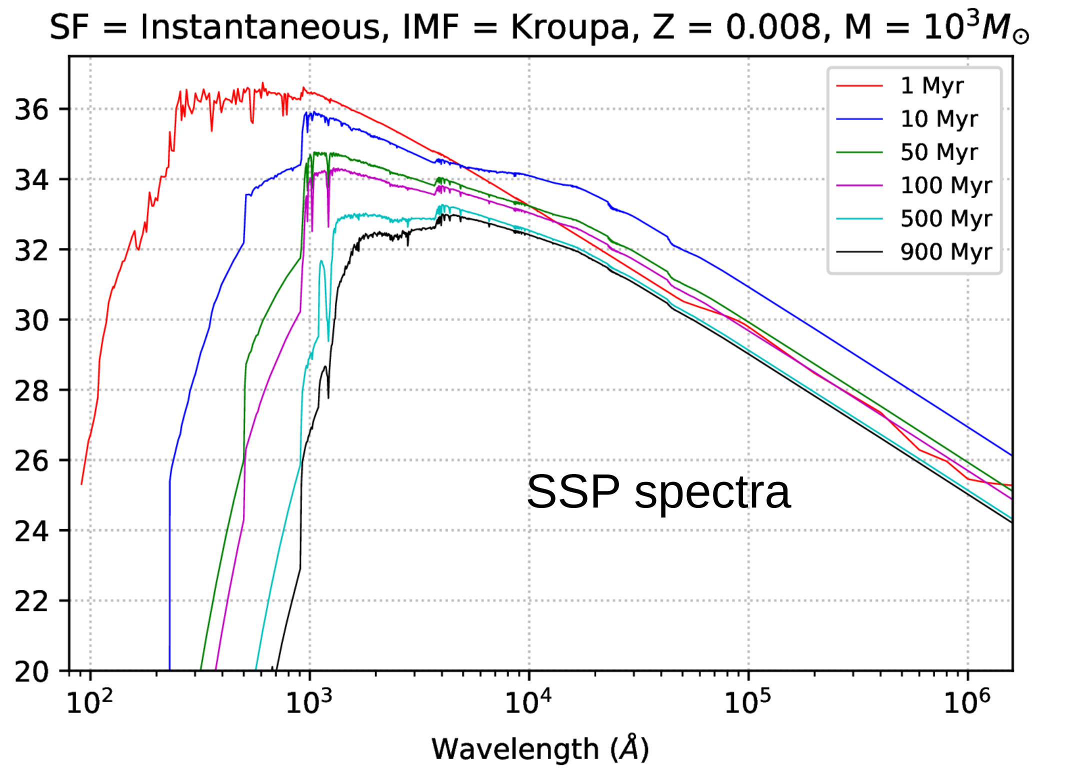
FWHM ~ 1.4 arcsec
FOV ~ 28 arcmin

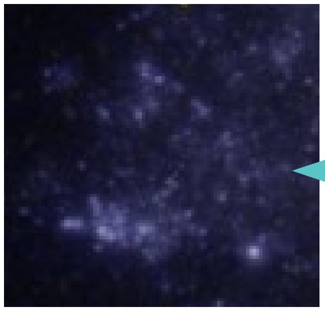


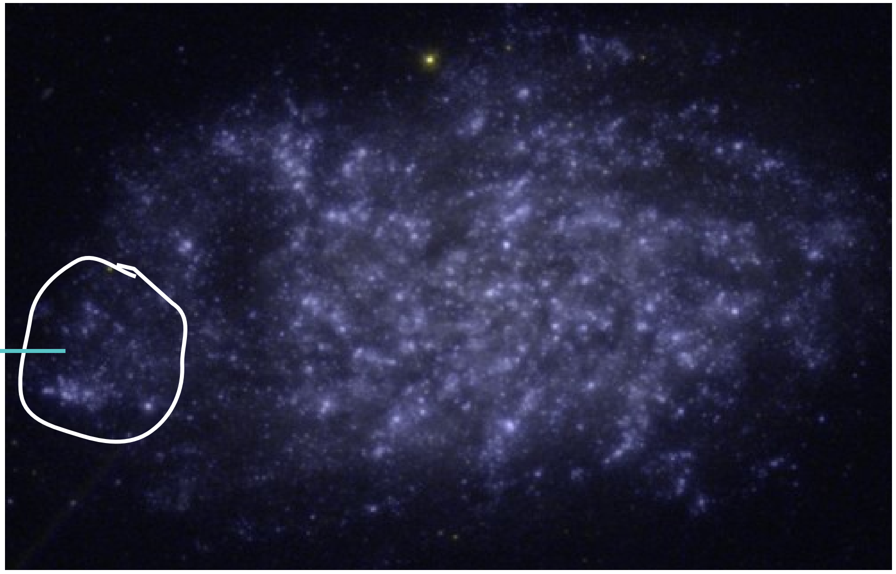
Tandon et al. 2017

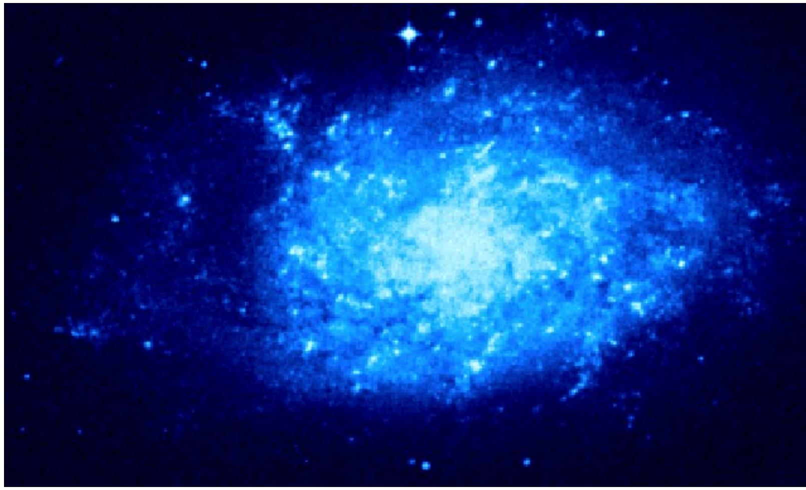
UVIT – imaging SF galaxies



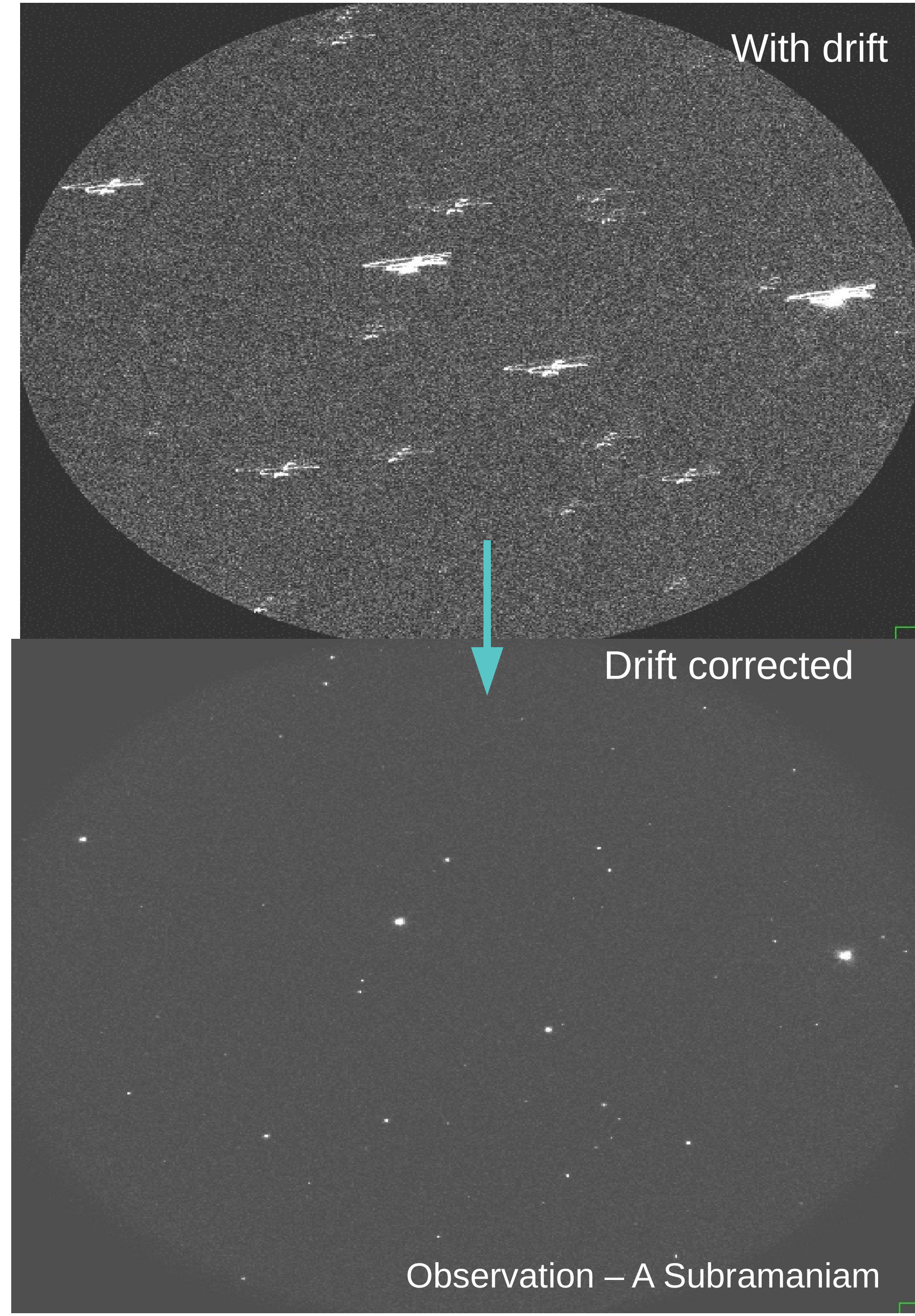








UVIT Imaging



UVIT data reduction pipeline

CCDLAB

UVIT data reduction pipeline: a CCDLAB and UVIT tutorial

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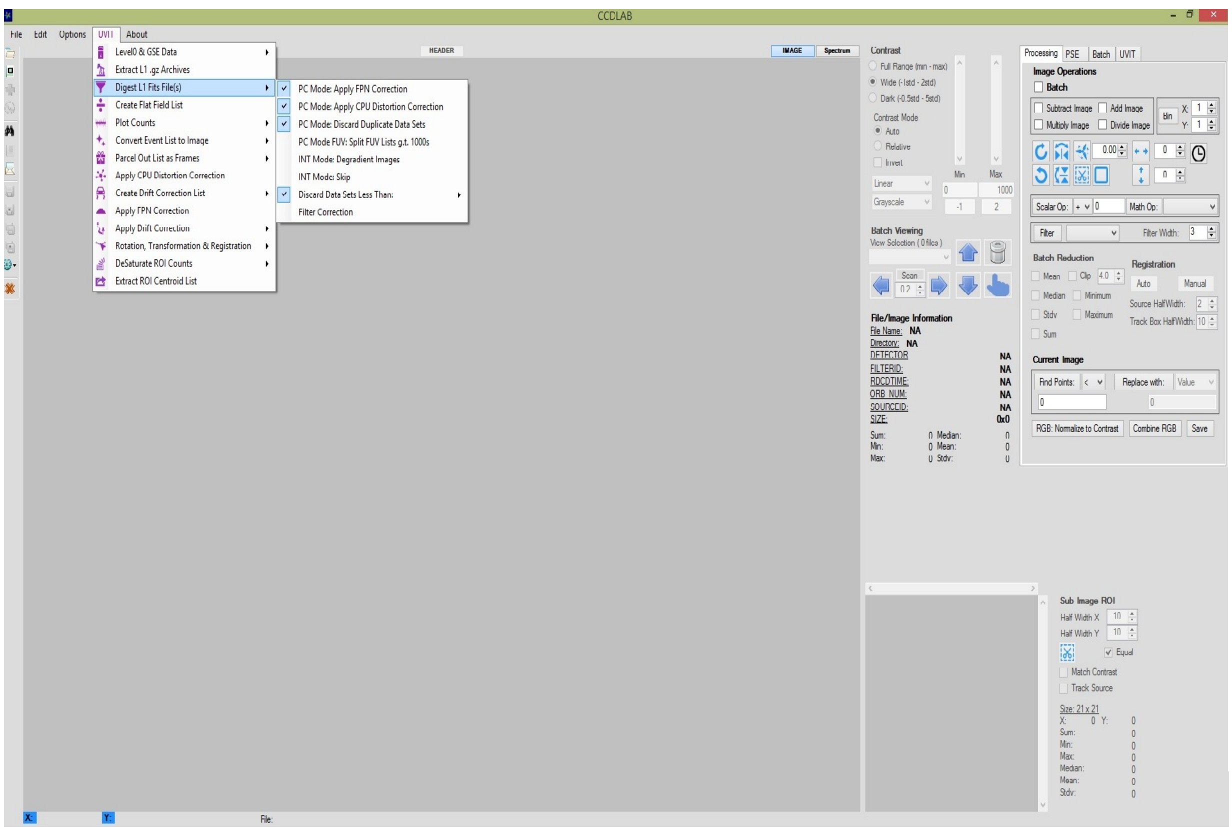
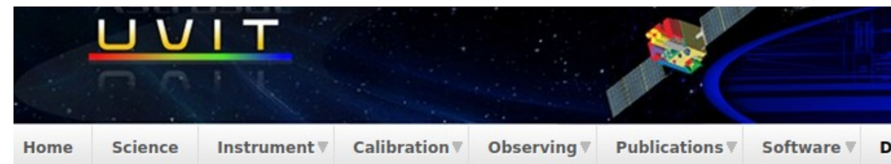
Department of Physics and Astronomy, University of Calgary, 2500 University Dr NW, Calgary, Alberta T2N 1N4, Canada.
E-mail: joepostma@live.ca; jpostma@ucalgary.ca



UVIT L2 pipeline



Download Area

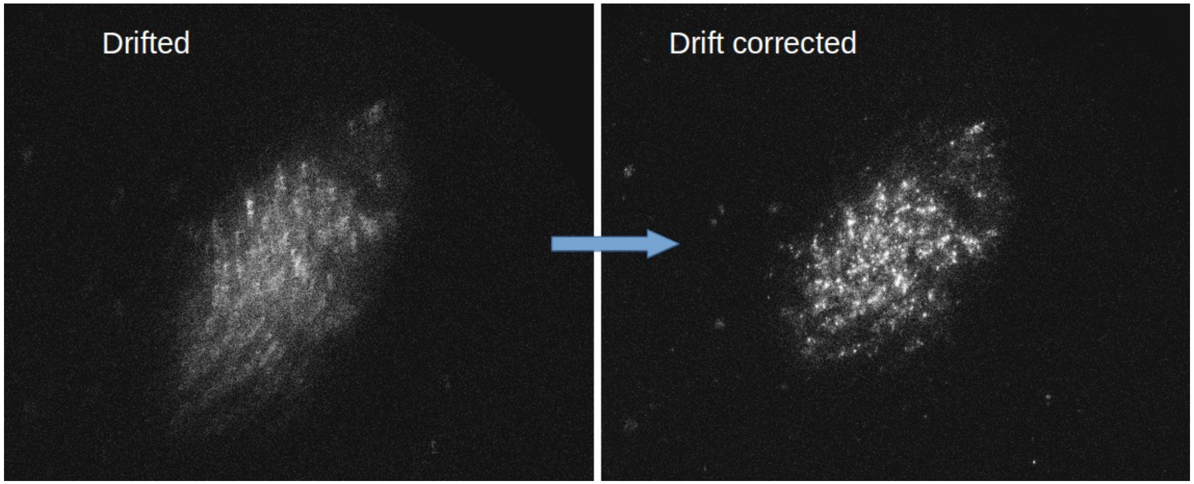
UVIT Level 2 Pipeline Installer (Linux x86_64)	Download	File size
UL2P v6.3 Release date: 2019-06-27	Installer (64 bit)	17.86 MB
UL2P v5.7 Release date: 2018-01-03	Installer (64 bit)	17.84 MB
UL2P v5.6 Release date: 2017-11-02	Installer (64 bit)	19.75 MB

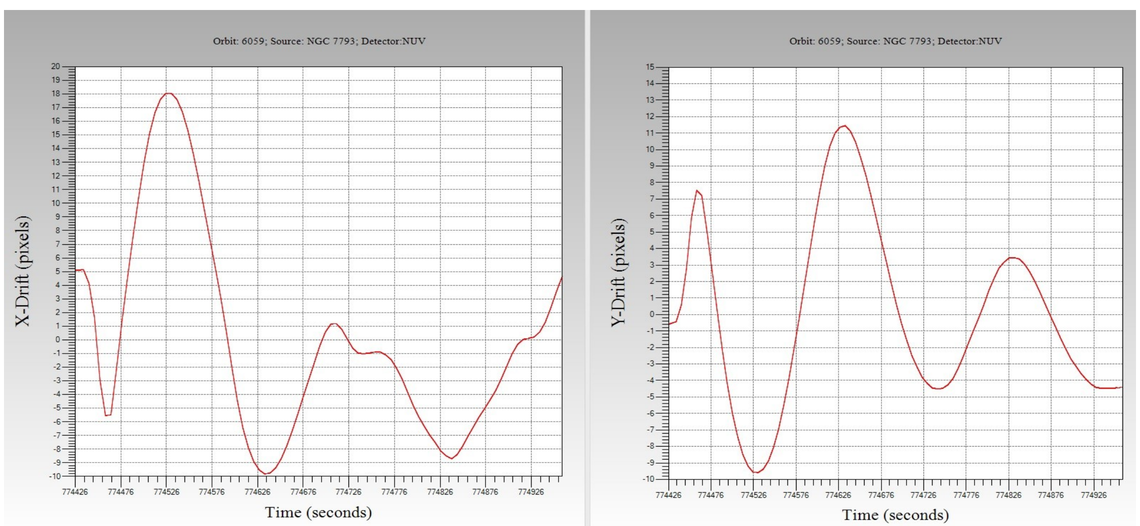
UVIT Level 2 Pipeline Documentation	Download	File size
UVIT_Pipeline_Cookbook_v5 Release date: 2019-06-27	pdf	0.09 MB
UL2P_quick_installation_and_output_product_help_v9 Release date: 2019-06-27	pdf	0.25 MB
UL2P_quick_installation_and_output_product_help_v7 Release date: 2017-11-02	pdf	0.19 MB
UVIT_Pipeline_Cookbook_v4 Release date: 2017-11-02	pdf	0.10 MB

UVIT Calibration Database	Download	File size
UVIT-CALDB-20190625.tar.gz Release date: 2019-06-25	tar.gz	52.90 MB
UVIT-CALDB-20171102.tar.gz Release date: 2017-11-02	tar.gz	33.26 MB

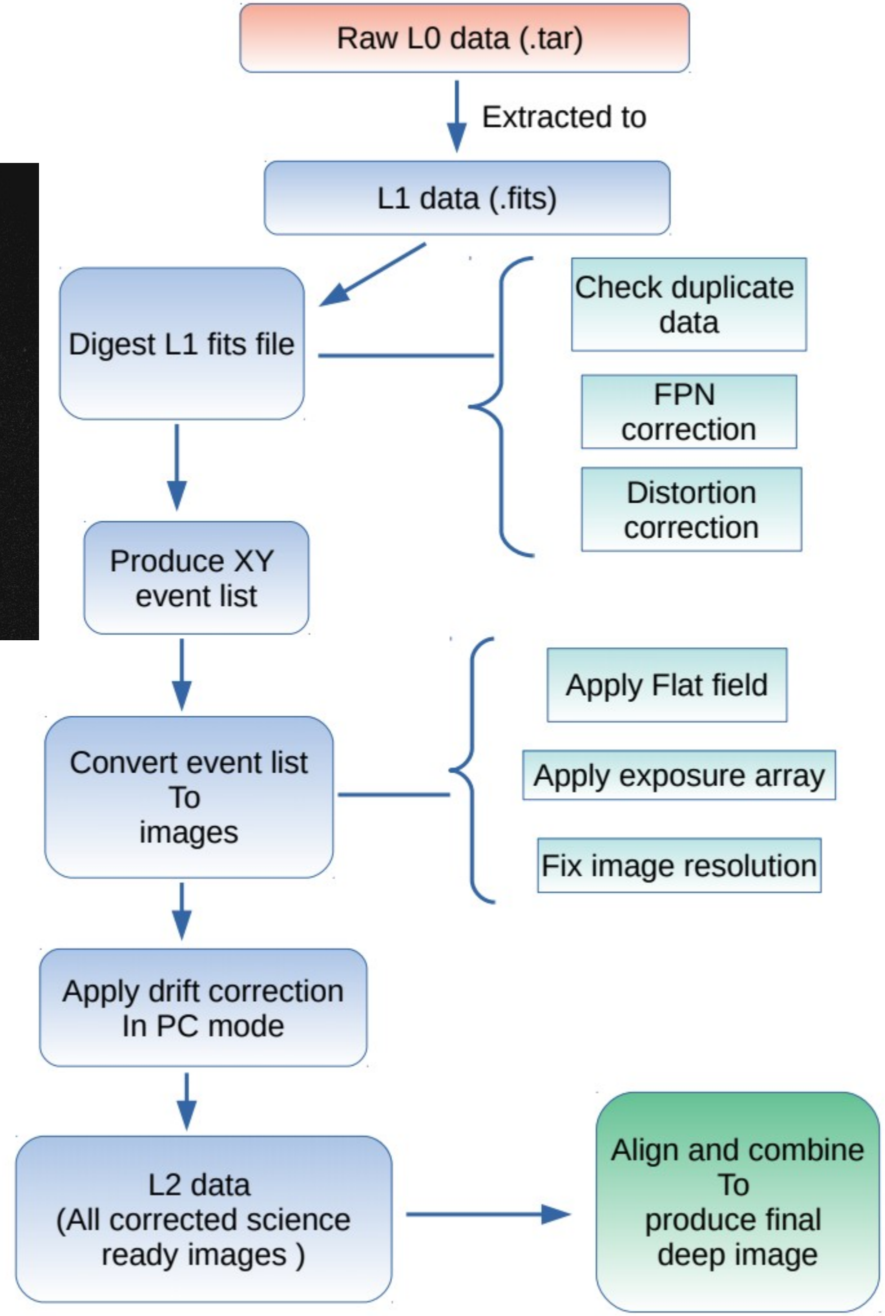
Star Catalogue for UVIT Level 2 Pipeline	Download	File size
USNOA2_VIS_GALEX_NUV_FUV_catalogue-20160927.db Release date: 2016-09-27	db.gz	1.77 GB

CCDLAB: UVIT L1 ----> L2





Drift pattern along X and Y pixel axes



L1 → L2 – steps followed in CCDLAB

Image – CCDLAB (Postma 2017)

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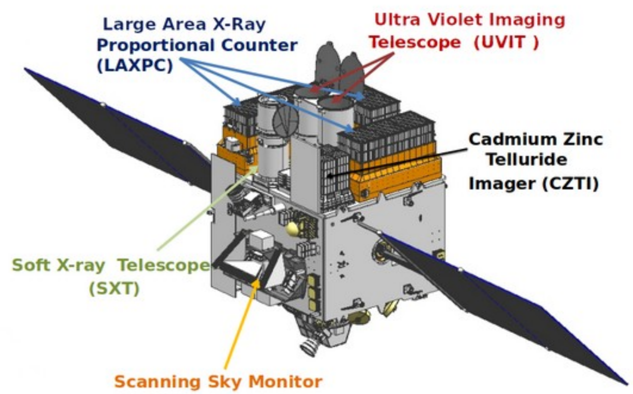
Welcome to ISRO Science Data Archive for AstroSat Mission

The science data from observations made by the instruments on board the spacecraft are available for download after the proprietary period from this portal.

ASTROSAT is India's first dedicated multi wavelength space observatory. This scientific satellite mission endeavours for a more detailed understanding of our universe.AstroSat observes universe in the optical, Ultraviolet, low and high energy X-ray regions of the electromagnetic spectrum. Multi-wavelength observations of ASTROSAT are further extended with co-ordinated observations using other spacecraft and ground based observations.

AstroSat with a lift-off mass of about 1513 kg was launched by India's Polar Satellite Launch Vechicle (PSLV) on 28th September 2015 into a 650 km circular orbit with an inclination of 6 deg. The spacecraft control centre at Mission Operations Complex (MOX) of ISRO Telemetry, Tracking and Command Network (ISTRAC) at Bangalore carries out the spacecraft health monitoring and control operations. The science data from the spacecraft is downloaded at a dedicated ground station established at Bylalu , Bengaluru and the data is made available to the users through the co-located Indian Space Science Data Centre (ISSDC). Science data processing, archival and dissemination are carried from ISSDC, the nodal point for the interface with the global scientific and user community.

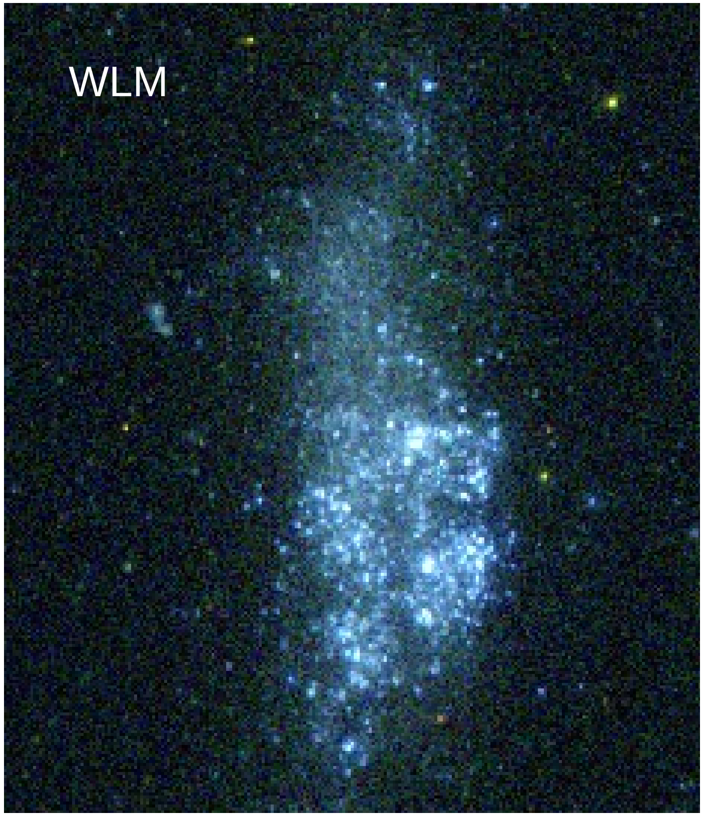
AstroSat is a proposal -driven, multi –wavelength observatory operated by Indian Space Research Organization (ISRO). ISRO releases periodic calls for proposal submission. Users can submit proposals for operating the science instruments on board using the web based utility AstroSat Proposal Processing System APPS hosted at ISSDC. **The science data along with the related software for processing can be downloaded from this portal**

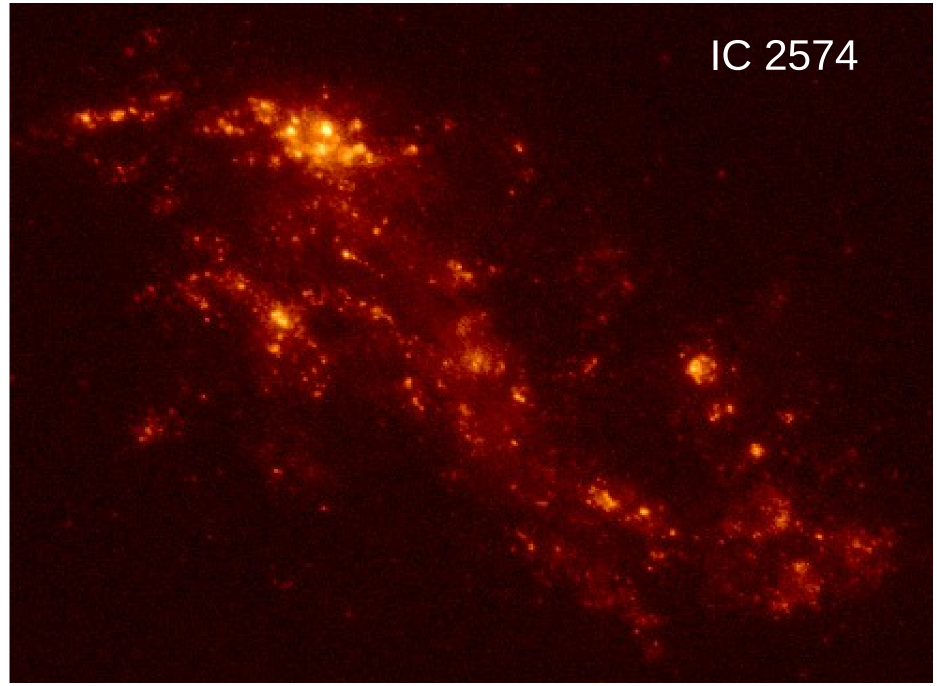


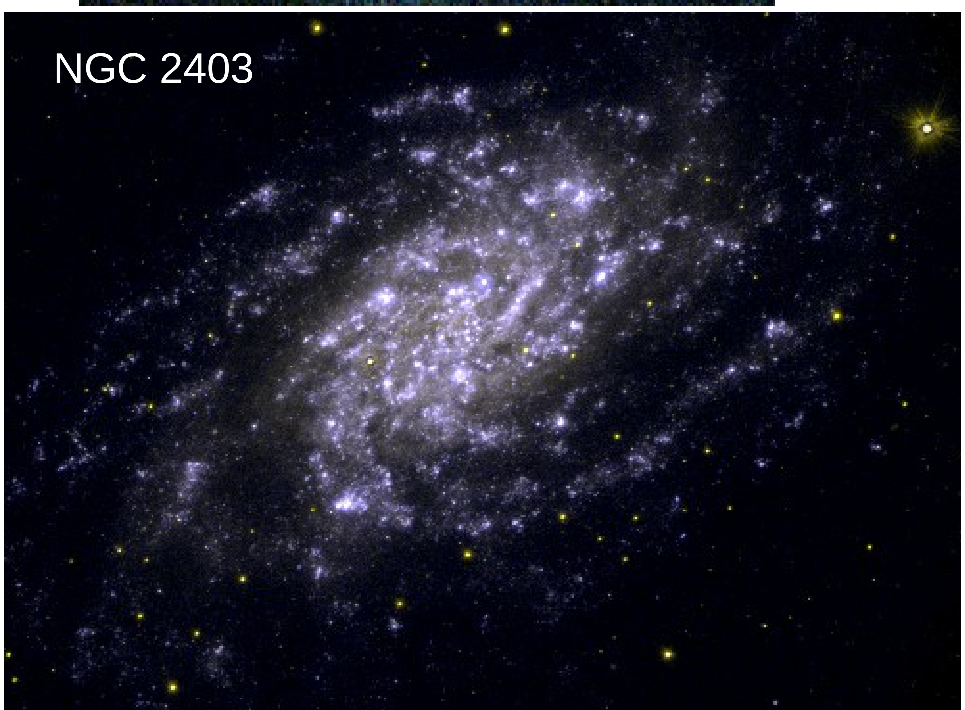
Download Dataset	Product Details	Sky Map	Proposal Id	Target Id	Observation Id	PI Name	Orbit	Version	L2 Pipeline Version	Source Name	RA	DEC	Instrument	Date Of Observation	Release Date
Q L1 L2			A02_028	T01	A02_028T01_9000000724	dleahy	5606	2.2	-	M31 No.1	10.710708	41.250228	UVT	10-Oct-2016	16-Mar-2019
Q L1 L2			A02_028	T03	A02_028T03_9000000788	dleahy	6088	2.2	6.3	M31 No.2	11.037	41.557347	UVT	12-Nov-2016	16-Mar-2019
Q L1 L2			A02_197	T01	A02_197T01_9000000748	tapasb	5819	1.2	6.3	M31-1	10.010708	41.198219	UVT	24-Oct-2016	16-Oct-2019
Q L1 L2			A02_197	T01	A02_197T01_9000000748	tapasb	5819	2.2	6.3	M31-1	10.010708	41.198219	UVT	24-Oct-2016	16-Oct-2019

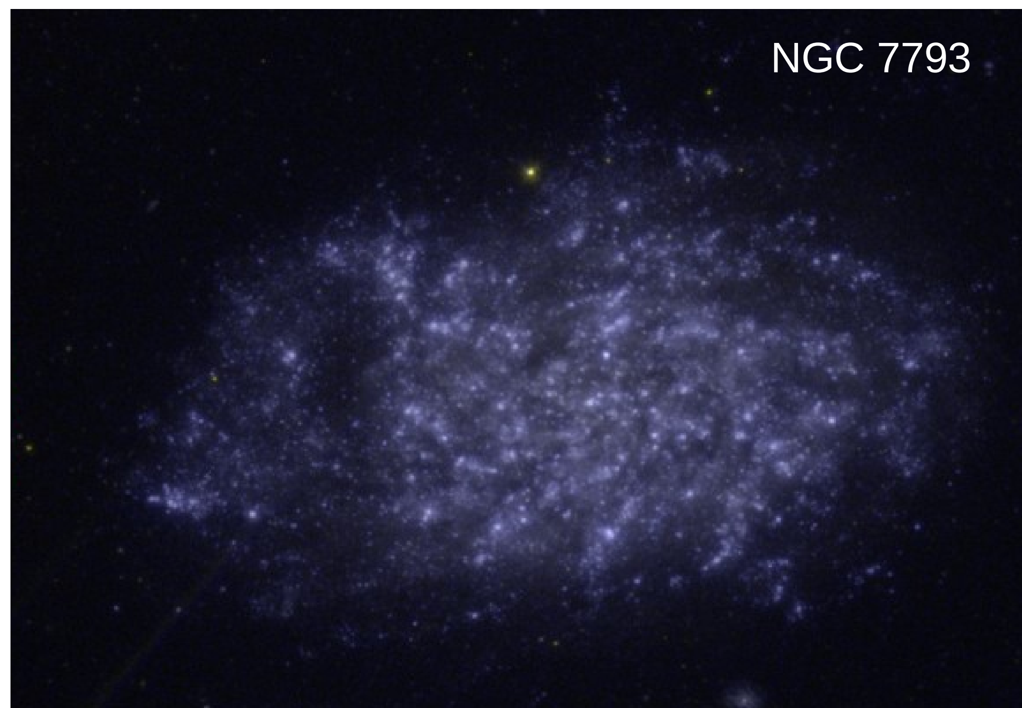
UVIT observed nearby galaxies

PI – A. Subramaniam

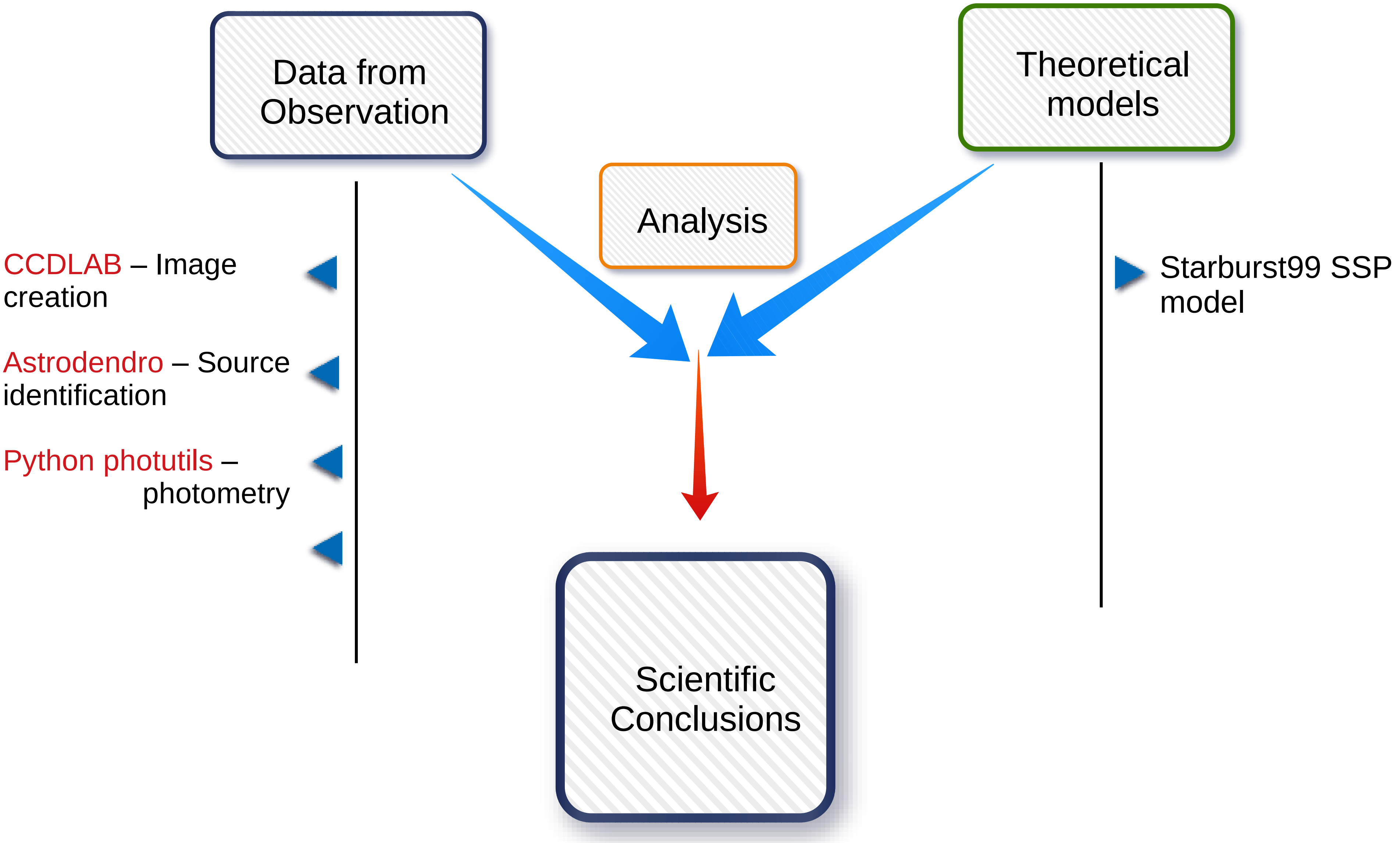




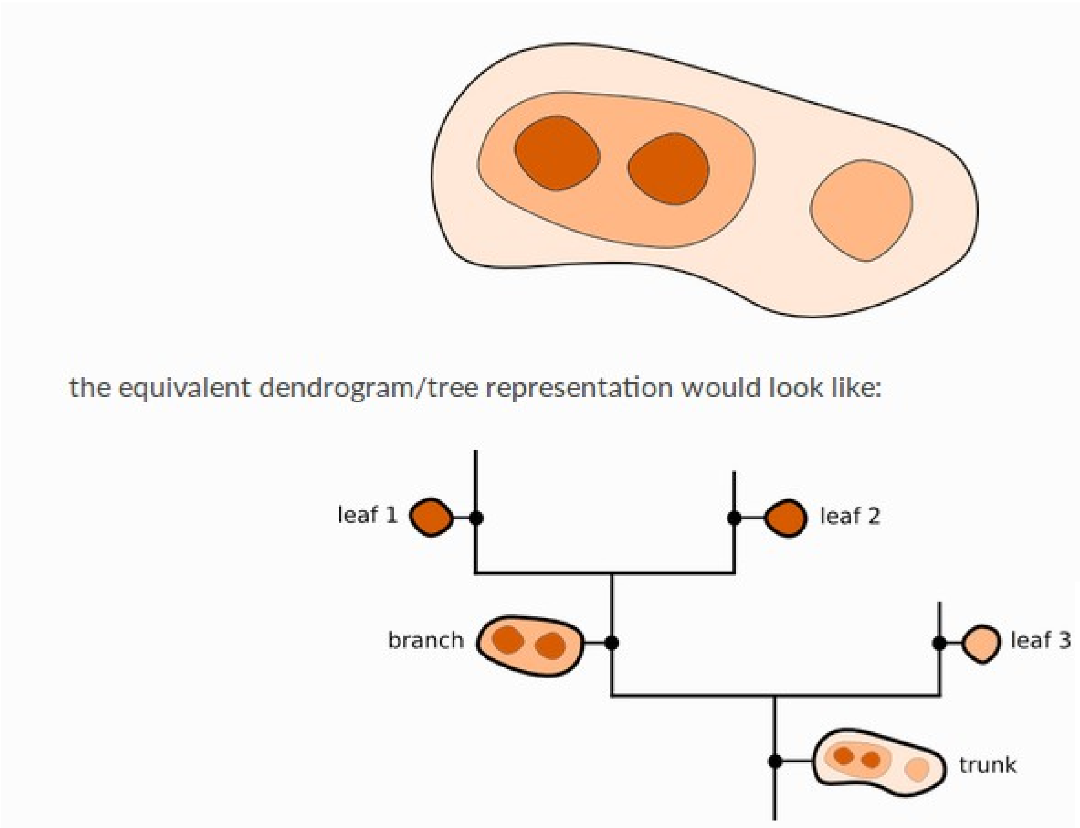




Methodology



Astrodendro



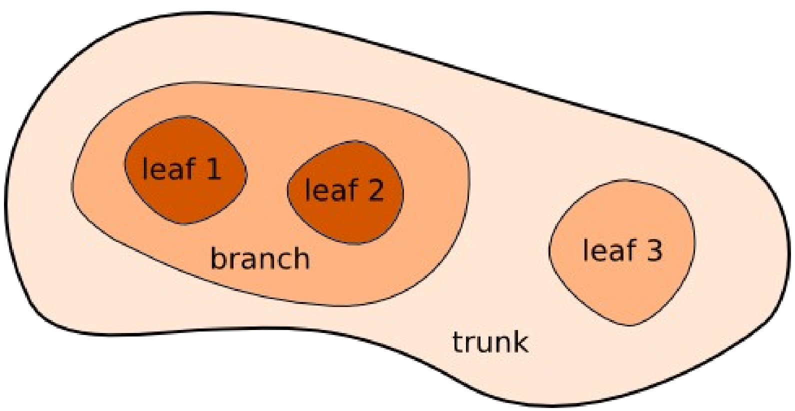
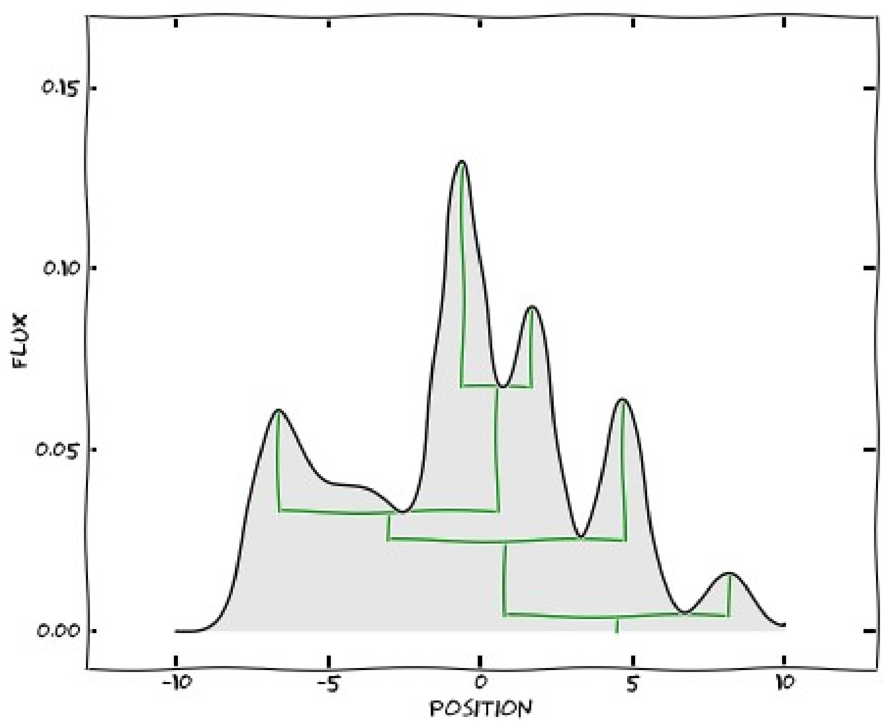


Figure: astrodendro official website

This python package helps to **identify** parent and child structures in astronomical data on the basis of -

1. Threshold flux

2. Minimum number of pixel to make a structure



Finding clumps

```
image = fits.getdata('abc.fits')
d = Dendrogram.compute(image, min_value=2.0, min_delta=1., min_npix=10)
```

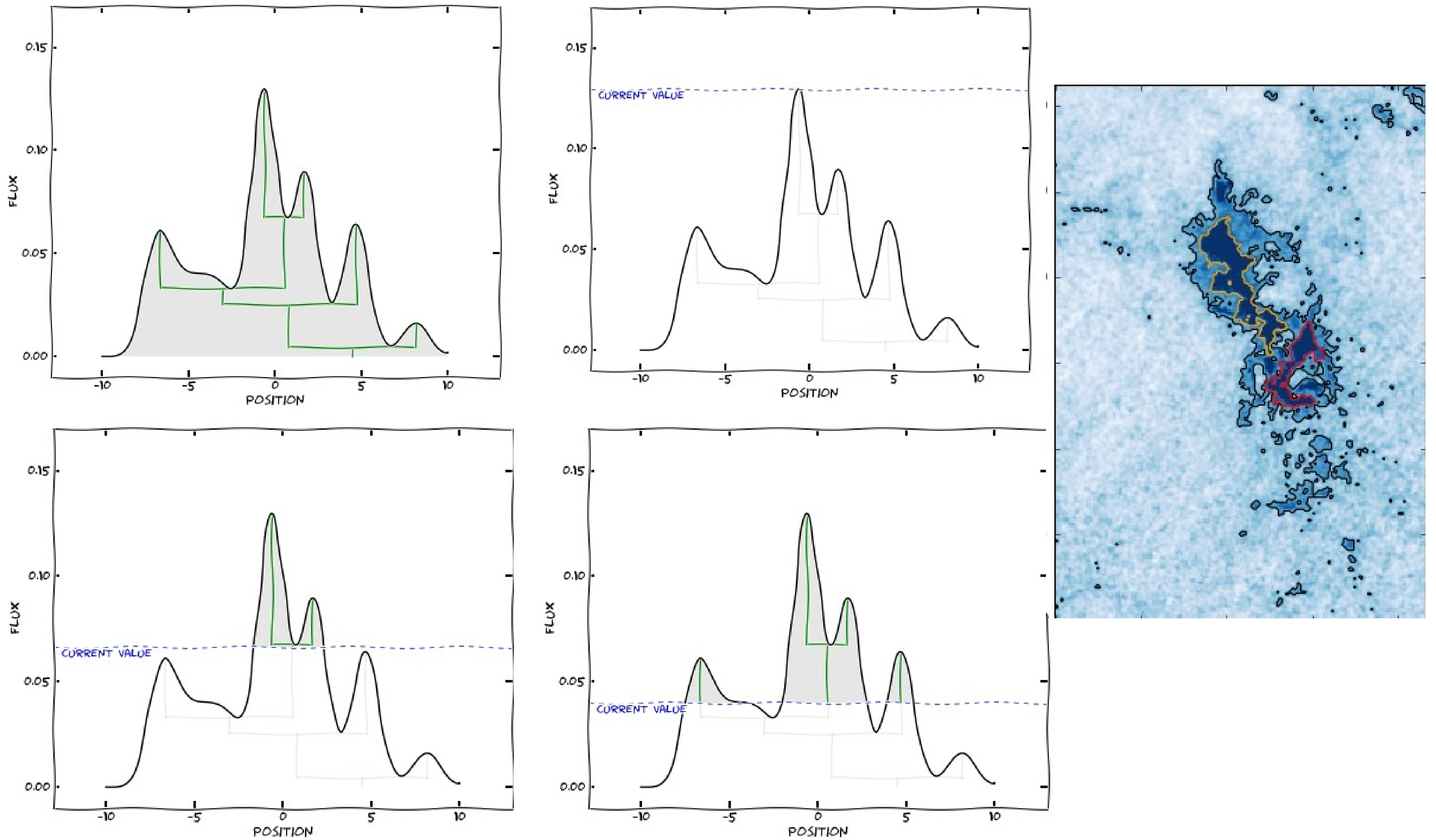
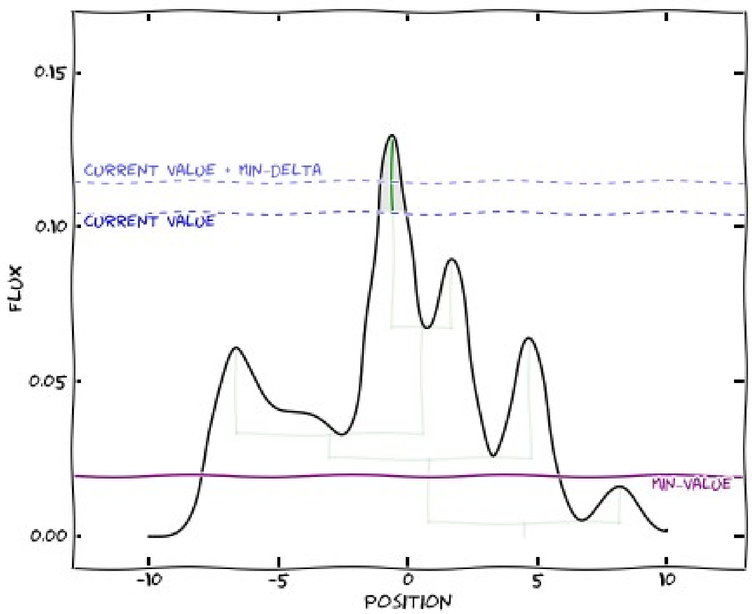
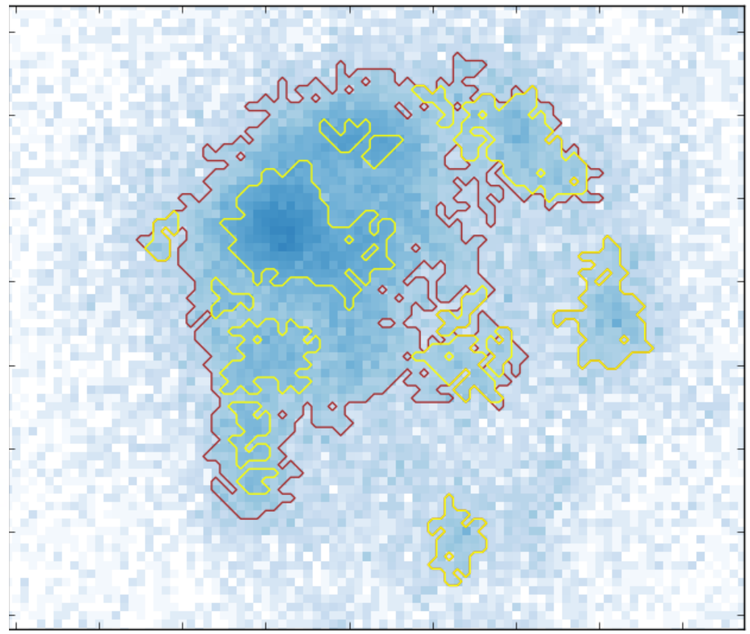


Figure: astrodendro official website

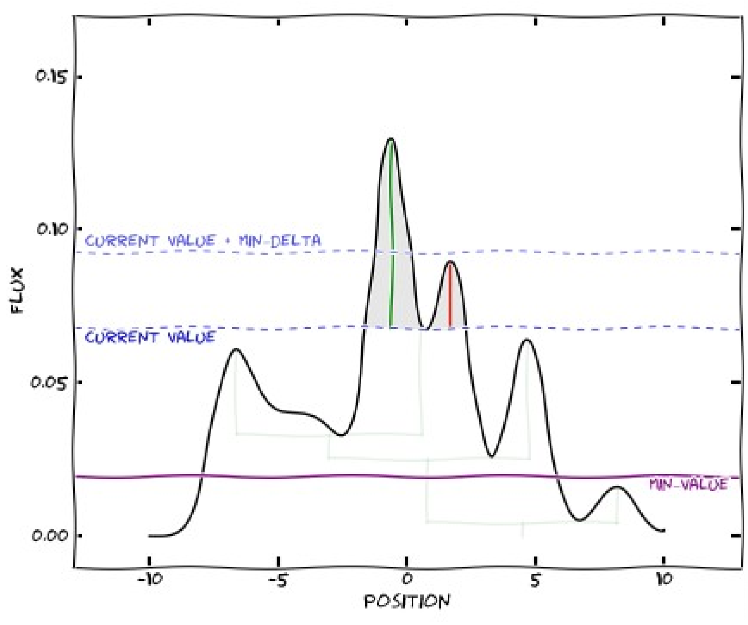
Accounting for noise

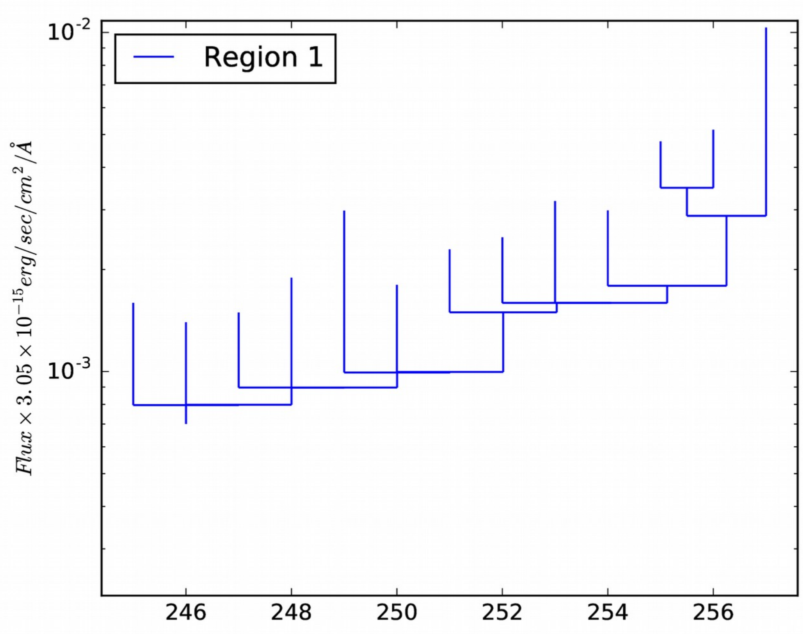




*Astrodendro provides Several parameters including **position, flux** and **area** of all the identified structures*

Ideal to study physical parameter of star-forming clumps and their hierarchical nature



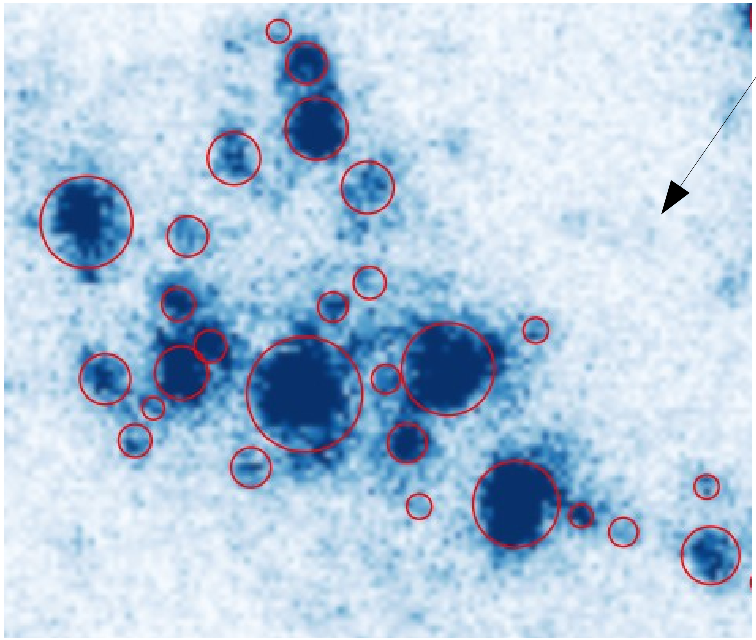


Photometry

Compact point-like source
PSF photometry

Extended Star-forming clumps
Custom Aperture photometry

photutils
An Astropy Package for Photometry

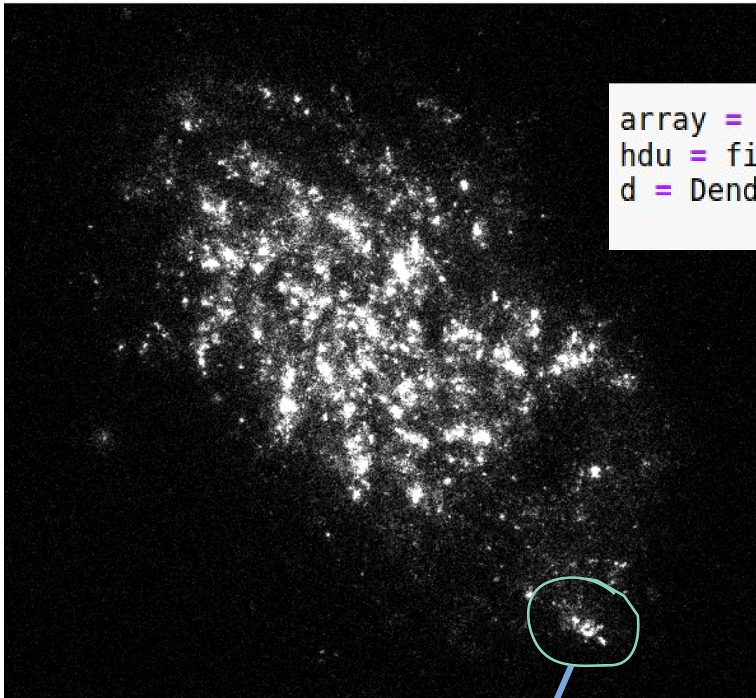


A star-forming region in NGC 7793

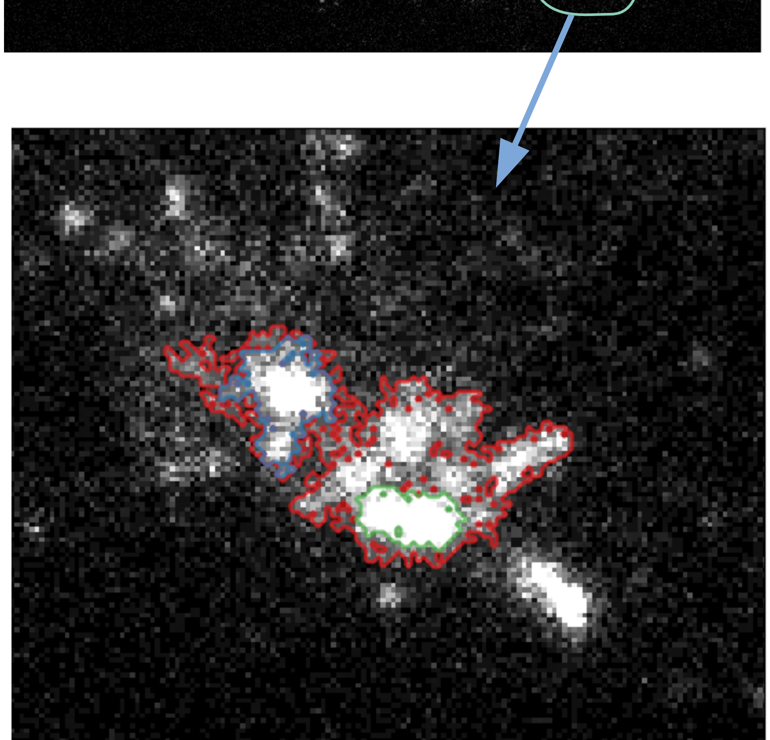
Identification – astrodendro
Output: position, size, flux

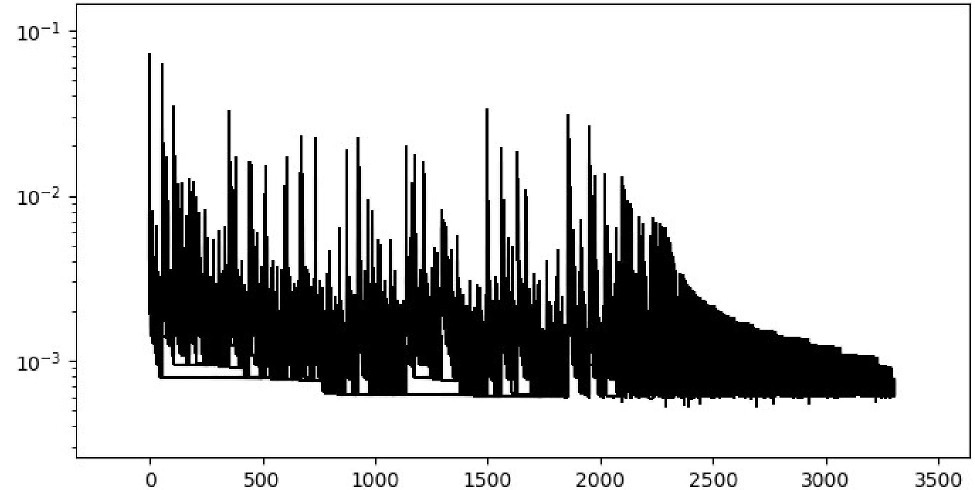
Photometry – photutils
Circular aperture photometry

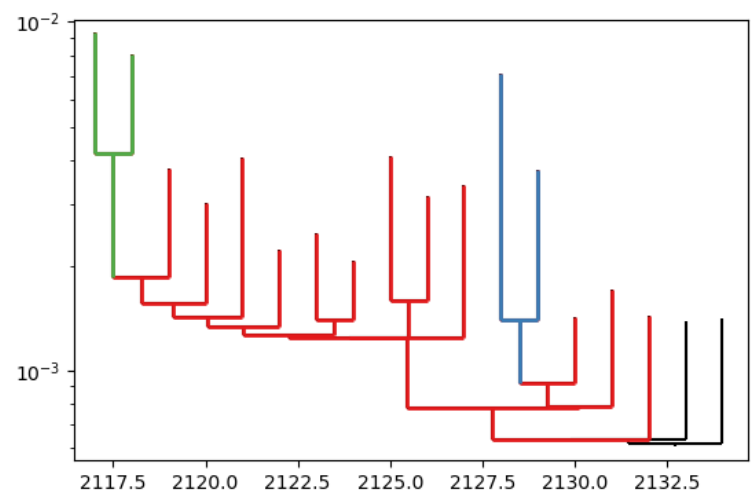
Identifying clumps – NGC 7793



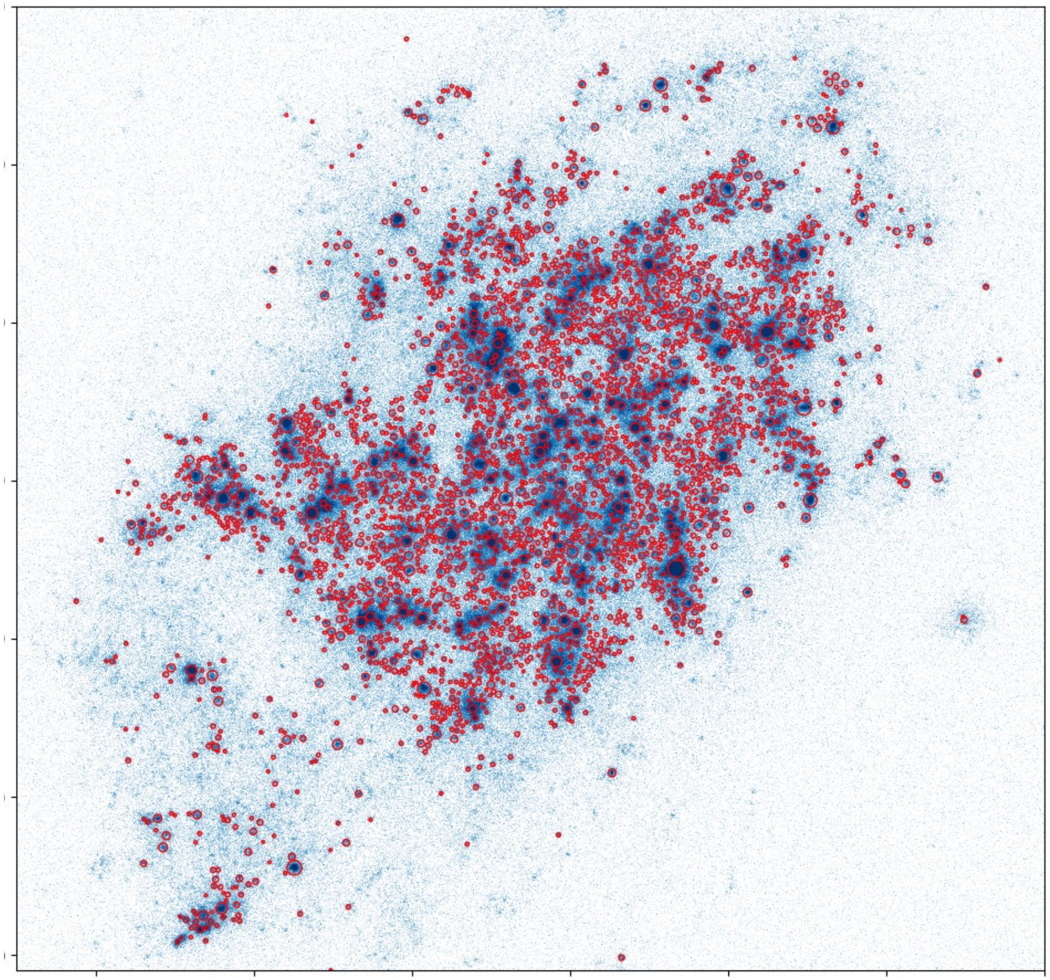
```
array = fits.getdata('NGC7793_fuv_norm.fits')
hdu = fits.open('NGC7793_fuv_norm.fits')[0]
d = Dendrogram.compute(array, min_value=0.000521, min_delta=0.000131, min_npix=10)
```

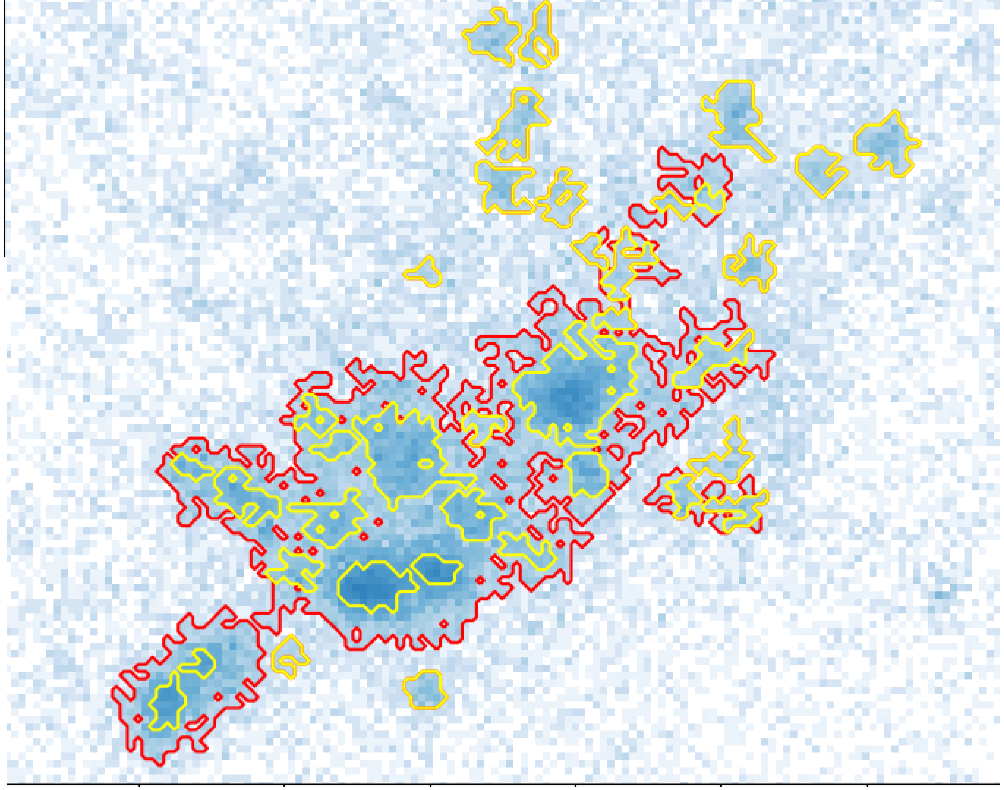


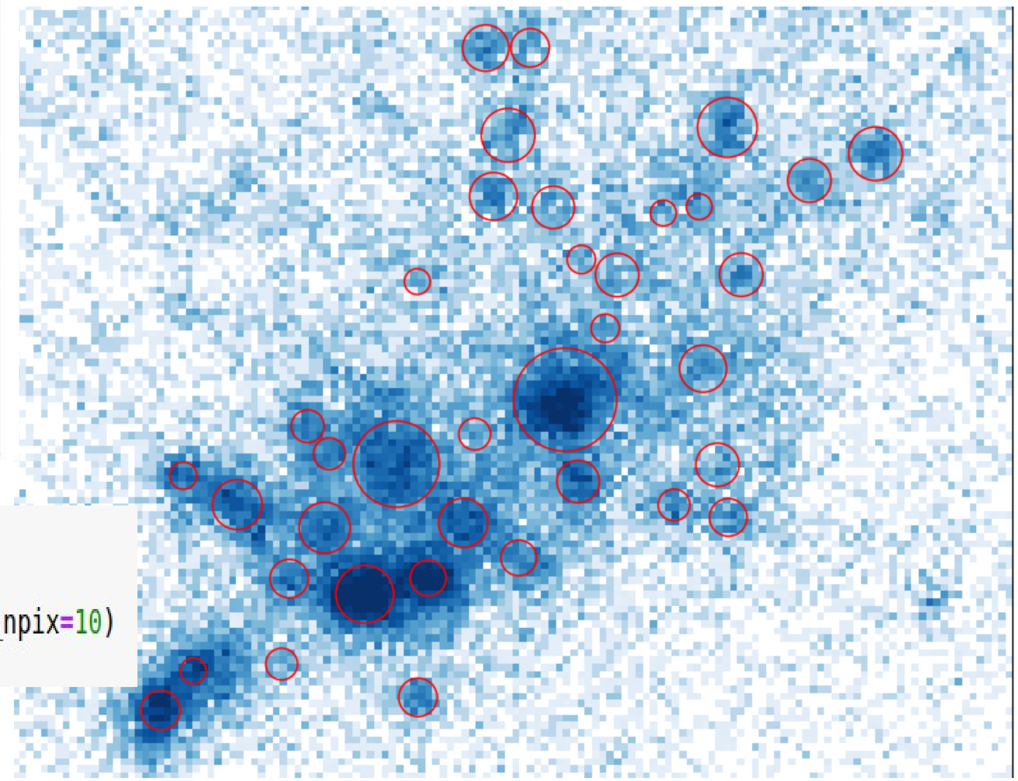




SF clumps - photometry







```
array = fits.getdata('NGC7793_fuv_norm.fits')
hdu = fits.open('NGC7793_fuv_norm.fits')[0]
d = Dendrogram.compute(array, min_value=0.000521, min_delta=0.000131, min_npix=10)
```

Properties of the clumps

Deriving clump position and size - ‘astrodendro’

```
from astropy.io import ascii
from astropy import units as u
metadata = {}
metadata['data_unit'] = u.Jy
metadata['spatial_scale'] = 1.0*u.arcsec
metadata['beam_major'] = 1.0*u.arcsec
metadata['beam_minor'] = 1.0*u.arcsec
cat = pp_catalog(d.leaves, metadata)
cat1 = pp_catalog(d.trunk, metadata)

ascii.write(cat, 'd_fuv_c1_leaves.csv', format='csv', fast_writer=False)
ascii.write(cat1, 'd_fuv_c1_trunk.csv', format='csv', fast_writer=False)
```

idx	area_ellipse	area_exact	flux	major_sigma	minor_sigma	position_angle	radius	x_cen	y_cen
0	12.912672364	35	0.0348434319647	1.89514985868	1.56449665395	106.93348877	1.72190464679	3790.64801663	271.937637946
1	4.29332501242	11	0.00906331942786	1.22507551996	0.804698087732	133.463601472	0.99288263568	3218.2798895	634.506953498
2	3.88010034545	10	0.00813836595404	1.02671303351	0.867752645682	-160.29844822	0.943892446829	3102.35623339	780.567224978
3	12.9503449665	37	0.0370504315061	2.33976915525	1.27089710395	-156.341153056	1.72441463787	2734.61075994	796.565024734
5	8.19709946303	23	0.0918783897379	1.82046659669	1.03390242652	104.018716501	1.37192741488	3295.90815112	816.143936342

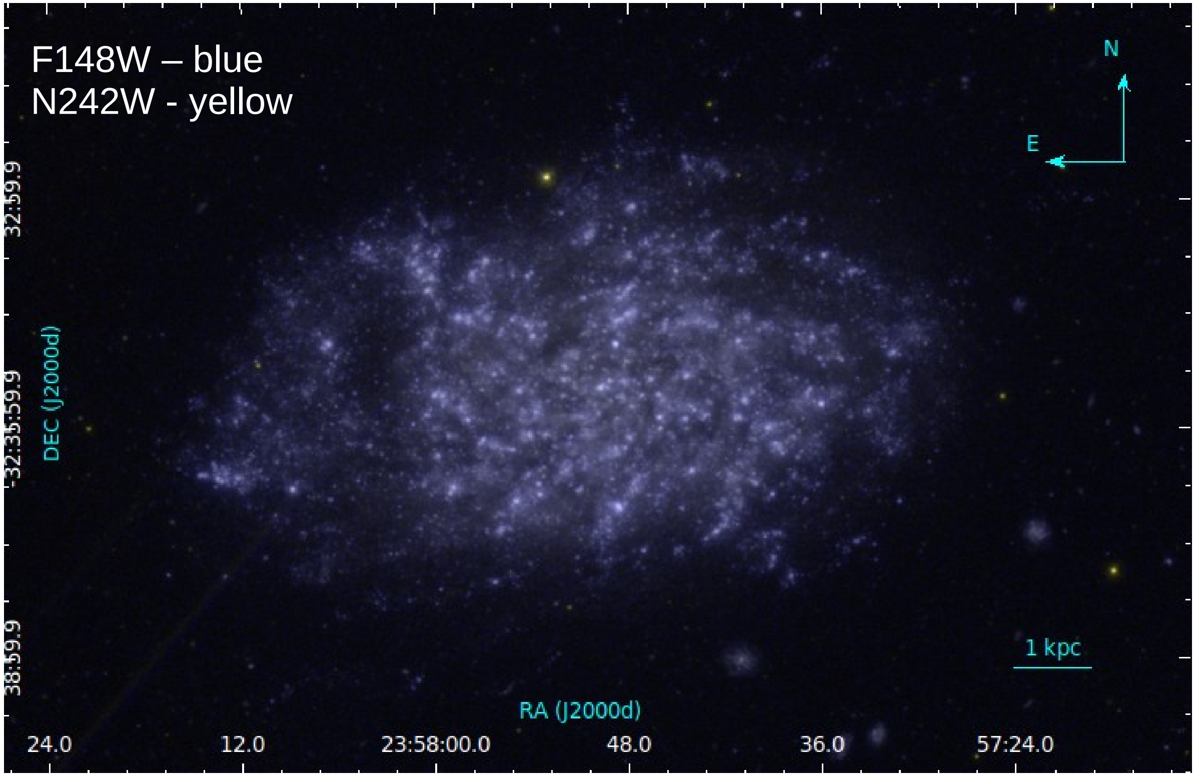
Estimating (F148W-N242W) colour - ‘photutils’

```
data1 = fits.getdata('NGC7793_fuv_norm.fits', 0)
data2 = fits.getdata('NGC7793_nuv_norm.fits', 0)
```

```
for index, row in coord1_df.iterrows():
    aperture1 = CircularAperture((row['x'], row['y']), r=row['radius'])
    phottab1 = aperture_photometry(data1, aperture1)
    phottab2 = aperture_photometry(data2, aperture1)
    coord1_df.loc[index,'radius_pc'] = float(row['radius']*6.798)
    coord1_df.loc[index, 'Counts_fuv'] = float(phottab1['aperture_sum'])
    coord1_df.loc[index, 'Counts_nuv'] = float(phottab2['aperture_sum'])
```

```
A_fuv1 = 1.75
A_nuv1 = 1.45
coord1_df.loc[index,'mag_corr_fuv'] = -2.5*math.log10(coord1_df.loc[index, 'Counts_bg_sub_fuv']) + 18.016 - A_fuv1
coord1_df.loc[index,'mag_corr_nuv'] = -2.5*math.log10(coord1_df.loc[index, 'Counts_bg_sub_nuv']) + 19.81 - A_nuv1
coord1_df.loc[index,'fuv_nuv'] = coord1_df.loc[index,'mag_corr_fuv']-coord1_df.loc[index,'mag_corr_nuv']
```

NGC 7793 – Flocculent spiral galaxy



Property	Value	Reference
Morphological type	SA(s)d	de Vaucouleurs et al. (1991)
RA	23 57 49.7	Skrutskie et al. (2006)
DEC	-32 35 27.6	Skrutskie et al. (2006)
Distance	3.4 Mpc	Zgirski et al. (2017)
R_{25}	4.62 kpc	de Vaucouleurs et al. (1991)
Metallicity (Z)	$0.6Z_{\odot}$	Van Dyk et al. (2012)
Inclination	53.7°	Carignan (1985)
PA of major axis	279.3°	Carignan (1985)

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https://doi.org/10.3847/1538-4357/abe0b4
CrossMark

Tracing Young Star-forming Clumps in the Nearby Flocculent Spiral Galaxy NGC 7793 with UVIT Imaging

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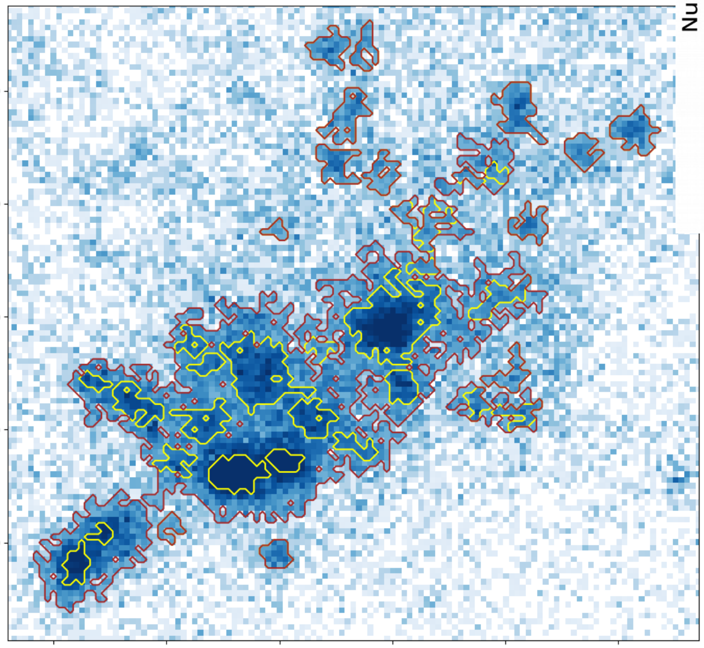
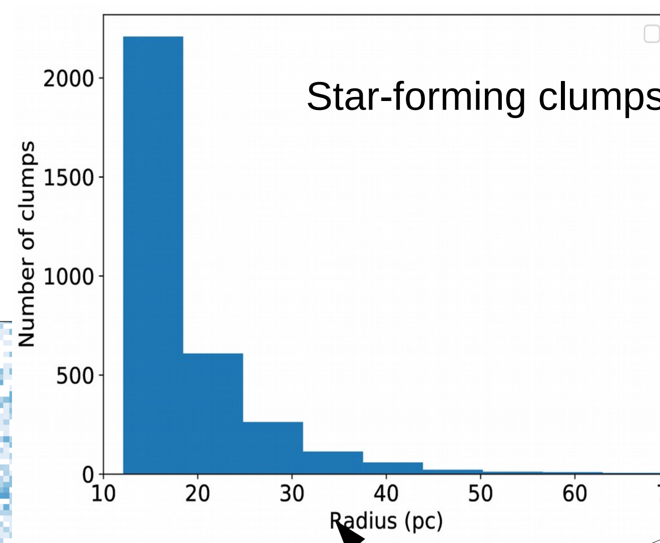
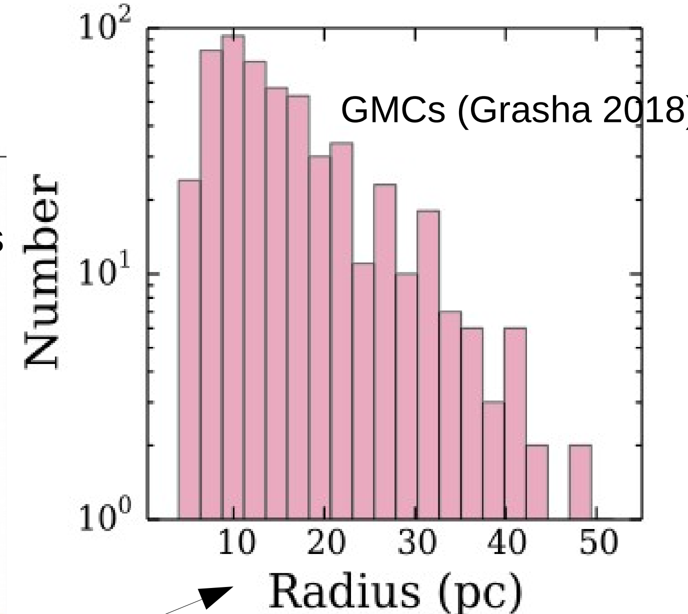
Image - UVIT

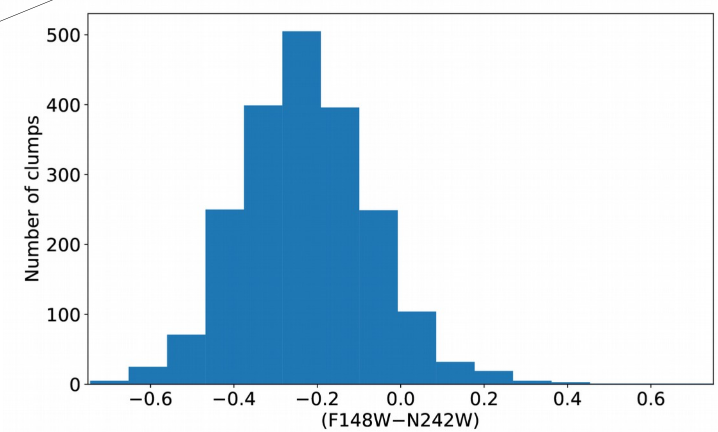
Identifying star-forming clumps



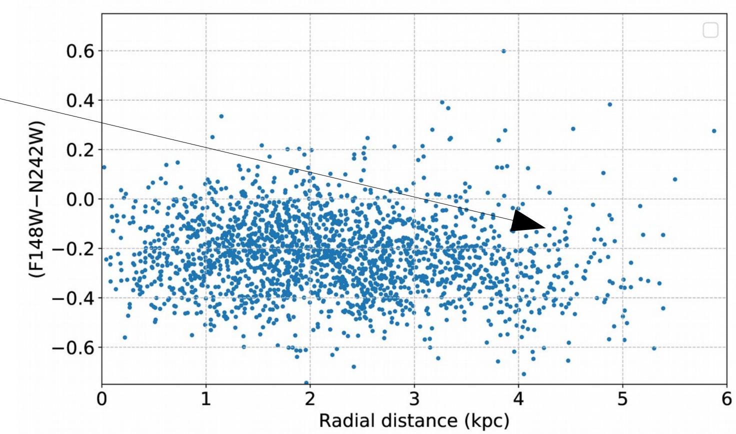




Size of young star-forming clumps is similar to that of GMCs



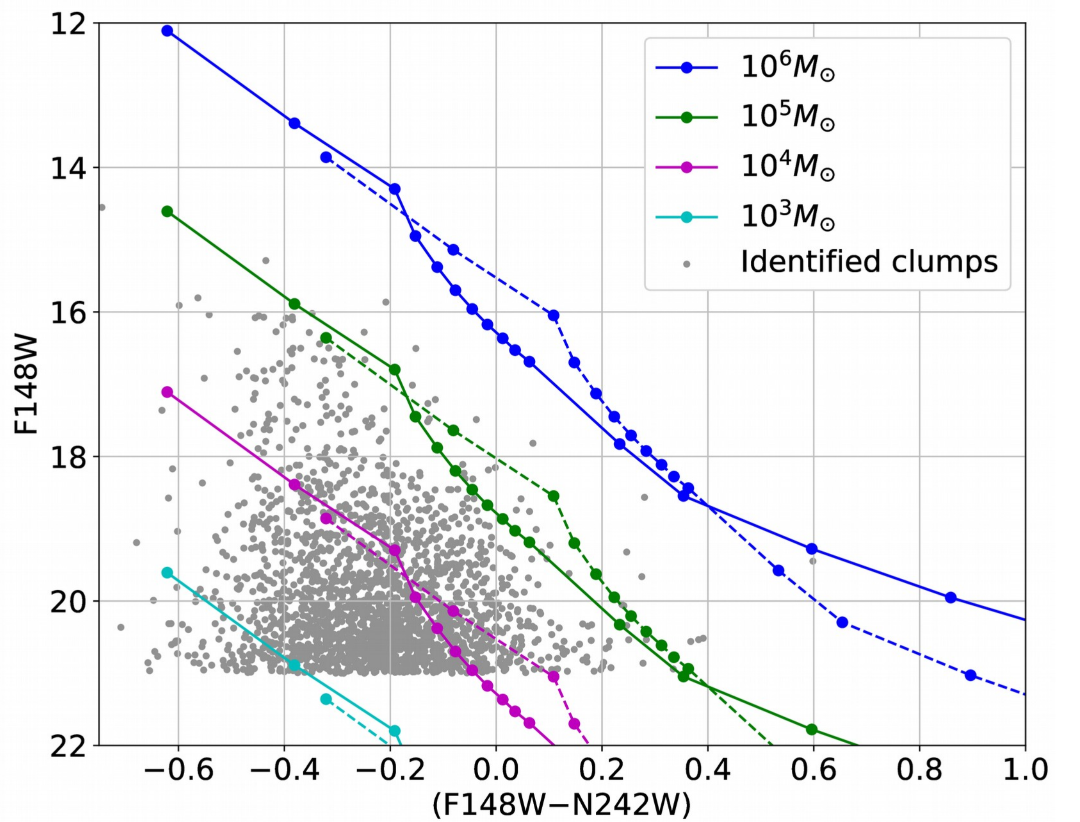
The outer part of the disk contains mostly younger clumps

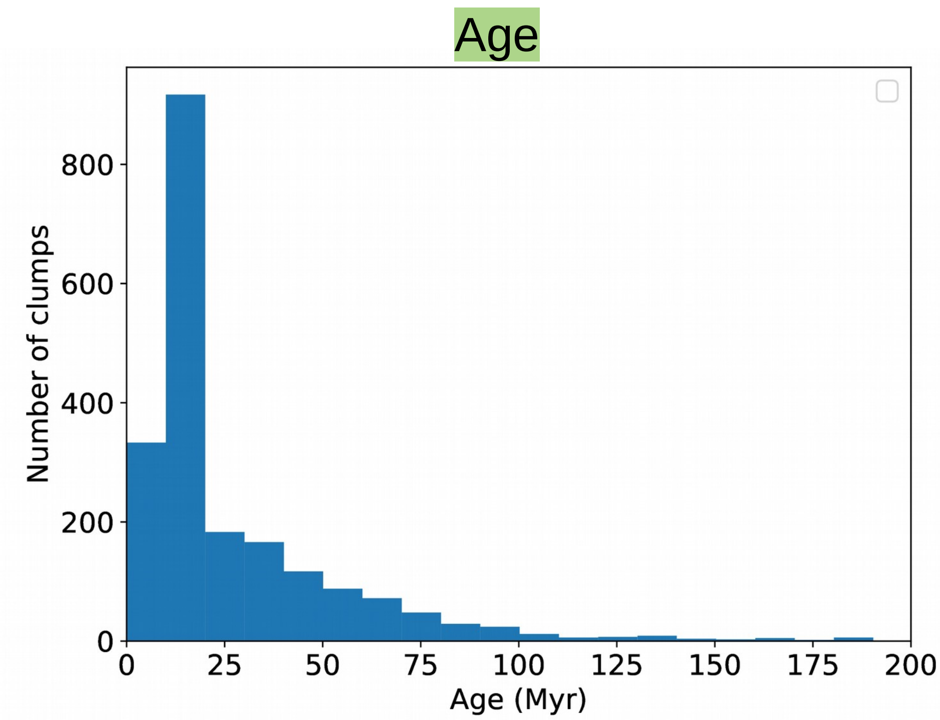


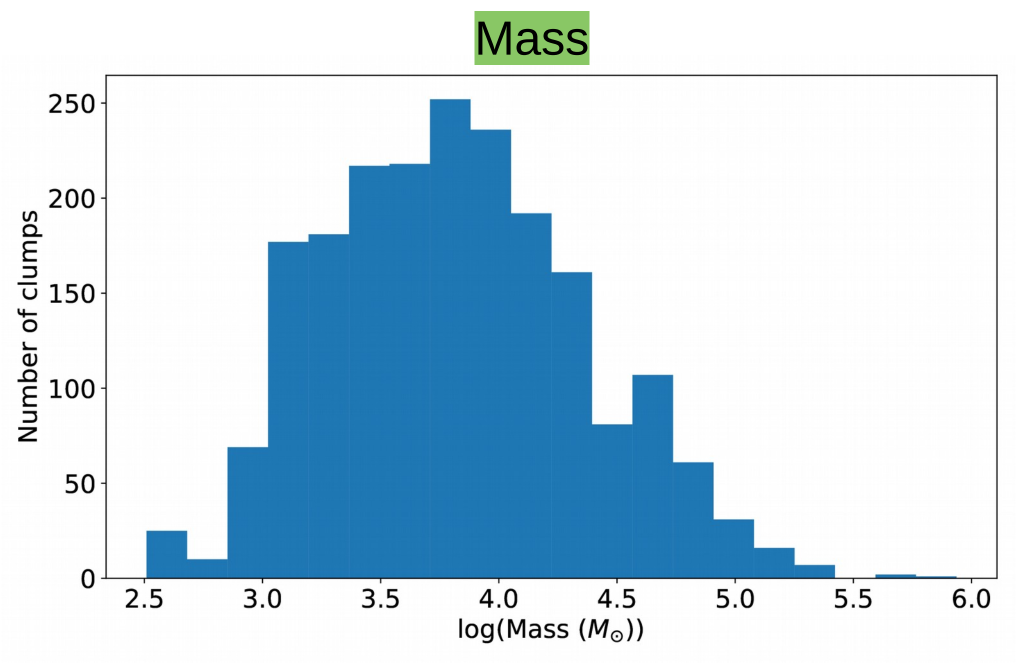
Age & Mass estimation of identified clumps

61% of the identified clumps are younger than 20 Myr --> signifies recent star-forming activities

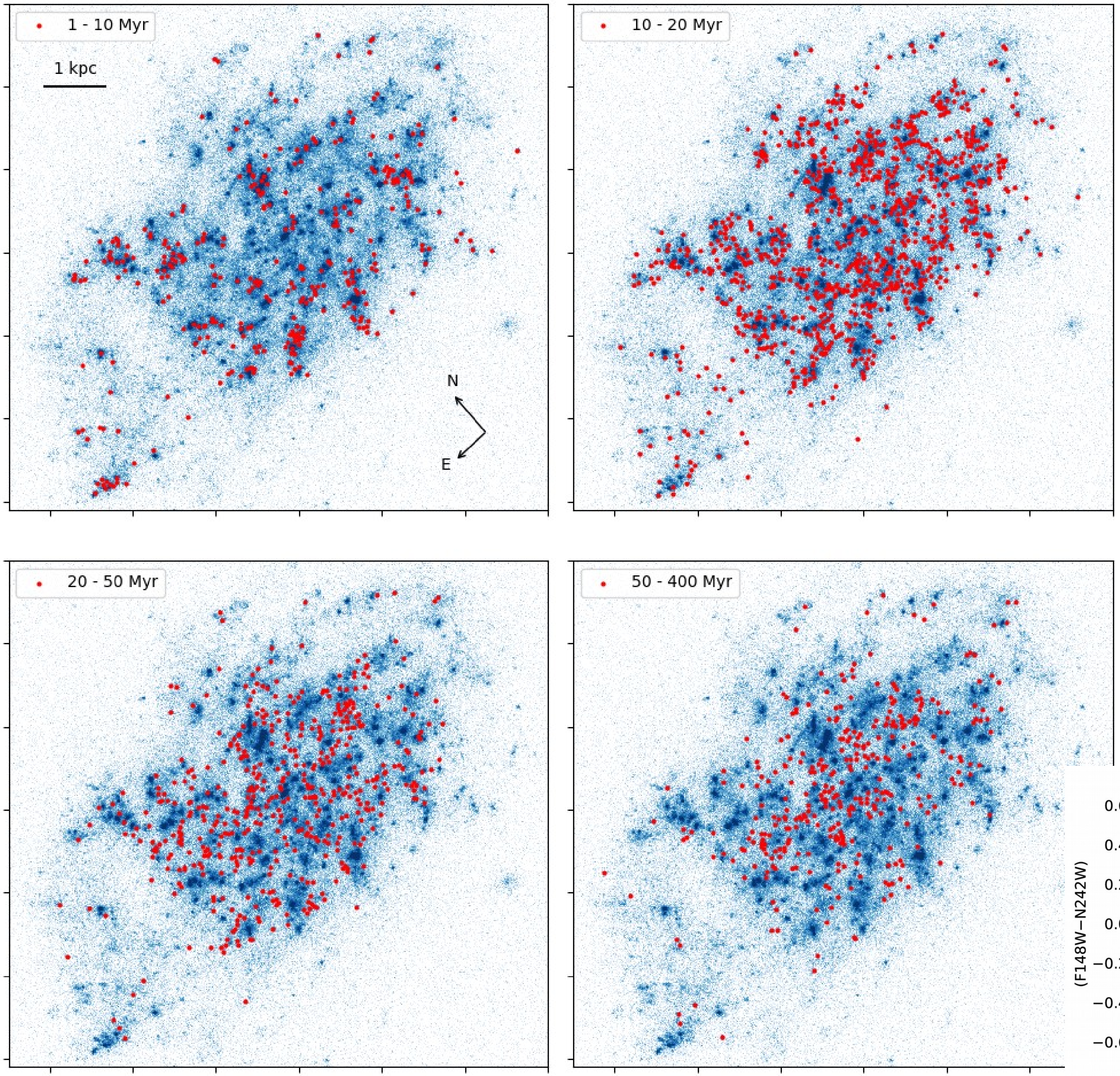
The clumps mostly cover a mass range between $10^3 - 10^5$ M_sun (*Matches with masses of GMCs*)







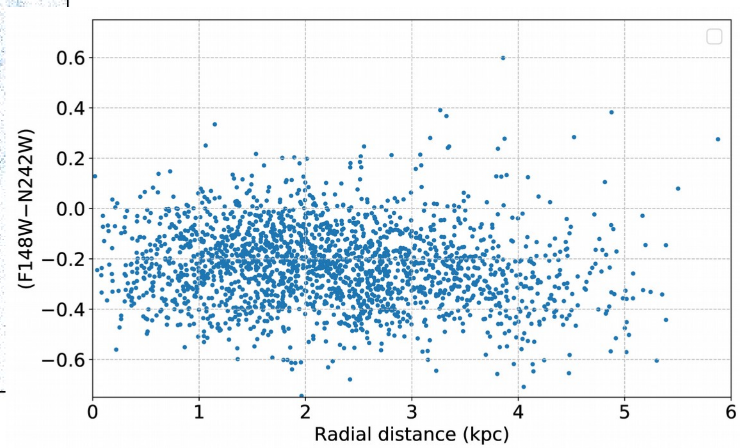
Age distribution



The youngest clumps (age < 10 Myr) delineate the flocculent arms of the galaxy

The central part shows no recent star formation (*lower density of molecular gas in the inner part – Muraoka 2016*)

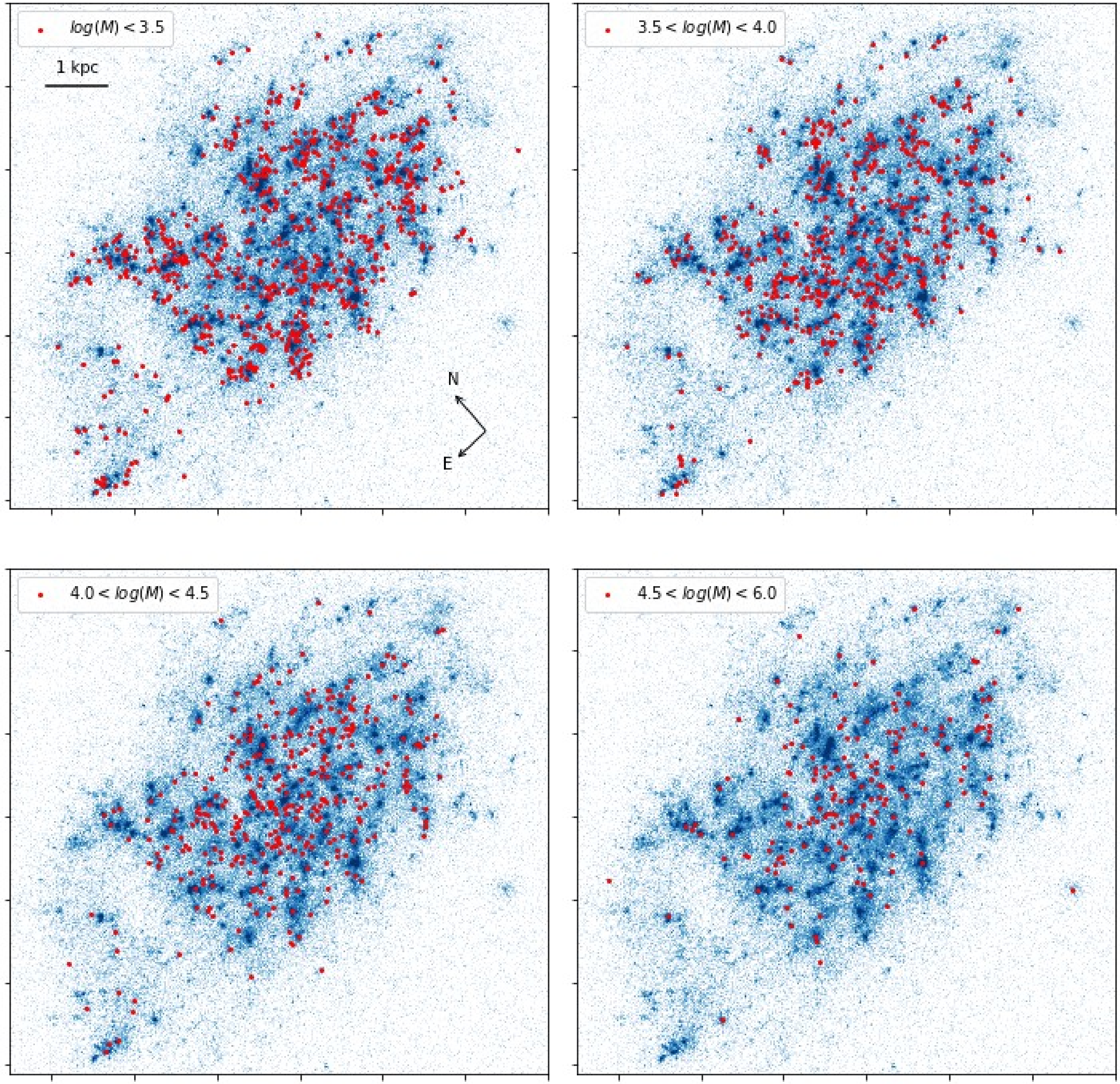
Outer part mostly has younger clumps



Mass distribution

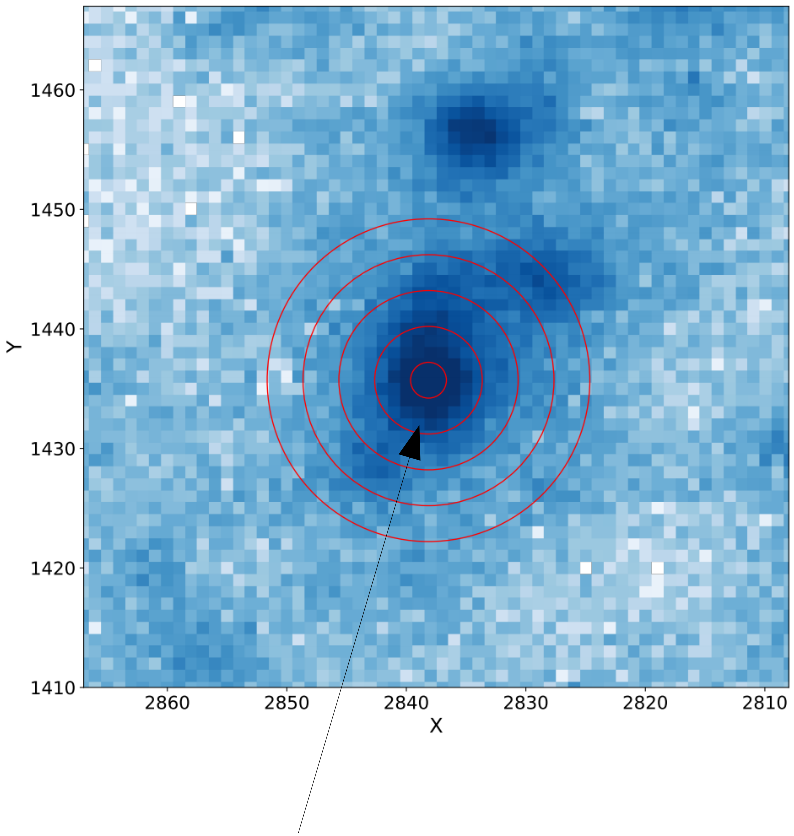
Massive clumps are more in the inner part

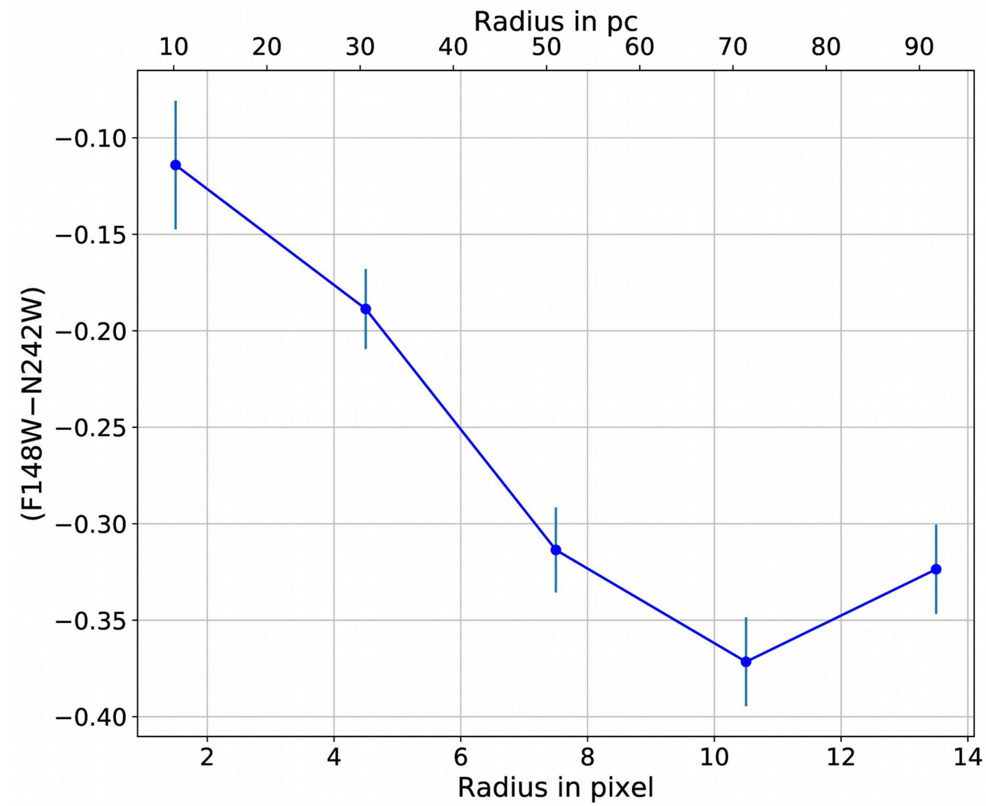
Along the flocculent arms we noticed a gradient in the clumps mass (tips are populated with more of low mass clumps)



Nuclear star cluster

- Carson et al. 2015 & Karachov et al. 2018 have noticed a decreasing effective radius for the NSC with increasing wavelength





Nuclear star cluster of NGC7793

Mass ~ 2×10^5 M_sun (younger component)

Age ~ 19 Myr

FUV-NUV color becomes more blue with increasing radius

Circum-nuclear star formation or accretion of younger population from the nearby stellar groups to the nuclear cluster.

What we learnt?

- ✓ UVIT is a unique instrument for imaging in UV.
- ✓ UVIT imaging could probe star-forming clumps up to much smaller scales.
- ✓ 'astrodendro' package is useful to identify star-forming clumps and study their hierarchy.
- ✓ We used 'photutils' package for custom aperture photometry of the identified clumps.
- ✓ The FUV magnitude and (FUV-NUV) colour can be used to characterize the mass and age of a SF clump.

- The identified FUV bright clumps have a size between ~ 12 – 50 pc, which is similar to the size of GMCs present in the galaxy.
- The youngest clumps (age < 10 Myr) distinctly trace the flocculent arms of the galaxy.
- The central part of the galaxy shows less recent star formation, whereas the clumps detected in the outer disk are mostly younger.
- The estimated masses of the clumps cover a range between 10^3 – 10^5 M_sun.