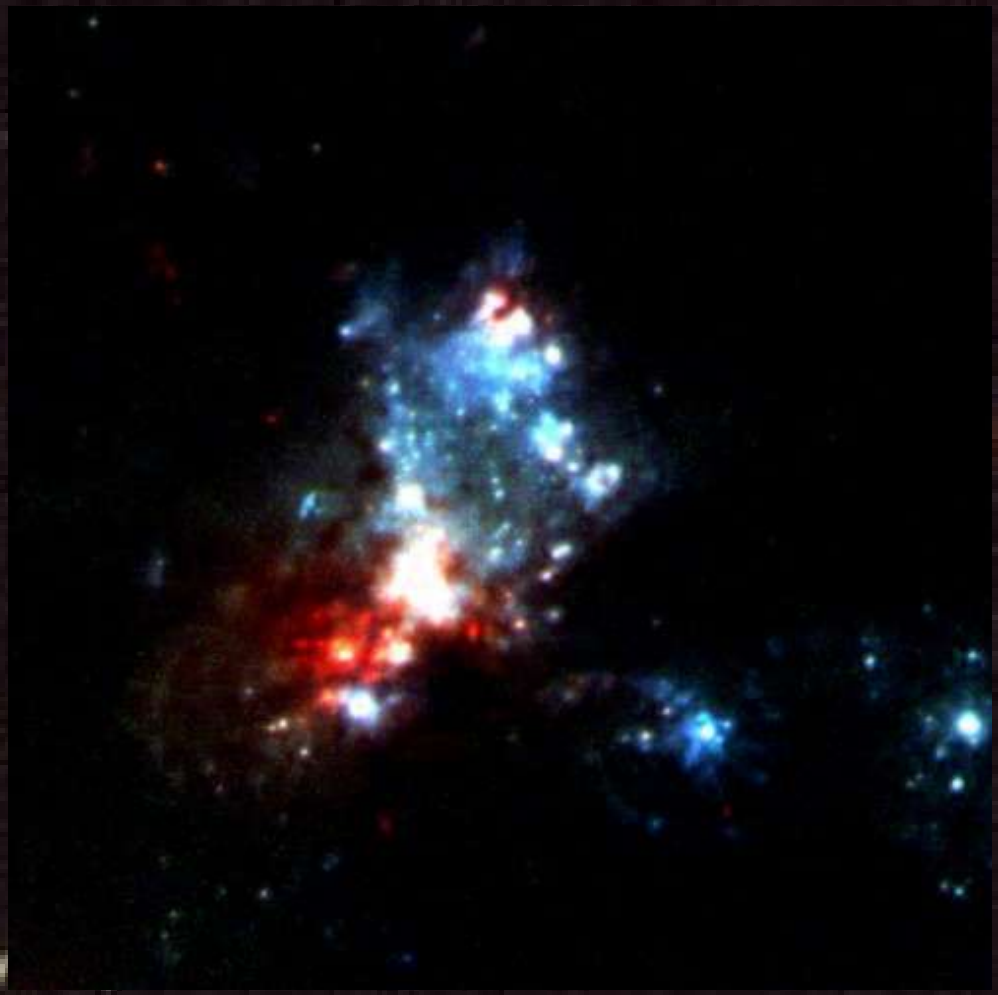
STAR FORMATION RATE IN ARP 299



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ULIRGs: UltraLuminous InfraRed Galaxies

- ULIRGs are multiple mergers probably descending from Compact Groups of Galaxies (CGG)
- $L_{IR} > 10^{12} L_{SOLAR}$
- As a rule they have tidal tails on large scales, bright star-forming regions and/or dusty AGN's at their centers
- They can evolve into elliptical galaxies

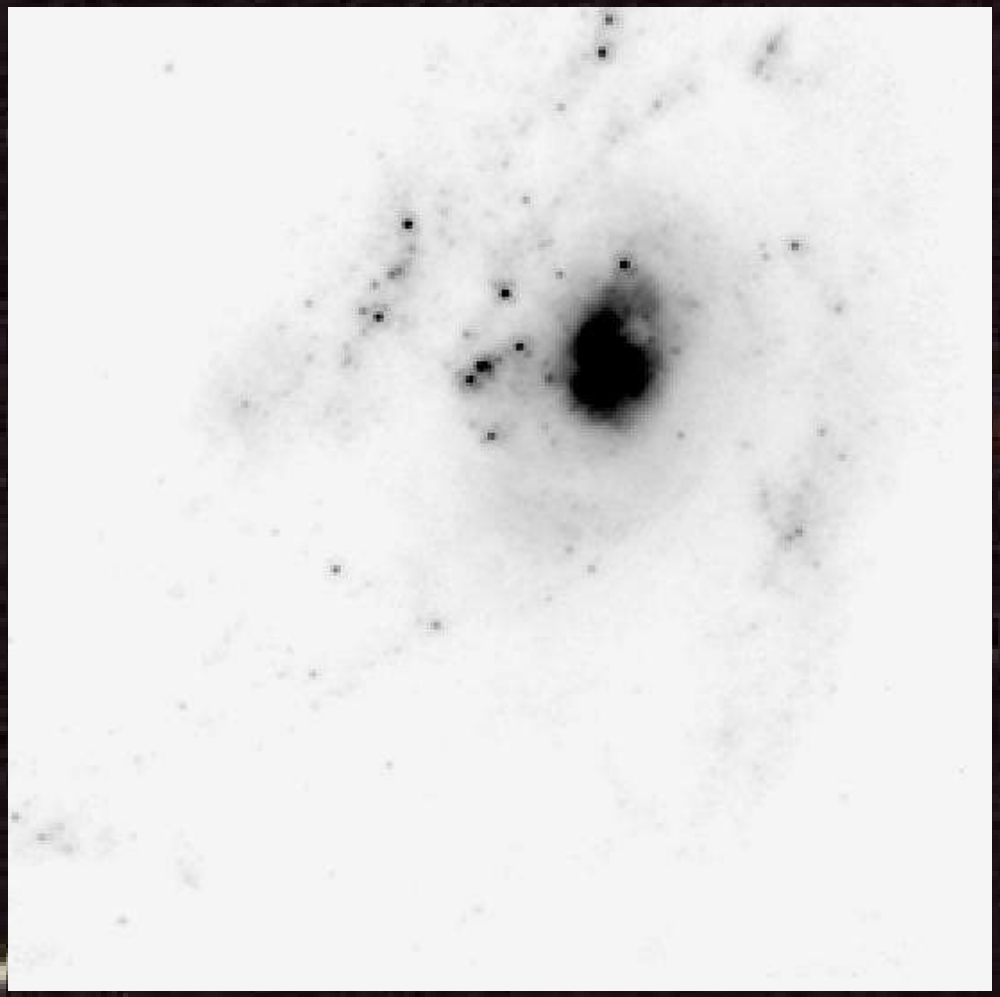
Characteristics of ARP 299

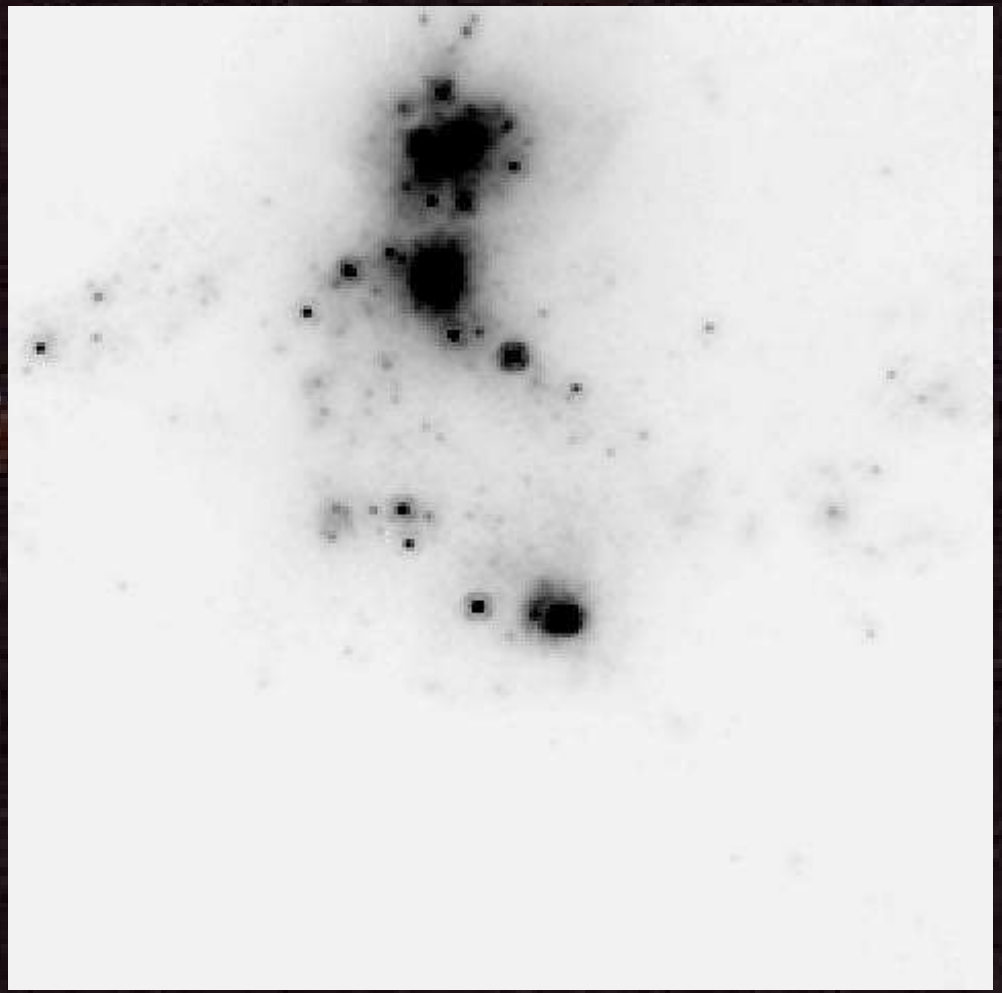
ARP 299 is an early merger of two gas rich galaxies

- IC 694:
  - SPIRAL GALAXY (Sbr)
  - AGN IN THE CENTER
  - MAGNITUDE 16
  - DISTANCE 41 Mpc
- NGC3690:
  - BARRED SPIRAL GALAXY (SBpec)
  - HII REGION IN THE CENTER
  - MAGNITUDE 12
  - DISTANCE 40.78 Mpc

IC 694

NGC 3690



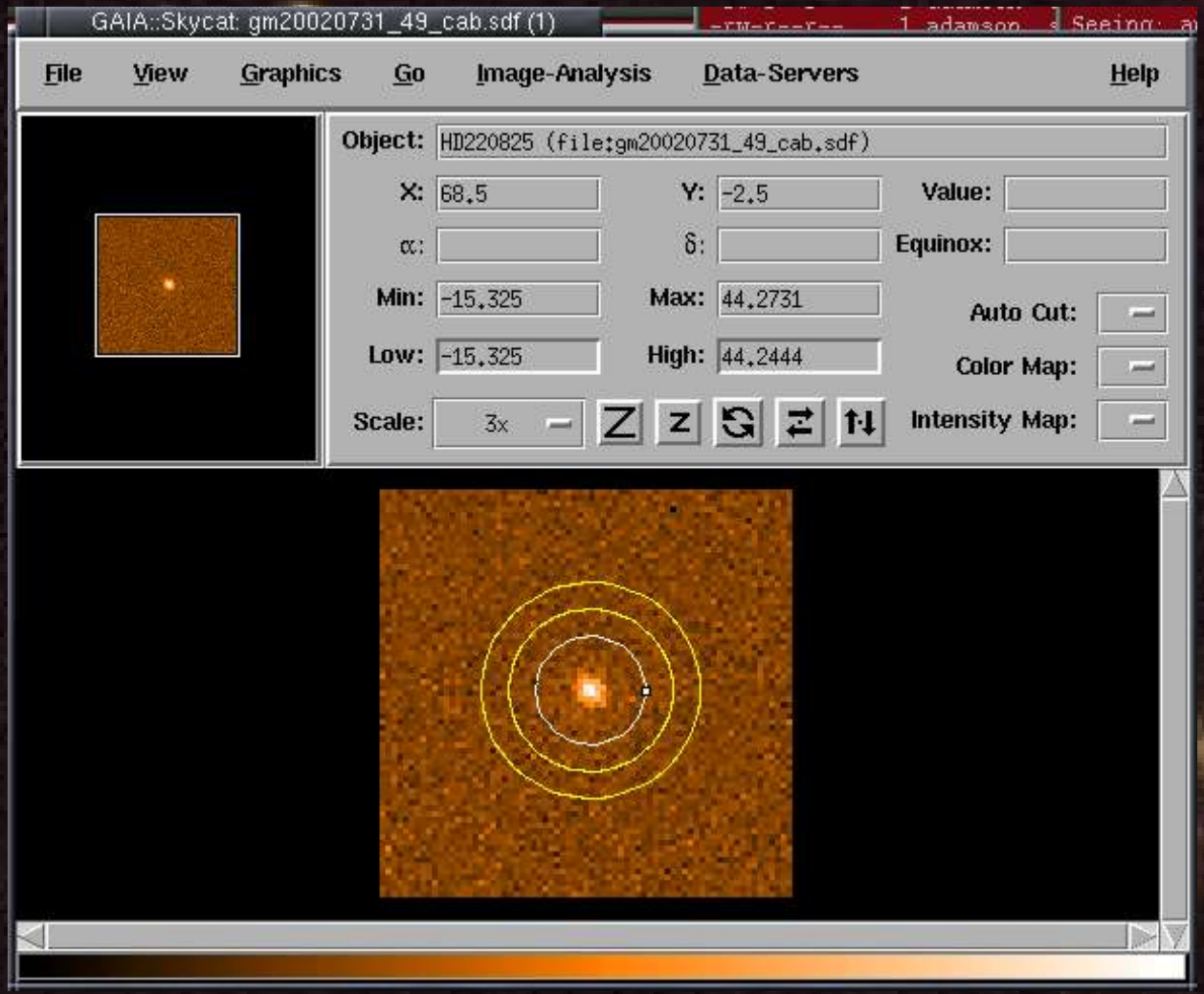


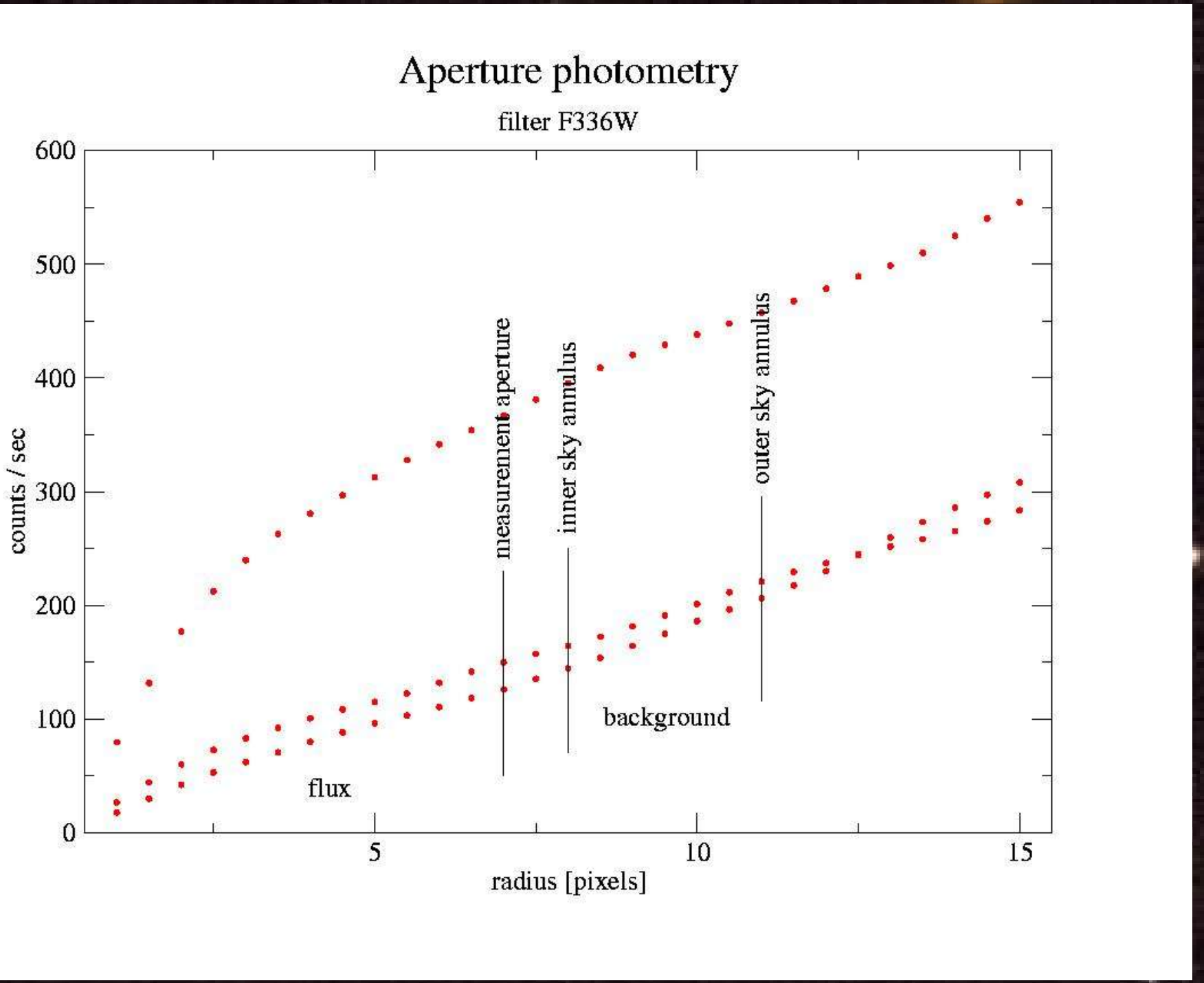
Data

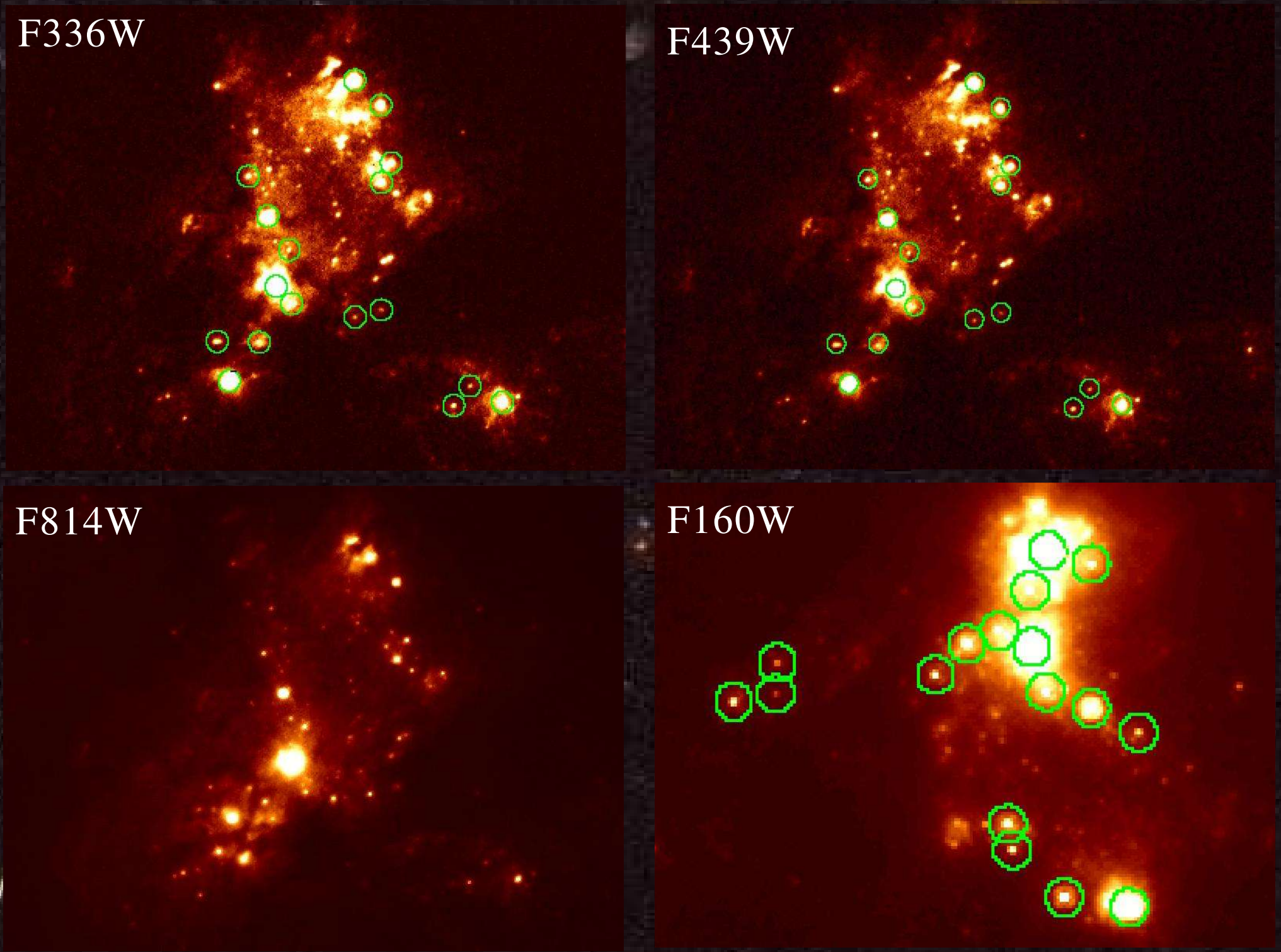
- 46 images retrieved from archive.eso.org
- PI names: Maiolino (9726), Malkan (5479), Meurer (6639)
- Images were reduced on-the-fly
- We selected 14 images for five filters:

  - Filter F336W (WFPC2) – 4 images (1600 sec)
  - Filter F439W (WFPC2) – 4 images (920 sec)
  - Filter F606W (WFPC2) – 1 image (500 sec)
  - Filter F814W (WFPC2) – 4 images (500 sec)
  - Filter F160W (NICMOS) – 1 image (120 sec)

Aperture photometry



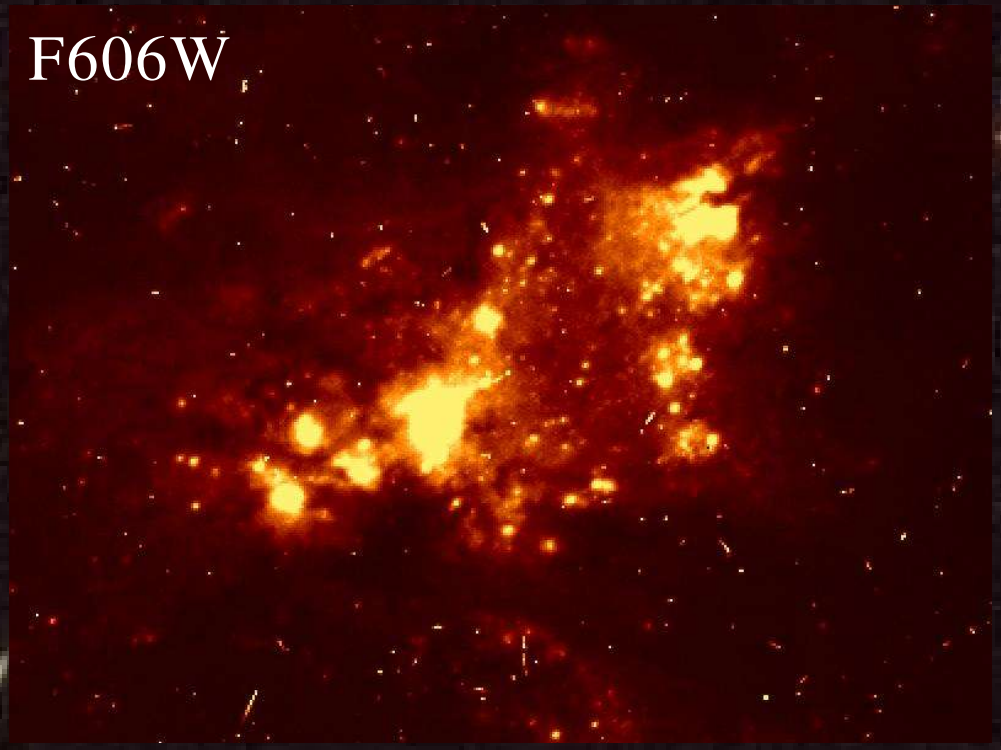

Aperture photometry
filter F336W
counts / sec
radius [pixels]
measurement aperture
inner sky annulus
outer sky annulus
flux
background
0
100
200
300
400
500
600
5
10
15

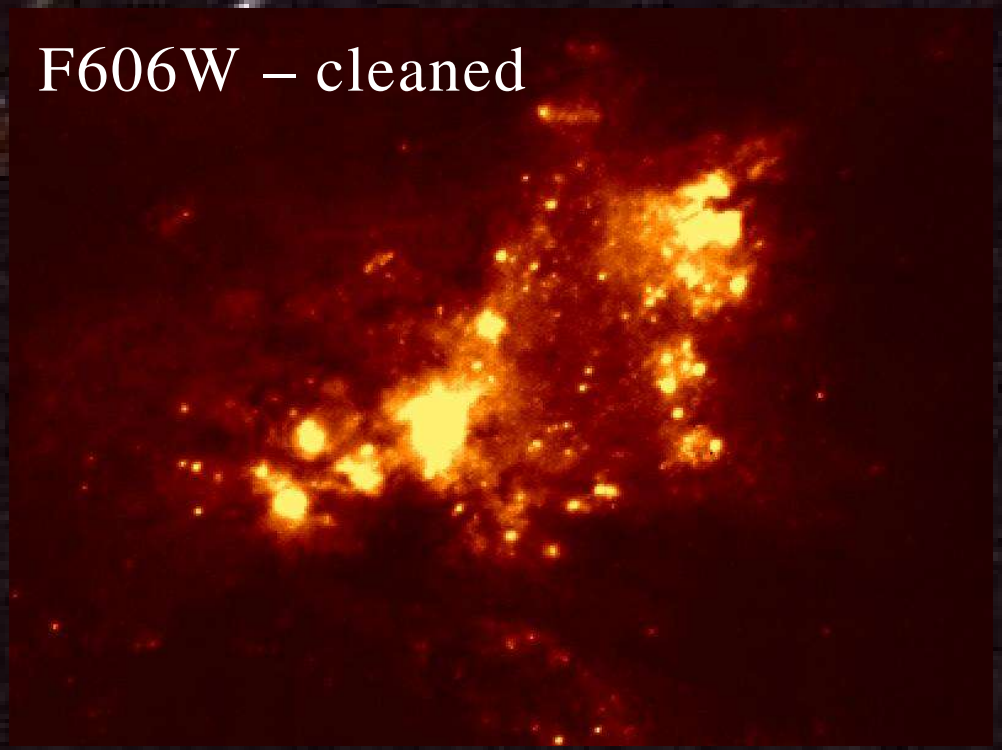

F336W
F439W
F814W
F160W

Cosmic rays

- We removed cosmic rays using subroutine L.A.Cosmic
- L.A.Cosmic runs under IDL
- L.A.Cosmic webpage:

http://www.astro.yale.edu/dokkum/lacosmic





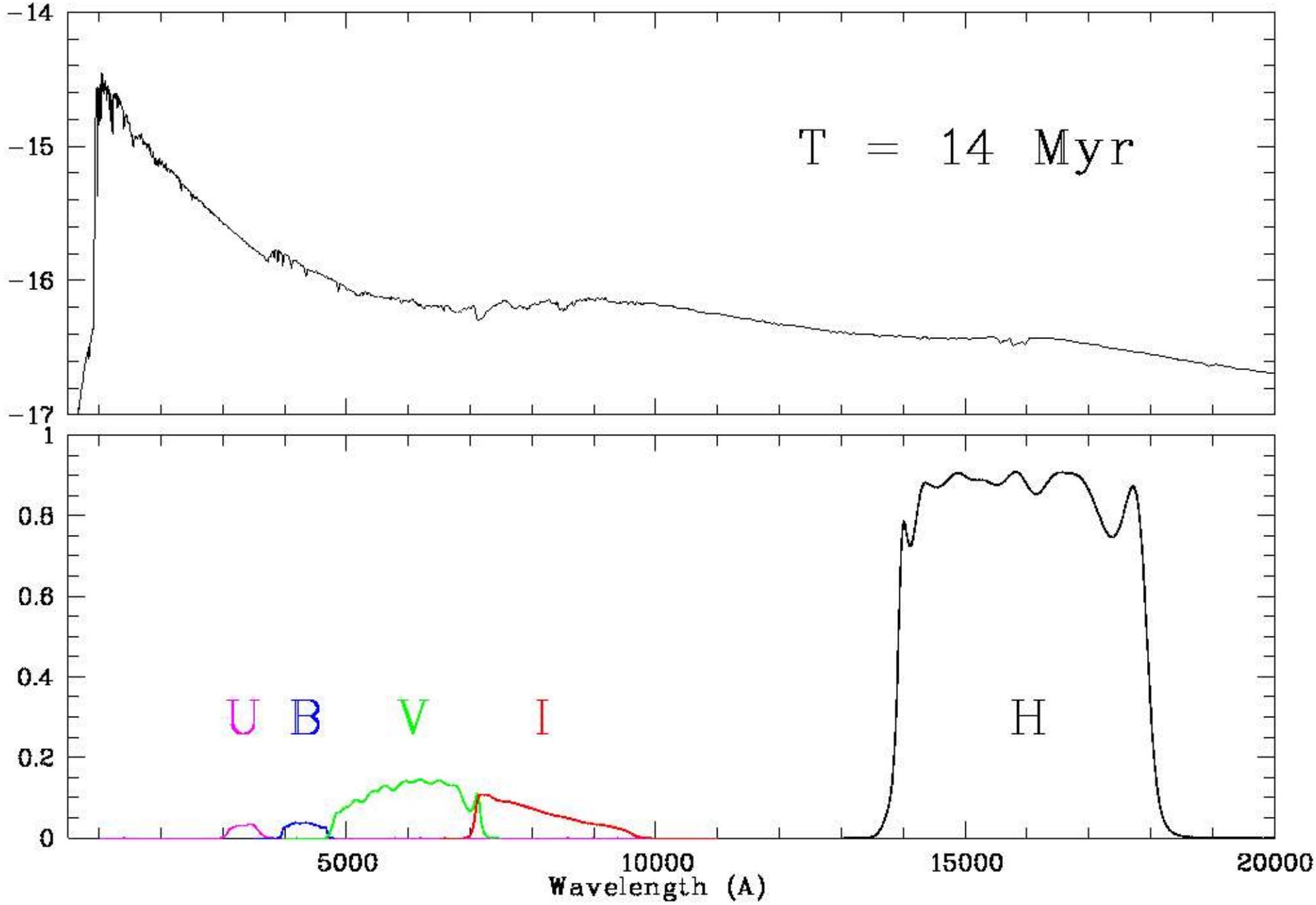
Magnitudes

$$m = -2.5 \log F + Z_p$$

Object	U	B	R	I	H
B1	15.5737	16.8134	16.2891	16.1995	13.0020
B2	14.6013	15.3852	15.0328	14.2629	12.6933
B23	18.6073	19.4623	19.8085	17.7991	15.5496
C1	16.3165	17.4394	17.5615	17.1901	14.2665
D1	16.6696	18.0847	18.1286	17.7912	16.6550
D2	20.5407	21.7436	20.8796	20.0366	18.0602

Filter	Z_p [mag]
U	18.558
B	20.045
R	22.084
I	22.844
H	22.103

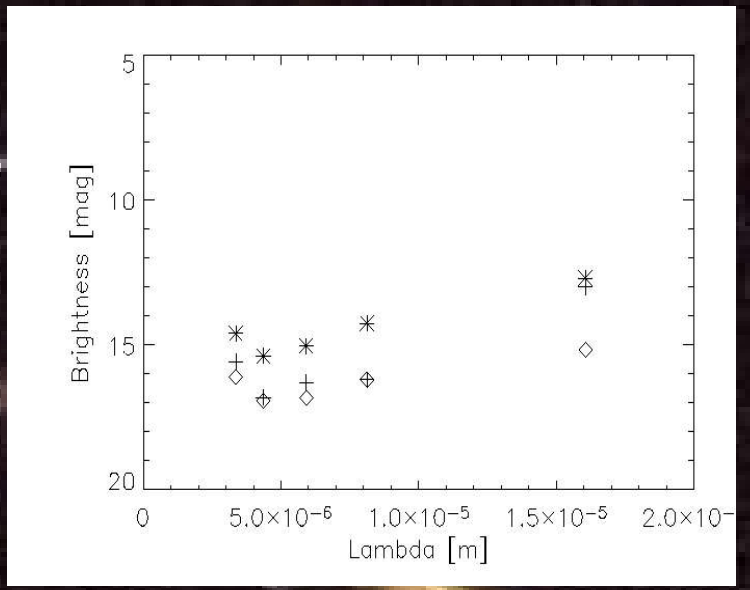

http://www.stsci.edu/science/starburst99/
www.stsci.edu/science/starbu


T = 14 Myr
U
B
V
I
H
Wavelength (A)

Data Analysis

To revise:

- 5-band photometry from 17 objects
- Model for photometry from Starburst99 (time-series)
- Interest: to derive the age and the mass of the star clusters
- To do this, we fit the observed photometry to model ----> Age of objects



- Model gives the *de-reddened* brightnesses
- Observations give the brightnesses that still have intrinsic reddening

---> The intrinsic reddening of objects must also be fitted

Data Analysis – Age and extinction

- Color excess E(B-R) is set between 0...5 magnitudes, using the steps of 0.01.
- For each E(B-R) and each age, the chi-square is calculated
- The smallest chi-square yields the fiducial timepoint and reddening

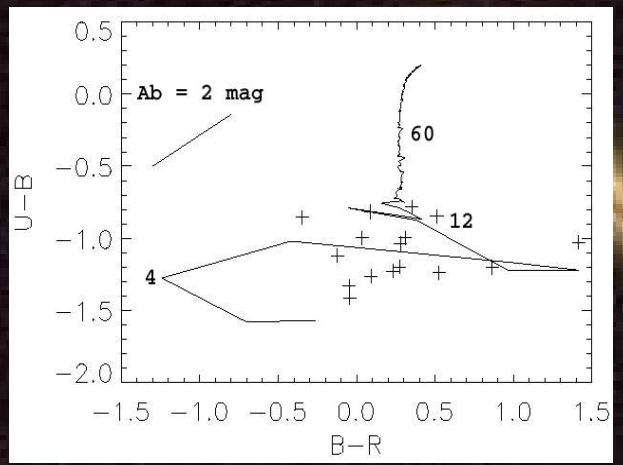
In the color-color diagram:

- The intrinsic extinction shifts the cluster from its original position.
- Photometry from the Starburst99 forms an evolutionary track
- The cluster is shifted back to the track, to a place that corresponds to a certain age

$$Chi^2 = \sum_{i=colors} \left(\frac{color_{obs,i} - (color_{mod,i} + E_{i,j})}{W}\right)^2$$

Reddening

Age $\begin{pmatrix} Chi^2 & \dots \\ \cdot & \dots \\ \cdot & \dots \end{pmatrix}$



Data Analysis – Masses

- From the Starburst99 we have the brightnesses that correspond to the initial mass setting (10^6 Mau)
- Mass is proportional to luminosity
- Extinction values from the fit are used to get the *de-reddened* magnitude of a cluster

---> The mass of a single cluster is derived by scaling its brightness to the brightness of a model with the same age of the cluster

$$F = 10^{0.4(Vmodel-Vo)}$$

---> Now we have the mass, and the age. And finally:

$$SFR = Mass / Age$$

Data Analysis – Results

- Ages: 8 – 18 Myr.
- Masses: 10^5 – $2*10^7$ M_{AU}
- SFR_{MAX} = 1.3 M_{AU} yr^{-1} (B2, central object)

This star formation rate is typical for normal galaxies.

The galaxies that are in the middle of the merging process show the SFR:s up to 100-200 M_{AU} yr^{-1} in their central regions.

Object	Mass [M_s]	Age [Myr]	SFR
B1	2.8	14.	0.2
B14	0.29	12.	0.024
B15	0.45	14.	0.032
B2	20.6	16.	1.29
B21	3.42	18.	0.19
B22	1.35	8.	0.17
B23	1.93	8.	0.24
B24	0.22	8.	0.028
B25	0.58	14.	0.041
B26	0.23	16.	0.014
C1	0.88	8.	0.11
C3	0.71	16.	0.044
C4	0.49	16.	0.031
C5	0.43	18.	0.024
D1	0.56	18.	0.031
D2	0.087	14.	0.0062
D3	0.12	16.	0.0075

Conclusions

- The fitting of the photometry from the Starburst99 model to the observed brightnesses suggests the typical age of 14 Myr for the star clusters in Arp299.
- The derived $SFR_{MAX} = 1.3\ M_{AU}\ yr^{-1}$ implies, that the interaction between the two galaxies is not powerfull enough to produce high star formation in the inner regions.
- Low SFR in Arp 299 implies that the large star formation rate takes place in the very late phase of merging process.

ACKNOWLEDGEMENTS

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This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

We have made use of the LEDA database (http://leda.univ-lyon1.fr).

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