Direct Detections of Young Stars in Nearby Ellipticals

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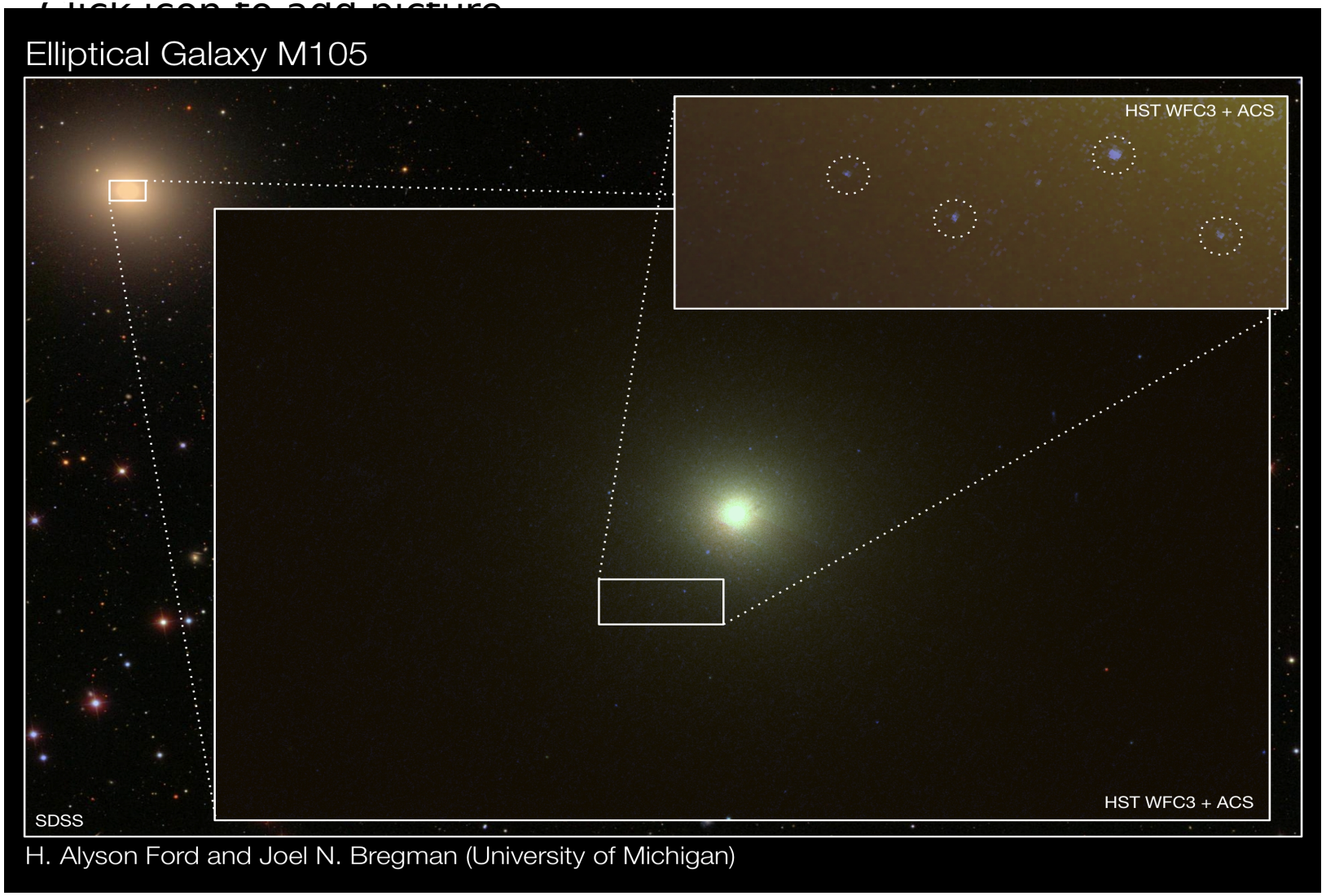
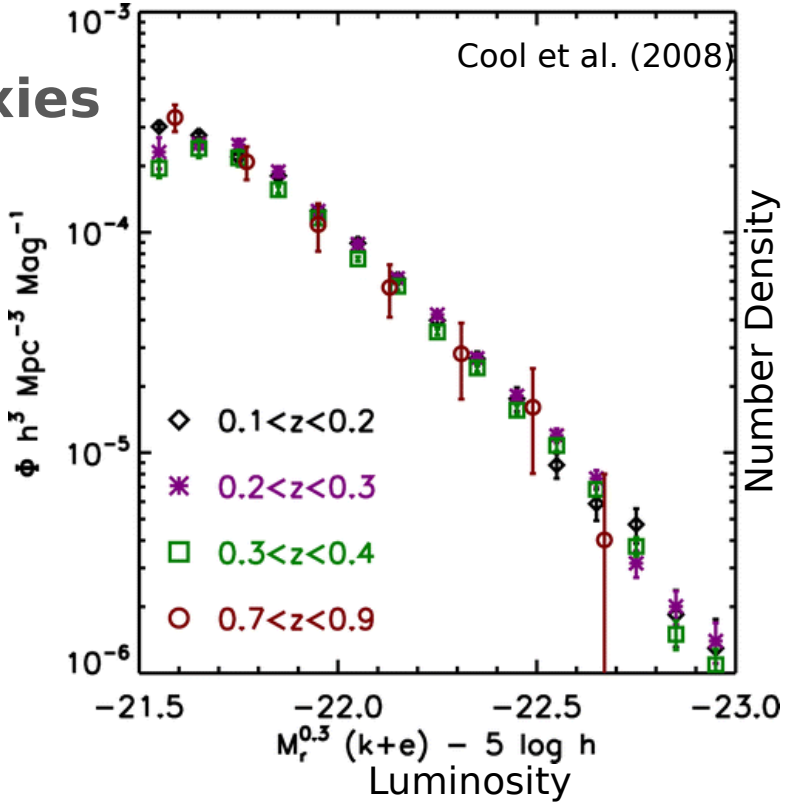


ApJ, in press (arXiv:1205.1066)

Red and Dead

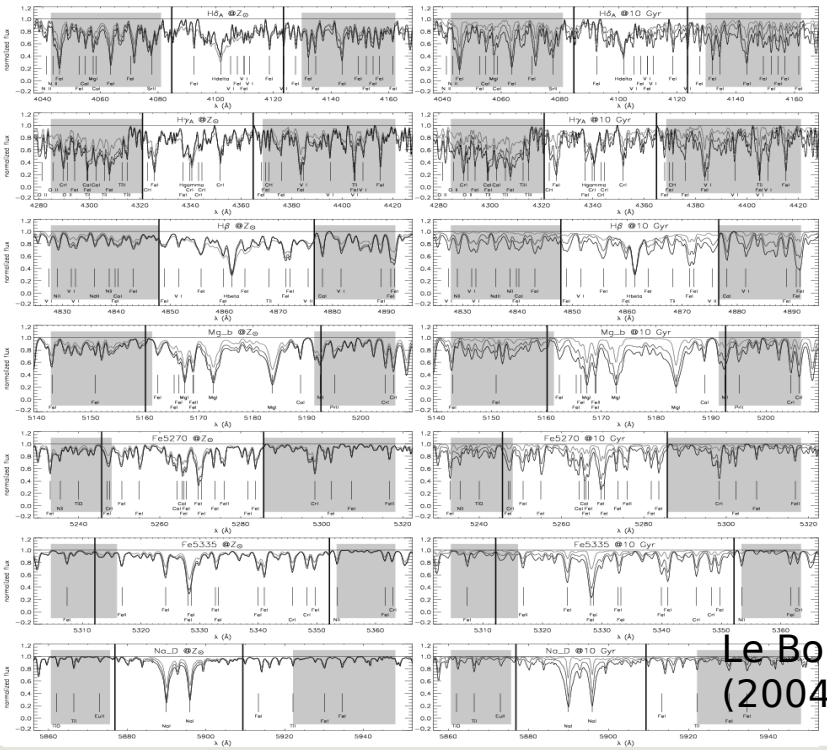
Conventional wisdom:
elliptical galaxies are "red and dead"

- Red colors consistent with stars forming at at z~3
- Luminosity functions of massive red galaxies consistent with no growth via star formation (SF) (Brown et al. 2007; Cool et al. 2008; Bell et al. 2006).



Evidence for Younger Stars

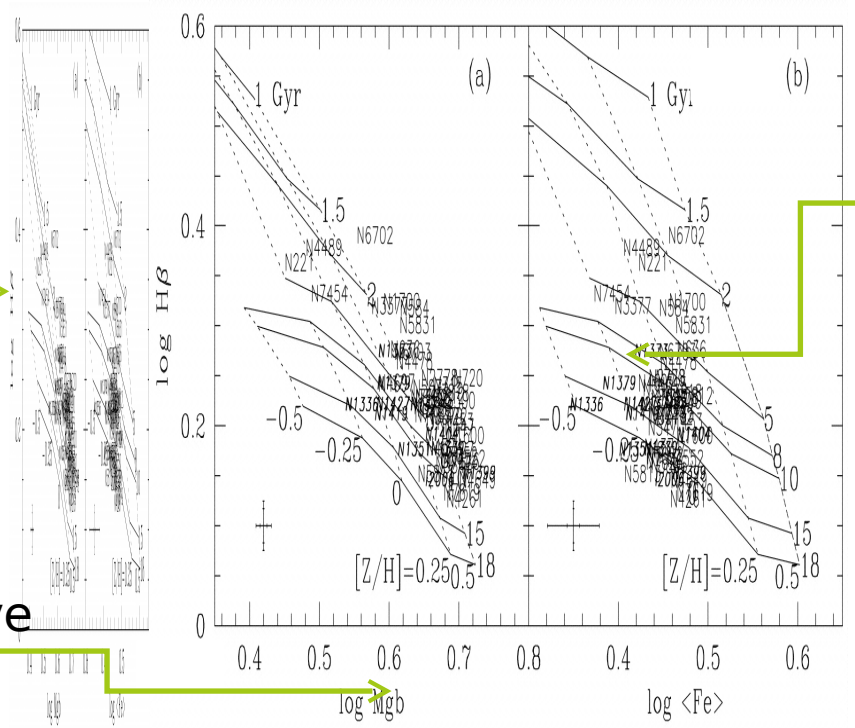
- Line-index dating:
  - Depth of Balmer lines indicative of young B and A stars



Evidence for Younger Stars

- Line-index dating:
  - Depth of Balmer lines indicative of young B and A stars

Age-sensitive
Lick index



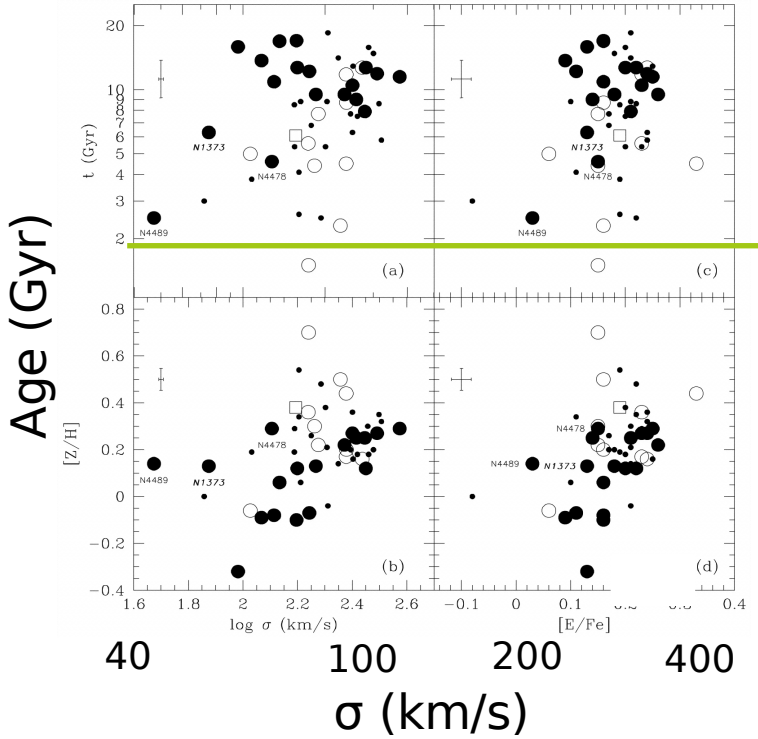
SSP Models

Metallicity-sensitive
Lick index

Trager et al. (2000)
50 local ellipticals

Evidence for Younger Stars

- Line-index dating:
  - Depth of Balmer lines indicative of young B and A stars



z=1

40% of ellipticals!

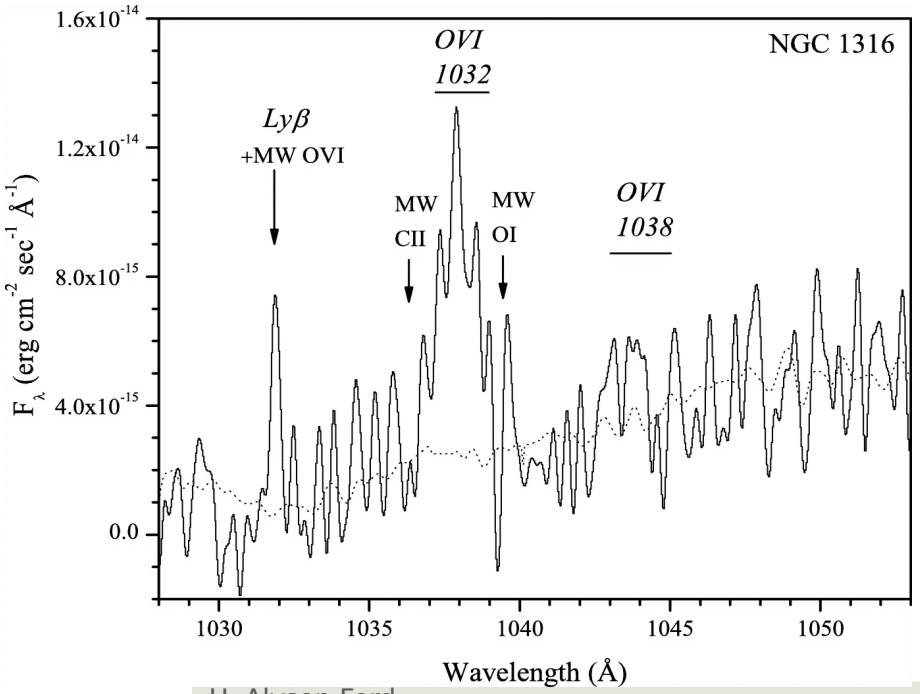
Trager et al. (2000)
50 Es (filled: Virgo Cluster)

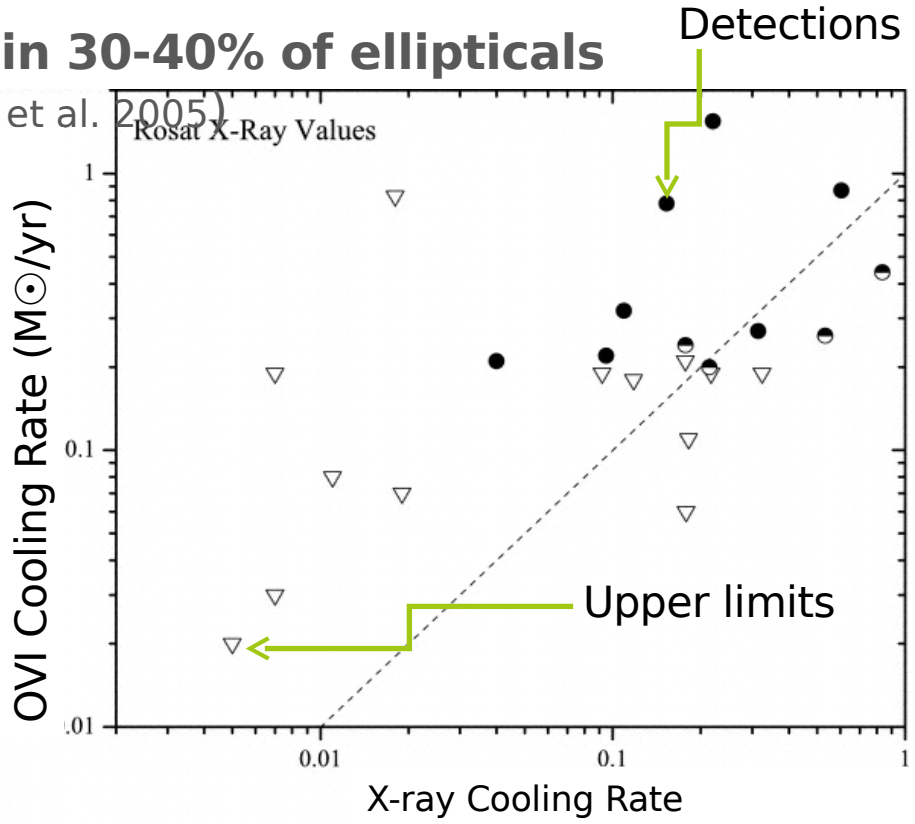
Evidence for Younger Stars

- Near-UV observations
  - Most ellipticals in z=0.4 cluster have young stellar mass fractions of >0.1% (Ferreras & Silk 2000)
  - 30% of 2100 early-type galaxies (ETGs) have colors that require a young (< 1Gyr) component (Kaviraj et al. 2007)
  - Near-UV excess over background without far-UV excess, indicative of young stars (56 ETGs; Donovan Meyer et al. 2010)

Fuel for Star Formation in Ellipticals

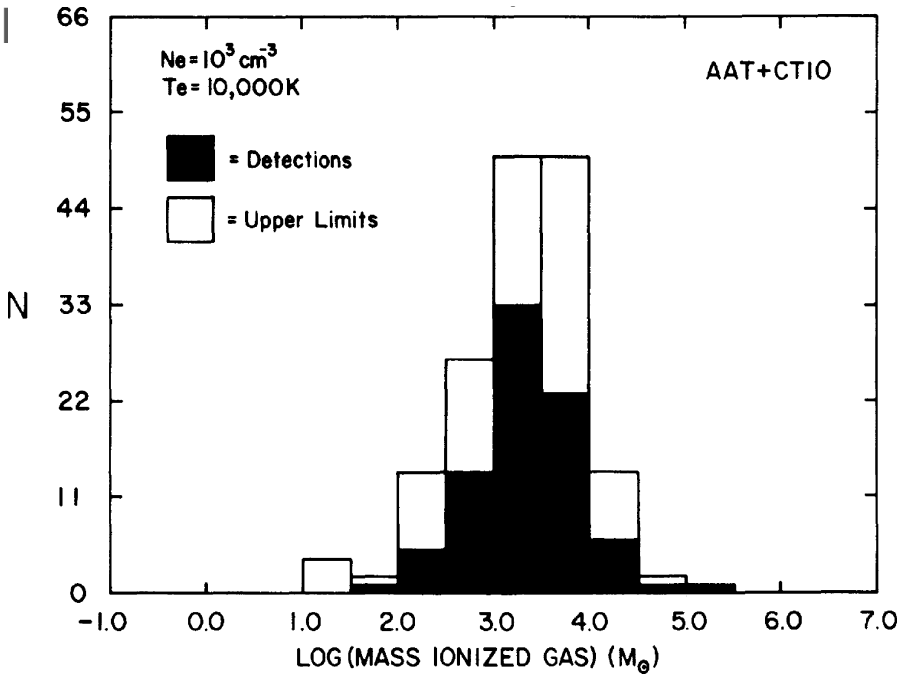
- Evidence for cool gas:
  - Radiatively **cooling gas in 30-40% of ellipticals** (FUSE OVI; Bregman et al. 2005)





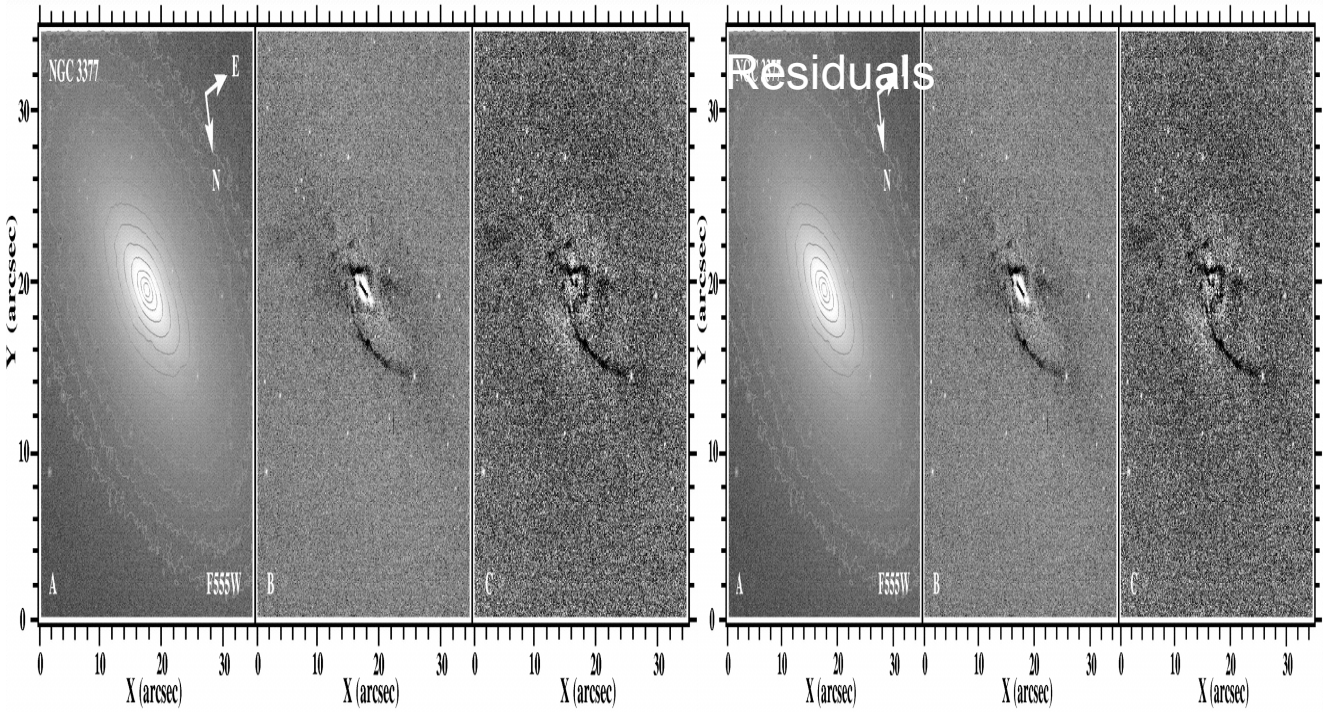
Fuel for Star Formation in Ellipticals

- Evidence for cool gas:
  - **Hα emission** from gas at ~104 K (**50% of ~200 |**



Fuel for Star Formation in Ellipticals

- Evidence for cool gas:
  - **dust/dust lanes** (e.g., Peng et al., 2002)



Star Formation in Ellipticals

- Evidence for star formation:
  - Optical line indices suggest young ages
  - Ultraviolet colors suggest young stars
  - Cool gas and dust exists

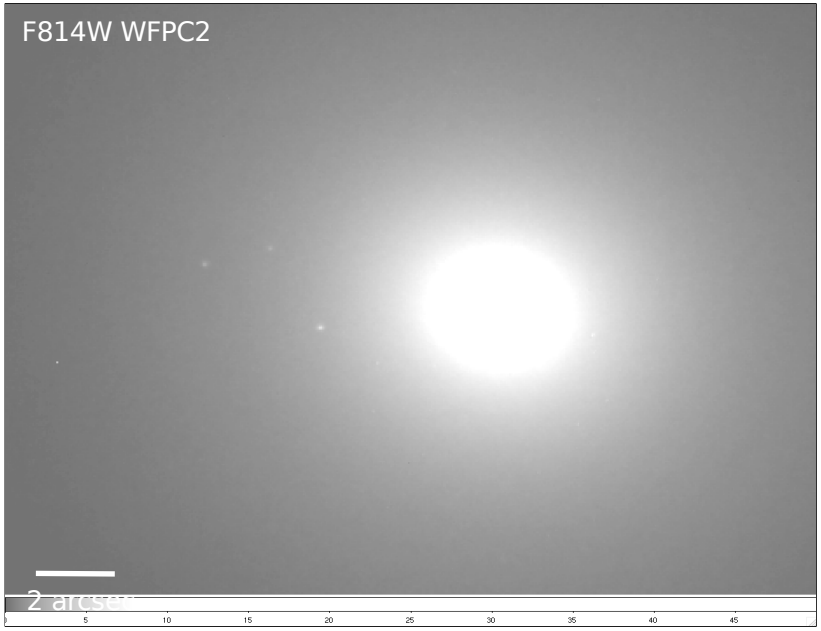
Low-level star formation is possible!

However, it's difficult to measure star formation rates less than ~10-2 M yr-1 at distances of nearby ellipticals (e.g., Young et al. 2009).

Detecting Young Stars in the Ultraviolet

Search for individual stars and star clusters

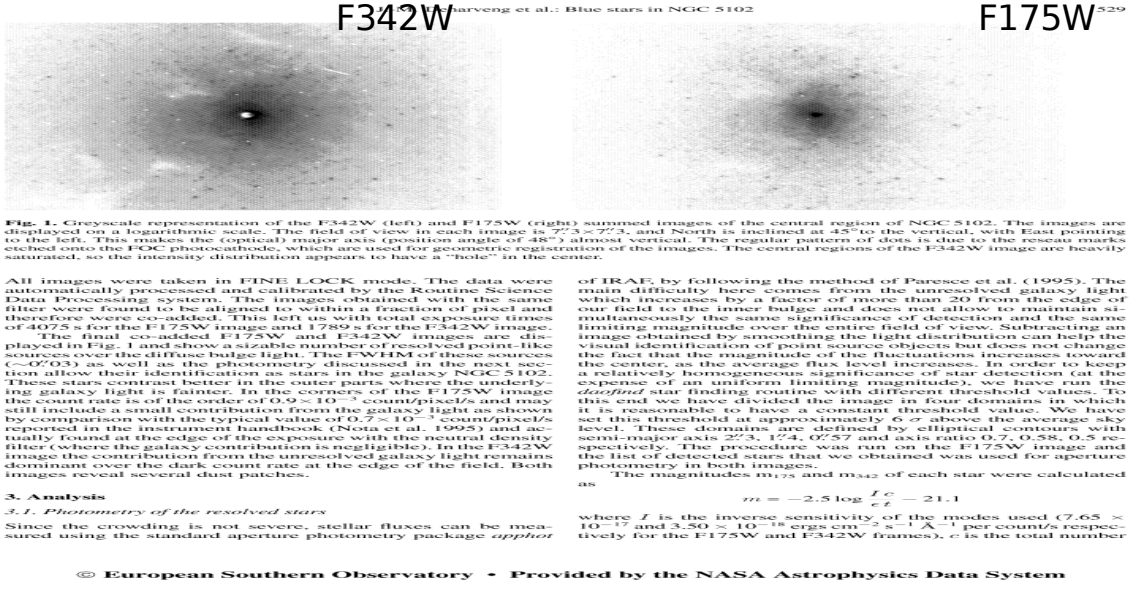
- Optical data: hopeless → background is too bright



- In the **ultraviolet**:
  - **young stars are brighter**
  - **less background**
    (old stars emit little)

Previous UV-Bright Star Searches

- NGC 5102 (S0)
  - HST/FOC
  - d = 4 Mpc
  - 5x10-4 M yr-1
- NGC 3115 (S0)
  - HST/FOC
  - d = 9.7 Mpc
  - No stars detected: too distant (Deharveng et al. 1997)



F342W F175W

Fig. 1. Greyscale representation of the F342W (left) and F175W (right) summed images of the central region of NGC 5102. The images are displayed on a logarithmic scale. The field of view in each image is 7.″3×7.″3, and North is inclined at 45° to the vertical, with East pointing to the left. This makes the (optical) major axis (position angle of 48°) almost vertical. The regular pattern of dots is due to the reseau marks etched onto the FOC photocathode, which are used for geometric registration of the images. The central regions of the F342W image are heavily saturated, so the intensity distribution appears to have a "hole" in the center.

All images were taken in FINE LOCK mode. The data were automatically processed and calibrated by the Routine Science Data Processing system. The images obtained with the same filter were found to be aligned to within a fraction of pixel and therefore were co-added. This left us with total exposure times of 4075 s for the F175W image and 1789 s for the F342W image.

The final co-added F175W and F342W images are displayed in Fig. 1 and show a sizable number of resolved point-like sources over the diffuse bulge light. The FWHM of these sources (~0.″03) as well as the photometry discussed in the next section allow their identification as stars in the galaxy NGC 5102. These stars contrast better in the outer parts where the underlying galaxy light is fainter. In the corners of the F175W image the count rate is of the order of 0.9×10^{-3} count/pixel/s and may still include a small contribution from the galaxy light as shown by comparison with the typical value of 0.7×10^{-3} count/pixel/s reported in the instrument handbook (Nota et al. 1995) and actually found at the edge of the exposure with the neutral density filter (where the galaxy contribution is negligible). In the F342W image the contribution from the unresolved galaxy light remains dominant over the dark count rate at the edge of the field. Both images reveal several dust patches.

3. Analysis

3.1. Photometry of the resolved stars

Since the crowding is not severe, stellar fluxes can be measured using the standard aperture photometry package *apphot* of IRAF, by following the method of Paresce et al. (1995). The main difficulty here comes from the unresolved galaxy light which increases by a factor of more than 20 from the edge of our field to the inner bulge and does not allow to maintain simultaneously the same significance of detection and the same limiting magnitude over the entire field of view. Subtracting an image obtained by smoothing the light distribution can help the visual identification of point source objects but does not change the fact that the magnitude of the fluctuations increases toward the center, as the average flux level increases. In order to keep a relatively homogeneous significance of star detection (at the expense of an uniform limiting magnitude), we have run the *daofind* star finding routine with different threshold values. To this end we have divided the image in four domains in which it is reasonable to have a constant threshold value. We have set this threshold at approximately 6 σ above the average sky level. These domains are defined by elliptical contours with semi-major axis 2.″3, 1.″4, 0.″87 and axis ratio 0.7, 0.58, 0.5 respectively. The procedure was run on the F175W image and the list of detected stars that we obtained was used for aperture photometry in both images.

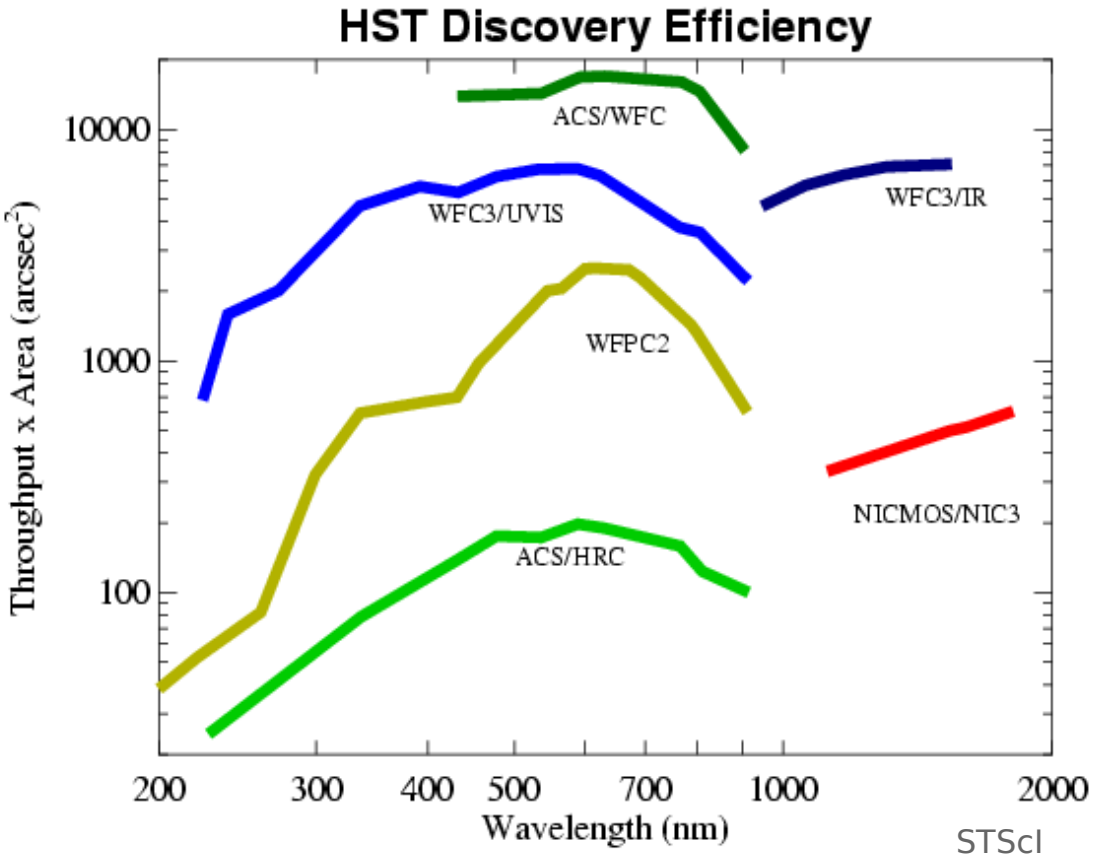
The magnitudes m_{175} and m_{342} of each star were calculated as

$$m = -2.5 \log \frac{I}{c} - 21.1$$

where I is the inverse sensitivity of the modes used (7.65×10^{-17} and 3.50×10^{-18} ergs cm^{-2} s^{-1} Å^{-1} per count/s respectively for the F175W and F342W frames), c is the total number

(Deharveng et al. 1997)

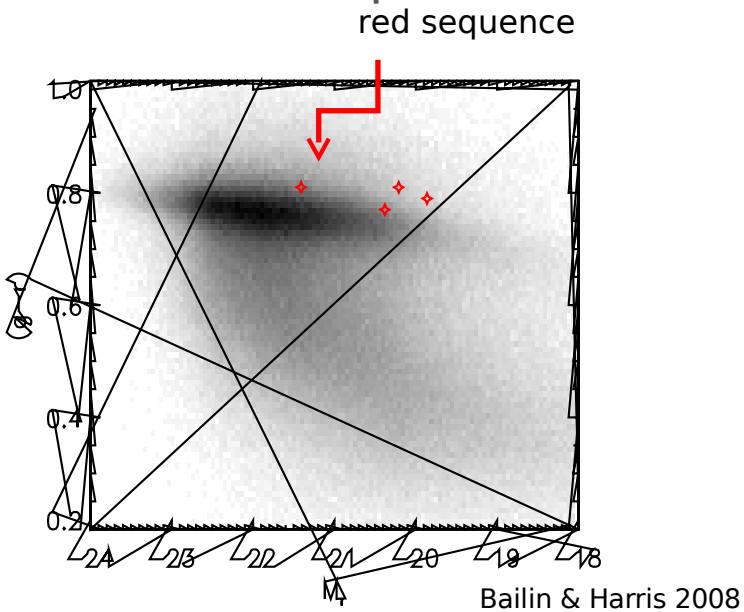
UV Imaging with Hubble



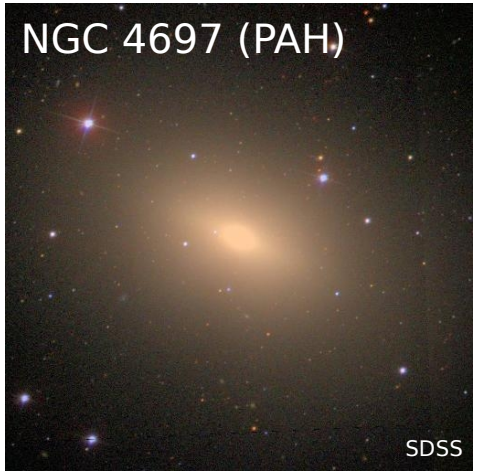
- Can measure SFR in nearby ellipticals to 10-5 M☒ yr-1 for distances ~ 18 Mpc using WFC3!

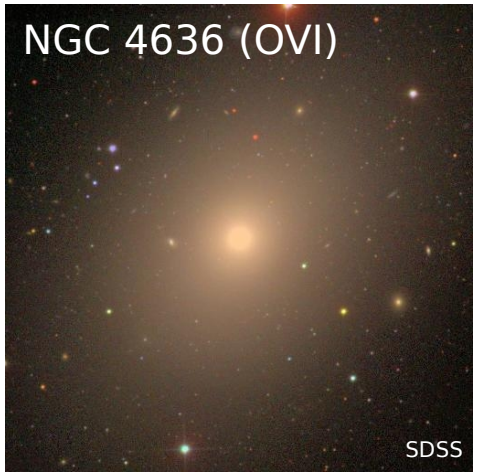
Targeted Elliptical Galaxies

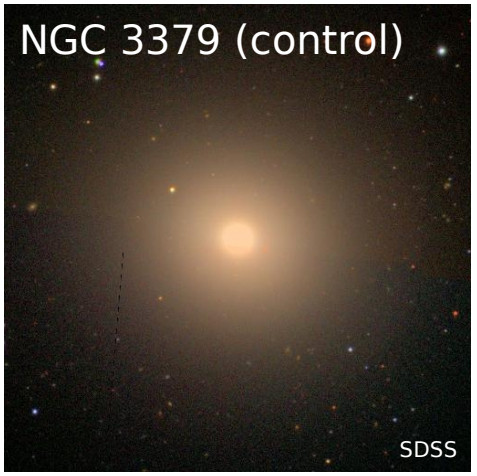
- 4 **"red and dead" nearby ellipticals** (10-18 Mpc)



Bailin & Harris 2008

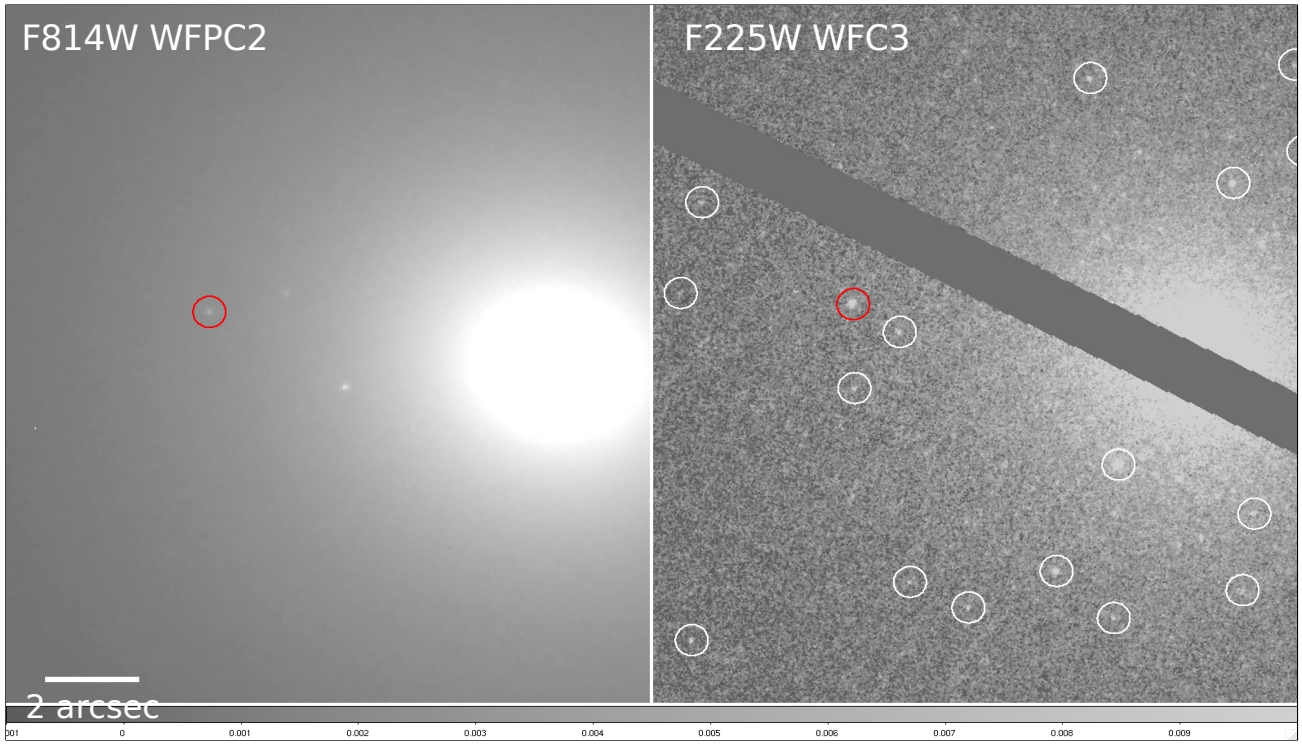




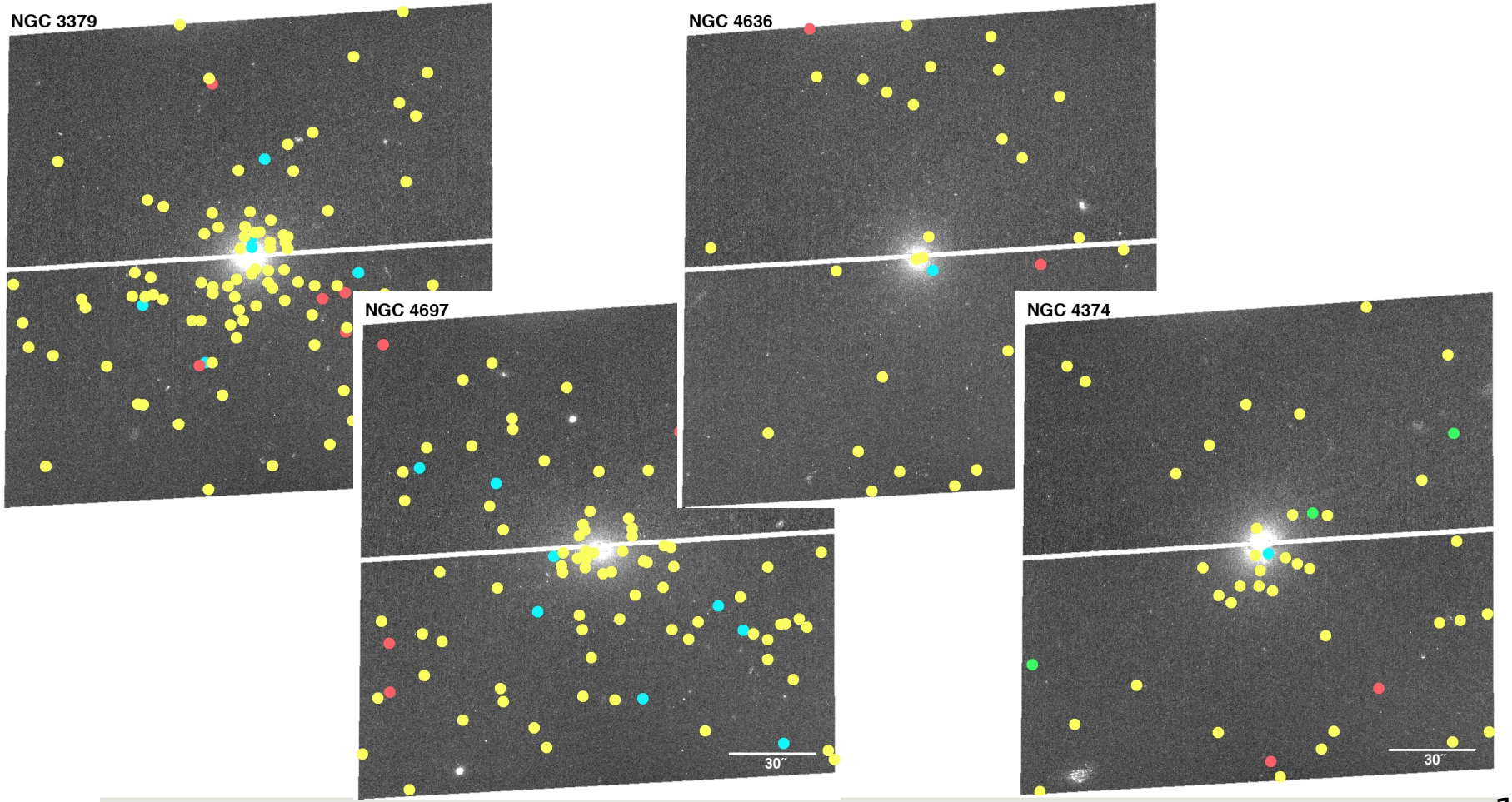


UV-Bright Sources

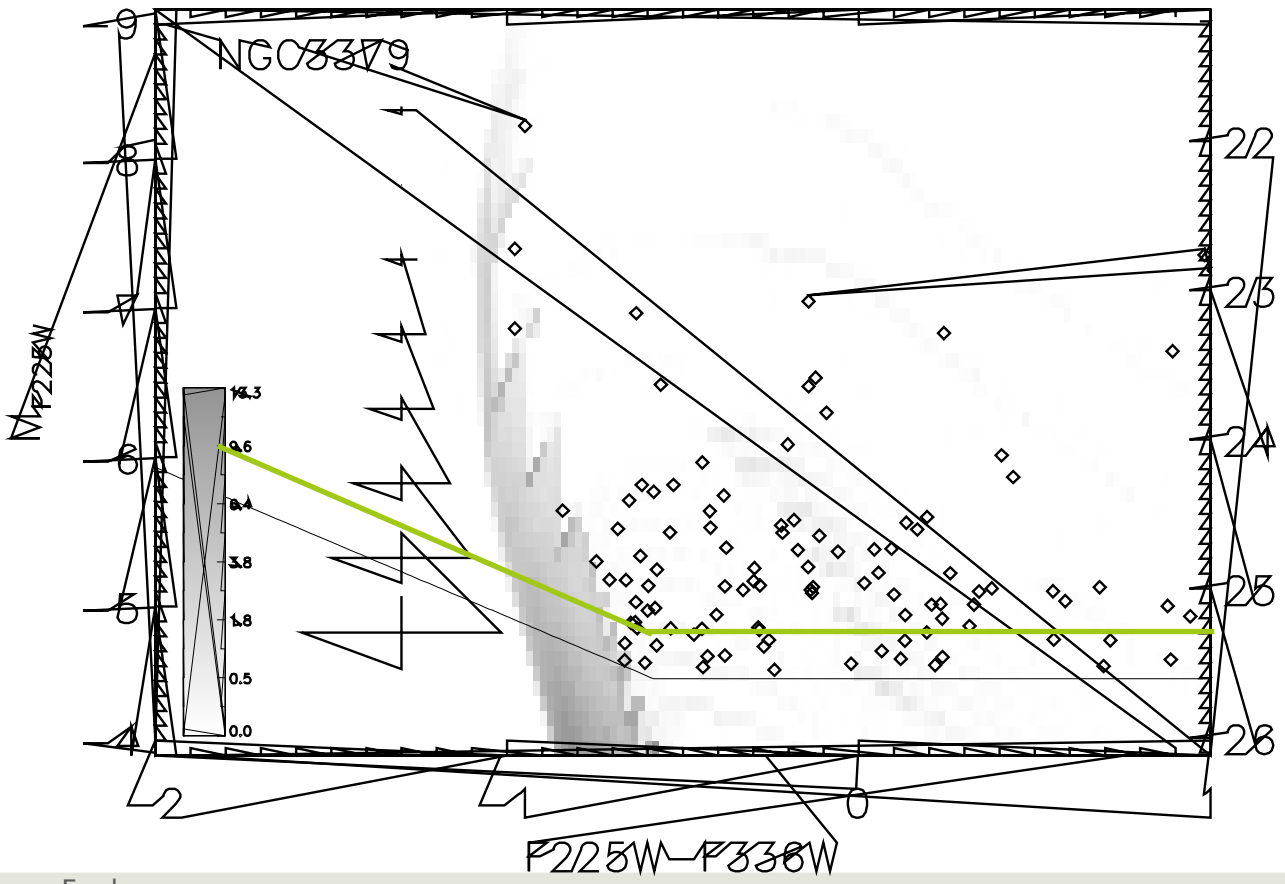
- UV HST/WFC3 imaging (F225W+F336W, 2 orbits per filter)
- Many sources in both WFC3 filters but not in previous optical data



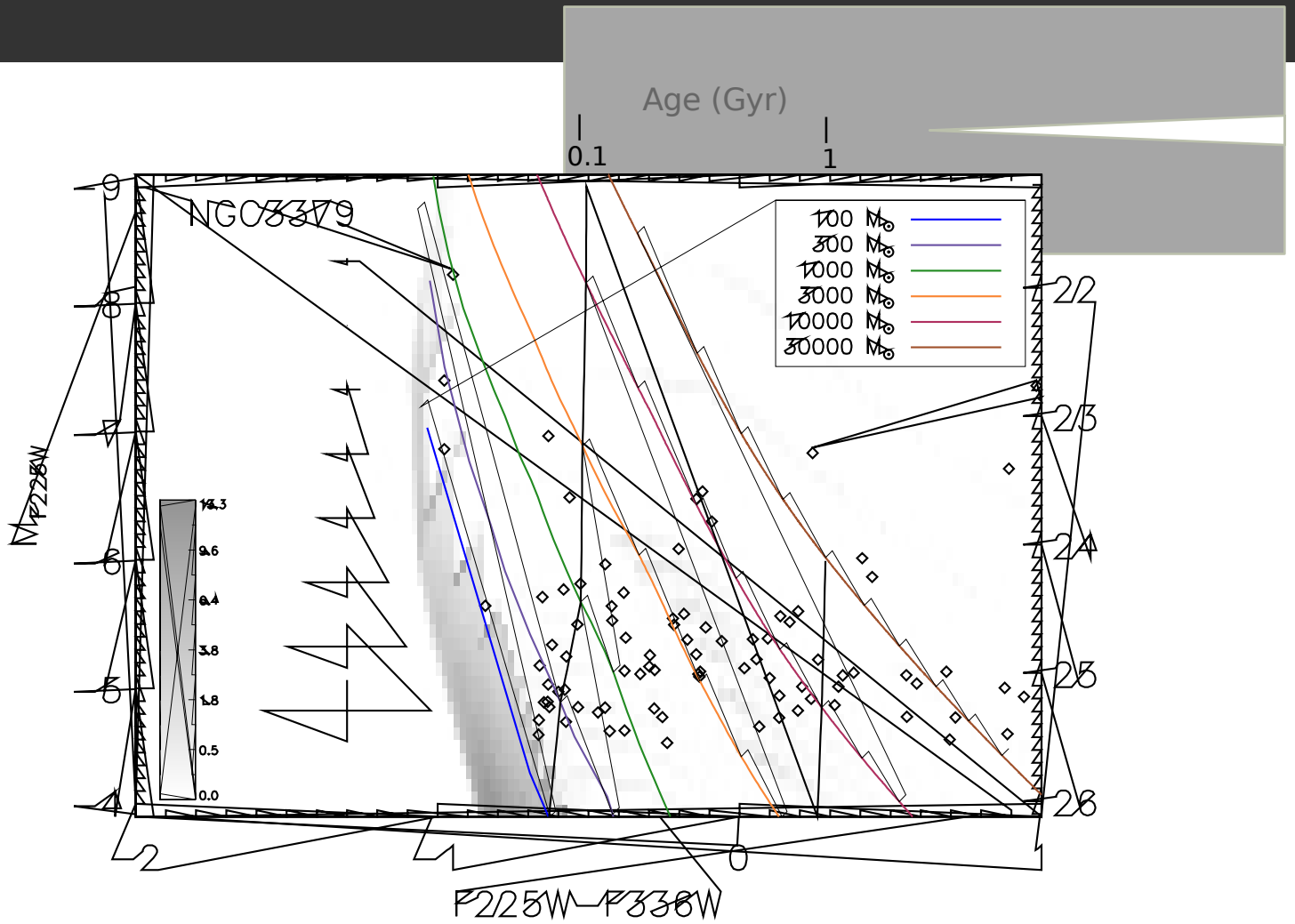
Distribution of Sources



Color-Magnitude Diagram

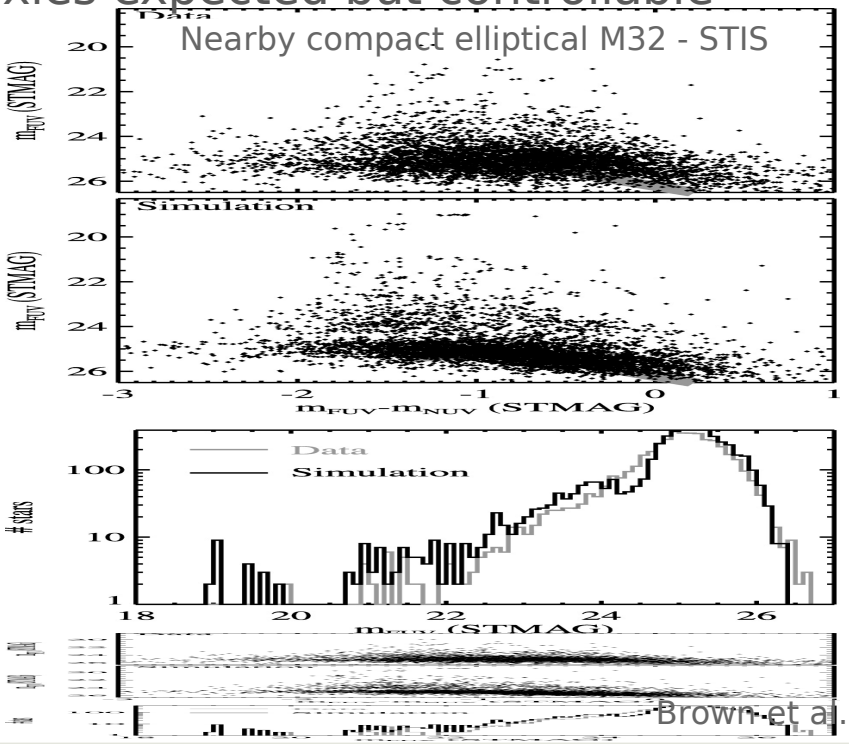


Consistent with Star Clusters



Potential Contaminants

- Background galaxies:
  - AGNs & star forming galaxies expected but controllable
- Globular clusters:
  - too “red”
- P-AGB/HB stars:
  - too faint
  - extremely short-lived

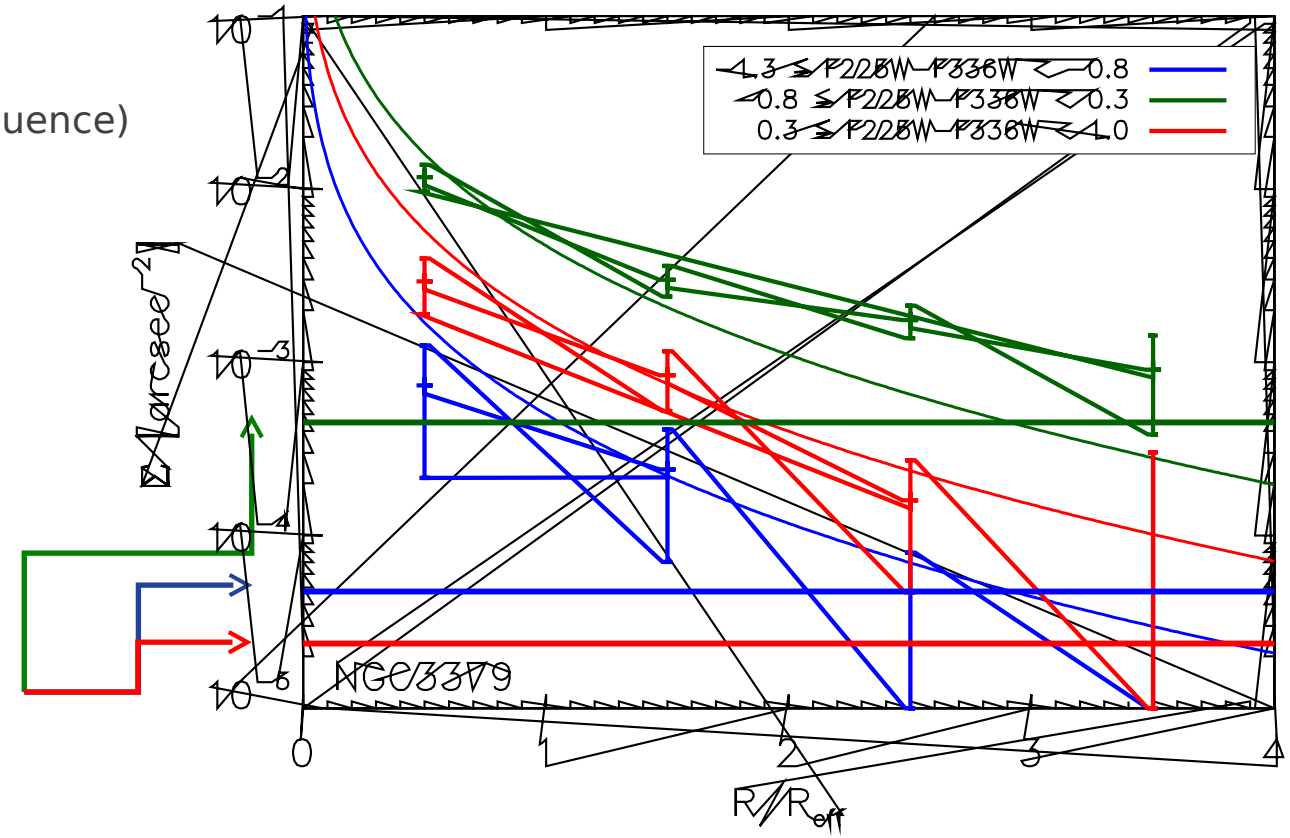


Brown et al. 2008

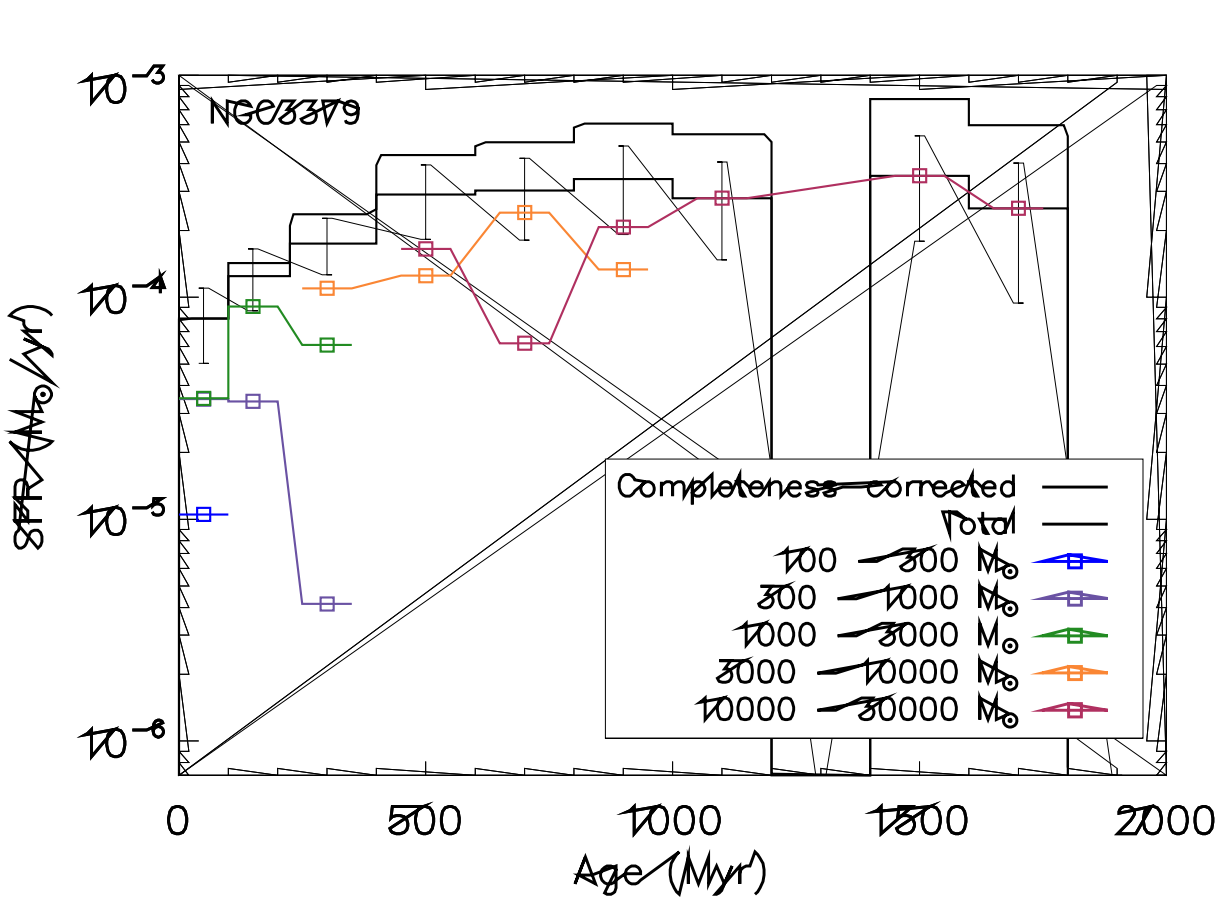
Radial Surface Density Profiles

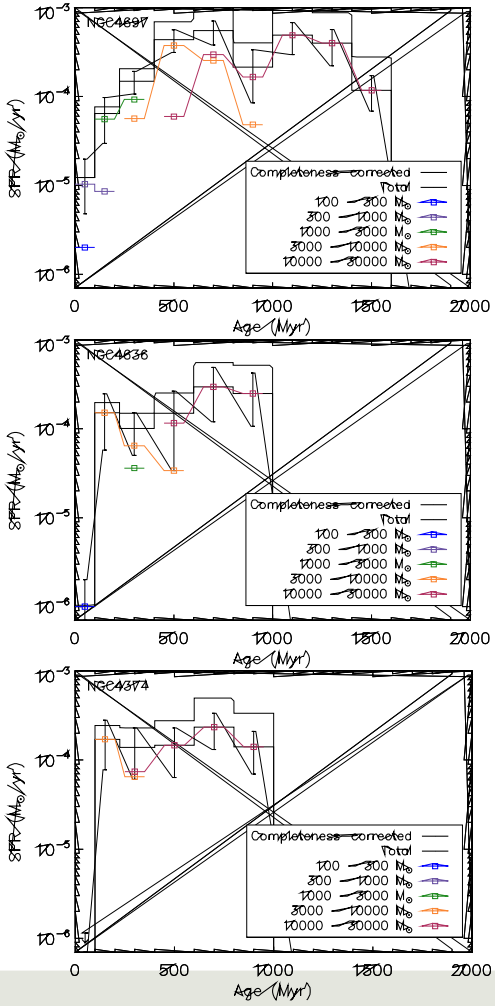
Age:
< 40 Myr (Blue; main sequence)
40 Myr to 1 Gyr (Green)
> 1 Gyr (Red)

Background level

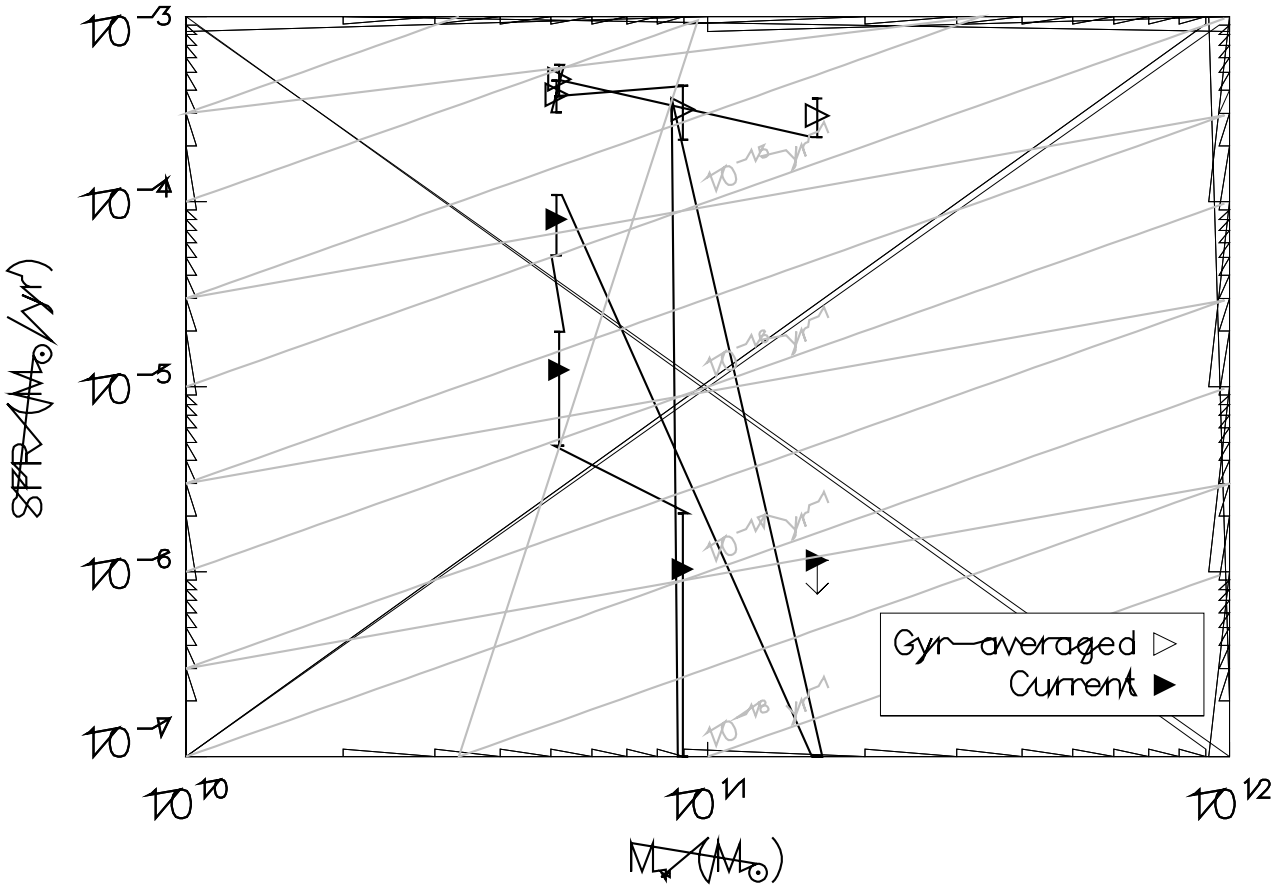


Star Formation Rates & Histories





Specific Star Formation Rates



Further Results

No clear correlation between SF indicators and detected SF

- SF is consistent with previously measured line index ages that indicated all observed galaxies are uniformly very old (Kuntschner et al. 2010; Sanchez-Blazquez et al. 2006; Trager et al. 2000)
  - ~0.03% of U-band light – wouldn't affect line index
- Level of frosting:
  - 10-8 of stellar mass younger than 100 Myr
  - 10-5 younger than 1 Gyr

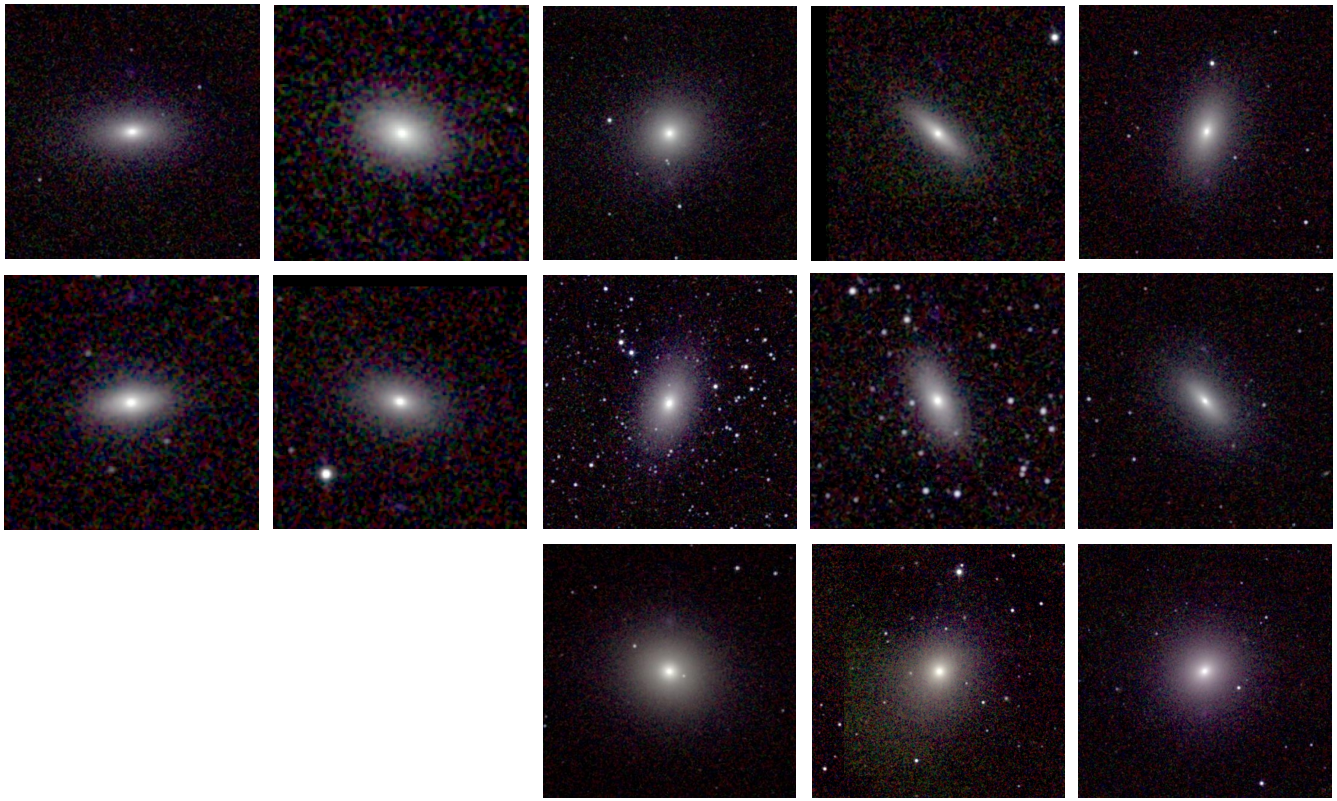
Summary

- First direct detection of young stars in elliptical galaxies using Hubble Space Telescope WFC3 UV imaging
- Ongoing, low level star formation detected in all targets (~10-5 M yr -1)
- Star formation history roughly constant from 0.5-1.5 Gyr (~4 x 10-4 M☒ yr -1), but decreased by a factor of several in past 0.3 Gyr
- Frosted by a fraction 10-8 of stars younger than 100 Myr, 10-5 younger than 1 Gyr

Future Work

Images from 2MASS

Future Work



- Interactions?
- AGNs?
- Ages?
- Masses?
- Cooling flows?
- ...?

Images from 2MASS