UCL DEPARTMENT OF SPACE AND CLIMATE PHYSICS
MULLARD SPACE SCIENCE LABORATORY

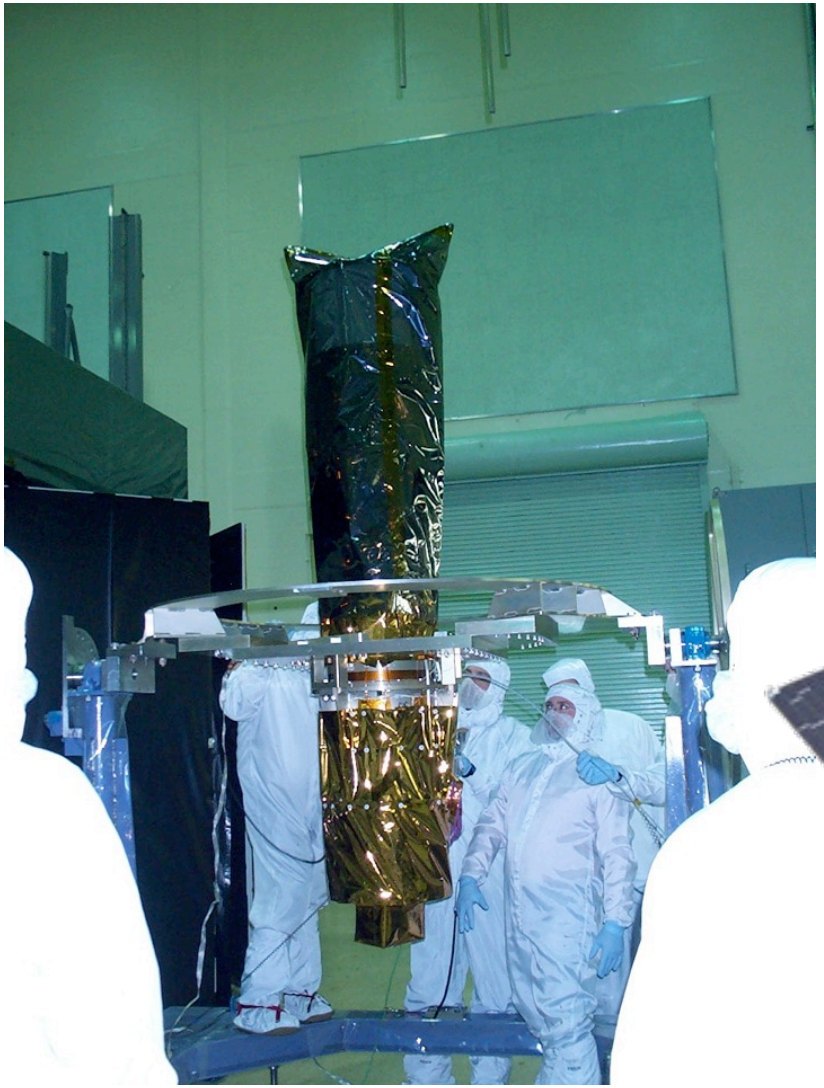
Spatially Resolved Star Formation in M100

Alison Newell, Mark Cropper & Ignacio Ferreras
Mullard Space Science Laboratory, University College London

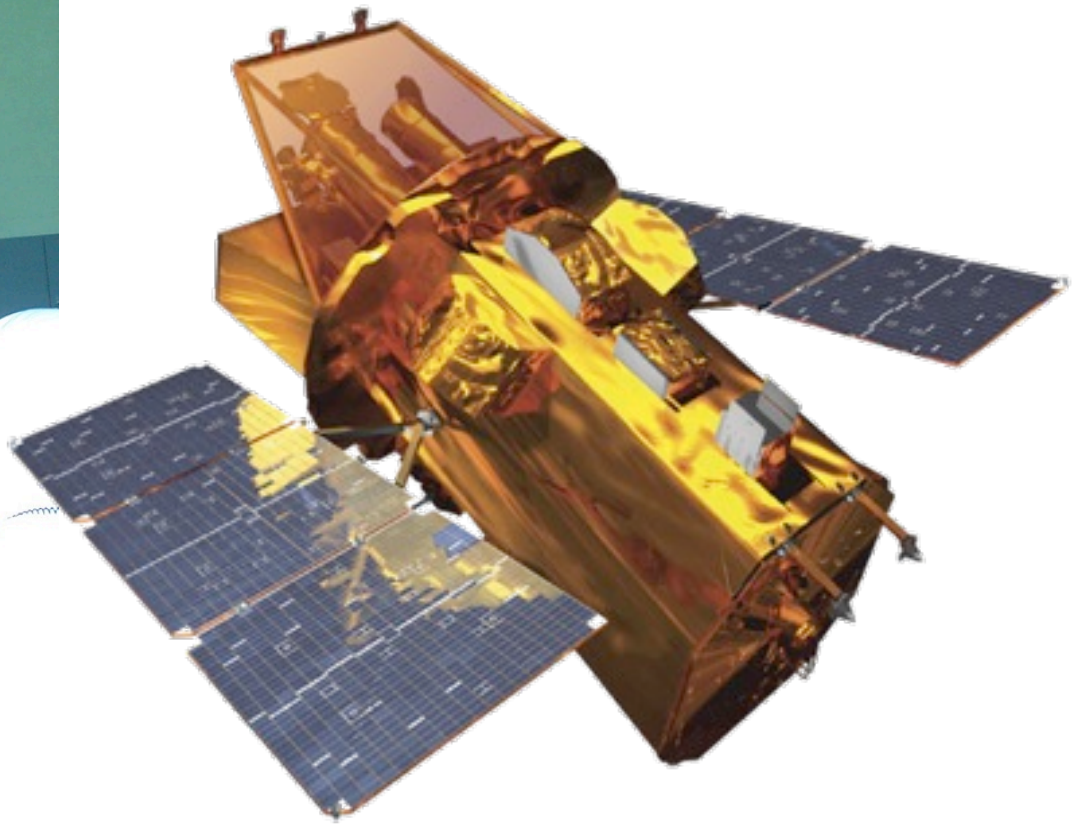
Background of this project

- This project aims to quantify the extent and nature of star formation in an important grand-design spiral galaxy, M100
- UV images reveal star formation regions very clearly, especially in face-on systems
- The UV is valuable for
  - understanding the recent star formation history of the universe
  - examining feedback processes in the interstellar medium (recycling of elements, superwinds)
  - initial mass function for star formation… *etc.*
- These are critical issues in galaxy evolution modelling
- They are essential for constructing Spectral Energy Distributions for galaxies in the early universe

Swift UVOT



- 30 cm modified R-C telescope
- 17x17 arcmin FoV
- photon counting detectors
- 1700 - 6000 Å

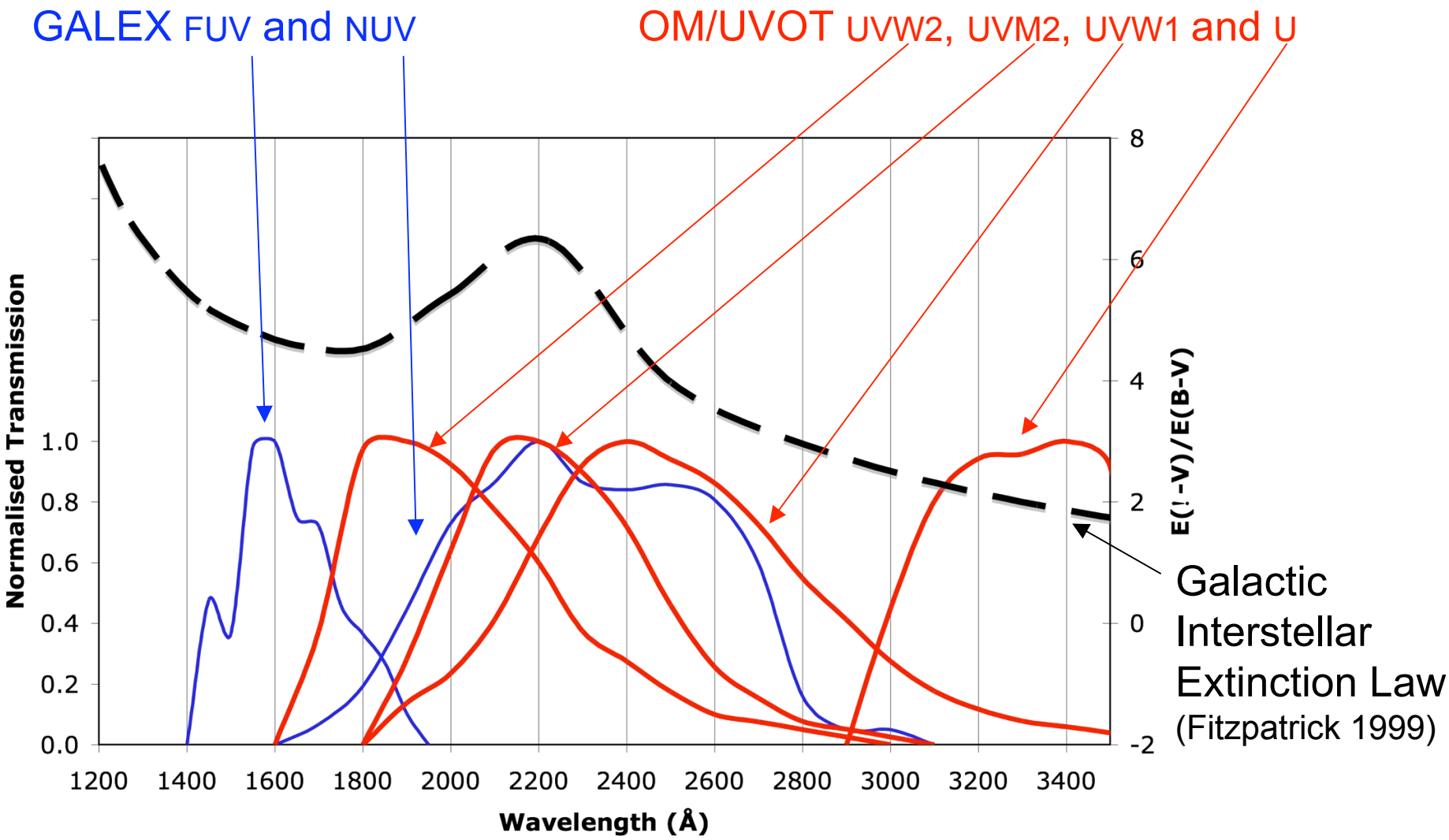


XMM-Newton Optical Monitor

UV Imaging Surveys: OM/UVOT and GALEX

- Spatial Resolution
  - *XMM*-OM
  - *Swift* UVOT } 2 arcsec — 3 UV bands (+3 optical)
  - *GALEX* — 5 arcsec — 2 UV bands
- OM+UVOT survey contains > 100 nearby galaxies
  - comparable to GALEX
  - some exposures very deep (driven by X-ray needs)
- OM/UVOT contains filter information centred on 2200Å peak of dust absorption
  - dust obscuration can be determined from UV observations alone
  - to be combined with optical bands from OM/UVOT (or other)
  - should also use *GALEX* and *Spitzer*-SINGS

OM/UVOT and GALEX filter bandpasses



Comparison between GALEX and Swift-UVOT or *XMM*-OM: the gain in spatial resolution

M81 with GALEX (2 UV colour)

M81 with *Swift*-UVOT (3 UV colour)

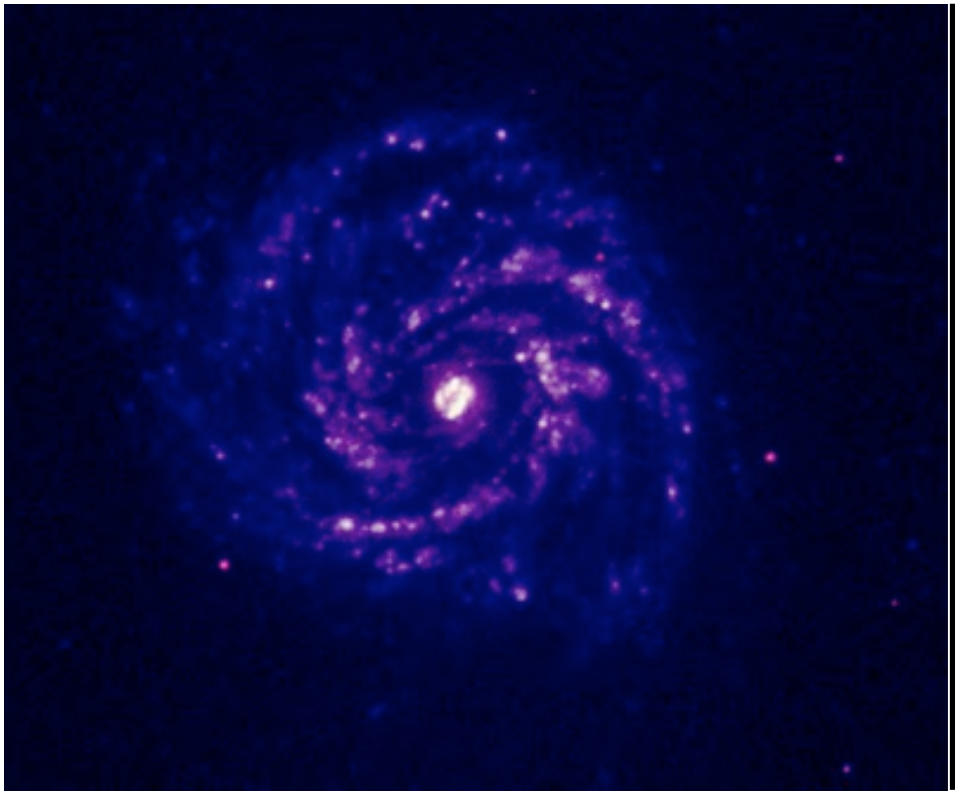
NGC1365

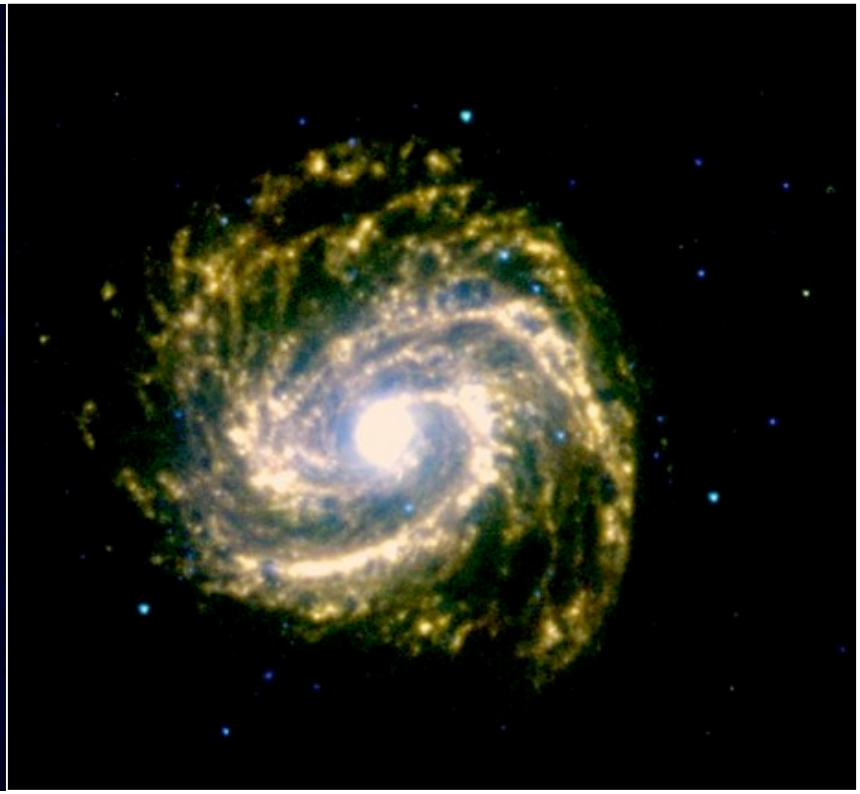
Swift-UVOT
UV+optical
image
(6 band)

M100

UVOT: 1700/2200/2500 Å

Spitzer IRAC: 3.56/5.73/7.9! m





M100: Basic Properties

- Sc spiral, LINER, nearly face-on, ~20 Mpc
- Well studied, central regions and spiral arms:
  - optical, IR, H alpha, Sloan.
  - CO maps
  - HST - spiral arm
  - GALEX - only NUV

UVOT Observations

- Data taken on 2005 November 5: ~100 pc/resolution element
- Exposures:
  - UVW2 1928Å 6832 sec
  - UVM2 2346Å 5108
  - UVW1 2600Å 3415
  - U 3465Å 1704
  - B 4392Å 1109
  - V 5468Å 1706

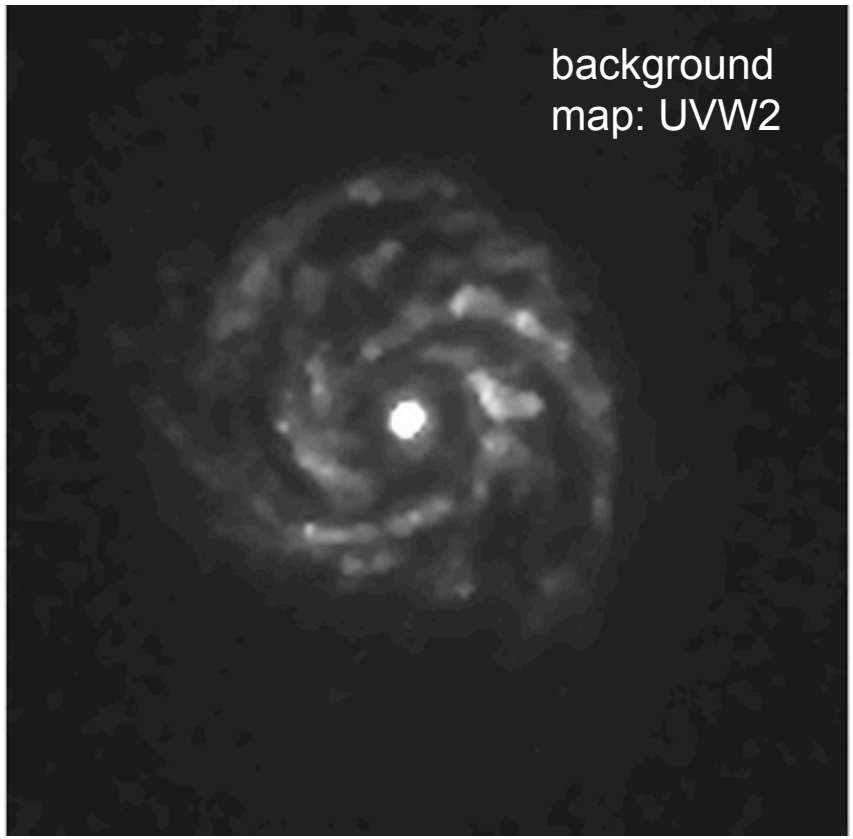
- UVOT software used to combine and register images → FITS (see http://heasarc.gsfc.nasa.gov/docs/swift/analysis/swift_tools.html); some aspect corrections refined using routines from Mat Page
- Max count rate (B) was 1.47 c/s/pix
  ⇒ no correction for coincidence losses

Data Analysis

- The star formation regions are
  - extended (somewhat diffuse) sources
  - crowded
- Different techniques considered:
  - circular apertures
  - elliptical apertures
  - tessellation
- All suffer from uncertainties in aperture shape and placement: used elliptical

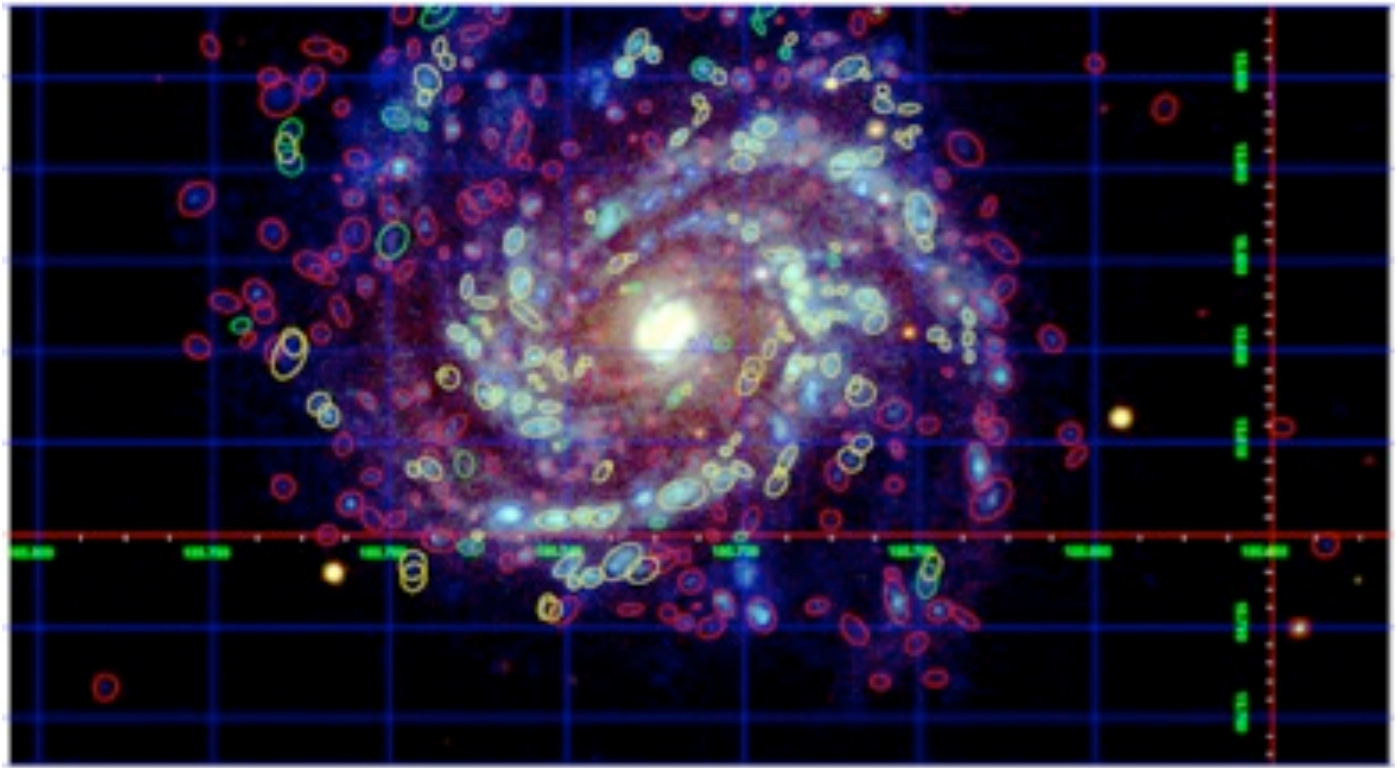
Data Analysis

- Background subtraction complex in presence of smooth component of stellar emission in spiral arms
- Needs to be determined locally for each region



- Foreground stars and obvious background galaxies eliminated using SDSS data

Data Analysis

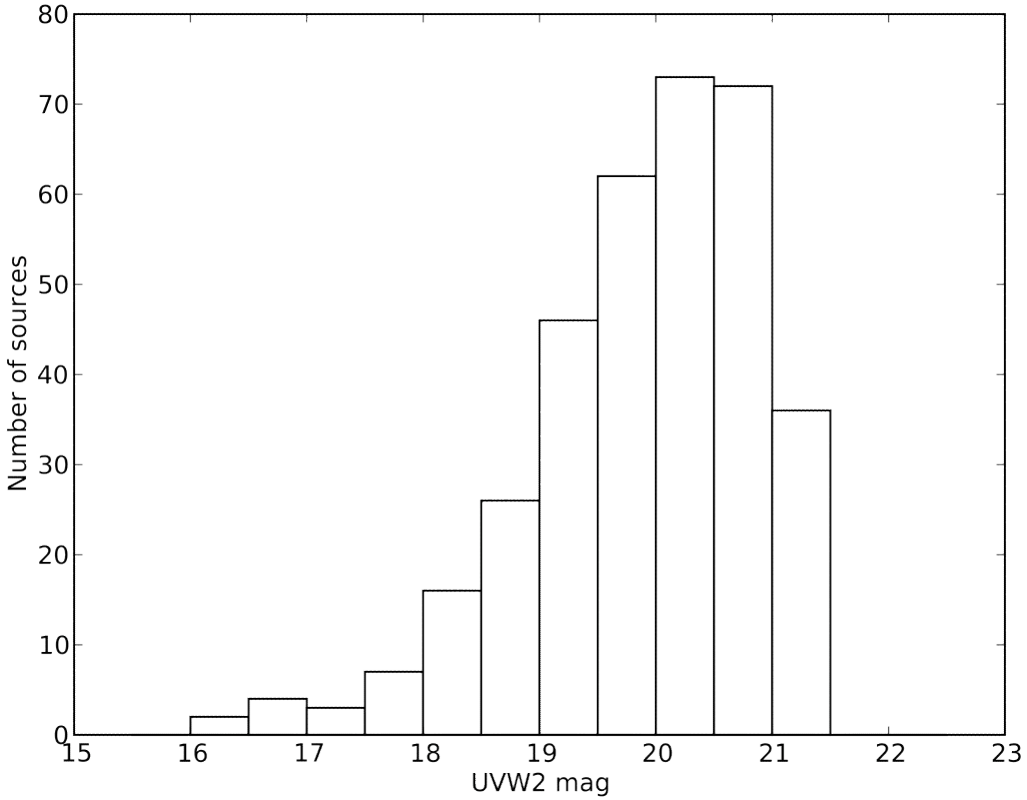


red OK
green OK deblended
yellow flux affected

- Use SExtractor with Kron radius for magnitude measurements
  - UVW2 (1928Å) image used to define star formation regions
  - all other bands used the same regions definition
- Smaller aperture on central region for colour measurements

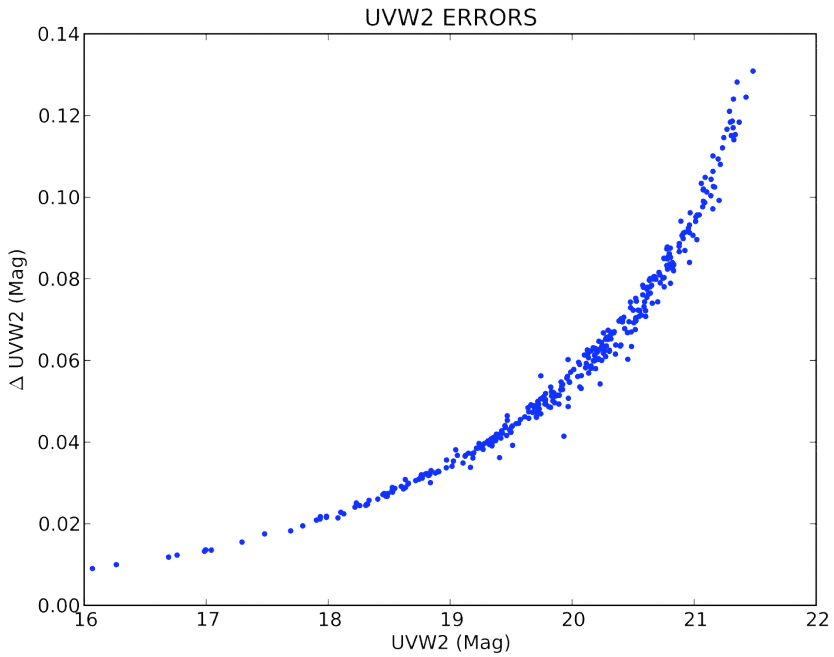
Data Resource and Modelling

- Colour magnitude diagrams and colour-colour diagrams available for
  - 341 SF regions with 3 UV magnitudes
  - 76 regions with 3 UV + 3 optical magnitudes



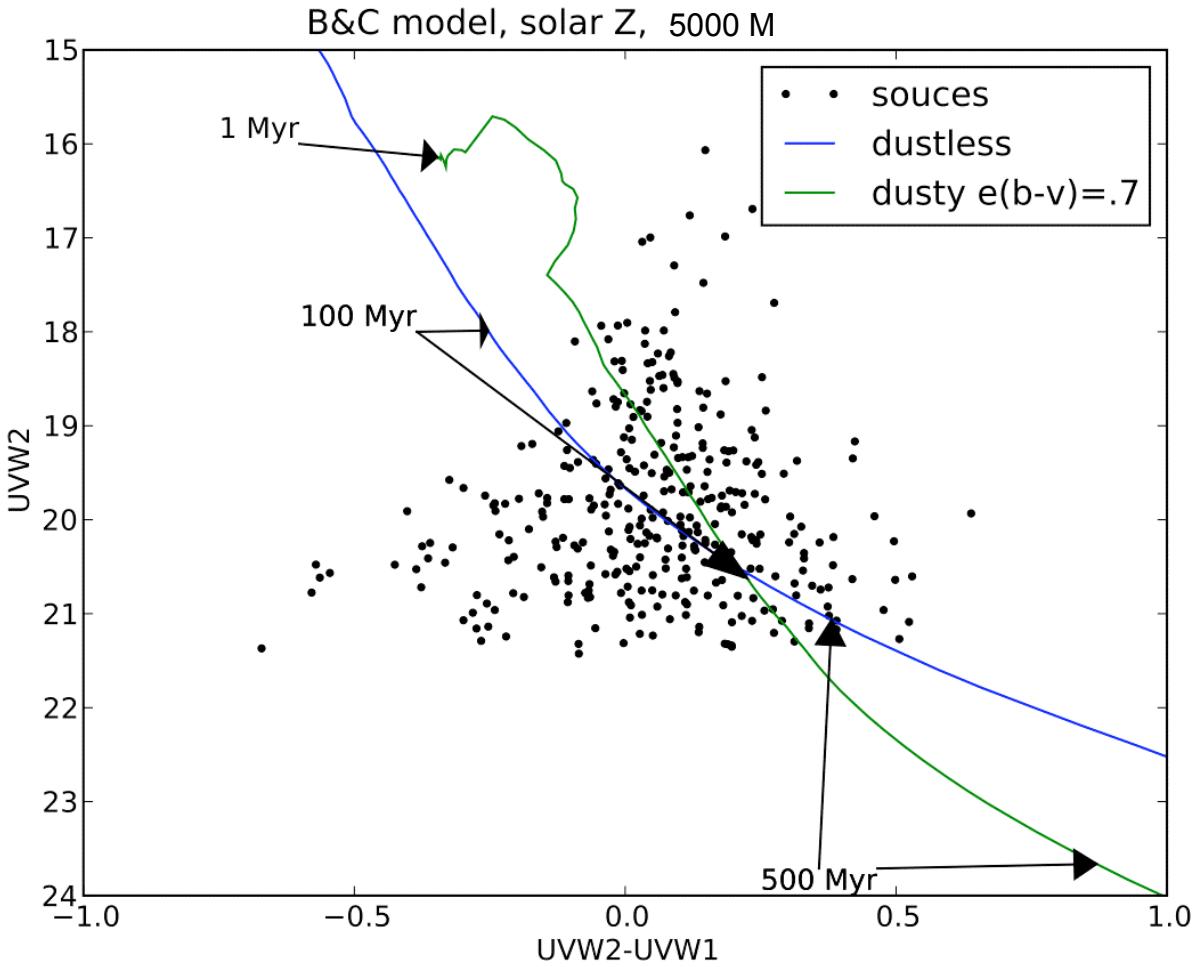
Data Resource and Modelling

- Limiting Vega magnitudes
  - UVW2 1928Å 23.3 (all 5 !)
  - UVM2 2346Å 23.8
  - UVW1 2600Å 22.3
  - U 20.9
  - B 20.7
  - V 20.3

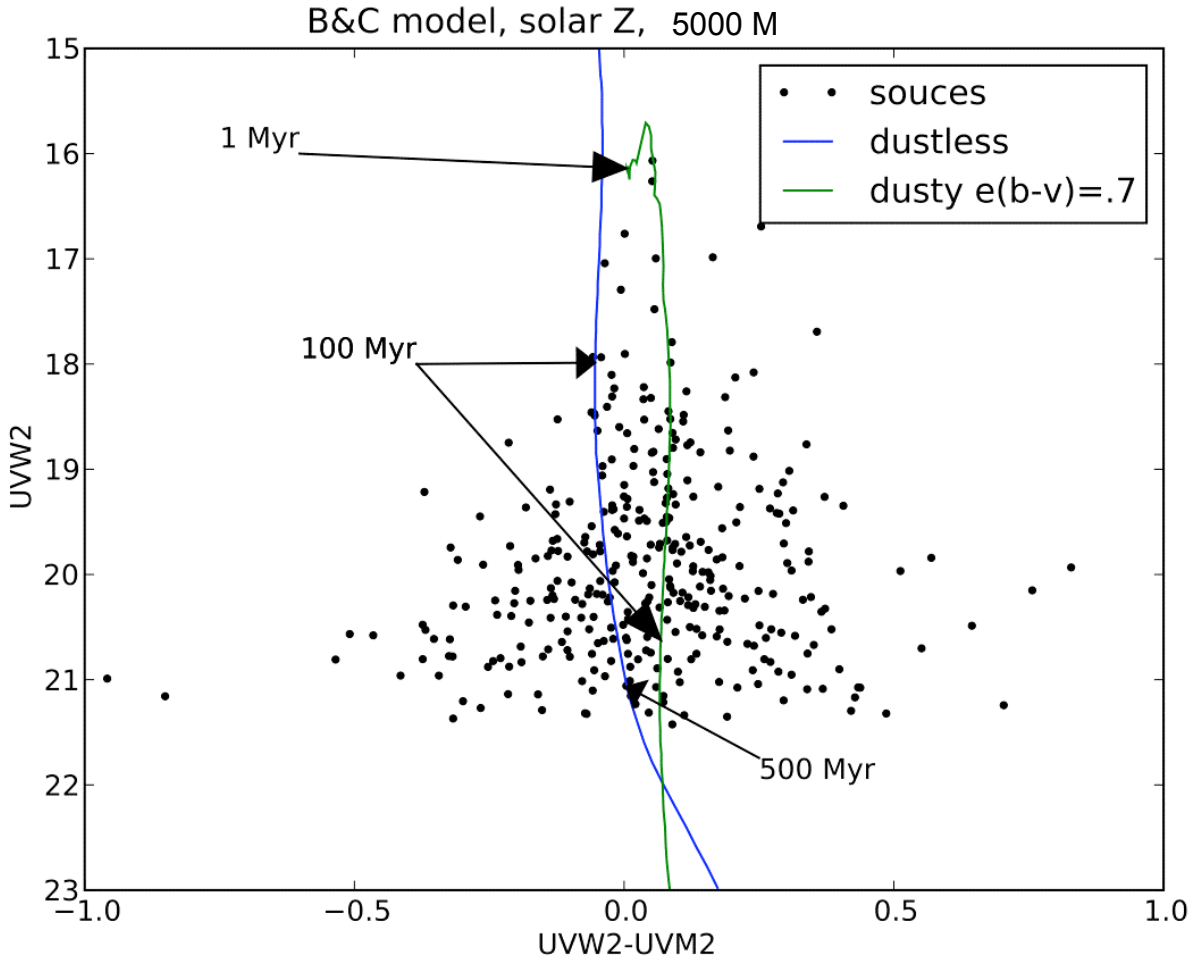


- Bruzual & Charlot (2003) models folded through UVOT filter responses (later also use Starburst99); Chabrier IMF

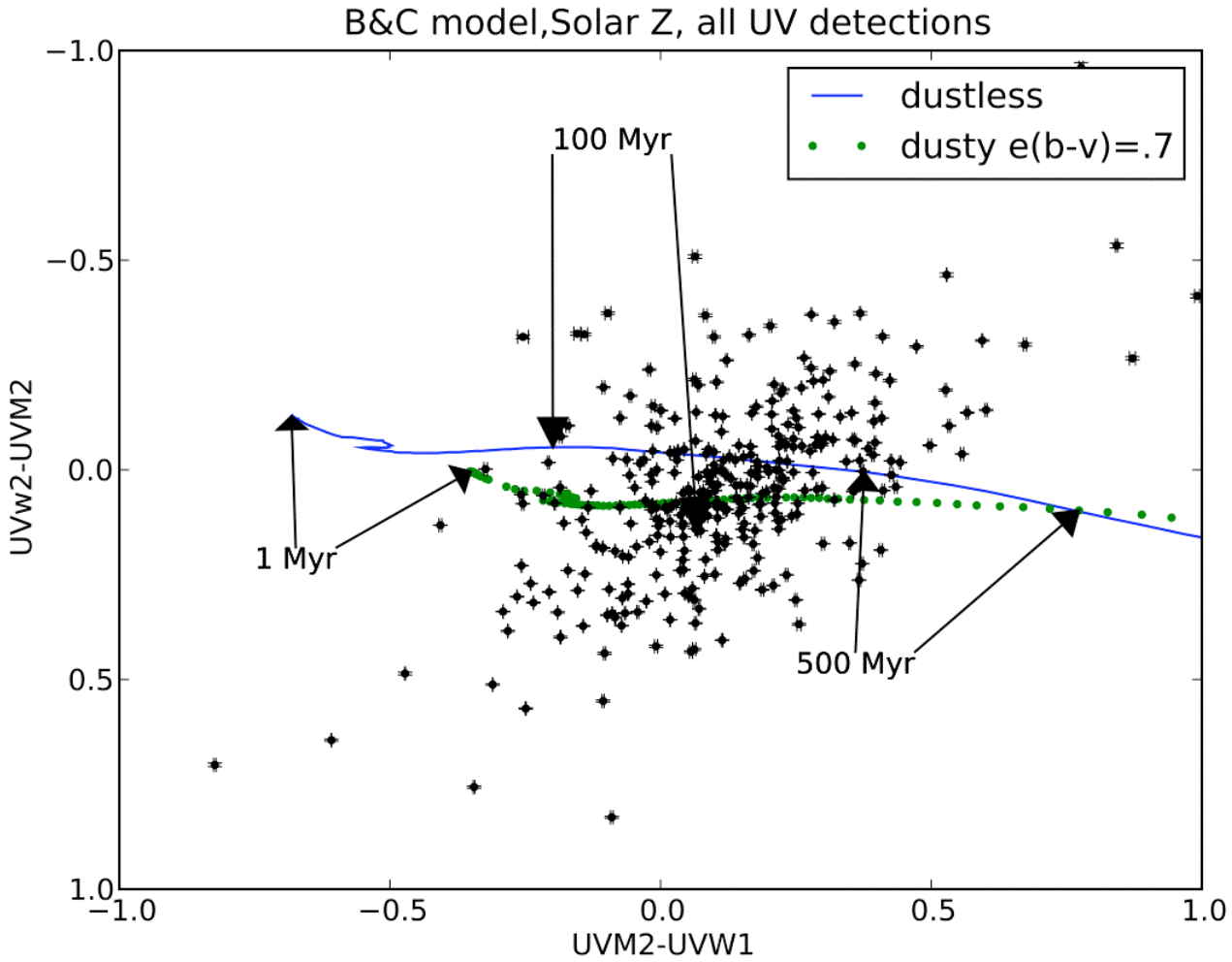
Colour-Magnitude Diagrams: UVW2 vs UVW2-UVW1



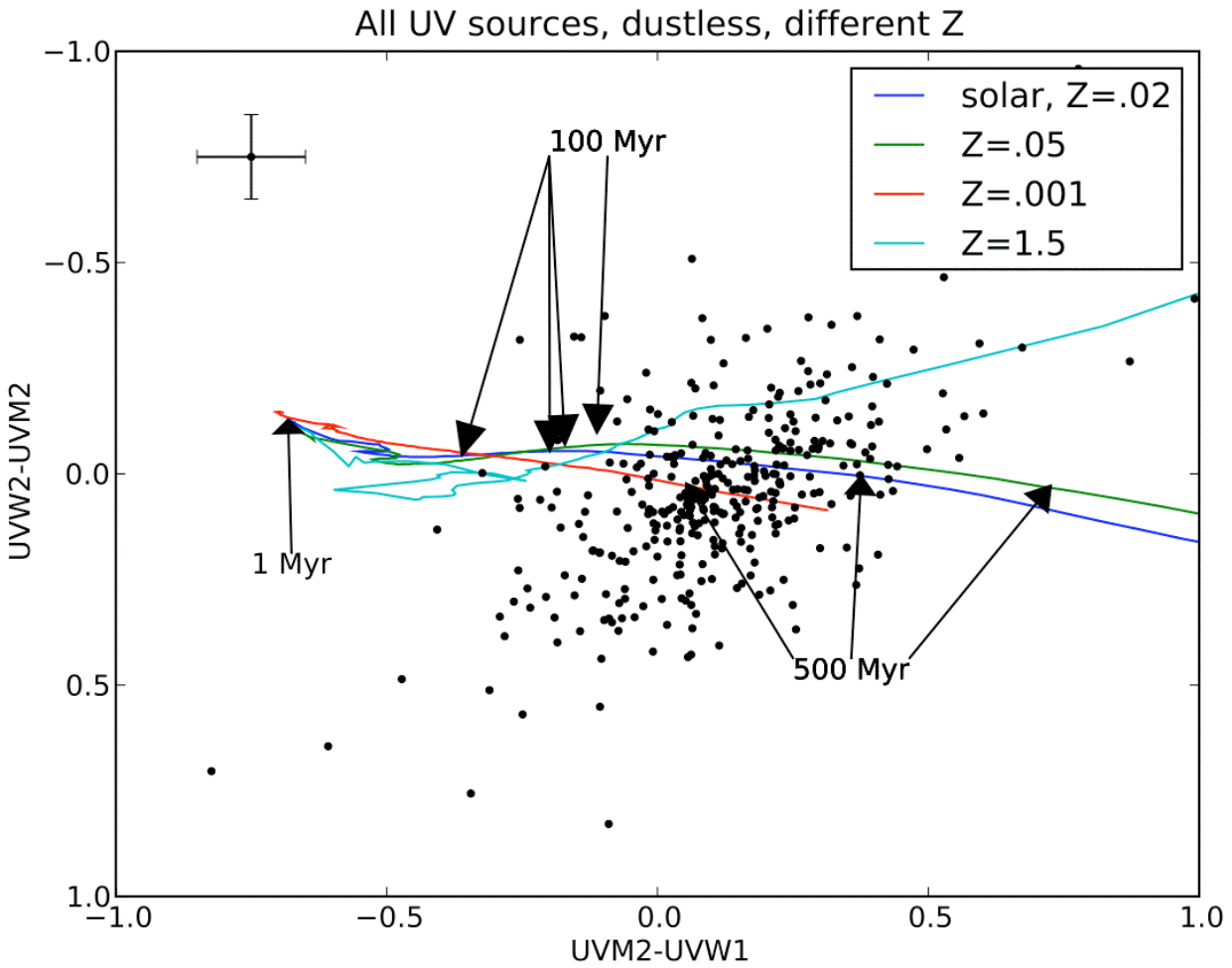
Colour-Magnitude Diagram: UVW2/UVW2-UVW1



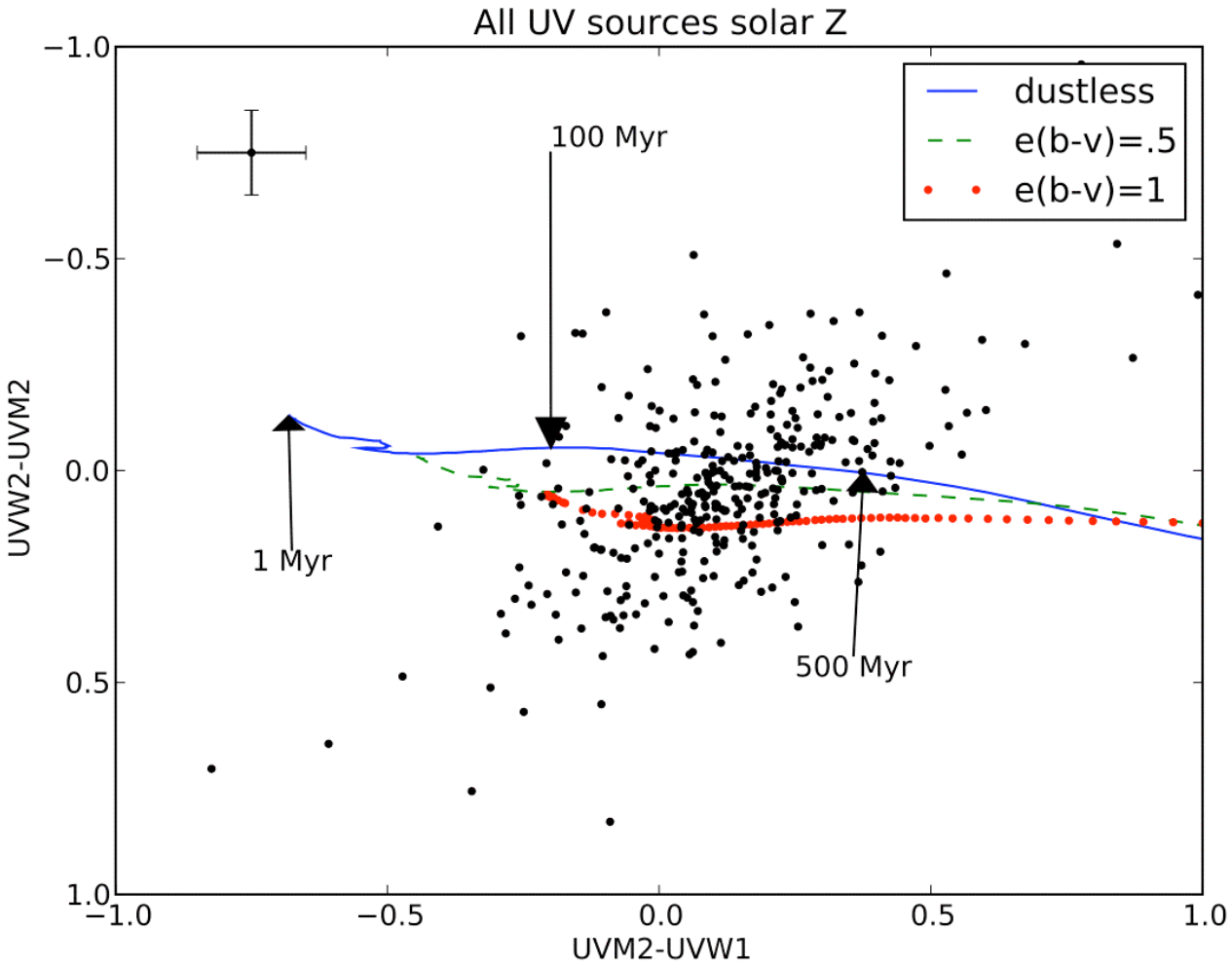
Colour-colour diagrams: UVW2–UVM2/UVM2–UVW1



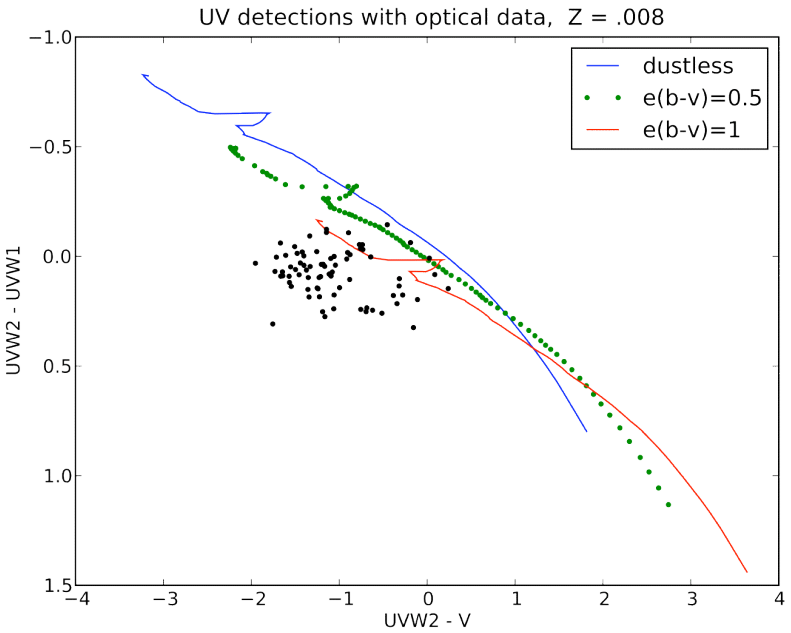
Colour-colour diagrams: metallicity

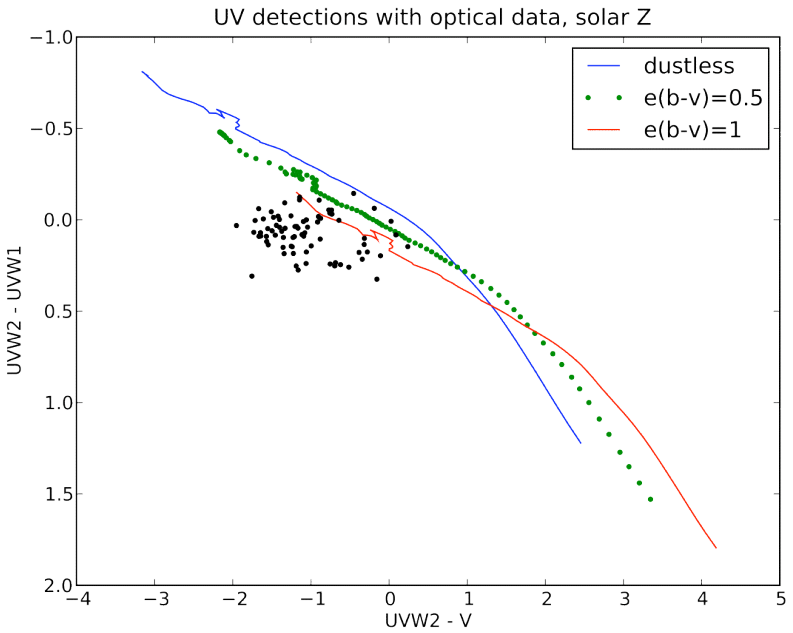


Colour-colour diagrams: dust



Colour-Colour Diagrams: UVW2–UVW1 vs UVW2–V





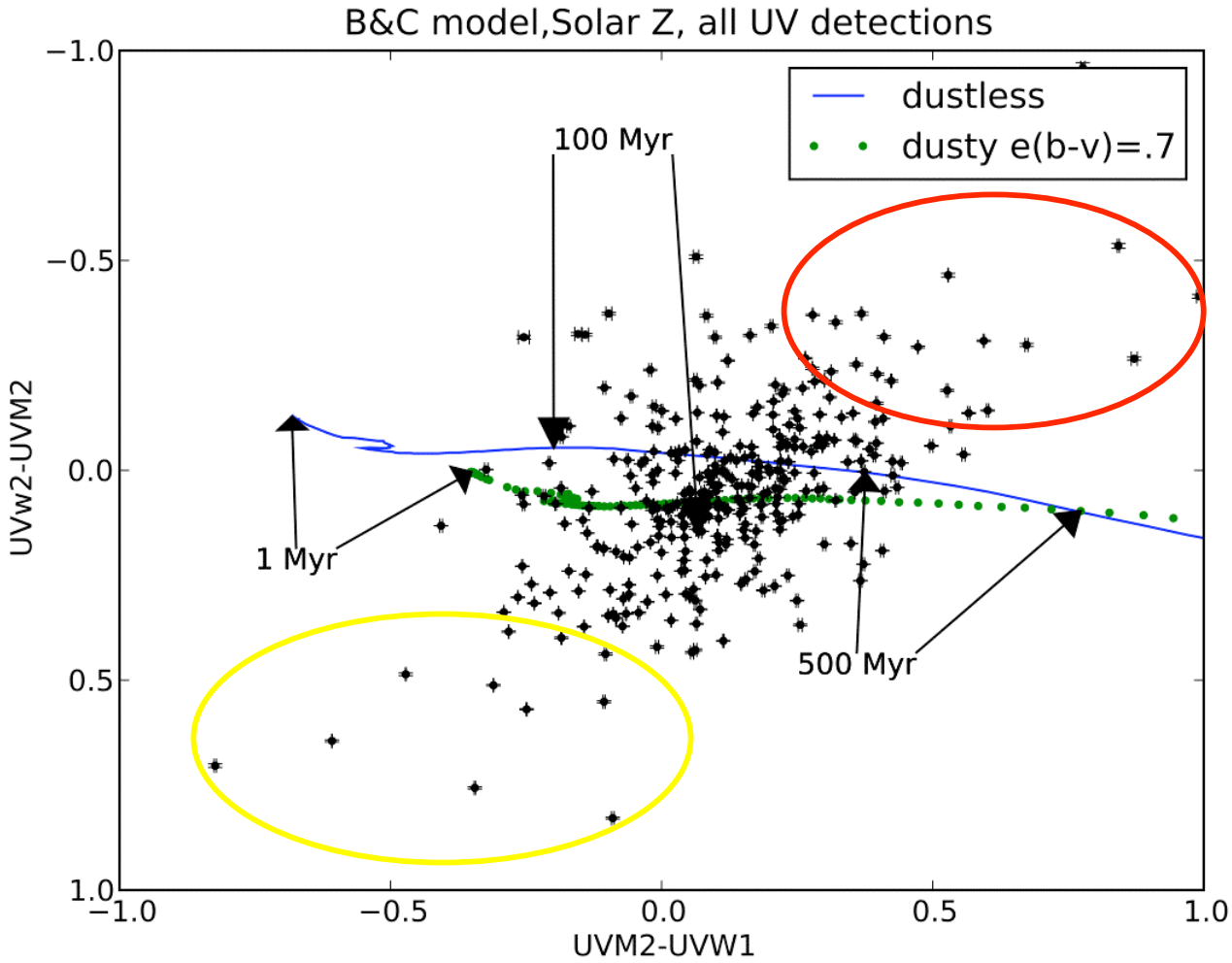
- Models don't describe population: origin of the discrepancy unclear
- Indicative of more dusty and more metal rich populations

Results

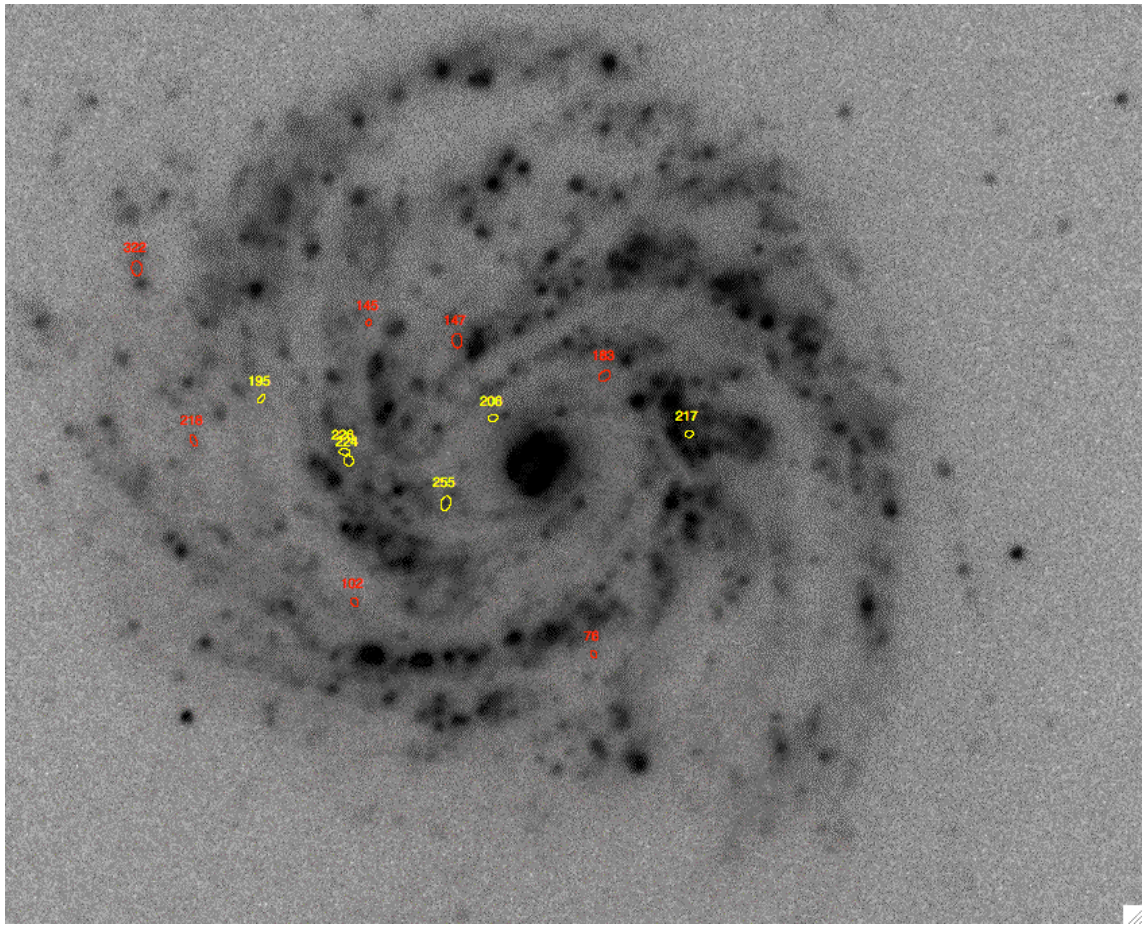
- Ages: ~100 Myr but with a range from ~30-300 Myr
- Metallicity: ~ Solar
- Extinction: E(B–V) ~ 0.7

- fairly large range in properties; some unexplained aspects

Colour-colour diagrams: outliers



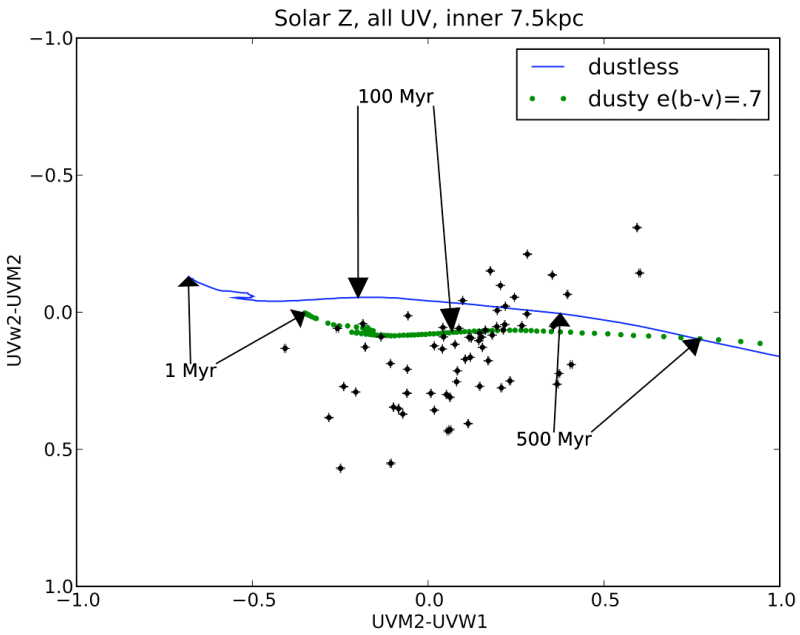
Outliers

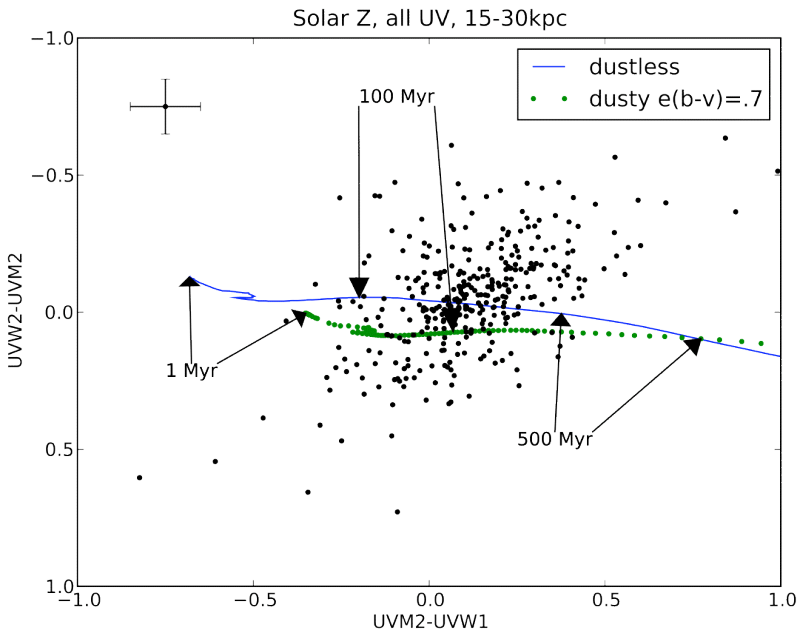


- Seem preferentially to be located in the inter-arm regions
- Nature unclear: possibly background AGN?

Extinction with Galactocentric Radius

- Extinction decreases with galactocentric radius
- From colour-colour diagrams E(B-V) ranges from ~0.4 to ~0.8





Star Formation Rates: still to be done

- Star formation rates will be calculated using STARBURST99/B&C03 and methodology in Buat et al 2002, Zasov & & Abramova (2006) *viz*

$$\mathrm{SFR} = \frac{\mathrm{SFR(UV)}}{1-\varepsilon} \qquad \mathrm{SFR(UV)} = C_{2000} L_{2000}$$

$$C_{2000} = 2.03 \times 10^{-40}\ (M_\odot/\mathrm{yr})/(\mathrm{erg\ s^{-1}\AA^{-1}})$$

- The luminosity function for clusters and associations will also be constructed

- Tests of global star formation relationships at local scales

Summary

- We have described the characteristics of UK-built vacuum-UV imagers which have complementary (and for some studies superior) capabilities to *GALEX*: under-utilised resource available to all
- We have selected the face-on spiral M100 for a study of the local star formation rates as a function of position in the galaxy: observations in 6 bands made in Nov 2005
- We have described the analysis procedures required to extract the magnitudes and colours of individual star formation regions
- We have compared these to Bruzual & Charlot 2003 models to determine ages, metallicities and extinctions
- Still to be done is to determine the star formation rates as a function of location within the galaxy, and to compare to standard measures