The Panchromatic Hubble Andromeda Treasury. XXX. Calibrating ultraviolet and infrared star formation tracers as a function of environment.

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and

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1. Summary

The proposed project is in many ways similar to the pilot study (Simones et al. 2014): measure SFRs for a set of regions based on integrated fluxes of a particular tracer and compare with the mean SFRs from the derived SFHs. The main difference is that we will have full control over the sample design, whereas the pilot sample contained only UV-bright regions and was limited in the range of physical sizes.

The overall concept of the project is to compare SFR maps from integrated tracer emission with a SFR map obtained from PHAT SFHs. We will consider at minimum FUV flux as a SF tracer, though if possible, I would like to include FUV+24 μm as well. Other currently available data include GALEX NUV, and Spitzer/MIPS 70 and 160 μm. Comparisons can be made on a pixel-by-pixel basis in the maps, and also on the basis of larger regions, e.g., representing different slices in galactic radius and surface brightness.

The purpose of this document is to clearly define the project and establish the main science questions at the beginning. This way, everyone involved will be on the same page and we will be able to move forward as efficiently as possible.

2. Data

2.1. SFR map

Alexia has calculated SFHs for all bricks except 1 and 3 in the bulge (Figure 1), with each brick divided into 450 rectangular subregions, or "pixels" (to distinguish from the term "regions", which will refer to larger areas made from groups of pixels). There are 9450 pixels total, each one approximately $25''$ per side. I have the following data in hand:

- Coordinates of the region corners in RA and dec
- F475W and F814W photometry

- Best-fit SFH for each pixel:
  - $A_{\mathrm{V},f}$ and dA_{V} extinction parameters
  - Model CMD data
  - SFR and [M/H] vs. t
- Uncertainties:
  - Random uncertainties from the HMC routine. All pixels.
  - Systematics due to isochrone uncertainties. Select pixels only. *In progress*
  - Systematics due to uncertainties in the $A_{\mathrm{V},f}, dA_{\mathrm{V}}$ parameters. All pixels? *In progress.*

For each SFR tracer of interest, I will average the SFHs in the pixels over the relevant timescale, Δt (e.g., the last 100 Myr for the FUV tracer) to obtain maps of the mean SFRs, $\langle \mathrm{SFR} \rangle_{\Delta t}$. The uncertainties in $\langle \mathrm{SFR} \rangle_{\Delta t}$ will be evaluated as described in Simones et al. (2014).

An extinction map is required for UV dust corrections. Ideally, an extinction map would be derived from just the best-fit $A_{\mathrm{V},f}$ and dA_{V} extinction parameters in each pixel. Doing so ensures self-consistency in the analysis and keeps the list of assumptions to a minimum (those already made by MATCH). The simplest approach is to calculate the mean total extinction, $A_{\mathrm{V},f} + dA_{\mathrm{V}}/2$. The more accurate approach is that of Ben Johnson, who modeled the intrinsic and reddened (according to the same $A_{\mathrm{V},f}, dA_{\mathrm{V}}$ extinction model) FUV magnitudes in Simones et al. (2014): 1) the modeled intrinsic spectrum is split up into several parts, emulating multiple lines of sight; 2) a value of A_{V} is drawn from a uniform distribution between $A_{\mathrm{V},f}$ and $A_{\mathrm{V},f} + dA_{\mathrm{V}}$ for each sight line; 3) the reddened spectra along the sight lines are added up to get the total reddened spectrum, which is converted to an FUV magnitude; 4) the difference between the intrinsic and reddened FUV magnitudes is the total FUV extinction. The challenge with this approach will be finding a method for estimating the total FUV extinction in a way that does not depend on the source spectrum (this is in progress).

There are a couple of issues that will need to be resolved before a final $\langle \mathrm{SFR} \rangle_{\Delta t}$ map can be constructed:

- Some of the pixels overlap each other. Should their $\langle \mathrm{SFR} \rangle_{\Delta t}$ values and uncertainties somehow be combined? The easiest approach would be to not combine overlapping data and choose one pixel over the other.
- The pixels are not on a uniform grid, resulting in overlapping pixels between bricks and pixels in one location of the map being rotated with respect to other locations. Should the SFR map be resampled onto a uniform grid? One way to do this is to choose a new pixel size (comparable to the original pixel size or larger, as the UV and 24 μm data have much smaller pixel scales) and draw a grid inside the boundaries of the PHAT survey. I would then add and subtract the SFHs as needed to obtain the SFH in each new pixel, from which $\langle \mathrm{SFR} \rangle_{\Delta t}$ can be calculated.

Timeline: Final $\langle \mathrm{SFR} \rangle_{\Delta t}$, uncertainty, and extinction maps should be obtained by June 1st. This step will require more new code to be written than any other step in the project (on top of what already exists from the pilot). It will also require experimentation to find reasonably-optimal methods for transforming the SFR data (including uncertainties) into a usable map. I allocate 1 week for constructing a polygon mesh (or some other representation) of $\langle \mathrm{SFR} \rangle_{\Delta t}$ values, and 1 week to refine the map by dealing with overlap and griding issues. With the map-making process established, I allocate 1 week to compute the corresponding uncertainty and extinction maps. Despite my best efforts to code everything efficiently, computation may become a bottleneck and I should prepare to secure additional processors (e.g., `vesuvius.spa.umn.edu`, `titanus.spa.umn.edu`).

2.2. GALEX mosaic

I have made GALEX FUV and NUV mosaics using Montage. The only remaining tasks are to double-check the WCS alignment with the Spitzer data (if we use it) and to confirm that flux has been conserved to a satisfactory degree with respect to the input FUV and NUV images. With a pixel scale of $1.5''$ (much smaller than the SFH pixel size), I do not expect this to be an issue.

If anyone knows of science-grade FUV and NUV mosaics that we can use, please tell me.

Timeline: This should only take a day or two, maybe a couple more if something goes wrong and I have to remake some mosaics.

2.3. Spitzer 24 μm mosaic

Karl Gordon kindly supplied us with Spitzer/MIPS 24, 70, and 160 μm mosaics of M31. I still need to learn a bit more about how these were created, but for now I am assuming they are acceptable to use. The pixel scale of the 24 μm image is approximately $1.2''$ (smaller than the documented MIPS pixel scale for the 24 μm channel). As with GALEX, this is much smaller than the size a SFH pixel.

3. Tracers

Kennicutt & Evans (2012) offer calibrations for FUV, NUV, 24 μm, 70 μm, FUV+24 μm, and NUV+24 μm. It might also be worth considering the FUV and FUV+24 μm calibrations from Leroy et al. (2012), the FUV calibration from Salim et al. (2007), as well as calibrations by other authors. At the very least, we will be comparing the SFH-based SFRs with SFRs from the FUV calibration. The next highest priority will be FUV+24 μm. Beyond that, the pipeline will be developed enough that trying out other types of calibrations will be trivial (assuming the same input GALEX and Spitzer data).

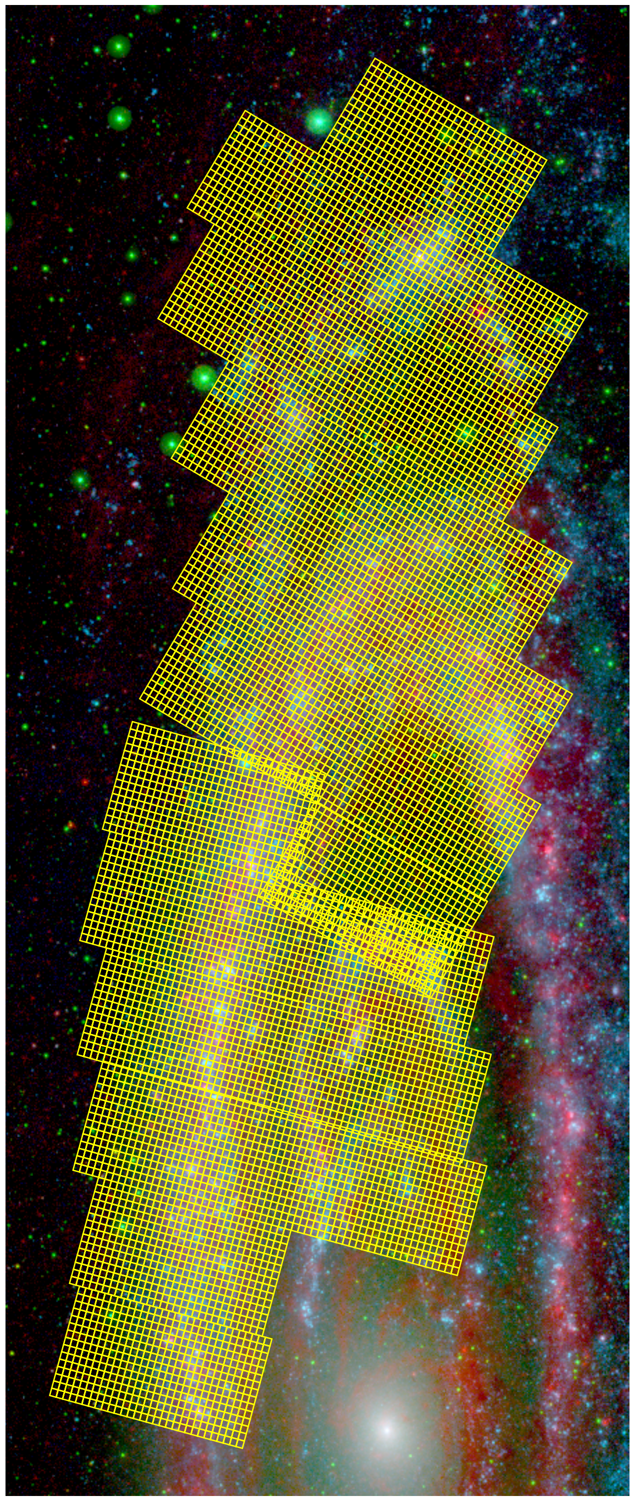

Fig. 1.— SFH pixel footprints over an RGB image of M31 (red: Spitzer 24 μm, green: GALEX NUV, blue: GALEX FUV).

4. Science

Main questions:

- How accurate is a given flux calibration for measuring SFR?
- How precise is it?
- Are accuracy and precision affected by environment (e.g., radius and surface brightness)?
- Are there any limitations for this tracer (from Simones et al. 2014, we already know that small areas/populations being problematic)?

Main products:

- Measurement of the uncertainties associated with using a particular flux calibration.
- A new calibration for at least FUV, perhaps as a function of environment and an overall value.

The main questions and products of the paper will guide the sample design. The two-dimensional approach that was proposed during the Fall 2013 PHAT team meeting still seems appropriate: divide up the survey area by surface brightness (proxy for SFR) and radius (proxy for metallicity). A simple version of this is shown in Figure 2. One suggestion that was brough up at the meeting was to base the regions on structure in the galaxy (e.g., entire spirals) instead of radial cuts. Exactly how we decide to do this will require some discussion, though drawing a new set of regions and getting results should not be too time-consuming, especially doing it one time through.

The most basic set of regions are just the SFH pixels themselves, which are much larger than the pixels in the UV and 24 μm images. This would allow us to do a pixel-by-pixel comparison of the flux-based and mean SFRs. A map of the SFR discrepancies could be very interesting, especially if there are spatial trends with where the flux calibrations work and where they don't.

Whatever regions are used, I will have to make sure that their SFHs are all relatively constant and that high-mass stars are well-represented in the CMDs to make sure that any observed discrepancies are not due to inconsistencies with the full-IMF and constant-SFR assumptions. We should also consider toetallicity effects. For example, what is the radial metallicity gradient in M31 and what are the final metallicities determined by MATCH?

Most if not all of the functionality required to extract fluxes and SFRs within arbitrary regions on a map has already been developed during the pilot project. Getting everything set up should only take a day.

Once all decisions have been made and a basic pipeline is place, it should only take a couple of days to do test runs and generate plots. The easiest way to complete a prototype is with a "5×5 grid" in surface brightness and radius, as shown in Figure 2. This is also a good time take a step back and evaluate the entire pipeline for efficiency, to make sure that it is scalable to the entire PHAT survey area.

Timeline: With the SFR maps ready at the beginning of June, all of my effort will go toward getting preliminary results for a small portion of the data (e.g., a prototype for a single brick). I will circulate results and informative visualizations within 1 week. The analysis process will be refined and adjusted based on comments from the coauthors, and the full-scale, final analysis should be underway by the third week of June. After this, my time will be split between interpretation and writing (the paper *and* my thesis), with the hope that I can gradually shift more of my time from analysis and interpretation of the results to writing. A first draft of the paper should be circulated by mid-July. With comments back by August 1st, I will be able to update the paper (and my thesis) and recirculate by mid-August. At this point, my thesis should be within a few days of completion so that I can defend the last week of August. I should have enough spare time post-graduation to guide the paper through to submission and then publication.

REFERENCES

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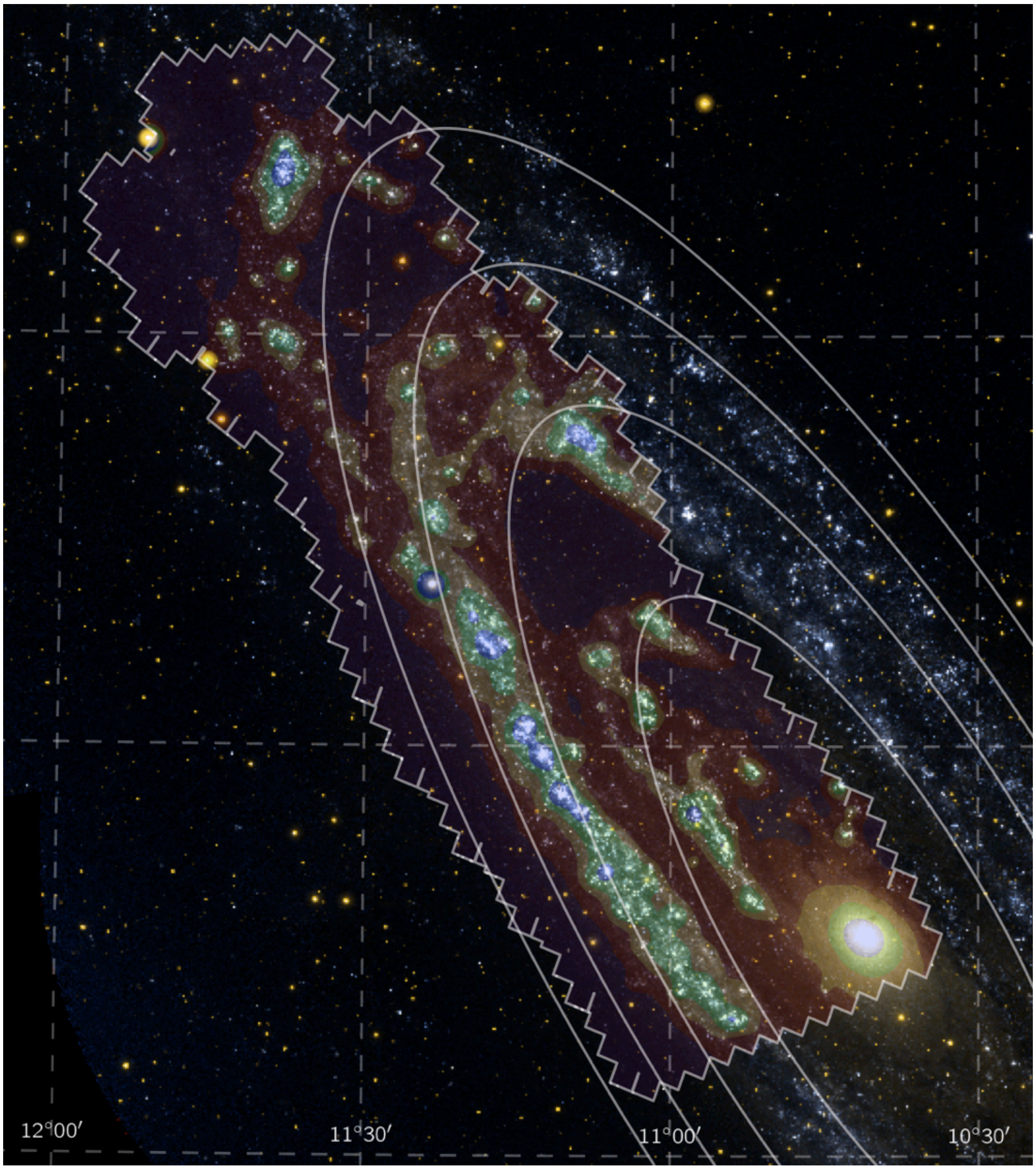

Fig. 2.— An example region sample defined by 5 sections in radius and 5 levels in FUV surface brightness (lowest to highest: purple, red, orange, green, and blue).