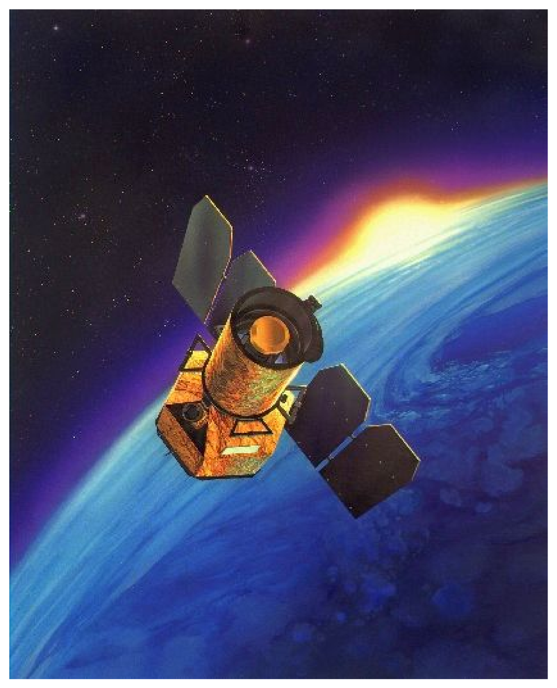
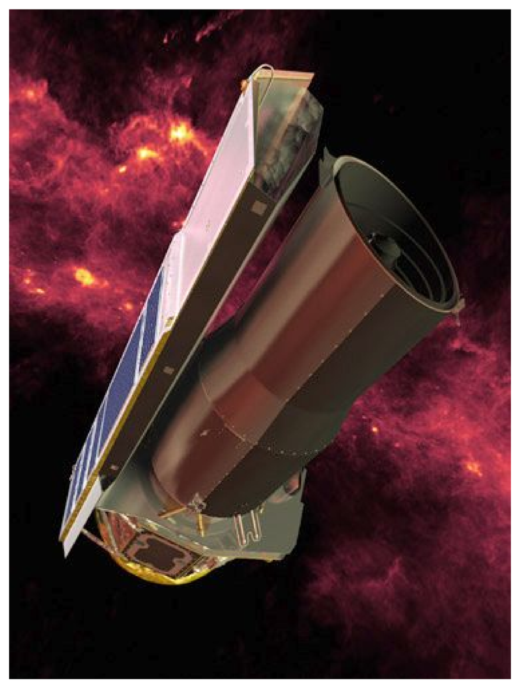


A complete census of massive star formation in M31 and M33: The relation between star formation and ISM properties



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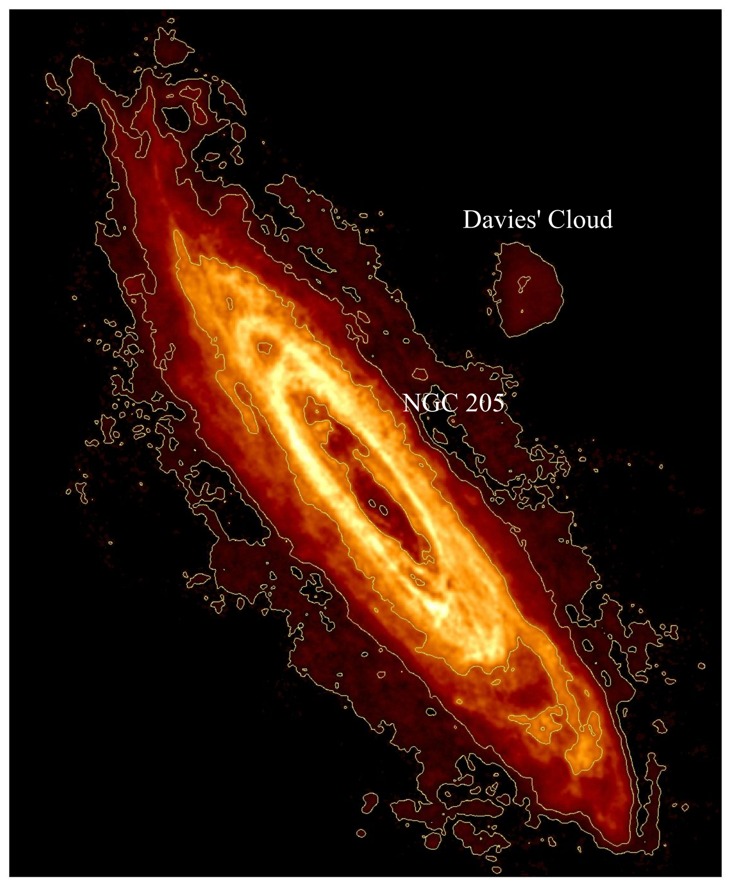
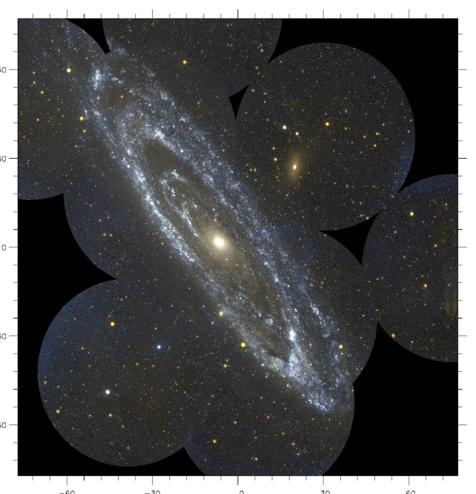
ABSTRACT: We utilize GALEX FUV and NUV observations (Thilker et al. 2005), Spitzer (MIPS), WSRT and VLA HI mosaics, plus published CO data of M31 and M33 to measure the spatial distribution of extinction-corrected star formation rate (SFR) and gas surface density. The powerful combination of UV and IR datasets allows us to firmly constrain the SFR over a comprehensive range of galactic environments, from relatively unobscured locales to highly extincted clusters embedded in the spiral arms. With this complete census of massive star forming regions, we have started to re-examine the relationship between the multi-phase ISM and recent star formation activity, focusing on the Schmidt Law and well-known star formation thresholds. This poster describes our initial (lowest-resolution) results, using all MIPS bands.

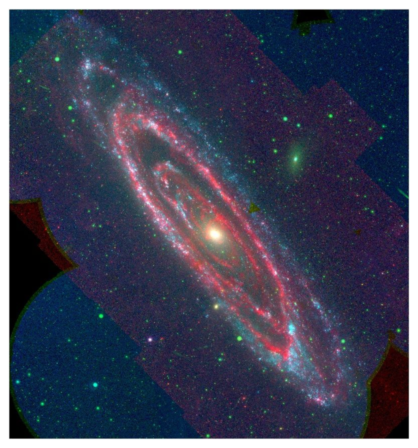
PREPRINTS at http://dolomiti.pha.jhu.edu/



Braun et al. 2005, in prep. (WSRT mosaic + GBT)
Integrated HI smoothed to 60" FWHM (3x full res.)
with 10^{19}, 10^{20}, 10^{21} cm^{-2} contours



GALEX FUV, NUV composite
Thilker et al. 2005, ApJL in press



MIPS 24µm, NUV, FUV

METHOD: Most of the energy radiated from an OB stellar population originates in the UV, however the emergent spectrum is environmentally modified by dust obscuration and reddening. The balance of UV photons lost to the circumcluster environment can be recovered by considering the thermal emission from dust grains. A first-order estimate of the original bolometric luminosity is obtained by summing the TIR (8-1000 µm) and UV luminosity *without any extinction correction*. In this study, we adopt the TIR+FUV luminosity as our fiducial SFR metric, computing TIR flux from all three MIPS bands following Dale & Helou 2002. The resolution of MIPS (25, 70, and 160 pc for 24, 70, and 160 µm) and GALEX (25 pc) in our Local Group targets (D = 0.77, 0.84 kpc for M31, M33) provides a chance to calibrate other SFR tracers against this robust fiducial at unprecedentedly small scales.

As shown by Calzetti et al. (#60.03) for SF complexes in M51, the MIPS 24µm band correlates well with the nebular (Pα) SFR on scales > 500 pc, yet any metric based on grain emission is by construction incomplete for natal environments largely cleared of dust, or missing it from the start. That is, no IR SFR metric can account (except statistically) for the fraction of a young stellar population's bolometric luminosity which suceeds in escaping without being absorbed by dust. Much of our effort will focus on establishing the 24µm band as a reliable metric for UV photons which are not as lucky, so we can gain a factor 6x in spatial resolution by avoiding dependence on the MIPS 70 and 160µm bands.

OBSERVATIONS:

IR (Spitzer/MIPS)

M31: G. Rieke and MIPS Instrument Team, K. Gordon's poster
M33: R. Gehrz and GGTOP Science Team, Hinz et al. 2005

UV (GALEX)

Both: Nearby Galaxy Survey, Thilker et al. 2005 for M31 and M33, Bianchi et al. 2003 for GALEX NGS

HI (21cm, ap. synthesis)

M31: WSRT+GBT, Braun et al. 2005 and Thilker et al. 2004
M33: VLA+GBT, Thilker 2000

CO (IRAM 30m, FCRAO, BIMA)

M31: M. Guelin et al. 2000
M33: coming soon...

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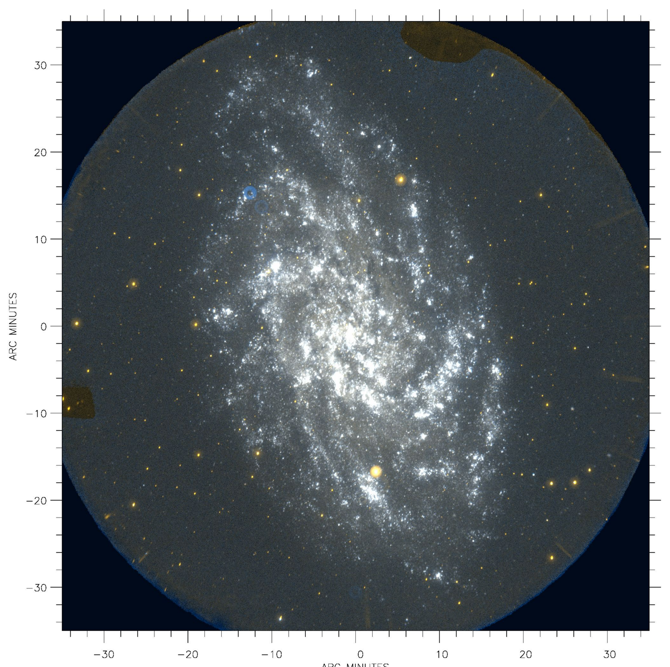
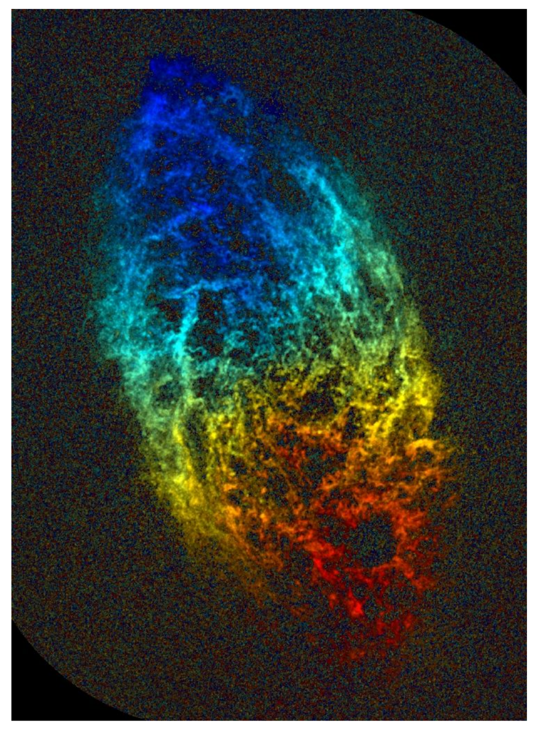
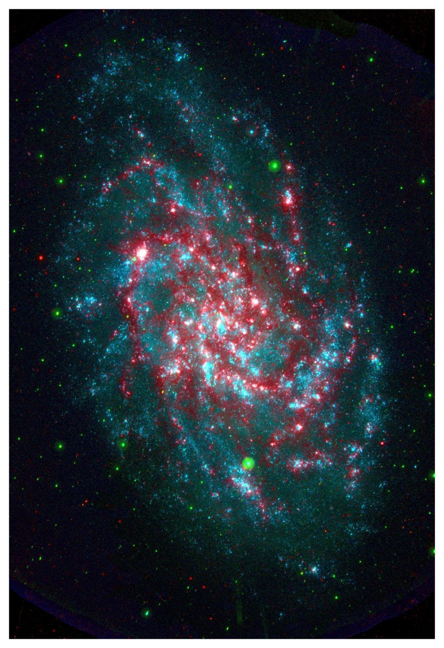


GALEX FUV, NUV composite
Thilker et al. 2005, ApJL in press



HI – Thilker 2000 (VLA B,C,D config)



MIPS 24µm, NUV, FUV

Global SFR measurements

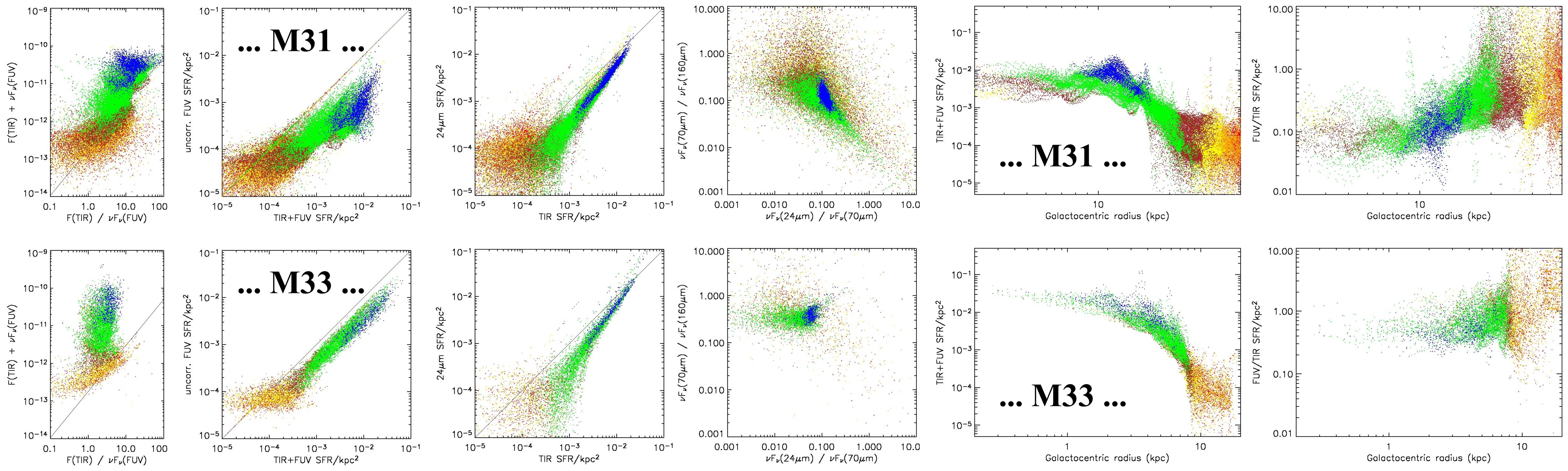
We measured the total SFR of M31 and M33 within radii of 35 and 9 kpc, respectively, using IR and UV SFR metrics. Calibration constants were from Kennicutt (1998) for TIR and FUV (uncorrected for extinction), and from Calzetti et al. 2005 for 24µm. The table below lists global measurements in units of $M_\odot yr^{-1}$.

	TIR	24um	FUV	TIR+FUV	Stellar CMD
M31	0.83	0.43	0.15	0.98	~1, Williams '03
M33	0.33	0.22	0.21	0.54	Garnett et al. Barker et al.

Extinction-free TIR SFR measurements only reflect 85 and 61% of the total (TIR+FUV) SFR, for M31 and M33 respectively, underscoring the need for *IR and UV* observations when gauging SFR in a galaxy. M33 is forming stars almost 3x faster per unit area (4.1×10^{-3} vs 1.4×10^{-3} $M_\odot yr^{-1} kpc^{-2}$), despite a lower global rate.

RESULTS:

Global UV+IR SFR analysis (at right) shows that the majority of intrinsic UV emission is typically reprocessed into the IR, and only leaves the galaxy indirectly. However, our MIPS/GALEX images of M31 and M33 also show that SF can occur in IR-faint locales, whether faint due to a dilute radiation field or simply a dust deficient environment. Only together can UV and IR tracers provide a complete census of SF activity. Below, datapoints are color-coded by HI column density (red=10^{19} cm^{-2}, blue=10^{22} cm^{-2}, step=0.5 dex). All images were convolved to 60" FWHM.



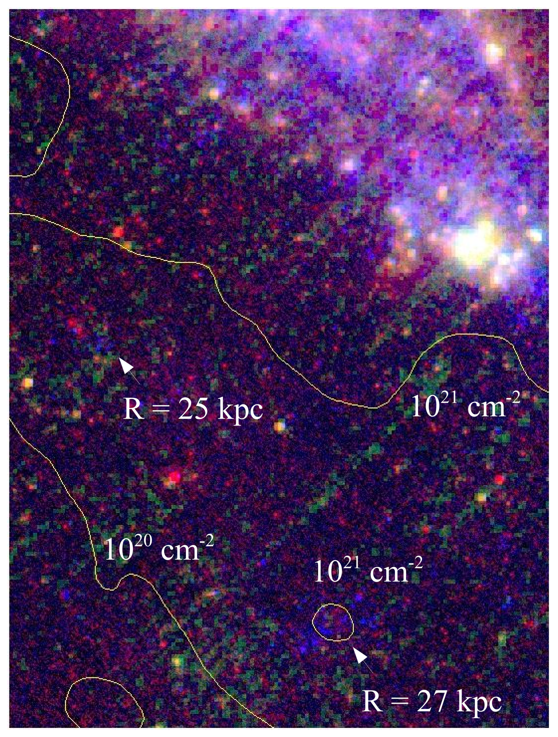
Column 1 shows the relation between bolometric luminosity (SFR) and dust obscuration, and the dependence of the former on N(HI). The line shows the slope of the starburst-specific correlation of Heckman et al. (1998). The UV obscuration in M33 is remarkably constant and doesn't seem to follow the starburst relation. In column 2, the SFR/kpc^2 determined from uncorrected FUV monochromatic flux is compared to our fiducial TIR+FUV measurement of the same quantity. In M31, there is >1 dex of scatter and a slope substantially shallower than unity (the line). The cleaner appearance of the M33 plot reflects the limited variation of A(FUV) over the disk evaluated on scales ~250pc. Column 3 shows a very tight correlation between 24µm and TIR estimates of SFR/kpc^2 using the Calzetti et al. 2005 calibration for 24µm. We were surprised to find deviation from unit (24µm/TIR) slope in both galaxies, by essentially the same degree, but suspect it may indicate that the TIR map is "contaminated" by heating from evolved stars (which would be relatively more important in low specific SFR regions of a galaxy). It could also be that the MIR-FIR SED, and hence dust temperature distribution, changes systematically as a function of position, N(HI), or SFR/kpc^2. This would systematically bias the conversion from MIPS flux densities to TIR. Column 4, containing IR color-color diagrams, illustrates the significant variation of dust SED vs. N(HI). In column 5, we show the radial variation of SFR per inclination-corrected unit area as a function of galactocentric radius in both targets. Although occuring at a comparatively low rate, star formation appears to be supported at larger radii than traditionally realized. Column 6 examines the emergent energy budget of this SF activity as a function of radius, showing that both galaxies become progressively UV-dominated in their outer disk.

FUTURE WORK:

Taking advantage of the highly-significant correlation between TIR SFR and 24µm luminosity (for most SF environments), we will recompute our maps of IR+FUV SFR per unit area using the 24µm band as a proxy for the composite (24, 70, 160µm) TIR luminosity. The benefit of this change will be greatly enhanced spatial resolution, reaching the limit of 6" (~25 pc) provided by both GALEX and MIPS. In very quiescent regions, such as the outermost disk, for which the dust temperature and dust-to-gas ratio are reduced, we will continue to rely on the TIR metric at lower resolution. In both cases we will obtain aperture-matched multiwavelength photometry for each (irregularly shaped) star-forming structure apparent in the composite (IR+UV) SFR image.

Combining our UV and IR observations with extensive ground-based optical imaging will permit fitting observed SEDs with artificially-reddened predictions of population synthesis models for various star formation histories and reddening laws / dust geometries. We anticipate being able to reliably delineate changes in both variables on scales down to a few hundred pc. For M31, we will make use of the recent SDSS stripe along the major axis, while for M33 we will employ the UBVRI+Hα images of Massey et al.

MIPS 24µm, 70µm, FUV in outer M31

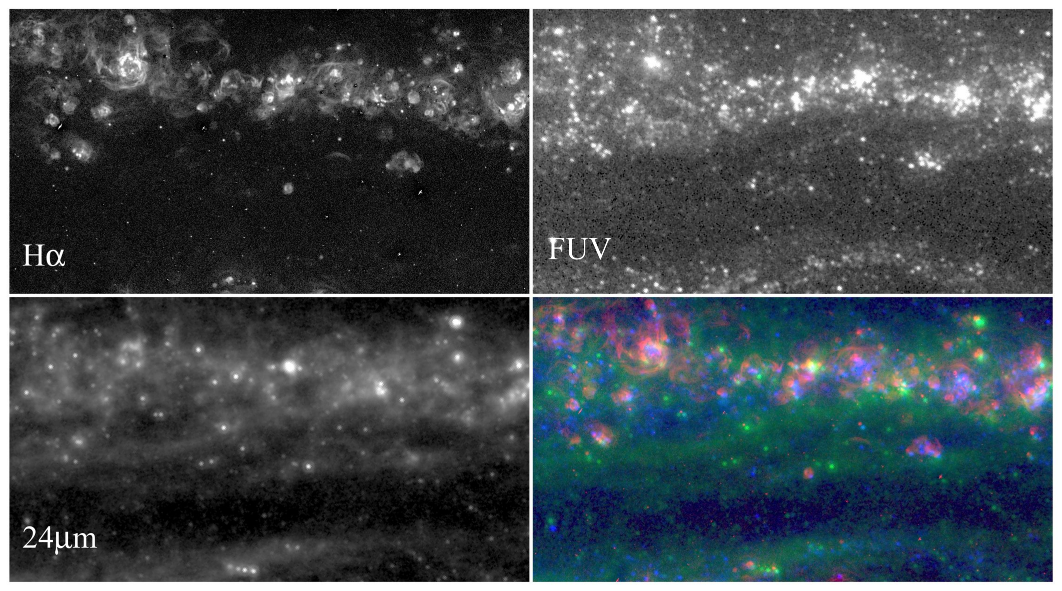


Star formation at large radii and low Σ_{gas}

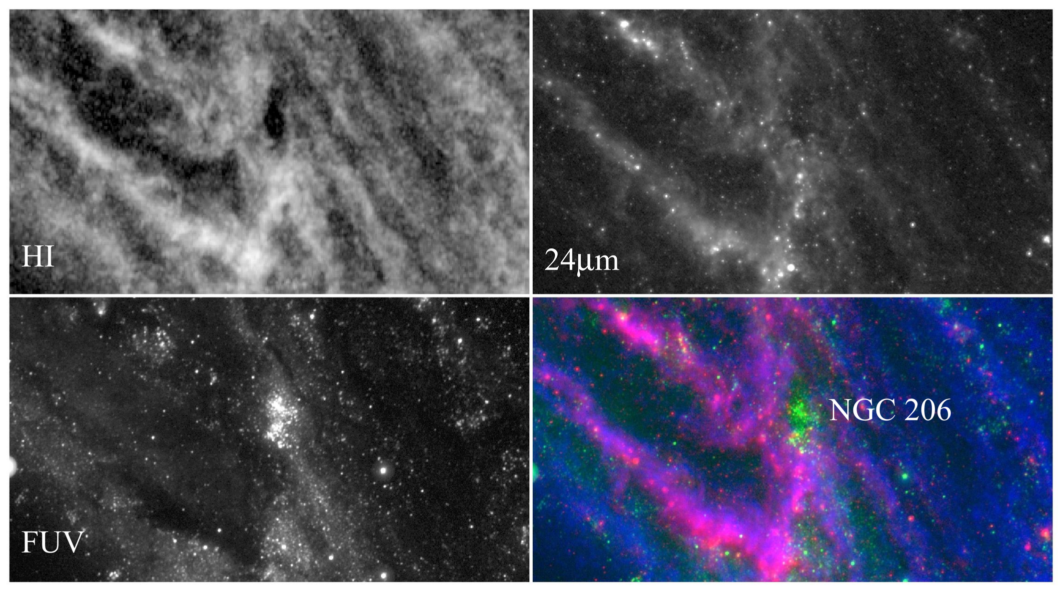
The incidence of (continuing?) SF in outer disks of spiral galaxies has historically been underappreciated. Only in the past decade have sensitive Hα (eg. Ferguson et al. 1998) and multi-color broadband surveys (eg. Cuillandre et al. 2001) revealed groupings of young stars at radii out to a few times R_{25}. The extraordinary sensitivity of GALEX has enhanced awareness of these sources, in some cases even suggesting continuous SFR profiles across the "threshold radius" conspicuously evident in the distribution of HII regions. M31 is no exception, and our GALEX mosaic reveals many clusters at large radii. We do not yet have a source catalog, due to the difficulty of excluding background galaxies, but work is in progress. Although the azimuthally averaged N(HI) is low at such galactocentric distances, star clusters appear to generally trace local maxima. These SF regions are rarely apparent in the IR.

Fundamental Limitations of the Schmidt Law and SFR tracers on small scales (in time and space)

As emphasized by Kennicutt (1998), the traditional calibration constants of continuum-based SFR tracers should not be used blindly (as we have!). Some assumptions validating SFR conversions (eg. a specific SFH) and the premise of a Schmidt Law are violated at scales probed by high-resolution Galex/Spitzer data. This is true in both a spatial and temporal sense, as the duration of a SF event correlates with its physical extent (below). Under a critical scale, we must consider SFH ~ burstlike. Stellar-gaseous feedback is also important. The second figure below shows why a prominent OB association like NGC206 would decidedly fail the Schmidt Law.



Hα and UV observations trace the unobscured massive stars, 24µm imaging reveals embedded SF cores (similar sources at an earlier epoch) plus diffuse emission on large scales. The HII regions (hence O stars) traced by Hα are dangerously short-lived versus UV and MIR tracers (predominantly tracing B stars).



HI, CO and dust maps delineate the structure of the multiphase ISM. Stars result from instabilities in this medium, but also influence its subsequent morphology and phase balance. NGC206 (prominent in the UV) illustrates this feedback process. The 40-50 Myr lifetime of NGC206 has allowed for clearing of the natal environment.