Observations of the ISM in M31 with *Herschel*

M31 at 24, 160 and 350 μm

Karin Sandstrom
Max Planck Institute for Astronomy

June 19, 2012
The Great Andromeda Galaxy

Collaborators

Maria Kapala

see poster here!

Brent Groves

at MPIA: Oliver Krause, Kathryn Kreckel, Hans-Walter Rix, Eva Schinnerer, Fatemeh Tabatabaei, Fabian Walter

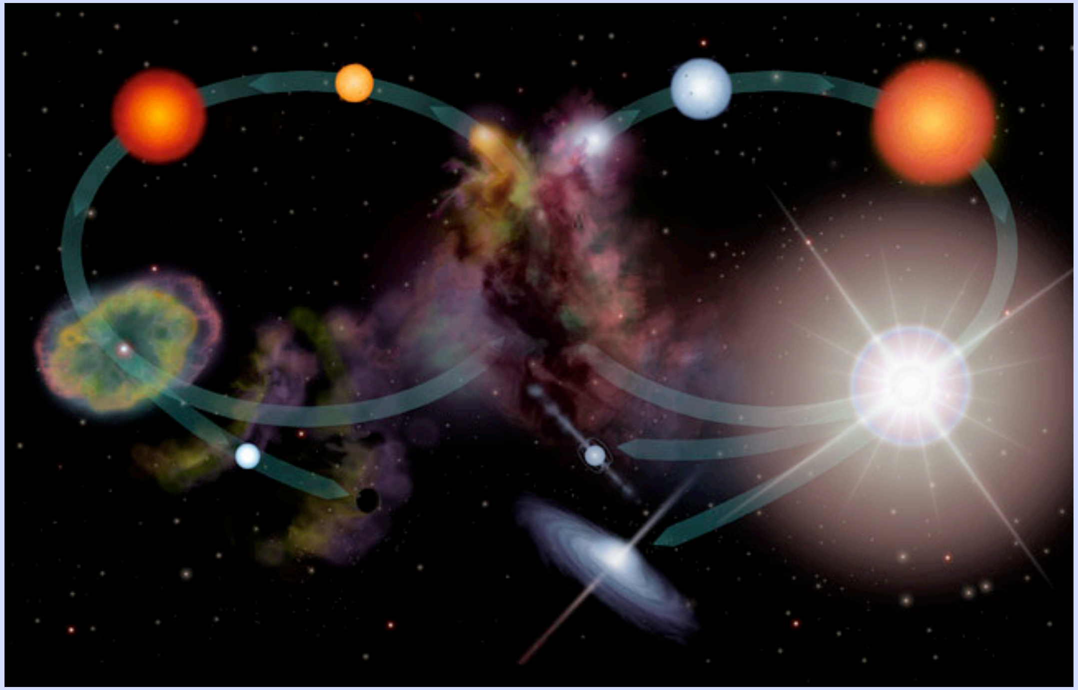
Gonzalo Aniano, Robert Braun, Kevin Croxall, Bruce Draine, Adam Leroy, Andreas Schruba

the PHAT team: especially Julianne Dalcanton, Karl Gordon, Daniel Weisz

Andromeda is crucial for studying the ISM because…

- we can resolve stars and study the interaction between stars & the ISM.

- we can study small scales & full-galaxy scales.



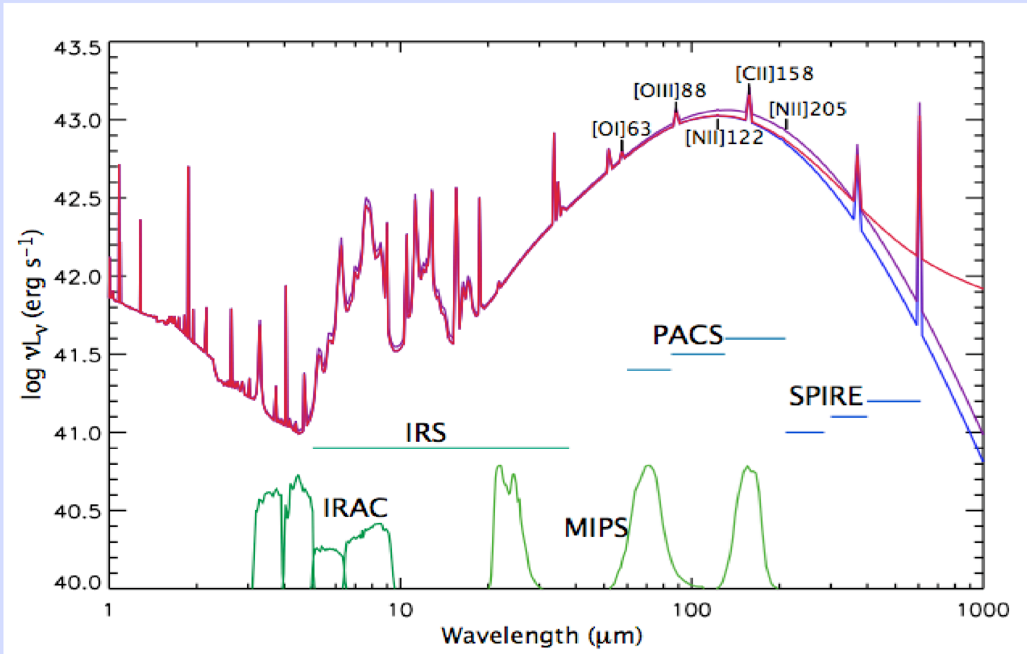
ISM & stellar evolution are closely linked.

radiative & mechanical feedback from stars drive ISM structure/dynamics/chemistry/etc

subsequent star-formation depends on properties of the ISM.

Many ISM tracers are re-processed starlight.

what can we diagnose about the ISM based on these tracers at various spatial resolutions?



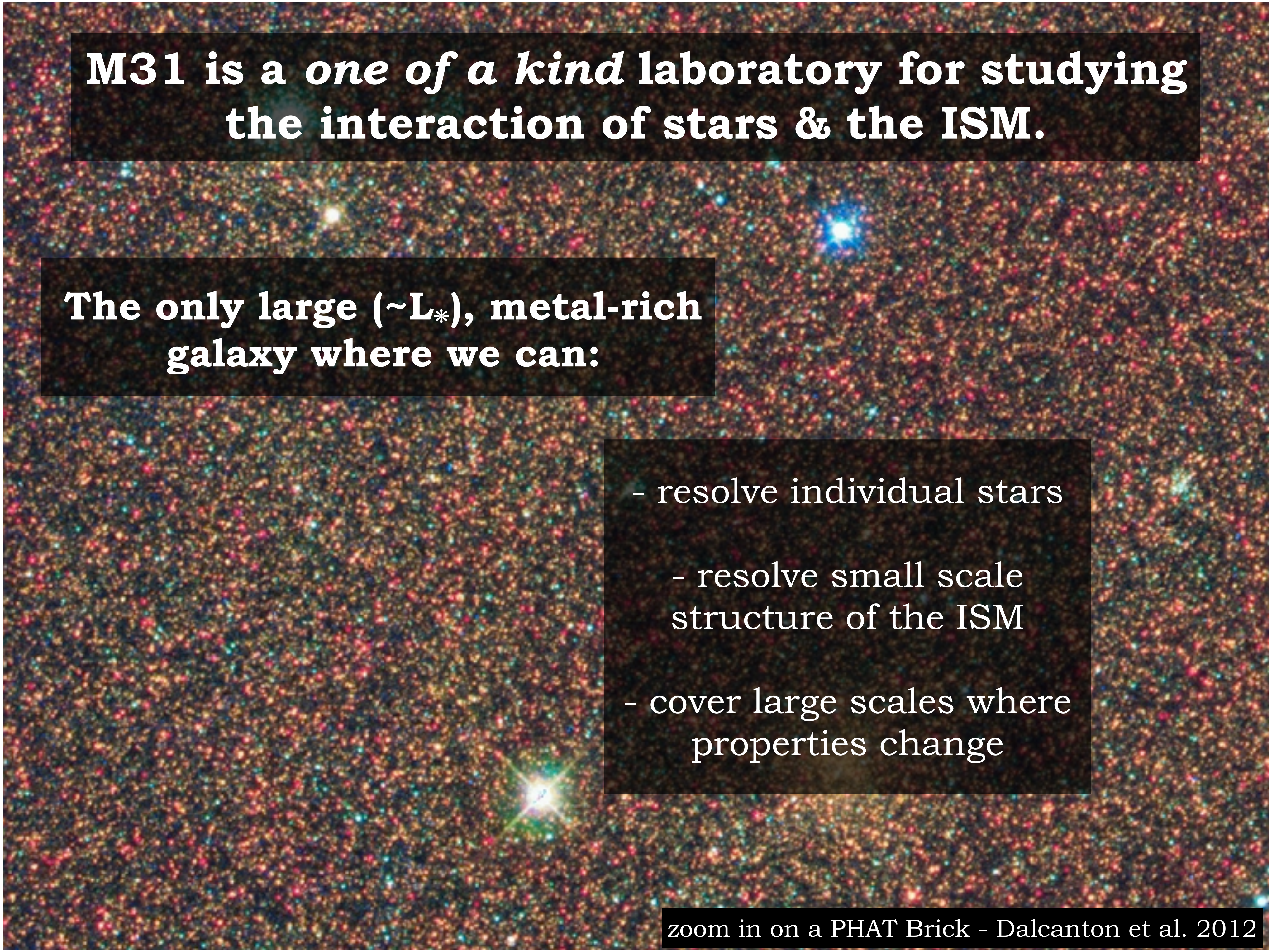
M31 is a *one of a kind* laboratory for studying the interaction of stars & the ISM.

The only large (~L_*), metal-rich galaxy where we can:

- resolve individual stars

- resolve small scale structure of the ISM

- cover large scales where properties change

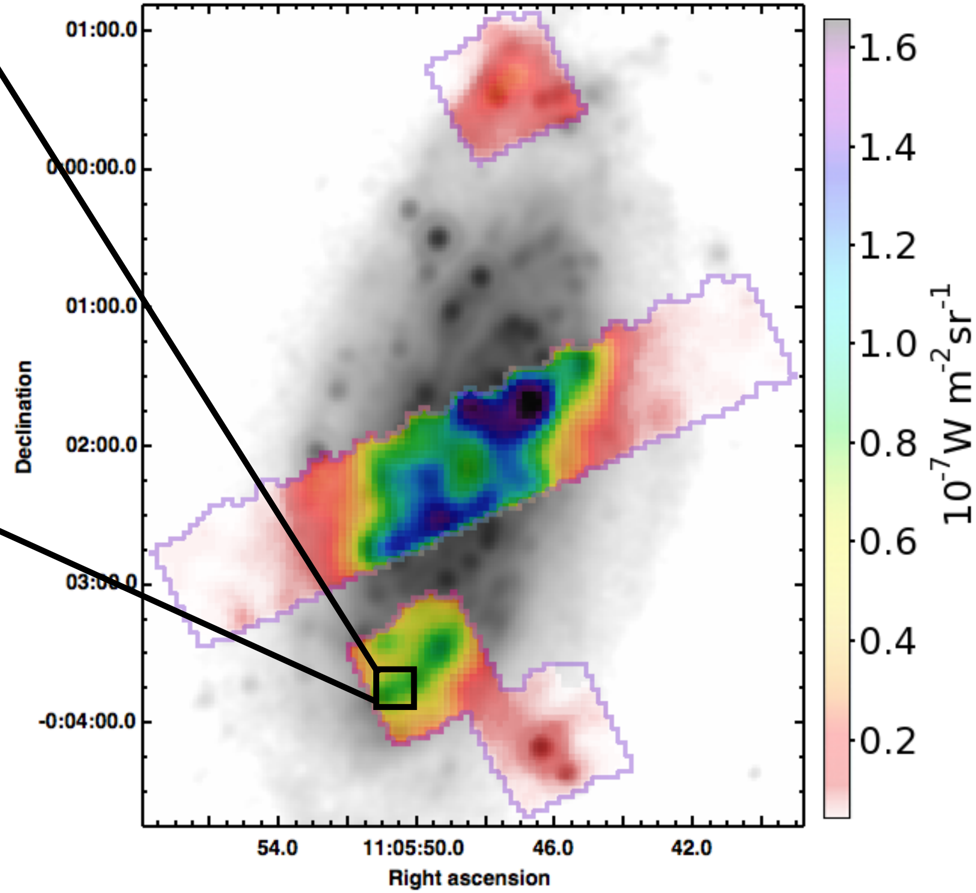


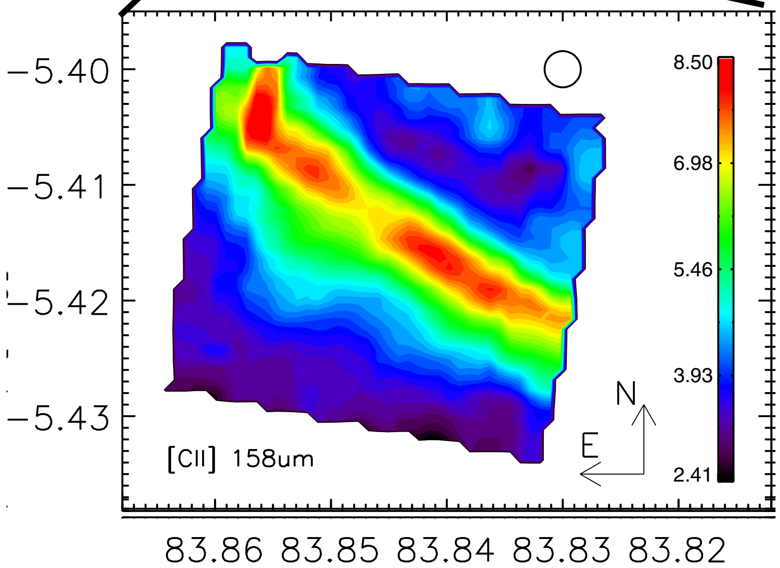
zoom in on a PHAT Brick - Dalcanton et al. 2012

~kpc^2 of ISM

Gap between "nearby galaxy" and MW studies.

[CII] mapping of NGC 3521
Croxall, KINGFISH et al (in prep)





[CII] mapping of the Orion Bar
Bernard-Salas et al. 2012

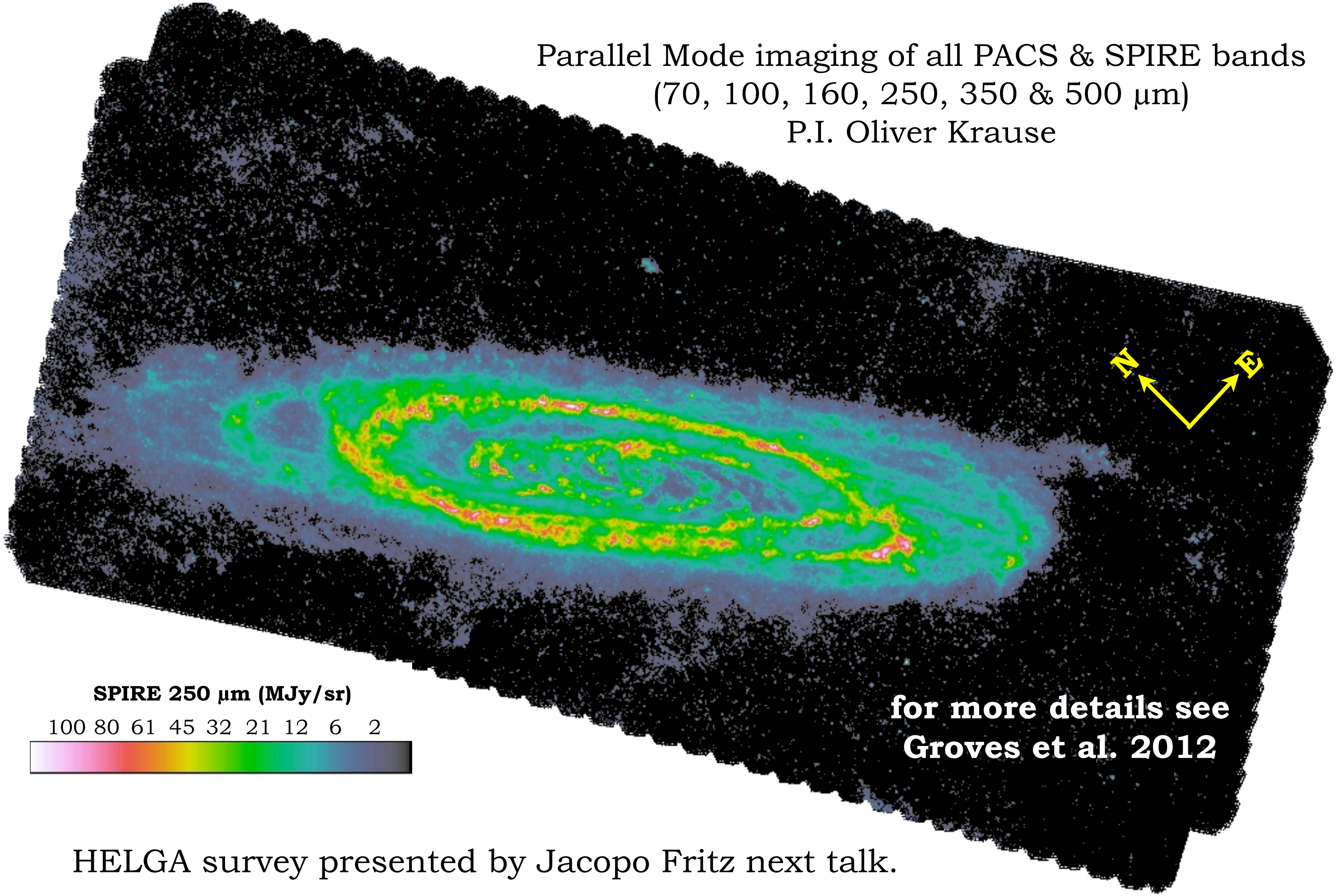
M31 bridges the gap between "nearby galaxy" studies and what we can observe in the MW.

What we hope to learn about the ISM from observations of M31

- How do different populations of stars contribute to the interstellar radiation field?
- How does the ISRF relate to dust & gas heating (or, which stars power emission in far-IR continuum & line tracers)?
- Do ~kpc averages of ISM properties reflect the underlying physical conditions of gas & dust?
- Overall goal: understanding energy budget of star-formation.

The *Herschel* Andromeda Survey

Parallel Mode imaging of all PACS & SPIRE bands
(70, 100, 160, 250, 350 & 500 μm)
P.I. Oliver Krause

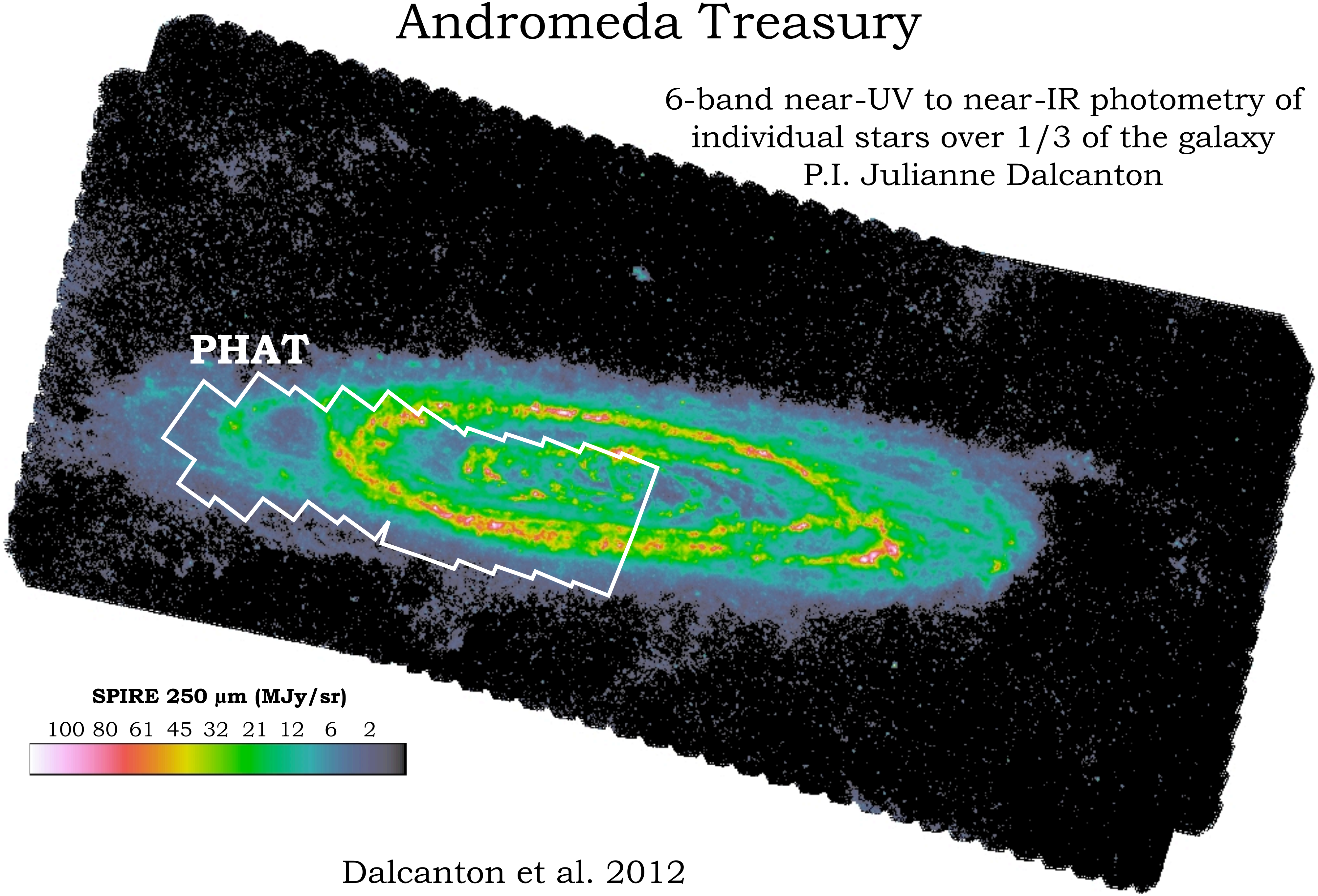


for more details see Groves et al. 2012

HELGA survey presented by Jacopo Fritz next talk.

The Panchromatic *Hubble* Andromeda Treasury

6-band near-UV to near-IR photometry of individual stars over 1/3 of the galaxy
P.I. Julianne Dalcanton

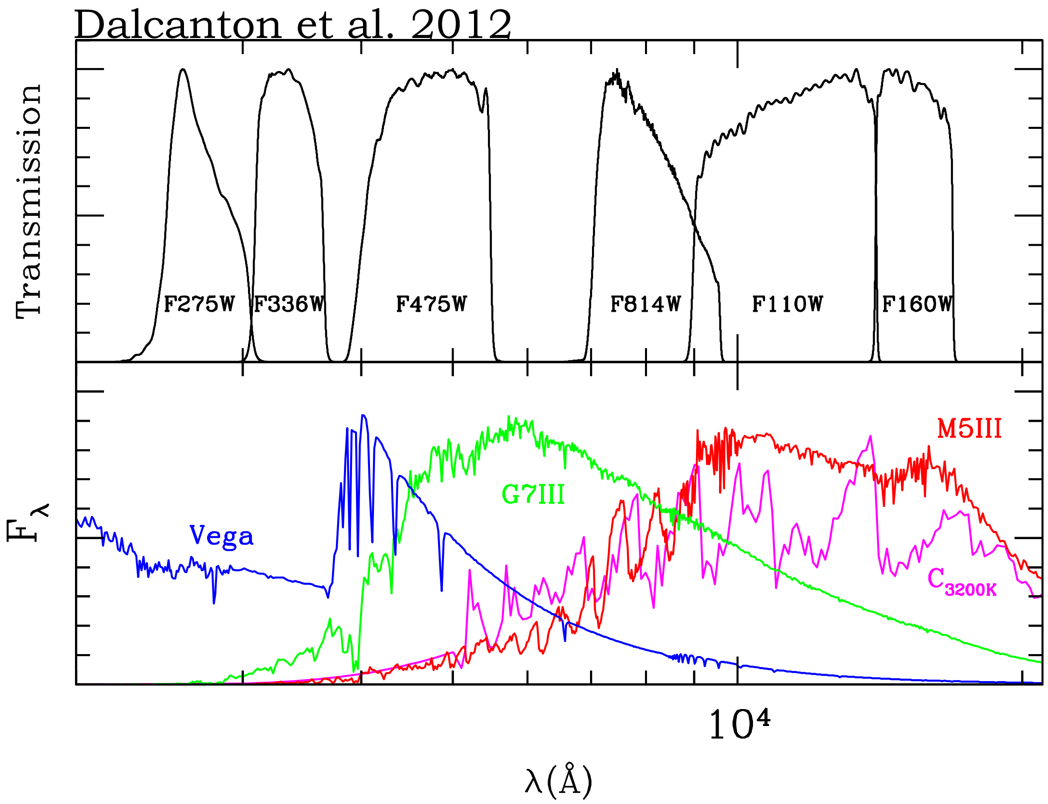


Dalcanton et al. 2012

The Panchromatic *Hubble* Andromeda Treasury

Stellar Properties from SED Fitting

(Gordon & PHAT team 2012, in prep.)



SED fits to the UV to IR photometry from PHAT yield stellar & extinction properties.

SED Fits Provide:

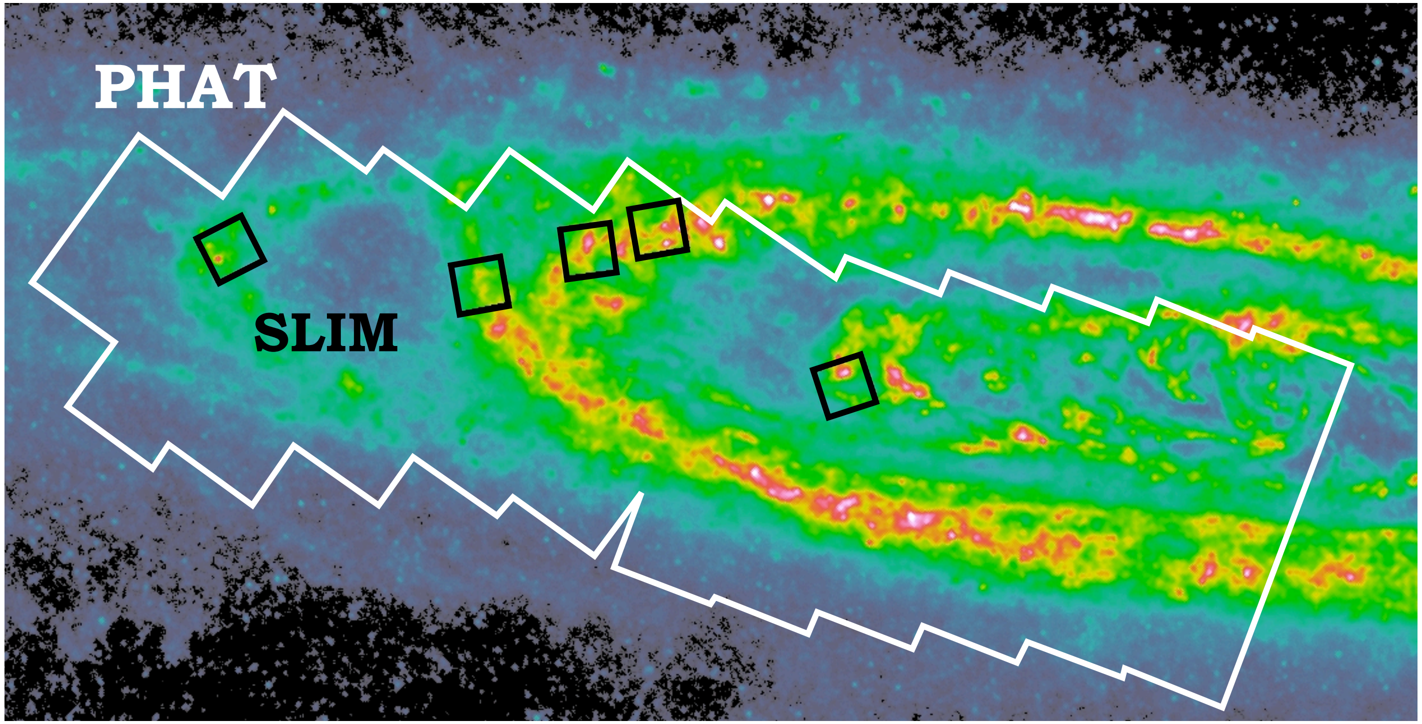
- stellar mass, Teff, L
- A_V, R_V
- intrinsic UV flux
- many other characteristics

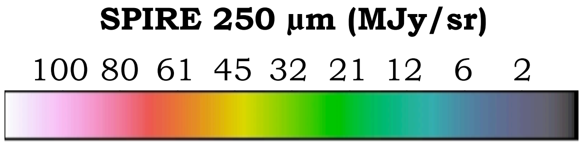
Can also get star-formation histories in small regions from CMD modelling across the galaxy.

Direct accounting of individual star's energy input to the ISM.

The Survey of Lines in M31

Fully sampled maps of [CII] 158 μm and [OI] 63 μm towards 5 ~kpc^2 regions of Andromeda
P.I. Karin Sandstrom





Observed in early 2012, reduction of [CII] maps complete, [OI] and [NII] 122 μm in progress.

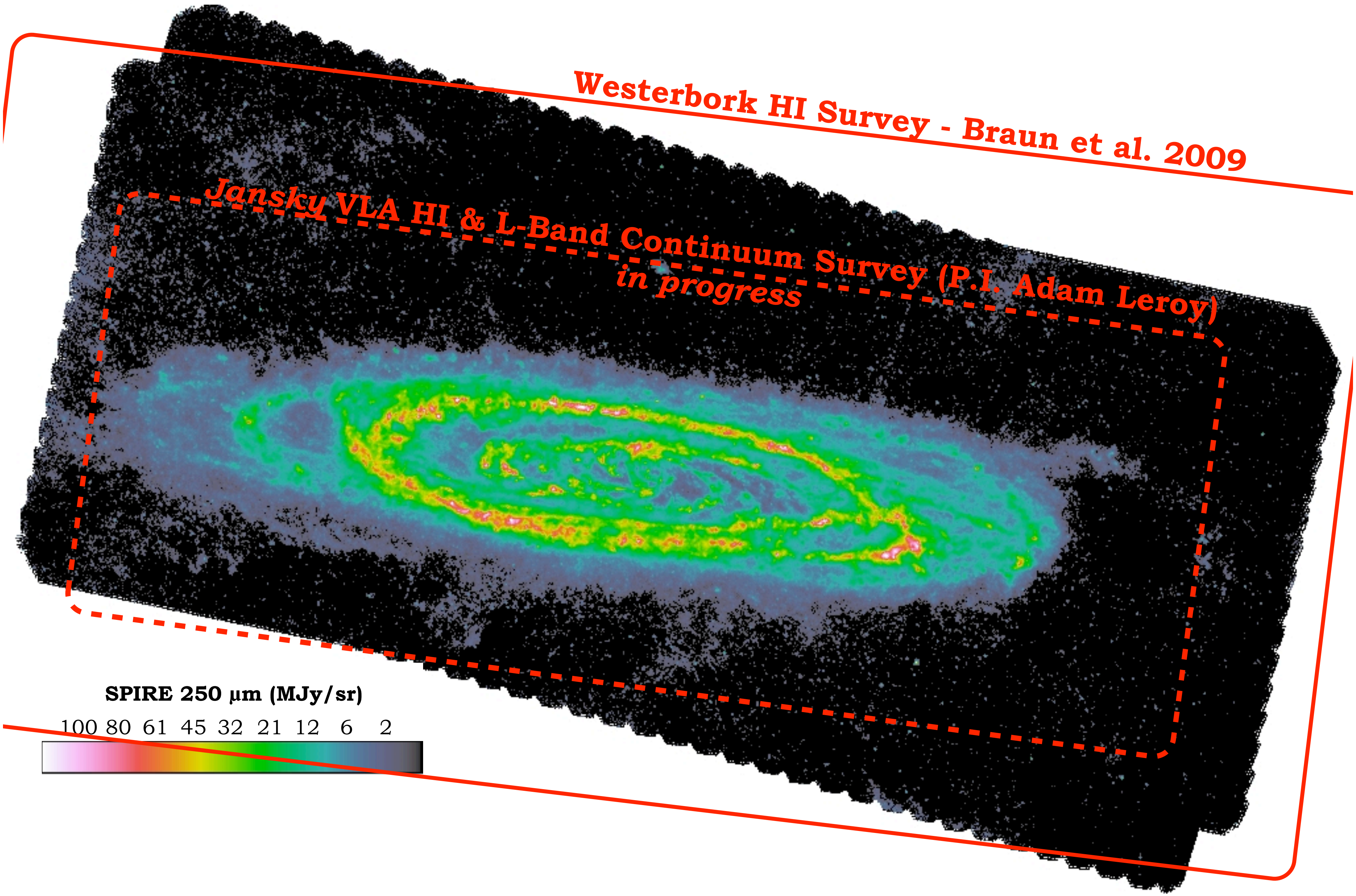
Other Surveys of Andromeda's ISM

Spitzer Imaging in all IRAC & MIPS bands (3.6-160 μm)
Barmby et al. 2006, Gordon et al. 2006

Blue: 3.6 μm, Green: 8.0 μm, Red: 24 μm

Between *Spitzer* and *Herschel*, full coverage of IR SED from 3.6-500 μm with spatial resolution of ~150pc.

Other Surveys of Andromeda's ISM



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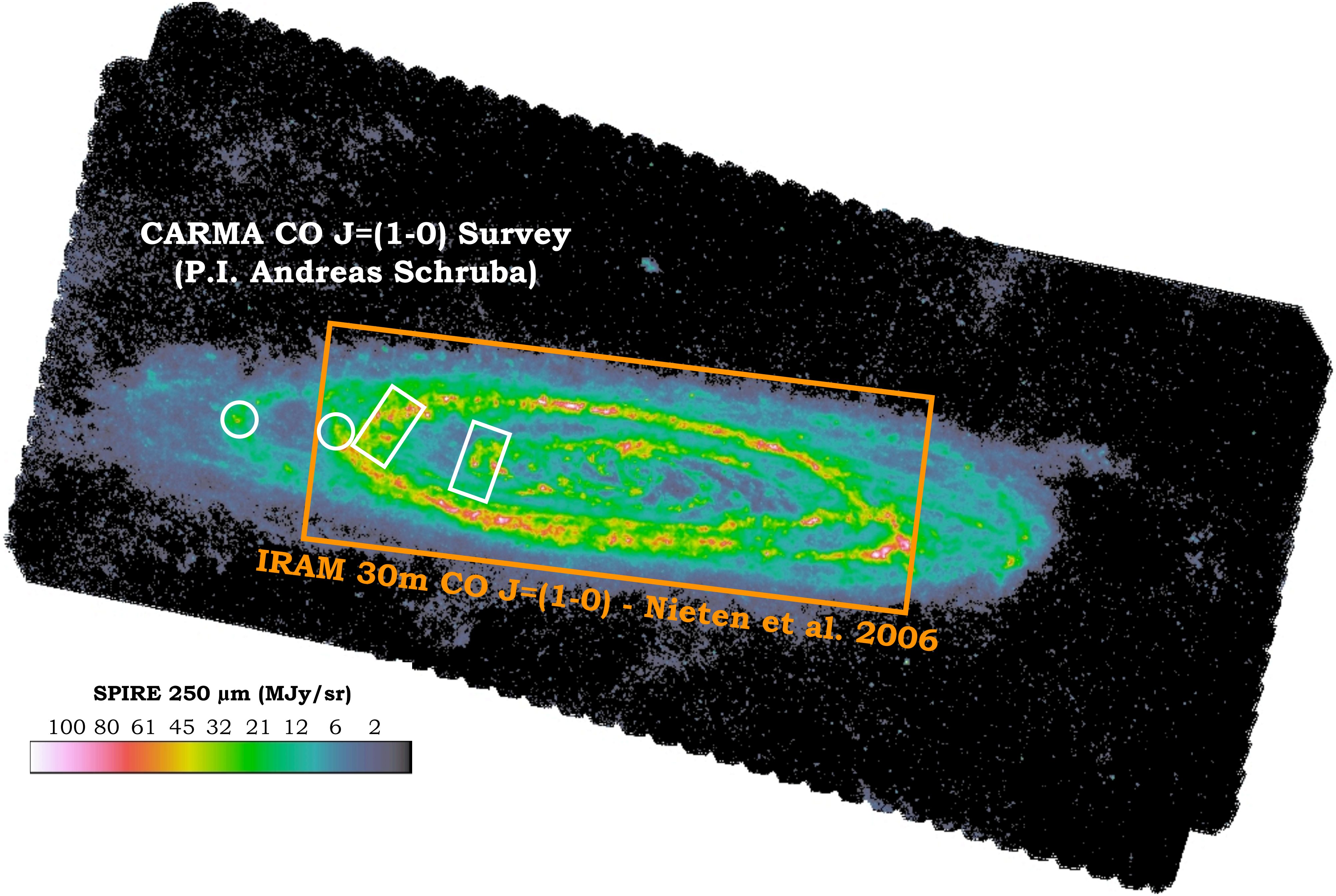

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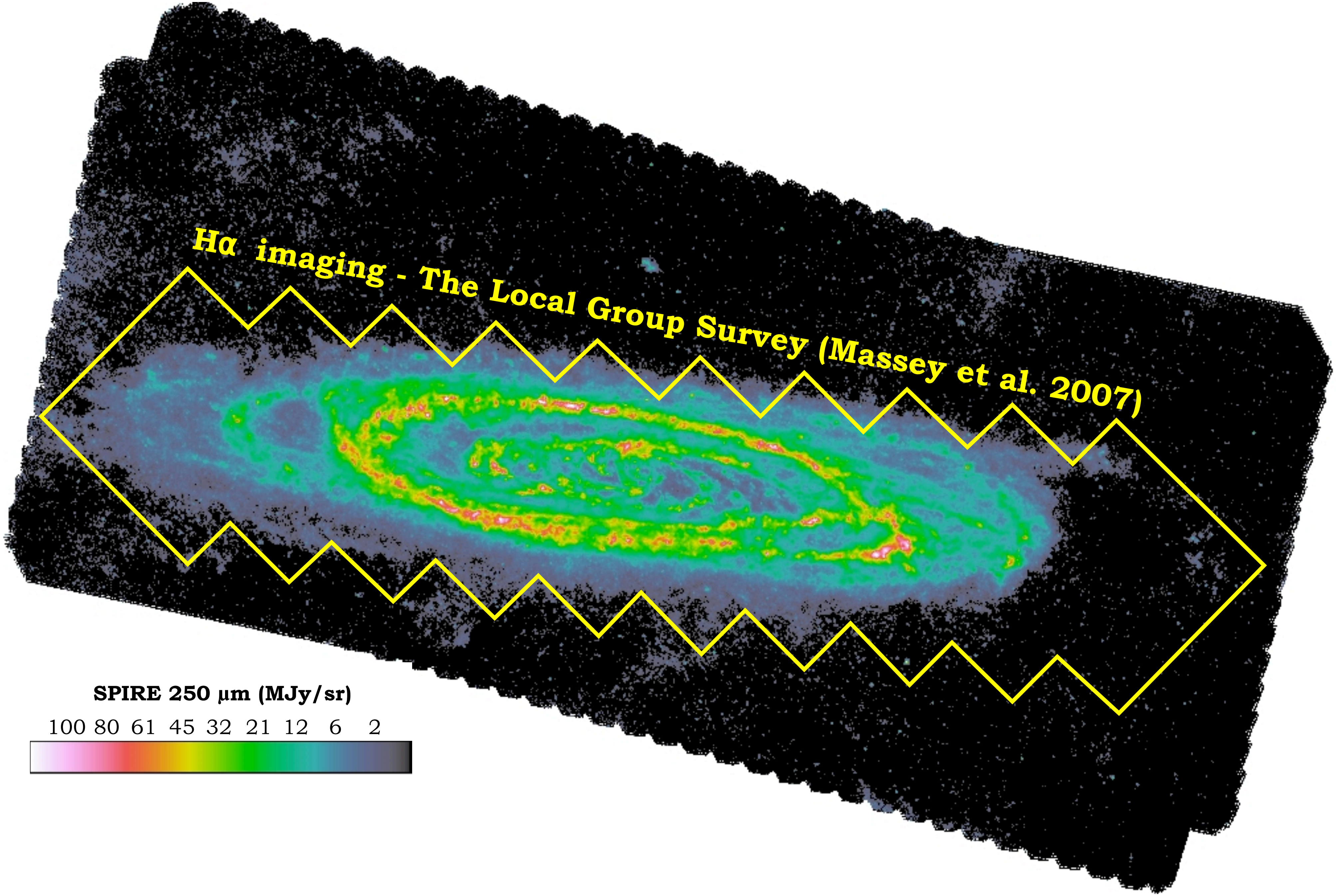
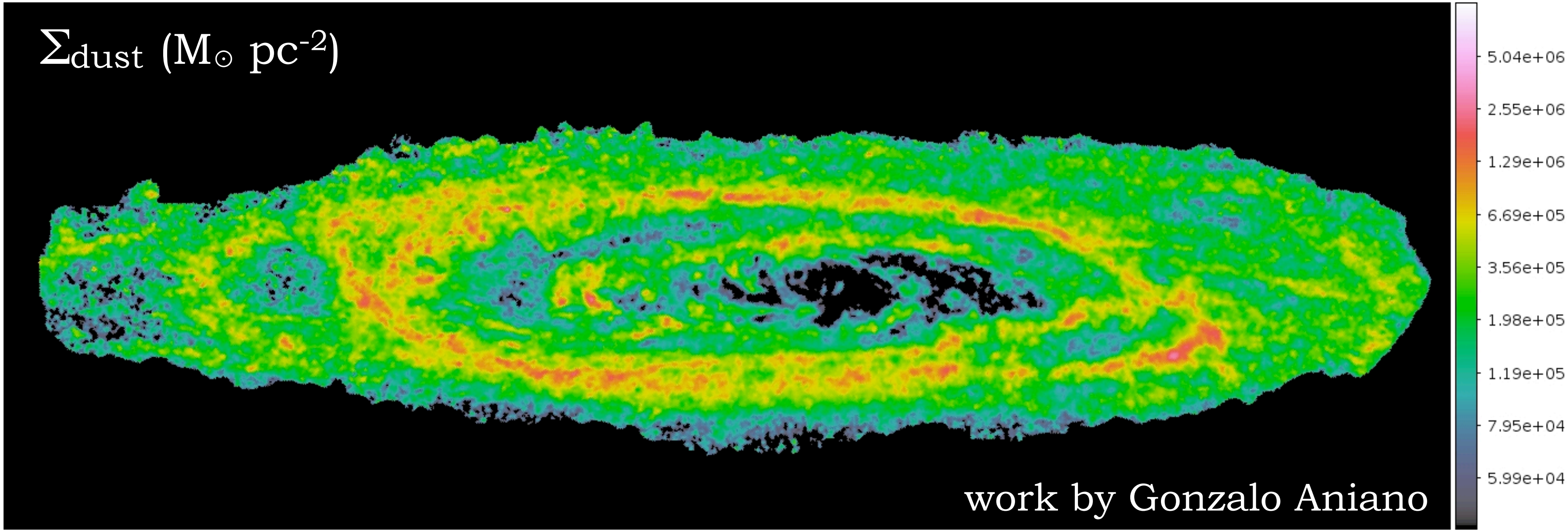


Mapping Dust Properties on ~100pc Scales



Pixel-by-pixel SED fitting from 3.6-350 μm using the Draine & Li (2007) models,

More details in Aniano et al. 2012a,b.

Never been done at sub-kpc scales in a $Z \sim Z_\odot$ galaxy!

- dust model (*fixed* - size distribution, composition, PAH properties)

- description of radiation field (*variable* - power law + delta function at U_{min})

- starlight (*fixed* SED, *variable* amount)

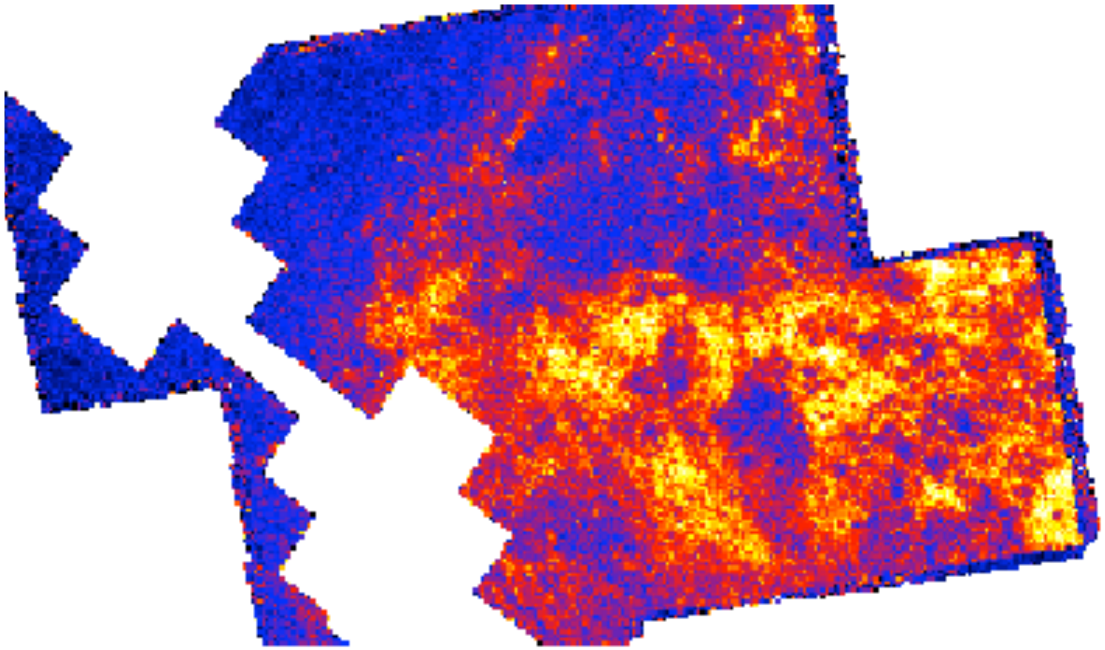
- PAH fraction q_{PAH} (*variable* - 0.4 - 4.6%)

The Panchromatic *Hubble* Andromeda Treasury

Extinction Curve Properties from stellar SED Fitting

(Gordon & PHAT team 2012, in prep.)

Good correspondence between A_V and Σ_{dust}.
Unique opportunity for studying dust properties!



PHAT Brick 12+ A_V
from stellar SED fit

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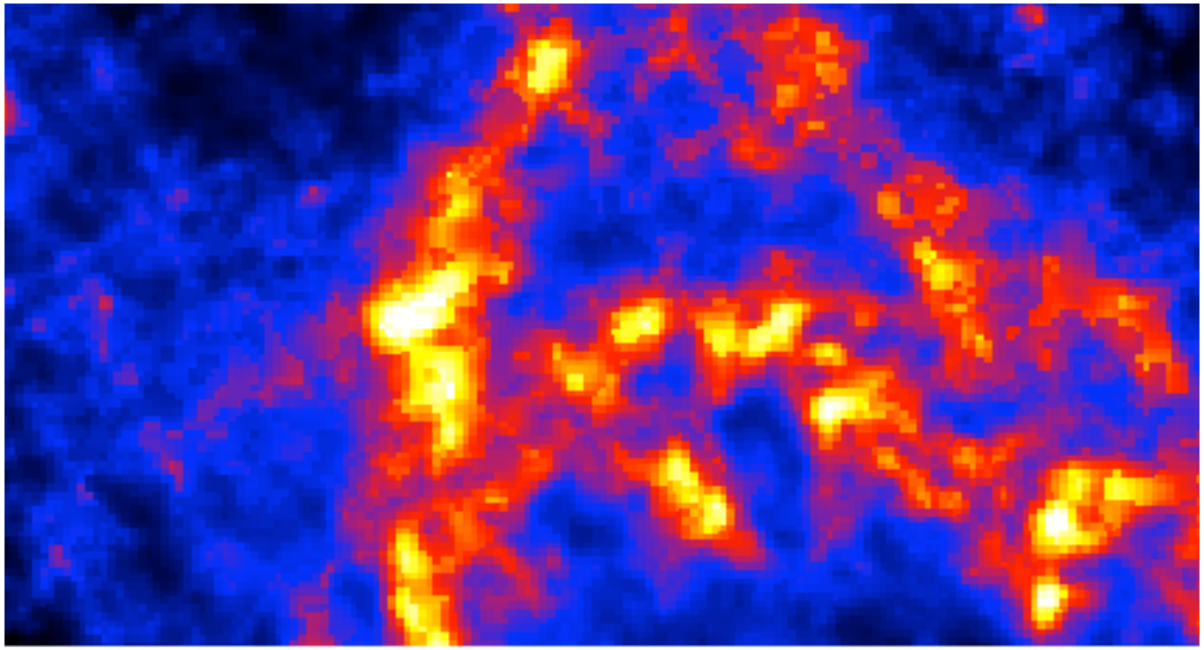
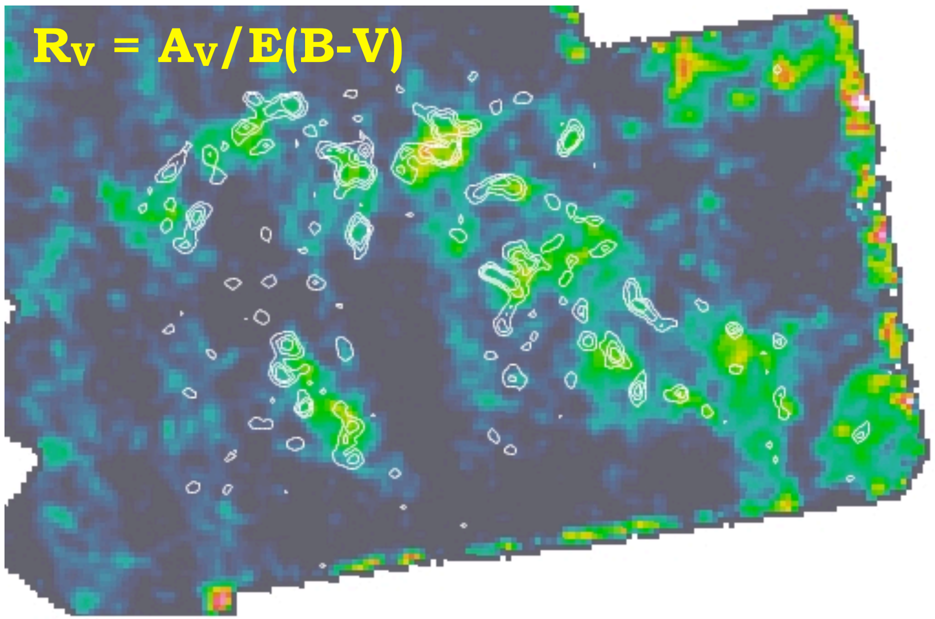


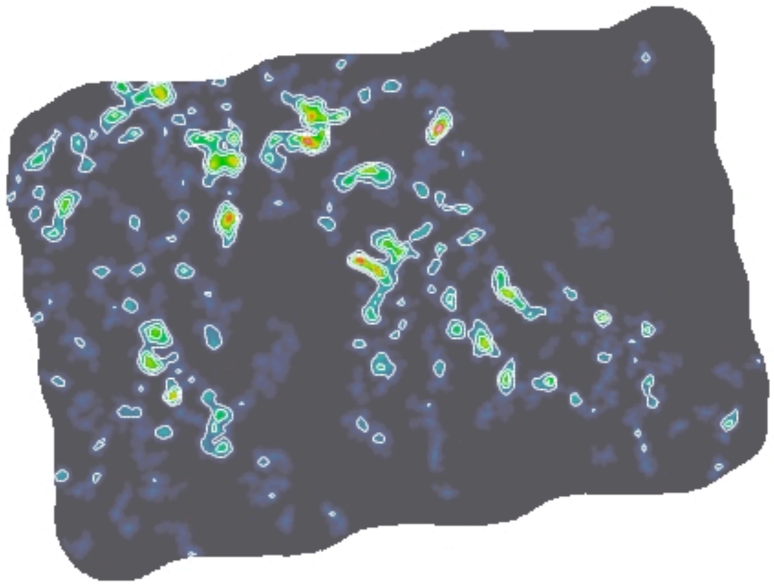
PHAT Brick 12+ A_V
from DL07 fit Σ_D

Dust Properties from Extincion & Emission

Never been done before: large scale maps of R_V (aka selective extinction)!

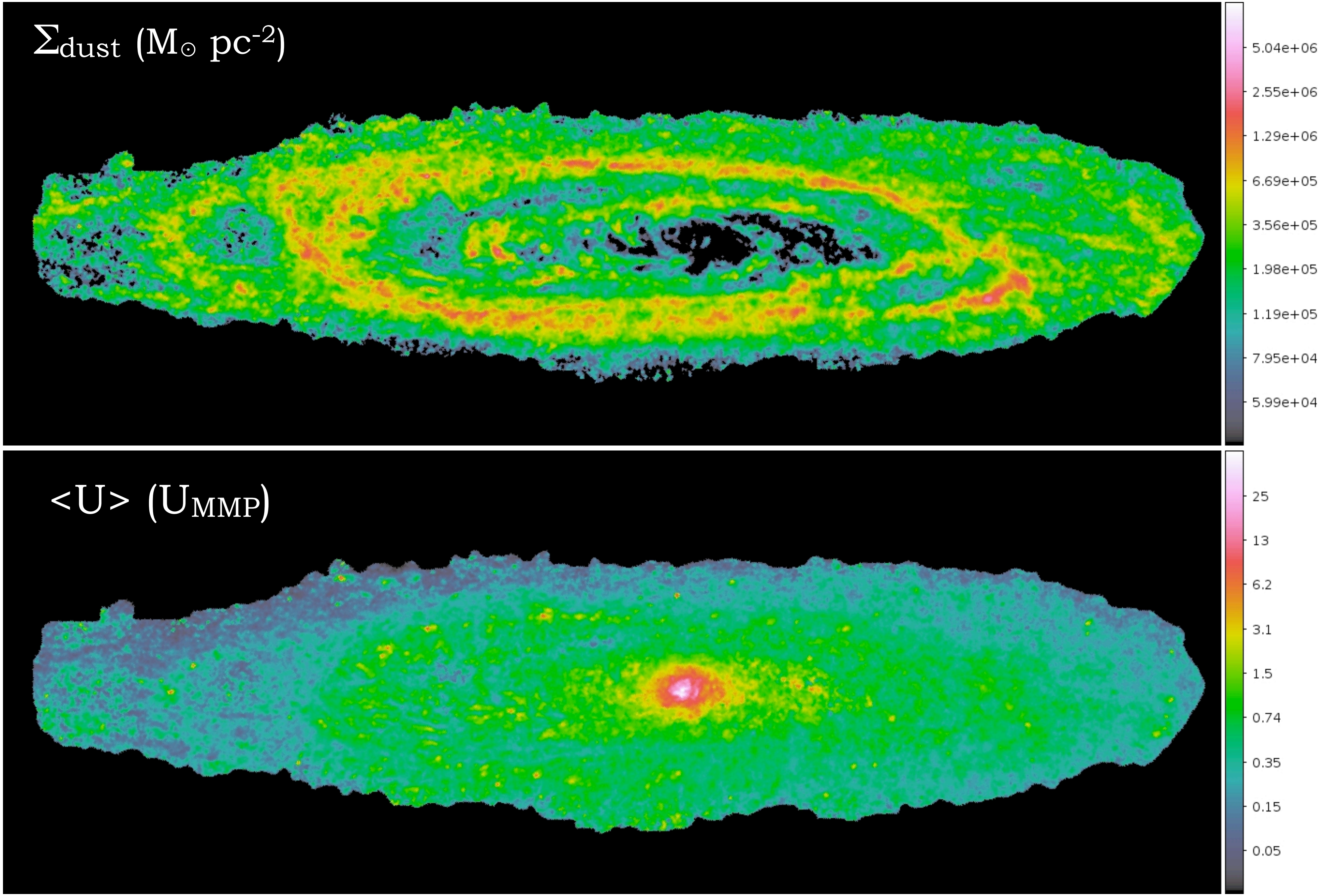


Map of R_V in PHAT Brick 15 derived from stellar SED fits to HST photometry - Gordon et al. (in prep)

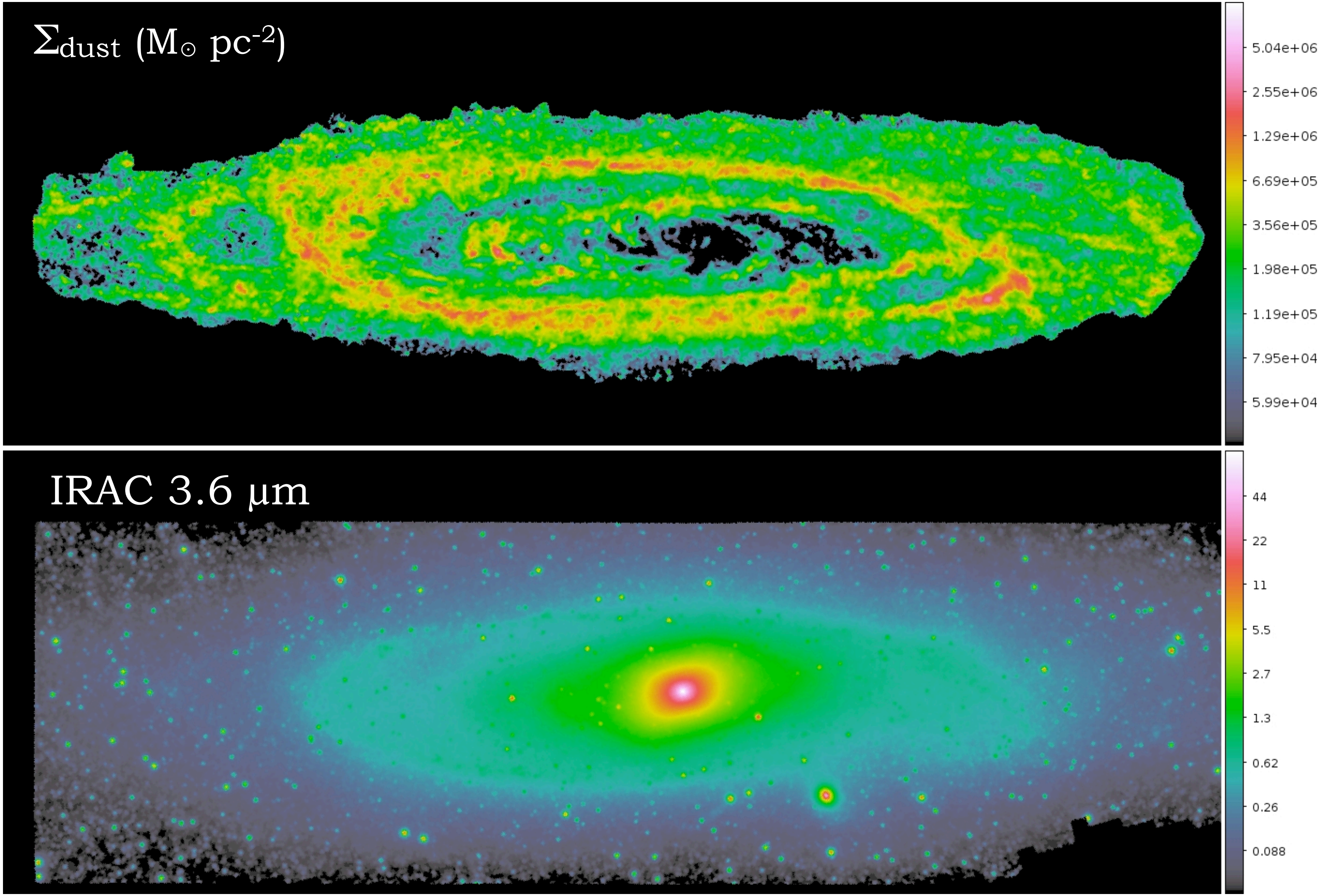


CO J=(1-0) from CARMA - Schruba et al. (in prep)

Radiation Field on ~100pc scales.



Radiation Field on ~100pc scales.

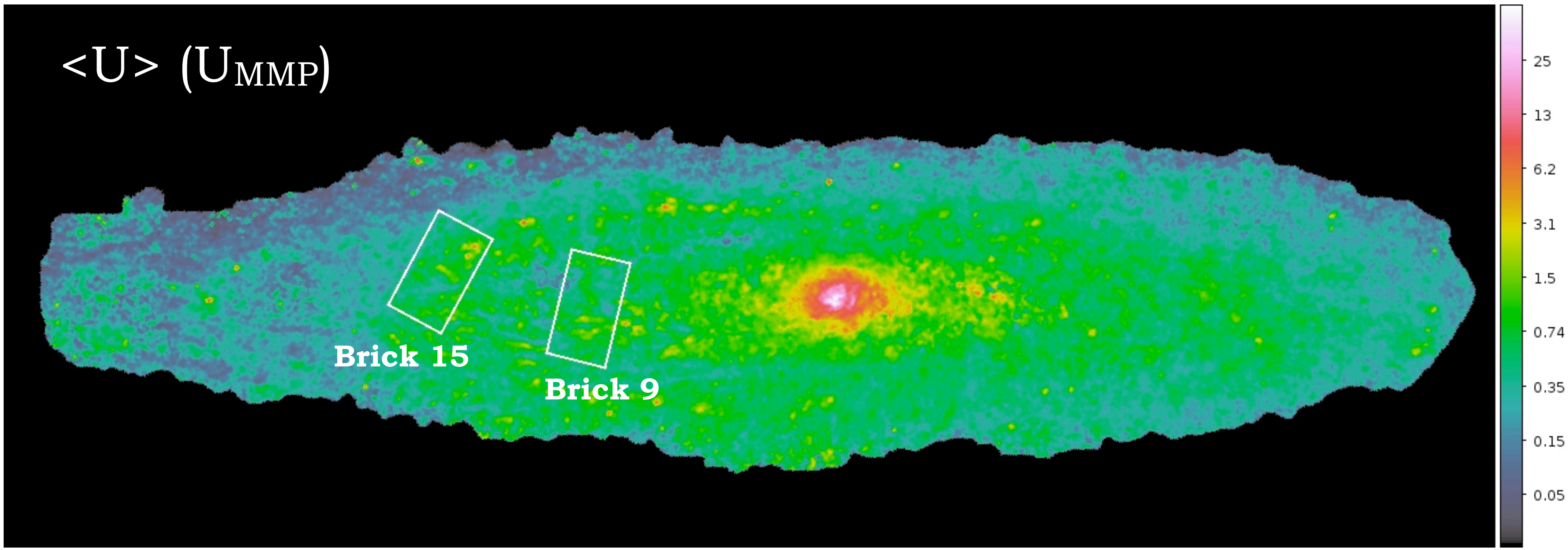


Dust Heating & Stellar Populations

The UV radiation field from resolved star photometry.

In M31 we can do much more…

Reconstruct input UV radiation field from individual stars getting their intrinsic UV flux and extinction from SED fits.
(Kapala et al, in prep)



Dust Heating & Stellar Populations

Direct census of stellar populations heating the dust.

Using stellar SED fit results from PHAT…

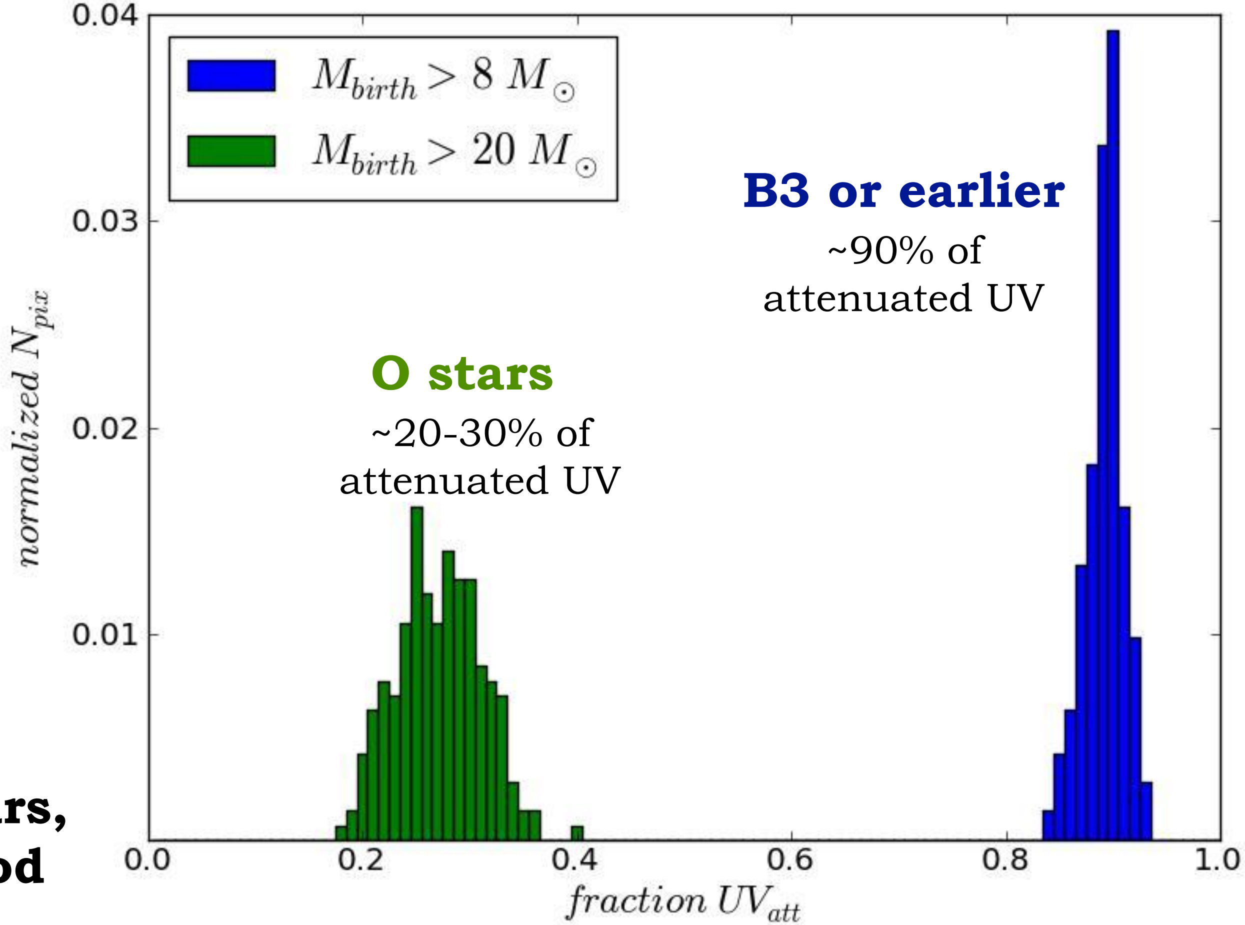
(1) calculate [intrinsic] - [observed] UV flux for each star

(2) select samples representative of various populations

(3) calculate fraction of the attenuated UV from those populations in 200pc pixels

UV field dominated by B stars, as in the solar neighborhood (Habing 1984).

Poster by Maria Kapala

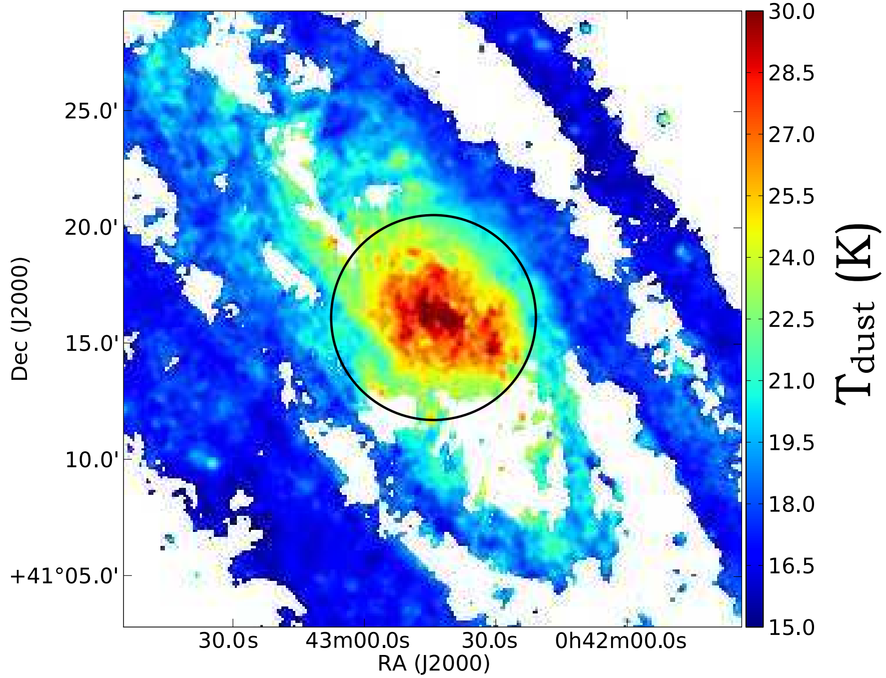


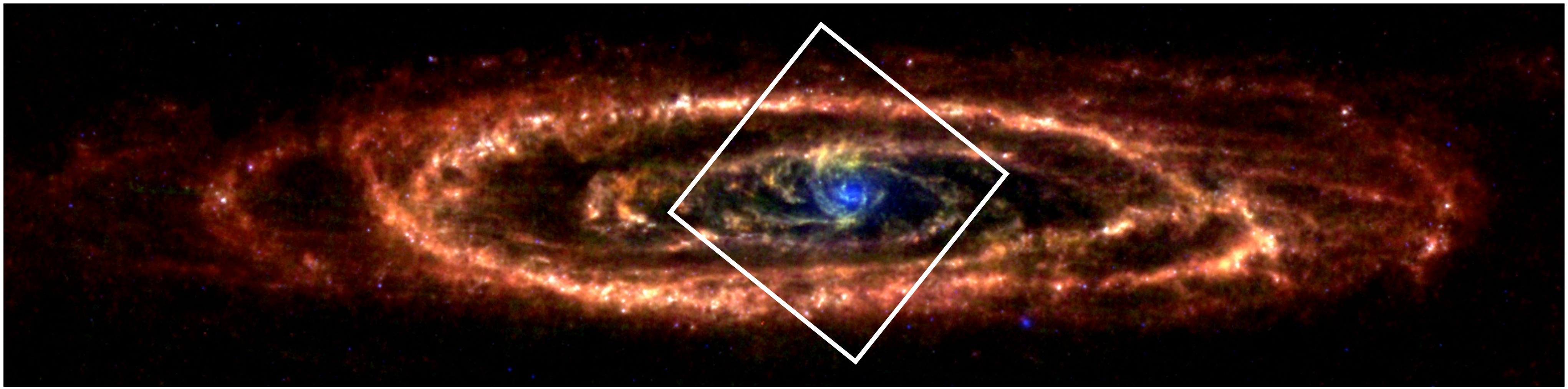
Dust Heating & Stellar Populations

M31's hot bulge dust - Groves et al. 2012

Presence of warm dust in M31's bulge has been known since IRAS.
(Habing et al. 1984)

Now, our far-IR maps from Herschel let us track the T_{dust} gradient at high spatial resolution.





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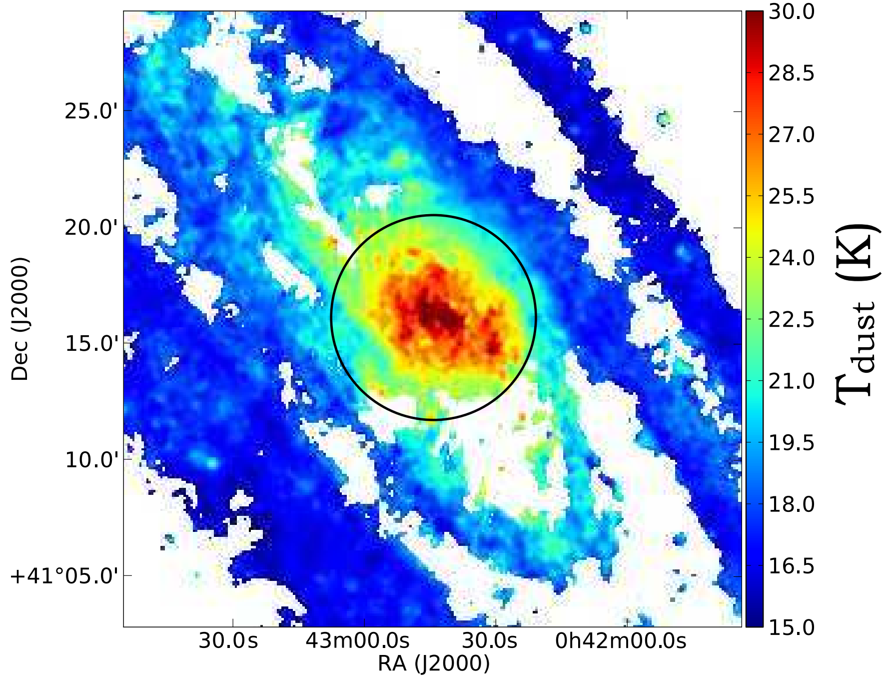

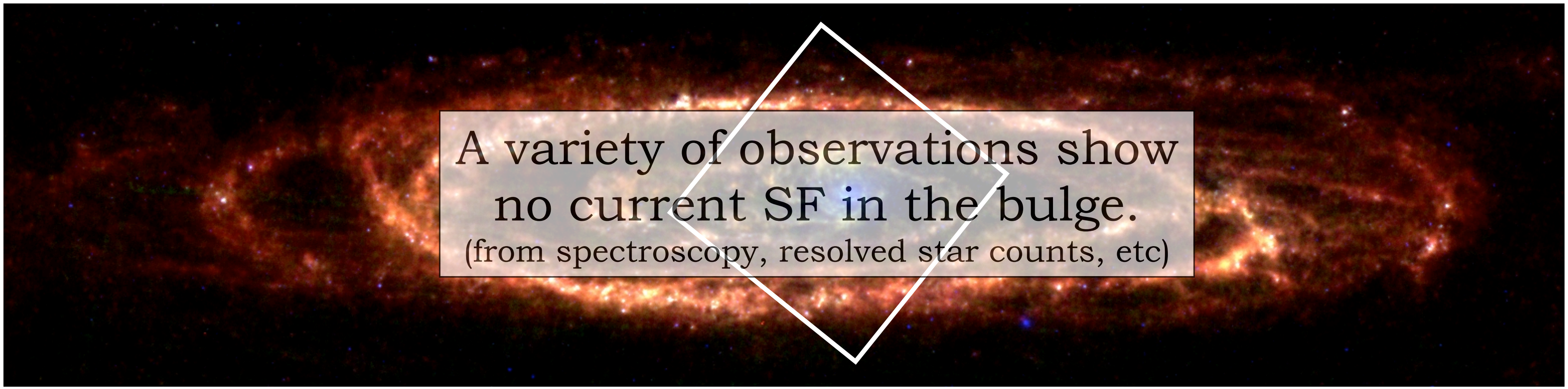

Dust Heating & Stellar Populations

M31's hot bulge dust - Groves et al. 2012

Use: 3D stellar density profile of bulge from Geehan et al. (2006).

estimate of unattenuated stellar SED

Assume: optically thin dust (a good assumption).

↓

Directly calculate radiation field & predict T_{dust}.

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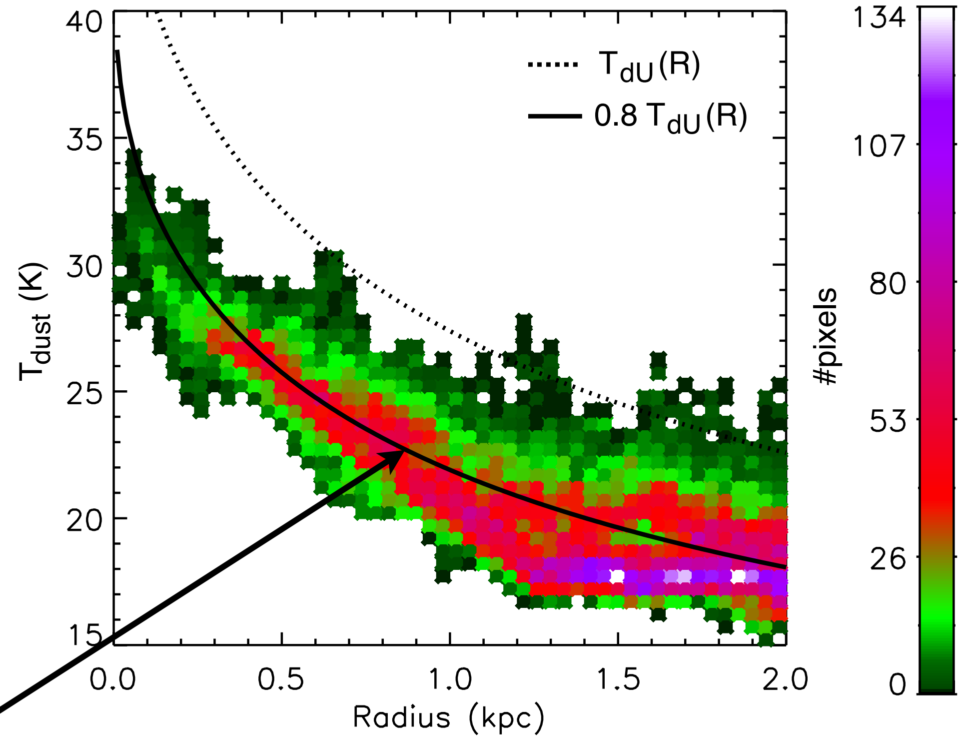

2-D Histogram of T_{dust} values as a function of radius in the inner 2 kpc.

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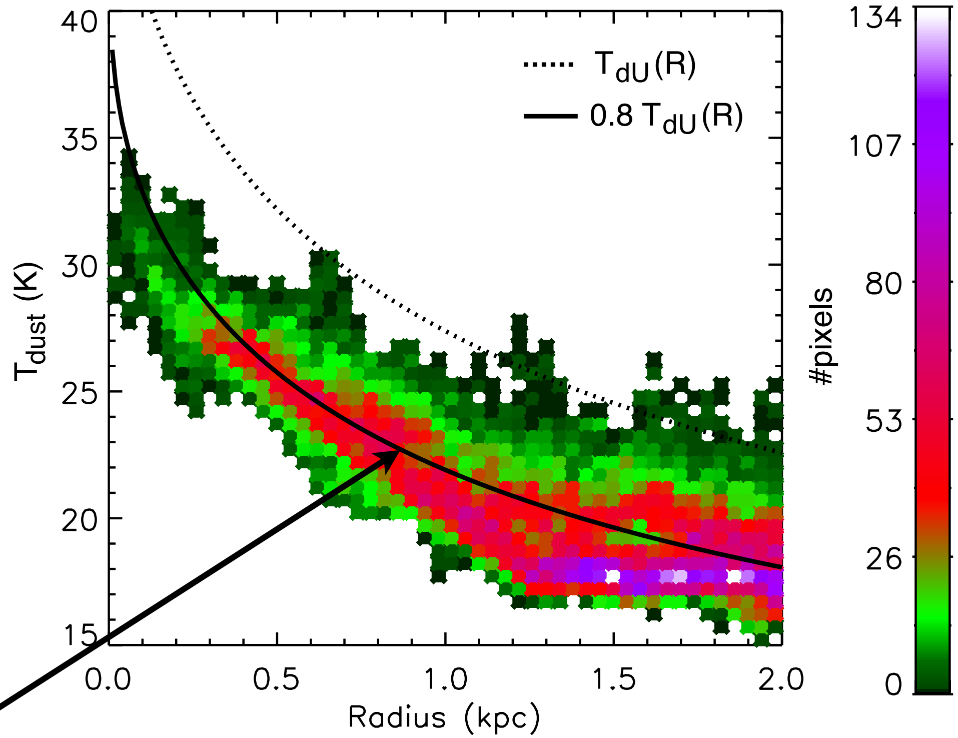
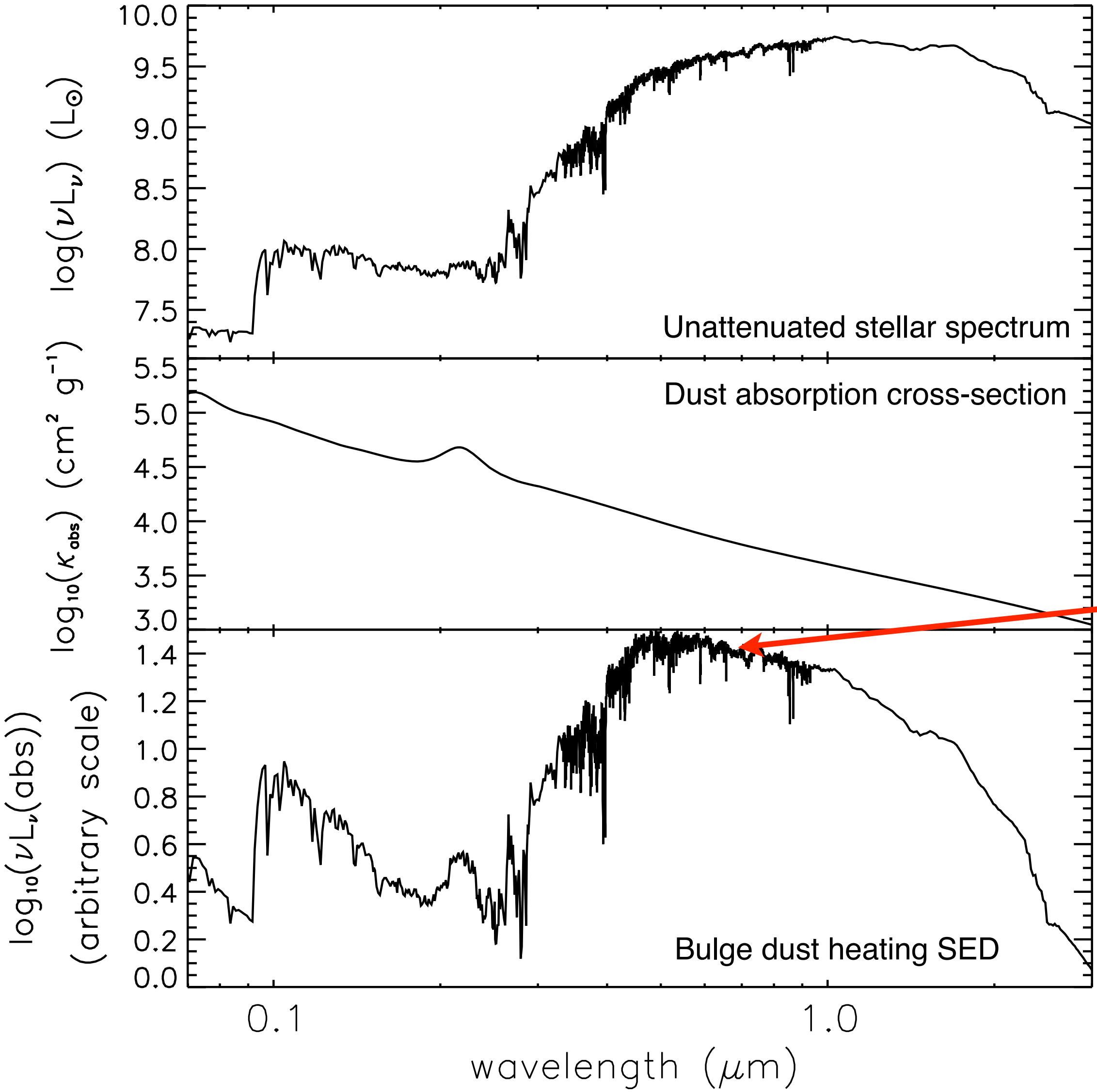


2-D Histogram of T_{dust} values as a function of radius in the inner 2 kpc.

Dust in M31's bulge heated by stars > 10 Gyr old.

Dust Heating & Stellar Populations

M31's hot bulge dust - Groves et al. 2012



Weight the input UV SED by the dust absorption cross-section to see what wavelengths contribute most to heating dust.

Most of the dust heating is done by optical photons.

UV not needed to heat dust to warm temperatures.

Gas Heating & [CII] 158 μm Emission

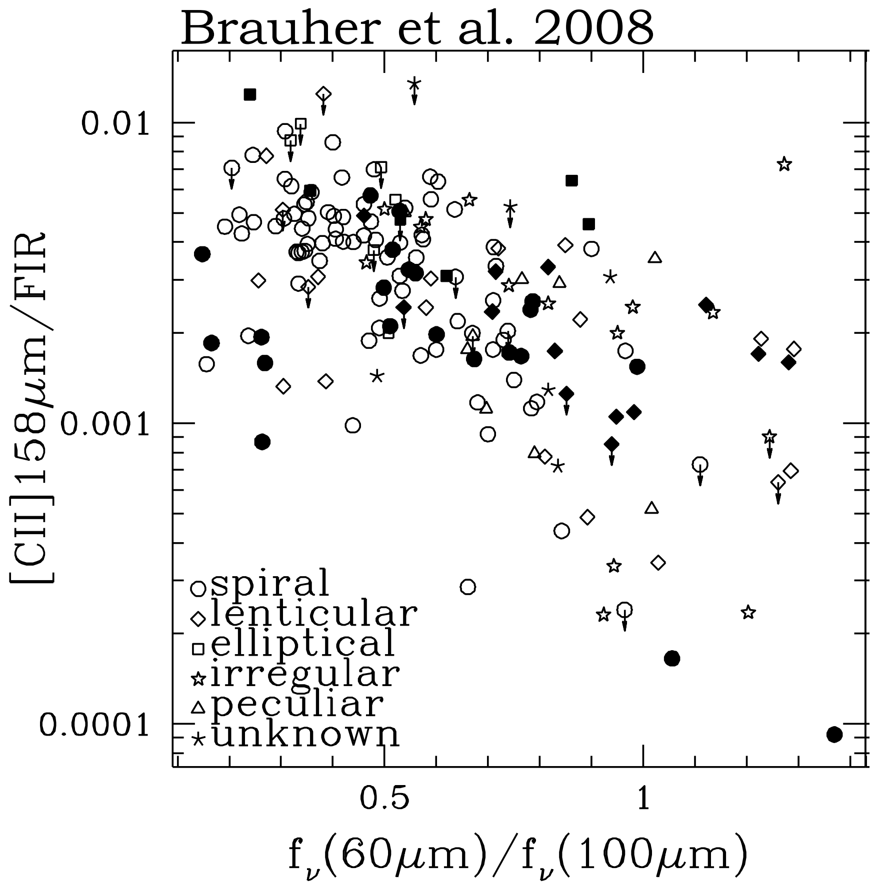
Neutral ISM gas is heated mainly by photoelectrons ejected from dust grains. Cooled by FIR lines of [CII] and [OI].

PE heating depends on:

- radiation field (strength, spectrum)
- amount of dust
- properties of dust (size, charge)

[CII] and [OI] are highly observable tracers of the ISM at a range of distances - important to understand their origins.

The Far-IR Line Deficit



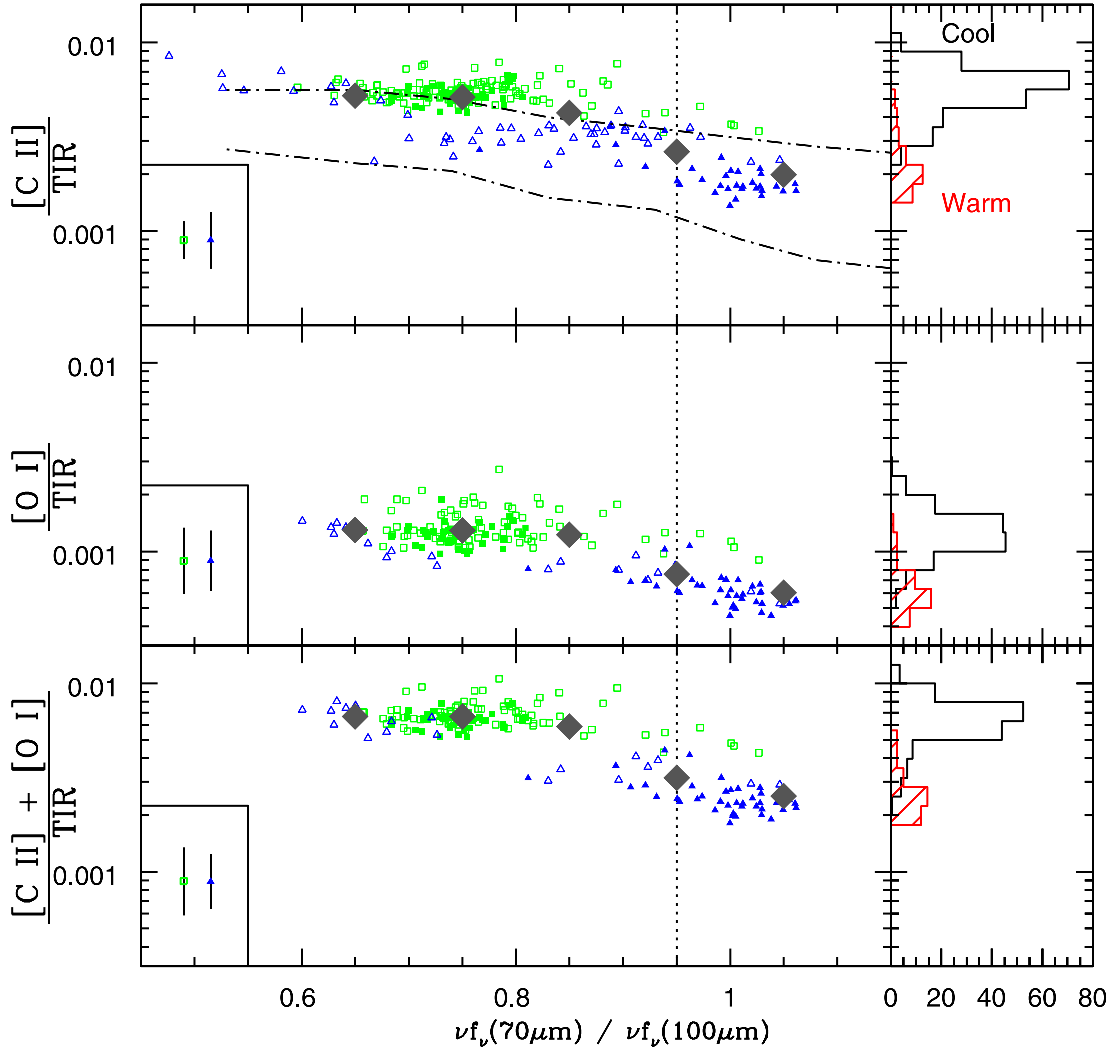
Measurements of [CII] and other far-IR lines with ISO show a "deficit" of line/dust continuum at warm dust temperatures. (Malhotra et al. 2001)

The Far-IR Line Deficit

Recent work using *Herschel* observations of galaxies on ~kpc resolution examine line deficit in more detail.

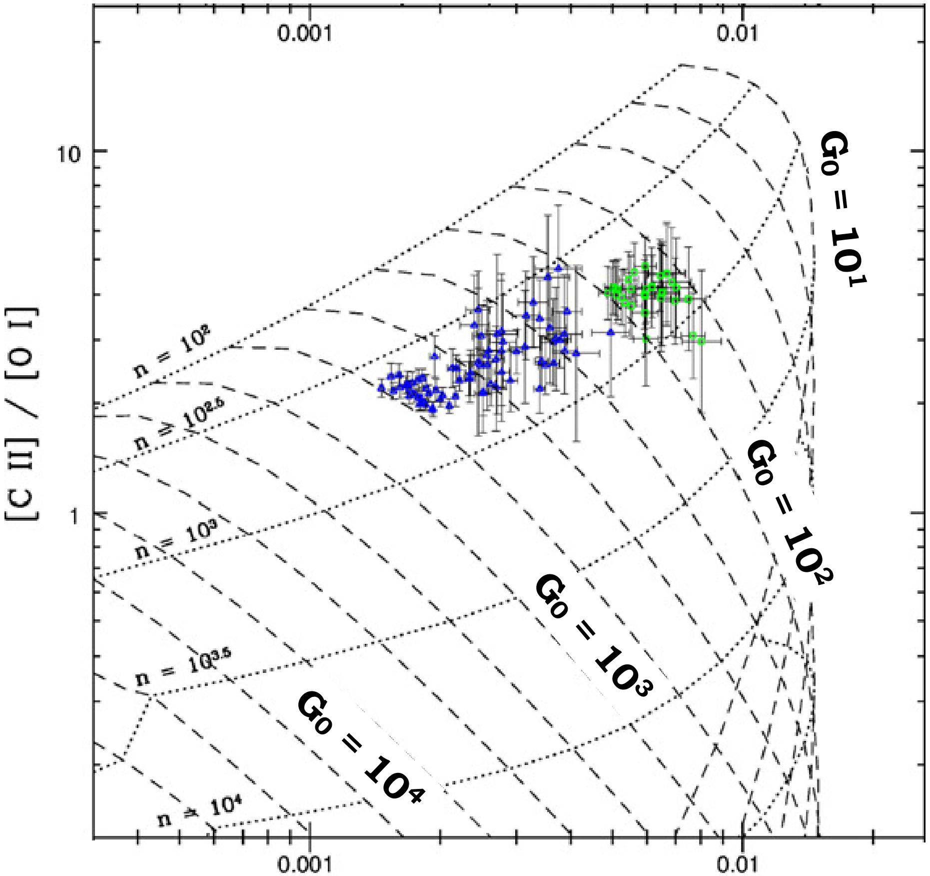
Line deficit persists on ~kpc scales.

Croxall et al. 2012



Contributions from different ISM components?

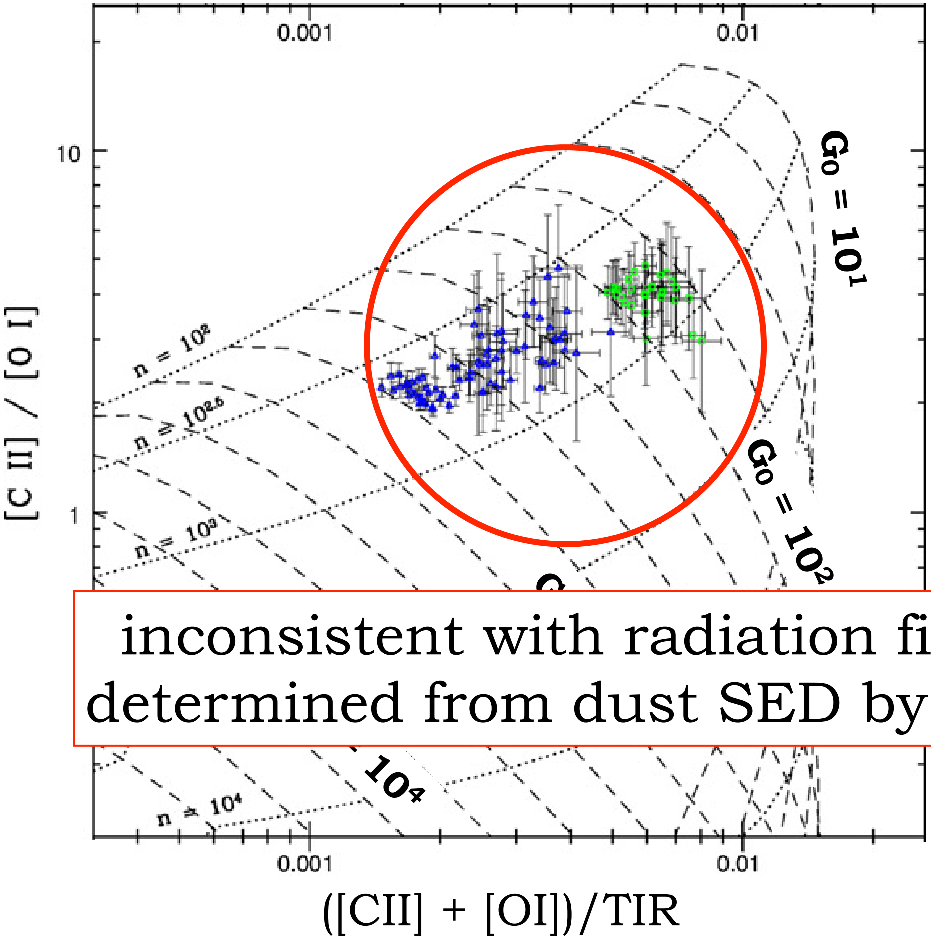
Croxall et al. 2012



([CII] + [OI])/TIR

Contributions from different ISM components?

Croxall et al. 2012



inconsistent with radiation field
determined from dust SED by 10x

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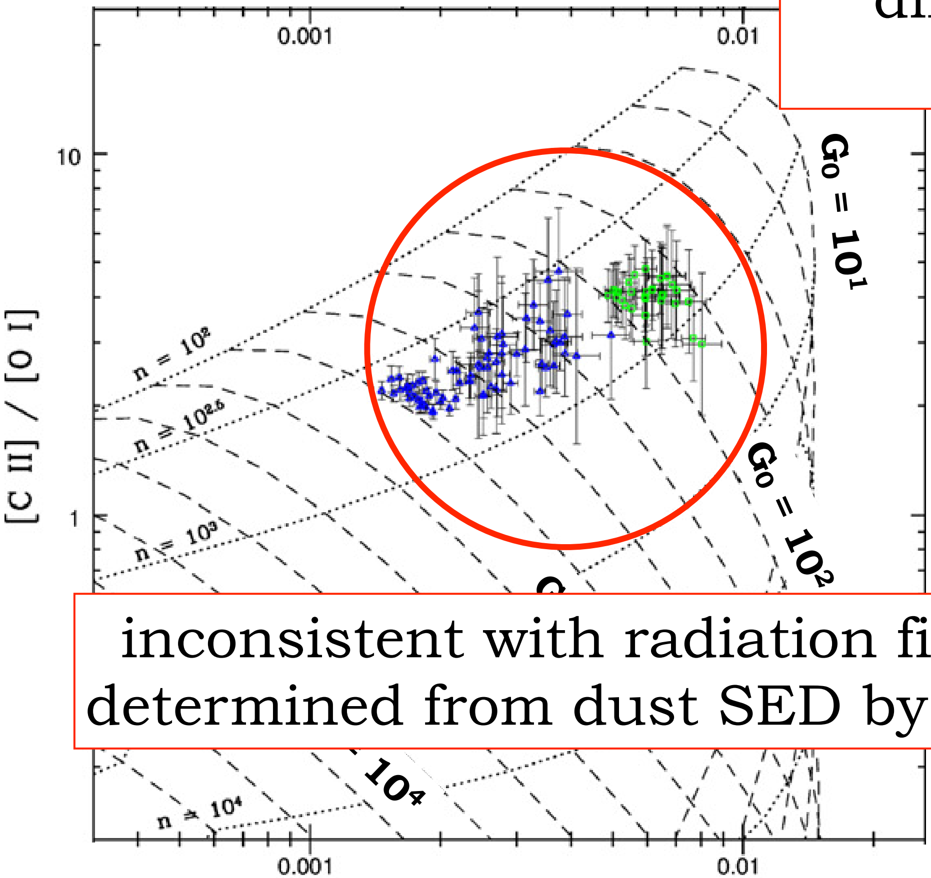
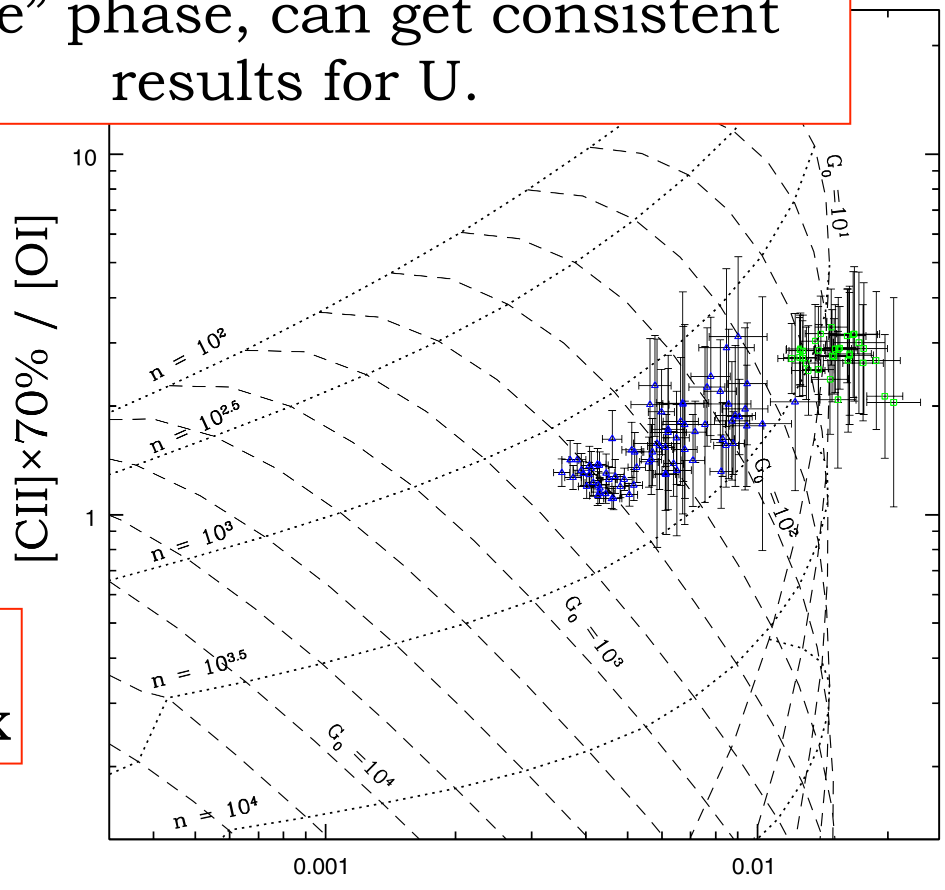


inconsistent with radiation field determined from dust SED by 10x

if 70% of TIR and 30% of [CII] from "diffuse" phase, can get consistent results for U.



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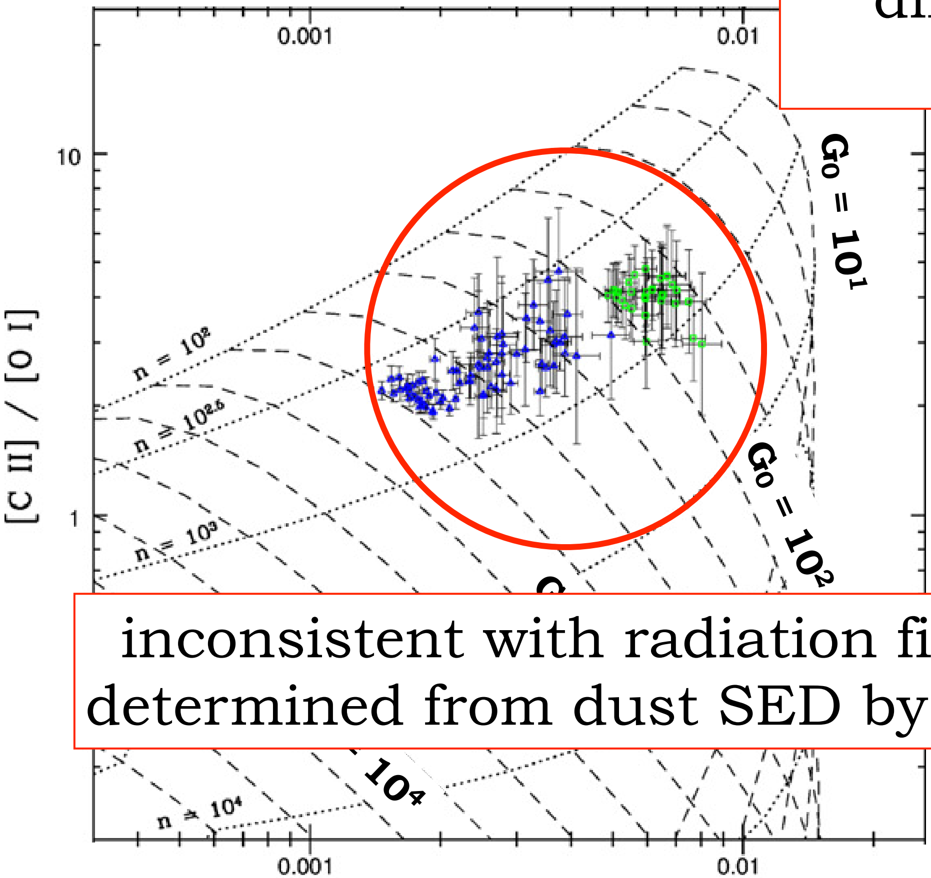

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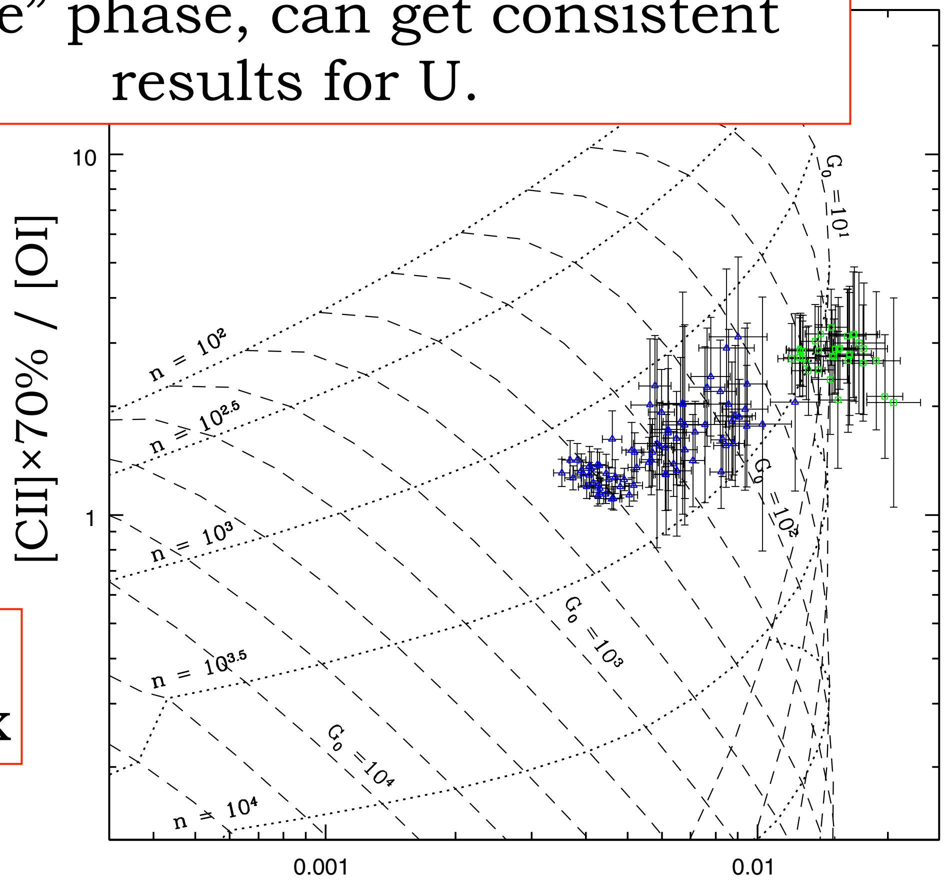
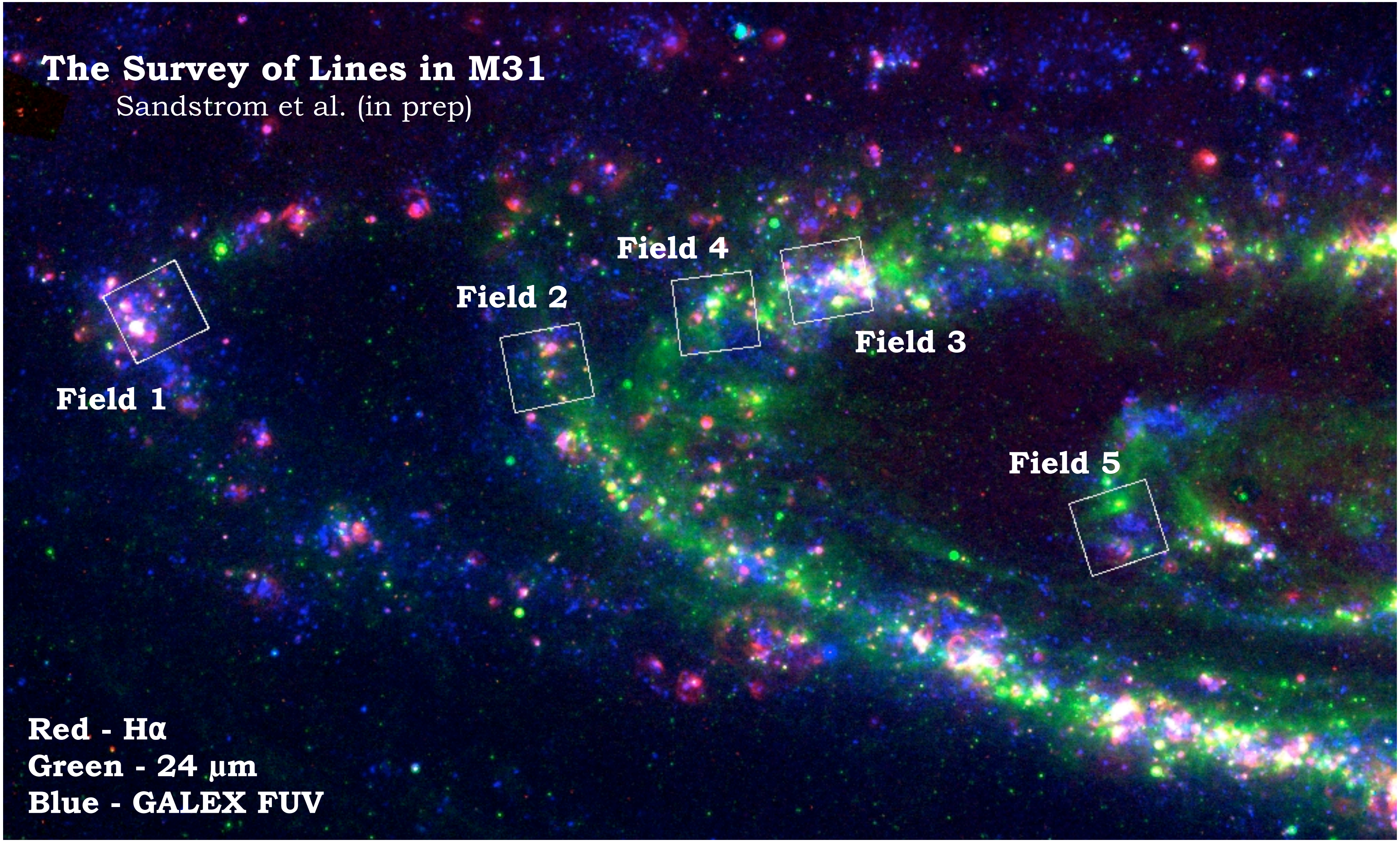
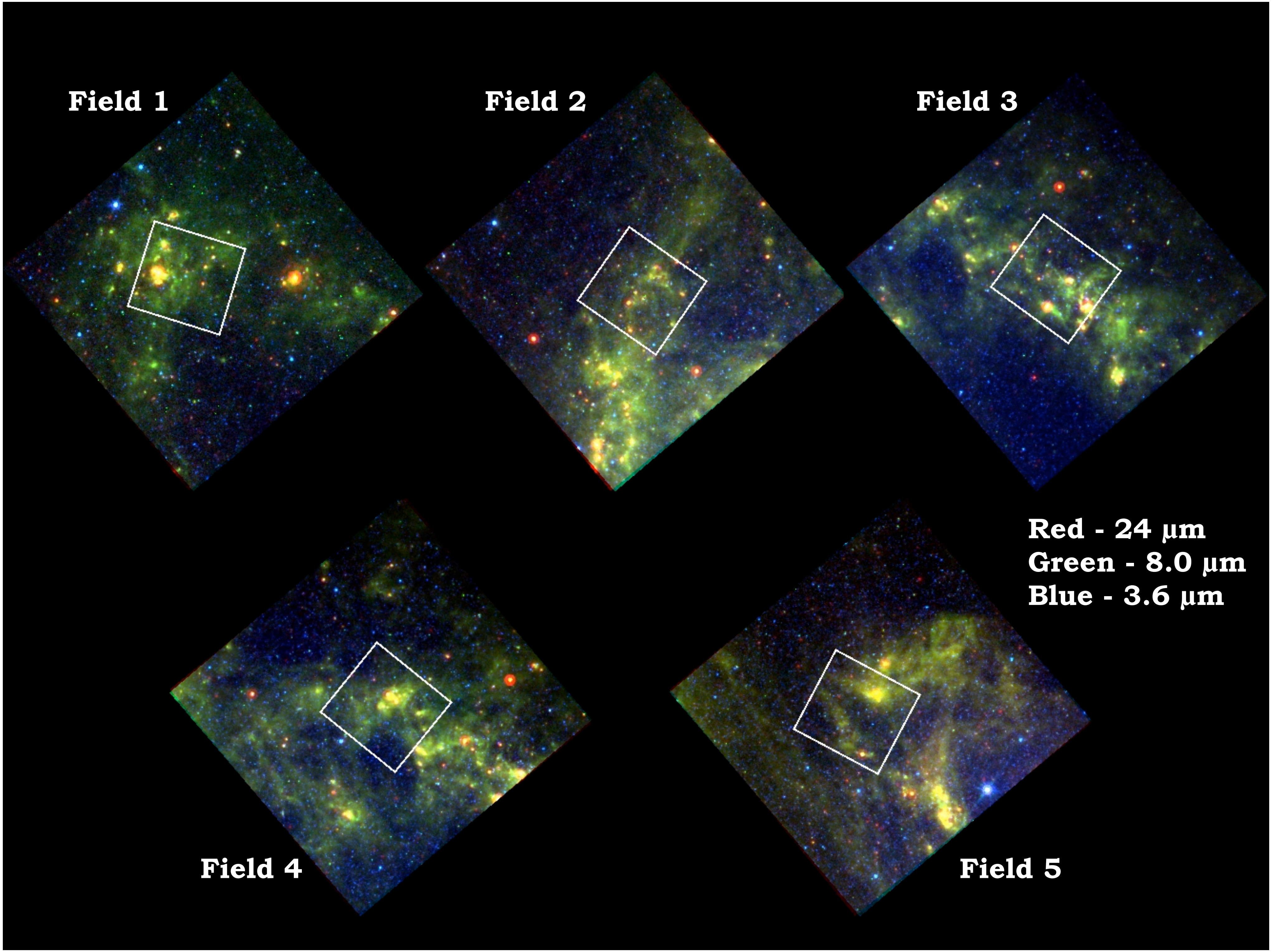
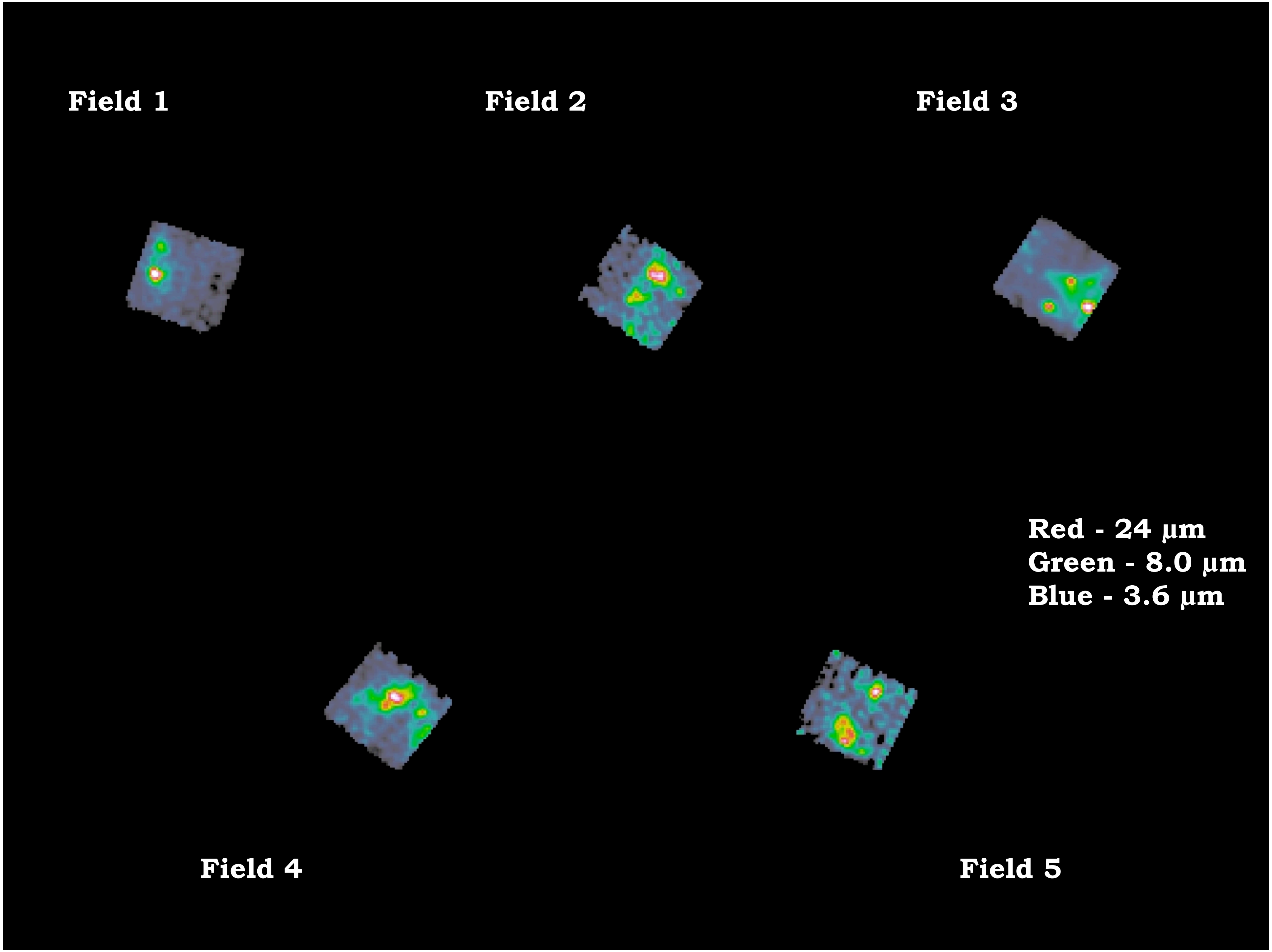


Need sub-kpc resolution to check this!!

The origin of [CII] emission on sub-kpc scales.




Field 1
Field 2
Field 3
Red - 24 μm
Green - 8.0 μm
Blue - 3.6 μm
Field 4
Field 5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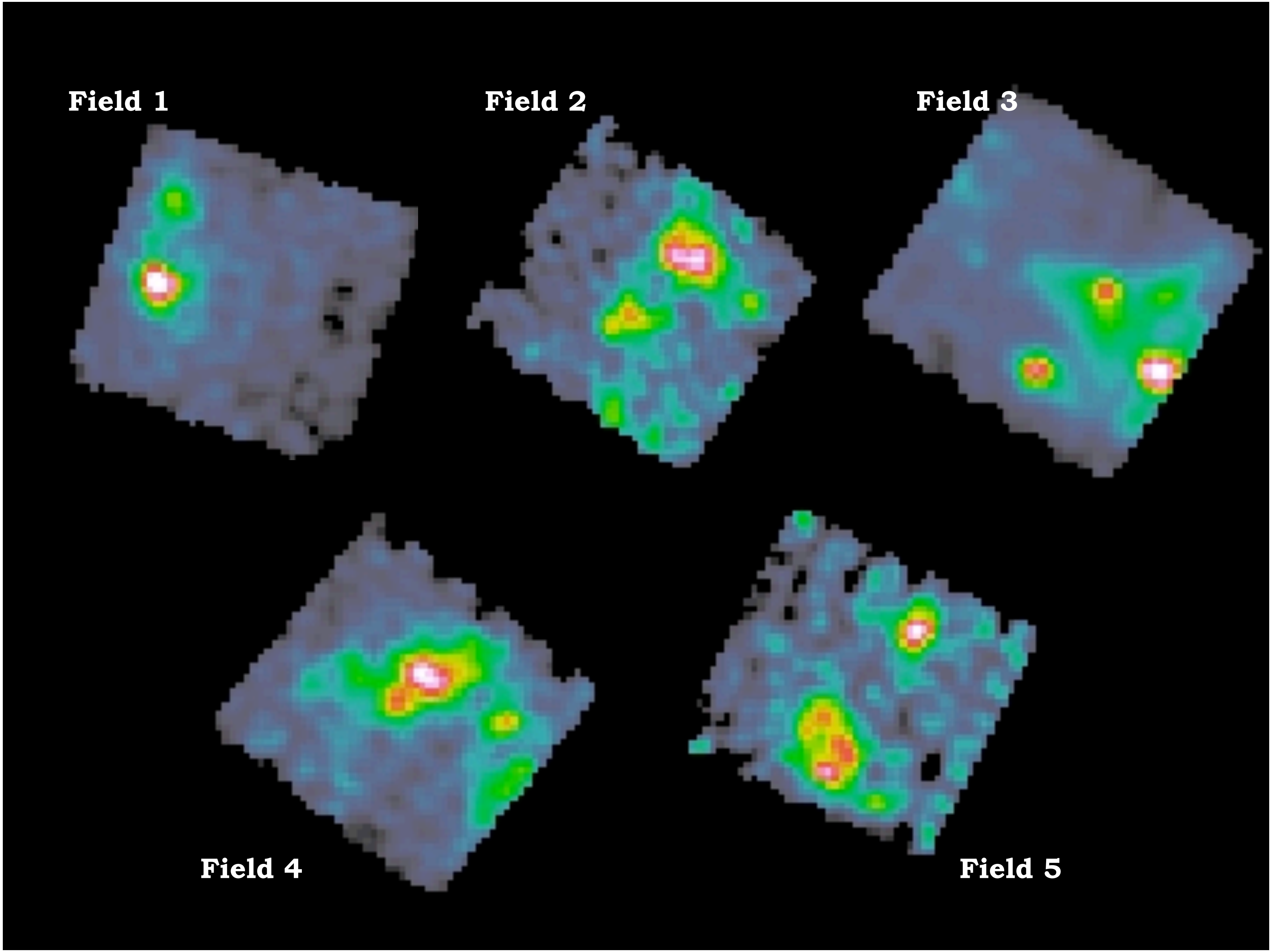
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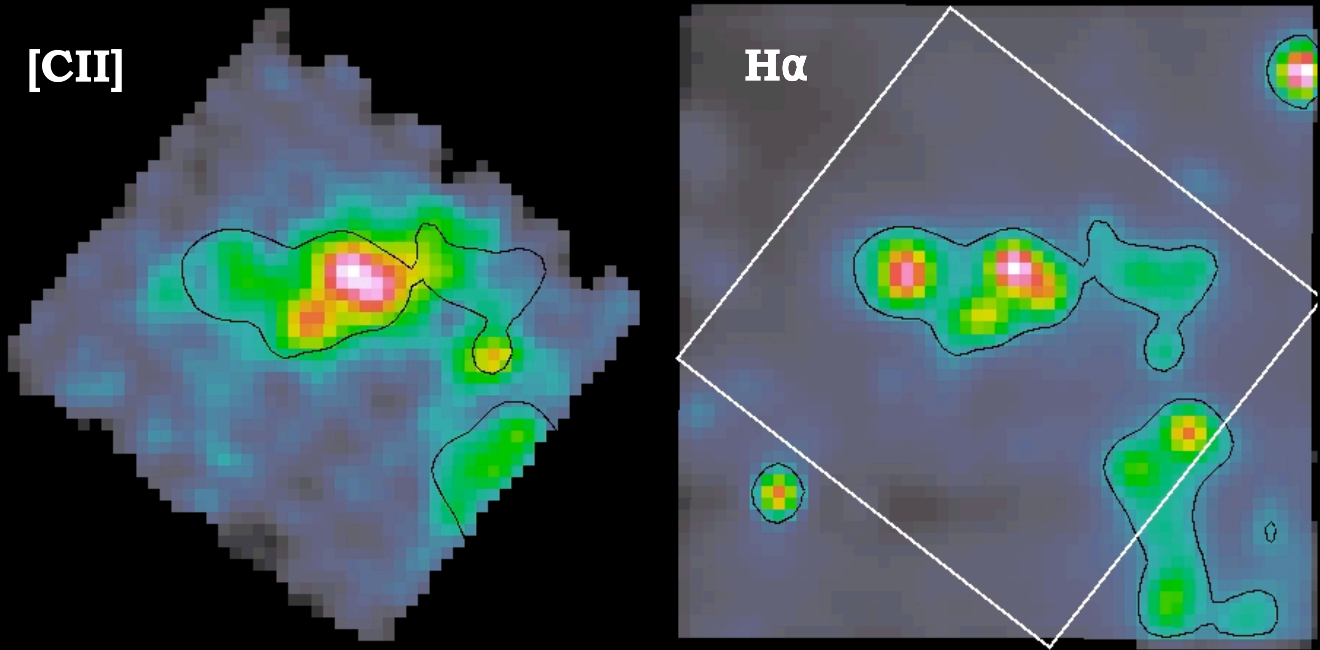
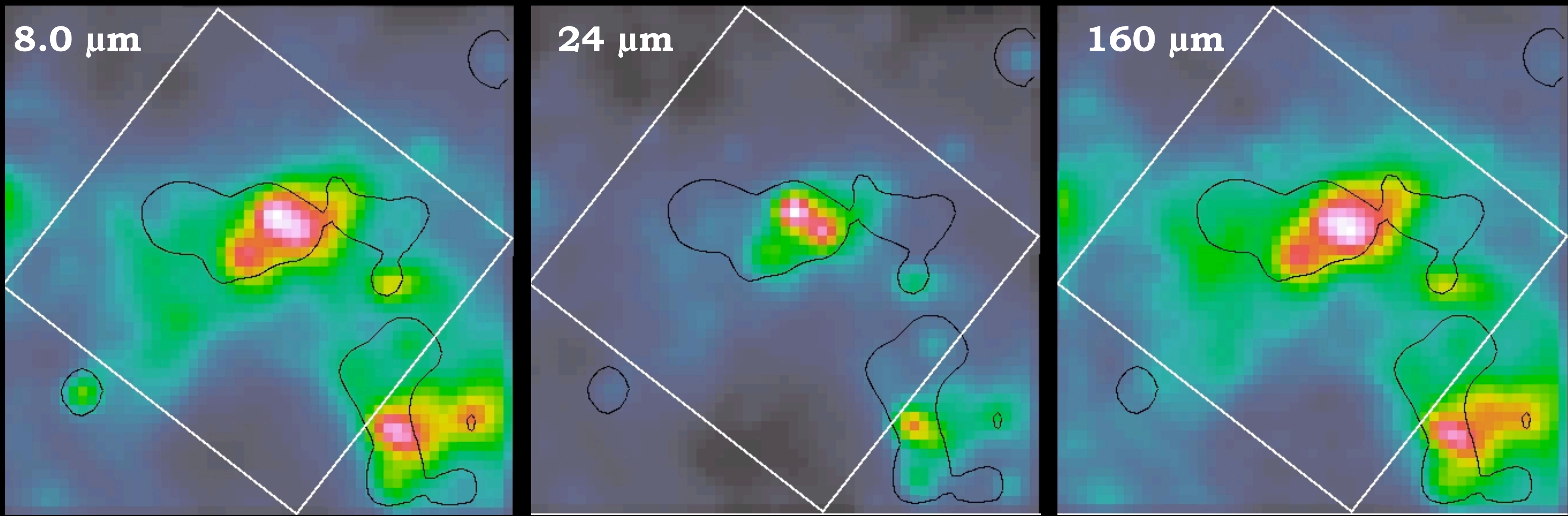
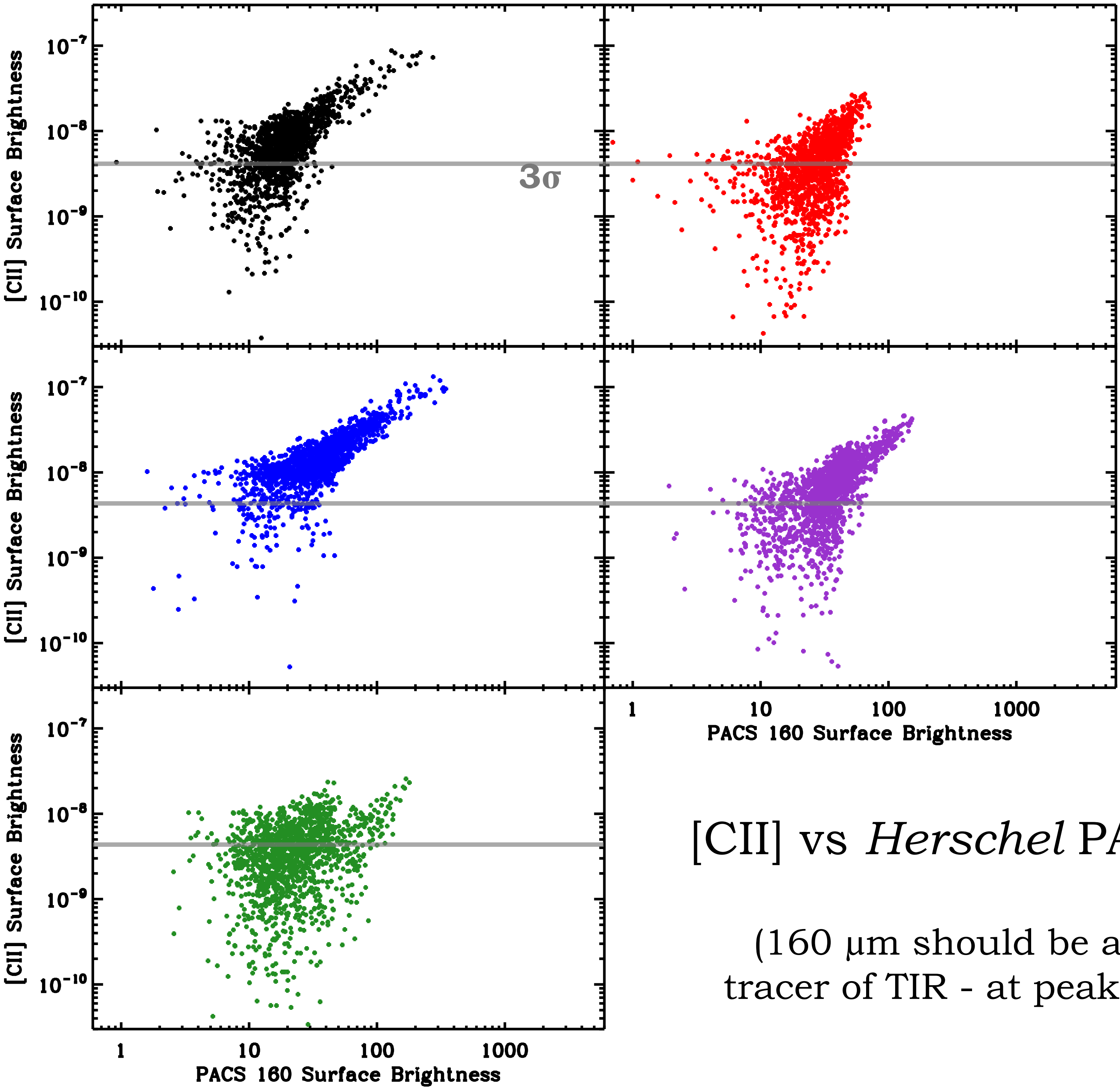


Field 4

matched resolution,
multi-wavelength comparison

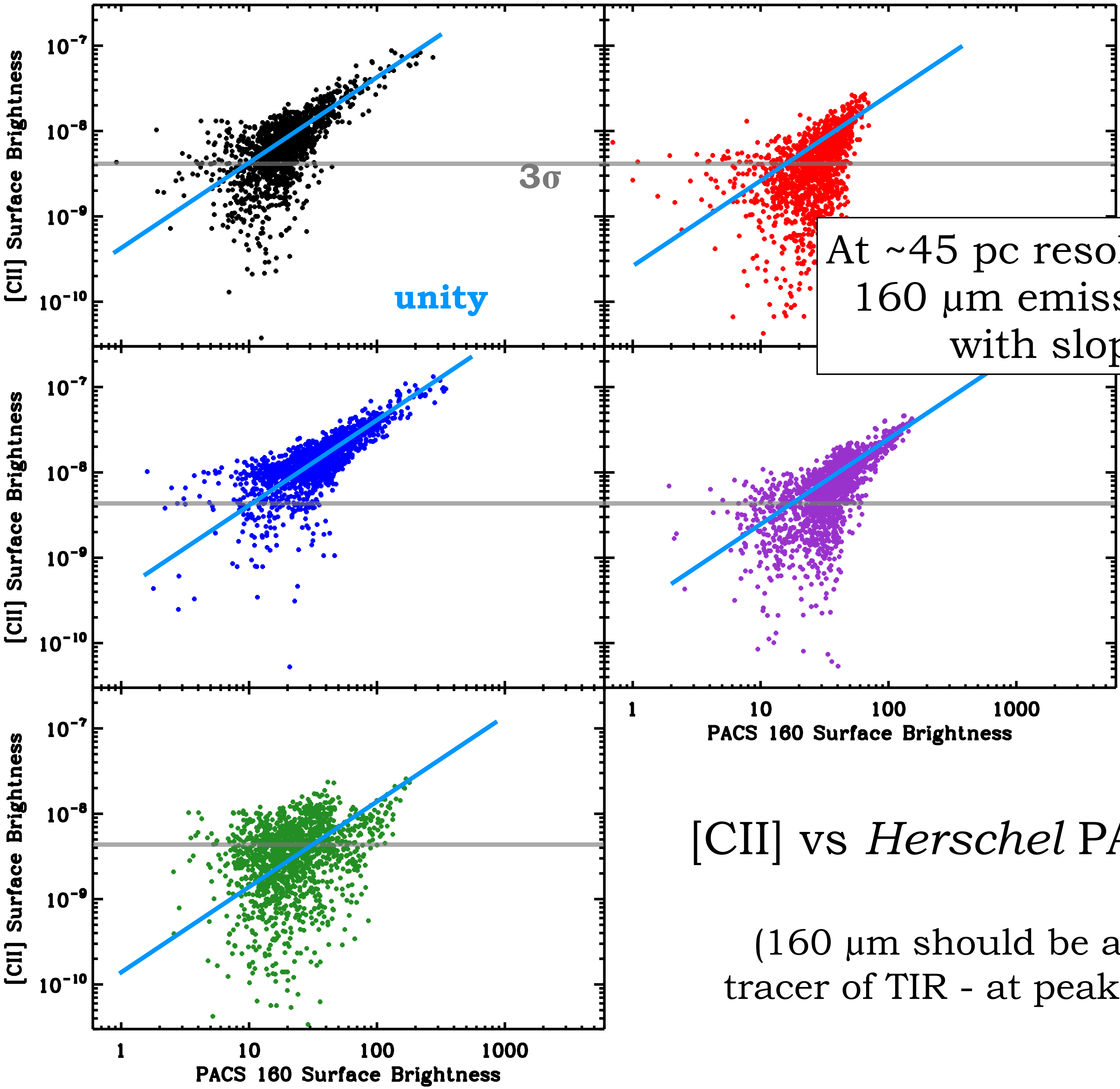
[CII] is more extended than Hα,
good spatial correspondence with dust emission





[CII] vs *Herschel* PACS 160 μm

(160 μm should be a reasonable tracer of TIR - at peak of dust SED)

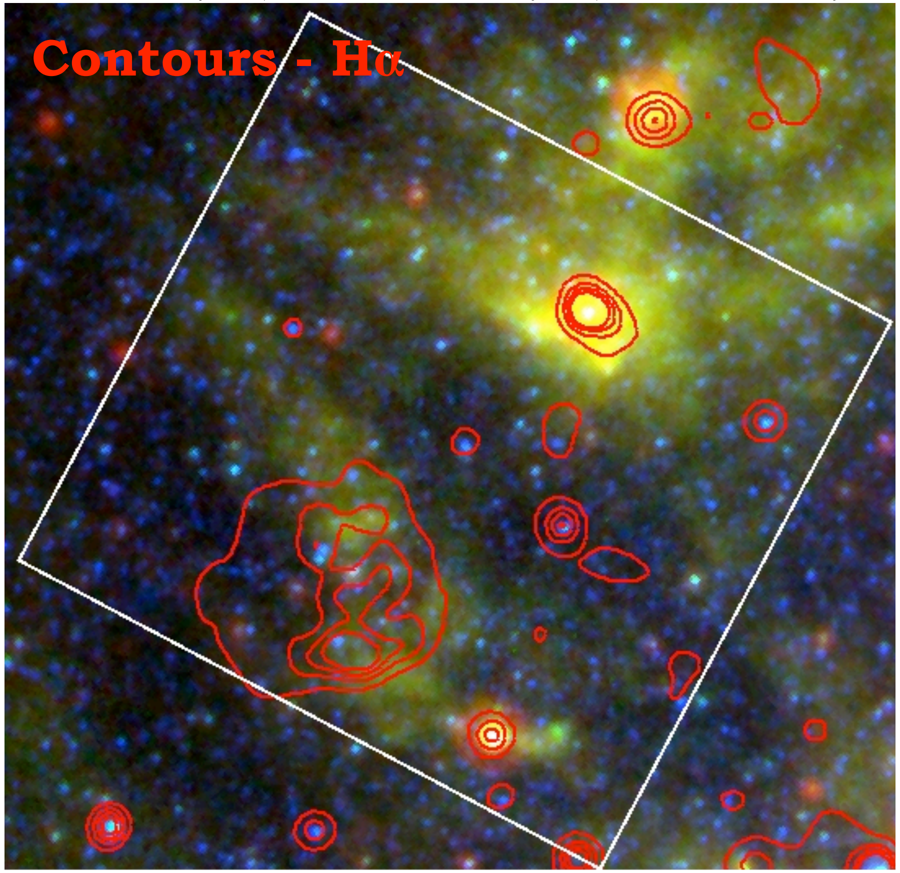


At ~45 pc resolution, [CII] and 160 μm emission correlated with slope ~unity.

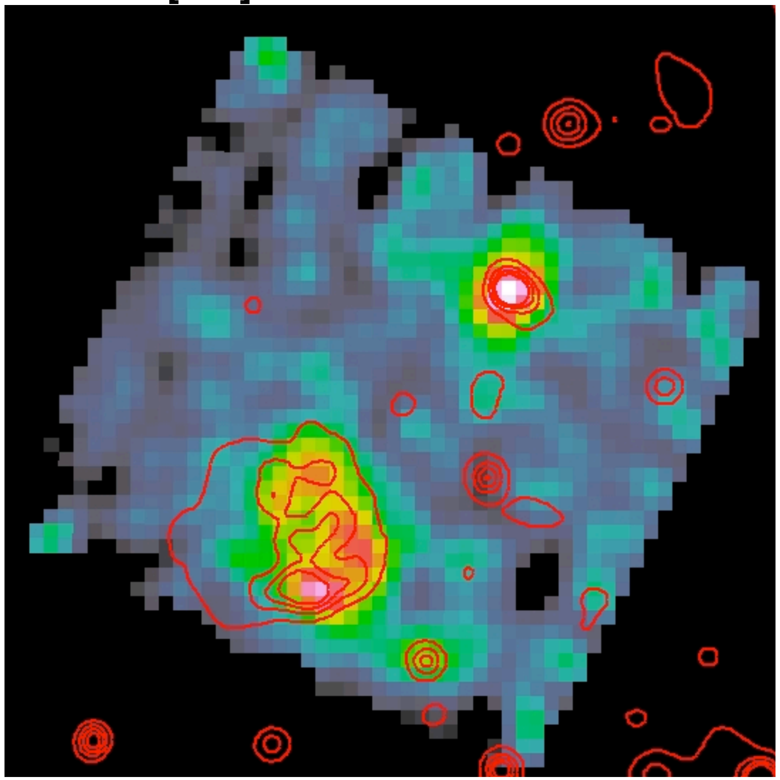
[CII] vs *Herschel* PACS 160 μm

(160 μm should be a reasonable tracer of TIR - at peak of dust SED)

Red - 24 µm, Green - 8.0 µm, Blue - 3.6 µm



Color - [CII]



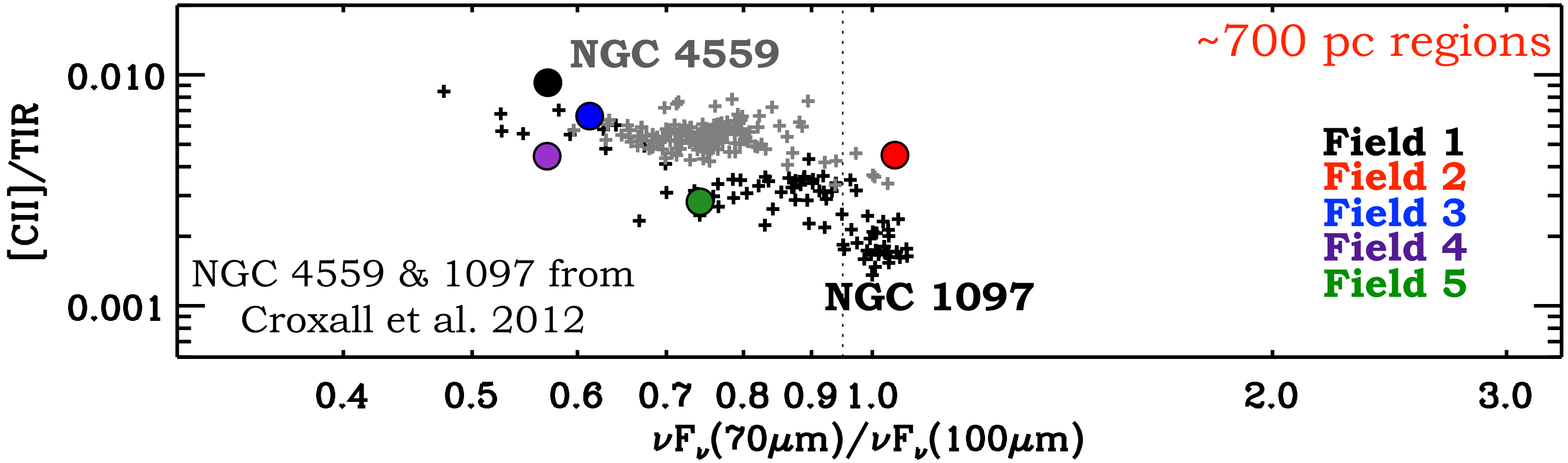
What is up with Field 5?

Large HII complex with little dust emission producing most of the [CII] in this region!

Case where [CII] and TIR do not correspond well on small scales.

[CII] emission at high spatial resolution

and its relation to the far-IR line deficit



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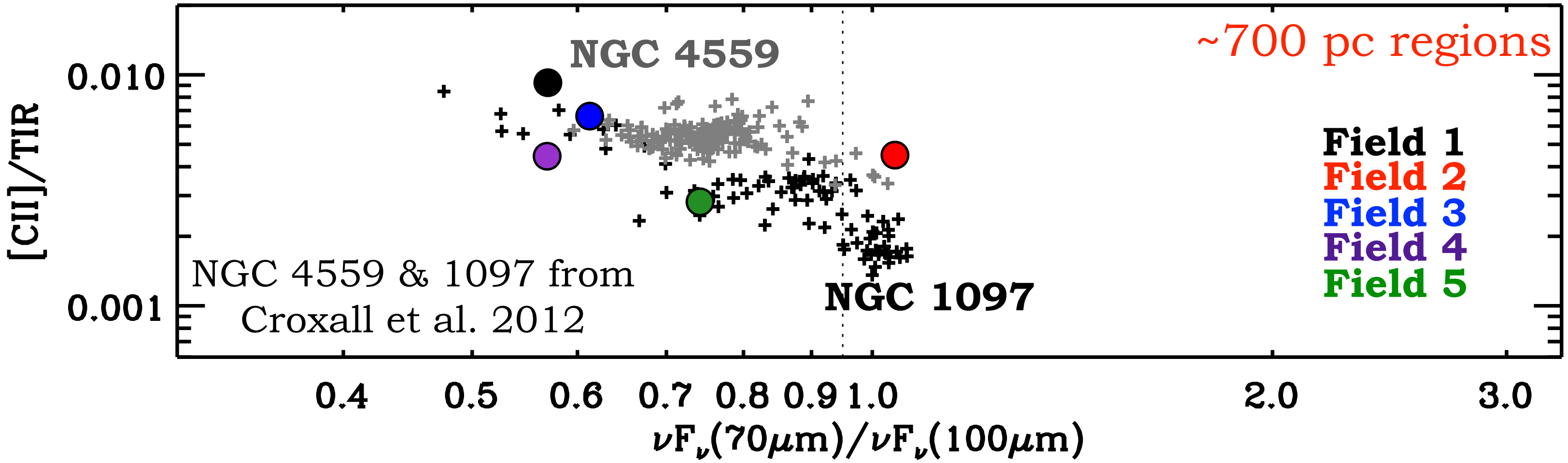
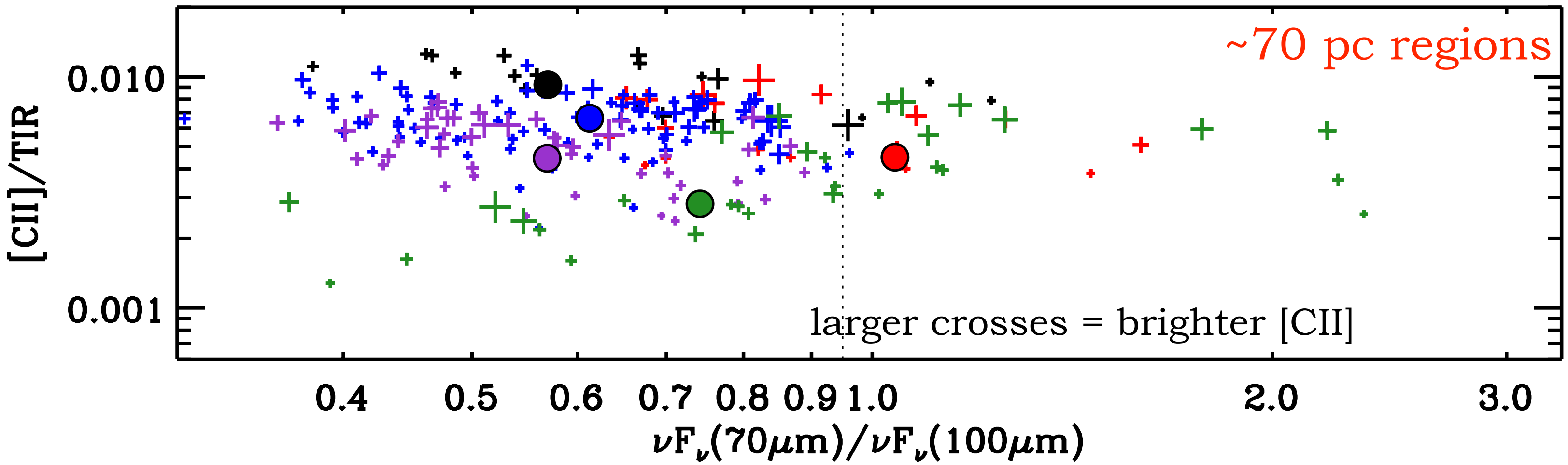
and its relation to the far-IR line deficit





What have we learned about the interaction of stars & the ISM in M31, so far...

- <U> is correlated with Σ_*, not Σ_{SFR} (from dust SED modeling).

- UV field determined from from resolved stars dominated by B stars (from PHAT stellar SED modeling).

- In bulge, radiation field is dominated by old stars and dust heating is mainly from of optical photons, not UV. Warm dust not necessarily a tracer of recent SF.

- [CII] vs TIR on ~45 pc scales is ~constant in most regions, with some exceptions.

- More detailed work using [OI] and [NII] 122 μm maps will address the origins of far-IR line emission at sub-kpc scales.