Dust as a gas tracer
Dust as a heating/SF tracer

Brent Groves
(MPIA)
(and the M31, KINGFISH, HERACLES, & THINGS teams)

RSF13
Schloss Ringberg
24-28th June 2013

Diagnostic Dust

- Strangely, dust is used twofold in the extragalactic Gas - SFR relation:
  - It is used to trace total gas mass
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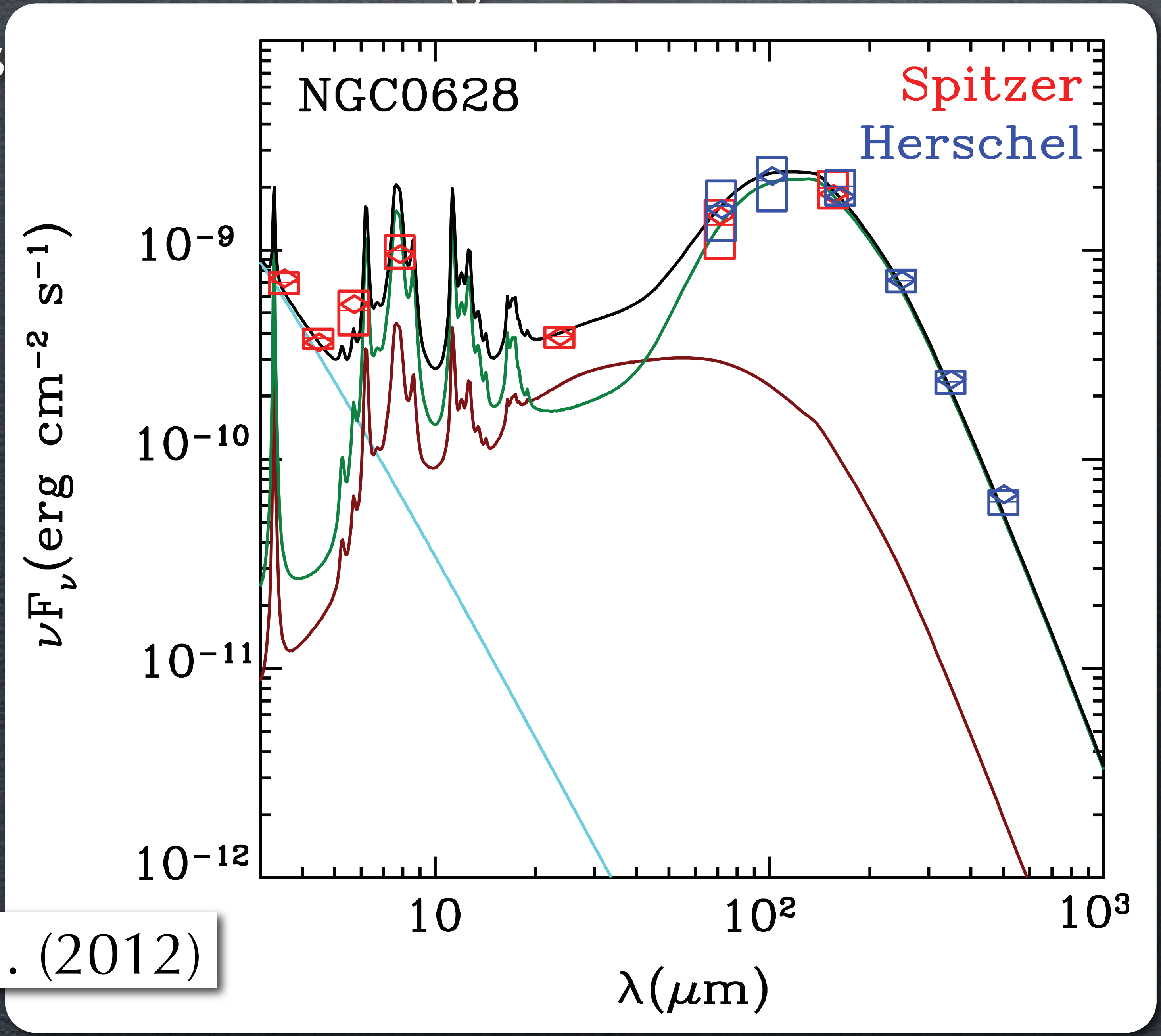
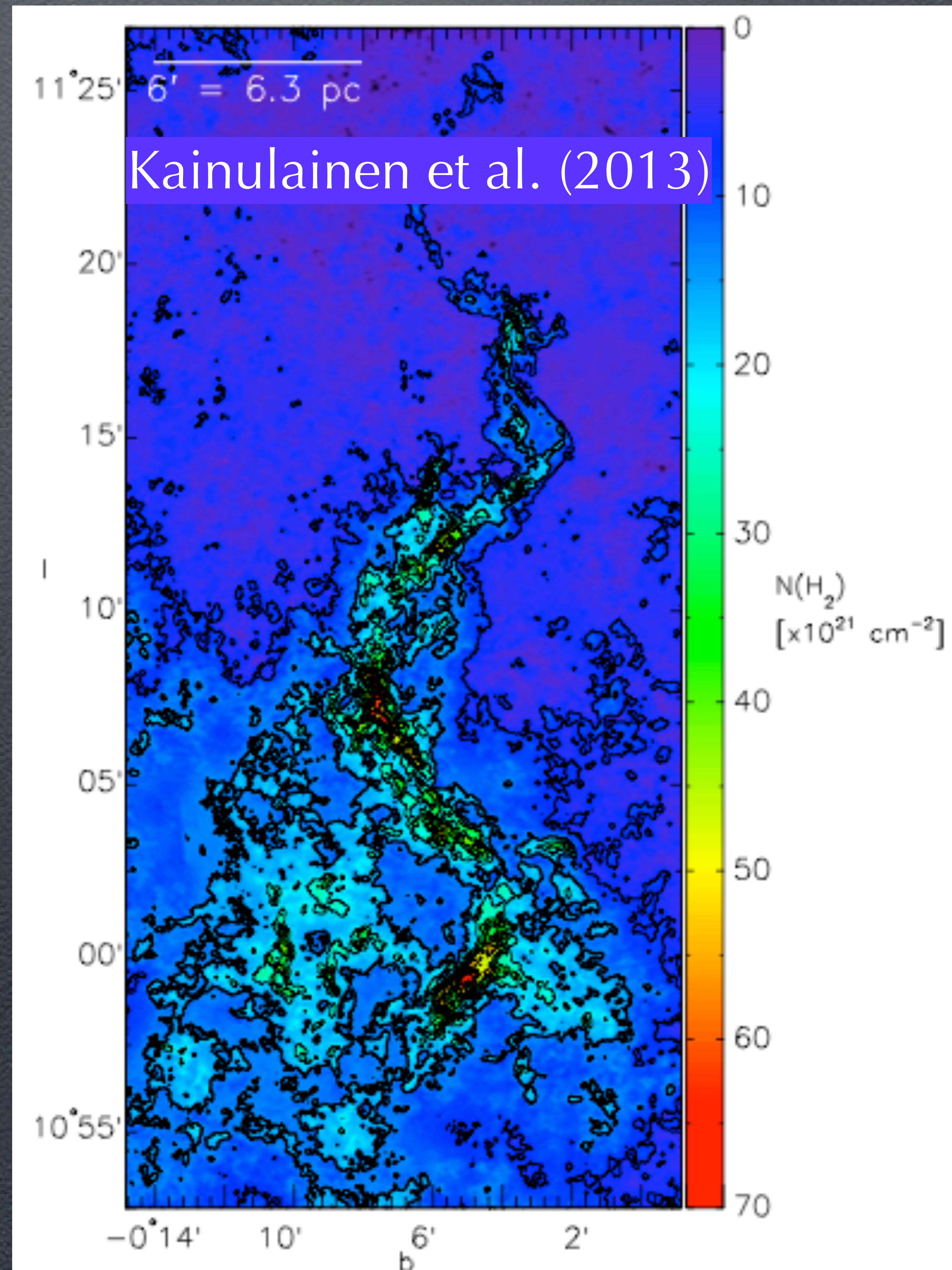


Aniano et al. (2012)

Diagnostic Dust

- Strangely, dust is used twofold in the extragalactic Gas - SFR relation:
  - It is used to trace total gas mass
  - It is used to trace total SFR
- How are the gas and dust related?
  - Dependence on metallicity, other parameters?
- How are the dust luminosity and SFR related
  - Diffuse heating
  - Dust and gas heating

Dust Extinction as a tracer



Dust Extinction as a tracer

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- In nearby galaxies, geometry starts to play a role

Dust Extinction as a tracer

- In

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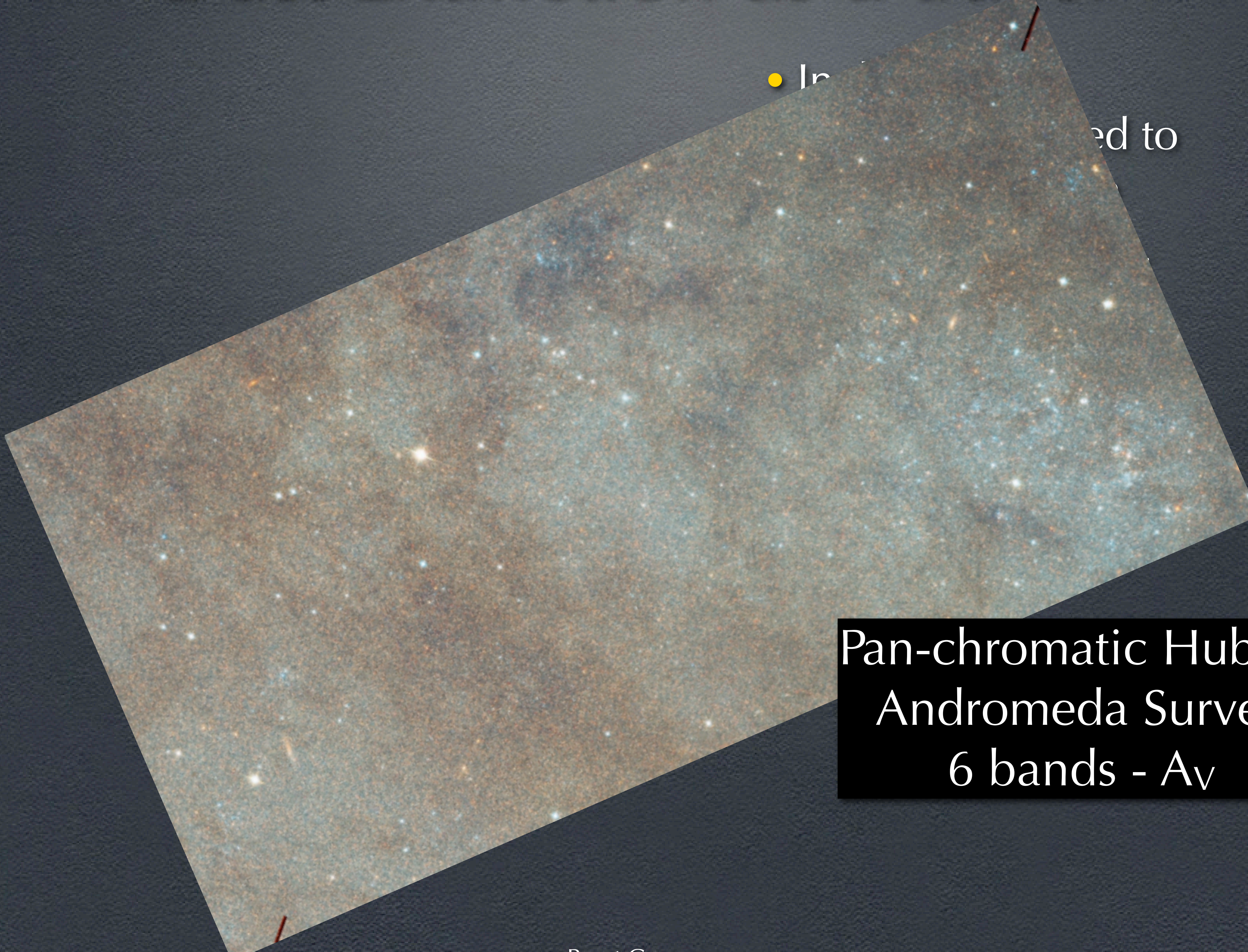
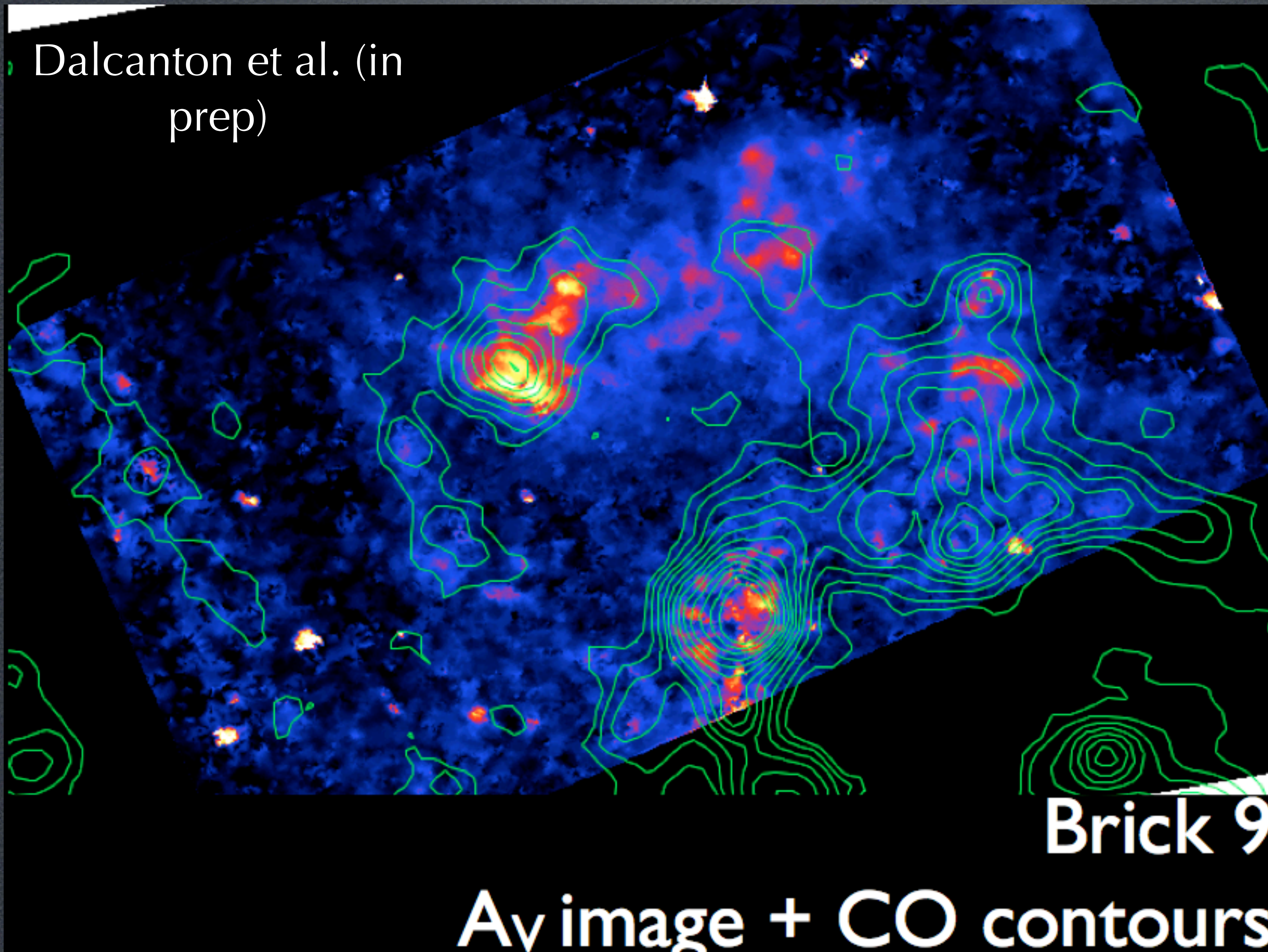


Pan-chromatic Hubble
Andromeda Survey
6 bands - A_V

Dust Extinction as a tracer



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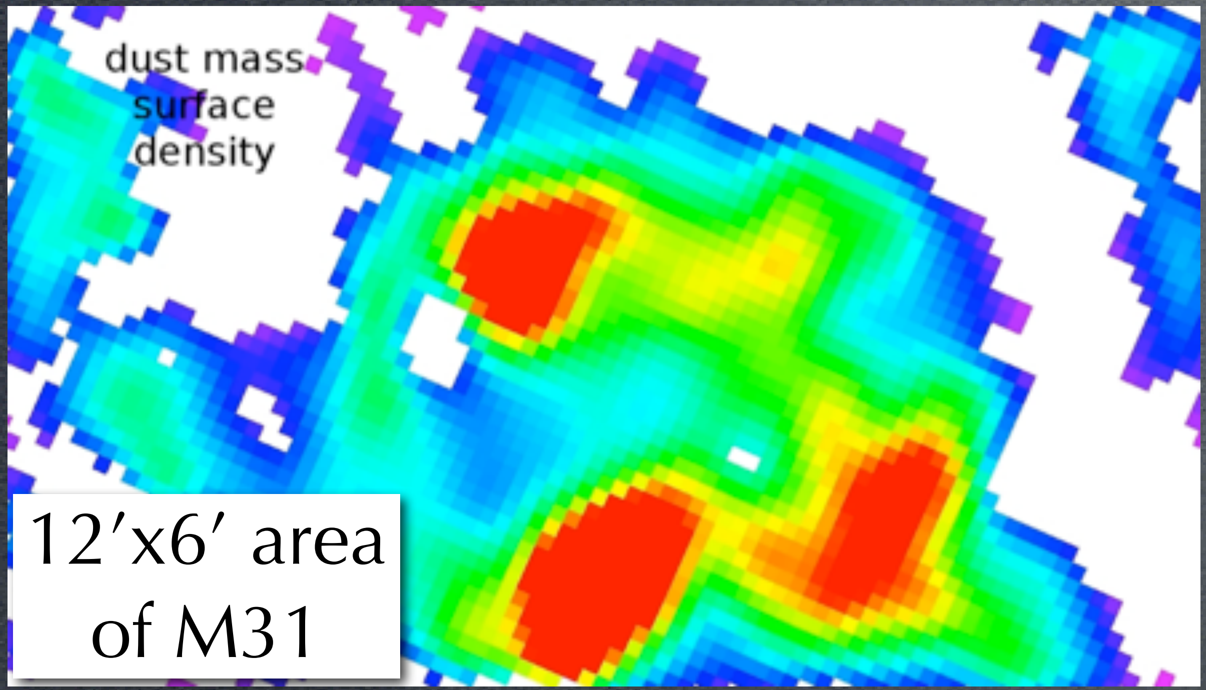

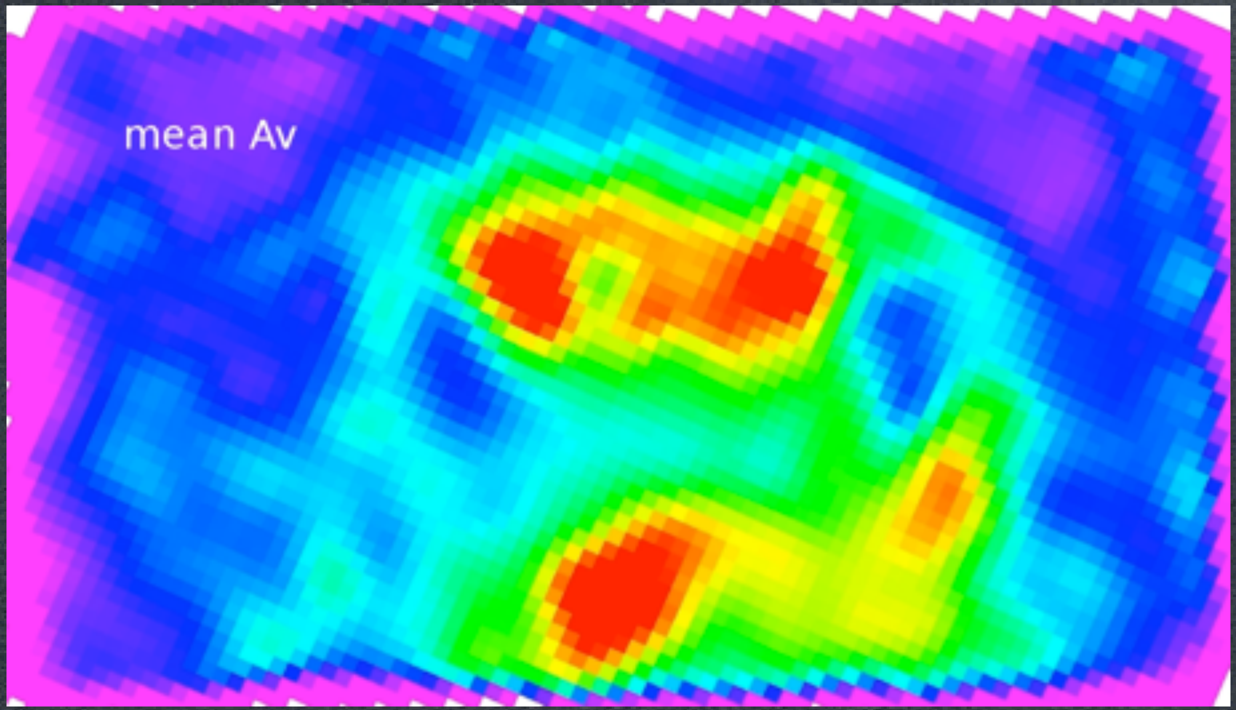

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Kapala, Sandstrom, B.G., et al. (in prep)

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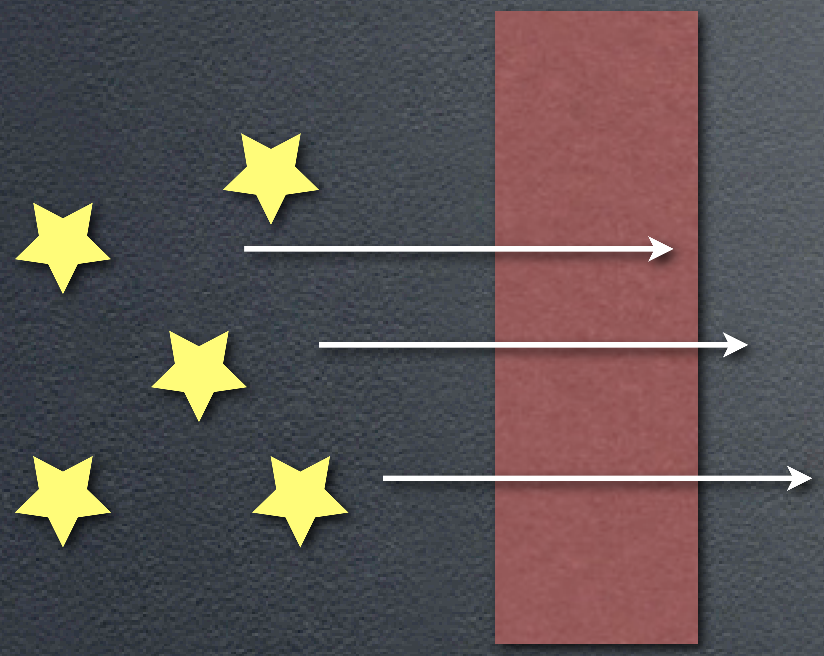

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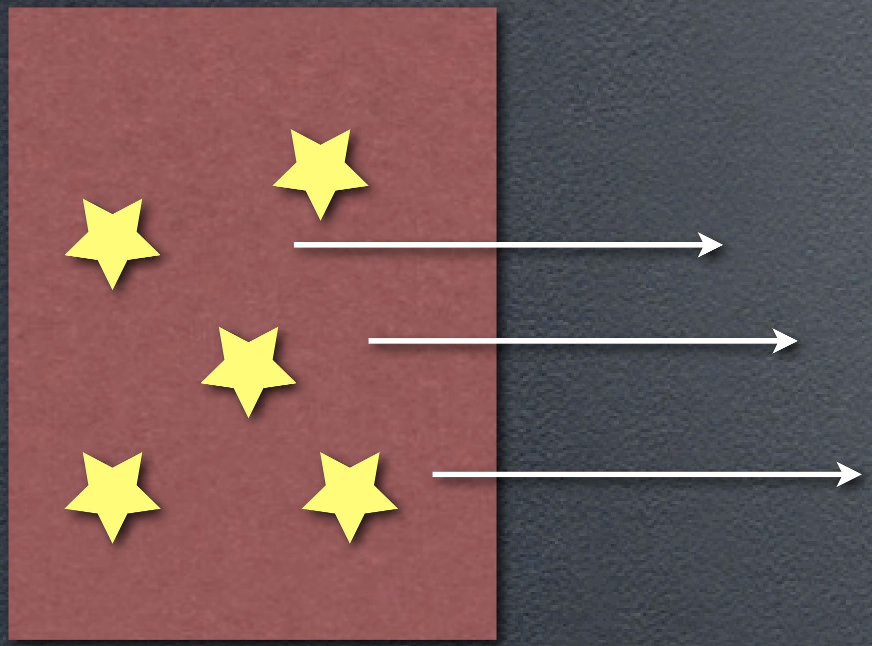

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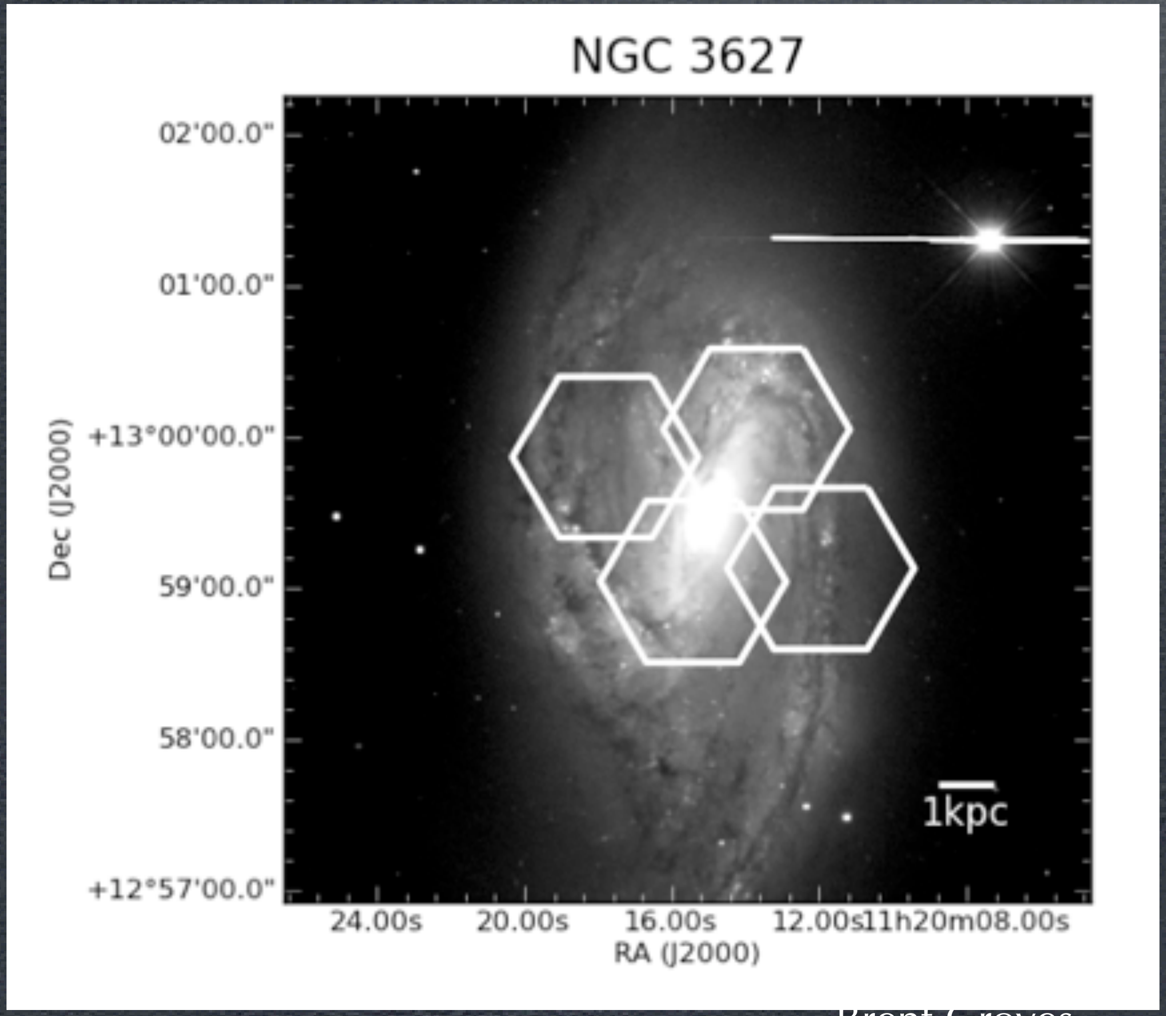
Dust Extinction as a tracer

Kreckel, BG, et al. (2013)



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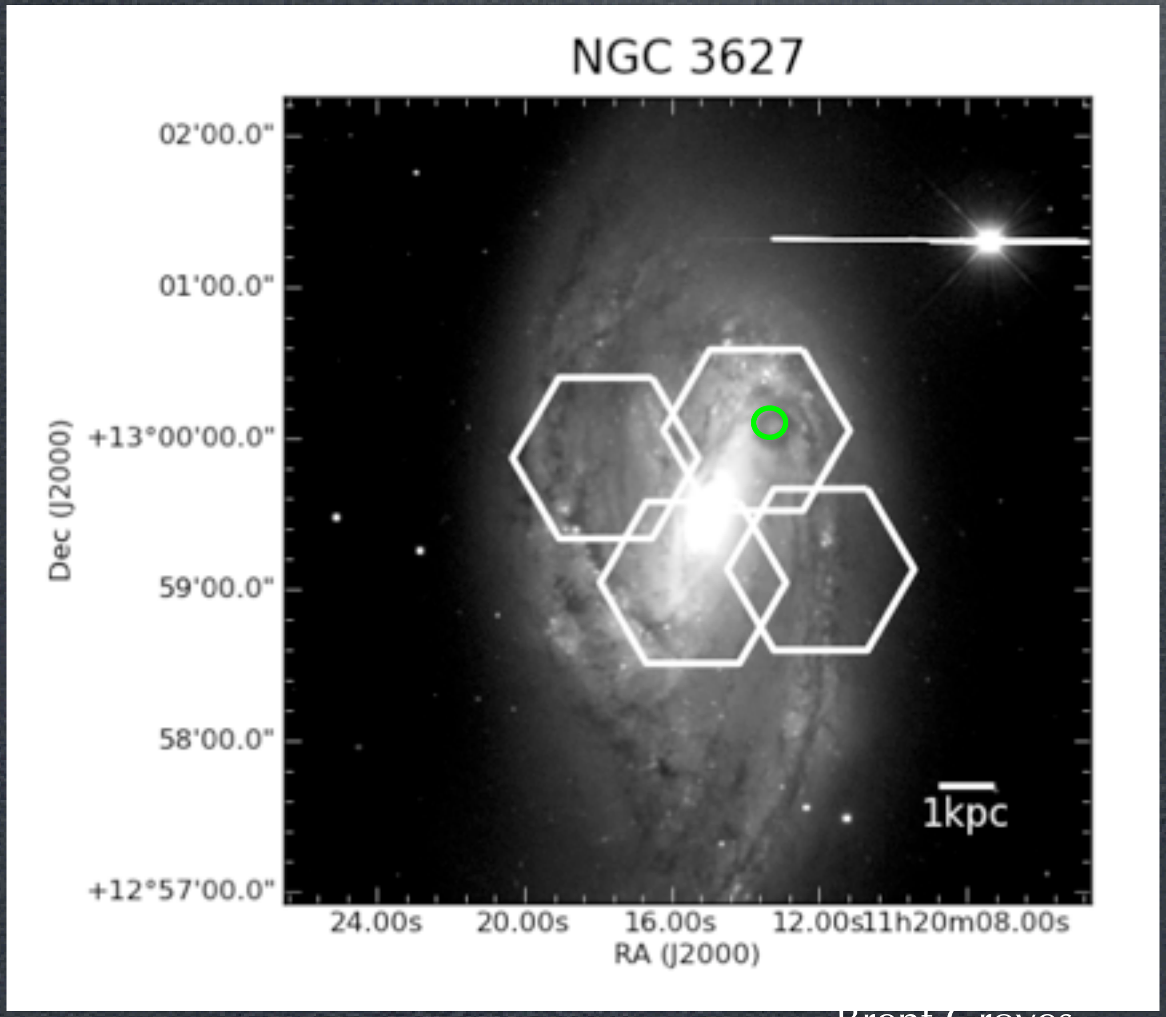

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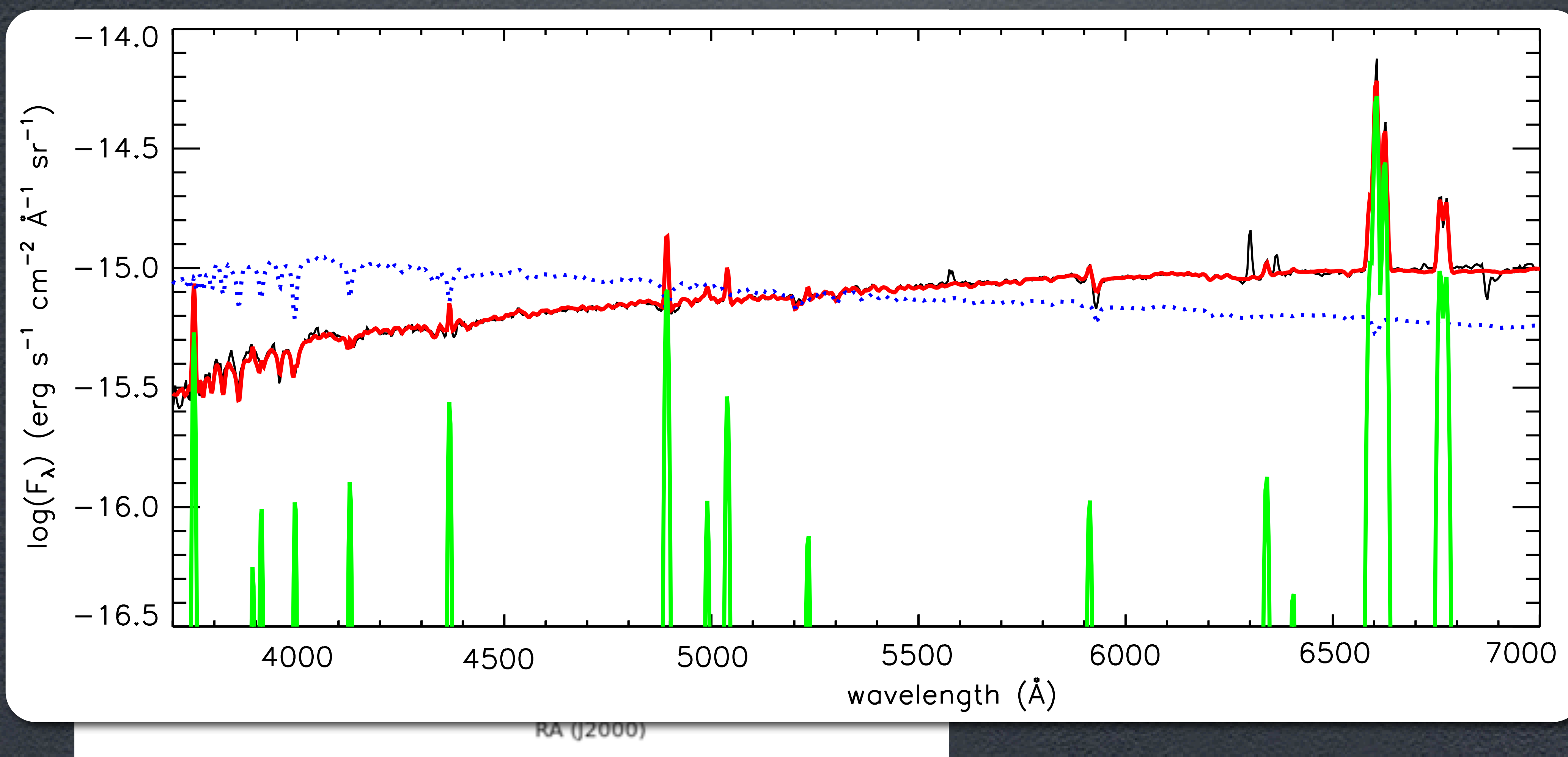

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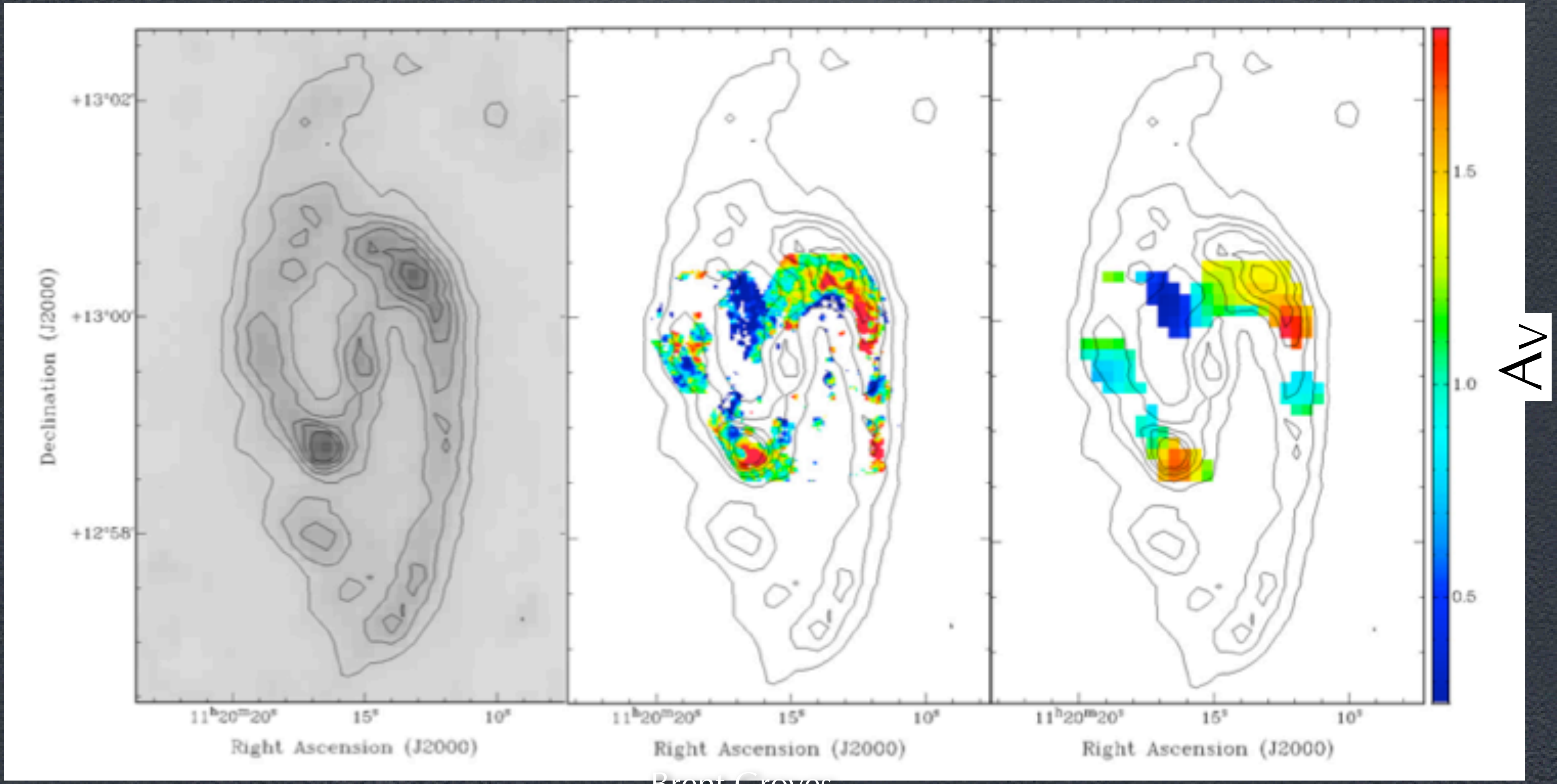

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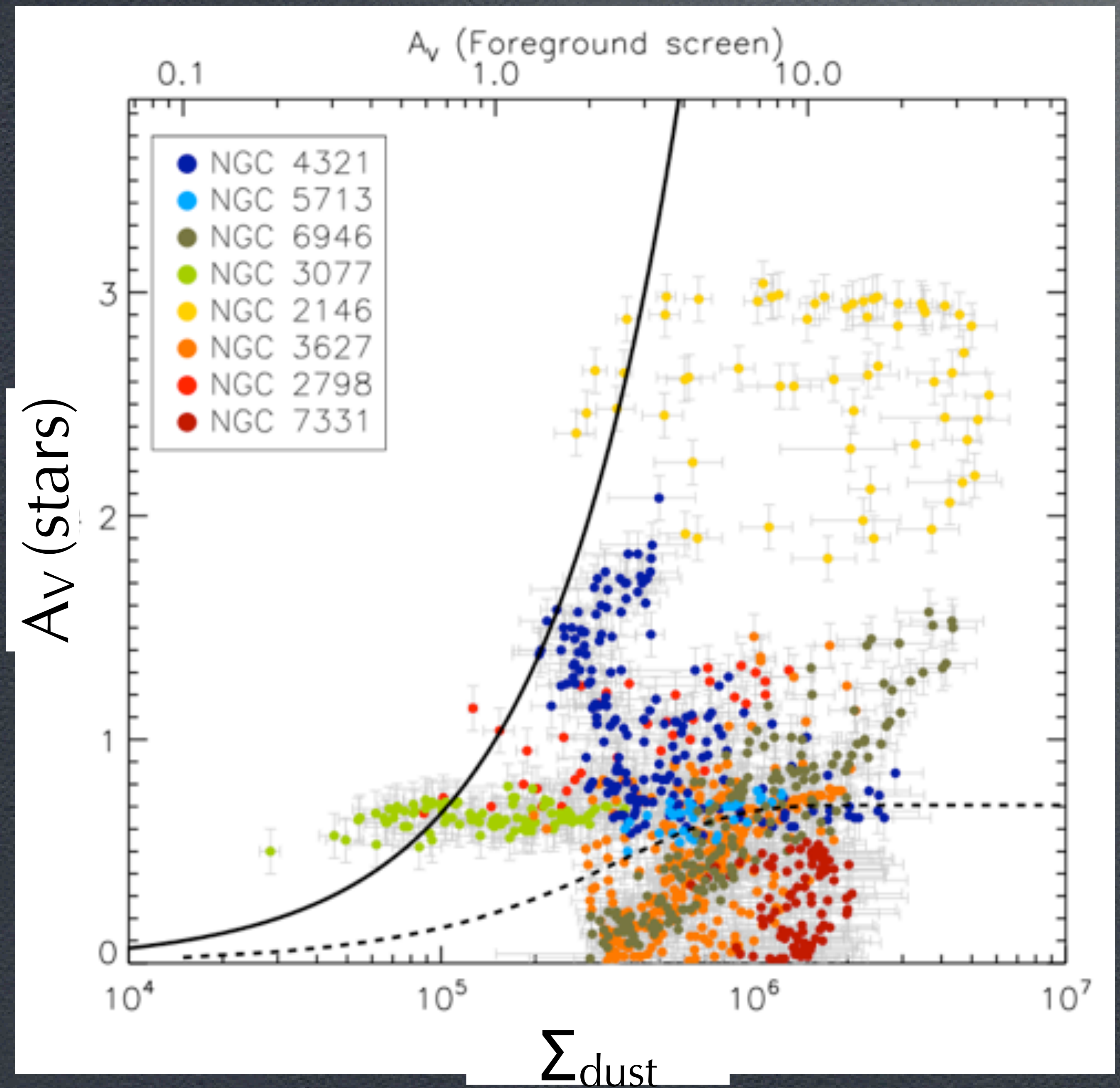

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- In the Galaxy extinction is used to trace gas column
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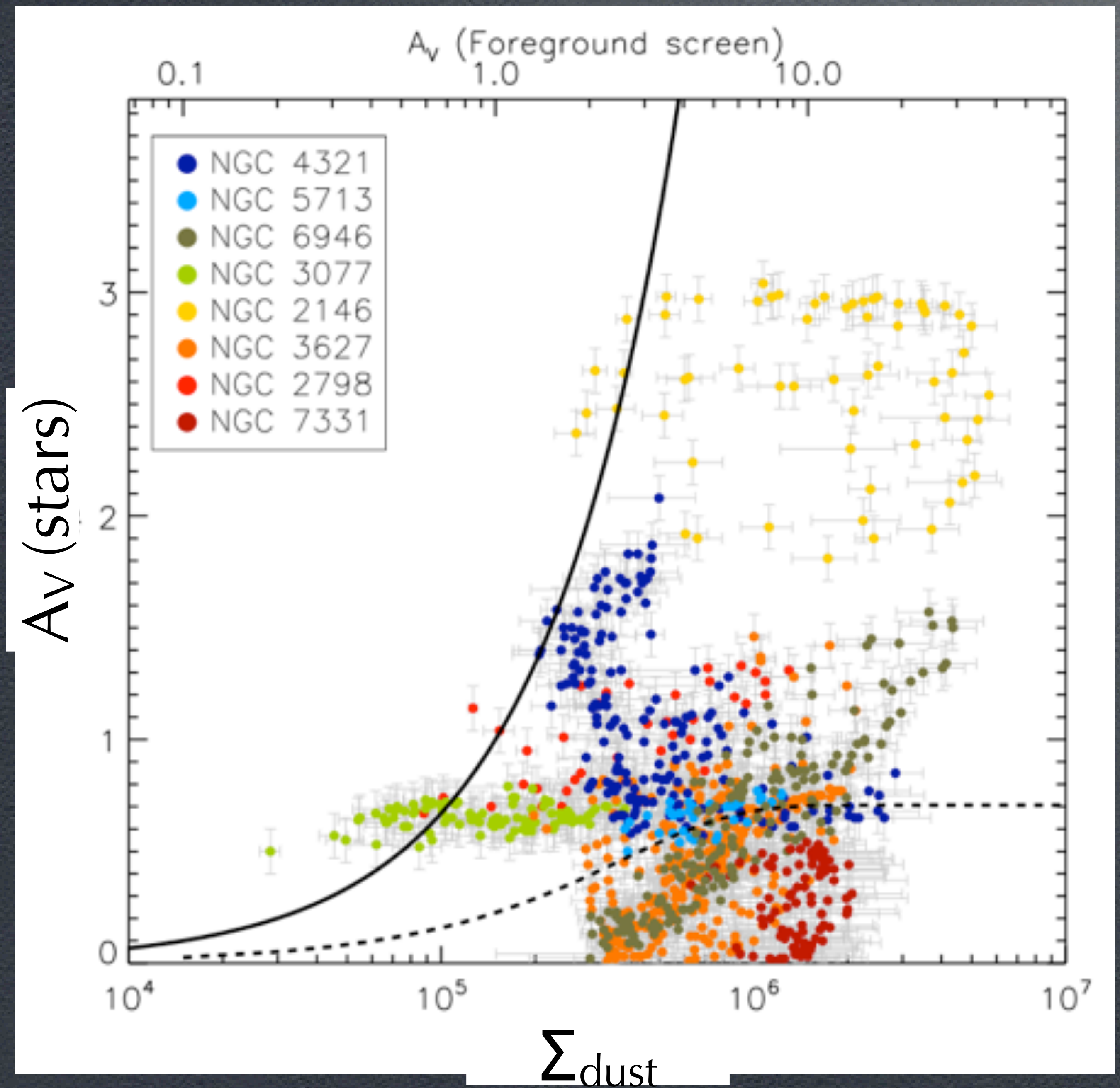
- More distant galaxies show greater scatter

Dust Extinction as a tracer



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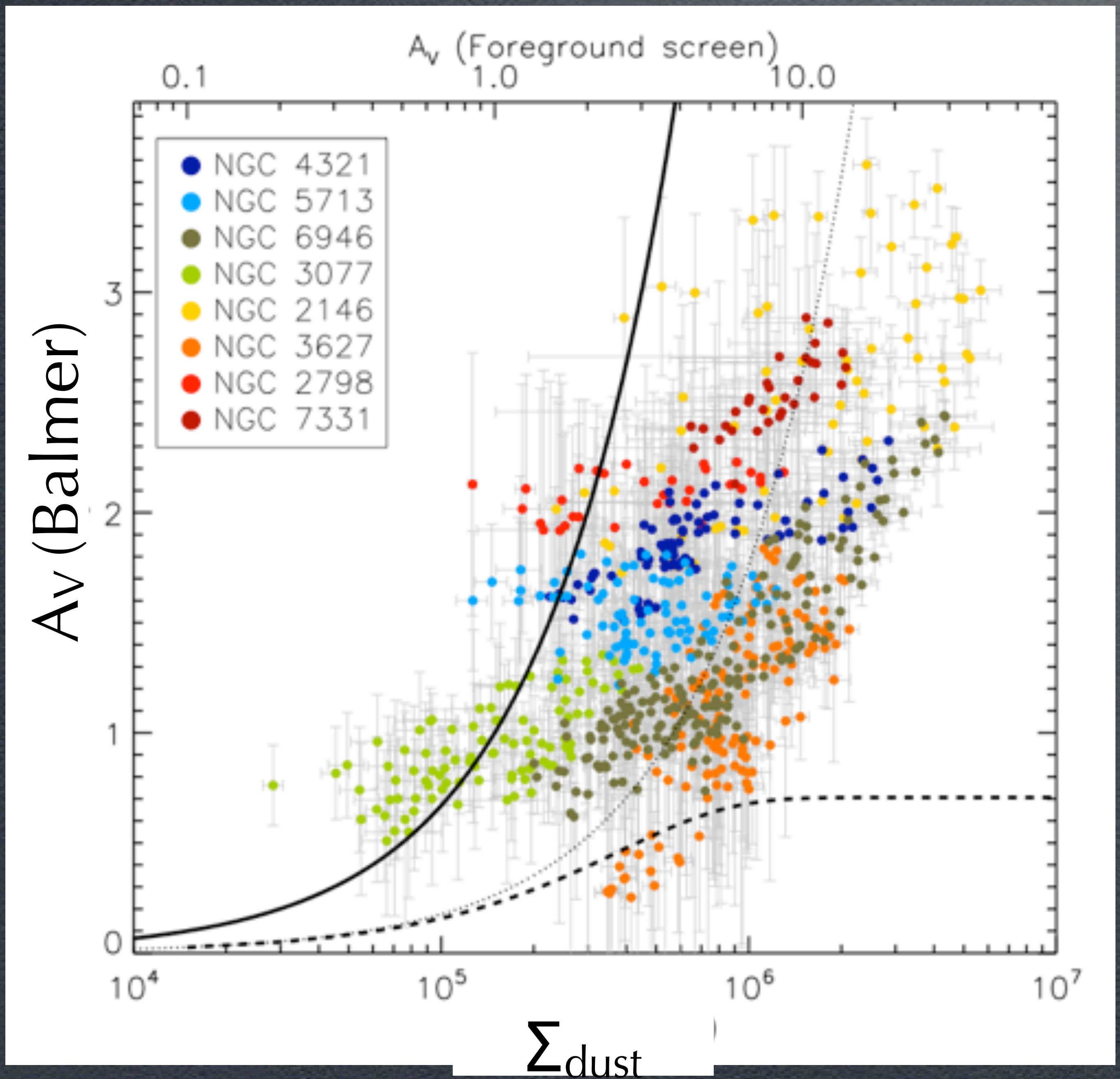

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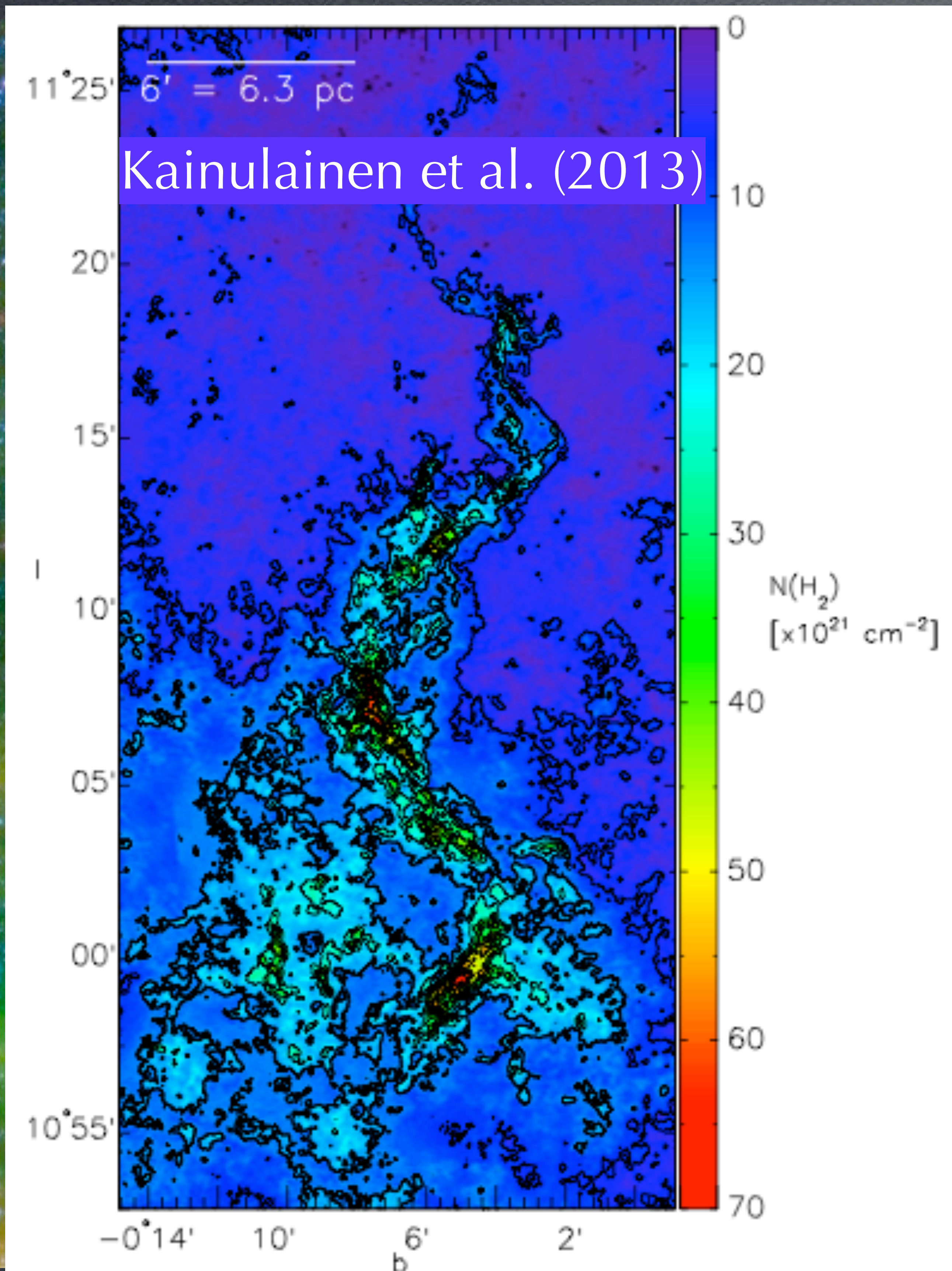
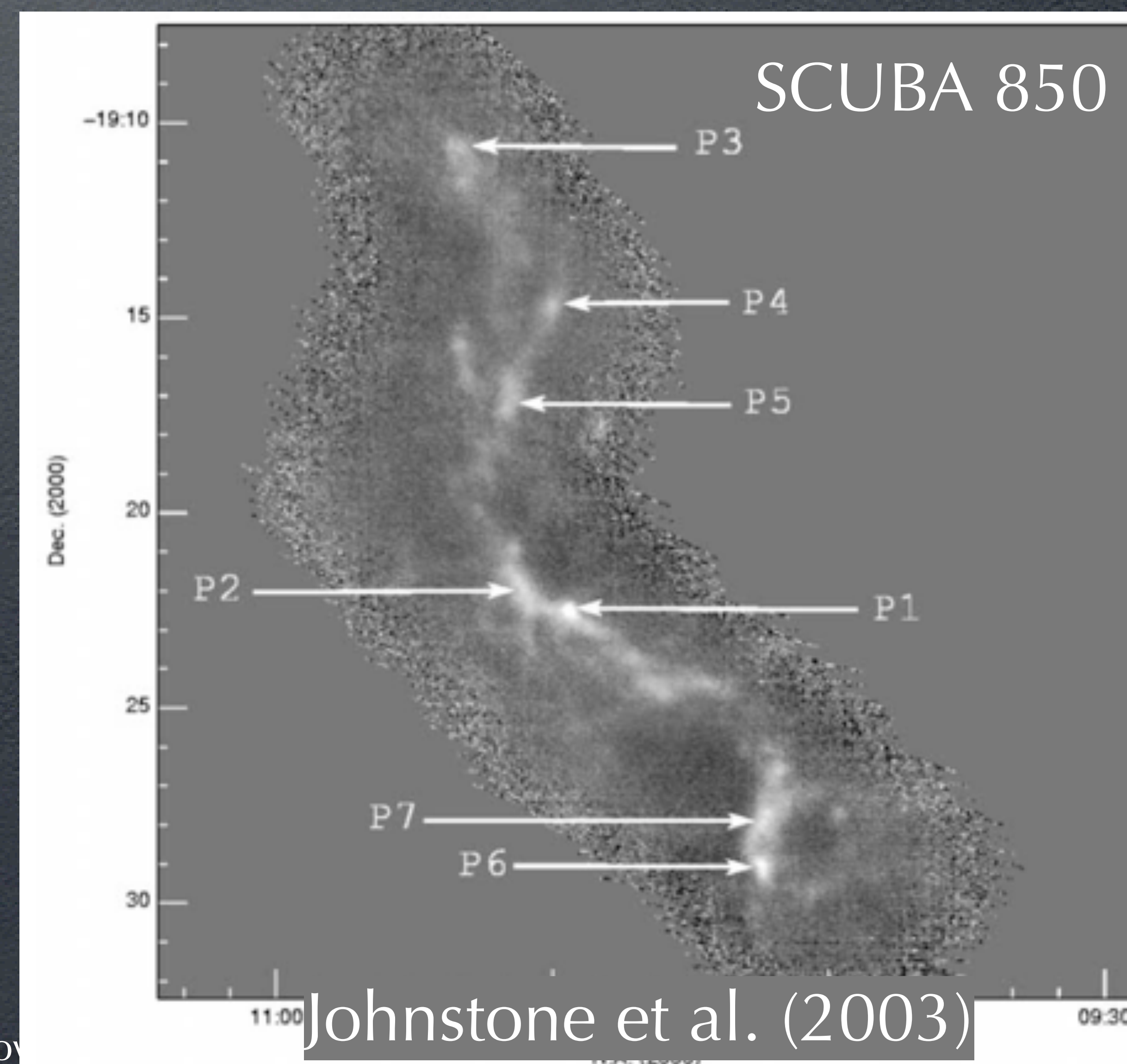
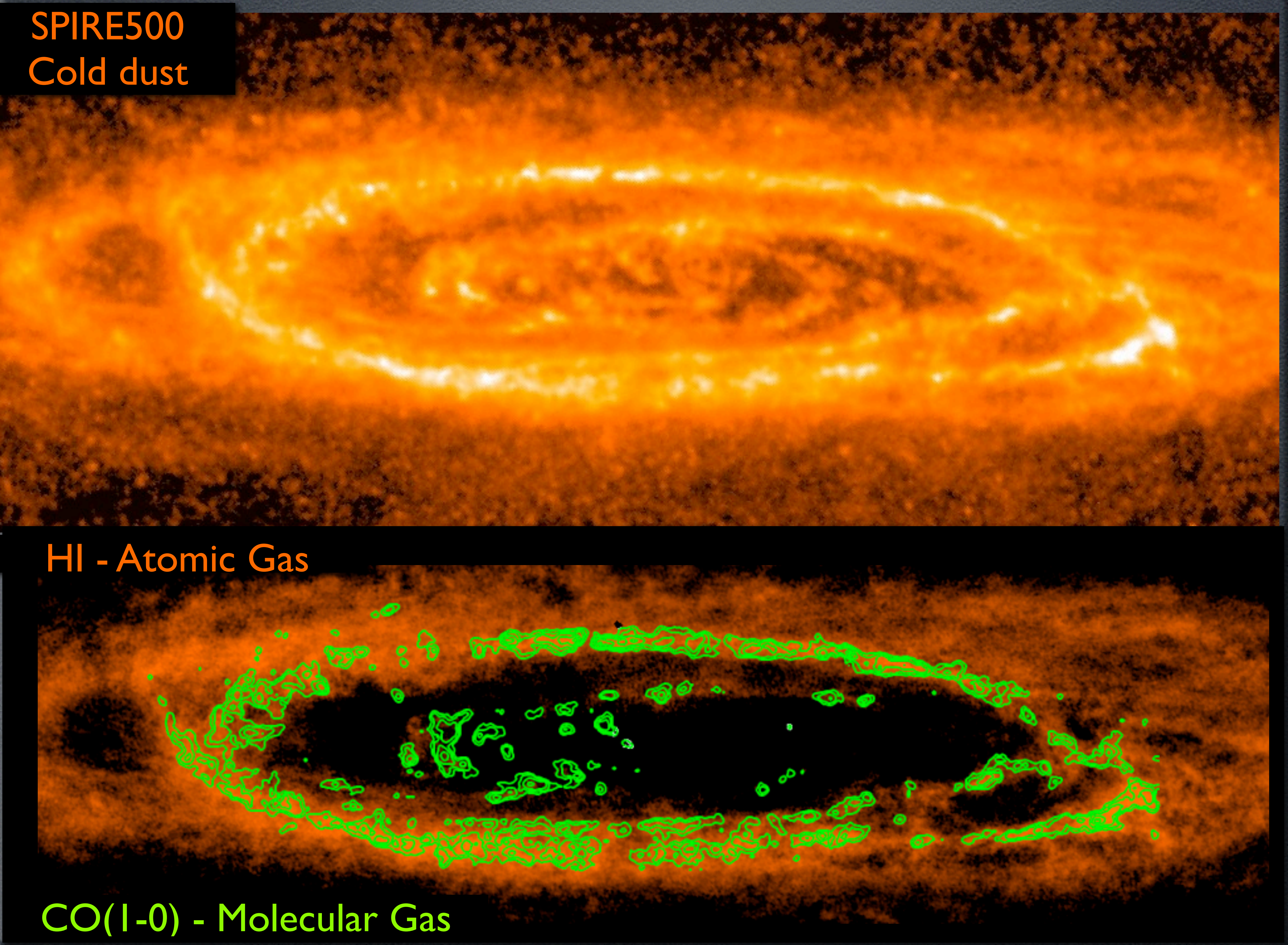
Sub-mm as a gas tracer

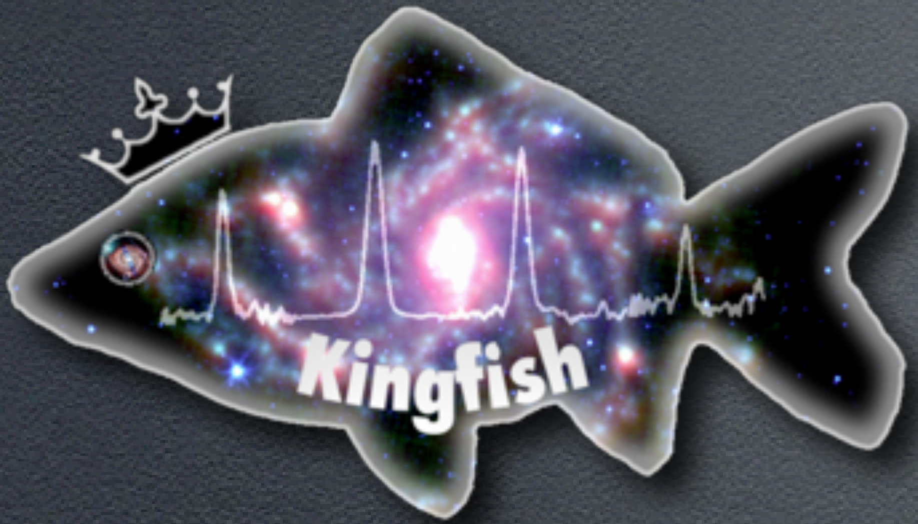


- In the Galaxy extinction is used to trace gas column
- Dust emission is also used




SPIRE500
Cold dust
HI - Atomic Gas
CO(1-0) - Molecular Gas

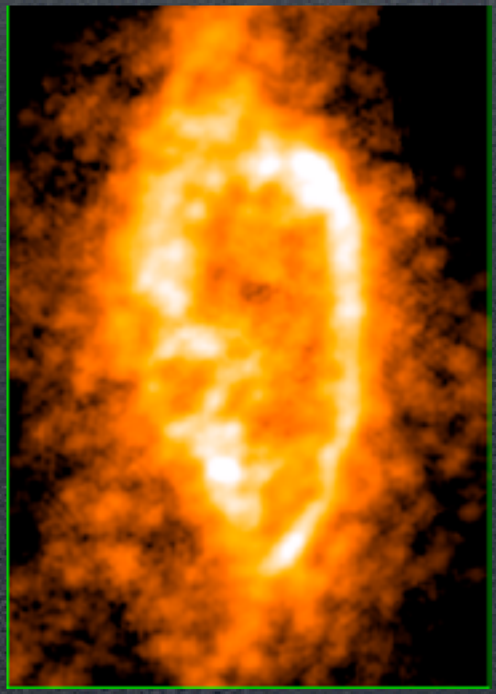
36 Nearby Galaxies

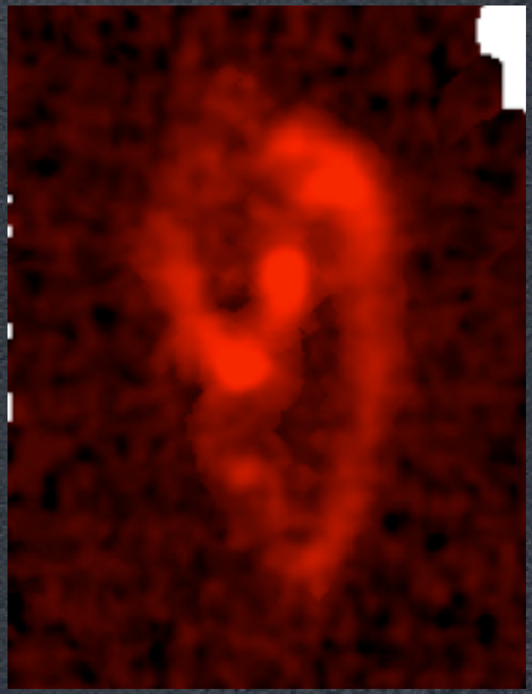


Key Insights into Nearby Galaxies: a Far-Infrared Survey with Herschel

The HI Nearby Galaxy Survey

HERACLES: The HERA CO Line Extragalactic Survey





Kingfish (Key Insights on Nearby Galaxies: a Far-Infrared Survey with Herschel)

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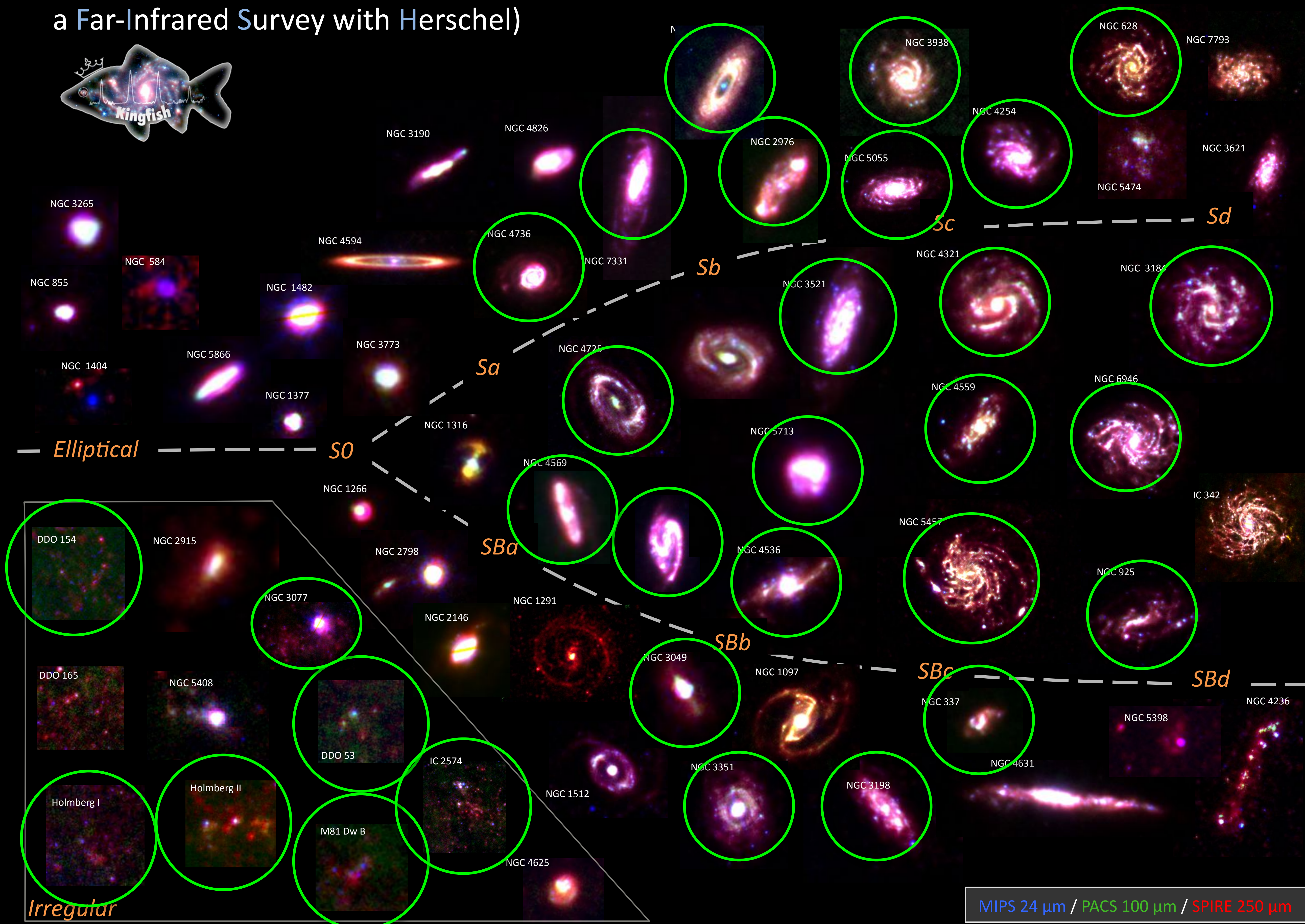
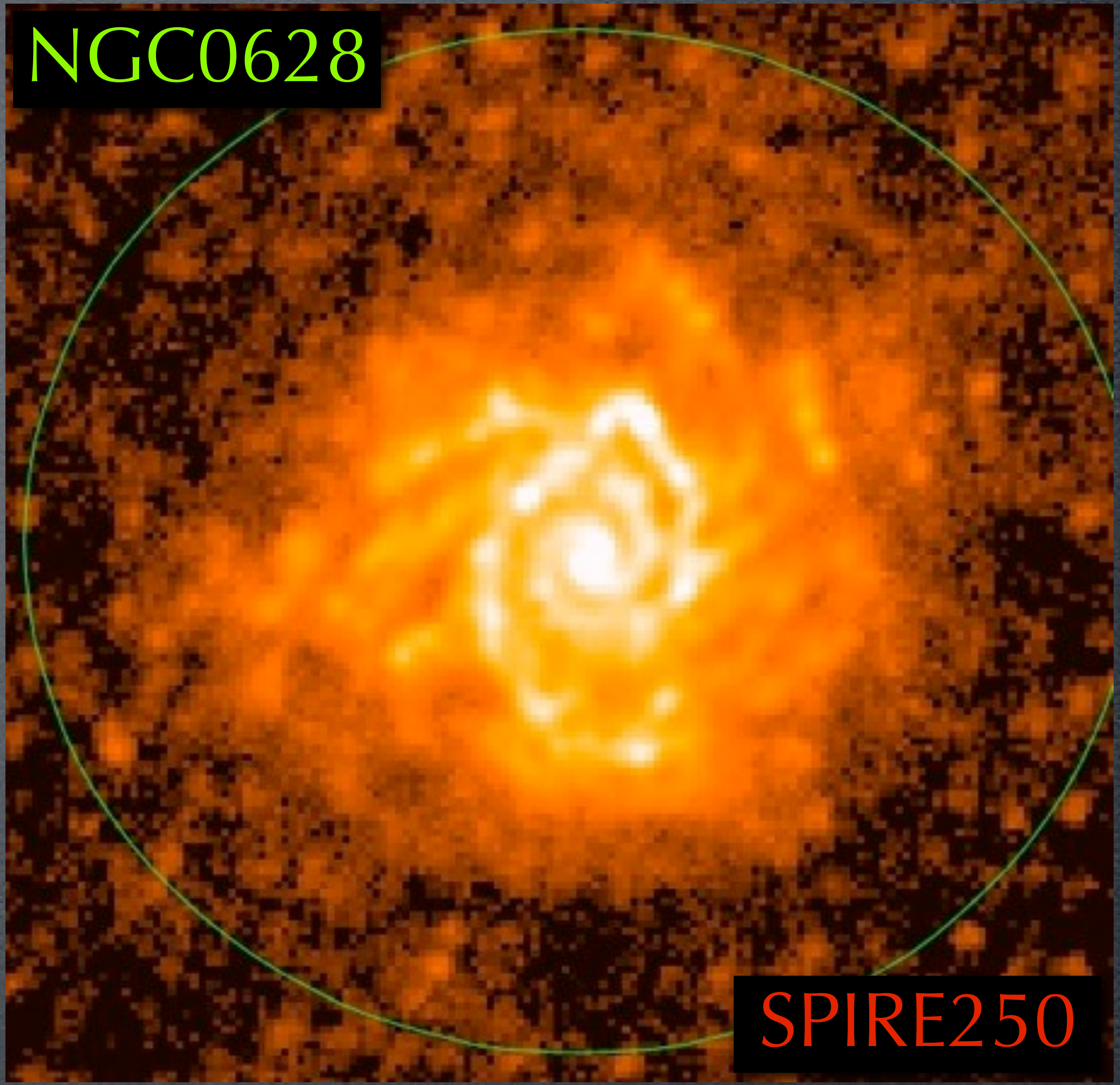


Measuring a Galaxy...



- Dale et al. (2012) apertures
  - (matched to optical and IR sizes)
- Integrate within these apertures
  - Herschel bands
  - THINGS HI
  - HERACLES CO
    - (use constant conversion of L_{CO} to M_{H2})

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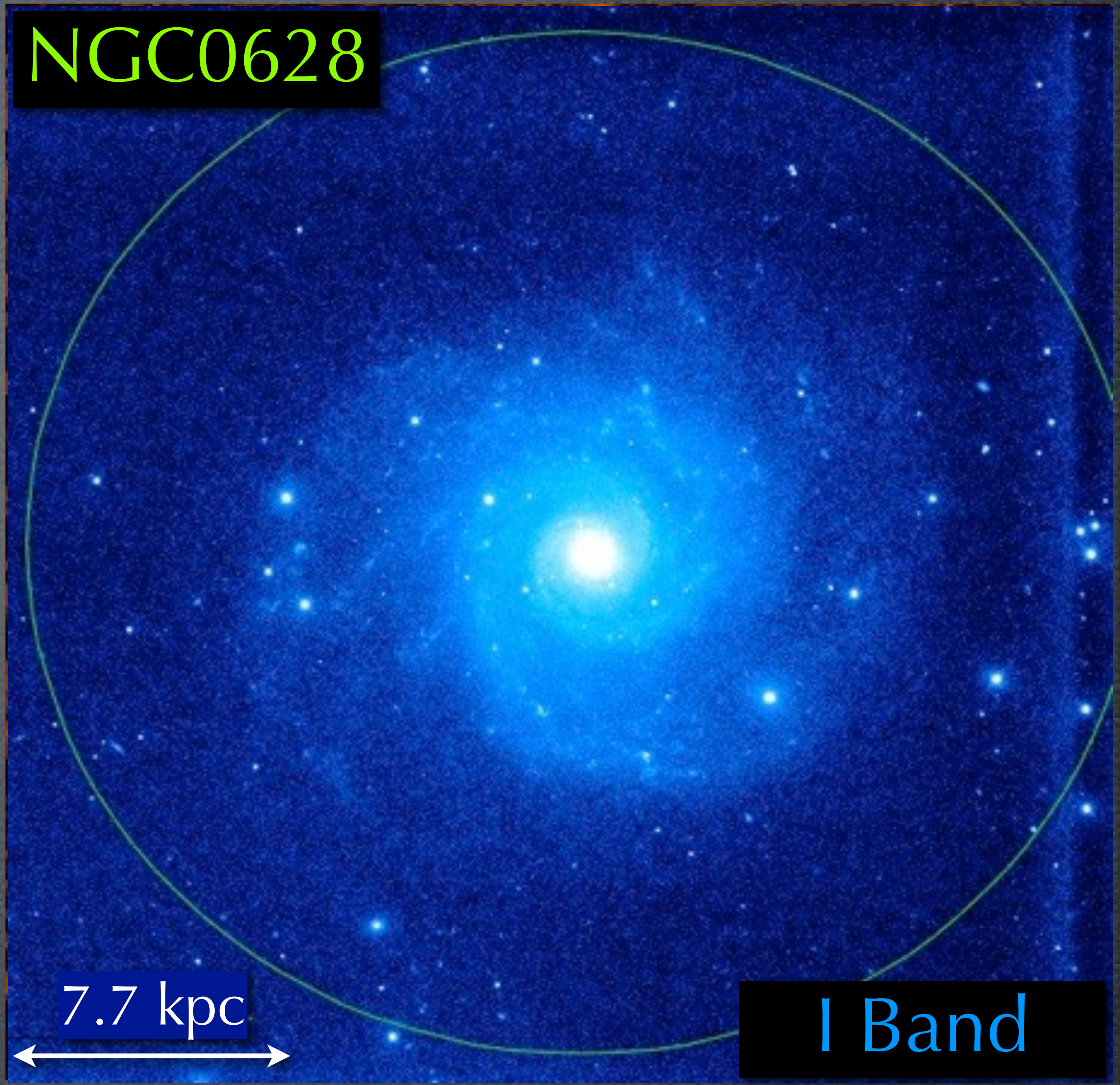
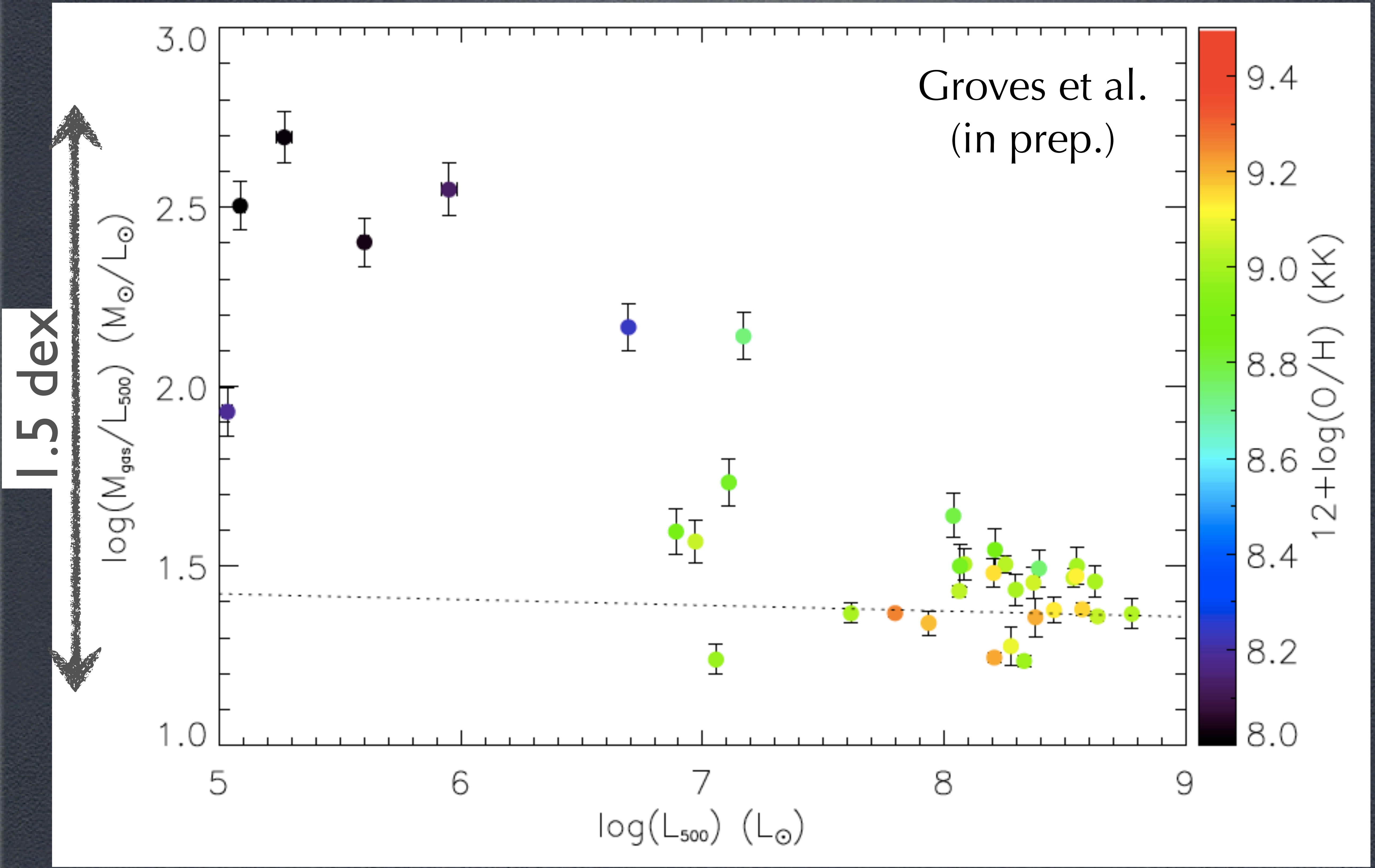


Sub-mm vs Gas mass



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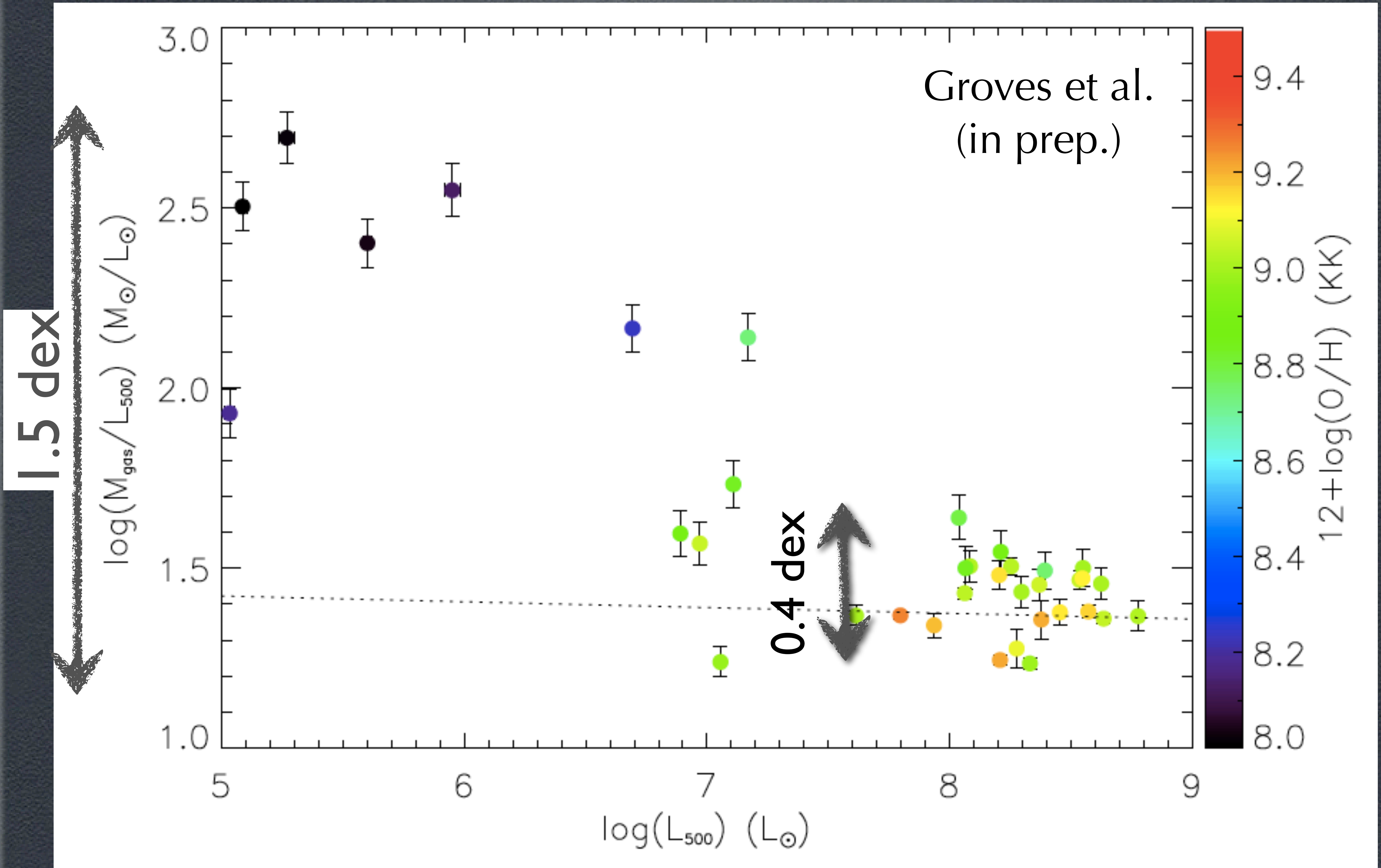

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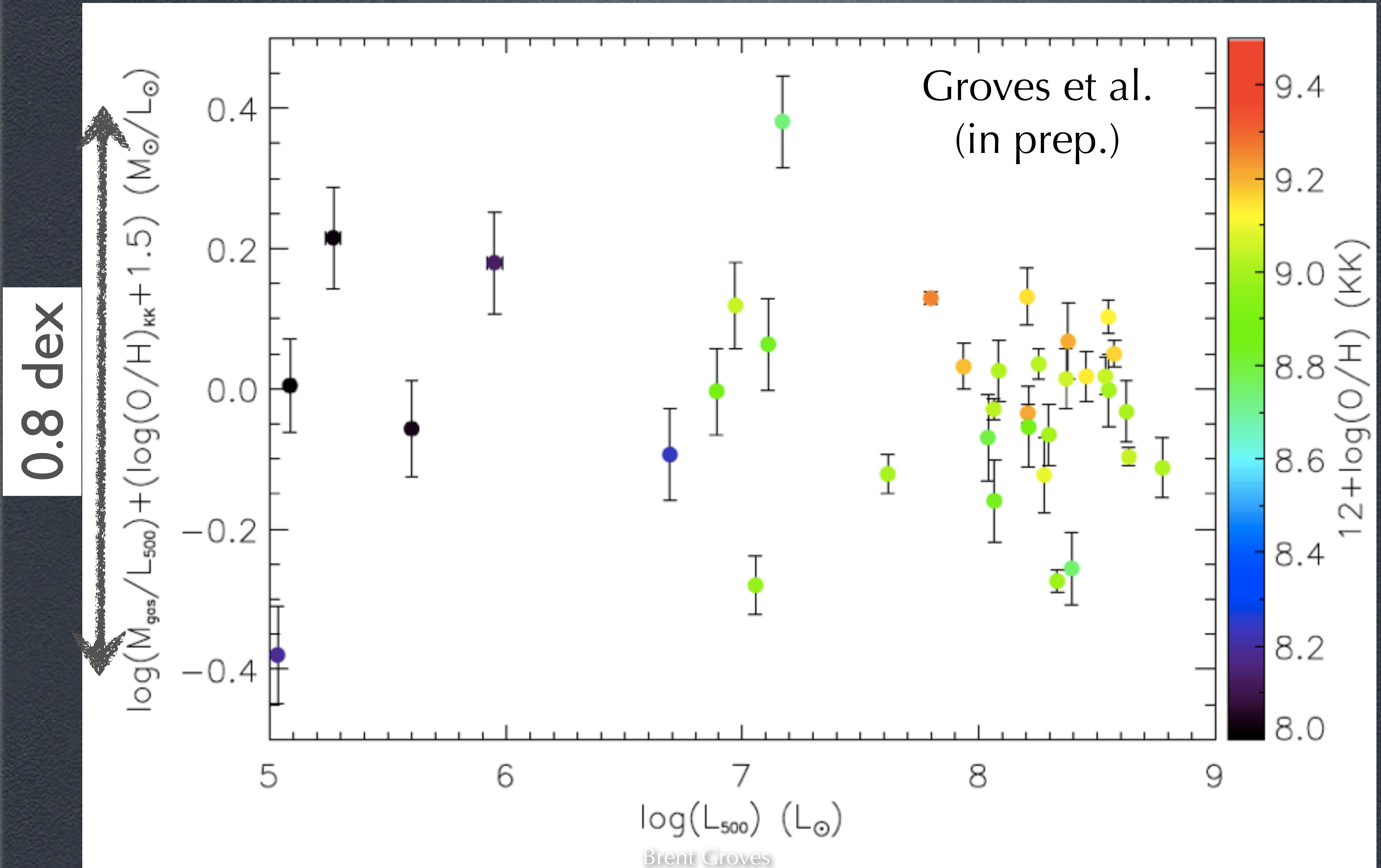
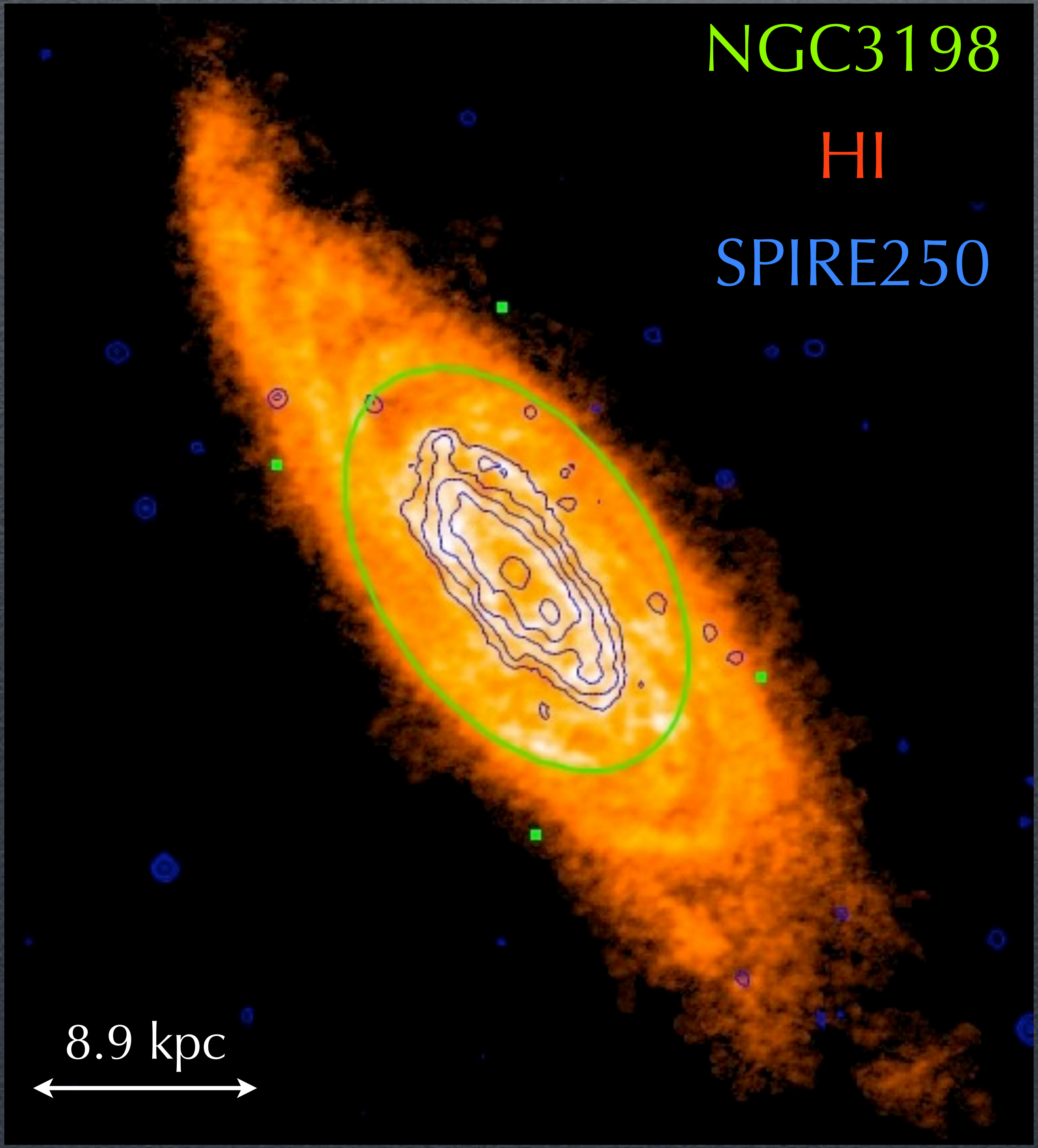


Extended Emission...



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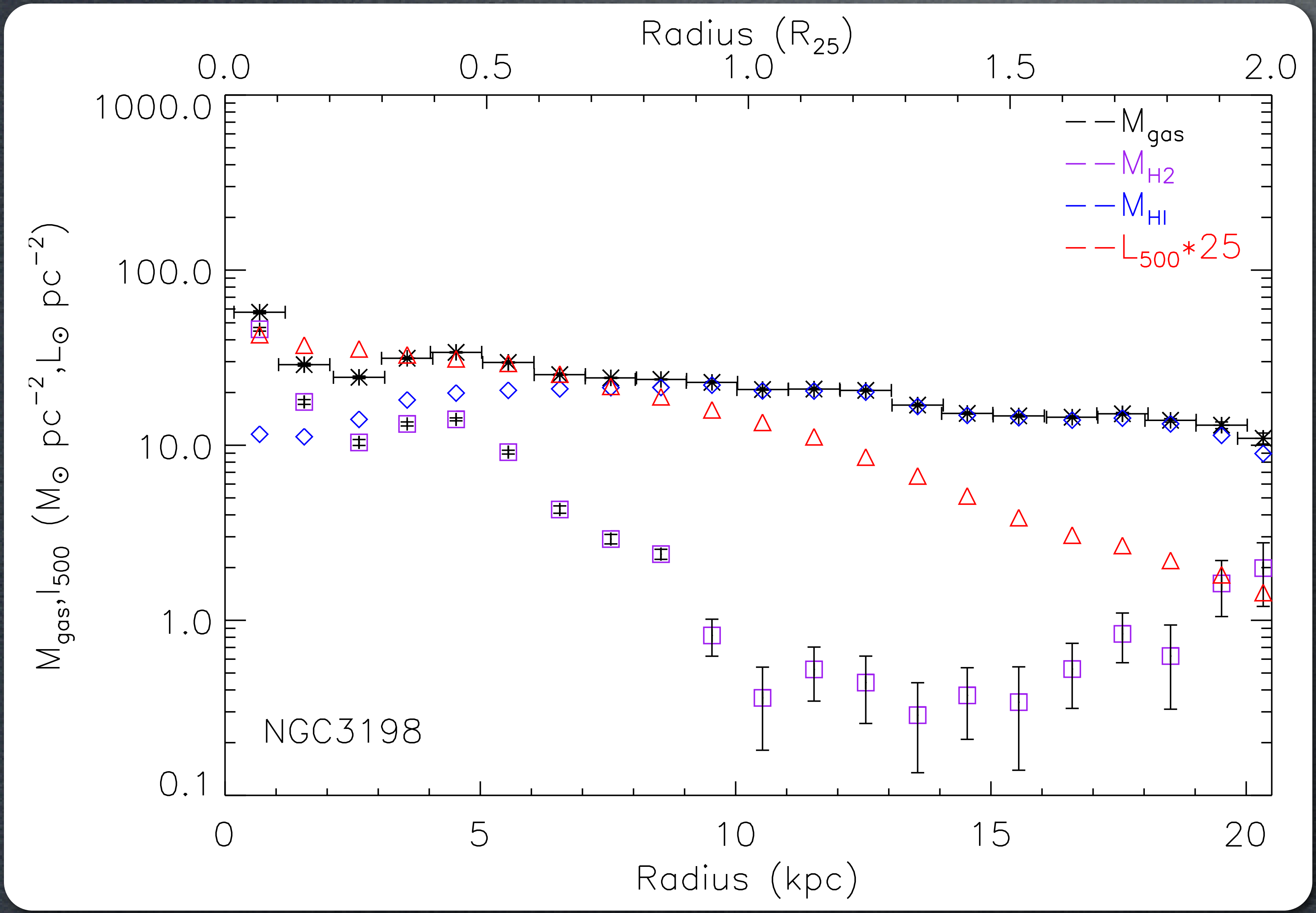

Schruba et al. (2011)
Gas data

Groves et al.
(in prep.)

Extended Emission

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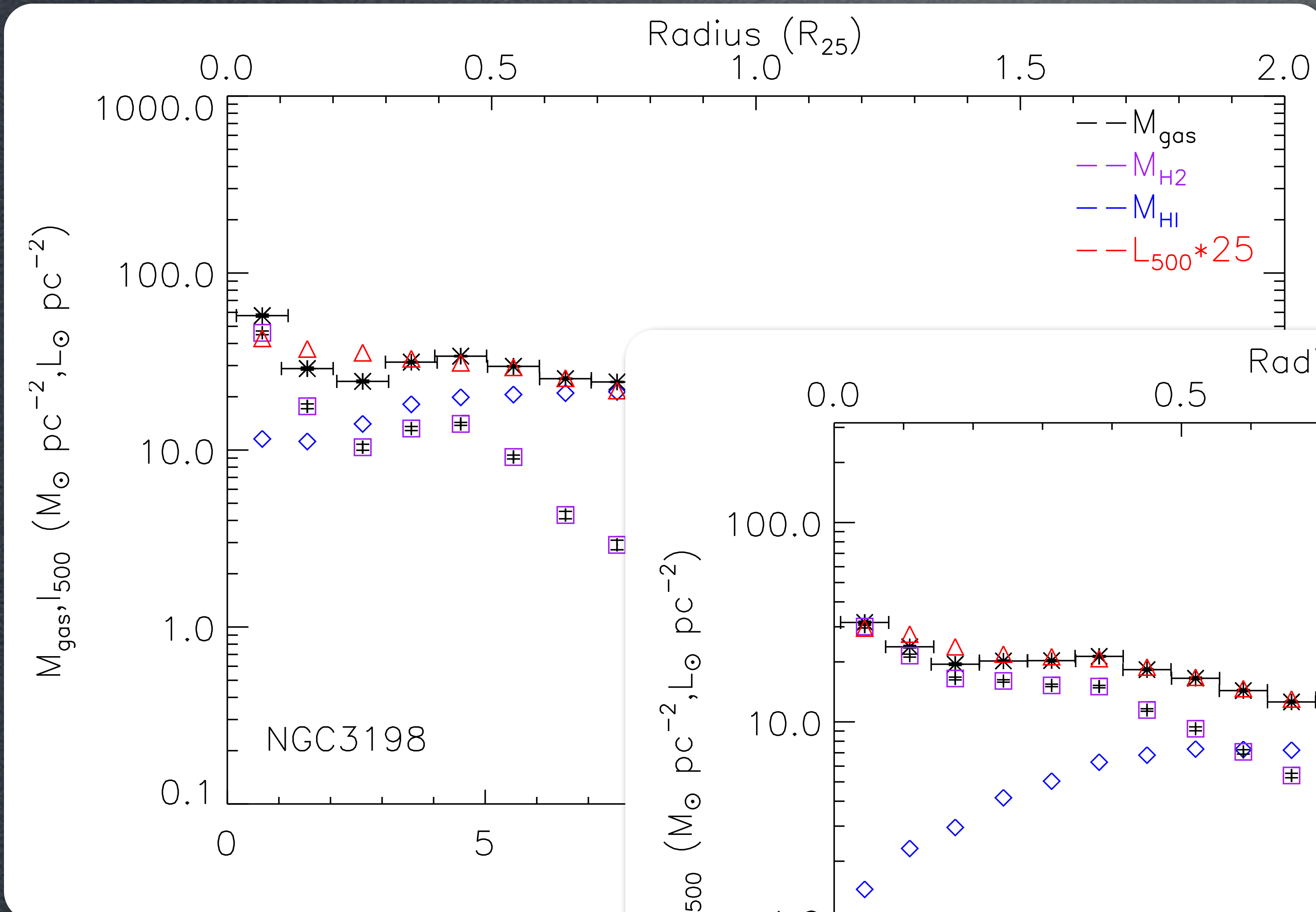
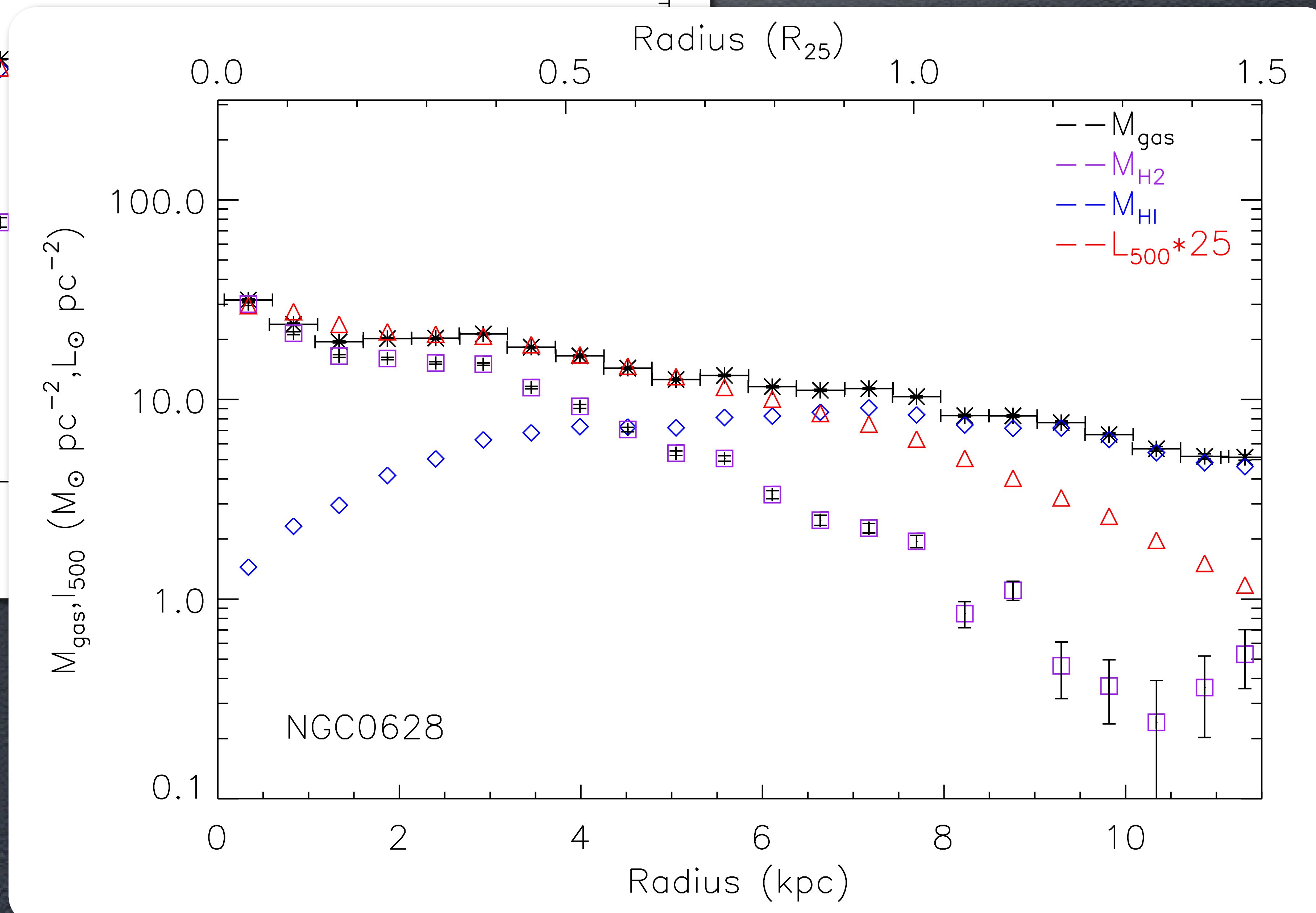
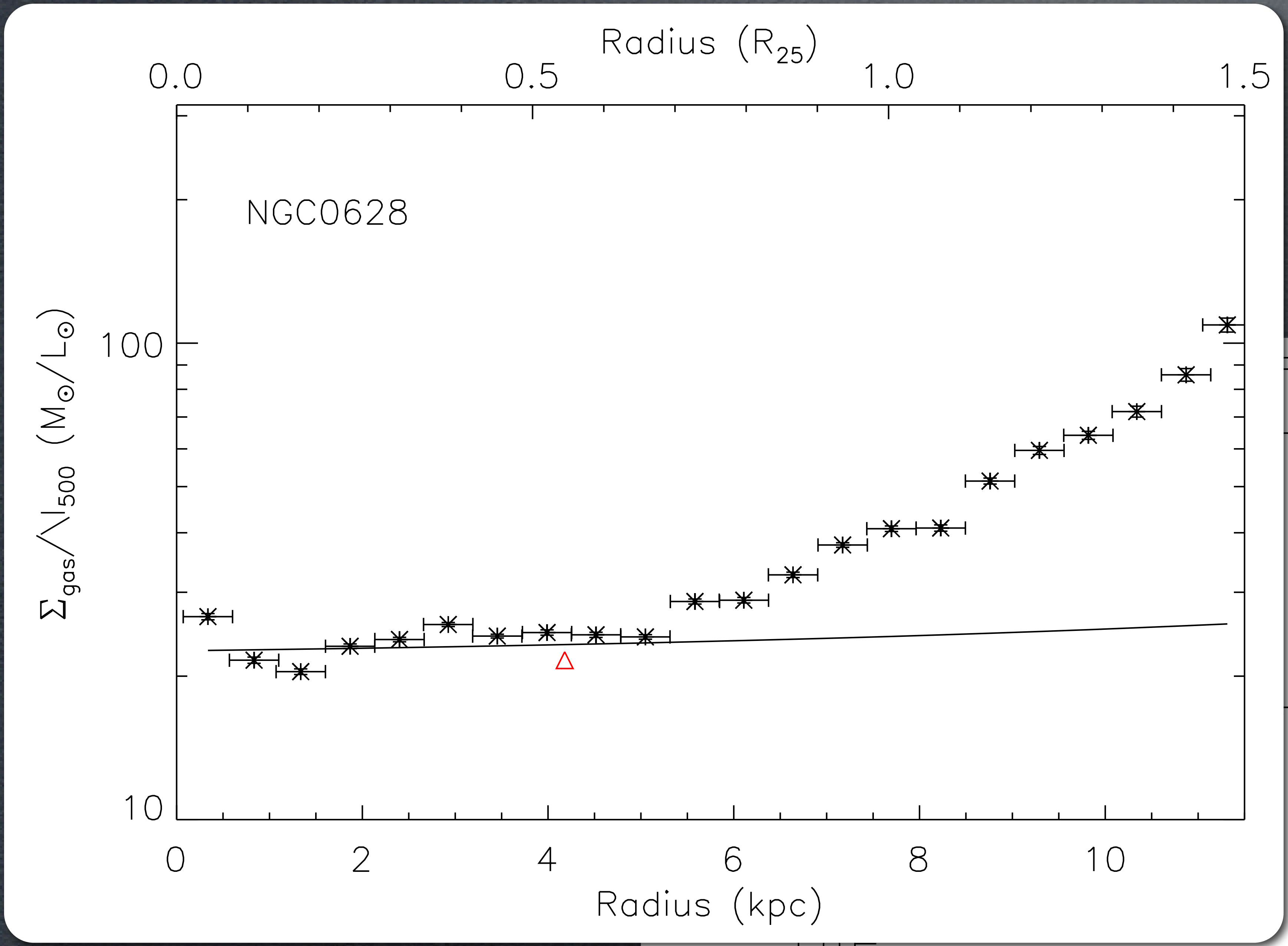


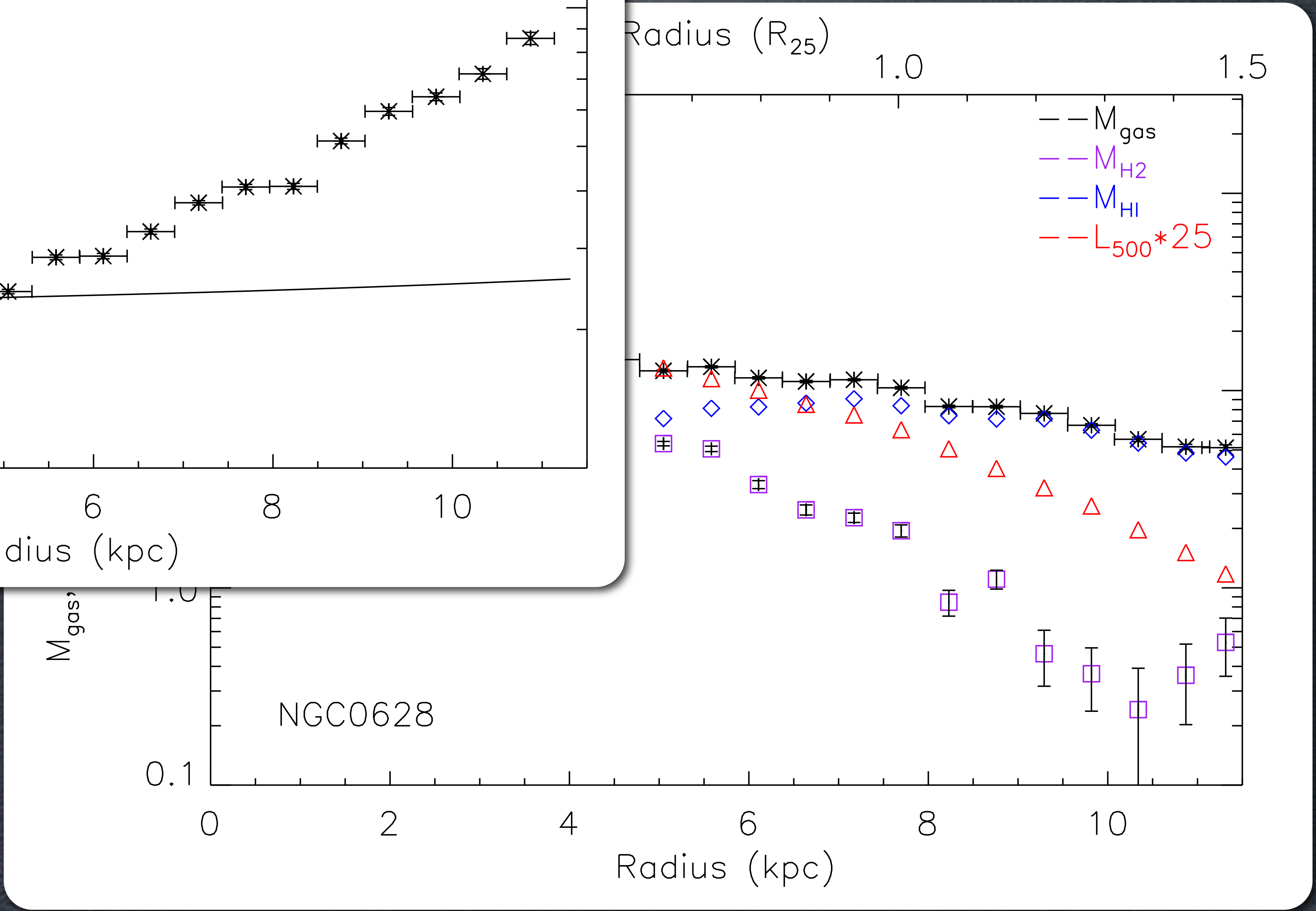


Groves et al.
(in prep.)

Extended Emission

Moustakas et al. (2009)
Metal gradients





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Dust heating

- Generally, total IR taken to be a SFR tracer
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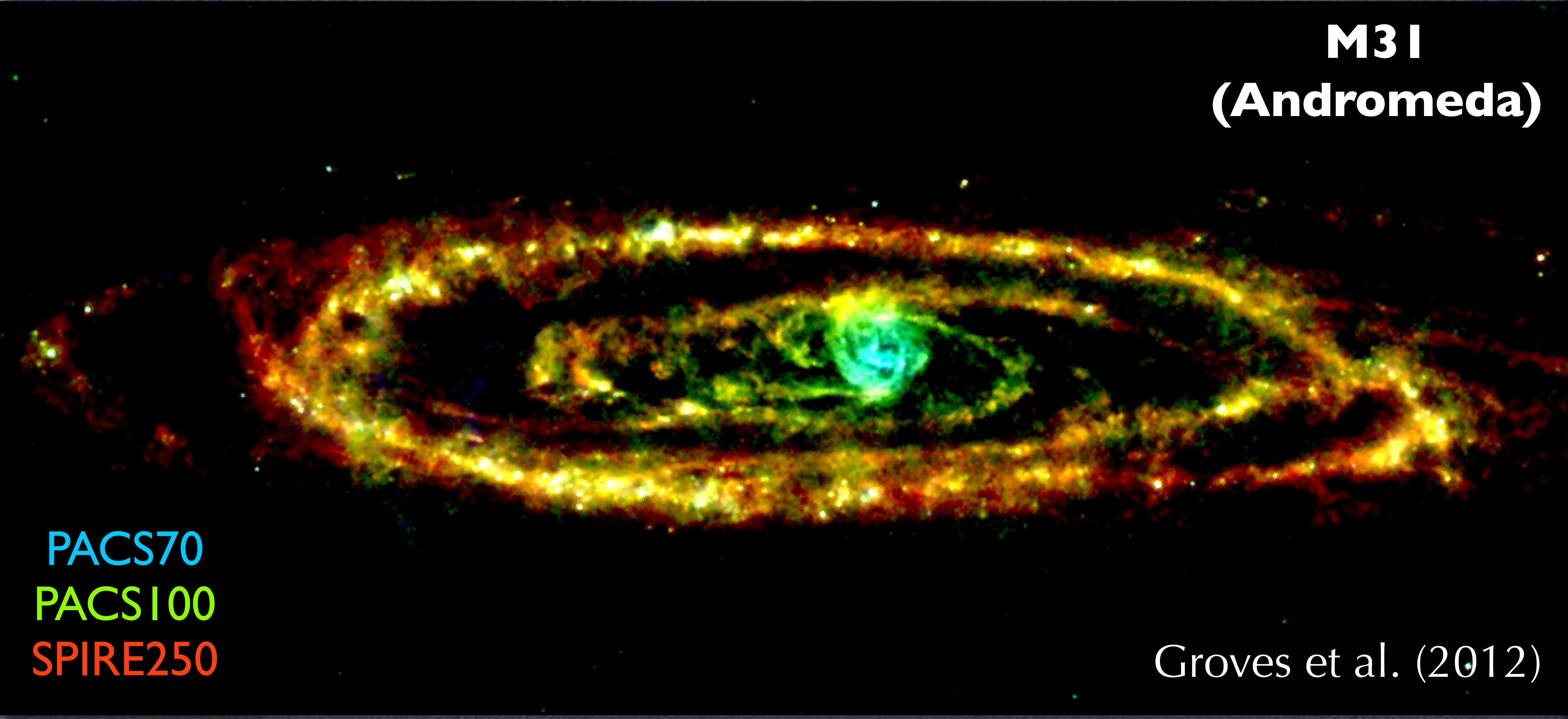

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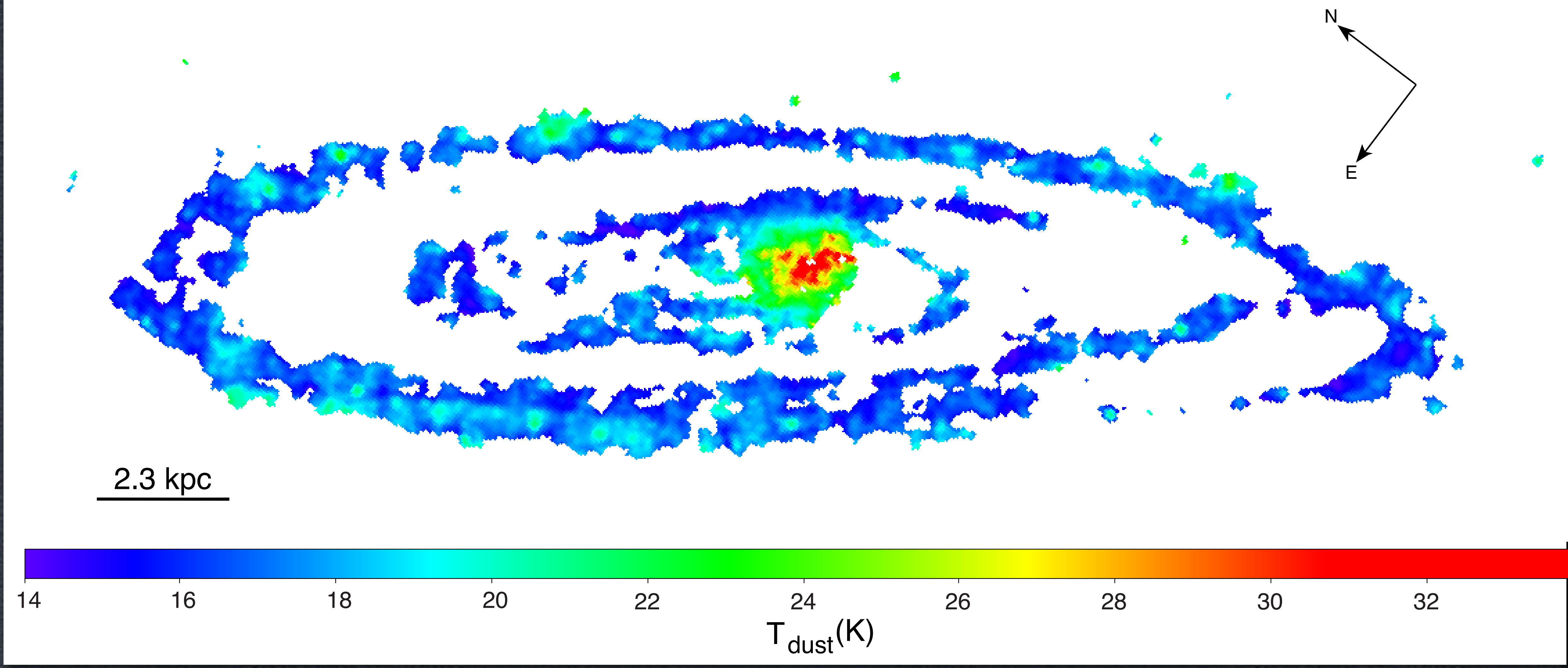
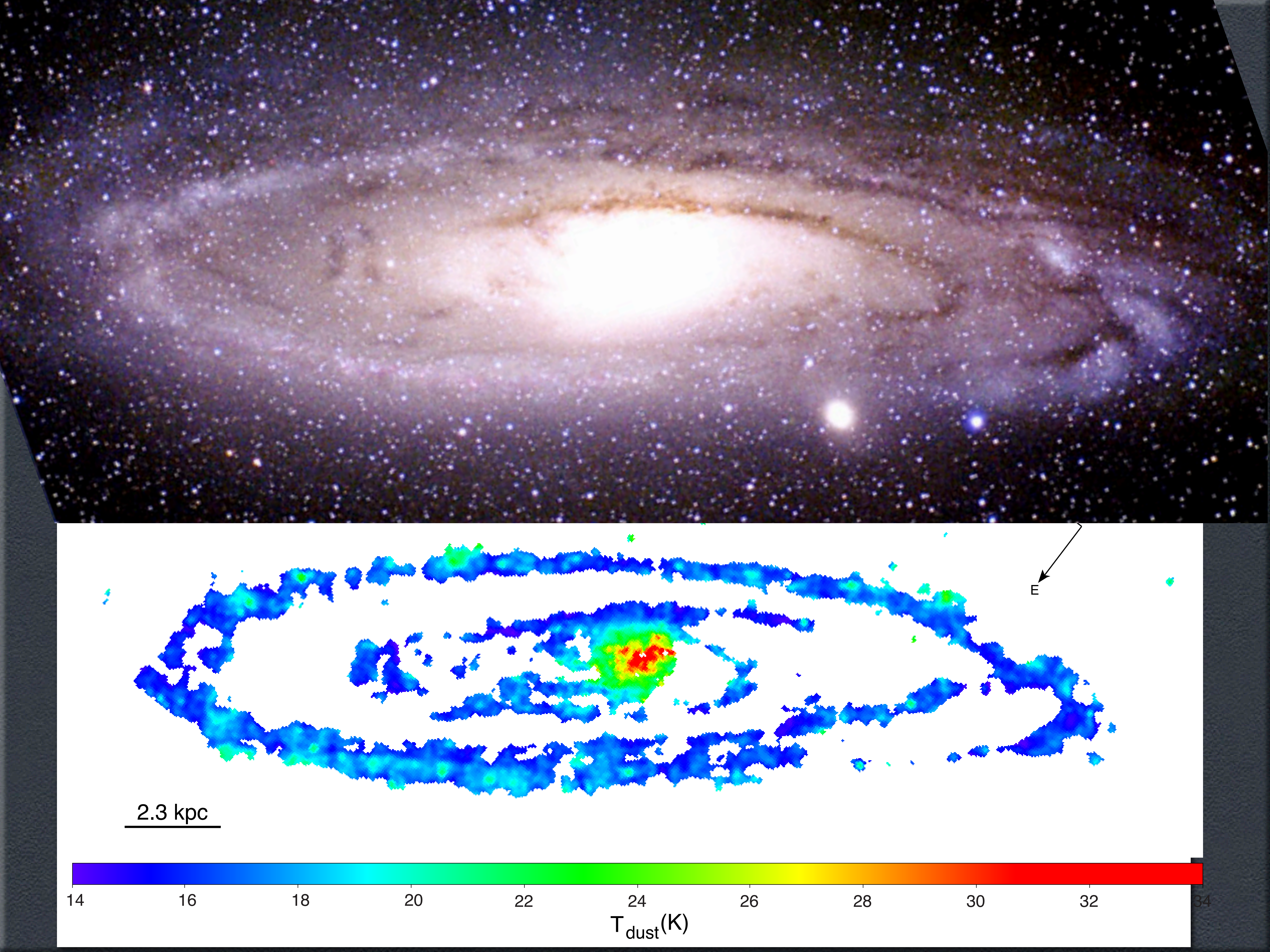
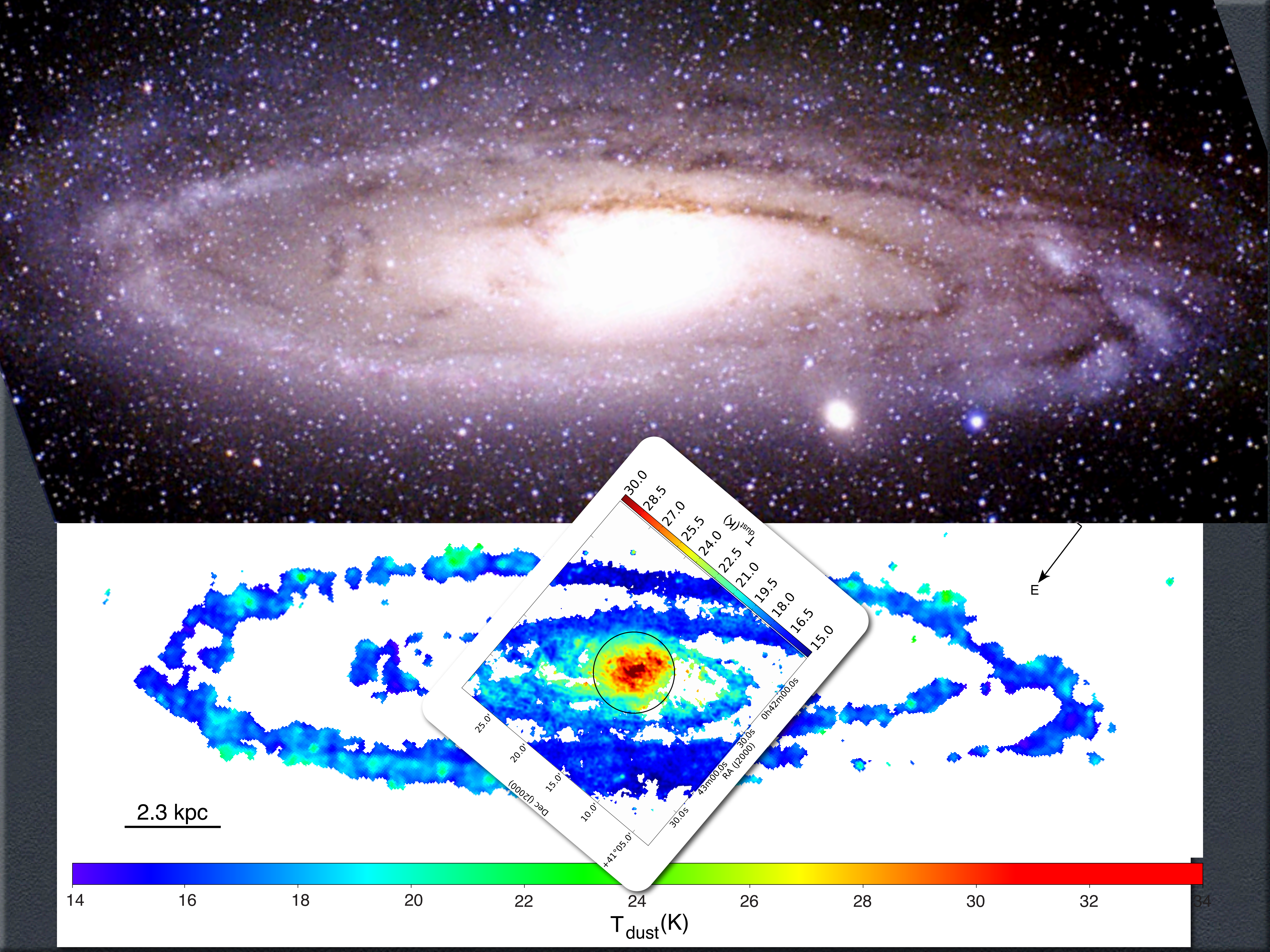
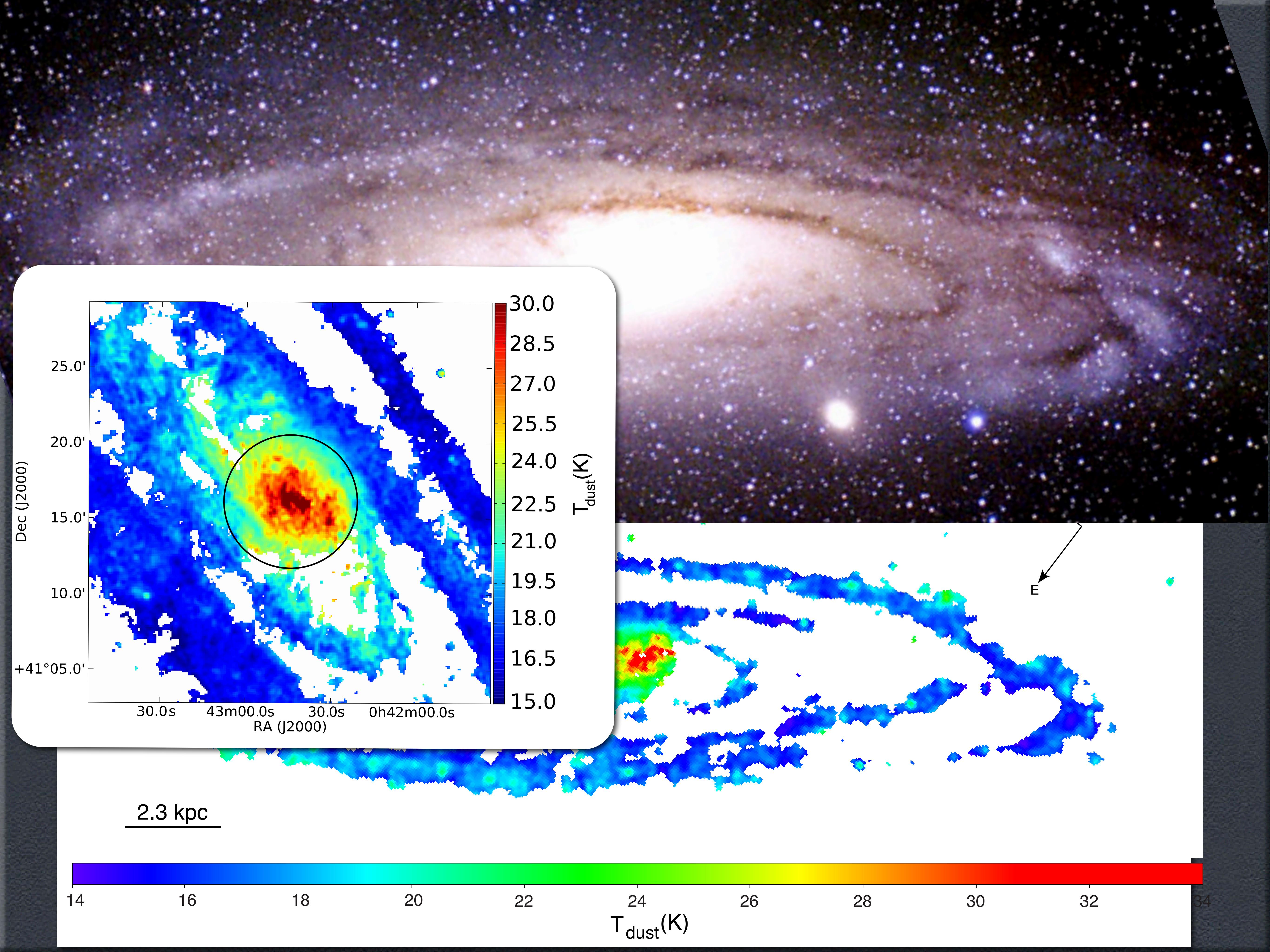



E
2.3 kpc
14
16
18
20
22
24
26
28
30
32
34
T_{dust}(K)


E
2.3 kpc
14
16
18
20
22
24
26
28
30
32
34
T dust (K)
30.0
28.5
27.0
25.5
24.0
22.5
21.0
19.5
18.0
16.5
15.0
Dec (J2000)
RA (J2000)


25.0'
20.0'
15.0'
10.0'
+41°05.0'
Dec (J2000)
30.0s
43m00.0s
30.0s
0h42m00.0s
RA (J2000)
30.0
28.5
27.0
25.5
24.0
22.5
21.0
19.5
18.0
16.5
15.0
T_{dust}(K)
E
2.3 kpc
14
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24
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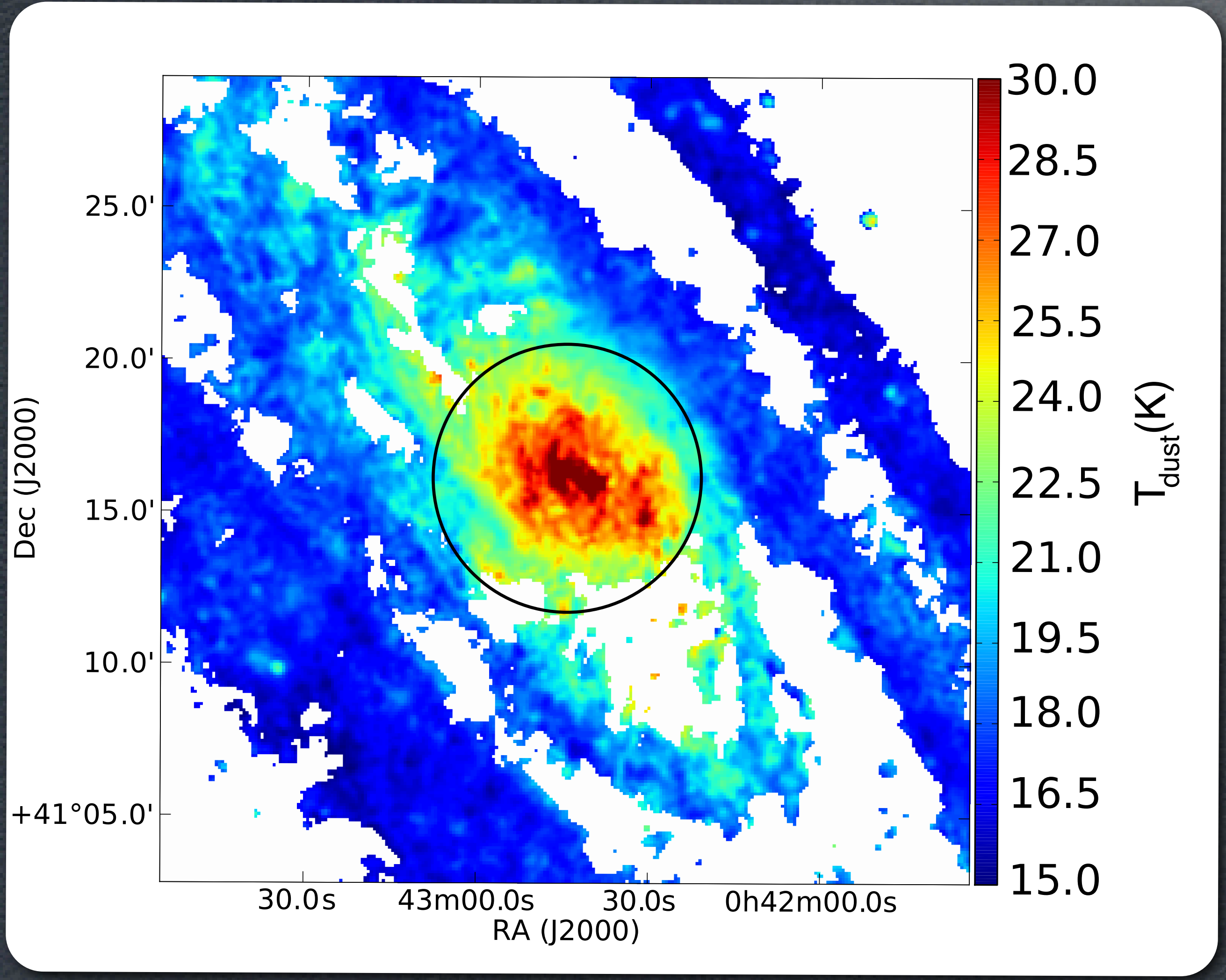
28
30
32
34
T_{dust}(K)

Dust heating



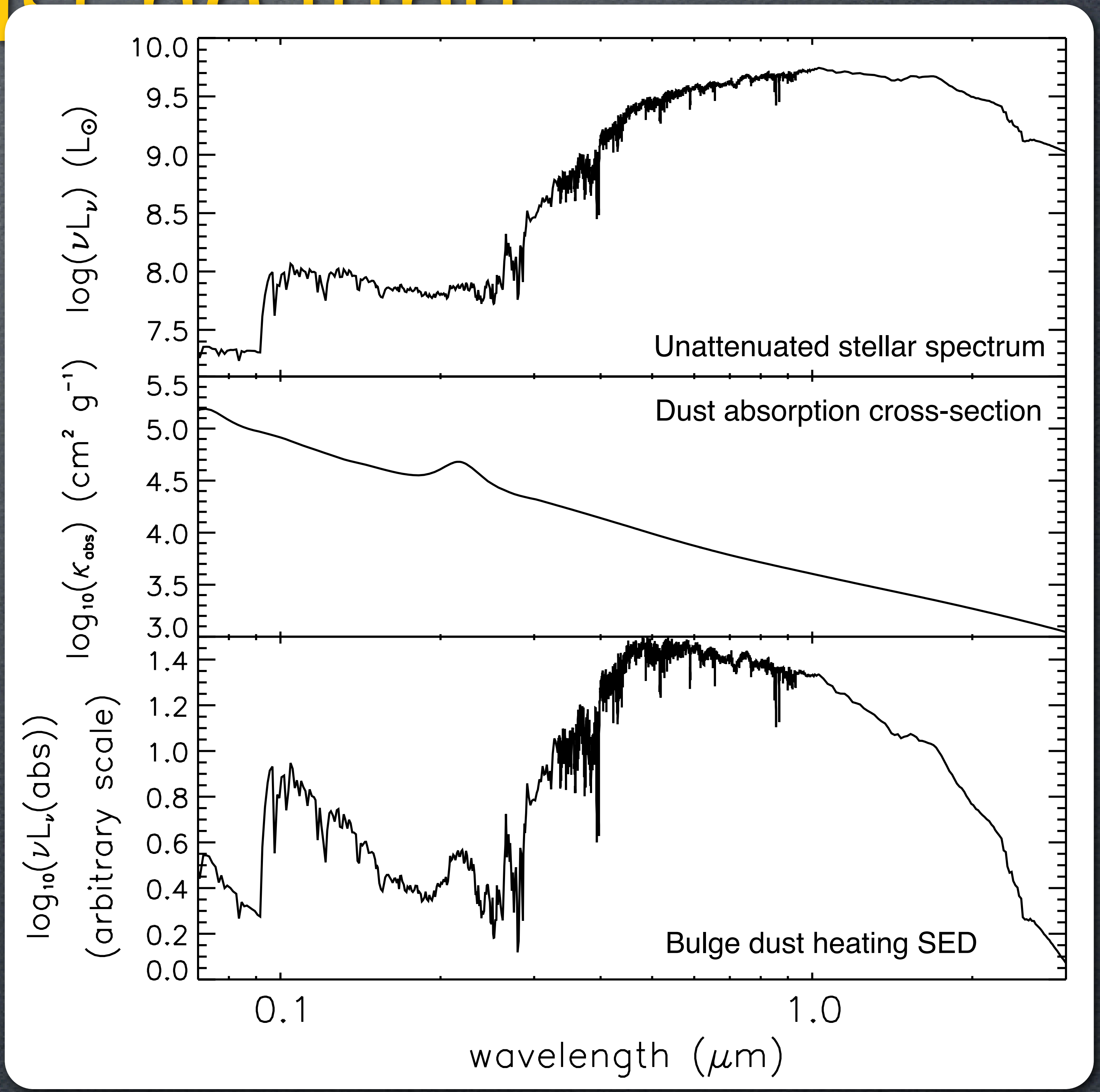
Groves et al. (2012)

- Hot dust follows bulge profile, but no young stars

Dust heating

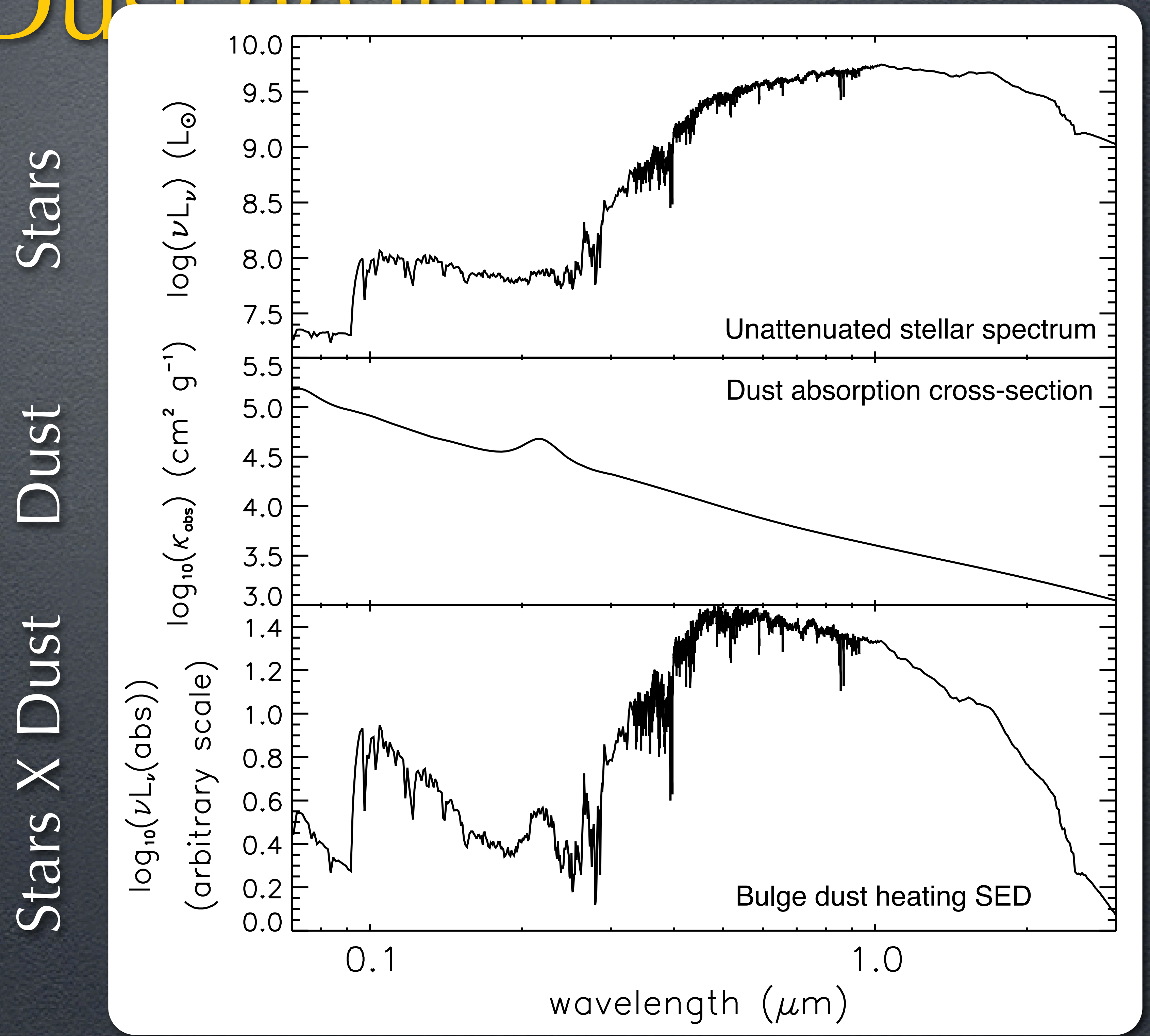
- Bulge stars so old (red)

Stars



Dust heating

- Bulge stars so old (red)
- Even with Steep dust opacity
- Optical light dominates dust heating



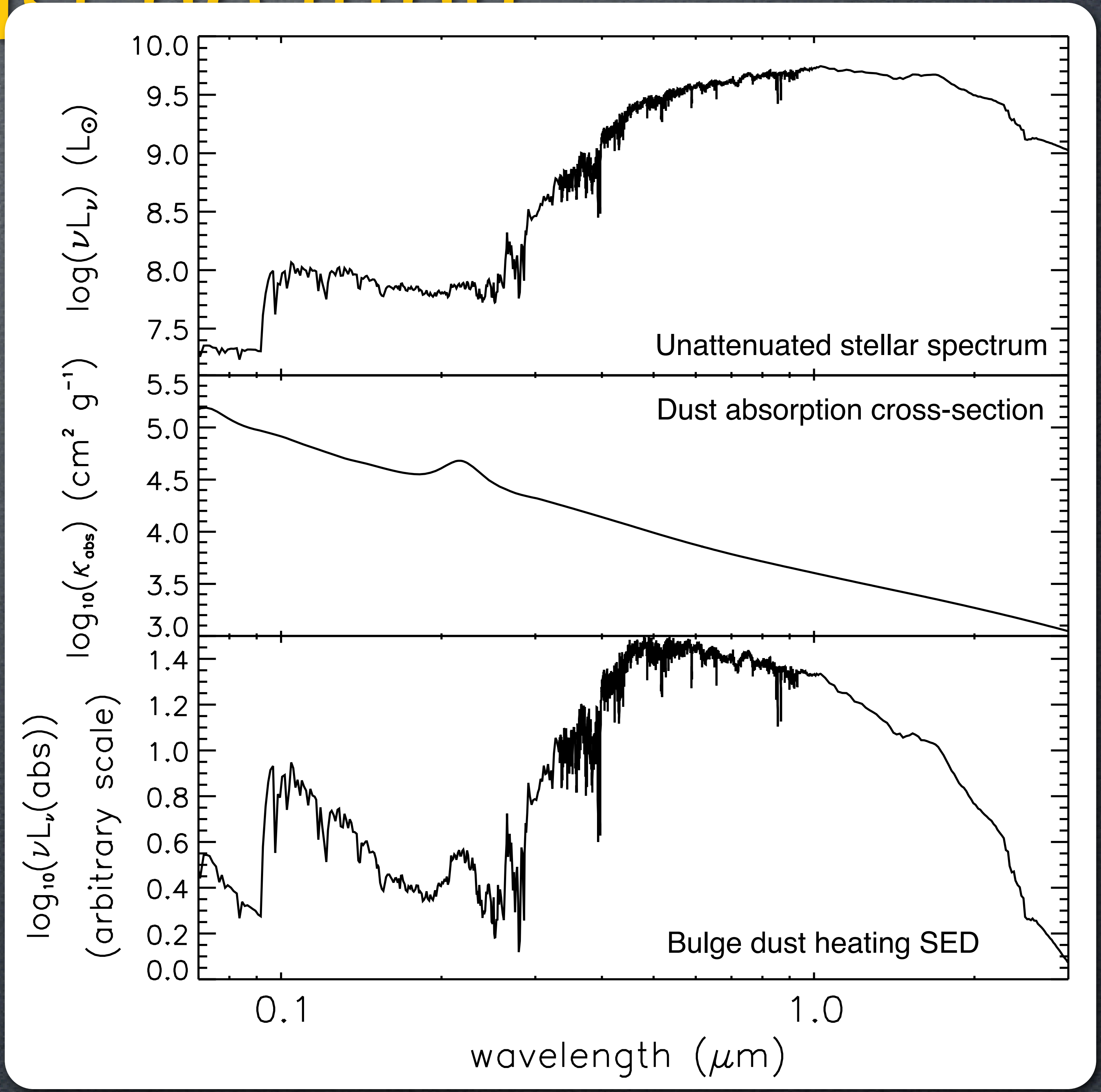
Dust heating

- Bulge stars so old (red)
- Even with Steep dust opacity
- Optical light dominates dust heating
- First clear example of dust heating by such old (>6 Gyr) stars

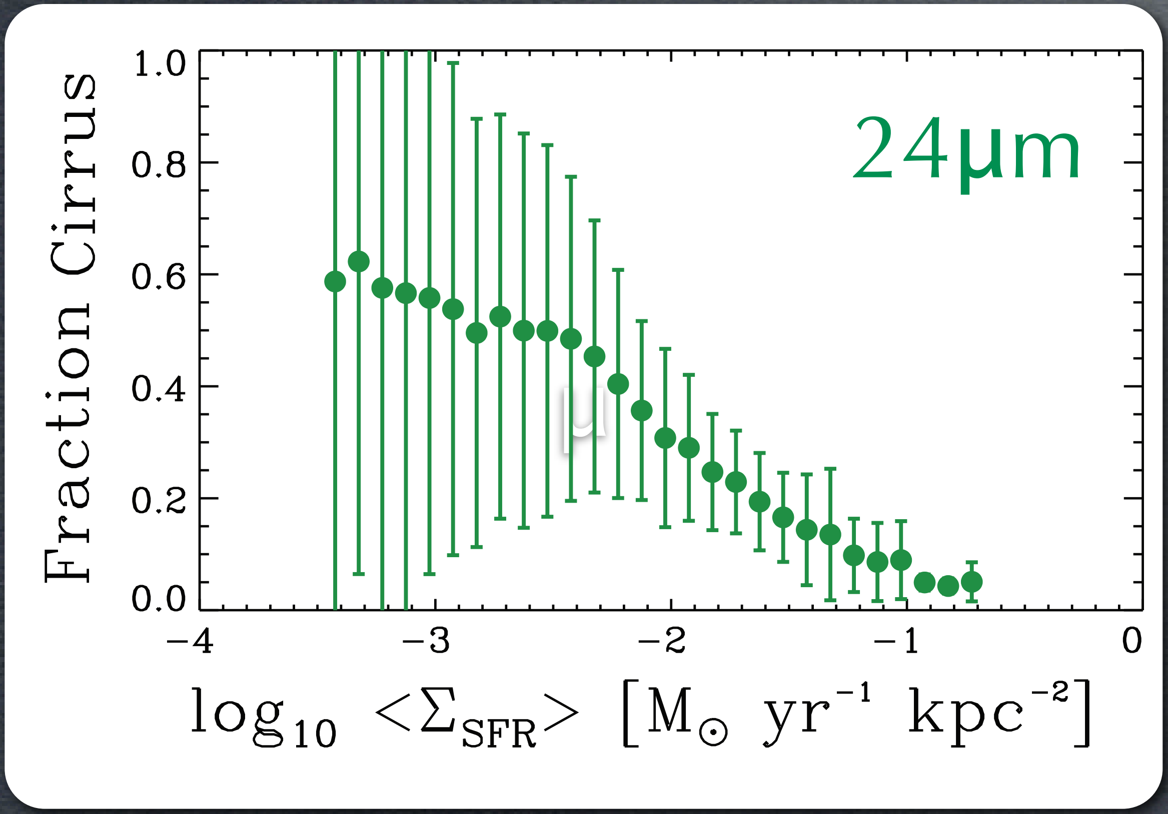
Stars

Dust

Stars X Dust



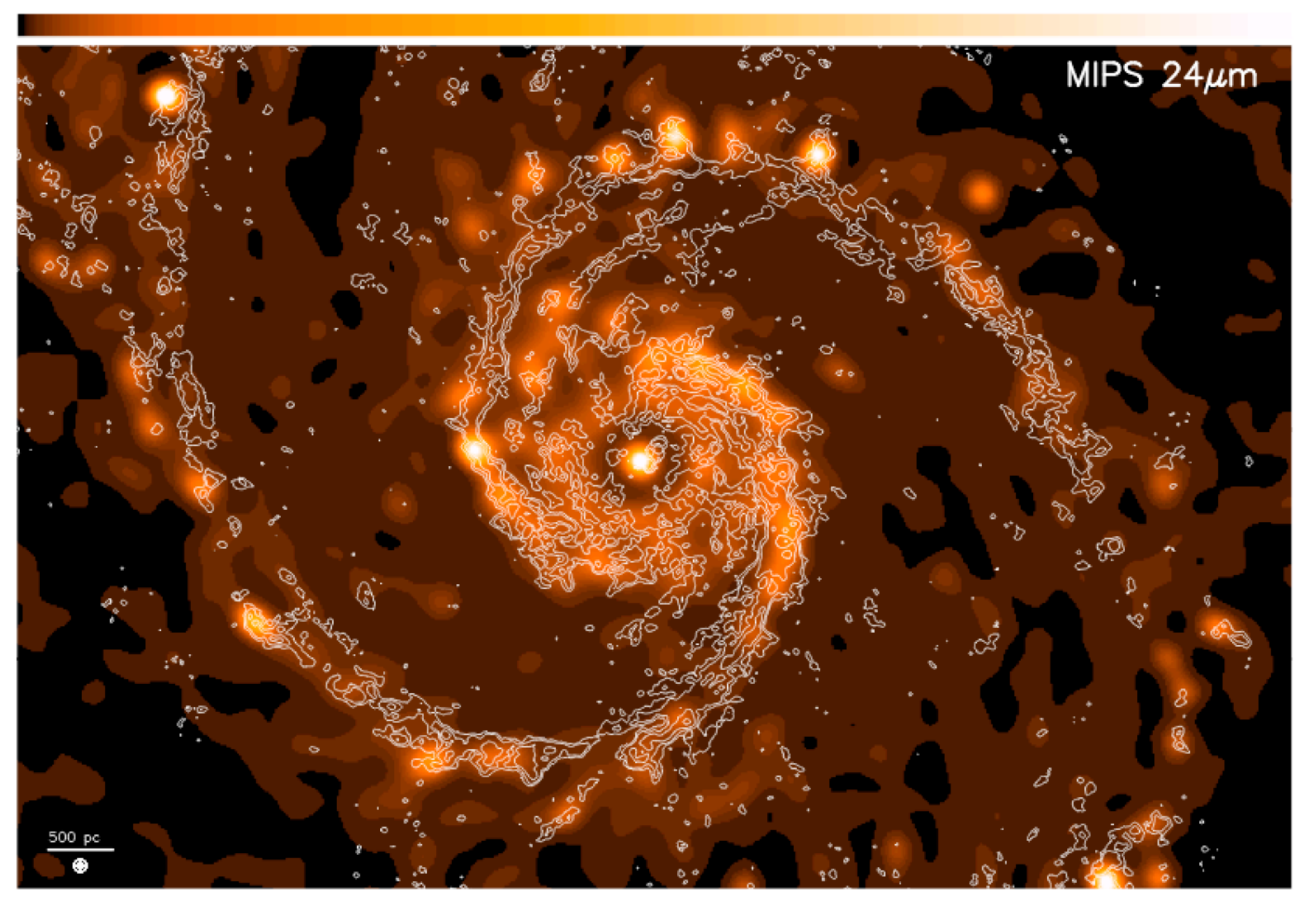
Dust Heating & SFR



Leroy et al. (2012)

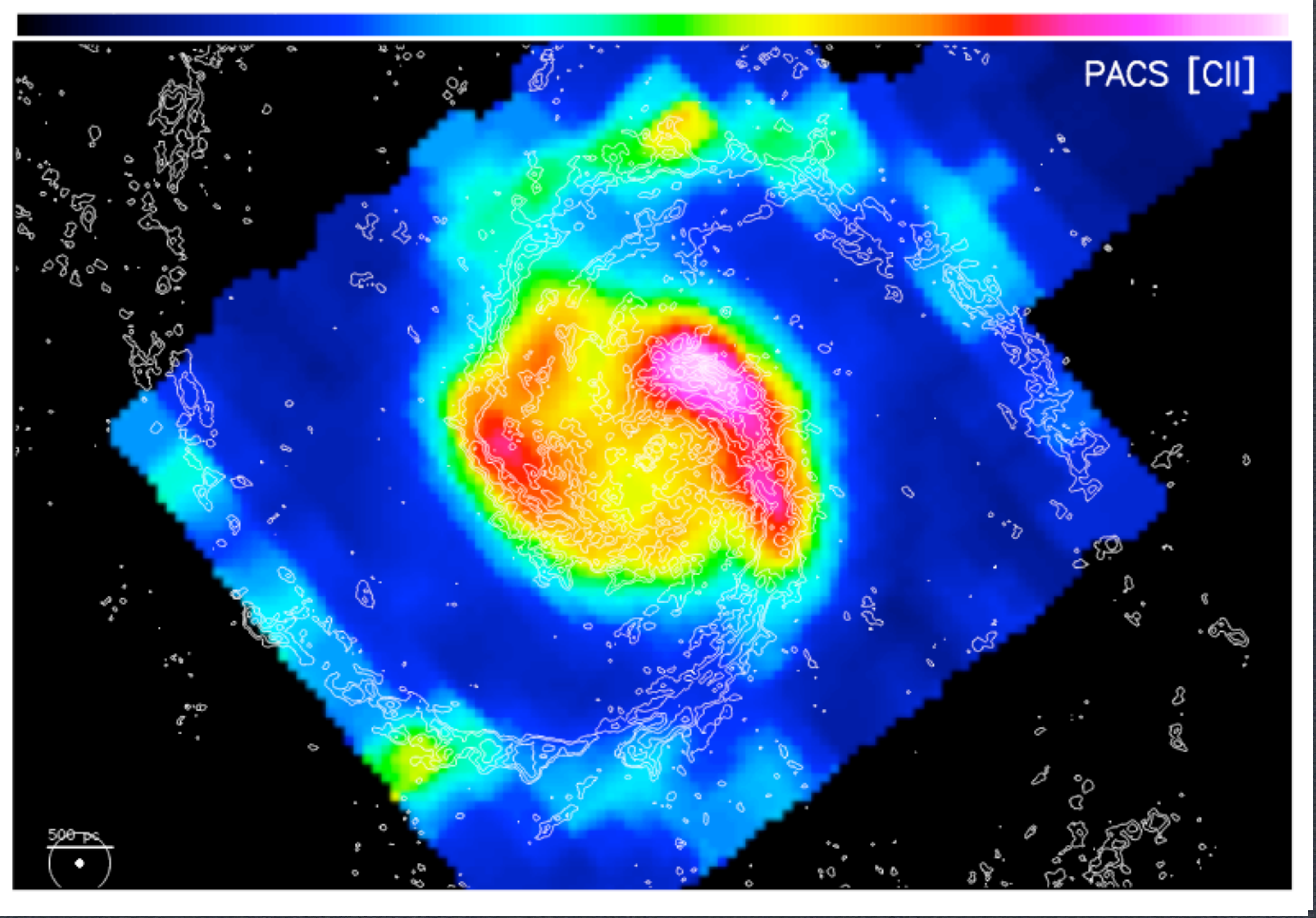
- Fraction diffuse or old star heating dependent on ratio of $\Sigma_{Old}/\Sigma_{SFR}$
- Biased to young stars with more UV, and higher A_V

Dust and Gas heating



Schinnerer et al. (2013)

Dust and Gas heating



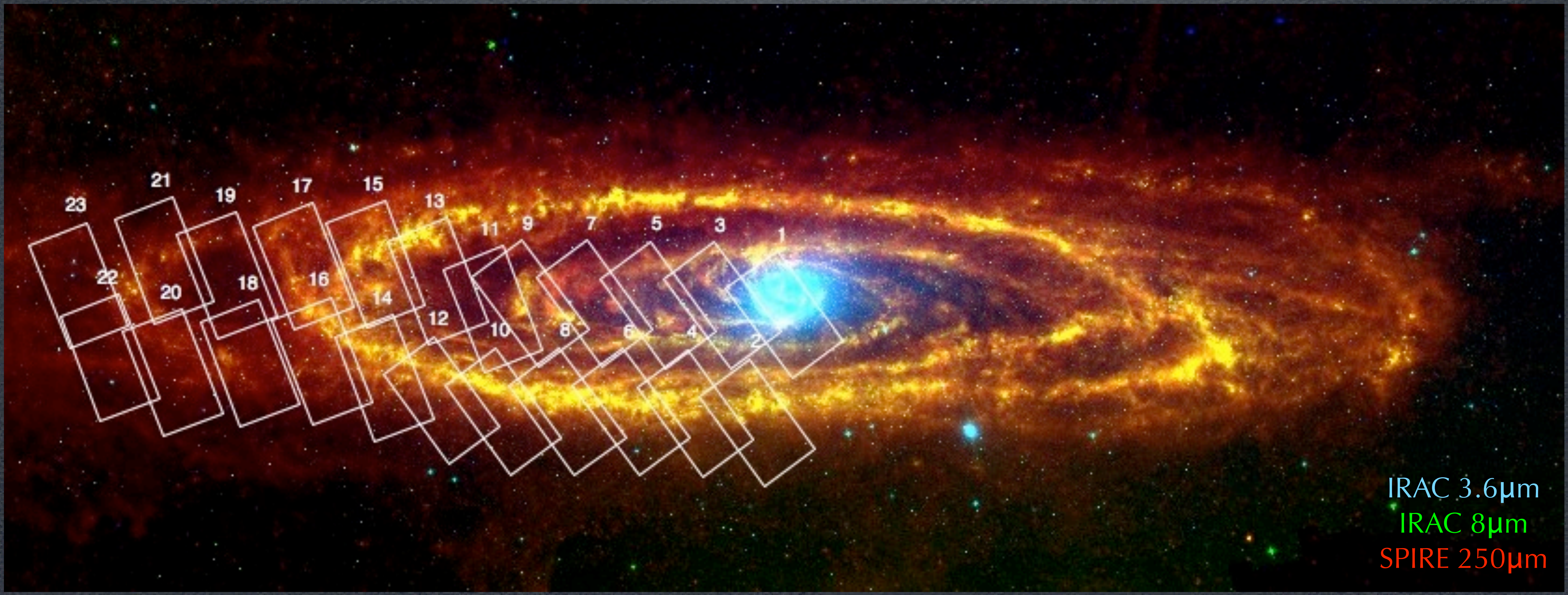
Schinnerer et al. (2013)

Dirty Ends...

- Dust can be used to trace gas
  - While extinction is useful for Galactic clouds, in Extragalactic systems geometrical effects limit this to a factor of 2
  - Emission in Sub-mm shows promise, but metallicity must be accounted for (and heating?)
- Dust can be used to trace SFR, but correction for diffuse heating necessary, especially in the bulge
- Connecting dust heating to gas temperature?

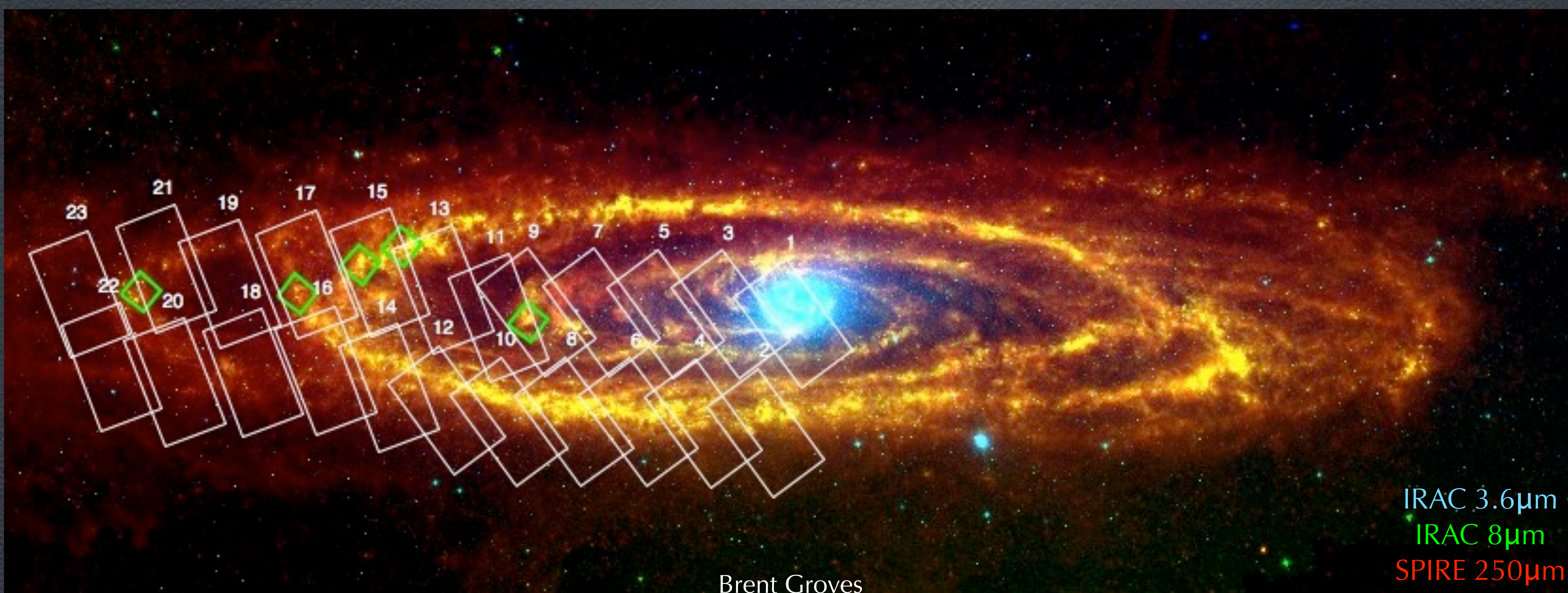
PHAT or big-boned?

- Pan-chromatic Hubble Andromeda Treasury Survey
  - PI. J. Dalcanton
- Trace:
  - exact stellar populations (i.e. heating sources for dust)
  - attenuation for individual stars

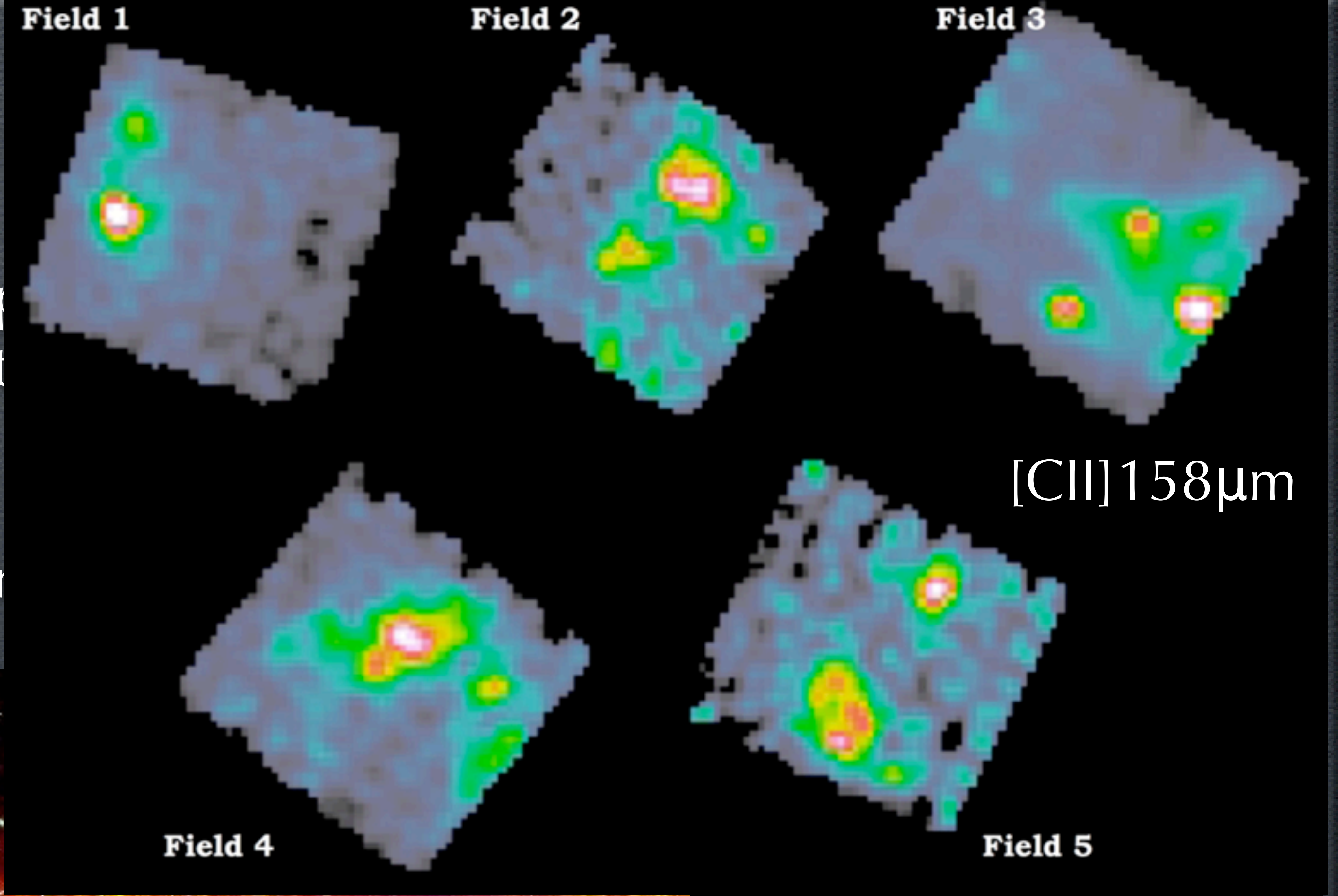


Seeing [CII]

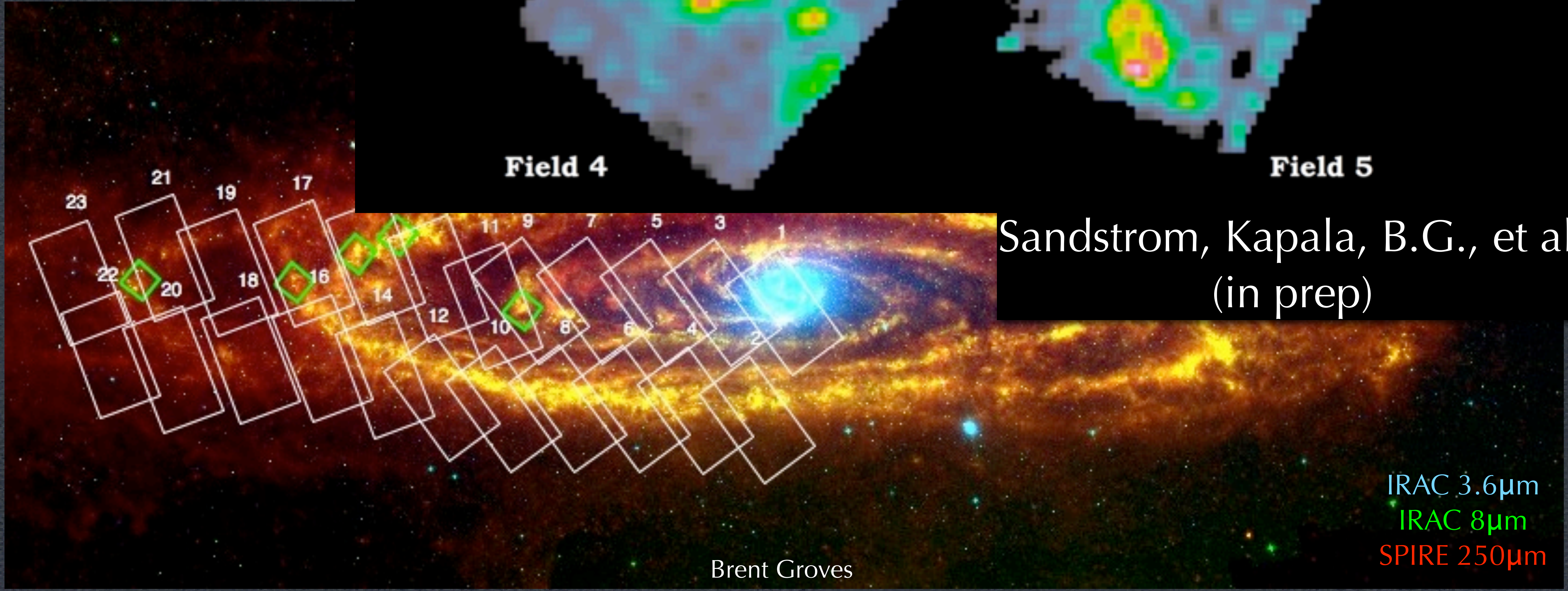
- PACS spectroscopy to measure dominant ISM coolants
  - [CII] 158m
  - [OI]
- Link directly to stars and dust



- PACS sp
  coolant
  - [CII] 1
  - [OI]
- Link di

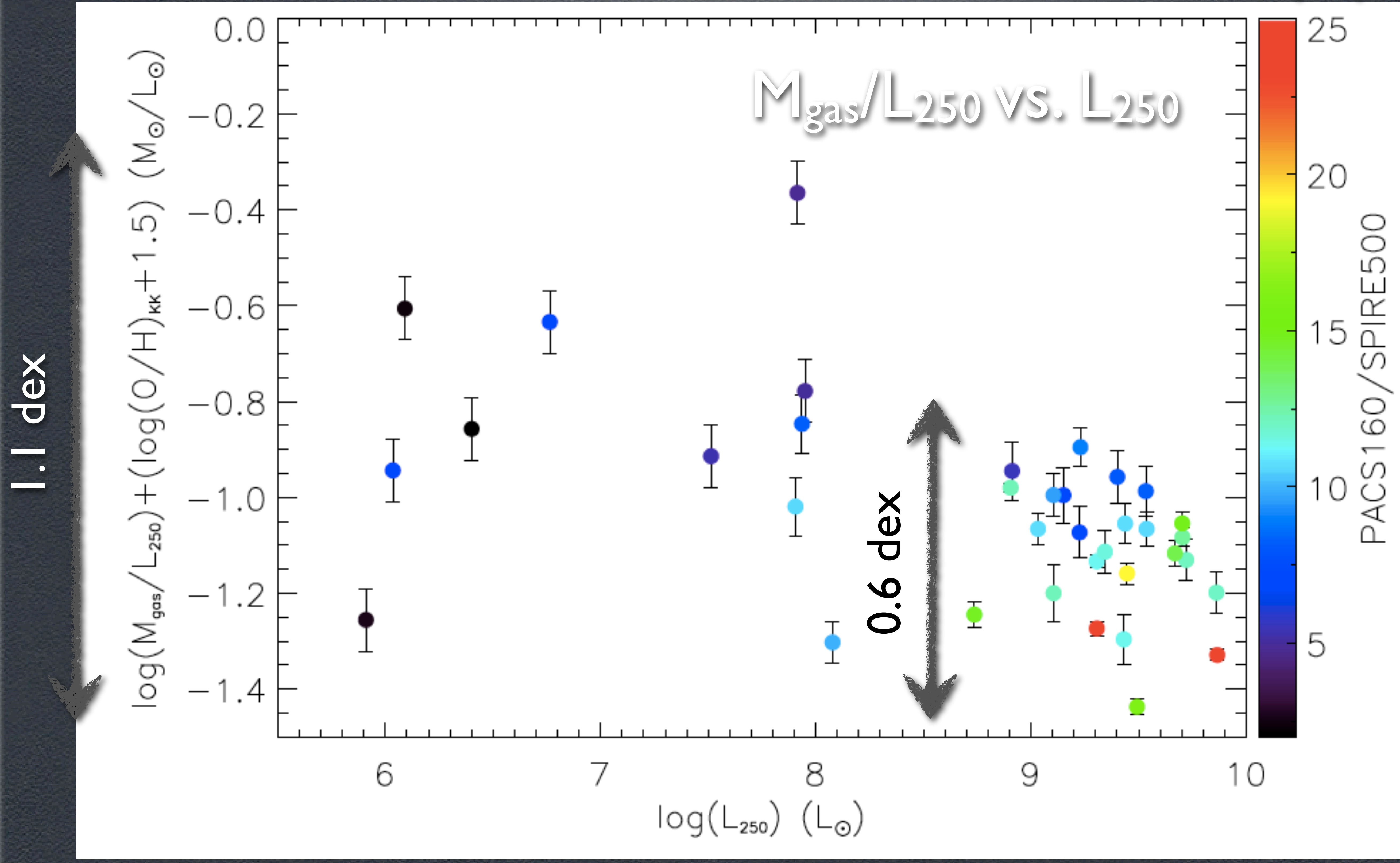


Sandstrom, Kapala, B.G., et al. (in prep)



beware of sub-mm sed slope

Groves et al. (in prep.)



Why does this work?

$$L_\nu = M_{\rm d} \kappa_{\nu 0} B_\nu(\mathrm{T_d}) \left(\frac{\nu}{\nu_0}\right)^\beta$$

- but $M_d/M_{gas} \propto$ metallicity
- So M_{gas}/M_d * metallicity ~ constant?

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$$\frac{M_{\rm gas}}{\nu L_{\nu(500)}} \propto \left(\frac{M_{\rm gas}}{M_{\rm d}}\right) B_{\nu(500)}(\mathrm{T_d})$$

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$$\sim \left(\frac{M_{\rm gas}}{M_{\rm d}}\right) \mathrm{T_d}$$

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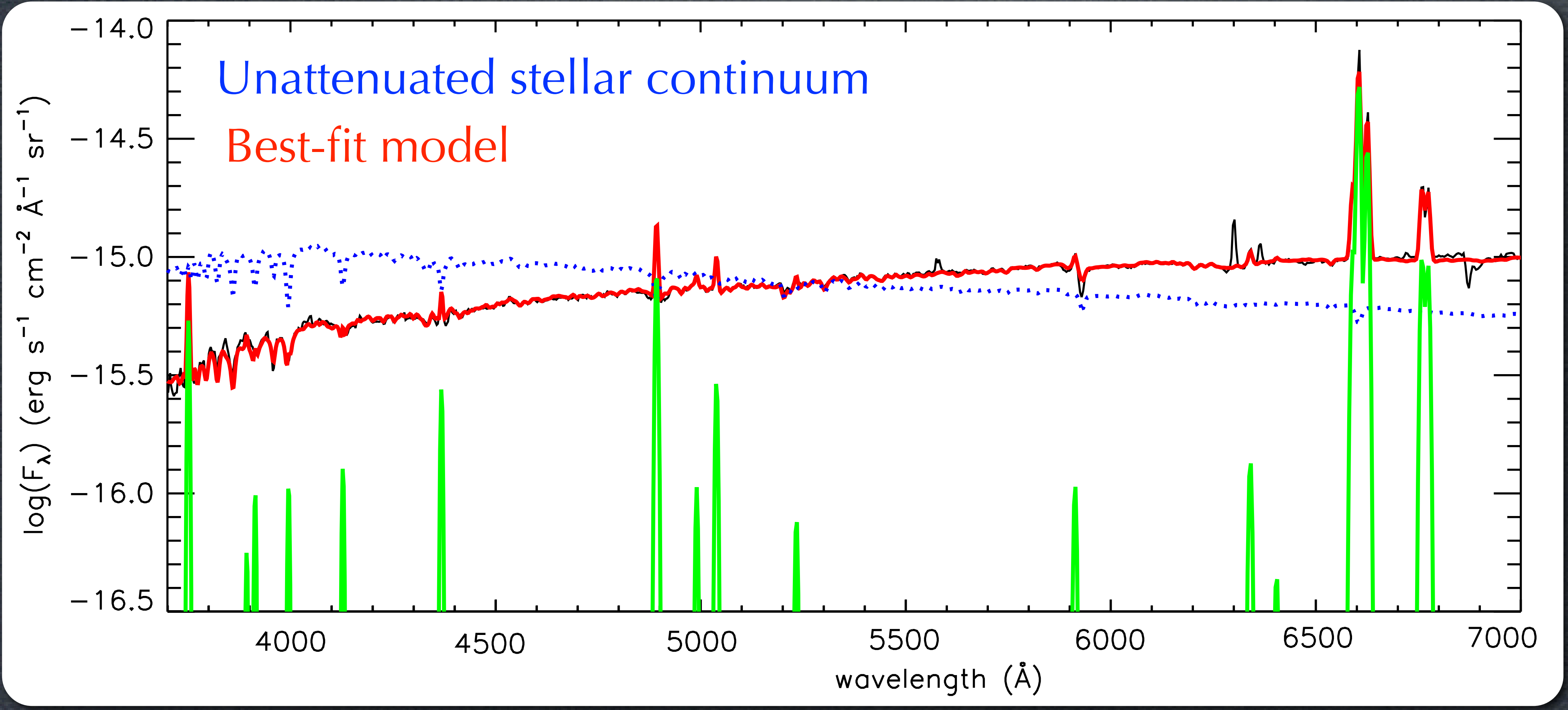
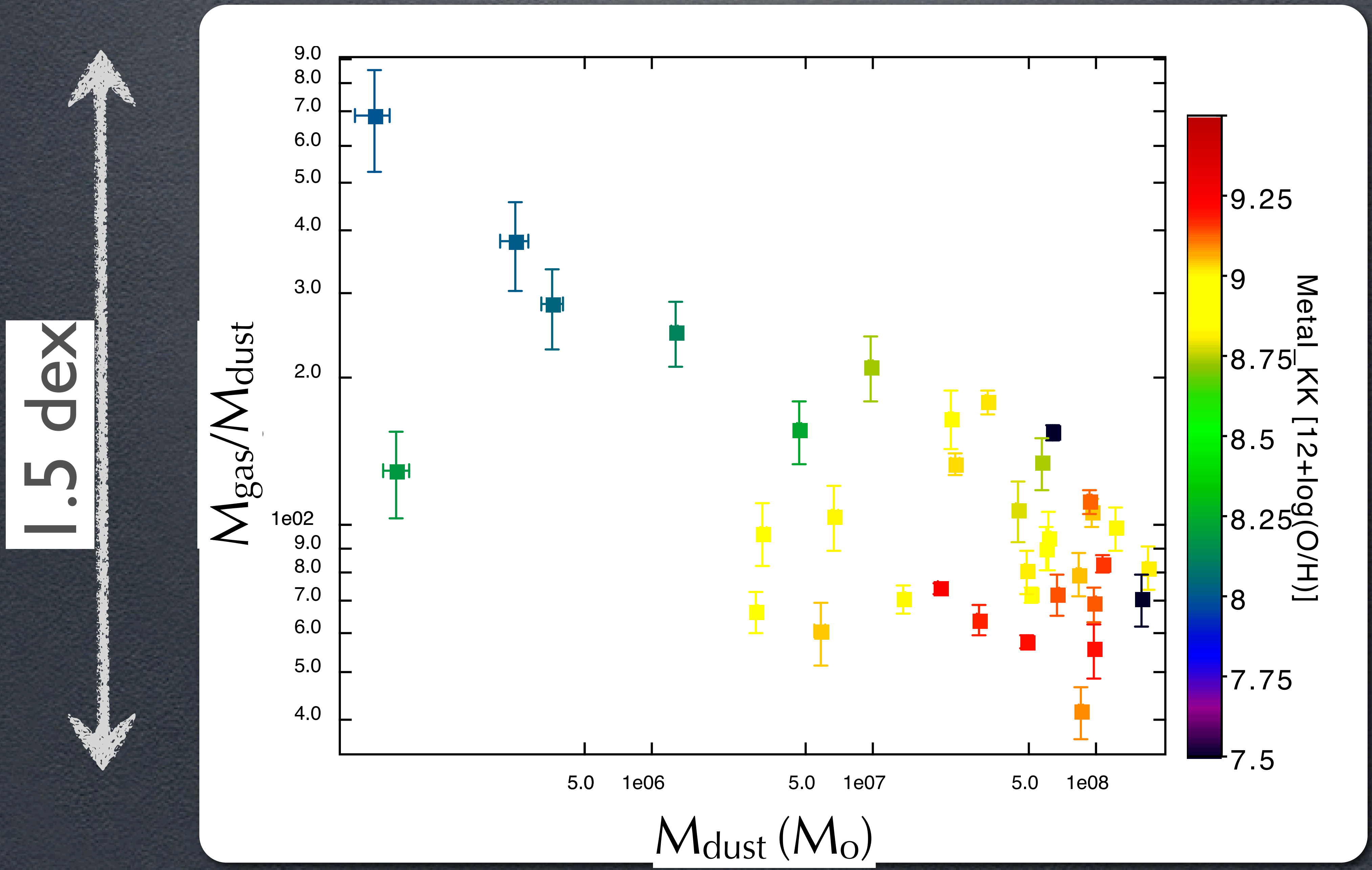
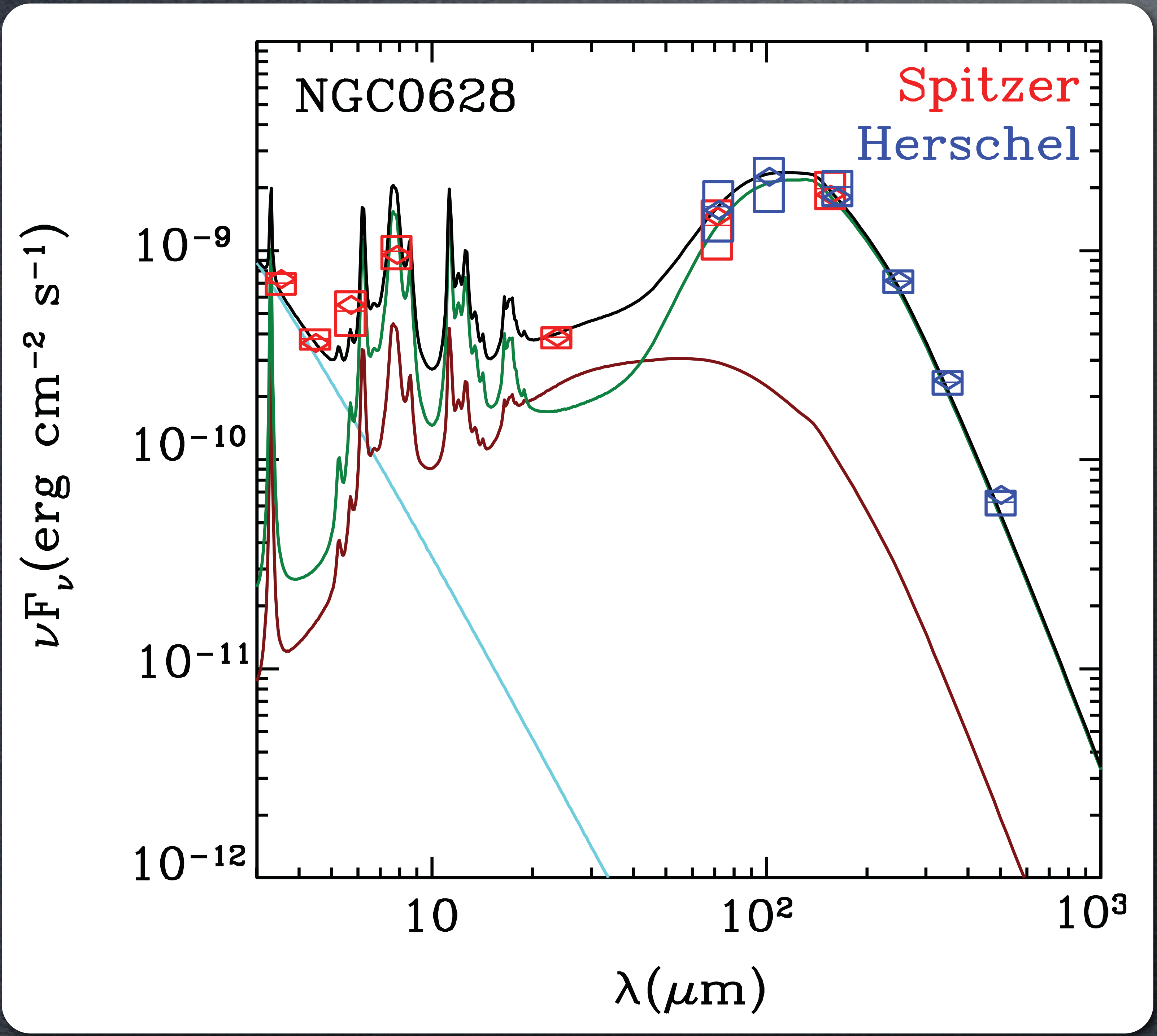


Unattenuated stellar continuum
Best-fit model
log(F_λ) (erg s^-1 cm^-2 Å^-1 sr^-1)
−14.0
−14.5
−15.0
−15.5
−16.0
−16.5
4000
4500
5000
5500
6000
6500
7000
wavelength (Å)

M_{dust} more scatter?



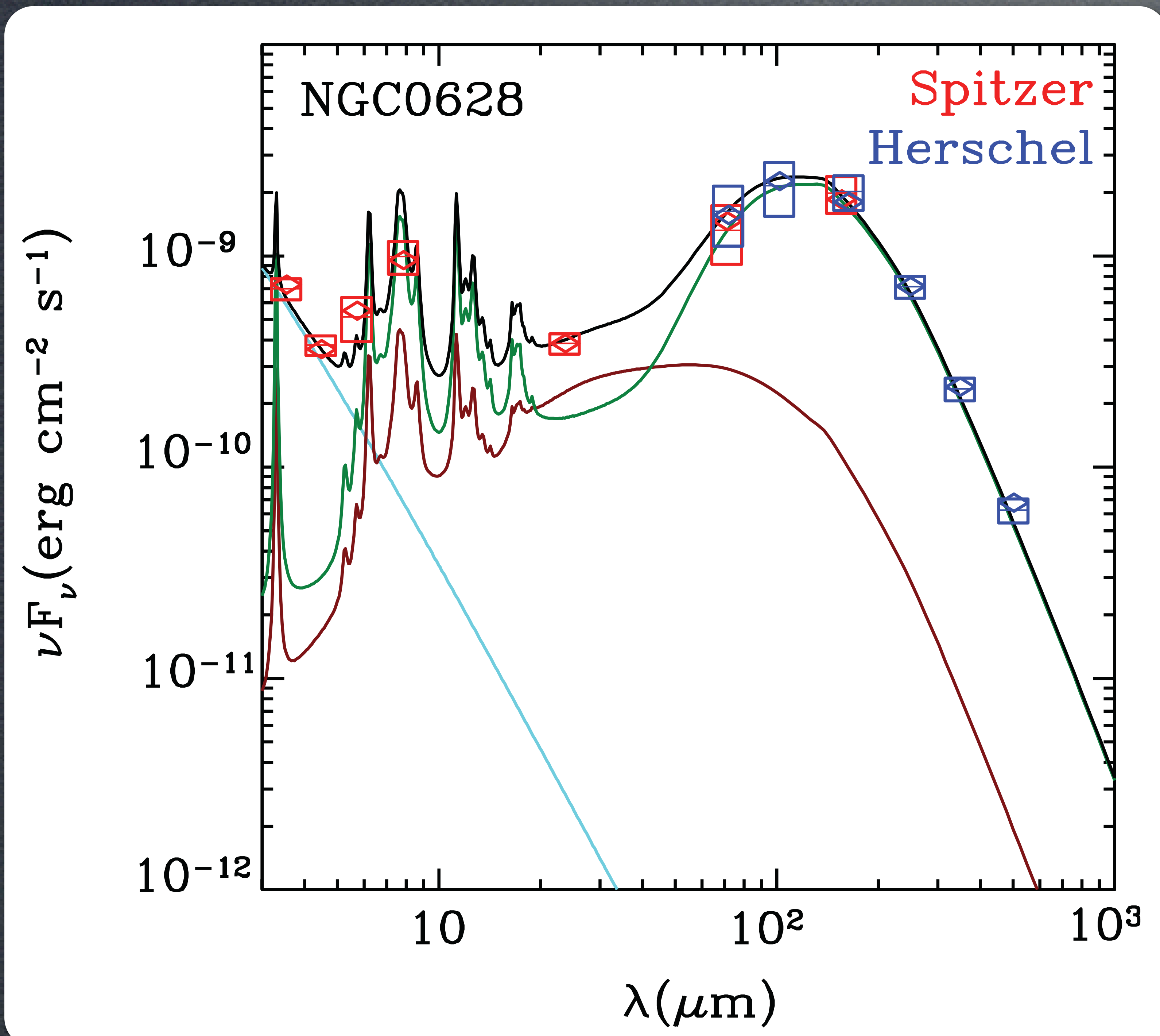
Total Dust & more



Aniano et al. (2012)

Draine & Li (2007) models

Total Dust & more



U_{min} = 1.50
α = 2.10
γ = 2.59 %
f_{PDR} = 10.7 %
q_{PAH} = 4.20 %
L_{PDR} = 7.24 x10^8 $L_\odot$
L_{dust} = 6.78 x10^9 $L_\odot$
M_{dust} = 2.78 x10^7 $M_\odot$

Aniano et al. (2012)

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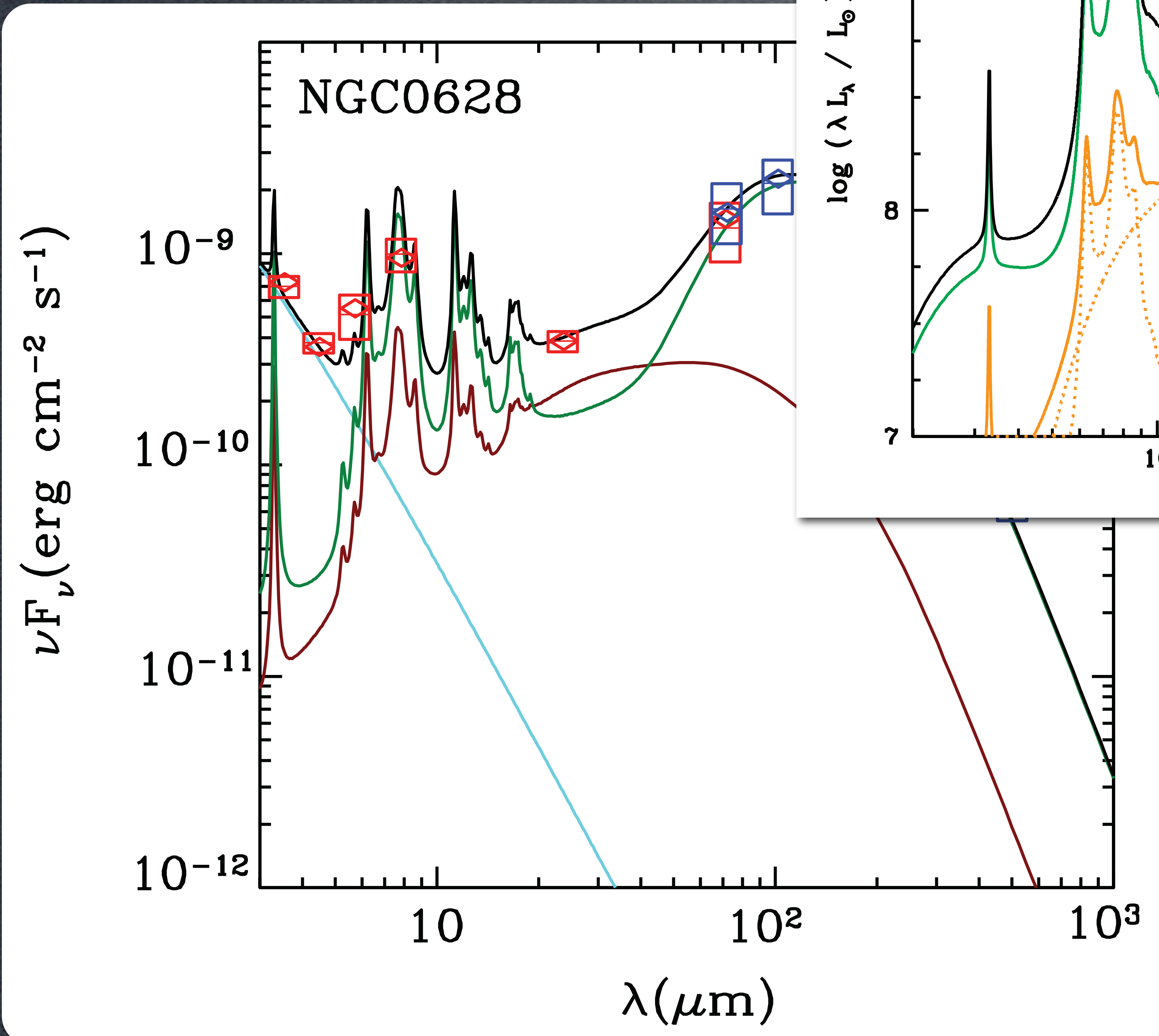
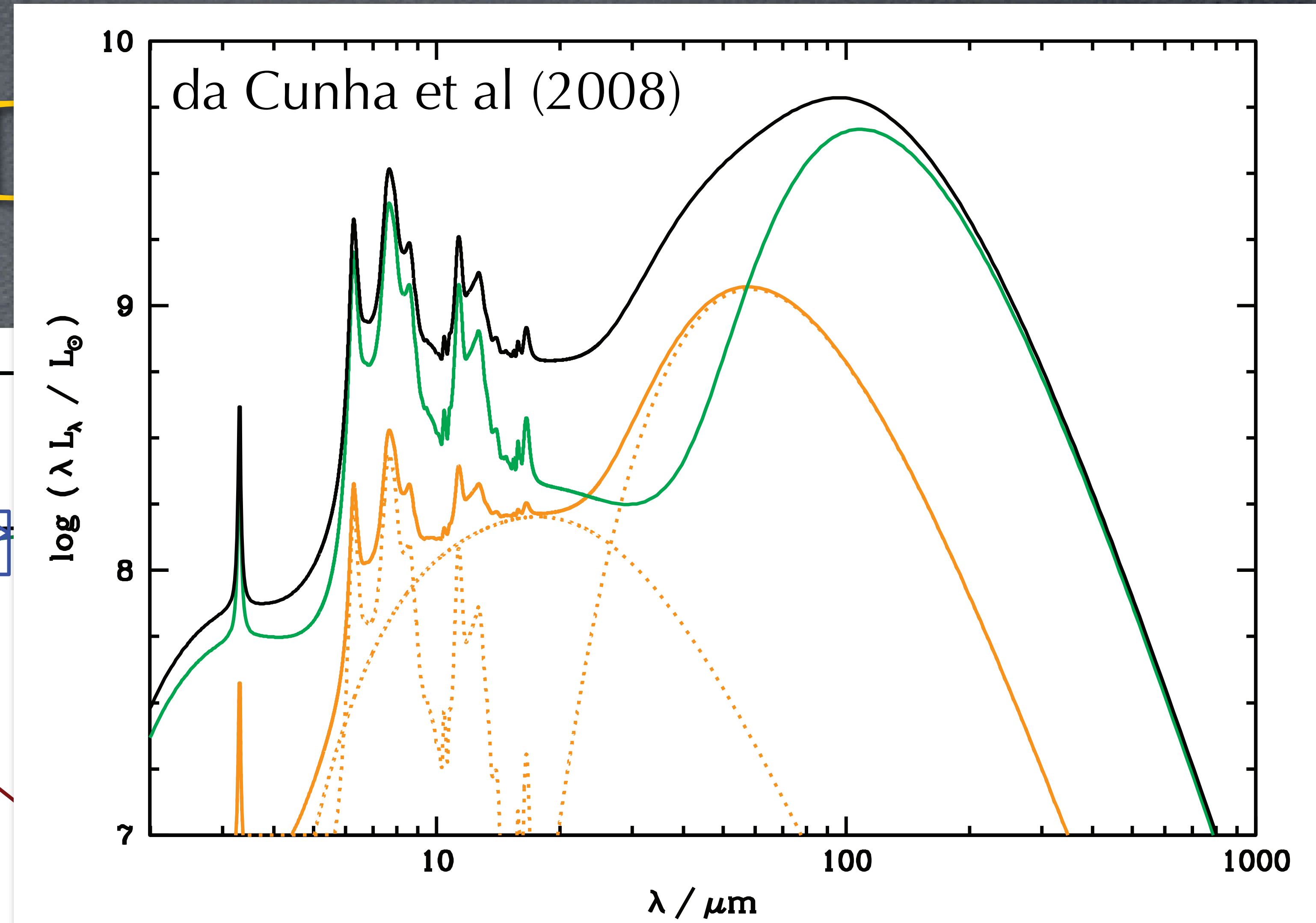
Total D





f_{PDR} = 10.7 %

q_{PAH} = 4.20 %

L_{PDR} = 7.24 x10^8 $L_\odot$

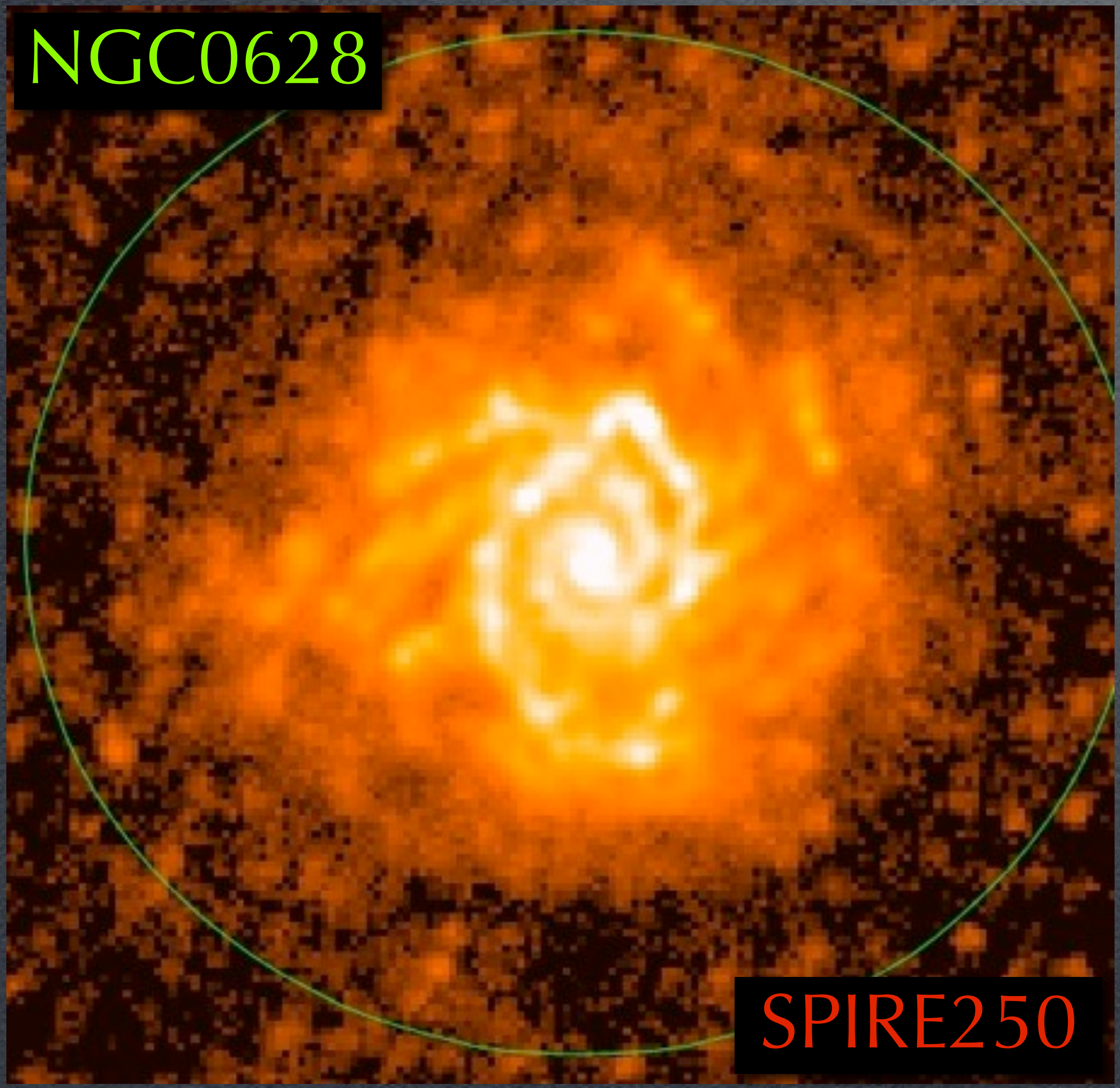
L_{dust} = 6.78 x10^9 $L_\odot$

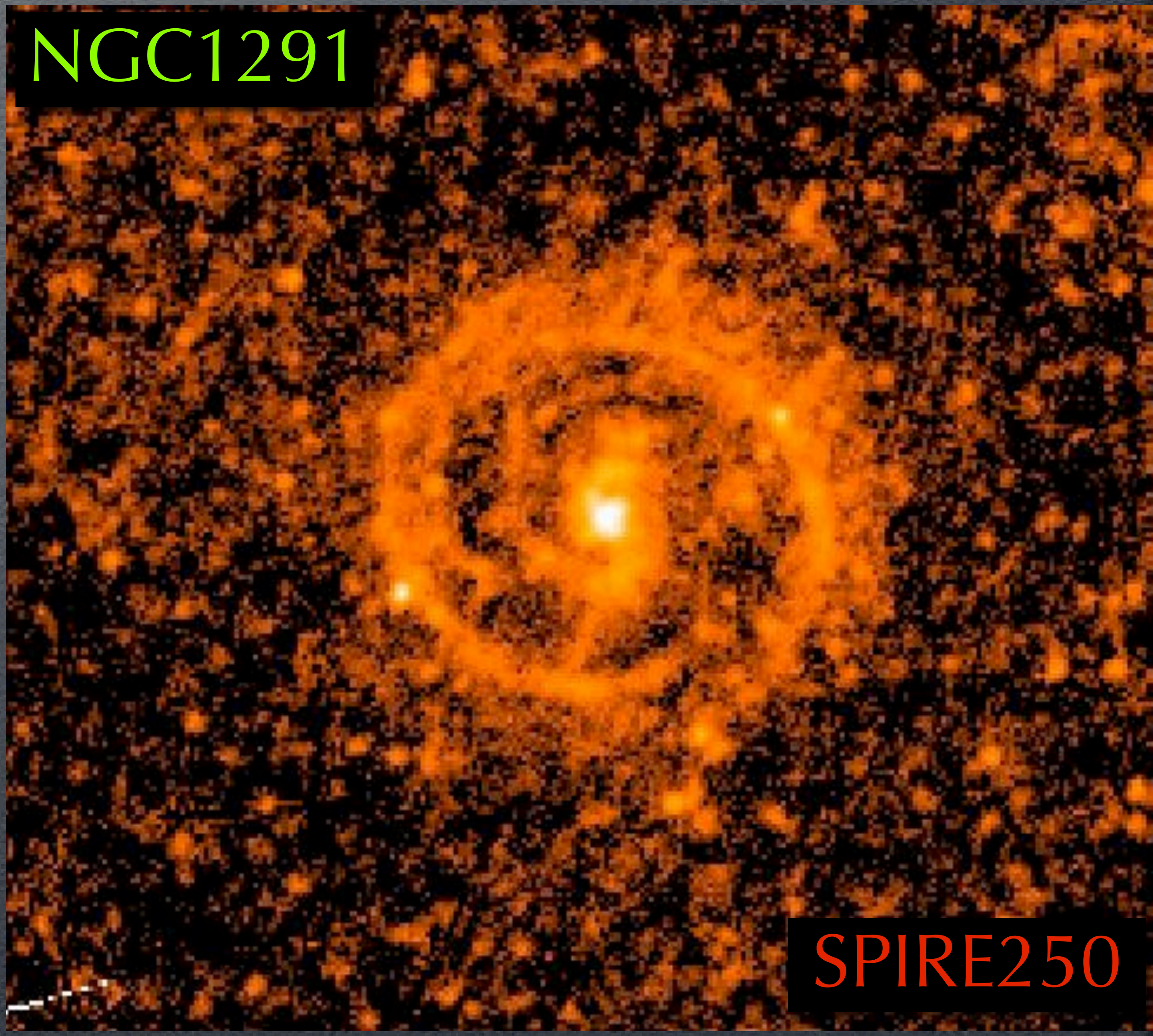
M_{dust} = 2.78 x10^7 $M_\odot$

Aniano et al. (2012)

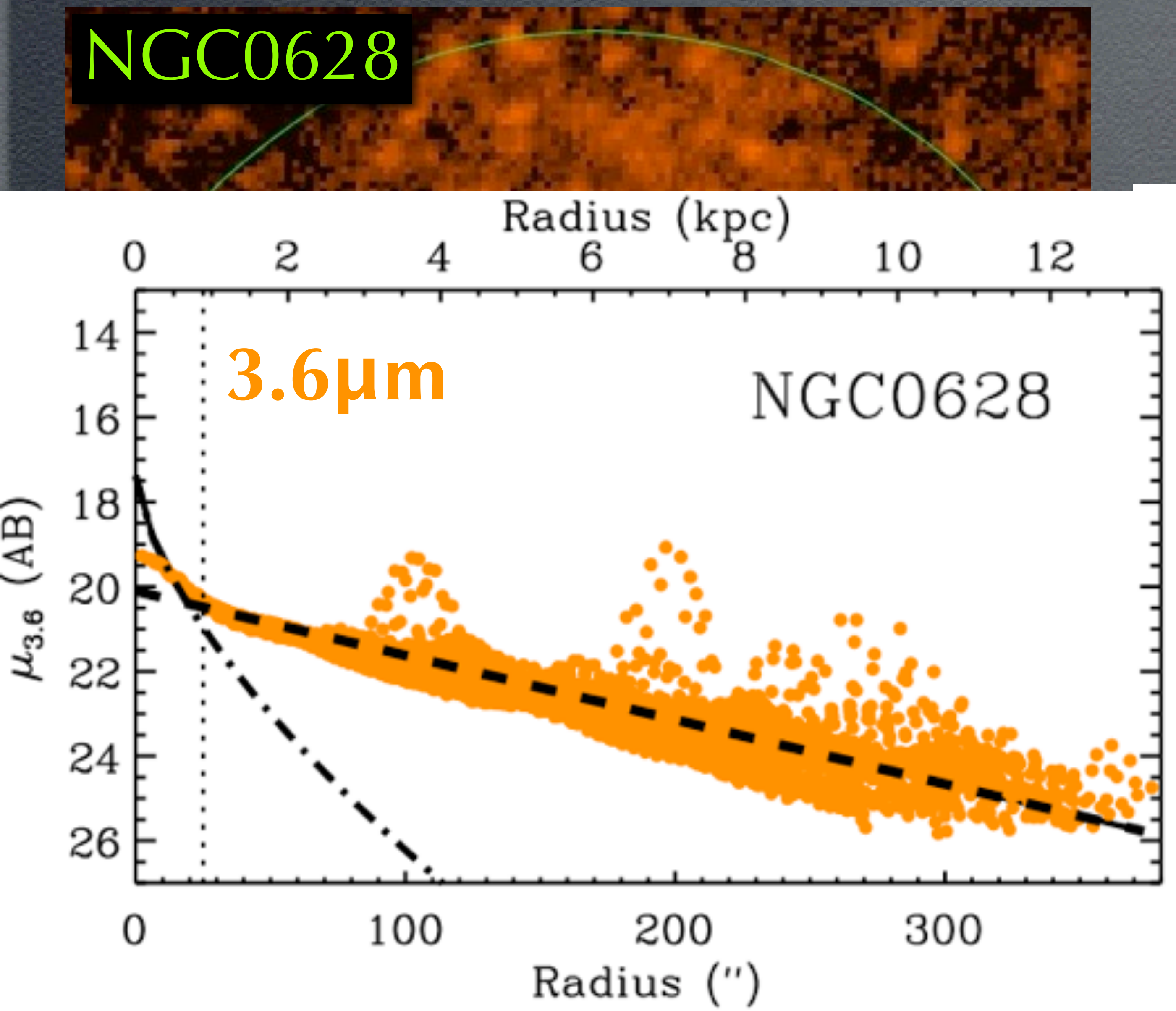
Draine & Li (2007) models

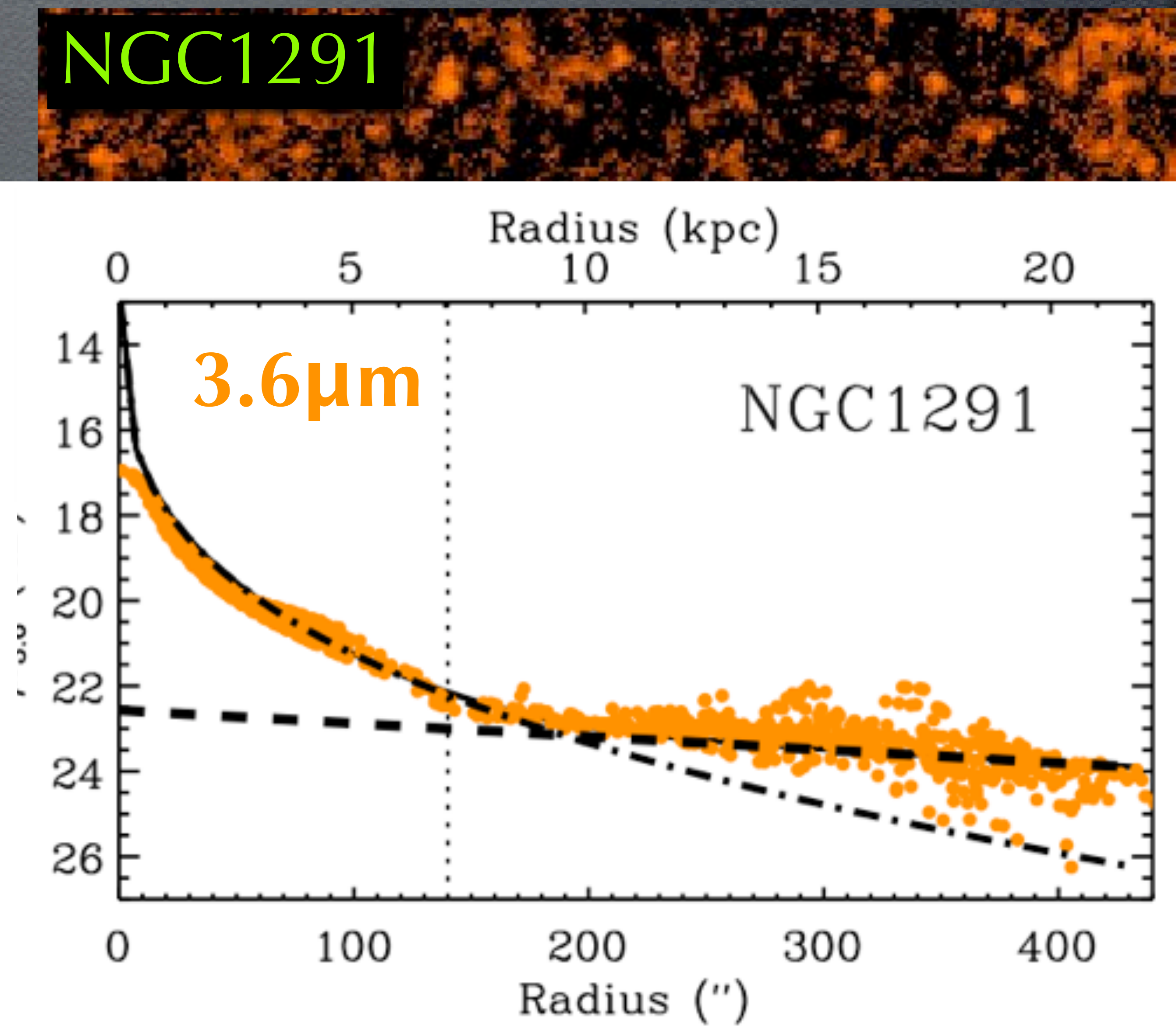
All the IR



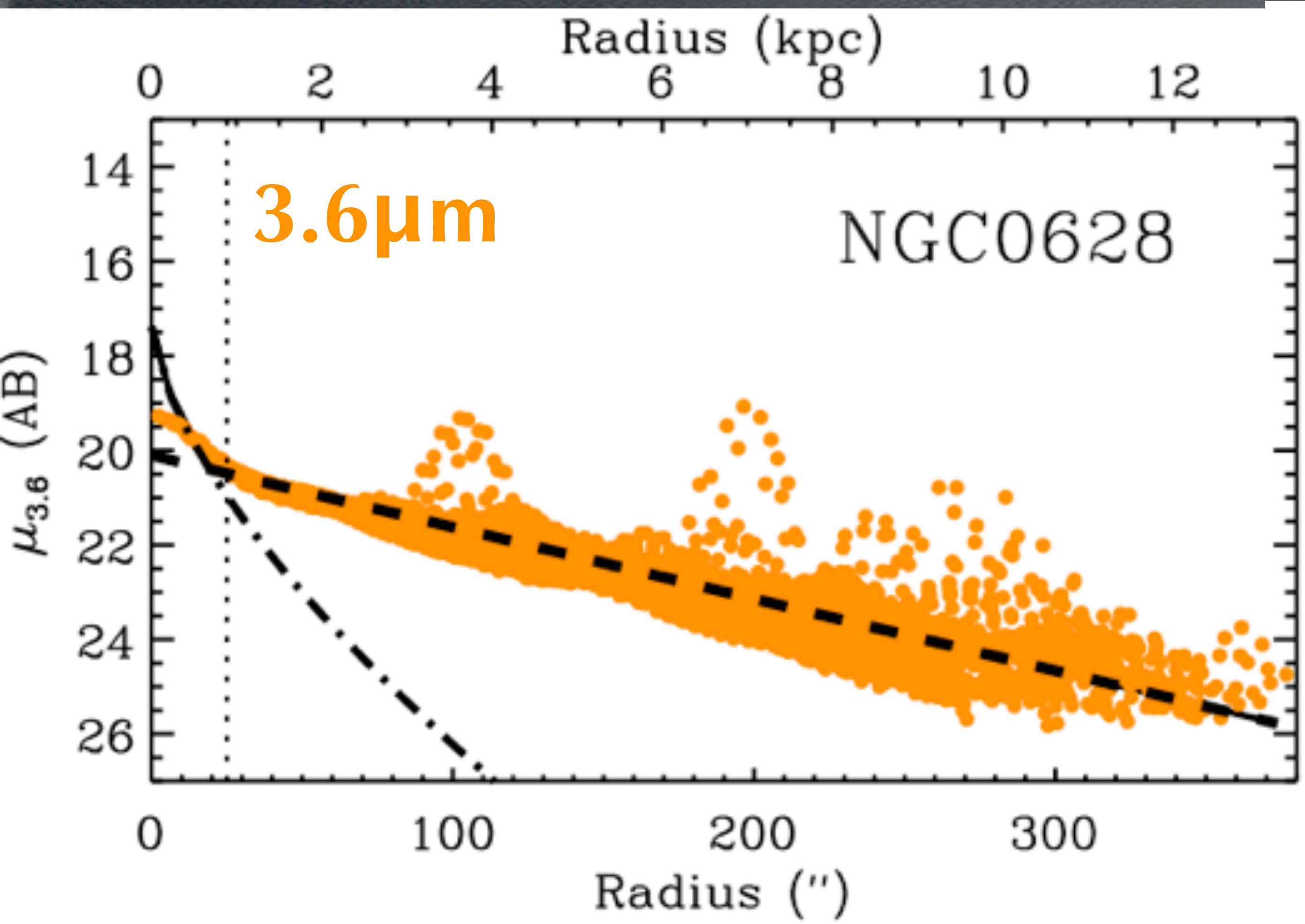


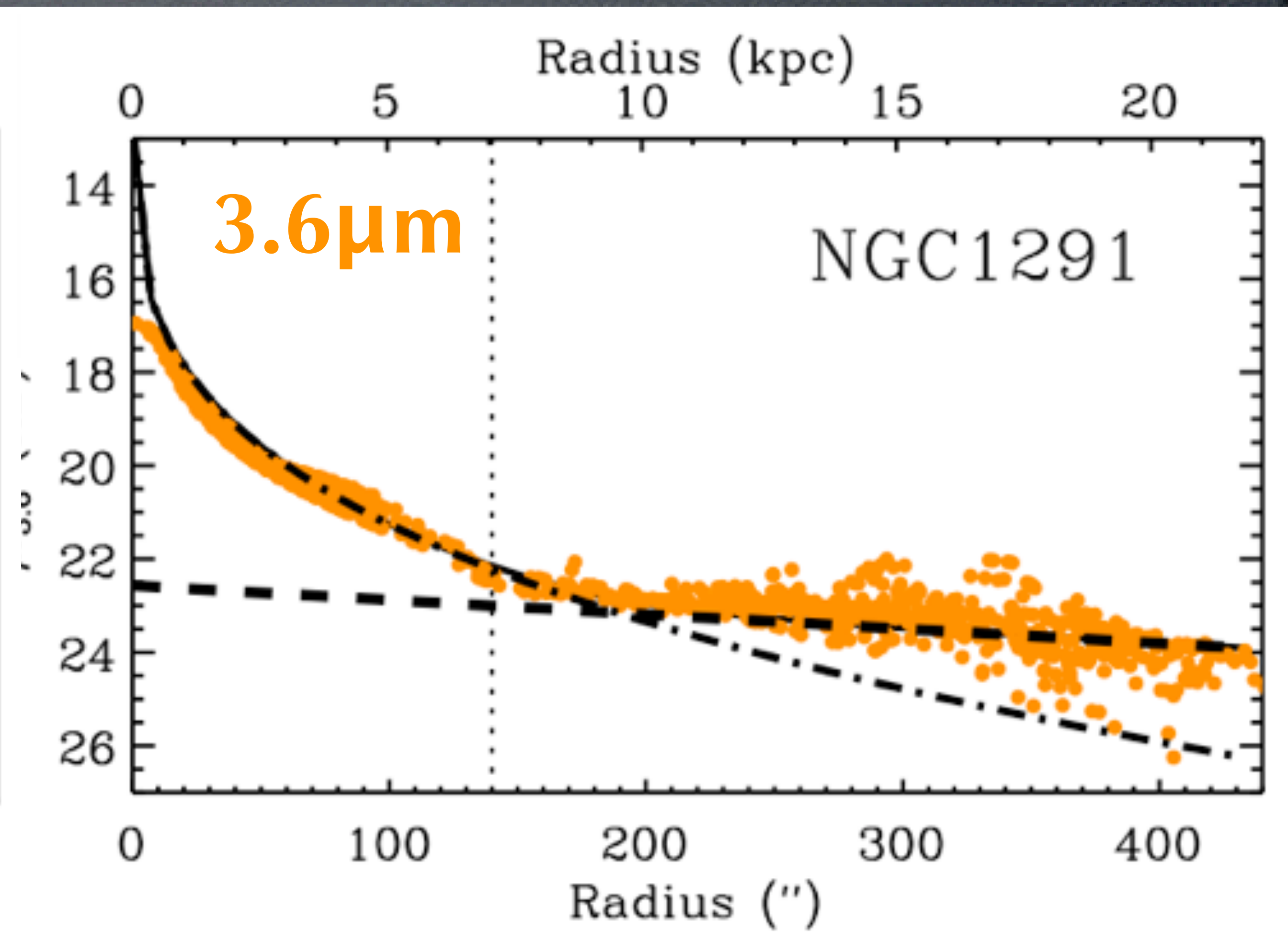
All the IR

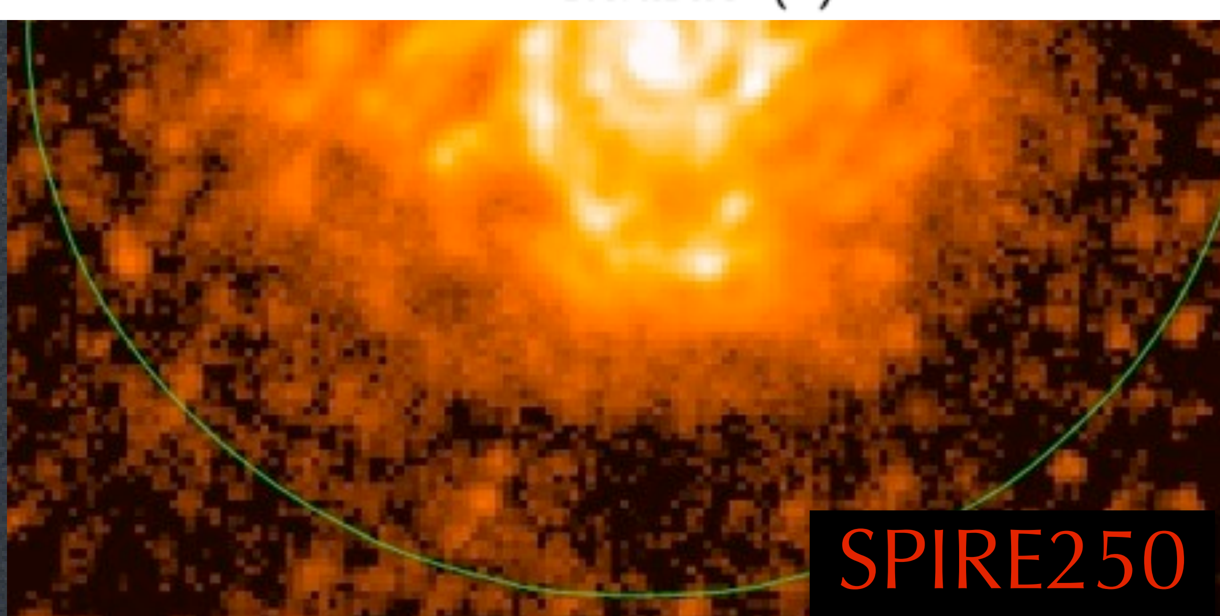


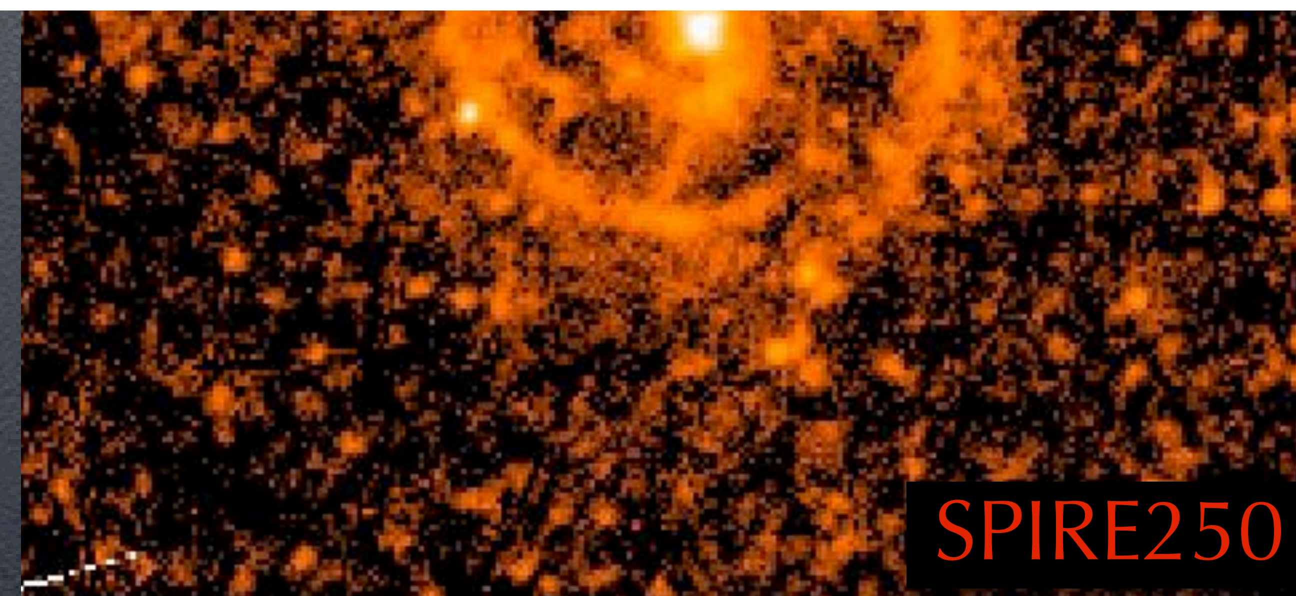


Johnson, Groves, et al. (2013)

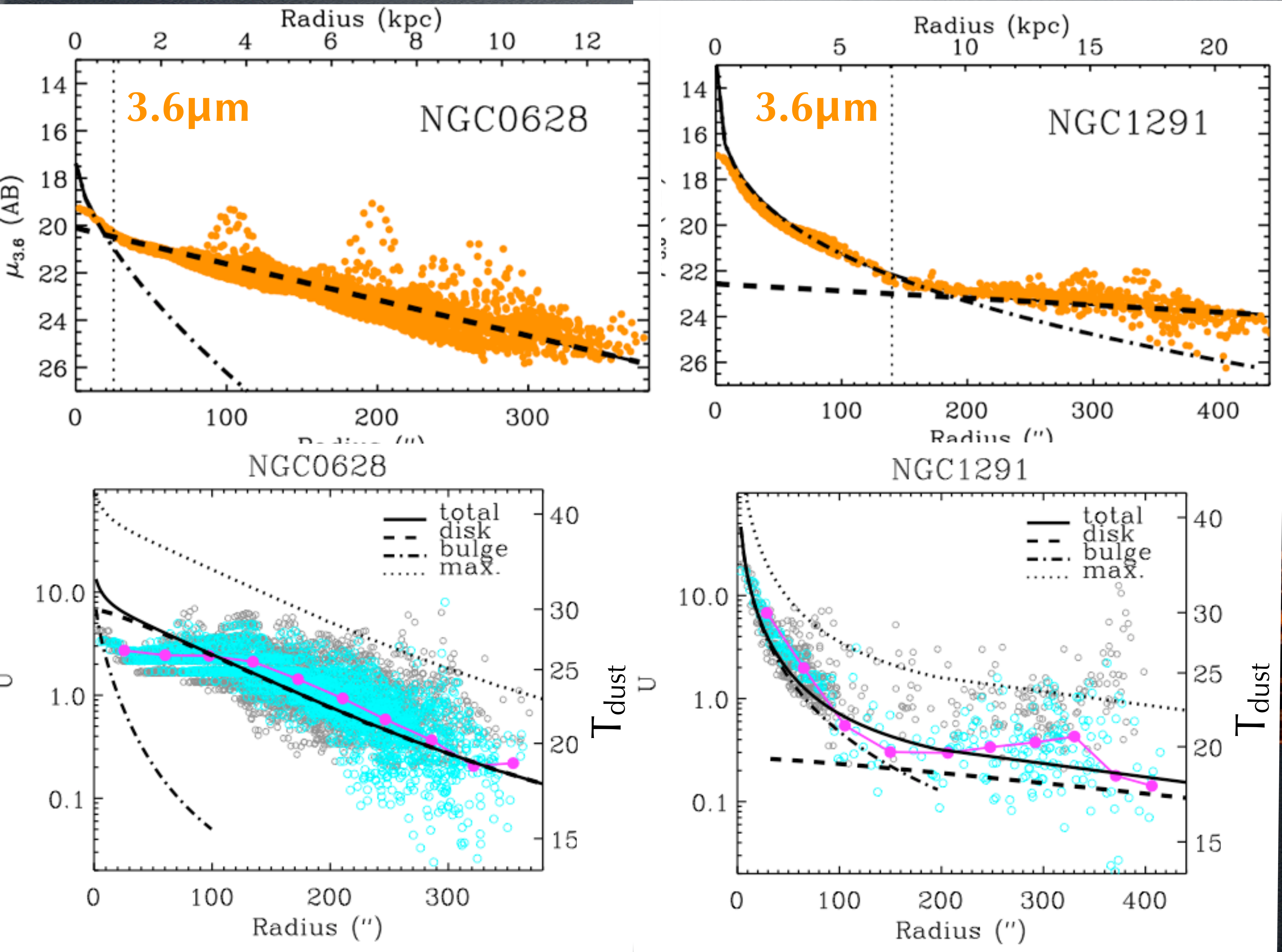




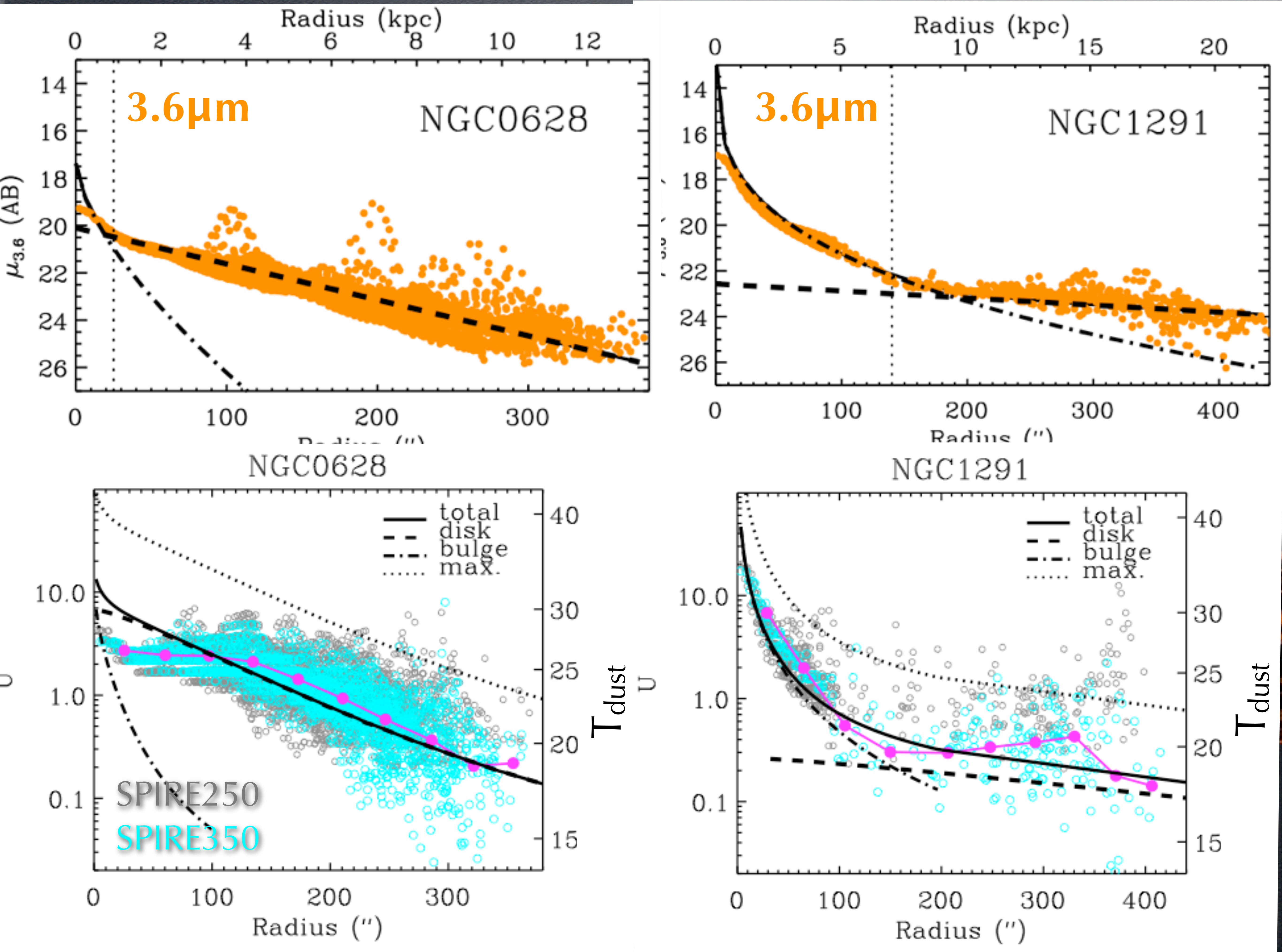




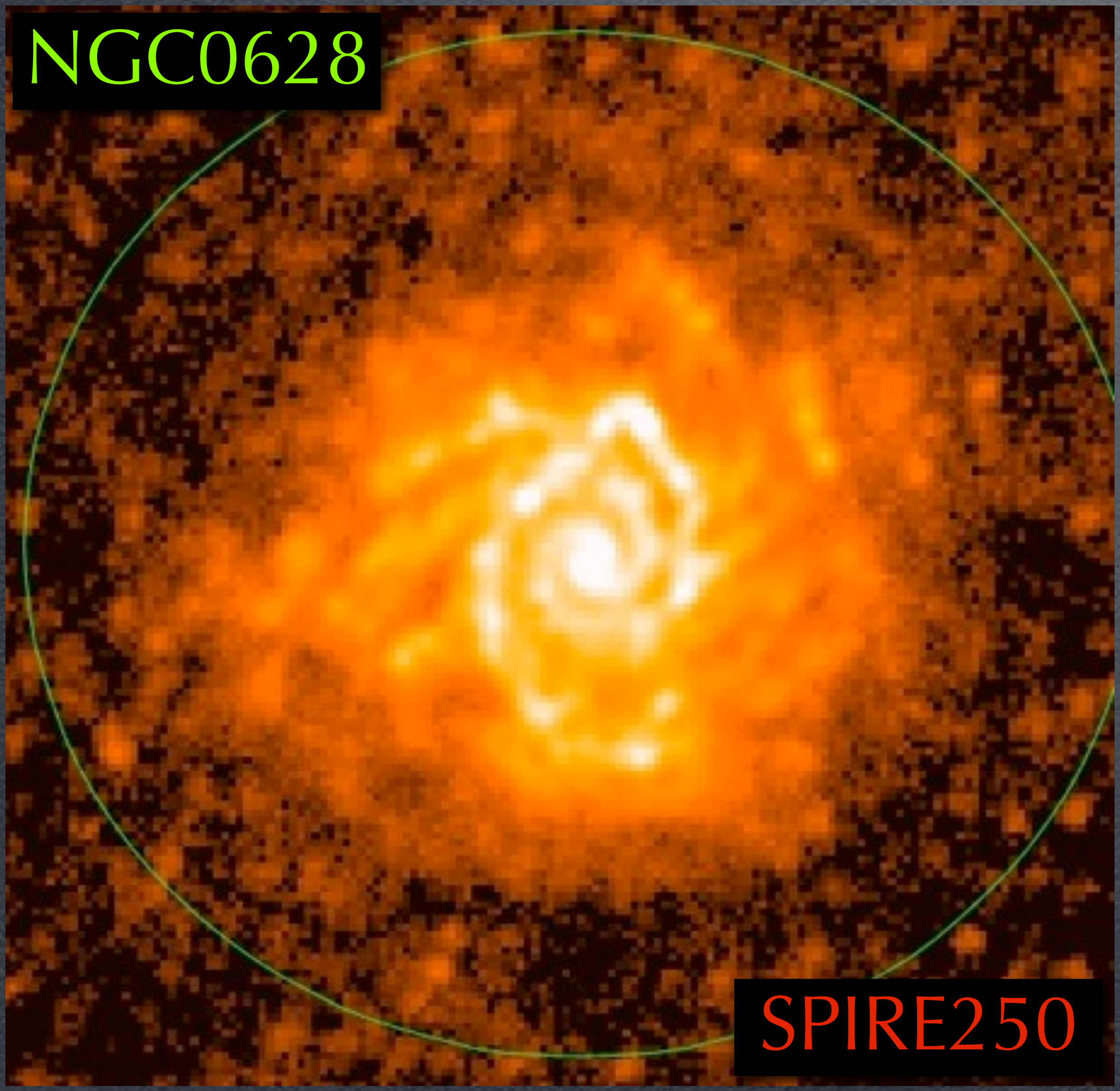
Johnson, Groves, et al. (2013)



Radius (kpc)
3.6µm
NGC0628
$\mu_{3.6}$ (AB)
Radius (″)
Radius (kpc)
3.6µm
NGC1291
Radius (″)
NGC0628
total
disk
bulge
max.
U
T_{dust}
Radius (″)
NGC1291
total
disk
bulge
max.
U
T_{dust}
Radius (″)


Radius (kpc)
3.6μm
NGC0628
$\mu_{3.6}$ (AB)
Radius (″)
Radius (kpc)
3.6μm
NGC1291
NGC0628
total
disk
bulge
max.
U
T_{dust}
SPIRE250
SPIRE350
Radius (″)
NGC1291
total
disk
bulge
max.
U
T_{dust}
Radius (″)

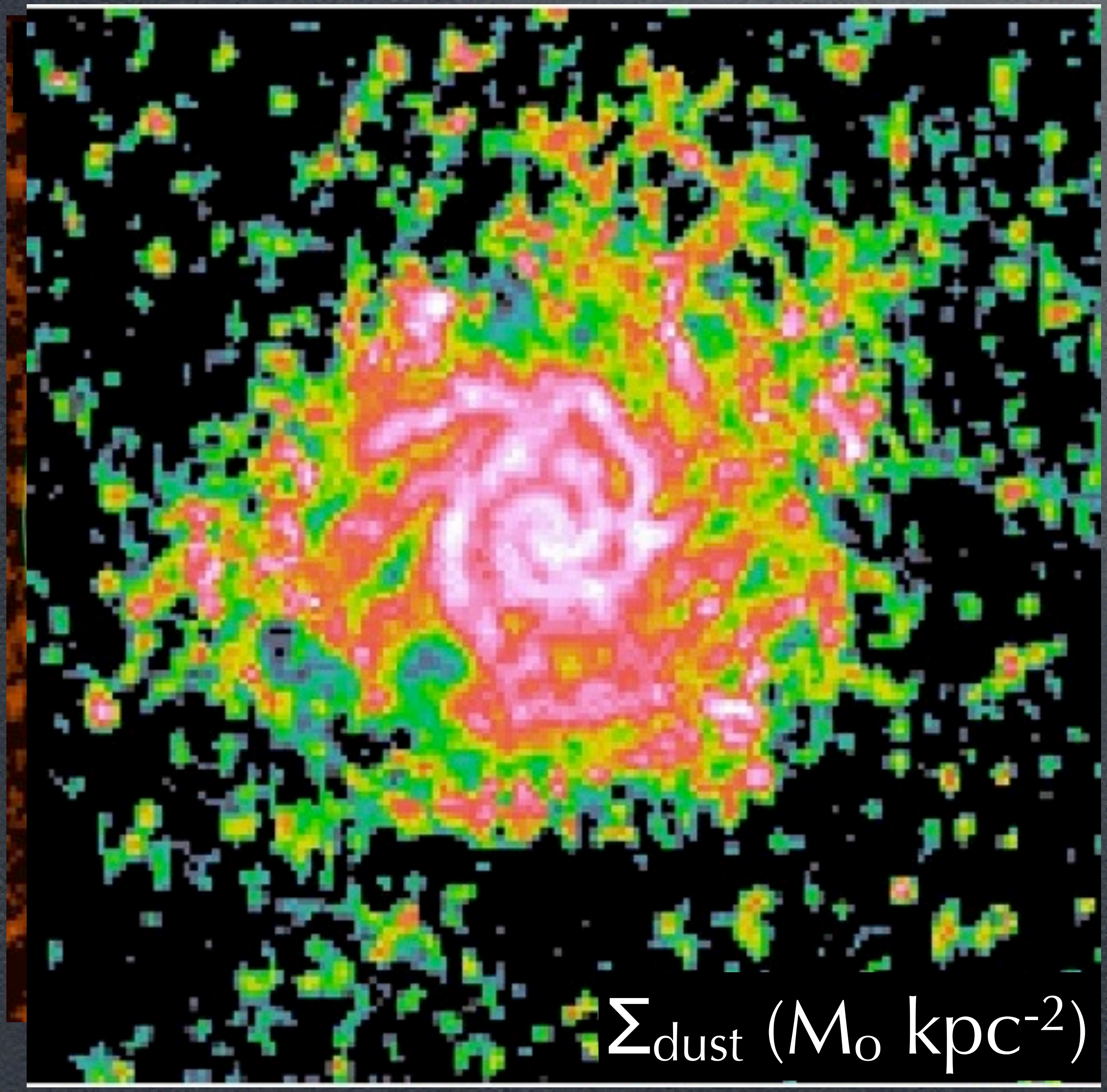
Maps of Dust



Aniano et al. (2012)

Draine & Li (2007) models

Maps of Dust



Aniano et al. (2012)

Draine & Li (2007) models

Convert shift along reddening vector to E(B-V)