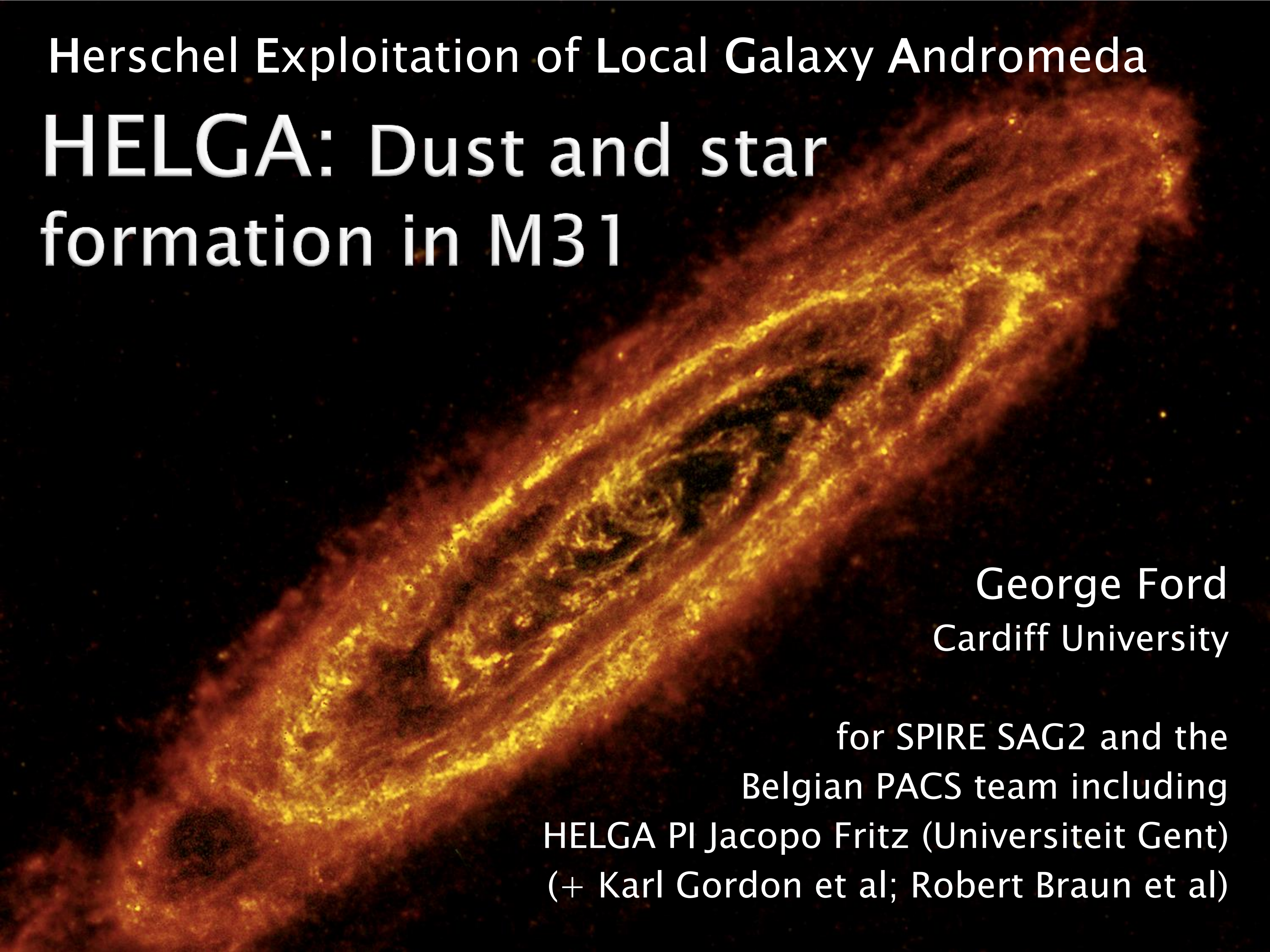
Herschel Exploitation of Local Galaxy Andromeda

HELGA: Dust and star formation in M31

George Ford
Cardiff University

for SPIRE SAG2 and the
Belgian PACS team including
HELGA PI Jacopo Fritz (Universiteit Gent)
(+ Karl Gordon et al; Robert Braun et al)

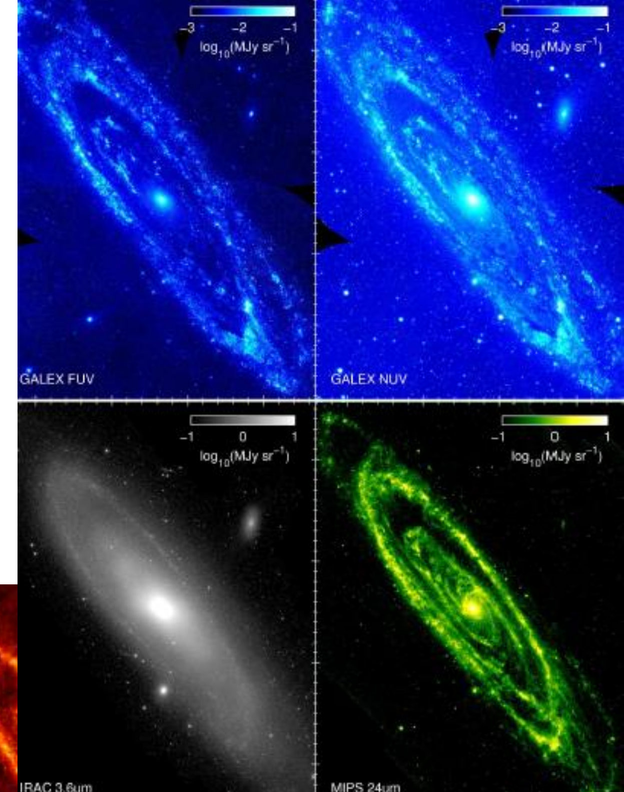


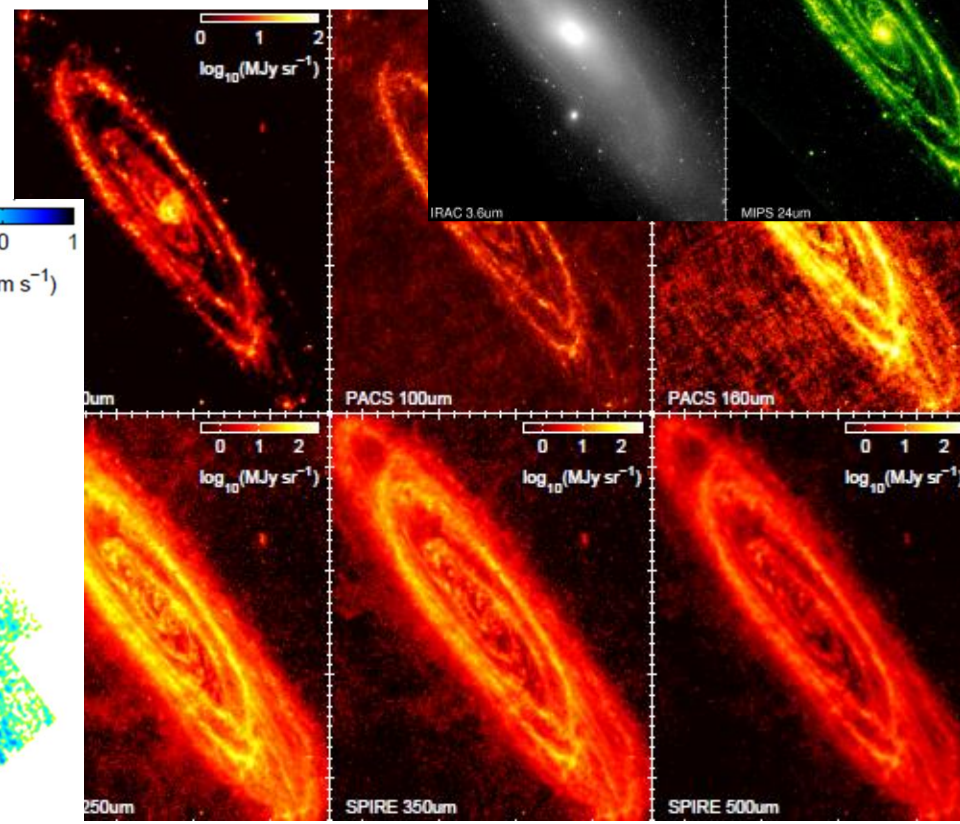
Why choose Andromeda?

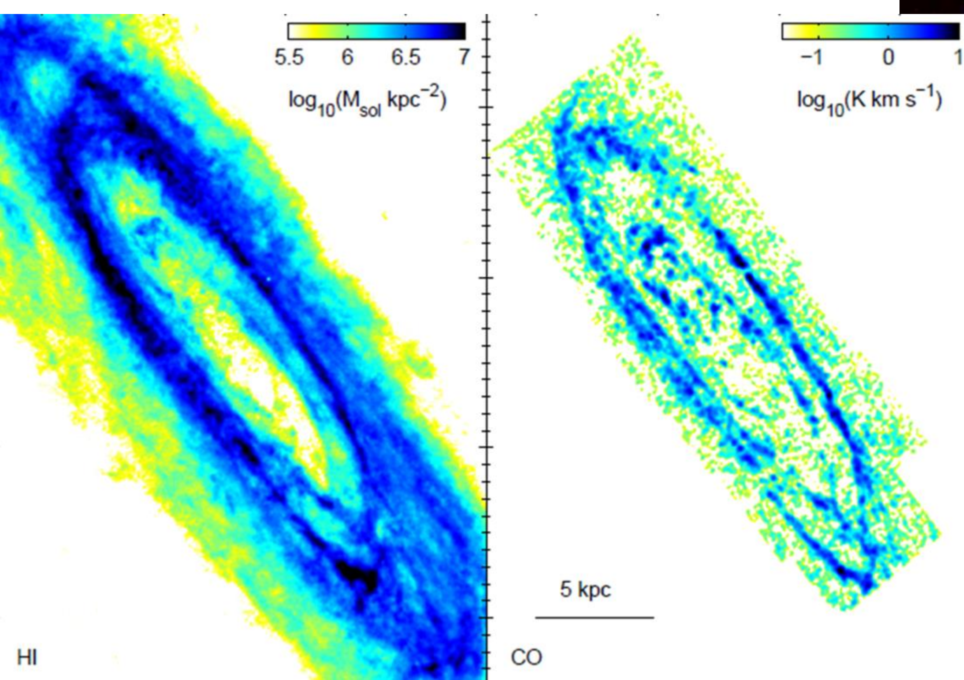
- It is large and close by, allowing us to resolve small scale features.
- Similar to the Milky Way.

A panchromatic view

- We can now study all components of M31 at high resolution:
  - Young and old stars, etc.
  - Molecular and atomic gas
  - Dust

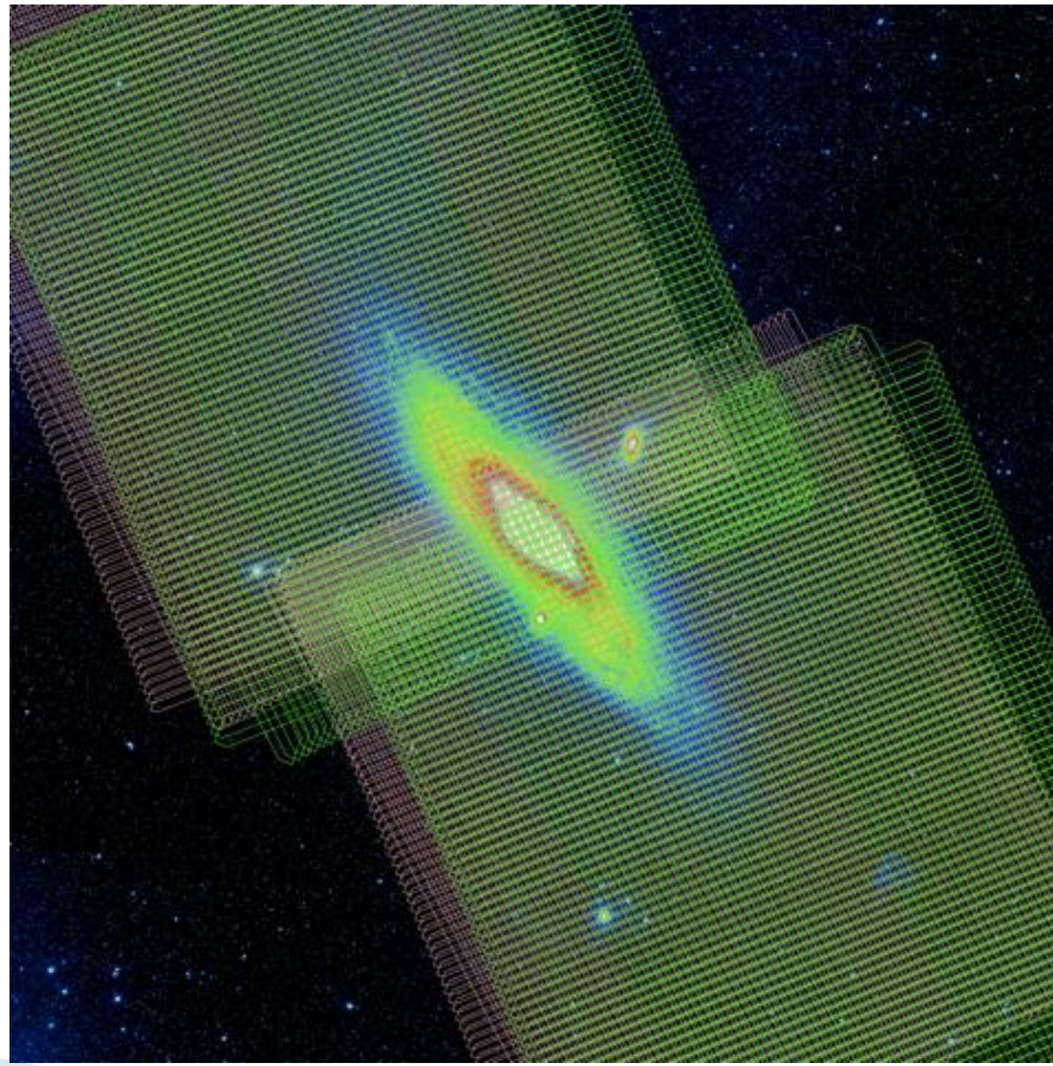




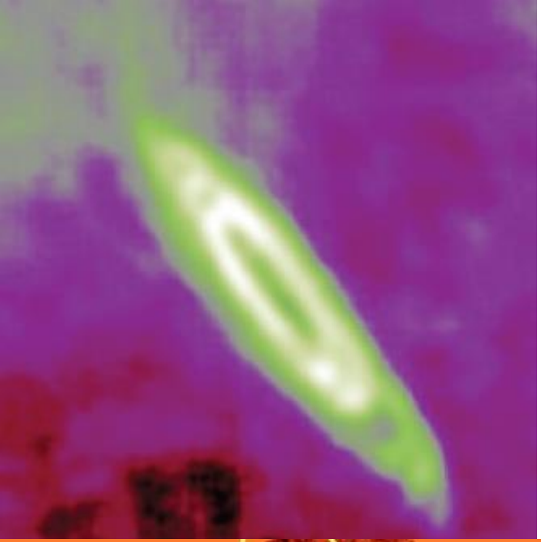


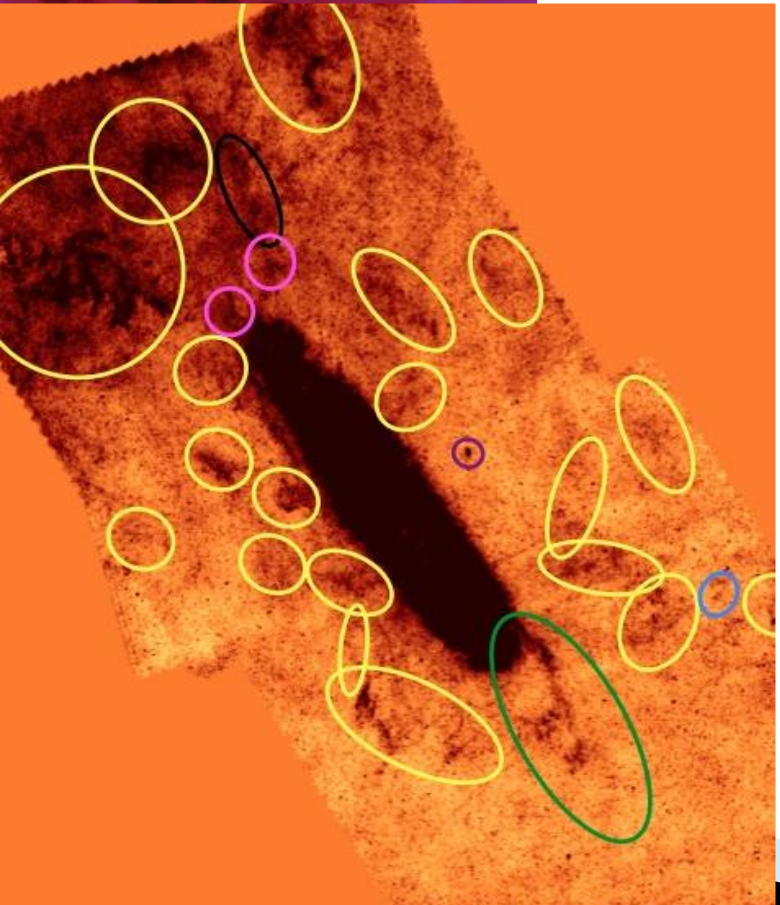
Observations (HELGA I; Fritz et al 2012)

- 18.2 hours
- 4 Scans
- 2.5x5.5 degrees
- Observed over Xmas & New year 2010/11



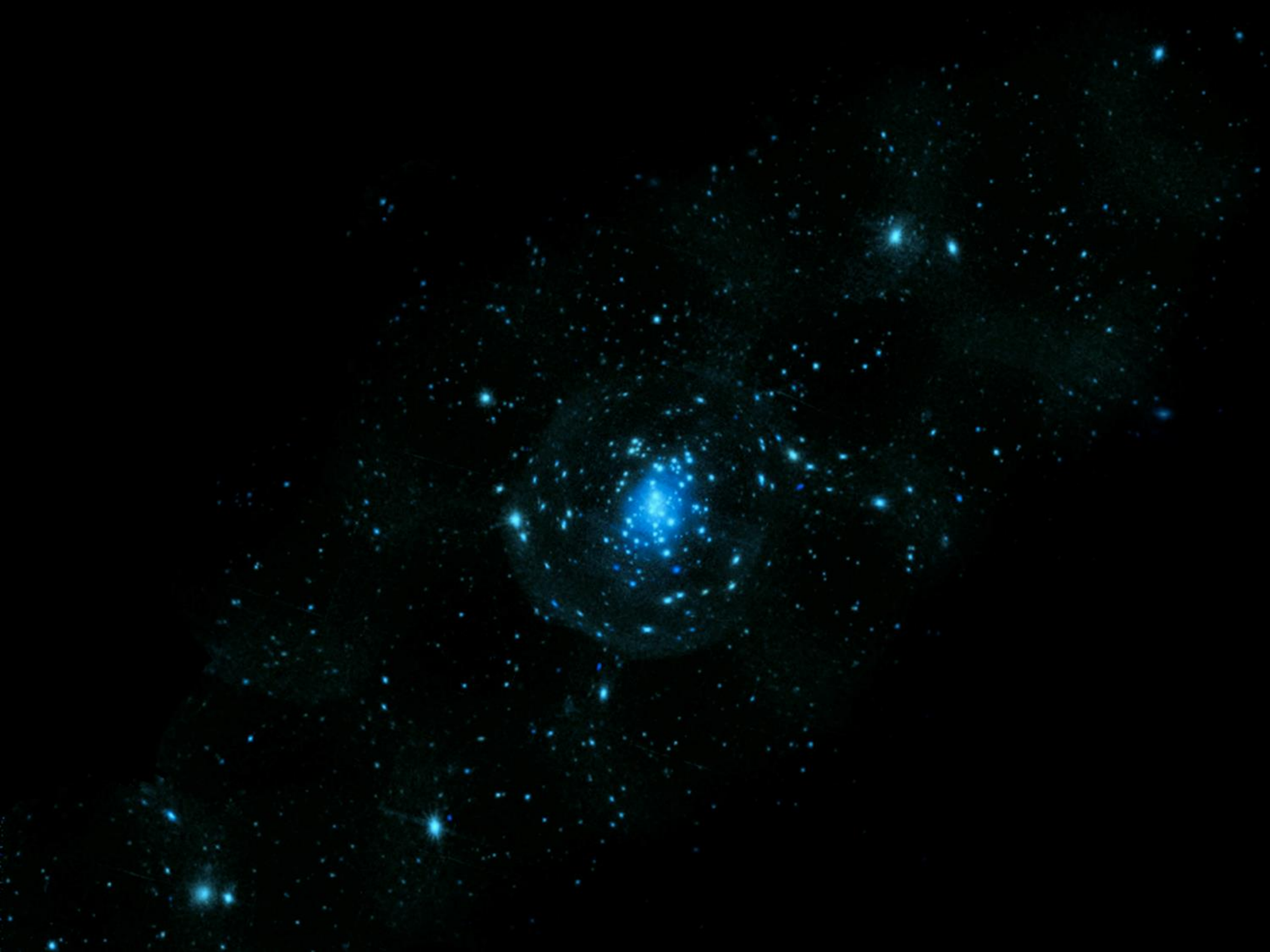
Cirrus Subtraction (HELGA I; Fritz et al 2012)





- Use HI data cubes that include Galactic velocities
- Unfortunately M31 rotation velocity ~ systemic velocity

- Yellow areas definitely milky way
- Faint ring in green circle definitely M31
- Pink & black ambiguous
- Purple = NGC205

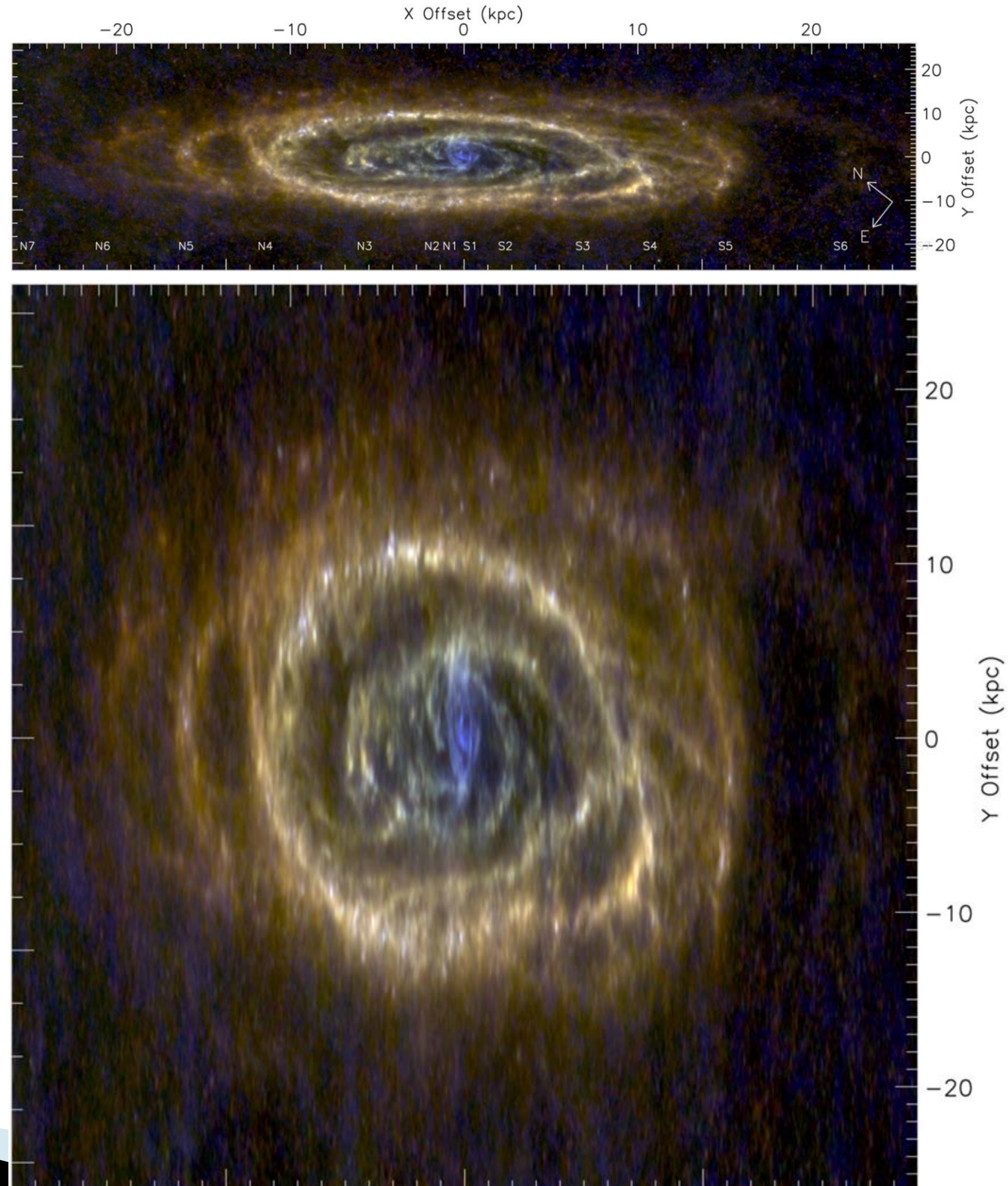


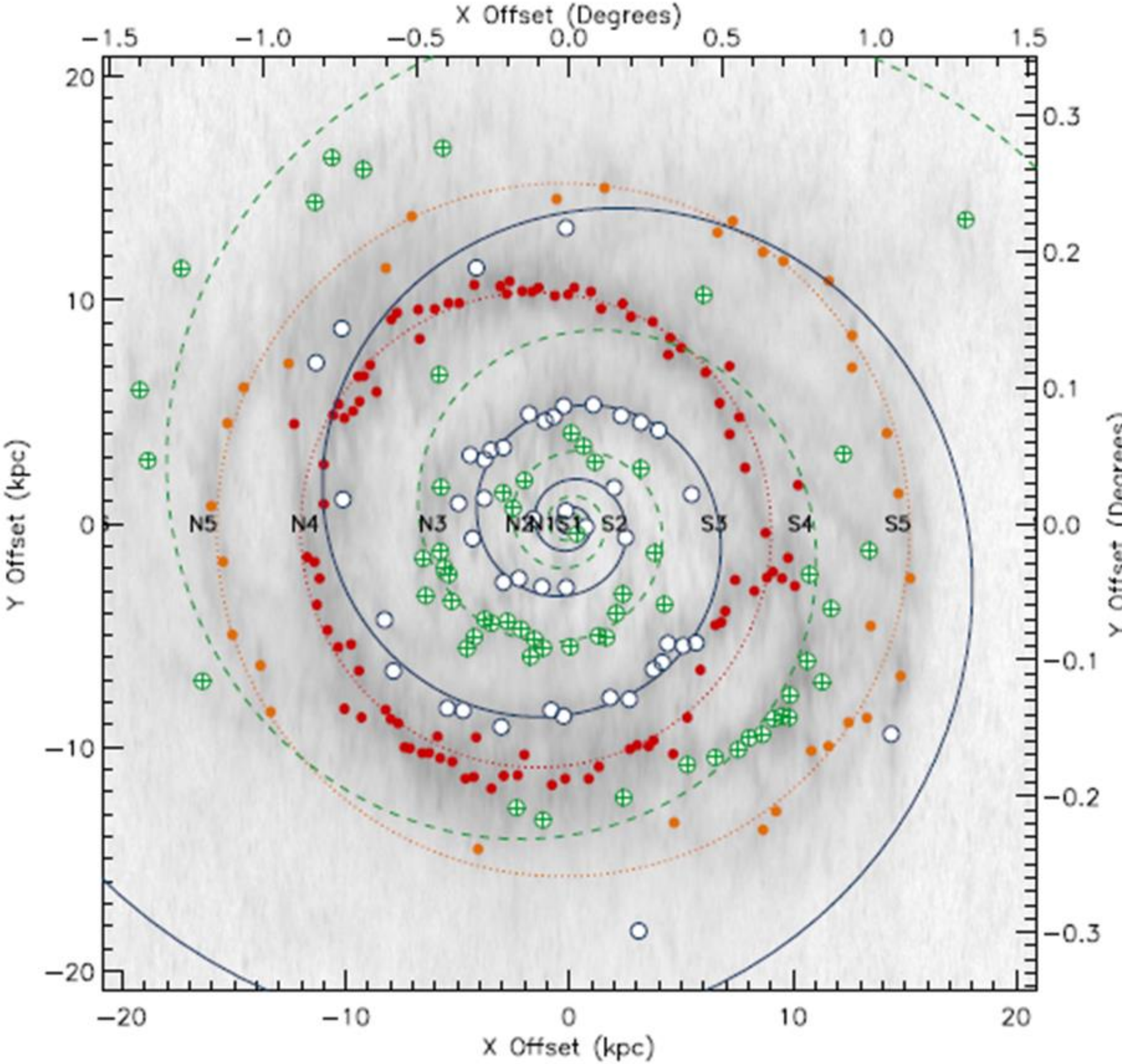
As seen on TV

HELGA IV:

(Kirk, J. M. et al 2013)

- Three colour image indicates warmer dust in the centre
- Deprojected galaxy shows evidence of a 'disturbed past.'

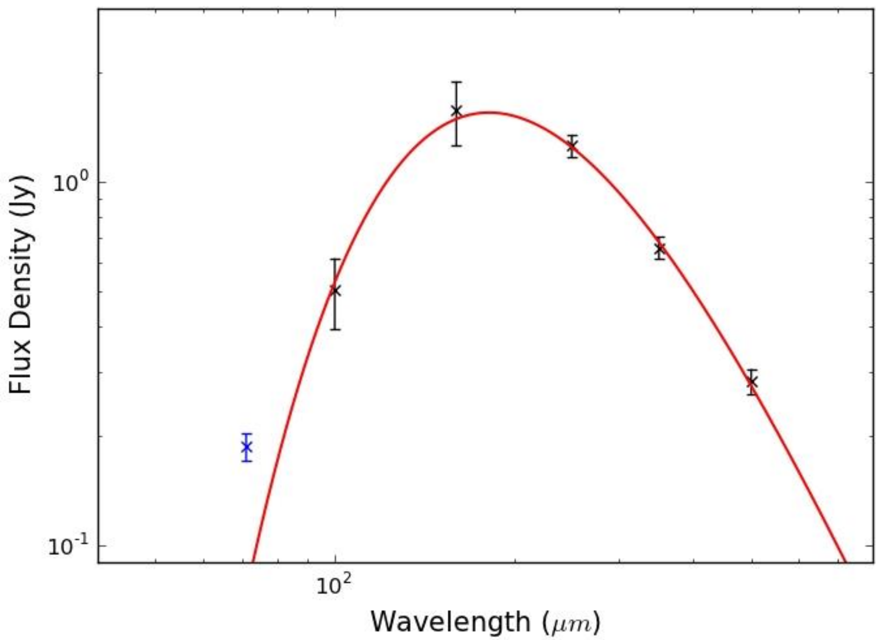


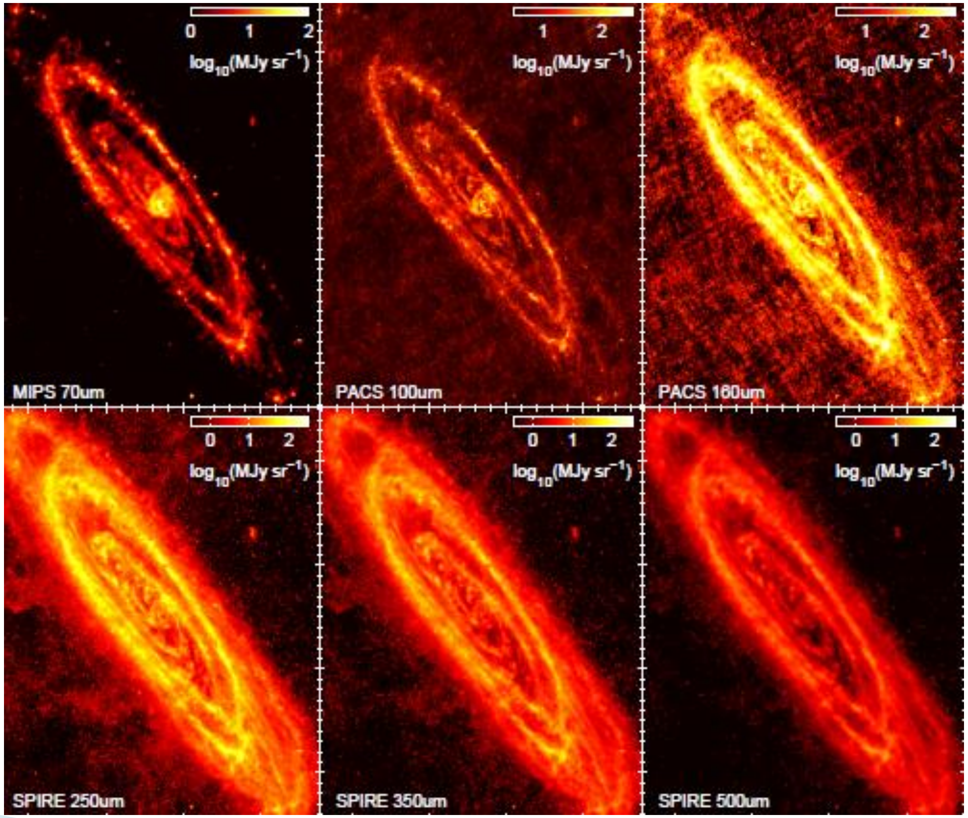


X Offset (Degrees)
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
20
10
0
−10
−20
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
Y Offset (kpc)
Y Offset (Degrees)
N5
N4
N3
N2
N1
S1
S2
S3
S4
S5
−20
−10
0
10
20
X Offset (kpc)

SED fits (HELGA II; Smith, M. W. L. et al 2012)

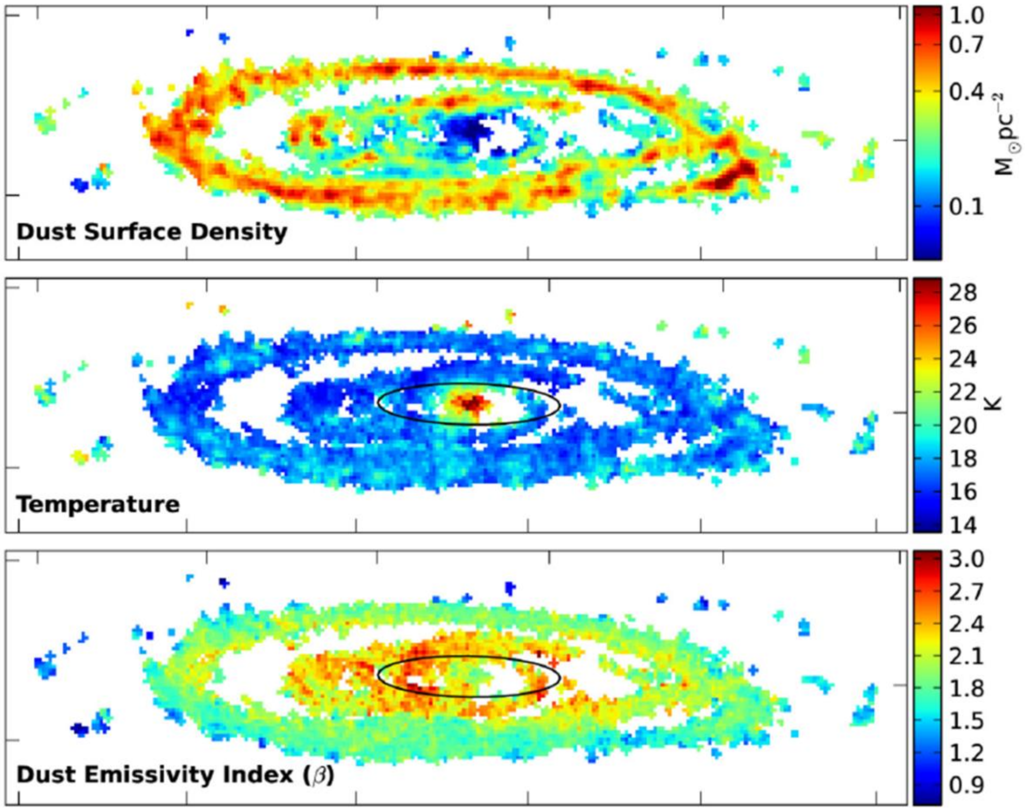
$$S_\nu = \frac{\kappa_\nu M_d B(\nu, T_d)}{D^2} \qquad \kappa_\nu \propto \nu^\beta$$





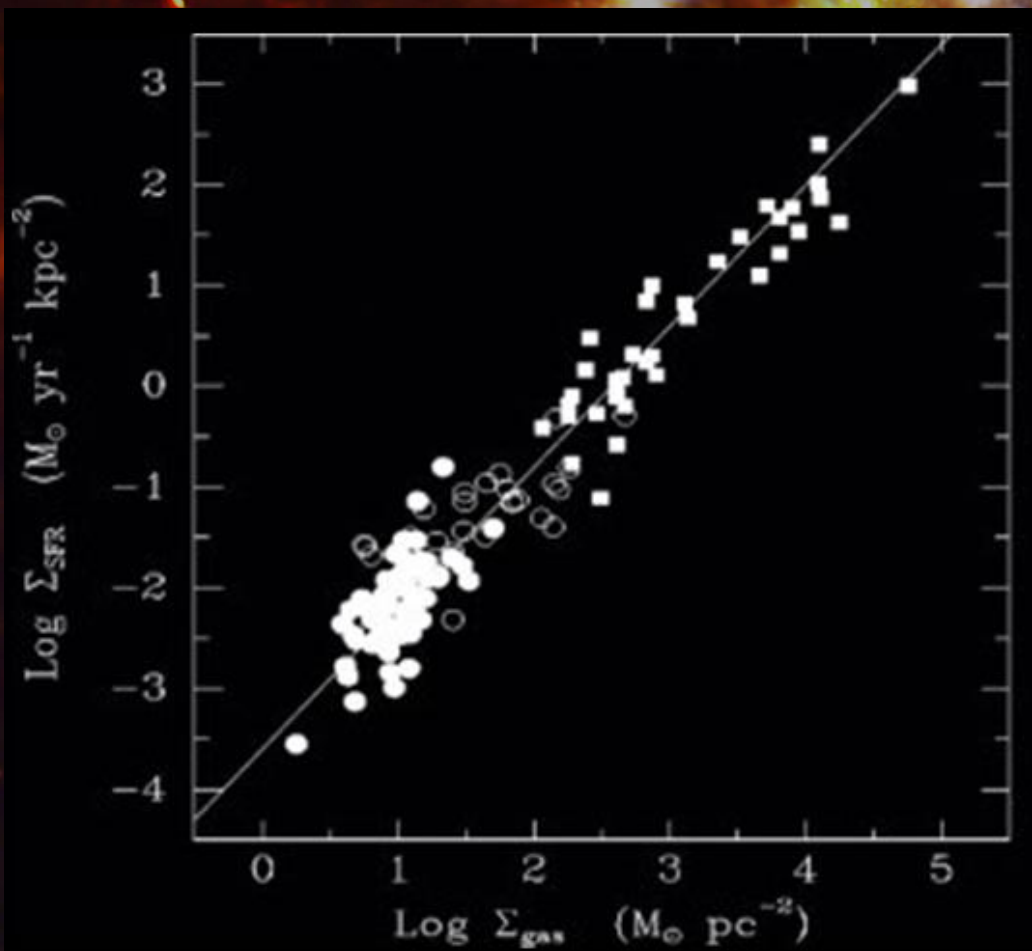
SED fits (HELGA II; Smith, M. W. L. et al 2012)

- Radial variation in gas-to-dust ratio matches that predicted from the metallicity gradient
- Heating in bulge dominated by old stars
- Dust emissivity index varies, suggests changing dust composition / size varies with radius.



HELGA III: The star formation 'law'; Ford, G. P. et al 2013

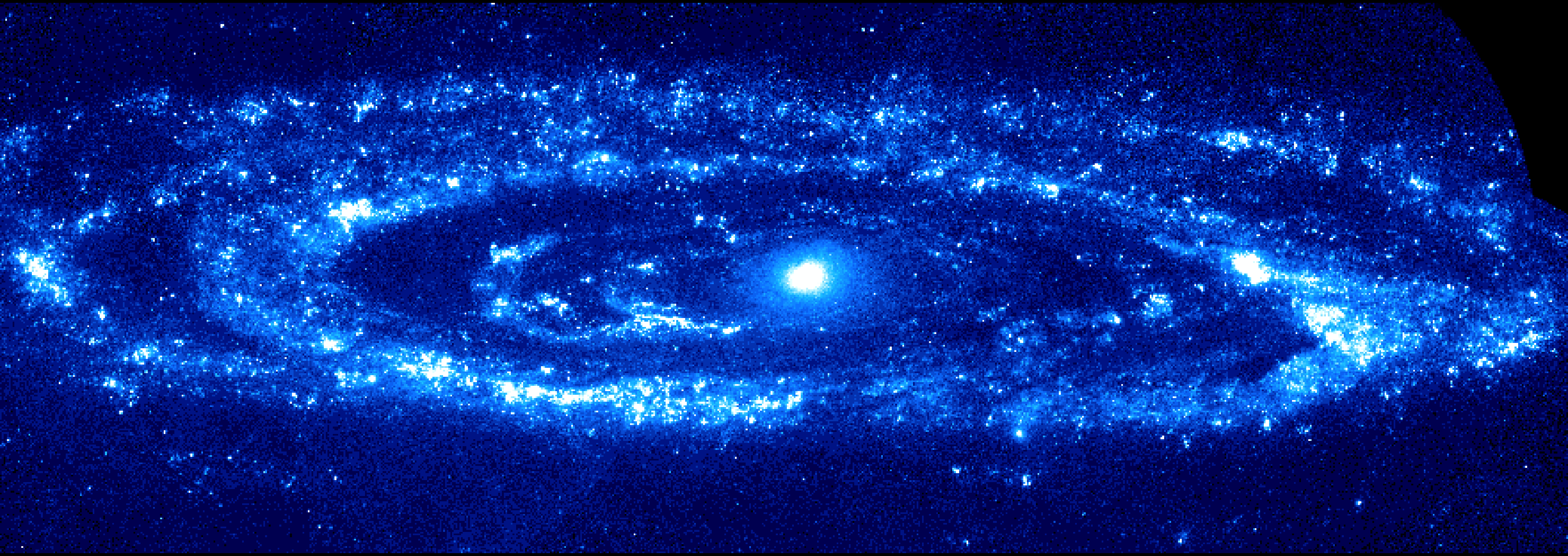
- Kennicutt, 1998 (Whole galaxies)



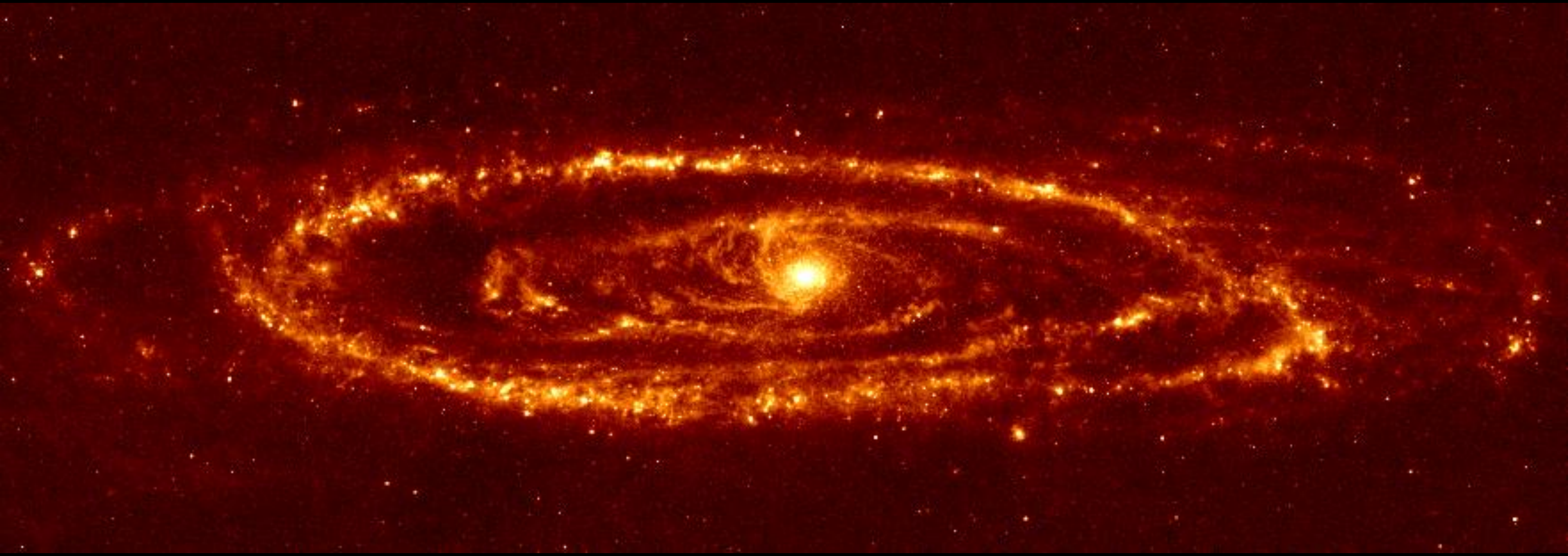
$$\Sigma_{SFR} = A\, \Sigma_{gas}^{N}$$
$$N = 1.4$$

$$SFR \sim M/\tau_{ff}$$
$$\sim \rho/\rho^{-1/2}$$
$$\sim \rho^{3/2}$$

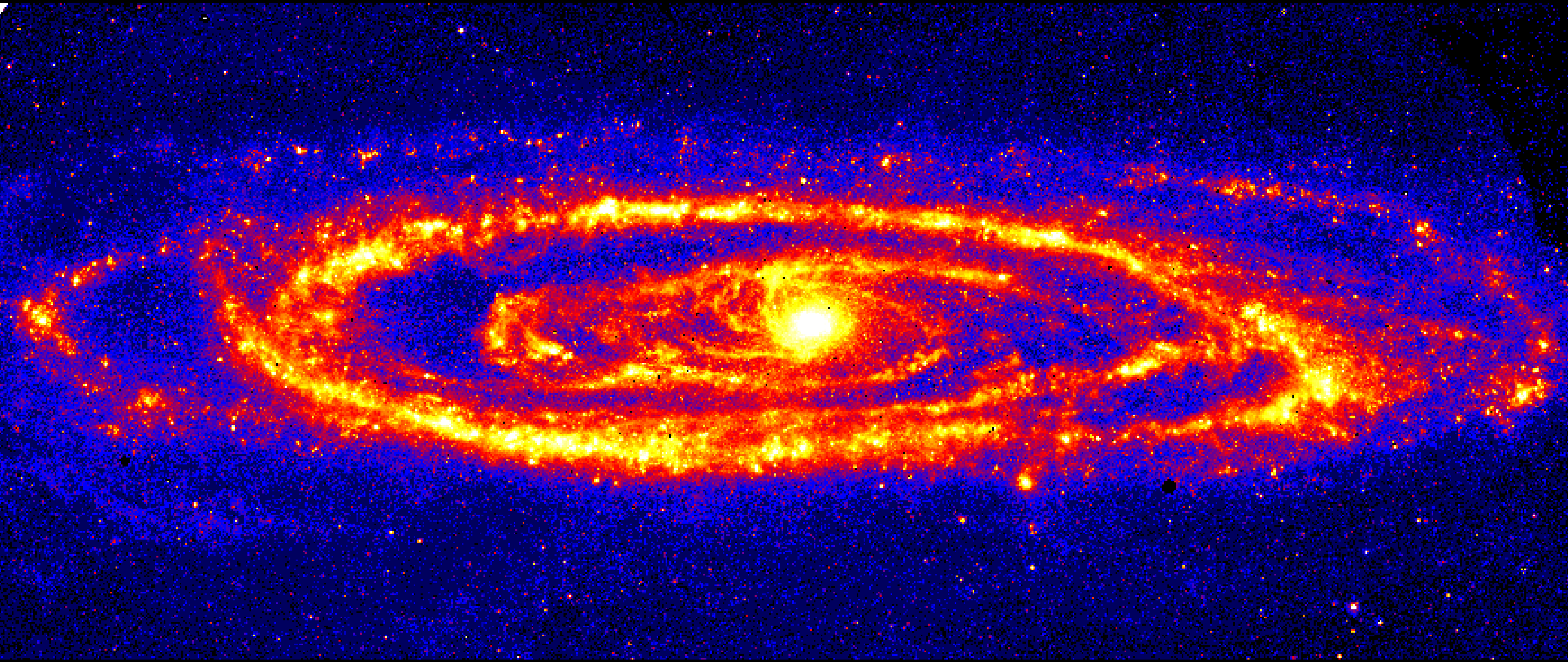
SFR tracers



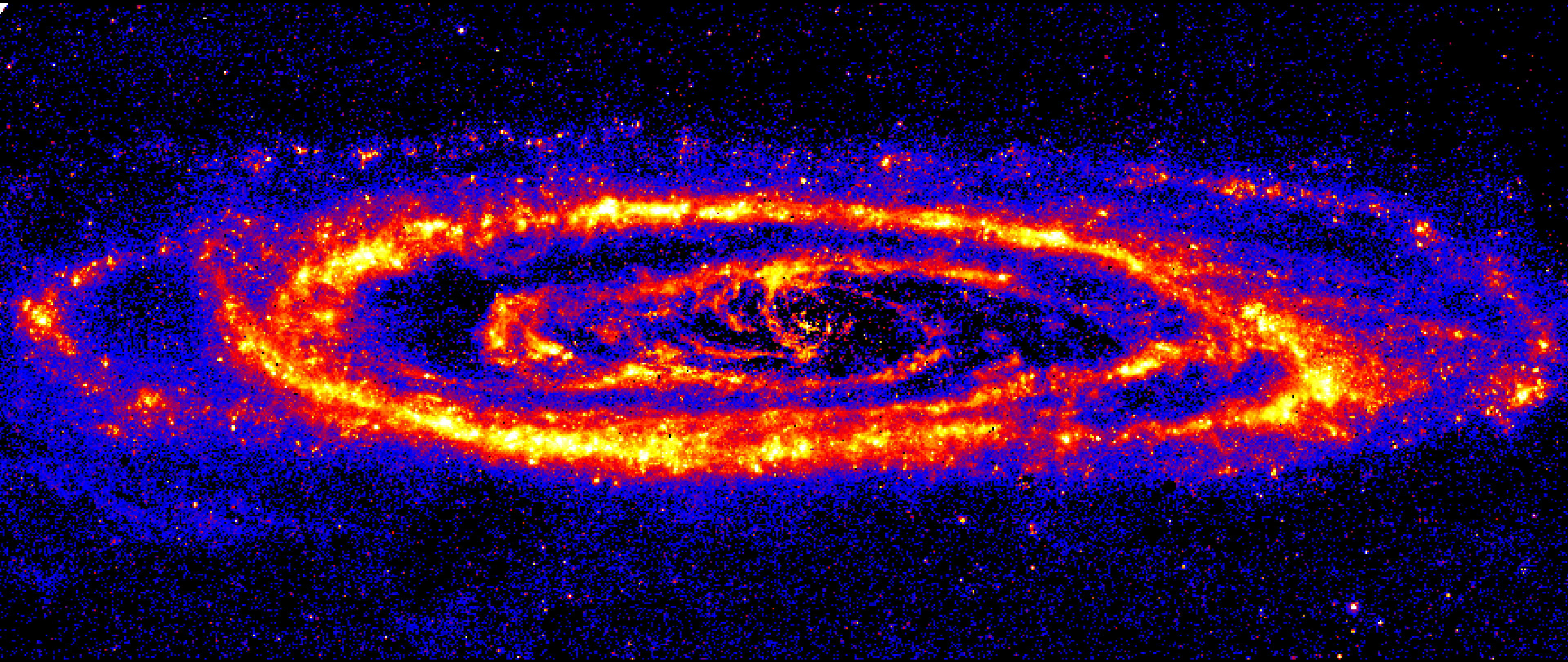
SFR tracers



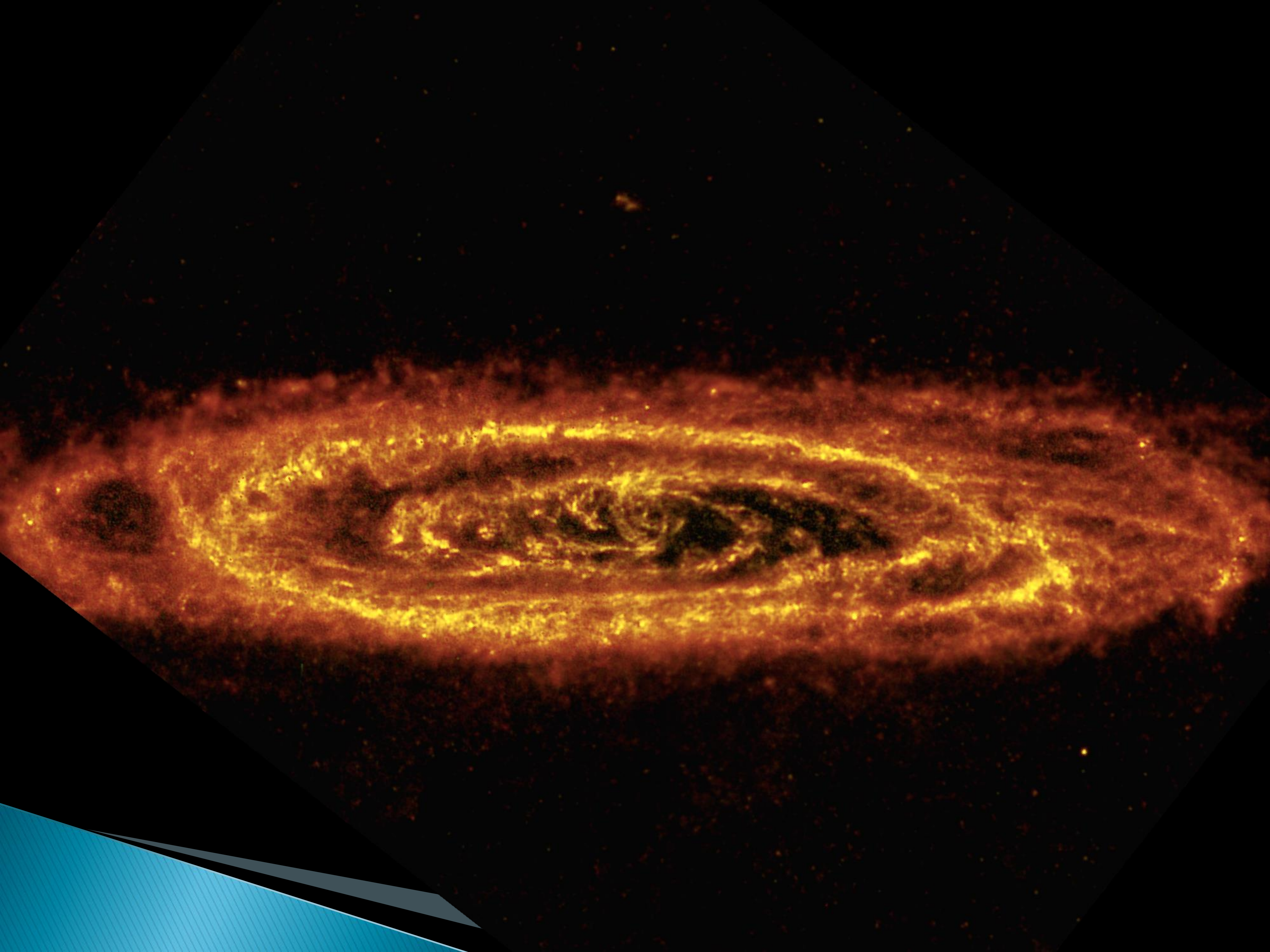
Star formation map



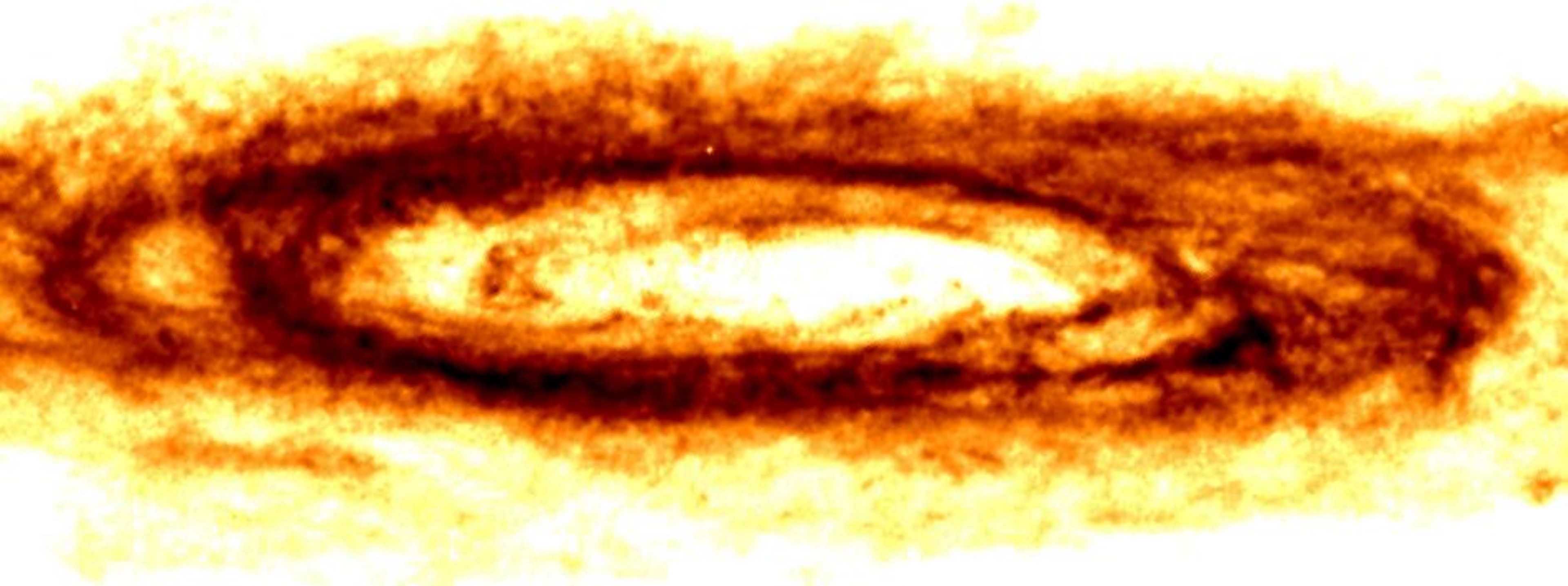
Star formation map

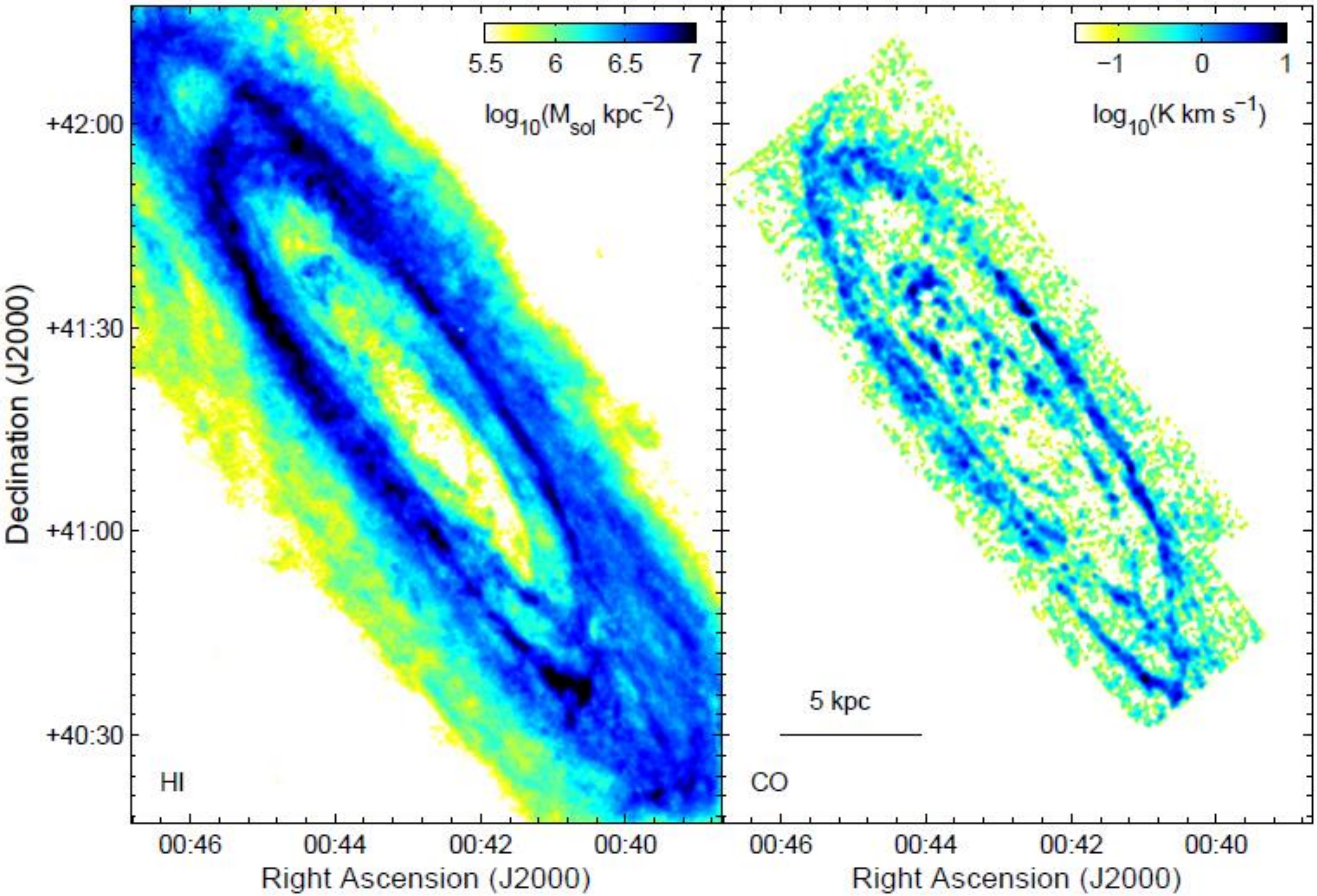


~0.25 M_{sol} / yr



Interstellar medium

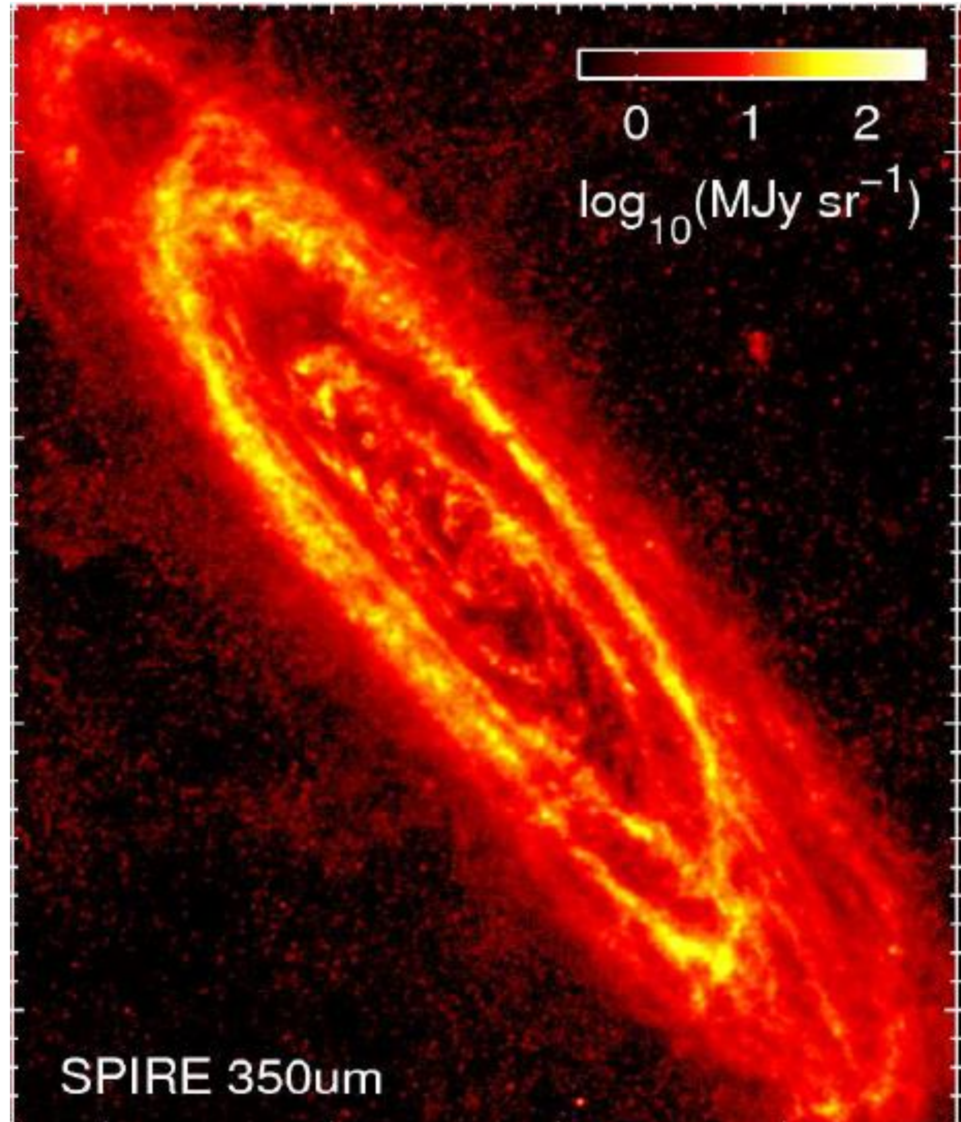


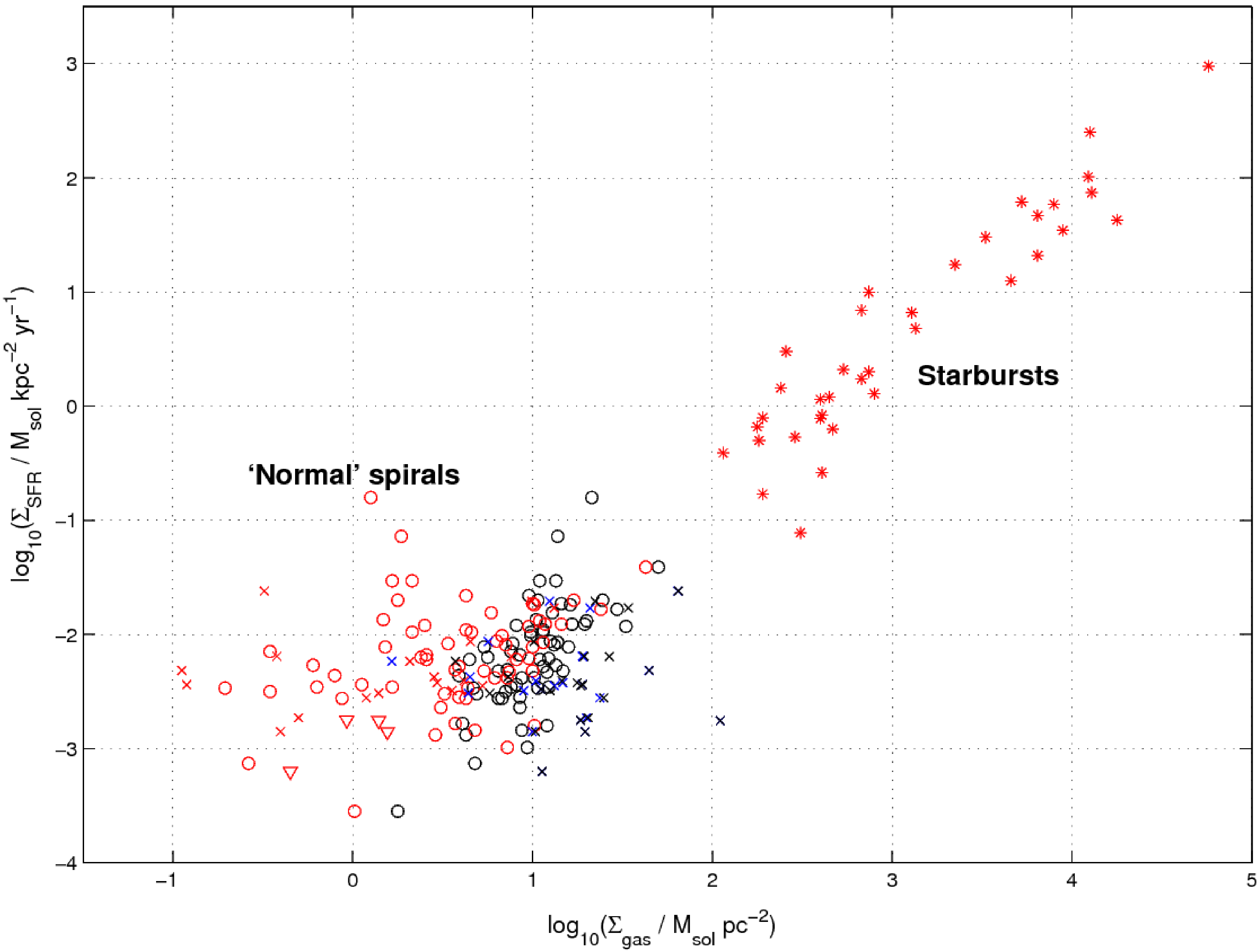


5.5
6
6.5
7
log10(Msol kpc−2)
−1
0
1
log10(K km s−1)
+42:00
+41:30
+41:00
+40:30
Declination (J2000)
HI
CO
5 kpc
00:46
00:44
00:42
00:40
Right Ascension (J2000)

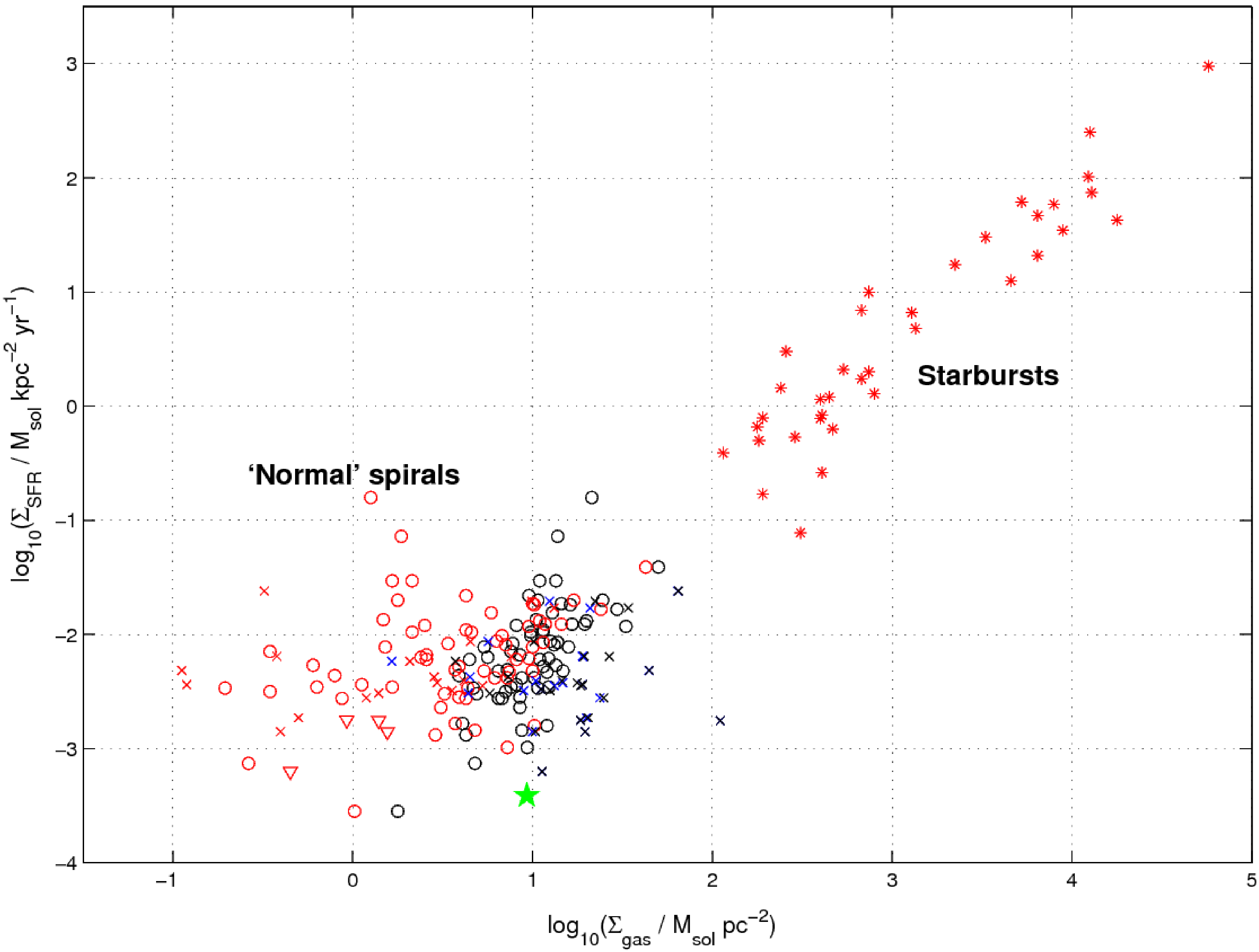
Interstellar medium: Dust

- We can also attempt to trace the total gas mass by looking at the distribution of dust (Eales, S. A. et al. 2012).
- Dust mass taken from Smith, M. W. L. et al. (2012)

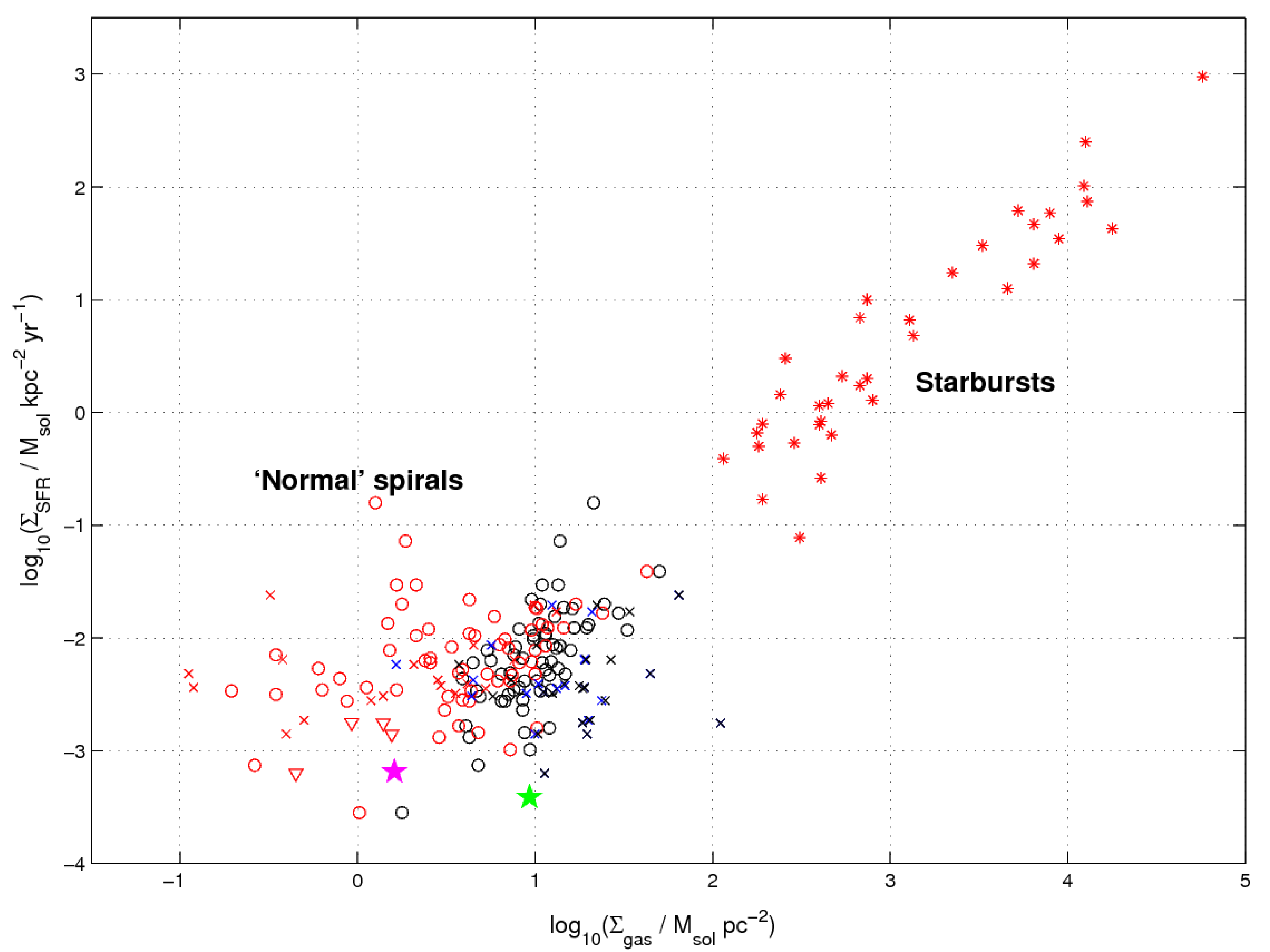




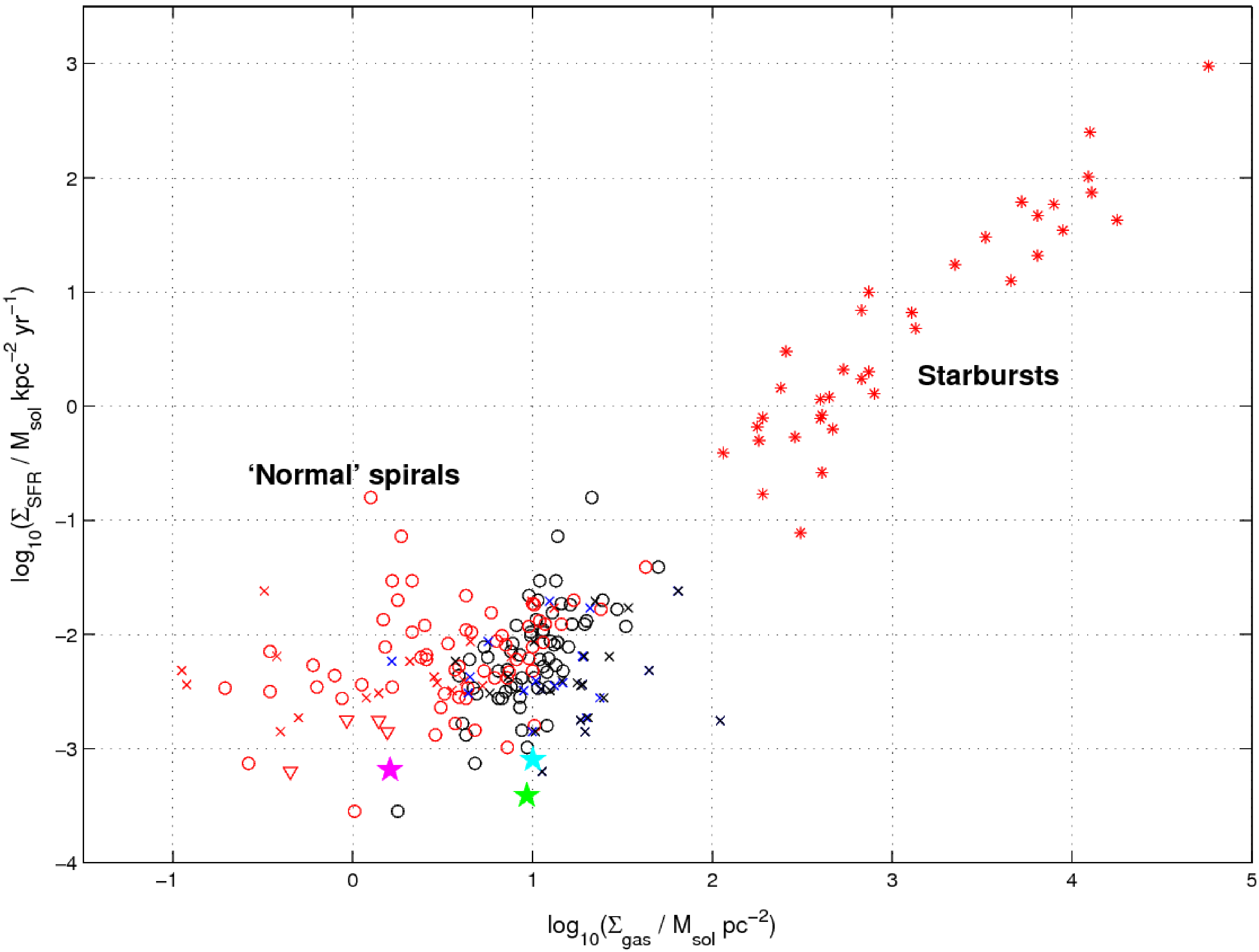
'Normal' spirals
Starbursts
log10(ΣSFR / Msol kpc−2 yr−1)
log10(Σgas / Msol pc−2)
3
2
1
0
−1
−2
−3
−4
−1
0
1
2
3
4
5



Starbursts
'Normal' spirals
$\log_{10}(\Sigma_{SFR} / M_{sol}\,kpc^{-2}\,yr^{-1})$
$\log_{10}(\Sigma_{gas} / M_{sol}\,pc^{-2})$
3
2
1
0
−1
−2
−3
−4
−1
0
1
2
3
4
5



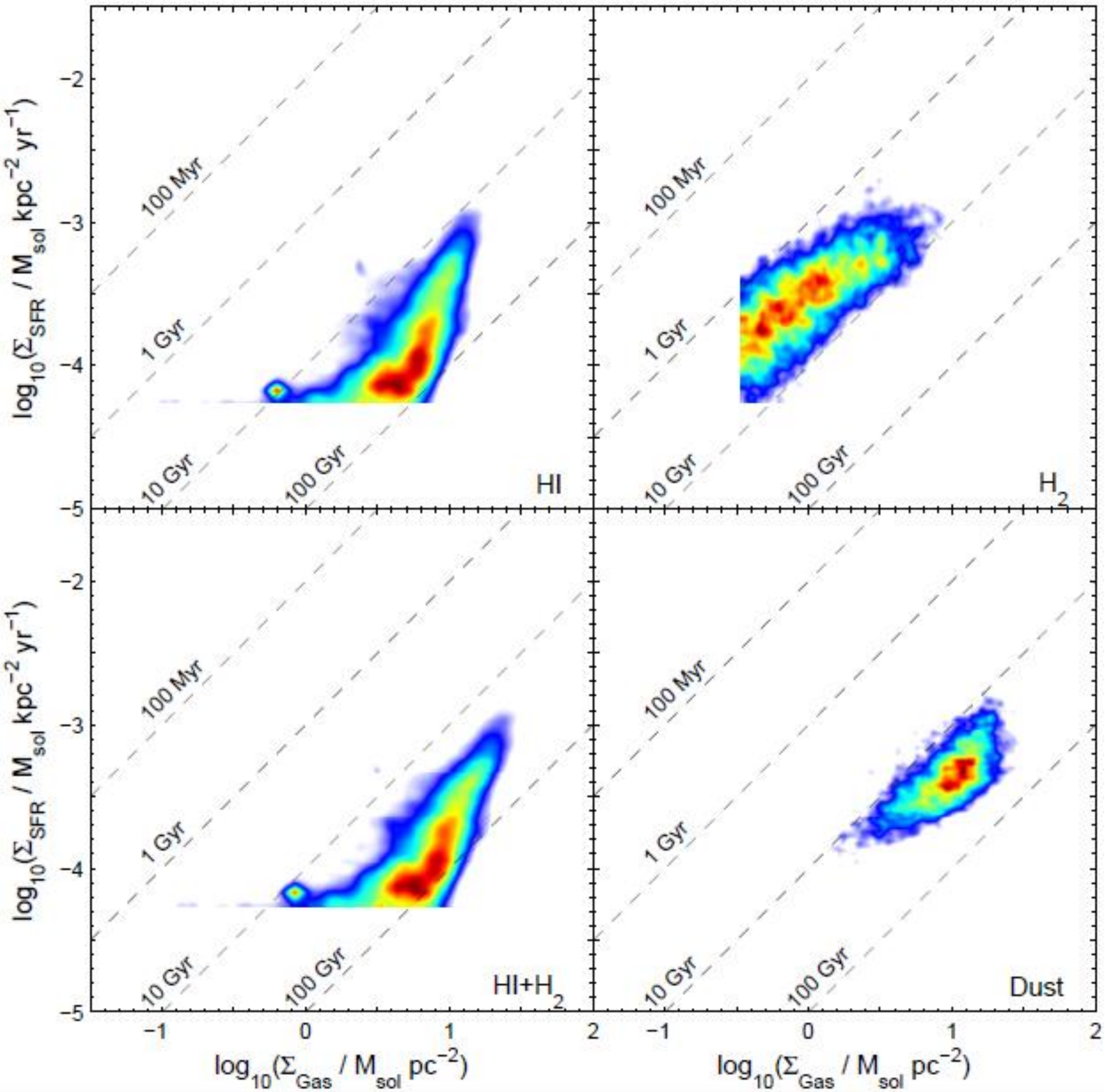
3
2
1
0
−1
−2
−3
−4
−1
0
1
2
3
4
5
Starbursts
'Normal' spirals
$\log_{10}(\Sigma_{SFR} / M_{sol}\ kpc^{-2}\ yr^{-1})$
$\log_{10}(\Sigma_{gas} / M_{sol}\ pc^{-2})$



'Normal' spirals
Starbursts
$\log_{10}(\Sigma_{SFR} / M_{sol}\,kpc^{-2}\,yr^{-1})$
$\log_{10}(\Sigma_{gas} / M_{sol}\,pc^{-2})$
3
2
1
0
−1
−2
−3
−4
−1
0
1
2
3
4
5

Resolved SF Law

- Total gas gives N~2, may be affected by saturation or HI turning molecular, but not being observed in CO.
- SF laws with molecular hydrogen and gas from dust give a consistently low index (N ~ 0.6)



Summary

- HELGA not just a pretty face
  - Key results on the dust properties and structure of our nearest neighbour
- HELGA III:
  - We measure a global SFR in Andromeda of ~$0.25 M_{sol}$/yr.
  - Both molecular gas and dust are more spatially correlated with star formation than total gas.
  - We find evidence for a sub-linear SF Law in M31 on small scales.

Thanks for listening.

HELGA I: Global dust & gas morphology
(Fritz, J. et al. 2012, A&A, 546, A34)

HELGA II: Dust and gas in M31
(Smith, M. W. L. et al. 2012, ApJ, 756, 40)

HELGA III: The star formation law in M31
(Ford, G. P.+ et al 2013, ApJ, 769, 55)

HELGA IV: GMC catalog & spiral structure
(Kirk, J. M. et al 2013, arXiv1306.2913)

HELGA V: Panchromatic SED fitting
(Vianne, S. et al, in prep.)

Comparison of SFR tracers

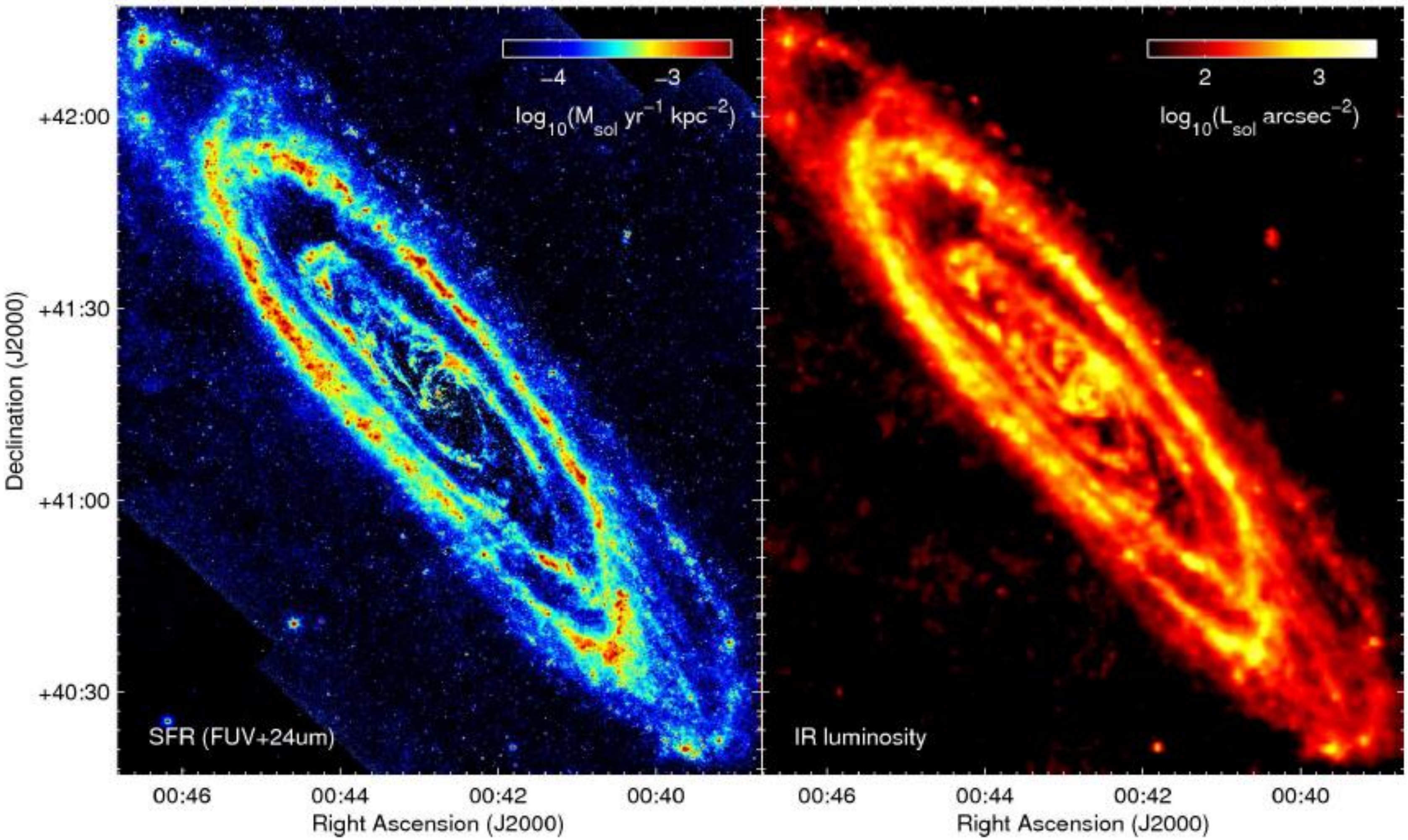


Figure 1.6 Left, star formation rate map obtained using the FUV and 24 μm emission (FWHM beamwidth = 6″, pixel size = 1.5″); right, total FIR luminosity at $\lambda > 70\,\mu m$ (FWHM beamwidth and pixel size = 36″), found by integrating the emission from *Herschel* and *Spitzer* observations shown in Figure 1.3. The SFR from infrared luminosity is found using a constant conversion factor based on the assumed IMF and assumed length of the continuous starburst.

Comparison of SFR tracers

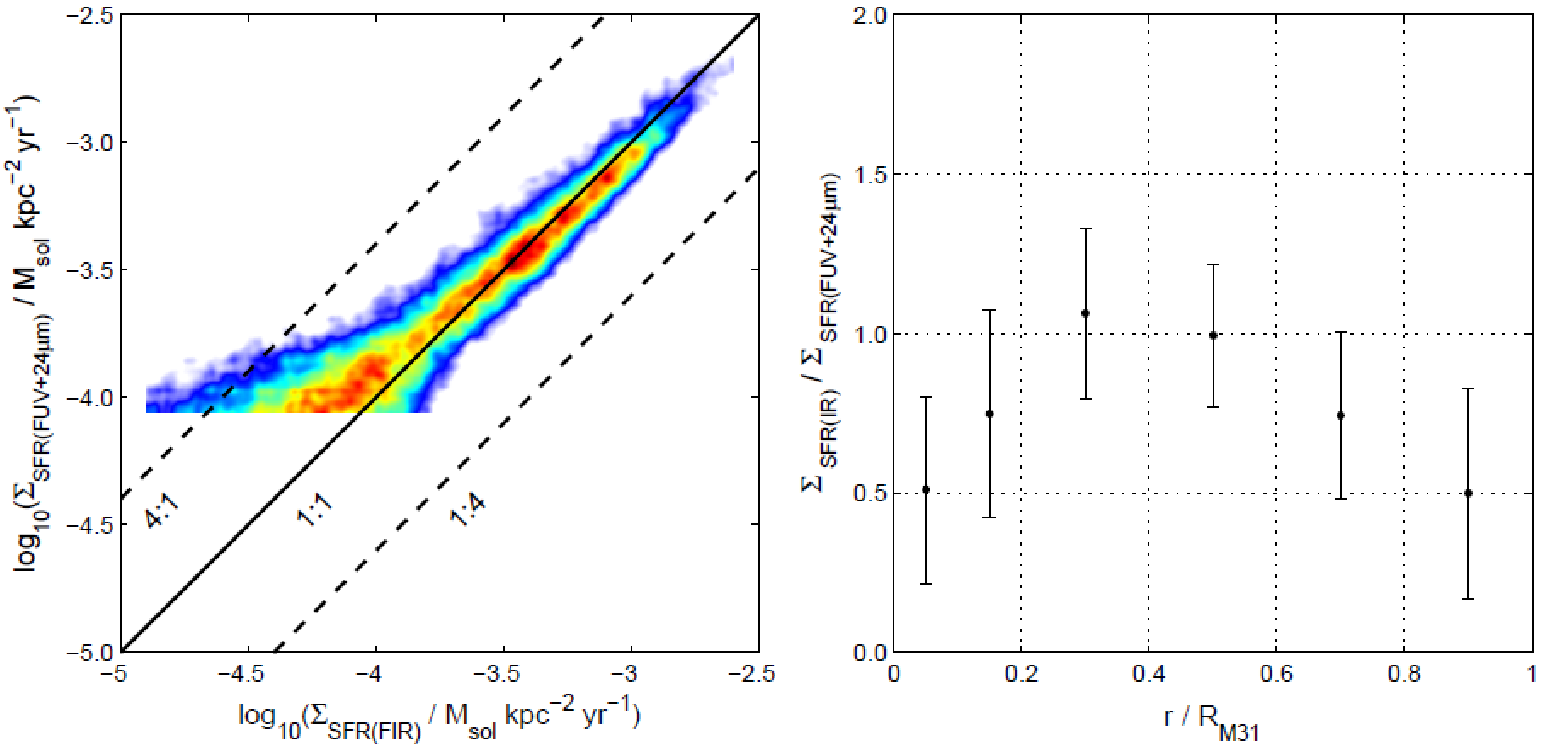


Figure 1.7 Left: $\Sigma_{\rm SFR}$ (star formation rate surface density) found from FIR luminosity (assuming a Salpeter IMF) vs $\Sigma_{\rm SFR}$ from FUV and 24 µm emission (scaled to match values assuming a Salpeter IMF and without a correction for the old stars). The colours represent the density of datapoints. The solid black line indicates a 1:1 relationship, the dashed black lines are factors of 4 offset. Right: ratio of $\Sigma_{\rm SFR}$ from FIR luminosity to $\Sigma_{\rm SFR}$ from FUV + 24 µm star formation surface density with radius. The errorbars represent one standard deviation of the scatter in this value across each elliptical annulus.

Correction for old stars

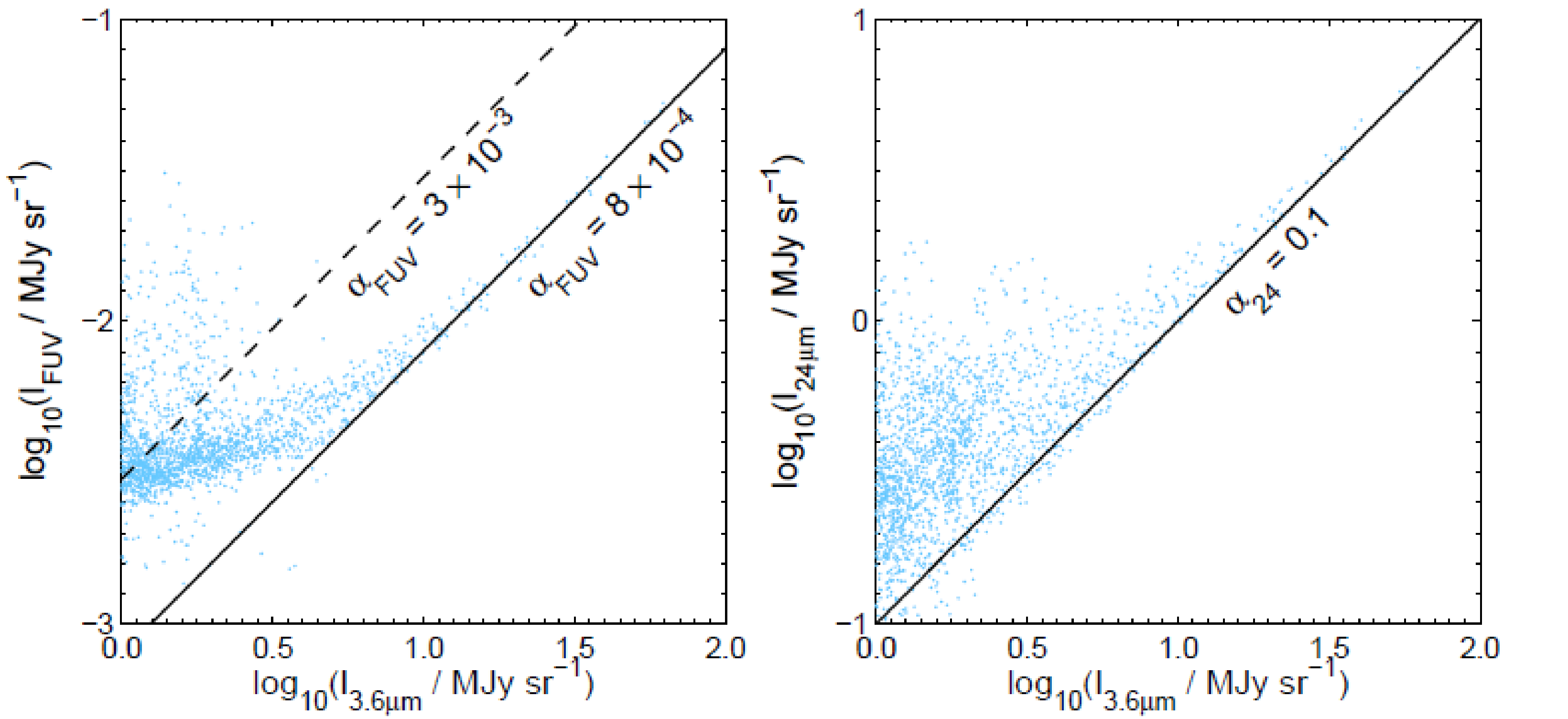


Figure 1.5 FUV (left) and 24 µm (left) vs 3.6 µm emission. The black dashed trendline in the left plot indicates the correction for the old stellar population used in Leroy et al. (2008), based on $I_{\rm FUV}/I_{3.6}$ found in ellipticals. The solid trendline is the best fit to FUV vs 3.6 µm in the inner regions of M31 ($r < 0.1R_{\rm M31}$, see Appendix). The solid trendline in the right plot is the best fit to 24 µm vs 3.6 µm in the inner regions. This agrees with the Leroy et al. (2008) value.

Gas-to-dust with radius

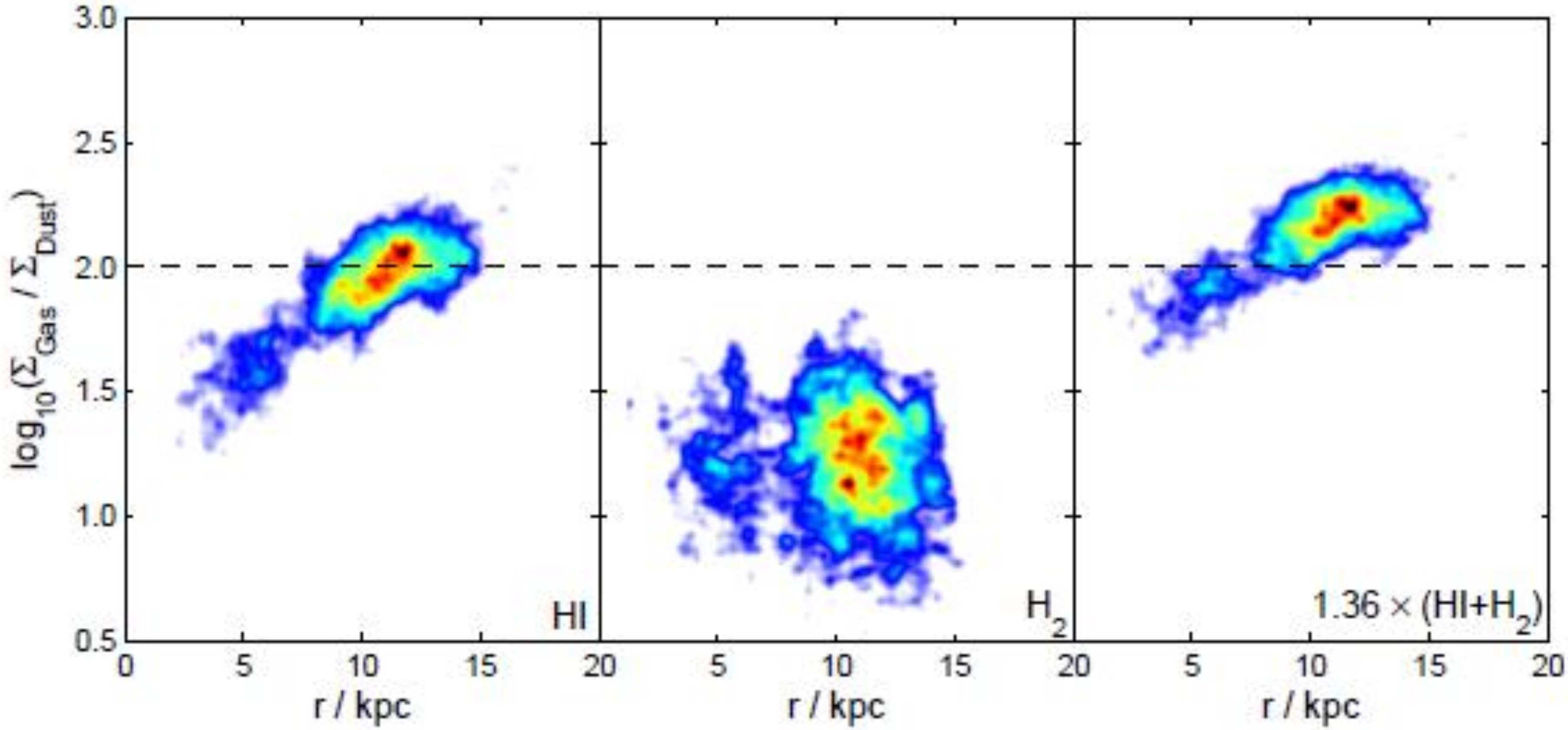
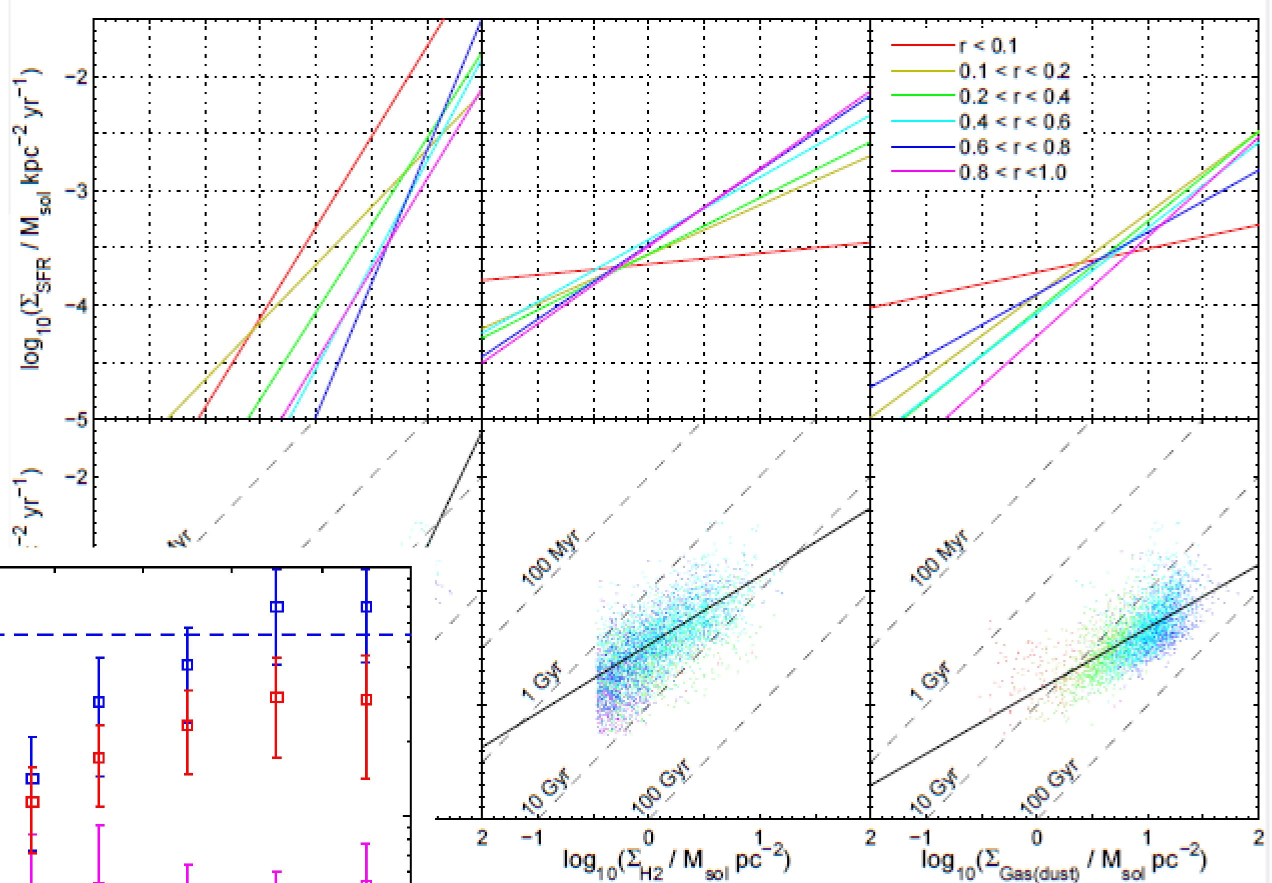


Figure 1.8 Gas to dust ratio with radius in M31 for monatomic hydrogen (HI), molecular hydrogen (H_2) and total gas (HI + H_2) with a factor of 1.36 for heavier element abundances.

Variation with radius



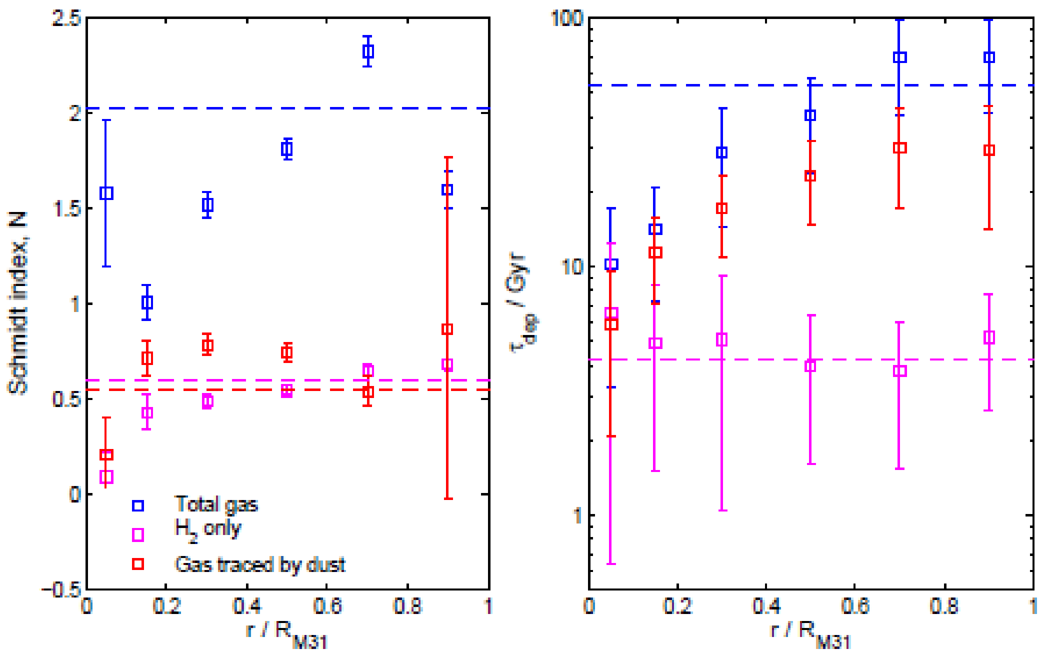


Figure 1.12 Kennicutt-Schmidt parameters with radius across M31. We compare the power law indices, N (left) and mean gas depletion time ($\tau_{\rm dep}$, right) using H I + H_2, H_2 only and total gas mass traced by dust. The dashed lines indicate the global values for M31. Errorbars represent the 2σ uncertainty in N and the standard deviation in the distribution of τ_{dep}.

Why the shallow slope?

- Recent work has suggested that the SF law is actually linear (N=1) assuming other factors remain constant.
- Still a very open question…