Measuring star formation rates in nearby dusty starburst galaxies using ALMA observations of millimeter recombination line and free-free emission

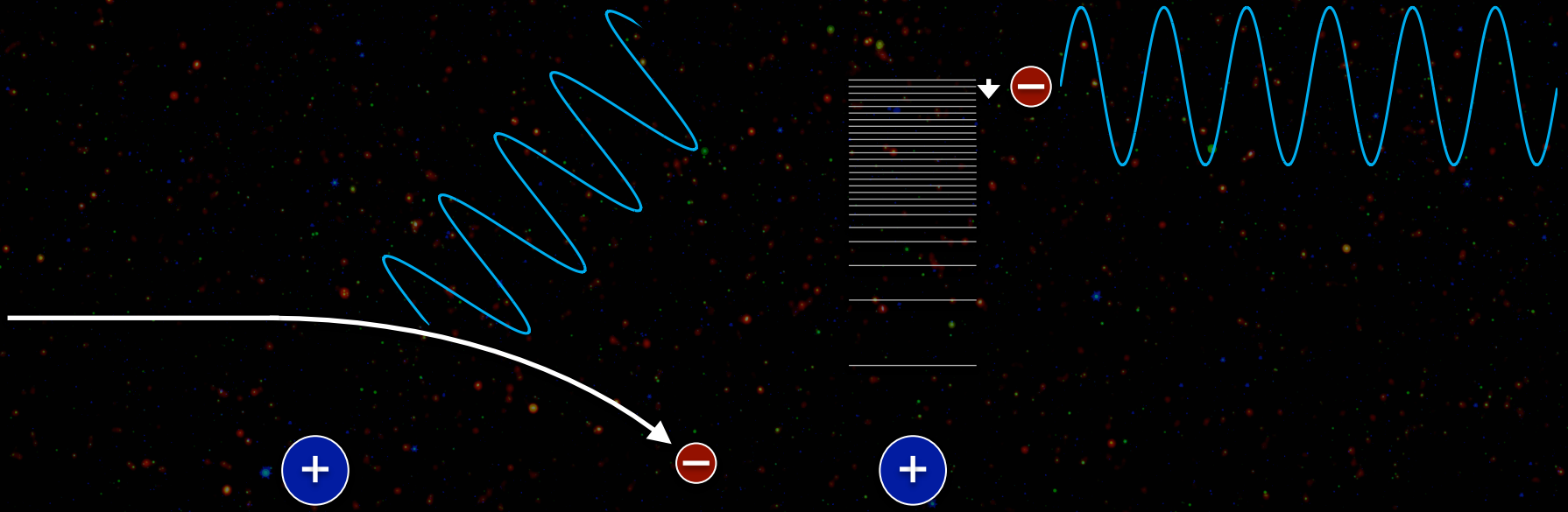
George J. Bendo
UK ALMA Regional Centre Node
Jodrell Bank Centre for Astrophysics

ALMA can detect emission from photoionized gas in two forms:

- Free-free continuum emission
- Higher order recombination line emission

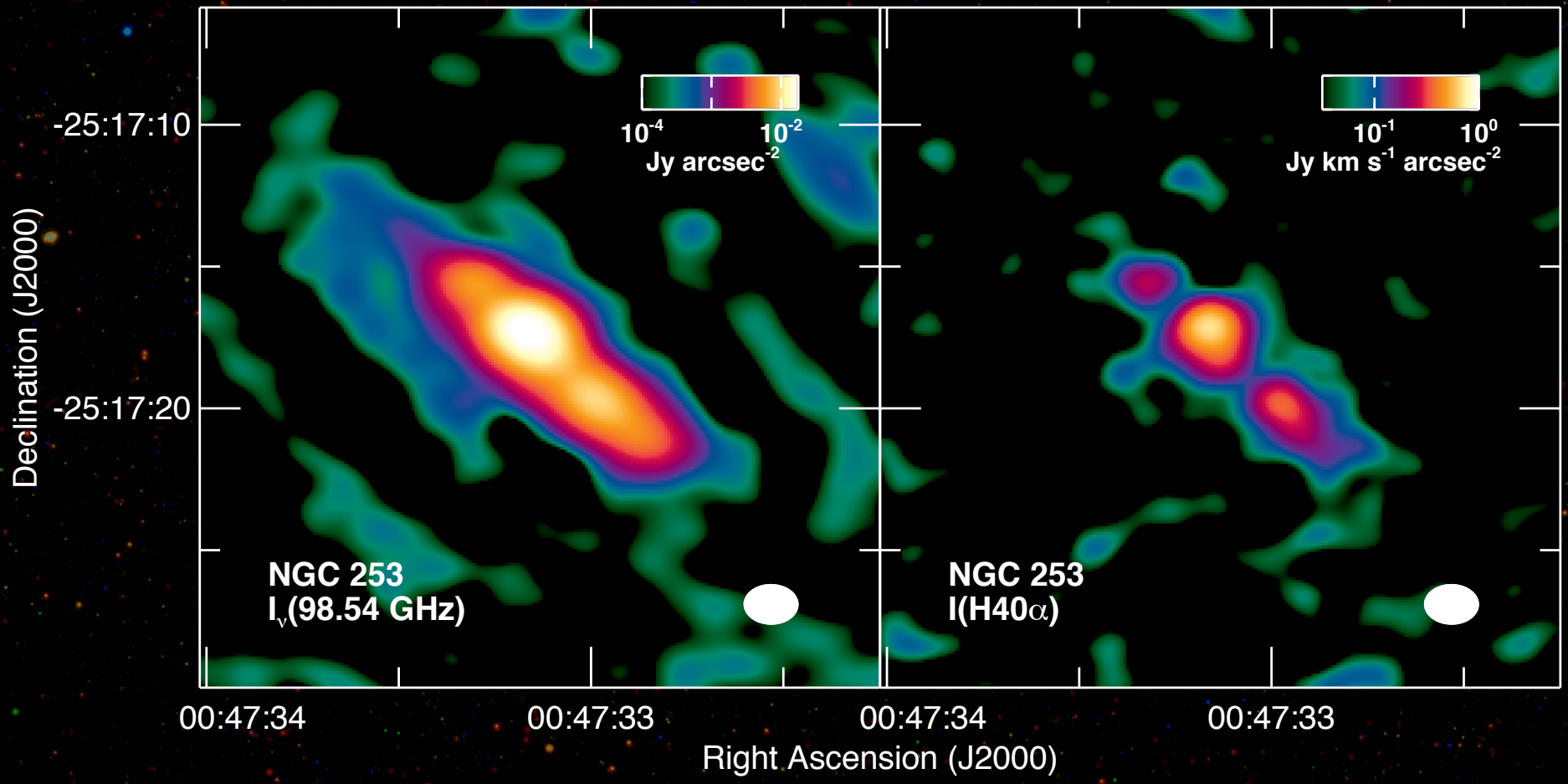
This emission has two advantages over other commonly-used star formation tracers:

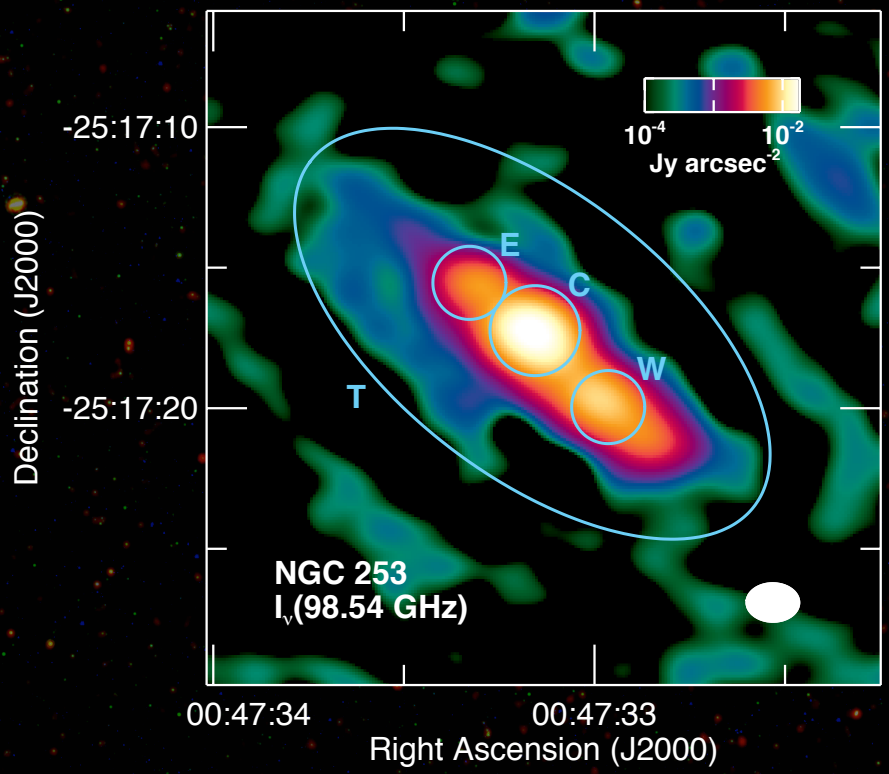
- It directly traces young, photoionizing stars.
- It is unaffected by dust attenuation.

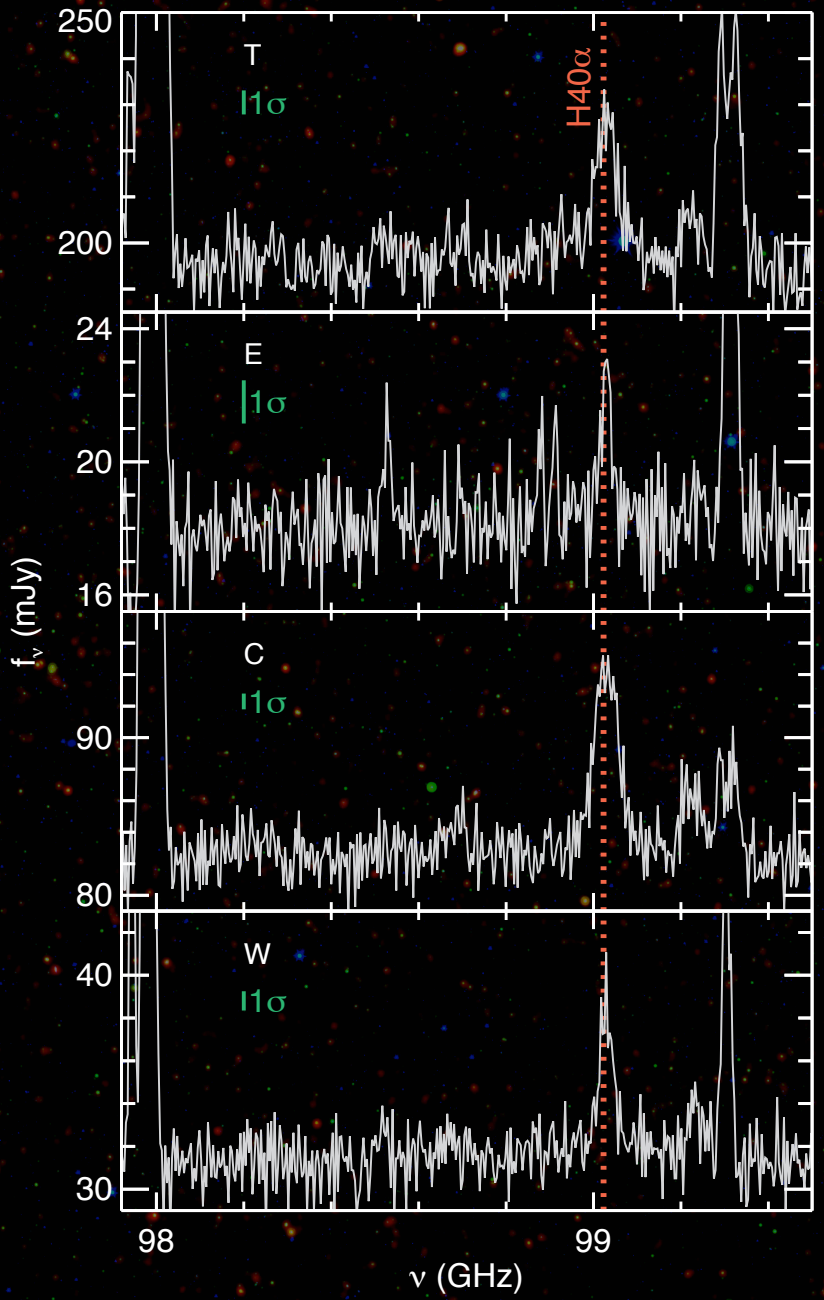


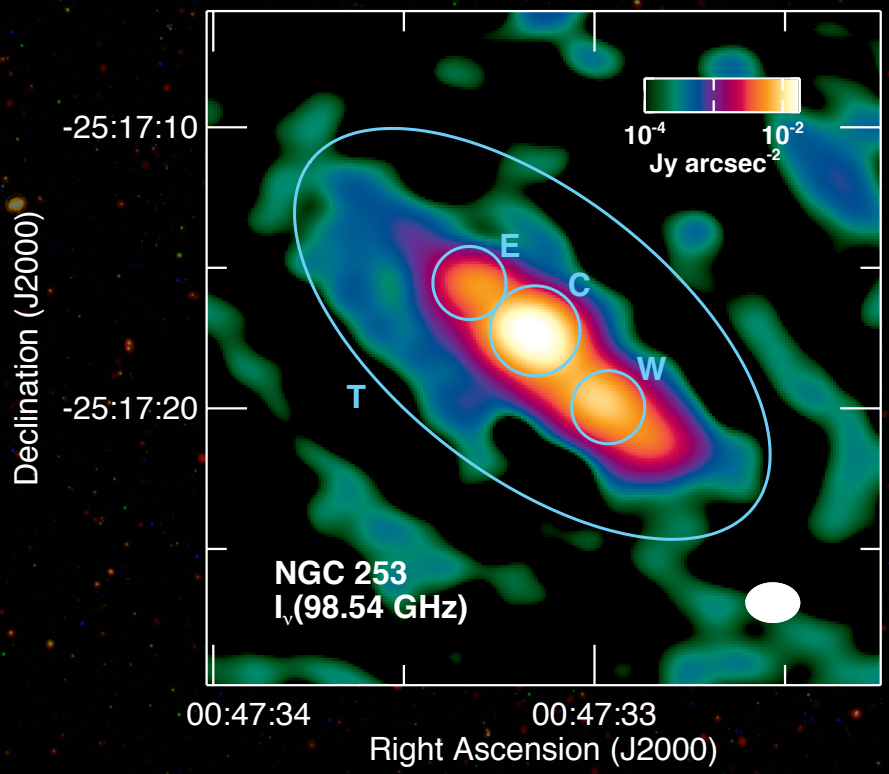
In this talk, I will talk about three galaxies where ALMA has detected recombination line emission:

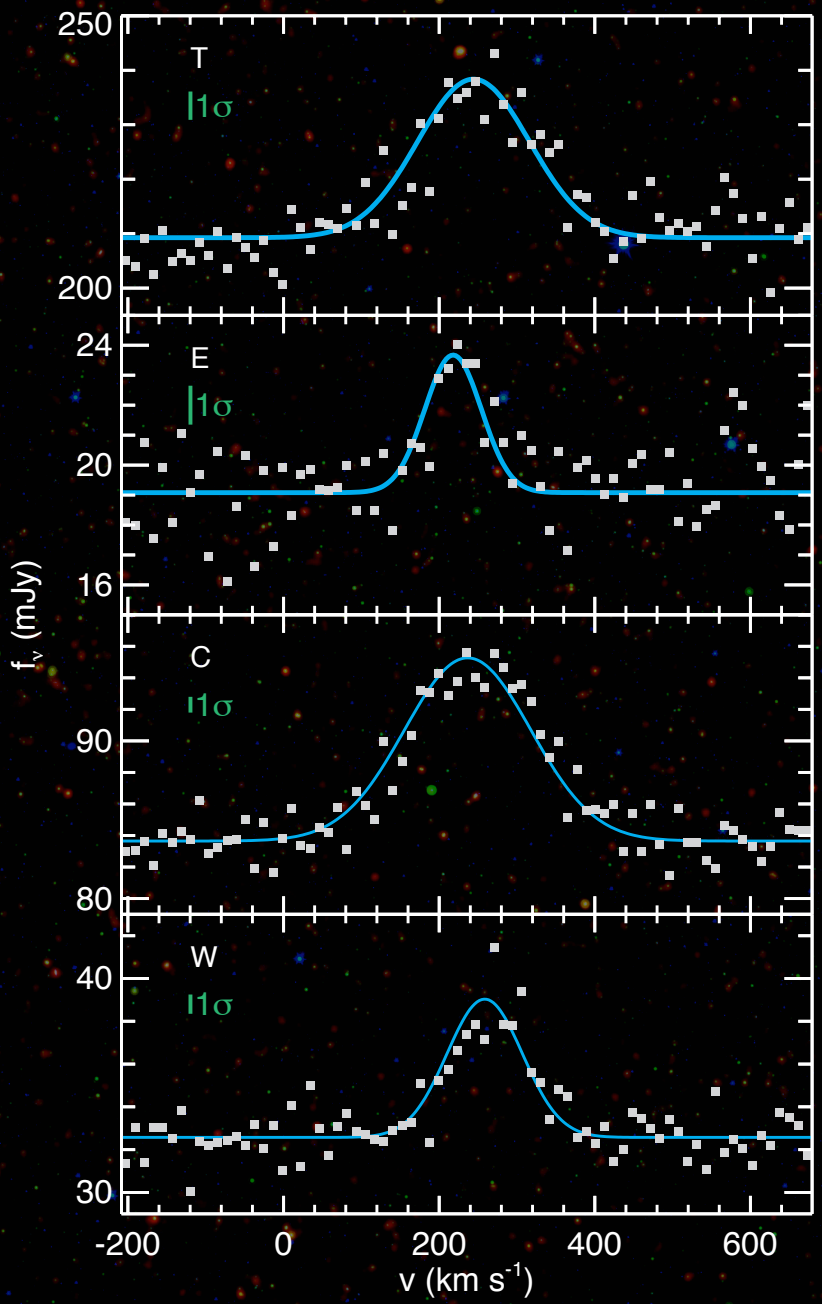
- NGC 253 (spiral galaxy with nuclear starburst)
  - Bendo et al., 2015, MNRAS, 450, L80
  - Meier et al., 2015, ApJ, 801, 63
- NGC 4945 (spiral galaxy with starburst/AGN nucleus)
  - Bendo et al., 2016, MNRAS, 463, 252
  - Hinkel et al., 2016, in preparation
- NGC 5253 (low metallicity blue compact dwarf galaxy)
  - Bendo et al., 2017, in preparation
  - Miura et al., 2017, in preparation


-25:17:10
-25:17:20
Declination (J2000)
10^{-4}
10^{-2}
Jy arcsec^{-2}
NGC 253
I_ν(98.54 GHz)
10^{-1}
10^{0}
Jy km s^{-1} arcsec^{-2}
NGC 253
I(H40α)
00:47:34
00:47:33
00:47:34
00:47:33
Right Ascension (J2000)


-25:17:10
-25:17:20
Declination (J2000)
00:47:34
00:47:33
Right Ascension (J2000)
10^-4
10^-2
Jy arcsec^-2
E
C
W
T
NGC 253
I_ν(98.54 GHz)


250
200
24
20
16
90
80
40
30
T
E
C
W
1σ
H40α
f_ν (mJy)
98
99
ν (GHz)


-25:17:10
-25:17:20
Declination (J2000)
00:47:34
00:47:33
Right Ascension (J2000)
10^-4
10^-2
Jy arcsec^-2
E
C
W
T
NGC 253
I_ν(98.54 GHz)

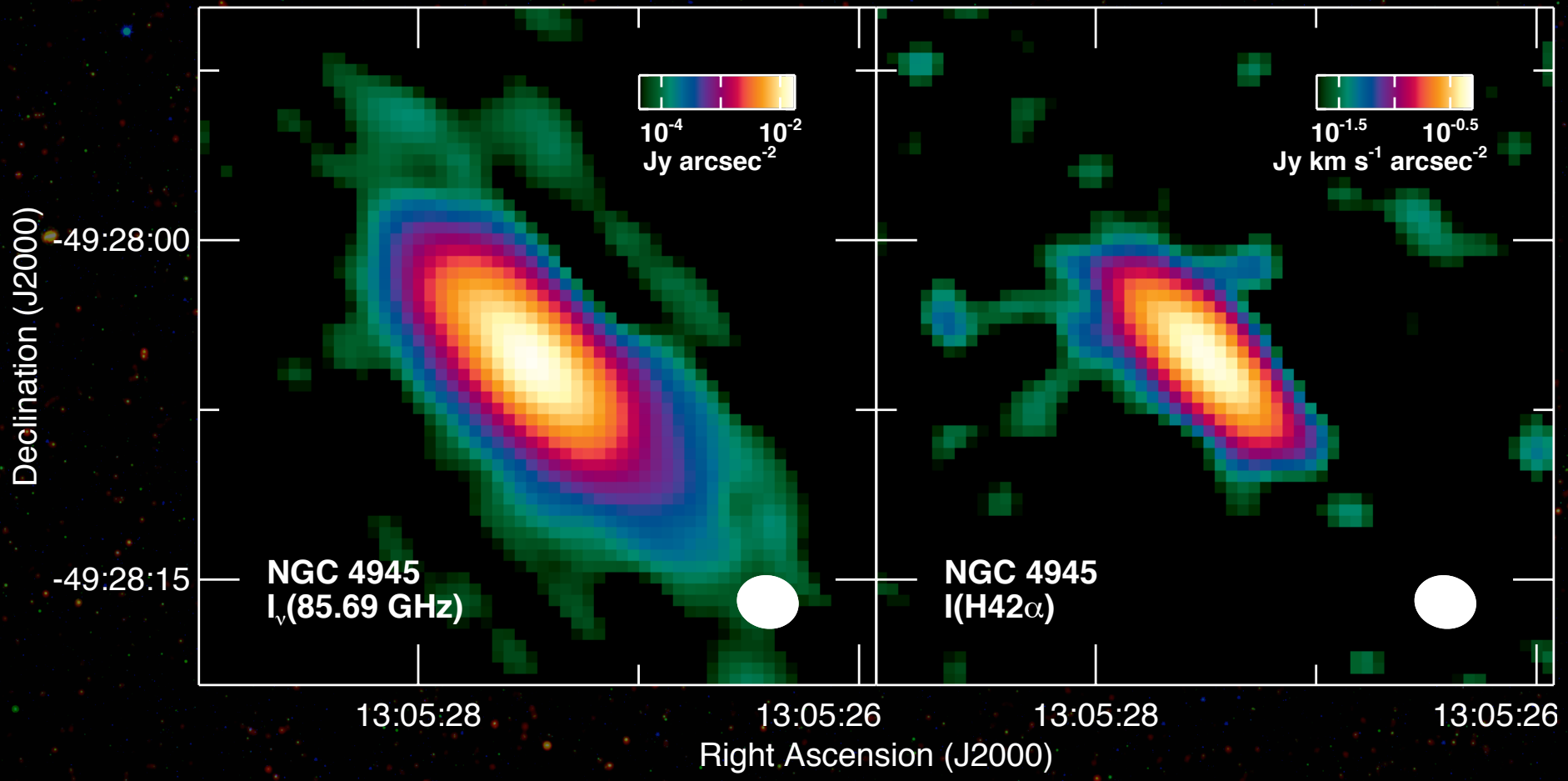

250
200
T
1σ
24
20
16
E
1σ
90
80
C
1σ
40
30
W
1σ
f_ν (mJy)
-200
0
200
400
600
v (km s^-1)

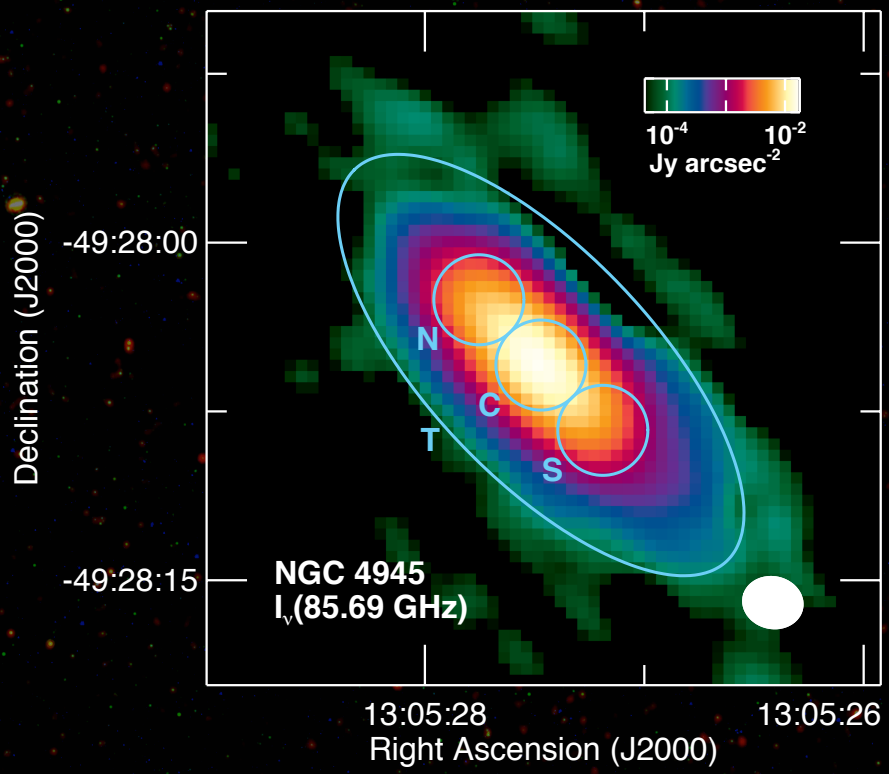
NGC 253 summary results

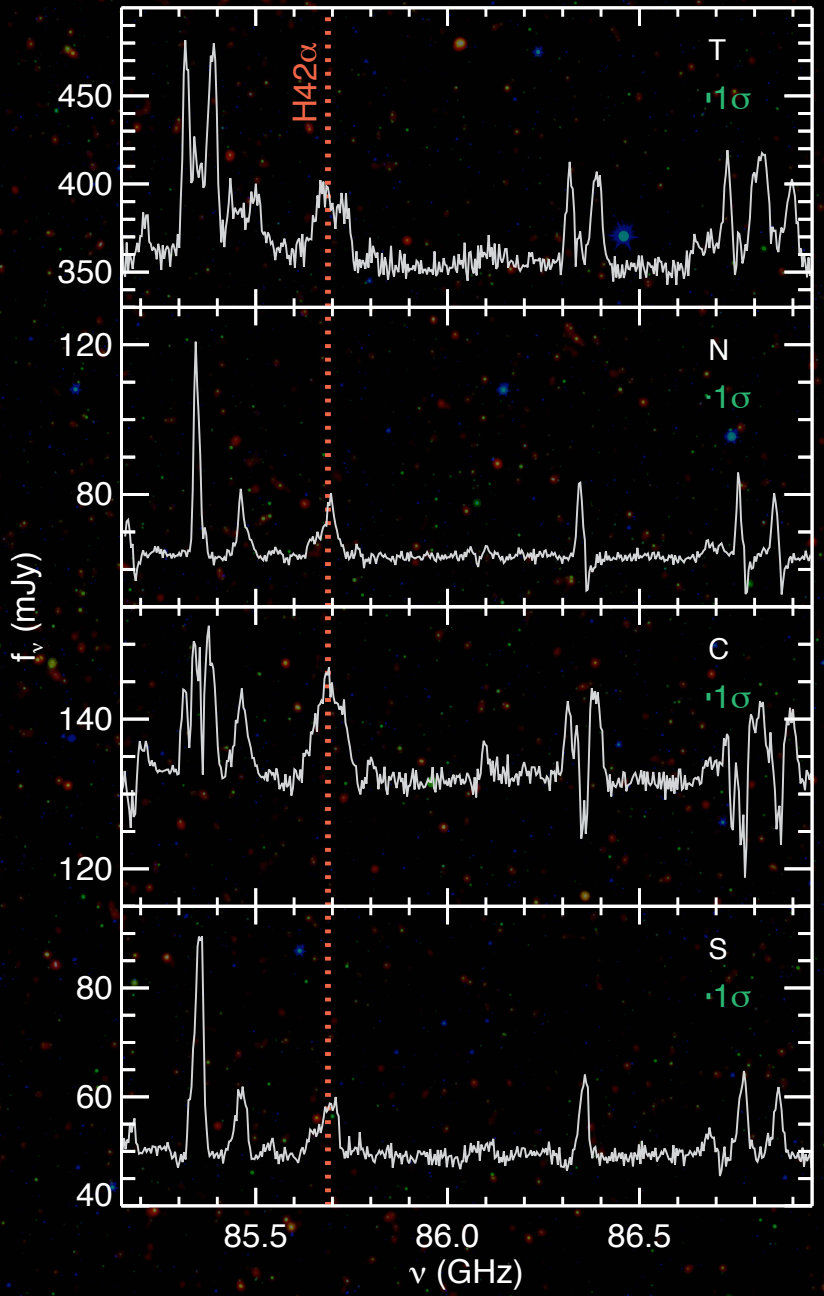
- Electron temperatures (from line/continuum ratio) is 3700-4500 K.
  - Matches measurements from inner regions of Milky Way Galaxy.

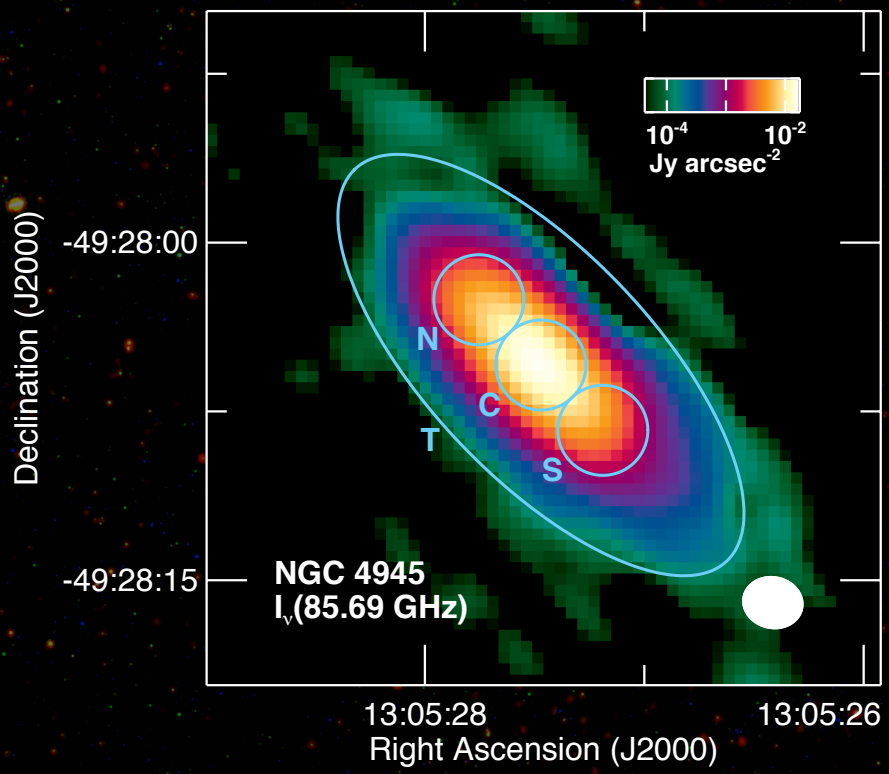
- Star formation rate for central 20”x10” is $1.73 \pm 0.12\ M_{\odot}\ yr^{-1}$.
  - Published range of values from mm/radio data is 0.6-4.9 $M_{\odot}\ yr^{-1}$.

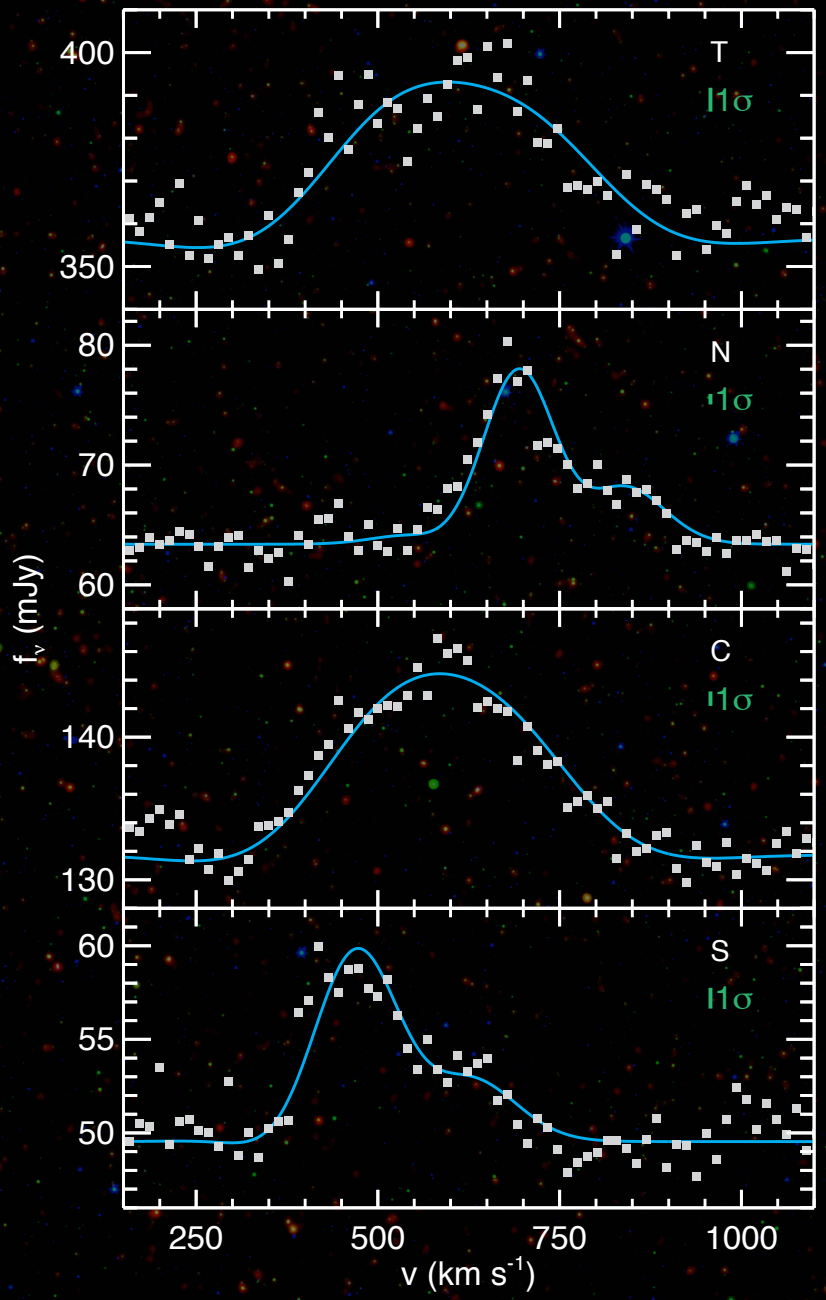
- Near-infrared dust attenuation is measured as $A_J = 3.4 \pm 0.2$ and $A_K = 2.1 \pm 0.2$.
  - ~1.5 magnitudes higher than previously-published measurements based on near-infrared data.


10^{-4} 10^{-2}
Jy arcsec^{-2}
NGC 4945
I_ν(85.69 GHz)
$10^{-1.5}$ $10^{-0.5}$
Jy km s^{-1} arcsec^{-2}
NGC 4945
I(H42α)
Declination (J2000)
-49:28:00
-49:28:15
13:05:28
13:05:26
13:05:28
13:05:26
Right Ascension (J2000)


10^-4
10^-2
Jy arcsec^-2
N
C
T
S
NGC 4945
I_ν(85.69 GHz)
-49:28:00
-49:28:15
Declination (J2000)
13:05:28
13:05:26
Right Ascension (J2000)


H42α
T
N
C
S
1σ
450
400
350
120
80
140
120
80
60
40
f_ν (mJy)
85.5
86.0
86.5
ν (GHz)


10^-4
10^-2
Jy arcsec^-2
N
C
T
S
NGC 4945
I_ν(85.69 GHz)
-49:28:00
-49:28:15
Declination (J2000)
13:05:28
13:05:26
Right Ascension (J2000)

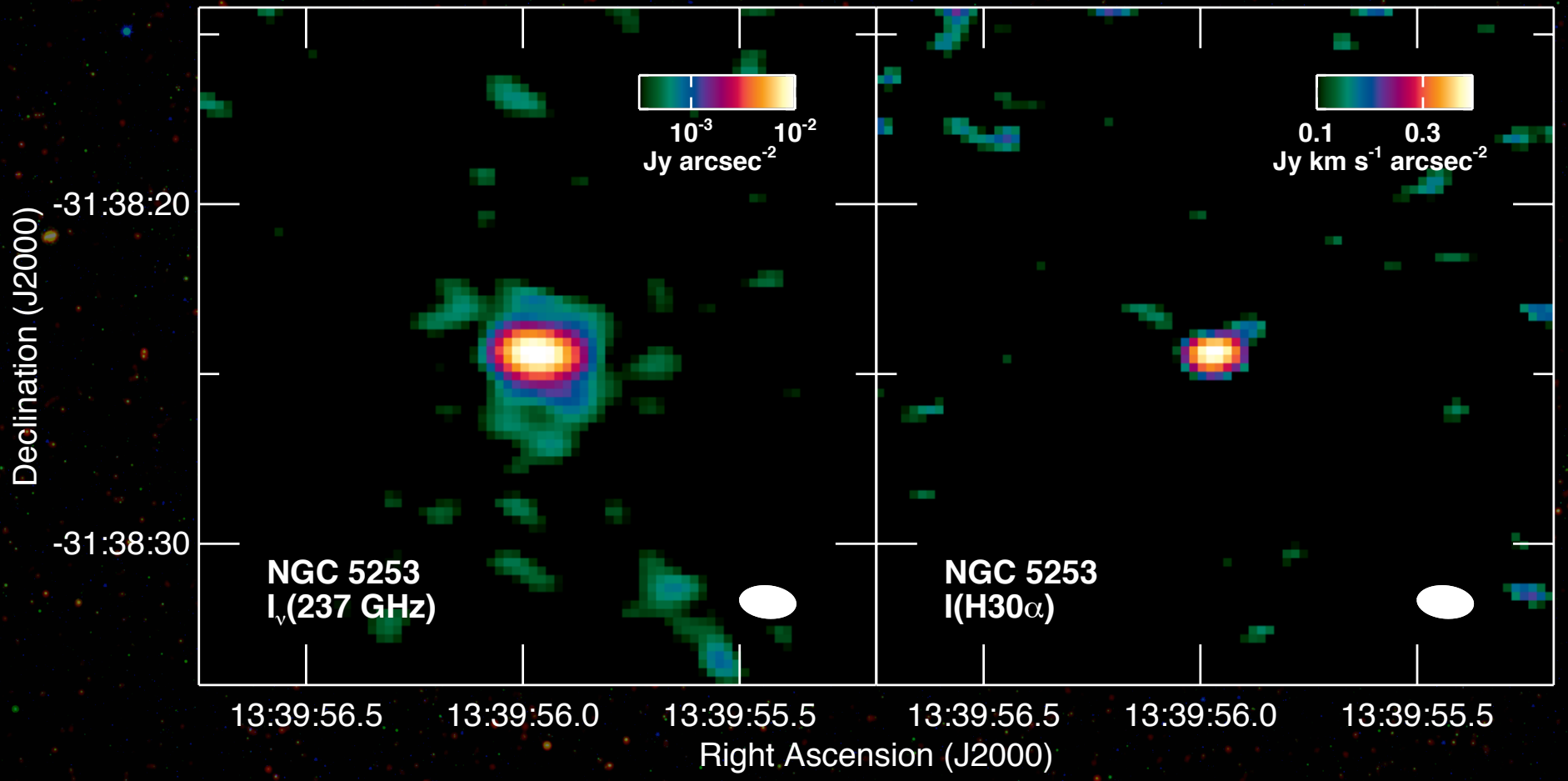

T
N
C
S
1σ
400
350
80
70
60
140
130
60
55
50
f_ν (mJy)
250
500
750
1000
v (km s^-1)

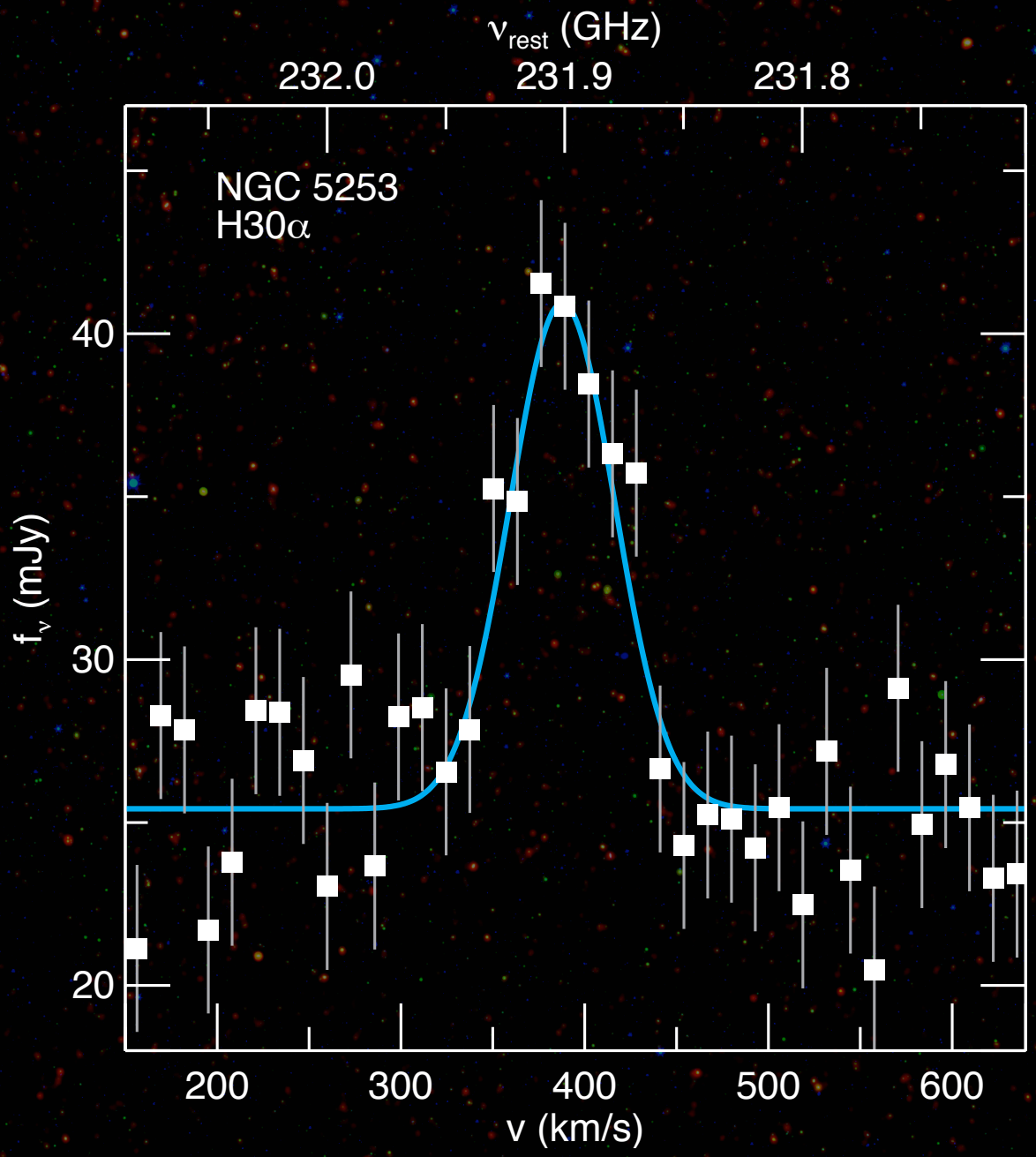
NGC 4945 results

- Free-free and recombination line emission primarily from exponential disc with scale length of ~2.1” (~40 pc).
  - No evidence of central peak associated with AGN.

- Electron temperatures (from line/continuum ratio) is 5400 K.
  - Matches measurements from inner regions of Milky Way Galaxy.

- Star formation rate for central disc is $4.35 \pm 0.25\ M_{\odot}\ yr^{-1}$.
  - Within ~30% of star formation rate from total infrared flux.
  - 10× higher than star formation rate from mid-infrared (22, 24 μm) flux densities.


10^{-3} 10^{-2}
Jy arcsec^{-2}
0.1 0.3
Jy km s^{-1} arcsec^{-2}
-31:38:20
-31:38:30
Declination (J2000)
NGC 5253
I_ν(237 GHz)
NGC 5253
I(H30α)
13:39:56.5
13:39:56.0
13:39:55.5
13:39:56.5
13:39:56.0
13:39:55.5
Right Ascension (J2000)


ν_{rest} (GHz)
232.0
231.9
231.8
NGC 5253
H30α
40
30
20
f_ν (mJy)
200
300
400
500
600
v (km/s)

NGC 5253 *preliminary* results

- All detected recombination line emission originates from central 4” diameter region.

- Global star formation rate is 0.092 ± 0.018 $M_{\odot}$ yr^{-1}.
  - Consistent with star formation rate from ultraviolet + total infrared and Hα + total infrared data .
  - Mid-infrared star formation rate is ~3× higher than other star formation rates.

Summary

- Millimetre free-free and recombination line emission can be detected from many nearby starbursts using ALMA.
- Early analyses with ALMA data have revealed problems with star formation rates from lower-frequency radio data and mid-infrared data.
- Future ALMA observations will allow us to examine the efficacy of other star formation tracers more thoroughly.