Metallicity Gradients in Spiral Galaxies from Sub-mm Dust Emission

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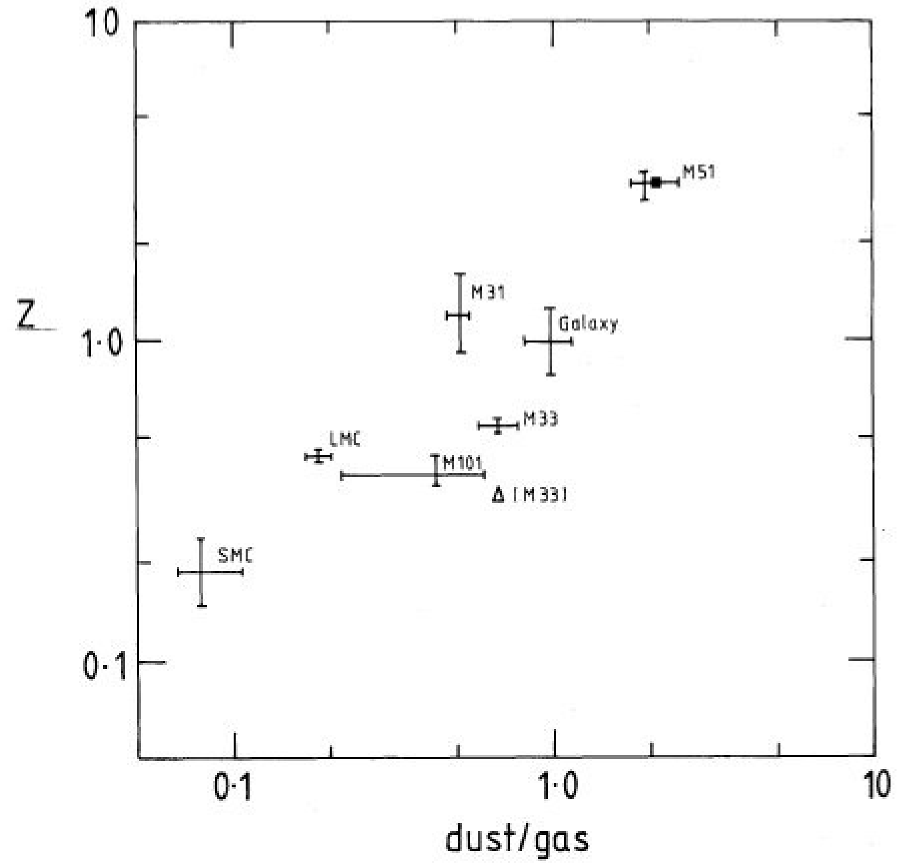
Dust and metallicity

Metallicity gradients in spiral galaxies hold information about the formation and evolution of the galaxies. The spatial distribution of the star formation rate over time should leave its imprint on the metallicity distribution.

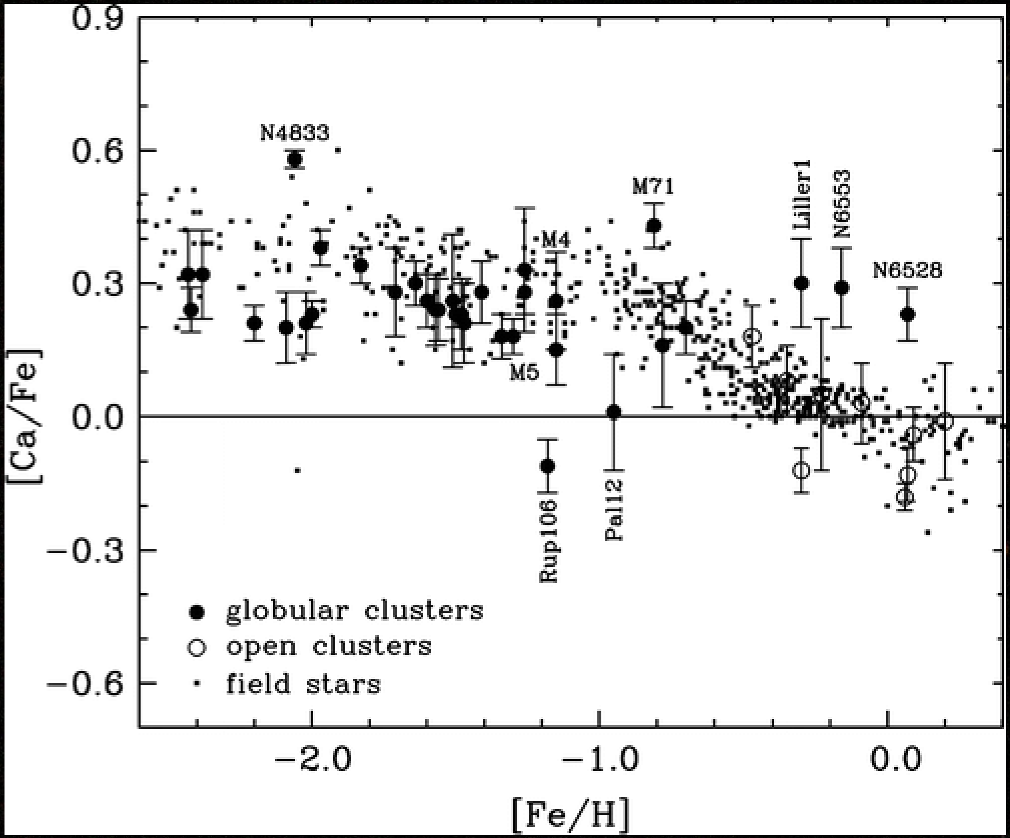
Dust/gas ratio (D/G) is correlated with [O/H] (*Issa et al. 1990*).

If we can use (D/G) to measure metallicity this may be both simpler and more sensitive than alternative methods. Especially relevant with new instruments.

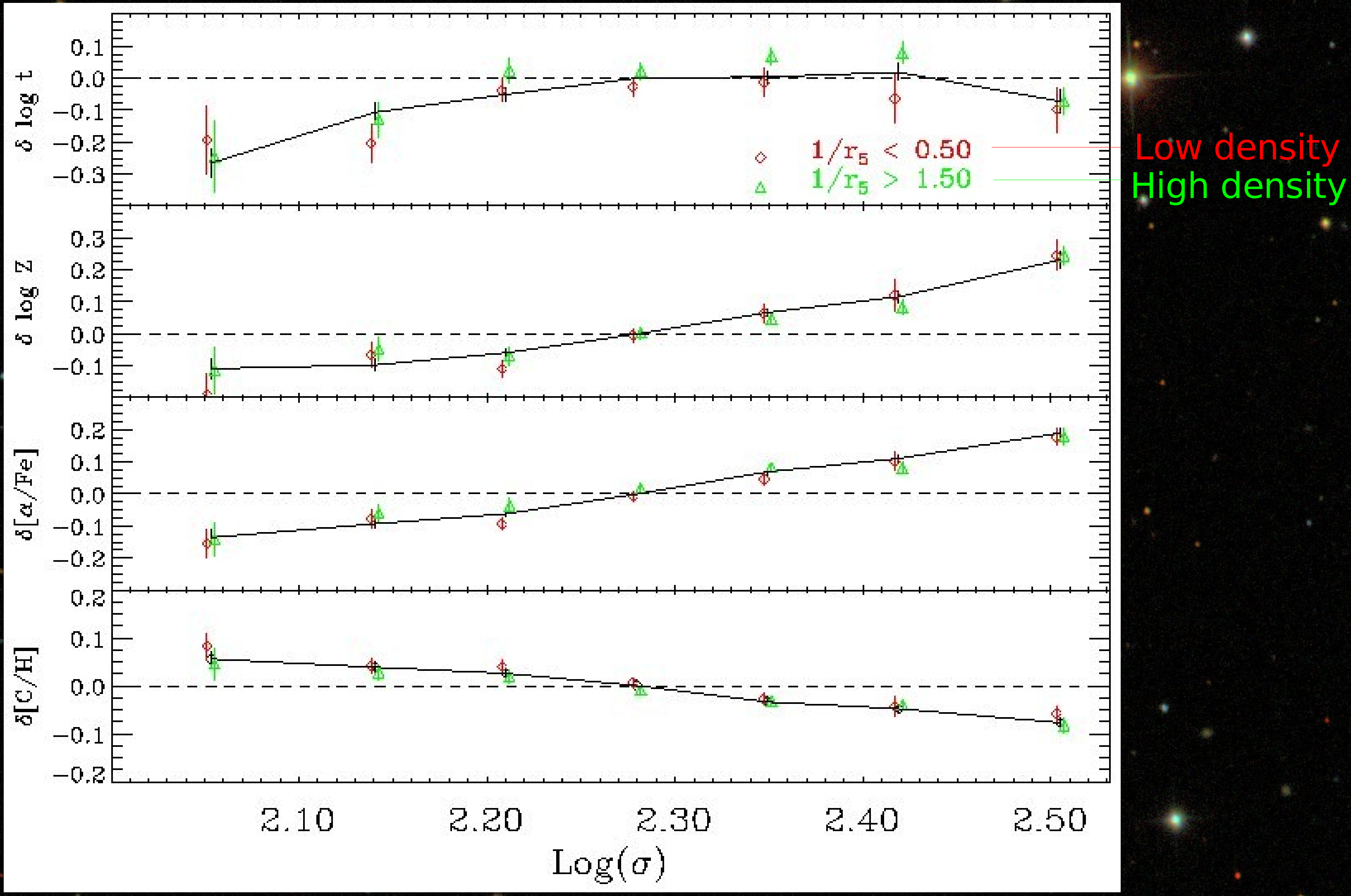


The Milky Way

Globular clusters metal poor but have super-solar [α/Fe] (old & formed rapidly).
Field stars show same trend but at higher metallicity show lower [α/Fe].
[α/Fe] falls with Galactocentric radius for field stars.



Analogy with the evolution of early-type galaxies: star formation history as a function of mass and environment



Clemens et al. 2006

Sample

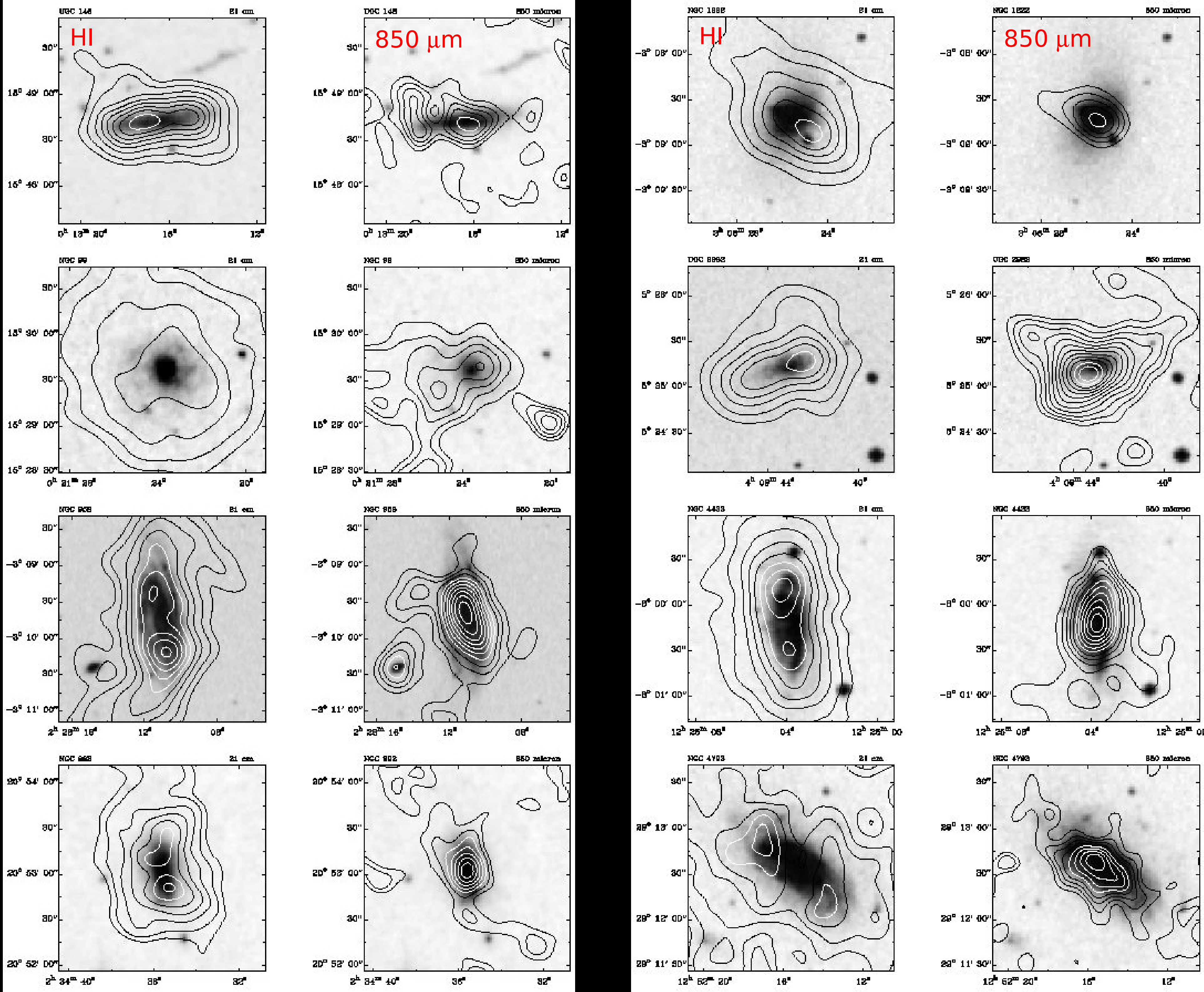
Mostly from IRAS bright SLUGS but some optically selected.

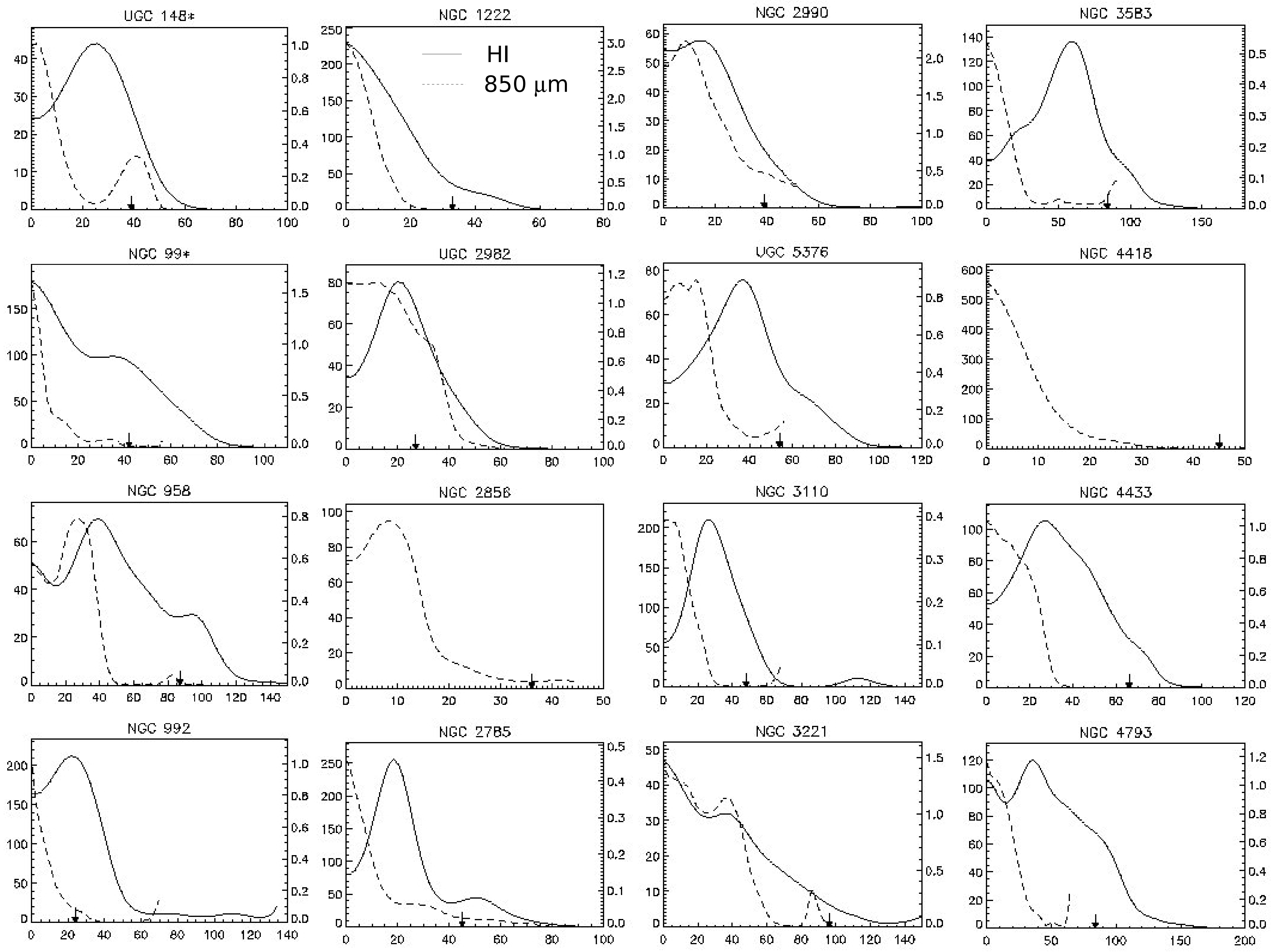
Observed with VLA in C-configuration.

- t_{int} ~ 15 min
- Δv = 25 km/s
- Beam 15-25”

Matched resolution.

(1) Name	(2) RA (B1950)	(3) Dec. (B1950)	(4) Type	(5) Nuclear type	(6) D_{25} (arcmin)	(7) PA (°)	(8) i (°)	(9) Notes
UGC 148	00 13 16.3	+15 48 43	S?	–	1.3	98	75	O
NGC 99	00 21 23.8	+15 29 37	Scd	–	1.4	70*	24*	O
NGC 958	02 28 11.0	−03 09 44	Sc	–	2.9	10	70	I
NGC 992	02 34 35.6	+20 53 04	S?	–	0.8	10	41	I
NGC 1222	03 06 25.6	−03 08 43	S0	–	1.1	155*	37	I
UGC 2982	04 09 43.0	+05 25 12	Sm	H II	0.9	111	63	I
NGC 2785	09 12 03.1	+41 07 33	Im	H II	1.5	120	70	I
NGC 2856	09 20 53.2	+49 27 49	S?	–	1.2	134	64	I
NGC 2990	09 43 39.7	+05 56 25	Sc	–	1.3	85	58	I
UGC 5376	09 57 51.3	+03 36 54	Sd	–	1.8	151	70	I
NGC 3110	10 01 31.8	−06 13 55	Sb	H II	1.6	185*	61	I
NGC 3221	10 19 35.1	+21 49 20	Scd	–	3.2	167*	78	I
NGC 3583	11 11 21.6	+48 35 24	Sb	–	2.8	125	50	I
NGC 4418	12 24 20.8	−00 36 04	Sa	Sy1,2	1.5	59	61	I
NGC 4433	12 25 03.8	−08 00 09	Sab	–	2.2	5	64	I
NGC 4793	12 52 15.6	+29 12 34	Sc	–	2.8	50	58	I
NGC 5020	13 10 10.7	+12 51 53	Sbc	–	3.2	10*	32	I
NGC 5104	13 18 49.5	+00 36 14	Sa	LINER	1.2	170	70	I
UGC 8739	13 47 01.9	+35 30 18	S?	–	2.0	122	78	I
NGC 5433	14 00 23.9	+32 45 02	Sd	–	1.6	3	76	I
NGC 5600	14 21 25.9	+14 51 56	Sc	–	1.5	0*	17*	I
NGC 5665	14 29 57.9	+08 17 57	Sc	–	1.9	145	45	I
NGC 5900	15 13 16.8	+42 23 35	Sb	–	1.7	131	71	I
NGC 5936	15 27 39.3	+13 09 35	Sb	H II	1.5	5*	30*	I
NGC 5937	15 28 09.9	−02 39 33	Sb	-	1.9	20	55	I
Arp 220	15 32 46.8	+23 40 08	S?	H II; Sy2	1.5	94*	36	I
NGC 5962	15 34 14.0	+16 46 21	Sc	H II	3.0	110	45	I
NGC 6052	16 03 01.1	+20 40 37	Sc	–	0.9	0*	39	I
IC 1211	16 15 38.2	+53 07 40	E	–	1.0	66*	21*	O
NGC 6120	16 18 01.2	+37 53 36	S?	H II	0.6	25*	39	O
UGC 10500	16 38 05.1	+57 49 17	S0/a	–	1.4	0*	17*	O
IC 5090	21 08 55.0	−02 14 17	Sa	–	1.4	26	65	O
IC 1368	21 11 40.4	+01 58 13	Sa	Sy 2	1.1	48	69	O
NGC 7047	21 13 53.0	−01 02 08	Sb	–	1.2	107	57	O
NGC 7081	21 28 52.1	+02 16 12	Sb	–	1.4	52*	12*	O
NGC 7591	23 15 43.9	+06 18 45	Sbc	LINER	2.0	145	66	I
NGC 7714	23 33 40.6	+01 52 42	Sb	H II; LINER	1.9	4	42	I
NGC 7722	23 36 09.3	+15 40 39	S0/a	–	1.7	150	36	O

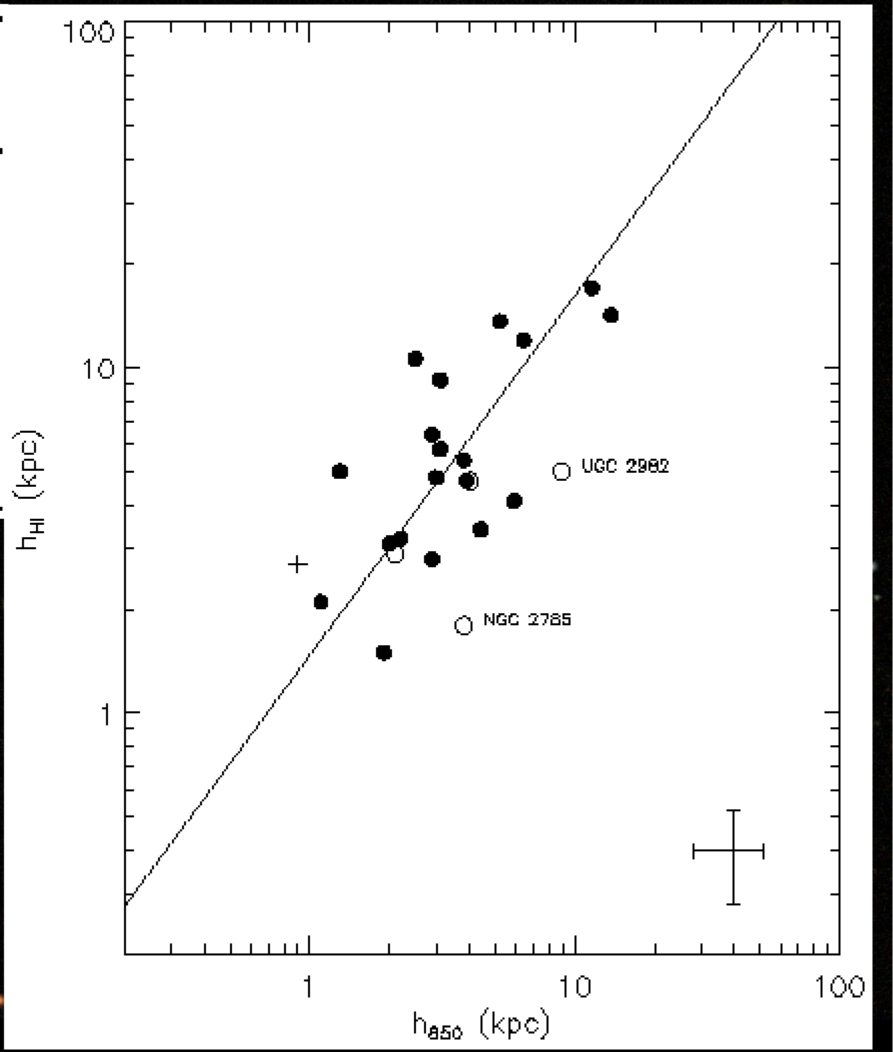

HI
850 μm
HI
850 μm


UGC 148*
NGC 1222
HI
850 μm
NGC 2990
NGC 3583
NGC 99*
UGC 2982
UGC 5376
NGC 4418
NGC 958
NGC 2856
NGC 3110
NGC 4433
NGC 992
NGC 2785
NGC 3221
NGC 4793

Results

HI radius not a function of morphological type, but
a tendency for later types to have more extended dust.

Type	$\langle h_{\rm HI} \rangle$ /kpc	$\langle h_{850} \rangle$ /kpc	$\langle h_{\rm HI}/R_{25} \rangle$	$\langle h_{850}/R_{25} \rangle$	$\langle h_{\rm HI}/h_{850} \rangle$
S0	6.1	0.9	0.46	0.17	2.9
Sa–Sab	5.0	3.3	0.37	0.20	3.7
Sb–Sbc	5.6 ± 1.4	3.4 ± 0.5	0.39 ± 0.06	0.28 ± 0.04	1.4 ± 0.2
Sc–Scd	8.0 ± 1.9	5.7 ± 1.6	0.52 ± 0.06	0.40 ± 0.08	1.8 ± 0.4
Sd/Sm/Im	4.7	3.6	0.40	0.46	0.9
All	6.2 ± 0.9	4.3 ± 0.7	0.44 ± 0.04	0.33 ± 0.04	1.7 ± 0.2



$$R_{25} > h_{HI} > h_{850}$$

$$h_{HI} = (1.5 \pm 0.4) h_{850}$$

Thomas et al. (2002, 2004a,b)

Determining the metallicity gradients

We do not have CO data.

As the scale-length of CO emission is typically $0.5R_{25}$ (*Young et al. 1995*) we assume that atomic gas traces the total gas mass beyond $0.5R_{25}$ (see later).

Parameterize metallicity gradient as $Z(R_{25})/Z(0.5R_{25})$.

We don't know the temperature profile either!

Assume various temperature profiles.

1) Constant T

2) $T(0.5R_{25})/T(R_{25}) = 0.75$

3) $T(0.5R_{25})/T(R_{25}) = 0.5$

Results

$Z(R_{25})/Z(0.5R_{25})$

$h_{\mathrm{H\,I}}/h_{850}$	T_{d} constant	$\Delta T_{\mathrm{d}} = 25$ per cent	$\Delta T_{\mathrm{d}} = 50$ per cent
1.1	0.89	1.18	1.76
1.5	0.62	0.83	1.25
1.9	0.46	0.64	0.94

Positive gradients!

$Z(R_{25})/Z(0.5R_{25}) = 0.7$ → $d(\log Z)/dr = -0.02$ dex/kpc

Values are flatter than tend to be found from optical line determinations.
E.g. *Vila-Costas & Edmunds (1992), van Zee et al. (1998)* find
$Z(R_{25})/Z(0.5R_{25}) = 0.4 – 0.5$ ([O/H]).

Other determinations of abundance gradients.

[O/H] in M33.

Author	d(logZ)/dr (dex kpc^{-1})	method
Beaulieu et al (2006)	-0.16	'beat' Cepheids
Garnett et al. (1997)	-0.11	HII regions
Magrini et al (2004)	-0.14	PNe
Crockett et al. (2006)	-0.012	HII regions
Urbaneja et al. (2005)	-0.06	B-type giants
Tiede et al. (2004)	-0.06	RGB photometry

The Milky Way

Esteban et al. (2005). UV-recombination lines:

d log(O/H) = -0.044 dex kpc^{-1}

d log(C/H) = -0.103 dex kpc^{-1}

d log(C/O) = -0.058 dex kpc^{-1} ...so composition changes with radius.

Reasons for discrepancy

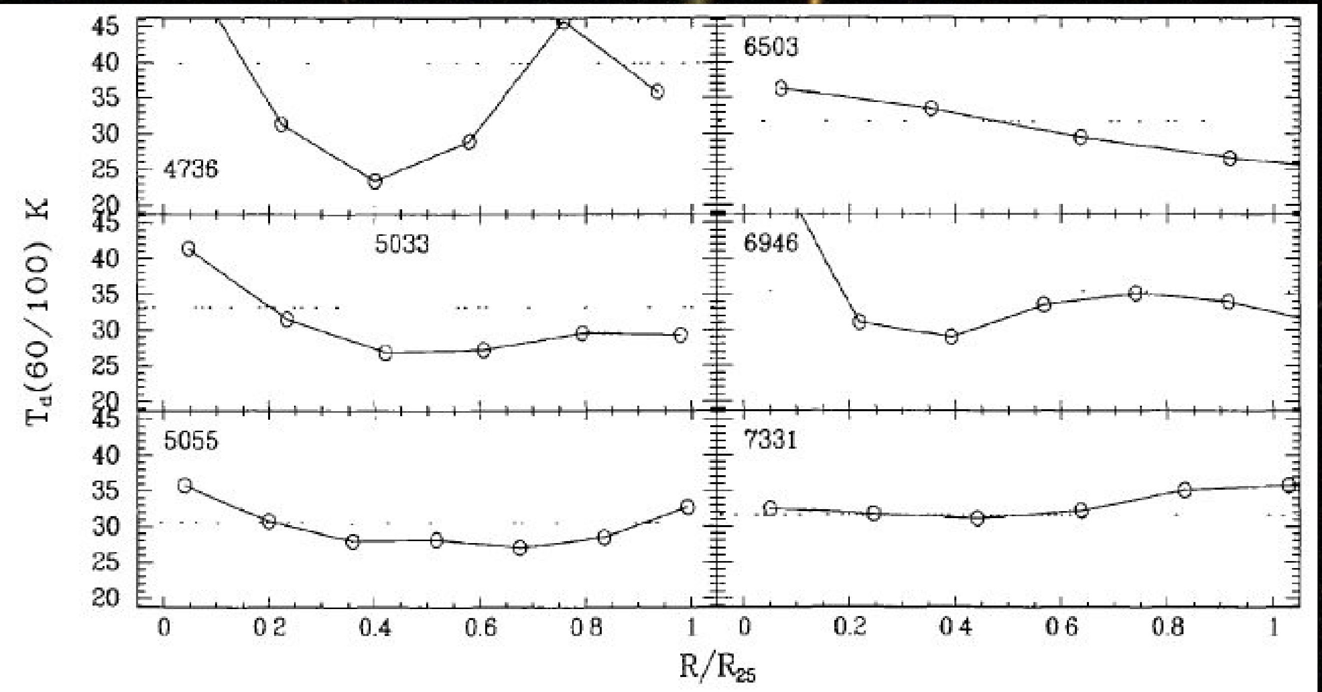
- Different samples, both [O/H] and dust trace 'metallicity'

  IRAS selected sample subject to radial mixing?

  Barred galaxies have shallower gradients, typically $Z(R_{25})/Z(0.5R_{25}) = 0.7$ (*Vila-costas & Edmunds, 1992*).

- Dust temp rises with radius? (not crazy)

  The temp of the warm dust component may rise with radius (*Mayya & Regaradjan, 1997*) but we don't know how the temp of the mass-dominant cool component changes with radius. It increasingly dominates at large R (*Trewhella et al., 2000*).



Emission increasingly dominated by VSG/PAH grains at large radii.

Expected if the ISM is less dense on average at large radii

(*Mathieu Compiegne's* talk)

Reasons for discrepancy

- Hidden molecular gas not traced by CO

  CO a bad tracer at low metallicity.

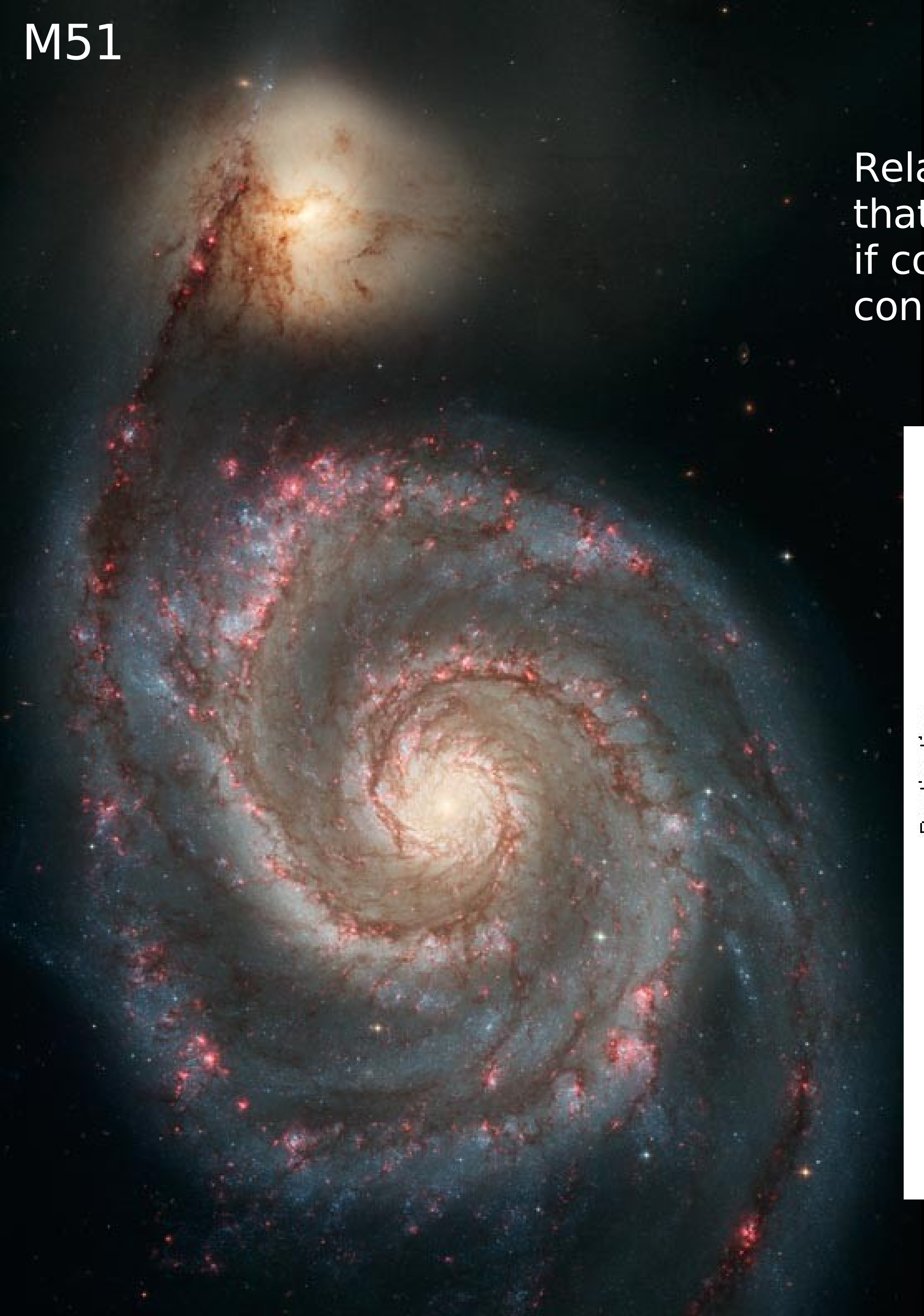
  Exponential 850 μm disk in M51 (*Meijerink et al. 2004*) evidence that cold dust traces total gas (HI + H_2).

- Depletion (dust composition) changes with radius

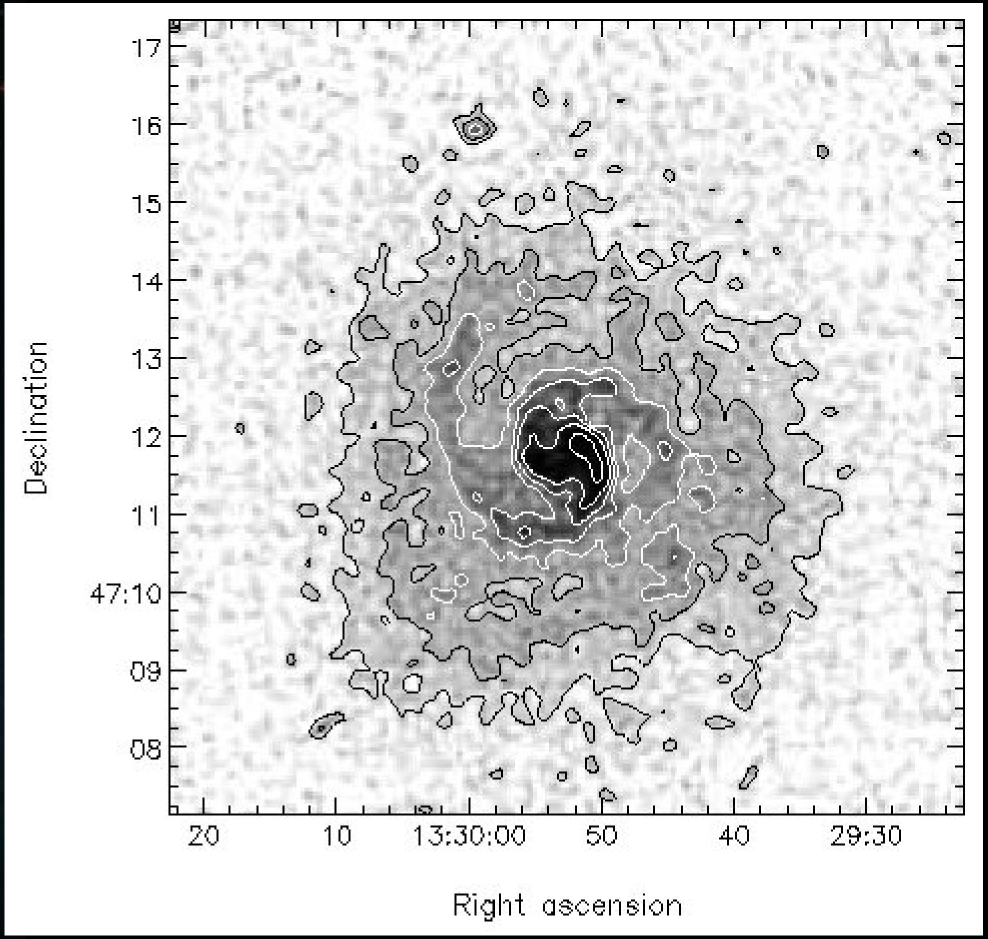
  If oxygen-rich mantles were more common at large galactocentric radii (lower photon flux) they would increase the D/G ratio.

- There has been more enrichment at large radii than previously thought.

M51



Relatively little flux in the spiral arms that dominate the CO emission, especially if contaminating CO (3-2) emission is considered.



Meijerink et al. 2004

The future

Radial temperature distributions for the dust. Our data don't exclude a constant (D/G).

Existing data seem well modelled with β=2 and 2 temperature components.

High resolution (~20”) observations at >100 μm can constrain temperature of cool component.

Trace molecular gas with atomic Carbon fine structure lines at 370 and 609 μm (SPIRE). [CI] is a better tracer in low density/metal poor environments (*Papadopoulos et al., 2004*). [CII] at 158 μm may be best (PACS).

H2EX (?) - trace molecular hydrogen *directly* via its infrared rotational lines at 28, 27, 12 and 9 μm.