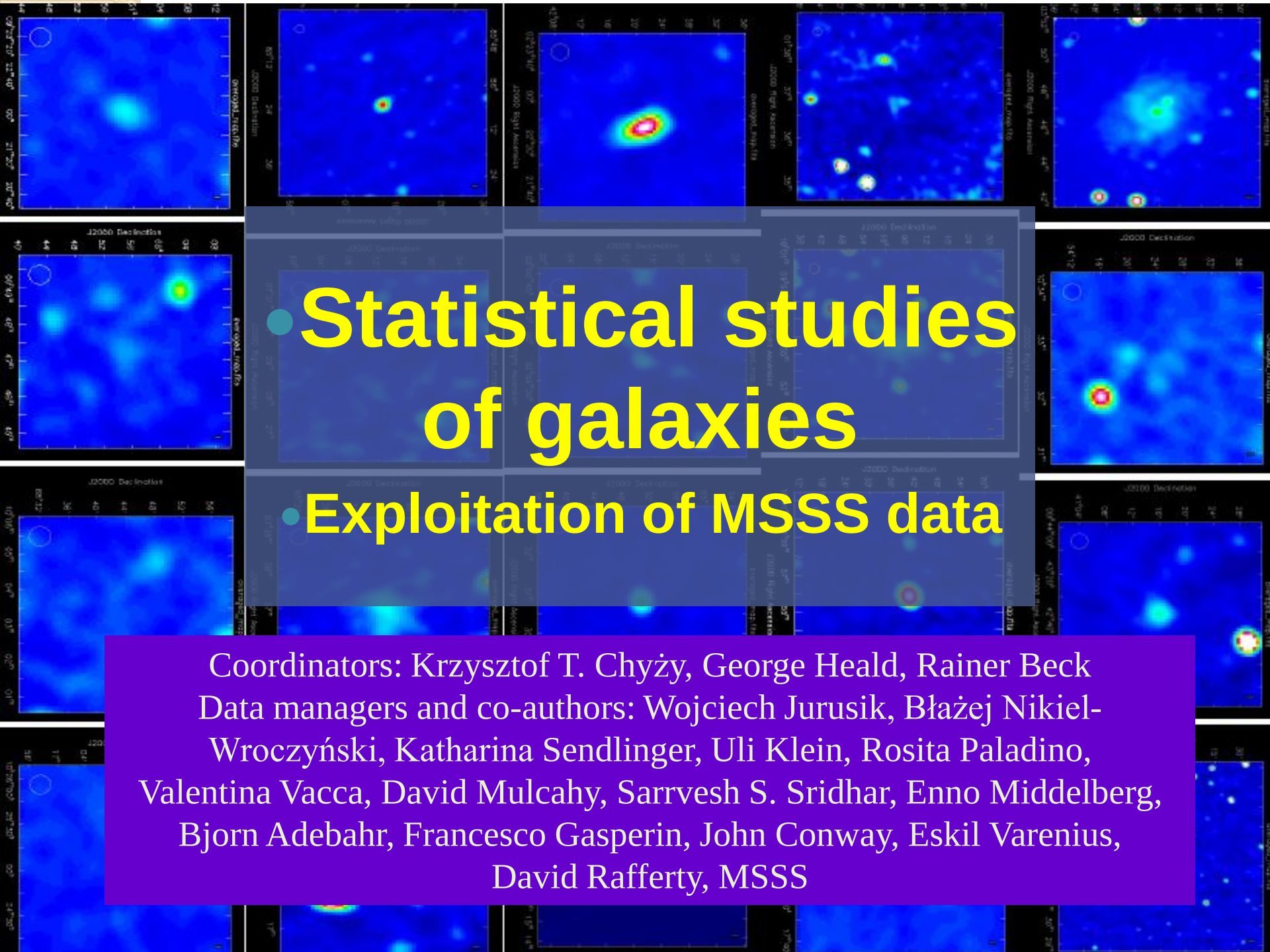


Statistical studies of galaxies

Exploitation of MSSS data

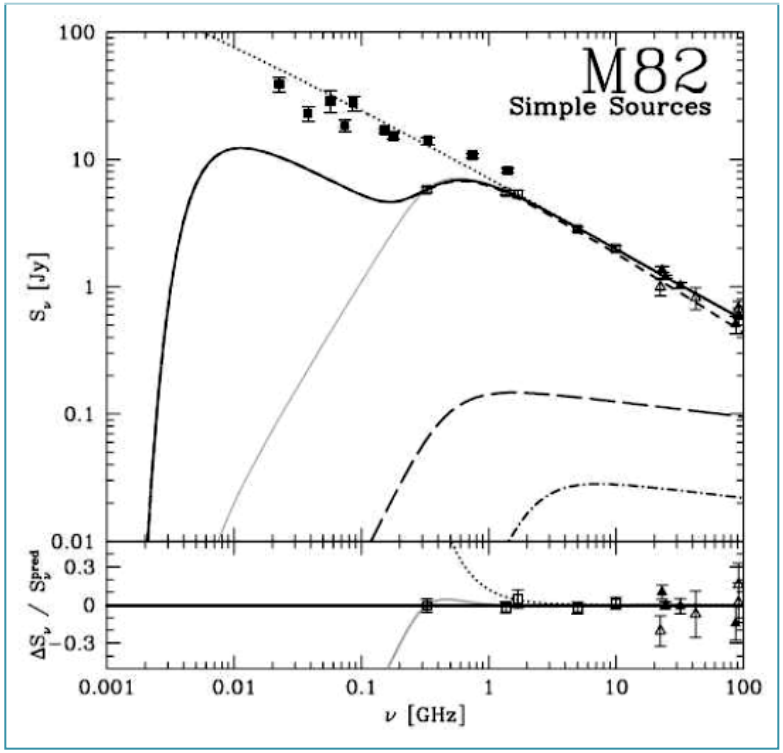
Coordinators: Krzysztof T. Chyży, George Heald, Rainer Beck
Data managers and co-authors: Wojciech Jurusik, Błażej Nikiel-Wroczyński, Katharina Sendlinger, Uli Klein, Rosita Paladino, Valentina Vacca, David Mulcahy, Sarrvesh S. Sridhar, Enno Middelberg, Bjorn Adebahr, Francesco Gasperin, John Conway, Eskil Varenius, David Rafferty, MSSS





Motivation

- Construct global spectra of a sample of galaxies. Constrain processes responsible for any turnover or spectra flattening (e.g. M82)
- Test if spectra are inclination dependent (f-f absorption)
- Determine low-freq radio-FIR correlation (nonthermal component)
- Estimate in the homogeneous way the magnetic field strength
- Local Universe sample to be compared with the high-z one
- Important step to future LOFAR data mining based on the incoming much deeper surveys (e.g. Tier 1), develop methods and tools



Lacki 2013, MNRAS 431, 2003
See also Adebahr et al. 2013, Yoast-Hull et al. 2013





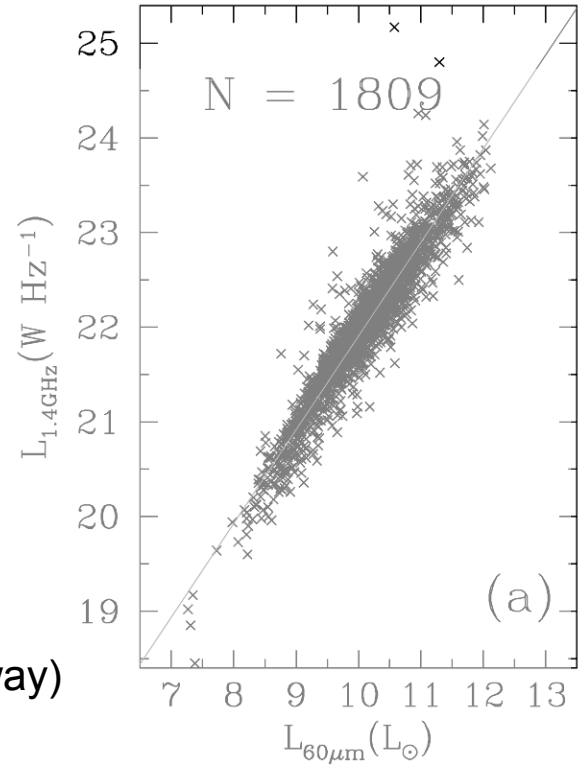
Sample selection

NVSS Cat of IRAS 2 Jy Galaxies, Yun, Reddy, Condon 2001 (1809 galaxies)

Used for studies of
- RLF
- radio – infrared correlation

Not complete. Added: b<10 - IC10, NGC 628, UGC12914, NGC3646, NGC4217, NGC4449, NGC5457 from Condon 1990, 1987

Selection criteria:
- D>2' (avoid LIRGs, another project led by John Conway)
- T>0, Dec>0
- Removed obvious AGN dominated galaxies



Sample	Yun limit 1.4 GHz	Number	MSSS 140 MHz	Number
Small	>150 mJy	49	>258 mJy	38
Medium	>100	80	>121	58
Large	>50	144	>66	98

Typical MSSS sensitivity ~15-20mJy
MSSS flux measurements from averaged maps: Wojciech Jurusik, Błażej Nikiel-Wroczyński, Katharina Sendlinger

New VLSSr studies

The Astronomical Journal, 149:32 (12pp), 2015 January doi:10.1088/0004-6256/149/1/32

INTEGRATED RADIO CONTINUUM SPECTRA OF GALAXIES

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Received 2013 June 21; accepted 2014 July 16; published 2015 January 5

ABSTRACT

We investigate the spectral shape of the total continuum radiation, between 74 MHz and 5 GHz (400–6 cm in wavelength), for a large sample of bright galaxies. We take advantage of the overlapping survey coverage of the VLA Low-Frequency Sky Survey, the Westerbork Northern Sky Survey, the NRAO VLA Sky Survey, and the Green Bank 6 cm Survey to achieve significantly better resolution, sensitivity, and sample size compared to prior efforts of this nature. For our sample of 250 bright galaxies we measure a mean spectral index, α, of −0.69 between

250 galaxies, NVSS, WENSS, VLSSr, not all detected
89 VLSSr sources detected, with flux at 1.4 >8.4 mJy, at 77 MHz >172 mJy

- Detection of curvature in the mean spectrum
- No trend in lowfrequency spectral flattening versus galaxy inclination
- Galaxies with high radio luminosity have steep spectra
- Early types tend to have excess radio emission when compared to the radio–infrared ratio of later types.

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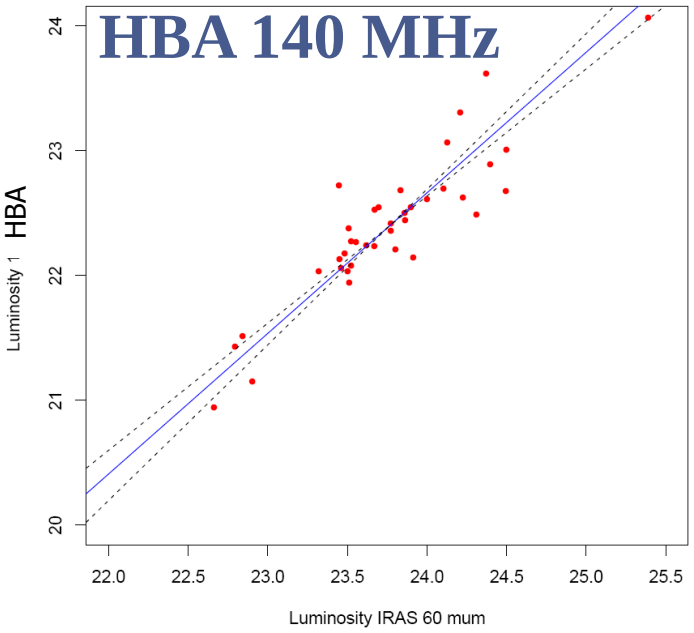
NG WG

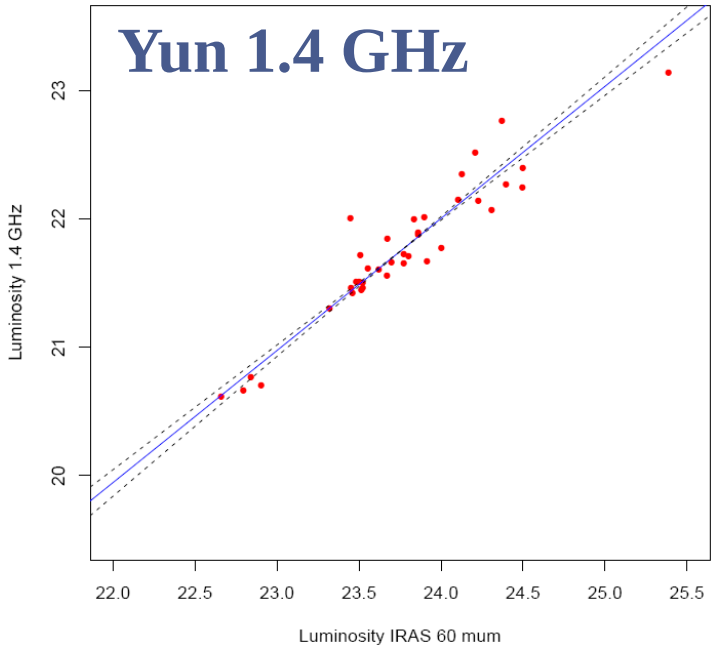
Ravenstein
9.03.2015

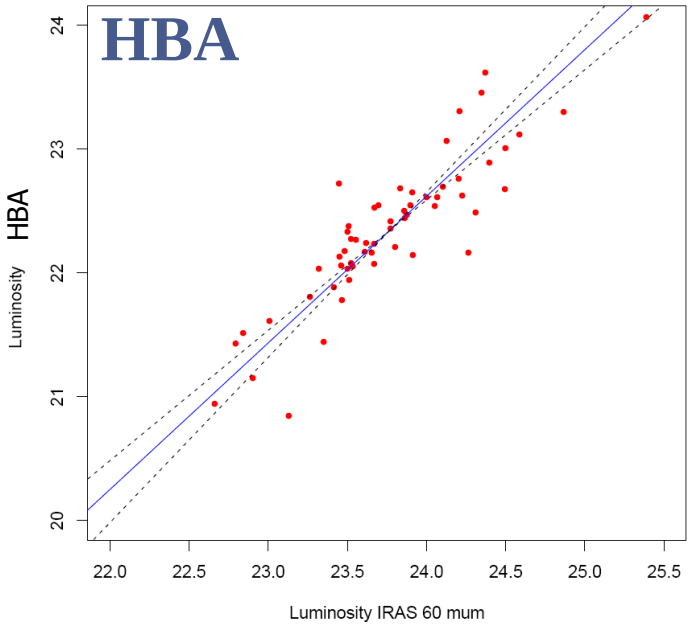
LOFAR HBA/NVSS radio – infrared correlation

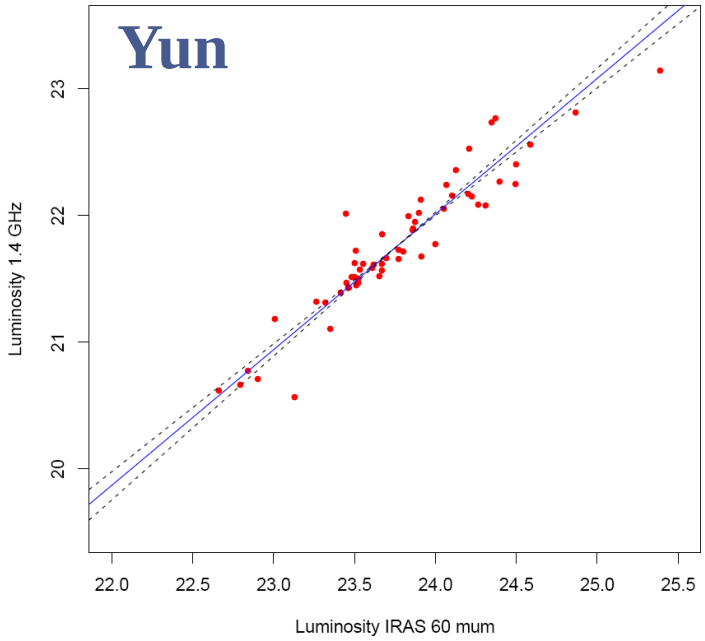
small

medium



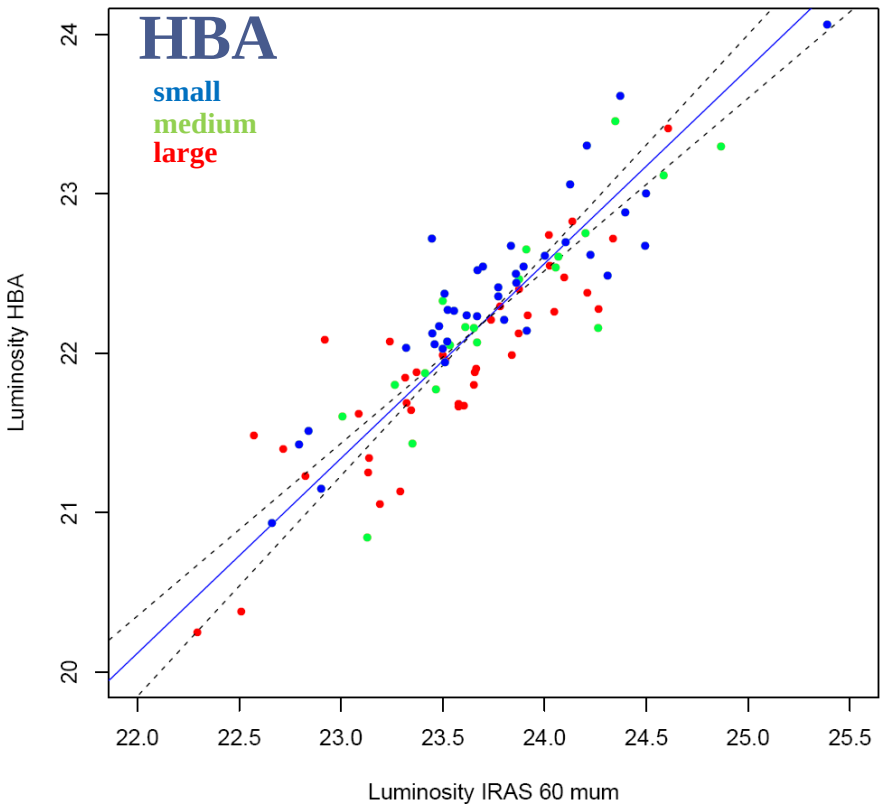






LOFAR MSSS/NVSS radio – infrared correlation

Large sample



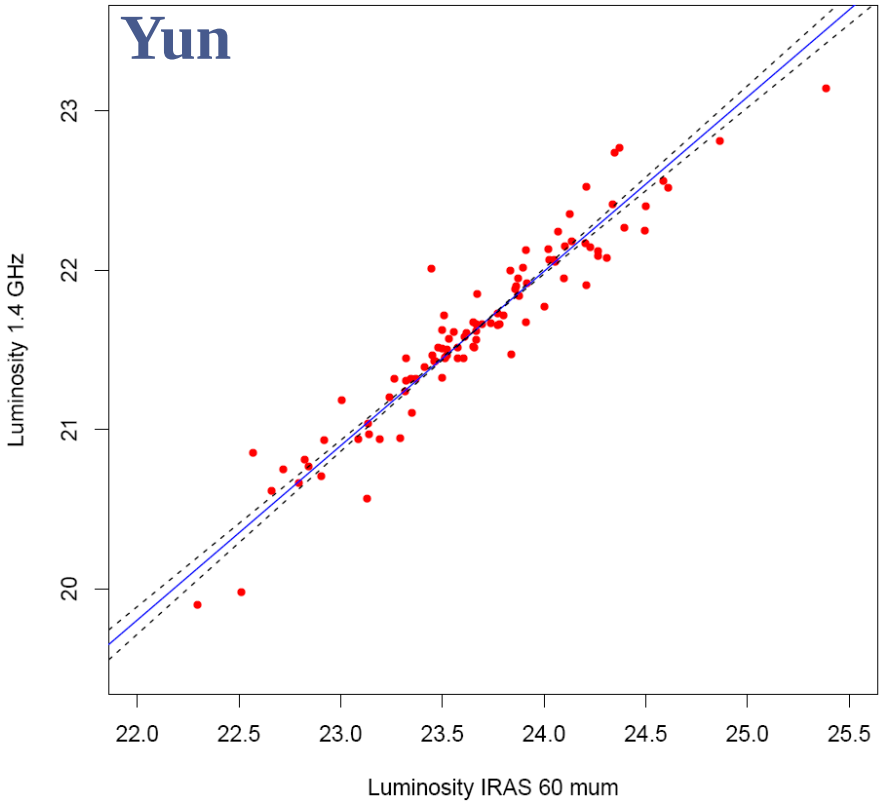


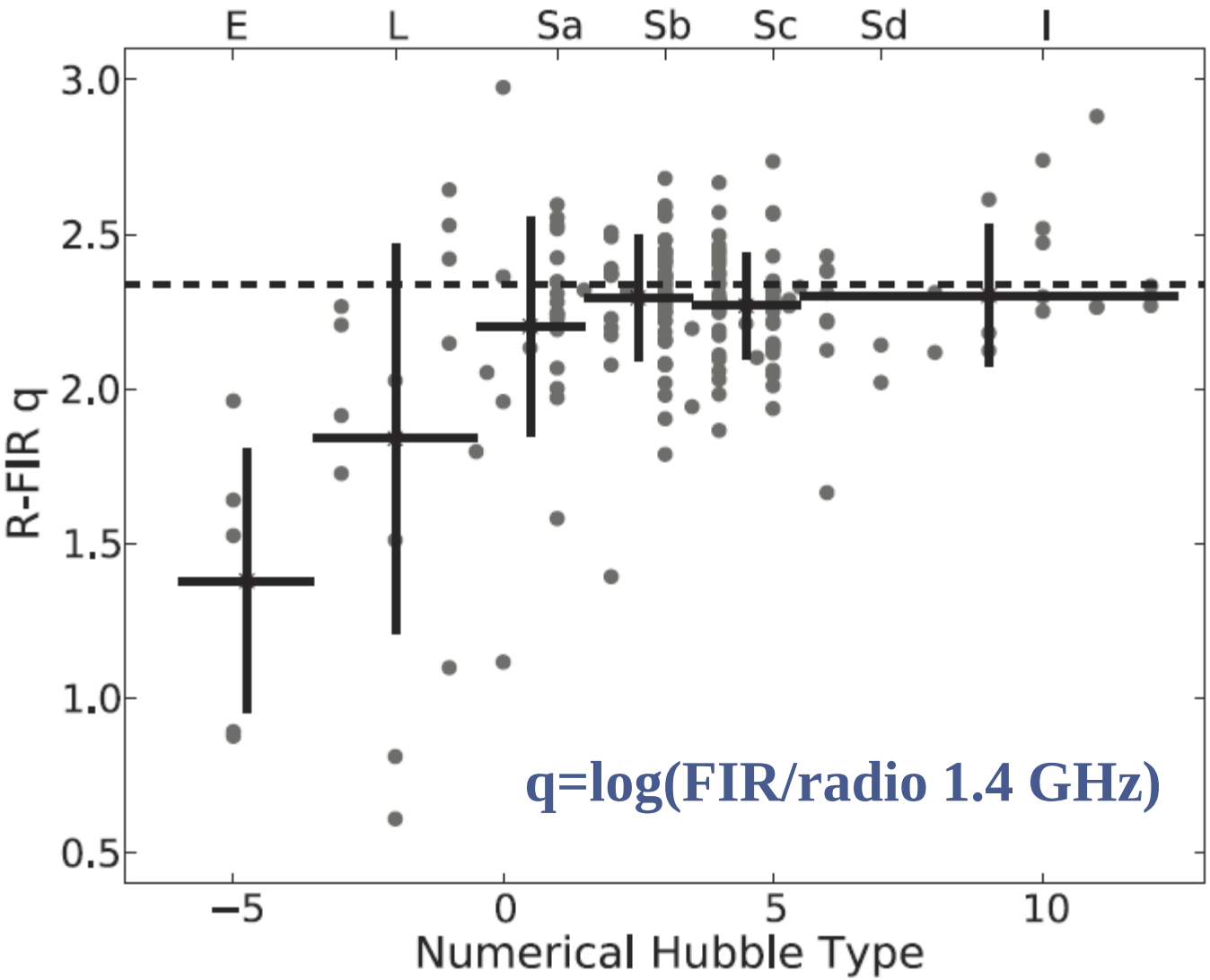
Table of (bisector) slopes

	LOFAR 140 MHz	Yun+ 1.4 GHz	
Small (38/49 78%)	1.13±0.08	1.03±0.06	(49 1.18±0.09)
Medium (58/80 73%)	1.18±0.08	1.07±0.06	(80 1.14±0.08)
Large (98/144 68%)	1.22±0.06	1.09±0.05	(144 1.11±0.05)





Marvil et al. 2015 – only q

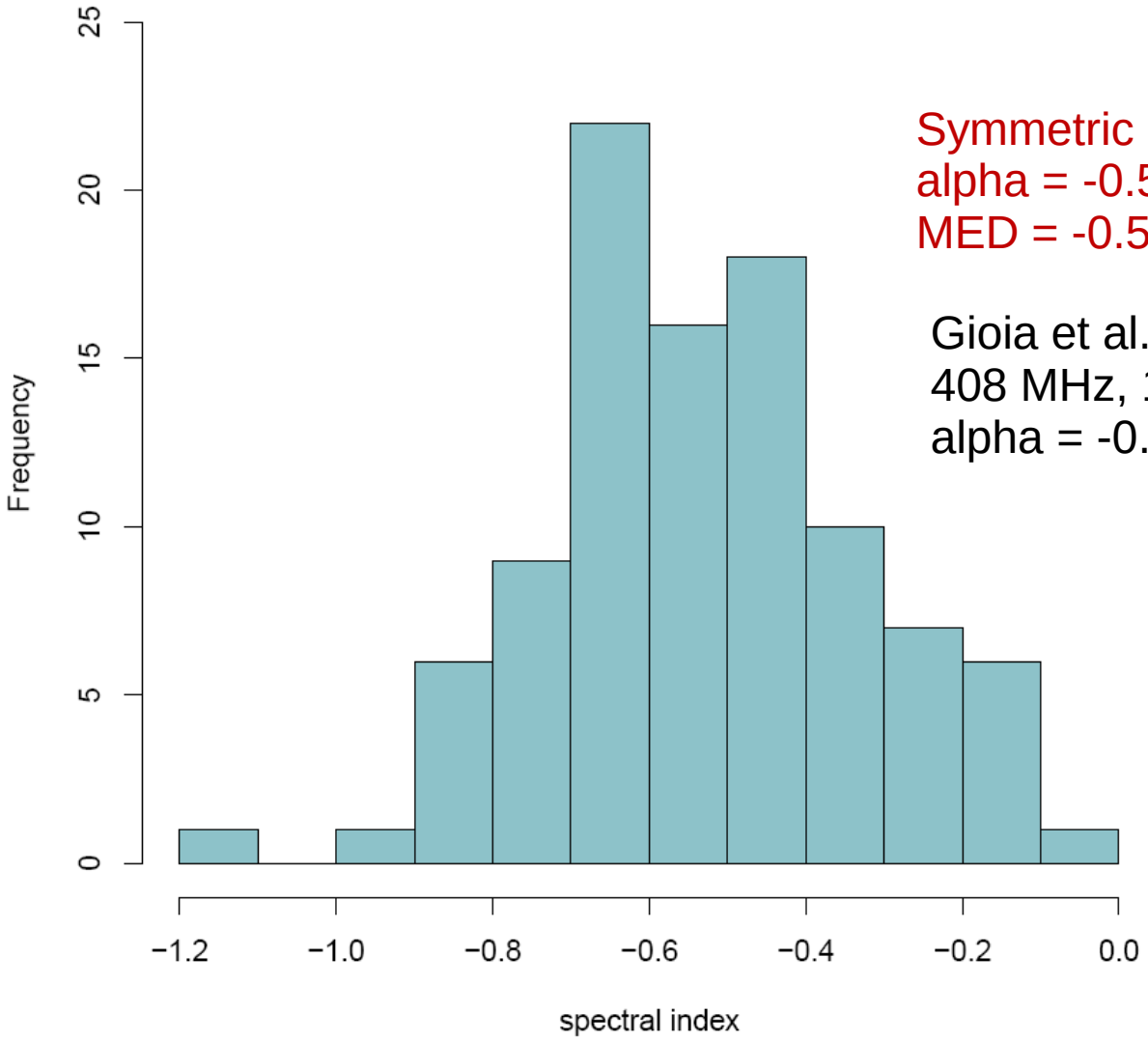


MSSS sample is more consistent





Spectral index MSSS(140 MHz)-NVSS(1.4 GHz)



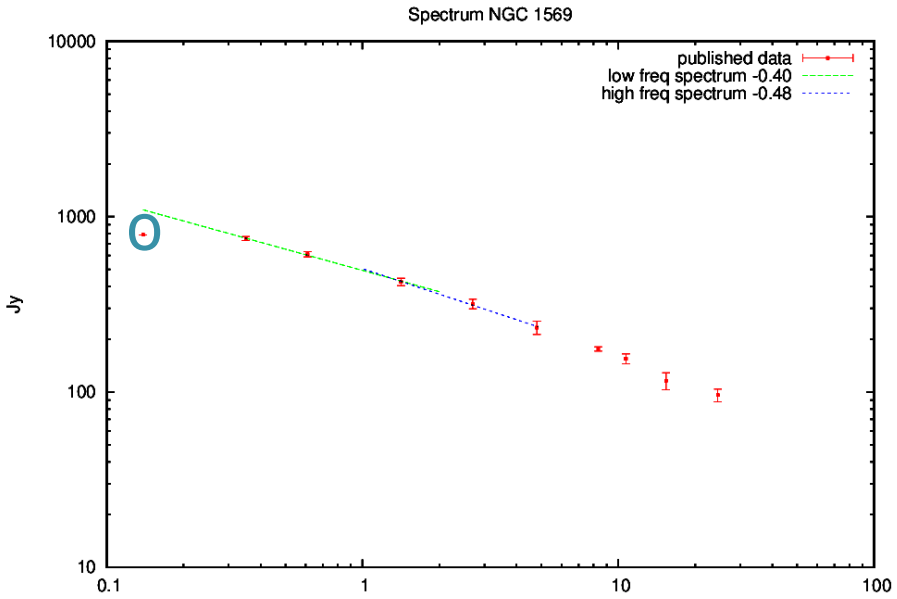
Symmetric distribution
alpha = -0.53±0.2
MED = -0.53, MAD=0.2

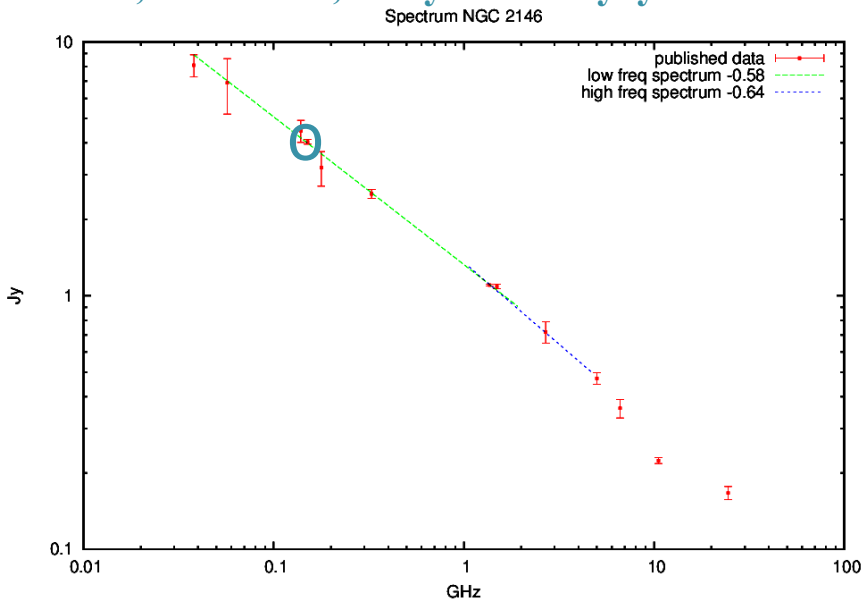
Gioia et al. 1982,
408 MHz, 10.7 GHz
alpha = -0.74±0.12

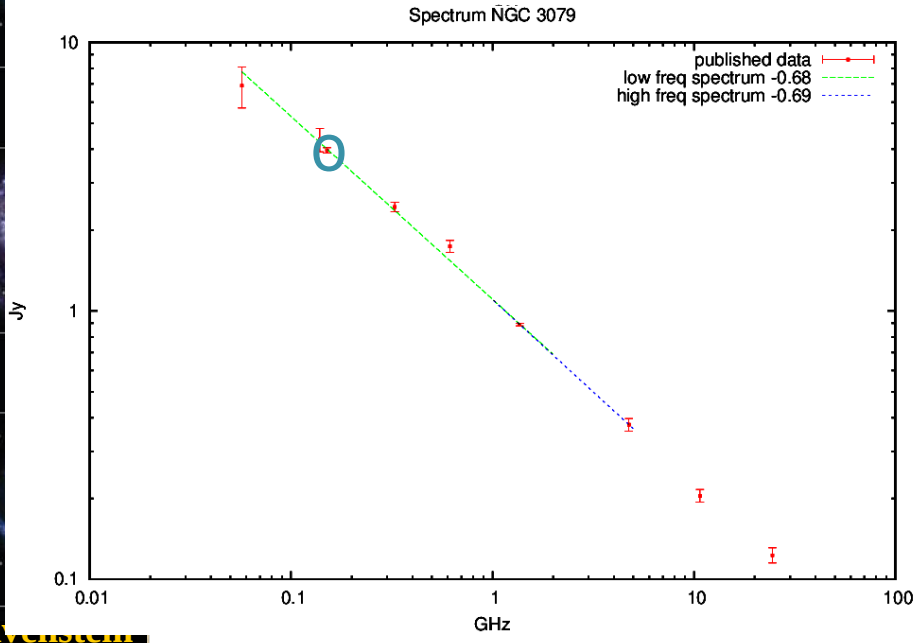
MSSS artifact or spectra are flatter at low frequencies?
f-f absorption?

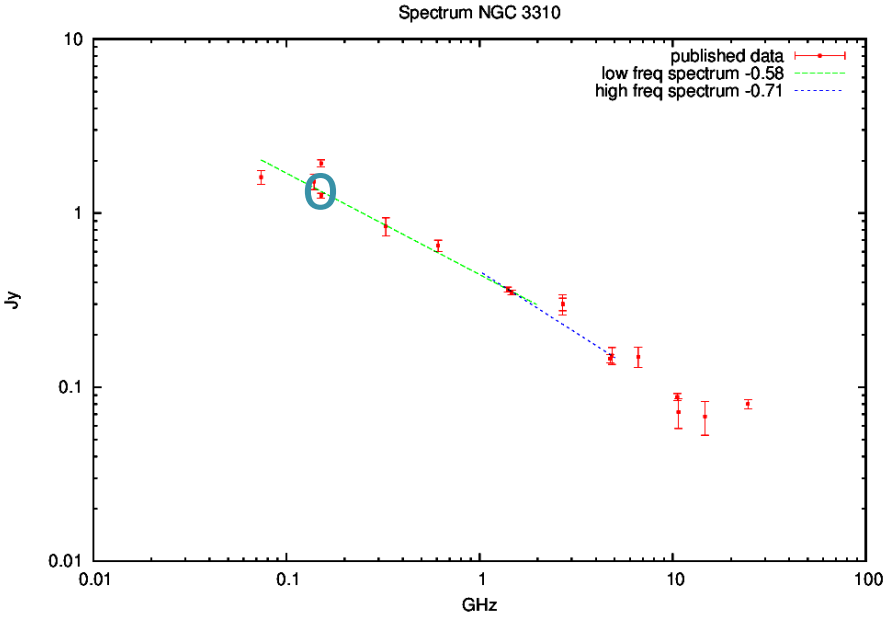
Spectral index

Literature search (50 galaxies): Rosita Paladino, Valentina Vacca, David Mulcahy, Sarrvesh S. Sridhar, Uli Klein, Krzysztof Chyży

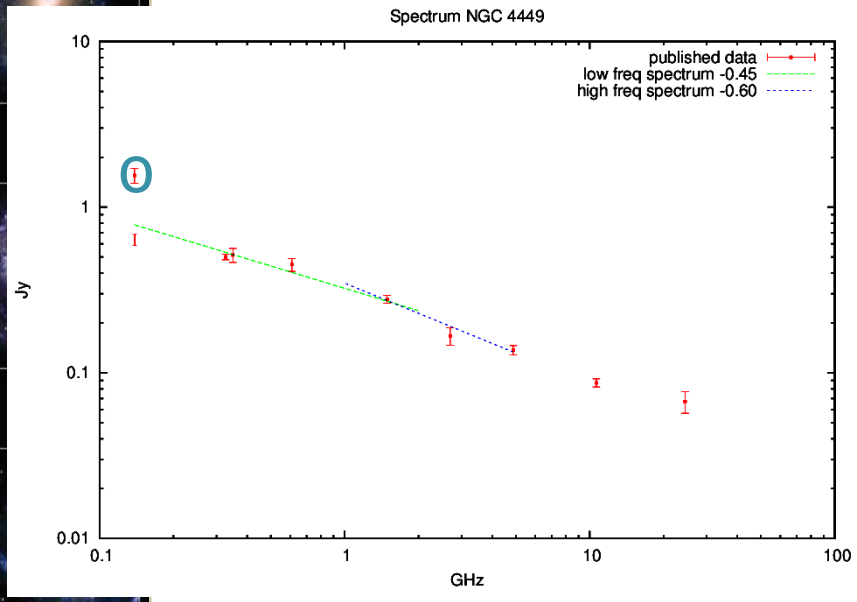


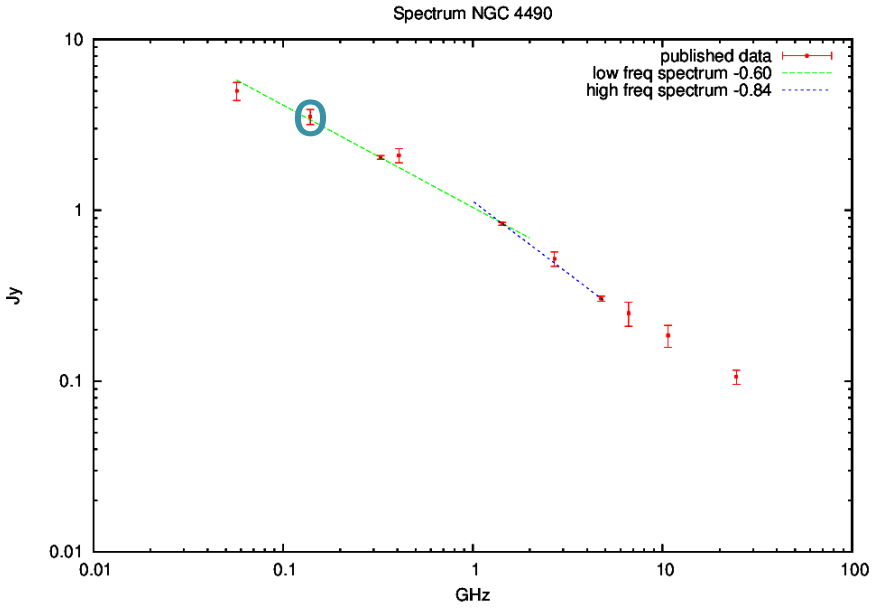


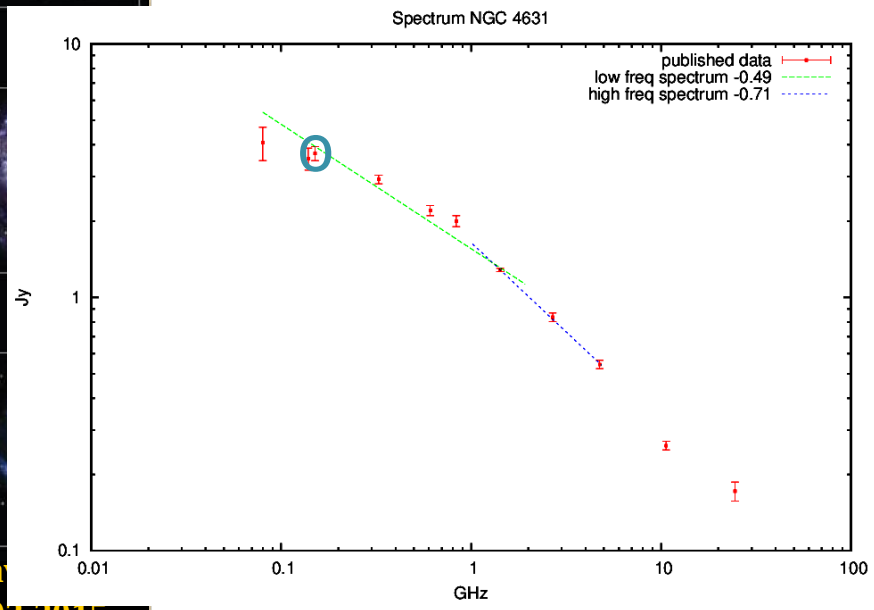


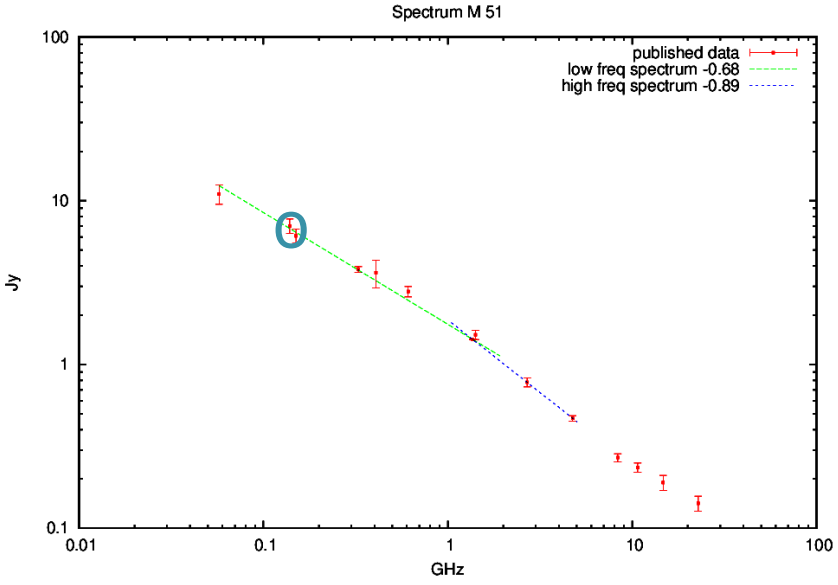


Spectral index (literature search 50 galaxies)

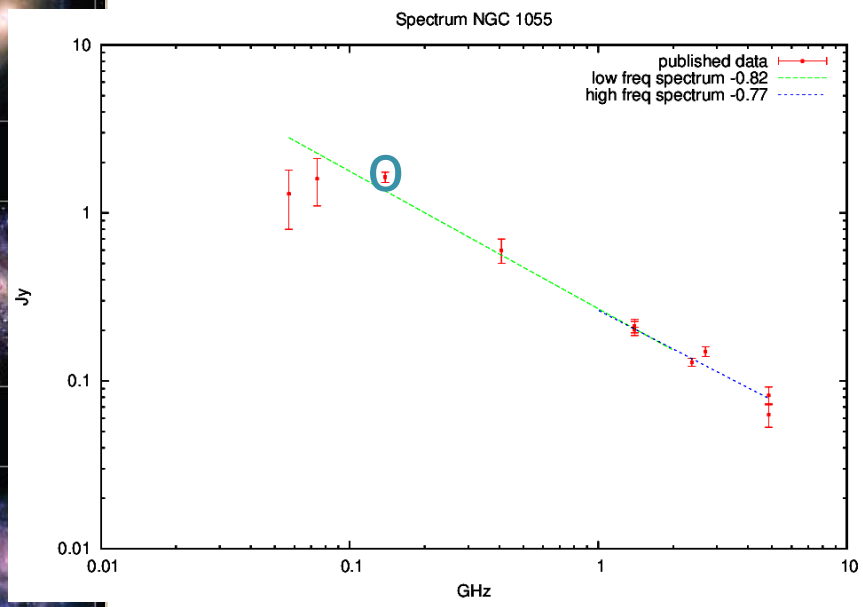


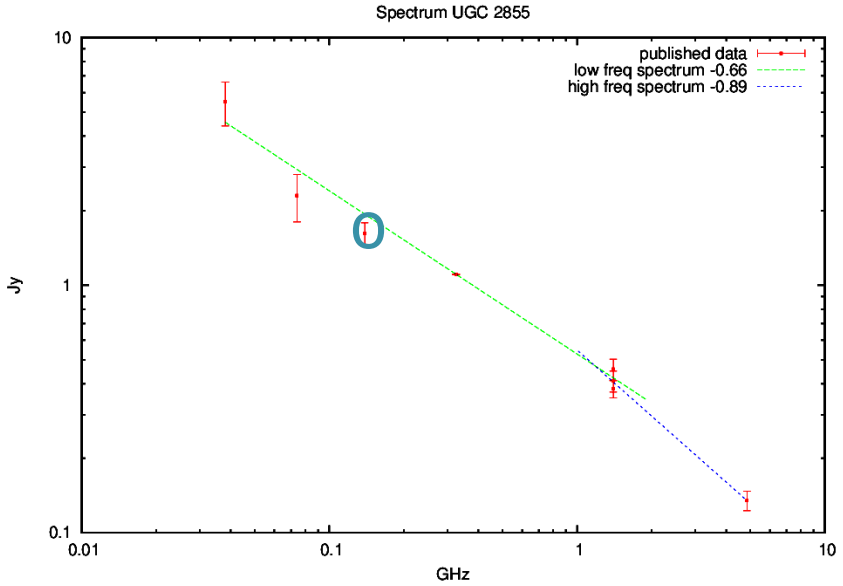


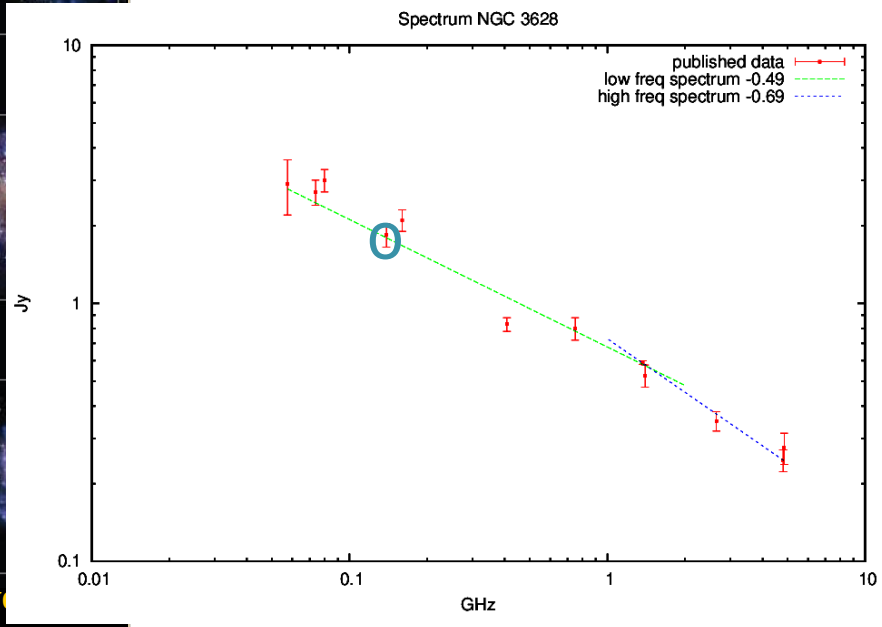


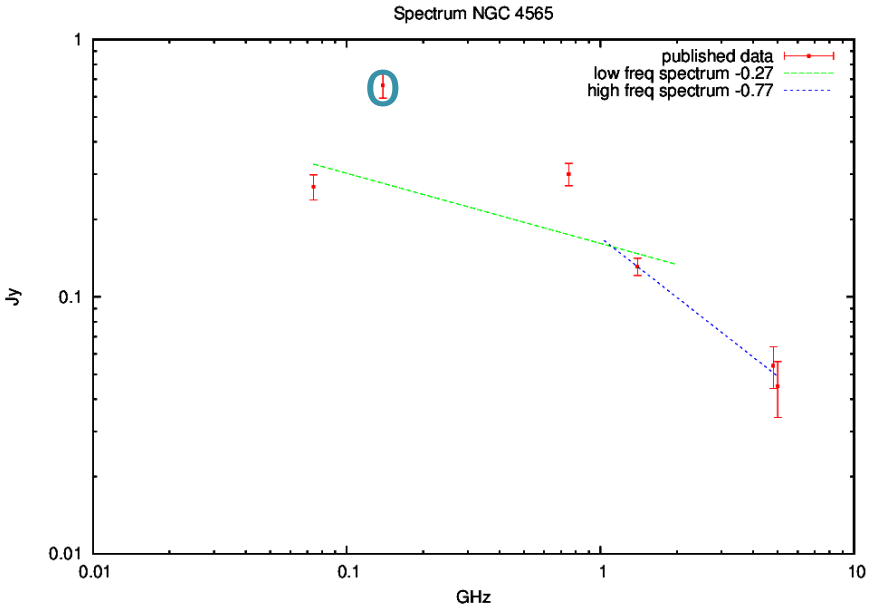


Spectral index (literature search 50 galaxies)

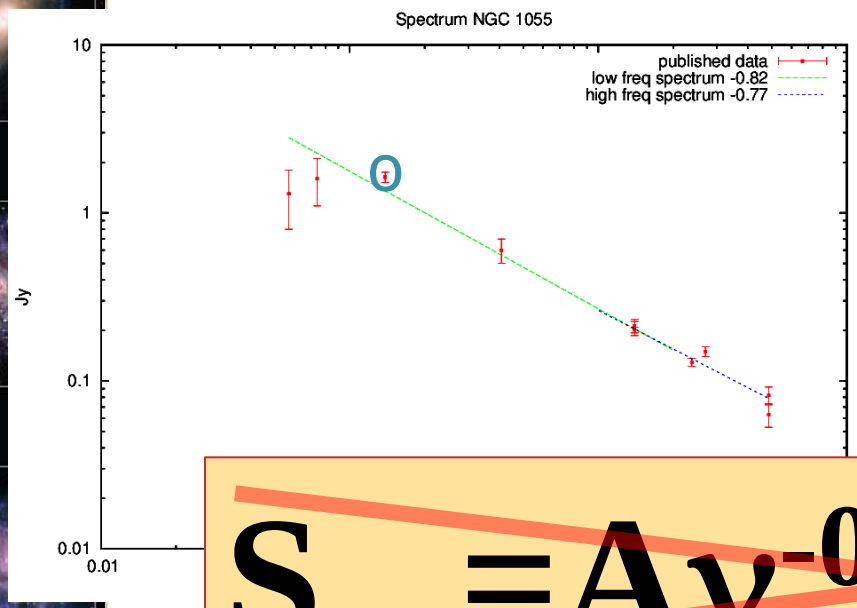


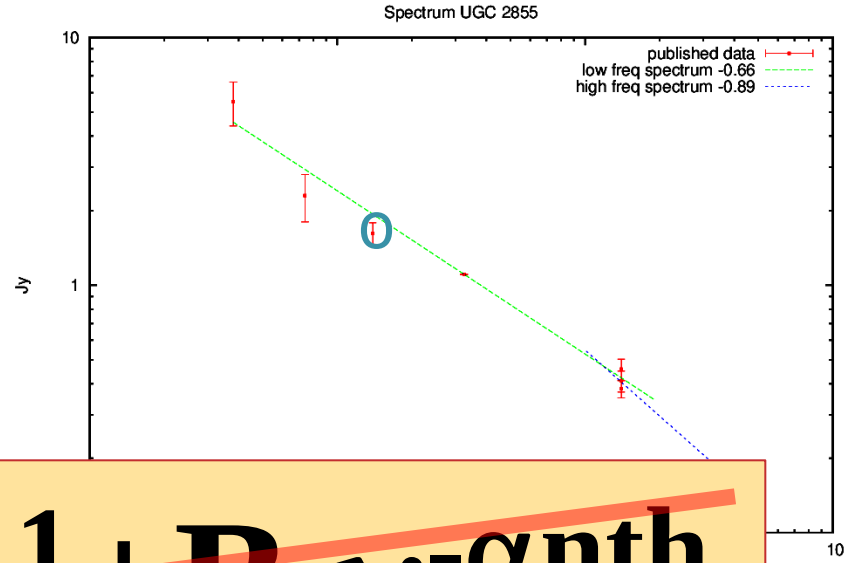




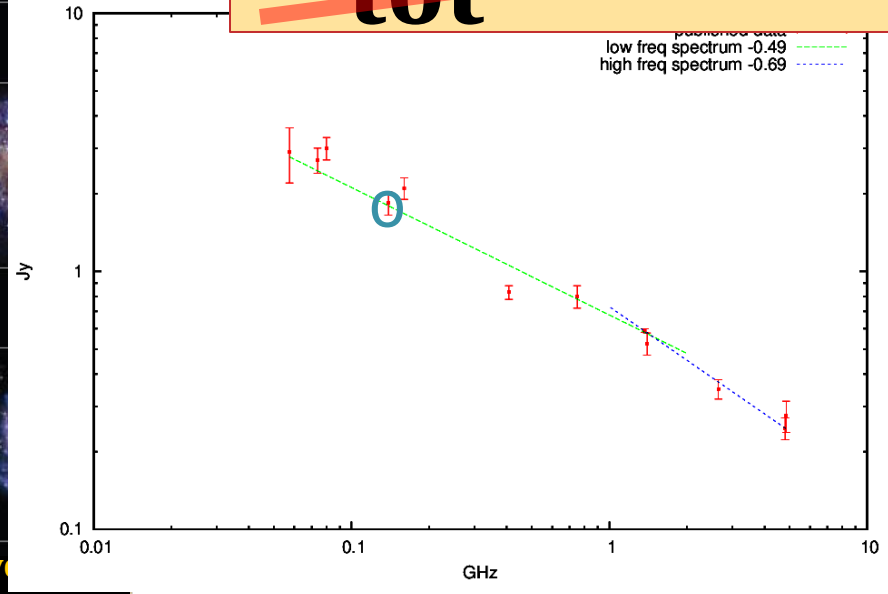


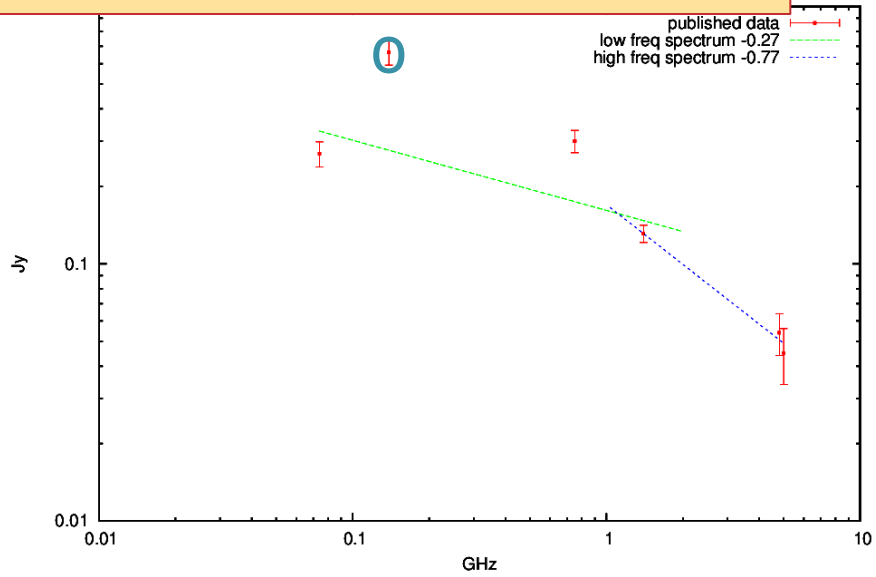
Spectral index (literature search 50 galaxies)





$$S_{tot} = A\nu^{-0.1} + B\,\nu^{-\alpha nth}$$





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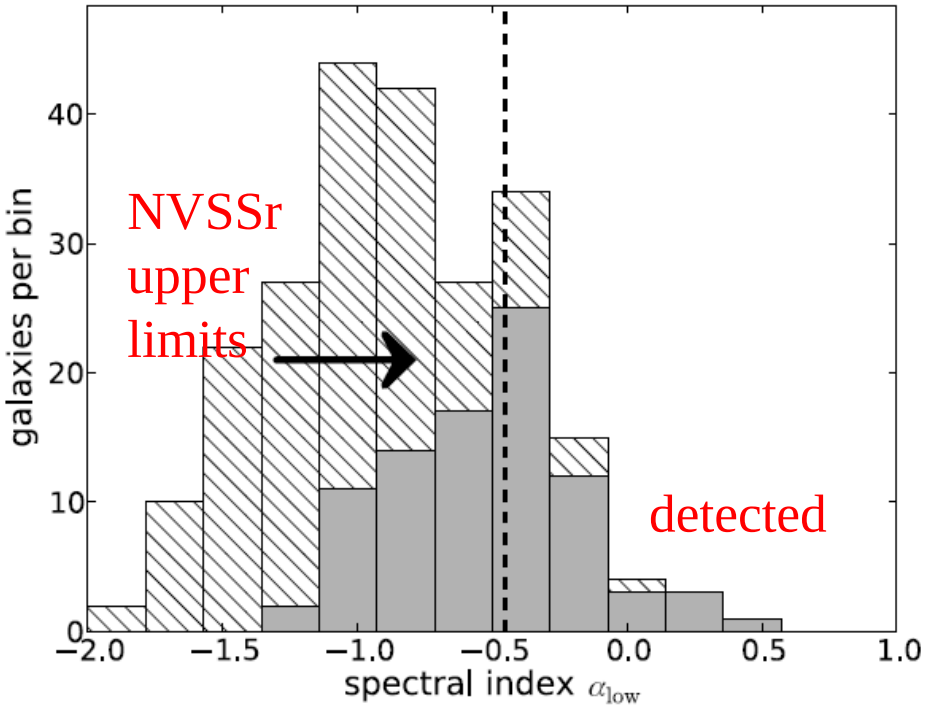
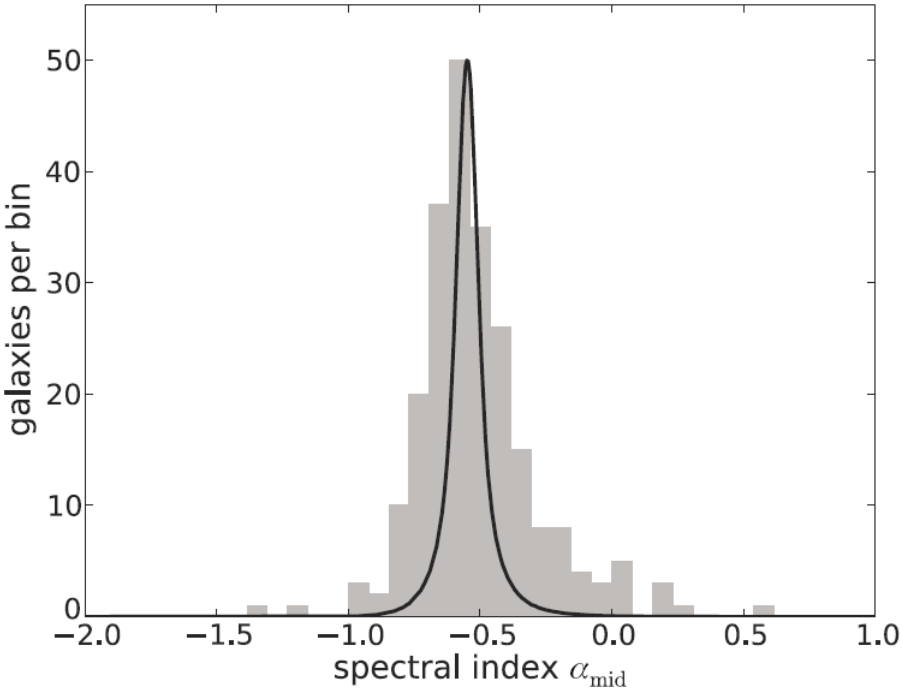
Marvil et al. 2015

VLSS-WENSS



WENSS-NVSS



alpha = -0.45±0.05
More asymmetric than MSSS
Positive spectral index?

alpha = -0.55±0.01
Positive spectral index?

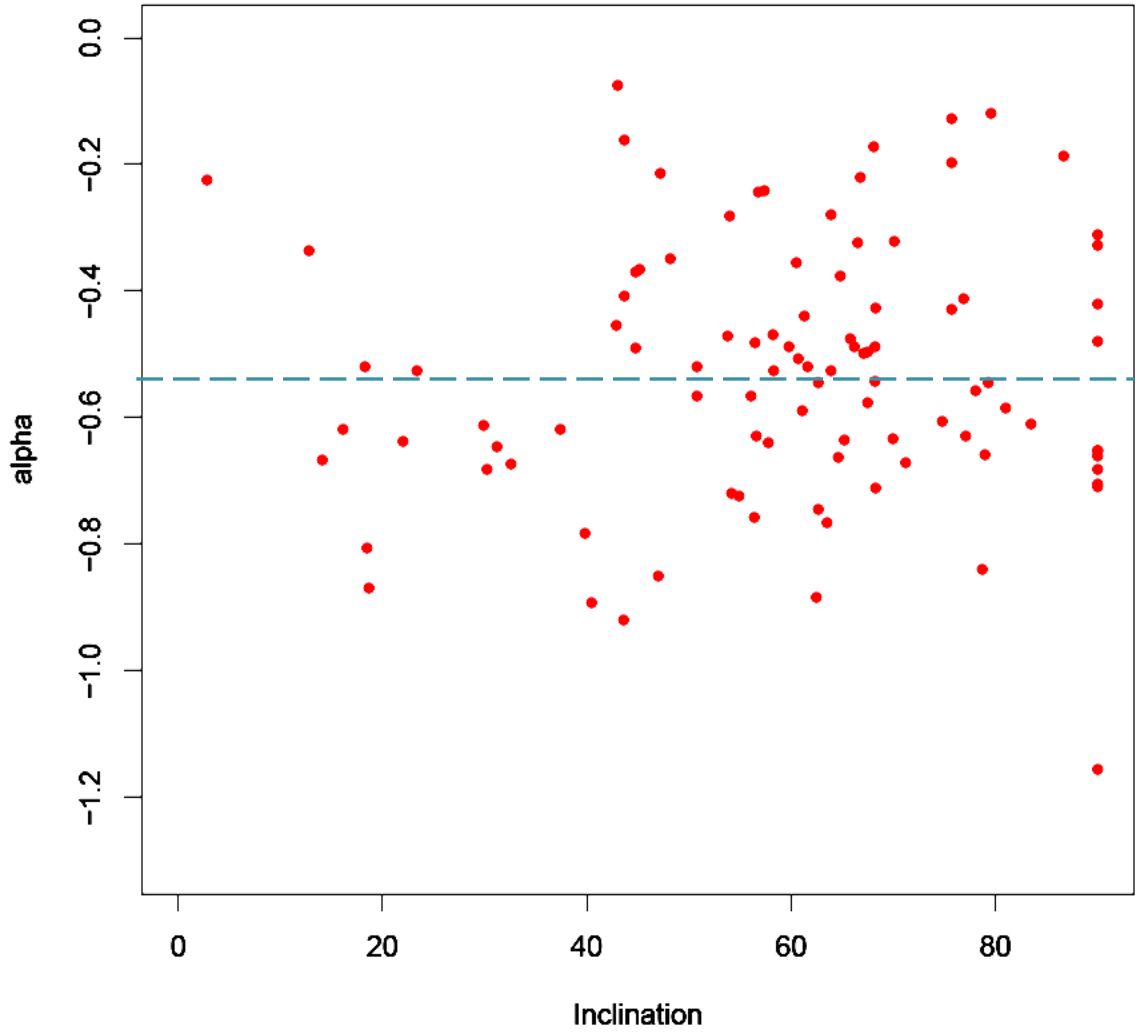
Detection of curvature in the mean spectrum

Ravenstein
9.03.2015





Spectral index (MSSS-NVSS) - inclination

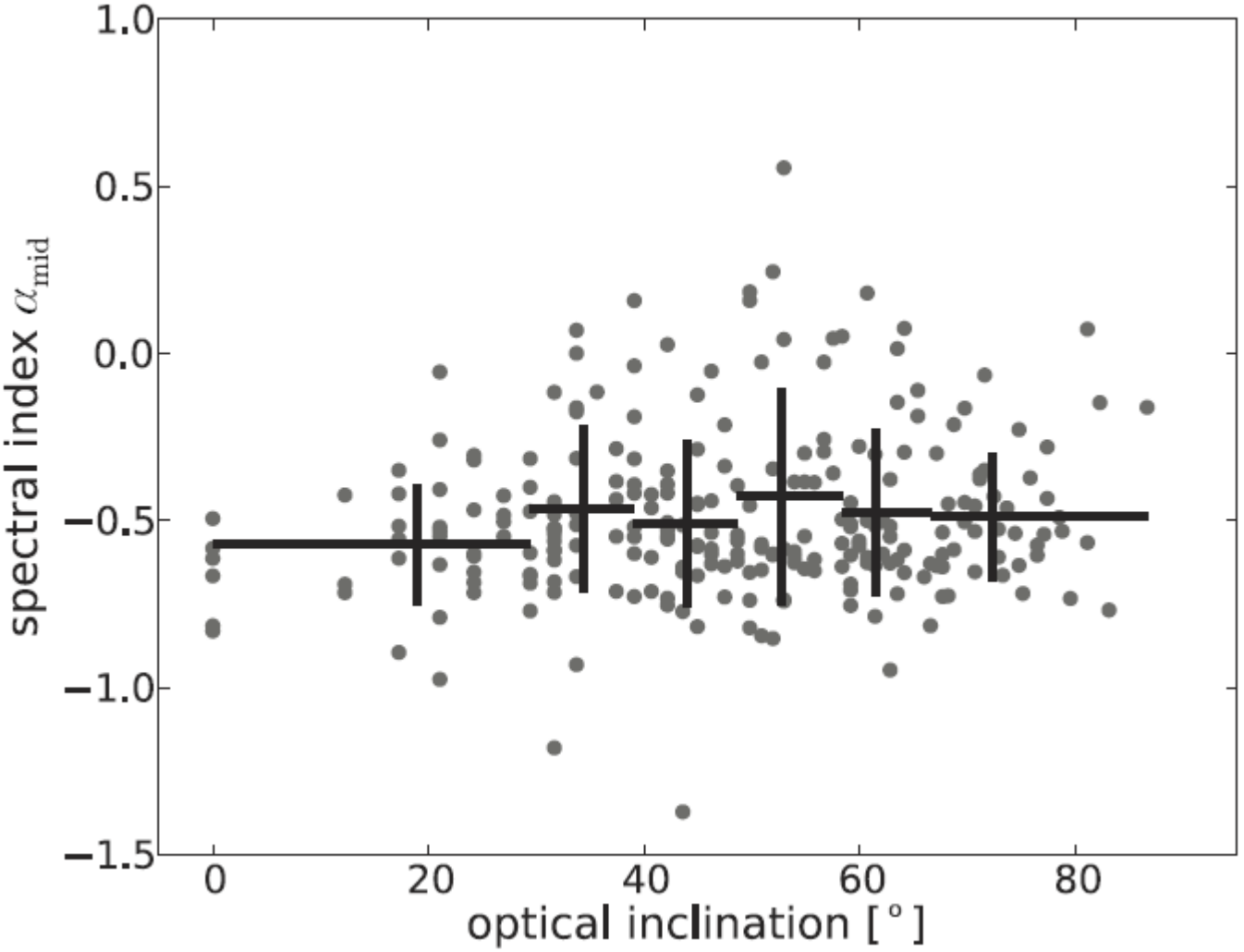


No trend of flatter spectra for highly inclined galaxies
Flattening not due to f-f absorption, synchrotron losses?





Marvil et al. 2015 (alpha: WENSS-NVSS)



Flatter spectra not due to thermal absorption
Sample includes T<1, alpha>0

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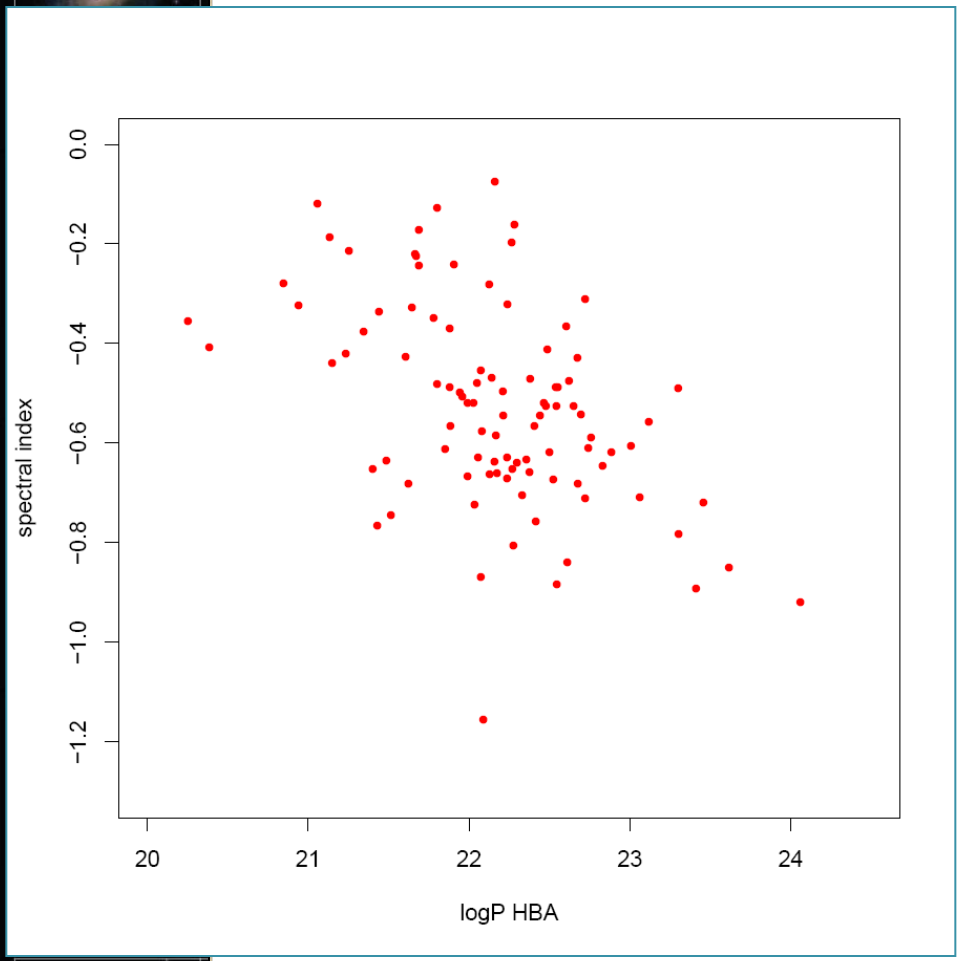
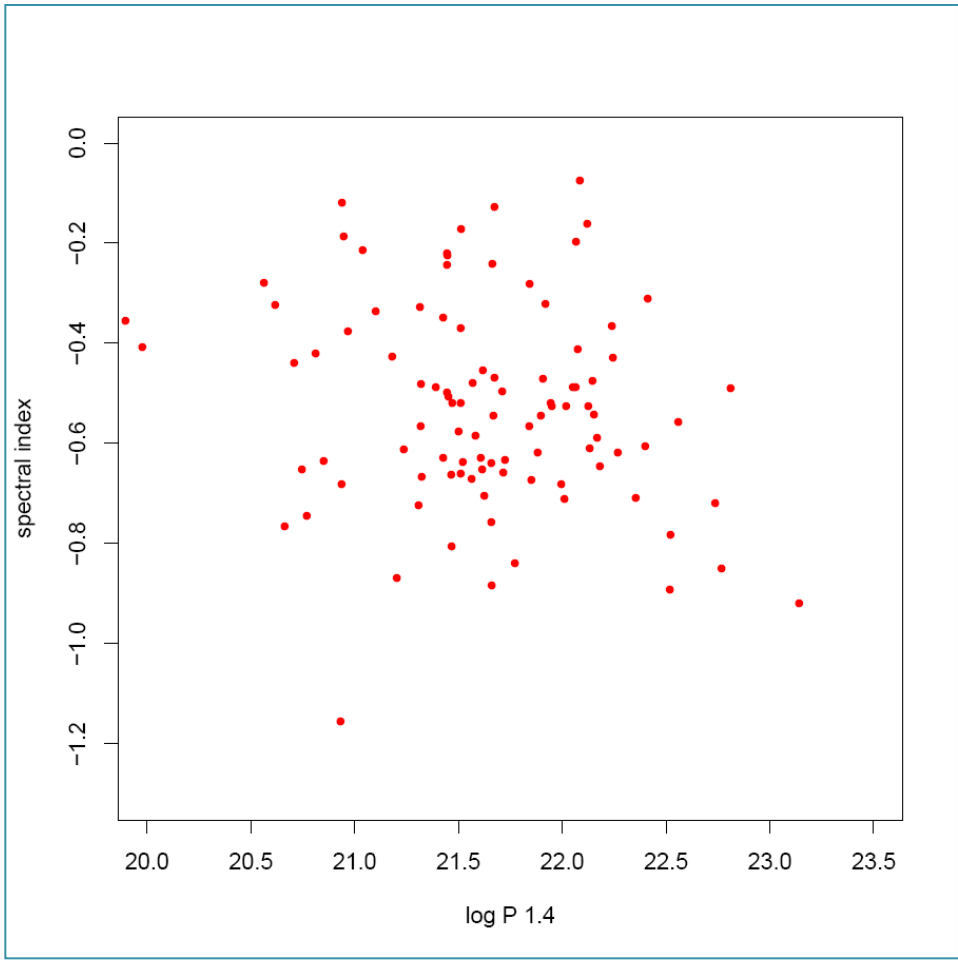
Spectral index (MSSS-NVSS) - luminosity





Spectral index shows a weak anti-correlation with luminosity

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9.03.2015

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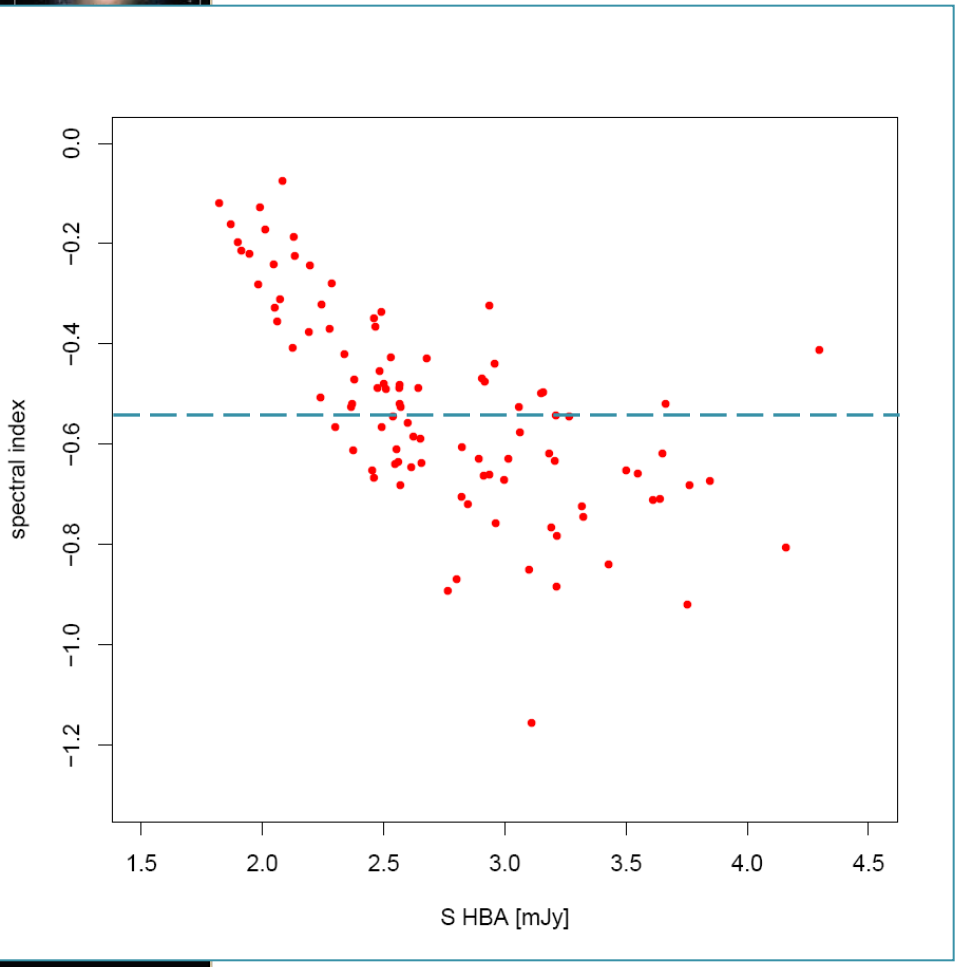
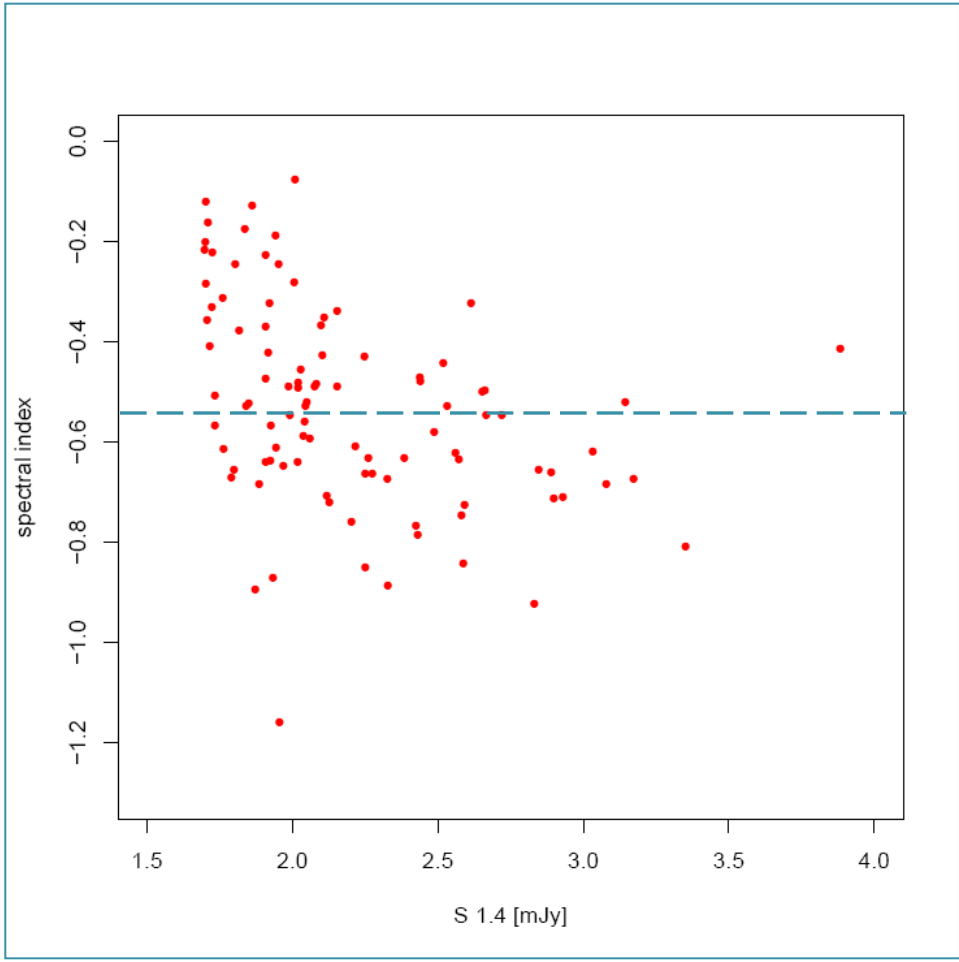
Spectral index - flux





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Spectral index also shows a weak anti-correlation with flux

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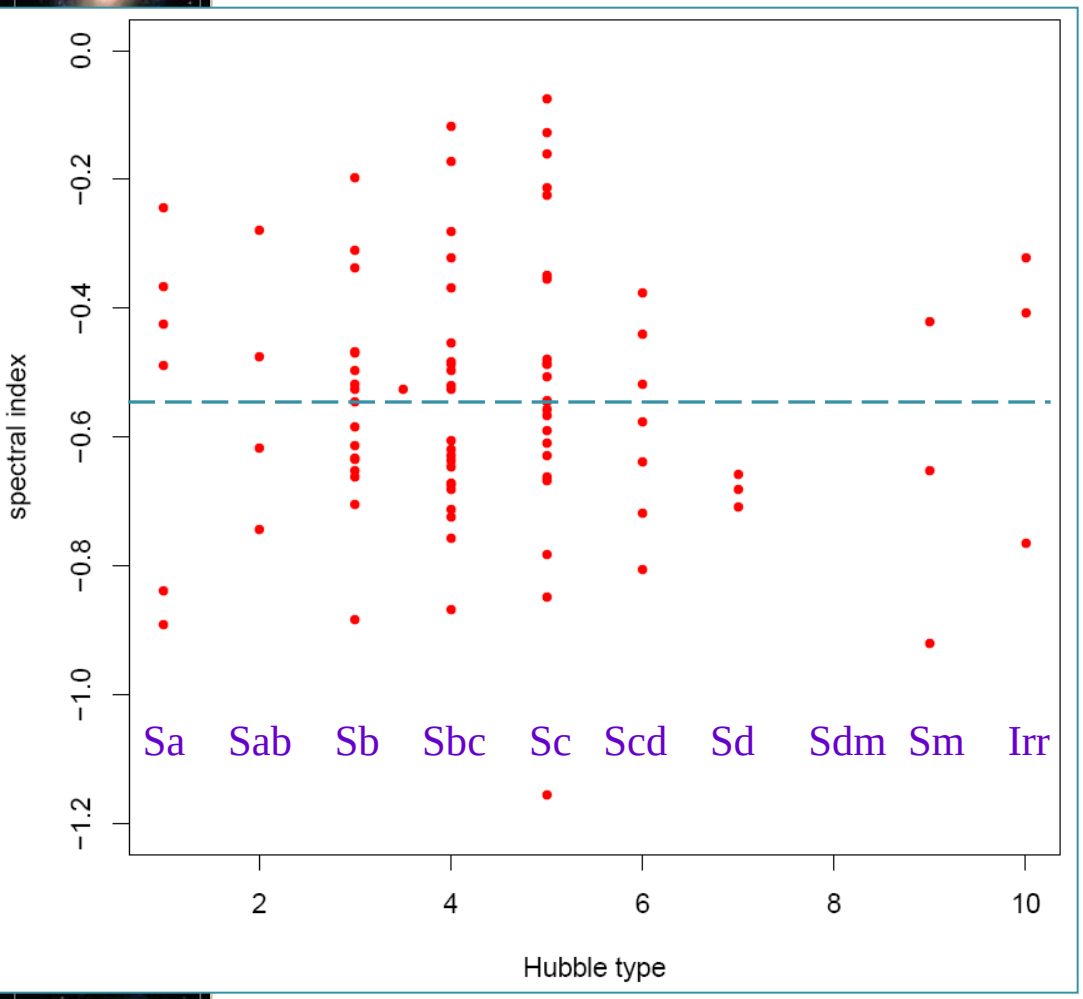
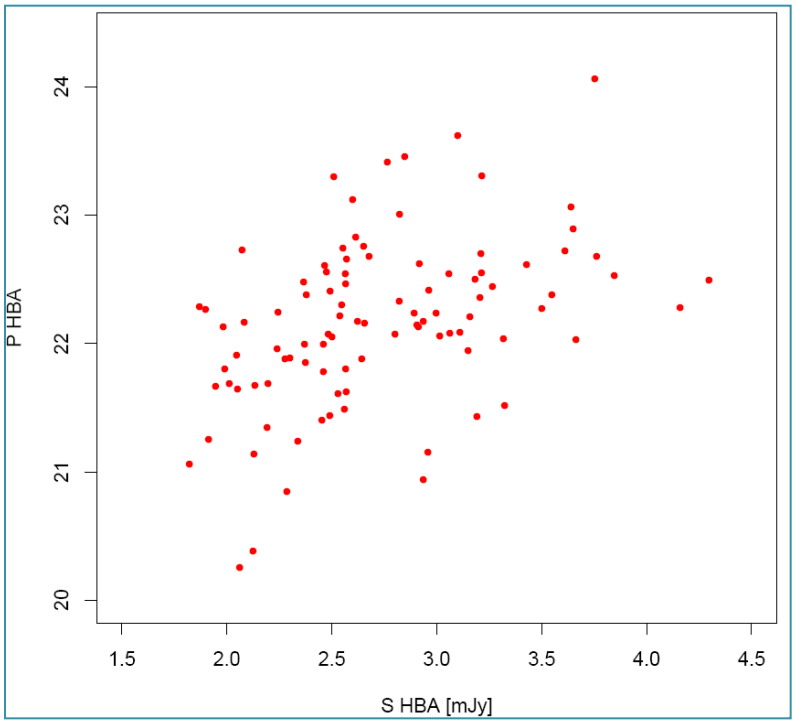
Spectral index – Hubble type



Flux – luminosity



No trend

Positive correlation

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Possible further investigation

Investigate the slopes of the spectra from individual MSSS subbands for a few bright galaxies

Determine magnetic fields in a uniform way for all galaxies (no problem with thermal emission)

Weaken selection criteria and allow angularly small galaxies:

- D<2’ (contact John Conway)

52 compact sources in Yun catalog >50 mJy
=> expect ~36 galaxies with measurable MSSS fluxes

- Comparison sample – recognize systematic effects
- LIRGS - the ”rosetta stone” of galaxy evolution
- First step to starbursts and high-z Universe studies of galaxies with LOFAR
- Follow-up studies with Tier-1 survey

MKSP
NG WG

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9.03.2015

Are flux measurements reliable?

Bright sources (S >> r.m.s)

Repeat flux measurements from averaged images after 1 year

	new	err	old	err	(old-new)/old
N2146	4,461	0,448	4,467	0,448	0,001
N2146	4,441	0,445	4,467	0,448	0,006
N6946	4,375	0,451	4,611	0,470	0,051
N4631	5,826	0,586	5,777	0,582	-0,009
N2841	0,373	0,046	0,363	0,046	-0,028
N7479	0,143	0,031	0,121	0,032	-0,179
N3432	0,304	0,040	0,218	0,041	-0,395

Repeat flux measurements in individual subbands after 1 year
NGC 4631 (extended)

Freq	new	err	old	err	(old-new)/old
119,627	7,080	0.711.27602116	7,009	0,705	-0,010
124,901	6,782	0,682	6,746	0,679	-0,005
128,807	6,157	0,620	6,132	0,618	-0,004
135,057	5,892	0,594	5,850	0,591	-0,007
143,260	5,752	0,581	5,714	0,578	-0,007
147,362	6,229	0,628	6,162	0,622	-0,011
151,268	5,684	0,574	5,642	0,571	-0,008
156,737	4,859	0,493	4,824	0,491	-0,007
	6,054		6,010		-0,007





Are flux measurements reliable?

Some **weak** sources (S > r.m.s)

NGC 7448 difference 100% (175 mJy)
NGC 3169 difference 100% (157 mJy)
NGC 6070 unclear detection

Some flux measurements of weak galaxies are problematic
The **large** sample actually constitutes the limit for galaxy studies with the MSSS





Is MSSS catalog useful for galaxy studies?

Compare our flux measurements and catalog values for extended galaxy NGC 4631

Freq	new	err	Catalog	(new-cat)/new
119,627	7,080	0,711	6,360	0,102
124,901	6,782	0,682	5,880	0,133
128,807	6,157	0,620	5,300	0,139
135,057	5,892	0,594	5,070	0,140
143,260	5,752	0,581	4,860	0,155
147,362	6,229	0,628	5,280	0,152
151,268	5,684	0,574	5,070	0,108
156,737	4,859	0,493	4,140	0,148
	6,054		5,245	0,135

14% difference

Compare flux measurements for compact galaxy NGC 2146

	Method 1		Method 2					
Freq	Common cont	err	Different cont	err	(met1-met2)/met1	Catalog	err	(met1-cat)/met1
119,627	4940,310	494,823	4677,407	474,824	0,056	4,382	0,075	0,113
124,901	5100,417	510,833	4940,685	499,891	0,032	5,069	0,070	0,006
128,807	4684,379	469,425	4416,237	447,079	0,061	4,482	0,065	0,043
135,057	4603,005	461,259	4422,017	446,358	0,041	4,738	0,060	-0,029
143,260	4495,403	450,617	4402,160	443,524	0,021	4,532	0,057	-0,008
147,362	4195,530	420,754	4018,387	404,473	0,044	3,918	0,054	0,066
151,268	4268,391	427,856	4195,235	421,877	0,017	4,162	0,052	0,025
156,737	4086,932	410,163	3870,049	389,553	0,056	3,753	0,057	0,082
					0,041			0,037

4% difference

Larger underestimation of the catalog's values for larger discrepancy in our methods
⇒ catalog's values deviate systematically due to different methods used
⇒ not suitable for extended sources, use for compact sources





Summary

- We constructed a large MSSS sample of ~100 galaxies
- First radio-FIR correlation at low frequencies, similar slope, larger scatter
- Spectral index – flattening at low freq., no relation with inclination (not due to f-f absorption)
- Spectral index – no relation with T but unticorrelation with luminosity and flux
- MSSS fluxes usually fit well the literature spectra, weak sources are more problematic
- MSSS catalog gives underestimated values of galaxy fluxes, could be used for compact galaxies
- Follow-up: investigate slopes, B, compact galaxies, use Tier 1