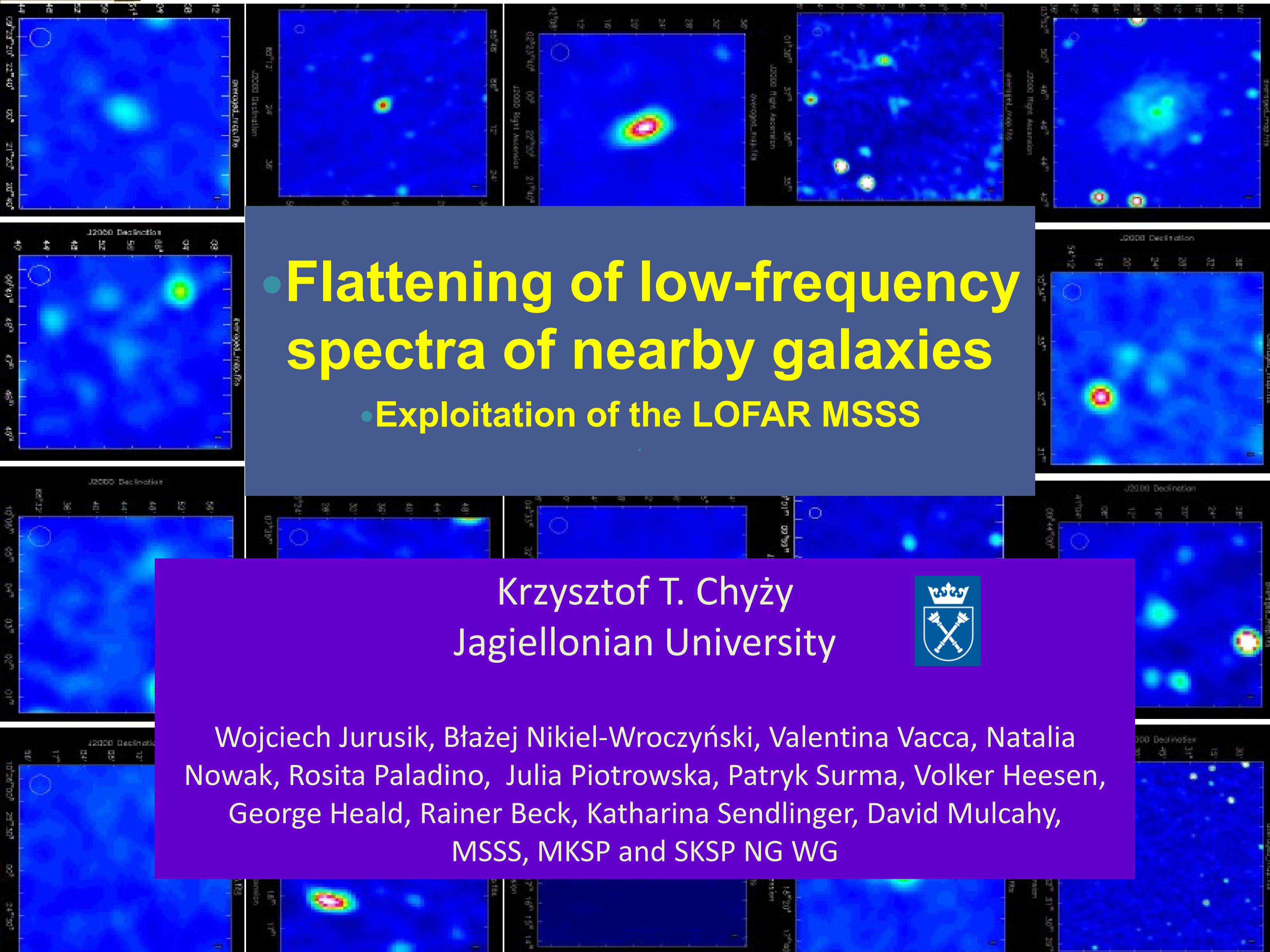

# Flattening of low-frequency spectra of nearby galaxies

## Exploitation of the LOFAR MSSS


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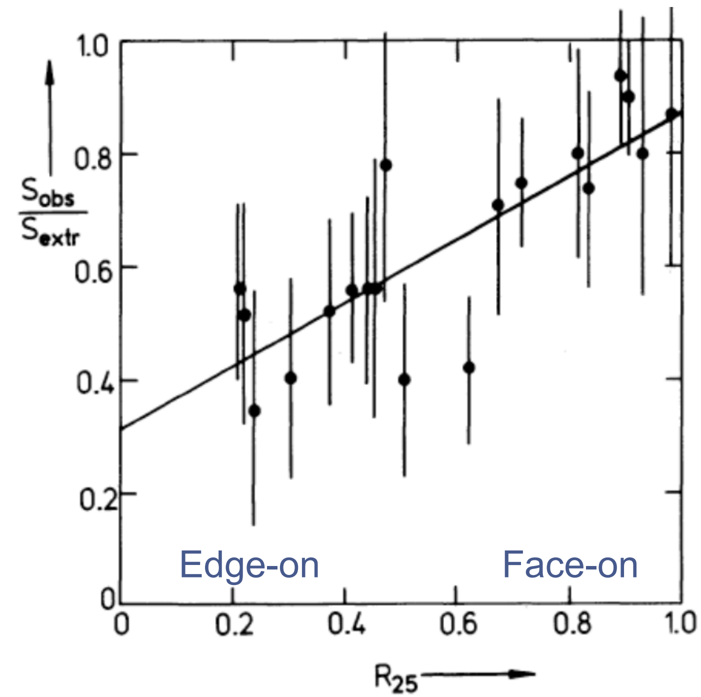
Wojciech Jurusik, Błażej Nikiel-Wroczyński, Valentina Vacca, Natalia Nowak, Rosita Paladino, Julia Piotrowska, Patryk Surma, Volker Heesen, George Heald, Rainer Beck, Katharina Sendlinger, David Mulcahy, MSSS, MKSP and SKSP NG WG

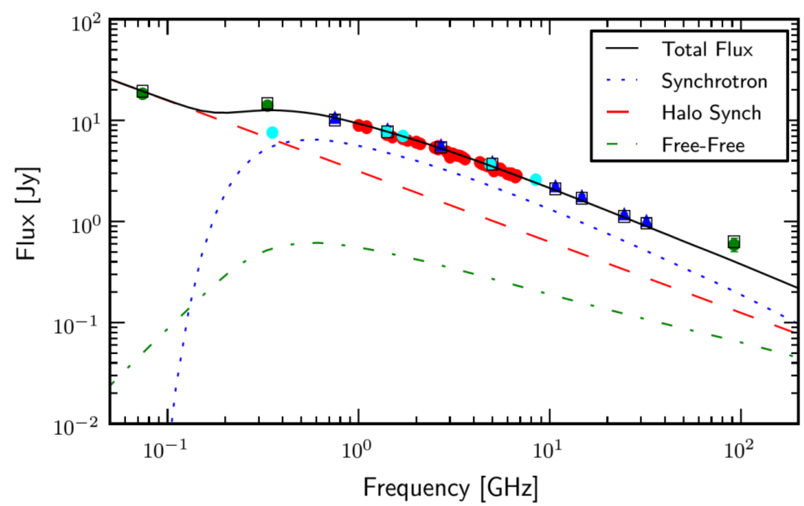
# Motivation

- F. Israel and M. Mahoney 1990 extrapolated high-freq. spectra
- Galaxy fluxes at 57 MHz were smaller than expected
  => increasing free-free absorption of synchrotron emission with increasing galaxy tilt
- f-f absorption from T<1000K gas in the thick disk
- Discussion: Condon et al. 1991, Condon 1992, Hummel 1991, Marvill et al. 2015)

LOFAR – excellent tool to offer suitable data to re-investigate the problem




Israel and Mahoney 1990




M82 - Yoast-Hull et al. 2013
See also Lacki 2013, Adebahr 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

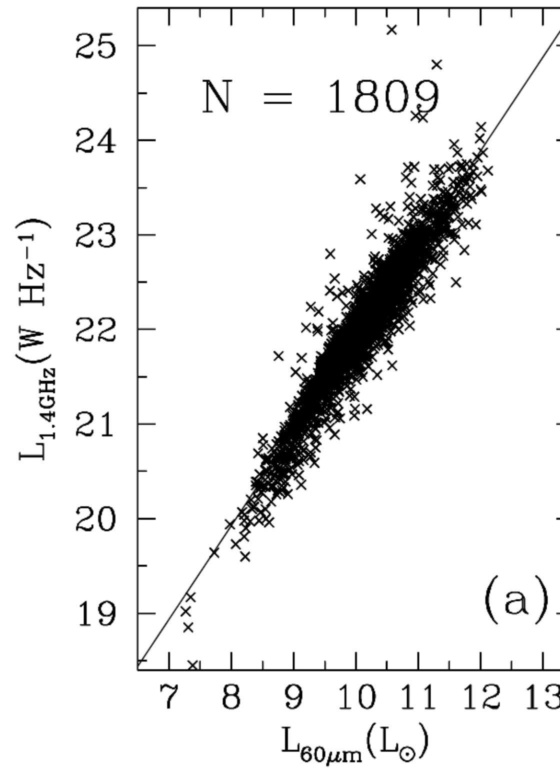
Selection criteria:
- S(1.4 GHz) >50 mJy
- Morphological type T>0, Dec>0
- Removed obvious AGN dominated galaxies

204 galaxies

LOFAR MSSS (Heald et al. 2015)
- Sensitivity ~15-20mJy/b.a. , resolution 2’
- Integrated fluxes in 8 spectral bands, interpolated flux at 150 MHz
- MSSS Catalog and our CASA measurements

122 classified for further analysis

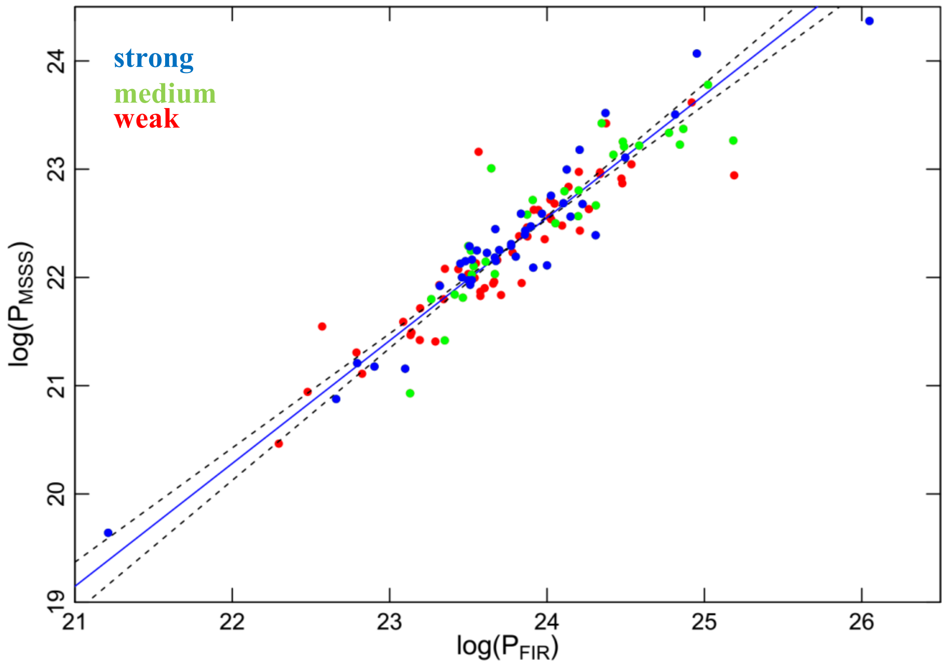
Yun et al. 2001



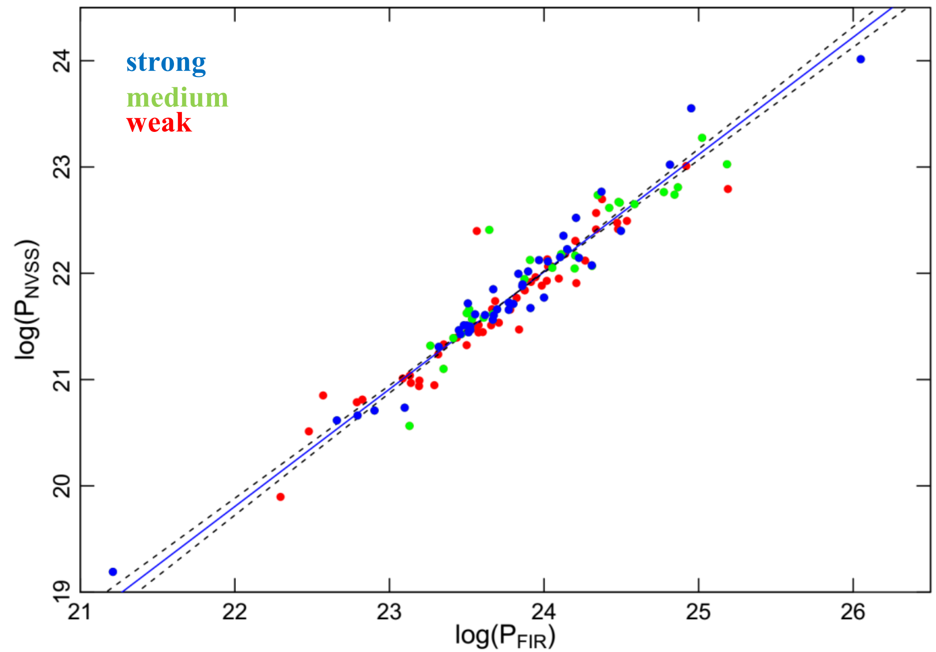

slope=0.99±0.01

# MSSS/NVSS radio – infrared correlation

MSSS 150 MHz



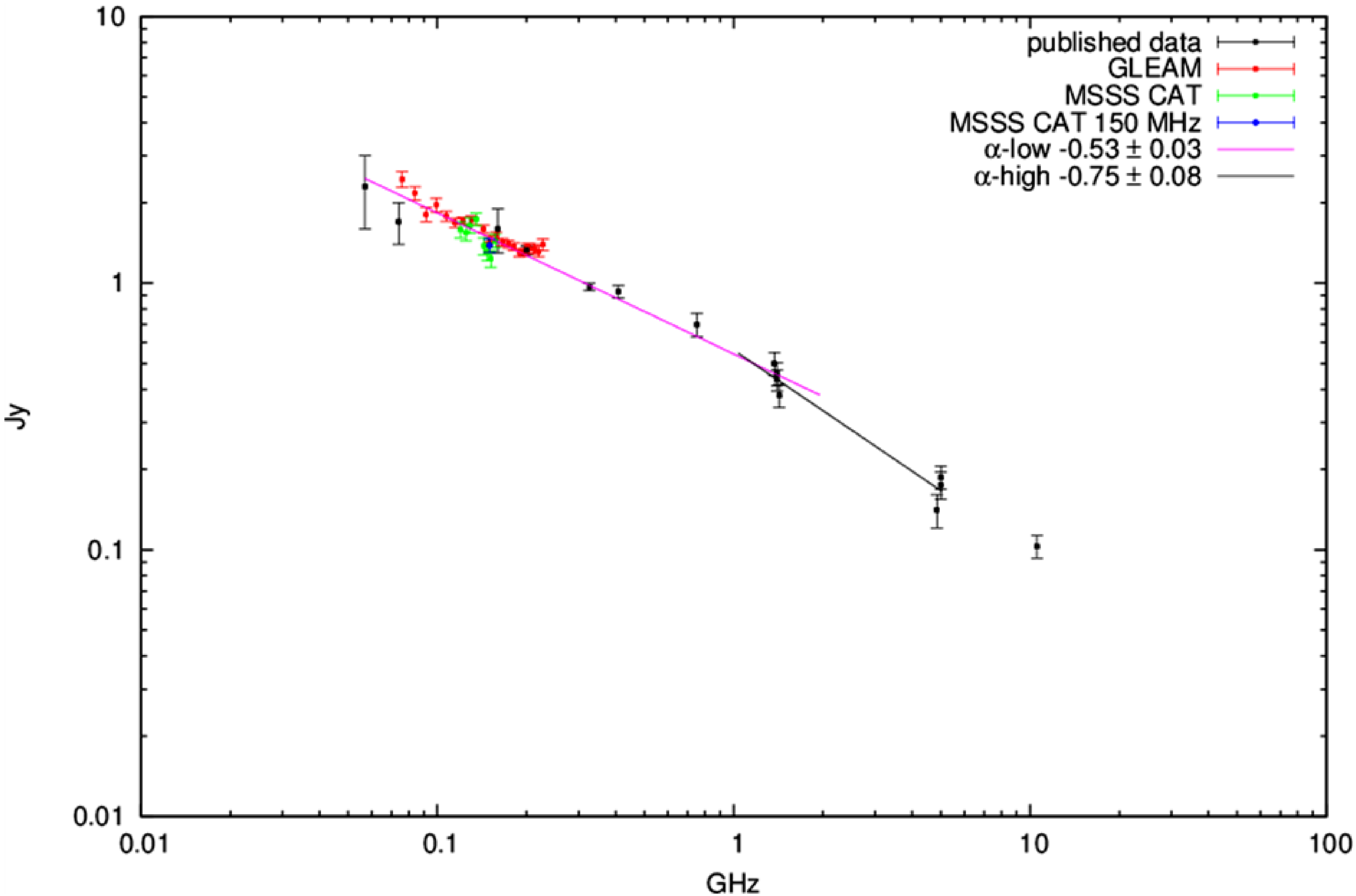

NVSS 1400 MHz




## Table of (bisector) slopes

| | MSSS 150 MHz | NVSS 1400 MHz |
|---|---|---|
| Strong (42) | 1.13±0.07 | 1.11±0.06 |
| +Medium (71) | 1.14±0.06 | 1.11±0.04 |
| +Weak (122) | 1.14±0.05 | 1.10±0.03 |

# Spectra of individual galaxies (NGC3627)

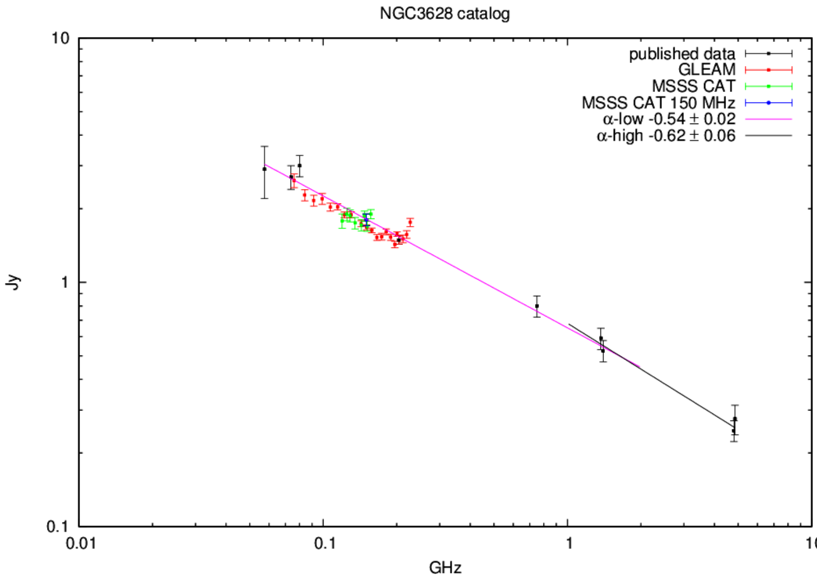


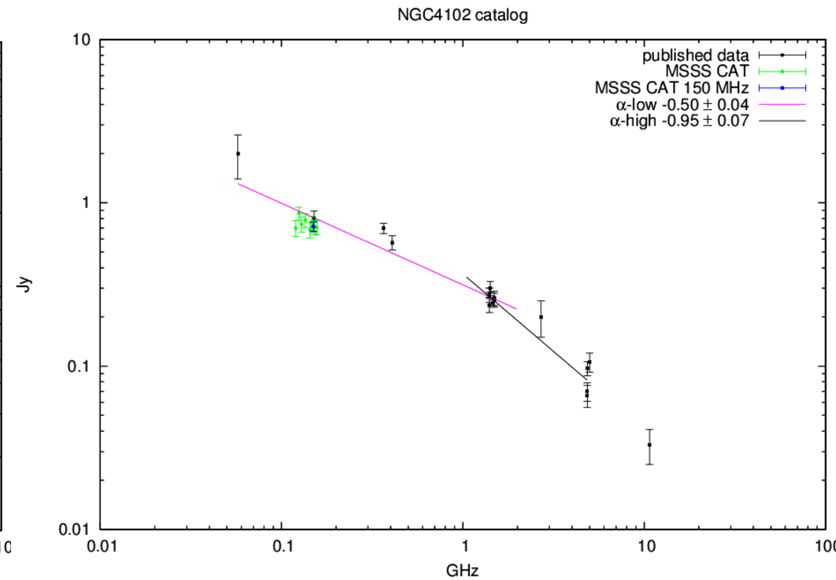

- Spectrum slightly flatter at low frequencies

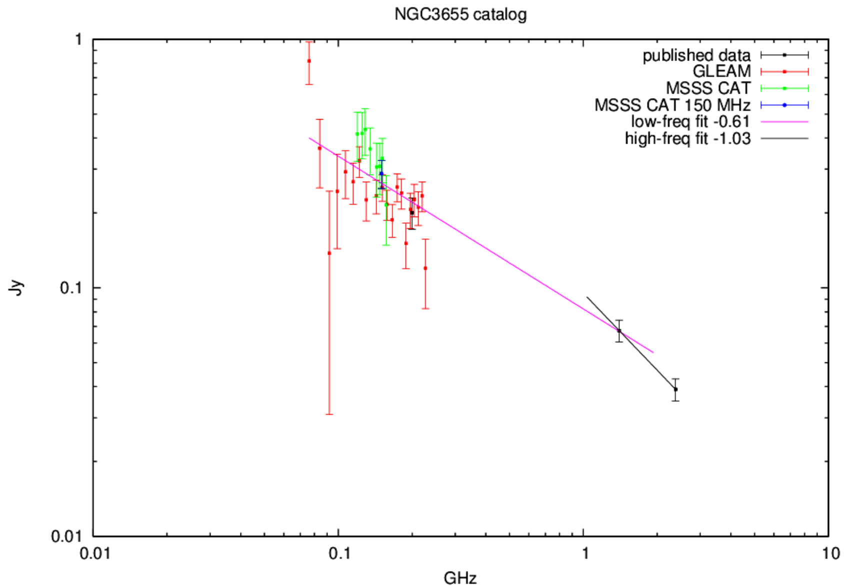
# Spectra of individual galaxies (more)

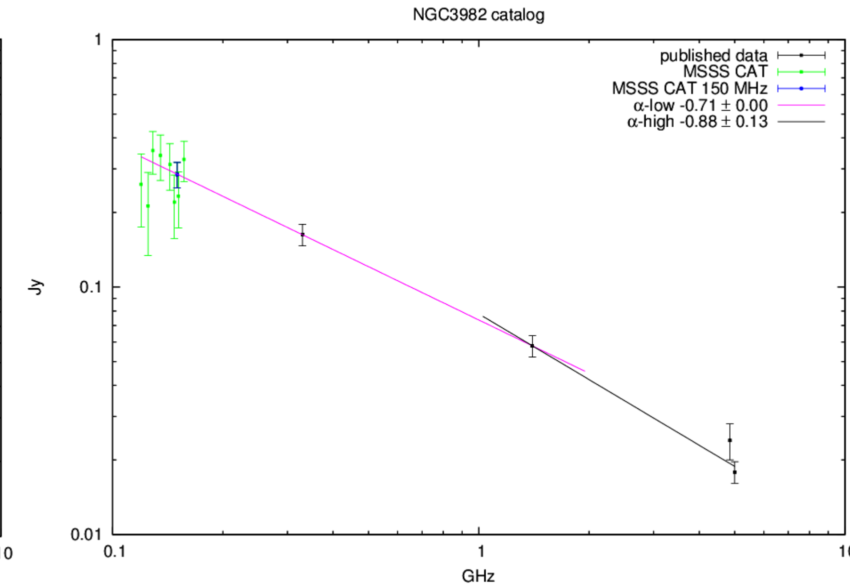







- Weak flattening at low frequencies
- f-f absorption?

# There is flattening at low frequencies!

$\alpha_{high}(1400 - 5000) = -0.76 \pm 0.21$

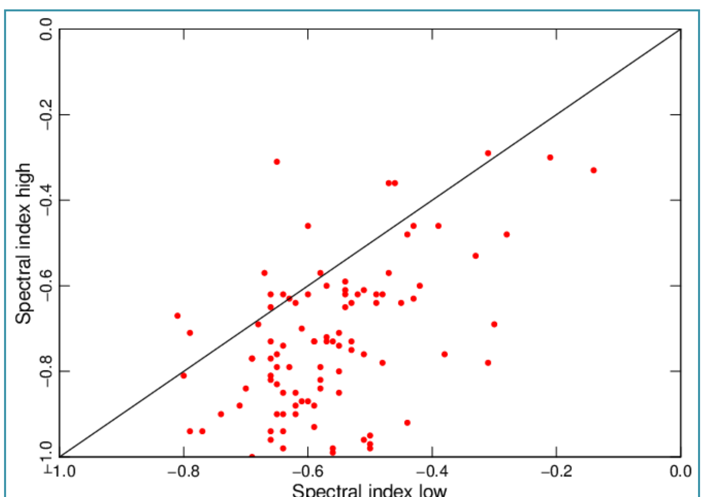
$\alpha_{low}(150 - 1400) = -0.59 \pm 0.10$

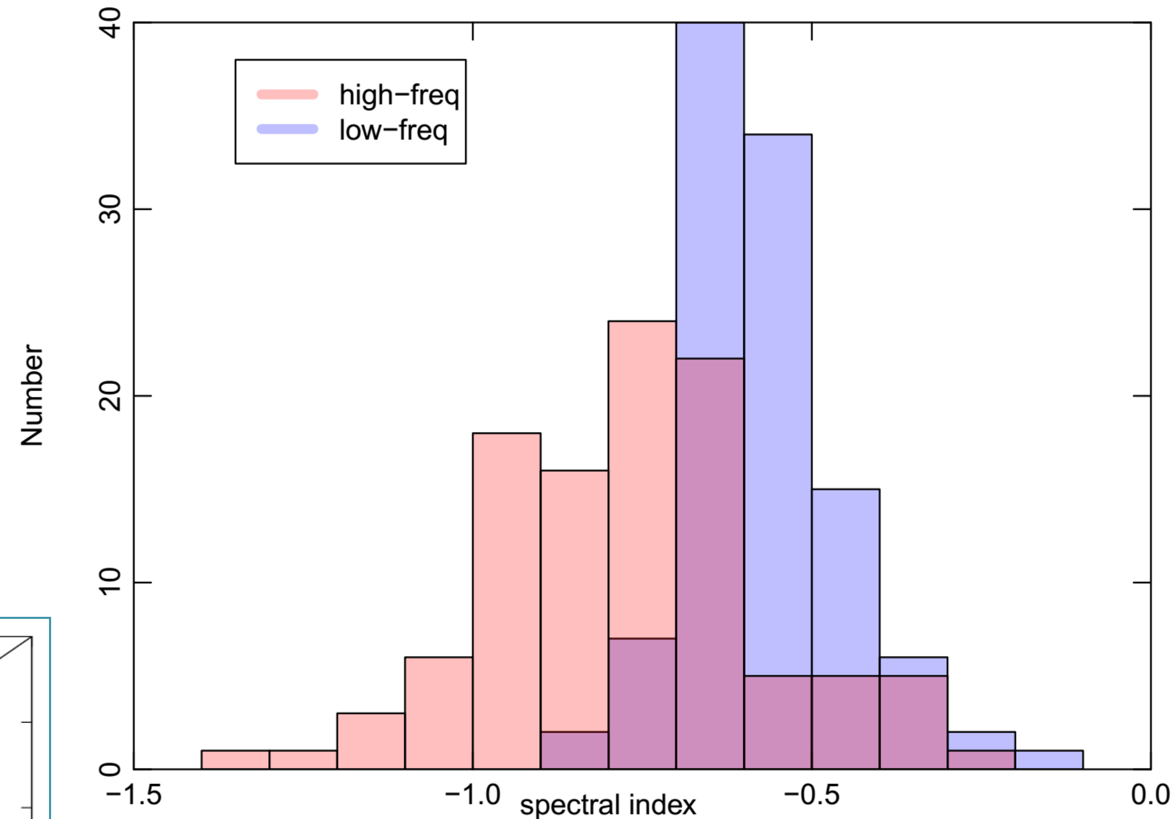
N=107

**Sp. Index difference:**
0.17±0.15 (MED±MAD)

**Two-sample K-S test**
p-value = 4.885e-15

**Kruskal-Wallis rank test**
p-value = 1.6e-14

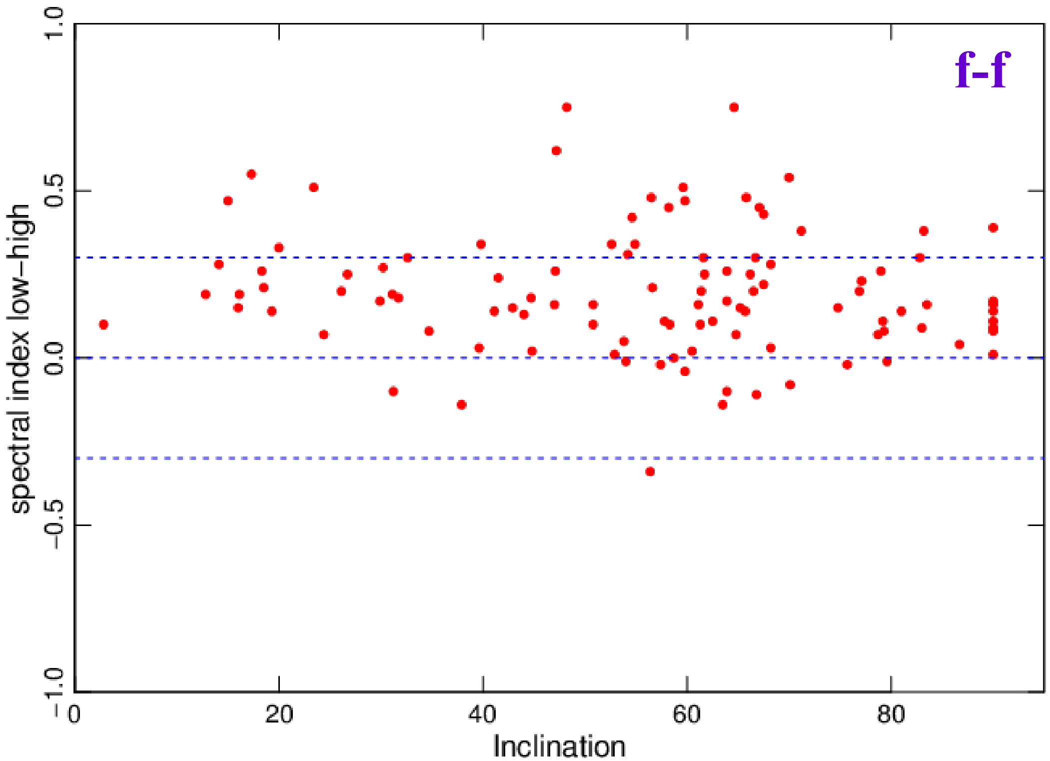


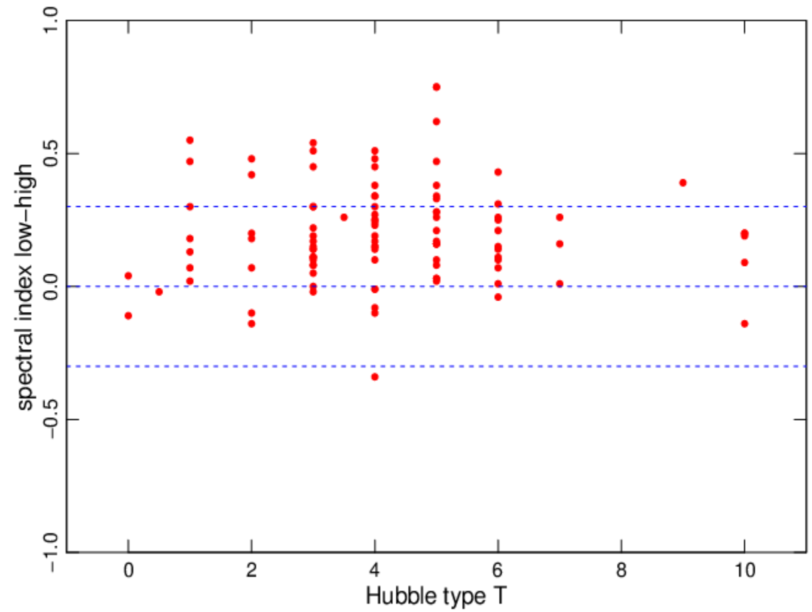



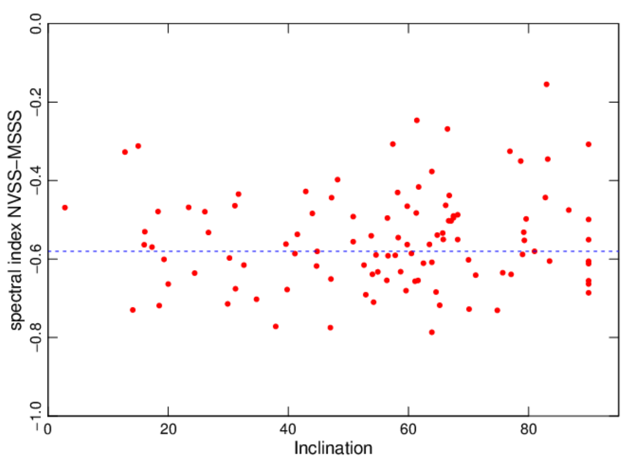

- Low-frequency flatter (high frequency steeper)
- The trend observed by Israel & Mahoney 1990?

# Thermal (f-f) absorption of synchrotron photons?

Low – high spectral index N=107




- No trend with galaxy tilt is observed
- Flattening not due to f-f absorption
- No relation with galaxy morphology

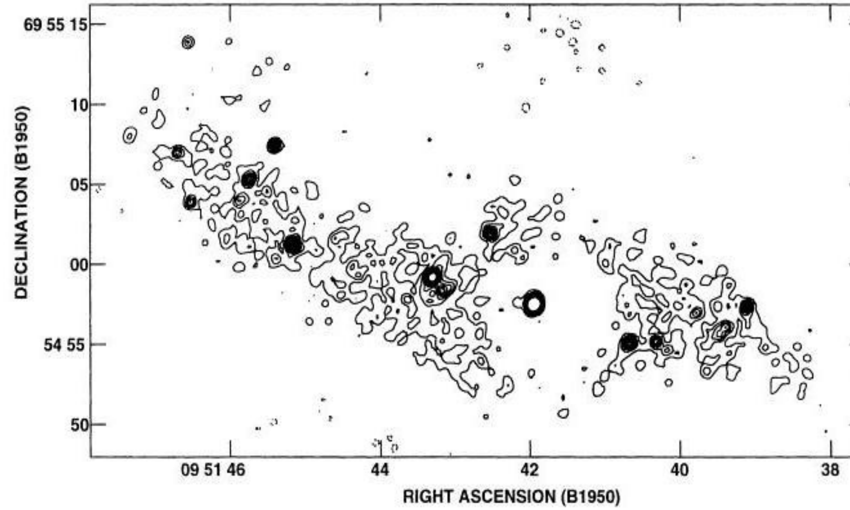




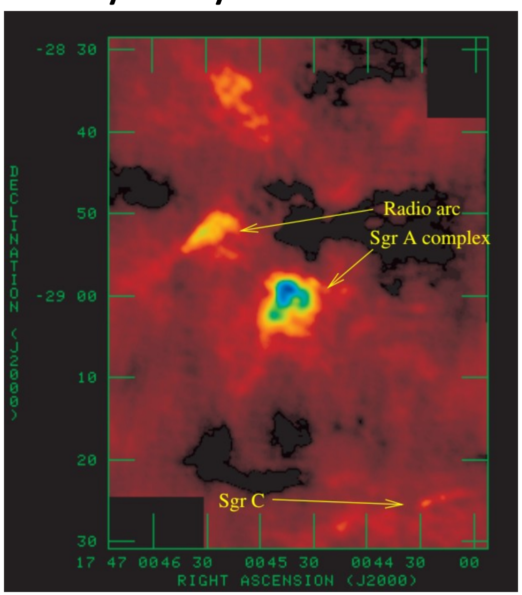
# But we see absorption effects

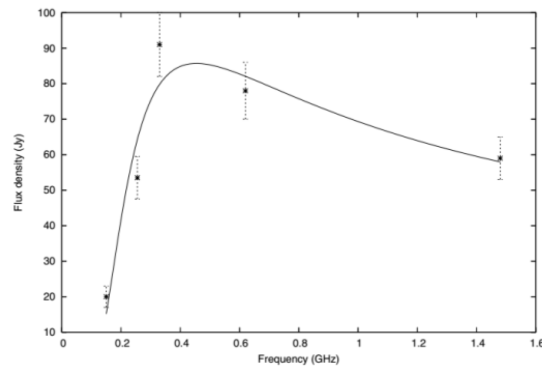
M82

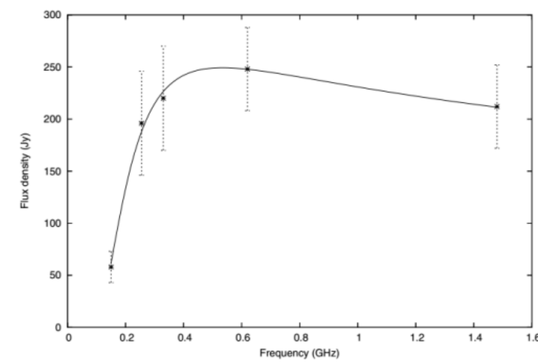
Wills 1997
MERLIN 408 MHz




Milky Way centre



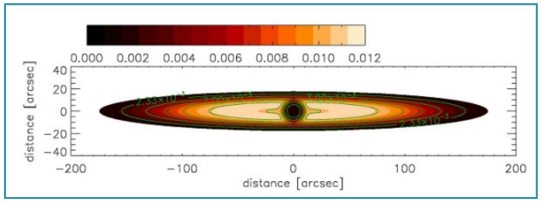



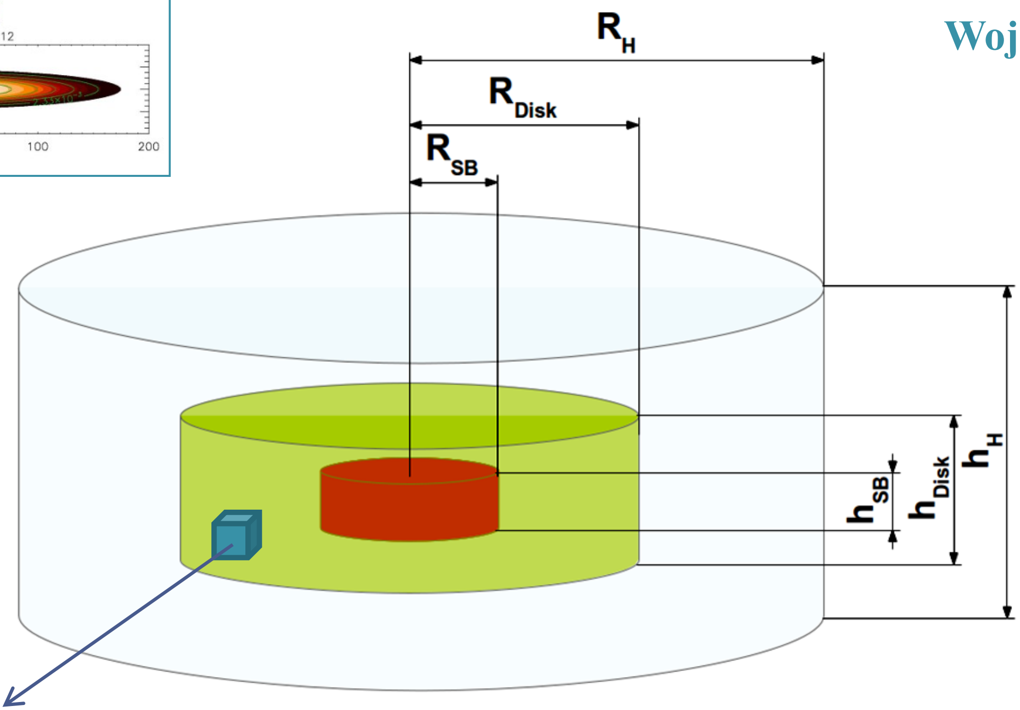




Roy & Rao 2006
GMRT 154 MHz, 255 MHz

# Modelling of f-f absorption

Wojciech Jurusik

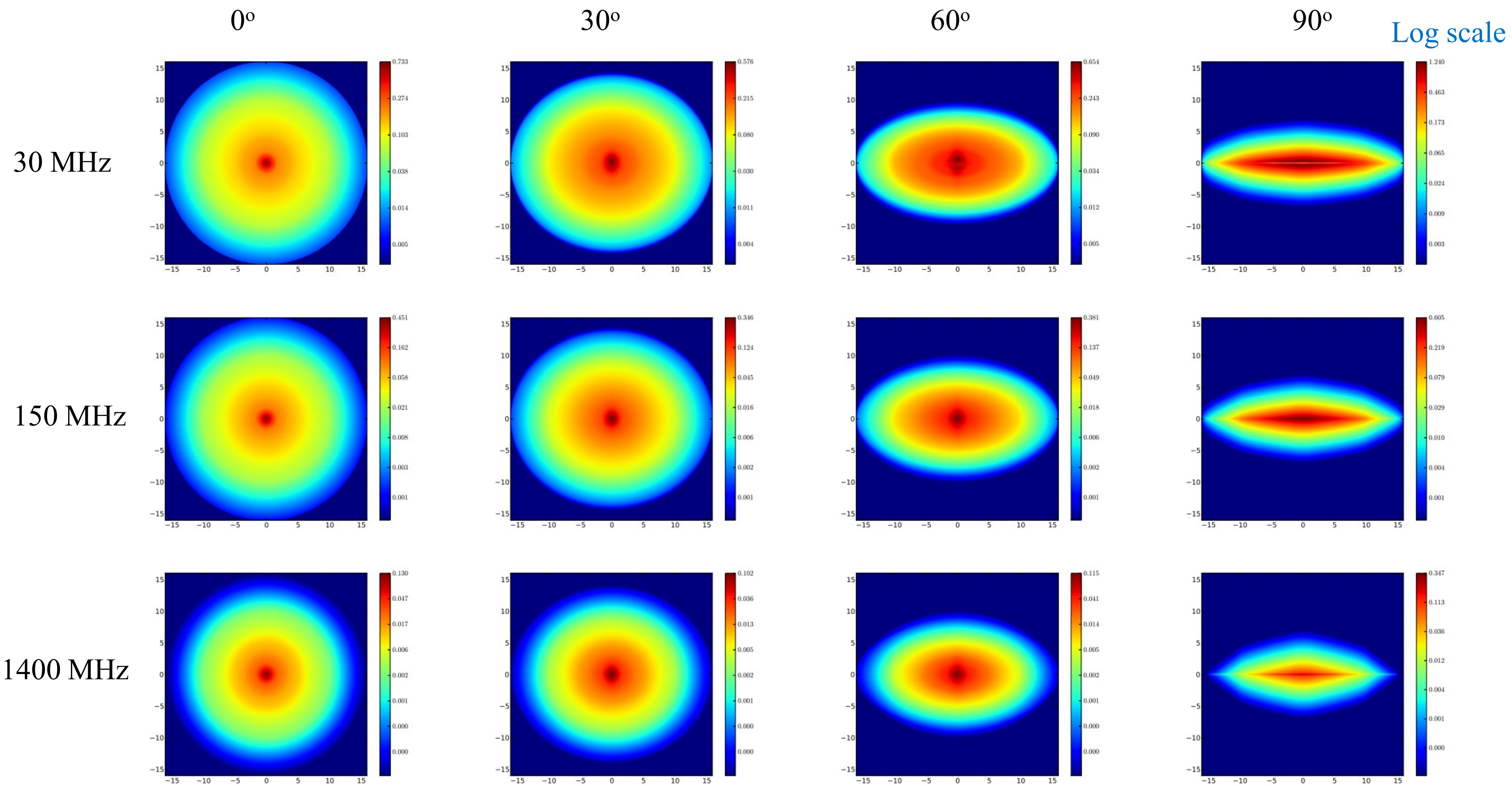



- Assume main galaxy components (e.g. compact centre, thin and thick disks, synchrotron halo)
- Set parameters in each cell describing thermal emission and absorption, synchrotron emission (em., abs. coef., filling factor), CRs propagation and B effects (emission profiles – scaleheights, scalelengths)
- Choose viewing angle and solve transfer equation along l.o.s. at various frequencies
- Obtain maps, integrate fluxes, construct model spectra, compare with actual ones

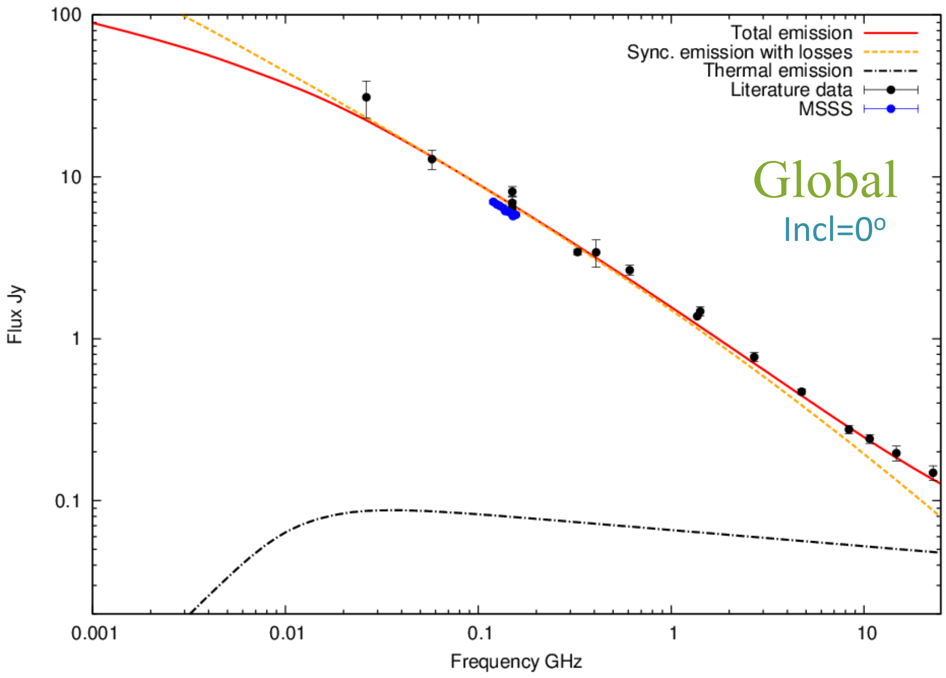
# M51-like galaxy

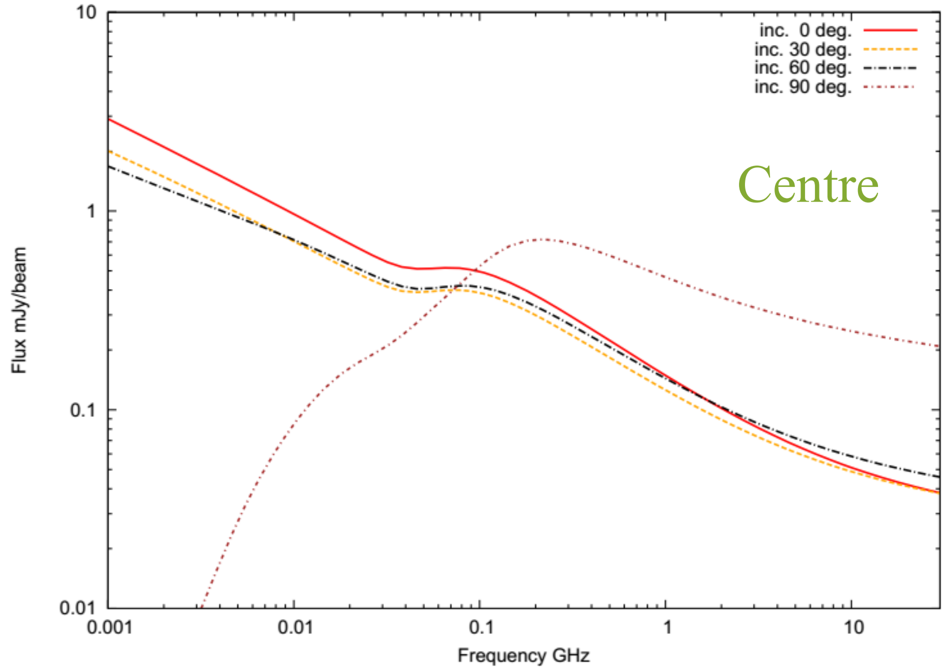
## modelled radio and spectral profiles




**Very weak effect of thermal absorption (~30 MHz, not 150 MHz)**

# M51 global and local spectra



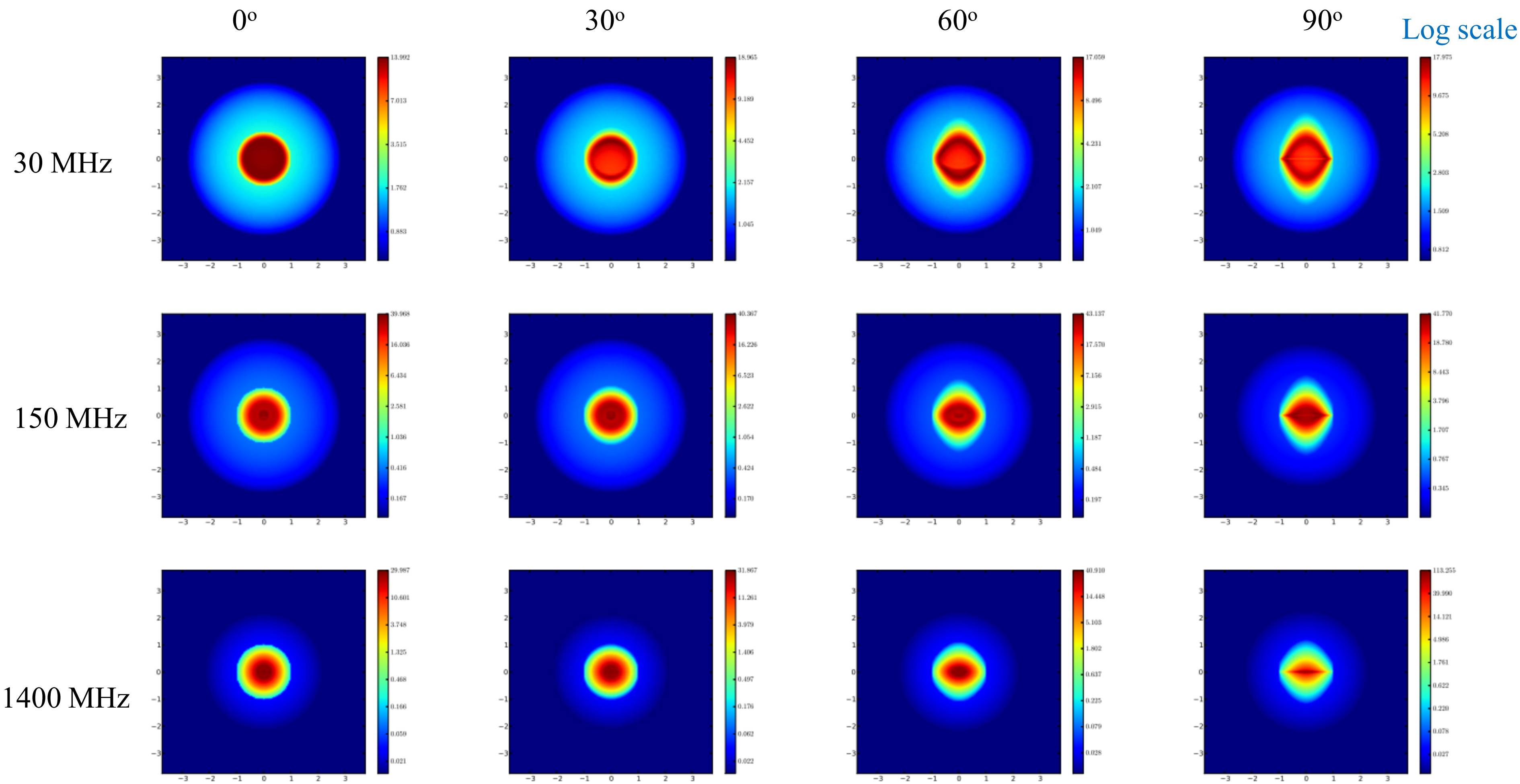

Modelled global spectrum fits the observed fluxes. Model also reproduces observed radial intensity and spectral profiles (Mulcahy et al. 2014)

Local spectrum from galaxy centre for different inclinations

- Global spectrum: weak f-f absorption effects below 10 MHz
- Local spectra are very different and strongly depend on inclination, a spectral turnover in edge-ons

# M82-like galaxy

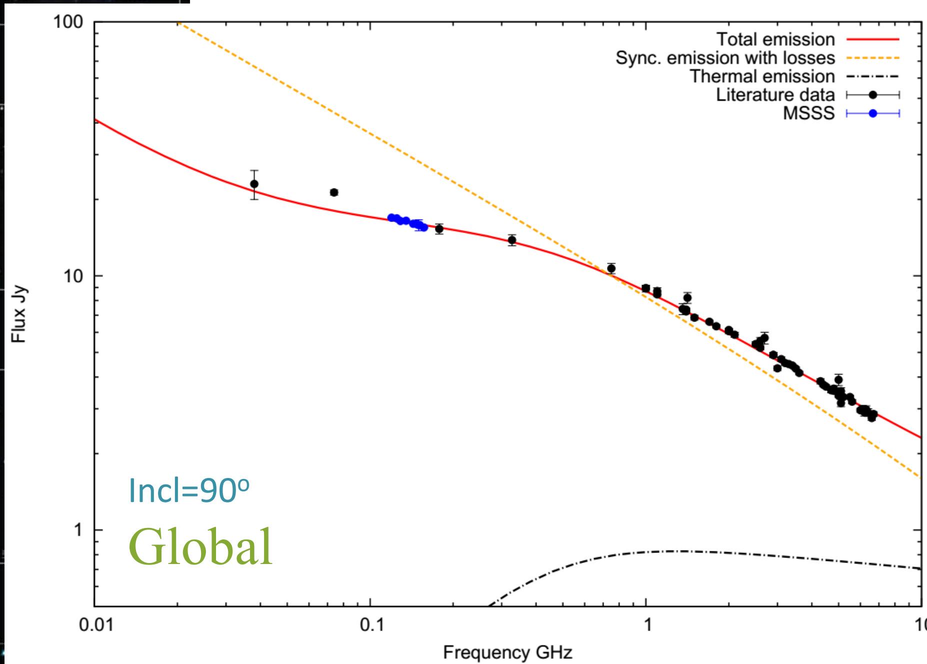
## modelled radio and spectral profiles

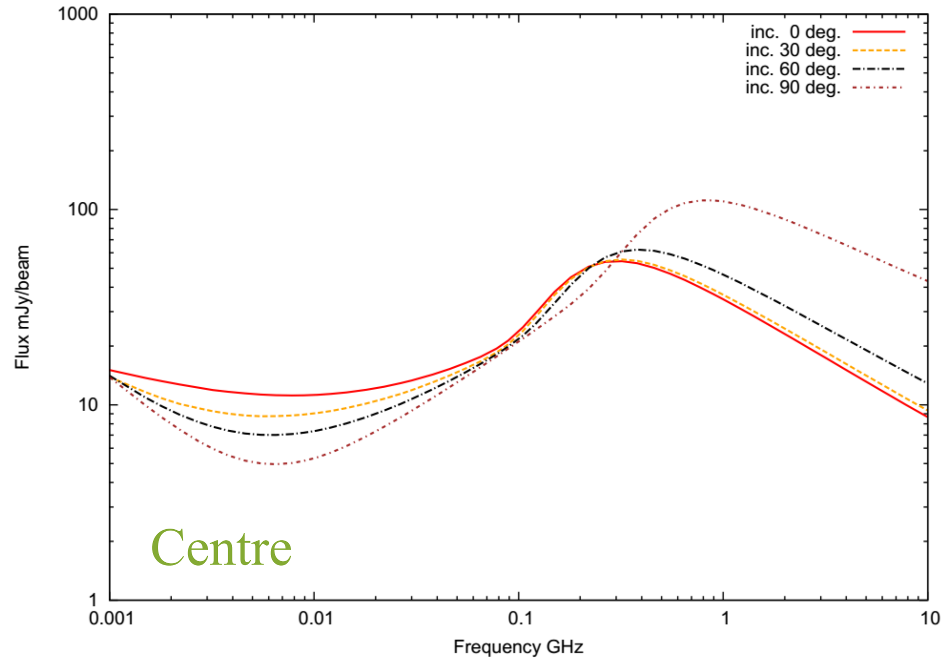



- f-f absorption already seen below a few hundred MHz (cf. Varenius et al. 2015, Wills 1997)

# M82 global and local spectra

## Where we can expect strong thermal absorption?




- Absorption seen in the global spectrum and in the compact centre for all inclinations
- We predict stronger absorption effects in LIRGS, high-z galaxies
- The impact of the MW foreground (~3MHz) – LOFAR on the Moon

# Summary

- We constructed a large MSSS sample of >100 galaxies, LOFAR MSSS fluxes fit well the literature spectra
- Spectral flattening at low frequencies
  - no relation with inclination (no f-f absorption)
  - no relation with morphology
- 3D modelling traces geometry, thermal absorption and inclination effects:
  - for typical galaxies weak flattenigs can be explained by curved synchrotron spectra
  - only compact SF regions produce strong spectral flattenings and turnovers
- We predict stronger absorption effects for distant SF galaxies –> composition and evolution of ISM
- We need LOFAR on the Moon (MW effects)