The MicroJy and NanoJy Radio Sky: Source Population and Multi-wavelength Properties

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Radio Sky

- a view of the Universe unaffected by the absorption

- radio bright (>1 mJy) radio sky consists for the most part of active galactic nuclei (AGN).

- Below 1 mJy there is an increasing contribution to the radio source population
  - synchrotron emission resulting from relativistic plasma ejected from supernovae associated with massive star formation in galaxies

Current radio surveys （10 年前）

- 大天区巡天（1.4Ghz）
  - The NRAO VLA Sky Survey (NVSS): 2.5 mJy
  - FIRST: 1 mJy

- Deep survey with VLA
  - $<$ 0.1 mJy at a few GHz, reaching a maximum area of $\sim$ 2 deg2 (VLA-COSMOS)
  - minimum flux density $\sim$ 15 μJy at 1.4 GHz (SWIRE) and $\sim$ 7.5 μJy at 8.4 GHz (SA 13).

SKA era

- Possibly "all-sky" 1 μJy survey at 1.4 GHz

- 70 MHz ~ 10 GHz extending well into the nanoJy regime with unprecedented versatility.

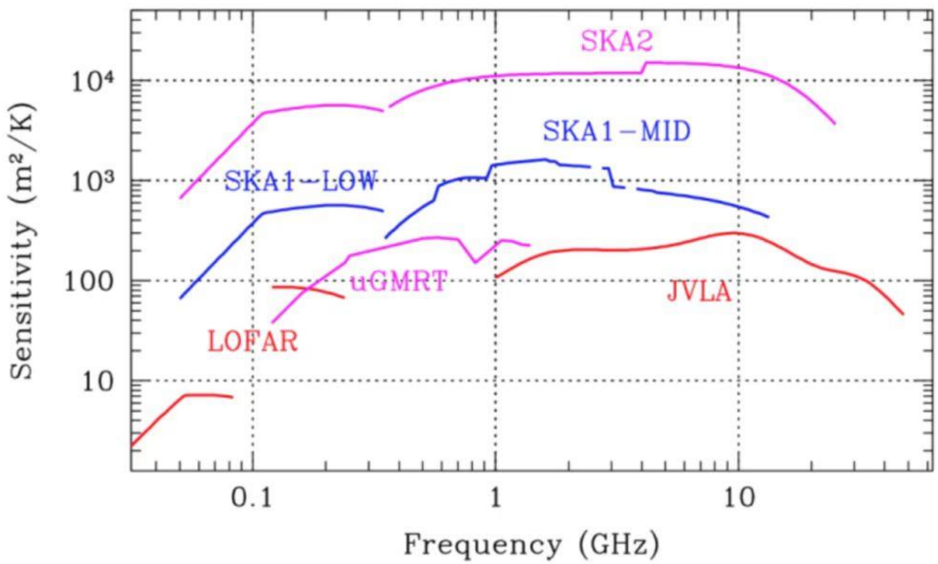
射电望远镜的灵敏度

1 Jy = 10^{-26} W Hz^{-1} m^{-2} = 10^{-23} erg s^{-1} Hz^{-1} cm^{-2}

$$m_{\rm AB} = -2.5 \log_{10}\left(\frac{f_\nu}{3631\ \rm Jy}\right),$$

m(AB,1 Jy) = 8.9 mag

1mirco Jy ~ 23.9 mag



射电望远镜的sensitivity

- 射电望远镜的灵敏度的表征的单位通常是m^2/K，这和源的流量密度的单位Jy有什么关系?
- 信噪比探测公式,详见 Radiometer_Equation以及 [1]

$$\frac{S}{N}=\frac{T_{src}}{T_{rms}}=\frac{T_{src}}{T_{sys}}\sqrt{\tau\Delta\nu}$$

  - 信号的探测能力取决于望远镜口径A，射电天文里面通常用温度来描述：

$$P(\text{接收到的功率})=A*S\text{（流量密度）}=2*k*T\text{（源温度）}$$

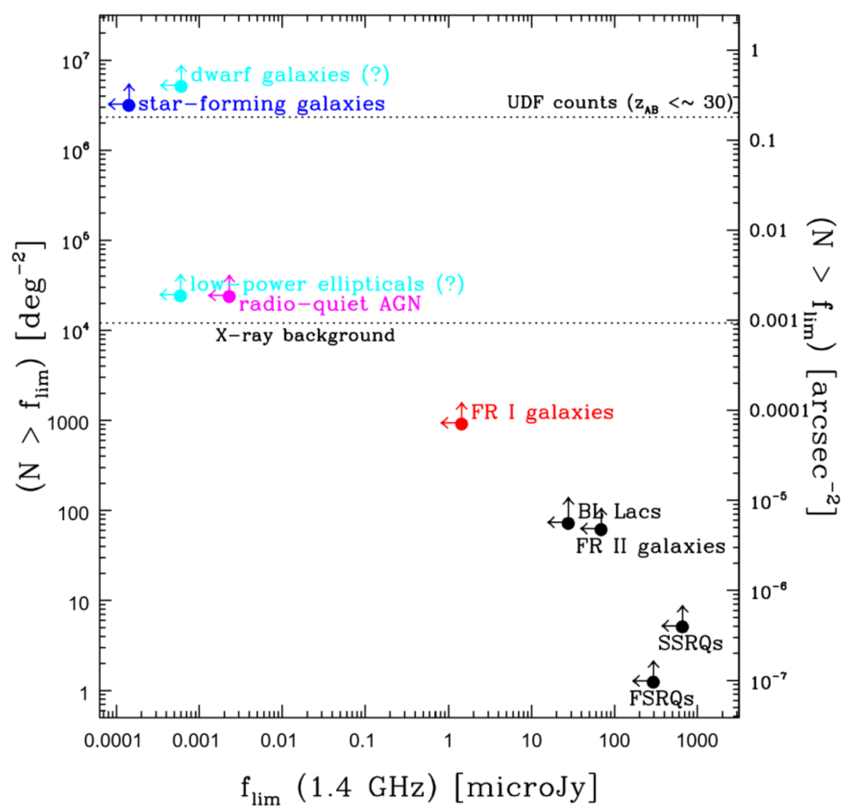
  - 对于1平方米接收面积来说，1Jy的源对应的温度大概是0.74mK
  - T_{sys}是系统的温度可以假设在200K左右。
  - 积分时长和带宽$\sqrt{\tau\Delta\nu}$可以提高信噪比,对于100MHz的带宽，60秒积分时间，这个因子大概是 $7.7*10^4$

Radio populations parameters

Class	$N_T(0)$ Gpc^{-3}	$P_{min}(0)$ W Hz^{-1}	LE	DE	z_{top}	z_{max}
FSRQs	12	2×10^{24}	$\exp[T(z)/0.23]^a$	...	2.25	5.5
SSRQs	59	3×10^{24}	$\exp[T(z)/0.15]^a$	...	2.25	5.5
FR IIs	590	3×10^{24}	$\exp[T(z)/0.26]^a$	...	2.25	5.5
BL Lacs	2,310	10^{23}	$\exp[T(z)/0.32]^a$	...	...	3.0
FR Is	29,300	10^{23}	...	...	...	3.0
RQ AGN	3.9×10^5	5×10^{19}	$(1+z)^{2.4}$	...	1.7	6.5
SFGs	4.5×10^7	2×10^{18}	$(1+z)^{2.7}$	$(1+z)^{0.15}$	2.0	6.0
Dwarf Galaxies	2.0×10^8	$< 2 \times 10^{18}$	$(1+z)^{2.7}$	...	2.0	3.0
Low-power Ellipticals	4.8×10^6	$< 3 \times 10^{19}$	...	$(1+z)^{-1.7}$	...	3.0

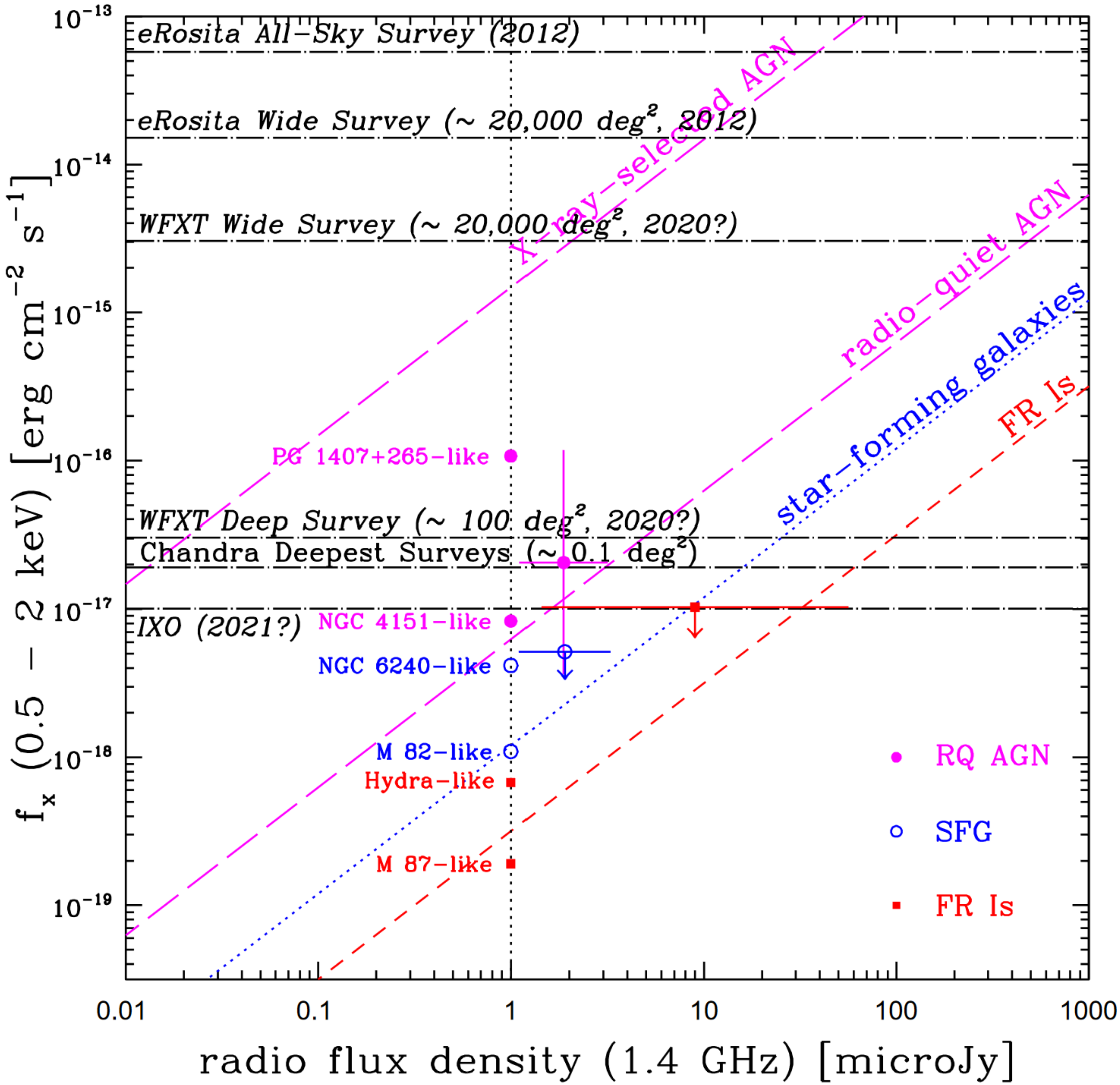
$^a H_0 = 50$, $q_0 = 0$; $T(z)$ is the look-back time

dwarf galaxies are likely to be the most numerous component of the faint radio sky.

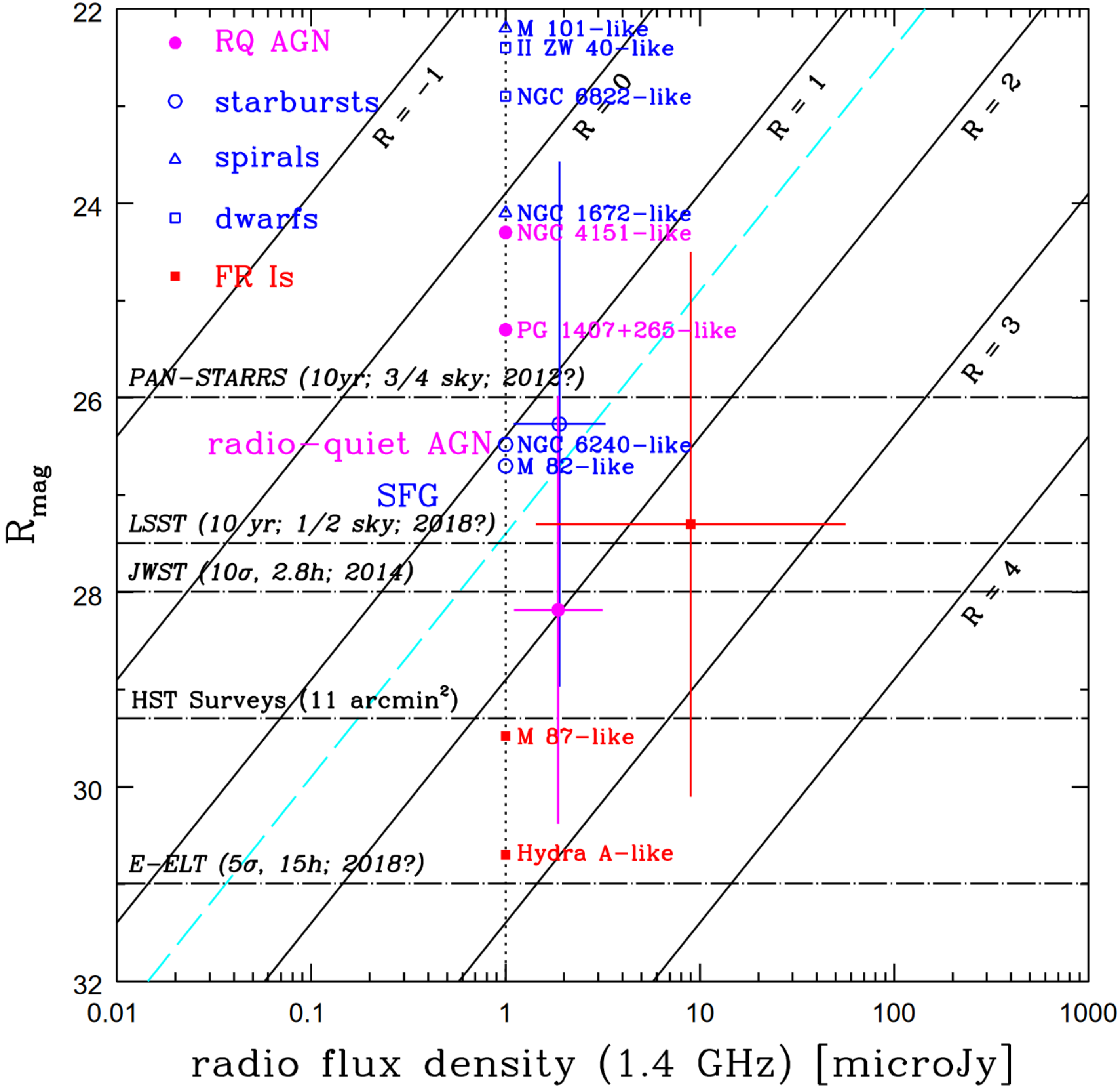


Could stellar objects also contribute substantially to the μJy and nanoJy sky?

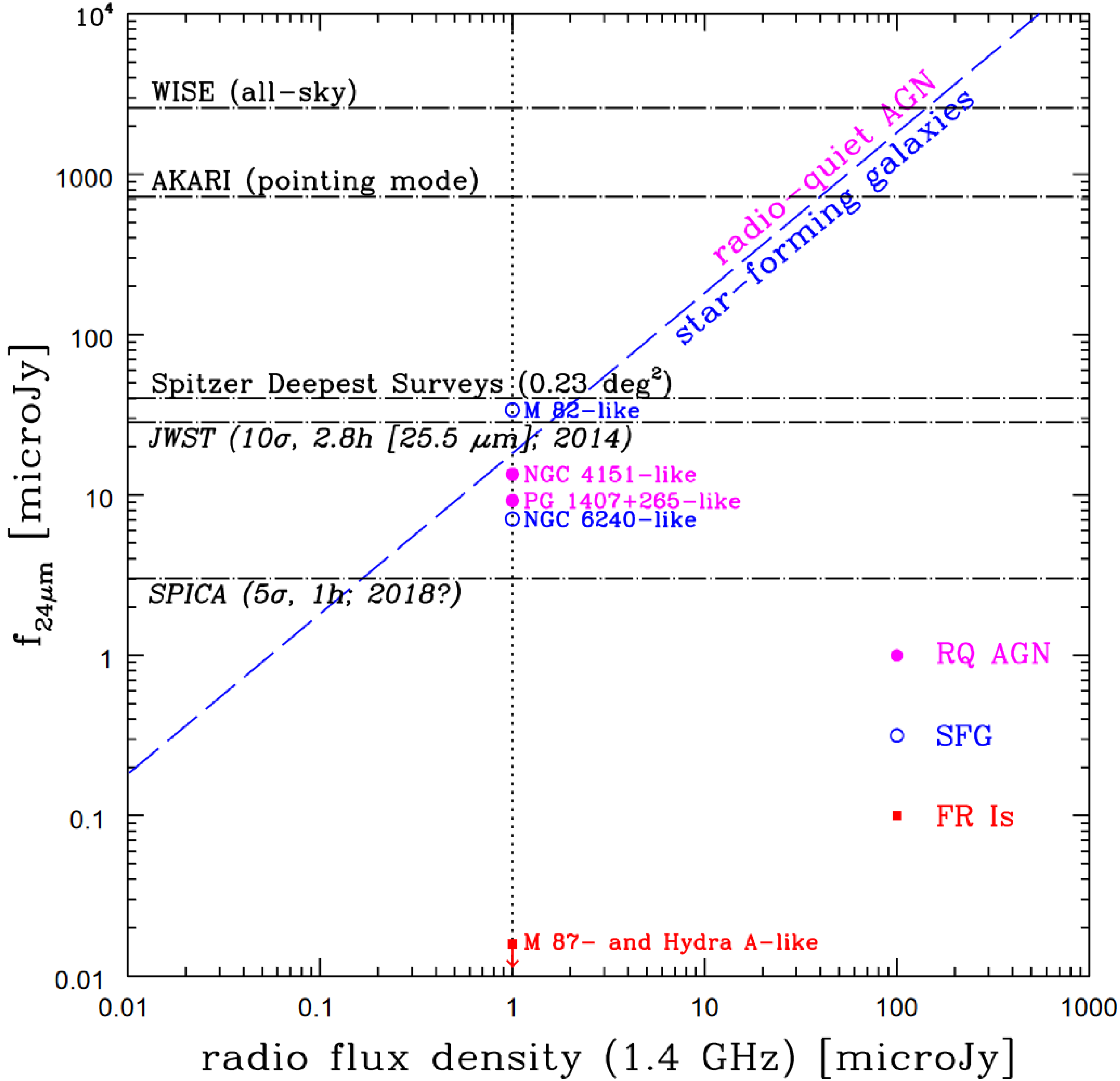
- Extremely unlikely.
- The radio thermal component of the Sun
    - $\sim$ 0.7 – 4 nanoJy at 10 Kpc.
- non-thermal flux density $\sim$ 0.001 nanoJy.



eRosita All−Sky Survey (2012)
eRosita Wide Survey (~ 20,000 deg², 2012)
WFXT Wide Survey (~ 20,000 deg², 2020?)
WFXT Deep Survey (~ 100 deg², 2020?)
Chandra Deepest Surveys (~ 0.1 deg²)
IXO (2021?)
X−ray−selected AGN
radio−quiet AGN
star−forming galaxies
FR Is
PG 1407+265−like
NGC 4151−like
NGC 6240−like
M 82−like
Hydra−like
M 87−like
RQ AGN
SFG
FR Is
f_x (0.5 − 2 keV) [erg cm⁻² s⁻¹]
radio flux density (1.4 GHz) [microJy]



RQ AGN
starbursts
spirals
dwarfs
FR Is
R = −1
R = 0
R = 1
R = 2
R = 3
R = 4
M 101−like
II ZW 40−like
NGC 6822−like
NGC 1672−like
NGC 4151−like
PG 1407+265−like
NGC 6240−like
M 82−like
M 87−like
Hydra A−like
PAN−STARRS (10yr; 3/4 sky; 2012?)
radio−quiet AGN
SFG
LSST (10 yr; 1/2 sky; 2018?)
JWST (10σ, 2.8h; 2014)
HST Surveys (11 arcmin²)
E−ELT (5σ, 15h; 2018?)
R_mag
radio flux density (1.4 GHz) [microJy]
22
24
26
28
30
32
0.01
0.1
1
10
100
1000



WISE (all-sky)
AKARI (pointing mode)
Spitzer Deepest Surveys (0.23 deg²)
JWST (10σ, 2.8h [25.5 μm]; 2014)
SPICA (5σ, 1h; 2018?)
radio-quiet AGN
star-forming galaxies
M 82-like
NGC 4151-like
PG 1407+265-like
NGC 6240-like
M 87- and Hydra A-like
RQ AGN
SFG
FR Is
f24μm [microJy]
radio flux density (1.4 GHz) [microJy]
10⁴
1000
100
10
1
0.1
0.01
0.01
0.1
1
10
100
1000

LOw Frequency ARray LOFAR

- Only instrument capable of deep, high-resolution imaging at frequencies below 100 MH
- **The LOFAR Multifrequency Snapshot Sky Survey (MSSS)**
  - the whole northern sky to a depth of around 10 mJy/beam
  - resolution of 2 arcmin.
- **LoTSS wide area**
  - whole northern sky at the full resolution of Dutch LOFAR (6 arcseconds)
  - declination-dependent sensitivity: typically ~ 100 μJy/beam.
- **LoTSS deep fields**
  - reach depths approaching 10 μJy/beam
- **LoLSS wide-area**
  - frequency range 42-66 MHz, a resolution of 15 arcsec, average rms noise of 1 mJy/beam.

ALMA

Band 1: 35 GHz - 50 GHz
Band 2: 67 GHz - 90 GHz
Band 3: 84 GHz - 116 GHz
Band 4: 125 GHz - 163 GHz
Band 5: 163 GHz - 211 GHz
Band 6: 211 GHz - 275 GHz
Band 7: 275 GHz - 373 GHz
Band 8: 385 GHz - 500 GHz
Band 9: 602 GHz - 720 GHz
Band 10: 787 GHz - 950 GHz

Common Parameters

- **Declination**: 00:00:00.00
- **Polarisation**: Dual
- **Observing Frequency**: 345 GHz
- **Observing Band**: ALMA_RB_07
- **Bandwidth per Polarization**: 7.500000 GHz
- **Water Vapour**: Automatic Choice / Manual Choice
- **Column Density**: 0.913mm (3rd Octile)
- **Trx, tau, Tsky**: 72 K, 0.158, 39.538 K
- **Tsys**: 153.278 K

Individual Parameters

	12 m Array		7 m Array		Total Power Array	
Number of Antennas	43		10		3	
Resolution	0	arcsec	0	arcsec	9.5	arcsec
Sensitivity (rms)	192.95594694337473	uJy	2.4234094057554807	mJy	4.734306968439023	mJy
Equivalent to	Unknown	mK	Unknown	K	0.000539	K
Integration Time	60	s	60	s	60	s