Magnetic fields in early-type galaxies (star-forming ETGs)

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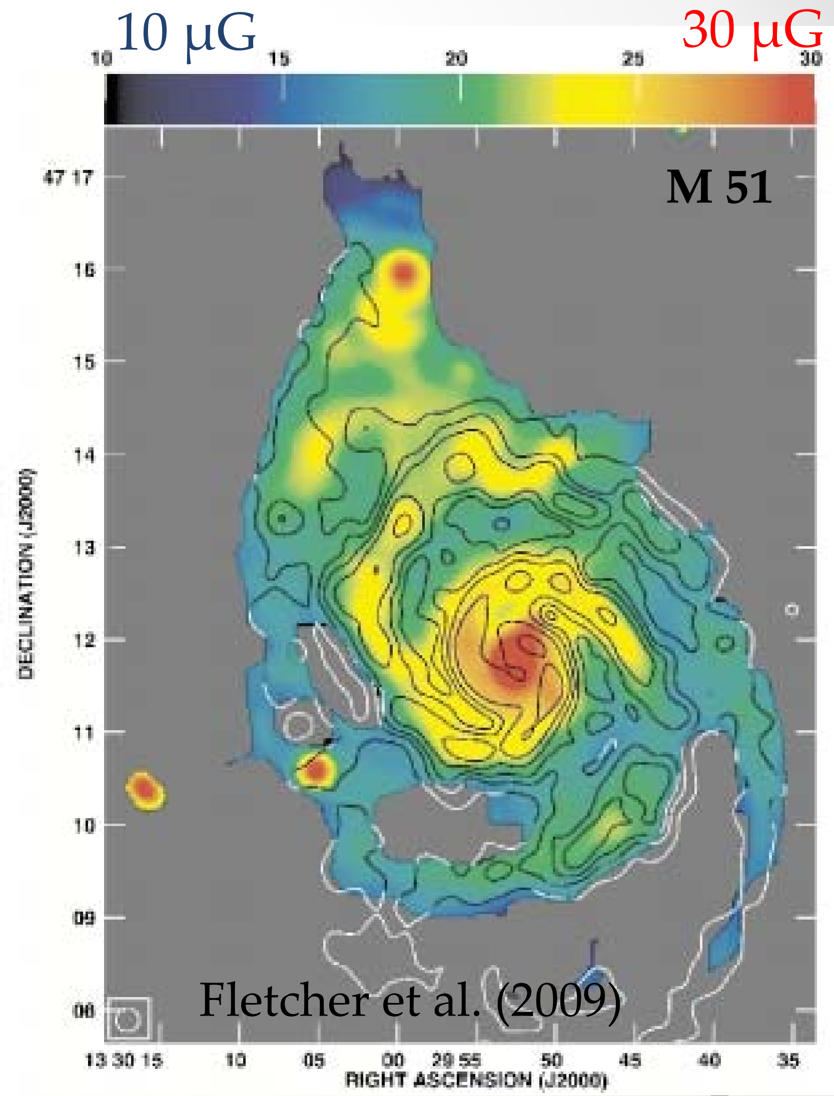
Magnetic fields in galaxies

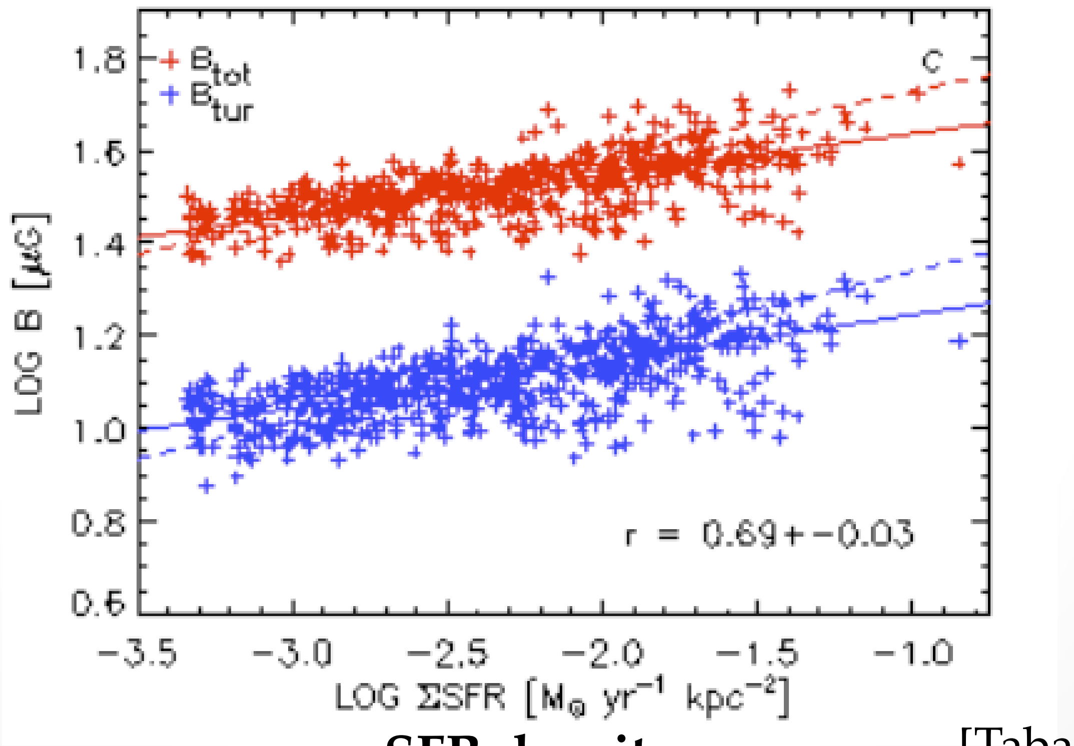
- Magnetic fields are known in the inter-stellar medium of **late-type (spiral, irregular)** galaxies
- Equi-partition field strengths are estimated as a few μG to a few tens of μG.
- Star-burst galaxies can have high field strengths (up to 100 μG).



- Fields can be both turbulent (random - pc scales) and coherent (regular – kpc scale)

- On sub-galactic scales, turbulent field strengths are well correlated with current star-formation rate (SFR).

Field



SFR density

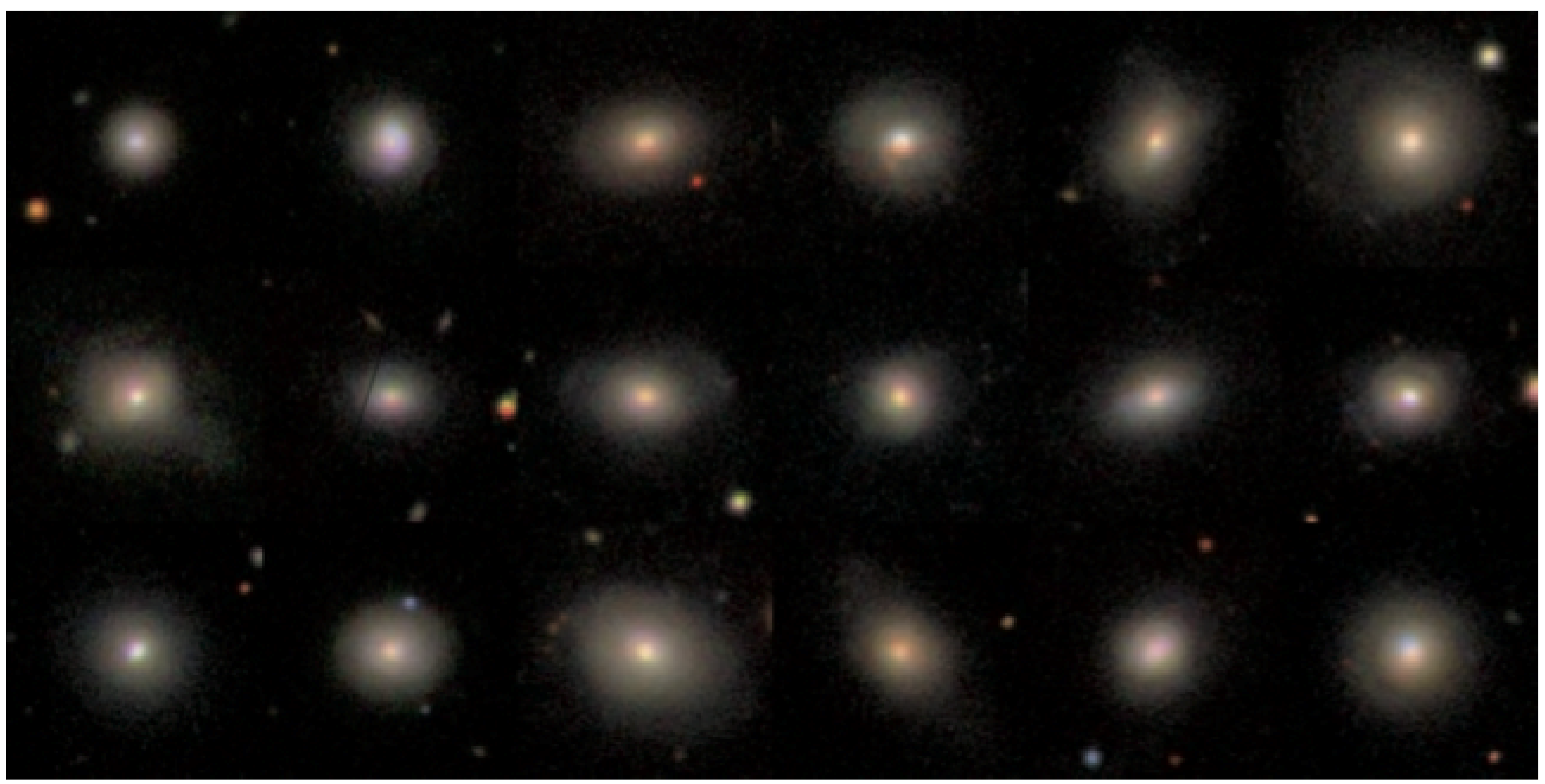
[Tabatabaei et al. 2013]

- Magnetic fields are usually inferred indirectly from the radio synchrotron emission at cm-wavelengths.
- Radio emission from star-forming galaxies is mainly (> 80%) due to synchrotron radiation, from the relativistic cosmic rays (CR) accelerated in the type-II supernovae explosions in the star-forming regions.
- Energy loss of CR particles in field makes synchrotron life time of a few 100 Myr at the most for cm-wave detections.
- Fields can be traced by synchrotron radiation only if galaxy has recently undergone a star-formation phase.

- Not a problem in spiral galaxies as continuous star-formation may last for a Gyr or so.
- Due to low or lack of star-formation in early-type galaxies (lenticulars and ellipticals; ETGs), magnetic fields are difficult to trace.
- Magnetic fields are not well constrained in ETGs.

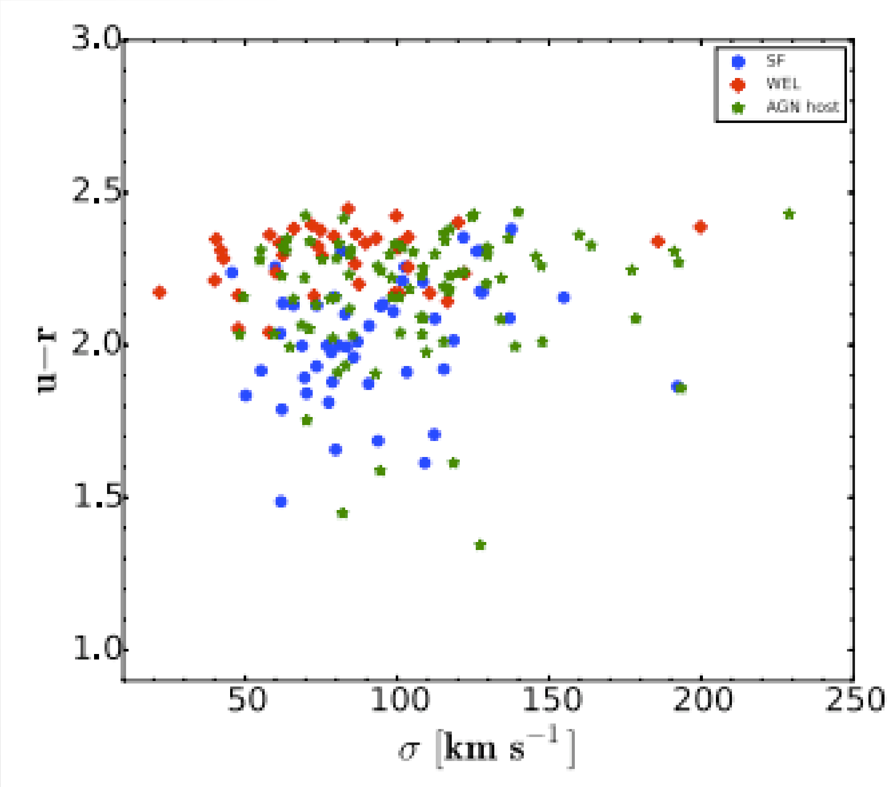
More than 200 **star-forming ETGs** in ($0.02 < z < 0.05$) are now known from Sloan Digital Sky Survey (SDSS).

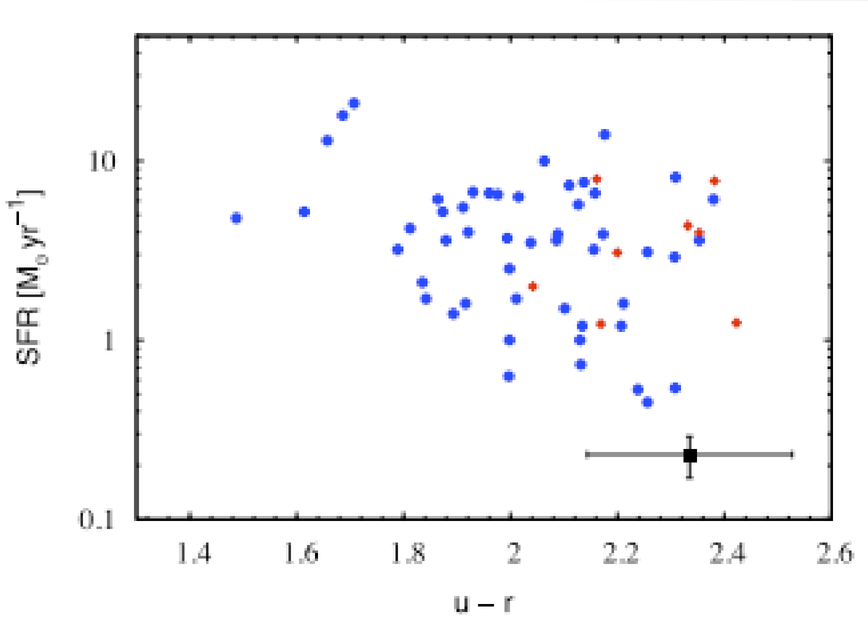
Median SFR (Hα) ~ 5 $M_\odot$ /yr



[Schawinski et al. (2009)]
(Galaxy-zoo database)

- $u-r$ color : 1.5 to 2.4 (about one mag bluer than classical ellipticals)
- Central stellar velocity dispersion : Median = 80 km/s (low-mass galaxies)
- Residing in low-density environment
- Median sizes : 26″ (~23 kpc) at median redshift: 0.043

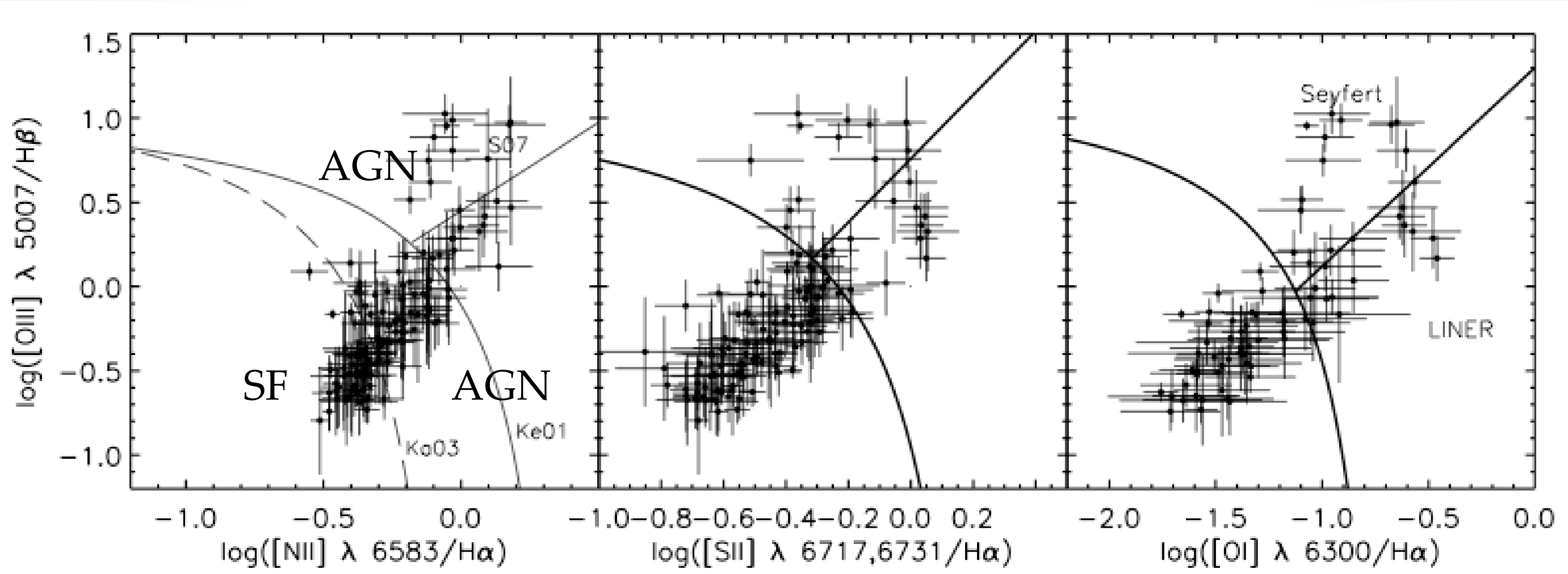




[Paswan & Omar (2016)]

Are these contaminated by AGN?

Nature of emission from the central region (3″ SDSS fibre) was classified in to pure SF, AGN or a mix of AGN based on optical-line ratio diagnostic diagram.



Galaxies identified as SF are good targets for study of magnetic fields

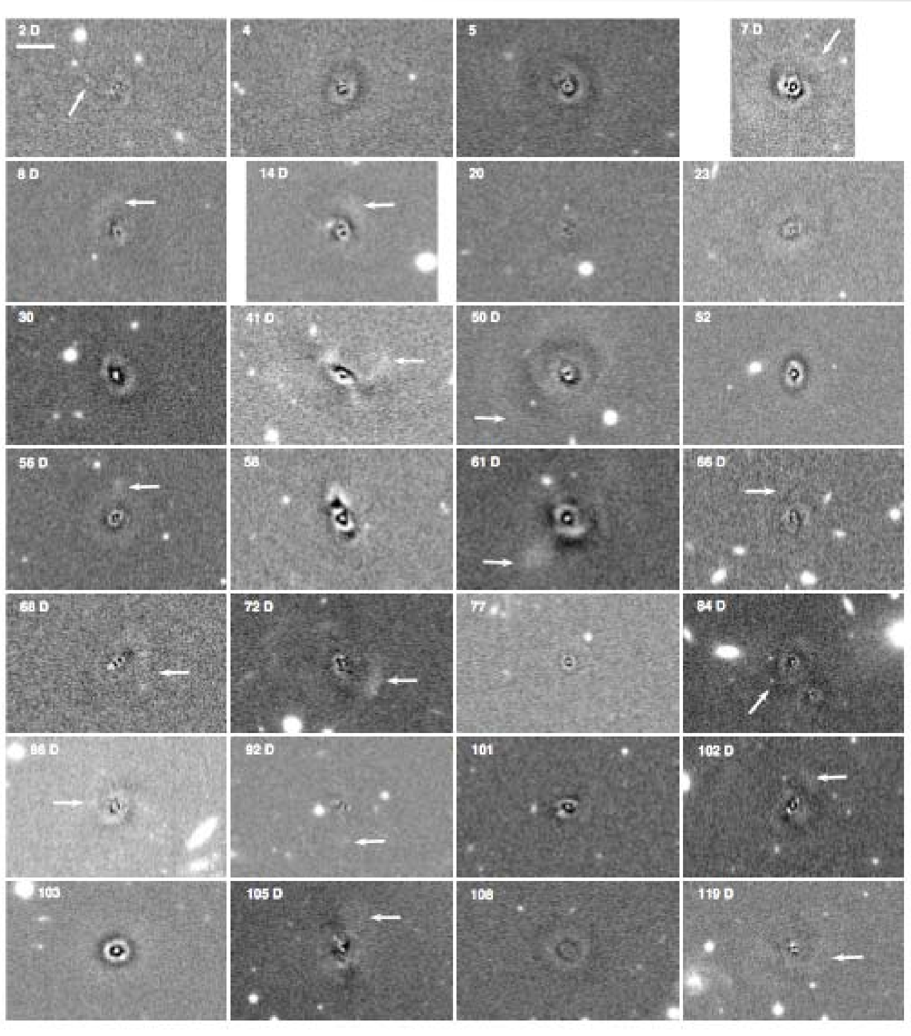
Are these early-type galaxies?

➢ Structural analysis (Sersic-profile fit) based on optical surface brightness

- Sersic index > 2 (up to 8) for majority of galaxies indicating true early-type (bulge-dominated) galaxies.

- Residual images show bright circum-nuclear ring and tidal debris (tails, shells, asymmetric light)

Sersic index	No. of galaxies
< 2	6
2 – 3	**15**
3 – 4	**4**
> 4	**16**



[George (2017)]

- 1.4 GHz radio emission searched in the NVSS and FIRST data-base.

- Far-infrared (60μm and 100μm) emission searched using SCANPI extraction tool for IRAS database.

Typical radio flux = 3 mJy
@ < z > ~ 0.043

Typical 60 μm flux = 0.2 Jy
Typical 100 μm flux = 0.6 Jy

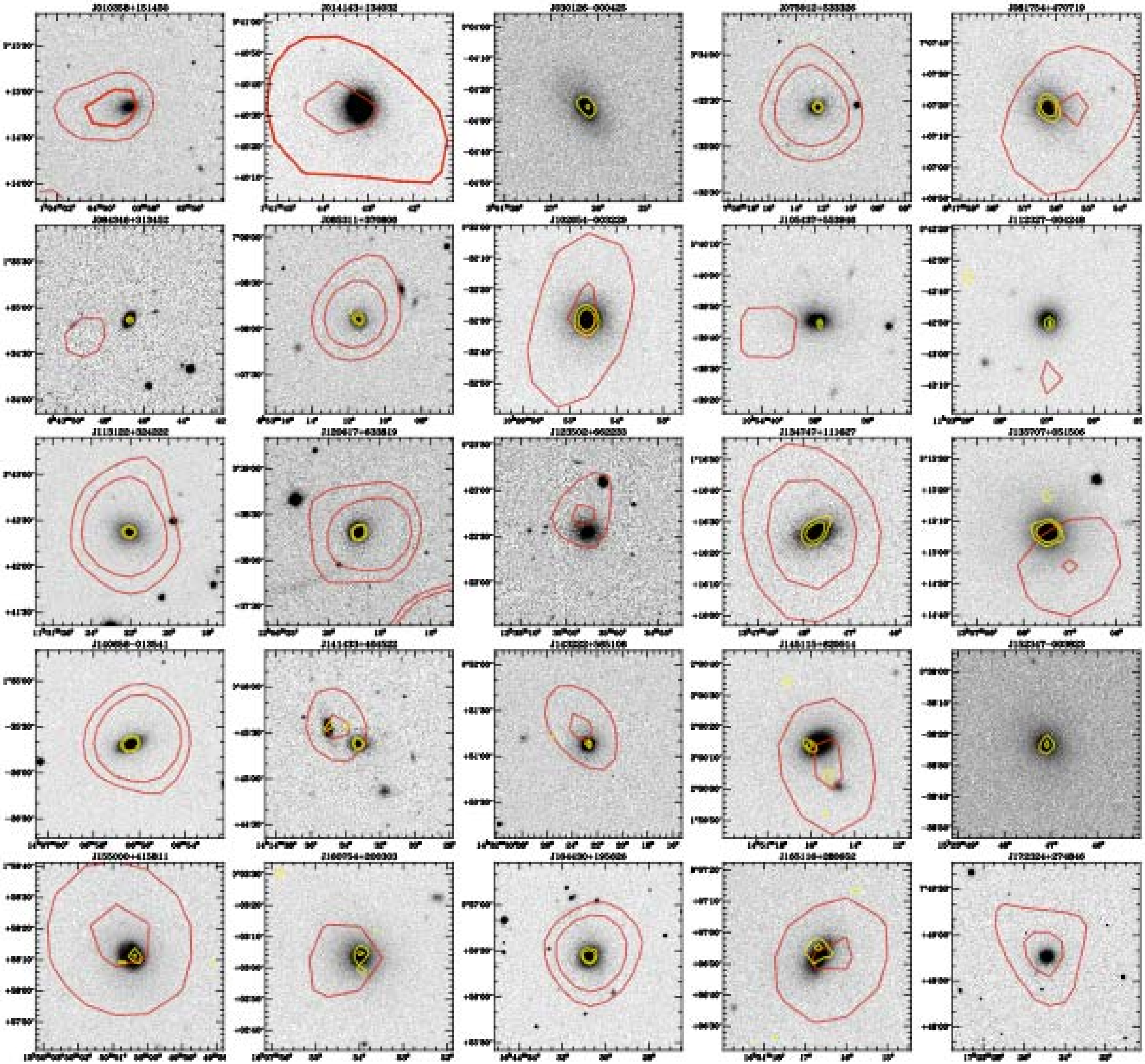
$$< L_{1.4GHz} > = 10^{22}\ \mathrm{W/Hz}$$

$$< L_{FIR} > = 10^{10.2}\ L_{\odot}$$

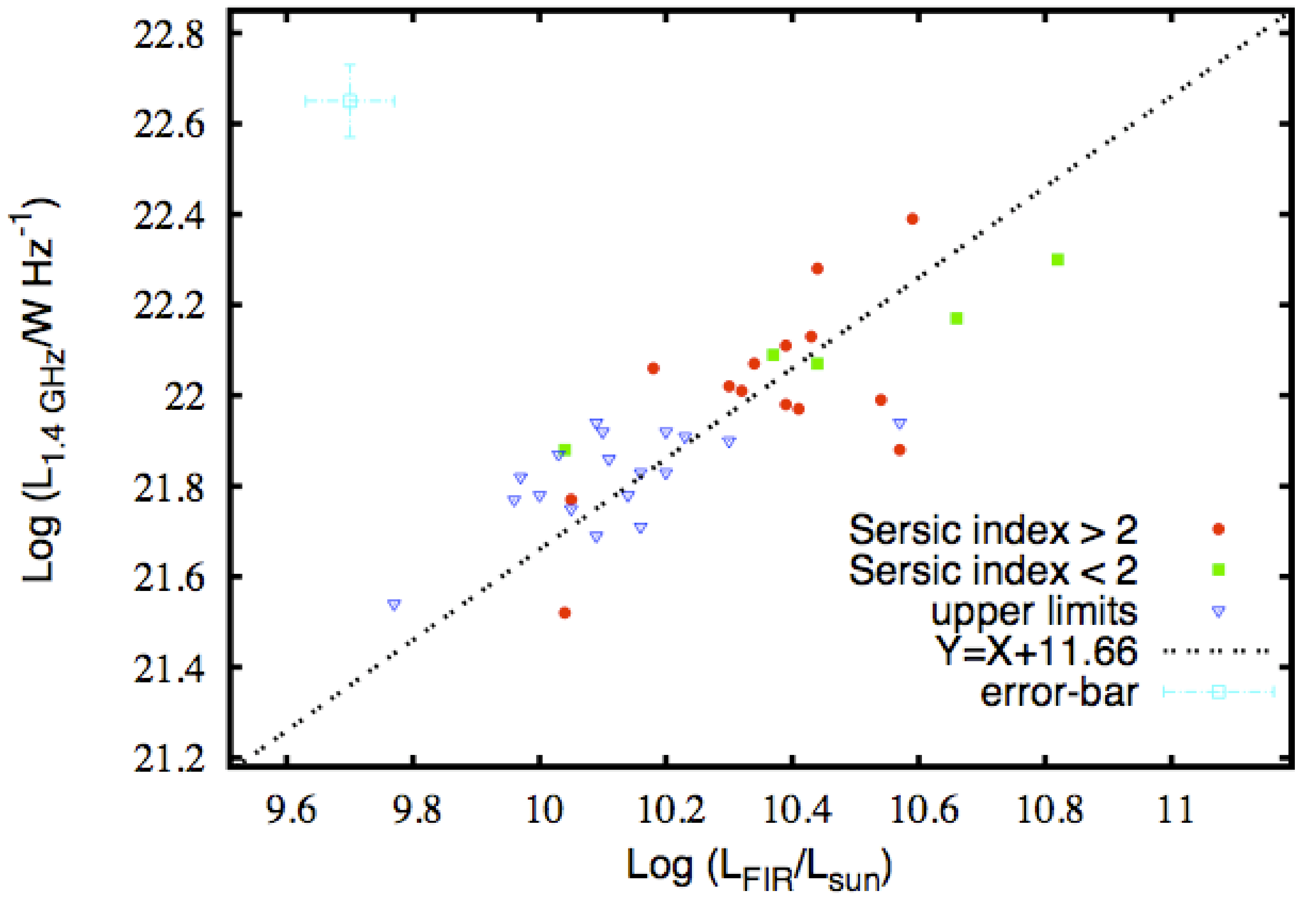
Radio thermal fraction (free-free emission) = 12%

<SFR (radio)> = 5.1 ; **<SFR (FIR)>** = 5.7 ; **<SFR (Hα)>** = 5.2 $M_{\odot}$ /yr

Radio detections in NVSS and FIRST

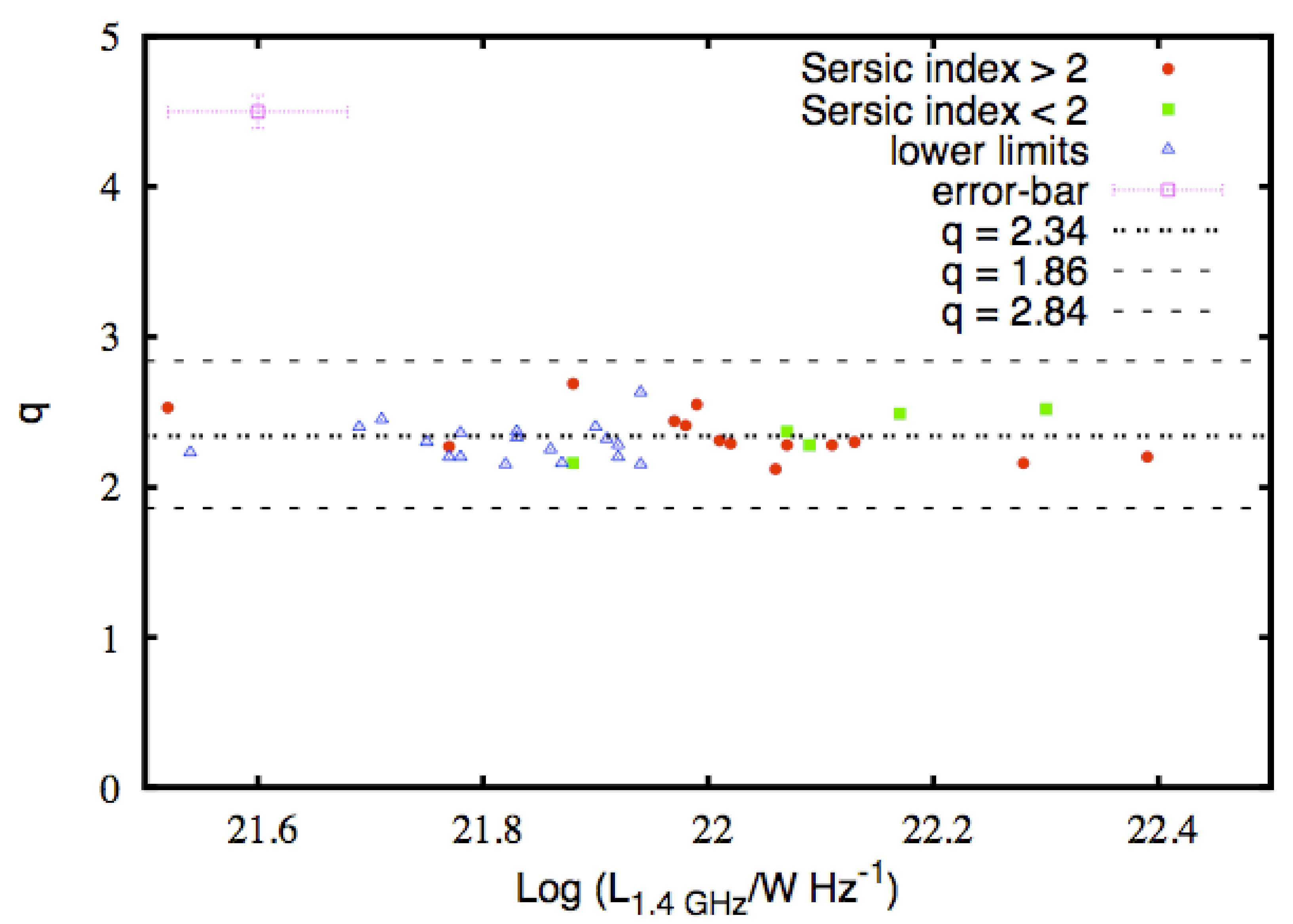


Far-infrared – radio correlation



FIR data taken from IRAS (SCANPI online extraction)

Far-infrared – radio correlation in ETGs



'q' = 14 + log (L_{FIR}) – log ($L_{1.4GHz}$) ~ 2.34 for late-type galaxies *[cf. Yun et al. (2001)]*

Is radio emission contaminated by AGN?

- FIR-Radio correlation indicates no large contamination.
- Star-formation history of blue ETGs indicates that SF activity and peak-AGN activities are separated by ~500 Myr.
- Nuclear star-bursts are short , usually < 50 Myr (in merger galaxies).
- Many nearby galaxies with star-burst + AGNs (Seyferts/LINER) indicates, AGN contribution is not more than 10%.
- Low radio power < $10^{22.4}$ W/Hz ; Studies indicate that significant AGN contamination seen only beyond ~$10^{22.7}$ W/Hz.

➢ *Although, AGN contamination is not indicated, we still assumed a*

Estimates of field strengths from the radio continuum

Magnetic field in circum-nuclear star-bursting region (<10 kpc)

= 12 (+11/-4) μG *

Magnetic field in extended region (>10 kpc)

= 3 – 7 μG

* *Field strengths estimated using Beck & Krause (2005), for a spectral index 0.75(±0.15), angular size 10″(±3″), and synchrotron path-length of 4(±2) kpc.*

Origin of magnetic field in ETGs

"Fluctuation dynamos" in turbulent regions are known to be highly efficient in amplifying seed fields to > 10 μG level in late-type star-forming galaxies.

- **A few μG** field near the center is expected, due to turbulence driven by **type-Ia supernovae** in quiescent ETGs. [(Moss & Shukurov 1996)]
- The field is amplified **to > 10 μG level** in turbulence driven by **type-II supernovae** in star-bursting region.
- Time-scale of amplification needs to be much less than 50 Myr, as required by a *tight* FIR-radio correlation in ETGs.

Conclusions

- ✓ Far-infrared - radio correlation holds good for star-forming ETGs.
- ✓ Magnetic fields (>10 μG) are confirmed in star-forming ETGs
- ✓ Fields (random) are amplified quickly (~10 Myr) in turbulence driven by type-II supernovae in star-bursting region
- ✓ Far-infrared - radio correlation is very likely linked to magnetic field (random) amplification in turbulent region.