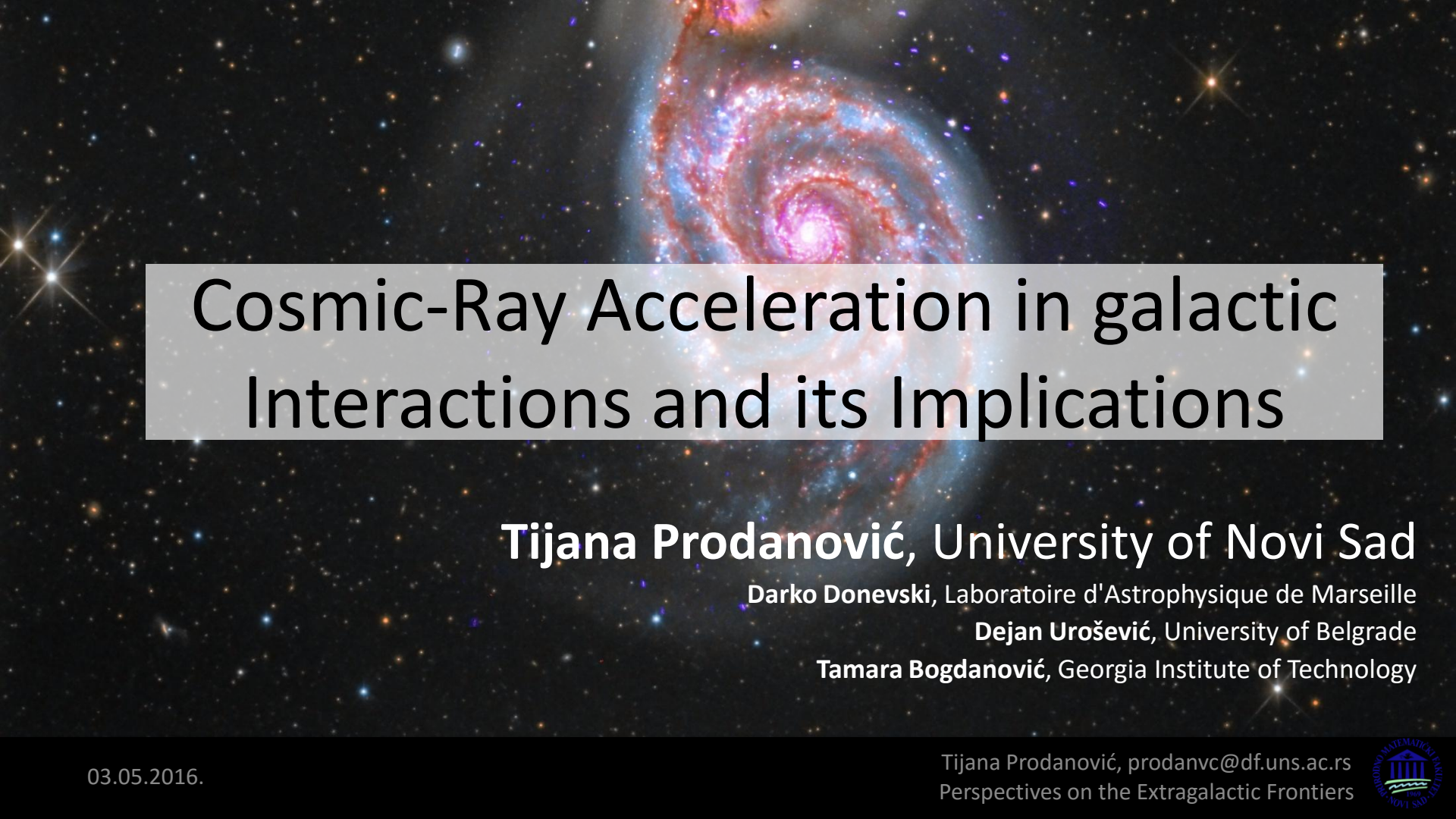
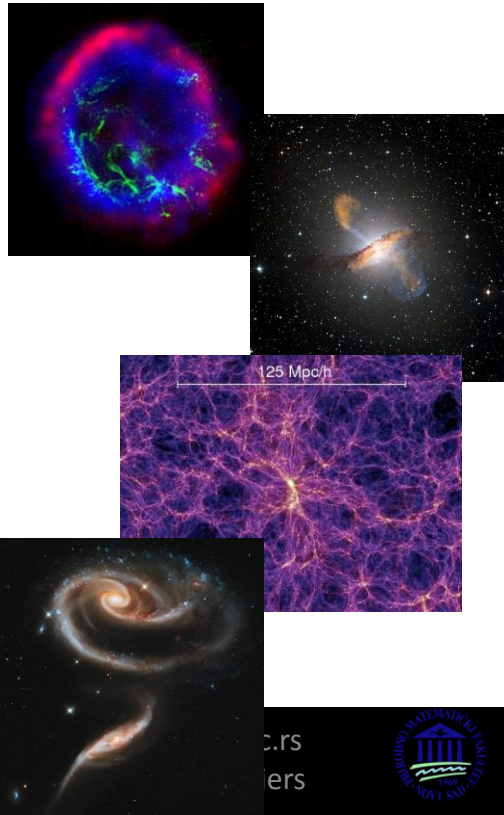


Cosmic-Ray Acceleration in galactic Interactions and its Implications

Tijana Prodanović, University of Novi Sad
Darko Donevski, Laboratoire d'Astrophysique de Marseille
Dejan Urošević, University of Belgrade
Tamara Bogdanović, Georgia Institute of Technology

Cosmic Ray Sources

- **Shocks + mag. fields** (Blandford & Eichler 1987)
- Galactic CRs – supernova remnants (Blandford & Ostriker 1978, Bell 1978, Drury 1983) - **see talk by Petrović!**
- UHECRs – AGNs (Abraham et al. 2008)
- Structure-formation CRs – structure-formation shocks (Suzuki & Inoue 2002, Miniati et al. 2001, Fields & Prodanović 2005, Dobardžić & Prodanović 2014) – **see talk by Ćiprijanović!**
- **Tidal Cosmic Rays** – tidal and merger shocks (Prodanović et al 2013)



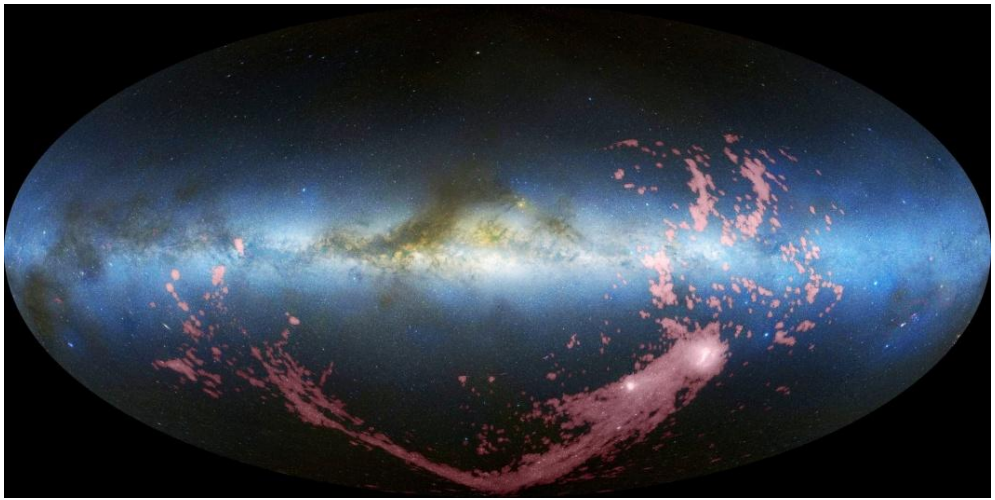
Galactic Interactions

- Interractions, collisions and close fly-bys impact galaxy morphology
- Especially pronounced on small satellite galaxies disrupted by large ones (eg. SMC & MW)

Interaction Shock Waves

- Strong tidal and merger shock waves on large scales (cf. Cox et al. 2006)
- **Heating** – affects far-infrared emission
- **Tidal Cosmic Rays**

"Magellanic stream" – due to tidal interaction between Magellanic clouds ~ 2Gyr ago? (Diaz & Bekki 2012)



Tidal Cosmic Rays: Effects

- **Nucleosynthesis** of cosmic dosimeters (LiBeB)
  - Could affect our understanding of the Li- problem
    - Gas of SMC shocked twice to account all 6Li? (Prodanović et al. 2013)
  - Li measured in SMC consistent with primordial? (Howk et al. 2012)

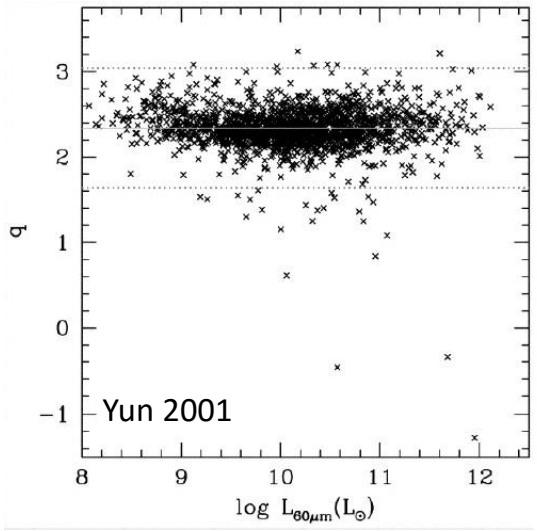
Tidal Cosmic Rays: Effects

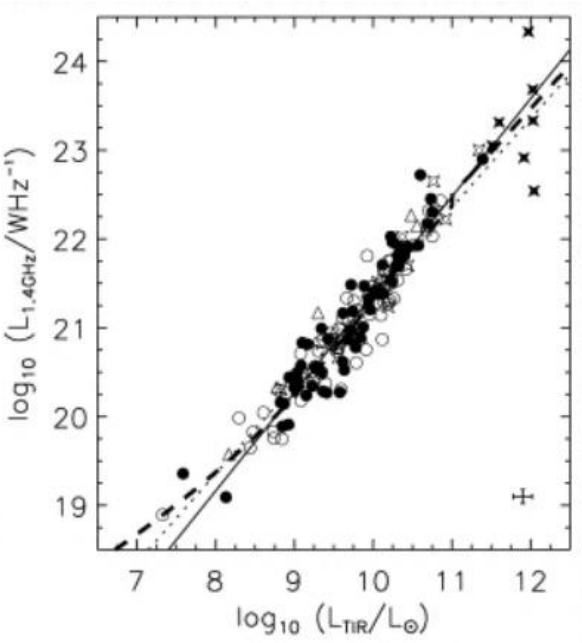
- Enhanced **non-thermal radiation** – gamma & radio
  - Disentangle from the effects of normal galactic cosmic rays
  - Expected enhanced synchrotron emission (Lisenfeld & Volk 2010)
- **Affected far-infrared –radio correlation in star-forming galaxies?** (Murphy 2013, Donevski & Prodanović 2015)
  - Could affects our estimates of star-formation rates
  - Implication for cosmic-star formation history (Horiouchi et al. 2011)

FIR-Radio Correlation

- Observed
- Origin
  - FIR emission of dust – processed stellar UV radiation
  - Synchrotron CR emission
- **Test its stability in interacting systems!**

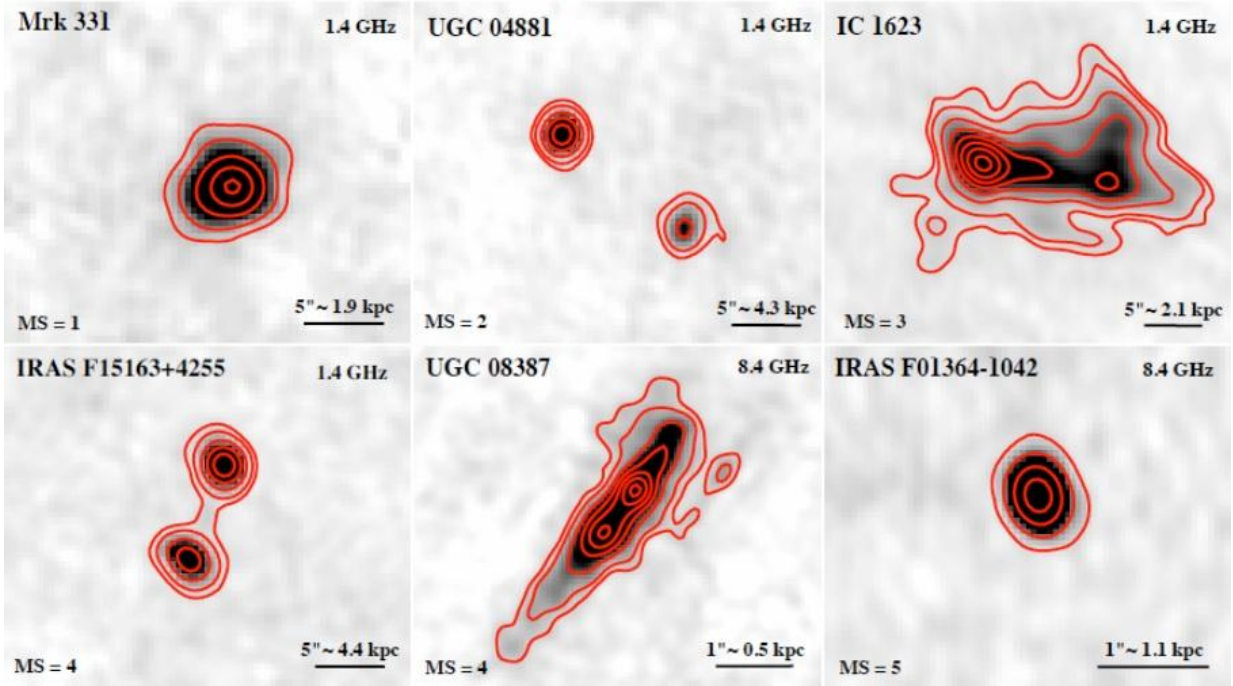
$$q_{IR} = \log\left[\frac{S_{\nu,IR}}{S_{\nu,1.4GHz}}\right] = 2.34 \pm 0.01$$





Interaction Sequence

"Toomre sequence" – interaction stages 1-5

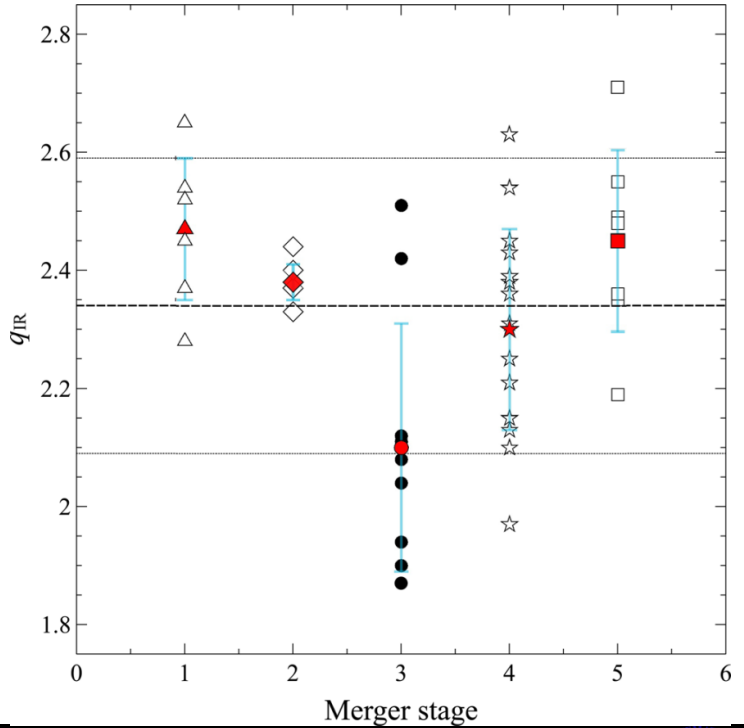


Murphy 2013

Impact of Interactions

- Available sample of 43 IR bright interacting galaxies
- FIR-radio correlation parameter vs. merger stage
- Expectations vs. merger stage
  - Stage 1-2 heating
  - Stage 3-4 Tidal cosmic-rays
  - Stage 4-5 star-formation

Donevski & Prodanović (2015)
arXiv 1501.06910



Interacting Galaxies: Special Attention!

- Indication of evolution of FIR-radio correlation with merger (scatter) (Donevski & Prodanović 2015)
- Observed star-forming galaxies where radio emitting region more extended than FIR (Miettinen et al. 2015)
- Could result in qIR decrease seen in COSMOS?
- Could “contaminate” star-formation rate
- Possible tool for detecting interacting systems at higher redshifts?

“To Do” list

- Check impact on star-formation rate determination (coming soon!)
- Larger sample of interacting galaxies local and high-z (e.g. COSMOS in radio, CANDELS in IR)
- N-body hydro models – shock propagation, strength, duration
- Model particle acceleration, non-thermal emission, heating

Thank you!
Questions?

Impact of Interactions

- Available sample of 43 interacting galaxies
- FIR-radio correlation parameter vs. merger stage
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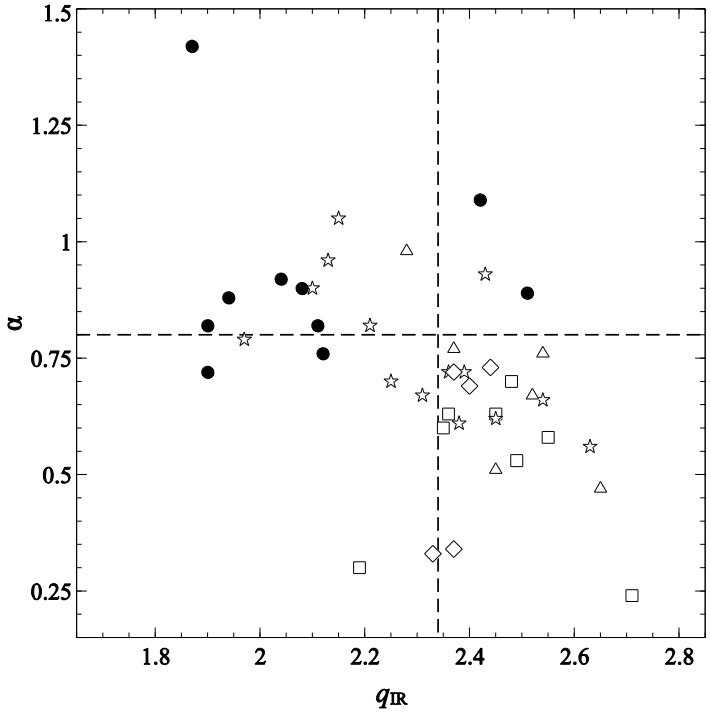
  - Stage 3-4 Tidal cosmic-rays
  - Stage 4-5 star-formation

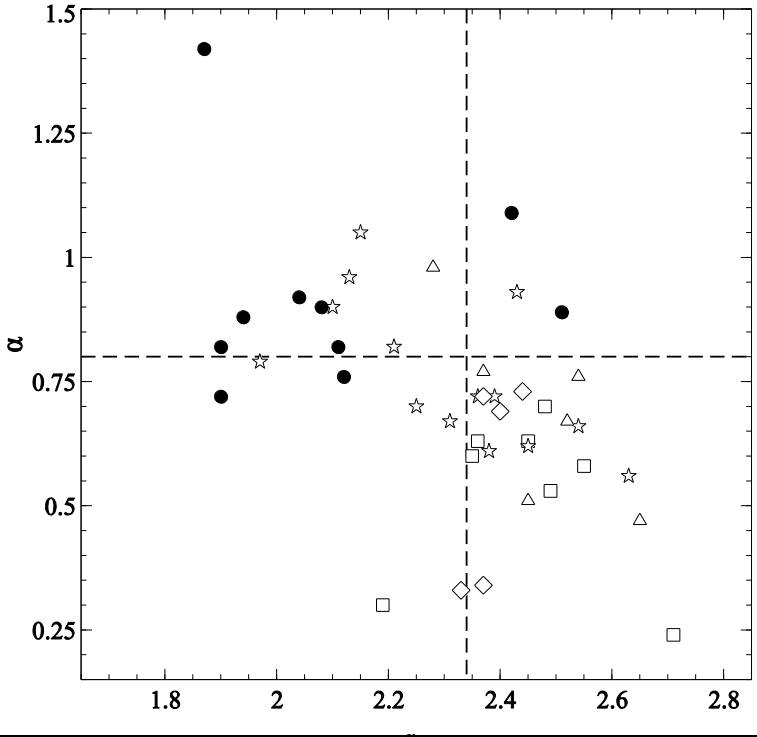
Donevski & Prodanović (2015)



- Spectral index also evolves vs, merger stage

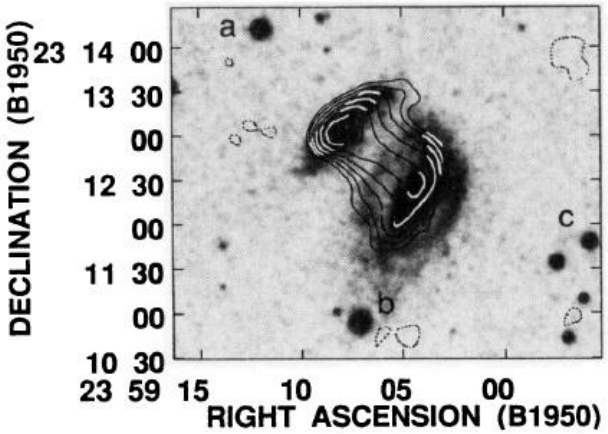
$$S_\nu \propto \nu^{-\alpha}$$

triangle – merger 1
diamond – merger 2
circle – merger 3
star – merger 4
square – merger 5



Model emission

- “Taffy” galaxies
  - Lisenfeld & Volk 2010 model for non-thermal bridge emission
  - Murphy 2013 looked into emission of “Taffy” galaxies vs. merger stage



Condon et al 1993

Data

- 43 IR-bright galaxies used
- Data sets from Dopita et al. (2002) and Murphy (2013).
  - Murphy (2013) data (15 sources) were drawn from *IRAS* revised Bright Galaxy Sample (Sanders et al. 2003).
  - Dopita et al. (2002) data set consists of two studies (Kewley et al. 2001; Corbett et al. 2002)
- our sample satisfies the overall criteria that all chosen galaxies are IR bright with 60 μmflux densities larger than 2.5 Jy and have IR luminosities $\geq 10^{10.5}$ L.
- We have excluded all sources classified as AGNs
- All galaxies presented here have well sampled radio spectra between 1.4 and 8.4 GHz
- Values of *qIR* were taken directly from Murphy (2013).