Characterizing the Recent Star Formation Histories of Galaxies Through a Comparison of their Cosmic-Ray and FIR Emission Distributions: Normal Galaxies to Star-bursting LIRGs

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Abstract

We present results on the diffusion of cosmic-ray (CR) electrons on sub-kpc scales within a sample of 18 nearby galaxies based on a comparison of Spitzer far-infrared (FIR) and WSRT radio continuum imagery. Prior to Spitzer, information on CR propagation had been strictly limited to the Milky Way, where direct measurements of CR nuclei are possible, and a few nearby galaxies via multi-wavelength radio continuum studies. It is only now that we are able to put into a better context the role of the relativistic ISM (i.e. a plasma of CRs bathed in a large-scale magnetic field) with the other well studied gaseous phases; this allows us to study their relationship with star formation and use the measured diffusion scale-lengths to infer information on the star formation histories of each galaxy. Although promising, this work is severely limited by Spitzer's small aperture; while being able to study nearby spirals, galaxies undergoing major starbursts such as luminous infrared galaxies (LIRGs) cannot currently be resolved at such spatial scales due to their large distances.

The combination of future FIR/submm data with available radio continuum imaging for such systems will allow us to compare the relative strengths of their radiation and magnetic field energy densities as well as estimate the diffusion lengths of their CRs, thereby providing information on the roles of negative feedback processes associated with CR pressure, supernovae, and starburst winds. Herschel and SPICA will allow us to begin probing these physical processes in a small number (< 10) of such objects. However, it is not until larger FIR/submm telescopes are in orbit, such as CALISTO/SAFIR, or ground-based facilities such as CCAT become available that we will be able to perform resolved FIR/submm studies of these cosmologically important objects in large (>~100) numbers.

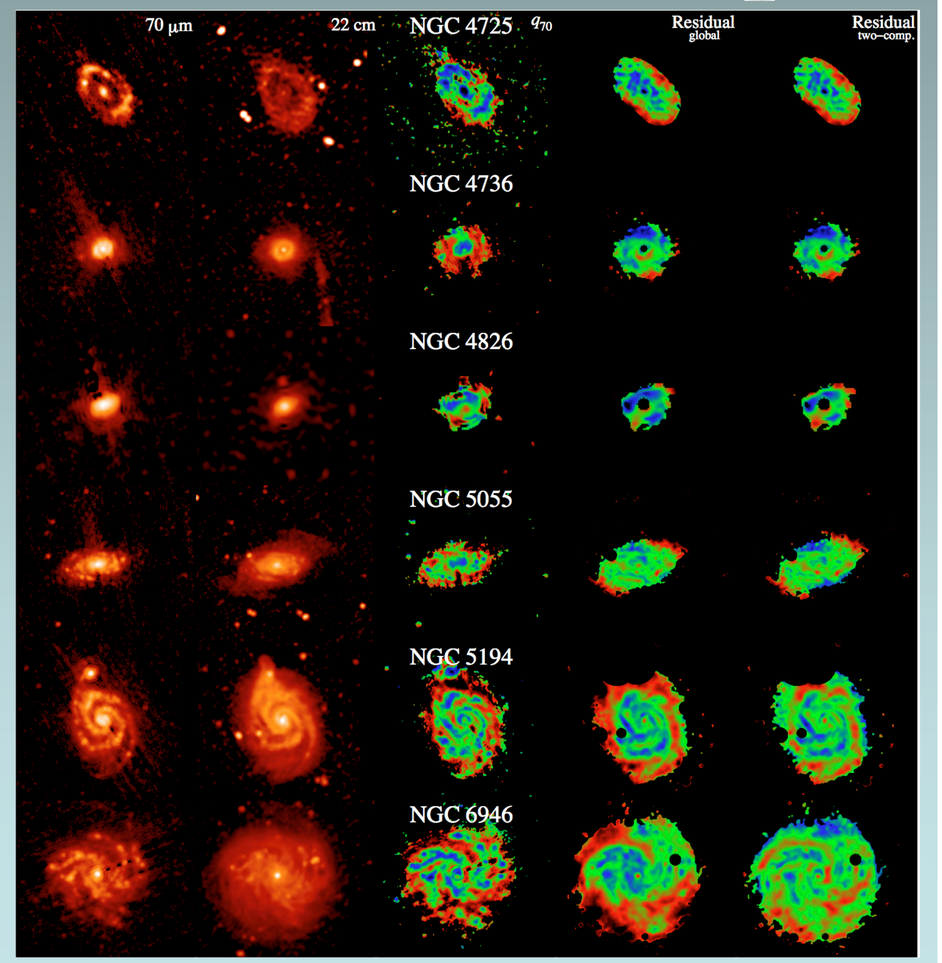
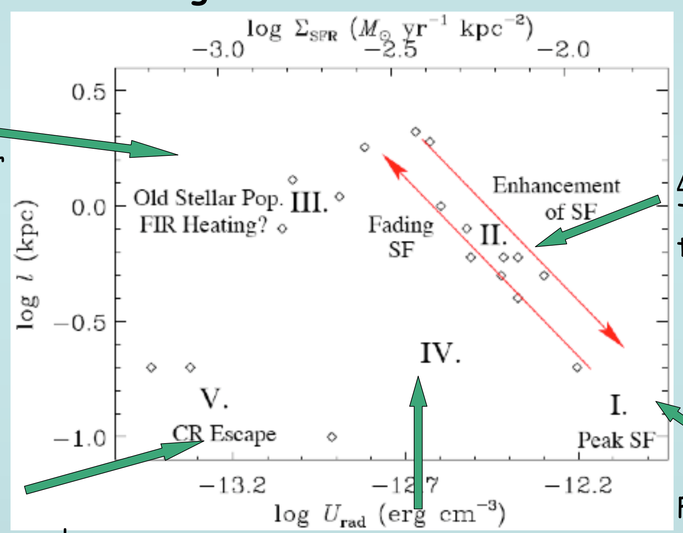


Fig. 1: A sub-sample of 70 um and 22 cm images are displayed in columns 1 and 2, respectively. These images are shown using a logarithmic stretch ranging from the 1-σ RMS level of the background to the maximum surface brightness of the galaxy. A normalized q_{70} map and the residual images between the 22 cm and 70 μm images, smoothed with the best-fit single smearing kernel and best-fit disk and structure smearing kernels are given in columns 3, 4 and 5 respectively. The stretch of each of these 3 maps runs from -0.75 to 0.75 dex; red and blue colors correspond to radio and infrared excesses in the residuals, respectively, while green corresponds to a residuals ~ 0. Regions removed for the residual calculations (e.g. background radio sources) appear as dark, circular holes in a few of the residual maps.

WSRT-SINGS galaxies resolved on scale < 1 kpc



Turnover due to S/N?

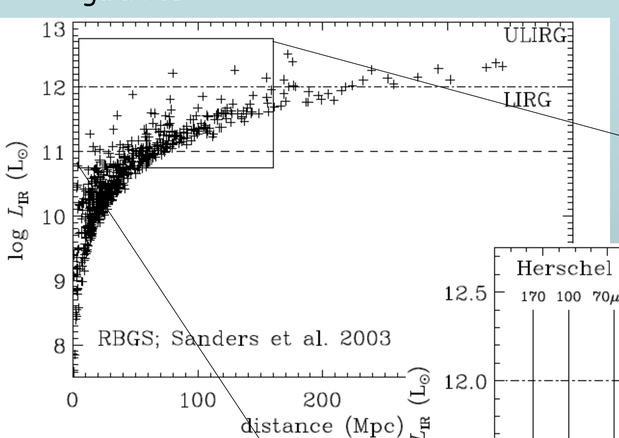
$\Delta\tau$ > 20 Myr Time to traverse this region.

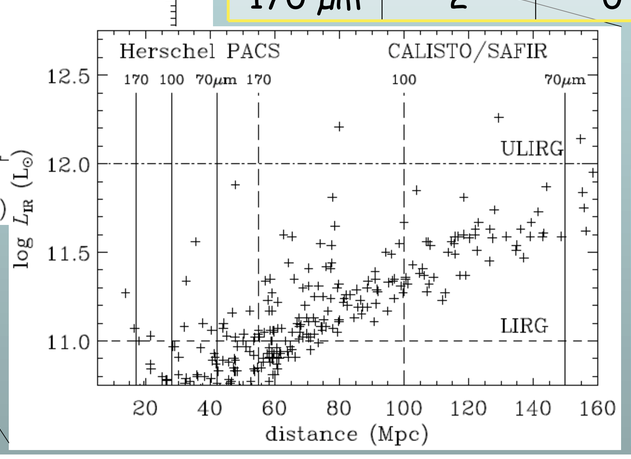
Irregular galaxies

Unpopulated area

FIR/radio co-spatial

Fig. 2: The smoothing kernel scale-lengths which best matched the IR and non-thermal radio images as a function of radiation field energy density. CR electrons reside much closer to their parent SF regions in galaxies with high SFR/area compared to galaxies w/ low SFR/area; this trend is found to arise due to an age effect. Accordingly, we can use the best-fit smearing scale-lengths to gain insight on the recent SFH of galaxies as shown here.





	Herschel - PACS		CALISTO/SAFIR	
	LIRGs	ULIRGs	LIRGs	ULIRGs
70 μm	9	0	166	2
100 μm	4	0	119	1
170 μm	2	0	22	0

Results/Conclusions

- Empirically, the FIR-RC correlation is best described by a phenomenological image-smearing model which incorporates the time-dependence of CR diffusion.
- The trend of best-fit scale-lengths decreasing with increasing star formation activity arises from an age effect:
  - The CR population in active star-forming galaxies is generally young due to a recent episode of enhanced star formation; variations in ISM parameters (affecting CR cooling and scattering) are secondary.

The Future

- Studying CR propagation in LIRGs and ULIRGs using this technique is currently impossible with current instrumentation; even with Herschel, only 10 LIRGs will be resolved at sub-kpc scales.
  - It is not until CALISTO/SAFIR that spatially resolved studies of cosmologically important LIRGs and ULIRGs will be possible