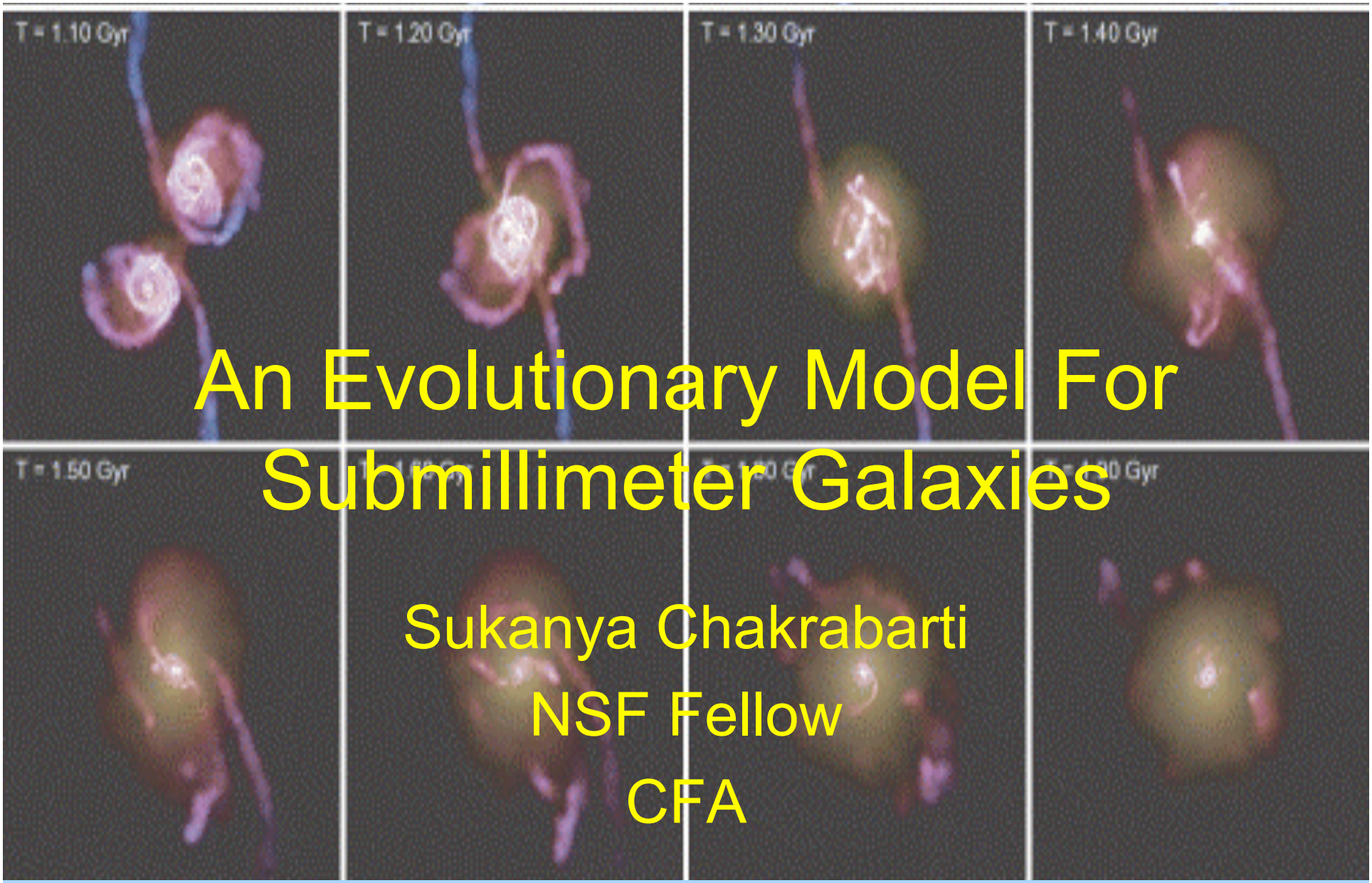

An Evolutionary Model For Submillimeter Galaxies

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NSF Fellow
CFA

Collaborators:
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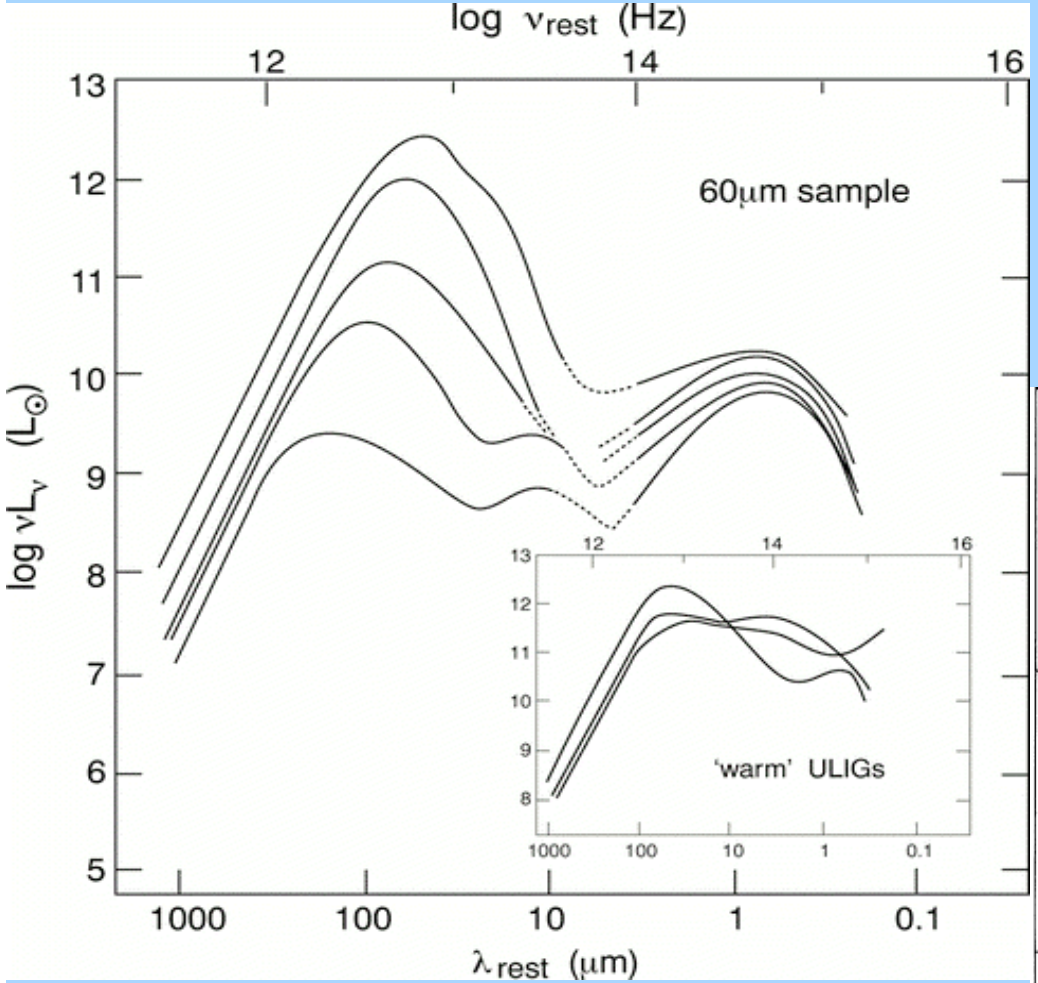
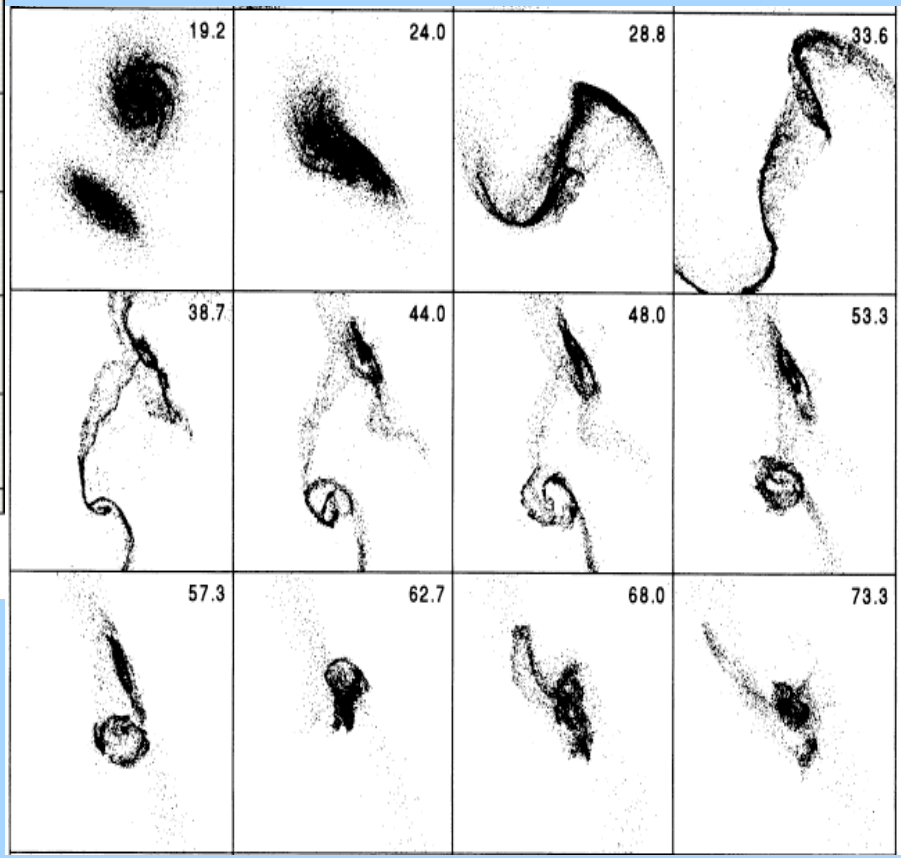
Merging Galaxies, Starbursts



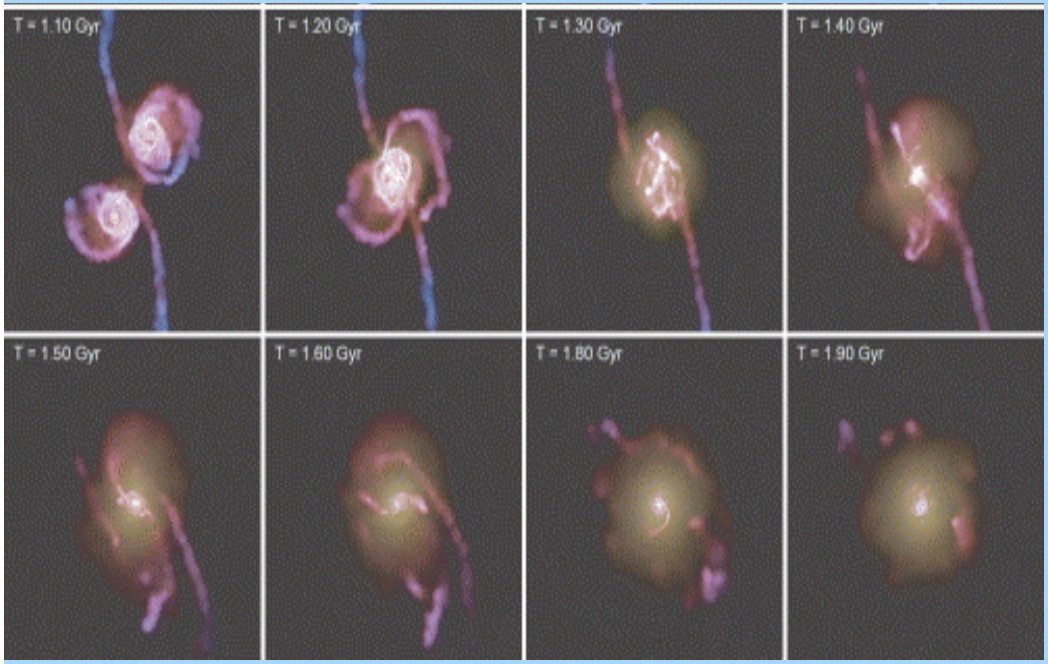
Sanders & Mirabel (1996)

Mergers ⇒ Dusty, Infrared Bright Galaxies ULIRGs – $L_{IR} > 10^{12} L_{sun}$

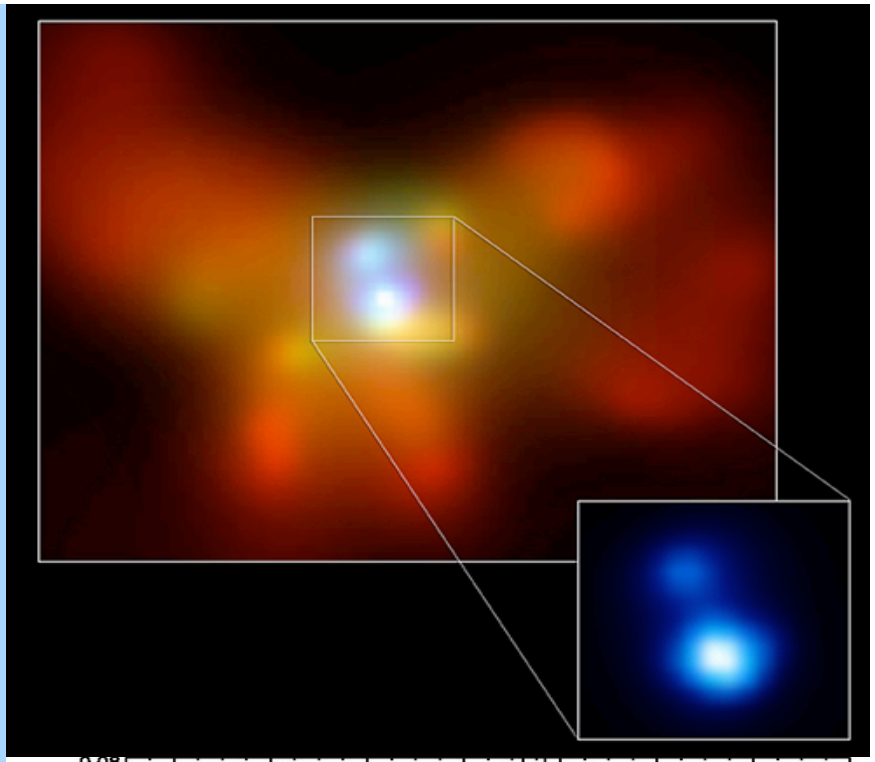
- Toomre & Toomre (1972): "*Galactic collisions can bring deep into a galaxy a fairly sudden supply of interstellar material*"
- Hydrodynamic simulations – Mihos & Hernquist (1996) – galactic bridges & tails, starbursts

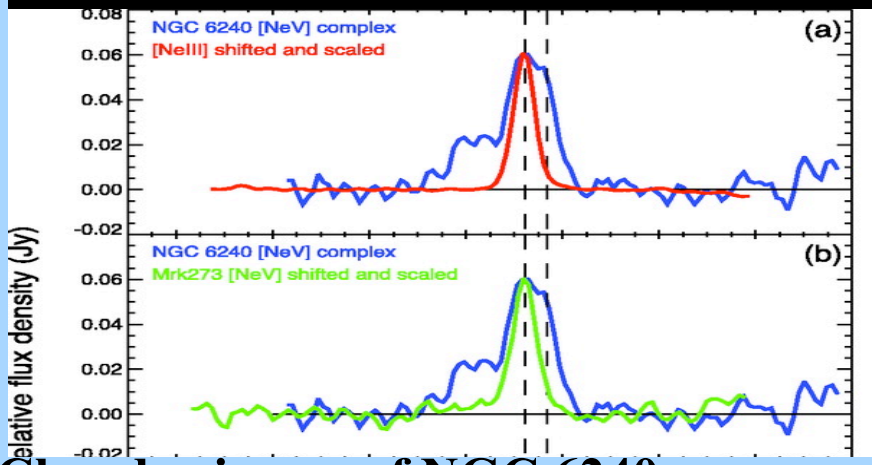


Merging Galaxies, Starbursts & AGN (fast-forwarding a few years…)



Recent HD Simulations with Black Holes: Springel et al. 2005





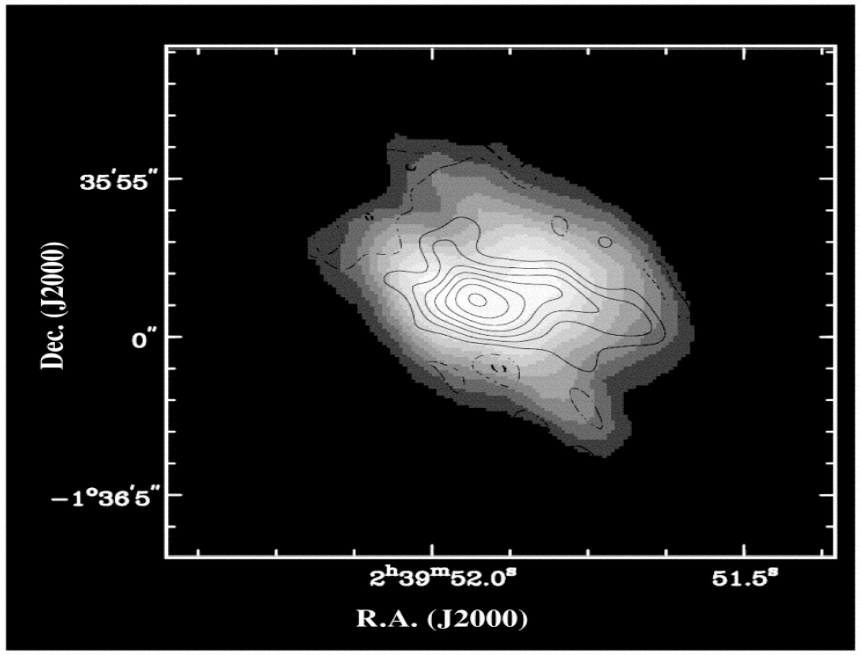
Chandra image of NGC 6240: (Komossa et al 03) – L_x + detection of fine-structure lines by Spitzer's IRS, NeV (Armus et al 06) – AGN.

Submillimeter Galaxies

What A SMG Is

- Massive galaxies, with SFR of ~500-1000 M_{sun}/yr. Discovered by sub-mm SCUBA surveys in late 90s (Smail et al 97).
- Empirical def of SMGs: F_{850} > 1 mJy. Local ULIRGs are SMGs. Arp 220: F_{850} ~100 mJy. Spectroscopic redshifts for higher redshift population (z ~ 2) obtained by Chapman for ~ 100 sources, median F_{850} ~ few mJy for z~2 population.
- Before Spitzer and SHARC-2 observations, mostly 450 micron, 850 micron, radio observations, and some mm imaging. Faint at infrared wavelengths.

SMM J02399-0136 (Genzel et al 03)



What A SMG Is Not!

Merging Galaxies, Starbursts, AGN (Feedback) and SMGs – ***what we don't know***

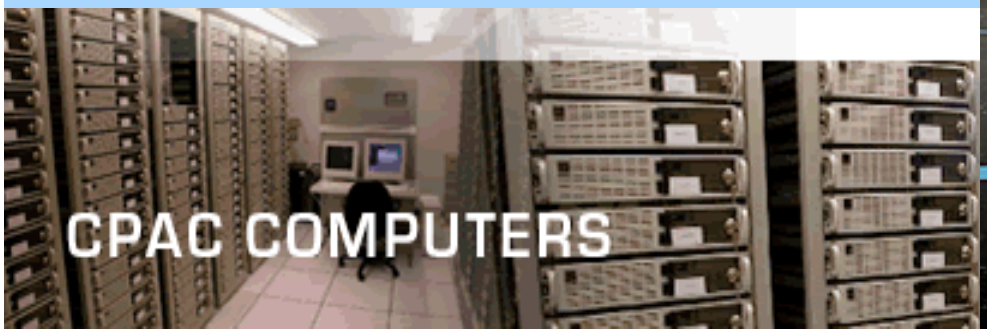
- Are they merging galaxies? [Dasyra et al 06: local ULIRGs – major mergers]
- SMGs at z~2 known to have AGN from X-ray observations (Alexander et al 05). Contribution from AGN to bolometric luminosity not known. Role of AGN in SMG population at z~2 not clear.
- How does feedback from AGN affect transition from z~2 SMG population to present day ellipticals?

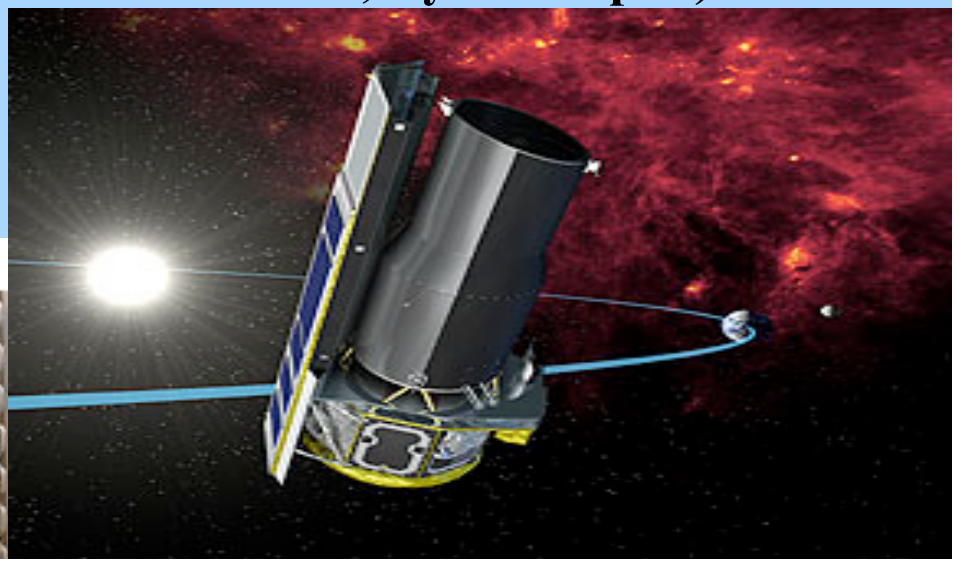
How we study SMGs (Feedback-Driven Method of Study)

Simulations of Galaxy Mergers

Radiative Transfer Calculations: Images, SED template factory, 6 panel movies (*Infrared, CO, Lyman continuum*, Lyman-alpha)

Compare to observations, refine and calibrate models





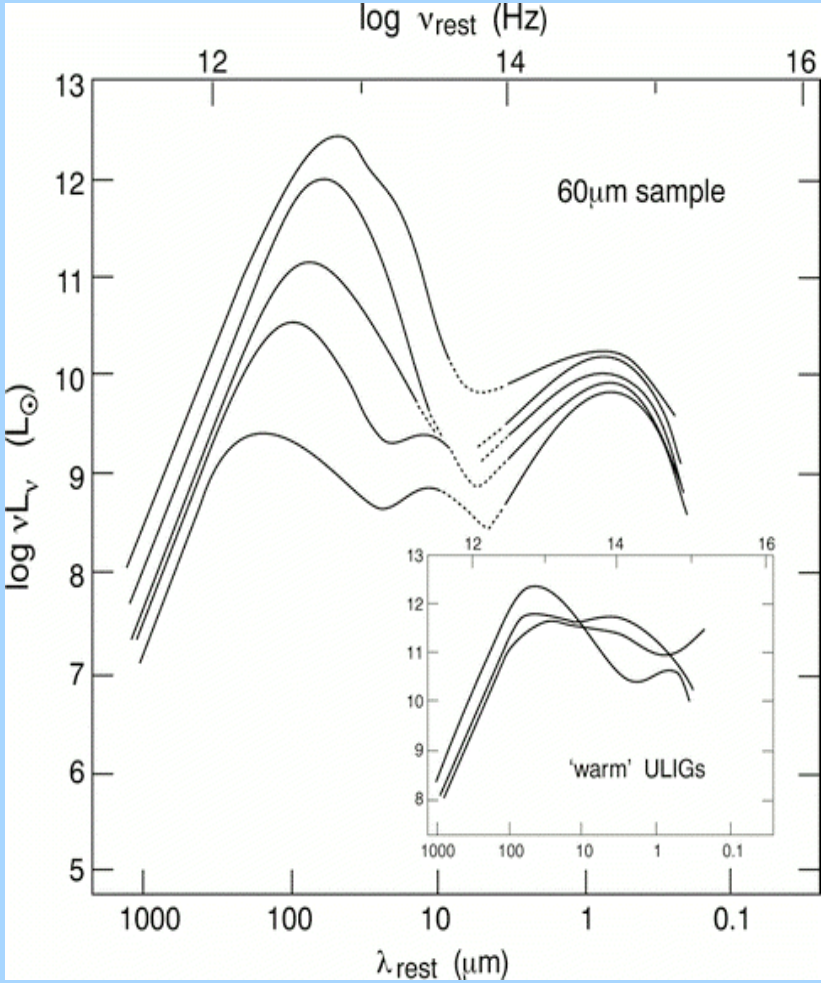
Infrared SEDs

- Merging galaxies are often *dusty*: produce a lot of infrared radiation. ULIRGs ($L_{IR} > 10^{12}$ Lsun) and LIRGs ($L_{IR} > 10^{11}$Lsun) radiate most of their energy in infrared.
- Infrared SED good tool to study them.

How these systems have been studied before:

1. Observational templates
2. Radiative transfer solutions for static templates (toroidal models/axisymmetric)

Improvement: we combine information from SPH merger simulations and three-dimensional radiative transfer calculations: **Chakrabarti & Whitney 2007**



From Sanders & Mirabel (1996)

Outline of Talk

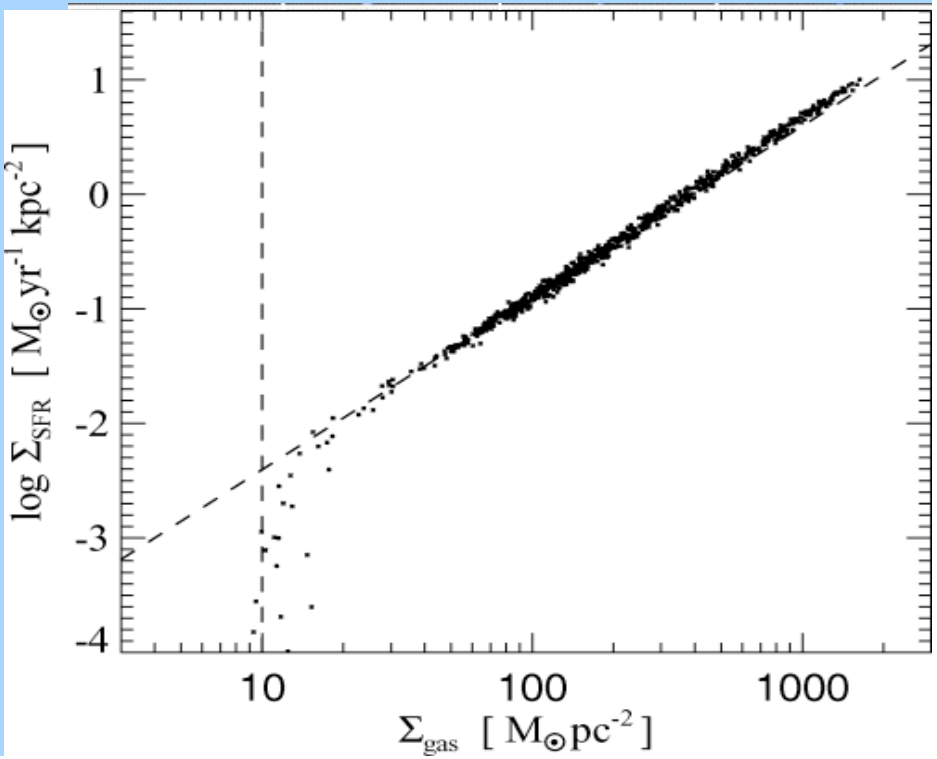
- **Simulations with AGN Feedback and starburst feedback for local LIRGS & ULIRGs - evolution of far-IR SEDs.** ***Cold-Warm IRAS classification.***
- **General trends: do these two kinds of feedback affect the evolutionary history differently?**

- **Submillimeter Galaxies at z ~ 2:**
  Photometric Properties: IRAC color-color plot
- **What is the Role of AGN in SMGs:**
  Infrared X-ray correlations
  Photo Albums of SMGs during their lifetimes
- **Preliminary Classfication & Evolutionary Scheme for SMGs**

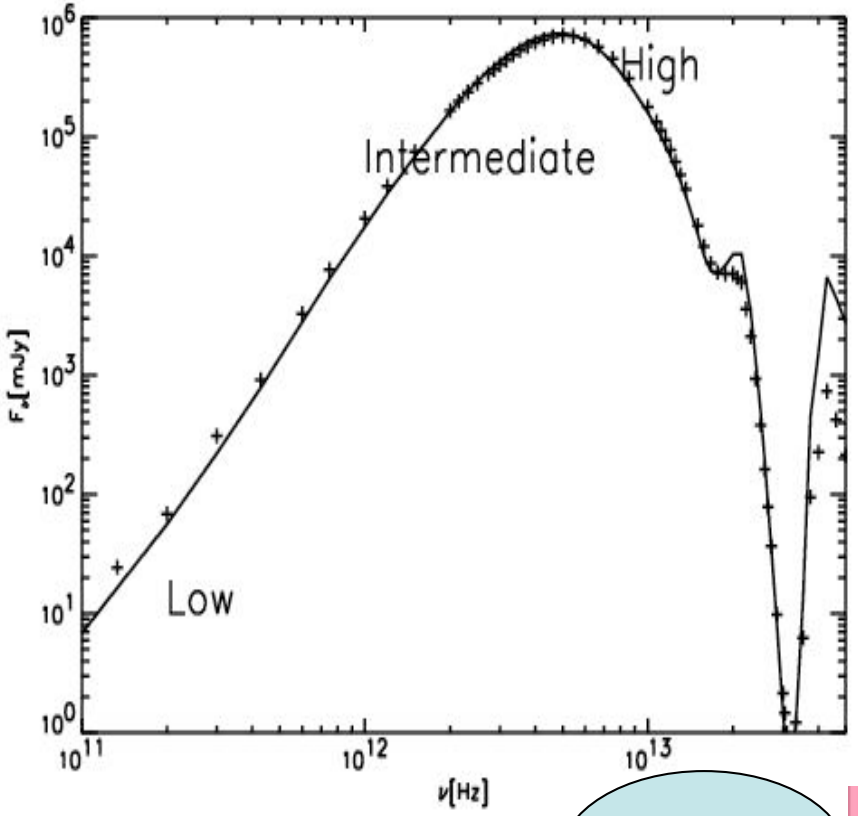
Merger Simulations

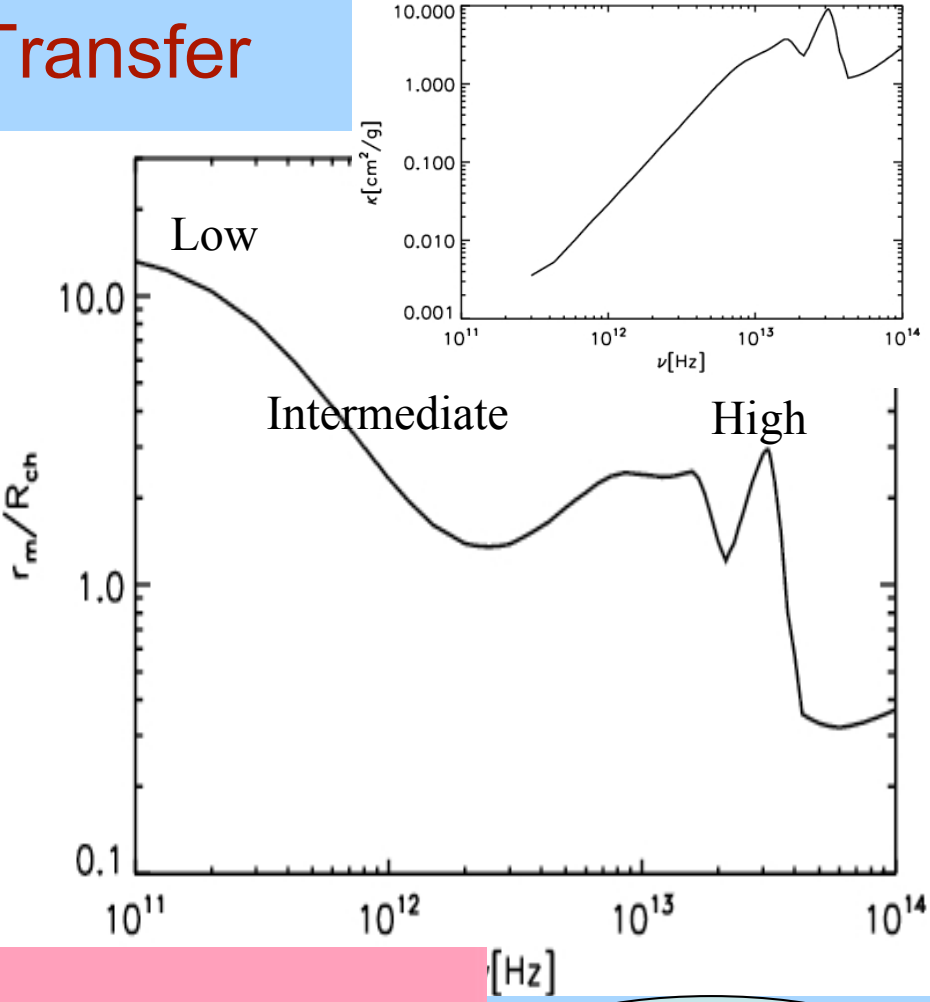
- Smooth Particle Hydrodynamics (Springel 2005), dark matter, stars, gas, black hole. **Binary "major" merger simulations**. Star formation processes treated in prescriptive way, with Kennicutt-Schmidt implementation. **Star Formation in Clusters** is not well understood. ***Many state of the art simulations still treat formation of stars in cores***, not clusters! (e.g. extensions of isolated star formation models). Massive stars form in a clustered mode.
- Large dynamic range – subgrid model for interstellar medium (Springel & Hernquist 2003). Motivated by observations of GMCs **include turbulent pressure in modeling ISM– Chakrabarti et al. 2006a**. $\sigma \sim 10\ c_{s,}$, $P_{turb} \sim 100\ P_{thermal}$.

Black hole swallows gas from local neighborhood – (after Di Matteo)

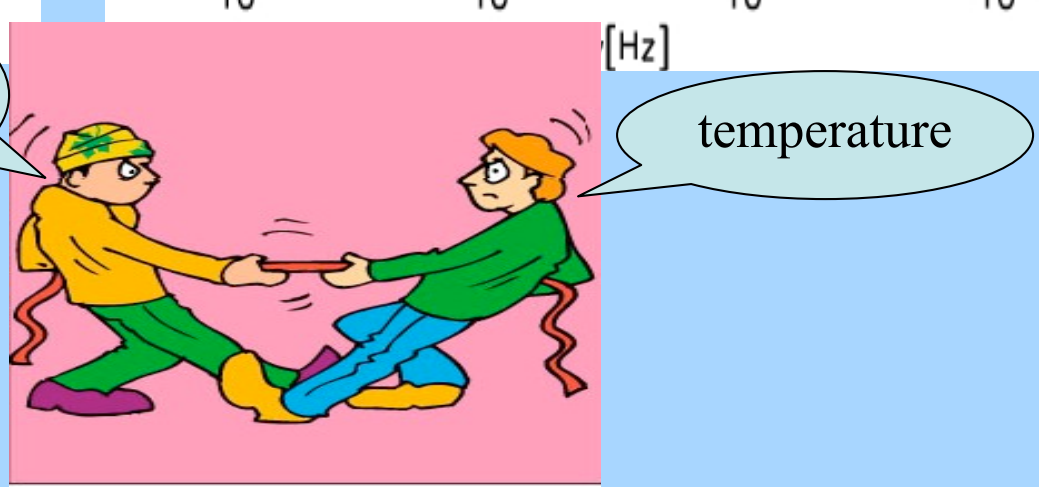


Basics of Radiative Transfer

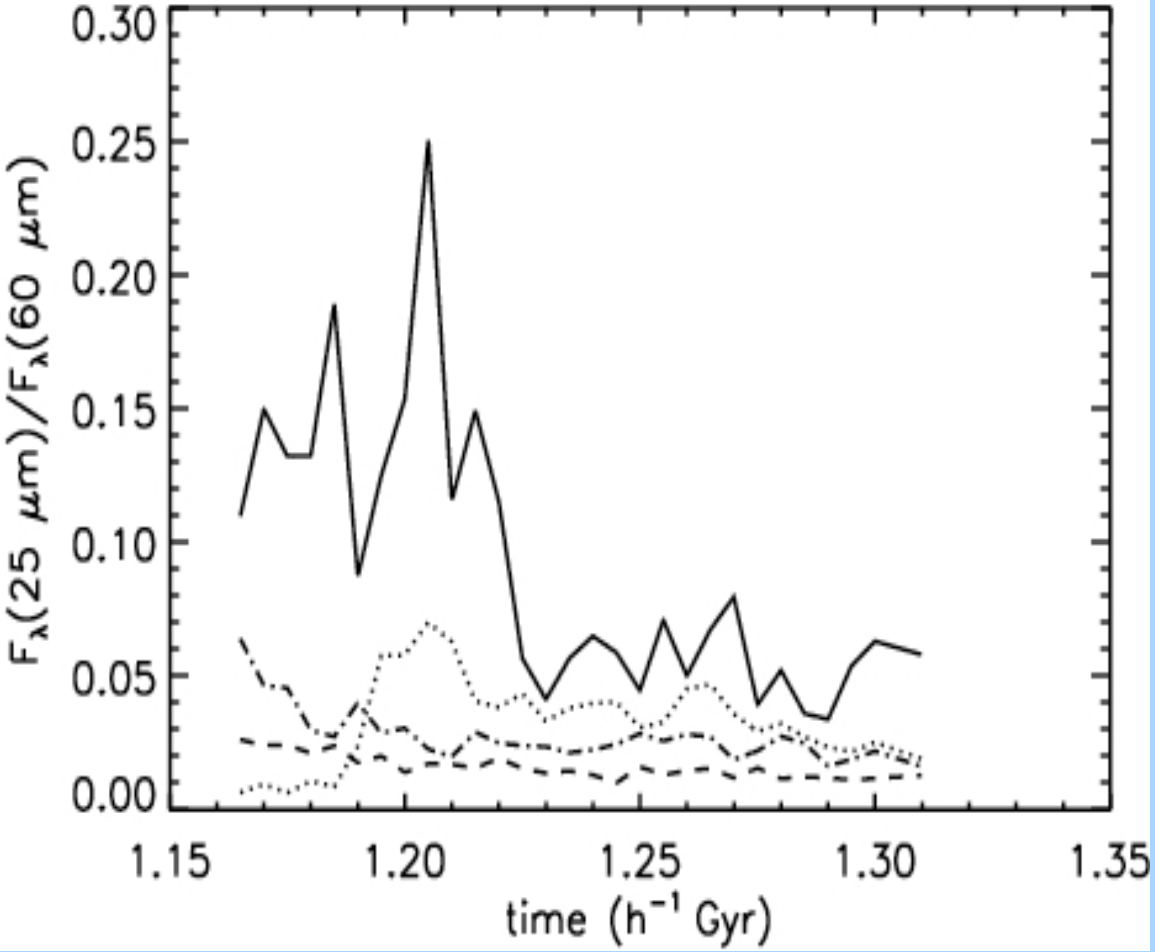




- Contribution functions & **Chakrabarti & McKee 2005**
- L/M and Σ. **Source of illumination does not matter for reprocessed far-IR SED**
- What does self-consistent RT calculation mean: div F =0 -> Radiative Equilibrium.



General Trends: **Cold-Warm Transition**

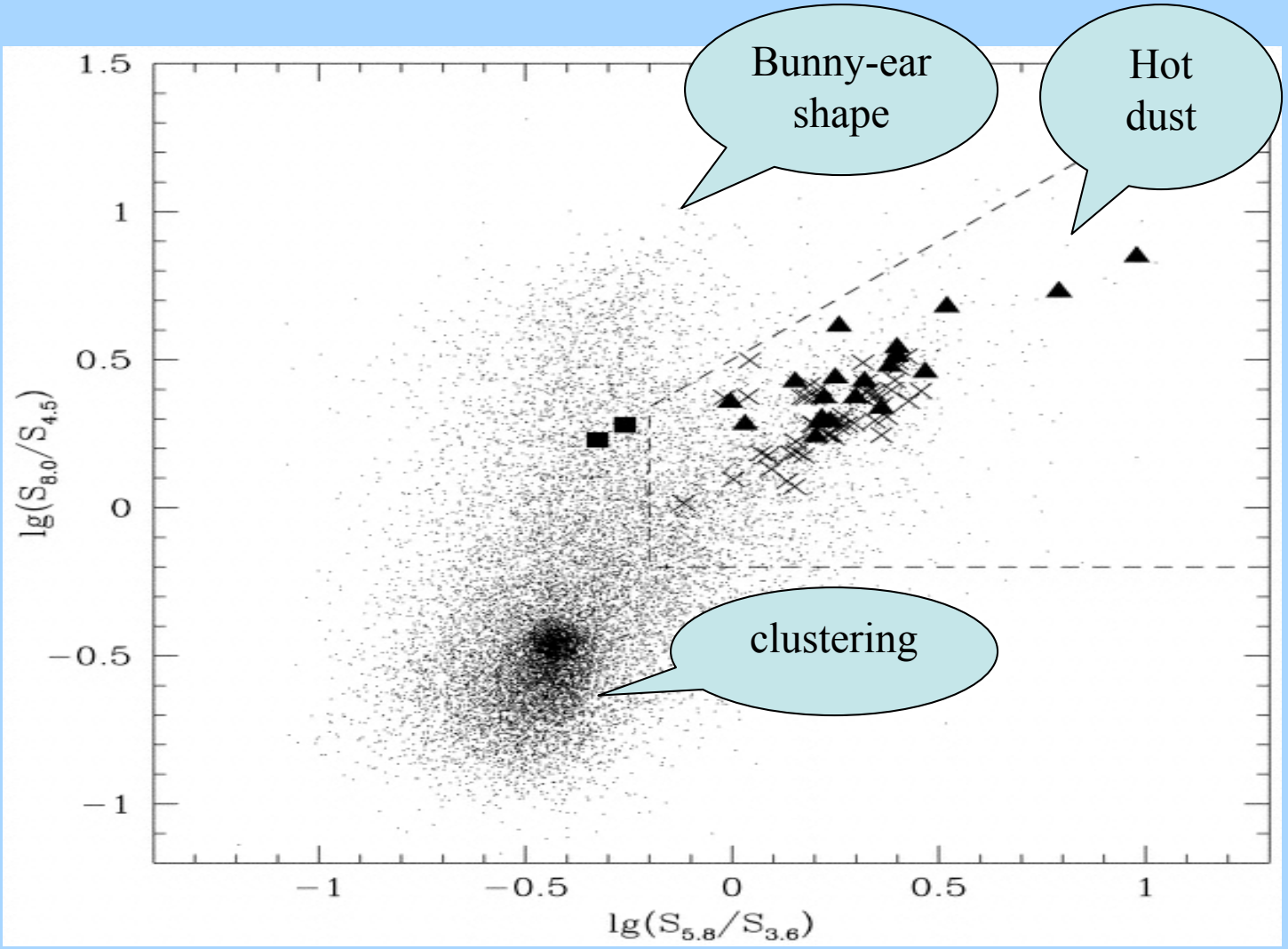


solid line: AGN feedback
dotted: η=0.5, dashed: η=0.05,
Dash dotted: η=0.005

- AGN feedback: generally disperses gas more effectively – **lower columns – more high frequency flux.**
- **Source of illumination irrelevant**
- Note trends in increasing F(25)/F(60) with increasing mass loading efficiency of starburst winds.

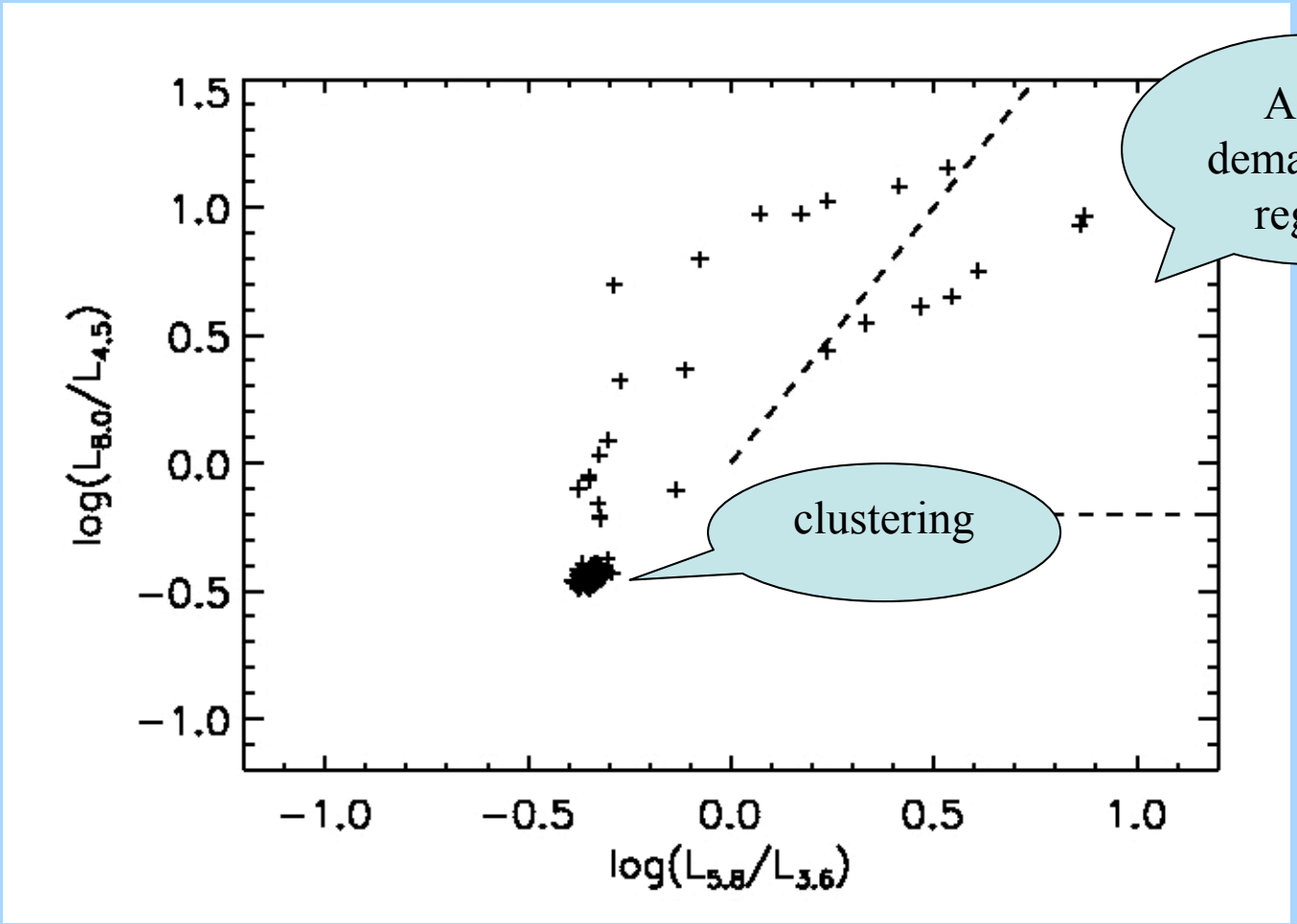
Chakrabarti, et al. (2006a) Accepted to ApJ, Astro-ph/0605652

IRAC color-color plot



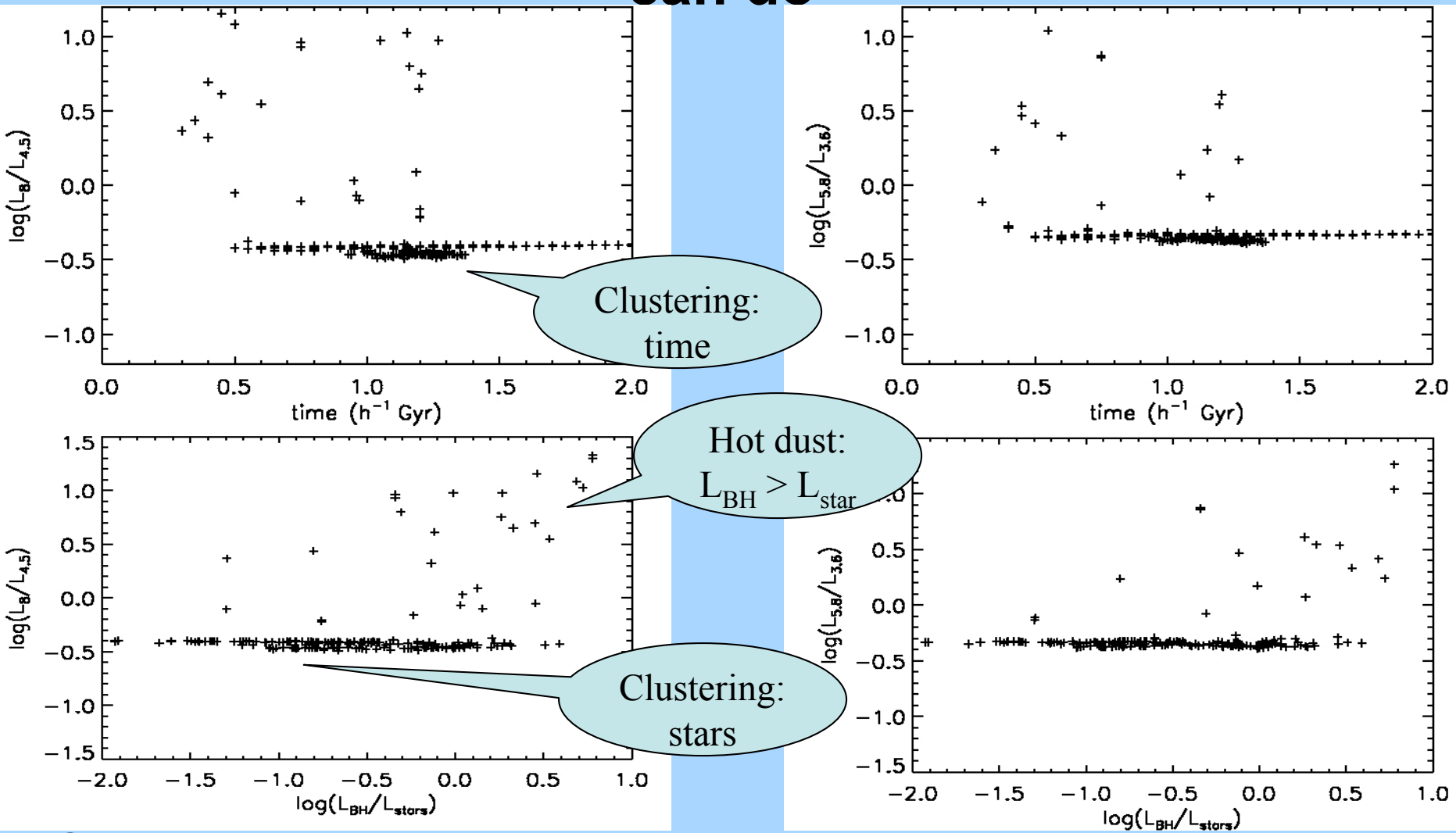
Lacy et al. (2004) from Spitzer FLS. Dashed lines mark “AGN-demarcated region”

IRAC color-color plots



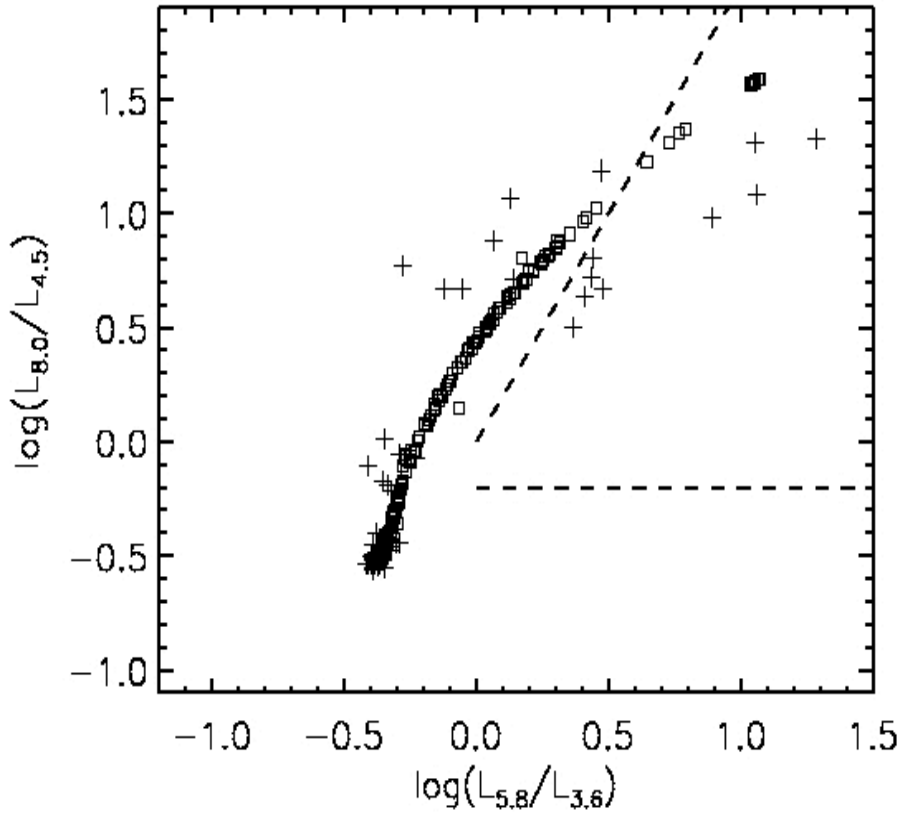
- **What is the clustering in the color-color plot due to?** (Chakrabarti et al. 2006b,**astro-ph/0610860**)

Unfolding IRAC color-color plots – what the sims can do

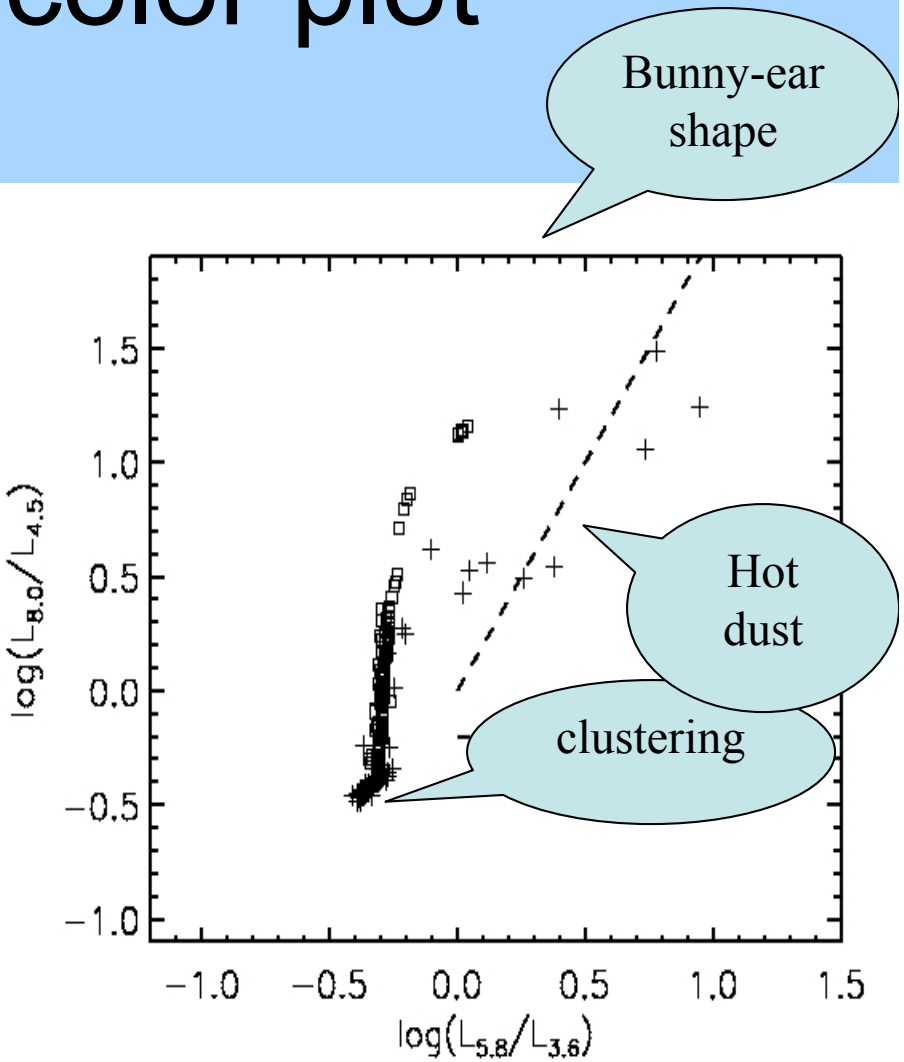


- ***Clustering*** **in color-color plots – correlated with time spent in region of color space and stars dominating in bolometric luminosity output.**

IRAC color-color plot



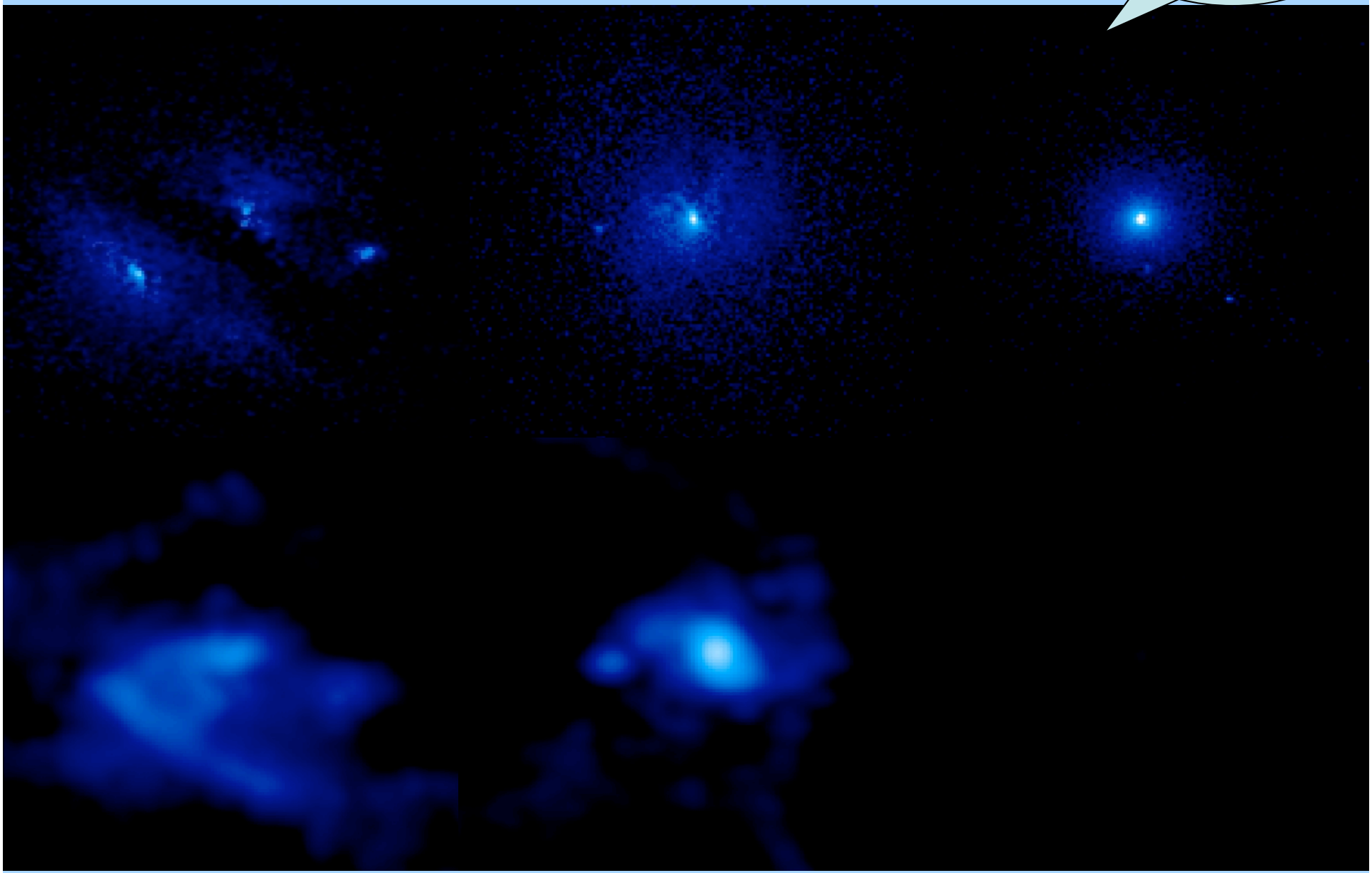
IRAC color-color plot in rest-frame



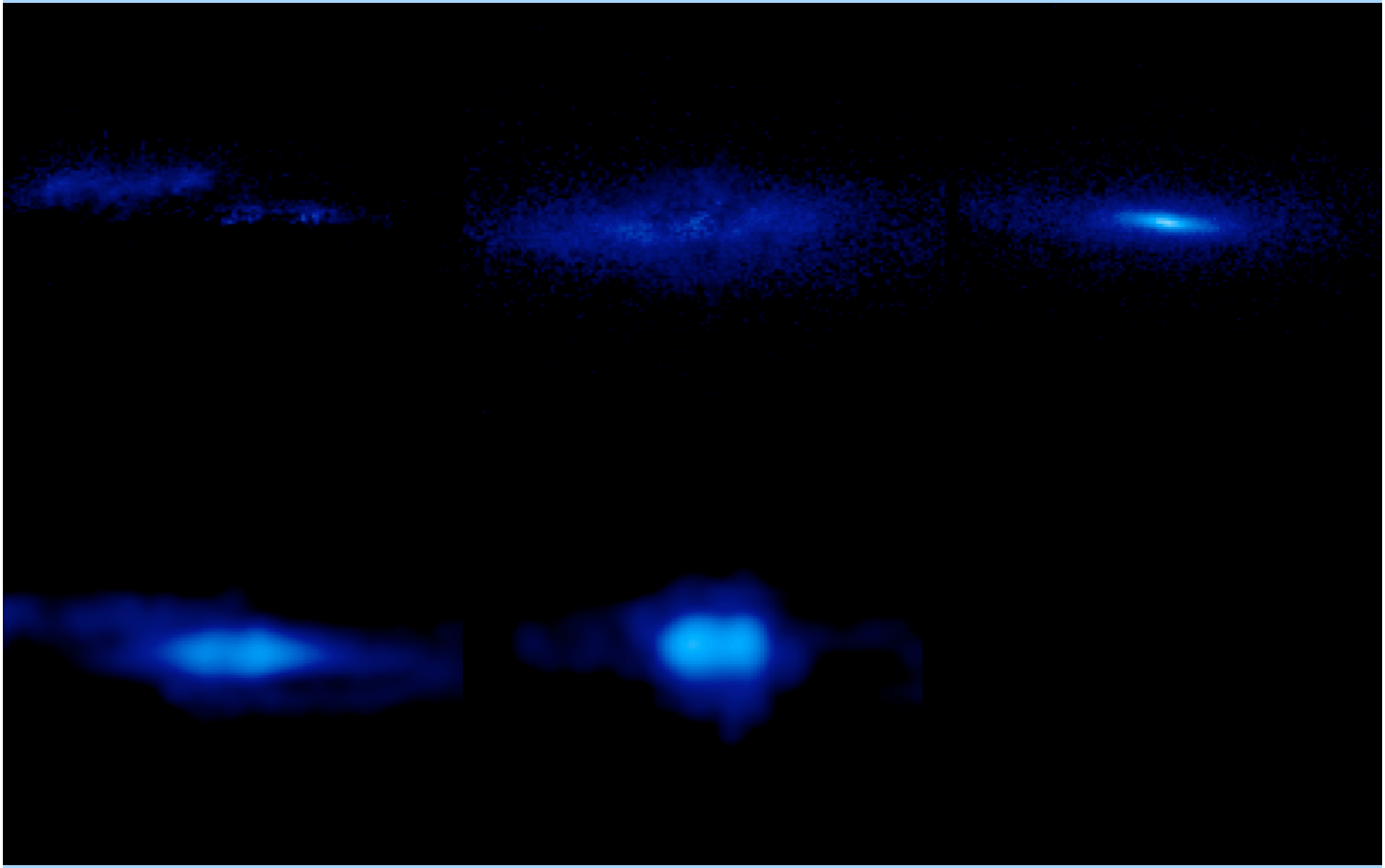
IRAC color-color plot for z=0.3 slice, bunny- ear shape.

Life of A Sub-mm Galaxy: Time

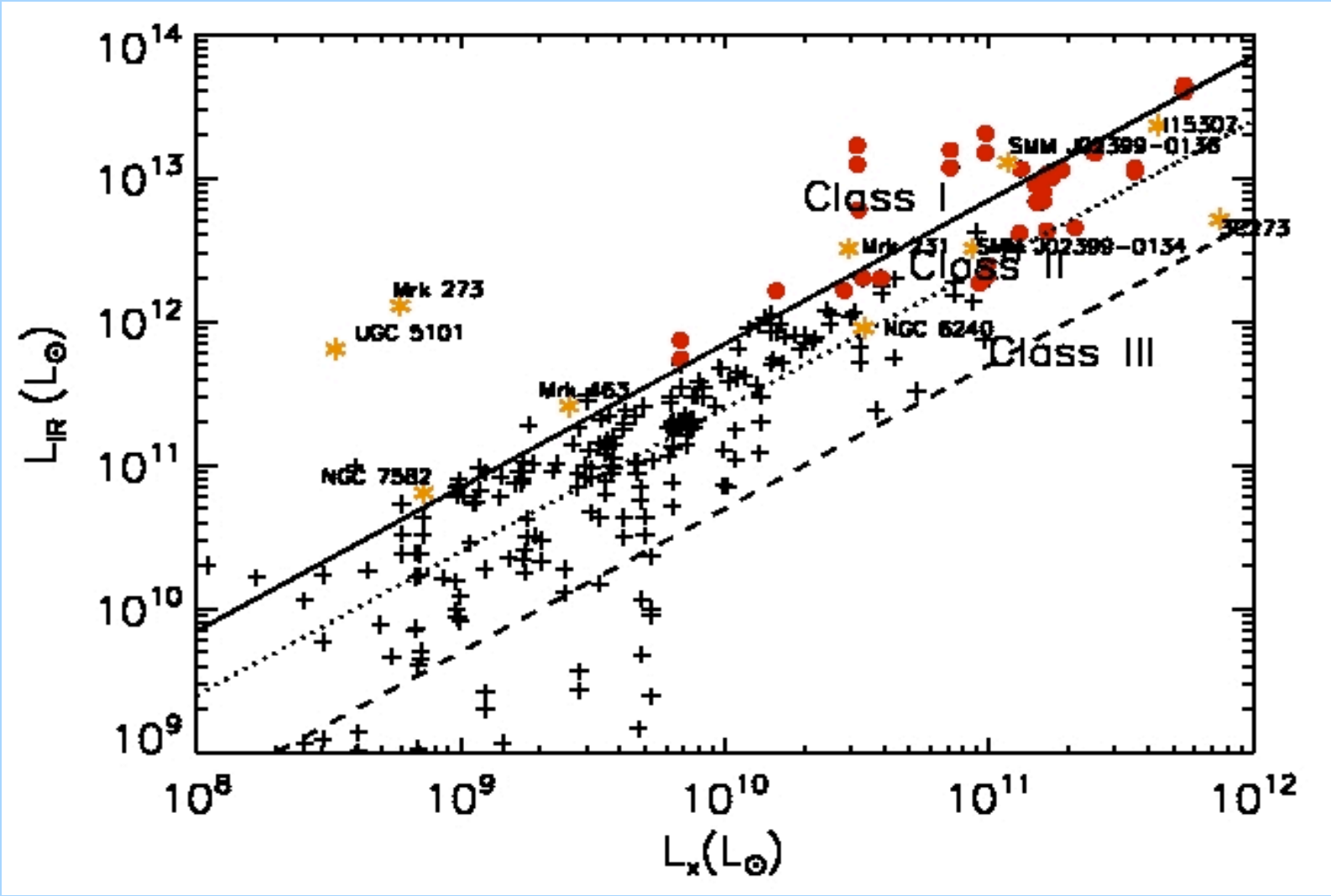
Cold -> Warm



Life of A Sub-mm Galaxy: Time →

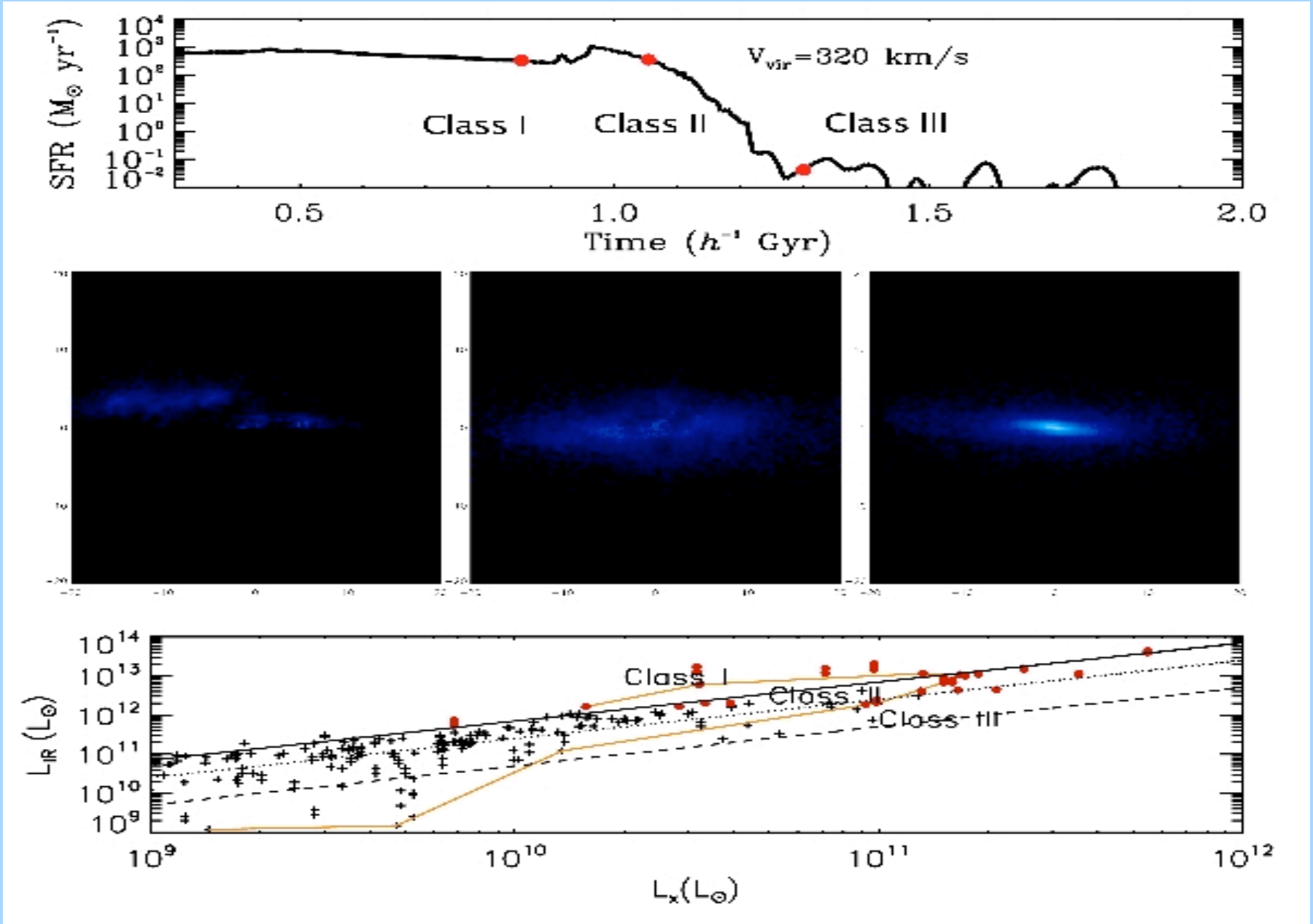


Towards A Classification Scheme for SMGs



- **SMGs are a *broader* class of objects than quasars or starbursts and *traverse the Class I – Class II divide*, Chakrabarti et al. 2006b, astro-ph/0610860**

Towards An Evolutionary Scheme for SMGs



Chakrabarti et al. 2006b, astro-ph/0610860

Main Points of Talk

- Major merger simulations to understand z~2 population of SMGs and local ULIRGs. (Local ULIRGs known to be merging systems)
- Confirm well-known correlations – **cold-warm transition for local ULIRGs** from radiative transfer solutions.
- **Unfolding** IRAC color-color plot. **Clustering**.
- SMGs – **broader class of objects than starbursts or quasars**. Photometric properties: many of the brighter SMGs will have energetically active AGN. Can be classified on the basis of L_{IR}-L_x ratios: Class I (pre-merger), Class II (close to main feedback phase), Class III (merger remnant)
- THANKS!