

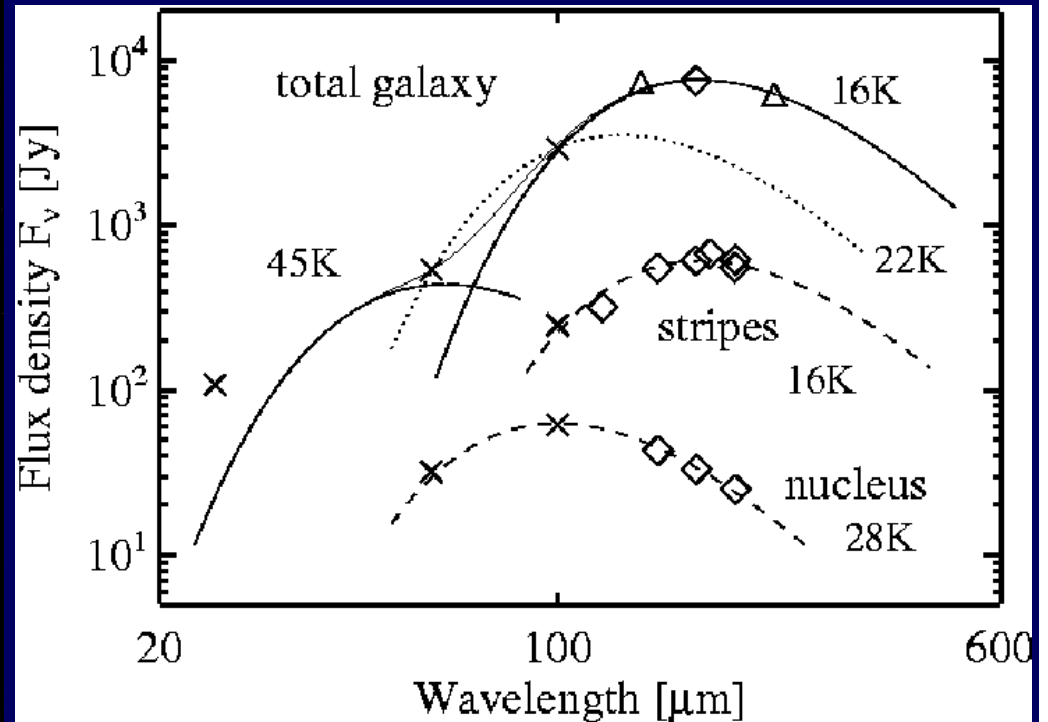
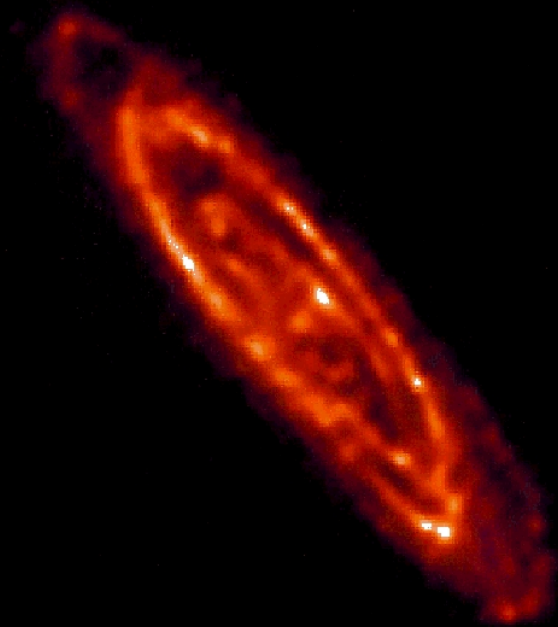
**ISO science  
highlights:  
normal galaxies**

**RICHARD TUFFS**

Astrophysics Department,  
Max-Planck-Institut für Kernphysik  
Heidelberg

# Spectral and morphological characterisation of disk galaxies (I): emission from cold diffuse dust

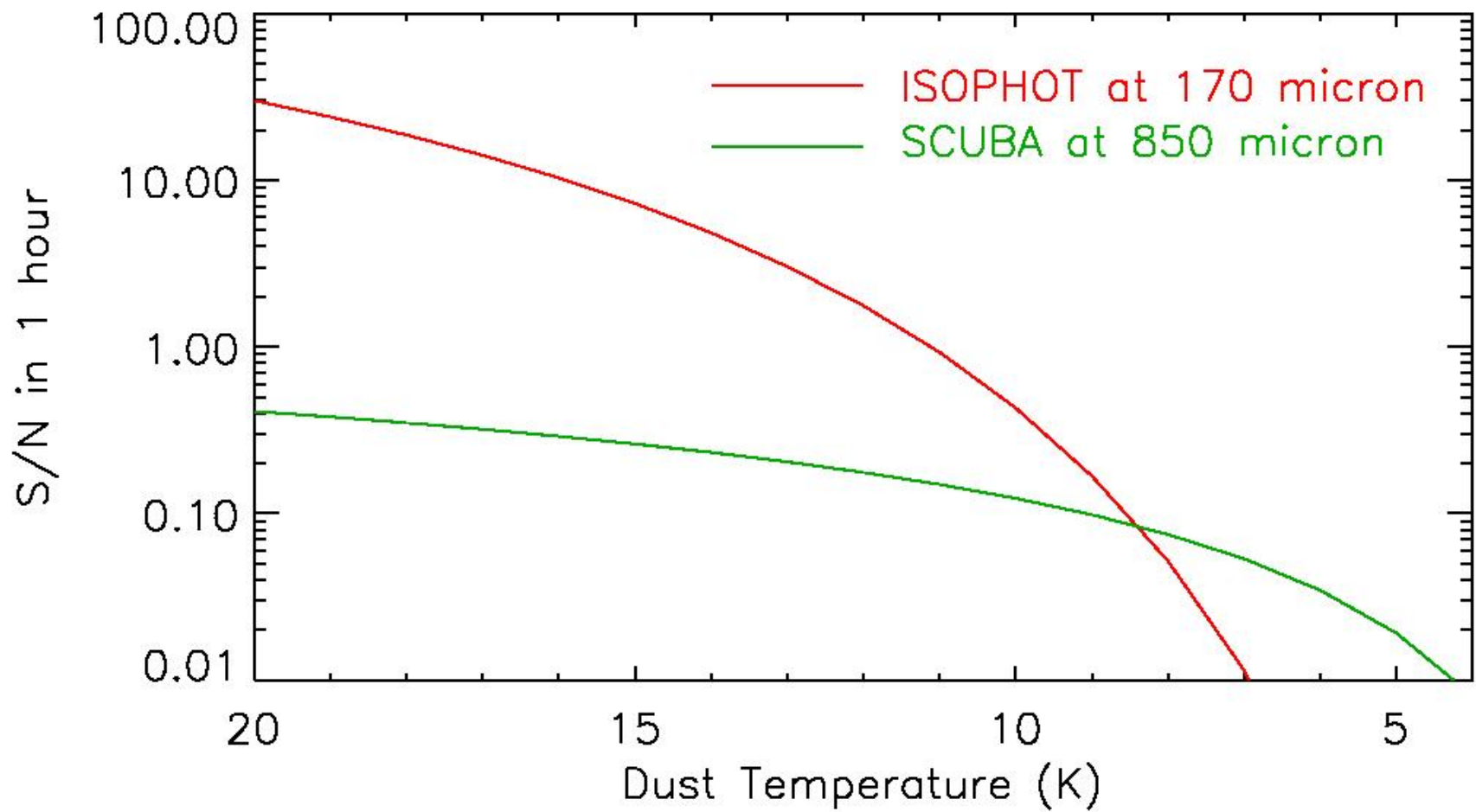
M31 at 170 $\mu$ m



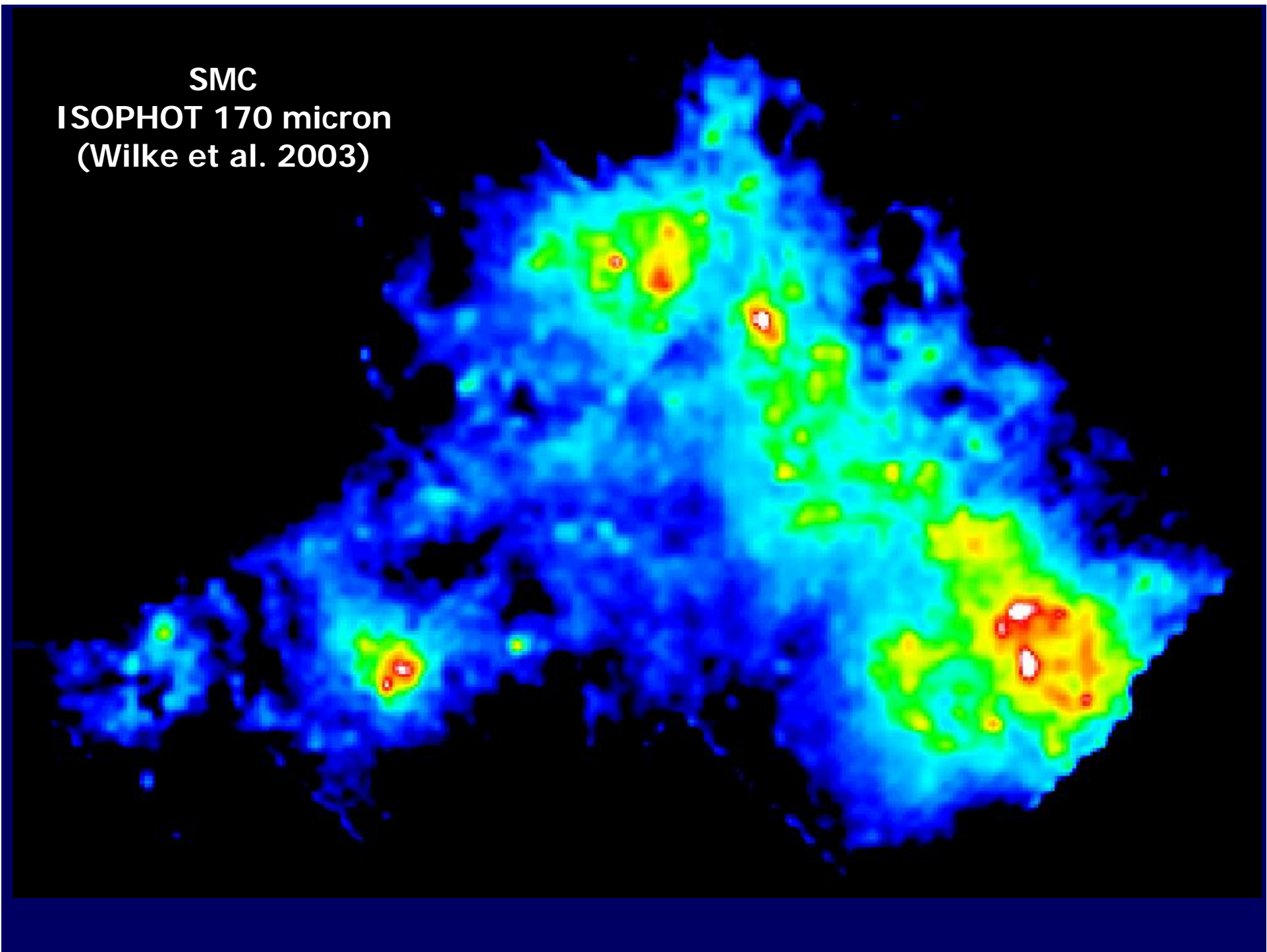
Haas et al. (1998)

in general disks have an underlying diffuse emission component  
with  $12 \leq T_D \leq 20$  K carrying the bulk of the 170  $\mu$ m emission

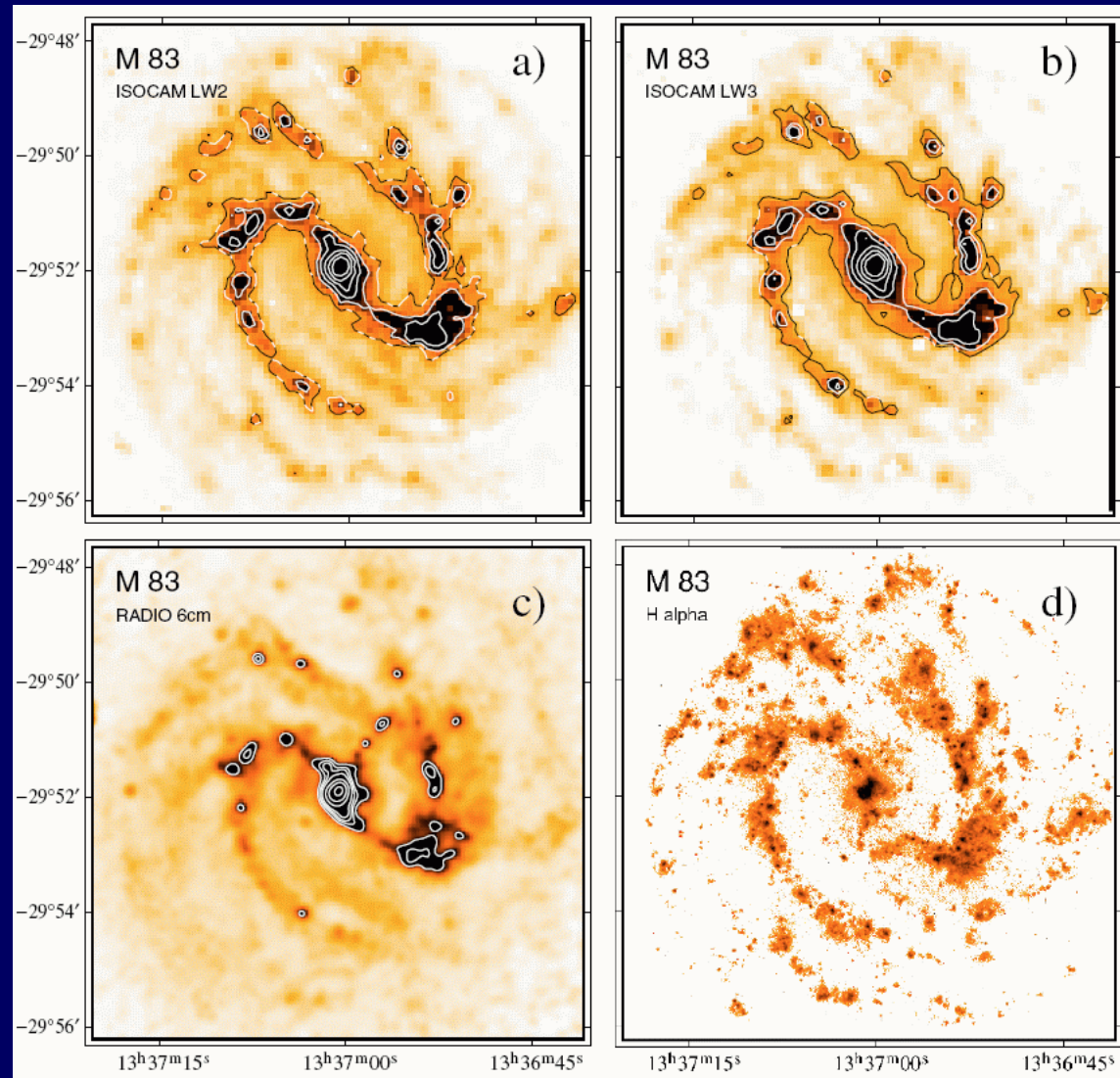
## Detectability of diffuse emission from cold dust



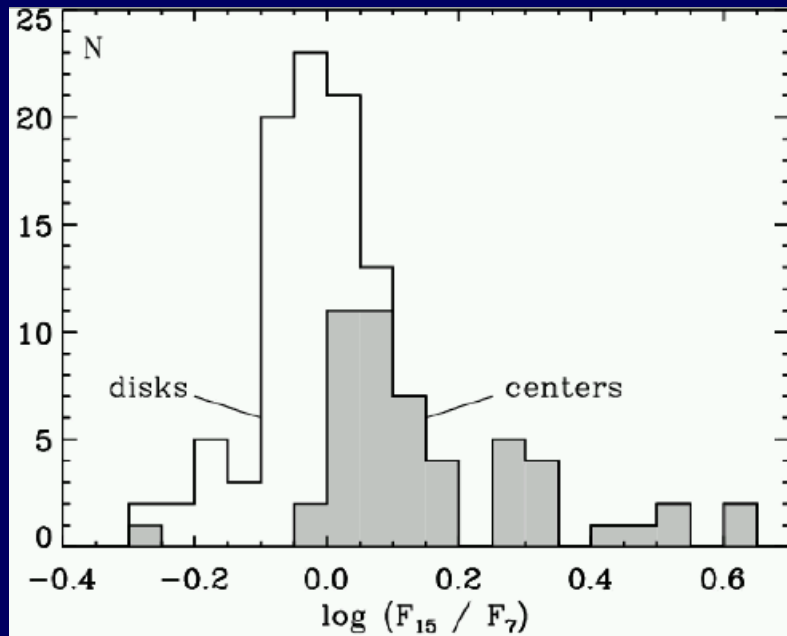
SMC  
ISOPHOT 170 micron  
(Wilke et al. 2003)



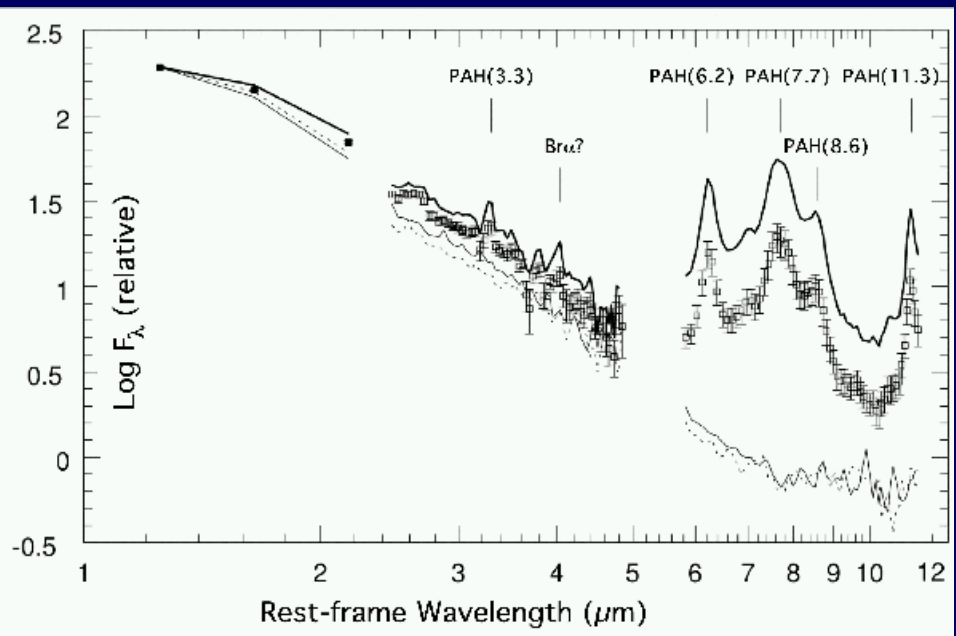
# Spectral and morphological characterisation of disk galaxies (II): **emission from PAH**



Vogler et al (2005)



Roussel et al. 2001



Lu et al. 2003

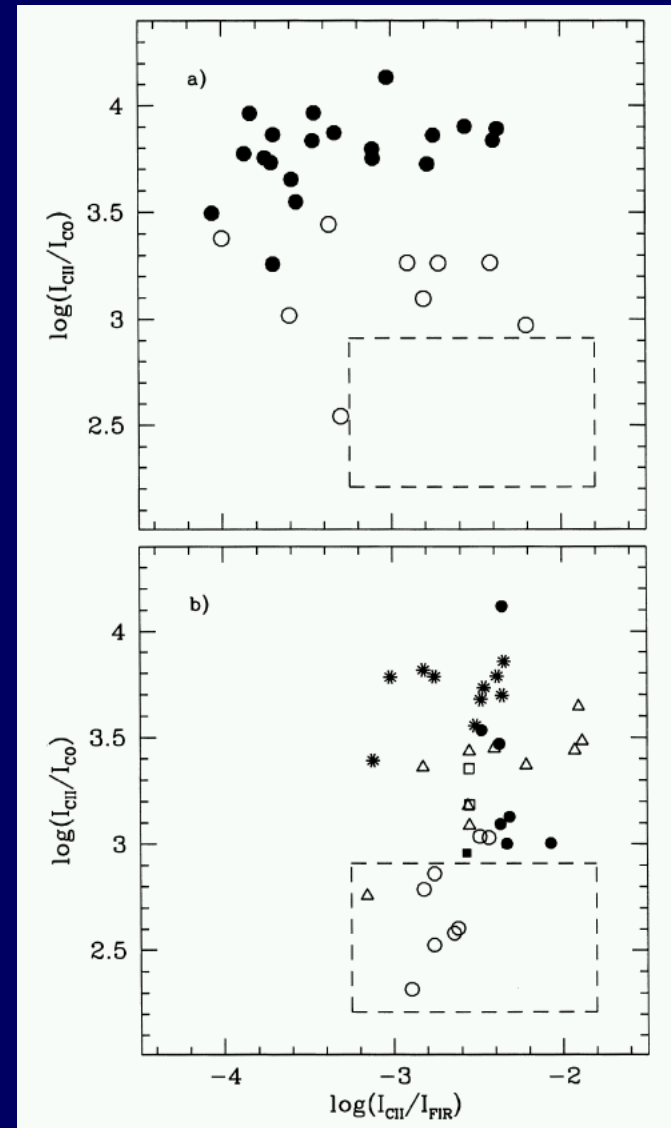
### 5 - 18 $\mu\text{m}$ spectrum of (local universe) galactic disks:

- luminosity mainly carried by stochastically heated PAH
- little colour variation between and within galaxies
- significant additional component of emission from grains in equilibrium with stronger radiation fields in nucleus

# Spectral and morphological characterisation of disk galaxies (III): **emission from [CII]**

[CII] 158  $\mu\text{m}$  emission also dominated by emission from diffuse disk, as for the dust continuum

- global [CII] in normal galaxies not dominated by PDR in star-forming complexes



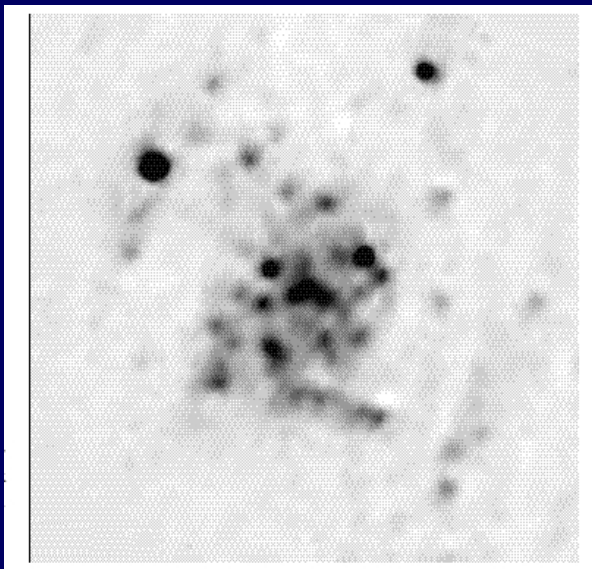
galactic sources

galaxies

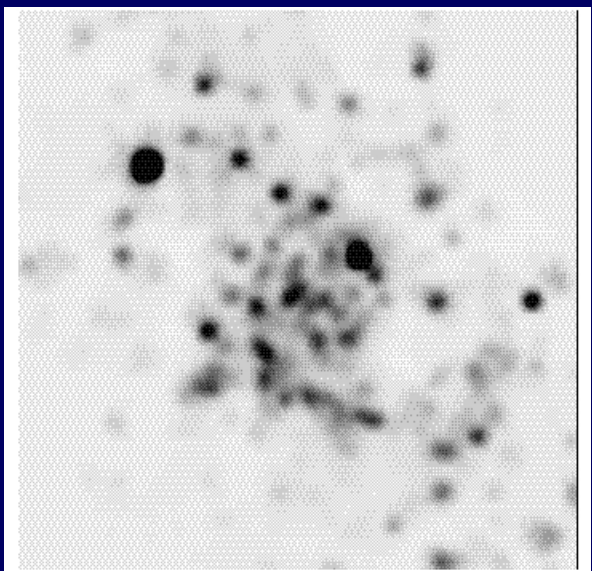
Pierini et al (1999)

# Revealing the complex relation of IR emission to star formation (I): star-forming complexes in M33 in the FIR

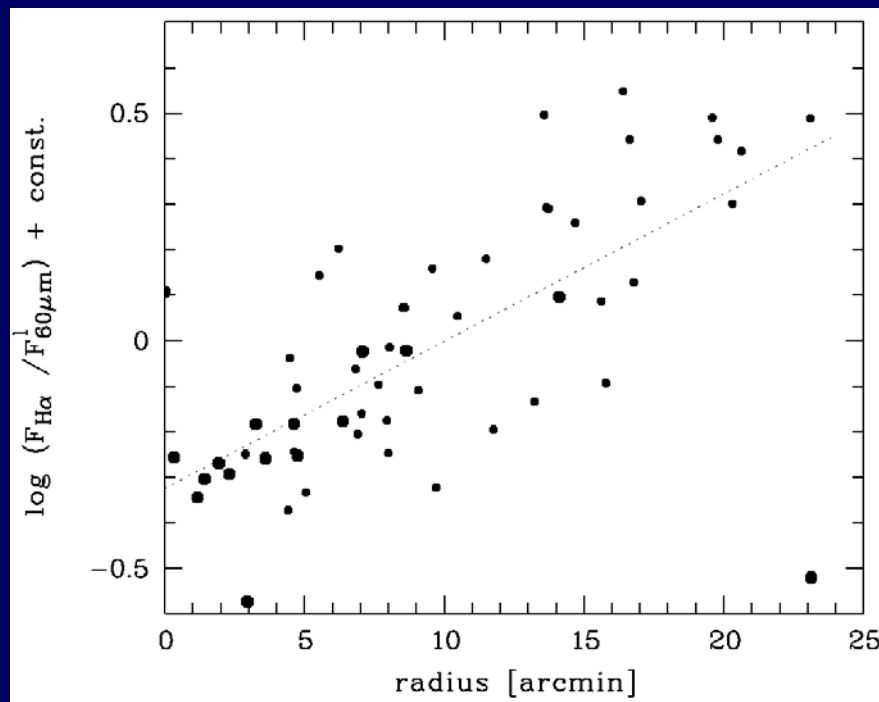
60  $\mu\text{m}$



H $\alpha$



(Hippelein et al. 2003)

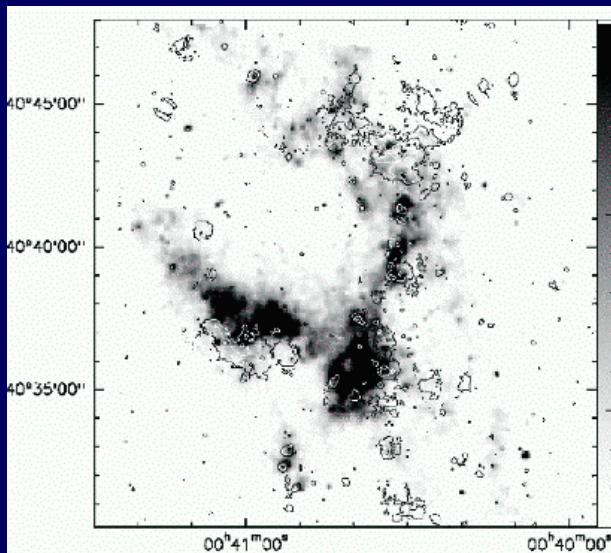
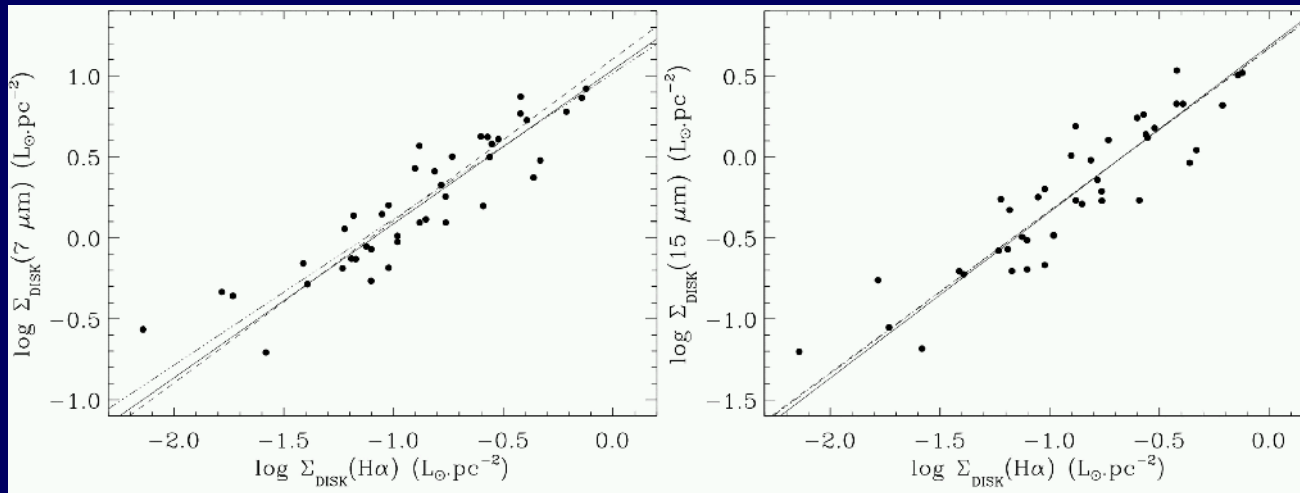


monochromatic flux densities  
unreliable measure of SFR:  
- FIR colours vary with  
galactocentric position

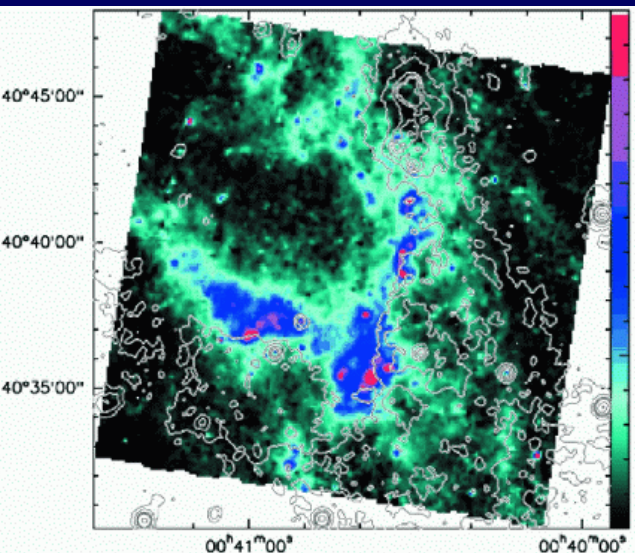


# Revealing the complex relation of IR emission to star formation (II): PAH

Roussel et al. 2001  
(global emission)



H $\alpha$  contours on LW2



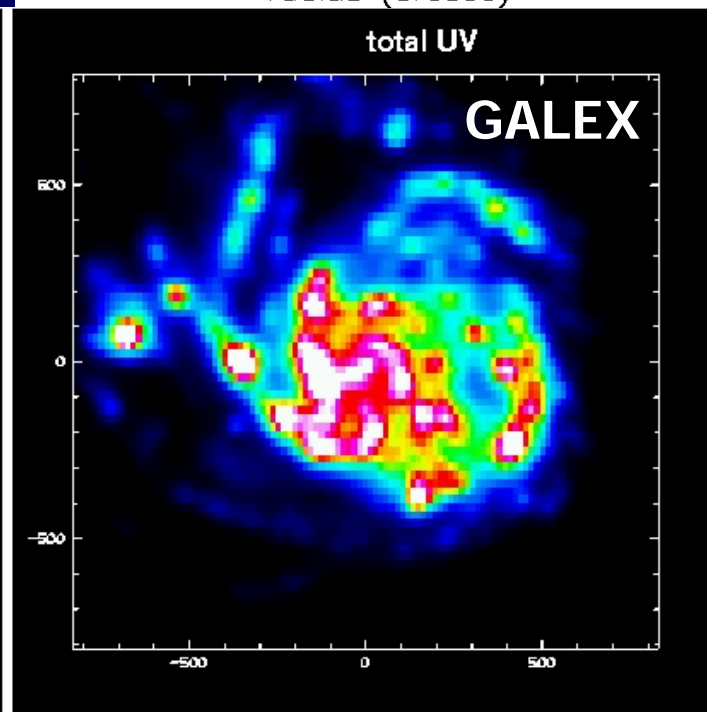
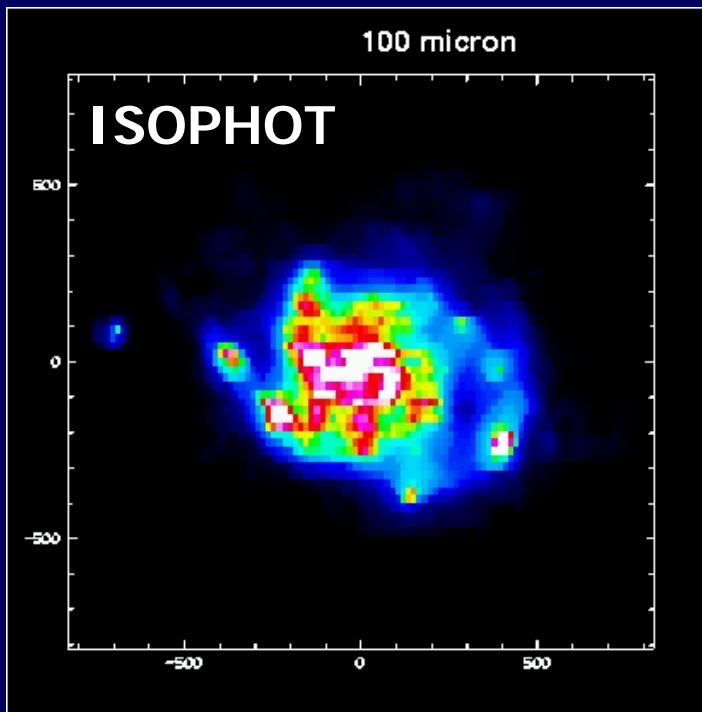
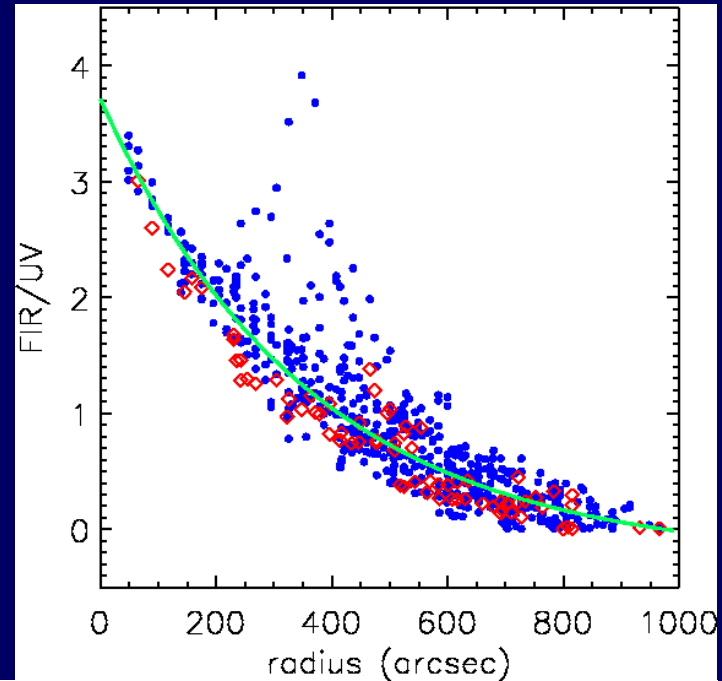
UV contours on LW2

Pagani et al. 1999  
(part of M31)

**PAH follows SFR (at least in the local universe, and despite lack of detailed spatial correspondence with UV and H $\alpha$ )**

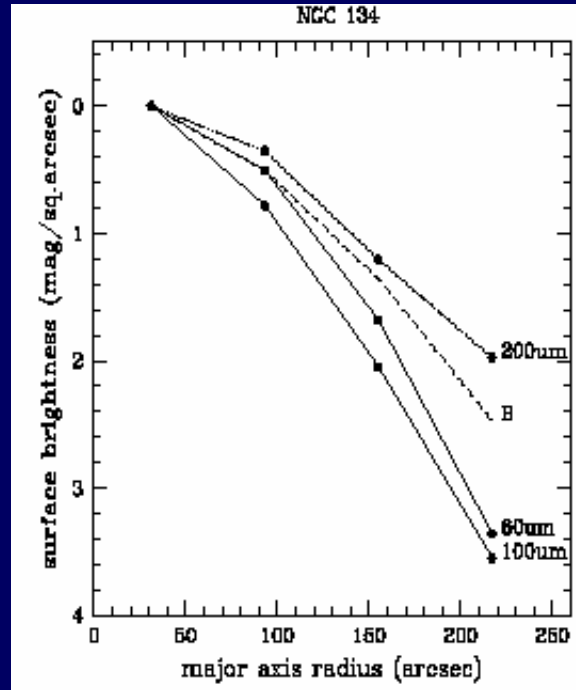
# Revealing the complex relation of IR emission to star formation (III): **FIR and UV in M101**

Popescu, et al (2005)

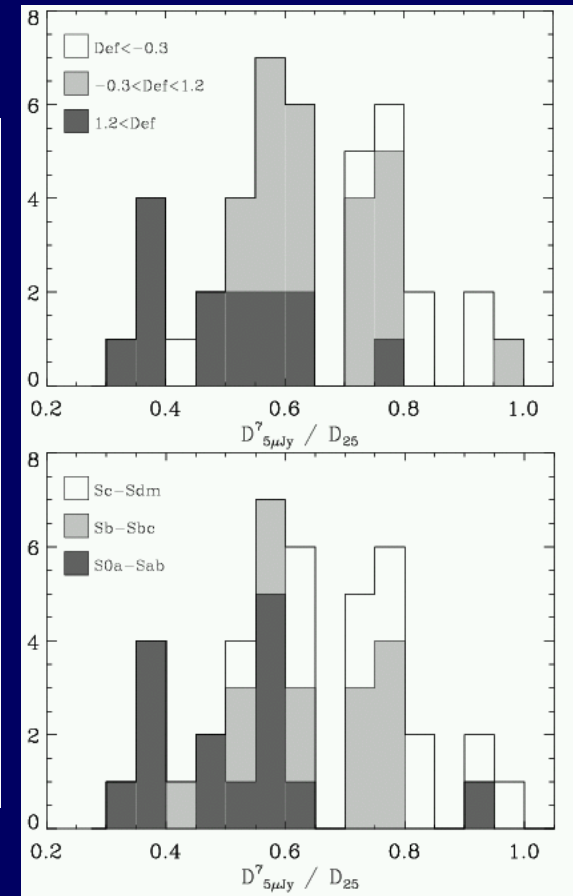


# Scalelengths of spiral disks in the IR

- scalelength of FIR emission increases with increasing wavelength
  - bulk of grains heated by a radially decreasing radiation field
- scalelength at 200  $\mu\text{m}$  *exceeds* scalelength of optical emission
  - intrinsic scalelength of dust *exceeds* intrinsic scalelength of stars
- scalelength of PAH emission < scalelength of cold dust emission

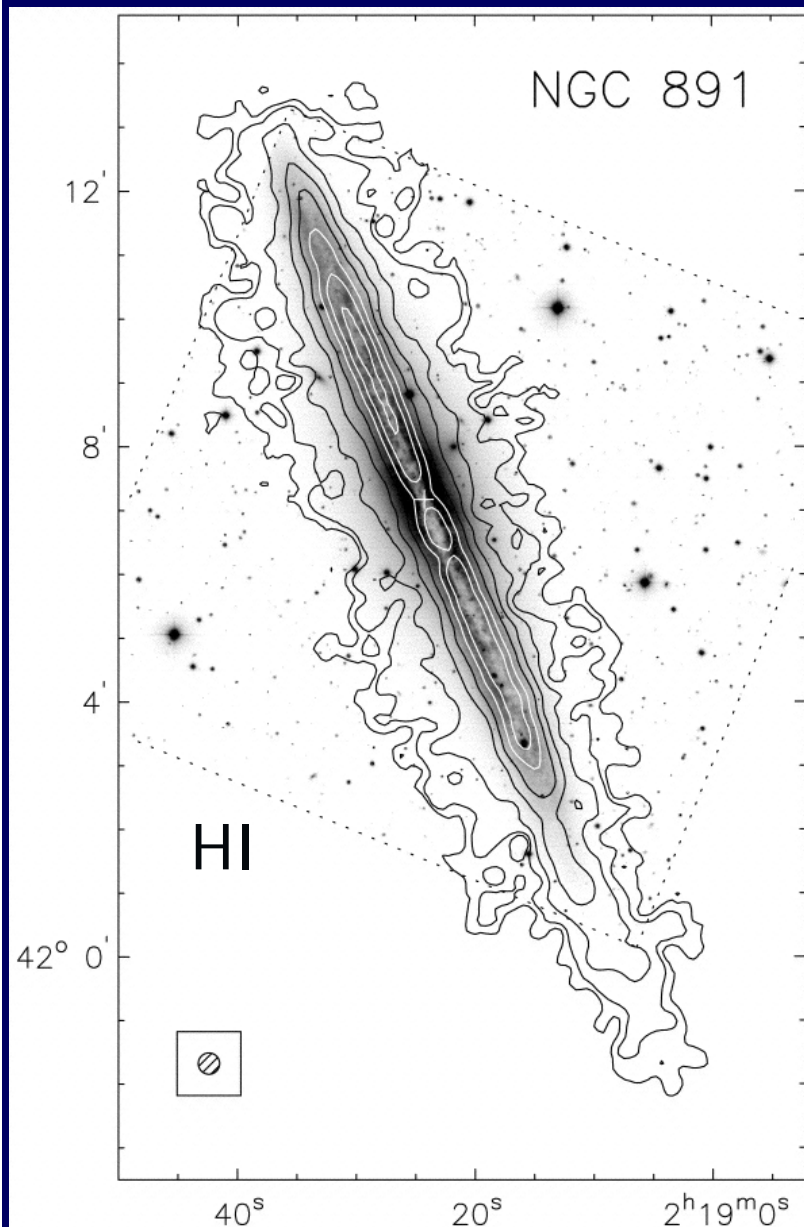


Alton et al. (1998)



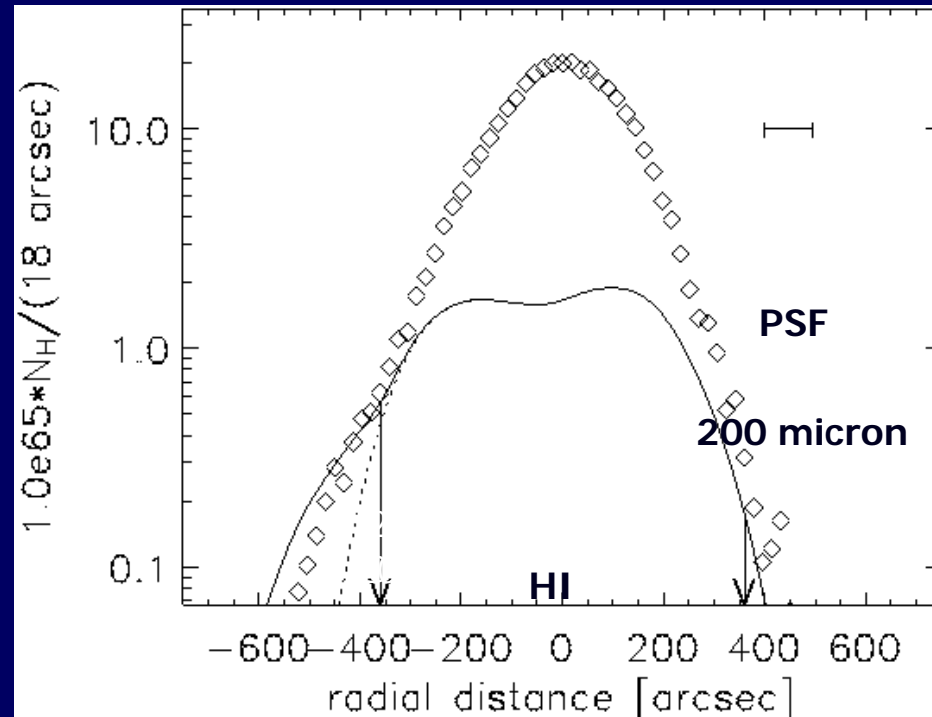
Roussel et al 2001

# The extent of spiral disks: **First detection of FIR emission from an extended HI disk**



Swaters et al. (1997)

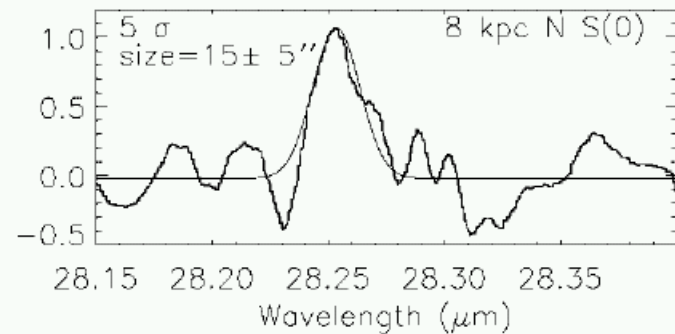
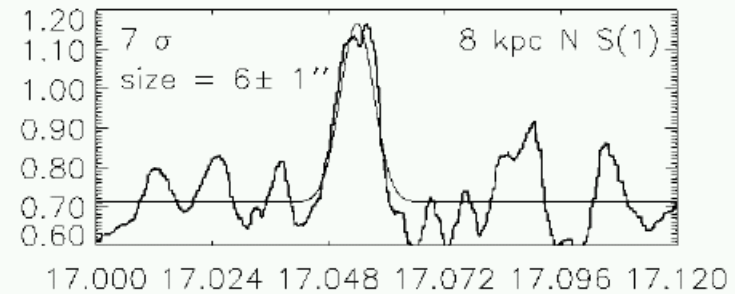
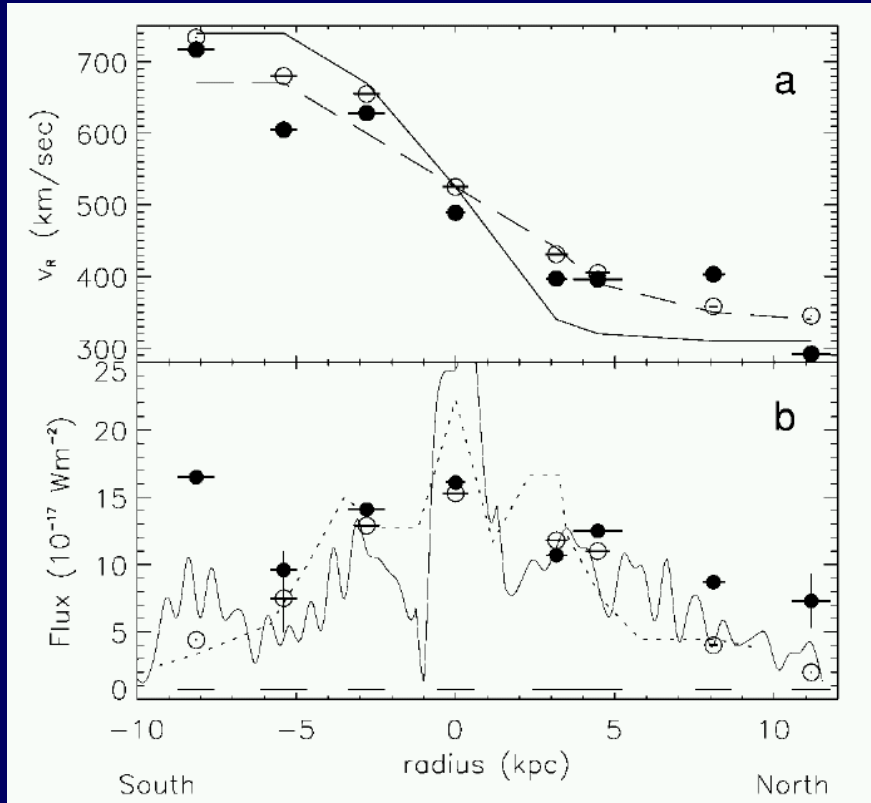
## ISOPHOT mapping of NGC 891



Popescu & Tuffs (2003)

- **extended HI disk is not primordial**
- **is the dust tracing unseen molecular gas?**

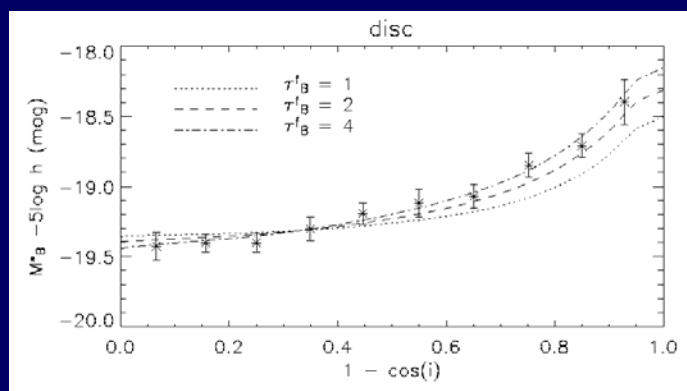
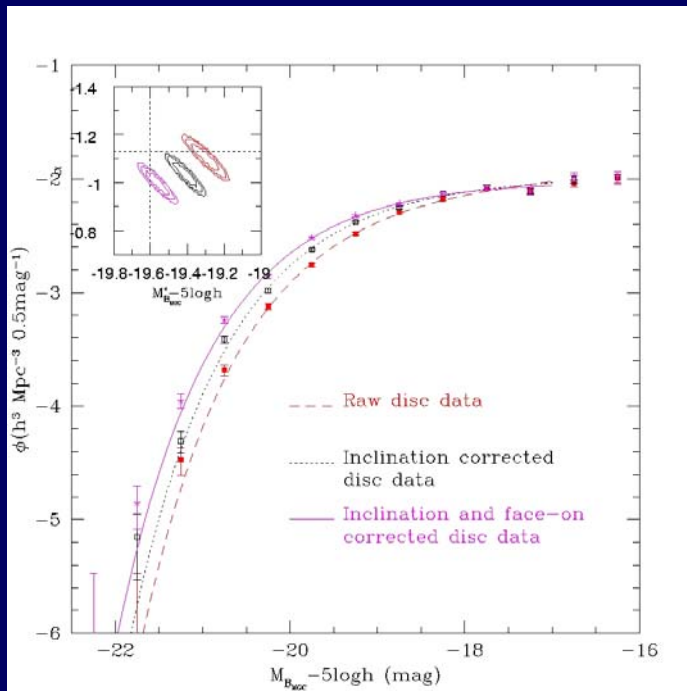
# First extragalactic direct detection of large-scale Molecular hydrogen (in NGC 891)



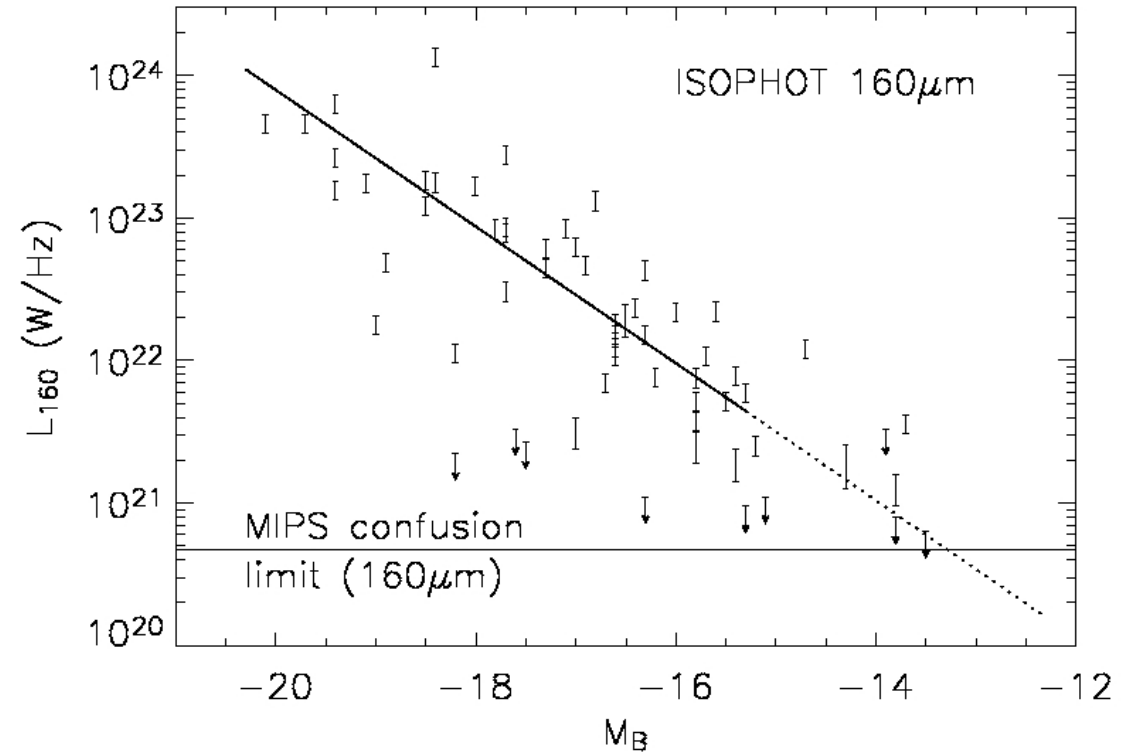
Valentijn & van der Werf (1999)

- a cool component ( $T = 80\text{-}90 \text{ K}$ ) dominates in the outer disk

# Characterisation of IR properties of optically faint galaxies

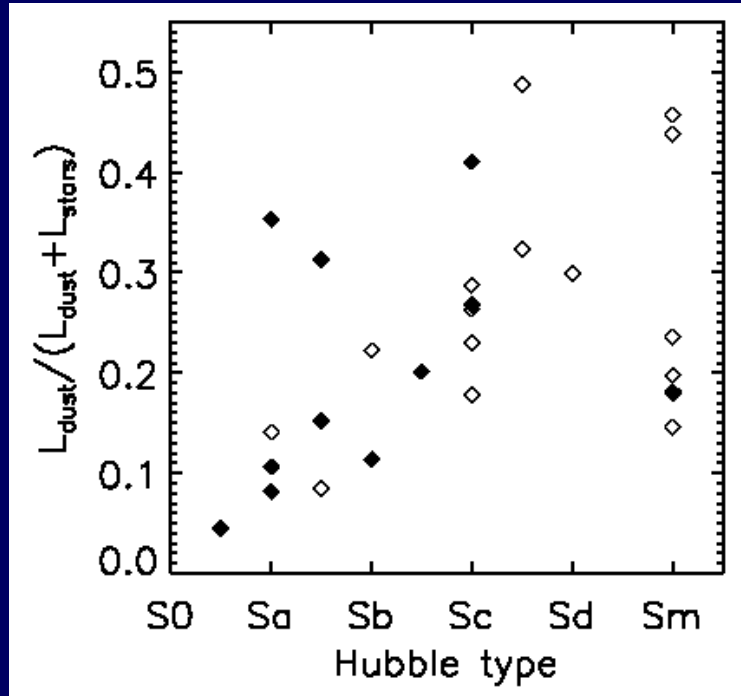


Driver et al. (2007)



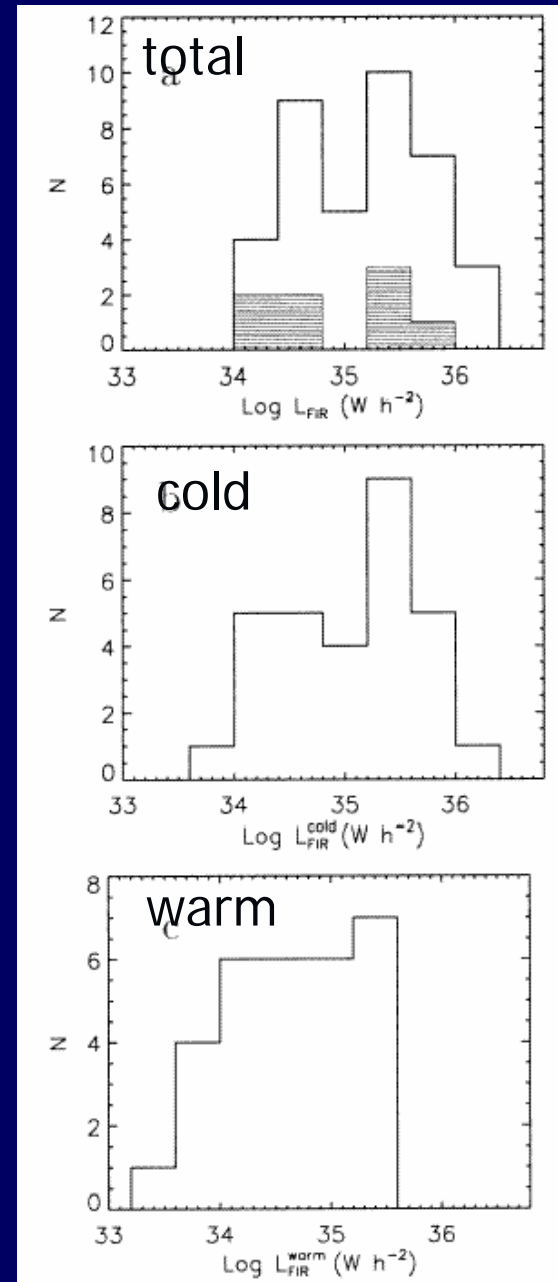
## ISO Virgo Cluster Deep Survey (Tuffs et al. 2002)

- deepest local universe survey in the FIR
- spans broad range in star-formation activity/morphological, also dwarfs



Popescu & Tuffs 2003

- mean percentage of starlight re-radiated by dust is 30 %
- percentage increases along Hubble sequence
- most of dust luminosity carried by cold dust component

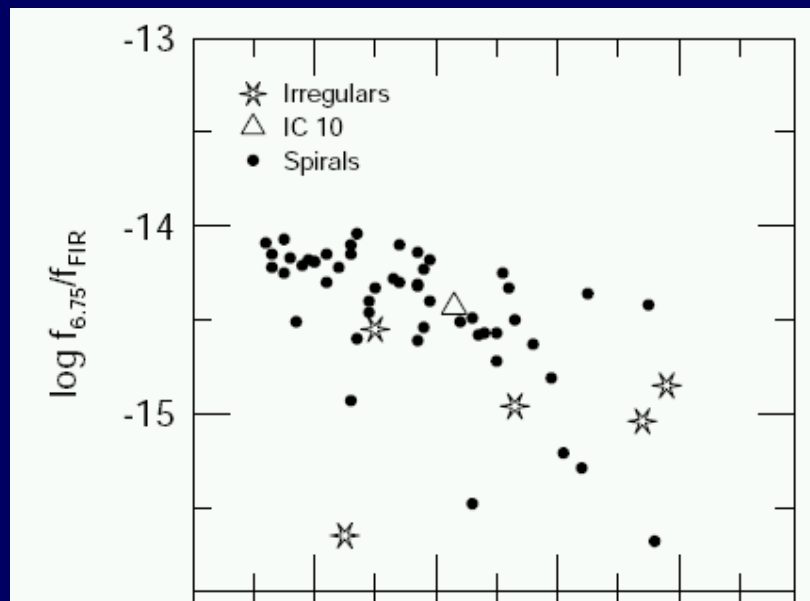
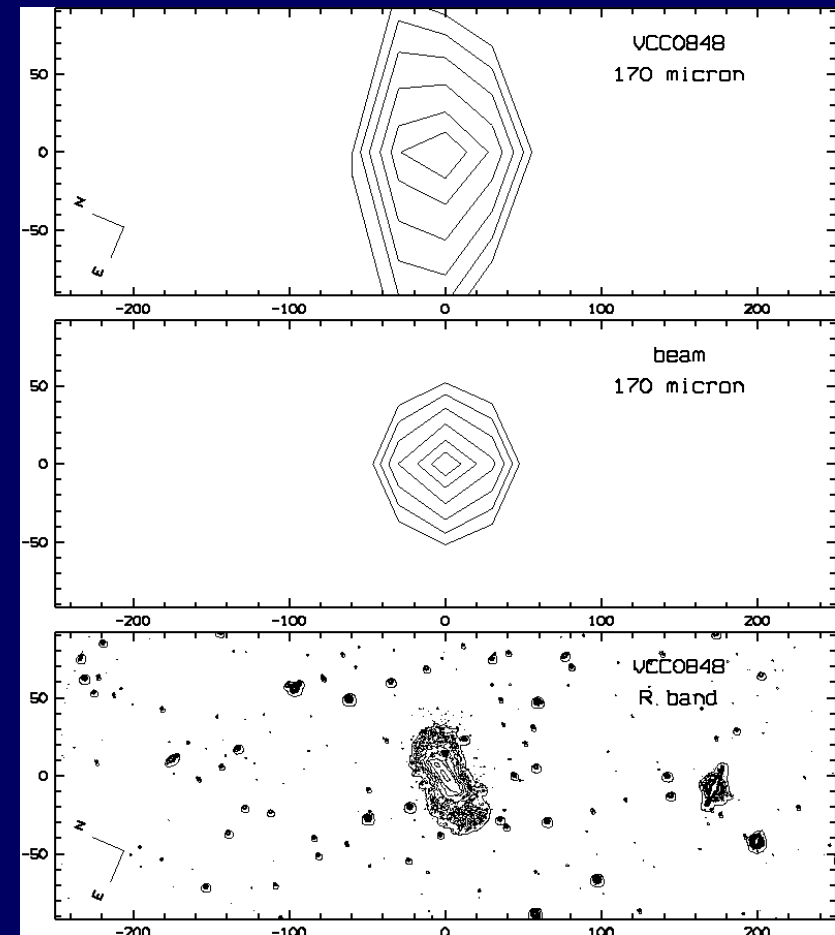


Popescu et al. (2002)

## Dwarf galaxies

SED dominated by emission from cold dust (Popescu et al. 2002):

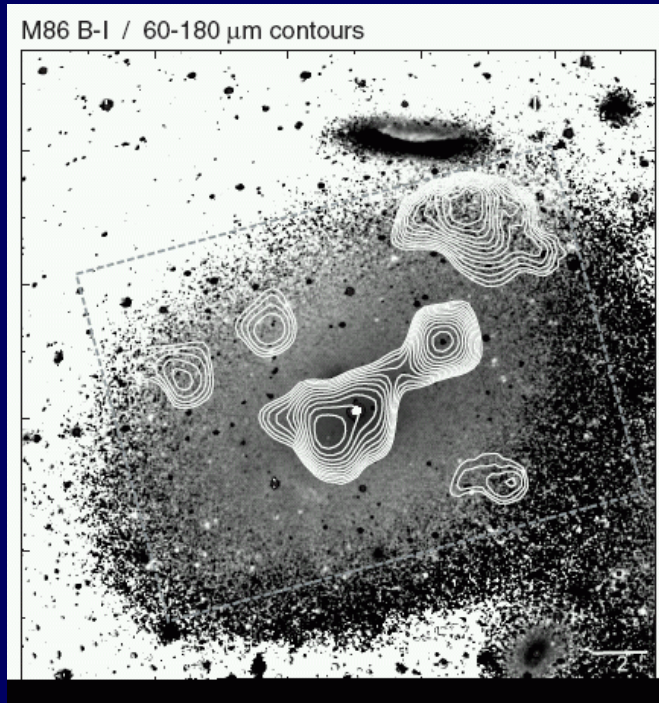
- 170  $\mu\text{m}$  emission sometimes resolved, extending beyond the optical body, and aligned with HI.



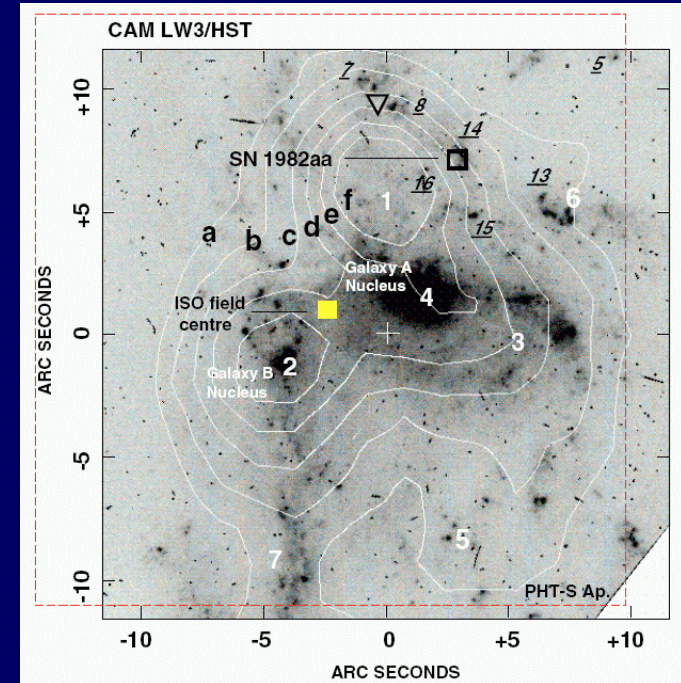
Unexpectedly low detection rate in the MIR (Boselli et al 1997, Hunter et al 2001).



# Star-formation in colliding/merging systems



Stickel et al. 2003



(Metcalf et al. 2005)

- cold FIR source without any optical counterpart discovered in the halo of M86 in the Virgo cluster.
- possible tidal removal of the ISM in a gravitational encounter of the spiral galaxy NGC4402 with M86
- SF triggered outside the interacting galaxies in Markarian 297, visible through PAH emission
- also seen in the Antennae, Stephan's Quintet, Arp299

# Comparison with the distribution of UV-emitting stars

ISOPHOT

M101

GALEX

100 micron

total UV

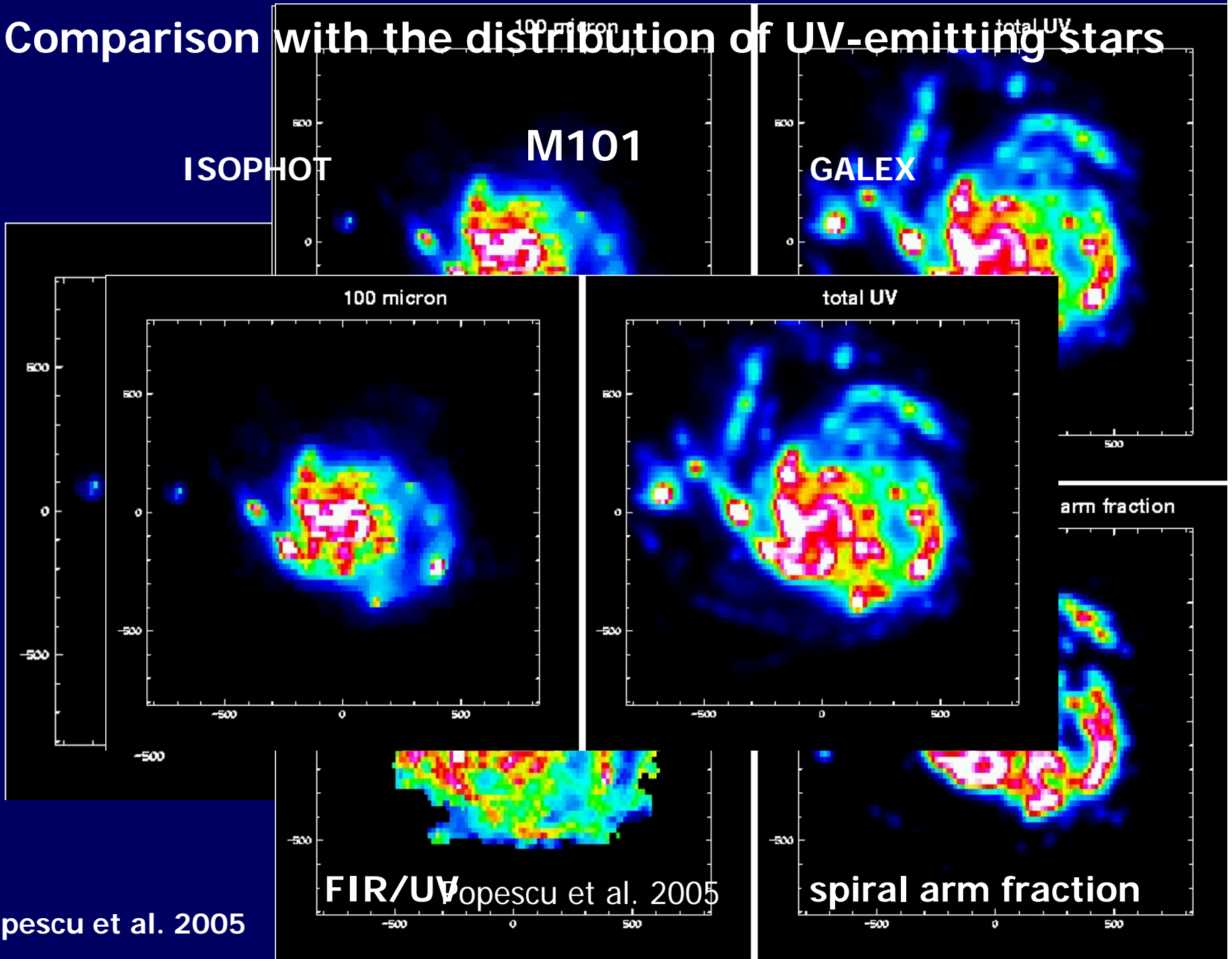
arm fraction

FIR/UV

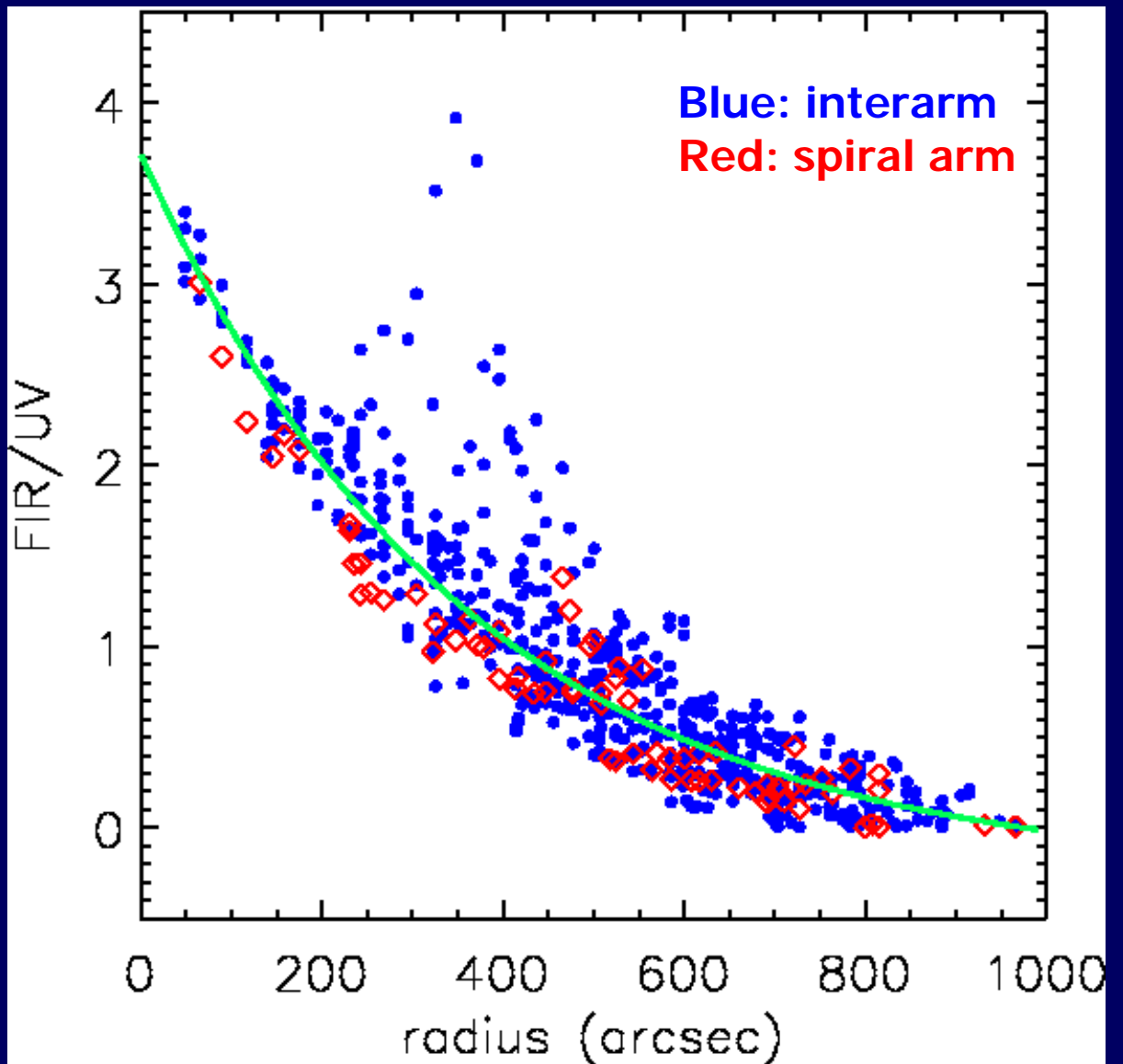
Popescu et al. 2005

spiral arm fraction

Popescu et al. 2005



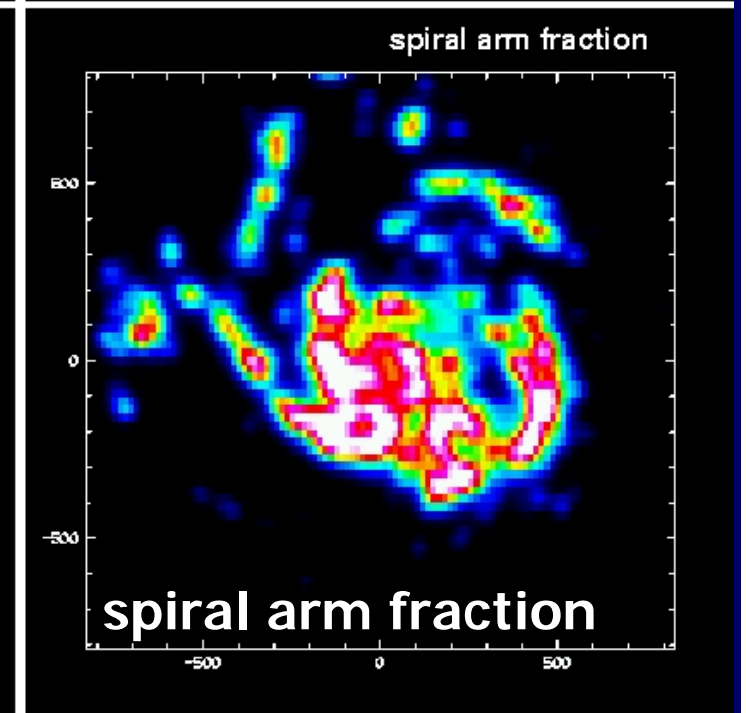
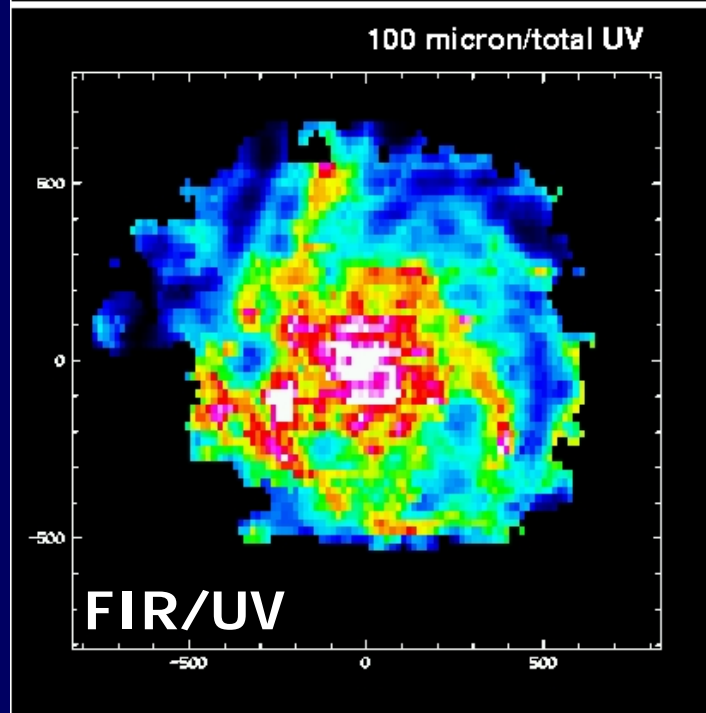
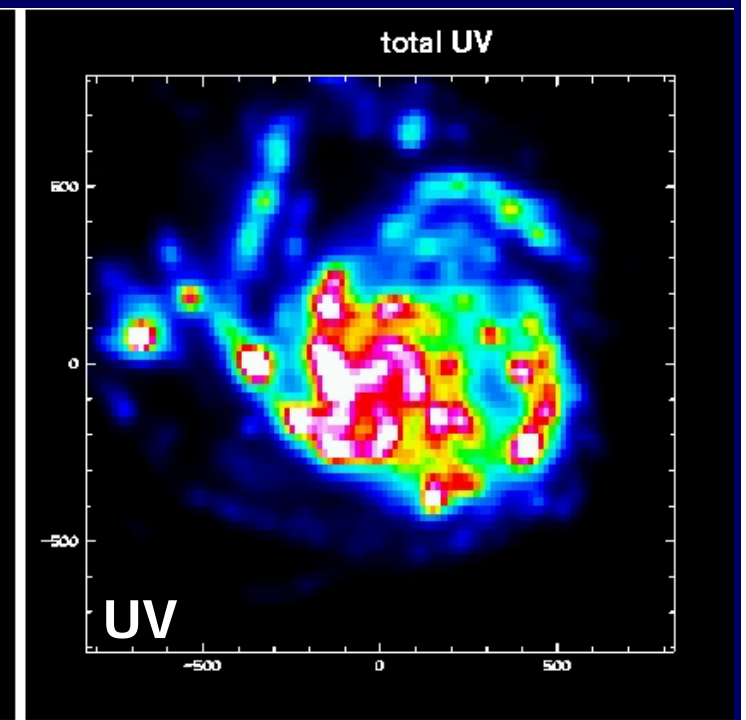
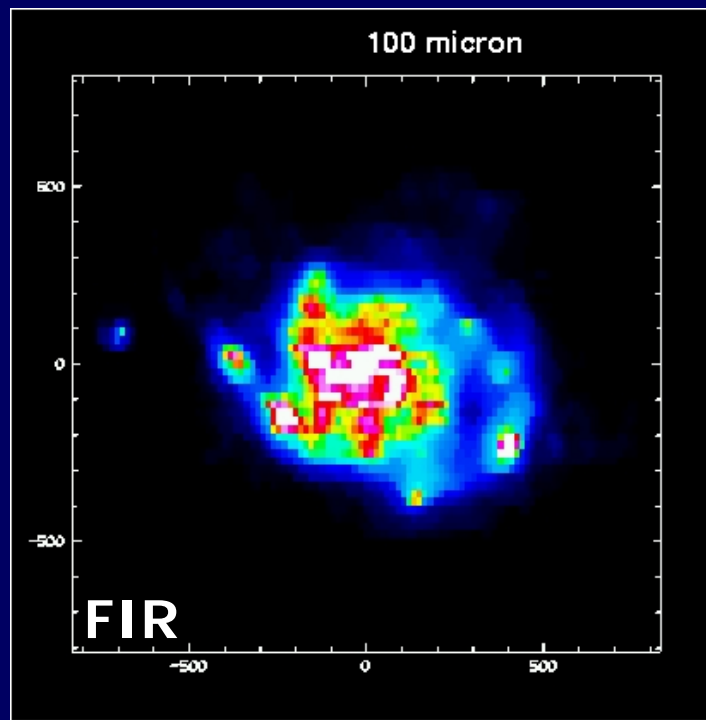
- presence of a large-scale distribution of diffuse dust having a face-on opacity which decreases with radius



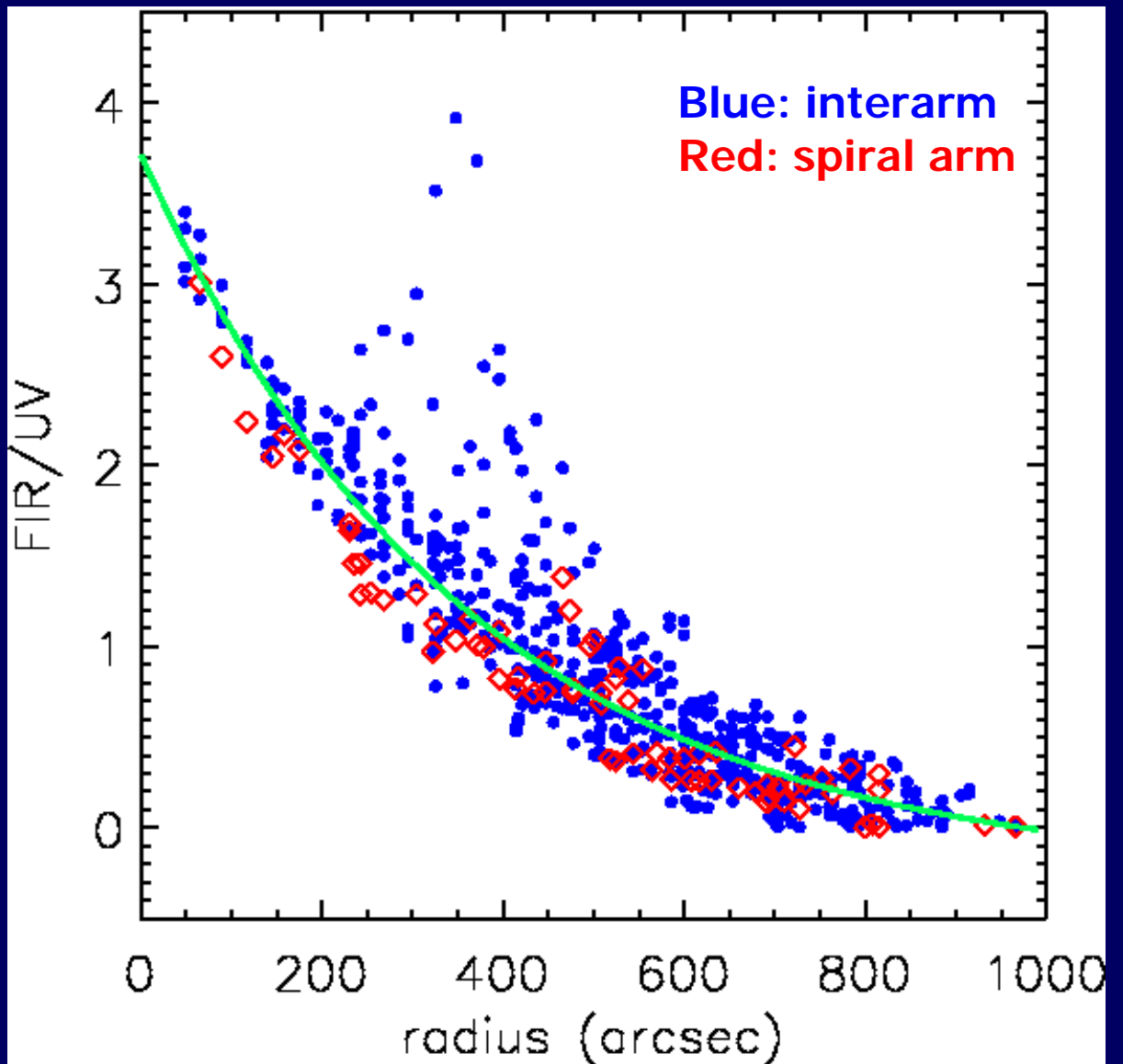
Popescu et al. (2005)

high FIR/UV  
traces  
interarm  
regions

Popescu et al. 2005



- a scattered-light origin for the diffuse interarm UV



Popescu et al. (2005)

# Statistical results

## ISOPHOT Virgo Cluster Deep Survey

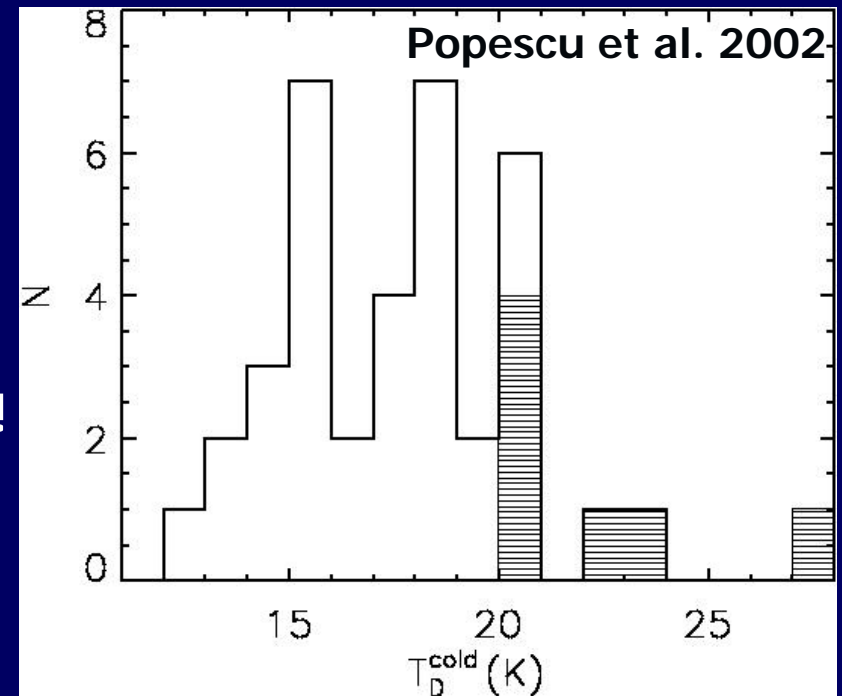
(Tuffs et al. 2002a,b; Popescu et al. 2002)

- a complete volume- and luminosity-limited optically selected sample
- 63 gas-rich galaxies in the Virgo Cluster
- ISOPHOT strip maps at 60, 100 & 170 micron
- deepest local universe survey in the FIR
- spans a broad range in star-formation activity and morphological types, including dwarfs

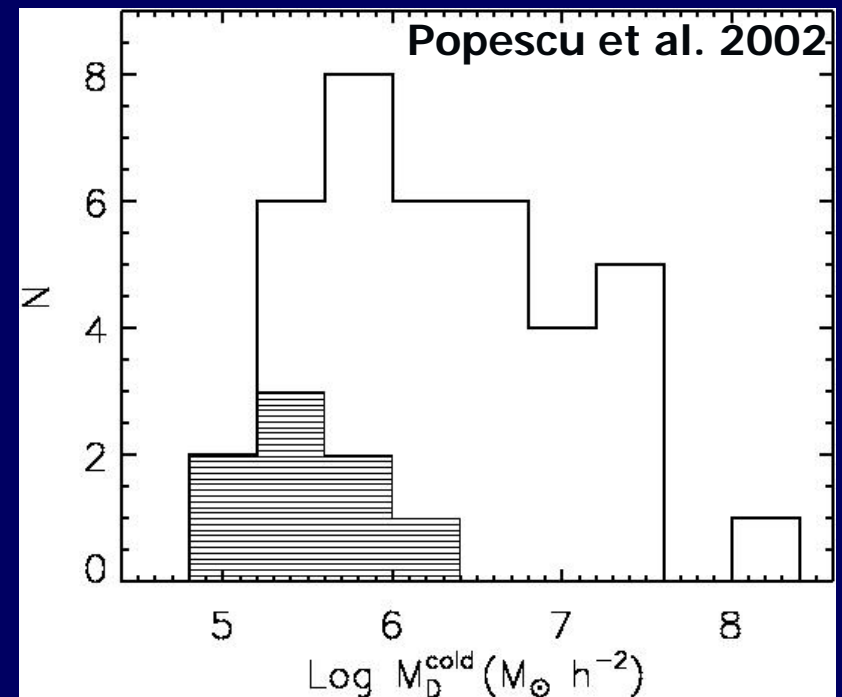
**Universality of cold dust component**

**Galaxies have both warm and cold  
dust emission components**

- cold dust temperatures broadly distributed, with median 18 K  
- 8-10 K lower than IRAS values!



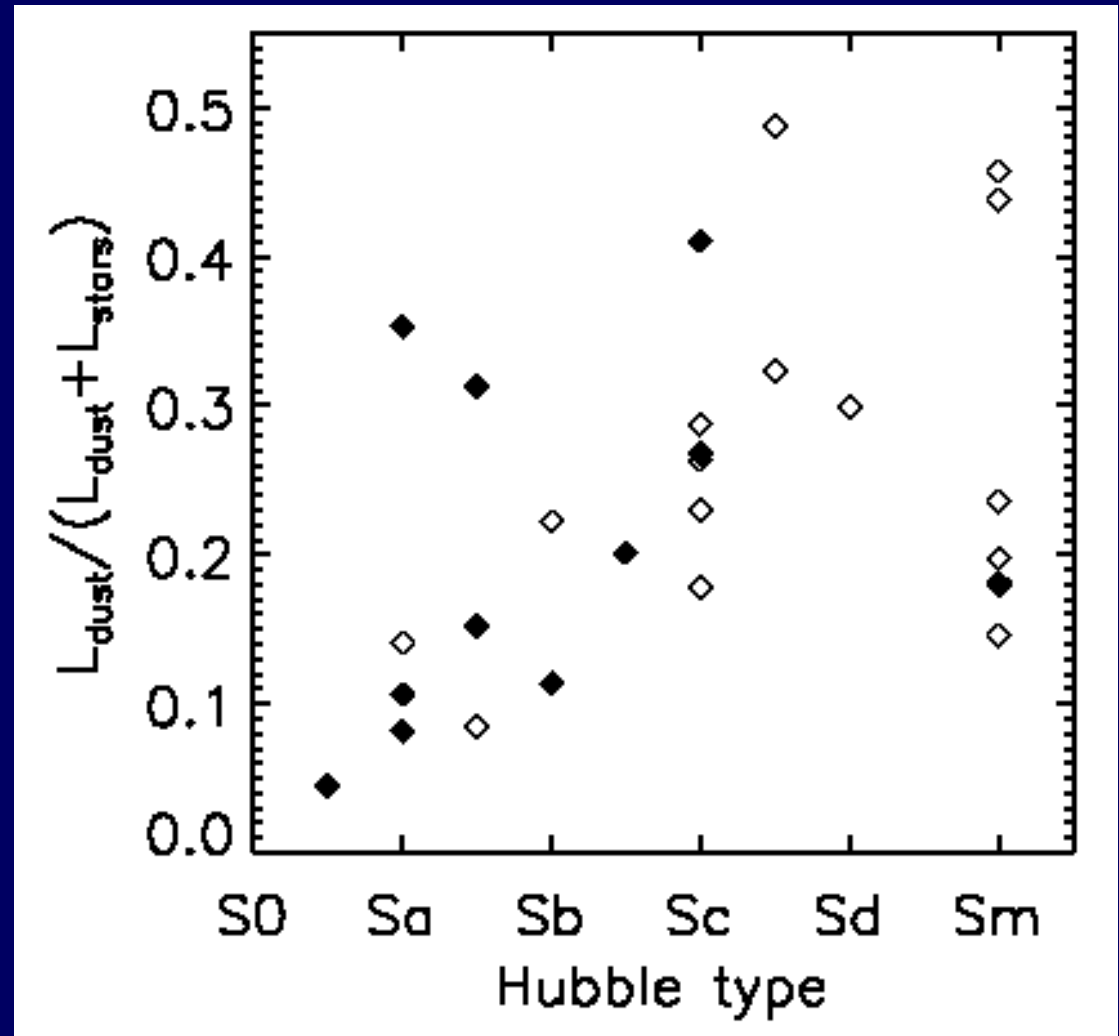
- dust masses higher by factors of 6-13 than IRAS values!





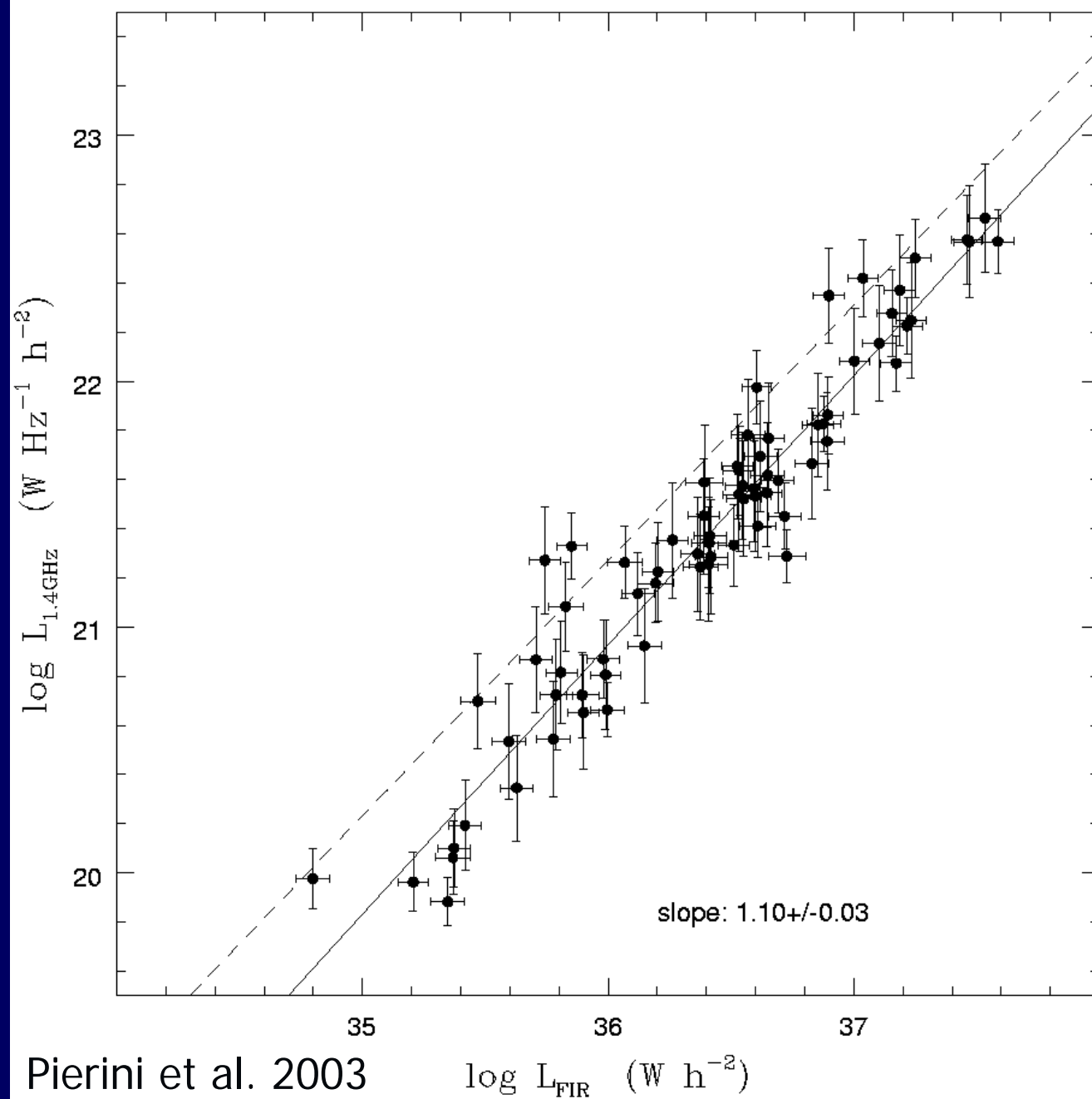
# The percentage of starlight re-radiated by dust

- mean percentage is 30 %
- percentage increases along Hubble sequence

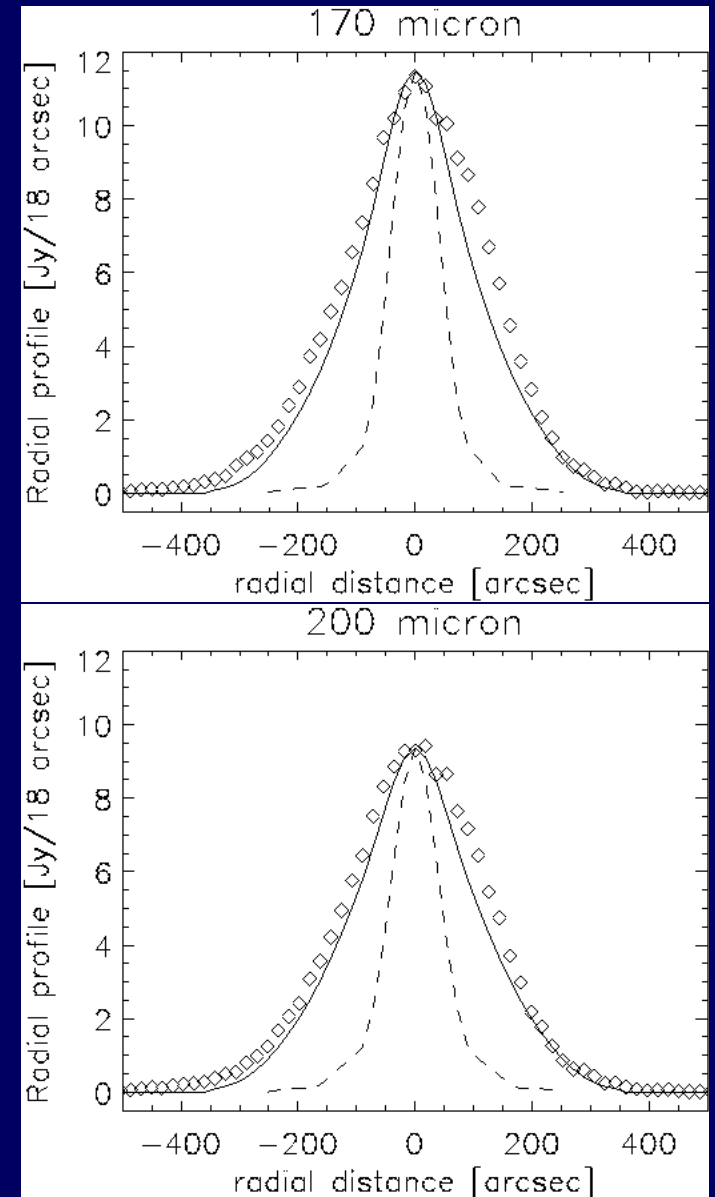
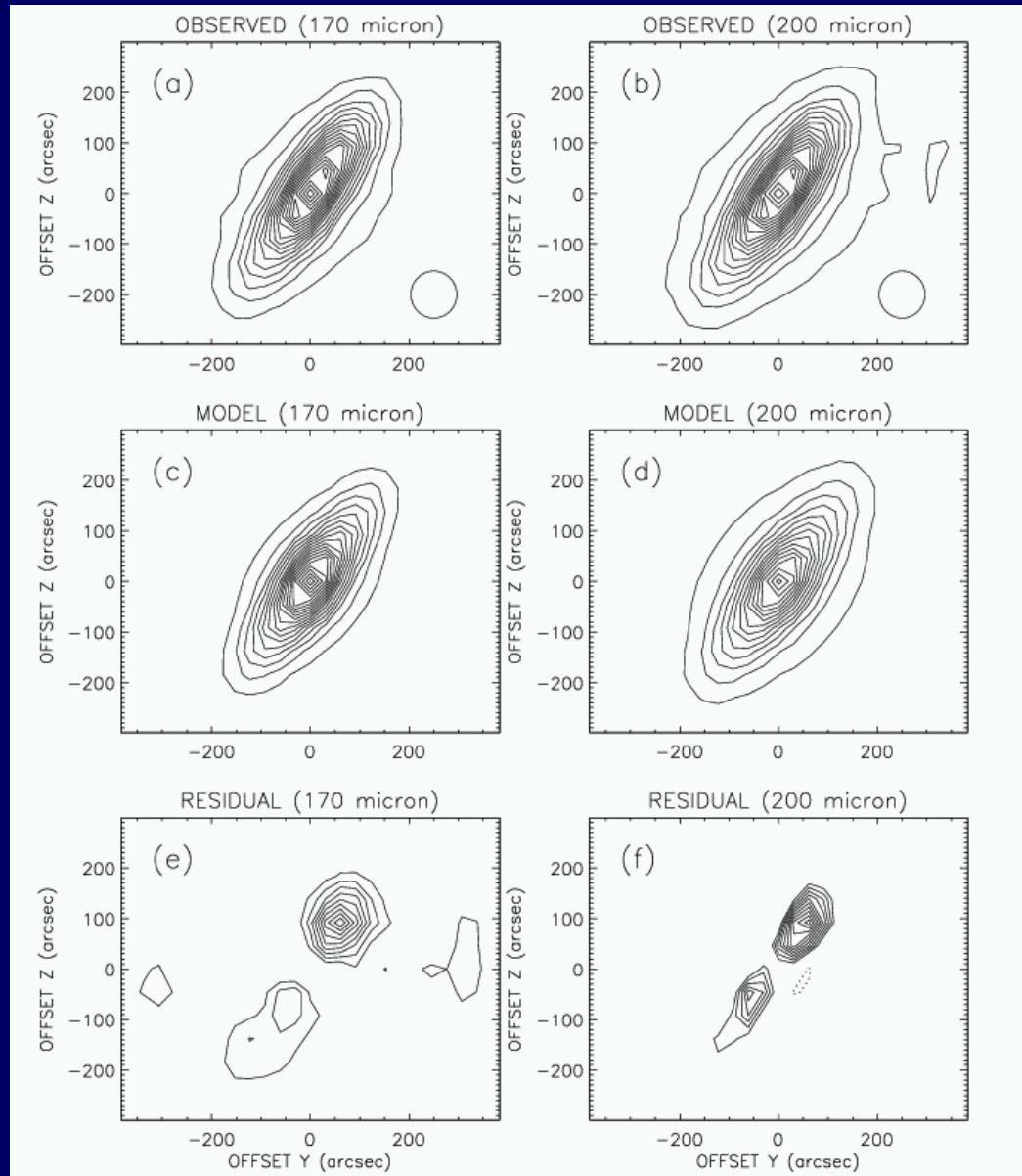


Popescu & Tuffs (2002)

# The radio-FIR correlation



# Predicted and observed FIR surface brightness distributions NGC 891

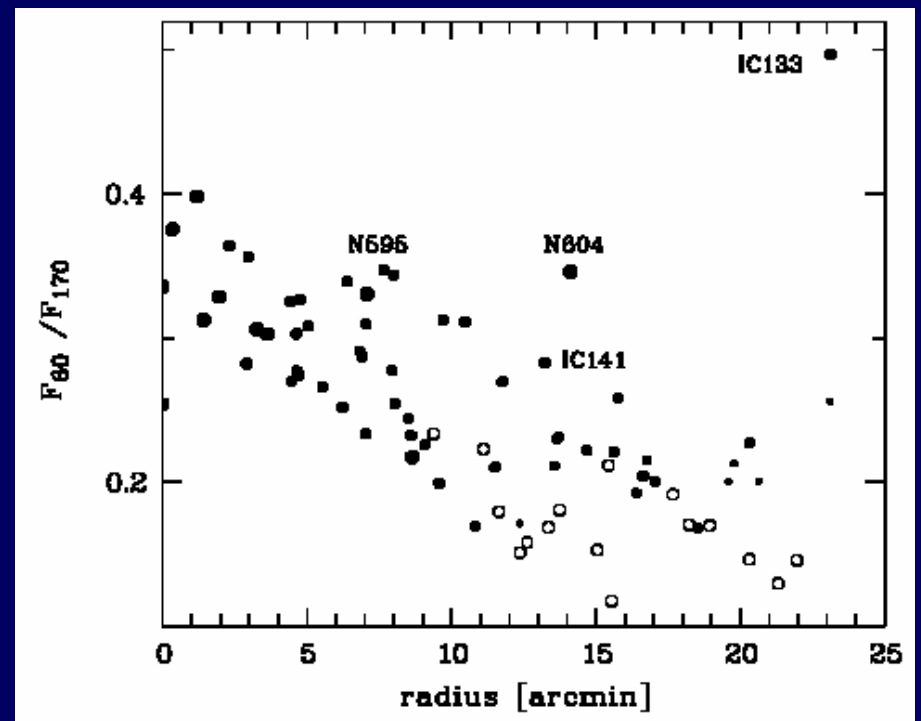
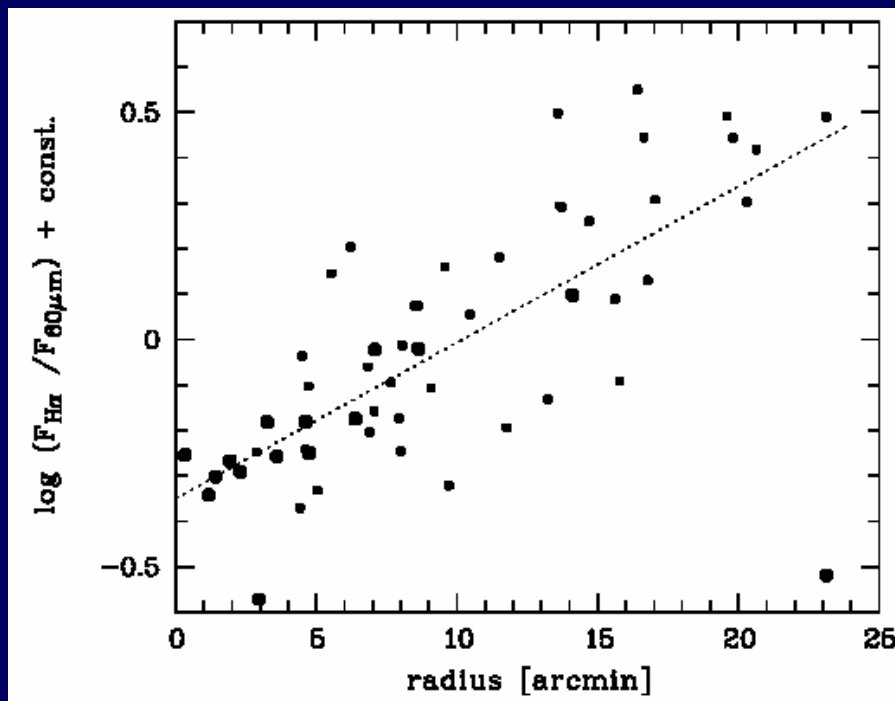


With increasing galactocentric radius:

- $F_{\text{H}\alpha}/F_{60}$  ratio *increases*
- $F_{60}/F_{170}$  ratio *decreases*

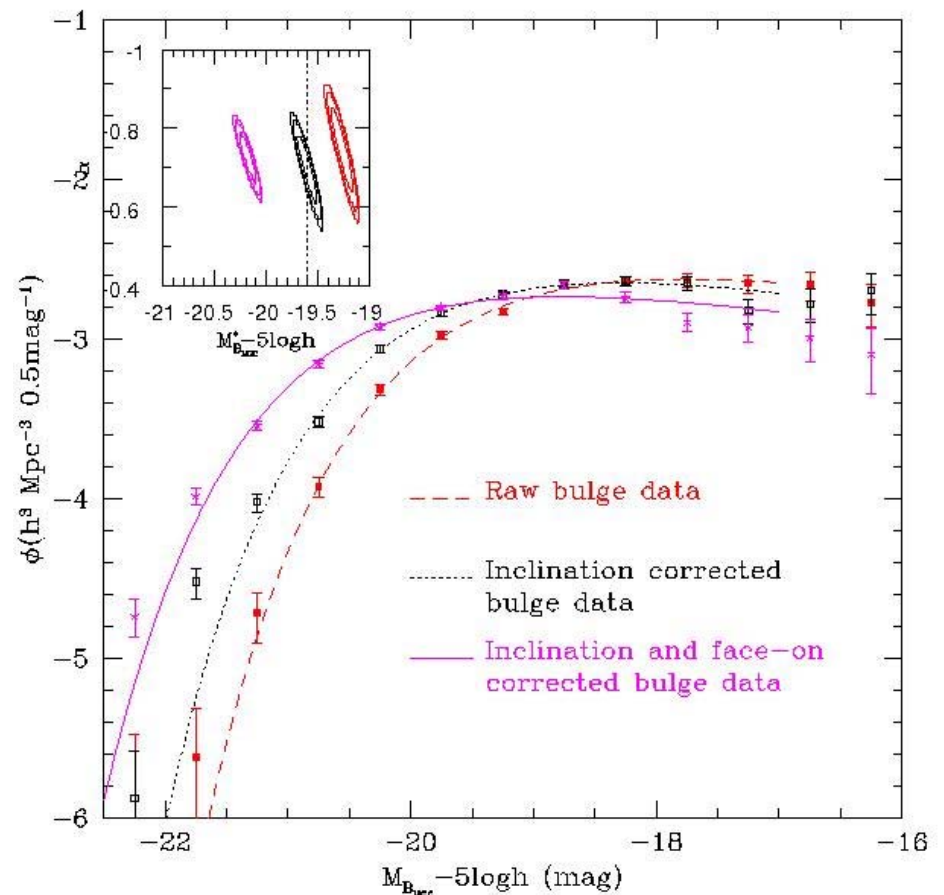
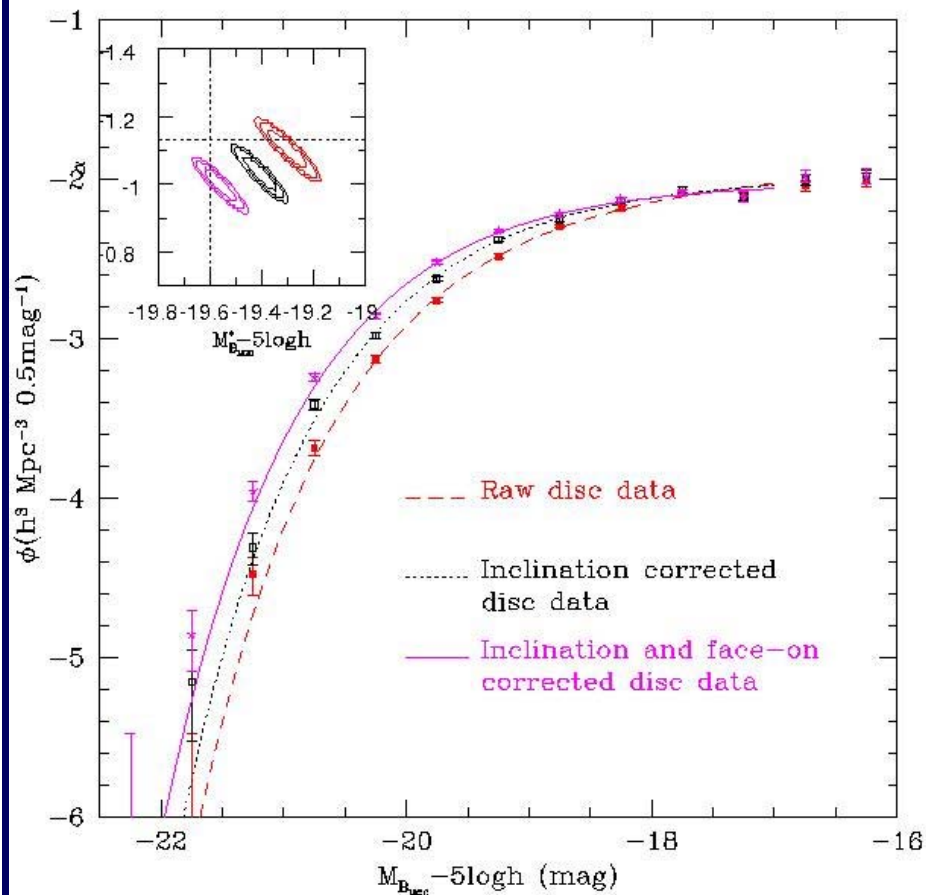
possible explanation is a combination of:

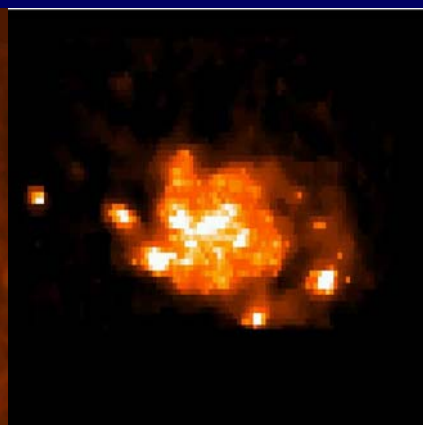
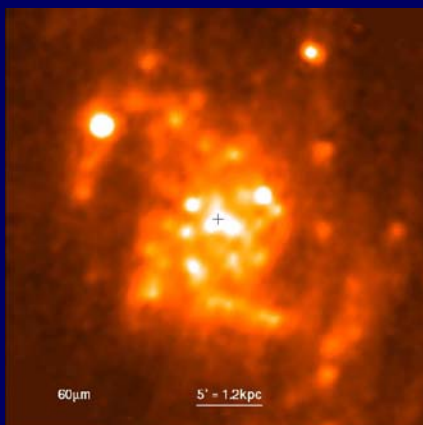
- large scale opacity gradient
- large scale radial pressure gradient



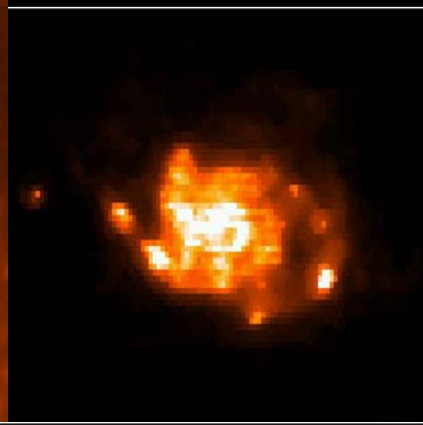
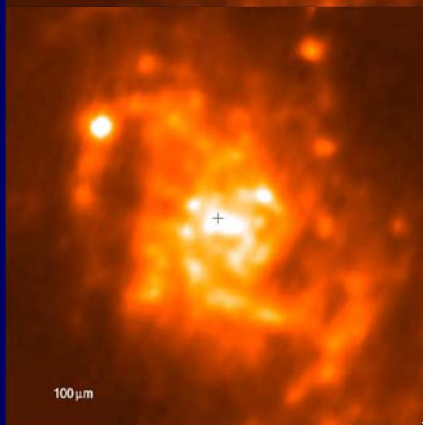
Hippelein et al. (2003)

# Dust corrected luminosity functions from the Millenium Galaxy Survey

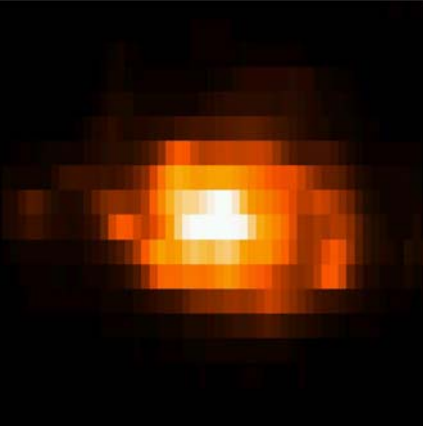
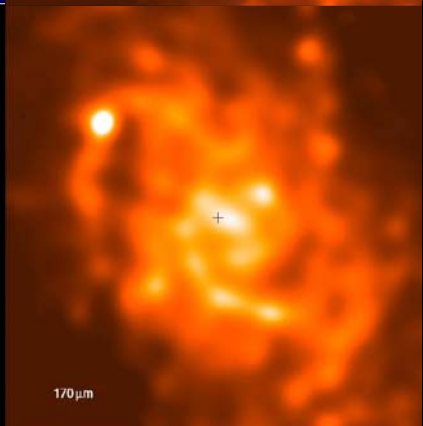
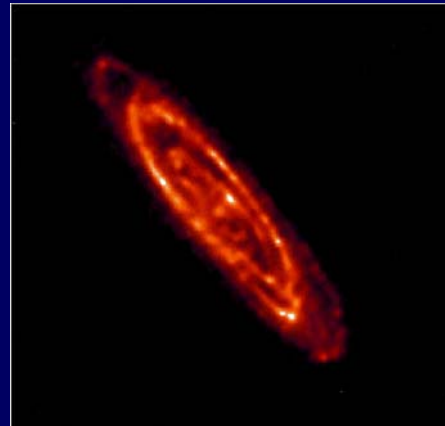




60 micron



100 micron



170 micron

**M31**

Haas et al. 98

**M33**

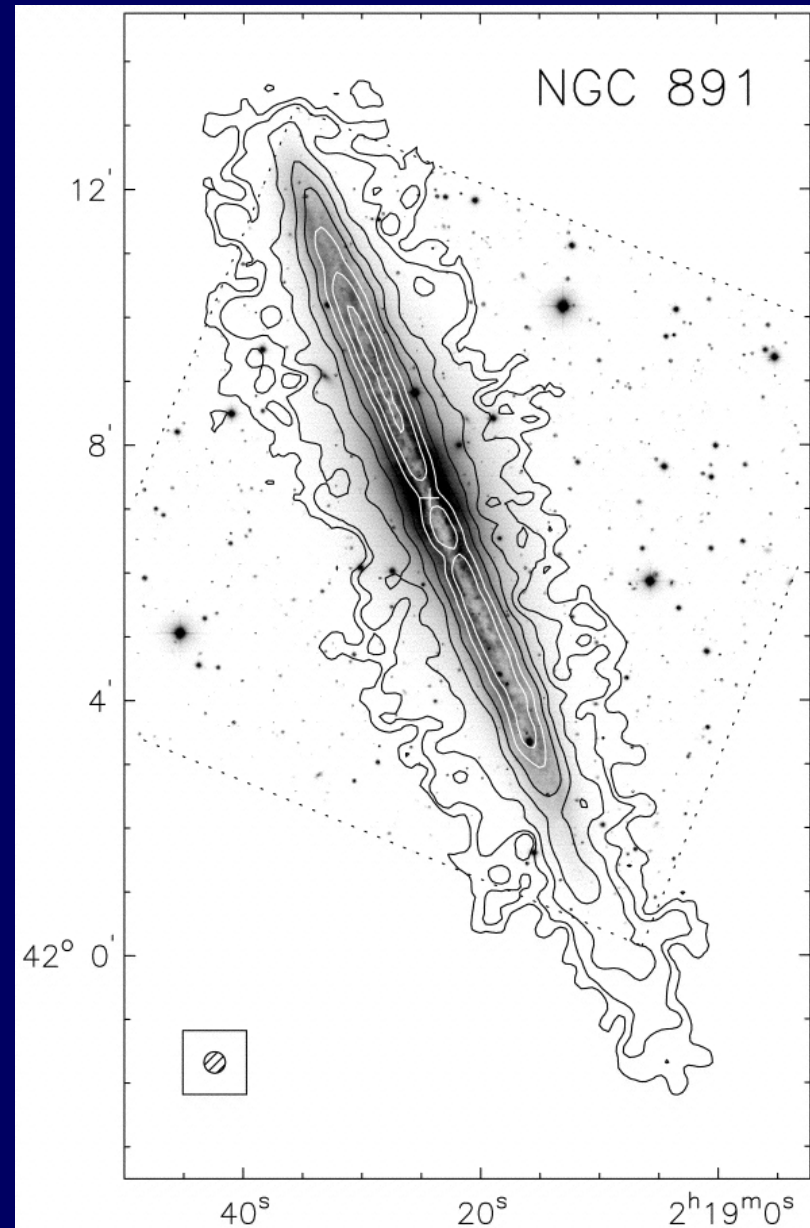
Hippelein et al. 03

**M101**

Tuffs & Gabriel 03

## The extent of the cold dust emission

- does the cold dust emission extend beyond the edge of the optical disk?
- do “extended HI disks” contain grains?

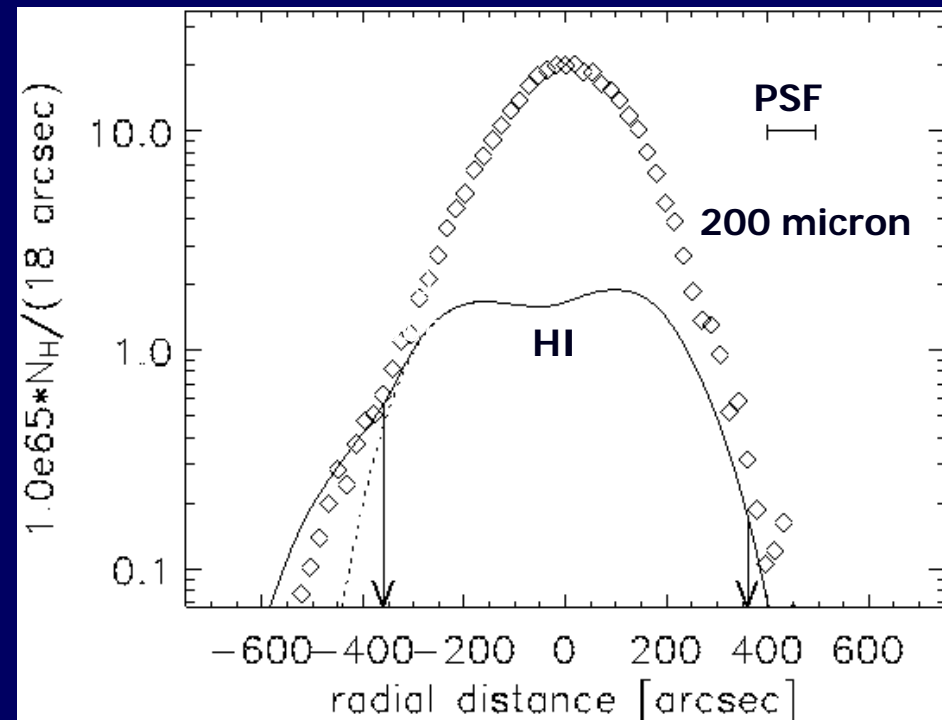


Swaters et al. (1997)

# The extent of the cold dust emission

- cold dust emission can extend beyond the edge of the optical disk
- “extended HI disks” can contain large quantities of grains
  - dust-to-HI mass ratio  $\sim 0.01$
  - extended HI disk not primordial

## ISOPHOT mapping of NGC 891



Popescu & Tuffs (2003)

Trace an “unseen” molecular component?

Could produce significant scattered-light (Bland-Hawthorn et al. 2005)



SMC  
ISOPHOT 170 micron  
(Wilke et al. 2003)

