Dust in Nearby Galaxies

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ESO visiting scientist, January 2008

Introduction

We live in a dusty Universe

- interstellar clouds
- star-forming regions
- supernova ejecta
- comets
- planetary systems
- distant galaxies

Normal spiral galaxies

- 30% of total stellar radiation is converted into dust emission

The Sombrero Galaxy (M104)

Introduction: why the submm?

1980s: advent of *IRAS*

first FIR investigations of dust in relatively large samples of galaxies

Limitations of FIR:

– small amount of warm dust can dominate emission from a larger proportion of cold dust

– *IRAS* insensitive to dust with T ≤ 30 K

– *IRAS* may have 'missed' ~90 per cent of the dust in late-type galaxies (e.g. Devereux & Young 1990)

Introduction: why the submm?

Current paradigm for dust in galaxies:

I. warm component (T > 30 K)
   – dust grains near to SF regions
   – heated by young OB stars

II. cool (T~20 K) component
   – diffuse dust
   – heated by general ISRF

90% of dust too cold to radiate in FIR will be producing most of its emission in the submm

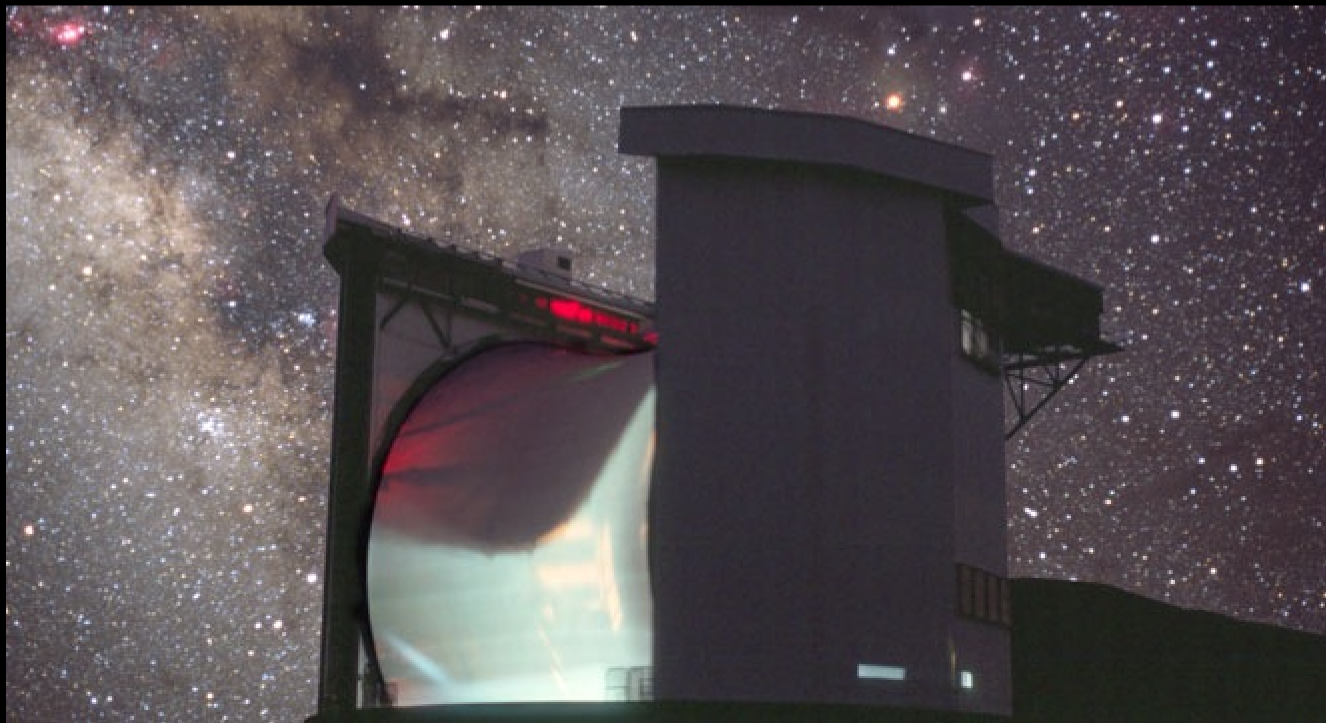
Overview

1. The SCUBA Local Universe Galaxy Survey (SLUGS)

2. The FIR–radio relationship at high and low-z

3. LABOCA observations of the Sombrero galaxy

JCMT, Hawaii: SCUBA



JCMT, Mauna Kea, Hawaii, ~4100m
15m telescope
SCUBA: 850 and 450μm ; FOV ~2 arcmin

APEX, Chile: LABOCA

APEX, Chajnantor, Chile, ~5100m : 12m telescope
LABOCA: 870μm ; FOV ~ 11 arcmin

1. The SCUBA Local Universe Galaxy Survey (SLUGS)

SLUGS

SLUGS – a systematic submm survey of galaxies in the local Universe – at 850μm and 450μm

Survey of ~200 nearby galaxies:

- 104 60μm-selected
  (Dunne et al. 2000, Dunne & Eales 2001)
- 81 optically-selected
  (Vlahakis et al. 2005; 2007)

“OS” aim:

investigate properties of dust along Hubble sequence
in particular the cool 20 K dust

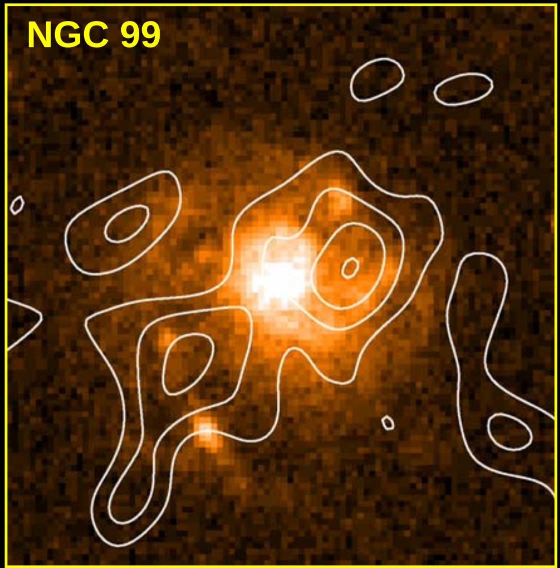
OS SLUGS results: submm morphology

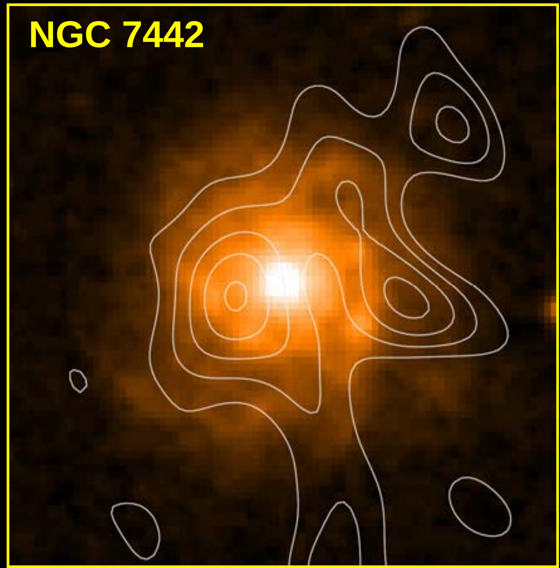
52 galaxies detected at 850μm
17 also detected at 450μm

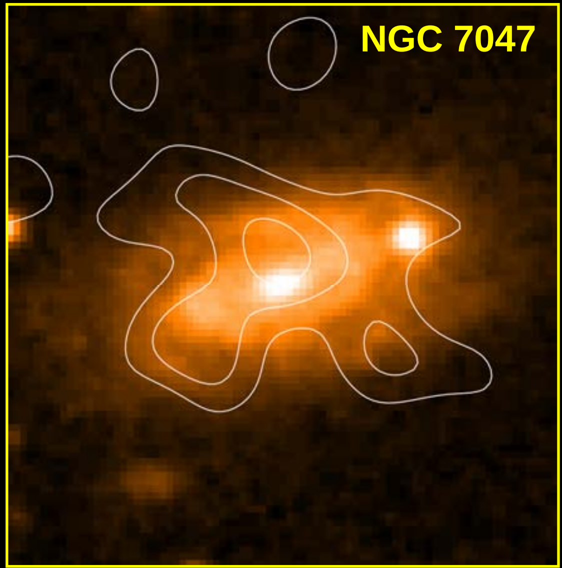
Several common features in the submm morphology of spirals:

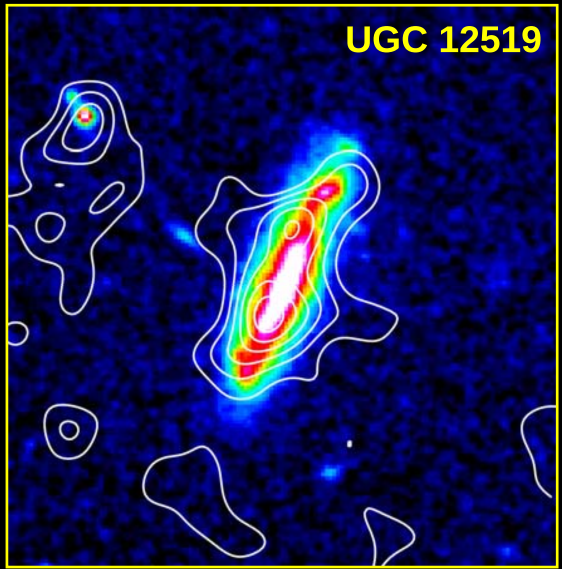
- two peaks of 850-μm emission, seemingly coincident with spiral arms
- core dominated (single central peak of submm emission)
- combination of features / irregular morphologies
- prominent dust lane

OS SLUGS results: submm morphology

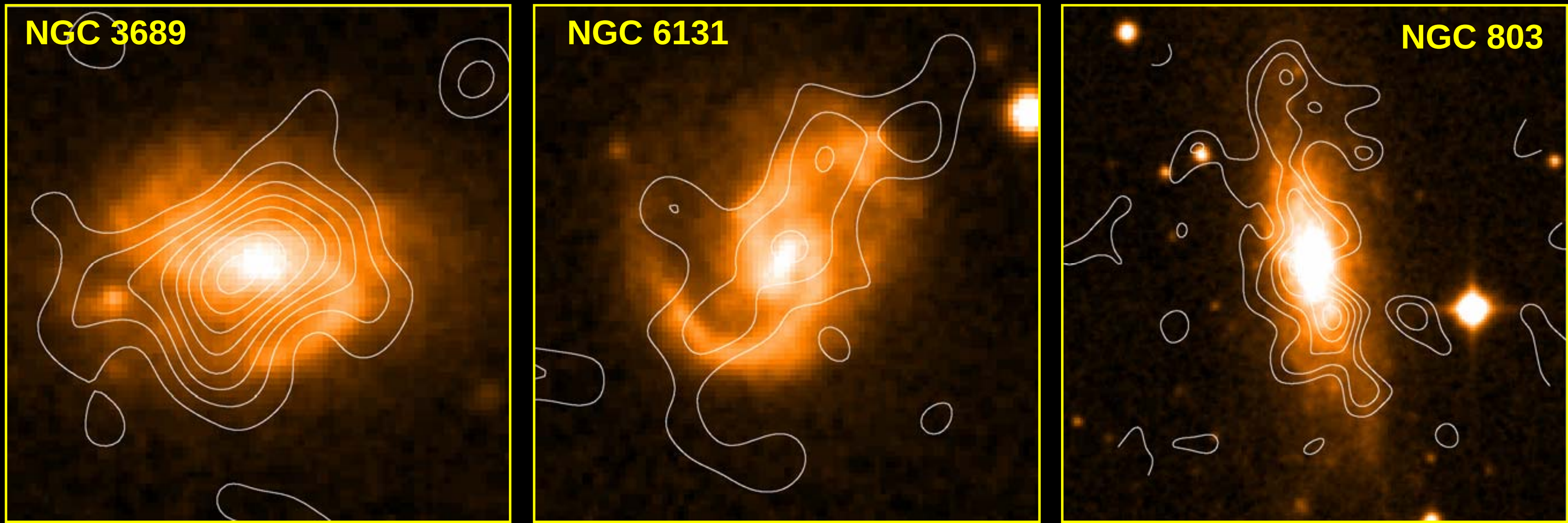




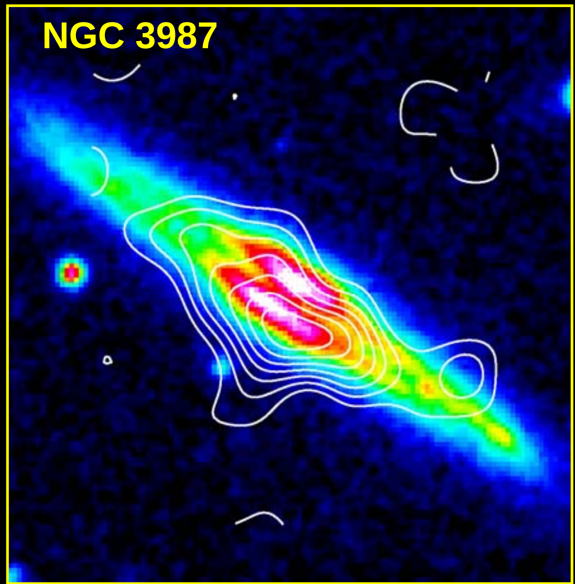


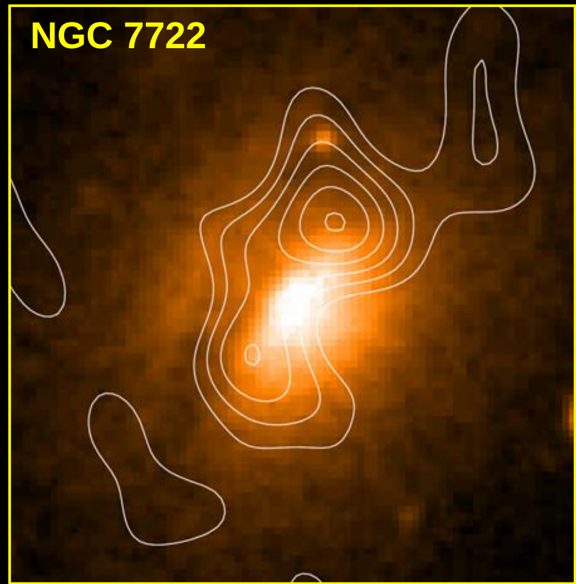


OS SLUGS results: submm morphology

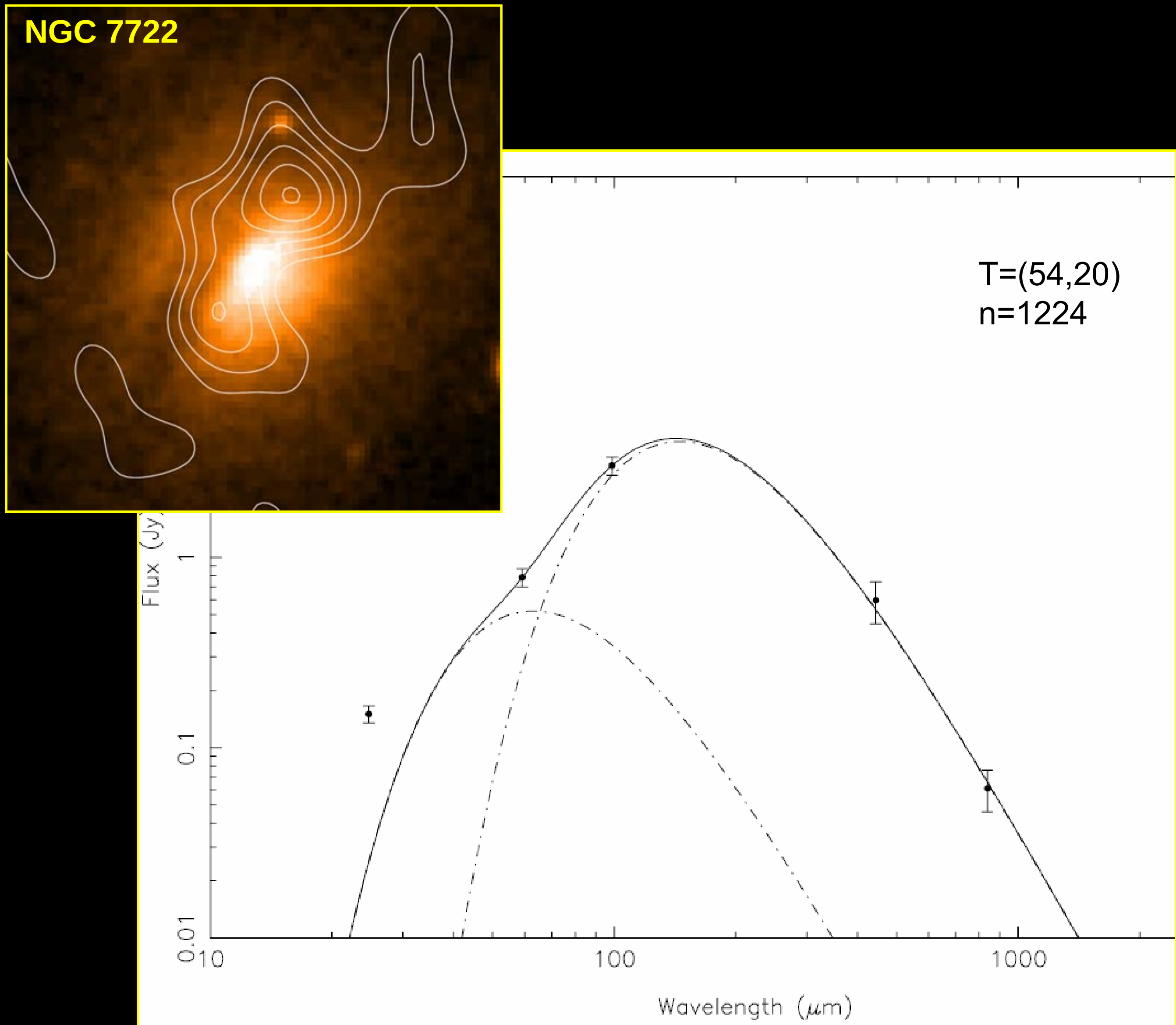


OS SLUGS results: submm morphology

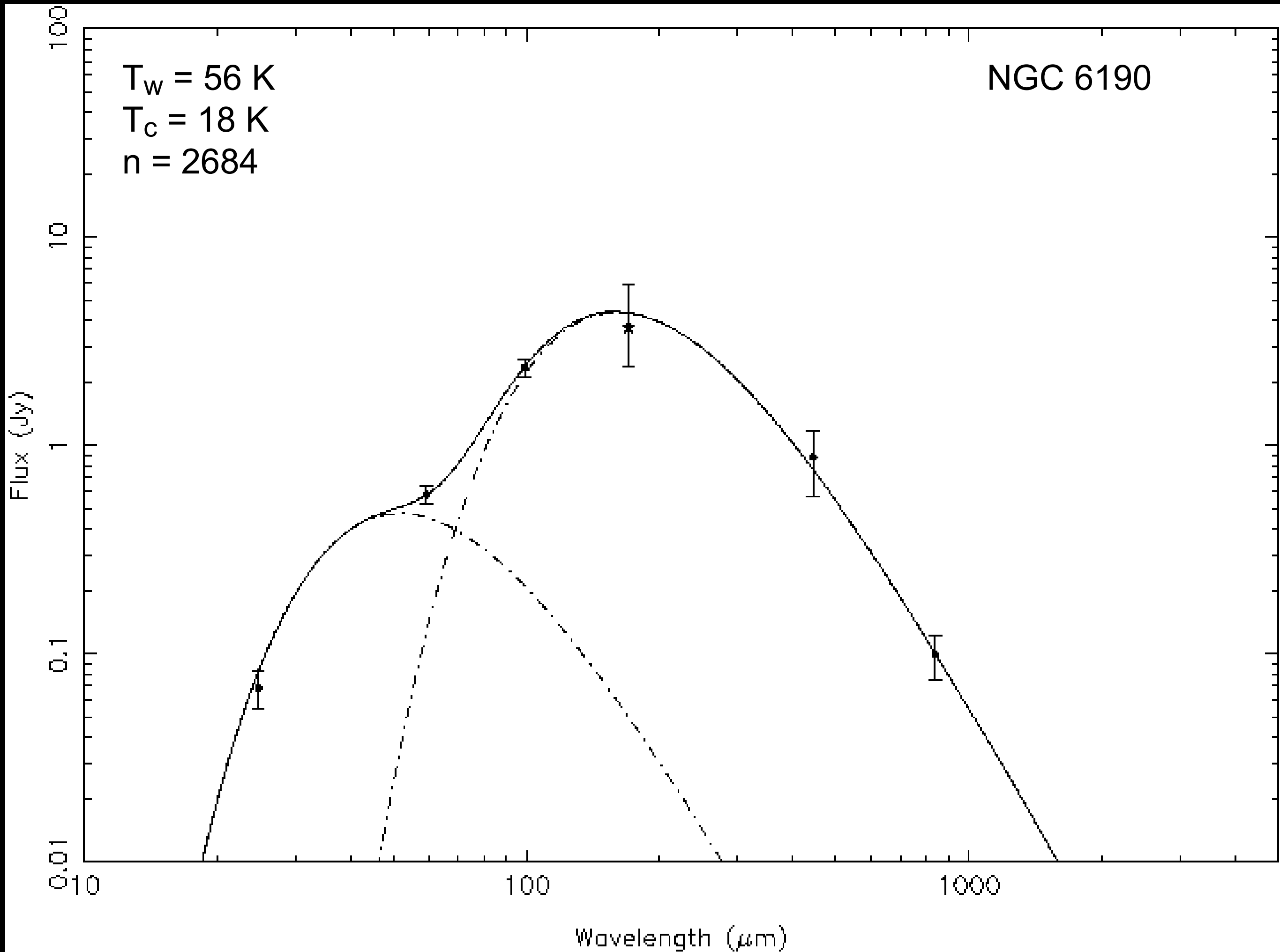




OS SLUGS results: two-component SED



OS SLUGS results: two-component SED



OS SLUGS results: two-component SED

60-, 100- (*IRAS*), 450- and 850-μm (SCUBA) data well fitted by two grey-bodies with dust emissivity index $\beta=2$

Range of T_W: 28 to 59 K
Range of T_C: 17 to 24 K (mean 20 K)

Mean Md1: $2.3 \times 10^7\ M_{sol}$
Mean Md2: $4.9 \times 10^7\ M_{sol}$

Ratio of mass of cold dust to mass of warm dust much higher for our OS galaxies than for *IRAS*-selected galaxies

- *can reach values of ~1000*

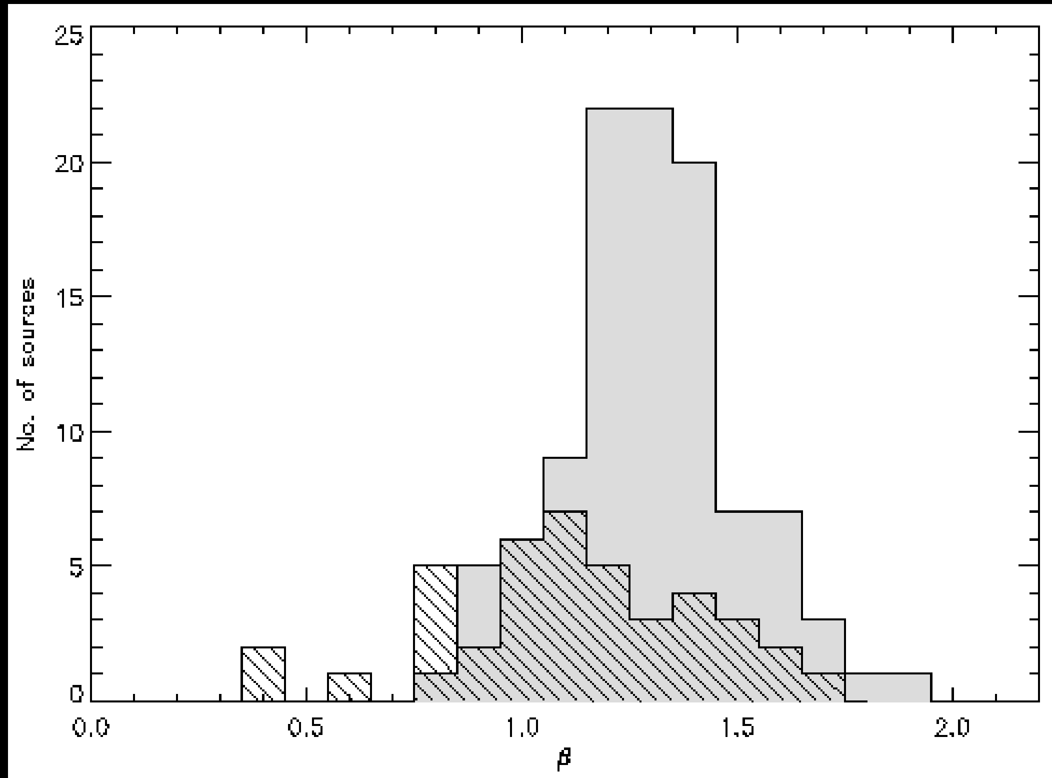
OS SLUGS results: single-component SED

Mean dust emissivity index β=1.1

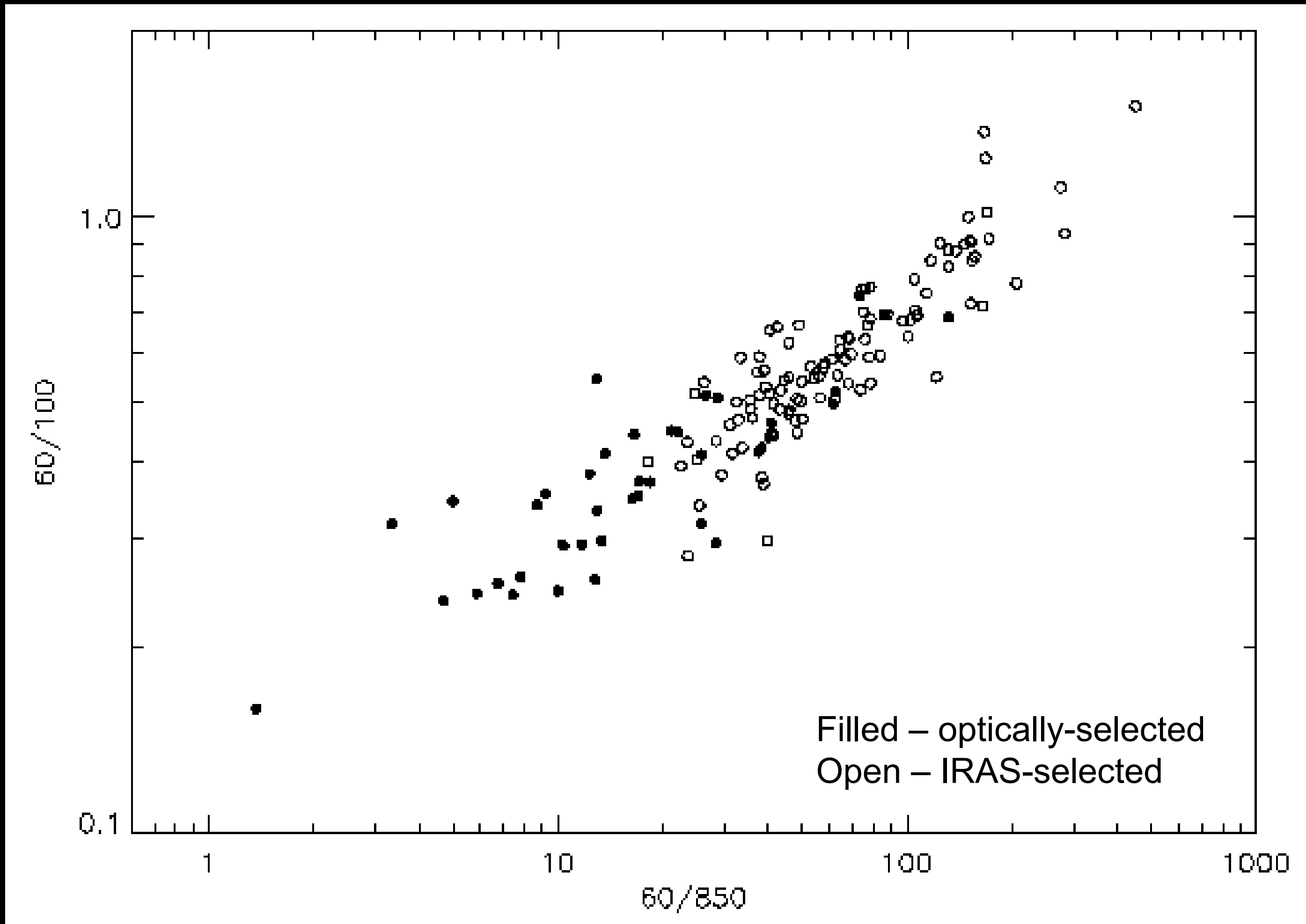
Significantly lower than the *IRAS* selected sample

Rather than a physical difference in the emissivity behaviour of the grains (β) we believe that it is due to a difference in the ratios of cold to warm dust

Distribution of β values



SLUGS results: Colour-colour plot



Population of galaxies containing a large proportion of cold dust - unrepresented in the *IRAS* sample

Summary 1: SLUGS

- 60-, 100- (*IRAS*), 450- and 850-μm (SCUBA) fluxes are well fitted by a two-component dust model with dust emissivity index β=2

- Ratio of mass of cold dust to mass of warm dust much higher for our OS galaxies than for *IRAS*-selected galaxies

2. The FIR–Radio relation at high–z and low–z

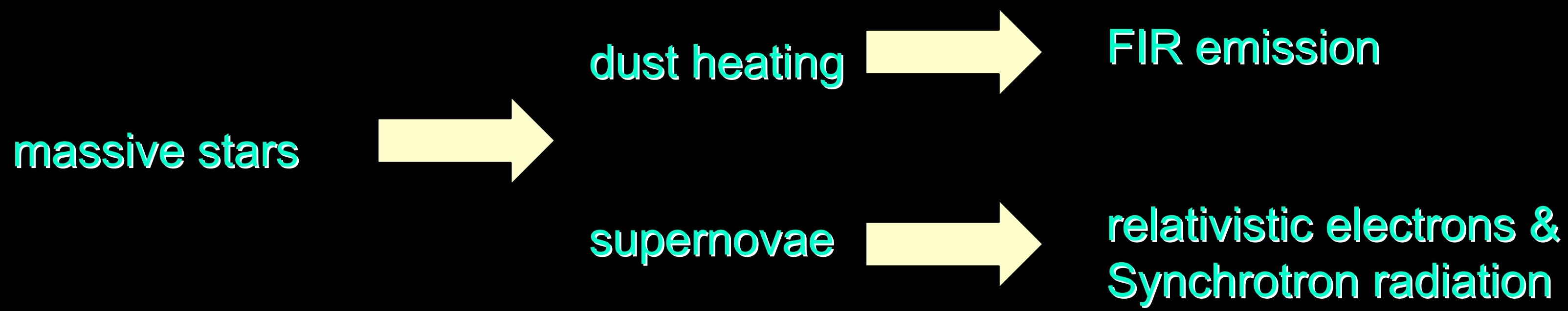
FIR-radio relation

Relation between non-thermal radio and FIR emission from galaxies

- *One of strongest correlations in astronomy*
- *Tight correlation over 5 decades of luminosity*

Cause of relationship still unclear

"Standard" explanation: both FIR and radio emission caused by high-mass stars



FIR-radio relation

Optically-selected SLUGS submm measurements allow us to test a basic prediction of the standard theory

Standard model prediction:

- FIR-radio correlation will be tighter than the submm-radio

Reason:

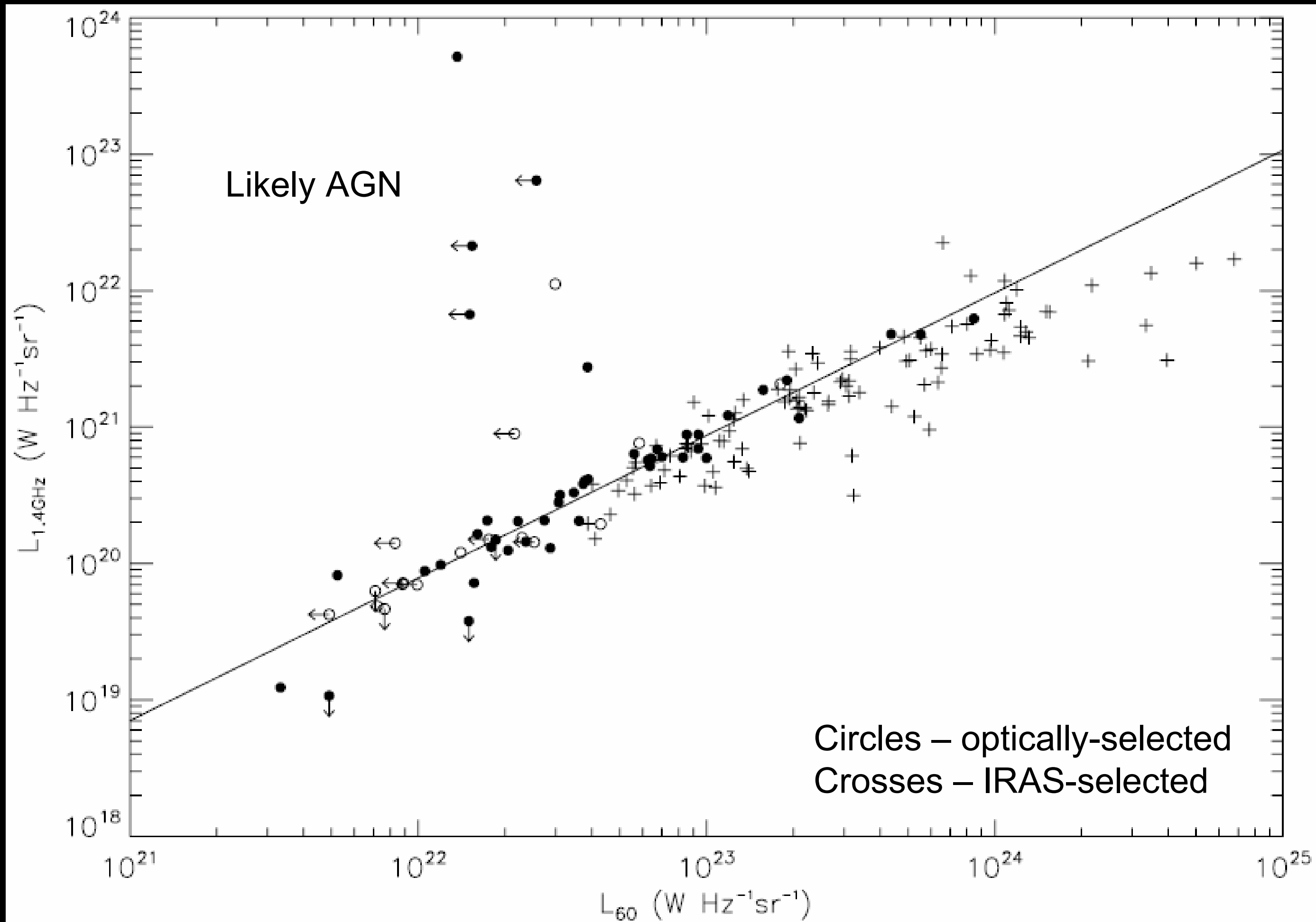
Regions with large no. of OB stars :

- ISRF more intense
- dust hotter than in general ISM
- gives rise to 60μm emission

850μm emission:

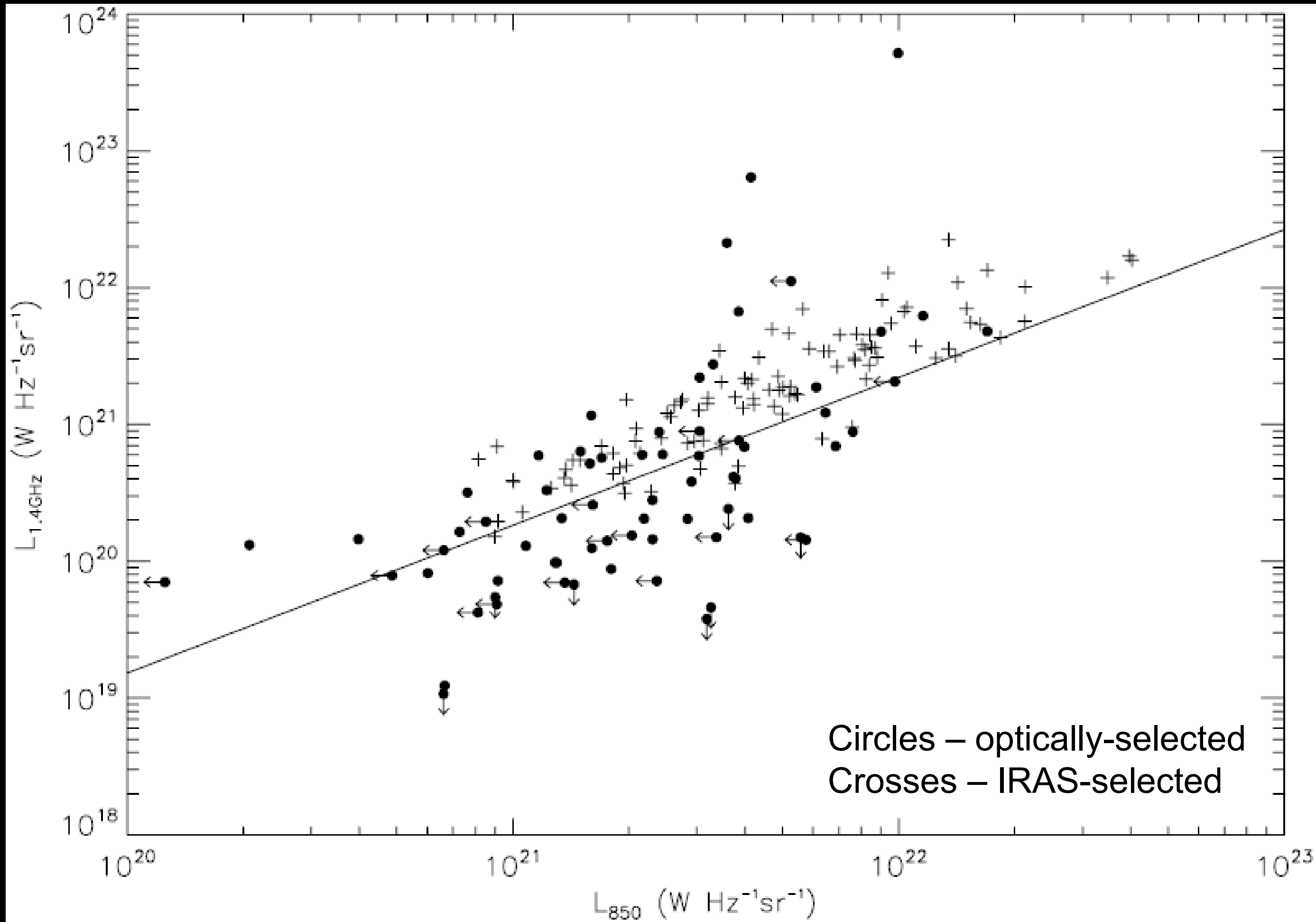
- traces colder dust heated by ISRF
- includes component from older stellar populations

SLUGS FIR-radio relation



Tight correlation between FIR and radio for OS sample

SLUGS submm-radio relation



Much larger scatter of submm-radio relation for OS sample

→ Exactly the behaviour we would expect if standard model is correct

High-z Universe: α-redshift relation

Carilli & Yun method:– Use redshift-sensitive nature of submm-radio flux density ratio as redshift estimator

$$\alpha_{1.4}^{850} \propto \log\left(\frac{S_{850}}{S_{1.4}}\right)$$

Based on assumption that the FIR-radio relation is the same at low-z and high-z

We use fitted SEDs for 17 OS SLUGS galaxies to

– Predict how α depends on redshift, for "normal" low-z galaxies

– Compare with deep SCUBA sources with spectroscopic redshifts (Chapman et al. 2005)

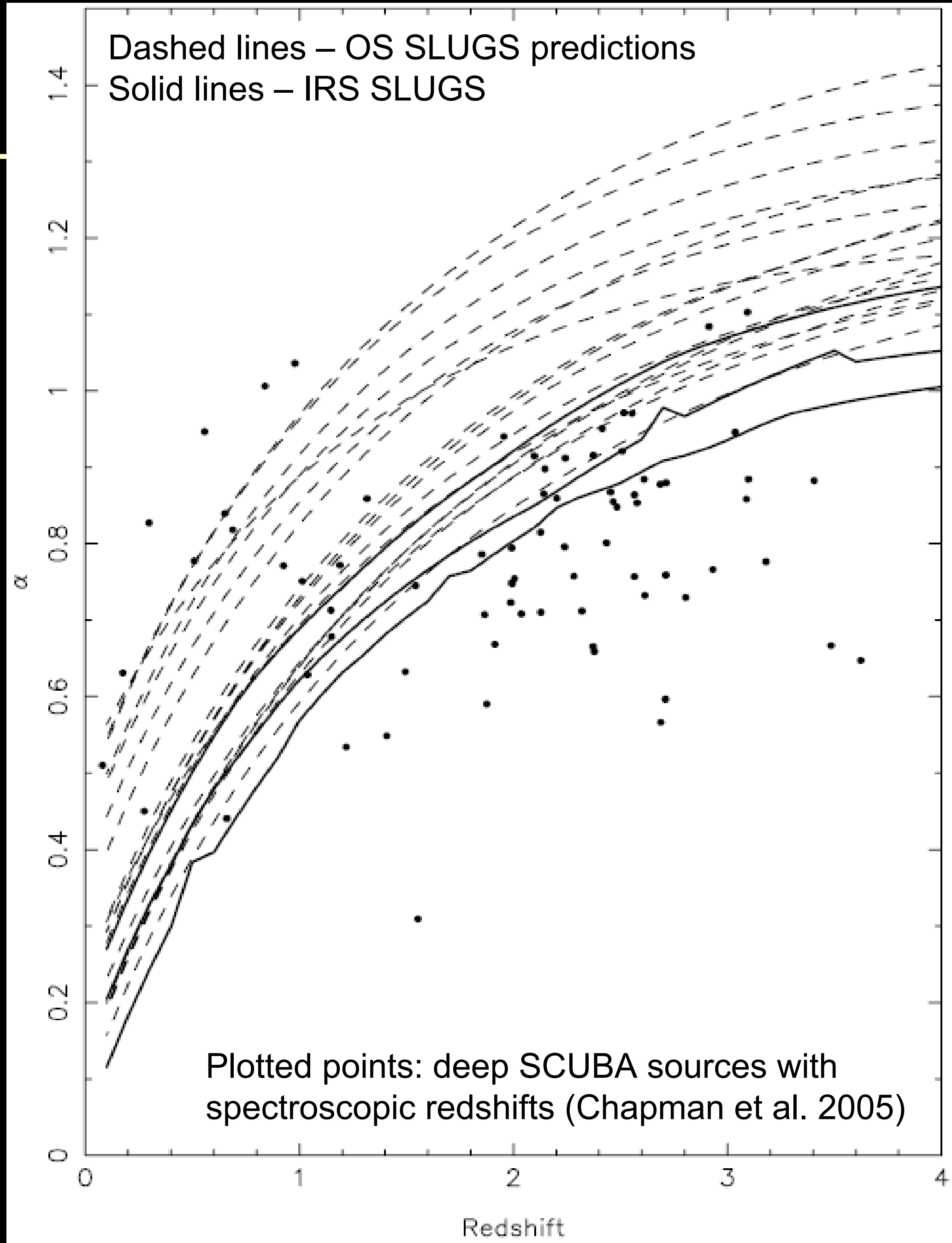
– Use this to assess reliability of CY method

α-redshift relation

- Source could be IRS-like and high-z or OS-like and low-z
- Temp affects position on α–z diagram
- Difficult to get reliable estimates of redshift in this way

Deep SCUBA sources:

- No correlation, but…
- Brighter in radio (or fainter in FIR) than the predictions for our local SLUGS samples
- A number of possible explanations



α-redshift relation: possible explanations

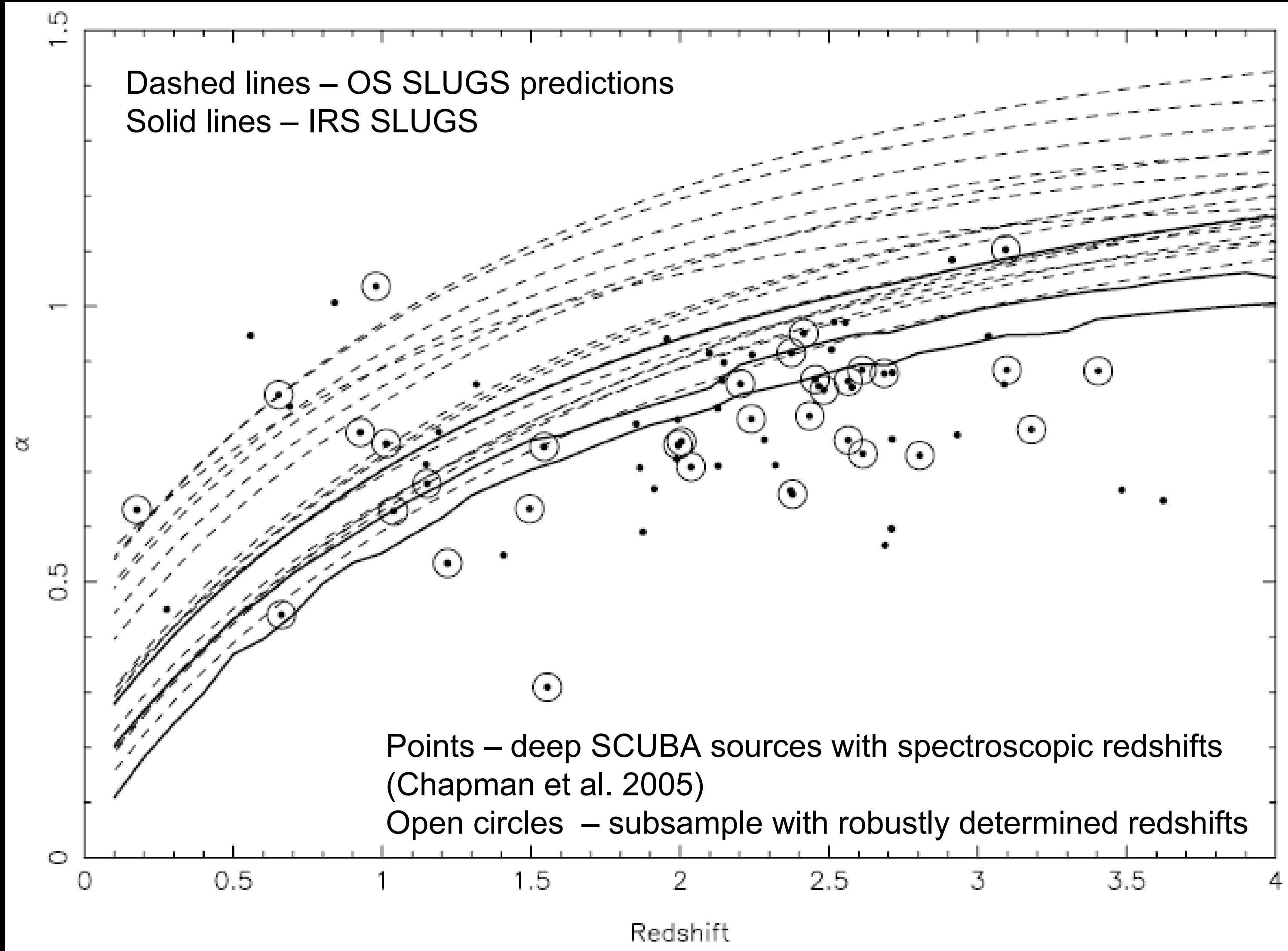
i. Correlation between α and luminosity at given z
   - Unlikely
     - No evidence for sufficient correlations out to high redshift

ii. Chapman sources: FIR and radio emission comes from AGN
   - Unlikely:
     - Not strong x-ray sources
     - Radio morphologies not typical of AGN
     - Optical spectra often starburst not AGN

iii. Redshifts of Chapman sources are unreliable
   - Unlikely
     - Test this using subsample with robustly determined redshifts (Aretxaga et al. 2007) and find no difference

iv. Relation between FIR and radio different at high and low z
   - Very different conditions compared to today → surprising if relation were the same
   - We feel is the most likely explanation

α-redshift relation: possible explanations



Summary 2: FIR–radio relation

- FIR-radio correlation for OS SLUGS much stronger than submm-radio, evidence that massive star formation is cause of FIR-radio relation
- Much more scatter in α–z relation for “normal” galaxies than for bright IRAS galaxies
  - For CY method to be reliable as redshift estimator for deep submm sources, first need measurement of dust temp
- α–z relation: deep submm galaxies brighter sources of radio emission than predicted from properties of local galaxies
  - possible explanation is evolution of FIR-radio relation

3. Dust in the Sombrero Galaxy

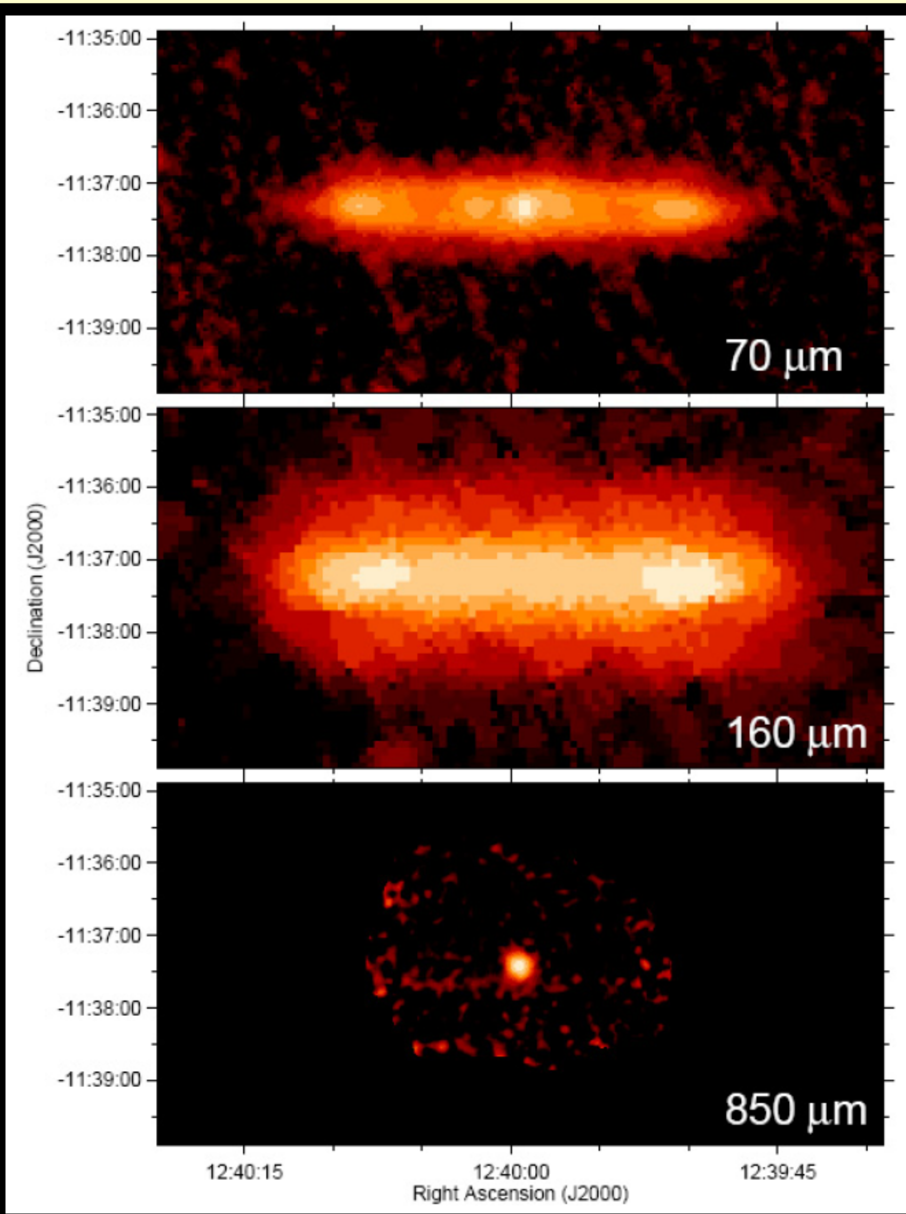
The Sombrero Galaxy (M104)

Sa galaxy with symmetric dust ring and low-luminosity AGN

The Sombrero

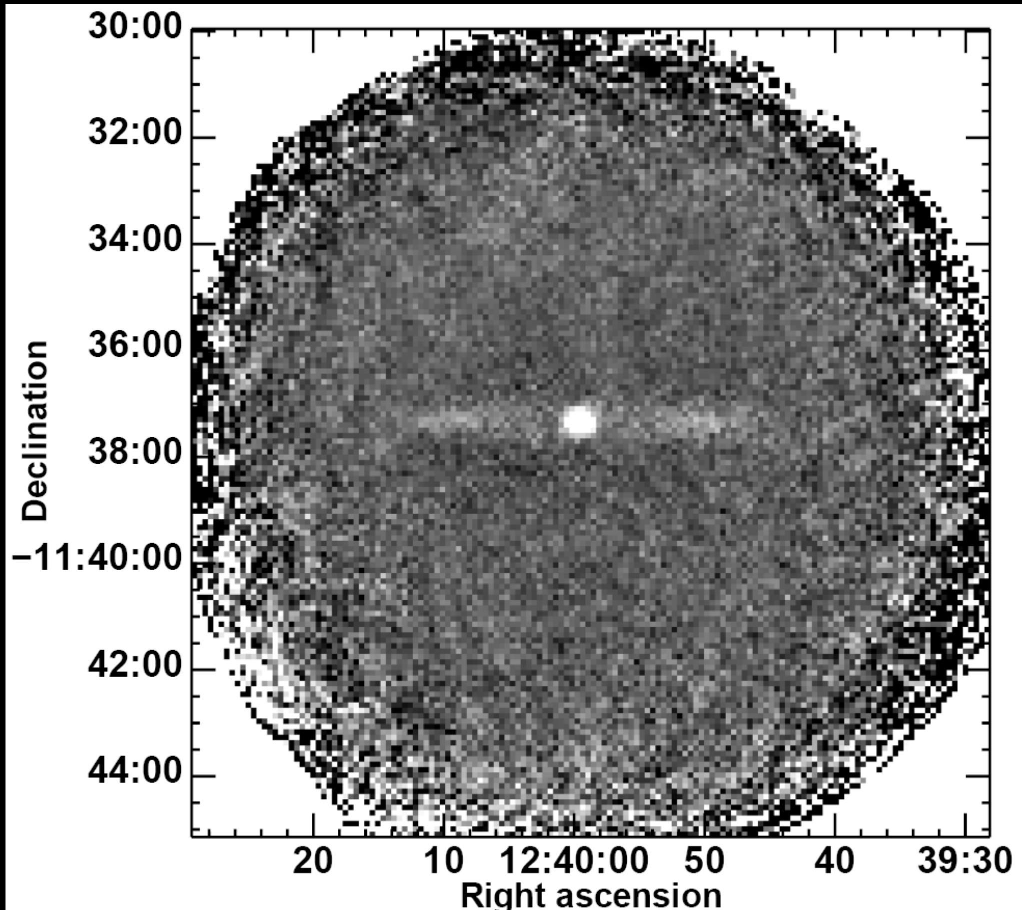
Components:
- Bulge
- Nucleus
- Inner Disk
- Ring

Ring radius 5.7–70μm:
145 arcsec

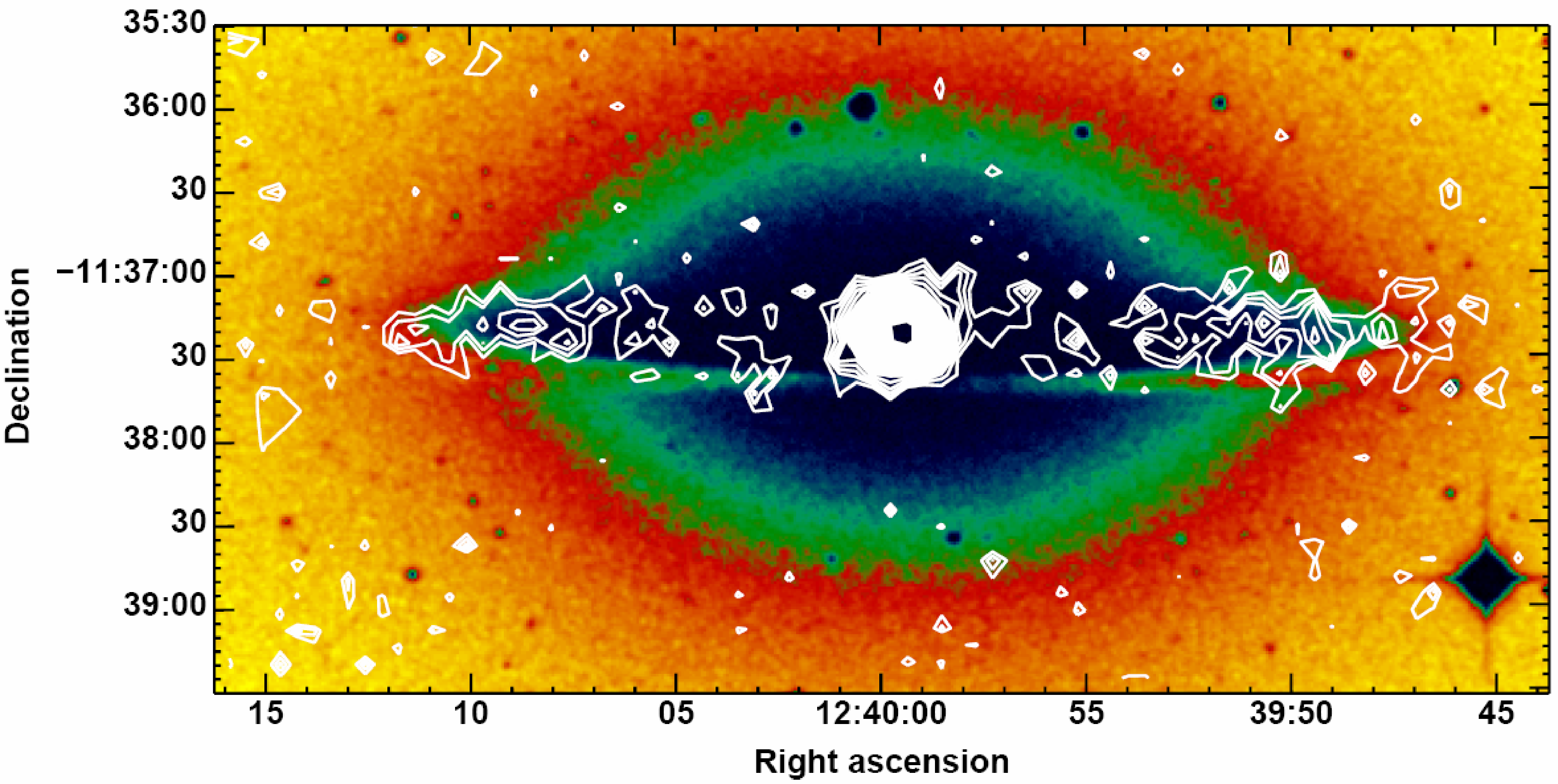


Bendo et al. 2006

The Sombrero: LABOCA 870μm



The Sombrero: LABOCA 870μm



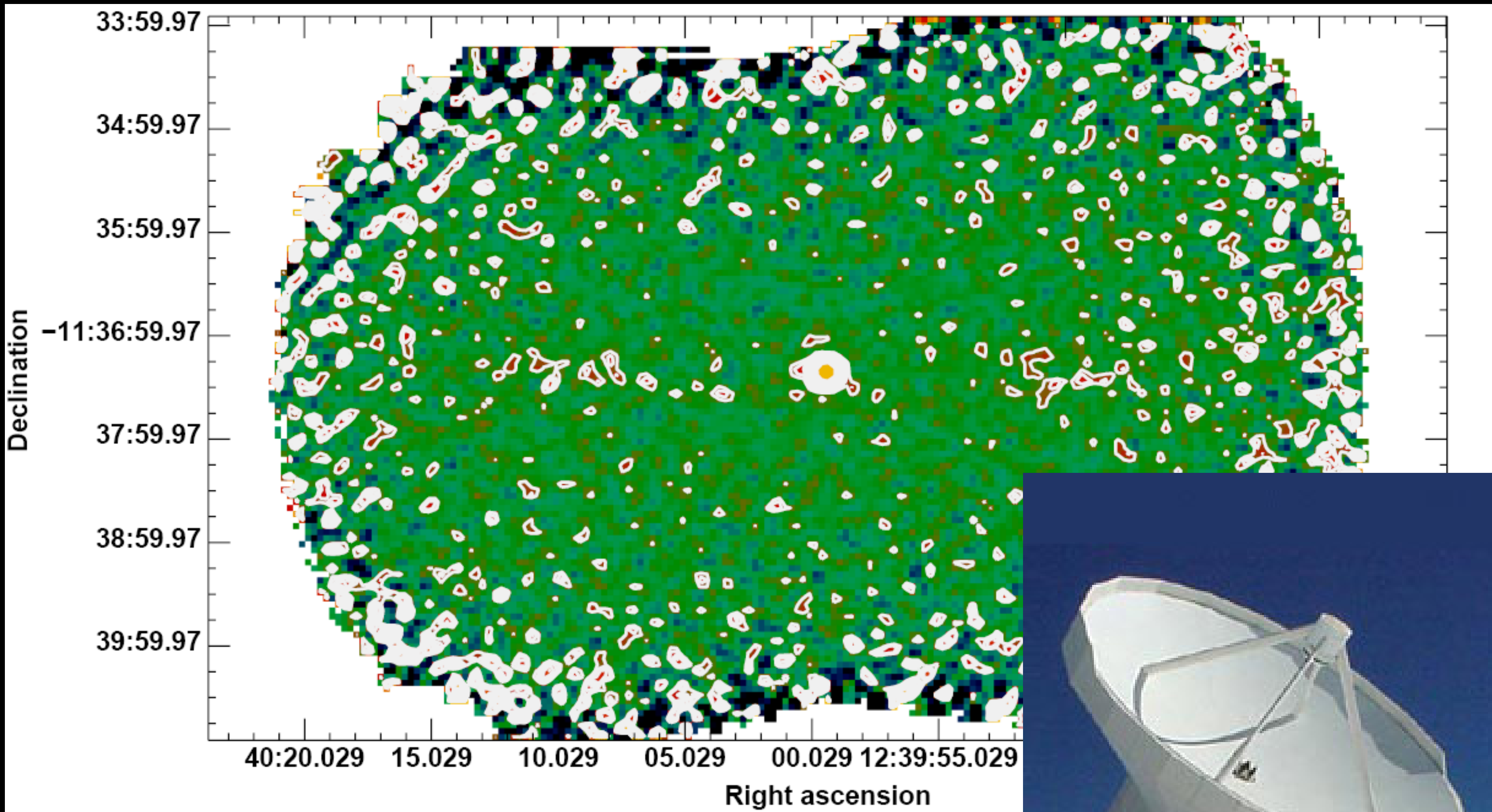
Ring radius = 162 arcsec

Ring width = 44 arcsec

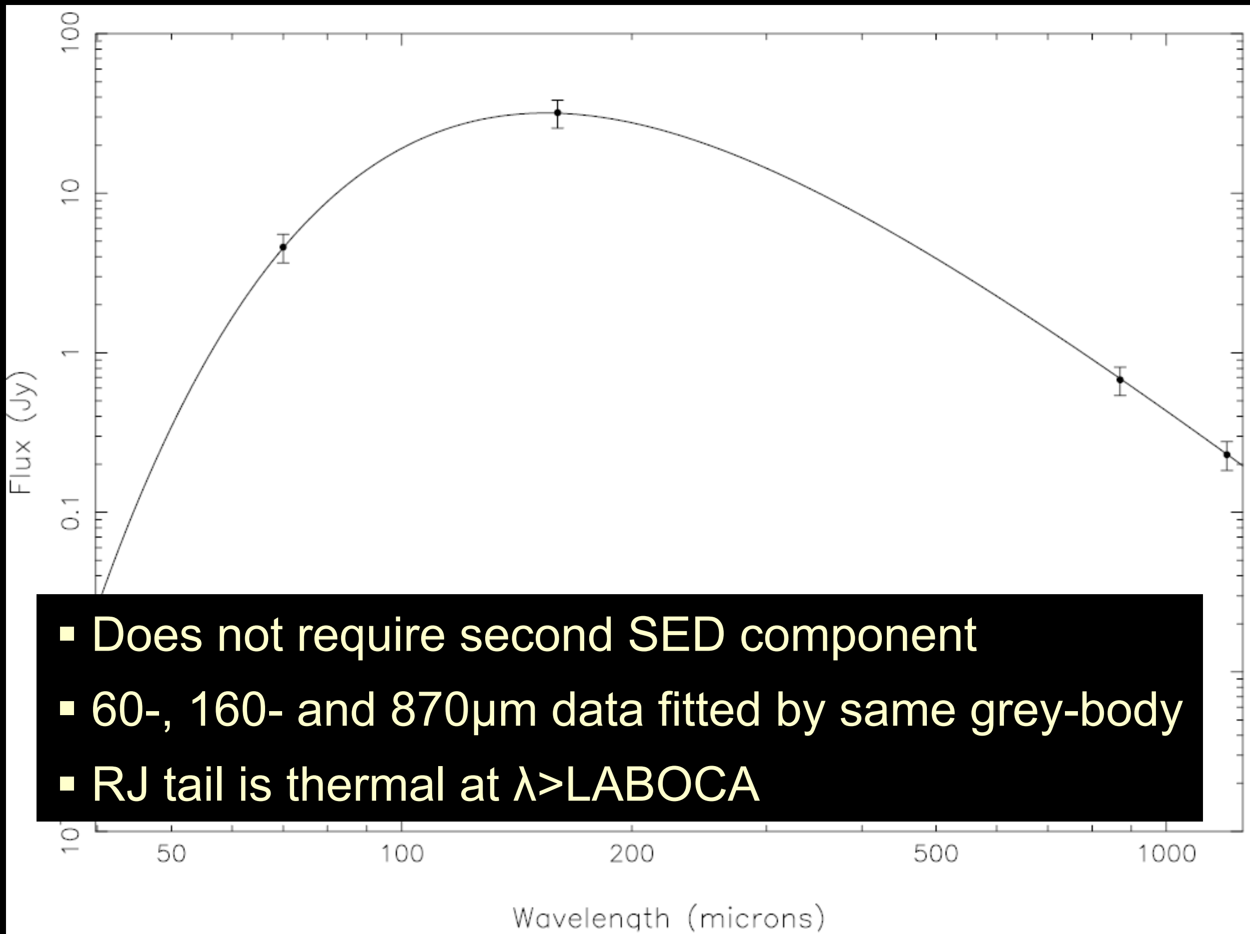
Ring: $S_{870} \sim 0.7$ Jy

Nucleus: $S_{870} \sim 0.24$ Jy

The Sombrero: MAMBO-2 1.2mm



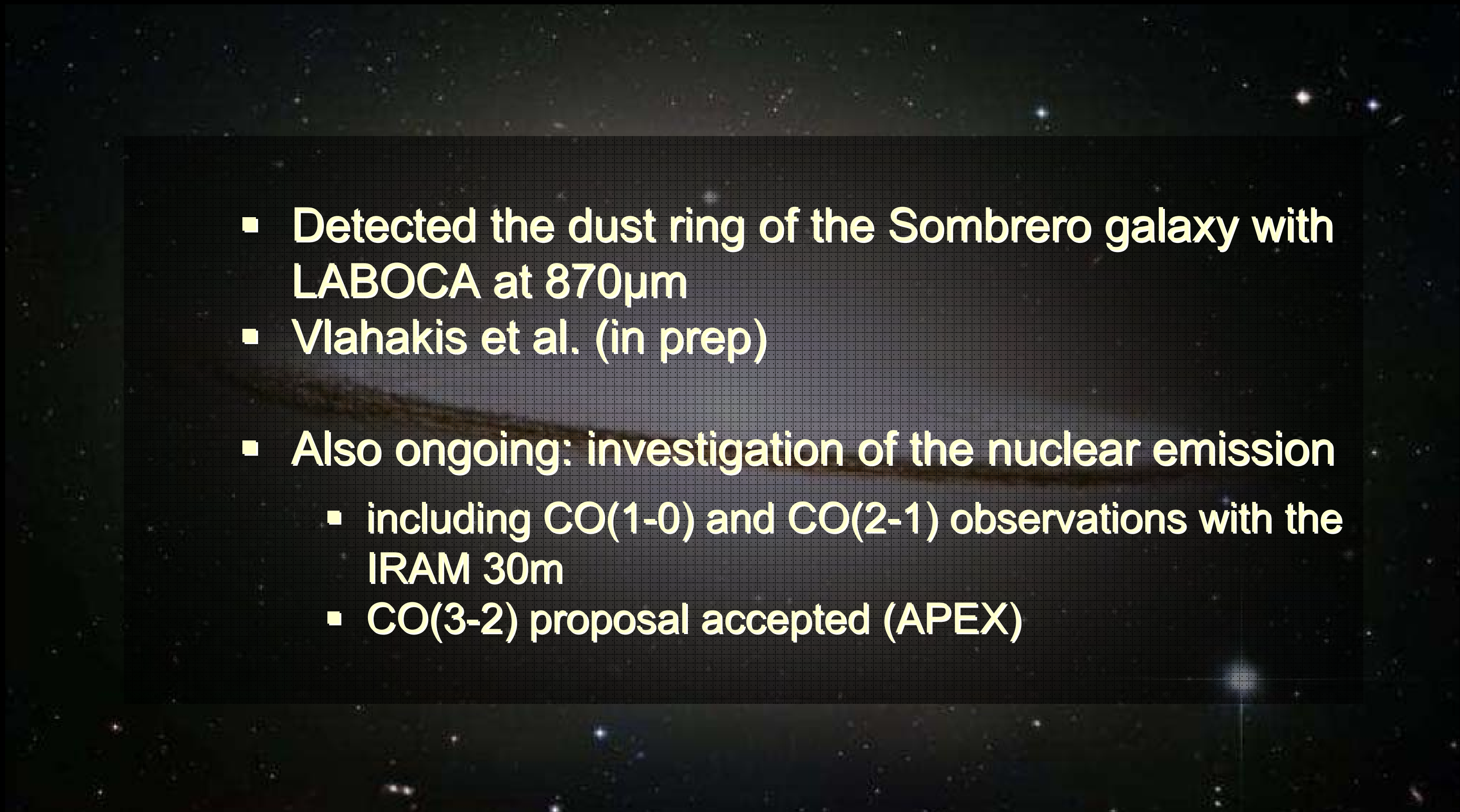
The Sombrero: SED



- Does not require second SED component
- 60-, 160- and 870μm data fitted by same grey-body
- RJ tail is thermal at λ>LABOCA

$M_d = 1.3 \times 10^7\ M_{sol}$

Summary 3: Sombrero galaxy



- Detected the dust ring of the Sombrero galaxy with LABOCA at 870μm
- Vlahakis et al. (in prep)

- Also ongoing: investigation of the nuclear emission
  - including CO(1-0) and CO(2-1) observations with the IRAM 30m
  - CO(3-2) proposal accepted (APEX)