Dust in dwarf galaxies: The case of NGC 4214

Ute Lisenfeld
Israel Hermelo
Monica Relaño
Richard Tuffs
Cristina Popescu
Joerg Fischera
Brent Grove

Image from HST WFC3
(Image: NASA/ESA/Hubble Heritage)

Dust in dwarf galaxies

Differences with respect to spiral galaxies due to:

- Lower metallicity
- Strong interstellar radiation (if actively star forming)

Observed differences in the dust SED:

- Lower PAH content at low metallicities (e.g. Draine+07, Engelbracht+2008)
  - Destruction of PAHs due to hard ISRF?
- Submillimeter "excess" in the SED of some galaxies, many of them starbursting, low-metallicity galaxies (Kruegel+98, Lisenfeld+ 01, Galliano+ 03, 05, Dumke+04, Bendo+06, Galametz+09, 2011, Israel+10, Bot+2010).
  - Large amount of cold (<10K) dust (Galliano 2003, 2005, Galametz 2009, 2011). But:
    - Large dust masses needed, problems with dust-to-gas mass ratio
    - How can large dust masses be so efficiently shielded?
  - Low value of the dust emissivity spectral index β=1 in the submm? Possibilities: VSGs with β=1 (Lisenfeld+02), amourphous grains (Meny +07), Fractal grains (Reach+95).
  - Spinning grains (e.g. Ferrara & Dettmar 1994, Draine & Lazarian 98). This process is able to explain excess in LMC/SMC (Bot+10).

Star formation and dust emission

A model is needed to interprete the relation between SF and dust emission. It has to consist at least of:

- Physical dust model, taking into account:
  - Big grains in thermal equilibrium,
  - Stochastically heated small grains,
  - PAHs.
- Dust in different region,exposed to different radiation fields, at least:
  - Dust in HII+PDR region.
  - Diffuse dust.

Ideally:

- Radiation transfer in a realistic geometry to get temperature distribution of the dust right.

Models for the dust SED

- Modified blackbody fit:

  + gives a first idea of the temperature of the dust

  - too simple. Neither temperature distribution, nor dust properties are taken into account.

- Semiempirical models, simulating dust in different regions (e.g. Dale+01, Draine+07, Galametz+09,11, da Cuhna+10)
  - e.g. dust immersed in a range of radiation fields,
  - low intensity to simulate diffuse dust, high intensity to simulated HII+PDR

  + mimics real situation in a galaxy

  - Many fit parameters, derived from the dust SED (not directly measured).

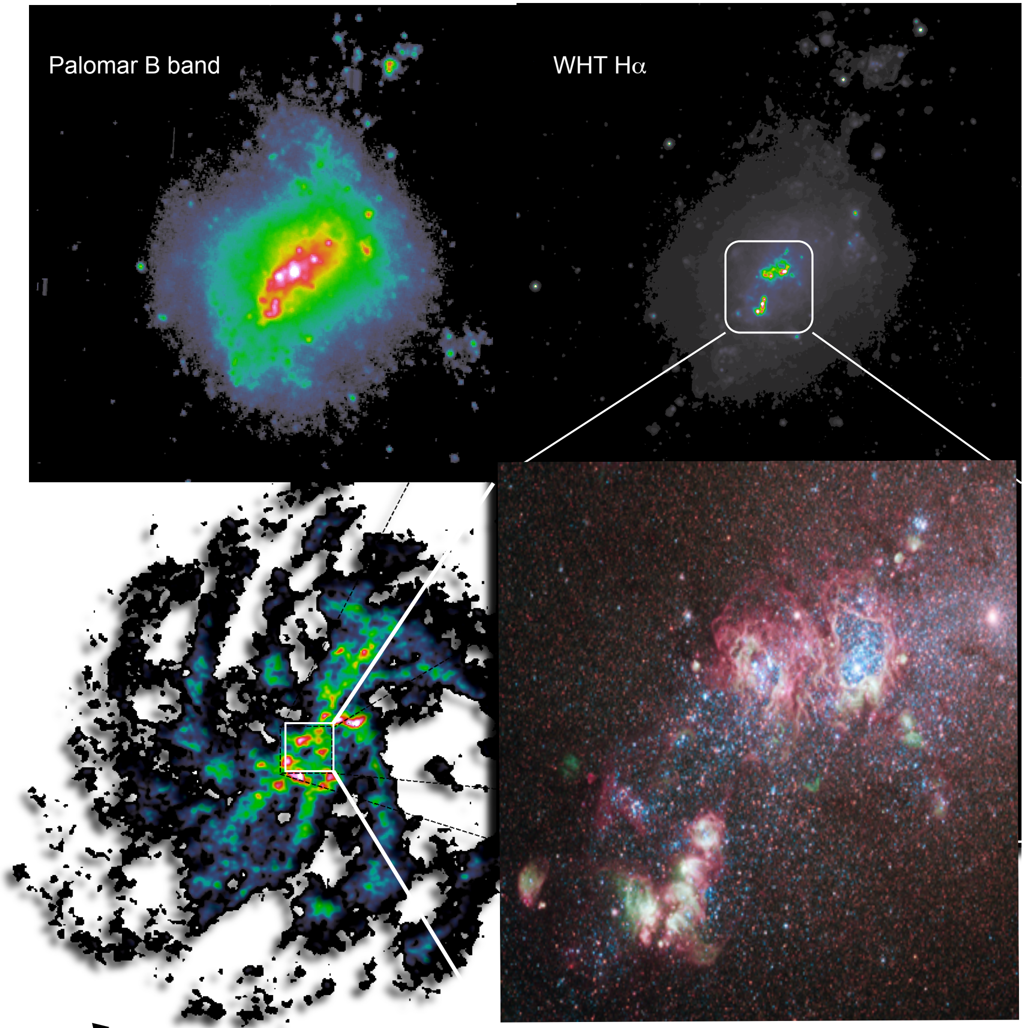
- Models including radiation transfer (e.g. Popescu+2011 (disk galaxies), Siebenmorgen & Kruegel 2007 (starburst galaxies))

  + If geometry is know, most precise results

  - Reality is complex, geometry has to be simplified - are simplifications correct and applicable to a large number of galaxies?

The case of NGC 4214

- NGC 4214 is a nearby (D=2.9 Mpc) starbursting dwarf galaxy
- It contains two large HII complexes in the center (each with various regions).
- It has a large HI disk with spiral arms
- A large amount of existing data:
  - Galex UV
  - HST images from UV to IR
  - Spitzer (IRAC, MIPS 24-160μm)
  - Herschel PACS and SPIRE
  - 1.2mm Mambo (IRAM)
  - Planck detections (350, 550, 850μm)
  - HI (THINGs)
  - CO (OVRO)



The case of NGC 4214

- NGC 4214 is a nearby
  starbursting dwarf gala
- It contains two large HI
  in the center (each with
  regions).
- It has a large HI disk w
- A large amount of exist
  - Galex UV
  - HST images from UV
  - Spitzer (IRAC, MIPS
  - Herschel photometry
  - 1.2mm Mambo (IRAM
  - Planck detections (35
  - HI (THINGs)
  - CO (OVRO)

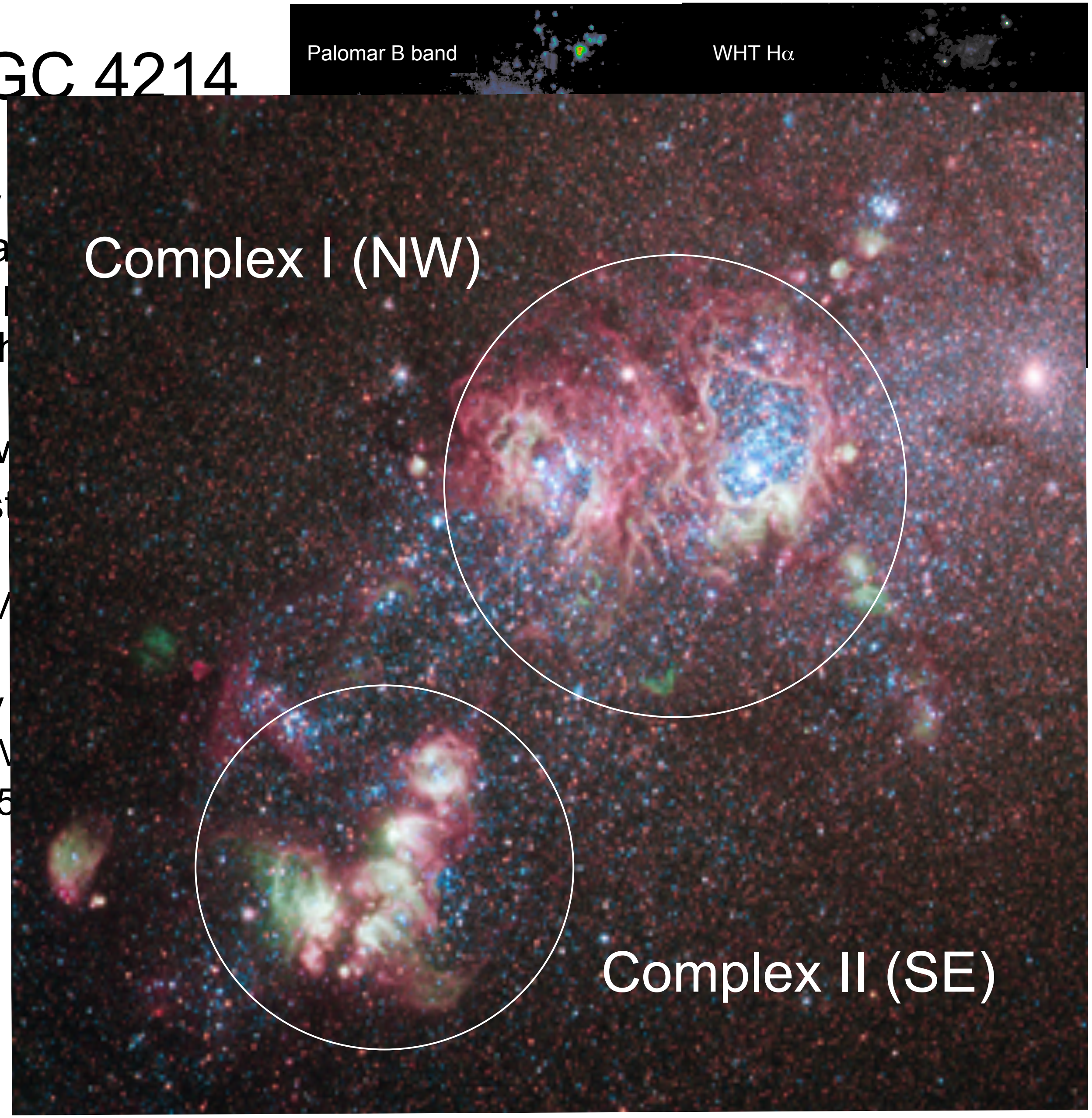
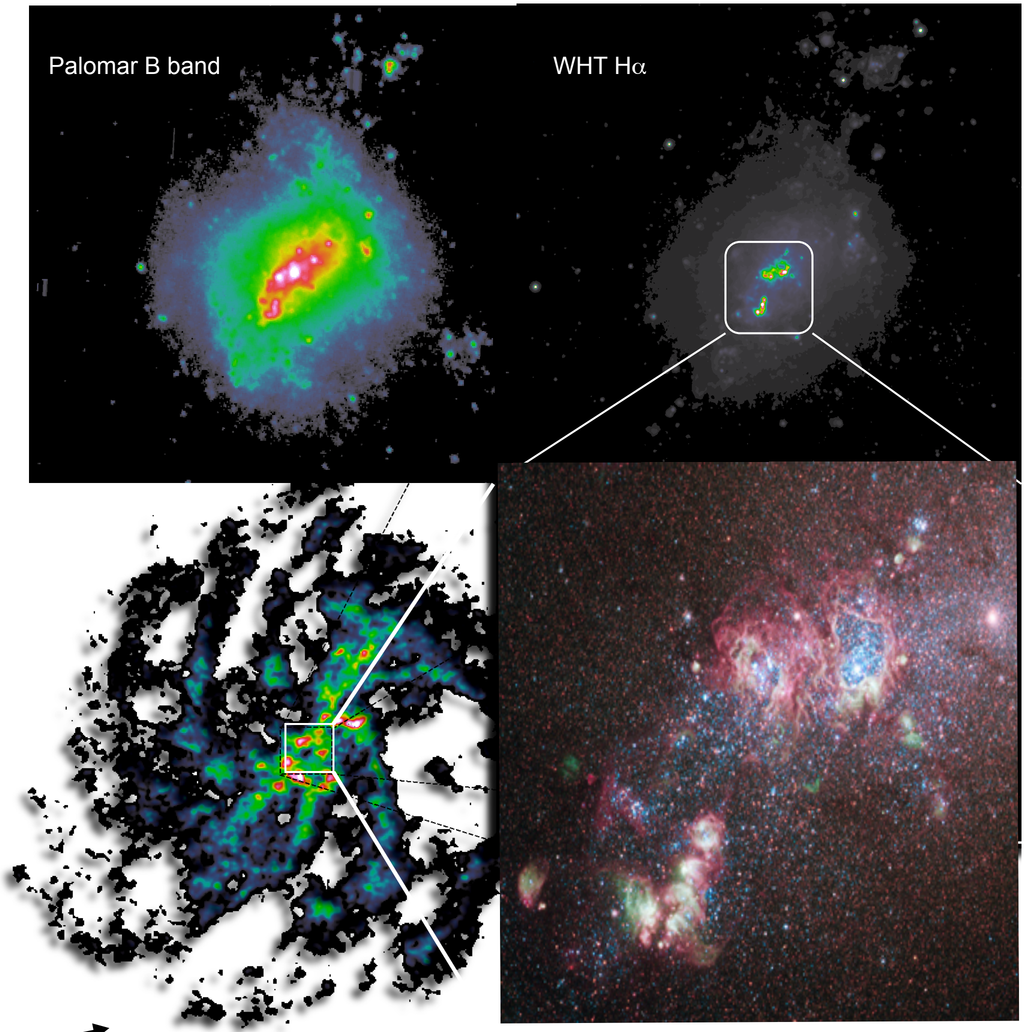


Image from HST WFC3
(Image: NASA/ESA/Hubble Heritage)

The case of NGC 4214

- NGC 4214 is a nearby (D=2.9 Mpc) starbursting dwarf galaxy
- It contains two large HII complexes in the center (each with various regions).
- It has a large HI disk with spiral arms
- A large amount of existing data:
  - Galex UV
  - HST images from UV to IR
  - Spitzer (IRAC, MIPS 24-160μm)
  - Herschel photometry
  - 1.2mm Mambo (IRAM)
  - Planck detections (350, 550, 850μm)
  - HI (THINGs)
  - CO (OVRO)



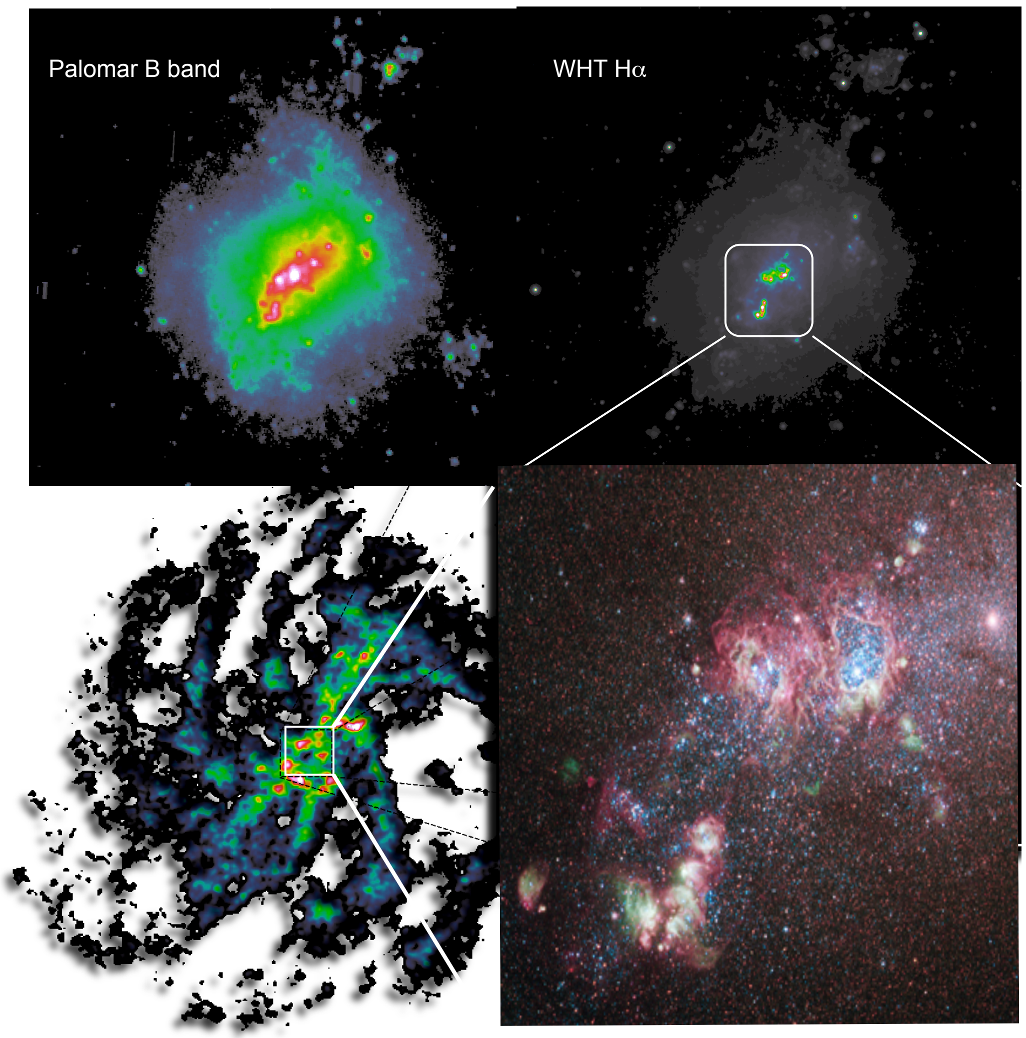
The case of NGC 4214

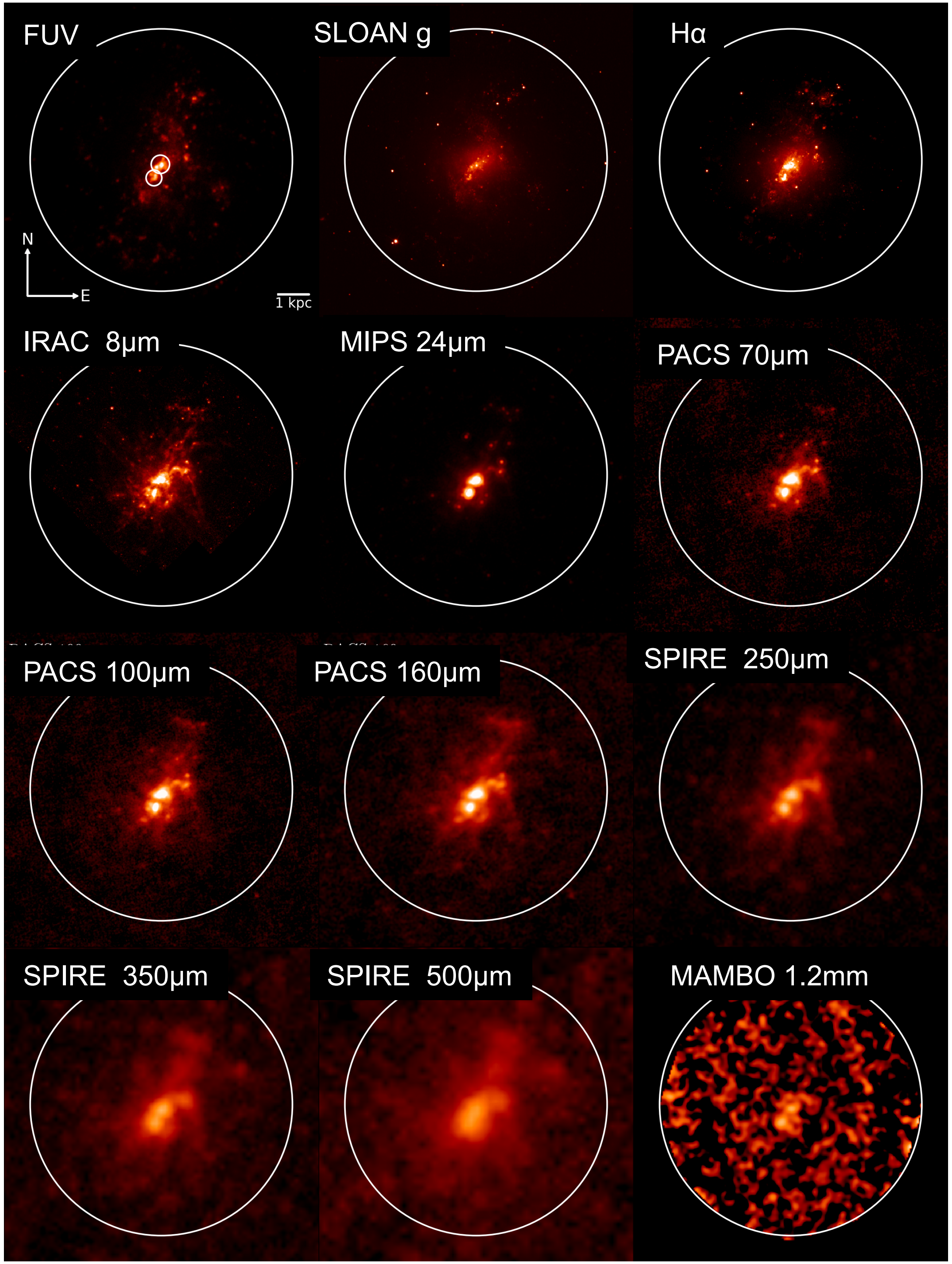
Large data set and high resolution allows to:

- Measure emission from dust in HII+PDR regions and diffuse ISM seperately.
- Apply physical models to each component.
- Determine most parameters of the models from observations.

This will allow us to answer:

- Do models work well?
- Interpret dust SED better, distinguish between different effects, e.g.
    - dust properties
    - dust temperature
    - geometry

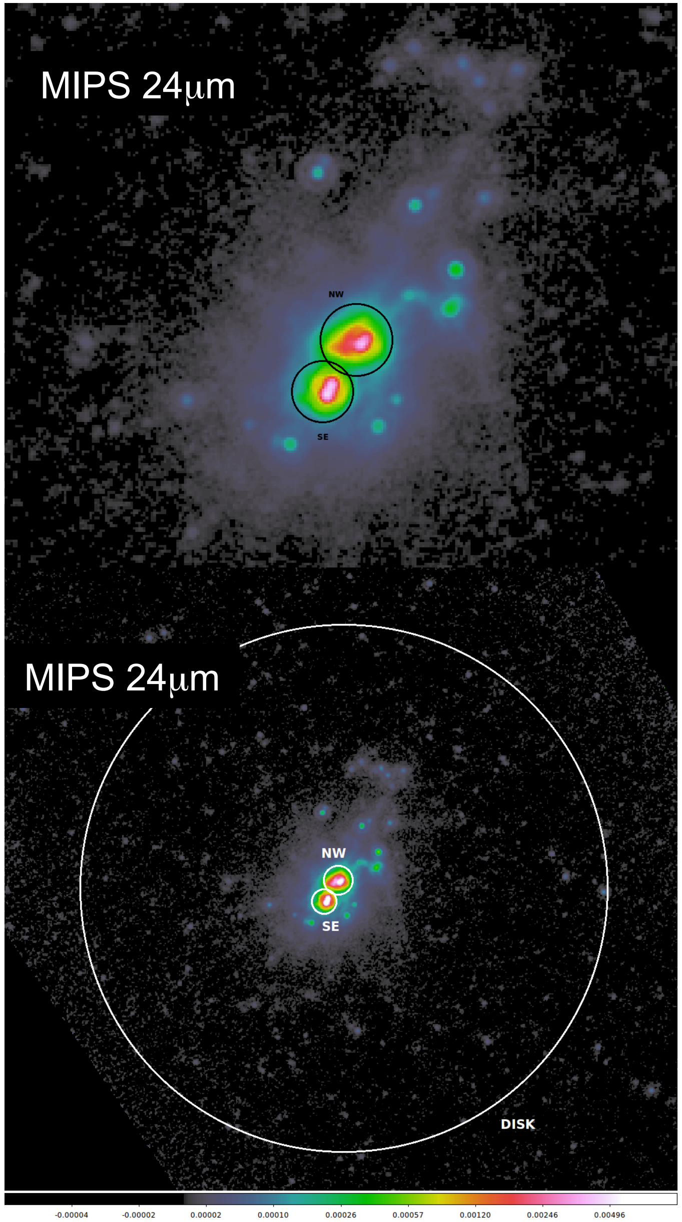




The data: UV to mm

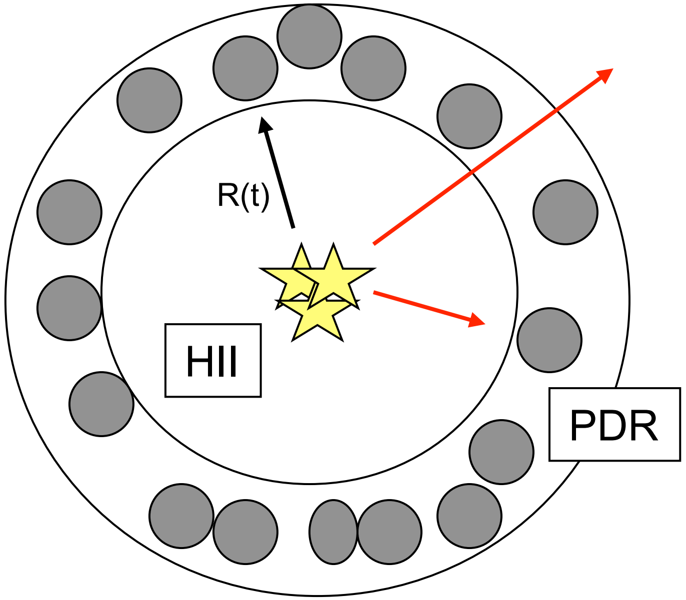
Modelling of the dust SED

- Separate the dust emission from HII regions and diffuse dust:
  - Emission from HII+PDR regions: Aperture photometry over regions (not possbile for SPIRE 350 and 500 μm)
  - Total emission: Photometry over large aperture and PLANCK data (not possible for 1.2mm)
  - Diffuse emission: Total emission minus emission from HII+PDR regions.
- Model each component separately using physical models for:
  - Processes in HII region+PDR (Groves +08).
  - Radiation transport and dust heating and emission in a disk (Popescu+11).



Modelling dust from HII+PDR regions

- Model of Groves+2008 for HII region with surrounding PDR describes
  - Stellar cluster, luminosity calculated with stellar population synthesis (Starburst 99)
  - Temporal evolution:
    - Stellar luminosity
    - Expansion of HII region and PDR due to mechnical energy input of stars and SNe
  - Uses nebular modelling code MAPPINGS III
  - Radiative transfer, dust heating and emission in HII regions and in surrounding PDRs.
- Parameters:
  - Metallicity
  - Age
  - Compactness parameter C: Parametrizes heating capacity of stellar cluster. Depends on $M_{cluster}$ and P
  - External pressure P (determines Radius (t))
  - Column density N_H of the PDR
  - Covering factor, f_{cov}, describing which fraction of the region is surrounded by dense material and which allows a direct view on the inner HII regions.



We can constrain most parameters (except N_H) from observations.

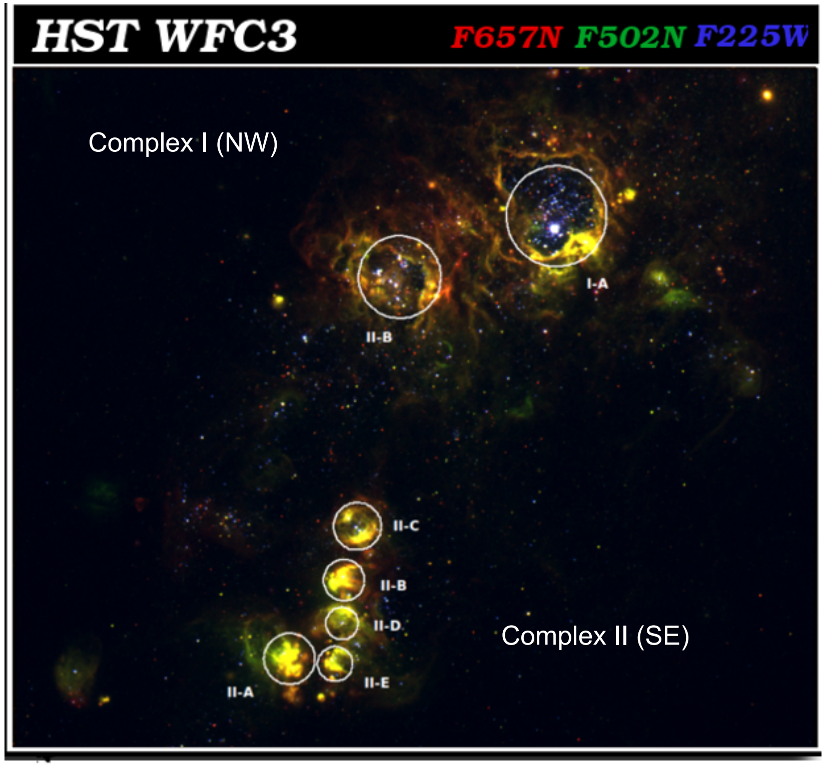
Parameters for NGC 4214

- Metallicity: 12+log(O/H) = 8.2-8.36 (Kolbunicky & Skillman 96)
- Ubeda+07ab have carried out a detailed study of the stellar populations and derived:
  - Masses of the clusters
  - Ages of the clusters
  - Radii of the HII regions.
  - We take average values for complex I and II
- External pressure P from R(t)
- Compactness parameter C from $M_{cluster}$ and P (and, redundantly, from L/R^2 and age)
- Estimate for the covering factor:

$$f_{cov} = L_{dust}/(L_{dust}+L_{stars})$$

(assumes dense regions absorb all stellar luminosity and that clumps and free regions are well mixed)

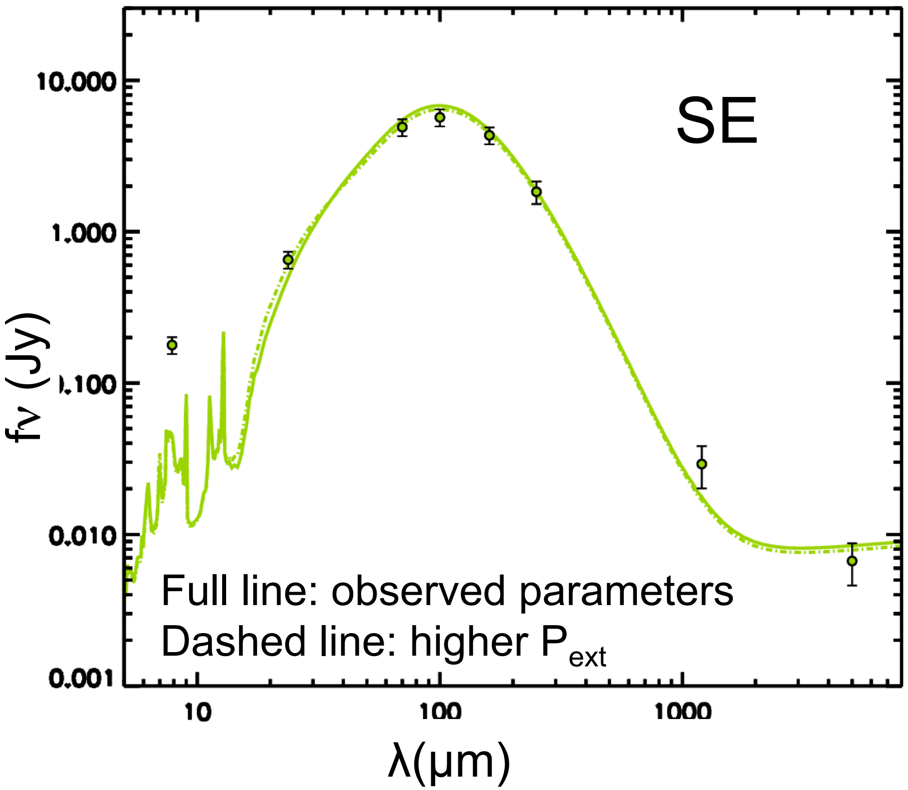
  - Complex I: f_{cov} = 0.45
  - Complex II: f_{cov} = 0.65

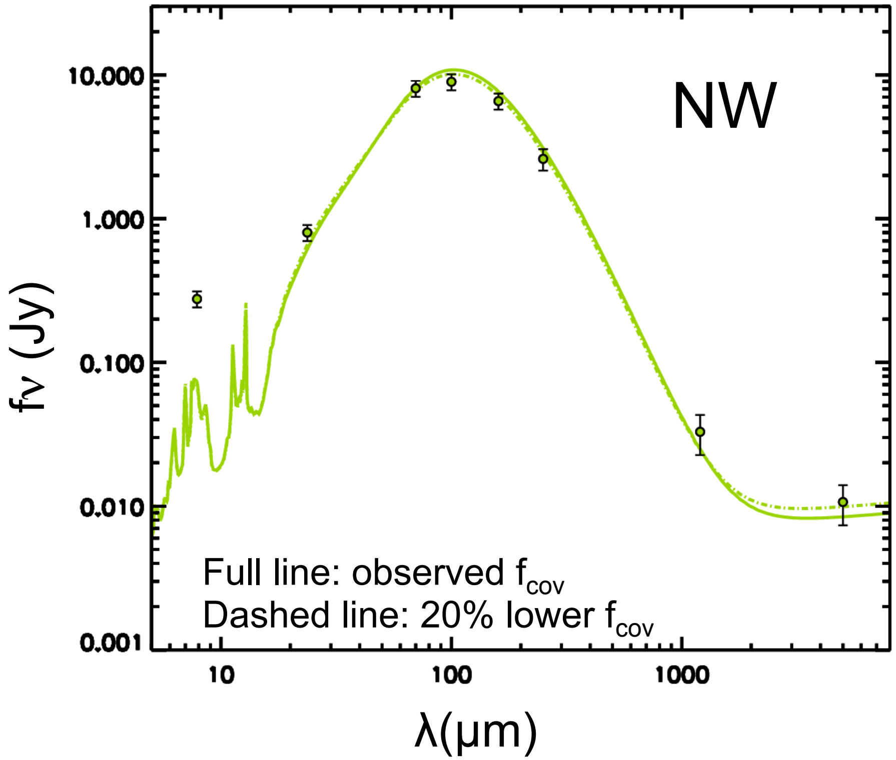


CLUSTER	AGE (Myr)	Mass ($10^3 M_\odot$)	R (pc)
I-A	5.0±0.0	156±19	44.82
I-B	5.0±0.0	34±4	35.78
II-A	3.1±1.4	34±23	44.26
II-B	2.0±0.8	43±10	24.10
II-C	1.7±0.6	63±14	35.78
II-D	4.0±4.0	7±5	21.27
II-E	3.1±1.4	7±3	22.68

Results of the fitting of the HII+PDR regions

- NW: Age = 5 Myr
- SE: AGE = 3.5 Myr
- $N_H = 10^{22}$ cm^{-2}

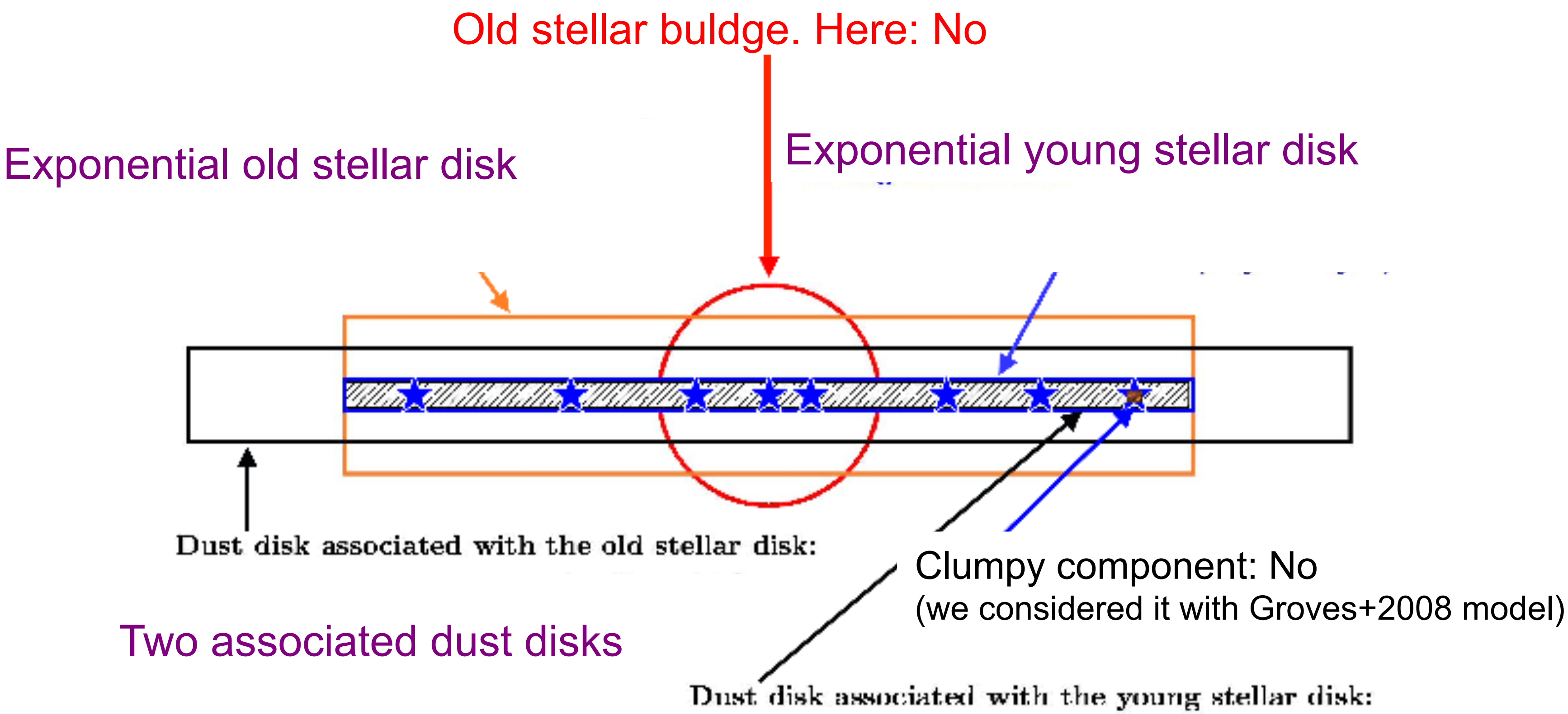




- ➢ Good fits for both regions for λ > 10 μm
- ➢ PAH abundance higher than model predictions in both region.
  - Model overpredicts PAH destruction?
  - Has NGC 4214 an exceptionally high PAH abundance (see Engelbracht+08)

Modelling of the diffuse dust

•We applied templates of the library of Popescu+2011, derived calculating the full radiation transfer for dust in a disk galaxy.
•We take into account young and old stellar disk and associated dust disks.



Ratio of the sizes of the different disks is fixed.

Parameters of the model

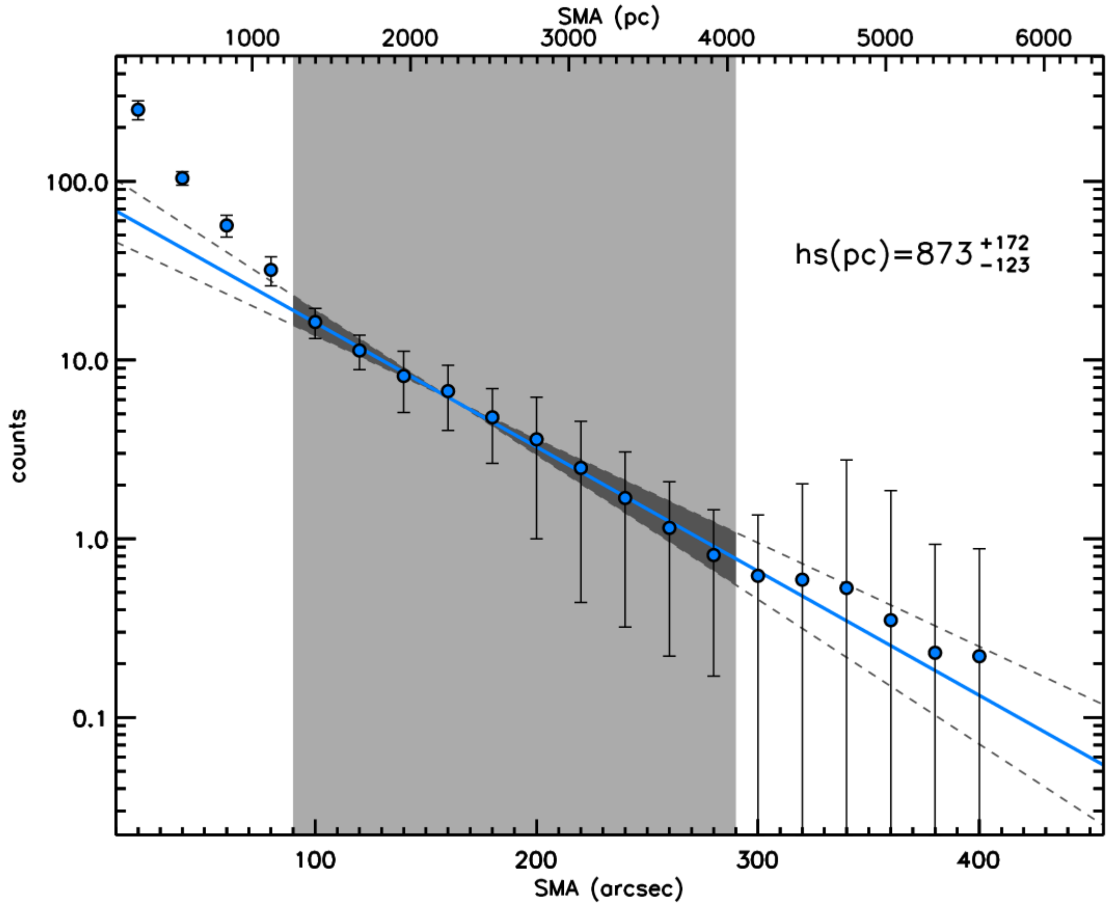
- **τ_B^f,** total central face-on B-band opacity
- **h_s,** scale-lenght in the B-band.
  - All scales in the model have a constant ratio with hs.
  - Compare to the scale-length of the model galaxy ($h_{s,0}$=5670kpc) in order to determine the intensity of the ISRF correctly
- **F**, clumpiness factor. F is the same as f_{cov} in model of Groves et al.
- **old**, normalized luminosity of the old stellar disk.
- **SFR'**, star formation rate powering diffuse emission. Total star formation rate SFR is derived from SFR' = (1-F) SFR

Parameters of the model

- **τ_B^f,** total central fac-on B-band opacity:
  - Free pararamter
- **h_s,** scale-lenght in the B-band.
  - Derived from blue image
- **F**, clumpiness factor:
  - Mean value of f_{cov} derived for NW and SE SF regions: F = 0.55
- **old**, normalized luminosity of the old stellar disk:
  - Derived from the de-attenuated luminosity in the IR
- **SFR'**, star formation rate powering diffuse emission.
  - Derived from integrated UV-optical luminosity

Parameters of the model

- τ_B^{f}, total centr
  - Free para
- h_s, scale-lengl
  - Derived f
- **F**, clumpiness f
  - Mean value
- **old**, normalize
  - Derived fro
- **SFR'**, star forr
  - Derived fro



Parameters of the model

- τ_B^{f}, total central fac-on B-band opacity:
  - Free pararmeter

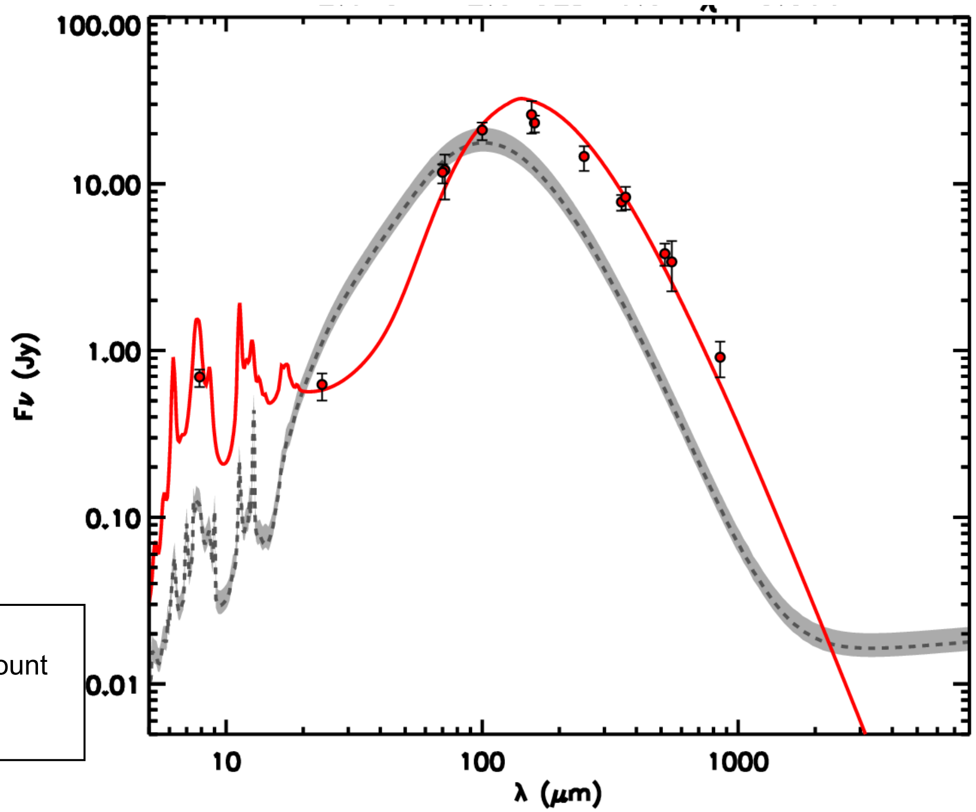
- h_s, scale-lenght in the B-band.
  - Derived from blue image: hs = 873^{+173}_{-122} pc

- **F**, clumpiness factor:
  - Mean value of f_{cov} derived for NW and SE regions (F≈ 0.5)

- **old**, normalized luminosity of the old stellar disk:
  - Derived from the de-attenuated luminosity in the IR

- **SFR'**, star formation rate powering diffuse emission.
  - Free parameter

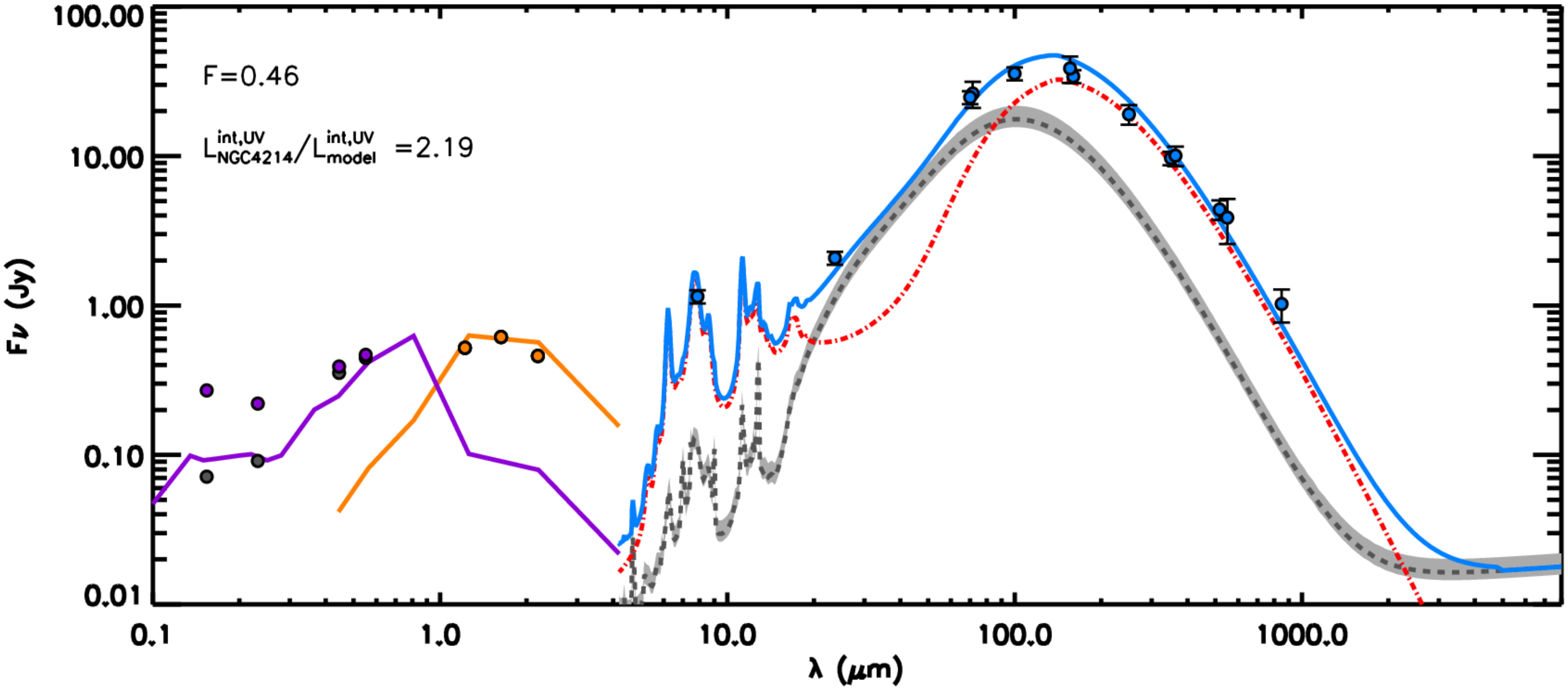
Results for the diffuse dust



Grey: emission from HII regions:
- Upper limit: SED of (NE+SW)*1.3 (to take into account emission from smaller HII regions).
- Lower limit: SED of NE+SW

- In the mid-IR the dominates the emission from HII regions - it is important to do the fitting separately for HII+PDR and diffuse component.
- Best fit for τ_B = 2±0.2
- A good fit is achieved for the diffuse dust emission.
- Note that the flux level of the dust emission is scaled to SFR_{model} - it's not a free parameter.

Total emission



- A good fit in the FIR/submm but it requires less UV emission than observed (about a factor of 2).
- The discrepancy in the UV is relieved to a factor 1.2-1.3 when using the longest possible scale-length h_s

What causes difference between diffuse model and data?

1. Escape of unattenuated UV radiation?
   - Escape of 20-50% of the UV radiation from the galaxy instead of heating the diffuse dust,
   - Possible due to porosity of ISM, holes and channels created by stellar winds and SN explosions (e.g Clarke & Peu 2002, Martin 1998)
2. A different geometry of dust and stars?
   - Different geometry of dwarf galaxies (in particular higher scale-height/ scale-lenght ratio)
3. An extended (colder) dust component?
   - Tentative evidence found in BCDs by Popescu+2002 from ISO data
   - We derived scale length from SPIRE and found no indication for a extended dust component

What causes
m

1. Escape of unat
   – Escape of 30-50%
     heating the diffus
   – Possible due to p
     winds and SN exp
2. A different geor
   – Different geometr
     scale-lenght ratio)
3. An extended (c
   – Tentative evidenc
   – We derived scale
     extended dust component

What causes difference between diffuse model and data?

1. Escape of unattenuated UV radiation? ✔
   - Escape of 30-50% of the UV radiation from the galaxy instead of heating the diffuse dust,
   - Possible due to porosity of ISM, holes and channels created by stellar winds and SN explosions (e.g Clarke & Peu 2002, Martin 1998)
2. A different geometry of dust and stars?
   - Different geometry of dwarf galaxies (in particular higher scale-height/ scale-lenght ratio)
3. An extended (colder) dust component?
   - Tentative evidence found in BCDs by Popescu+2002 from ISO data
   - We derived scale length from SPIRE and found no indication for a extended dust component

What causes difference between diffuse model and data?

1. Escape of unattenuated UV radiation? ✔
   - Escape of 30-50% of the UV radiation from the galaxy instead of heating the diffuse dust,
   - Possible due to porosity of ISM, holes and channels created by stellar winds and SN explosions (e.g Clarke & Peu 2002, Martin 1998)
2. A different geometry of dust and stars?
   - Different geometry of dwarf galaxies (in particular higher scale-height/ scale-lenght ratio)
3. An extended (colder) dust component? **NO**
   - Tentative evidence found in BCDs by Popescu+2002 from ISO data
   - We derived scale length from SPIRE and found no indication for a extended dust component

Summary

- The large amount of data and good resolution allows to carry out the modelling of the dust SED of NGC 4214 **separately** for HII+PDR region and the diffuse ISM.
- We apply the physical models of Grove+2008 (dust in HII+PDR) and Popescu+2011 (diffuse dust).
- We achieve good fits for the dust SED from the HII complexes as well as for the diffuse dust.
- We found indiactions for an escape of UV radiation from the galaxy, without heating the diffuse dust.
- In the future: This kind of analysis can be applied to other nearby dwarf galaxies in order to better understand the relation between SF and dust heating/emission.