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Dust radiative transfer modeling of nearby galaxies

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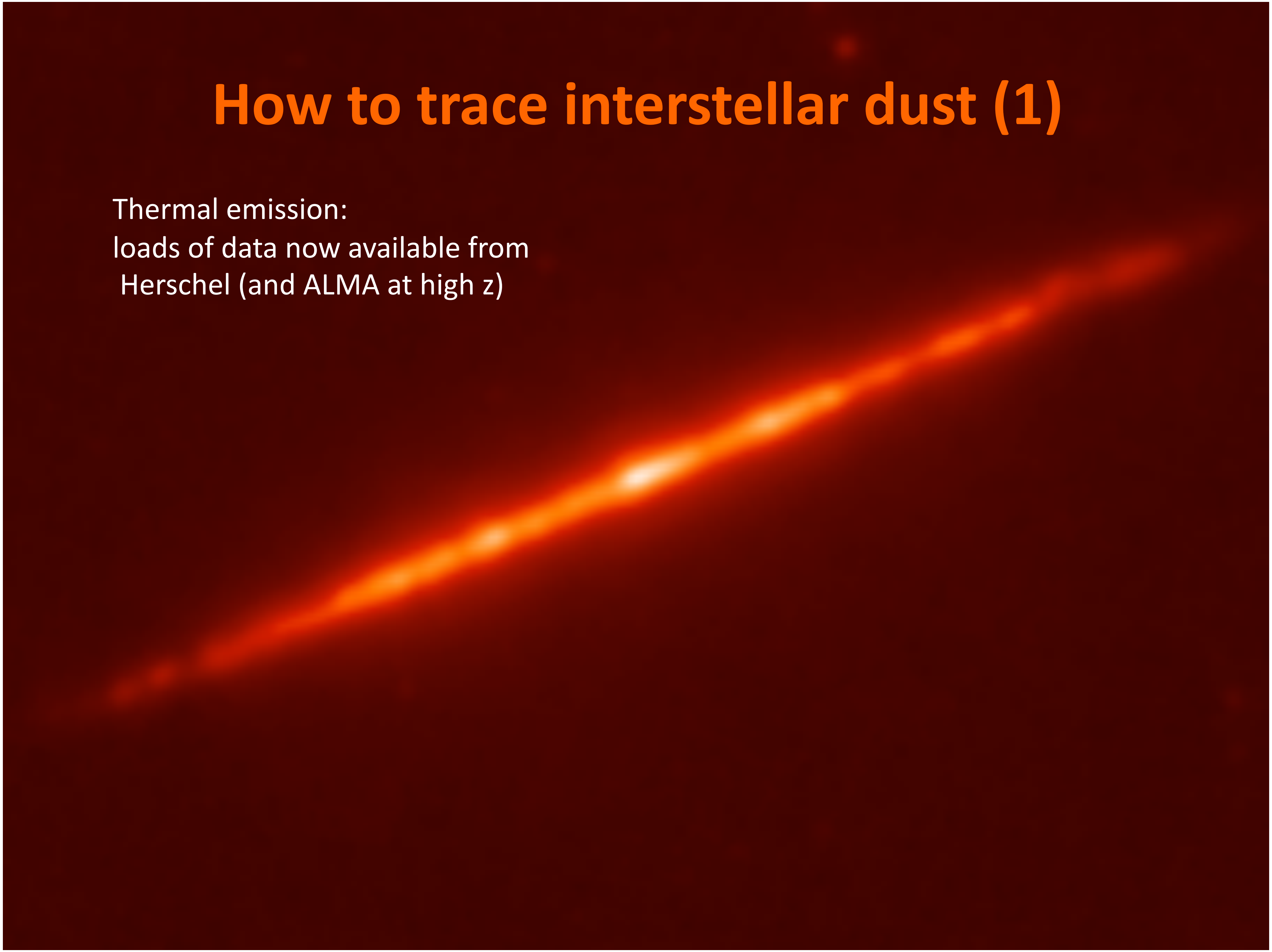
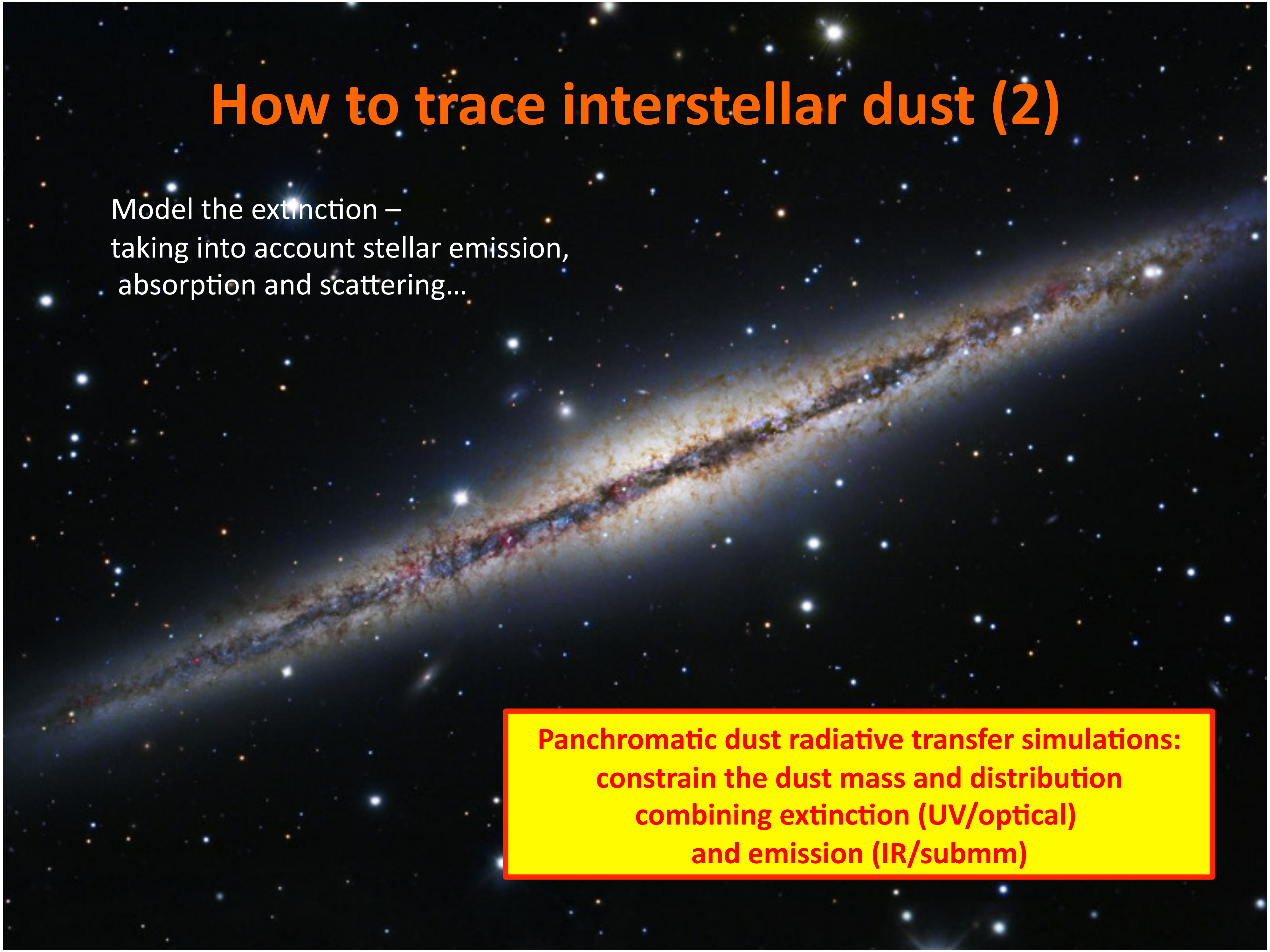
How to trace interstellar dust (1)

Thermal emission:
loads of data now available from
Herschel (and ALMA at high z)



How to trace interstellar dust (2)

Model the extinction –
taking into account stellar emission,
absorption and scattering…



Panchromatic dust radiative transfer simulations: constrain the dust mass and distribution combining extinction (UV/optical) and emission (IR/submm)

www.skirt.ugent.be

Baes et al. 2003, 2011; Camps & Baes 2015

SKIRT

Full treatment of absorption, anisotropic scattering, thermal emission (LTE and NLTE)

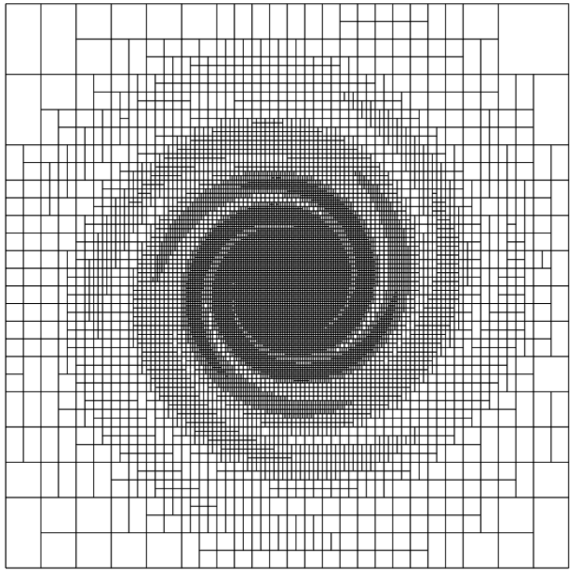
Monte Carlo process strongly optimized using standard and novel techniques.

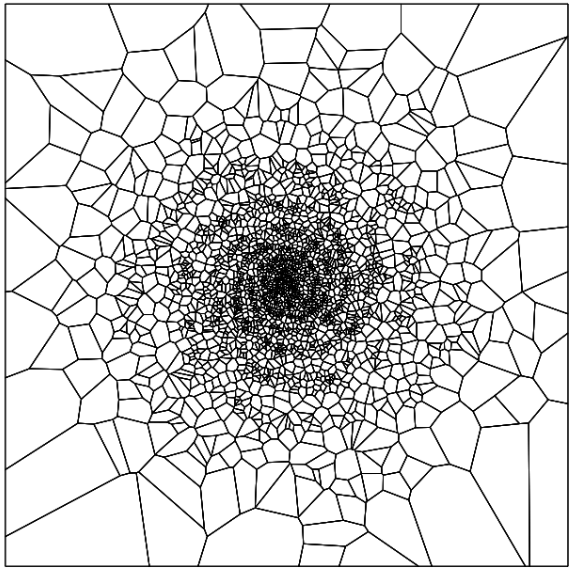
Fully 3D, support arbitrary geometries thanks to advanced grid structures

Large library of components, can directly be coupled to SPH, AMR and moving mesh hydro codes

User- and developer-friendly interface

More about 3D dust radiative transfer in general:
Steinacker, Baes & Gordon 2013, ARA&A





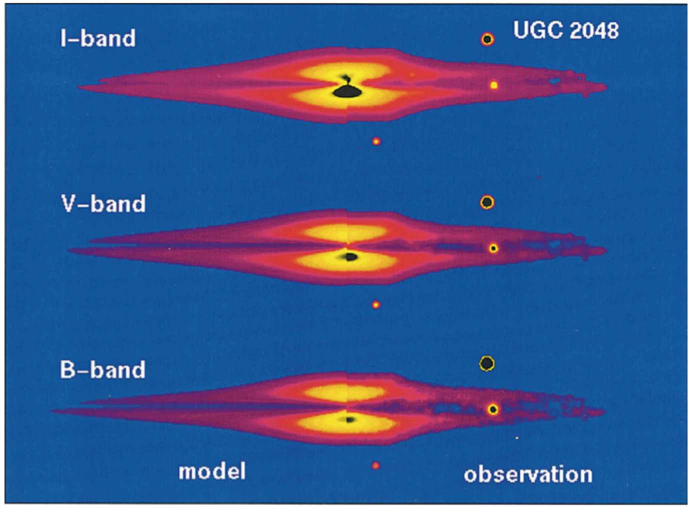
Baes et al. 2003, 2011; Camps & Baes 2015

Edge-on spiral galaxies

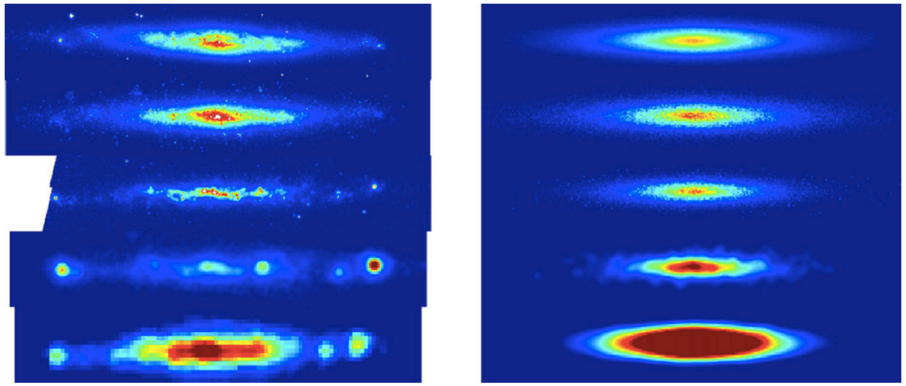
Advantages/disadvantages

- dust clearly seen in extinction (UV/optical) and emission (FIR)
- direct information on the vertical structure
- "simple" enough to create a model with a reasonable number of parameters (details on the distribution are washed out)

Edge-on spirals: favorite targets for radiative transfer modellers !



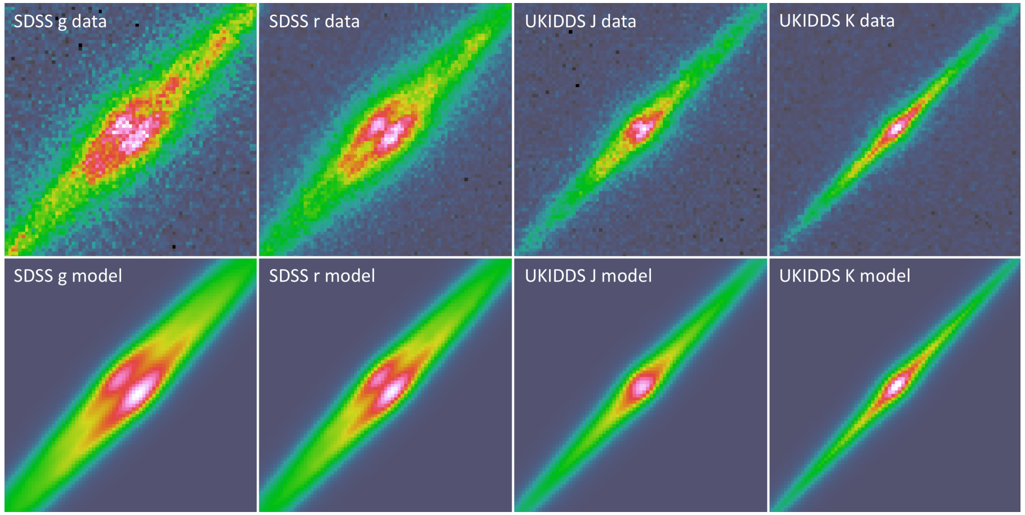
Xilouris et al. 1997



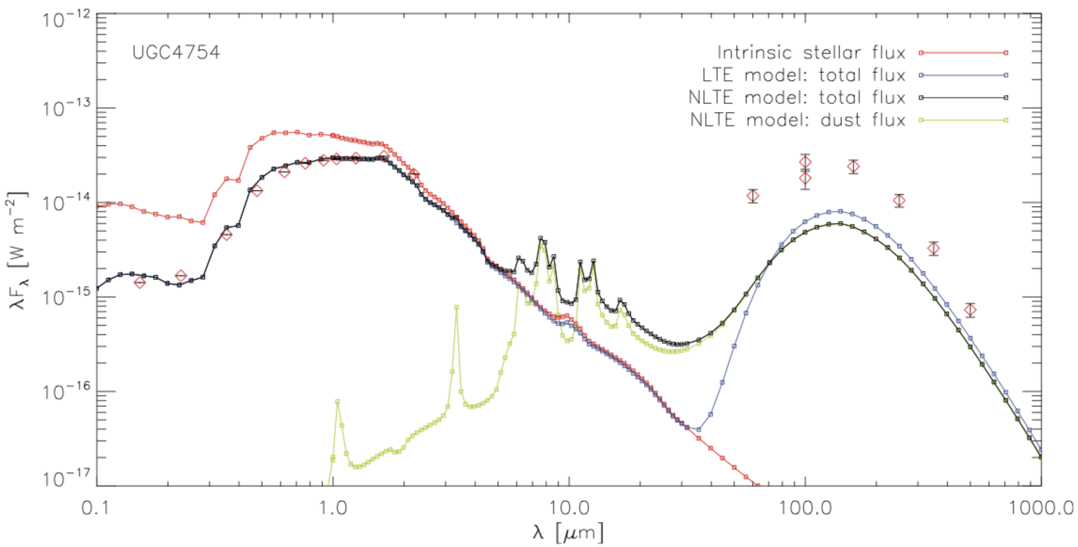
MacLachlan et al. 2011

See also Popescu+ 2000, 2011; Alton+ 2004; Bianchi 2007, 2008; Schechtman-Rook+ 2012, De Looze+ 2012…

Dust energy balance: UGC 4754



The dust "seen" in the optical (i.e. needed to explain the optical extinction) underestimates the FIR/submm emission by a factor 3-4.



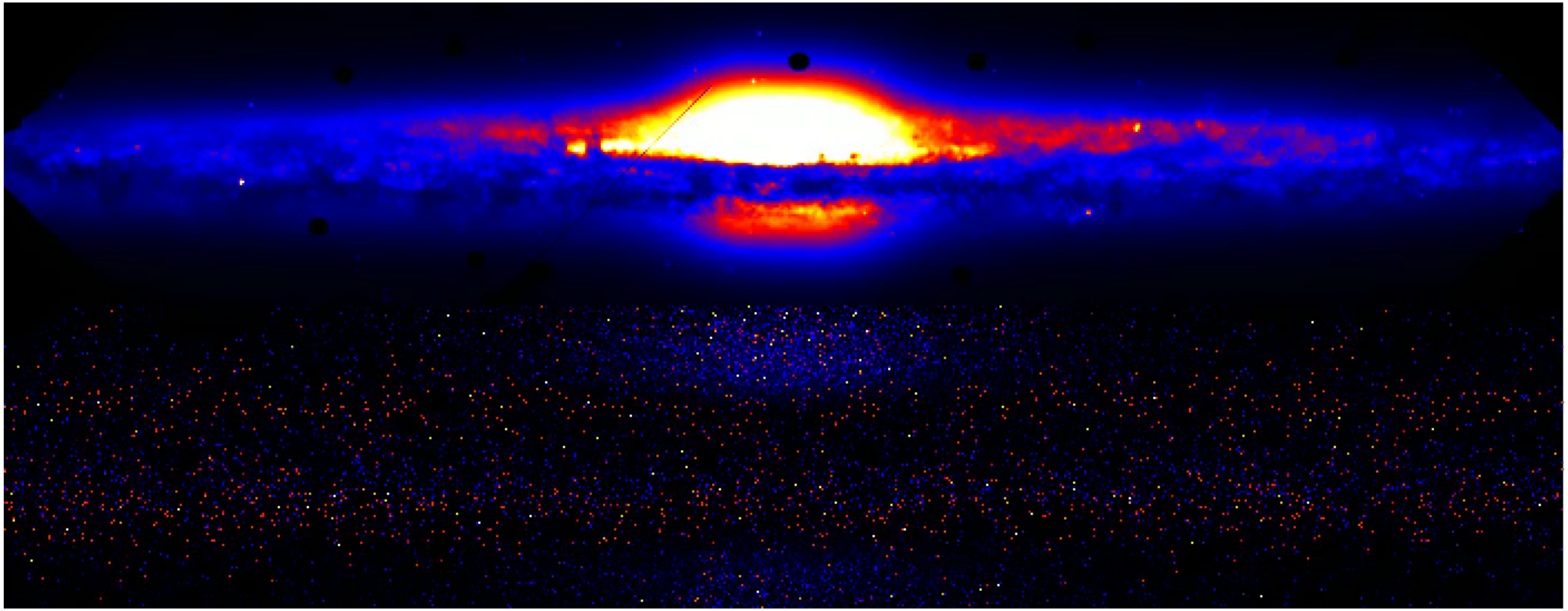
Baes et al. 2010, 2011

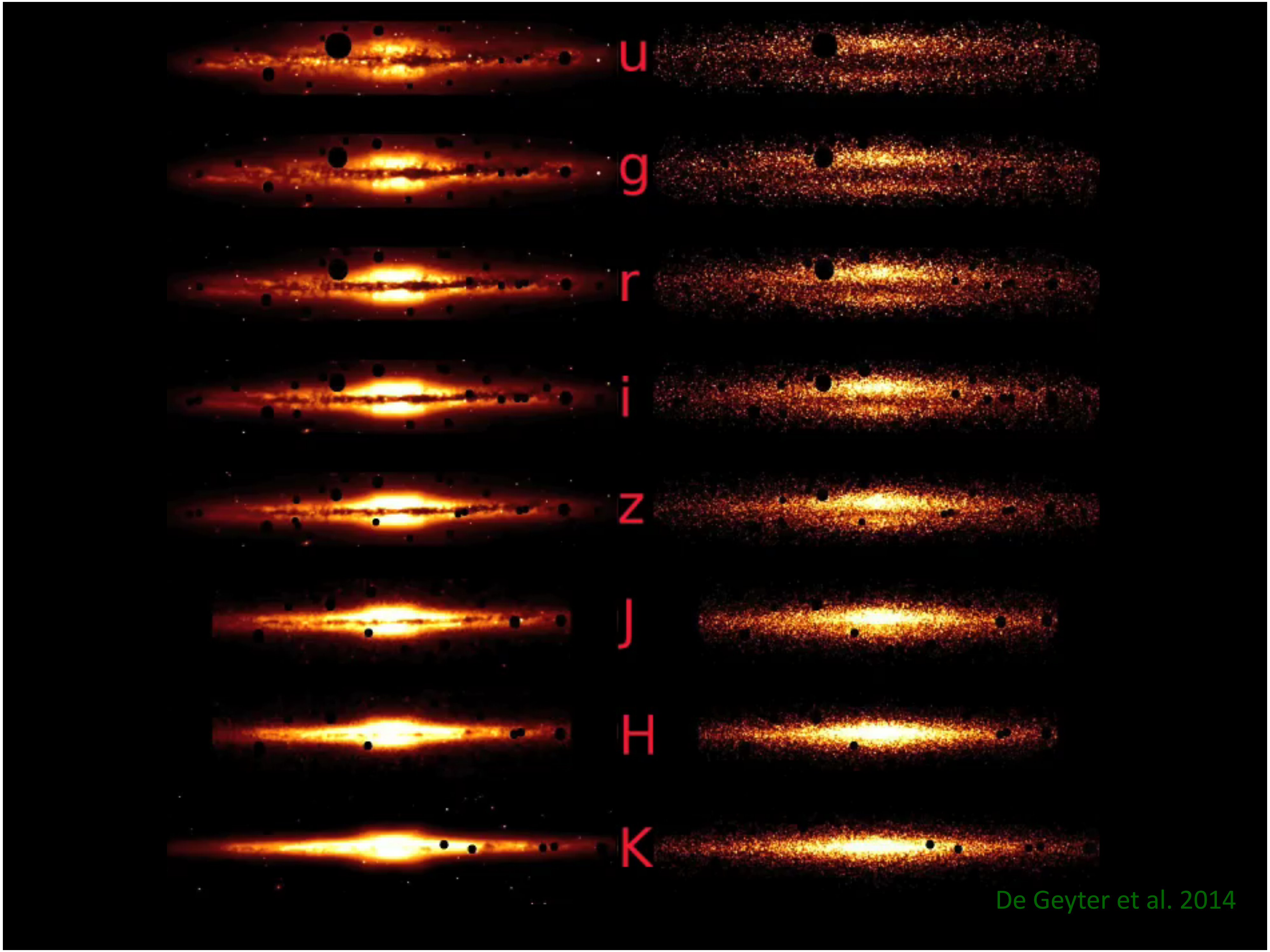
FitSKIRT

Tool to fit parametric 3D models to a set of UV/optical/NIR images.

- couples the SKIRT radiative transfer code to a genetic algorithm optimization routine
- (almost) fully automated and unbiased

De Geyter et al. 2013





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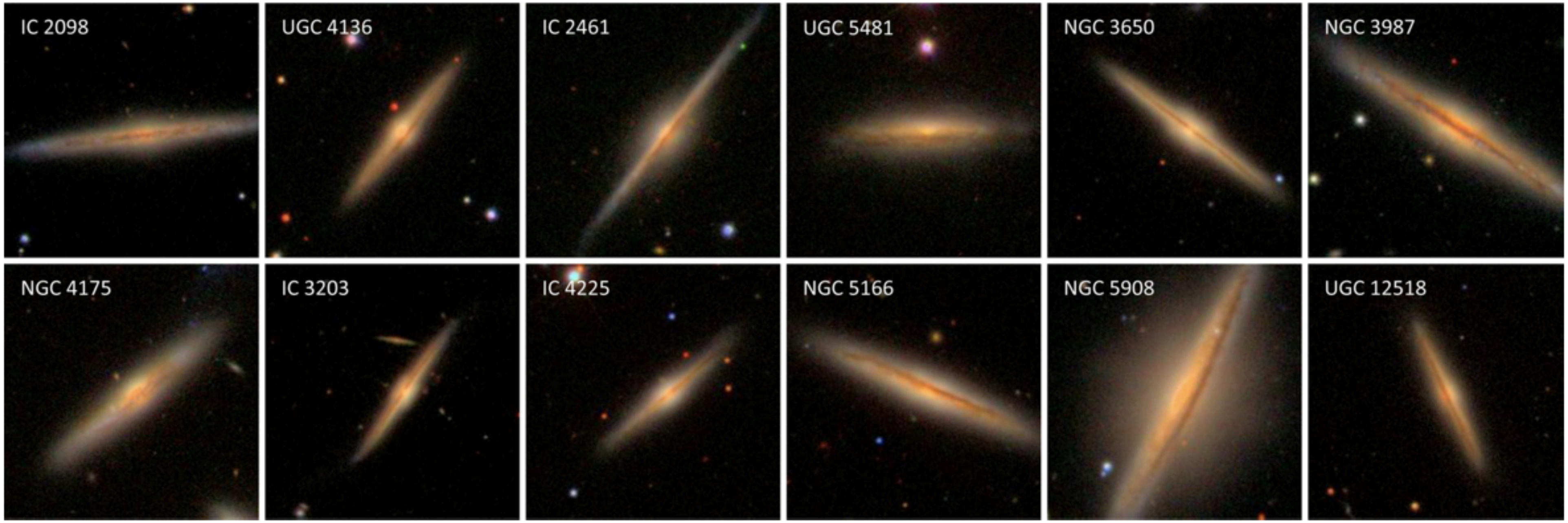
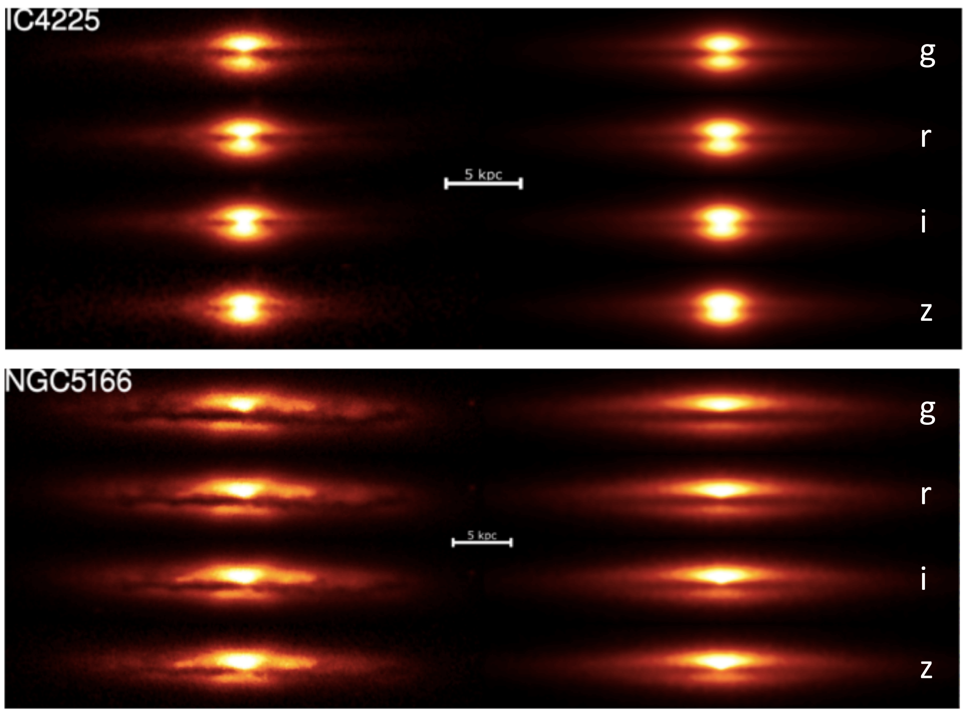
De Geyter et al. 2014





observed FitSKIRT fit

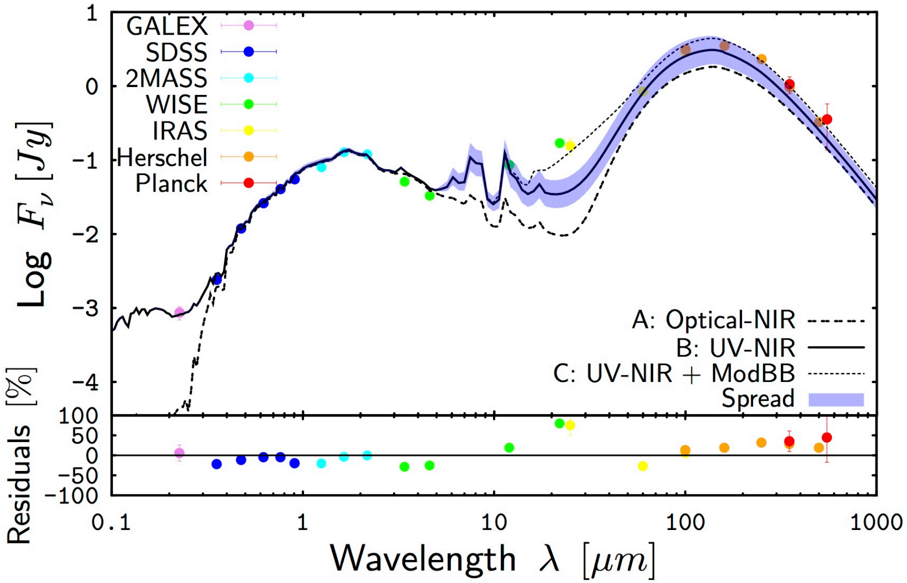
Sample of 12 edge-on spiral galaxies from CALIFA survey: 10 could be accurately reproduced.

Models agree largely with previous results for individual galaxies

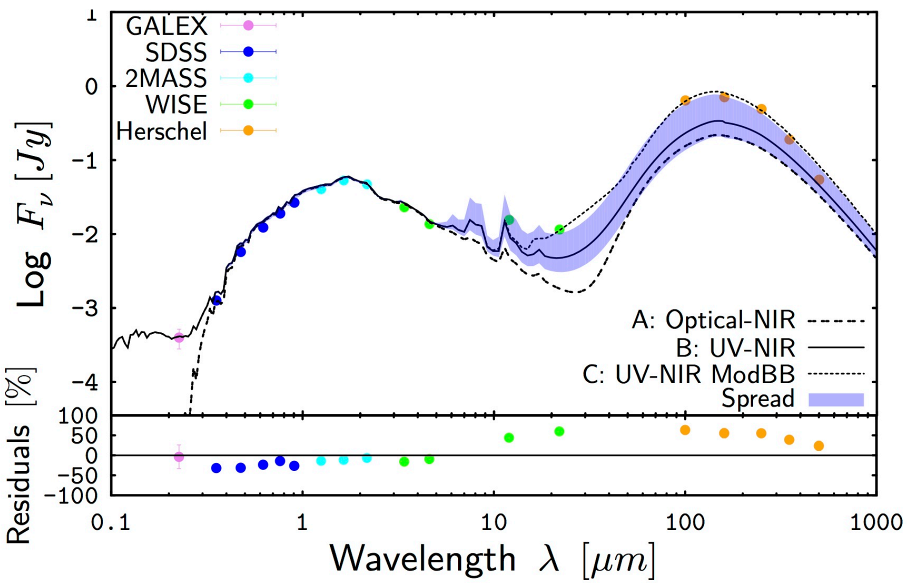
- large spread within sample for face-on optical depth
- dust disks about 70% more extended than stellar disks

De Geyter et al. 2014

Dust energy balance revisited



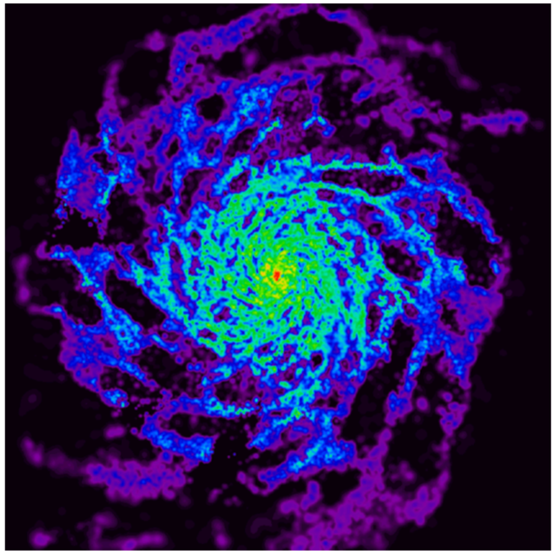
NGC 5166: radiative transfer model predicts the SED (and the images from UV to submm) fairy well

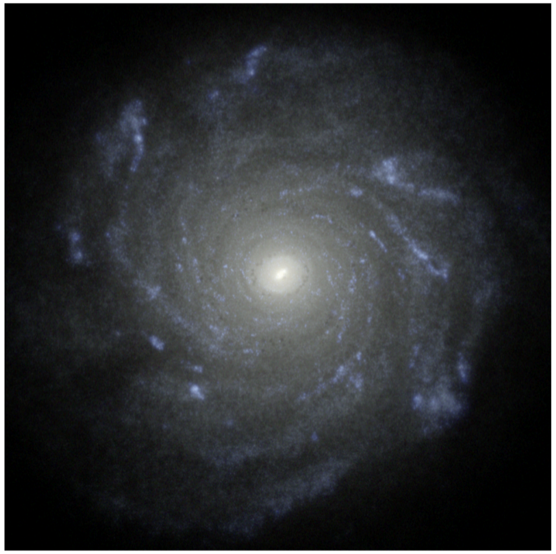


IC 4225: dust energy balance problem: FIR fluxes underestimated by a factor of about three !

De Geyter et al. 2015

Dust energy balance problem





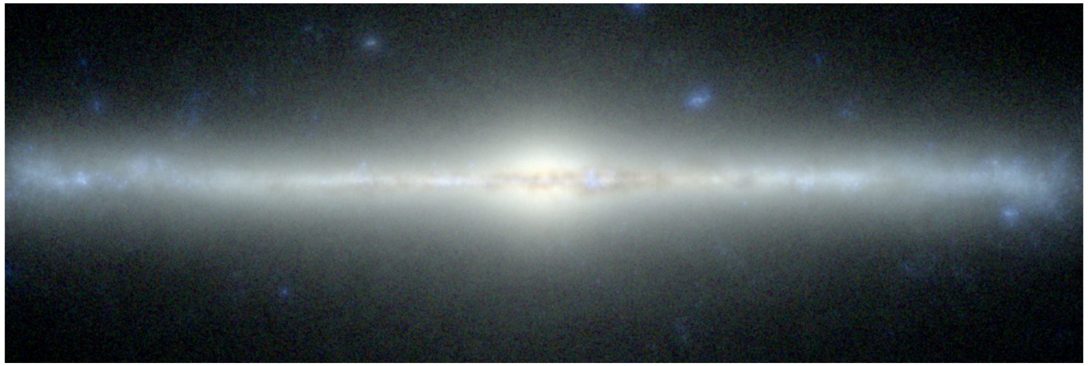
Due to an underestimation of the dust emissivity at FIR/submm wavelengths? **NO**

Due to small/large-scale structure ?

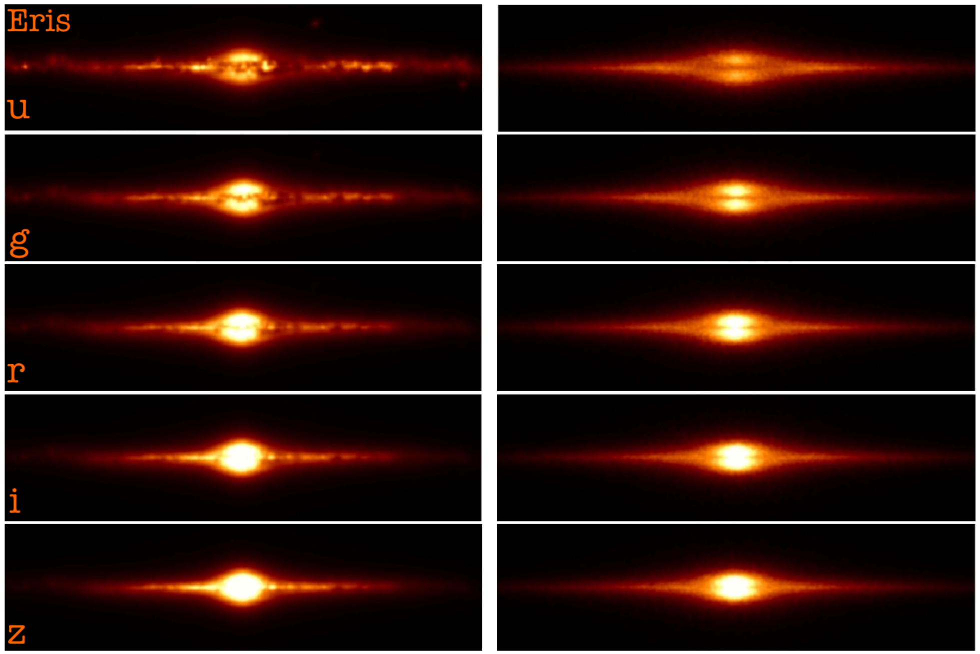
- take a realistic spiral galaxy model
- create mock edge-on images
- fit radiative transfer models to these images using FitSKIRT
- compare input and output dust masses

Saftly et al. 2015

Dust energy balance problem



Saftly et al. 2015



mock observation FitSKIRT fit

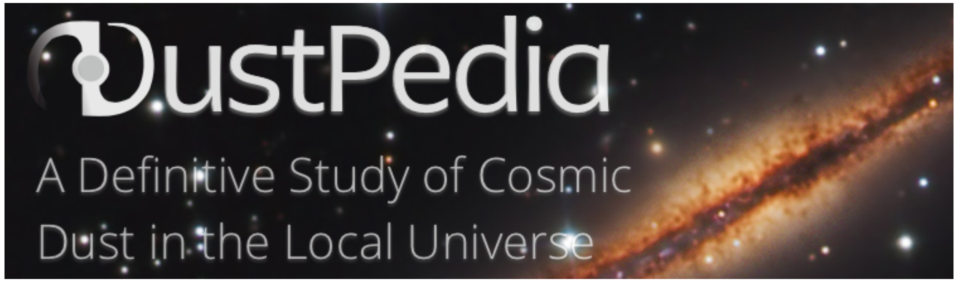
Result: "observed" dust mass underestimates the "true" dust mass by a factor of about three...

Small and large-scale structure might help to explain the dust energy balance problem in edge-on spiral galaxies.

RT modeling of face-on galaxies

Advantages/disadvantages

- attenuation hard to quantify
- assumptions need to be made about the vertical structure
- small- and large-scale structure can be taken into account
- many (large) galaxies with excellent data sets available



~100 large galaxies with

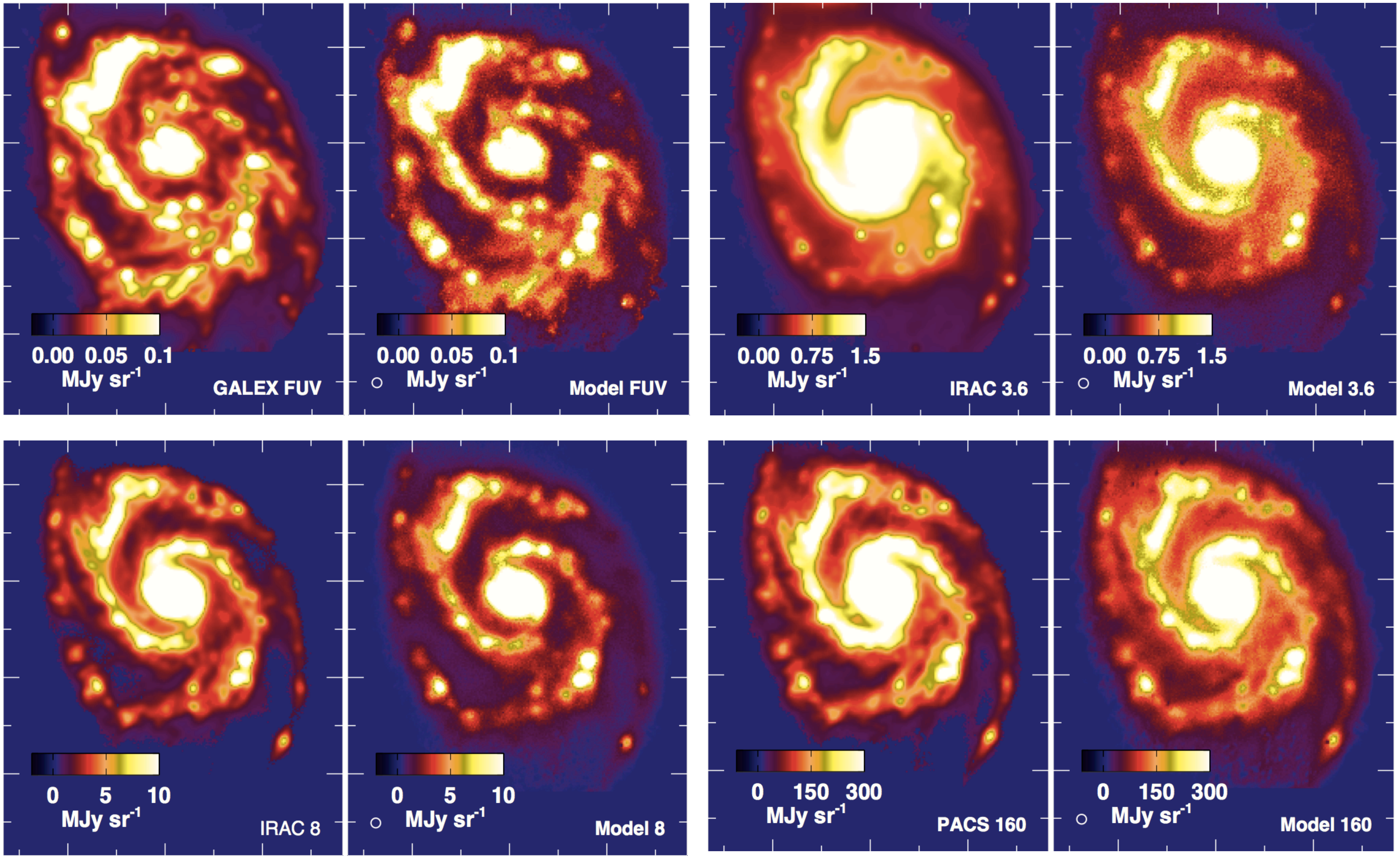
- D_{25} > 5 arcmin
- multi-wavelength imaging (including Herschel)

Framework to model face-on spiral galaxies

- several stellar components, each one based on deprojected images
- dust distribution based on FUV attenuation

GALEX FUV – young stars

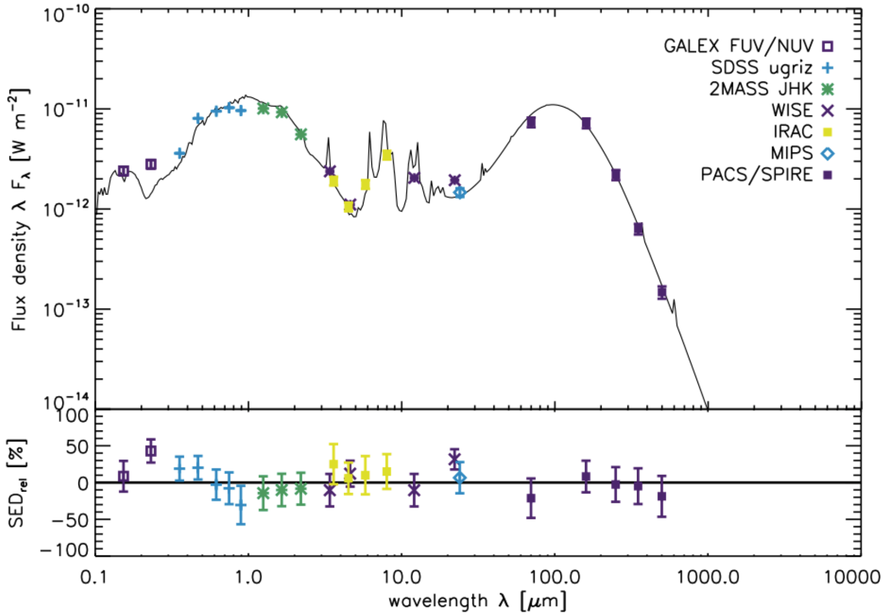
IRAC 3.6 µm – evolved stars



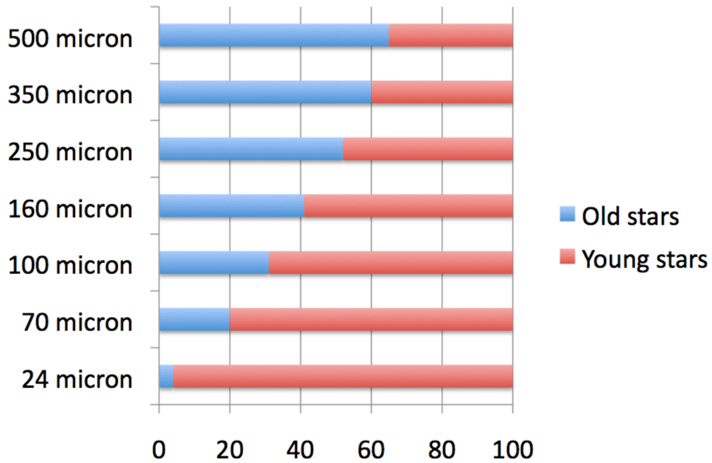
IRAC 8 µm – hot dust

PACS 160 µm – cool dust

RT model of M51



Dust emission from the model agrees with the observed FIR SED. No dust energy balance problem.



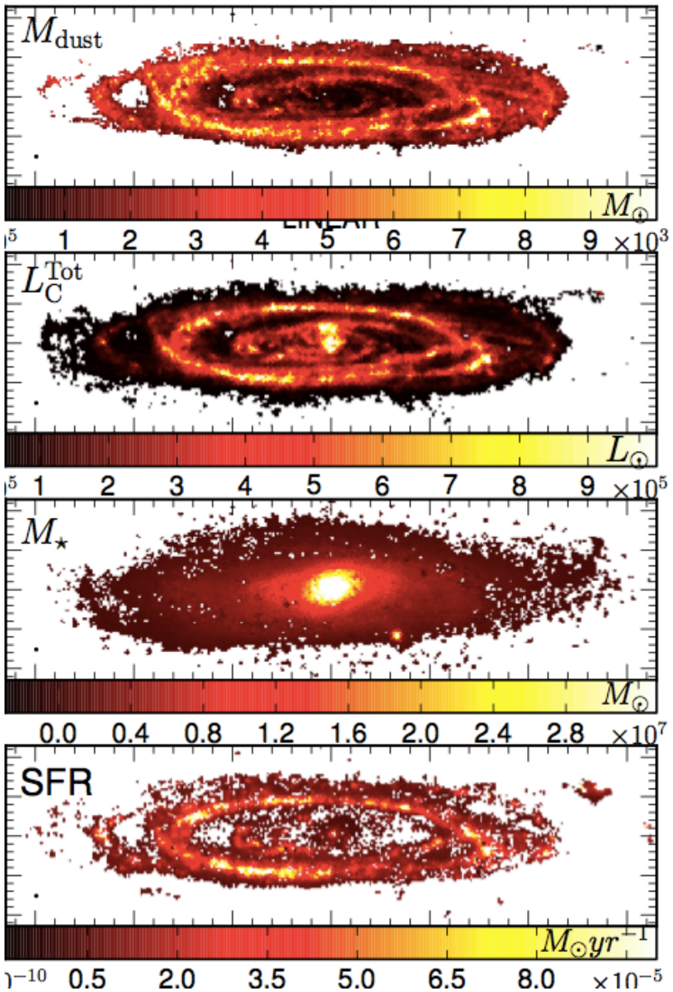
Global dust heating is dominated by young stellar populations, but old stars do contribute substantially as well (37%).

De Looze et al. 2014

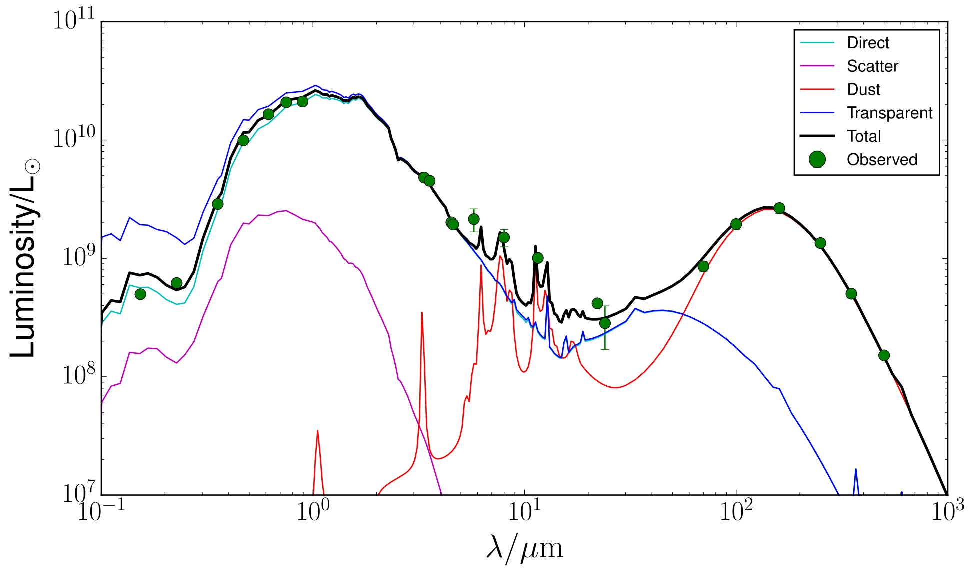
See talk by
Matt Smith

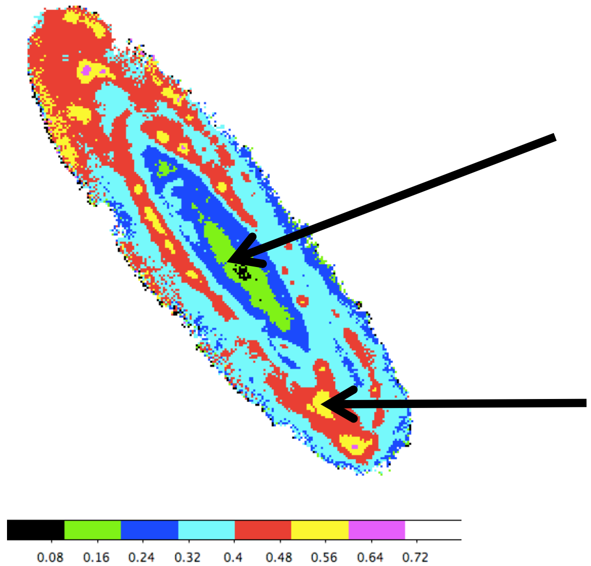
Fritz et al. 2012
Smith et al. 2012
Viaene et al. 2014

RT model of M31



Viaene et al. 2014





Heating by evolved stars

Heating by young stars

Viaene et al., in prep

Summary

1. Panchromatic radiative transfer modeling is a powerful technique to explore the dust mass, distribution and heating sources.

2. 3D dust RT: not straightforward, but significant progress on different areas (computing power, algorithms,…).

3. Edge-on spiral galaxies
   - full, unbiased fitting to images is possible
   - dust energy balance problem in some galaxies, in others not…
   - large and small-scale structure seems to be capable to “hide” dust in edge-on galaxies.
   - more systematic modeling is ongoing…

4. Face-on spiral galaxies
   - so far, no dust energy balance problem encountered
   - evolved stellar populations not negligible as heating sources
   - more systematic modeling is ongoing…