Astrophysics and High Performance Computing

Andreas Efstathiou

European University Cyprus

Introduction

- Three main types of activity in galaxies: star formation in quiescent disk galaxies, bursts of star formation in starbursts and accretion of matter onto a supermassive black hole (active galactic nuclei or AGN).
- All three processes associated with a lot of gas.
- Gas is associated with a small amount of material (~1%) in solid form (dust) which is much more opaque than gas.
- Dust absorbs the optical and ultraviolet radiation and re-emits in the infrared (1-1000μm)
- We therefore need observations of galaxies from 0.1-1000μm and radiative transfer models for their emission in order to interpret the observations

History of Infrared Astronomy

- First infrared observations in 1965
- Launch of Infrared Astronomical Satellite (IRAS) in 1983
- Infrared Space Observatory (ISO) in 1995
- SCUBA at the JCMT in 1996
- Spitzer space telescope in 2003
- AKARI in 2006
- Herschel in 2009
- ALMA in 2011
- JWST in 2015?
- SPICA in 2018?

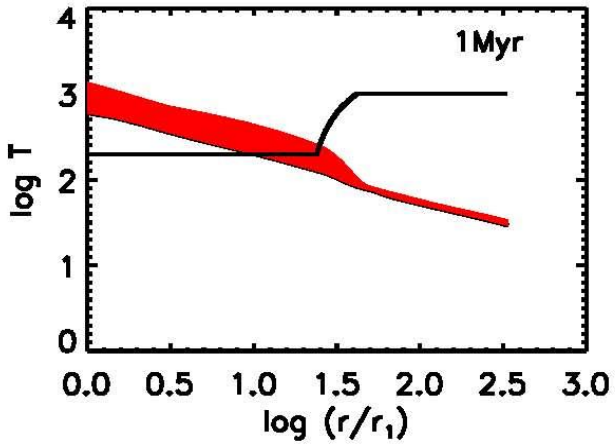
Radiative transfer models

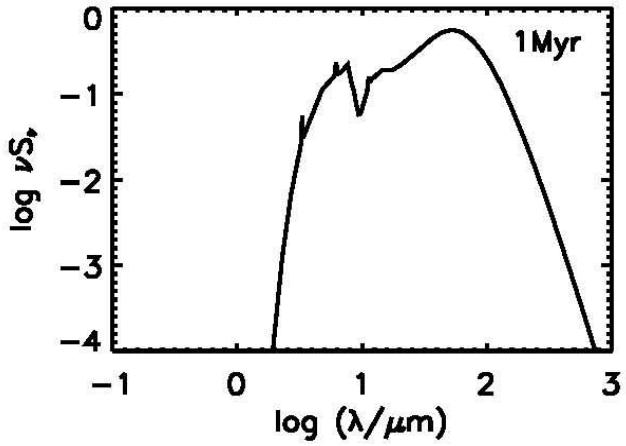
- Radiative transfer in a dusty medium is described by an integro-differential equation
- Solution must take into account absorption, scattering and re-emission by dust grains
- Two different methods of solution have been applied: Ray-tracing and Monte Carlo
- First spherically symmetric radiative transfer models were developed in the mid-70s
- First axisymmetric (2D) radiative transfer models in the early 90s
- We now have fully 3-D models

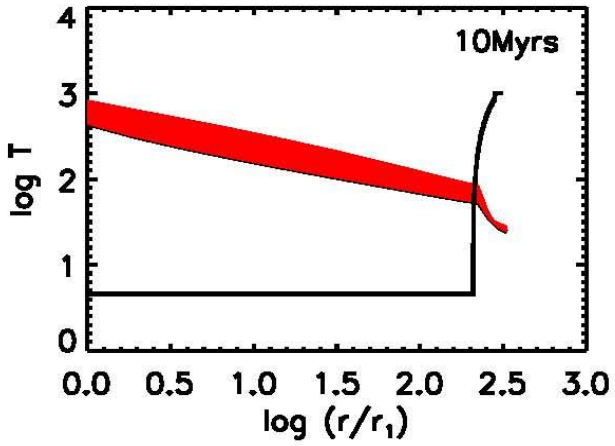
Starburst model of Efstathiou, Rowan-Robinson & Siebenmorgen (2000)

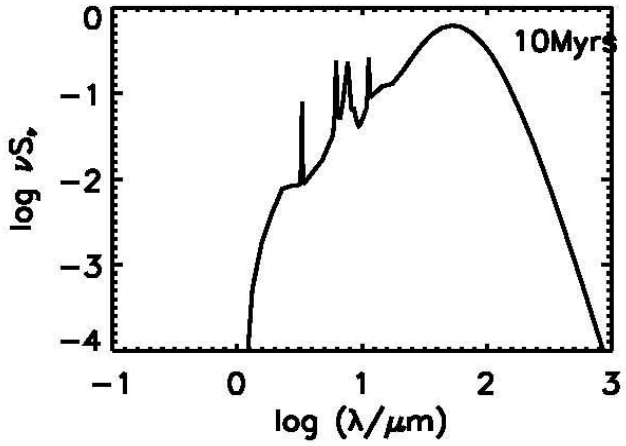
- Incorporates the stellar population synthesis model of Bruzual & Charlot that gives the spectrum of the stars as a function of their age
- Radiative transfer that includes the effect of small grains/PAHs (Siebenmorgen & Krugel)
- Simple model for the evolution of giant molecular clouds that constitute the starburst

Evolution of the spectrum of a giant molecular cloud

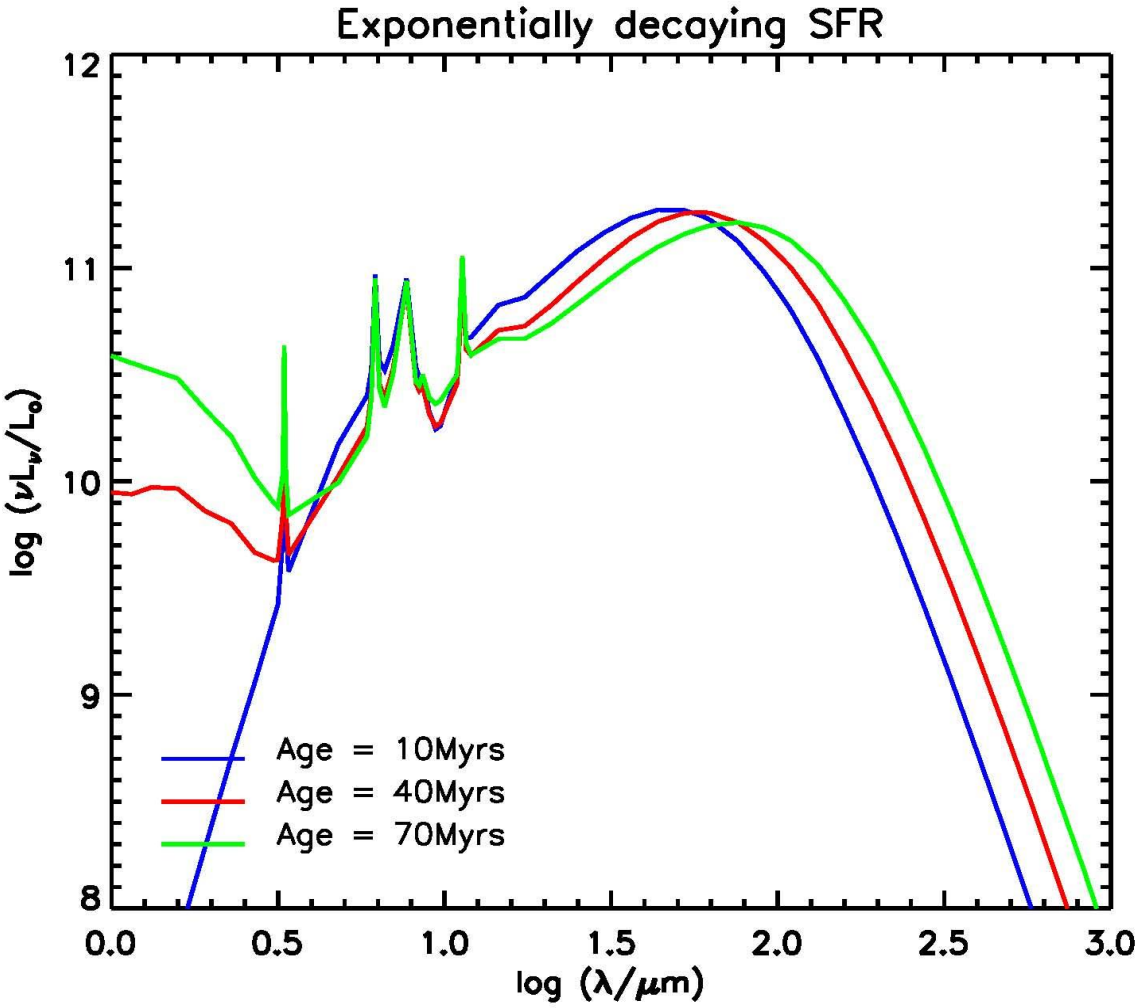




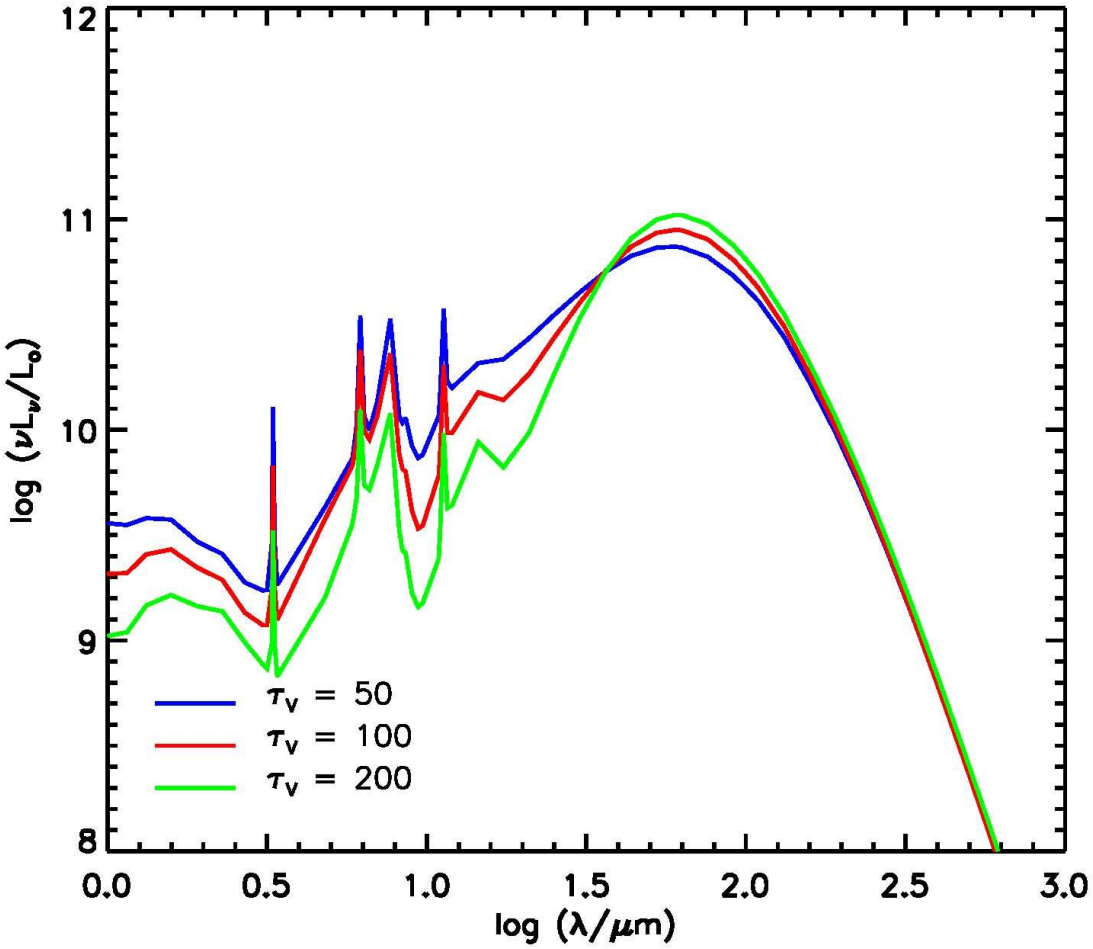




Effect of changing the age of a starburst



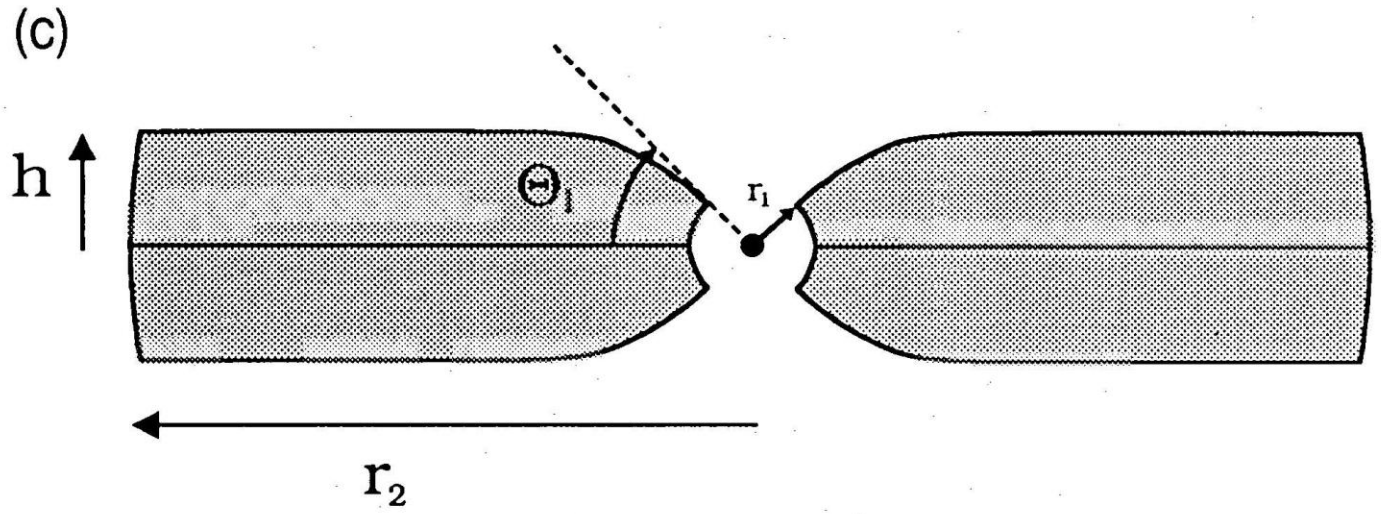
Effect of changing the optical depth of a starburst

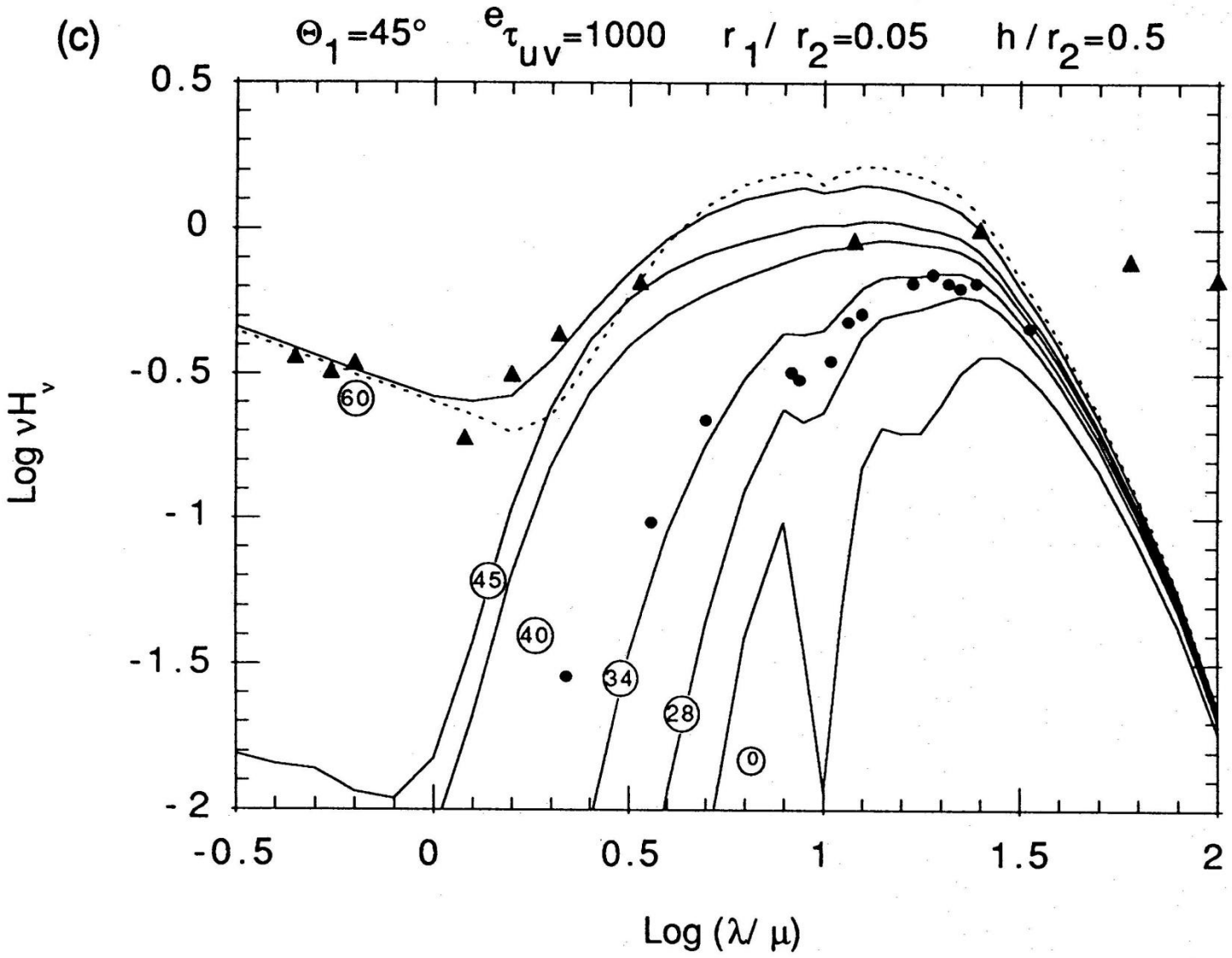


Challenge #1

- Because of rotation, stellar winds and supernovae we expect significant deviations of star-forming clouds from spherical symmetry
- Run the whole time sequence of Efstathiou et al. models in 2-D
- We need ~ 3000 hours

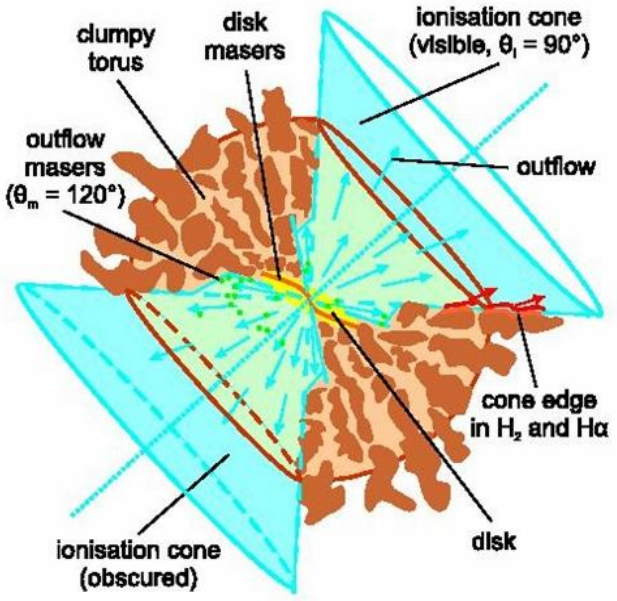
AGN torus model of Efstathiou & Rowan-Robinson (1995)



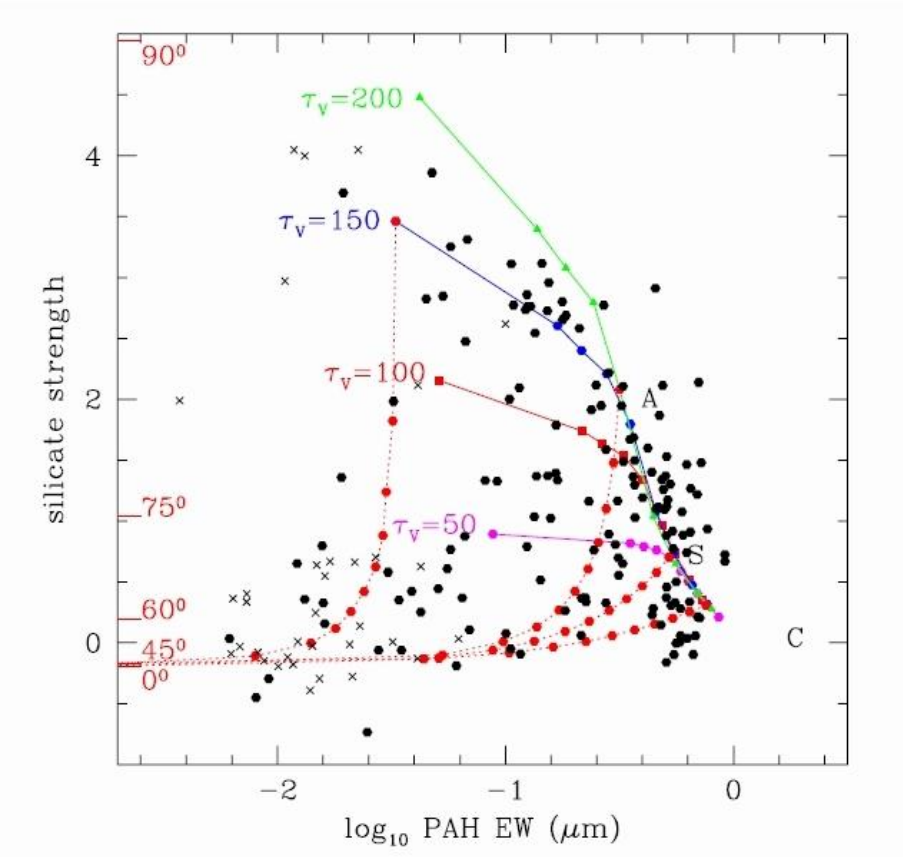

(c)
Θ1=45°
eτuv=1000
r1/ r2=0.05
h / r2=0.5
0.5
0
-0.5
-1
-1.5
-2
Log νHν
-0.5
0
0.5
1
1.5
2
Log (λ/ μ)
60
45
40
34
28
0

Challenge #2

- There are good observational and theoretical arguments that the dust distribution in the AGN torus is clumpy
- Run a grid of clumpy torus models using a Monte Carlo code
- ~ 1000 hours



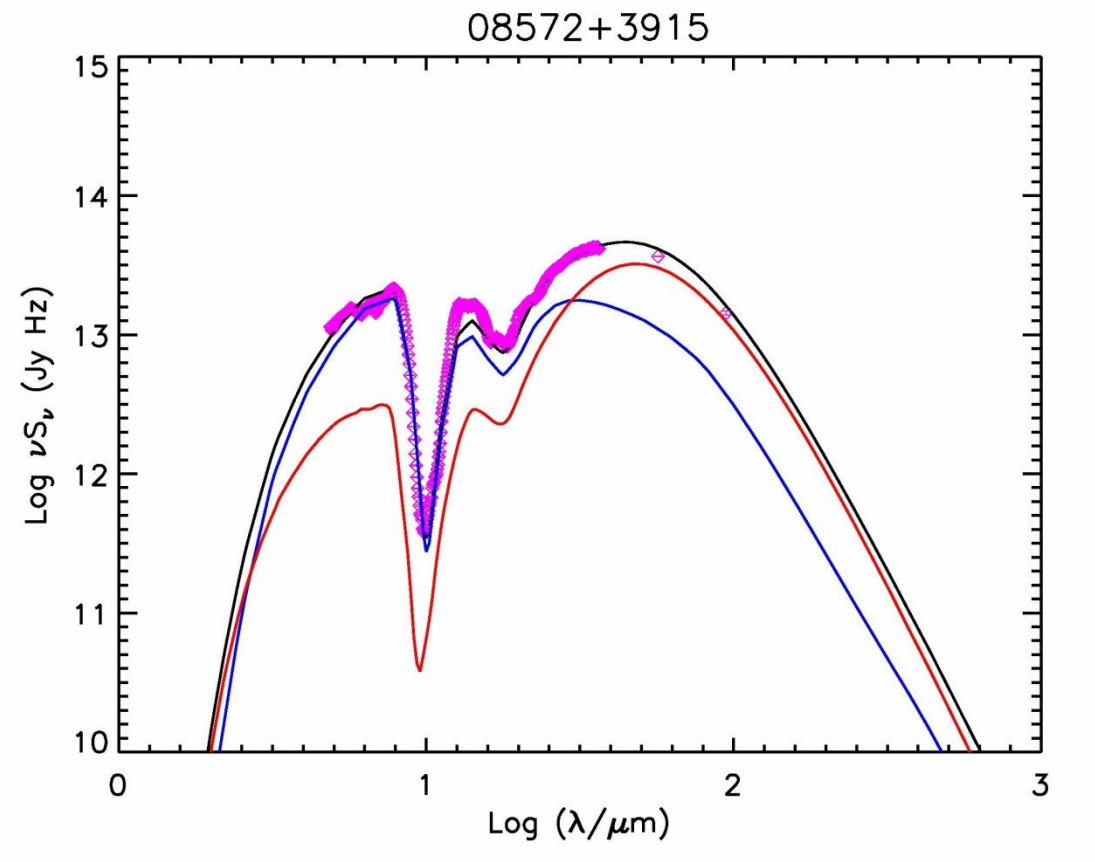
Modelling the Spoon diagram
Rowan-Robinson & Efstathiou (2009)



Herschel ULIRG Survey

- Largest extragalactic open time project that is carried out with the Herschel space telescope (250 hours)
- Survey of ~ 40 ultraluminous infrared galaxies (ULIRGs) in spectroscopic and photometric mode
- Aim to understand the nature of these galaxies which are believed to be the result of a merger of two large spiral galaxies

Example of starburst/AGN decomposition



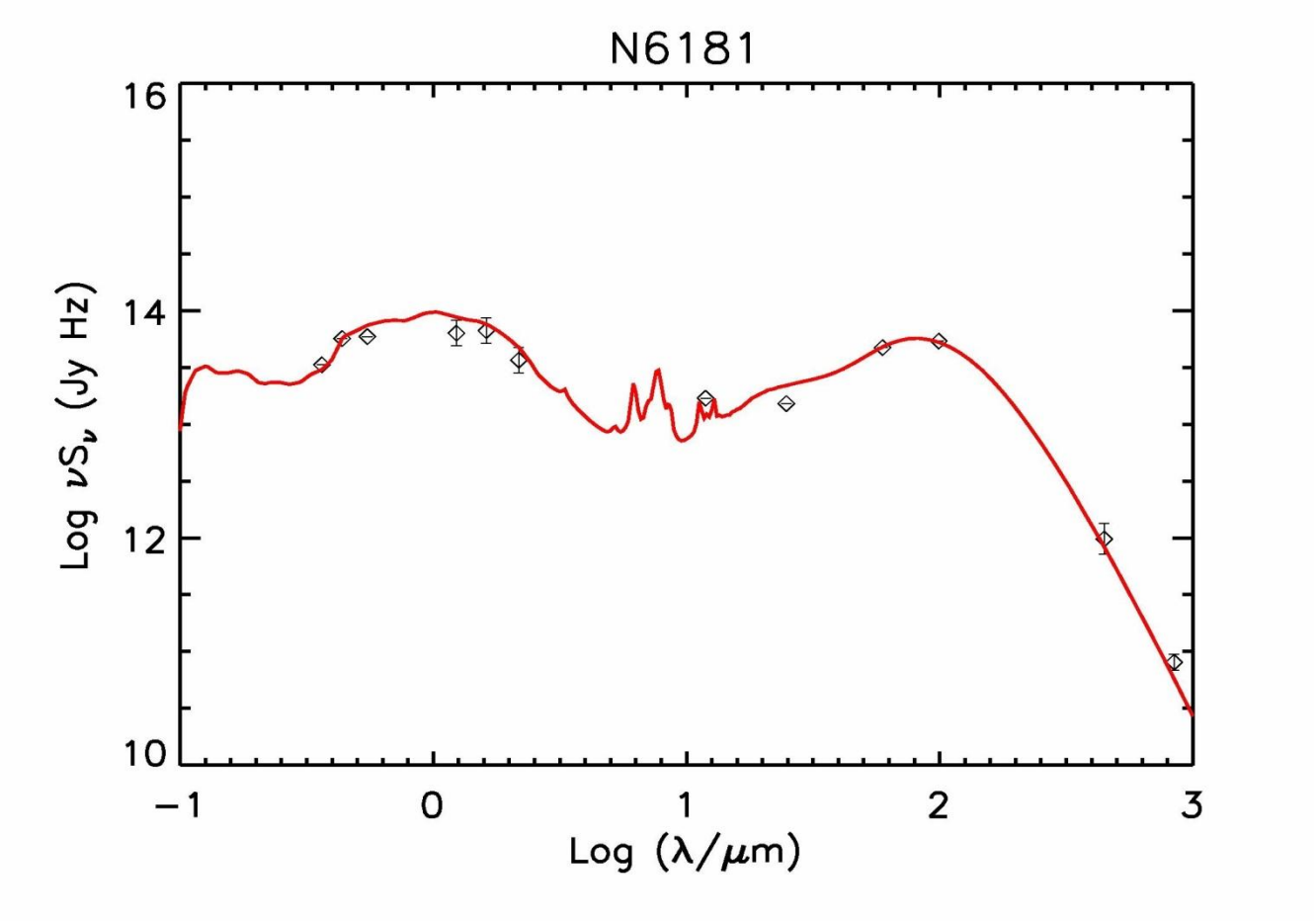
Challenge #3

- Model the ultraluminous infrared galaxies (ULIRGs) that will be observed with the Herschel ULIRG Survey (HERUS) using a combination of starburst and AGN torus models
- This work can further be extended to model all 200 ULIRGs that appear on the Spoon diagram + other samples

Phoenix and fastPhoenix

- A new pair of codes that calculate the ultraviolet to millimetre emission of galaxies
- They incorporate the stellar population synthesis model of Bruzual & Charlot
- They incorporate the starburst model of Efstathiou, Rowan-Robinson & Siebenmorgen
- They incorporate the AGN tapered disc model of Efstathiou & Rowan-Robinson
- Phoenix will run in 1 minute and fastPhoenix in 1s

Phoenix fit to the spectrum of the spiral galaxy NGC6181



Semi-analytic models of galaxy formation

- Models that take into account most of the physics of galaxy formation we know about
- In order to compare with observations we need to take into account the effects of dust
- Most successful attempt to do this is the collaboration of the Durham and Padova groups

Challenge #4

- Incorporate Phoenix or fastPhoenix into the Sussex semi-analytic model of galaxy formation that uses the results of the Millenium simulation.
- Need to run the code ~ 10 x 30 million times which needs ~ 100 years for fastPhoenix and ~ 6000 years for Phoenix