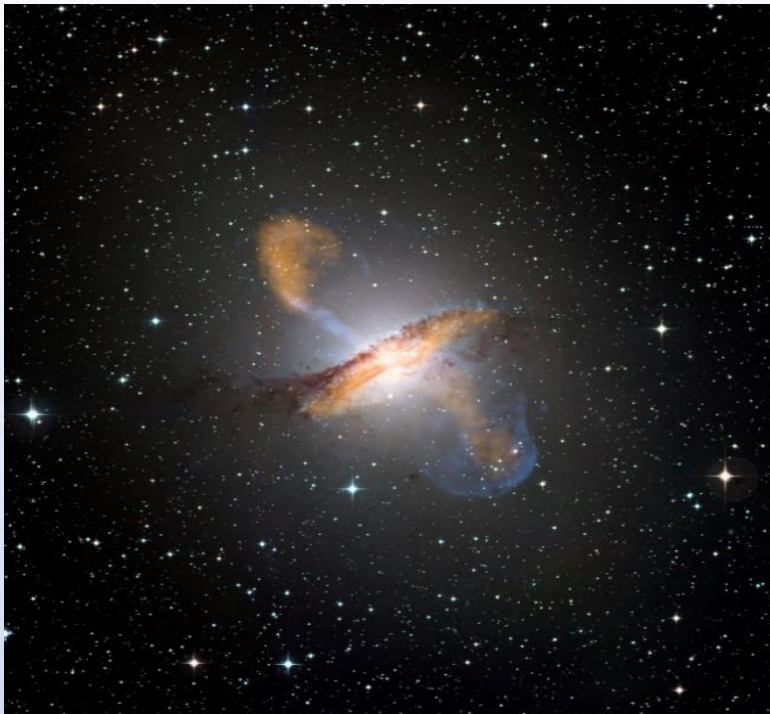




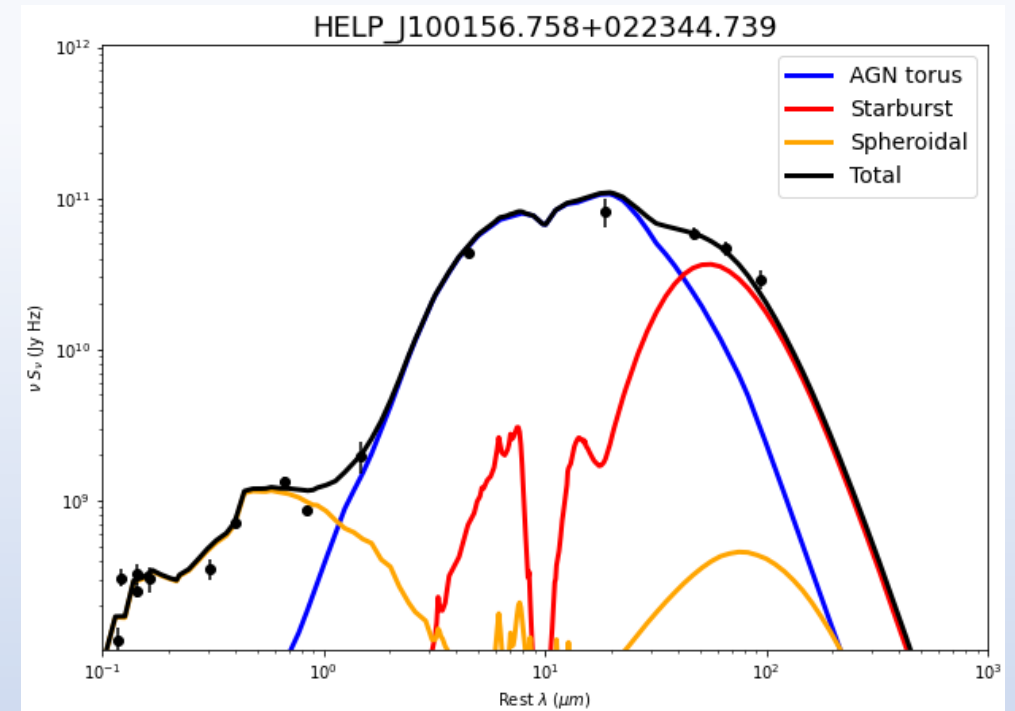
# SMART

Charalambia Varnava

# Two complementary ways of looking at galaxies: Images (*left*) and Spectral Energy Distributions or SEDs (*right*)



*Nearby radio galaxy Centaurus A*



*SED of an obscured hyperluminous quasar  
at  $z \sim 4.3$  (Varnava & Efstathiou, 2024)*

# SMART: Spectral energy distributions Markov chain Analysis with Radiative Transfer models

- Developed a new Markov chain Monte Carlo (MCMC) SED fitting code, **SMART**, which fits SEDs *exclusively* with radiative transfer models. Available at: <https://github.com/ch-var/SMART>
- Takes comparable time to popular SED fitting methods based on energy balance (e.g. CIGALE, Noll et al. 2009; Boquien et al. 2019)
- Can be used to fit the SED of a galaxy at any redshift
- Promises to be very useful for analysing multi-wavelength SEDs of galaxies and obscured active galactic nucleus (AGN) from a number of ground-based and spaceborn facilities, such as:



*SPITZER*  
(IR)



*HERSCHEL*  
(FIR to submillimetre)



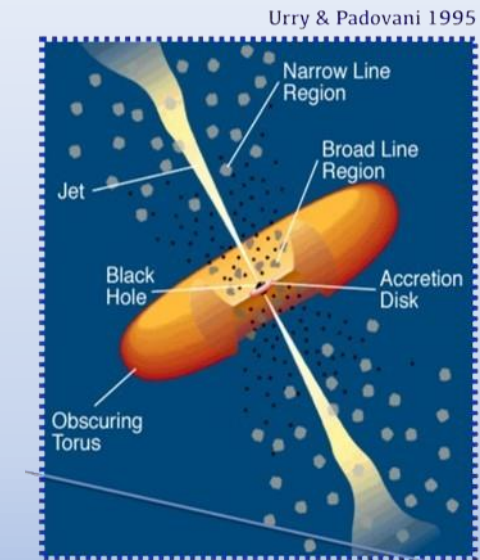
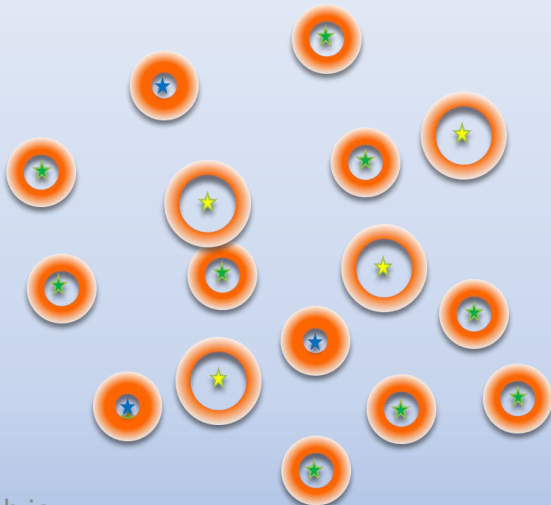
*JWST*  
(optical to MIR)

# Novel Features of SMART

1. More physically motivated and versatile compared to popular energy balance methods, such as CIGALE (Noll et al., 2009; Boquien et al., 2019) and MAGPHYS (da Cunha et al., 2008), that do not take properly into account the effects of dust in a realistic geometry
2. The code is parallelized and considerably faster than other MCMC codes, such as SATMC
3. Makes use of four different types of pre-computed AGN torus libraries, as in Efstathiou et al. (2022)
4. As in Efstathiou et al. (2022), can optionally add a component of polar dust in the fitting
5. Designed to fit an SED in comparable time with a spheroidal or disc host galaxy model
6. Can fit part of a galaxy and, if necessary, switch off any of the four components (AGN torus, starburst, spheroidal/disc, polar dust)
7. Can fix any of the model parameters

# Description of SMART

- Developed a new method for fitting radiative transfer models to data, using an MCMC code
- As an MCMC sampler it utilizes the publicly available *emcee* code (Foreman-Mackey et al., 2013)
- Fits the ultraviolet to submillimetre SEDs *exclusively* with radiative transfer models that currently constitute four types of pre-computed libraries:
  - Starburst (Efstathiou et al., 2000; Efstathiou & Siebenmorgen, 2009)
    - independent of redshift
  - AGN torus
    - independent of redshift





# Description of SMART

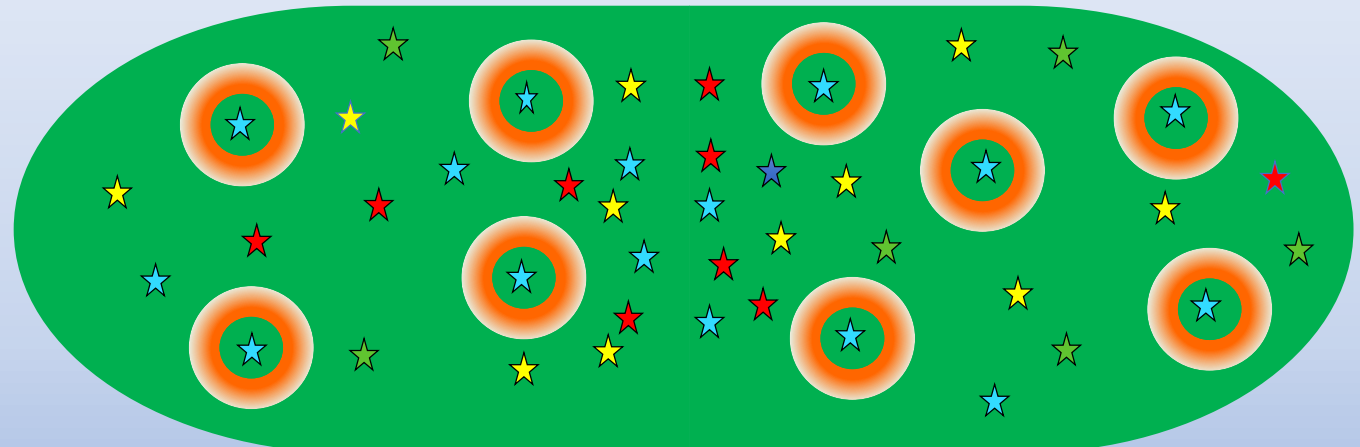
- AGN polar dust (Efstathiou et al., 1995)
  - independent of redshift
  - optionally incorporated in **SMART**



- Spheroidal (Efstathiou et al., 2021)
  - dependent on redshift

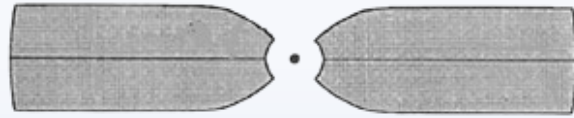


- Disc (Efstathiou et al., in preparation)
  - dependent on redshift



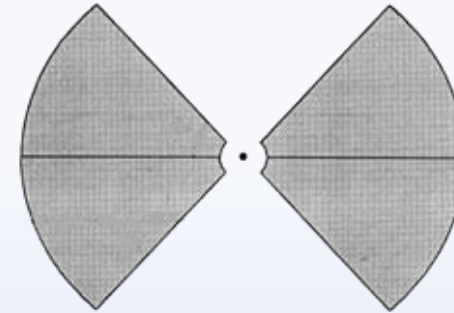
# Description of SMART

- Allows us to explore the impact of four different AGN torus models and therefore constrain the properties of the obscuring torus:

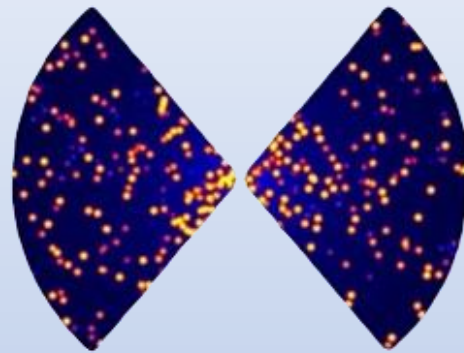


CYGNUS

(Efstathiou & Rowan-Robinson, 1995)

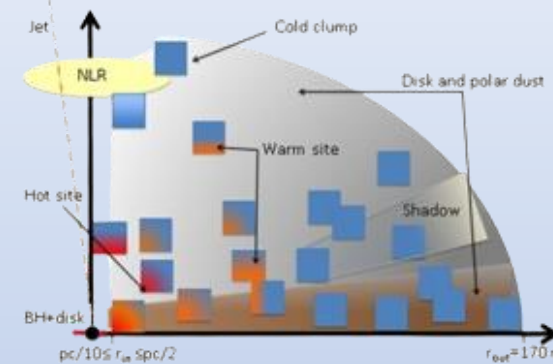


Fritz et al. (2006)



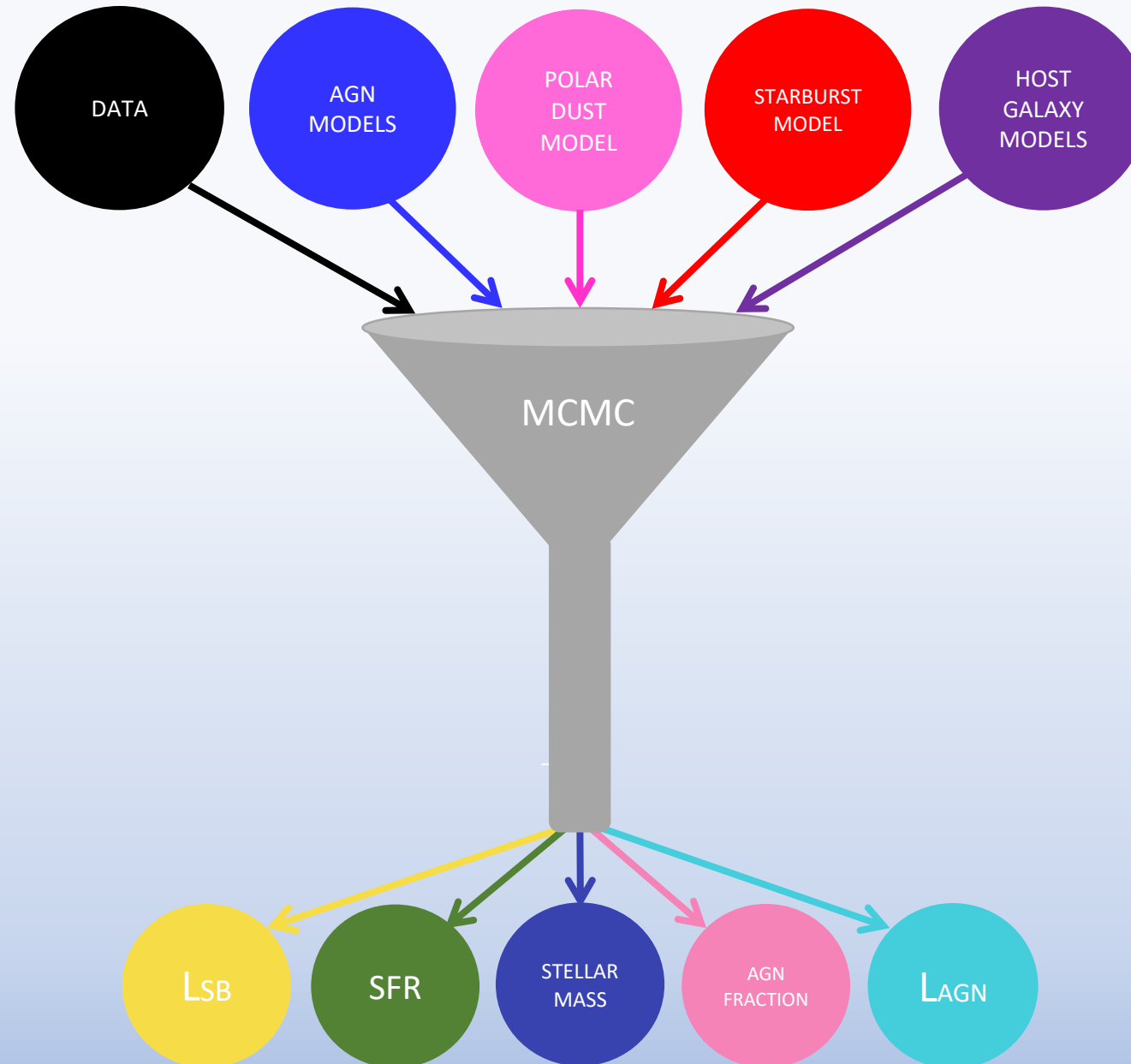
SKIRTOR

(Stalevski et al., 2016)



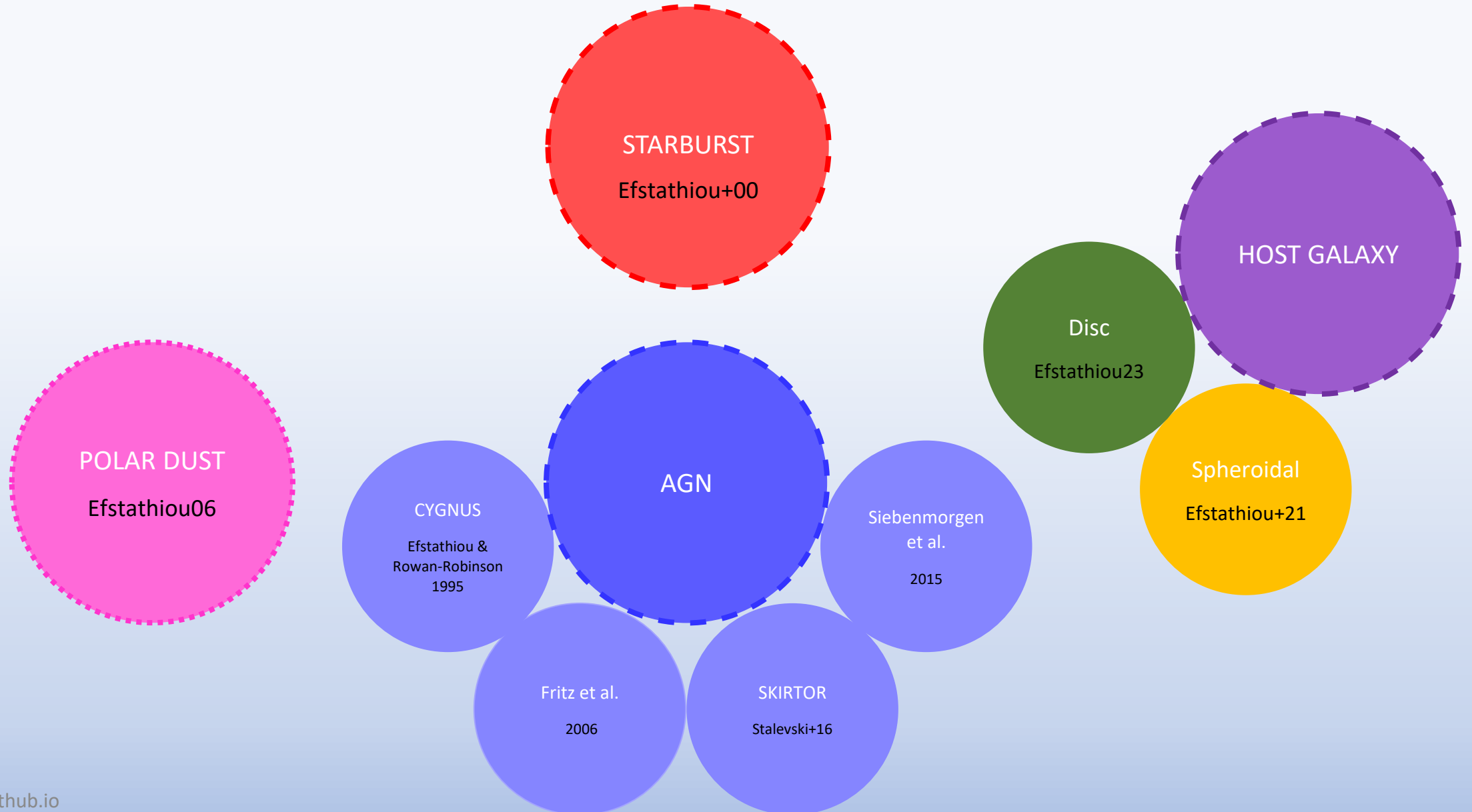
Siebenmorgen et al. (2015)

# The SMART Method

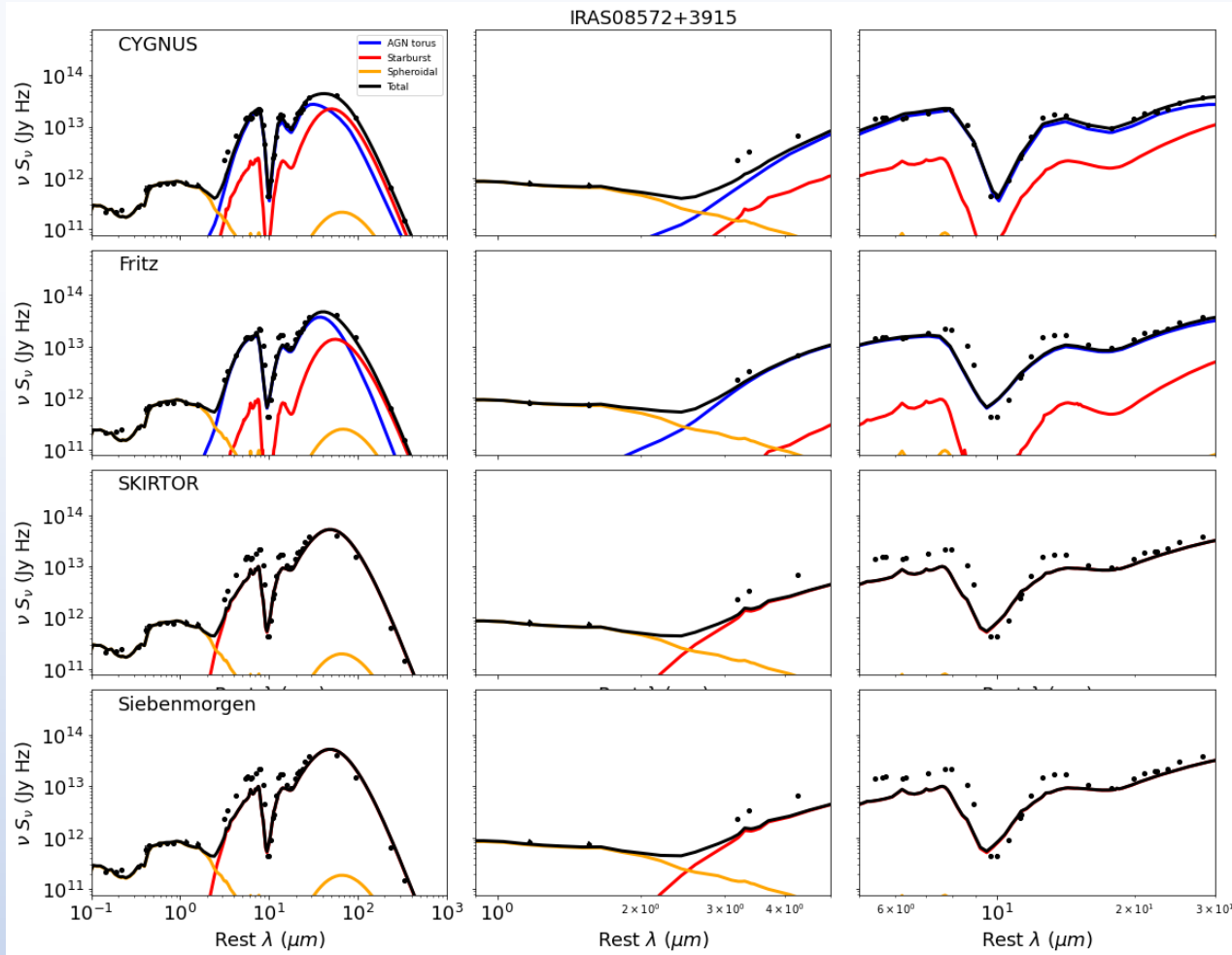




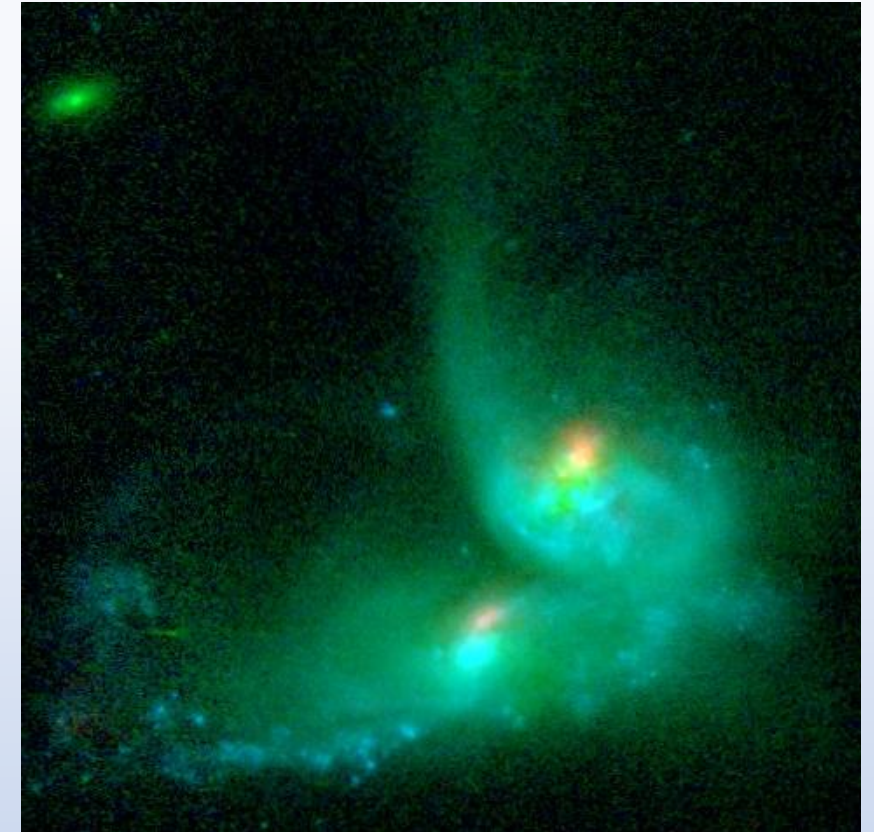
# Models used by SMART



# Comparison SED fit plots of the deeply obscured ultraluminous infrared galaxy (ULIRG) IRAS 08572+3915 (Varnava & Efstathiou, 2024)

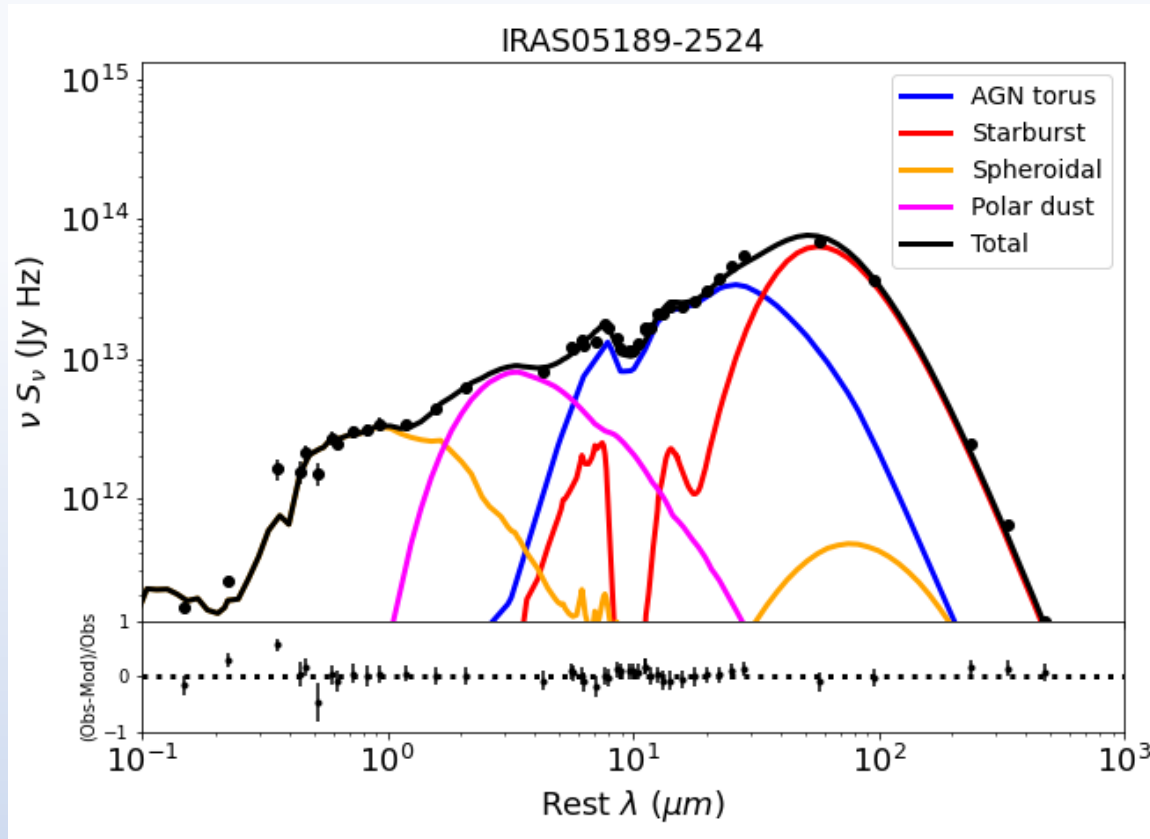


Comparison SED fit plots of IRAS 08572+3915: AGN torus (blue), starburst (red), spheroidal host (orange), total (black)

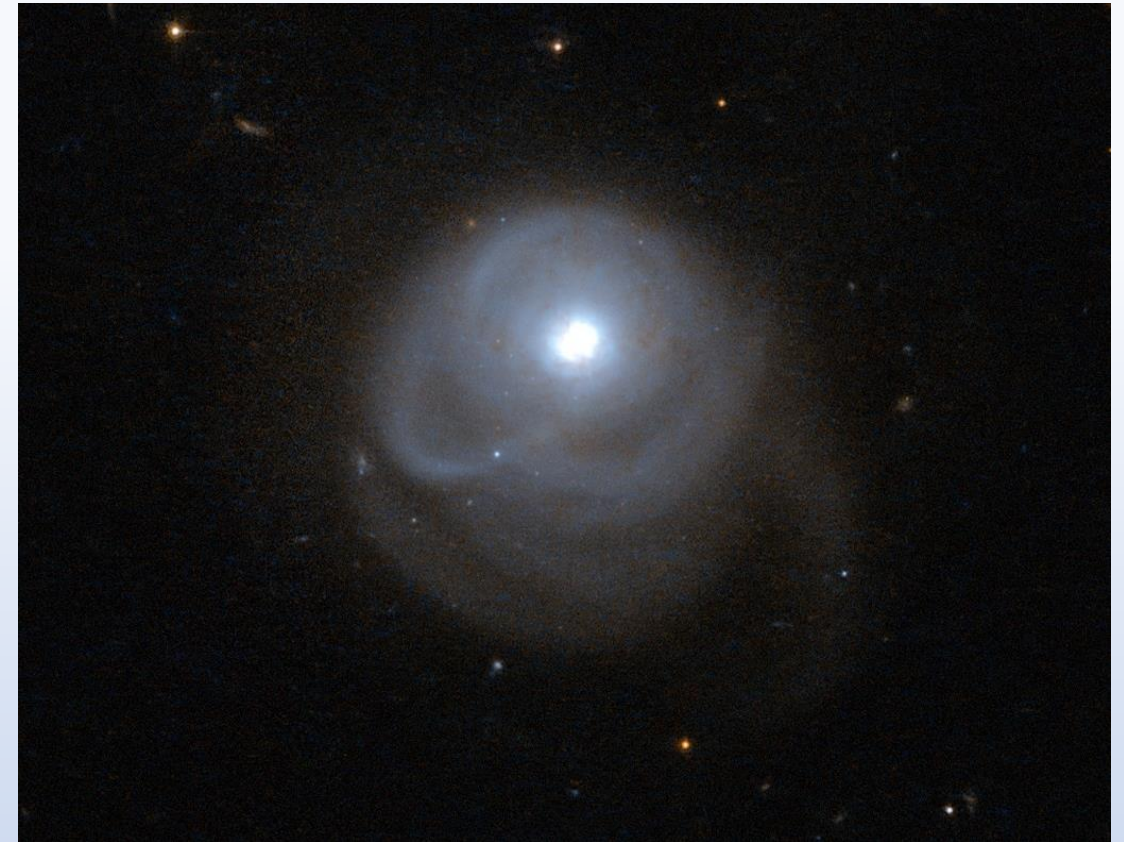


Optical Hubble Space Telescope image of IRAS 08572+3915

# SED fit plot of a ULIRG associated with polar dust, IRAS 05189-2524 (Varnava & Efsthathiou, 2024)

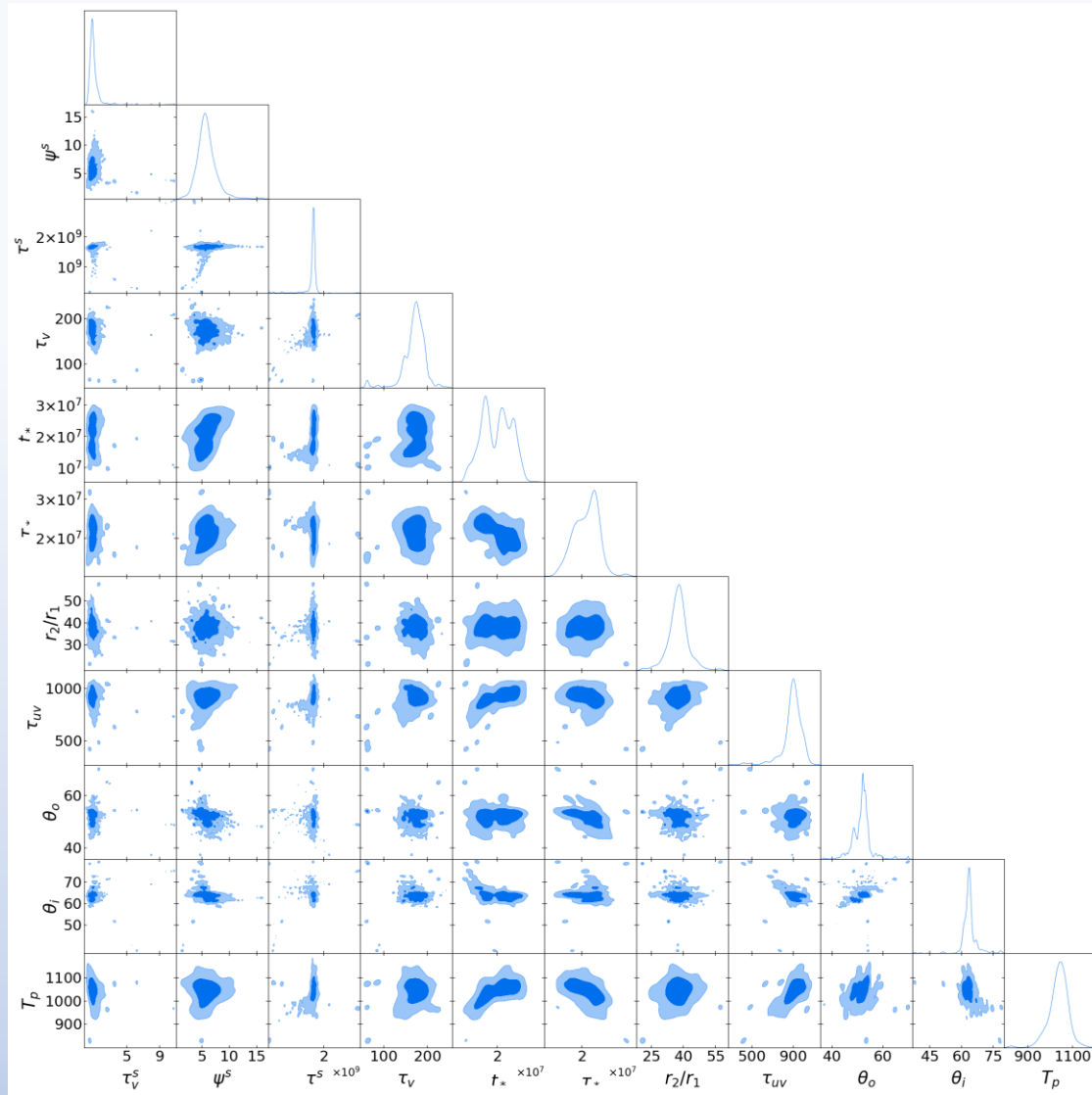


*SED fit plot of IRAS 05189-2524: AGN torus (blue), starburst (red), spheroidal host (orange), polar dust (magenta), total (black)*



*Optical Hubble Space Telescope  
Image of IRAS 05189-2524*

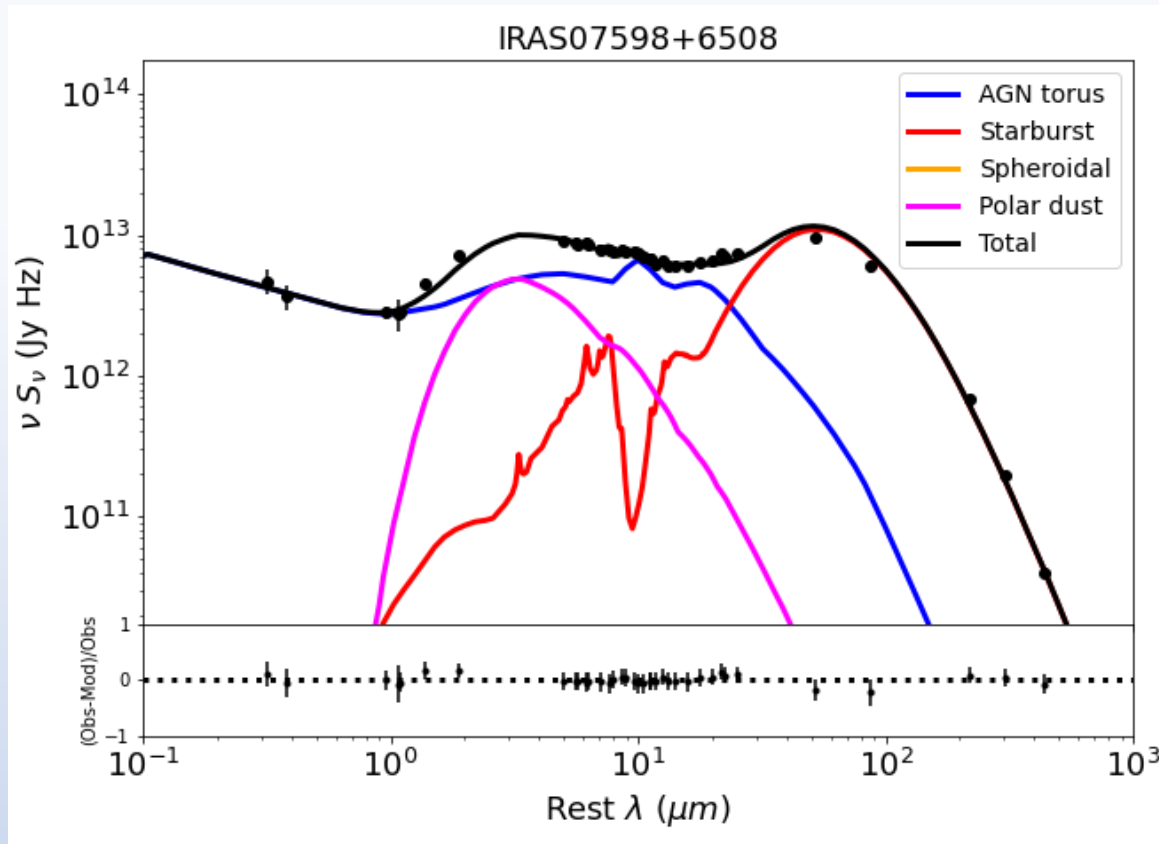
# Corner plot of the galaxy IRAS 05189-2524 (Varnava & Efstathiou, 2024)



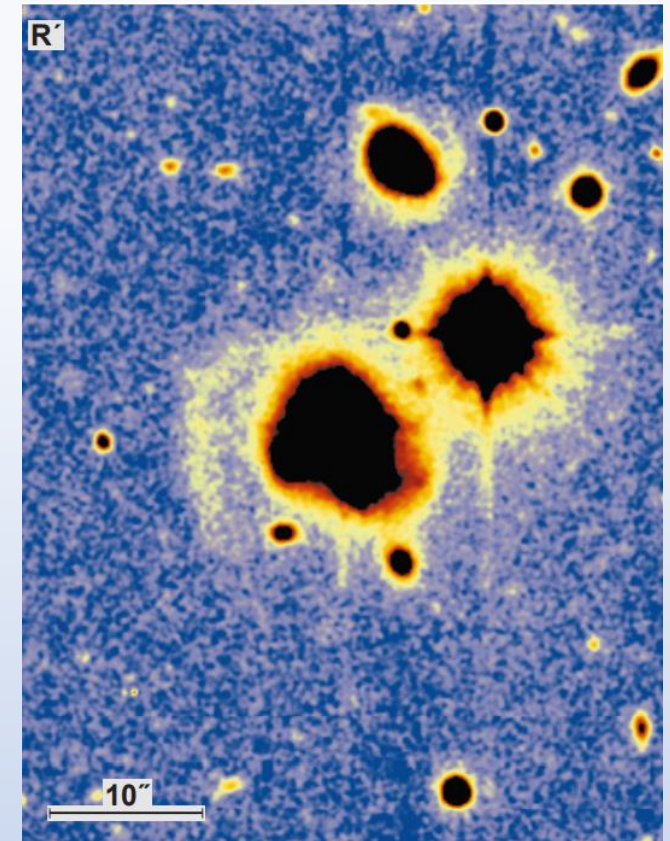
Corner plot of IRAS 05189-2524



# SED fit plot of a ULIRG with an unobscured quasar and also associated with polar dust, IRAS 07598+6508 (Varnava & Efstathiou, 2024)

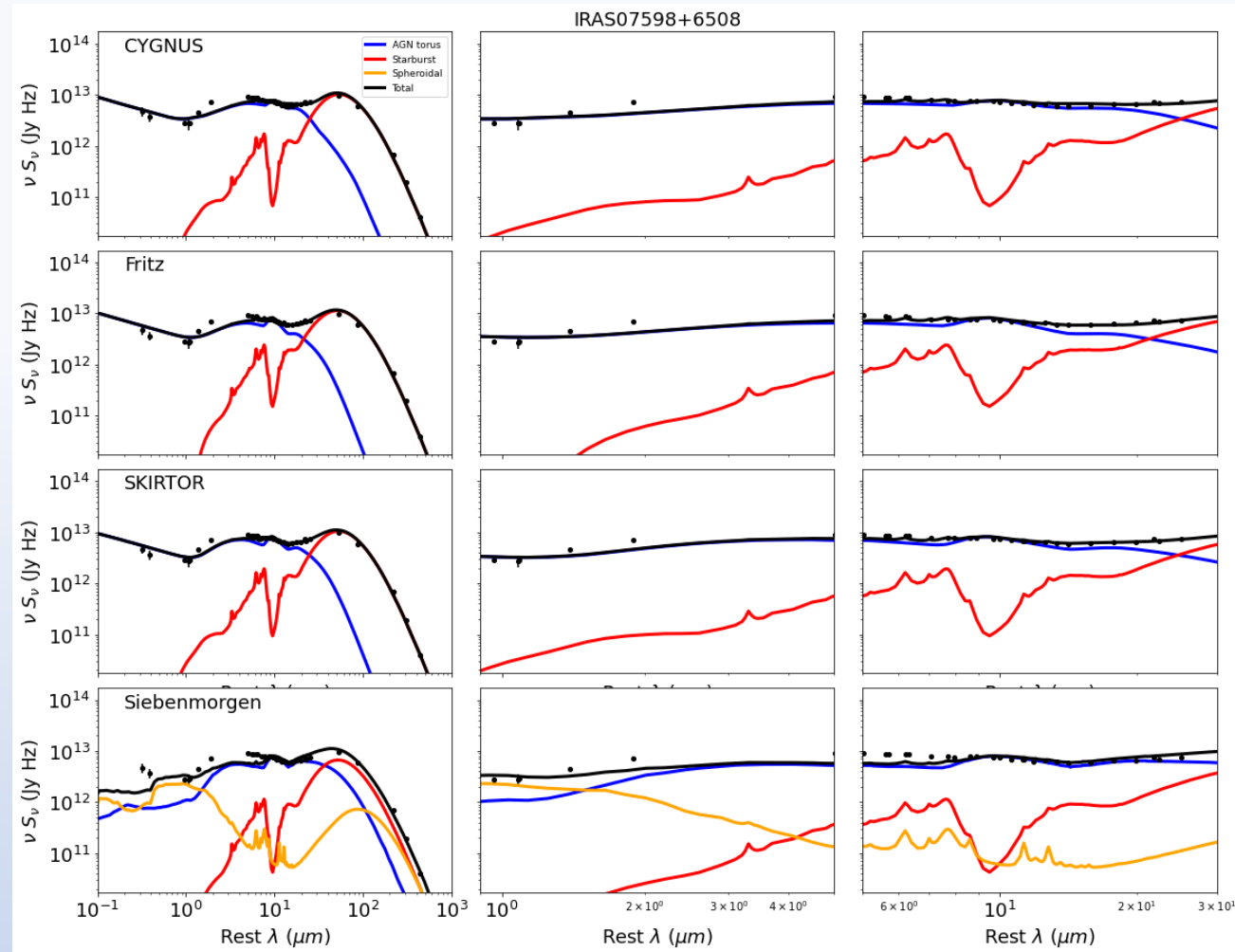


*SED fit plot of IRAS 07598+6508: AGN torus (blue), starburst (red), spheroidal host (orange), polar dust (magenta), total (black)*



*R' image of IRAS 07598+6508 (Canalizo & Stockton, 2000)*

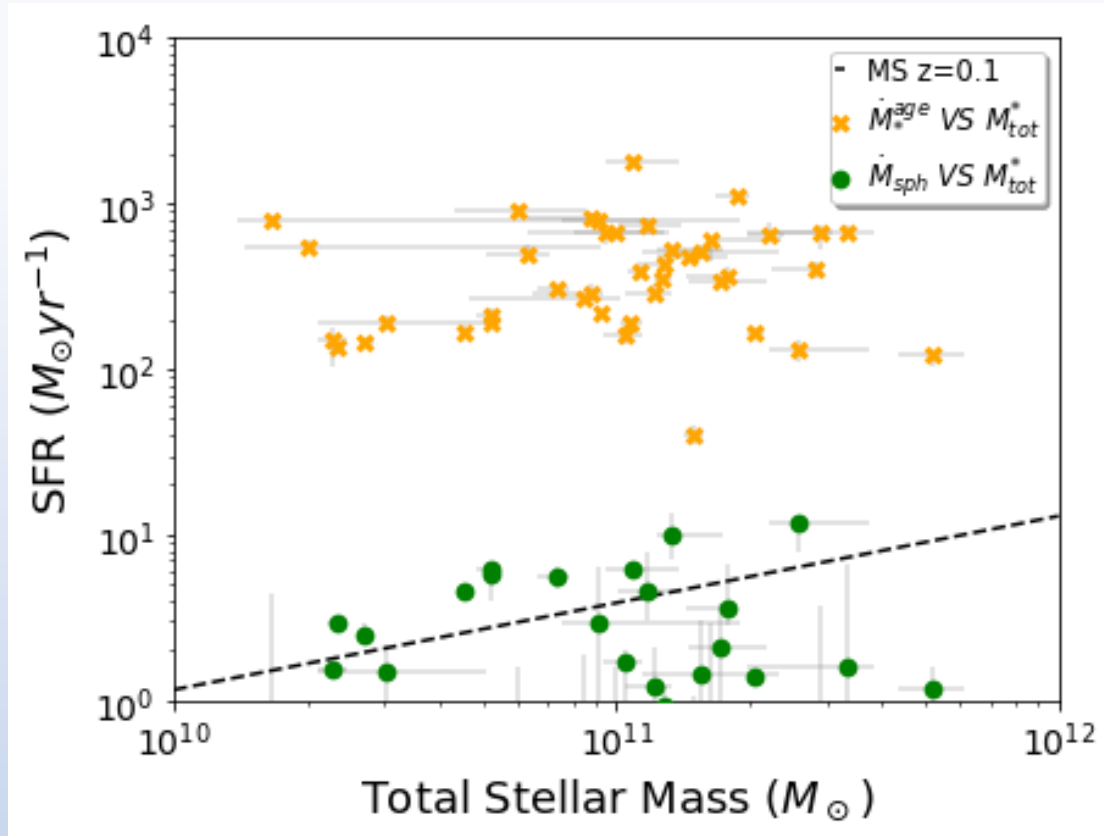
# Comparison SED fit plots of the galaxy IRAS 07598+6508 without using the polar dust component (Varnava & Efstathiou, 2024)



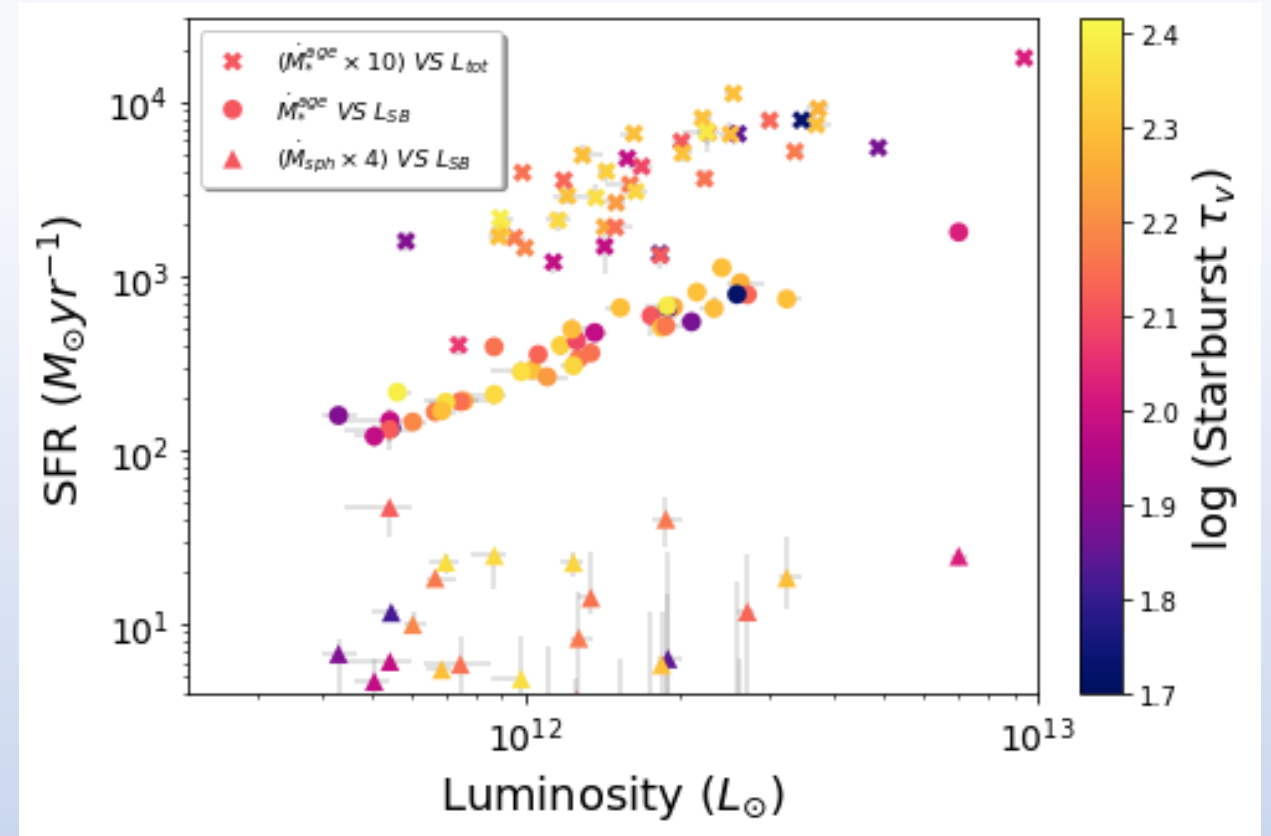
*Comparison SED fit plots of IRAS 07598+6508 without using the polar dust component: AGN torus (blue), starburst (red), spheroidal host (orange), total (black)*



# Examples of selected extracted physical quantities for the HERschel Ultraluminous Infrared Galaxy Survey (HERUS) sample, using the CYGNUS combination of models (Varnava & Efstathiou, 2024)

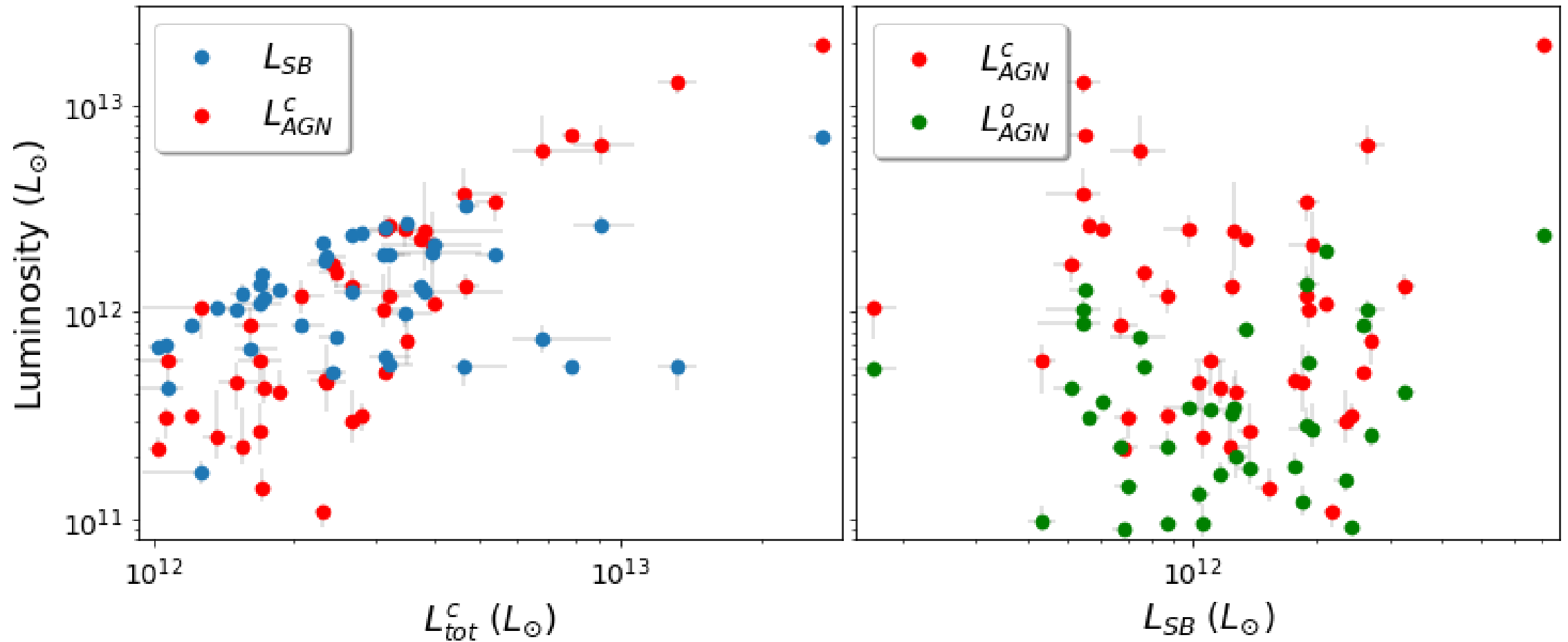


*Starburst or host SFR against total stellar mass*



*SFR against IR luminosities (starburst or total)*

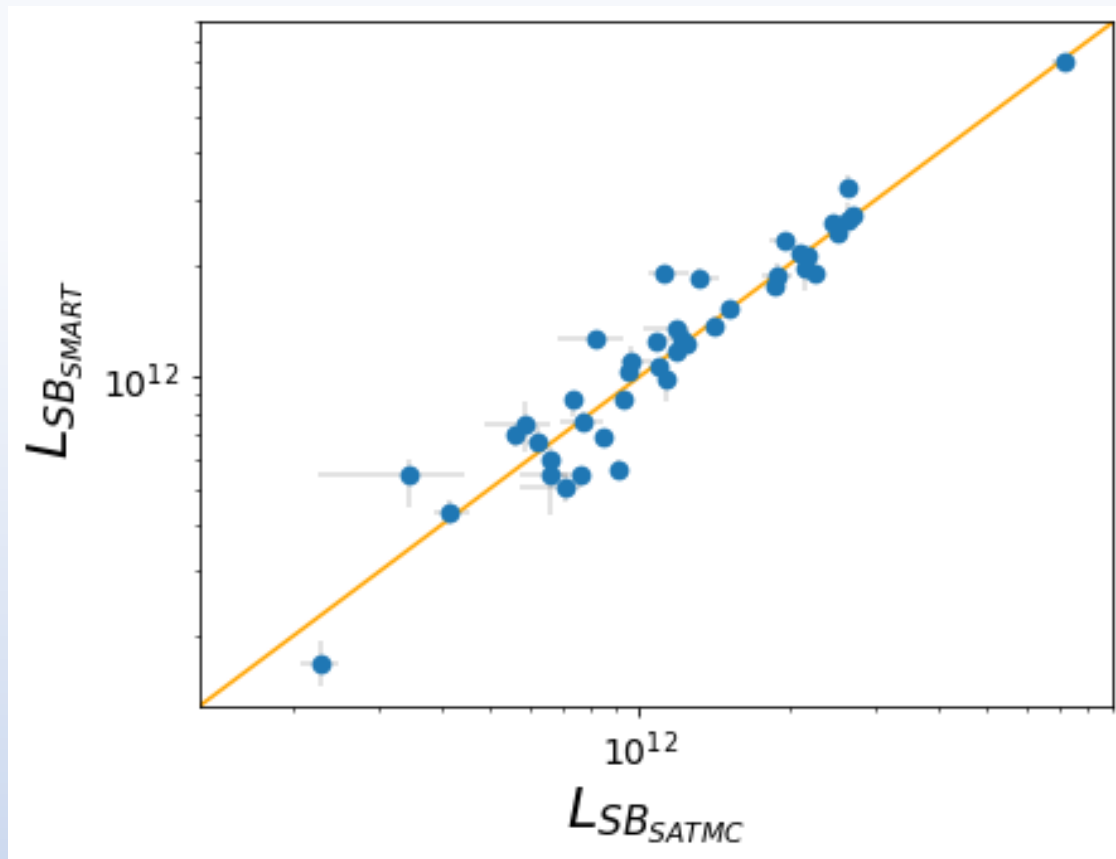
# Examples of selected extracted physical quantities for the HERUS sample, using the CYGNUS combination of models (Varnava & Efstathiou, 2024)



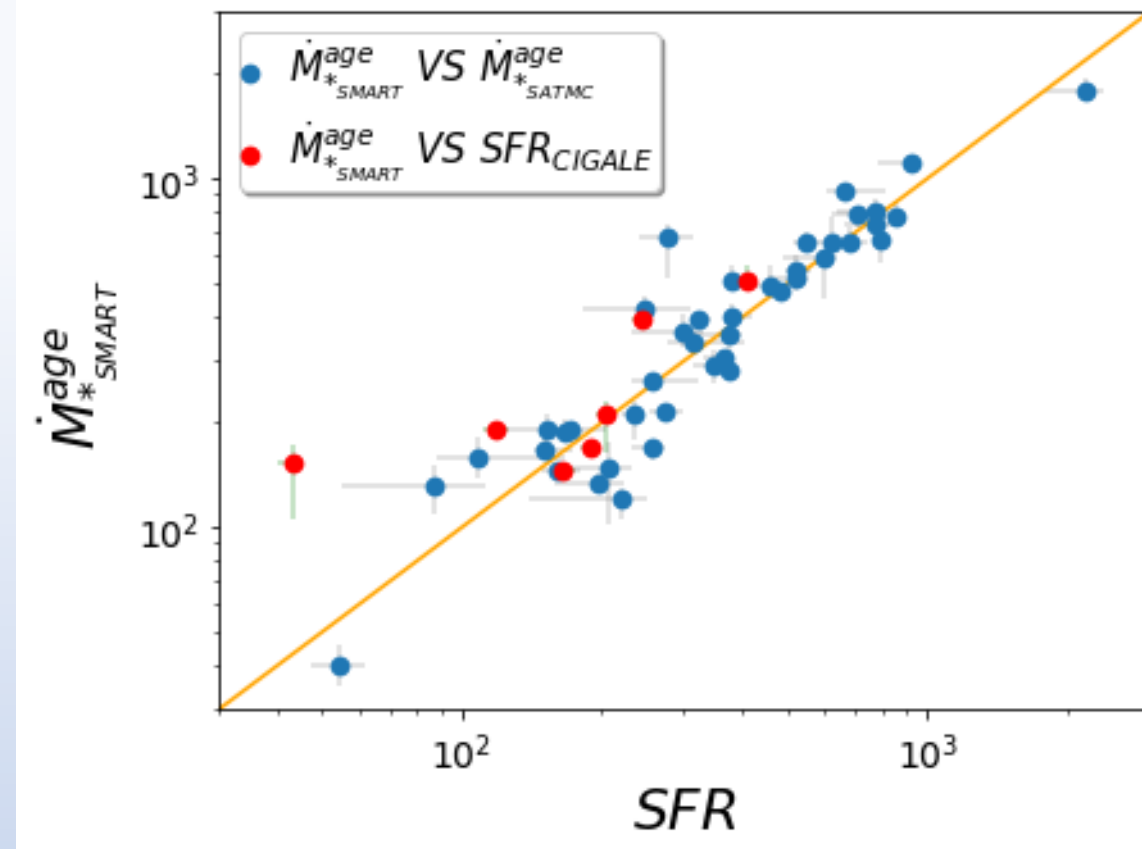
*Left: Starburst and anisotropy-corrected AGN luminosity against total corrected IR luminosity*

*Right: Observed and anisotropy-corrected AGN luminosity against starburst luminosity*

# Comparison with results from other approaches for the HERUS sample (Varnava & Efsthathiou, 2024)

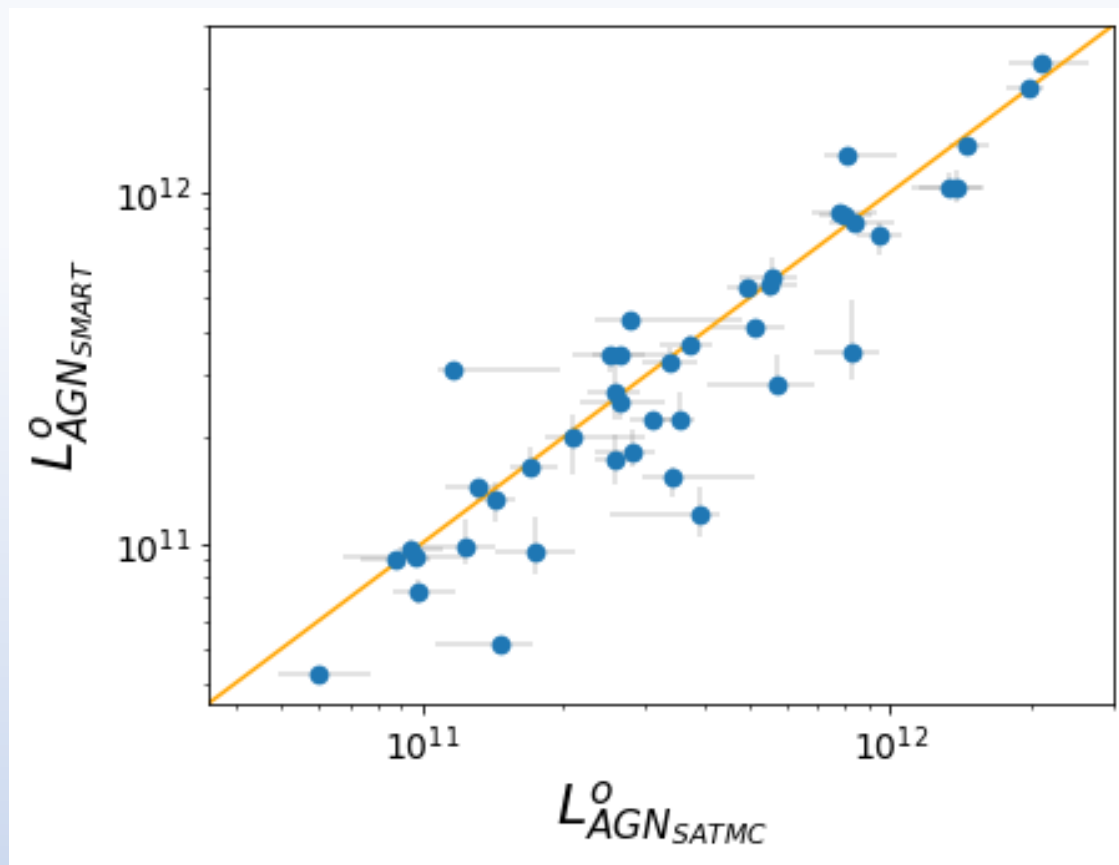


Plot of the starburst luminosity extracted by **SMART** against the same quantity extracted by SATMC

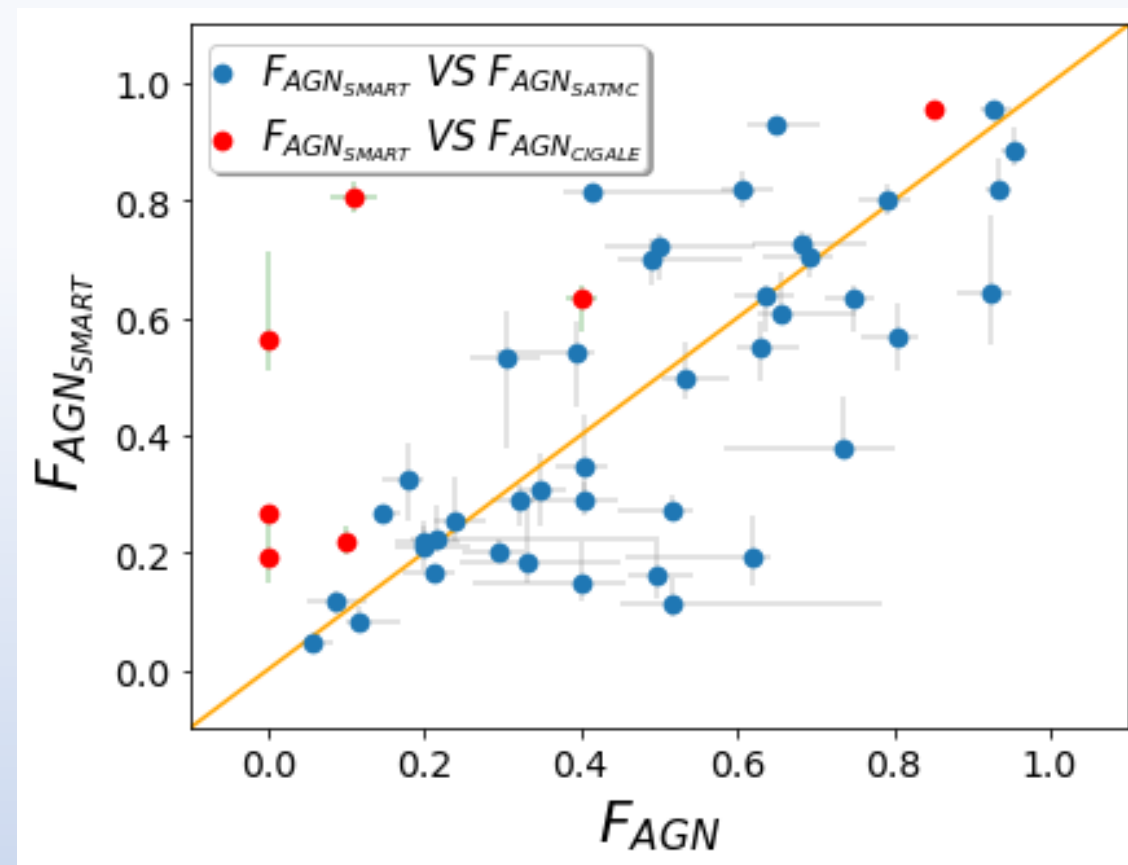


Plot of the starburst SFR extracted by **SMART** against the same quantity extracted by SATMC and CIGALE

# Comparison with results from other approaches for the HERUS sample (Varnava & Efsthathiou, 2024)

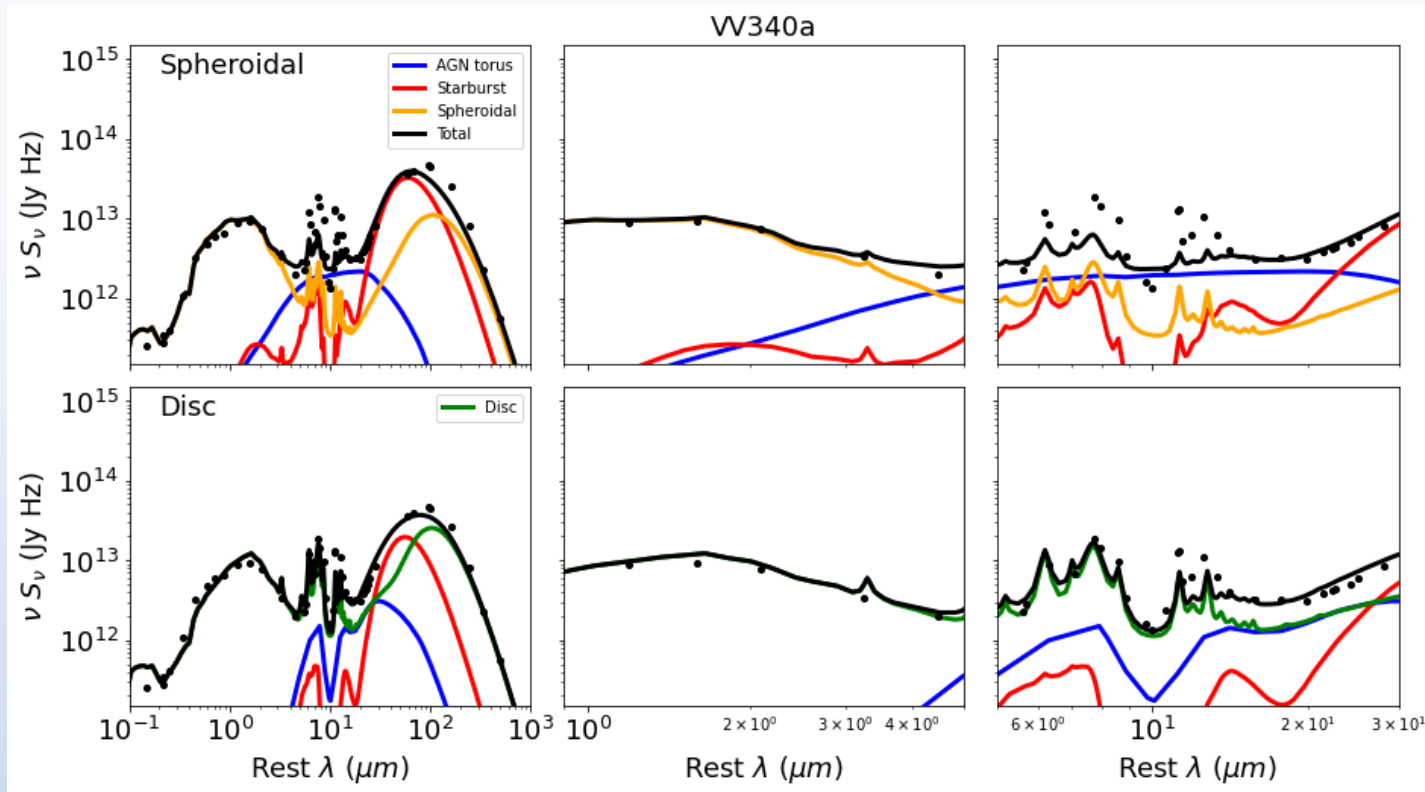


Plot of the observed AGN torus luminosity extracted by **SMART** against the same quantity extracted by SATMC



Plot of the AGN fraction extracted by **SMART** against the same quantity extracted by SATMC and CIGALE

# Comparison of the two different host galaxy models used by SMART for a luminous infrared galaxy associated with a spiral galaxy (Varnava & Efstathiou, 2024)

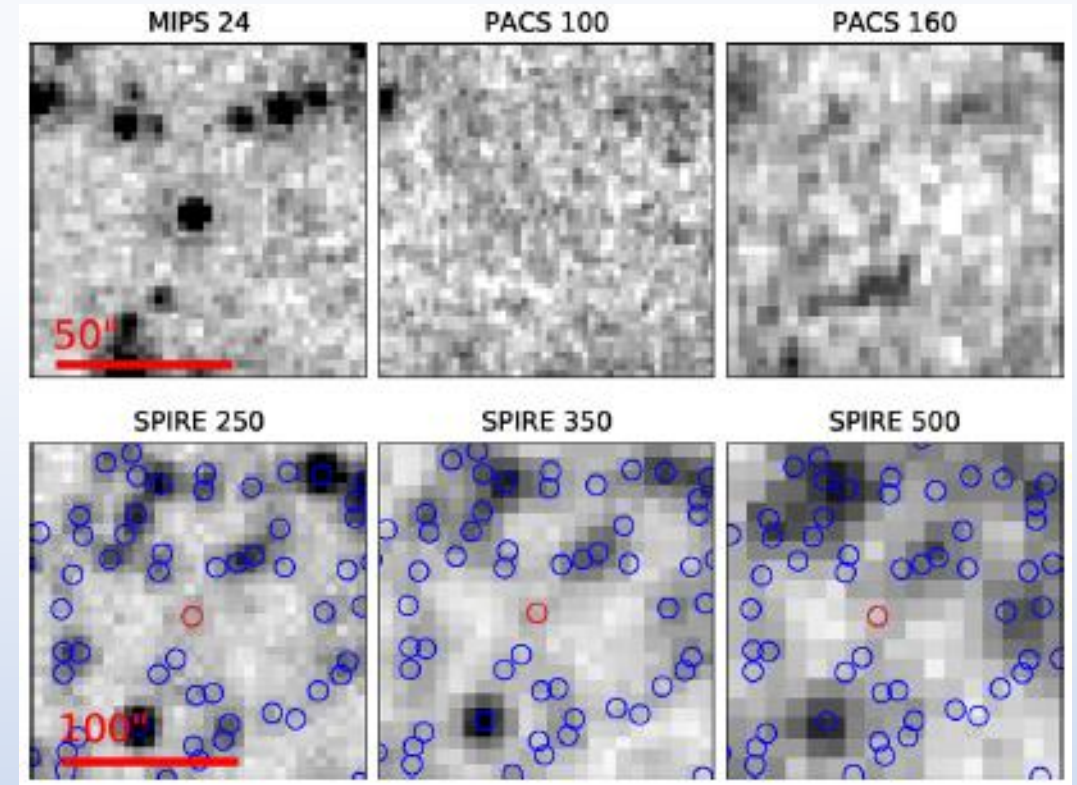
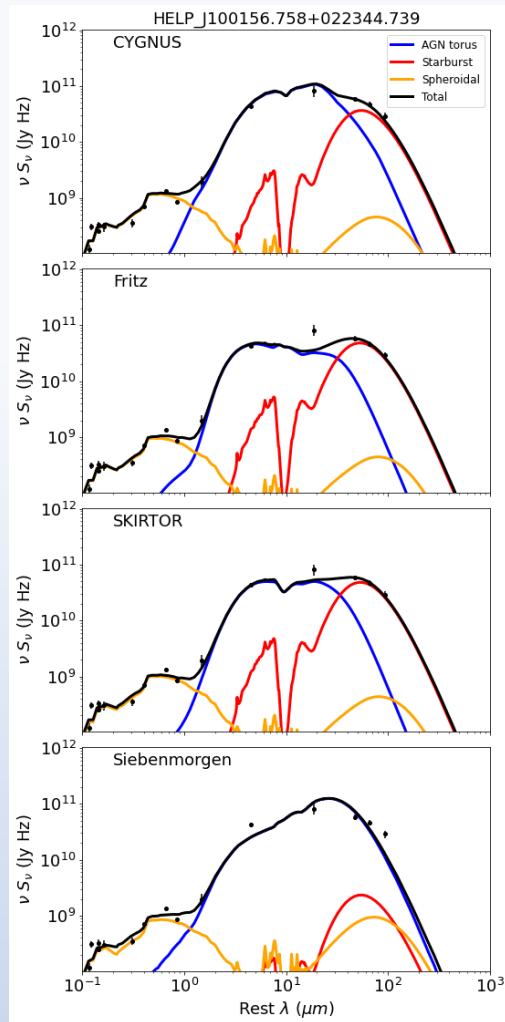


Comparison SED fit plots of the galaxy VV 340a that **SMART** predicts it has a spiral morphology: AGN torus (blue), starburst (red), spheroidal host (orange), disc host (green), total (black)



Composite image of X-ray data from Chandra (purple) and optical data from Hubble Space Telescope (red, green, blue) of VV 340

# Comparison SED fit plots of the hyperluminous obscured quasar HELP\_J100156.75+022344.7 at $z \sim 4.3$ (Varnava & Efstathiou, 2024)



*Postage stamps in various filters  
(Efstathiou et al., 2021)*

*Comparison SED fit plots of HELP\_J100156.75+022344.7: AGN torus (blue), starburst (red), spheroidal host (orange), total (black)*



# Conclusions

- Developed a new fast MCMC SED fitting code, which uses *exclusively* radiative transfer models
- Takes comparable time to energy balance codes like CIGALE and MAGPHYS
- Tested with a range of obscured AGN in the redshift range  $\sim 0-7$
- As **SMART** can fit with four different AGN torus models, it allows us to constrain the properties of the obscuring torus in AGN and quantify the uncertainties in AGN fraction and star formation rate
- Promises to be very useful for understanding galaxies and AGN at any redshift in the *JWST* era, as well as galaxy formation and evolution in general



**SMART**

can be found at:

<https://doi.org/10.1093/mnras/stae1141>

The code is available at:

<https://github.com/ch-var/SMART>

Thank you!

**Charalambia Varnava**

<https://ch-var.github.io>