Evidence for quenching in high redshift radio galaxies from multi-resolution radio-to-IR SED fitting

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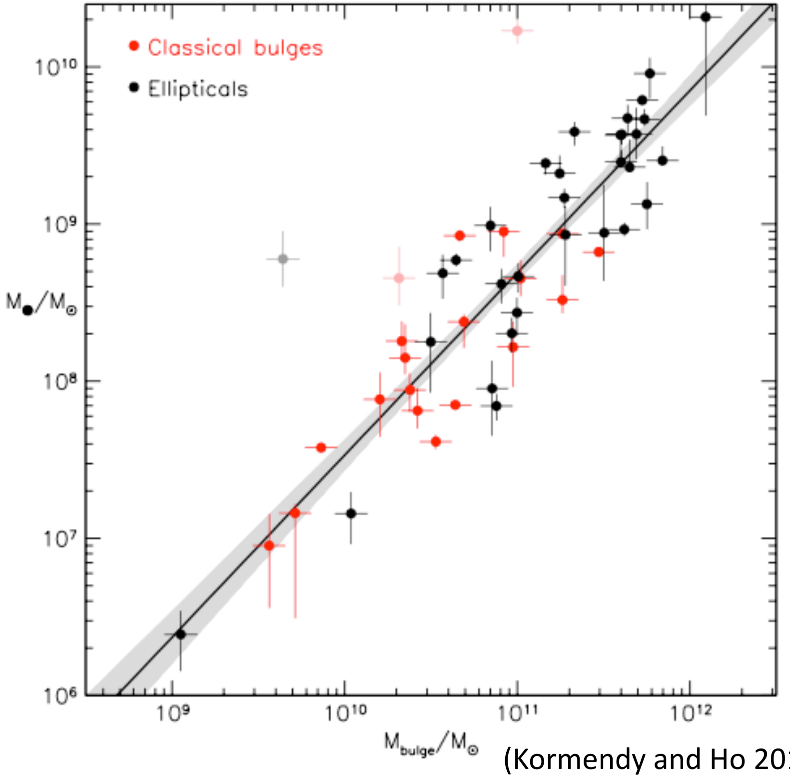
Galaxy evolution

- What is the relationship between the growth of galaxies and their super massive black hole?
- Do AGN regulate the growth of their host galaxies? Is ”AGN feedback” positive or negative?
- One approach to fill some gaps of our understanding is to **constrain theoretical models with observations** by studying high redshift galaxies



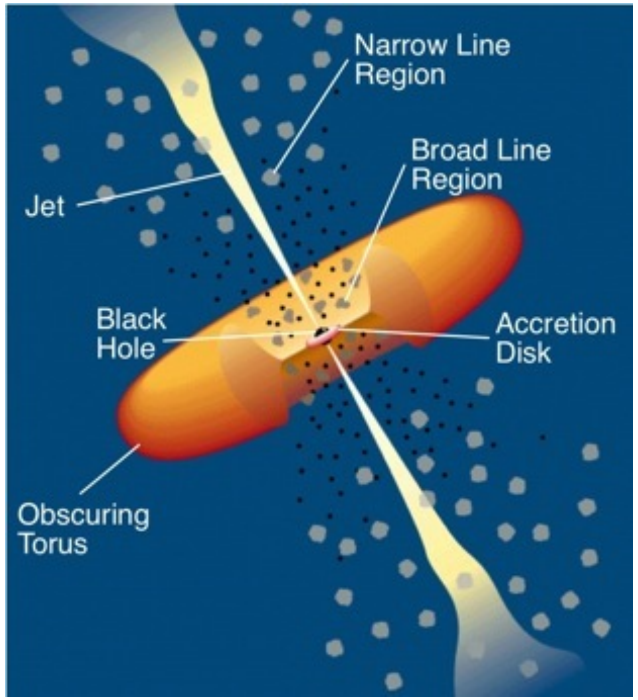
(Kormendy and Ho 2013)

Why Radio Galaxies?

- High redshift Radio Galaxies are unique and interesting objects
- Their edge-on orientation makes studying the host much easier than in quasars

High redshift Radio Galaxies have:

1. Luminous AGN
2. Massive host galaxies
3. Powerful radio jets and bright lobes which extent from 10 to 100 kpc

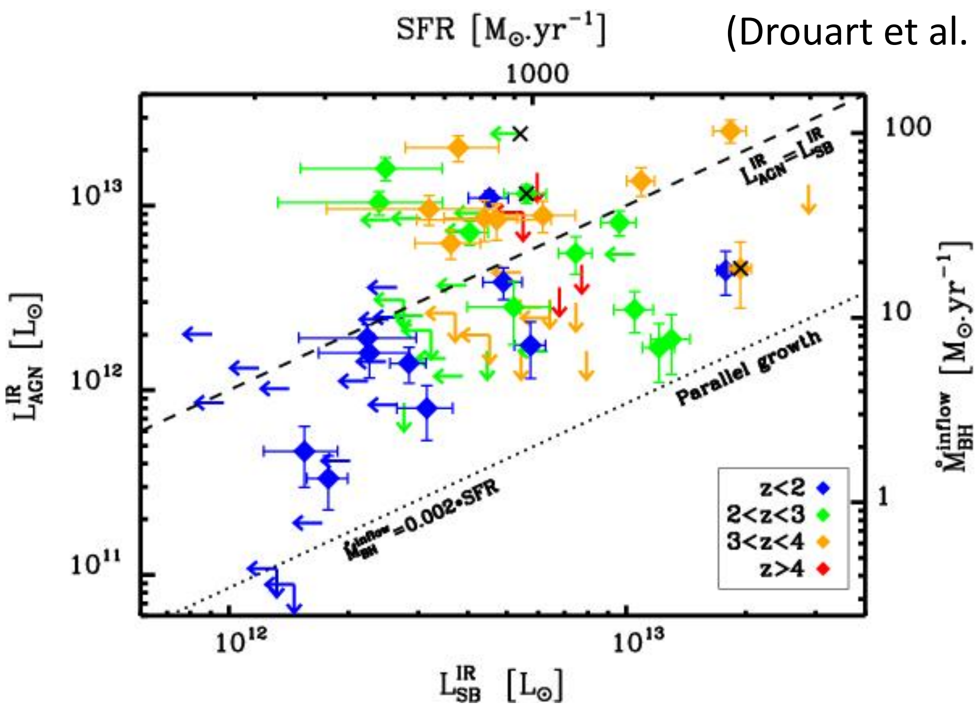


(Urry and Padovani 1995)

→ Making them prime targets to gain insight on the connection between the galaxy and their black hole growth and the influence of AGN on host and environment

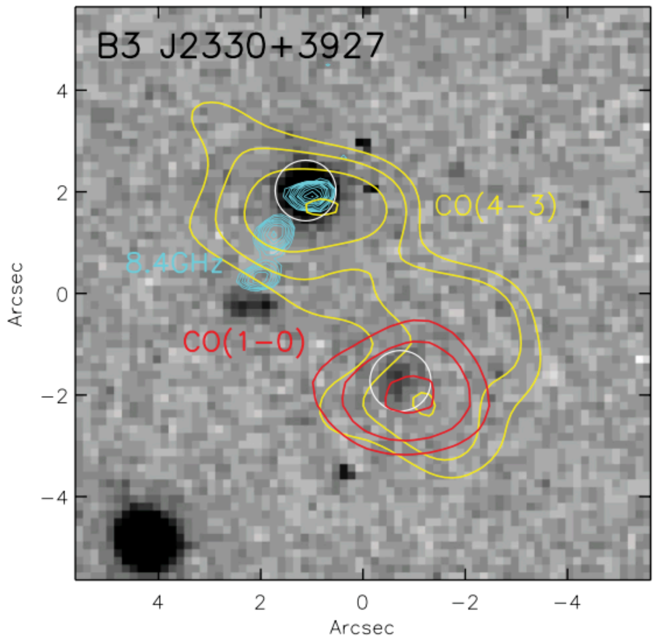
Previous work

(Drouart et al. 2014)



Low resolution SED fitting, *Herschel, Spitzer*, LABOCA show that that AGN are too massive and host have difficulties catching up.

(Ivison et al. 2012)



Complex morphology of dust, gas and AGN in high z radio galaxy, where CO(1-2) emission is offset the host galaxy.

ALMA band 6/3 continuum observations

Sample of 25 high-redshift Radio Galaxy

1<z<5.2

~0.3/1 arcsec resolution

rms~50 μJy

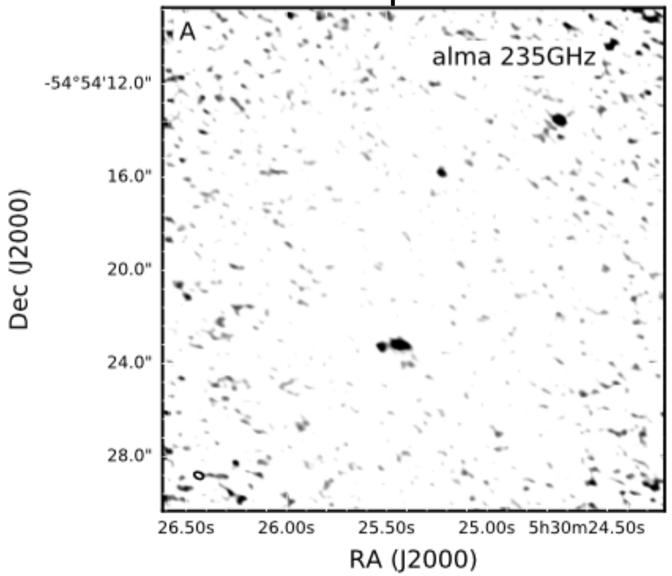
<u>Parent sample, 71 Radio galaxies</u>

$M_* \approx$ 1-5×$10^{11} M_\odot$

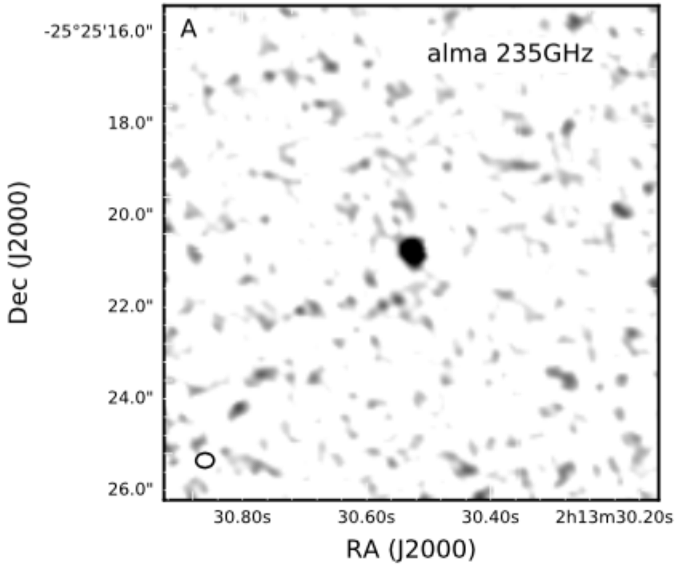
$L_{3GHz} > 10^{26}\mathrm{WHz}^{-1}$ at $z > 1$

Steep spectra $\alpha = -1; S_\nu \propto \upsilon^\alpha$at$\upsilon_{obs}$~1.4GHz

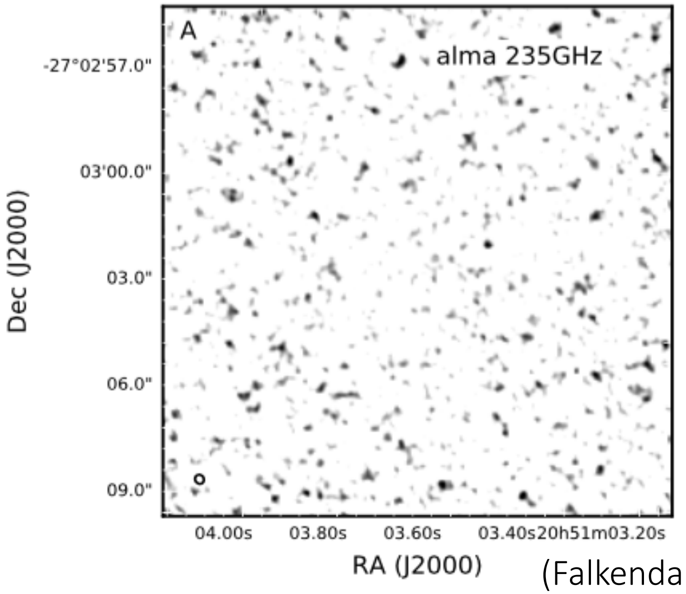
7 galaxies with multi-components



10 galaxies with a one component at the core



8 non-detections



(Falkendal et al. in prep.)

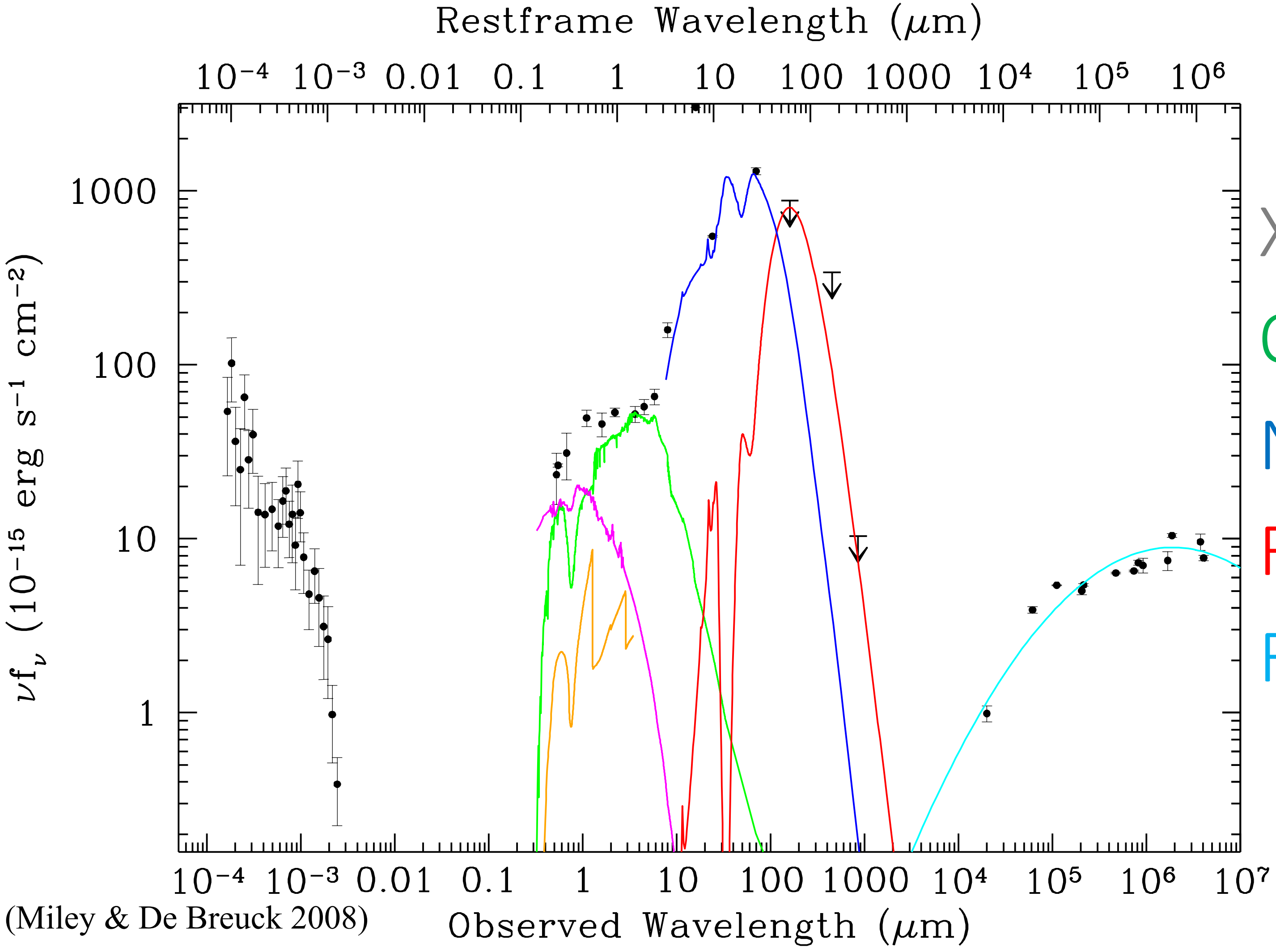
ALMA band 6/3 continuum observations

With this new high resolution data we want to:

- Revise previous Star Formation Rates (SFR)
- Determine where star formation is taking place and estimate the SFR of companions and host galaxy
- Look at the relation between the growth of the black hole and host galaxy

→ SED fitting

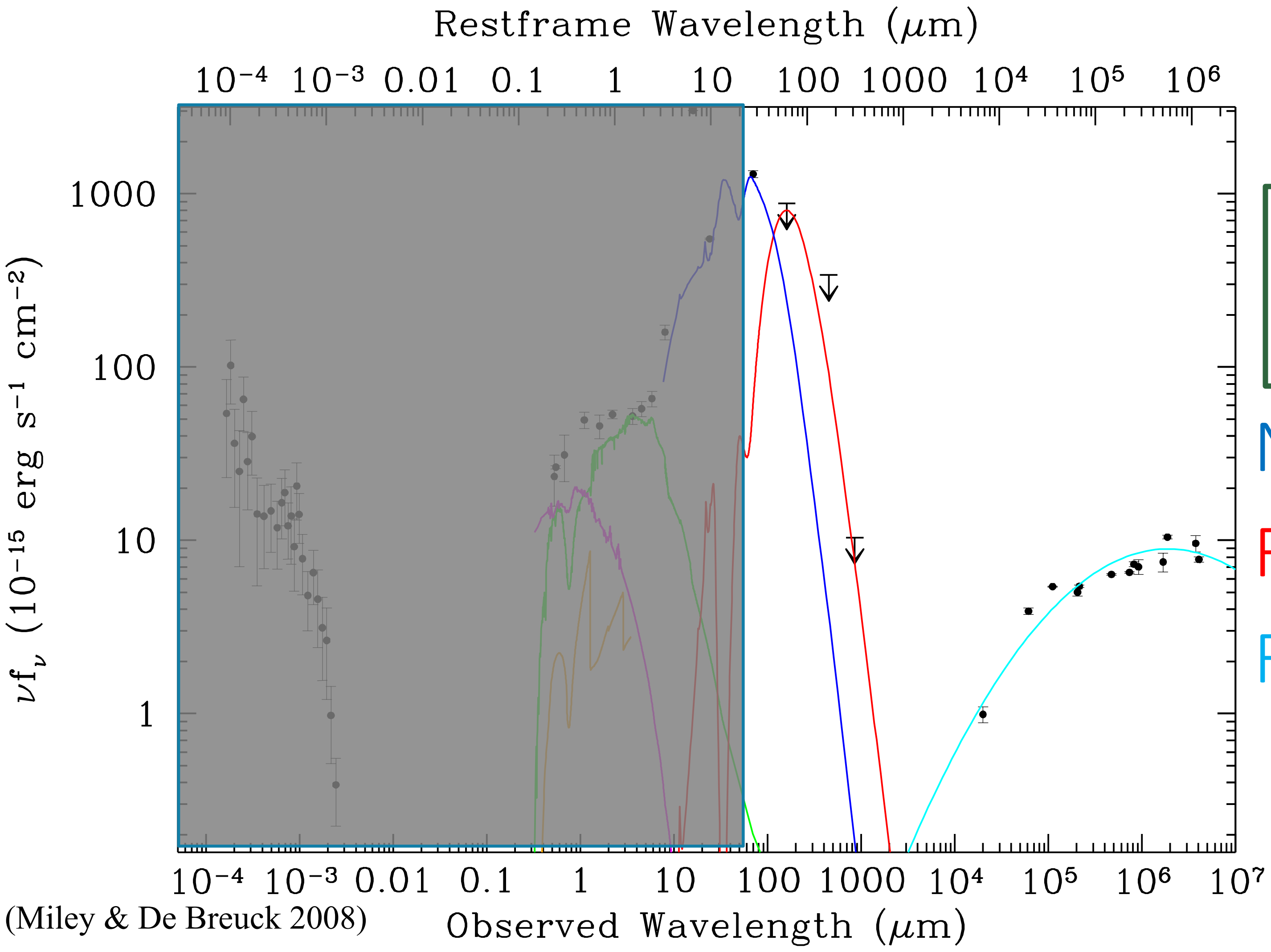
Spectral Energy Distribution (SED)



(Miley & De Breuck 2008)

X-ray	AGN, jets
Optical	Stars
Near-IR	AGN-heated dust
Far-IR	Starburst-heated dust
Radio	Synchrotron lobes

Spectral Energy Distribution (SED)

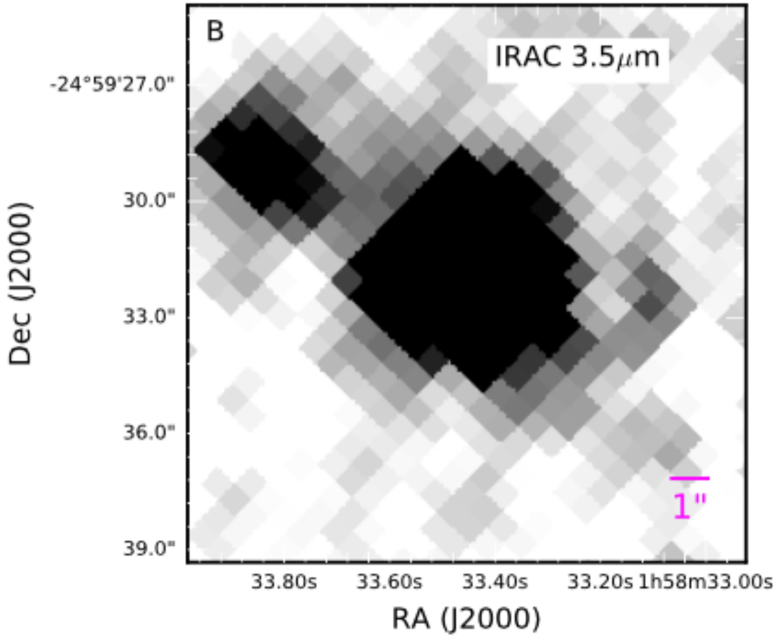


(Miley & De Breuck 2008)

My work focus on SED fitting MIR-Radio

Near-IR	AGN-heated dust
Far-IR	Starburst-heated dust
Radio	Synchrotron lobes

1. Problem with resolution



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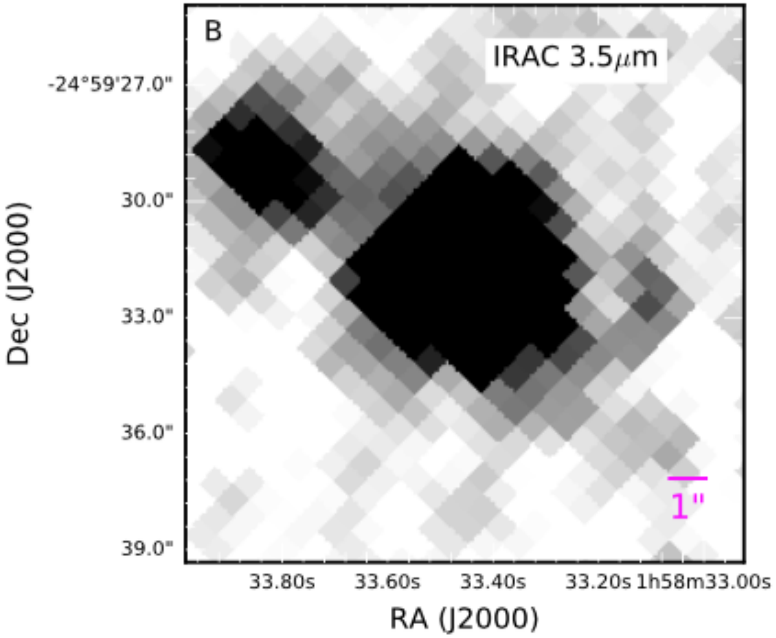

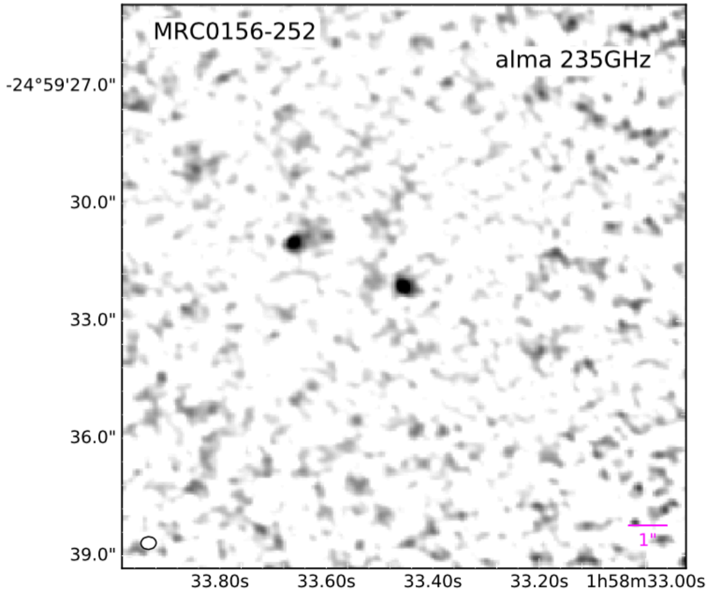

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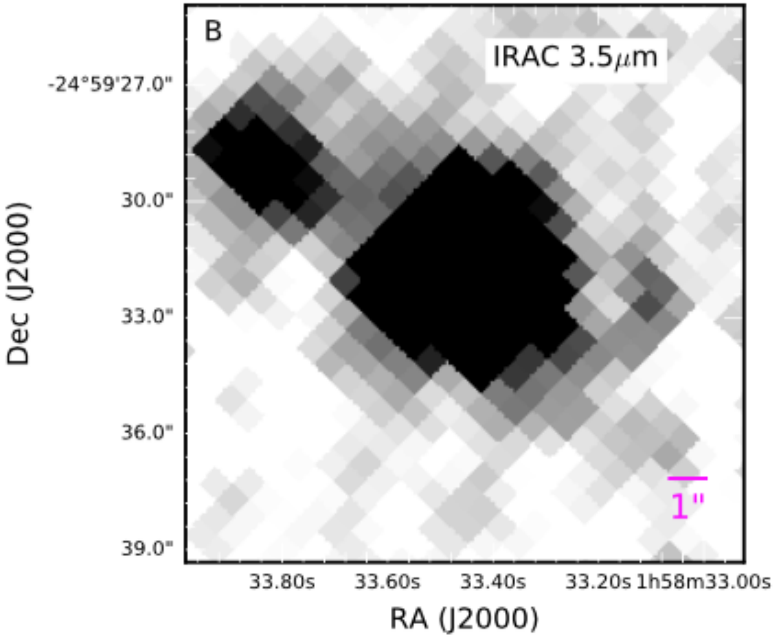

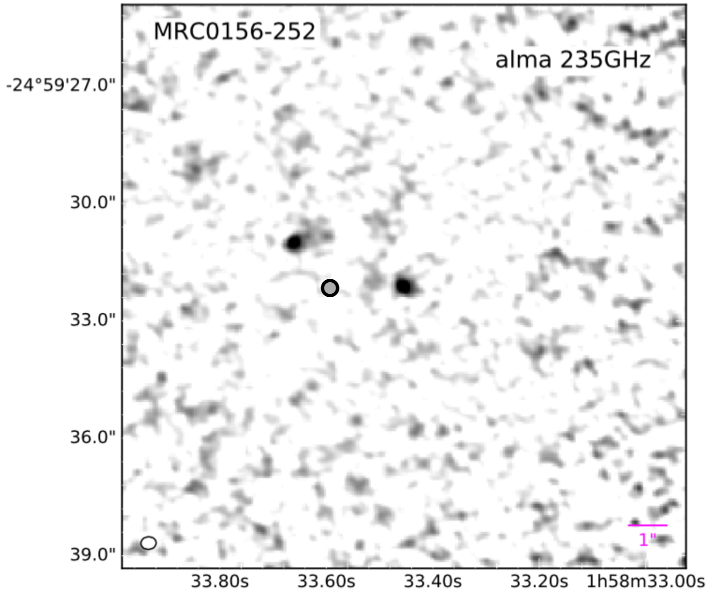

ALMA 0.3”

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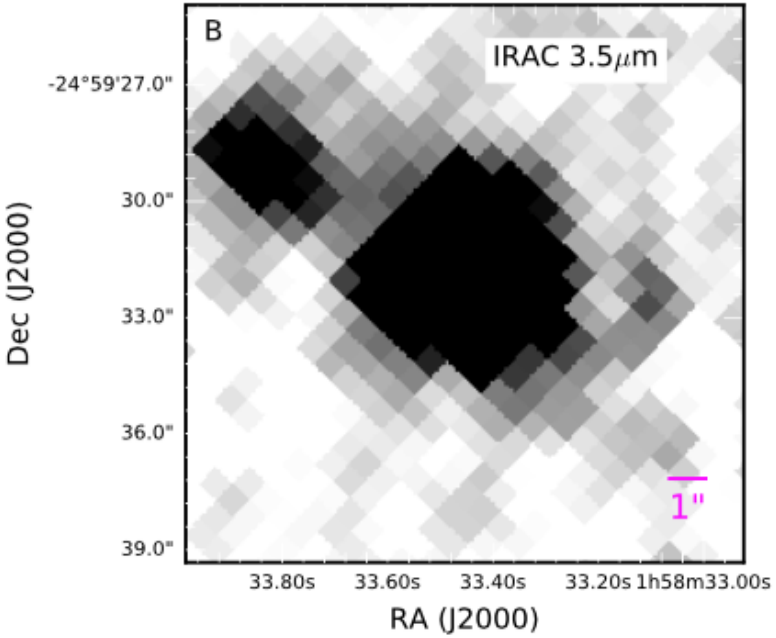

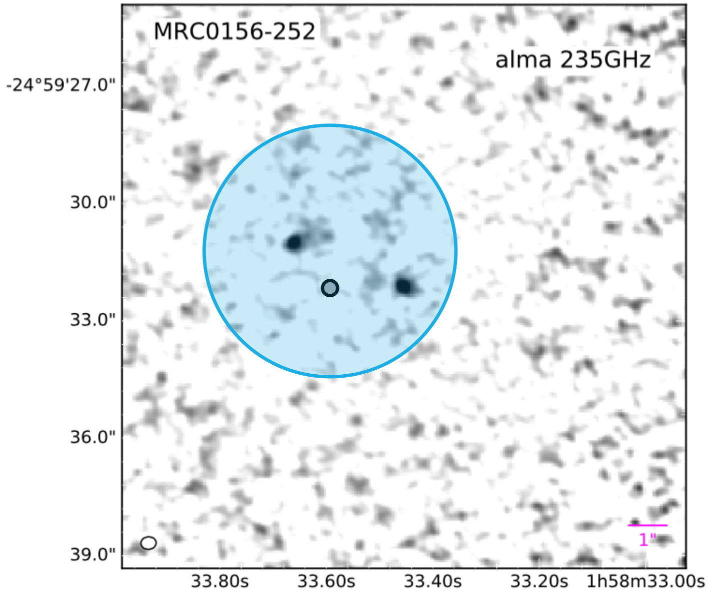

ALMA

Spitzer

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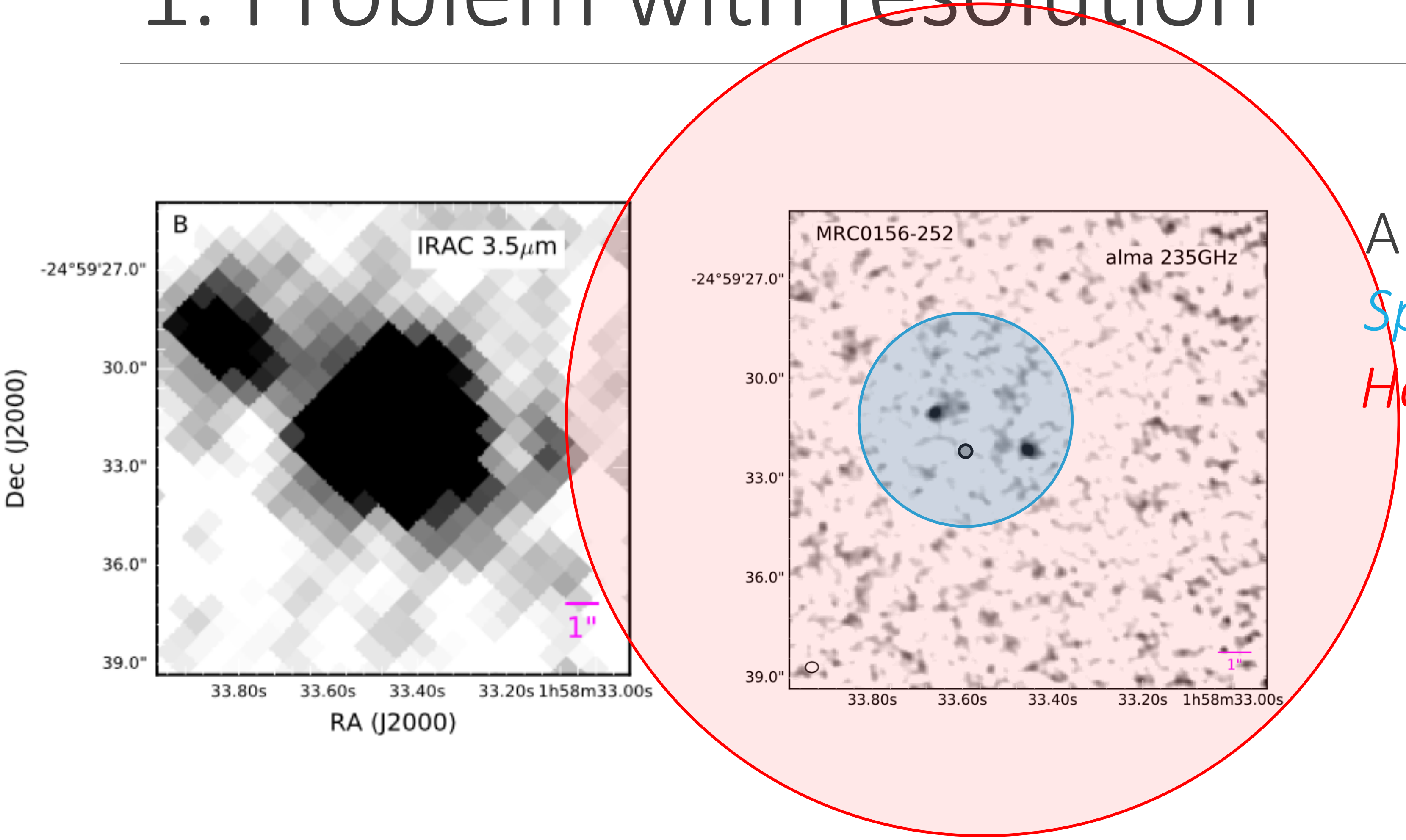


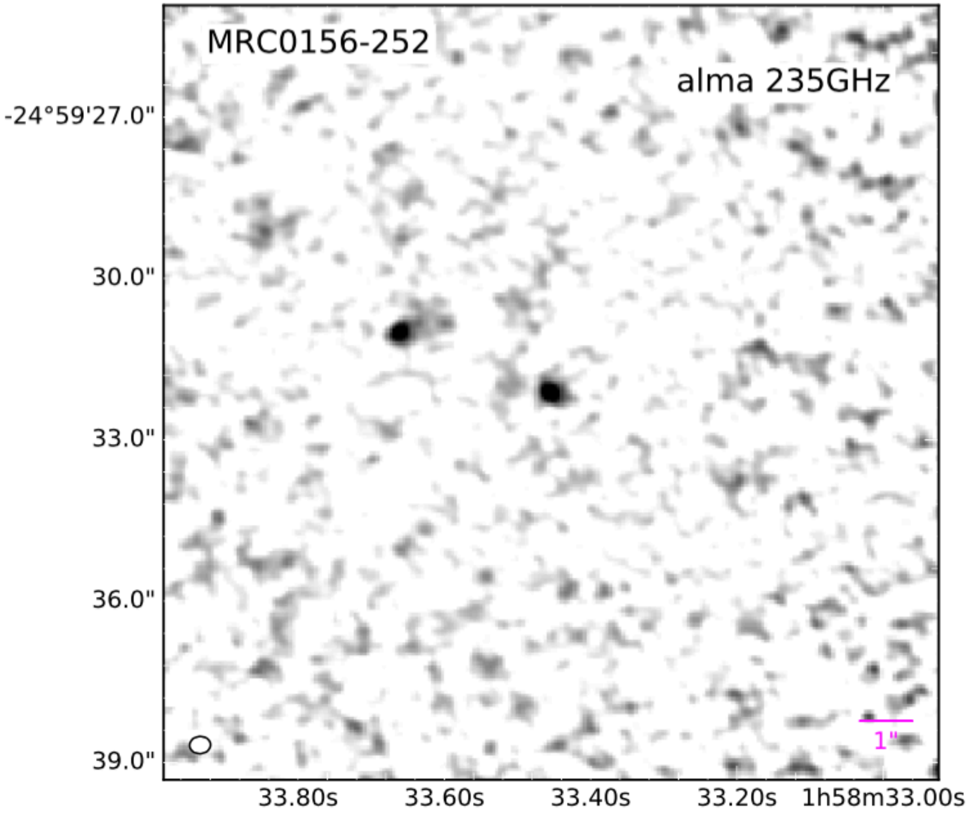
ALMA

Spitzer

Herschel

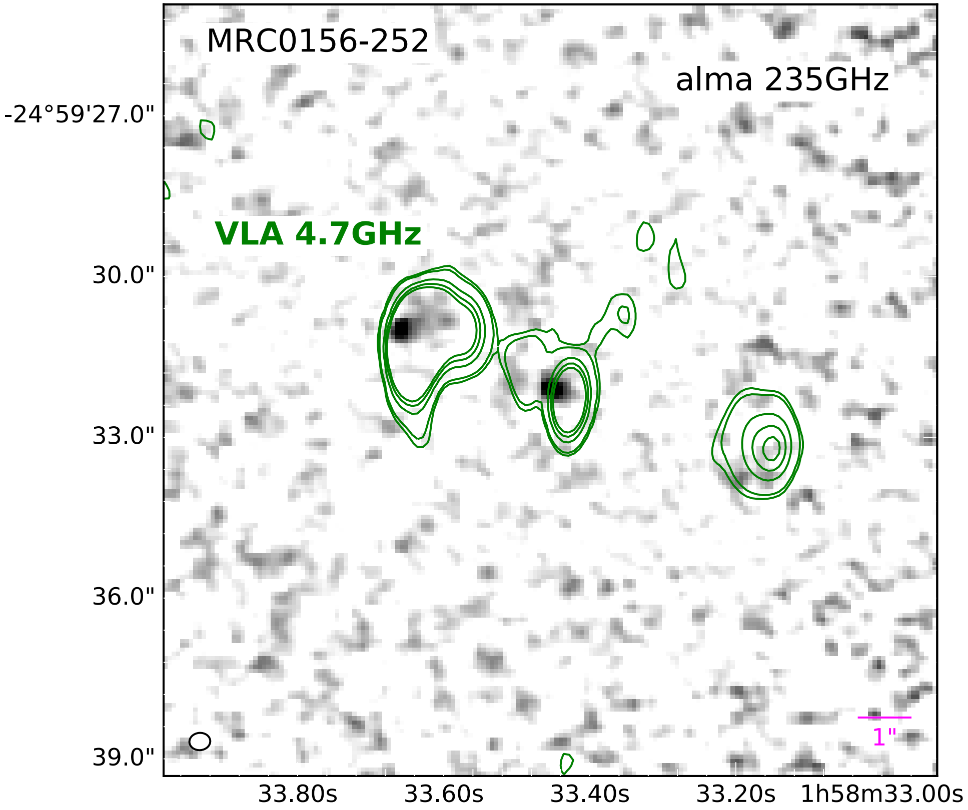
Want to use the additional information given by ALMA

2. Problem with synchrotron contamination



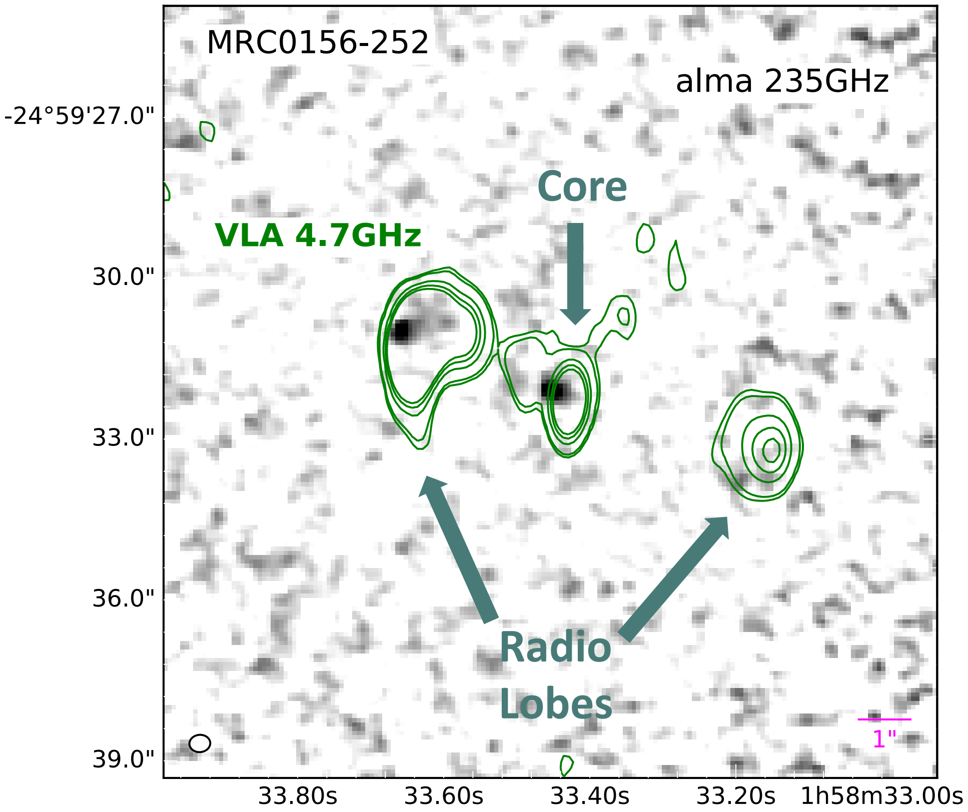
ALMA 235 GHz

2. Problem with synchrotron contamination



ALMA 235 GHz + VLA 4.7 GHz

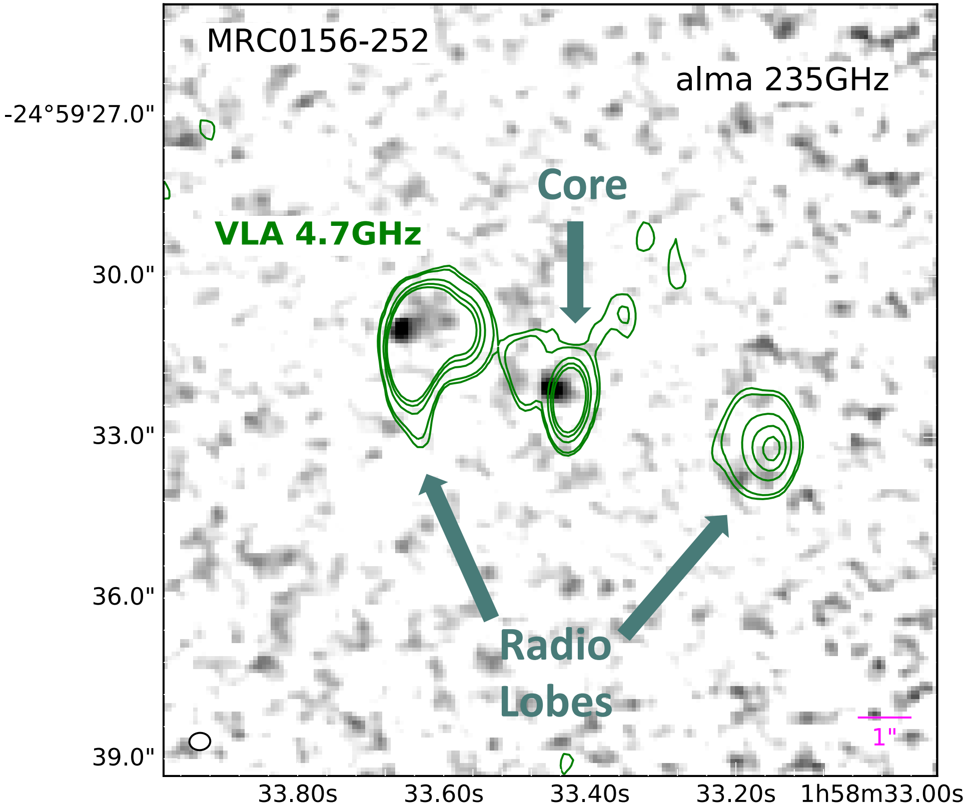
2. Problem with synchrotron contamination



ALMA 235 GHz + VLA 4.7 GHz

Have potential synchrotron contamination at ~1mm

2. Problem with synchrotron contamination



ALMA 235 GHz + VLA 4.7 GHz

Have potential synchrotron contamination at ~1mm

Motivation to make a code that can deal with these two problems

Developed a new SED fitting code

Mr-Moose: Multi Resolution, Multi-Object/Origin Spectral Energy distribution fitting code

- Include synchrotron
- Disentangle AGN and starburst heated dust
- Multiple components, to make use of high resolution data
- Flexibility, in choosing freely combination of different models
- Deals with upper limits in a continuous way

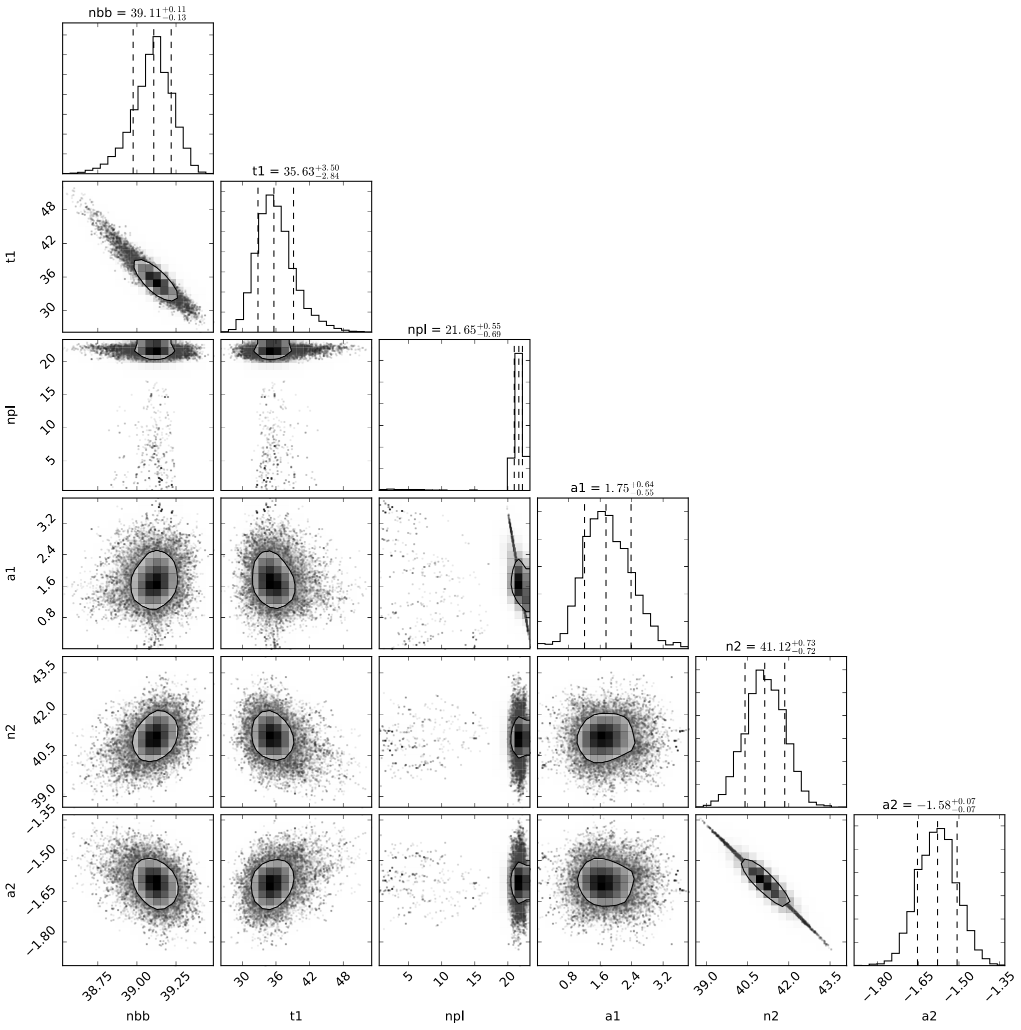
(Drouart & Falkendal, submitted)

Open source, available for download on Github: https://github.com/gdrouart/MrMoose

Mr-Moose, fitting procedure

<u>MCMC approach</u>

- Uses the python package *Emcee* (Foreman-Mackey et al. 2013)
- Fit all the models simultaneously to find the most likely solution and pdf for each of the free parameters
- Continuously including upper limits (Sawicki 2012)



Mr-Moose, models

Analytic models:

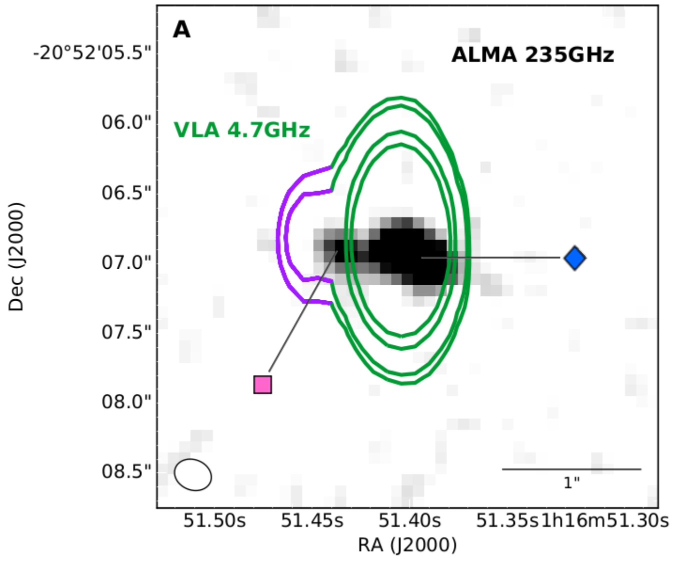
Starburst heated dust	Modified black body, fixed β for this sample
AGN heated dust	Power law with exponential cut of at 33 µm rest frame
Synchrotron emission	Single index power law

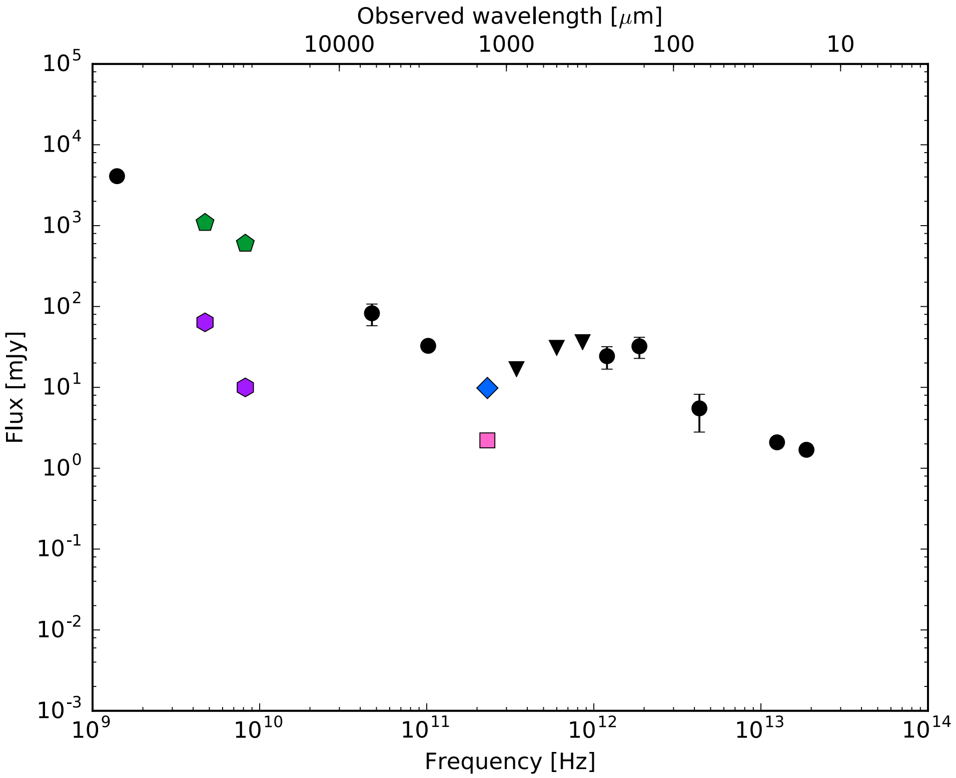
- Full control of the number of models used to fit the data
- Simple analytic models to not over interpreted the data

For now only analytic models, temples to be added later on

Mr-Moose, fitting example

radio and mm data

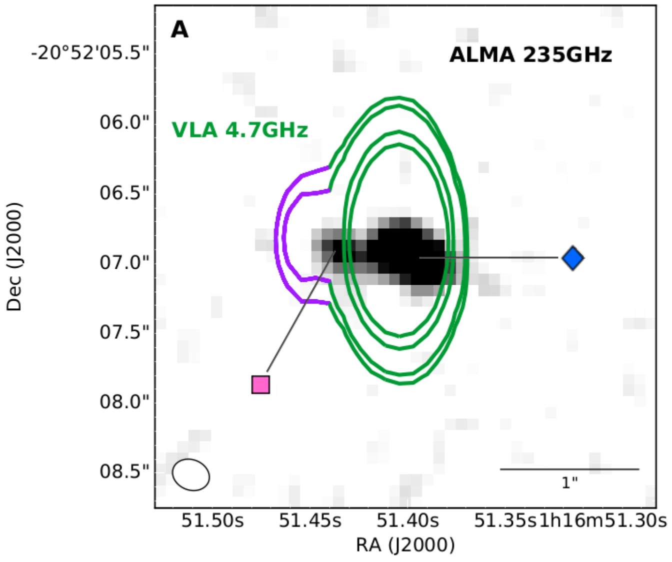


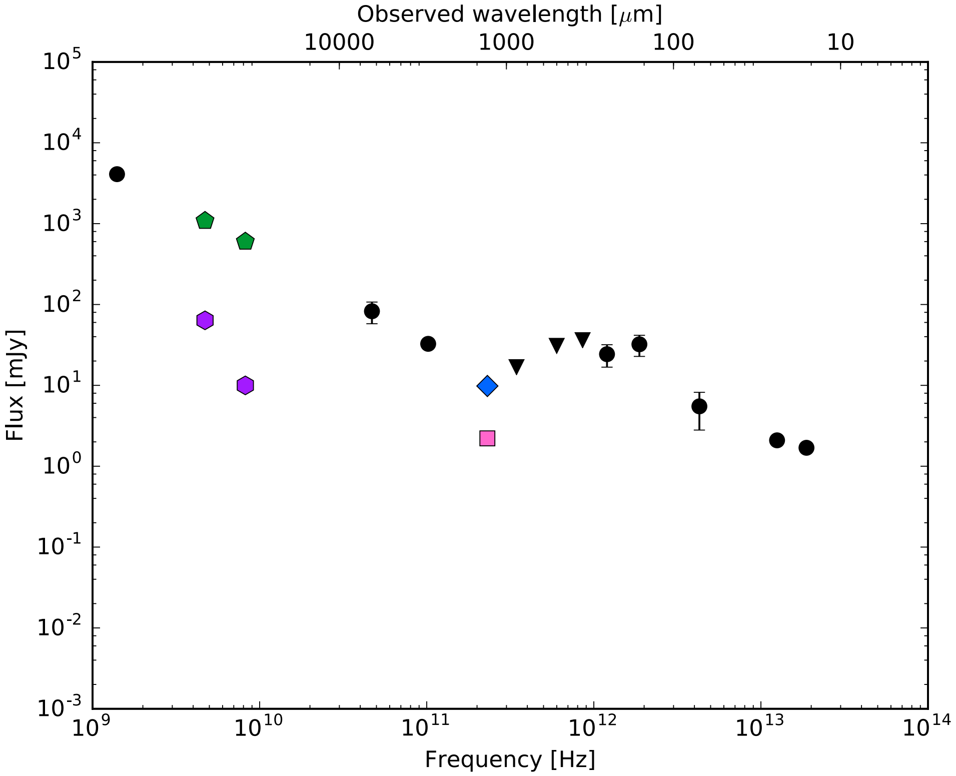


(Falkendal et al. in prep.)

Mr-Moose, fitting example

radio and mm data



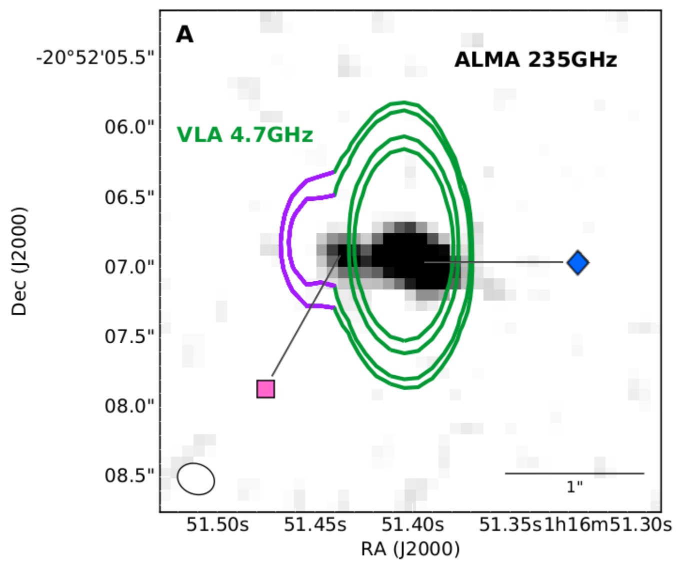


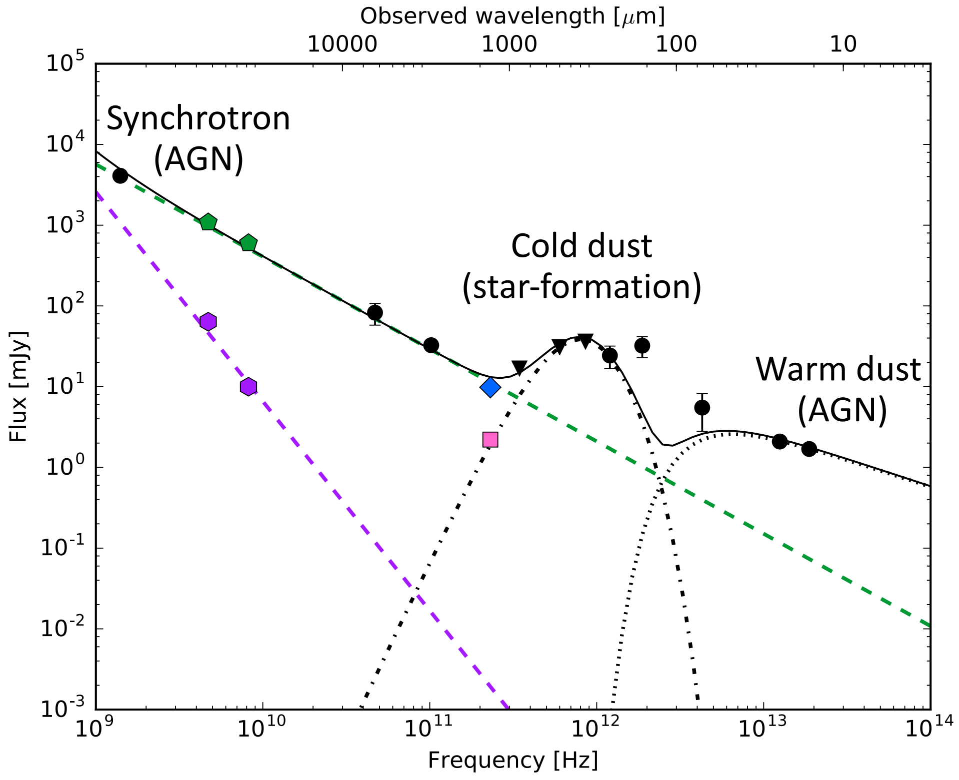
(Falkendal et al. in prep.)

- Fit with 5 models
  - 1 AGN
  - 2 mod BB
  - 2 synchrotron power laws
- 10 free parameters
- Assign ALMA data both mod. BB and Synchrotron

Mr-Moose, fitting example

radio and mm data





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- Fit with 5 models
  - 1 AGN
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New estimates when including ALMA and radio data

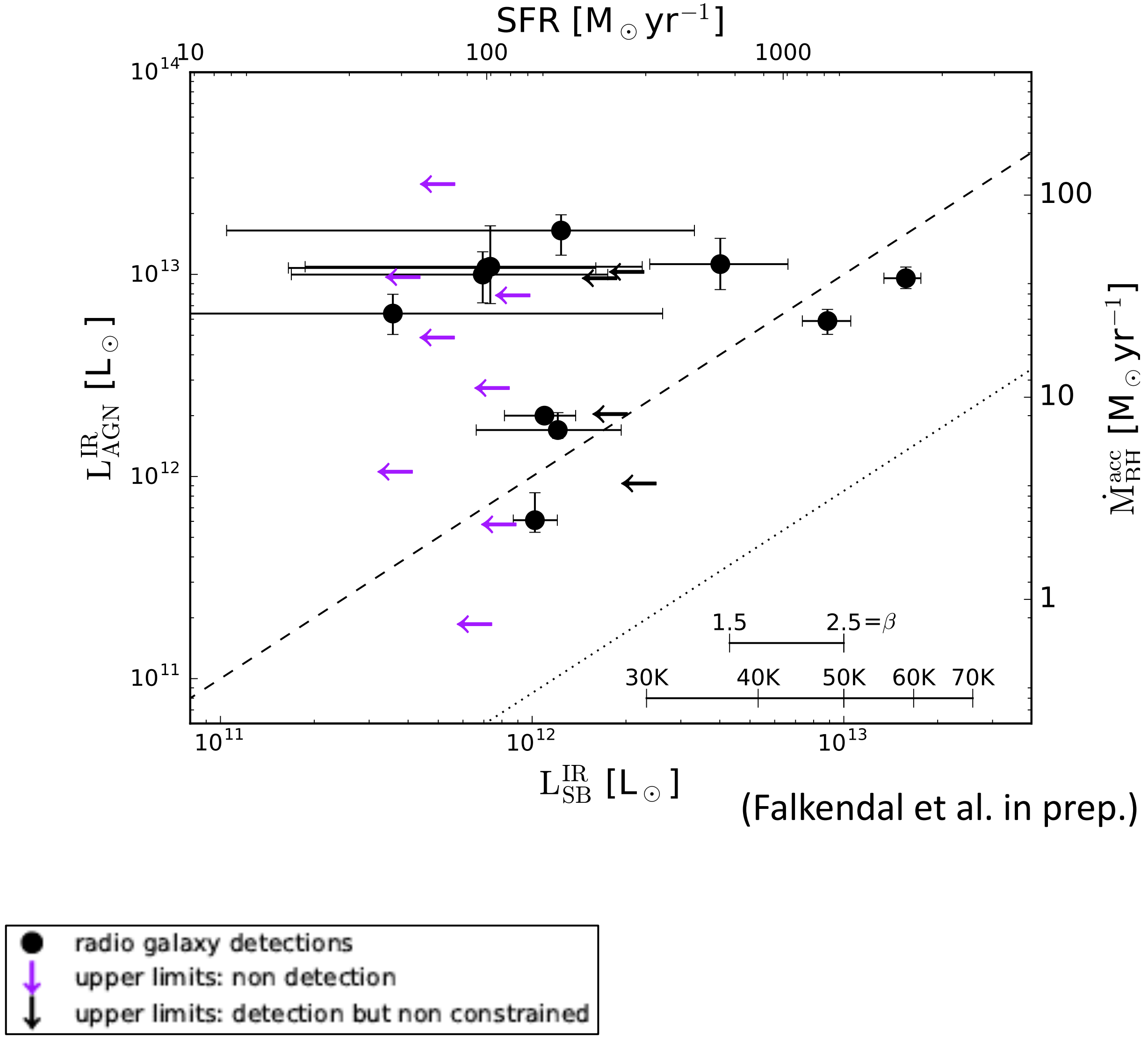
- L_{IR}^{AGN} and L_{IR}^{SB} integrated IR luminosity 8-1000 μm
- Get revised SFR using Kennicutt 1998 relation and L_{IR}^{SB}

→Find 3-5 times lower SFR then previously estimated with only low resolution *Herschel* data (Drouart et al. 2014)

- Stellar masses from De Breuck et al. 2010 and Drouart et al. 2016

  Compare to the Main Sequence of star forming galaxies

Host galaxy and AGN growth



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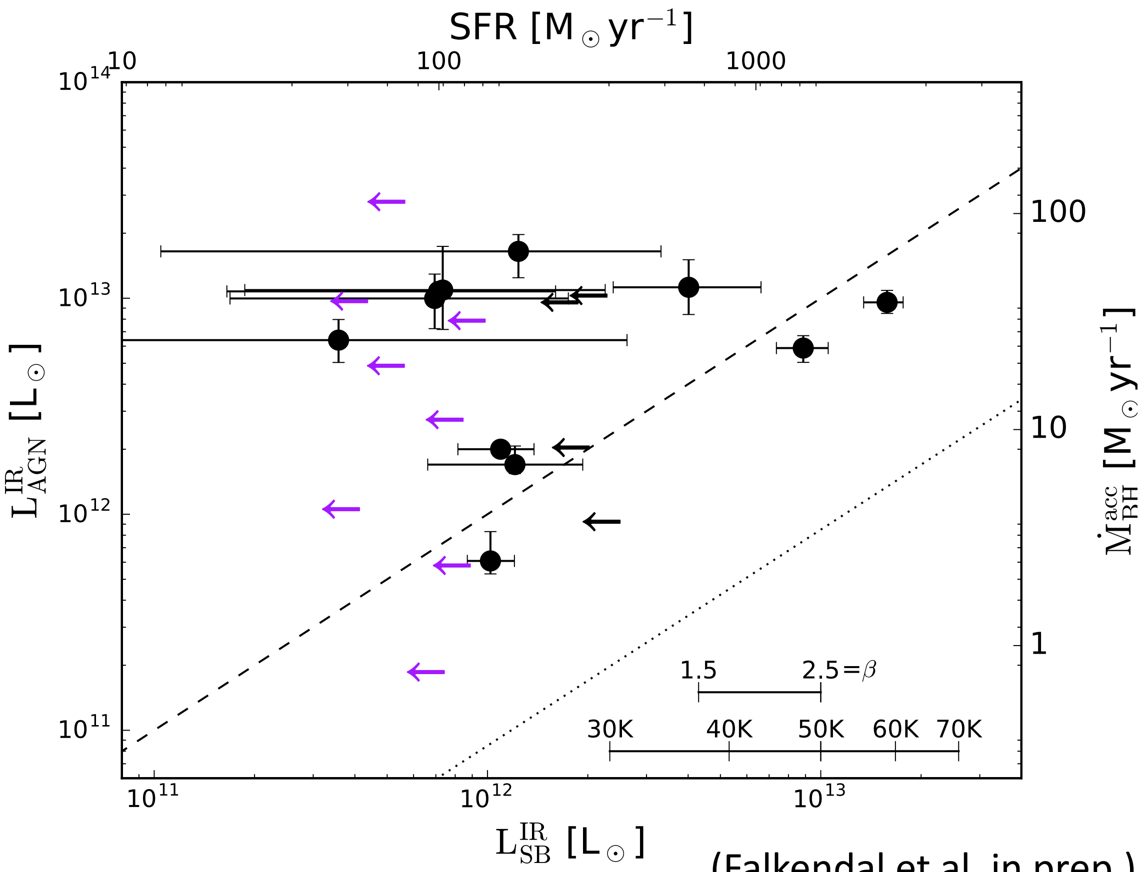
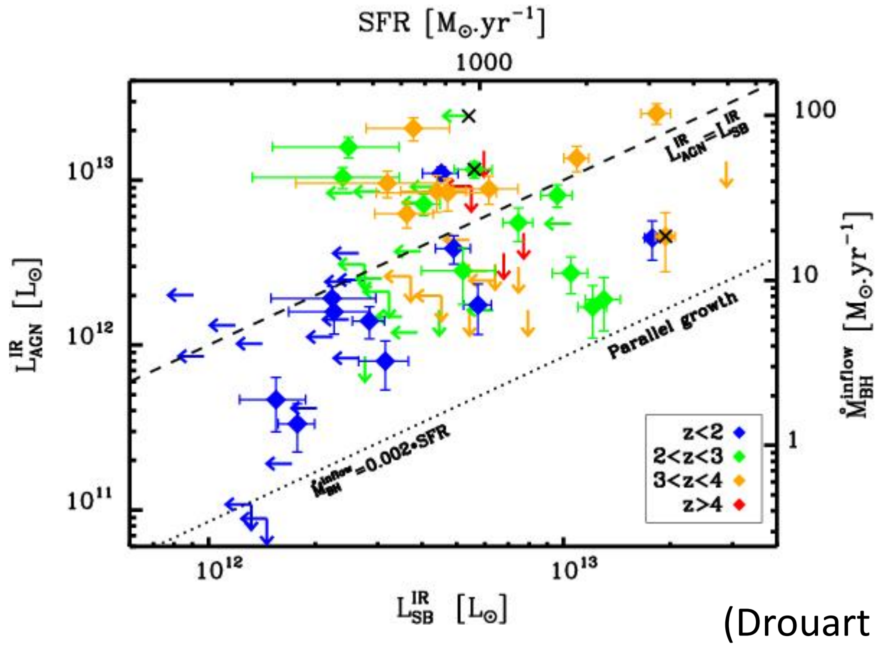
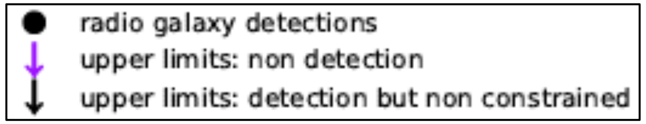


(Falkendal et al. in prep.)

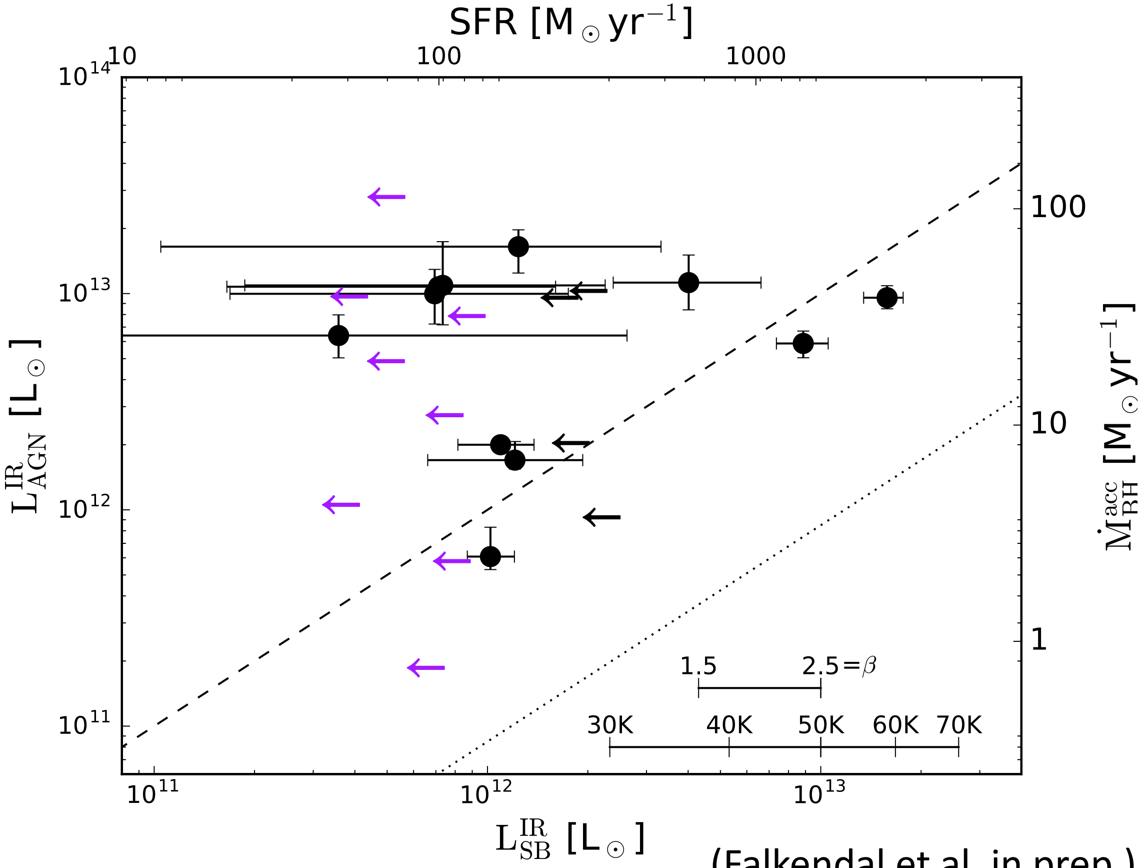
Previous work with only *Herschel* data



(Drouart et al. 2014)



Host galaxy and AGN growth



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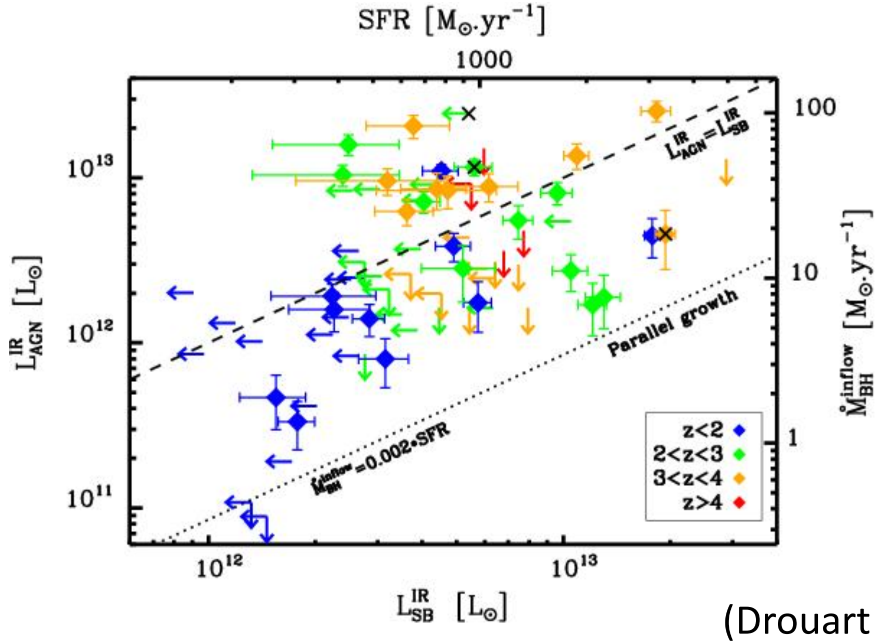

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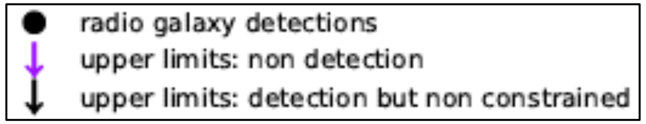
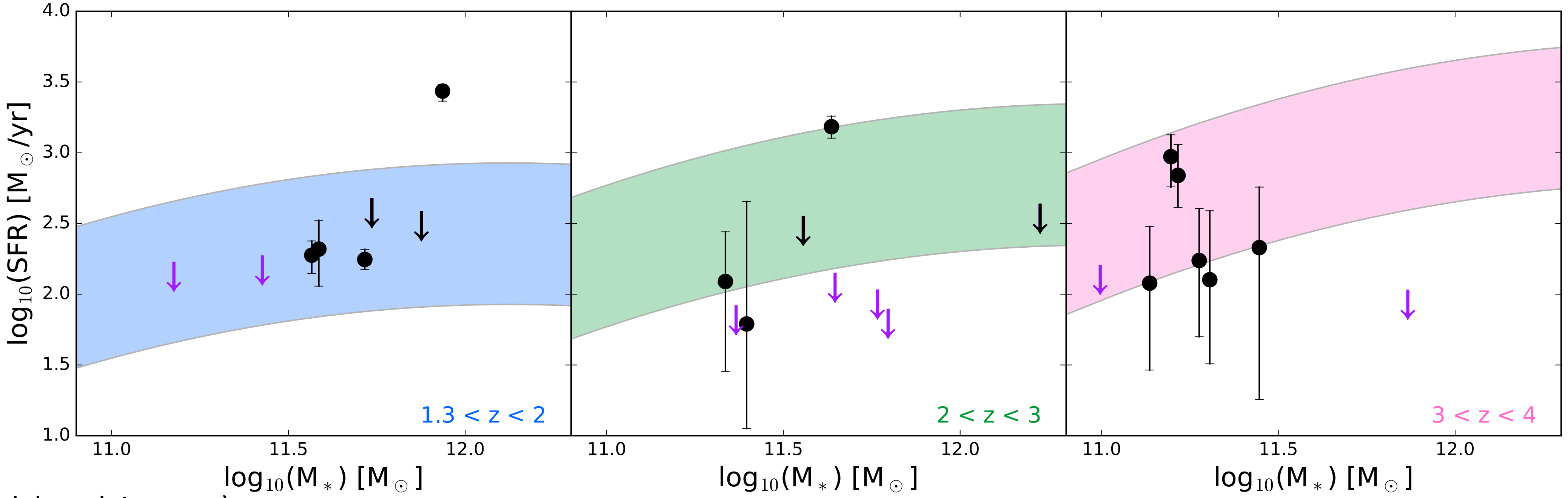


Still find that the SMBH are over massive in comparison to the host galaxy if they should follow the local relation

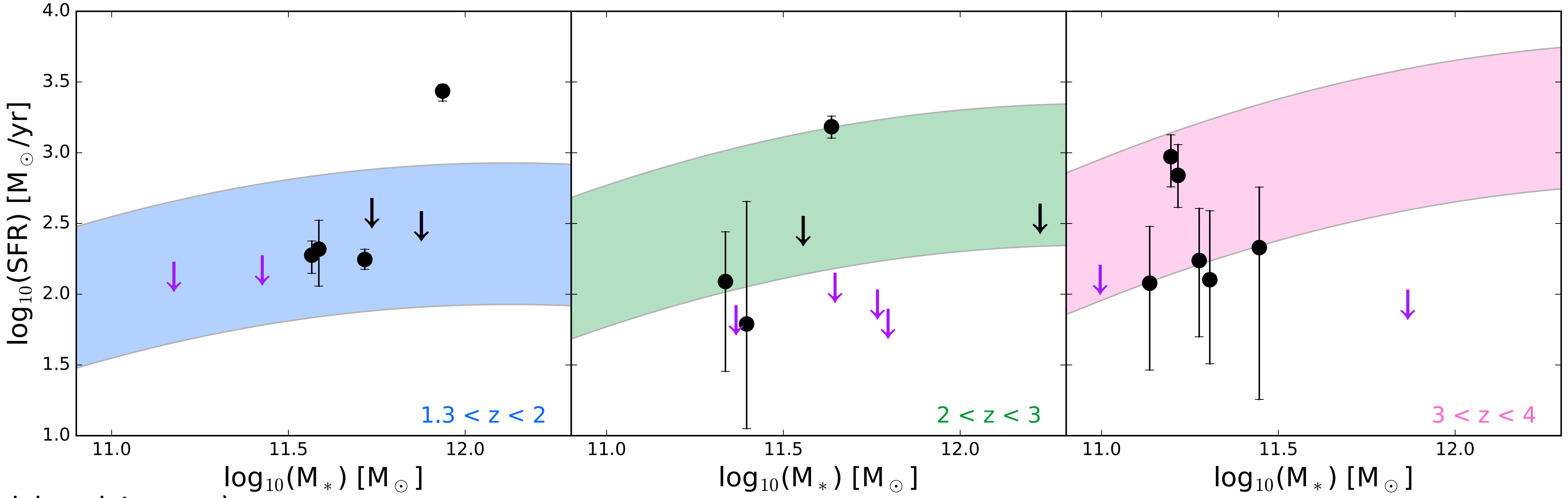
Sample of 25 radio galaxies in 3 redshift bins



MS from (Schreiber et al. 2015)

(Falkendal et al. in prep.)

Sample of 25 radio galaxies in 3 redshift bins



MS from (Schreiber et al. 2015)

(Falkendal et al. in prep.)

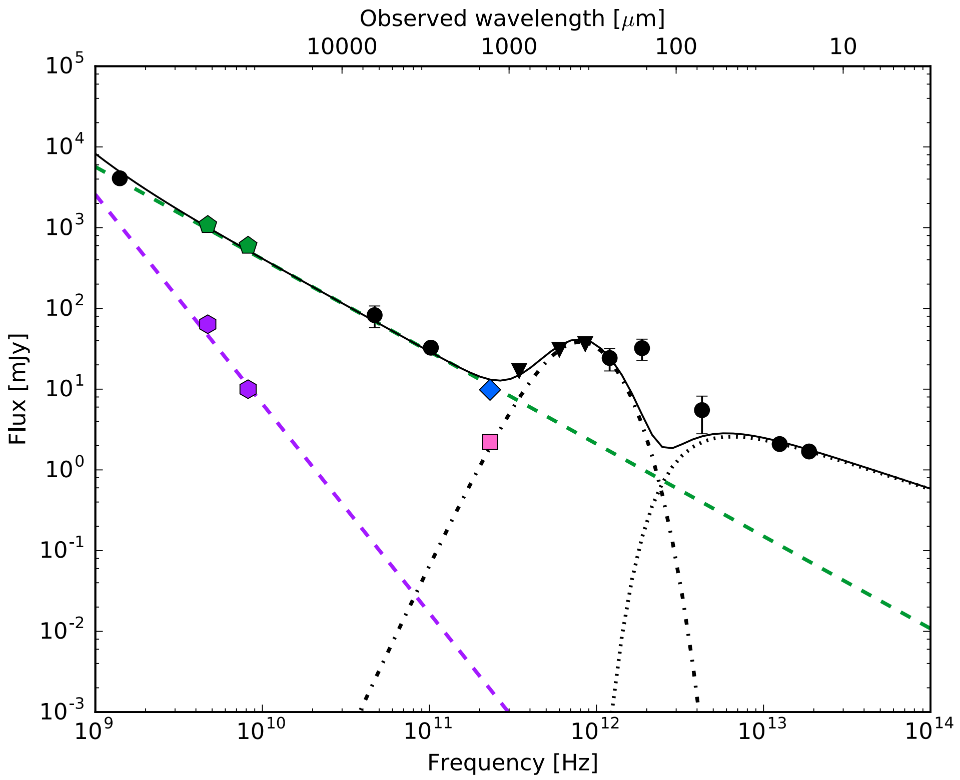
Find that the radio galaxies now lay on or below the MS

Summary

- ALMA band 6/3 data reveals a more complicated picture of the mm regime than previously thought
  - Multiple components
  - Emission from heated dust and synchrotron
- The AGNs are too massive and host galaxy have difficulties catching up
- Using the new SED code Mr-Moose we find that SFR are lower than previously estimated estimated from *Spire, Herschel* and LABOCA data
- The radio galaxies in our sample are no longer extreme star burst but rather quenched or on the road to being quenched

First two free parameters belonging to Mod. BB 1 completely unconstraint

Given total synchrotron contribution



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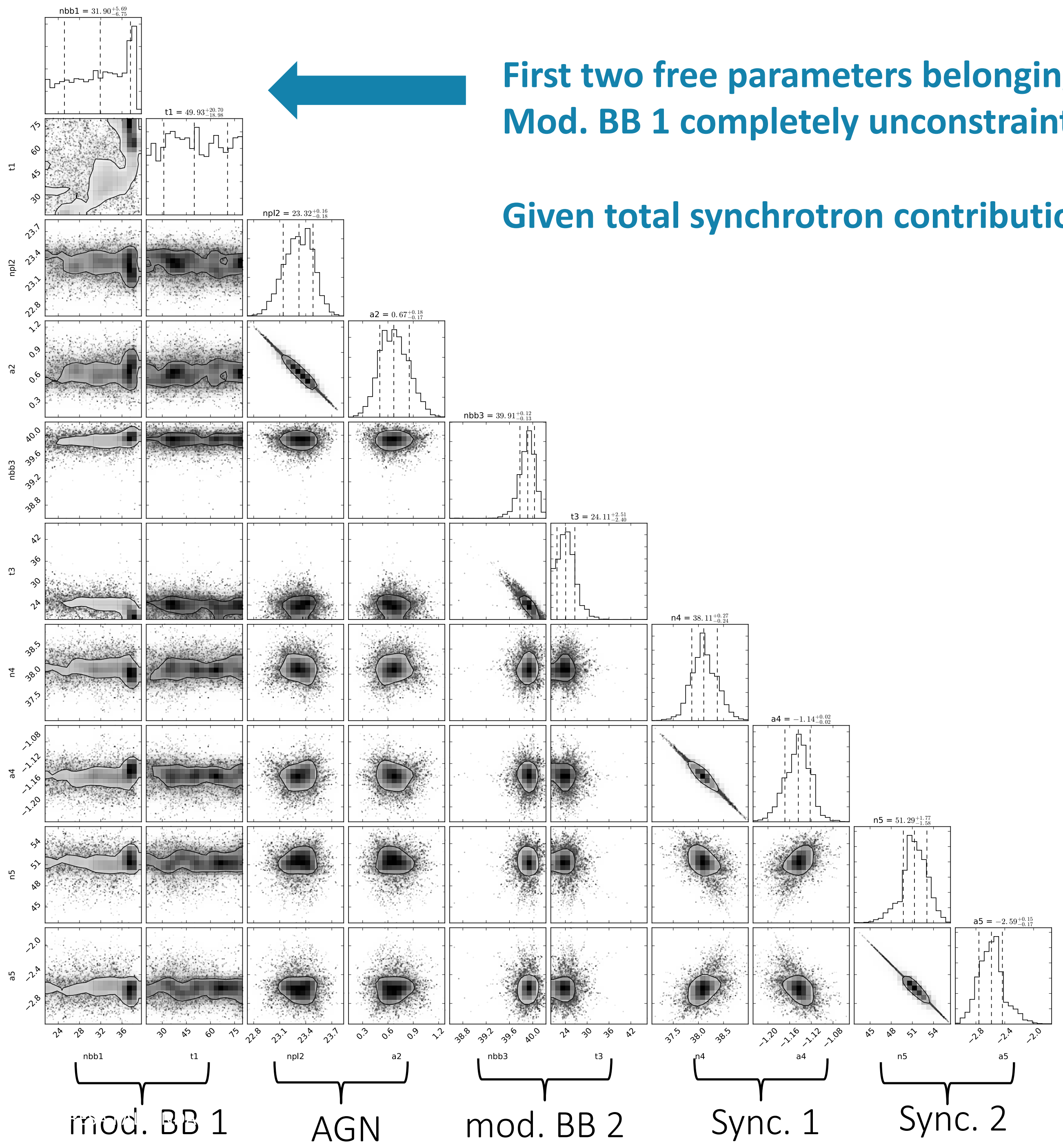
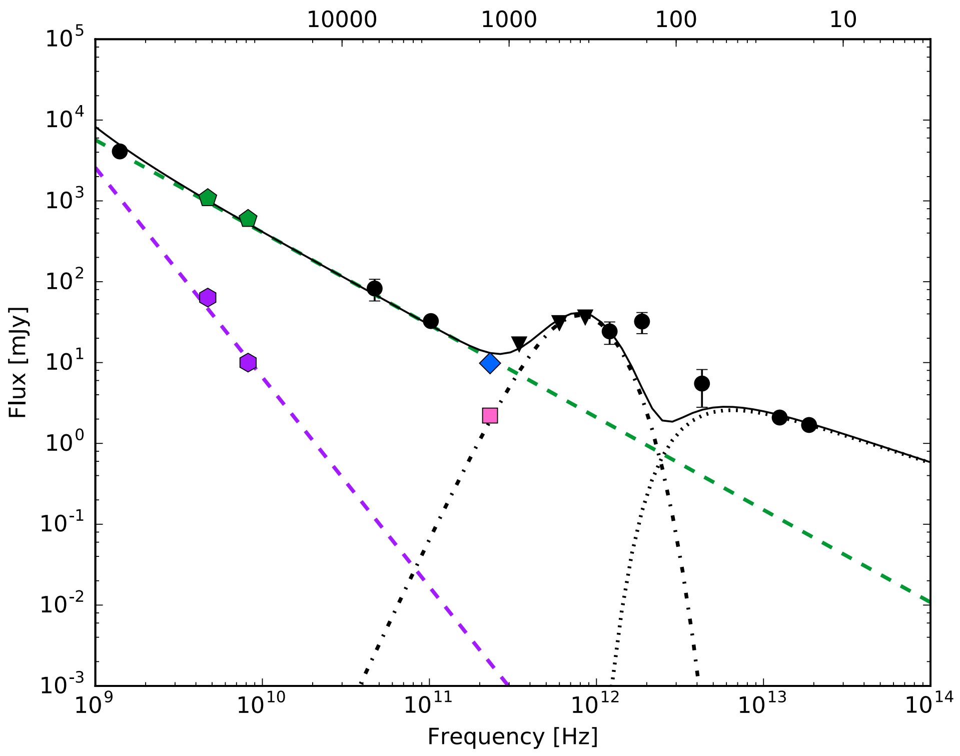


Best fit solution



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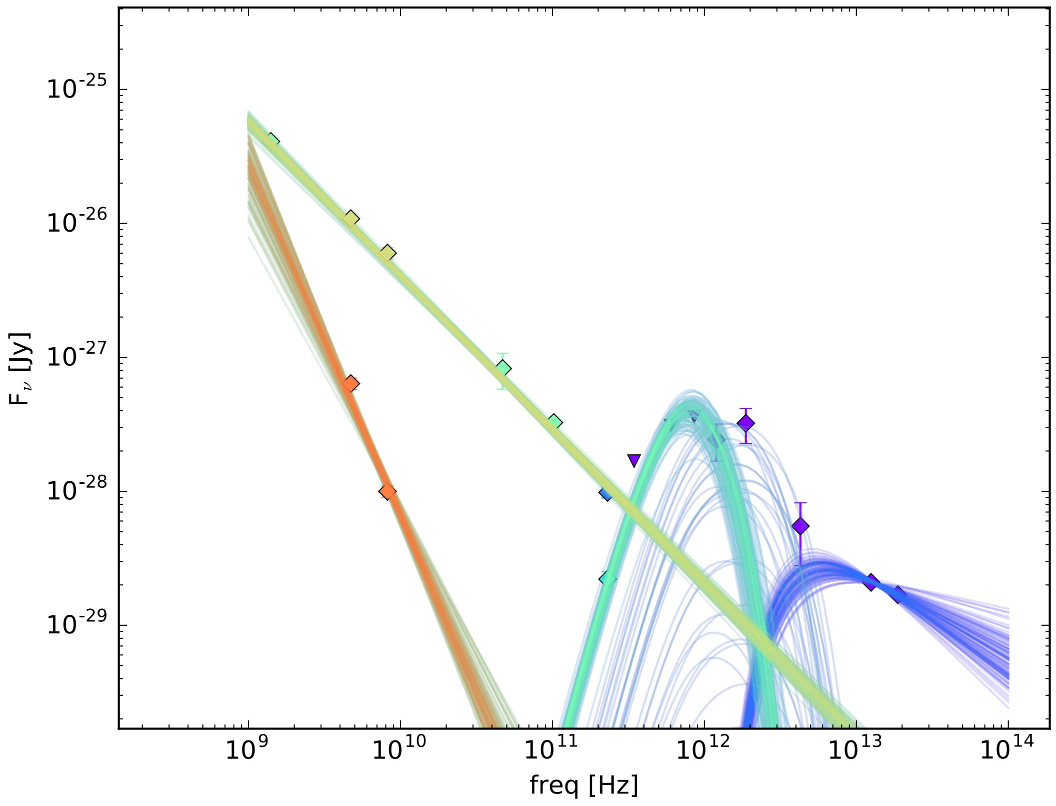
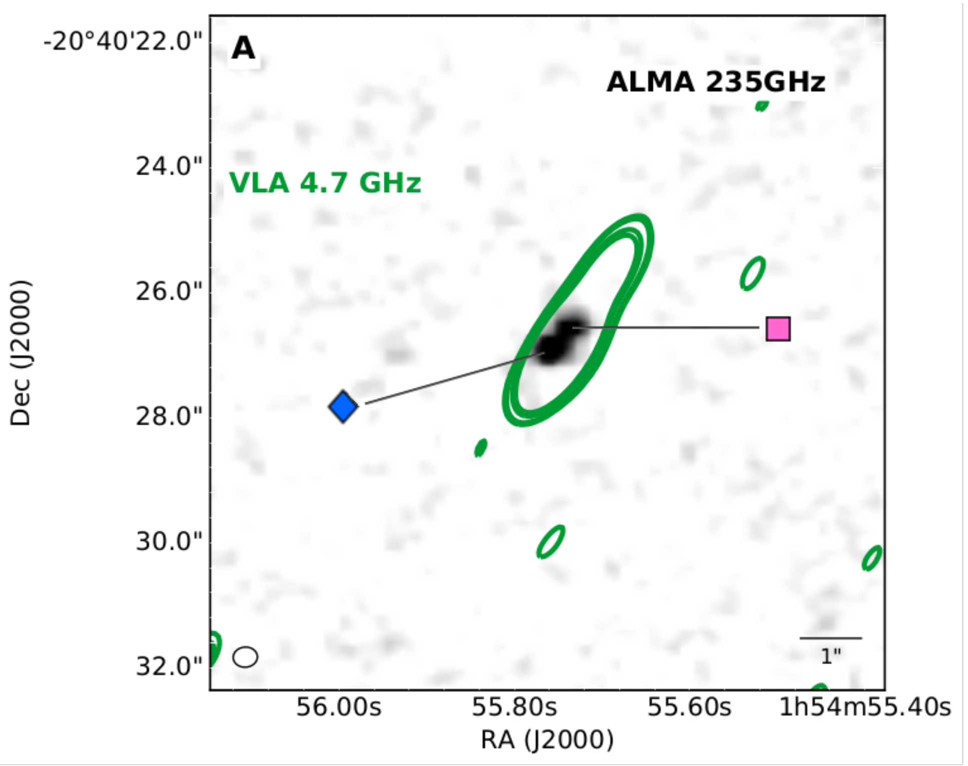
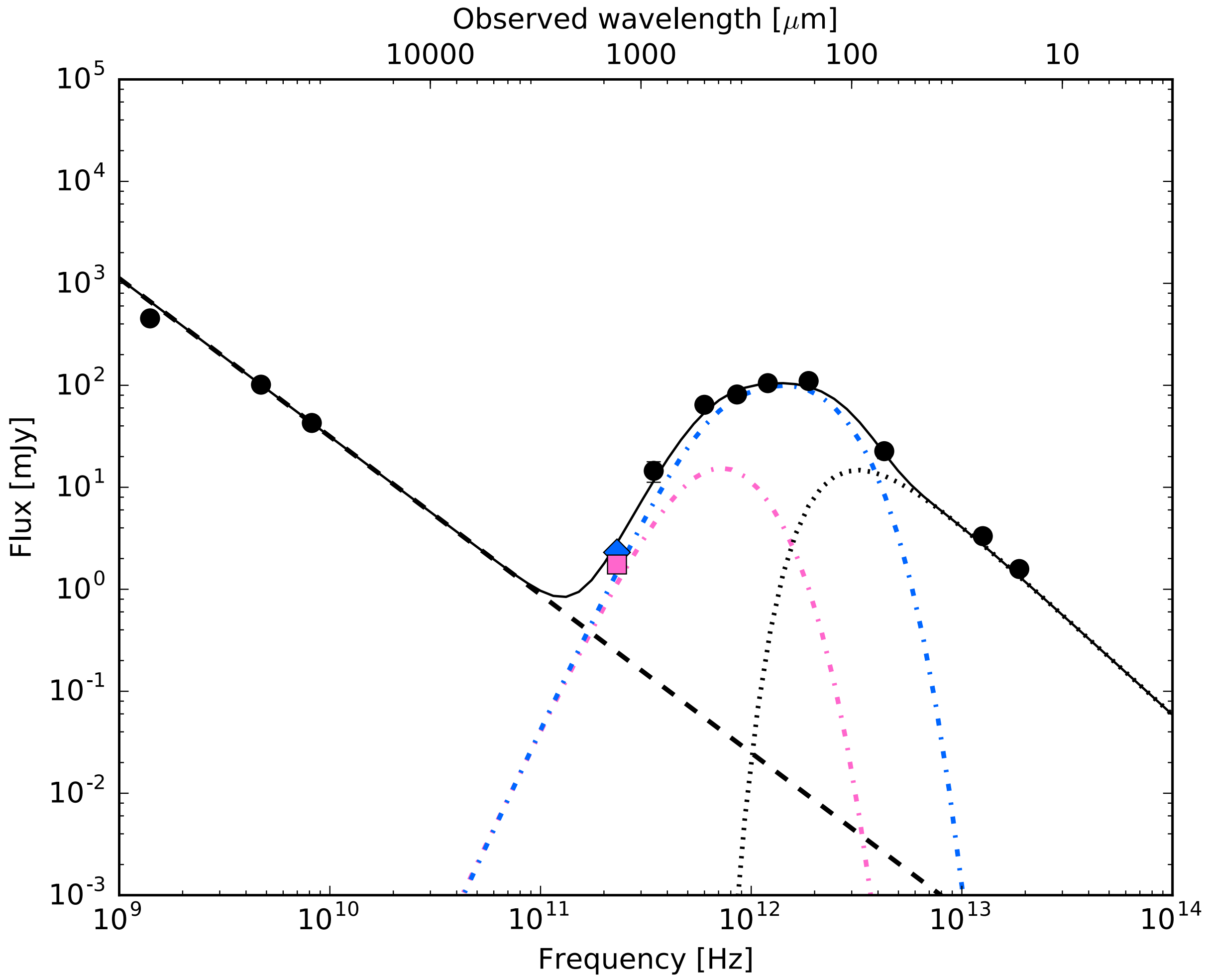
100 solutions drawn in the same plot

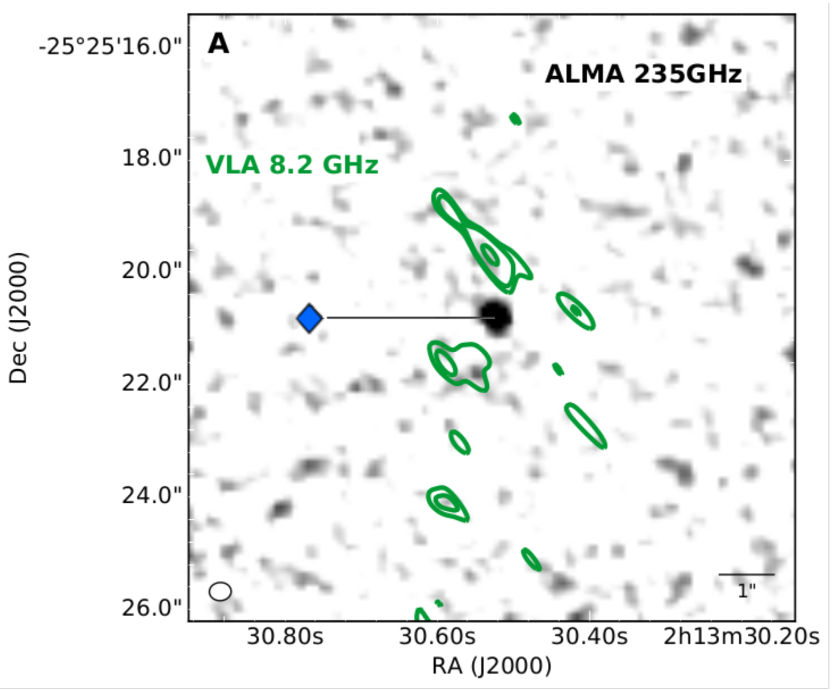


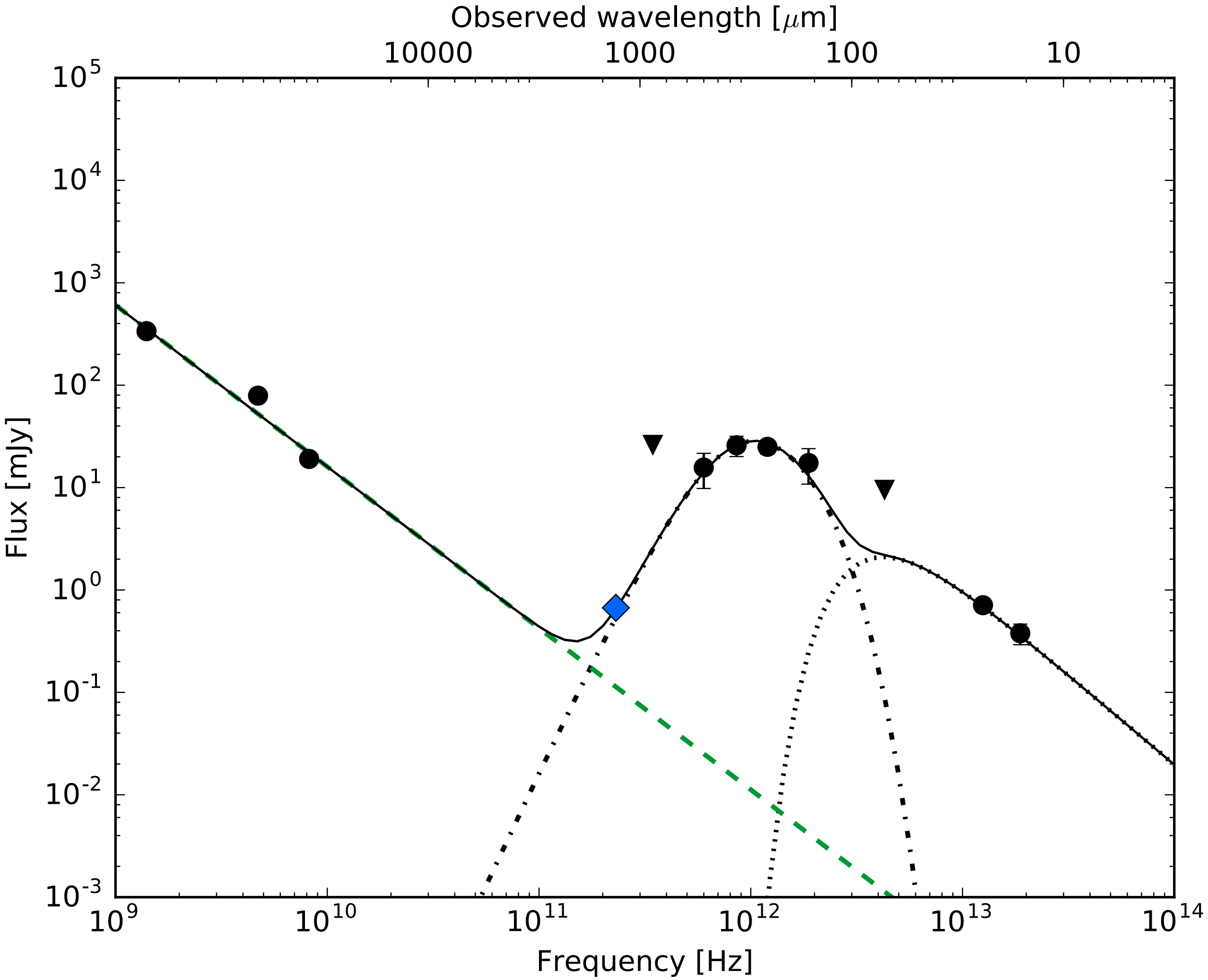
Two star forming components



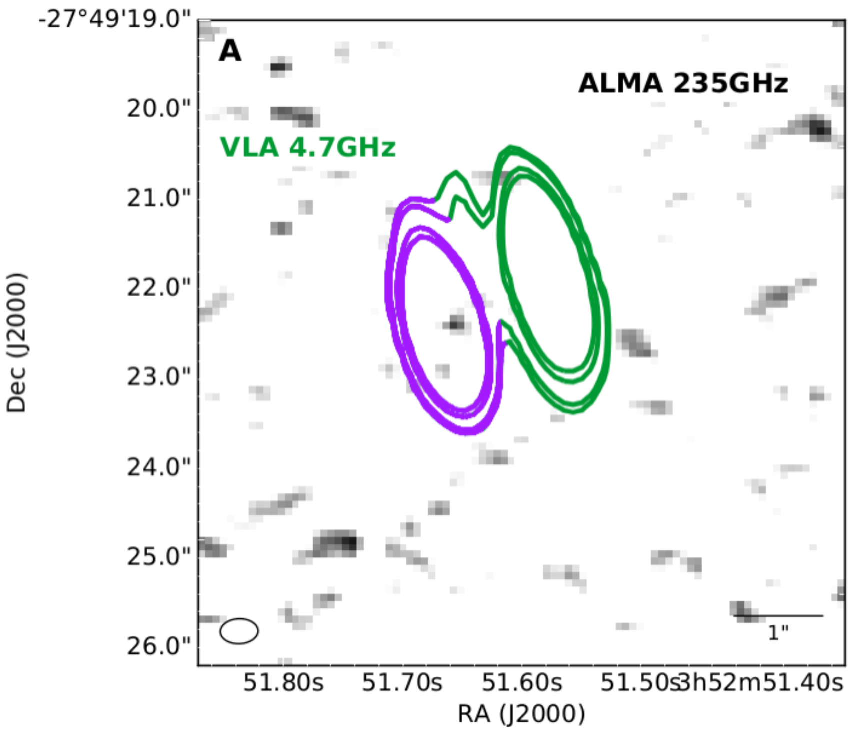


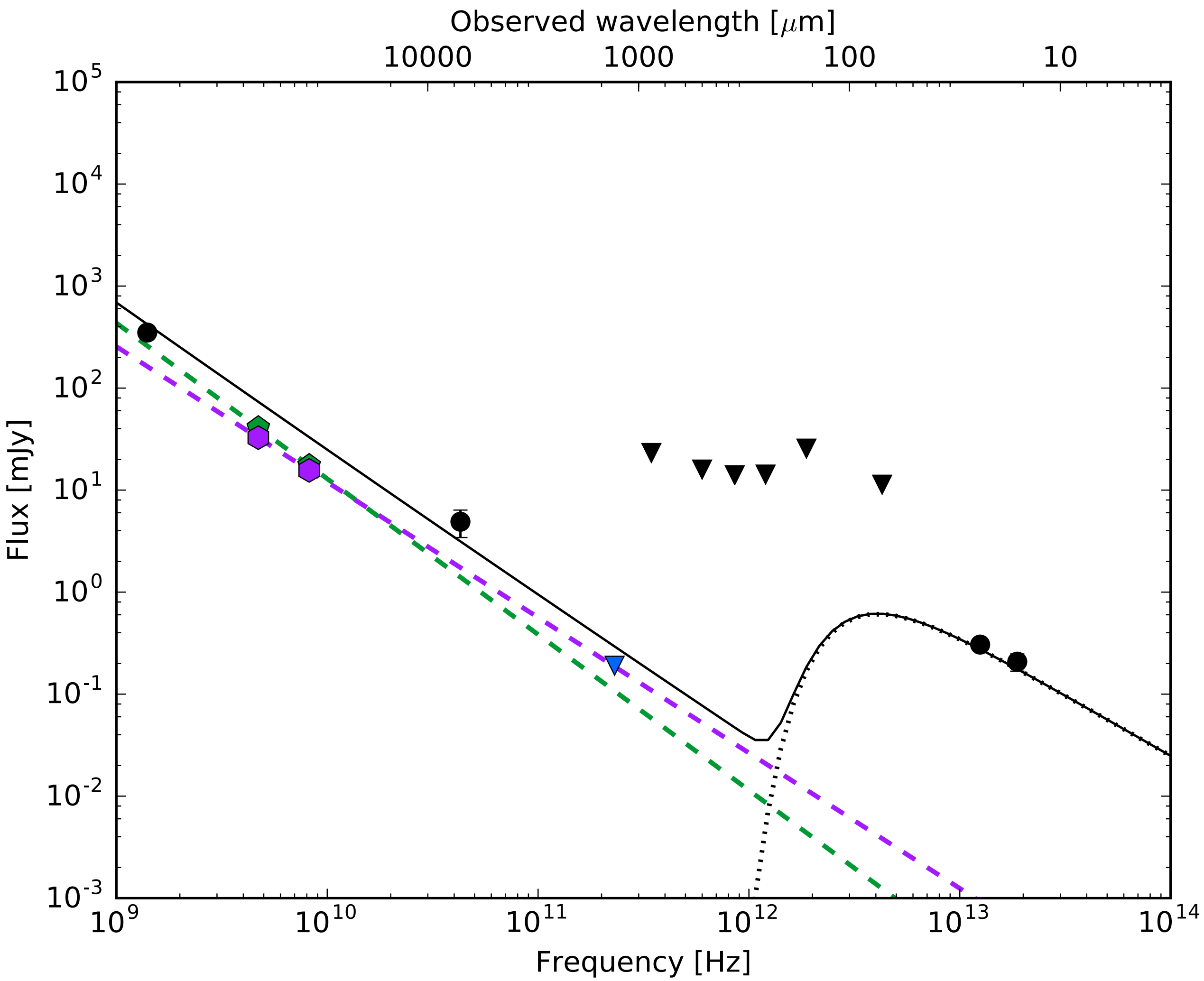
Single ALMA detection



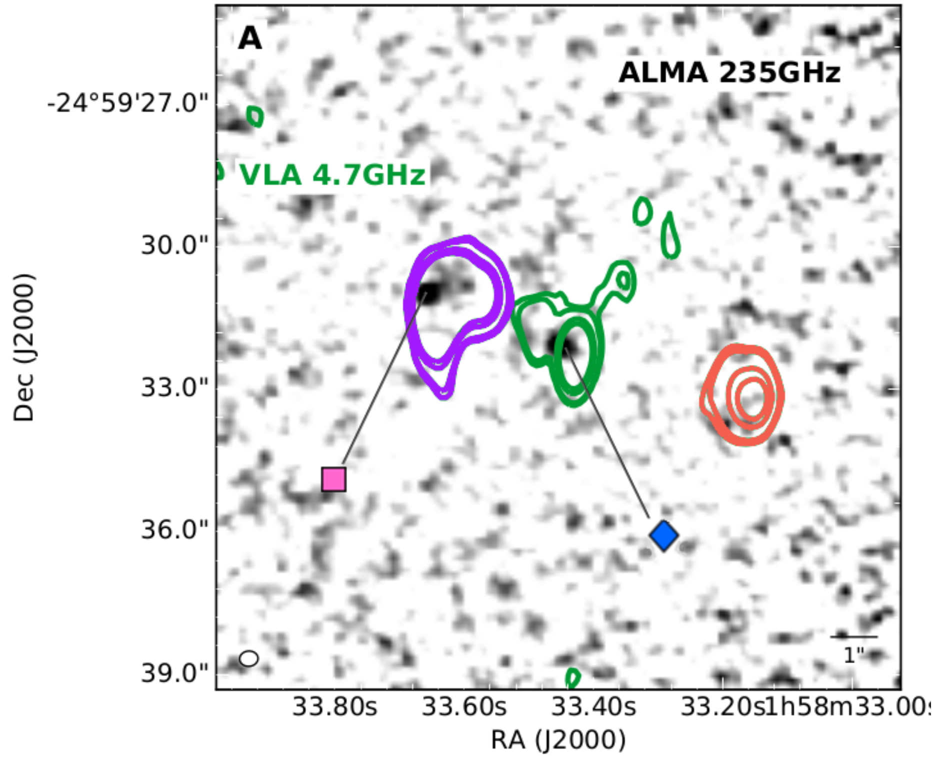


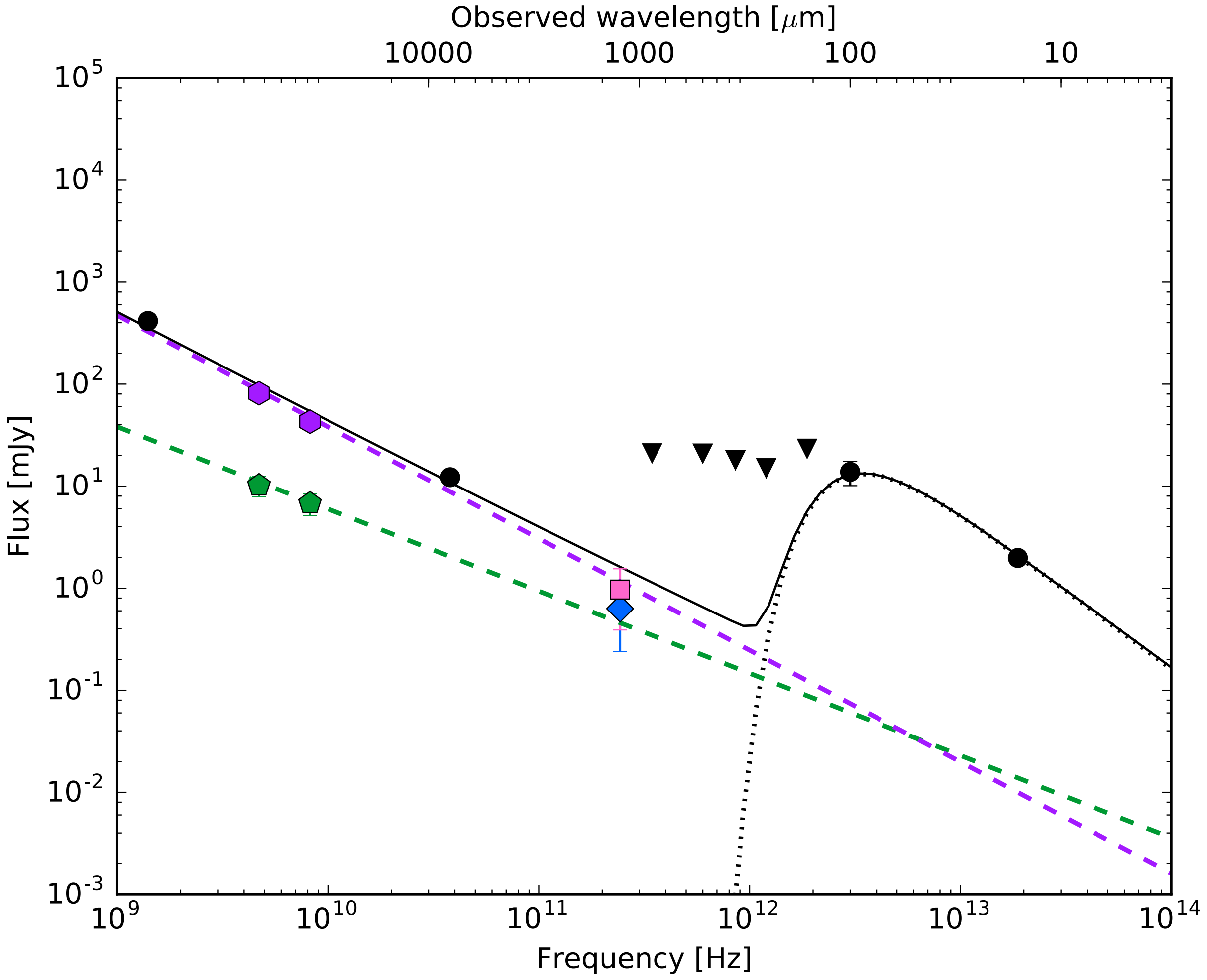
No ALMA detection





Two synchrotron components in ALMA?





(Drouart et al. 2014)