Millimeter Properties of Narrow-Line Seyfert 1 Galaxies

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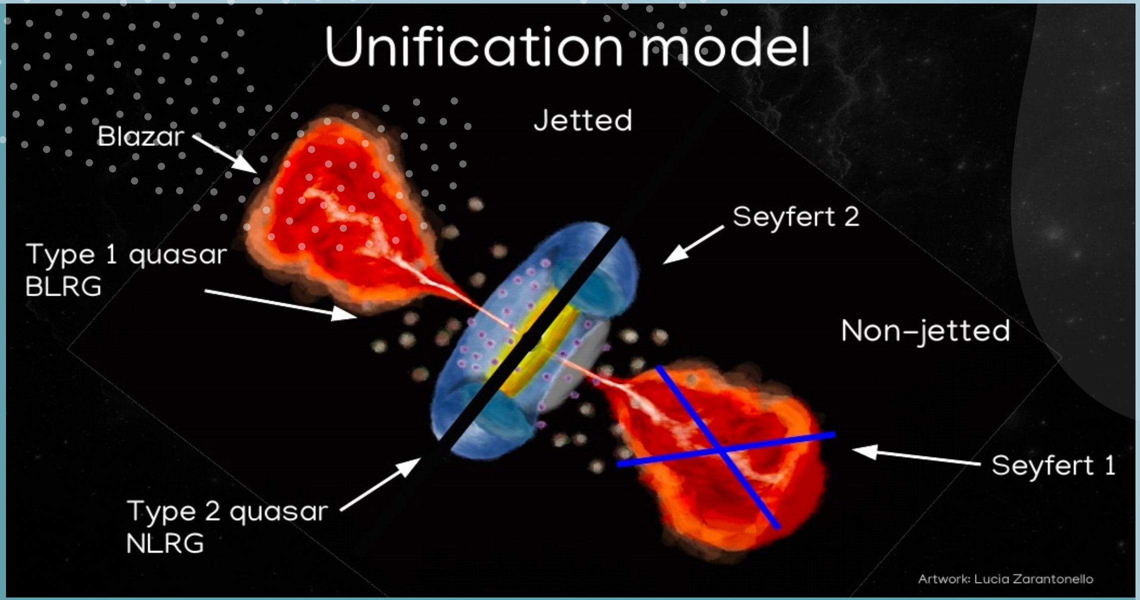
University of Oklahoma NSF-REU Program

In This Talk…

- Introduction: AGN and NLS1s
- Relativistic Jets, Variability
- Case of Unusual Sources
- About the IRAM 30m Telescope
- Data Reduction
- Radio Maps
- Calculating Spectral Index
- Results & Next Steps
- Citations & Special Thanks

What are Active Galactic Nuclei (AGN)?



- Center of galaxy with supermassive black hole that is actively accreting matter
- Extremely luminous and not from stars, radiation ranging across electromagnetic spectrum
  - Can outshine its entire host galaxy!
- Since their discovery they have been classified into many different categories, including quasars, blazars, Narrow-Line Seyfert 1 galaxies.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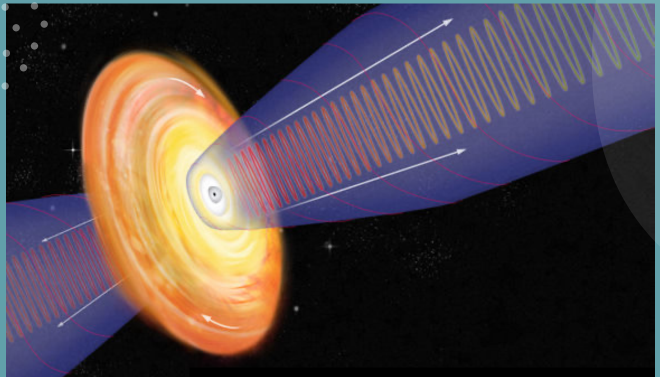
Narrow-Line Seyfert 1 Galaxies (NLS1s)

- Early-stage AGN
- Low-intermediate black hole masses ($<10^8$ solar masses)
- Permitted lines from broad-line region are narrow
- Strong X-ray emitters, but many not detected in radio
- Some strong radio sources with jets

Relativistic Jets and Variability

- **Relativistic Jets-** plasma accelerated and ejected from vicinity of black hole to beyond host galaxy
- Sources can have detected variability in different wavelengths
  - Time scales from days to years
  - Shortest variability time scale depends on size of region and relativistic Doppler factor



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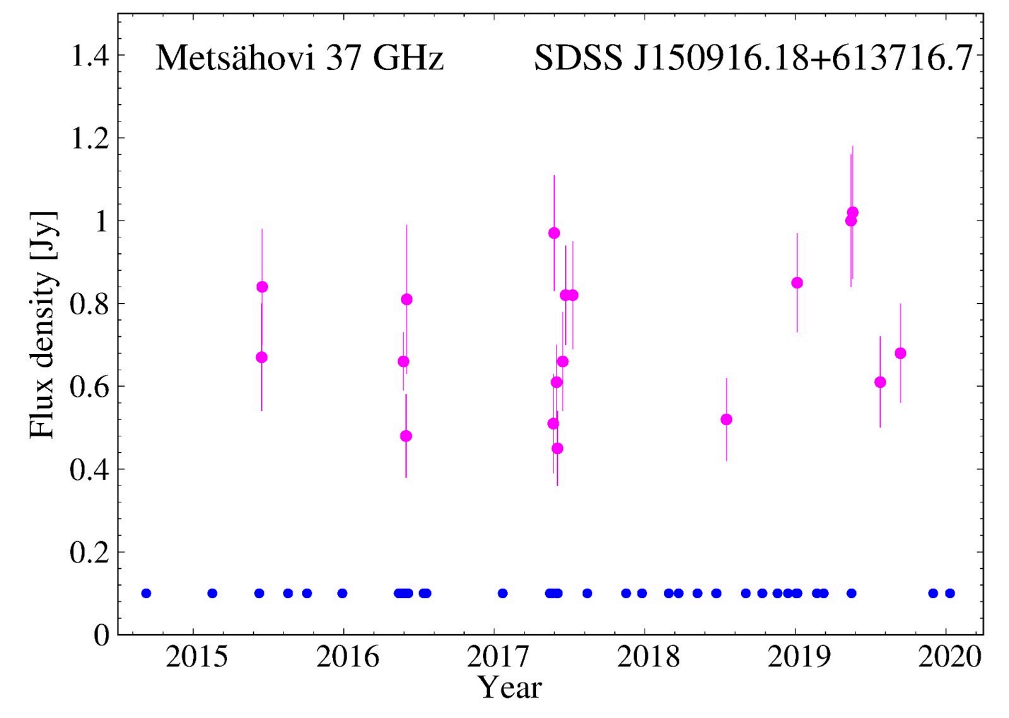
Unusual Sources

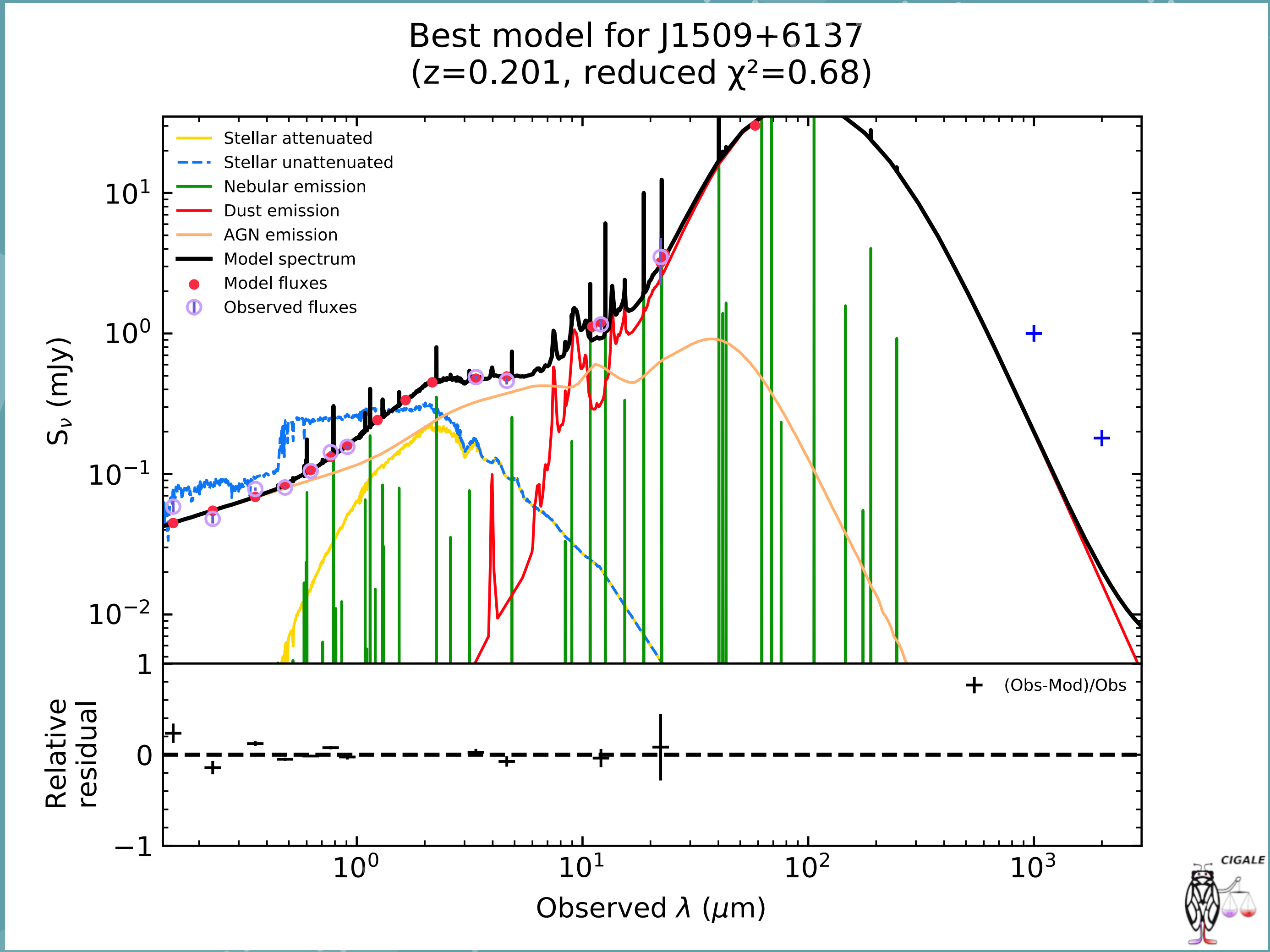


$$\Delta S(t) = \Delta S_{\max} e^{(t - t_{\max})/\tau}$$

How fast the flare rises or decays

- Sources weak in radio frequencies identified for recurring flares in 37 GHz (~8mm), over timescales ranging in days
  - Never observed in AGN in radio before!
  - Radio is usually in timescales of weeks or longer
  - High variability can indicate presence of jets
- Jets not detected at longer wavelengths
  - Synchrotron Self Absorption (SSA)
    - Photons emitted and absorbed by same field
  - Free Free Absorption (FFA)
    - Photons absorbed by external screen

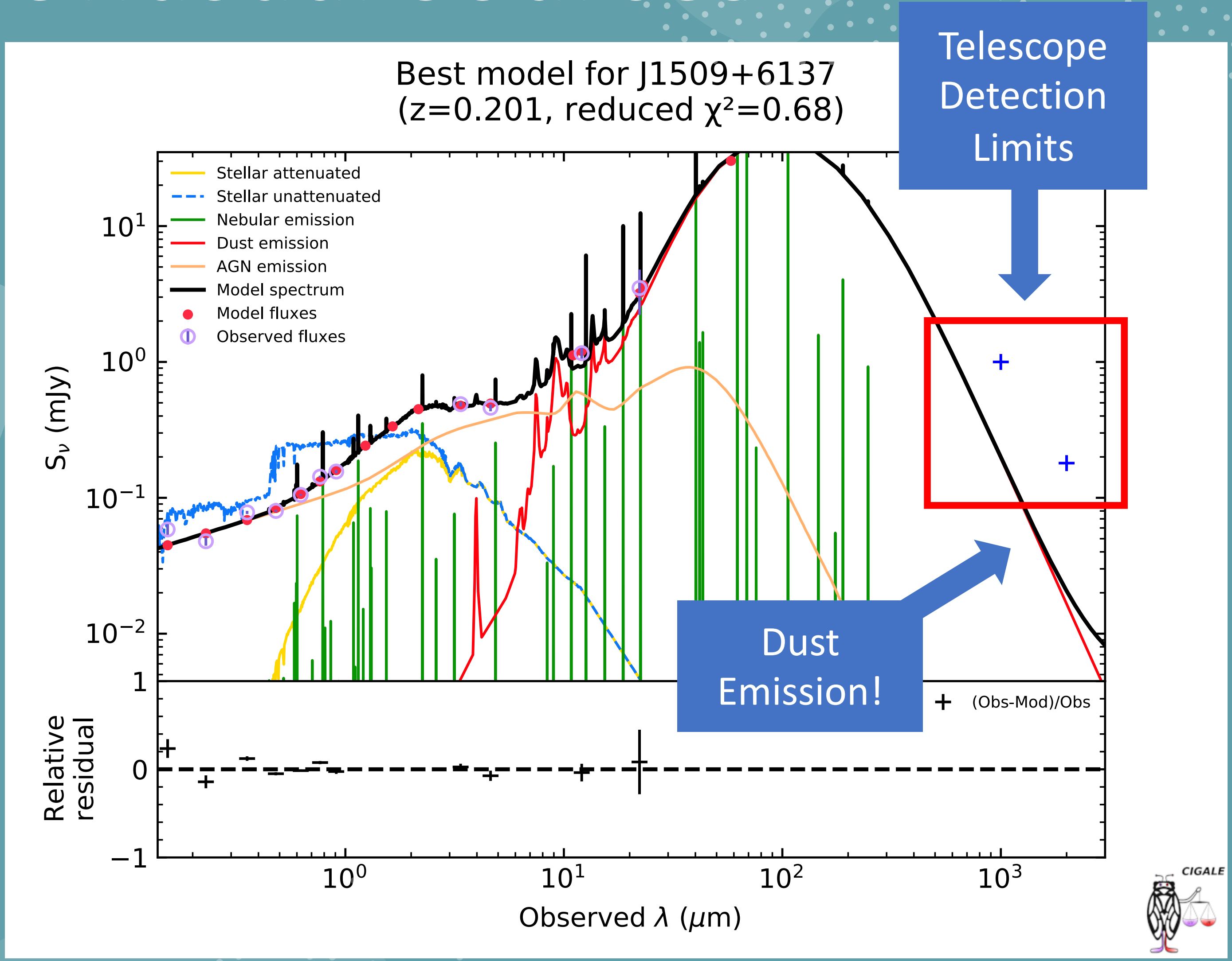
Unusual Sources



From Salomé, Quentin

- Could detect jets at shorter wavelengths (2 and 1.15mm or 150 and 260GHz)
  - Two wavelengths in order to get an idea of the shape of the spectrum
  - Inverted spectra = emission from dust, not jets

Unusual Sources



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IRAM 30-Meter Telescope, Spain

- Single-dish telescope scans small areas of the sky to create radio map
- NIKA2 camera – two wavelengths at once
- 3 Receivers
  - A1 + A3 for 1.15mm, A2 for 2mm

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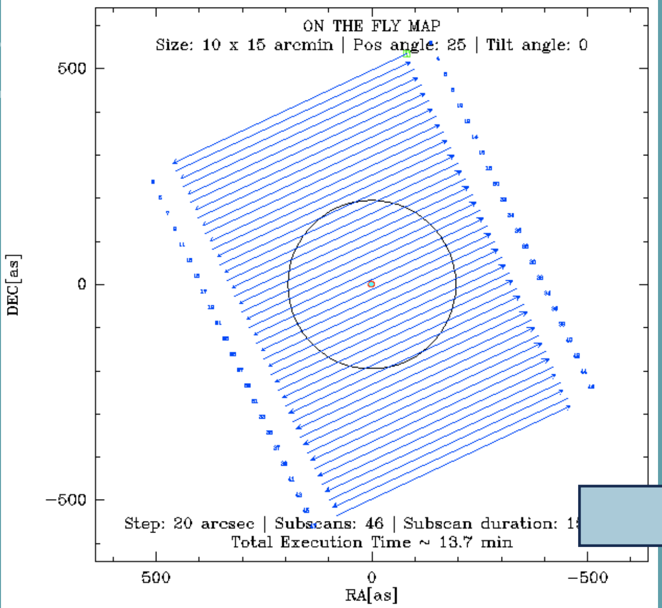


Pointing & Imaging In Continuum (PIIC) Pipelines

- Data reduction software for NIKA2
- Make scripts for each dataset
- Used Python to assemble datasets for each source + wavelength from archive of observations
- Some difficulties with PIIC

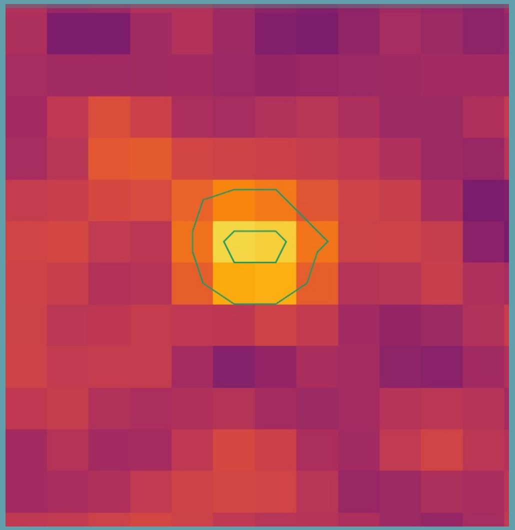
```
init inList
init outList
inDir  imbfitsDir
outDir red
inList "source_a"'nikaBand' ! e.g. Superantennae_a2, give without the default extension .LIST
select obs m                ! only maps
sort inList
list

!------------------------------------------- parameter setting ---------------------------------------

let weakSou   no    ! if yes signal >5*rmsOfNIKA2pixel (see above) masked after the sky noise subtraction

let deepField no    ! yes for e.g. GOODSNorth, COSMOS, HDF, DeepField1, ...

let souSign "+"     ! "-" if source with negative signal, e.g. SZ; "+-" if positive and negative sources

let posSeq " "      ! [H M S D AM AS] centre of the final (R.A.,DEC) map
                    ! necessary only if individual maps have different centres

let eqExtrAS    0.0 ! [arcsec] half map extent in EQ, 0 to calculate it (all maps must have the same centre)
let souRAoffAS  0.0 ! [arcsec] R.A. offset of the source relative to posSeq
let souDECoffAS 0.0 ! [arcsec] DEC  offset of the source relative to posSeq

let blOrderOrig 2   ! order of instability corrections in subscans, for compact sources >2 might be better

let nIterSource 20  ! number of iterations; higher values might be necessary

if nIterSource.ge.1 then
   let rZmEq 0.0    ! [arcsec] if >0 outside of this radius the data of the iterative source are neglected
   let polZmEq " "  ! [arcsec] relative to posSeq, action as for rZmEq but using this polygon
   let smSNRpar 0.0 ! if >0 S/N is calculated using the smoothed map but the iterative source not smoothed,
                    ! if <0 also the iterative source smoothed; the ITERATIVE MAPS ARE NEVER SMOOTHED
end if

@ mapTPoptionalSets
pause main
```

Example of data reduction script: default template plus few custom parameters. Berta, Stefano and Zylka, Robert

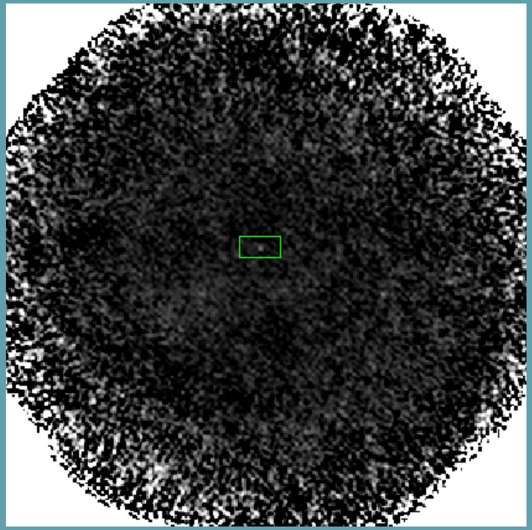
Radio Maps

Final Maps

- Point-like sources
- Add contours for calculating peak flux density



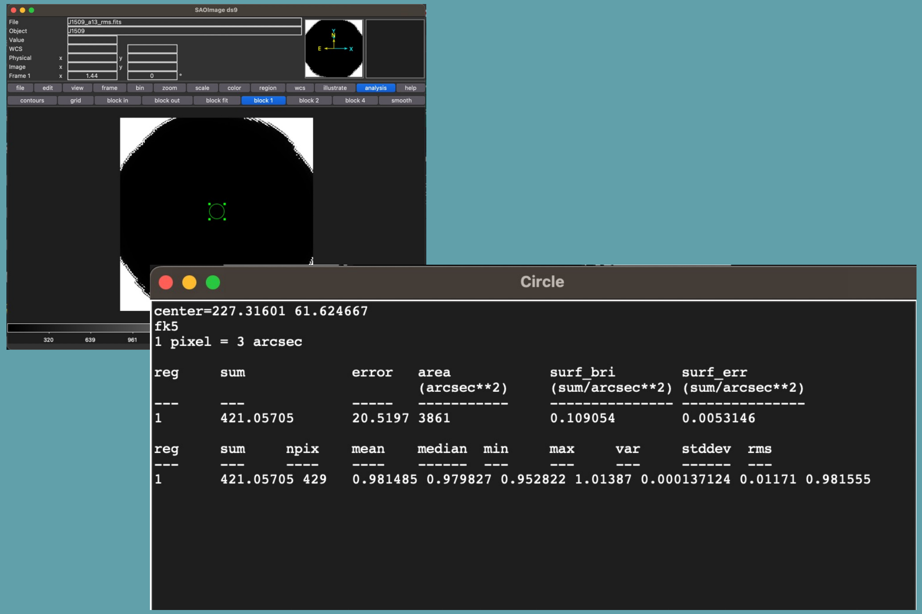
J1509 Contour map plotted with CARTA



J1509 radio map plotted with DS9

RMS Maps

- Allow us to measure RMS to determine detections or limit noise

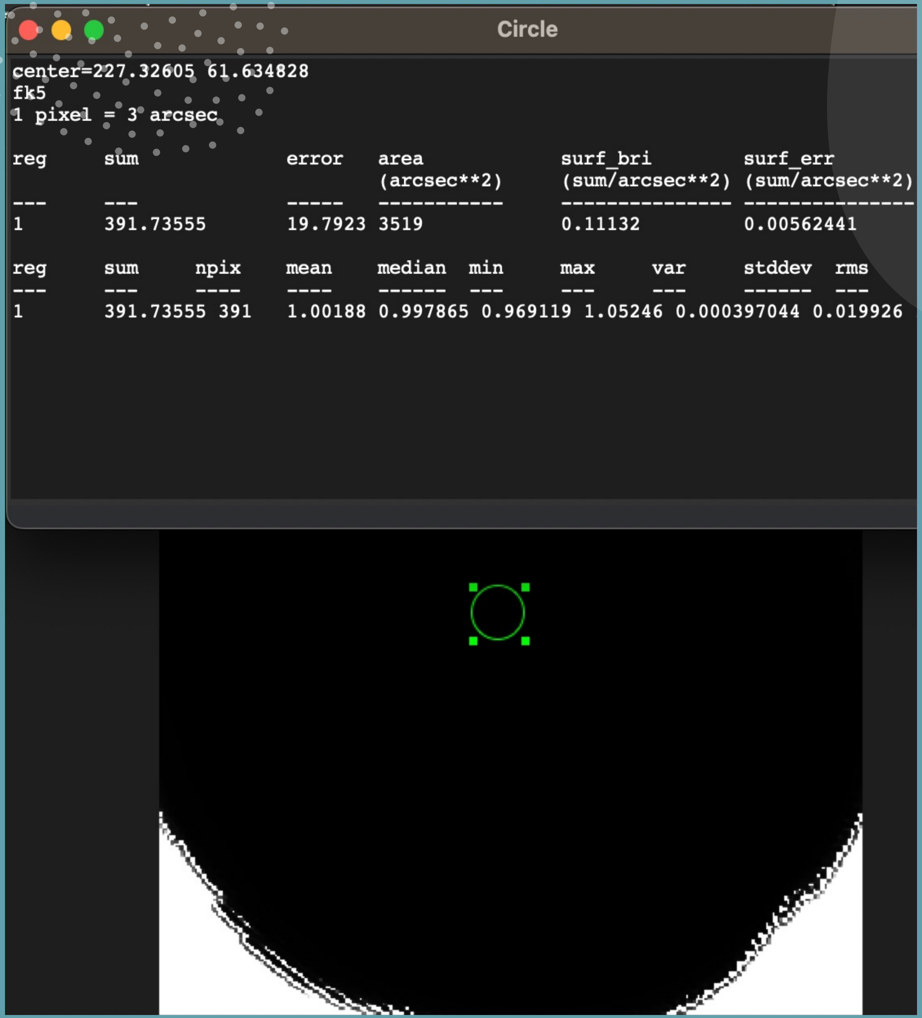


J1509 statistics made with DS9

Imaging software used: DS9, CARTA and CASA

Finding Spectral Index

- Measure RMS, we use 3-sigma detection limit
- Plot contour map
- Use to find peak flux density per beam
    - Point source so only peak flux density matters



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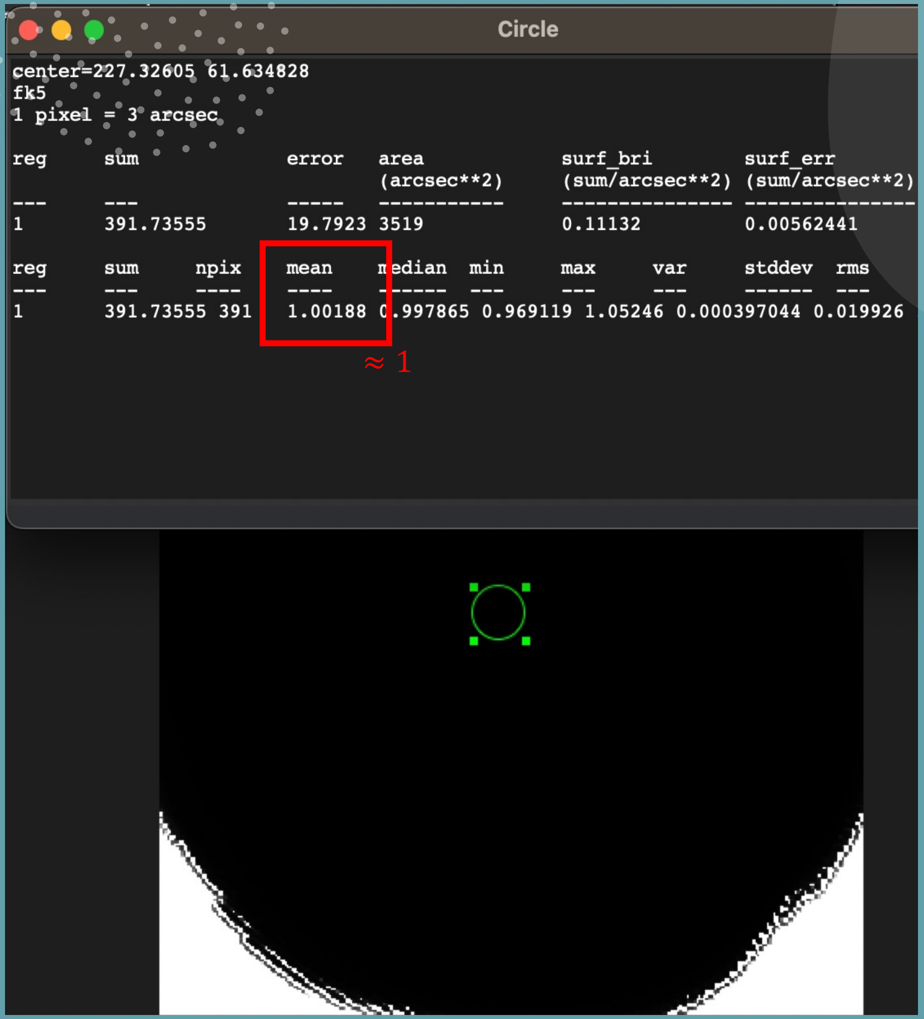

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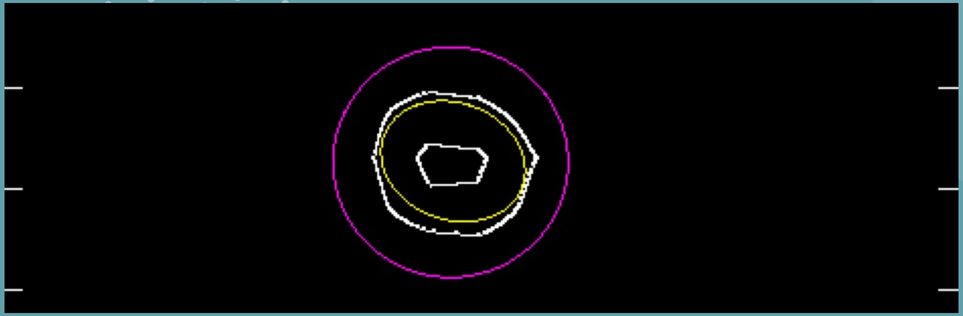

Contour map and statistics plotted with CASA

Image component size (convolved with beam) ---
--- major axis FWHM: 8.74 +/- 0.76 arcsec
--- minor axis FWHM: 6.94 +/- 0.44 arcsec
--- position angle: 70 +/- 11 deg

Clean beam size ---
--- major axis FWHM: 11.60 arcsec
--- minor axis FWHM: 11.60 arcsec
--- position angle: 90.00 deg
Image component size (deconvolved from beam) ---
Could not deconvolve source from beam. Source may be (only marginally) resolved in only one direction.
Flux ---
--- Integrated: 3.43 +/- 0.60 mJy
--- Peak: 7.62 +/- 0.56 mJy/beam
--- Polarization:

Spectrum ---

Imaging software used: DS9, CARTA and CASA

Finding Spectral Index

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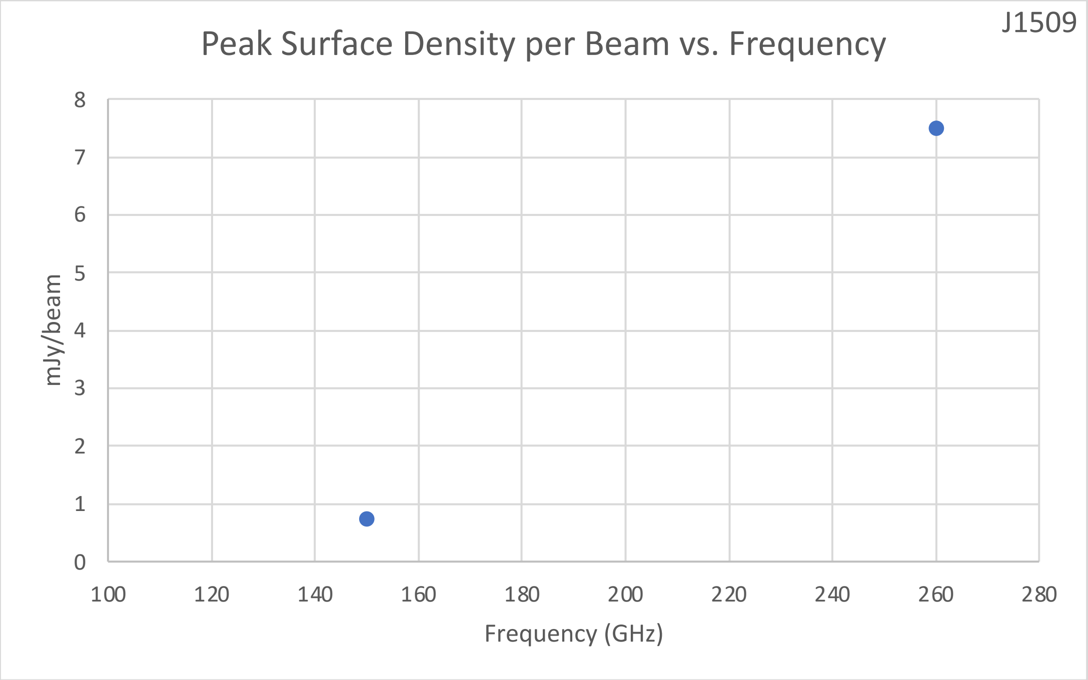
Contour map and statistics plotted with CASA

Finding Spectral Index

- Use equation to calculate spectral index **α** (log base 10):

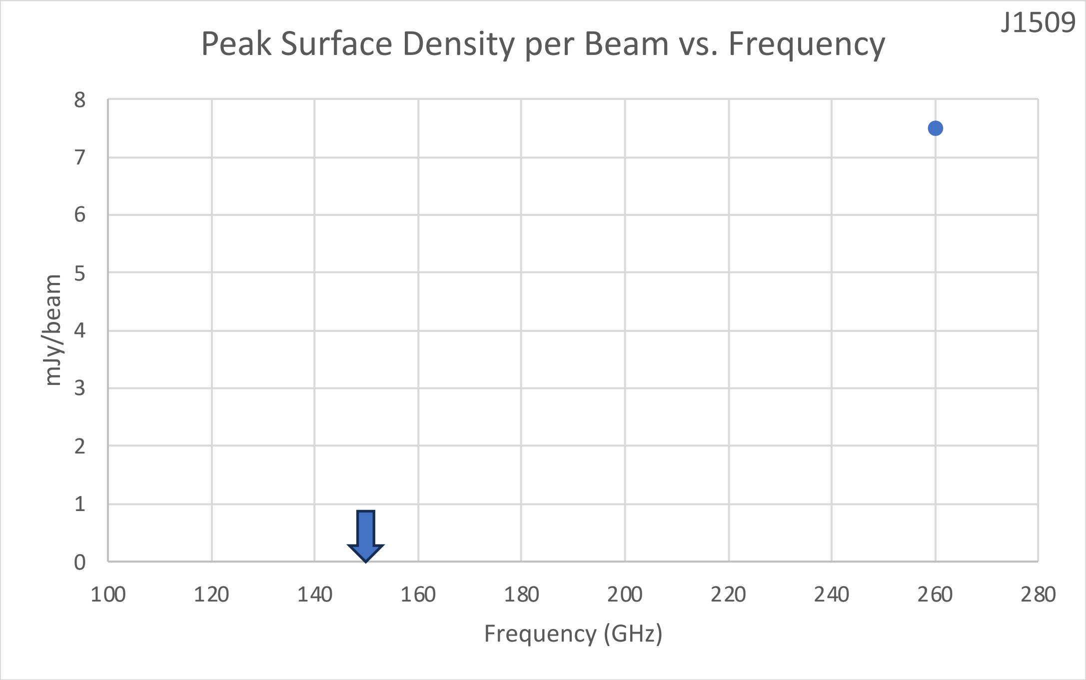
$$\alpha = \frac{\log(\frac{s_1}{s_2})}{\log(\frac{\nu_1}{\nu_2})}$$

  - s indicates peak flux density per beam
  - ν indicates frequency



What if only one detection is made?

- Can still get upper limits from data
  - Receivers cannot pick up weaker emission!
- Use RMS map
  - Upper limit = $3 * RMS$ for 3-sigma detection limit



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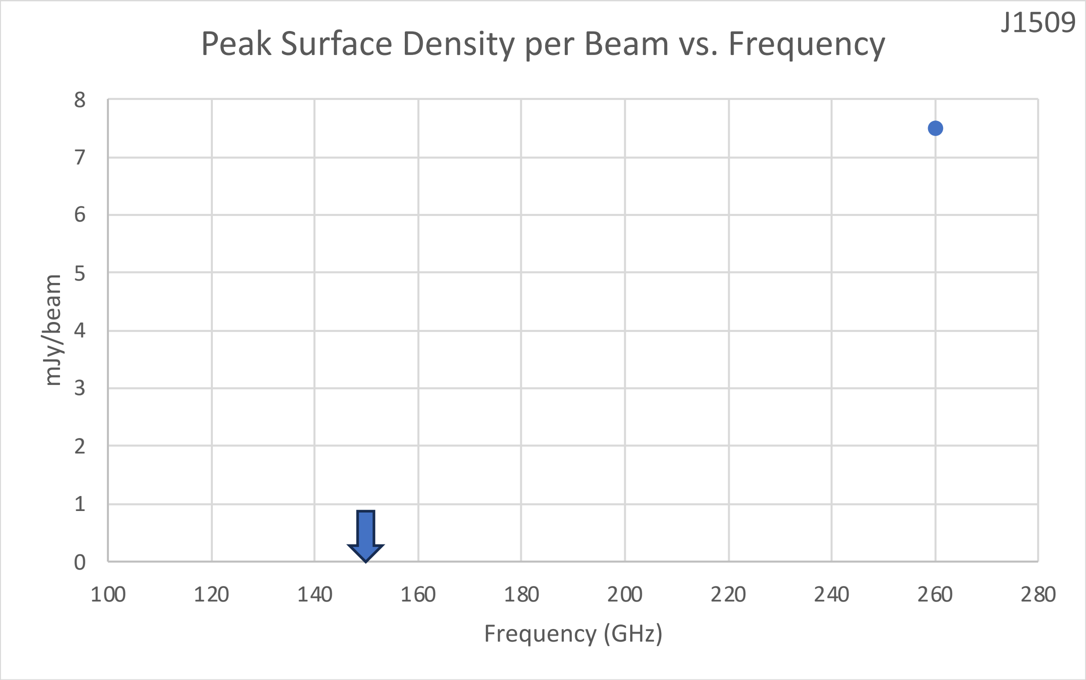

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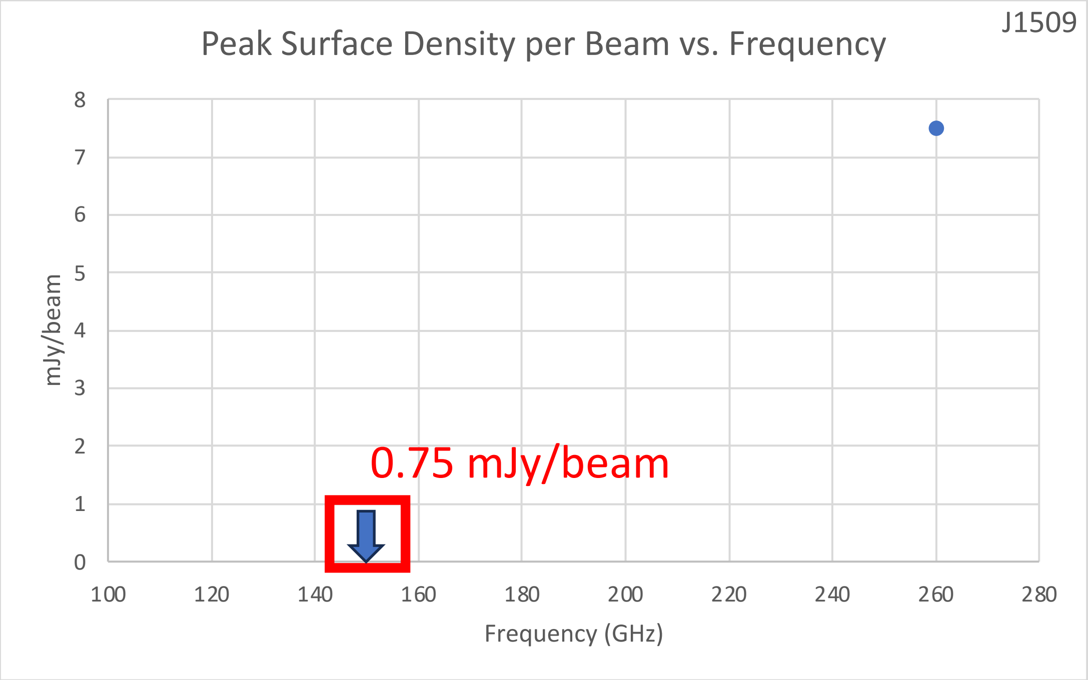

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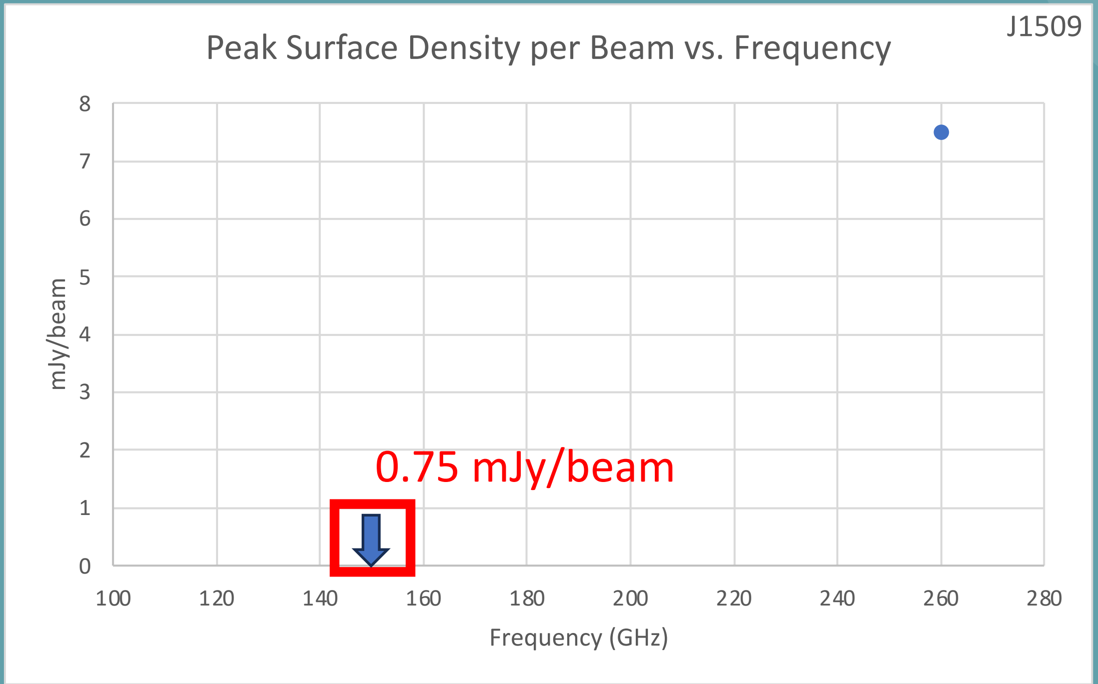
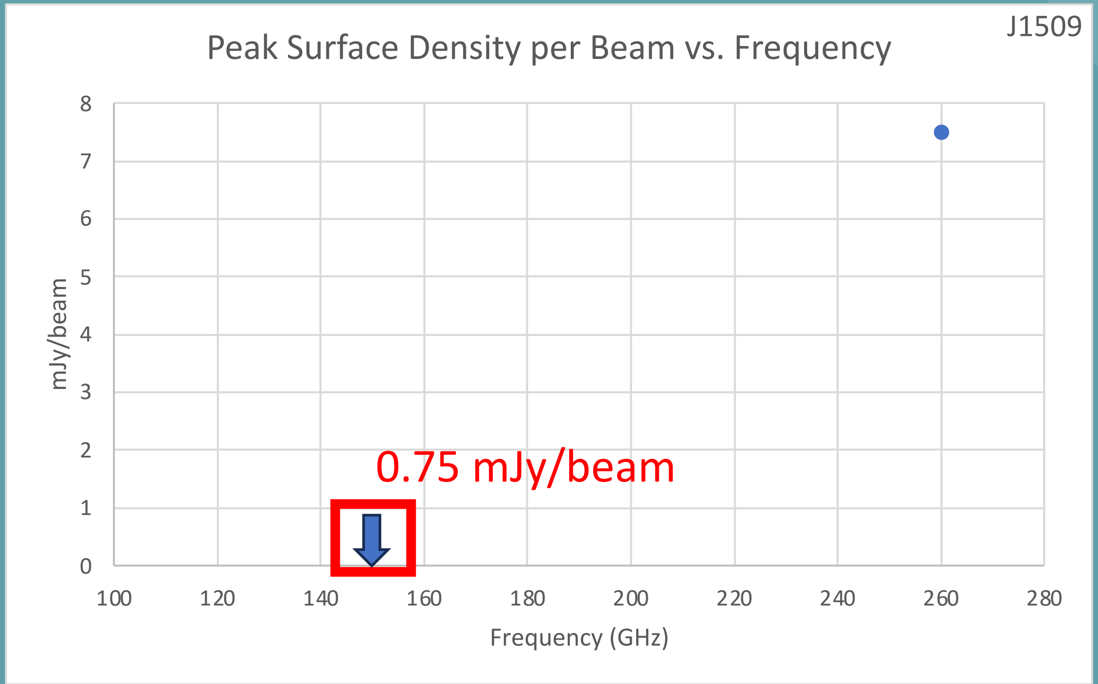
$$\alpha > \frac{\log(\frac{7.6}{0.75})}{\log(\frac{260}{150})} \approx 4.2!$$



Using Spectral Index (α)

$$\alpha > \frac{\log(\frac{7.5}{0.75})}{\log(\frac{260}{150})} \approx 4.2!$$

- Spectral Index is an indication of absorption type
  - Synchrotron Self-Absorption α up to 2.5
  - Free-Free Absorption α up to 4
  - α > 4 indicates dust, not jets



Results & Next Steps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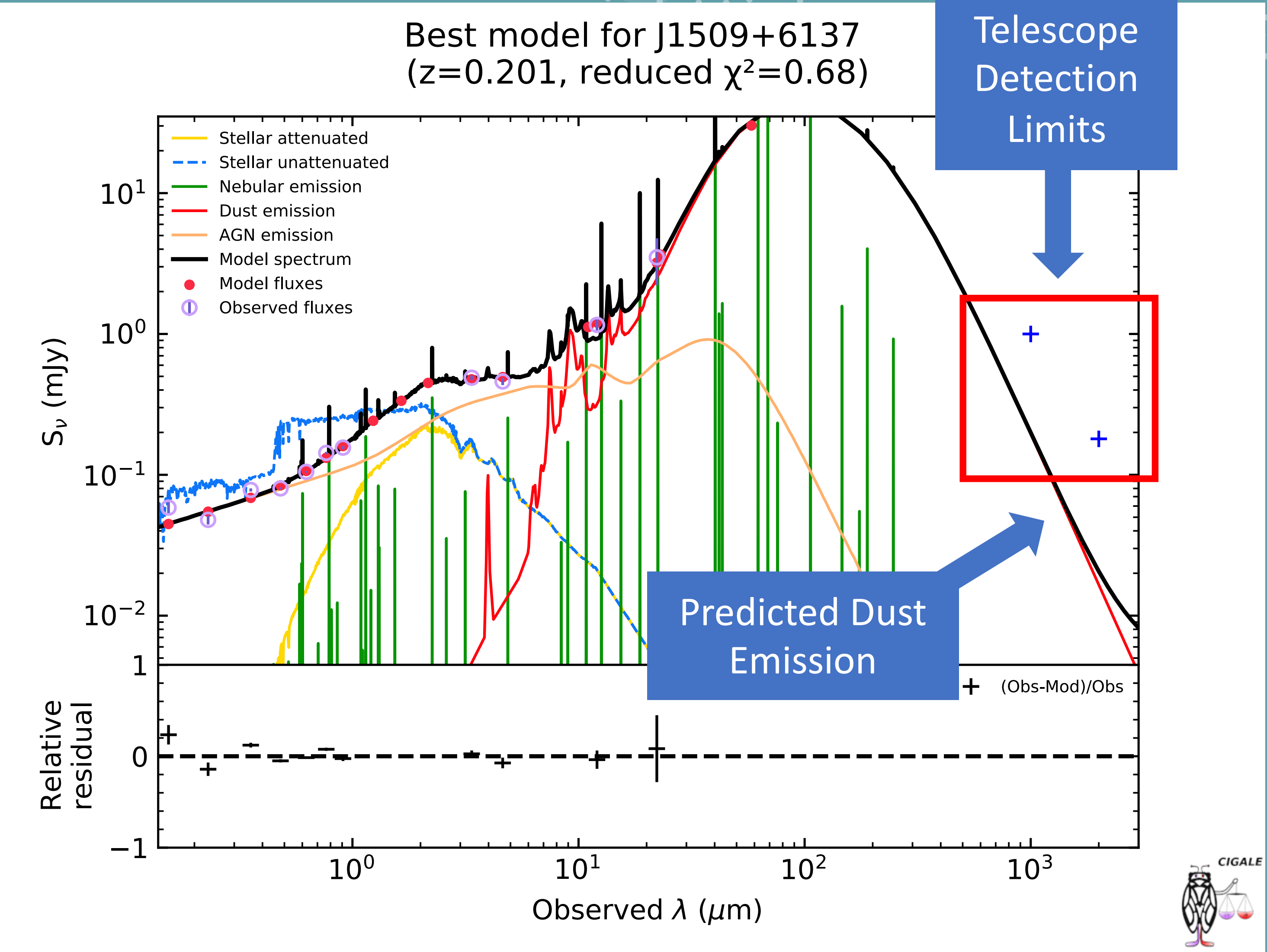
- Most sources undetected at 2mm and 1.15mm
- J1509 confirmed detection at 1.15mm
  - Spectral index indicates that emission is from dust
  - **Further study required:** models indicate dust should not be detectable at this wavelength
- Detections of dust can be used to fine-tune Spectral Energy Distribution (SED) model of galaxies

Results & Next Steps



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From Salomé, Quentin

Citations & Special Thanks

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New Girl
Tuesday sno cone truck

- Beckmann, V., & Shrader, C. (2013). *Active galactic nuclei*. Wiley.
- Järvelä, E. (2018). *Narrow-line Seyfert 1 galaxies: Observational and statistical analysis* [PhD thesis]. Aalto University.
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- Järvelä, E. *Millimetre view of the absorbed jets in NLS1s*.
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- Software:
  - PIIC Pipelines, DS9, CASA, CARTA