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BROADBAND EMISSION OF INTENSE STAR FORMING GALAXIES

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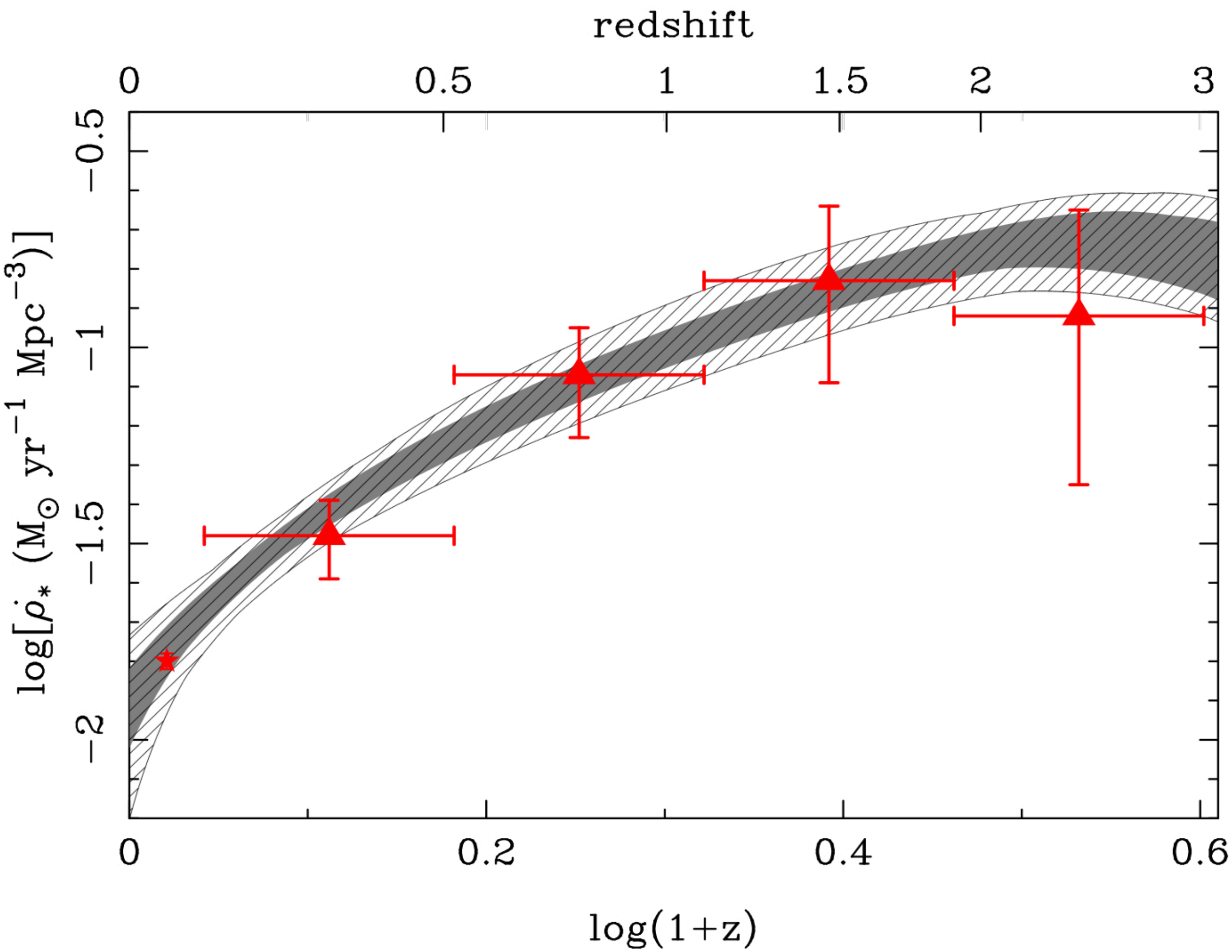
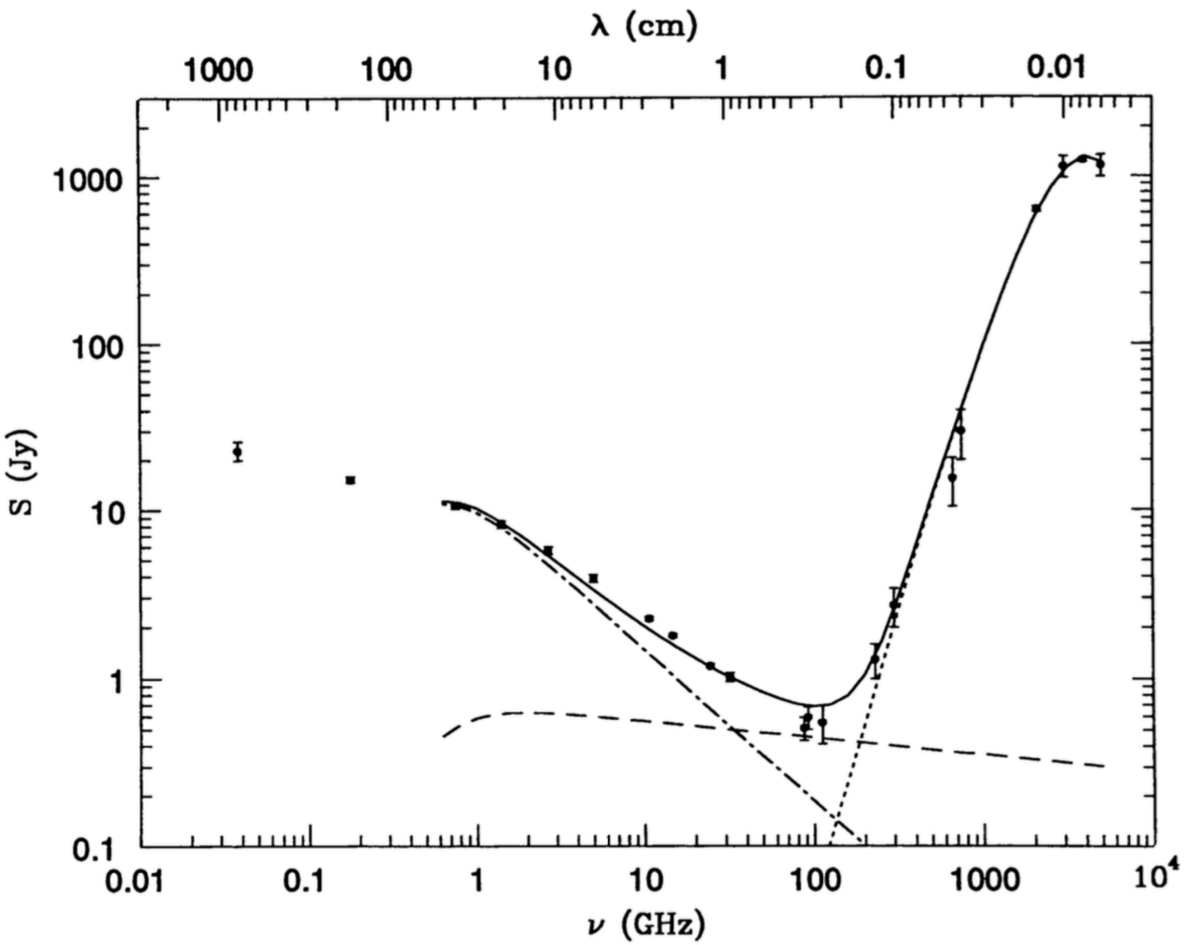
STAR FORMATION HISTORY OF THE UNIVERSE



Red = 1.4GHz SFR of objects in the 13H *XMM-Newton/ Chandra* Deep Field

Seymour et al. (2008)

M82 – CONDON 1992



An example of a star forming galaxy

Synchrotron ~ $\nu^{-0.8}$

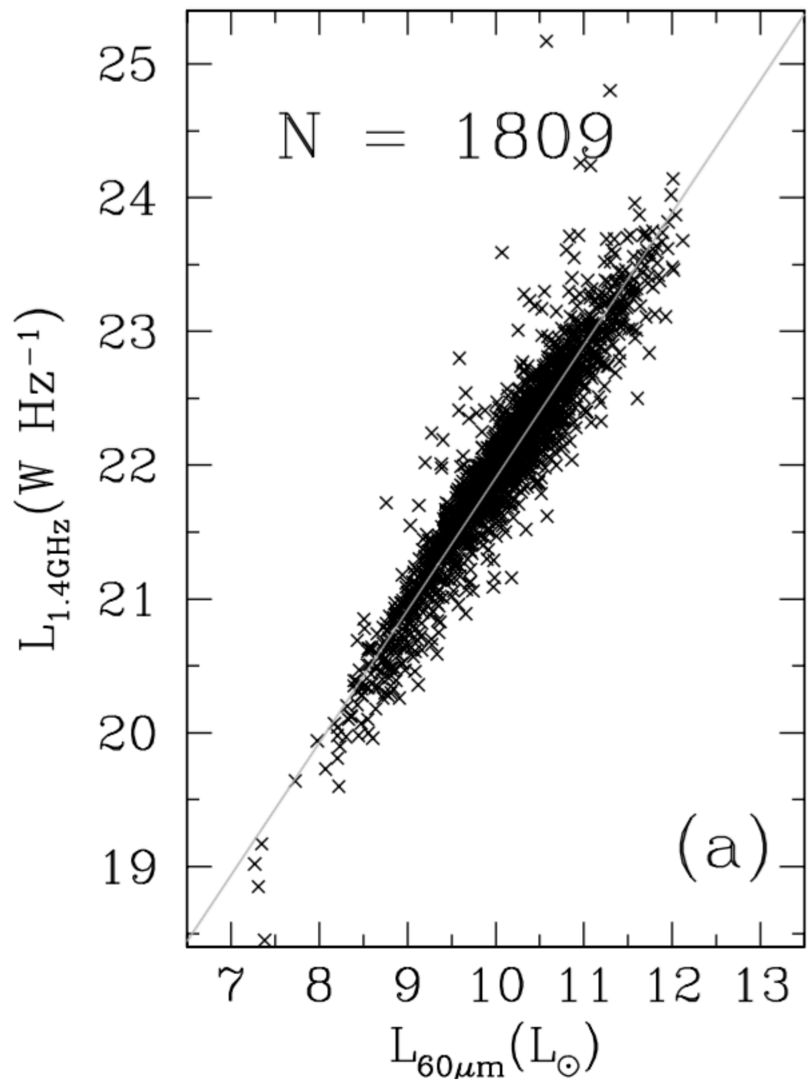
Free-Free ~ $\nu^{-0.1}$

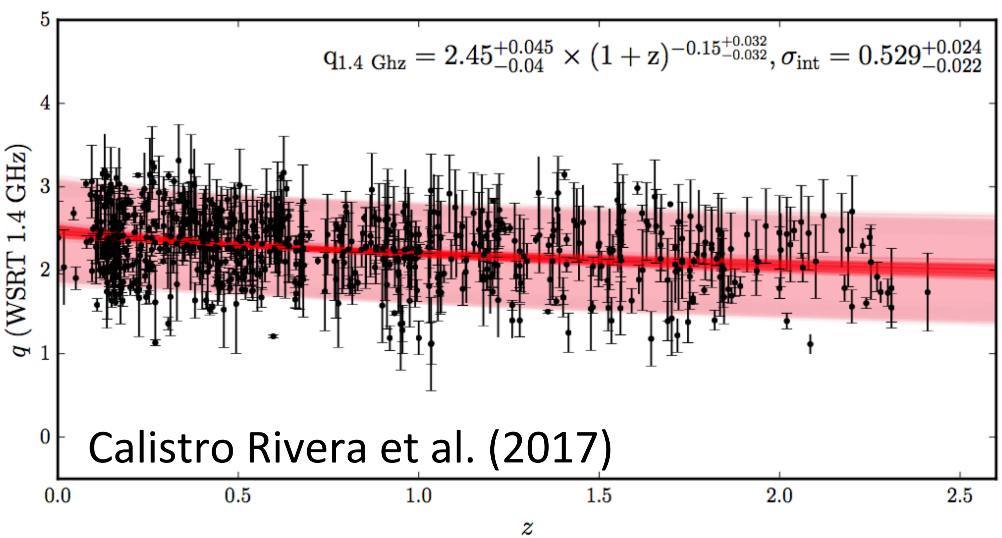
Infrared ~ greybody

SFR IN HIGH-Z

- Radio SFRs exploit the FRC
- Uncertainty as to how it scales with redshift
  - Ivison et al.(2010) and Mao et al. (2011) indicate no evolution
  - Murphy 2009 predicts evolution, recent studies report evolution

Yun et al. (2001)





Calistro Rivera et al. (2017)

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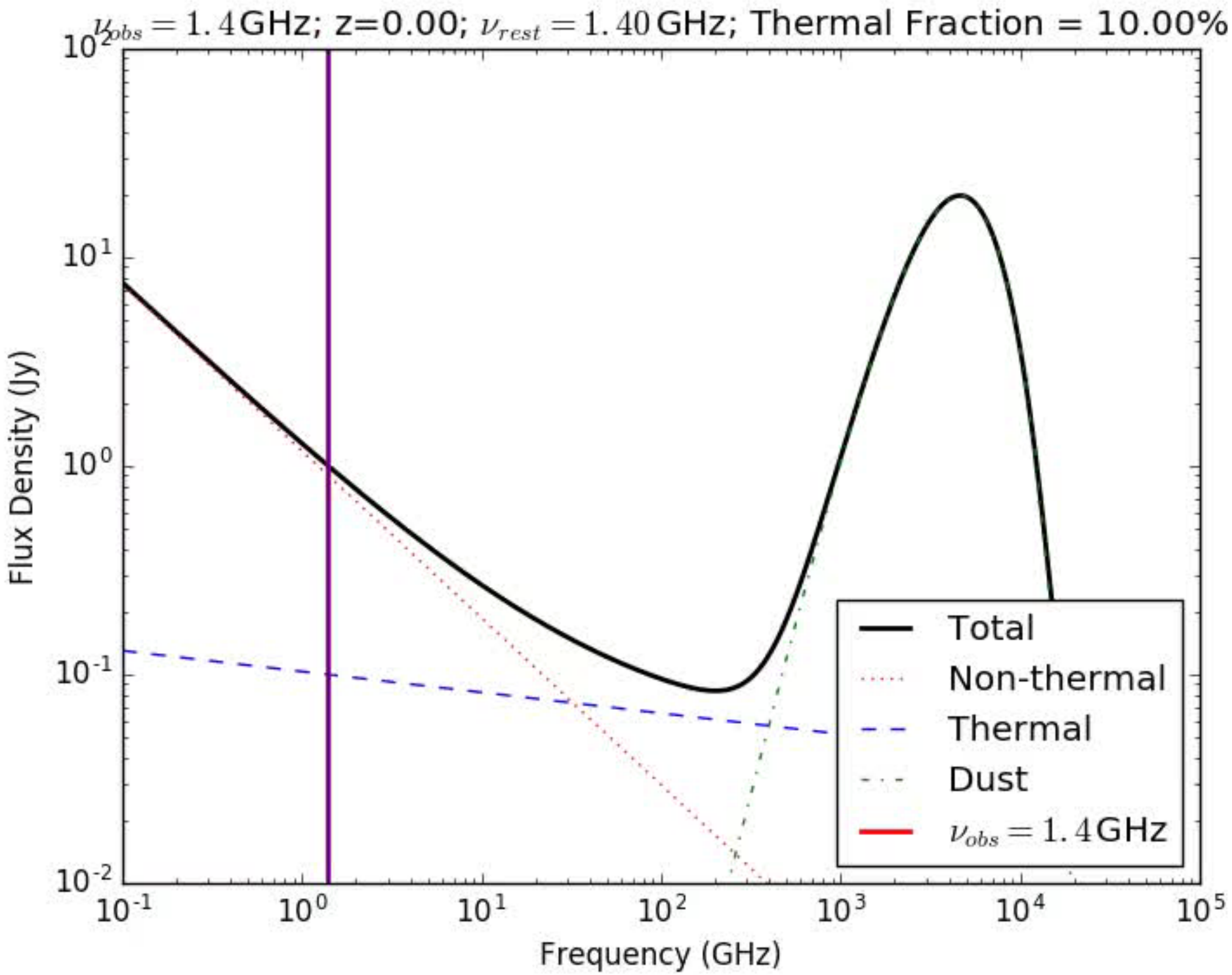
INCREASING REDSHIFTS



THIS WORK

Produce broadband radio continuum SEDs of starburst galaxies that are representative of galaxies we expect in EMU and beyond

Characterise the thermal free-free component, which is a direct tracer of SFR not effected by dust

Compare to other SFR measures from stellar emission lines (Hα, Paα) and other typical tracers tracers (IR, mixed tracers)

SAMPLE USED

19 Luminous Infrared Galaxies (LIRGS) selected

- Wang et al. 2014 used to select sources
- Detected in SUMSS
- Objects with AGN indicators were excluded (radio-excess, IR template fitting)
- Redshifts between 0.067 to 0.227

Radio-continuum data from 80 MHz to 50 GHz

- Data from GLEAM used – both detected sources and with priorized fits to wide-band images
- ATCA observations taken at 2.1, 5, 6.8, 8.8, 17, 21, 43, 48 GHz in 6A, 750C, H214 and H168 arrays. Higher frequencies, more focus on shorter baselines. Took what I could get in greentime!
- Iterative method of imaging to maximize the data points

EXAMPLE SED 1

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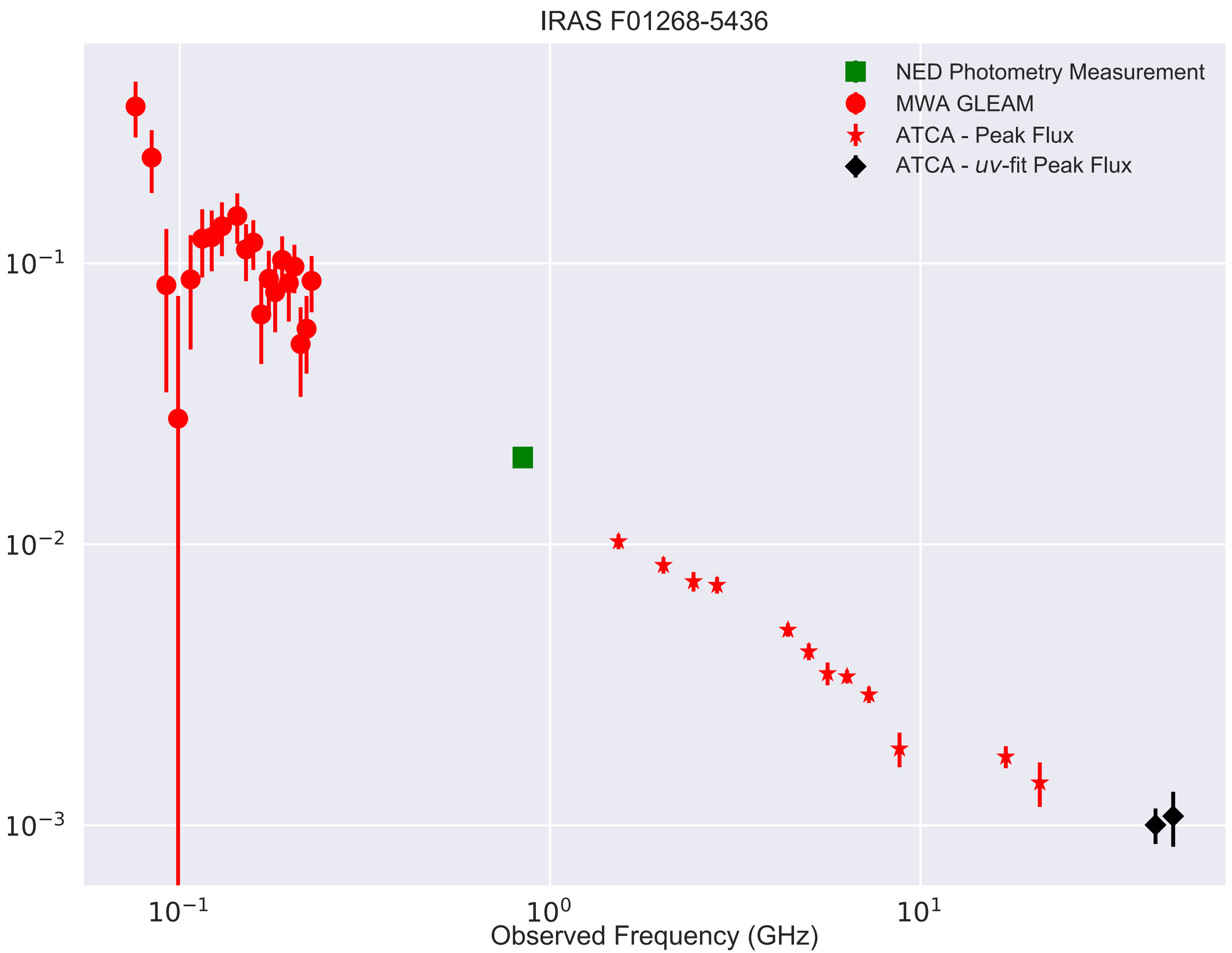
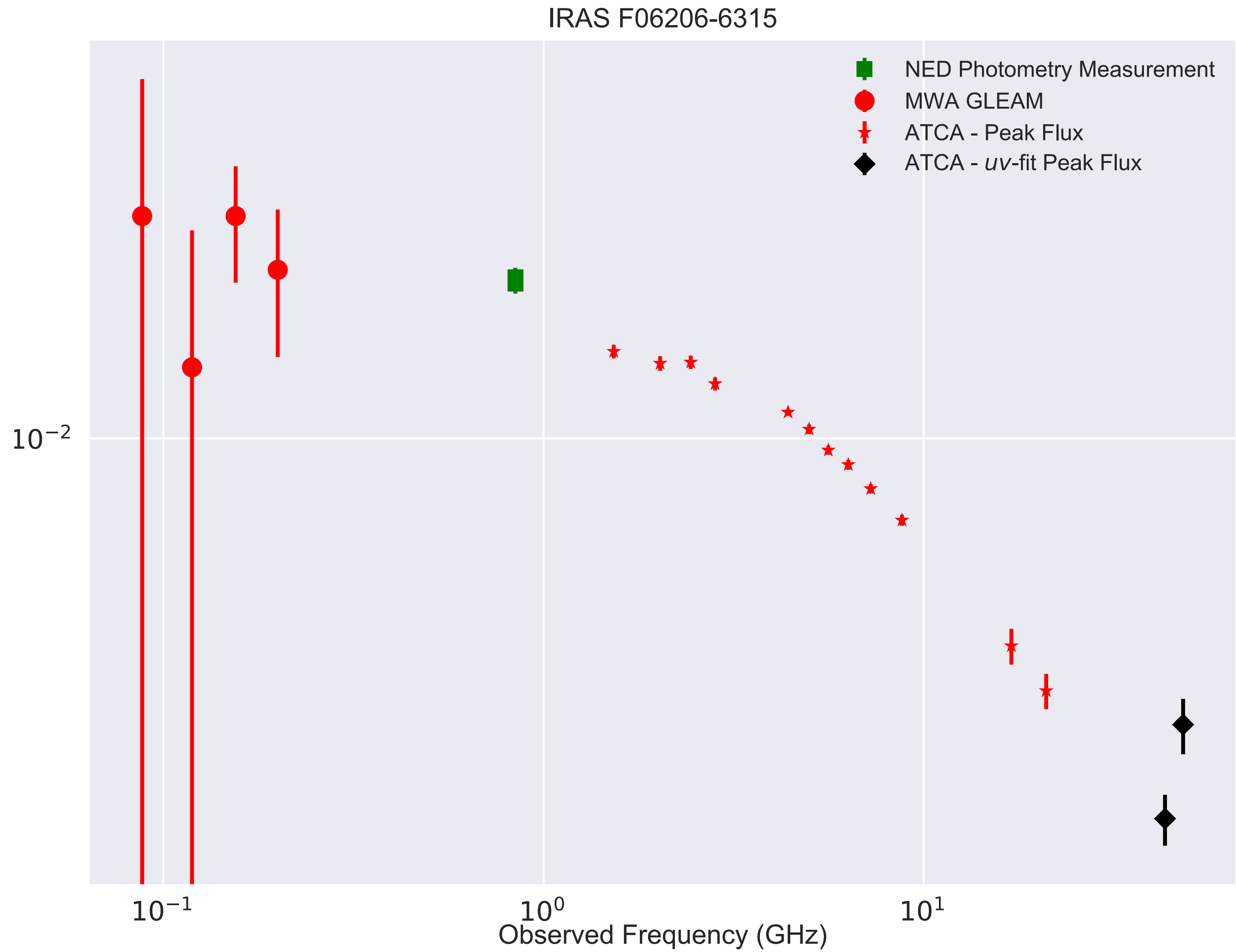
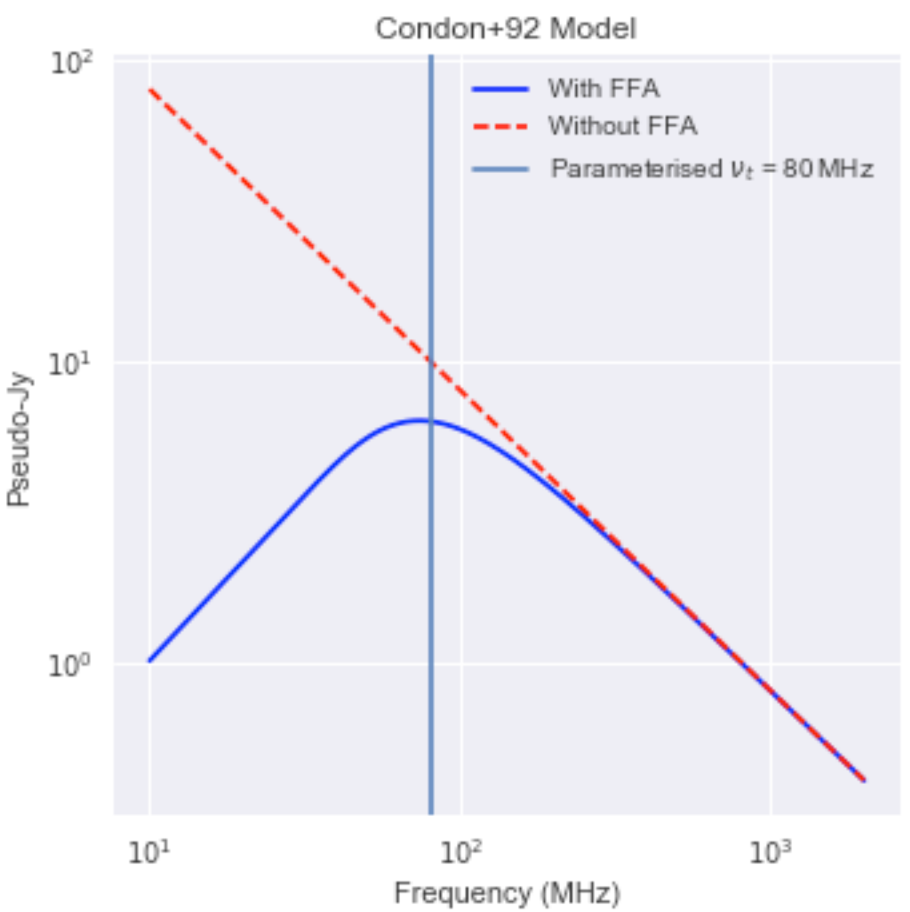


EXAMPLE SED 2



MODELS CONSTRAINED

- Not as simple as first thought across 80MHz to 50GHz
- Potential models
  - Power law
  - Synchrotron + Free-Free
  - Synchrotron + Free-Free + Free-Free Absorption
  - (Synchrotron + Free-Free + Free-Free Absorption) * 2
  - And a few in between
- Free-Free Absorption
  - When synchrotron and free-free are mixed, suppression happens
  - Parameterized as $(v/v_t)^{-2.1}$
  - v_t represents the turnover frequency



MODELS

Bayesian framework used for model optimisation and selection – see the MultiNest algorithm

$$S_\nu = A\left(\frac{\nu}{\nu_0}\right)^{\alpha}.$$

Power Law

$$S_\nu = A\left(\frac{\nu}{\nu_0}\right)^{\alpha} + B\left(\frac{\nu}{\nu_0}\right)^{-0.1},$$

Synchrotron+Free-Free

$$S_\nu = (1 - e^{-\tau})\left[B + A\left(\frac{\nu}{\nu_{t,1}}\right)^{0.1+\alpha}\right]\left(\frac{\nu}{\nu_{t,1}}\right)^{2},$$

Synchrotron+Free-Free with FFA where Tau = $(\nu/\nu_t)^{-2.1}$

$$S_\nu = (1 - e^{-\tau_1})\left[B + A\left(\frac{\nu}{\nu_{t,1}}\right)^{0.1+\alpha}\right]\left(\frac{\nu}{\nu_{t,1}}\right)^{2} + (1 - e^{-\tau_2})\left[D + C\left(\frac{\nu}{\nu_{t,2}}\right)^{0.1+\alpha}\right]\left(\frac{\nu}{\nu_{t,2}}\right)^{2},$$

Same as above, but a second component added

CONSTRAINED SEDS

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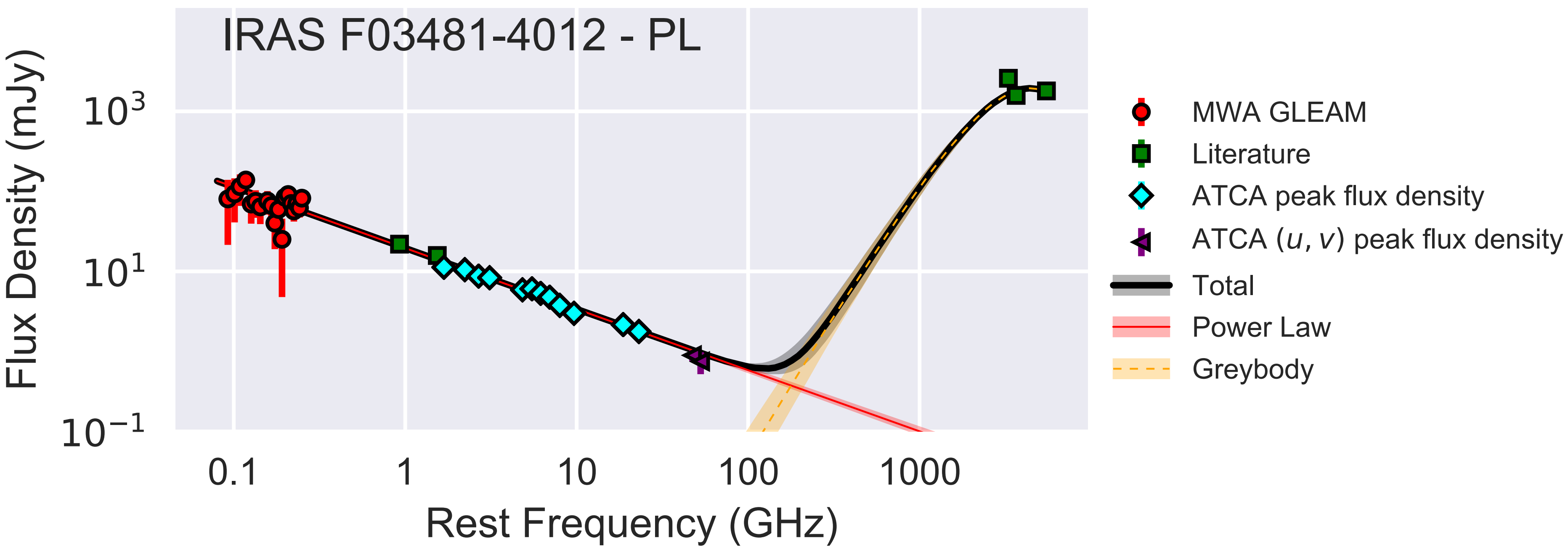
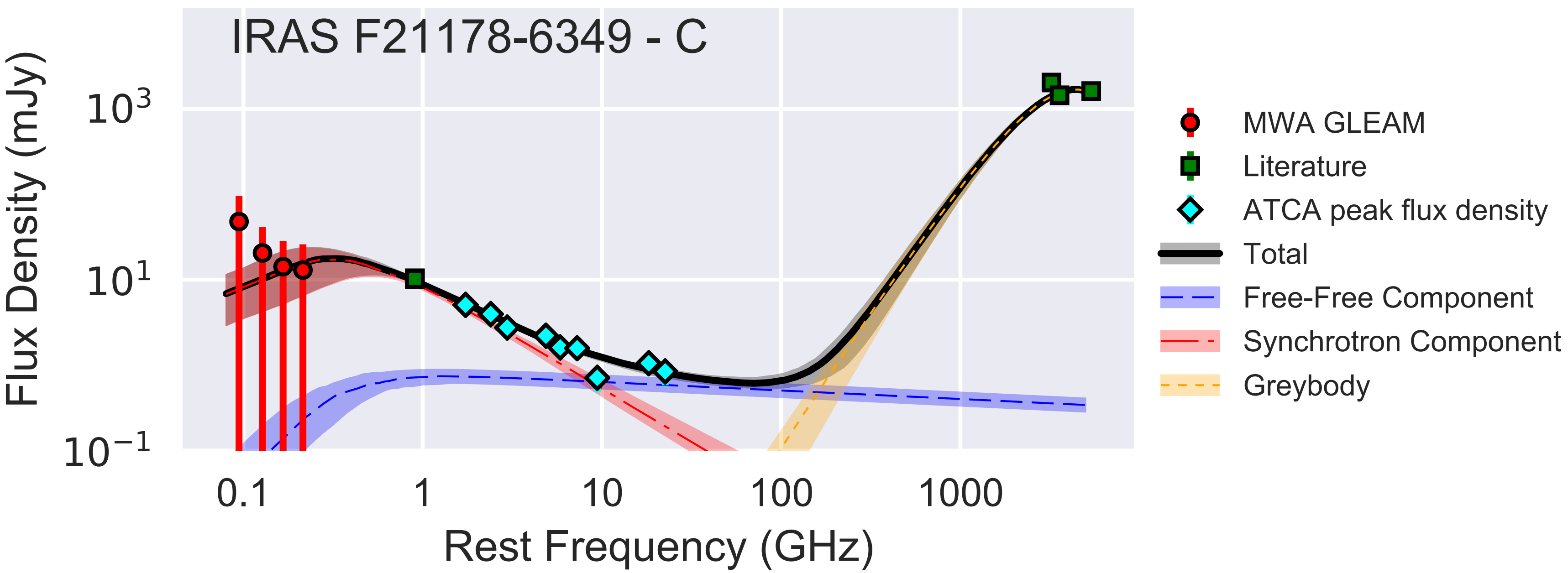


CONSTRAINED SEDS



CONSTRAINED SEDS

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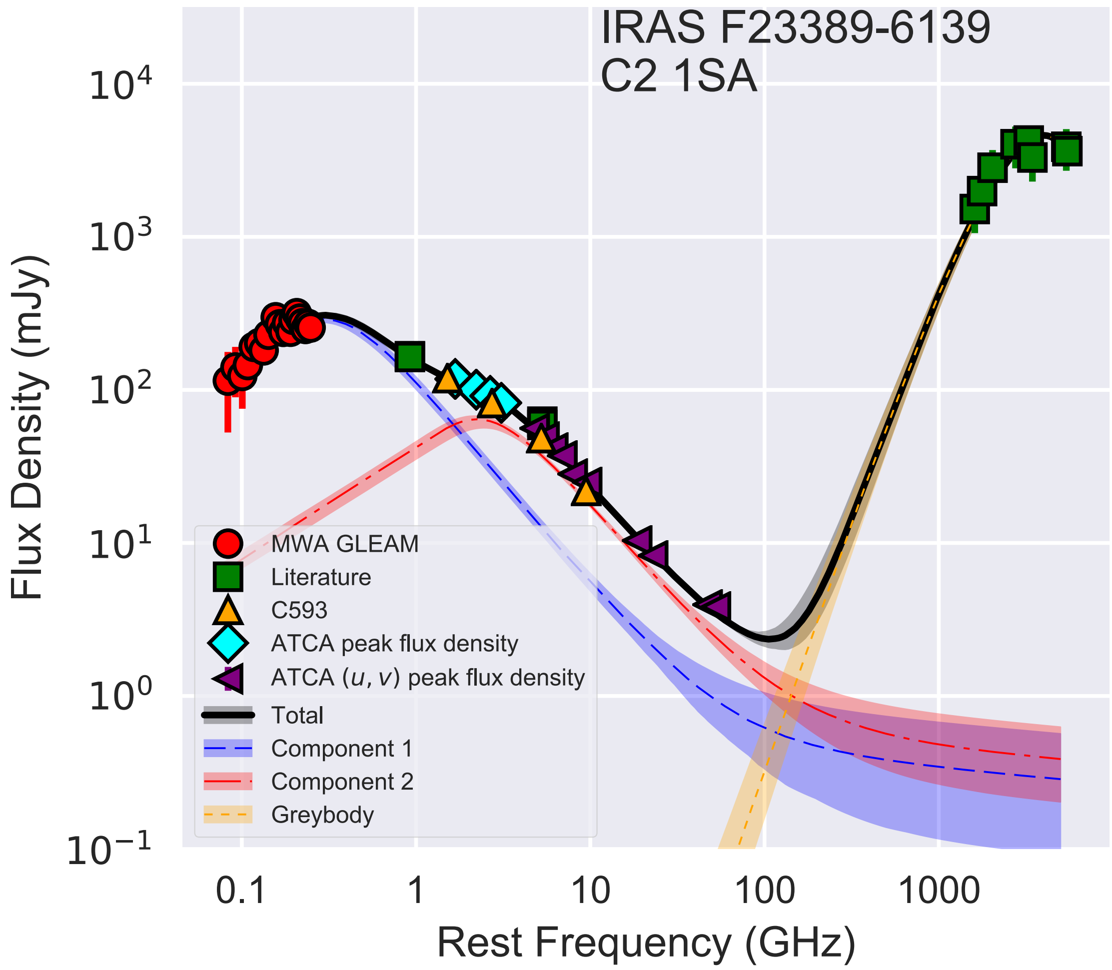

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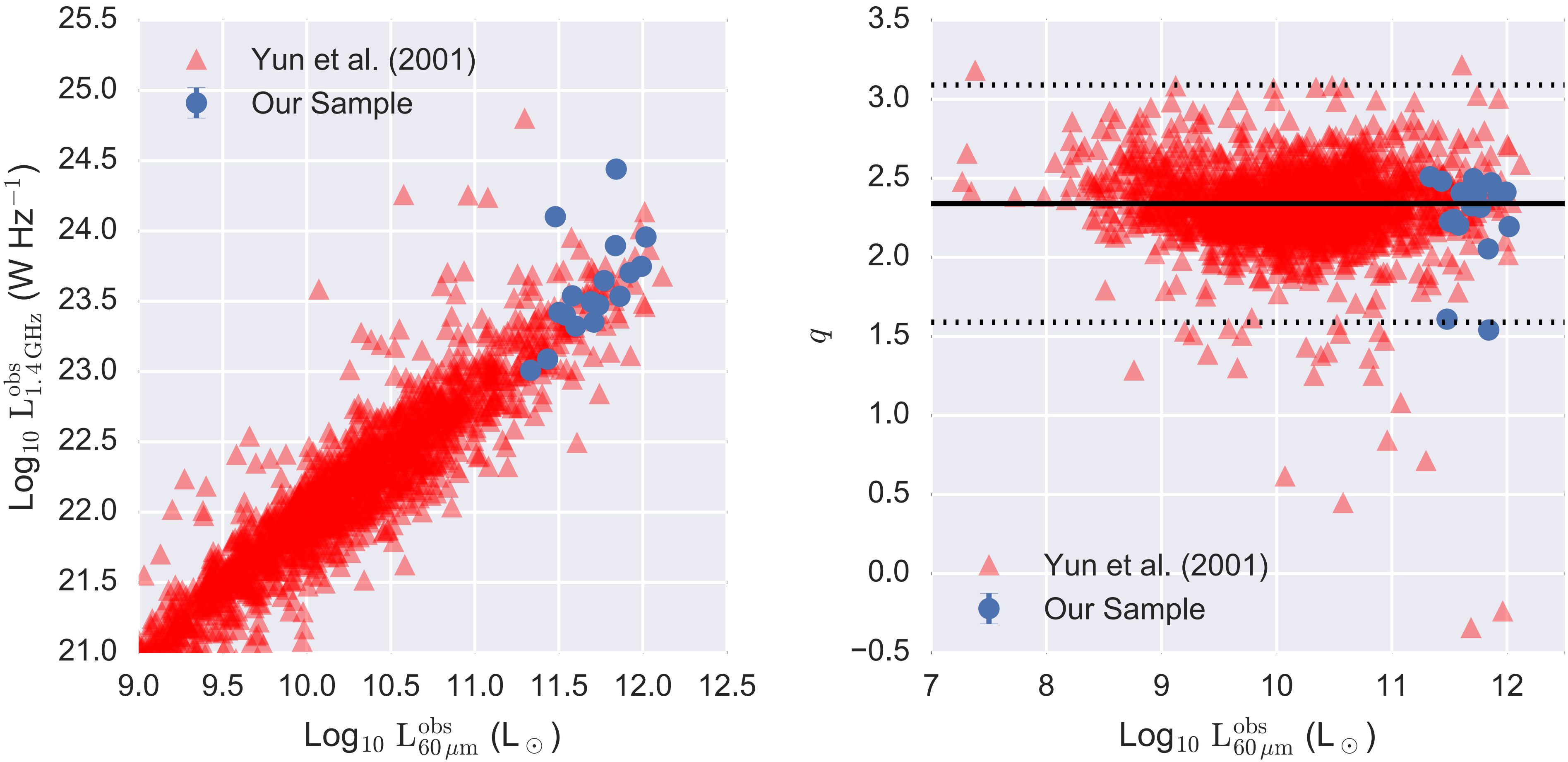
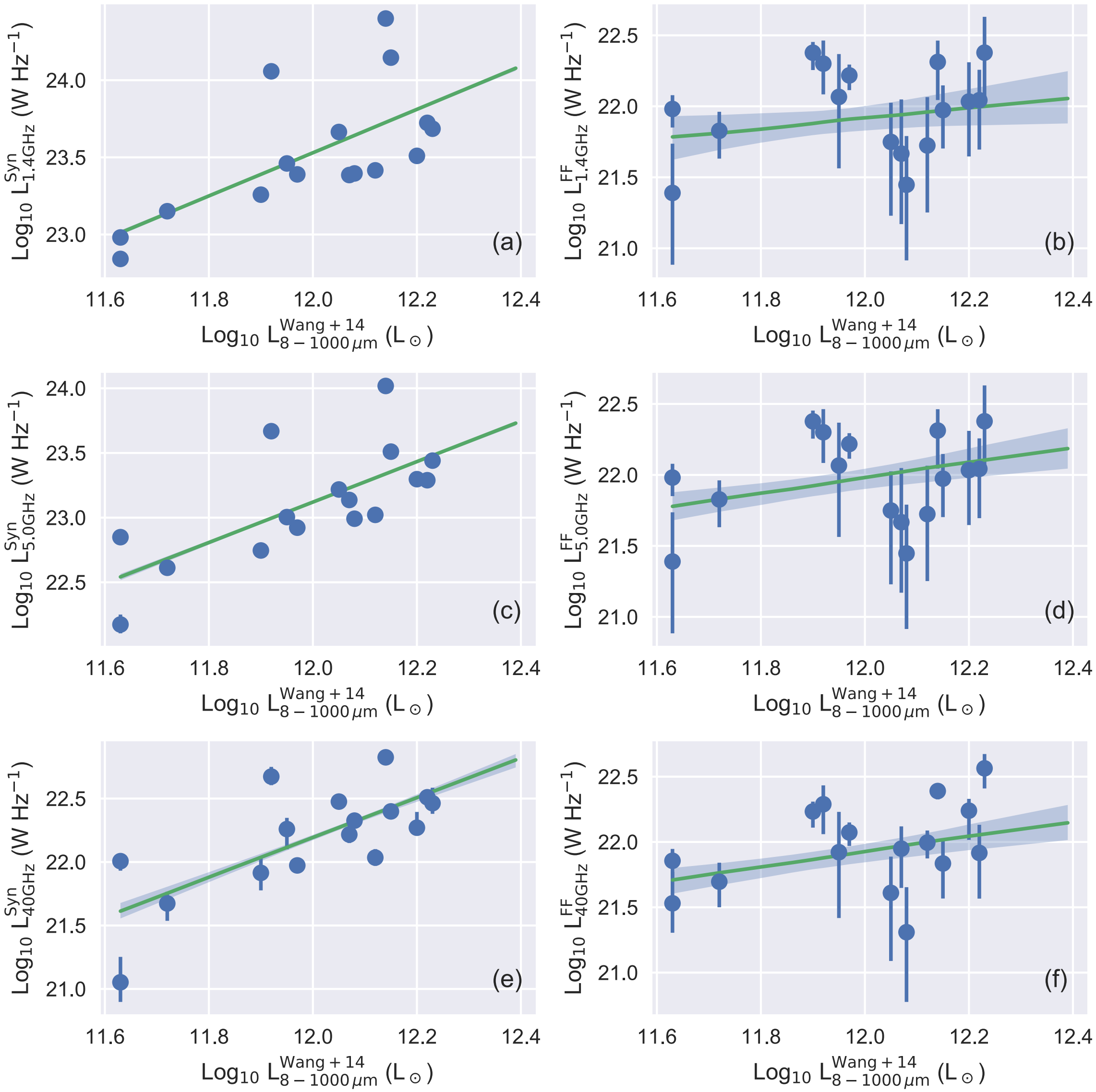
WHERE THEY SIT ON THE FRC



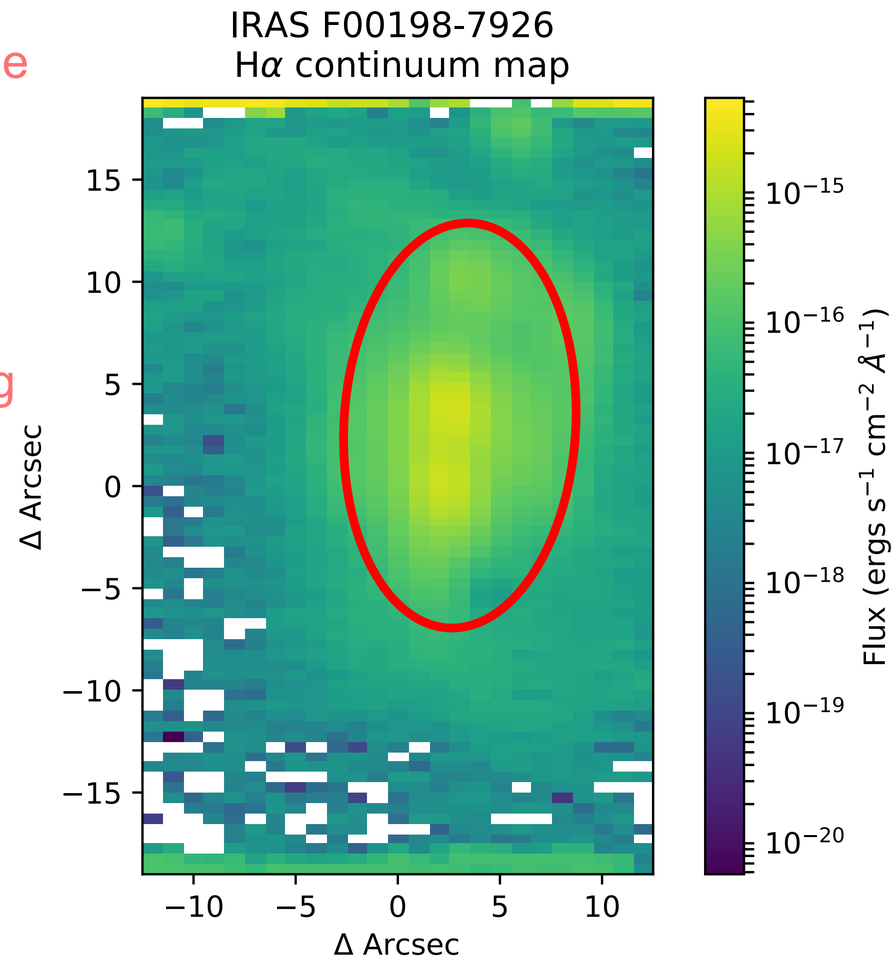
FAR-INFRARED TO RADIO COMPONENTS



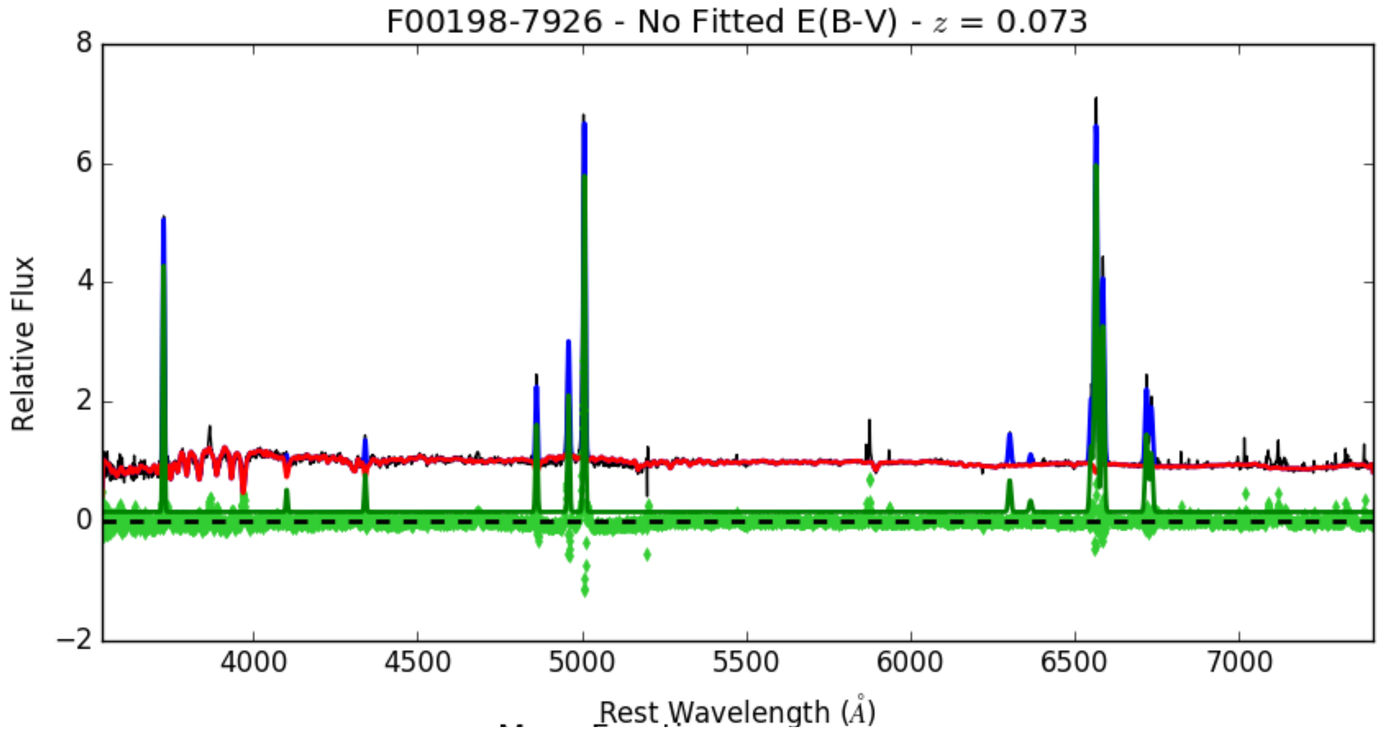
ν (GHz)	Emission	Gradient	Norm. (Log_{10} W Hz^{-1})
1.4	Syn	$1.40^{+0.03}_{-0.04}$	$6.68^{+0.47}_{-0.41}$
5.0	Syn	$1.56^{+0.06}_{-0.05}$	$4.36^{+0.62}_{-0.66}$
40.0	Syn	$1.57^{+0.13}_{-0.15}$	$3.39^{+1.77}_{-1.56}$
1.4	FF	$0.33^{+0.43}_{-0.33}$	$17.95^{+3.92}_{-5.10}$
5.0	FF	$0.53^{+0.27}_{-0.25}$	$15.60^{+2.93}_{-3.27}$
40.0	FF	$0.58^{+0.25}_{-0.23}$	$14.97^{+2.74}_{-2.97}$

STELLAR EMISSION LINES

- Thermal free-free emission comes from the same emitting material that produces Hα and Paα
- Six nights on the 2.3 meter ANU WiFeS telescope
- IFU with a 38” by 25” field of view covering 3000-9000Å
- Goal to produce dust corrected Hα SFRs



EXAMPLE SPECTRA



Summing spectra over the galaxy gives, for stronger sources, produces excellent spectra

pPXF produces excellent fits and is able to recover stellar ages and metallicities

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DUST CORRECTED H-ALPHA VS FREE-FREE LUMINOSITY

PUT PLOT HERE ONCE I HAVE IT!

☹

…. Its almost there

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COMPLEXITY IN THE RADIO CONTINUUM

Evidence for multiple components, in one form or another, for 10 sources

- And 6 for a single turn over due to FFA
- Only 3 objects have SEDs that most preferred power law or simple combination of synchrotron and free-free
- Low frequency data from GLEAM was critical

Imagine multiple regions of SF

- Different distribution of plasma
- Different orientation to us (simple assumption typically is cylinder facing us)
- Different electron populations (mergers)
- ALL summed up by the large radio synthesized beam

EVIDENCE IN WIFES?

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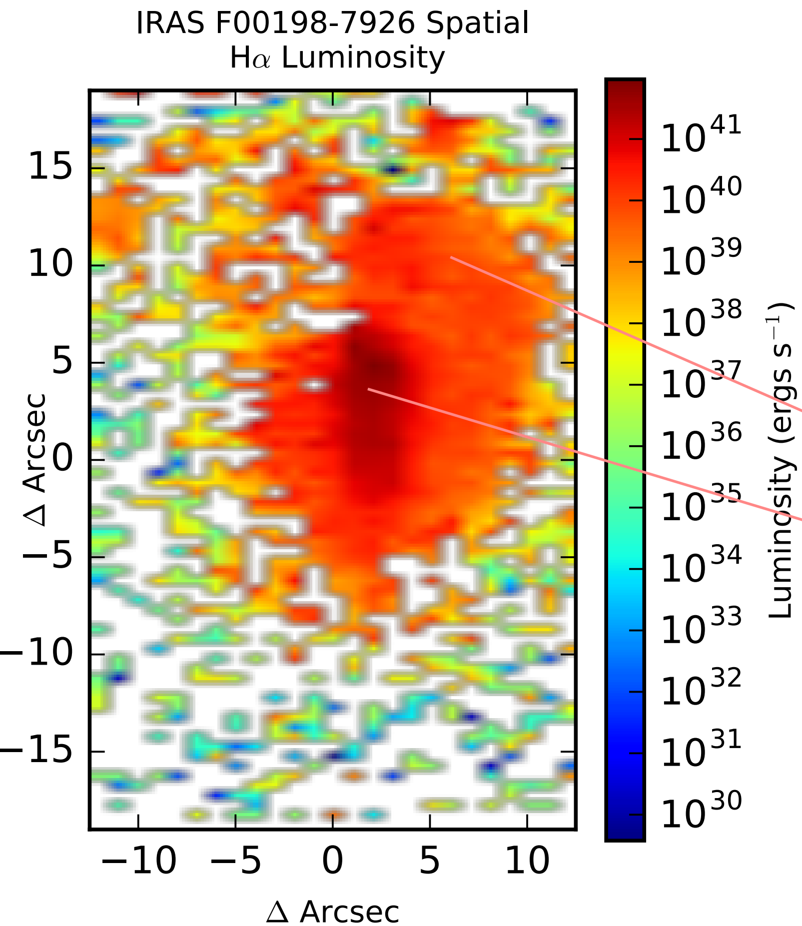
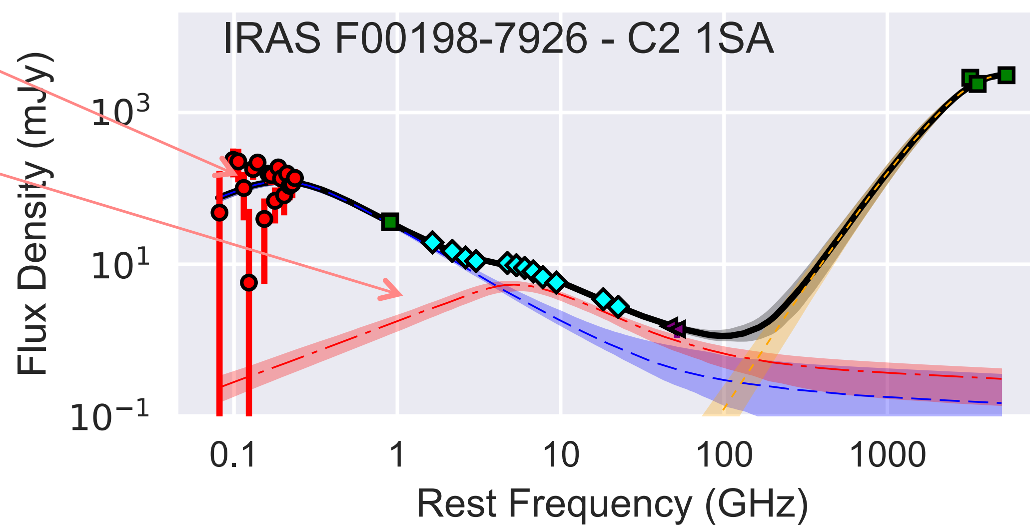
Maybe. More to come…



$$\tau_\nu = 3.28 \times 10^{-7} \left(\frac{T_e}{10^4\,\mathrm{K}}\right) \left(\frac{\nu}{\mathrm{GHz}}\right)^{-2.1} \left(\frac{EM}{\mathrm{pc\,cm^{-6}}}\right),$$

$$\frac{EM}{\mathrm{pc\,cm^{-6}}} = \int_{\mathrm{los}} \left(\frac{N_e}{\mathrm{cm^{-3}}}\right)^2 d\left(\frac{s}{\mathrm{pc}}\right)$$



CONCLUSIONS + FUTURE WORK

- Radio continuum can be decomposed into its synchrotron and free-free components, and these correlate well with IR
- Higher order complexity in the radio continuum of intense starbursts exists
- Likely that we can link the optical profile of the galaxy and its geometry to the broadband SED in the radio
- High frequency data targeting thermal free-free emission key to crafting reliable SFR indicators
  - GLASS and G23 multi-λ
  - ATCA proposal – ECDFS at 10GHz down to 2.9uJy RMS
  - ATCA proposal – FRC at 33/35GHz

As Gandalf famously said in the Phantom Menace – ‘Any questions?’