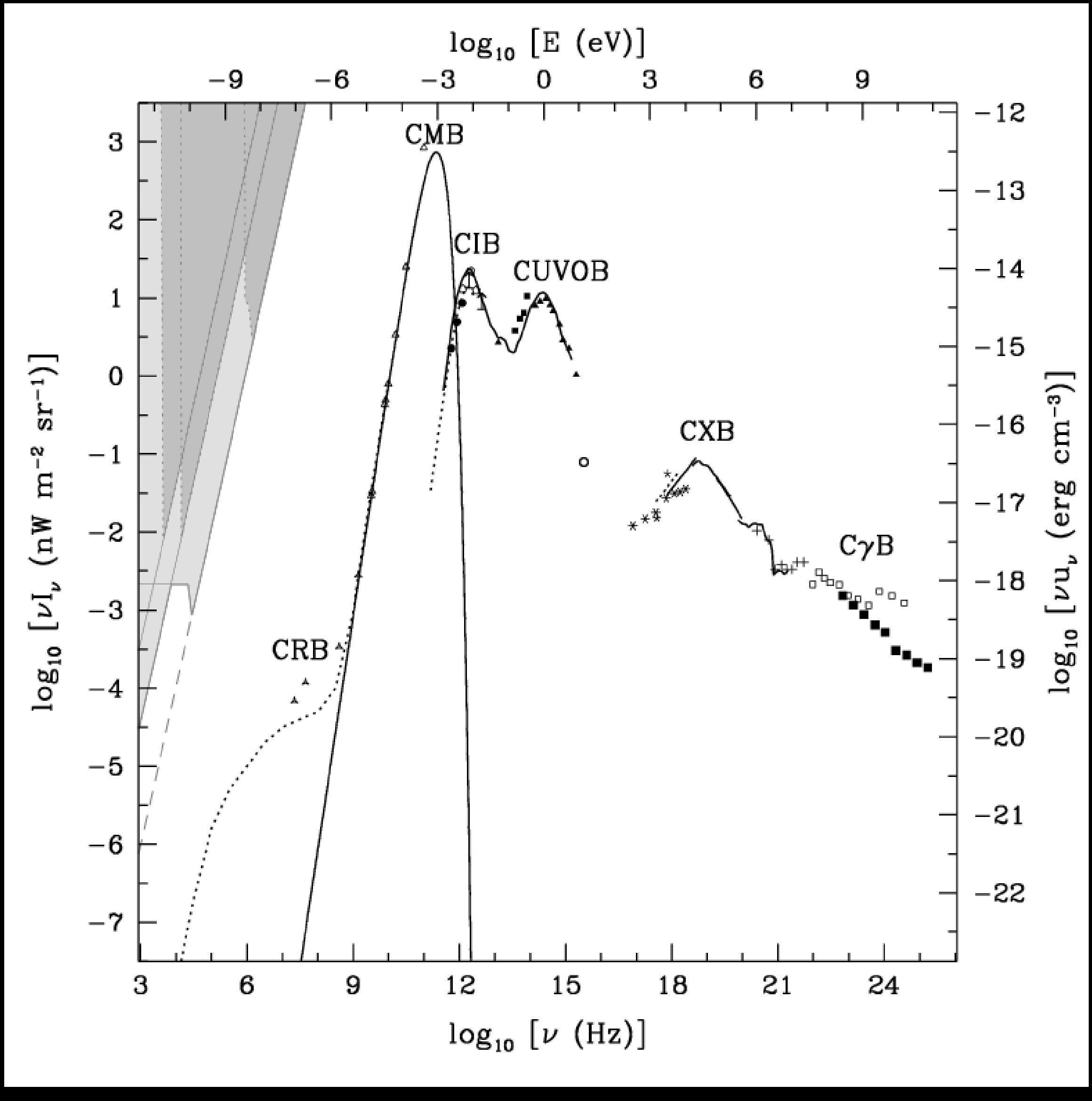
All Radiation Backgrounds from Star-Forming Galaxies

Brian Lacki (IAS/NRAO)

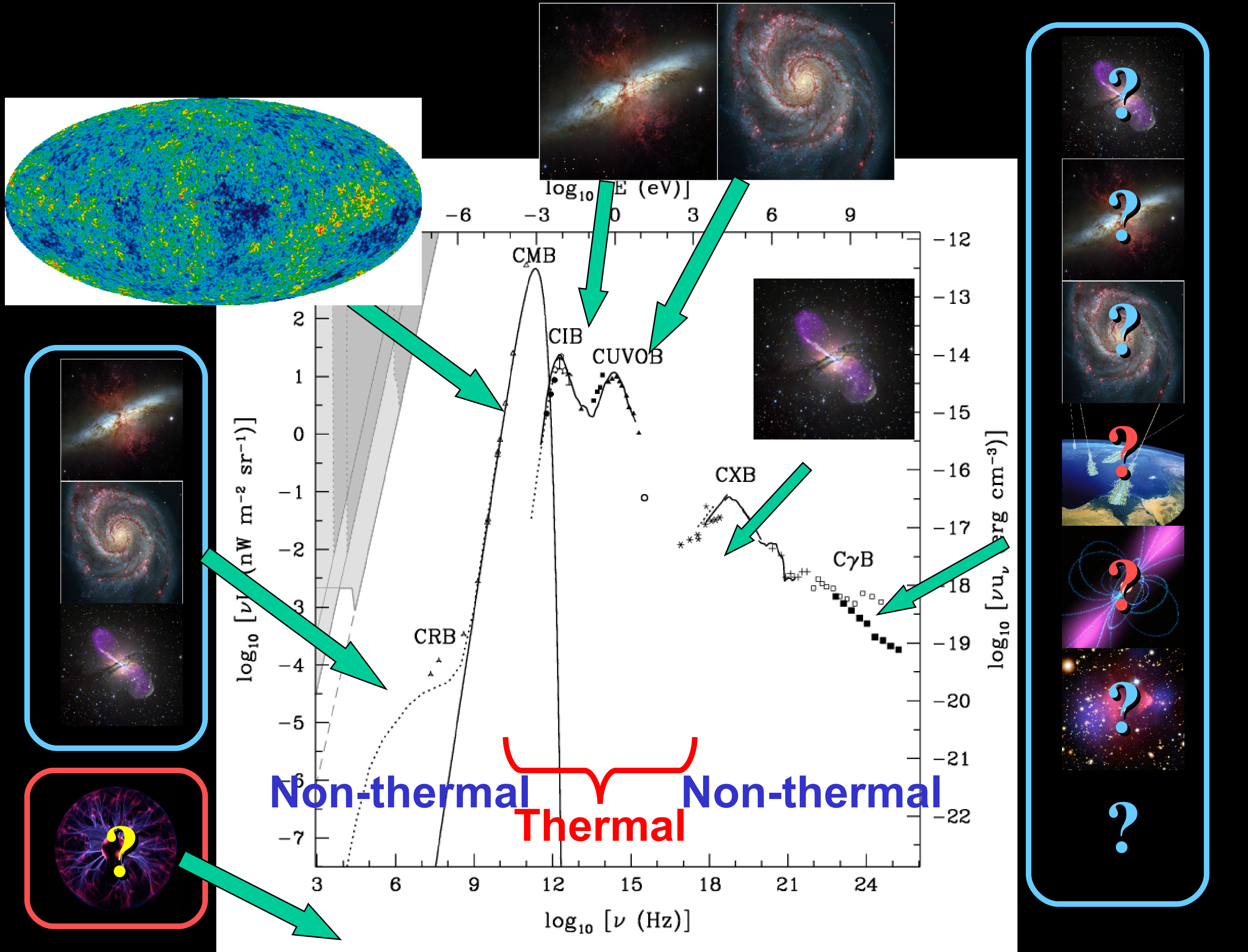
9 June 2014

Credit: ESA / SPIRE / HerMES

The Cosmic SED



Credit: Lacki (2010) and references therein



Credit: Lacki (2010); Simon Swordy (U. Chicago) / NASA / APoD; Luc Viator

Motivation

SFGs significantly contribute to many of the cosmic backgrounds

- Different energy and messenger backgrounds related!

Want ***self-consistent*** – and when possible, ***physically motivated*** – models of SFG emission across all energies

- Radio: Don't directly assume FIR-radio correlation (FRC)
  - Instead assume B motivated by FRC, run model of CR population, calculate synchrotron spectrum
  - Also get gamma rays, neutrinos, nonthermal X-rays from these models
- EBL that attenuates gamma rays generated by SFGs

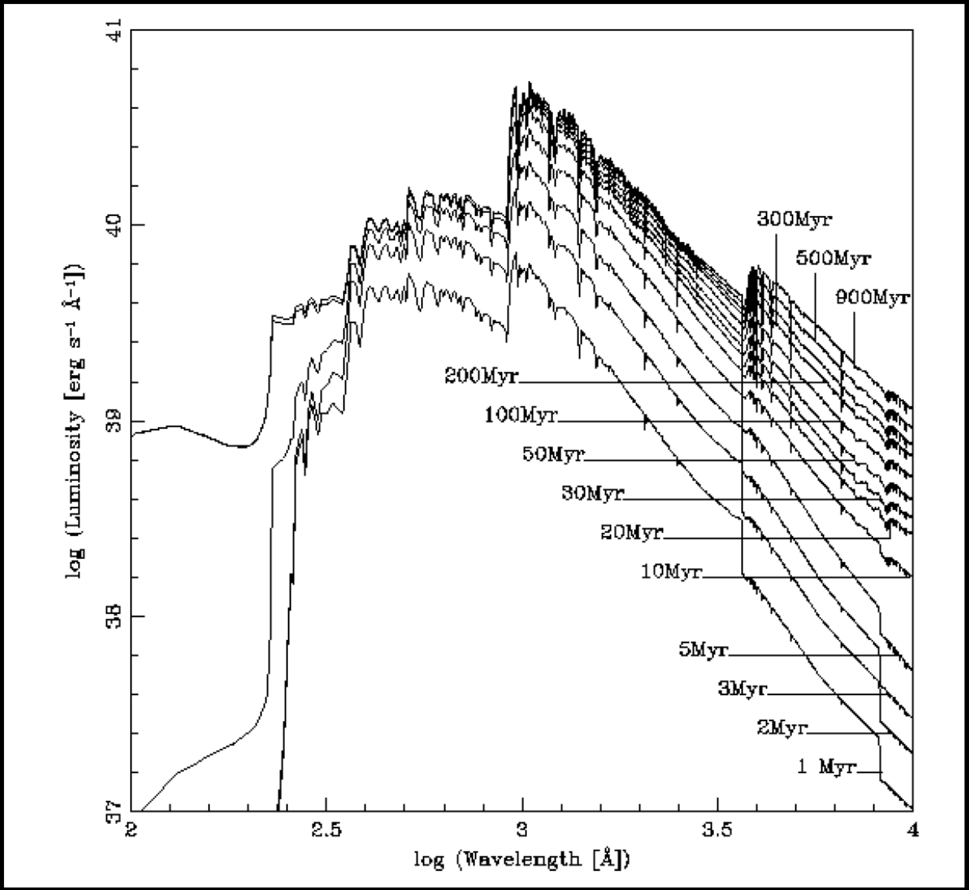
One-zone models

Each galaxy's properties derived from:

- Main sequence SSFR *or* starburst t_{gas}
  - Relates mass to SFR
- Schmidt Law
  - Relates gas to SFR
- Toomre Q = 1
  - $h/R = \sigma/v_{circ} = f_{gas} / 2$
- Baryonic Tully-Fisher relation
  - Relates v_{circ} to mass
- Fundamental mass-metallicity relation

Use Bethermin et al. (2012) luminosity functions to calculate total background

The Unabsorbed UV/O/IR Spectra



Starburst99 Spectra

Continuously forming stars for 1/SSFR

Credit: Leitherer et al. (1999)

Dust Absorption and Emission: One Zone Models

Most star-formation in Universe is heavily extinguished

Dust (1) absorbs UV/O light and (2) emits IR light

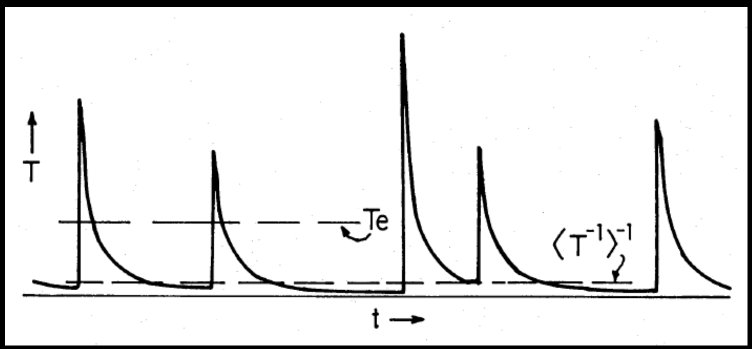
Both are linked: internal SED sets grain temperatures

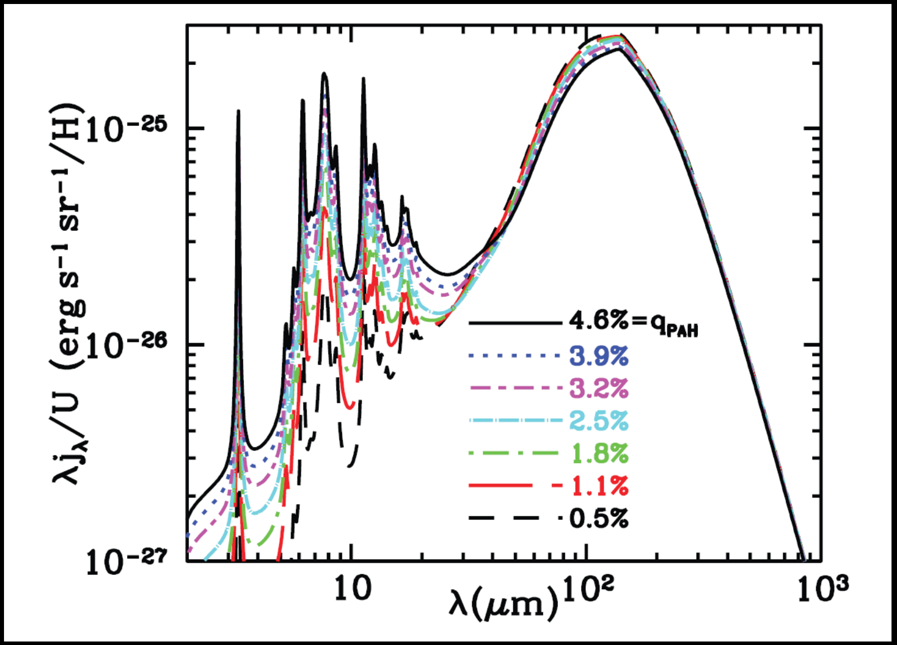
One zone model for internal SED

$$u_\lambda \sim s/c\,(\varepsilon_{stars} + \varepsilon_{dust})$$

Iterative process – guess first u_λ, feed into ε_{dust}, repeat

MIR Emission: Not Just One T





Grains transiently heated by UV light

Cooling responsible for MIR emission

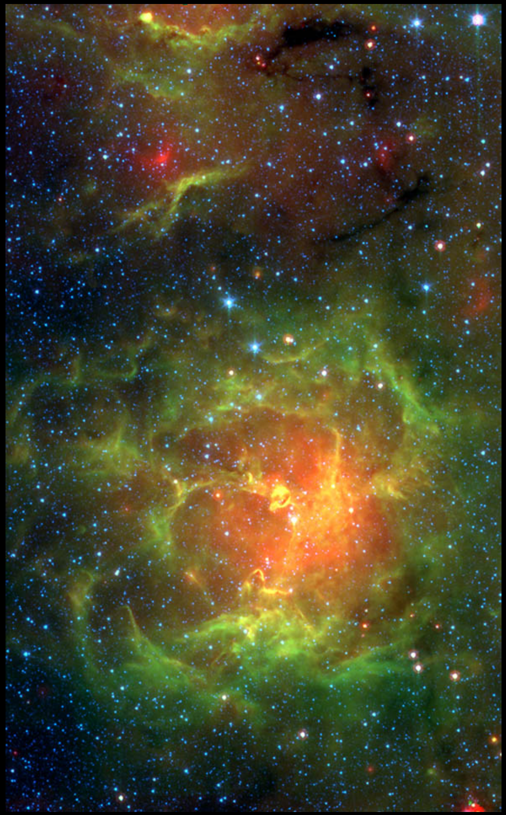
Problem: SEDs can be very different

Dwarfs: much light in UV – strong MIR

Starbursts: most light in FIR – weak MIR

Credit: Purcell (1976); Draine & Li (2007)

What's Missing? PDRs



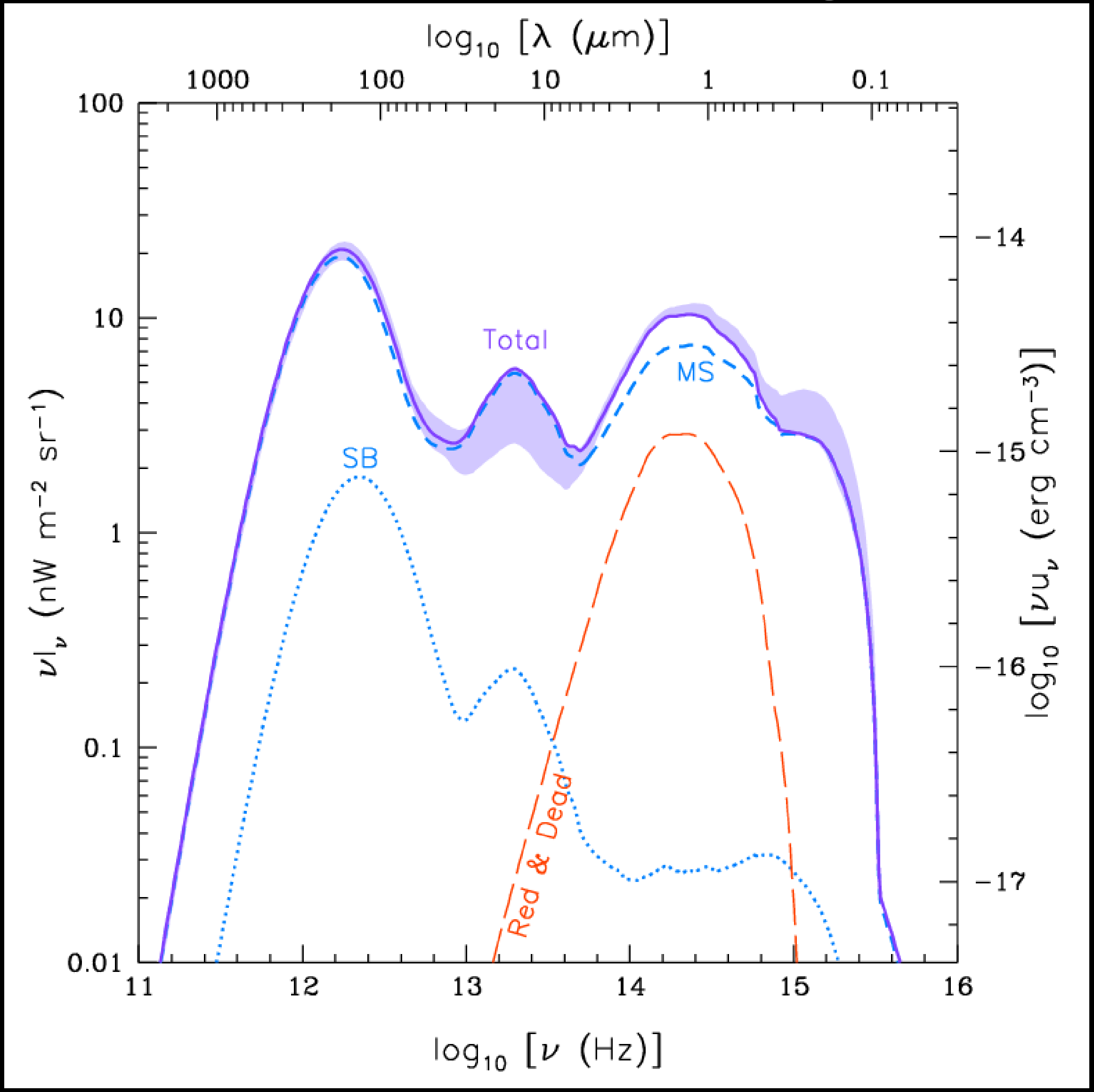
Dust within star-forming regions is hotter

Contributes to blue side of FIR bump, MIR emission

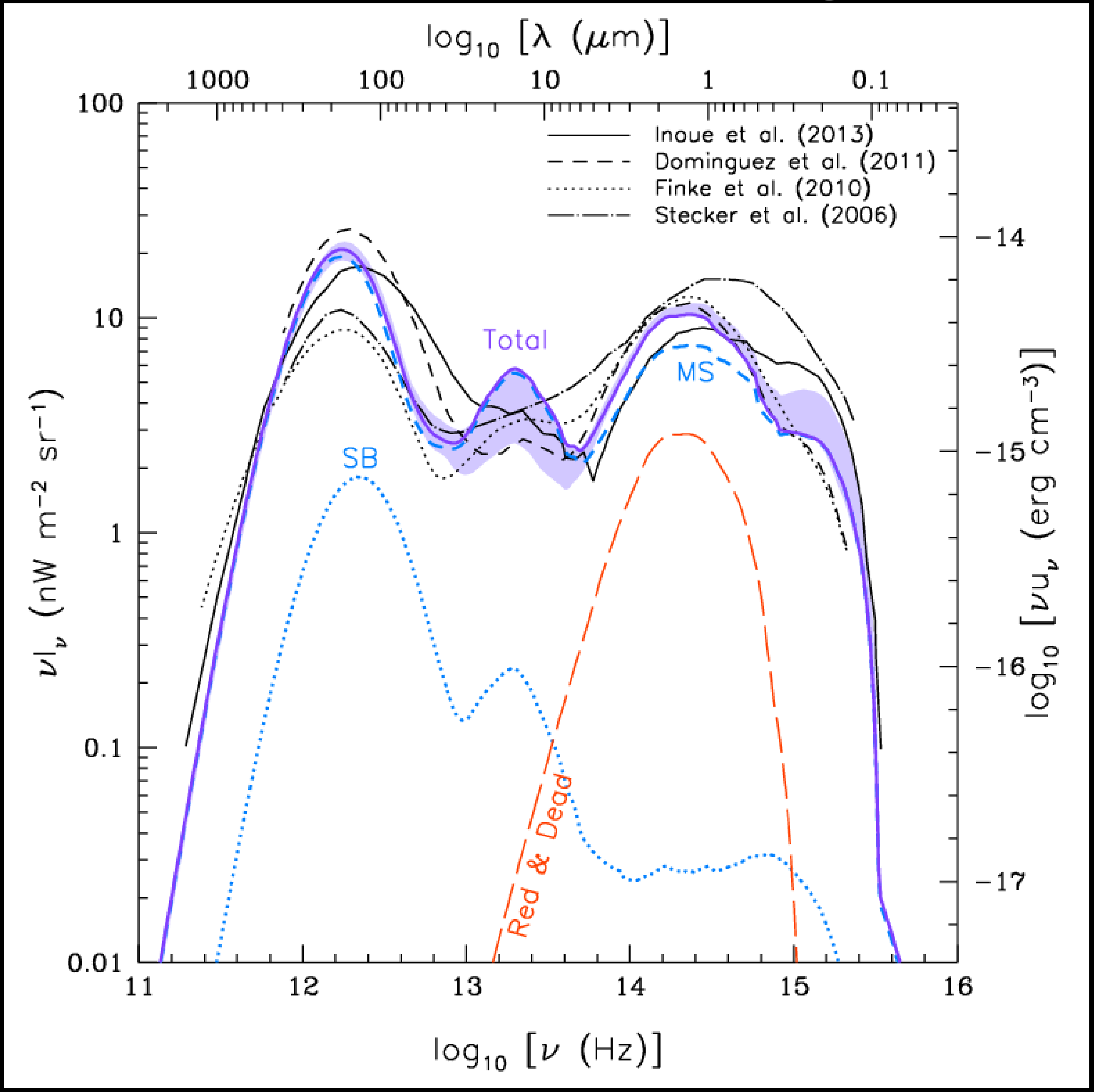
Including it would require (*even more*) ad hoc parameters

Credit: NASA/JPL-Caltech/J. Rho (SSC/Caltech)

The UV/O/IR Background



The UV/O/IR Background



CR Populations: The Simplest Version

$$Q(E) \times t(E) \sim N(E)$$

Rate at which particles injected at energy E

Time particles survive with energy E

Number of particles with energy E

Shorter t(E) at high E – steeper (softer) spectrum

Shorter t(E) at low E – flatter (harder) spectrum

Other emission

Hard X-ray emission

- From low mass and high mass X-ray binaries
- LMXBs correlate with M*
- HMXBs correlate with SFR

Soft X-ray emission

- Hot gas from SNRs, galactic winds
- Use a soft X-ray—SFR correlation

Soft γ-ray emission

- Lines and continuum from core collapse supernova
- Lines from radioactive decay in ISM (e.g., ^{26}Al)
- Positron annihilation radiation
- Supernova neutrinos

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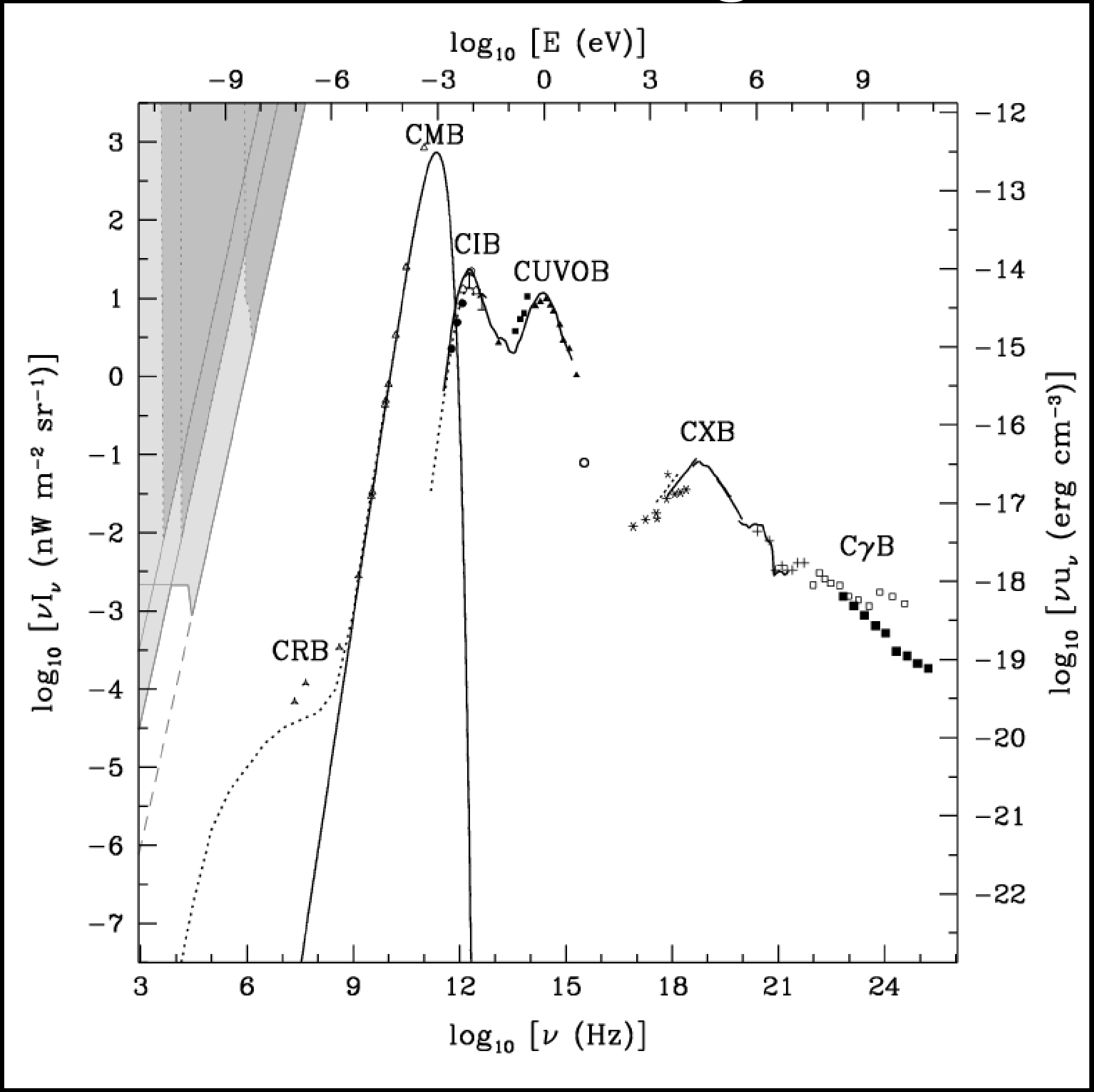

Credit: Lacki (2010) and references therein

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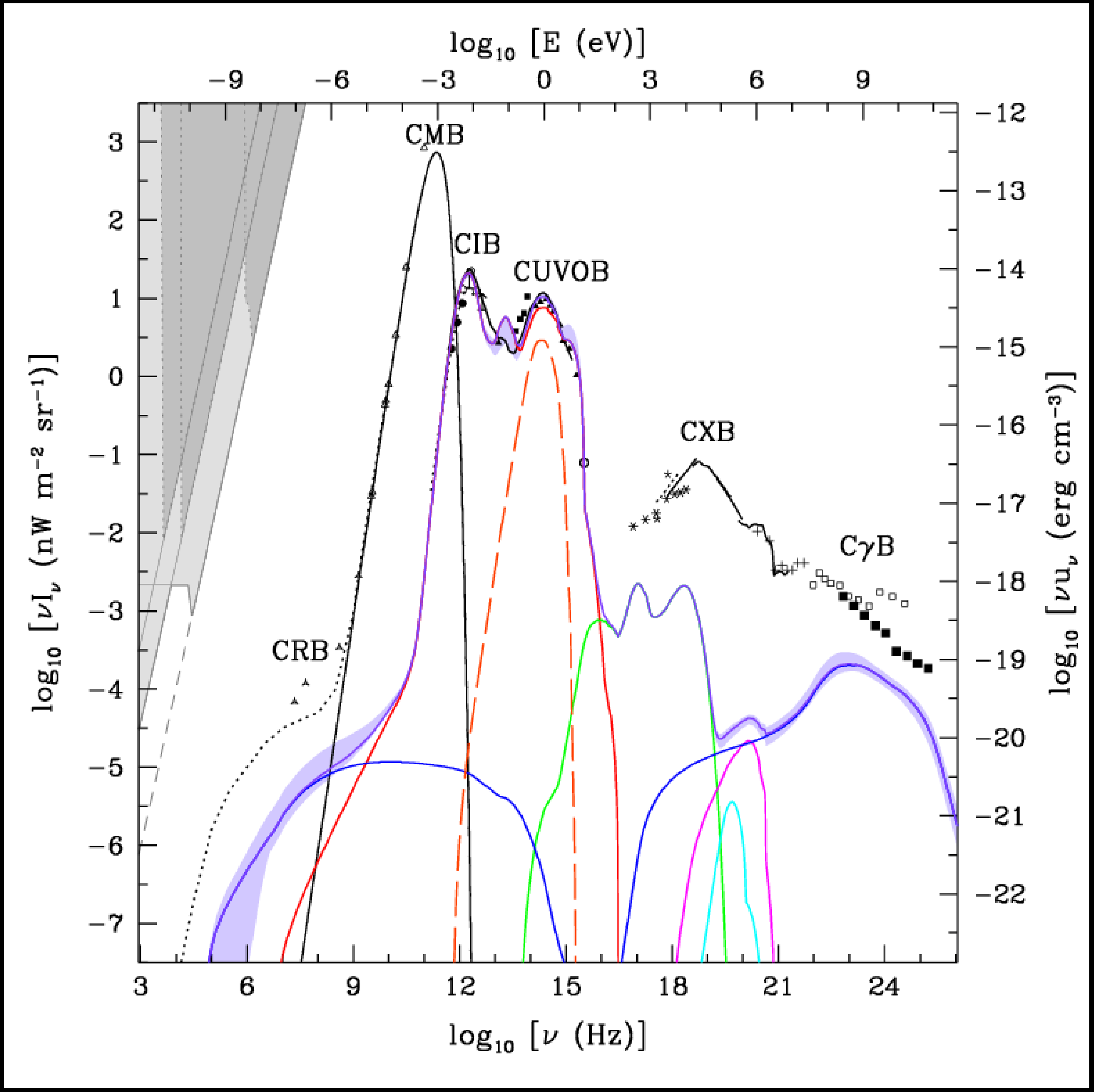
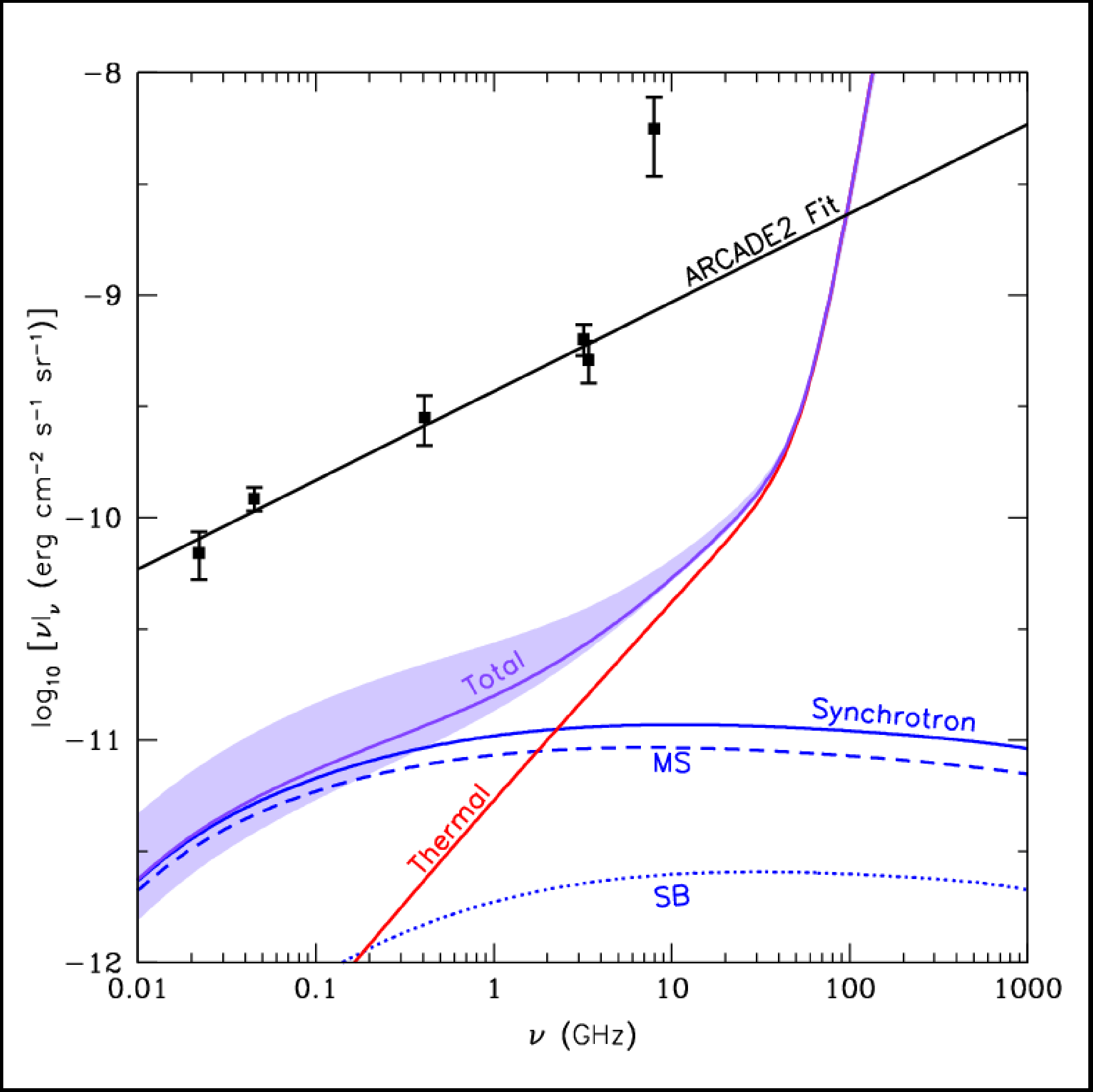


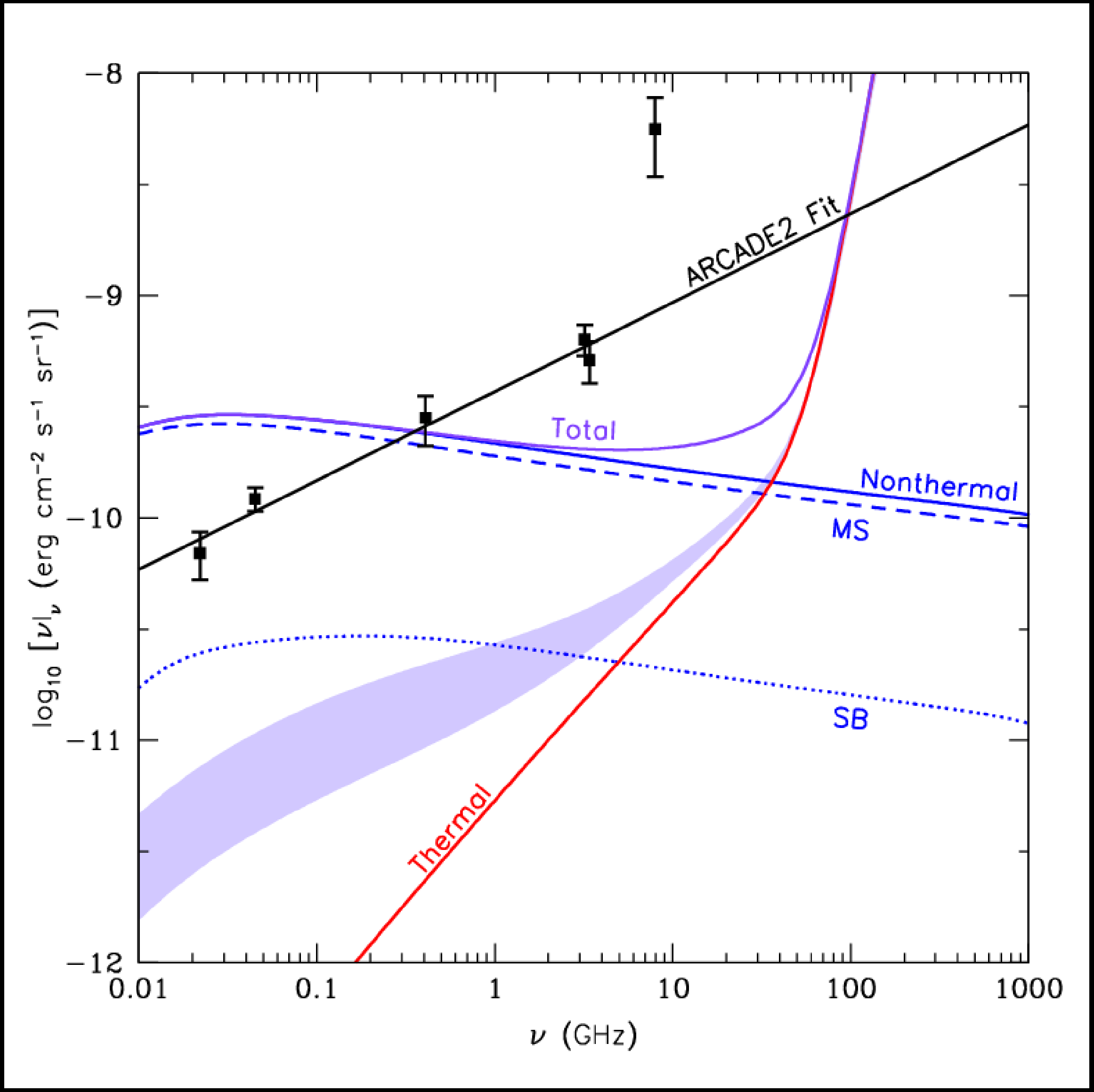
Credit: Lacki (2010) and references therein

The Radio Background



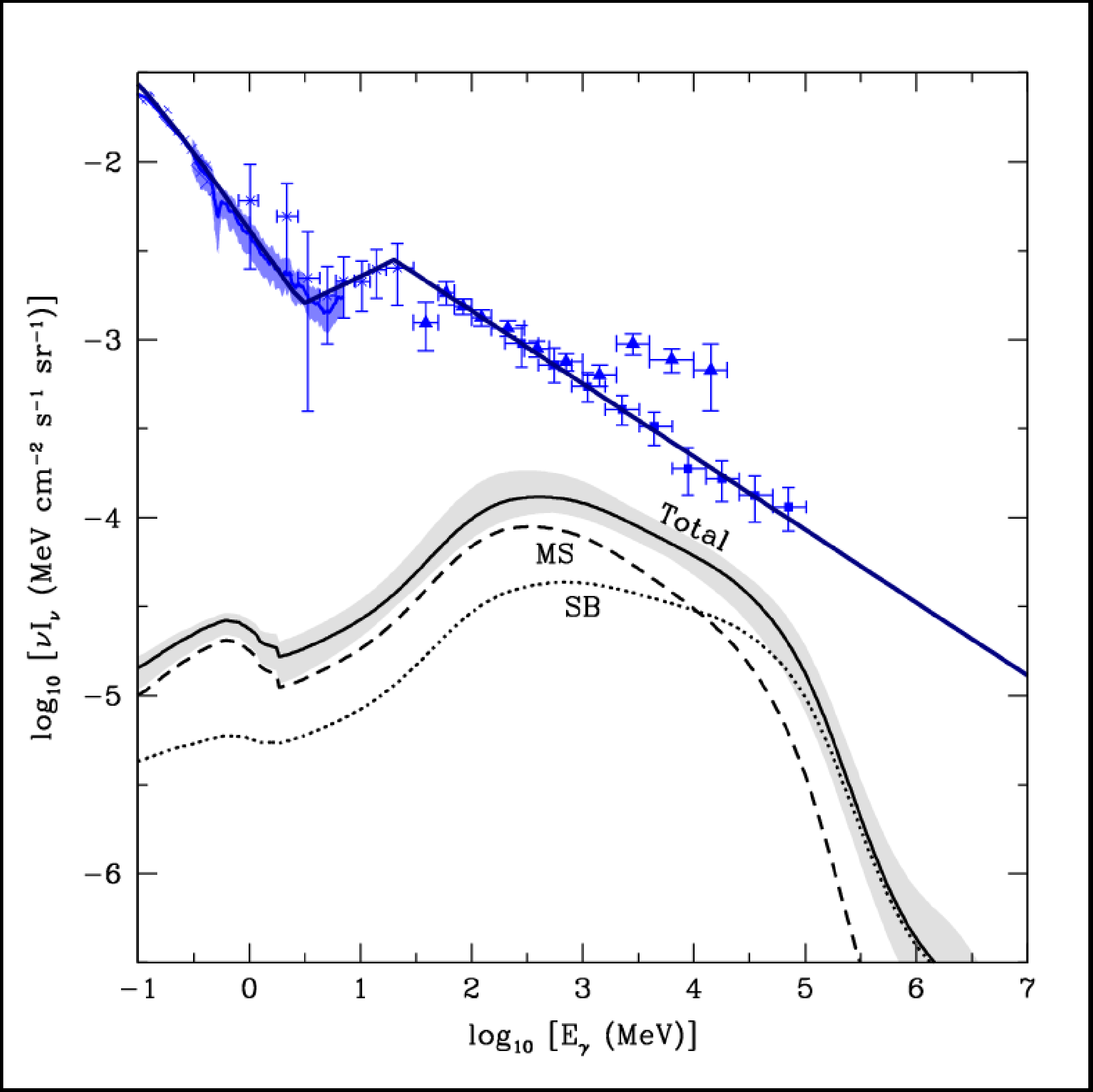
Credit: Seiffert et al. (2009) and references therein

Full ARCADE Excess Impossible



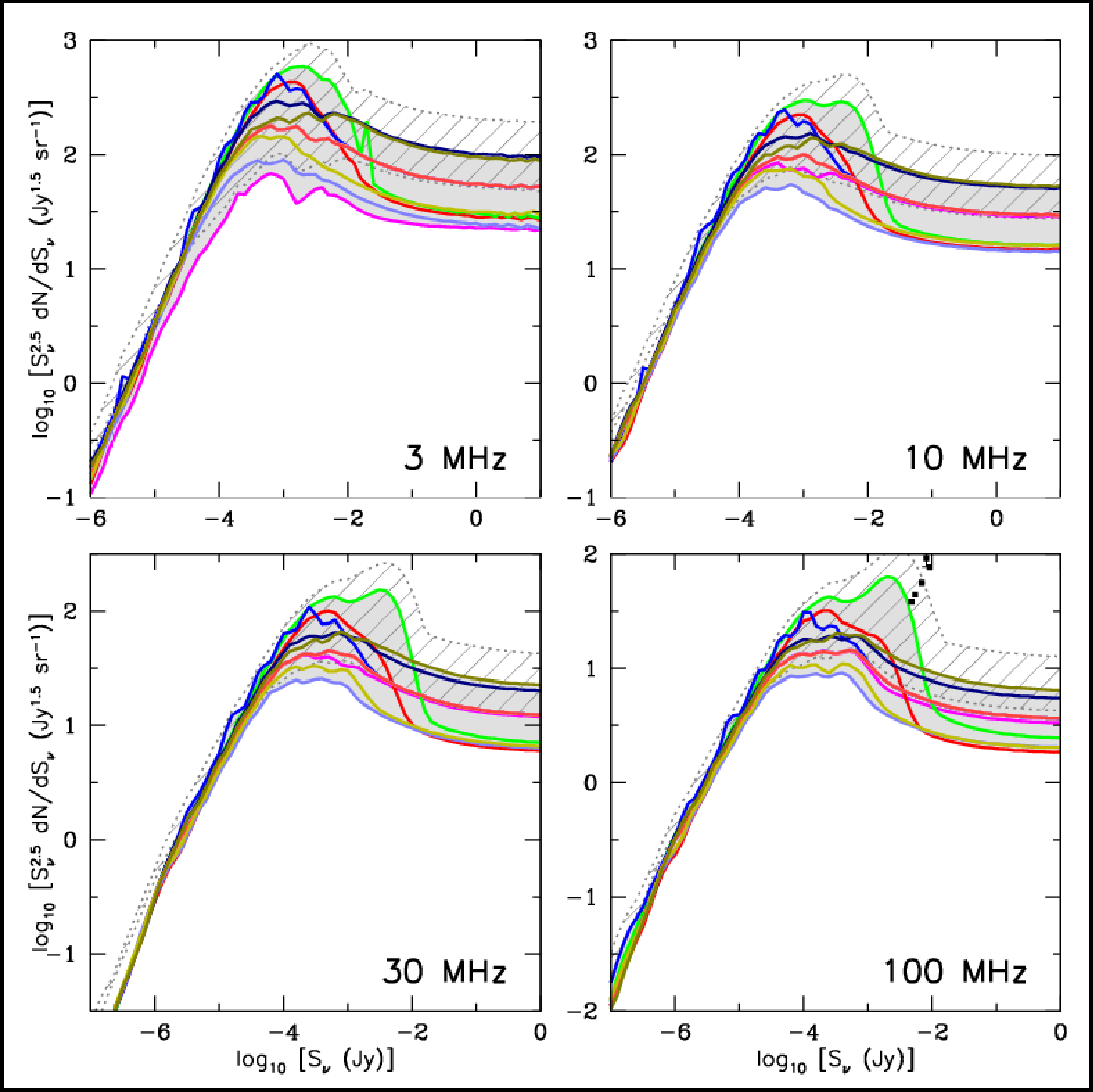
Credit: Seiffert et al. (2009) and references therein

The Gamma-Ray Background



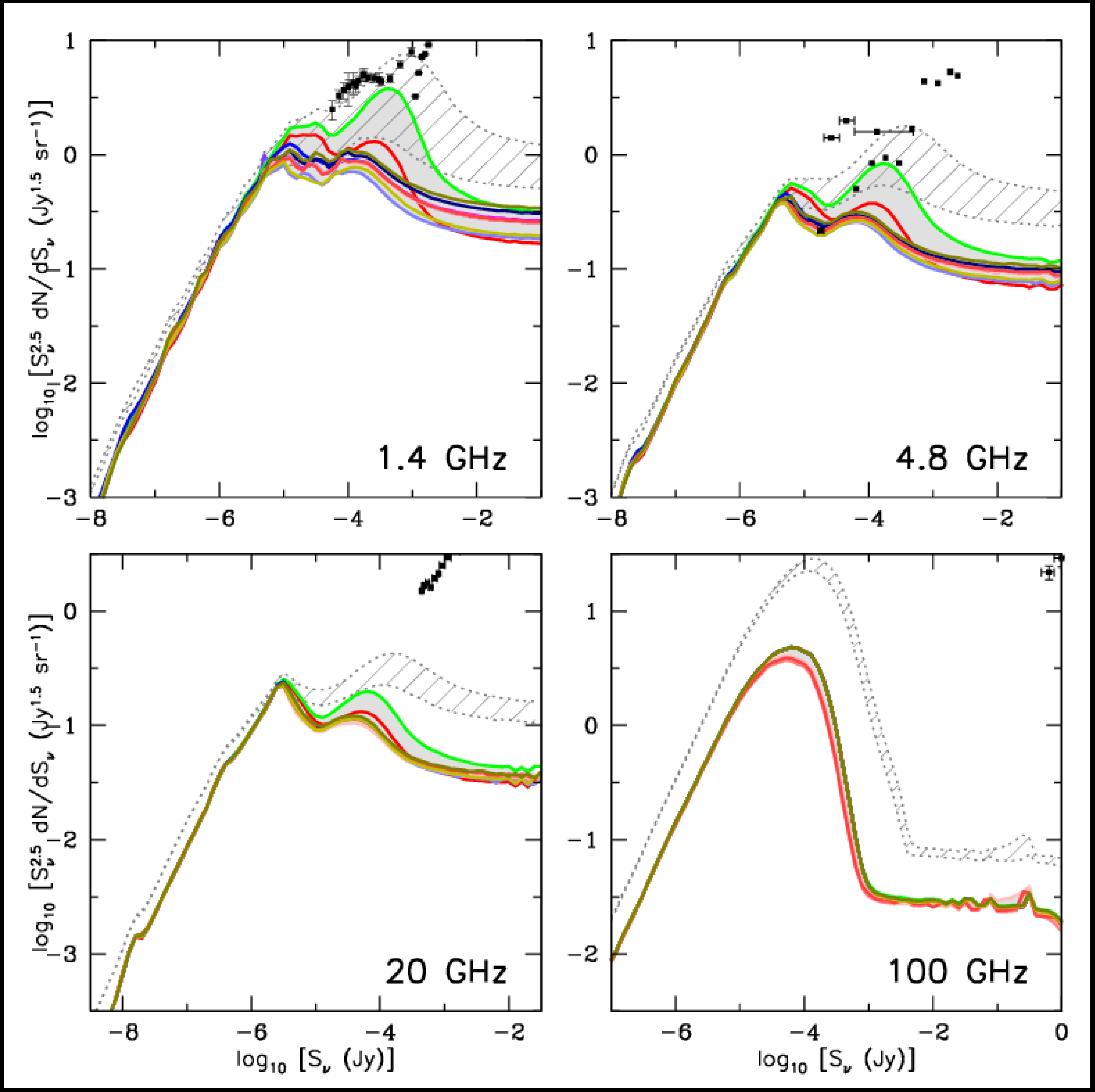
Credit: Lacki et al. (2014) and references therein

Source Counts: MHz Radio



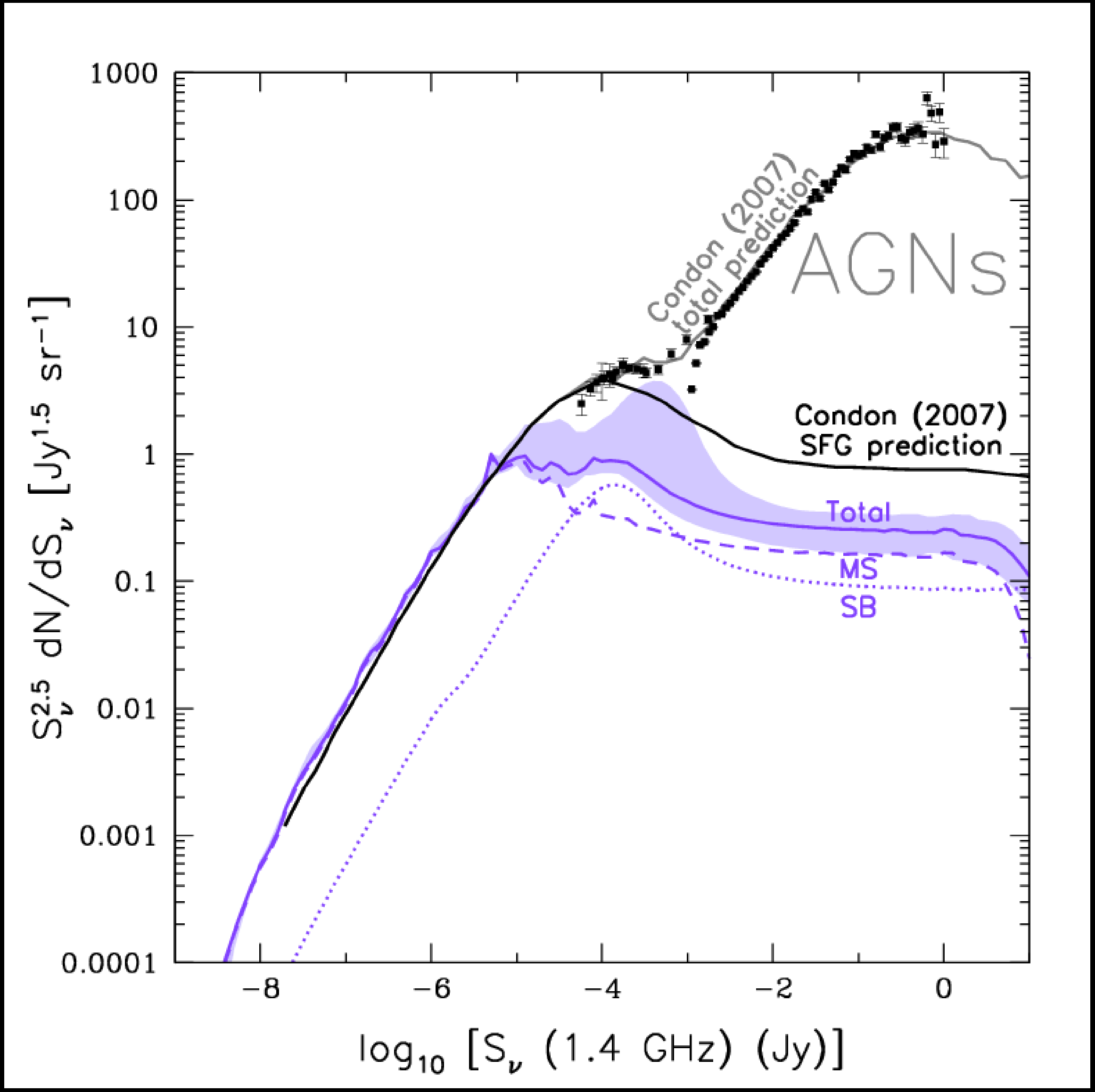
Data Credit: Intema et al. (2011); Ishwara-Chandra & Marathe (2010)

Source Counts: GHz Radio



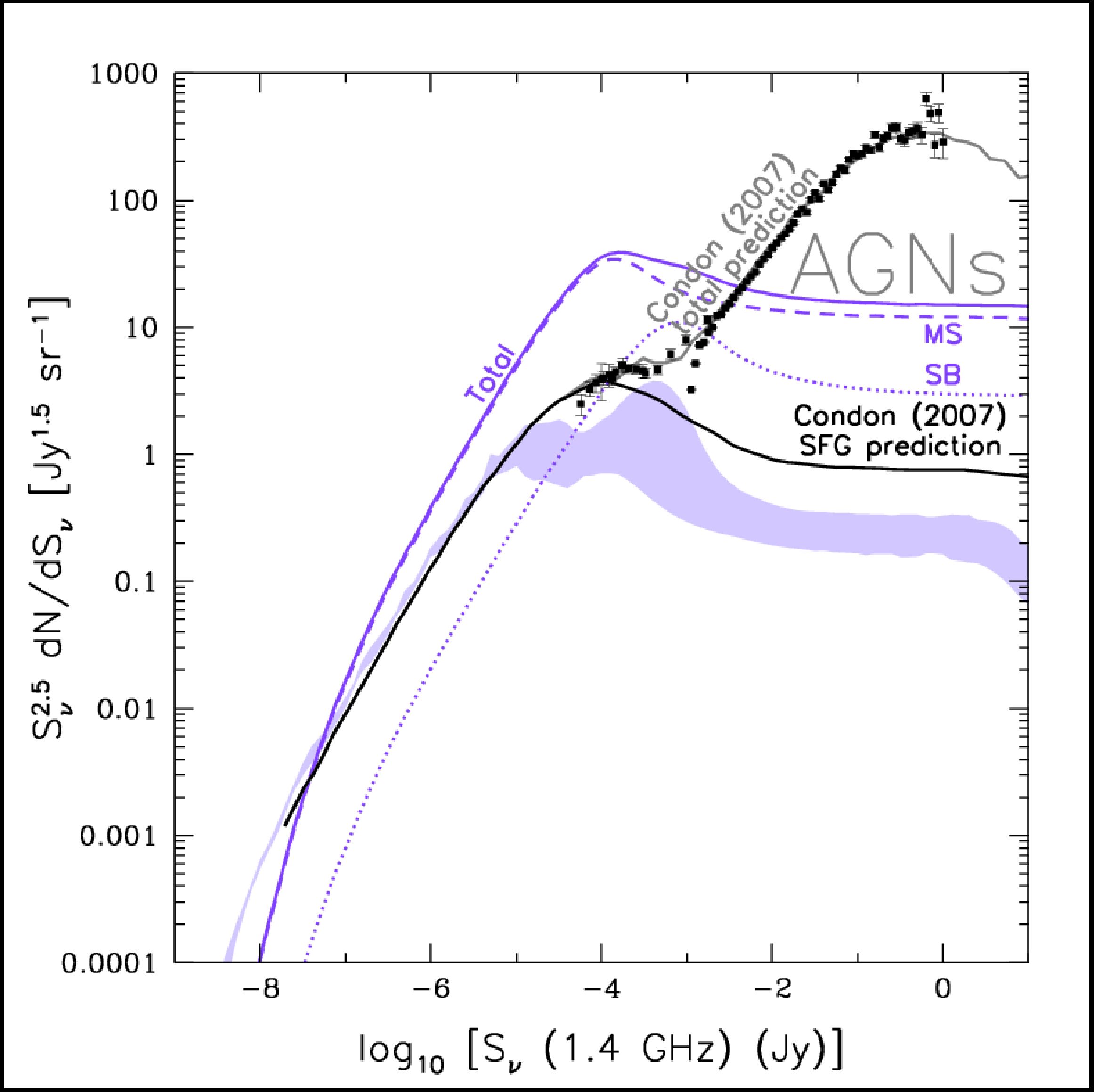
Data Credit: White et al. (1997); Hopkins et al. (2007); Fomalont et al. (1991); Huynh et al. (2012); AMI Consortium (2011); Planck (2013)

1.4 GHz Source Counts



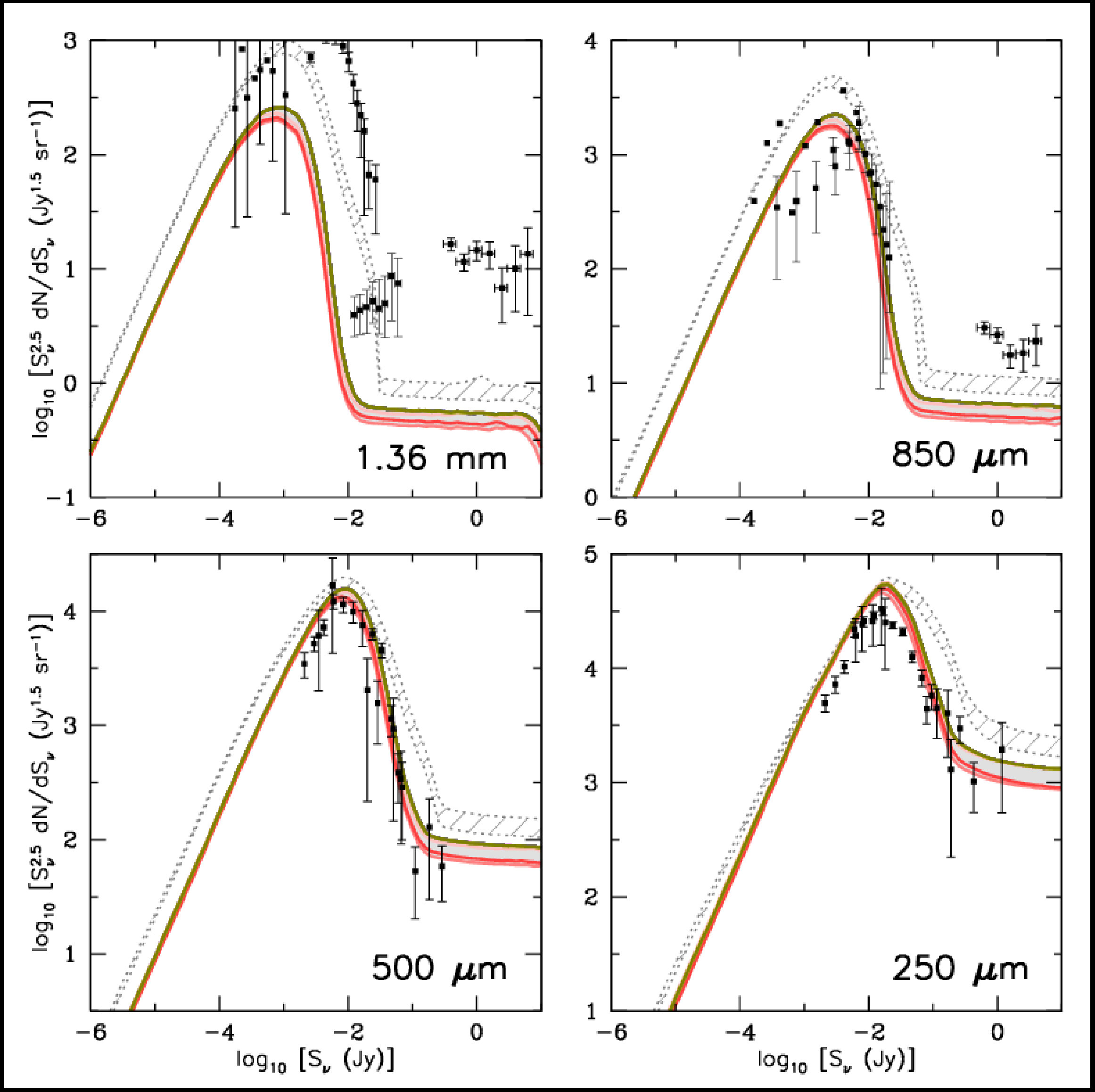
Credit: White et al. (1997); Hopkins et al. (2003); Condon (2007)

Full ARCADE Excess Impossible



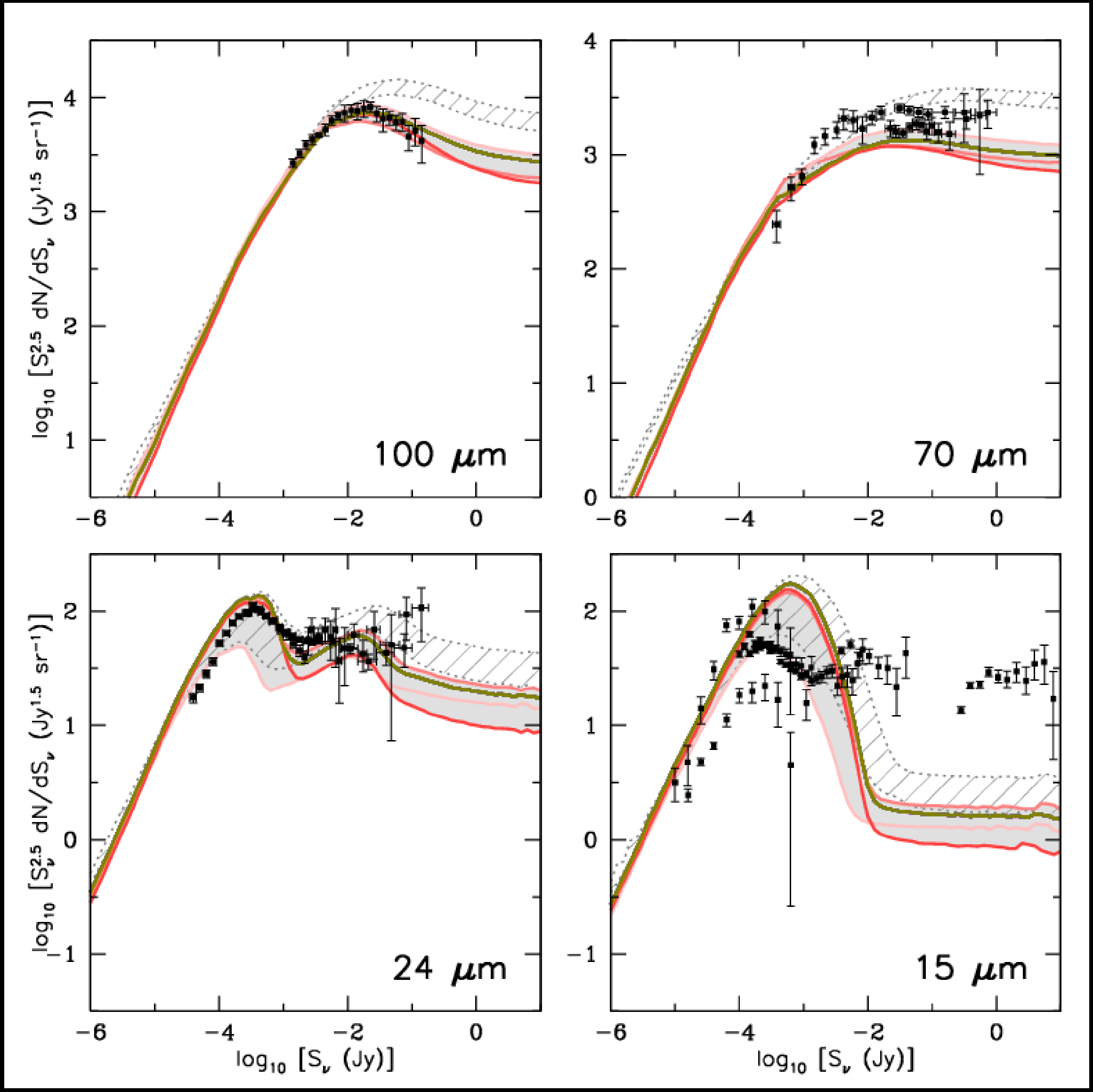
Credit: White et al. (1997); Hopkins et al. (2003); Condon (2007)

Source Counts: Submillimeter / FIR



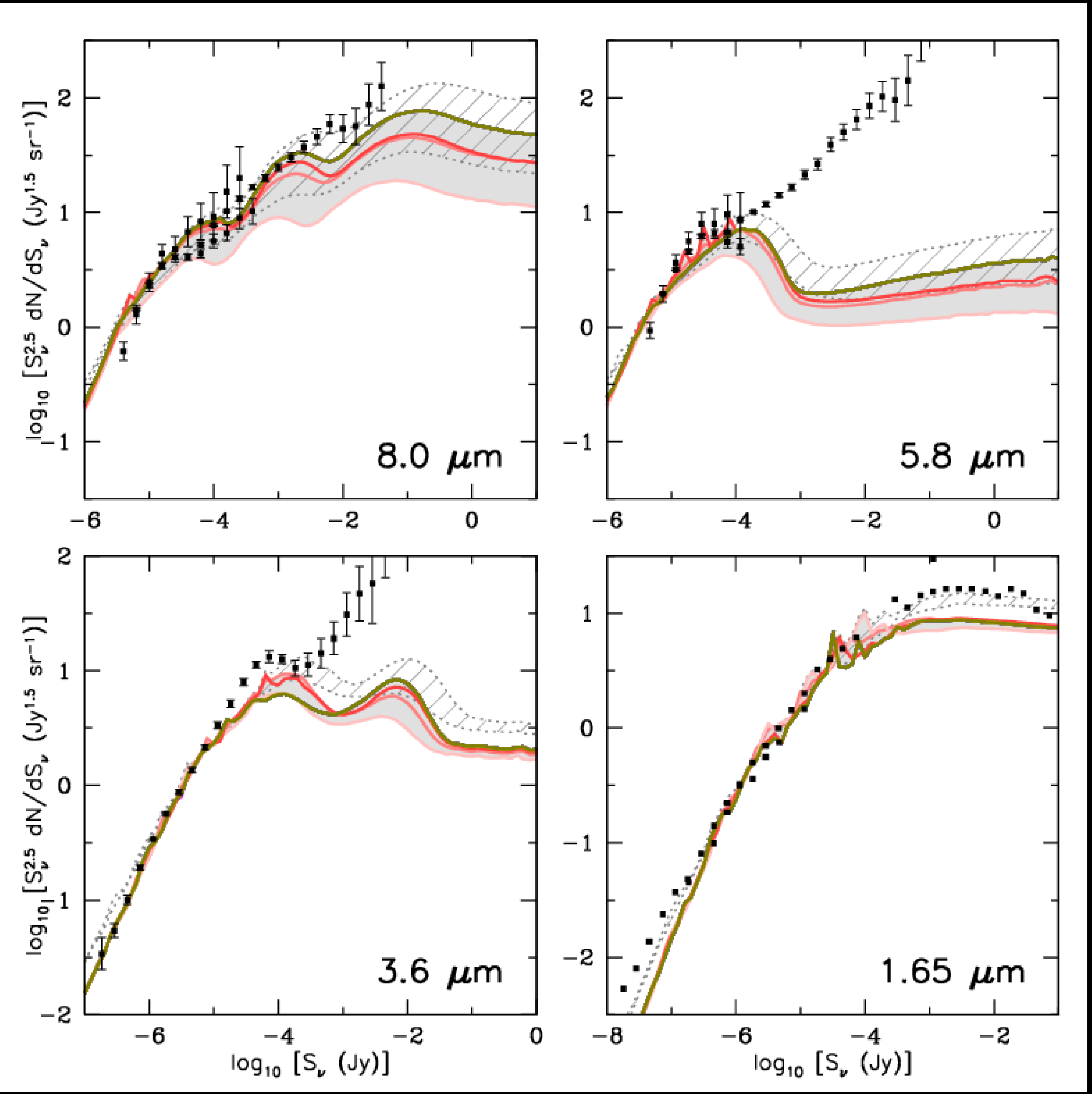
Data Credit: Vieira+(2010); Planck+(2013); Hatsukade+(2013); Ono+(2014); Scott+(2012); Coppin+(2006); Knudsen+(2008); Zemcov+(2010); Bethermin+(2010); Bethermin+(2012); Oliver+(2010)

Source Counts: MIR



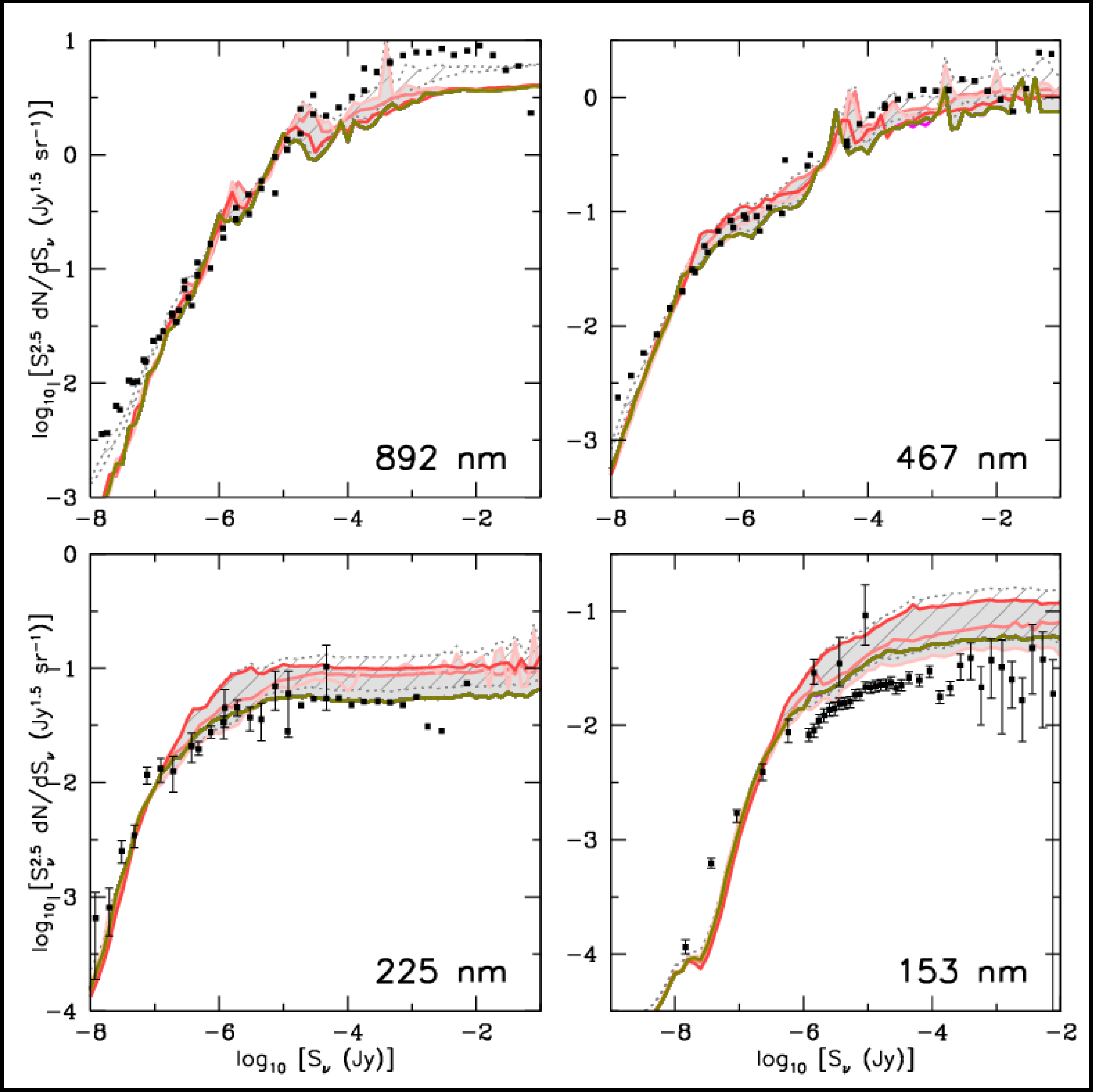
Data Credit: Berta+(2011); Bethermin+(2010); Clements+(2011); Rush+(1993); Serjeant+(2010); Burgarella+(2009); Hopwood+(2010); Pearson+(2010)

Source Counts: NIR



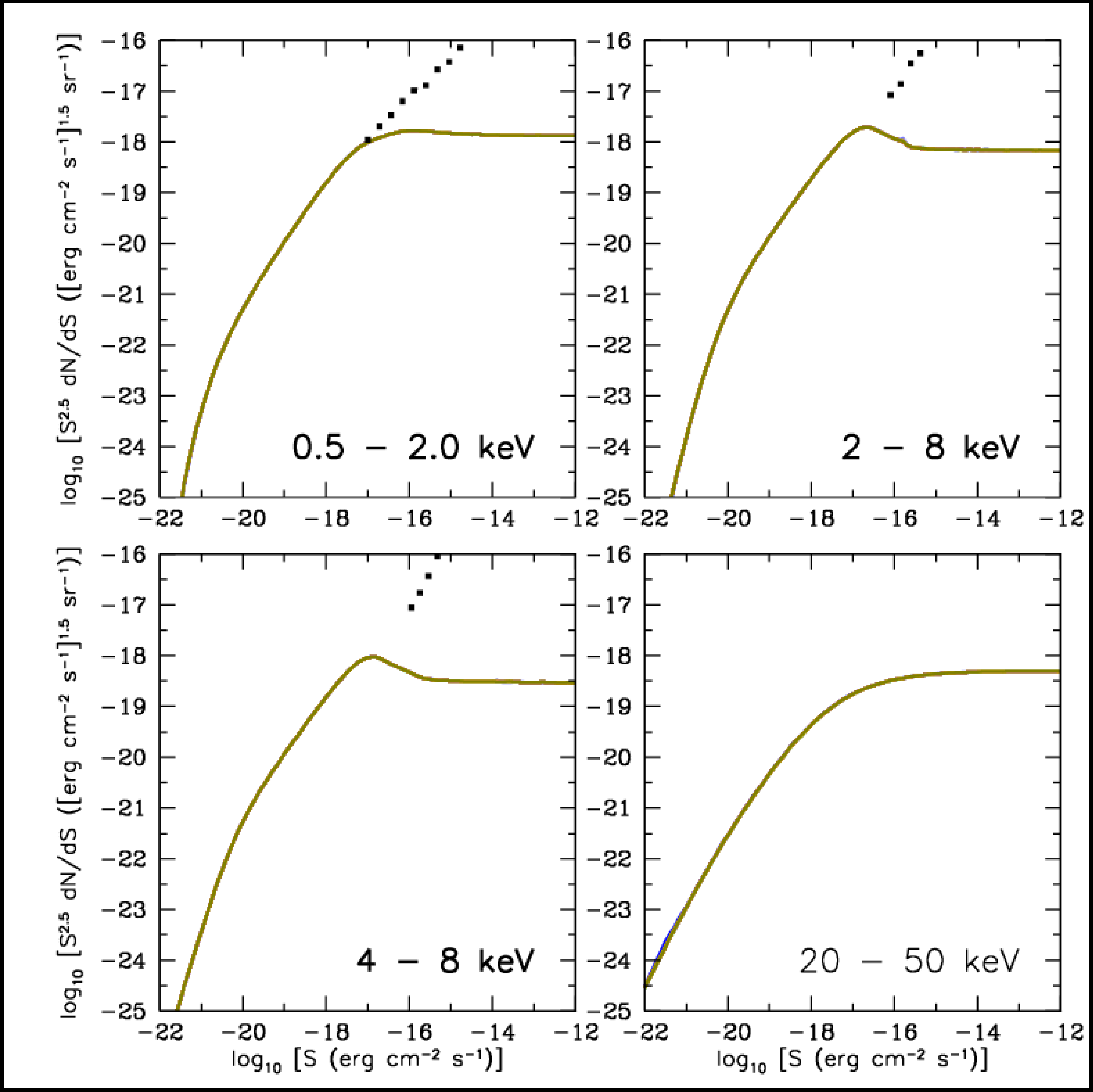
Data Credit: Fazio et al. (2004); Ashby et al. (2013); Windhorst et al. (2011)

Source Counts: Optical / UV



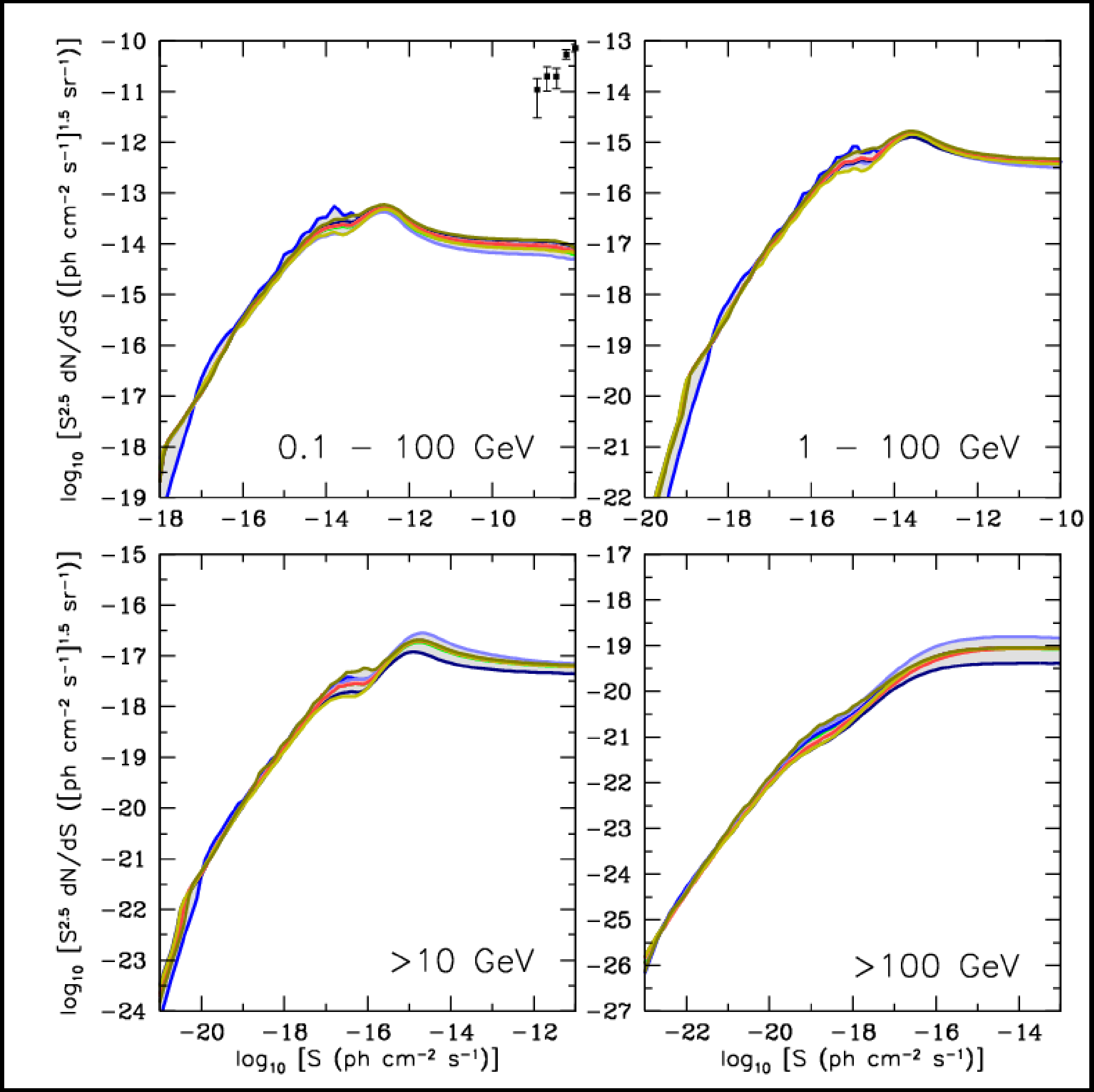
Data Credit: Windhorst et al. (2011); Xu et al. (2005); Voyer et al. (2011)

Source Counts: X-Rays



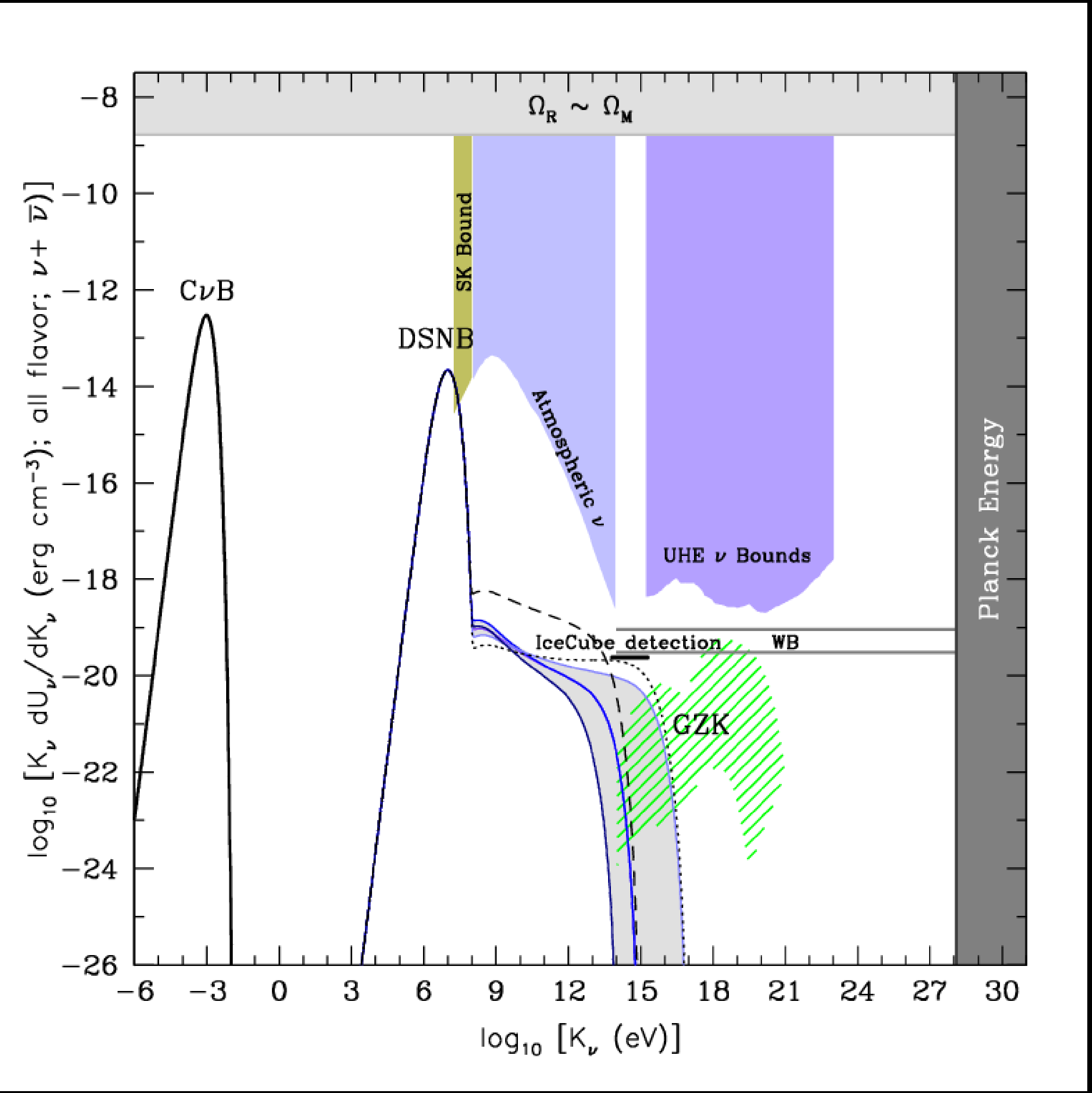
Data Credit: Lehmer et al. (2012)

Source Counts: GeV Gamma Rays



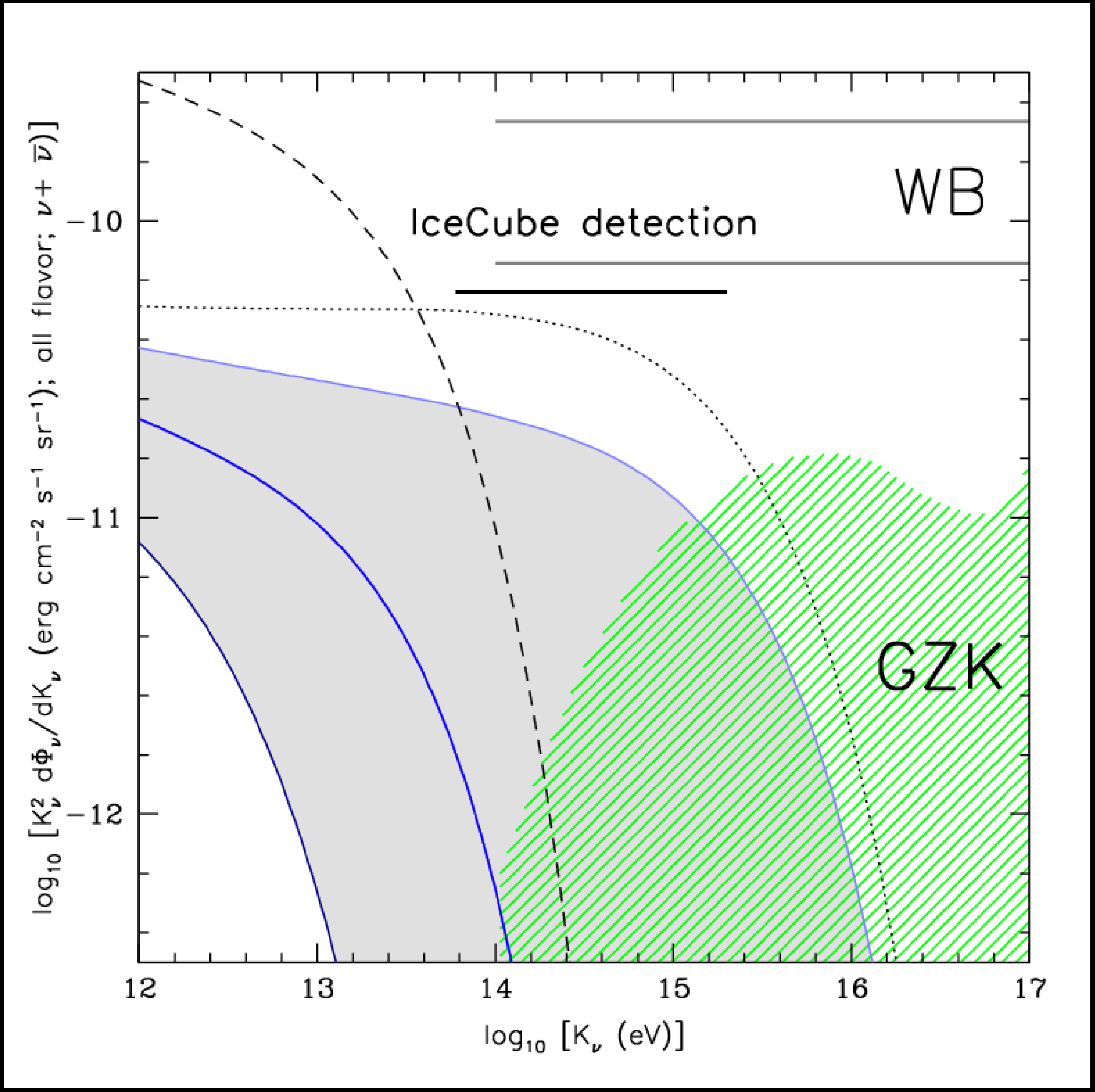
Data Credit: Abdo et al. (2010)

The Neutrino Background



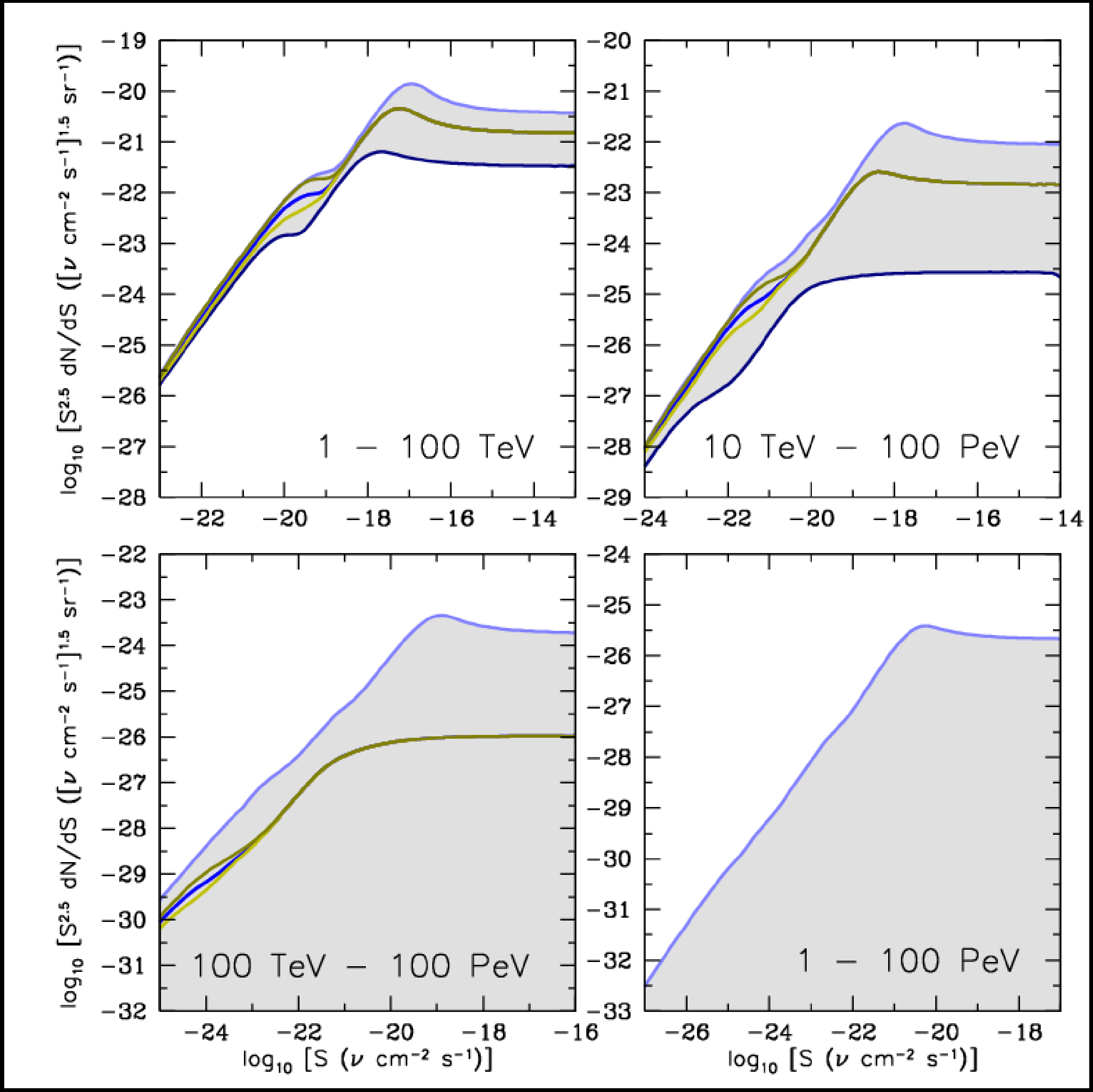
Credit: References given in Lacki (2012) (UHE; WB; Atmospheric; Super-K); Whitehorn (2013) (IceCube); Kotera et al. (2011) (GZK)

The IceCube Background is Difficult



Credit: Waxman & Bahcall (1995); Kotera et al. (2010); Whitehorn (2013)

Source Counts: TeV/PeV Neutrinos



Conclusions

Simple one-zone framework for physical models of galaxy emission at all wavelengths

- Get integrated backgrounds, source counts
- SFGs can't explain ARCADE radio background
- SFGs are ~1/3 of GeV gamma-ray background
- Conventional CR populations in SFGs have trouble making IceCube background

Other processes to include in future

- Is there any simple way to include PDR IR emission?
- Stellar neutrinos?
  - May require detailed stellar population models
- Do ultra-high energy CRs come from SFGs?