Constraining Cosmic Ray Origins Through Spectral Radio Breaks In Supernova Remnants

The emission of non-thermal gamma radiation in supernova remnants (SNR) is thought to indicate the production of cosmic rays. Here we extend the radio spectrum to higher frequencies for multiple remnants in order to better constrain the radiative processes responsible for gamma ray production.

SCIENCE

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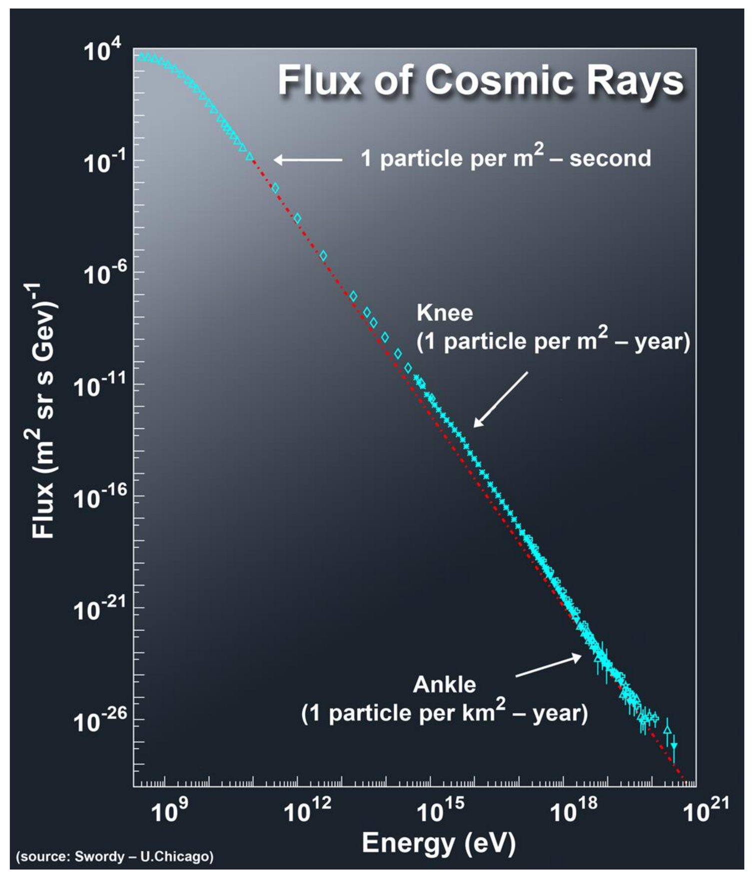
Do cosmic rays originate in supernova remnants?



Cosmic Rays:

- 90% highly energetic protons
- Follow a power law distribution in energy
- PeV and lower originate within the galaxy
- Origin unknown? See below

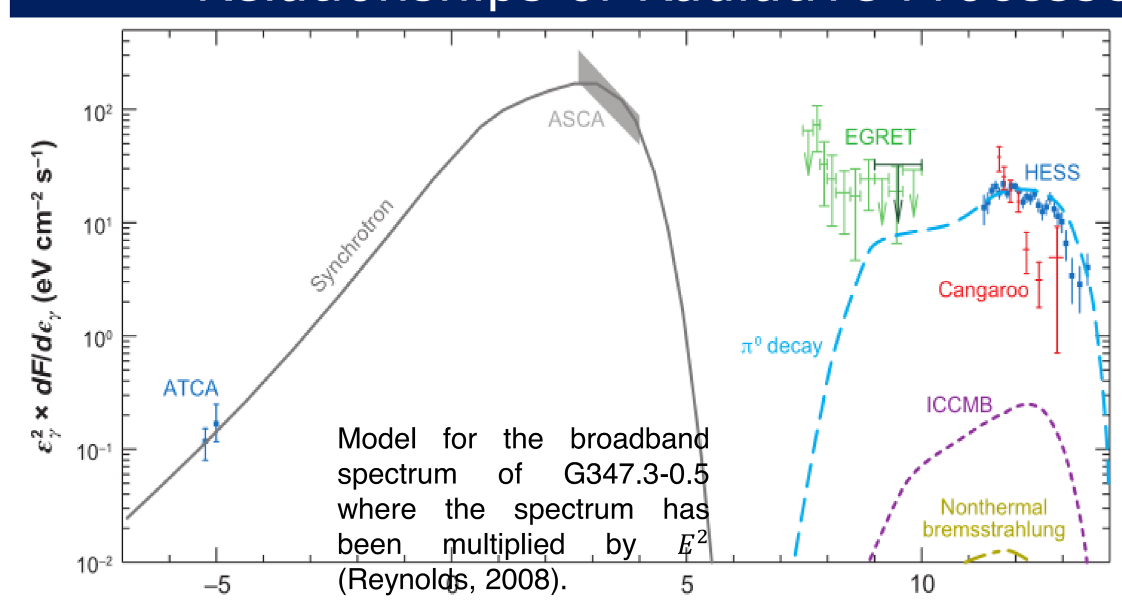
Supernova Remnants:

- Expel 10^{51} ergs of kinetic energy
- Produce shock fronts capable of accelerating particles
- Last tens of thousands of years

Puppis A Image Credit: NASA/JPL-Caltech/WISE Team

- Supernova remnants radiate gamma rays through three primary radiative processes: inverse Compton scattering, bremsstrahlung radiation, and neutral pion decay.
- If we eliminate the first two processes from electrons as the sources of gamma radiation, then supernova remnants accelerate protons to cosmic ray energies.
- This requires understanding the radio synchrotron emission to better understand whether the environment is sustainable for the other two leptonic processes.

Relationships of Radiative Processes



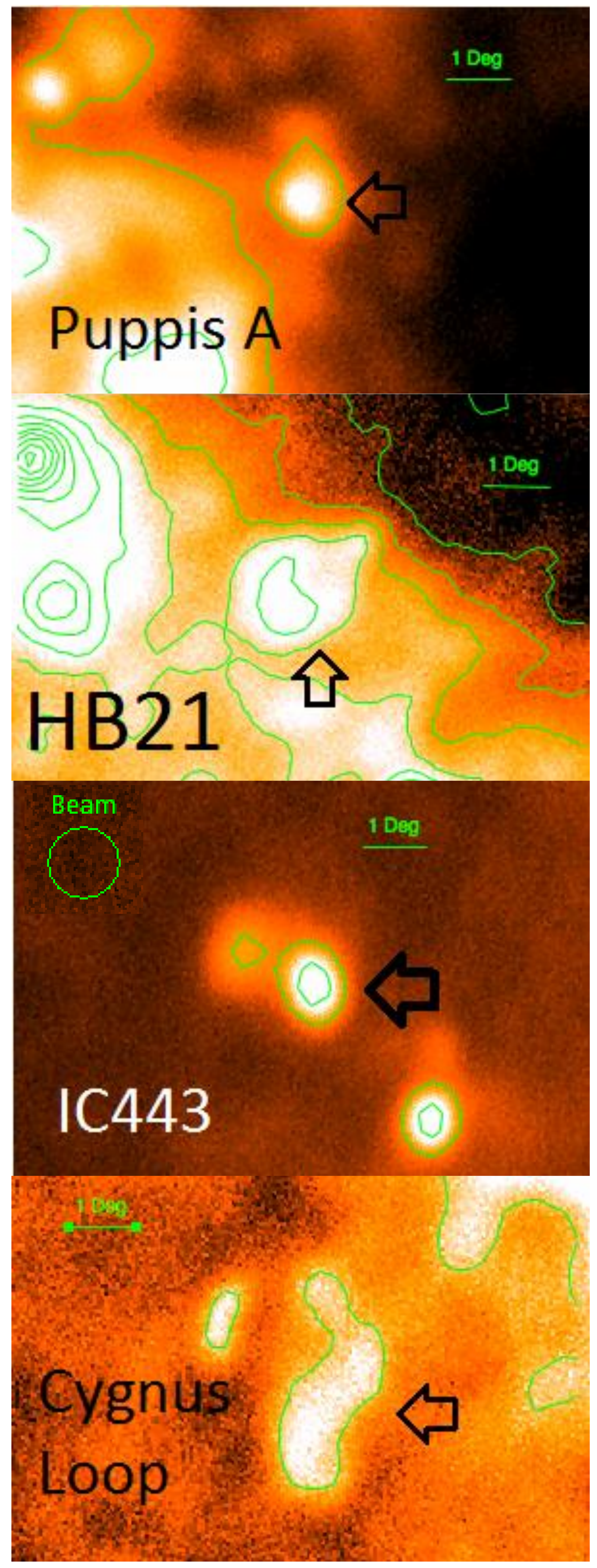
Model for the broadband spectrum of G347.3-0.5 where the spectrum has been multiplied by E^2 (Reynolds, 2008).

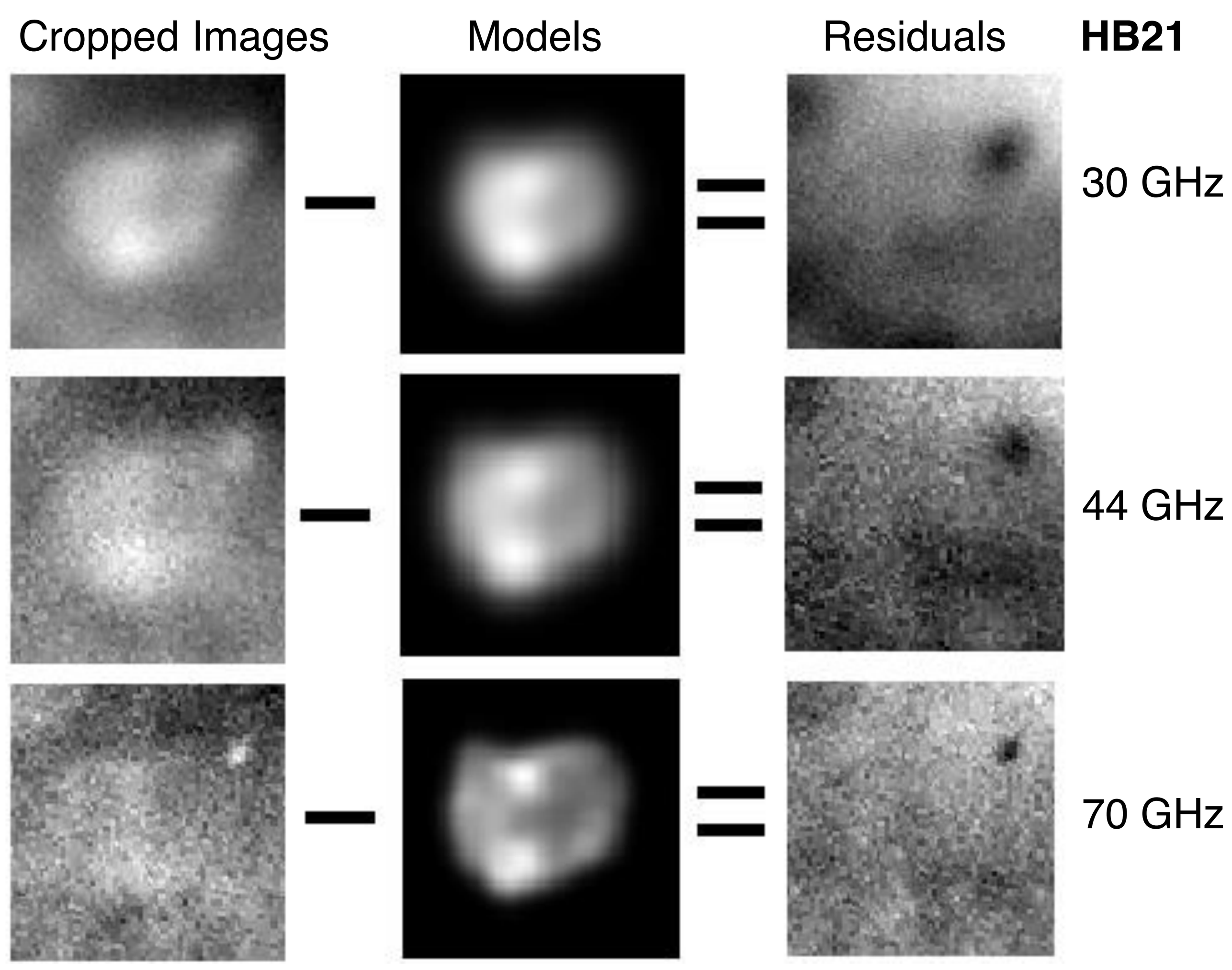
- The particle distribution of synchrotron radiation is $N(E) = E^{-s}$, while the emission spectrum is $S(\nu) = \nu^{-\alpha}$. E is energy in GeV, and ν is frequency in GHz.
- The power law index s is related to the spectral index α by $s = 1 + 2\alpha$ for bremsstrahlung and neutral pion decay. Inverse Compton scattering follows $s = 1 + \alpha$.
- The electron energy is related to the frequency break and the magnetic field by $E(GeV) = 14.7(\frac{\nu(GHz)}{B(\mu G)})^{1/2}$.

Fitting Supernova Remnants with Planck

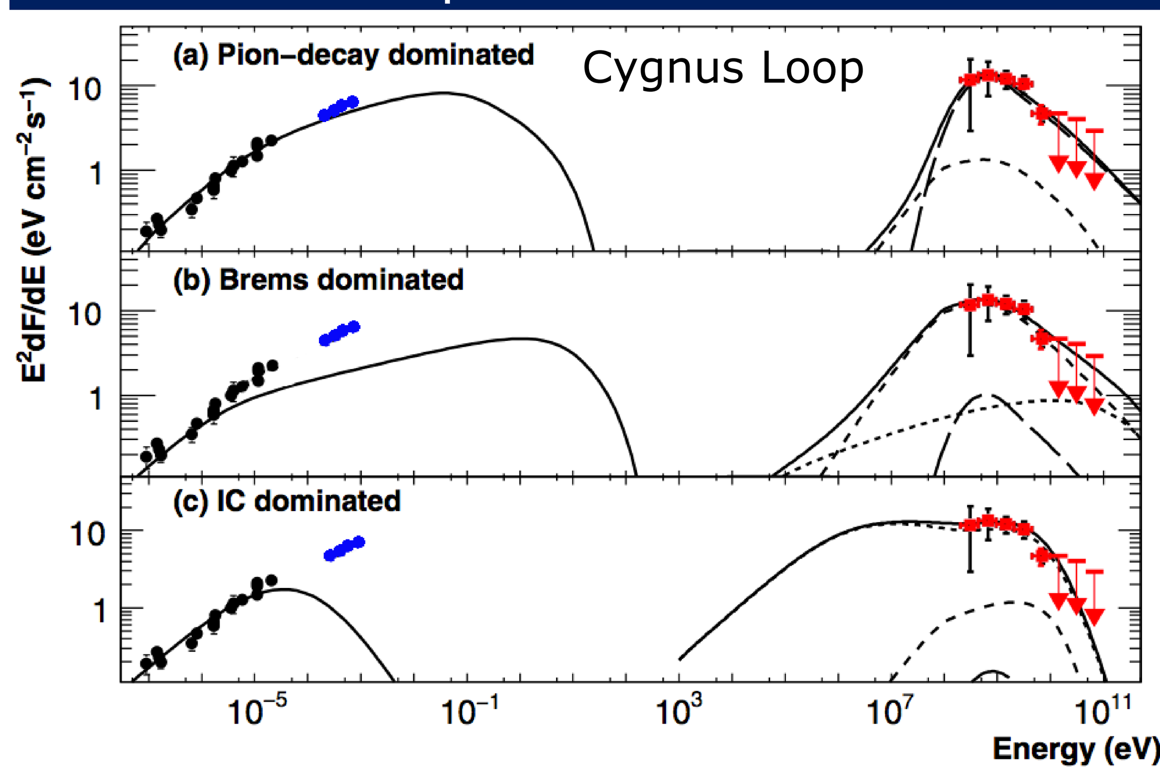
Planck was a space observatory designed to observe the entire sky in the microwave to infrared band (30 – 857 GHz). This extension of microwave data is just enough to see the break in synchrotron radiation for some remnants. We chose the four remnants to the right based on their brightness and complementary gamma ray detection. The images were cropped, and then regridded to the coordinate system of a radio template. →

The model from this process would act as a beam parameter since these SNRs are not Gaussian. The cropped images were then fitted to the models and the flux of the SNR was extracted. The residuals were studied to make sure the alignment was sufficient (as seen below with HB21). For calibration purposes, three point-like remnants (Cassiopeia A, 3C58, Crab Nebula) were also fitted. Once the fluxes were converted to Janskys, the data was then plotted as a function of frequency. The data, along with WMAP data and radio data from the literature, was fitted with a broken power law, and the confidence was determined by using an f-test. ↓↓↓





Implications of Radio Breaks for Gamma-ray Origins



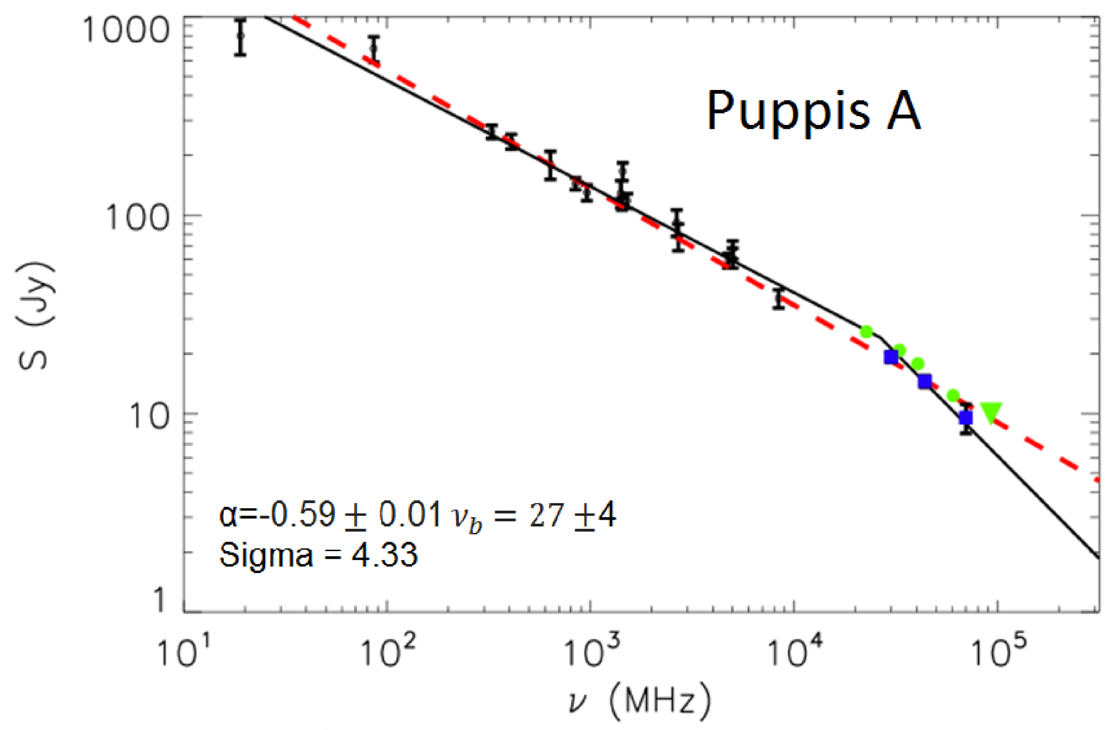
The plot to the left is a multi-band spectra of Cygnus Loop. The black and red circles are the radio and gamma data from the literature respectively (Katagiri et al.). The blue circles are the Planck data overlaid. The lack of a break for Cygnus Loop shows that it fits the hadronic model better, which is interestingly unlike the three other remnants.

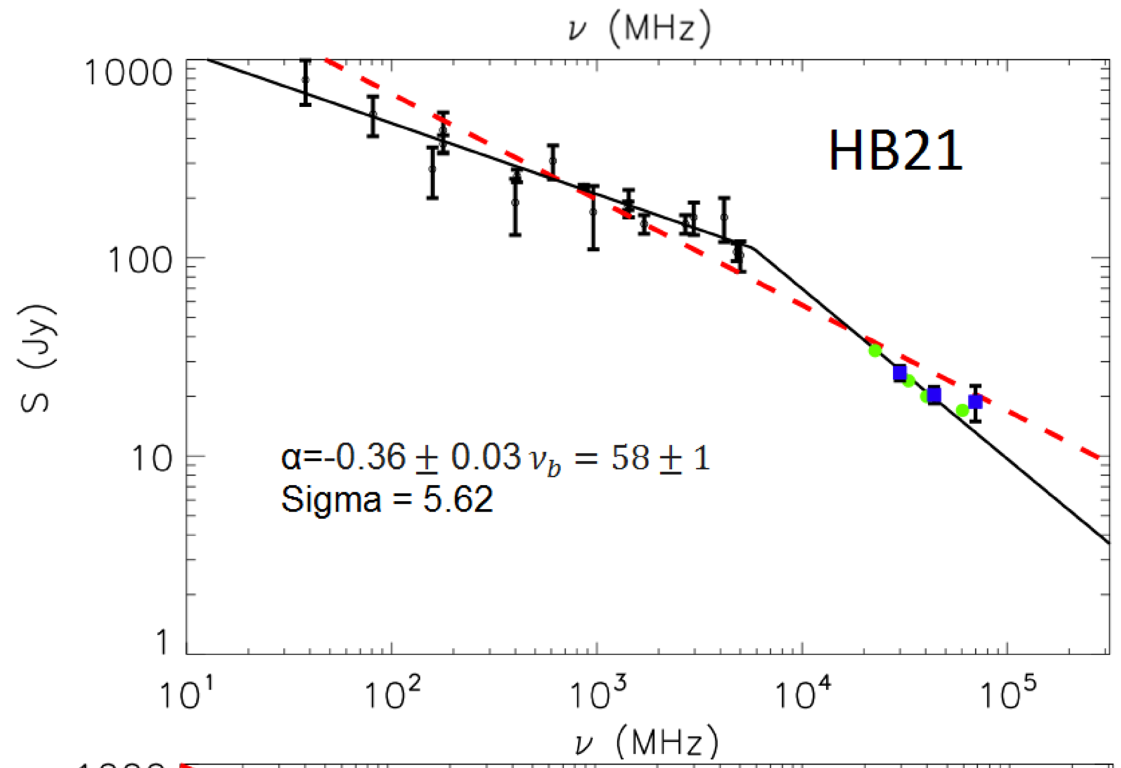
Puppis A is the only one out of the other three remnants with a corresponding magnetic field lower than the ISM (valued at about 3μG); however, inverse Compton scattering can be ruled out for all three remnants since the power-law indices are not related.

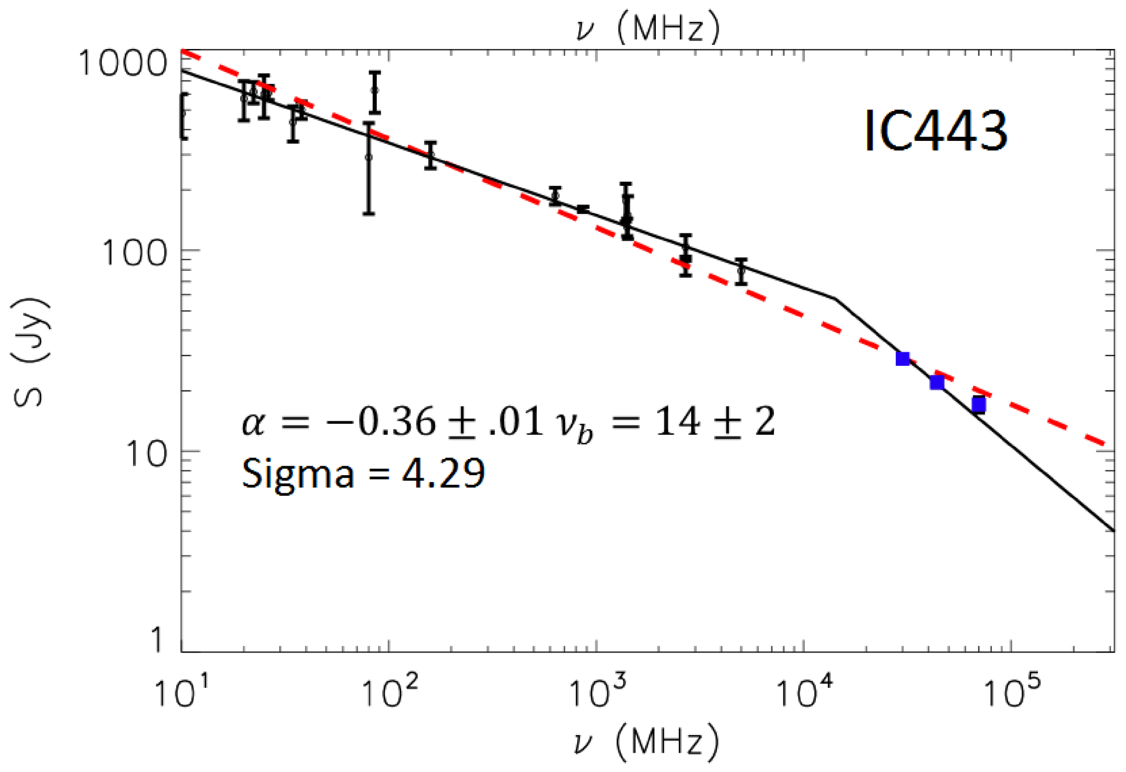
SNR	$E(GeV)$	$B(\mu G)$	$\nu_b(GHz)$	α	s (IC/Pion)
Puppis A	100 (Hewitt et al. 2012)	0.583 ± 0.09	27 ± 4	0.59 ± 0.01	1.59 ± 0.01 2.18 ± 0.02
HB21	$0.789 \pm .065$ (Pivato et al., 2013)	20000 ± 4000	58 ± 1	0.36 ± 0.03	1.36 ± 0.03 1.72 ± 0.06
IC443	3.25 ± 0.6 (Abdo et al., 2010)	300 ± 100	14 ± 2	0.36 ± 0.01	1.36 ± 0.01 1.72 ± 0.02

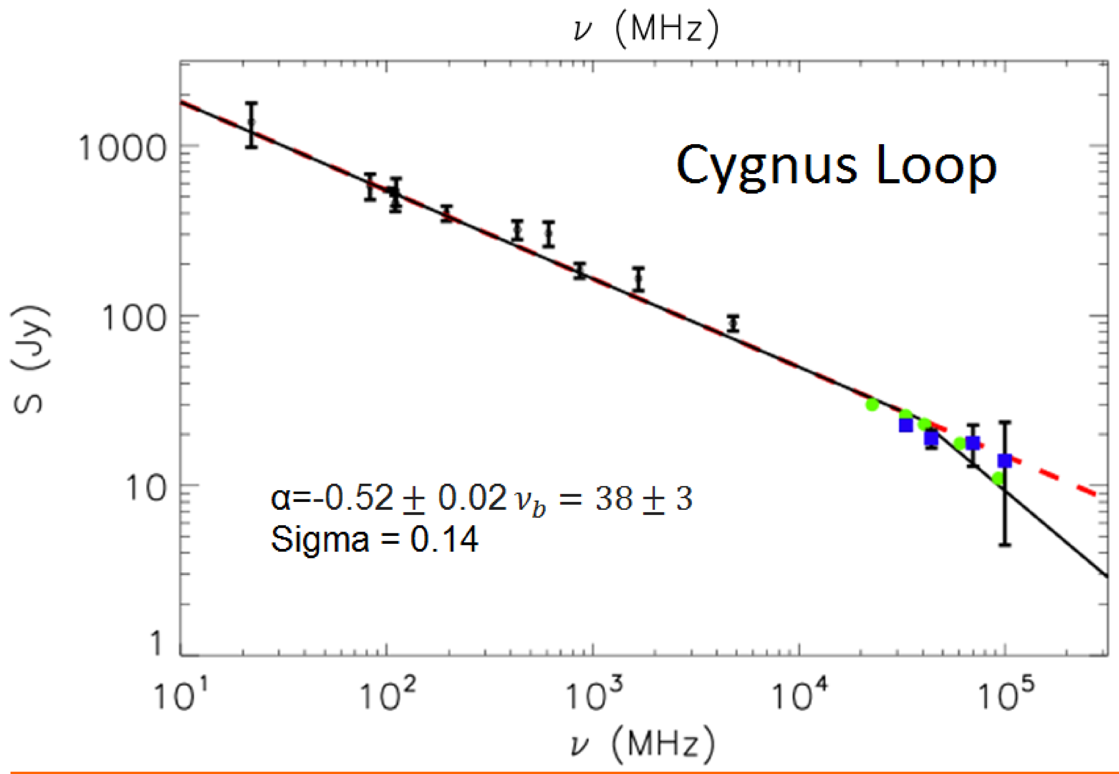
Extending Radio Spectra

The black boxes are the radio data from the literature, the green circles are WMAP data from the literature, and the blue squares are Planck data. The data is fit to a power law and a broken power law. The significance is based on how well the data fits the model.









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