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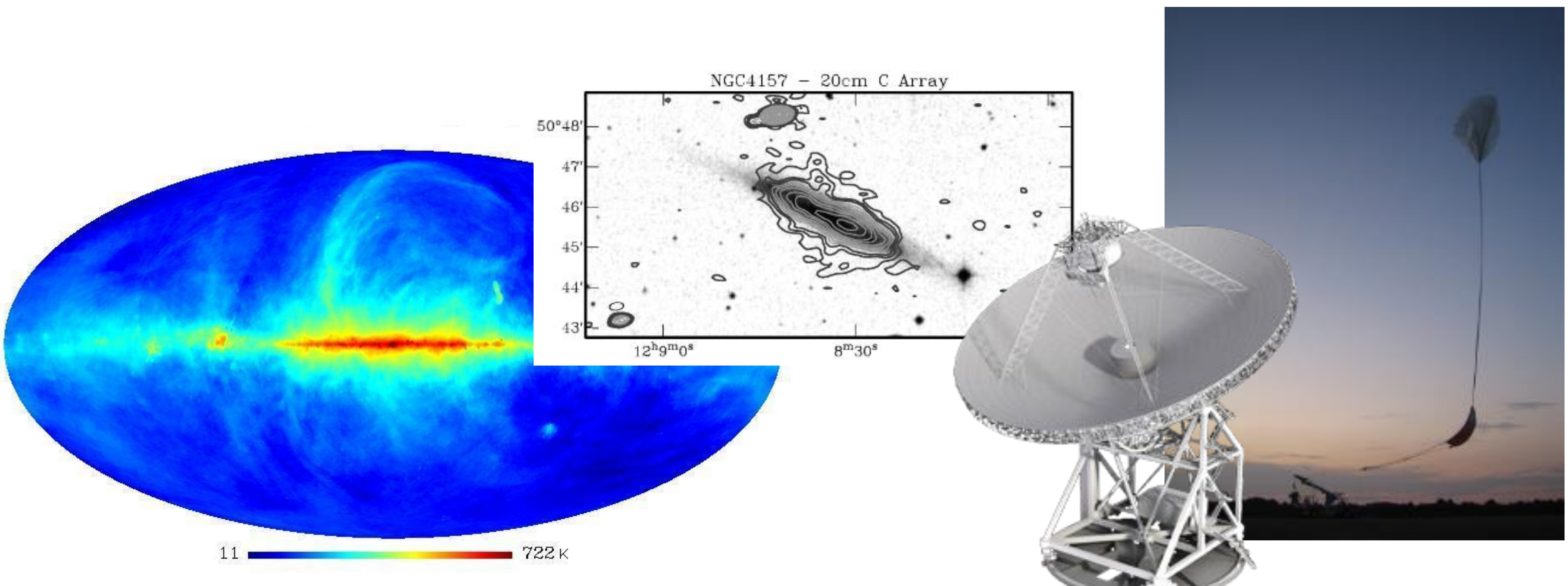
RSB Workshop
July 2017

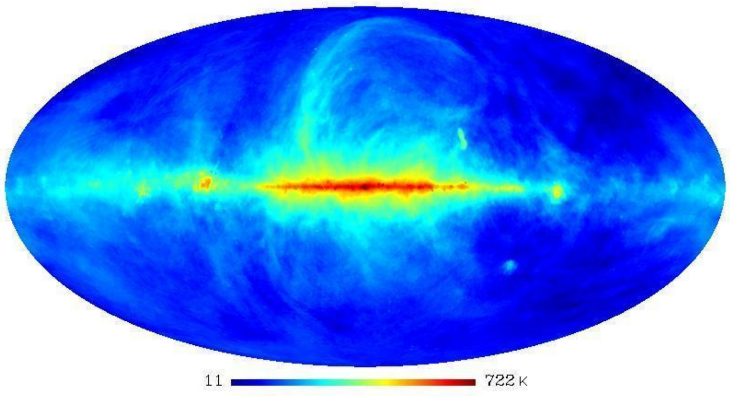
Tests of Simple Galactic Origin Models

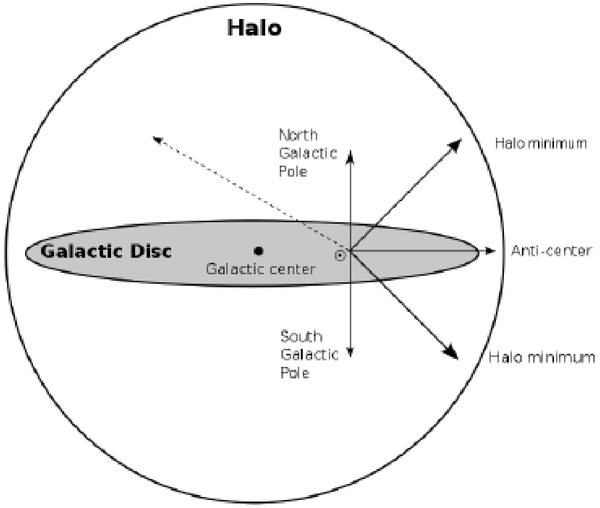


A Case *For* Galactic

R. Subrahmanyan & R. Cowsik, 2013, *ApJ*, 776, 42 "*Is there an unaccounted excess Extragalactic Cosmic Radio Background?*"

They use a 2-component 5-parameter vs frequency Galactic spatial model for radio emission to get a high halo component which could give the RSB surface brightness.





Some Cases ***Against*** Galactic

(to be addressed in turn)

- Inverse-Compton

- Observations of other galaxies like ours

- Large scale Galactic radio emission is well fit by a csc(b) spatial model, and a correlation of radio with C+ emission at 158 μm agrees

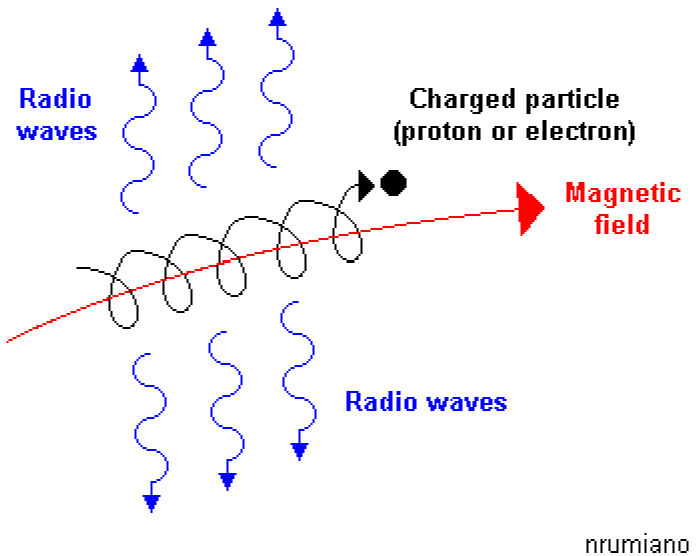
Inverse-Compton

- J. Singal, L. Stawarz, V. Petrosian, & A. Lawrence (2010, *MNRAS*, 409, 1172)

- Synchrotron emissivity is a combination of electron energy density (U_{e-}) and magnetic field energy density (U_B)

- For a given observed synchrotron level $\nu_{syn} U_{\nu_{syn}}$ if $U_B \downarrow$ then $U_{e-} \uparrow$

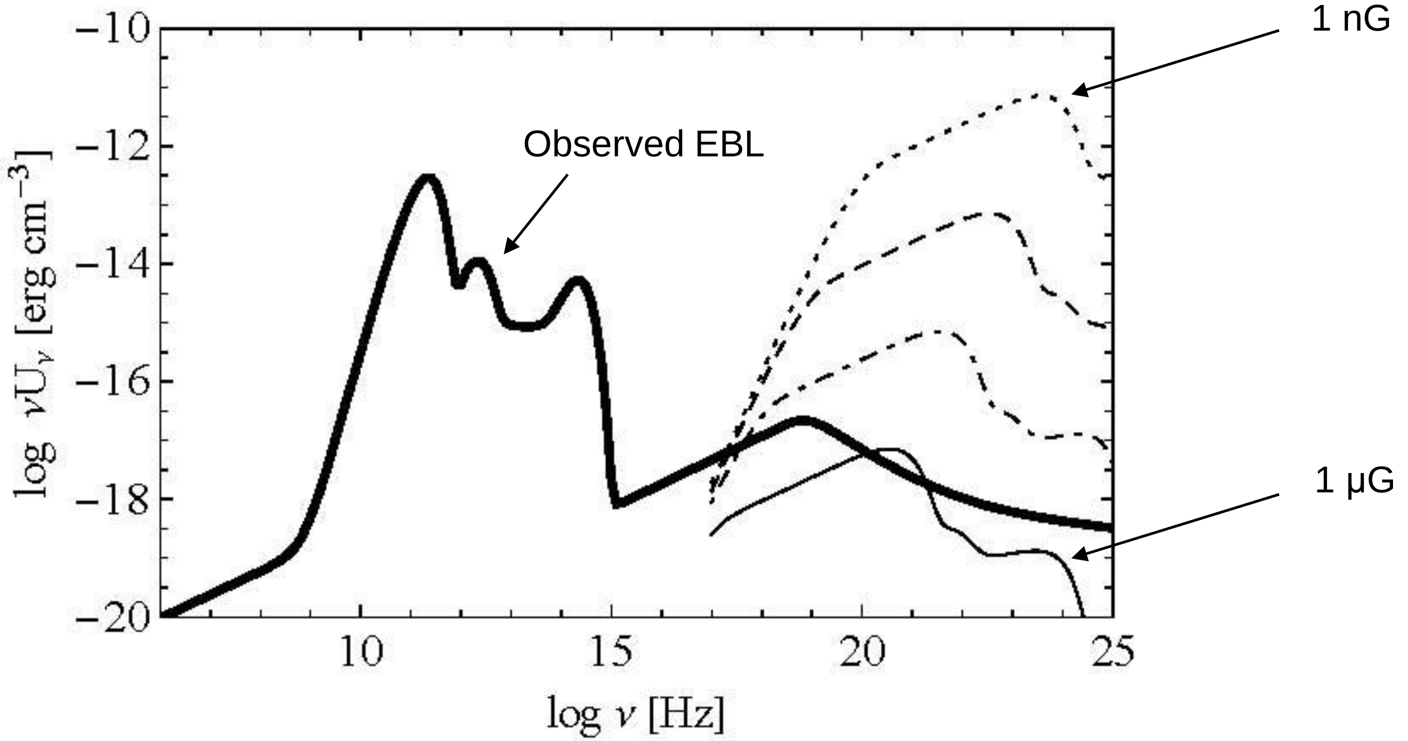
- If $U_{e-} \uparrow$ then inverse-Compton upscattering by these electrons increases



Inverse-Compton

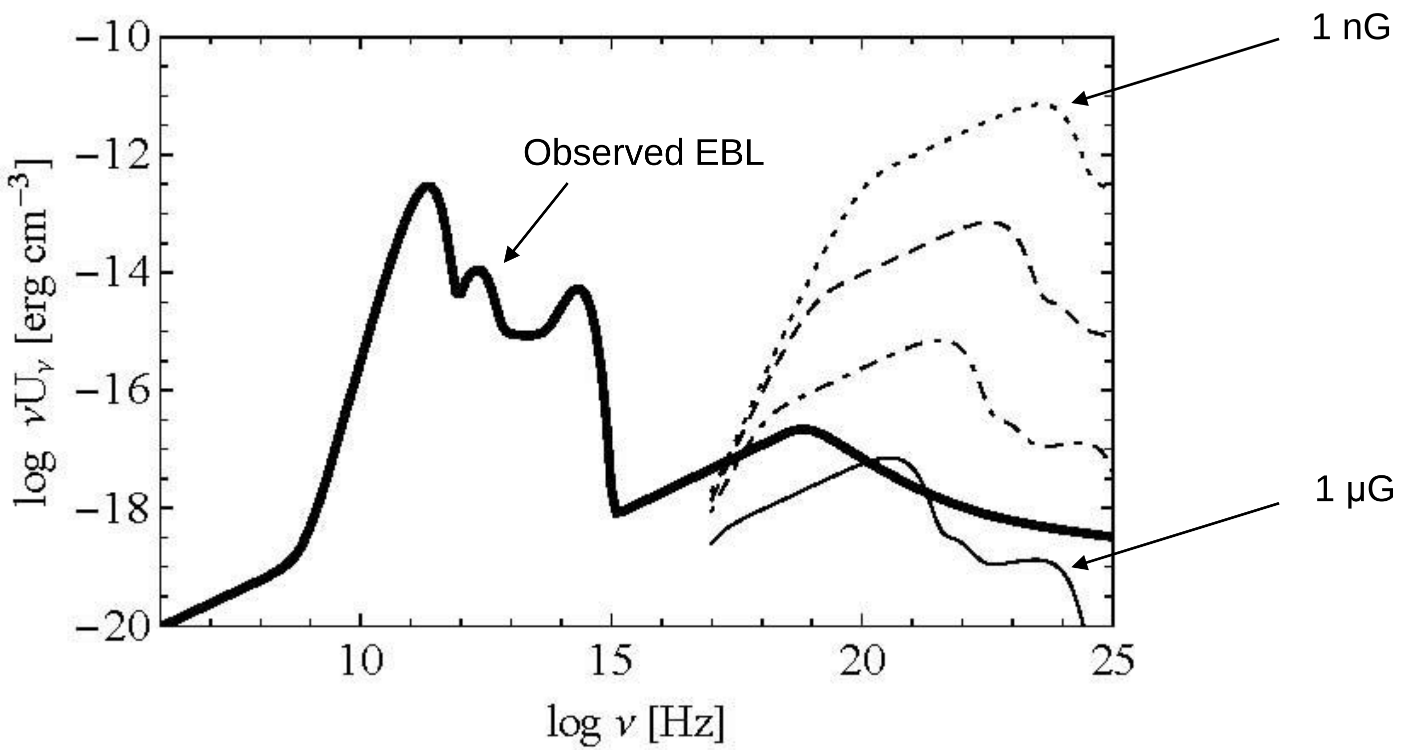
- Singal et al. (2010, *MNRAS*, 409, 1172)

The electrons that produce the radio emission through synchrotron cannot overproduce another background via inverse-Compton – places a lower limit on the magnetic field in the emitting regions



Inverse-Compton

• The same X-ray inverse-Compton argument applies to our Galactic halo, where FR measures show the mag field is ~1 μG (Taylor et al, 2009, *ApJ*, 702, 1230) but optical/UV flux is higher than in intergalactic space

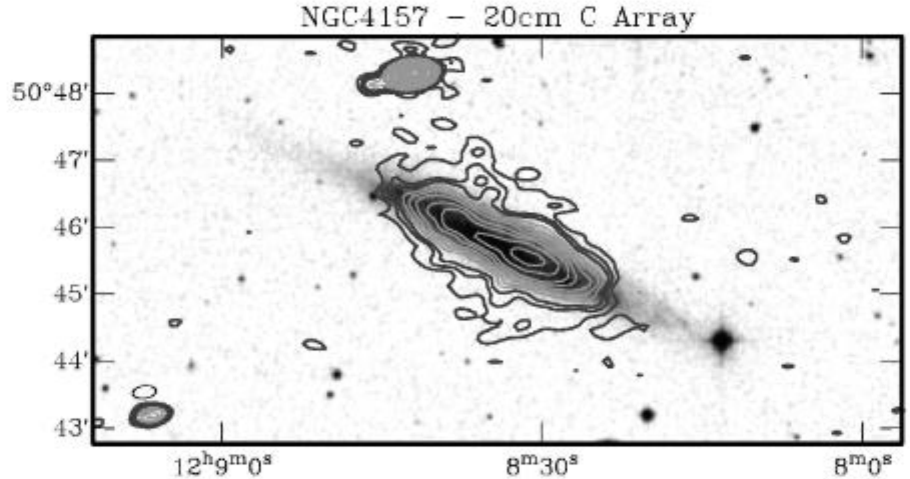


Other Galaxies

We can see whether galaxies similar to ours have a large bright radio halo

- J. Singal, A. Kogut, E. Jones, & H. Dunlap, 2015, *ApJL*, “Axial Ratio of Edge-On Spiral Galaxies as a Test For Bright Radio Halos.” 799, L10

• There are radio emission contour maps of galaxies nearby enough to be resolved and which are seen edge-on



• Do they have a shape structure (round-ish halos bulging above and below the plane of the disk) that would be predicted by the Subrahmanyan & Cowsik model?

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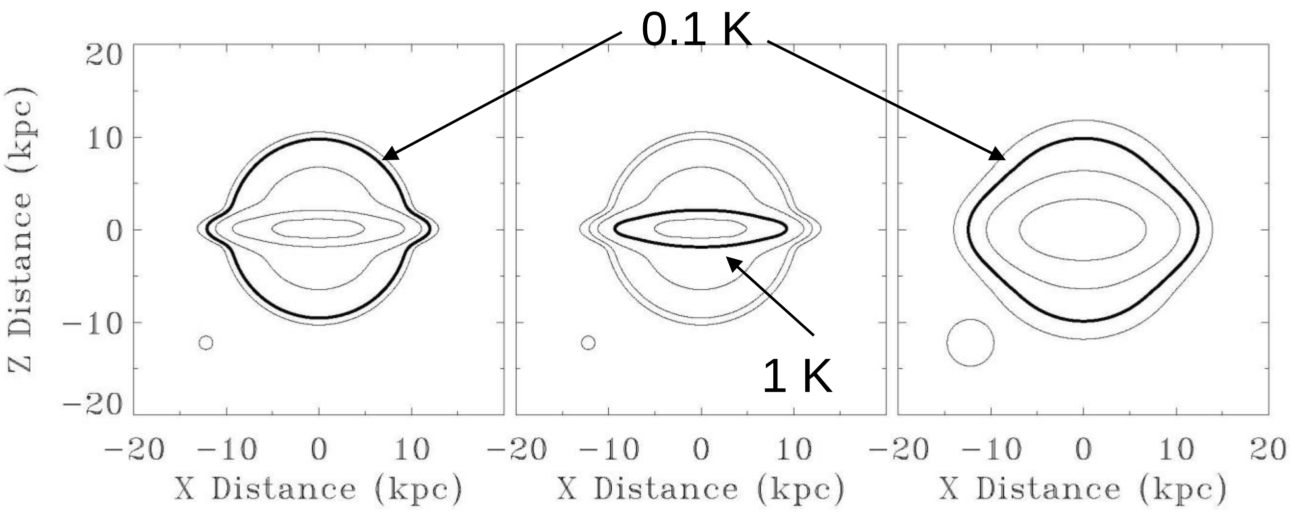
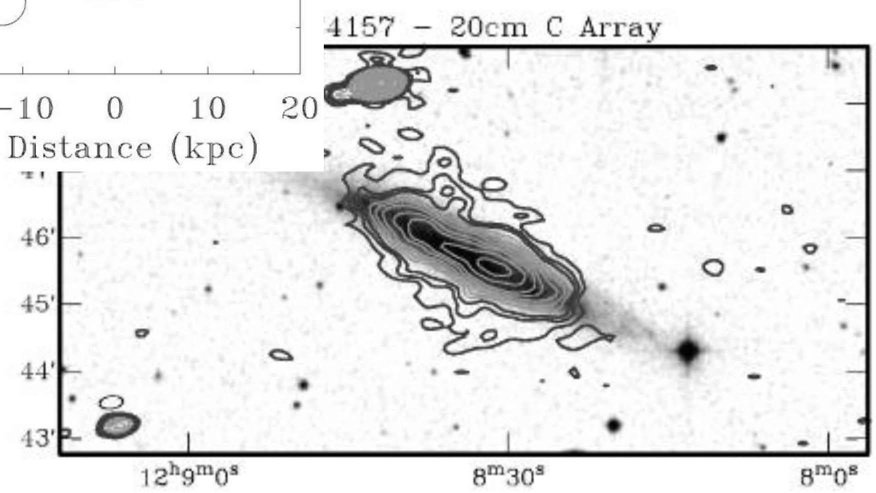
• Do they have a shape structure (round-ish halos) that would be predicted by the Subrahmanyan & Cowsik model?



Predicted contours at 0.03, 0.1, 0.3, 1, and 3 K for the SC model at 1.5 GHz.



Contours near 0.1 K or below can distinguish the presence of a halo if the beam smearing is small enough.

(It needs to be round-ish for there to be an SC halo).

Other Galaxies

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All edge-on (>75º inclination) normal spirals mapped between 150 and 1500 MHz that have a contour that can distinguish the presence or absence of a spherical halo

Table 1
Measured and Model Axial Ratios

Absolute Contour Level Comparison

Galaxy	Frequency (MHz)	Inclination (Deg)	FWHM (″)	Beam Ratio[a]	Contour (K)	Axial Ratio $A/B-1$ Data	Axial Ratio $A/B-1$ Model	Reference
NGC 0253	1500	78	74.0	17.8	0.11	1.47	0.20	Beck et al. (1994)
NGC 0891	1420	89	14.7	47.7	0.10	1.06	0.23	Oosterloo et al. (2007)
NGC 0891	1490	89	48.0	13.2	0.12	1.16	0.25	Condon (1987)
NGC 3628	1490	87	54.0	12.5	0.09	1.90	0.22	Condon (1987)
NGC 4192	1490	83	54.0	7.6	0.07	0.88	0.20	Condon (1987)
NGC 4216	1490	89	54.0	6.8	0.09	1.99	0.23	Condon (1987)
NGC 4565	1490	86	60.0	11.6	0.07	2.59	0.21	Condon (1987)
NGC 4631	1490	85	60.0	13.8	0.15	0.69	0.25	Condon (1987)
NGC 4631	1490	85	40.0	20.9	0.16	0.30	0.25	Hummel et al. (1988)
NGC 5907	1490	88	48.0	10.8	0.08	2.35	0.21	Condon (1987)

Fractional Contour Level Comparison

Galaxy	Frequency (MHz)	Inclination (Deg)	FWHM (″)	Beam Ratio[a]	Contour (K)	Axial Ratio $A/B-1$ Data	Axial Ratio $A/B-1$ Model	Reference
NGC 0253	330	78	30.0	41.8	0.5	0.47	0.04	Carilli et al. (1992)
NGC 0253	1400	78	30.0	64.5	0.02	1.32	0.36	Carilli et al. (1992)
NGC 0253	1500	78	74.0	17.8	0.4	1.47	0.21	Beck et al. (1994)
NGC 0891	1490	89	48.0	13.2	0.6	1.16	0.22	Condon (1987)
NGC 2613	1500	79	16.0	20.4	3.3	1.51	0.31	Irwin et al. (1999)
NGC 3044	1465	86	15.0	17.3	1.6	1.22	0.22	Hummel & Van der Hulst (1989)
NGC 3044	1500	86	12.2	15.8	2.5	1.07	0.28	Irwin et al. (1999)
NGC 3221	1465	84	15.0	11.9	1.6	1.77	0.21	Hummel & Van der Hulst (1989)
NGC 3221	1500	84	11.7	9.2	1.0	1.59	0.20	Irwin et al. (1999)
NGC 3556	1500	75	15.6	27.9	1.3	1.22	0.18	Irwin et al. (1999)
NGC 3628	1490	87	54.0	12.5	0.2	1.90	0.23	Condon (1987)
NGC 4157	1465	82	14.4	16.8	2.5	0.85	0.27	Irwin et al. (1999)
NGC 4157	1465	82	15.0	17.5	3.1	0.75	0.29	Hummel & Van der Hulst (1989)
NGC 4192	1490	83	54.0	7.6	2.2	0.88	0.22	Condon (1987)
NGC 4517	1500	85	13.5	32.4	2.5	5.65	0.49	Irwin et al. (1999)
NGC 4565	1490	86	60.0	11.6	3.1	2.59	0.30	Condon (1987)
NGC 4631	408	85	96.4	13.8	5.6	1.38	0.04	Pooley (1969)
NGC 4631	1490	85	40.0	20.9	0.4	0.30	0.23	Hummel et al. (1988)
NGC 4631	1490	85	60.0	13.8	0.6	0.69	0.22	Condon (1987)
NGC 5907	1490	88	48.0	10.8	2.2	2.35	0.24	Condon (1987)

[a] Ratio of major axis to beam FWHM. Maps with beam ratio <6 confuse halo with plane emission and are not used.

Absolute level comparison:

Compares contours in observed maps to same absolute level contour in predicted SC model map

Fractional level comparison:

Compares contours in observed maps to contour at same fraction of peak brightness in predicted SC model map

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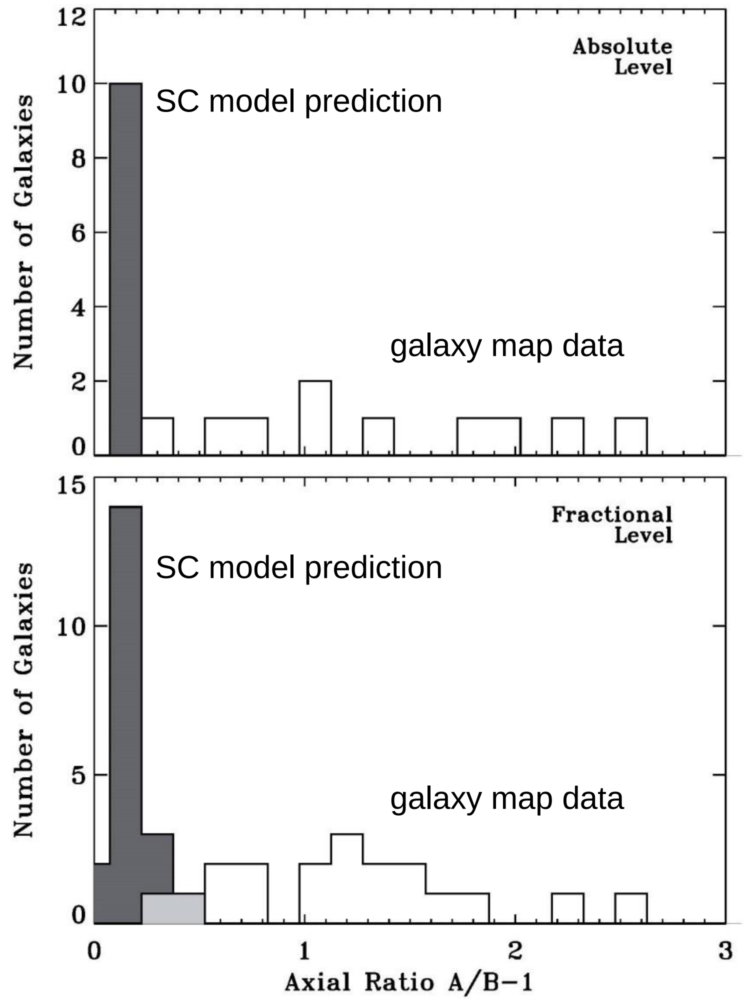
We can see whether galaxies similar to ours have a large bright radio halo

- Singal et al., 2015, *ApJL*, “Axial Ratio of Edge-On Spiral Galaxies as a Test For Bright Radio Halos.” 799, L10

We use all radio contour maps of nearby edge-on spiral galaxies with a contour capable of distinguishing the presence of a bright spherical halo at the level of the SC model



Absolute comparisons compare absolute levels in the model with those observed – insensitive to structure in the plane but potentially sensitive to normalization of galaxy brightness.

Fractional comparisons are insensitive to normalization of brightness but potentially sensitive to structure in the plane.

Galaxies similar to the Milky Way are more elliptical than the SC model, disfavoring this type of large radio halo

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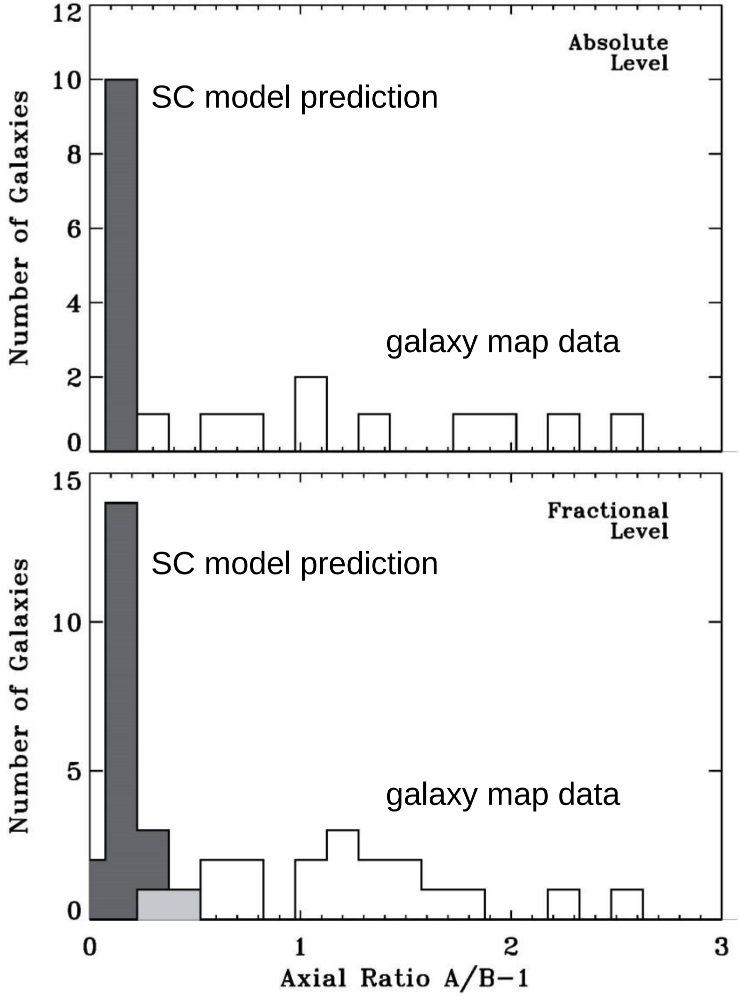
Galaxies similar to the Milky Way are more elliptical than the SC model, disfavoring this type of large radio halo

To modify the SC halo to fit the observed data would require dimming it by a factor of four. This would place most of the isotropic signal into a non-halo (presumably extragalactic) component.

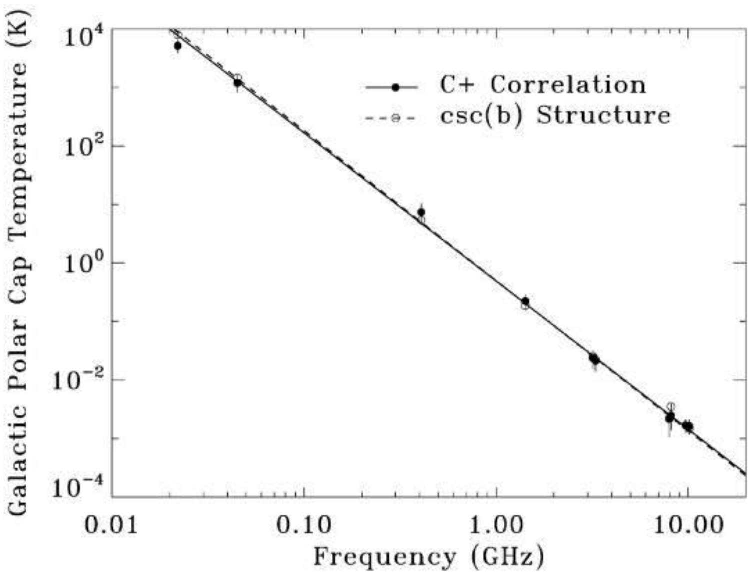


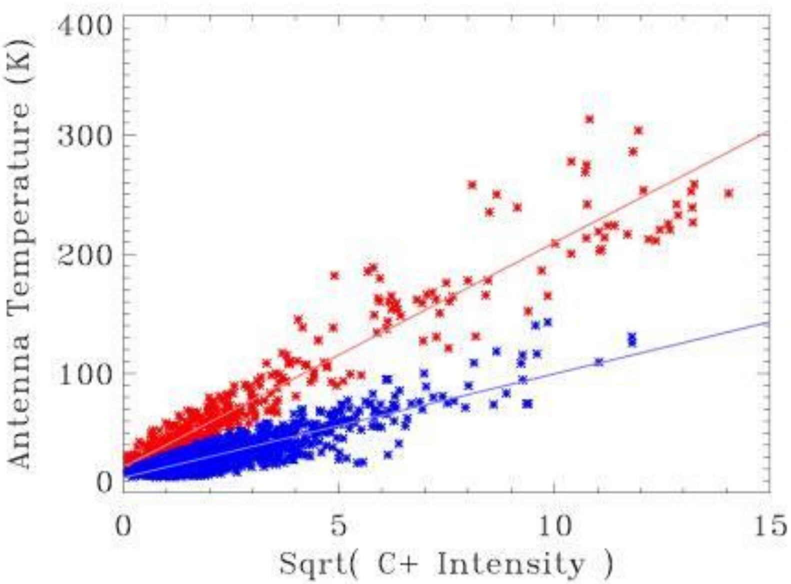
Two Galactic Emission Models

How to distinguish (from maps alone) between Galactic monopole and extragalactic component?

1) Model Galactic radio emission with some function of latitude

2) Correlate Galactic radio emission with some other emission of known spatial structure

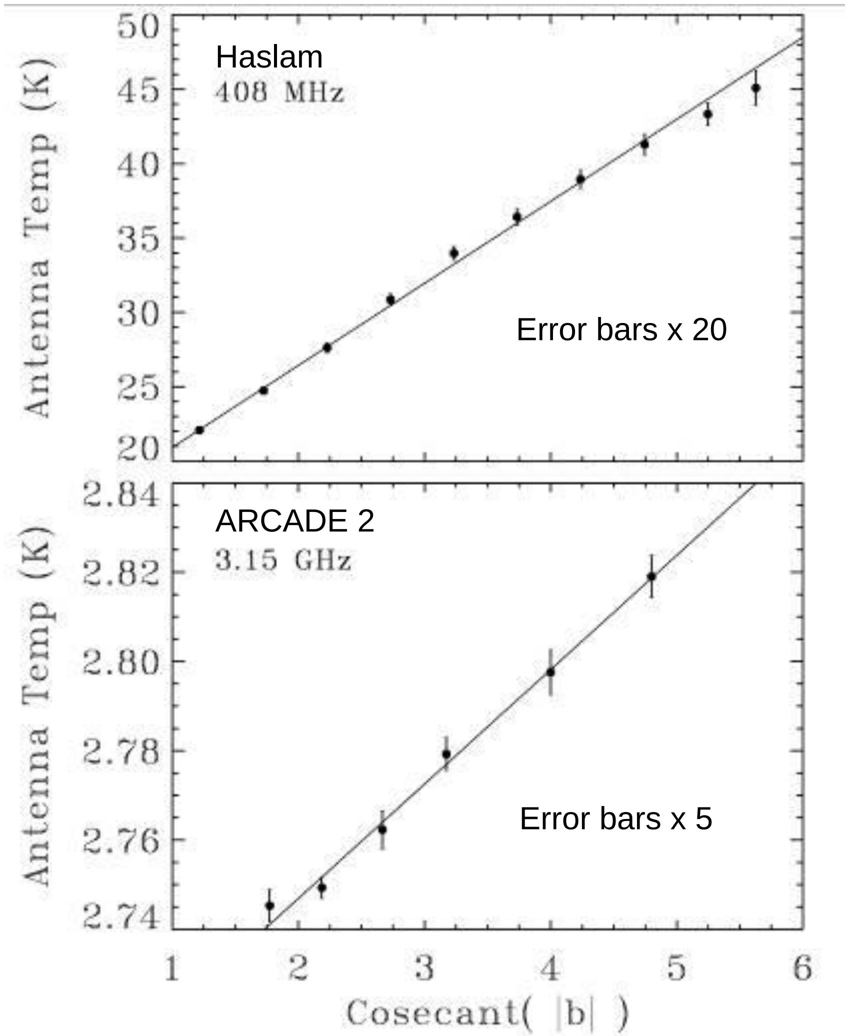




See Kogut et al. (2011, *ApJ*, 734, 4)

csc(|b|)

Average sky temp in pixels at latitude (b) vs. csc(|b|) for b >10º



Scatter about lines comes from higher order spatial structure

To get Galactic polar cap emission temperature, extrapolate line to 90º latitude

Radio C+ correlation

Idea: find a Galactic emission map with a well defined high latitude temperature to correlate with our spatial maps

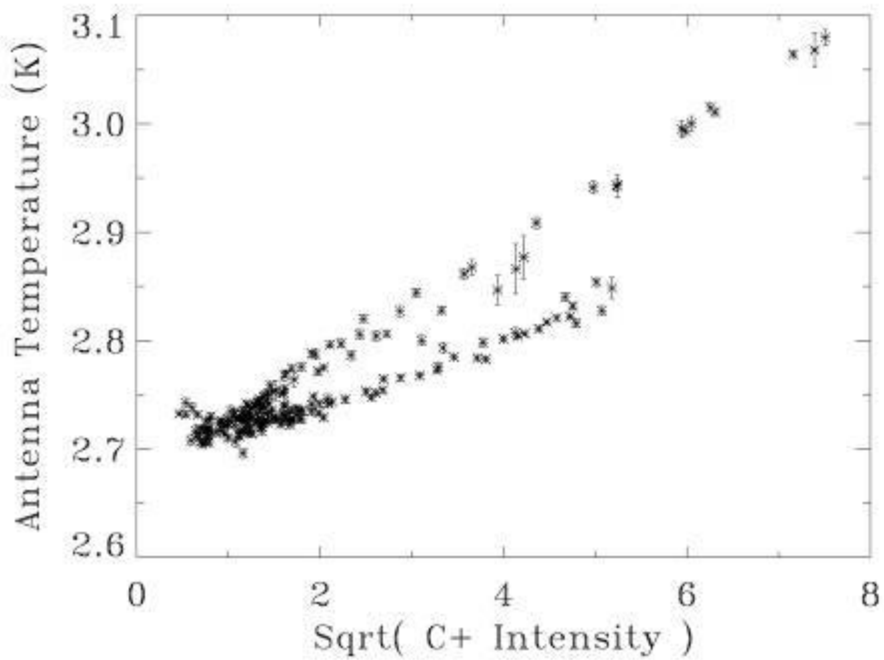
- Needs to be measured over full sky
- Well defined absolute level along every line of sight (WMAP is out)
- Doesn't suffer from extinction (Thermal dust and Hα are out)
- Needs to be present in highly ionized regions (21 cm map is out)

If only such a thing existed…

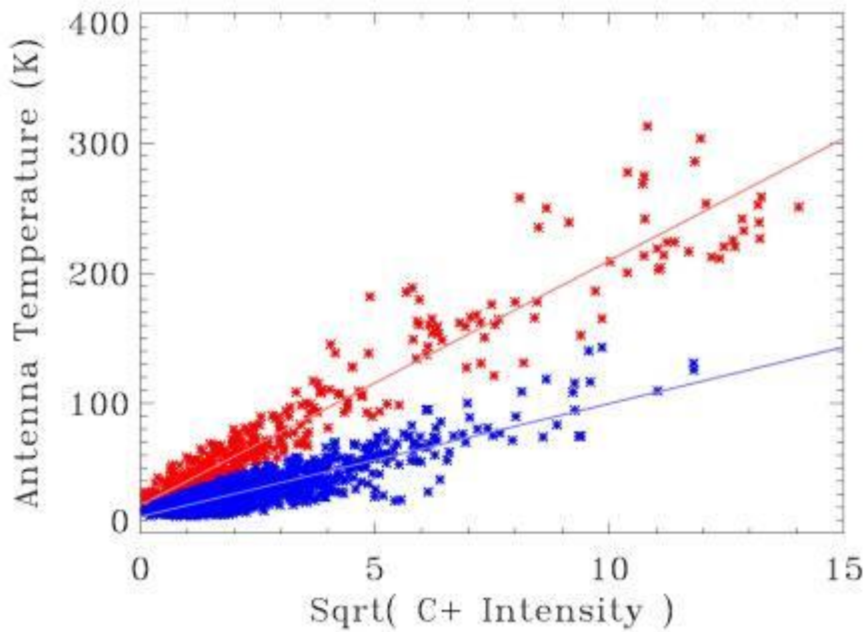
It does! The FIRAS C+ emission map (158 μm)

Radio C+ correlation (2)

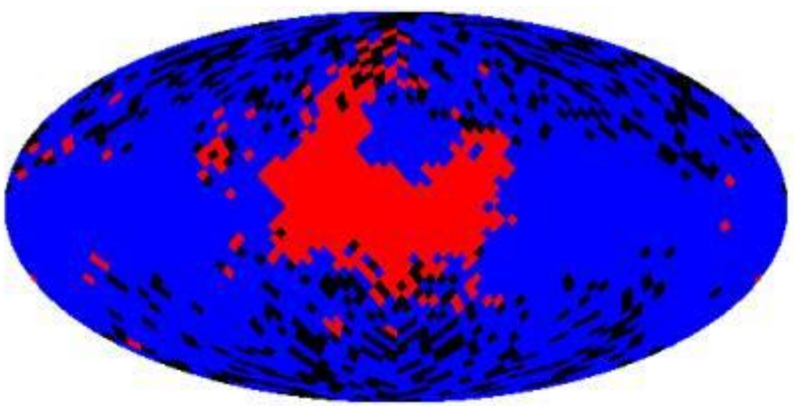
ARCADE 2 3.15 GHz vs. C+



Haslam 408 MHz vs. C+

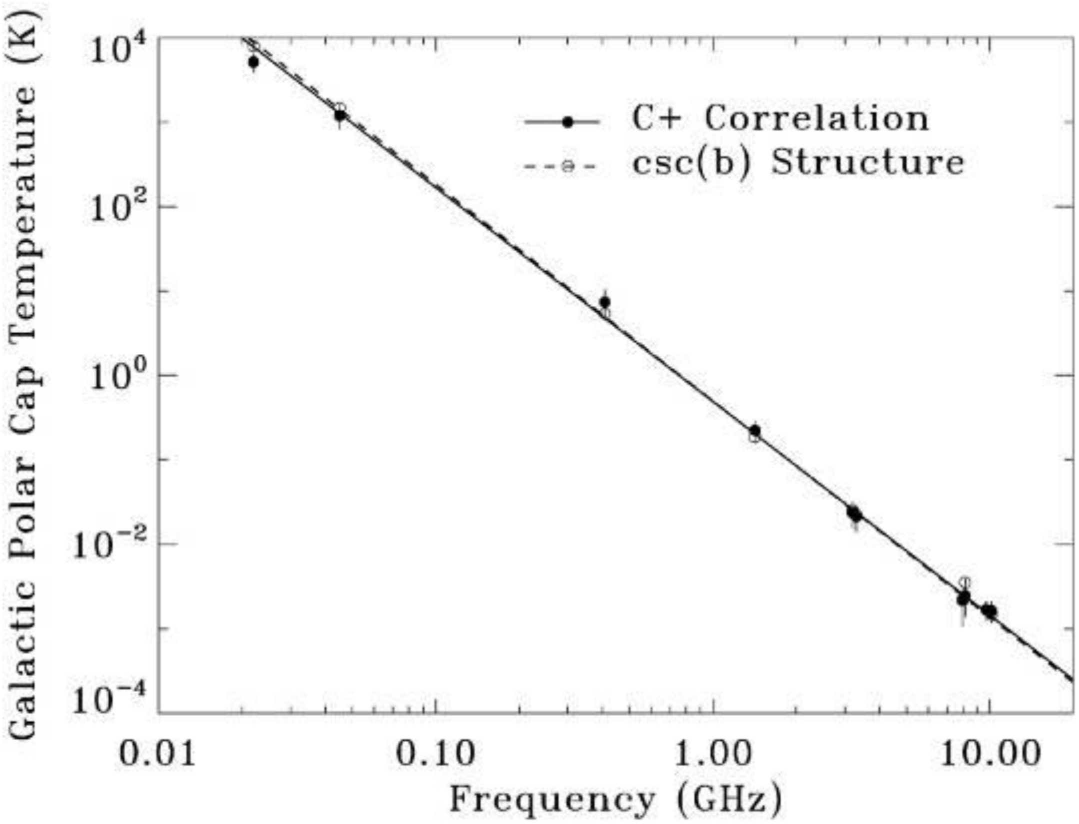


Breaks into two distinct regions.
One near Galactic center (upper)
and one near Cygnus arm (lower).



To get polar cap temp at a frequency:
Multiply the C+ polar cap intensity
by the slope of the lower line

They both agree



So with a Galactic polar cap temperature one can calculate a Galactic monopole term

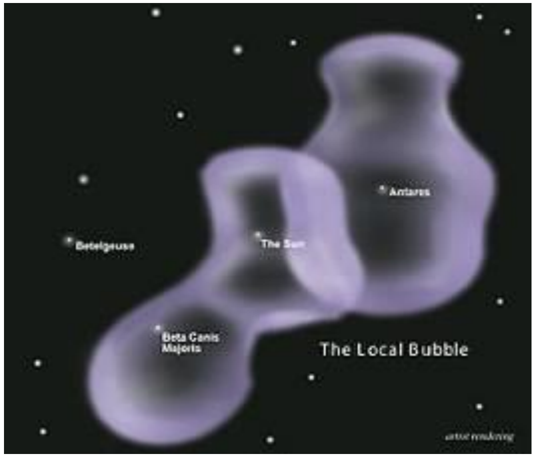
More Local?

What about the Local Bubble?

(A region that the sun and nearby stars are passing through that has hot x-ray emitting gas and a low density compared to the average ISM)

- It would be highly polarized since the Galactic magnetic field is locally pretty constant. In that case, we would expect to see some quadrupole polarization structure in WMAP 22 GHz aligned with the local Galactic magnetic field, but we don’t.

- We don’t see similar localized radio bubbles in other places



Conclusions

- A very radio bright Galactic Halo would lead to a number of issues:
  - The x-ray background would be overproduced via inverse-Compton unless strangely high magnetic fields were present in the halo
  - Our Galaxy would be quite anomalous compared to similar ones
  - There would have to be anomalous radio emission that does not correlated with C+ emission