Galactic Cosmic Ray Tomography with LOFAR

Irene Polderman
Marijke Haverkorn
SKSP

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Science at Low Frequencies II

Radboud University

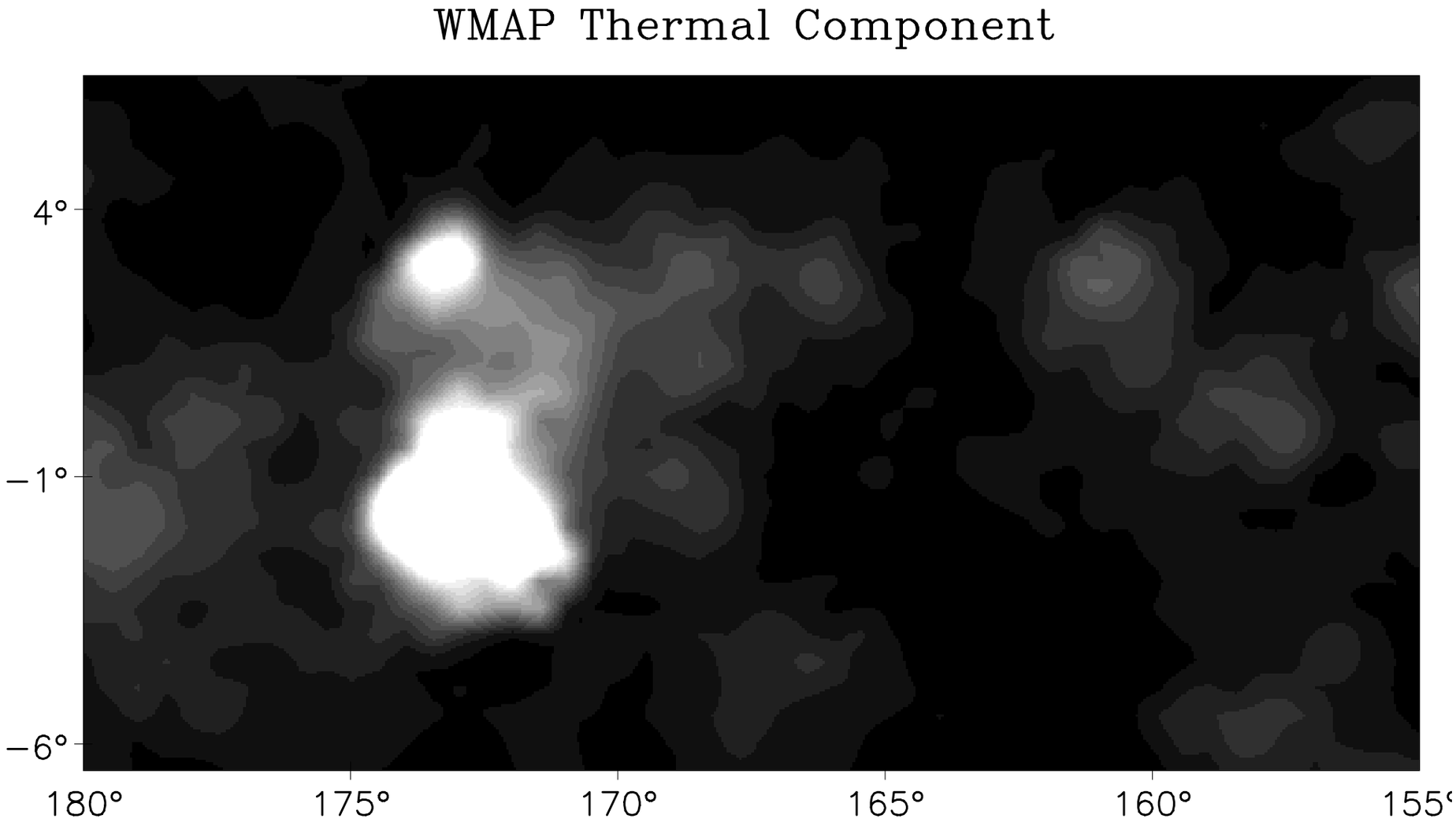
Introduction

Tomography: a technique for displaying a representation of a cross section through ~~a human body or other solid object~~ the Milky Way using ~~X-rays or ultrasound~~ radio waves.

What do we need:
- Synchrotron emission from Galactic Cosmic Rays
- LOFAR LBA: 30 - 90 MHz
- HII regions in the Milky Way

What do we want:
1. 2D or 3D Galactic Cosmic Ray distribution model
2. 2D or 3D Galactic Cosmic Ray spectral index model

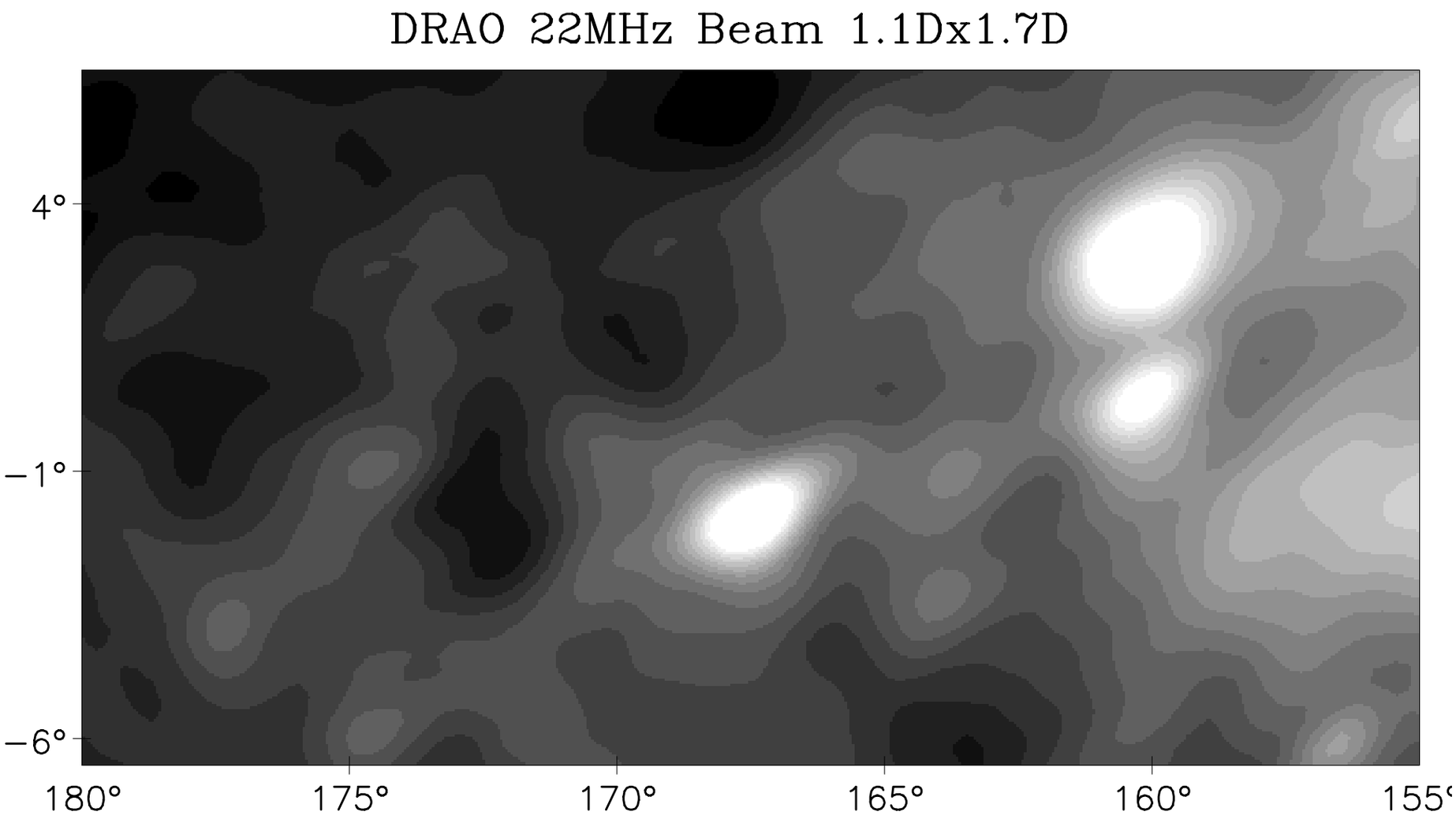
HII regions in emission



Free-free emission at 23GHz: HII region at l = 174, b = -1.5 in emission

Image courtesy: Wolfgang Reich

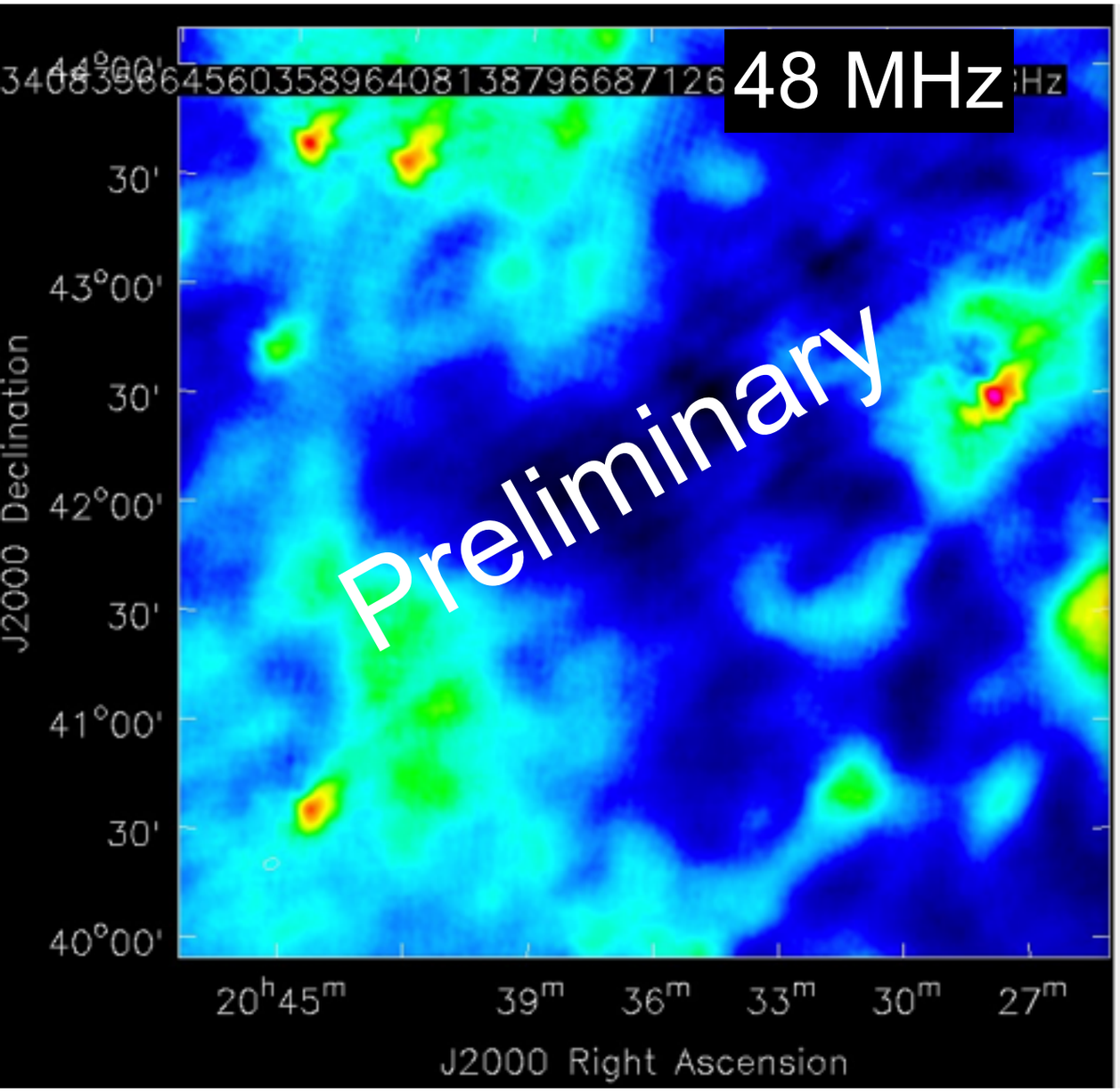
HII regions in absorption

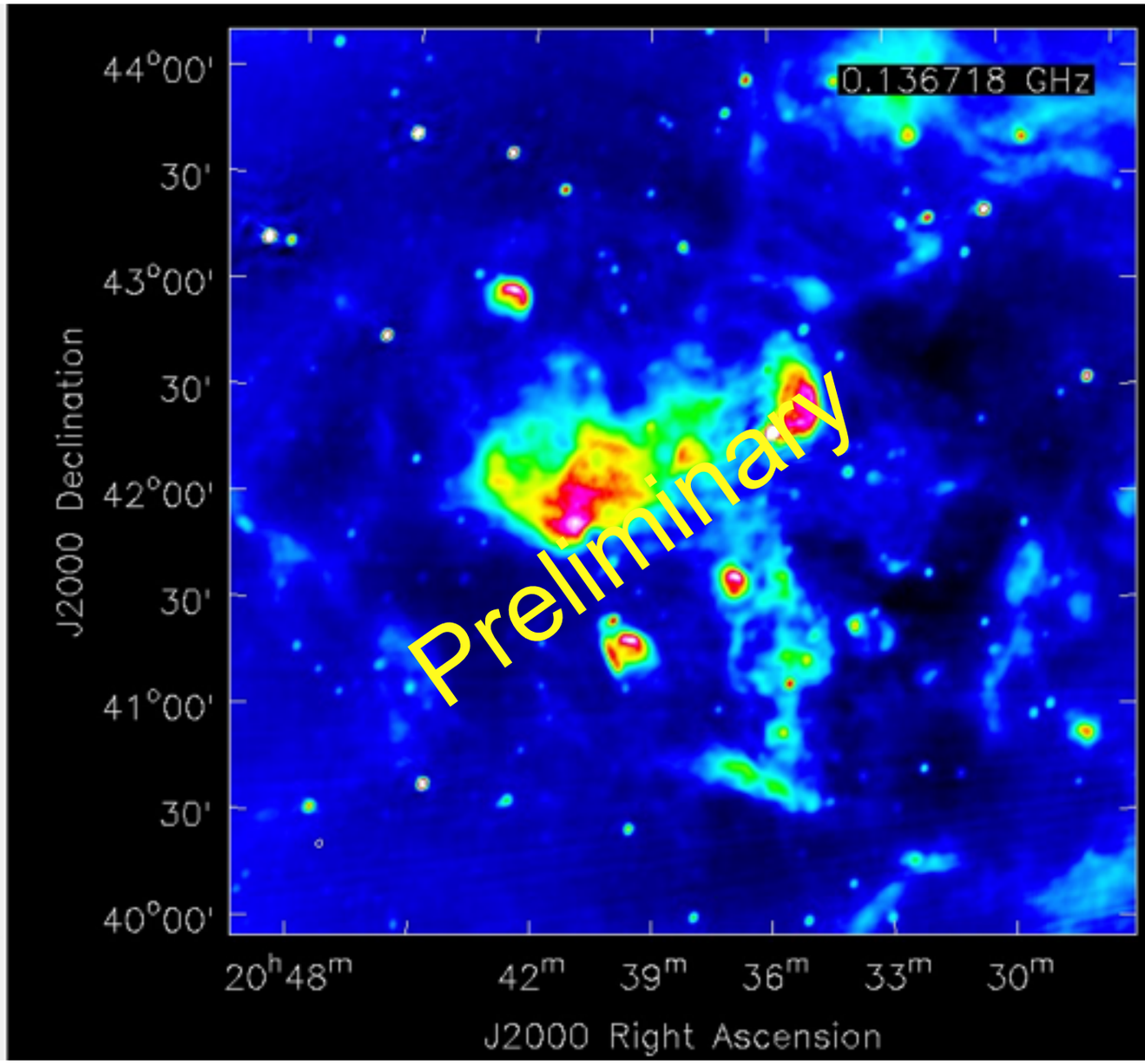


Synchrotron emission at 22 MHz: HII region at l = 174, b = -1.5 in absorption

Image courtesy: Wolfgang Reich

LBA - Cyg X - HBA

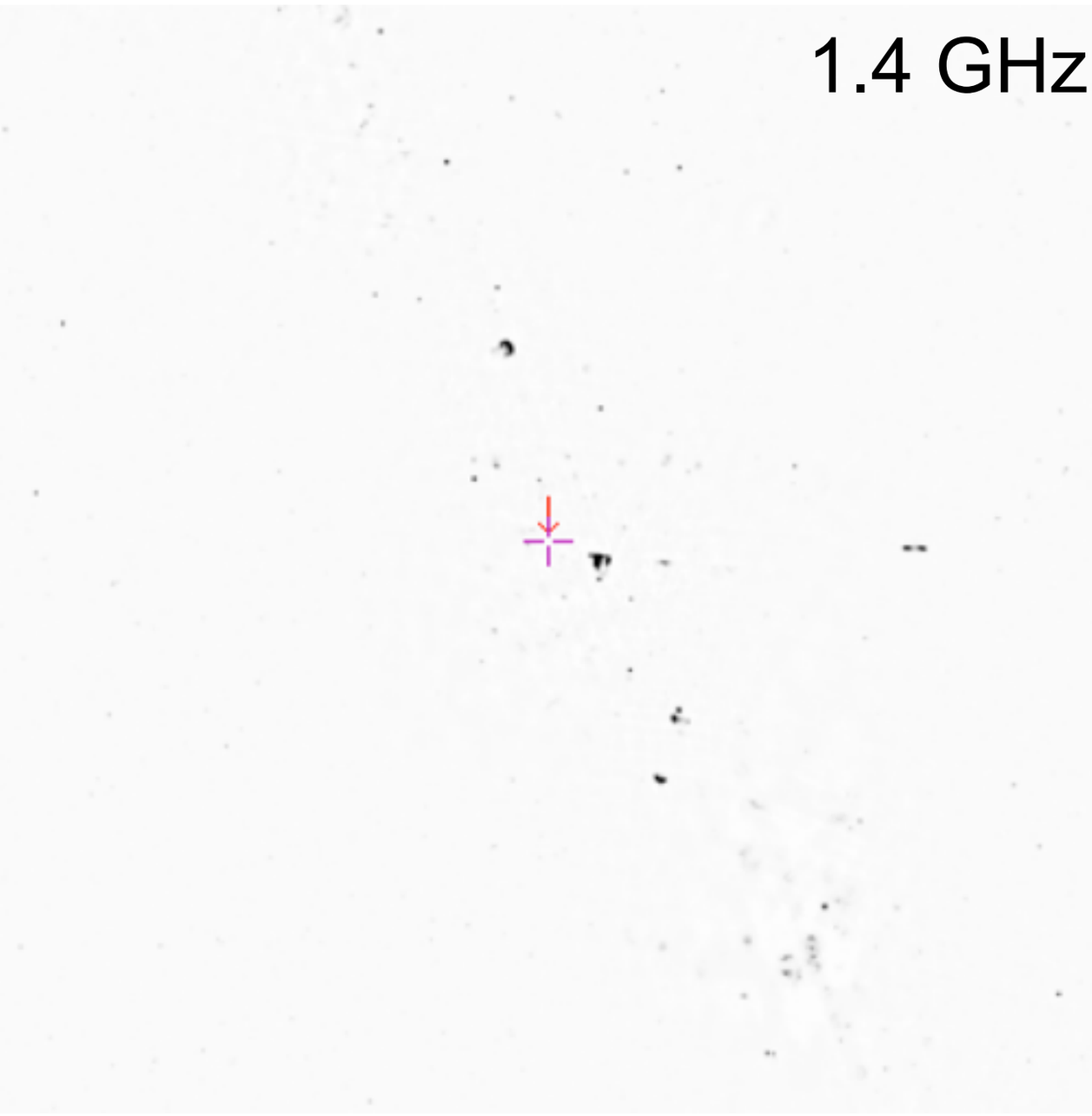


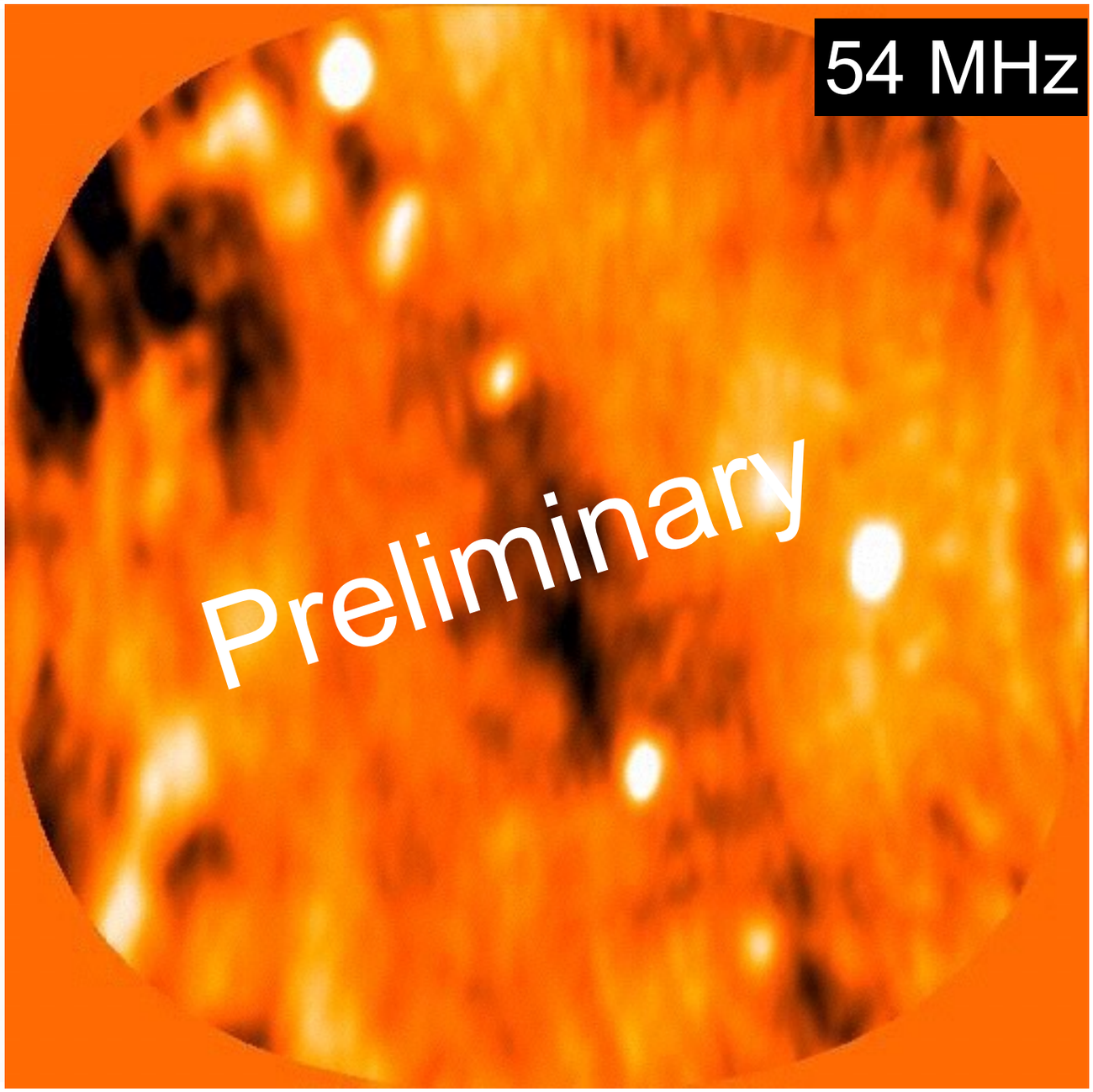


White et al. in preparation

First image of G33b

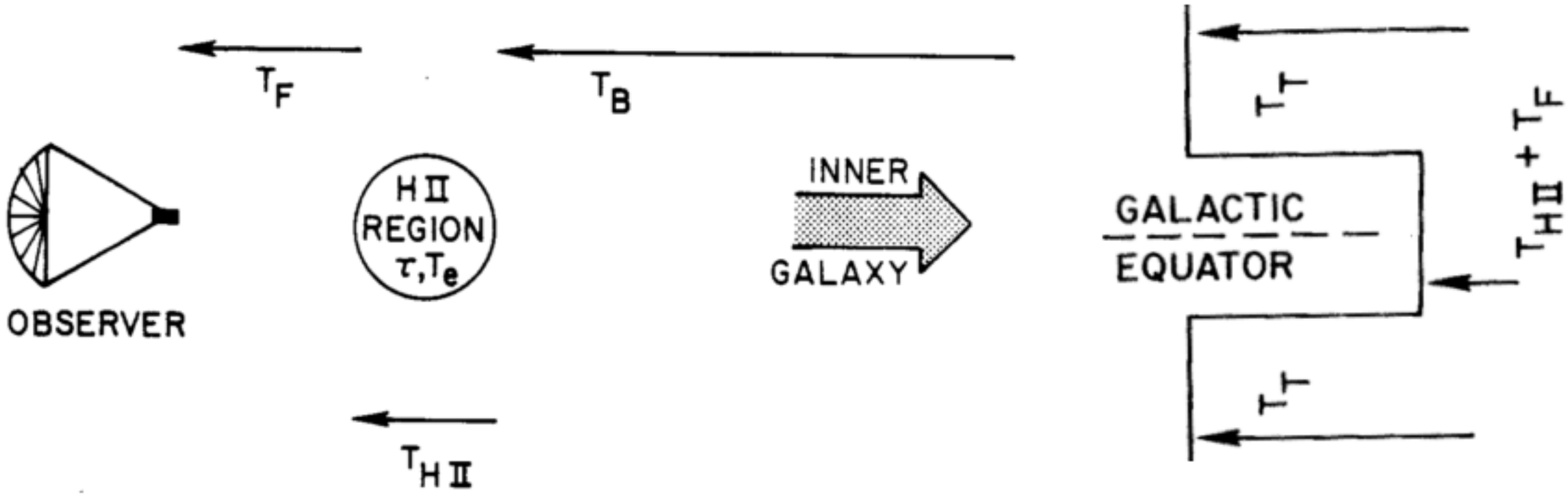
1.4 GHz





Basic idea - single dish

Kassim 1990



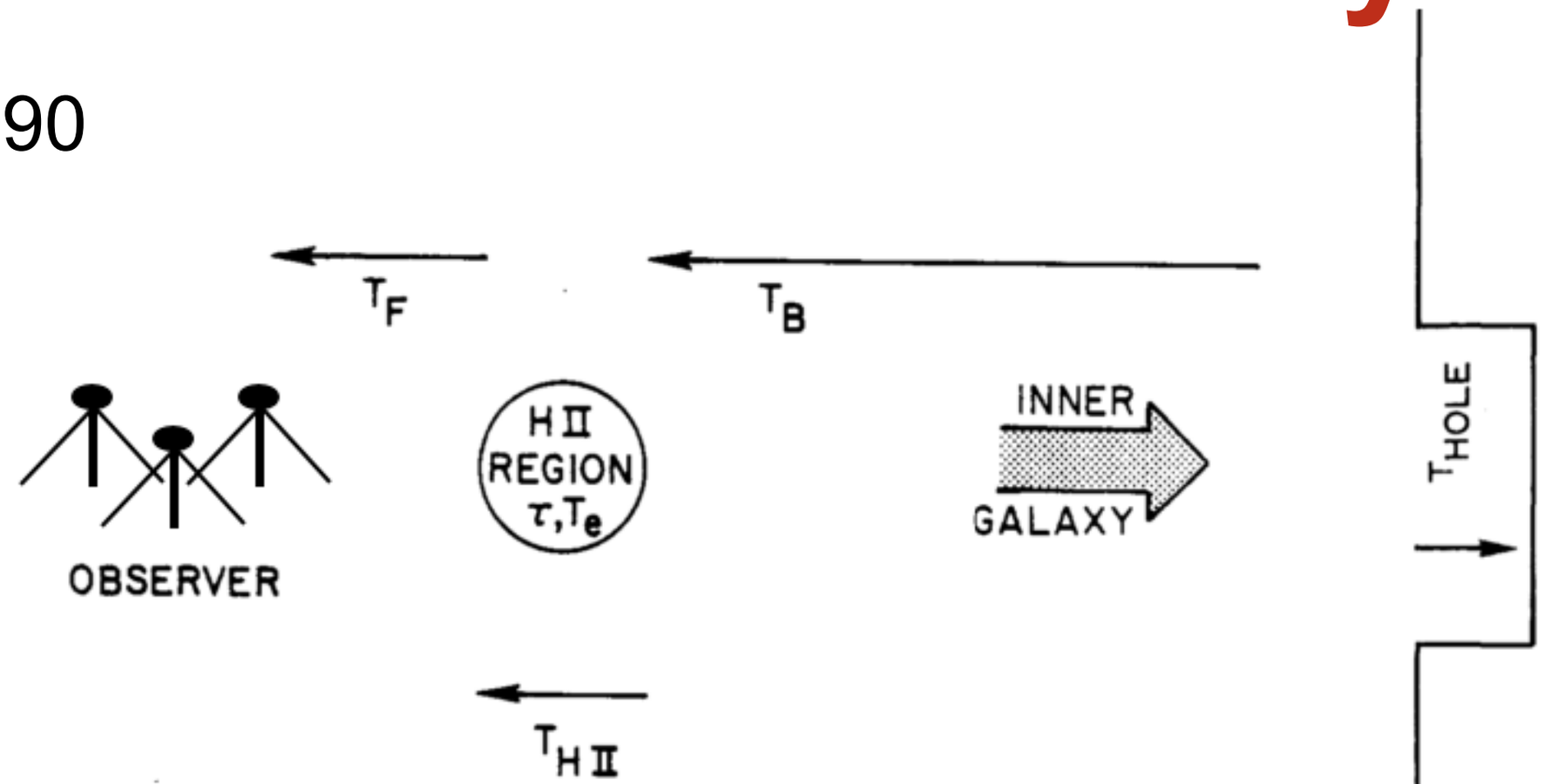
$T = T_e(1 - e^{-\tau}) + T_B\, e^{-\tau} + T_F$

$T = T_e + T_F$ for $\tau >> 1$ (low frequency)

$T_T = T_B + T_F$

Interferometer - in theory

Kassim 1990



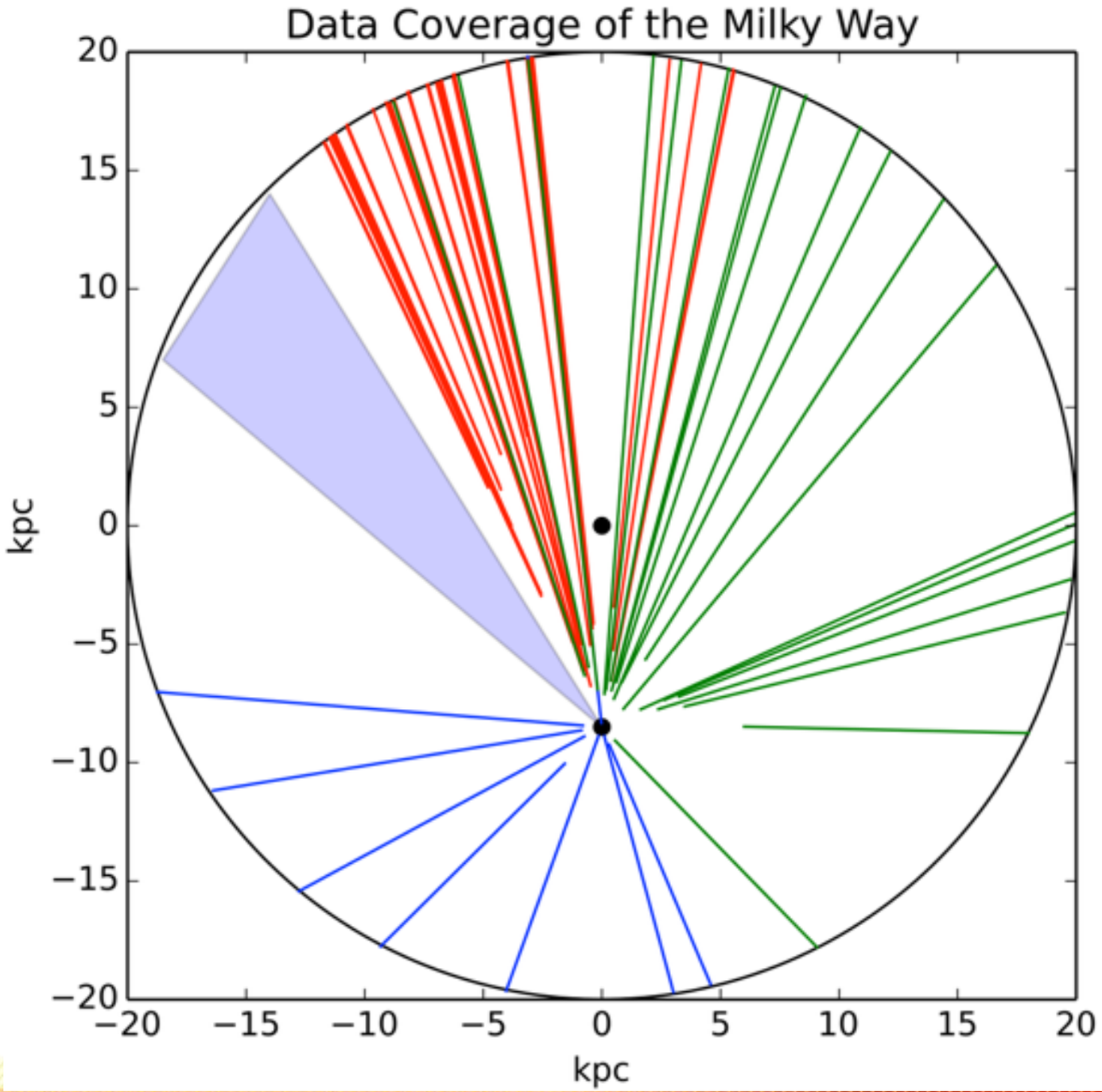
Low frequency approximation ($\tau >> 1$)

$T_{HOLE} = T_e + T_F - T_T = T_e + T_F - [\, T_F + T_B \,] = T_e - T_B$

For typical T_B

$T_{HOLE} = T_e - T_B < 0$

Available Data

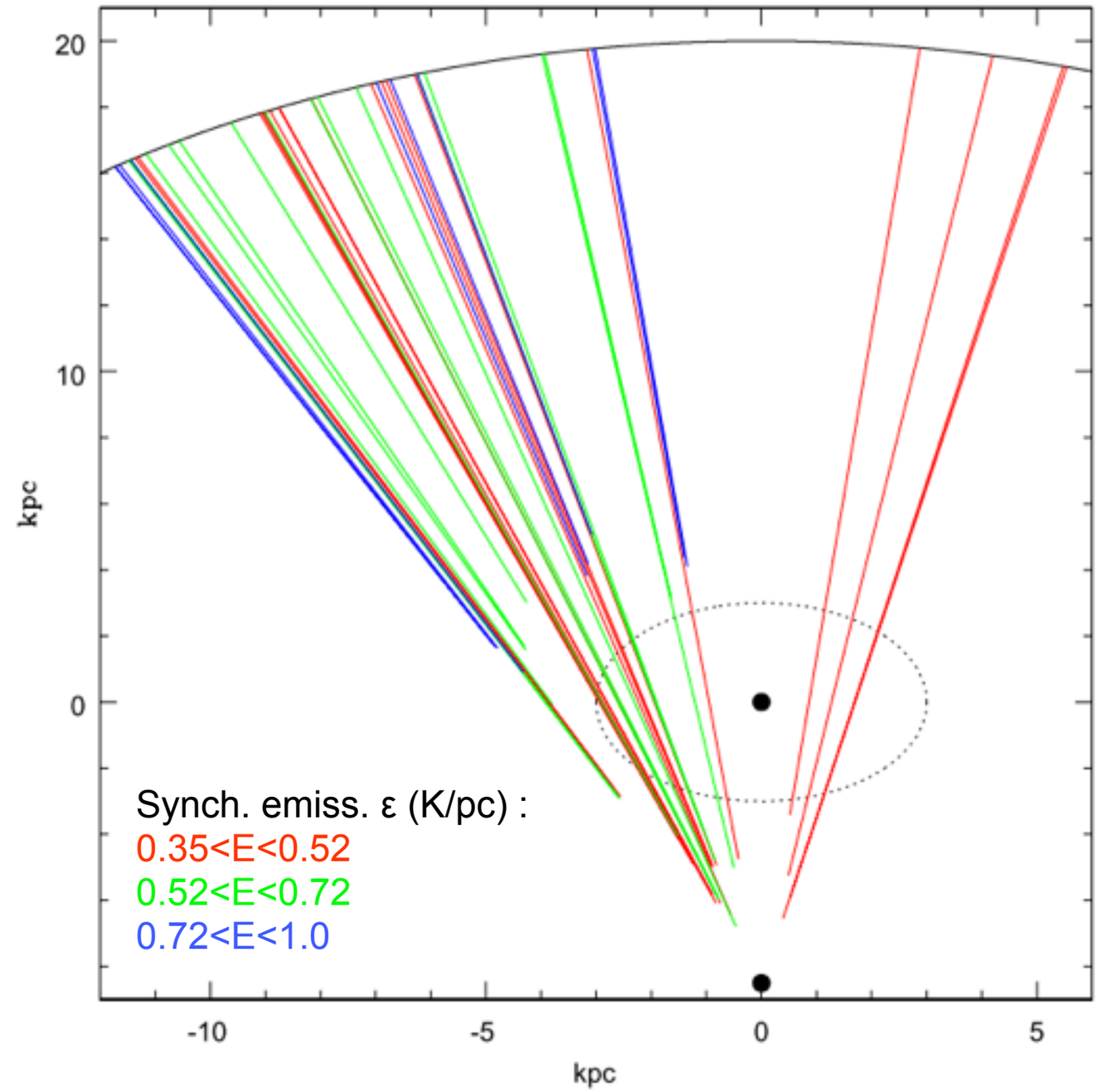


- Green: Jones&Finlay 1974
- Blue: Roger etal. 1999
- Red: Nord etal. 2006
- Triangle: Available LOFAR data

Proof of principle: Nord etal 2006

- $T_{observed} = T_e - T_B$
- $T_e \sim 7000 \pm 2000$ K

- new model: dashed circle at 3 kpc area of underdensity
- not conclusive
- more observations needed



Summary

Currently
- Large part of Milky Way covered
- Large amount of unprocessed data available

Near future
- Build models based on existing data
- Process new LOFAR data

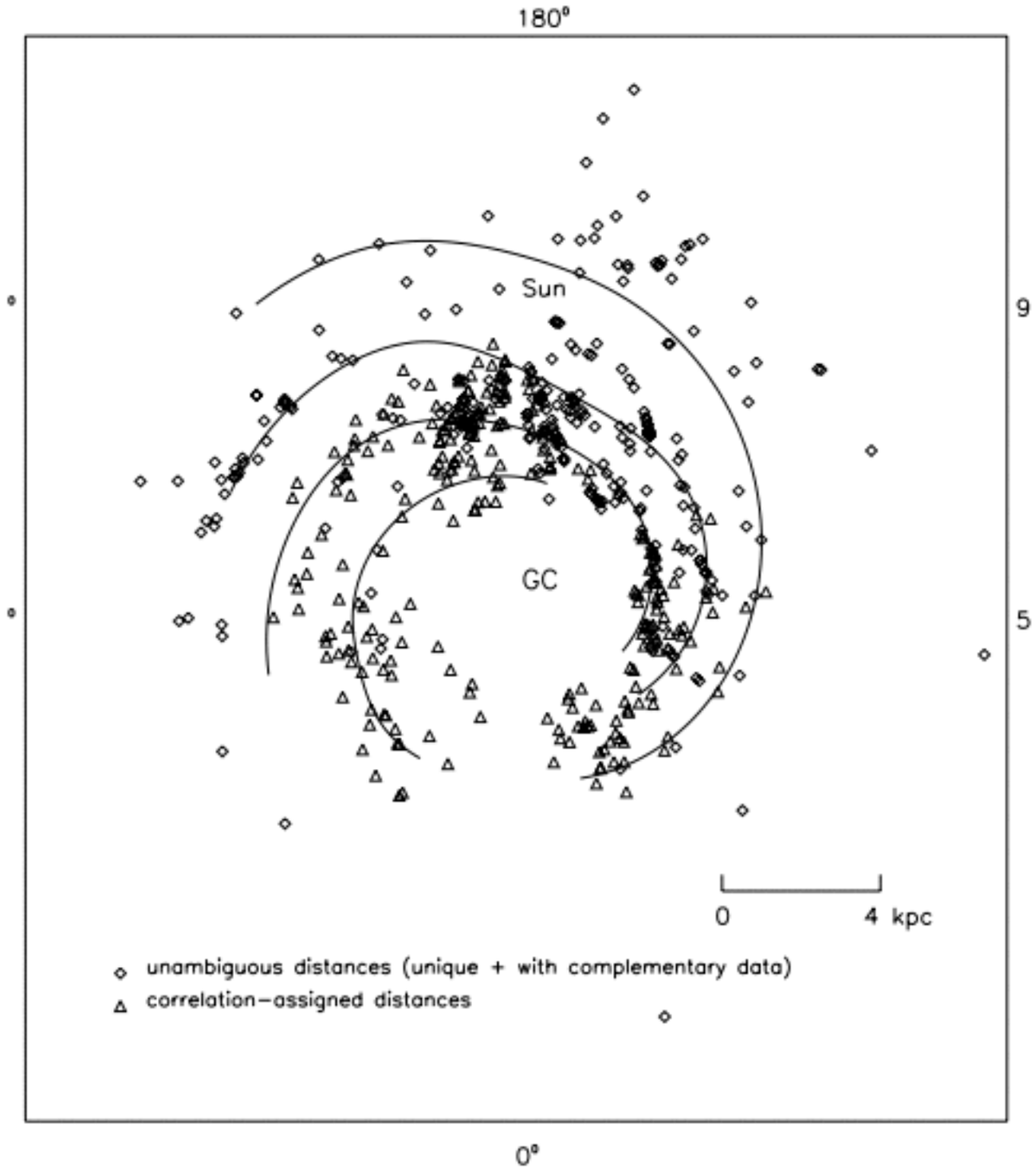
Future:
=> 2D or 3D Galactic Cosmic Ray distribution model

HII regions

Plot with HII regions by
- Paladini etal 2004

Spiral arm model
- Taylor&Lazio 1993

Catalogues help solve ambiguities



Proof of principle; Nord etal 2006

Table 2. HII Regions in the Field of G21.5−0.5

#	l	b	RA	DEC	I	T_{obs}	T_{gb}	T_e	D	ε
			(J2000)		(Jy beam^{-1})		($\times 10^3$ Kelvin)		(kpc)	(Kelvin pc^{-1})
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
201	15.1	−0.7	18 20 37.5	−16 8 51	-4.1 ± 1.3	-7.3 ± 2.3	13.2 ± 2.5	5.9 ± 1.0	2.1	0.51 ± 0.10
204	15.2	−0.6	18 20 27.2	−16 0 43	-4.4 ± 1.3	-8.0 ± 2.3	17.5 ± 2.5	9.5 ± 1.0	1.8	0.66 ± 0.09
218	16.9	+0.8	18 18 40.1	−13 51 9	-3.9 ± 0.9	-6.9 ± 1.7	13.0 ± 1.9	6.1 ± 1.0	2.7	0.52 ± 0.08
219	17.0	+0.8	18 18 51.8	−13 45 52	-3.9 ± 0.9	-7.0 ± 1.6	13.1 ± 1.9	6.1 ± 1.0	2.5	0.52 ± 0.08
220	17.0	+0.9	18 18 30.1	−13 43 1	-5.6 ± 0.9	-10.0 ± 1.6	18.1 ± 1.9	8.1 ± 1.0	2.7	0.72 ± 0.08
224	17.1	+0.8	18 19 3.5	−13 40 34	-5.4 ± 0.9	-9.7 ± 1.6	$16.7^{a} \pm 2.6$	7.0 ± 2.0		
234	18.2	+1.9	18 17 13.1	−12 11 13	-2.4 ± 0.8	-4.3 ± 1.5	10.1 ± 1.8	5.8 ± 1.0		

Comparison to 408 and 1400 MHz maps, expected emissivity ~ 1 K pc^{-1}