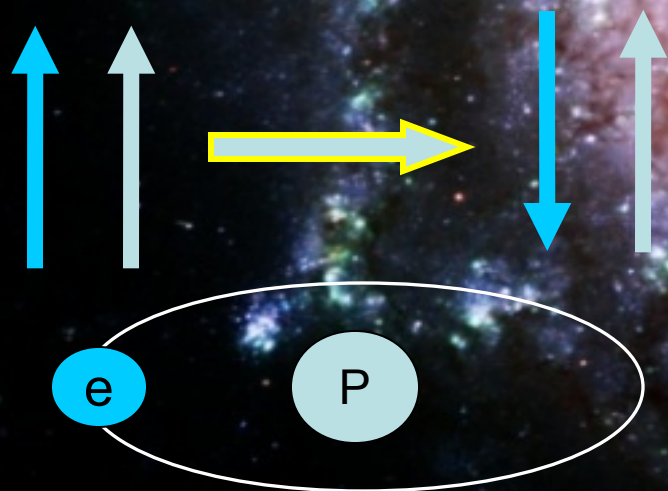
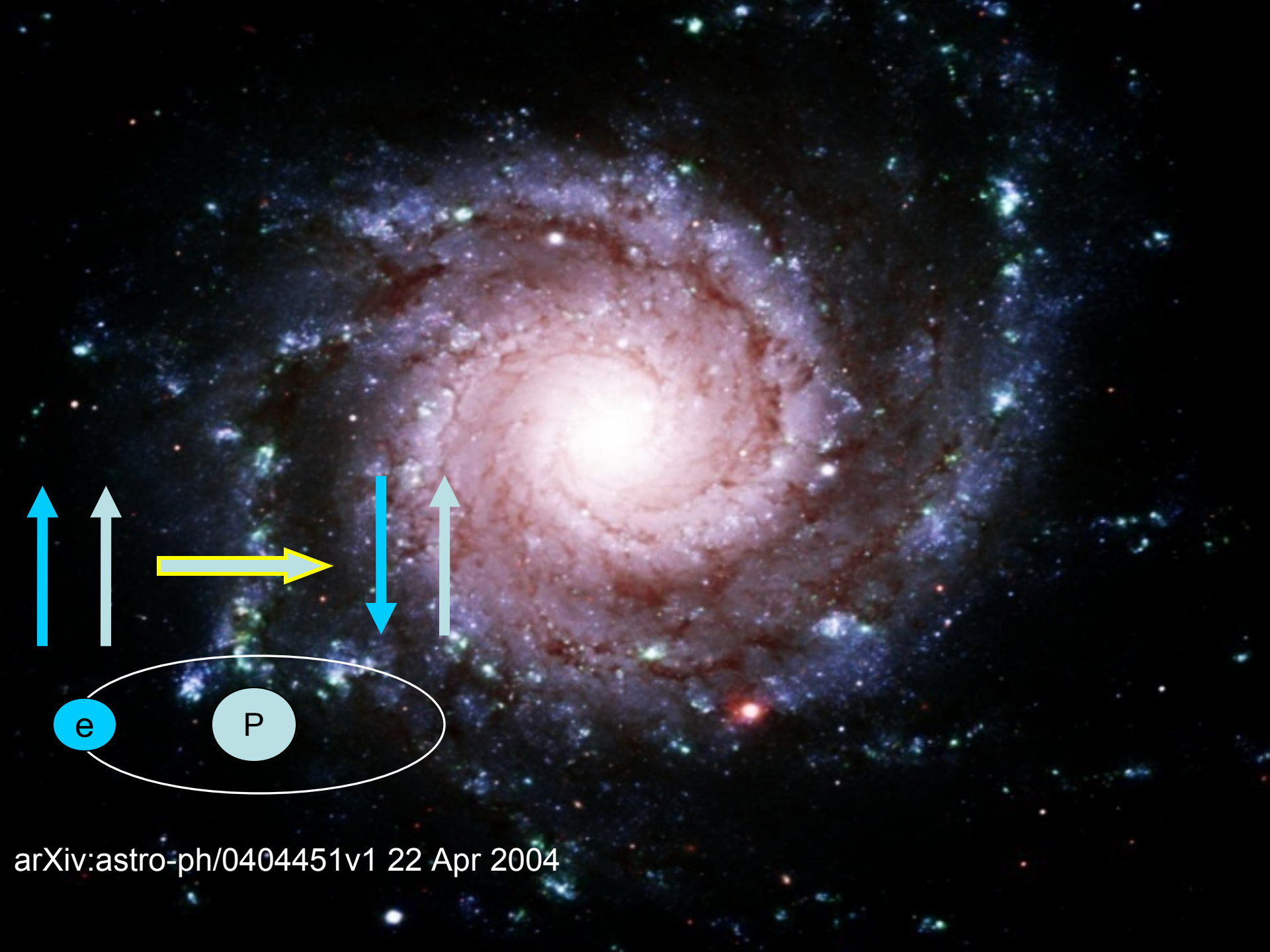




Probing Turbulence in the ISM of Galaxies

Prasun Dutta
Somnath Bharadwaj,
Jayaram N Chengalur,
Ayesha Begum
Nirupam Roy



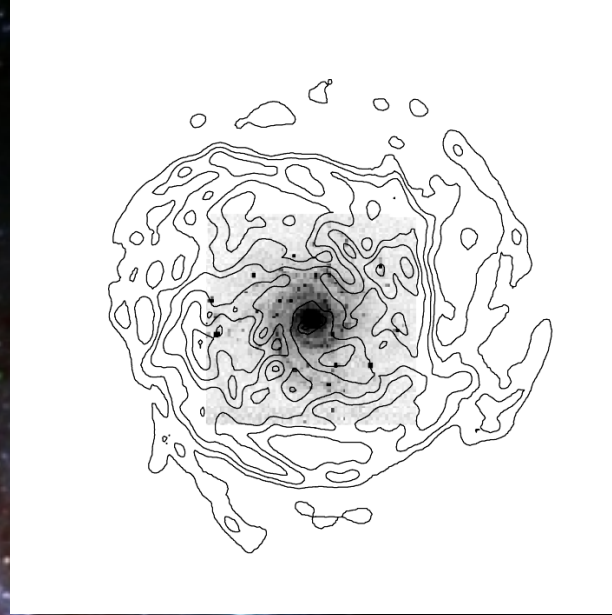
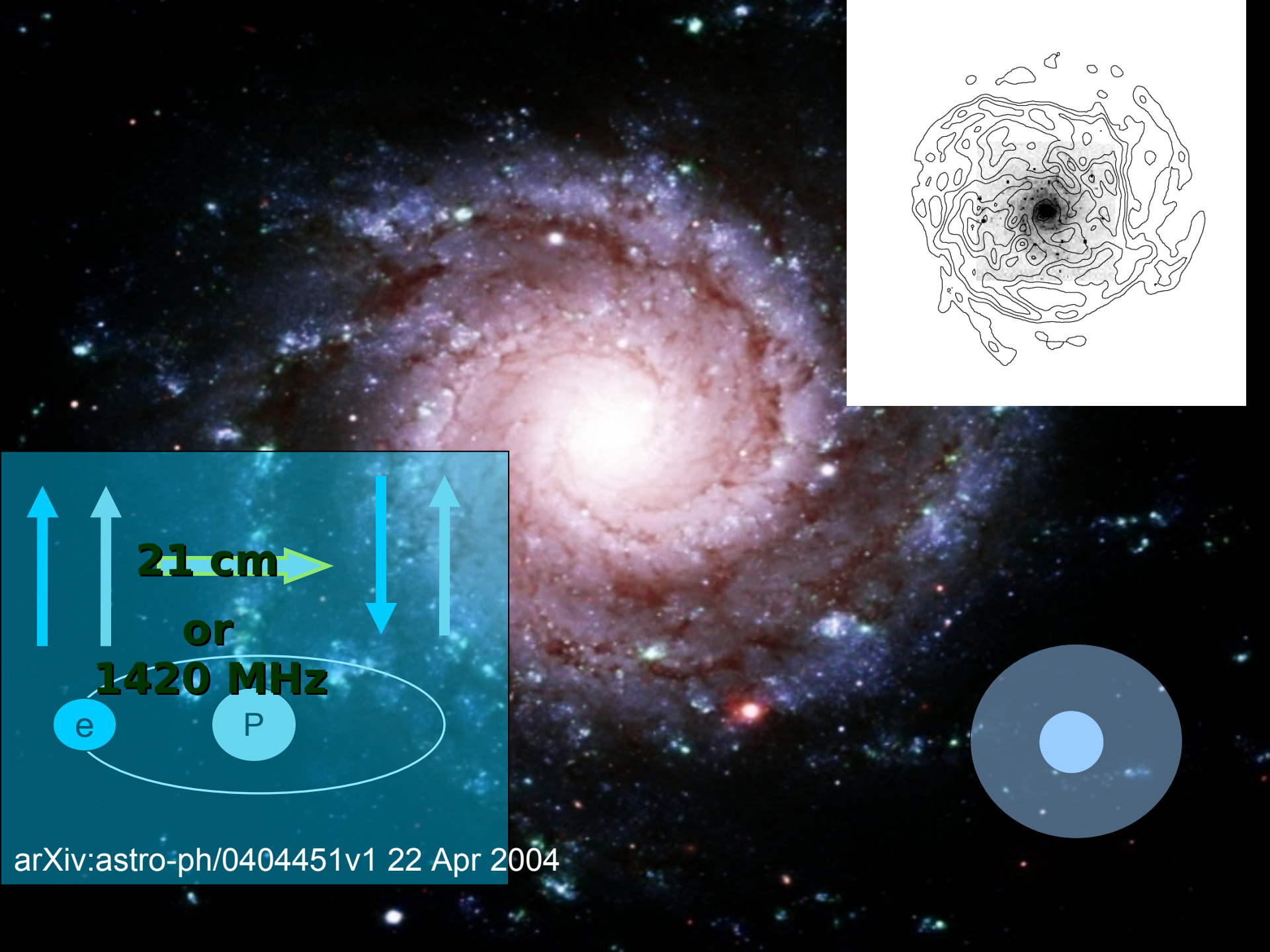
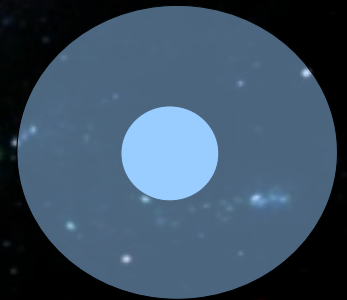
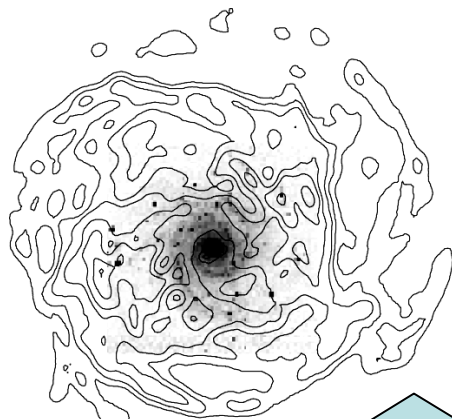


Diagram illustrating the 21 cm hydrogen line transition. It shows two blue circles labeled 'e' (excited state) and 'P' (ground state) within a white oval. Above the circles, a yellow arrow points right, labeled **21 cm** or **1420 MHz**. Four blue arrows indicate the transition: two pointing up on the left and two pointing down on the right.

arXiv:astro-ph/0404451v1 22 Apr 2004





$I(l, m)$

Radio Observation



Fourier
Transform

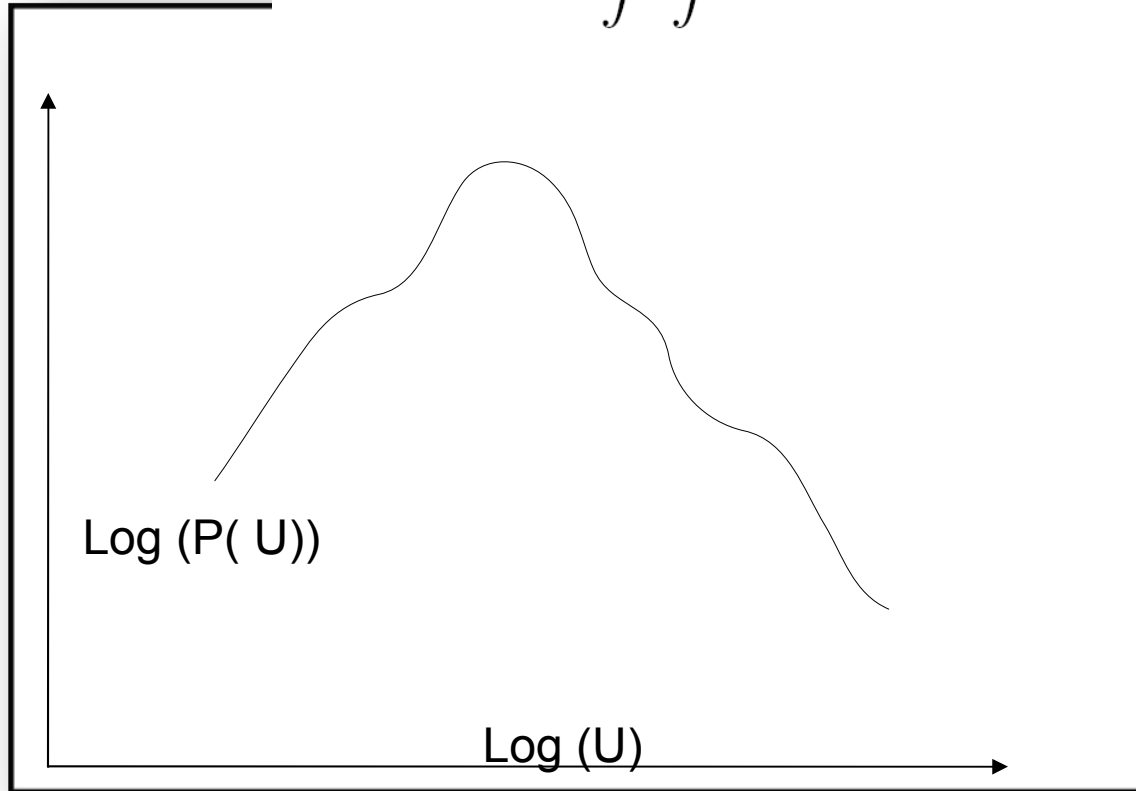
Fourier
transform
of galaxy
 $V(u, v)$

Back Fourier
Transform

$$V(u, v) = \text{FT} \{I(l, m)\}$$

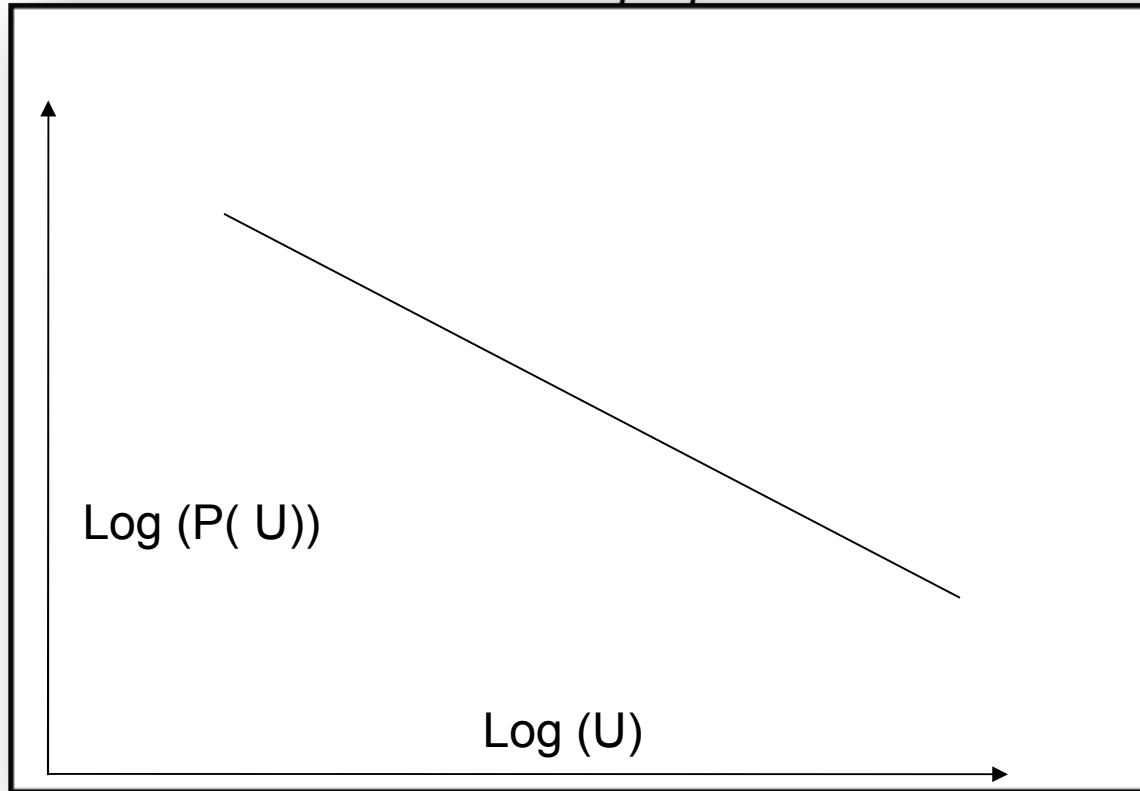
$$\xi(l - l', m - m') = \langle \delta I(l, m) \delta I(l', m') \rangle$$

$$P_{\text{HI}}(u, v) = \int \int \xi(l, m) e^{-i2\pi(ul+vm)} dl dm$$



$$\xi(l - l', m - m') = \langle \delta I(l, m) \delta I(l', m') \rangle$$

$$P_{\text{HI}}(u, v) = \int \int \xi(l, m) e^{-i2\pi(ul+vm)} dl dm$$



$$\xi(l-l',m-m')=\langle \delta I(l,m)\delta I(l',m')\rangle$$

$$\mathrm{P}_{\mathrm{HI}}(u,v)=\int\int \xi(l,m)\,e^{-i2\pi(u l+v m)}\,dl\,dm$$

$$\langle \mathcal{V}_\nu(\vec{U}) \mathcal{V}_\nu^*(\vec{U}) \rangle = \boxed{|\tilde{W}_\nu(\vec{U})|^2 \otimes} P_{HI}(\vec{U}) \boxed{+ \langle |\mathcal{N}_\nu(\vec{U})|^2 \rangle}$$



Window
Function



Noise Bias

Ayesha Begum^{1*}, Jayaram N. Chengalur² and Somnath Bharadwaj^{3†}

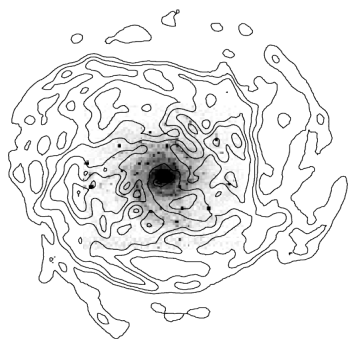
arXiv:astro-ph/0607367 v1 17 Jul 2006

$$\langle \mathcal{V}_\nu(\vec{U}) \mathcal{V}_\nu^*(\vec{U}) \rangle = \left| \tilde{W}_\nu(\vec{U}) \right|^2 \otimes P_{HI}(\vec{U}) \boxed{+ \langle |\mathcal{N}_\nu(\vec{U})|^2 \rangle}$$

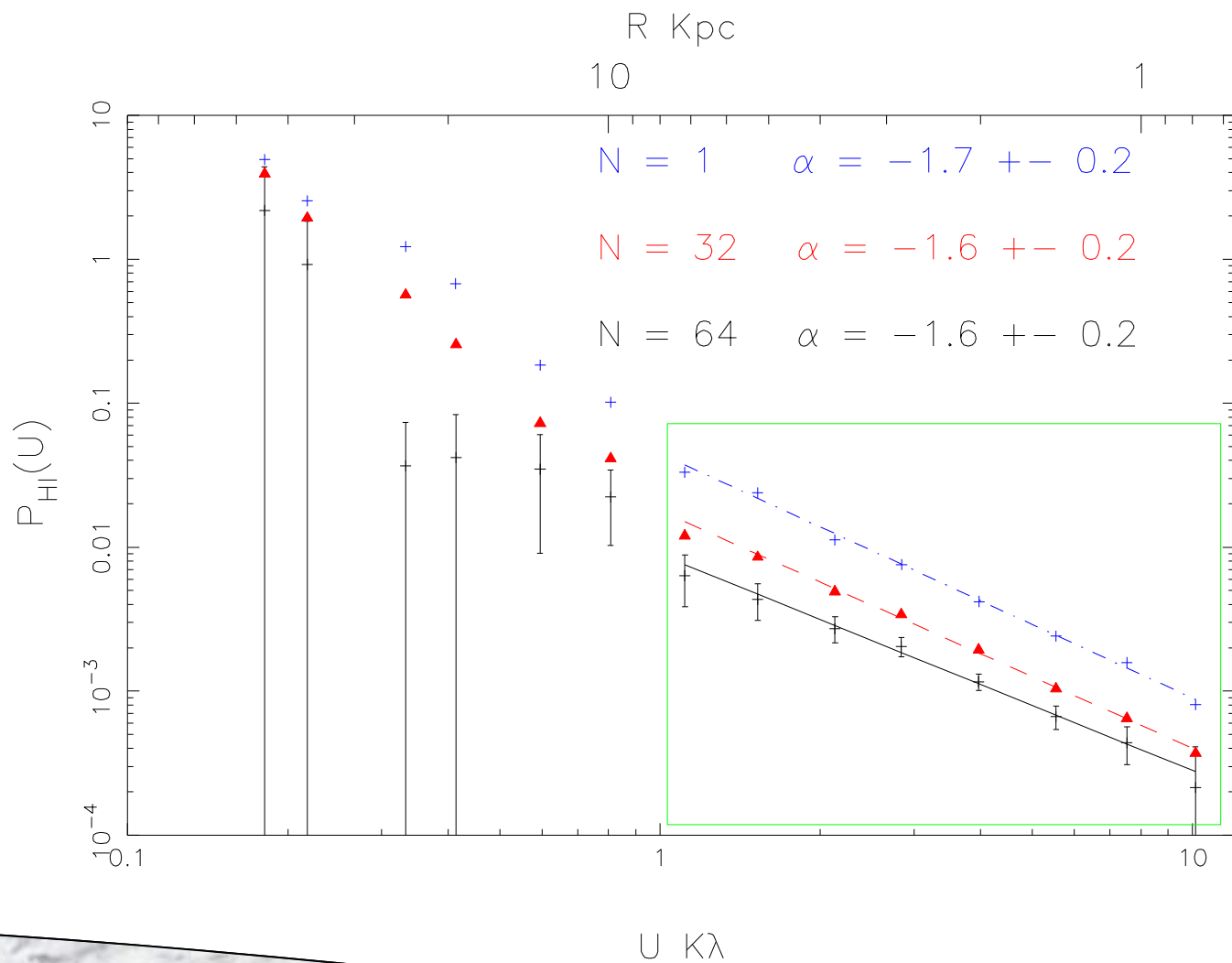
$$\begin{aligned} \hat{P}_{\text{HI}}(\vec{U}, \Delta\vec{U}) &= \langle \mathcal{V}_\nu(\vec{U}) \mathcal{V}_\nu^*(\vec{U} + \Delta\vec{U}) \rangle \\ &= \int d^2U' W_\nu(\vec{U} - \vec{U}') W_\nu^*(\vec{U} + \Delta\vec{U} - \vec{U}') P_{\text{HI}}(\vec{U}') \end{aligned}$$

Ayesha Begum^{1*}, Jayaram N. Chengalur² and Somnath Bharadwaj^{3†}

arXiv:astro-ph/0607367 v1 17 Jul 2006



800 pc



Mon. Not. R. Astron. Soc. **384**, L34–L37
(2008)

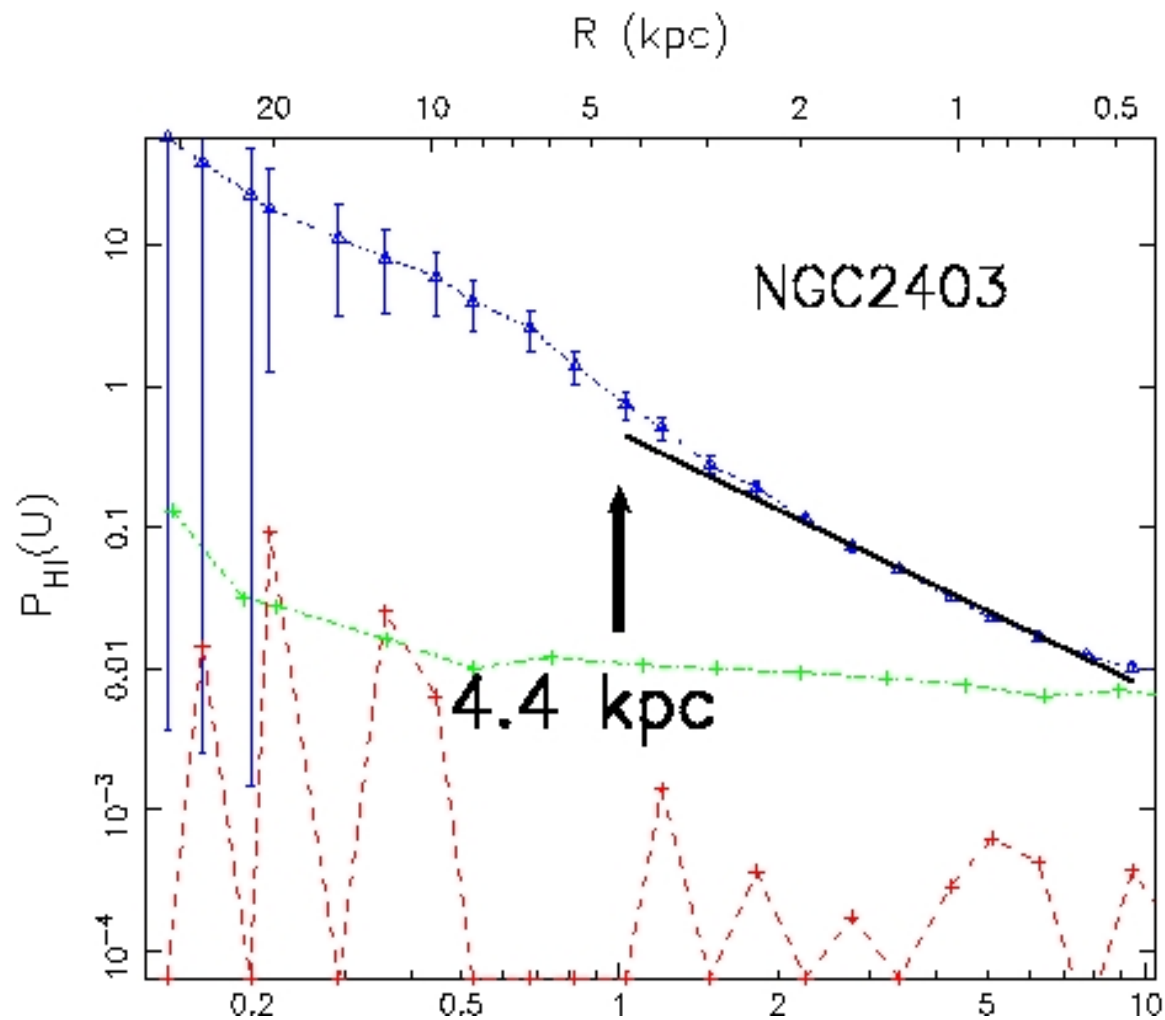
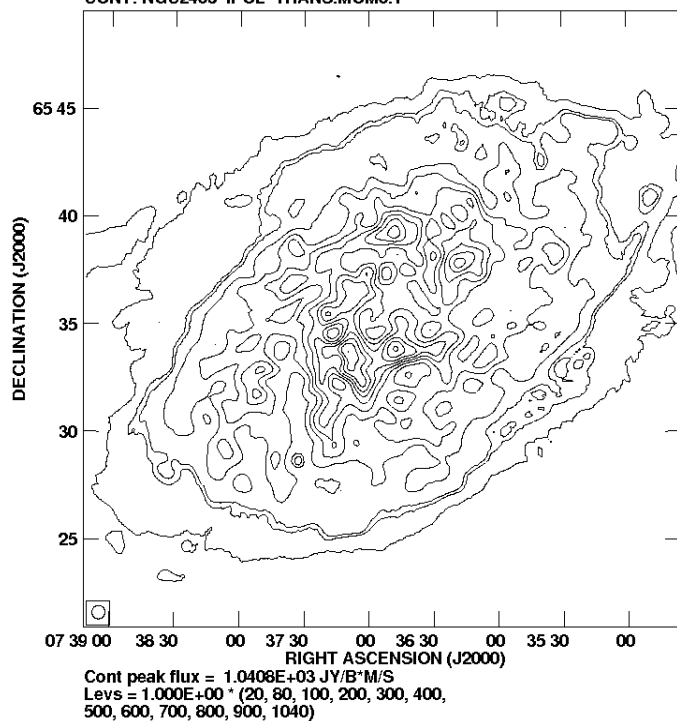
Table 2. The results for the eight galaxies in our sample. Rows 1–6 give (1) N the number of channels averaged over, (2) the corresponding velocity width (3) α the best-fitting slope for the H I power spectrum, (4) U range over which the power-law fit is valid, (5) length-scales over which the power-law fit is valid and (6) the goodness of fit χ^2 per degree of freedom. (7) Possible limits for the spectral slope of the velocity structure function.

Galaxies	DDO 210	NGC 628	NGC 3741	UGC 4459	GR 8	AND IV	KK 230	KDG 52
(1 a) N	1	1	1	1	1	1	1	1
(2 a) velocity width (km s ⁻¹)	1.65	1.29	1.65	1.65	1.65	1.65	1.65	1.65
(3 a) α	-2.3 ± 0.6	-1.6 ± 0.2	-2.2 ± 0.4	-1.8 ± 0.6	-1.1 ± 0.4	-1.3 ± 0.3	–	–
(4 a) $U_m - U_u$ (k λ)	3.7 – 13.0	1.0 – 10.0	1.6 – 16.0	3.1 – 22.0	1.6 – 23.0	0.6 – 6.7	–	–
(5 a) $D/U_u - D/U_m$ (kpc)	0.06 – 0.27	0.8 – 8.0	0.19 – 1.9	0.18 – 1.16	0.1 – 1.3	0.56 – 6.2	–	–
(6 a) χ^2/ν	0.3	0.2	0.2	0.7	0.6	0.4	–	–
(1 b) N	10	64	8	12	8	16	8	8
(2 b) velocity width (km s ⁻¹)	16.5	82.56	13.2	19.8	13.2	26.4	19.8	19.8
(3 b) α	-2.1 ± 0.6	-1.5 ± 0.2	-2.5 ± 0.4	-1.7 ± 0.4	-0.7 ± 0.3	–	–	–
(4 b) $U_m - U_u$ (k λ)	3.7 – 13.0	1.0 – 10.0	1.6 – 16.0	3.1 – 22.0	1.6 – 23.0	–	–	–
(6 a) $D/U_u - D/U_m$ (kpc)	0.06 – 0.27	0.8 – 8.0	0.19 – 1.9	0.18 – 1.16	0.1 – 1.3	–	–	–
(6 b) χ^2/ν	0.4	0.2	1.3	0.3	0.2	–	–	–
(7) ζ_2	0 ± 1.2	0 ± 0.4	0 ± 0.8	0 ± 1.2	0 ± 0.8	0 ± 0.6	–	–

Table 2. The results for the eight galaxies in our sample. Rows 1–6 give (1) N the number of channels averaged over, (2) the corresponding velocity width (3) α the best-fitting slope for the H I power spectrum, (4) U range over which the power-law fit is valid, (5) length-scales over which the power-law fit is valid and (6) the goodness of fit χ^2 per degree of freedom. (7) Possible limits for the spectral slope of the velocity structure function.

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(3 a) α	-2.3 ± 0.6	-1.6 ± 0.2	-2.2 ± 0.4	-1.8 ± 0.6	-1.1 ± 0.4	-1.3 ± 0.3	–	–
(4 a) $U_{\text{m}} - U_{\text{u}}$ (k λ)	3.7 – 13.0	1.0 – 10.0	1.6 – 16.0	3.1 – 22.0	1.6 – 23.0	0.6 – 6.7	–	–
(5 a) $D/U_{\text{u}} - D/U_{\text{m}}$ (kpc)	0.06 – 0.27	0.8 – 8.0	0.19 – 1.9	0.18 – 1.16	0.1 – 1.3	0.56 – 6.2	–	–
(6 a) χ^2/ν	0.3	0.2	0.2	0.7	0.6	0.4	–	–
(1 b) N	10	64	8	12	8	16	8	8
(2 b) velocity width (km s ⁻¹)	16.5	82.56	13.2	19.8	13.2	26.4	19.8	19.8
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(4 b) $U_{\text{m}} - U_{\text{u}}$ (k λ)	3.7 – 13.0	1.0 – 10.0	1.6 – 16.0	3.1 – 22.0	1.6 – 23.0	–	–	–
(6 a) $D/U_{\text{u}} - D/U_{\text{m}}$ (kpc)	0.06 – 0.27	0.8 – 8.0	0.19 – 1.9	0.18 – 1.16	0.1 – 1.3	–	–	–
(6 b) χ^2/ν	0.4	0.2	1.3	0.3	0.2	–	–	–
(7) ζ_2	0 ± 1.2	0 ± 0.4	0 ± 0.8	0 ± 1.2	0 ± 0.8	0 ± 0.6	–	–

Plot file version 1 created 22-NOV-2008 19:53:31
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Galaxy	type	α
DDO 210	Dwarf	-2.6 ± 0.6
NGC 3741	Dwarf	-2.3 ± 0.3
GR 8	Dwarf	-1.1 ± 0.4
AND IV	Dwarf	-1.3 ± 0.3
UGC 4459	Dwarf	-1.8 ± 0.6
NGC 628	Spiral	-1.7 ± 0.2
NGC 1058	Spiral	-2.5 ± 0.5
NGC 4254	Spiral	
NGC 2403	Spiral	-1.8 ± 0.5
NGC 7331	Spiral	-1.1 ± 0.6
NGC 2985	Spiral	-0.9 ± 0.2

THINGS

The HI Nearby Galaxy Survey

NGC 2841

NGC 3621

NGC 7331

NGC 4826
(M64)

NGC 3198

NGC 6946

NGC 3184

NGC 925

NGC 3351
(M95)

NGC 5194
(M51)

NGC 5236
(M83)

NGC 3521

NGC 4214

NGC 2976

DDO 53

NGC 1569

M81dwB

M81dwA

Our Galaxy
HI stars

NGC 2366

IC 2574

NGC 3627
(M66)

NGC 4449

Holmberg II

DDO 154

NGC 4736
(M94)

NGC 3077

Holmberg I

NGC 7793

NGC 5055

NGC 2903

NGC 628
(M74)

NGC 5457
(M101)

NGC 3031
(M81)

NGC 2403

↔
10 kpc



Data: Walter et al 2008
Milky Way HI map: Oort et al (1958)
Milky Way art: NASA/JPL, R. Hurt (SSC)

THINGS

The HI Nearby Galaxy Survey

Galaxy	α
NGC 2841	-1.3 ± 0.2
NGC 3184	-1.4 ± 0.2
NGC 4214	-1.8 ± 0.1
NGC 5055	-0.7 ± 0.2
NGC 925	-1.1 ± 0.2
NGC 2366	-1.2 ± 0.3
NGC 2903	-1.5 ± 0.2
NGC 3184	-1.4 ± 0.2
NGC 628	-1.6 ± 0.2
NGC 6946	-2.1 ± 0.3
NGC 4214	-2.3 ± 0.2

NGC 3198

NGC 5236
(M83)

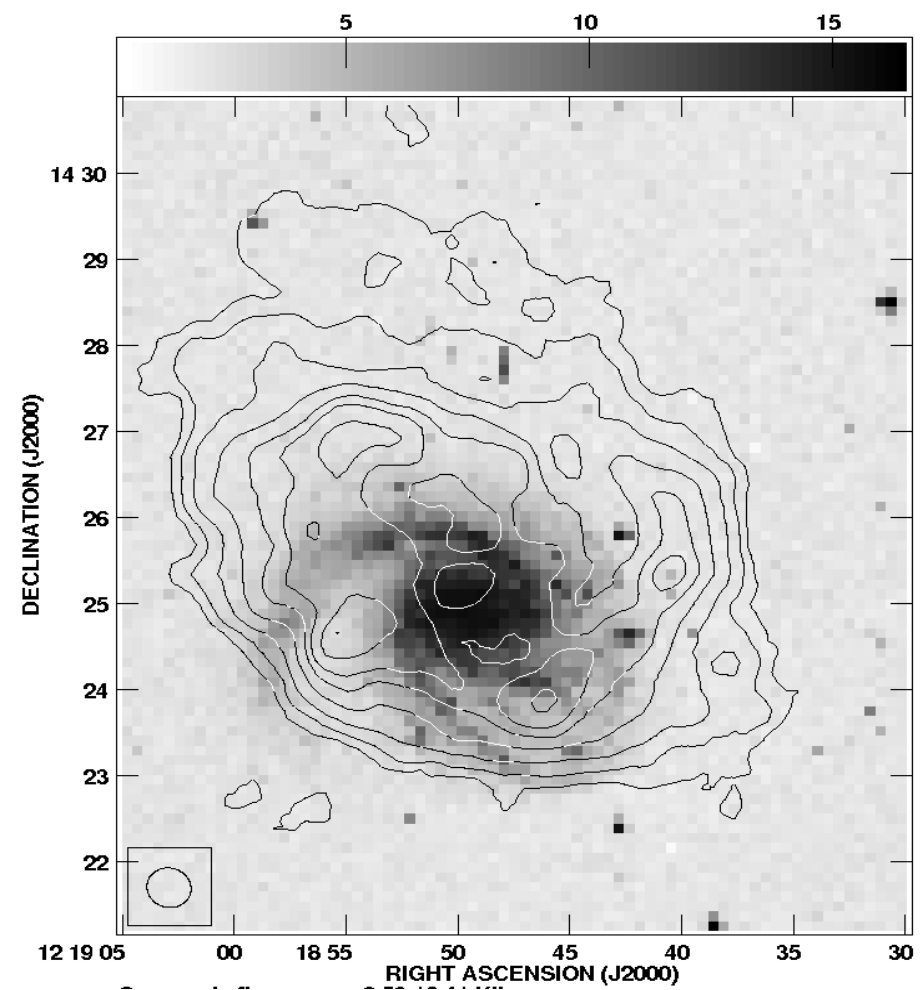
NGC 5055

↔
10 kpc



Data: Walter et al 2008
Milky Way HI map: Oort et al (1958)
Milky Way art: NASA/JPL, R. Hurt (SSC)





NGC 4254

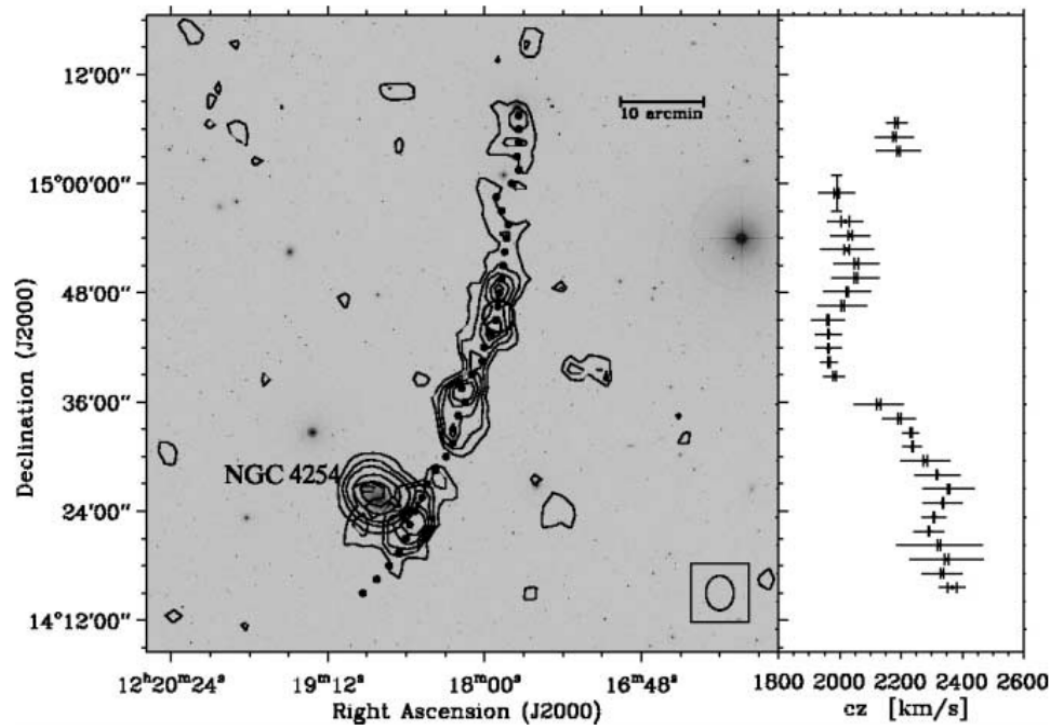
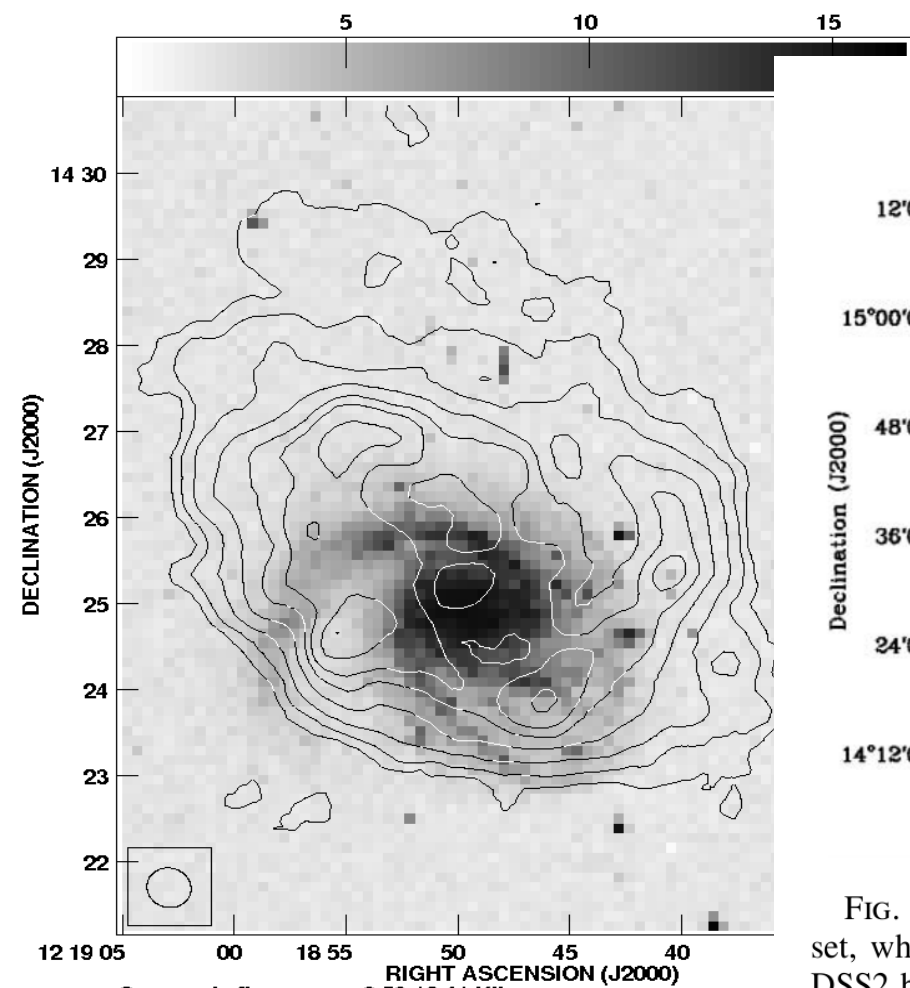
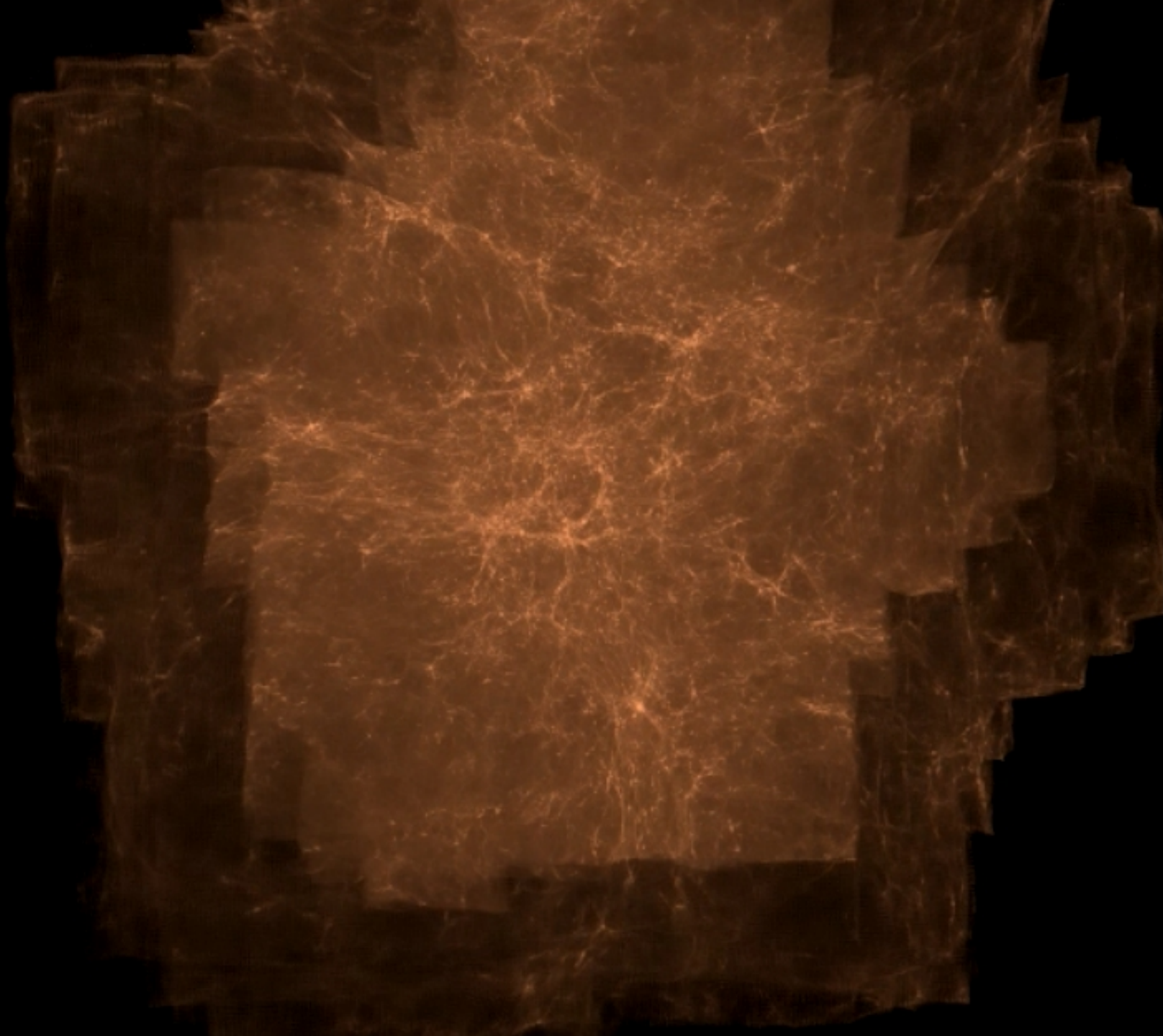
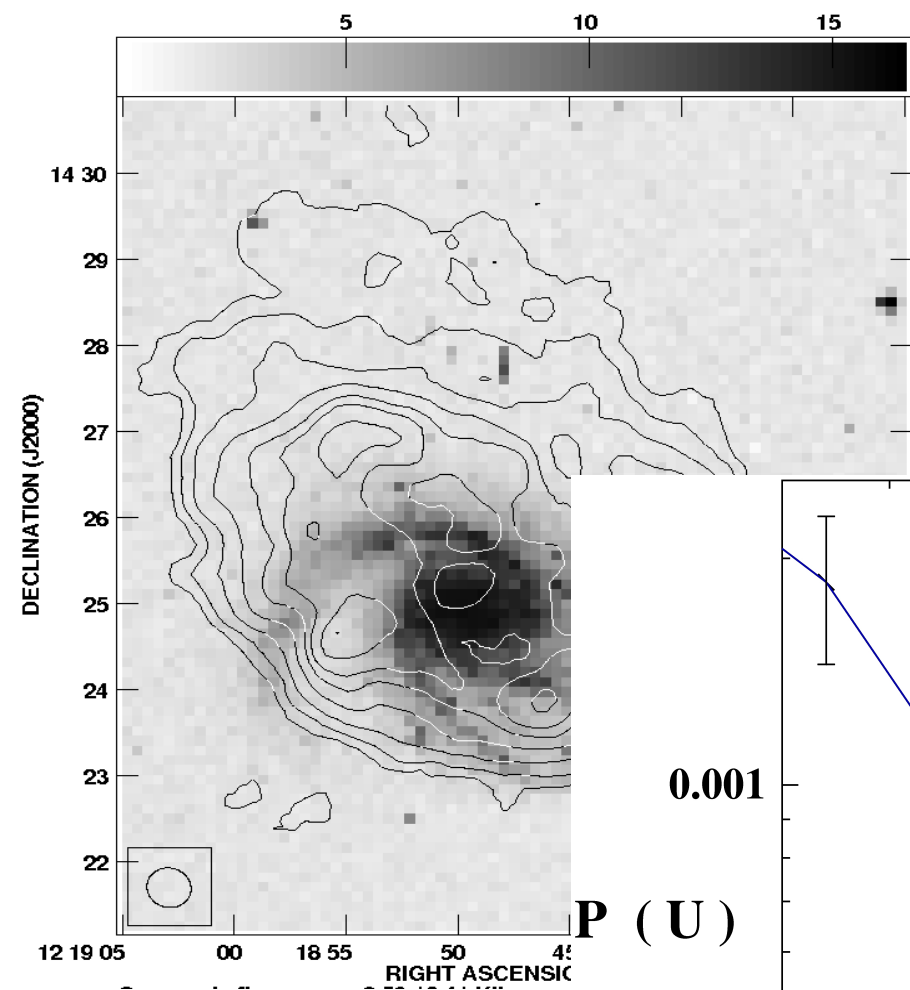


FIG. 1.—*Left*: H I flux contours extracted from the ALFALFA survey data set, which mapped the full field represented in the image, superposed on a DSS2 blue image. The 36 filled circles indicate the locations of beam centers for the successive LBW observations. The contours centered on NGC 4254 are at 10, 15, 20, 30, and 40 $\text{Jy beam}^{-1} \text{ km s}^{-1}$, integrated from 2259 to 2621 km s^{-1} . The contours for the H I stream are at 0.35, 0.52, 0.70, 0.87, and 1.0 $\text{Jy beam}^{-1} \text{ km s}^{-1}$, integrated from 1946 to 2259 km s^{-1} . Note the difference in dynamic range of contours for the galaxy and the stream, selected for viewing ease. The 3' circle in midstream indicates the position of VIRGOHI 21 reported by Minchin et al. (2005a). The ellipse on the bottom right indicates the size of the Arecibo beam. *Right*: Velocities of the H I emission peaks as seen in LBW pointings. Some of the LBW spectra yielded poor baselines or poor peak definition.

=10.6





1 - 5 kpc

NGC 4254

0.001

P (U)

4.0

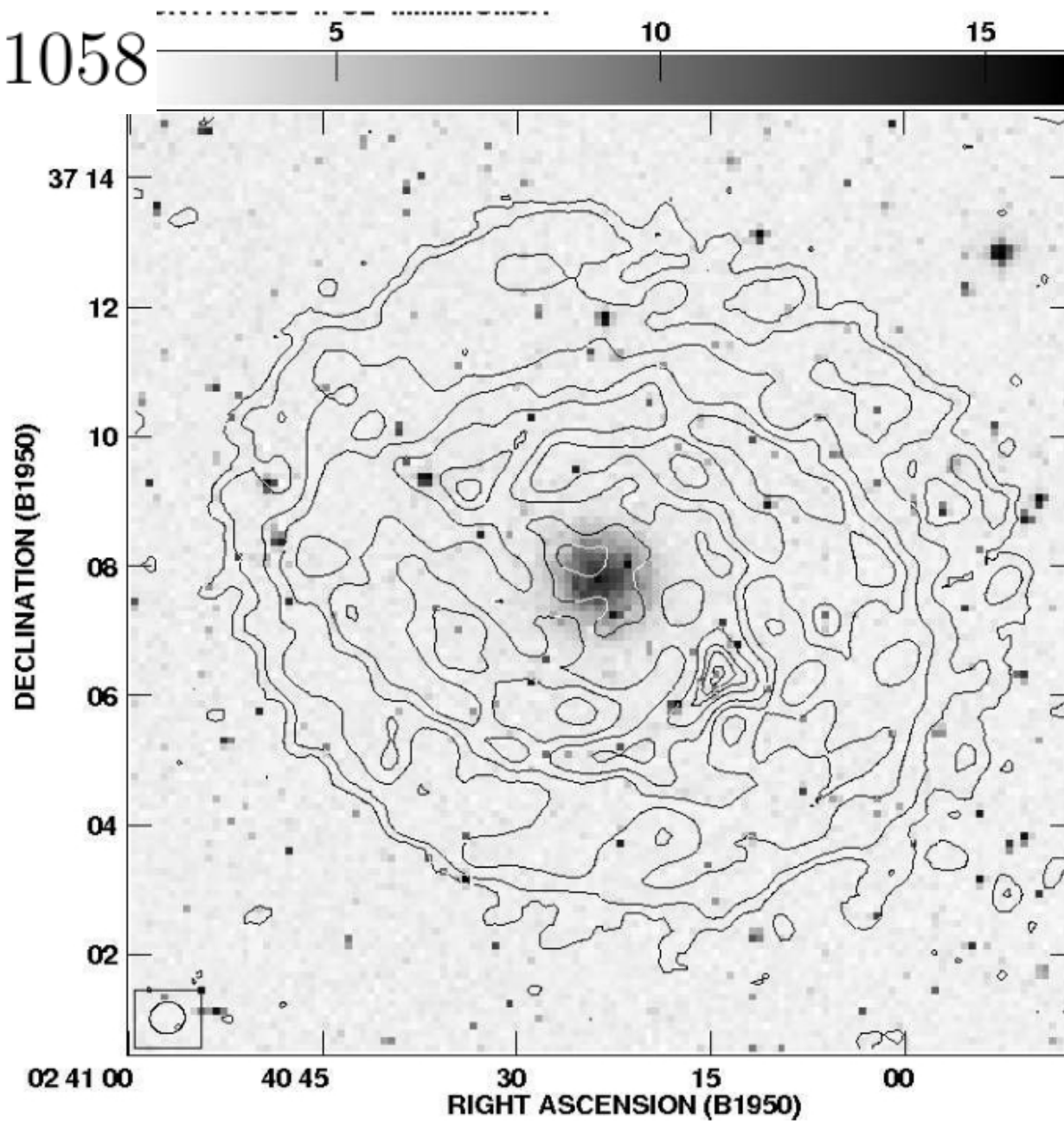
6.0

8.0

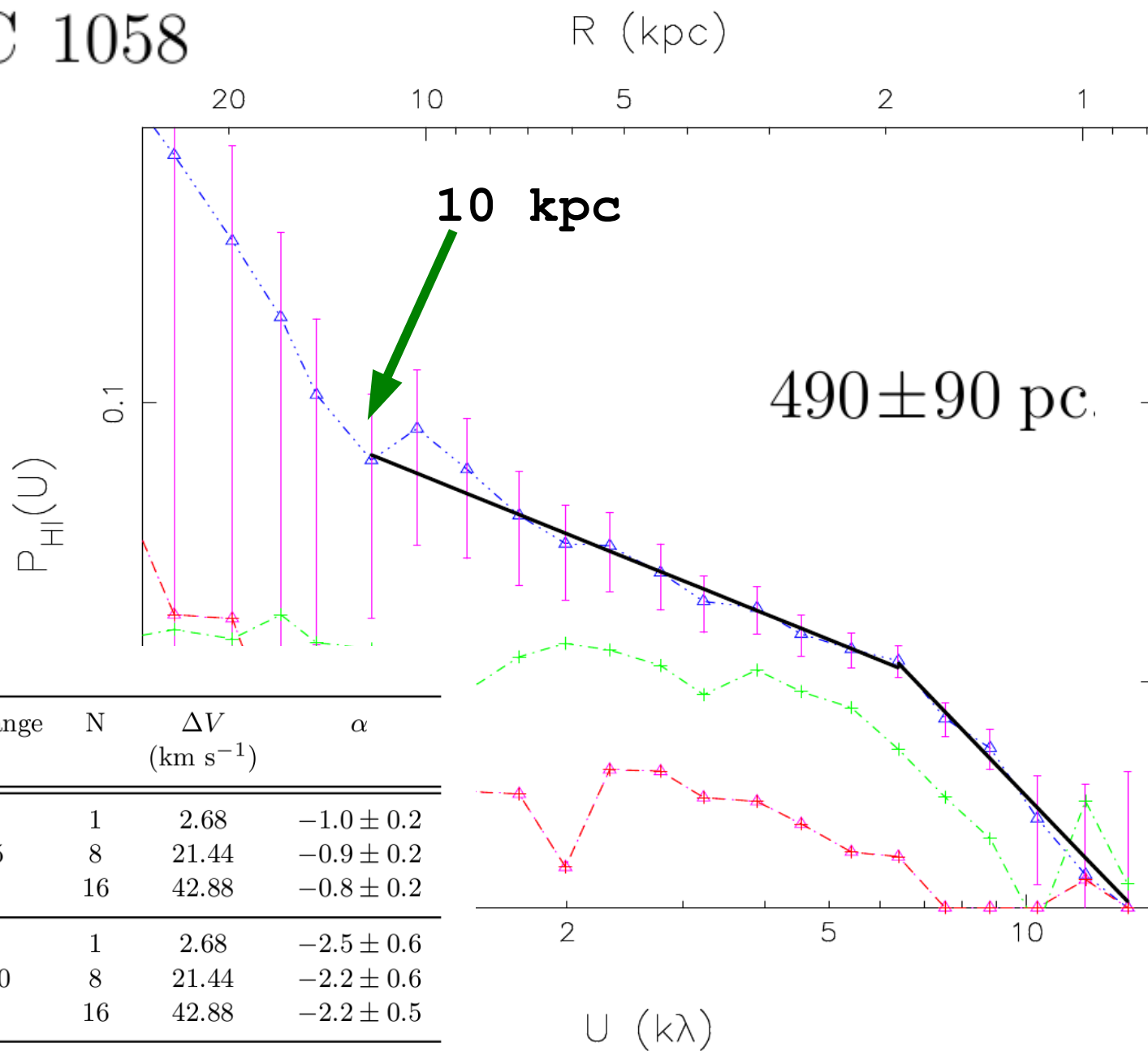
U (k λ)



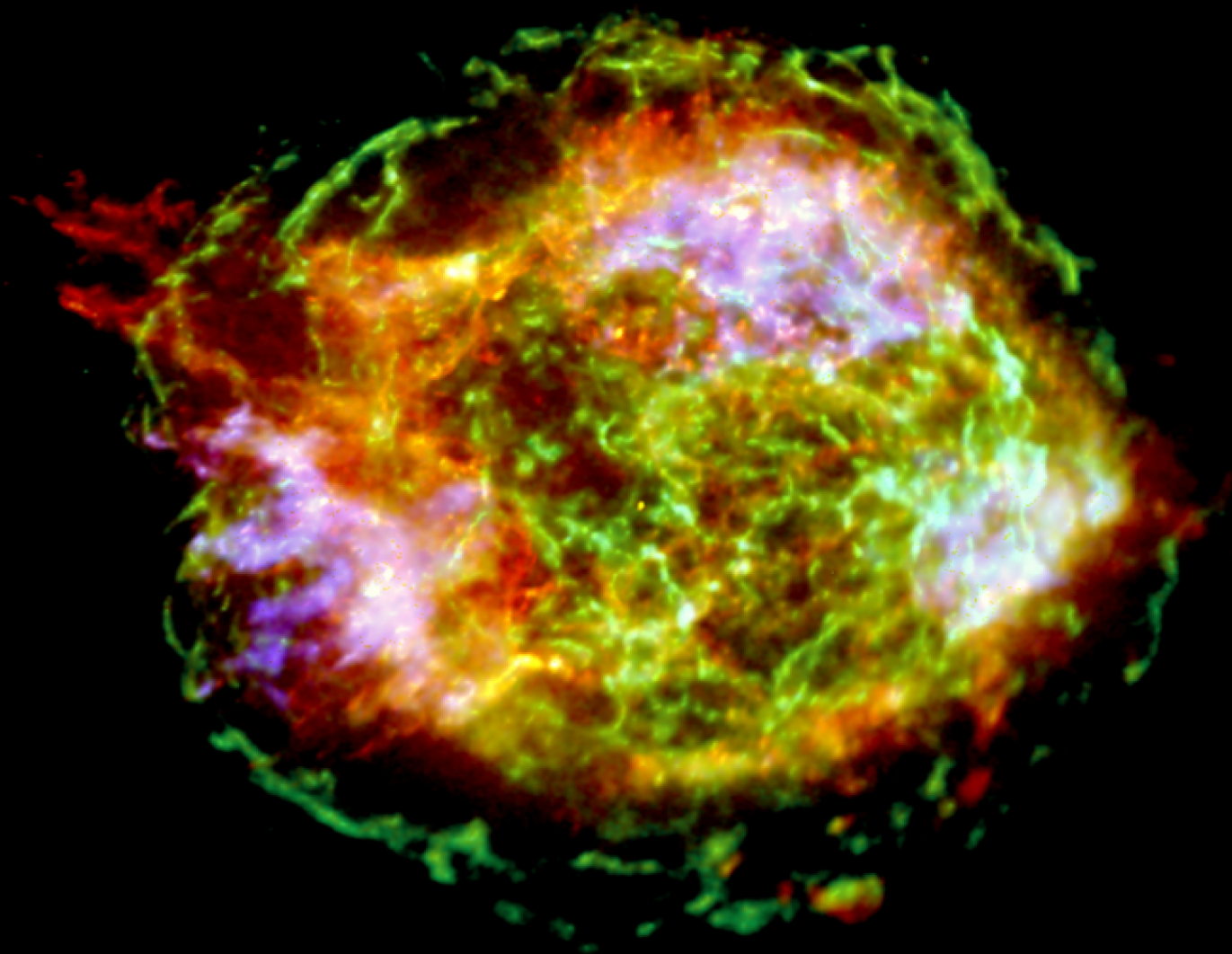
NGC 1058



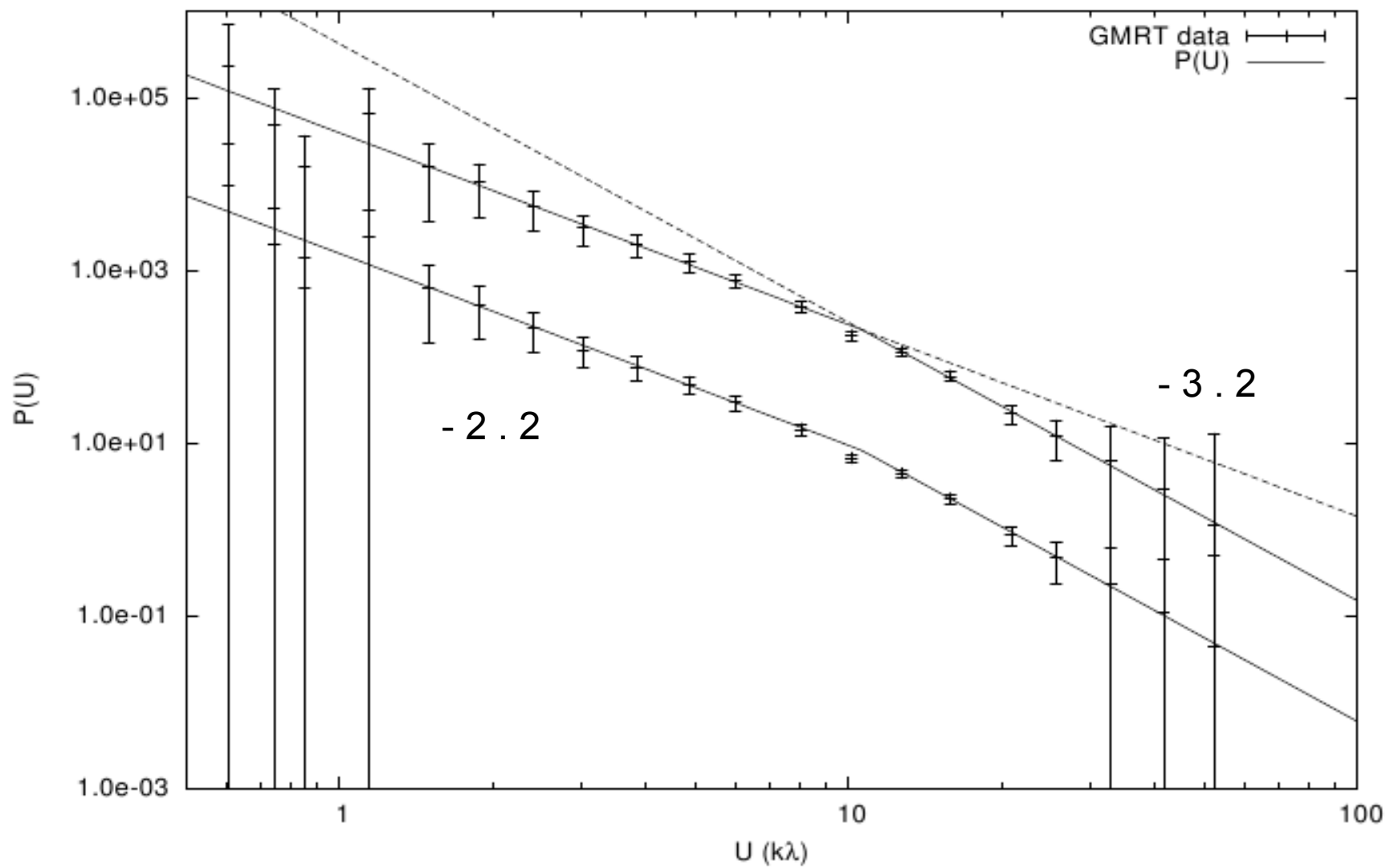
NGC 1058

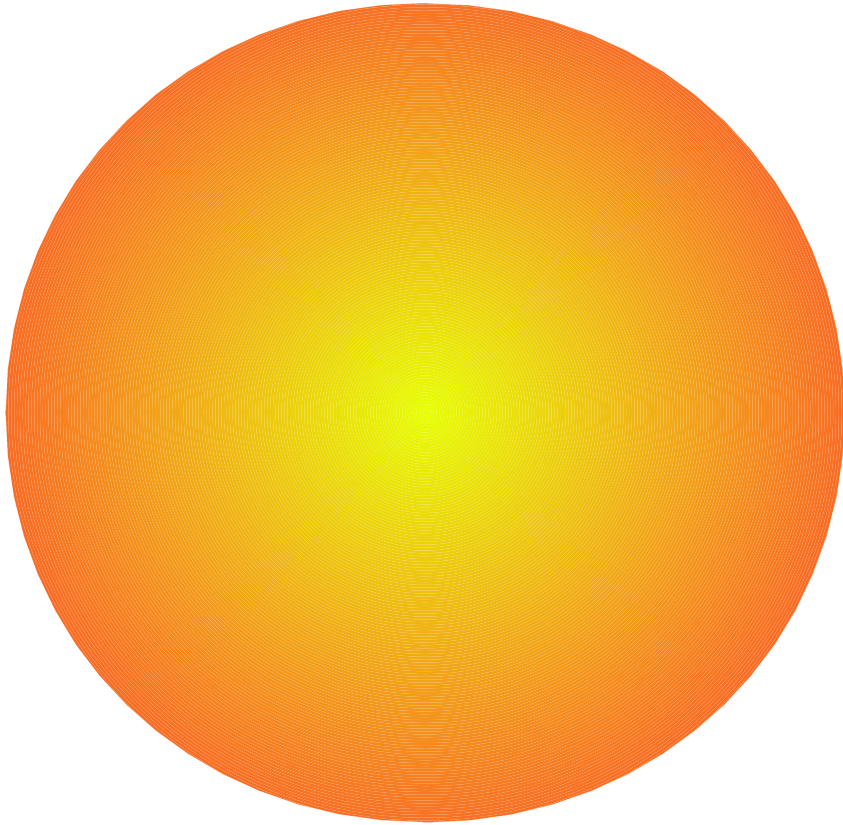


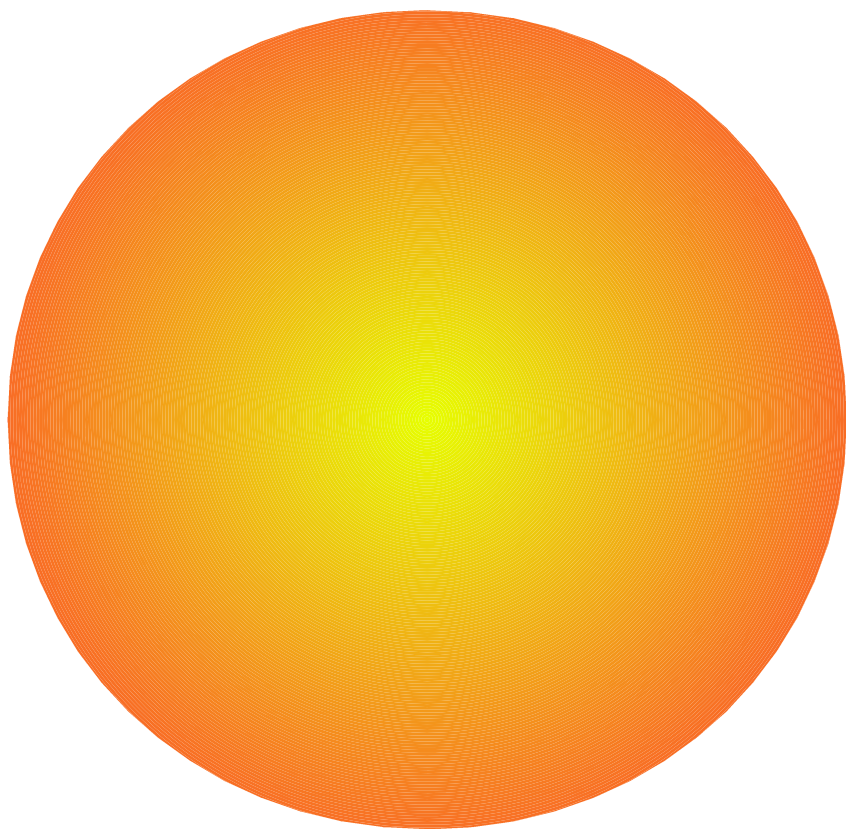




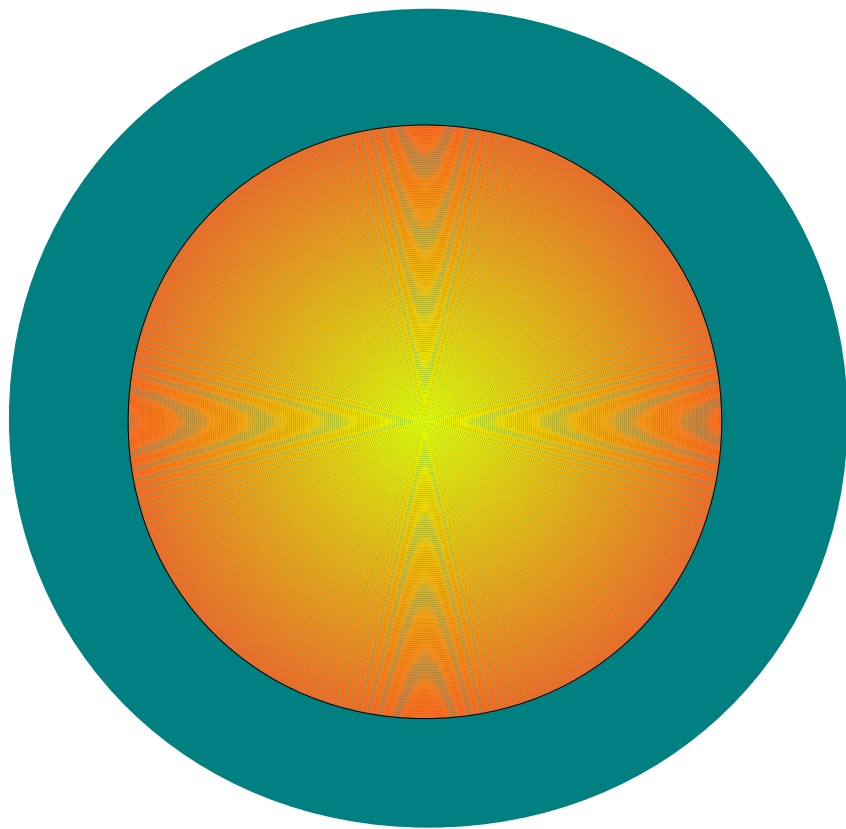
Cas A GMRT L-band



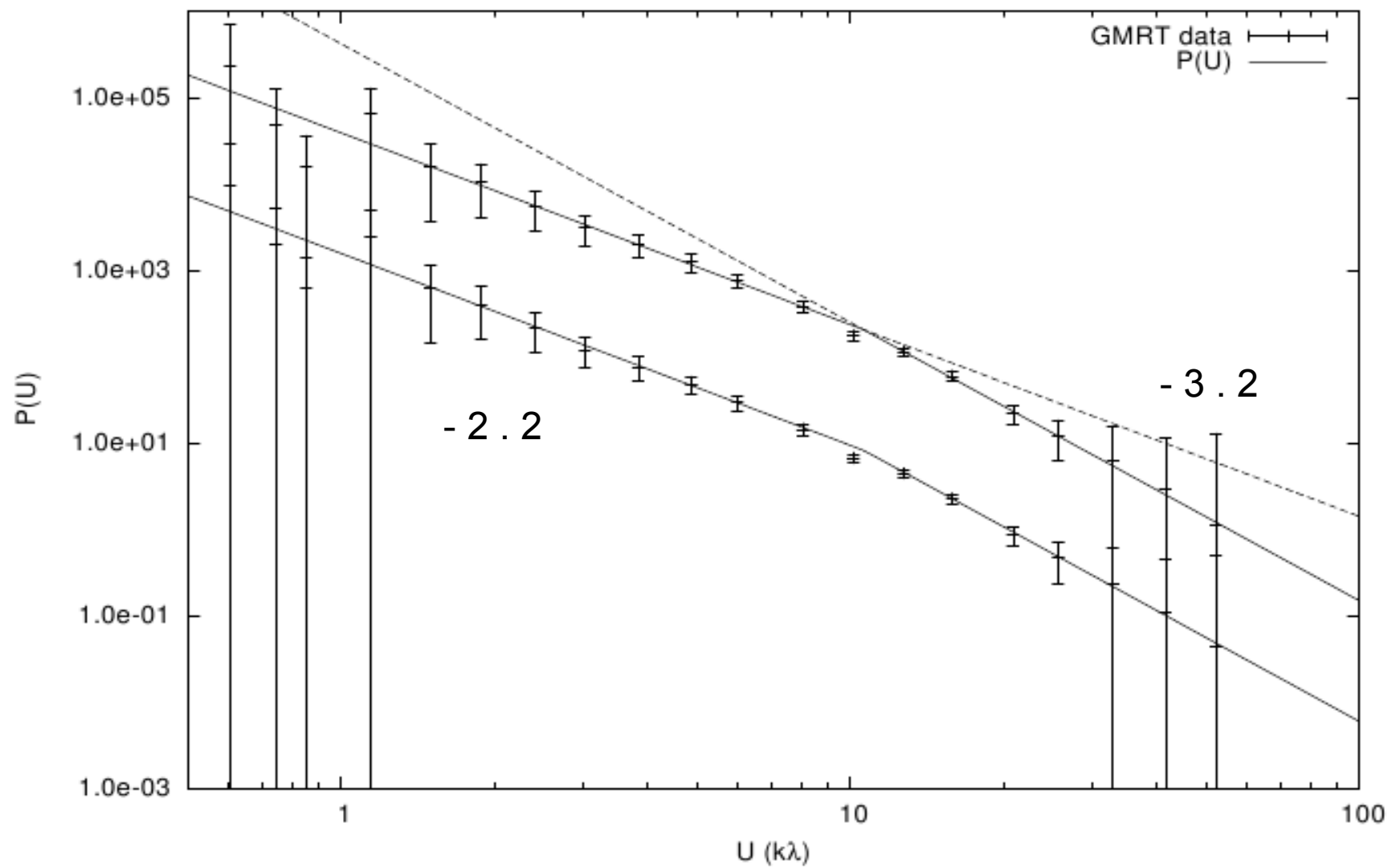




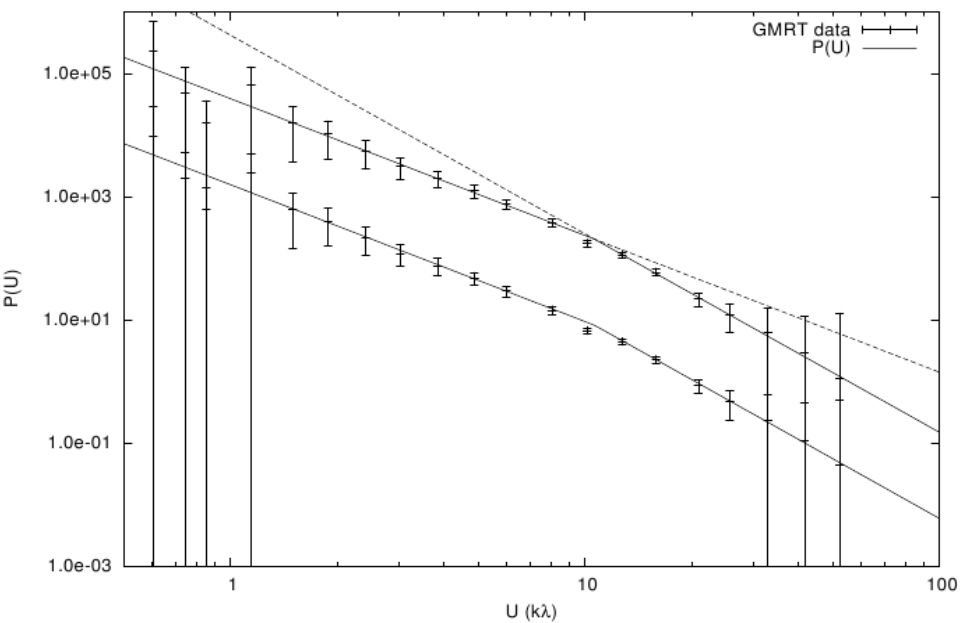
o



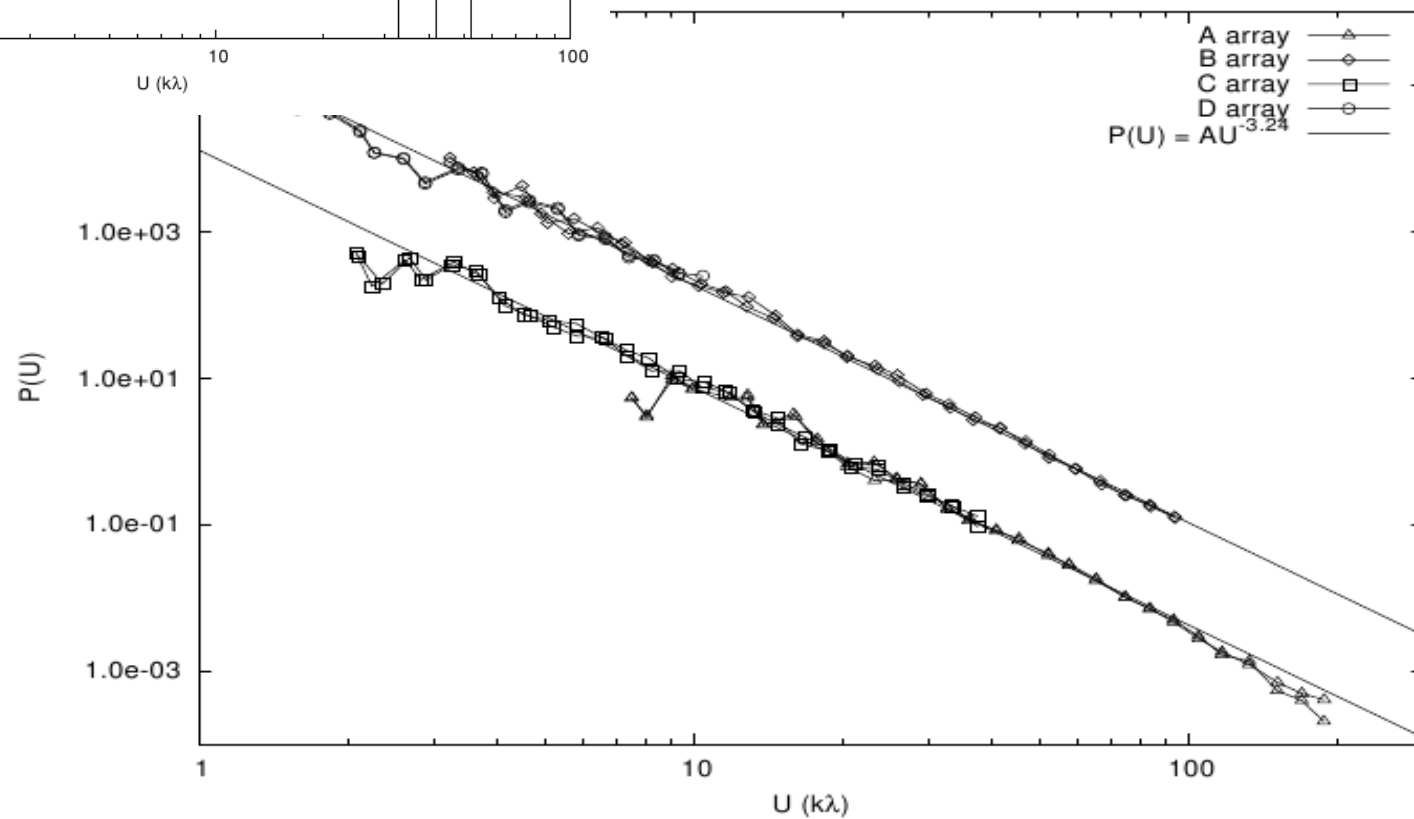
Cas A GMRT L-band

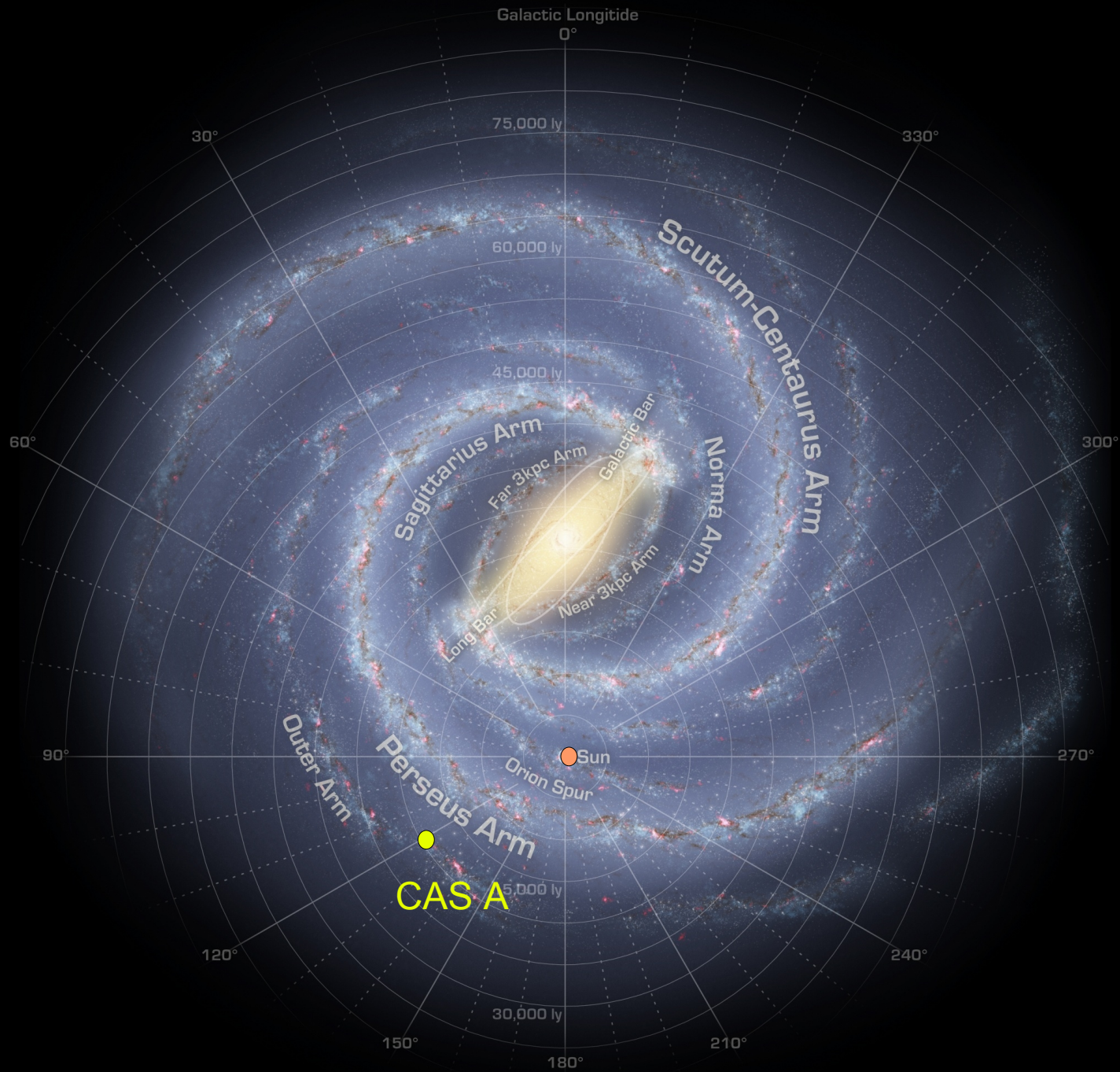


Cas A GMRT L-band



Crab Nebula VLA C-band





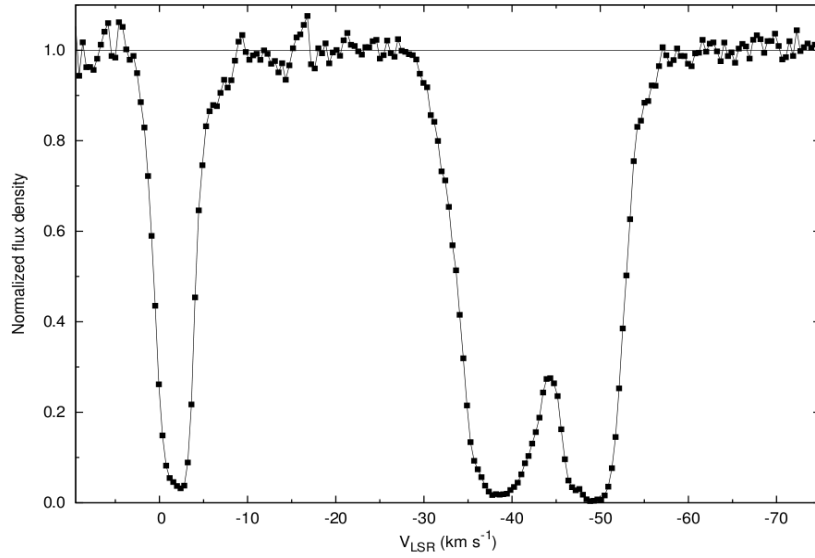


Figure 1. Integrated H I 21 cm absorption spectrum towards the supernova remnant Cas A. The continuum corresponds to the total flux density of Cas A. The wide feature at negative LSR velocity is the absorption produced by gas from the Perseus spiral arm and the absorption near zero LSR velocity is from the Local arm gas.

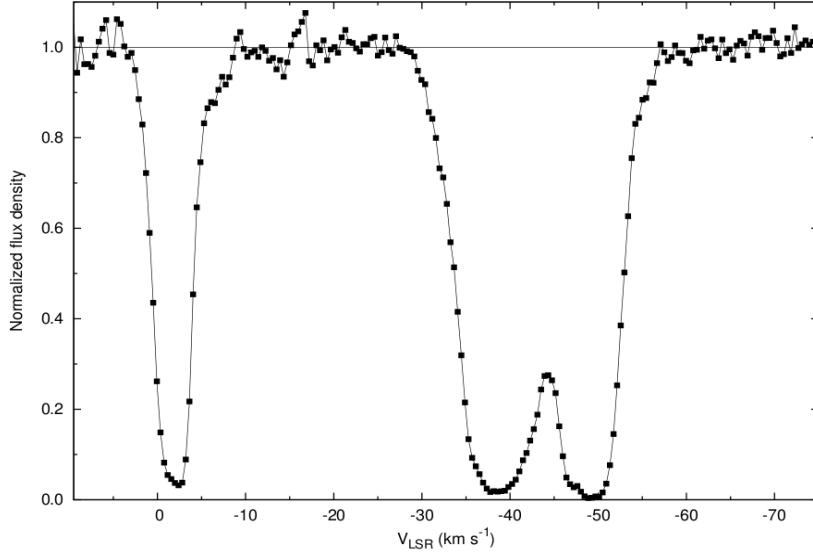


Figure 1. Integrated H I 21 cm absorption spectrum towards the supernova remnant Cas A. The continuum corresponds to the total flux density of Cas A. The wide feature at negative LSR velocity is the absorption produced by gas from the Perseus spiral arm and the absorption near zero LSR velocity is from the Local arm gas.

$$P_S = \mathcal{F}\{\xi_S\} = e^{-2\tau^0 + \sigma_\tau^2} (I_c^{0\,2} + P_{I_c}) \otimes \mathcal{F}\{e^{\xi_\tau}\}$$

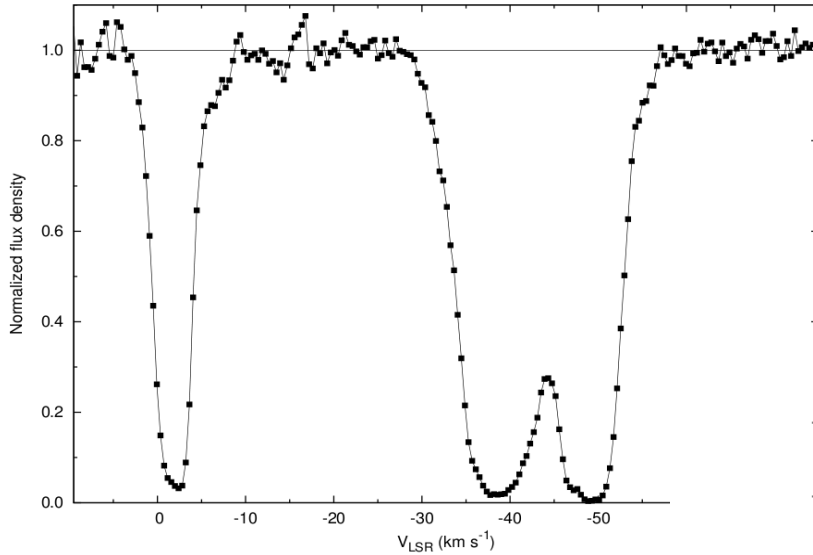


Figure 1. Integrated H I 21 cm absorption spectrum toward remnant Cas A. The continuum corresponds to the total Cas A. The wide feature at negative LSR velocity is produced by gas from the Perseus spiral arm and the absorption velocity is from the Local arm gas.

5 – 250 arcsec

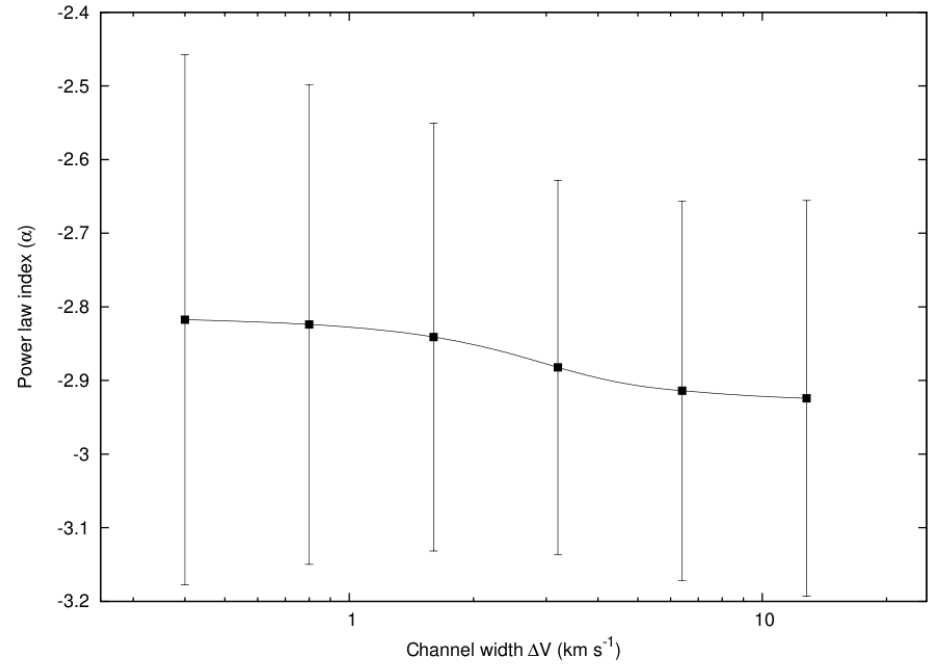


Figure 4. Power law index of the opacity fluctuation power spectrum for

$$P_S = \mathcal{F}\{\xi_S\} = e^{-2\tau^0 + \sigma_\tau^2} (I_c^{02} + P_{I_c}) \otimes \mathcal{F}\{e^{\xi_\tau}\} \quad \begin{matrix} -33 \text{ km s}^{-1} \\ .8 \text{ km s}^{-1} \text{ is} \end{matrix}$$



HALL OF RESURGENCE
HALL-III