Diffractive Scintillation in J1819+3845: How low (in T_b) can you go?

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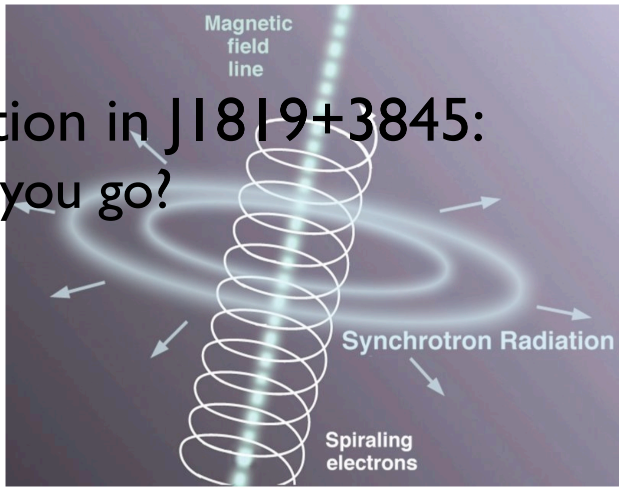
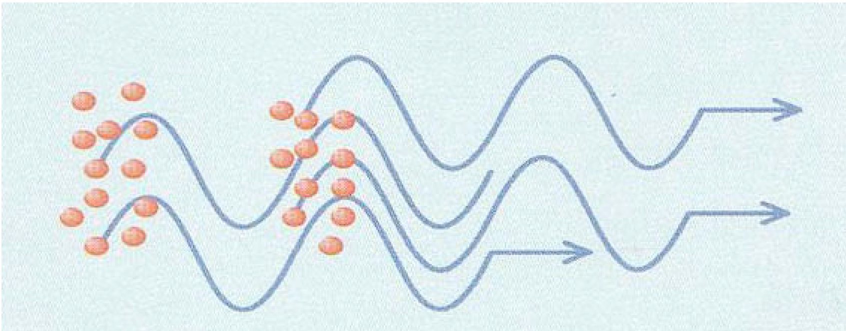
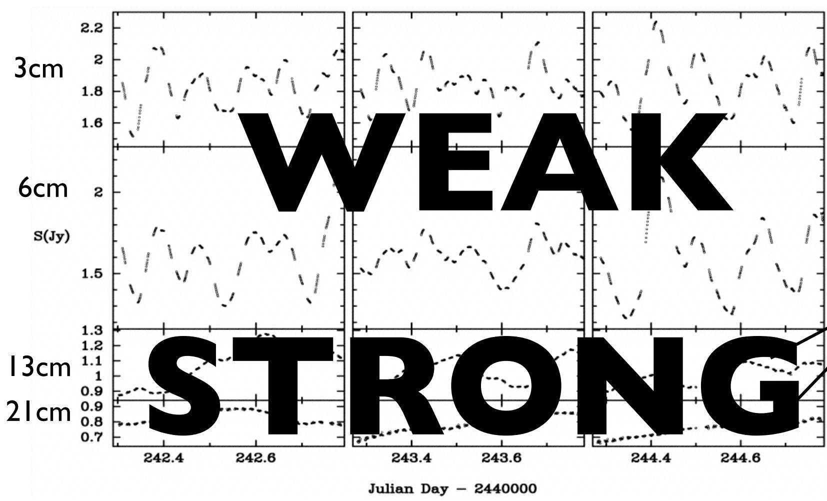


vs



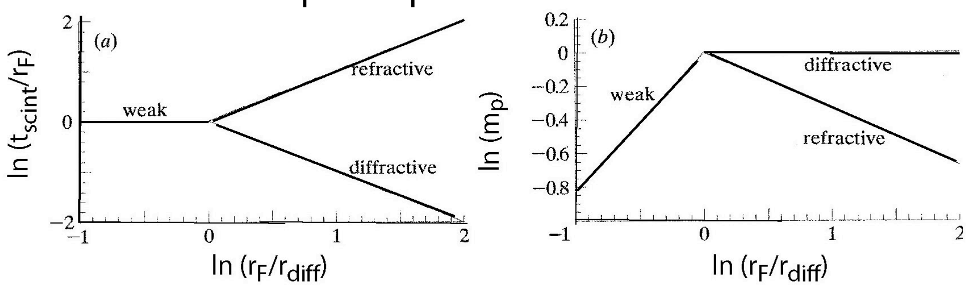
Variations in a 'normal' IDV source



PKS 0405-385
(Kedziora-Chudczer et al. 1997)

Slow, smooth variations caused by refractive scintillation

Expected point source behaviour



What is diffractive scintillation?

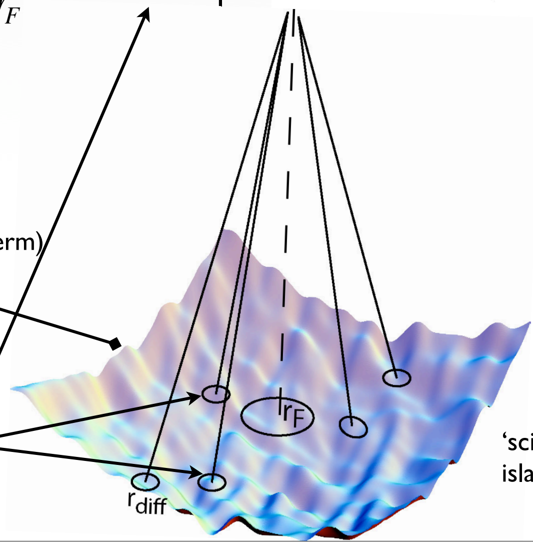
- Fast, narrowband intensity fluctuations occurring in the regime of strong scattering.
- Point source timescale: $t_{diff} \sim r_{diff}/v_{ISS} \ll r_{ref}/v_{ISS}$
- Point source decorrelation bandwidth: $\Delta\nu \approx \nu(r_{diff}/r_F)^2 \ll \nu$
- Requires small angular diameter ~ r_{diff}/z

$$u(\vec{X}) = \frac{e^{-i\pi/2}}{2\pi r_F^2} \int \exp\left[i \frac{(\vec{x} - \vec{X})^2}{2 r_F^2} + i\phi(\vec{x}) \right] d\vec{x}$$

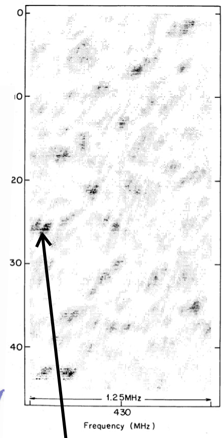
$$r_F = \sqrt{\frac{\lambda D}{2\pi}}$$

Slow paraboliodal phase curvature due to geometric phase delay (Fresnel term)

Interference between ray bundles gives fast, narrowband intensity fluctuations



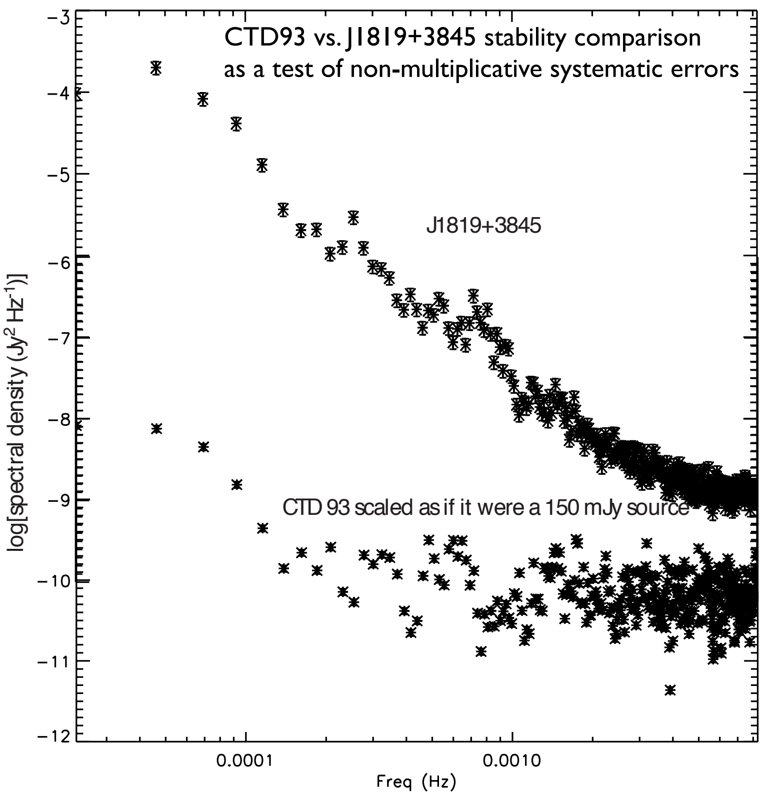
A sample dynamic spectrum (Cordes et al. 1985)



'scintles' - islands in freq and time

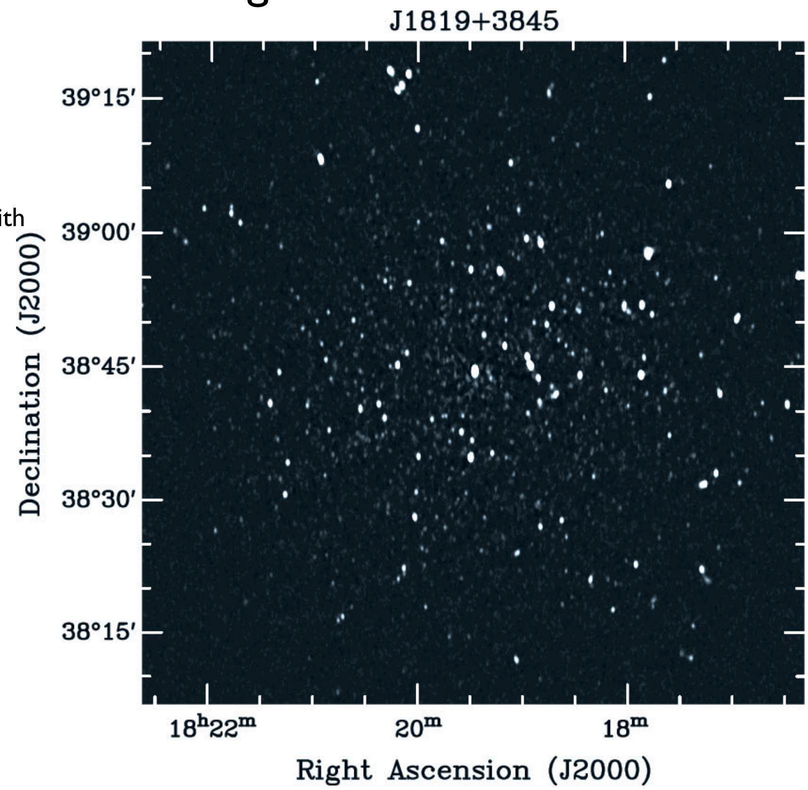
Observing setup and technical considerations

- At 21cm
- 30-60s time sampling, 8 x 20 MHz sub-bands
  - each sub-band: 32x625 kHz channels
- noise:10-15 μJy/beam
- Other effects (weather, telescope pointing, backend nonlinearity) all less than 1%
- 1MHz spectral overlap with intermittent T=9.6s Eelde radar leads to 4 min beating with 10s noise source monitoring in lowest band.

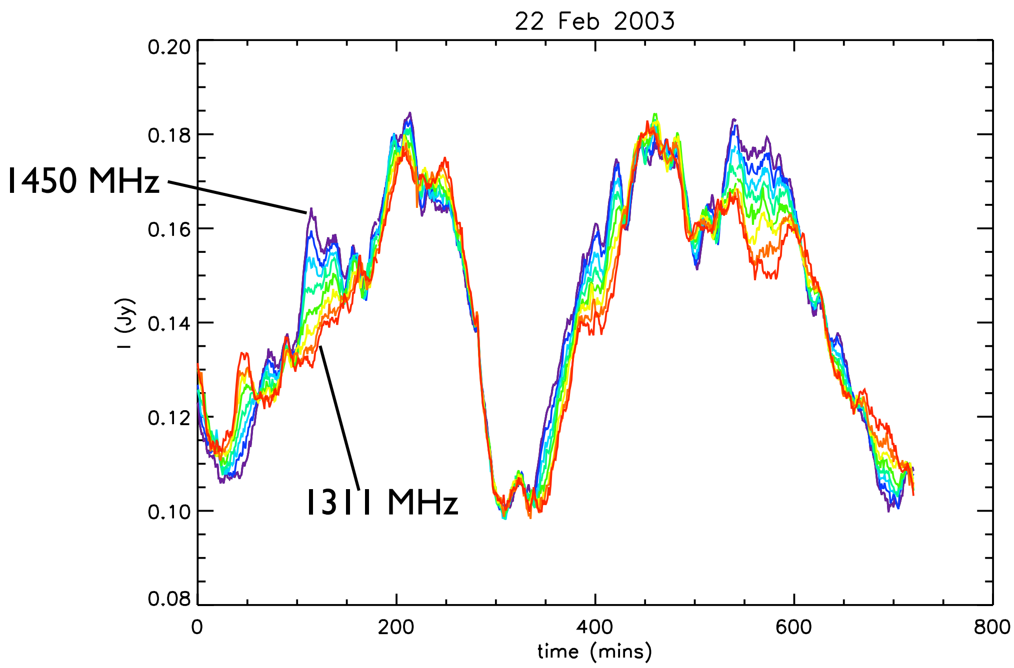


The surrounding 21cm field

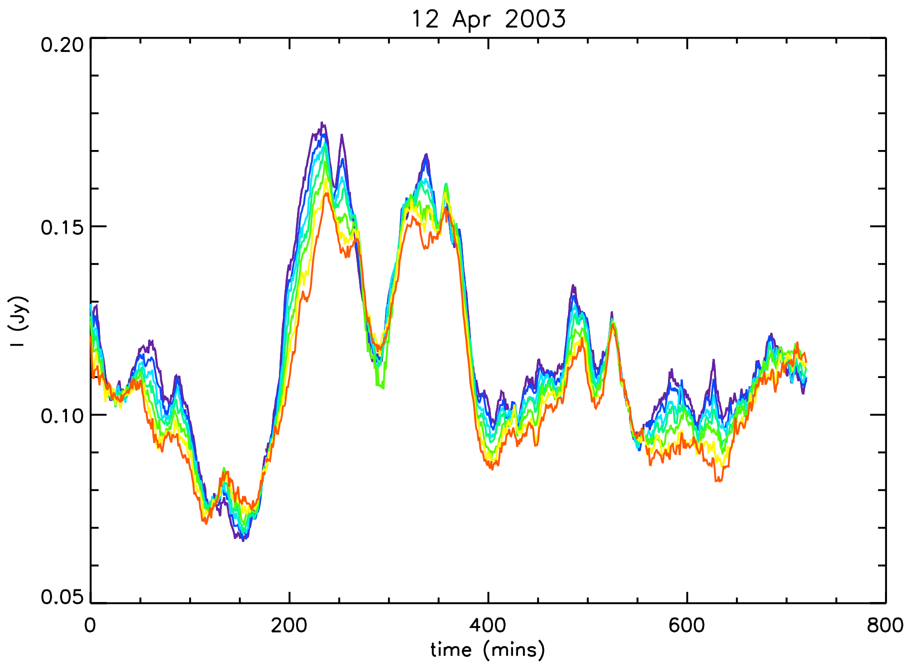
- Contribution of > 250 field sources with 0.1<S<13 mJy removed from visibility amplitudes
  - Residual confusion <1%, with no long term memory
- Polarization less than 1%
- Field is observed to be stable
- Solar fringing (Sun entering through 90 deg sidelobes) removed by deleting short spacings at appropriate hour angles.



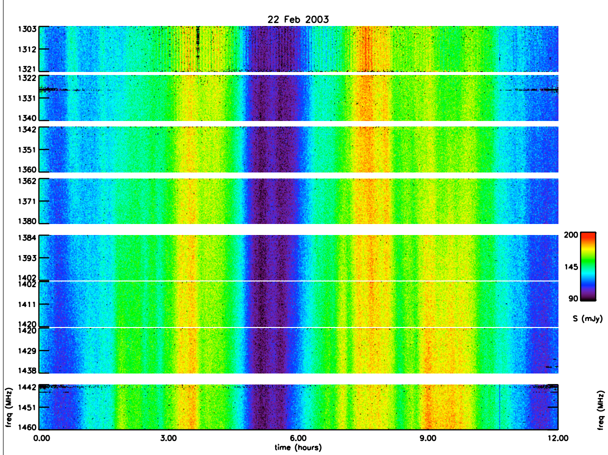
Frequency-dependent fluctuations at 21cm

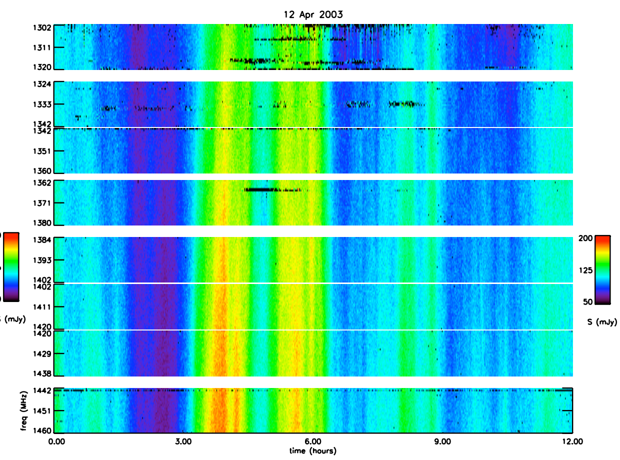


Frequency-dependent fluctuations at 21cm

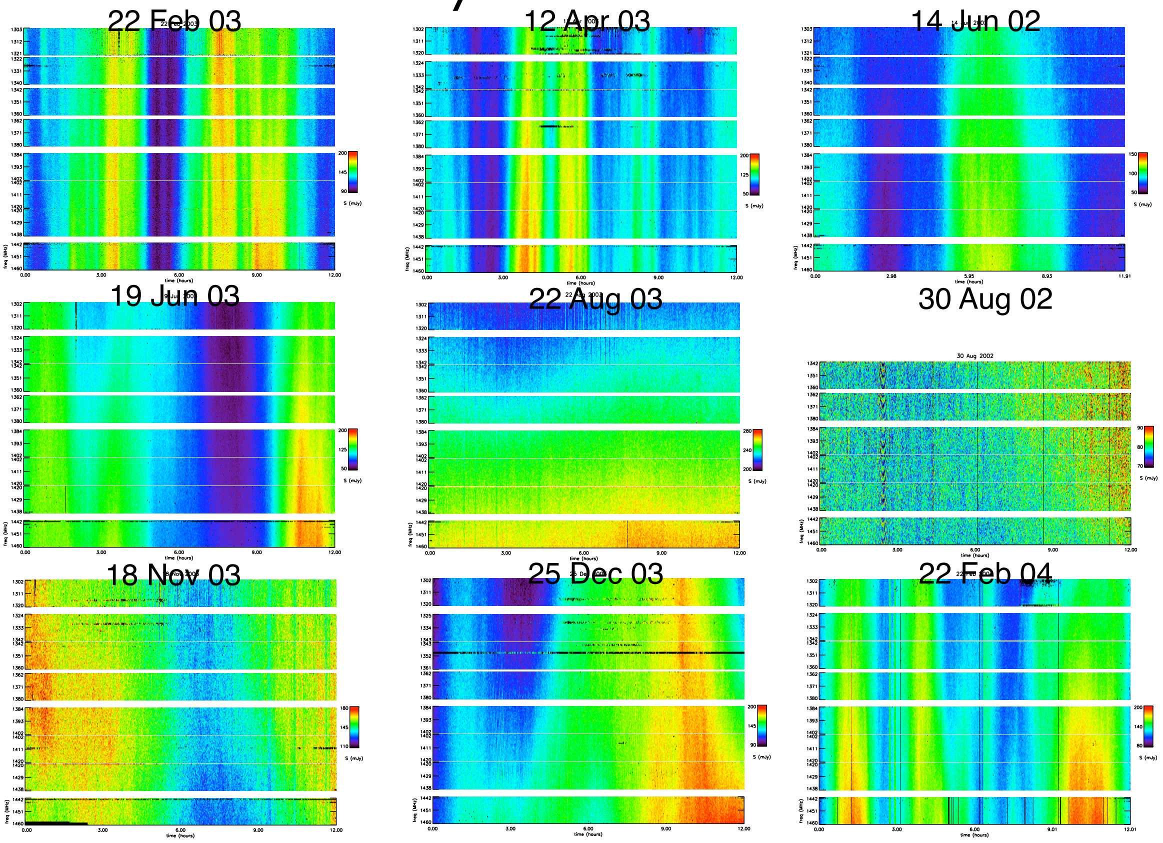


Dynamic spectrum





Time scale cycles & source evolution

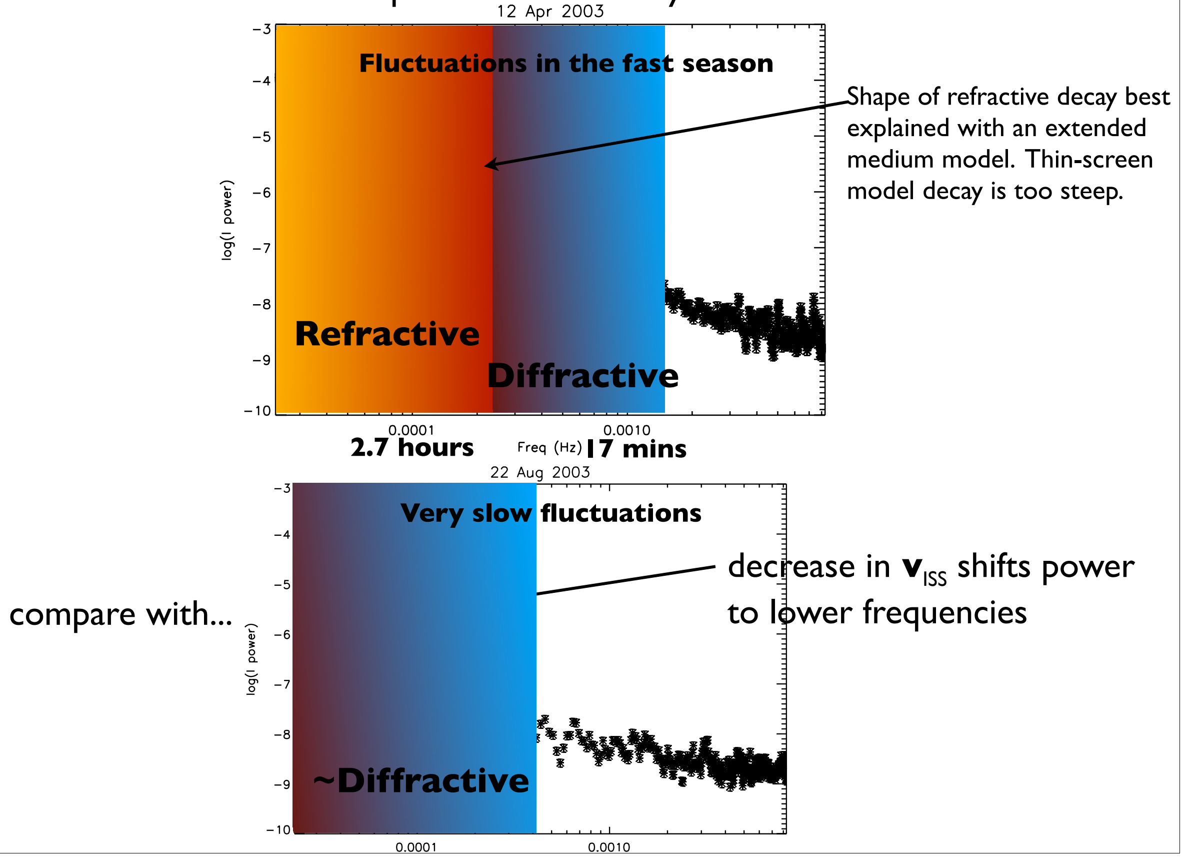


Dynamic spectra properties

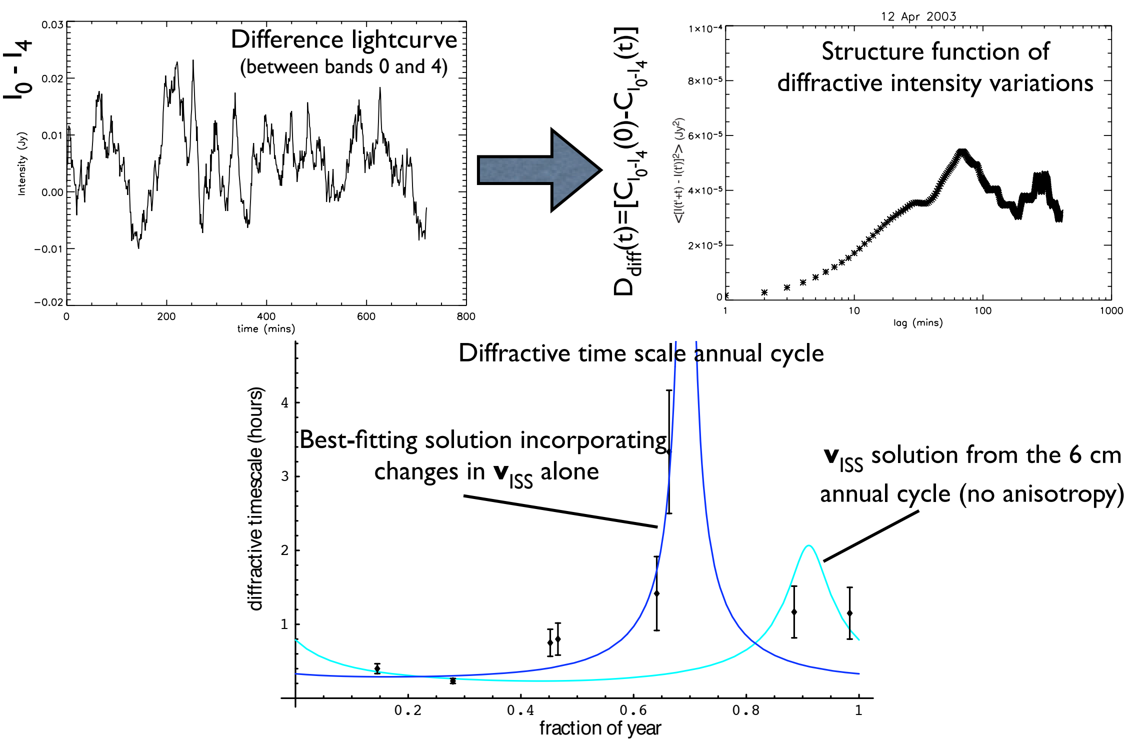
- Frequency dependent streaks in all dynamic spectra
- Diffractive scintillation occurs continuously, and exhibits identical time scales for the same DoY over several years
  - Source evolution is NOT the main cause of time scale changes
- Changing temporal scintillation width indicates changes in $\mathbf{v}_{ISS}$ important
  - Anisotropy inherent to source or medium, associated with direction changes in $\mathbf{v}_{ISS}$, possibly also influences time scale

Need to quantify time scale and spectral decorrelation...

Power spectrum of intensity fluctuations

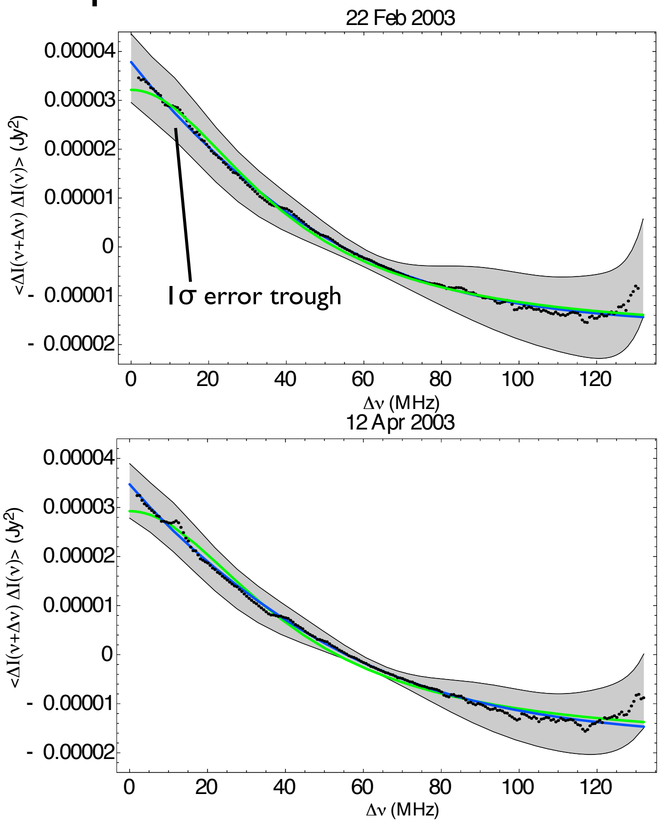


Diffractive time scale variations



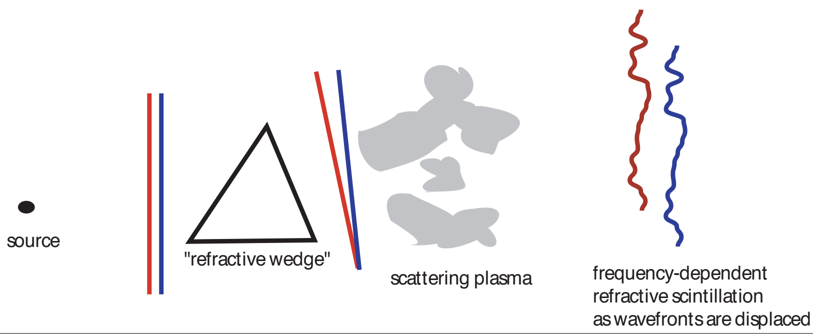
Spectral dependence

- Measured with the spectral autocorrelation function
- Effect of intrinsic spectral slope across the band is removed prior to calculation
- 22 Feb 03 &12 Apr 03 are best datasets, since greatest no. of scints. Other sets are consistent within the (sometimes large) errors.
- Decorrelation bandwidth approx. 20-40 MHz, consistent with the nearby PSR1814+4013 (~10 MHz) (courtesy Ben Stappers)



Achromatic effects associated with refractive scintillation?

- Deccorelation bandwidth of refractive scintillation is comparable to observing frequency itself.
  - contributes at most 0.8 mJy decorrelation over 80 MHz
- Refracting plasma wedge not plausible...
  - A large plasma gradient could work in conjunction with refractive scintillation to give sharp frequency structures (drift slopes in pulsar dynamic spectra)
  - Slope needs to cause a huge displacement of $\gtrsim 0.1\ r_{ref}$ across 160 MHz to explain the variations observed here
    - Drift slope should change orientation in the dynamic spectrum with time as direction of $\mathbf{v}_{ISS}$ changes wrt to gradient



Source & medium parameters

- Spectral decorrelation is the cleanest way to extract parameters
  - Fit to the form of the spectral decorrelation form and supplement this information with the physical size of the scattering pattern, s_0 (using $\mathbf{v}_{ISS}$ and t_{diff})
- Try both thin-screen and extended medium models from Chashei & Shishov (1976)

$$\text{Thin: } s_0 = r_{\text{diff}}\sqrt{1+\left(\frac{\theta_{\text{src}}}{\theta_{\text{cr}}}\right)^2}$$

s_0 increases ~ linearly with source size, θ_{src}

θ_{cr}~angular size of point source pattern

$$\text{Extended: } s_0 = r_{\text{diff}}\sqrt{\frac{1+\frac{1}{3}\left(\frac{\theta_{\text{src}}}{\theta_{\text{cr}}}\right)^2}{1+\frac{1}{12}\left(\frac{\theta_{\text{src}}}{\theta_{\text{cr}}}\right)^2}}$$

s_0 asymptotes to $2r_{diff}$ as source size dominates

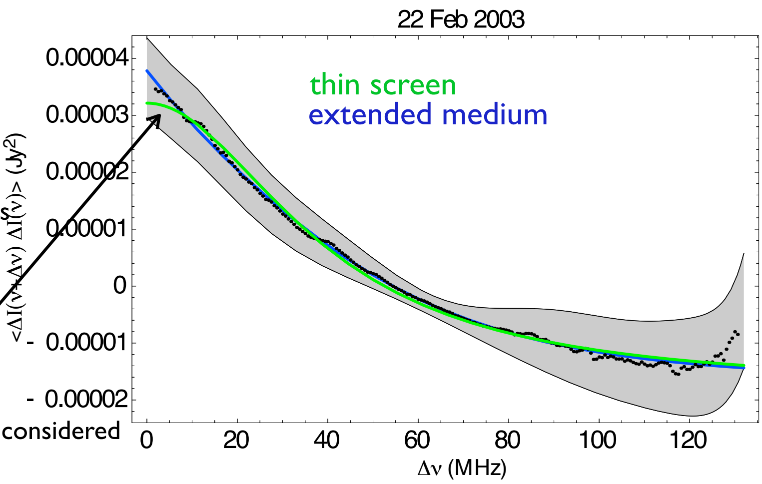
Source & medium parameters (cont.)

- Spectral decorrelation in the thin-screen case

$$F_{\text{thin}}(\Delta\nu) = A_{\text{off}} + S_{\text{diff}}{}^2\left(1+\frac{\theta_{\text{src}}^2}{\theta_{\text{cr}}^2}+\frac{\Delta\nu^2}{\Delta\nu_{\text{dc}}^2}\right)^{-1}$$

Chashei & Shishov 1976; Gwinn et al. 1998

- Thin screen model degenerate to the combination S_{diff}, $(\theta_{src}/\theta_{cr})$ and $\Delta\nu_{dc}$ so keep S_{diff} as a free parameter and impose external constraints (e.g. refractive time scale).
- Extended medium spectral decorrelation more complicated but no degeneracies.
- Fit to 22 Feb 2003 and 12 Apr 2003 data as these contain the most scintles (smallest random errors).



small difference not significant here, but is when ACFs from all epochs are considered

The Results

Fit parameters

	fit parameter	22 Feb 2003	12 Apr 2003
thin screen	offset $A_{\rm off}$ (Jy^2)	$-1.83 \pm 0.04 \times 10^{-5}$	$-1.88 \pm 0.06 \times 10^{-5}$
	bandwidth $\Delta\nu_{\rm dc} S_{\rm diff}$ (MHz mJy)	290 ± 6	310 ± 8
	relative source size $(1 + \theta_0^2/\theta_{\rm cr}^2) S_{\rm diff}^{-2}$ (mJy^{-2})	$2.01 \pm 0.02 \times 10^{-2}$	$2.13 \pm 0.03 \times 10^{-2}$
extended medium	offset $A_{\rm off}$ (Jy^2)	$-1.67 \pm 0.05 \times 10^{-5}$	$-1.78 \pm 0.06 \times 10^{-5}$
	component flux density $S_{\rm diff}$ (mJy)	7.39 ± 0.07	7.25 ± 0.09
	bandwidth $\Delta\nu_{\rm dc}$ (MHz)	17.7 ± 0.9	20.3 ± 1.4
	relative source size $\theta_0/\theta_{\rm cr}$	0.41 ± 0.02	0.43 ± 0.03

agree well between epochs

Derived source & medium parameters (after combination with time scales)

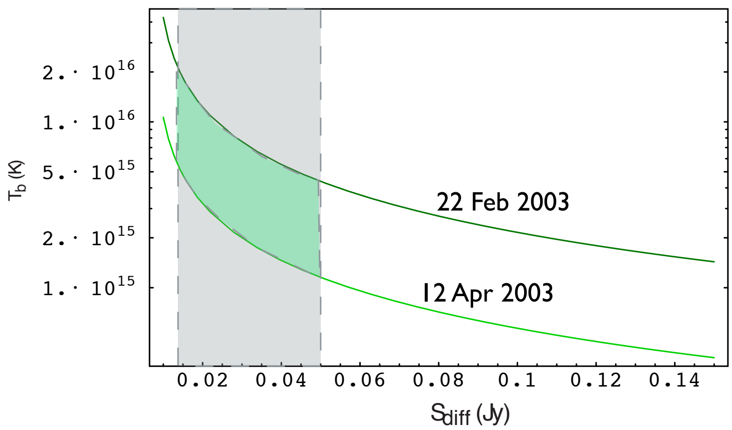
model	quantity	22 Feb 2003	12 Apr 2003
thin screen	screen distance (pc)	$7.4\, S^{-1} t_{24}^2 v_{50}^2$	$2.2\, S^{-1} t_{14}^2 v_{50}^2$
	max. source size (μas) ($S = 150$ mJy)	$4.9\, t_{24}^{-1} v_{50}^{-1}$	$9.4\, t_{14}^{-1} v_{50}^{-1}$
	brightness temperature (K)	$> 1.4 \times 10^{15}\, t_{24}^2 v_{50}^2$	$> 3.8 \times 10^{14}\, t_{14}^2 v_{50}^2$
extended medium	medium thickness (pc)	$1.2 \times 10^3\, t_{24}^2 v_{50}^2$	$350\, t_{14}^2 v_{50}^2$
	source size (μas)	$0.08\, t_{24}^{-1} v_{50}^{-1}$	$0.17\, t_{14}^{-1} v_{50}^{-1}$
	brightness temperature (K)	$2.5 \times 10^{17}\, t_{24}^2 v_{50}^2$	$5.6 \times 10^{16}\, t_{14}^2 v_{50}^2$

disagreement between epochs best estimate of error

The Results (cont.)

Thin screen gives lower limit on T_b: how low is the lowest possible value?

Thin-screen brightness temperature range



Requirement 3 hrs < $t_{\rm ref}$ < 12 hrs

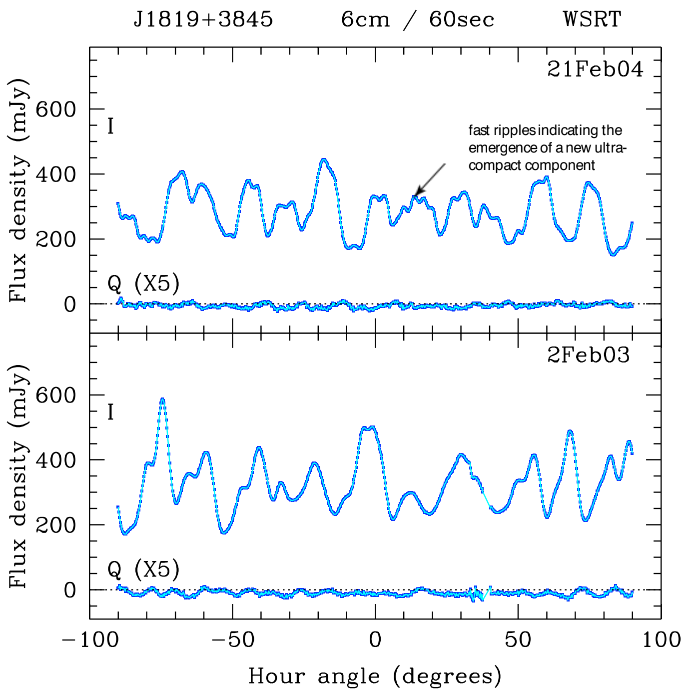
$\Rightarrow$ 13 mJy < $S_{\rm diff}$ < 50 mJy

Model assumptions

- Source & medium anisotropy unimportant
  - thin screen
  - extended medium
    - at most ~3:1 medium anisotropy in ext. medium and little effect of source on s_0.
- That Chashei & Shishov (1976) (& Gwinn et al. 1998) formalism is correct
  - ...and applicable to this regime of scattering
    - likely since $r_F/r_{diff} > 8$
- θ_{cr}/θ_{src} and S_{diff} assumed constant across band

Intrinsic source evolution

- Increase from 7 to 14 mJy rms variations in 25 Dec 03 and 22 Feb 04 data
  - spectral decorrelation identical, indicating source brightening, but no expansion
- Spectral index changes:
- New 6cm compact component?



date	mean flux density (mJy)	spectral index α
14 Jun 2002	85	0.79 ± 0.01
30 Aug 2002	80	–
22 Feb 2003	144	0.29 ± 0.01
12 Apr 2003	111	1.01 ± 0.01
19 Jun 2003	115	1.19 ± 0.01
22 Aug 2003	242	(1.21 ± 0.02)
18 Nov 2003	151	–
25 Dec 2003	147	1.05 ± 0.01

21cm spectral index changes?

Conclusions

- Diffractive scintillation is detected in J1819 at 21cm
  - Time scale as fast as 15 min, decorrelation bandwidth ~20-30 MHz
- Diff. scint. occurs continuously, and exhibits identical time scales for the same DoY over several years
  - Source is stable on time scales of ~ 1 year
  - But recent evidence for (flux density) evolution
- Scintillation analysis based on Chashei & Shishov (1976) indicates a brightness temperature > 10^{15} K