Ooty Radio Telescope

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National Centre for Radio Astrophysics
Tata Institute of Fundamental Research

Observing Facilities

Giant Metrewave Radio Telescope

Ooty Radio Telescope

Radio Astronomy Facilities

NCRA • TIFR

- Giant Meter wavelength Radio Telescope (near Pune)
  - Multi-frequency synthesis imaging system
  - 25-km baseline
  - 30 antennas of each 45 m diameter
  - In the NCRA campus, 15m antenna (various Radio Physics Lab. projects)

- Ooty Radio Telescope (southern part of India)
  - Observing frequency 327 MHz
  - Steerable antenna of size 530m x 30m parabolic cylindrical antenna
  - Various astronomical observations and solar wind studies
  - Callisto Solar Spectrograph (part of worldwide radio net)
    - Frequency range 45 – 890 MHz
    - 300 kHz – each channel bandwidth
    - solar radio spectrograph
  - Muthorai Radio Telescope – for dedicated solar observations
    - 290 – 350 MHz
    - Steerable antenna of size 92m x 9m
    - fixed-frequency solar observations (high temporal resolution ~1 ms)

Ooty Radio Telescope (ORT)

- **Latitude: 11°23’ North Longitude: 76°40’ East**
- **Equatorially mounted, off-axis parabolic cylinder**
- **530m (N-S) x 30m (E-W)**
- **Reflecting surface made of 1100 stainless steel wires**
- **Feed – 1056 $\lambda/2$ dipoles**
- **E-W Tracking and N-S Steering of ORT (~9.5 hours, ± 60^o)**

IPS measurements - advantages

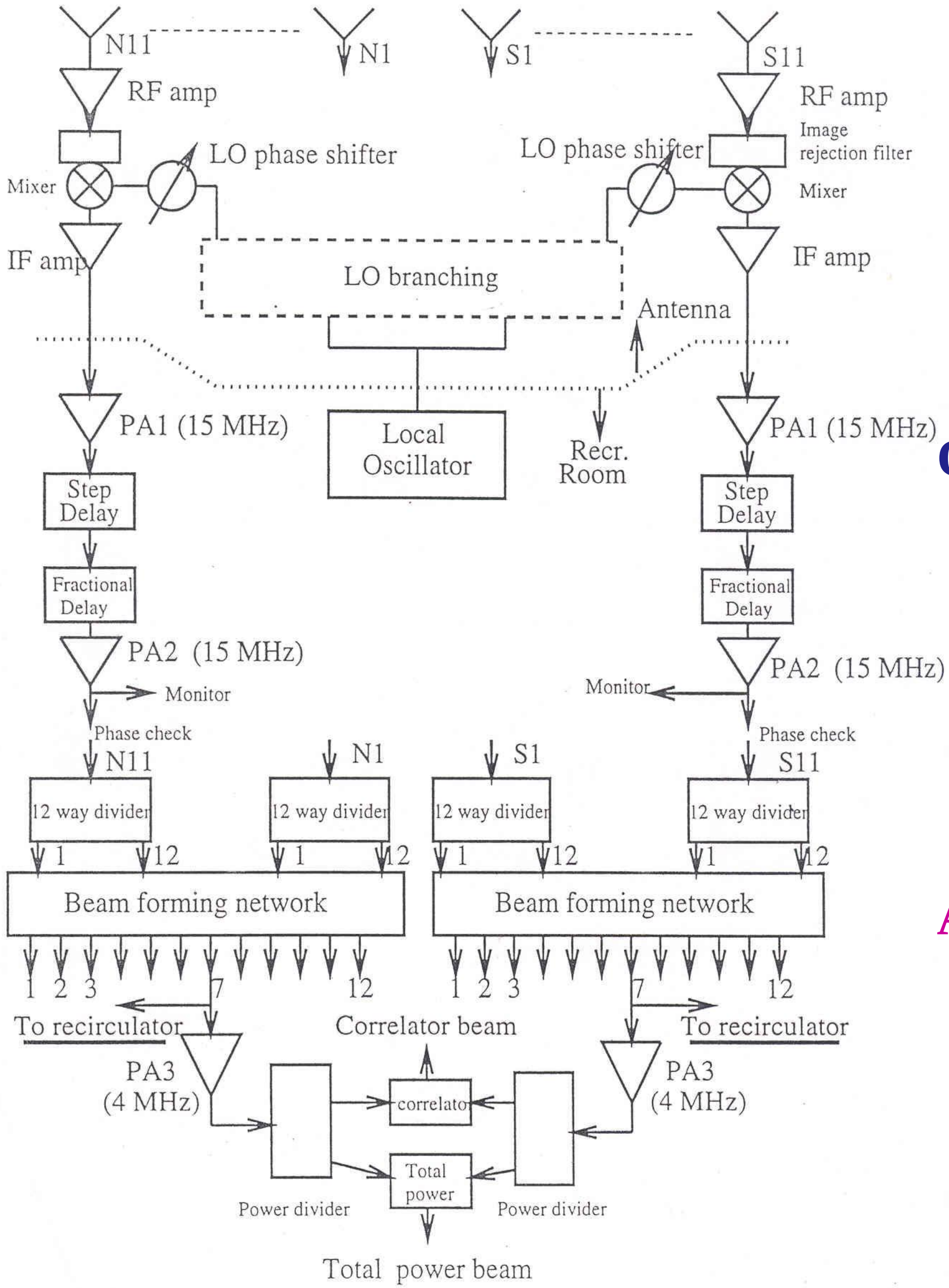
- **High sensitivity**
- **tracking**
- **good declination coverage**
- **less radio interference in this region**

Operated by
Radio Astronomy Centre
National Centre for Radio Astrophysics
Tata Institute of Fundamental Research
(NCRA-TIFR)

- 530m (N-S) x 30m (E-W) – east-west tracking of ~9.5 hours
- North-South beam steering (± 65 deg. declination)
- High sensitivity, S/N ~ 25 (1s integration, BW 4 MHz)

http://rac.ncra.tifr.res.in


Reflector is made of 1100 thin ss wires



Block diagram of the ORT receiver system

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Linear array of dipoles 1056

- **LNA behind each dipole**
- **4-bit phase shifter for a dipole**

Operating frequency 326.5 MHz

- **LO 296.5 MHz**
- **IF 30 MHz**

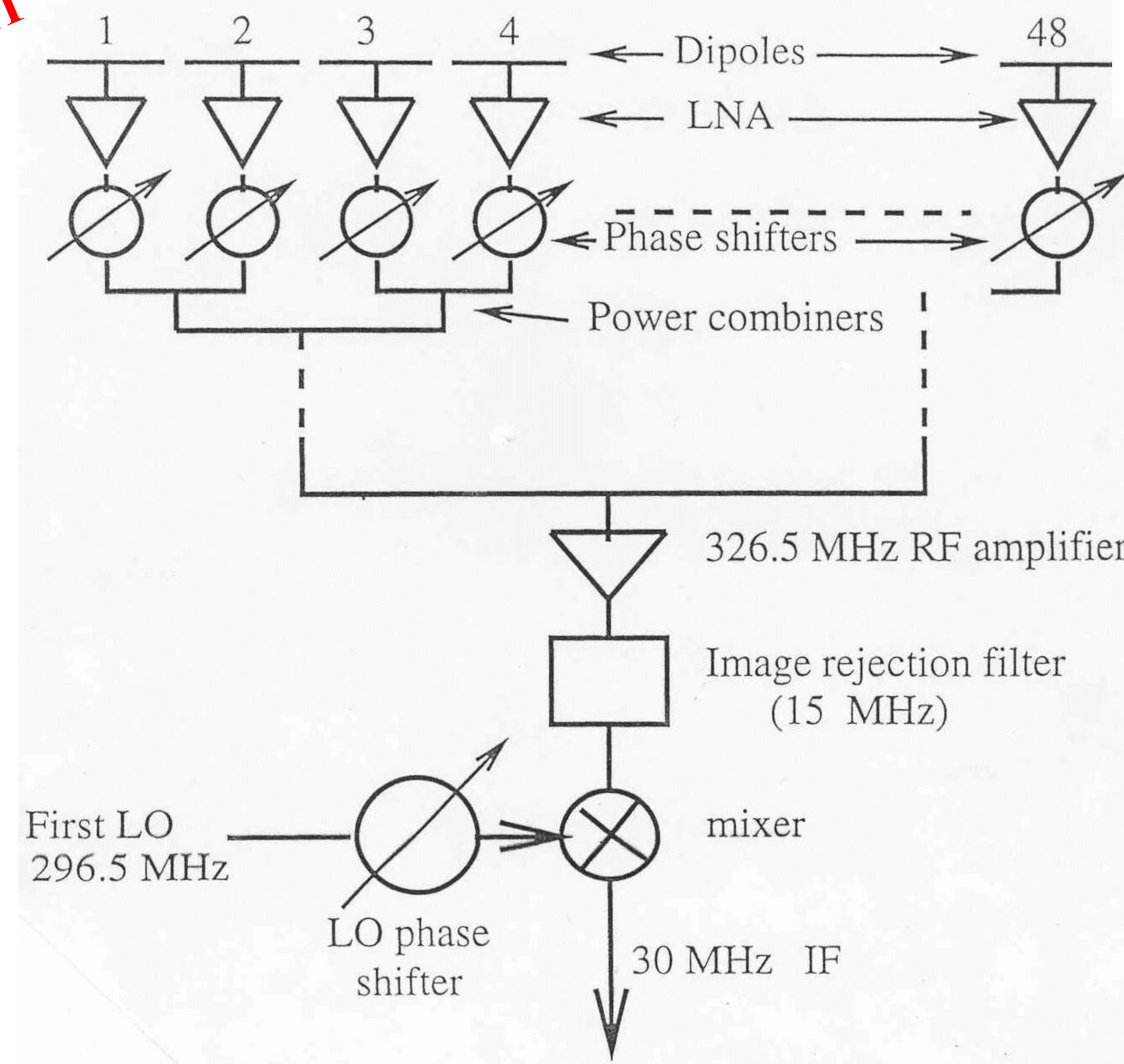
22 Modules (N1-N11 and S1-S11)

- **48 dipoles in each module**

Analog beams – 12-beam system

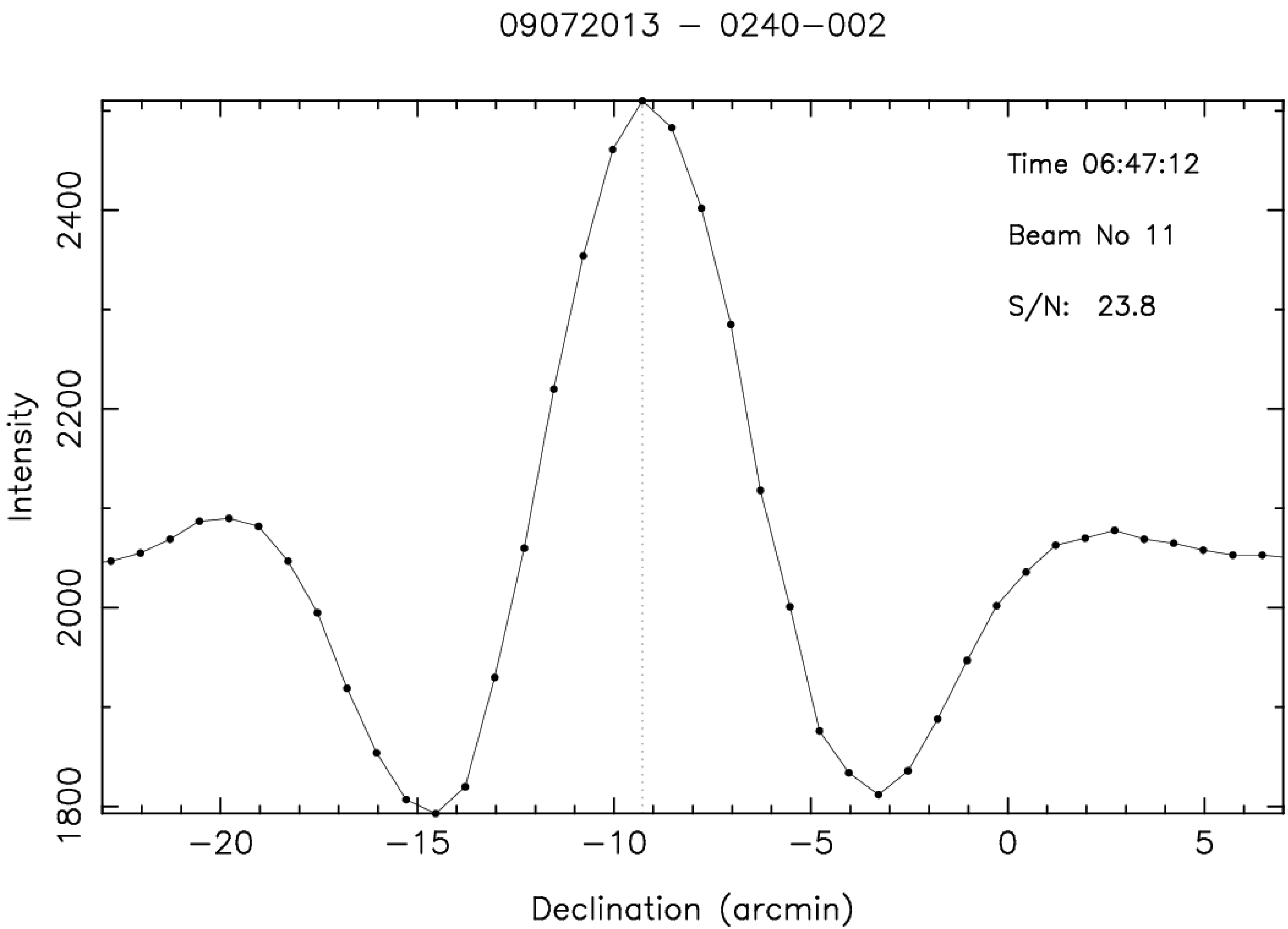
- **3 arcmin separation**
- **covers 2^{o} x 36' sky**
- **total-power mode**
- **correlated-beam mode**

One module of ORT

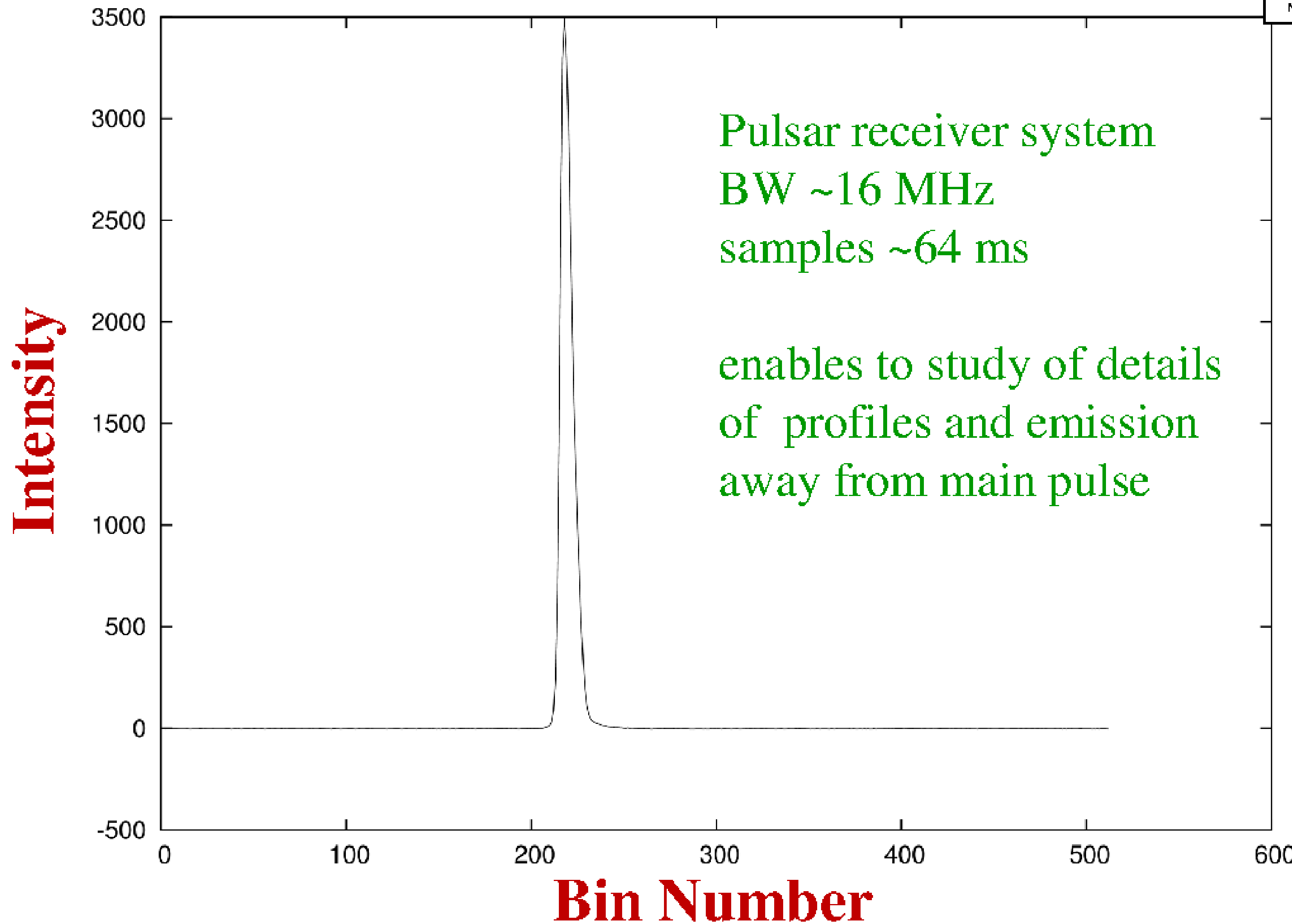


Block diagram of a module of the ORT

ORT Correlated Beam Shape



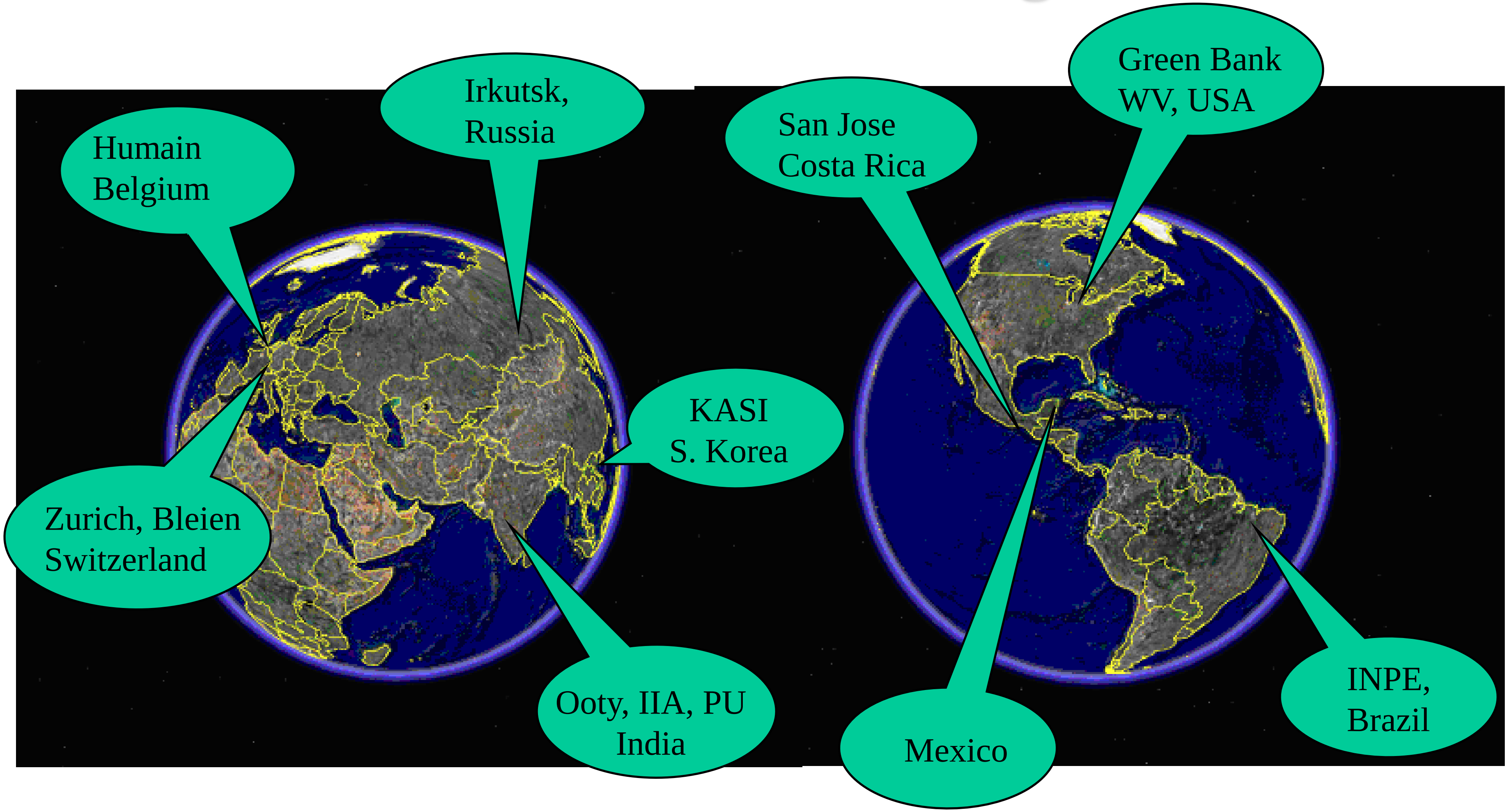
PSR B1642-03 Profile on 16 September 2012



Pulsar receiver system
BW ~16 MHz
samples ~64 ms

enables to study of details
of profiles and emission
away from main pulse

e-Callisto – Worldwide Radio Network
24-hour Solar Observing



measurements: type II radio bursts, CMEs, shock waves, type III bursts etc.

Data available at http://www.e-callisto.org/

Ooty e-Callisto

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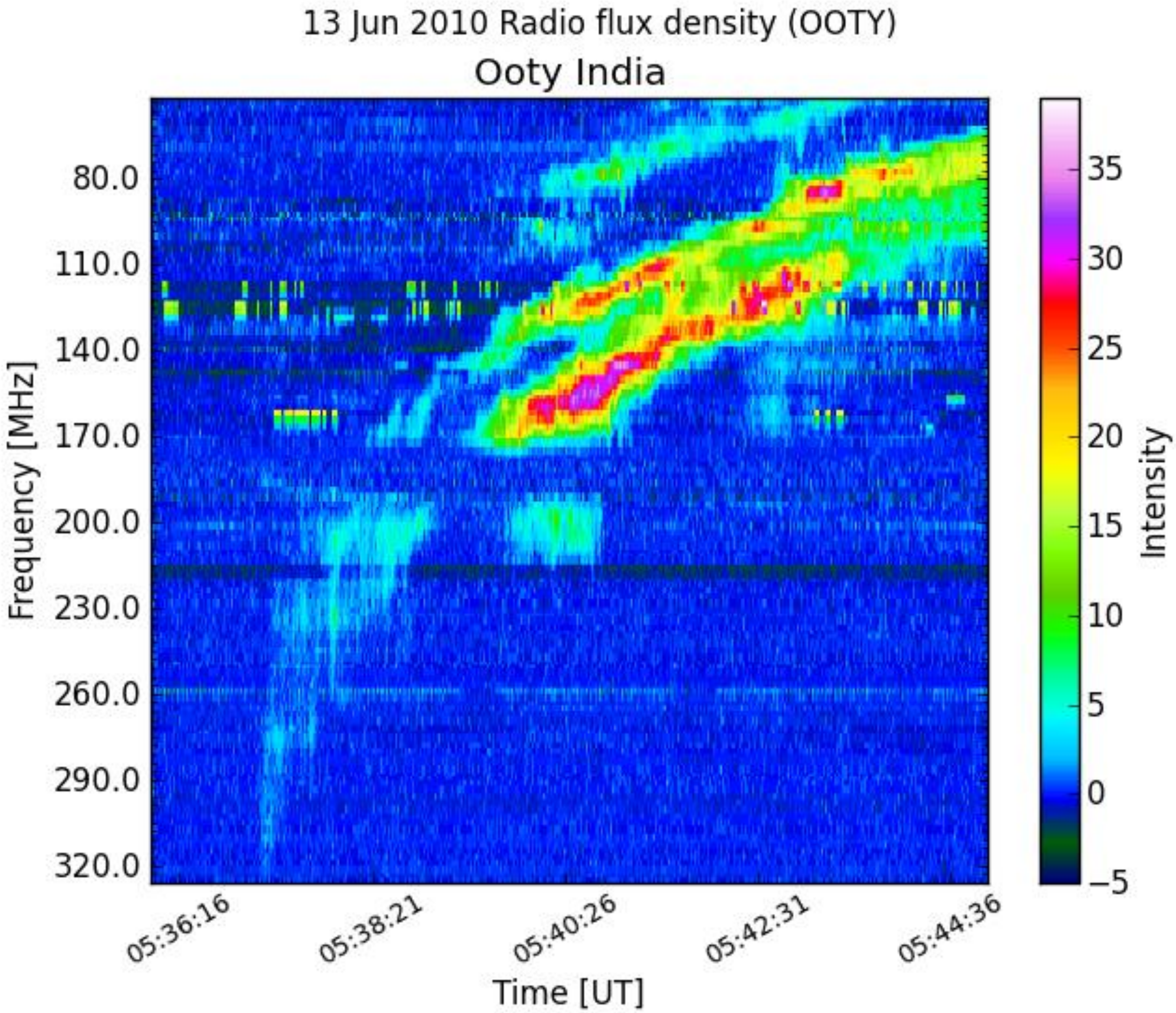

Upgrades for Ooty Radio Telescope

In collaboration with Raman Research Institute, Bangalore

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ORT upgrade –Phase I

ORT as a 44-element programmable telescope

- Digitize RF from 44 half modules (11.5mx30m section of ORT)
- 44 numbers of Stage 1 and Stage 2 amplifiers, respectively, at the feed and at the bottom of the telescope
- Transporting signal via fiber optic link
- A distributed signal processing chain (12-ch A/D converts with Xilinx Spartan-6 FPGA-based pre-processing capability)
- RF digitization tested for all half modules, data transfer over optical fibre to central computers completed
- Software offline FX correlator developed and tested

Phase I

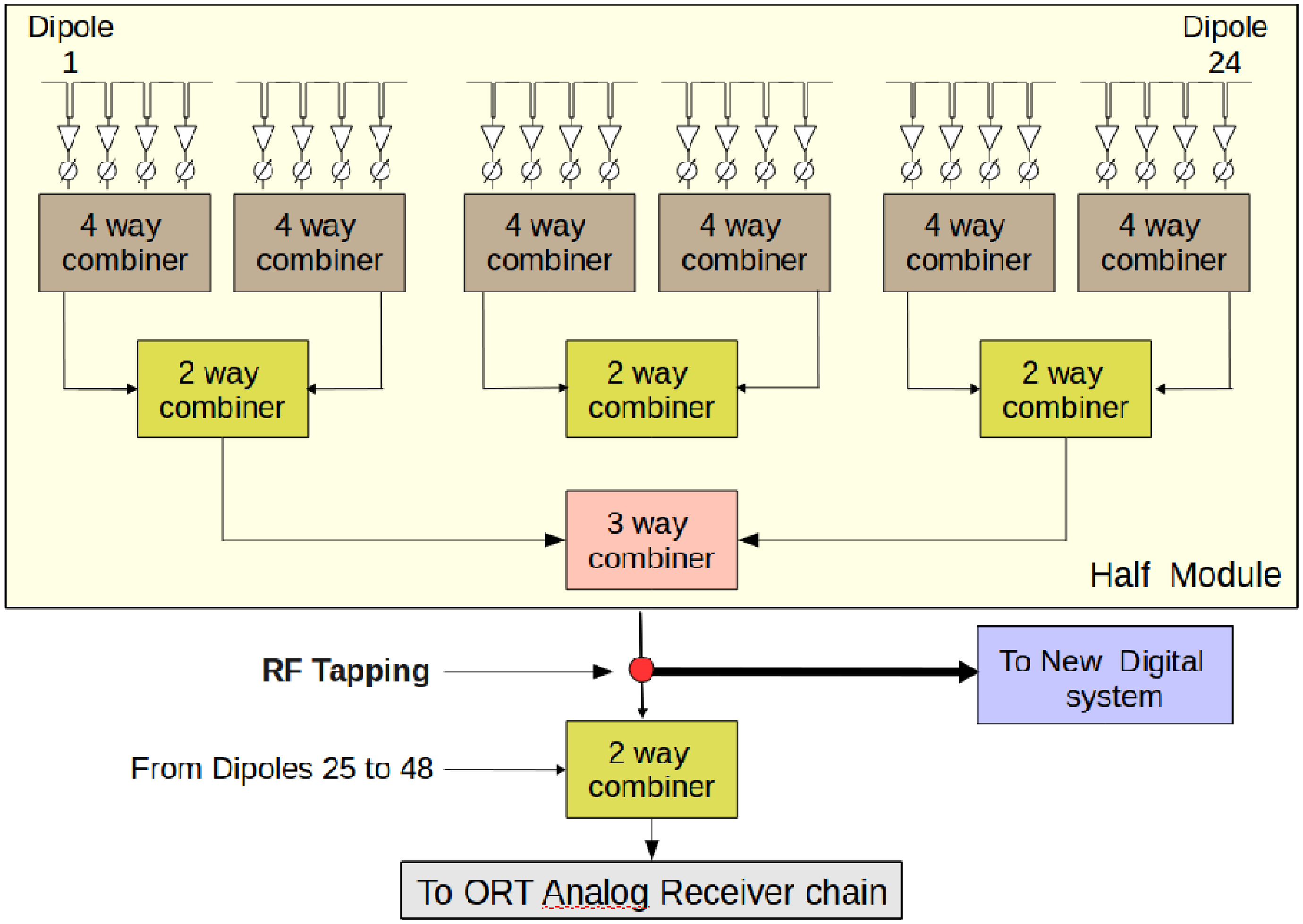

Figure 3.1: *ORT RF Frontend for an array of 24 dipoles (Half module). The RF tapping location for the RF digital receiver is shown. The RF frontend is implemented within the line feed of the telescope.*

Phase I

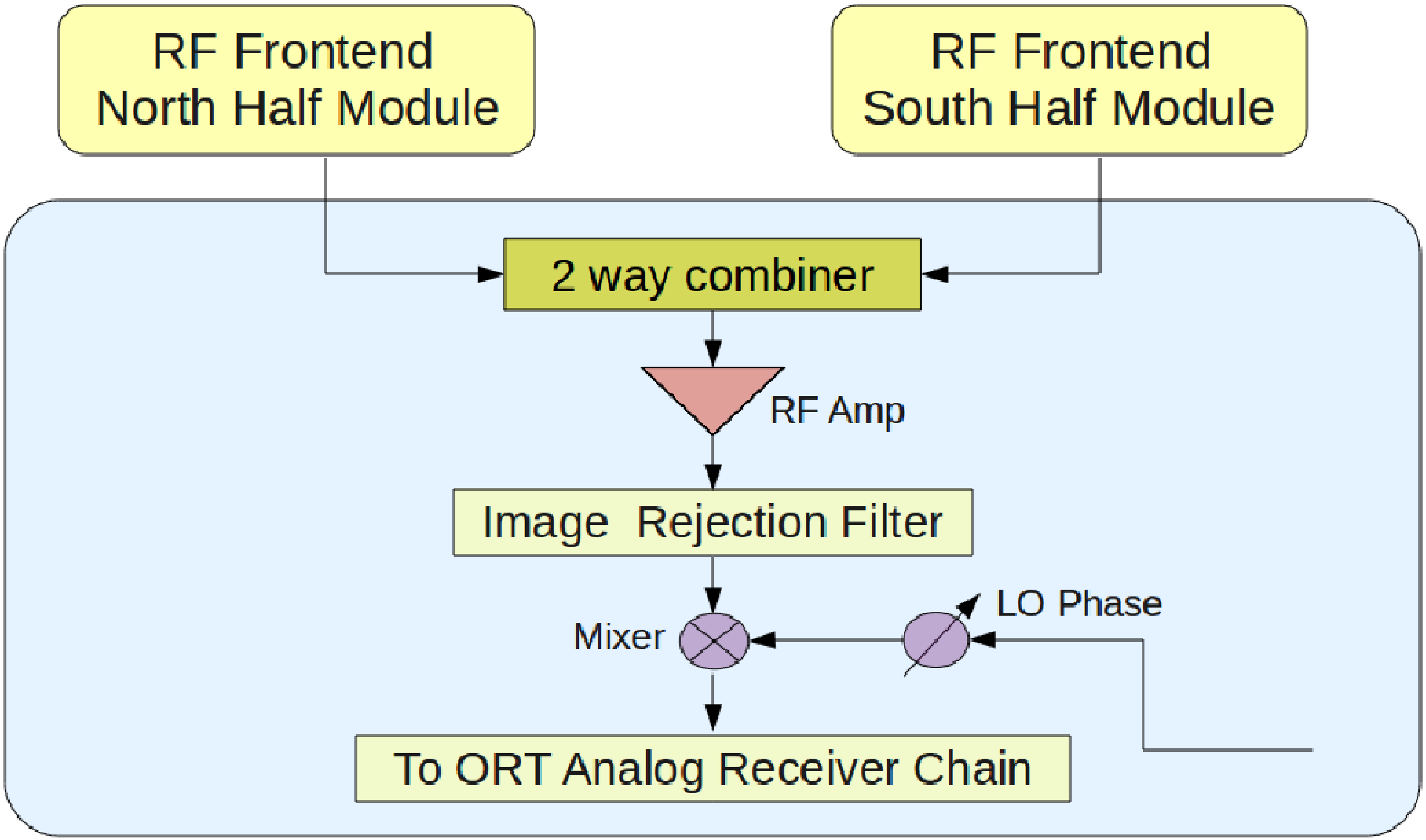

Figure 3.2: *Frontend IF conversion subsystem, which generates a single IF output by combining the RF of 48 phased dipoles. The generated IF is then sent to the central receiver room for further processing.*

Phase I – 44 half-module signals

ORT upgrade –Phase II

Major components

- ORT has been configured as a 264-element programmable telescope
  - To digitize RF for every 4-phased dipoles (2m x 30m section; 264 sections along the feed of ORT)
- 264 pre-amplifiers and a set of 264 low-loss cables bring RF outputs of pre-amplifiers to the fixed enclosures
- 264 Stage-II amplifiers plus filter (to provide ~80 dB gain)
- Fiber optic communication for distributing clock and data between central receiver and base of each module

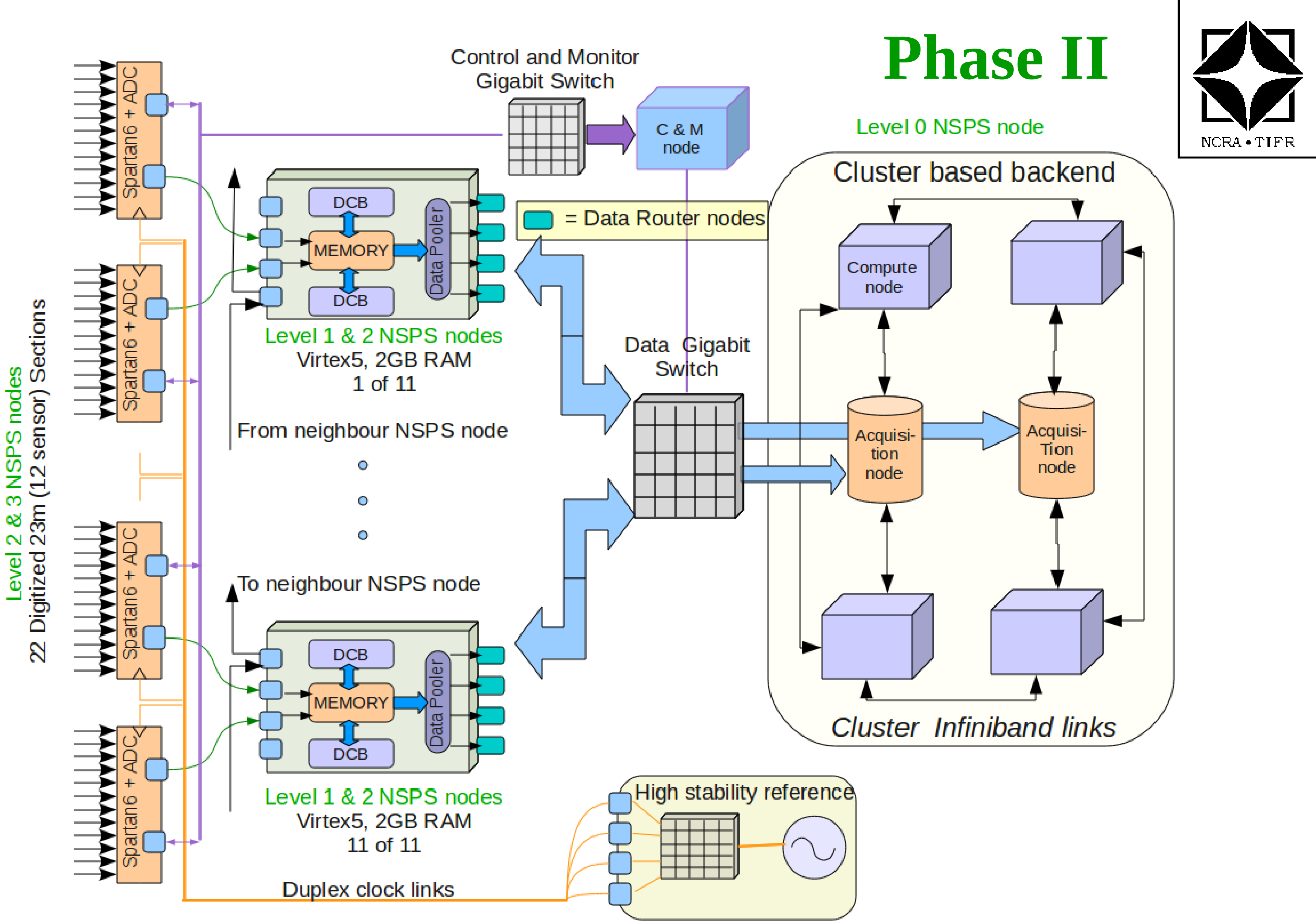

Figure 3.20: *Proposed NSPS implementation for configuring ORT as a 264 element programmable telescope.*

ORT – Recent upgrades – sensitivity and field of view

- 2 Phases
  - Digitize RF from every 24 phased dipoles (~12-m section)
  - Digitization of 4-phased dipoles (~2-m section)
    - Field view 27 deg.
    - Full 264-element programmable system
- Software-based FX correlator

Parameter	Current	Phase-1	Phase-2
Bandwidth	4 MHz	18 MHz	40 MHz
FoV	2.3° x 2.2°	2.3° x 4.6°	2.3° x 27°
Sensitivity ($\tau = 1$ s)	40 mJy	12 mJy	8 mJy

Science with new Programmable Digital Receiver

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ORT – a new versatile system for many astrophysical studies

IPS with ORT

- wide field of view (2° x 27°) – within the field of view, number of beams can be formed (or beam can be formed at any given direction of the scintillating source)
- at a given time (~2-3 min of observing time) several scintillating sources can be observed
- provides increased spatial resolution of the sky coverage
- Improved tool for space weather Studies (physics of propagation of solar eruptions)

Interplanetary Scintillation

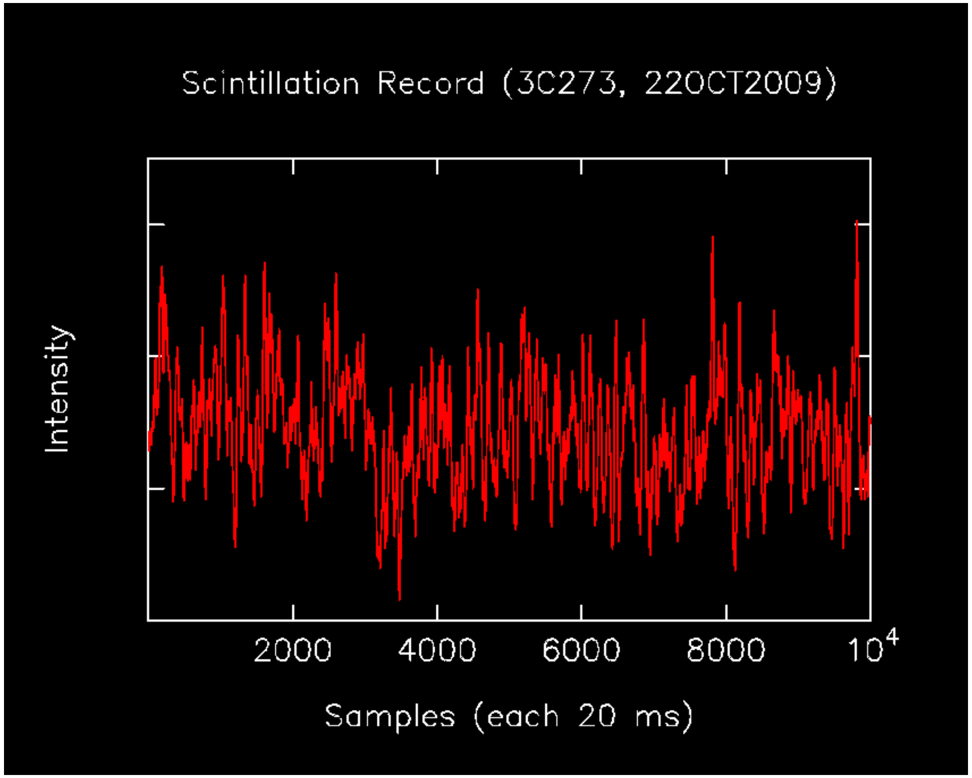
High sensitivity of ORT allows day-to-day IPS monitoring of large number of compact radio sources

Ooty IPS at 327 MHz

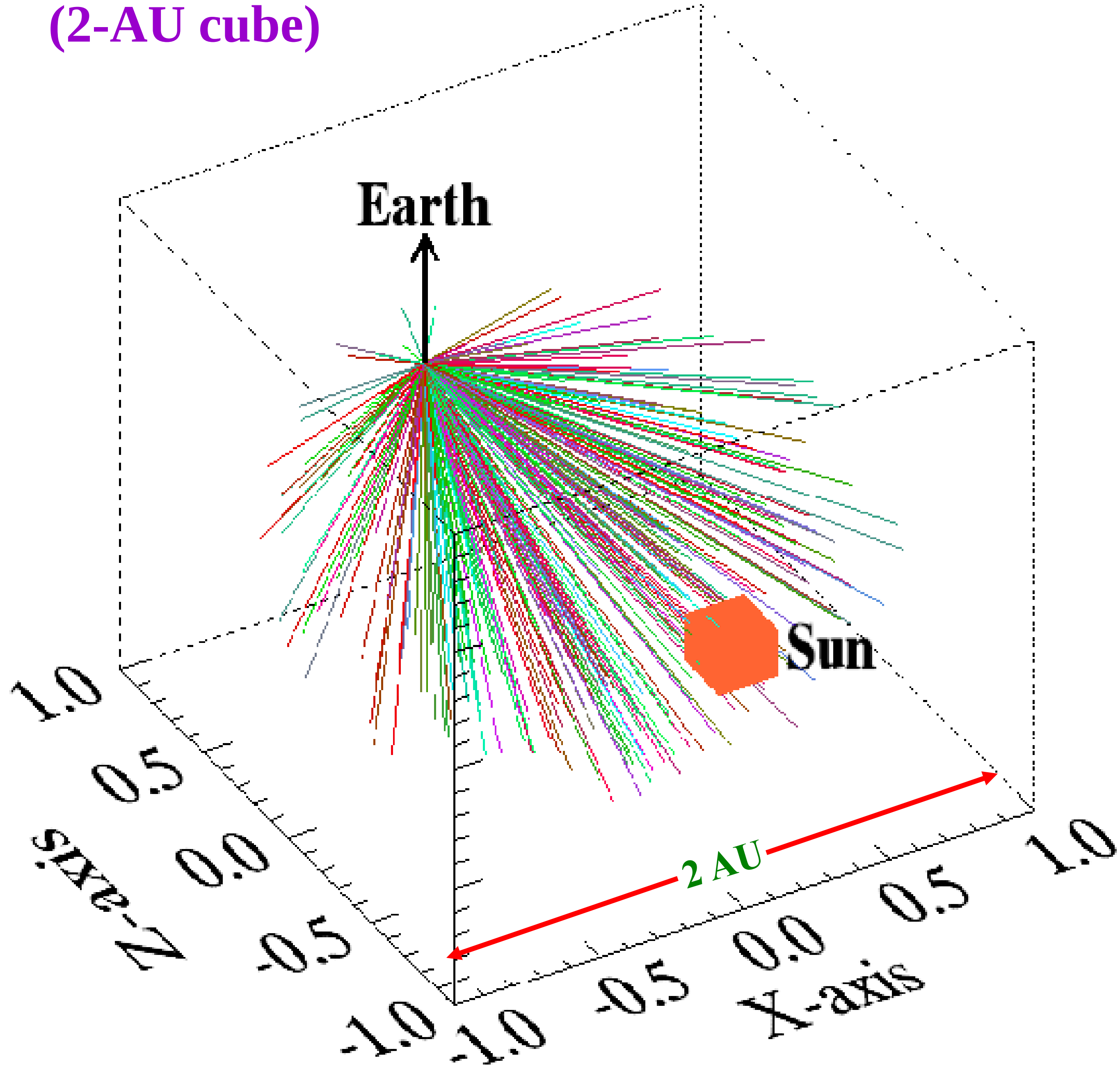
- **Sensitive to solar wind irregularities scale size of ~10 – 500 km**
- **Heliospheric coverage**
  - **10 – 250 Rsun**
  - **at all helio latitudes**

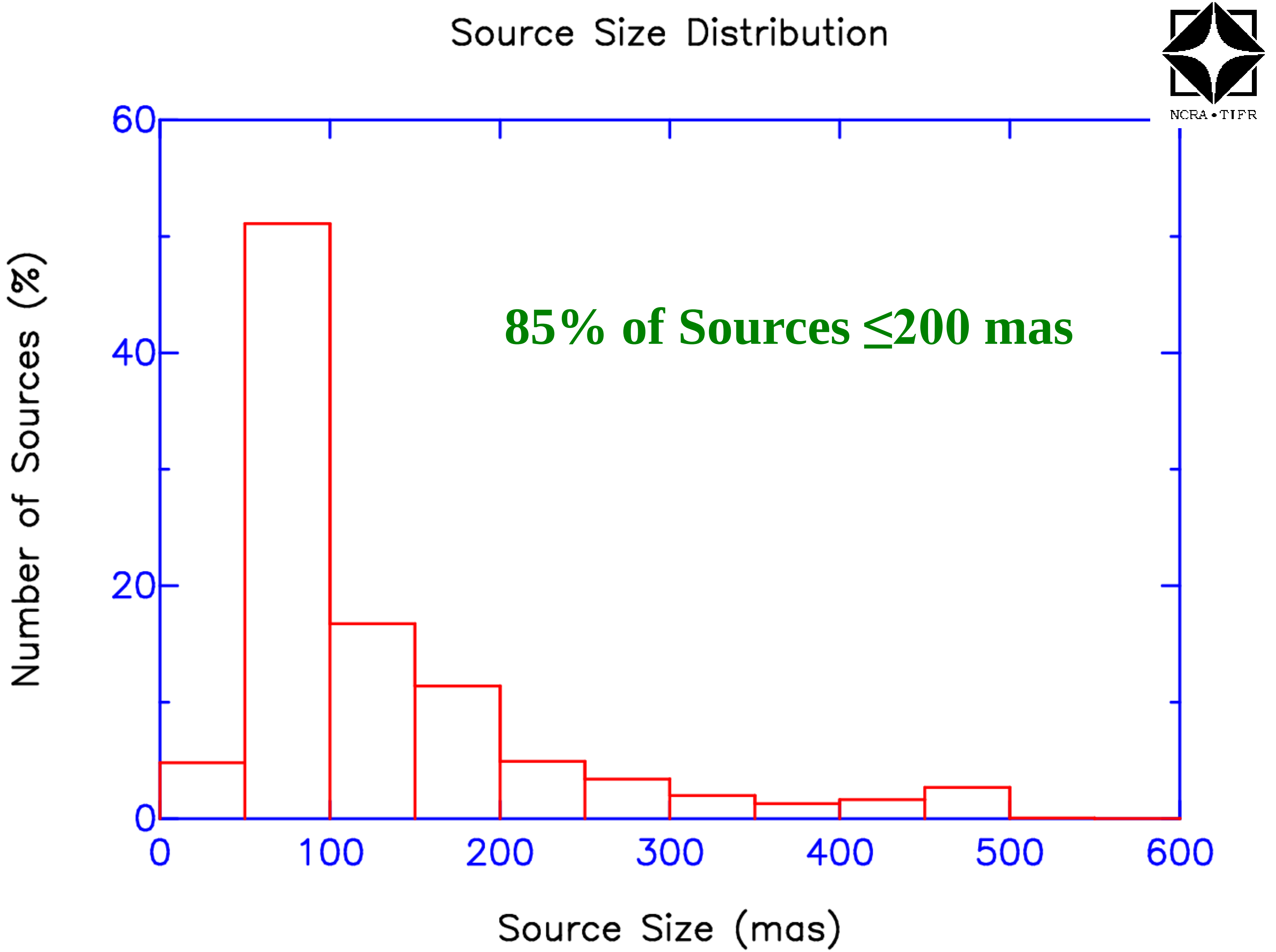
For each source- estimation of
- **power spectrum**
- **scintillation index**

Suitable calibration provides
- **solar wind velocity**
- **density turbulence level**



Lines of sight typically observed in a day (2-AU cube)





Source Size Distribution
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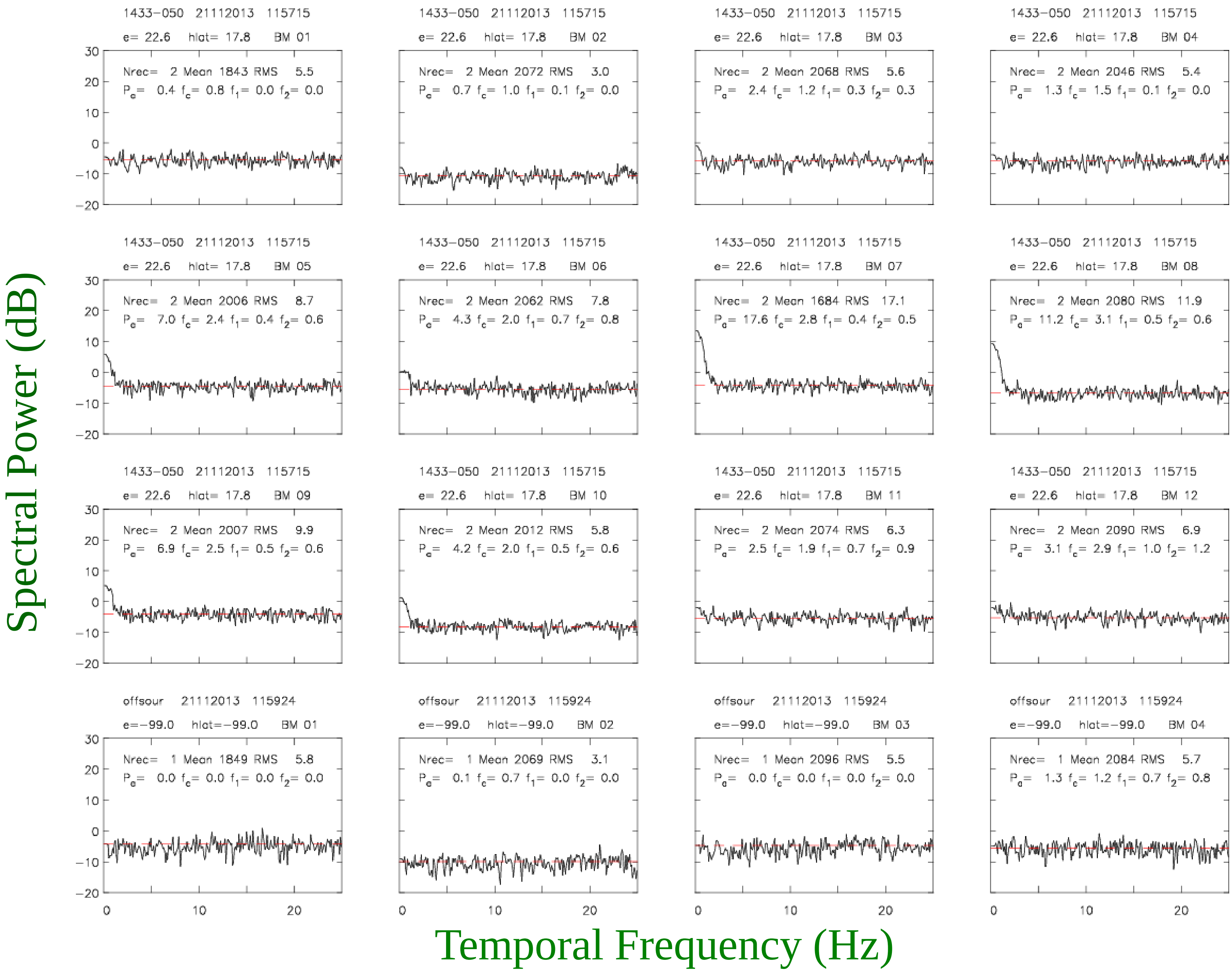
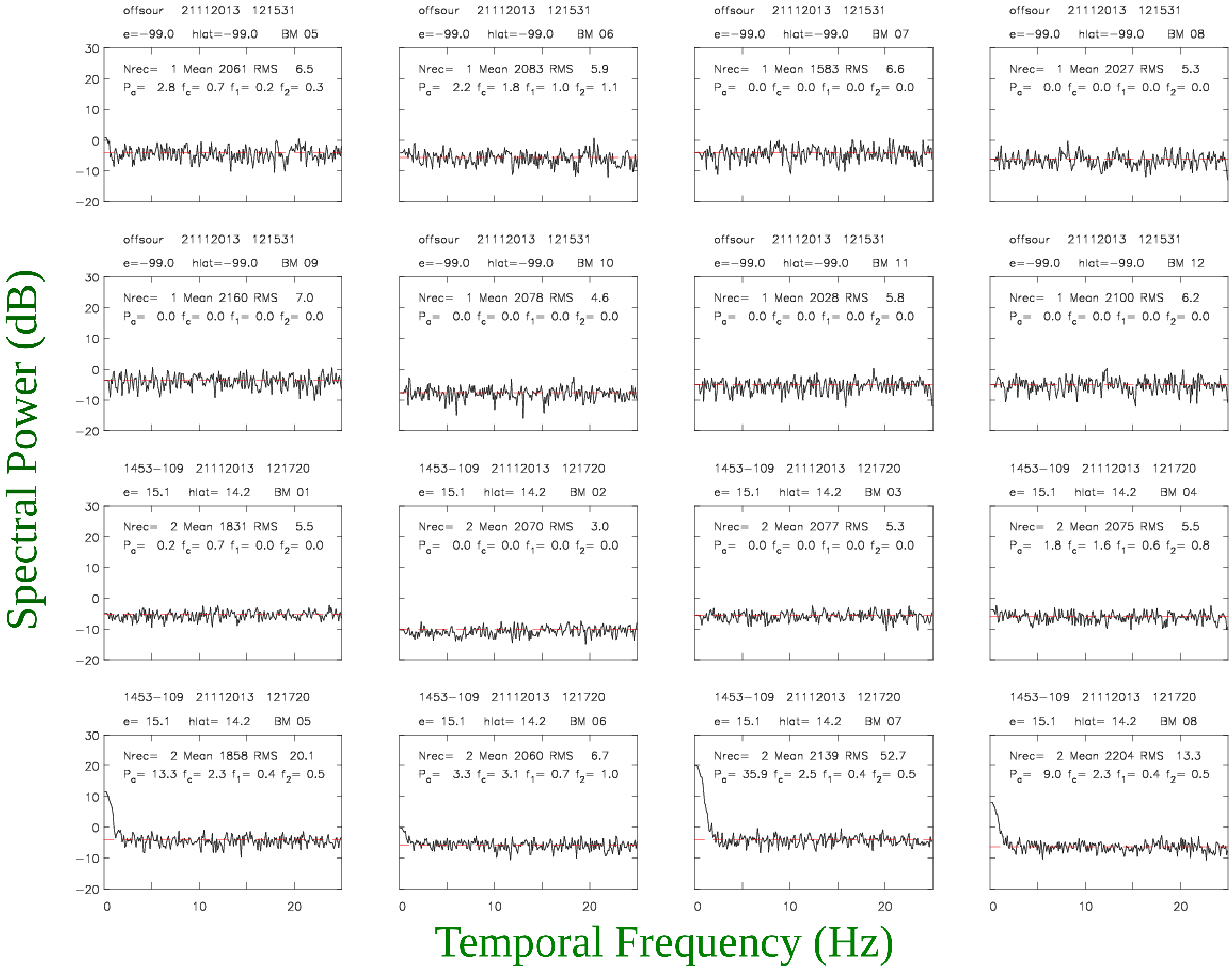
60
40
20
0
Number of Sources (%)
85% of Sources ≤200 mas
0
100
200
300
400
500
600
Source Size (mas)



Spectral Power (dB)
1433−050 21112013 115715
e= 22.6 hlat= 17.8 BM 01
Nrec= 2 Mean 1843 RMS 5.5
P_c= 0.4 f_c= 0.8 f_1= 0.0 f_2= 0.0
1433−050 21112013 115715
e= 22.6 hlat= 17.8 BM 02
Nrec= 2 Mean 2072 RMS 3.0
P_c= 0.7 f_c= 1.0 f_1= 0.1 f_2= 0.0
1433−050 21112013 115715
e= 22.6 hlat= 17.8 BM 03
Nrec= 2 Mean 2068 RMS 5.6
P_c= 2.4 f_c= 1.2 f_1= 0.3 f_2= 0.3
1433−050 21112013 115715
e= 22.6 hlat= 17.8 BM 04
Nrec= 2 Mean 2046 RMS 5.4
P_c= 1.3 f_c= 1.5 f_1= 0.1 f_2= 0.0
1433−050 21112013 115715
e= 22.6 hlat= 17.8 BM 05
Nrec= 2 Mean 2006 RMS 8.7
P_c= 7.0 f_c= 2.4 f_1= 0.4 f_2= 0.6
1433−050 21112013 115715
e= 22.6 hlat= 17.8 BM 06
Nrec= 2 Mean 2062 RMS 7.8
P_c= 4.3 f_c= 2.0 f_1= 0.7 f_2= 0.8
1433−050 21112013 115715
e= 22.6 hlat= 17.8 BM 07
Nrec= 2 Mean 1684 RMS 17.1
P_c= 17.6 f_c= 2.8 f_1= 0.4 f_2= 0.5
1433−050 21112013 115715
e= 22.6 hlat= 17.8 BM 08
Nrec= 2 Mean 2080 RMS 11.9
P_c= 11.2 f_c= 3.1 f_1= 0.5 f_2= 0.6
1433−050 21112013 115715
e= 22.6 hlat= 17.8 BM 09
Nrec= 2 Mean 2007 RMS 9.9
P_c= 6.9 f_c= 2.5 f_1= 0.5 f_2= 0.6
1433−050 21112013 115715
e= 22.6 hlat= 17.8 BM 10
Nrec= 2 Mean 2012 RMS 5.8
P_c= 4.2 f_c= 2.0 f_1= 0.5 f_2= 0.6
1433−050 21112013 115715
e= 22.6 hlat= 17.8 BM 11
Nrec= 2 Mean 2074 RMS 6.3
P_c= 2.5 f_c= 1.9 f_1= 0.7 f_2= 0.9
1433−050 21112013 115715
e= 22.6 hlat= 17.8 BM 12
Nrec= 2 Mean 2090 RMS 6.9
P_c= 3.1 f_c= 2.9 f_1= 1.0 f_2= 1.2
offsour 21112013 115924
e=−99.0 hlat=−99.0 BM 01
Nrec= 1 Mean 1849 RMS 5.8
P_c= 0.0 f_c= 0.0 f_1= 0.0 f_2= 0.0
offsour 21112013 115924
e=−99.0 hlat=−99.0 BM 02
Nrec= 1 Mean 2069 RMS 3.1
P_c= 0.1 f_c= 0.7 f_1= 0.0 f_2= 0.0
offsour 21112013 115924
e=−99.0 hlat=−99.0 BM 03
Nrec= 1 Mean 2096 RMS 5.5
P_c= 0.0 f_c= 0.0 f_1= 0.0 f_2= 0.0
offsour 21112013 115924
e=−99.0 hlat=−99.0 BM 04
Nrec= 1 Mean 2084 RMS 5.7
P_c= 1.3 f_c= 1.2 f_1= 0.7 f_2= 0.8
30
20
10
0
−10
−20
0
10
20
Temporal Frequency (Hz)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e=−99.0 hlat=−99.0 BM 05
Nrec= 1 Mean 2061 RMS 6.5
Pa= 2.8 fc= 0.7 f1= 0.2 f2= 0.3
offsour 21112013 121531
e=−99.0 hlat=−99.0 BM 06
Nrec= 1 Mean 2083 RMS 5.9
Pa= 2.2 fc= 1.8 f1= 1.0 f2= 1.1
offsour 21112013 121531
e=−99.0 hlat=−99.0 BM 07
Nrec= 1 Mean 1583 RMS 6.6
Pa= 0.0 fc= 0.0 f1= 0.0 f2= 0.0
offsour 21112013 121531
e=−99.0 hlat=−99.0 BM 08
Nrec= 1 Mean 2027 RMS 5.3
Pa= 0.0 fc= 0.0 f1= 0.0 f2= 0.0
offsour 21112013 121531
e=−99.0 hlat=−99.0 BM 09
Nrec= 1 Mean 2160 RMS 7.0
Pa= 0.0 fc= 0.0 f1= 0.0 f2= 0.0
offsour 21112013 121531
e=−99.0 hlat=−99.0 BM 10
Nrec= 1 Mean 2078 RMS 4.6
Pa= 0.0 fc= 0.0 f1= 0.0 f2= 0.0
offsour 21112013 121531
e=−99.0 hlat=−99.0 BM 11
Nrec= 1 Mean 2028 RMS 5.8
Pa= 0.0 fc= 0.0 f1= 0.0 f2= 0.0
offsour 21112013 121531
e=−99.0 hlat=−99.0 BM 12
Nrec= 1 Mean 2100 RMS 6.2
Pa= 0.0 fc= 0.0 f1= 0.0 f2= 0.0
1453−109 21112013 121720
e= 15.1 hlat= 14.2 BM 01
Nrec= 2 Mean 1831 RMS 5.5
Pa= 0.2 fc= 0.7 f1= 0.0 f2= 0.0
1453−109 21112013 121720
e= 15.1 hlat= 14.2 BM 02
Nrec= 2 Mean 2070 RMS 3.0
Pa= 0.0 fc= 0.0 f1= 0.0 f2= 0.0
1453−109 21112013 121720
e= 15.1 hlat= 14.2 BM 03
Nrec= 2 Mean 2077 RMS 5.3
Pa= 0.0 fc= 0.0 f1= 0.0 f2= 0.0
1453−109 21112013 121720
e= 15.1 hlat= 14.2 BM 04
Nrec= 2 Mean 2075 RMS 5.5
Pa= 1.8 fc= 1.6 f1= 0.6 f2= 0.8
1453−109 21112013 121720
e= 15.1 hlat= 14.2 BM 05
Nrec= 2 Mean 1858 RMS 20.1
Pa= 13.3 fc= 2.3 f1= 0.4 f2= 0.5
1453−109 21112013 121720
e= 15.1 hlat= 14.2 BM 06
Nrec= 2 Mean 2060 RMS 6.7
Pa= 3.3 fc= 3.1 f1= 0.7 f2= 1.0
1453−109 21112013 121720
e= 15.1 hlat= 14.2 BM 07
Nrec= 2 Mean 2139 RMS 52.7
Pa= 35.9 fc= 2.5 f1= 0.4 f2= 0.5
1453−109 21112013 121720
e= 15.1 hlat= 14.2 BM 08
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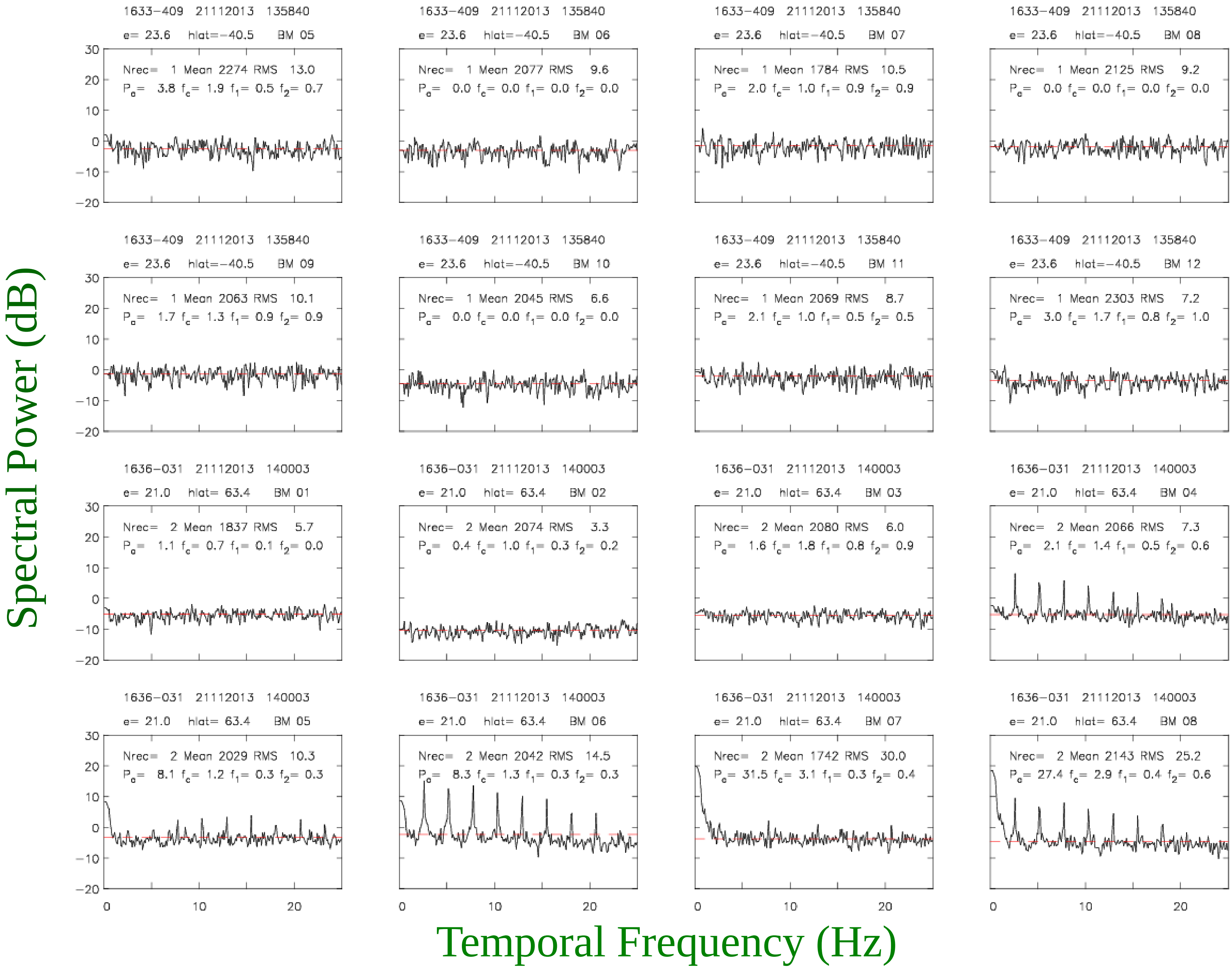
Spectral Power (dB)
Temporal Frequency (Hz)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1633−409 21112013 135840
e= 23.6 hlat=−40.5 BM 06
Nrec= 1 Mean 2077 RMS 9.6
P_a= 0.0 f_c= 0.0 f_1= 0.0 f_2= 0.0
1633−409 21112013 135840
e= 23.6 hlat=−40.5 BM 07
Nrec= 1 Mean 1784 RMS 10.5
P_a= 2.0 f_c= 1.0 f_1= 0.9 f_2= 0.9
1633−409 21112013 135840
e= 23.6 hlat=−40.5 BM 08
Nrec= 1 Mean 2125 RMS 9.2
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e= 23.6 hlat=−40.5 BM 09
Nrec= 1 Mean 2063 RMS 10.1
P_a= 1.7 f_c= 1.3 f_1= 0.9 f_2= 0.9
1633−409 21112013 135840
e= 23.6 hlat=−40.5 BM 10
Nrec= 1 Mean 2045 RMS 6.6
P_a= 0.0 f_c= 0.0 f_1= 0.0 f_2= 0.0
1633−409 21112013 135840
e= 23.6 hlat=−40.5 BM 11
Nrec= 1 Mean 2069 RMS 8.7
P_a= 2.1 f_c= 1.0 f_1= 0.5 f_2= 0.5
1633−409 21112013 135840
e= 23.6 hlat=−40.5 BM 12
Nrec= 1 Mean 2303 RMS 7.2
P_a= 3.0 f_c= 1.7 f_1= 0.8 f_2= 1.0
1636−031 21112013 140003
e= 21.0 hlat= 63.4 BM 01
Nrec= 2 Mean 1837 RMS 5.7
P_a= 1.1 f_c= 0.7 f_1= 0.1 f_2= 0.0
1636−031 21112013 140003
e= 21.0 hlat= 63.4 BM 02
Nrec= 2 Mean 2074 RMS 3.3
P_a= 0.4 f_c= 1.0 f_1= 0.3 f_2= 0.2
1636−031 21112013 140003
e= 21.0 hlat= 63.4 BM 03
Nrec= 2 Mean 2080 RMS 6.0
P_a= 1.6 f_c= 1.8 f_1= 0.8 f_2= 0.9
1636−031 21112013 140003
e= 21.0 hlat= 63.4 BM 04
Nrec= 2 Mean 2066 RMS 7.3
P_a= 2.1 f_c= 1.4 f_1= 0.5 f_2= 0.6
1636−031 21112013 140003
e= 21.0 hlat= 63.4 BM 05
Nrec= 2 Mean 2029 RMS 10.3
P_a= 8.1 f_c= 1.2 f_1= 0.3 f_2= 0.3
1636−031 21112013 140003
e= 21.0 hlat= 63.4 BM 06
Nrec= 2 Mean 2042 RMS 14.5
P_a= 8.3 f_c= 1.3 f_1= 0.3 f_2= 0.3
1636−031 21112013 140003
e= 21.0 hlat= 63.4 BM 07
Nrec= 2 Mean 1742 RMS 30.0
P_a= 31.5 f_c= 3.1 f_1= 0.3 f_2= 0.4
1636−031 21112013 140003
e= 21.0 hlat= 63.4 BM 08
Nrec= 2 Mean 2143 RMS 25.2
P_a= 27.4 f_c= 2.9 f_1= 0.4 f_2= 0.6
30
20
10
0
−10
−20
0
10
20
Spectral Power (dB)
Temporal Frequency (Hz)

IPS – Power Spectrum

$$\rho\left(r,t\right)=\left\langle \Delta I(r_o,t_o)\,\Delta I(r_o+r,t_o+t)\right\rangle$$

$$P_I=\frac{1}{2\pi}\int_{-\infty}^{+\infty}\rho(0,t)\exp(-i2\pi\,f\,t)dt$$

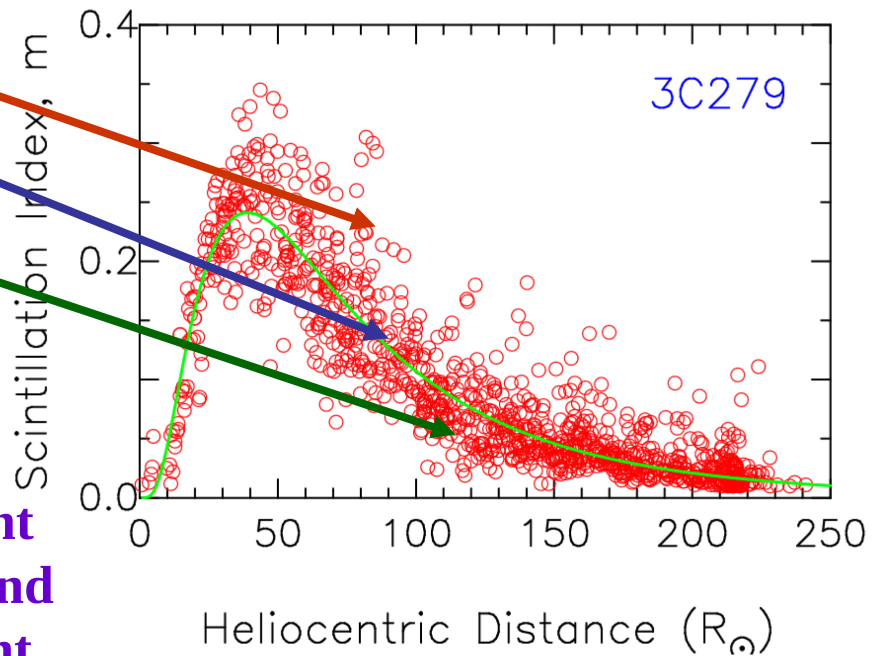
$$m^2=\frac{1}{\langle I\rangle^2}\left[\int_{-\infty}^{+\infty}P_I(f)df\right]$$

Solar wind Density Turbulence

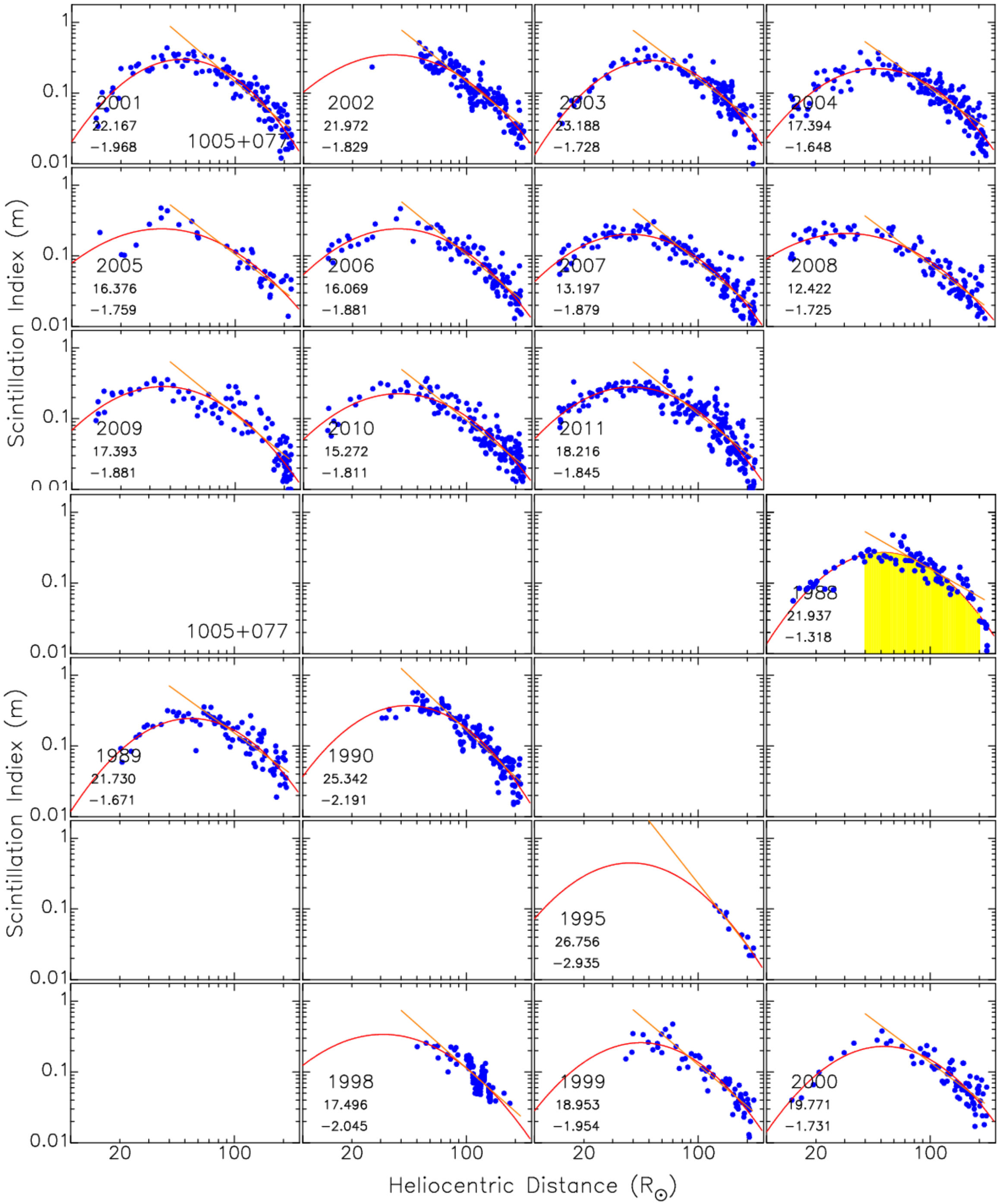
Density Turbulence

* Scintillation index, m, is a measure of level of turbulence
* Normalized Scintillation index, g = m(R) / <m(R)>
* Quasi-stationary and transient/disturbed solar wind

- $g > 1 \rightarrow$ enhancement in δNe
- $g \approx 1 \rightarrow$ ambient level of δNe
- $g < 1 \rightarrow$ rarefaction in δNe



Scintillation enhancement w.r.t. the ambient wind identifies the presence of the solar wind transient (CME/CIR) along the line-of-sight to the radio source



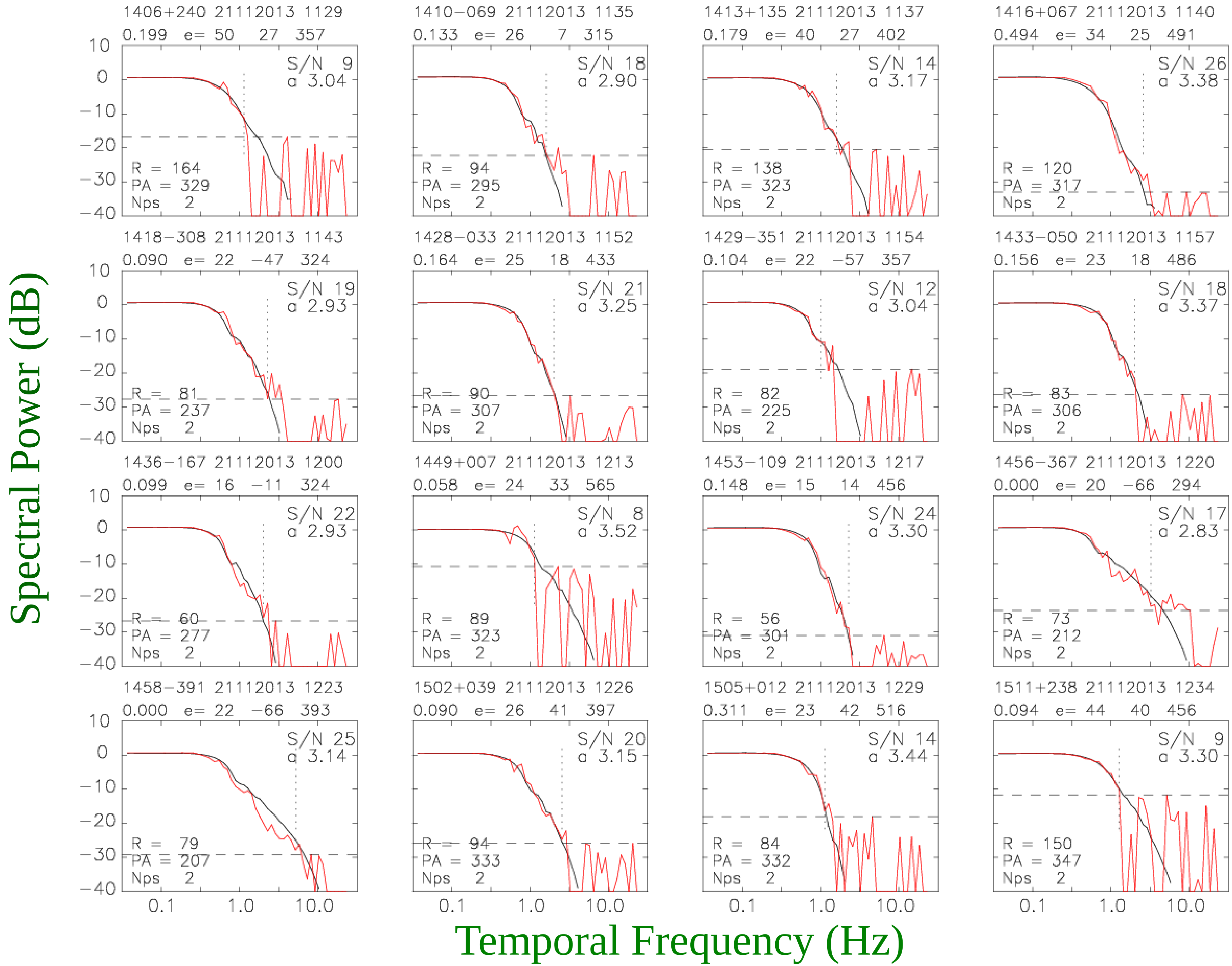
Scintillation Indiex (m)
Heliocentric Distance ($R_\odot$)
1005+077
2001 22.167 −1.968
2002 21.972 −1.829
2003 23.188 −1.728
2004 17.394 −1.648
2005 16.376 −1.759
2006 16.069 −1.881
2007 13.197 −1.879
2008 12.422 −1.725
2009 17.393 −1.881
2010 15.272 −1.811
2011 18.216 −1.845
1988 21.937 −1.318
1989 21.730 −1.671
1990 25.342 −2.191
1995 26.756 −2.935
1998 17.496 −2.045
1999 18.953 −1.954
2000 19.771 −1.731

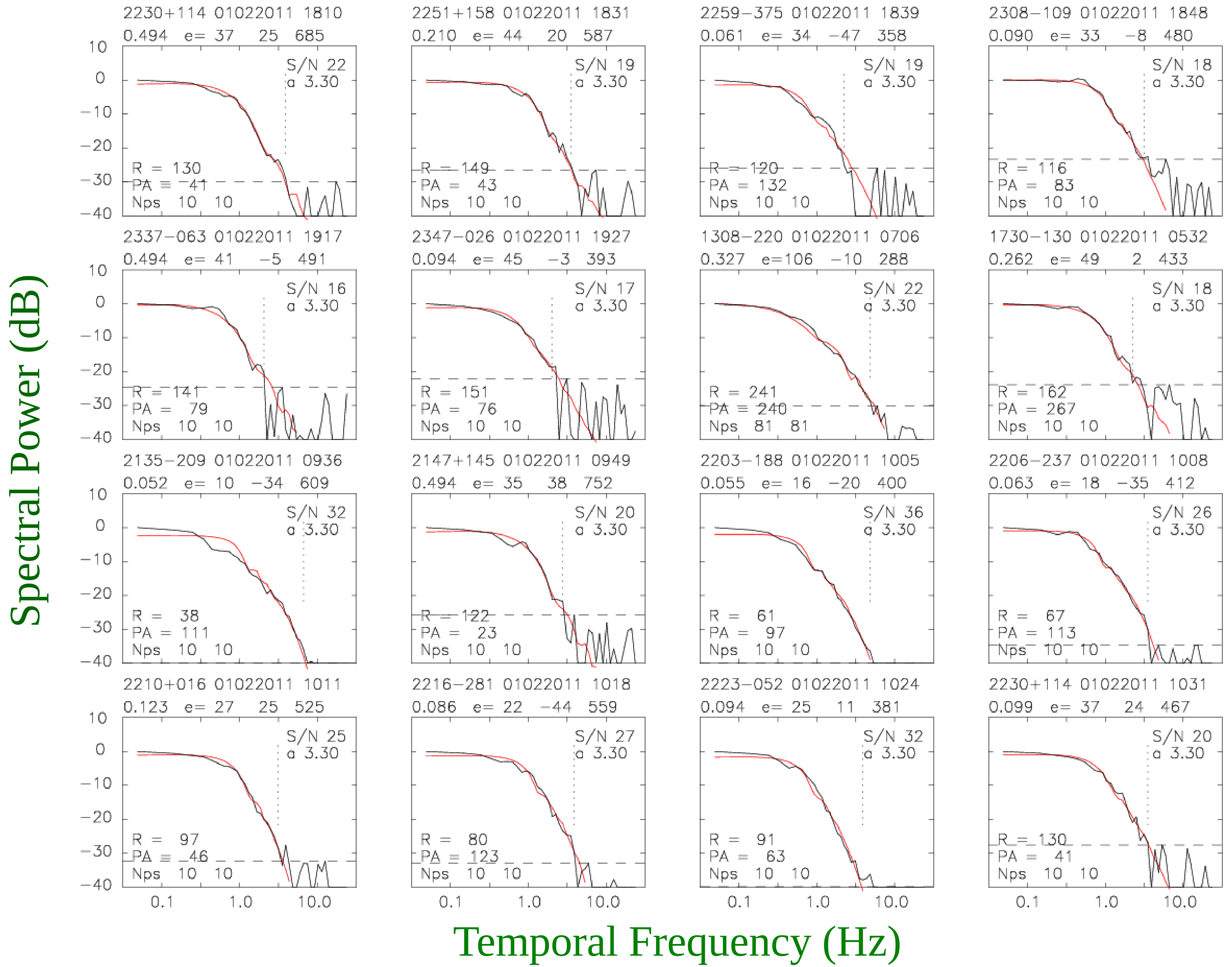
IPS temporal power spectrum

IPS – intensity fluctuations are caused by the solar wind density turbulence - time series transformation provides the temporal power spectrum

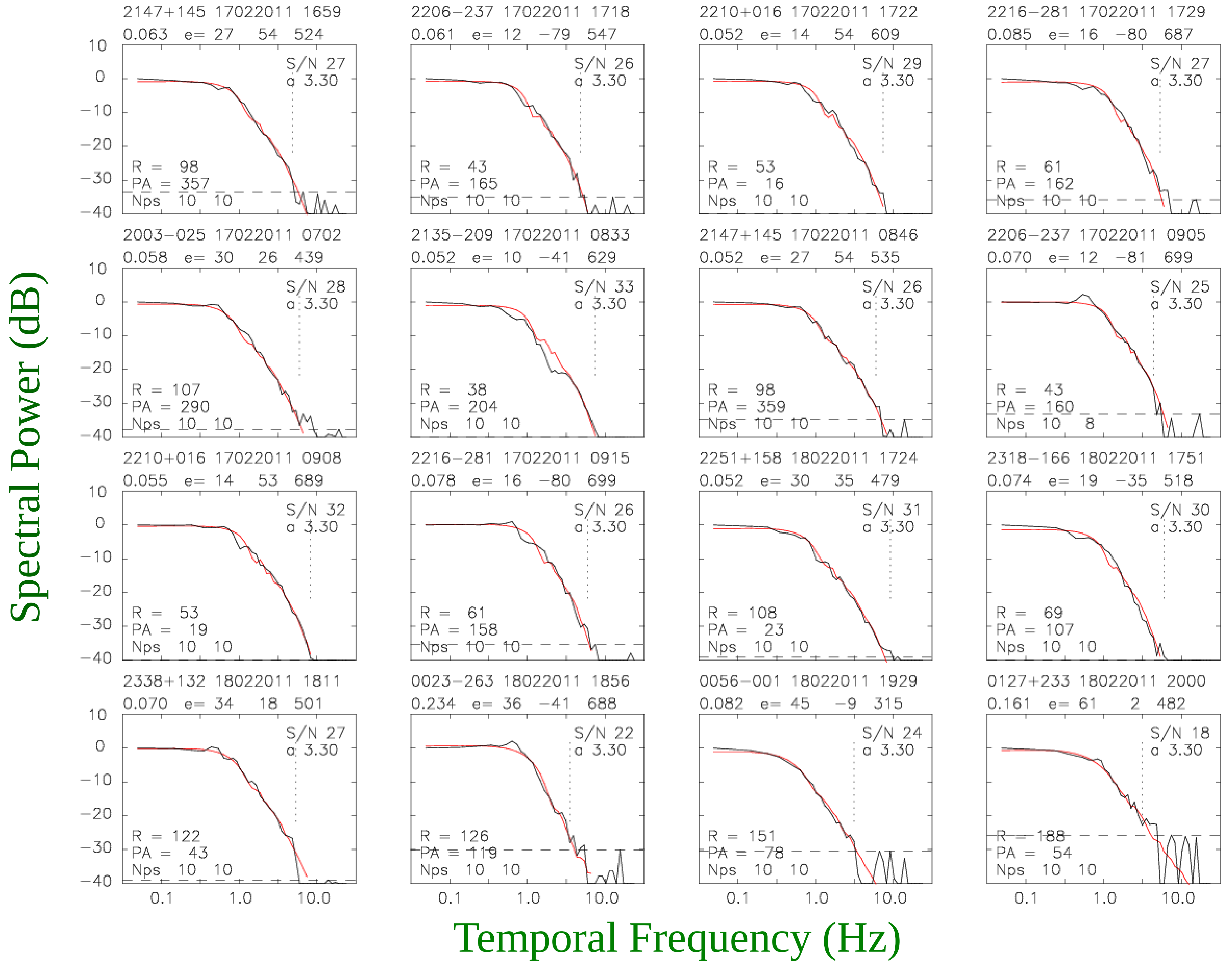
$$\mathrm{P(f)} = (2\pi \mathrm{r_e} \lambda)^2 \int \mathrm{dq}\, \mathrm{C}^2_{\mathrm{N_e}}\, \Phi_{\mathrm{N_e}}(\mathrm{q})\, \mathrm{F_{diff}}(\mathrm{q})\, \mathrm{F_{source}}(\mathrm{q})$$

$$\mathrm{P(f)} = (2\pi\, \mathrm{r_e} \lambda)^2 \int_{-\infty}^{z} \frac{\mathrm{dz}}{\left|\mathrm{V_p(z)}\right|} \int_{-\infty}^{\infty} \mathrm{dq_y}\, 4\sin^2\left(\frac{\mathrm{q^2 z}}{2\mathrm{k}}\right) \left|\mathrm{V(q, z, \theta)}\right|^2 \mathrm{R}^{-\beta} \mathrm{q}^{-\alpha}$$

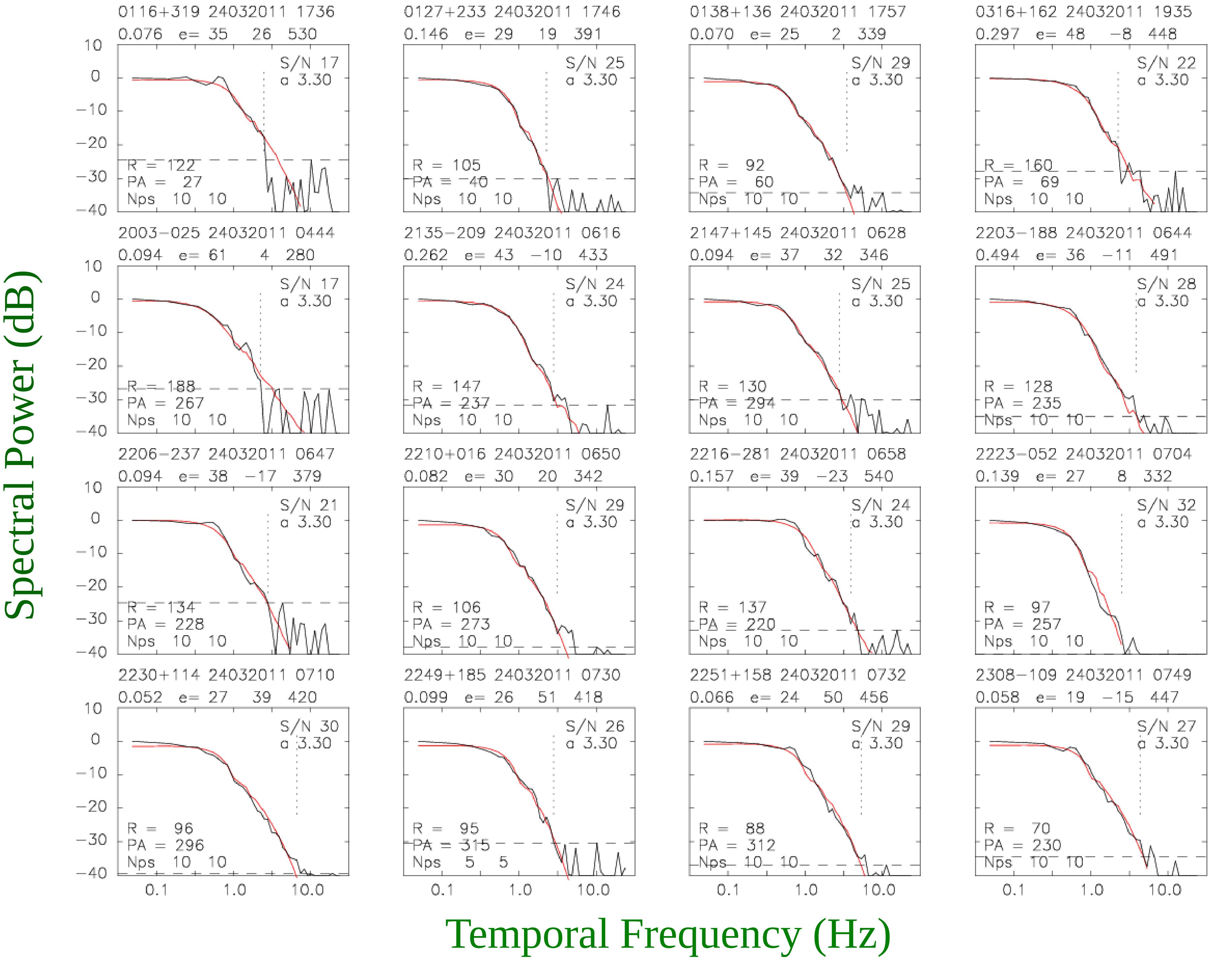

Spectral Power (dB)
Temporal Frequency (Hz)
1406+240 21112013 1129
0.199 e= 50 27 357
S/N 9
a 3.04
R = 164
PA = 329
Nps 2
1410−069 21112013 1135
0.133 e= 26 7 315
S/N 18
a 2.90
R = 94
PA = 295
Nps 2
1413+135 21112013 1137
0.179 e= 40 27 402
S/N 14
a 3.17
R = 138
PA = 323
Nps 2
1416+067 21112013 1140
0.494 e= 34 25 491
S/N 26
a 3.38
R = 120
PA = 317
Nps 2
1418−308 21112013 1143
0.090 e= 22 −47 324
S/N 19
a 2.93
R = 81
PA = 237
Nps 2
1428−033 21112013 1152
0.164 e= 25 18 433
S/N 21
a 3.25
R = 90
PA = 307
Nps 2
1429−351 21112013 1154
0.104 e= 22 −57 357
S/N 12
a 3.04
R = 82
PA = 225
Nps 2
1433−050 21112013 1157
0.156 e= 23 18 486
S/N 18
a 3.37
R = 83
PA = 306
Nps 2
1436−167 21112013 1200
0.099 e= 16 −11 324
S/N 22
a 2.93
R = 60
PA = 277
Nps 2
1449+007 21112013 1213
0.058 e= 24 33 565
S/N 8
a 3.52
R = 89
PA = 323
Nps 2
1453−109 21112013 1217
0.148 e= 15 14 456
S/N 24
a 3.30
R = 56
PA = 301
Nps 2
1456−367 21112013 1220
0.000 e= 20 −66 294
S/N 17
a 2.83
R = 73
PA = 212
Nps 2
1458−391 21112013 1223
0.000 e= 22 −66 393
S/N 25
a 3.14
R = 79
PA = 207
Nps 2
1502+039 21112013 1226
0.090 e= 26 41 397
S/N 20
a 3.15
R = 94
PA = 333
Nps 2
1505+012 21112013 1229
0.311 e= 23 42 516
S/N 14
a 3.44
R = 84
PA = 332
Nps 2
1511+238 21112013 1234
0.094 e= 44 40 456
S/N 9
a 3.30
R = 150
PA = 347
Nps 2
10
0
−10
−20
−30
−40
0.1
1.0
10.0



Spectral Power (dB)
Temporal Frequency (Hz)
2230+114 01022011 1810
0.494 e= 37 25 685
S/N 22
a 3.30
R = 130
PA = -41
Nps 10 10
2251+158 01022011 1831
0.210 e= 44 20 587
S/N 19
a 3.30
R = 149
PA = 43
Nps 10 10
2259-375 01022011 1839
0.061 e= 34 -47 358
S/N 19
a 3.30
R = 120
PA = 132
Nps 10 10
2308-109 01022011 1848
0.090 e= 33 -8 480
S/N 18
a 3.30
R = 116
PA = 83
Nps 10 10
2337-063 01022011 1917
0.494 e= 41 -5 491
S/N 16
a 3.30
R = 141
PA = 79
Nps 10 10
2347-026 01022011 1927
0.094 e= 45 -3 393
S/N 17
a 3.30
R = 151
PA = 76
Nps 10 10
1308-220 01022011 0706
0.327 e=106 -10 288
S/N 22
a 3.30
R = 241
PA = 240
Nps 81 81
1730-130 01022011 0532
0.262 e= 49 2 433
S/N 18
a 3.30
R = 162
PA = 267
Nps 10 10
2135-209 01022011 0936
0.052 e= 10 -34 609
S/N 32
a 3.30
R = 38
PA = 111
Nps 10 10
2147+145 01022011 0949
0.494 e= 35 38 752
S/N 20
a 3.30
R = 122
PA = 23
Nps 10 10
2203-188 01022011 1005
0.055 e= 16 -20 400
S/N 36
a 3.30
R = 61
PA = 97
Nps 10 10
2206-237 01022011 1008
0.063 e= 18 -35 412
S/N 26
a 3.30
R = 67
PA = 113
Nps 10 10
2210+016 01022011 1011
0.123 e= 27 25 525
S/N 25
a 3.30
R = 97
PA = -46
Nps 10 10
2216-281 01022011 1018
0.086 e= 22 -44 559
S/N 27
a 3.30
R = 80
PA = 123
Nps 10 10
2223-052 01022011 1024
0.094 e= 25 11 381
S/N 32
a 3.30
R = 91
PA = 63
Nps 10 10
2230+114 01022011 1031
0.099 e= 37 24 467
S/N 20
a 3.30
R = 130
PA = 41
Nps 10 10
10
0
-10
-20
-30
-40
0.1
1.0
10.0



2147+145 17022011 1659
0.063 e= 27 54 524
S/N 27
a 3.30
R = 98
PA = 357
Nps 10 10
2206−237 17022011 1718
0.061 e= 12 −79 547
S/N 26
a 3.30
R = 43
PA = 165
Nps 10 10
2210+016 17022011 1722
0.052 e= 14 54 609
S/N 29
a 3.30
R = 53
PA = 16
Nps 10 10
2216−281 17022011 1729
0.085 e= 16 −80 687
S/N 27
a 3.30
R = 61
PA = 162
Nps 10 10
2003−025 17022011 0702
0.058 e= 30 26 439
S/N 28
a 3.30
R = 107
PA = 290
Nps 10 10
2135−209 17022011 0833
0.052 e= 10 −41 629
S/N 33
a 3.30
R = 38
PA = 204
Nps 10 10
2147+145 17022011 0846
0.052 e= 27 54 535
S/N 26
a 3.30
R = 98
PA = 359
Nps 10 10
2206−237 17022011 0905
0.070 e= 12 −81 699
S/N 25
a 3.30
R = 43
PA = 160
Nps 10 8
2210+016 17022011 0908
0.055 e= 14 53 689
S/N 32
a 3.30
R = 53
PA = 19
Nps 10 10
2216−281 17022011 0915
0.078 e= 16 −80 699
S/N 26
a 3.30
R = 61
PA = 158
Nps 10 10
2251+158 18022011 1724
0.052 e= 30 35 479
S/N 31
a 3.30
R = 108
PA = 23
Nps 10 10
2318−166 18022011 1751
0.074 e= 19 −35 518
S/N 30
a 3.30
R = 69
PA = 107
Nps 10 10
2338+132 18022011 1811
0.070 e= 34 18 501
S/N 27
a 3.30
R = 122
PA = 43
Nps 10 10
0023−263 18022011 1856
0.234 e= 36 −41 688
S/N 22
a 3.30
R = 126
PA = 119
Nps 10 10
0056−001 18022011 1929
0.082 e= 45 −9 315
S/N 24
a 3.30
R = 151
PA = −78
Nps 10 10
0127+233 18022011 2000
0.161 e= 61 2 482
S/N 18
a 3.30
R = 188
PA = 54
Nps 10 10
10
0
−10
−20
−30
−40
0.1
1.0
10.0
Spectral Power (dB)
Temporal Frequency (Hz)



0116+319 24032011 1736
0.076 e= 35 26 530
S/N 17
a 3.30
R = 122
PA = 27
Nps 10 10
0127+233 24032011 1746
0.146 e= 29 19 391
S/N 25
a 3.30
R = 105
PA = -40
Nps 10 10
0138+136 24032011 1757
0.070 e= 25 2 339
S/N 29
a 3.30
R = 92
PA = 60
Nps 10 10
0316+162 24032011 1935
0.297 e= 48 -8 448
S/N 22
a 3.30
R = 160
PA = 69
Nps 10 10
2003-025 24032011 0444
0.094 e= 61 4 280
S/N 17
a 3.30
R = 188
PA = 267
Nps 10 10
2135-209 24032011 0616
0.262 e= 43 -10 433
S/N 24
a 3.30
R = 147
PA = 237
Nps 10 10
2147+145 24032011 0628
0.094 e= 37 32 346
S/N 25
a 3.30
R = 130
PA = 294
Nps 10 10
2203-188 24032011 0644
0.494 e= 36 -11 491
S/N 28
a 3.30
R = 128
PA = 235
Nps 10 10
2206-237 24032011 0647
0.094 e= 38 -17 379
S/N 21
a 3.30
R = 134
PA = 228
Nps 10 10
2210+016 24032011 0650
0.082 e= 30 20 342
S/N 29
a 3.30
R = 106
PA = 273
Nps 10 10
2216-281 24032011 0658
0.157 e= 39 -23 540
S/N 24
a 3.30
R = 137
PA = 220
Nps 10 10
2223-052 24032011 0704
0.139 e= 27 8 332
S/N 32
a 3.30
R = 97
PA = 257
Nps 10 10
2230+114 24032011 0710
0.052 e= 27 39 420
S/N 30
a 3.30
R = 96
PA = 296
Nps 10 10
2249+185 24032011 0730
0.099 e= 26 51 418
S/N 26
a 3.30
R = 95
PA = 315
Nps 5 5
2251+158 24032011 0732
0.066 e= 24 50 456
S/N 29
a 3.30
R = 88
PA = 312
Nps 10 10
2308-109 24032011 0749
0.058 e= 19 -15 447
S/N 27
a 3.30
R = 70
PA = 230
Nps 10 10
10
0
-10
-20
-30
-40
0.1
1.0
10.0
Spectral Power (dB)
Temporal Frequency (Hz)

Density Turbulence Spectrum

"Interplanetary Scintillations" (IPS)

intensity fluctuations caused by the solar wind density turbulence

This time series transformation provides the temporal power spectrum

$$P(f) = (2\pi r_e \lambda)^2 \int dq \, C_{N_e}^2 \, \Phi_{N_e}(q) \, F_{diff}(q) \, F_{source}(q)$$

λ is wavelength of observation; r_e is classical electron radius.
$F_{diff}(q)$ = Fresnel diffraction filter (attenuates low-frequency part of the spectrum)
$F_{Source}(q)$ = Brightness distribution of the source (attenuates high frequency part)

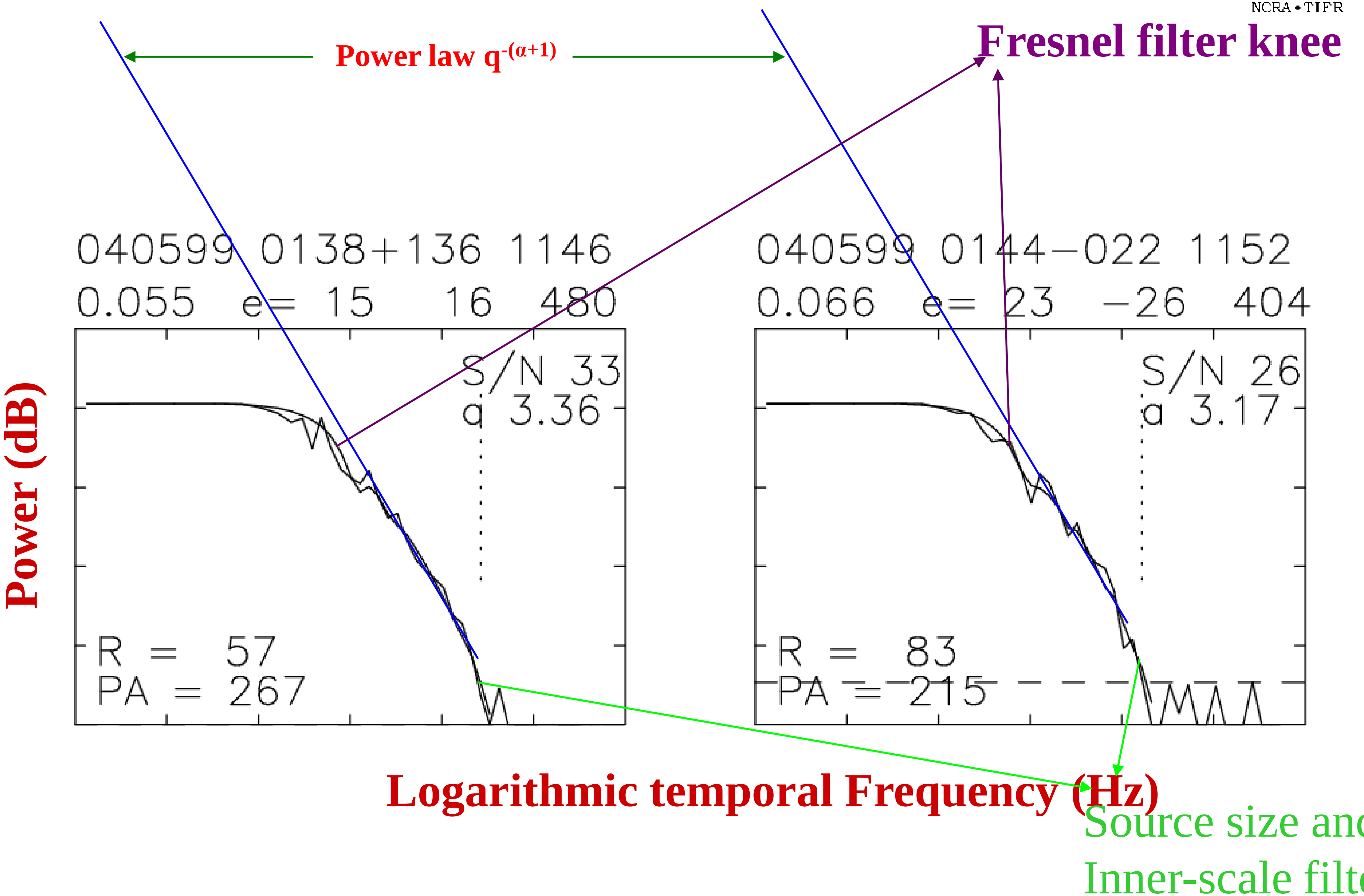
Axial Ratio of Irregularity

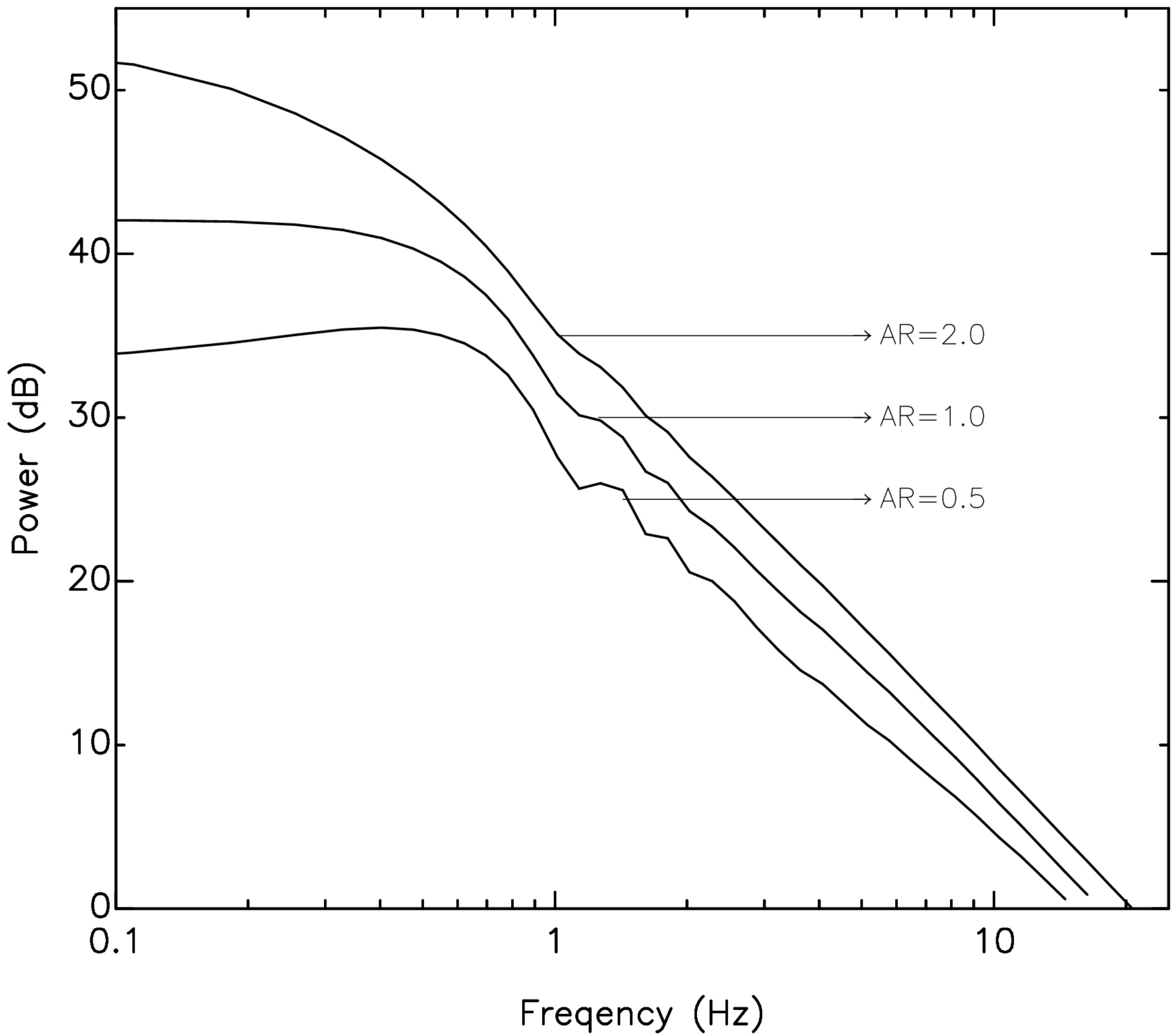
When the density irregularities are field aligned and approximated with an ellipsoidal symmetry, the spatial spectrum of density fluctuations, $\Phi_{Ne}(q)$, for a radio source with the finite size, θ, will be

$$\Phi_{N_e}(q,0) \mid B(\theta) \mid^2 = (q_x^2 + \frac{q_y^2}{AR^2})^{-\frac{\alpha}{2}} \exp(-\frac{q^2}{q_i^2})$$

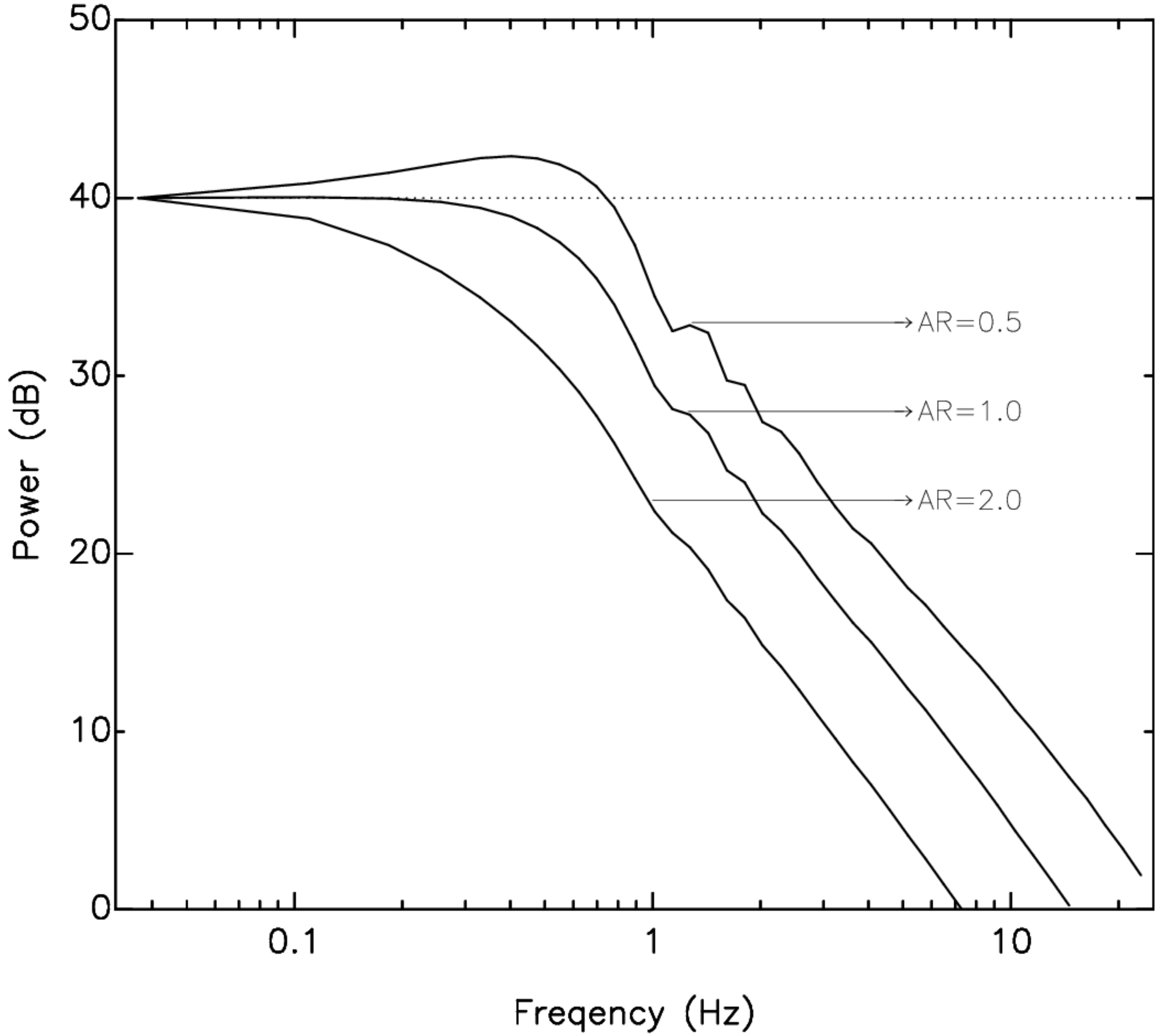
AR is the ratio of major to minor axes (axial ratio), which is the measure of degree of anisotropy of irregularities (α power-law index. q_i cut-off scale i.e., inner-scale size).

Interplanetary scintillation spectra

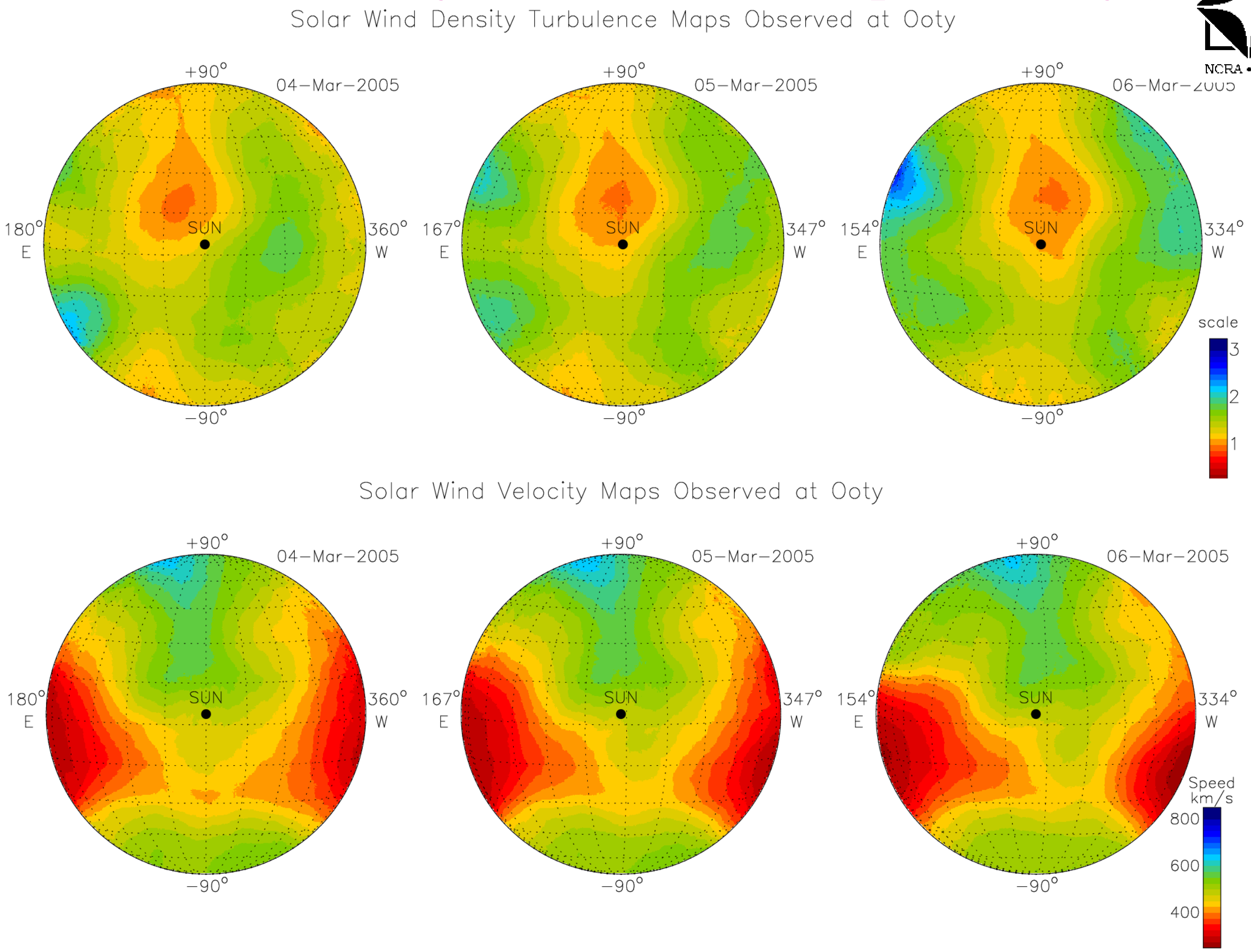


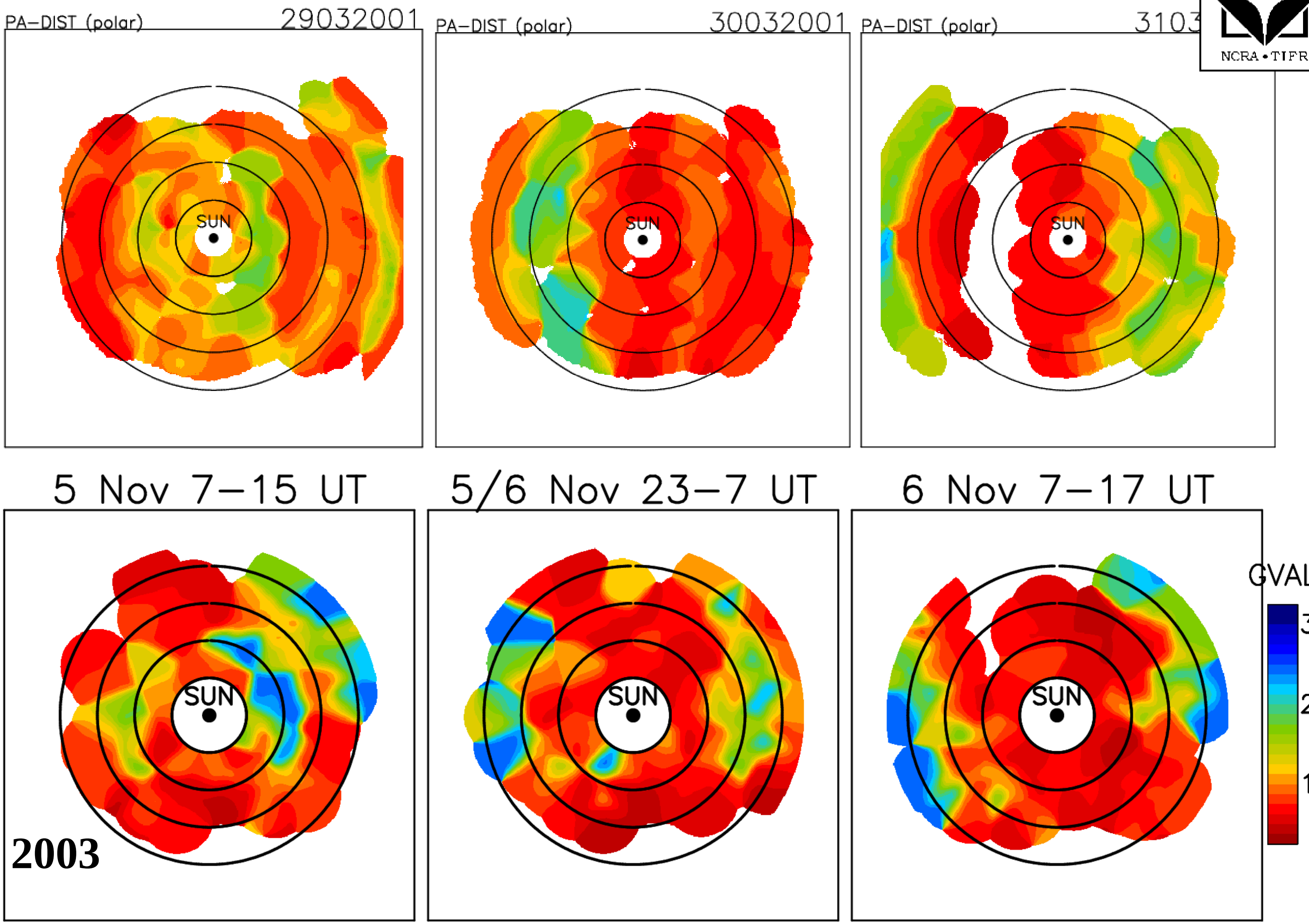


NCRA • TIFR

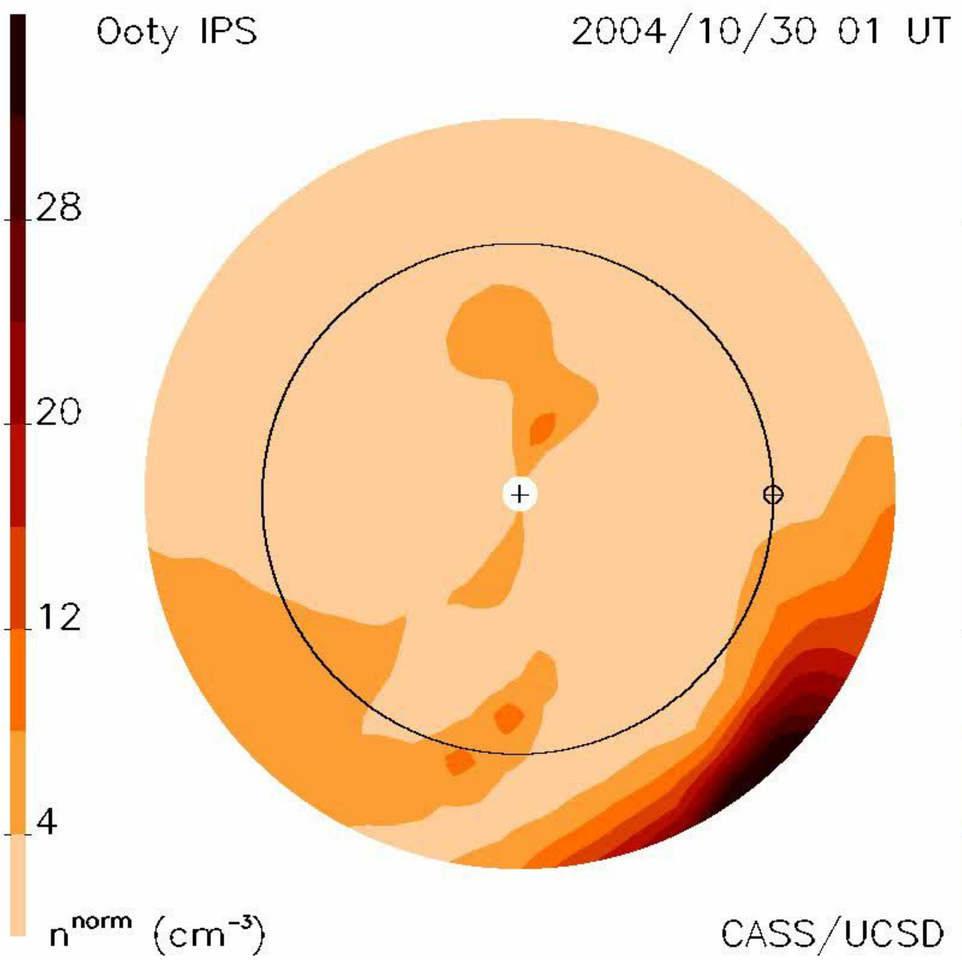

50
40
30
20
10
0
Power (dB)
0.1
1
10
Freqency (Hz)
AR=0.5
AR=1.0
AR=2.0

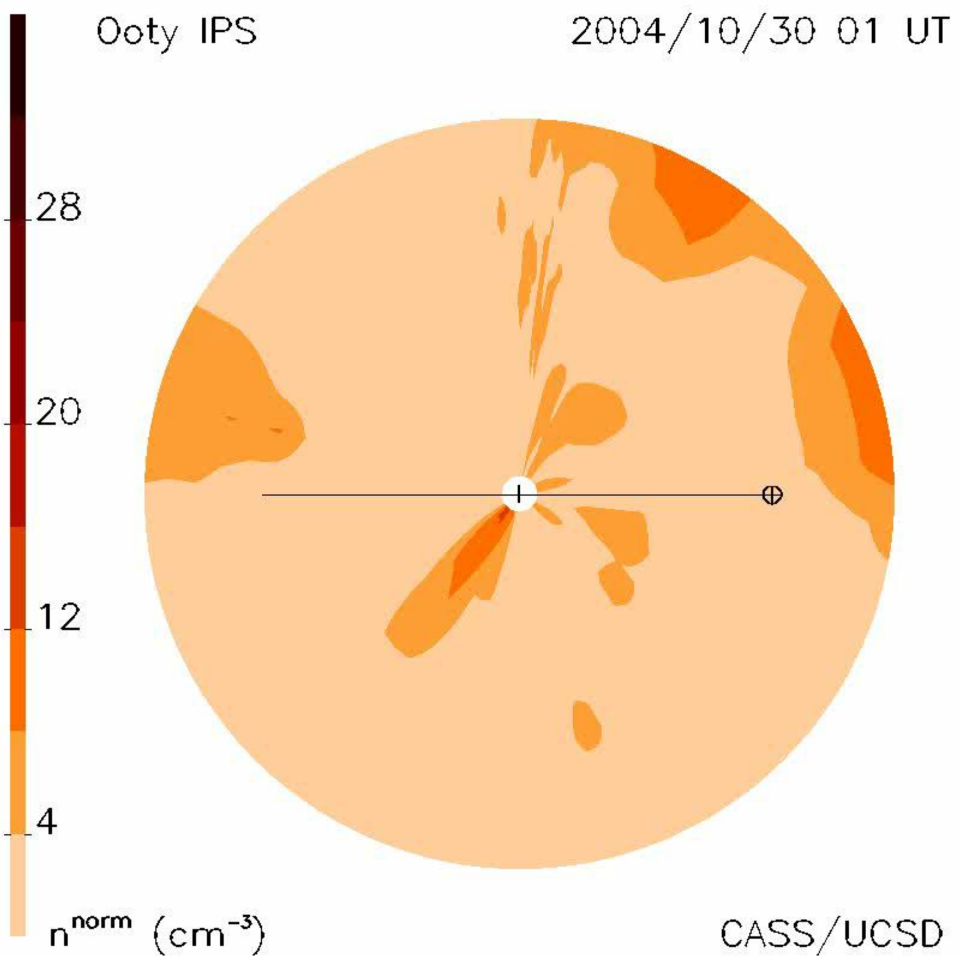
Solar Wind Density Turbulence and Speed (3 days)




PA–DIST (polar)
29032001
PA–DIST (polar)
30032001
PA–DIST (polar)
SUN
5 Nov 7–15 UT
5/6 Nov 23–7 UT
6 Nov 7–17 UT
GVAL
3
2
1
2003

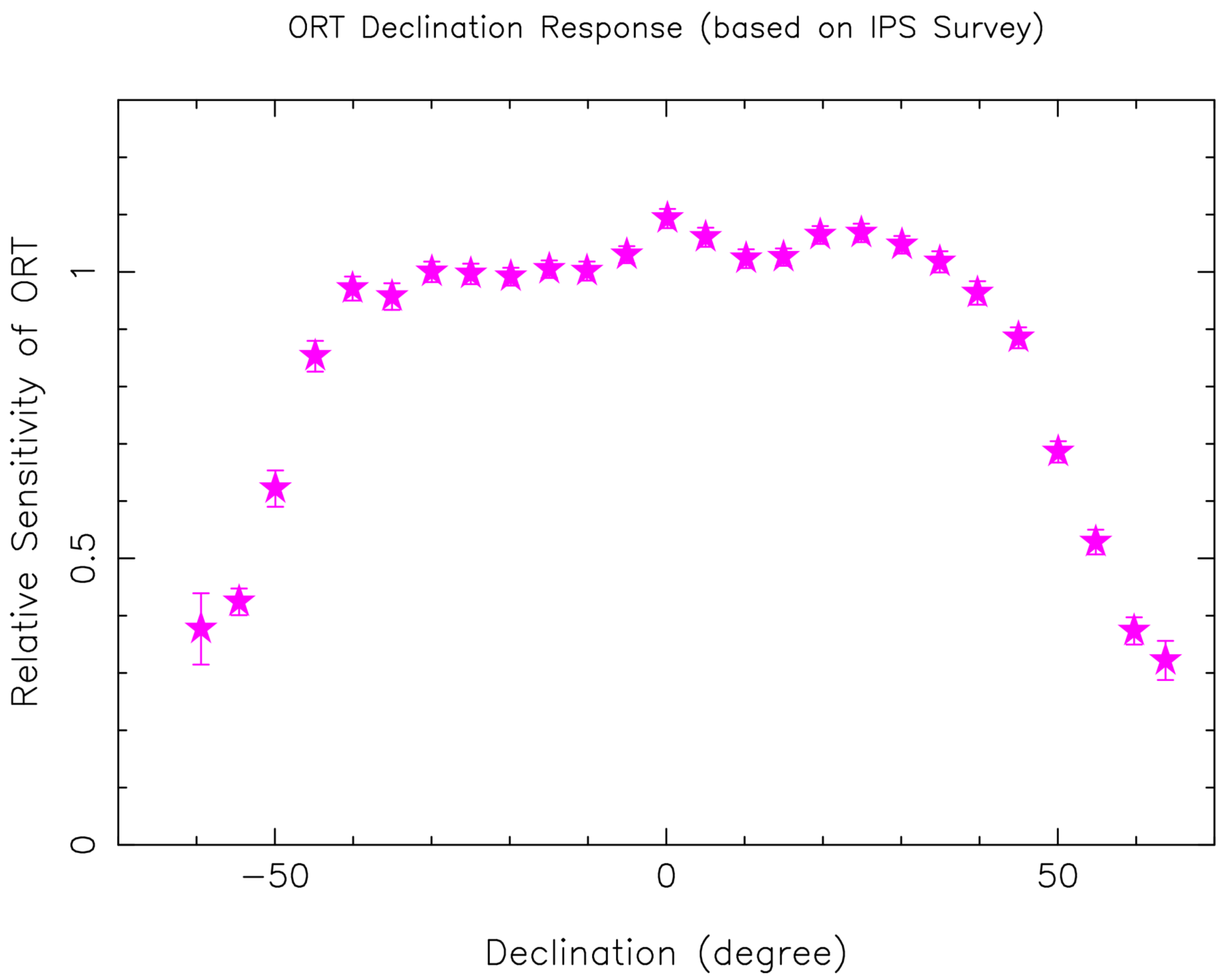
Current 3D Ooty Density Reconstruction





The left movie shows an ecliptic cut through the 3D Ooty IPS density reconstruction and the right movie show a meridional cut (from East of the Sun-Earth line) of the same; both with the Earth on the right-hand side and it’s orbit shown in each case

Thank You


ORT Declination Response (based on IPS Survey)
Relative Sensitivity of ORT
0
0.5
1
−50
0
50
Declination (degree)