

**Small-size space debris
data collection
with EISCAT radar
facilities**

Background



2000-2001

**MEASUREMENTS OF SMALL-SIZE DEBRIS
WITH BACKSCATTER OF RADIO WAVES**

J Markkanen, M Lehtinen, A Huuskonen, A Väänänen

Is feasible

Sodankylä Geophysical Observatory

2003-2004

**REAL-TIME
SMALL-SIZE SPACE DEBRIS DETECTION
WITH EISCAT RADAR FACILITIES**

J Markkanen and M Postila

Is practical

EISCAT Scientific Association

... SD data collection ...

Phase I (2005)

- W.P. 1 Updating of data processing methods and algorithms
- W.P. 2 Routine data collection during common program measurements

700 h 8000 events

WP 2

Routine data collection during CP measurements

Measurements

- Manda CPI 11-13 Aug, 51 h, 806 events
- Tau2 CP2 7-29 Sep, 545(-) h, 5151 events
- Tau0 CP3 10 Nov, 24 h, 650 events
- Manda CPI 17-20 Nov, 79 h, 1349 events

Delivered result files

- events.txt - Daily listing of event parameters
- events.pdf - Daily compilation of summary plots
- .epar .eps .hlist - In each event's result directory
- info - Miscellaneous campaign-wise info.

Not delivered but stored permanently

- /Events - complete sample-level data for all events.
- /Scans - plots of each hit, false-alarms included.
- /Raw - unprocessed raw data for some campaigns.
- /Deb - software. Under version control (only) since Summer 2005.
- www.sgo.fi/~jussi/spade/ - key project documents since 2000, and most of results.

EISCAT SD data

- Two wavelengths (0.60 m and 0.32 m)
- Two latitudes (70 and 78 N)
- Beam-multipark modes (4 positions in CP2)
- Long time series (~month)
- But only statistical info on RCS

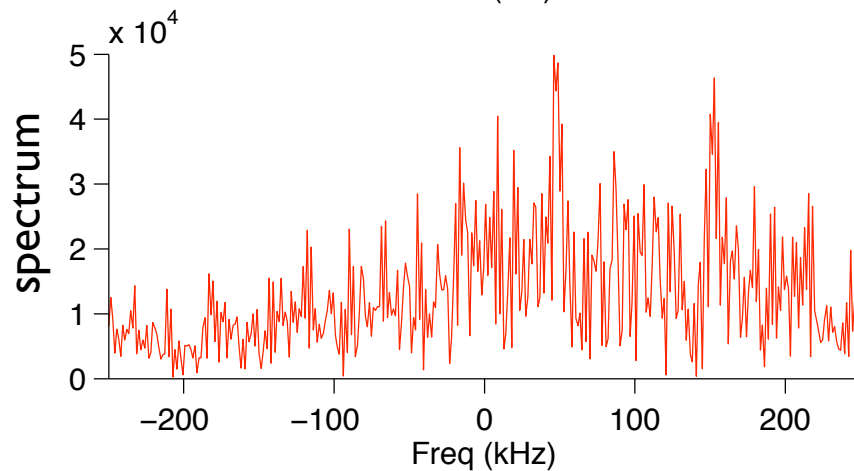
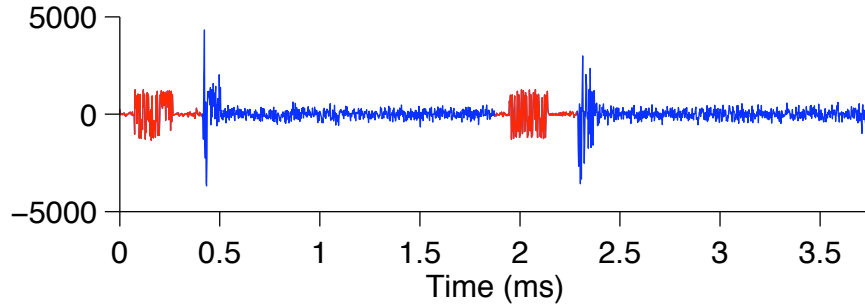
A variety of transmissions

Manda

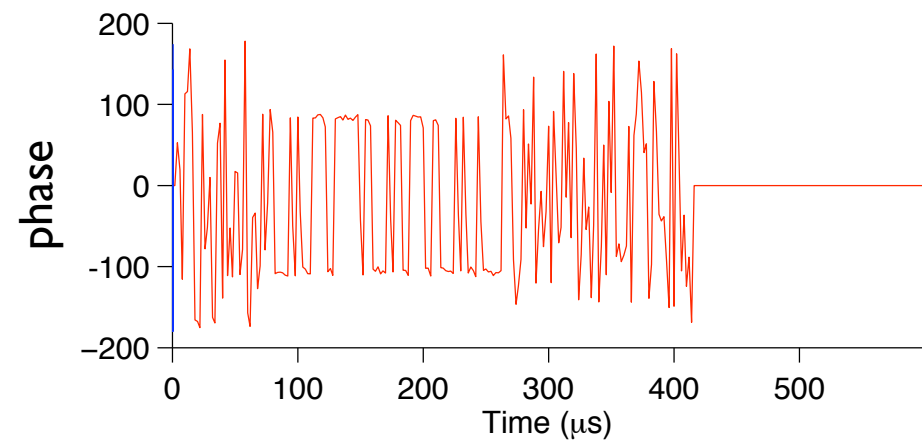
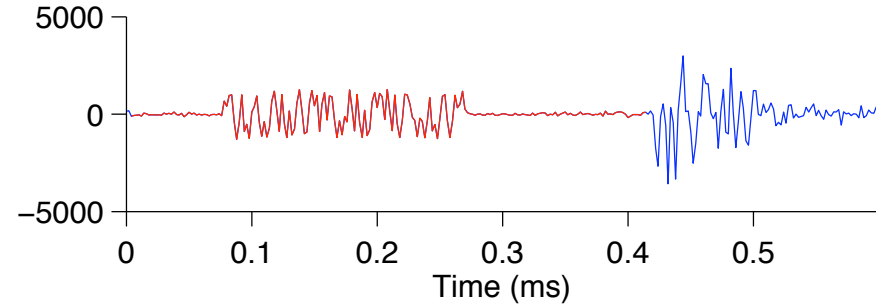
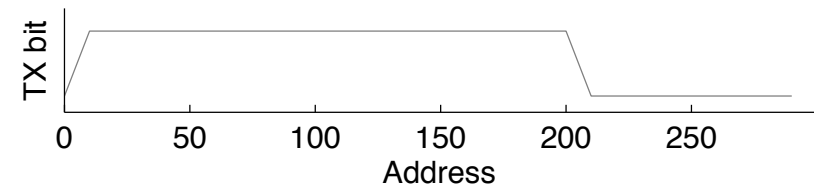
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/Volumes/jdisk/Events/050812/manda_2000/U20050812_000026_821
UHF20050812000002_00012 manda_2000
1679<1875> 00:00:24.00
```

```
/Volumes/jdisk/Events/050812/manda_2000/U20050812_000026_821
UHF20050812000002_00012 manda_2000
2614<300> 00:00:24.00
```

1679 < 1875 > 3553



2614 < 300 > 2913

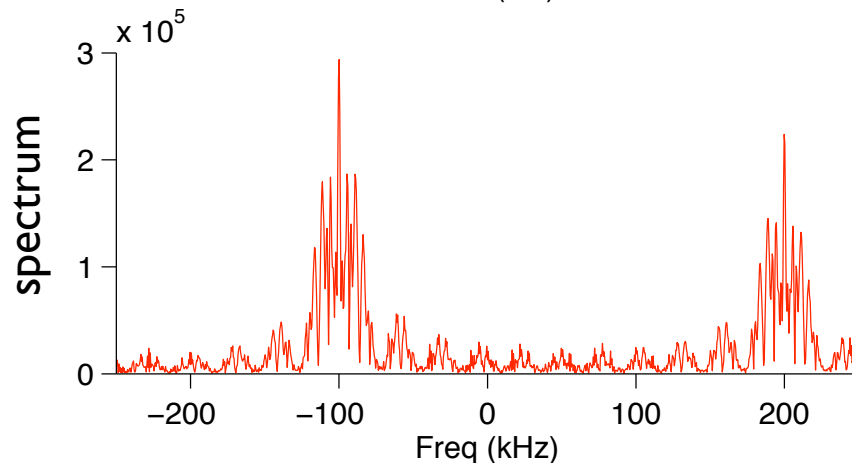
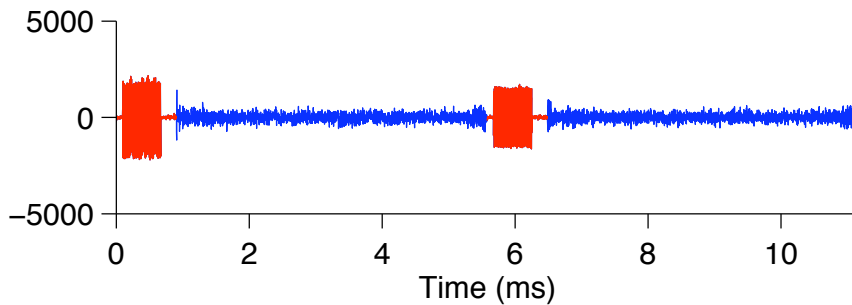
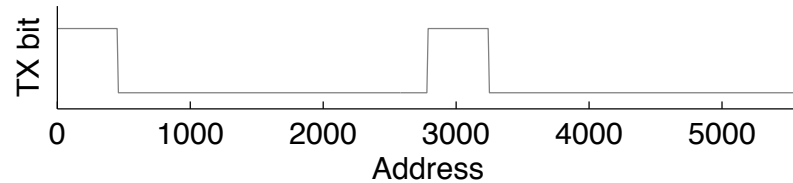


A variety of transmissions

tau2

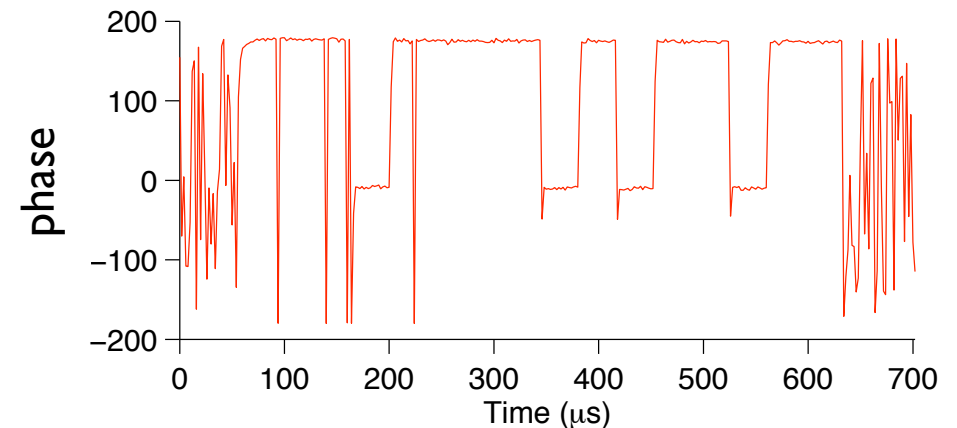
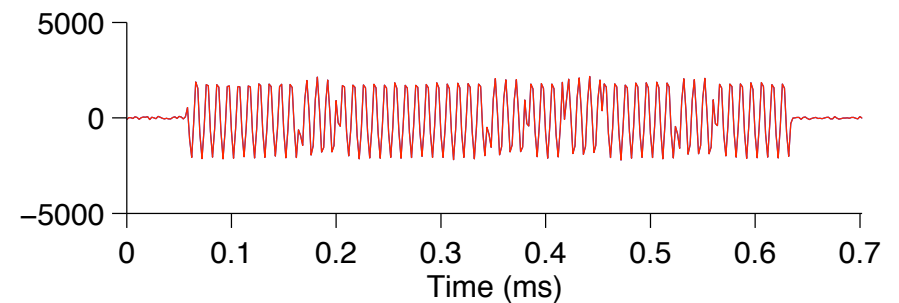
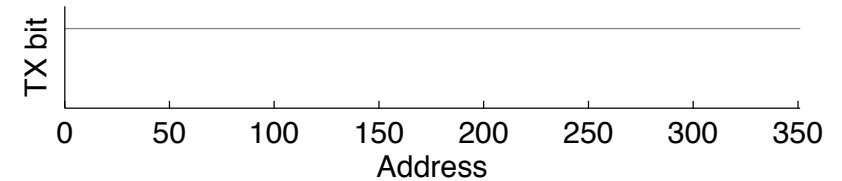
```
/Volumes/jdisk/Events/050924/tau2_2000_cp2pos4/U20050924_0041:  
UHF20050924004112_00013 tau2_2000_cp2pos4  
3234<5580> 00:41:36.00
```

3234 < 5580 > 8813



```
/Volumes/jdisk/Events/050924/tau2_2000_cp2pos4/U20050924_0041:  
UHF20050924004112_00013 tau2_2000_cp2pos4  
3234<5580> 00:41:36.00
```

3253 < 352 > 3604



A variety of transmissions

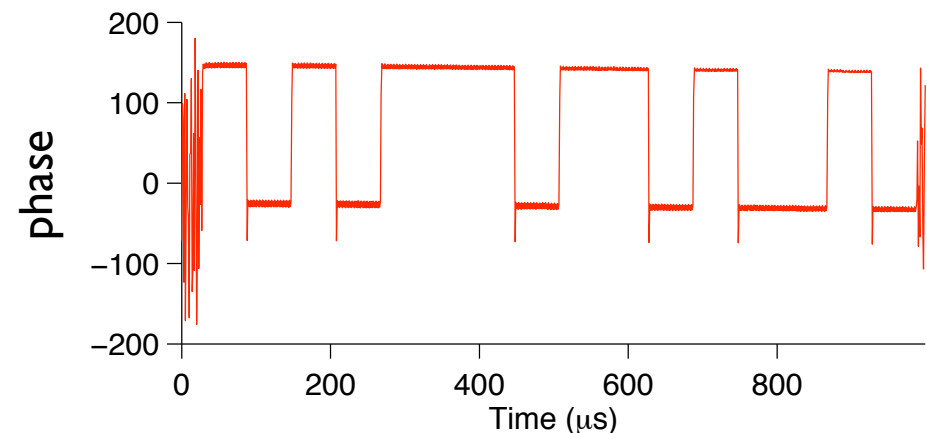
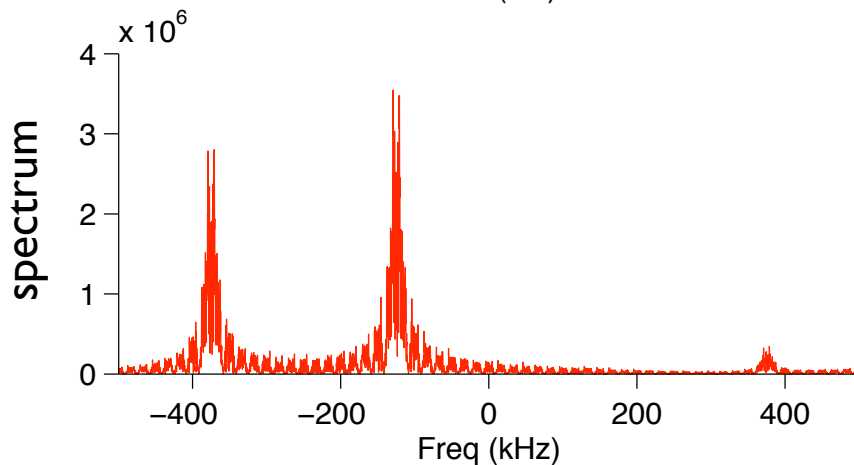
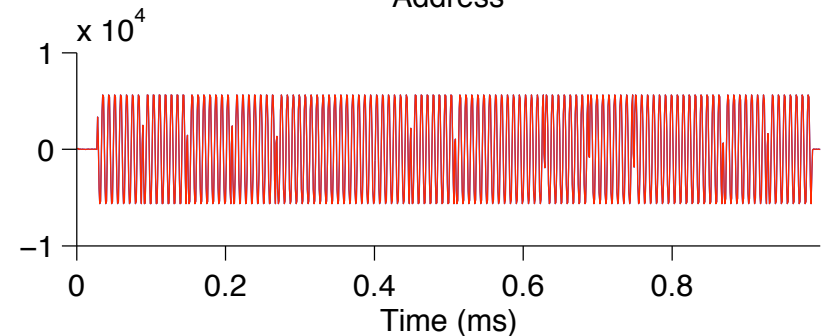
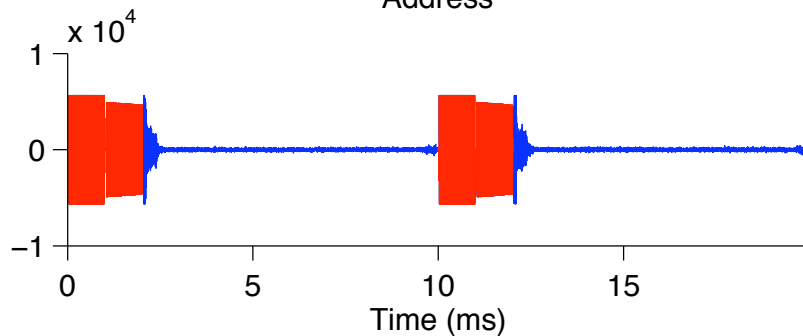
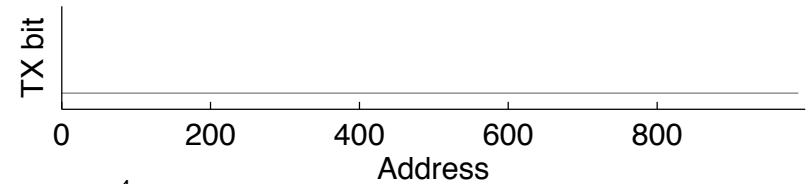
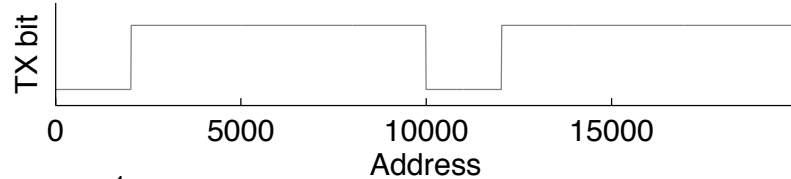
tau0 (ESR)

```
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UHF20051110000124_00035 tau0_1000
25425<19980> 00:01:58.02
```

```
/Volumes/jdisk/Events/051110/tau0_1000//U20051110_000159_405
UHF20051110000124_00035 tau0_1000
5445<1000> 00:01:58.00
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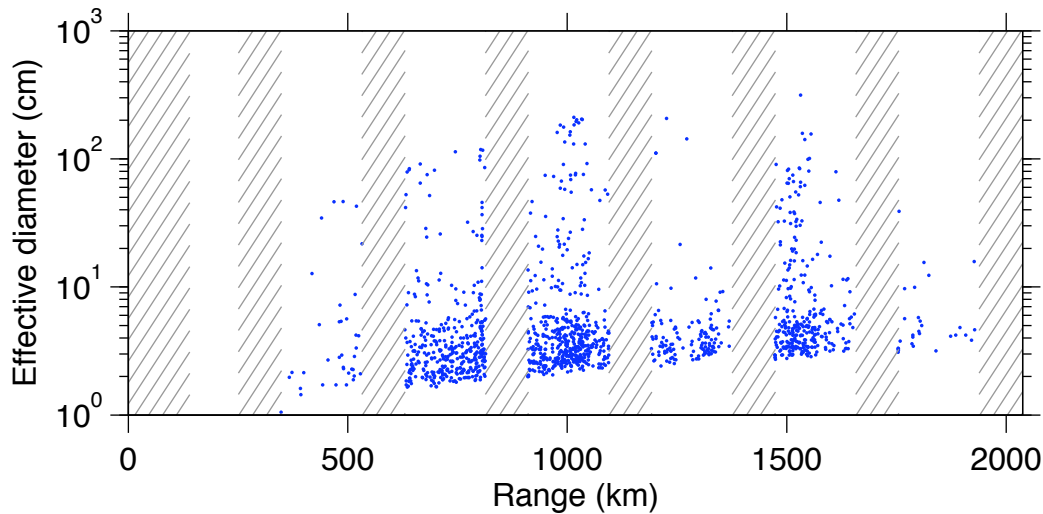
25425 < 19980 > 45404

5445 < 1000 > 6444

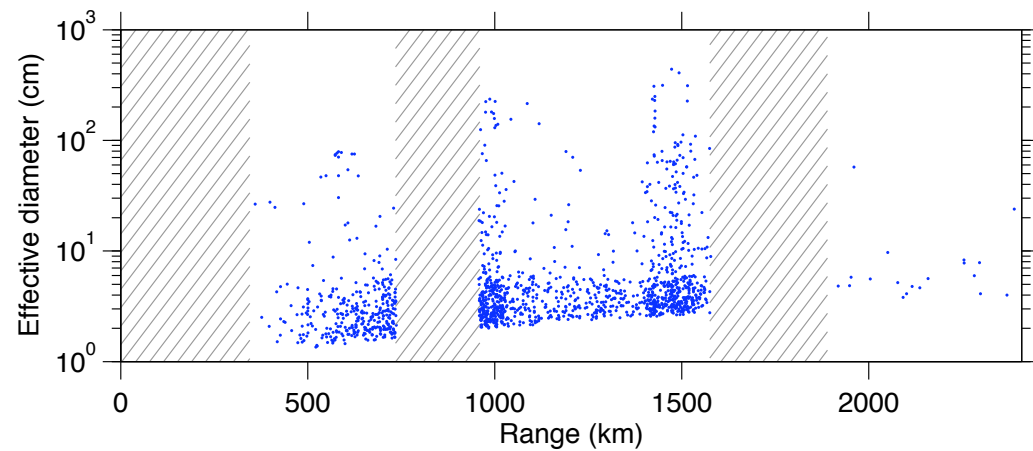


A variety of reception windows

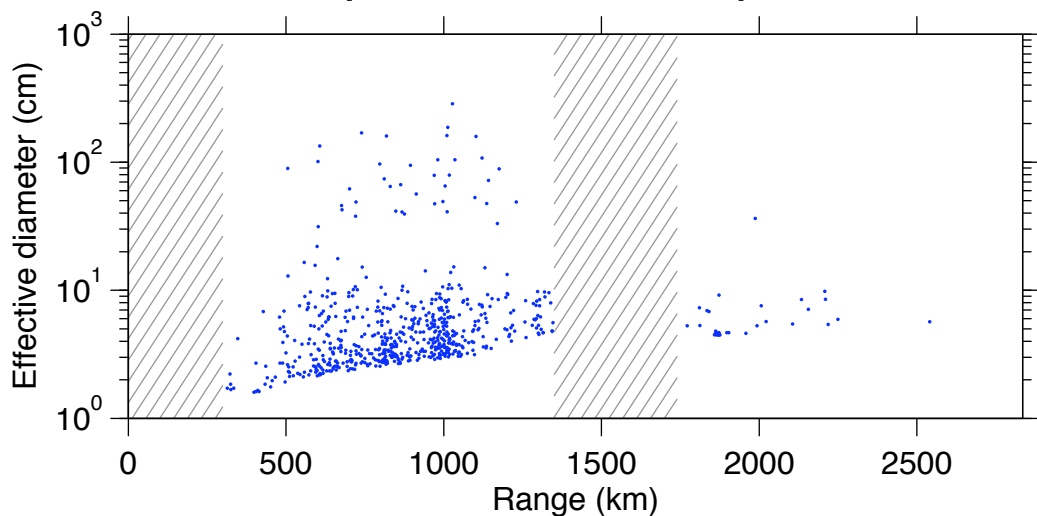
Manda (A 181 E 77)



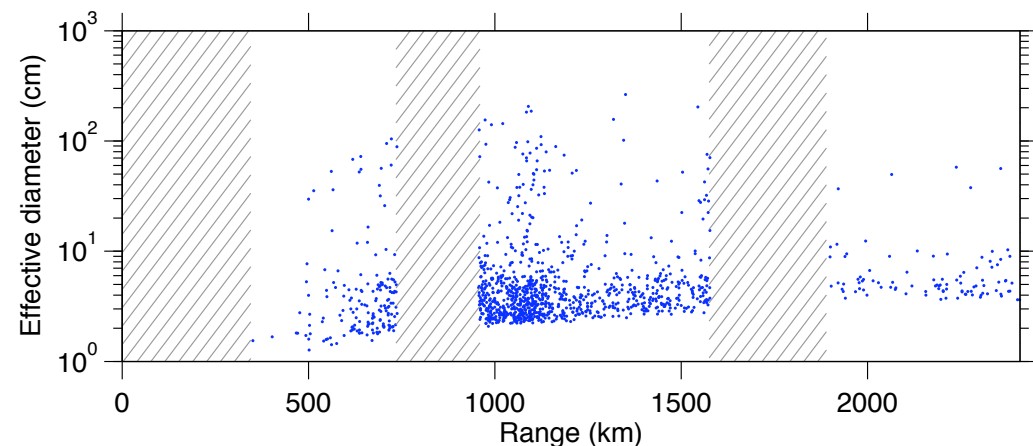
Tau2 (vertical)



Tau0 (A 182 E 82)

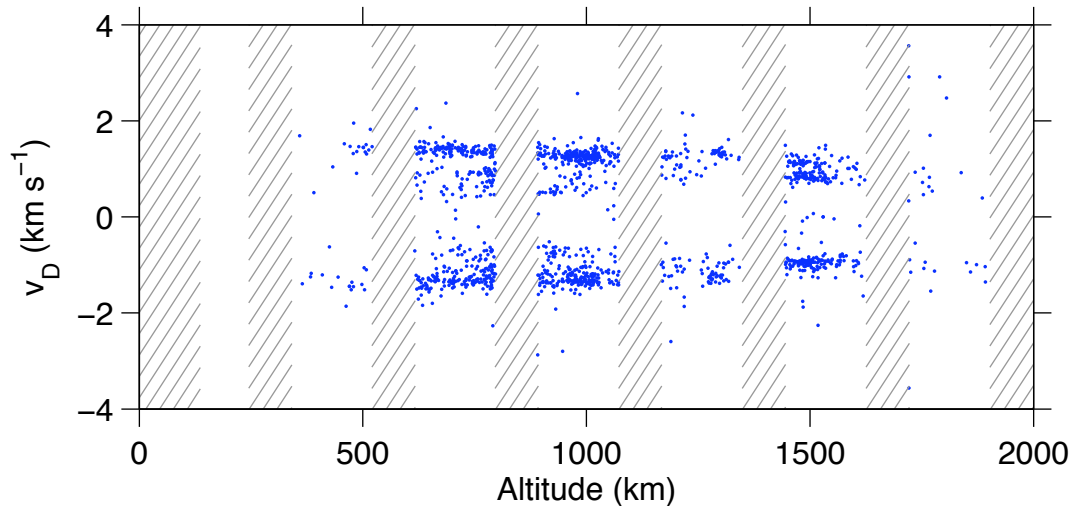


Tau2 (A 133 E 62)

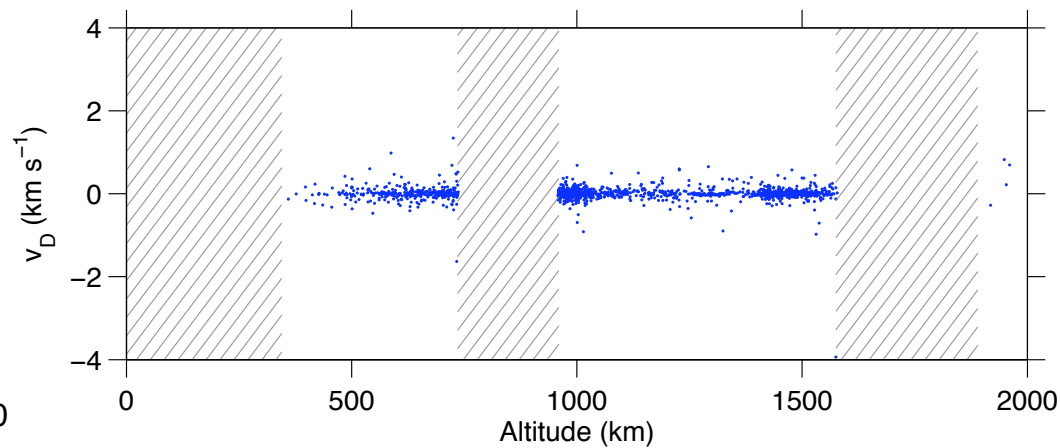


Reception windows

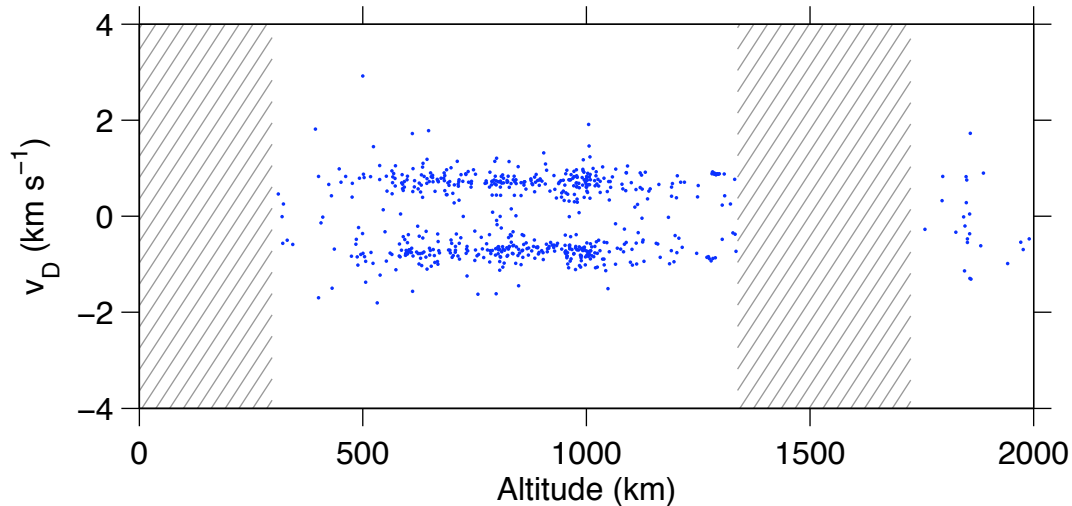
Manda (A 181 E 77)



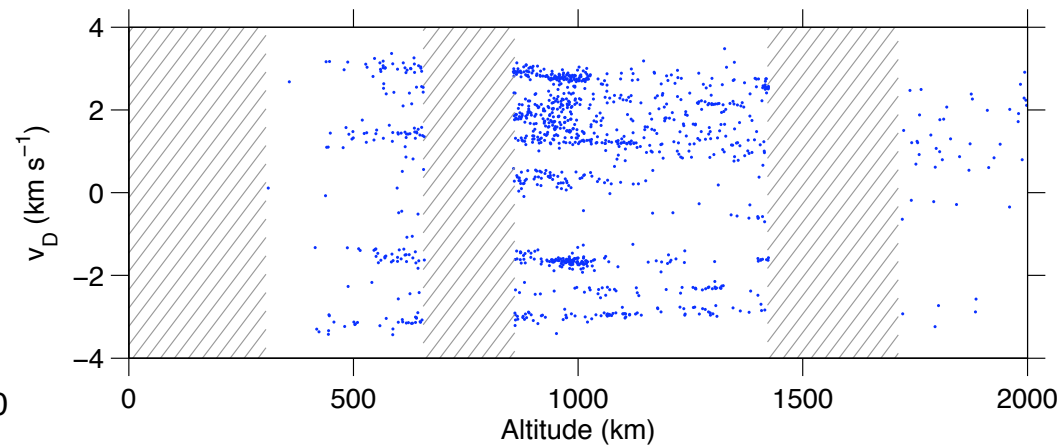
Tau2 (vertical)



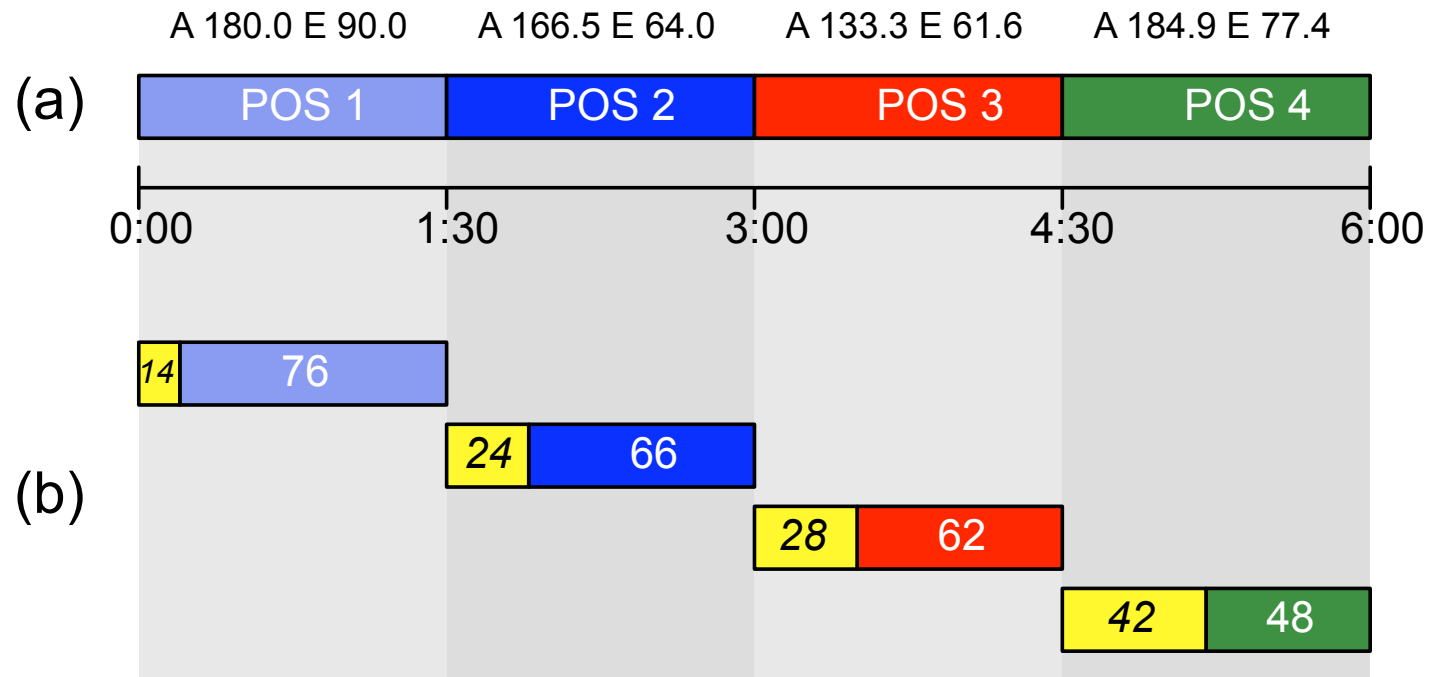
Tau0 (A 182 E 82)



Tau2 (A 133 E 62)



A variety of pointings

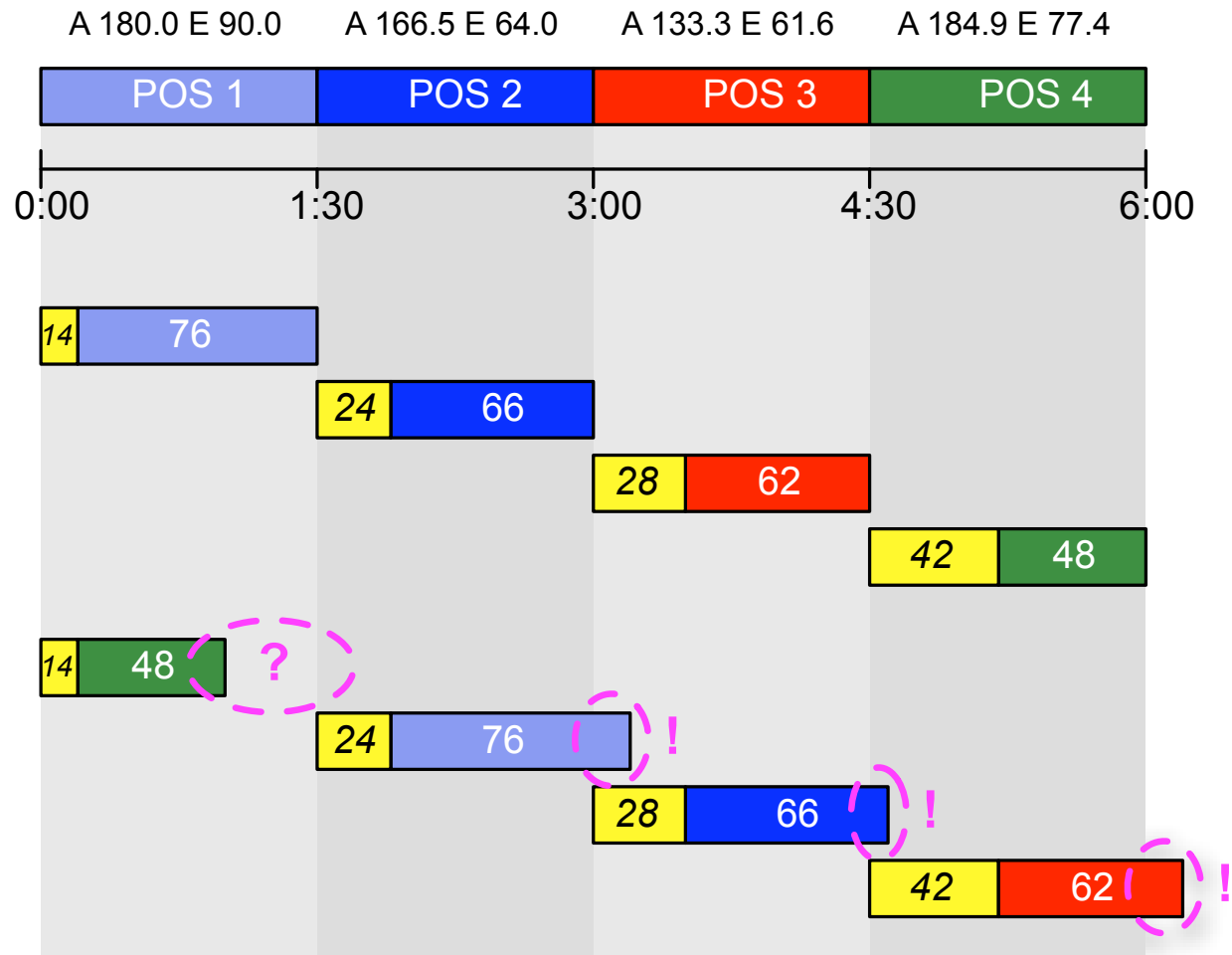


Tau2 CP2 at Tromso UHF 7-29 September 2005

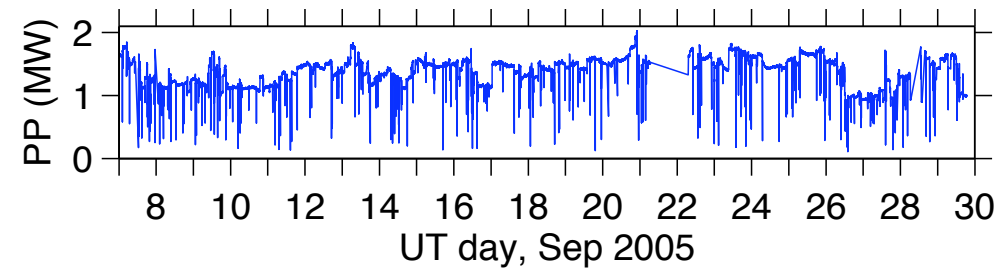
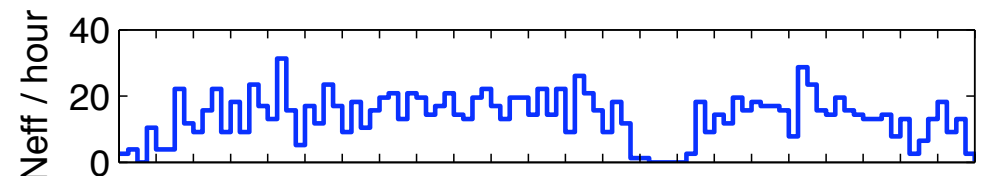
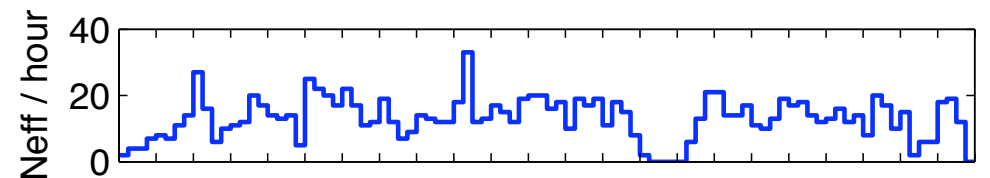
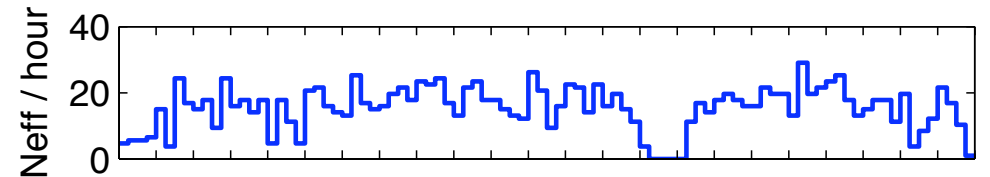
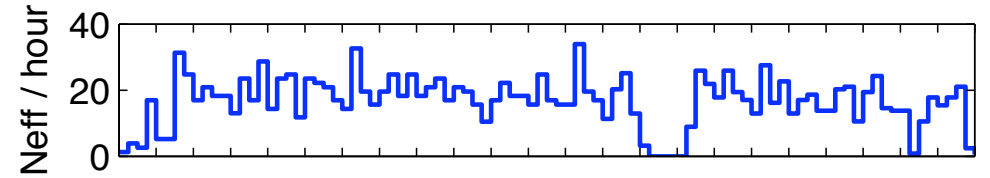
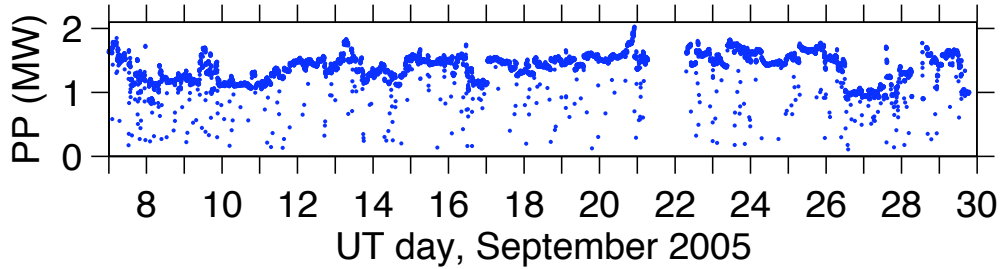
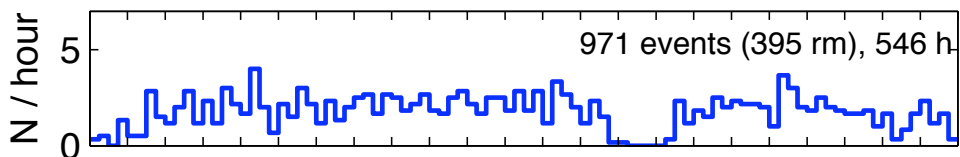
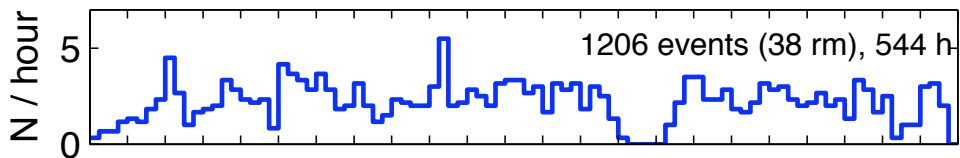
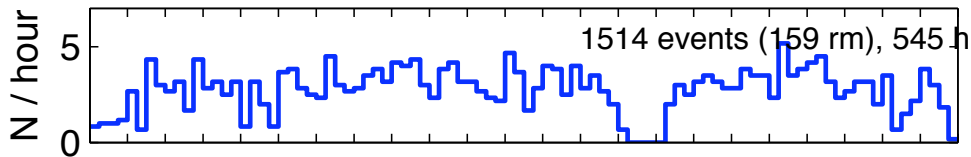
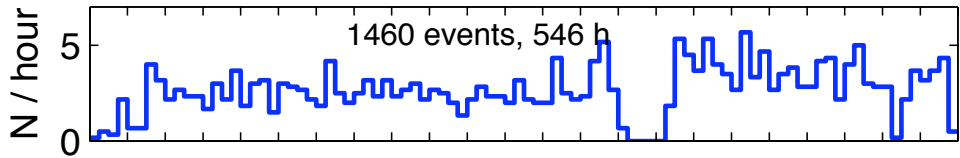
545 (-) hours, 5150 events



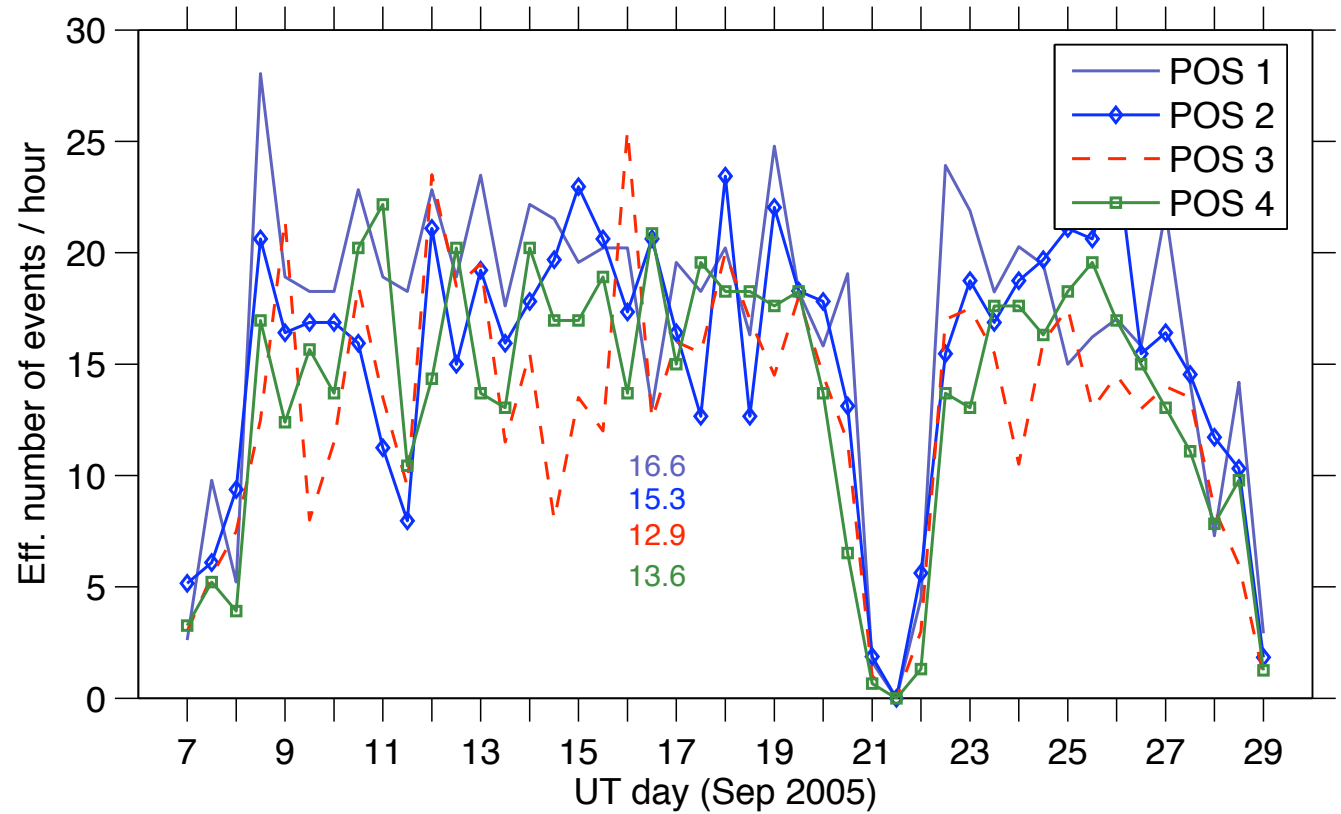
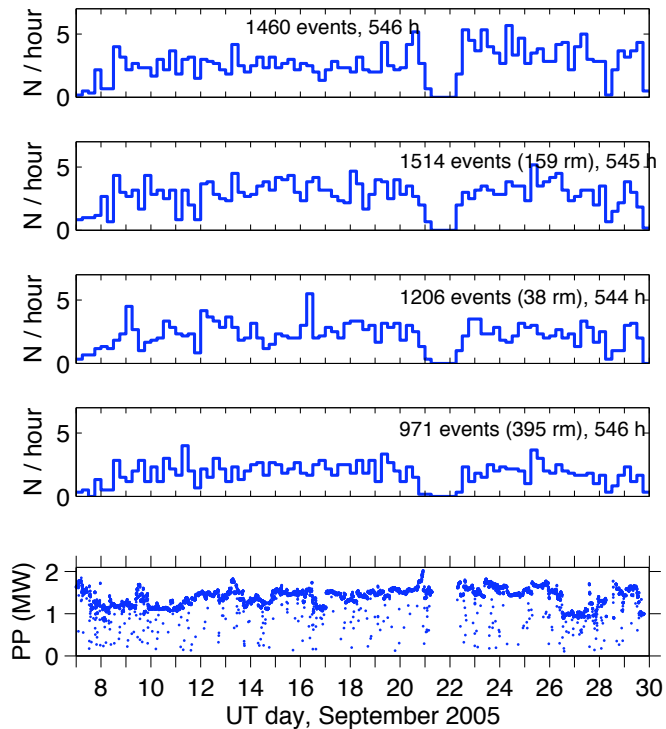
CP2 antenna pointing & SD recording



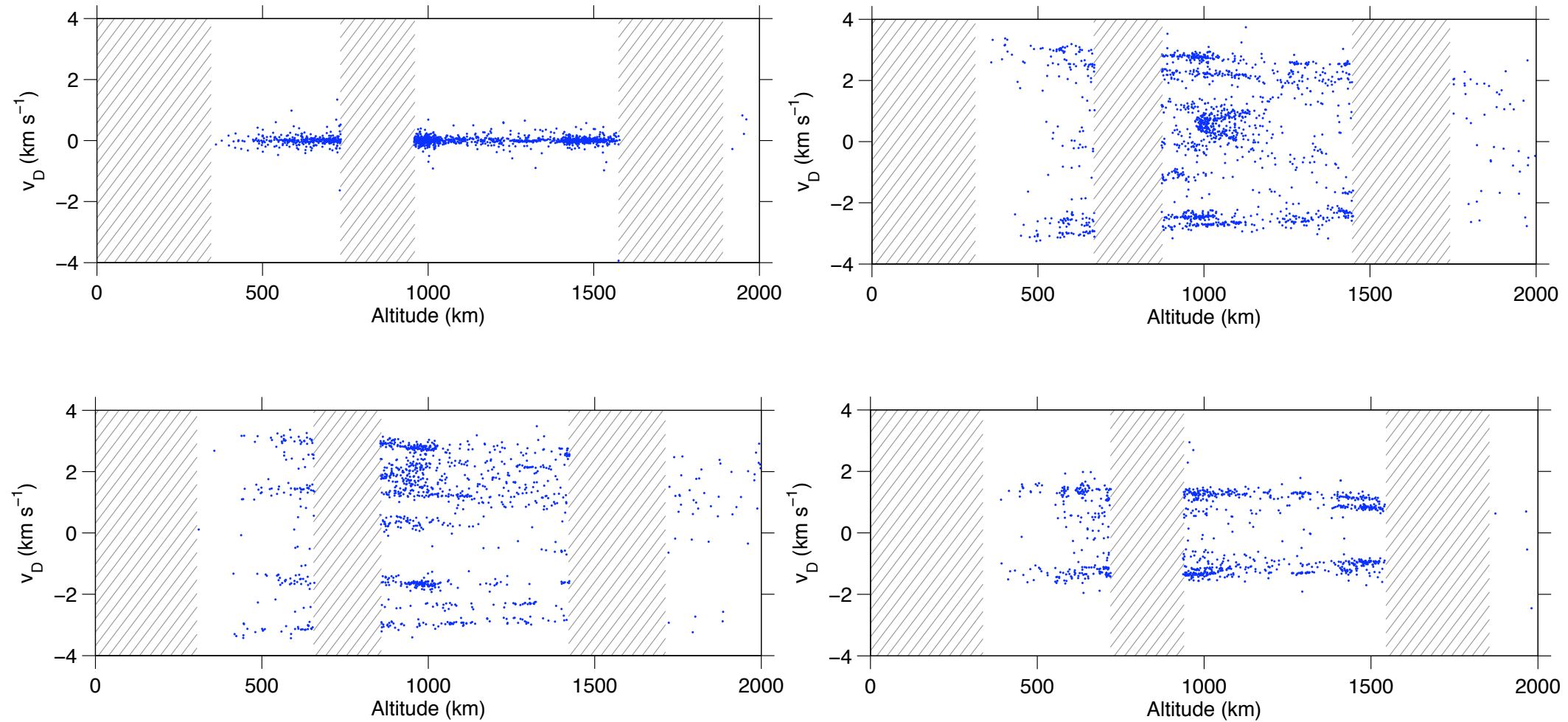
CP2 - Event rate v time



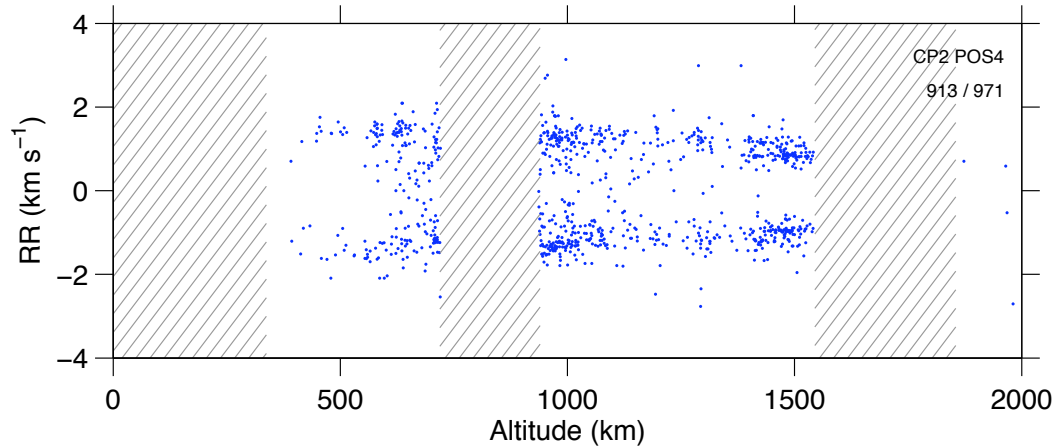
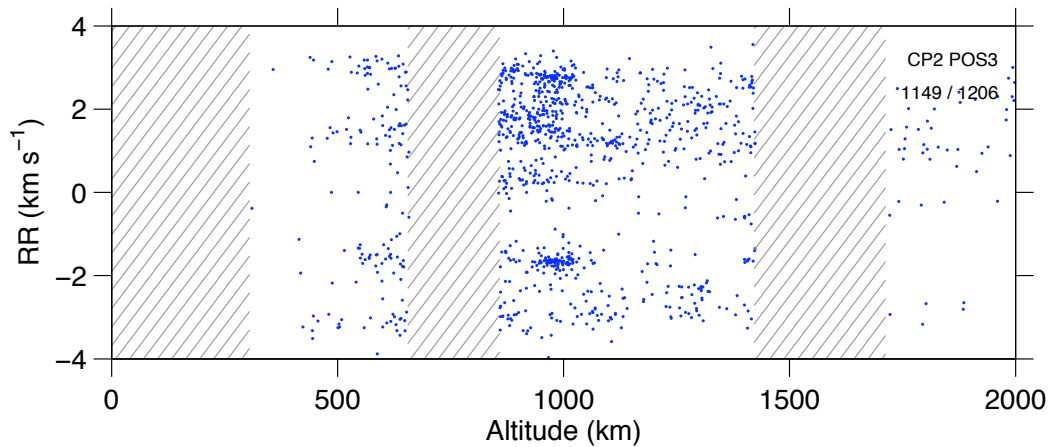
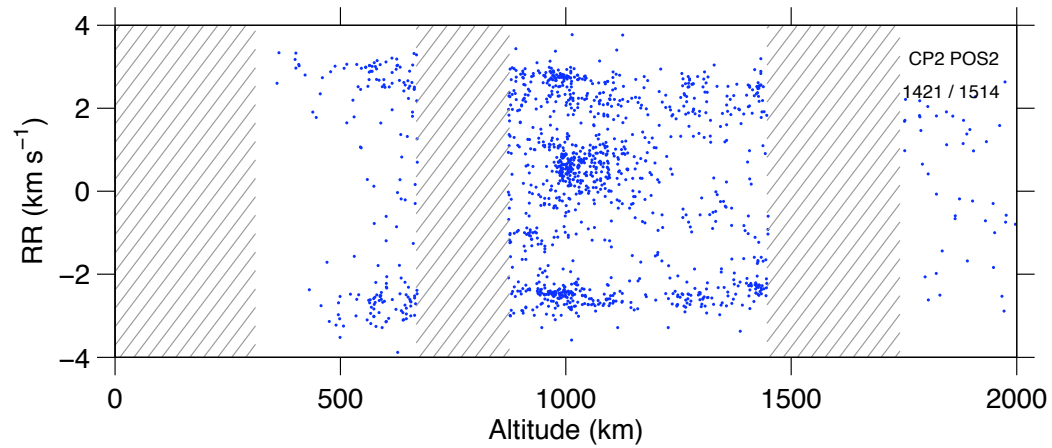
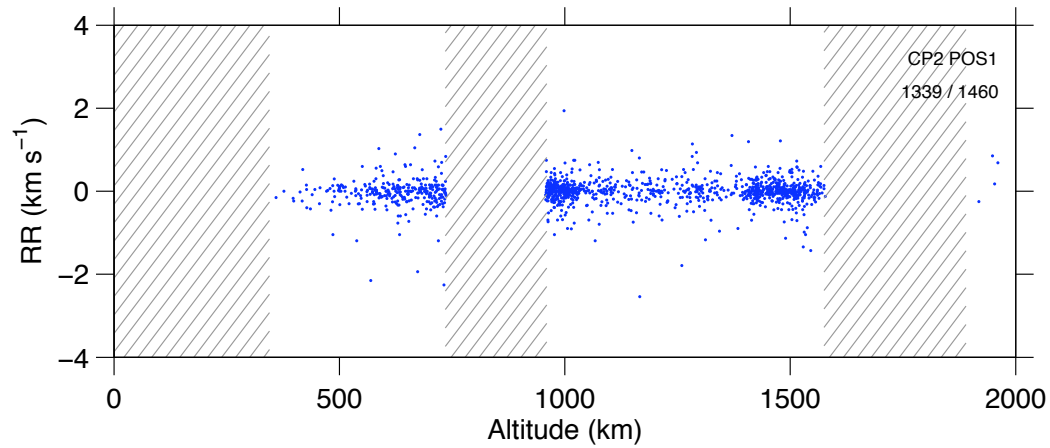
CP2 - Effective event rate v time



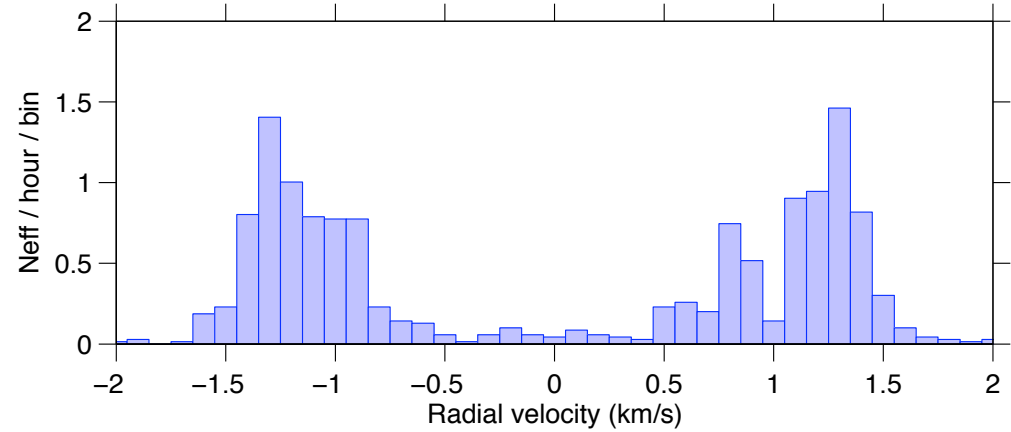
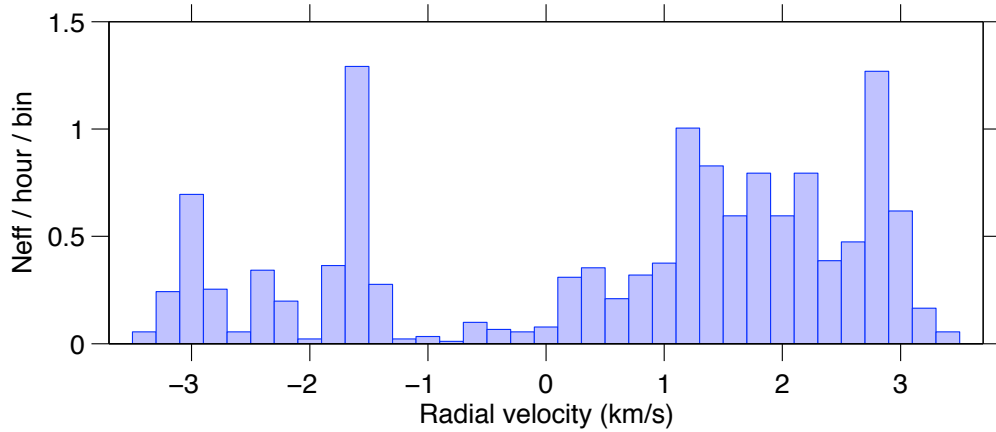
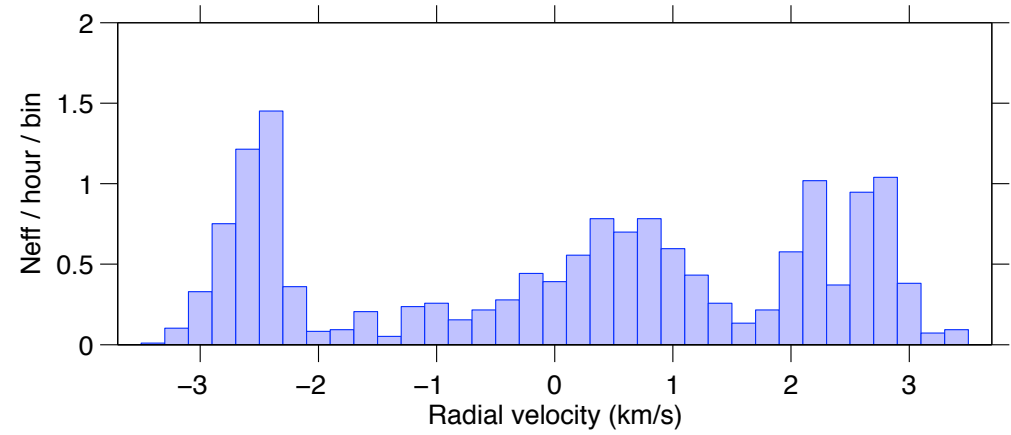
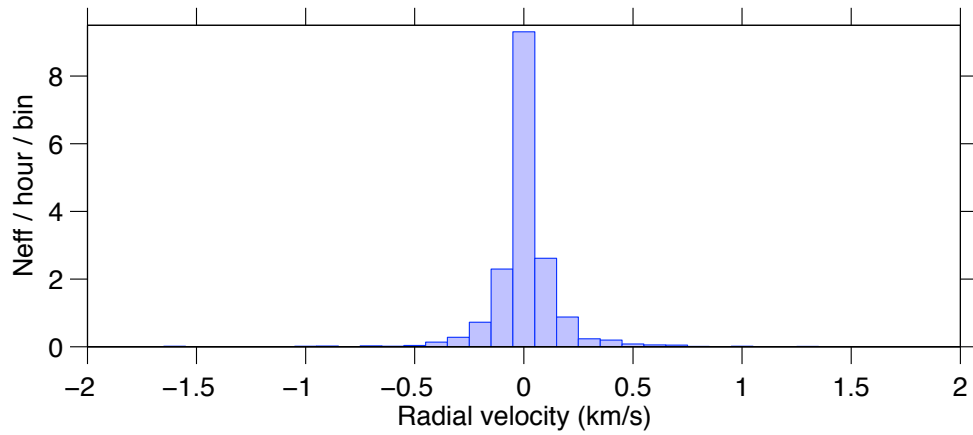
CP2 - V_r (from Doppler)



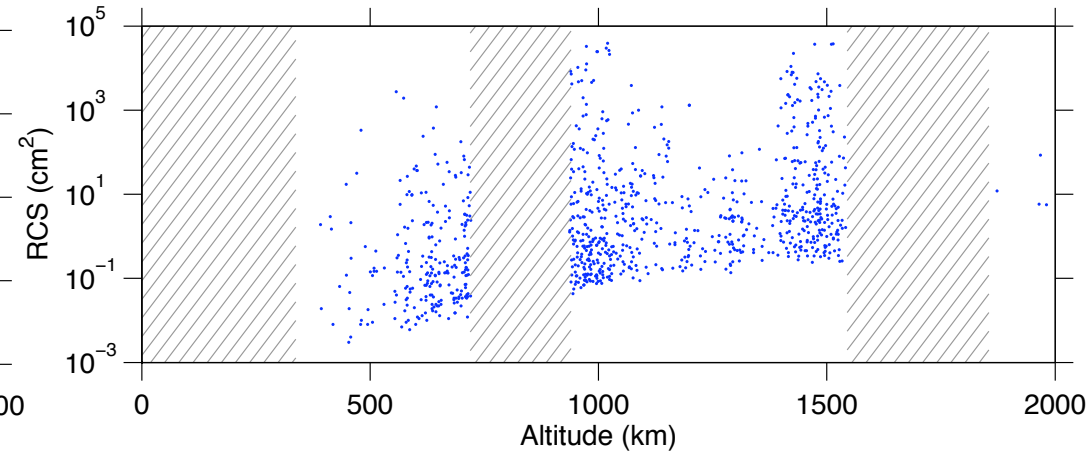
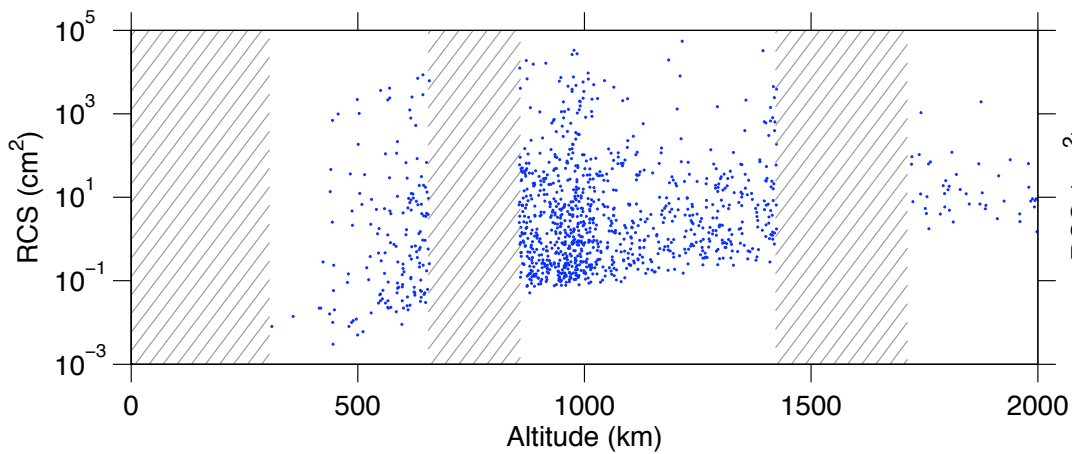
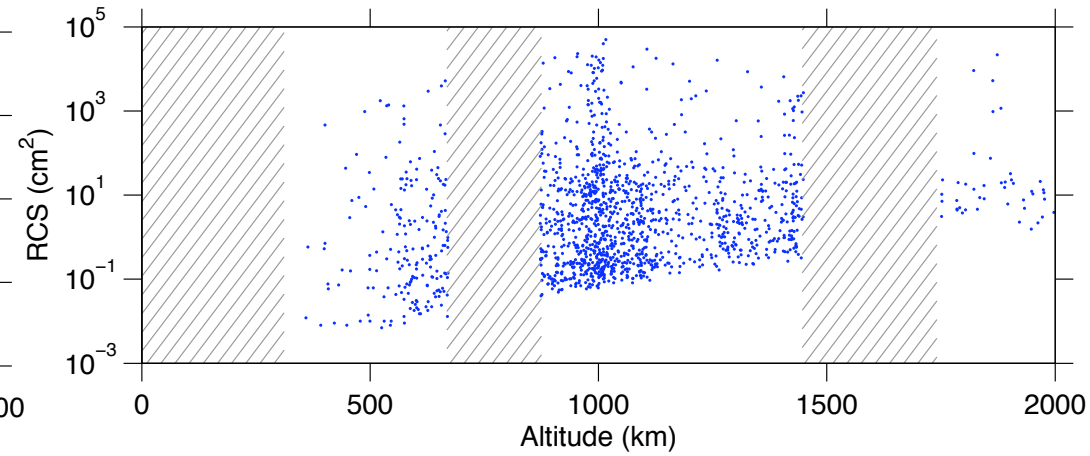
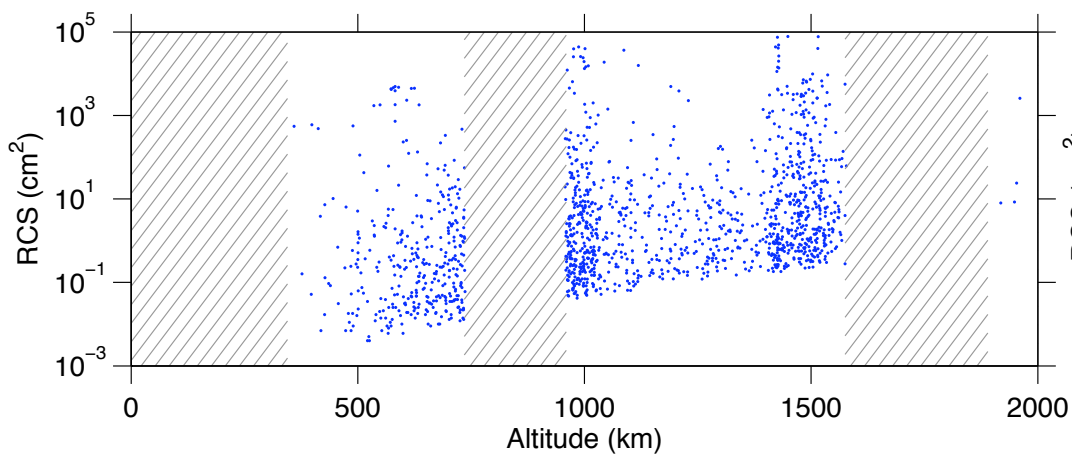
CP2 - V_r (from $R(t)$)



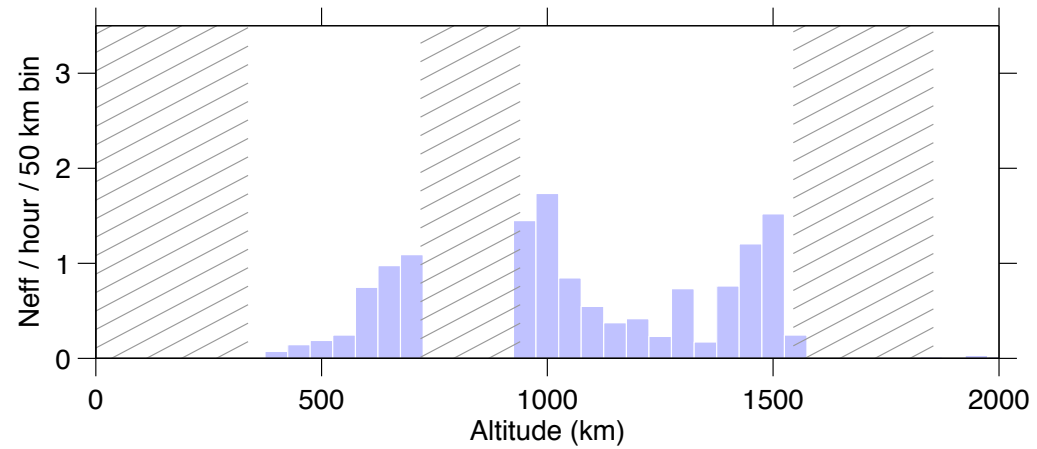
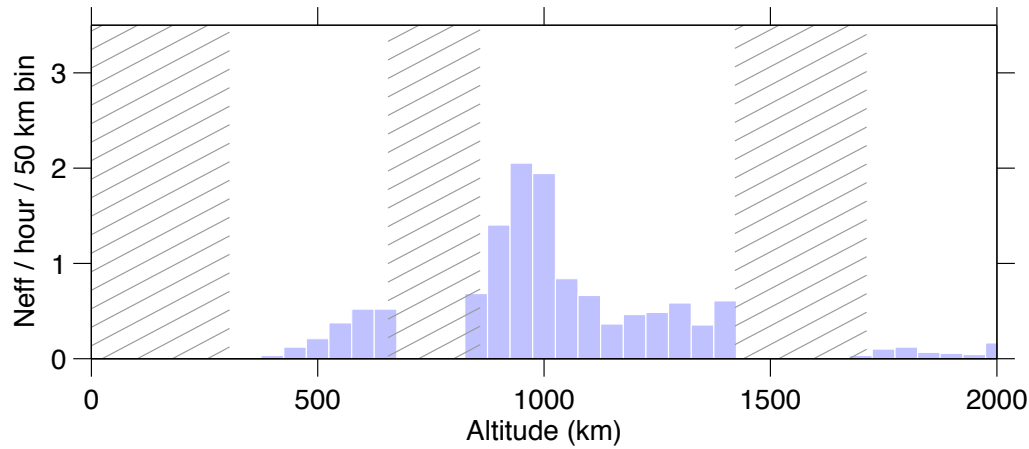
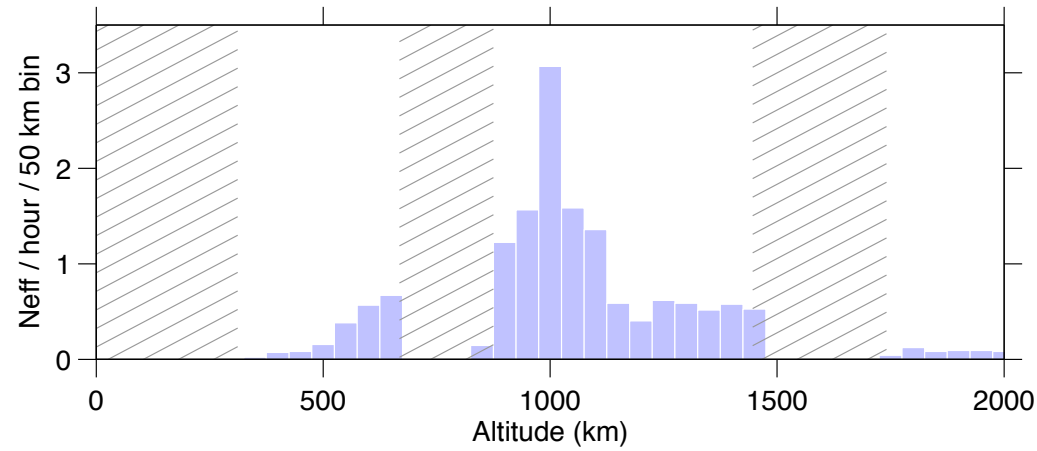
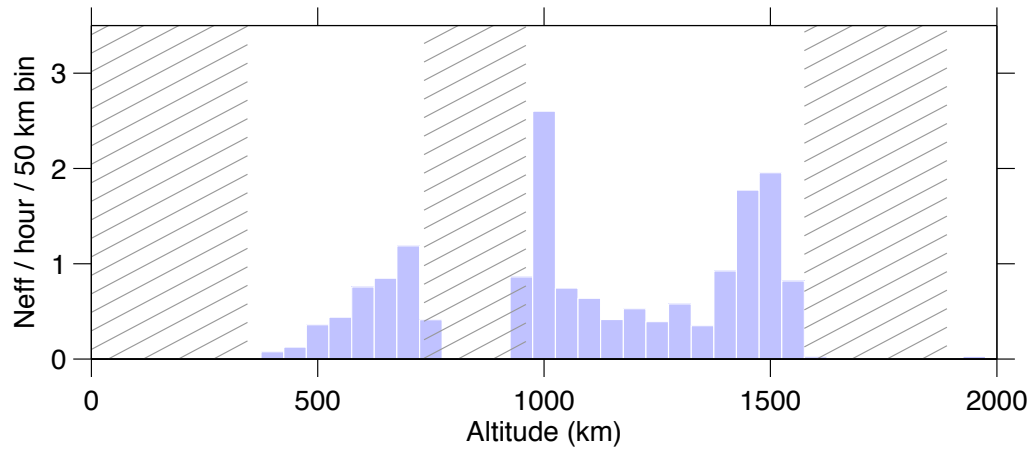
CP2 - V_r distribution



CP2 - RCS v Altitude



CP2 - Eff. event rate v Altitude

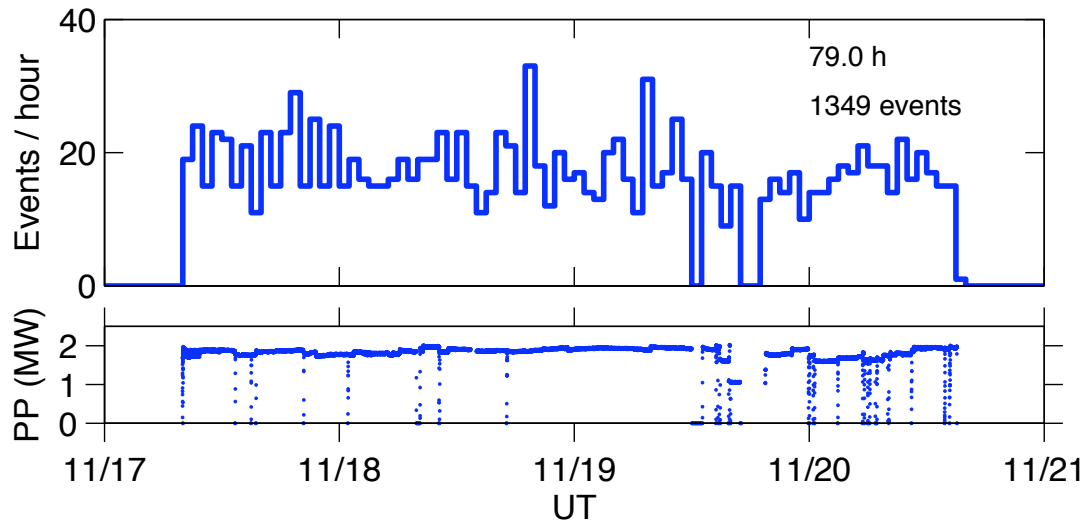


Manda CPI at UHF

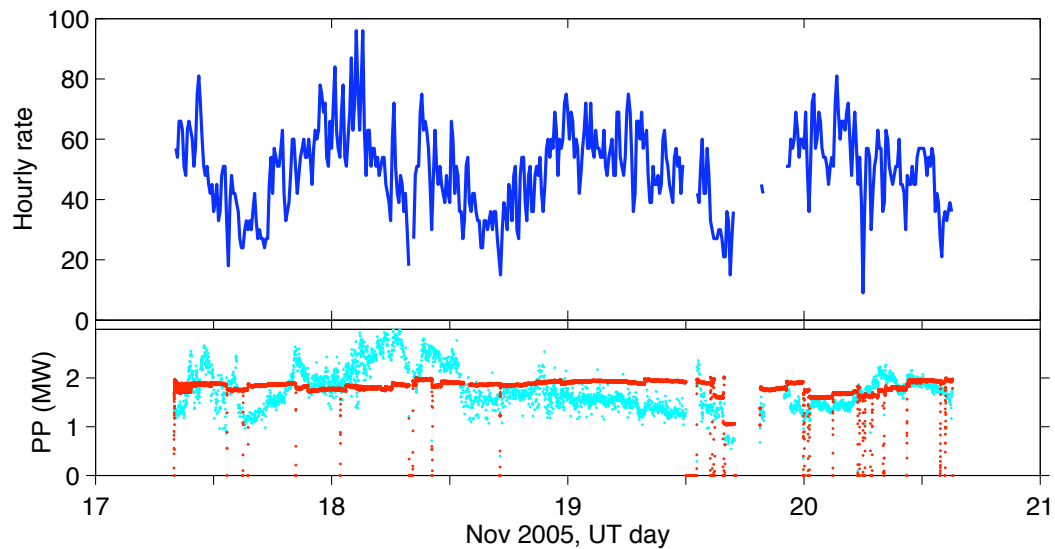
17-20 November 2005

79 hours, 1349 events (+ 3653 meteor events)

Manda - Hourly event rate



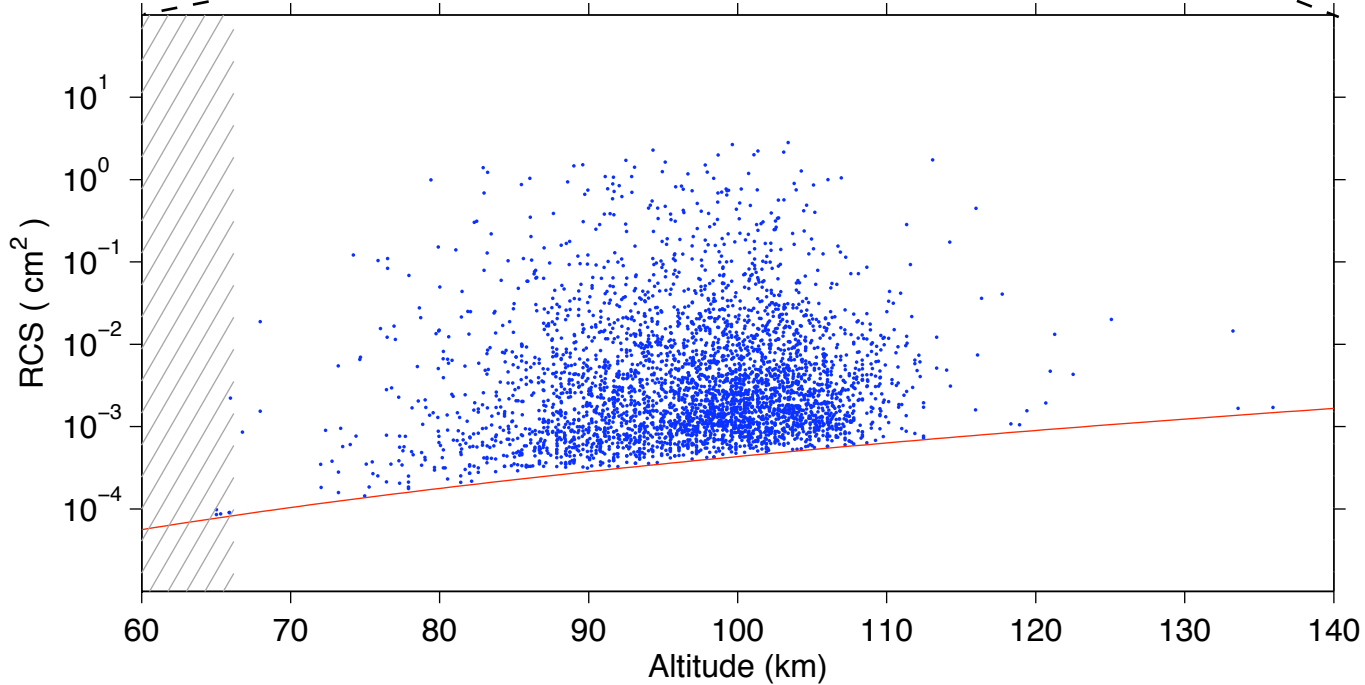
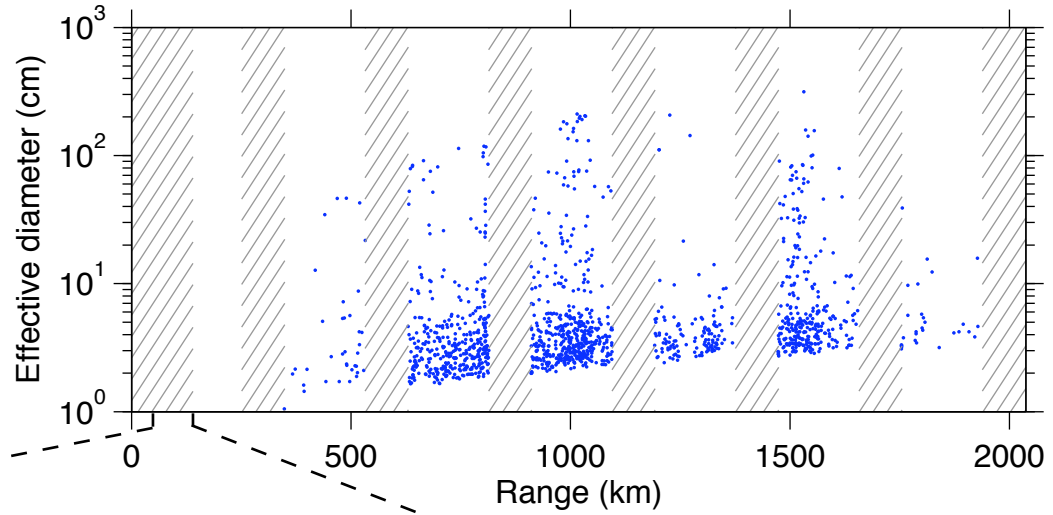
Debris events



Meteor events

Manda - Size

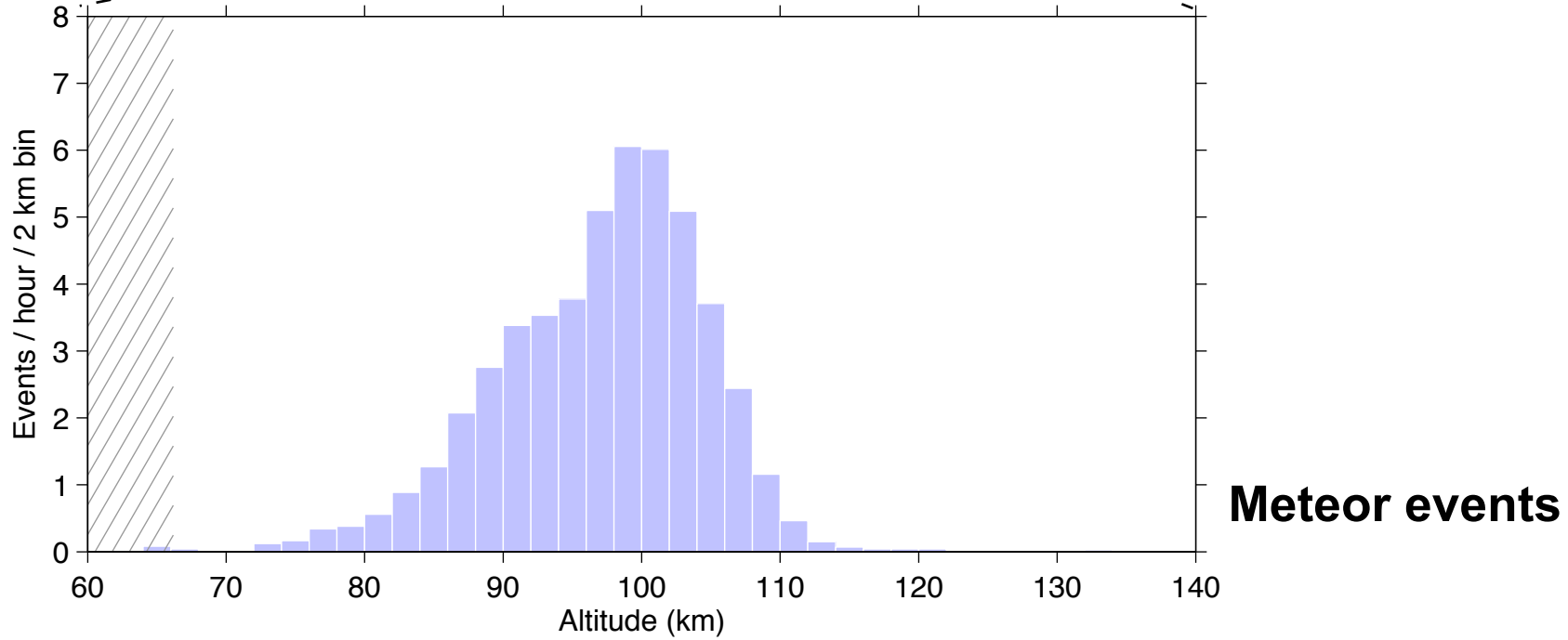
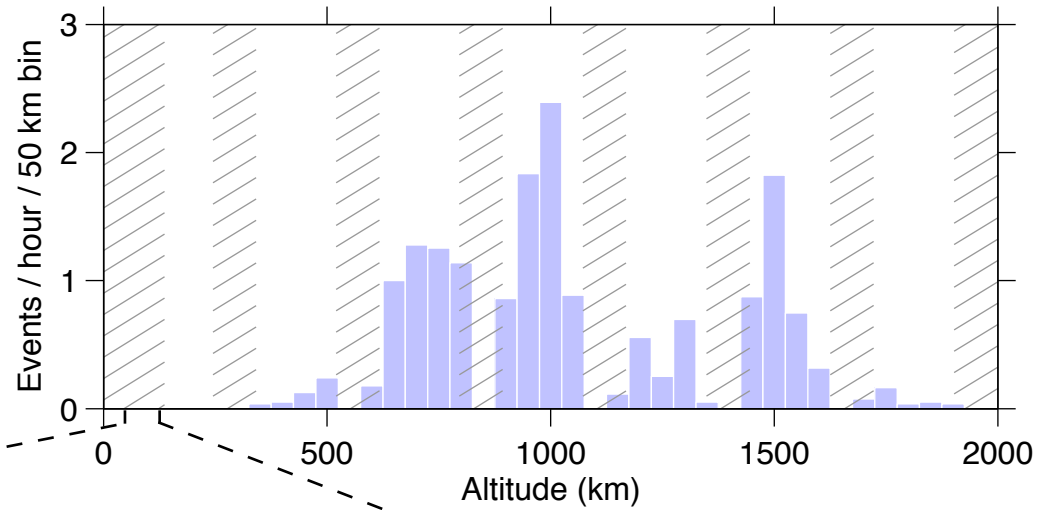
Debris events



Meteor events

Manda - Event rate v altitude

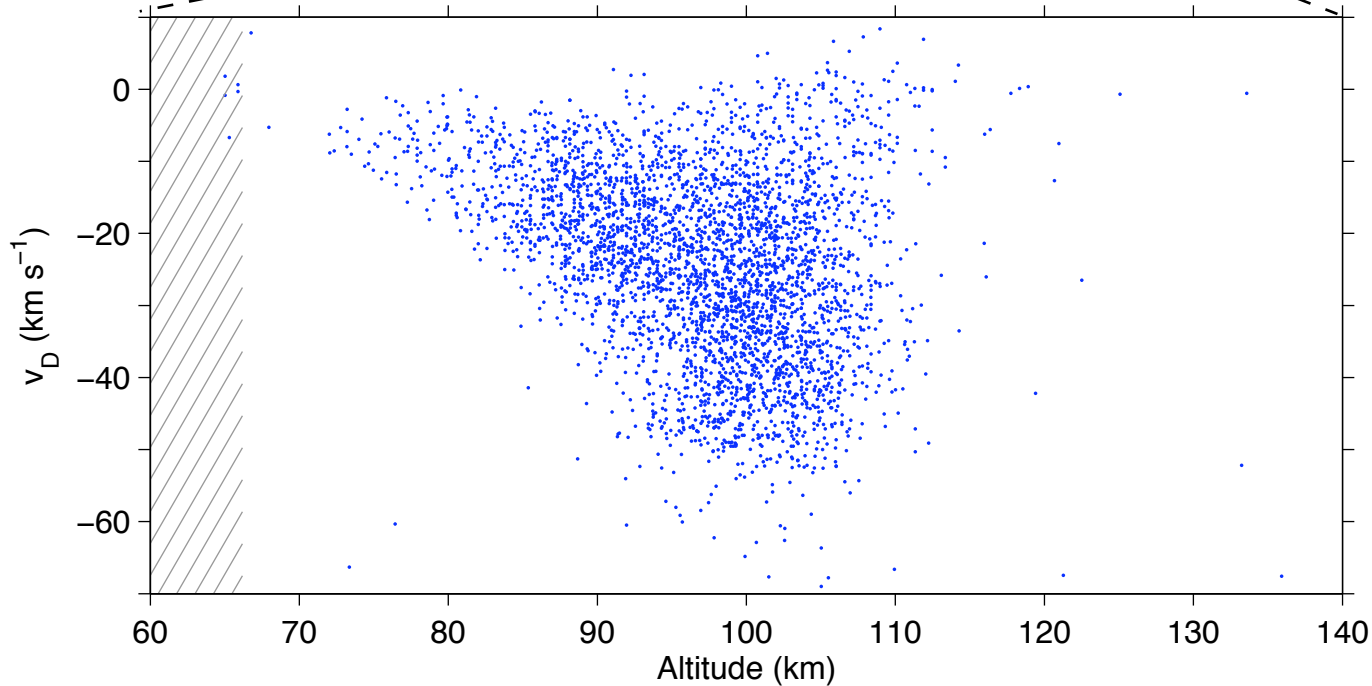
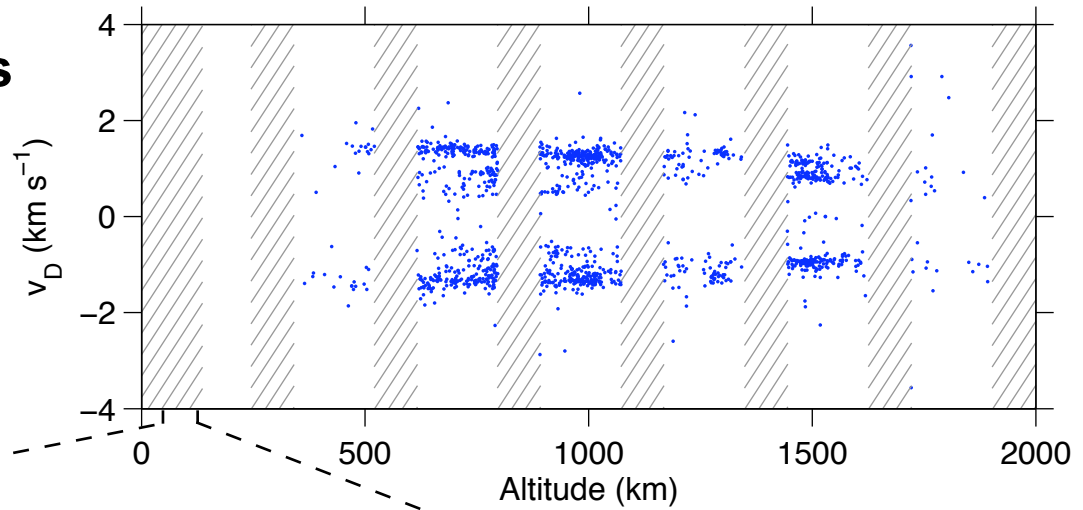
Debris events



Meteor events

Manda - Radial velocity

Debris events



Meteor events

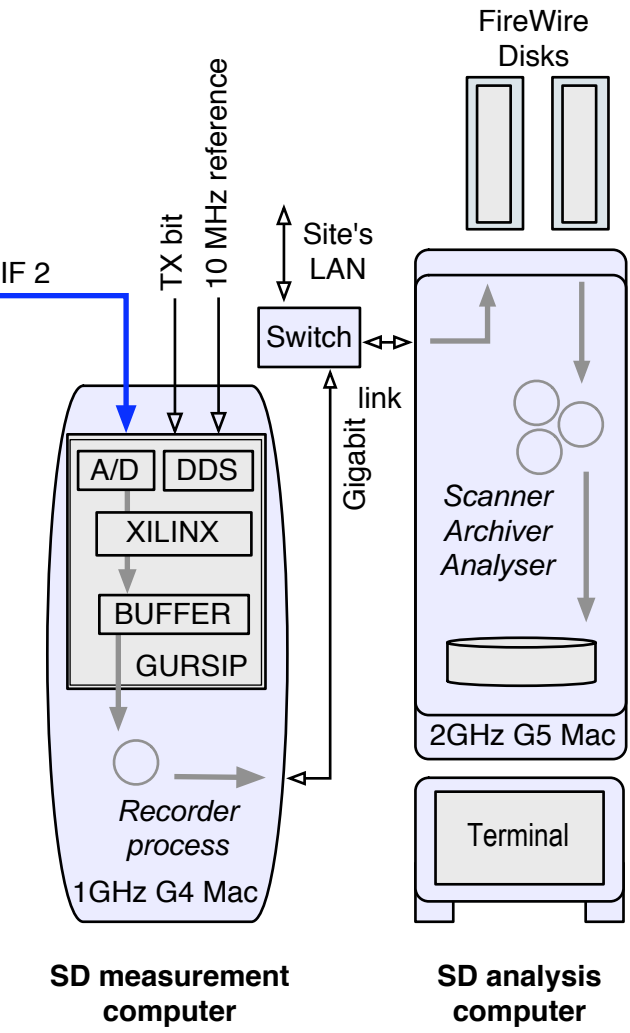
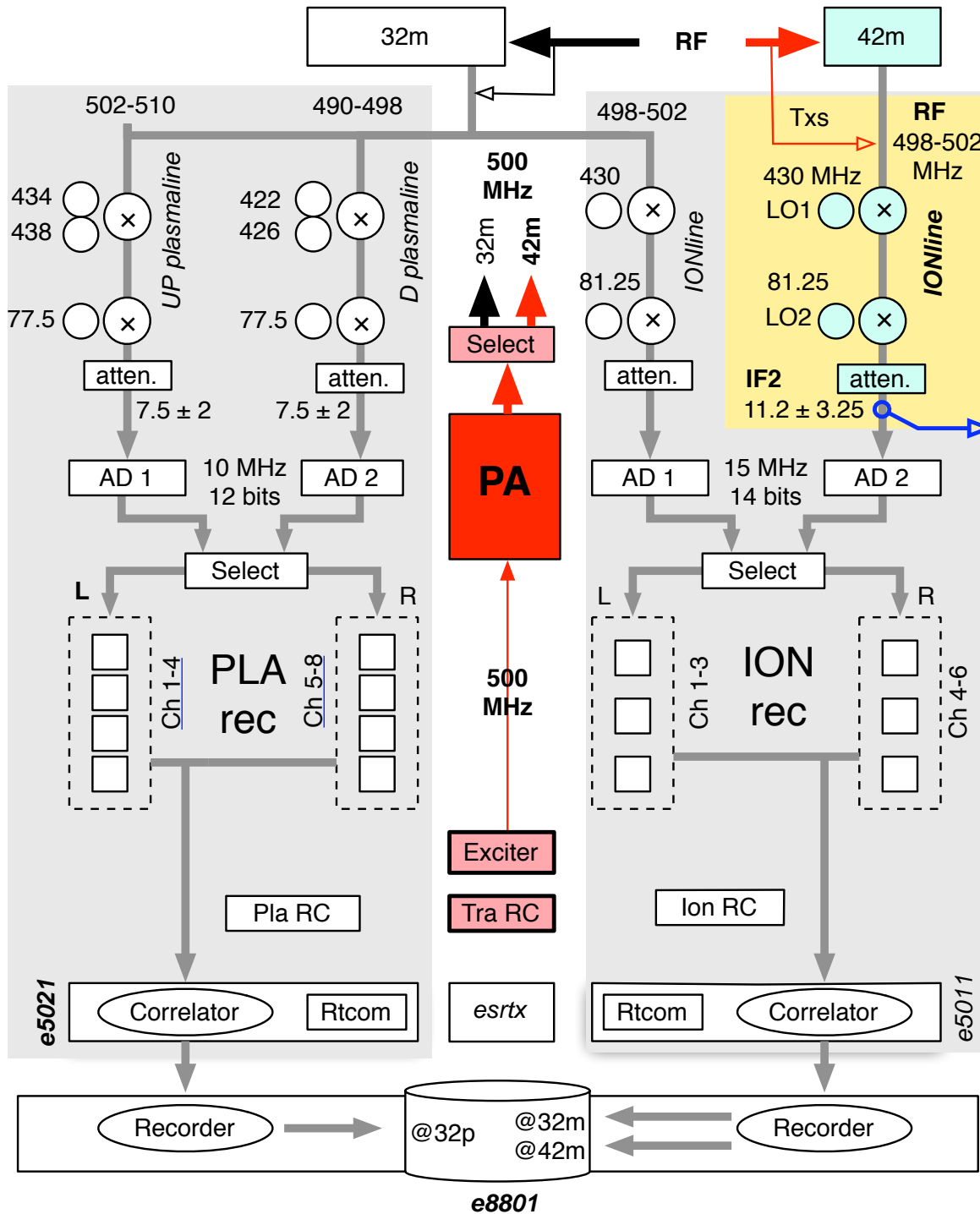
Tau0 CP3 at ESR

10 November 2005

24 hours, 650 (+455) events

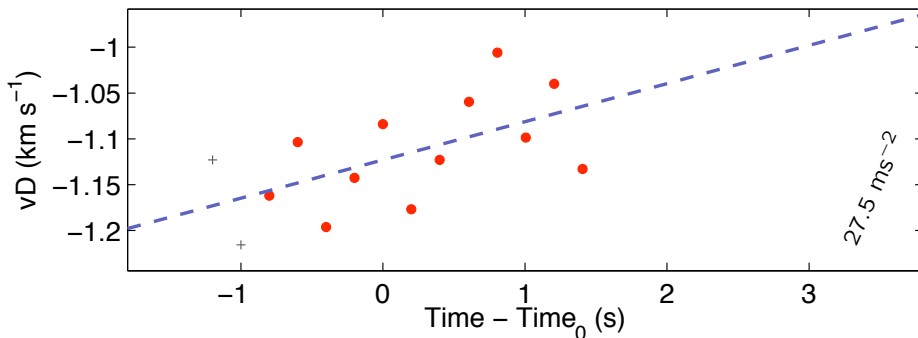
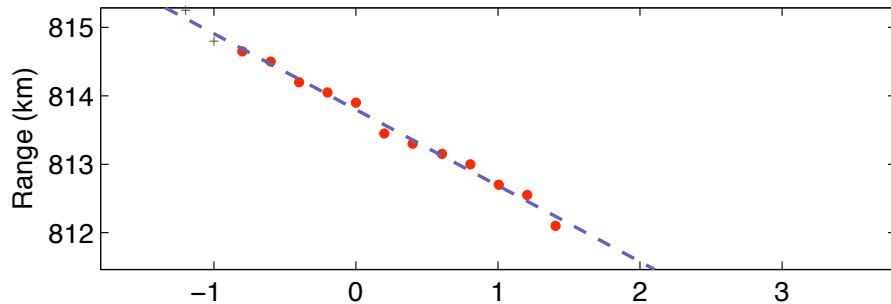
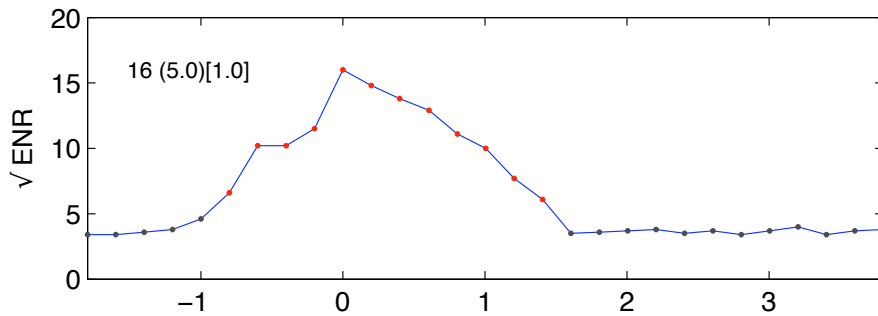


SD@ESR



Tau0 - an event

10-Nov-2005 00:31:49.2 tau0_1000 42M<182.1/81.6> 17
 FMF(15) Tc=0.2 s Ch1,2 dR=0.15 km <Tx=0.8 Ts=70> T/N=32.52
 R=813.8 vD=-1.12 d=3.8 RR=-1.11 aD=42 aRR=NaN aTH=61.4(59.5)



U20051110_003147_405.epar

```
% VS File format version ID.
% NM Event name UT.
% XI Experiment ID string.
% TM UT of max Ratio.
% ST System temperature K.
% AG Antenna gain dB.
% WL Radar wavelength m.
% TX Transmission power MW.
% AZ Azimuth degr, N=0, E = 90.
% EL Elevation degr.
% RT Max Ratio ( = estimate of sqrt(SNR_N)).
% RG Range km.
% RR Range rate (km/s).
% VD Doppler velocity (km/s), positive away from radar.
% AD Acceleration from VD, m/s^2.
% DI Effective diameter cm. Estimated from ST, PW, RT. RN, AG, WL.
% CS log10 of a lower bound of radar cross sectio cm^2. Estimated as DI.
% TS (Transmission sample power)/(Noise power), dB, arbitrary reference point.
% EN Event number.
% ED Event duration, seconds.
% TP Transmission sample power, dB, arbitrary reference point.
```

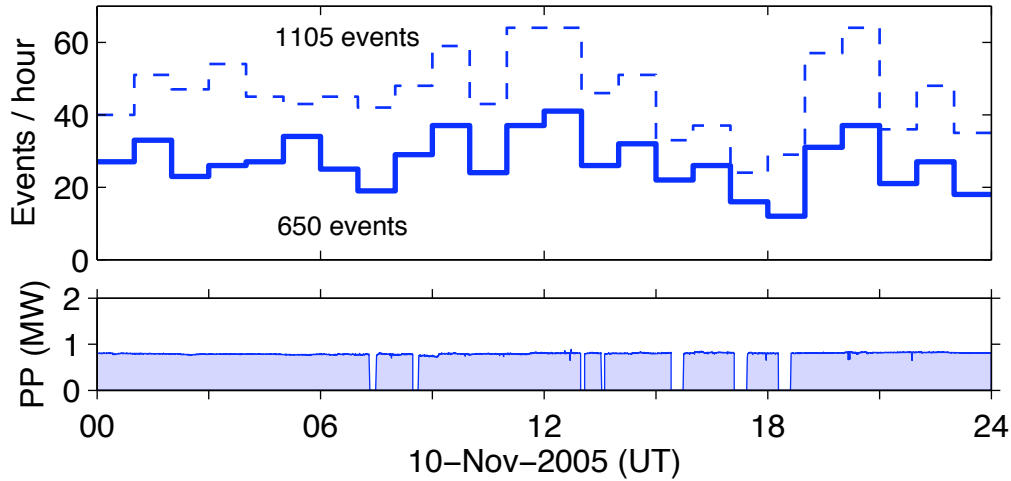
% NaN = Bad.

% 04-Dec-2005 01:09:19

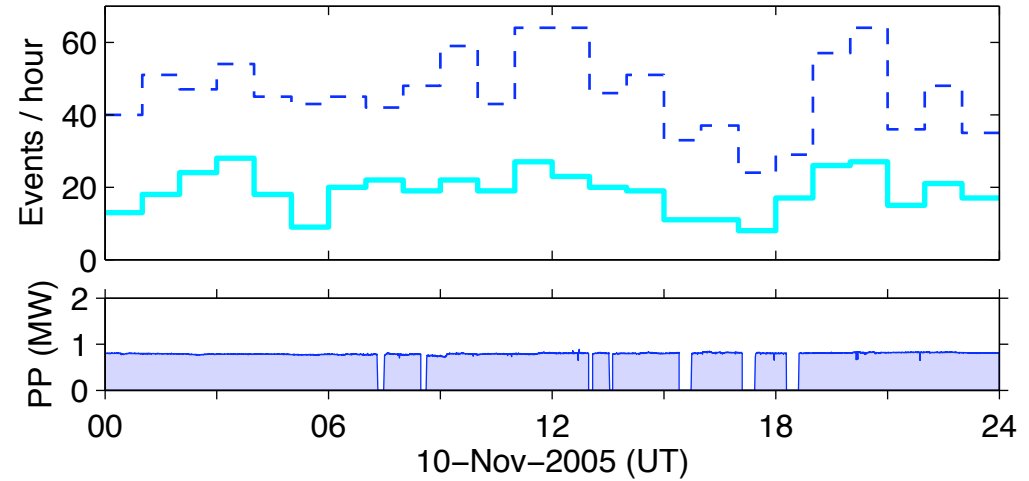
```
VS = 1.0
NM = U20051110_003147_405
XI = tau0_1000
TM = 2005 11 10 00 31 49.207
ST = 70
AG = 45.3
WL = 0.600
TX = 0.80
AZ = 182.1
EL = 81.6
RT = 16.0
RG = 813.798
RR = -1.111
VD = -1.123
AD = 41.71
DI = 3.81
CS = -0.790
TS = 32.515
EN = 17
ED = 2.204
TP = 74.750
```

Tau0 - hourly event rate

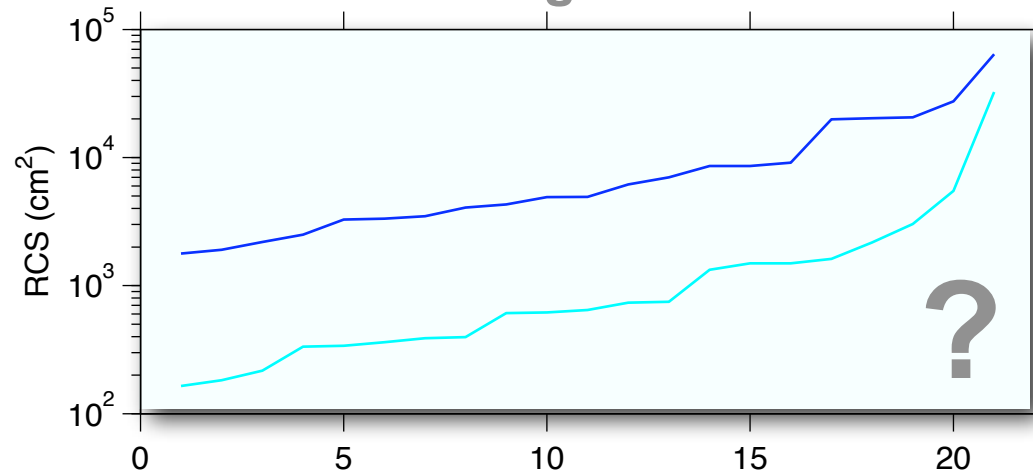
regular events



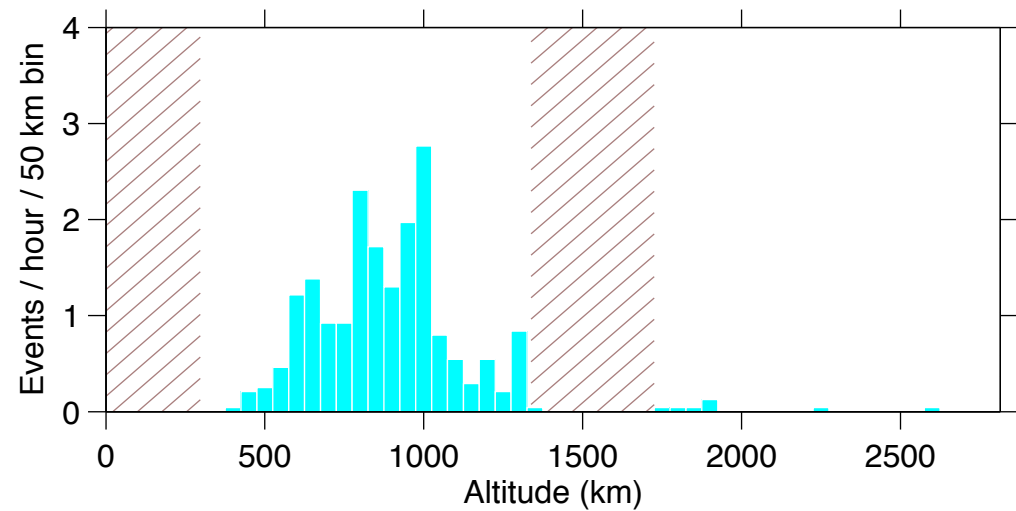
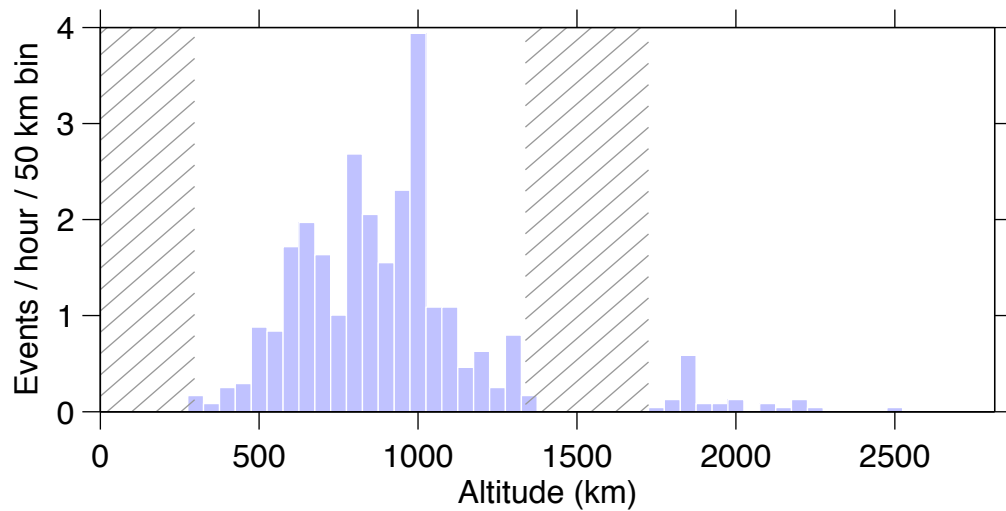
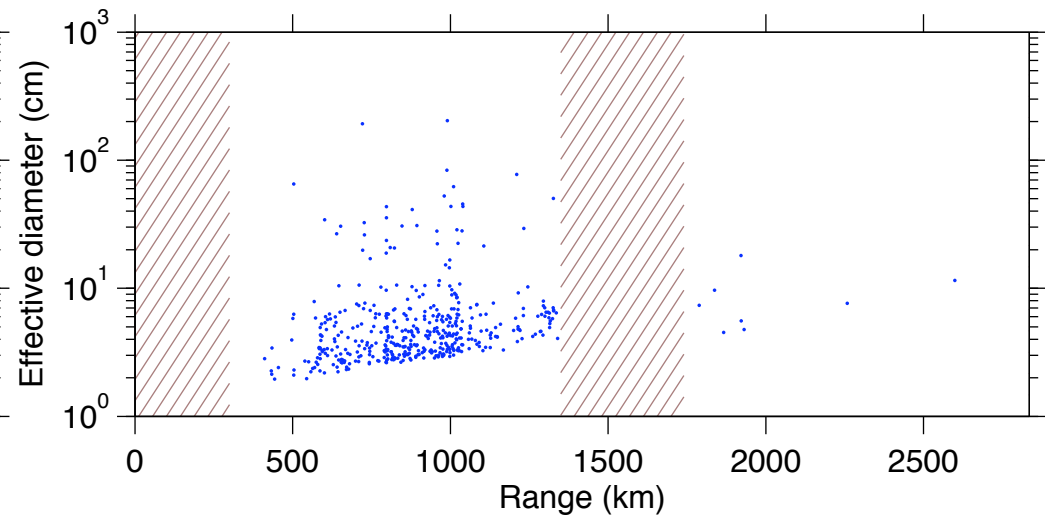
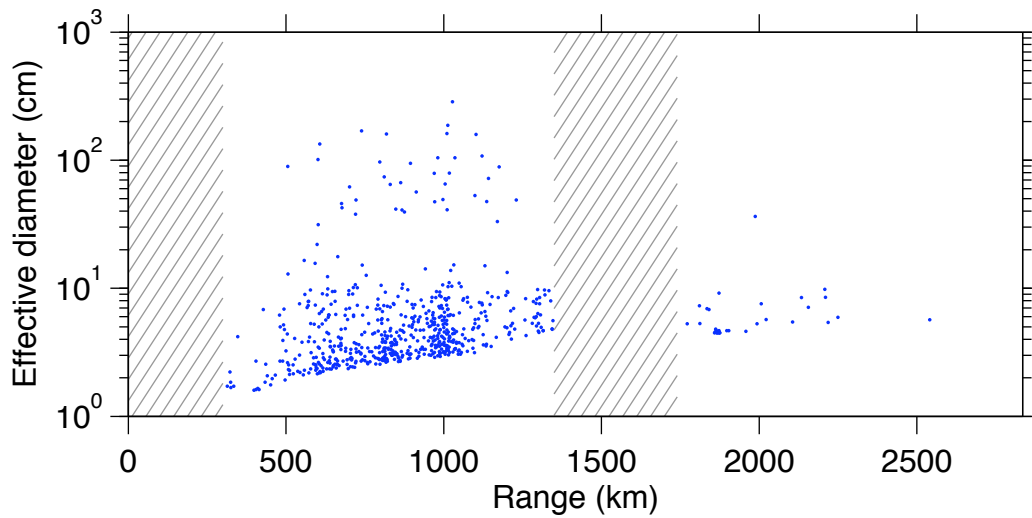
bonus events



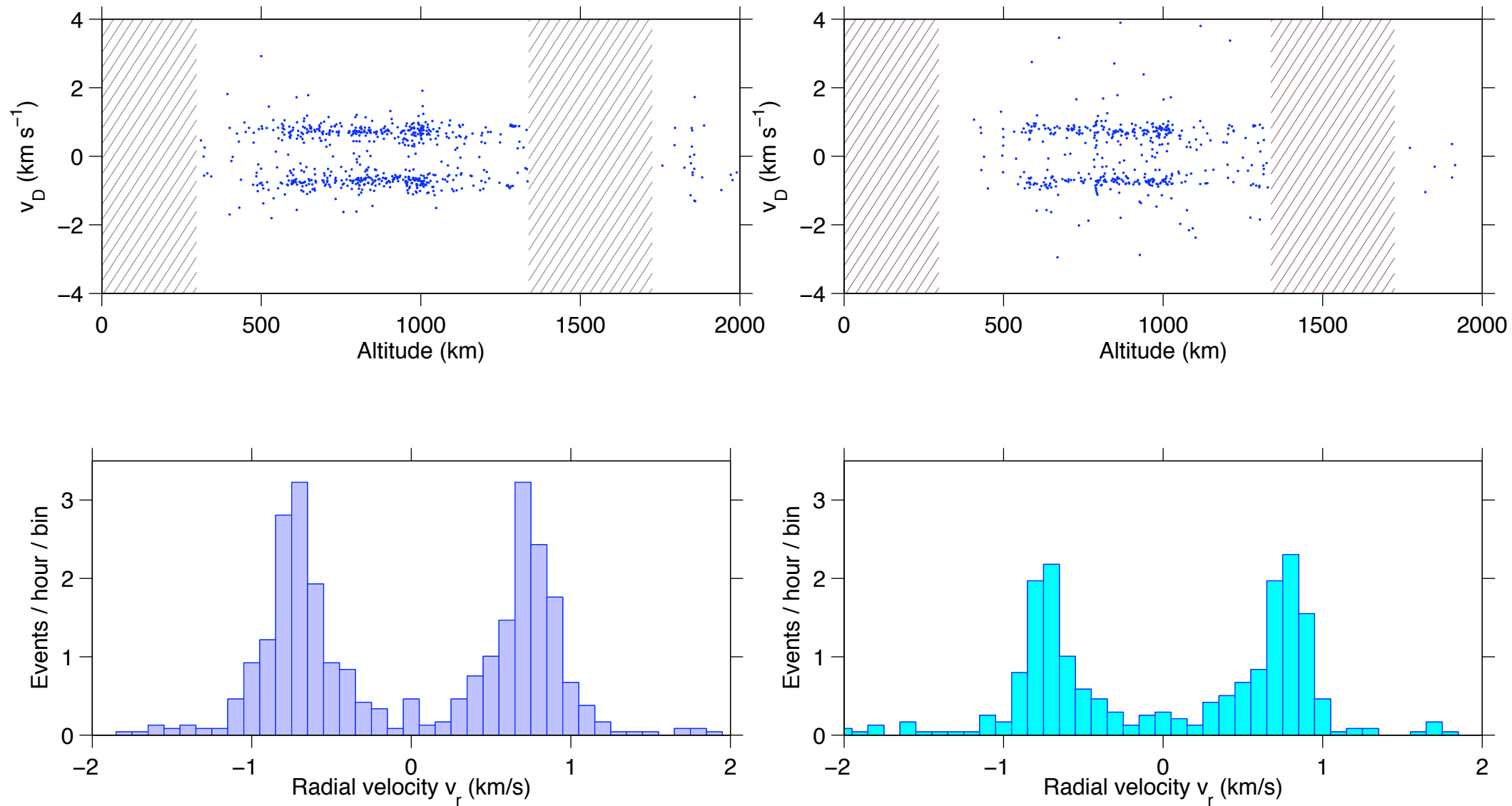
20 largest RCS



Tau0 - diam. v range



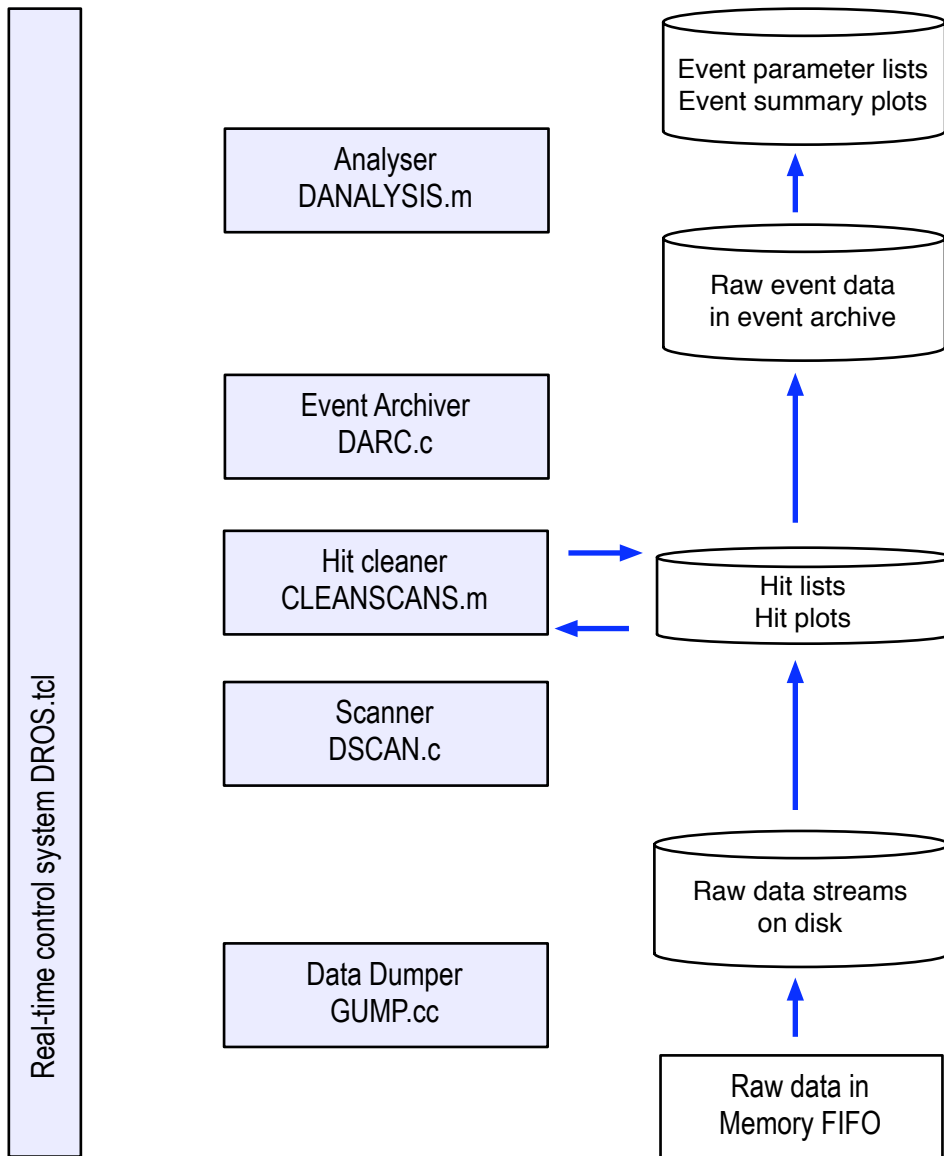
Tau0 - radial velocity



WP I

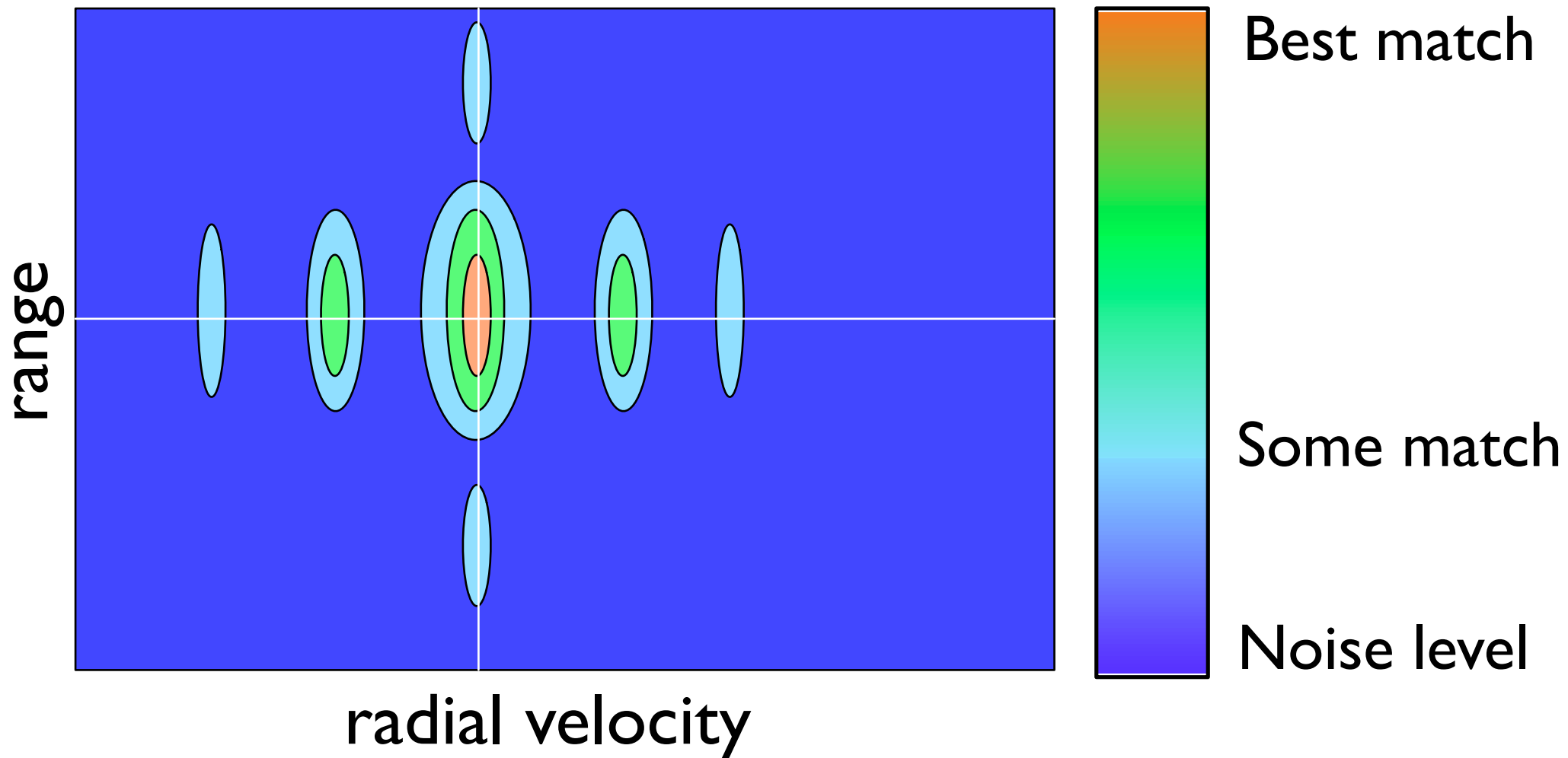
Updating data processing methods and algorithms

Updating of data processing

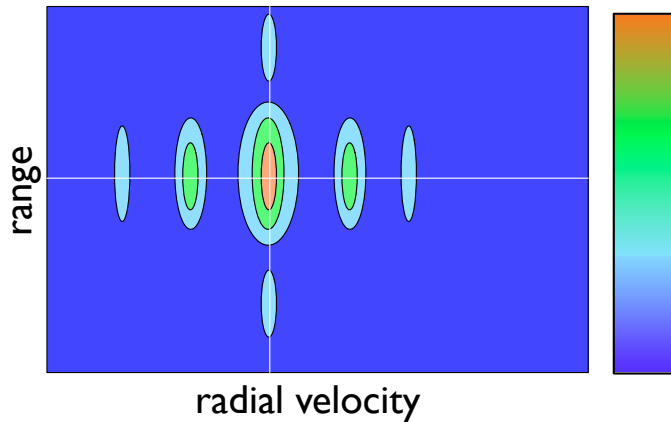


The match function

$$MF(v, R)$$



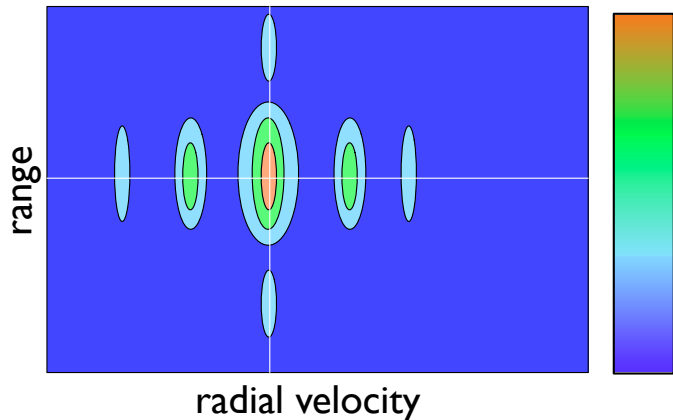
The match function



$$\text{MF}(v, R) = \frac{|\langle \mathbf{s} + \gamma, \chi_{v,R} \rangle|}{\|\chi_{v,R}\|}$$

$$\chi_{v,R}(t) = x\left(t - \frac{2R}{c}\right) \cdot e^{-i2\pi \frac{v}{\lambda/2} t}$$

The match function



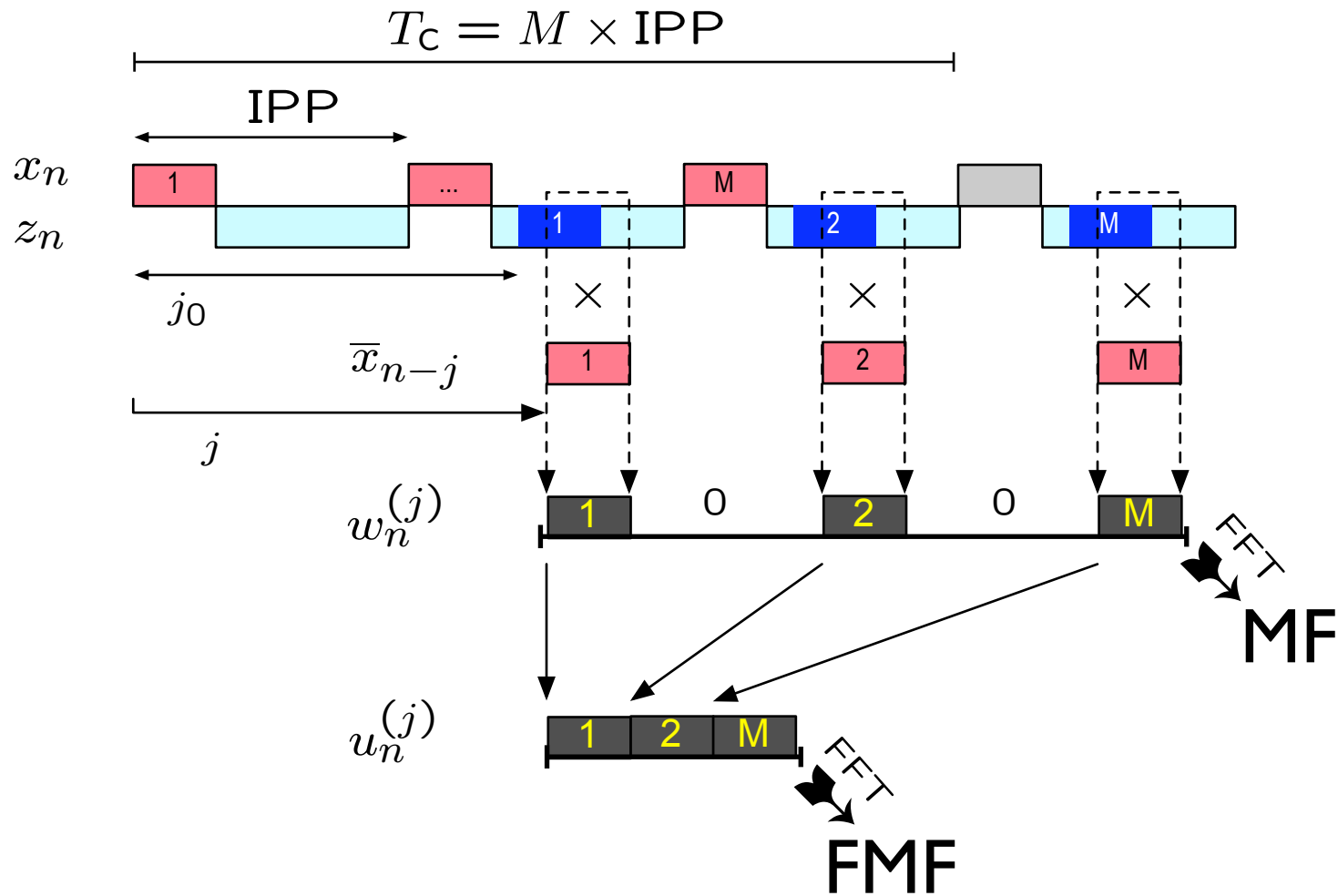
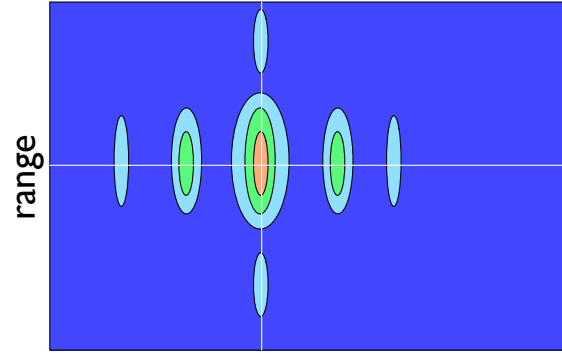
$$(\hat{v}, \hat{R}) = \arg \max \text{MF}$$

$$\text{ENR} \equiv \frac{E_s}{kT_{\text{sys}}}$$

$$\widehat{\text{ENR}} = \max \frac{\text{MF}^2}{\sigma_\gamma^2} - 1$$

$$\text{Detection} \leftrightarrow \frac{\max \text{MF}}{\sigma} > \Theta$$

The match function

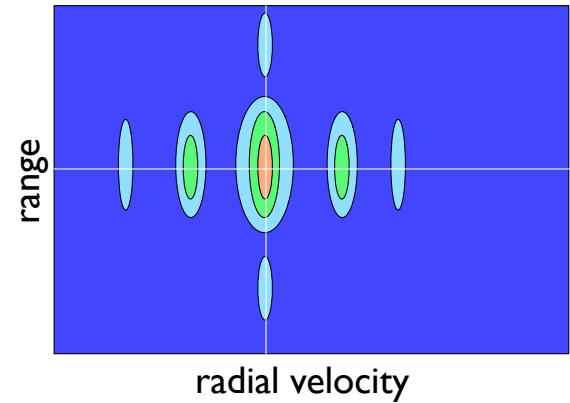


The match function

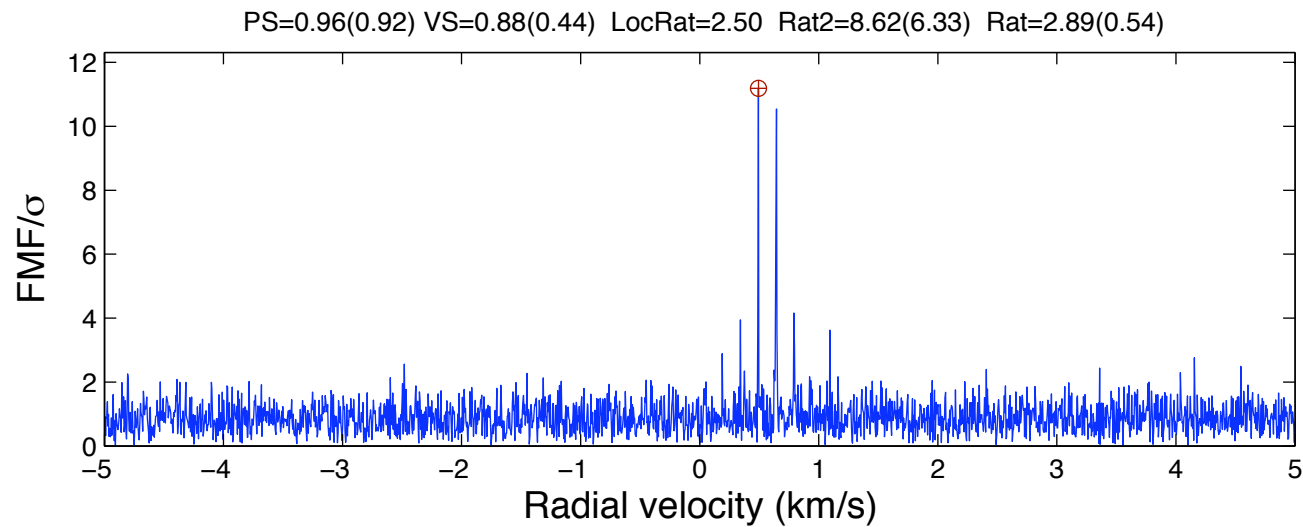
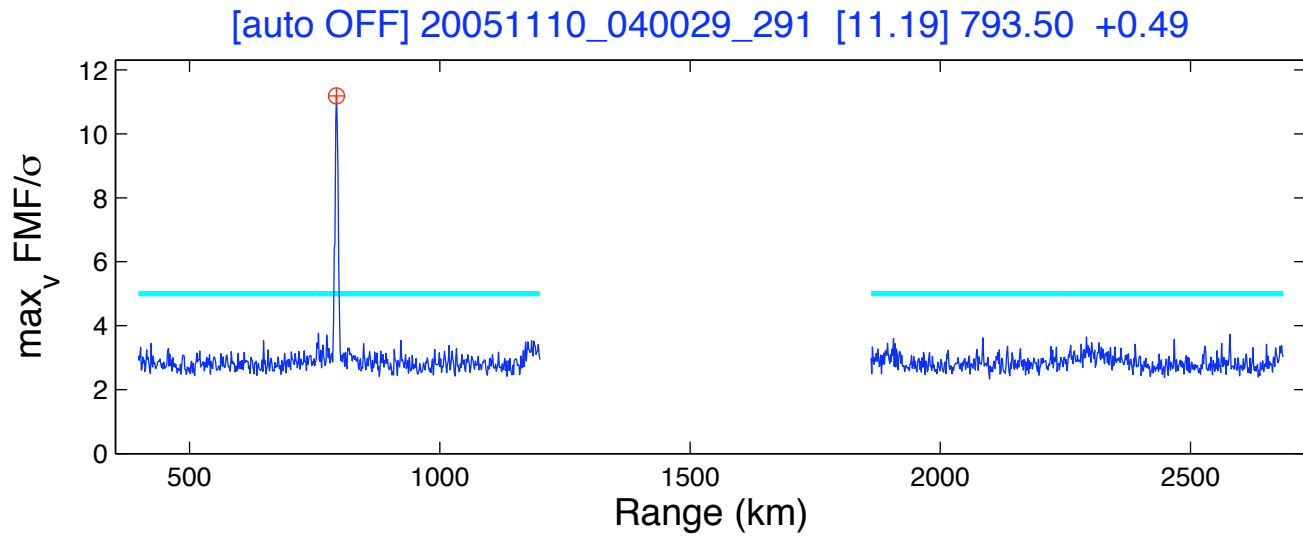
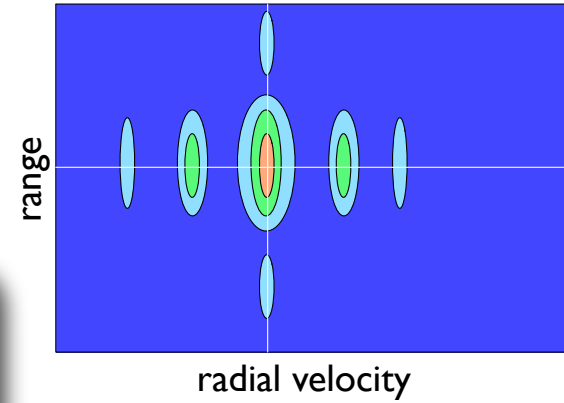
$$MF_{nc}(v, R)$$

“Non-coherent integration of M pulses”

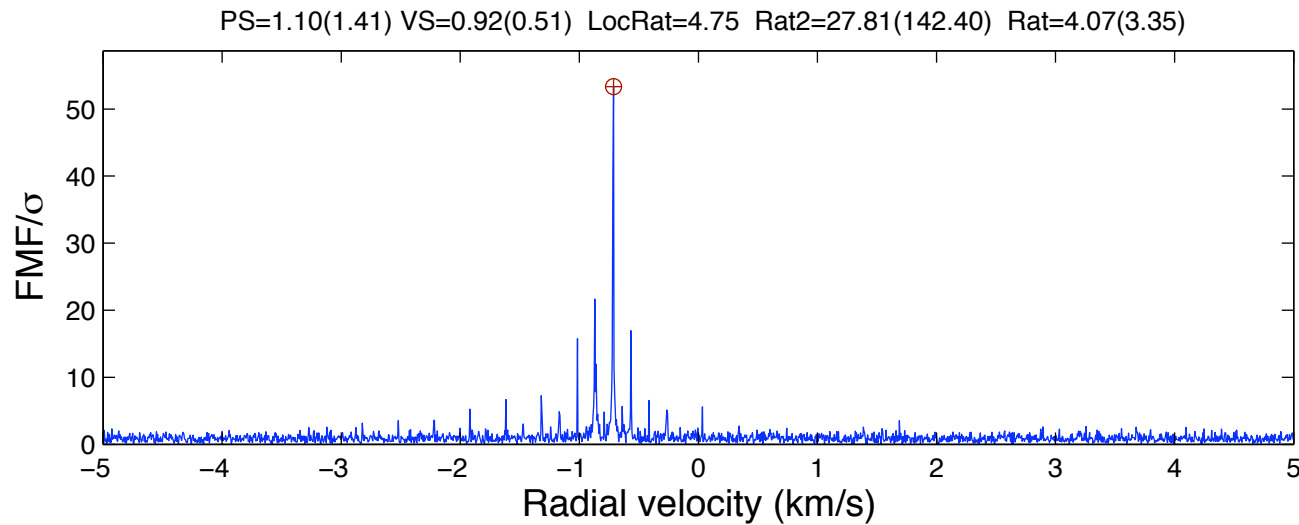
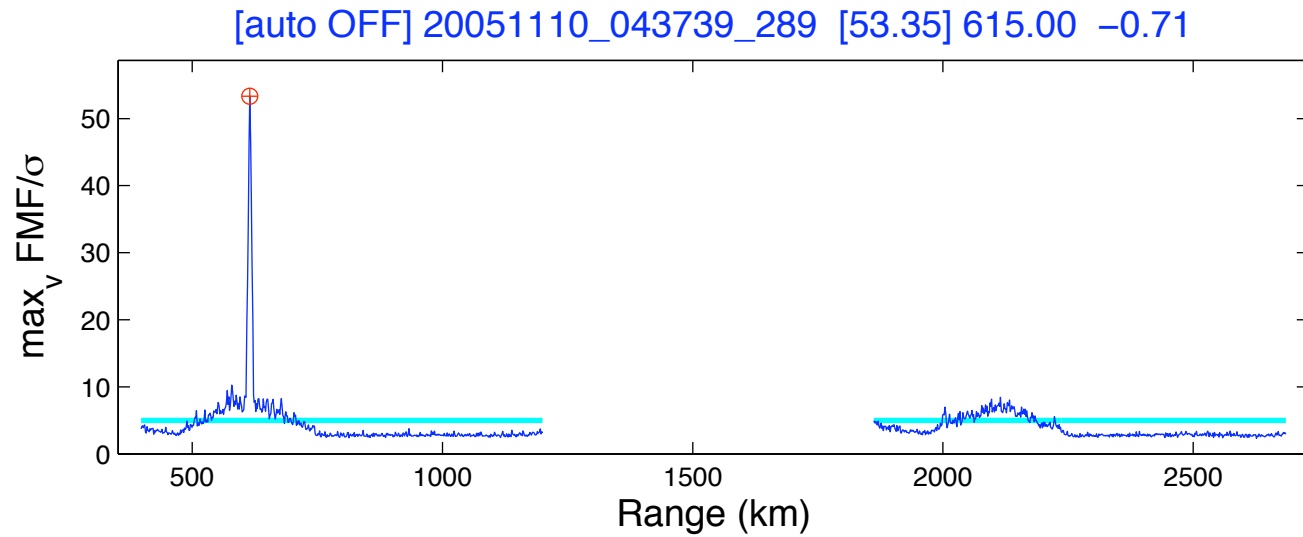
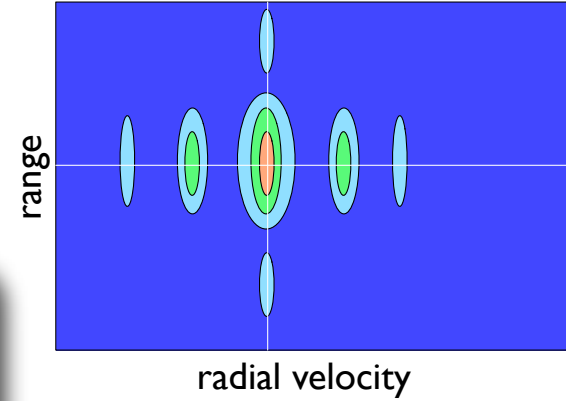
$$MF_{nc}^{(M)}(t; v, R) = \sqrt{\frac{1}{M} \sum_{m=0}^{M-1} [MF^{(1)}(t + mP; v, R)]^2}$$



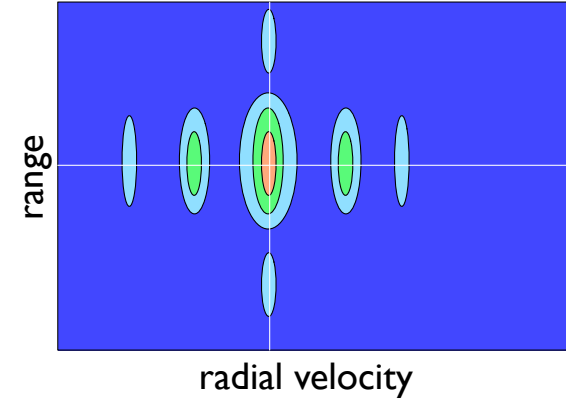
The match function



The match function



The match function



Probability of false alarm

$$P_D \equiv \mathbb{P}(\max \frac{\text{MF}}{\sigma} > \Theta | s = 0) \sim f(\Theta, M)$$

$$X_{kj} = \frac{\langle z, \chi v_k R_j \rangle}{\sigma \|\chi\|}$$

False-alarm time

$$t_{\text{fa}} \equiv \frac{T_c}{P_{\text{fa}}} \sim f(\Theta, M)$$

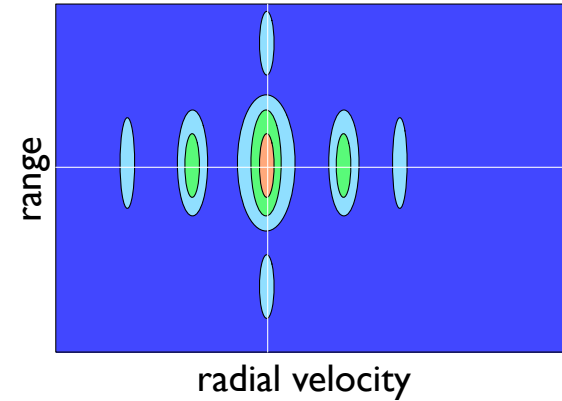
Probability of detection

$$P_D \equiv \mathbb{P}(\max \frac{\text{MF}}{\sigma} > \Theta | \|s\| \geq 0) \sim f(\Theta, M, \text{ENR})$$

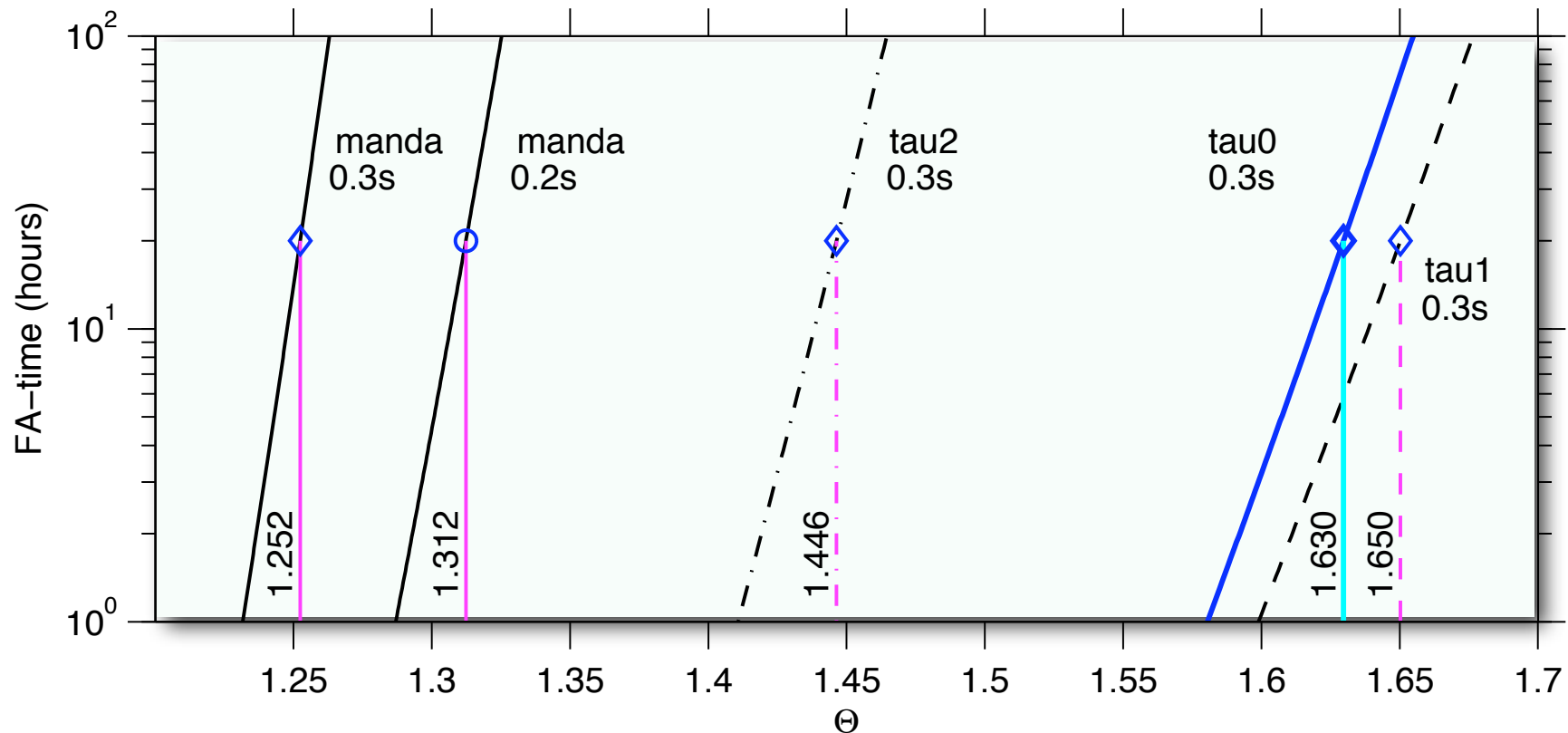
The match function

$$t_{fa} = \frac{T_c}{P_{fa}} \quad P_{fa} = \mathbb{P}\left(\max \frac{MF_{nc}}{\sigma} > \Theta \mid s = 0\right)$$

$$t_{fa} \approx \frac{\lambda}{N_g \mathcal{D} 4v_{\max} \gamma_{\text{inc}}^u(M\Theta^2, M)}$$



False-alarm time in non-coherent integration

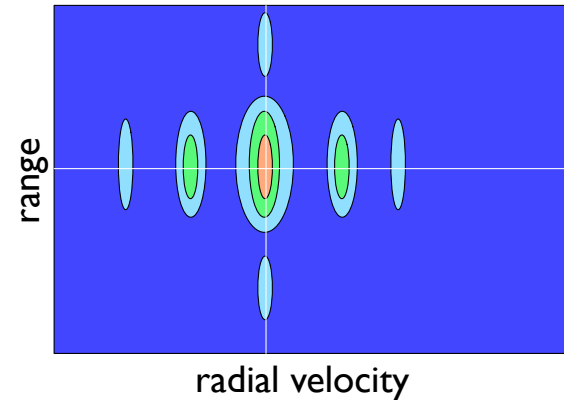


The match function

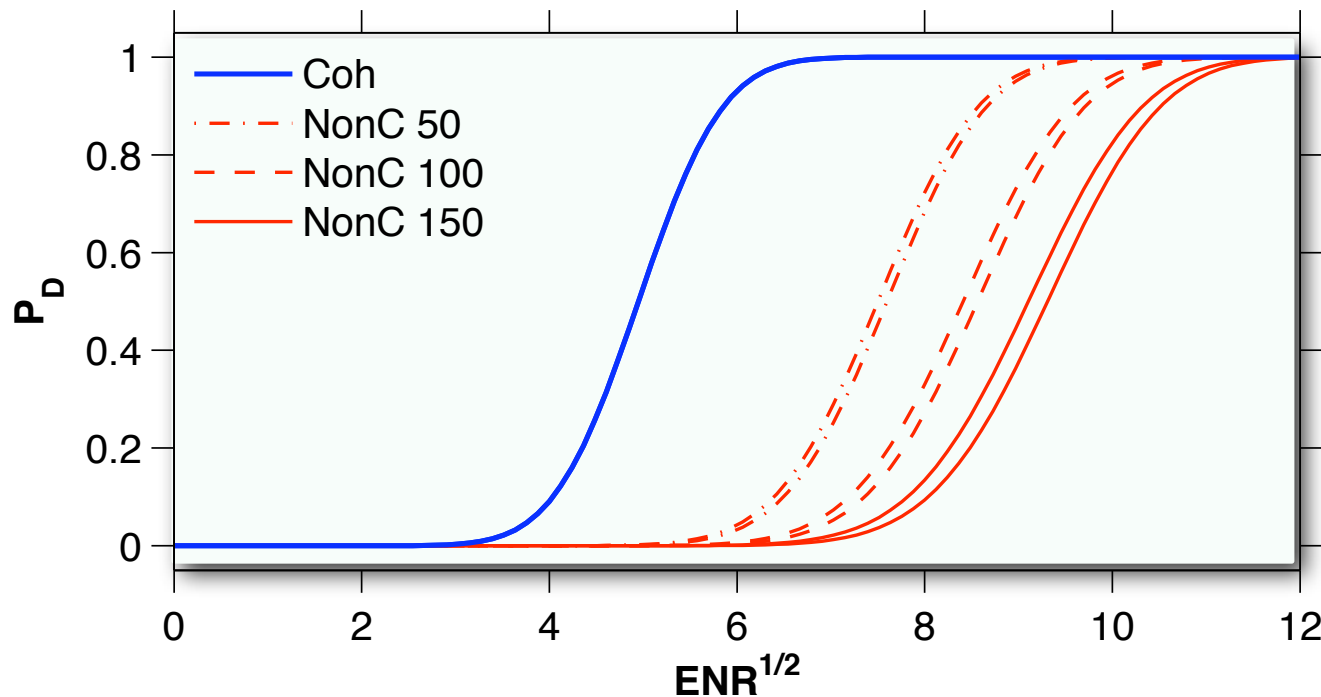
$$P_D = \mathbb{P}(\max \frac{MF}{\sigma} > \Theta \mid ENR, M)$$

$$f_X(x; ENR, M) = e^{-(x+ENR)} \cdot \left(\frac{x}{ENR}\right)^{\frac{M-1}{2}} \cdot I_{M-1}(2\sqrt{ENR x})$$

$$P_D(\Theta) = \int_{M\Theta^2}^{\infty} dx f_X(x; ENR, M)$$



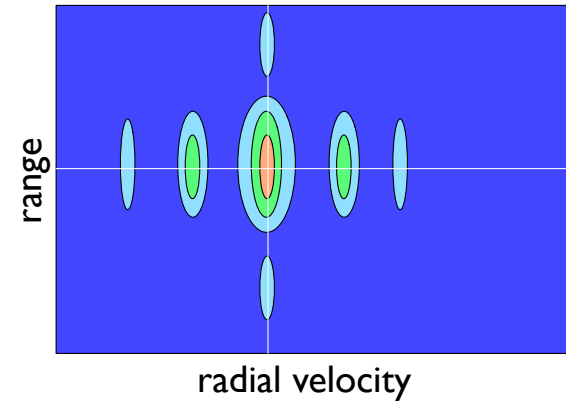
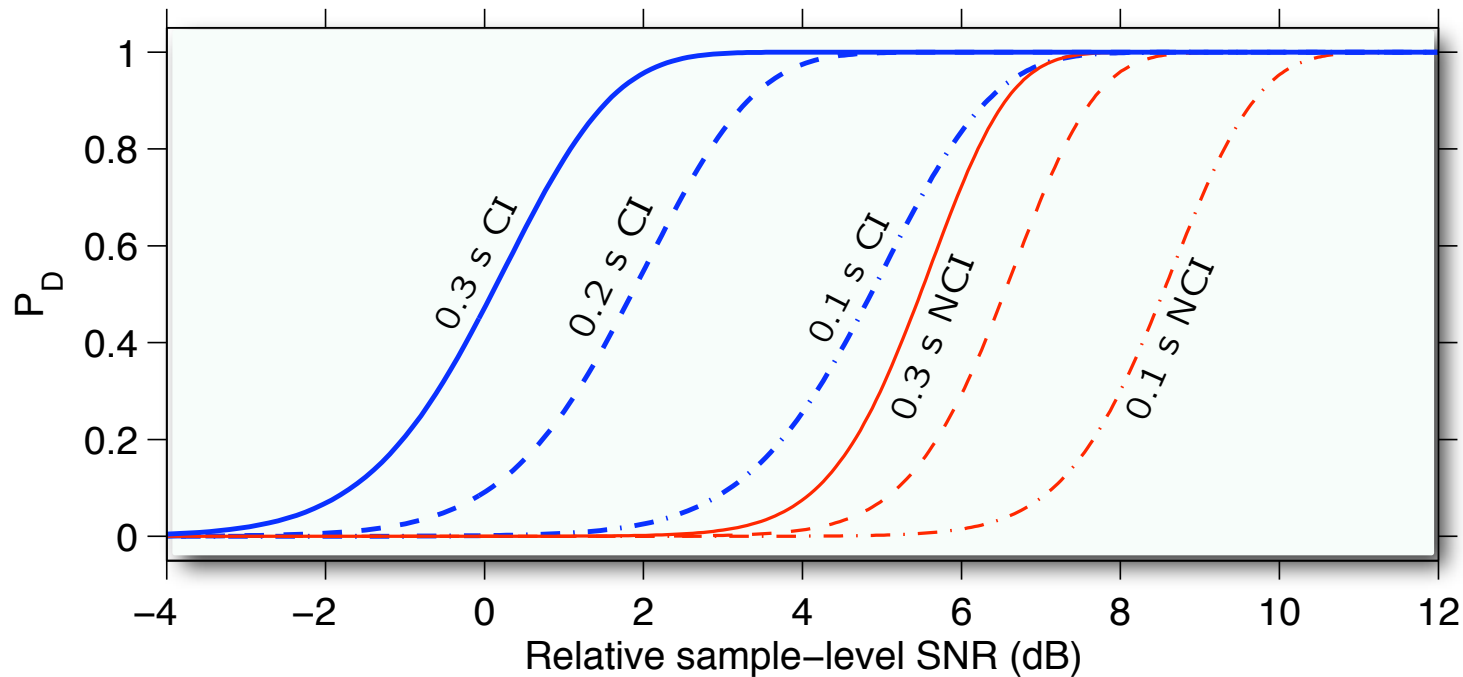
Probability of detection in the manda experiment $t_{fa} \sim 20$ h



The match function

$$P_D = \mathbb{P}(\max_{\sigma} \frac{MF}{\sigma} > \Theta \mid \text{ENR}, M)$$

Probability of detection in the manda experiment

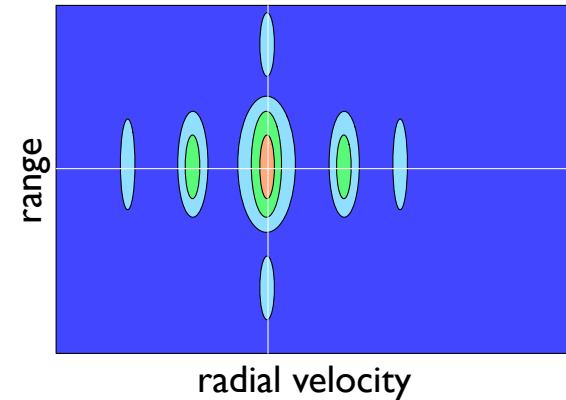
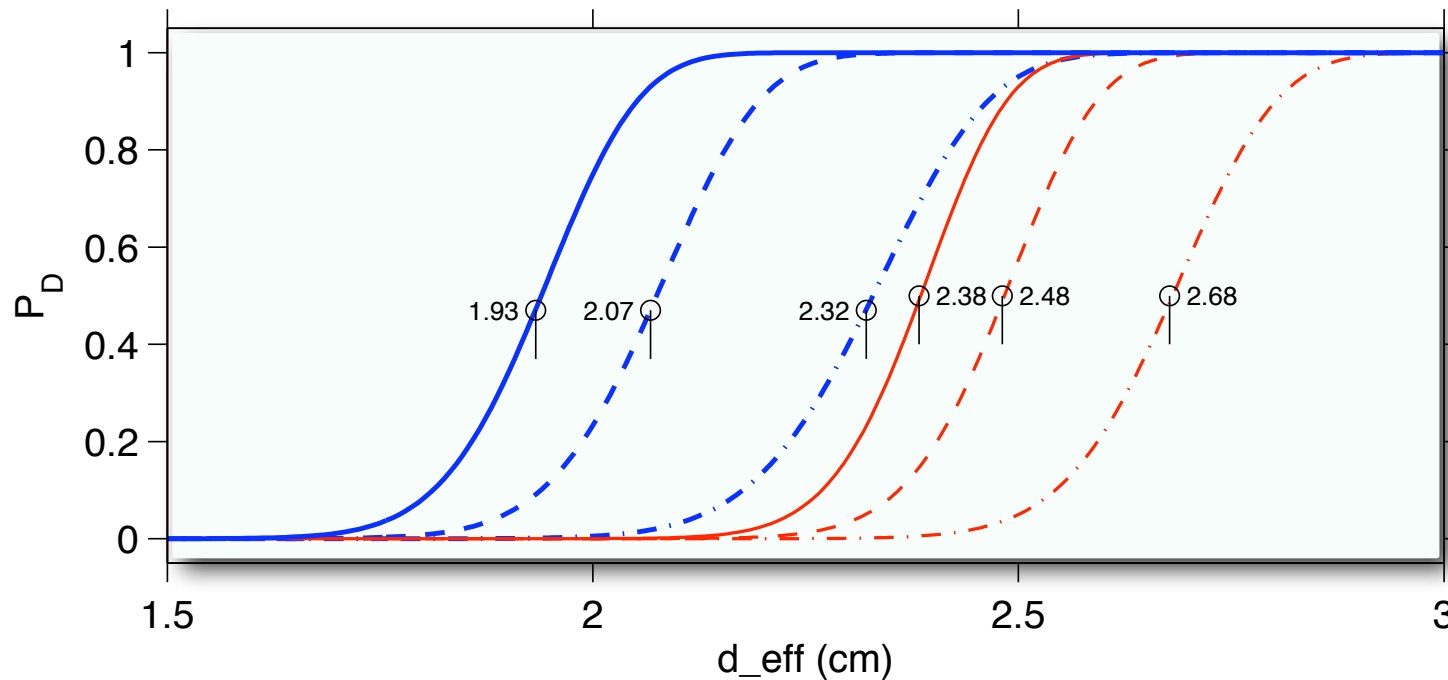


$t_{fa} \sim 20$ h

The match function

$$P_D = \mathbb{P}(\max \frac{MF}{\sigma} > \Theta \mid ENR, M)$$

Probability of detection in the manda experiment



$t_{\text{fa}} \sim 20 \text{ h}$

...SD data collection
with EISCAT...

Does it make enough sense?

Does it make enough sense ?

SD data collection with EISCAT Phase II (2006)

- W.P. 3 Acquisition of an alternative [receiver] interface card
- W.P. 4 Description of a model of EISCAT measurements for MASTER/PROOF
- W.P. 5 Observations and analysis

... SD ... collection
with EISCAT
Phase II (2006)

Does it make enough sense ?

- Is it practical, in the near future, to use EISCAT data
 - to constrain MASTER²⁰⁰⁵ ?
 - to motivate further enhancements of PROOF ?

... SD data collection
with EISCAT
Phase II

Does it make enough sense?

- Problem 1: Cannot, in practice, differentiate between main-lobe and side-lobe detections.
- Problem 2: Probability of detection with our coherent integration depends on too many factors. Cannot get quantitative hold of integration loss. Not PROOF-able.

Solution strategy

EISCAT data

➔ MASTER²⁰⁰⁵

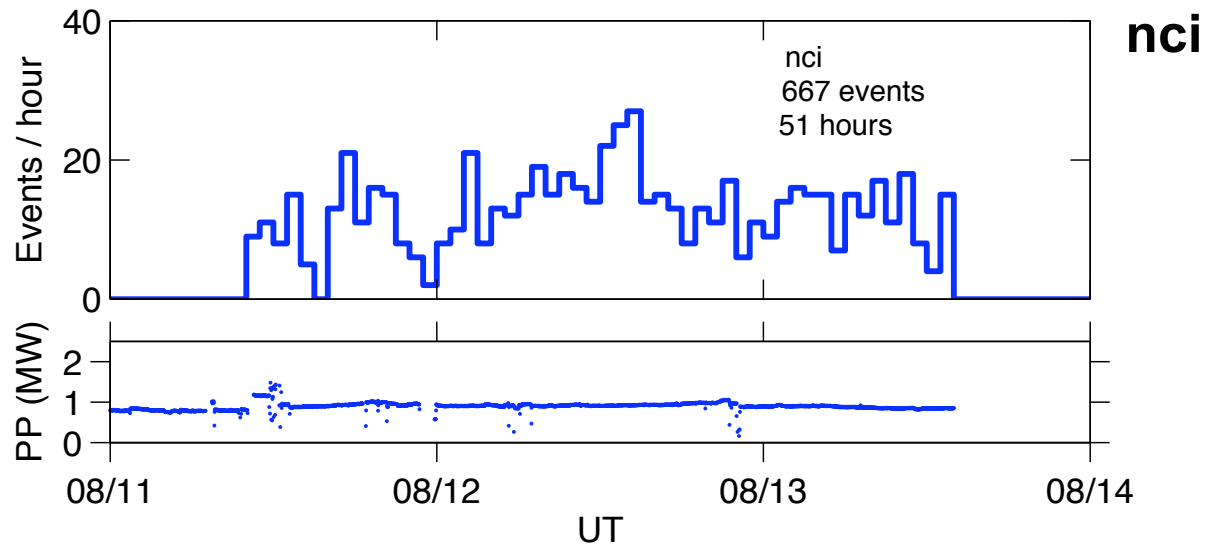
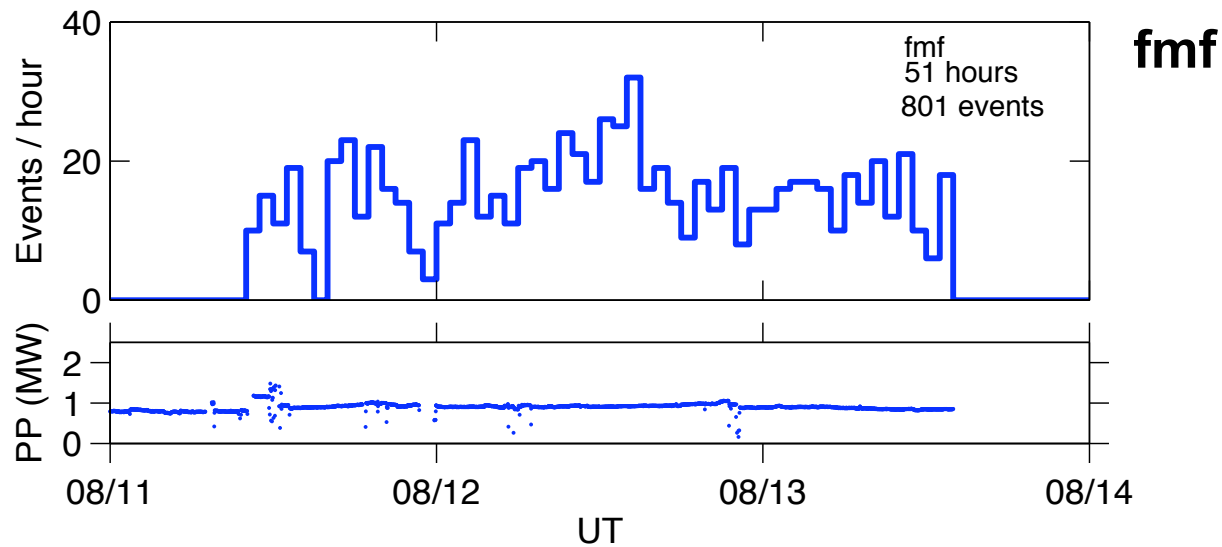
- Detect with coherent pulse-to-pulse integration for reasons of speed, convenience, and maximum sensitivity.
- Re-detect with non-coherent integration, with lowered sensitivity, to have proper control on the probability of detection.
- Analyse events with coherent integration for maximal parameter accuracy.

Manda CPI at UHF

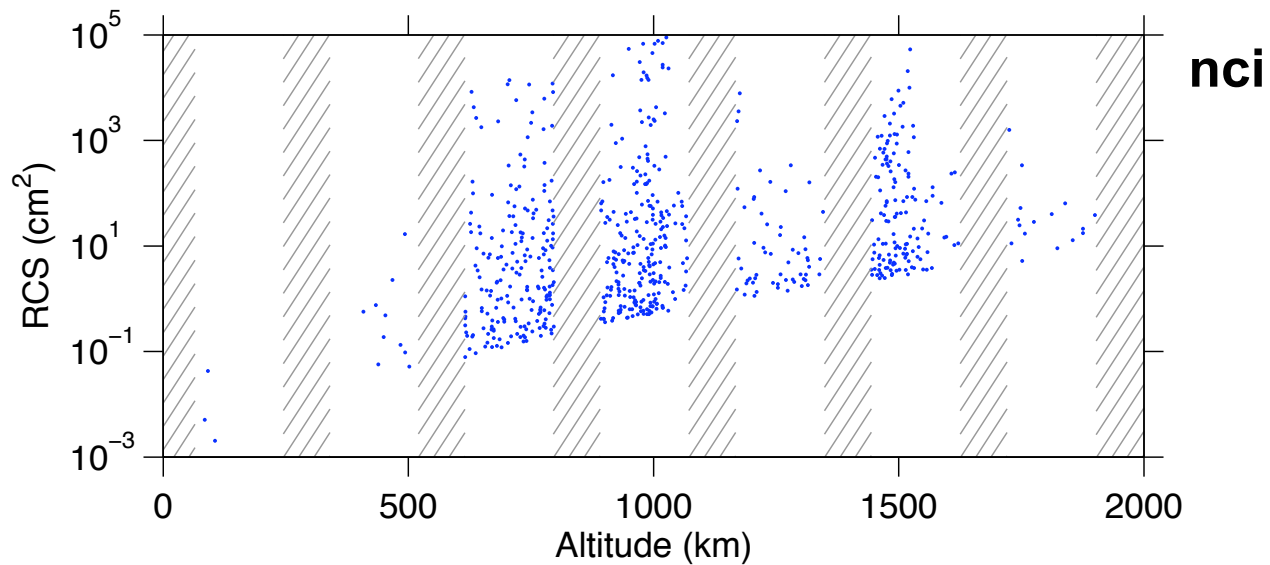
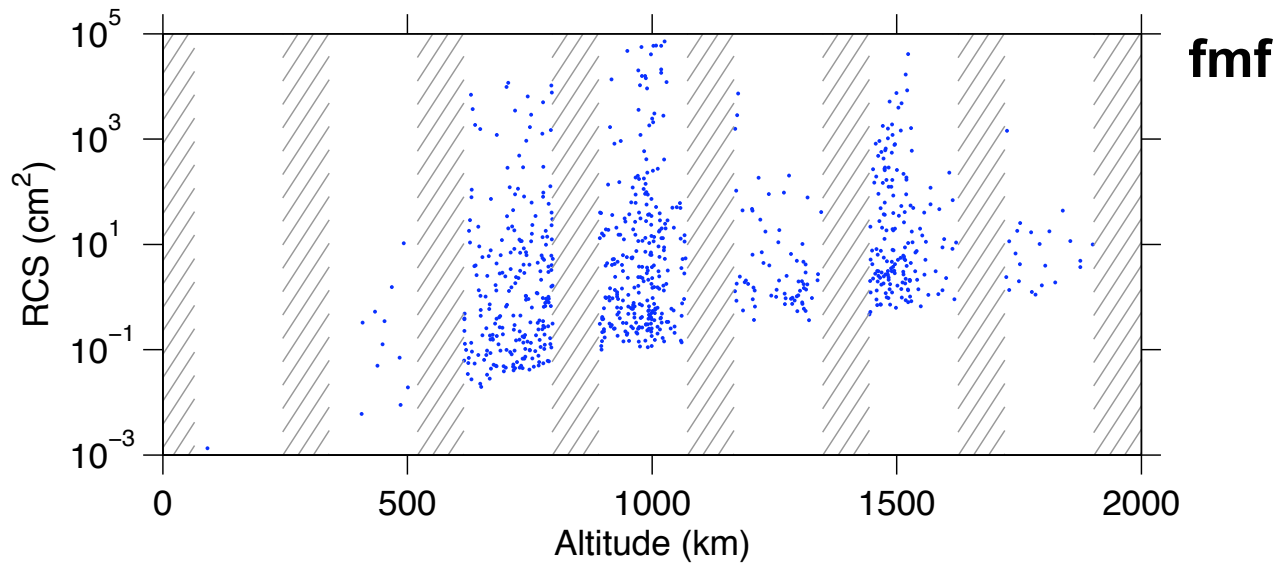
11-13 August 2005

51 hours, 801 events (fmf), 667 events (nci)

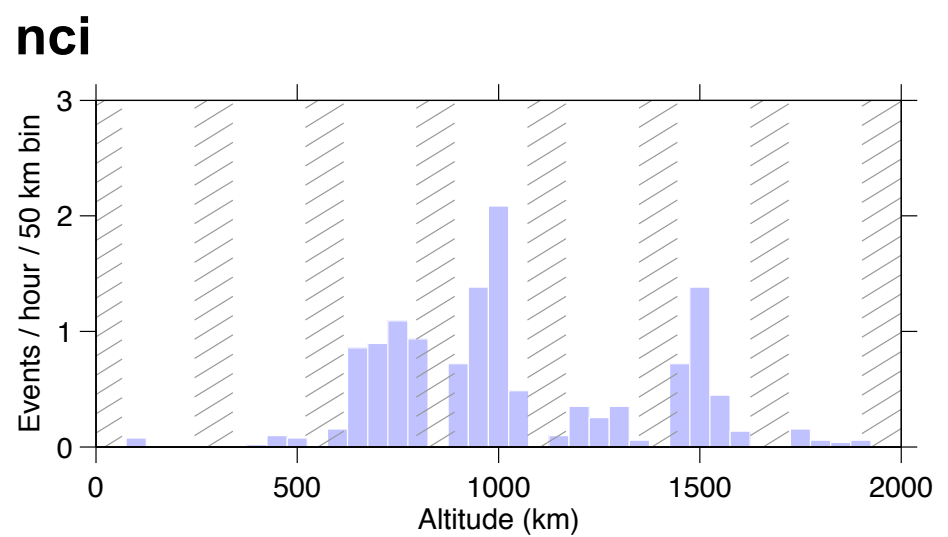
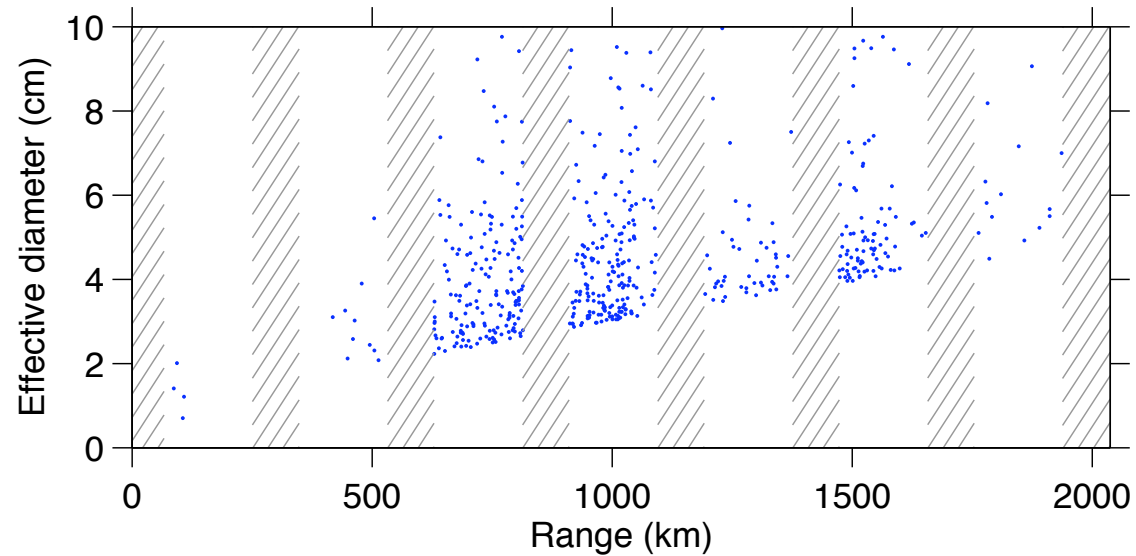
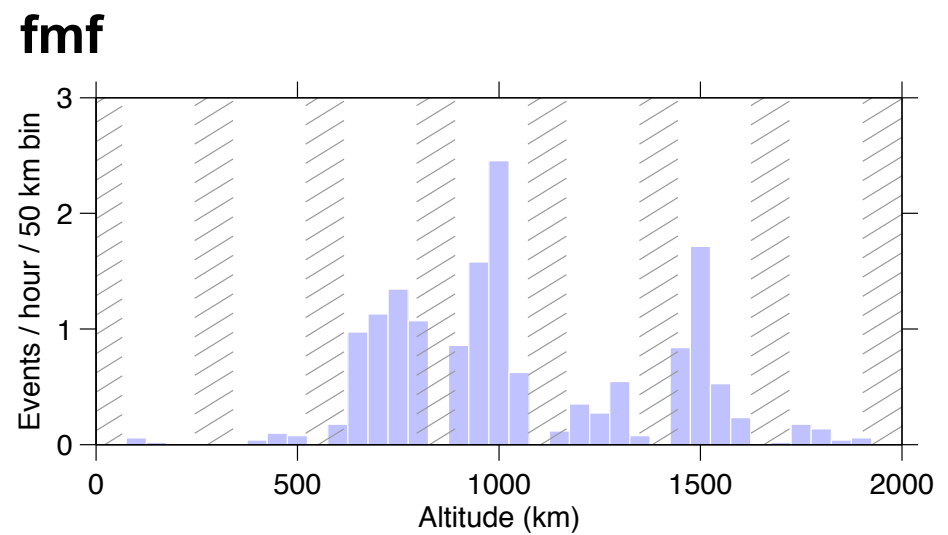
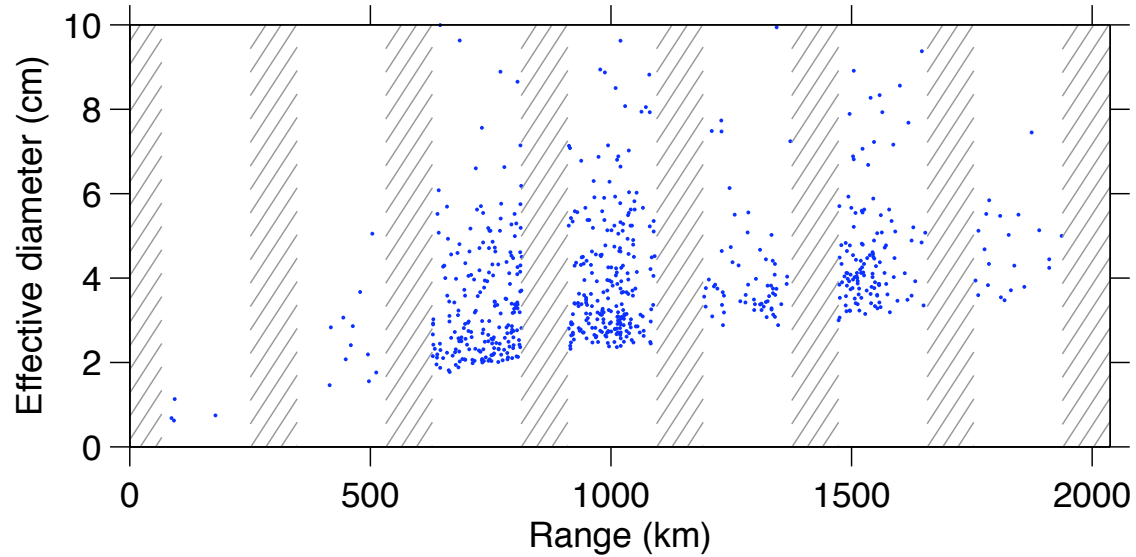
Manda Aug- Hourly event rate



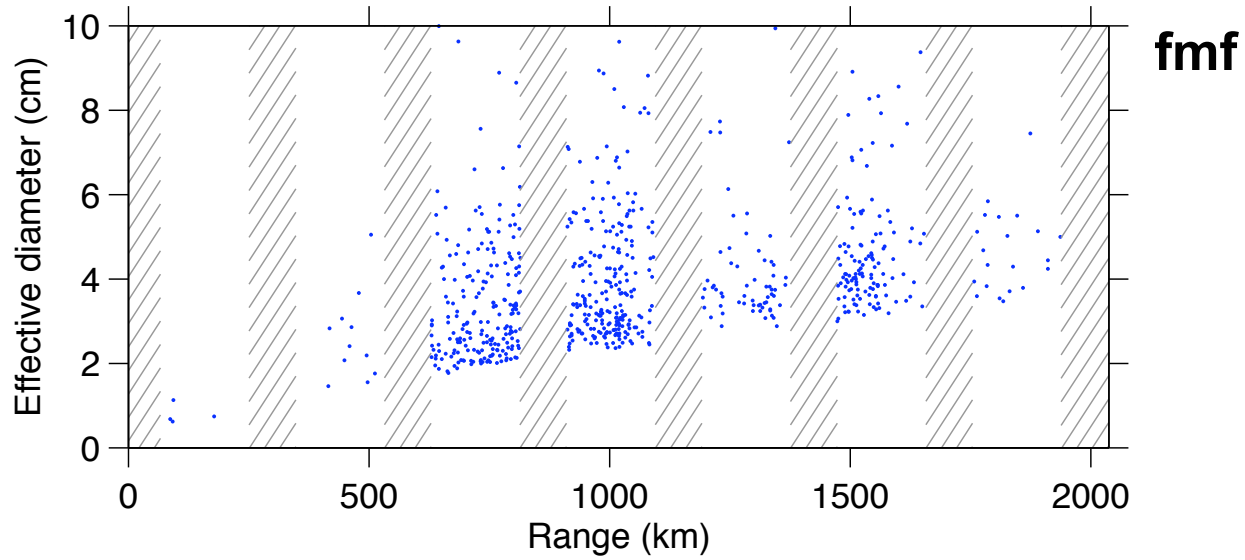
Manda Aug- RCS



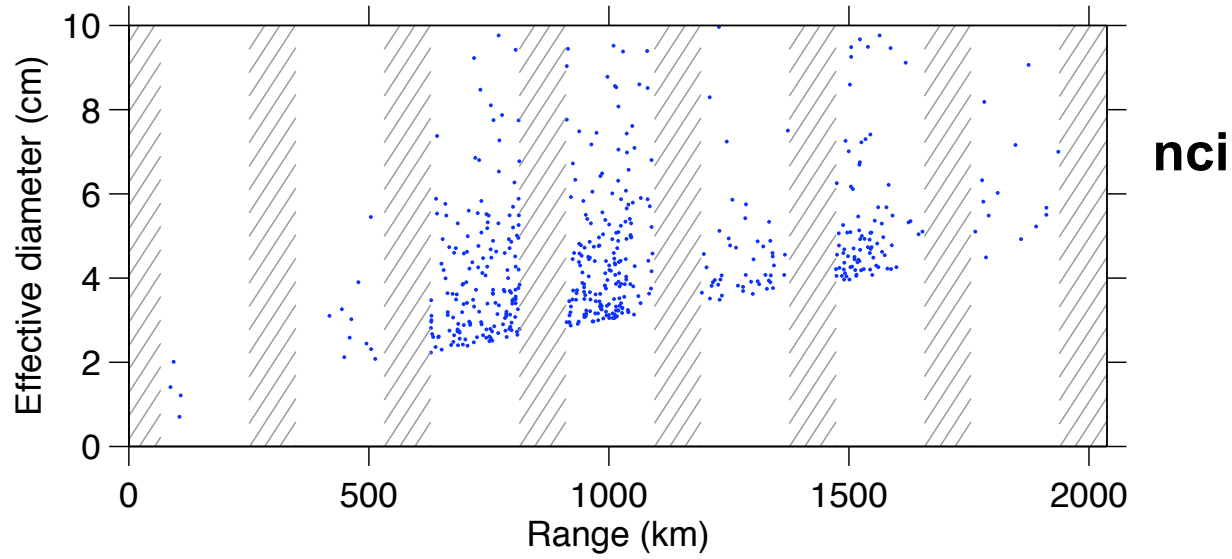
Manda Aug- Size



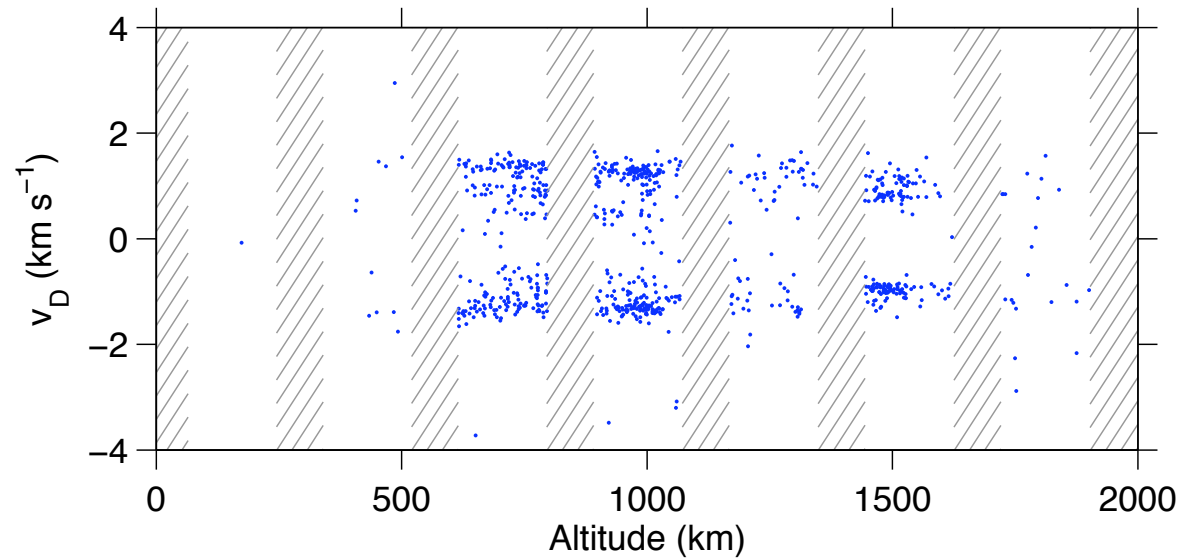
Manda Aug- Size



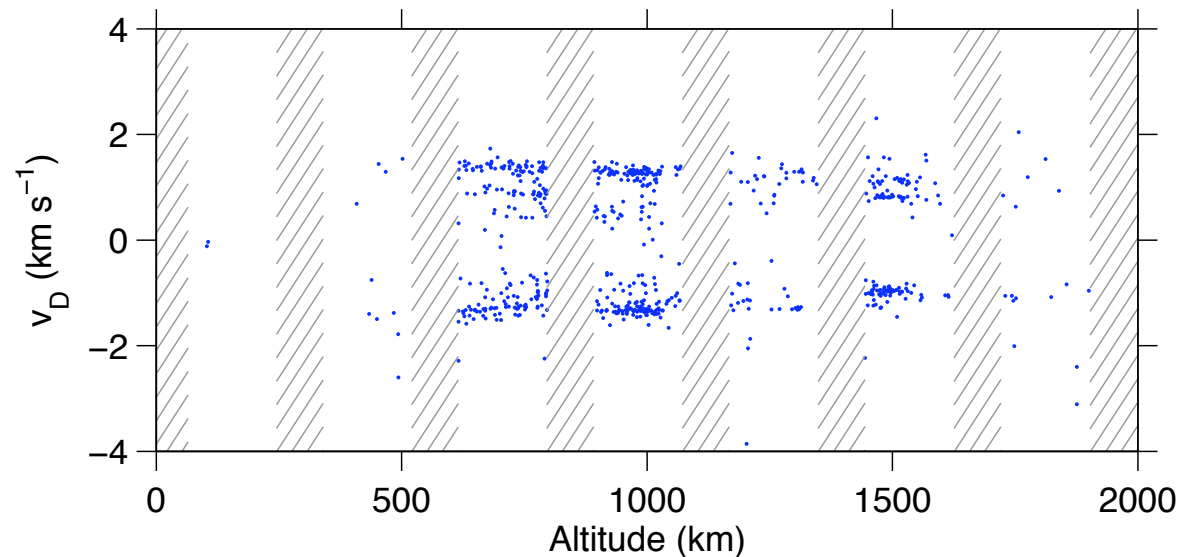
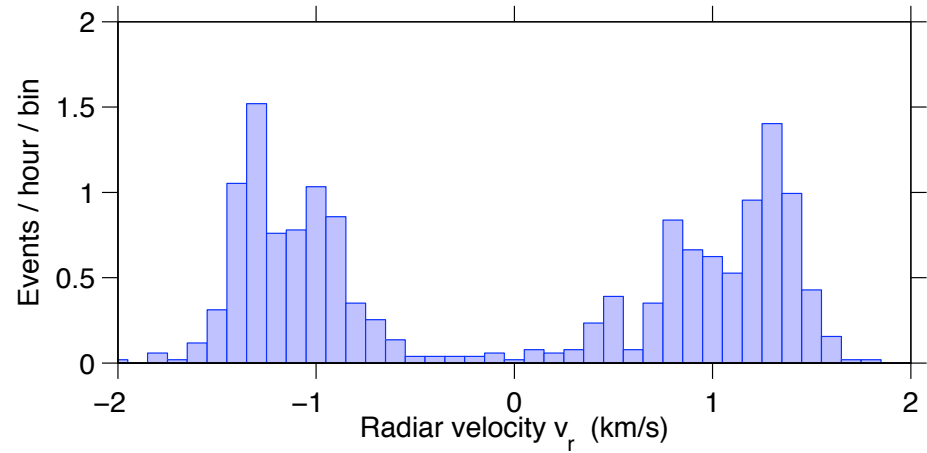
Manda Aug- Size



Manda Aug- Radial velocity



fmf



nci

