

CASSINI-RPWS-HFR / KRONOS Database at LESIA/Obs.Paris-PSL (Meudon)

P. Zarka, B. Cecconi, D. Vogl, G. Boisnard, V1.8, 01/2021

DOI: [10.25935/j7br-f293](https://doi.org/10.25935/j7br-f293)

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1. DATA ACCESS, ORGANIZATION & STRUCTURE

1.1 DATA ACCESS

Data and products are available from the web server

<http://www.lesia.obspm.fr/kronos>

(Authentication required)

The web page contains:

- "HFR Data Access": the list of all files available in the data base, sorted with 3 months periods and with data level (see section 1.3).
- "Browse HFR Data": a data browser built from the summary plots
- "HFR OpMode Database Search": a tool to search a into the operating mode of the HFR.
- "HFR Routines": list of routines (to be done)
- "HFR Documentation": list of documentation files and papers related to the HFR data.

It is also possible navigate directly (**no authentication**) in the data directories using that link:

<http://www.lesia.obspm.fr/kronos/data>

1.2 DATA ORGANIZATION

Data and products are organized in directories `yyyy_ddb_dde/` where

`yyyy` is the year

`ddb` is the beginning day of the period (included)

`dde` is the ending day of the period (included)

Each directory contains a trimester of data and products. A year `yyyy` is divided in 4 directories:

`yyyy_001_090/`

`yyyy_091_180/`

`yyyy_181_270/`

`yyyy_271_366/` (NB: even if only 365 days)

Each directory `yyyy_ddb_dde/` contains the following subdirectories:

`bg/` background files

`ephem/` 1 min resolution ephemeris+attitude files per source (Jupiter, Sun, Saturn, Earth ... from team page tools, depending on the period studied)

`k/` kronos files retrieved from IOWA

`lis/` mode lists (files `yyyyddd.lis` - see `DescrModesLis.doc`)

`n1/` level 1 data products (raw, sorted)

`n2/` level 2 data products (calibrated)

`n3/` level 3 data products (GP results, merged from `n3a-f...`)

n3a/	level 3 data products (GP results, Powell 3 ant.)
n3b/	level 3 data products (GP results, DI 3 ant.)
n3c/	level 3 data products (GP results, DI 3 ant., U=Q=0)
n3d/	level 3 data products (GP results, DI 2 ant., U=Q=0)
n3e/	level 3 data products (Polar results, DI 2 ant., , fixed)
n3f/	level 3 data products (GP results, SVD 3 ant.)
n3g/	level 3 data products (Flux density, cal. Short dipole/Galaxy)
...	as needed
pdf/	summary plots in pdf
temp/	temporary files

Other data directories for limited periods corresponding to specific events in the Cassini lifetime include:

Turn_on/	data from instrument post-launch turn-on: 1997298 to 1997299
Venus1/	data from first Venus flyby: 1998116
Ico_m14/	data from first test period (launch+14 months): 1998364 to 1999005
Venus2/	data from second Venus flyby: 1999175
Earth/	data from Earth flyby: 1999227 to 1999257

These directories have the same subdirectory structure as above.

1.3 DATA STRUCTURE

The Cassini/RPWS/HFR instrument is a sweeping frequency receiver, observing from 3.5 kHz to 16.1 MHz. The instrument is recording the data as sweeps with increasing frequencies, with various receivers (A, B, C, H1 and H2, see, Gurnett et al. 2004). Each sweep is composed of a series of records, with identical structure. Each record is results from a measurement on the pair of selected antenna at the time of the measurement, and contains 4 quantities: 2 autocorrelations of the radio electric power measured on each of the 2 antenna; and the real and imaginary part of the cross-correlation of the radio electric signals measured on each antenna.

The data is available as hourly or daily files (depending on the data level). In order to keep of the recorded data sweeps from being split into different files, the time of each record is set to that of beginning of the sweep. A function is available to recompute the accurate time of each individual record within a sweep. In the case of the last sweep of the file, it may occur that the actual accurate record times are beyond the file time range.

All data products saved in binary files, fixed length records, little endian.

Some N3a-f files might be empty (zero bytes long) in case of no ephemeris data for the concerned period.

k/ raw data (hourly files)

Raw data **k** files are retrieved from the PI institute (University of Iowa). They are extracted from telemetry RPWS files and decompressed (meander lossless compression). The raw data **k** files are hourly files with nomenclature « Kyyyyddd.hh » corresponding to year yyyy, day of year ddd, time [hh, hh+1[.

Estimated single file size: 100-1000 KB.

n1/ level 1 products (hourly files)

The **n1** data result from reading, decoding and sorting K files (structure adapted from the output of LIT_HFR.pro & EXTRAIT_HFR.pro).

Structure of one record of **n1** data:

```
N1 = {ydh: 0L, $ ; yyyydddhh of current file
      num: 0L $ ; index of record in current file
      ti: 0L, $ ; time index
      fi: 0L, $ ; frequency index
      dt: 0, $ ; integration time (msec)
      c: 0B, $ ; hundreds of second
      ant: 0B, $ ; antenna selection: 0-3=NoDF
          ; (Ex=Off,+X,-X,D), 11=DF/+X, 12=DF/-X
      agc1: 255B, $ ; agc 'X'
      agc2: 255B, $ ; agc 'Z'
      auto1: 255B, $ ; auto-correlation 'X'
      auto2: 255B, $ ; auto-correlation 'Z'
      cross1: -999, $ ; cross-correlation (real)
      cross2: -999 } ; cross-correlation (Imaginary)
```

Structure: 13 tags,
Data length: 28 bytes.

Notes:

- `ydh` (same for all records of a given file) & `num` (0 to n-1) indices uniquely define each data. They are repeated in all level > 1 products for traceability.
- time & frequency indices (`ti` and `fi`) uniquely define each data status.
- `dt` = integration time: 125-1000 msec in bands ABC, 20-160 msec in H1, 10-80 msec in H2.
- `c` = hundreds of second to be added to `ti` for exact time of start of packet.
- `agc`, `auto` and `cross` values remain at initialized values if corresponding measurement does not exist (e.g., when antenna 2 = OFF).

Time index definition: `yydddsssss`

with `yy` = year - 1996 (1997=1, 1998=2 ...)
`ddd` = day of year (1 - 366)
`sssss` = second of day (0 - 86400)

Frequency index definition: `bcccfnn`

with `b` = band (0=A, 1=B, 2=C, 3=H1, 4=H2)
`ccc` = synthesizer position in H1 & H2 bands (kHz/25), 0 in ABC bands
`ff` = number of filters per band (1,2,4,8,16,32)
`nn` = rank of filter in the band (0 - 31)

The **n1** data are archived at CNES, with nomenclature « `Ryyyyddd.hh` ».

Estimated single file size: ~ 5.5 KB

n2/ level 2 products (hourly files)

The **n2** data are calibrated values (V^2/Hz).

Structure of one record of **n2** data:

```
N2 = {ydh: 0L,    $ ;    yyyydddhh of current file
      num: 0L    $ ;    index of record in current file
      t97: 0.d0, $ ;    time (decimal days, epoch = 1997.0)
      f: 0.,    $ ;    frequency (kHz)
      dt: 0.,    $ ;    effective integration time (msec)
      df: 0.,    $ ;    effective bandwidth (kHz)
      autoX: 0., $ ;    auto-correlation 'X' ( $V^2/Hz$ )
      autoZ: 0., $ ;    auto-correlation 'Z' ( $V^2/Hz$ )
      crossR: -999., $ ;    cross-correlation (real)
      crossI: -999., $ ;    cross-correlation (Imaginary)
      ant: 0B } ;    antenna selection: 0-3=NoDF
                        ;    (Ex=Off,+X,-X,D), 11=DF/+X, 12=DF/-X
```

Structure: 11 tags

Data length: 45 bytes

Notes:

- ydh, num & ant identical to n1 data. One-to-one correspondence between N1 and N2 records.
- t97 is the time of sweep start.
- dt and df are effective quantities computed for the current measurement.
- auto and cross values remain at initialized values if corresponding measurement does not exist (e.g., when antenna 2 = OFF). Cross-correlation values are normalized and corrected for the phase shift introduced by the instrument.

The **n2** data are archived at CNES, with nomenclature « Pyyyyddd.hh ».

Estimated single file size: ~ 9 KB

n3a/ level 3 products (hourly files)

Warning: this dataset is not available.

The **n3a** data are GP results from Powell method applied to 3 antenna measurements (*cf. Vogl et al., 2004*).

Structure of one record of n3a data:

```
N3a = {ydh: 0L,    $ ;    yyyydddhh of current file
      num: 0L    $ ;    index of record in current file
      S: 0.,    $ ;    Intensity ( $V^2m^{-2}Hz^{-1}$ )
      q: 0.,    $ ;    Normalized linear polarization
      u: 0.,    $ ;    parameters Q & U
      v: 0.,    $ ;    Normalized circular polar. V
      th: 0.,    $ ;    Source colatitude ( in S/C frame)
      ph: 0.,    $ ;    Source azimuth ( in S/C frame)
```

```

chi: 0., $ ; chi-square residual
  zr: 0., $ ; ratio of 2 Azz val.
                (Azz+-Azz-) / (Azz++Azz-)
  SN: fltarr(4) } ; S/N ratio on autocorrel. values

```

Structure: 11 tags,
Data length: 56 bytes.

Notes:

- ydh & num identical to n1 data. N3a records correspond to a subset of N1 and N2 records.
- S is an intensity multiplied by the h_z antenna squared length. The h_z antenna length is supposed to be 1 here. Use Zarka et al. JGR 2004 to obtain a calibrated intensity in Wm⁻²Hz⁻¹.

The **n3a** files nomenclature « N3a_XYY_yyyyddd.hh »

where

X = 1-character code defining the antenna parameter set used:

```

r for rheometry,
j for Jupiter-Cal
d for December 2004 calibration

```

YY = 2-character code defining the radiSOURCE of reference:

```

su=Sun, ea=Earth, ju=Jupiter, sc=Saturn's center, sn=Saturn_North,
ss=Saturn_South

```

Estimated single file size: ~ 5.5 KB

n3b/ level 3 products (hourly files)

The **n3b** data are GP results from Direct Inversion (DI) method applied to 3 antenna measurements (*cf. Cecconi & Zarka, 2004*).

Structure of one record of n3b data:

```

N3b = { ydh: 0L, $ ; yyyydddhh of current file
  num: lonarr(2), $ ; indices of record in current file
  S: fltarr(2), $ ; Intensity (V2m-2Hz-1)
  q: fltarr(2), $ ; Normalized linear polarization
  u: fltarr(2), $ ; parameters Q & U
  v: fltarr(2), $ ; Normalized circular polar. V
  th: 0., $ ; Source colat ( in S/C frame)
  ph: 0., $ ; Source azimuth ( in S/C frame)
  zr: 0., $ ; ratio of 2 Azz val.
                (Azz+-Azz-) / (Azz++Azz-)
  SN: fltarr(4) } ; S/N ratio on autocorrel. values

```

Structure: 10 tags,
Data length: 72 bytes.

Notes:

- S, Q, U, V are computed separately for each pair of antennas in the 3 antenna set. If Q, U, V are all = 0, then a specific inversion is used instead (see n3c).

- S is an intensity multiplied by the h_z antenna squared length. The h_z antenna length is supposed to be 1 here. Use Zarka et al. JGR 2004 to obtain a calibrated intensity in $Wm^{-2}Hz^{-1}$.

The **n3b** files nomenclature « N3b_YY_YYYYddd.hh » with same conventions as N3a

Estimated single file size: ~ 6.5 KB

n3c/ level 3 products (hourly files)

The **n3c** data are GP(V only) results from Direct Inversion (DI) method applied to 3 antenna measurements, with $U=Q=0$ (cf. Cecconi & Zarka, 2004).

Structure of one record of n3c data:

```

N3c = {ydh: 0L,      $      ;      yyyydddhh of current file
       num: lonarr(2), $      ;      indices of record in current file
       S: 0.,        $      ;      Intensity ( $V^2m^{-2}Hz^{-1}$ )
       q: 0.,        $      ;      Normalized linear polarization
       u: 0.,        $      ;      parameters Q & U
       v: fltarr(2), $      ;      Normalized circular polar. V
       th: fltarr(2), $      ;      Source colat. (in S/C frame)
       ph: fltarr(2), $      ;      Source azimuth (in S/C frame)
       zr: 0.,       $      ;      ratio of 2  $A_{zz}$  val.
                               ( $A_{zz+}-A_{zz-}$ ) / ( $A_{zz+}+A_{zz-}$ )
       SN: fltarr(4) }      ;      S/N ratio on autocorrel. values

```

Structure: 10 tags

Data length: 68 bytes.

Notes:

- S is an intensity multiplied by the h_z antenna squared length. The h_z antenna length is supposed to be 1 here. Use Zarka et al. JGR 2004 to obtain a calibrated intensity in $Wm^{-2}Hz^{-1}$.

The **n3c** files nomenclature « N3c_YY_YYYYddd.hh » with same conventions as N3a

Estimated single file size: ~ 6 KB

n3d/ level 3 products (hourly files)

The **n3d** data are Polarization results from Direct Inversion (DI) method applied to 2 antenna measurements, with a selected source direction (cf. Cecconi & Zarka, 2004).

Structure of one record of n3e data: *identical to N3d*

```

N3d = {ydh: 0L,      $      ;      yyyydddhh of current file
       num: 0L       $      ;      index of record in current file
       S: 0.,        $      ;      Intensity ( $V^2m^{-2}Hz^{-1}$ )
       q: 0.,        $      ;      Normalized linear polarization
       u: 0.,        $      ;      parameters Q & U

```

```

v: 0., $ ; Normalized circular polar. V
th: 0., $ ; Source colatitude ( in S/C frame)
ph: 0., $ ; Source azimuth ( in S/C frame)
SN: fltarr(2) ; S/N ratio on autocorrel. values

```

Structure: 9 tags
Data length: 40 bytes.

Notes:

- S is an intensity multiplied by the h_z antenna squared length. The h_z antenna length is supposed to be 1 here. Use Zarka et al. JGR 2004 to obtain a calibrated intensity in $Wm^{-2}Hz^{-1}$.

The **n3d** files nomenclature « N3d_XYY_yyyyddd.hh » with same conventions as N3a

Estimated single file size: ~ 8 KB

n3e/ level 3 products (hourly files)

The **n3e** data are GP (V) results from Direct Inversion (DI) method applied to 2 antenna measurements, with $U=Q=0$ (cf. Cecconi & Zarka, 2004).

Structure of one record of n3d data:

```

N3d = {ydh: 0L, $ ; yyyydddhh of current file
num: 0L $ ; index of record in current file
S: 0., $ ; Intensity ( $V^2m^{-2}Hz^{-1}$ )
q: 0., $ ; Normalized linear polarization
u: 0., $ ; parameters Q & U
v: 0., $ ; Normalized circular polar. V
th: 0., $ ; Source colatitude ( in S/C frame)
ph: 0., $ ; Source azimuth ( in S/C frame)
SN: fltarr(2) ; S/N ratio on autocorrel. values

```

Structure: 9 tags
Data length: 40 bytes.

Notes:

- S is an intensity multiplied by the h_z antenna squared length. The h_z antenna length is supposed to be 1 here. Use Zarka et al. JGR 2004 to obtain a calibrated intensity in $Wm^{-2}Hz^{-1}$.

The **n3e** files nomenclature « N3e_XYY_yyyyddd.hh » with same conventions as N3a

Estimated single file size: ~ 8 KB

n3f/ level 3 products (hourly files)

Warning: this dataset is not available

The **n3f** data are GP results from SVD method applied to 3 antenna measurements (cf. Ladreiter et al., 1995).

n3g/ level 3 products (hourly files)

The **n3g** data are flux densities calibrated with short dipole ($f \leq 2$ MHz) and/or Galaxy ($f \geq 1$ MHz) (cf. Zarka et al., 2004).

Structure of one record of n3g data:

```
N3g = { ydh: 0L,    $    ;    yyyydddhh of current file
        num: 0L    $    ;    index of record in current file
        fluxX: 0.,  $    ;    flux density 'X' (W/m2Hz)
        fluxZ: 0.}  $    ;    flux density 'Z' (W/m2Hz)
```

Structure: 4 tags

Data length: 16 bytes.

Notes:

- One-to-one correspondence between n3g and n1/n2 records.

The n3g files nomenclature « Fyyyyddd.hh »

Estimated single file size: ~ 3 KB

n3/ final level 3 products (hourly files)

Warning: this dataset is not available

The **n3** data (S,Q,U,V, θ , ϕ , χ^2 ,Zr,SNR,...) will result from comparison, validation and merging of n3a-f... products.

Expected single file size: ~ 6 KB

pdf/ & lis/ summary plots & mode lists (daily files)

- Summary plots « yyyyddd.pdf » : 2 dynamic spectra displayed (with/without background subtraction), with graphical indication of Df 'on' in ABC, H1, H2 bands.
Volume \leq 200 Kbytes / day.
- Mode lists « yyyyddd.lis » (compact format) : see detailed description in DescrModesLis.doc
Volume \leq 50 Kbytes / day.

2. DATA PROCESSING

The whole data set is available on the web, on a password protected web page (<http://www.lesia.obspm.fr/kronos>).

2.1 RPWS-Kronos SOFTWARE

The Kronos software has been developed in IDL and is available here:

<https://lesia.obspm.fr/kronos/routines/>

(no authentication)

The Kronos IDL library is distributed under MIT license (although not stated in the software files).

Further documentation and other languages (Python) is under development.

2.2 RETRIEVING AND PROCESSING RPWS DATA

The **k** files as well as the ephemeris and attitude data are retrieved from a web server at University of Iowa. The `n1`, `n2`, `n3a-g`, `pdf`, and `lis` files are produced and archived on a regular basis.

All data products (`n1`, `n2`, `n3a-g`) consist of hourly files.

Summary plots (`pdf`) and mode lists (`lis`) are daily files.

⇒ Use `summary.pro` to produce `pdf` files.

⇒ Use `make_lis_files.pro` to produce `lis` files

Data products are written as binary files, each containing N "records" of data (unformatted read/write). Each record can be written/read as an IDL structure (fixed length, little endian). The ratio `file_size / record_length` gives the number of records to be read.

⇒ Use `make_n1_files.pro` to produce `n1` files.

⇒ Use `make_n2_files.pro` to produce `n2` files.

⇒ Use `make_n3b_files.pro` to produce `n3b` files.

⇒ Use `make_n3c_files.pro` to produce `n3c` files.

⇒ Use `make_n3d_files.pro` to produce `n3d` files.

⇒ Use `make_n3e_files.pro` to produce `n3e` files.

⇒ Use `make_n3g_files.pro` to produce `n3g` files.

⇒ Use `read_data_binary.pro` to read files.

Level `n3a-f` data result from GP analyses. Several methods are used, producing corresponding data sets `n3a-f`:

`n3a` GP Powell 3 antennas (*Vogl et al., 2004*)

`n3b` GP Direct Inversion (DI) 3 antennas (Cecconi & Zarka, 2004)

`n3c` GP (V only) DI 3 antennas, $U=Q=0$ (*C&Z, 2004*)

`n3d` Polar. DI 2 antennas, , fixed (*C&Z, 2004*)

`n3e` GP (V only) DI 2 antennas, $U=Q=0$ (*C&Z, 2004*)

`n3f` GP SVD 3 antennas (*Ladreiter et al., 1995*)

Level `n3a-f` data are computed from level `n2` + background subtraction, S/N computation, data selection (2 or 3 antennas, max. frequency...).

Computation also requires in input :

- a reference antenna set (3 antenna effective height vectors defining the electrical equivalent dipoles): available sets include rheometry (*Rucker et al., 1996*), Jupiter-calibration (*Vogl et al., 2004*).
- spacecraft attitude information (position of the source of interest in the spacecraft frame, used both for initialization and final check of DF results concerning the wave **k**-vector)

Level `n3g` data are flux densities calibrated with short dipole ($f \leq 2$ MHz) and/or Galaxy ($f \geq 1$ MHz) (*cf. Zarka et al., 2004*).

bg/ background (quarterly files)

Background data is computed from histograms of intensities per frequency and recorded as binary files.

The **bg** file nomenclature (in `yyyy_ddb_dde/bg/`) is :

<code>bg_yyyy_ddb_dde</code>	(whole interval)
<code>bg_yyyyddb_hb_yyyydde_he</code>	(selection)

⇒ Use `make_bg_files.pro` to produce `bg` files.

Structure of **bg** data (one record per frequency):

```
bg = { h: lonarr(1601,4), $ ; 1601 bins x 0.05 dB
      ; in [-170,-90] dB range
      ; 0=Z, 1=+X, 2=-X, 3=D
      bt: fltarr(4), $ ; <df*dt> per antenna
      ; over the period studied
      nbt: fltarr(4), $ ; N values for bt computation
      fi: 0L, $ ; Frequency Index (see n2 data)
      xf: 0., $ ; Frequency (kHz)
      sig: fltarr(4), $ ; RMS on fon(4)
      fon: fltarr(4), $ ; mode of histogram of intensities
      fon5: fltarr(4), $ ; 5% level of histogram
      fon10: fltarr(4)} ; 10% level of histogram
```

The background data can be computed with various number of histogram bins (from 320 to 3200 bins), but the available dataset has been computed with 1600 bins.

ant/ Antenna parameter

Antenna parameters sets are available from:

<https://lesia.obspm.fr/kronos/data/rpws/ant/>

Most of the available data have been computed using the Dec04 calibration files (`calDec04_ABC.ant` and `calDec04_H12.ant`), which define a slightly different set of antenna for A, B and C receivers, and H1 and H2 ones.

Antenna parameter list:

The list of antenna valid files is described in

https://lesia.obspm.fr/kronos/data/rpws/pro/ant_list.txt

The file contains 1 row per antenna parameter, as 'colon' separated values. The first field is the antenna set name, while the second is the file name to be used (where the `.ant` extension is optional). Lines starting with `#` are comment lines.

ephem/ Ephemeris and Attitude

The ephemeris and attitude data are retrieved from a web server of University of Iowa as ASCII tables.

The binary ephemeris and attitude files are then computed for each source of interest (Sun, Earth, Jupiter, Saturn). Files contain (x, y, z, θ, ϕ) sets with 1 min resolution, with (x, y, z) = position of Cassini in the selected frame coordinates and in km, and (θ, ϕ) = position of source in Cassini frame (radians). The attitude data is stored in the form of quaternion that are used to transform the coordinates from the spacecraft frame to the another. Depending on the science case, various source ephemeris and coordinate frames can be used.

The ephemeris (positional) data file nomenclature is `YYYYDDD.vTTT`, where `TTT` is the short name for the selected target source. The attitude (orientation) data file nomenclature is `YYYYDDD.qFFF`, where `FFF` is the short name for the selected coordinate system. The `TTT` and `FFF` shorts names are defined in the source list file.

⇒ Use `make_ephem_files.pro` to produce ephemeris and attitude files.

Source list

The list of valid sources files is described in

https://lesia.obspm.fr/kronos/data/rpws/pro/src_list.txt

As for the antenna parameter list file (see previous sub-section), the data is stored as a `colon` separated table. The file header (commented section) describes the various fields.

During the Saturn orbital mission, most of the GP data have been computed using the `sq` setup (as found in their file name). The source list file shows that it corresponds to Saturn's center ephemeris (`.vsat` files) and Saturn Solar Equatorial coordinate system (`.qssq` files).

Data selection before GP.

All the records available in `n1` data files are not processed. The computation is done using the following criteria :

- auto-correlations all > 0 (after background subtraction)
- $|\text{cross-correlations}| \leq 1$
- ephemeris / attitude available.

Data not meeting these criteria are either eliminated or set to the max/min acceptable value. In output, $S/N \geq \text{threshold (dB)}$, and $(\text{autoZ}) < n\%$ within 3 antenna data set, allow for further selection.

Angular distance between DF results (θ, ϕ) and the selected source can be recomputed from GP results and interpolated data from the ephemeris file.

References

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