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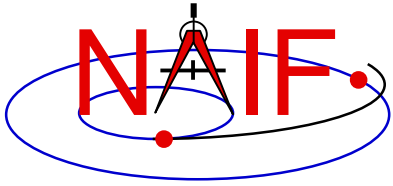
Navigation and Ancillary Information Facility

# **“Camera-matrix” Kernel CK**

**(Orientation or Attitude Kernel)**

**Emphasis on CK files for Cassini**

**October 2004**

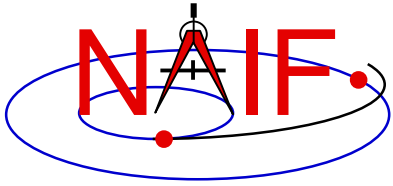


# Scope

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Navigation and Ancillary Information Facility

- **This tutorial covers use of predict and reconstruction CKs produced by the Cassini AACS Team.**
- **It does not cover use of “image navigated” (sometimes called “c-smithed”) CKs made by the Imaging Team, or any other CKs.**
  - **Those topics are best presented by the producers of such CK files.**

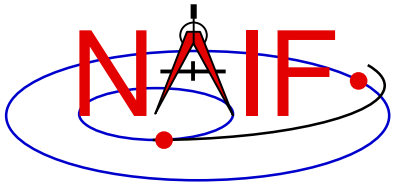


# Cassini CK Contents - 1

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Navigation and Ancillary Information Facility

- **A CK file holds orientation data for the Cassini spacecraft .**
  - “Orientation data”  $\Rightarrow$  quaternions that may be used to rotate vectors from a base reference frame to a target frame
    - » For Cassini:
      - the base frame is the Earth Equator and Equinox of 2000 inertial frame
        - SPICE frame name is “**J2000**”
      - the target reference frame is the Cassini spacecraft
        - SPICE frame name is “**CASSINI\_SC\_COORD**”
- **A CK file also contains angular velocity of the target frame with respect to the base frame.**

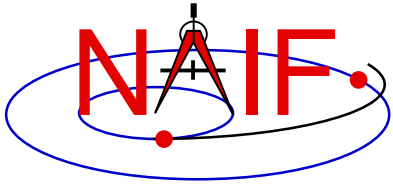


# Cassini CK Contents - 2

## Navigation and Ancillary Information Facility

- **CK files also contain comments (metadata).**
  - **For reconstruction CK files, the comments include:**
    - » parameters used in the creation of the file.
    - » segment summaries showing time bounds for the:
      - entire segment
      - interpolation intervals within each segment
  - **For predict CK files, the comments include:**
    - » names of products used in making the predict CK
- **These comments may be displayed on your computer using the COMMNT utility program supplied with the SPICE Toolkit.**
  - To display comments, run COMMNT as follows:

```
% commnt -r <binary CK file name> | more
```
  - See **COMMNT User's Guide** ([toolkit/doc/commnt.ug](http://toolkit/doc/commnt.ug)) for complete usage



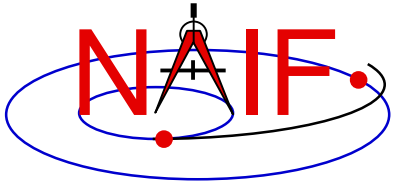
# Cassini CK Files-1

Navigation and Ancillary Information Facility

**Cassini CK files produced at JPL are either “predict” or “reconstruction”**

## •Predict

- Predict CK files are made using information that predicts the orientation some time in the future, as generated by Cassini’s Kinematic Predictor Tool (KPT).
- Due to their high quality (good fidelity and, by definition, no data gaps) they may be used to fill “gaps” in reconstructed CKs.
- Normally a predict CK covers one sequence.
- To achieve the best possible accuracy a predict CK should be used with the same SCLK data used in the CK generation.
  - » This is found in the SCLK used in generation of the predict CK.
  - » This **may\*** also be found in a later-made SCLK.
    - \* see later discussion about re-made predict CKs
- Latest file naming schema: [start]\_[end][p][version]\_[xxxxxx].[ext]
  - » E.G. 03215\_03220pa\_port1.bc

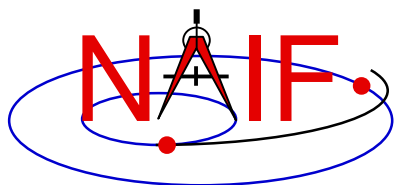


# Cassini CK Files-2

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Navigation and Ancillary Information Facility

- **Reconstruction**
  - Reconstruction CK files are made from orientation telemetry returned from the Cassini spacecraft.
  - To achieve the best possible accuracy, a reconstruction CK should be used with an SCLK produced after the last data in the CK.
  - File naming schema: [start]\_[end][**r**][version]\_[xxxxxx].[ext]  
\_\_\_\_\_ optional



# Cassini Reconstruction CK Coverage - 1

Navigation and Ancillary Information Facility

While the Cassini CK naming scheme may suggest that a CK file provides continuous coverage for the interval of time specified in the file name, in reality this is rarely the case for “**reconstruction**” CK files – they almost always contain gaps in coverage. Below is an example of this.

## Coverage of....

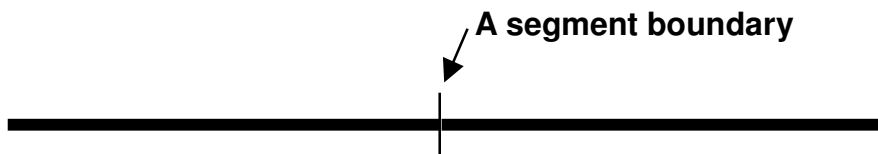
### CK file

as suggested by file name



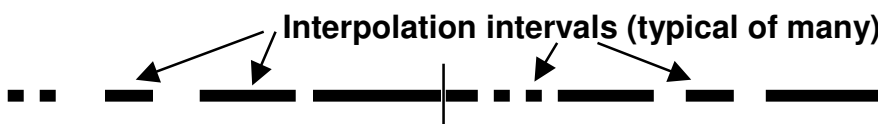
### CK file segments

as appears in ckbrief and spacit summaries, and in comment area



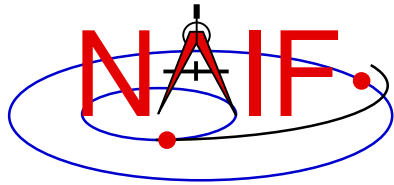
### CK segments containing “continuous” data

this is what is actually available to the SPICE high-level interfaces



Black lines represent interpolation intervals within which pointing data may be returned. White spaces represent gaps in the data.

CK segments may overlap slightly (not shown here).



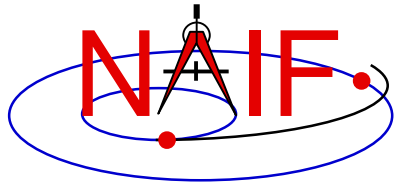
## Cassini Reconstruction CK Coverage - 2

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Navigation and Ancillary Information Facility

- **All Cassini CK files are of Type 3, in which segments contain discrete pointing instances.**
  - In “reconstruction” CK files, the nominal spacing between orientation data points extracted from telemetry is 4 seconds.
- **These pointing instances are partitioned into groups, called “interpolation intervals,” within which linear interpolation between adjacent instances is valid and is done by SPICE code.**
- **Gaps in coverage in “reconstruction” CKs result from insufficient source orientation data, i.e. telemetry.**



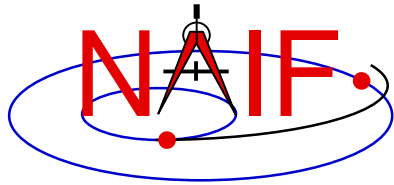


## Cassini Reconstruction CK Coverage - 3

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Navigation and Ancillary Information Facility

- **Interpolation intervals can be thought of as representing intervals of time over which the pointing of the spacecraft is available continuously.**
  - In Cassini reconstruction CK files, the intervals are constrained such that interpolation is valid between any two adjacent points that are less than or exactly 16 seconds apart. This means that interpolation will be done if up to three adjacent pointing instances are missing. If four instances are missing, there will be a gap in the segment.
- **SPICE CK reader routines compute and return pointing using linear interpolation between the attitude data points that bound the user's pointing request time as long as that time is within an interpolation interval.**

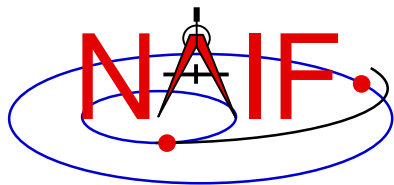


# Cassini Reconstruction CK Coverage - 4

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Navigation and Ancillary Information Facility

- The time periods between interpolation intervals are gaps during which the CK readers are **not** able to compute pointing
- Information about the start and stop time for each interpolation interval can be obtained using two methods
  - by examining a “reconstruction” CK file’s comments using the **COMMNT** utility
  - by summarizing a CK file using **CKBRIEF** with the “-dump” option



# Cassini Reconstruction CK Coverage - 5

Navigation and Ancillary Information Facility

- To view the interpolation intervals table provided in a reconstruction CK file's comments using **COMMNT**:

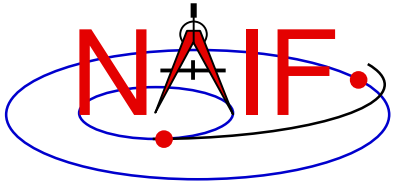
```
% commnt -r 04059_04066ra.bc
...
*****
INTERPOLATION INTERVALS IN THE FILE SEGMENTS:
*****
SEG.SUMMARY: ID -82000, COVERG: 2004-02-28T13:00:00 2004-03-03T22:27:22
-----
                2004-02-28T13:00:00.989      2004-02-29T14:16:28.395
                2004-03-01T07:05:43.750      2004-03-01T14:52:19.568
...

```

- To view a summary of interpolation intervals in a reconstruction CK using **CKBRIEF**:

```
% ckbrief 04215_04220ra.bc cas00085.tsc naif0007.tls -utc -dump
...
Segment No.: 1
Object: -82000
Interval Begin UTC      Interval End UTC      AV
-----
2004-AUG-02 00:00:01.275 2004-AUG-02 01:56:53.479 Y
2004-AUG-02 01:59:21.478 2004-AUG-04 11:28:19.880 Y
...

```

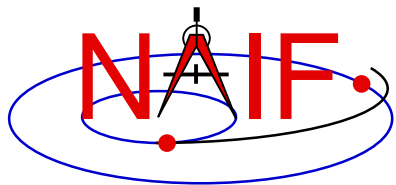


# Cassini Predict CK Coverage

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Navigation and Ancillary Information Facility

- **Cassini “predict” CK files are also of Type 3, in which segments contain discrete pointing instances.**
  - Spacing between points varies depending on the simulated attitude mode and the actual method of generation.
- **By definition, predict CK files have no data gaps and thus provide continuous coverage throughout the entire span of the file.**
  - “Continuous coverage” means you always get a pointing solution.
- **The coverage of a predict CK file may be seen using the ckbrief utility.**

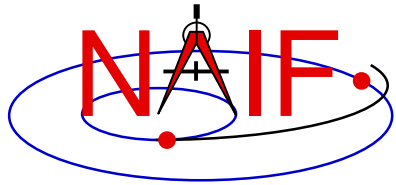


# When Are Cassini CKs Made?

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Navigation and Ancillary Information Facility

- 1. A predict CK for an entire sequence is made prior to uplink of the sequence.**
  - There may be multiple instances of this; if you use it be sure to get the very last version prior to uplink
- 2. During execution of the sequence, reconstruction CKs are made about every week.**
- 3. After completion of the sequence, the predict CK for that sequence may be re-made using the latest SCLK, and...**
- 4. After completion of the sequence, a single reconstruct CK covering the entire sequence is made using the latest SCLK.**

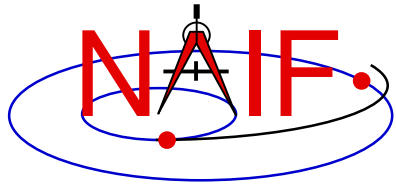


# Using Predict CKs To Fill Gaps - 1

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Navigation and Ancillary Information Facility

- You may require continuous spacecraft orientation data may to process science data.
- Reconstruction CKs have gaps and therefore cannot provide 100% continuous coverage.
- Predict CKs have no gaps and are of very high fidelity; these can be used to “fill” the gaps in reconstruction CKs.
- Therefore, for continuous coverage, both predict and reconstruction CKs must be loaded into a user’s program.
- To make sure that reconstruction data is used when available, the **predict** CK should be loaded **first** and reconstruction CK(s) loaded afterwards.
  - SPICE gives the latest loaded file the highest priority and will therefore take data from the latest file, if possible.

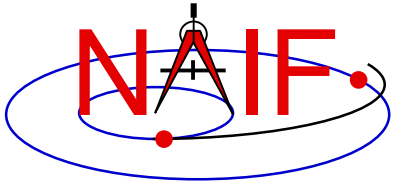


# Using Predict CKs To Fill Gaps-2

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Navigation and Ancillary Information Facility

- **Since only one SCLK file can be loaded, it is important to use the correct file for this procedure.**
- **If processing data from a sequence while that sequence is still active:**
  1. **Load the latest predict CK made for that sequence (the one uplinked).**
  2. **Load one or more “weekly” reconstruction CK(s).**
  3. **Load the SCLK used in making the aforementioned predict CK.**
- **If processing data from a sequence that has finished executing:**
  1. **Load the latest predict CK for that sequence, made perhaps after the sequence is finished.**
  2. **Load the single reconstruction CK for that sequence, made after the sequence is finished.**
  3. **Load the SCLK used in making the aforementioned predict and reconstruction CKs, or use any later-made SCLK.**



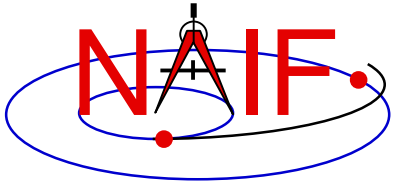
# Validation of Predict CKs

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Navigation and Ancillary Information Facility

- **AACS validates each predict CK by comparing it with the reconstruction CKs for the same time period.**
- **The results of this validation are presented as a set of plots showing the difference between predict and reconstruction orientation (where it is available) broken down into rotational deltas about individual axes of the s/c frame.**
  - See slides 25-30 for examples.
- **These reports will be available on the Web. (mid-October)**
  - Currently they are being stored in AACS AFS space.
  - ([/afs/jpl/home/b/burkt/public/ck\\_compare](/afs/jpl/home/b/burkt/public/ck_compare))



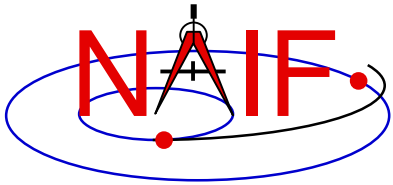


# Accessing Cassini CKs - 1

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Navigation and Ancillary Information Facility

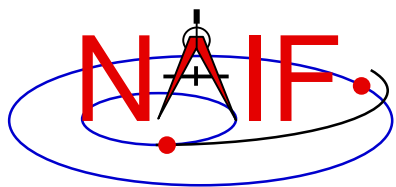
- **To get the orientation (rotation matrix) and angular velocity of the spacecraft, one usually needs four SPICE file types: CK, SCLK, LSK and FK.**
  - **Spacecraft orientation kernel (CK).**
  - **Spacecraft Clock Kernel (SCLK) and Leapseconds Kernel (LSK).**
    - » **Used to convert between ephemeris time (ET) and spacecraft clock time (SCLK).**
  - **Frames Kernel (FK), when high level SPICE interfaces are used to access CK data.**
    - » **Used to associate e.g., an instrument frame with the CK (e.g. spacecraft) frame.**
    - » **See the next page for examples of high level SPICE interfaces.**



# Accessing Cassini CKs - 2

Navigation and Ancillary Information Facility

- **The high-level SPICELIB routines should normally be used to access CK data. These high-level routines are:**
  - **Position or state transformation matrix determination**
    - » **PXFORM**: return a rotation matrix (3x3) from one frame to another, either of which can be a CK frame
    - » **SXFORM**: return a state transformation matrix (6x6) from one frame to another, either of which can be a CK frame
  - **Position or state vector determination**
    - » **SPKPOS**: return a position vector (1x3) in a specified frame, which can be a CK frame or have a CK frame as one of the “links” in its chain
    - » **SPKEZR**: return a state vector (1x6) in a specified frame, which can be a CK frame or have a CK frame as one of the “links” in its chain
  - **The above mentioned routines are discussed in the frames (fk.\*, using\_frames. \*) and spk (spk. \*) tutorials.**



# Accessing Cassini CKs - 3

Navigation and Ancillary Information Facility

Initialization ... typically once per program run

**Tell your program which SPICE files to use (“loading” files).**

```
CALL FURNISH( 'lsk_file_name' )  
CALL FURNISH( 'sclk_file_name' )  
CALL FURNISH( 'ck_file_name' )  
CALL FURNISH( 'fk_file_name' )
```

Better yet, use a “furnsh kernel”  
to load all the needed files.

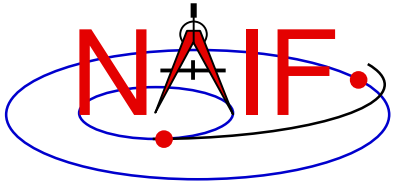
Loop ... do as often as you need

**Convert UTC to Ephemeris Time (et)**

```
CALL STR2ET( 'utc_string', et )
```

**Get 3x3 position vector rotation matrix (cmat), or 6x6 state vector rotation matrix (camat) at your requested time.**

```
CALL PXFORM ( 'from_frame', 'to_frame', et, cmat )  
or  
CALL SXFORM ( 'from_frame', 'to_frame', et, camat )  
                                                                      
                                  inputs                                  output
```

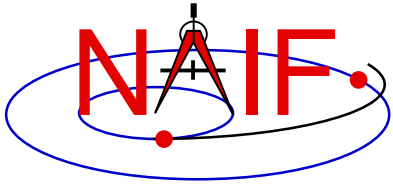


# Accessing Cassini CKs - 4

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Navigation and Ancillary Information Facility

- **The original CK access routines, CKGP and CKGPAV, are also available but not recommended for use because they don't have the ability to combine transformations provided by the high level interfaces.**
  - **The exception to this is if one wants to know if pointing is available for a particular time prior to calling one of the high-level routines, in order to prevent those from signaling an error.**
  - **In this case CKGP or CKGPAV can be called before calling high-level routines, and the FOUND flag returned by this call can be checked to see if pointing is available.**
    - » **Use the Cassini spacecraft ID (-82000), encoded Cassini SCLK, tolerance 0.0 and reference frame 'J2000' when calling CKGP or CKGPAV for that purpose**



# Accessing Cassini CKs - 5

Navigation and Ancillary Information Facility

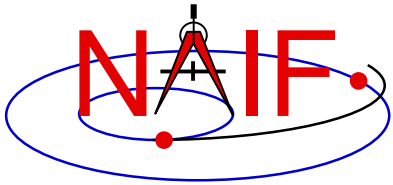
A small FORTRAN program below illustrates a way of computing transformation from the ISS NAC frame to the J2000 inertial frame, incorporating pointing data from Cassini spacecraft CKs.

```
PROGRAM READ_CASSINI_CK_EXAMPLE

IMPLICIT NONE

C
C   Declare variables
C
CHARACTER* (32)      UTCBEG
CHARACTER* (32)      UTCEND
DOUBLE PRECISION    ET
DOUBLE PRECISION    ETBEG
DOUBLE PRECISION    ETEND
DOUBLE PRECISION    ETSTEP
DOUBLE PRECISION    SCLK
DOUBLE PRECISION    HMAT   ( 3, 3 )
DOUBLE PRECISION    CMAT   ( 3, 3 )
LOGICAL             FOUND

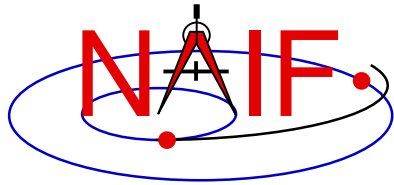
C
C   Load needed kernels -- LSK, SCLK, CK and FK.
C
CALL FURNISH ( 'naif0007.tls'      )
CALL FURNISH ( 'cas00084.tsc'     )
CALL FURNISH ( '04059_04066ra.bc' )
CALL FURNISH ( 'cas_v38.tf'       )
```



# Accessing Cassini CKs - 6

## Navigation and Ancillary Information Facility

```
C
C      Set begin and end UTC and time step. Convert UTCs to ETs.
C
C      UTCBEG = '2004-FEB-29 14:10'
C      UTCEND = '2004-FEB-29 14:30'
C      ETSTEP = 60.D0
C      CALL STR2ET( UTCBEG, ETBEG )
C      CALL STR2ET( UTCEND, ETEND )
C
C      Loop over times.
C
C      ET = ETBEG
C      DO WHILE( ET .LE. ETEND )
C
C          Convert ET to Cassini encoded SCLK and call CKGP to verify
C          that s/c pointing is available in the loaded Cassini CK(s).
C
C          CALL SCE2T( -82, ET, SCLK )
C          CALL CKGP ( -82000, SCLK, 0.D0, 'J2000', CMAT, SCLK, FOUND )
C
C          If pointing is available, compute matrix rotating vectors
C          from ISS NAC frame to J2000 inertial frame.
C
C          IF ( FOUND ) THEN
C              CALL PXFORM ( 'CASSINI_ISS_NAC', 'J2000', ET, CMAT )
C              WRITE (*,*) ' ET, Rotation matrix: ', ET, CMAT
C          ELSE
C              WRITE (*,*) 'S/C POINTING IS NOT FOUND AT ET: ', ET
C          END IF
C
C          ET = ET + ETSTEP
C      END DO
C
C      END
```



# Common Error When Reading CK

Navigation and Ancillary Information Facility

- **The file, or files, you loaded do not cover the time at which you requested orientation**

– You may get an error message like:

=====

```
Toolkit version: N0057
```

```
SPICE (NOFRAMECONNECT) --
```

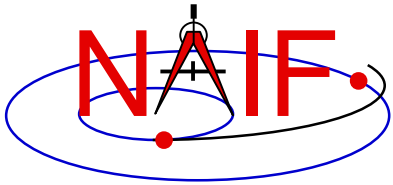
```
There is insufficient information available to ROTform from -82360  
(CASSINI_ISS_NAC) to frame 1 (J2000). Frame -82360 could be transformed to  
-82000 (CASSINI_SC_COORD). Frame 1 could be transformed to 1 (J2000).'
```

```
A traceback follows. The name of the highest level module is first.  
RADEC --> GBV --> PXFORM --> REFCHG
```

```
Oh, by the way: The SPICELIB error handling actions are USER-TAILORABLE. You  
can choose whether the Toolkit aborts or continues when errors occur, which  
error messages to output, and where to send the output. Please read the ERROR  
"Required Reading" file, or see the routines ERRACT, ERRDEV, and ERRPRT.
```

=====

- Check file coverage on the segment level by summarizing the file(s) using CKBRIEF or SPACIT.
- Check interpolation interval coverage using CKBRIEF with option “-dump,” or by examining comments provided in the comment area of the file – you may be asking for data within a coverage gap (outside of interpolation intervals).



# Additional Information on CK

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## Navigation and Ancillary Information Facility

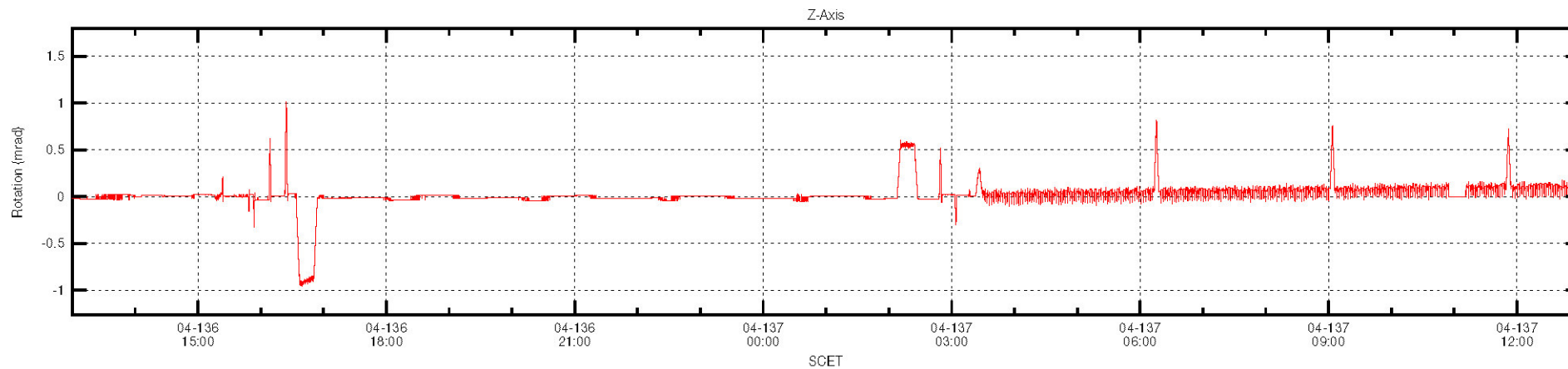
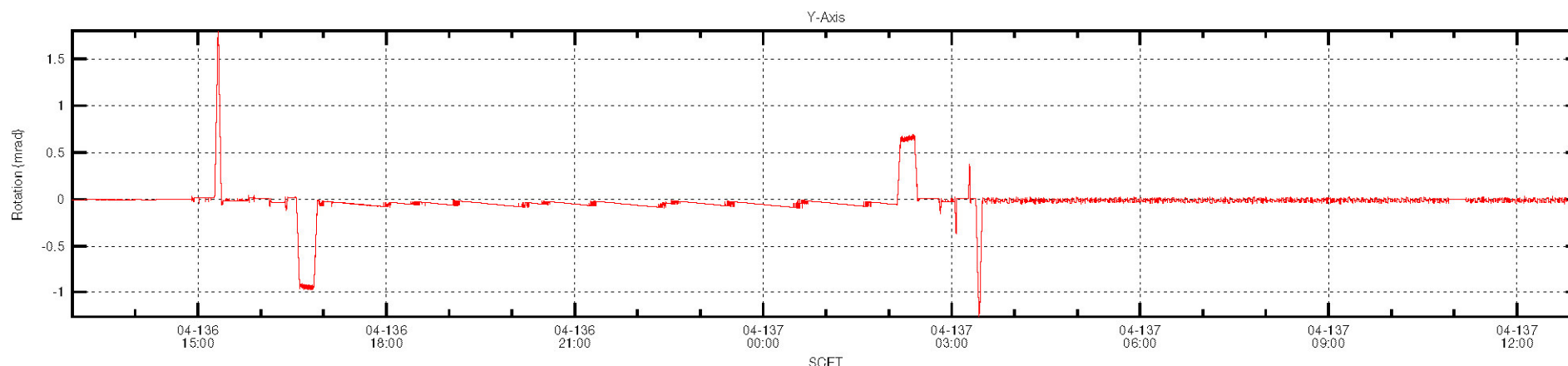
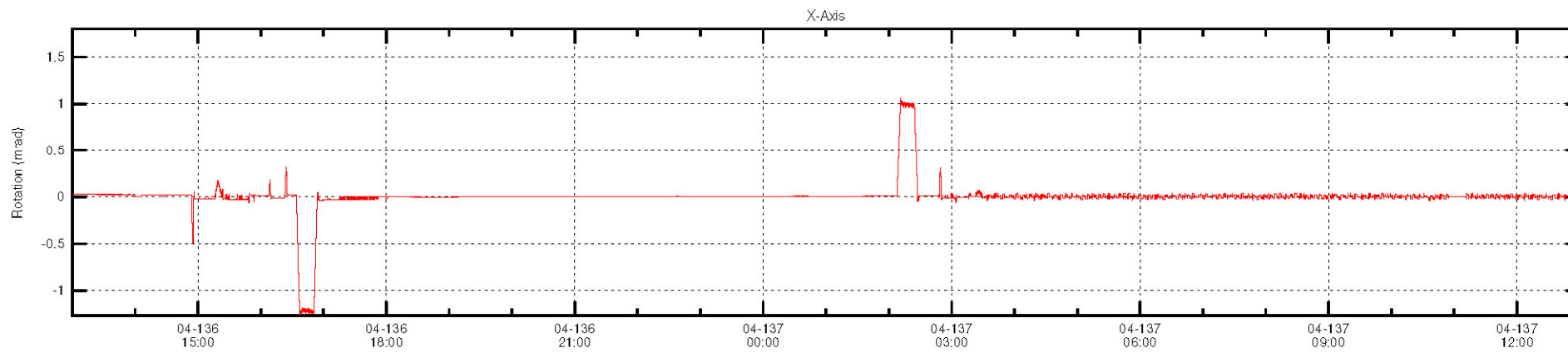
- **For more information about CK, look at the following documents**
  - Headers for PIFORM, SXFORM, SPKPOS and SPKEZR
    - » If needed, see headers for CKGP and CKGPAV
  - Generic CK Tutorial
  - Frames tutorial
  - CK and Frames Required Reading
  - CKBRIEF and SPACIT User's Guides
  - Most Useful SPICELIB Routines
  - Porting\_Kernels tutorial
- **Related documents**
  - SCLK Required Reading
  - Time Required Reading
  - Frames Required Reading
  - NAIF\_IDS Required Reading
  - Rotations Required Reading
- **For a general guide to locating documents, see**  
**[ftp://naif/pub/naif/toolkit\\_docs/Tutorials/pdf/individual\\_docs/39\\_finding\\_components.pdf](ftp://naif/pub/naif/toolkit_docs/Tutorials/pdf/individual_docs/39_finding_components.pdf)**



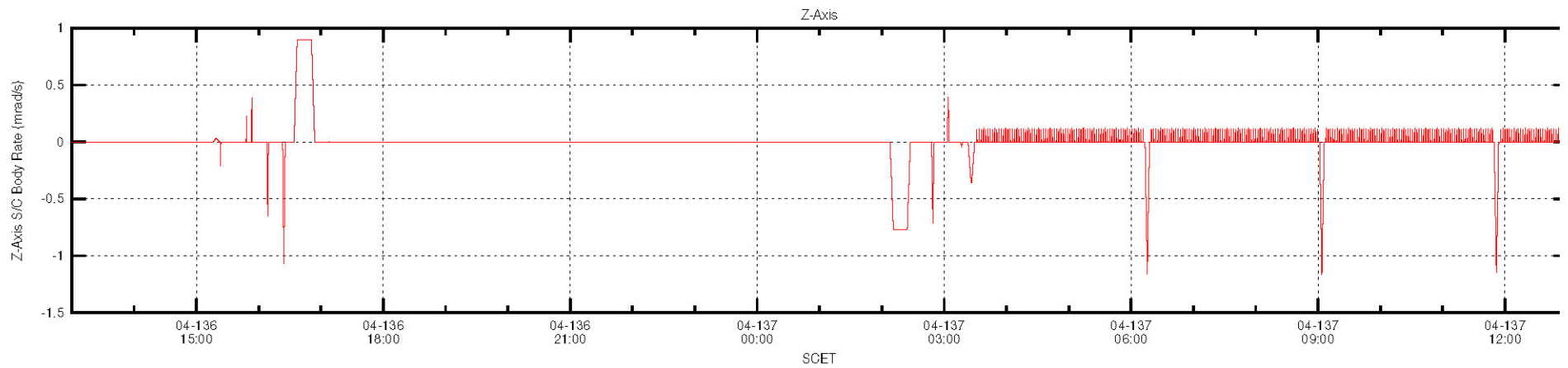
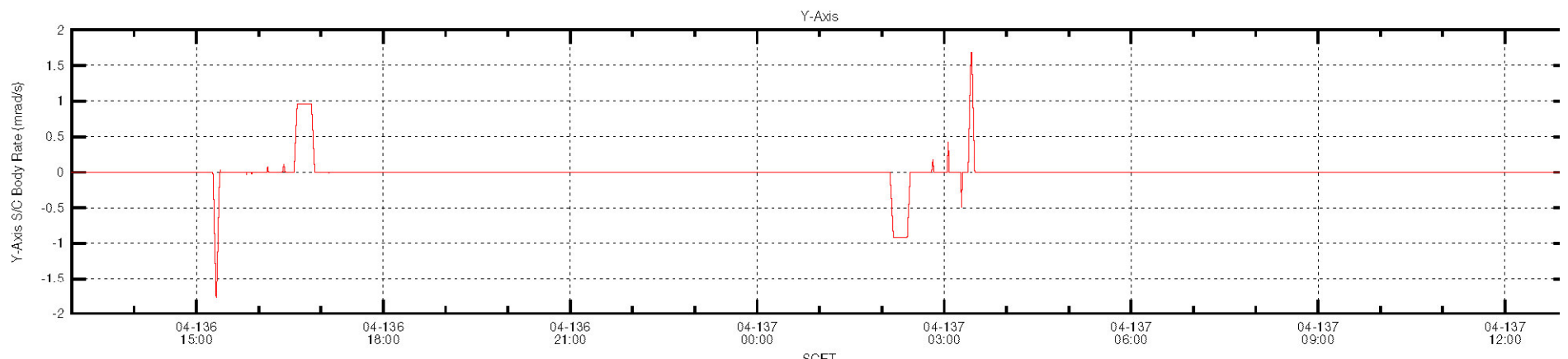
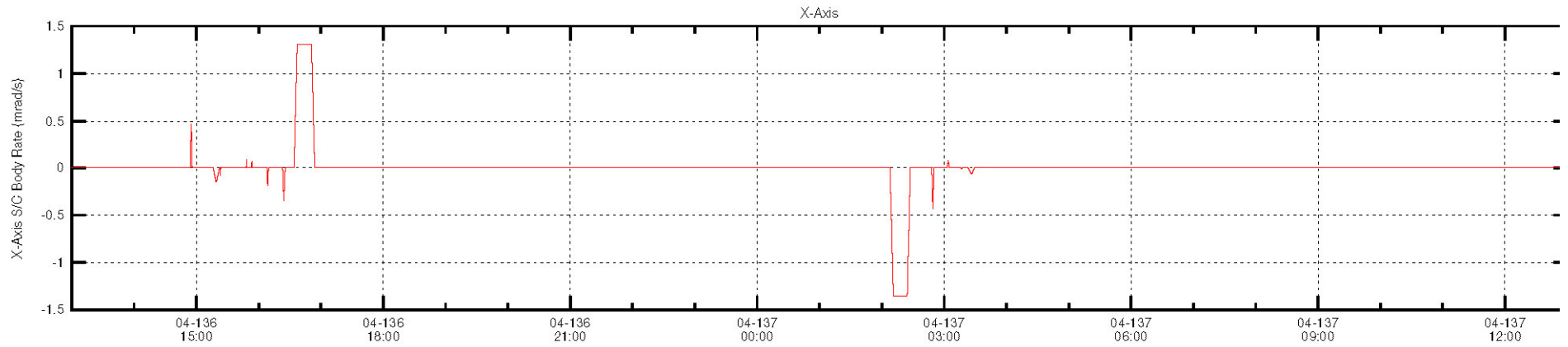
# AACS CK-Compare Reports

- **Each report covers 5-7 days of attitude data**
- **Each report includes:**
  - Interval and gap times in SCET format (e.g. 2004-DOYT00:00:00.000)
  - 24-hours of data per plot
  - Tabular data of mean and 1-sigma attitude difference, each axis, for that 24-hour period (also tabulated on a continuous trend report)
  - The plots contain:
    - » Page 1 -- Attitude difference data expressed as a rotation (in mrad) about the S/C axes (X, Y, and Z) “from” the predicted attitude “to” the reconstructed attitude
    - » Page 2 -- Predicted S/C body rates (X, Y, and Z) in mrad/sec
    - » Page 3 -- Data present indication
      - 0 = All data is present
      - 1 = Gap in Recon CK
      - 2 = Real-time activity (predict not applicable)

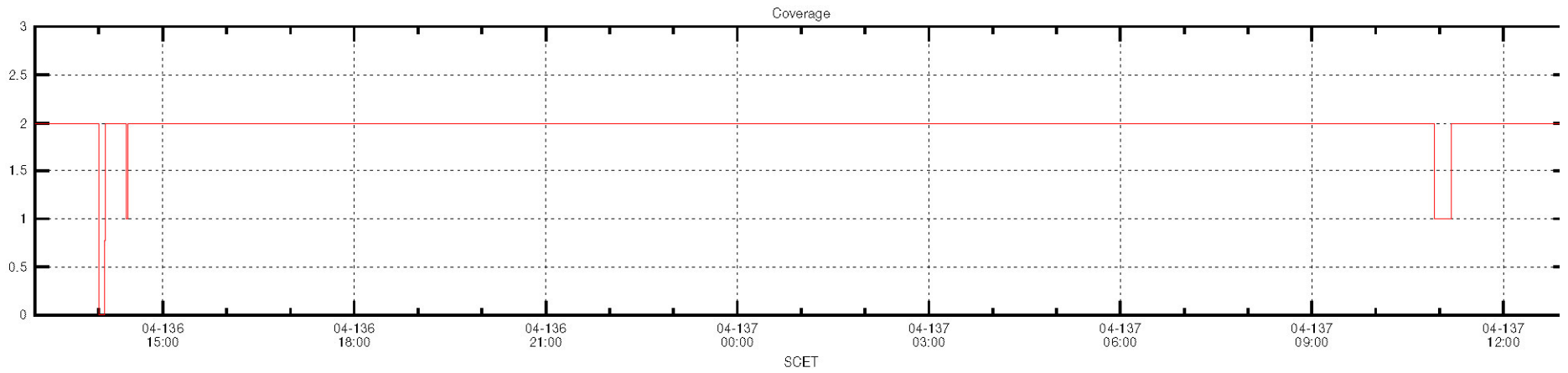
# Rotation From Predicted S/C Attitude to Reconstructed S/C Attitude (DOY 136-137)



# Predicted S/C Body Rates (DOY 136-137)



All Data Present = 2, Recon Missing = 1, Real-Time Activity (Predict Not Applicable) = 0 (DOY 136-137)



AACS Proposed C-Kernel Prediction/Reconstruction Comparison

Recon CK: /home2/gsw/dbeach/utils/ckernel\_dir/04136\_04142ra.bc

PRODUCT\_CREATION\_TIME = 2004-145T17:37:57  
QUERY\_START\_TIME = 2004-136T13:00:01  
QUERY\_STOP\_TIME = 2004-142T23:58:57  
INTERVALS = 20

	Interval	Gap
1.	2004-136T13:00:01 2004-136T14:25:45	2004-136T14:25:45 2004-136T14:27:17
2.	2004-136T14:27:17 2004-137T10:54:57	2004-137T10:54:57 2004-137T11:11:09
3.	2004-137T11:11:09 2004-138T17:39:52	2004-138T17:39:52 2004-138T17:40:44
4.	2004-138T17:40:44 2004-138T18:31:52	2004-138T18:31:52 2004-138T18:33:08
5.	2004-138T18:33:08 2004-138T22:38:32	2004-138T22:38:32 2004-138T22:38:52
6.	2004-138T22:38:52 2004-138T22:41:20	2004-138T22:41:20 2004-138T22:42:36
7.	2004-138T22:42:36 2004-138T22:56:08	2004-138T22:56:08 2004-138T22:56:52
8.	2004-138T22:56:52 2004-138T23:09:28	2004-138T23:09:28 2004-138T23:09:56
9.	2004-138T23:09:56 2004-138T23:13:12	2004-138T23:13:12 2004-138T23:14:12
10.	2004-138T23:14:12 2004-138T23:34:48	2004-138T23:34:48 2004-138T23:35:40
11.	2004-138T23:35:40 2004-139T09:30:32	2004-139T09:30:32 2004-139T09:33:00
12.	2004-139T09:33:00 2004-140T06:41:27	2004-140T06:41:27 2004-140T06:45:31
13.	2004-140T06:45:31 2004-140T07:11:19	2004-140T07:11:19 2004-140T07:14:51
14.	2004-140T07:14:51 2004-140T14:54:51	2004-140T14:54:51 2004-140T14:56:59
15.	2004-140T14:56:59 2004-141T07:37:34	2004-141T07:37:34 2004-141T07:37:54

Day No 1 (DOY 136-137)

2004-136T13:00:01.675 to 2004-137T13:00:01.675

Maximum Error

X 1.26 mrad at 2004-136T16:37:26.675

Y 1.80 mrad at 2004-136T15:19:11.675

Z 1.01 mrad at 2004-136T16:24:36.675

Mean Deviation

X 0.17 mrad

Y 0.15 mrad

Z 0.13 mrad

Day No 2 (DOY 137-138)

2004-137T13:00:01.675 to 2004-138T13:00:01.675

Maximum Error

X 2.98 mrad at 2004-137T20:17:36.675

Y 2.86 mrad at 2004-137T23:42:41.675

Z 3.07 mrad at 2004-137T20:40:56.675

Mean Deviation

X 0.59 mrad

Y 0.57 mrad

Z 0.69 mrad

Day No 3 (DOY 138-139)

2004-138T13:00:01.675 to 2004-139T13:00:01.675

Maximum Error

X 1.10 mrad at 2004-138T18:35:21.675

Y 1.39 mrad at 2004-138T19:50:11.675

Z 0.66 mrad at 2004-138T18:35:56.675

Mean Deviation

X 0.11 mrad

Y 0.11 mrad

Z 0.07 mrad