What's In ALMA Data

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ALMA Data Reduction Workshop

Dec. 1, 2011

Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

Outline

- What different kinds of data are taken
  - Pointing
  - Tsys
  - WVR
  - CASA names and ids
- Example TDM dataset
- Example FDM dataset
- Example FDM Mosaic dataset
- Cycle 0 data package

What Data Were Taken (1)?

NAASC

Raw ALMA = ASDM. They are imported to CASA with *importasdm* task

After import, the following CASA task will print a summary of the observations, optionally making a hardcopy text file if *listfile* is set

listobs(vis='your.ms',listfile='your.ms.listobs',verbose=T)

- Provides the keys to understanding your data, though it can seem a bit complicated at first glance

- The **Observing Intents** will tell you exactly what each source observed was/is to be used for -- the same observation can be used for multiple intents
  - CALIBRATE_POINTING
  - CALIBRATE_ATMOSPHERE (i.e. Tsys)
  - CALIBRATE_WVR
  - CALIBRATE_BANDPASS
  - CALIBRATE_PHASE
  - OBSERVE_TARGET

- **TDM:** Time Division Mode – low spectral resolution, high time resolution possible. BW=2 GHz per baseband, **128 channels** per pol. Used for pointing and Tsys calibration
- **FDM:** Frequency Division Mode – high spectral resolution, BW 0.056 to 1.875 GHz, **3840 channels** per pol

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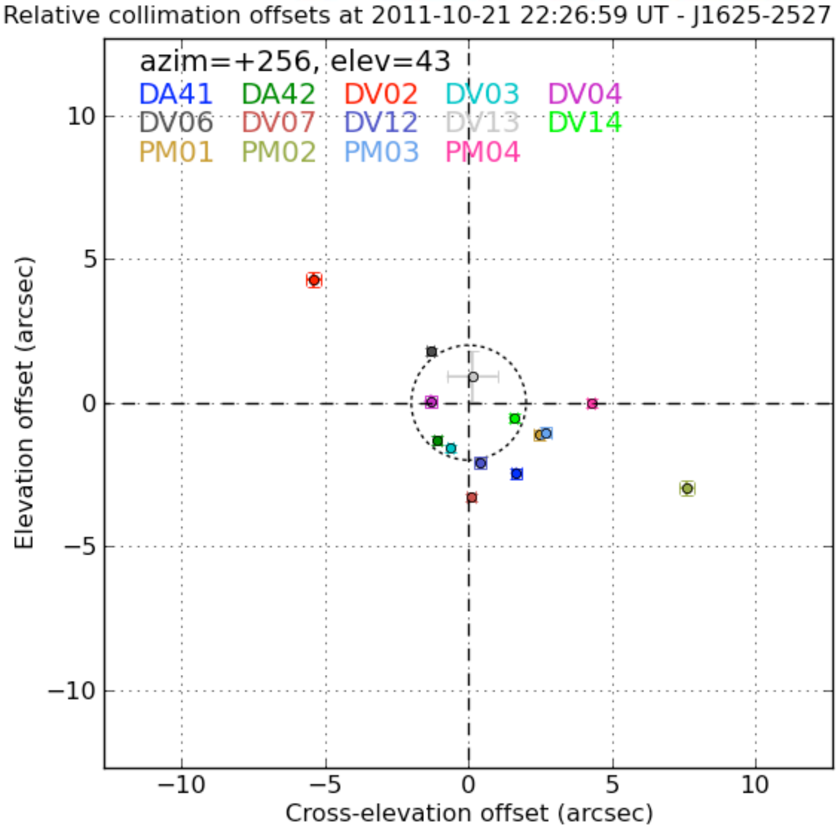
Pointing Calibration

Specifications

- All-sky pointing: 2.0 arcsec
- Offset pointing within 2 degrees: 0.6 arcsec

Reality

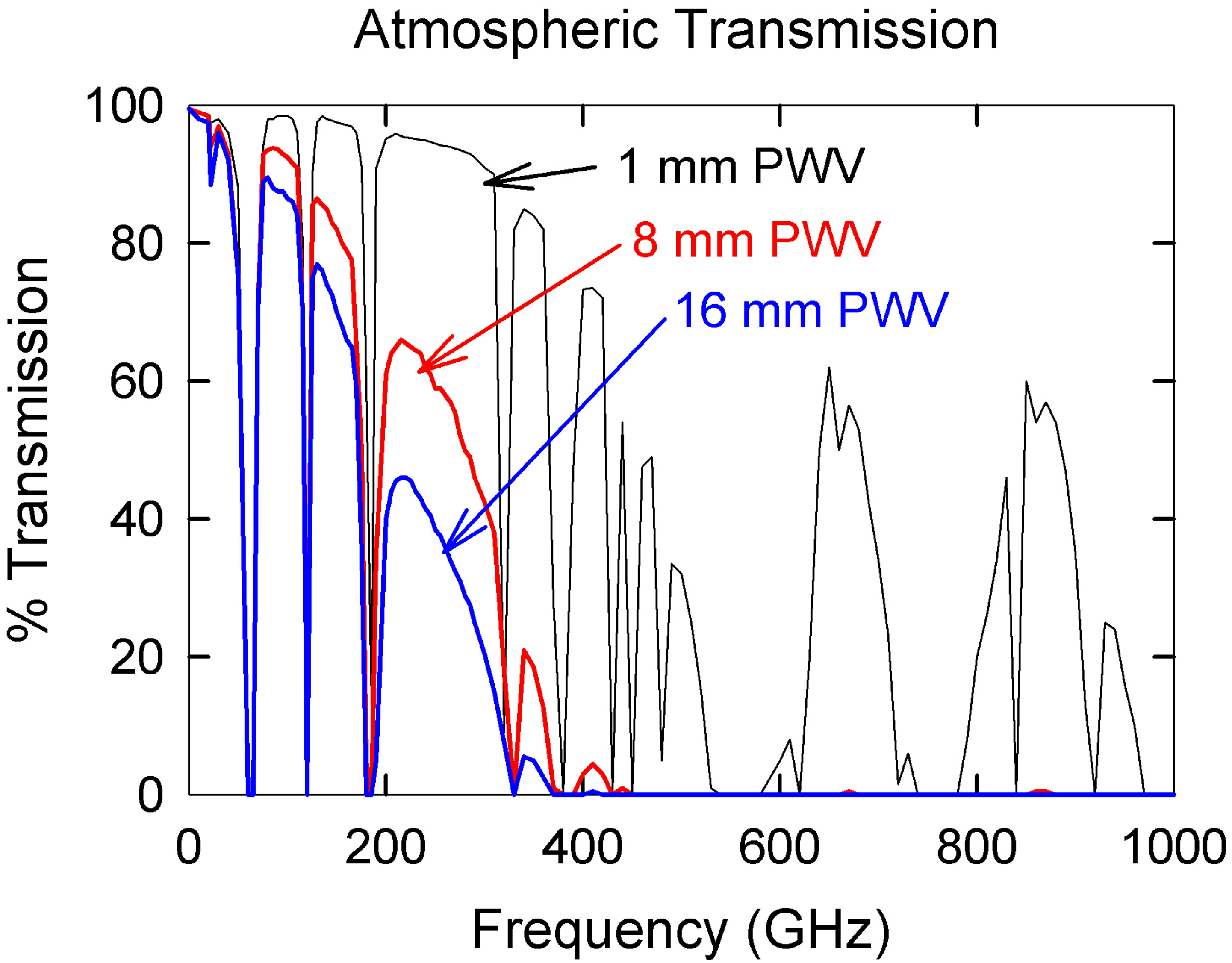
- Thermal gradients during daytime and sunset/sunrise will cause variations larger than spec
- Pointing models for newly integrated antennas take time to perfect
- Band to band "offsets" must also be calibrated -- pointing typically done at Band 3, sometimes Band 6 and extrapolated to other bands



Current practice

- Moves > ~30 degrees
- About once per hour otherwise

Opacity as a Function of PWV (PWV=Precipitable Water Vapor)



Sensitivity: System noise temperature

In addition to receiver noise, at millimeter wavelengths the atmosphere has a significant brightness temperature (T_{sky}):

For a perfect antenna, ignoring spillover and efficiencies

$$T_{noise} \approx T_{rx} + T_{sky}$$

$$\text{where } T_{sky} = T_{atm}\,(1 - e^{-\tau}) + T_{bg}e^{-\tau}$$

$$\text{so } T_{noise} \approx \underset{\substack{\uparrow \\ \text{Receiver temperature}}}{T_{rx}} + \underset{\substack{\uparrow \\ \text{Emission from atmosphere}}}{T_{atm}(1-e^{-\tau})}$$

T_{atm} = temperature of the atmosphere ≈ 300 K

T_{bg} = 3 K cosmic background

Before entering atmosphere the source signal $S= T_{source}$

After attenuation by atmosphere the signal becomes $S=T_{source}\ e^{-\tau}$

Consider the signal-to-noise ratio:

$$S / N = (T_{source}\ e^{-\tau}) / T_{noise} = T_{source} / (T_{noise}\ e^{\tau})$$

$$T_{\mathbf{sys}} = T_{noise}\,e^{\tau} \approx T_{\mathbf{atm}}(e^{\tau} - 1) + T_{\mathbf{rx}}e^{\tau}$$

⇨ The system sensitivity drops exponentially as opacity increases

System Temperature

Typical optical depth for 230 GHz observing at zenith:

τ_{225} = 0.15 = 3 mm PWV, so at elevation = 30° $\Rightarrow$ τ_{225} = 0.3

$T_{sys} = e^{\tau}(T_{atm}(1-e^{-\tau}) + T_{rx}) = 1.35(77 + 75) \sim 200$ K

assuming T_{atm} = 300 K and T_{rx} = 75 K

ALMA Bands 9 and 10 are double sideband receivers , thus the effective T_{sys} for spectral lines (which are inherently single sideband) is doubled

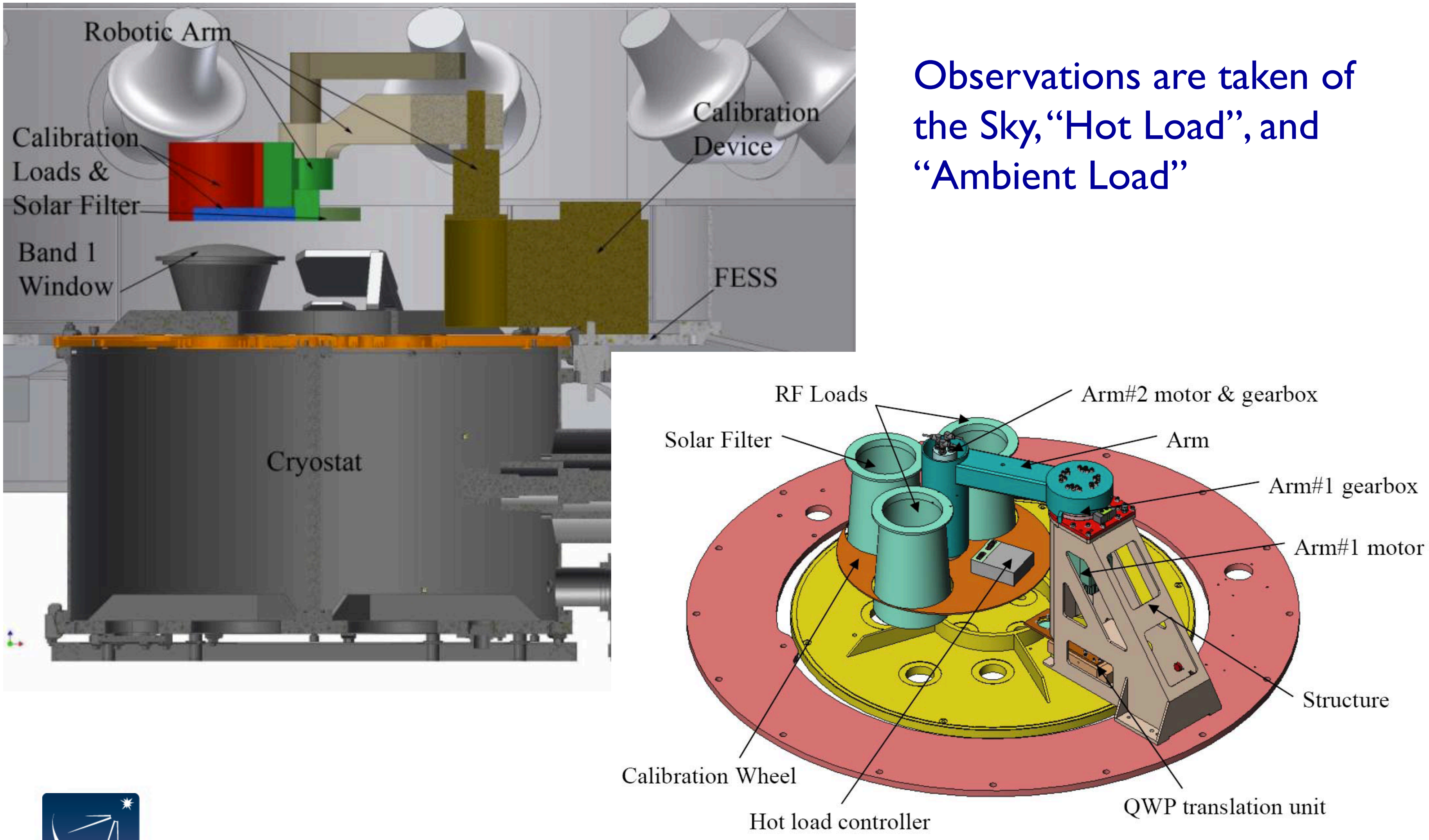
⇨ Atmosphere adds considerably to T_{sys} and since the opacity can change rapidly, T_{sys} must be measured often

⇨ A single load system only gives Tsys (i.e. sum in equation above)

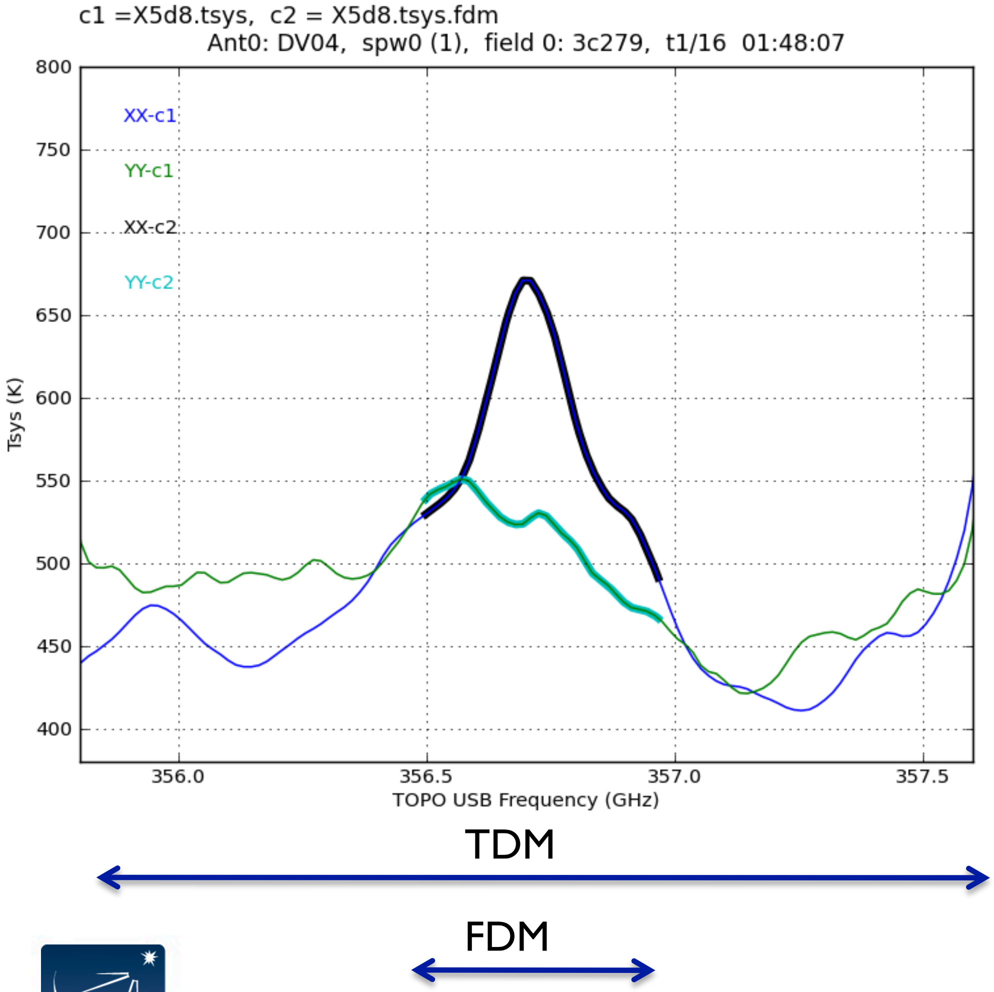
⇨ A two load system allows independent measure of T_{rx}, and other efficiencies that can be used to improve performance (like optimizing tuning)

ALMA 2-Load Calibration Device

Observations are taken of the Sky, "Hot Load", and "Ambient Load"



Examples of ALMA Tsys: TDM vs FDM



- Currently ALL ALMA Tsys are done in 2 GHz per baseband TDM mode
- If Science data are taken in high spectral resolution FDM mode: TDM Tsys is interpolated to FDM spectral grid before application

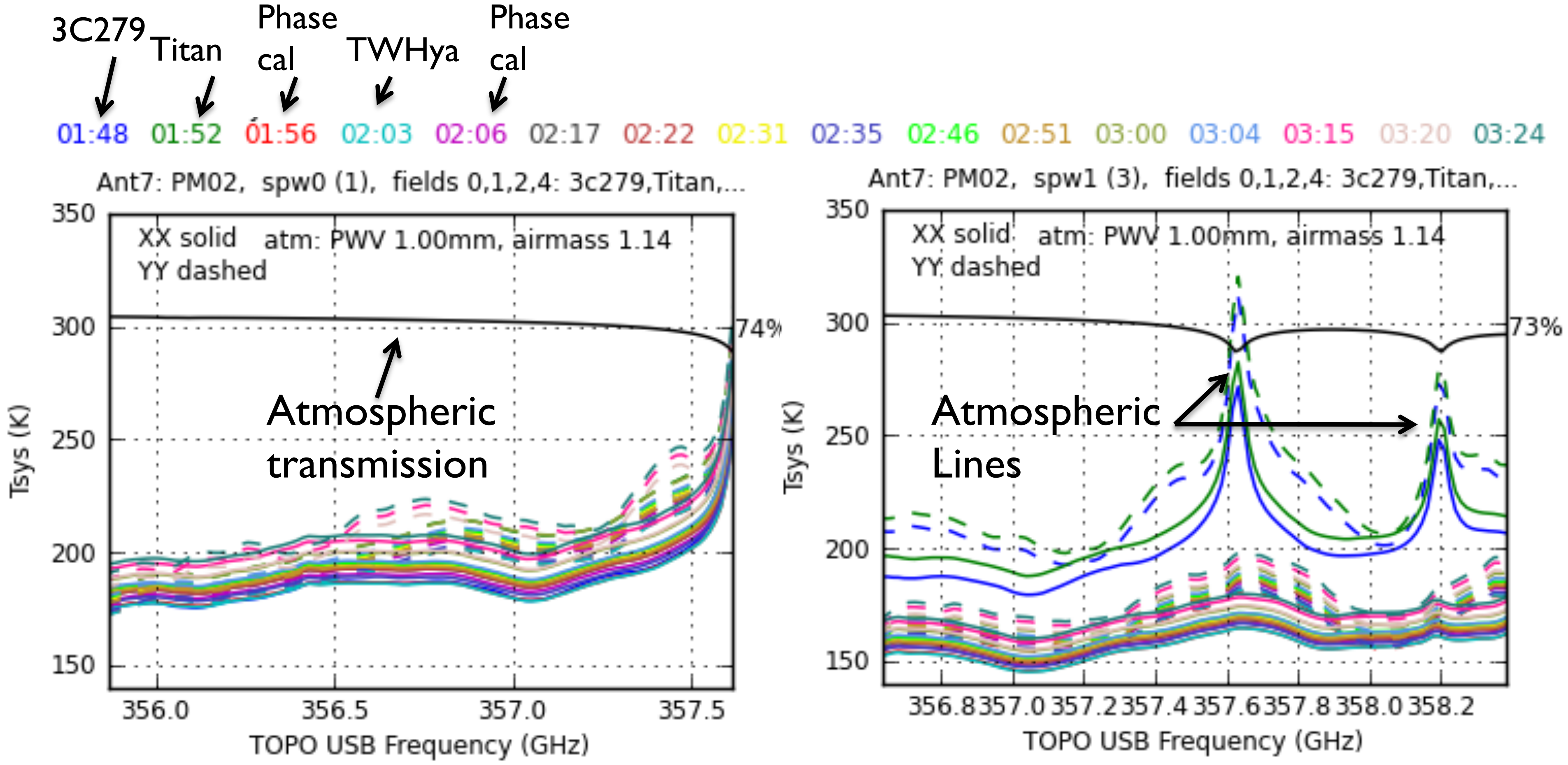
Example: TWHya Band 7 SV Data

- Science data taken with 0.5 GHz FDM spectral windows
- Tsys taken in 2 GHz TDM mode and interpolated to "science" FDM mode

Examples of ALMA Tsys: Time

NAASC

Colors = scans with Tsys measurements = variations with time and elevation for one antenna



3C279

Titan

Phase cal

TWHya

Phase cal

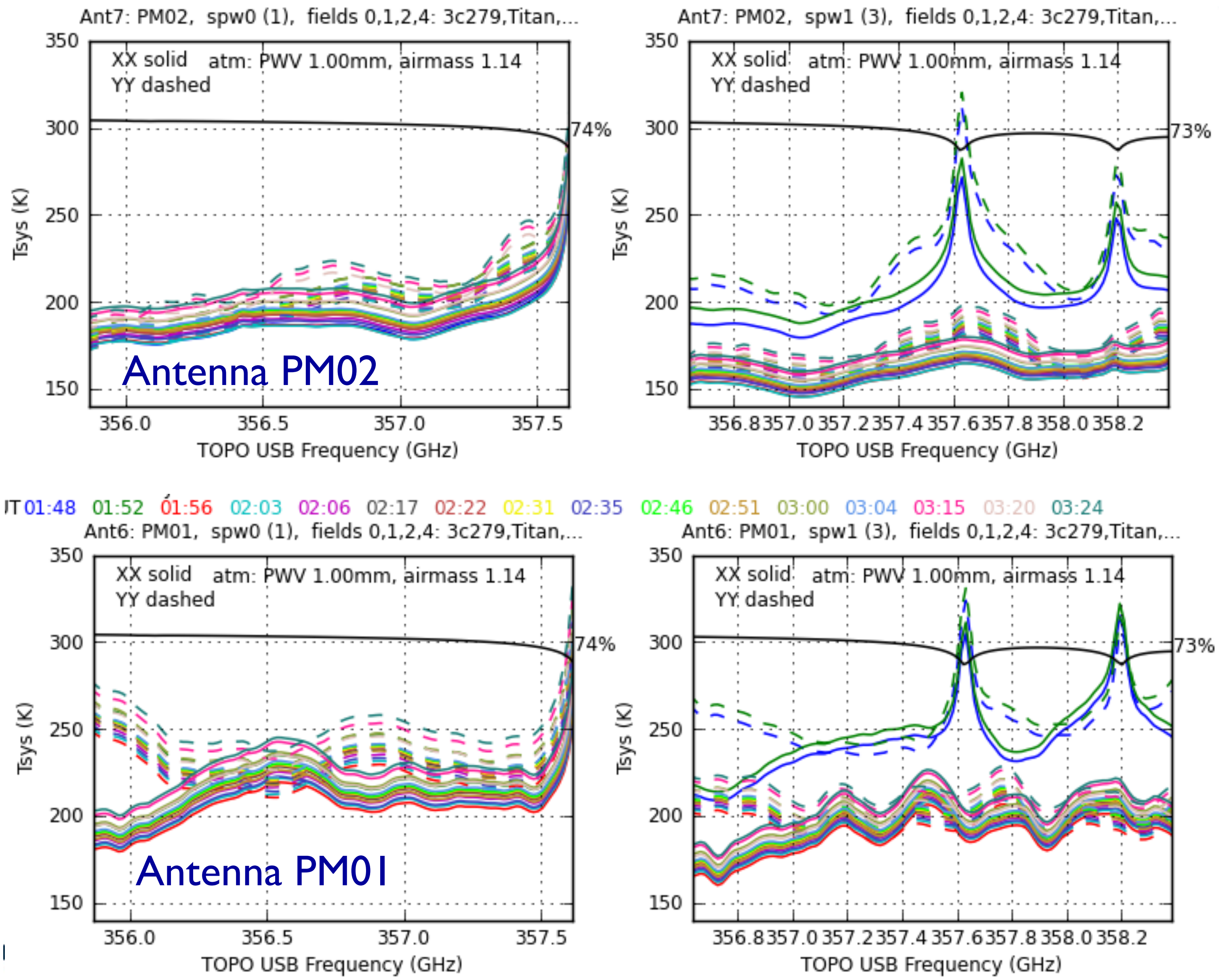
Atmospheric transmission

Atmospheric Lines

Spw=0

Spw=1

ALMA System Temperatures: Tsys



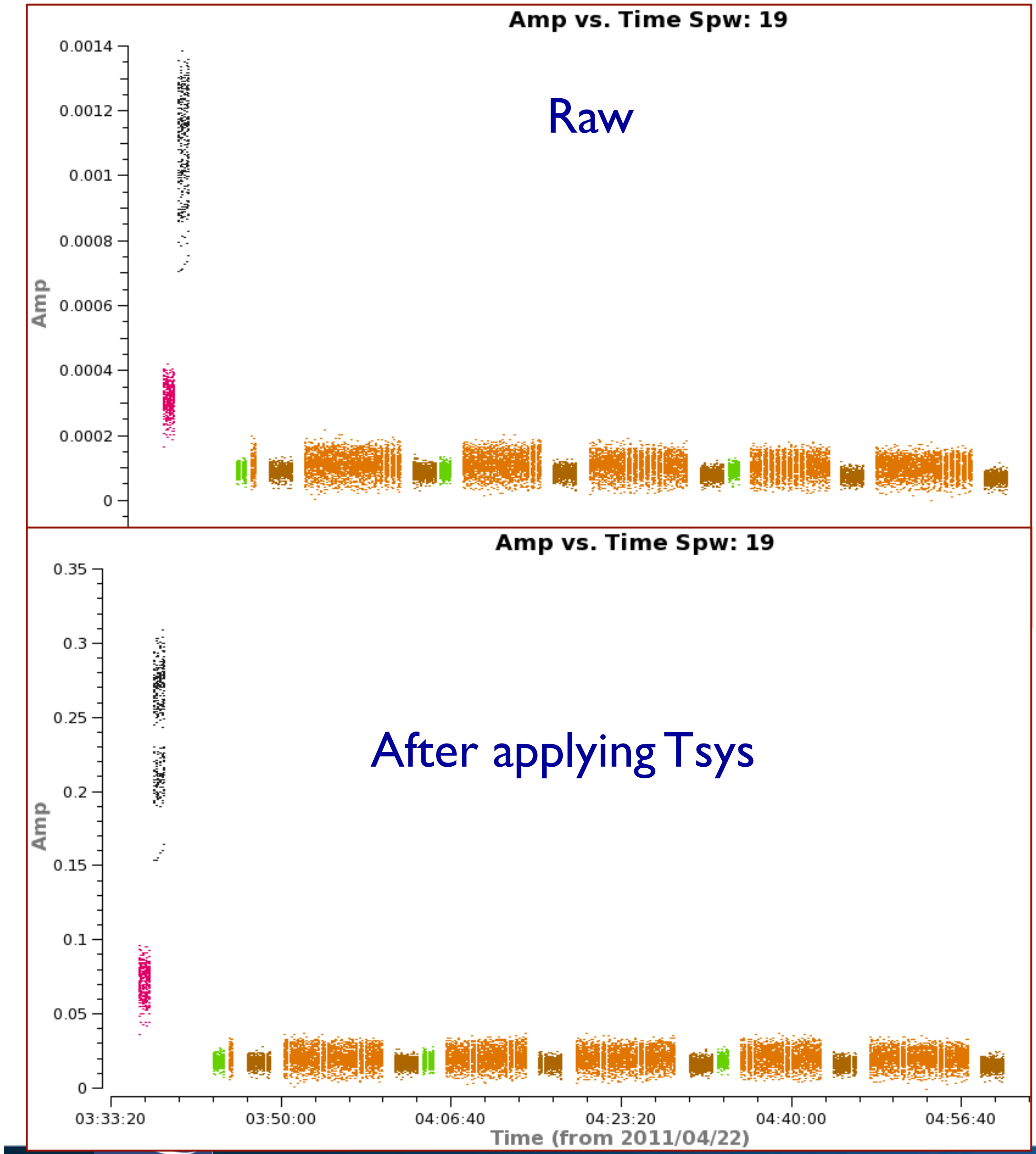
Antenna PM02

Antenna PM01

$$\mathit{Visibility\,Weight} \propto \frac{1}{T_{sys}(i)T_{sys}(j)}$$

Data from baselines with good Tsys get up-weighted compared to baselines with poorer Tsys

Before and After Tsys



- Notice change in Amp scale.
- Amplitudes multiplied by:

$$S = S_o * [T_{sys}(1) * T_{sys}(2)]^{0.5}$$

To estimate approximate Jy scale, multiply by ALMA antenna efficiency factor:

about 40 Jy/K

ALMA WVR System

NAASC

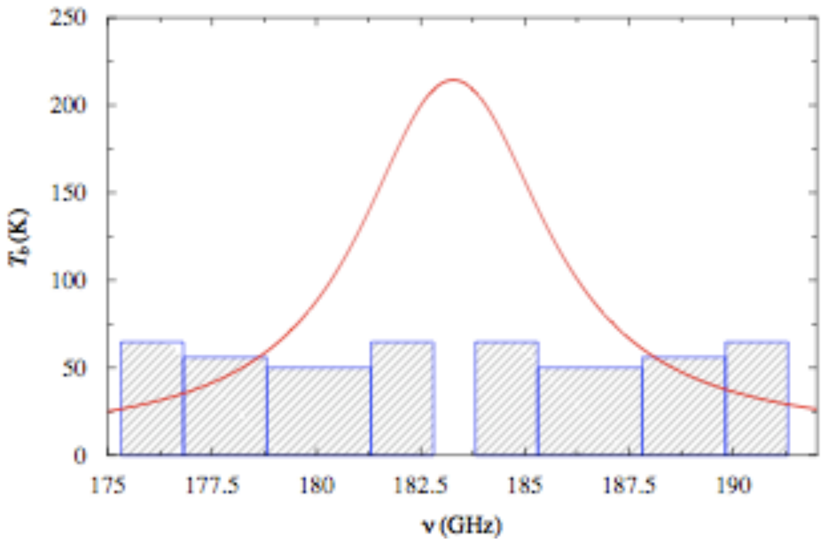
Water Vapor Radiometry (WVR) : measure the rapid fluctuations in T_B^{atm} with a radiometer at each antenna, then use these measurements to derive changes in water vapor column (Δw) and convert to phase corrections using:

$$\Delta\phi_e \approx 12.6\,\pi\,\Delta w / \lambda$$

Installed on every 12-m antenna

The 183 GHz Water Vapour Line

Blue rectangles are the production WVR filters



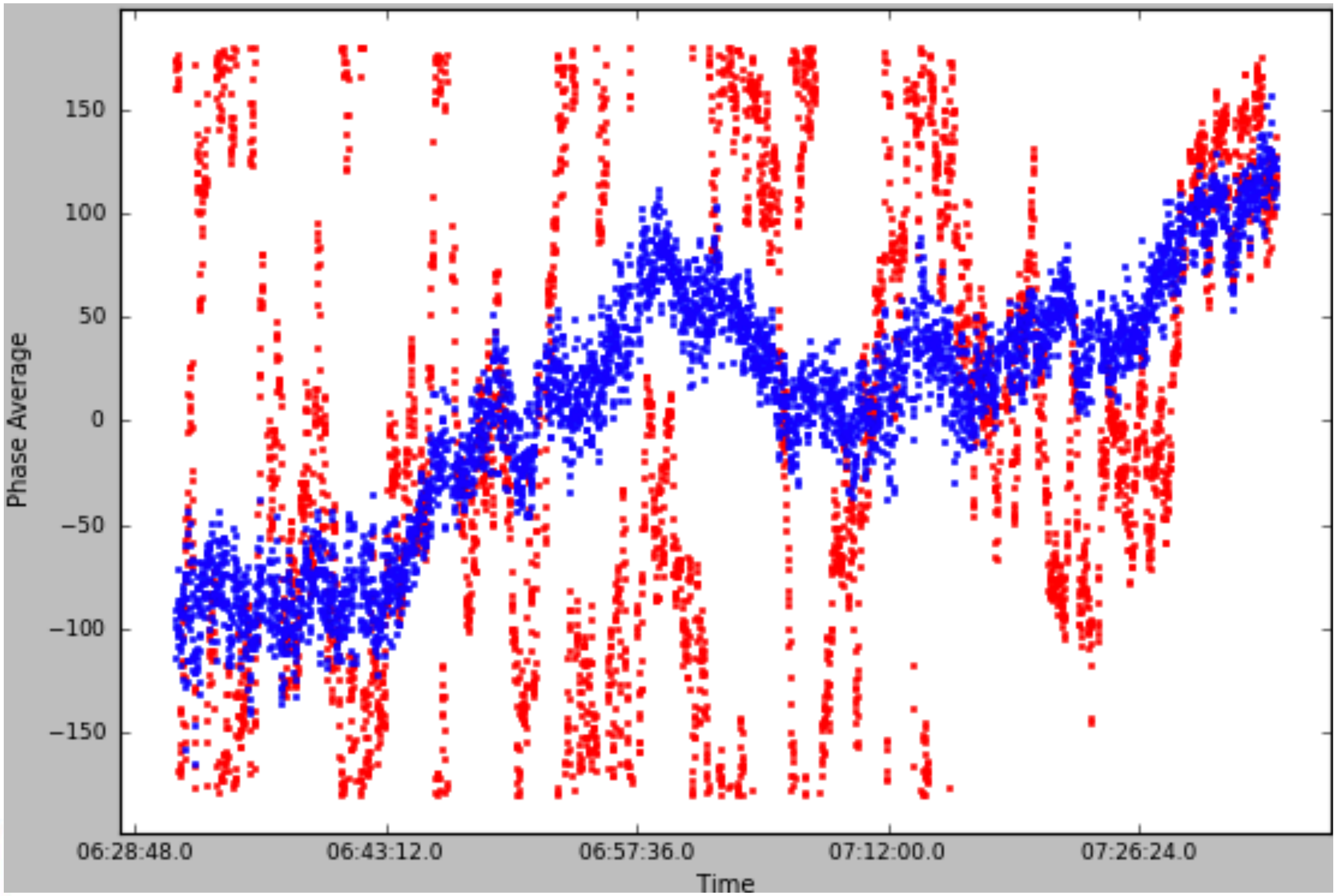
There are 4 "channels" flanking peak of the 183 GHz water line

- The four channels allow flexibility for avoiding saturation
- Data will always be in spw=0
- Data taken each second; matching data from opposite sides are averaged
- Next challenges are to perfect models for relating the WVR data to the correction for the data beyond simplified equation above

WVR example

600m baseline, Band 6, Mar 2011

(red=raw data, blue=corrected)



What Data Were Taken (2)?

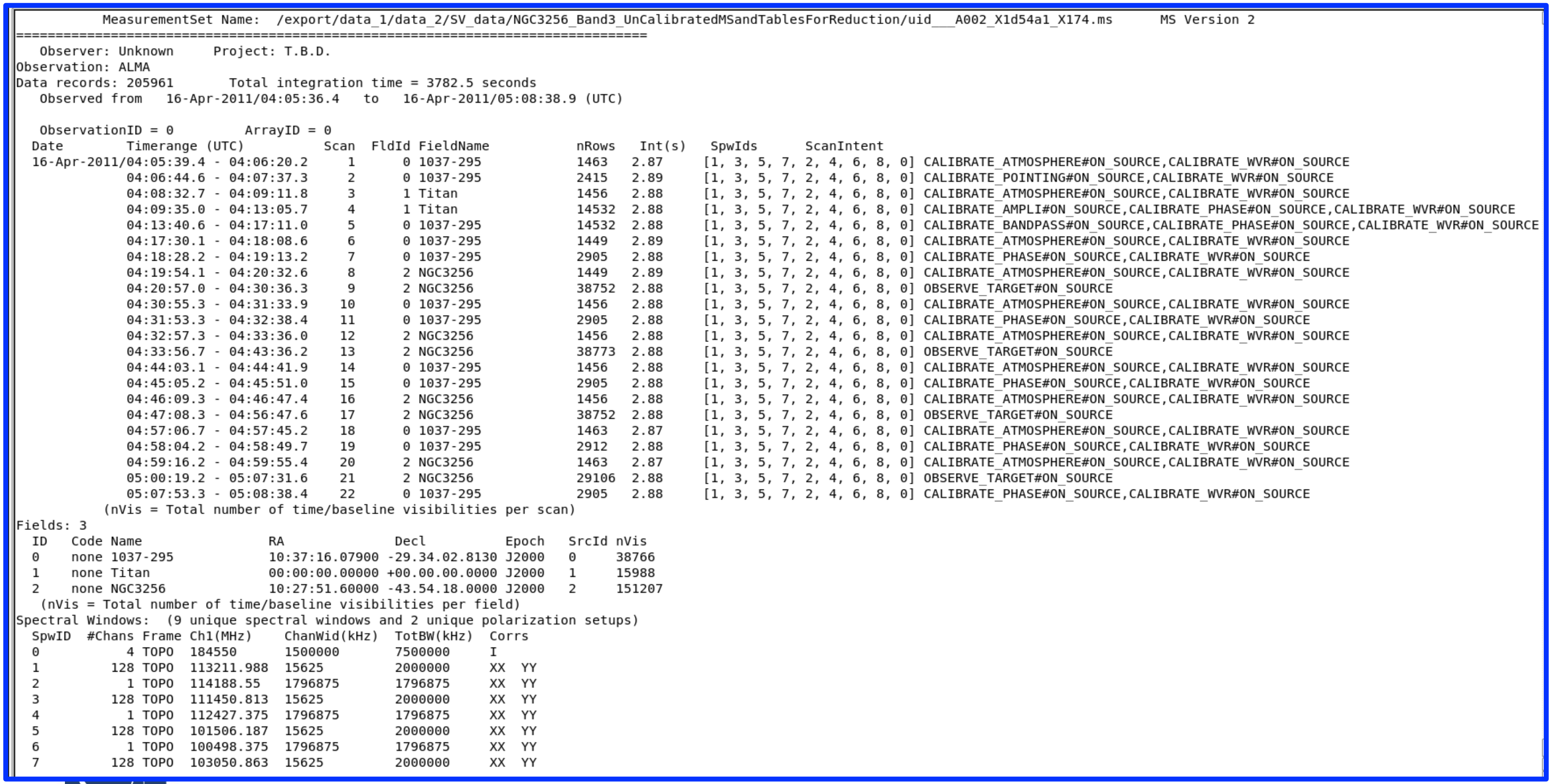
The following CASA task will print a summary of the observations, optionally making a hardcopy text file if *listfile* is set

listobs(vis='your.ms',listfile='your.ms.listobs',verbose=T)

- In the Order they are encountered in the data:
  - Each position that is observed is given a **field id**; inside CASA objects can be selected via their **Names** (* wildcard use possible) or **field id**
  - The spectral setups are indicated by a **spectral window (spw) id**
  - Each antenna used in the observing array is given an **Antenna id**
  - Each distinct target is also given a **source id – i.e. only different for mosaics** (not currently used inside CASA)

Example TDM: SV data NGC3256

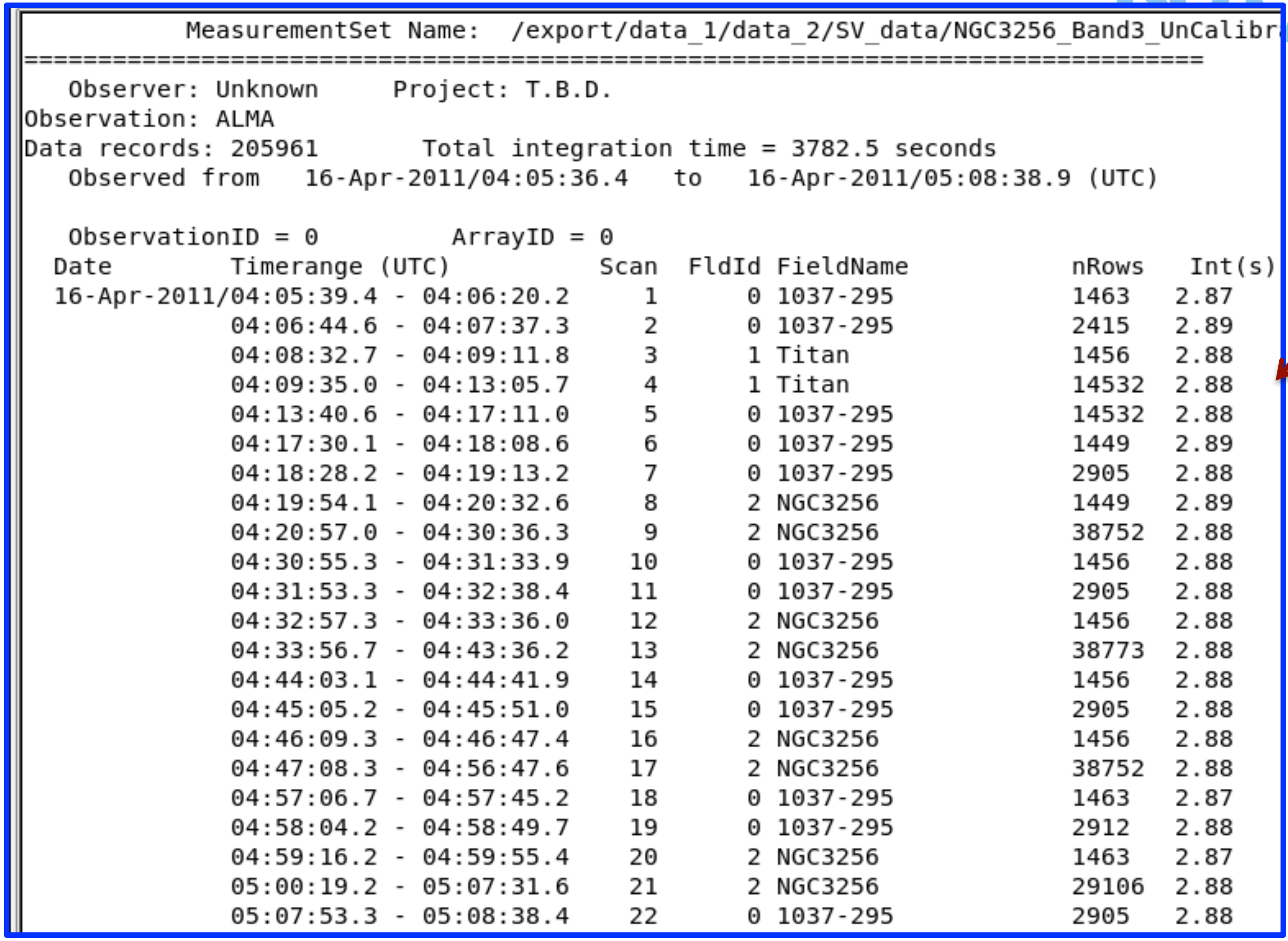
- Top portion of verbose *listobs*
- In next slides we zoom in on different parts



```
           MeasurementSet Name:  /export/data_1/data_2/SV_data/NGC3256_Band3_UnCalibratedMSandTablesForReduction/uid___A002_X1d54a1_X174.ms      MS Version 2
================================================================================
   Observer: Unknown     Project: T.B.D.
Observation: ALMA
Data records: 205961       Total integration time = 3782.5 seconds
   Observed from   16-Apr-2011/04:05:36.4   to   16-Apr-2011/05:08:38.9 (UTC)

   ObservationID = 0         ArrayID = 0
  Date        Timerange (UTC)          Scan  FldId FieldName            nRows   Int(s)   SpwIds      ScanIntent
  16-Apr-2011/04:05:39.4 - 04:06:20.2     1      0 1037-295            1463   2.87     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:06:44.6 - 04:07:37.3     2      0 1037-295            2415   2.89     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_POINTING#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:08:32.7 - 04:09:11.8     3      1 Titan               1456   2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:09:35.0 - 04:13:05.7     4      1 Titan               14532  2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_AMPLI#ON_SOURCE,CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:13:40.6 - 04:17:11.0     5      0 1037-295            14532  2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_BANDPASS#ON_SOURCE,CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:17:30.1 - 04:18:08.6     6      0 1037-295            1449   2.89     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:18:28.2 - 04:19:13.2     7      0 1037-295            2905   2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:19:54.1 - 04:20:32.6     8      2 NGC3256             1449   2.89     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:20:57.0 - 04:30:36.3     9      2 NGC3256             38752  2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] OBSERVE_TARGET#ON_SOURCE
              04:30:55.3 - 04:31:33.9    10      0 1037-295            1456   2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:31:53.3 - 04:32:38.4    11      0 1037-295            2905   2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:32:57.3 - 04:33:36.0    12      2 NGC3256             1456   2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:33:56.7 - 04:43:36.2    13      2 NGC3256             38773  2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] OBSERVE_TARGET#ON_SOURCE
              04:44:03.1 - 04:44:41.9    14      0 1037-295            1456   2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:45:05.2 - 04:45:51.0    15      0 1037-295            2905   2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:46:09.3 - 04:46:47.4    16      2 NGC3256             1456   2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:47:08.3 - 04:56:47.6    17      2 NGC3256             38752  2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] OBSERVE_TARGET#ON_SOURCE
              04:57:06.7 - 04:57:45.2    18      0 1037-295            1463   2.87     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:58:04.2 - 04:58:49.7    19      0 1037-295            2912   2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              04:59:16.2 - 04:59:55.4    20      2 NGC3256             1463   2.87     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
              05:00:19.2 - 05:07:31.6    21      2 NGC3256             29106  2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] OBSERVE_TARGET#ON_SOURCE
              05:07:53.3 - 05:08:38.4    22      0 1037-295            2905   2.88     [1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
           (nVis = Total number of time/baseline visibilities per scan)
Fields: 3
  ID   Code Name                RA              Decl           Epoch   SrcId nVis
  0    none 1037-295            10:37:16.07900 -29.34.02.8130 J2000   0     38766
  1    none Titan               00:00:00.00000 +00.00.00.0000 J2000   1     15988
  2    none NGC3256             10:27:51.60000 -43.54.18.0000 J2000   2     151207
   (nVis = Total number of time/baseline visibilities per field)
Spectral Windows:  (9 unique spectral windows and 2 unique polarization setups)
  SpwID  #Chans Frame Ch1(MHz)    ChanWid(kHz)  TotBW(kHz)  Corrs
  0           4 TOPO  184550      1500000       7500000     I
  1         128 TOPO  113211.988  15625         2000000     XX  YY
  2           1 TOPO  114188.55   1796875       1796875     XX  YY
  3         128 TOPO  111450.813  15625         2000000     XX  YY
  4           1 TOPO  112427.375  1796875       1796875     XX  YY
  5         128 TOPO  101506.187  15625         2000000     XX  YY
  6           1 TOPO  100498.375  1796875       1796875     XX  YY
  7         128 TOPO  103050.863  15625         2000000     XX  YY
```

Example TDM: SV data NGC3256



```
           MeasurementSet Name:  /export/data_1/data_2/SV_data/NGC3256_Band3_UnCalibr
================================================================================
   Observer: Unknown     Project: T.B.D.
Observation: ALMA
Data records: 205961       Total integration time = 3782.5 seconds
   Observed from   16-Apr-2011/04:05:36.4   to   16-Apr-2011/05:08:38.9 (UTC)

   ObservationID = 0         ArrayID = 0
  Date        Timerange (UTC)          Scan  FldId FieldName           nRows   Int(s)
  16-Apr-2011/04:05:39.4 - 04:06:20.2     1      0 1037-295            1463   2.87
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              04:08:32.7 - 04:09:11.8     3      1 Titan               1456   2.88
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              04:13:40.6 - 04:17:11.0     5      0 1037-295            14532  2.88
              04:17:30.1 - 04:18:08.6     6      0 1037-295            1449   2.89
              04:18:28.2 - 04:19:13.2     7      0 1037-295            2905   2.88
              04:19:54.1 - 04:20:32.6     8      2 NGC3256             1449   2.89
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              04:32:57.3 - 04:33:36.0    12      2 NGC3256             1456   2.88
              04:33:56.7 - 04:43:36.2    13      2 NGC3256             38773  2.88
              04:44:03.1 - 04:44:41.9    14      0 1037-295            1456   2.88
              04:45:05.2 - 04:45:51.0    15      0 1037-295            2905   2.88
              04:46:09.3 - 04:46:47.4    16      2 NGC3256             1456   2.88
              04:47:08.3 - 04:56:47.6    17      2 NGC3256             38752  2.88
              04:57:06.7 - 04:57:45.2    18      0 1037-295            1463   2.87
              04:58:04.2 - 04:58:49.7    19      0 1037-295            2912   2.88
              04:59:16.2 - 04:59:55.4    20      2 NGC3256             1463   2.87
              05:00:19.2 - 05:07:31.6    21      2 NGC3256             29106  2.88
              05:07:53.3 - 05:08:38.4    22      0 1037-295            2905   2.88
```
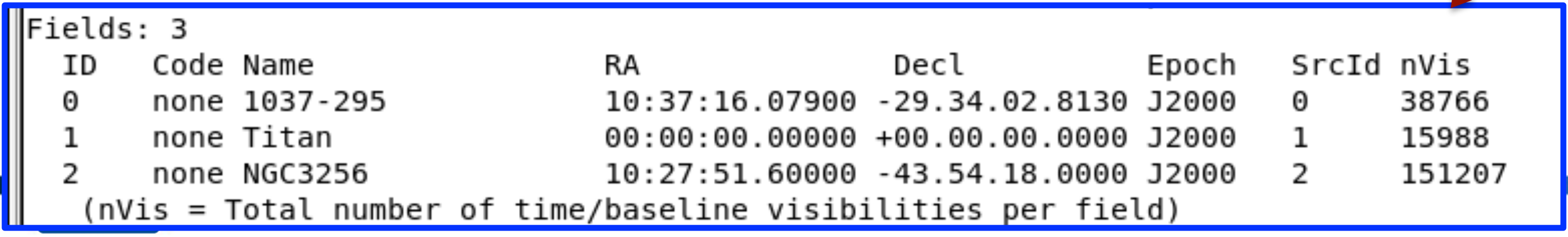
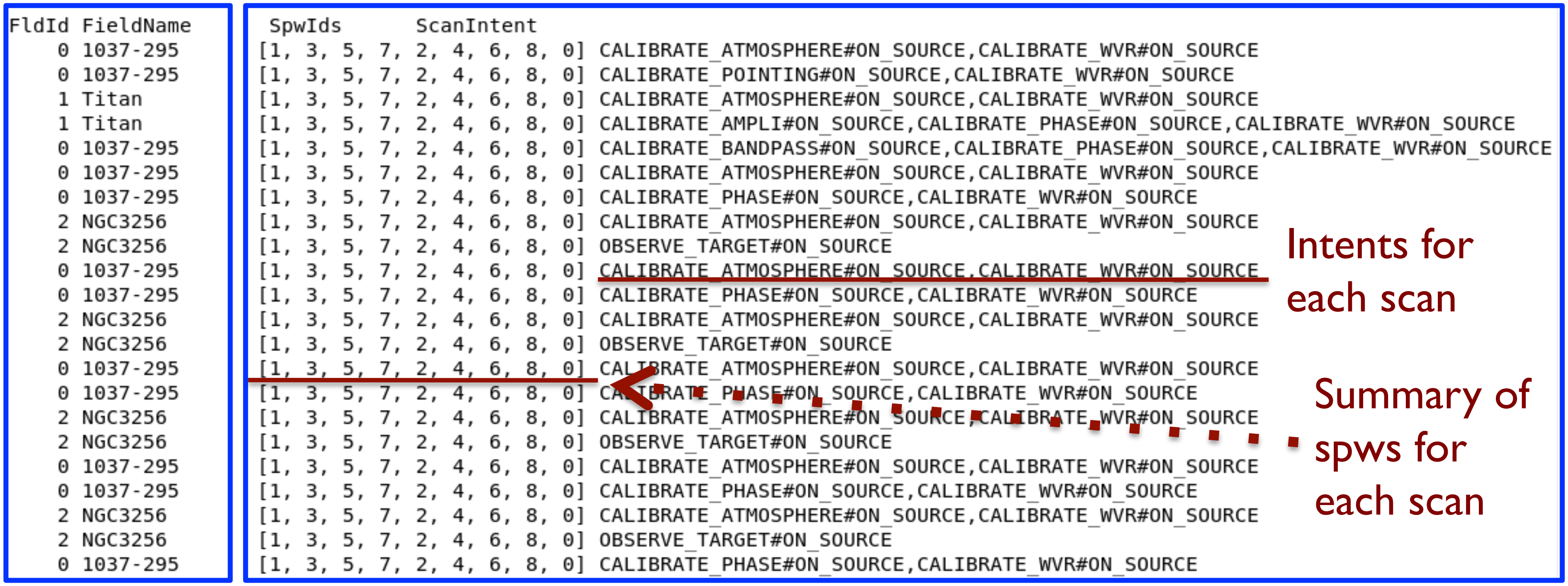

Sequence of observing with scan and field ids, and intrinsic integration time

Summary of of sources observed



```
Fields: 3
  ID   Code Name            RA               Decl           Epoch   SrcId nVis
  0    none 1037-295        10:37:16.07900 -29.34.02.8130 J2000   0     38766
  1    none Titan           00:00:00.00000 +00.00.00.0000 J2000   1     15988
  2    none NGC3256         10:27:51.60000 -43.54.18.0000 J2000   2     151207
   (nVis = Total number of time/baseline visibilities per field)
```

Example TDM: SV data NGC3256

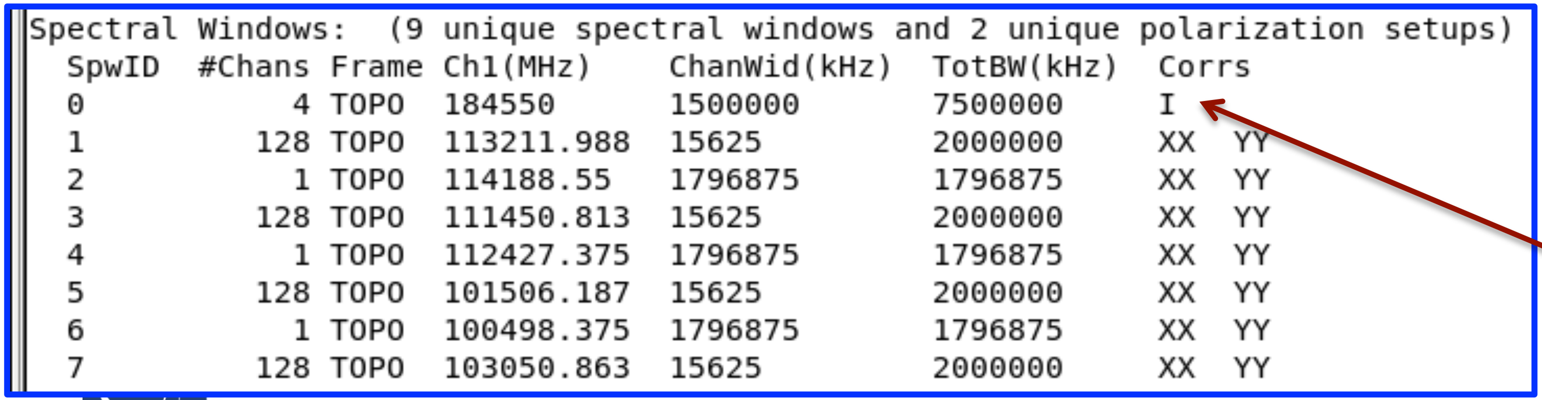


```
FldId FieldName
    0 1037-295
    0 1037-295
    1 Titan
    1 Titan
    0 1037-295
    0 1037-295
    0 1037-295
    2 NGC3256
    2 NGC3256
    0 1037-295
    0 1037-295
    2 NGC3256
    2 NGC3256
    0 1037-295
    0 1037-295
    2 NGC3256
    2 NGC3256
    0 1037-295
    0 1037-295
    2 NGC3256
    2 NGC3256
    0 1037-295
```

```
 SpwIds        ScanIntent
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_POINTING#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_AMPLI#ON_SOURCE,CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_BANDPASS#ON_SOURCE,CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] OBSERVE_TARGET#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] OBSERVE_TARGET#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] OBSERVE_TARGET#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] OBSERVE_TARGET#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
```

Intents for each scan

Summary of spws for each scan



```
Spectral Windows:  (9 unique spectral windows and 2 unique polarization setups)
  SpwID  #Chans Frame Ch1(MHz)    ChanWid(kHz)  TotBW(kHz)  Corrs
  0           4 TOPO  184550      1500000       7500000     I
  1         128 TOPO  113211.988  15625         2000000     XX  YY
  2           1 TOPO  114188.55   1796875       1796875     XX  YY
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  4           1 TOPO  112427.375  1796875       1796875     XX  YY
  5         128 TOPO  101506.187  15625         2000000     XX  YY
  6           1 TOPO  100498.375  1796875       1796875     XX  YY
  7         128 TOPO  103050.863  15625         2000000     XX  YY
```
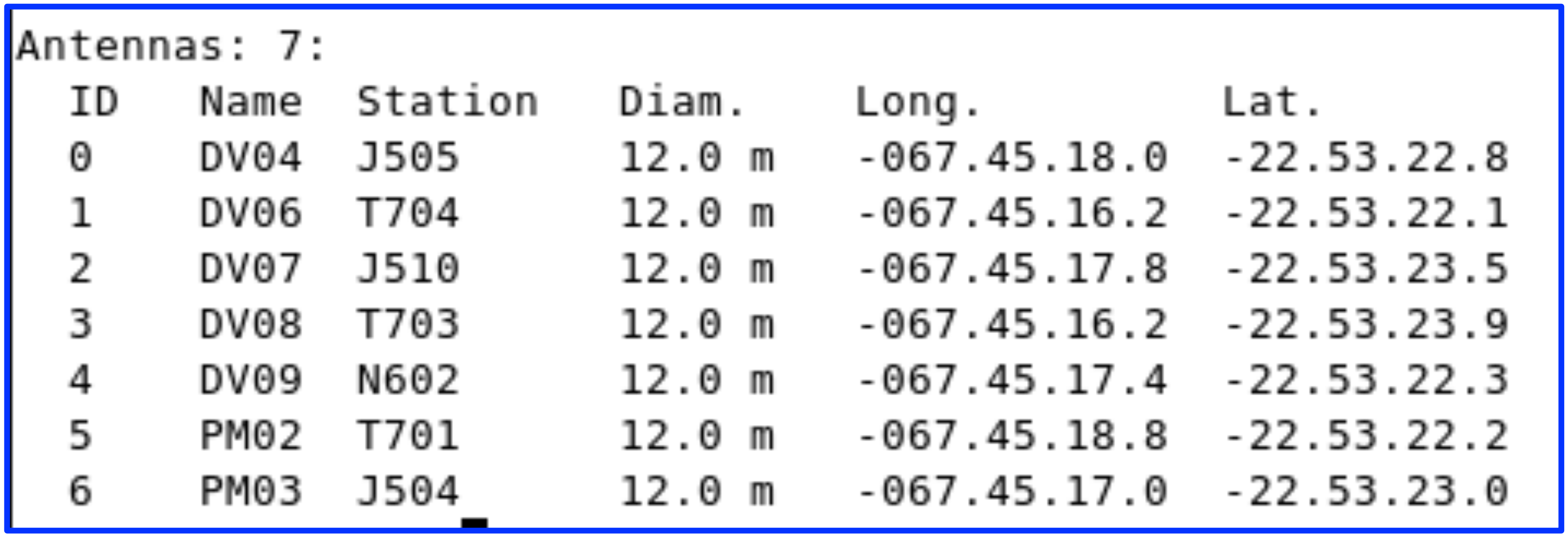

Summary of spectral setup

WVR data

Example TDM: SV data NGC3256



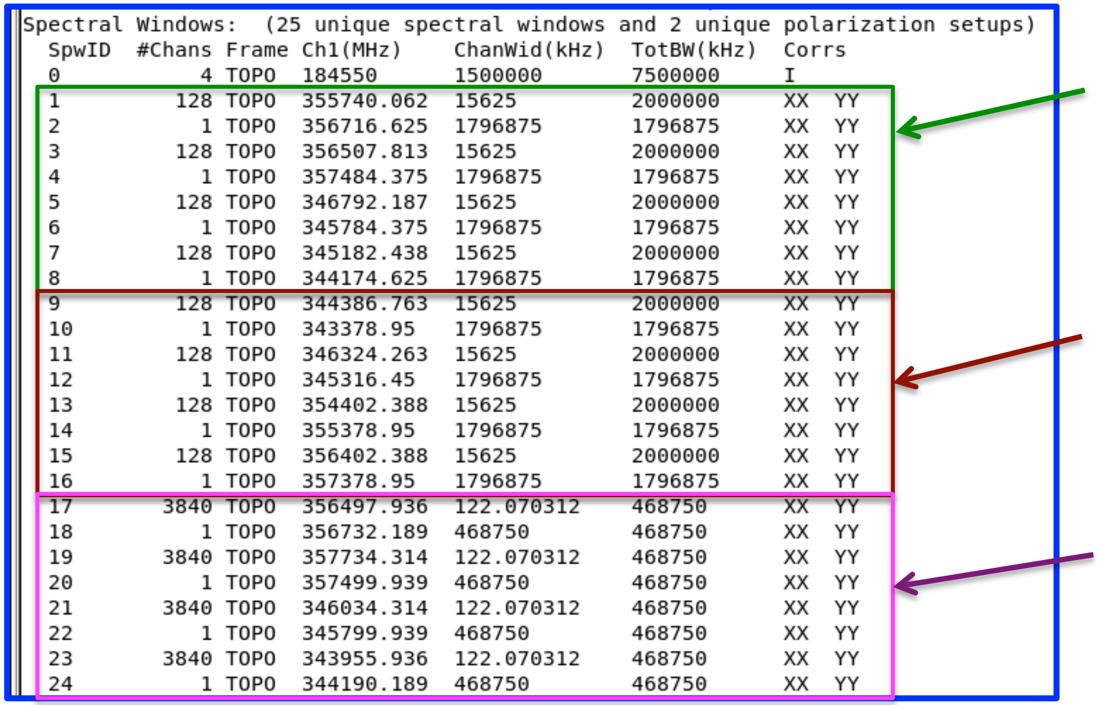
```
Antennas: 7:
  ID    Name   Station    Diam.     Long.          Lat.
  0     DV04   J505       12.0 m    -067.45.18.0   -22.53.22.8
  1     DV06   T704       12.0 m    -067.45.16.2   -22.53.22.1
  2     DV07   J510       12.0 m    -067.45.17.8   -22.53.23.5
  3     DV08   T703       12.0 m    -067.45.16.2   -22.53.23.9
  4     DV09   N602       12.0 m    -067.45.17.4   -22.53.22.3
  5     PM02   T701       12.0 m    -067.45.18.8   -22.53.22.2
  6     PM03   J504       12.0 m    -067.45.17.0   -22.53.23.0
```

Summary of antenna ids, antenna names, and station (pad) names. Note: it is always best to use antenna names in your data reduction to avoid confusion.

When necessary, antenna position corrections can be generated using *gencal* and applied like any other calibration table

Example FDM: SV data TWHya

NAASC

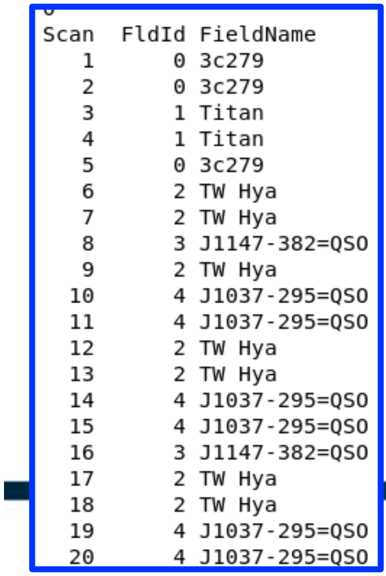


```
Spectral Windows:  (25 unique spectral windows and 2 unique polarization setups)
  SpwID  #Chans Frame Ch1(MHz)     ChanWid(kHz)  TotBW(kHz)  Corrs
  0           4 TOPO  184550       1500000       7500000     I
  1         128 TOPO  355740.062   15625         2000000     XX  YY
  2           1 TOPO  356716.625   1796875       1796875     XX  YY
  3         128 TOPO  356507.813   15625         2000000     XX  YY
  4           1 TOPO  357484.375   1796875       1796875     XX  YY
  5         128 TOPO  346792.187   15625         2000000     XX  YY
  6           1 TOPO  345784.375   1796875       1796875     XX  YY
  7         128 TOPO  345182.438   15625         2000000     XX  YY
  8           1 TOPO  344174.625   1796875       1796875     XX  YY
  9         128 TOPO  344386.763   15625         2000000     XX  YY
  10          1 TOPO  343378.95    1796875       1796875     XX  YY
  11        128 TOPO  346324.263   15625         2000000     XX  YY
  12          1 TOPO  345316.45    1796875       1796875     XX  YY
  13        128 TOPO  354402.388   15625         2000000     XX  YY
  14          1 TOPO  355378.95    1796875       1796875     XX  YY
  15        128 TOPO  356402.388   15625         2000000     XX  YY
  16          1 TOPO  357378.95    1796875       1796875     XX  YY
  17       3840 TOPO  356497.936   122.070312    468750      XX  YY
  18          1 TOPO  356732.189   468750        468750      XX  YY
  19       3840 TOPO  357734.314   122.070312    468750      XX  YY
  20          1 TOPO  357499.939   468750        468750      XX  YY
  21       3840 TOPO  346034.314   122.070312    468750      XX  YY
  22          1 TOPO  345799.939   468750        468750      XX  YY
  23       3840 TOPO  343955.936   122.070312    468750      XX  YY
  24          1 TOPO  344190.189   468750        468750      XX  YY
```

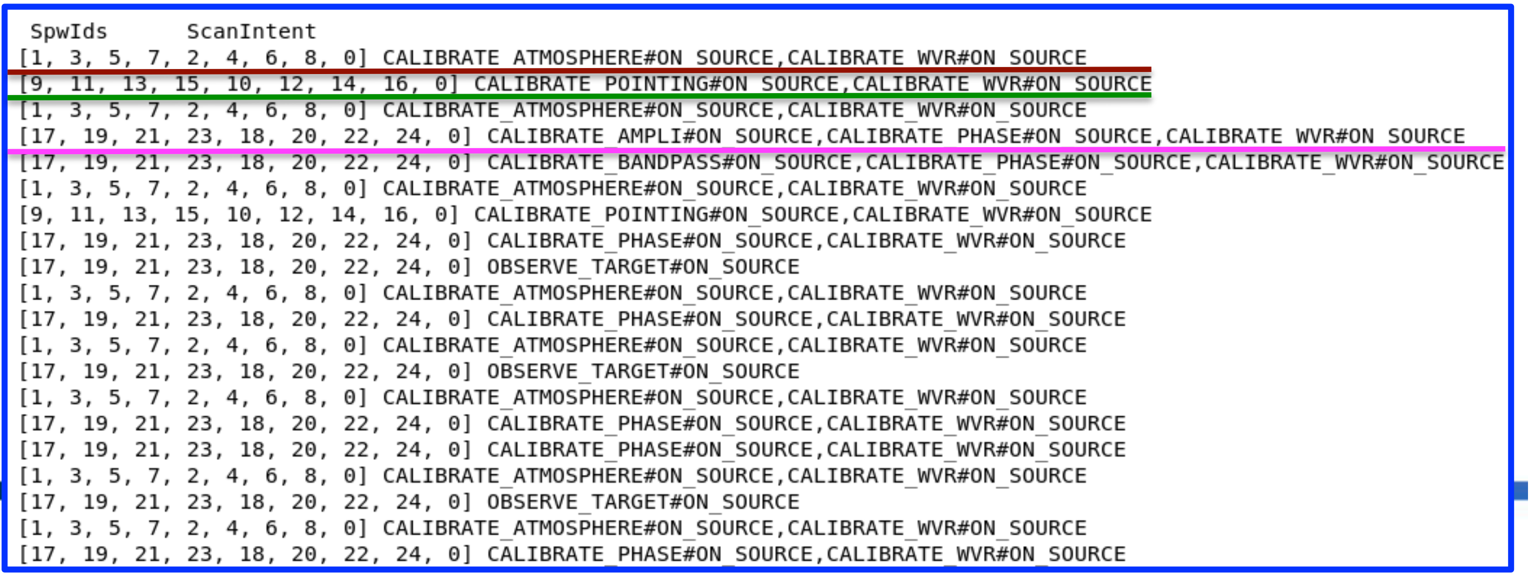
TDM used for Tsys measurements

TDM used for pointing (in ES would have been done in Band 3)

FDM "Science"

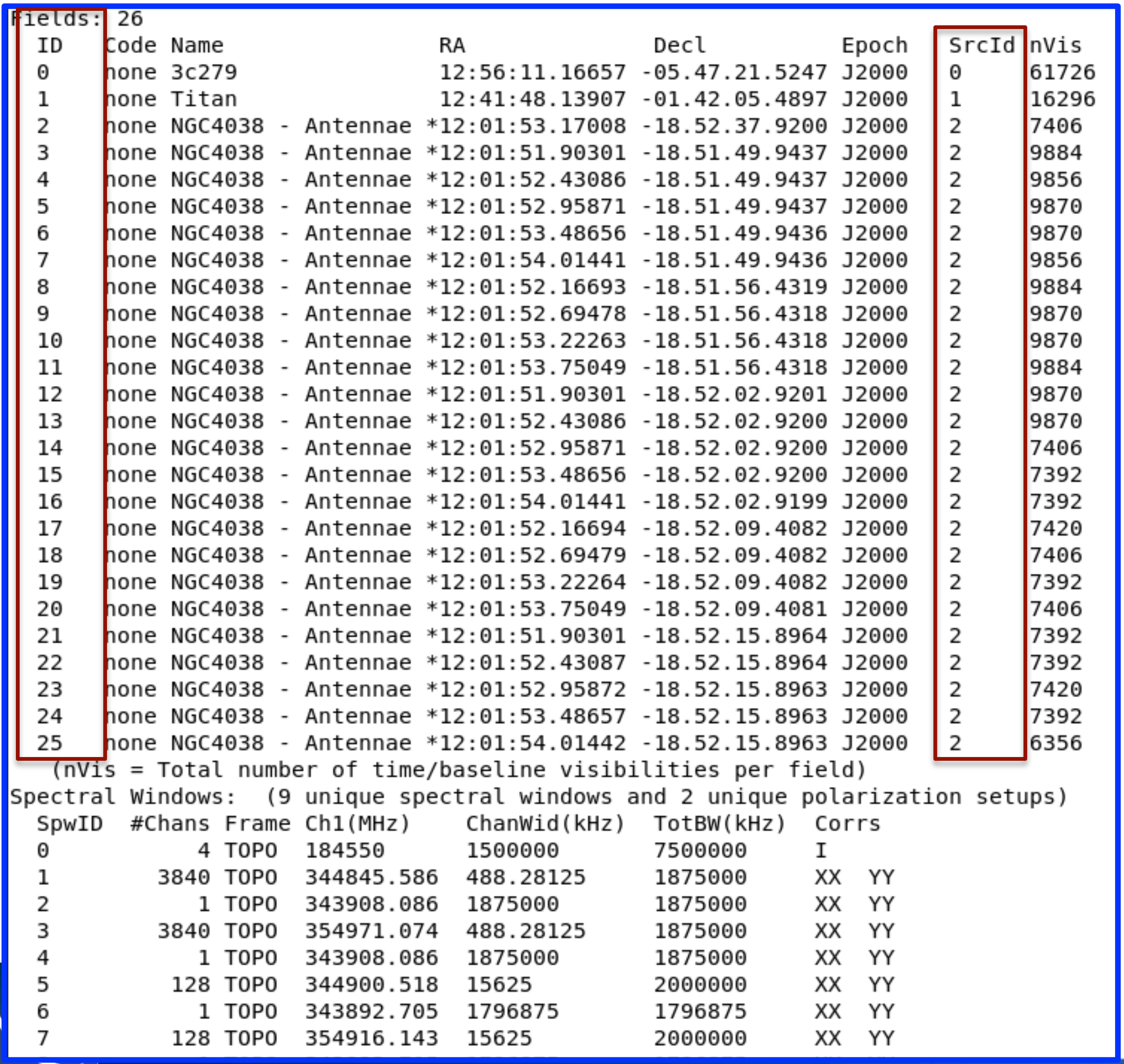


```
Scan  FldId FieldName
  1       0 3c279
  2       0 3c279
  3       1 Titan
  4       1 Titan
  5       0 3c279
  6       2 TW Hya
  7       2 TW Hya
  8       3 J1147-382=QSO
  9       2 TW Hya
 10       4 J1037-295=QSO
 11       4 J1037-295=QSO
 12       2 TW Hya
 13       2 TW Hya
 14       4 J1037-295=QSO
 15       4 J1037-295=QSO
 16       3 J1147-382=QSO
 17       2 TW Hya
 18       2 TW Hya
 19       4 J1037-295=QSO
 20       4 J1037-295=QSO
```



```
 SpwIds       ScanIntent
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[9, 11, 13, 15, 10, 12, 14, 16, 0] CALIBRATE_POINTING#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[17, 19, 21, 23, 18, 20, 22, 24, 0] CALIBRATE_AMPLI#ON_SOURCE,CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[17, 19, 21, 23, 18, 20, 22, 24, 0] CALIBRATE_BANDPASS#ON_SOURCE,CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[9, 11, 13, 15, 10, 12, 14, 16, 0] CALIBRATE_POINTING#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[17, 19, 21, 23, 18, 20, 22, 24, 0] CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[17, 19, 21, 23, 18, 20, 22, 24, 0] OBSERVE_TARGET#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[17, 19, 21, 23, 18, 20, 22, 24, 0] CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[17, 19, 21, 23, 18, 20, 22, 24, 0] OBSERVE_TARGET#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[17, 19, 21, 23, 18, 20, 22, 24, 0] CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[17, 19, 21, 23, 18, 20, 22, 24, 0] CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[17, 19, 21, 23, 18, 20, 22, 24, 0] OBSERVE_TARGET#ON_SOURCE
[1, 3, 5, 7, 2, 4, 6, 8, 0] CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
[17, 19, 21, 23, 18, 20, 22, 24, 0] CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE
```

Example FDM Mosaic:
SV data Antennae



```
Fields: 26
  ID   Code Name                RA               Decl           Epoch   SrcId nVis
  0    none 3c279               12:56:11.16657 -05.47.21.5247 J2000   0     61726
  1    none Titan               12:41:48.13907 -01.42.05.4897 J2000   1     16296
  2    none NGC4038 - Antennae *12:01:53.17008 -18.52.37.9200 J2000   2     7406
  3    none NGC4038 - Antennae *12:01:51.90301 -18.51.49.9437 J2000   2     9884
  4    none NGC4038 - Antennae *12:01:52.43086 -18.51.49.9437 J2000   2     9856
  5    none NGC4038 - Antennae *12:01:52.95871 -18.51.49.9437 J2000   2     9870
  6    none NGC4038 - Antennae *12:01:53.48656 -18.51.49.9436 J2000   2     9870
  7    none NGC4038 - Antennae *12:01:54.01441 -18.51.49.9436 J2000   2     9856
  8    none NGC4038 - Antennae *12:01:52.16693 -18.51.56.4319 J2000   2     9884
  9    none NGC4038 - Antennae *12:01:52.69478 -18.51.56.4318 J2000   2     9870
  10   none NGC4038 - Antennae *12:01:53.22263 -18.51.56.4318 J2000   2     9870
  11   none NGC4038 - Antennae *12:01:53.75049 -18.51.56.4318 J2000   2     9884
  12   none NGC4038 - Antennae *12:01:51.90301 -18.52.02.9201 J2000   2     9870
  13   none NGC4038 - Antennae *12:01:52.43086 -18.52.02.9200 J2000   2     9870
  14   none NGC4038 - Antennae *12:01:52.95871 -18.52.02.9200 J2000   2     7406
  15   none NGC4038 - Antennae *12:01:53.48656 -18.52.02.9200 J2000   2     7392
  16   none NGC4038 - Antennae *12:01:54.01441 -18.52.02.9199 J2000   2     7392
  17   none NGC4038 - Antennae *12:01:52.16694 -18.52.09.4082 J2000   2     7420
  18   none NGC4038 - Antennae *12:01:52.69479 -18.52.09.4082 J2000   2     7406
  19   none NGC4038 - Antennae *12:01:53.22264 -18.52.09.4082 J2000   2     7392
  20   none NGC4038 - Antennae *12:01:53.75049 -18.52.09.4081 J2000   2     7406
  21   none NGC4038 - Antennae *12:01:51.90301 -18.52.15.8964 J2000   2     7392
  22   none NGC4038 - Antennae *12:01:52.43087 -18.52.15.8964 J2000   2     7392
  23   none NGC4038 - Antennae *12:01:52.95872 -18.52.15.8963 J2000   2     7420
  24   none NGC4038 - Antennae *12:01:53.48657 -18.52.15.8963 J2000   2     7392
  25   none NGC4038 - Antennae *12:01:54.01442 -18.52.15.8963 J2000   2     6356
   (nVis = Total number of time/baseline visibilities per field)
Spectral Windows:  (9 unique spectral windows and 2 unique polarization setups)
  SpwID  #Chans Frame Ch1(MHz)    ChanWid(kHz)  TotBW(kHz)   Corrs
  0           4 TOPO  184550      1500000       7500000      I
  1        3840 TOPO  344845.586  488.28125     1875000      XX  YY
  2           1 TOPO  343908.086  1875000       1875000      XX  YY
  3        3840 TOPO  354971.074  488.28125     1875000      XX  YY
  4           1 TOPO  343908.086  1875000       1875000      XX  YY
  5         128 TOPO  344900.518  15625         2000000      XX  YY
  6           1 TOPO  343892.705  1796875       1796875      XX  YY
  7         128 TOPO  354916.143  15625         2000000      XX  YY
```

- Every unique position observed gets a unique field id
- For mosaics, the source id will be the same for all the pointings in a mosaic
- Source ids are not currently used in CASA

NOTE: CASA's *clean* task in *imagermode='mosaic'* will attempt to mosaic ALL fields given to it, whether they were observed that way or not!

Data Package for Cycle 0

You will receive a tar file containing the following directories

1. 'raw' contains an ms that has ALREADY been calibrated for WVR, Tsys, and any antenna position corrections, and only the "science" spectral windows.
   A. It also contains the calibration tables (bandpass, phase, amplitude, flux) and backup flag tables from each stage of reduction (the data itself contain the final flag state so you don't need to do anything if you are happy with it).
2. 'calibrated' contains the fully calibrated ms (i.e. ready for imaging).
3. 'science' contains fits files for the **reference** images.
4. 'script' contains the CASA data reduction script.
5. 'qa' contains the Quality Assurance "2" report (estimates of achieved rms noise etc).
6. 'logs' contains the CASA log files.

➔ Attempt to loosely replicate what the pipeline will serve in Full Science (items A, 3-6 + raw ASDM)

➔ It is likely that you will want to perfect the images to suit your science goals

- Extra slides

Interferometric MM Measurement of T_{sys}

- How do we measure $T_{sys} = T_{atm}(e^{\tau} - 1) + T_{rx}e^{\tau}$ without constantly measuring T_{rx} and the opacity?
- The “chopper wheel” method: putting an ambient temperature load (T_{load}) in front of the receiver and measuring the resulting power compared to power when observing sky T_{atm} (Penzias & Burrus 1973).

Load in $V_{in} = G\,T_{in} = G\,[T_{rx} + T_{load}]$

Load out $V_{out} = G\,T_{out} = G\,[T_{rx} + T_{atm}(1-e^{-\tau}) + T_{bg}e^{-\tau} + T_{source}e^{-\tau}]$

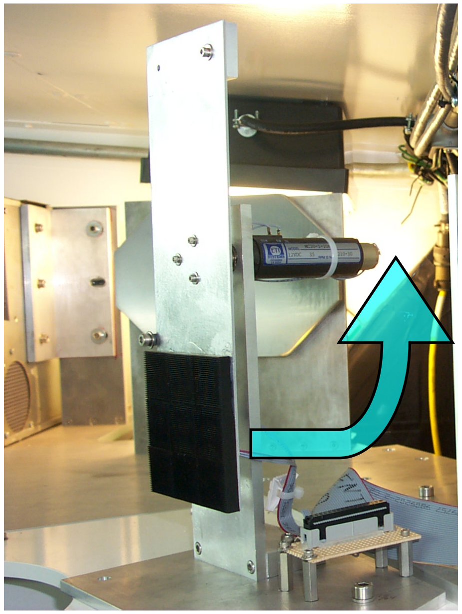
assume $T_{atm} \approx T_{load}$

Comparing in and out $$\frac{V_{in} - V_{out}}{V_{out}} = \frac{T_{load}}{T_{sys}}$$

$$\boxed{T_{sys} = T_{load} * T_{out} / (T_{in} - T_{out})}$$

Power is really observed but is ∝ T in the R-J limit

- IF $T_{atm} \approx T_{load}$, and T_{sys} is measured often, changes in mean atmospheric absorption are corrected. ALMA will have a two temperature load system which allows independent measure of T_{rx}



SMA calibration load swings in and out of beam