Observing Pulsars with LOFAR

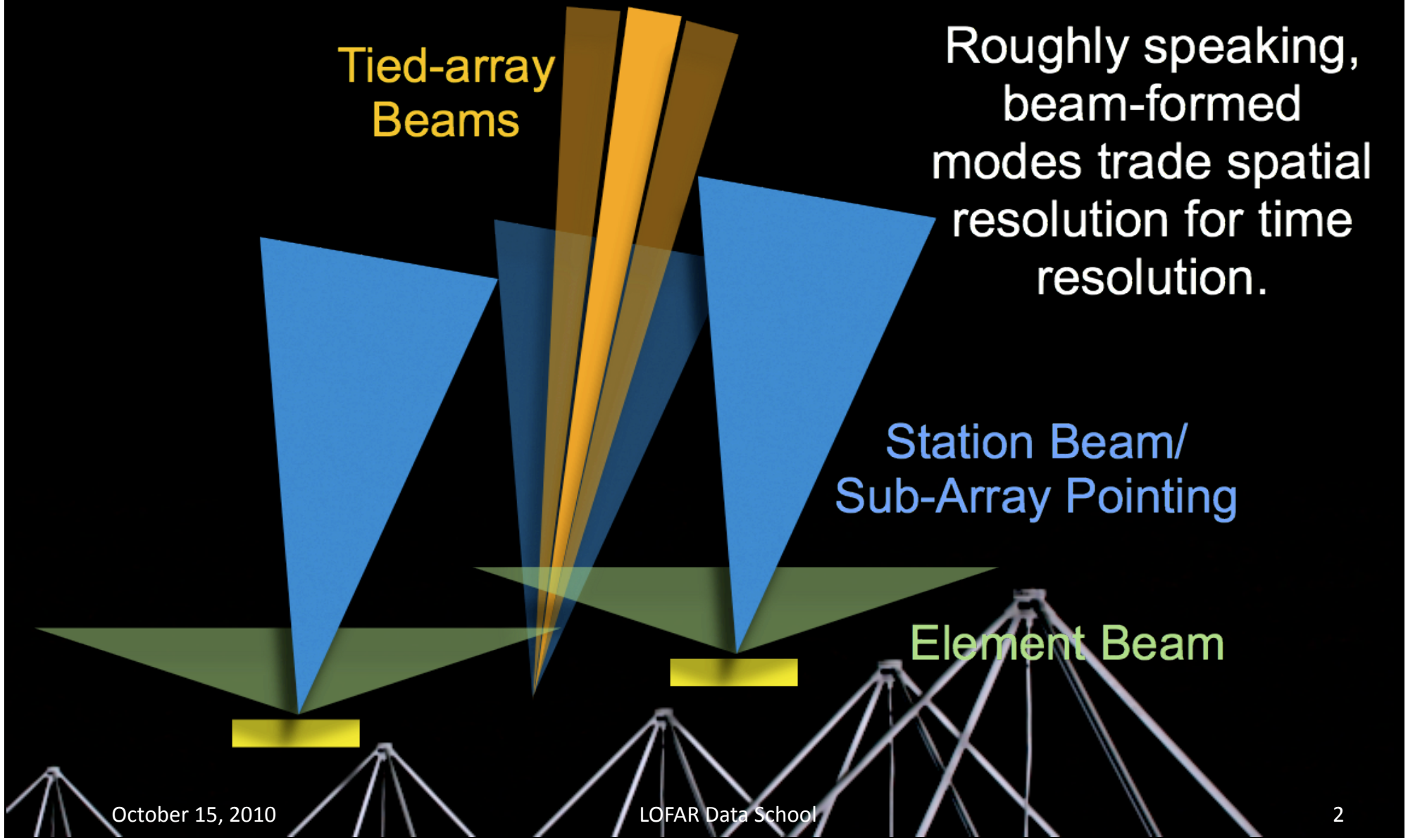
Anastasia Alexov

On behalf of the Pulsar Working Group (PWG)

LOFAR Data School

October 15, 2010 (ASTRON)

Beam-Forming

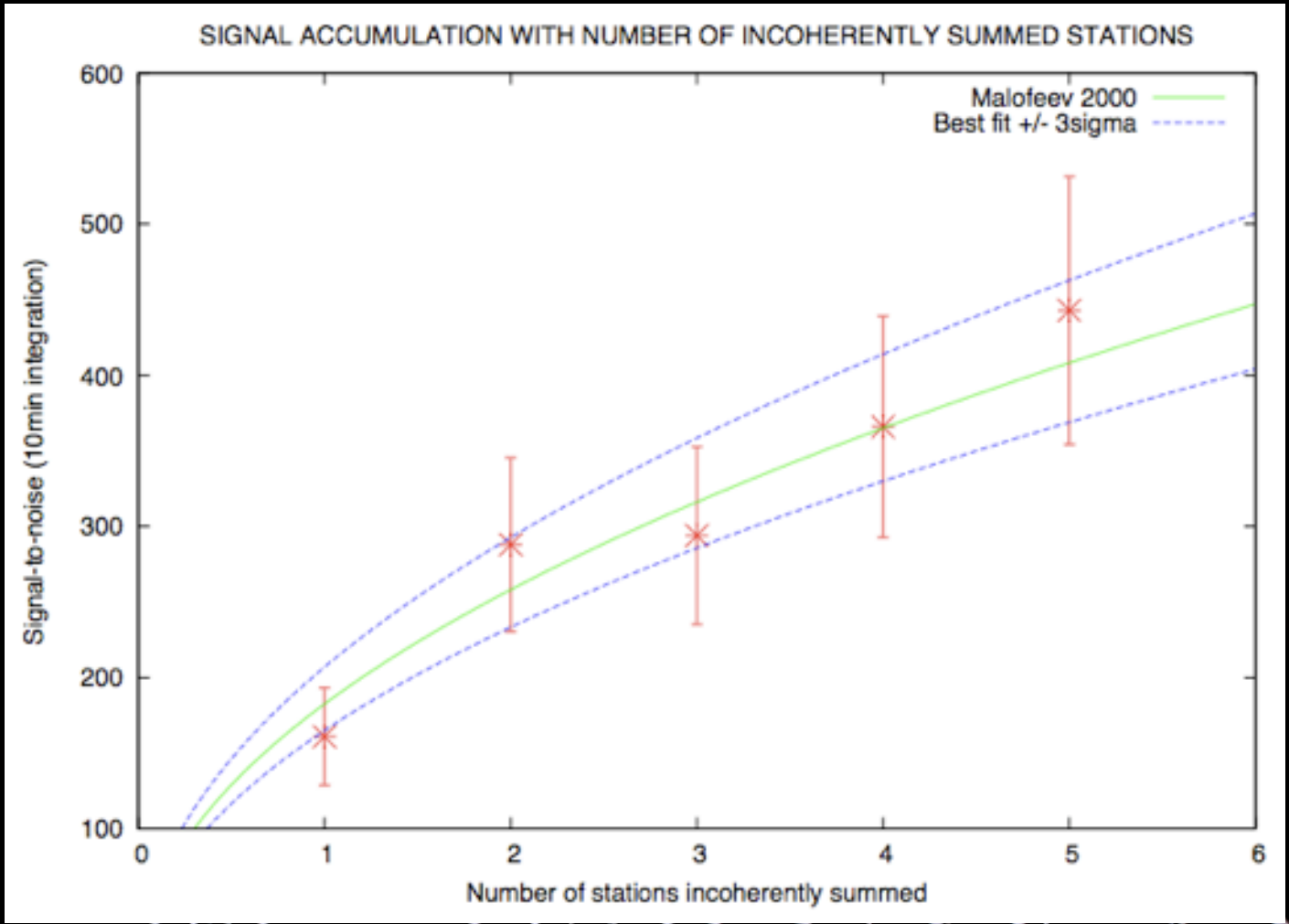


Beam-Formed modes… there are many possible…

Mode	Description	Data Rate	FoV (sq. deg.)	Res. (deg.)	Sens. (norm.)
Incoherent (par. imaging)	Stations added without proper phase correction.	2-250 GB/hr	12.5	2	6.0
Tied-array	Stations added properly in phase.	Up to 23TB/hr	0.2	0.03	36.0
Single Station	For projects with high time, but lower sensitivity requirements.	2-250 GB/hr	12.5	2	1.0
Superstation	Interesting balance of sensitivity and FoV.	Up to 23TB/hr	9.0	0.2	12.0
Fly's Eye	Maximize total FoV for bright transient survey.	Up to 8TB/hr	450	2	1.0

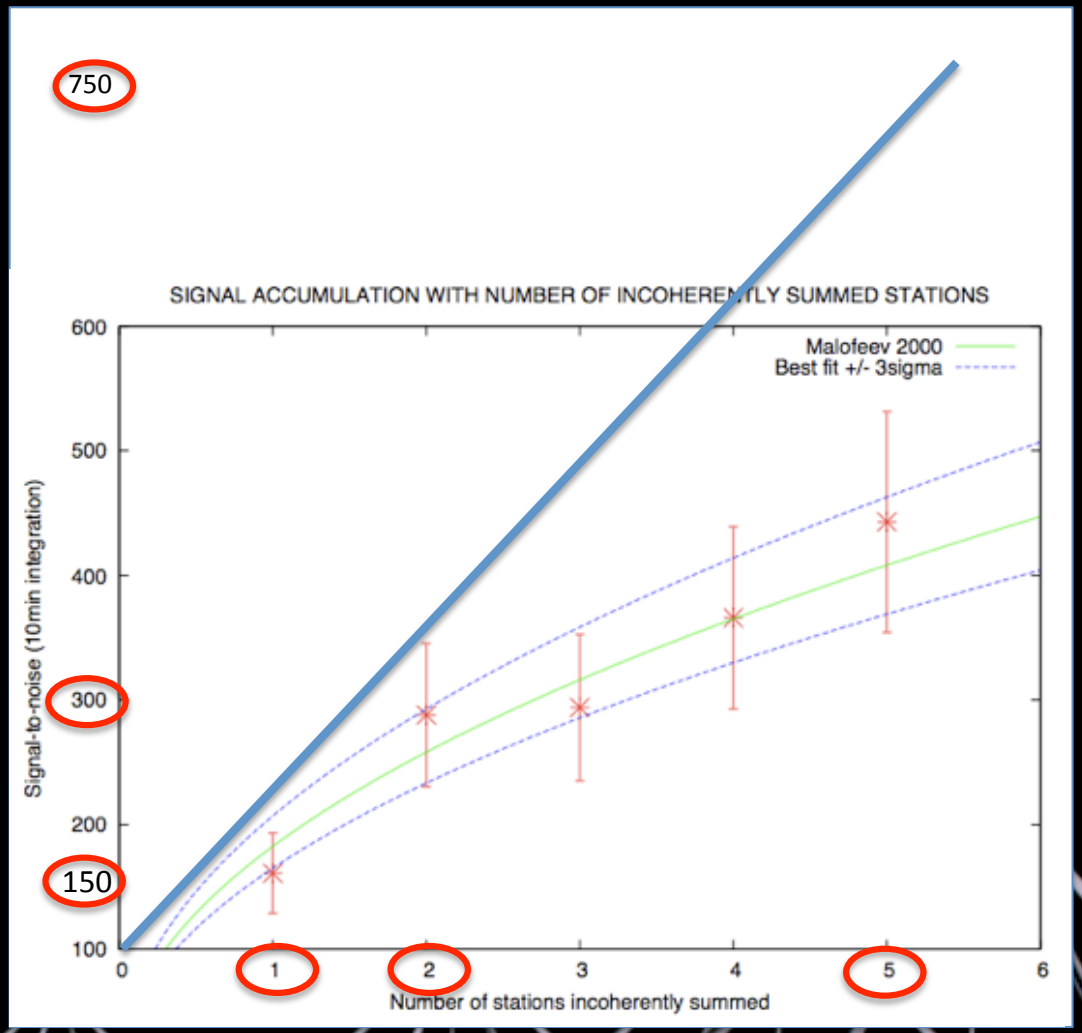
Test of Incoherent Summing

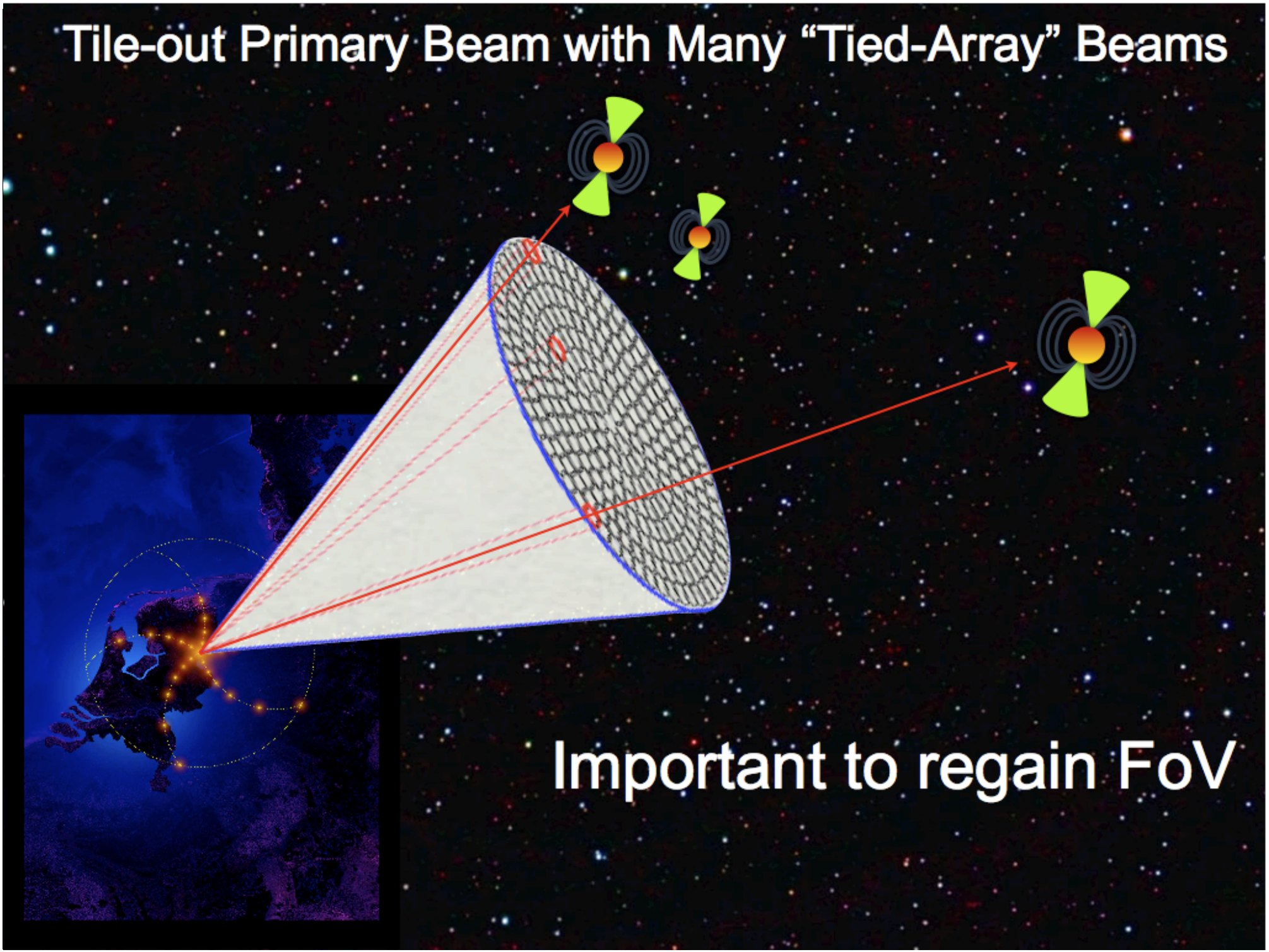
- Current primary BF observing mode (>700 obs)



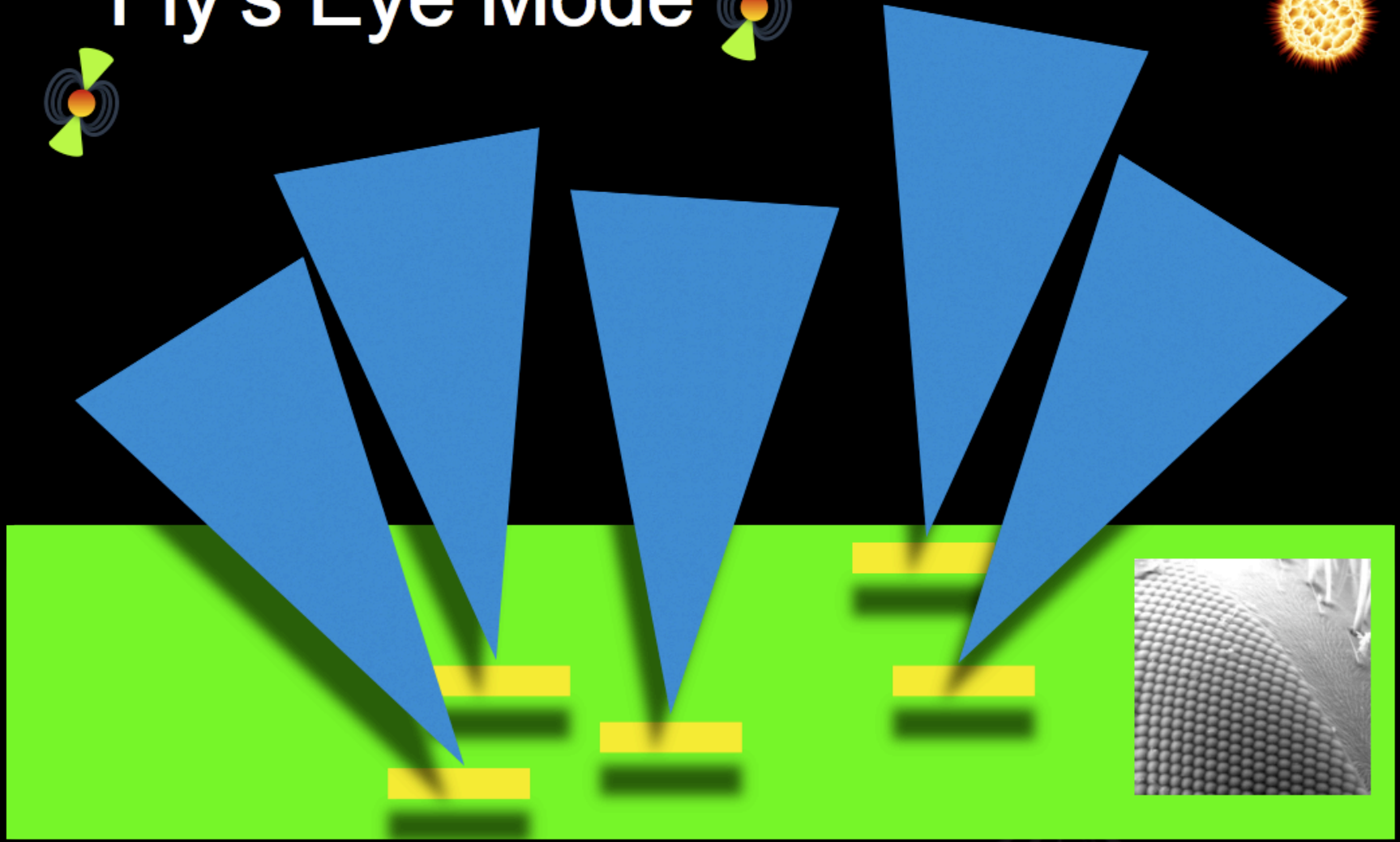
Coherent Summing

- ~Working, but true "coherent" summing requires station calibration, precise phase corrections, ionospheric corrections

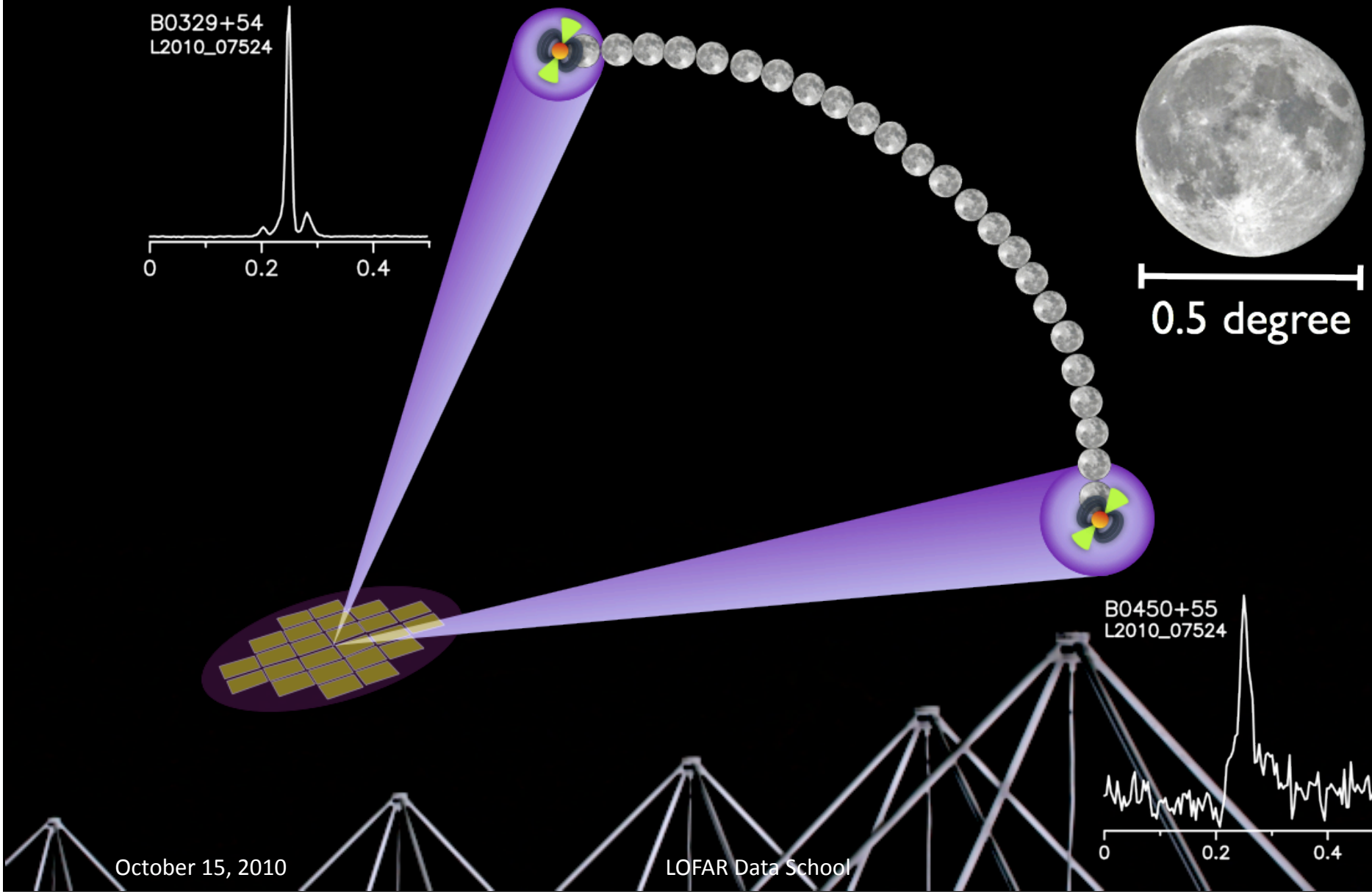



Tile-out Primary Beam with Many “Tied-Array” Beams
Important to regain FoV

Fly's Eye Mode



Multiple Station Beams



Beam-Formed modes… many are working and actively used

Mode	Description	Data Rate	FoV (sq. deg.)	Res. (deg.)	Sens. (norm.)
Incoherent (par. imaging)	Stations added without proper phase correction.	2-250 GB/hr	12.5	2	6.0
Tied-array	Stations added properly in phase.	Up to 23TB/hr	0.2	0.03	36.0
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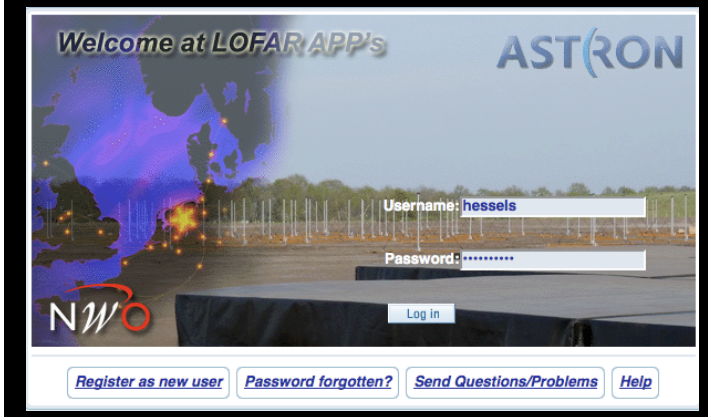
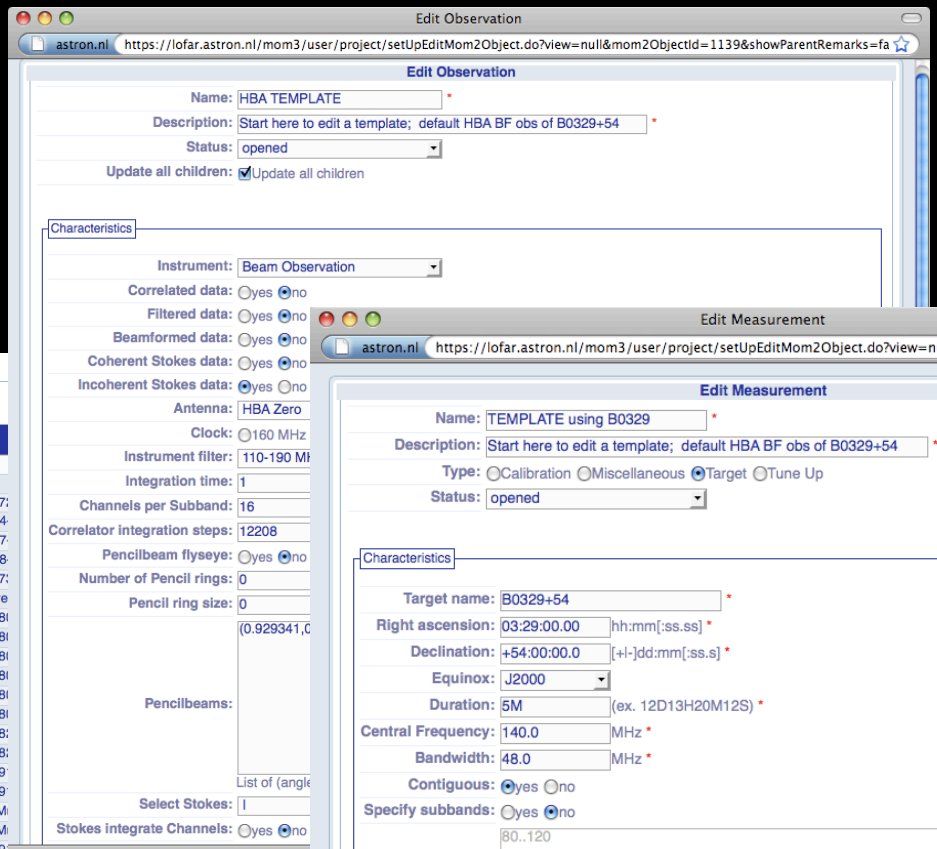
Stats on LOFAR BF Observations

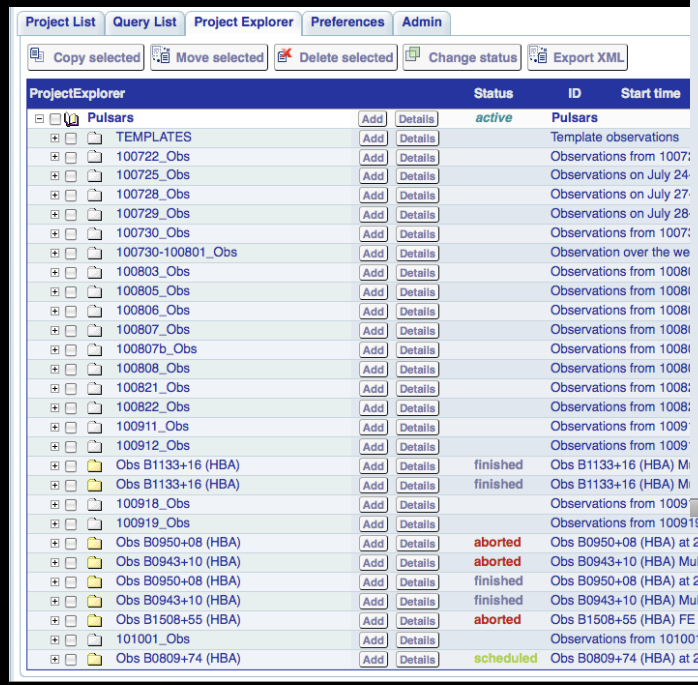
- July 2009 – present (durations: 5 min – 60+ hrs)
- Total 1086 BF-related Observations (1705 hrs of data)

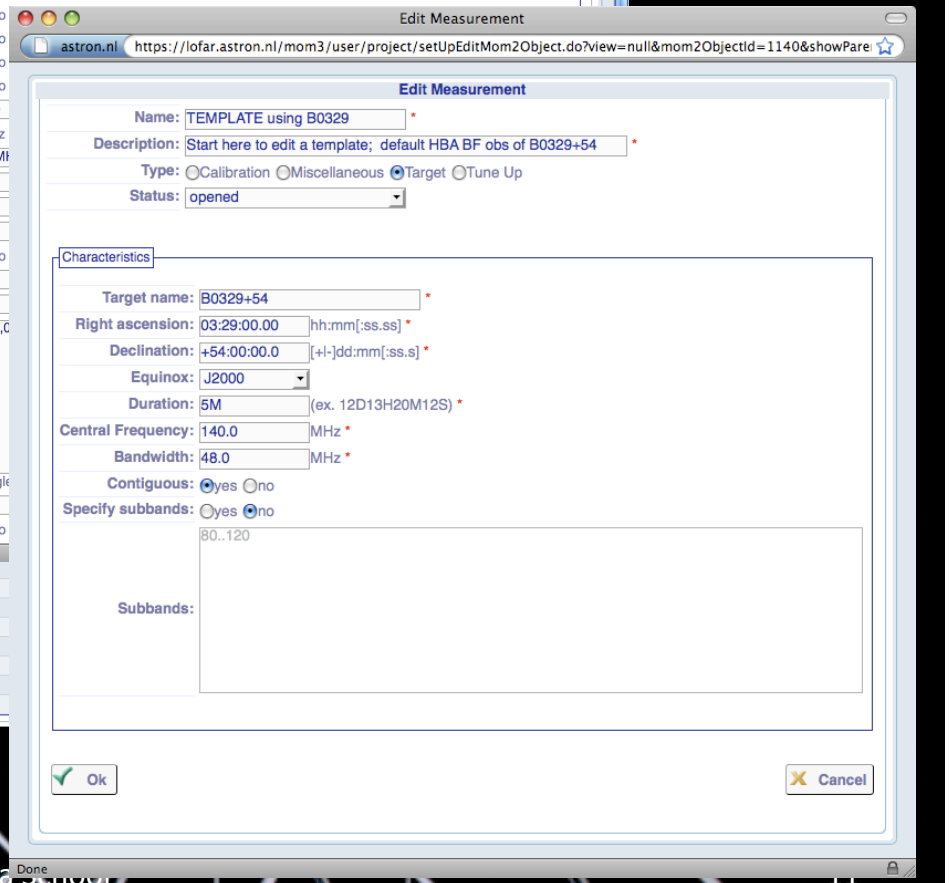
Observation Type	Number OBSIDs July 2009 - now (on disk)	Number OBSIDs July 2010 - now (on disk)
Incoherent-stokes	719	561
Coherent-stokes	30	3
Fly's Eye	85	55
Imaging + BF	29	10
Combinations/Other	223	12
Total RAW OBSIDs:	**1086**	**641**
Total Processed OBSIDs:	**643 (59%)**	**503 (78%)**
Total TB RAW	**28.3 TB**	**19.9 TB**
Total TB Processed	**10.1 TB**	**6.2 TB**

Management of Measurements (MoM)









LOFAR Observing using MoM (I)

- MoM – Astronomer's tool to create LOFAR Observations (GUI-based/user-interactive)
- Multiple Observations => lots of clicking on GUIs and typing!
- MoM is not practical for 'survey-mode' or multiple observations or regular monitoring of sources with short time-intervals
- MoM is XML-based; allows for XML import and XML export of LOFAR Observation settings
- Added automation of observations: new program takes lists of objects/positions and creates MoM XML observations template
- Added automation of processing: new program takes MoM post-observation template and produces pipeline processing scripts
- Working with LOFAR Observer Support to create a "Cookbook" using the above programs/procedure

LOFAR Observing using MoM (II)

- Script requires an ASCII input file with observation details
- Input pointings can be:
  1. Pulsar names
  2. 3C-Object names
  3. RA DEC positions

```
#pulsar
B0154+61
B0331+45
J0459-0210
```

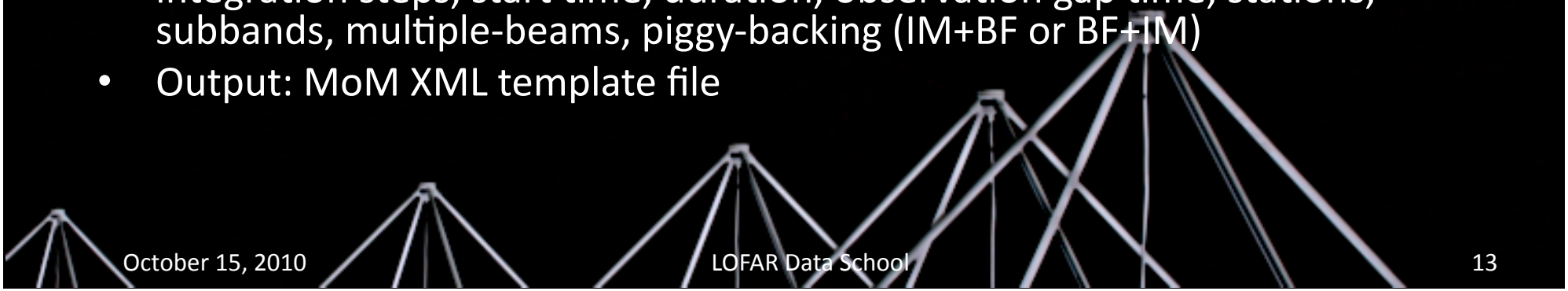
```
# object
3C99
3C327
372.1
```

```
# ra      dec
13.98    +68.487
70.498   +1.728
217.17    -1.623
```

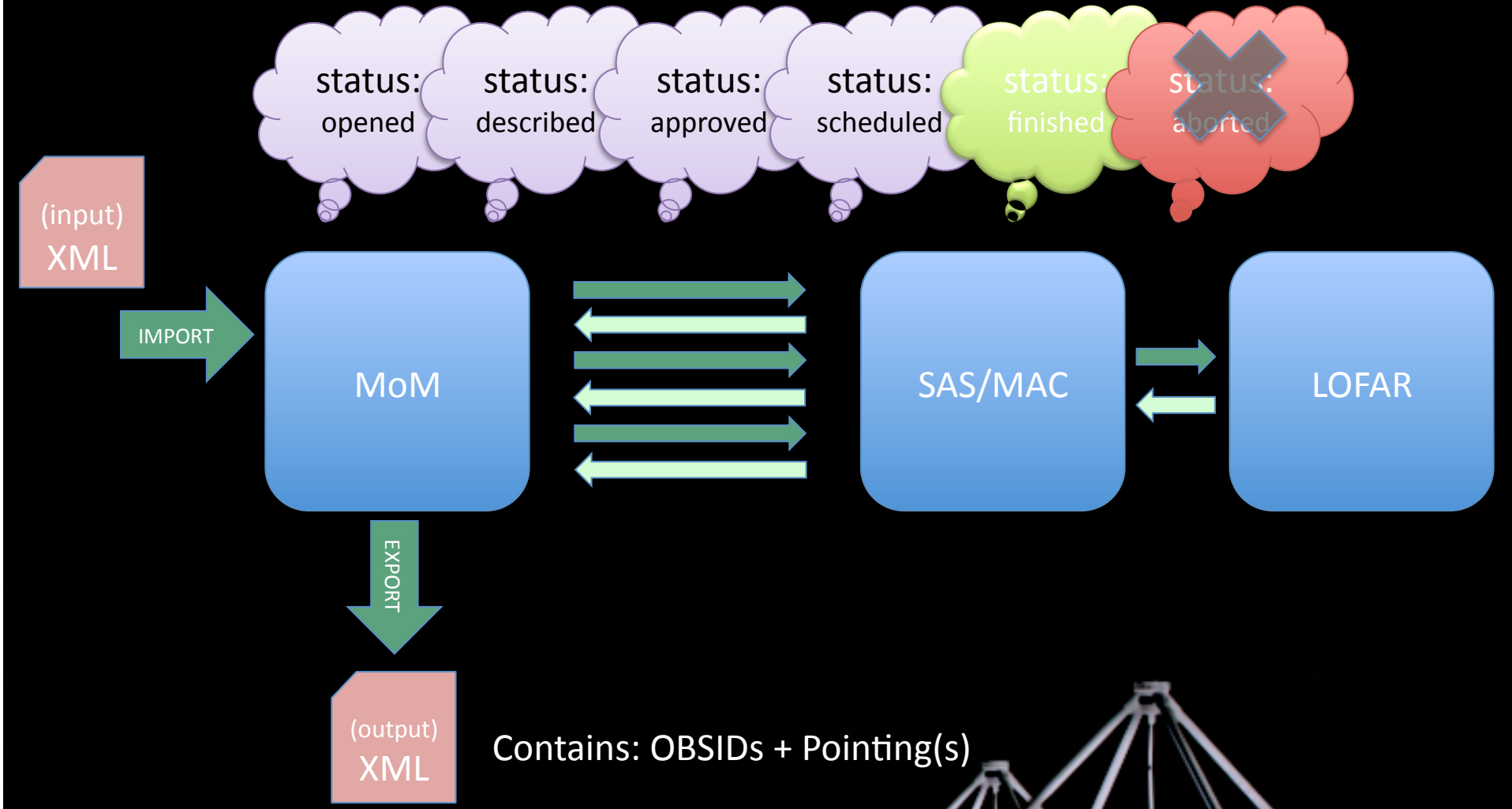
- Observation details can be specified via input file or can command-line driven


```
#pulsar
B0154+61
B0331+45
J0459-0210
```

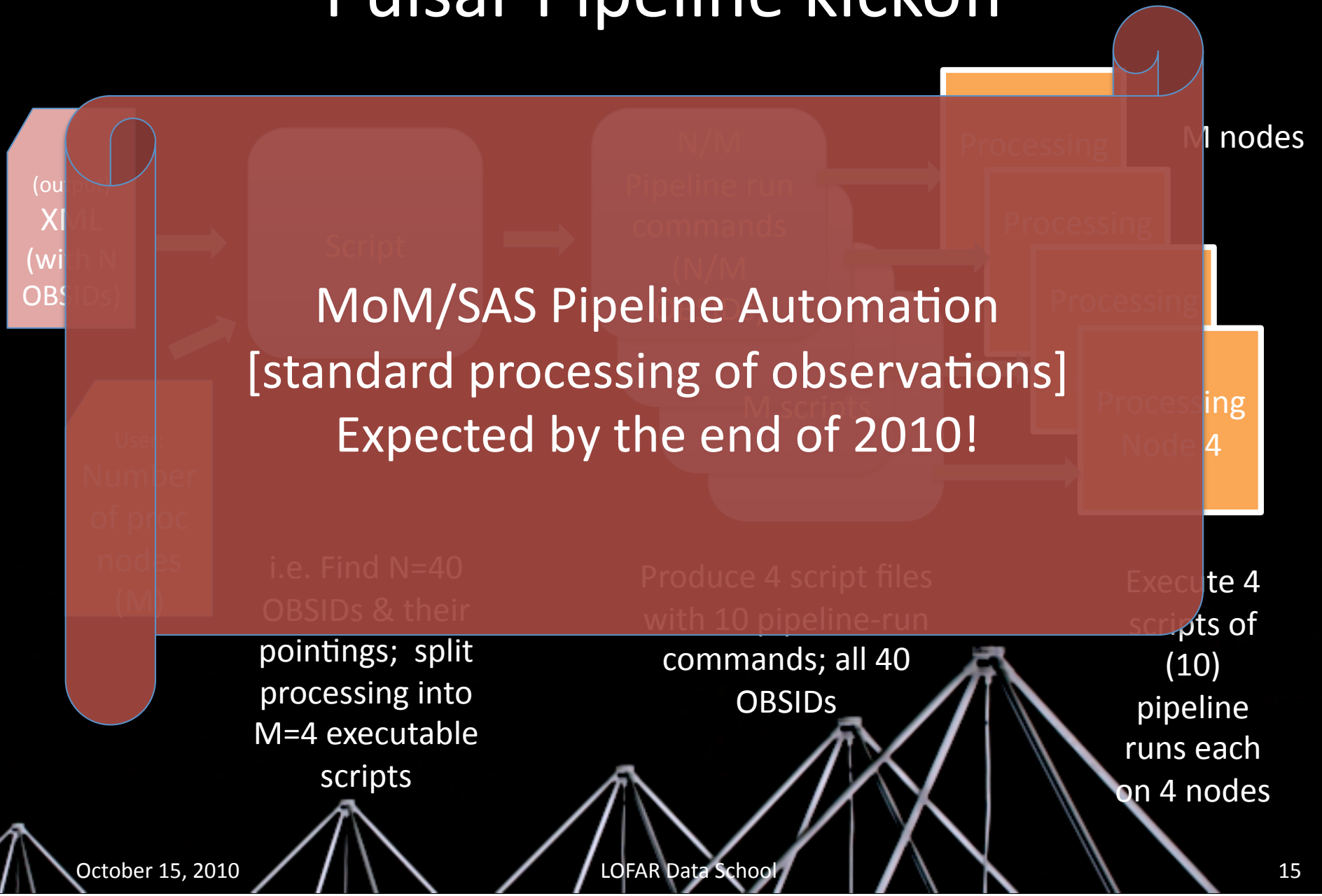

- Input variables: IM or BF, MoM project, antenna, channels per subband, integration steps, start time, duration, observation gap time, stations, subbands, multiple-beams, piggy-backing (IM+BF or BF+IM)
- Output: MoM XML template file



LOFAR Observing using MoM

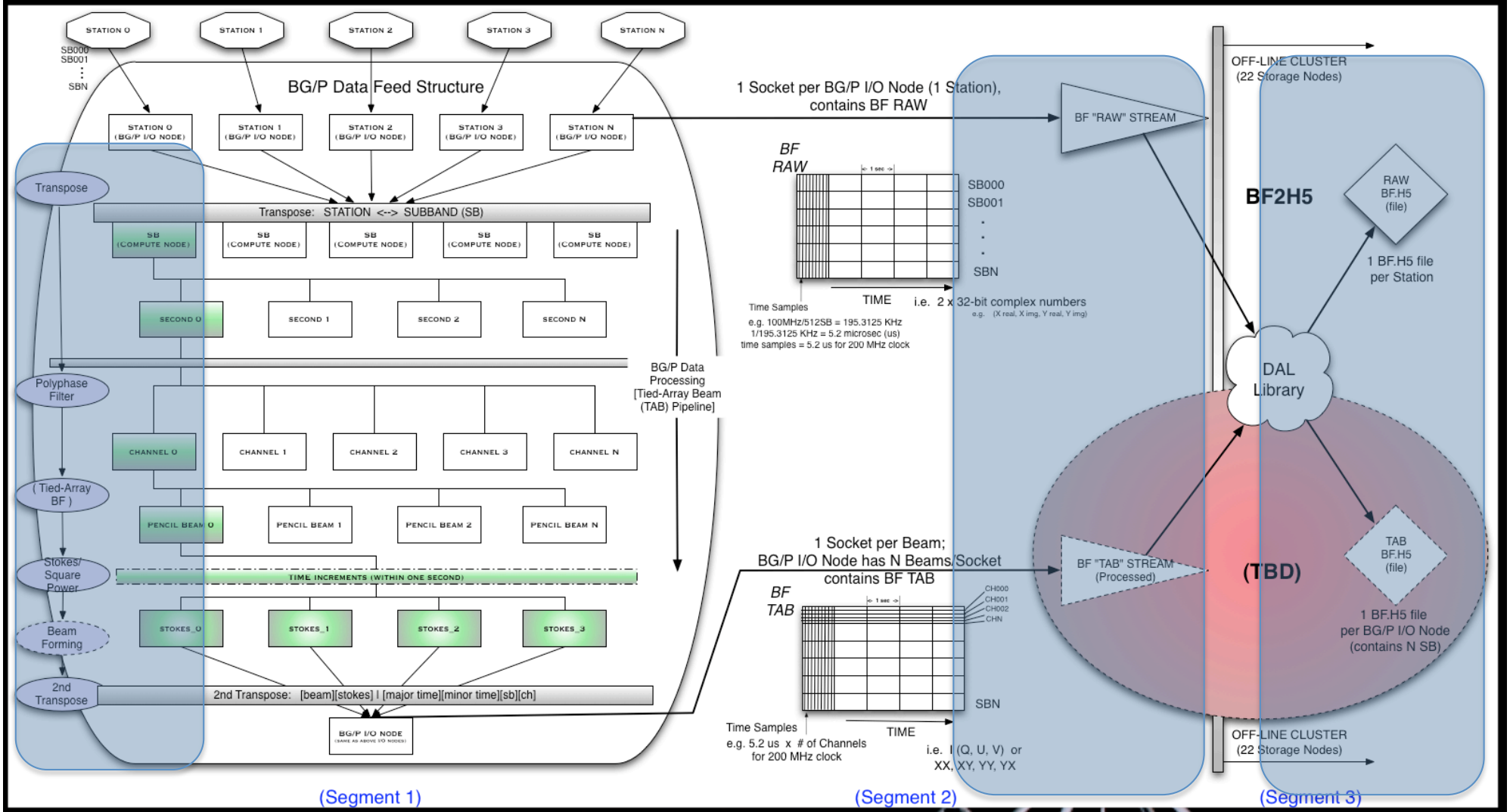


MoM "finished" XML-template to Pulsar Pipeline kickoff



MoM/SAS Pipeline Automation
[standard processing of observations]
Expected by the end of 2010!

Beam-Formed Data Flow

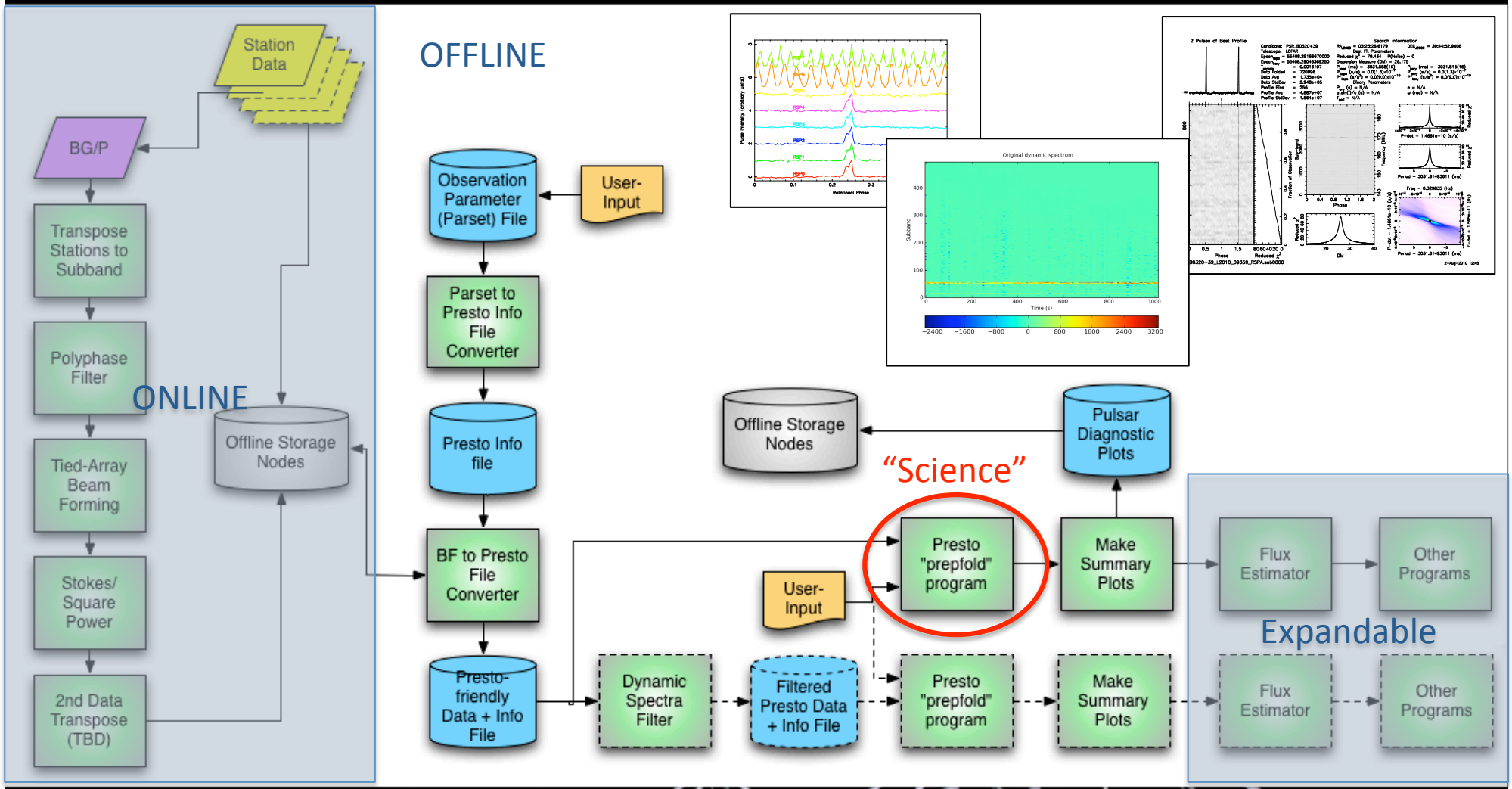


On-Line TAB Pipeline

BF Writer

BF Offline Pipeline

Known Pulsar (Offline) Shell-Script Pipeline: Folding & De-dispersion



Dispersion of the Pulse Signal

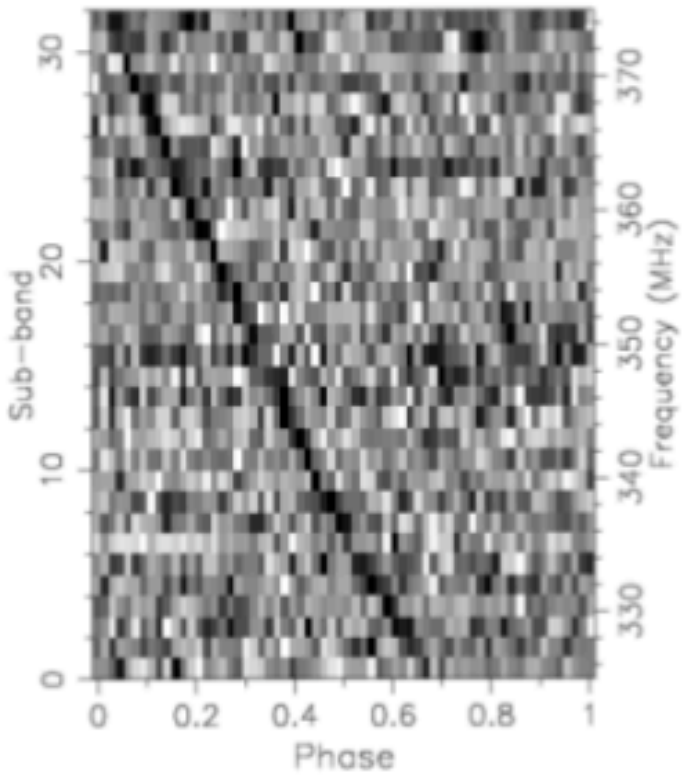
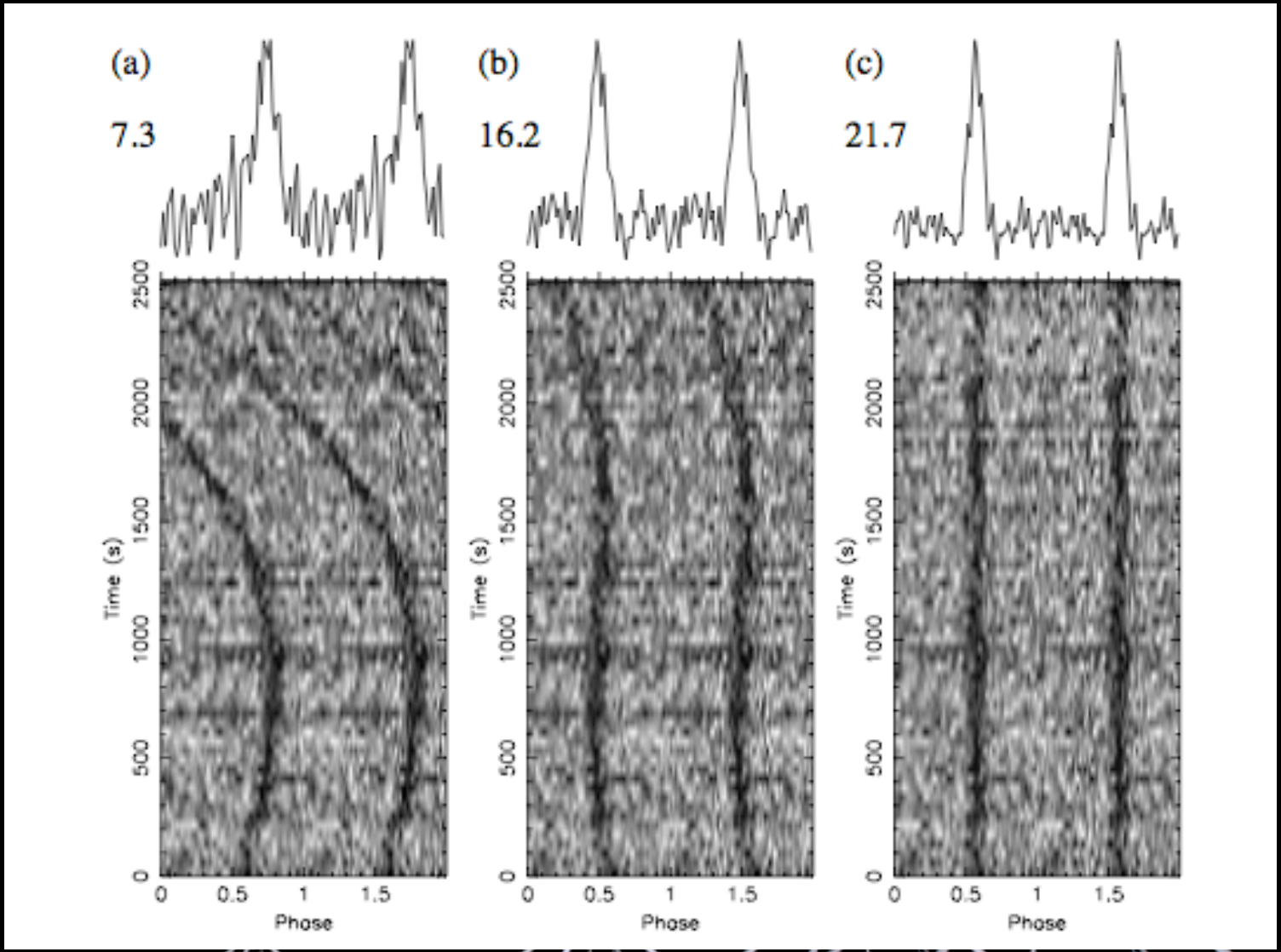


Figure 2.2: Signal from the newly discovered pulsar J2345+62 (Chapter 8) as a function of frequency and pulse phase. The 50 MHz bandwith is divided into 32 subbands. The dispersive effect of the interstellar medium has not been corrected for, and thus the lower frequency subbands arrive at later pulse phase.

"*Pulsar Handbook*", by Lorimer & Kramer

Folding Pulses to create "Pulse Profiles"



"*Pulsar Handbook*", by Lorimer & Kramer

User Support Group (USG) Pulsar Software & Pipeline

- Daily Build “use LUS” (LOFAR User Software)
- USG svn repository: “How To” Build/Install/Run Presentation (Apr 7, 2010)

  LOFAR wiki, Meetings…, Transients - Ongoing Work

  http://www.lofar.org/operations/doku.php?id=science:ksp:transients
- Pulsar Off-The-Shelf Tools:
  - Single precision FFTW v3.1.2
  - TEMPO v1.1 (http://www.atnf.csiro.au/research/pulsar/tempo/)
  - Presto (http://www.cv.nrao.edu/~sransom/presto/)
  - SIGPROC v4.3 (http://sigproc.sourceforge.net/)
  - Python bindings to PGPLOT (ppgplot) v1.1 (http://www.astro.rug.nl/~breddels/python/ppgplot/)
  - [PSRCHIVE v13.0 (http://sourceforge.net/projects/psrchive/) - Ubuntu Linux only]
  - [DSPSR v1.0]
  - [PSRDADA snapshot@date Aug 18, 2010]

  NOT in Daily Build!
- Pulsar Pipeline & associated scripts

Running the Pulsar "Shell-Script" Pipeline (pulp.sh)

- Examples with processing times for 1-hour observation; (8) multi-core script:

1) Basic run with no additional switches; uses 8 cores ➔ takes 5 min

   - pulp.sh -id L2010_06296 -p B2111+46 -o /net/sub5/lse013/data4/ \
     LOFAR_PULSAR_ARCHIVE_lse013/L2010_06296_red

2) Basic run using 4 cores; deleting previous results ➔ takes 10 min

   - pulp.sh –core 4 -del -id L2010_06296 -p B2111+46 –o L2010_06296_red

3) Run with RFI option turned on; 8 cores ➔ min 6 min

   - pulp.sh -del -id L2010_06296 -p B2111+46 -rfi –o L2010_06296_red

4) Run with ALL subbands option ➔ takes 13 min

   - pulp.sh -id L2010_06296 -p B2111+46 -all –o L2010_06296_red

5) Run with ALL subbands option and RFI option turned on ➔ takes 13 min

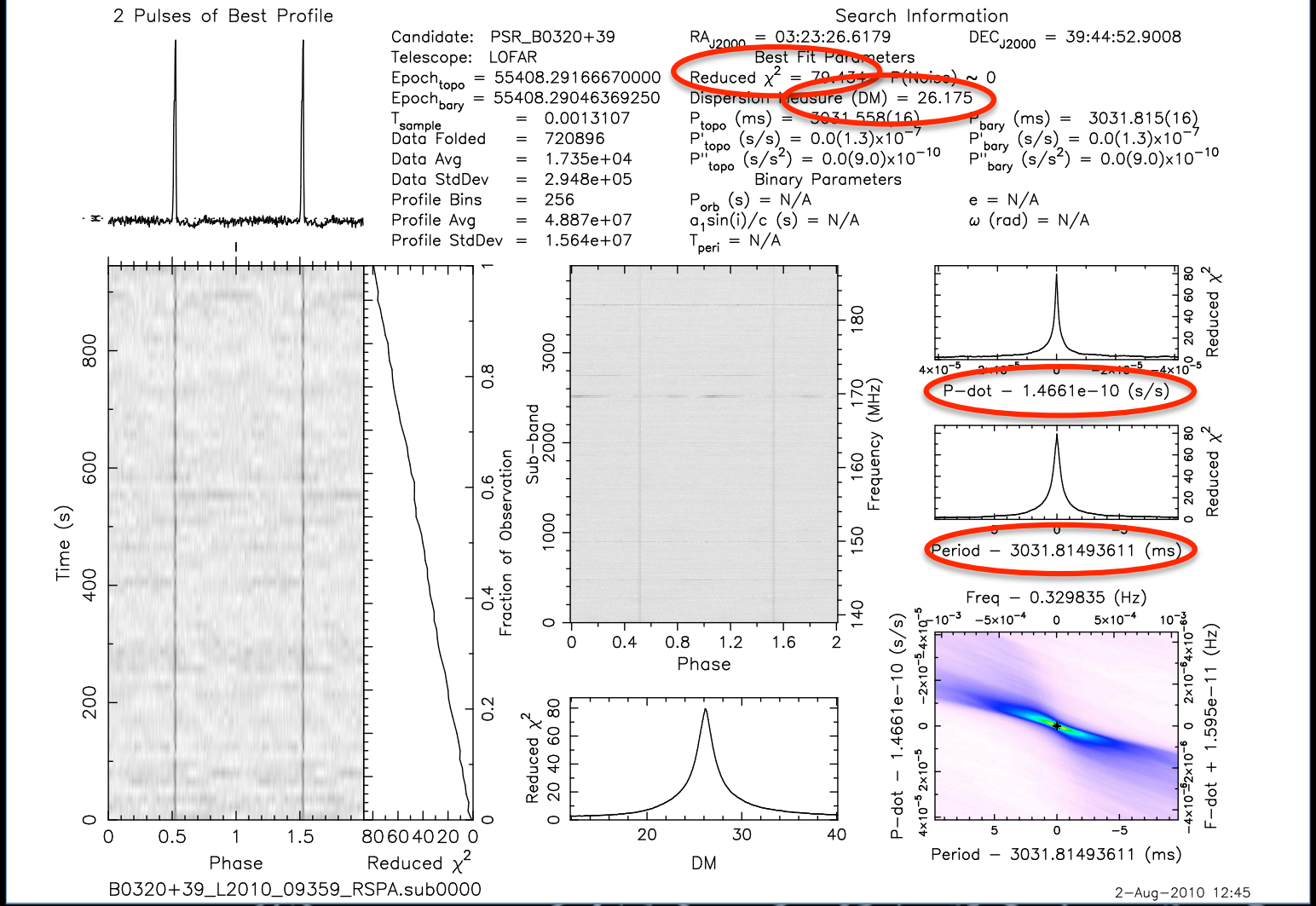
   - pulp.sh -id L2010_06296 -p B2111+46 -all -rfi –o L2010_06296_red

(Offline) Known Pulsar Shell-Script Pipeline & Tools

- Known Pulsar Pipeline can process LOFAR observing modes:
  - Incoherentstokes
  - Coherentstokes
  - Fly's Eye
  - Multi-Beam Observations
- Fold multiple pulsars within one dataset using pipeline switch "-p B2011+38,B2027+37,J2032+4127"
- Pulsar name can be replaced by 3C-source name, "-p 3C33" or position (find N pulsars around sky location, N=3), "-p position"
- Typical LOFAR data processing time for single beam Incoherentstokes:
  - 1min - 1 hour observation ➔ ~13 minutes [~5 min quick-preview]
  - 1 hr - 6 hours observation ➔ ~13 min x N hr-observation [~5 min x N hr quick-preview]

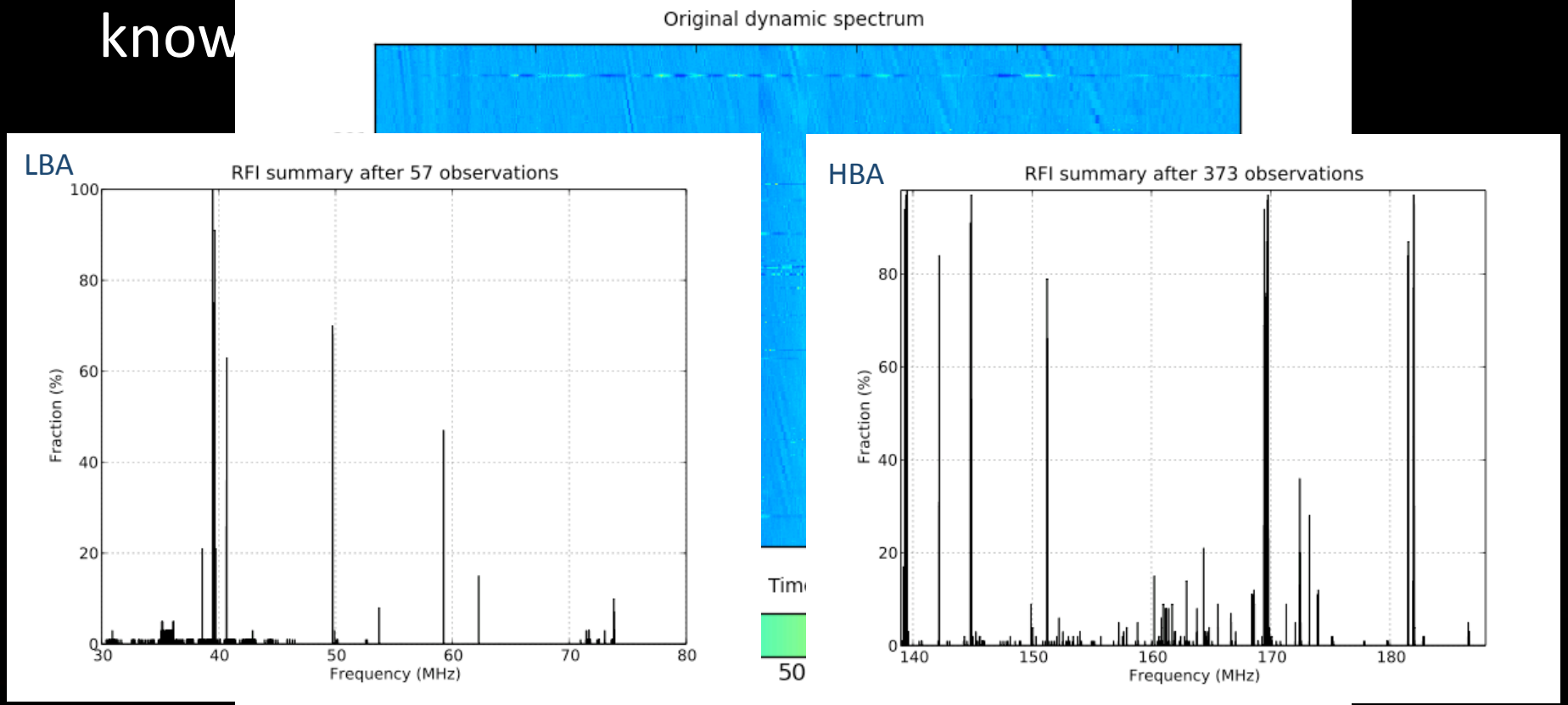
N Beams

Known Pulsar Pipeline Results



Long-term RFI Statistics

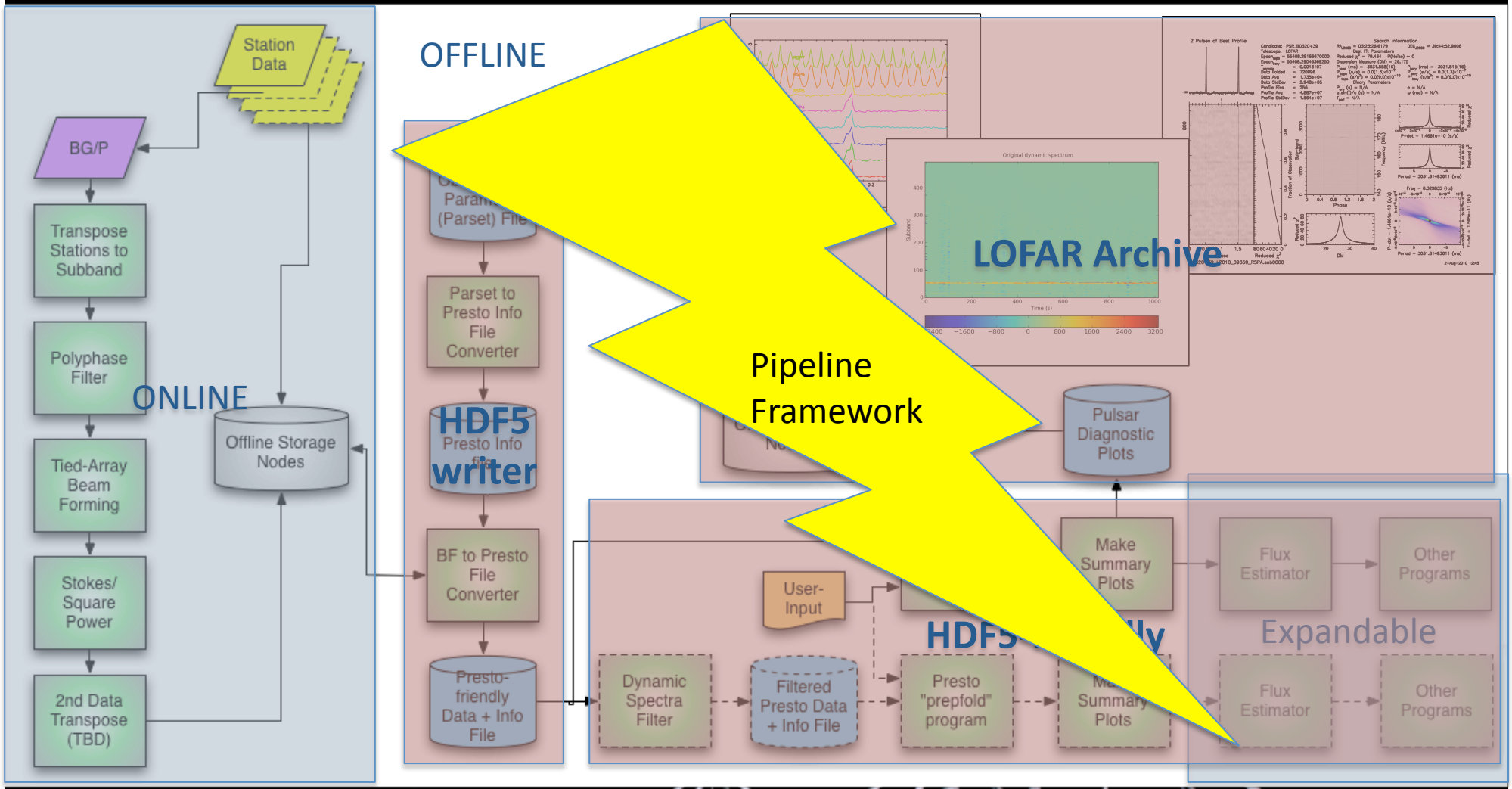
- RFI-summary performed per core split to show noisy subbands (channels)
- RFI Statistics for future mitigation of subbands with know



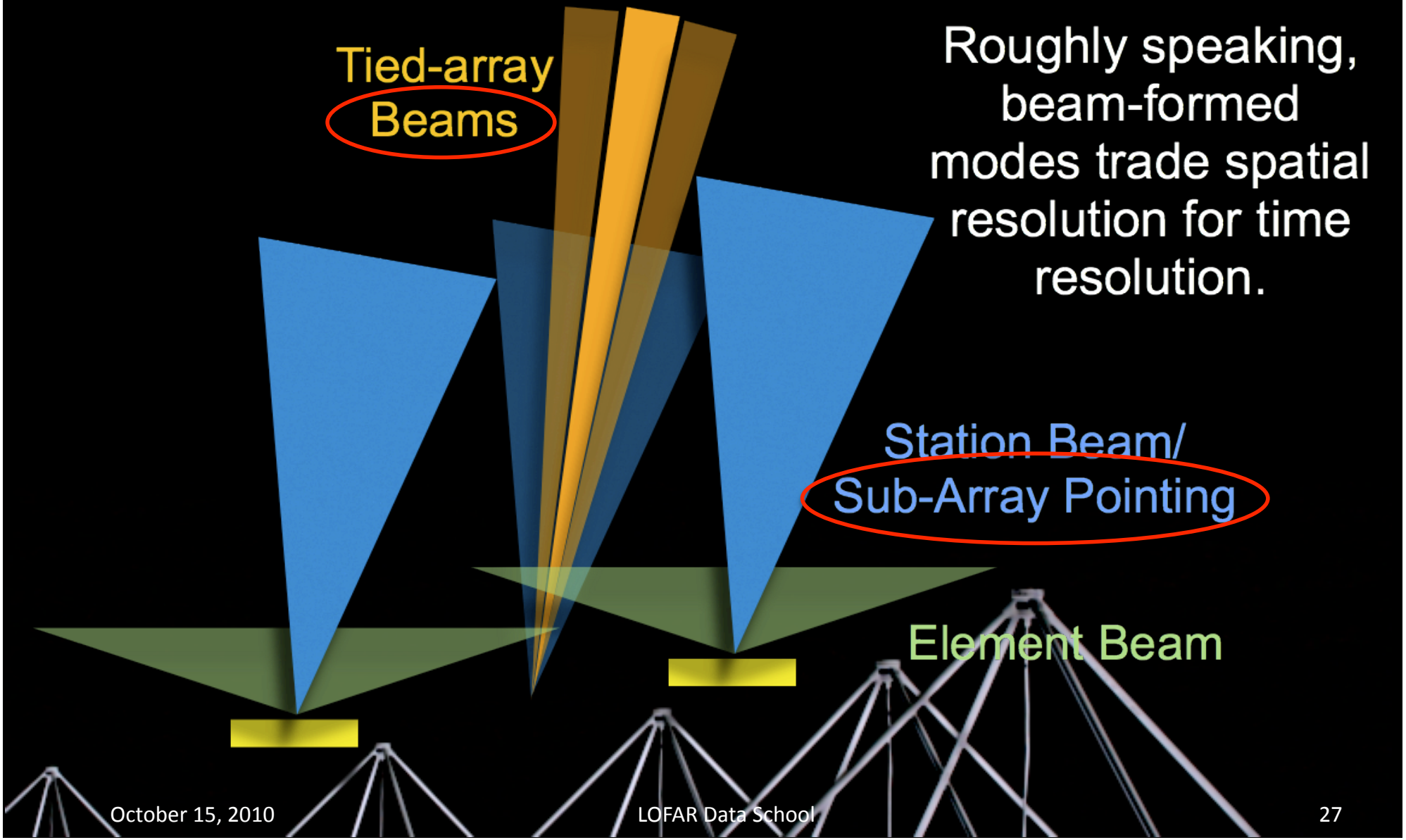
Known Pulsar Pipeline: Results Summary Web Pages

- Pulsar Data Summary Web Pages (new observations are updated nightly; database rebuilt weekly)
  - http://www.astron.nl/~kondratiev/lofar/megapulsars-obsid.html
- Similar observation "summaries" will likely be implemented for the entire cluster

Known Pulsar (Offline) Pipeline: Future Enhancements

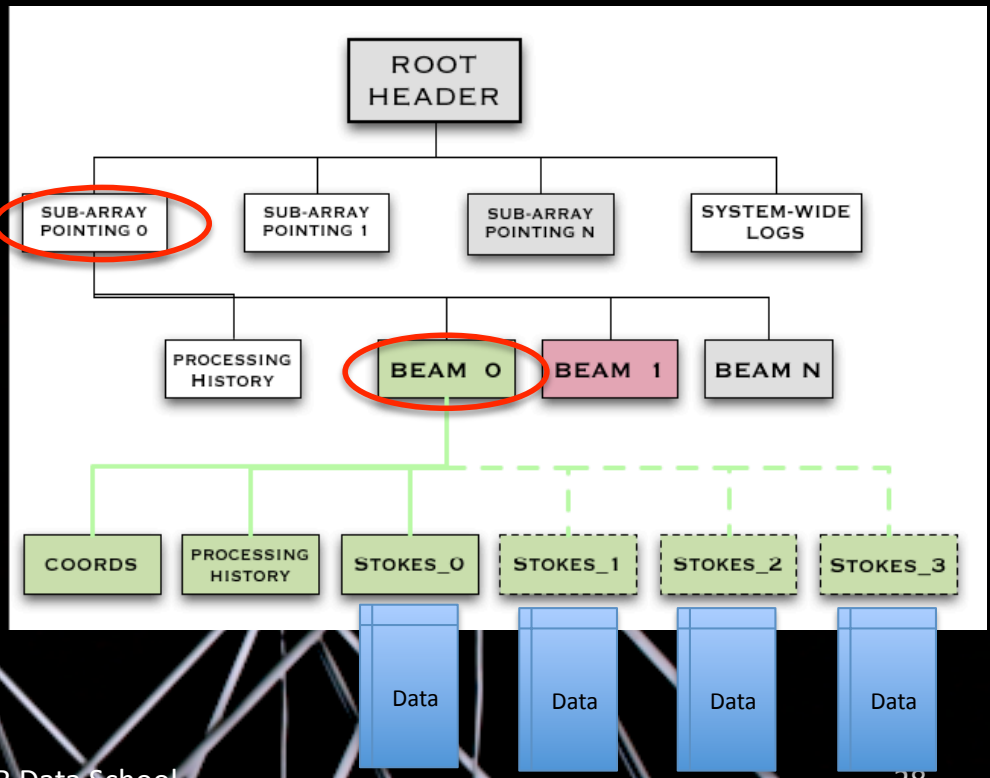


Terminology: Sub-Array "Pointing" & "Beam"



Beam-Formed Data Format: Hierarchical Data Format, version 5 (HDF5)

- Why HDF5? FITS/CASA just does not cut it for LOFAR…
- HDF5 is a data model, library, and file format for storing and managing large and complex data.
- It supports an unlimited variety of datatypes, and is designed for flexible and efficient I/O and for high volume and complex data.
- HDF5 is portable, extensible, and parallelizable, allowing applications to evolve in their use of HDF5.
- The HDF5 Technology suite includes a 20-year history of tools and applications for managing, manipulating, viewing, and analyzing data in the HDF5 format.

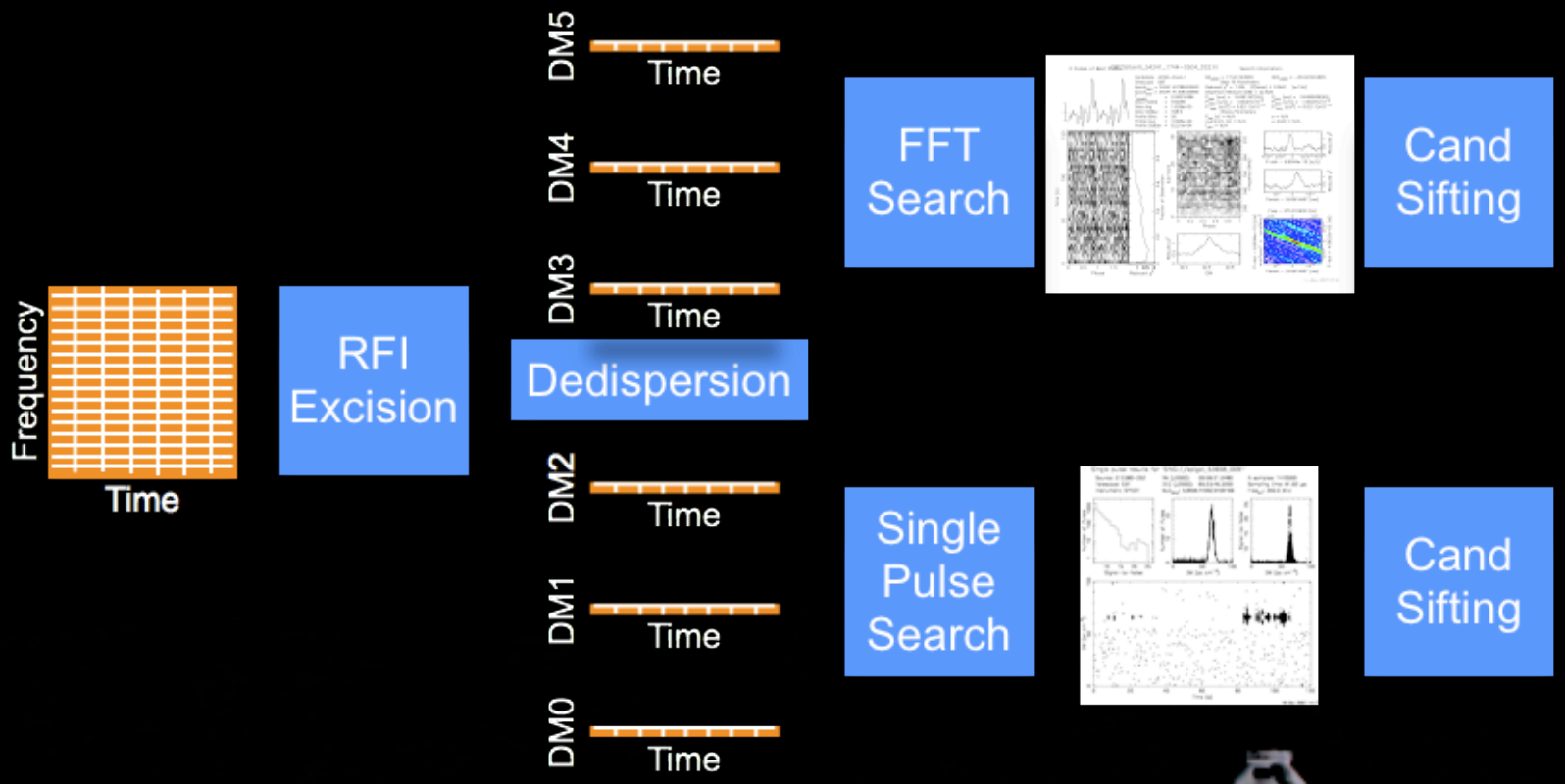


LOFAR Pulsar Search Pipeline (by Vishal Gajjar)

DATA_SETS	PSR	Extra_PSR	Radial_Distance
L2010_08582	B0450+55	-	-
L2010_08583	B0329+54	-	-
L2010_08587	B0823+26	-	-
L2010_08588	B0809+74	-	-
L2010_08589	B0525+21	-	-
L2010_08593	B0950+08	-	-
L2010_08594	B0919+06	-	-
L2010_08595	B0834+06	-	-
L2010_08599	B1508+55	-	-
L2010_08600	B1237+25	-	-
L2010_08601	B1133+16	-	-
L2010_08607	B1541+09	-	
L2010_08623	B1911-04	B1919+21	26.63
		B1508+55	78.16
L2010_08624	B1907+10	B1919+21	11.22
		B1508+55	64.0
L2010_08630	B1929+10	B1919+21	11.18
L2010_08631	B1919+21	-	-
L2010_08635	B2016+28	B2020+28	1.2
L2010_08641	B2111+46	-	-
L2010_08642	B2020+28	B2016+28	1.2
		B1919+21	15.4
L2010_08646	B2310+42	B1919+21	52.0
L2010_08647	B2217+47	-	-
L2010_08648	B2154+40	B1919+21	37.58

- Debug Presto pipeline to get better SNR
- Develop flexible search pipeline using Python
- Total 22 data sets analyzed with the pulsar search pipeline
- In almost all data sets, pipeline found the pulsar which was at the field center
- In 10 data sets pulsars which are far away from the field center were also found
- Few anomalies were also found which are difficult to associate with any pulsar or RFI behavior

Methods of Searching BF Data:



Pulsar Busy Weeks (#10 Nov 1-5, 2010)

- Get hands-on experience during the Pulsar Busy Weeks at ASTRON
- Email a.alexov@uva.nl if you want to participate

Pulsar/Planet Busy Week VI

Dec 7-11, 2009