The LOFAR Transients Pipeline

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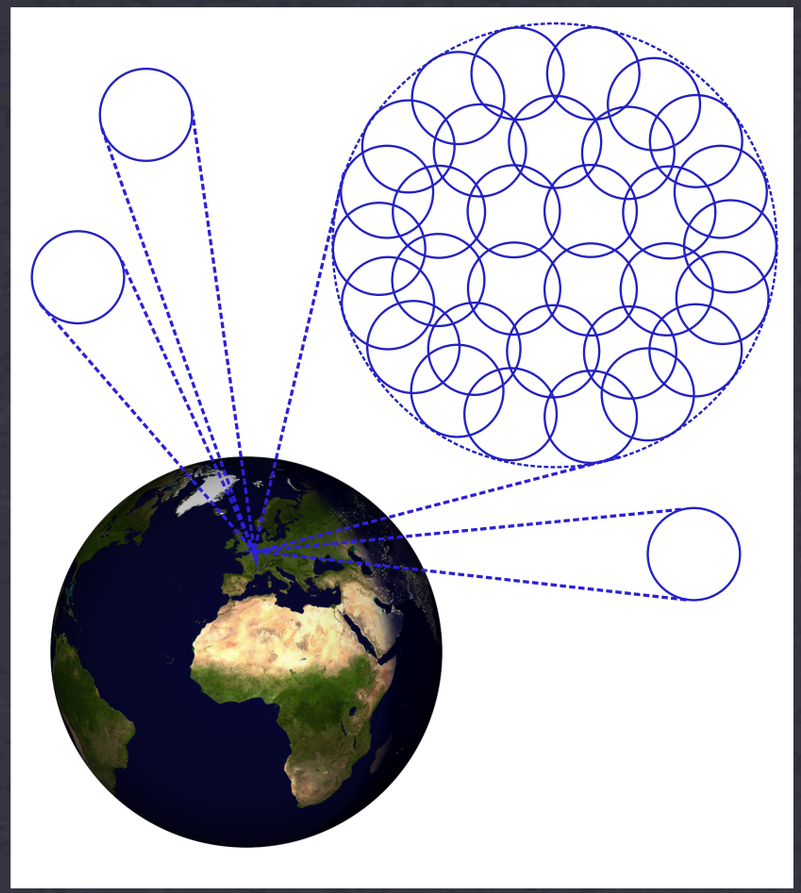
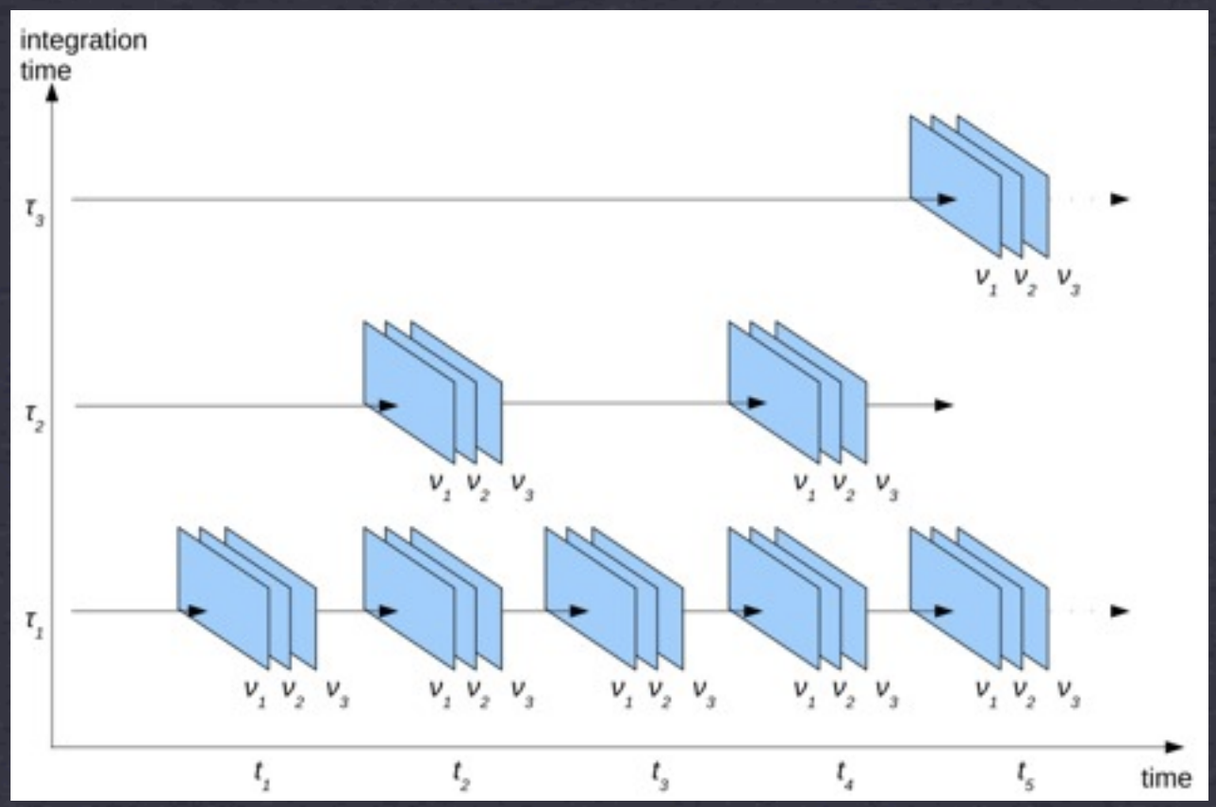
The “transients pipeline”

- ➡ Ingests image cubes (position, frequency, polarization)
- ➡ Identifies and classifies transients & variable sources within the images
- ➡ Results in:
  - ➡ Alerts, either within LOFAR or to the community
  - ➡ Archive database of classified lightcurves

The Radio Sky Monitor

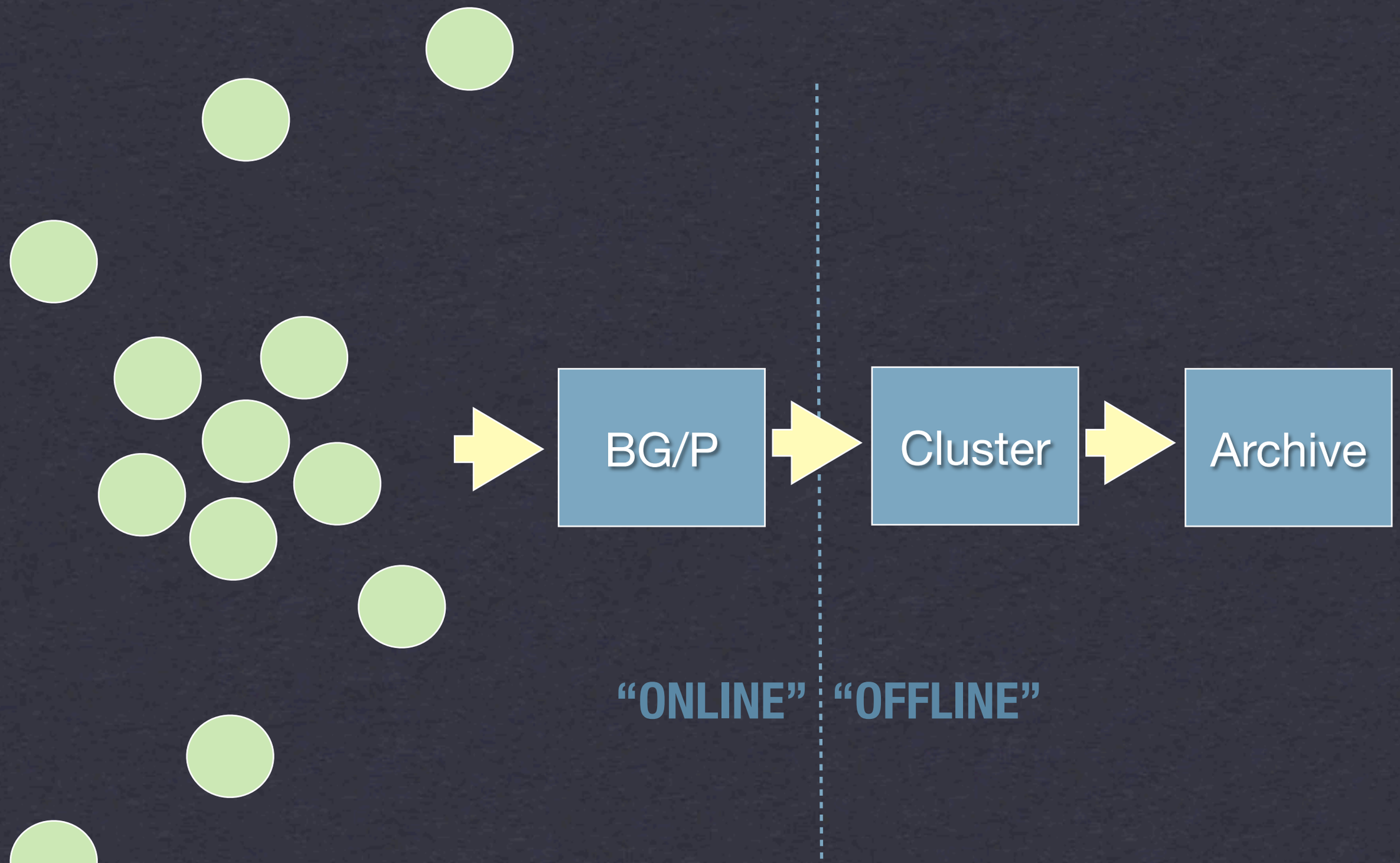
- ➡ Multiple LOFAR beams tile out the sky
- ➡ Individual beams on specific targets
- ➡ Imaging at 1, 2, 5, 10, ... second cadence
- ➡ Observation strategy under development



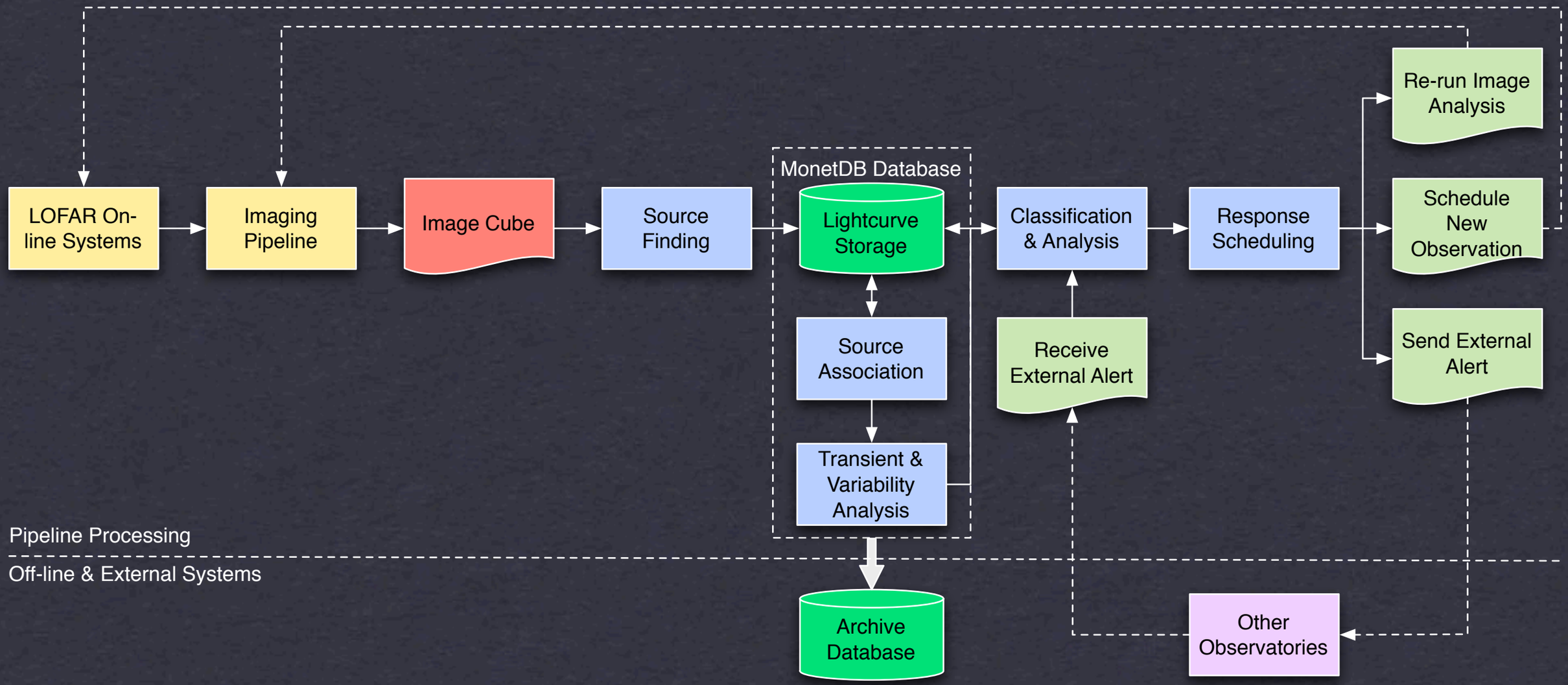


...but also

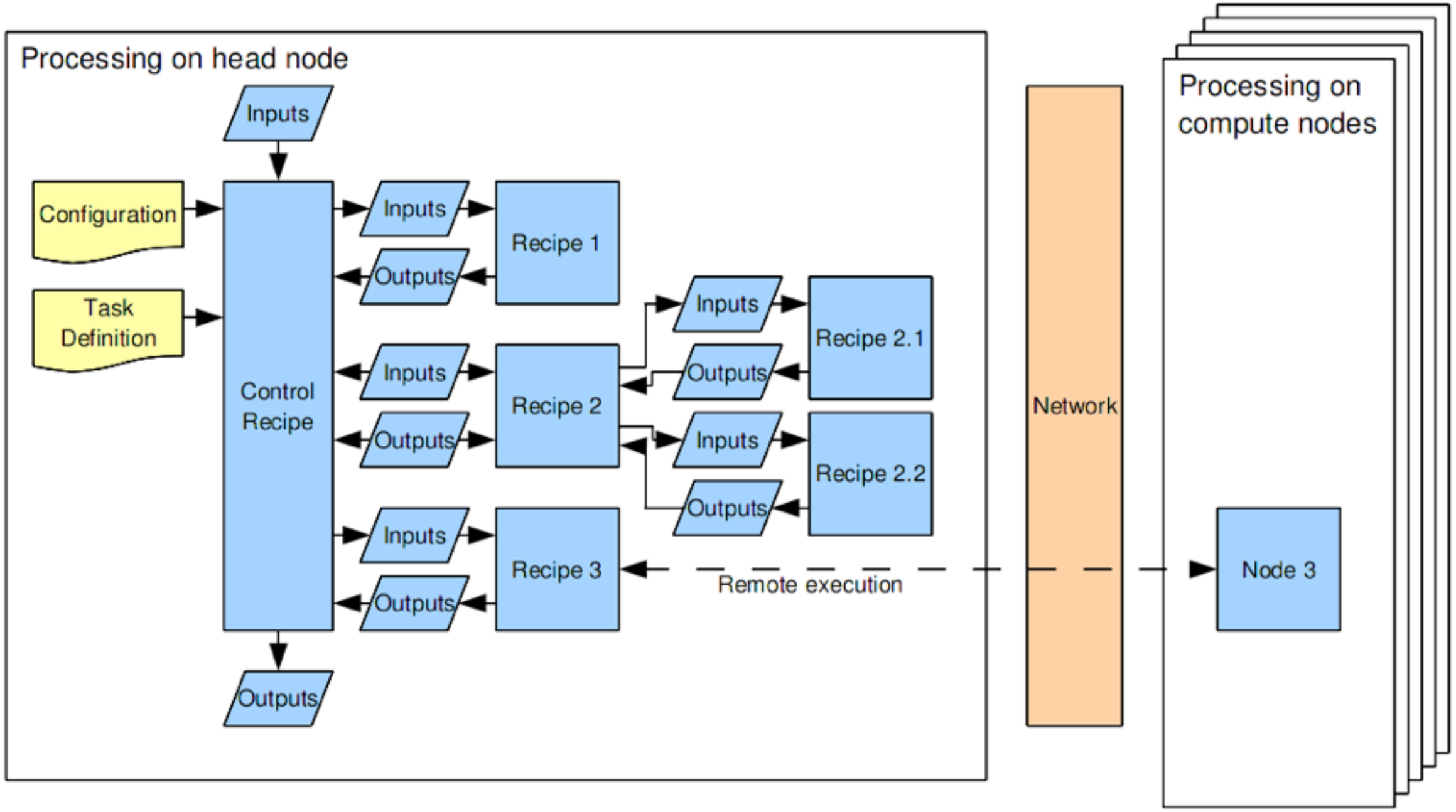
- ➡ Monitoring of specific fields
- ➡ Piggybacking
- ➡ Trawling through the LOFAR archive
- ➡ Trawling through other archives (VLA...)
- ➡ AARTFAAC
- ➡ ...etc



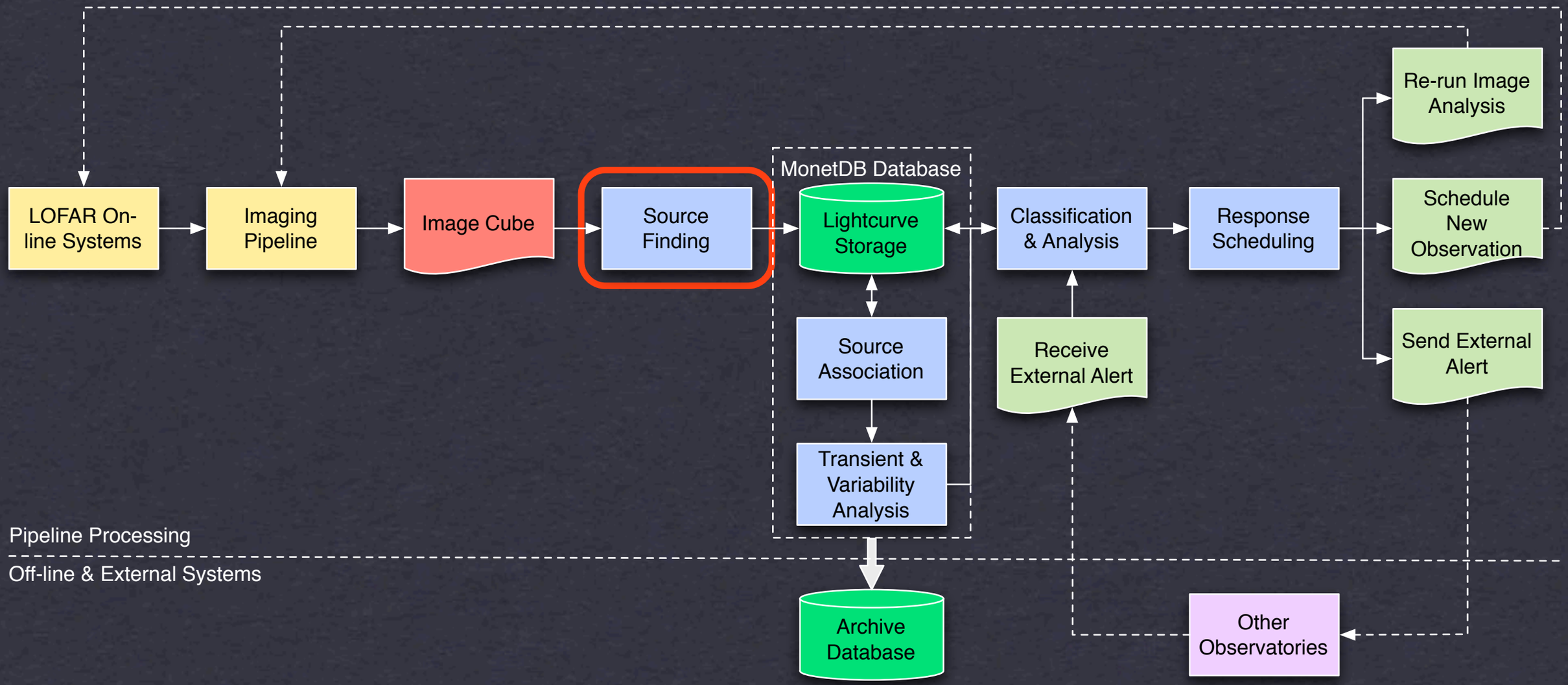
OUTLINE LOFAR TOPOLOGY



LOFAR TRANSIENTS SYSTEM OVERVIEW



THE LOFAR PIPELINE FRAMEWORK



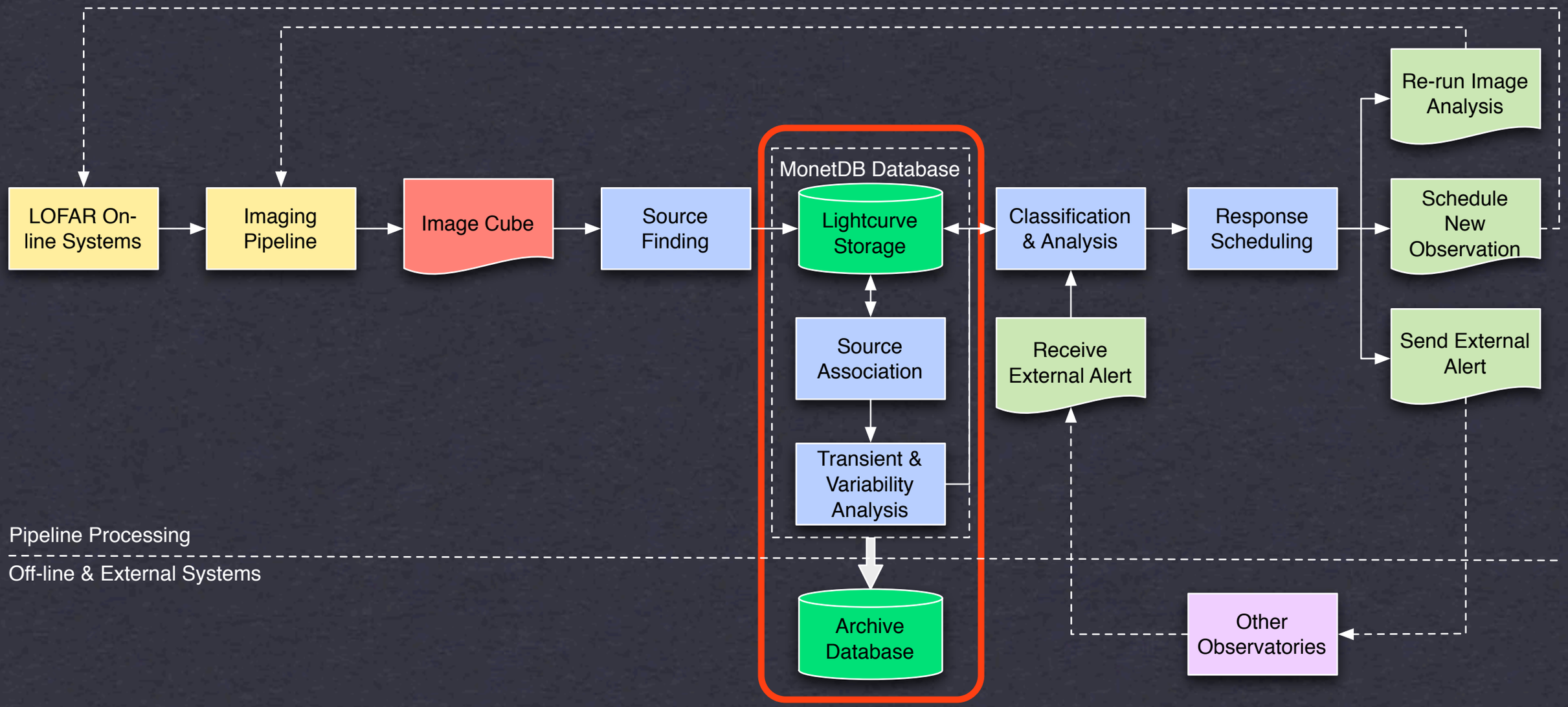
LOFAR TRANSIENTS SYSTEM OVERVIEW

Source-finding

- ➡ Custom-developed source-finding code
- ➡ (Almost) pure Python (+ NumPy, SciPy, etc)
- ➡ Available both in a pipeline form, and for interactive use
- ➡ Largely developed by Hanno Spreeuw as part of his PhD work at the University of Amsterdam
- ➡ New maintainer: John Sanders (Univ. Portsmouth); gearing up for a proper release

Another sourcefinder...

- ➡ Fitting all detected sources with elliptical Gaussians (or other shapes)
- ➡ Deblending composite sources
- ➡ False detection rate algorithm (Benjamini & Hochberg, 1995)
- ➡ Proper treatment of errors in the presence of correlated noise (after Condon, 1997)
- ➡ Formidable battery of statistical tests (see Spreeuw's thesis, 2010)



LOFAR TRANSIENTS SYSTEM OVERVIEW

Database

- Two databases: “pipeline” and “archive”
  - Both based on the same architecture
    - Pipeline database supports real-time pipeline processing
    - Archive database provides long term storage and data mining of up to 100 TB/year.
- Subject of PhD thesis by Bart Scheers (2011); ongoing development by Scheers

Source Association

- ➡ Sourcefinder results are uploaded directly into the database
- ➡ Lightcurves are built automatically as new results arrive
- ➡ Association is done by position, taking into account measurement errors, background source counts, etc.
- ➡ In progress development to associate across frequencies per image cube.

Transient detection

- Also in the database, automatically as lightcurves are grown
- Measuring magnitude and significance of flux variation; easy to add more measures
- Query for significant objects directly into pipeline

$$V_\nu = \frac{1}{\overline{I_\nu}} \sqrt{\frac{N}{N-1}\left(\overline{I_\nu^2} - \overline{I_\nu}^2\right)}$$

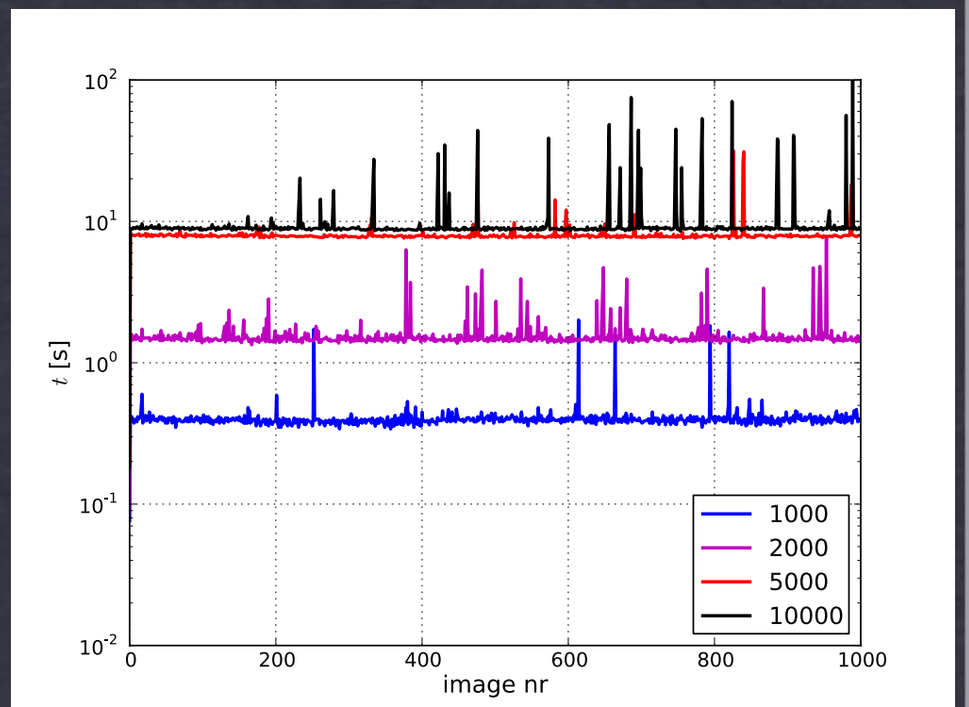
$$\eta_\nu = \frac{1}{N-1} \sum_{i=1}^{N} \frac{(I_{\nu,i} - \overline{I_\nu}^*)^2}{\sigma_{I_{\nu,i}}^2}$$

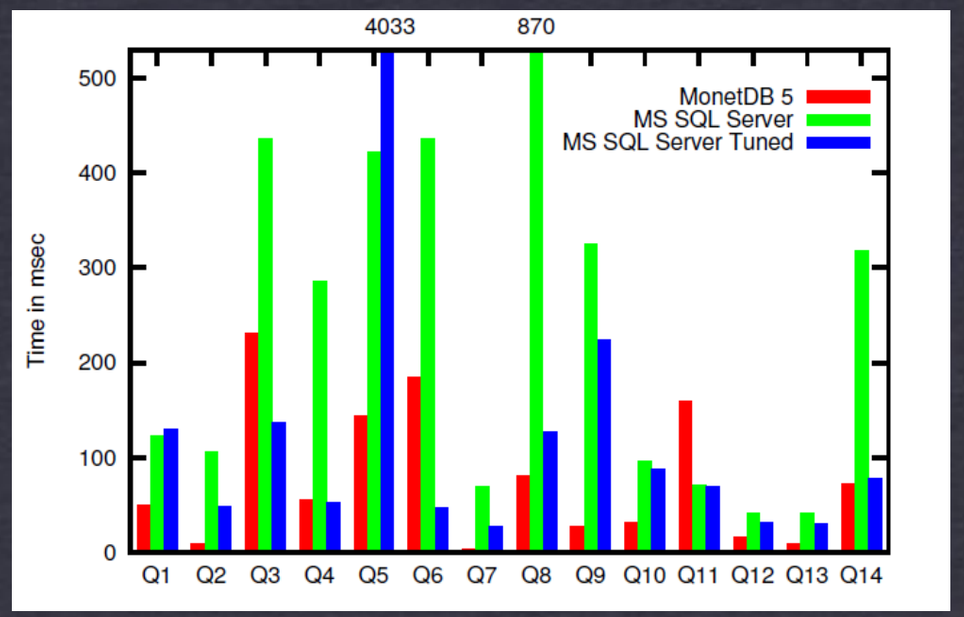
$$\overline{I_\nu}^* = \frac{\sum_{i=1}^{N} \omega_{\nu,i} I_{\nu,i}}{\sum_{i=1}^{N} \omega_{\nu,i}}$$

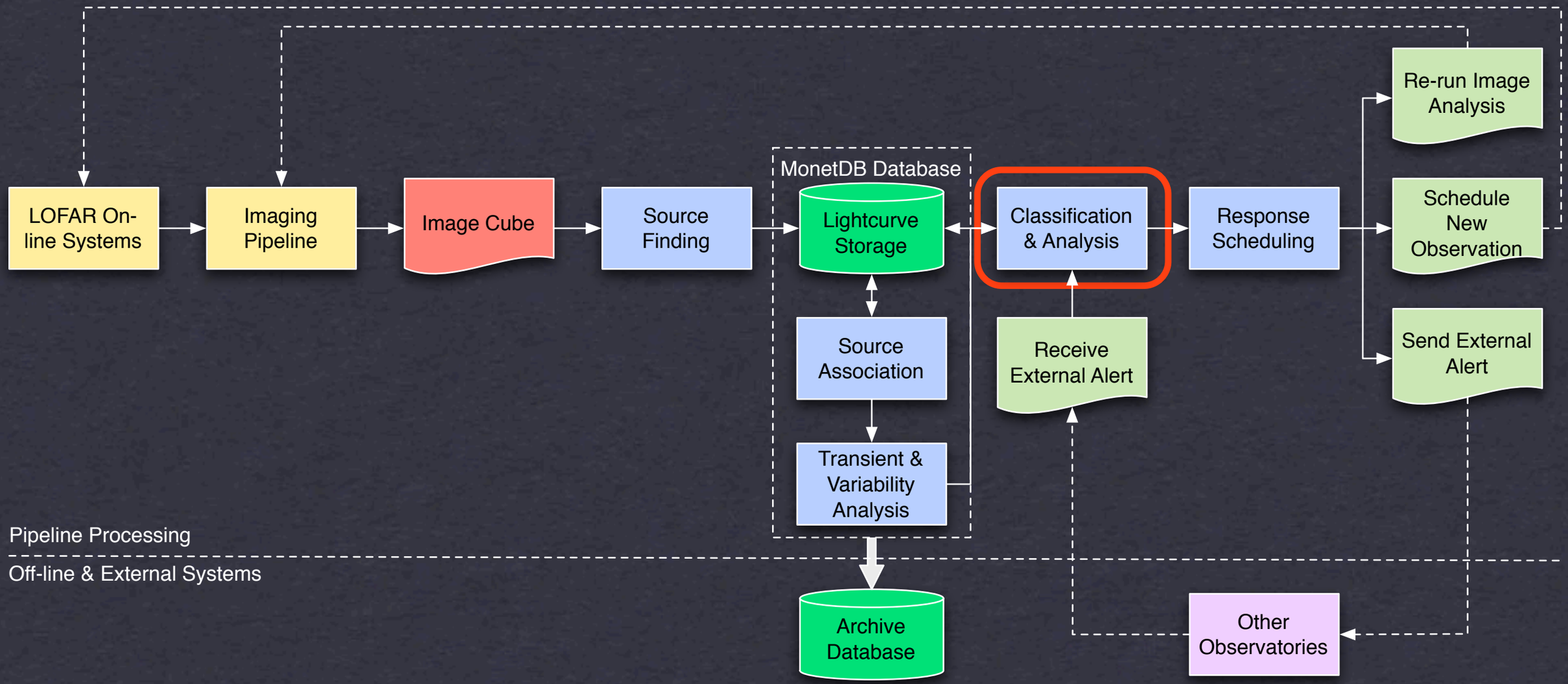
$$\omega_{\nu,i} = \frac{1}{\sigma_{I_{\nu,i}}^2}$$

MonetDB: performance

- ~10000 insertions/second for "full rate" radio sky monitor
- *MonetDB* makes this practical
  - "Column store" architecture
  - High-perf numeric kernel
  - etc etc
- Killer feature: collaboration with CWI developers







LOFAR TRANSIENTS SYSTEM OVERVIEW

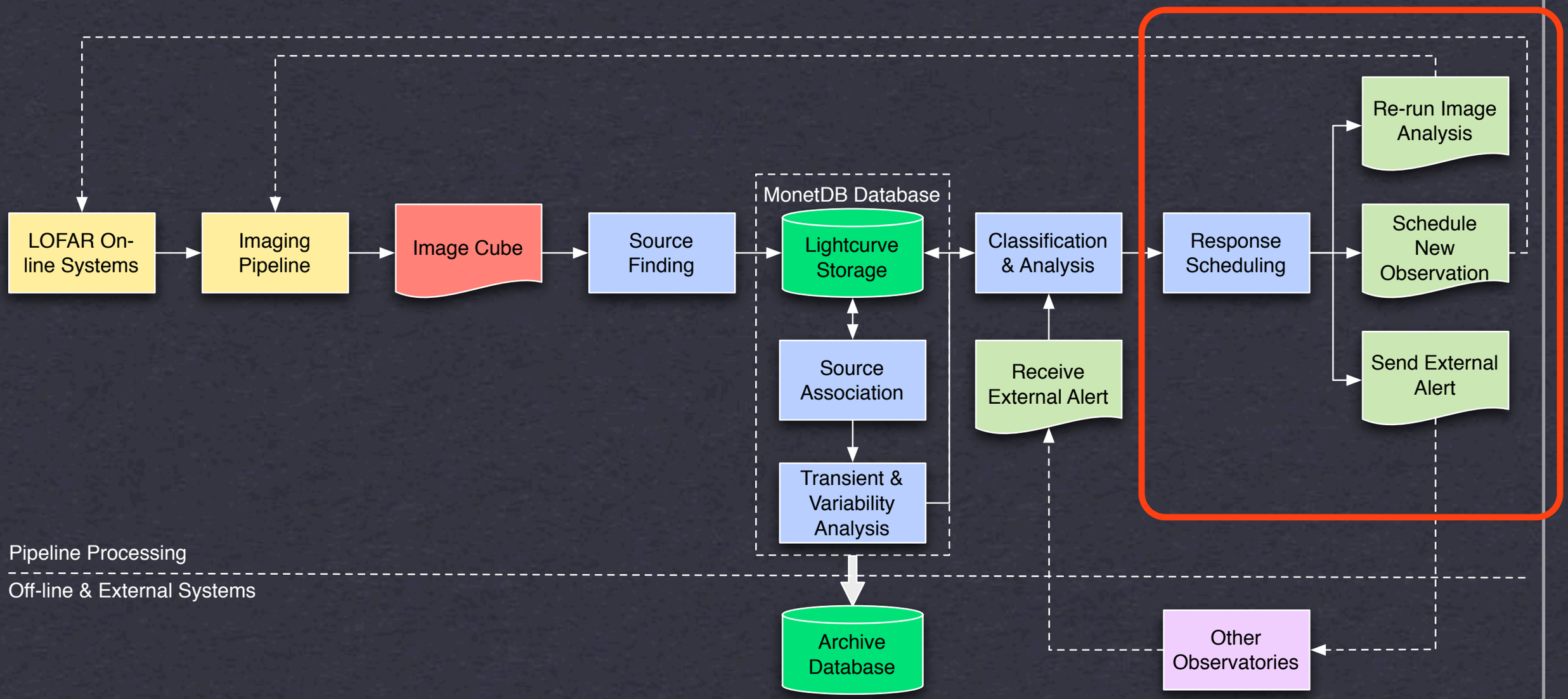
Feature measurement

- ➡ Simple Python code that operates on a lightcurve extracted from the database
- ➡ Arbitrary properties can be defined, from the simple (average flux, ...) to the complex (fitting parameters, ...)
- ➡ The lightcurve is annotated with the features, then passed to the classifier.

Classification

- Manual
  - Astronomer-designed “plugins” identify certain combinations of features
  - Easy to extract your “favourite” sources from the data... if you can describe how they behave
- Automatic
  - Speculative!
  - See Masters thesis by Thijs Coenen (2008)
  - Re-use of feature-extraction code

```
class SlowTransient(ClassifiedTransient):

    """Slow transient"""

    def test_duration(self):
        if self.duration > 1e6:
            return 0.9

    def test_variability(self):
        if self.variability > 1e4:
            return 0.9


class GRBPrompt(ClassifiedTransient):

    """GRB prompt emission"""

    def test_duration(self):
        if 1 < self.duration < 1e4:
            return 0.6

    def test_voevent_delay(self):
        if 0 < self.vo_event.delay < 1e5:
            return 0.6

    def test_variability(self):
        if 0 < self.variability < 1e3:
            return 0.6
```



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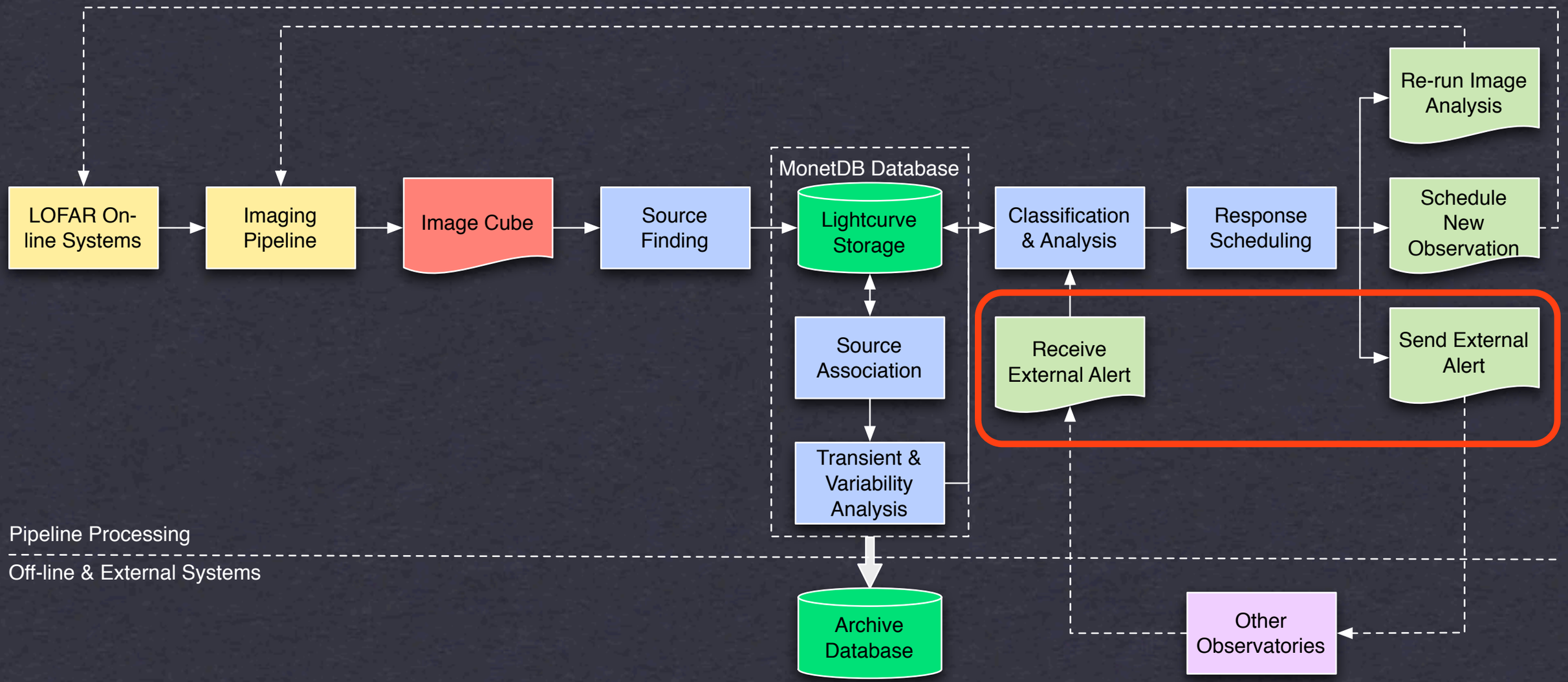

LOFAR TRANSIENTS SYSTEM OVERVIEW

VOEvent

version, ivorn,
role = test, observation, prediction, utility
Who
What
WhereWhen
How
Why
Citations
D, R

WhereWhen

longitude, latitude, positionalError, time, timeError
*observatory, coord_system **
* equivalent information

How

D, R

VOEvent2 in a Nutshell

Who

AuthorIVORN or
Author
title, shortName, logoURL, contactName, contactEmail, contactPhone, contributor
Date
D, R

Why

importance, expires
Name
Concept
Inference
probability, relation
Name, Concept, D, R
D, R

Citations

EventIVORN
cite = followup, supersedes, retraction
D

What

Param
name, unit, UCD, dataType, utype, value
Value, D, R
Group
name, type
Param, D, R
Table
name, type
Param, Field, Data, D, R
Field
name, unit, UCD, dataType, utype, value
D, R
Data
TR
TD
D, R

Reference

uri, meaning, mimetype

Description

Elements in black
Attributes in green
D = Description
R = Reference

VOEVENT

XML. MACHINE READABLE. FAST TRANSMISSION. AUTOMATIC PROCESSING. THE FUTURE...

Status & results

- Initial versions of the database and sourcefinding systems have been tested, and produced real science:
  - Bell, M.E. et al, *An automated archival VLA transients survey*, accepted by MNRAS
  - See Martin's talk on Thursday

Status & results 2

- ➡ LOFAR is now regularly observing fields regarded as “interesting” from a transients point of view
- ➡ “Offline” imaging pipeline being run for commissioning & science purposes
- ➡ All this data to be fed into the transients pipeline system

Status & results (3)

- ➡ “On-line” LOFAR imaging pipeline + AARTFAAC imaging pipeline coming in the next ~year
- ➡ Transients pipeline development progressing apace; we must be ready
- ➡ VOEvent trigger system tested: we have received and acted on triggers from LIGO

More information

- LOFAR Transients
  - http://www.transientskp.org/
- TKP Pipeline Docs
  - http://docs.transientskp.org/
- LOFAR Pipeline Framework
  - http://usg.lofar.org/documentation/pipeline/
- MonetDB
  - http://monetdb.cwi.nl/MonetDB/
  - http://www.scilens.org/
- PhD Theses (Spreeuw & Scheers)
  - http://www.astro.uva.nl/research/theses_phd/