Lensed QSOs with Gaia
DPAC, data releases, methods

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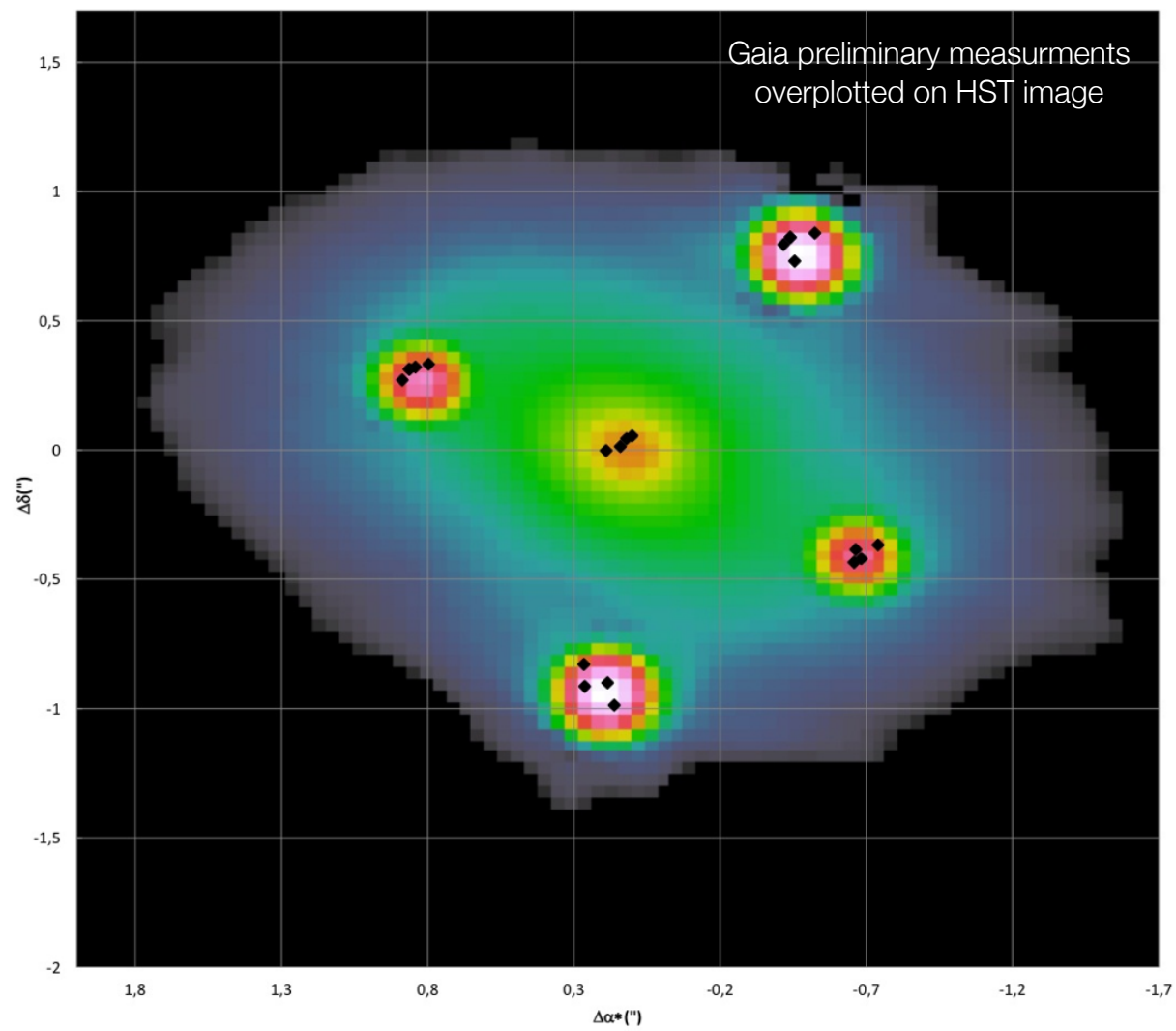
Alberto Krone-Martins
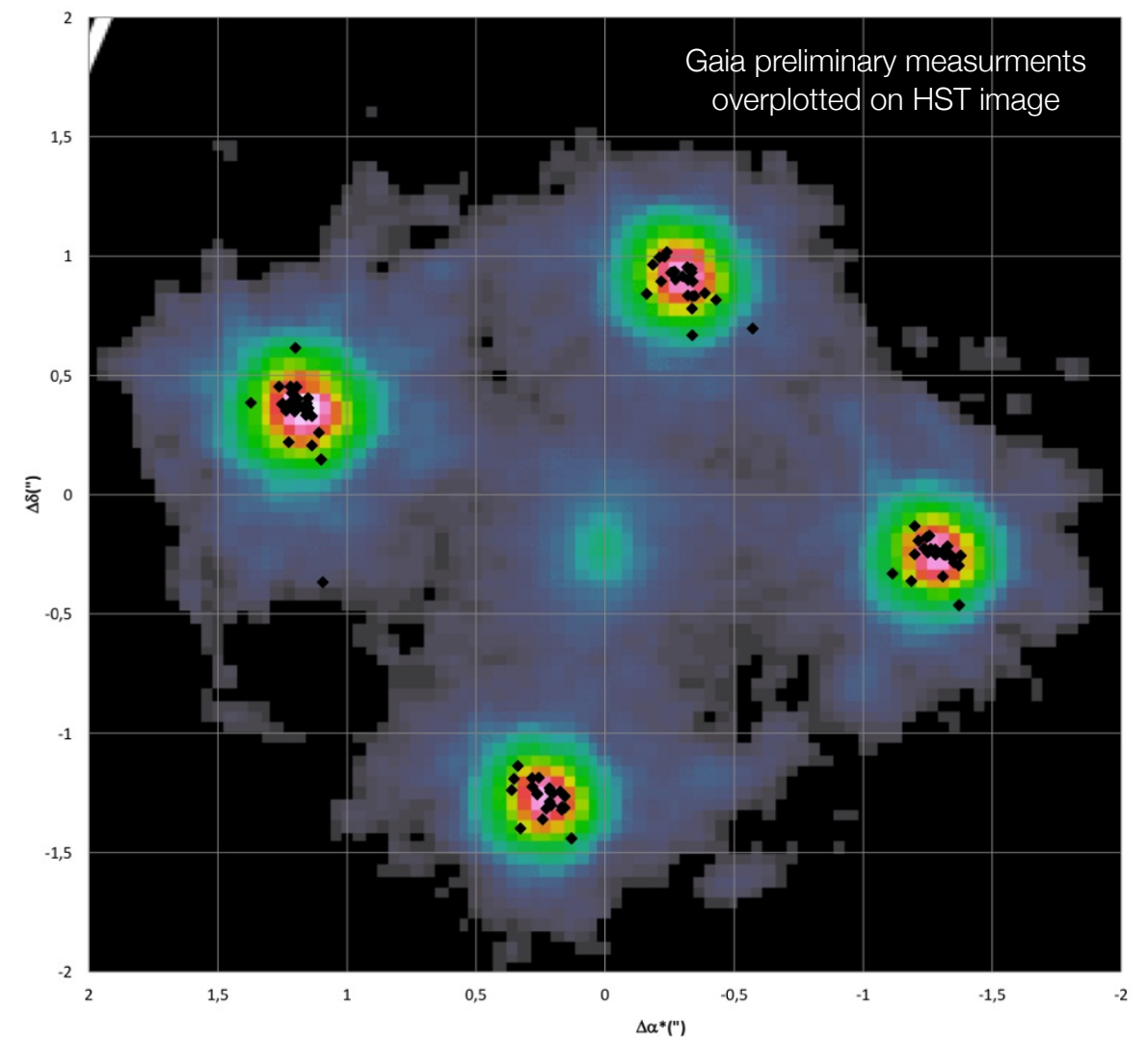
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But... just why?

- Gaia will be the first exaustive all-sky survey of QSOs with space-resolution

- And what that means?

  - All QSOs within Gaia's magnitude range that are multiply imaged due to gravitational lensing will be resolved.

  - And also duplicity, and many other things...

Example

Q2237+030

Gaia preliminary measurments
overplotted on HST image

HE0435-1223

Gaia preliminary measurments
overplotted on HST image

w / C. Ducourant, J.-F. le Campion, F. Mignard, L. Galluccio, R. Teixeira, J. Surdej, E. Slezak

But... how?

- Ok... we are doing this within DPAC

  - And thus **the last data release will very likely contain a flag** to indicate if a given QSO is candidate for a gravitational lens;

- But we will also be doing based on each public Gaia data release

  - Incremental releases with lists of candidate lensed QSOs that will become less contaminated after each data release.

  - Today we will be talking about the first DR strategies, only...

The (planned) Gaia Data Release 1

- Expected data **for most sources**:

  - Unique **RA&Dec** for each Gaia object (each IDT object);

  - Unique **G** magnitudes for each Gaia object.

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Gaia preliminary measurments overplotted on HST image
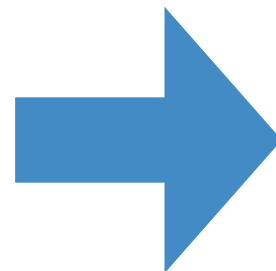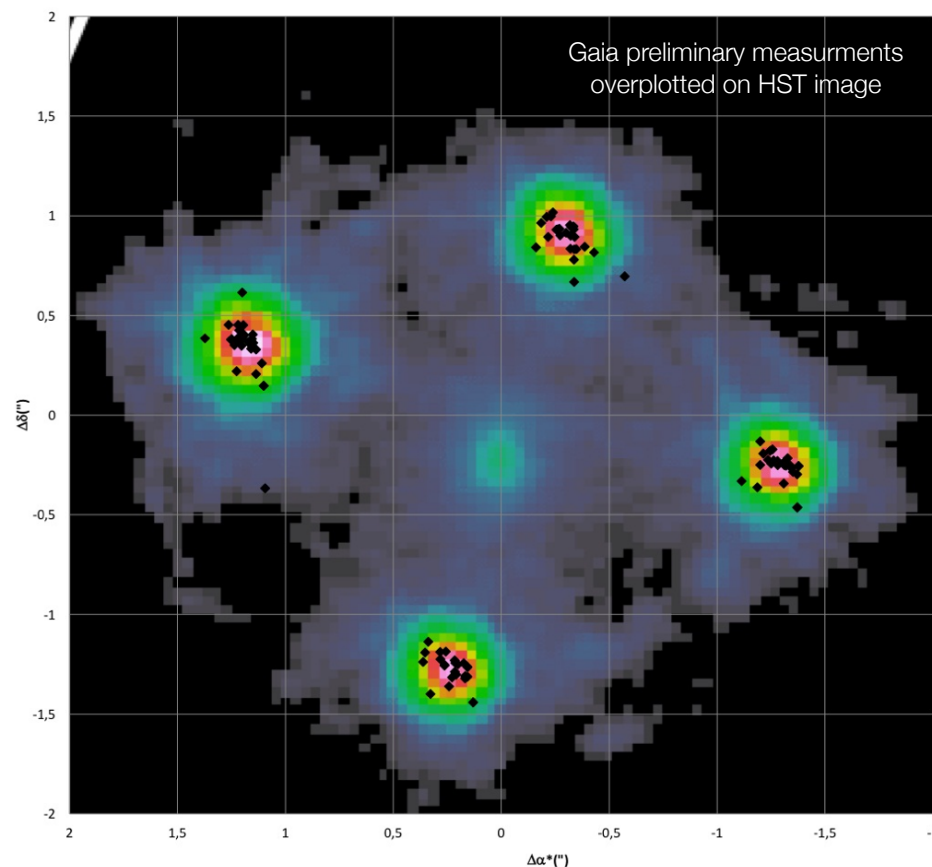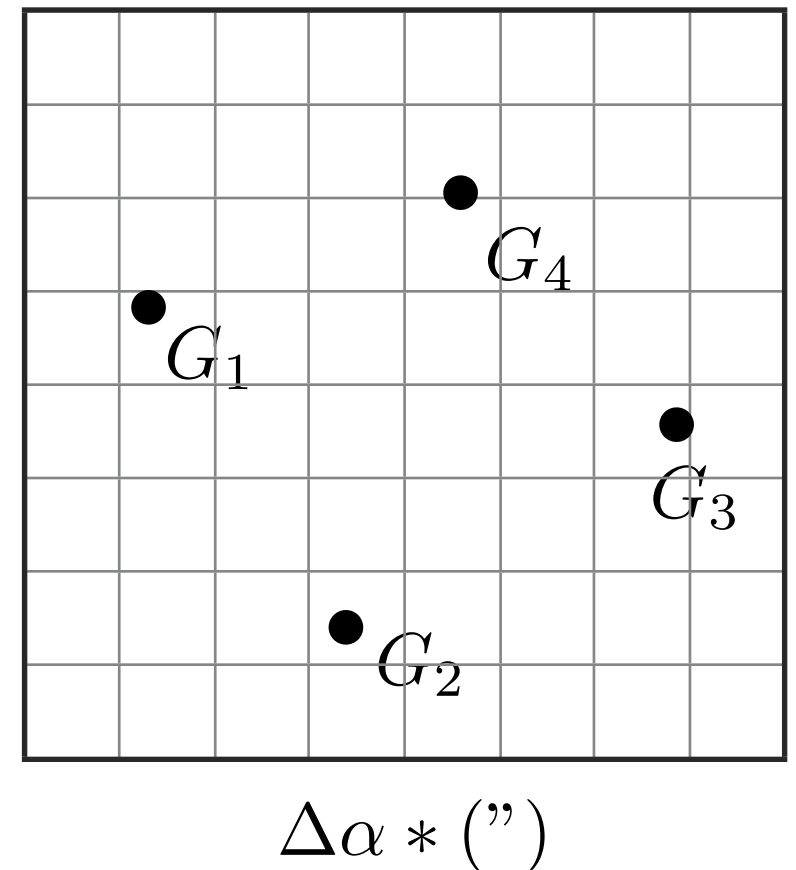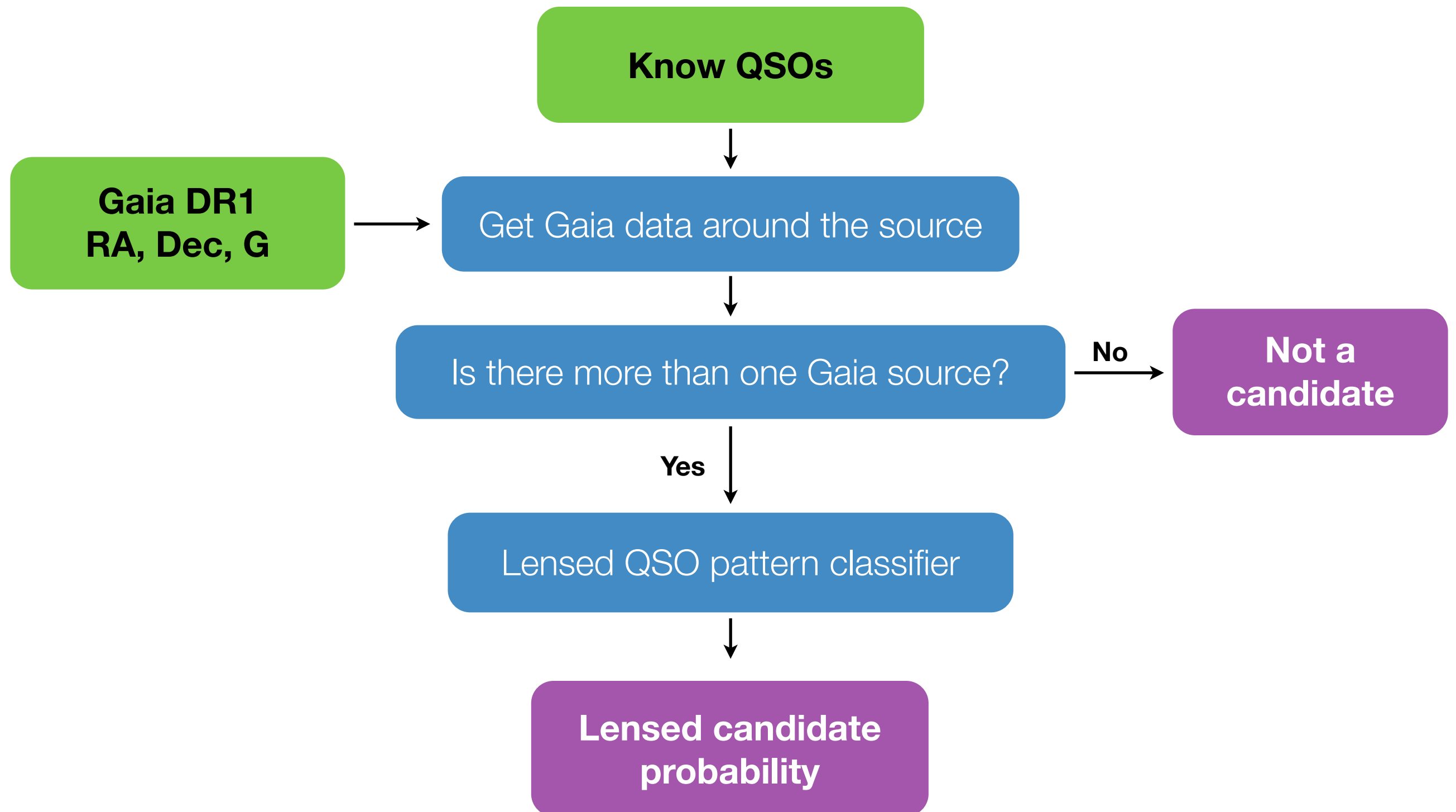
The (planned) Gaia Data Release 1

- Expected data **for most sources**:

  - Unique **RA&Dec** for each Gaia object (each IDT object);

  - Unique **G** magnitudes for each Gaia object.

- Expected problems (just a few):

  - **False sources**, ex. due to diffraction patterns.

  - **Incomplete coverage**, ex. due to data link saturation.

  - ...

What can we do with RA, Dec & G only ?

- Well...

  - The vast majority of the QSO lenses will be resolved!

- But... there is no classification!

  - What to do? Two strategies...

DR1 Strategy - For Known QSOs

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Know QSOs

~10⁶ easily feasible

**Gaia DR1
RA, Dec, G** → Get Gaia data around the source

Is there more than one Gaia source? — **No** → **Not a candidate**

Yes

Lensed QSO pattern classifier

Lensed candidate probability

DR1 Strategy - For the entire catalogue

```
Gaia DR1
RA, Dec, G    ──────▶    For each Gaia source
                                  │
                                  ▼
                         Get Gaia data around the source
                                  │
                                  ▼
                         Is there more than one Gaia source?  ──No──▶  Not a candidate
                                  │
                                 Yes
                                  │
                                  ▼
                         Lensed QSO pattern classifier
                                  │
                                  ▼
                         Lensed candidate probability
```

DR1 Strategy - For the entire catalogue

Gaia DR1 RA, Dec, G

For each Gaia source

$\sim 10^9$ ok... it is doable, hard, but doable

Get Gaia data around the source

Is there more than one Gaia source? — **No** → **Not a candidate**

Yes

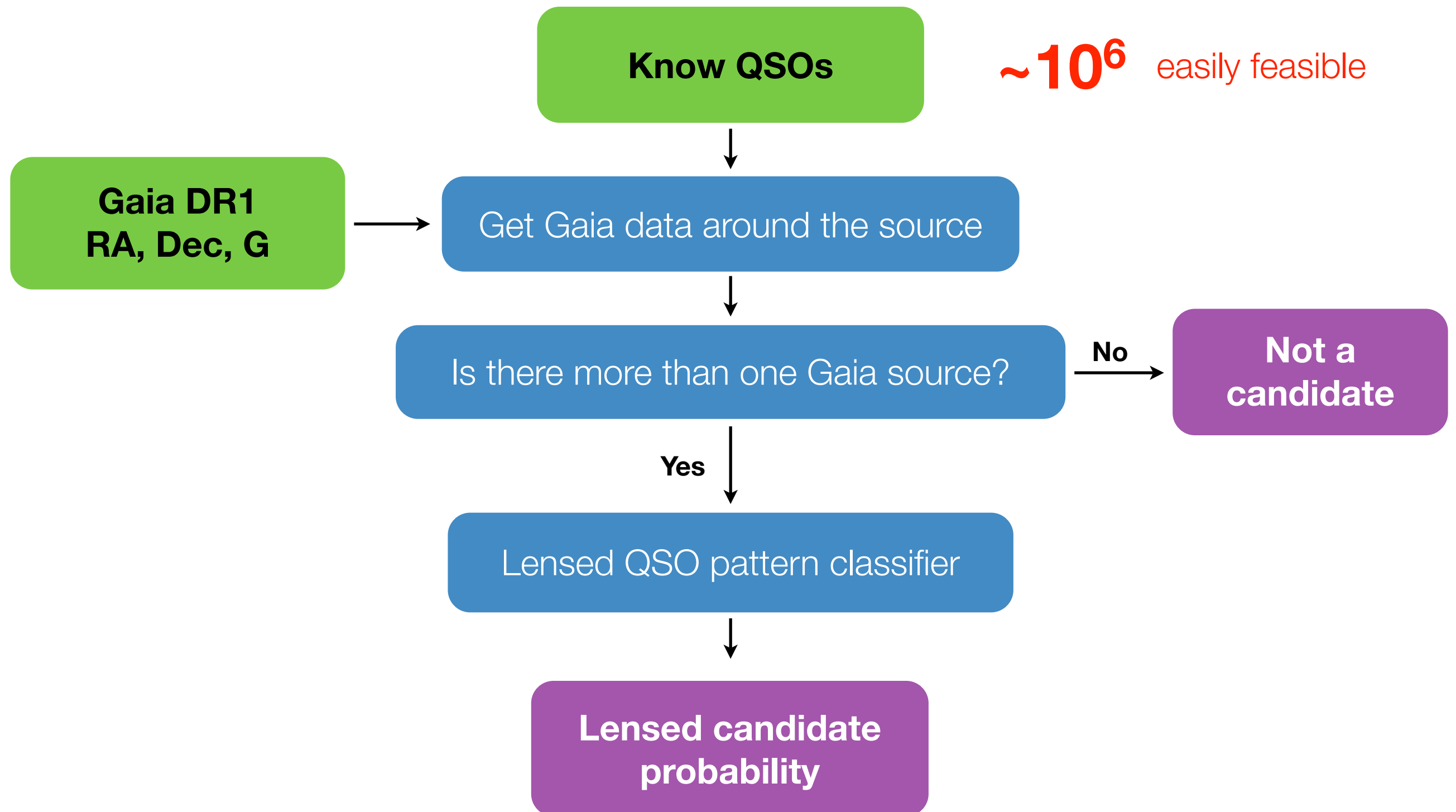Lensed QSO pattern classifier

Lensed candidate probability

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- Well...

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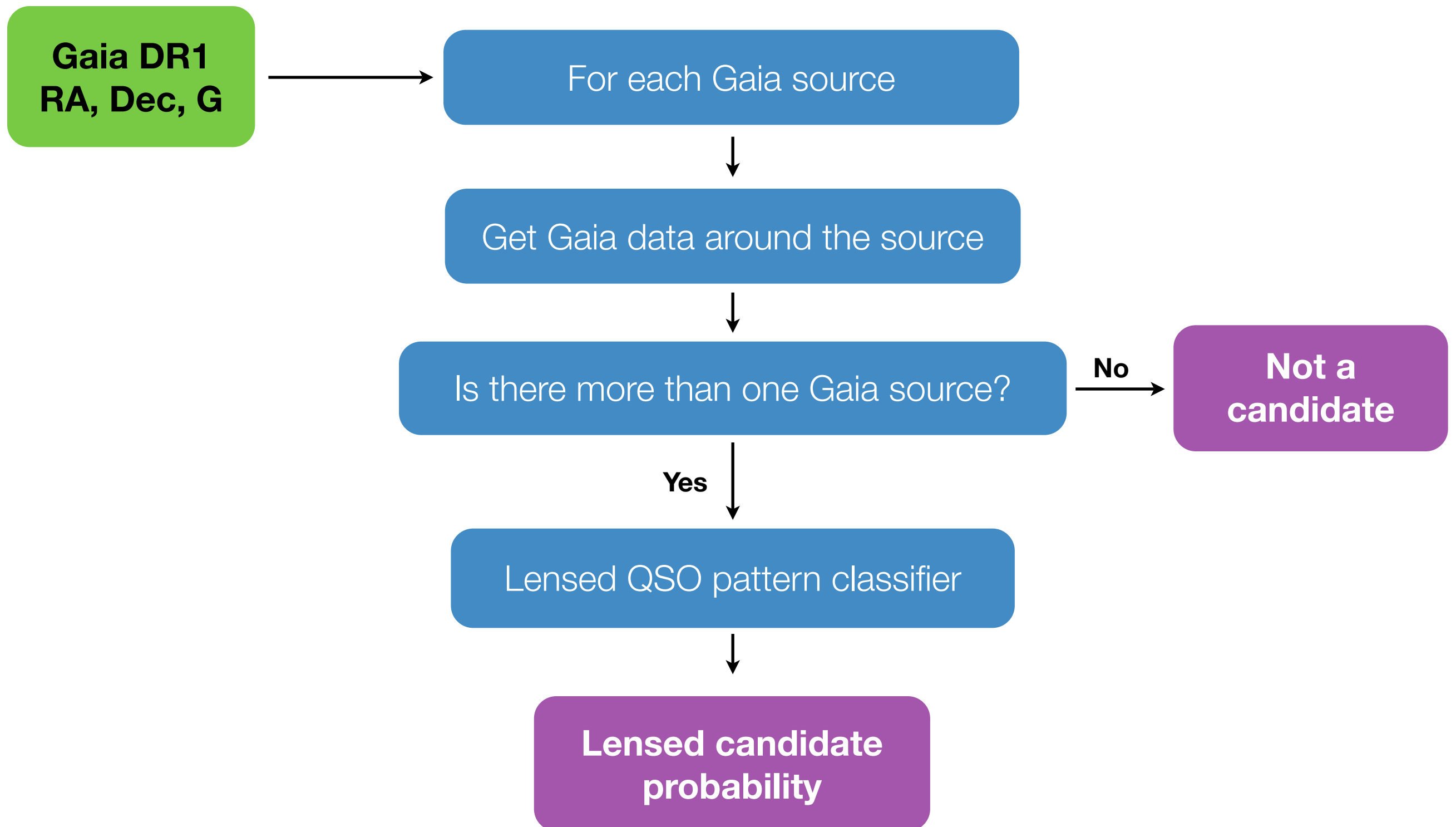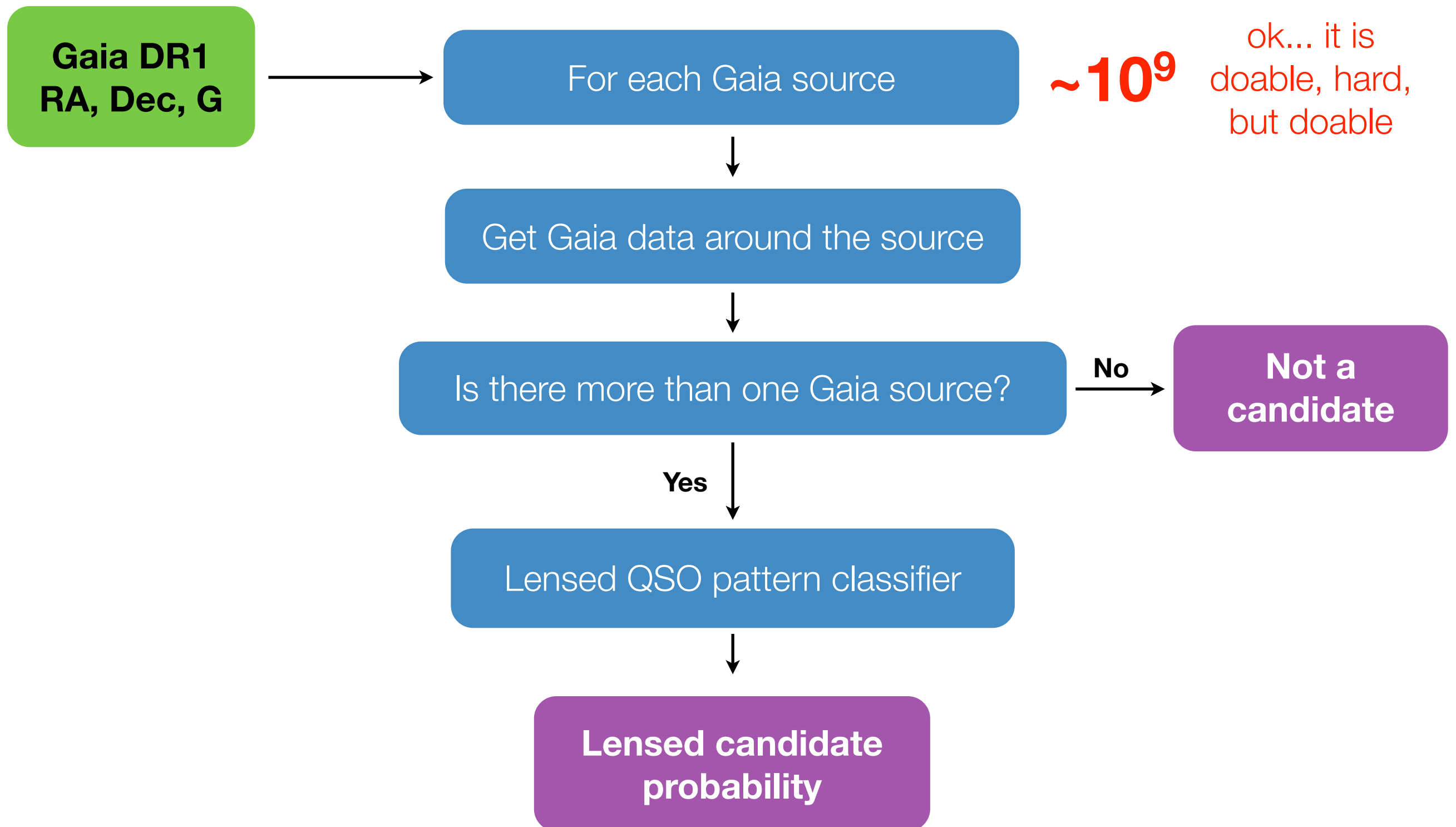
- But... there is no classification!

  - What to do? Two strategies...

    - First, **check all known QSOs** and verify if in Gaia data they split into multiple point sources, and if they do, if they fit into a lens pattern;

    - Second, **check all Gaia detections that contains neighbours** and check if they fit into a lens pattern.

Donc...

- Check all Gaia sources for nearby companions; **Efficiently doable at the public Gaia Archive level**

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  - But we can also do it efficiently by using Trees...

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- Perform a joint classification to separate the lenses from line-of-sight projections and other cases;

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  - Computer Science taught us that there are efficient supervised and semi-supervised machine learning methods out there... e.g. Random Forests, SVMs, transductive-SVMs, NNs, etc.

Donc...

- Check all Gaia sources for nearby companions;

- Perform a joint classification to separate the lenses from line-of-sight projections and other cases;

  - Computer Science taught us that there are efficient supervised and semi-supervised machine learning methods out there... e.g. Random Forests, SVMs, transductive-SVMs, NNs, etc.

Ok... so, lets check how well a "naive" supervised method would deal with the issue...

Classifying the lenses - Random Forests

Definition 1.1. A random forest is a classifier consisting of a collection of tree-structured classifiers $\{h(\mathbf{x}, \Theta_k), \ k = 1, \ldots\}$ where the $\{\Theta_k\}$ are independent identically distributed random vectors and each tree casts a unit vote for the most popular class at input $\mathbf{x}$.
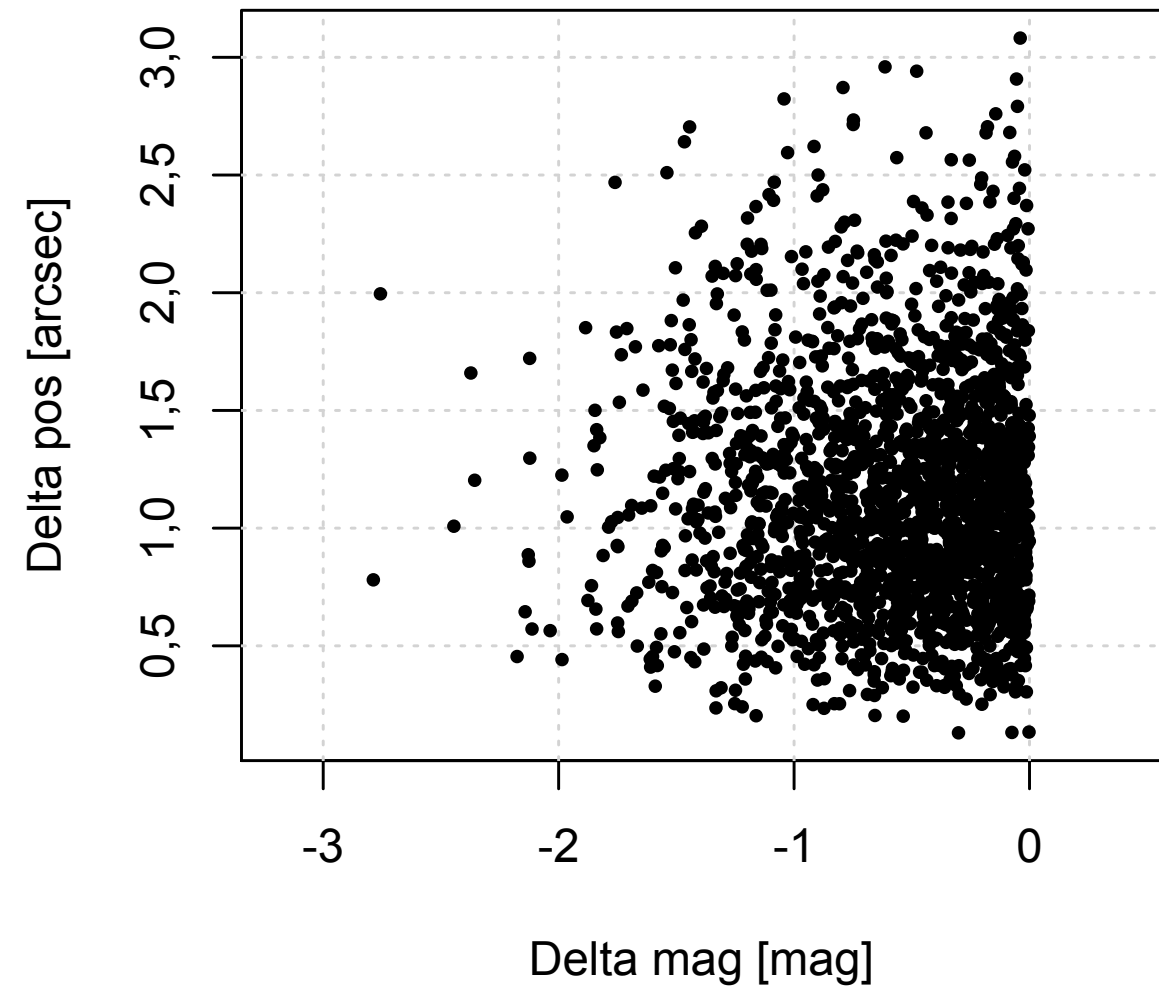
Breiman, L., Machine Learning, 45, 5-32, 2001

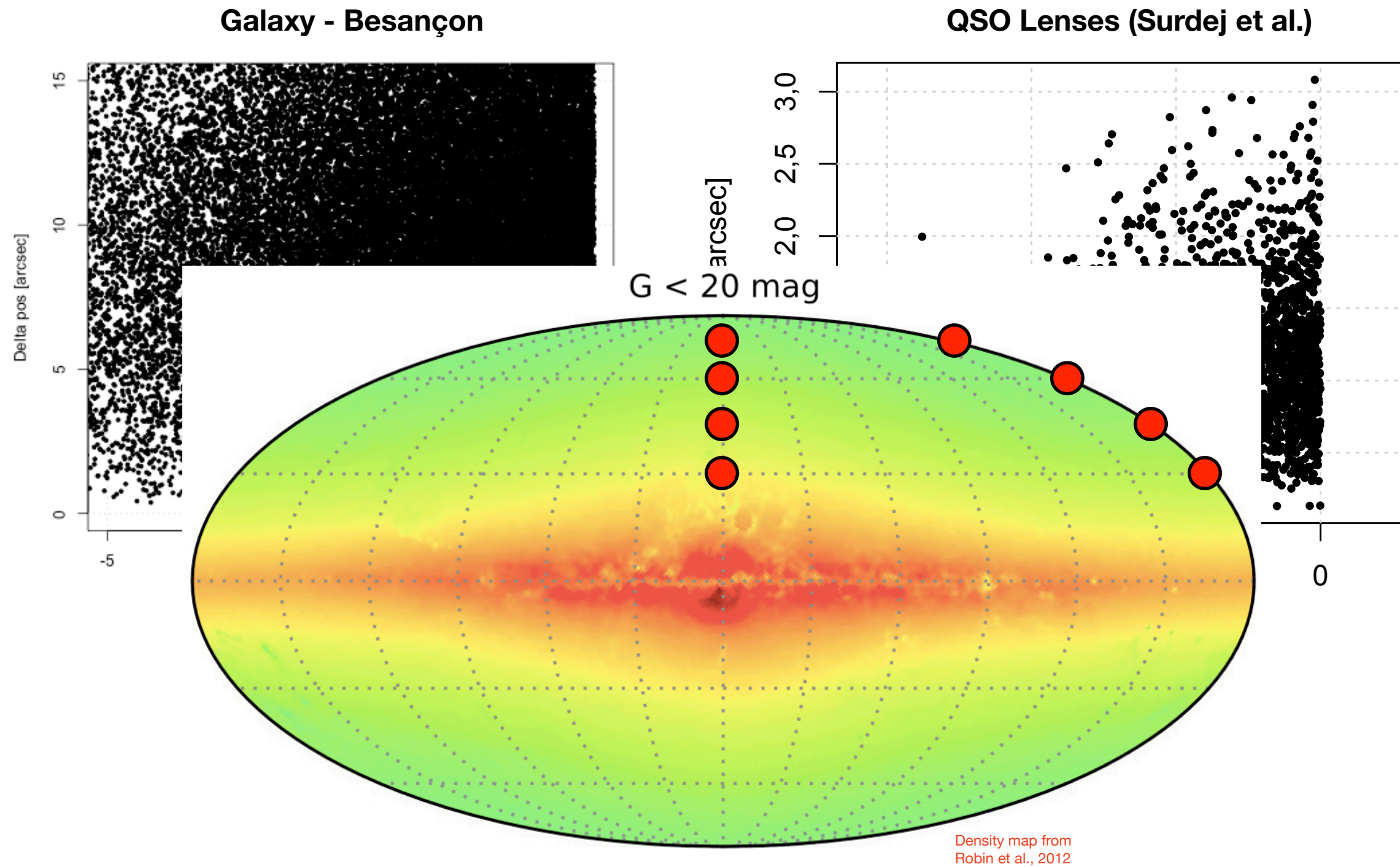# Simulated data - DR1 parameter space

Galaxy - Besançon
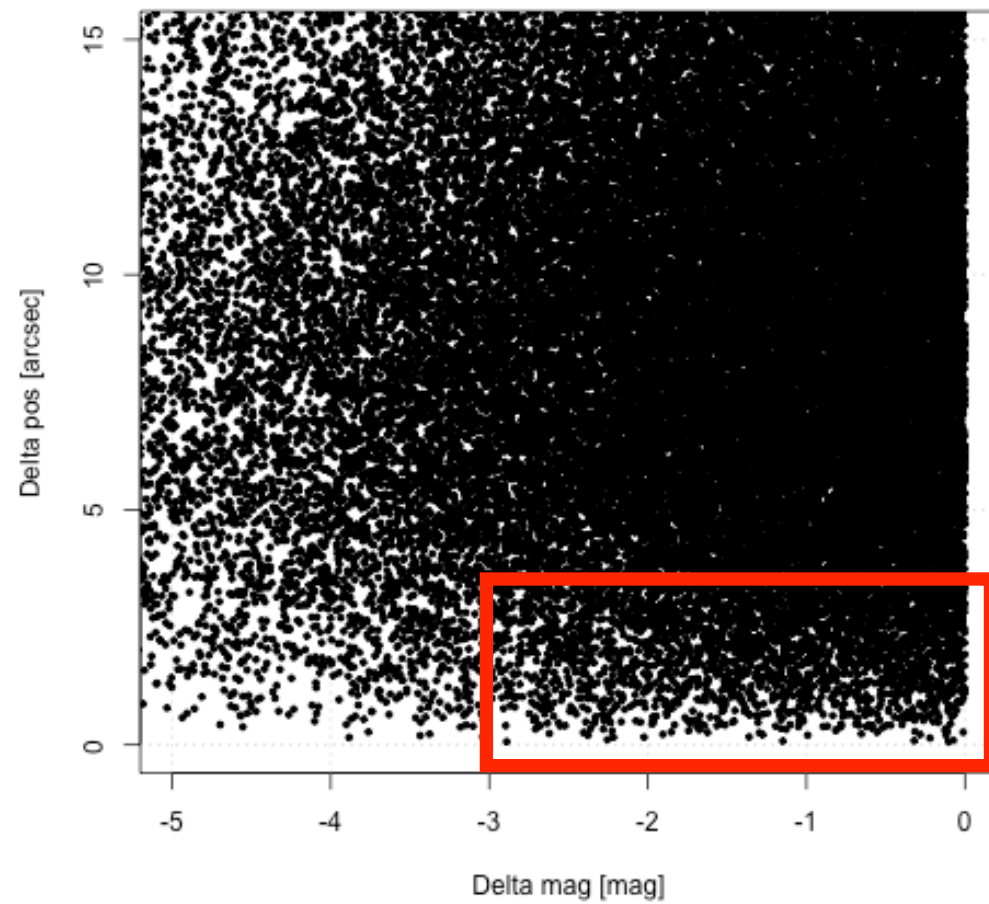
QSO Lenses (Surdej et al.)
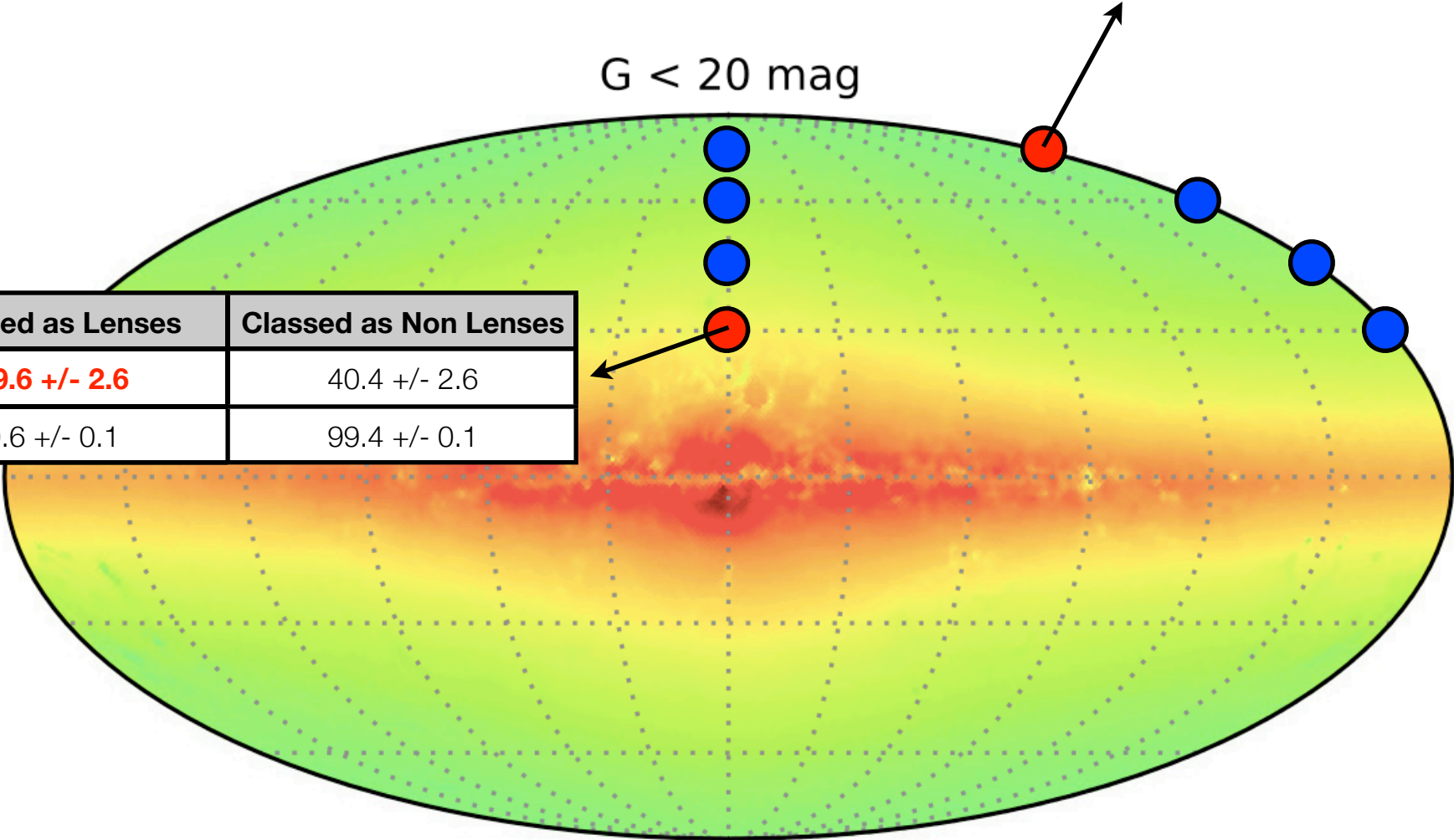
Simulated data - Gaia Universe Model + Lenses

Galaxy - Besançon

QSO Lenses (Surdej et al.)

G < 20 mag

Density map from
Robin et al., 2012

Simulated data - Random Forest Classifications

- Confusion matrices

	Classed as Lenses	Classed as Non Lenses
True Lenses	**99.7 +/- 0.2**	0.3 +/- 0.2
True Non lenses	0.2 +/- 0.1	99.8 +/- 0.1

G < 20 mag

	Classed as Lenses	Classed as Non Lenses
True Lenses	**59.6 +/- 2.6**	40.4 +/- 2.6
True Non lenses	0.6 +/- 0.1	99.4 +/- 0.1

# Simulated data - Random Forest Classifications

- Confusion matrices

	Classed as Lenses	Classes as Non Lenses
True Lenses	**99.2 +/- 0.6**	0.8 +/- 0.6
True Non lenses	0.3 +/- 0.1	99.7 +/- 0.1

	Classed as Lenses	Classed as Non Lenses
True Lenses	**99.7 +/- 0.2**	0.3 +/- 0.2
True Non lenses	0.2 +/- 0.1	99.8 +/- 0.1

	Classed as Lenses	Classed as Non Lenses
True Lenses	**93.8 +/- 1.6**	6.2 +/- 1.6
True Non lenses	0.4 +/- 0.1	99.6 +/- 0.1

	Classed as Lenses	Classed as Non Lenses
True Lenses	**59.6 +/- 2.6**	40.4 +/- 2.6
True Non lenses	0.6 +/- 0.1	99.4 +/- 0.1

	Classed as Lenses	Classed as Non Lenses
True Lenses	**97.1 +/- 1.5**	2.3 +/- 1.5
True Non lenses	0.3 +/- 0.1	99.7 +/- 0.1

G < 20 mag
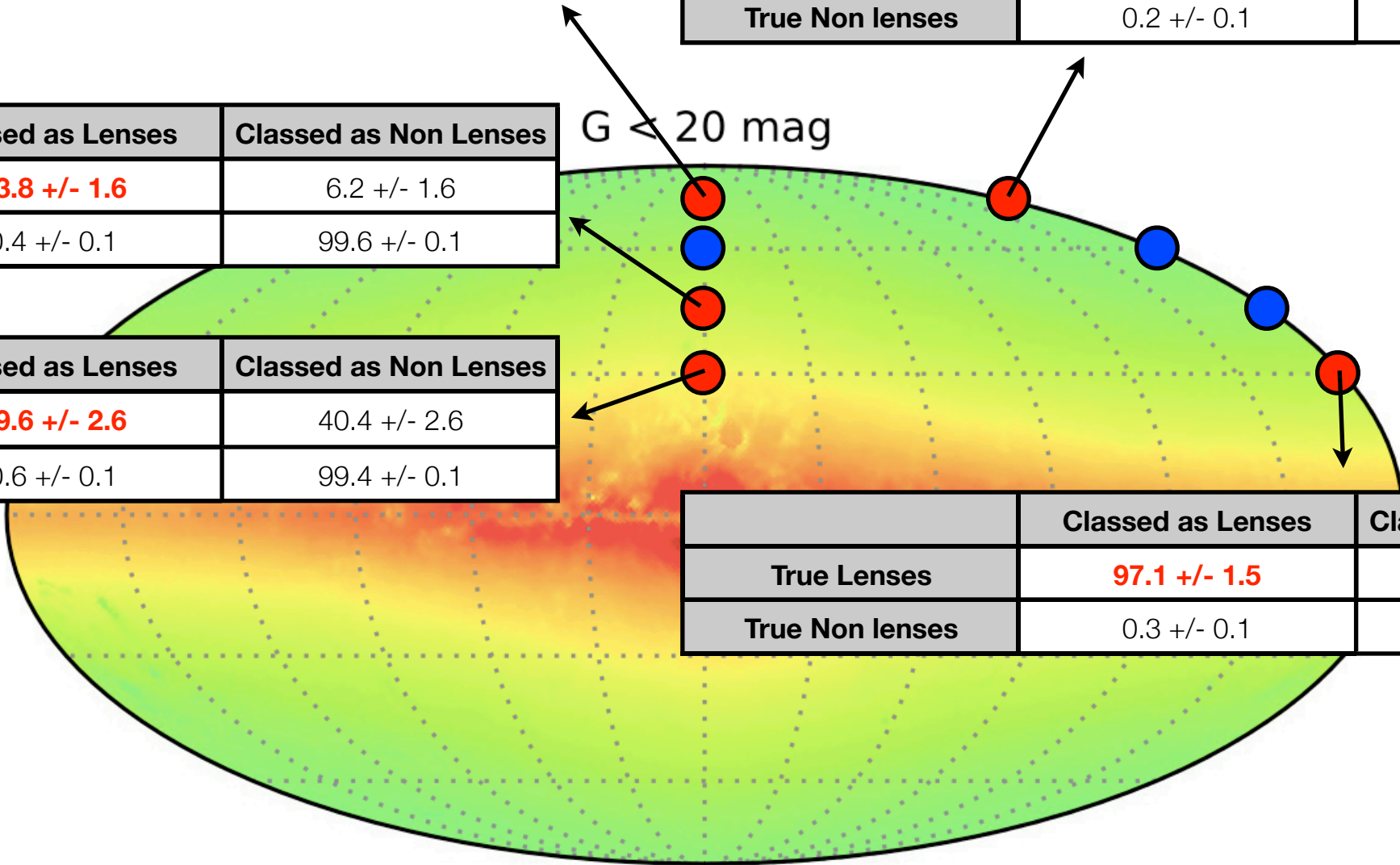
Conclusions

- Gaia will provide the first all-sky, exhaustive survey of lensed QSOs;

- It is detecting the known lensed QSOs that are already known;

- DPAC will very likely provide a flag to indicate lensed QSOs at the last Data Release using all information contained in Gaia measurements;

- A first, preliminary method, to create catalogues of candidate lensed QSOs from the first Gaia public Data Release was developed and was tested with simulations, showing encouraging results.

Thanks!