GRAVITATIONAL LENSES IN GAIA

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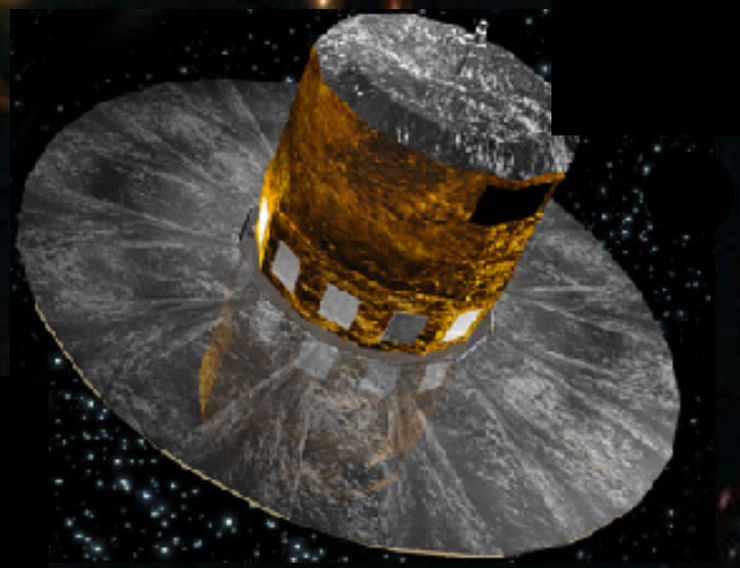


ORIGINS OF THE PROJECT

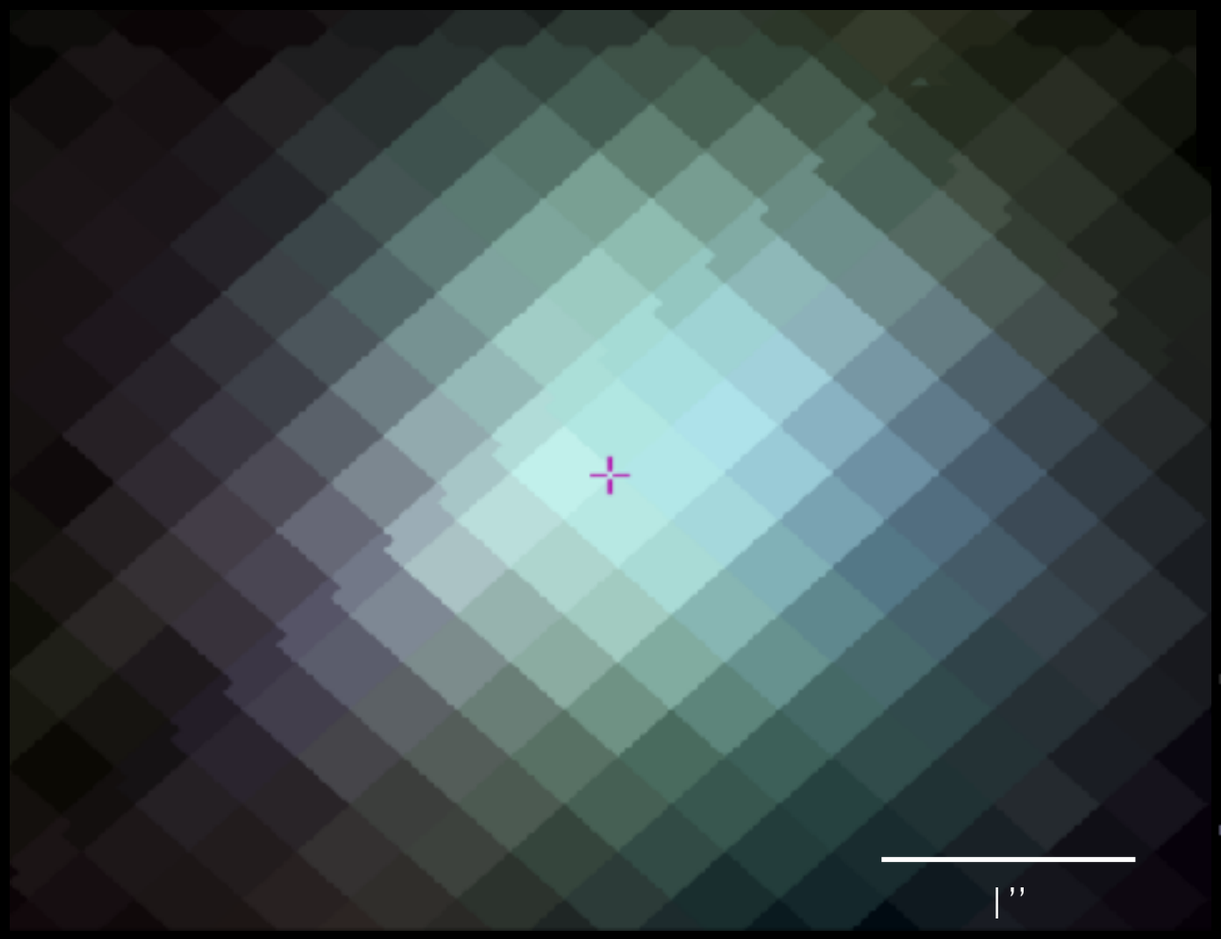
Firenze - CU4 meeting- 2013

Gaia observes many extragalactic objects
(1 M Galaxies + 0.5 M QSOs)

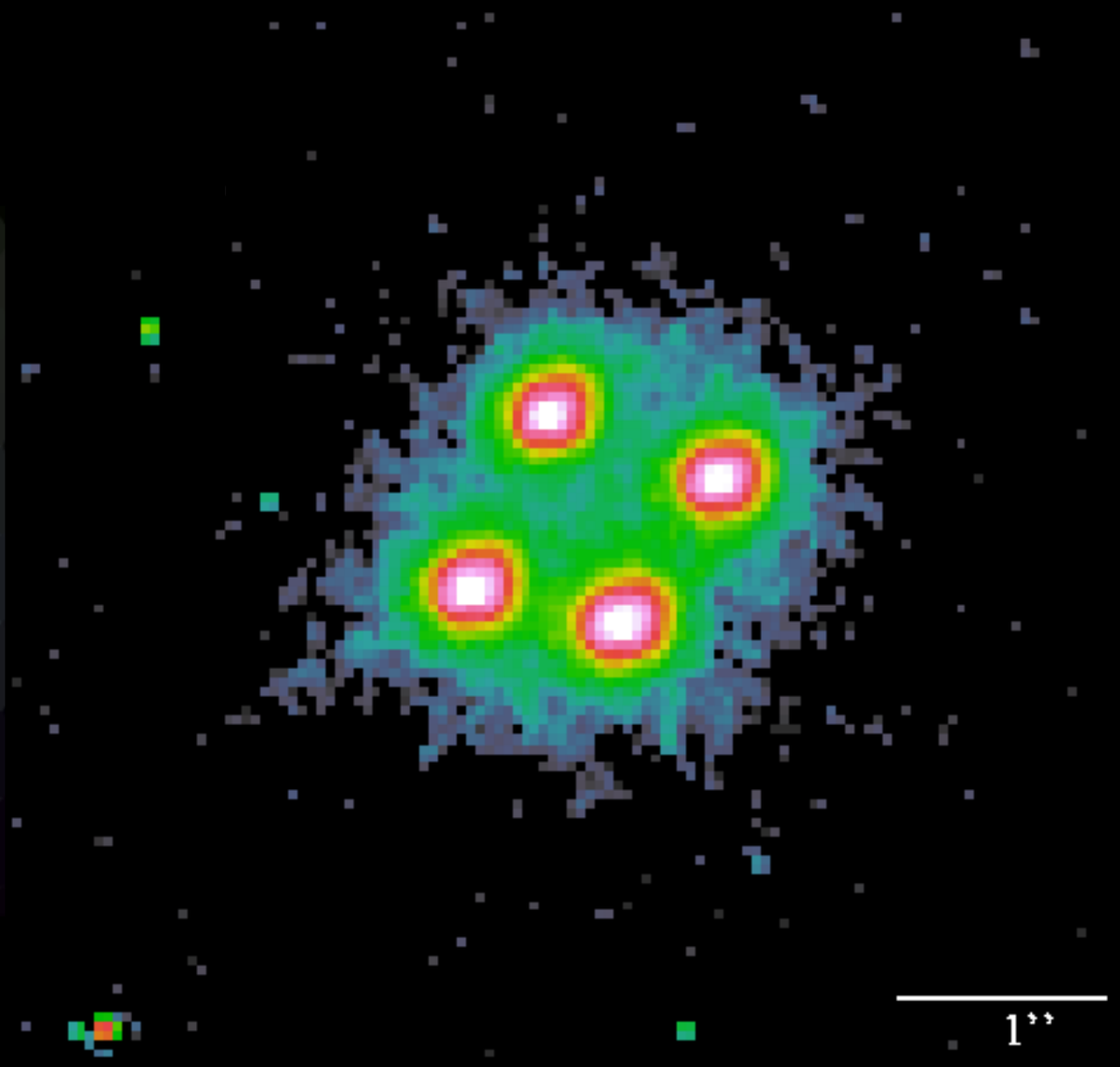
Although designed for the Milky Way content, it is the **first all-sky survey from space** of **gravitational lenses** (GL) with the acuity of **unprecedented resolving power!**

Gravitational Lenses in Gaia

H1413+117
From Ground (SDSS9)



H1413+117
From space (HST)

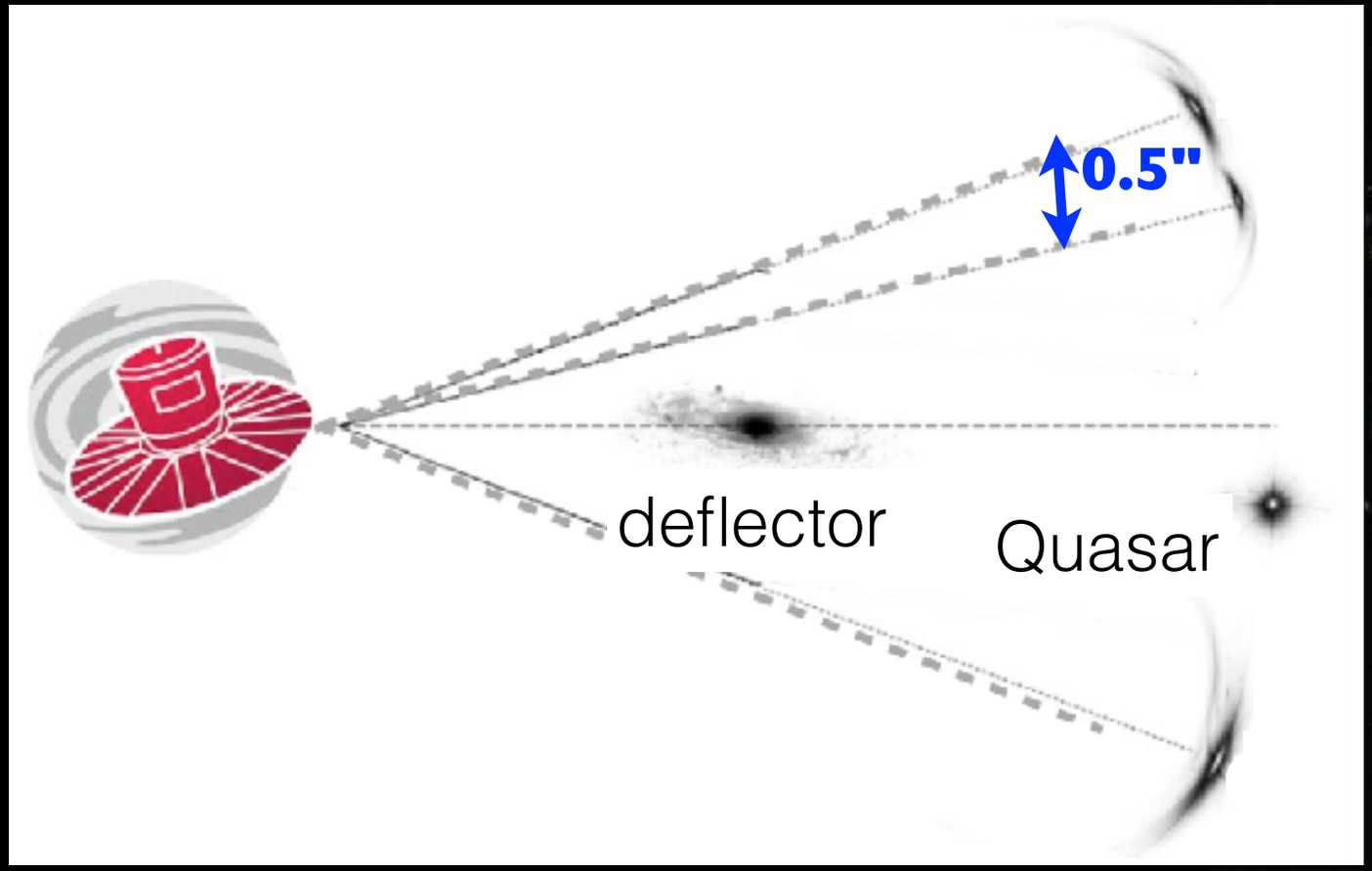


Credit : Castles database, HST images

Gravitational Lenses in Gaia

- Depending on deflecting galaxy population **100 - ~1000 lensed quasars in Gaia**
- Most cases : 2 images, few 3 or 4 images, no arc!
- ~100 known today

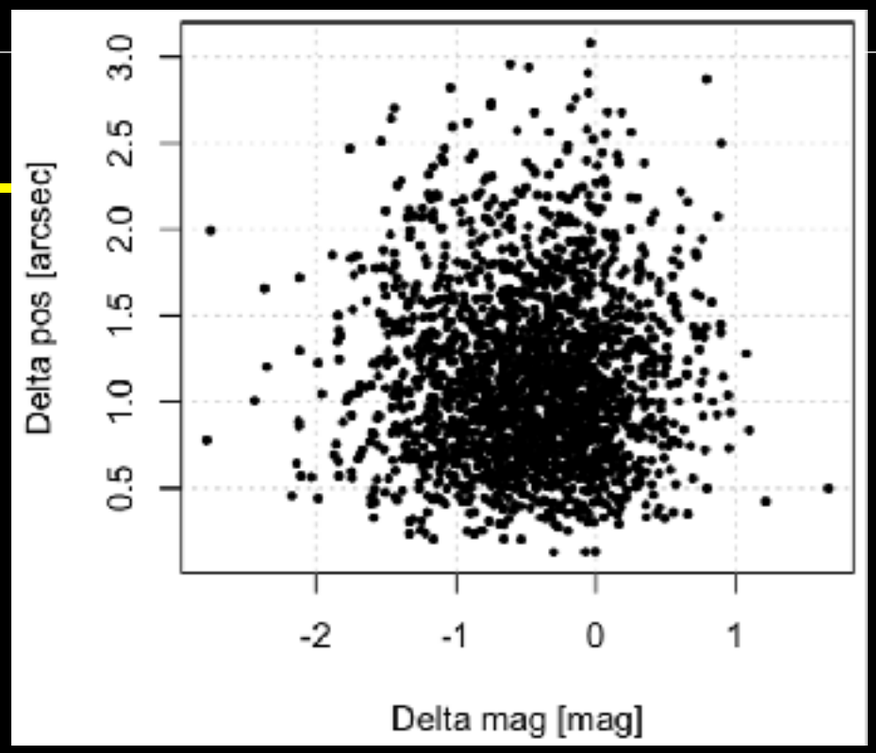
➡ Counts will bring independent constraints on cosmological parameters H_0, Ω_0, λ_0, mass distribution of the galaxy lenses…

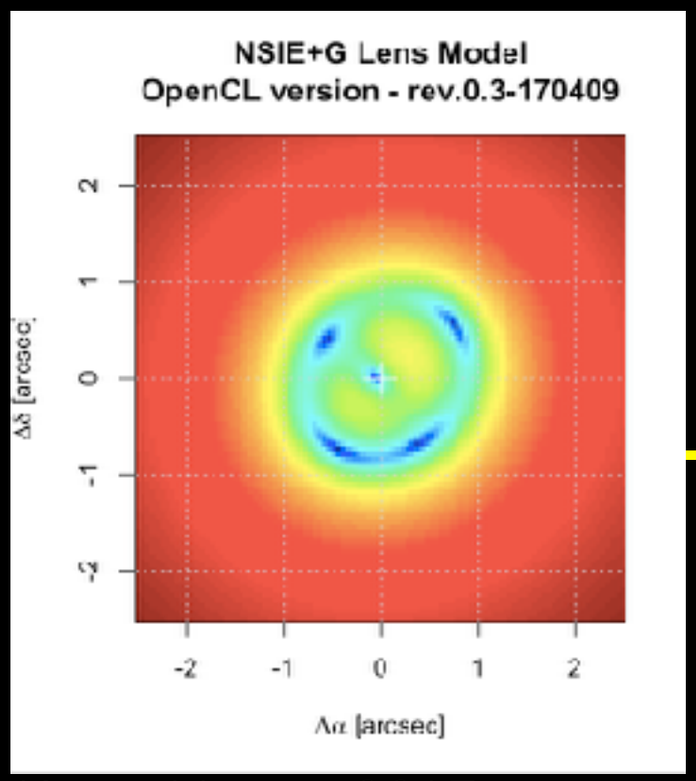


Surdej et al. 2010

Detection of lenses, how ?

Specific (Δmag,Δpos)

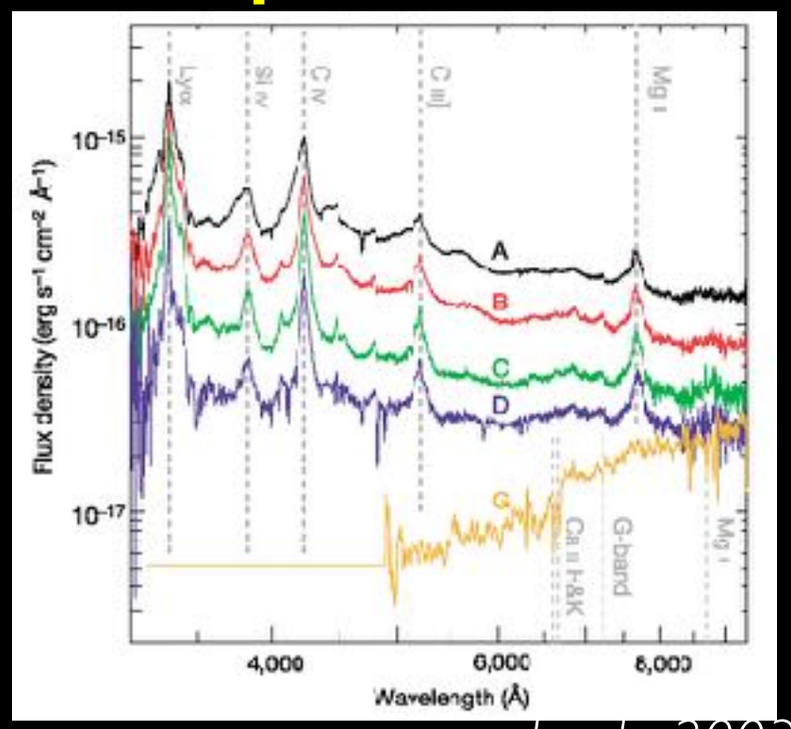




Krone-Martins 2017

Specific patterns

Same colour/spectra



Inada 2003

Strategy

1 - Look for known lenses

Updated Database
DR1 + Gaia observations (IDT/IDU)

2 - Search around known quasars

Automatic search for optical projections around quasars

3 - Blind search in Gaia DR1

Search for lens configurations in DR1 (Δmag, Δpos)
Modeling of the detected candidate lenses

1 - Known Lenses : a new database

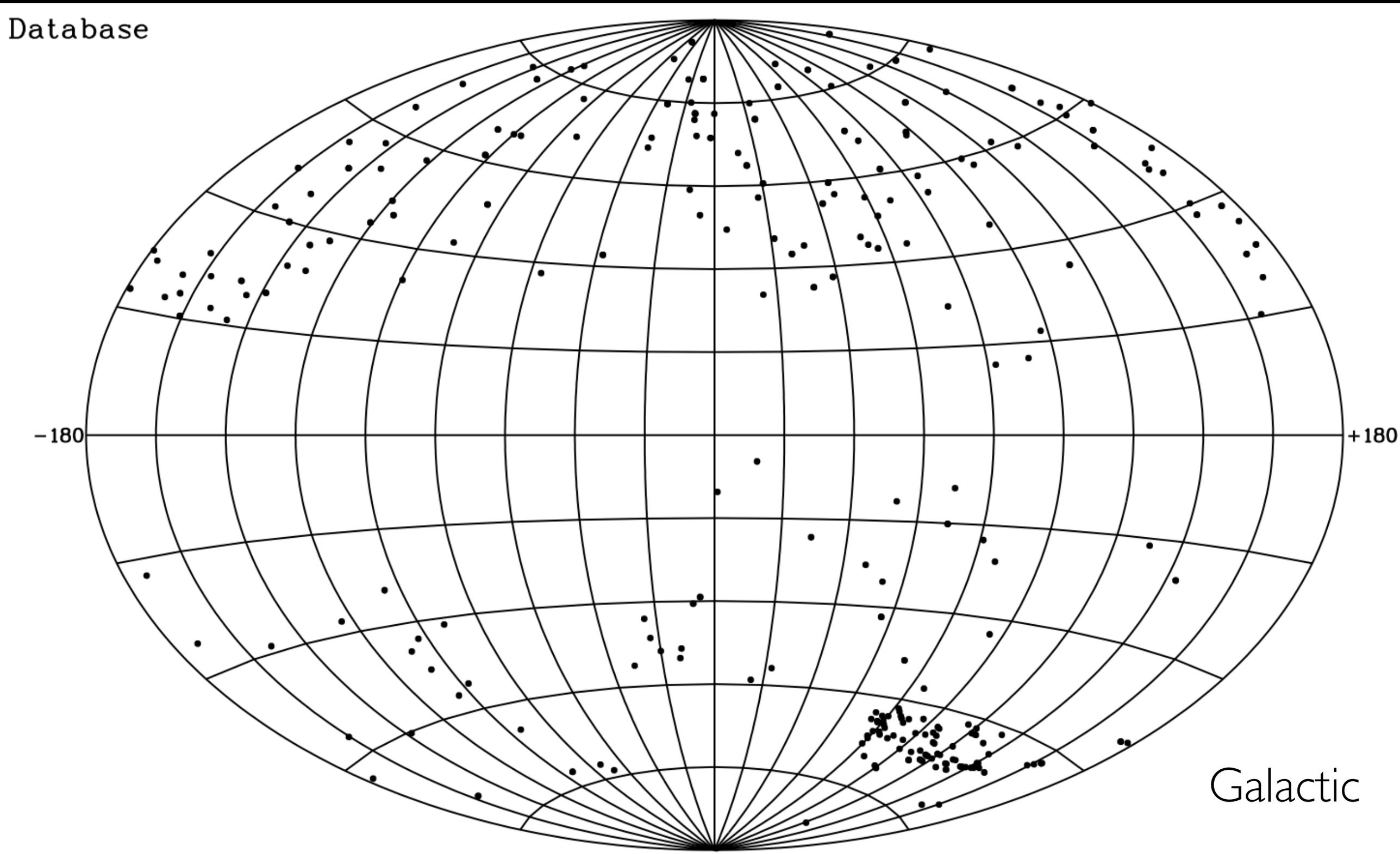
- ➡ **Castles** (https://www.cfa.harvard.edu/castles/),
  - HST images (same resolution as Gaia) , 100 lenses+18 bin quasars (<2006)
- ➡ **SQLS** (http://www-utap.phys.s.u-tokyo.ac.jp/~sdss/sqls/lens.html)
  - SDSS, 49 additional lenses (<2012) —> unresolved and resolved multi images
- ➡ **SDSS - III BOSS quasar lens survey**
  - 13 lensed quasars (2images) + 11 quasar pairs
- ➡ **others** (BELLS, DES, CASSOWARY,…)

➡ **276 lenses/candidates**

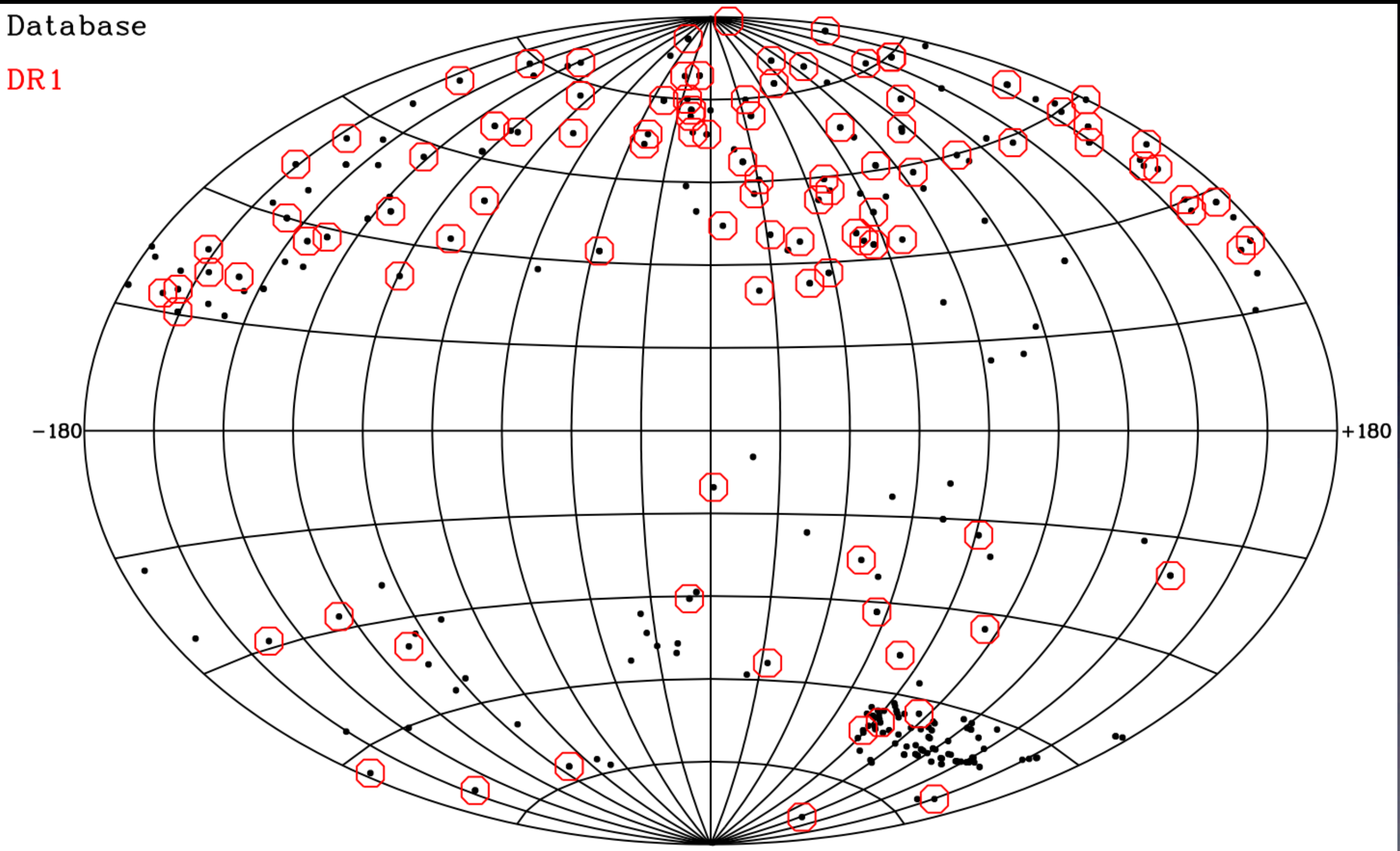
165 - with 1 component
90 - with 2 components
20 - with >= 3 components

Heterogeneous database with sometimes poor astrometry

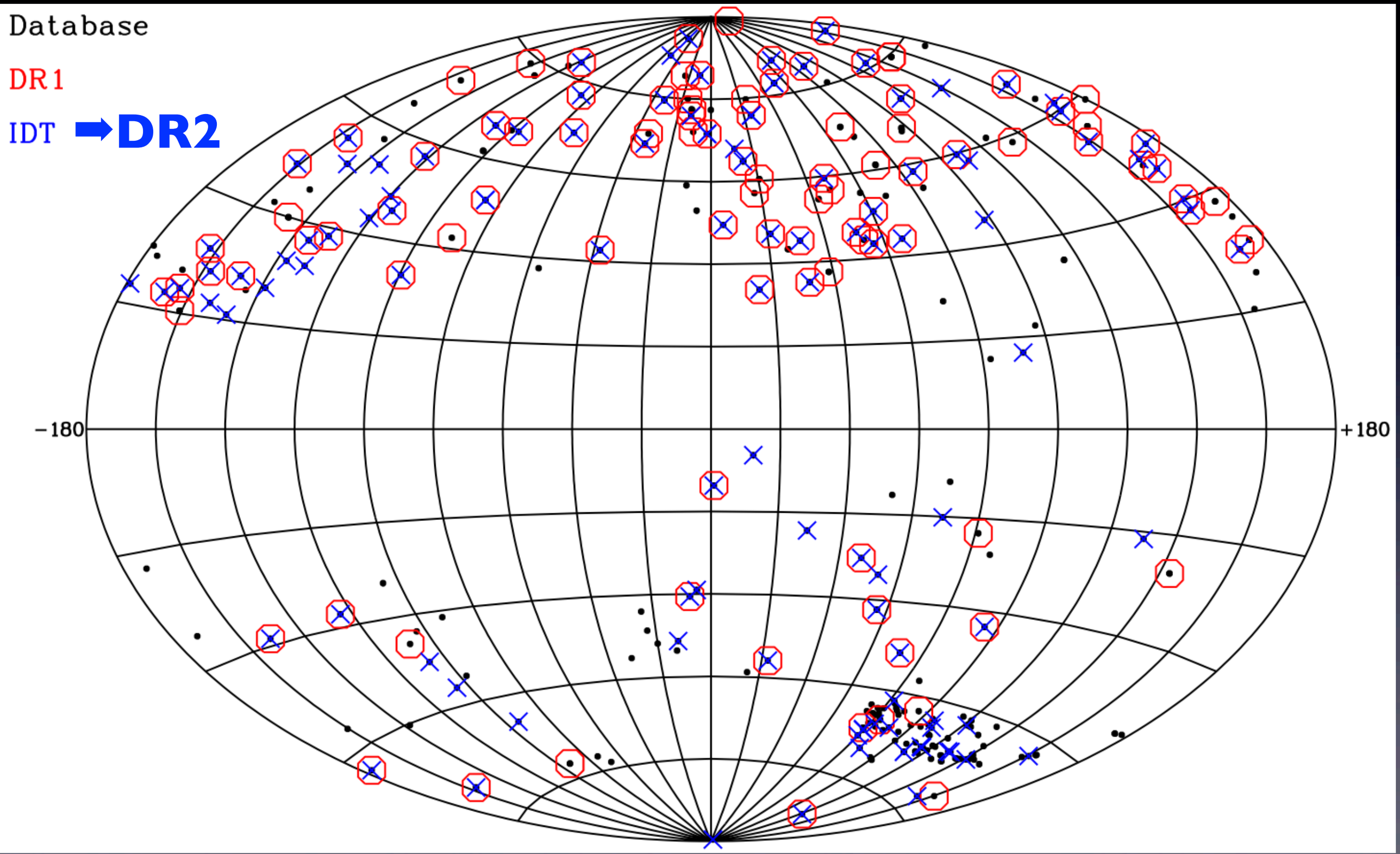
Sky coverage and detection

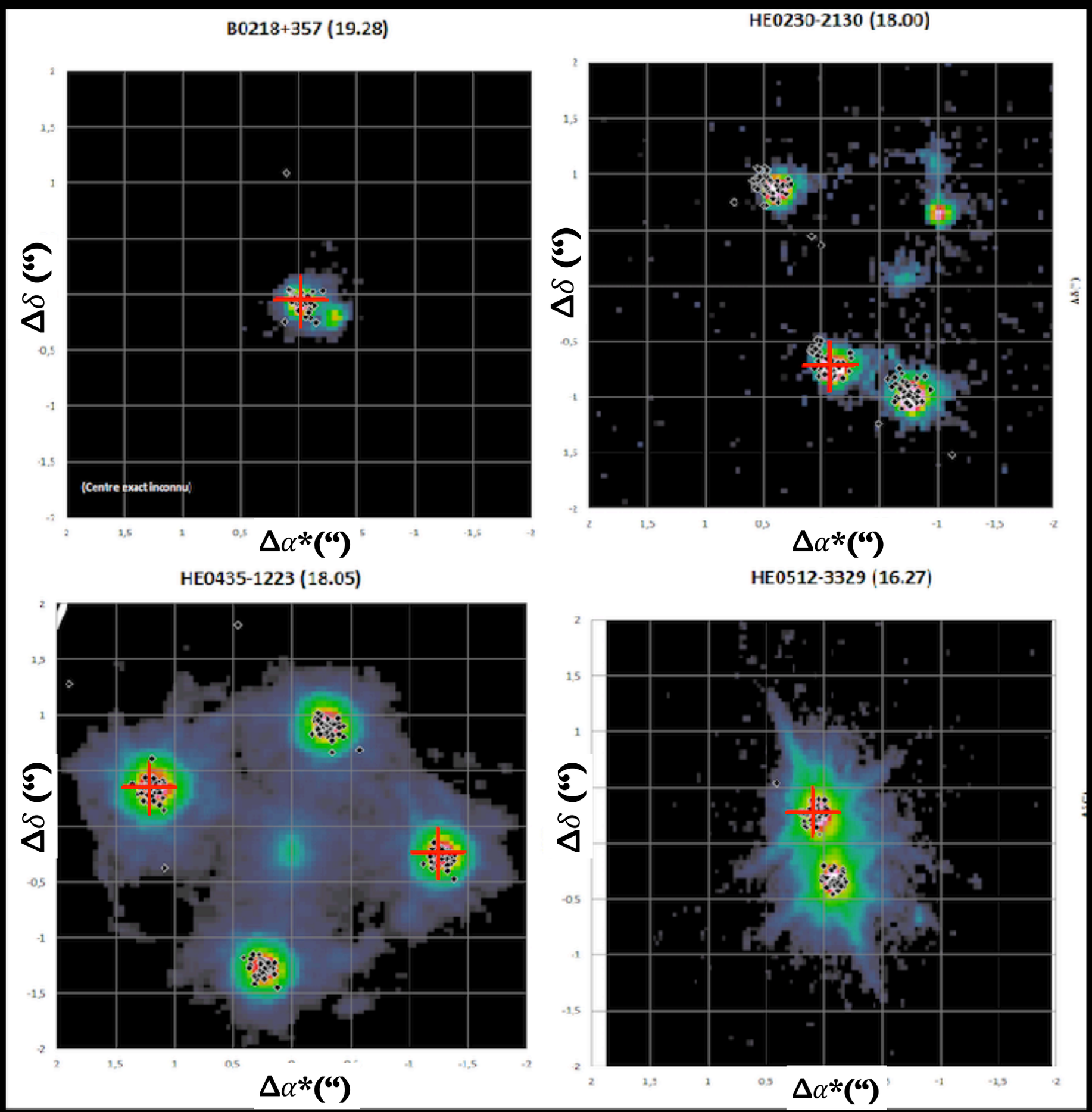


Sky coverage and detection



Sky coverage and detection



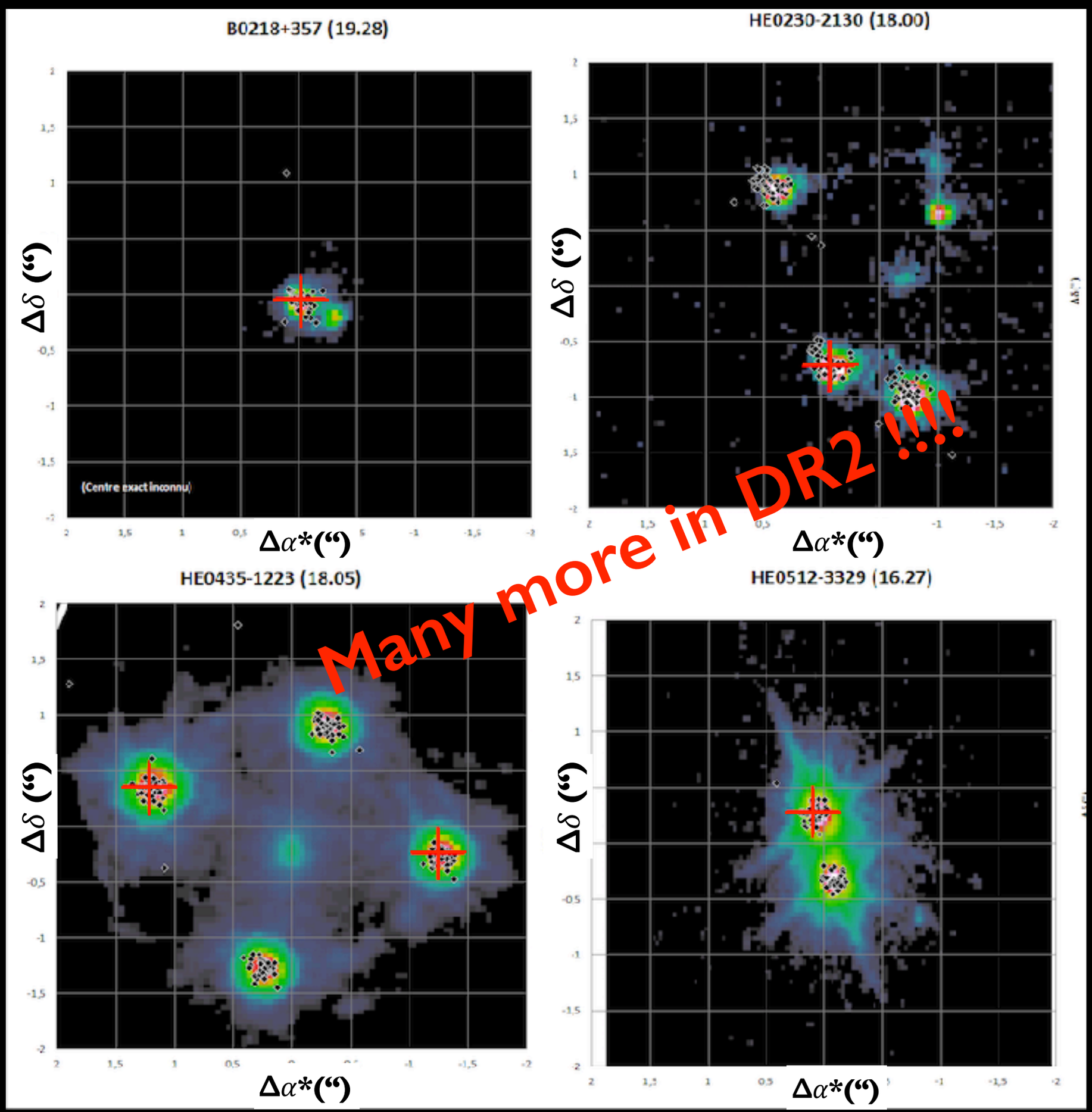


DR1

IDT mes.

HST images

Credit : Castles database, HST images



DR1

IDT mes.

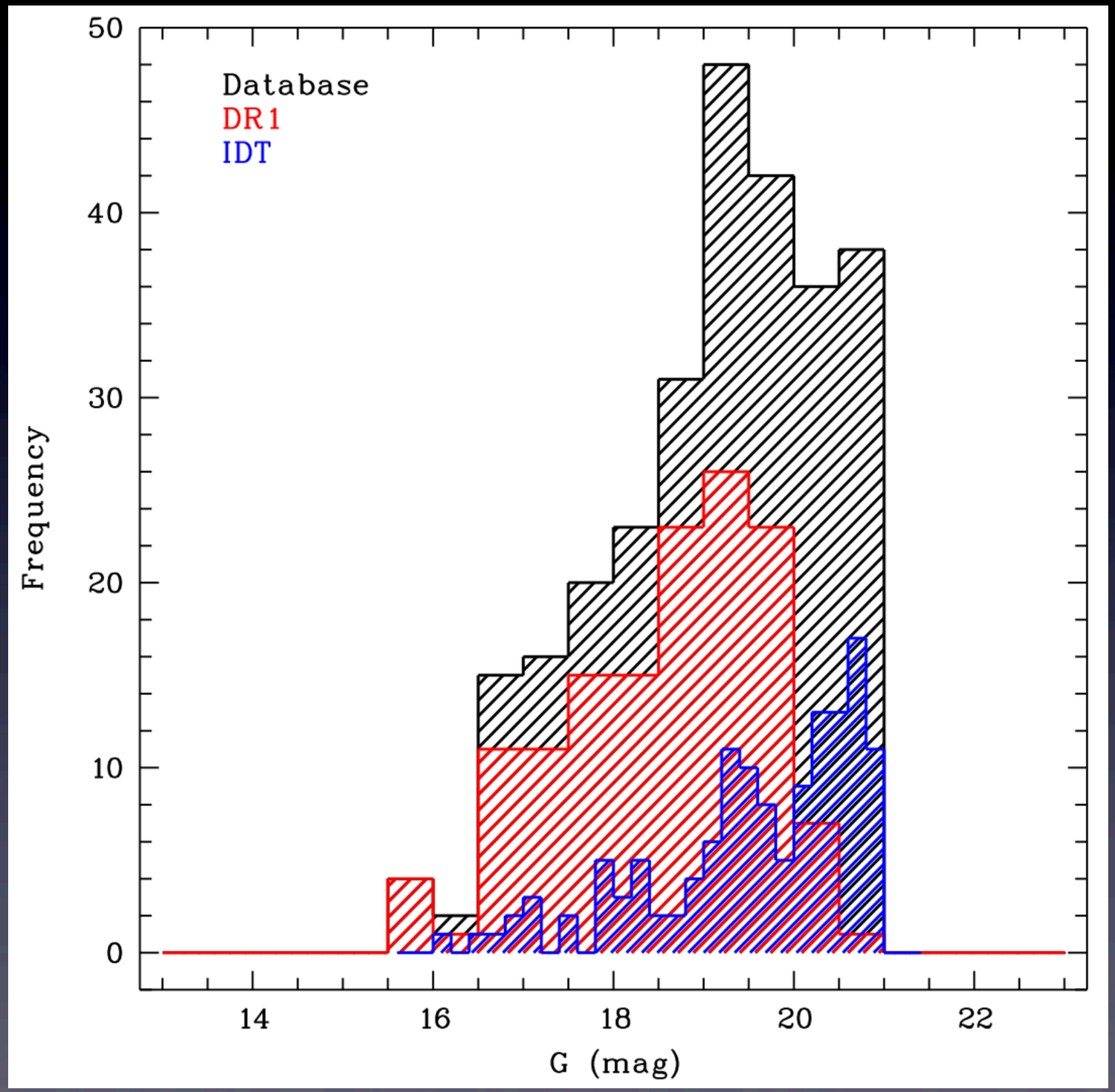
HST images

Credit : Castles database, HST images

G magnitude

Database : 276 lenses
Detection : 147
(not all components)

- 79 partially in DR1
- 68 only in IDT



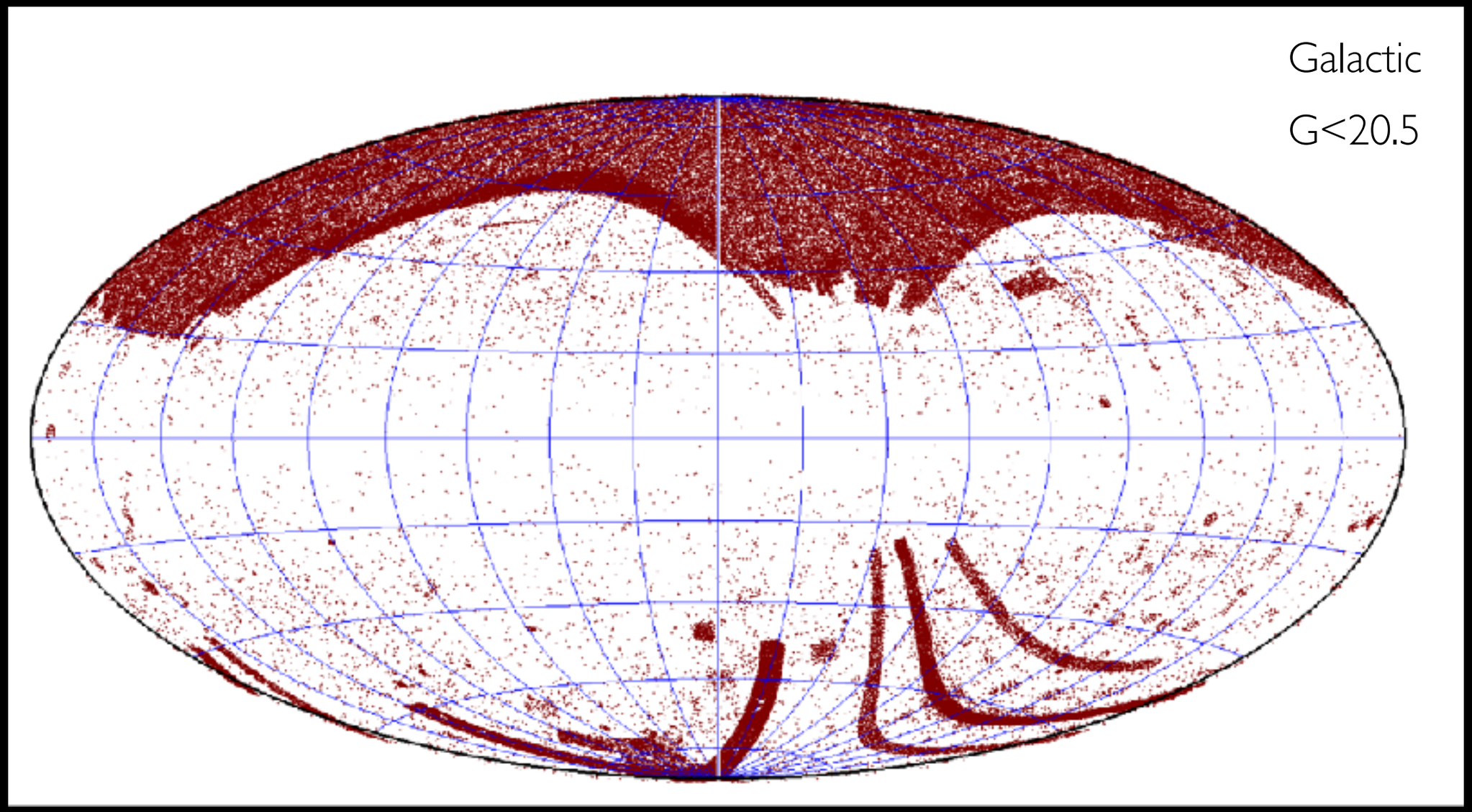
- **Reliable astrometry**
- **Expect many more in DR2**

2 - Automatic search around known quasars

➡LQAC3 : Large Quasar Astrometric Catalogue

(Souchay et al. 2015)

- 322 000 entries (Quasars, 14 000 AGNs, 1200 BL Lac)



Credit : F. Mignard, L. Galluccio

Mining and clustering Gaia observations

➡1 - Extraction of LQAC3 Quasars observations

- Explore 30 billions of Gaia transits
- 4.2 millions match with a LQAC source (< 3")

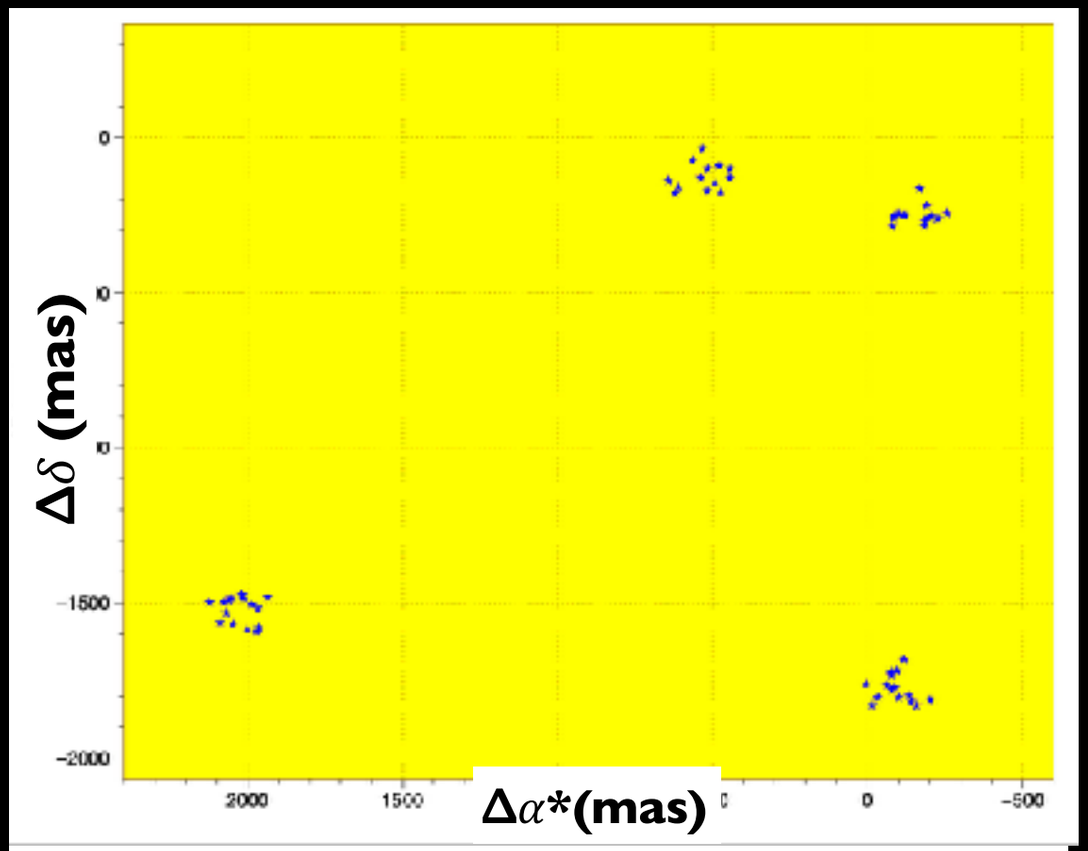
➡ **250,000** quasars detected (217 000 with 5+ observations)

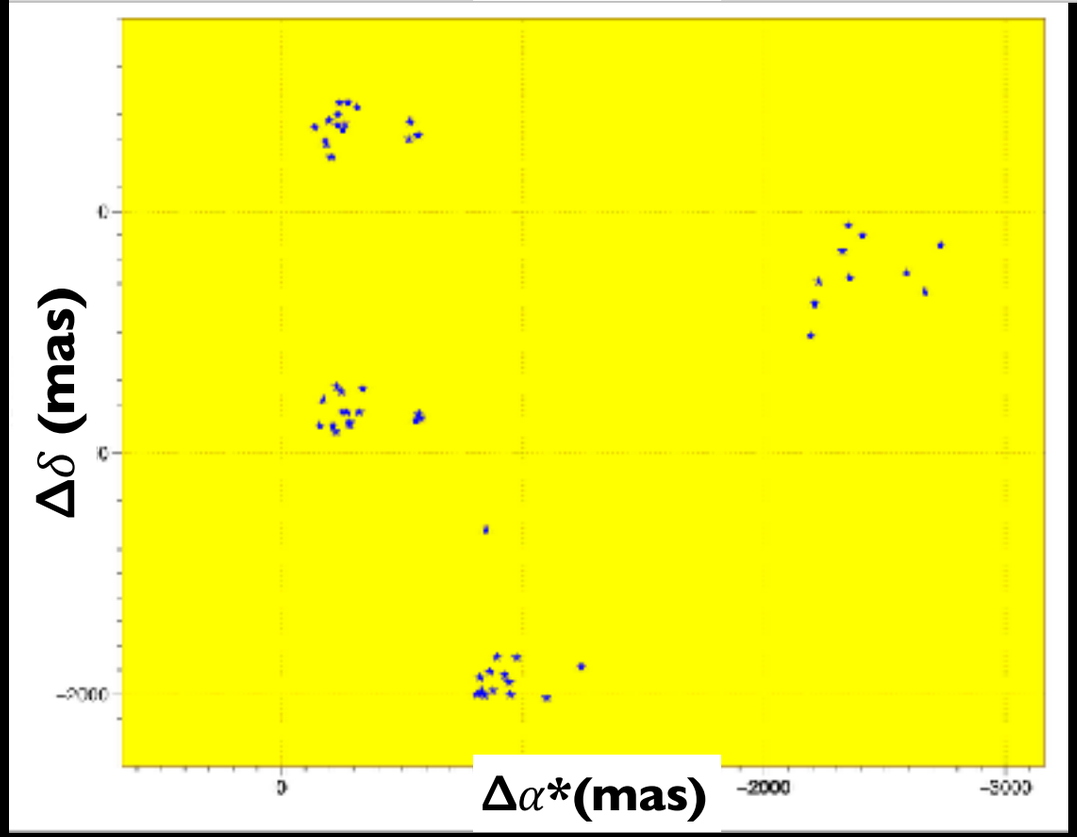
➡2 - Clustering analysis

- identify groups of points in the area (rad=3") = sources
- identify cluster of sources (incl. quasar)

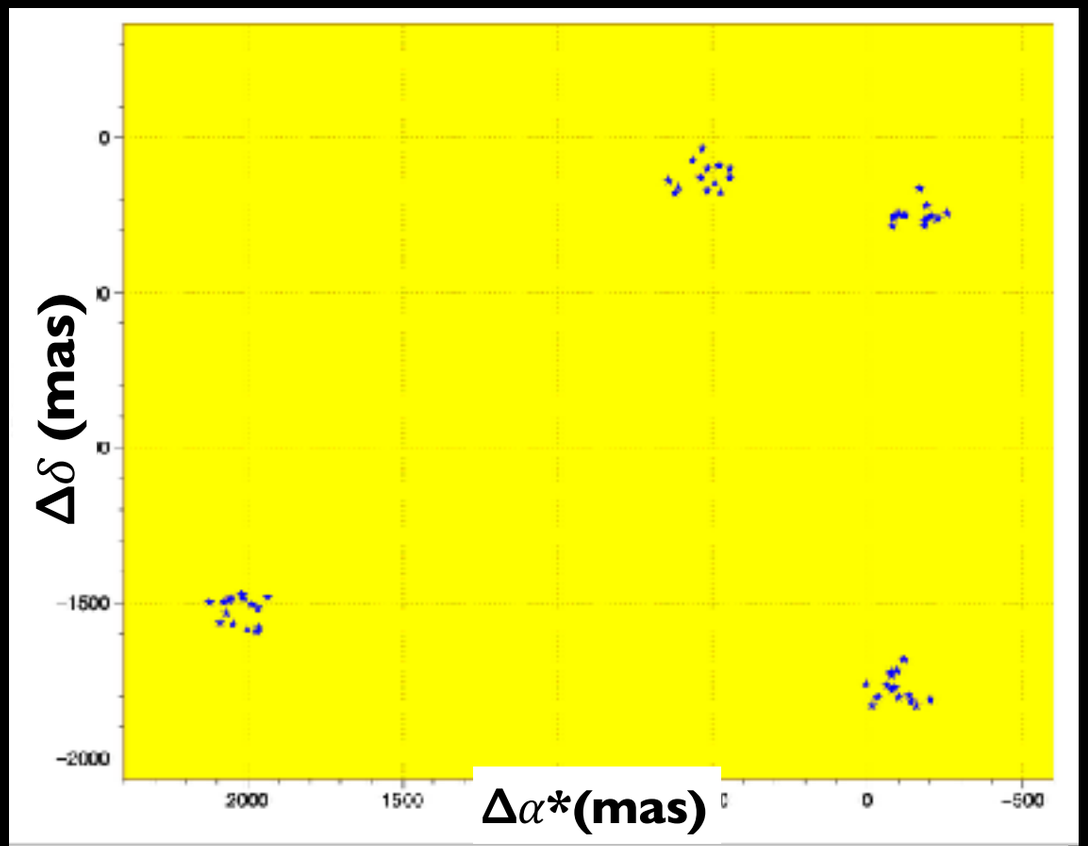
➡ unique source, no outlier, clustered	175,000	80%
➡ unique source, < 20% outliers	32,000	15%
➡ anomalous observations, large scatter	~ 2000	
➡ 2 point sources	**~ 1300**	
➡ 3 sources	**~ 70**	
➡ >= 4 point sources or images	**10**	

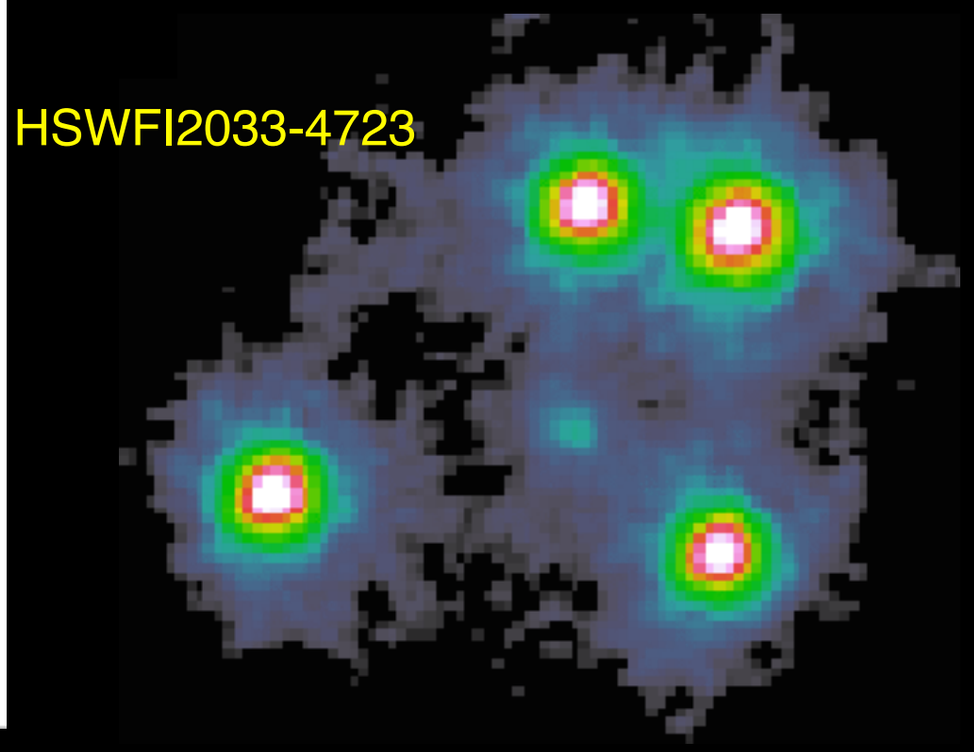
4 images configurations

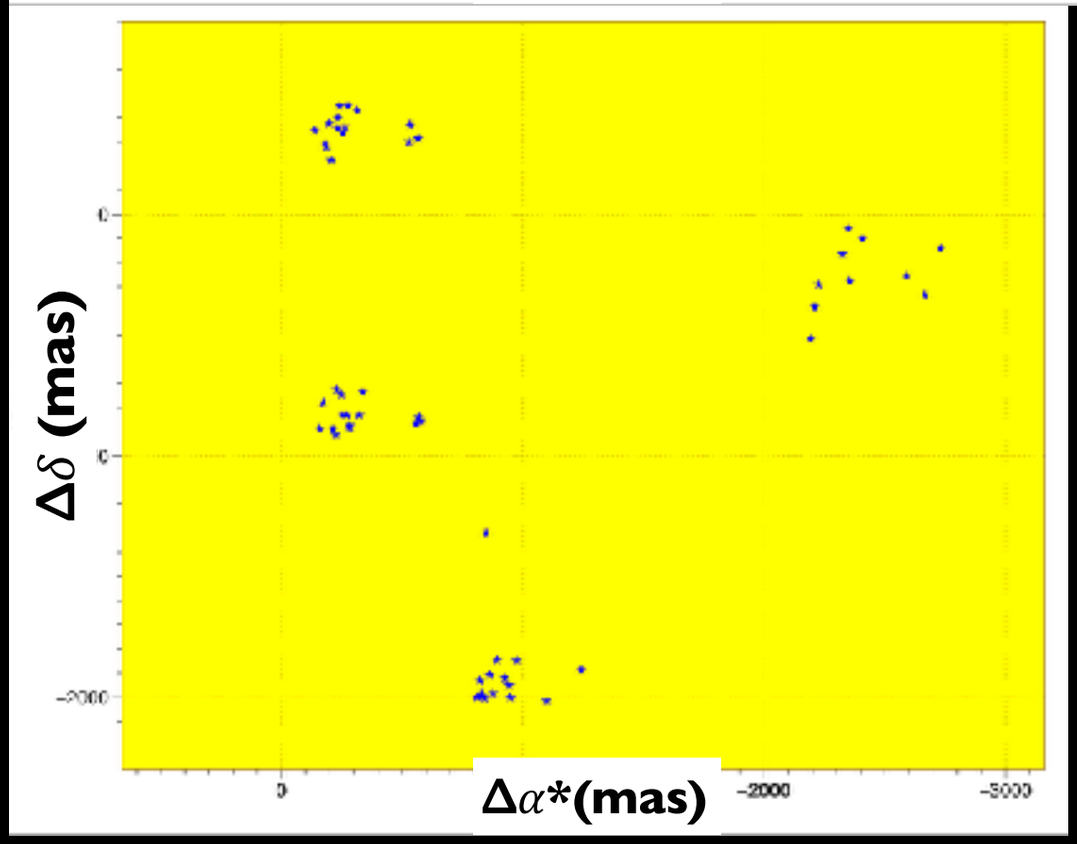


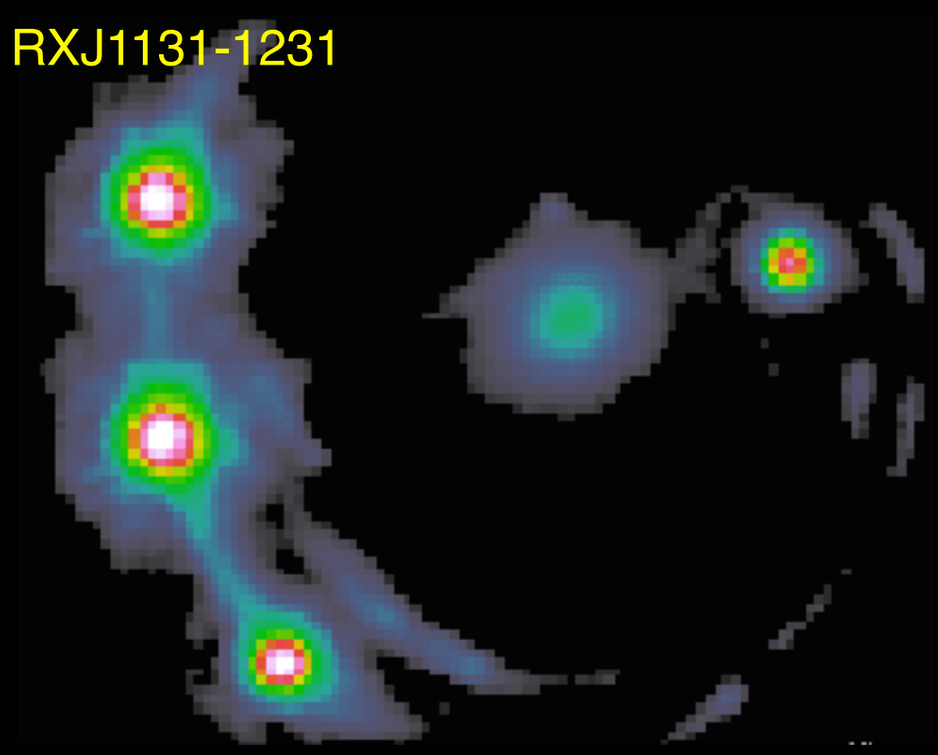


4 images configurations

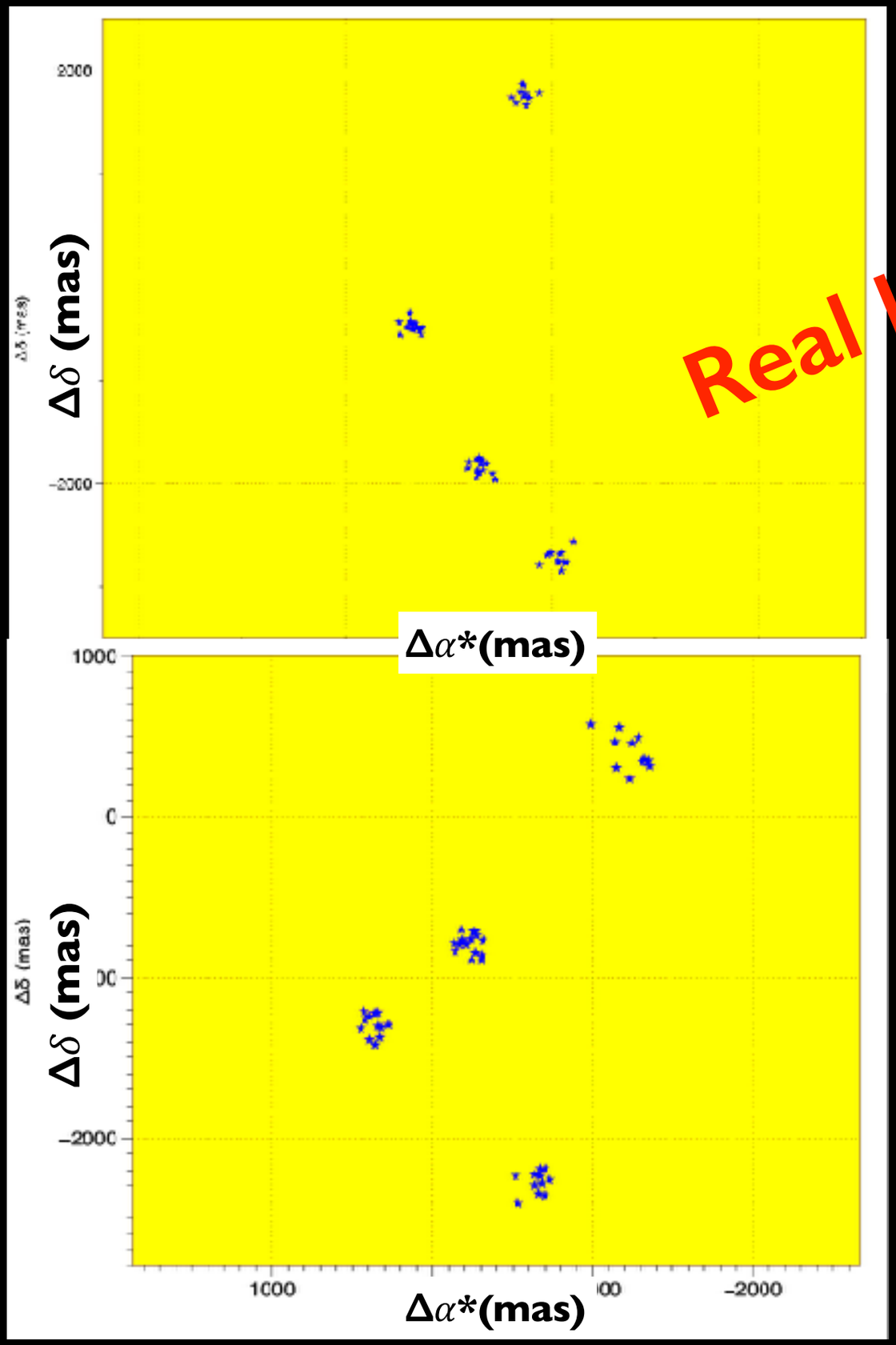








Others 4 images configurations



Real lenses ?

- **Good Candidates :**
  - **29 (3 or 4 components, <4")**
  - **39 (2 components, <1" high galactic latitude)**
- **Necessity to validate the new candidates with :**
  - 1 - Gaia photometry
  - 2 - Lens modelling

➡ **Wait for DR2**

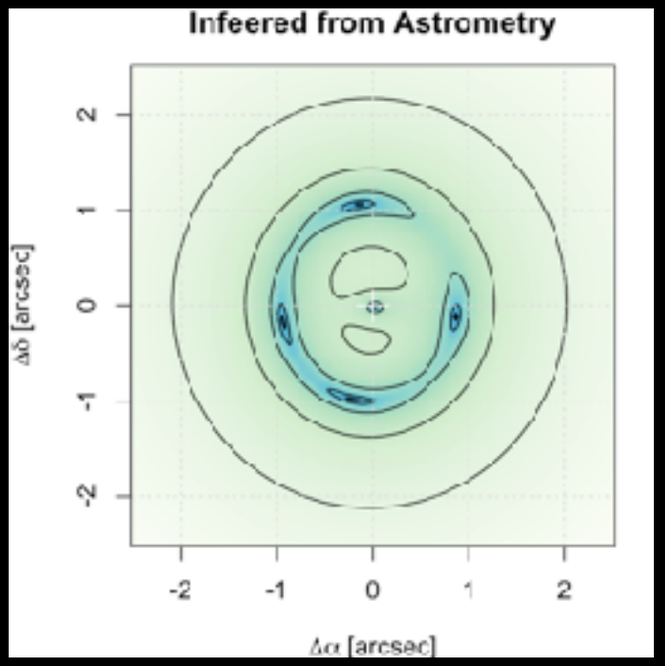
3 - Automatic blind Detection in Gaia DR1

SELenA : Systematic Exploration of Lenses from Astrometry

- An “intelligent” and adaptable framework (kd-trees + machine learning based classifier + lens direct model) for searching lenses in **astrometric** catalogues.
- Can consider *additional* constrains: *photometry, spectroscopy, time-series, ...*

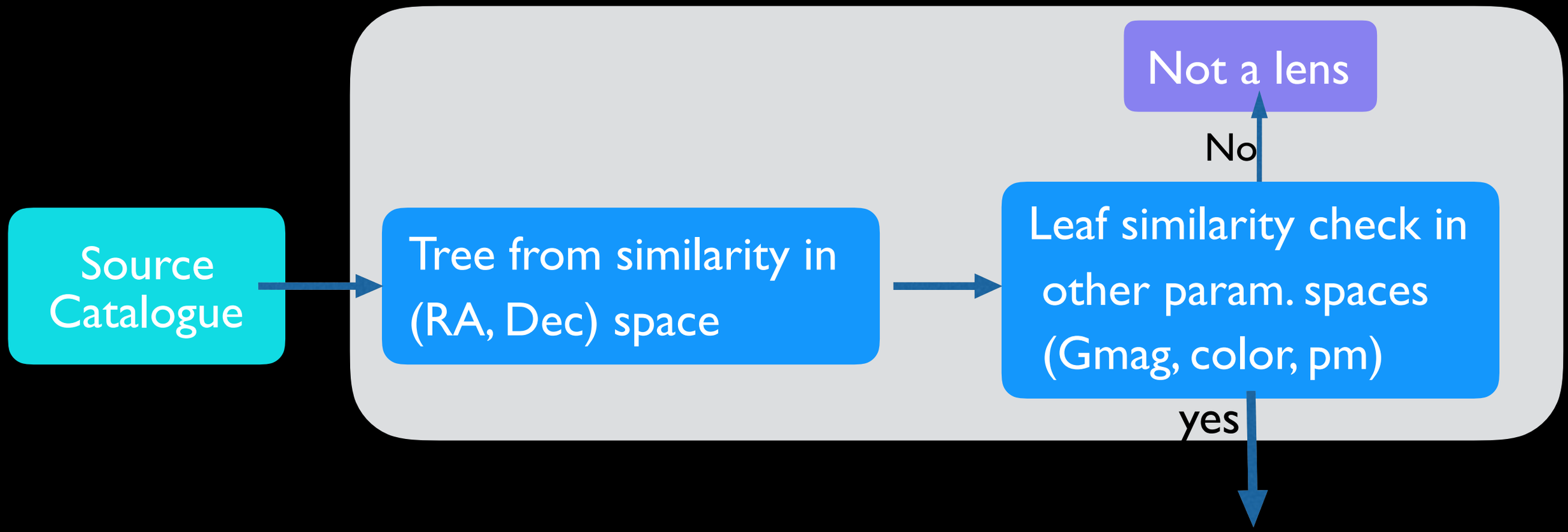
Dedicated UV30 machine in São Paulo
(Gaia DR1 in memory + SSD disks)

Archiue

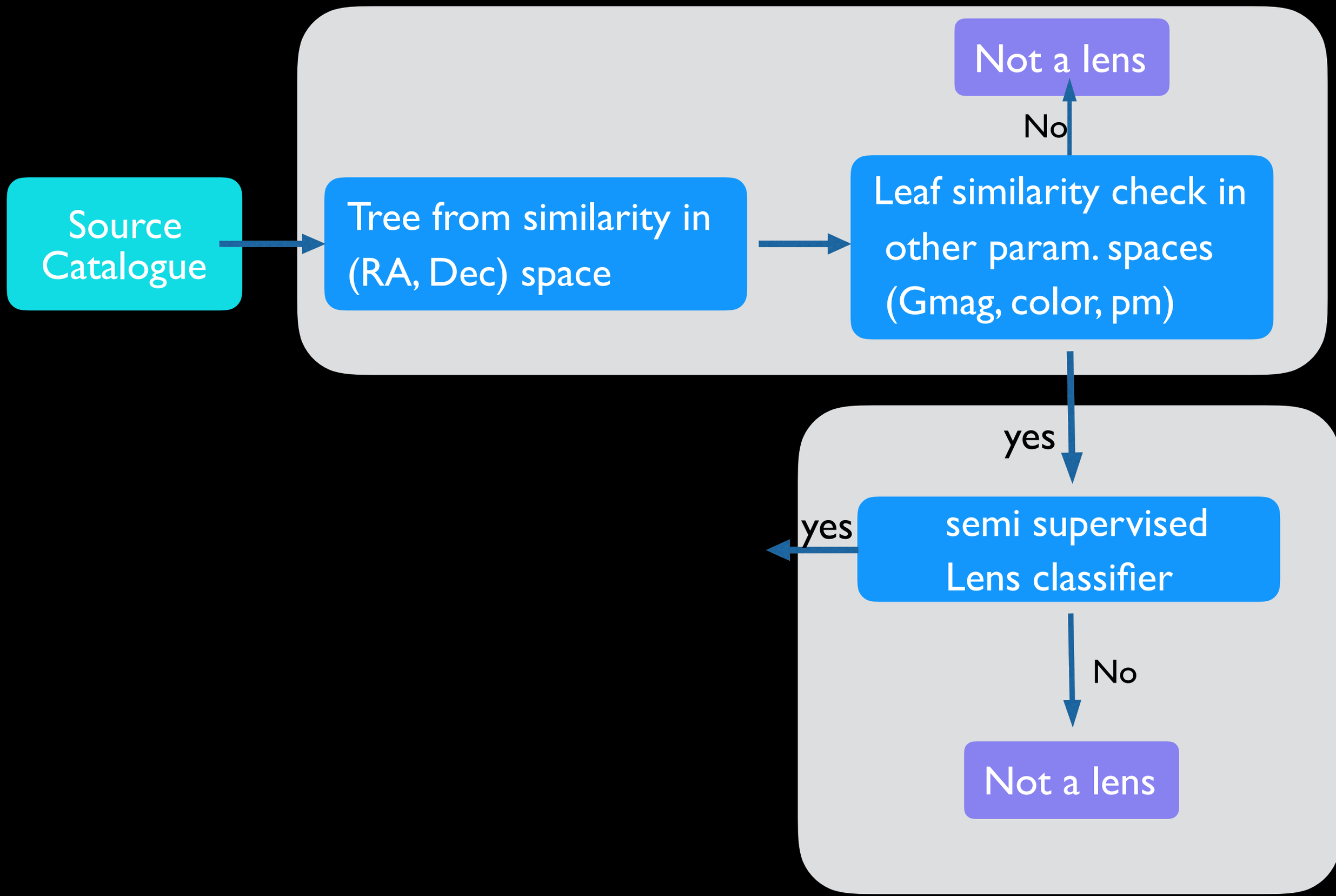


- Gaia DR1 = 1.5 G sources
- Processing time huge = 197 days in a single core ~4 days in 48 cores *(not including lens system modelling!)*

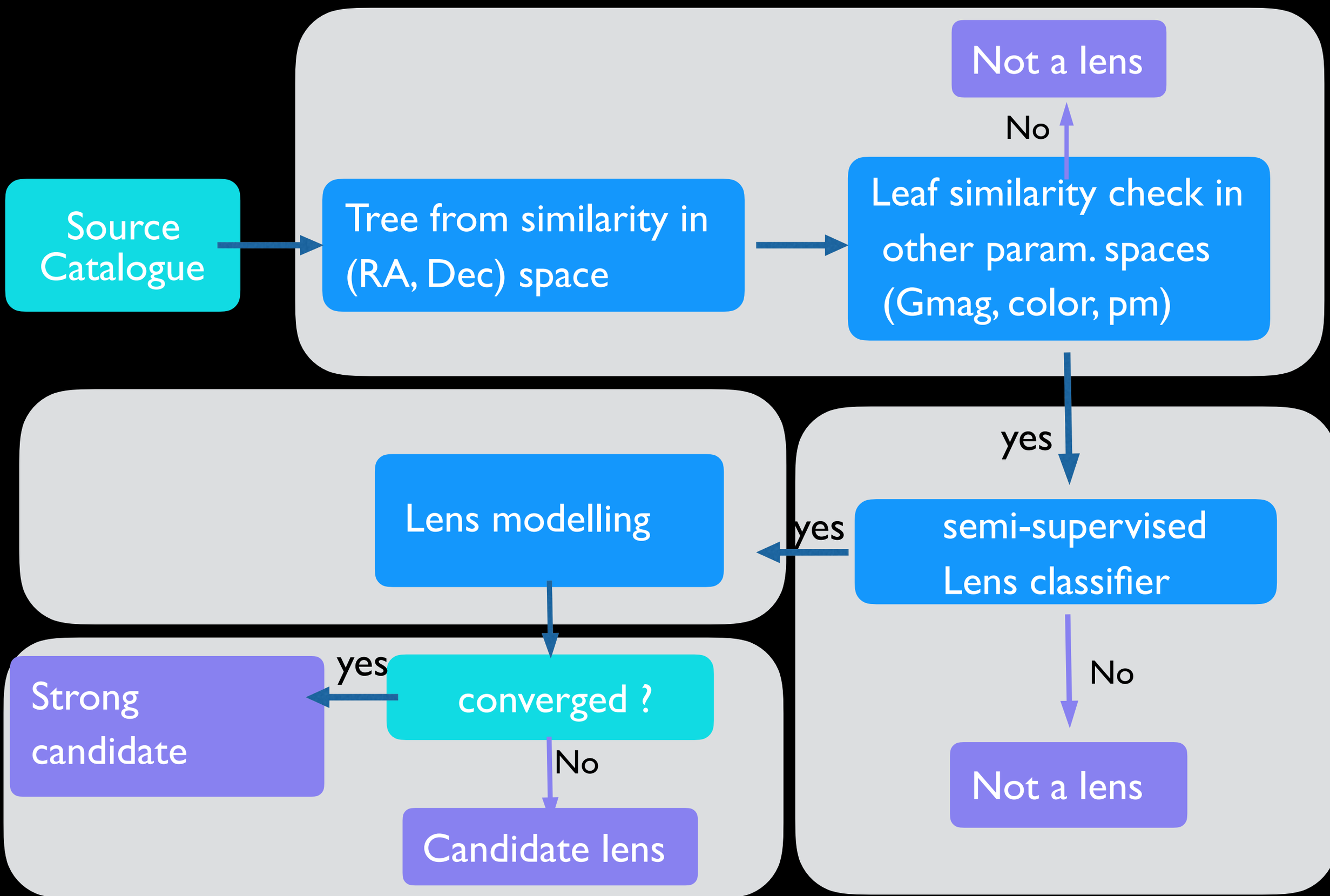
SELenA method



SELenA method

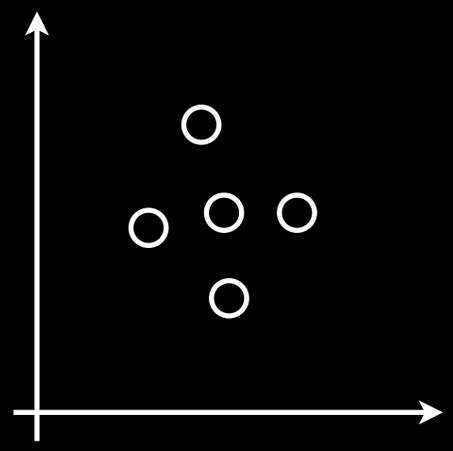


SELenA method



Lens modelling : the problem to be solved

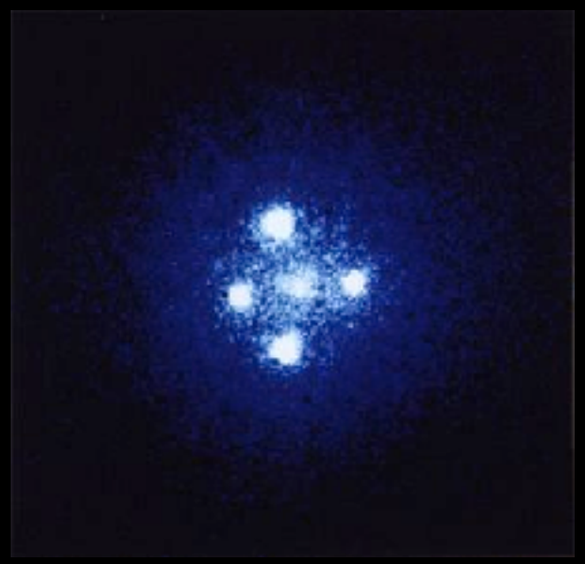
Gaia data



give-me all the parameters of the lens system!

Deflector :: axis ratio, major axis, Einstein radius (H0+Mass+redshift), pos. angle, shear terms (g, ang.)
Background QSO :: ang.dist to lens pos.angle

But to do that, we need something that allow us to do the inverse!



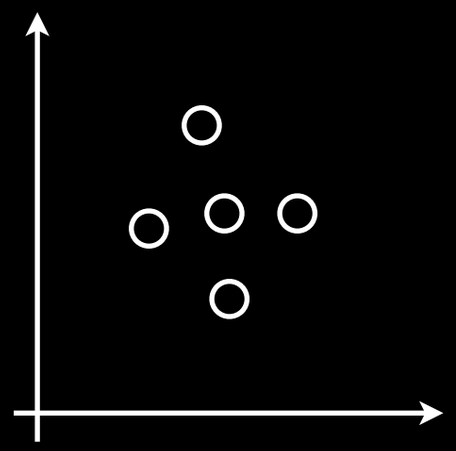
Deflector :: axis ratio, major axis, Einstein radius (H0+Mass+redshift), pos. angle, shear terms (g, ang.)
Background QSO :: ang.dist to lens pos.angle

Lens modelling : the problem to be solved

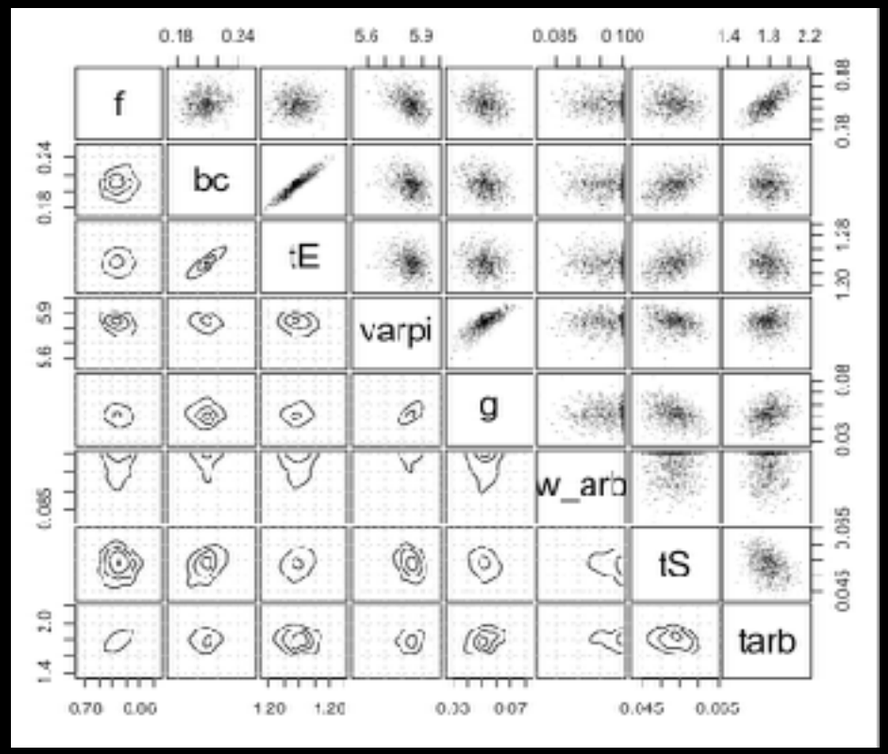
- Forward model implemented in OpenCL (runs in CPU, GPU or FPGA) : **millions of lens configurations can be simulated per second.**

Efficient sampling of the parameter space for the Bayesian inference process

Gaia data



Parameter inference



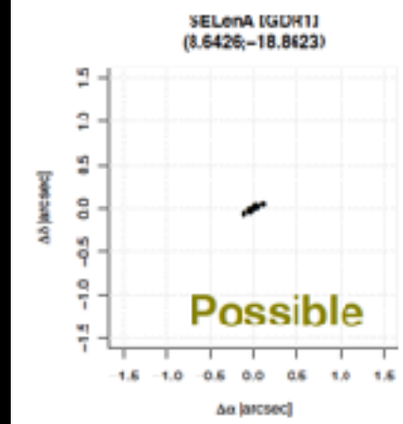
Preliminary Results on DR1

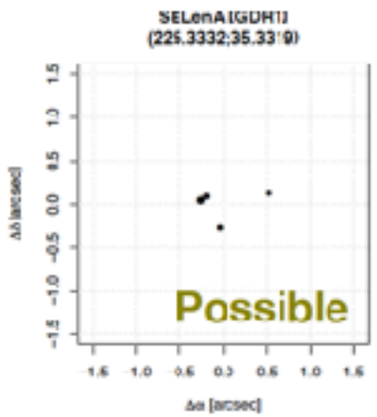
- **Automatic processing outside Galactic Plane** (Dpos < 1.5", Dmag < 1 mag)

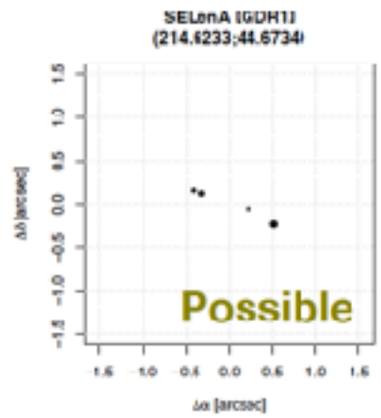
|b| cut	Individuals	2-sources	3-sources	4-sources
50° to 55°	6 546 674	10 905	139	0
55° to 60°	5 284 145	9 351	126	0
> 60°	13 233 625	35 199	621	13

- **No classifier and lens modelling yet !**

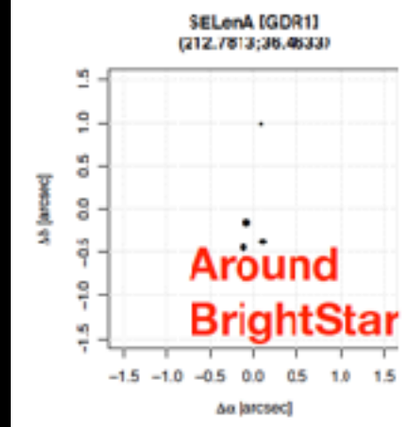
4 images candidates from DR1

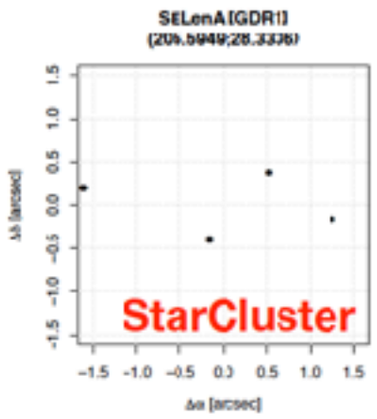


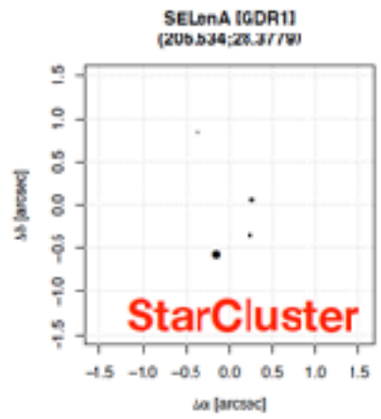


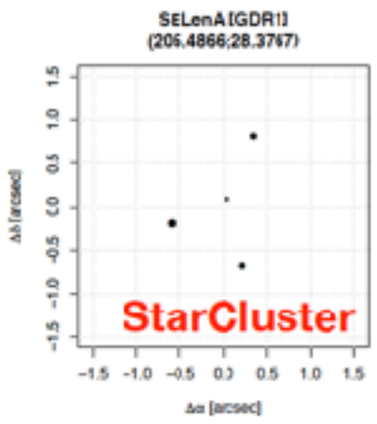


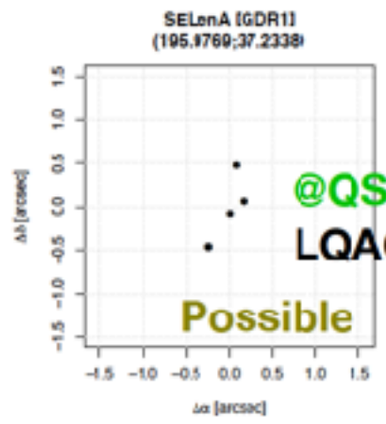
Possible
@QSO
Galaxy
StarCluster
BrightStar



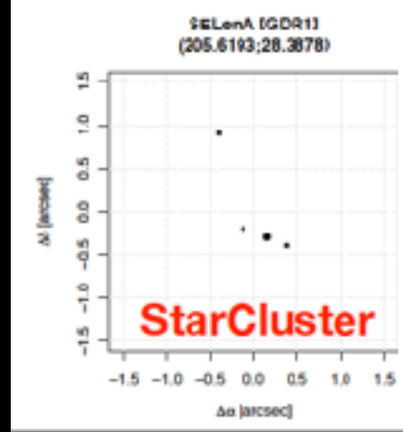


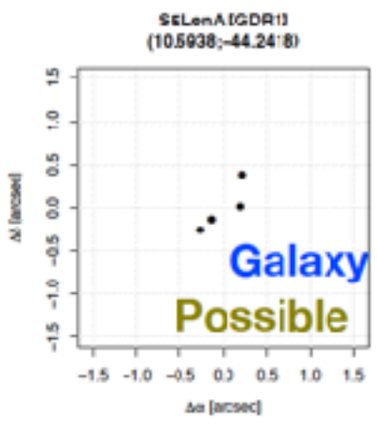


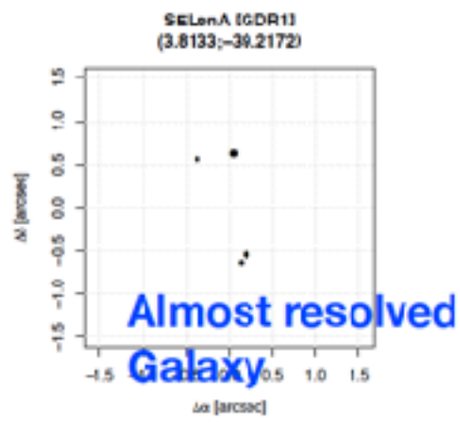


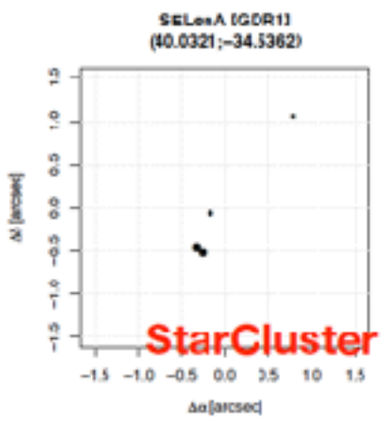


@QSO
LQAC 195+037_013



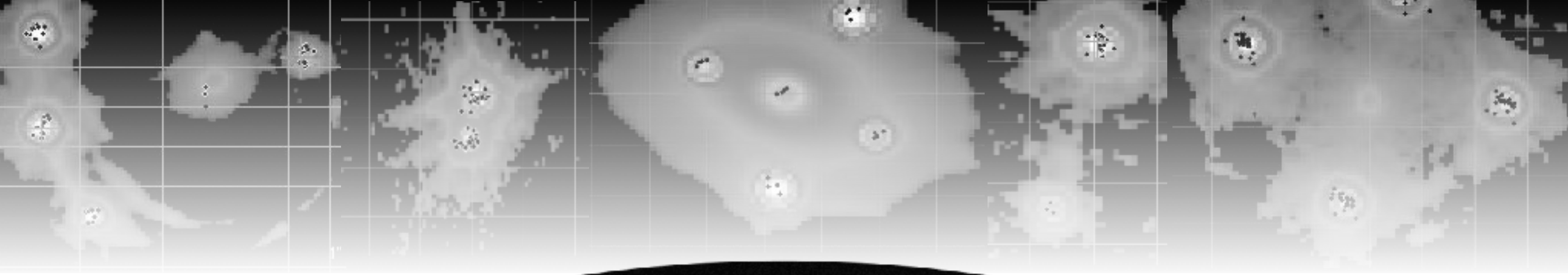


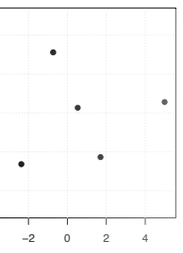


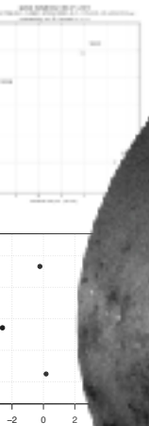


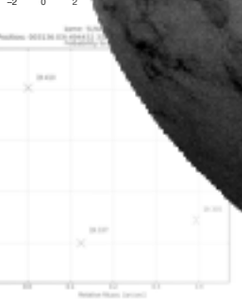
Conclusion

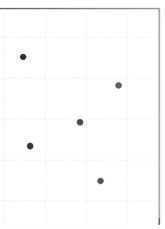
- **List of good candidates with 3 and 4 images from DR1.**
- **Proposal at the DOT (Devasthal Optical Telescope) 3.6m telescope (India) for a multi-photometry validation of DR1 candidates.**
- **We expect many more/complete configurations in DR2.**

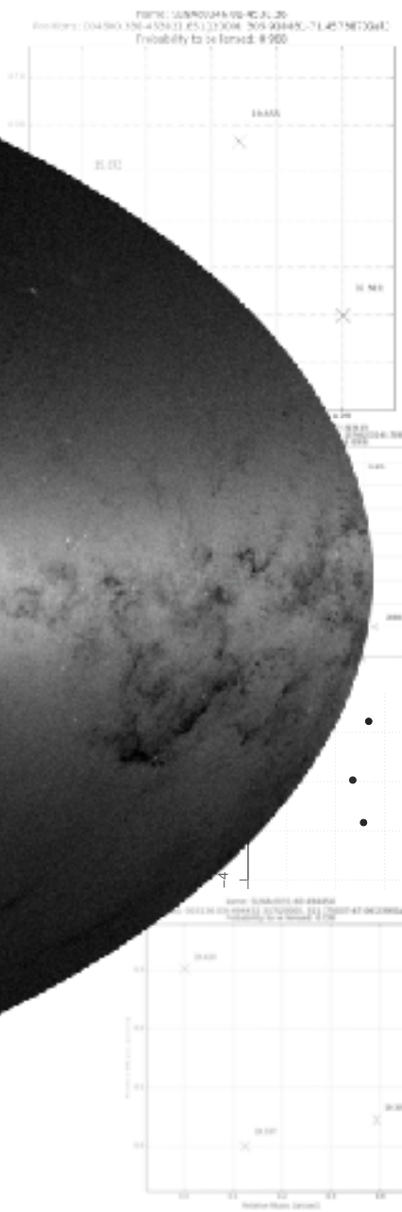


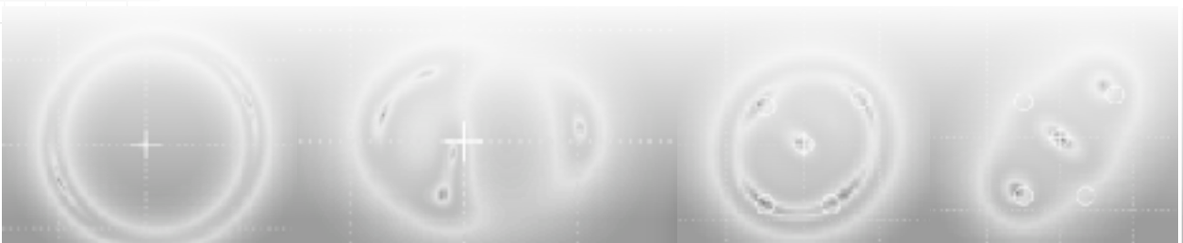


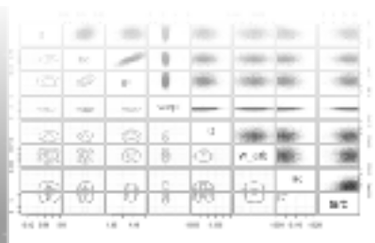












Thank you!