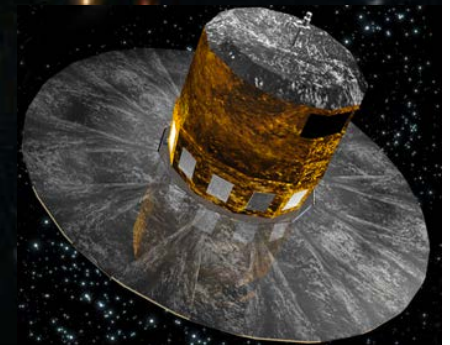


Gaia GraL Gravitational Lenses in Gaia DR2

A. Krone-Martins, L. Delchambre, O. Wertz, L. Galluccio, R. Teixeira, E. Slezak, J.F. Le Campion, F. Mignard, J. Surdej, S.G. Djorgovski, D.P. Stern, M.J. Graham, C. Boehm, J. Klüter, J. Wambsganss, U. Bastian

Christine Ducourant - LAB - Bordeaux France

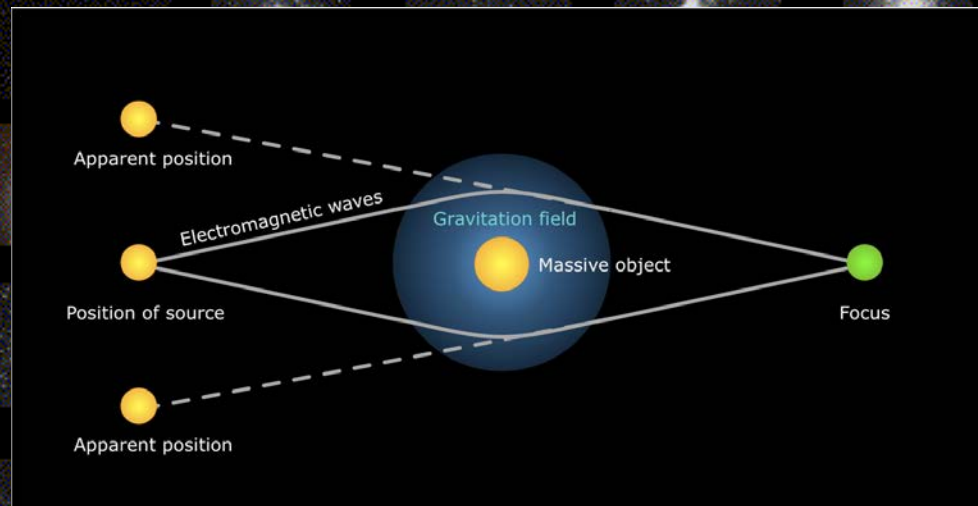


SF2A - Atelier Général PN GRAM - May 14th 2019 - Nice

Gaia is a scanning mission that observes all detectable objects
(1 M Galaxies + 0.5 M QSOs)

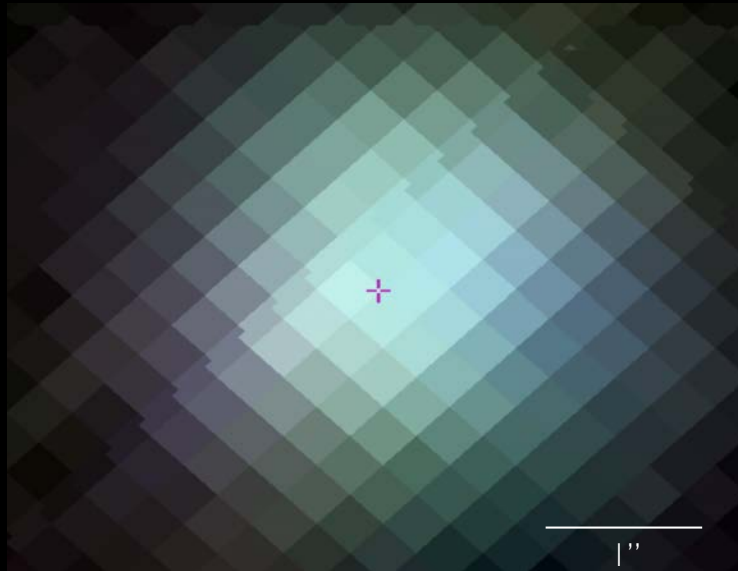
**It also observes multiply imaged quasars by
gravitational lensing**

**Gaia is the first all-sky survey from space of
gravitational lenses**

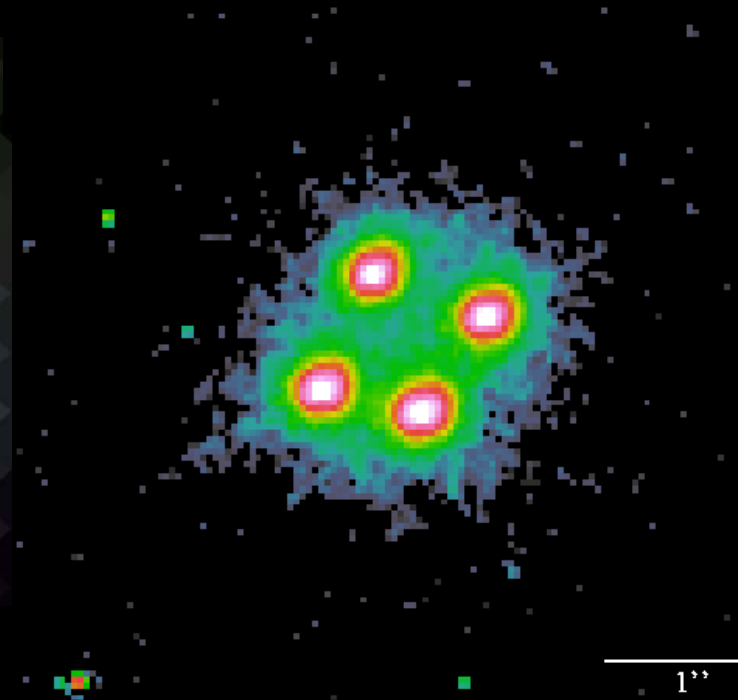


Gravitational Lenses from ground and space

HI413+117
From Ground (SDSS9)



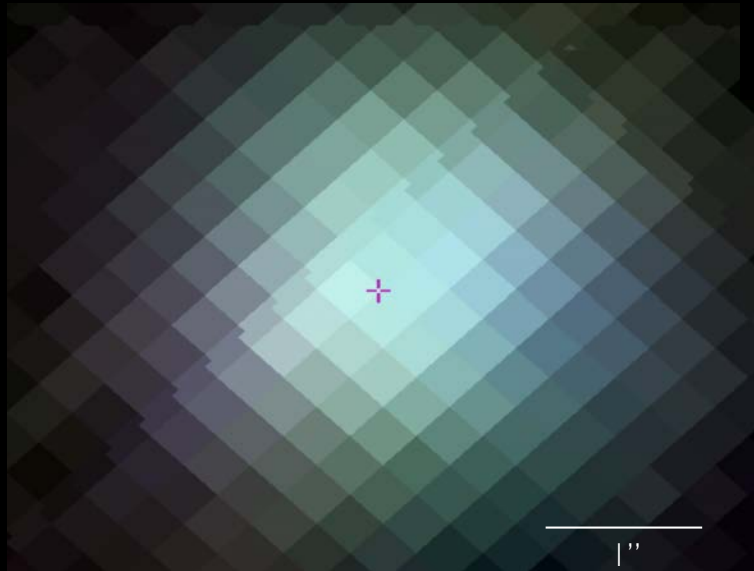
HI413+117
From space (HST)



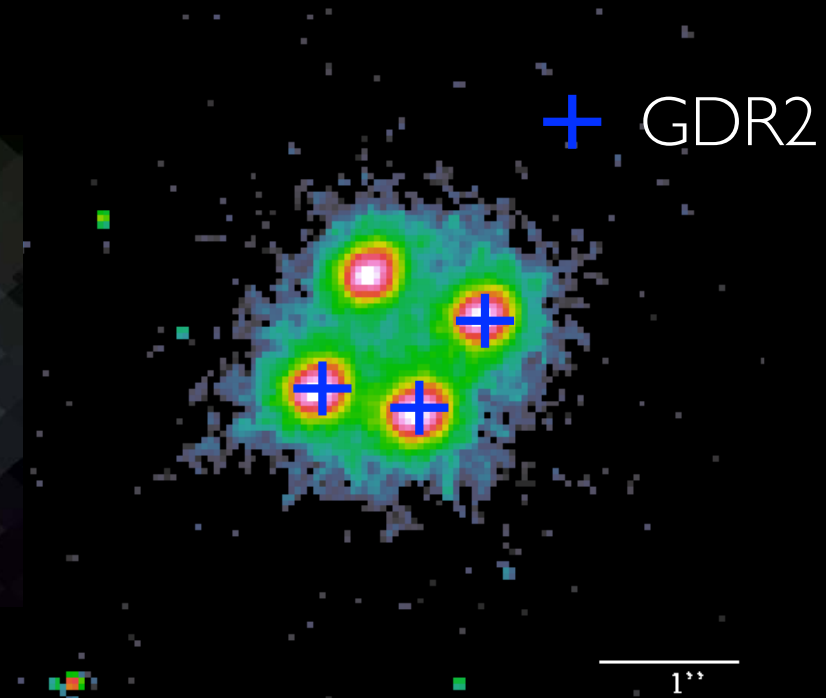
Credit : Castles database, HST images

Gravitational Lenses in Gaia

HI413+117
From Ground (SDSS9')



HI413+117
From space (HST)



Credit : Castles database, HST images

- **Gaia has a fantastic potential for GL**

- spatial mission & all-sky survey
- amazing resolving power $\sim \mathbf{0.18''}$
- exceptional astrometric precision/accuracy $\sim \mathbf{100 \mu as}$

- **We expect Gaia to detect** (Finet & Surdej 2016)

- 2650 GL with 2 images
- **250 with 3+ images**
- no arc

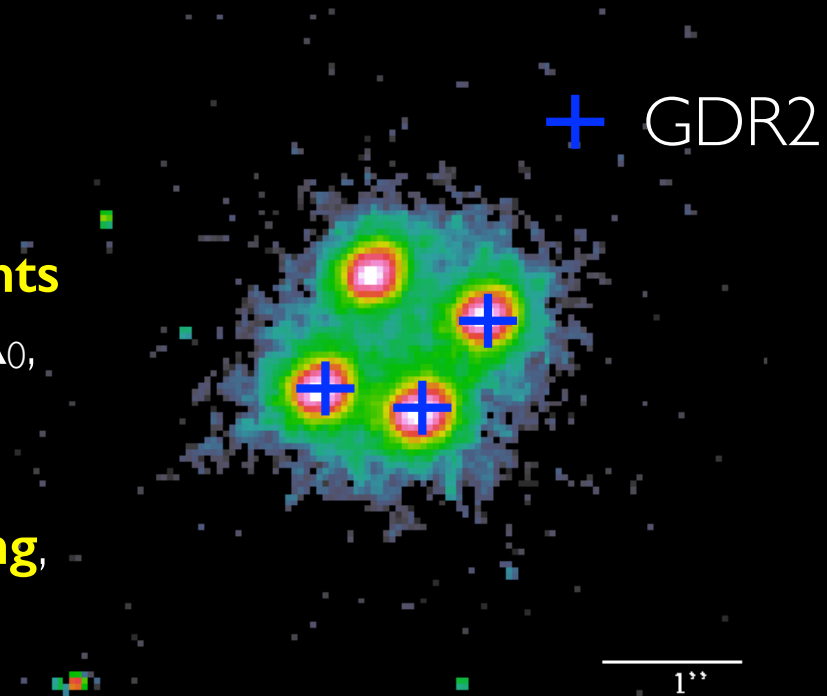
➔ **Counts** will bring independent **constraints** on **cosmological parameters** (H_0 , Ω_0 , λ_0 , mass distribution of the deflector galaxy pop...)

➔ Sub-mas astrometry : **accurate modelling**, for the understanding of lensing galaxy population, distant quasars,...

$$\text{time-delay (photometry)} \quad \tau = \frac{\text{spectroscopy + photometry + astrometry}}{\frac{(1+z_L)}{H_0} \frac{d_L d_S}{d_{LS}} \left[\frac{1}{2} |\vec{\theta} - \vec{\beta}| - \psi_{2D}(\vec{\theta}) \right]}$$

H1413+117

From space (HST)



Credit : Castles database, HST images

Gaia GraL project

1 - Known lenses : benchmark for testing Gaia capabilities

2 - Search around known quasars

3 - Blind search in Gaia DR2

4 - Ground-based validation

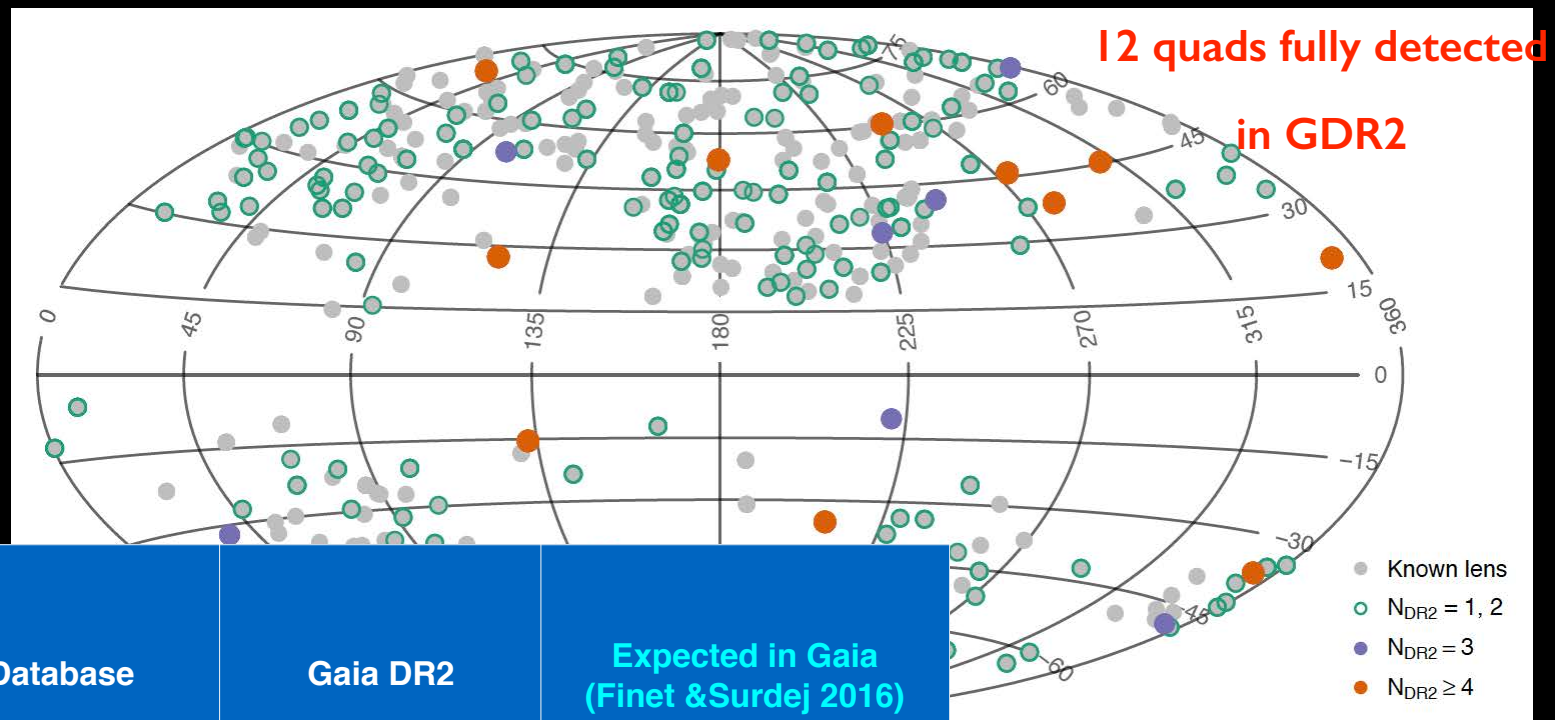
(5 - Modelling)

- Quasars + host galaxy

➡ Structure optic/radio of QSOs

I - Database of known GLs

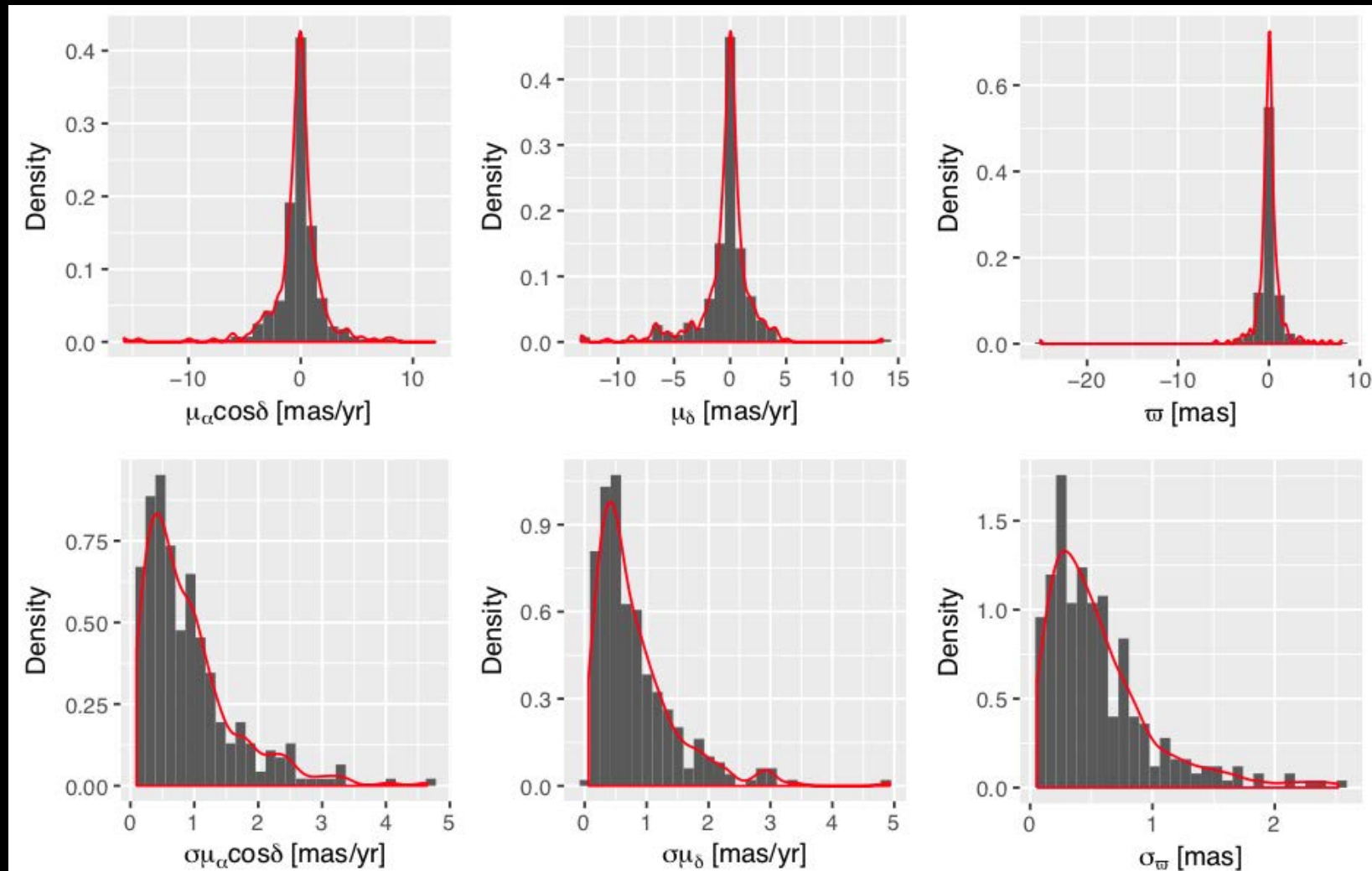
Heterogeneous database of **481** multiply-imaged quasars



Ducourant et GraL, A&A,

images	Database	Gaia DR2	Expected in Gaia (Finet & Surdej 2016)
2	434	172	2 650
3+	47	34	250
Total	481	206	2 900

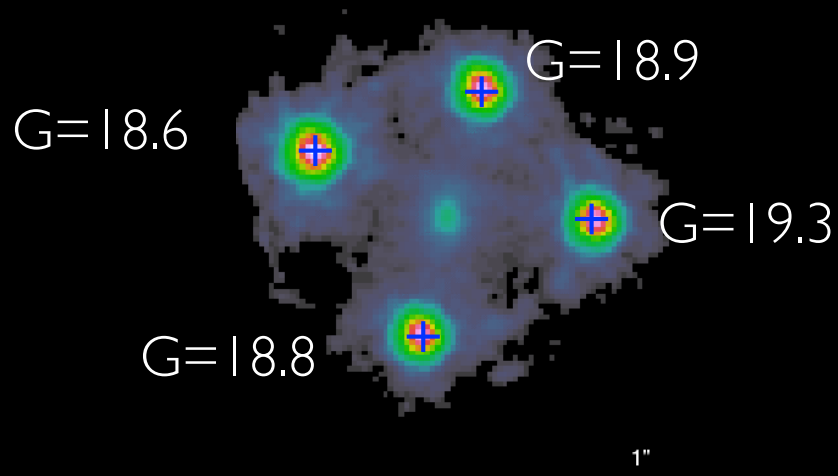
GDR2 Astrometry of Lensed Quasars



- Important for blind search **to filter the Galaxy** Ducourant et GrdL, A&A, 2018
- Soft astrometric cut in DR2 because **$\mu, \varpi \neq 0$**

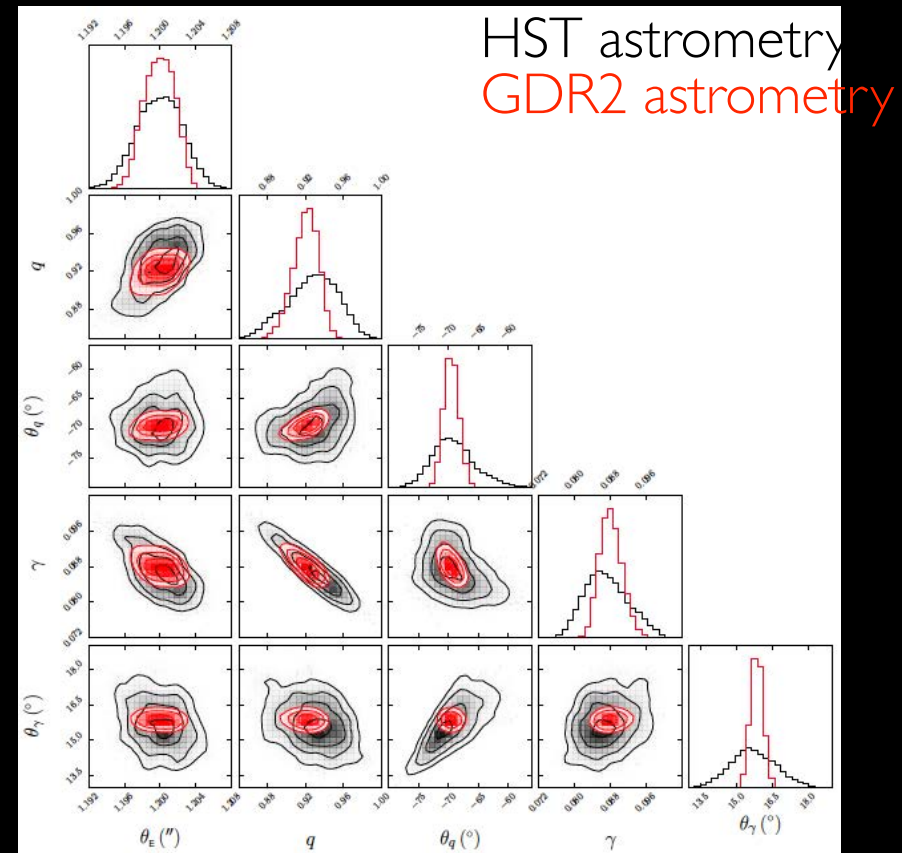
Modelling with Gaia DR2

HE0435-1223



Credit : Castles database, HST images

- With **sub-mas precisions**
- Improved **fitted parameters**
- Great **potential** for **realist modelling** !



Ducourant et GraL, A&A, 2018

II - Search around known quasars

➔ Compilation of quasar catalogues

- 3 M sources : 1.8 M in DR2

Gaia DR2 sources	Astrometry	Astrometry & Color	Astrometry & Color, $\Delta\theta \leq 1''$
2	16,500	320	28
3	1,874	46	0
4	269	8	0
≥ 5	66	0	0

➔ Extraction of GDR2 sources around quasars

Krone-Martins et GraL, A&A, 2018

➔ Soft astrometric cuts

- Exclude Galactic plane $|b| > 15^\circ$
- $\varpi - 3\sigma_\varpi < 4 \text{ mas}$ and $|\mu| - 3\sigma_\mu < 4 \text{ mas/yr}$

➔ Clusters of sources

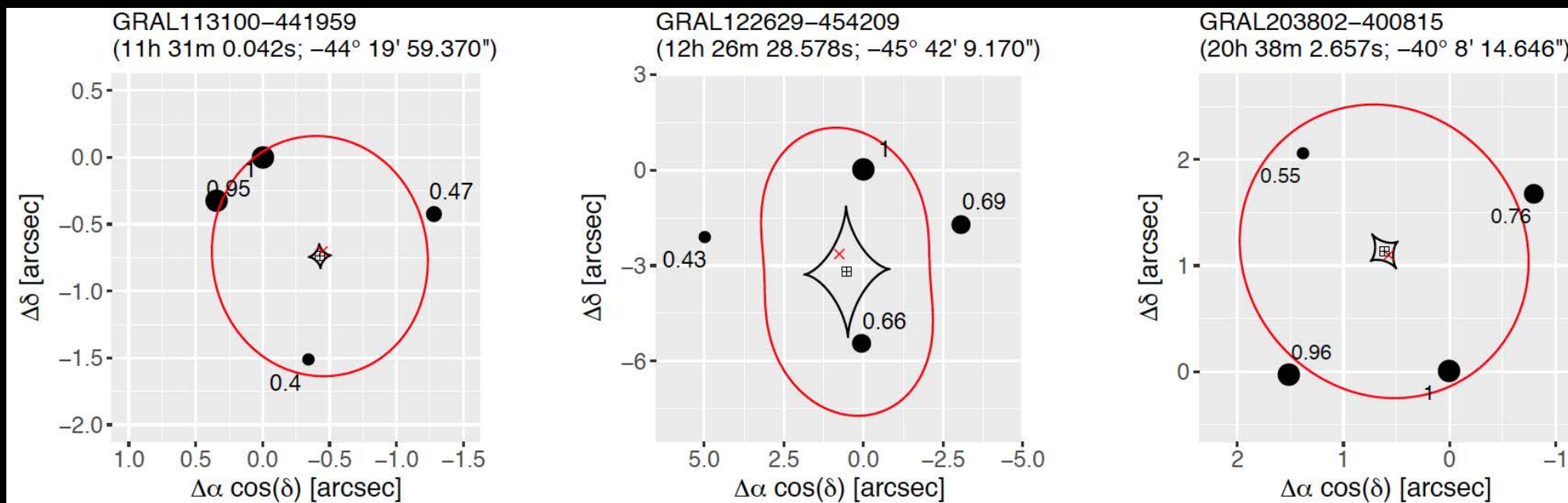
➔ Filtering of clusters

- Astrometric compatibility (ϖ, μ , color) : $|\varpi_i - \varpi_j| < 3\sigma_{|\varpi_i - \varpi_j|}$
- Color compatibility (G, BP, RP) (when available)
- Machine learning lens classifier using astrometry

- 3 good quads candidates
- Gaia DR2 incomplete for small separations

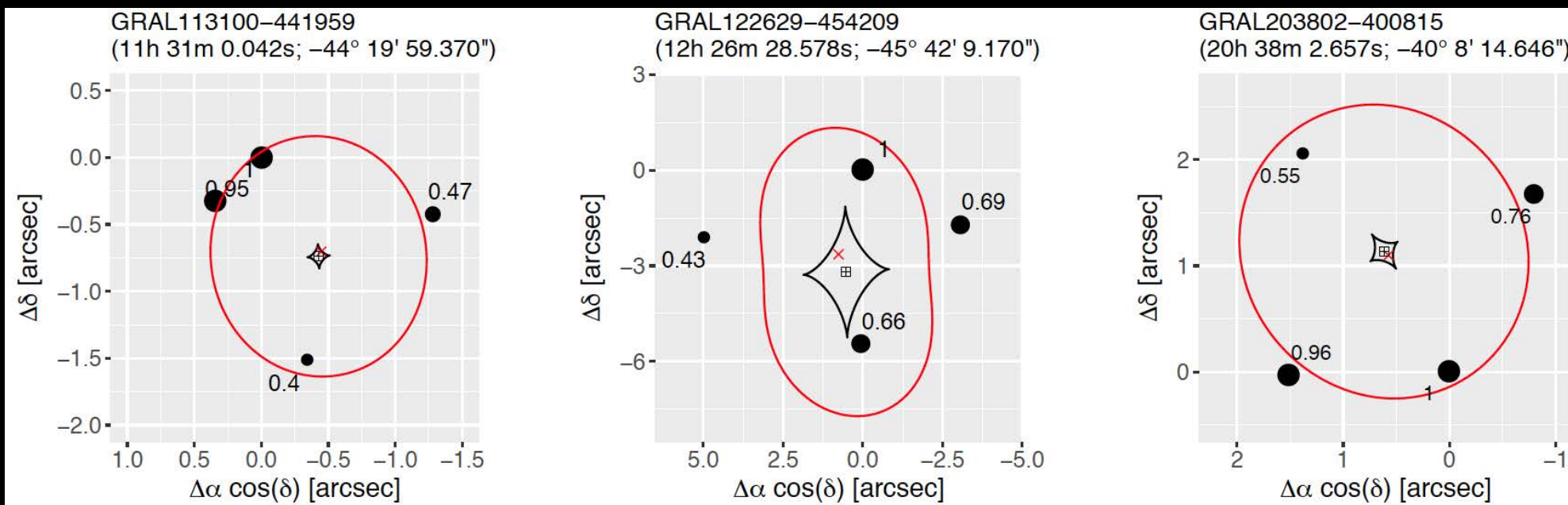
Three quadruply imaged quasars

Krone-Martins et GraL, A&A, 2018

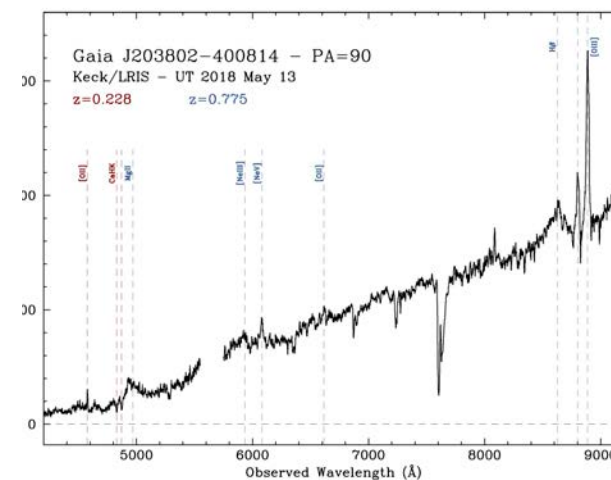
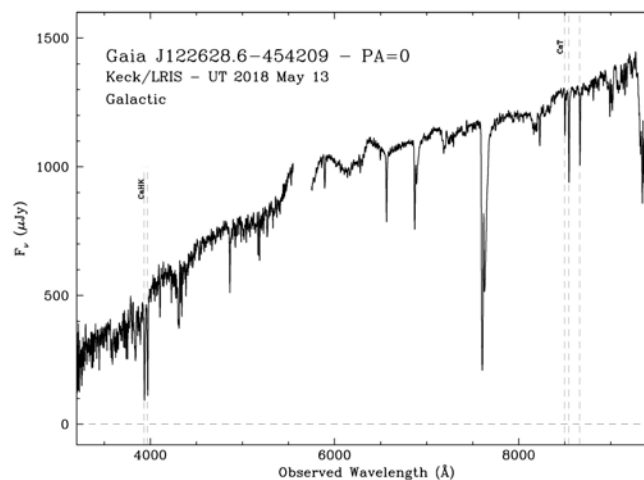
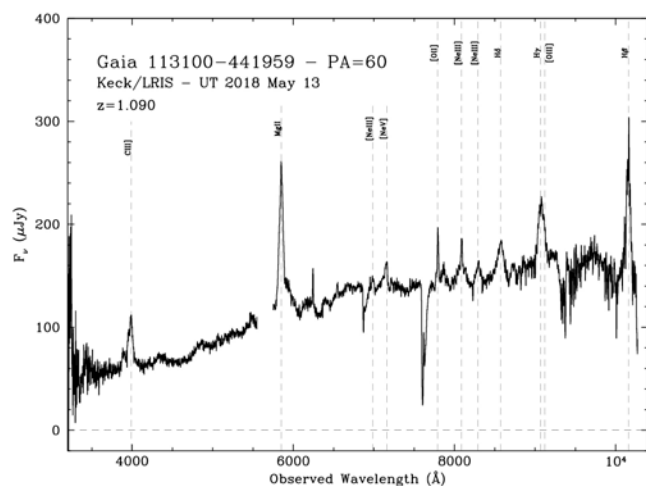


Three quadruply imaged quasars

Krone-Martins et GraL, A&A, 2018

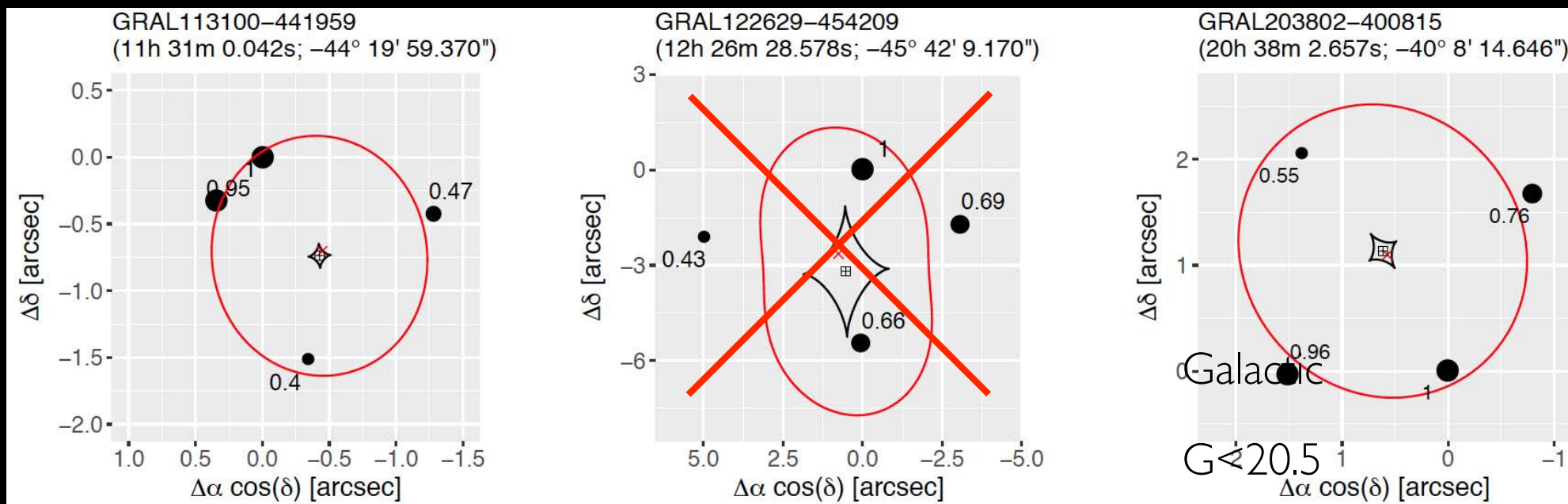


→ Spectroscopic validation at Keck/LRIS (May 2018)

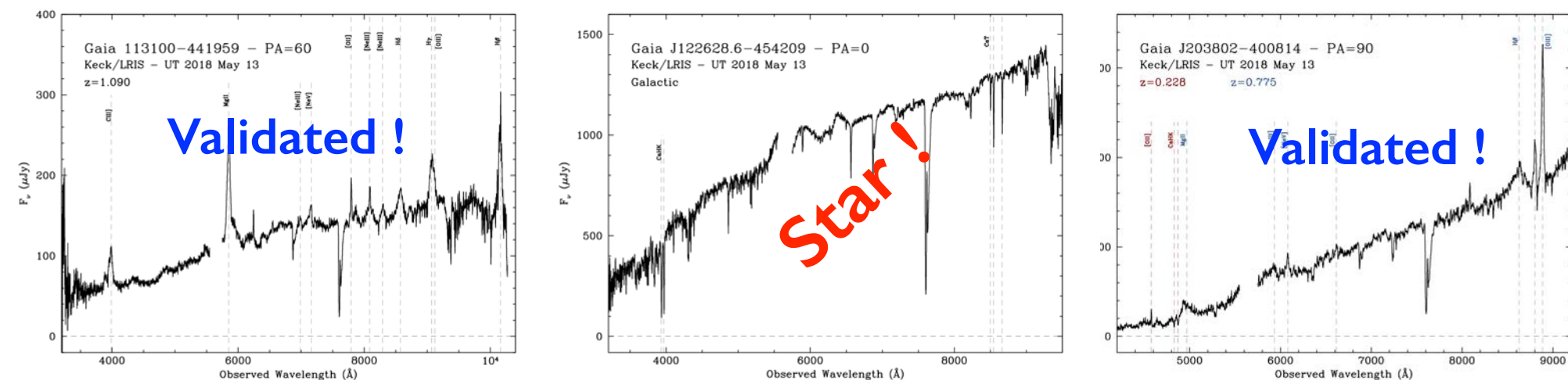


Three quadruply imaged quasars

Krone-Martins et *GrA*L, A&A, 2018



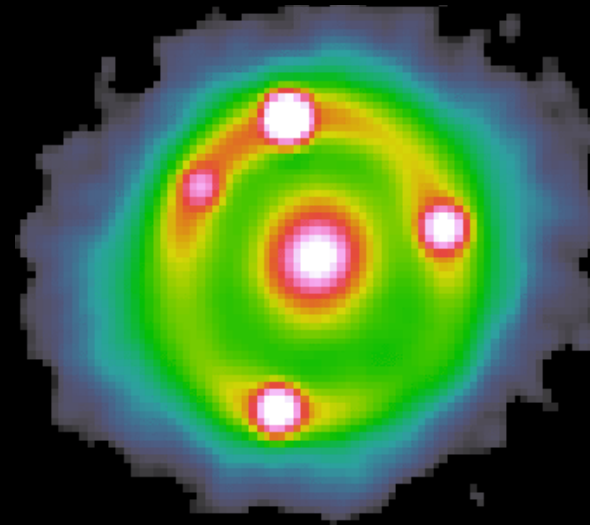
➔ Spectroscopic validation at Keck/LRIS (May 2018)



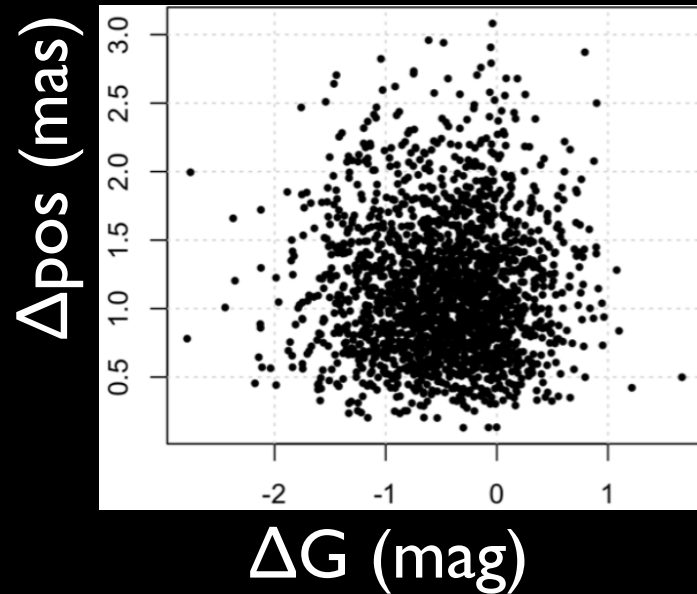
Krone-Martins et *GrA*L, in prep

III - Blind Search in Gaia DR2 :

Specific patterns

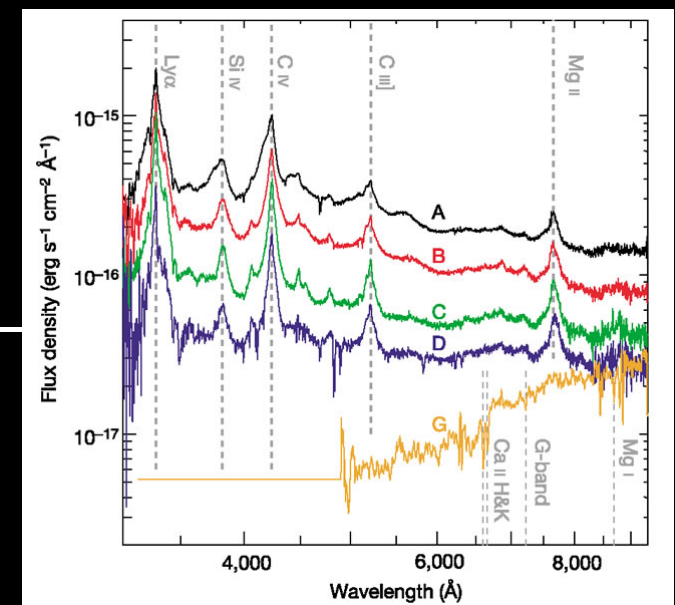


Credit : Castles database, HST images

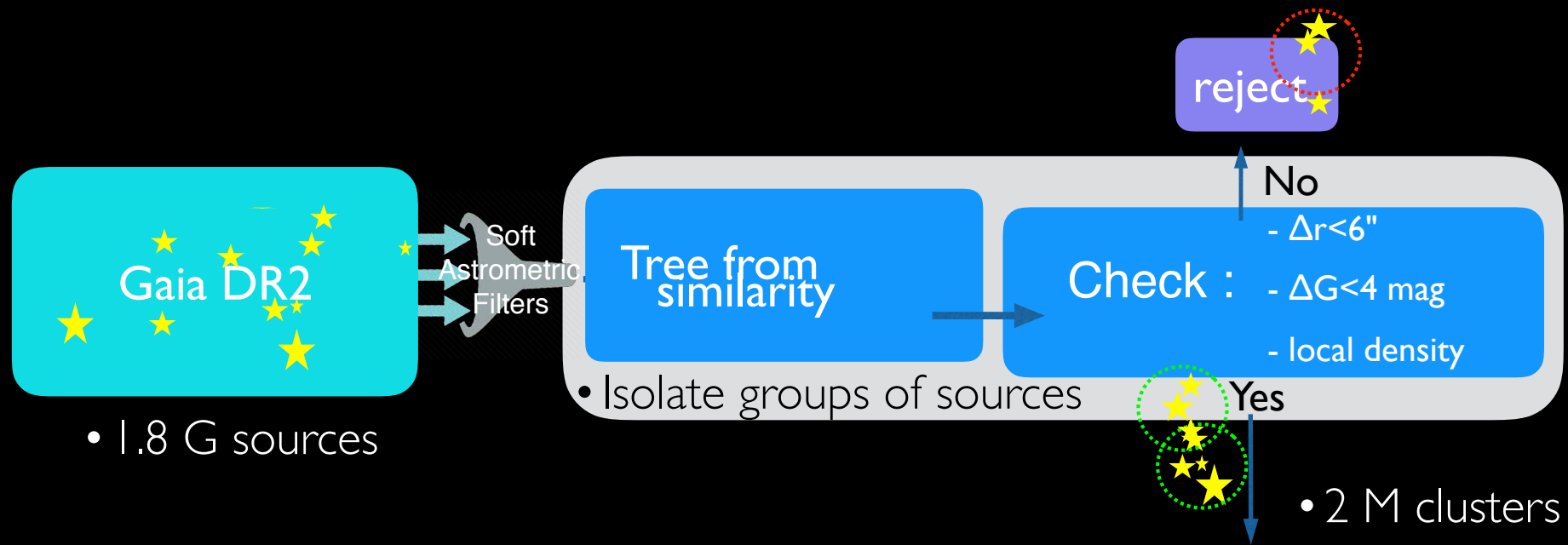


Specific ($\Delta G_{\text{mag}}, \Delta \text{pos}$)

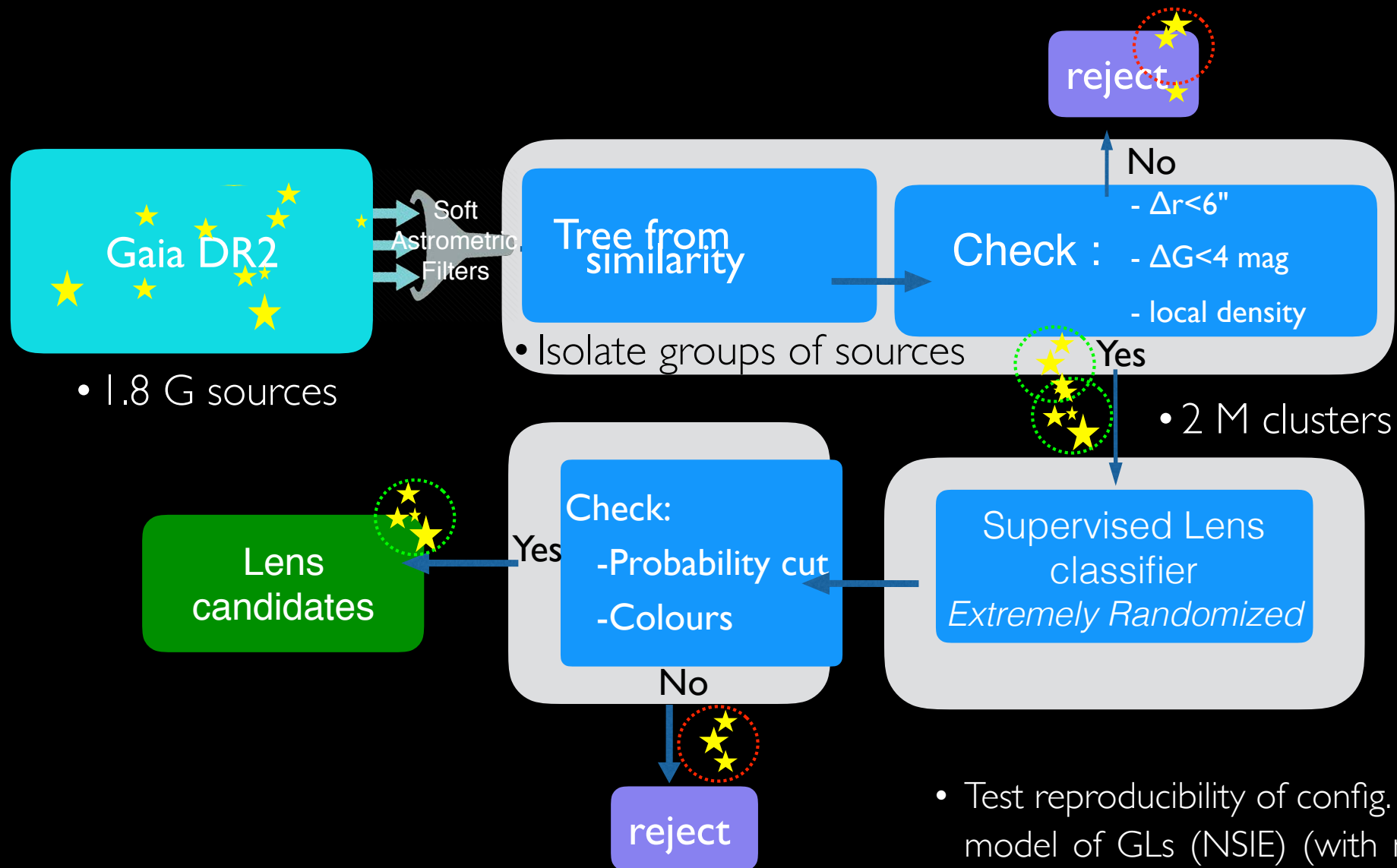
Same colour/spectra



Extraction of clusters of sources



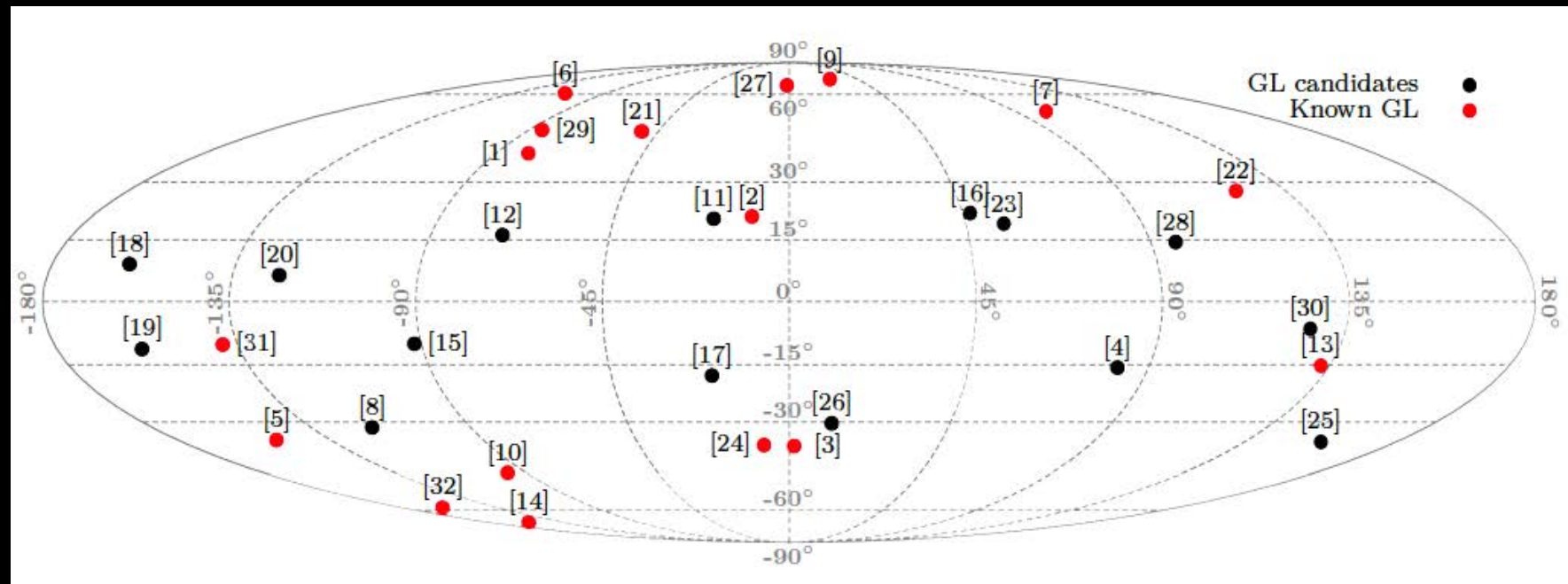
Extraction of clusters of sources



• **30 quadruply
images strong candidates !**

- Test reproducibility of config. by simple model of GLs (NSIE) (with noise and missing images)
- Assign a "probability"

30 Quads : 15 new candidates + 15 known GLs

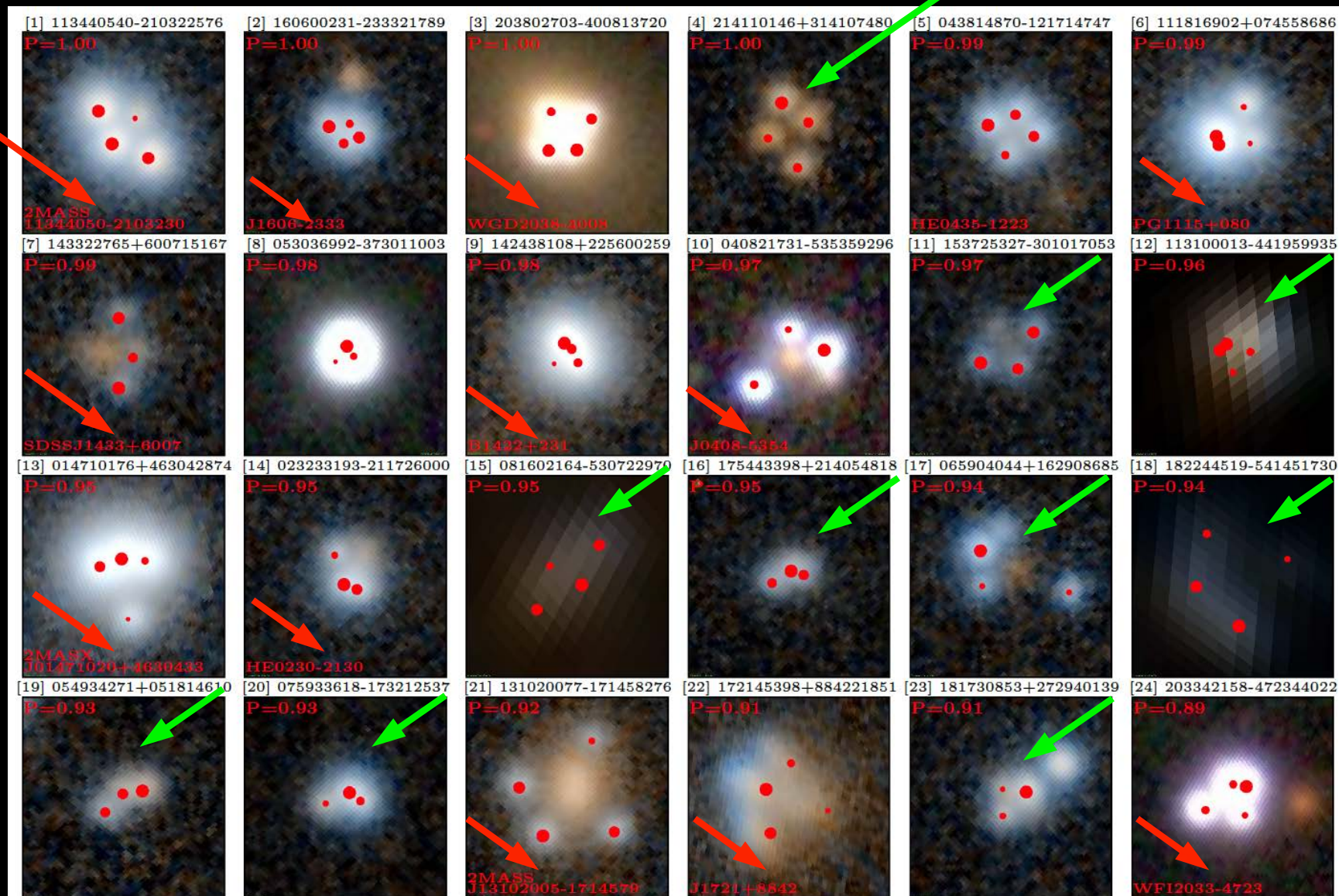


Delchambre et GraL, 2019

Visual inspection

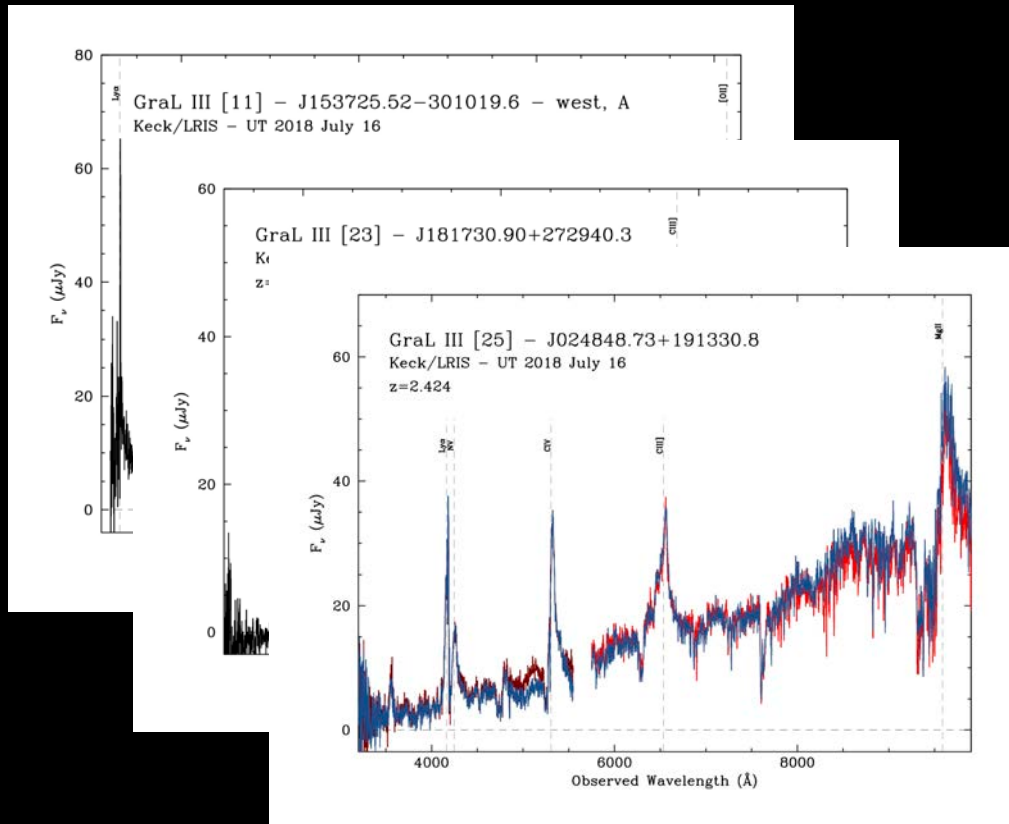
Candidates

Known



Delchambre et GraL, 2019

Spectroscopic validation (Feb 2018, April 2019)



Palomar



NTT



Gemini south



Keck

Wertz et GraL, 2018, Krone-Martins et GraL in prep, Stern et GraL in prep

- Spectroscopy
- 8 candidates validated so far !

Conclusions

- Methodology of blind search validated !
- 15 new quadruply imaged quasars strong candidates (only 41 previously known)
- 8 quads spectroscopically validated
- Gaia DR2 is largely incomplete $\Delta\Theta < 2''$
- Great expectations for GDR3 (~2021)

Thank you!