

# FINDING A NEEDLE IN A HAYSTACK: BIG DATA ANALYTICS FOR GRAVITATIONALLY LENSED QUASARS IN THE DARK ENERGY SURVEY

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# RESEARCH BACKGROUND

$$\sqrt{\frac{F_g}{a^2}}$$

Gravitational lensing in quasars discovered in **1979**  
Approximately **120** gravitationally lensed quasars confirmed to date

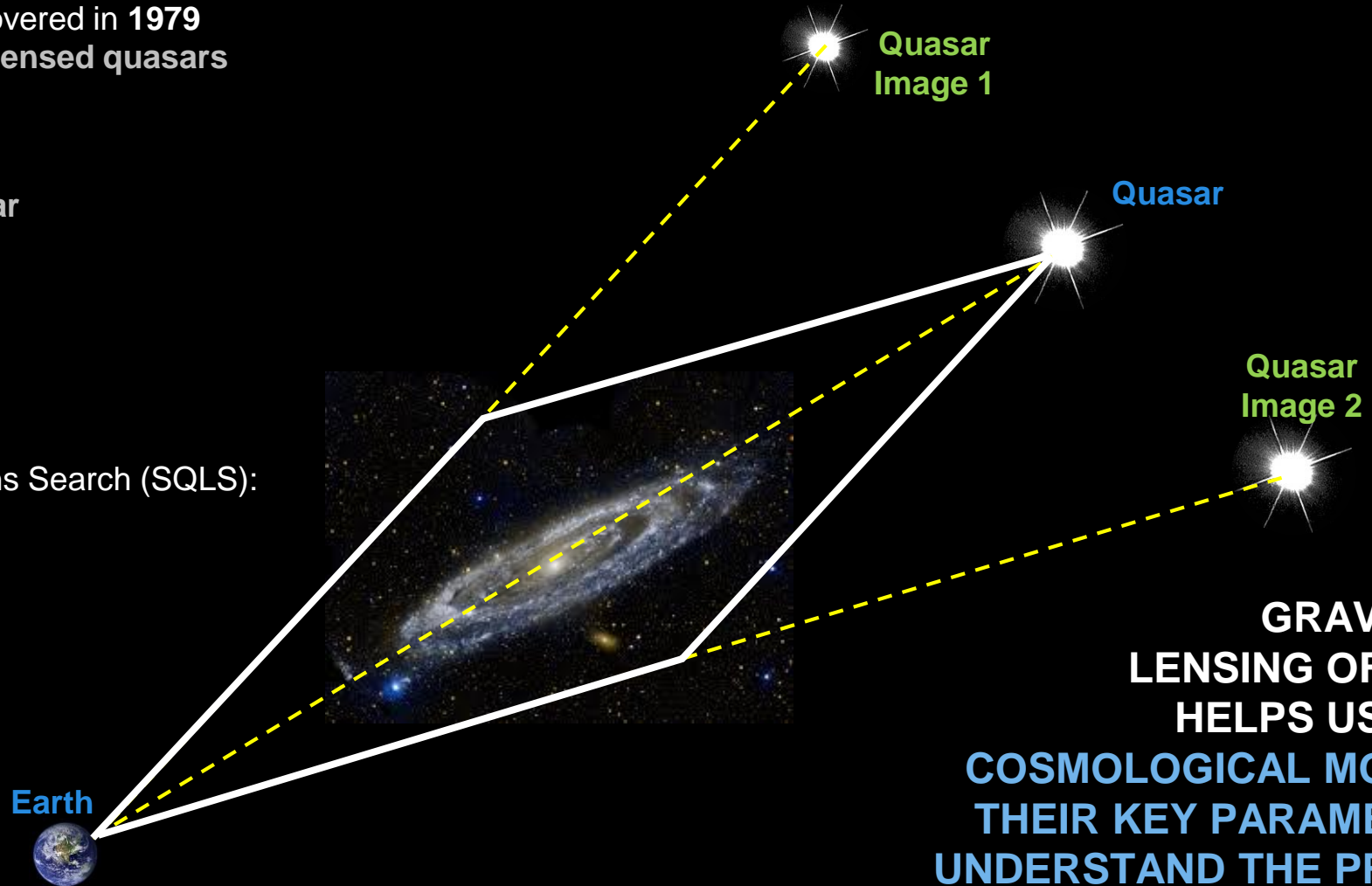
Turner et al. (**1984**)  
First theoretical modeling of quasar lensing

HST Snapshot Survey: Maoz (**1993**)  
First significant survey of lensed quasars

Sloan Digital Sky Survey Quasar Lens Search (SQLS):  
Oguri et al. (**2006**)  
Tens of thousands of quasars

Sivakumar et al. (**2016**)  
Hundreds of thousands of quasars

Agnello et al. (**2015**)  
First lensed quasars from Dark Energy Survey (DES)



**STUDYING  
GRAVITATIONAL  
LENSING OF QUASARS  
HELPS US VALIDATE  
COSMOLOGICAL MODELS AND  
THEIR KEY PARAMETERS AND  
UNDERSTAND THE PROPERTIES  
OF DARK MATTER AND DARK ENERGY**

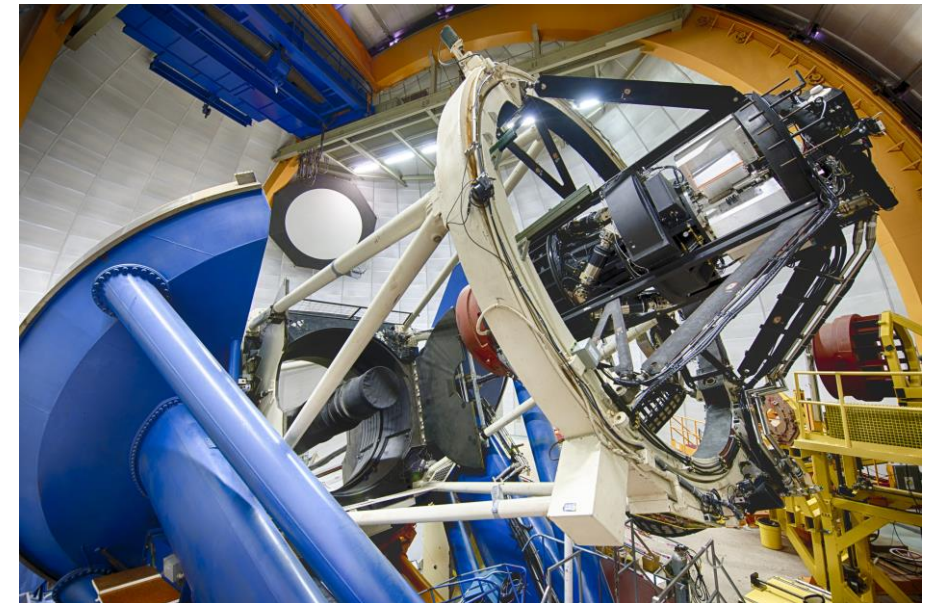
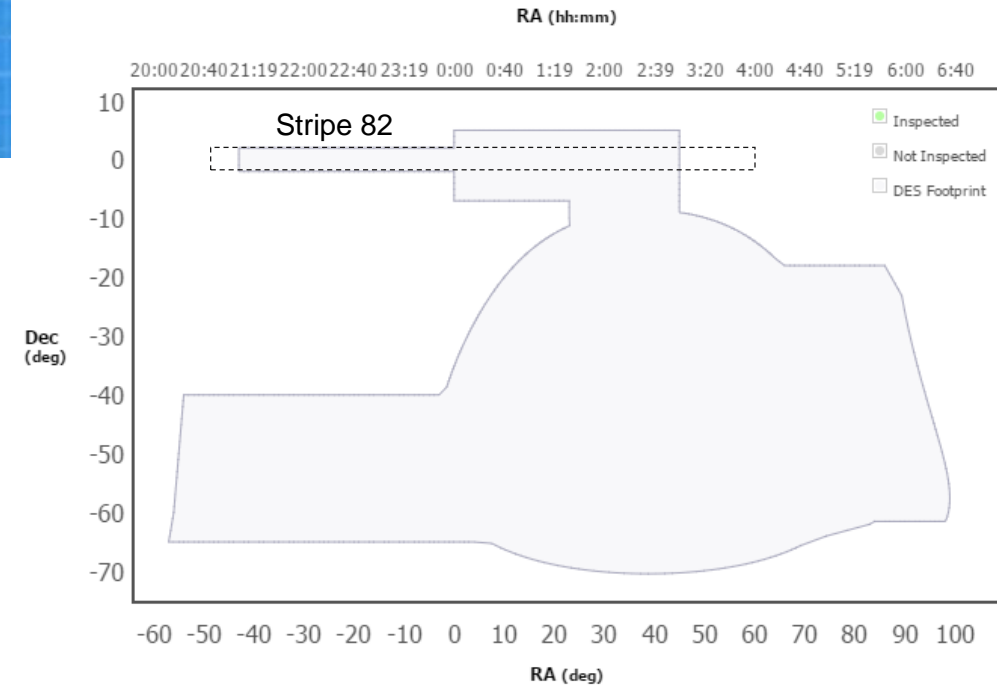
# WHAT IS DES?

## The good...

- 5000 square degrees –  $\frac{1}{4}$  of Southern Hemisphere sky,  $\frac{1}{8}$  of whole sky – taken using DECam
- Magnitude limit of about 30, as opposed to about 27 for SDSS
- Includes most of Stripe 82, allowing deeper searches in areas where SDSS candidates were found

## And the bad...

- No spectra
  - no clear way to identify a quasar
  - no spectral redshifts; other methods of obtaining redshift are inaccurate for quasars
- Hard to detect lensed quasars in some areas, for example in the Magellanic stream ( $< -60$  degrees declination) where stellar density is high
- Data less organized than in SDSS  $\rightarrow$  harder to extract some parameters

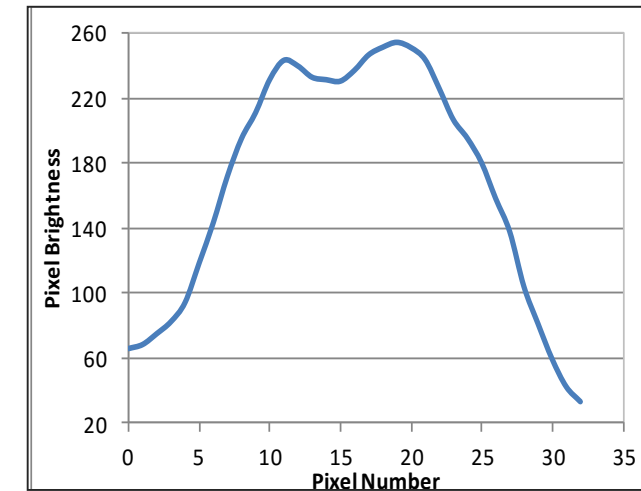
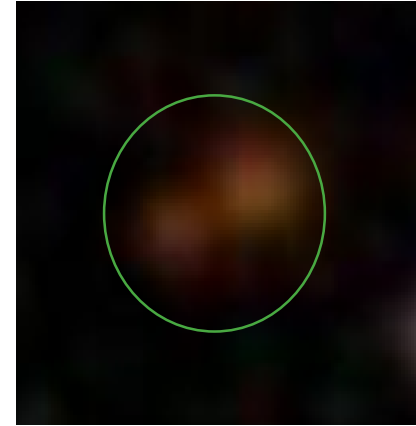
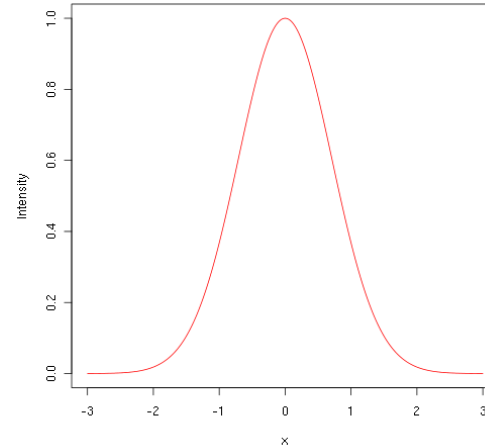
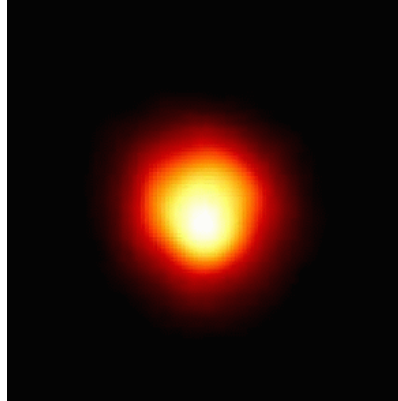




# LENSED QUASAR IDENTIFICATION ALGORITHMS

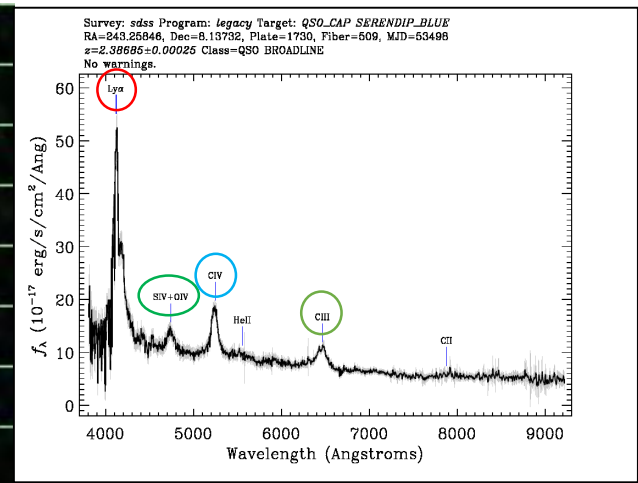
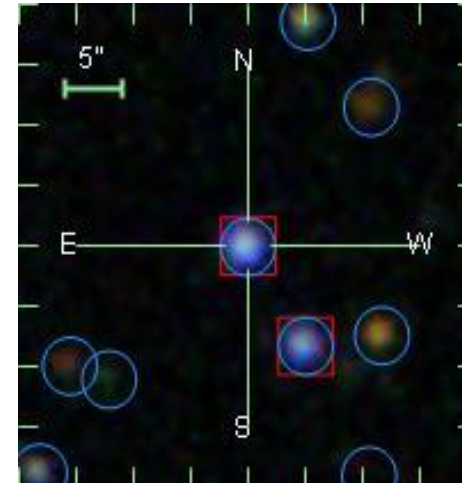
## Close-separation lenses

Point Spread Function (PSF)  
Difference Algorithm



## Wide-separation lenses

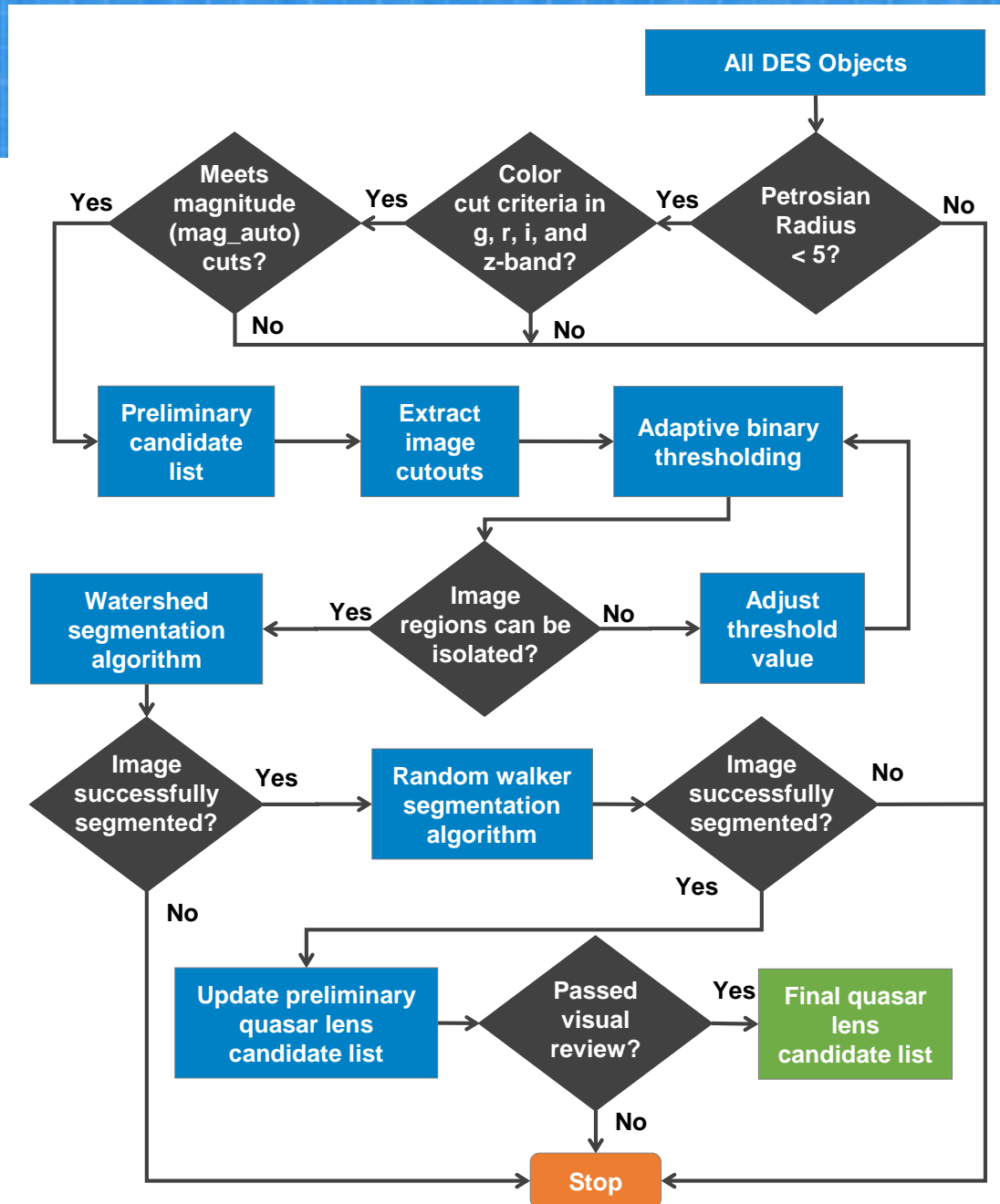
Morphological Algorithm



# SELECTION OF FINAL CANDIDATE LIST

## Multi-stage review process to extract final candidate list from DES

- Write & run SQL query, extract results into text file with ObjID, RA, Dec
- Upload SQL candidates to DES Portal
- Run cutout tool from DES Portal, export cutouts
- Crop, convert to 8-bit grayscale, and scale cutouts
- Run images through segmentation algorithm
- Two-step visual review of candidates

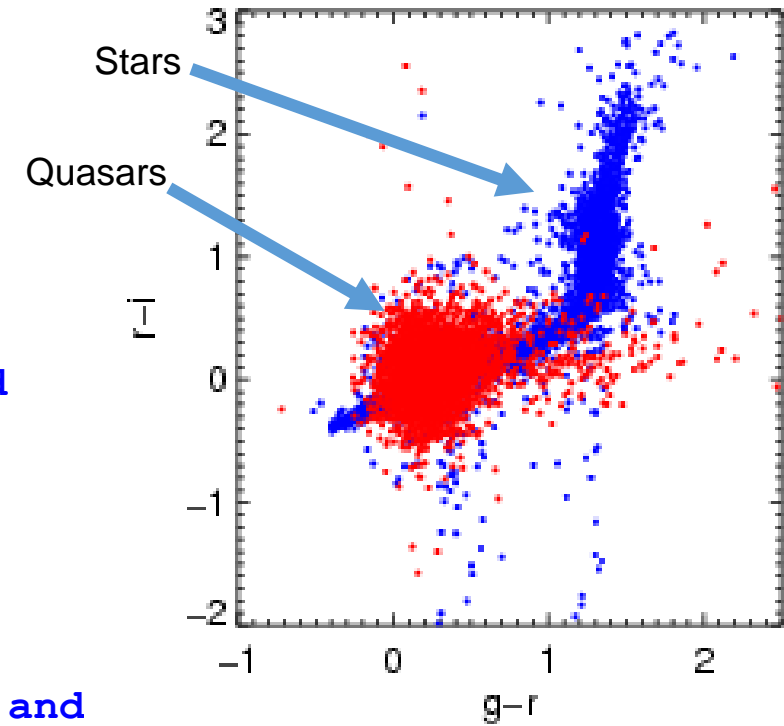


# SQL QUERY

How do you narrow 139 million DES objects down to a reasonable number of candidates?

```
SELECT Coadd_Objects_ID, ra, dec
from Y1A1_COADD_OBJECTS
WHERE Petro_Radius < 5
and (Mag_Auto_g - Mag_Auto_r) >= (0.24-0.002*0.24-0.01) and
(Mag_Auto_g - Mag_Auto_r) < (0.35-0.002*0.35-0.01)
and (Mag_Auto_r - Mag_Auto_i) >= (-0.27+0.154*-0.27) and
(Mag_Auto_r - Mag_Auto_i) < (0.57+0.154*0.57)
and (Mag_Auto_i - Mag_Auto_z) >= (-0.35-0.17*0.35+0.01) and
(Mag_Auto_i - Mag_Auto_z) < (0.7-0.17*0.7+0.01)
and Mag_Auto_g > 17 and Mag_Auto_r > 17 and Mag_Auto_g < 22 and
Mag_Auto_r < 22
and ABS(Mag_PSF_r - Mag_Auto_r) > 0.12
and (Flags_g = 1 or Flags_g = 3) and not(Flags_g >= 4 or Flags_g >=
4) and not (Flags_r >= 4 or Flags_r >= 4);
```

112,820 candidates remain

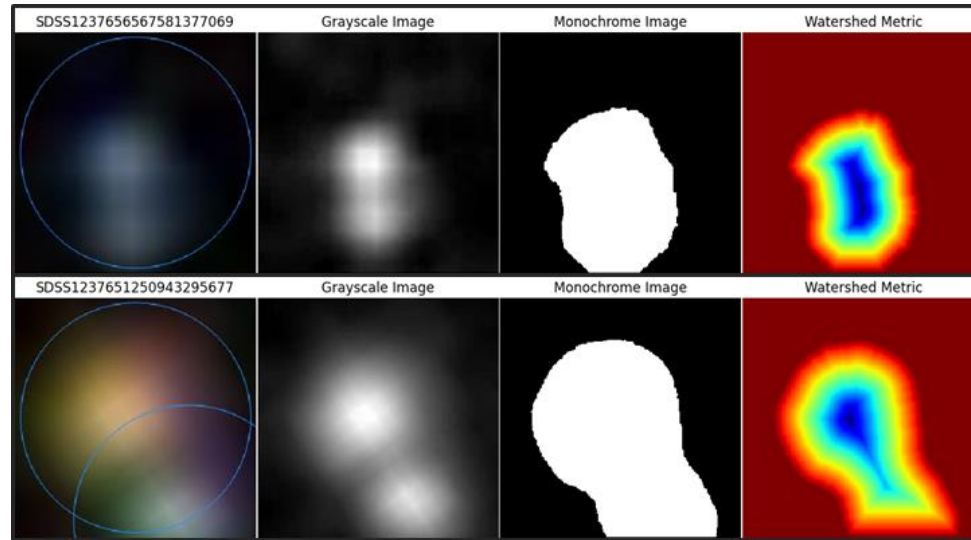




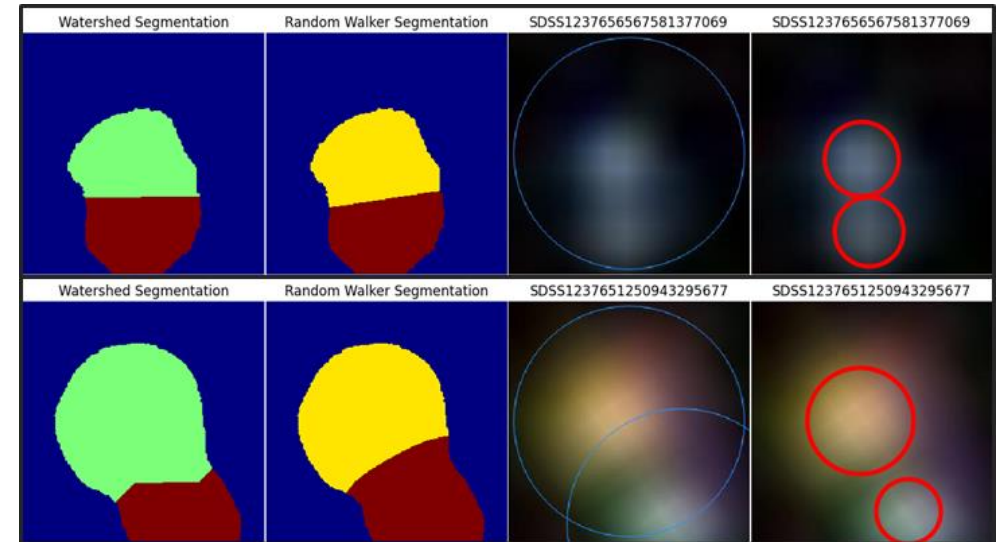
# PSF-DIFFERENCE ALGORITHM -- DEBLENDING

$$\sqrt{\frac{F_g}{a_x}}$$

Image preparation  
and metric  
generation



Segmentation  
steps and results



70,823 candidates remain

# VISUAL REVIEW



**Tens of thousands of candidates still passed the segmentation algorithm. What's next?**

- **Visual Scan 1: Pranav**

- Looked for candidates with similar visual colors and brightness
- Ignored extended, faint, and unclear lens candidates
- Most likely candidates labeled as Type 1 and move on to second scan
- Other possible candidates classified as Type 2 or Type 3 depending on similarity of possible lensed images

**156 candidates remain**

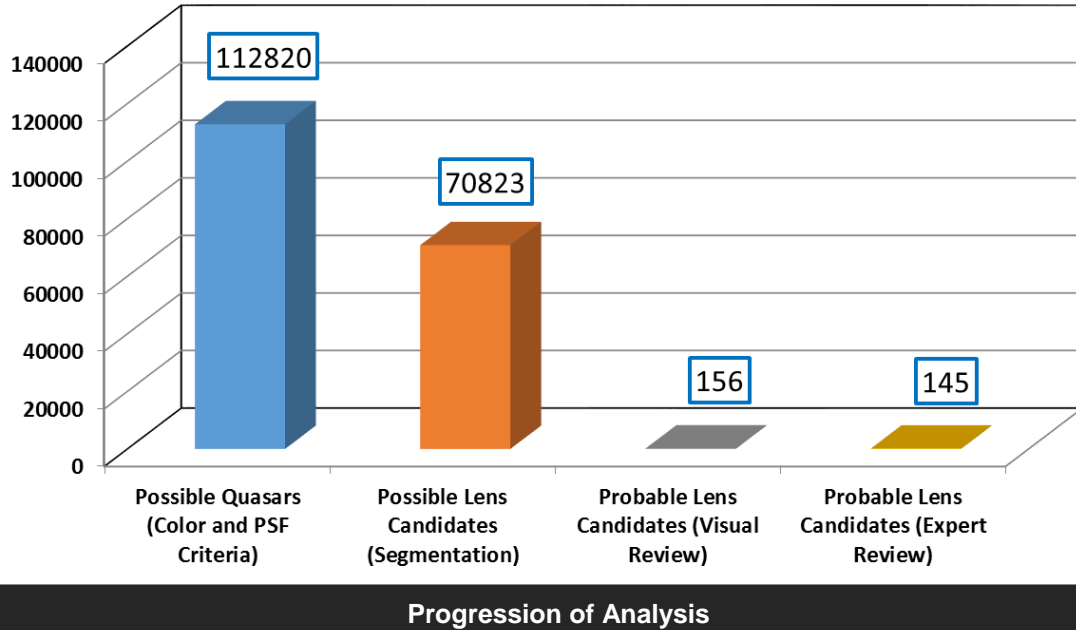
- **Visual Scan 2: FNAL scientists**

**145 final lensed quasar candidates!**

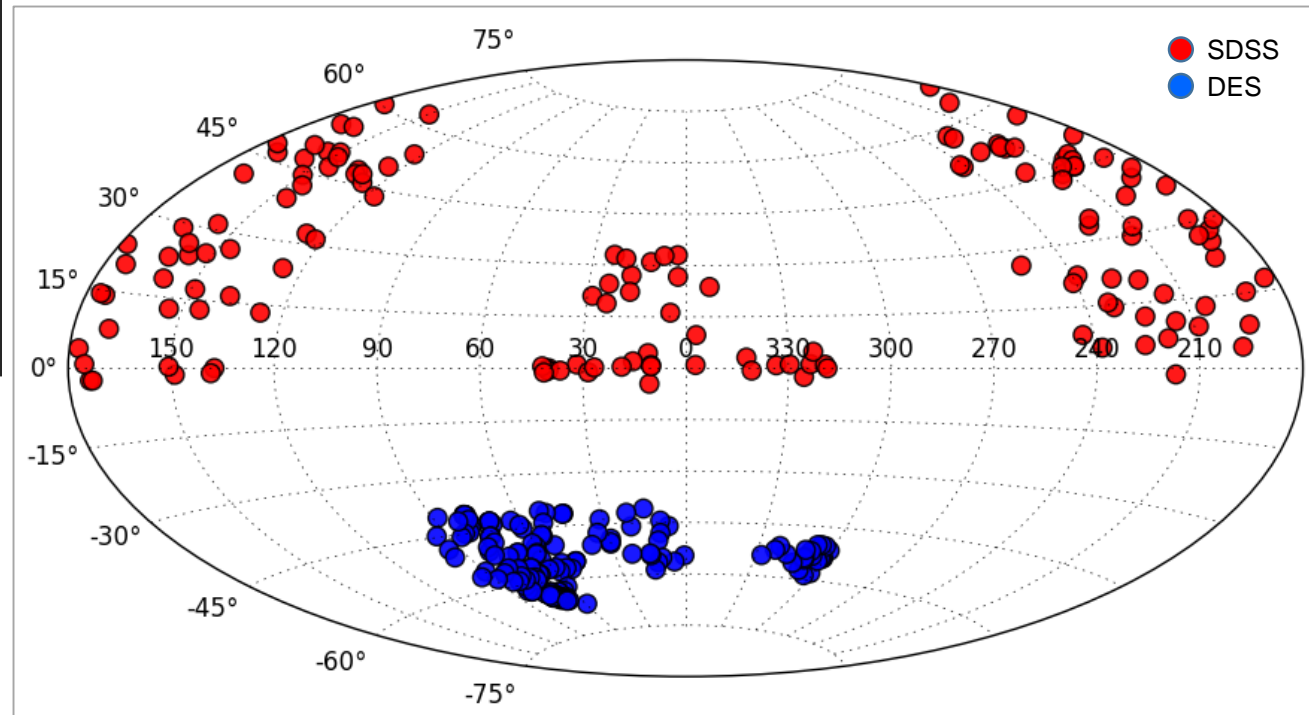


# RESULTS SUMMARY

$$\sqrt{\frac{F_g}{a^2}}$$



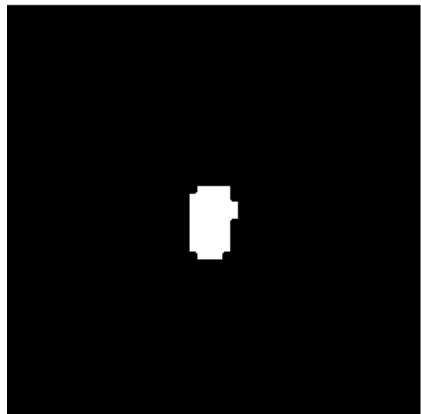
Candidate List	Visual Observation Criteria	# of Candidates
Type 1	High level of similarity	156
Type 2	Medium level of similarity	111
Type 3	Low level of similarity	698



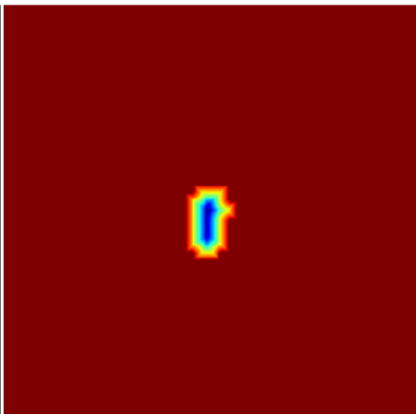
# HIGH-PROBABILITY LENS CANDIDATES

$$\sqrt{\frac{Fg}{ax}}$$

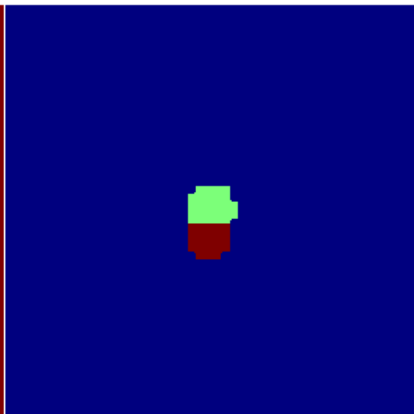
Monochrome Image



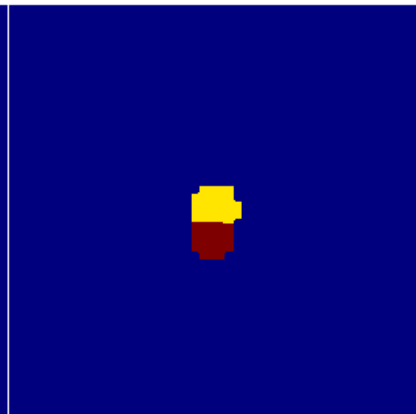
Watershed Metric



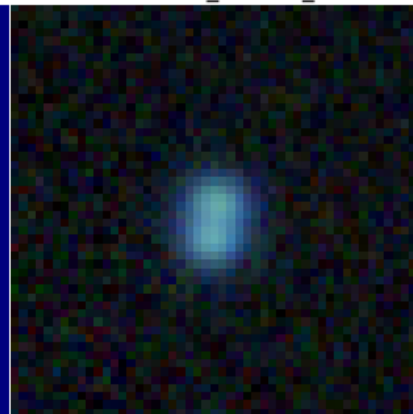
Watershed Segmentation



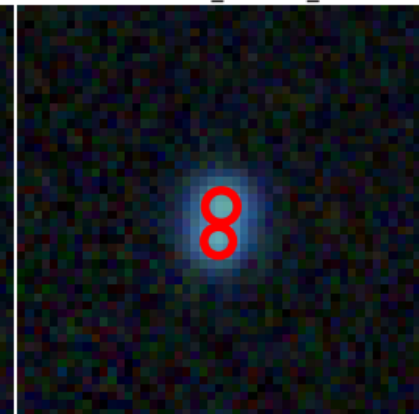
Random Walker Segmentation



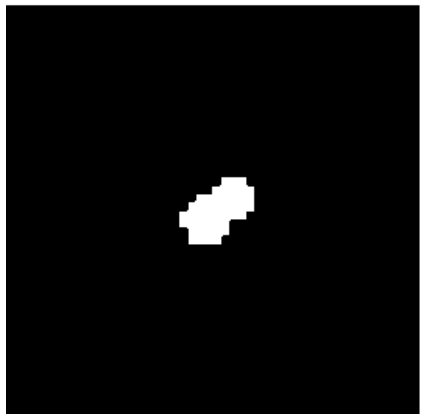
DES0123-4206\_21.241\_-41.954



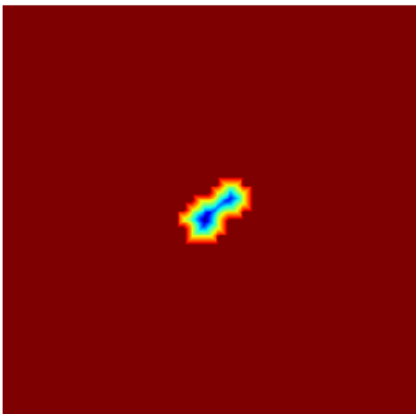
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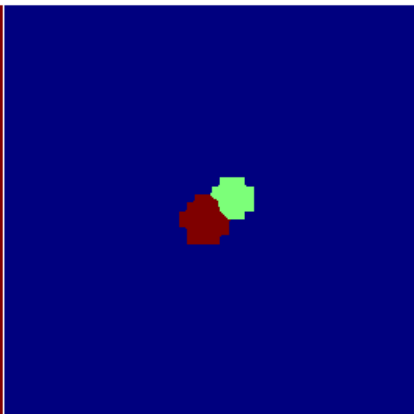
Monochrome Image



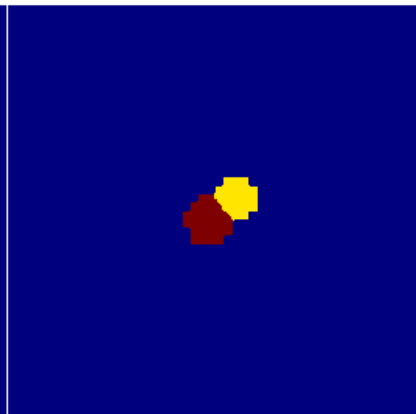
Watershed Metric



Watershed Segmentation



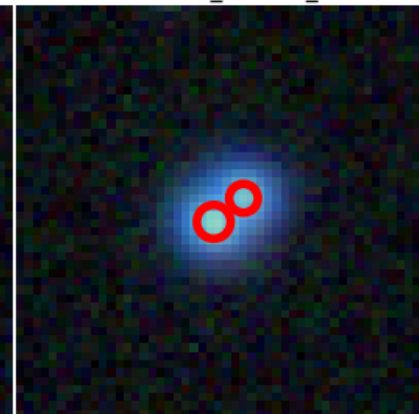
Random Walker Segmentation



DES0100-5414\_15.005\_-53.951



DES0100-5414\_15.005\_-53.951





# CURRENT AND FUTURE WORK

$$\sqrt{\frac{F_g}{a_x}}$$

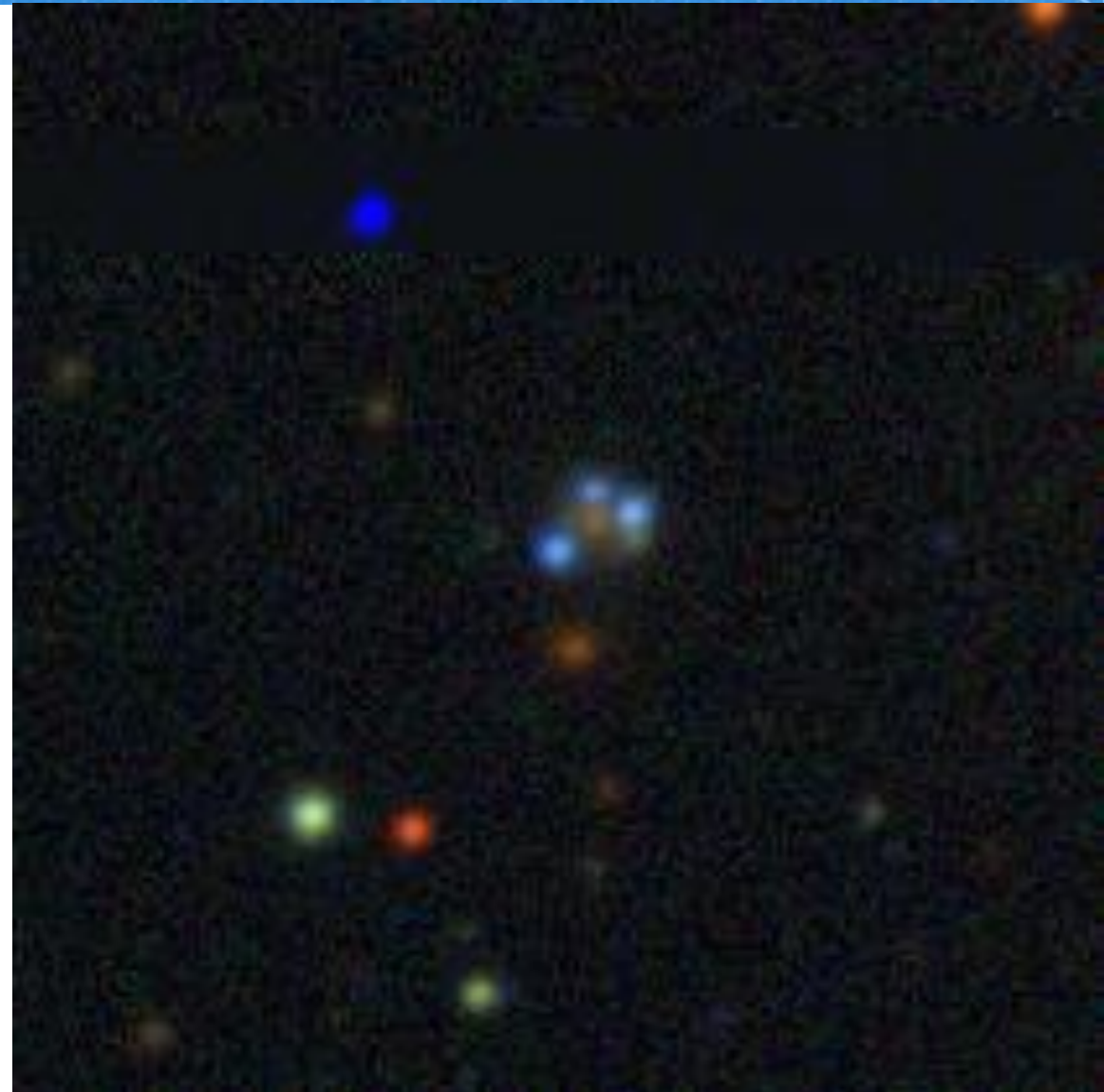
In addition to matching known lensed quasars, the **algorithm identified many new lensed quasar candidates from DES**

- **Current work**

- Use WISE magnitudes to confirm that identified candidates are quasars
- PSF cross-correlation with candidates and confirmed lenses identified by other DES groups
- Applying morphological algorithm to DES data

- **Extensions to research**

- Follow-up on PSF candidates using Gemini
- Testing PSF-difference algorithm on simulations to gauge effectiveness
- Gravitational lens modeling using GLAFIC / GravLens to identify potential lensing objects and mass models
- Applications to dark matter and dark energy

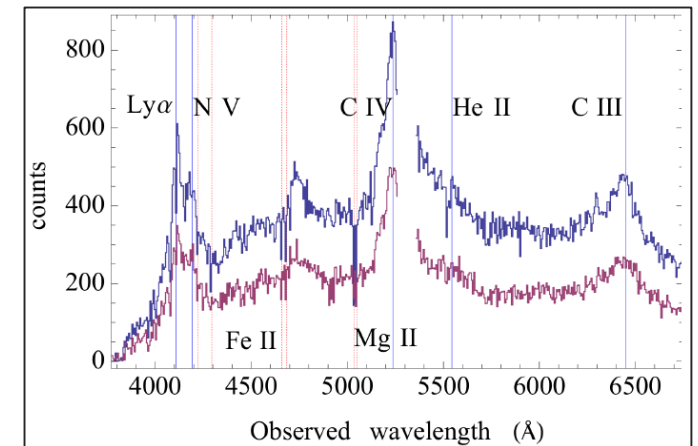
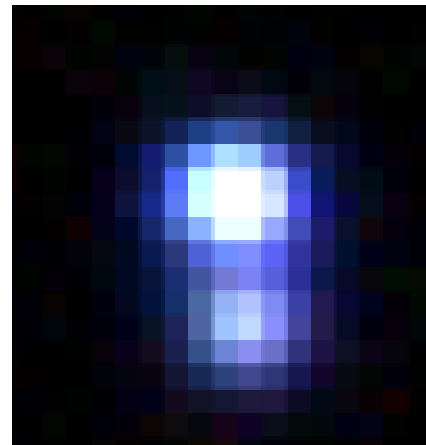


# GEMINI FOLLOW-UP

$$\sqrt{\frac{F}{a^2}}$$

**About 10 final candidates (possibly more) to be confirmed using Gemini**

- Gemini – 8-meter telescope located in Hawaii
- Imaging and spectral observations
  - Check for presence of lensed images
  - Check for lensing galaxy
  - Compare spectra of lensed images





# ACKNOWLEDGMENTS

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Fermilab, Co-Mentor

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Fermilab

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Fermilab

**DES Collaboration**

**QuarkNet Program**



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