

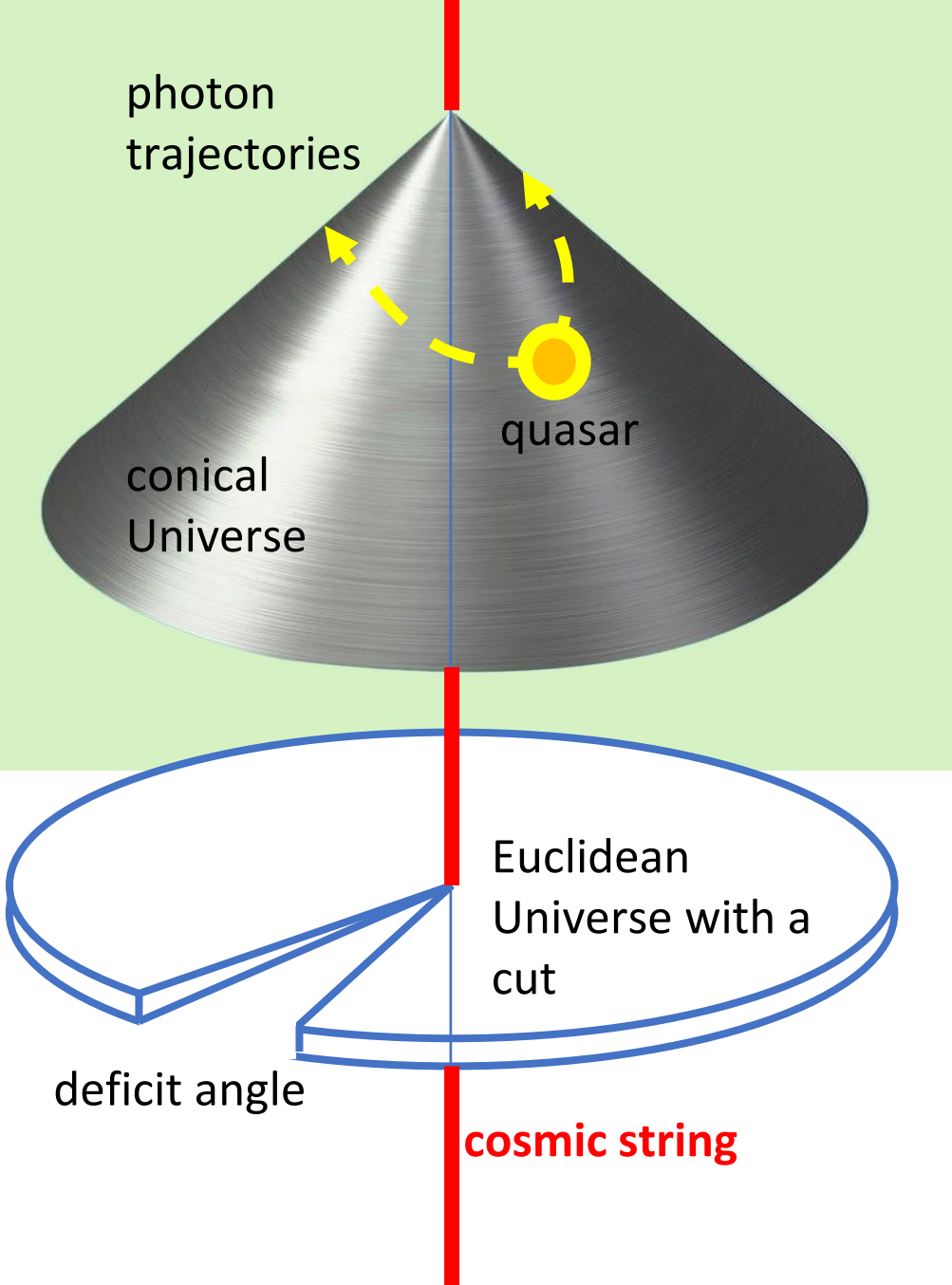
Search for cosmic strings: modeling of gravitational lensing and observational perspectives

Olga Sazhina
(SAI MSU)

with Igor Bulygin, Olga Solodilova

QUARKS-2026

18–23.05.2026



$$E = \int d^3x T^{00} = \mu \int d\sigma = \mu \cdot \Delta\sigma$$

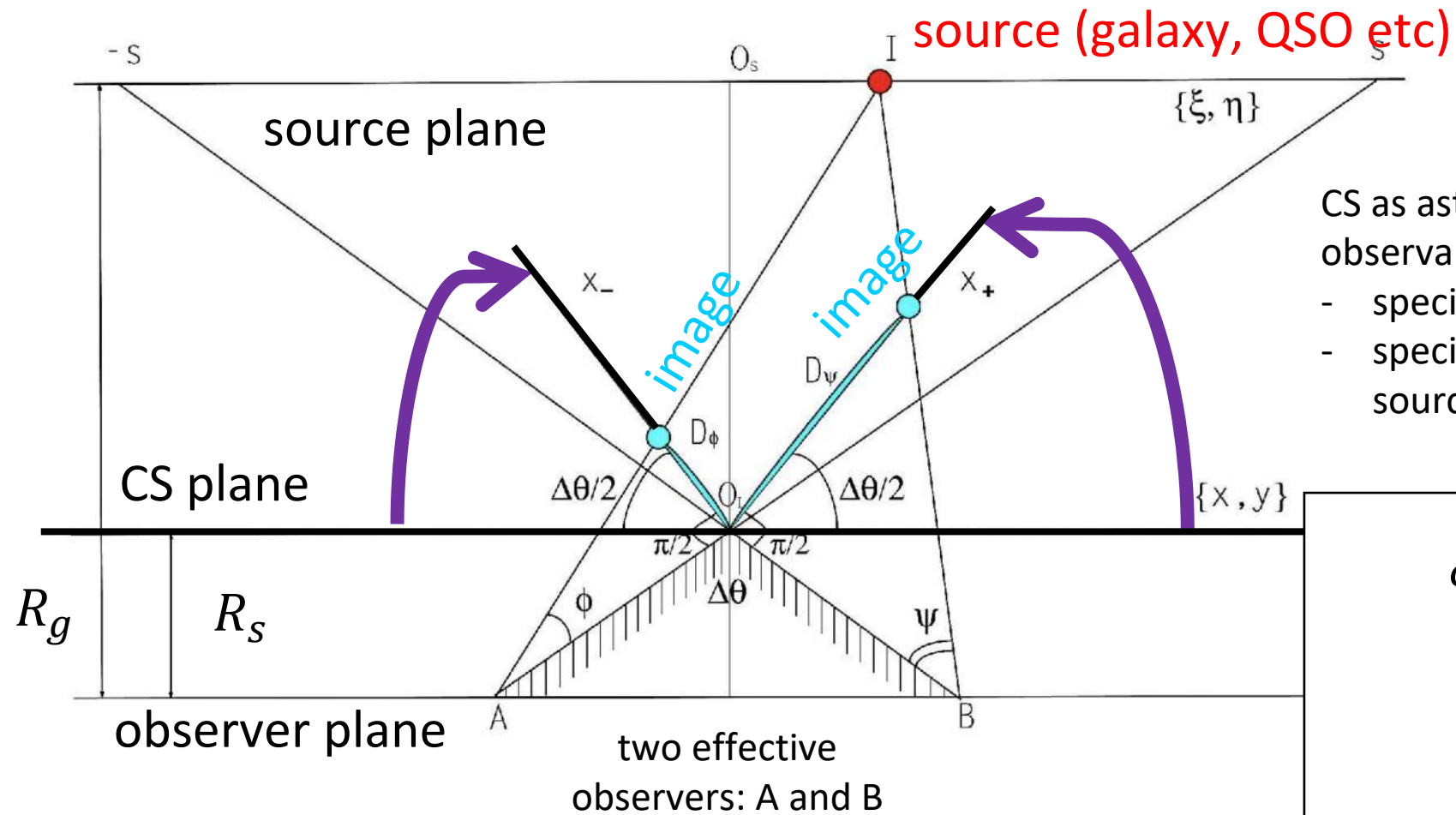
$$ds^2 = c^2 dt^2 - dz^2 - dr^2 - r^2 \left(1 - \frac{4G\mu}{c^2}\right)^2 d\varphi^2$$

A. Vilenkin,
1980

$$\varphi' = \varphi(1 - 4G\mu/c^2), \quad \varphi' \in [0, 2\pi - \Delta\theta],$$

$$\Delta\theta = 8\pi G\mu/c^2$$

All effects are related with angles (when re-defining the angle, we get a flat metric). Flat space with cut is the cone.



CS as astrophysical object could generate the observable effects due to the conical space-time:

- specific anisotropy in CMB,
- specific gravitational lensing of background sources.

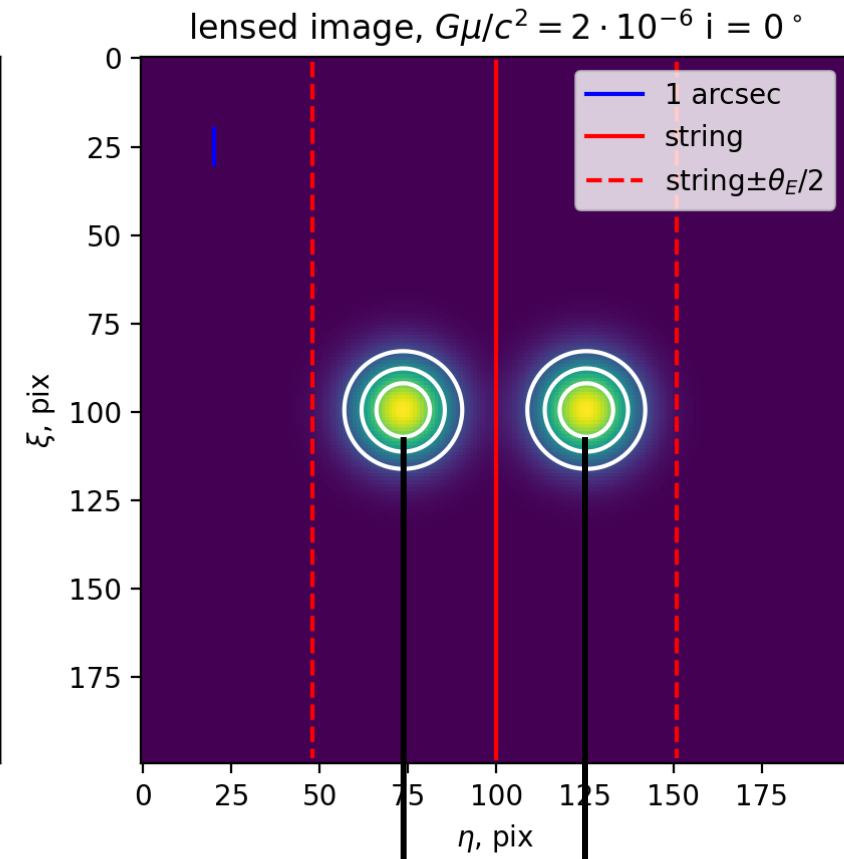
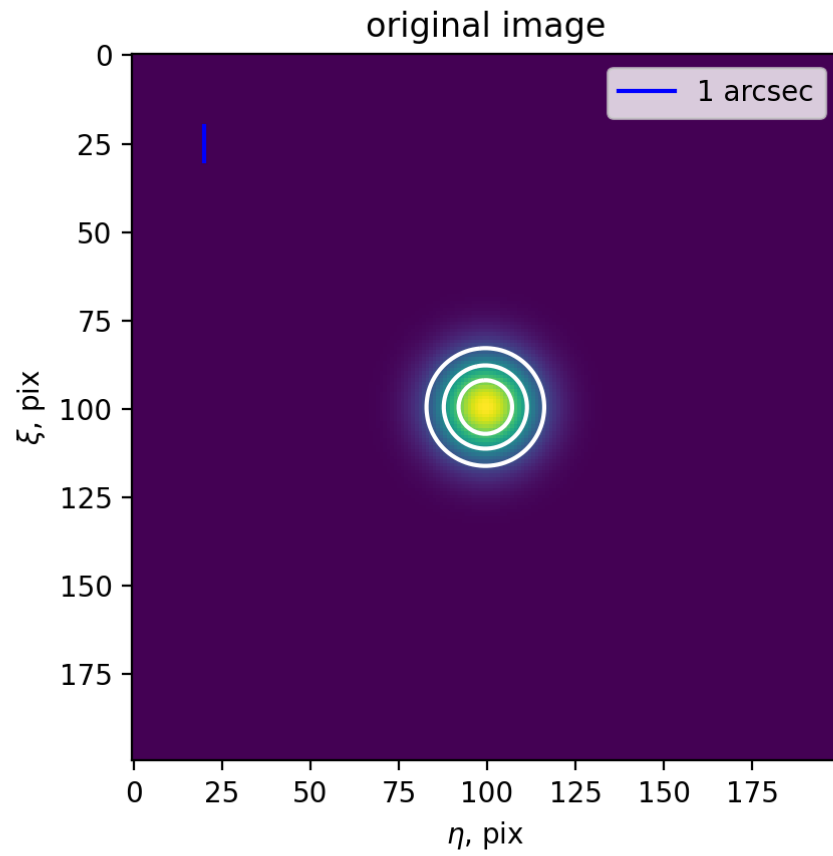
$$\phi = -\eta + 4\pi \cdot G\mu \left(1 - \frac{R_s}{R_g}\right)$$

$$\psi = \eta + 4\pi \cdot G\mu \left(1 - \frac{R_s}{R_g}\right)$$

$$I_1(\eta, \xi) = \begin{cases} I(\eta - \theta_E/2, \xi), & \eta > -\theta_E \\ 0, & \eta \leq -\theta_E \end{cases}$$

$$I_2(\eta, \xi) = \begin{cases} I(\eta + \theta_E/2, \xi), & \eta < \theta_E \\ 0, & \eta \geq \theta_E \end{cases}$$

Approximation of geometric optics.
A locally flat metric.



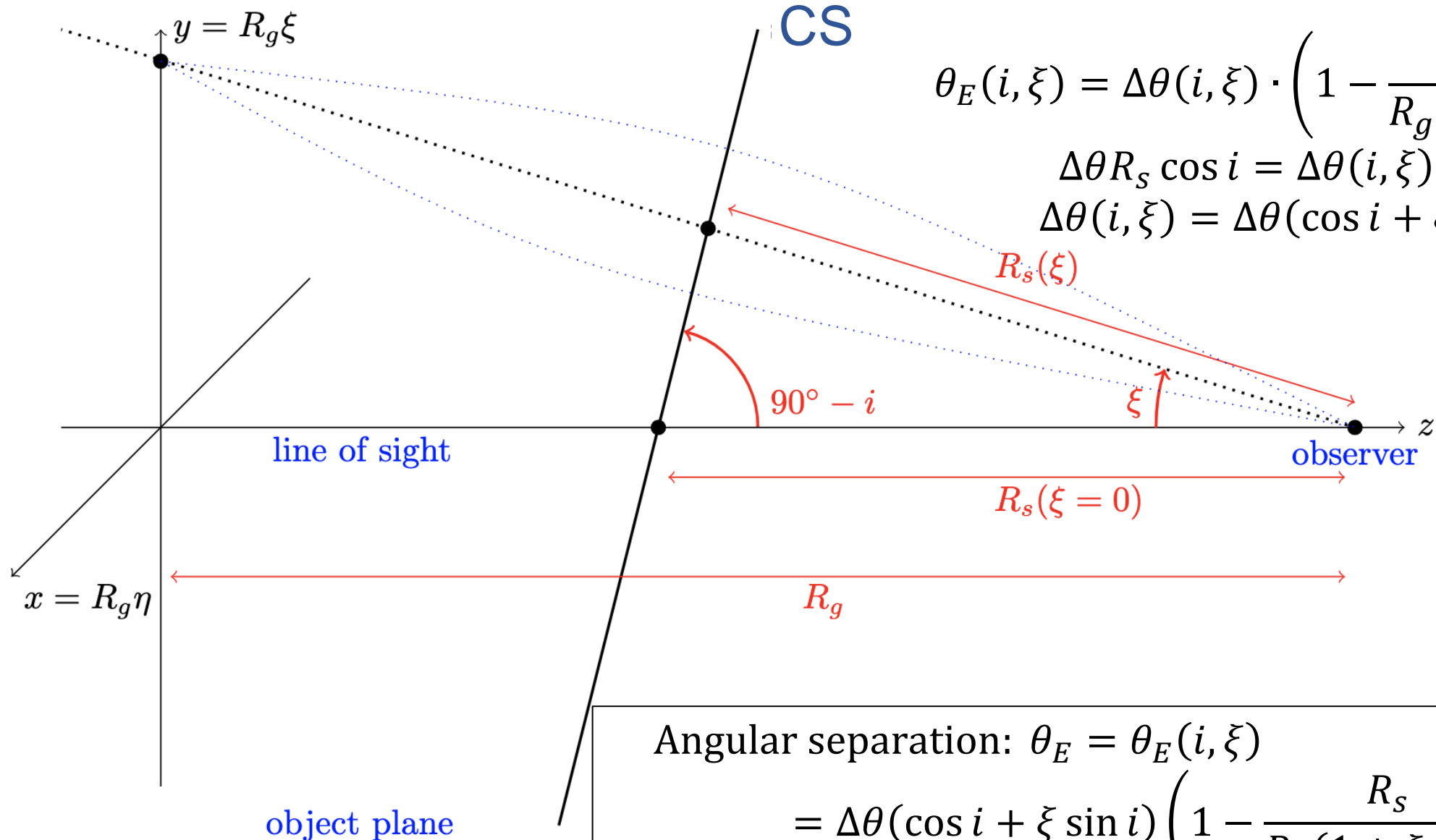
$$I_{1+2}(\eta, \xi) = \begin{cases} I(\eta + \theta_E/2, \xi), & \eta < -\theta_E \\ I(\eta + \theta_E/2, \xi) + I(\eta - \theta_E/2, \xi), & |\eta| \leq \theta_E \\ I(\eta - \theta_E/2, \xi), & \eta > \theta_E \end{cases}$$

Angular separation: $\theta_E = \Delta\theta \left(1 - \frac{R_s}{R_g}\right)$

$$\Delta\theta = 8\pi G\mu/c^2$$

CS with inclination

$$R_s(\xi) = \frac{R_s}{\cos \xi + \text{tg } i \sin \xi} \approx \frac{R_s}{1 + \xi \text{tg } i}$$



$$\theta_E(i, \xi) = \Delta\theta(i, \xi) \cdot \left(1 - \frac{R_s}{R_g(1 + \xi \text{tg } i)} \right)$$

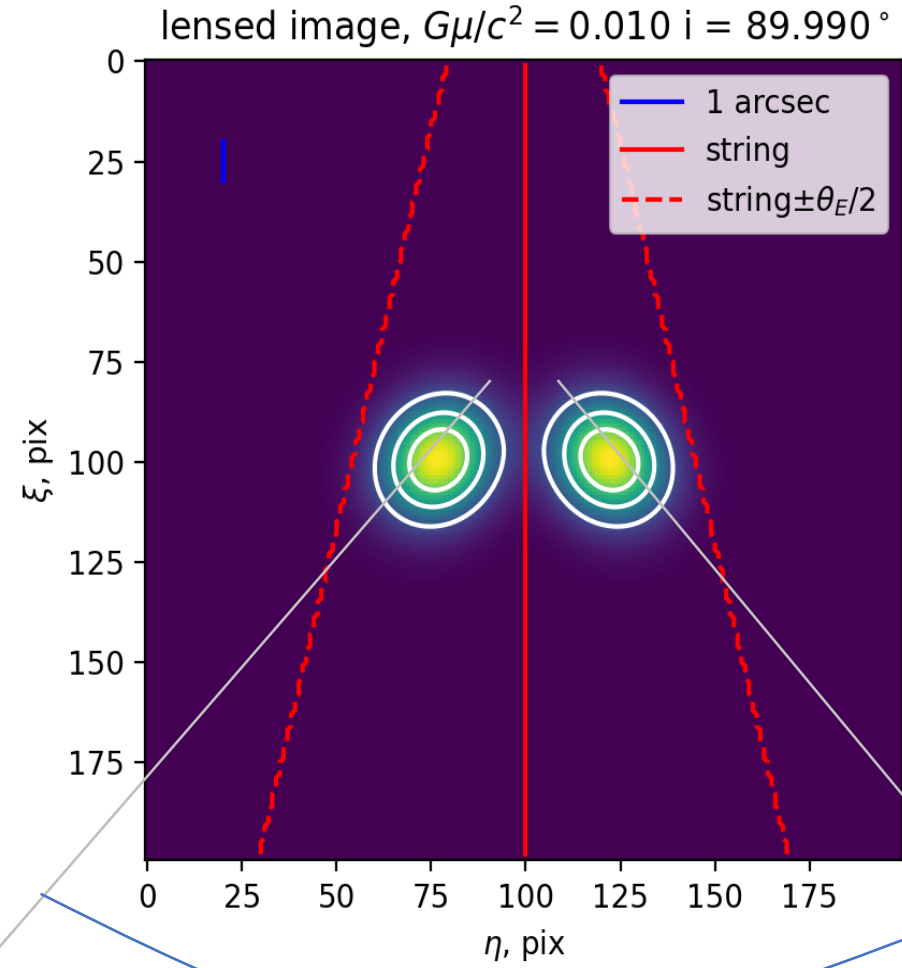
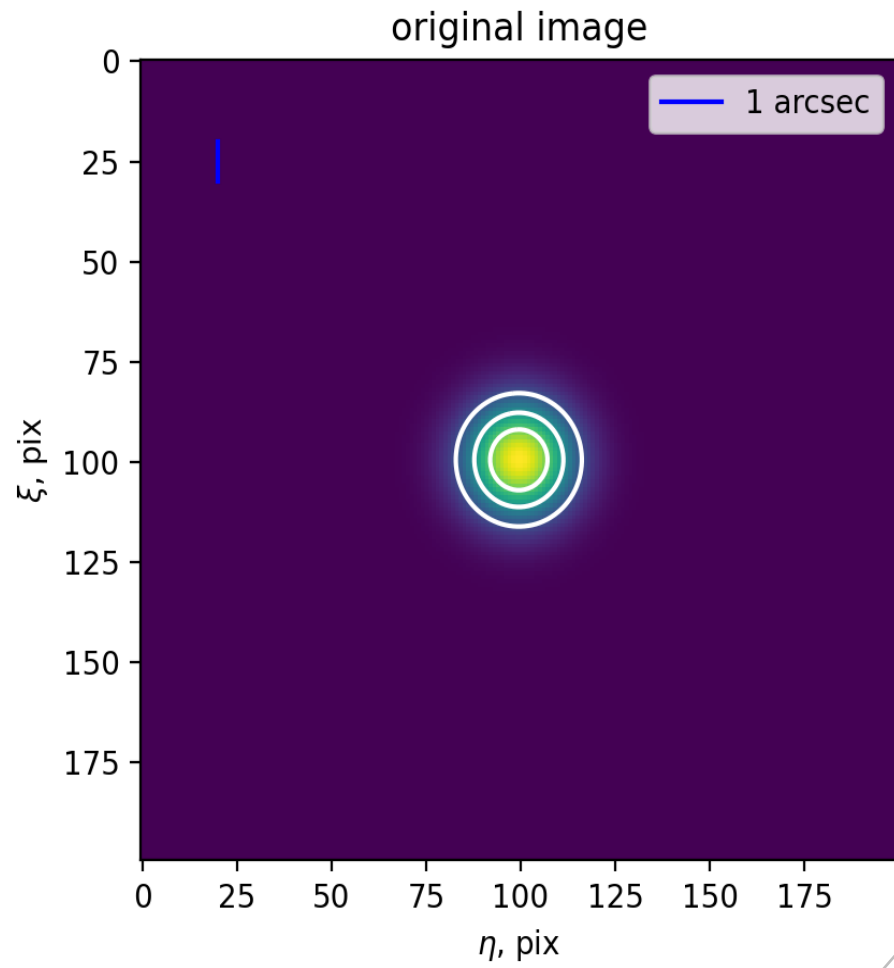
$$\Delta\theta R_s \cos i = \Delta\theta(i, \xi) R_s(\xi)$$

$$\Delta\theta(i, \xi) = \Delta\theta(\cos i + \xi \sin i)$$

Angular separation: $\theta_E = \theta_E(i, \xi)$

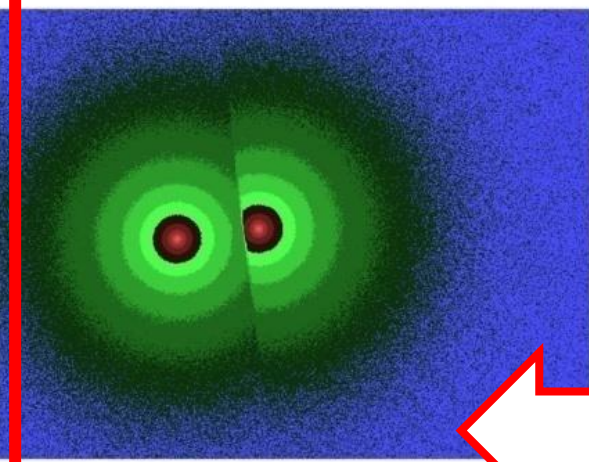
$$= \Delta\theta(\cos i + \xi \sin i) \left(1 - \frac{R_s}{R_g(1 + \xi \text{tg } i)} \right) \neq \text{const}$$

CS with inclination



positional angle

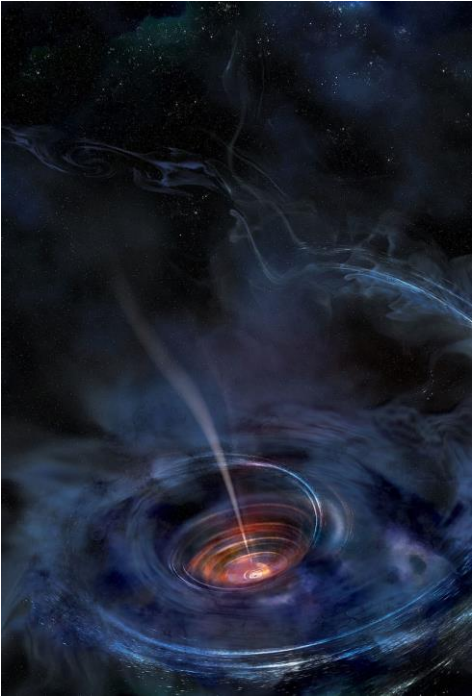
Modern methods of cosmic string detection:



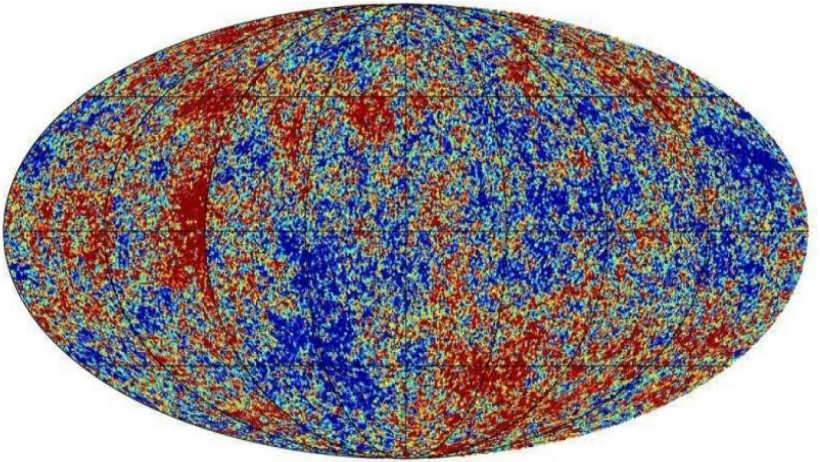
search for special gravitational lensing events (excess in number, isophotes cut etc).

For CS perpendicular to the line "observer - source"

The diagram shows two red dots representing sources, each surrounded by concentric green circles representing light waves. A vertical grey line represents the cosmic string. A red arrow points from the text to the diagram.

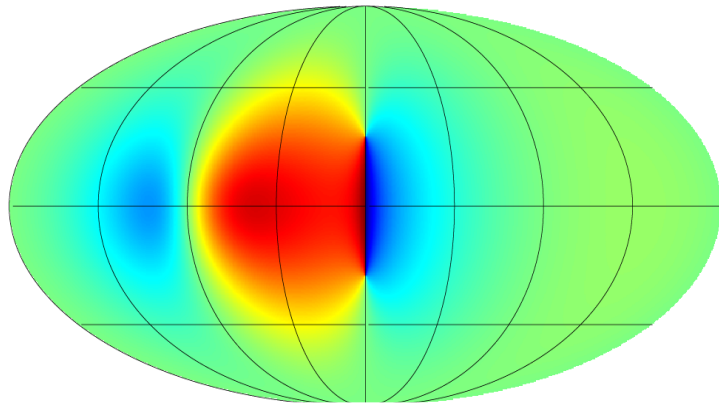
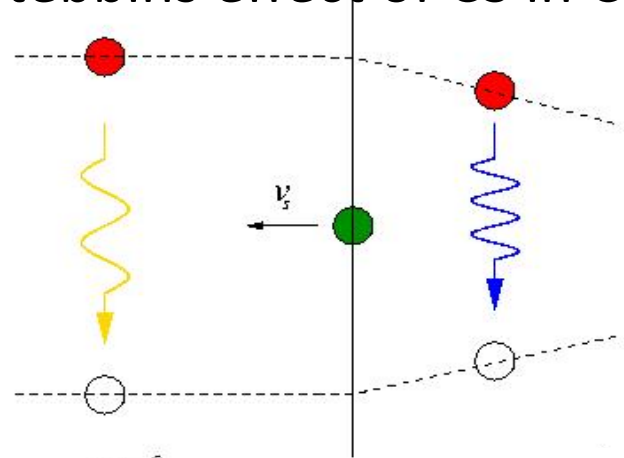
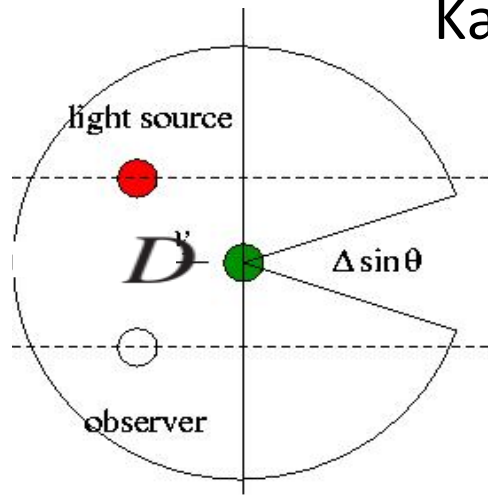


gravitational radiation of CS loops;
the CS-BH, CS-CS interactions;
the decay of heavy particles emitted by a CS;
some model depended exotic methods.

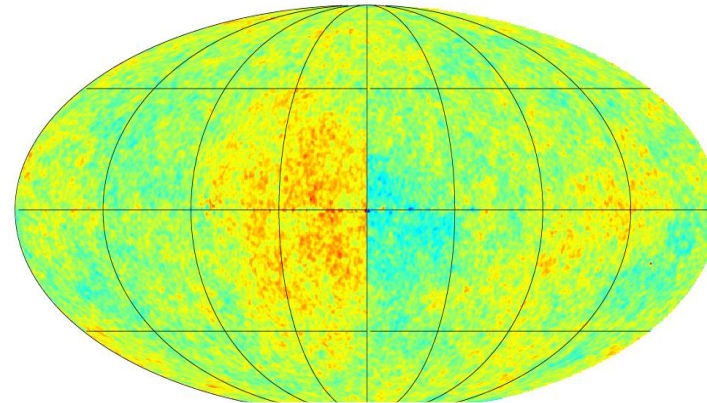


analysis of the anisotropy structure of CMB (WMAP, Planck etc).

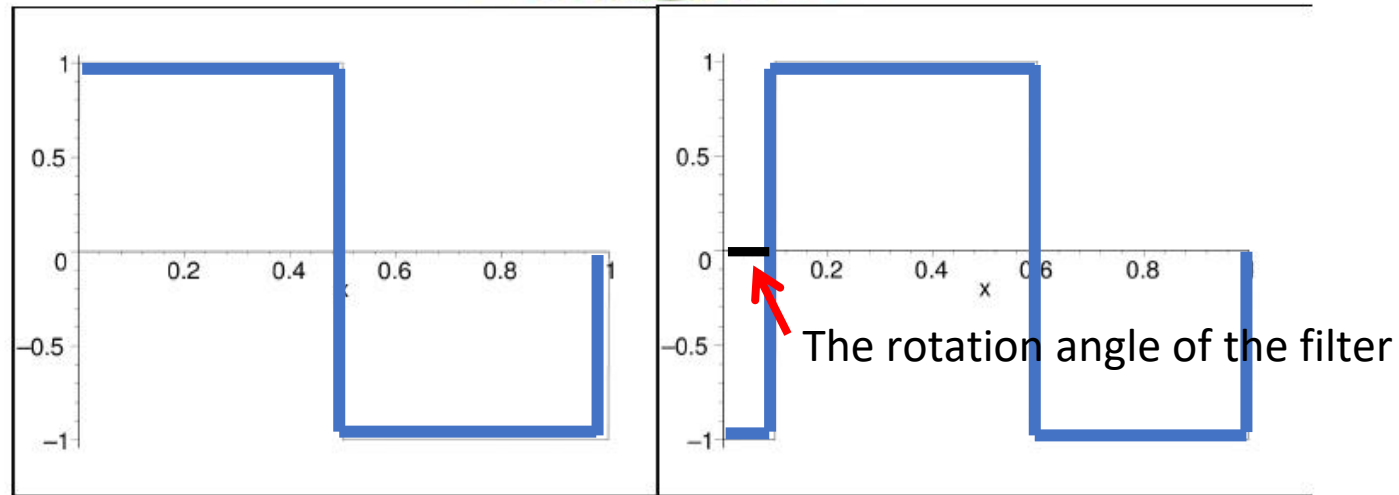
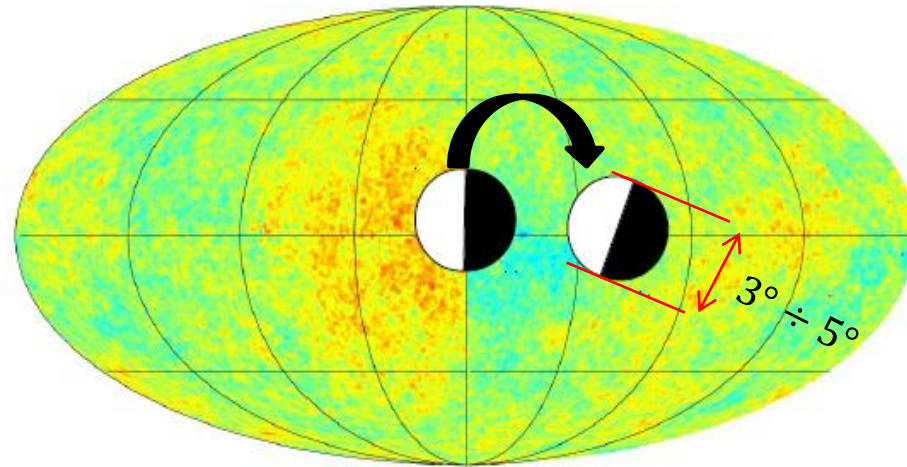
Kaiser-Stebbins effect of CS in CMB anisotropy



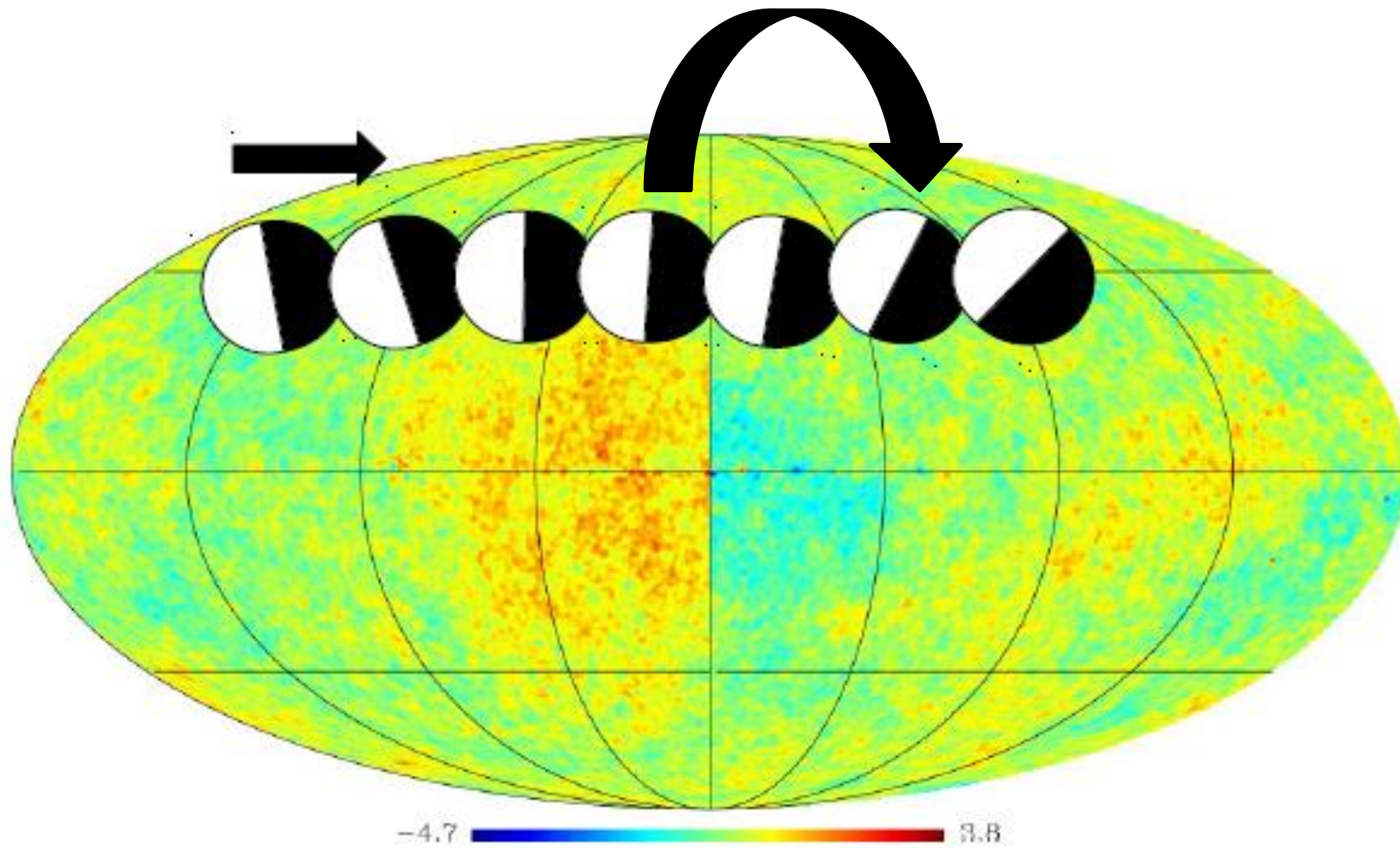
Model of anisotropy induced by single straight CS



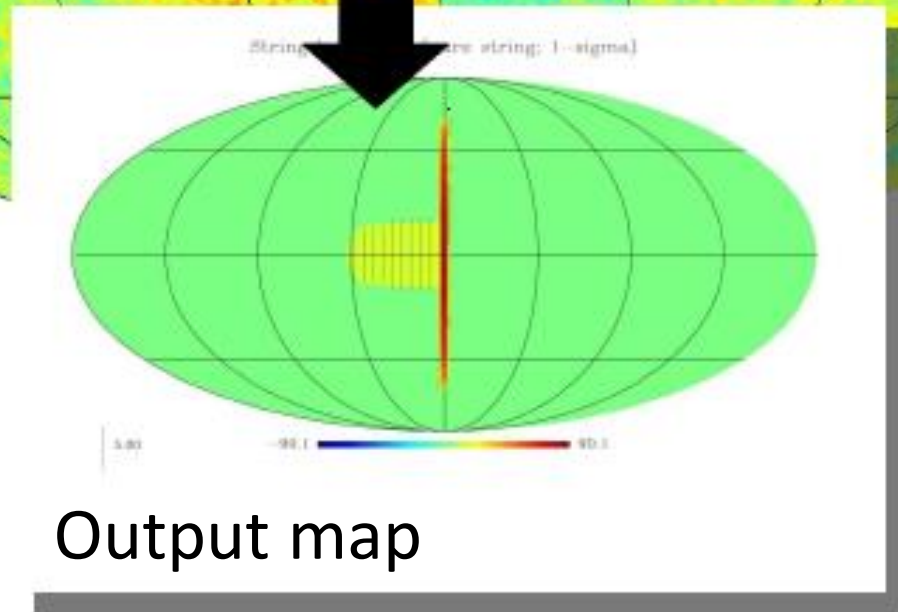
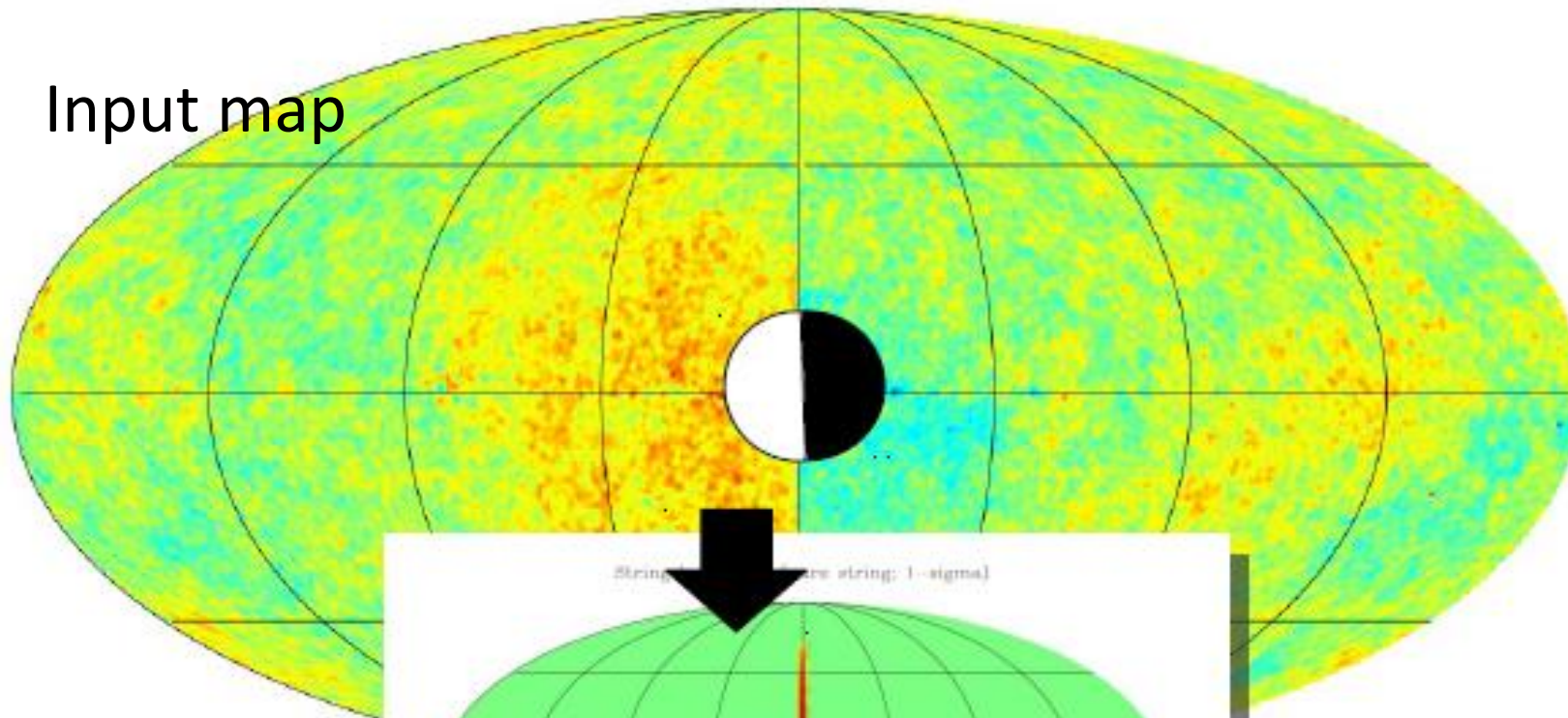
WMAP data + model of anisotropy induced by single straight CS ($\delta T \approx 150 \mu K$)



Modified Haar wavelet



Input map



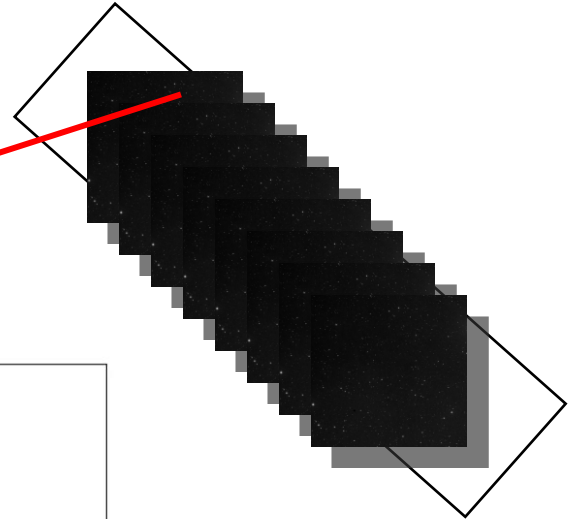
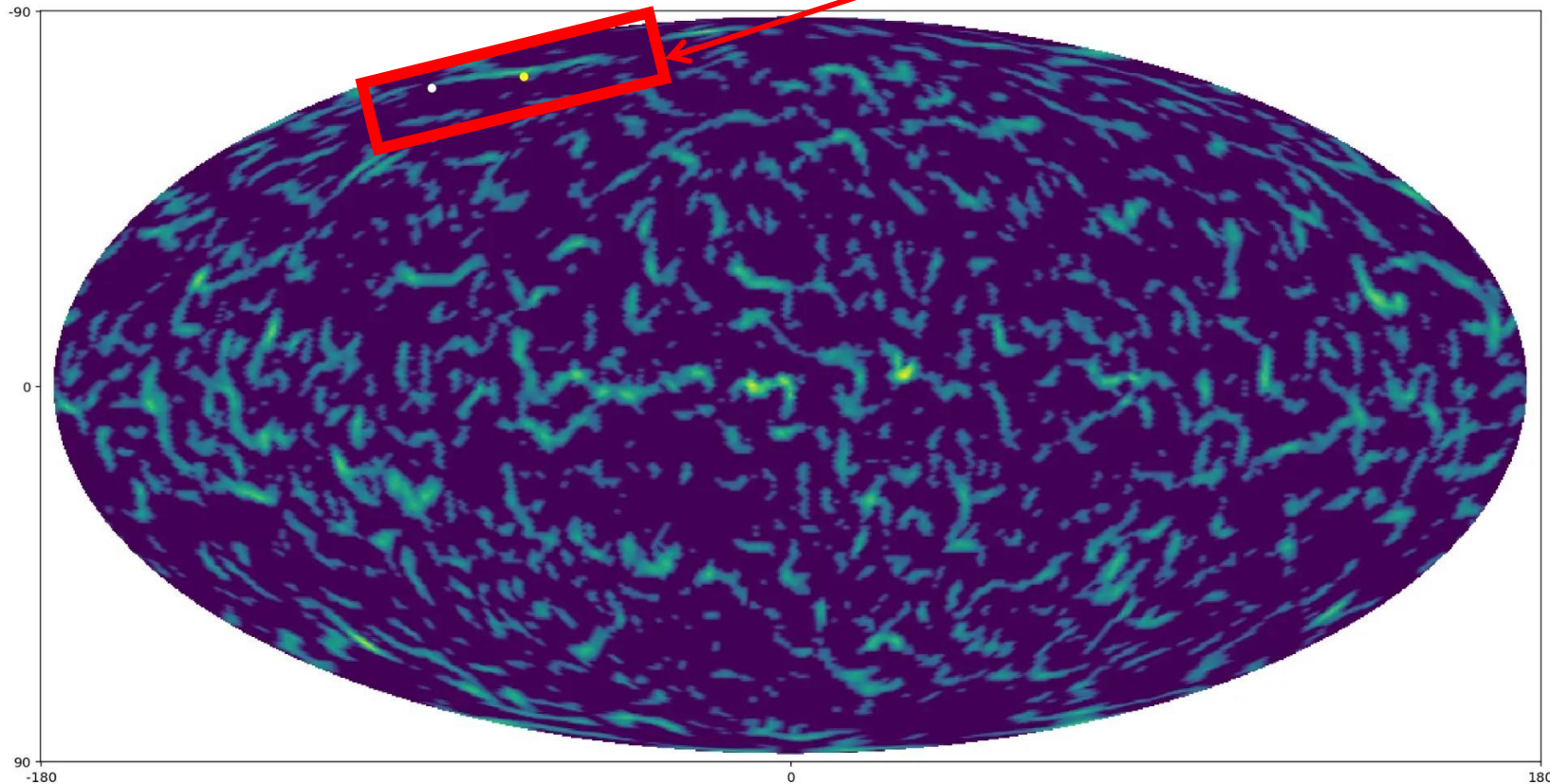
Output map

The result of processing the CMB data (Planck) by the Haar filter

$$\delta T \approx 40 \mu K, \Delta \theta \approx 3'' (v = 0.9c)$$

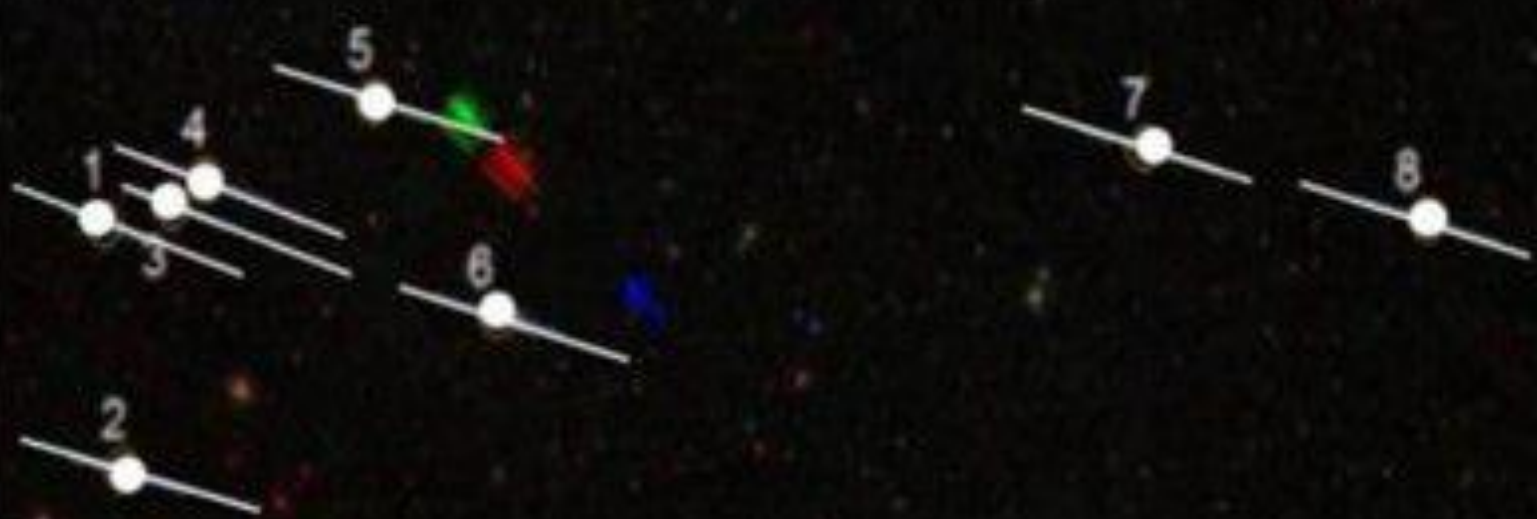
$$\alpha = 11:29:03, \delta = +15:23:37;$$

$$\alpha = 10:57:47, \delta = +25:03:51.$$



GR candidates (double galaxies)
with the same CS orientation

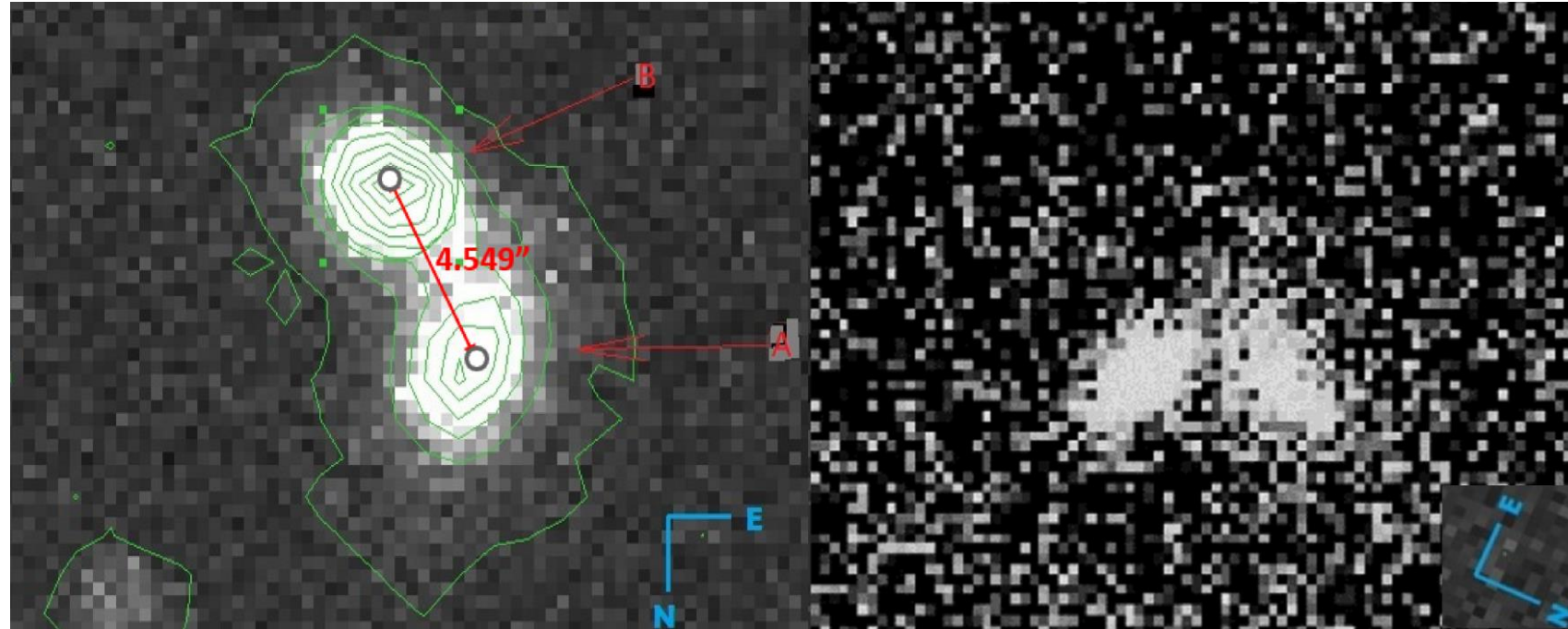
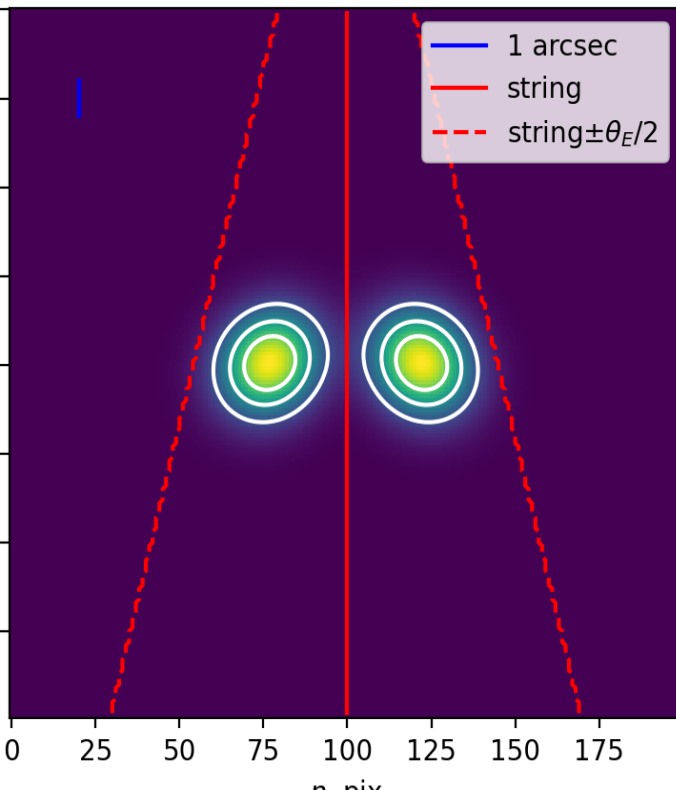
SDSSJ110429

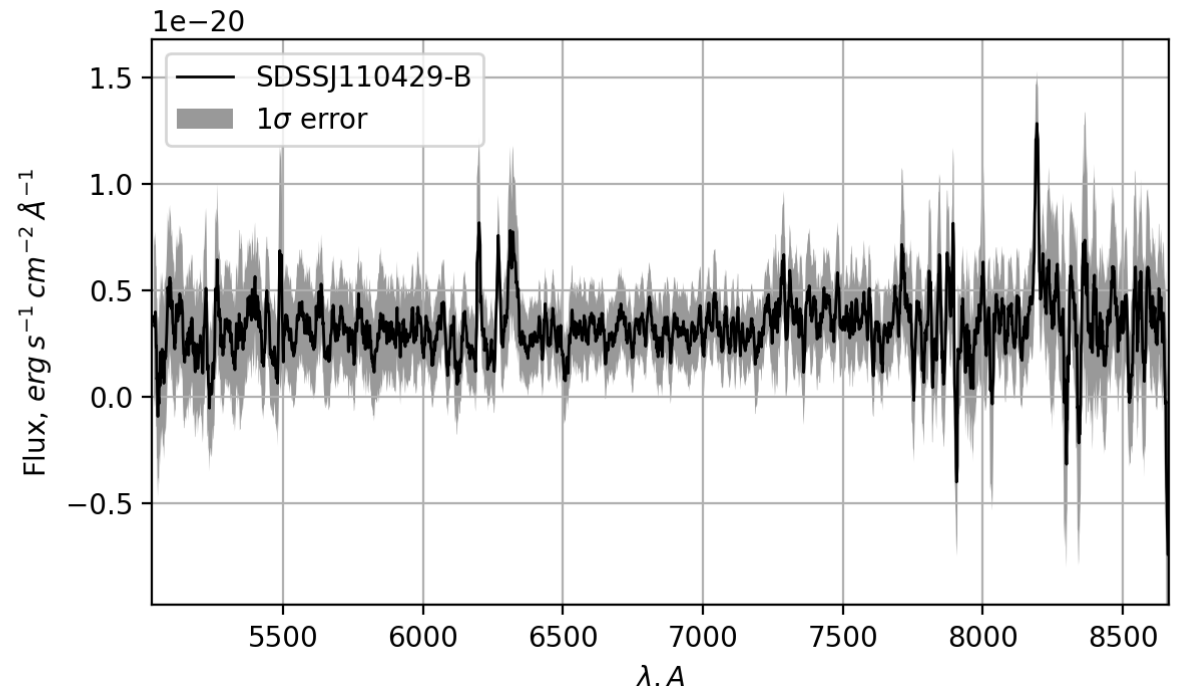
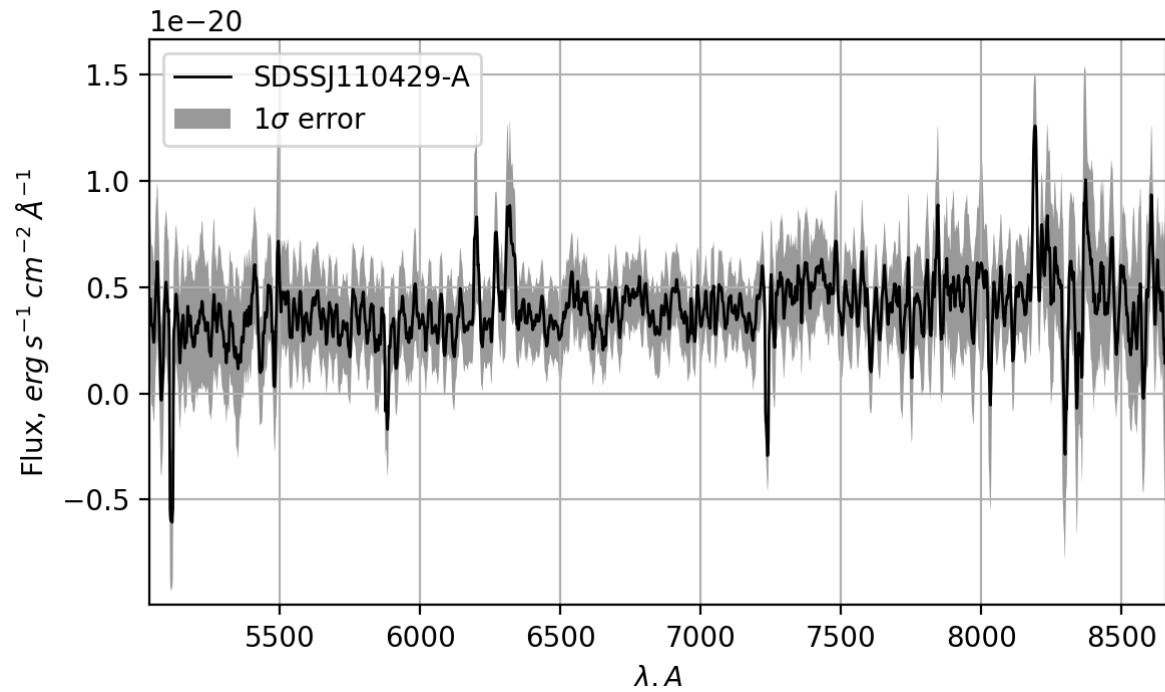


Object SDSS J110429 (7.03.2022 observations)

Himalayan Chandra Telescope of the Indian
Astronomical Observatory (IAO), located at 4500 m above sea
level; $D = 2,0$ m
 $0.296''/\text{pix}$

lensed image, $G\mu/c^2 = 0.010$ $i = 89.990^\circ$





Smoothing on the scale $\delta\lambda = 3.6 \text{\AA}$

$z = 0.236$

$p = 90\%$

($N = 1000$; Pearson\Spearman\Kendall r :
0.571\0.613\0.447)

Strong indication on gravitational nature of two components.

Several lines ($\text{H}\alpha$, $\text{H}\beta$, $[\text{OIII}]\lambda 5007$, $[\text{NII}]\lambda 6583$, $[\text{SII}]\lambda 6718$, $[\text{SII}]\lambda 6733$ and $[\text{OI}]\lambda 6300$) were identified and fitted by a Gaussian profile. In order to analyze the properties of spectra without the noisy continuum, χ^2 criteria was calculated for profiles of strongest lines $\text{H}\alpha$, $\text{H}\beta$ and $[\text{OIII}]\lambda 5007$, and for the widths of all lines. Identity with p-value 90%.

$$\frac{G\mu}{c^2} = 0.05$$

$$i = 89.9995^\circ$$

$$R_s \setminus R_g = 0.31$$

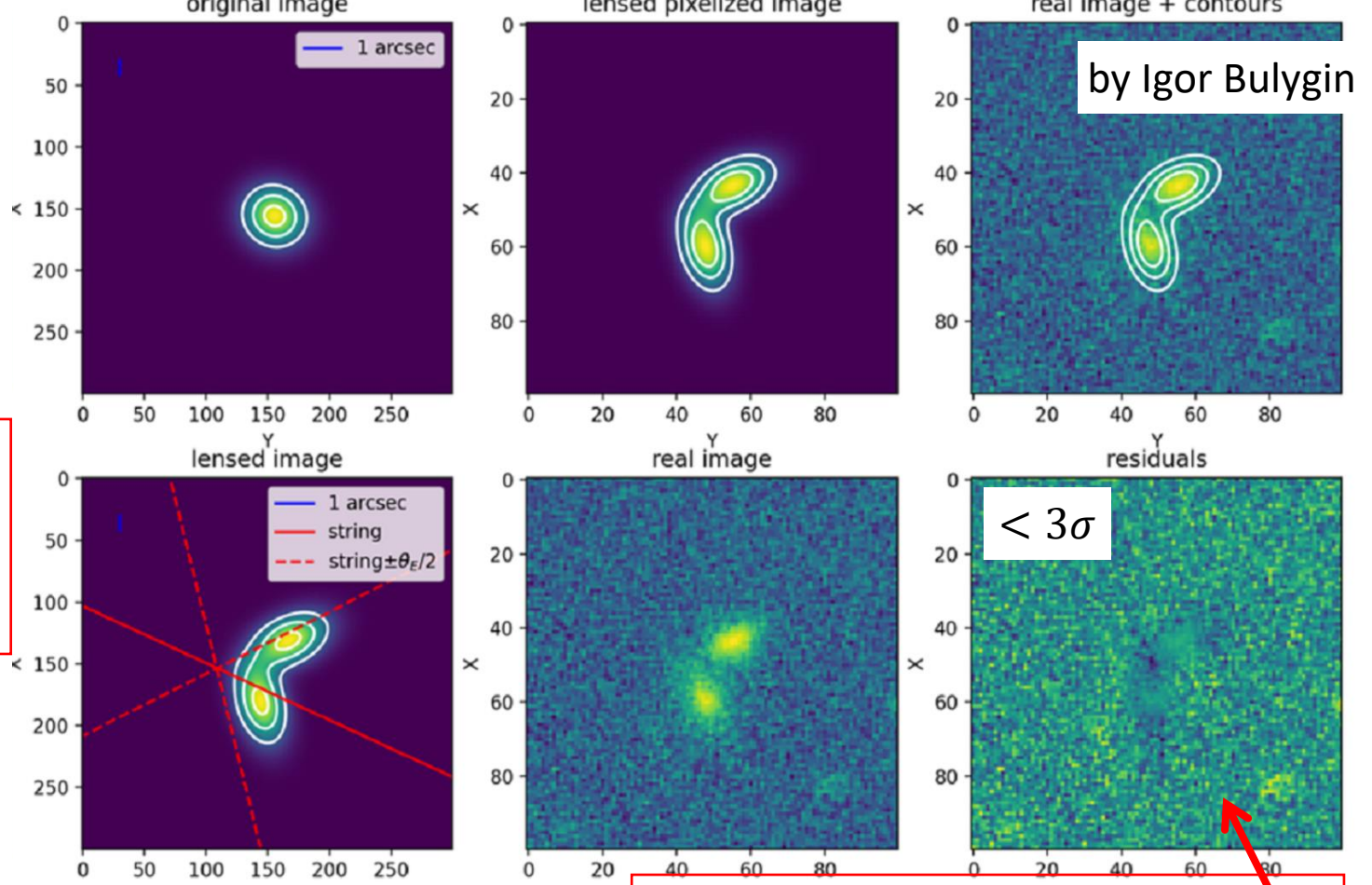
GUT ($> 10^{16} GeV$)
cosmic string? non
topological cosmic
string?

$v \ll c$; rejection of
the concept of
relativistic cosmic
strings?

$$\frac{\delta T}{T} \approx \frac{G\mu}{c^2} \cdot \gamma \cdot \frac{v}{c}$$

$$\delta T \approx 38 \mu K$$

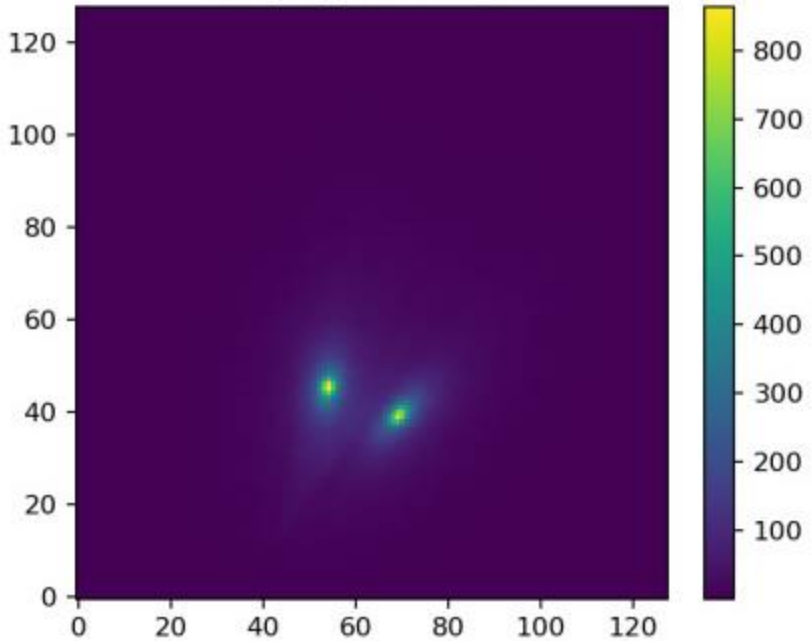
$$\chi^2 = \sum_{i,j} \frac{\left((I^{(model)} * PSF)_{ij} - I_{ij}^{(observation)} \right)^2}{\sigma_{ij}^2}$$



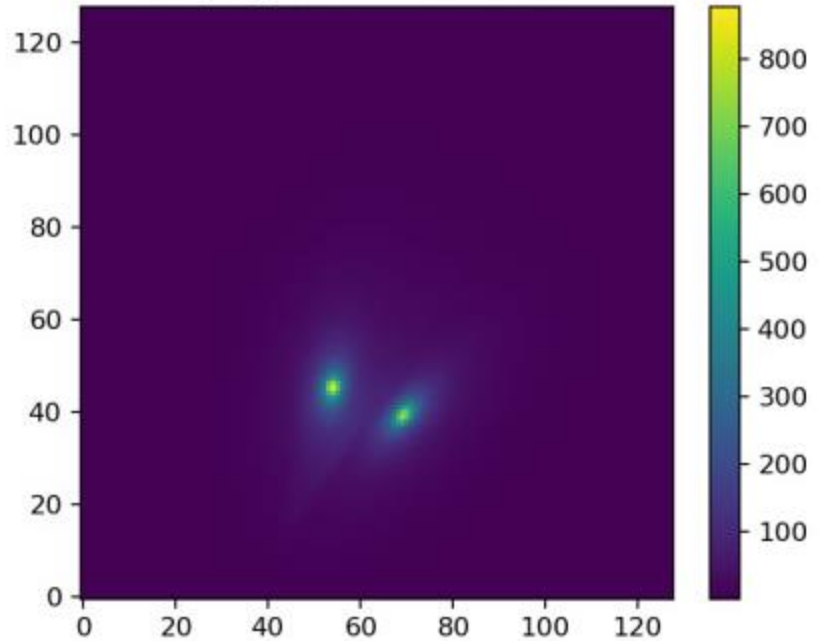
The difference between the
gravitational lensing model of a
galaxy on an inclined CS and the
observational data of the object
SDSS J110429

2026, by Igor Bulygin

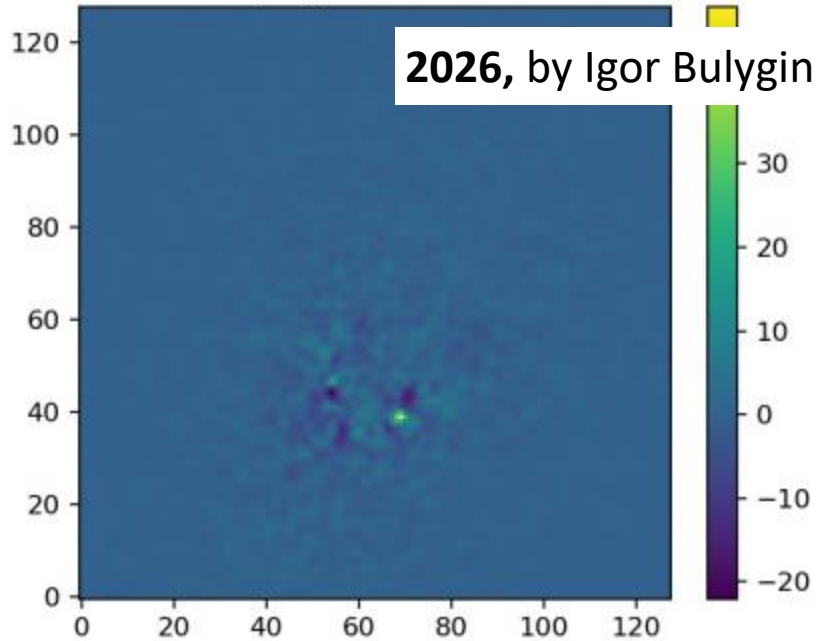
sample_00007: data



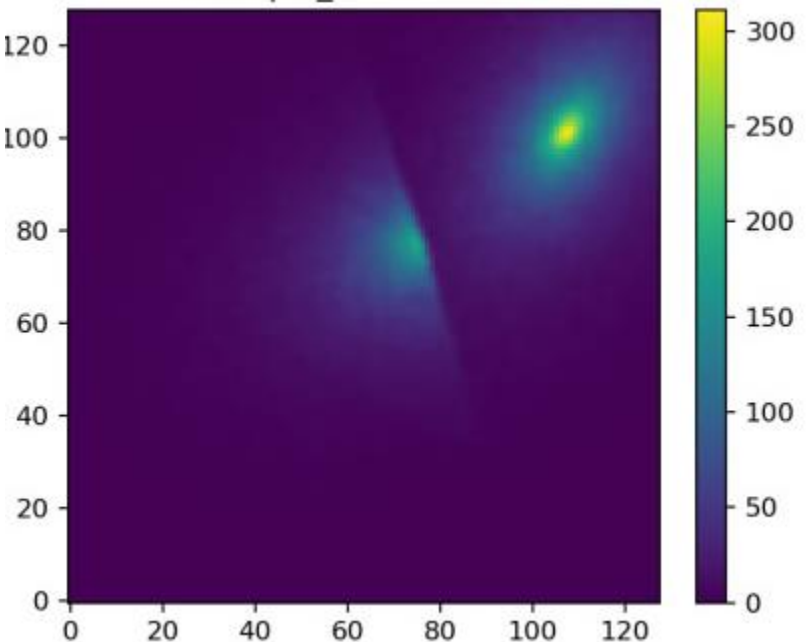
sample_00007: best-fit model



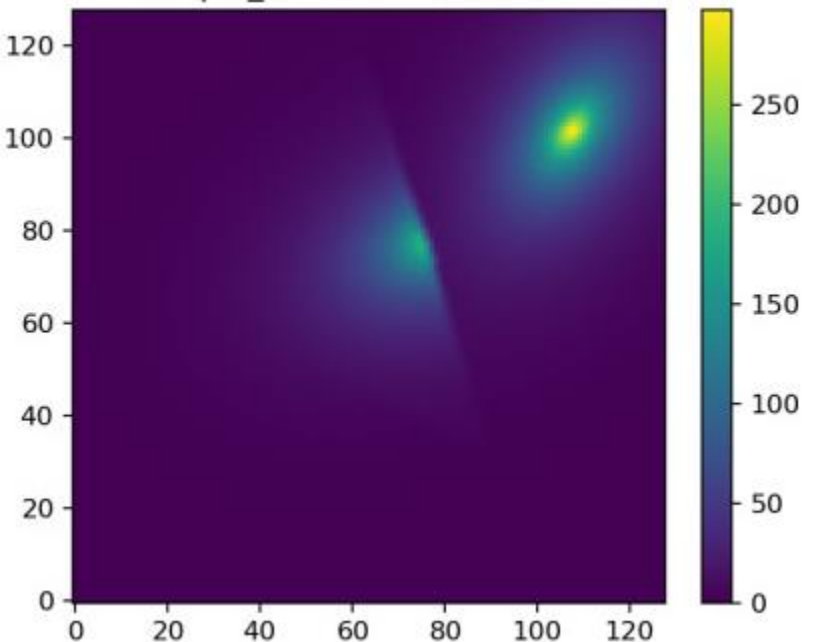
sample_00007: residual



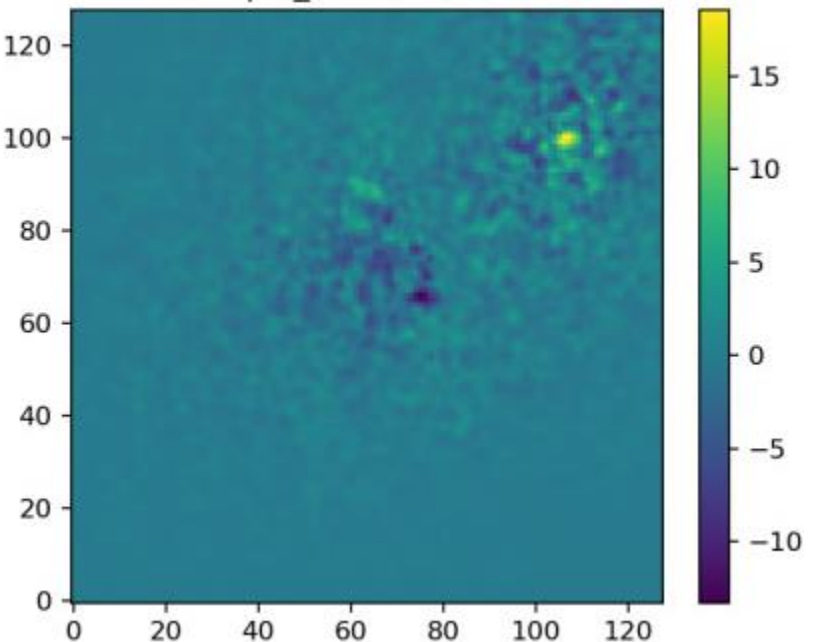
sample_00008: data



sample_00008: best-fit model

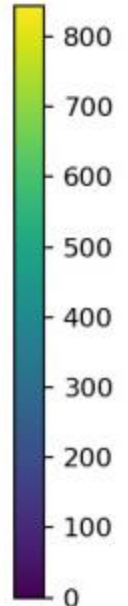
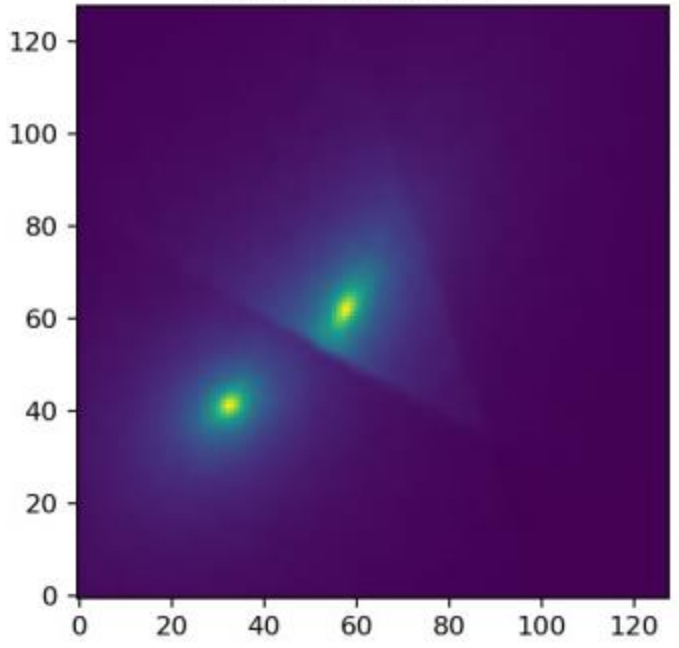


sample_00008: residual

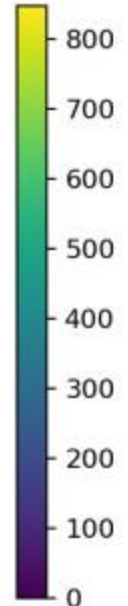
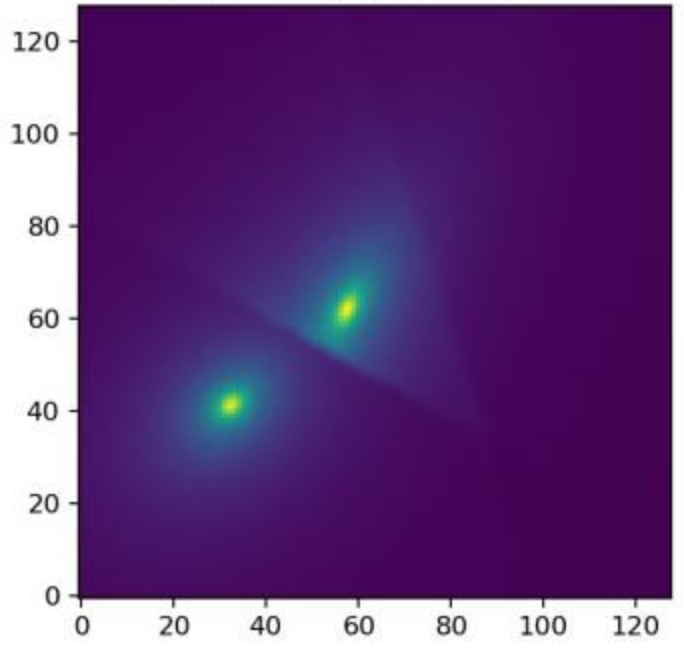


2026, by Igor Bulygin

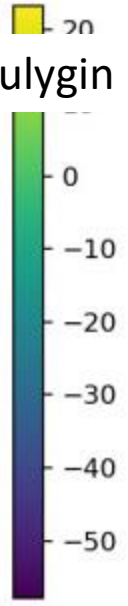
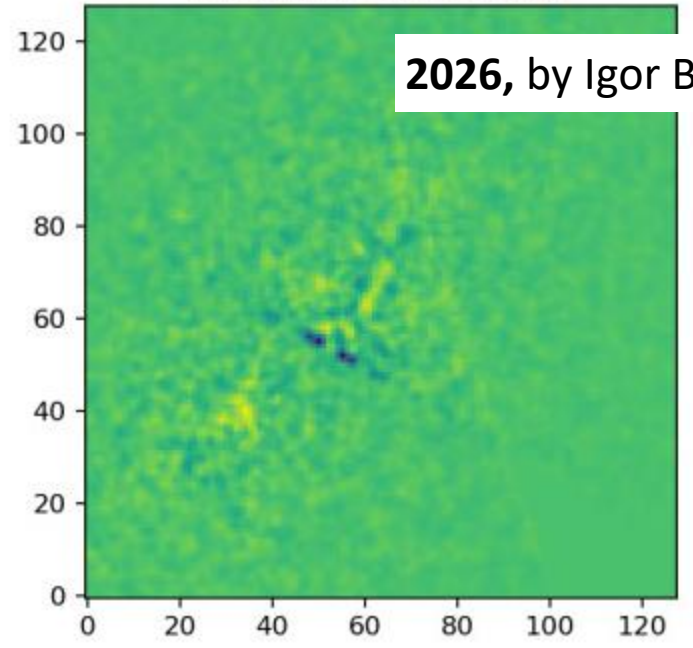
sample_00009: data



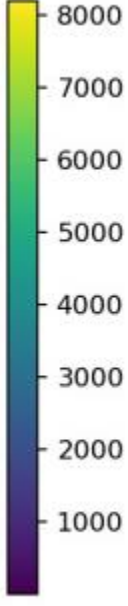
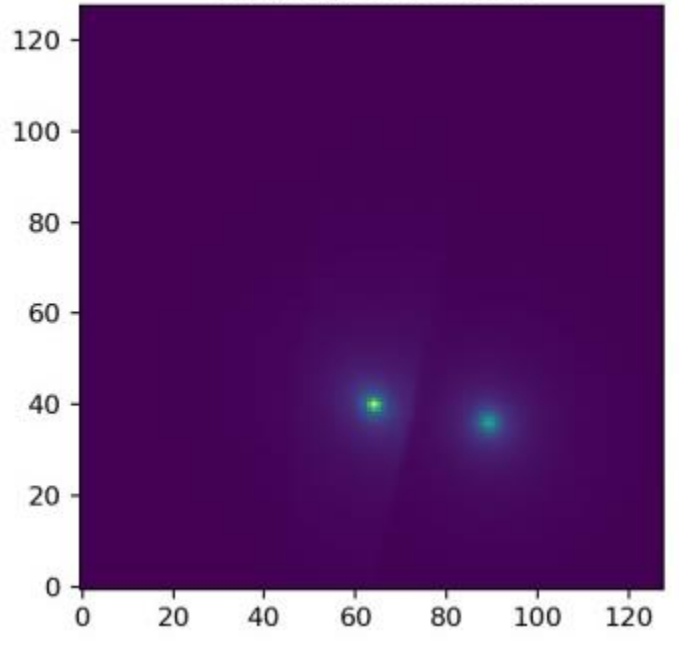
sample_00009: best-fit model



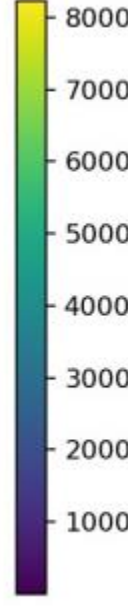
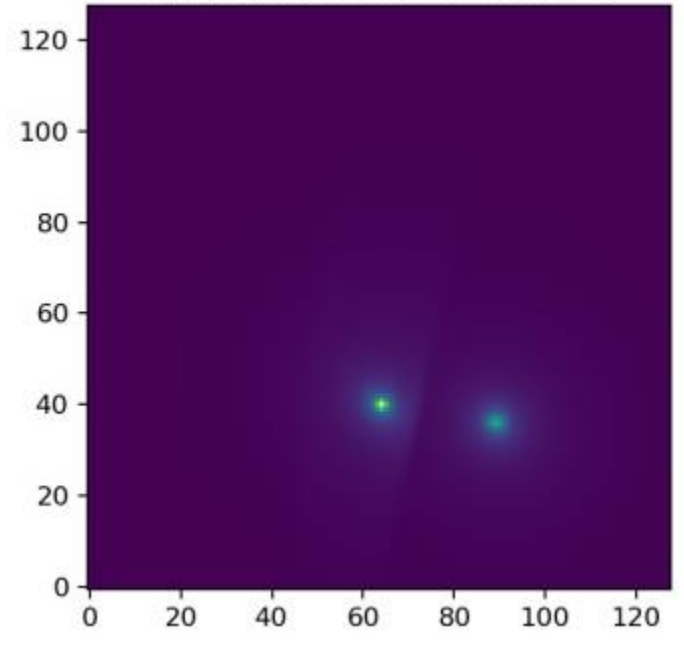
sample_00009: residual



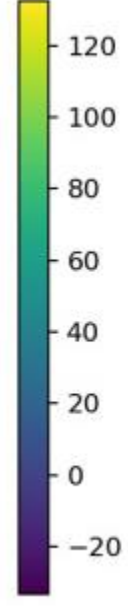
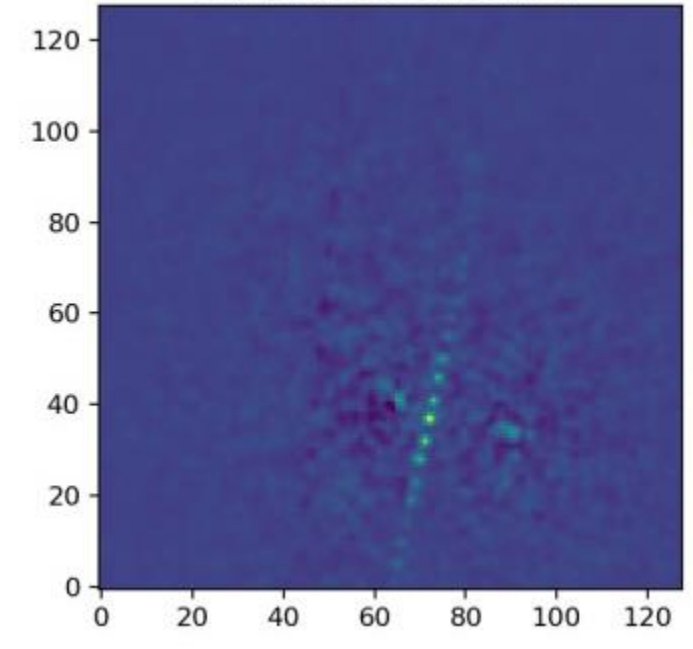
sample_00000: data



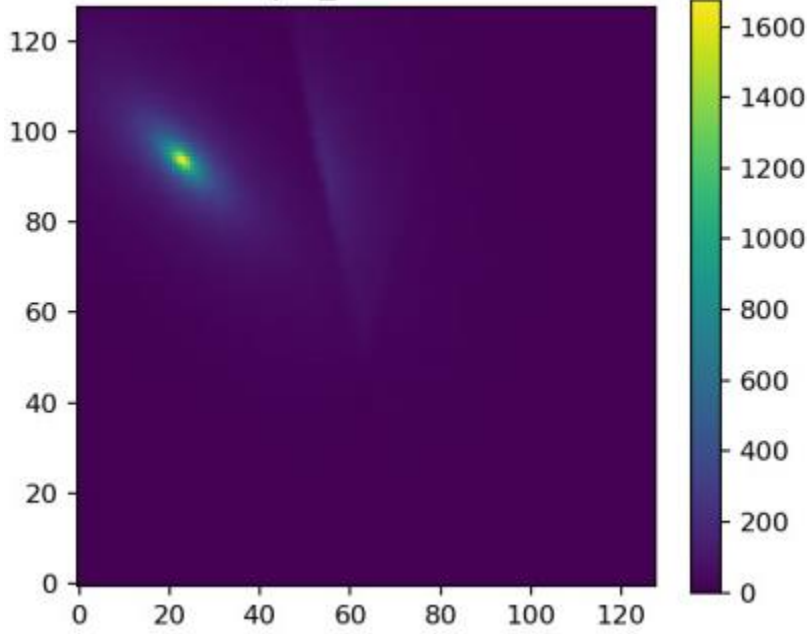
sample_00000: best-fit model



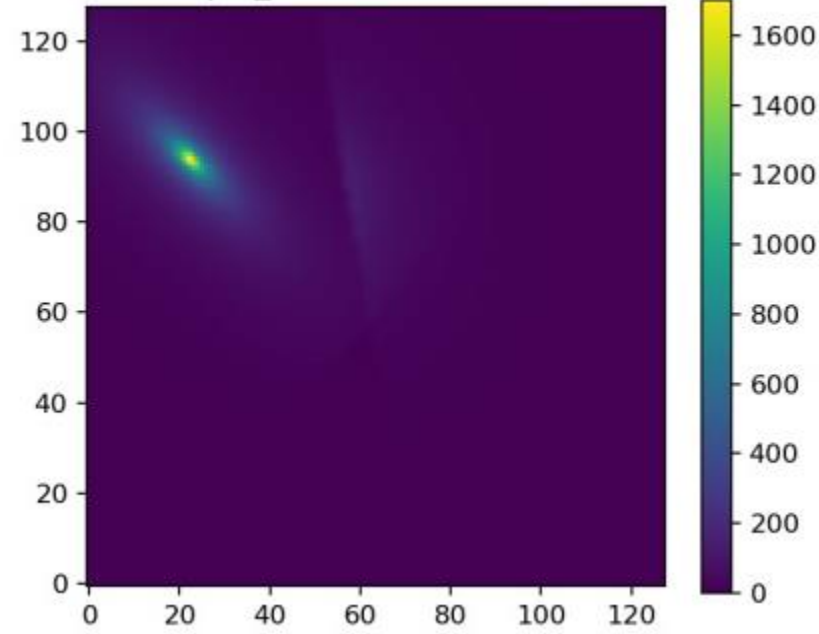
sample_00000: residual



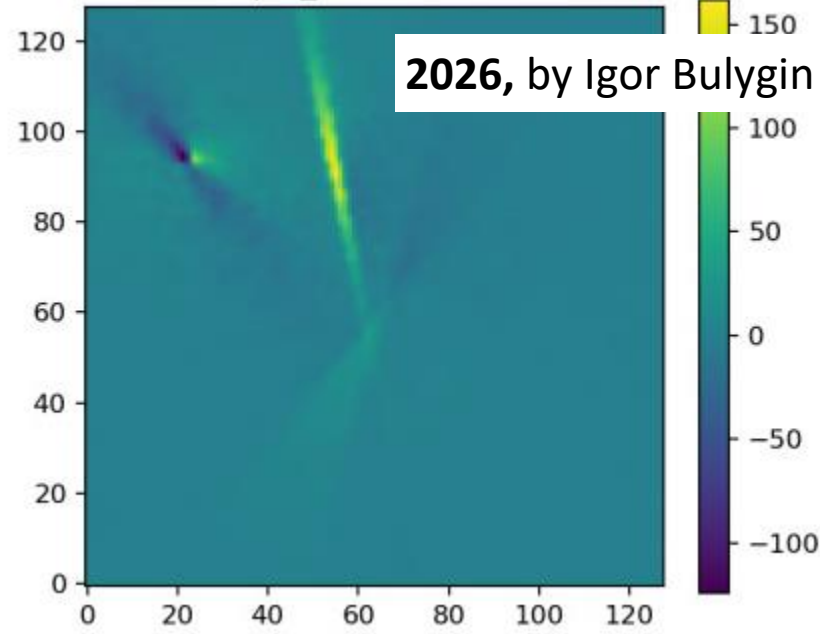
sample_00011: data

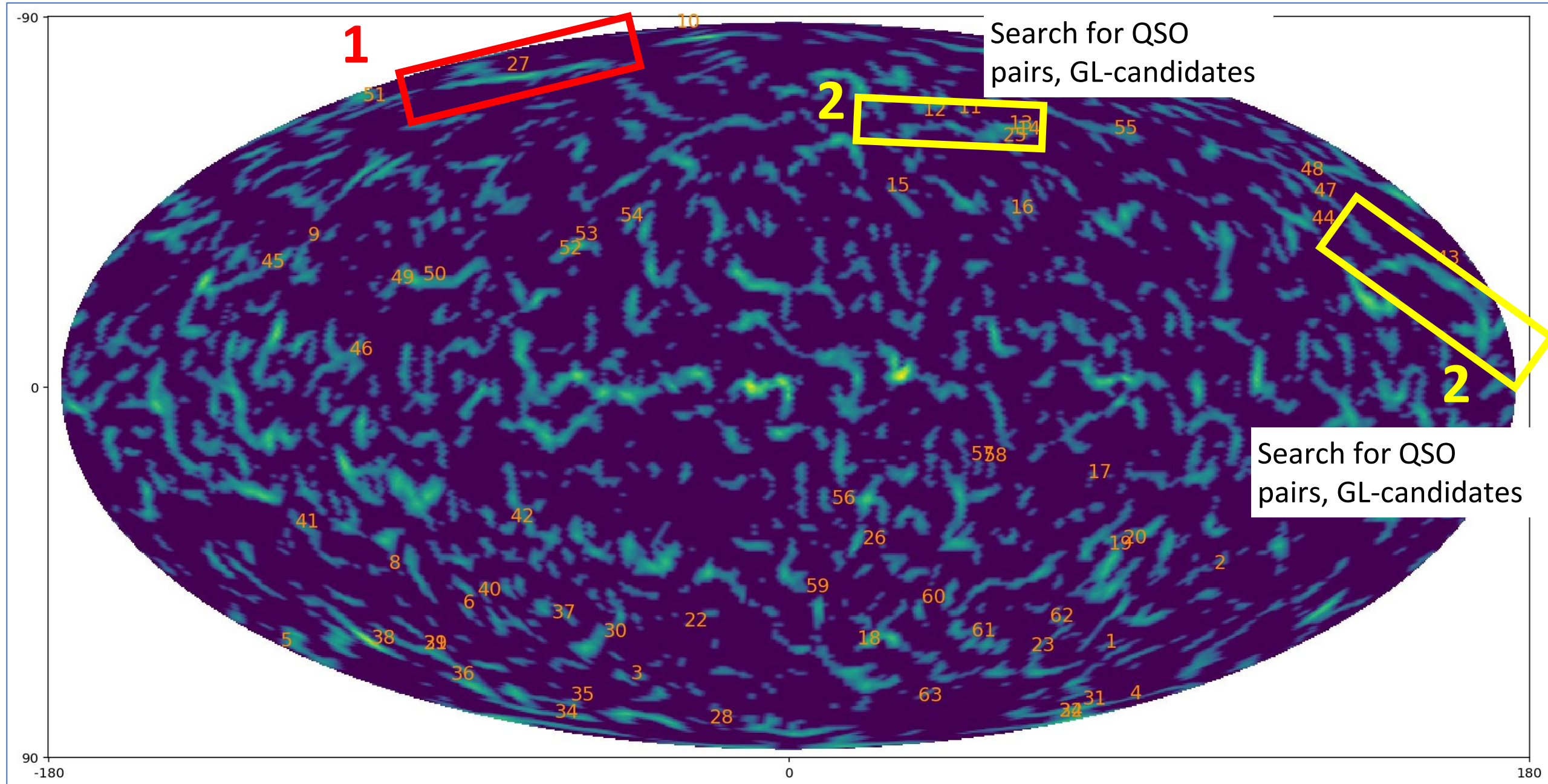


sample_00011: best-fit model



sample_00011: residual





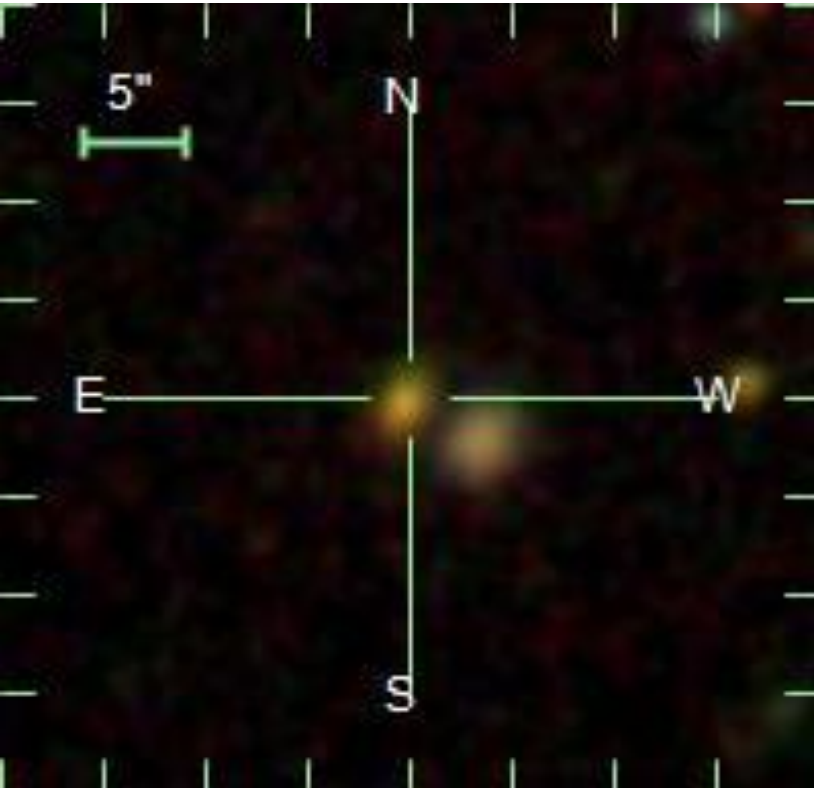
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2

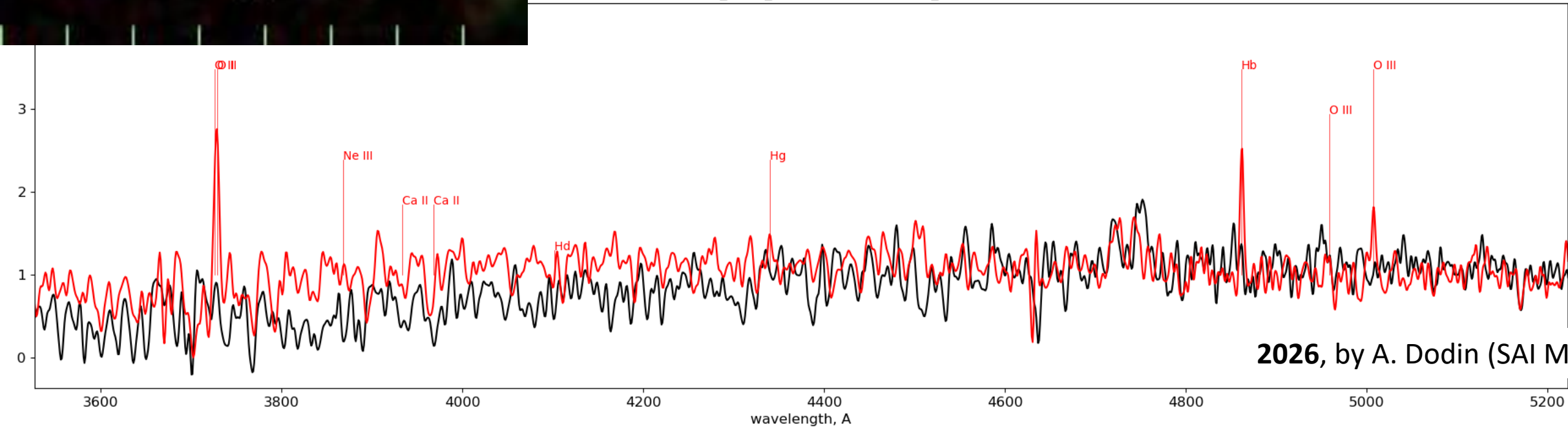
2

Search for QSO pairs, GL-candidates

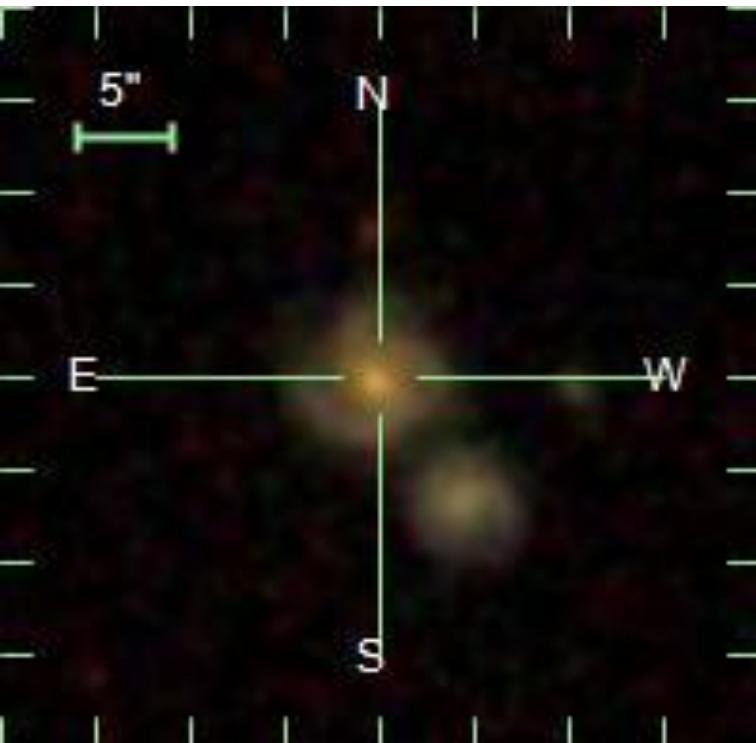
Search for QSO pairs, GL-candidates



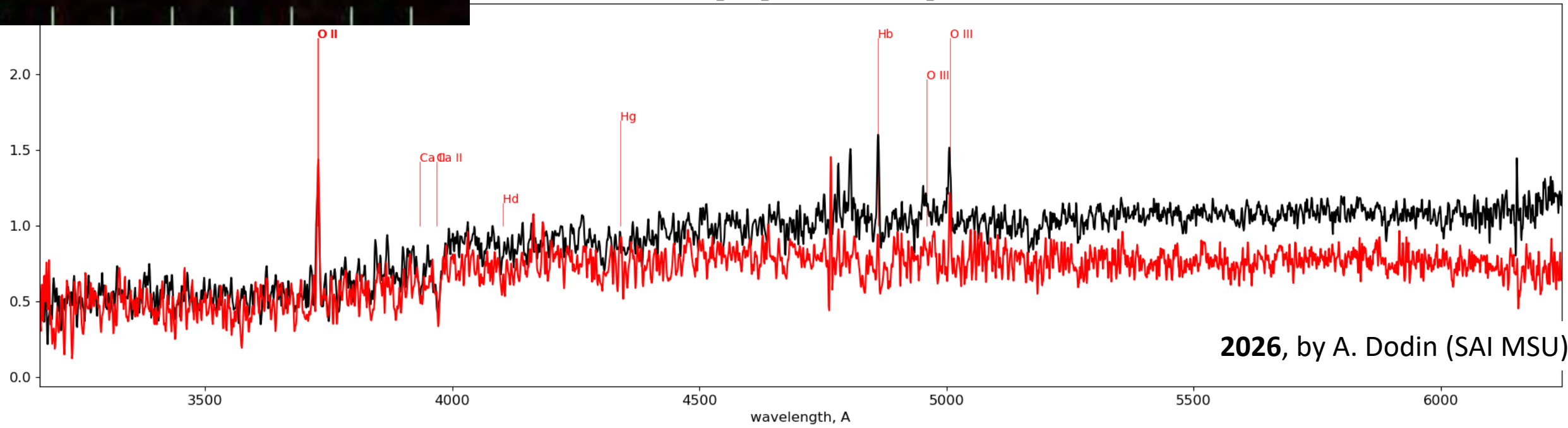
20260510_SDSS_J112911.28+161806.1_1.

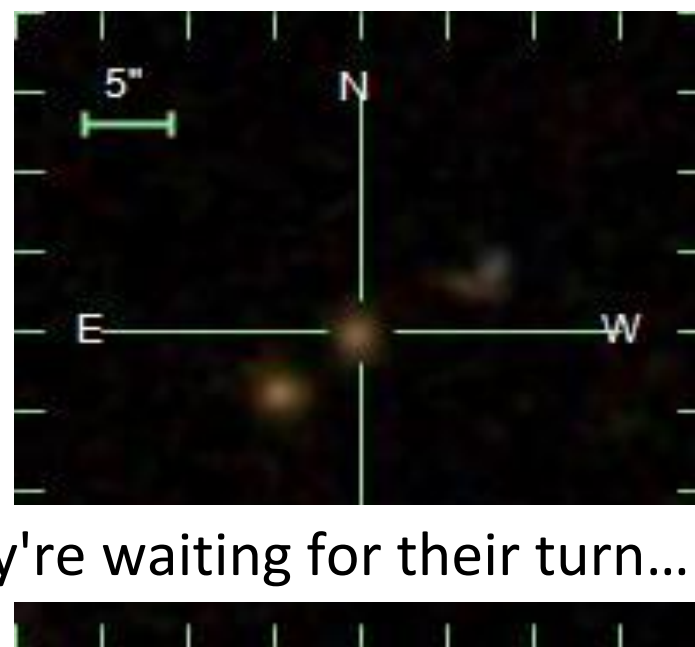
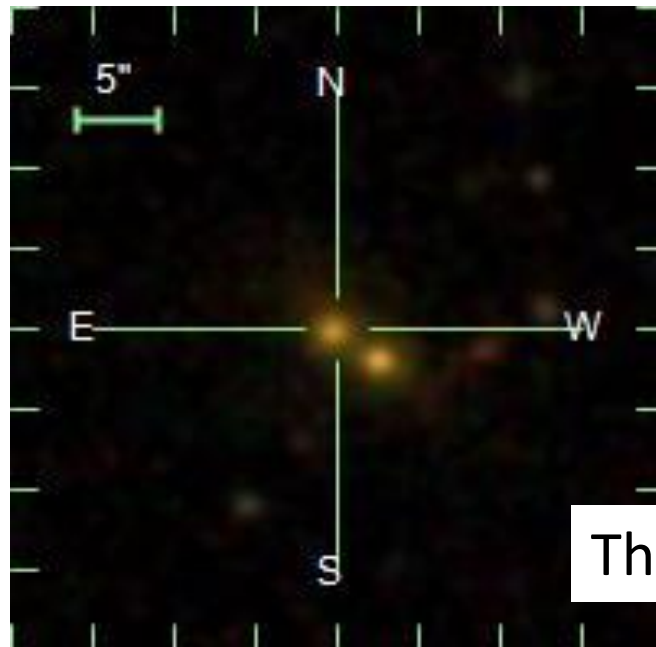
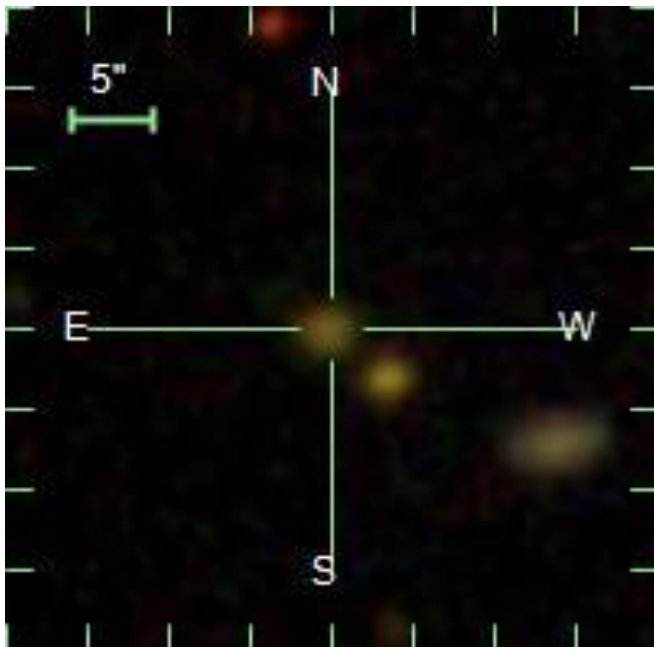
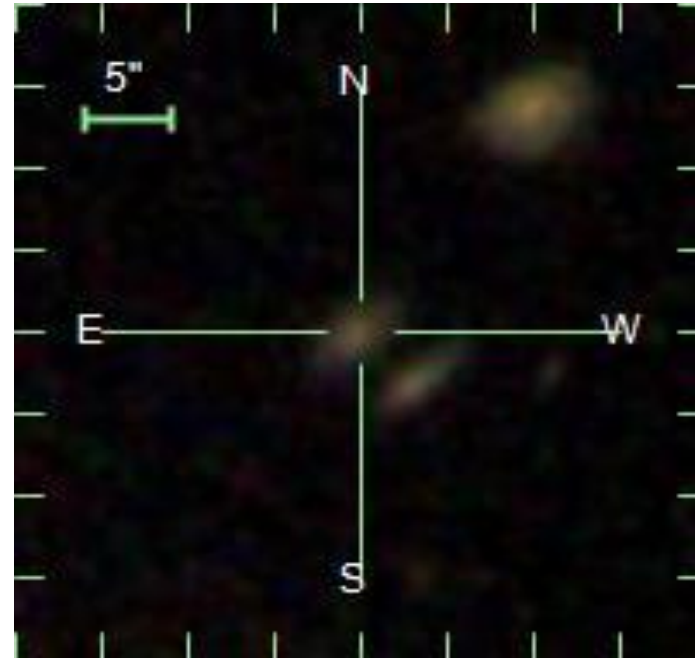
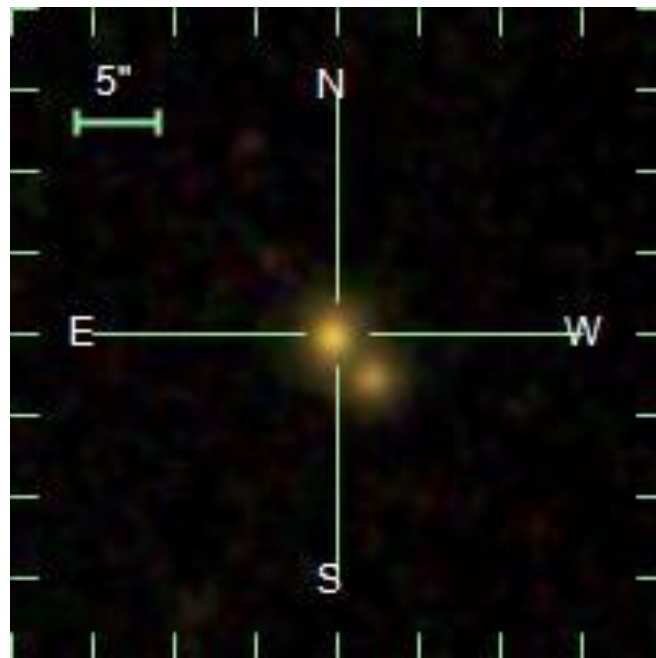
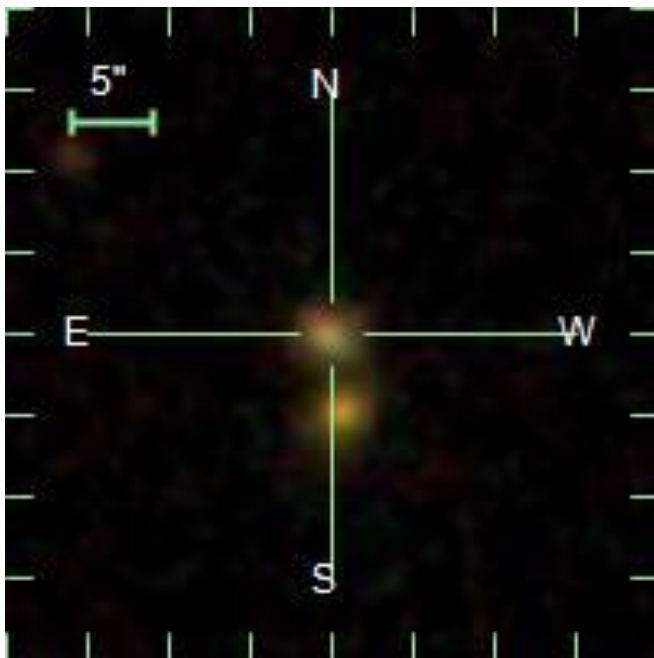


2026, by A. Dodin (SAI MSU)

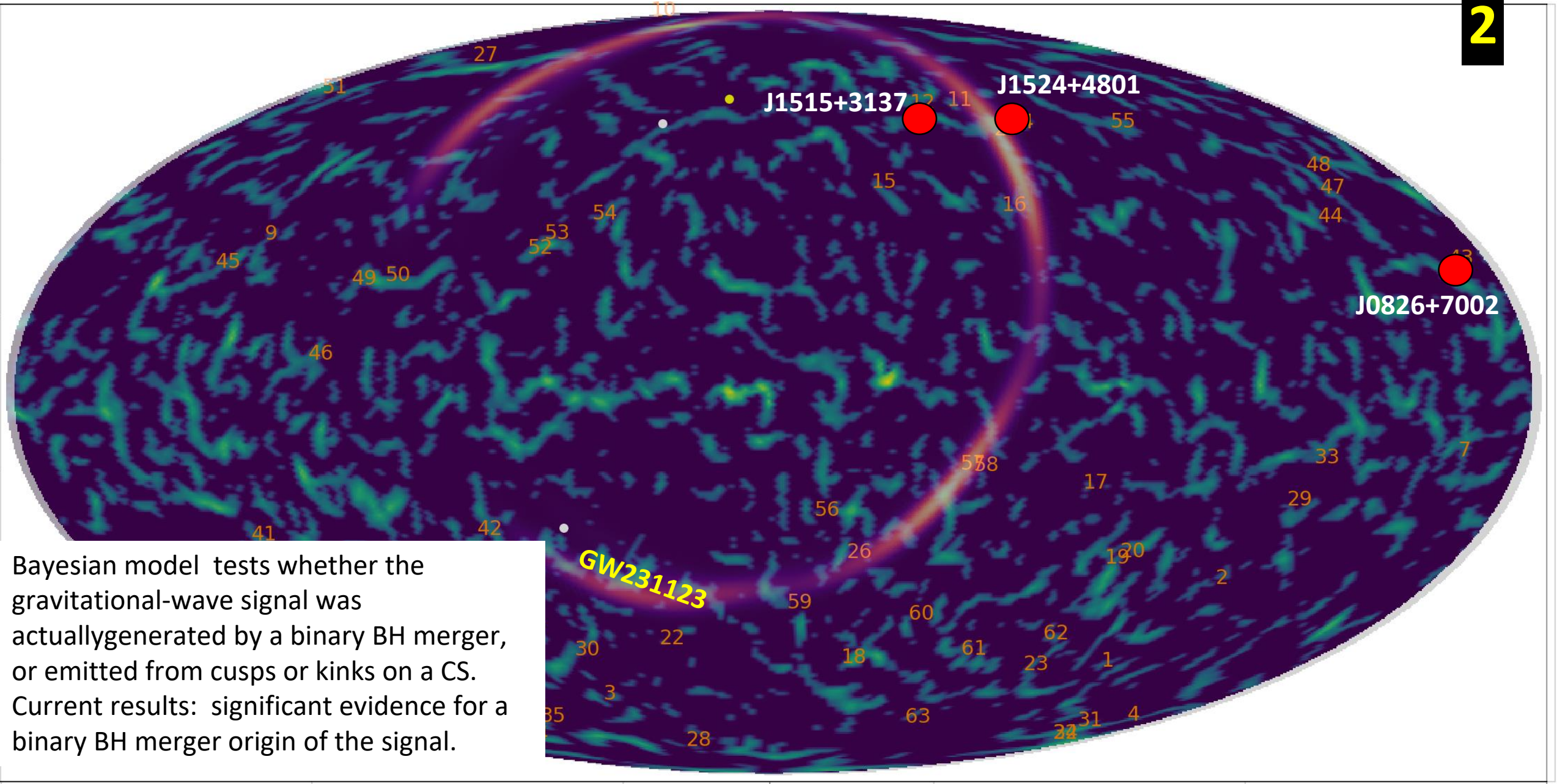


20260214_SDSS_J112728.38+163154.3_s1.





They're waiting for their turn...



Bayesian model tests whether the gravitational-wave signal was actually generated by a binary BH merger, or emitted from cusps or kinks on a CS. Current results: significant evidence for a binary BH merger origin of the signal.

J1515+3137

228.9106; 15.19309;

$z=0.742$;

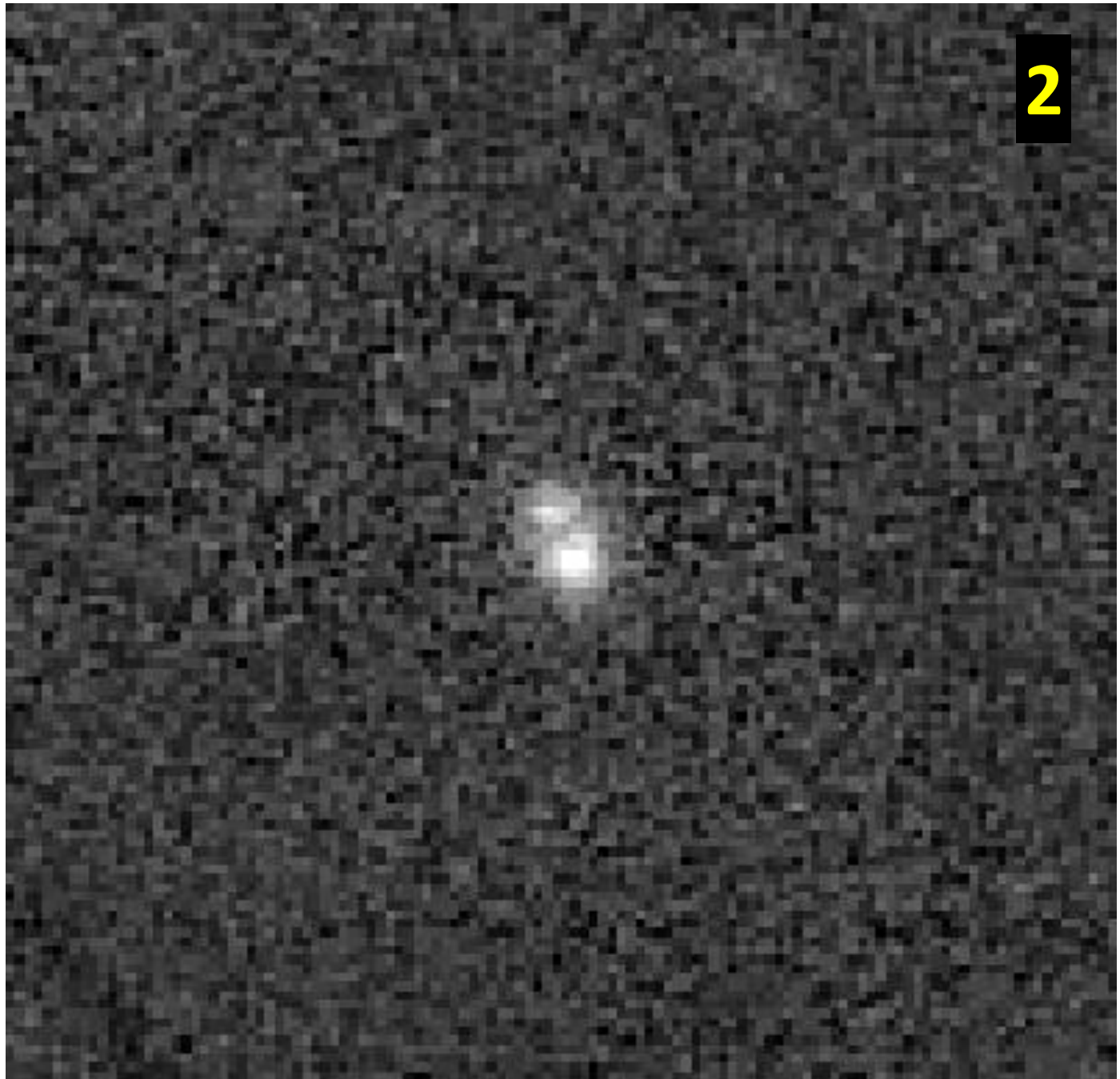
sep.= 1.5 (lensed QSO database:

<https://research.ast.cam.ac.uk/lensedquasars/indiv/J1515+3137.html>)

mag.: 18.03; 18.41.

Comments: (a) confirmed GL-system, (b) it was found a lens for this pair, but the lens is not visible on the photometry, (c) the morphology of the pair is preliminary good for CS.

Now we are waiting for BTA (*6 m, Special Astrophysical Observatory located in the Zelenchuksky District of Karachay-Cherkessia*) observations.



J1524+4801

231.124279; 48.0205585;

$z=1.70$;

sep.=2.22;

mag.: 20.29; 20.60.

Comment: (a) confirmed GL-system, (b) it does not found a lens for this pair, (c) the morphology of the pair is preliminary good for CS.

Now we are waiting for BTA observations.



J0826+7002

126.5341; 70.0456;

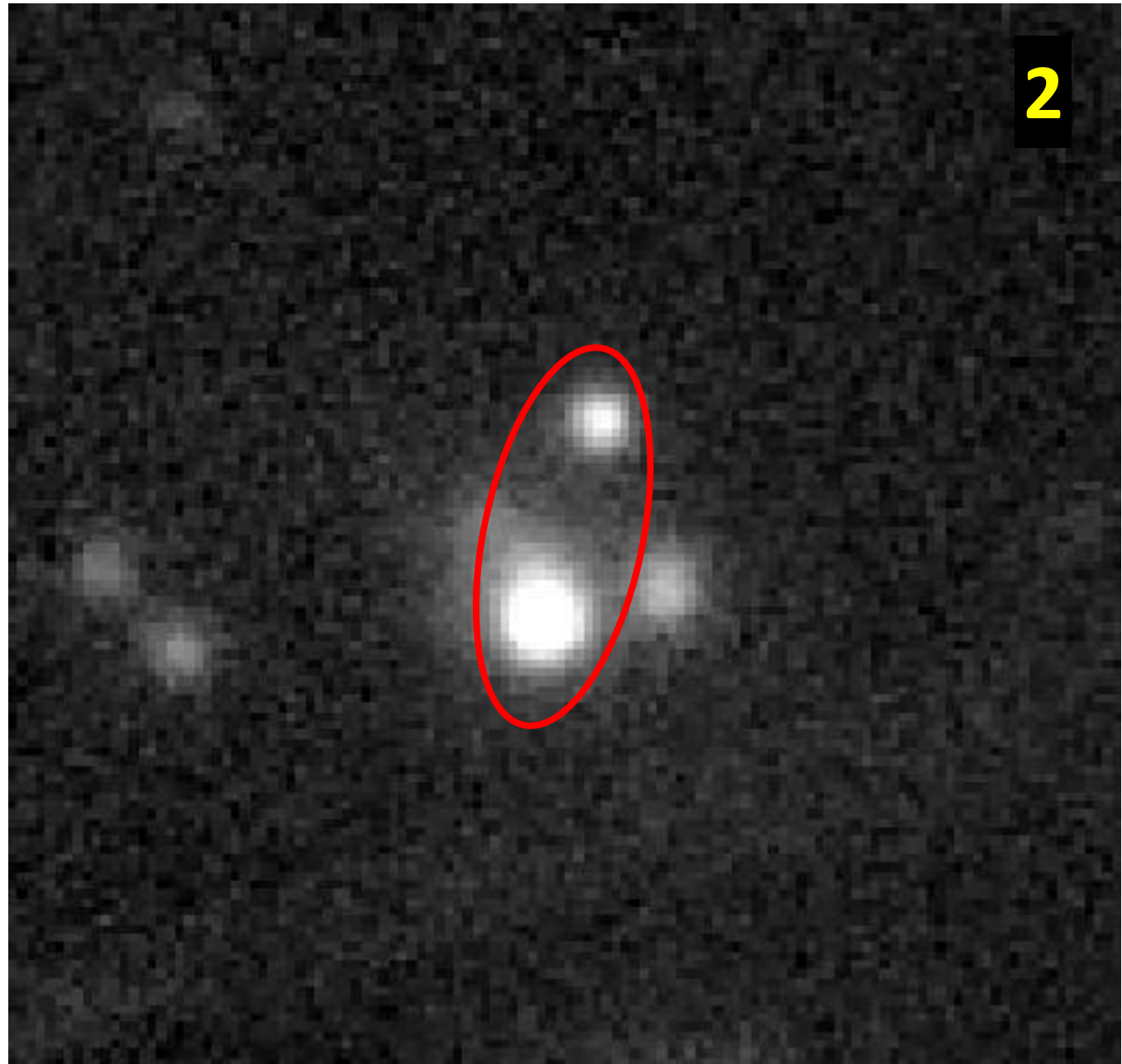
mag.: 17.46; 19.30;

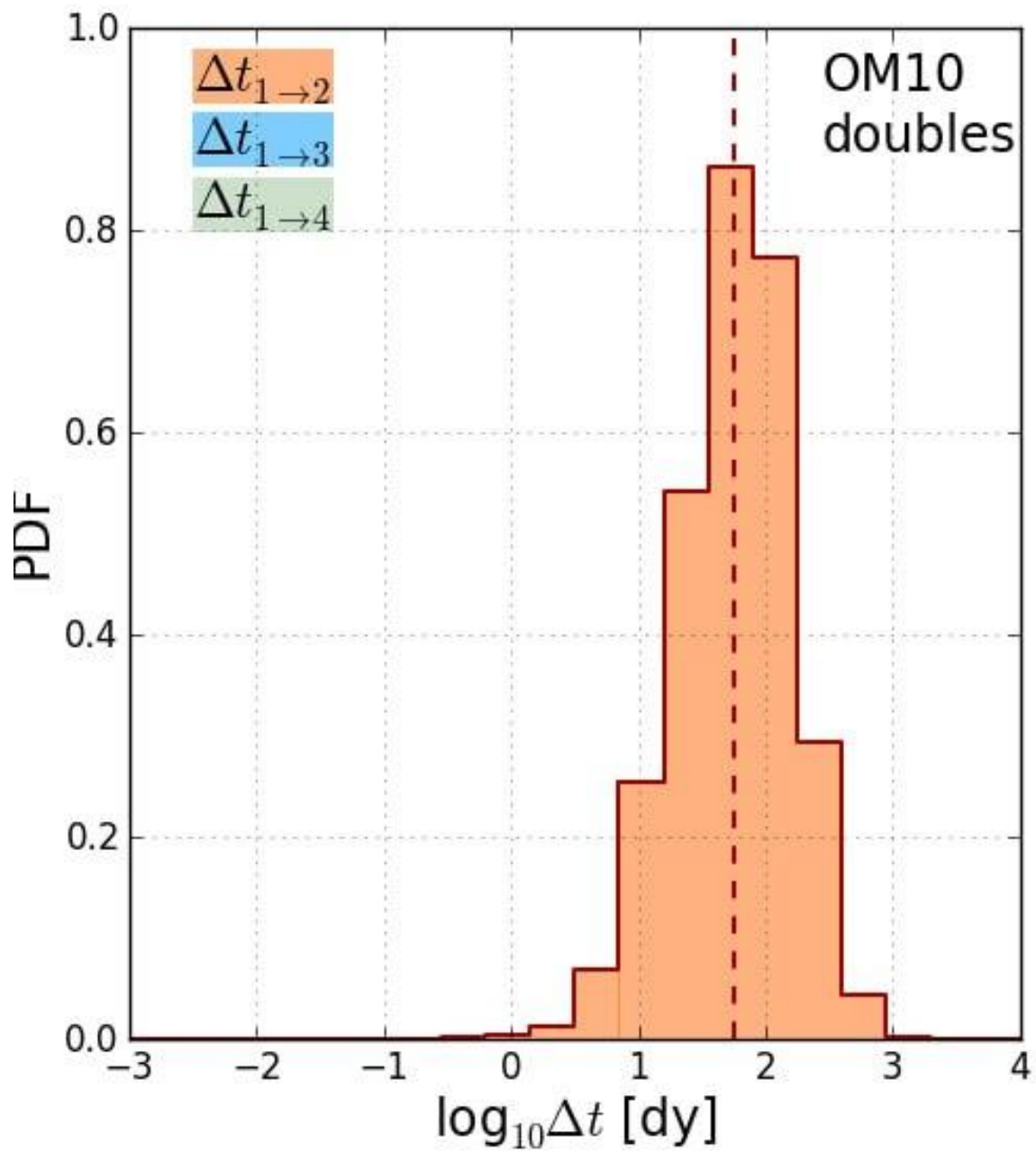
sep.=5.83;

z=1.618.

Comment: (a) preliminary GL-system, (b) preliminary it does not found a lens for this pair, (c) two more preliminary “pairs” in the neighborhood.

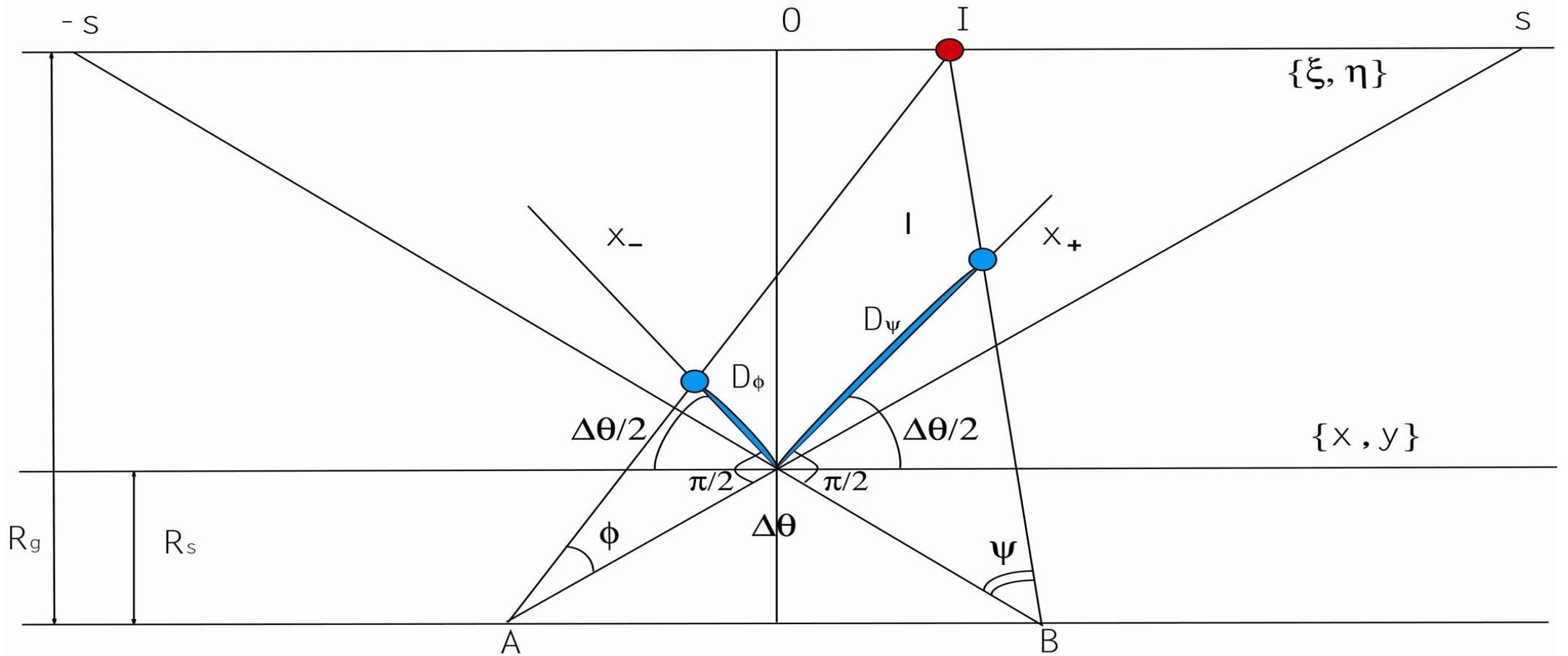
Now we are waiting for BTA observations.





Статистическое распределение
величин временных задержек для
каталога гравитационных линз
(arXiv:1310.4830v3)

PDF



$$AI = \frac{r_{QSO}}{\cos\left(\frac{\Delta\theta}{2} - \phi\right)}$$

$$BI = \frac{r_{QSO}}{\cos\left(\frac{\Delta\theta}{2} - \psi\right)}$$

$$\Delta t = \frac{1}{2H} \cdot f(z_{CS}, \Omega_m, \Omega_\Lambda) \cdot \Delta\theta \cdot |\phi - \psi|$$

Simple matter dominated Universe:

$$r_{QSO} = \frac{2}{H_0} \cdot \left(1 - \frac{1}{\sqrt{1 + z_{QSO}}} \right)$$
$$t_2 - t_1 = \frac{1}{H_0} |\varphi - \psi| \cdot \Delta\theta \cdot \left[1 - \frac{1}{\sqrt{1 + z_{QSO}}} \right]$$

For static CS:

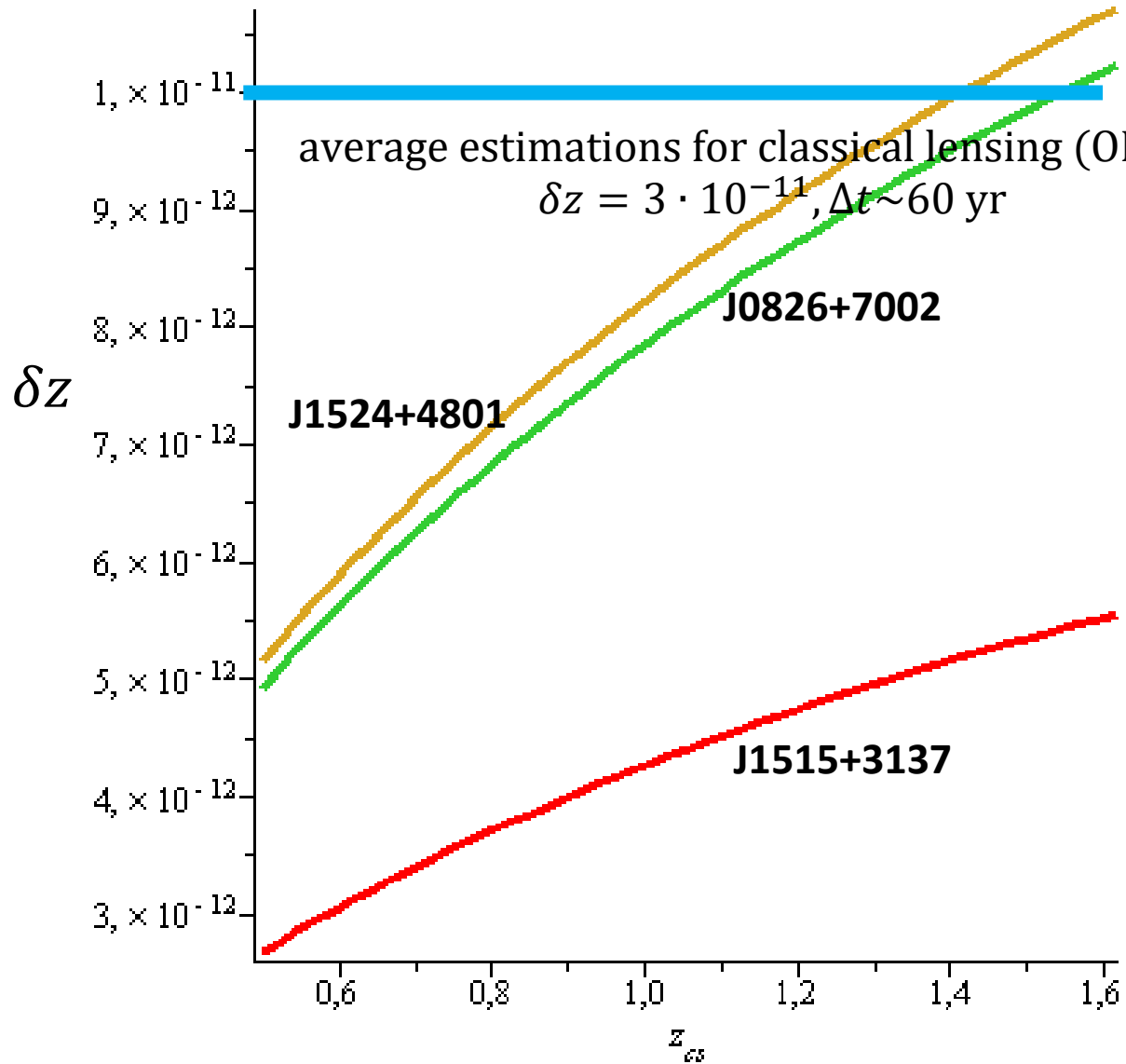
$$\delta z \sim (t_2 - t_1) \cdot H_0 \cdot (1 + z_{QSO})^{\frac{3}{2}} = \left(\frac{8\pi G\mu}{c^2} \right)^2 \cdot \left[1 - \frac{1}{\sqrt{1 + z_{QSO}}} \right] \cdot (1 + z_{QSO})^{\frac{3}{2}}$$

For moving CS:

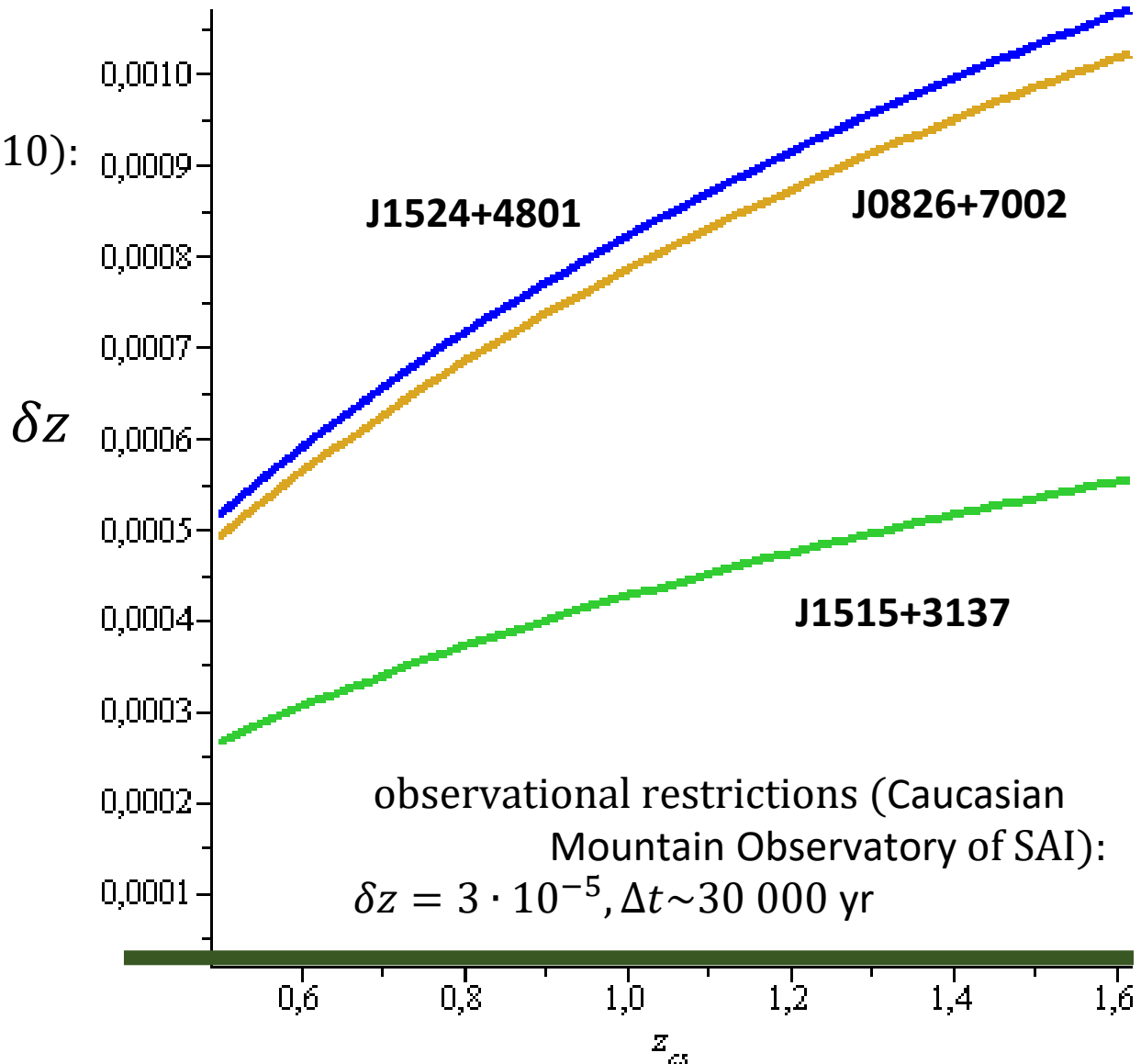
[GRAVITATIONAL TENSING EFFECTS OF VACUUM STRINGS: EXACT SOLUTIONS (1985) by J. Richard Gott III]

$$\delta z \sim O \left(\frac{8\pi G\mu}{c^2} \right)$$

$$\delta z = \delta z(z_{CS}) \text{ for } \frac{G\mu}{c^2} \sim 10^{-7}$$



$$\delta z = \delta z(z_{CS}) \text{ for } \frac{G\mu}{c^2} \sim 10^{-3}$$



Conclusions

1. Our current understanding of CS search issues:
 - promising models are single inclined and bended CS, specially single heavy CS, which could be formed in the inflation epoch or could be non-topological;
 - it is preferable to search for compact "clusters" of GL instead of chains of GL
2. We are waiting for the observational data (19.05.26).

Только что сообщили, сегодня на БТА дожди...