Observation and Period-Luminosity Relationship Analysis of Cepheid Variable Stars

Abstract: Cepheid Variable Stars are a kind of variable star that changes brightness with time periodically. They have a clear period-luminosity relationship to be used as a candle in the measurement of astronomical distance. In this experiment, we observe three Cepheids belonging to different types and measure their parameters.

1. Introduction

Cepheid Variable Stars (Cepheid) are a kind of variable stars with high brightness periodic pulsation, that is, their brightness changes periodically with time. Their light variation period is proportional to their luminosity, and such a relation is concluded by Leavitt as the period-luminosity (P-L) relationship.[1] Such a relationship makes Cepheid one of the most frequently-used candles in the measurement of intergalactic distance.

1.1 Historical Background

On September 10, 1784, Edward Piggott detected a luminosity variation in Eta Aquilae when he compared its brightness with another star, Theta Serpentis. This is the first classical Cepheid variable documented. After monitoring Eta Aquilae for some time, Piggott established the period of Eta Aquilae to be 7.18 days.[2] However, such a kind of variable star was named Cepheid by John Goodricke when he discovered the luminosity changes of Delta Cepheus A.[3] The period of Delta Cepheus A is 5.367 days, and its apparent magnitude changes from 3.48 to 4.37.[4]

In 1908, Henrietta Levitt of the Harvard Observatory surveyed 1,777 variable stars in the Magellanic Clouds and found that the longer the period of light, the greater the apparent magnitude of a Cepheid variable. She used Cepheid variables in the Small Magellanic clouds to establish the exact relationship between apparent magnitude and period.[5] In 1912, she solved the problem of zero calibration of the relation between the period and luminosity, converted the apparent magnitude to the absolute magnitude, and published a paper describing the relation between the period of light and the absolute magnitude.[1] In 1917, the mechanism of the varying nature of the Cepheid variables was understood as star heat engine proposed by Arthur Stanley Eddington.[11]

1.2 Classification of Cepheid Variables

Cepheids include three types with different properties: Cepheid variable stars of the population I (or classical Cepheid variable stars), Cepheid variable stars of population II (or Virgo W-type variable stars), and RR Lyr. They have their own P-L relationships and zero points. For the same period, the luminosity of the former is about 1.4 less than that of the latter. Type I Cepheid variables, also known as classical Cepheid variables, are usually bright yellowish-white or yellow giant stars. Type II Cepheid variables are the result of the unstable core production of old, low-mass stars at the end of their evolution. They are very old, lack metal, and are often billions or even 10 billion years old. Compared with the former 2 kinds of Cepheid, RR Lyr's brightness and metal content are lower. And their P-L relationship has irreconcilable differences from the other two. So this type is becoming more and more accepted as a variant of the classical Cepheid variable.[6]

1.3 Importance and Purpose

Cepheid variables can be used as "standard candles". We can determine a candle's distance from us based on the simple relationship that brightness is inversely proportional to the square of the distance.[7] Knowing the absolute magnitude of a Cepheid variable at a given distance would make it possible to measure the period of the Cepheid's luminosity.

All the research on Cepheid has to do with the P-L relationship. The purpose of this paper is to observe three Cepheid belonging to different types: Type I: BI Cas; Type II: NSV 4148; RR Lyrae, and measure their P-L relationship,

2. Parameter and Approach

2.1 Parameter of Object Cepheid

Name	Type	RA(J2000)/ deg	Dec(J2000)/ deg	Exposure Time/s
BI Cas	Type I (DCEP)	00 43 31.193	+62 39 55.91	40
NSV 4148	Type II (CWB)	08 34 12.055	-68 36 01.15	50
RR Lyrae	RR Lyr	19 25 27.913	+42 47 03.69	1

Fig.1 Parameter of Object Cepheids

2.2 Parameter of Telescope

Name	Telescope Class	Pixel Scale (std.binning)	Field of View	Overhead per Frame	Filter Option
SBIG 6303	0.4-meter	0.571 (bin 1×1)	$29' \times 19'$	14 s	9

Fig.2 Parameters of Telescope

2.3 Filters

Name	Wavelength Center (Å)	Wavelength Width (Å)
SDSS u’	3540	570
SDSS g’	4770	1500
SDSS r’	6215	1390
SDSS i’	7545	1290

Fig.3 Parameters of Filters

2.4 Approach

The Object Cepheids are observed for a period of time, and their data are collected separately for 10 times. The apparent magnitude is obtained by finding the difference in magnitude between the object Cepheid and another reference star with no significant brightness change. To be specific, the reference star of each Cepheid is listed below.

Cepheid	Reference Star	RA(J2000)/ deg	Dec(J2000)/ deg	Apparent Magnitude
BI Cas	HD 3949	00 42 48.51	+62 45 57.09	7.94

NSV 4148	HD 73743	08 35 26.48	-68 26 34.45	8.91
RR Lyr	BD+42 3334	19 25 04.77	+42 41 31.27	10.38

Fig.4 Parameters of Reference Stars

The apparent magnitudes from filter ugri are not available for the three reference stars. So the data used above are from filter B.

3. Data

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3.1 BI Cas

The graphs are pictured from 28th Nov. 2022 to 30th Nov. 2022 and processed by BANZAI in LCO

3.1.1 Filter u’

Observation time/ Day hour:minute:second	Time Line/ days	ΔMagnitude*	Apparent Magnitude
28 19:07:11	0	-4.43	12.37
28 19:24:09	0.0118	-4.65	12.59
28 23:44:11	0.1924	-4.28	12.22
29 00:42:02	0.2326	-4.18	12.12
29 01:28:21	0.2659	-3.93	11.87
29 20:06:45	1.0423	-3.43	11.37
29 20:12:44	1.0465	-3.70	11.64
29 22:26:18	1.1396	-4.53	12.47
30 01:22:27	1.2645	Undetected	

30 01:33:57	1.2729	Undetected

Fig.5 Data for BI Cas (Filter u')

*: ΔMagnitude = Magnitude (Reference Star) – Magnitude (Cepheid)

The measurement is executed in the usage of AstroImageJ. The figure of each measurement for BI Cas using filter u' is in Appendix A-A1.

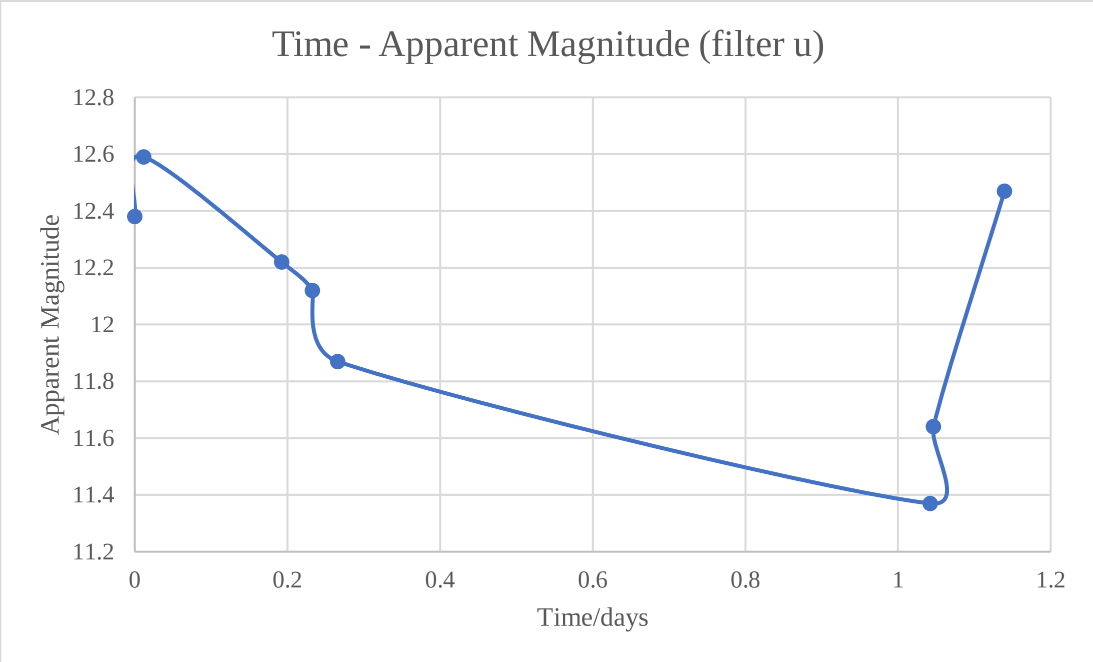


Fig.6 Time–Apparent Magnitude Dot Plot for BI Cas (Filter u')

From the 2 graphs, the observed amplitude for BI Cas using filter u' is 1.22. The observed period is 1.0606 days.

3.1.2 Filter g'

Observation time/ Day hour:minute:second	**Time Line/ days**	**ΔMagnitude***	**Apparent Magnitude**
28 19:04:08	0	-5.24	13.18
28 19:21:07	0.0118	-5.41	13.35
28 23:41:10	0.1924	-5.26	13.20
29 00:39:03	0.2326	-5.07	13.01
29 01:25:20	0.2659	-5.13	13.07
29 20:03:45	1.0423	-5.65	13.59
29 20:09:44	1.0465	-5.45	13.39
29 22:23:19	1.1396	-5.35	13.29
30 01:19:27	1.2645	-5.12	13.06
30 01:31:56	1.2729	-5.13	13.07

Fig.7 Data for BI Cas (Filter g’)

*: ΔMagnitude = Magnitude (Reference Star) – Magnitude (Cepheid)

The measurement is executed in the usage of AstroImageJ. The figure of each measurement for BI Cas using filter g’ is in Appendix A-A2.

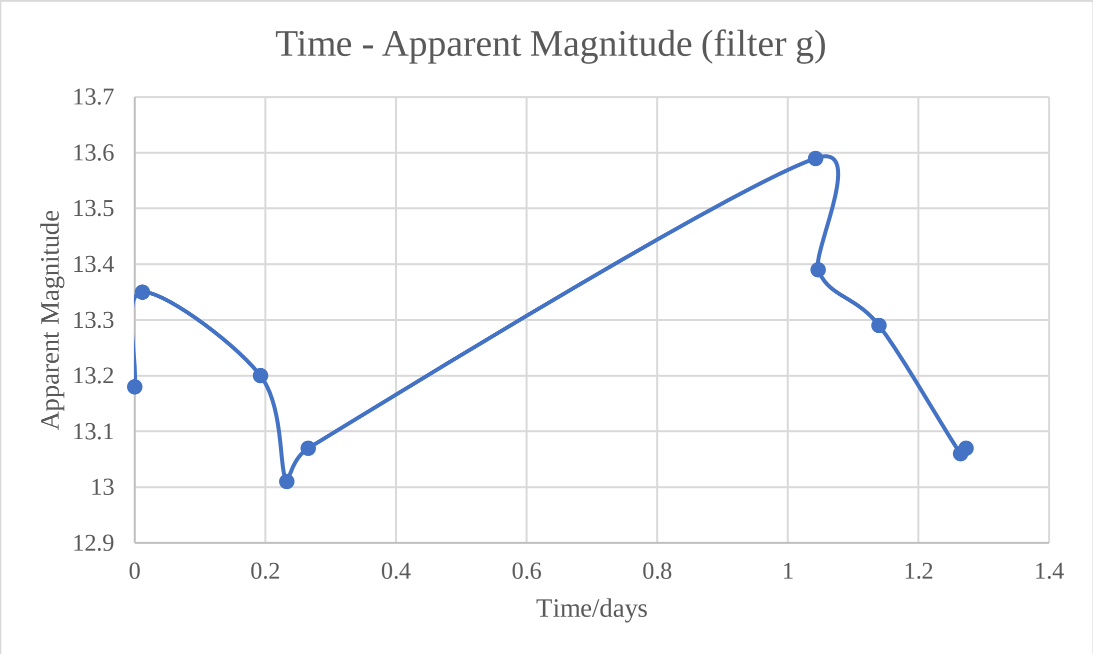


Fig.8 Time–Apparent Magnitude Dot Plot for BI Cas (Filter g')

From the 2 graphs, the observed amplitude for BI Cas using filter g' is 0.58. The observed period is 1.0674 days.

3.1.3 Filter r'

Observation time/ Day hour:minute:second	**Time Line/ days**	**ΔMagnitude***	**Apparent Magnitude**
28 19:06:07	0	-4.20	12.14
28 19:23:07	0.0118	-4.26	12.20
28 23:43:08	0.1924	-4.24	12.18
29 00:41:00	0.2326	-4.09	12.03
29 01:27:19	0.2659	-4.27	12.21
29 20:05:44	1.0423	-4.87	12.81
29 20:11:45	1.0465	-4.68	12.62

29 22:25:17	1.1396	-4.42	12.36
30 01:21:27	1.2645	-4.07	12.01
30 01:33:56	1.2729	-4.17	12.11

Fig.9 Data for BI Cas (Filter r’)

*: ΔMagnitude = Magnitude (Reference Star) – Magnitude (Cepheid)

The measurement is executed in the usage of AstroImageJ. The figure of each measurement for BI Cas using filter r’ is in Appendix A-A3.

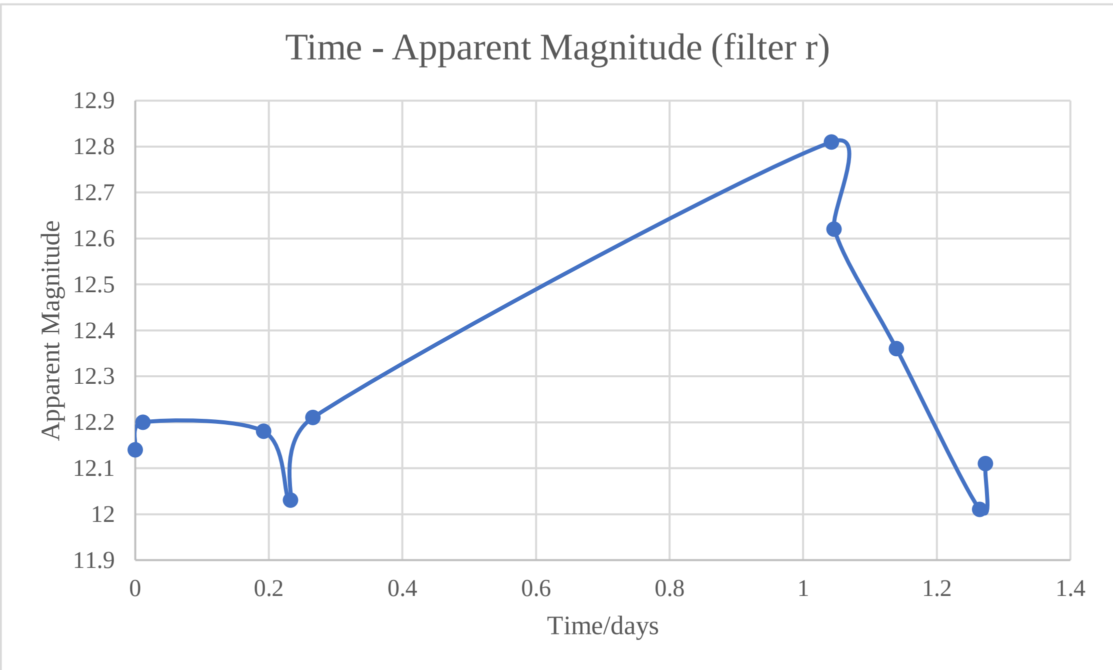


Fig.10 Time–Apparent Magnitude Dot Plot for BI Cas (Filter r’)

From the 2 graphs, the observed amplitude for BI Cas using filter r’ is 0.78. The observed period is 1.0248 days.

3.1.4 Filter i’

Observation time/ Day hour:minute:second	Time Line/ days	ΔMagnitude*	Apparent Magnitude
28 19:05:09	0	-4.00	11.94
28 19:22:08	0.0118	-4.04	11.98
28 23:42:10	0.1924	-3.90	11.84
29 00:40:03	0.2326	-3.91	11.85
29 01:26:20	0.2659	-3.94	11.88
29 20:04:45	1.0423	-4.56	12.50
29 20:10:44	1.0465	-4.50	12.44
29 22:24:19	1.1396	-4.12	12.06
30 01:20:28	1.2645	-3.85	11.79
30 01:32:55	1.2729	-3.94	11.88

Fig.11 Data for BI Cas (Filter i’)

*: ΔMagnitude = Magnitude (Reference Star) – Magnitude (Cepheid)

The measurement is executed in the usage of AstroImageJ. The figure of each measurement for BI Cas using filter i’ is in Appendix A-A4.

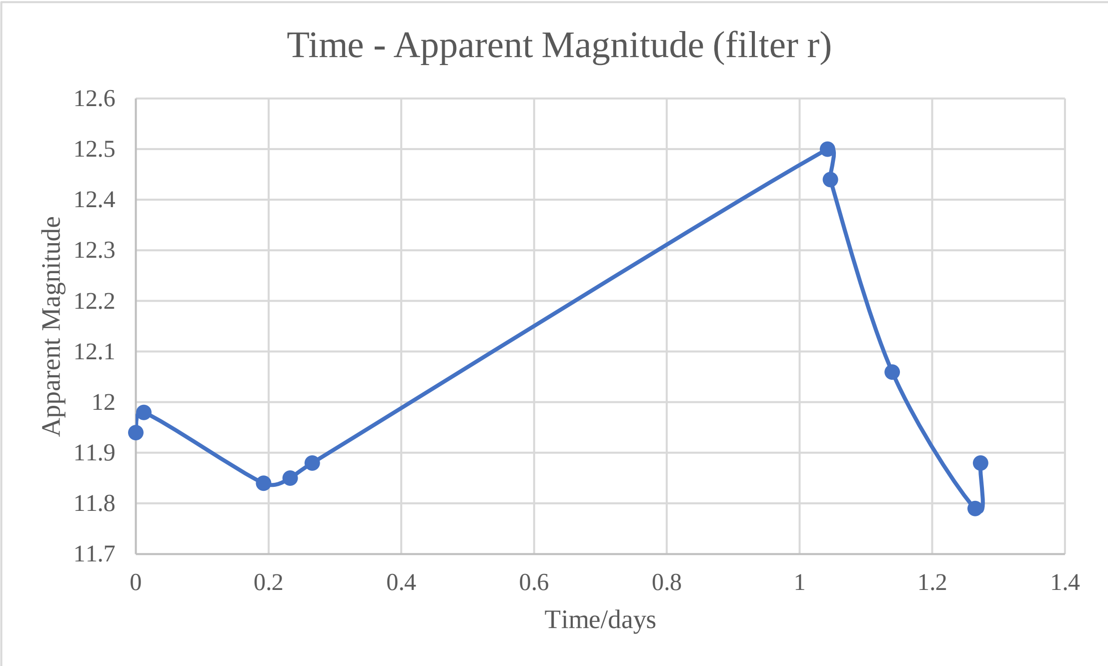


Fig.12 Time–Apparent Magnitude Dot Plot for BI Cas (Filter i')

From the 2 graphs, the observed amplitude for BI Cas using filter i' is 0.66. The observed period is 1.0474 days.

3.2 NSV 4148

The graphs are pictured on 23rd Nov. 2022 and processed by BANZAI in LCO

The observatory window for NSV 4148 is too short to collect enough data, so there are only 12 pictures total, and 3 for each filters.

3.2.1 Filter u'

Observation time/ Day hour:minute:second	Time Line/ min	ΔMagnitude*	Apparent Magnitude
23 06:17:16	0	-5.07	13.98

23 06:18:16	1	Undetected	
23 06:18:16	2	-4.14	13.05

Fig.13 Data for NSV 4148 (Filter u')

*: ΔMagnitude = Magnitude (Reference Star) – Magnitude (Cepheid)

The measurement is executed in the usage of AstroImageJ. The figure of each measurement for NSV 4148 using filter u' is in Appendix A-B1.

3.2.2 Filter g'

Observation time/ Day hour:minute:second	Time Line/ min	ΔMagnitude*	Apparent Magnitude
23 06:20:16	0	-2.85	11.76
23 06:21:16	1	-2.80	11.71
23 06:22:16	2	-2.86	11.77

Fig.14 Data for NSV 4148 (Filter g')

*: ΔMagnitude = Magnitude (Reference Star) – Magnitude (Cepheid)

The measurement is executed in the usage of AstroImageJ. The figure of each measurement for NSV 4148 using filter g' is in Appendix A-B2.

3.2.3 Filter r'

Observation time/ Day hour:minute:second	Time Line/ min	ΔMagnitude*	Apparent Magnitude
23 06:23:13	0	-2.49	11.40

23 06:24:13	1	-2.47	11.38
23 06:25:13	2	-2.48	11.39

Fig.15 Data for NSV 4148 (Filter r')

*: ΔMagnitude = Magnitude (Reference Star) – Magnitude (Cepheid)

The measurement is executed in the usage of AstroImageJ. The figure of each measurement for NSV 4148 using filter r' is in Appendix A-B3.

3.2.4 Filter i'

Observation time/ Day hour:minute:second	Time Line/ min	ΔMagnitude*	Apparent Magnitude
23 06:26:14	0	-2.37	11.28
23 06:27:14	1	-2.37	11.28
23 06:28:14	2	-2.37	11.28

Fig.16 Data for NSV 4148 (Filter i')

*: ΔMagnitude = Magnitude (Reference Star) – Magnitude (Cepheid)

The measurement is executed in the usage of AstroImageJ. The figure of each measurement for NSV 4148 using filter i' is in Appendix A-B4.

3.3 RR Lyrae

The graphs are pictured at 10th Nov. 2022 and processed by BANZAI in LCO.

3.3.1 Filter u’

Observation time/ Day hour:minute:second	Time Line/ days	ΔMagnitude*	Apparent Magnitude
10 01:08:23	0	0.87	9.51
10 01:21:07	0.0092	0.86	9.52
10 02:21:10	0.0507	2.92	7.46
10 04:40:11	0.1472	Undetected	
10 05:21:25	0.1757	Undetected	
10 19:15:00	0.7549	Undetected	
10 19:21:11	0.759	Undetected	
10 20:21:17	0.8007	Undetected	

Fig.17 Data for RR Lyrae (Filter u’)

*: ΔMagnitude = Magnitude (Reference Star) – Magnitude (Cepheid)

The measurement is executed in the usage of AstroImageJ. The figure of each measurement for RR Lyrae using filter u’ is in Appendix A-C1.

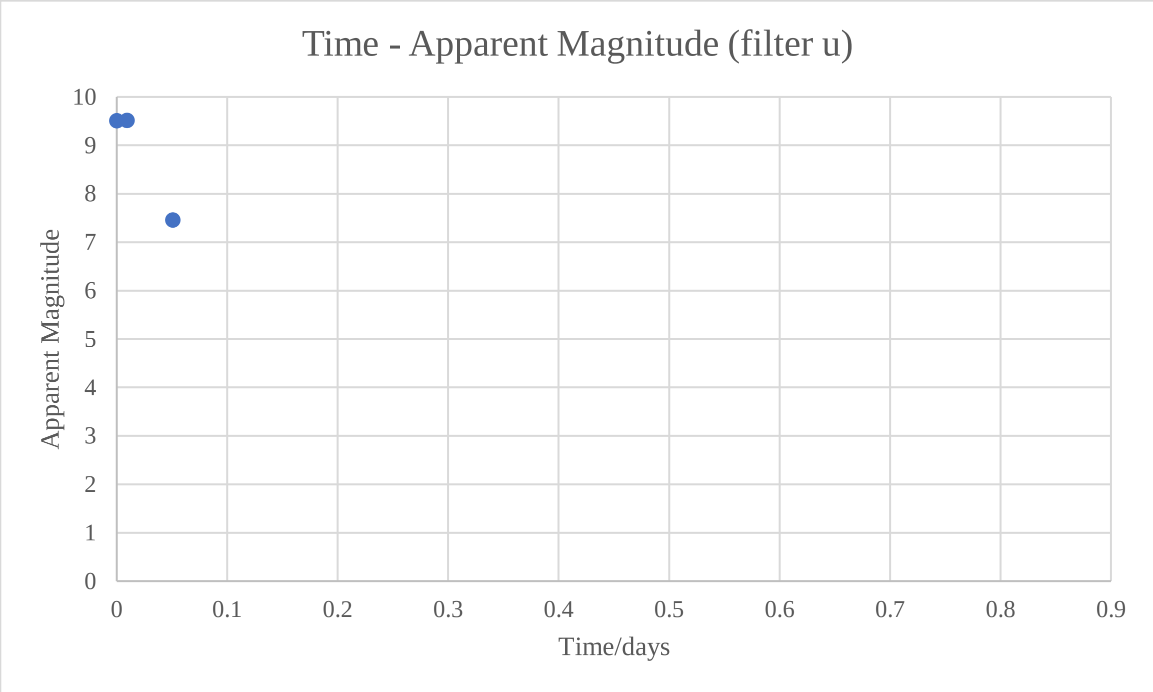


Fig.18 Time–Apparent Magnitude Dot Plot for RR Lyrae (Filter u')

The data from filter u' is not clear, so the data set cannot be used to measure the amplitude and period.

3.3.2 Filter g'

Observation time/ Day hour:minute:second	Time Line/ days	ΔMagnitude*	Apparent Magnitude
10 01:08:56	0	2.84	7.54
10 01:21:40	0.0092	2.78	7.60
10 02:21:43	0.0507	2.65	7.73
10 04:40:49	0.1472	2.37	8.01
10 05:22:14	0.1757	2.38	8.00
10 19:15:51	0.7549	2.34	8.04

10 19:22:03	0.759	2.31	8.07
10 20:22:07	0.8007	2.24	8.14

Fig.19 Data for RR Lyrae (Filter g')

*: ΔMagnitude = Magnitude (Reference Star) – Magnitude (Cepheid)

The measurement is executed in the usage of AstroImageJ. The figure of each measurement for RR Lyrae using filter g' is in Appendix A-C2.

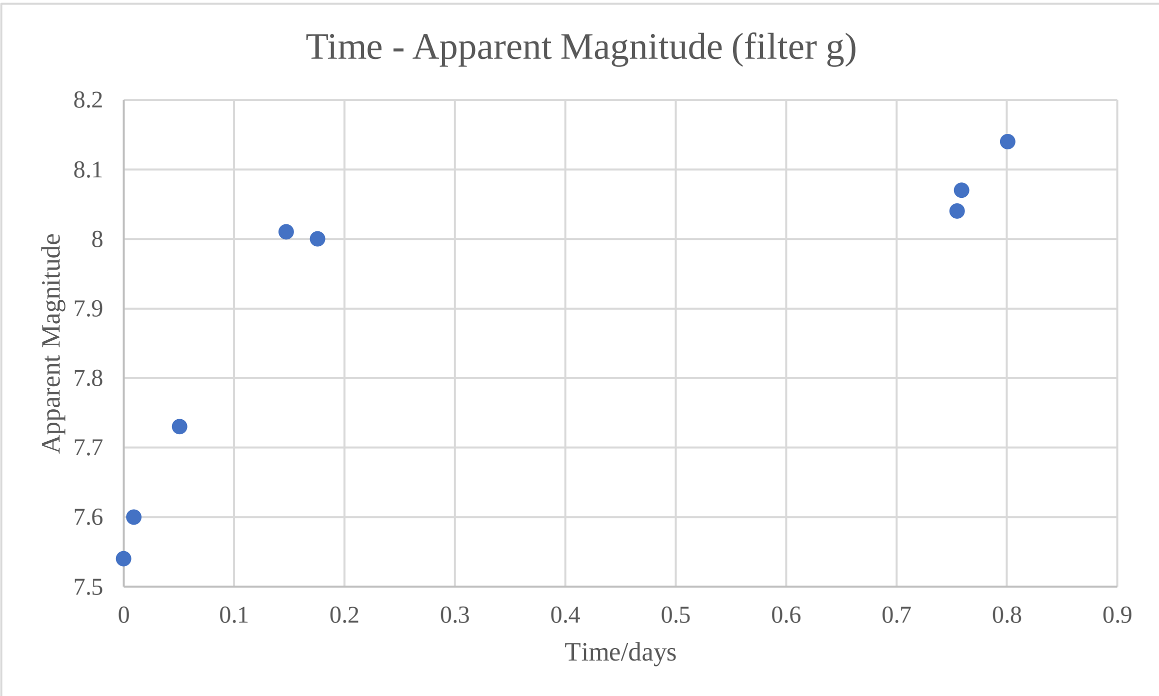


Fig.20 Time–Apparent Magnitude Dot Plot for RR Lyrae (Filter g')

From the 2 graphs, the observed amplitude is 0.60 with no clear period.

3.3.3 Filter r'

Observation time/ Day hour:minute:second	**Time Line/ days**	**ΔMagnitude***	**Apparent Magnitude**

10 01:09:32	0	2.84	7.54
10 01:22:13	0.0092	2.78	7.60
10 02:22:15	0.0507	2.68	7.7
10 04:41:50	0.1472	2.67	7.71
10 05:23:00	0.1757	2.38	8.00
10 19:16:41	0.7549	2.59	7.79
10 19:22:53	0.759	2.55	7.83
10 20:22:59	0.8007	2.49	7.89

Fig.21 Data for RR Lyrae (Filter r')

*: ΔMagnitude = Magnitude (Reference Star) – Magnitude (Cepheid)

The measurement is executed in the usage of AstroImageJ. The figure of each measurement for RR Lyrae using filter r' is in Appendix A-C3.

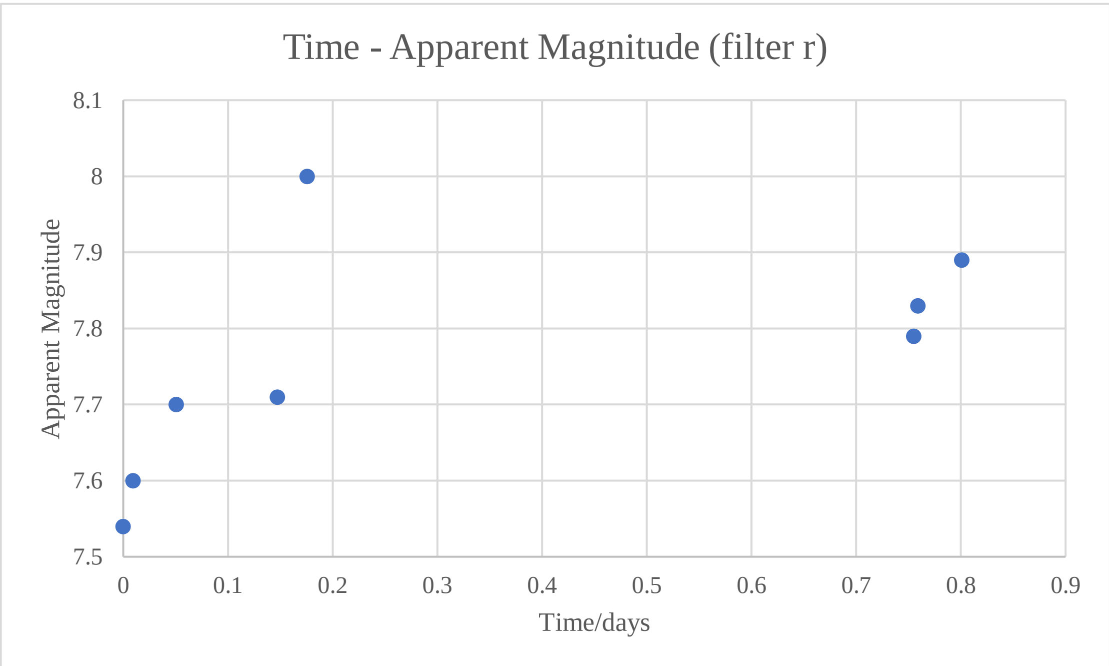


Fig.22 Time–Apparent Magnitude Dot Plot for RR Lyrae (Filter r')

From the 2 graphs, the observed amplitude is 0.46 with no clear period.

3.3.4 Filter i'

Observation time/ Day hour:minute:second	Time Line/ days	ΔMagnitude*	Apparent Magnitude
10 01:10:04	0	2.94	7.44
10 01:22:45	0.0092	2.90	7.48
10 02:22:50	0.0507	2.83	7.55
10 04:42:42	0.1472	2.63	7.75
10 05:23:47	0.1757	2.55	7.83
10 19:17:40	0.7549	2.81	7.57
10 19:23:43	0.759	2.83	7.55
10 20:23:49	0.8007	2.77	7.61

Fig.23 Data for RR Lyrae (Filter i')

*: ΔMagnitude = Magnitude (Reference Star) – Magnitude (Cepheid)

The measurement is executed in the usage of AstroImageJ. The figure of each measurement for RR Lyrae using filter i' is in Appendix A-C4.

The Time-Apparent Magnitude Dot Graph is displayed below.

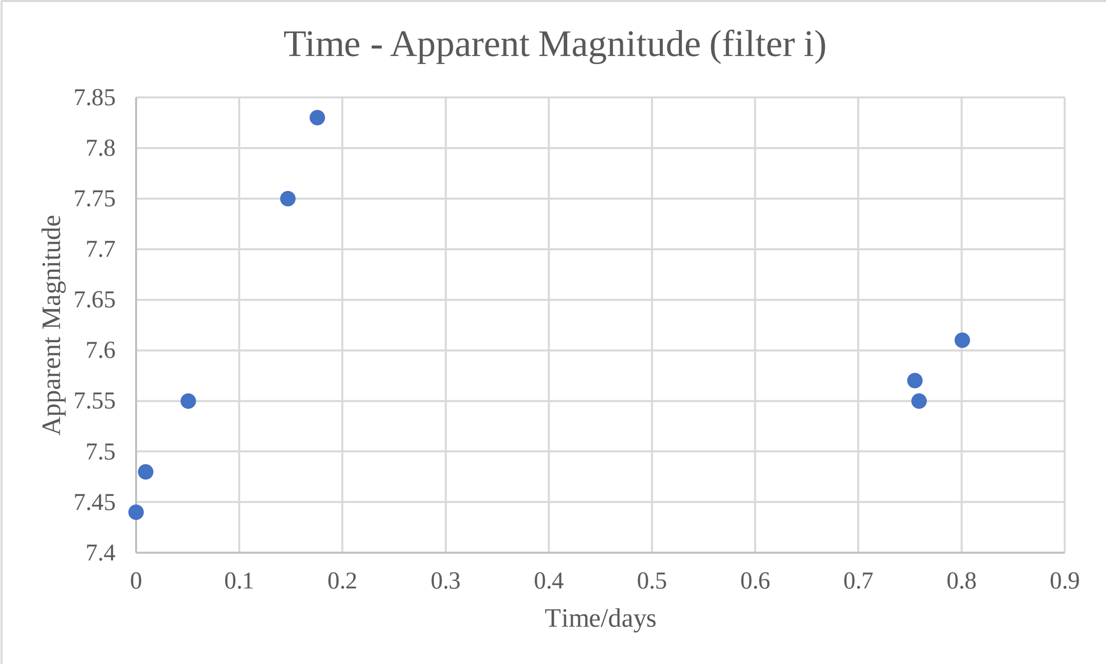


Fig.24 Time–Apparent Magnitude Dot Plot for RR Lyrae (Filter i')

From the 2 graphs, the observed amplitude is 0.39 with no clear period.

4. Data Analysis and Discussion

4.1 Summary of BI Cas and Comparison

	Filter u'	Filter g'	Filter r'	Filter i'	ASASSN Data
Apparent Magnitude	11.37-12.59	13.01-13.59	12.03-12.81	11.84-12.50	12.48-13.12
Amplitude	1.22	0.58	0.78	0.66	0.64
Period/days	1.0606	1.0674	1.0248	1.0474	1.0993

Fig.25 Summary of Data of BI Cas, including Apparent Magnitude, Amplitude and Period of Filters u', g', r', and i', and Their Comparison with the Data from ASASSN Database

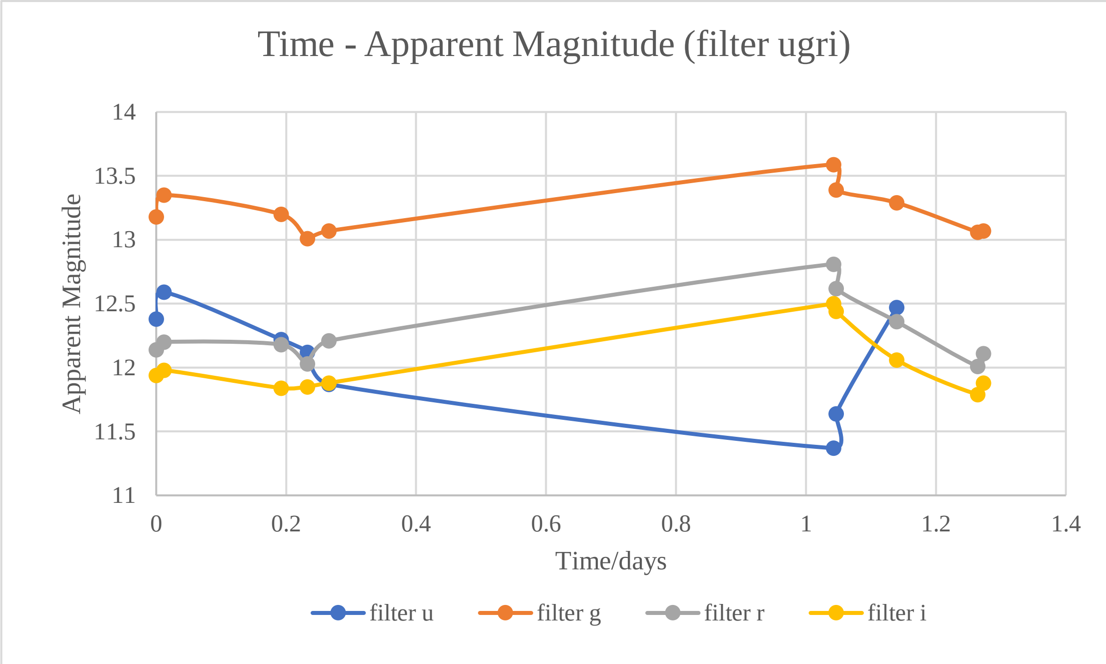


Fig.26 Time-Apparent Magnitude of BI Cas of Filters u’, g’, r’, and i’

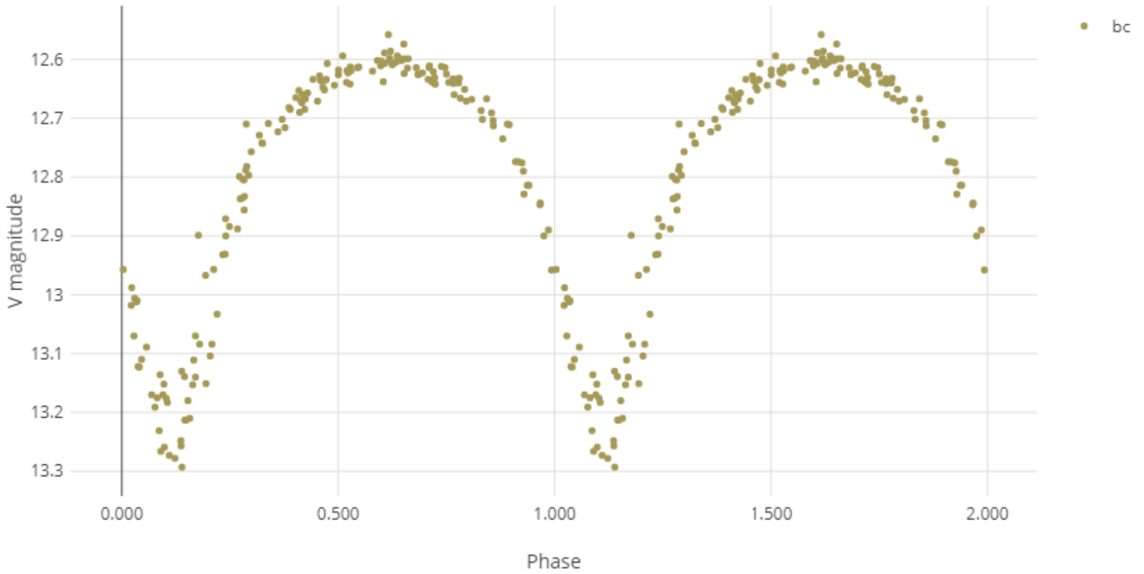


Fig.27 Reference Data of BI Cas from ASASSN Database[8]

From the graph “Time – Apparent Magnitude (filter ugri)”, we find that the apparent magnitude change measured by the filter u’ does not agree with the other three filters. We think this may be caused by atmospheric interference and the problems on filter u' itself. Not concerning the data set of filter u'. The other three data sets display a similar trend of the change in apparent magnitude; however, there are fixed value differences between them. This is caused by the indiscriminative usages of the apparent magnitude from filter V of reference stars, which is a problem that is hard to solve using the available database. In the consideration of errors caused by the calibration, the ranges of the observed apparent magnitude and observed period are generally in agreement with the reference data from the database. To solve this problem, we need to use filters B, V, G, J, H, and K to observe.

Because of the lack of data, the trajectory of change in apparent magnitude cannot coincide with the reference data. In order to improve the experiment, the amount of data should increase 2-3 times. Simultaneously, finding a reference star is also important to the measurement. So it will be better to observe the target Cepheid and the specified reference star at the same time.

Some of the problems are also applied to the other two stars, so we will briefly talk about the similar problems in the following content.

4.2 Summary of NSV 4148 and Comparison

Because of the lack of data, the change in magnitude and period cannot be found, so only the average apparent magnitude will be computed and compared with the reference data.

	Filter u'	**Filter g'**	**Filter r'**	**Filter i'**	**ASASSN Data**
Average	13.52	11.75	11.39	11.28	11.79

Magnitude					
Amplitude					0.73
Period/days					0.8940

Fig.28 Summary of Data of NSV 4148, including Average Magnitude, Amplitude and Period of Filters u', g', r', and i', and Their Comparison with the Data from ASASSN Database

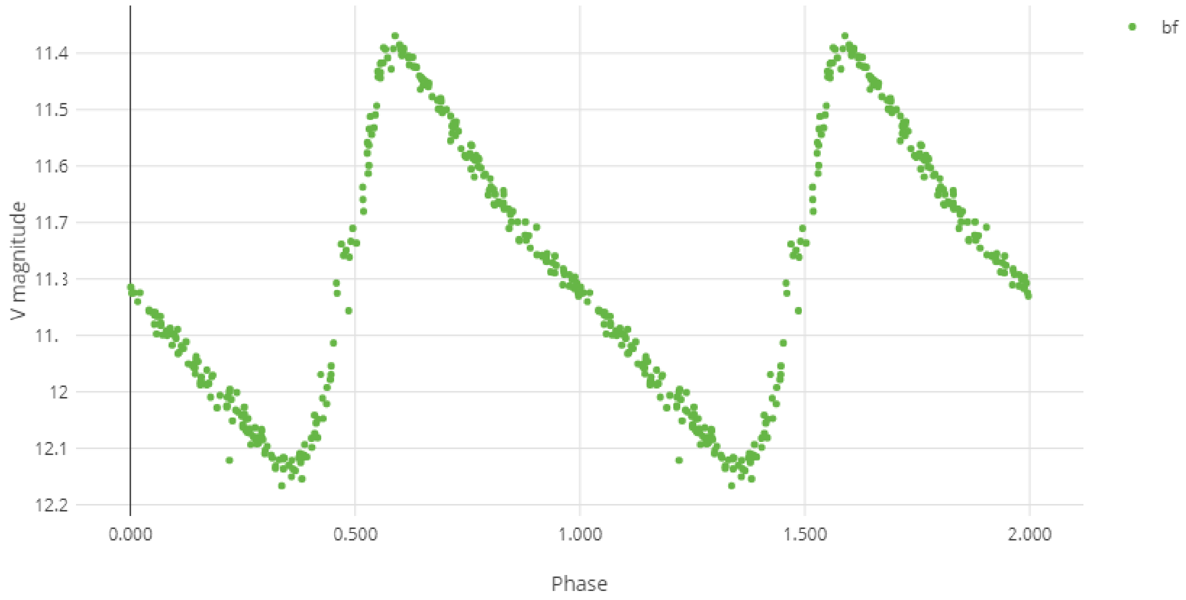


Fig.29 Reference Data of NSV 4148 from ASASSN Database[9]

The problems of filter u' is also displayed in the observation of this star. Although the data set is not enough, the average magnitudes computed from the other three filter are still in good agreement with the reference data.

The observed window for NSV 4148 is short compared to the other two, so it is difficult to get enough data in a long range of time. We think we may choose another Type II Cepheid to observe if we redo this part again. Also, calibration is still a problem in this part.

4.3 Summary of RR Lyrae and Comparison

	Filter u’	Filter g’	Filter r’	Filter i’	ASASSN Data
Apparent Magnitude	7.46-9.52	7.54-8.14	7.54-8.00	7.44-7.83	8.08-9.02
Amplitude	2.06	0.60	0.46	0.39	0.94

Fig.30 Summary of Data of RR Lyrae, including Apparent Magnitude and Amplitude of Filters u’, g’, r’, and i’, and Their Comparison with the Data from ASASSN DataBase

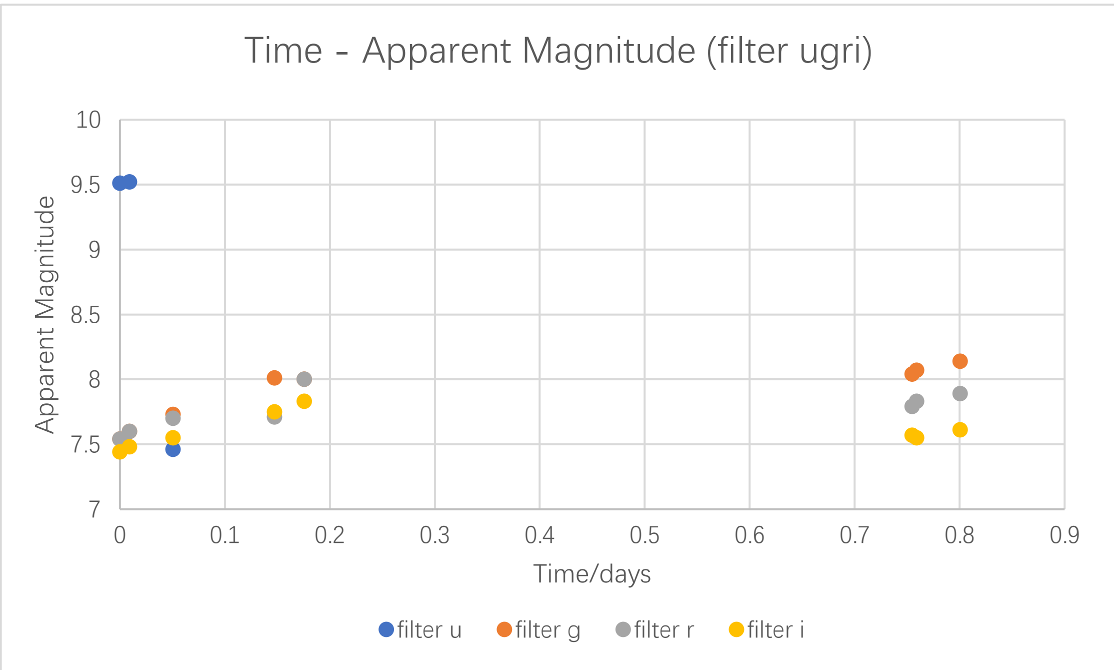


Fig.31 Time-Apparent Magnitude of RR Lyrae of Filters u’, g’, r’, and i’

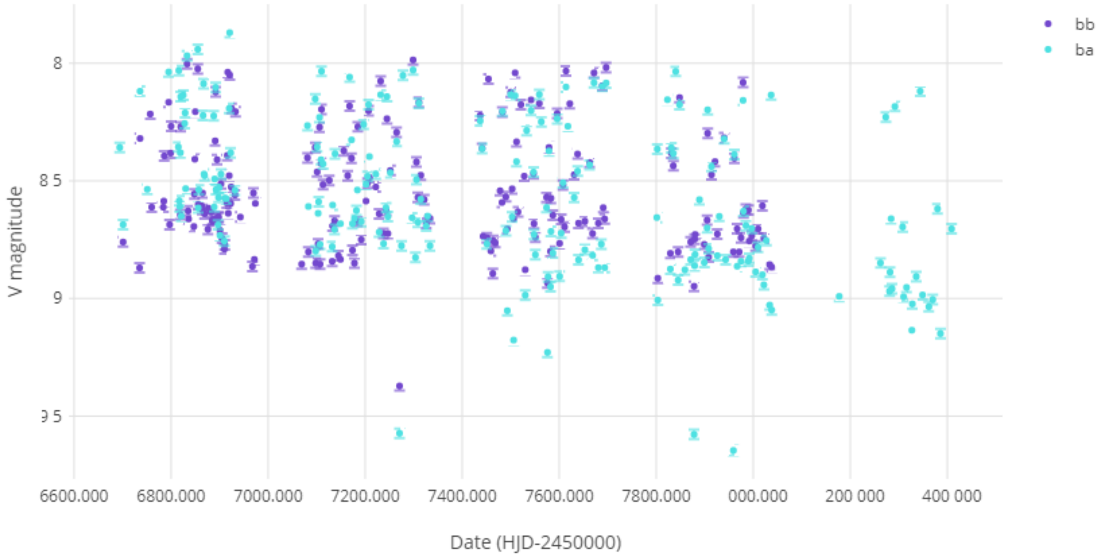


Fig.32 Reference Data of RR Lyrae from ASASSN Database[10]

Because RR Lyrae has no clear trend of change in apparent magnitude, there is no period for this kind of Cepheid variable. Lack of data and calibration are still problems in this set. And images from filter u' also do not show a clear spotting so we cannot collect useful data from this part. Another problem is that the data collected is too discrete in time scale, so the analysis between the clots of data is convictive. We need to collect more data from every time period in a day to provide more convincible result.

5. Conclusion

The data collected in this experiment is not satisfactory for the purpose of measuring the parameters of Cepheid. To be specific, the data in BI Cas is the best, the images of filter g, r, i, all provide a clear view so that the measurement of data is easy. Some images of RR Lyrae also provide a clear view for measurement. But because of the unpredictable change in the apparent magnitude of this type of Cepheid, we still need to collect enough amount of data to get a clear cognition of its parameters. NSV 4148 has the shortest observing window, so we did not collect enough data to analyze it.

If we can redo this experiment, we can make several improvements. The most important thing is that we will collect more data, spreading evenly throughout the whole day. And observing stars with enough observing windows is also important. Also, we suspect that the filter u' may not be suitable for observing such kinds of stars. And reference data used for calibration is also unavailable on the internet. We may need to use other filters to observe.

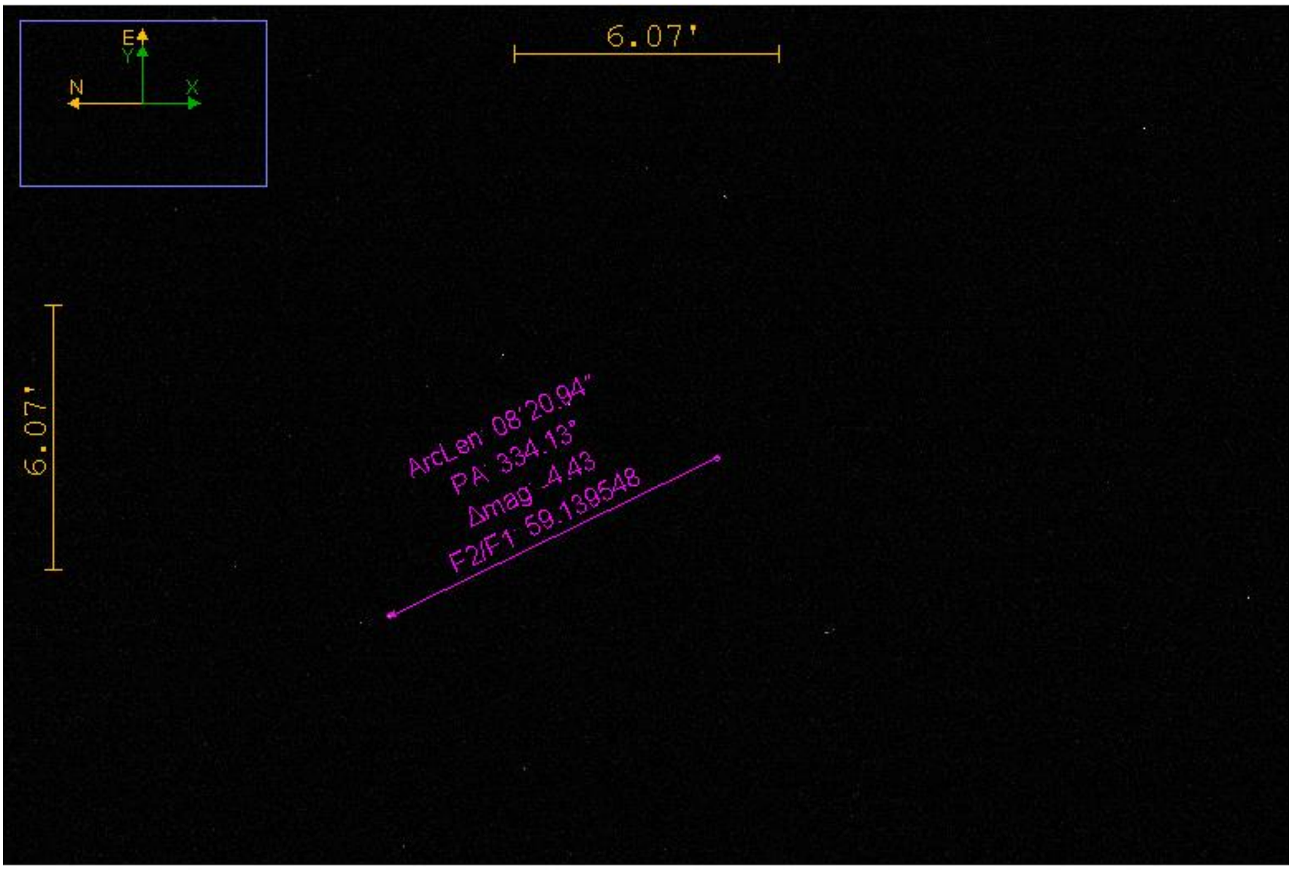
6. Acknowledgements

I would like to be thankful to Professor Philip Lubin and T.A. Mr. Kim for their technical and methodological support. I would also like to thank my partners, Vincent Wei, and Jiayu Wang. We faced a lot of difficulties during the experiment, but we overcame them and finish this observation. At last, I would show my gratitude to the Physics Department of UCSB for providing the resources that help me finish this research.

Appendix

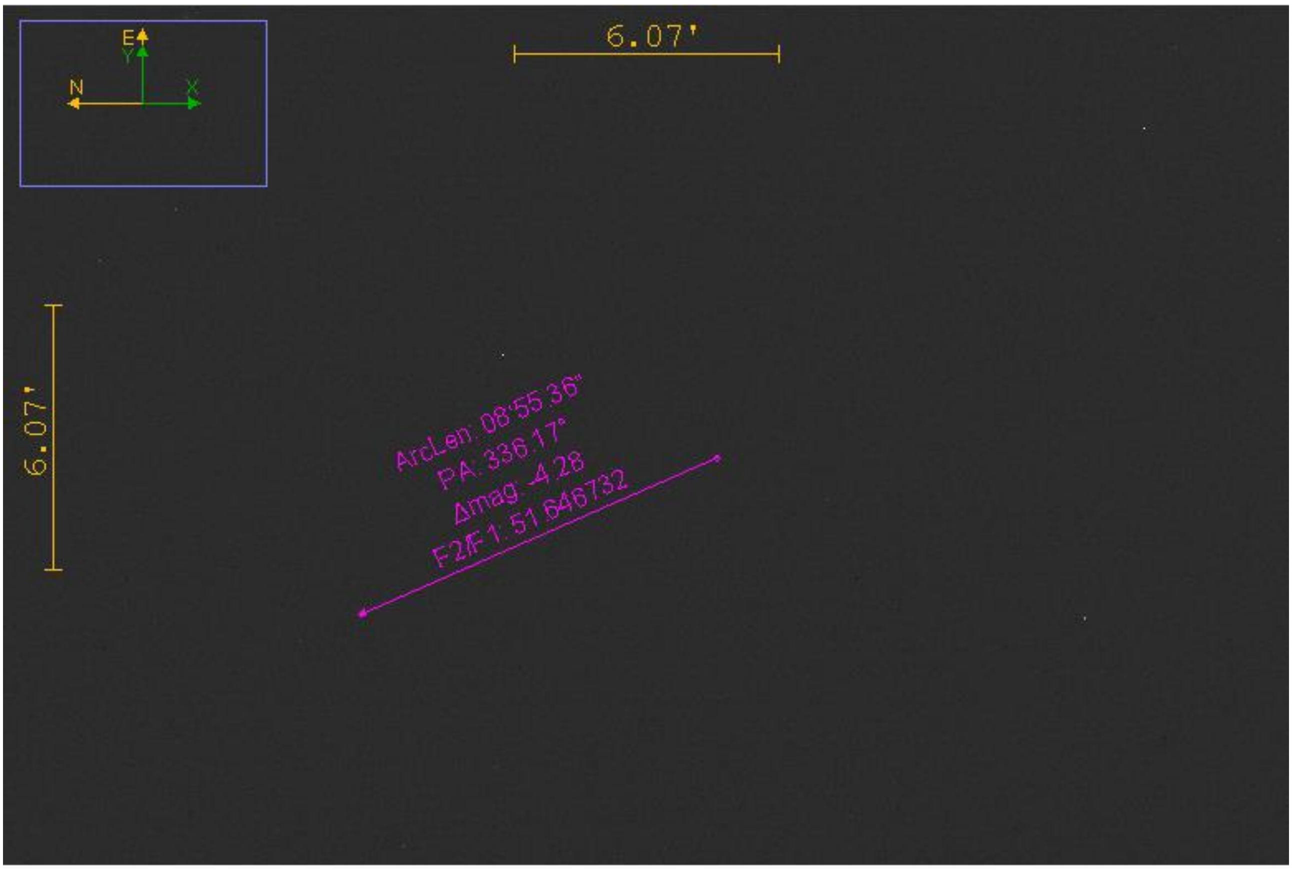
A

A1

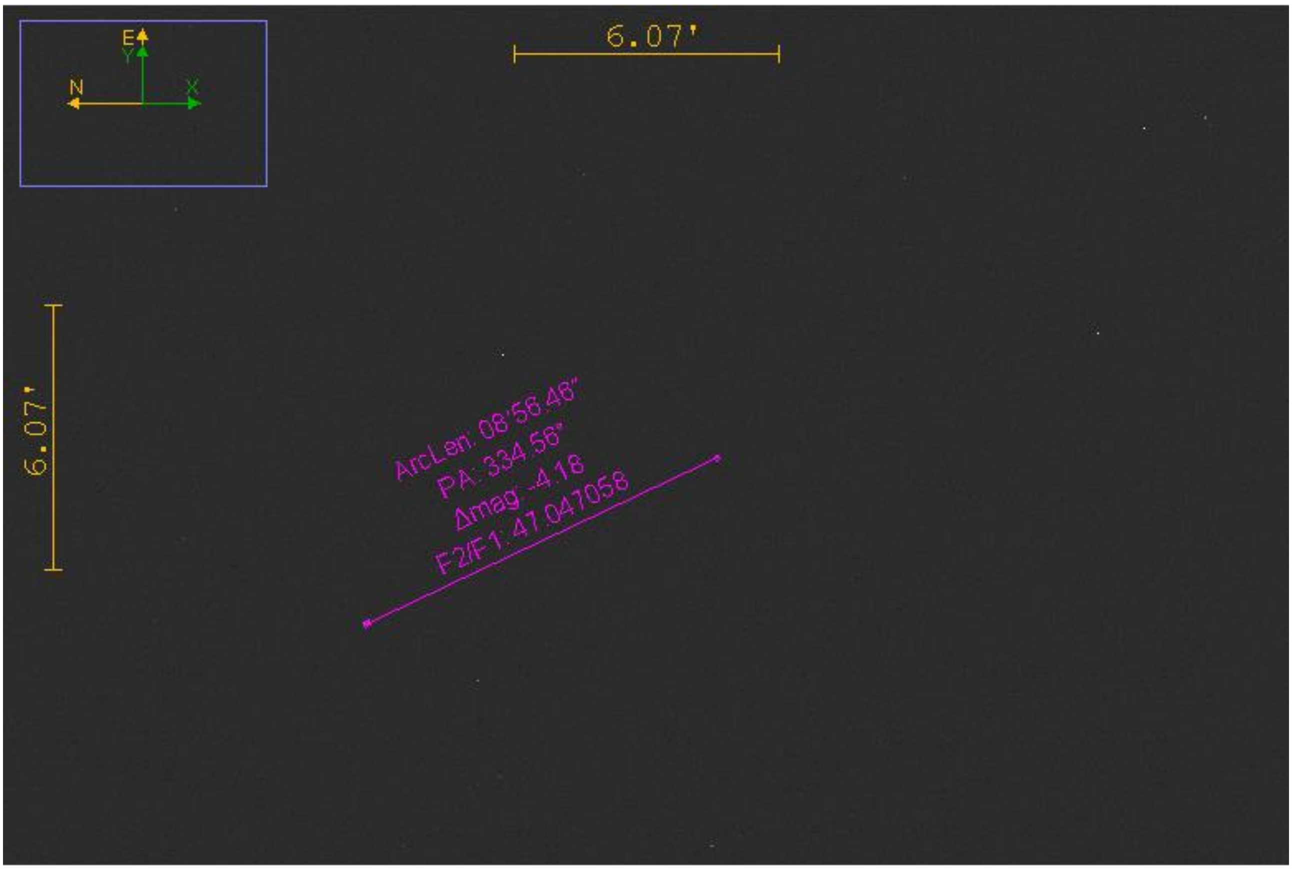


28th 19:07:11

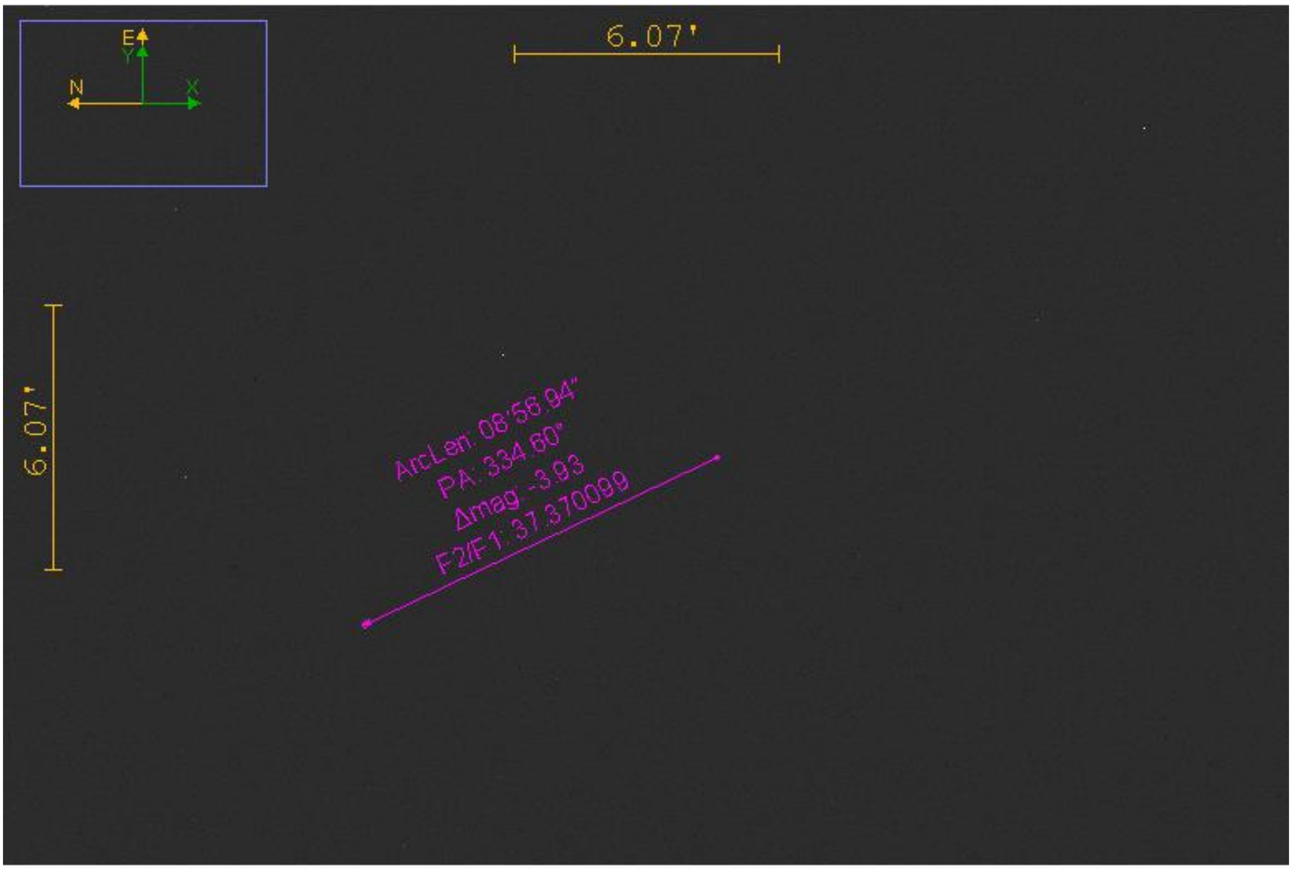
28th 19:24:09



28th 23:44:11



29th 00:42:02



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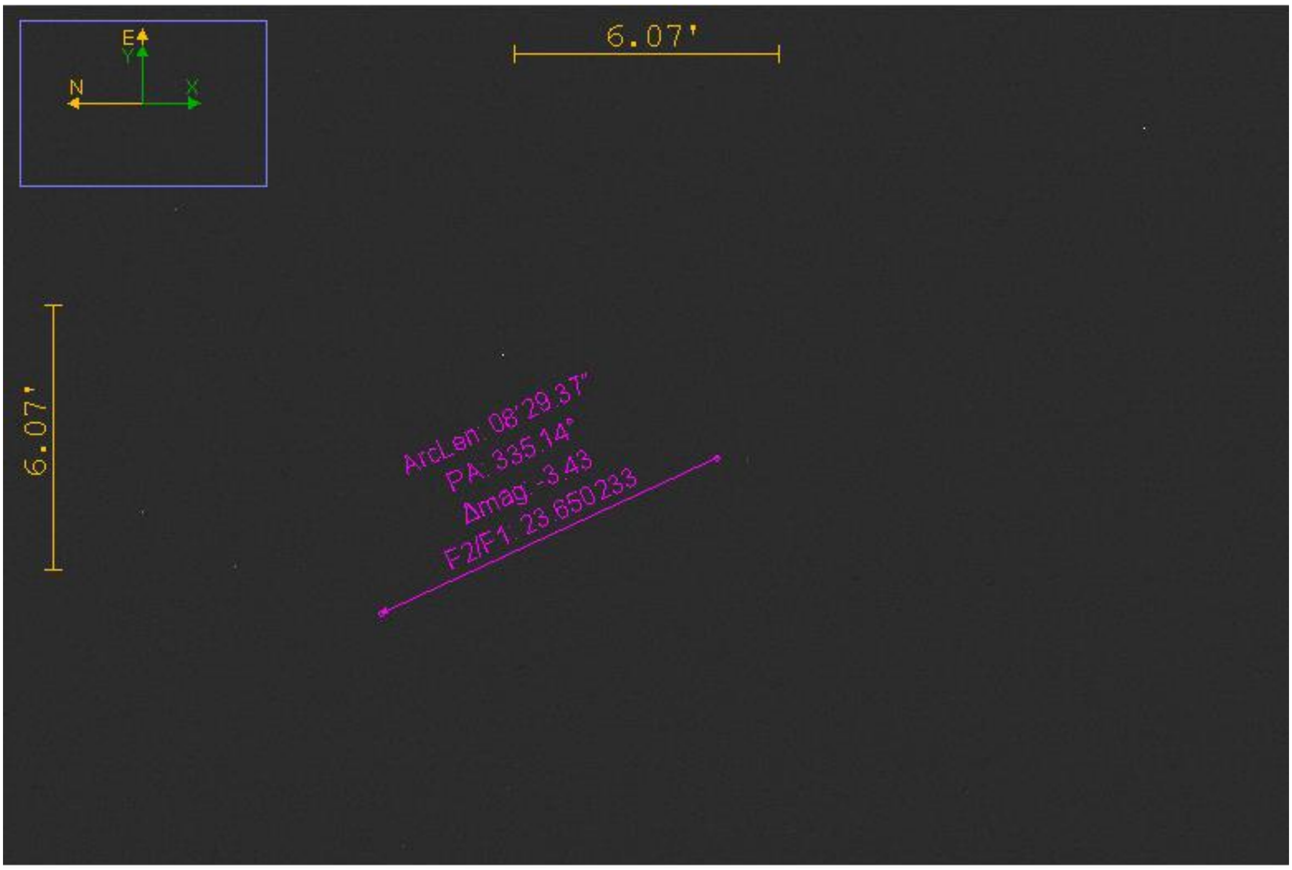

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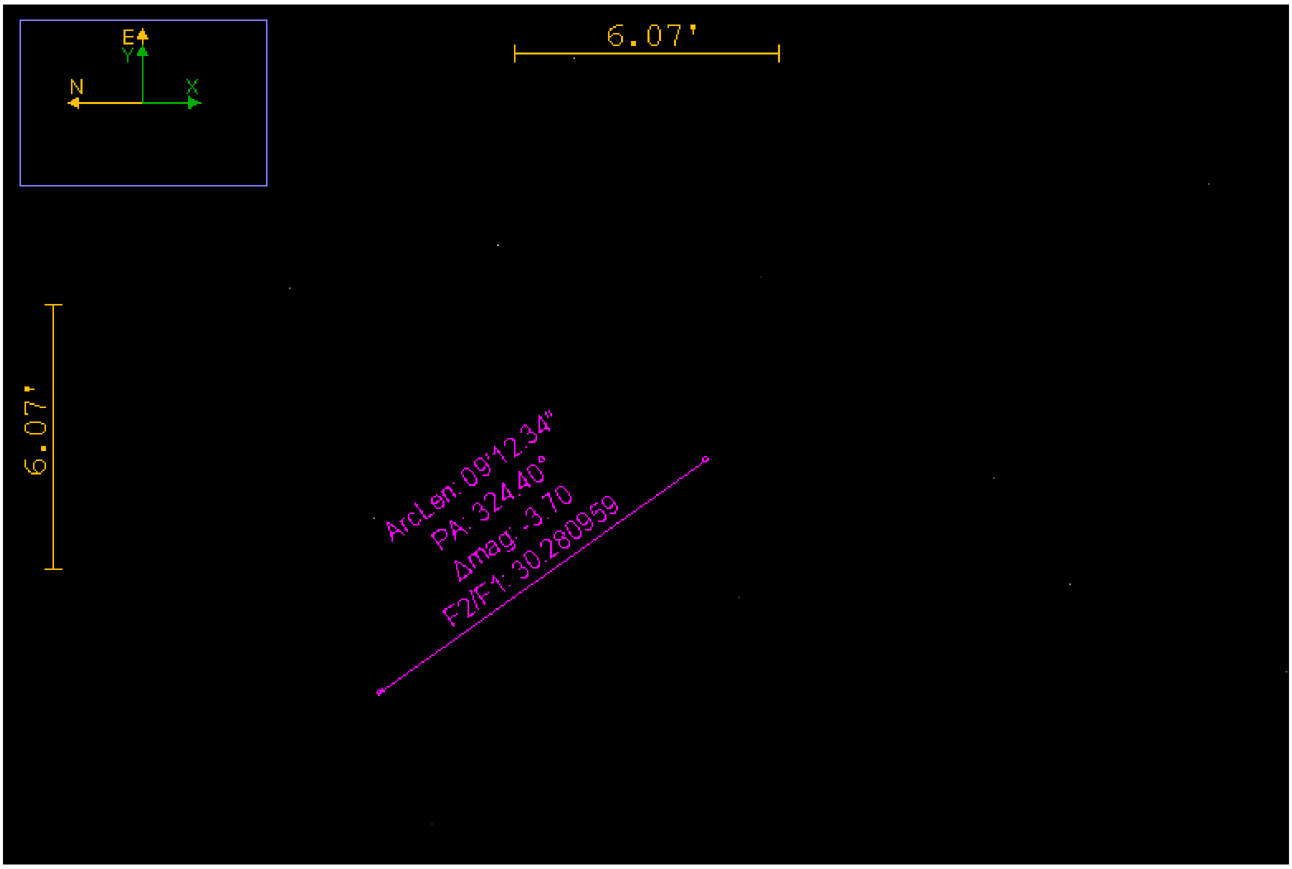

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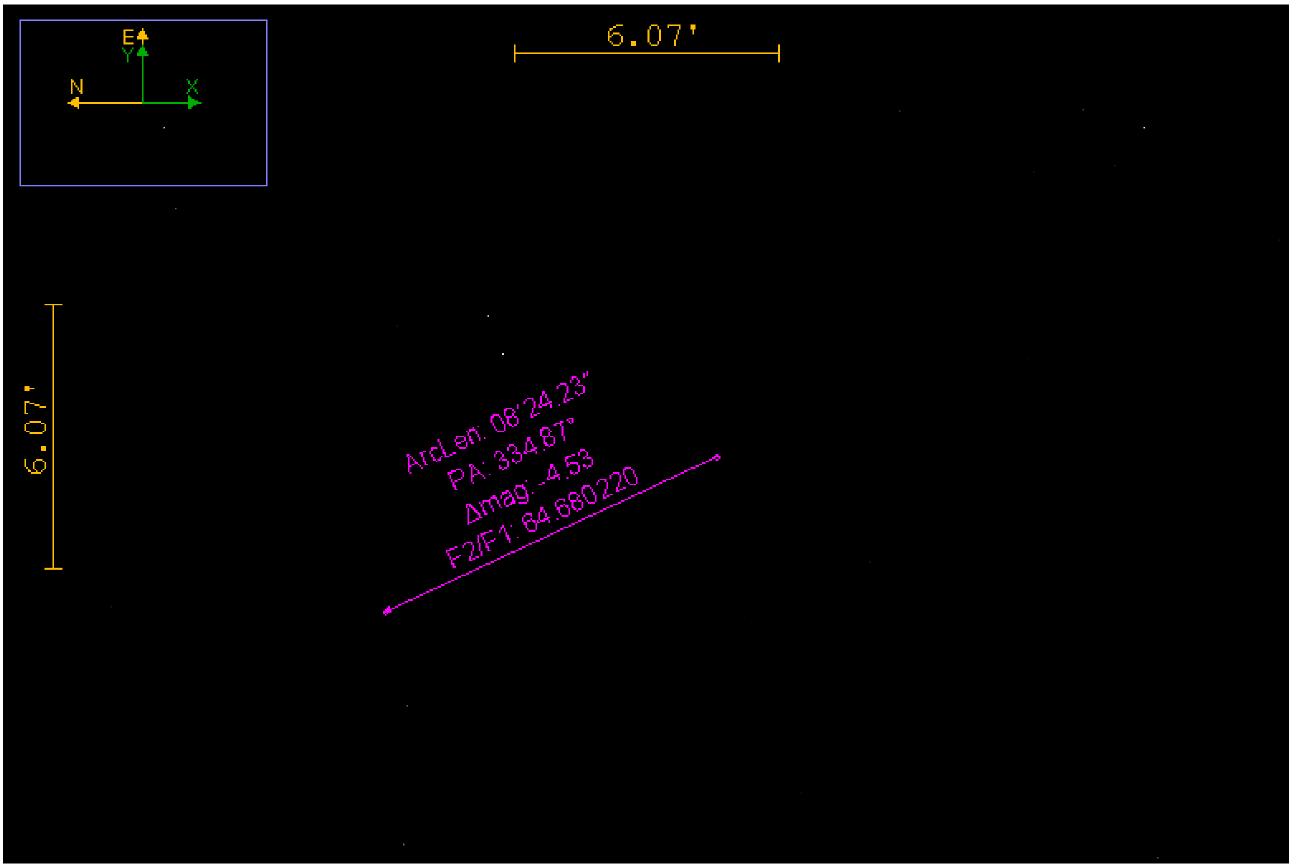

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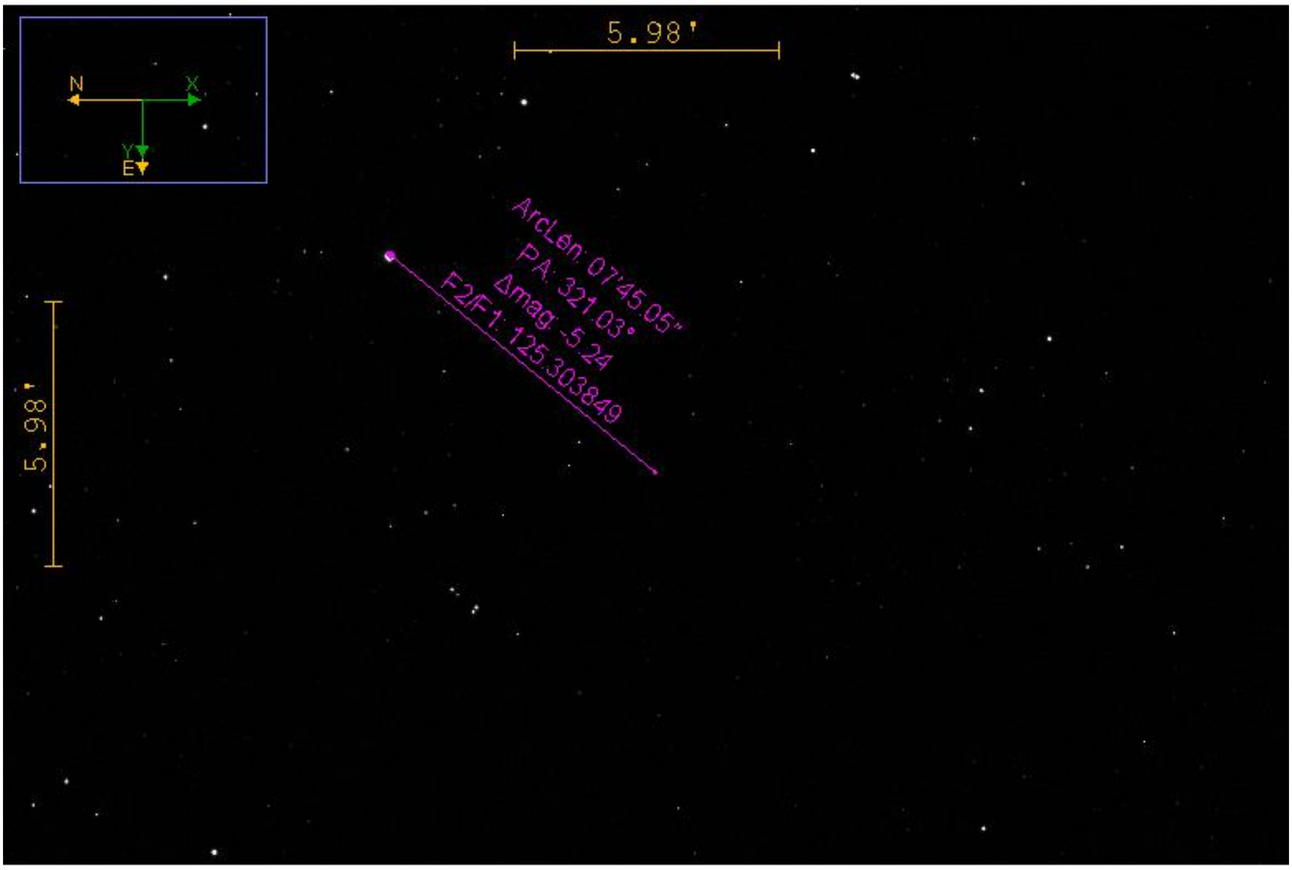

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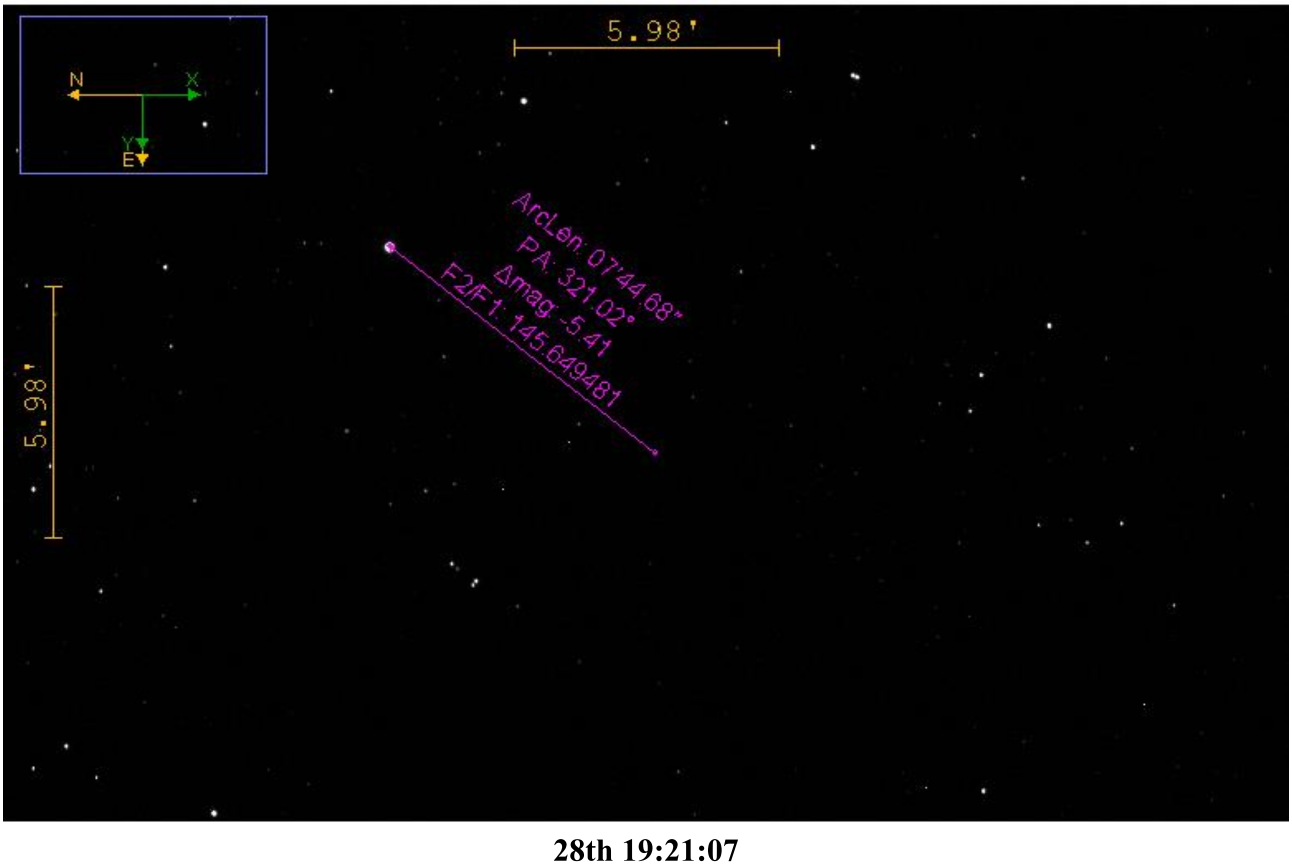

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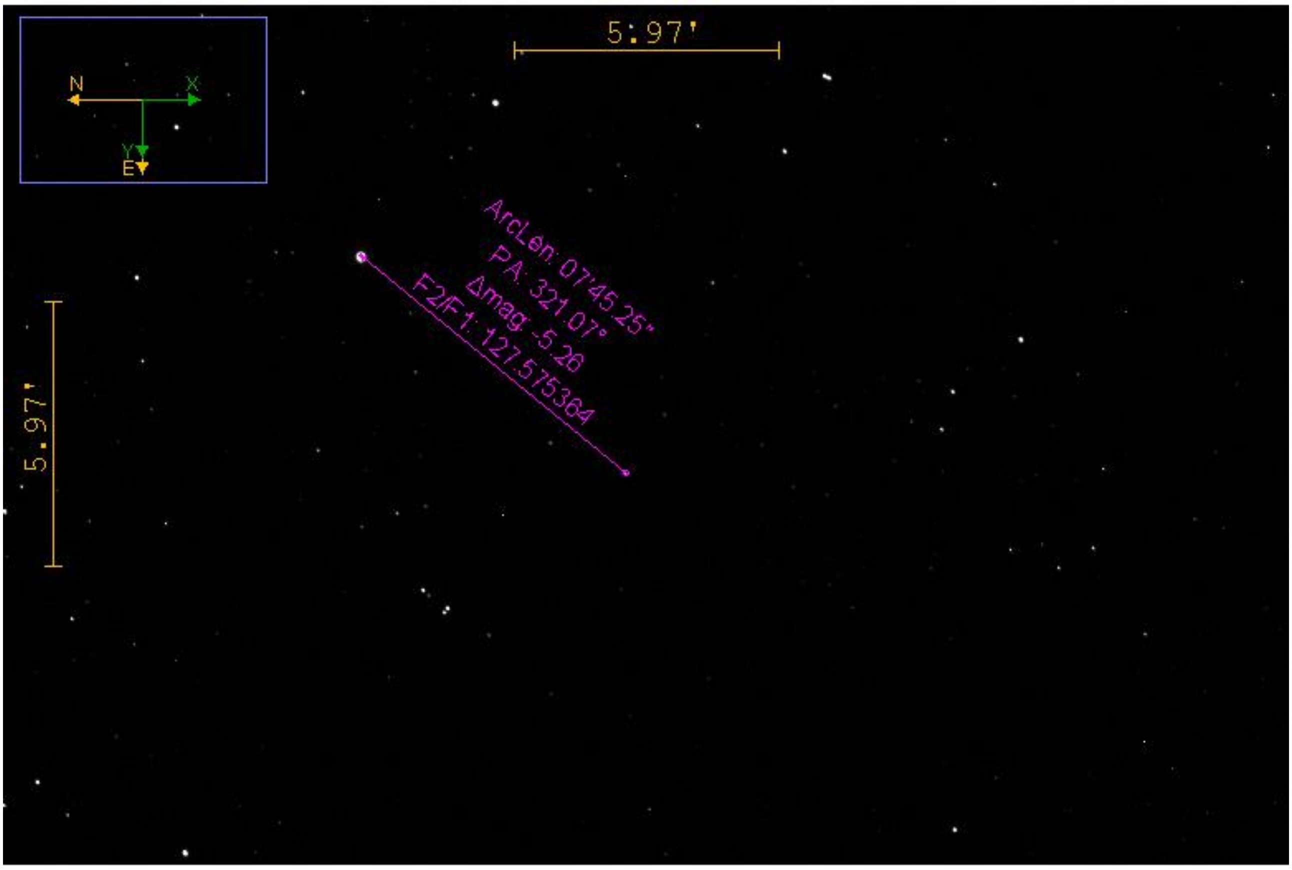

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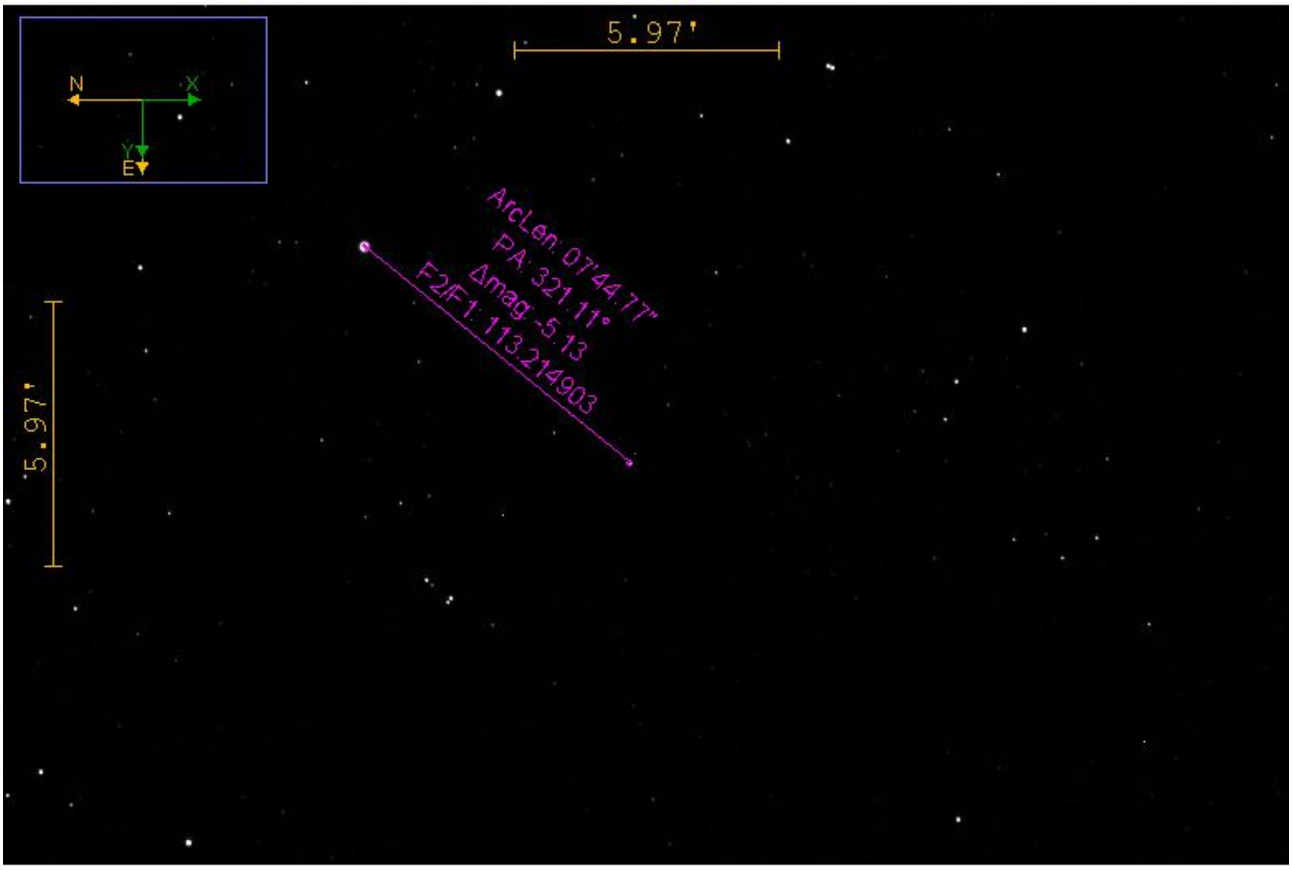

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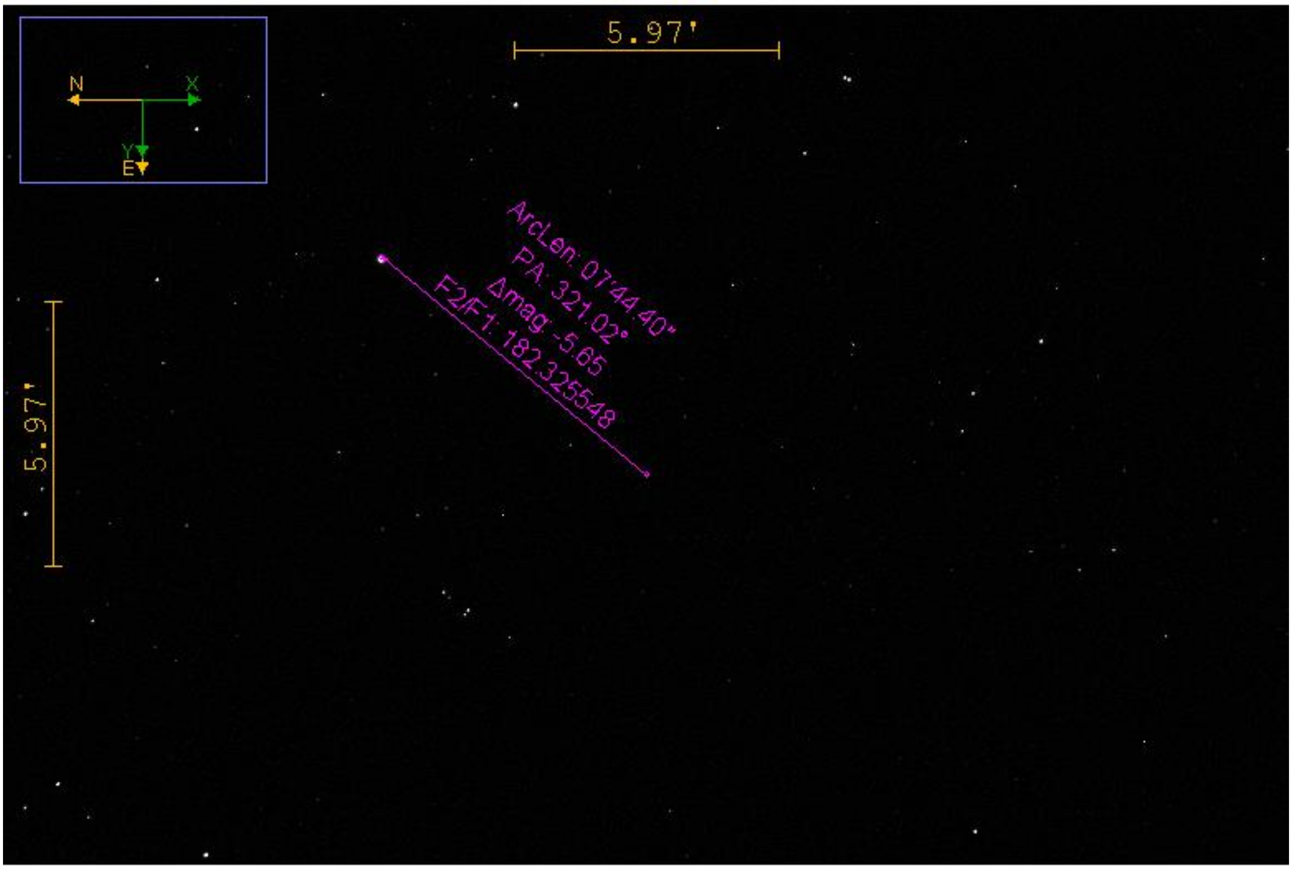

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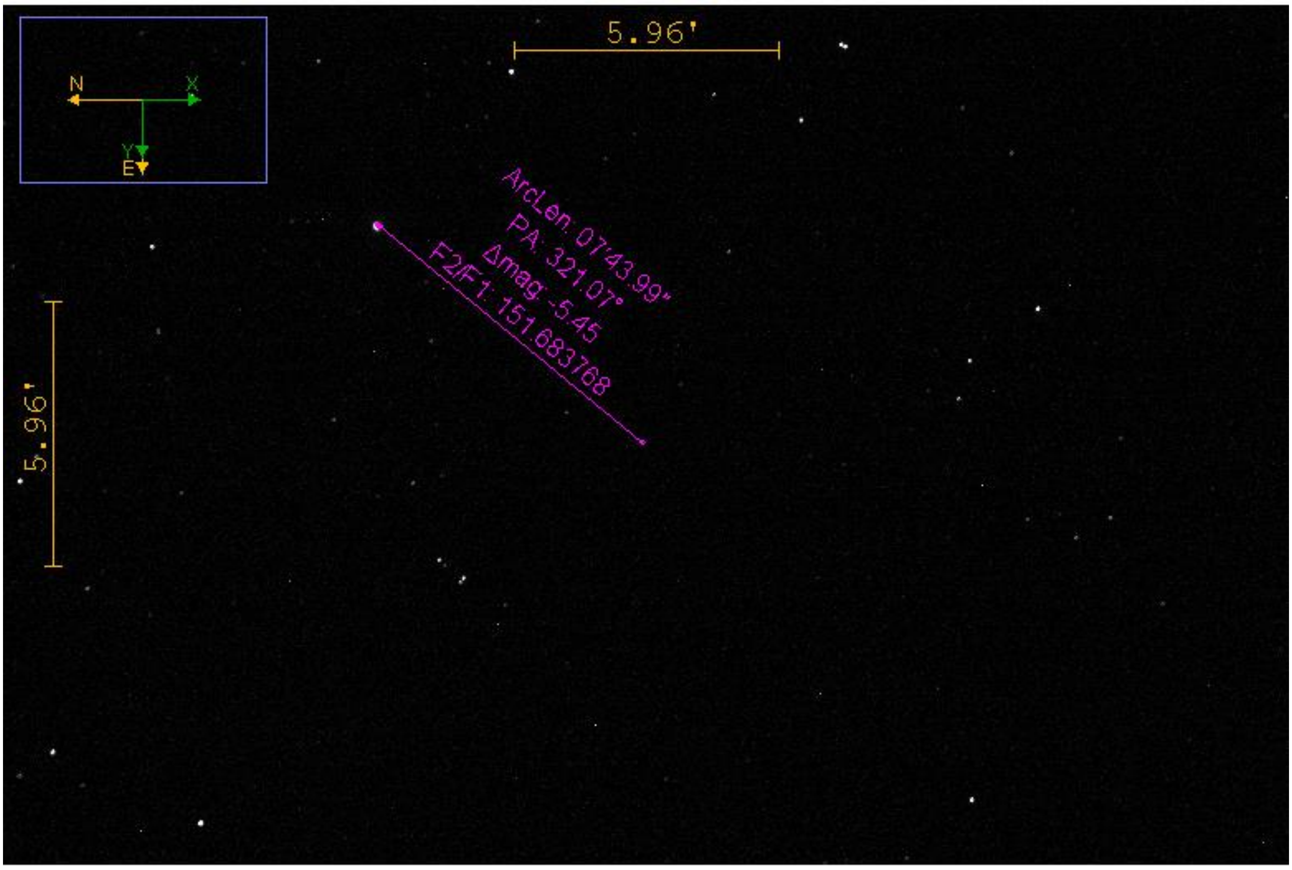

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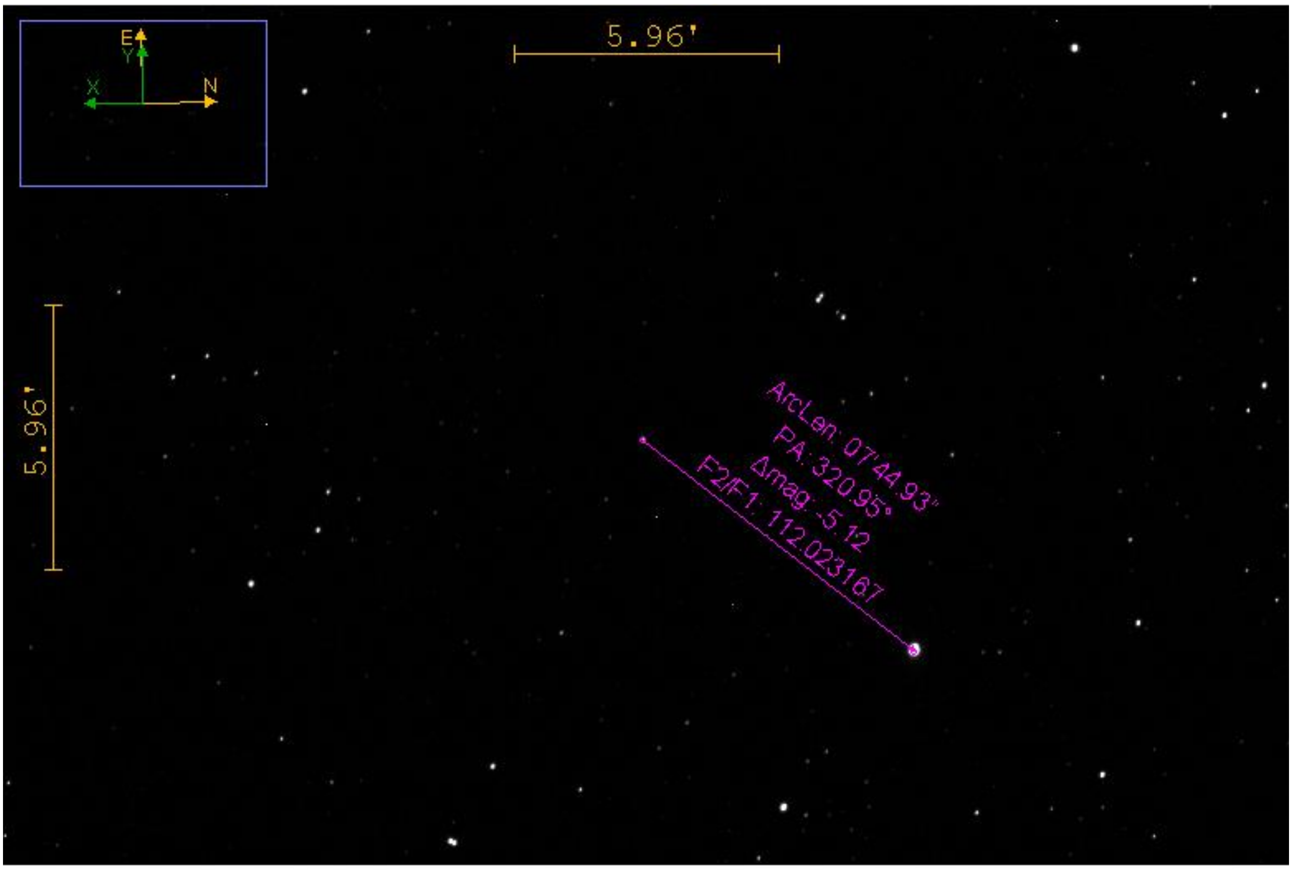

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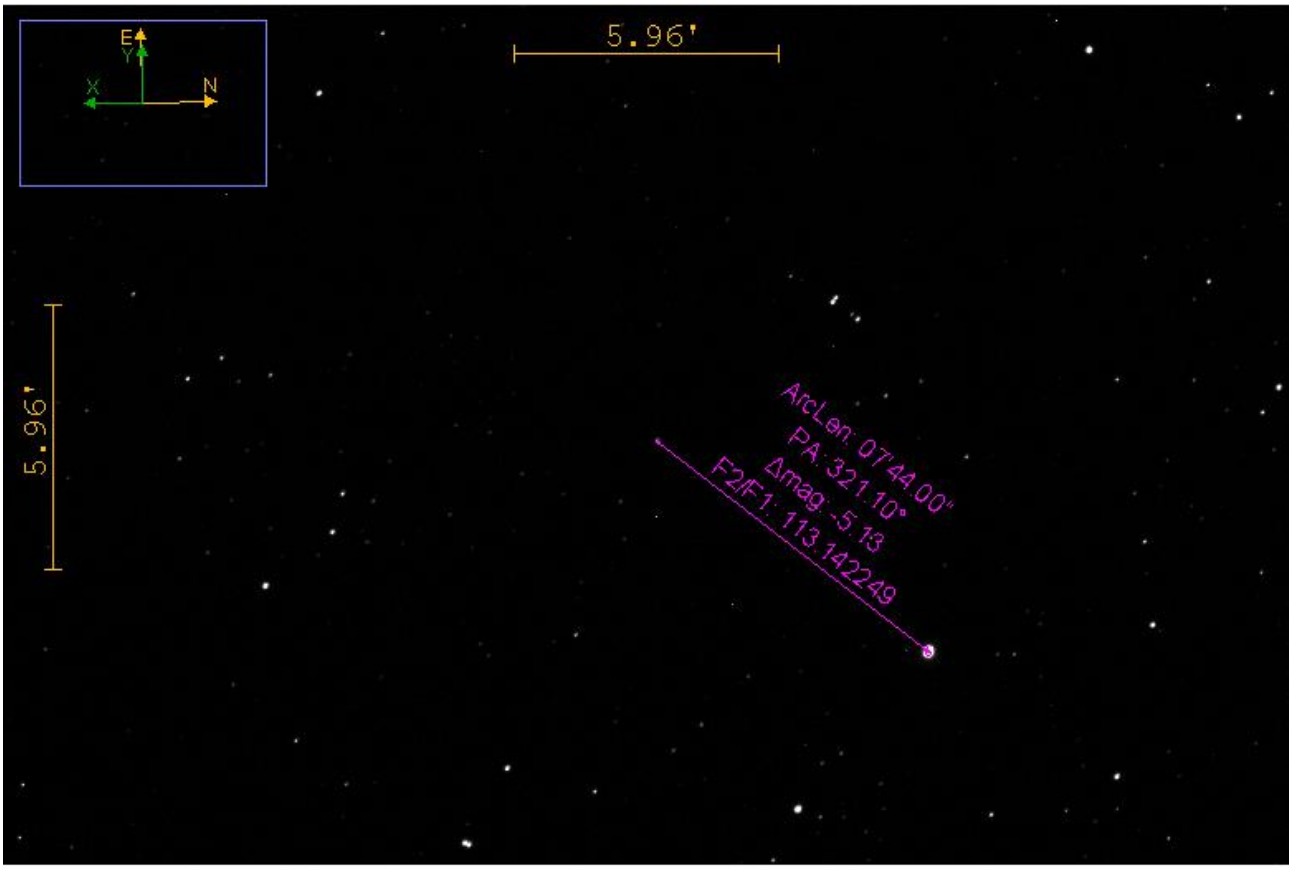

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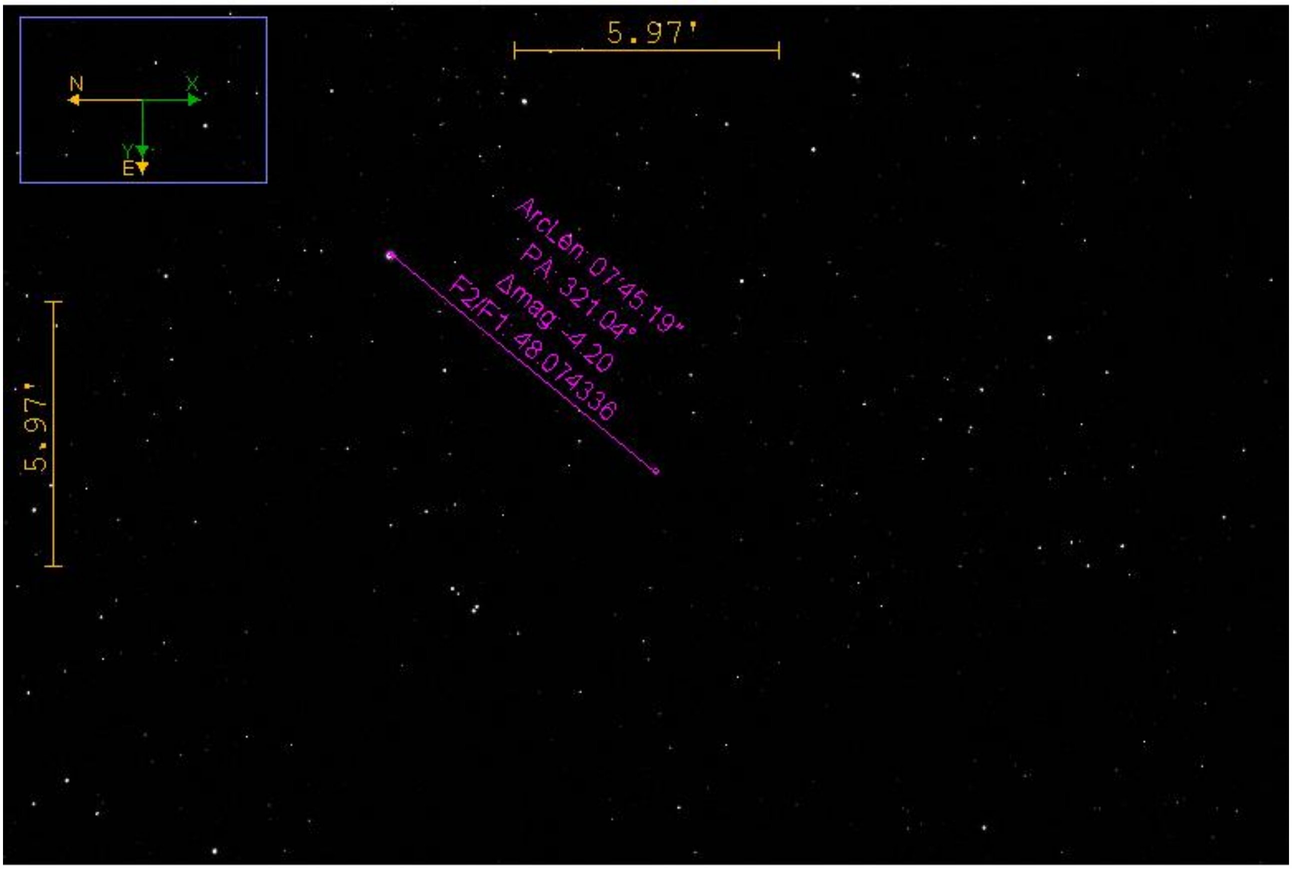

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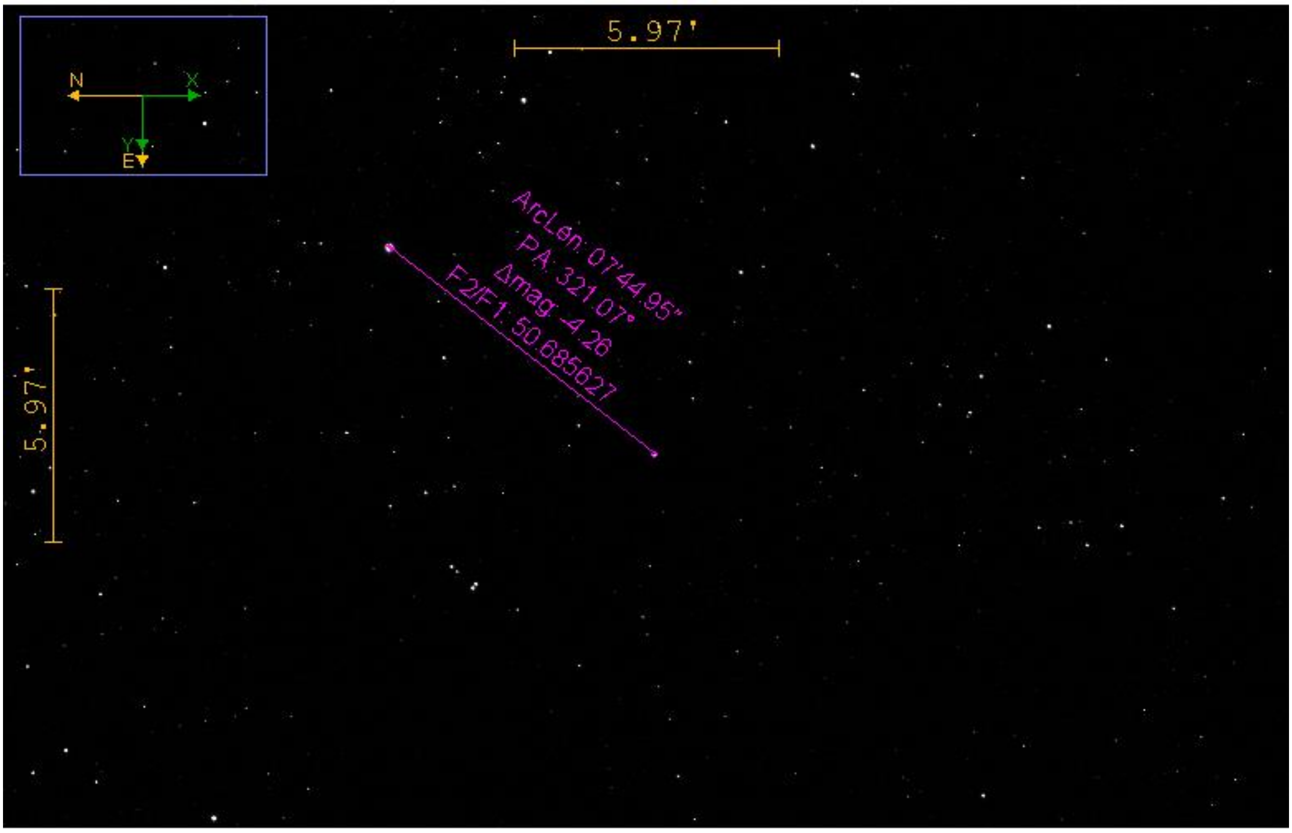

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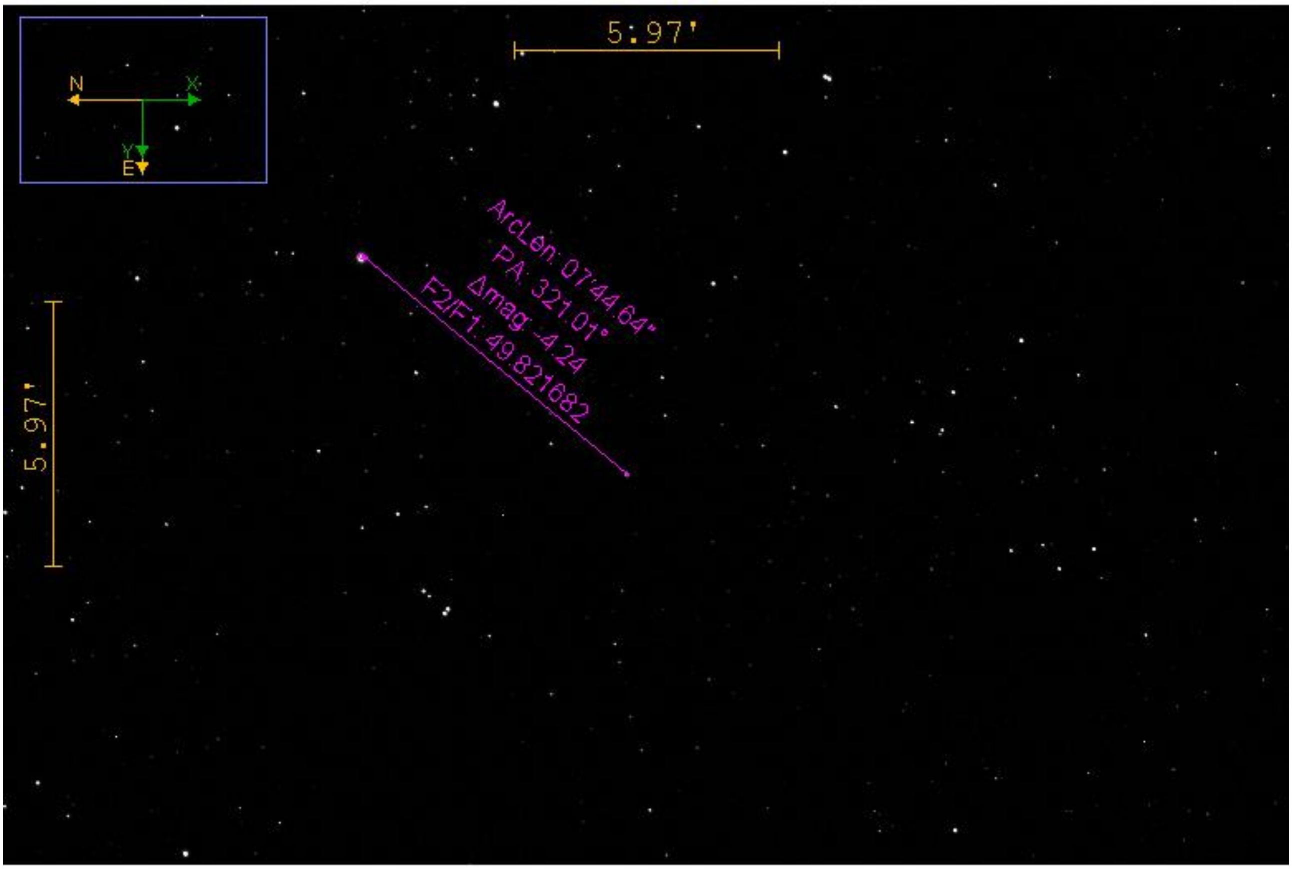

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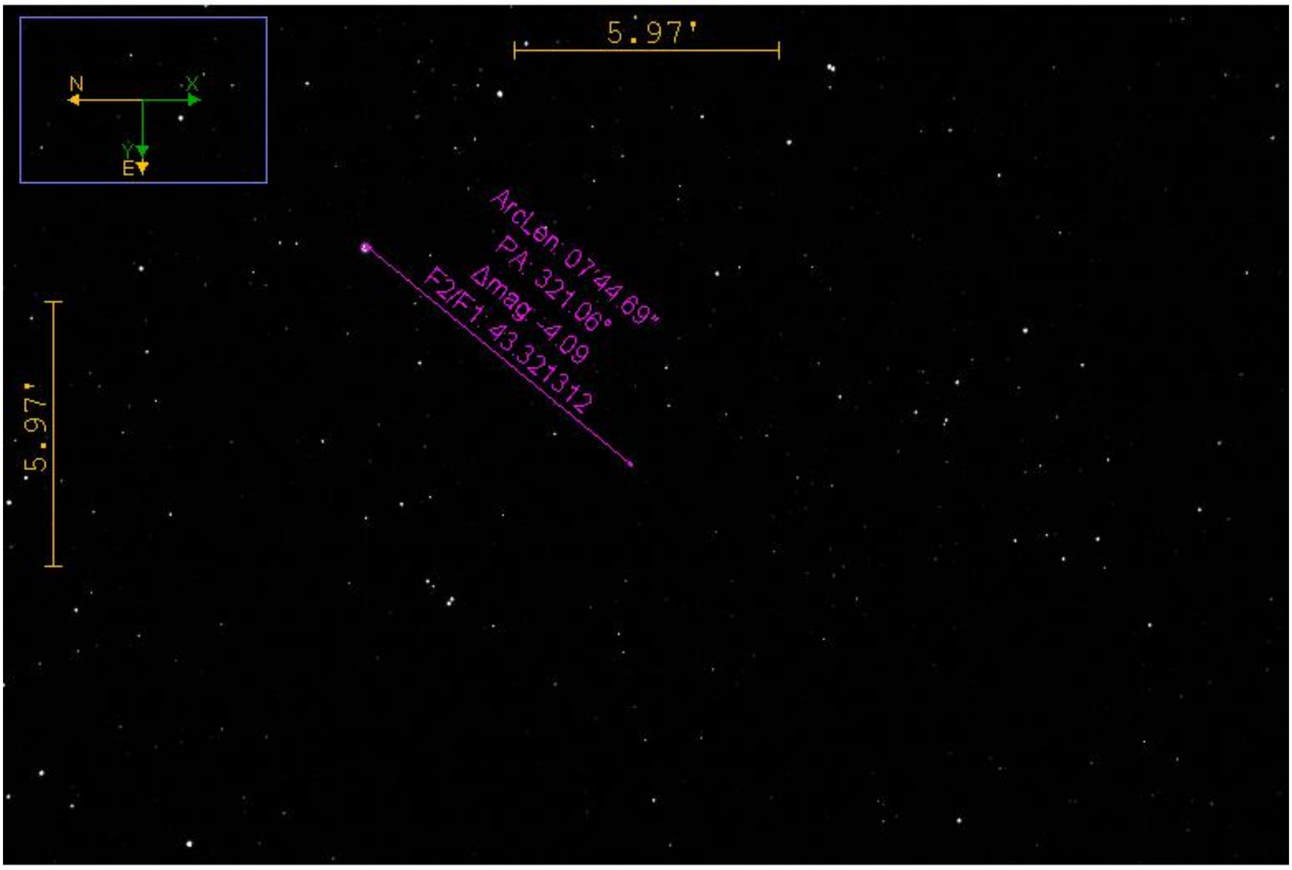

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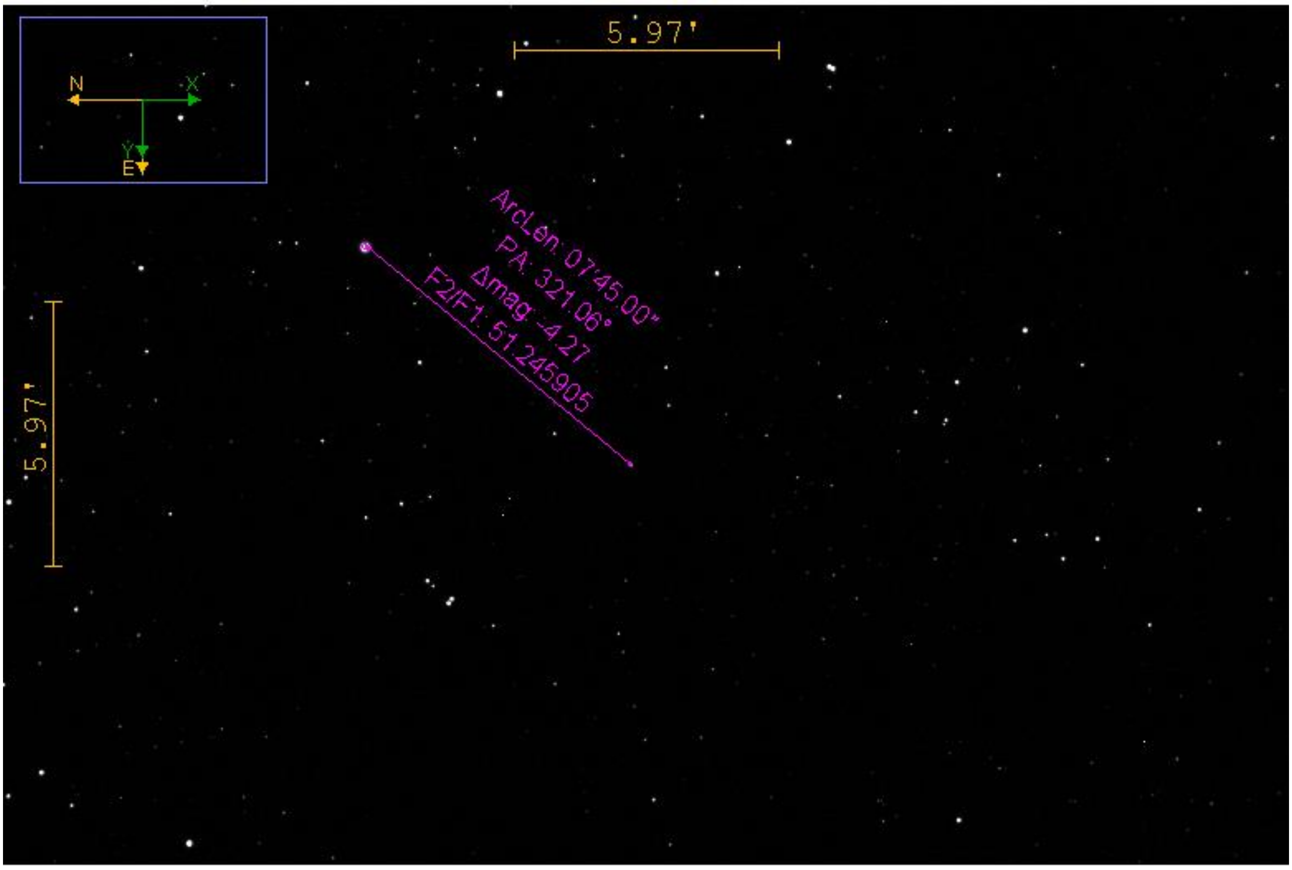

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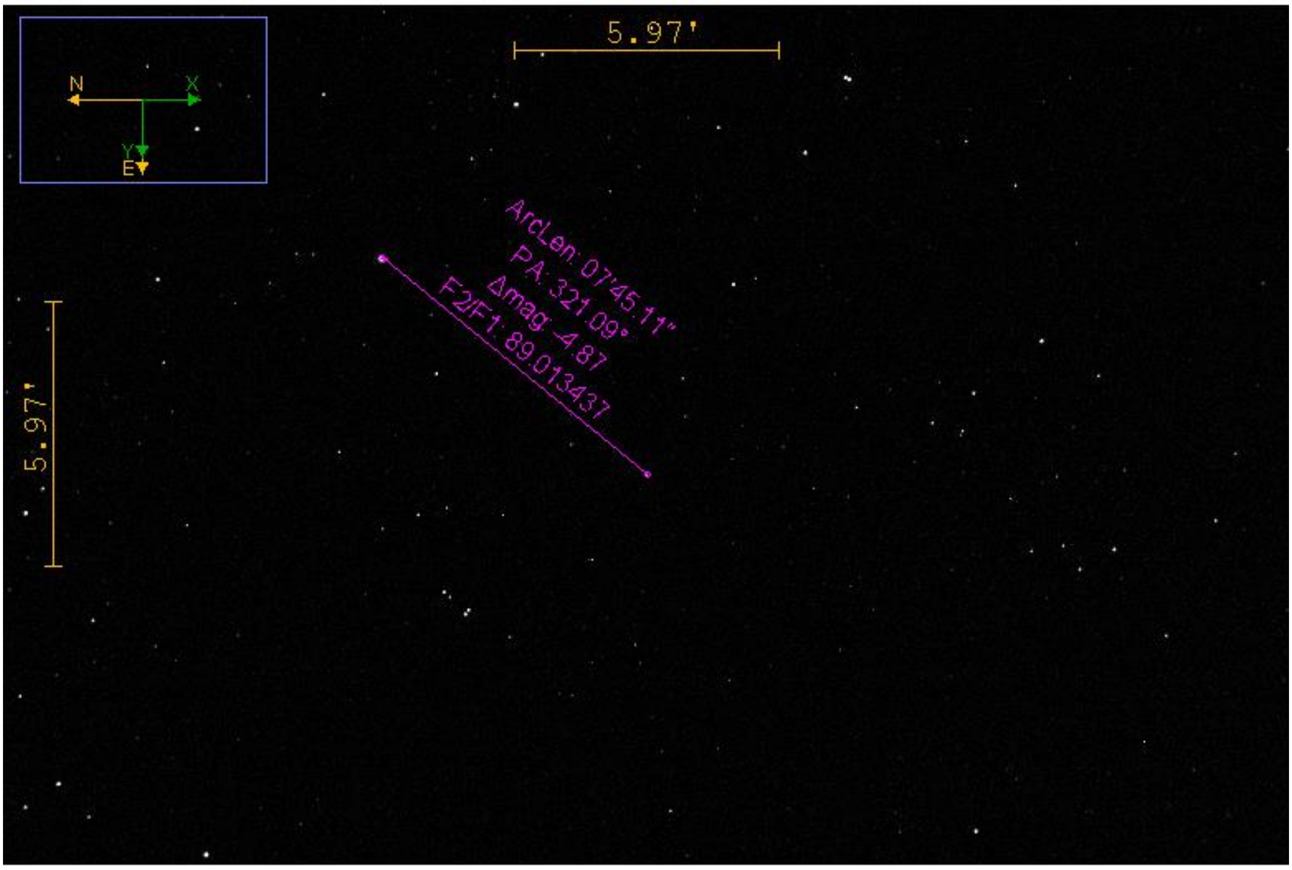

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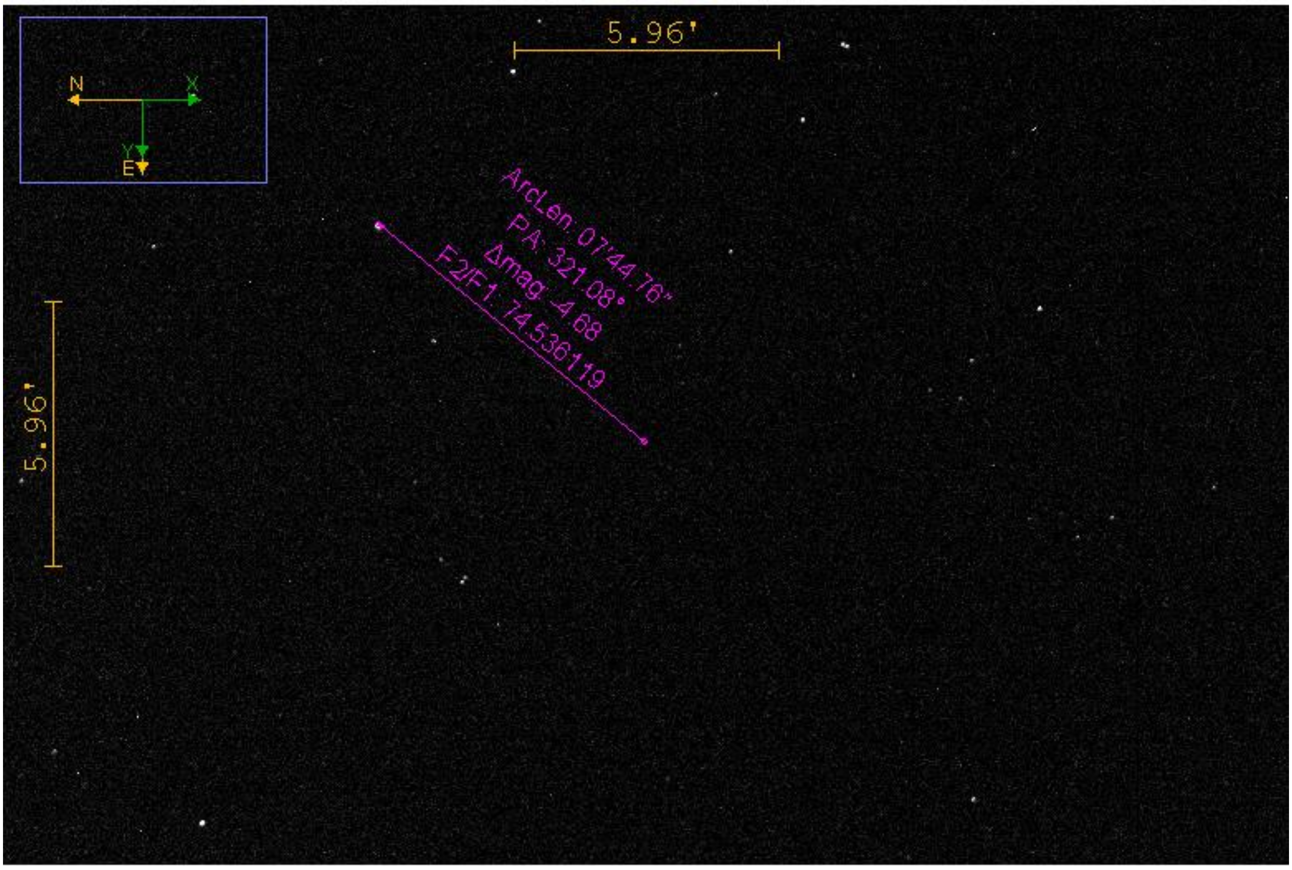

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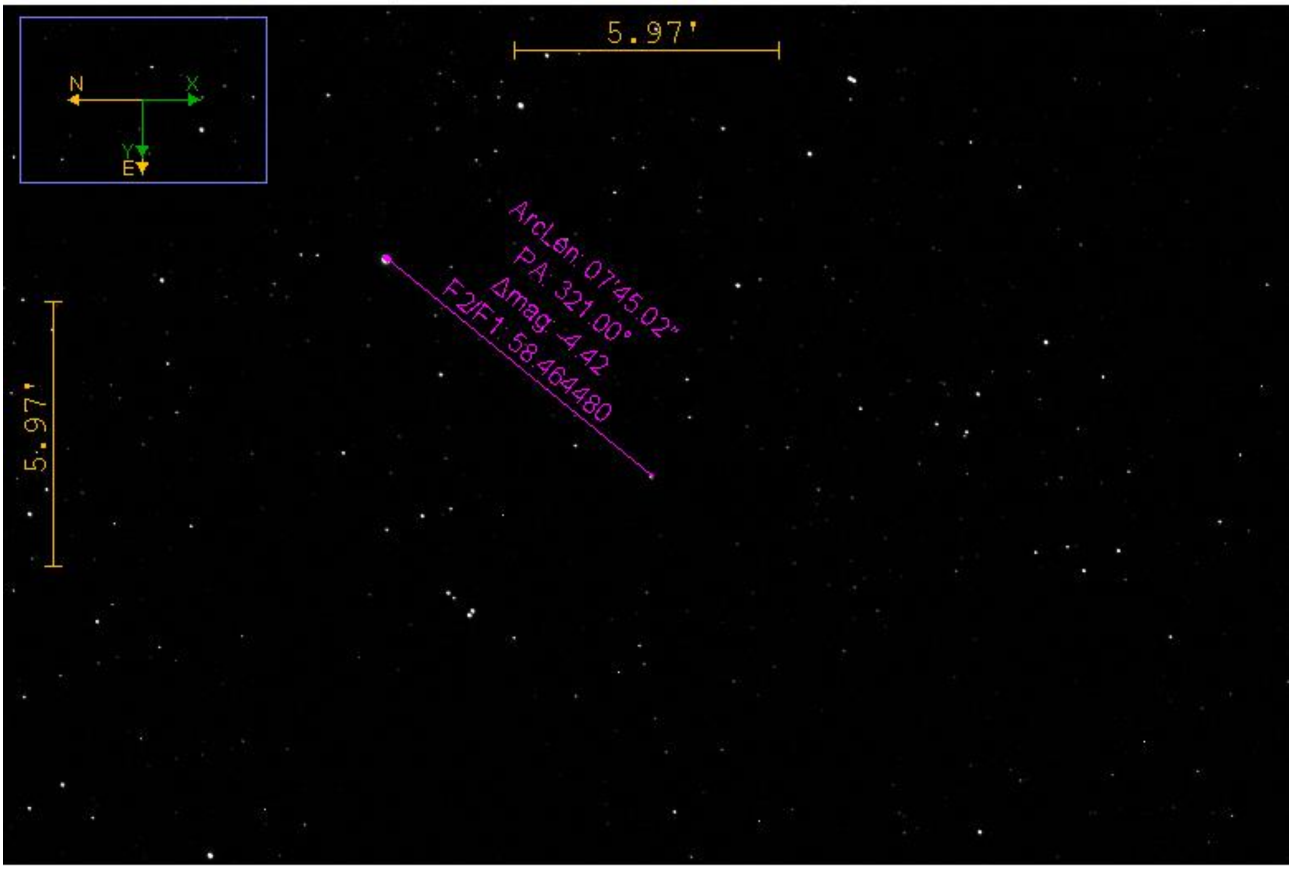

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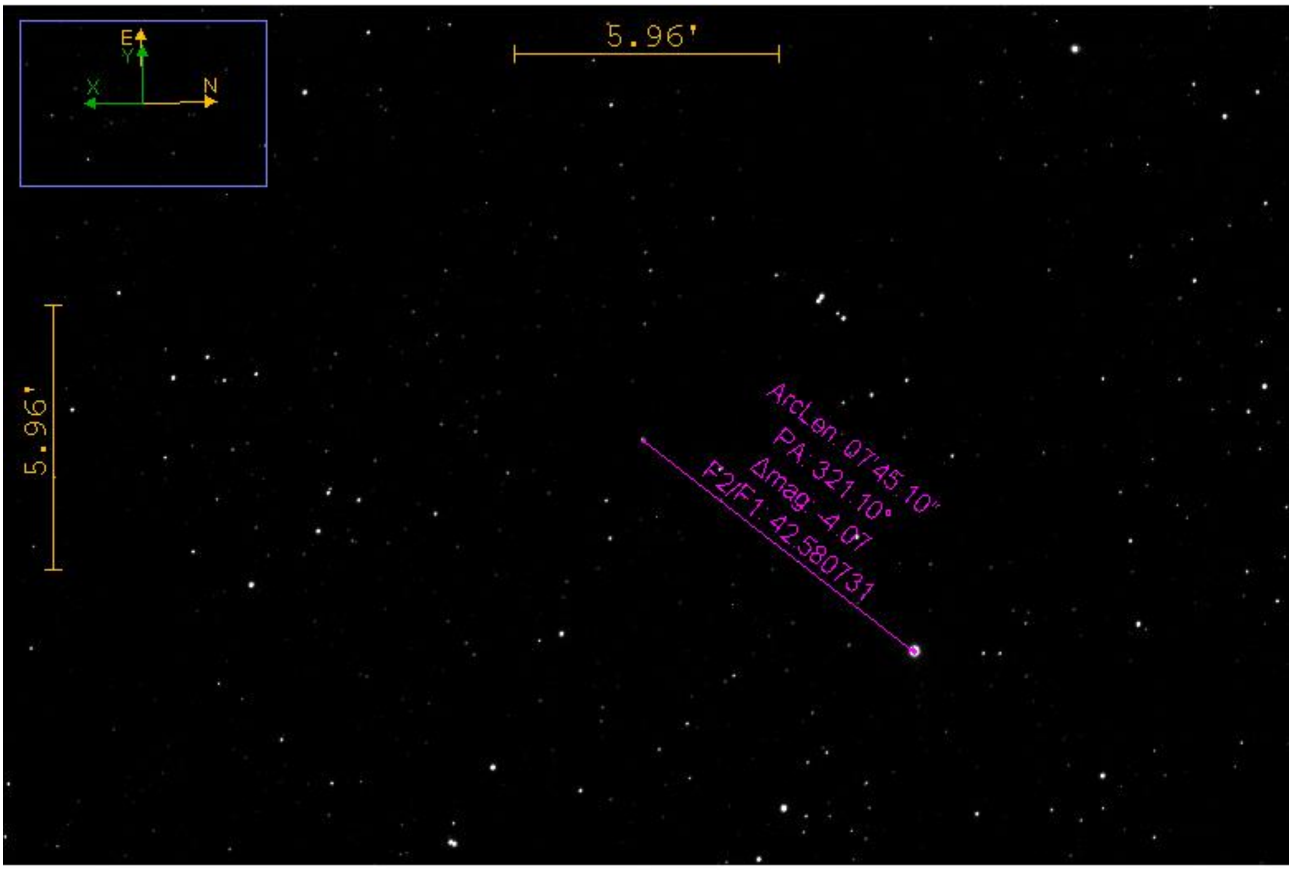

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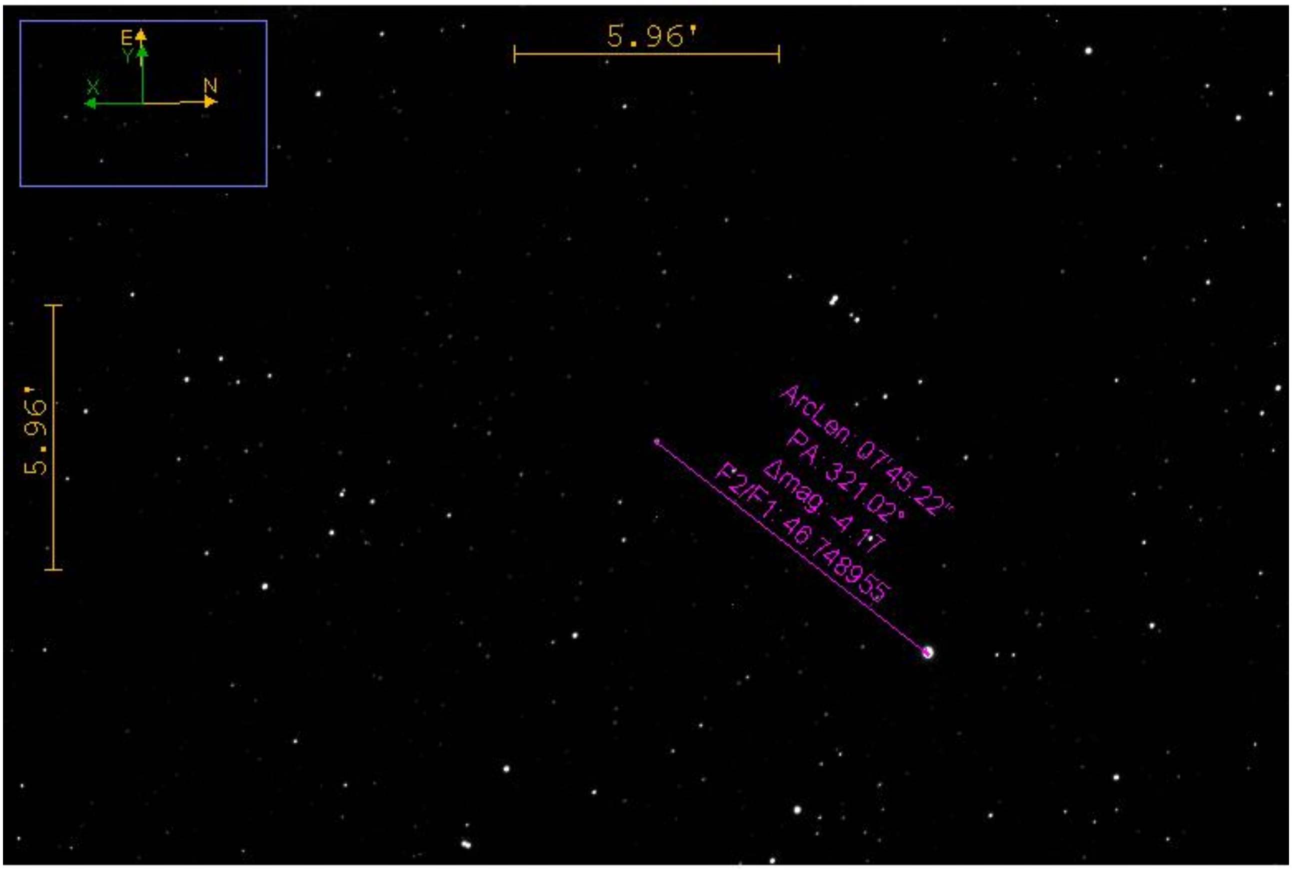

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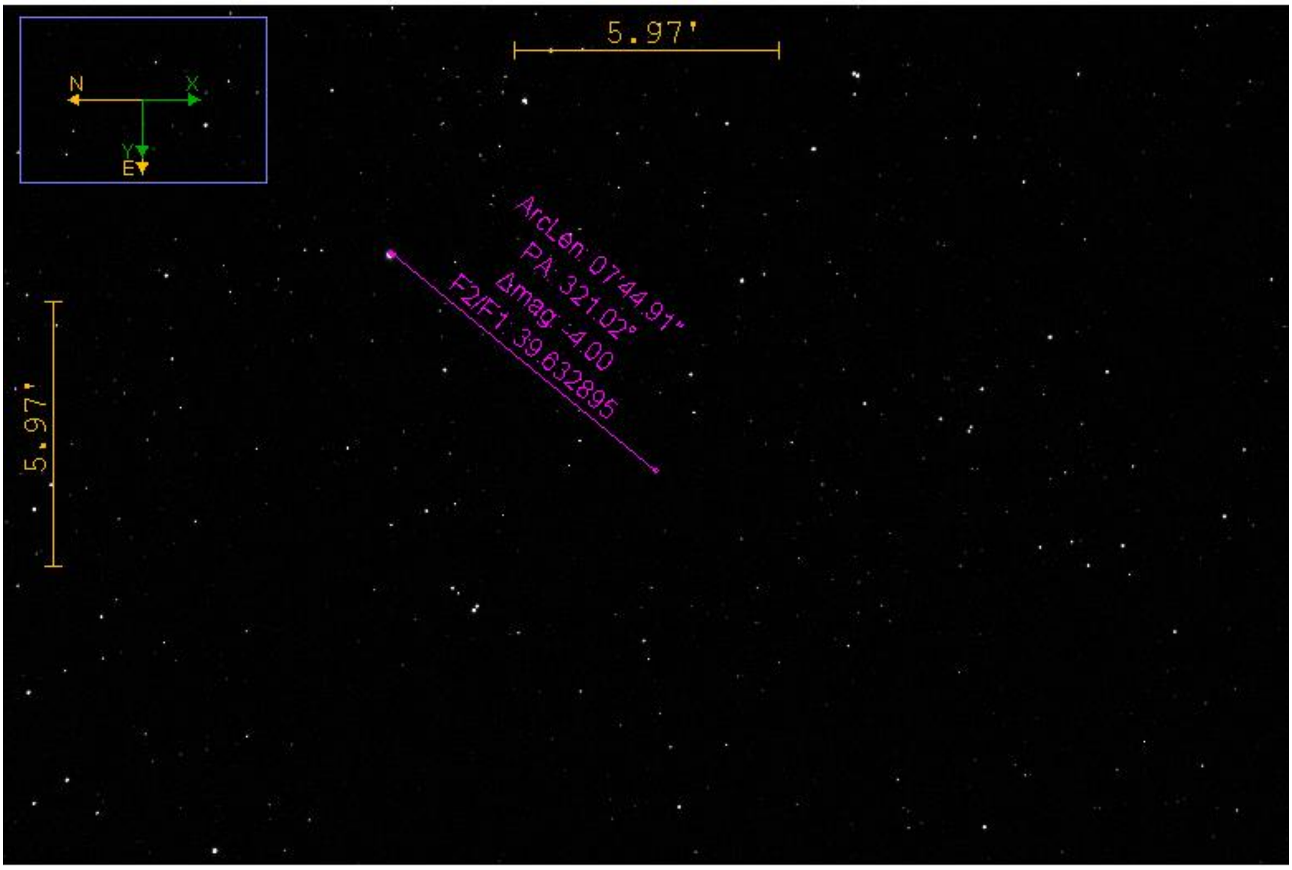

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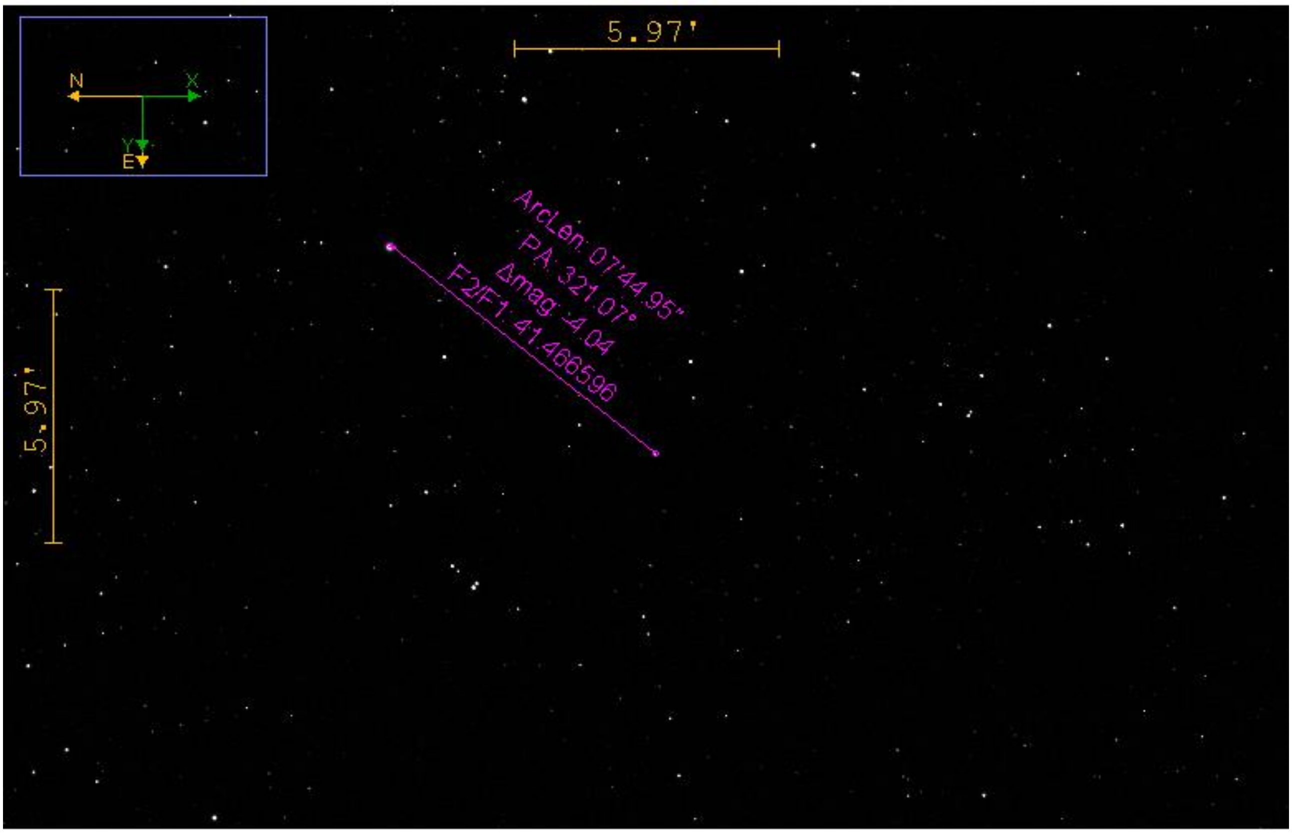

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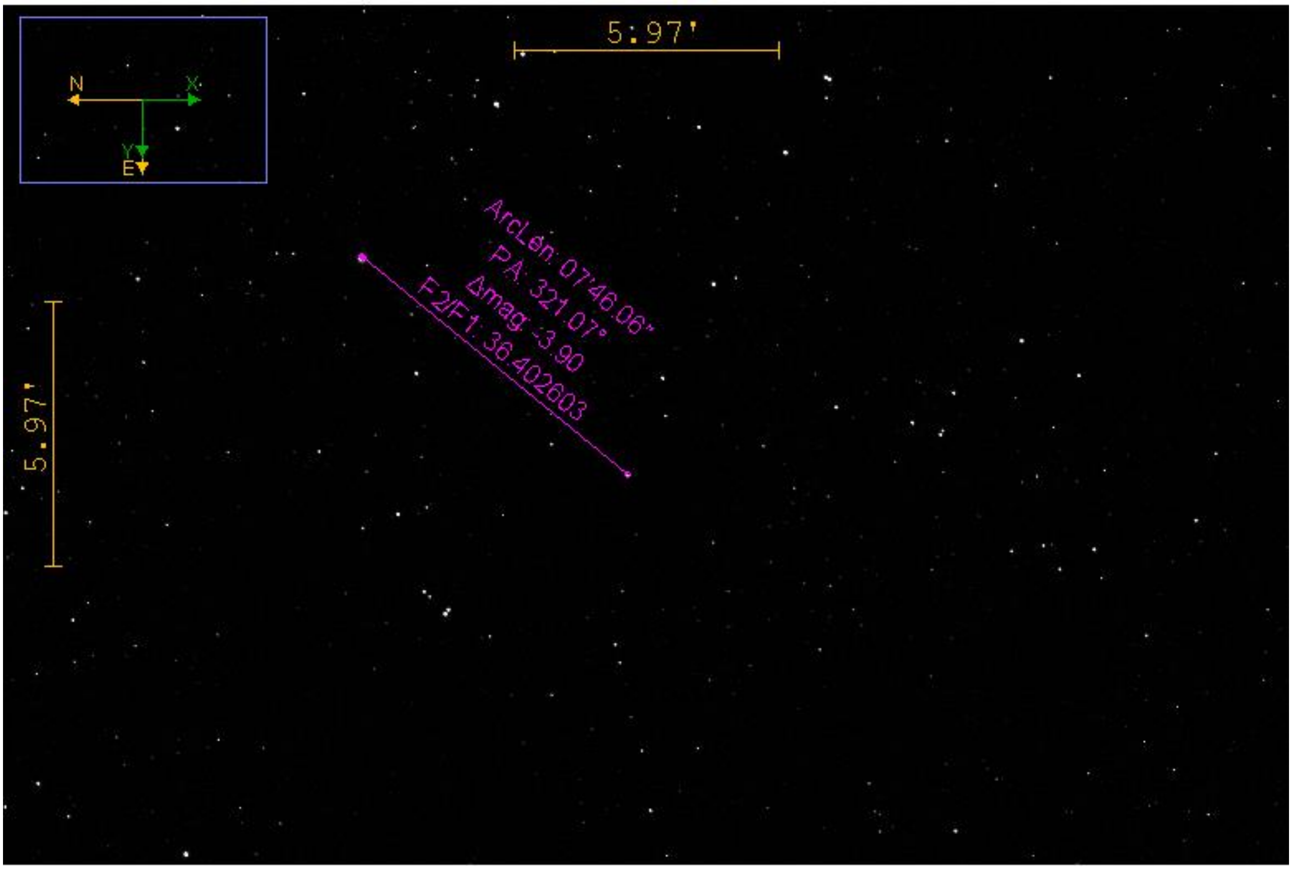

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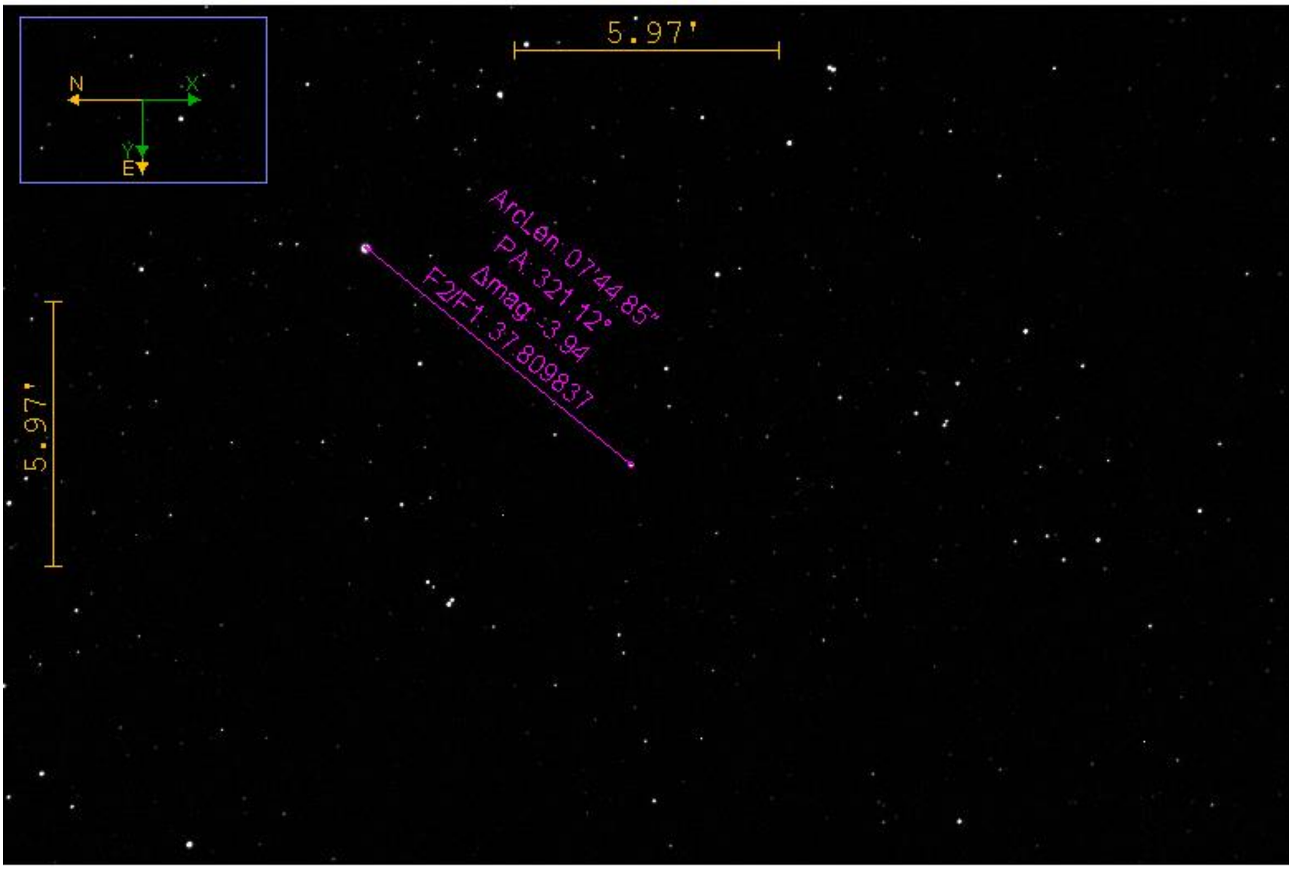

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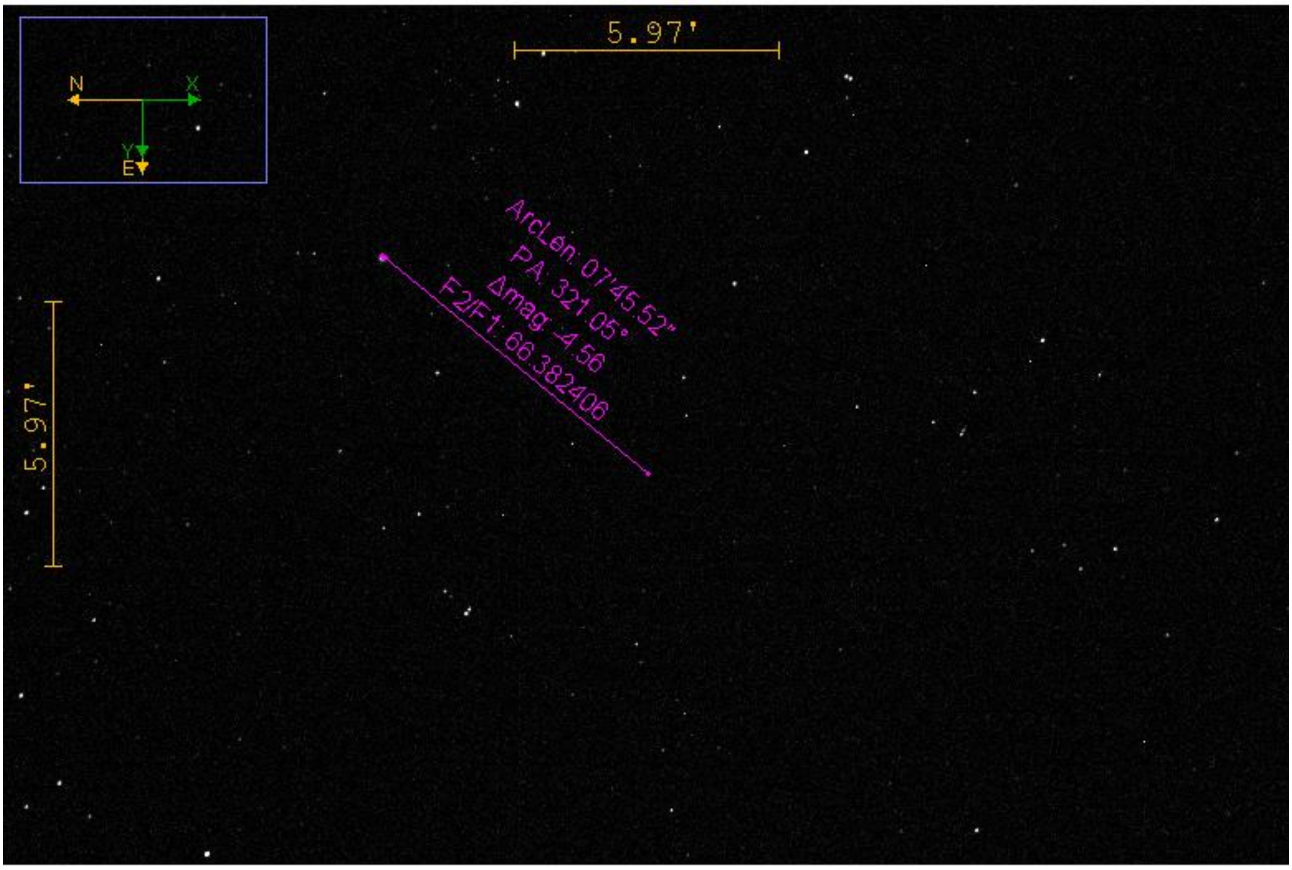

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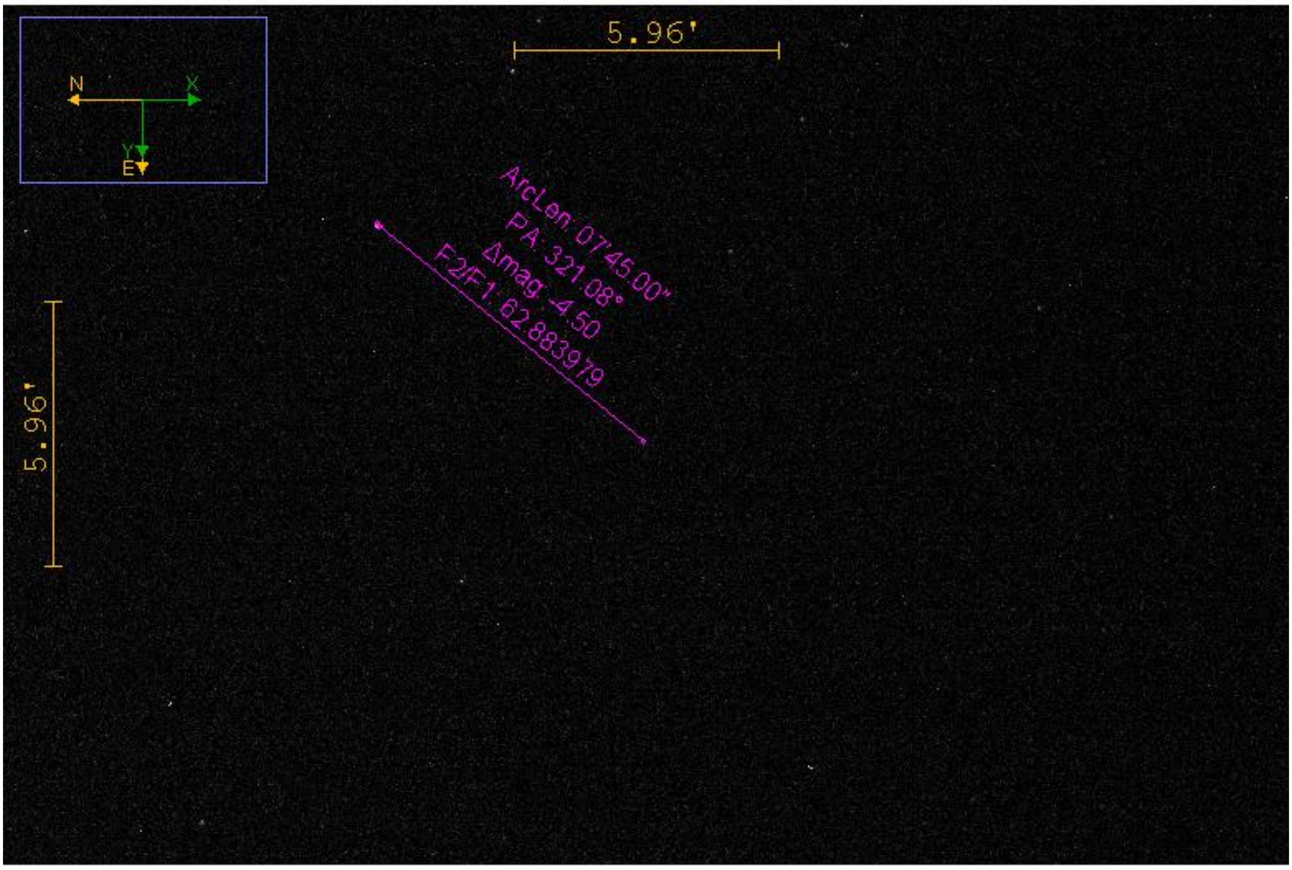

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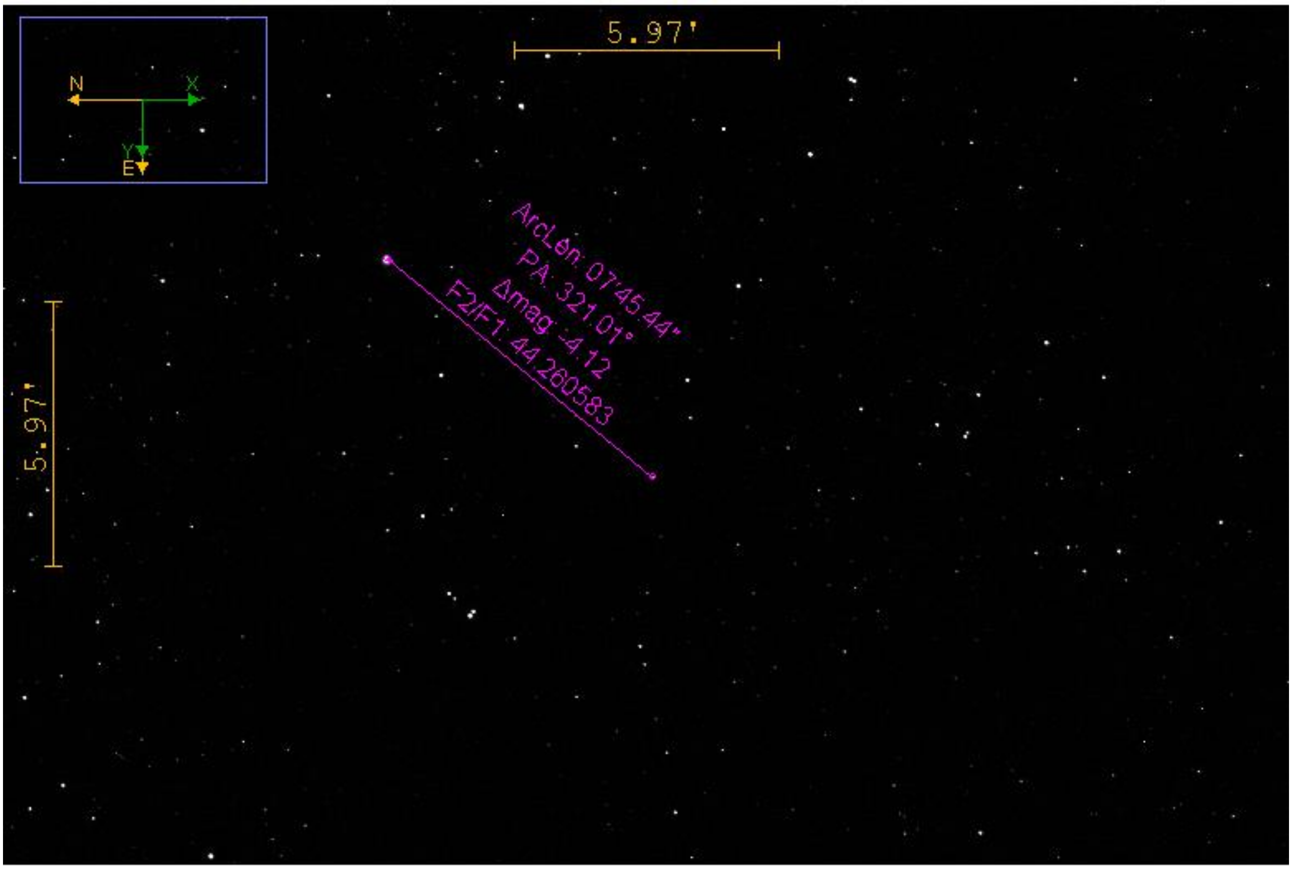

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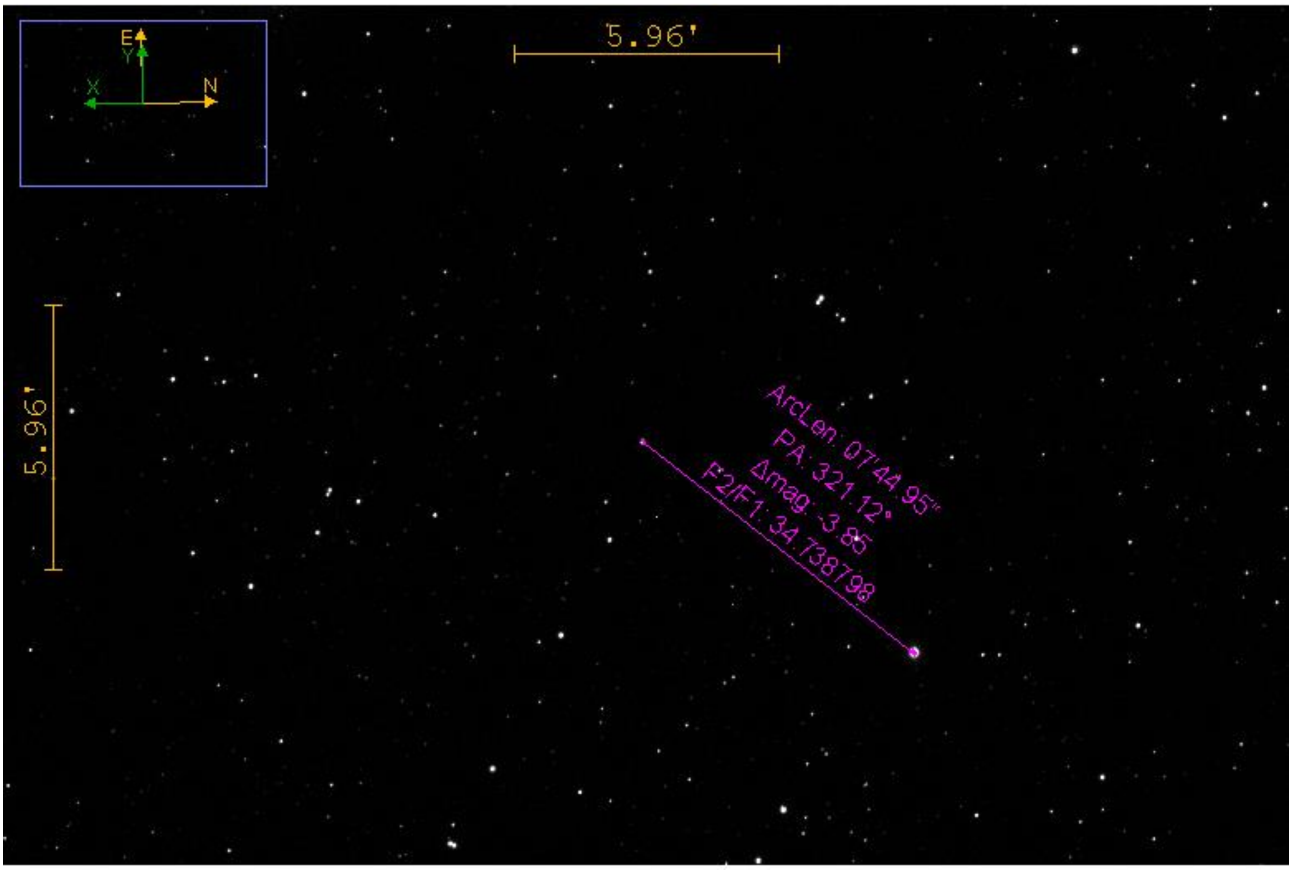

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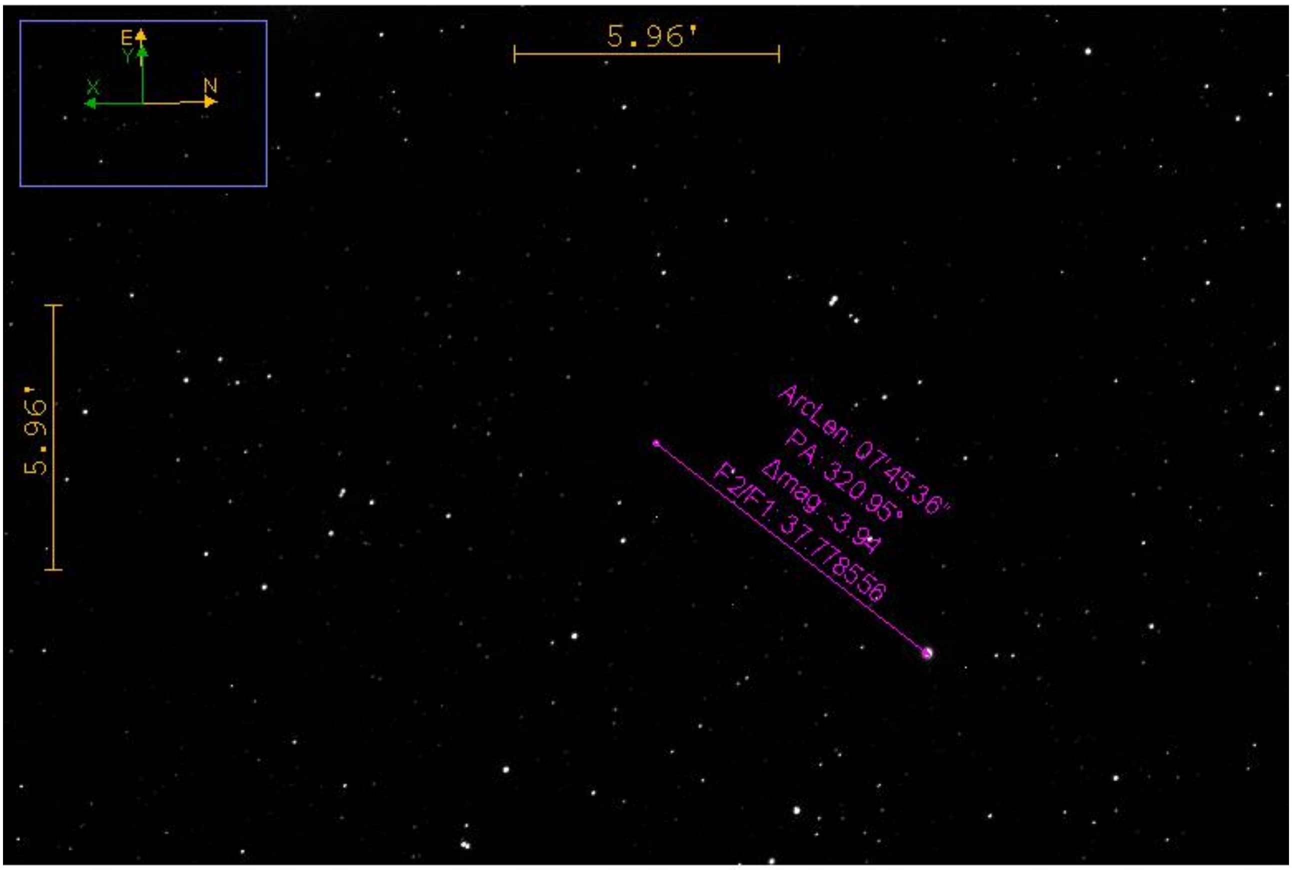

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B

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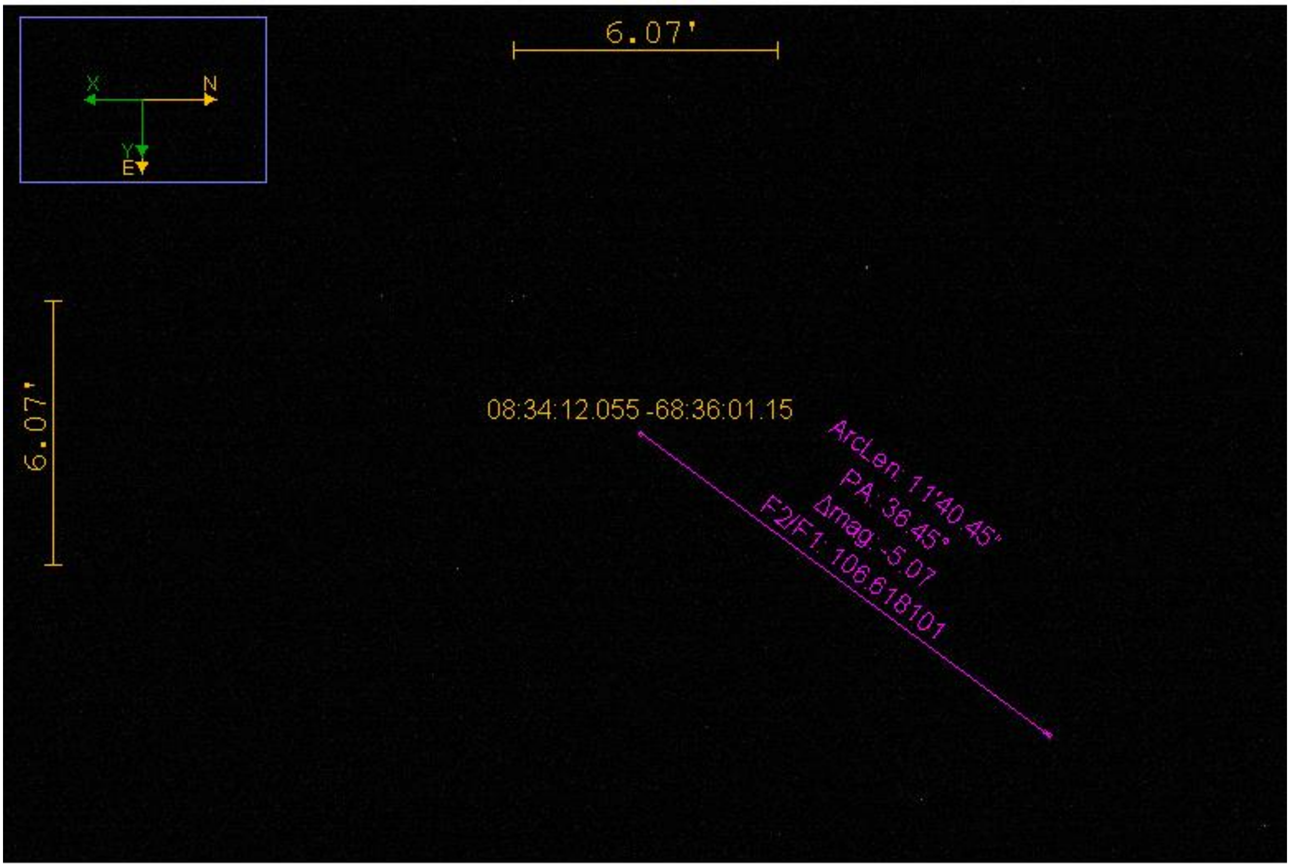

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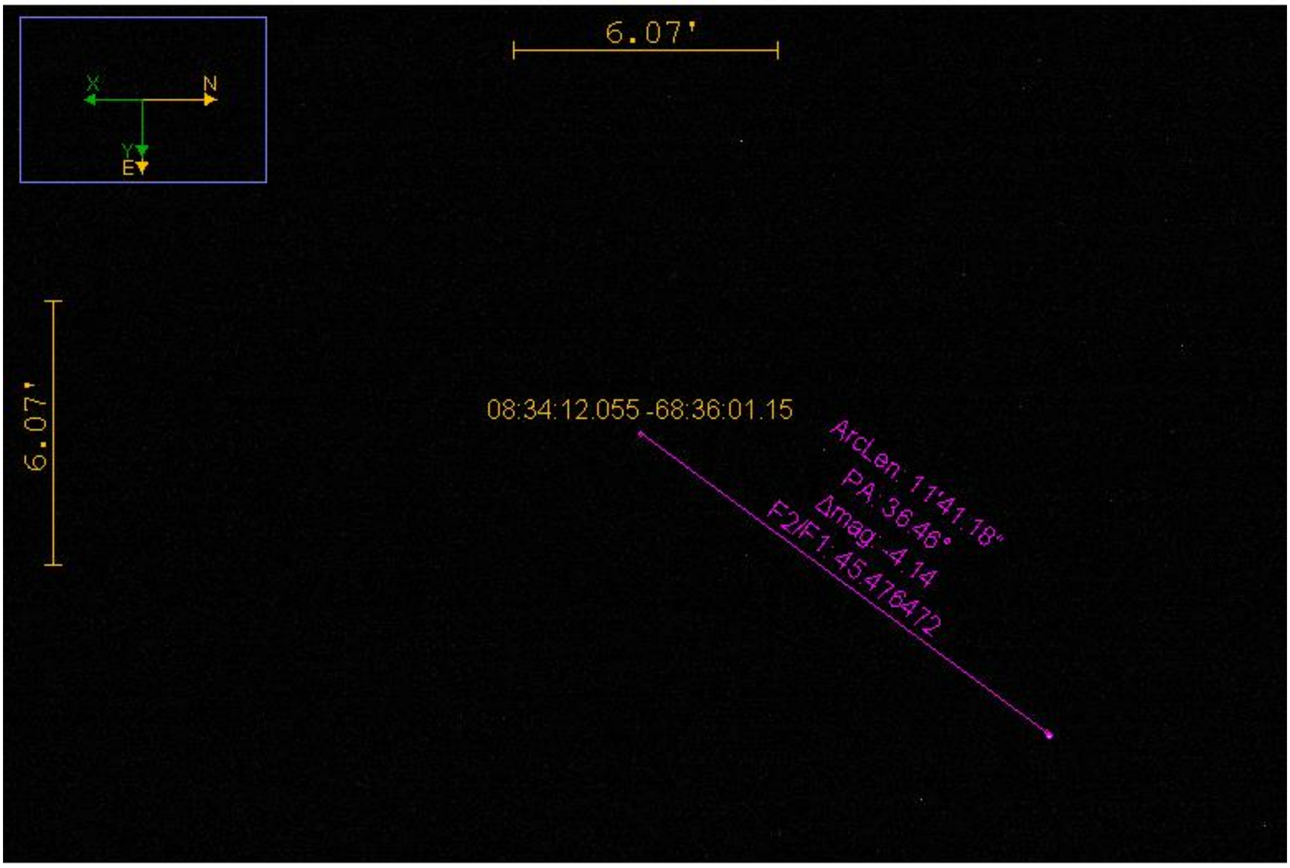
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X
N
Y
E
6.07'
08:34:12.055 -68:36:01.15
ArcLen: 11'41.18"
PA: 38.46°
Δmag: -4.14
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23th 06:19:14

B2

23th 06:20:17

23th 06:21:15

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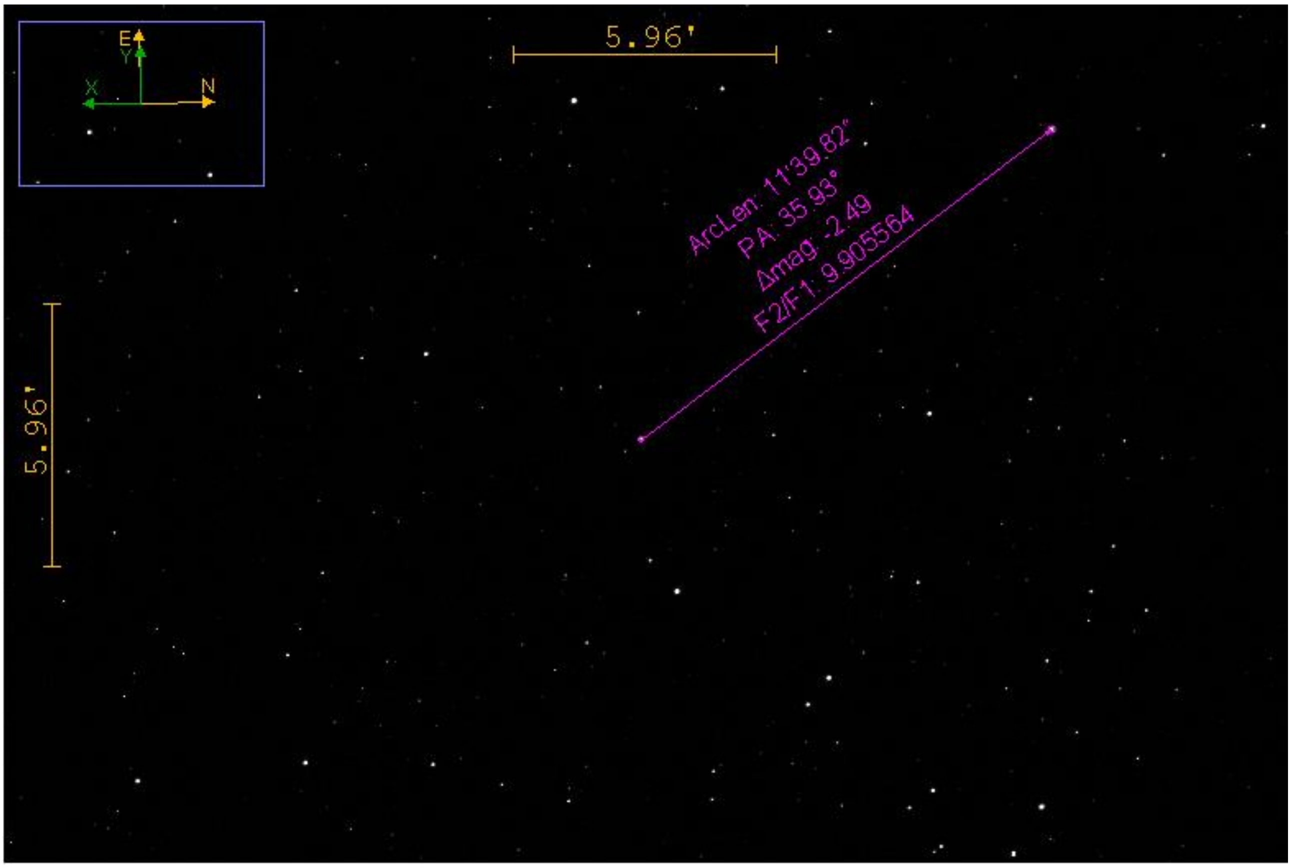
B3



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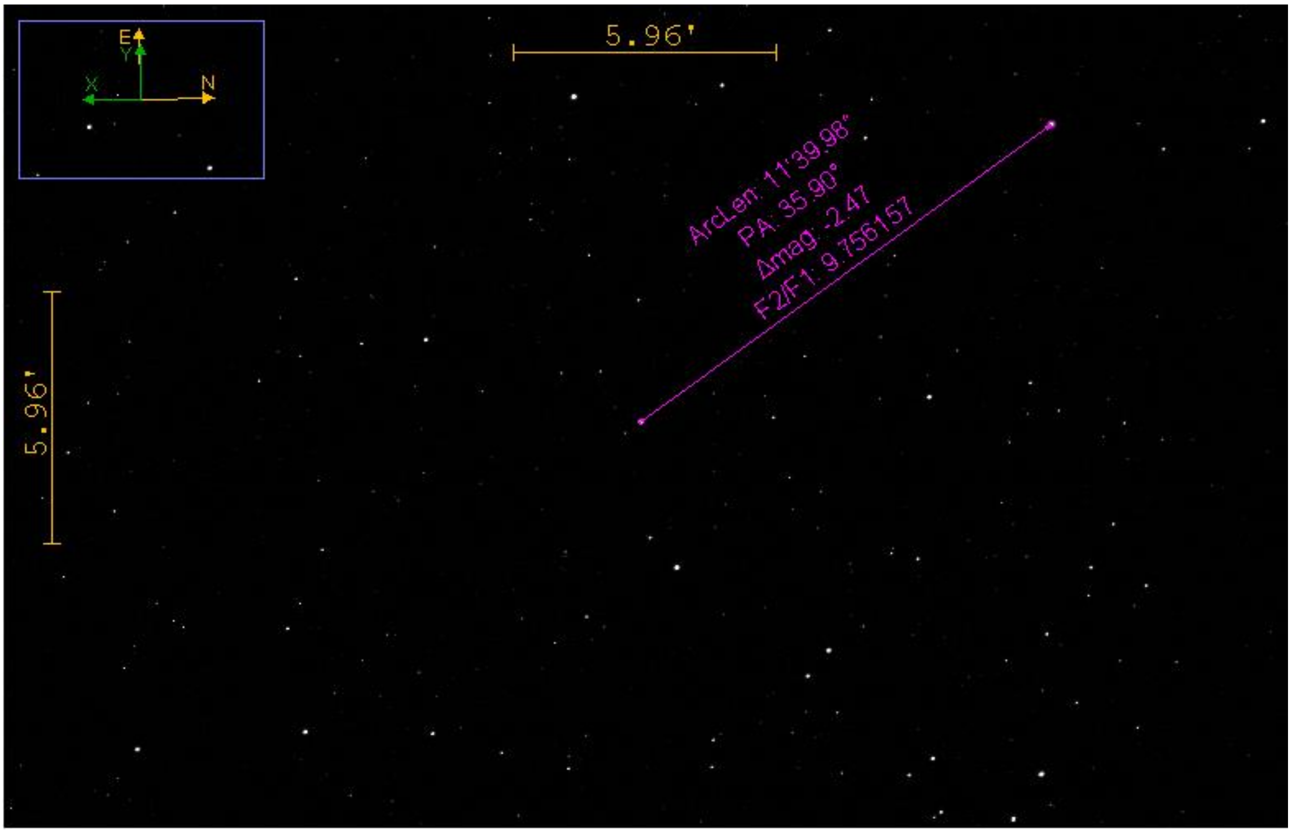

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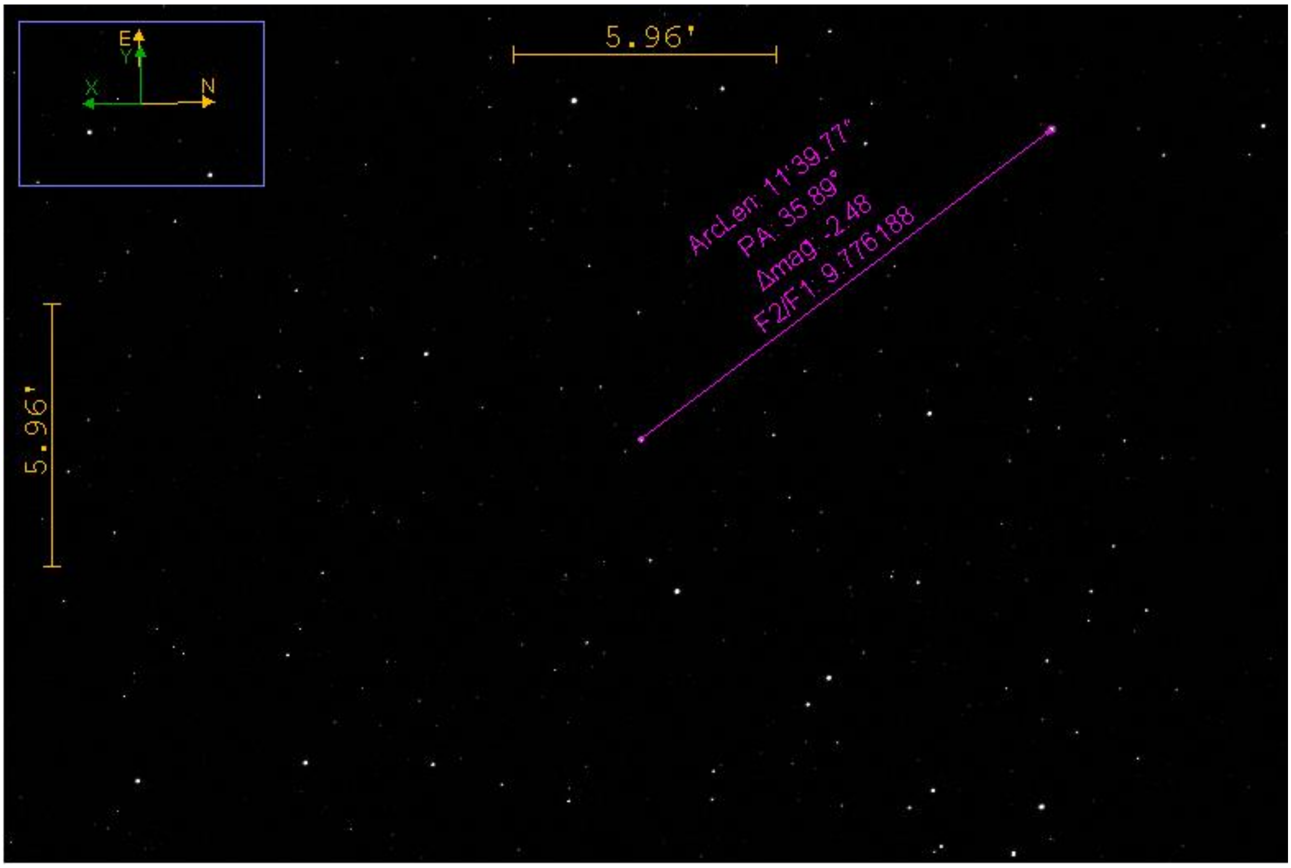

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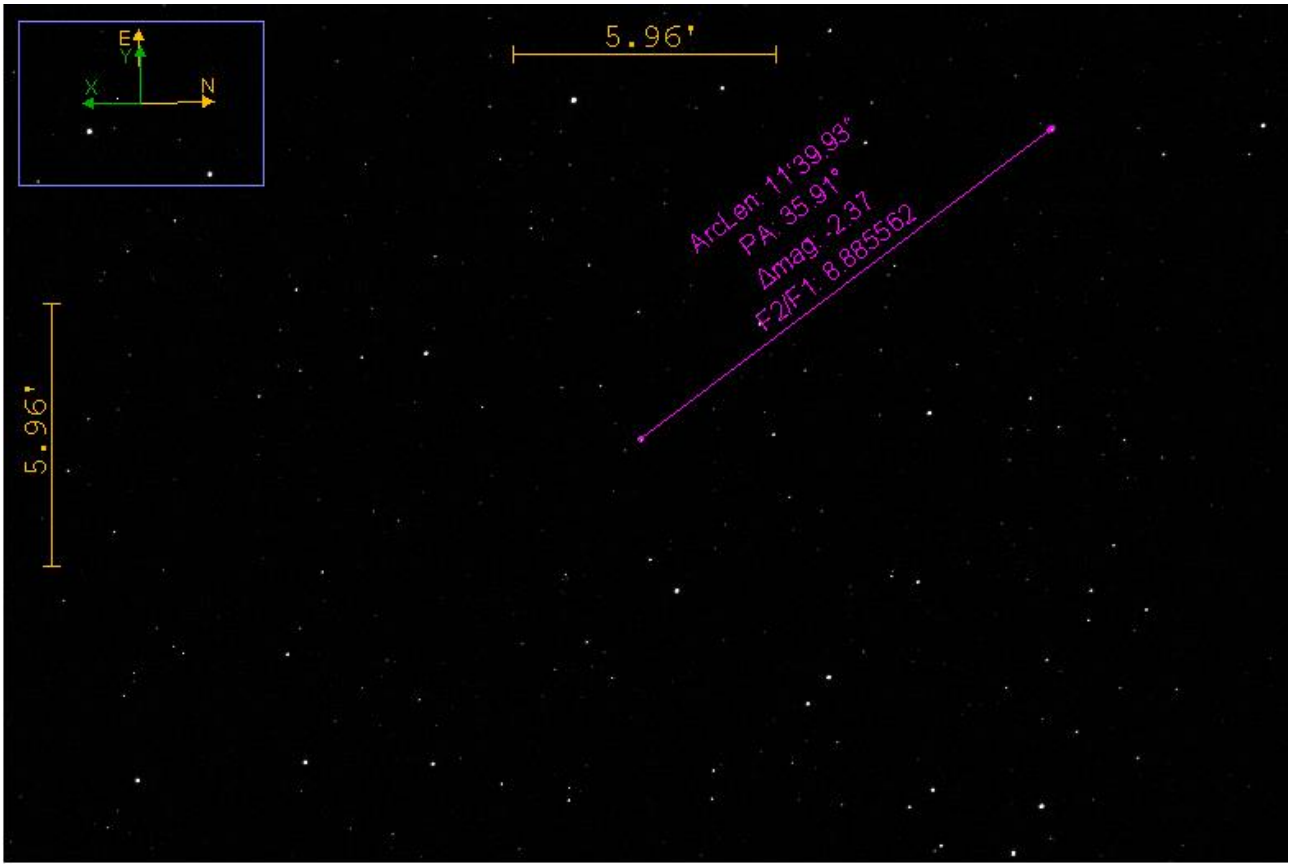

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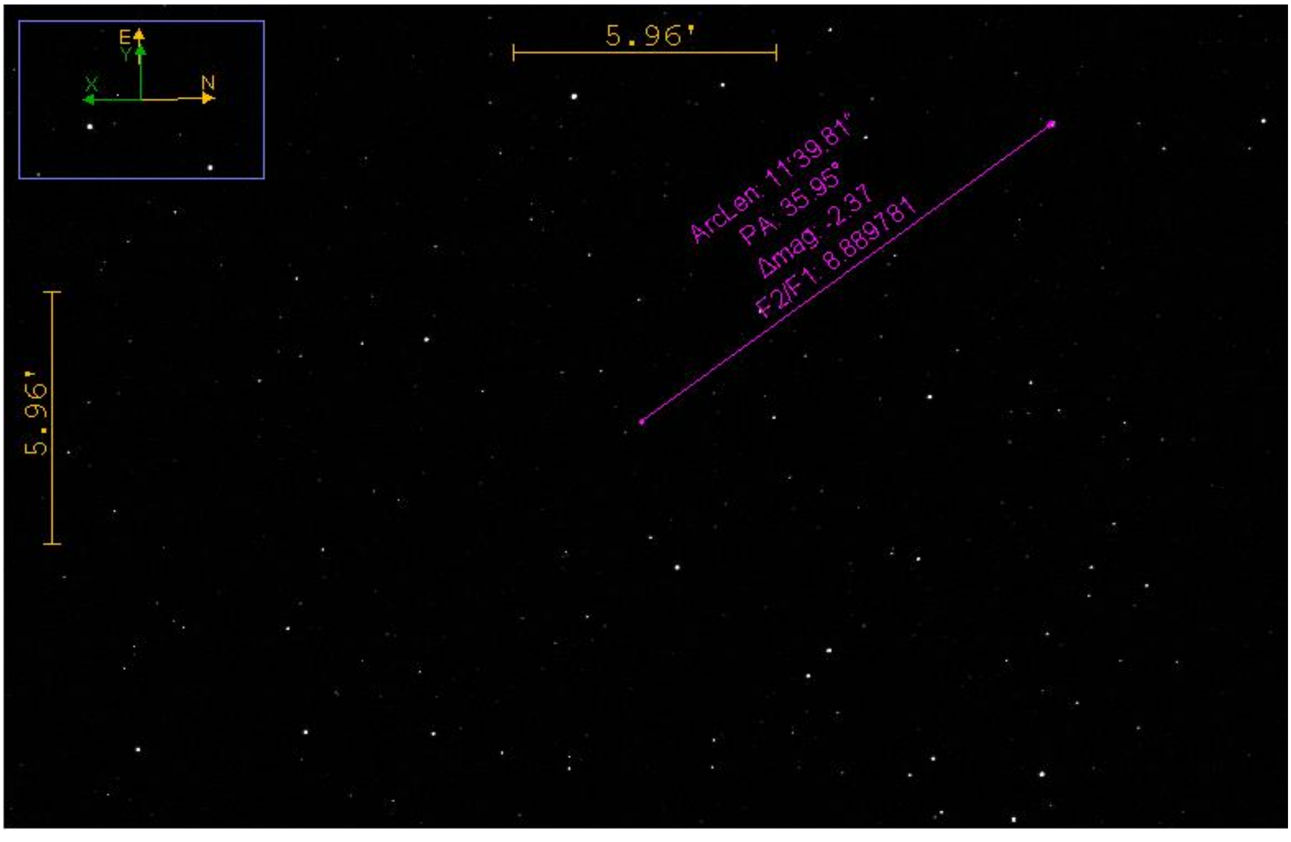

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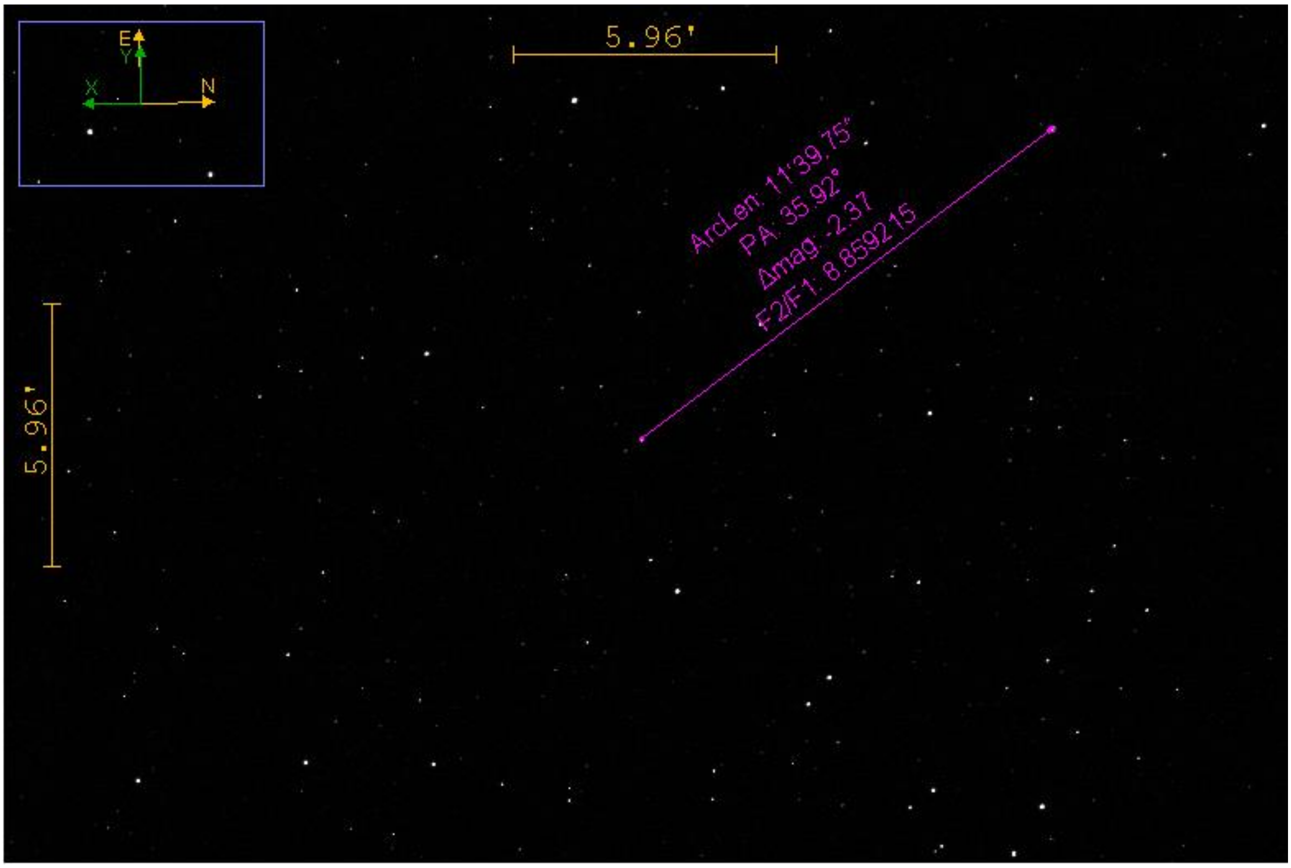

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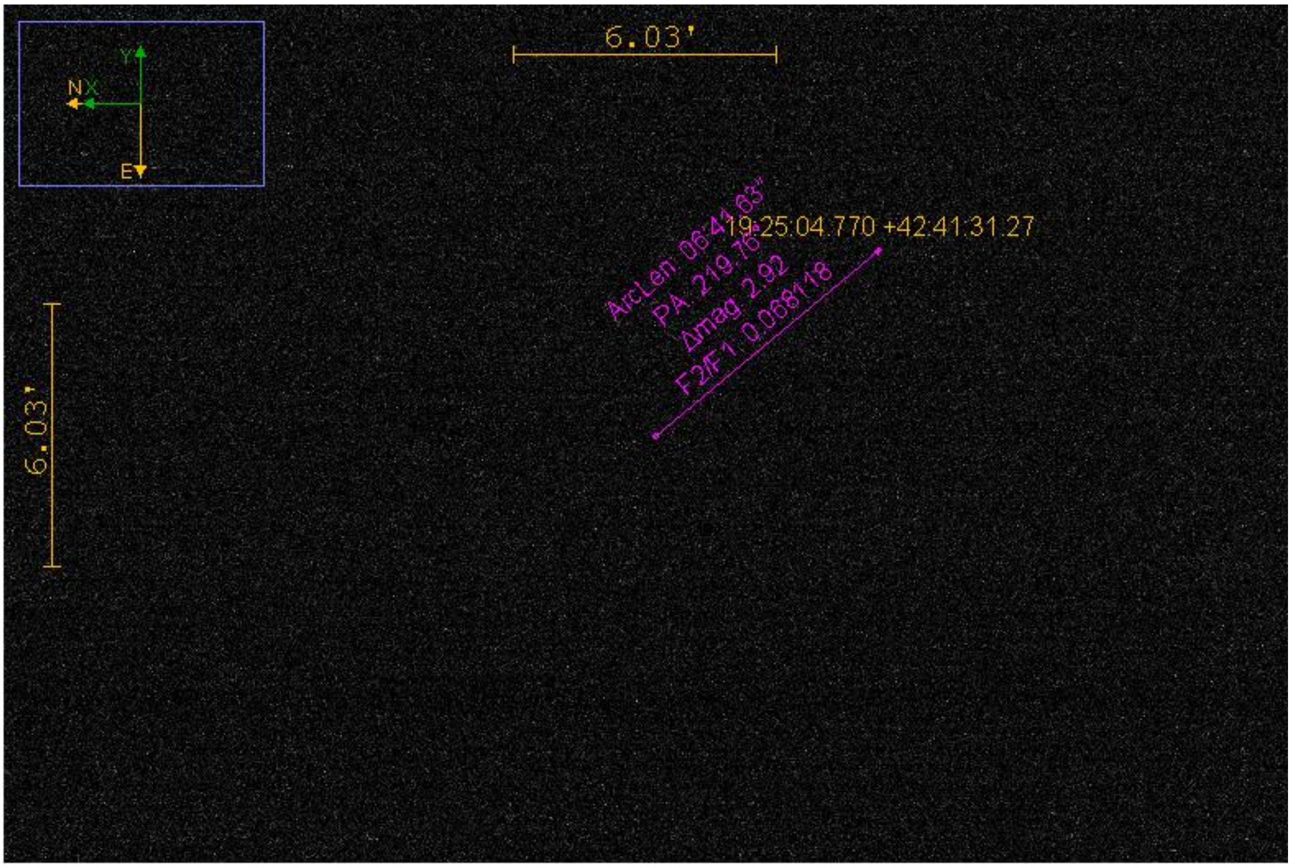
C

C1



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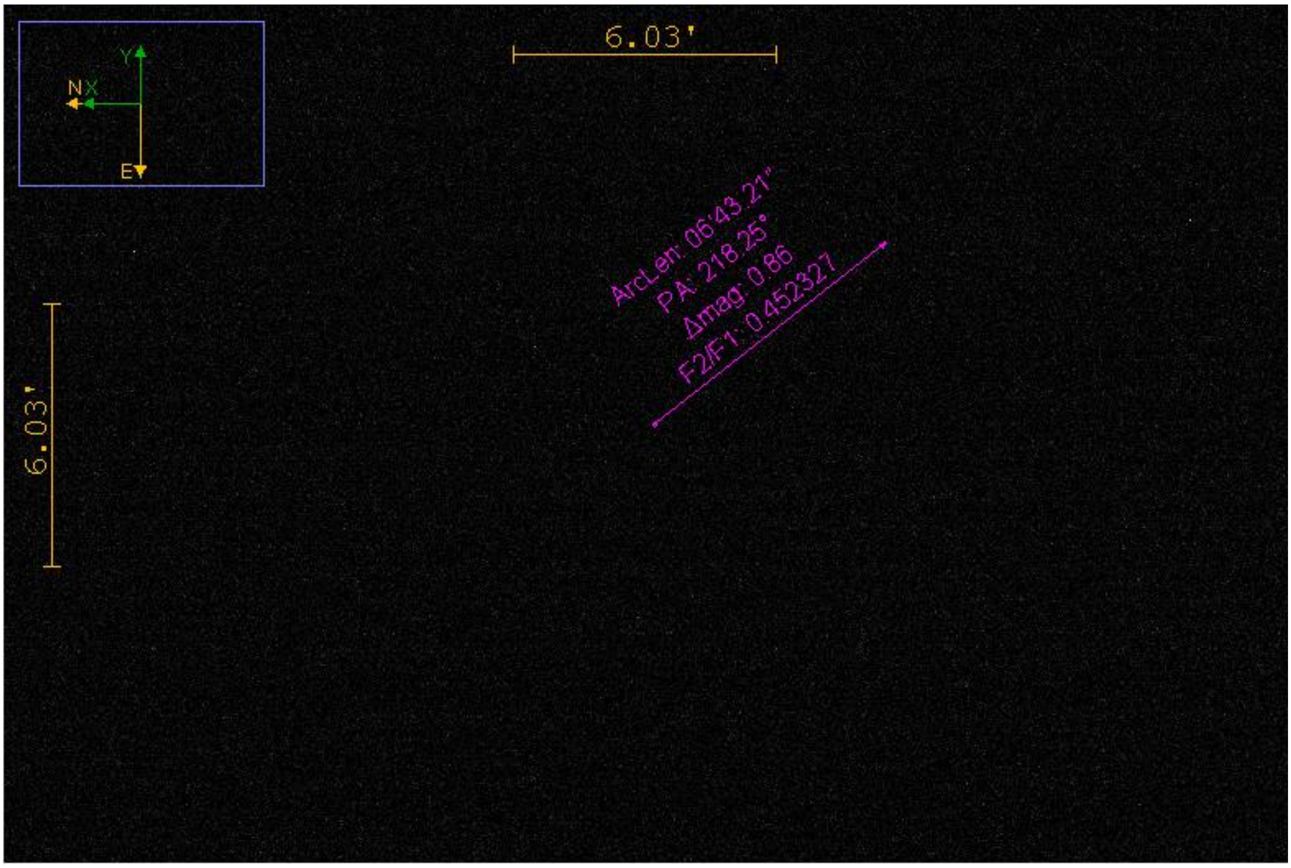

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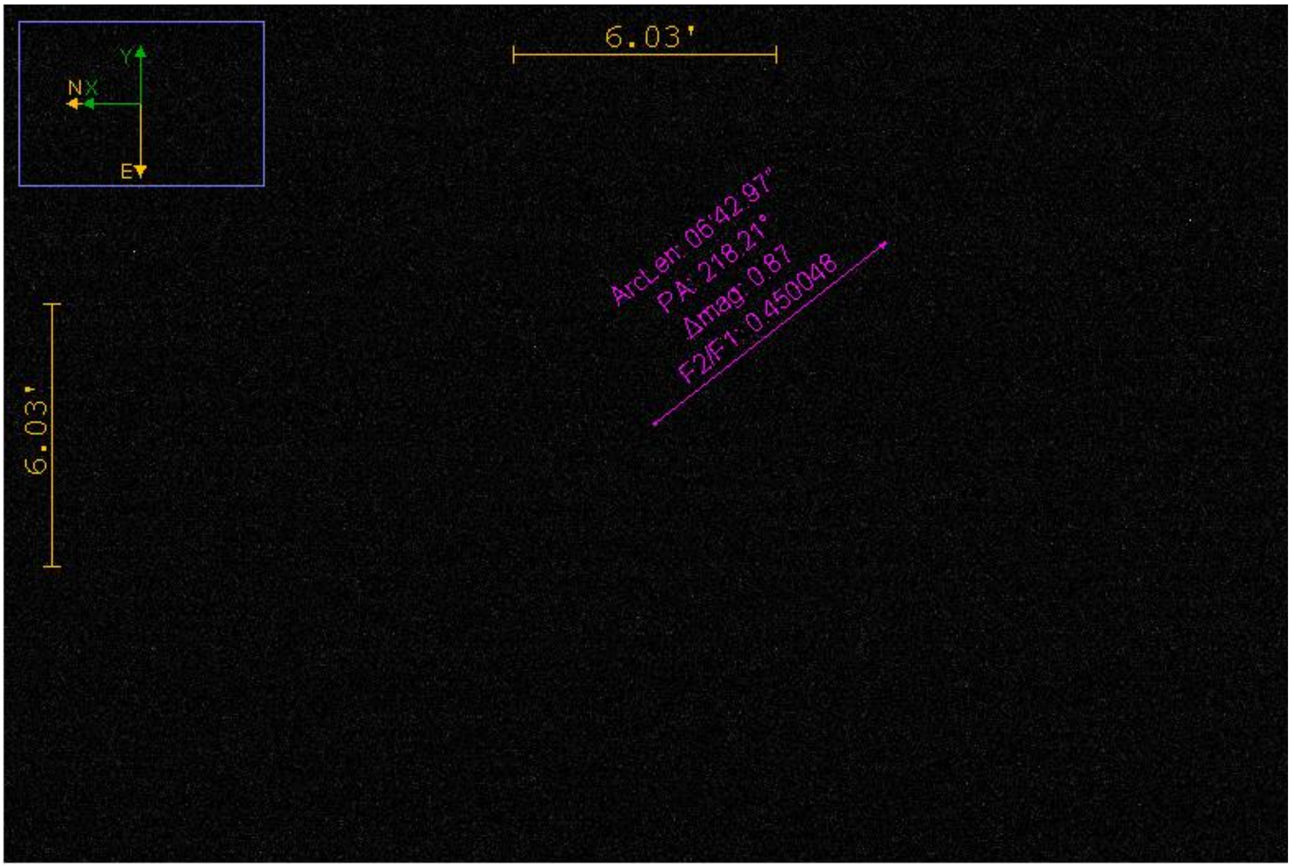

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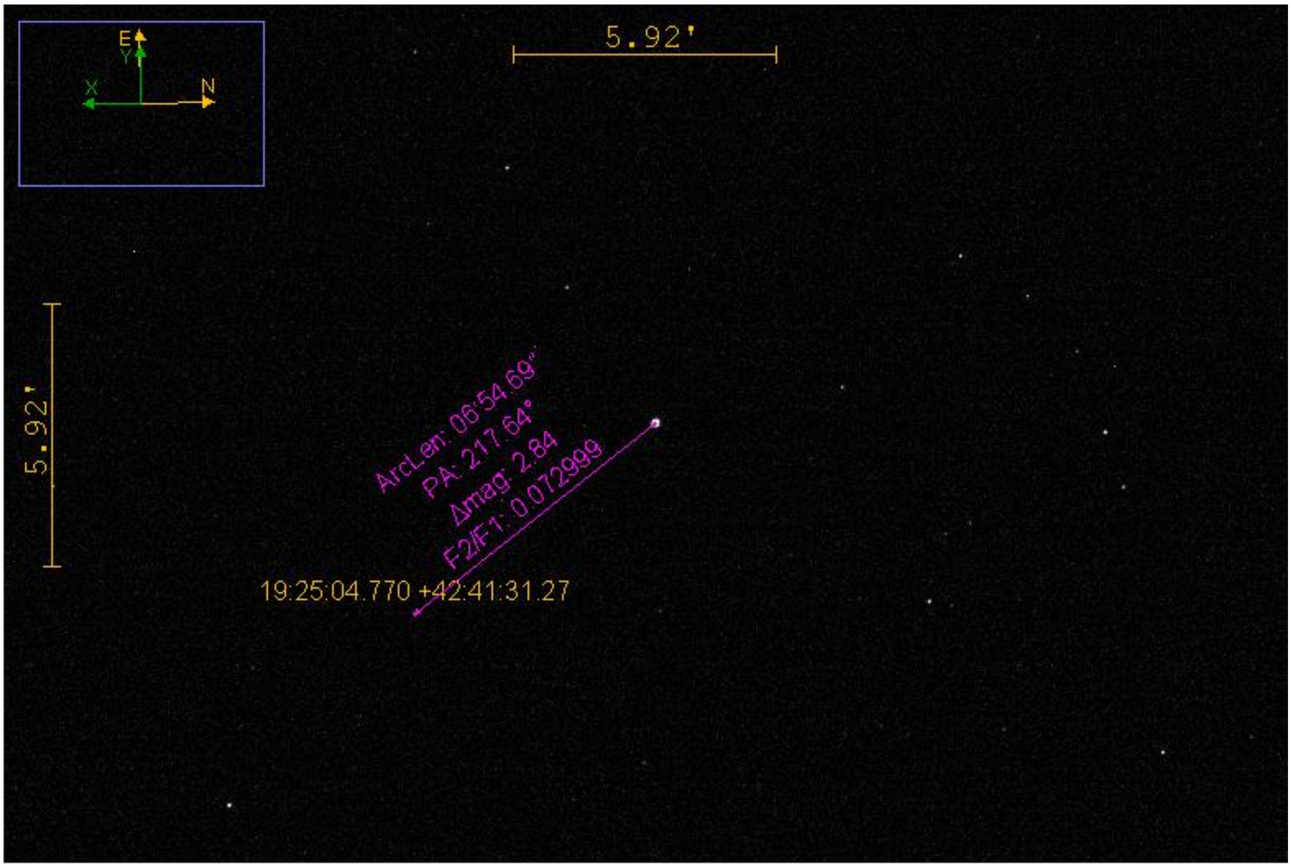

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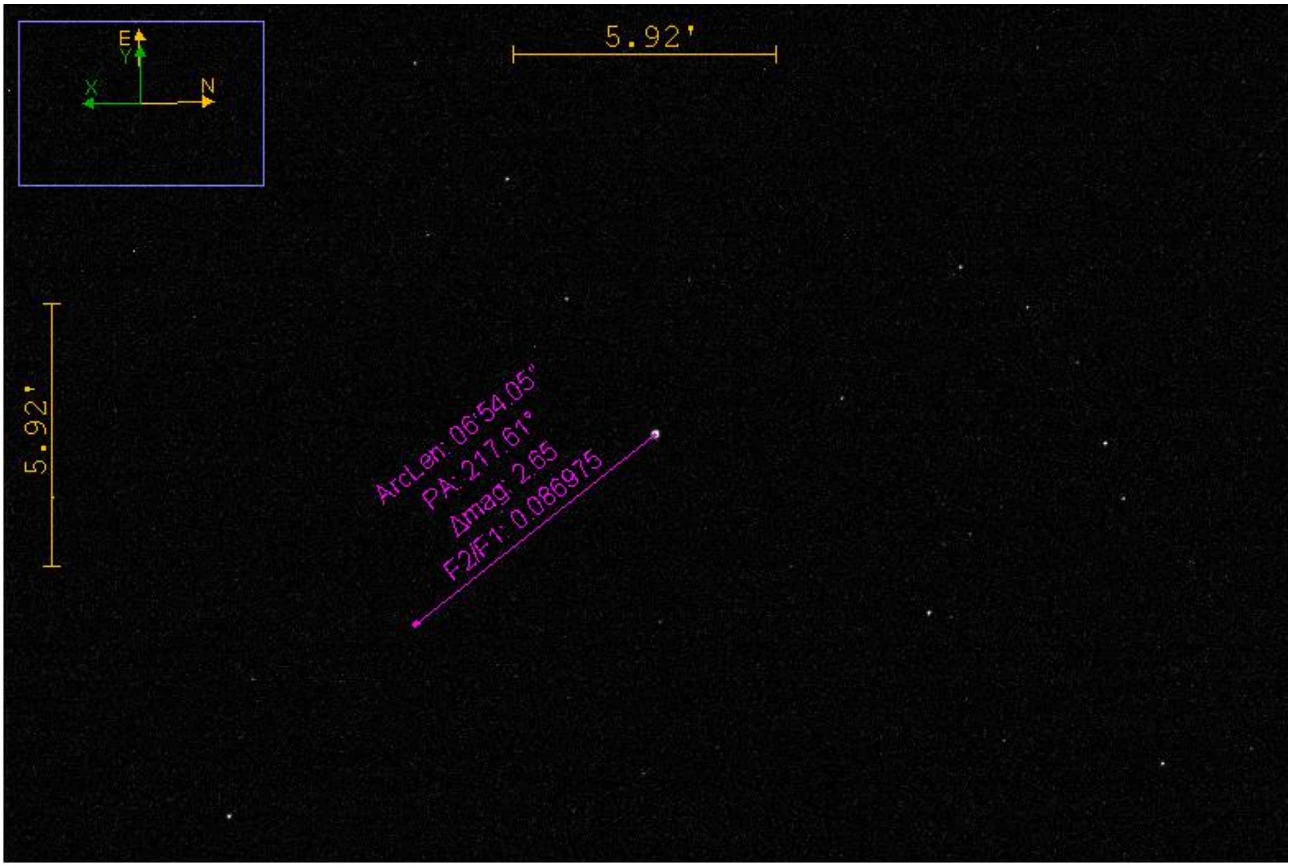

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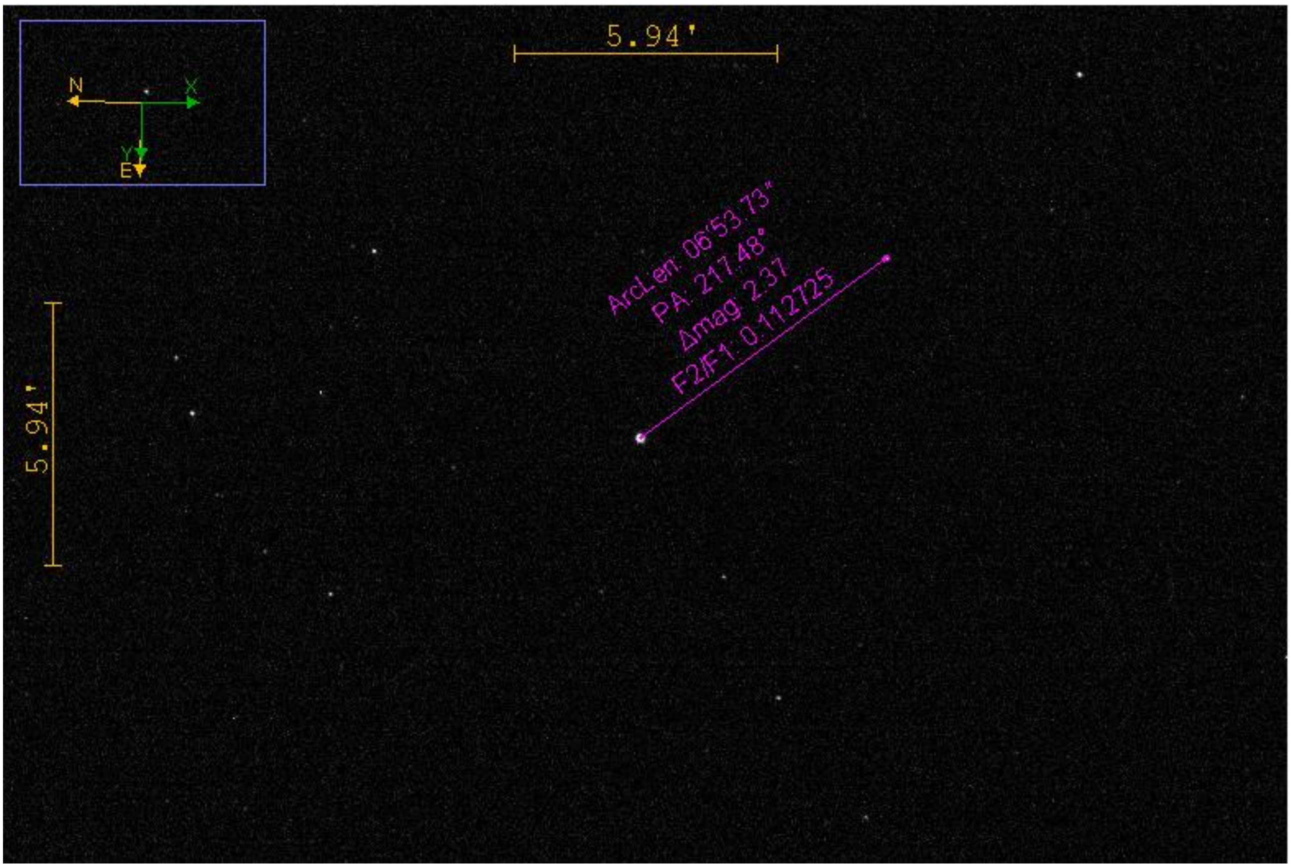

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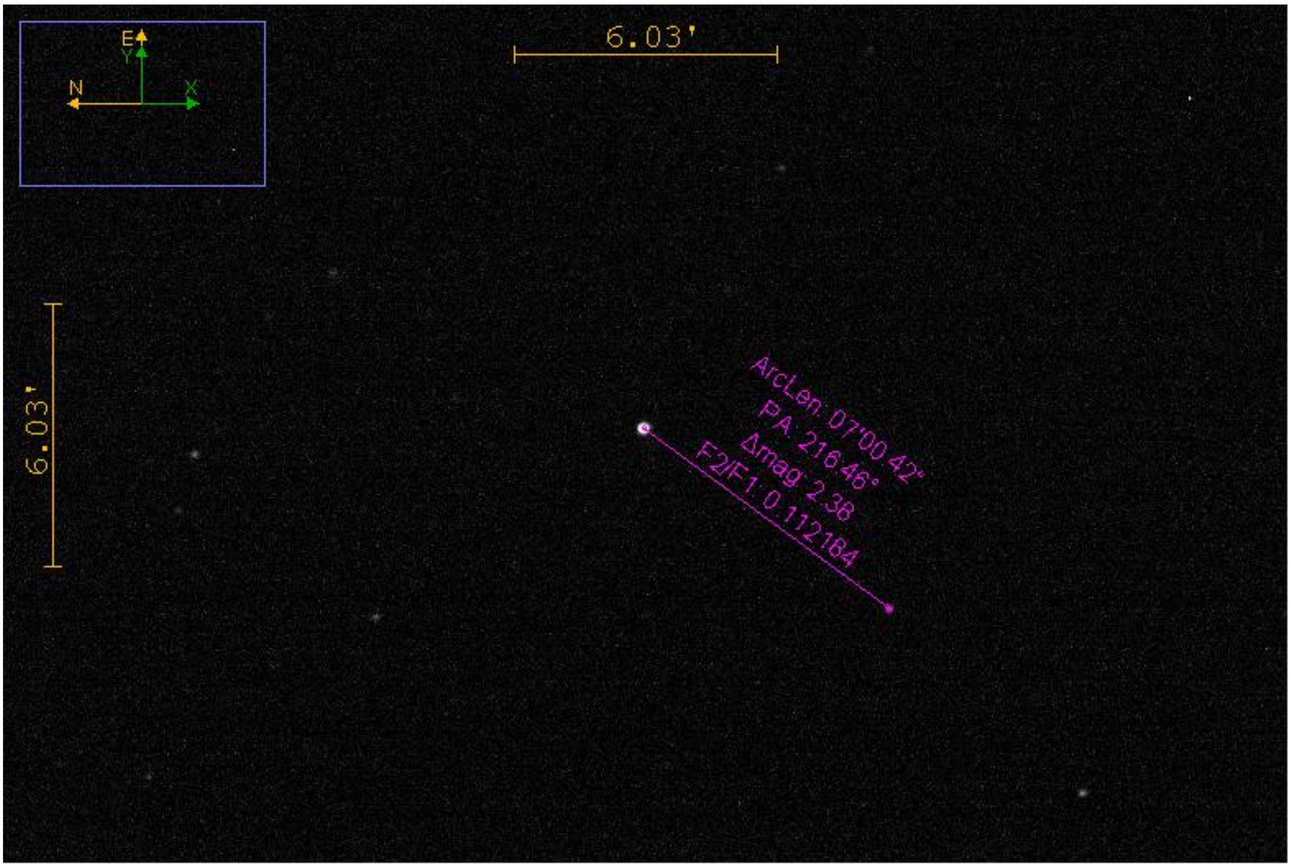

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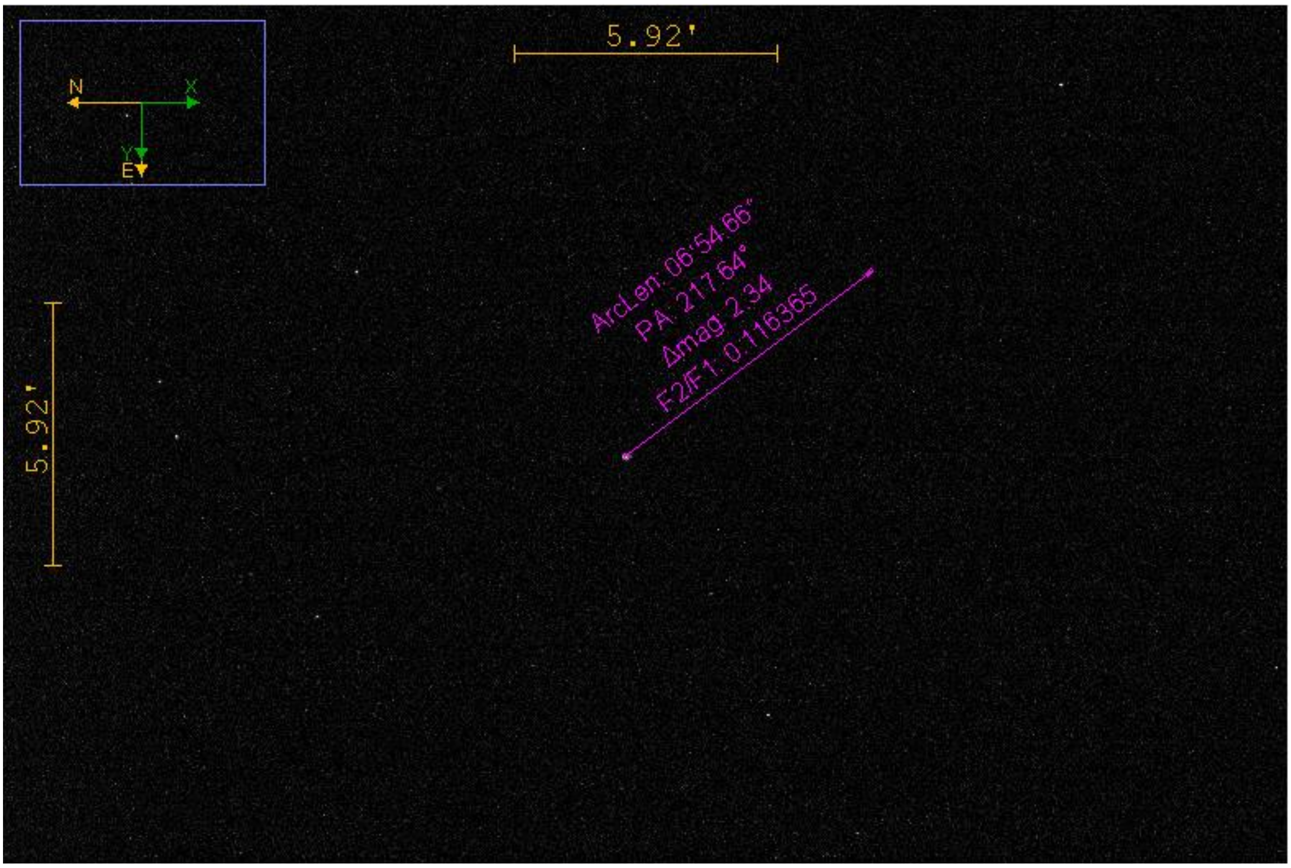

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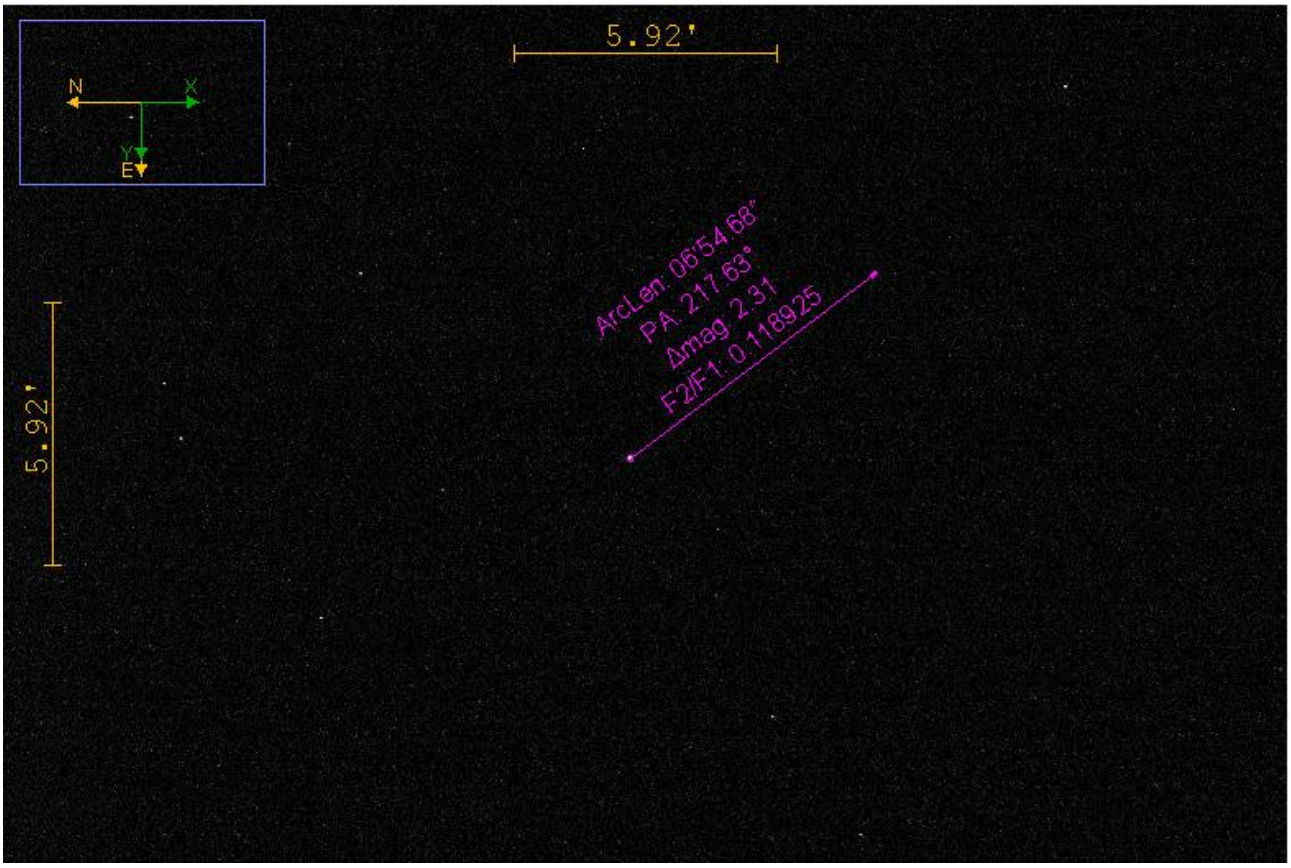

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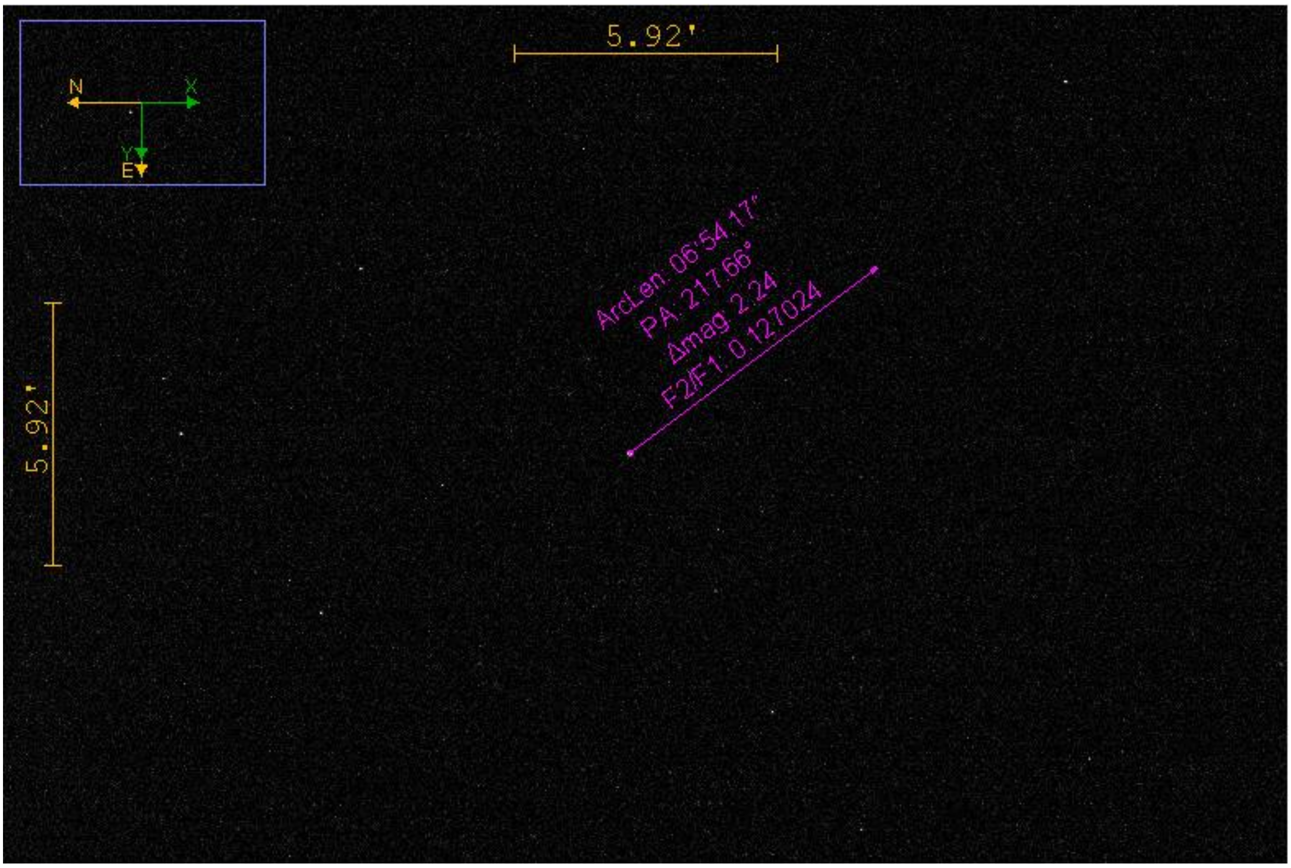

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C3

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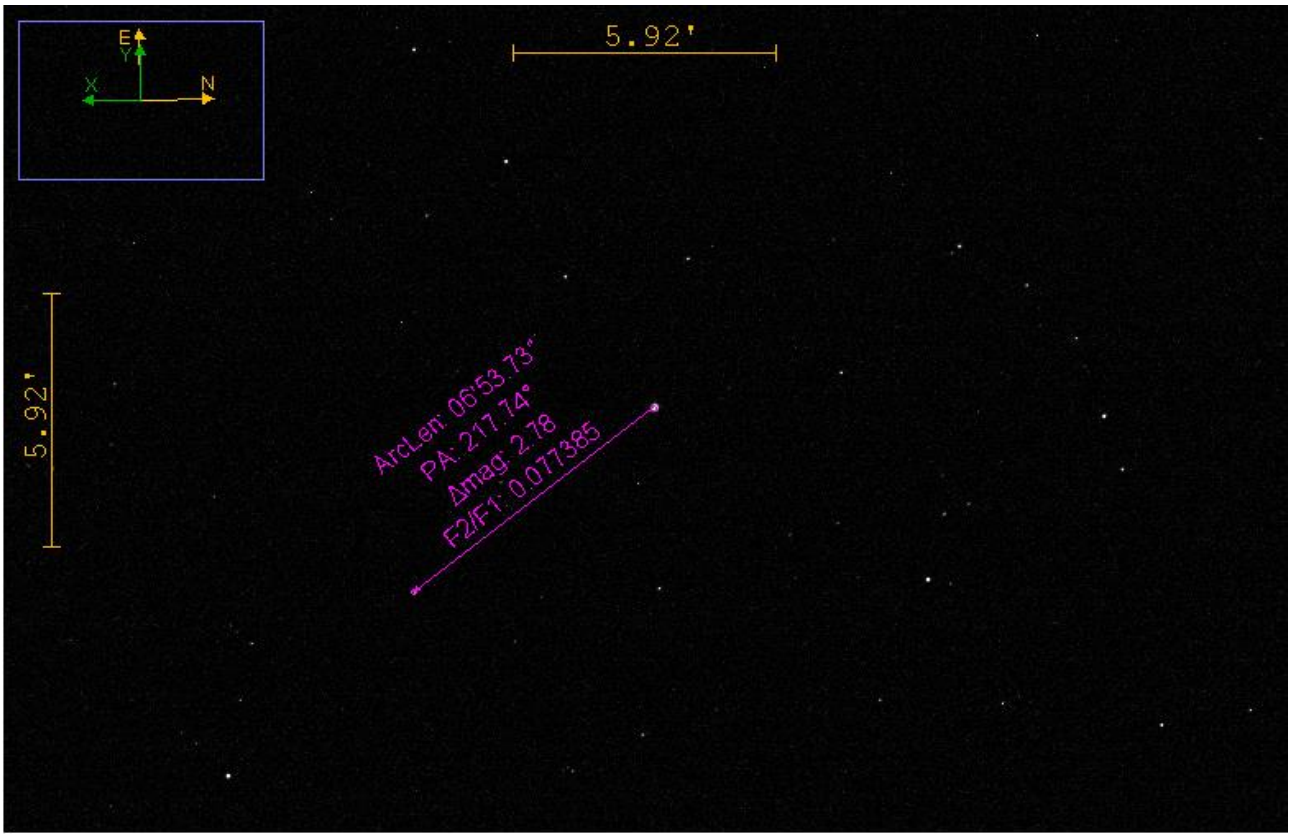

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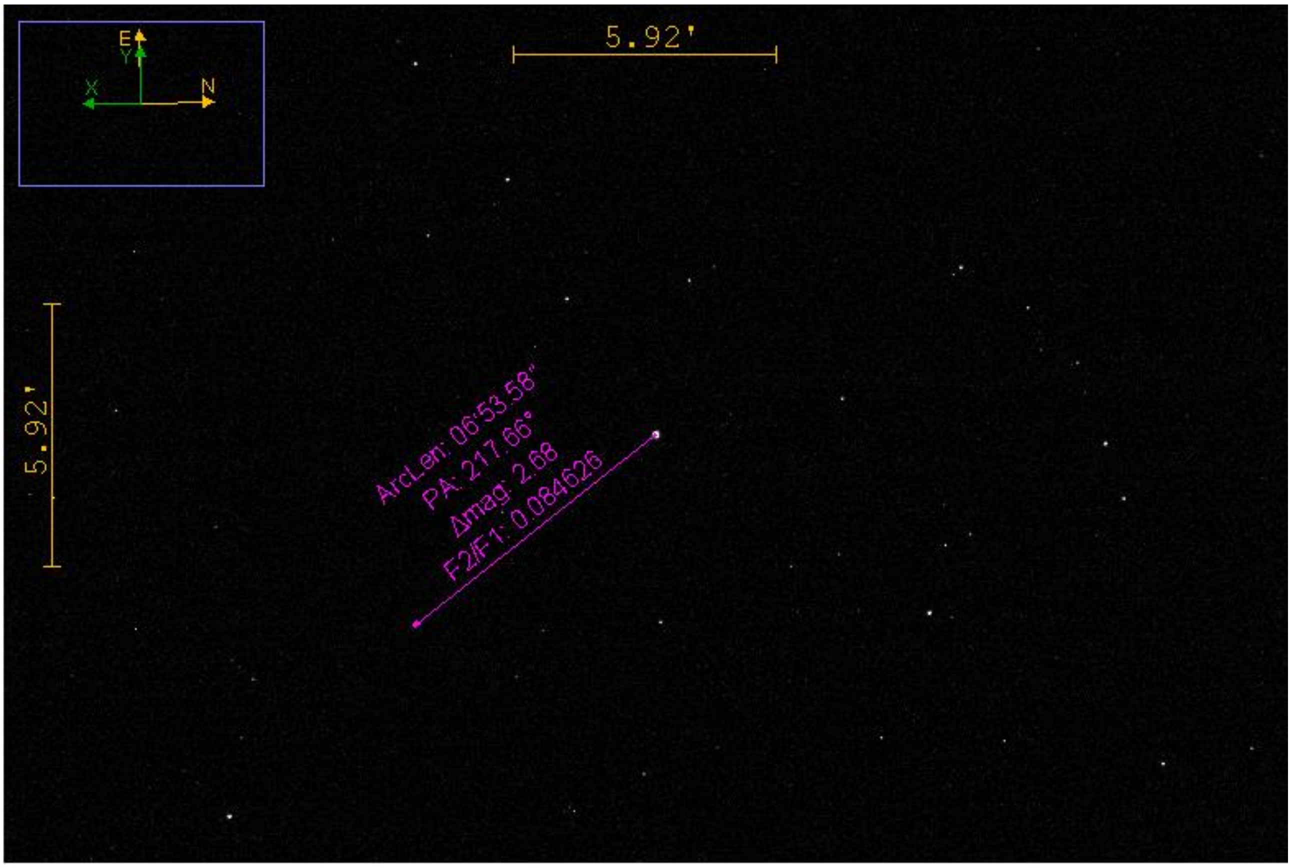

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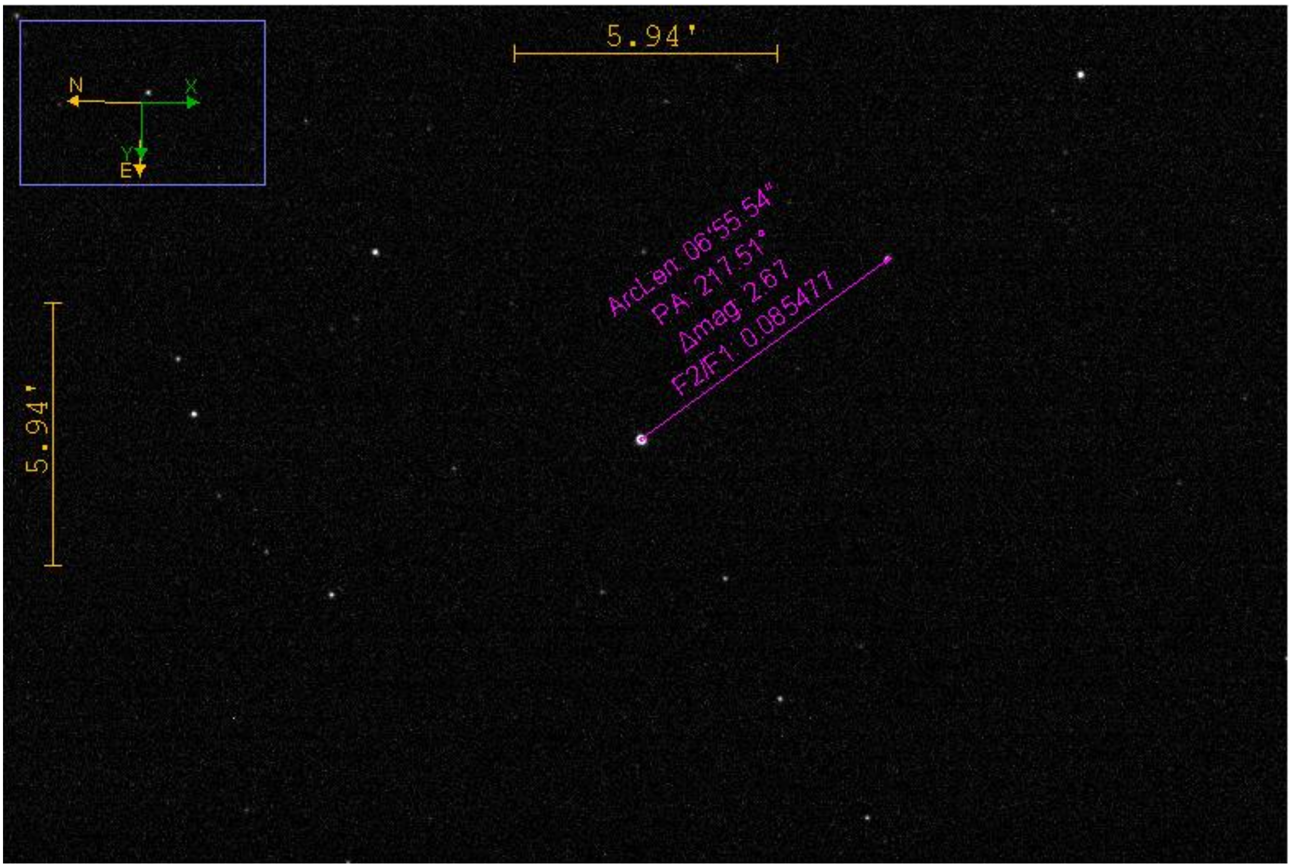

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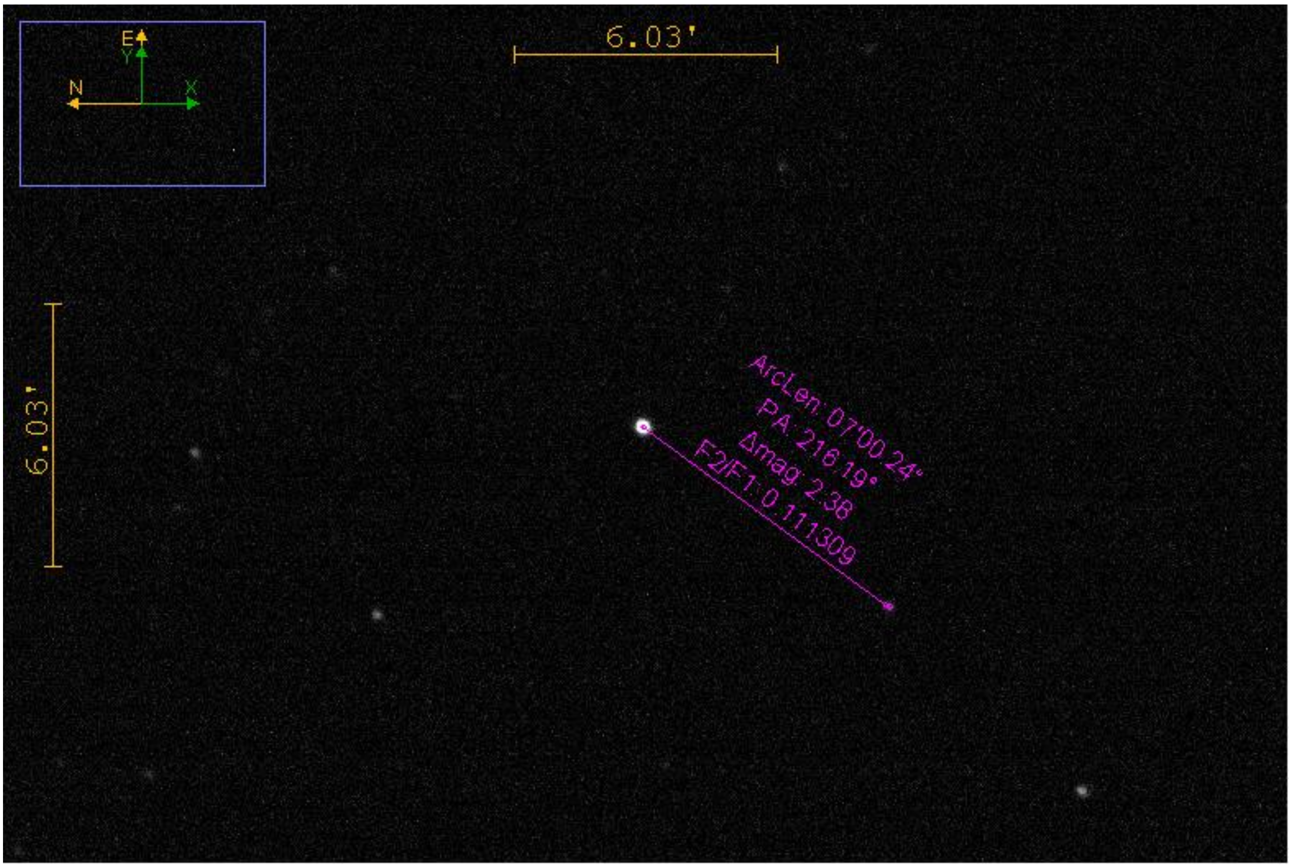

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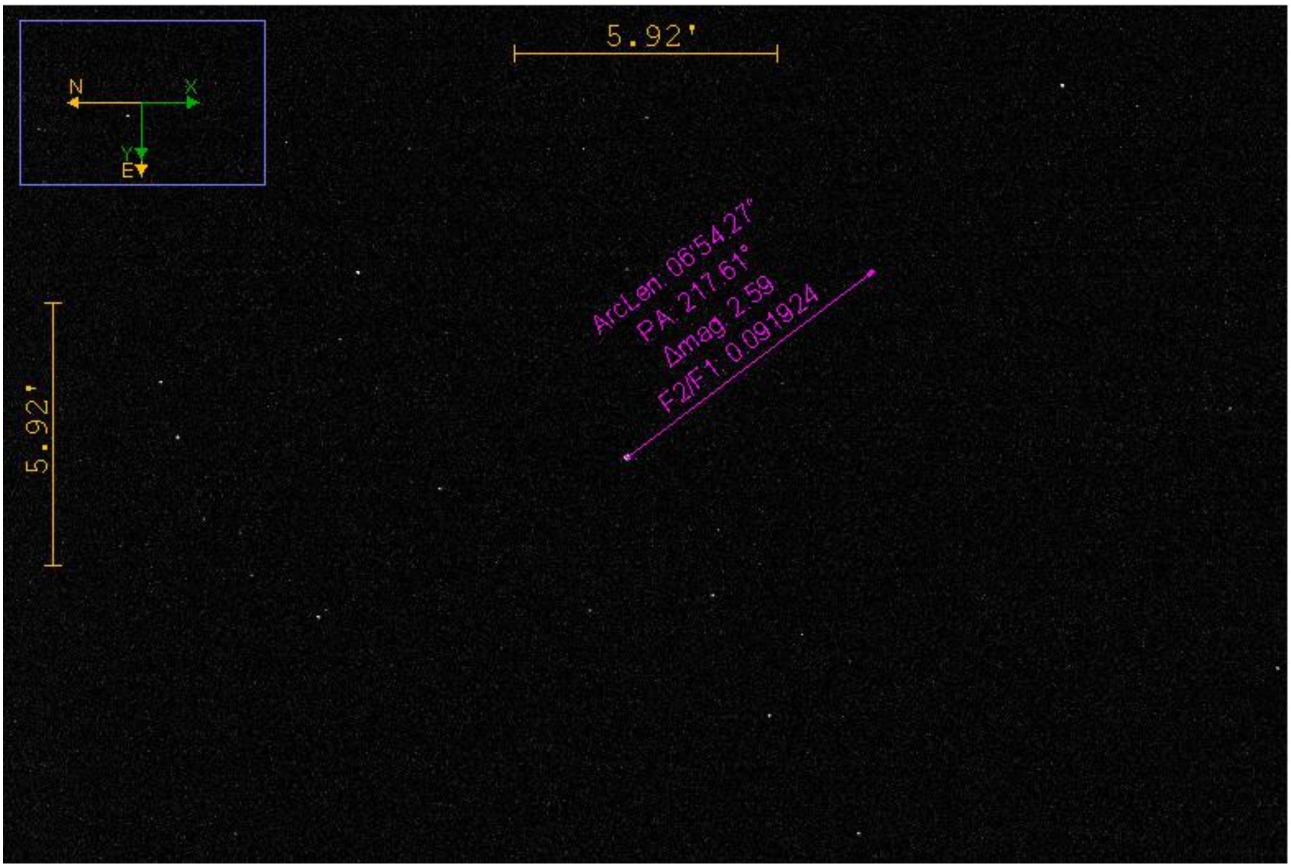

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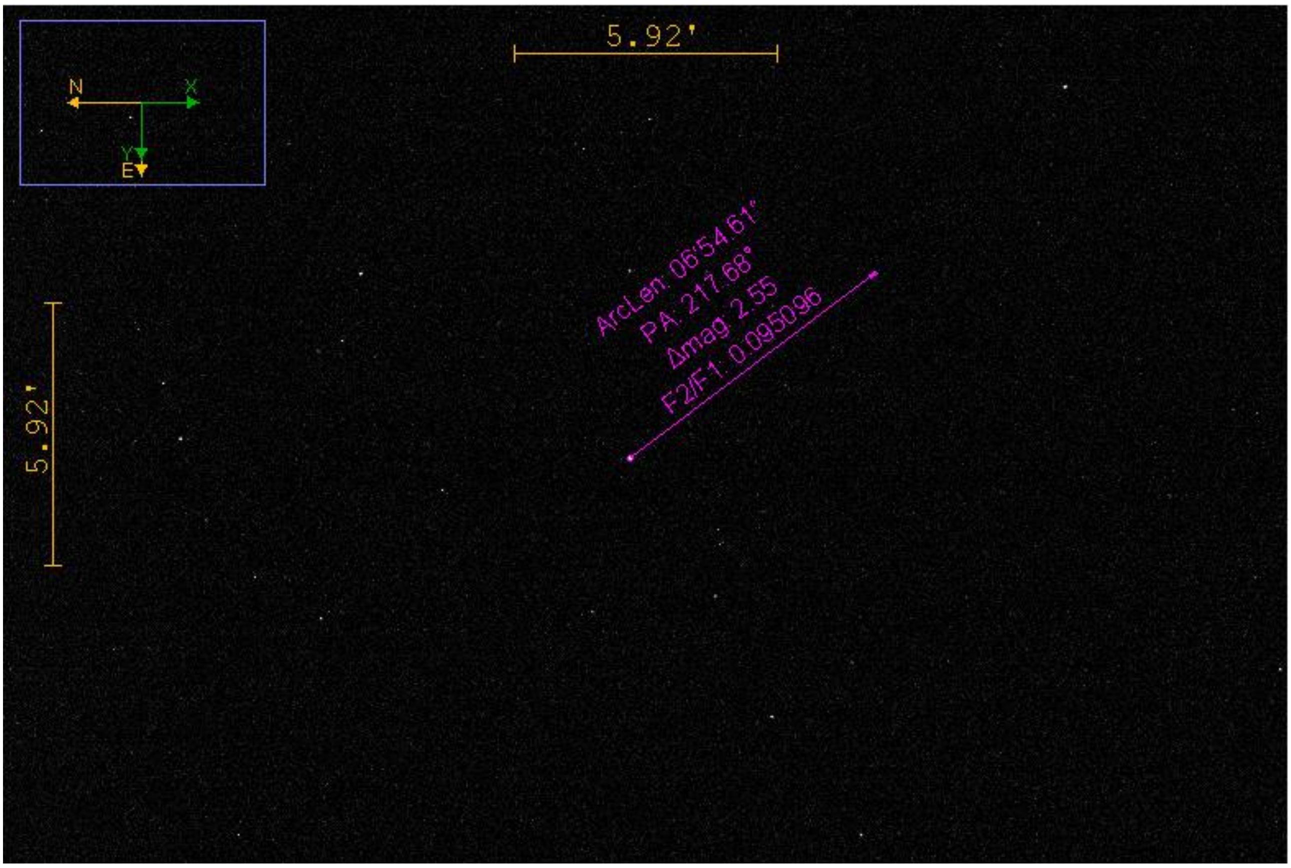

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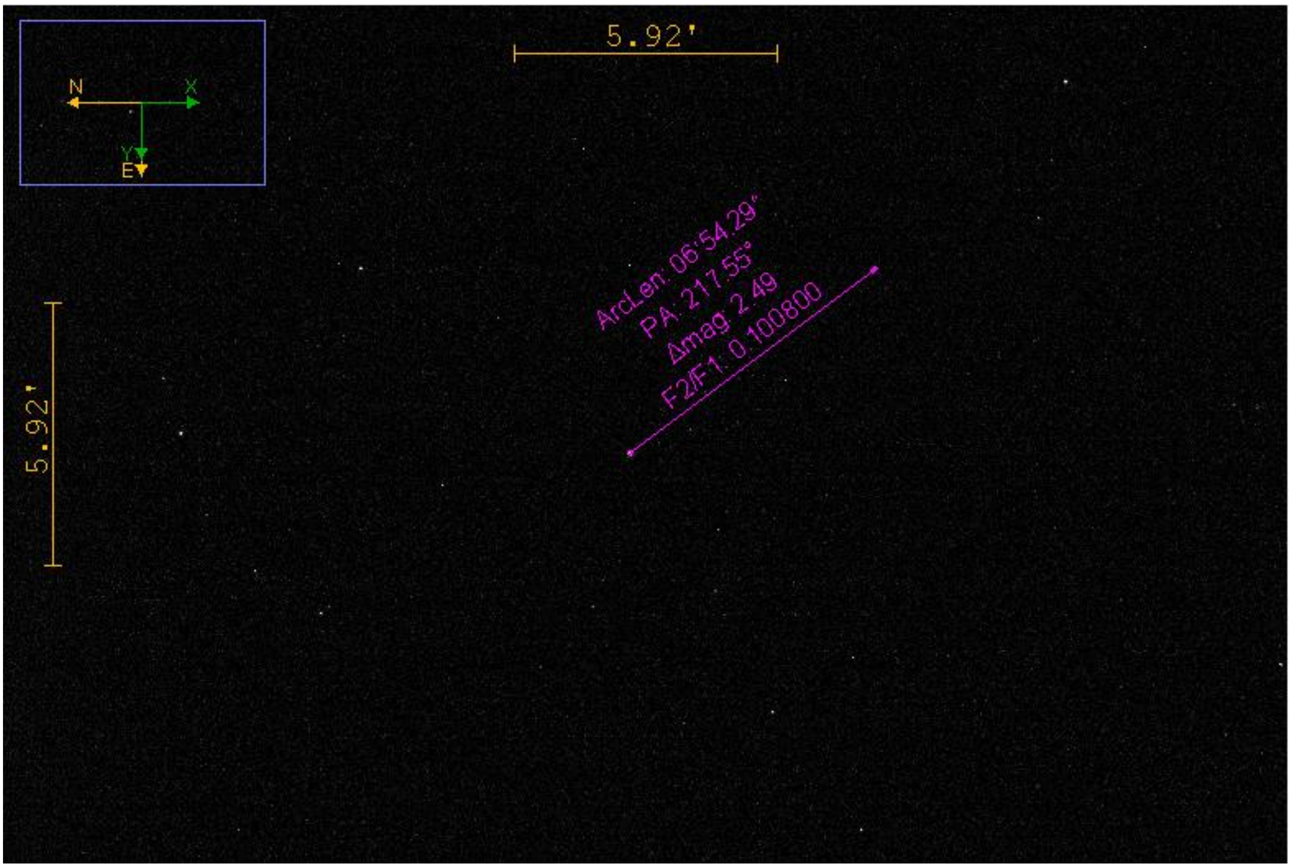

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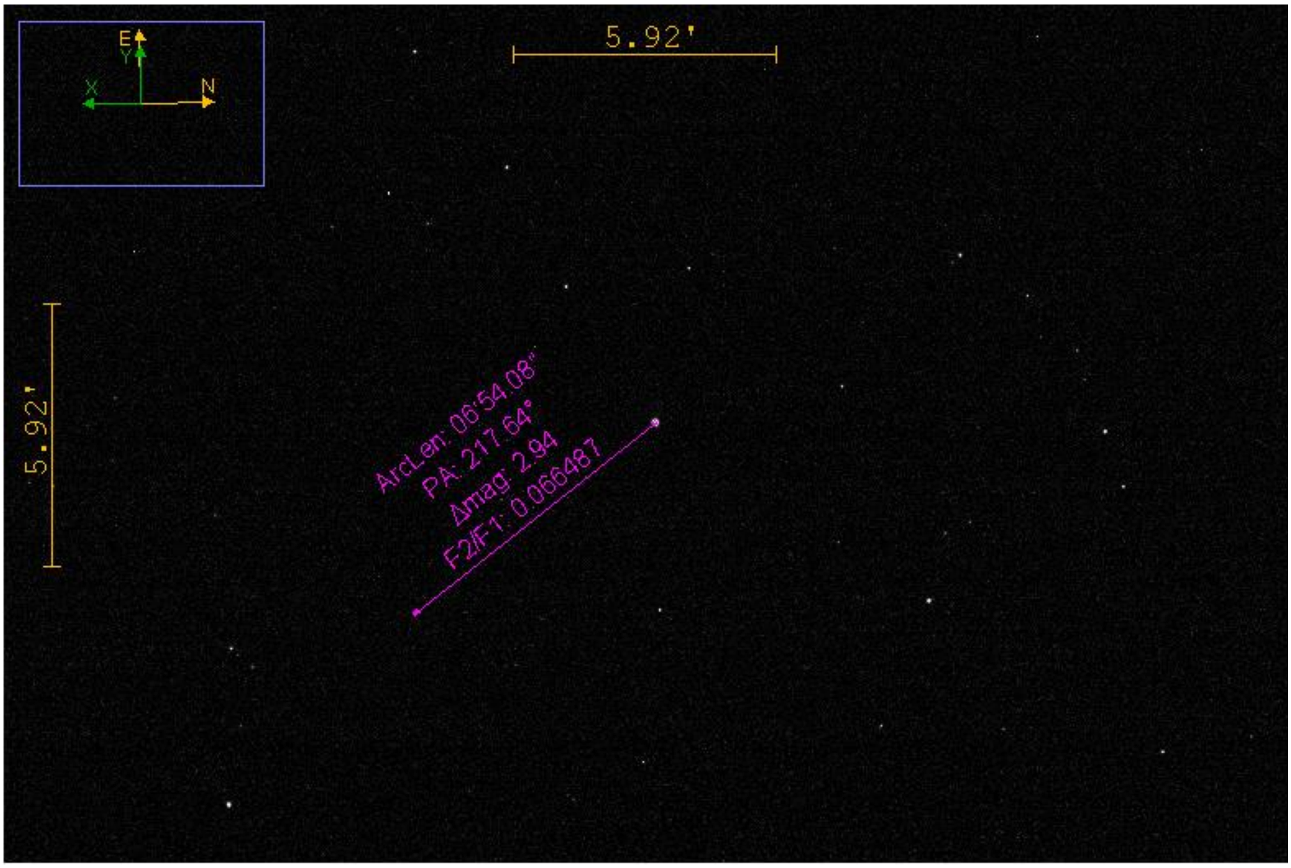

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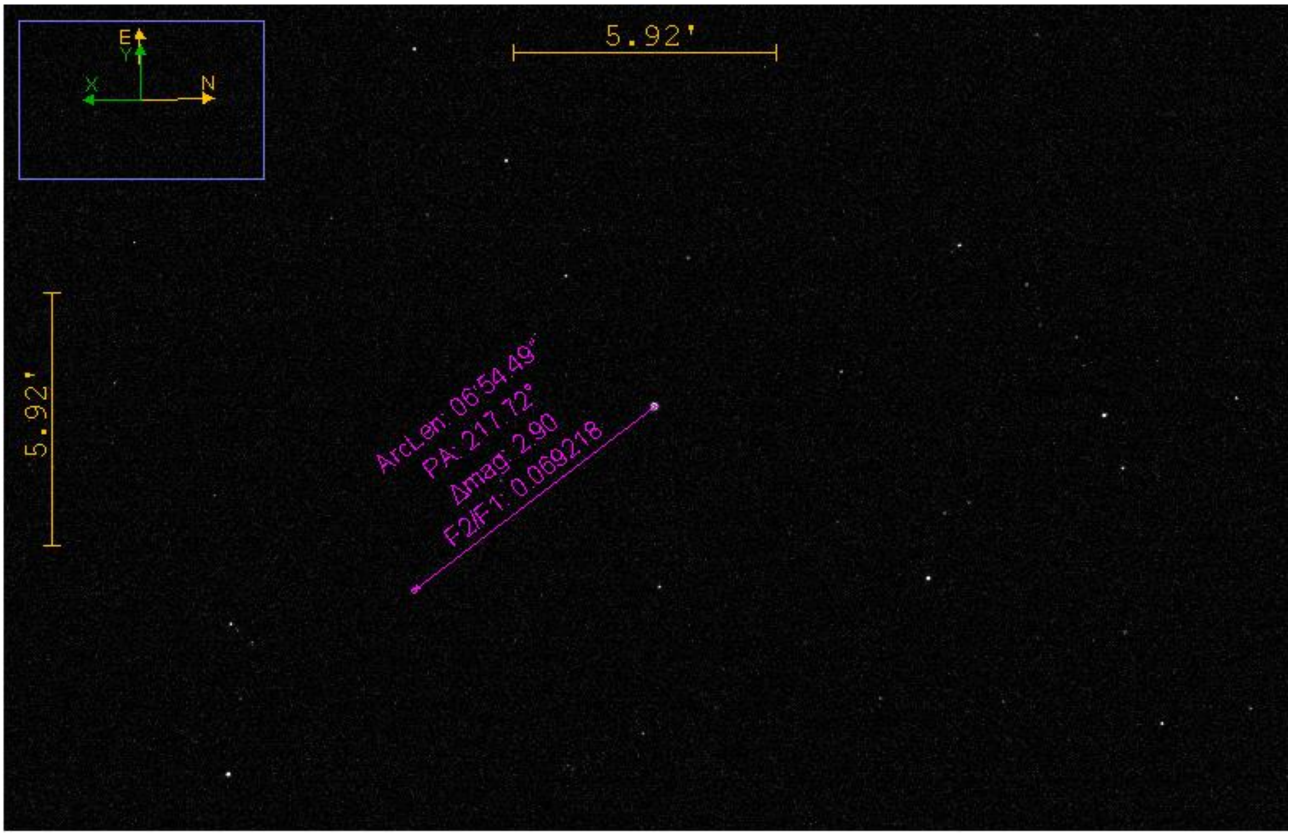

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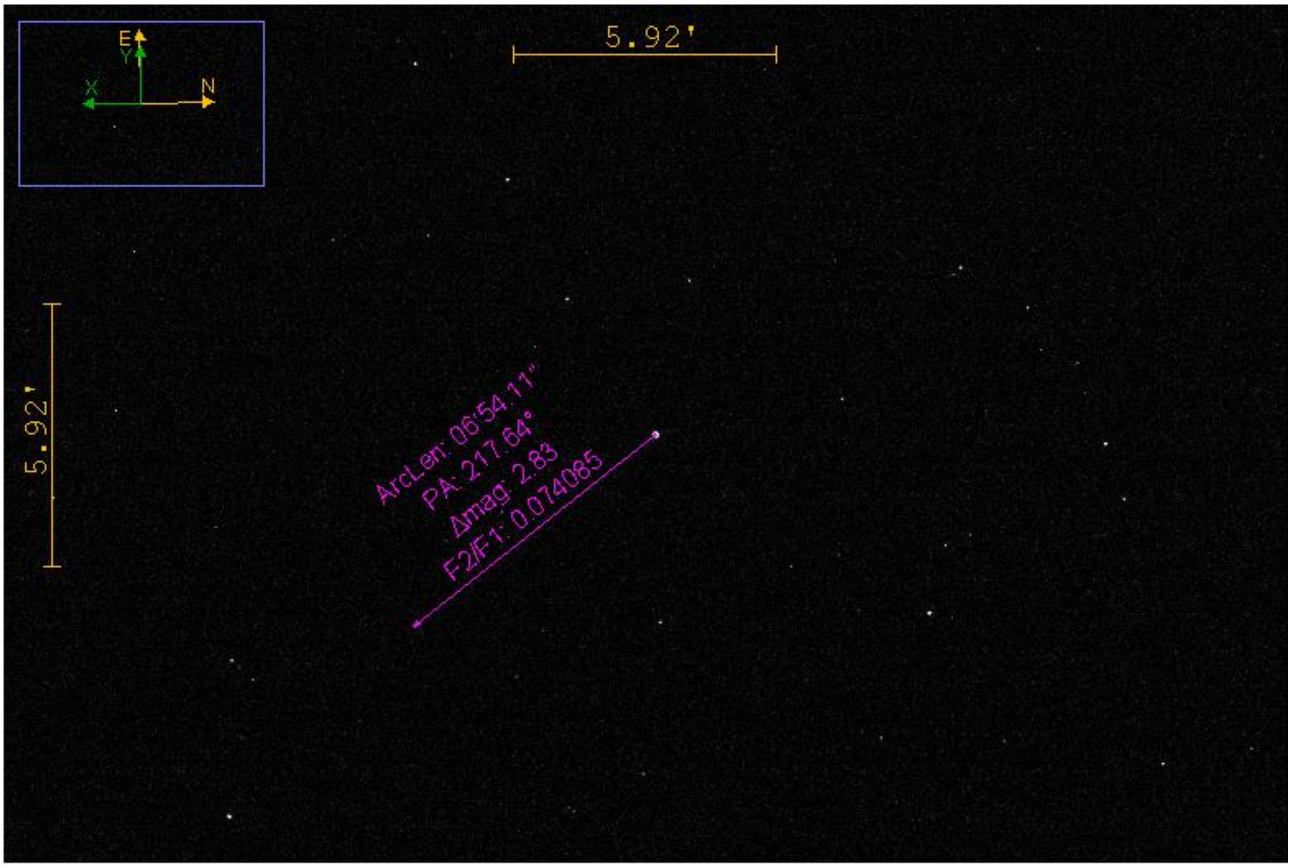

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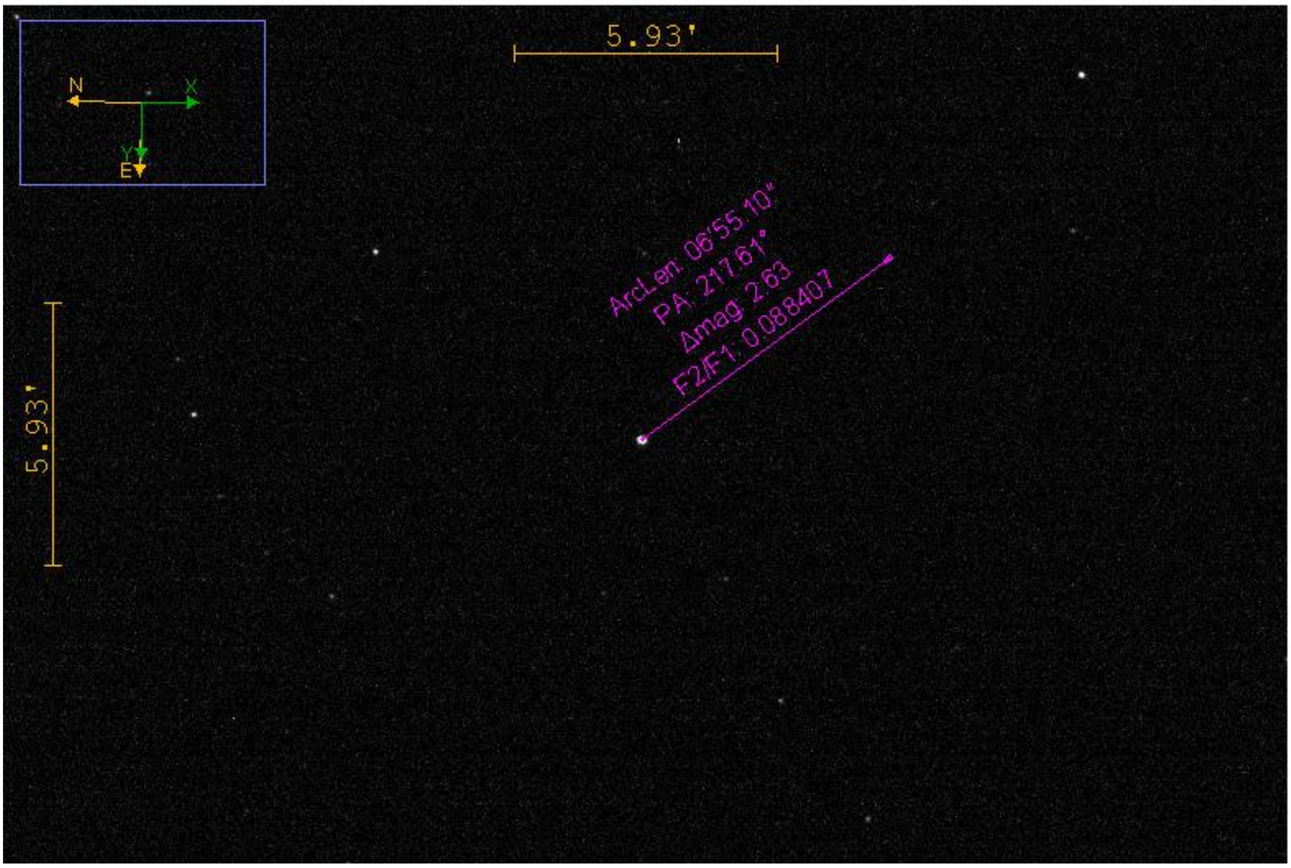

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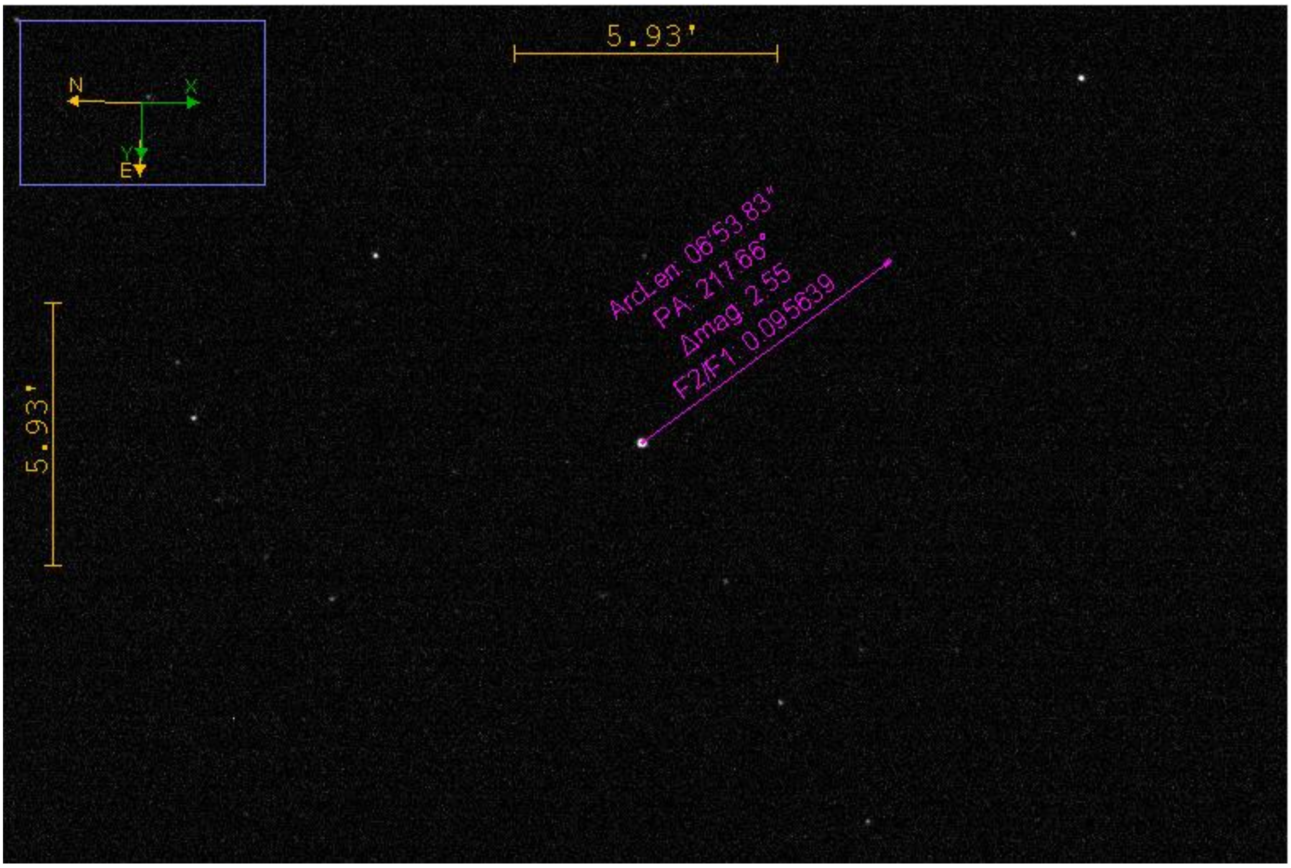

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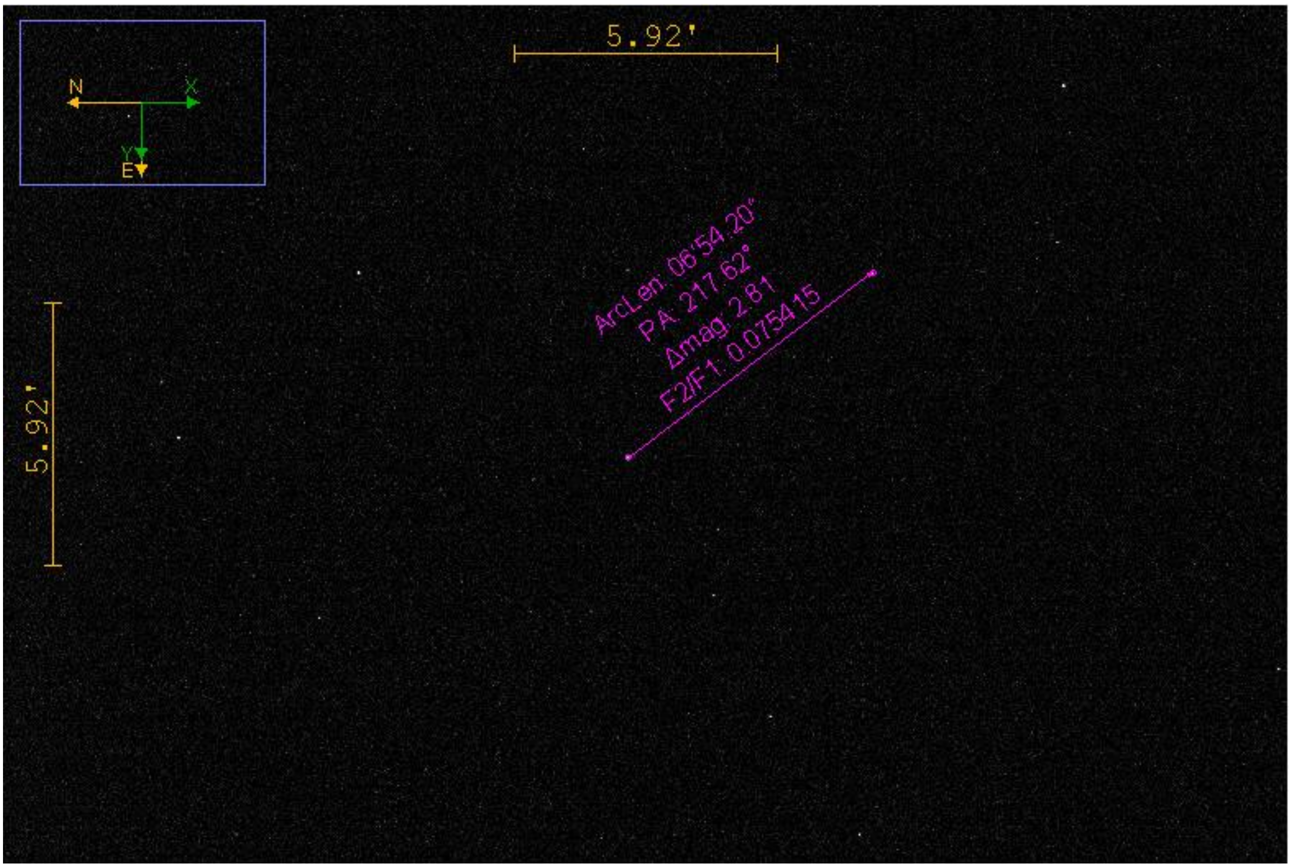

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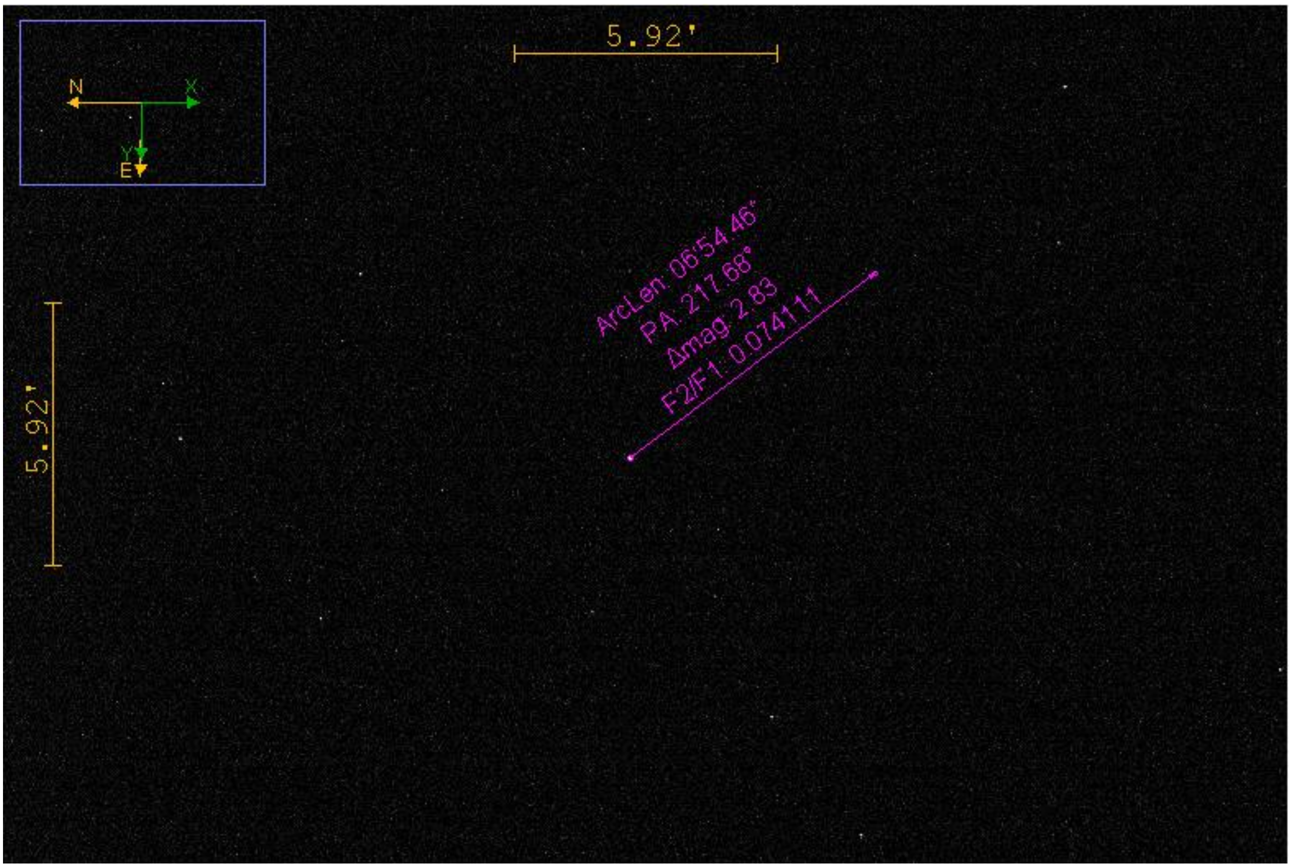

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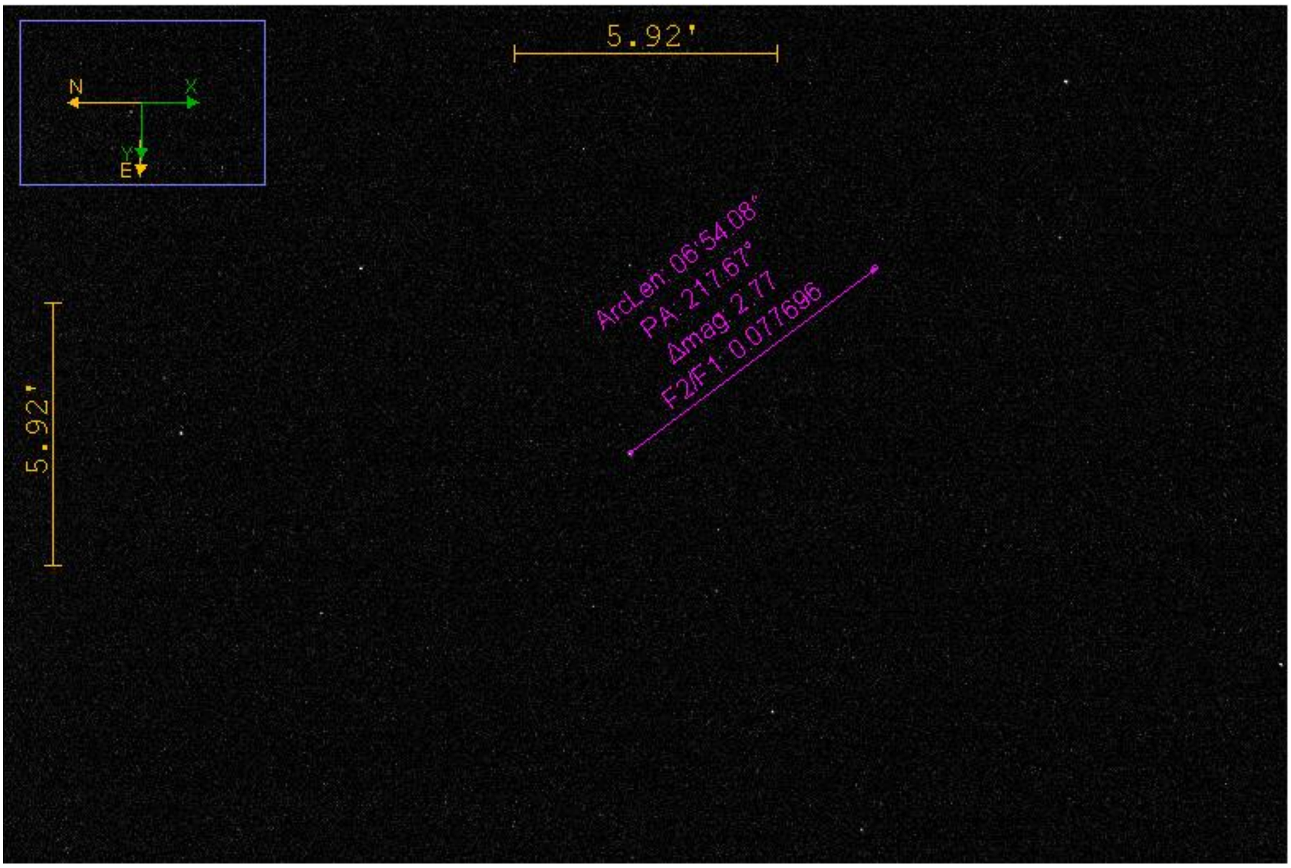

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Reference

[1]: Leavitt, H. S. & Pickering, E. C. 1912, 'Periods of 25 Variable Stars in the Small Magellanic Cloud.' *Harvard College Observatory Circular, vol. 173, pp.1-3*

[2]: Ken Crosswel 1997, 'The first cepheid.' *Sky & Telescope, vol. 94, n4, p90(2)*

[3]: Goodricke John 1786, 'II. A series of observations on, and a discovery of, the period of the variation of the light of the star marked δ by Bayer, near the head of Cepheus. In a letter from John Goodricke, Esq. to Nevil Maskelyne, D.D. F. R. S' *Phil. Trans. R. Soc.7648–61*

[4]: *SIMBAD Astronomical Database - CDS (Strasbourg)*, https://simbad.cds.unistra.fr/simbad/sim-id?Ident=delta+Cep

[5]: Leavitt, H. S. 1908, '1777 variables in the Magellanic Clouds.' *Annals of Harvard College Observatory, vol. 60, pp.87-108.3*

[6]: Horace A. Smith. RR Lyrae Stars. The Pitt Building, Trumpington Street, Cambridge, U.K.: The Press Syndicate of the University of Cambridge; 1995.

[7]: Standard Candle | COSMOS, [Accessed: December 4, 2022].
https://astronomy.swin.edu.au/cosmos/S/Standard+Candle

[8]: *ASASSN Variable Stars Database*, https://asas-sn.osu.edu/variables/2e32dd3a-da42-52ae-993d-26e65bdf88b5

[9]: *ASASSN Variable Stars Database*, https://asas-sn.osu.edu/variables/6e156e84-05c0-58dc-935c-f929284fe5ce

[10]: *ASASSN Variable Stars Database*, https://asas-sn.osu.edu/variables/07442b9a-5036-5bca-a1e1-34caf0a07d03

[11]: Eddington, A. S. 1917, 'The pulsation theory of Cepheid variables'. *The Observatory, Vol. 40,*

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