Short-period variation of 6.7 GHz methanol masers

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6.7GHz methanol masers

- Associated in massive star forming regions (Menten 1991)
- Radiatively pumped by IR emission of warm dusts (~100-200K; Cragg et al. 2005) radiated by protostar.

→ The maser brightness could be effected by a luminosity variation of forming massive stars.

Periodic variation of 6.7GHz methanol masers

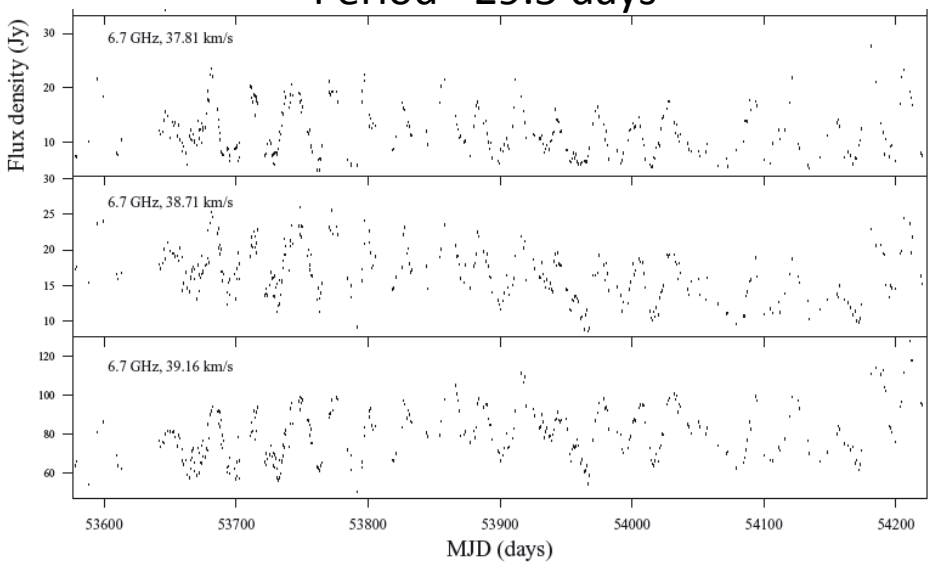
- Known periodic variable sources : 12

  (Goedhart et al. 2004, 2009; Araya et al. 2010;

  Szymczak et al. 2011; Fujisawa et al. 2014)

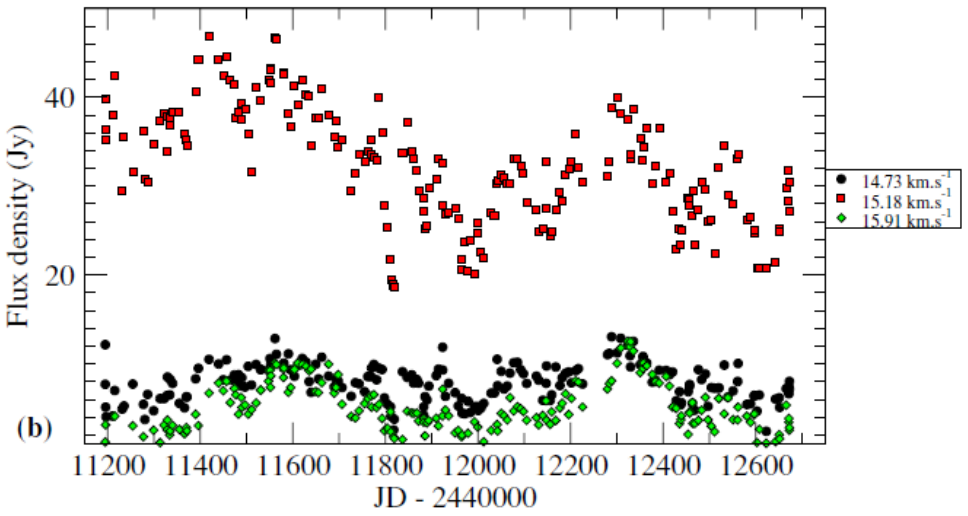
- Range of period : 30 – 668 days

Period =29.5 days



G12.89+0.46 (Goedhart et al. 2009)

Period = 668 days



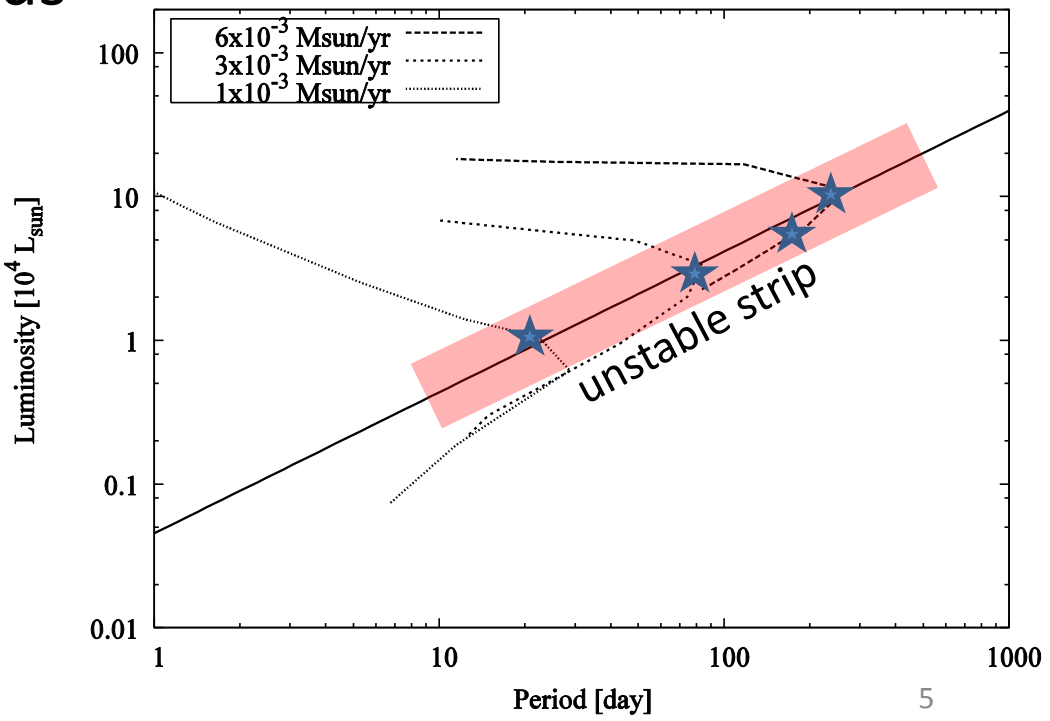
G196.45-1.68 (Goedhart et al. 2004)

Pulsational unstable model for periodic variation (Inayoshi et al. 2013)

- Rapidly accreting ($\gtrsim 10^{-3}\ M_\odot\ yr^{-1}$) protostars become pulsationally unstable.
  - Periodic variation of the luminosity of forming massive stars
- Typical pulsation periods
  = ~10 – 100 d

Compatible with

observed maser periods

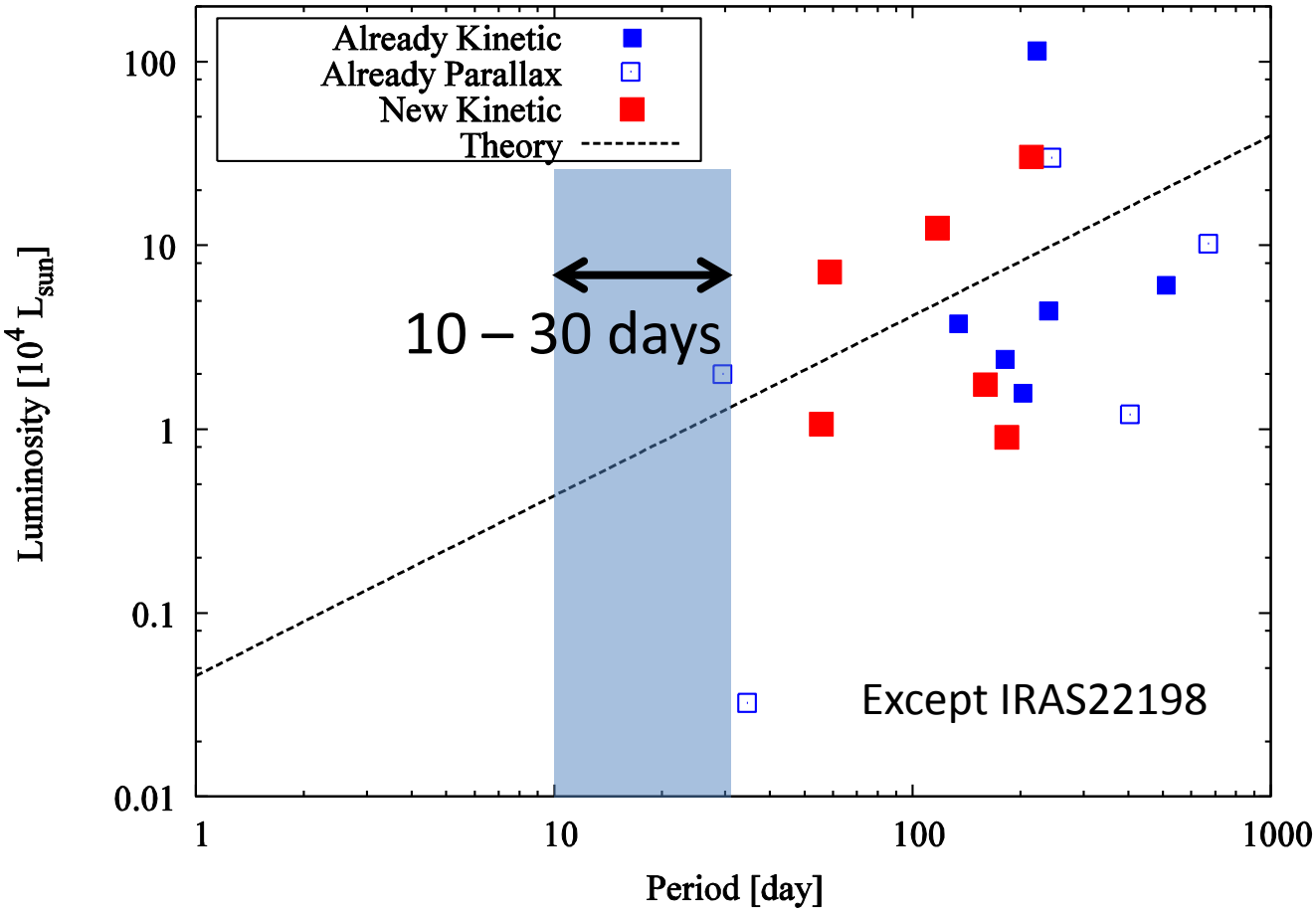


Monitoring observations to 6.7GHz masers used the Hitachi Ant.

- Monitoring sources : 425
  - Date : 2012/12/30 ～.
  - the interval of 9 days for each source.
  - Consist of
    - 398 : From maser catalogs (Dec. > -30° and except overlap)
      Xu et al. (2009), Caswell et al. (2010), Green et al. (2010), Pandian et al. (2011), Green et al. (2012)
    - 4 : JVN/EAVN monitoring sources (Dec. < -30°)
    - 3 : Newly detected at the Yamaguchi Ant.
      (Hiramoto, Takase, Fujisawa sources)
    - 20 : DBSM (Motogi sources)

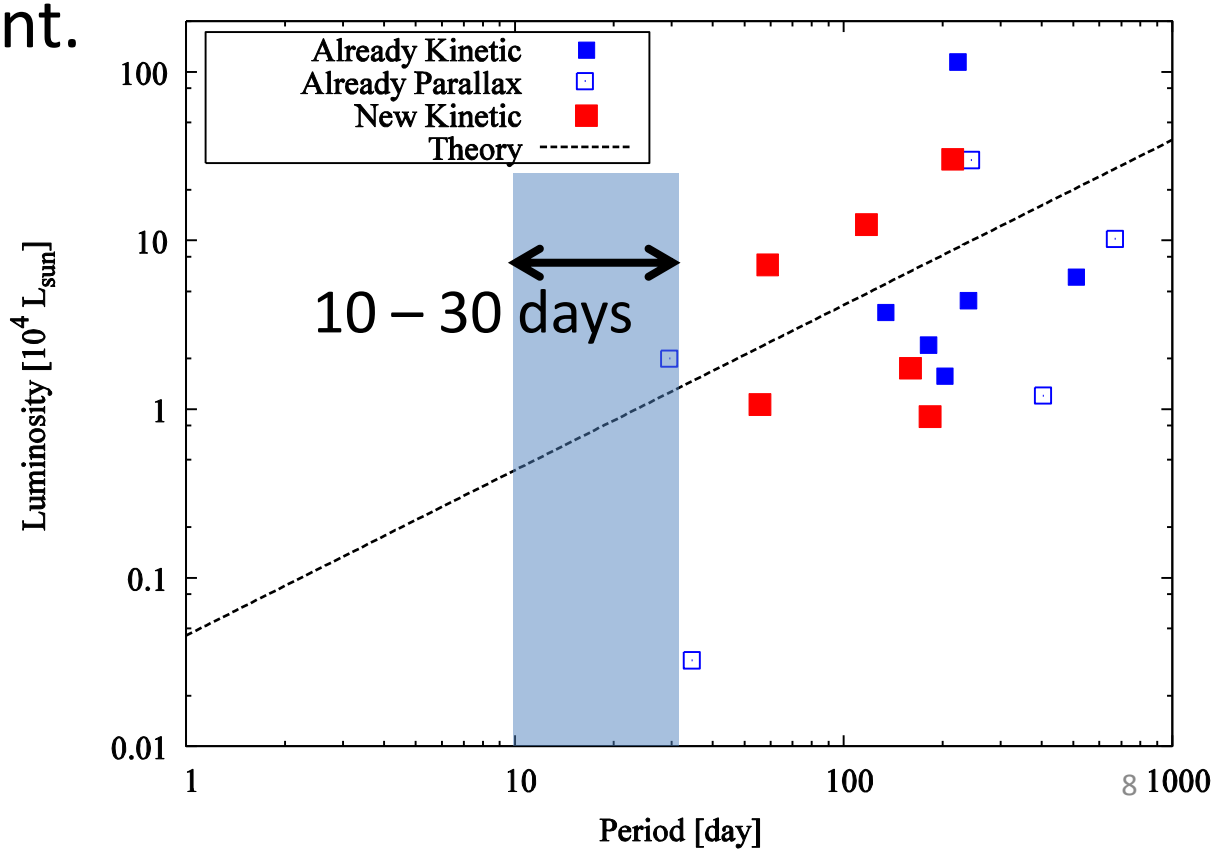
Monitoring observations to 6.7GHz masers used the Hitachi Ant.

- 6 sources were newly detected at the Hitachi Ant.
- Sample is not enough in the range of 10 – 30 days



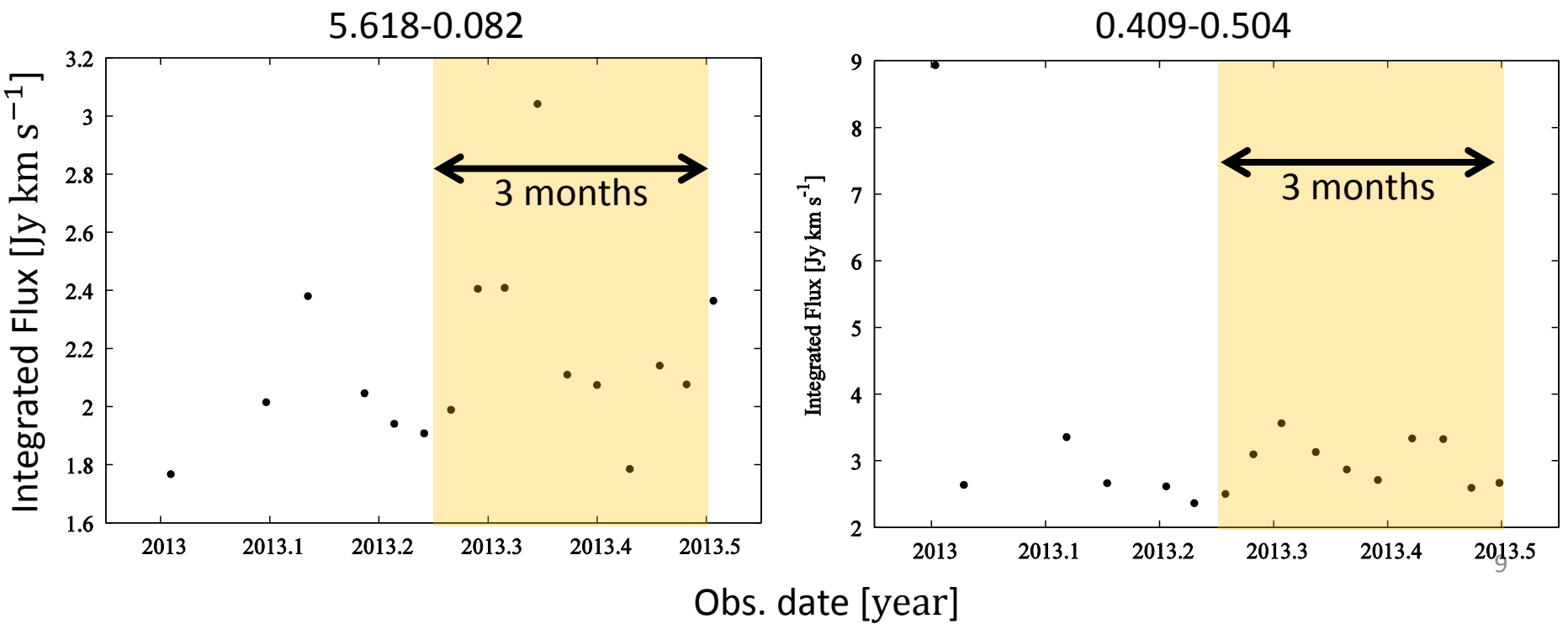
Purpose of obs. at the Takahagi Ant.

- To detect variable maser sources with a period of about <u>10 days</u>
  - Undetectable variation in 9-days interval monitor at the Hitachi Ant.



Selection of target sources

- The mother : the Hitachi monitoring sources of 411 (observed in 2012/12/30 – 2013/07/07).
- Estimation of variability.
  - Variation of Integrated flux density & Spectrum shape



Selection of target sources

- The mother : the Hitachi monitoring sources of 411 (observed in 2012/12/30 – 2013/07/07).
- Estimation of variability.
  - Variation of Integrated flux density & Spectrum shape
- Selected possible variable sources

  with a period of $\lesssim$ 3 months.

→51 sources

(including ref. sources; 09.621+0.196, IRAS22198)

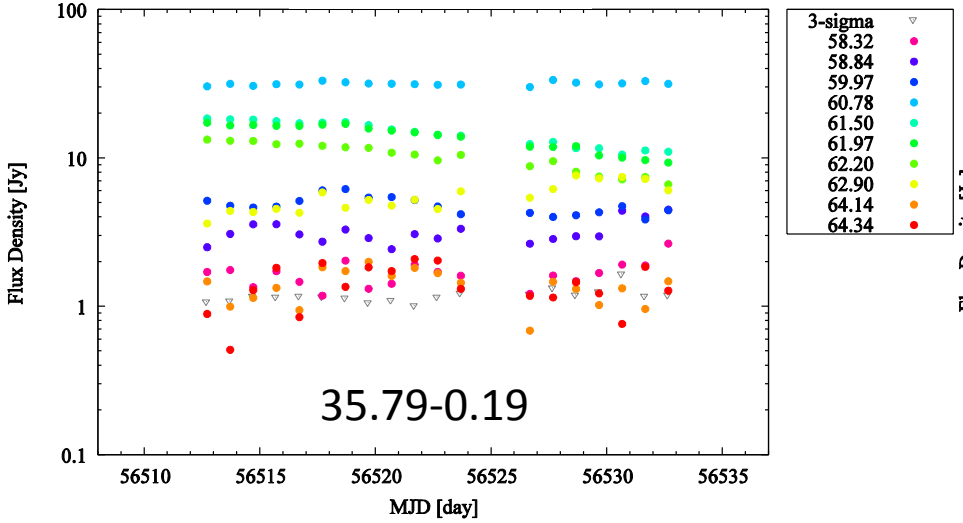
Observational parameters

- Station: Takahagi 32-m Antenna
- Date : 2013/08/08 – 28 (for 21 days)
  - 51 maser sources were observed everyday,
  - but except 8/20, 21.
- Freq. : 6667 – 6672 MHz
- Channel resolution : 0.044 km/s
- Integrated time : 5min/source × 2 (ON, OFF)
- 1-sigma noise level : ~0.3 Jy

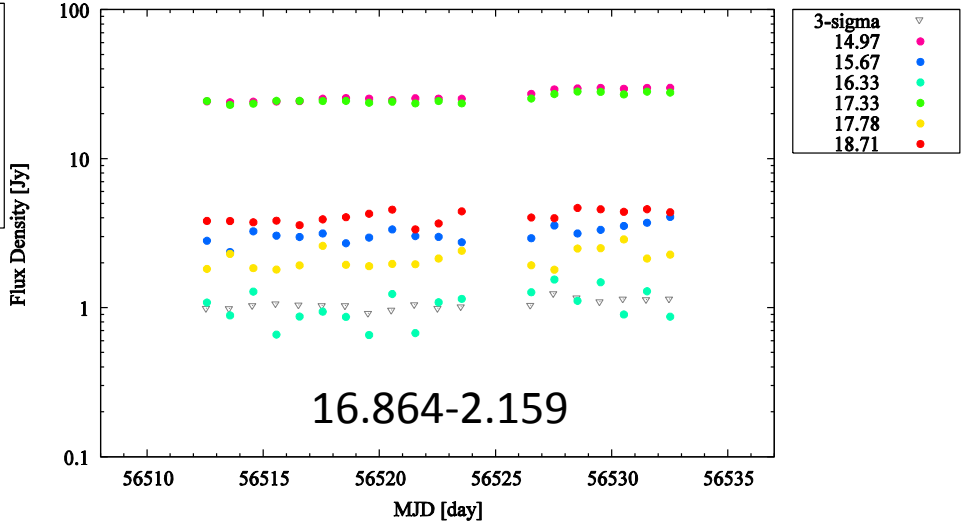
Results

Selection of sources with possibility of variability

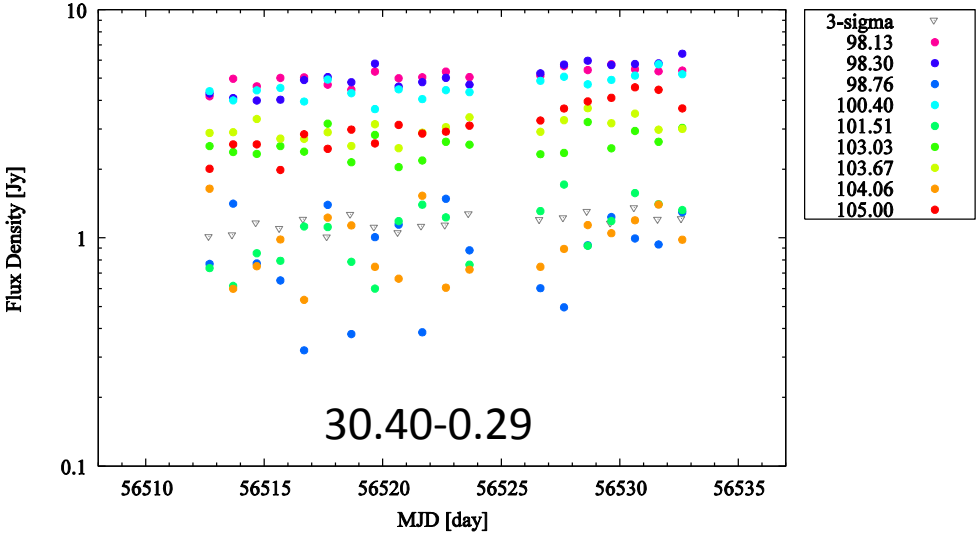
Decrease



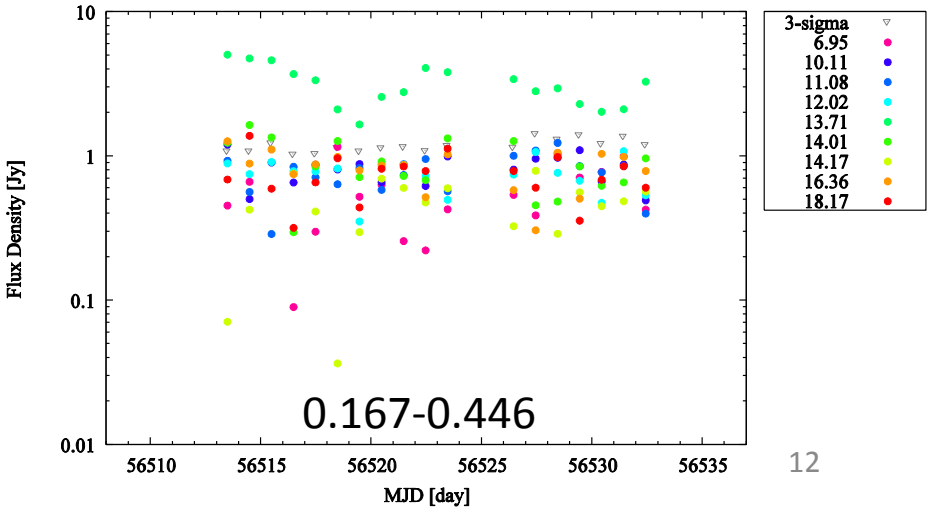
No variation



Increase



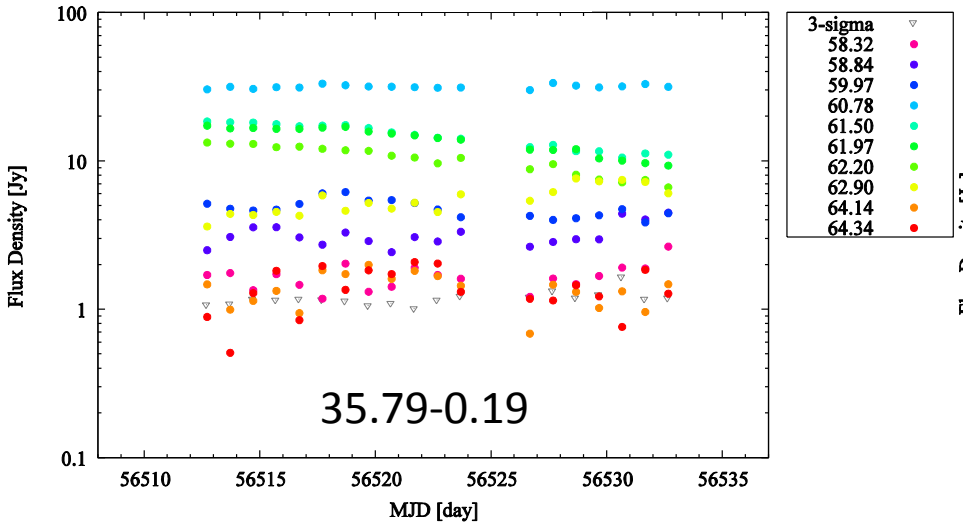
Increase and decrease



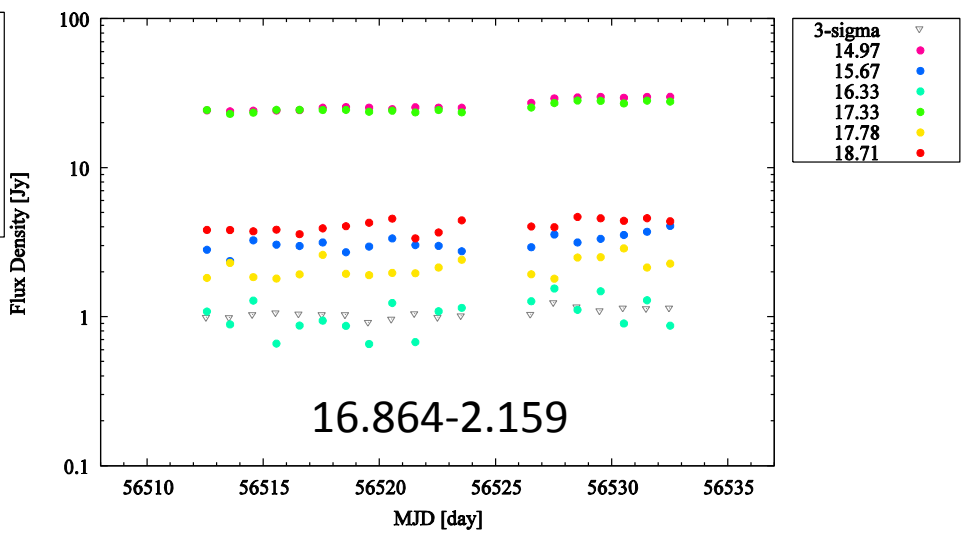
Results

Selection of sources with possibility of variability

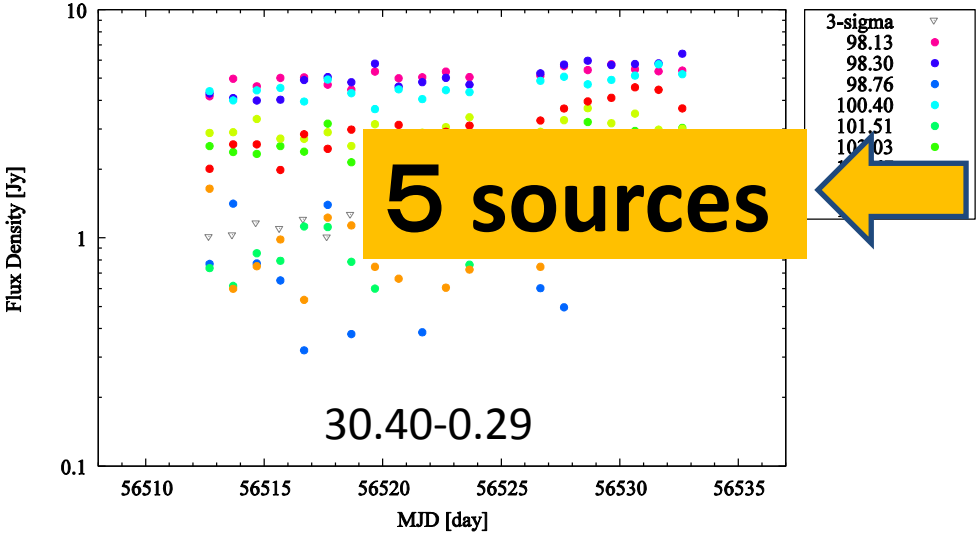
Decrease



No variation

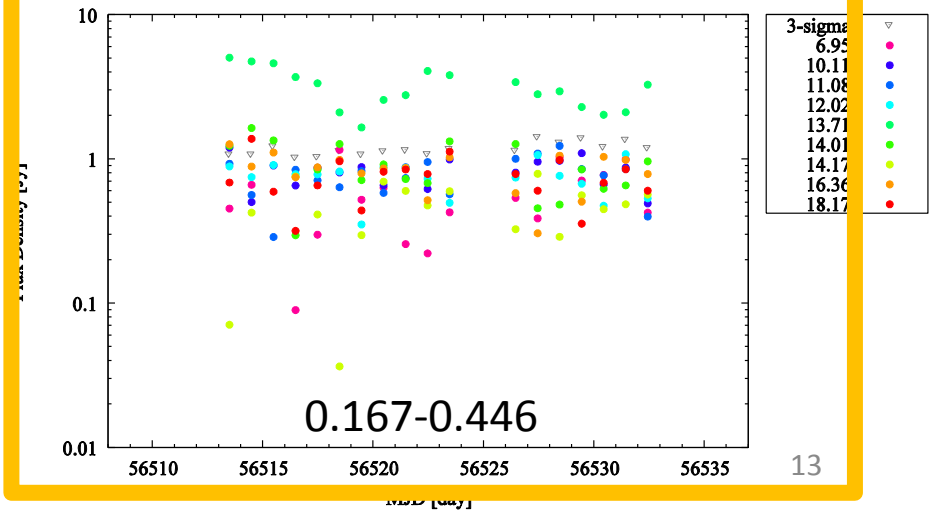


Increase



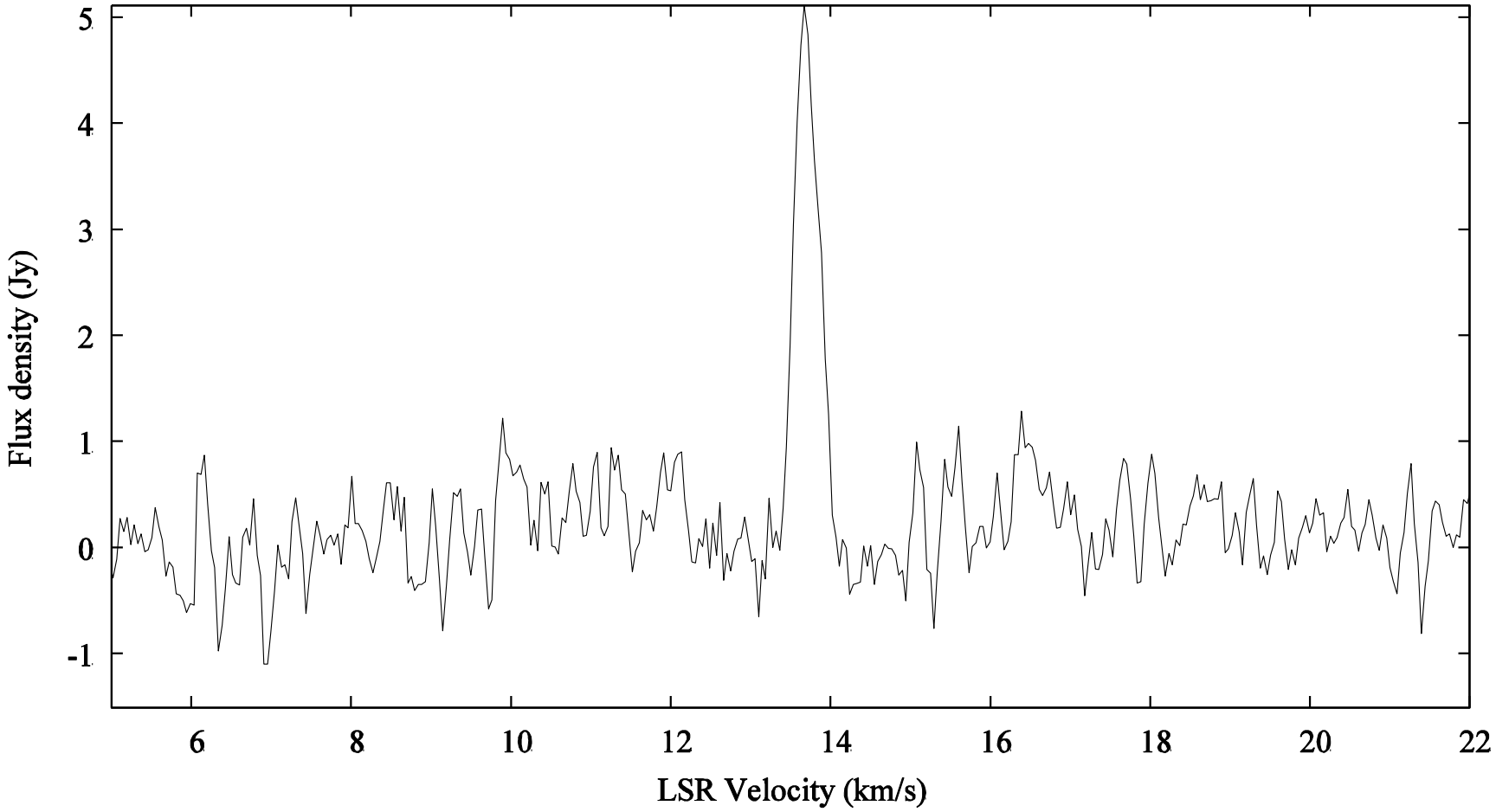
5 sources

Increase and decrease



0.167-0.446

DOY= 221



0.167-0.446

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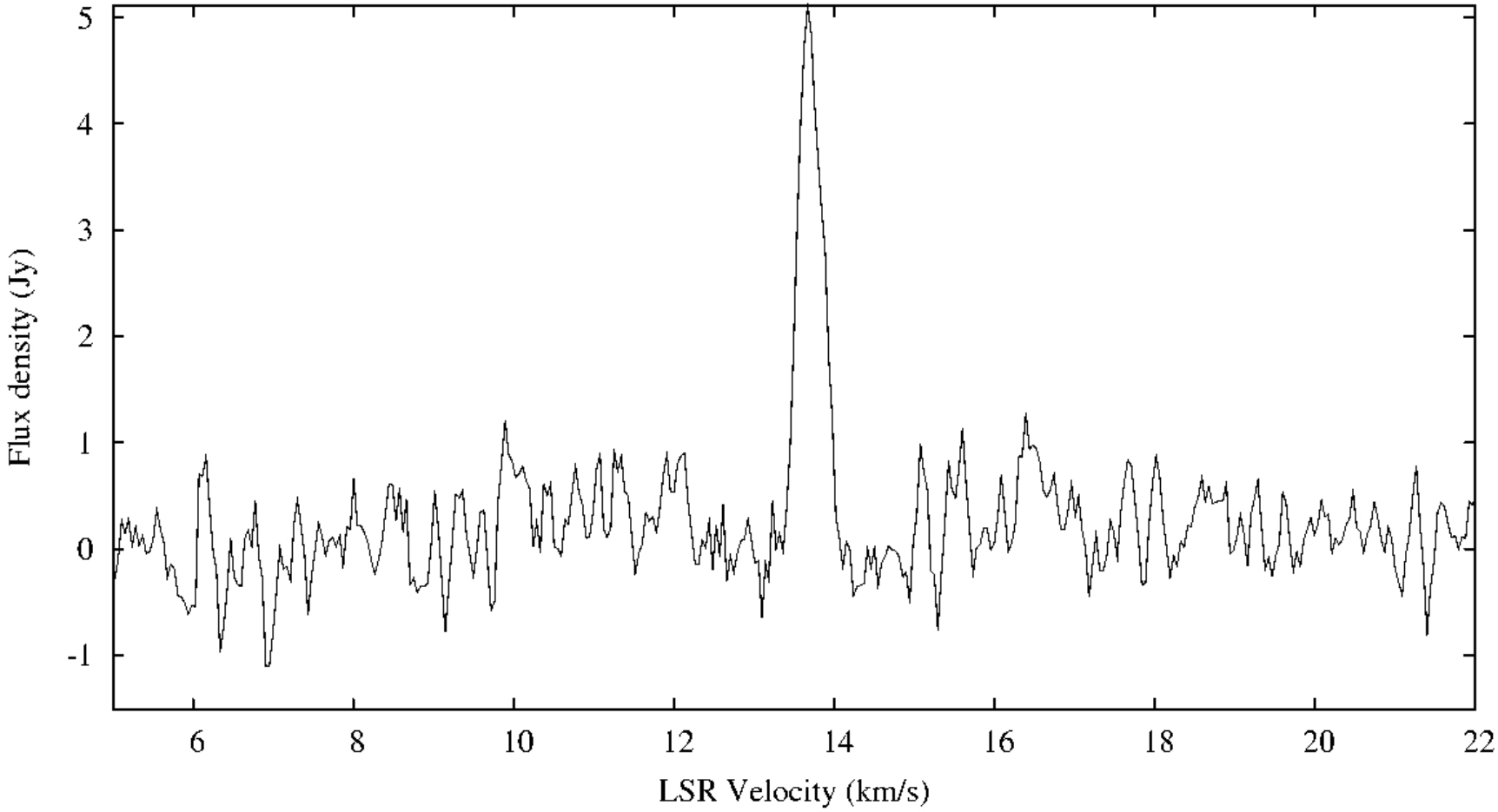
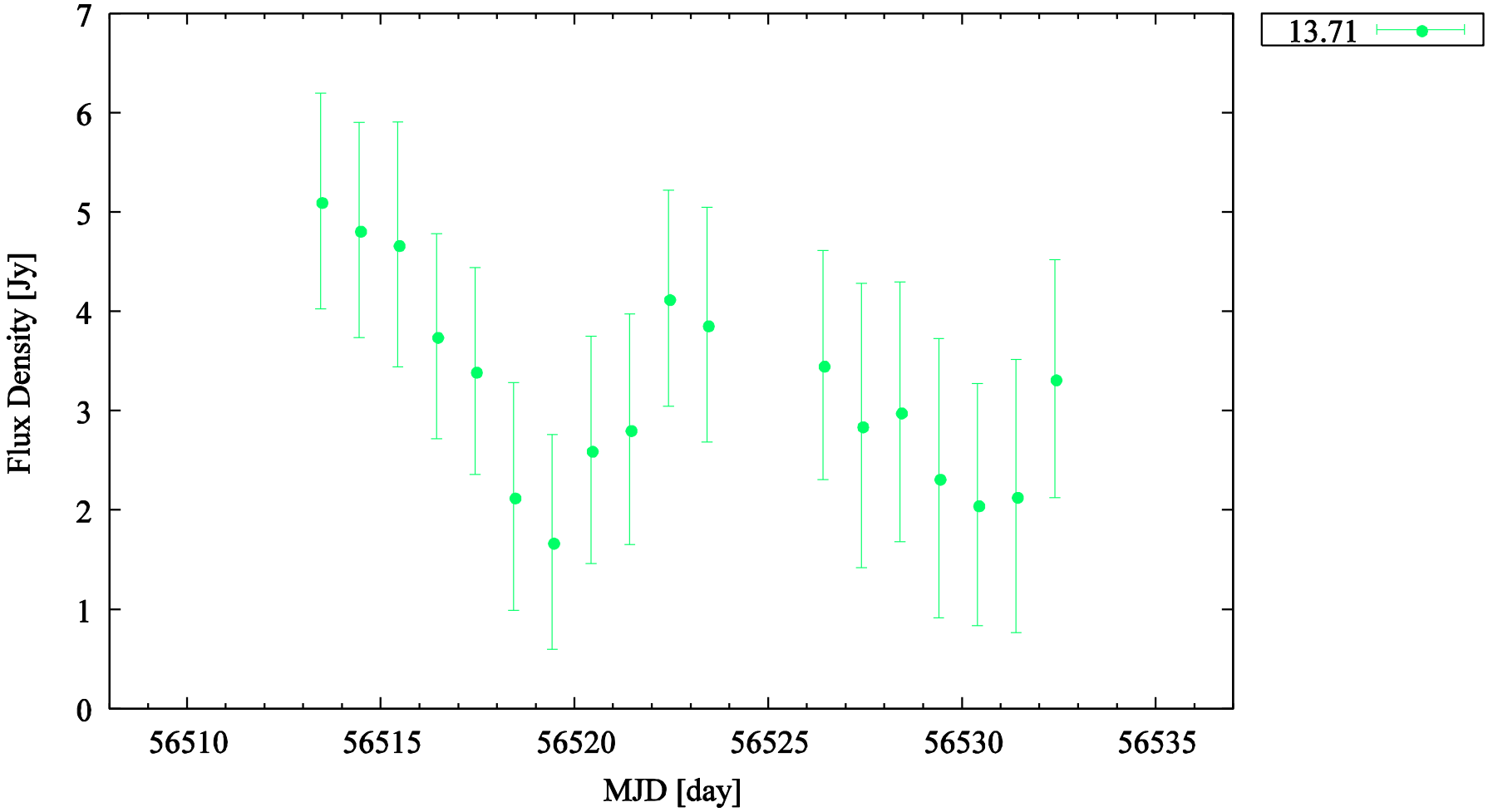
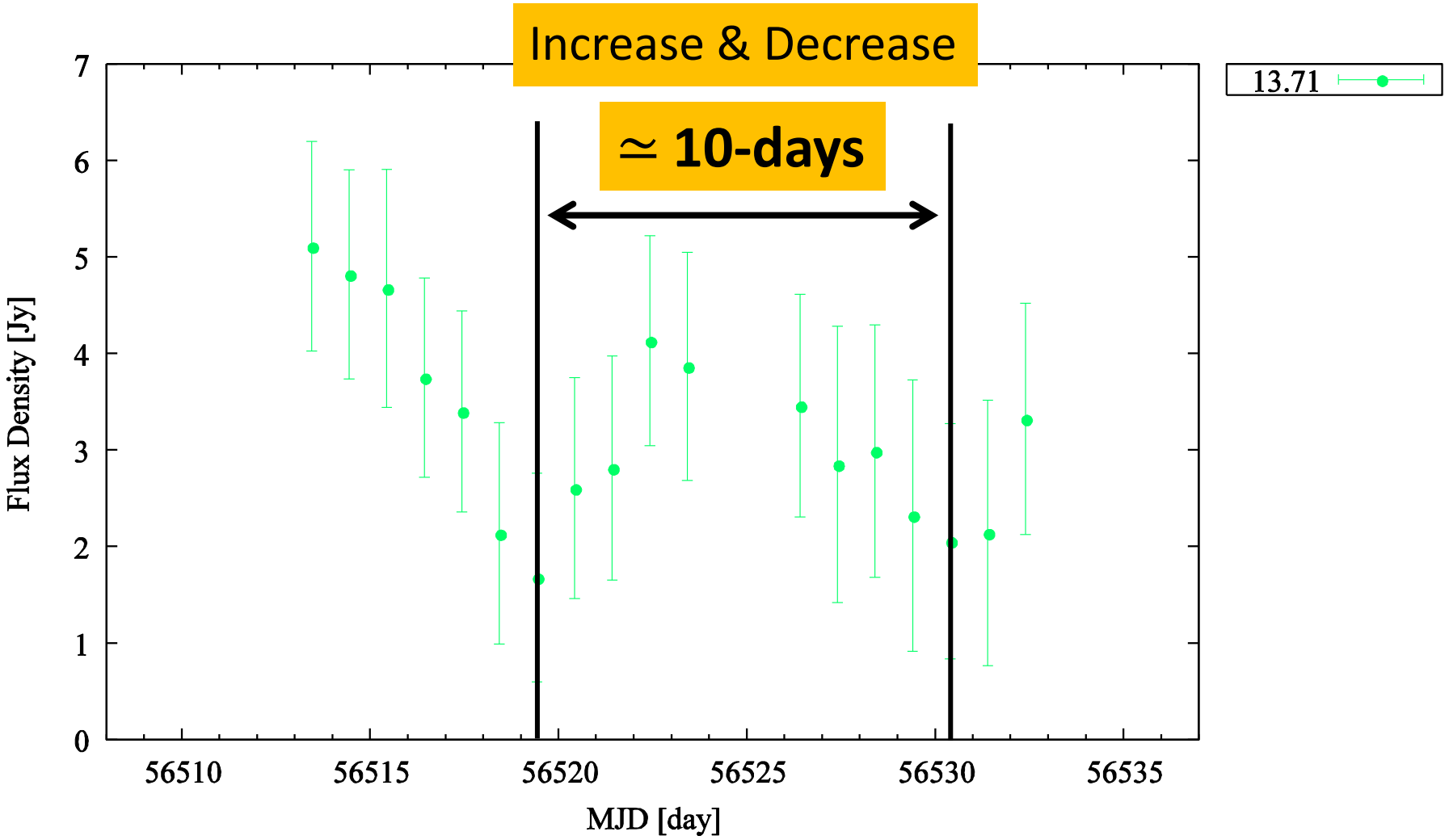


0.167-0.446

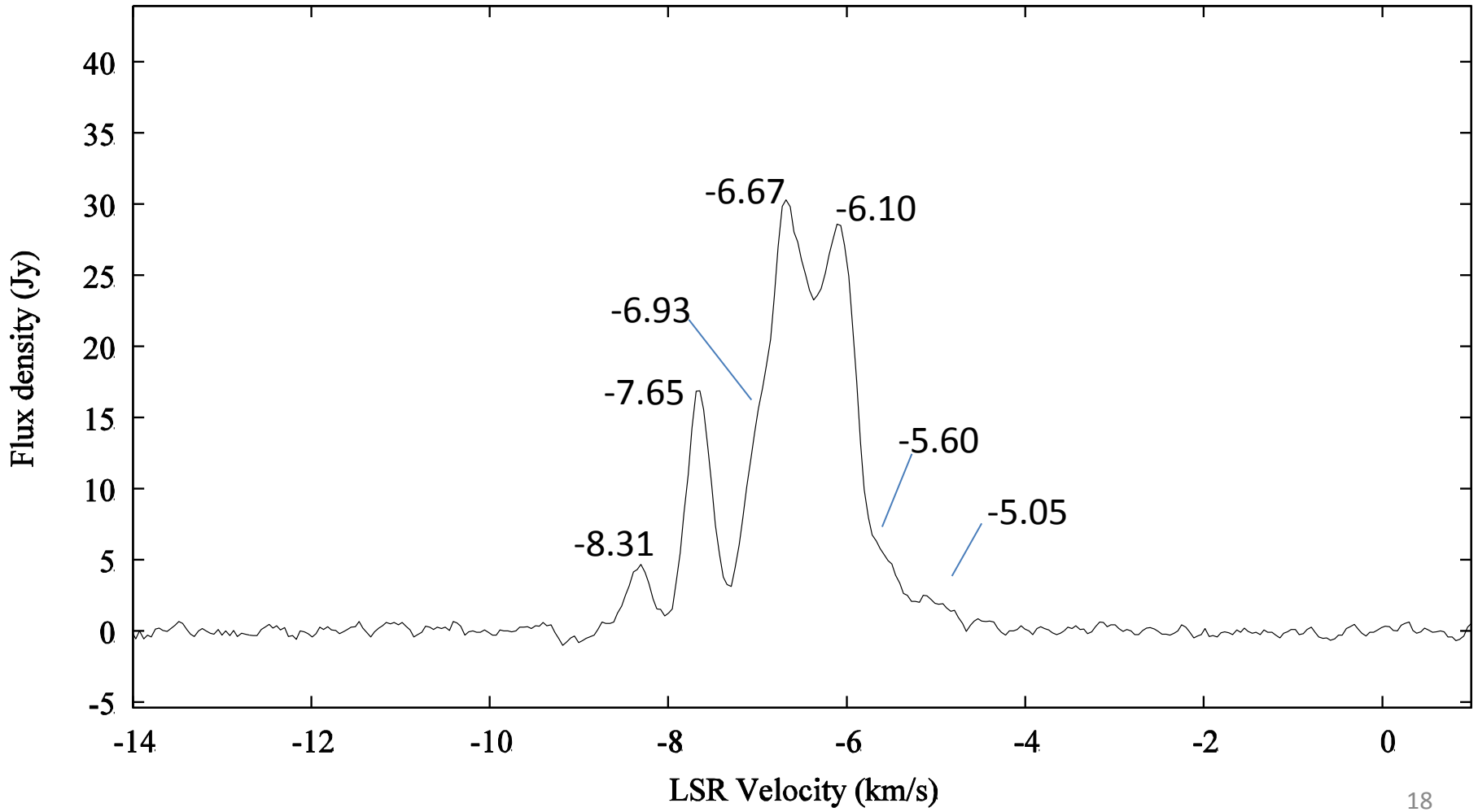

13.71
Flux Density [Jy]
MJD [day]
0
1
2
3
4
5
6
7
56510
56515
56520
56525
56530
56535

0.167-0.446


Increase & Decrease
≃ 10-days
13.71
Flux Density [Jy]
MJD [day]
0
1
2
3
4
5
6
7
56510
56515
56520
56525
56530
56535

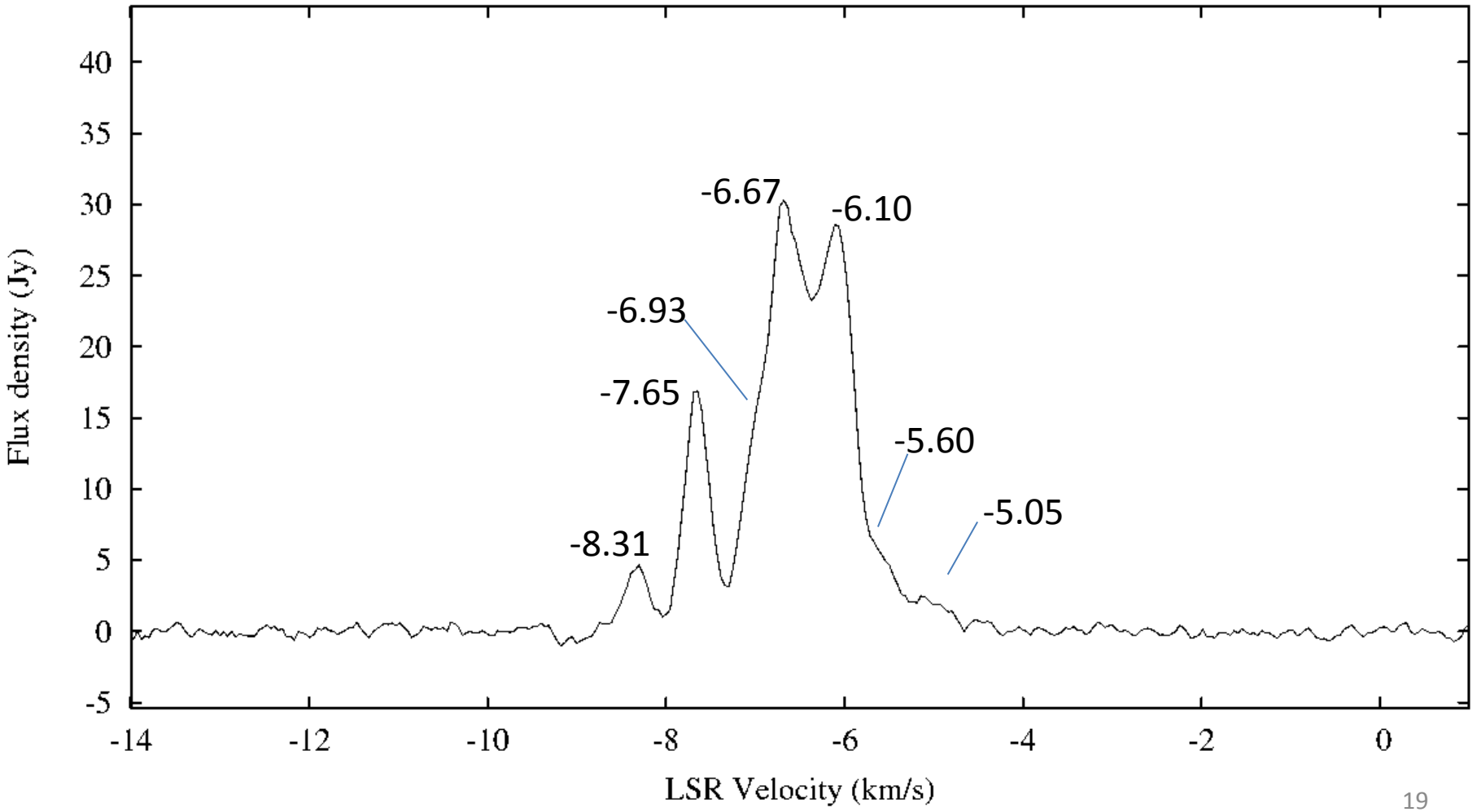
78.10+3.64

DOY= 220

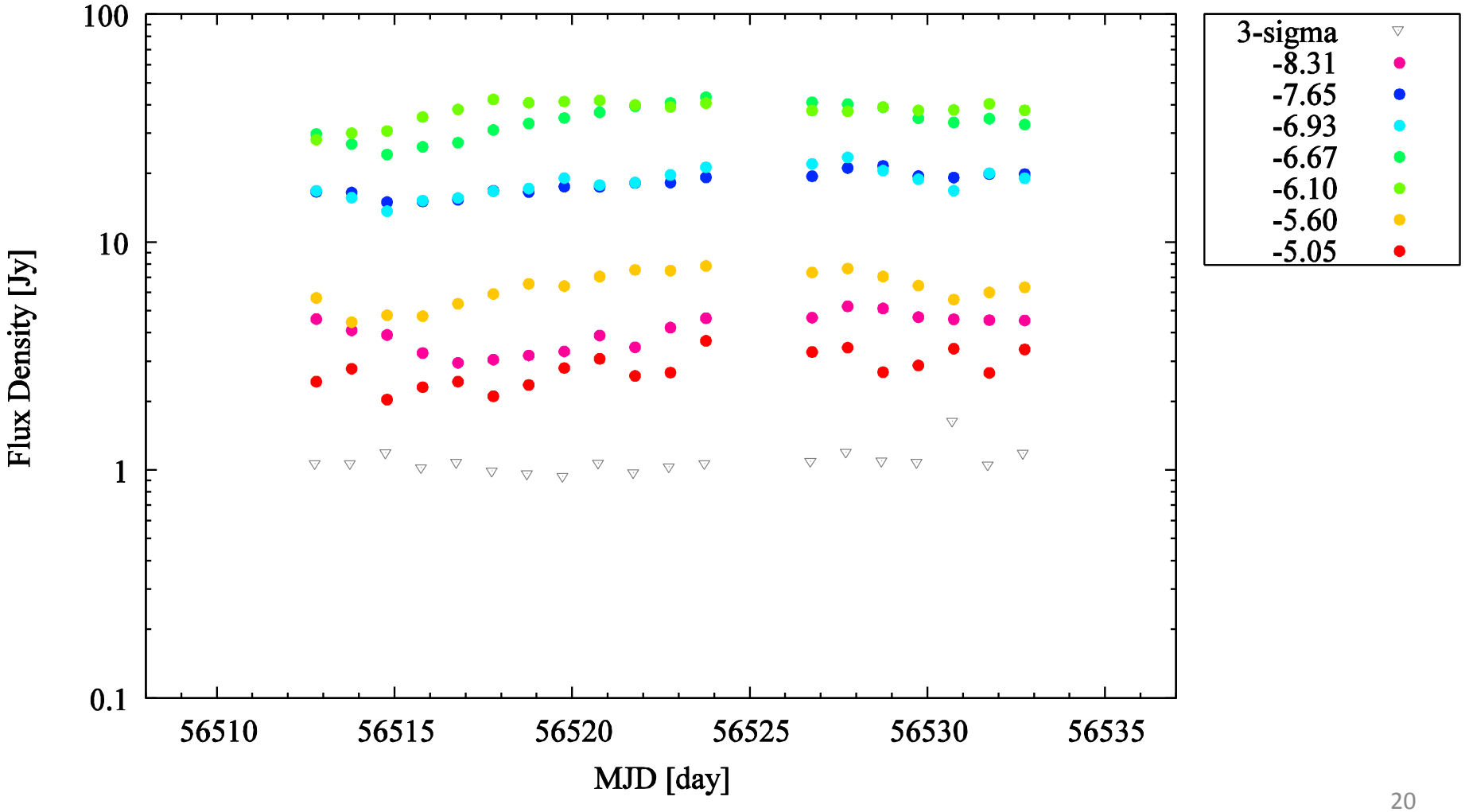


78.10+3.64

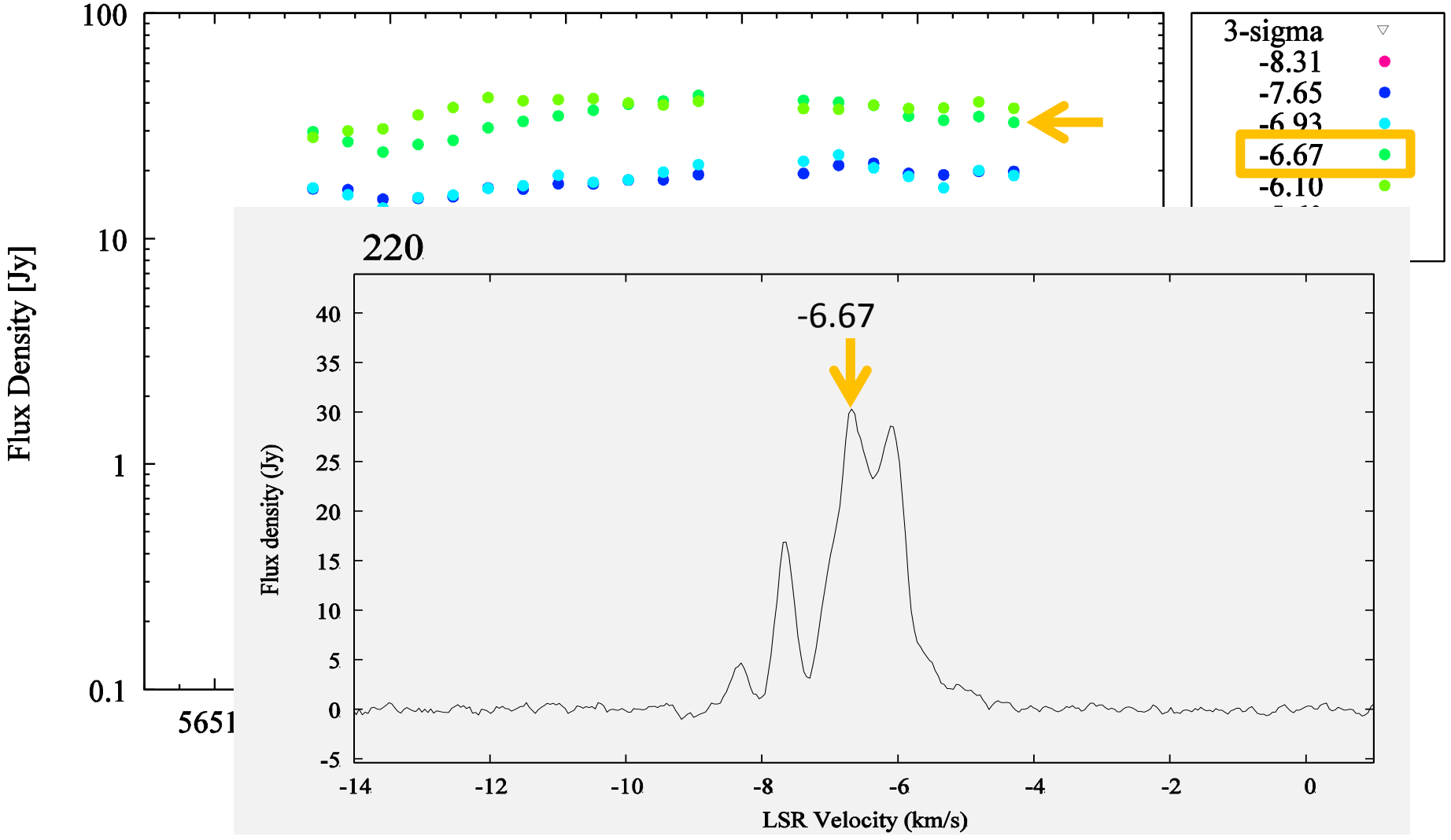
DOY= 220



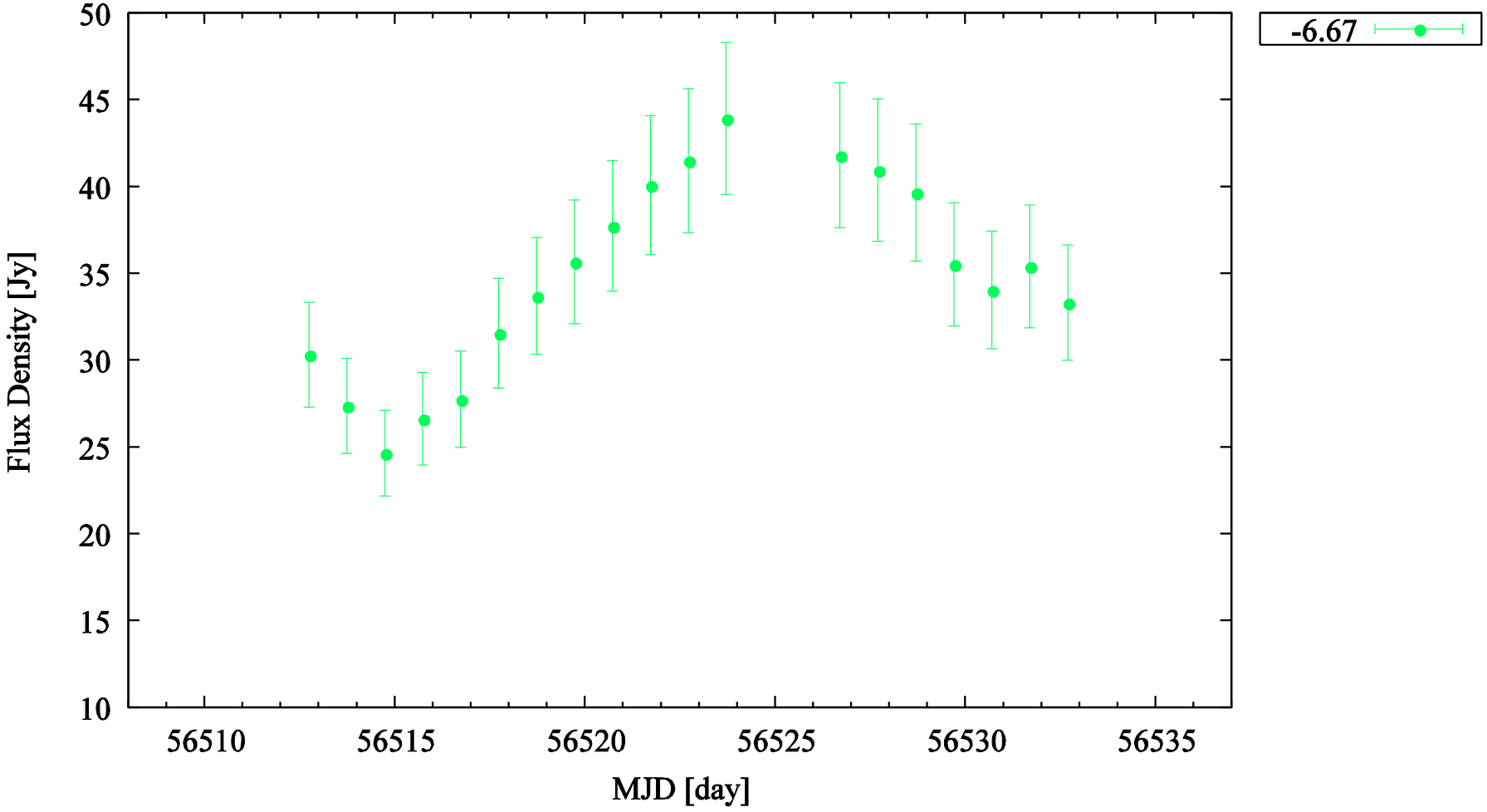
78.10+3.64


100
10
1
0.1
Flux Density [Jy]
56510
56515
56520
56525
56530
56535
MJD [day]
3-sigma
-8.31
-7.65
-6.93
-6.67
-6.10
-5.60
-5.05

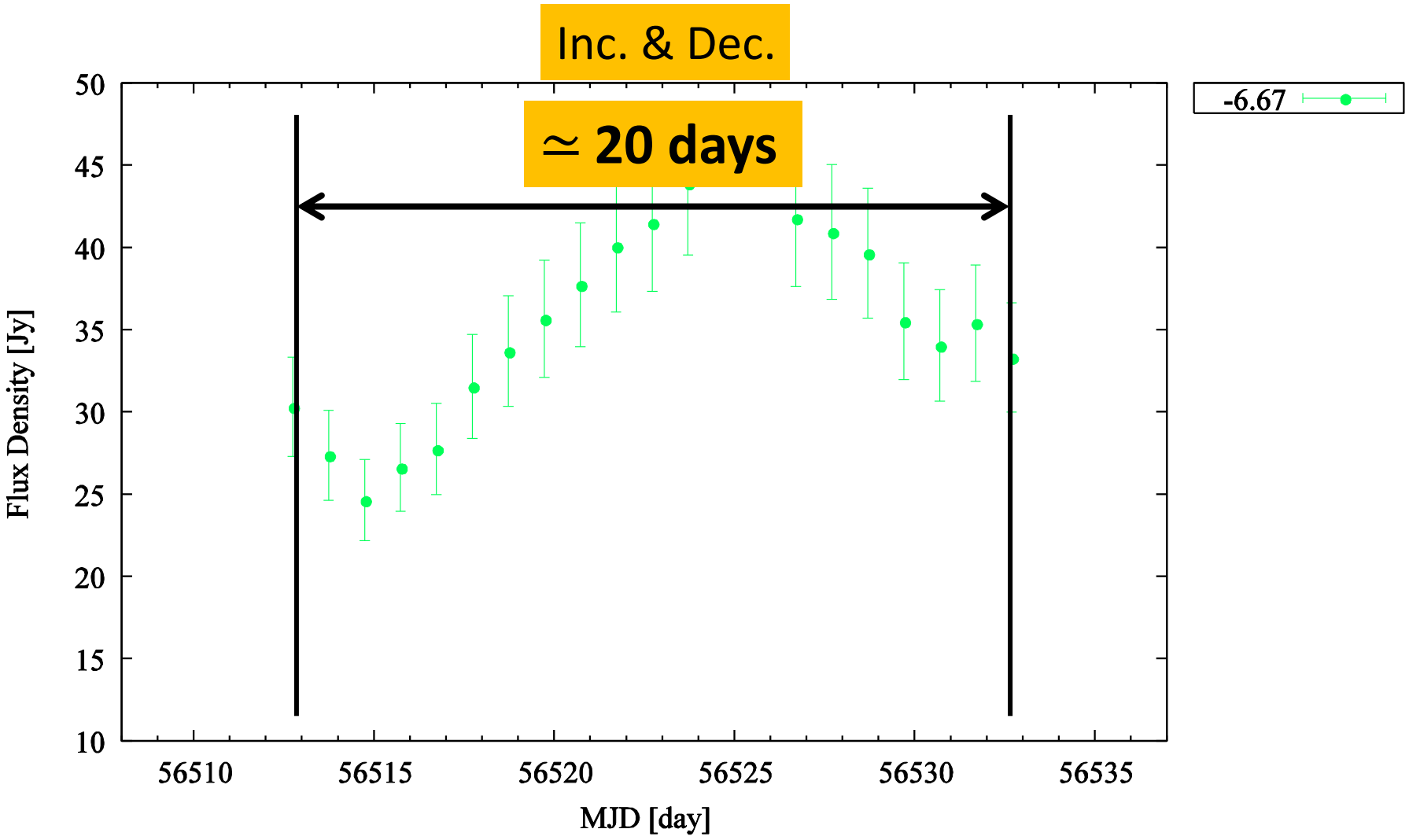
78.10+3.64

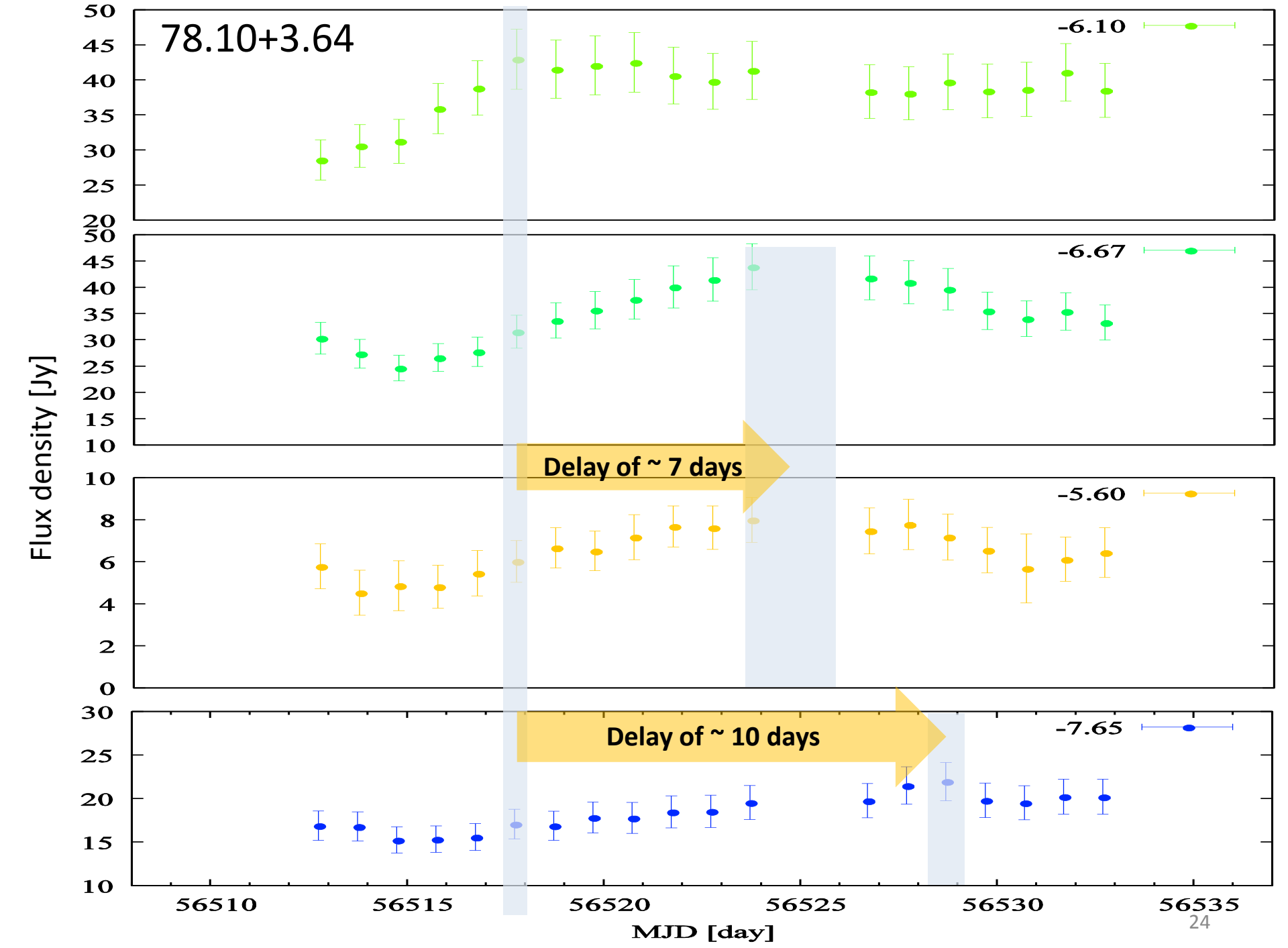

100
10
1
0.1
Flux Density [Jy]
5651
3-sigma
-8.31
-7.65
-6.93
-6.67
-6.10
220
-6.67
Flux density (Jy)
40
35
30
25
20
15
10
5
0
-5
-14
-12
-10
-8
-6
-4
-2
0
LSR Velocity (km/s)

78.10+3.64


-6.67
Flux Density [Jy]
MJD [day]
50
45
40
35
30
25
20
15
10
56510
56515
56520
56525
56530
56535

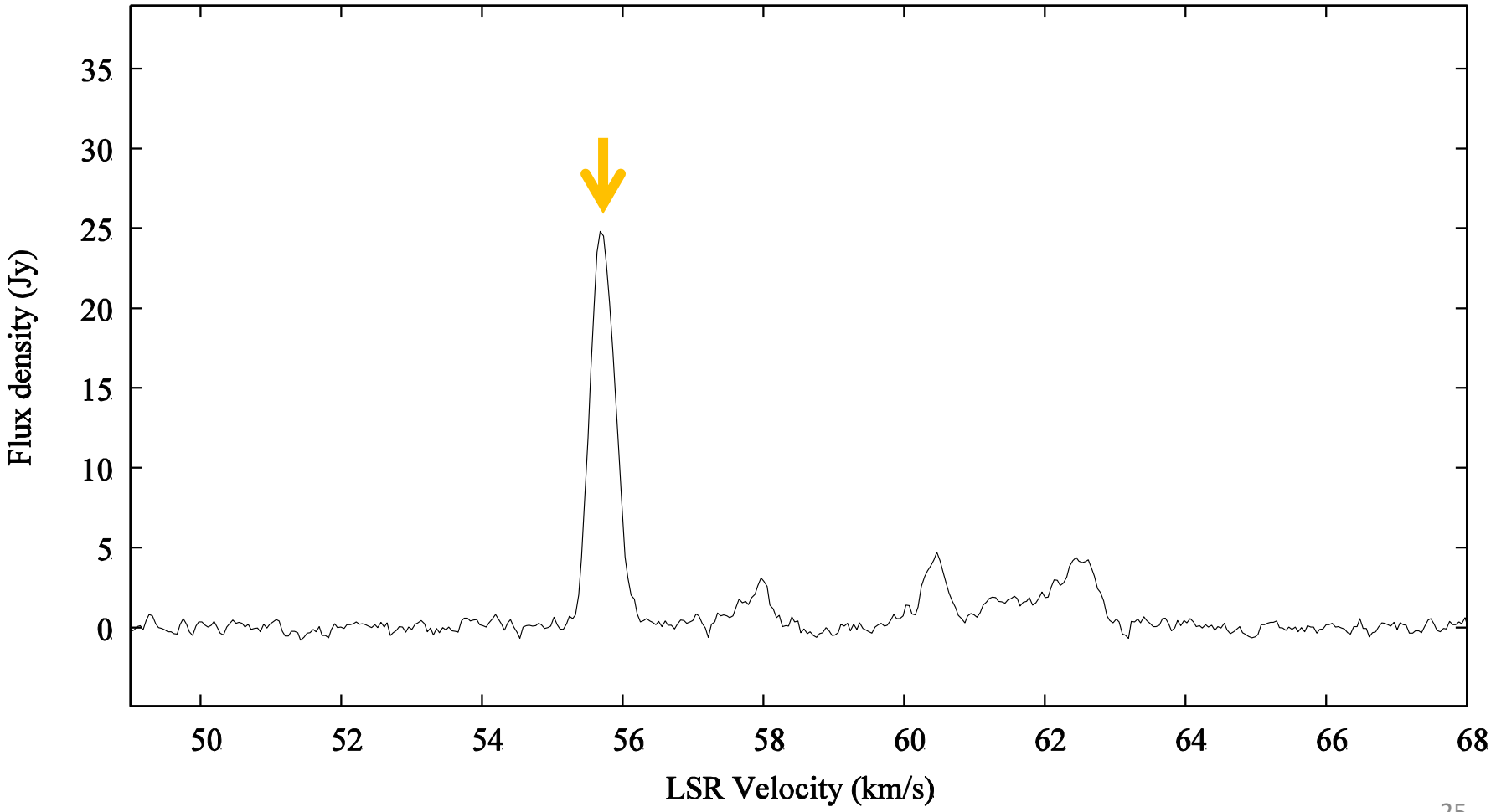
78.10+3.64


Inc. & Dec.
≃ 20 days
-6.67
Flux Density [Jy]
MJD [day]
50
45
40
35
30
25
20
15
10
56510
56515
56520
56525
56530
56535


78.10+3.64
-6.10
-6.67
-5.60
-7.65
Delay of ~ 7 days
Delay of ~ 10 days
Flux density [Jy]
MJD [day]
56510
56515
56520
56525
56530
56535

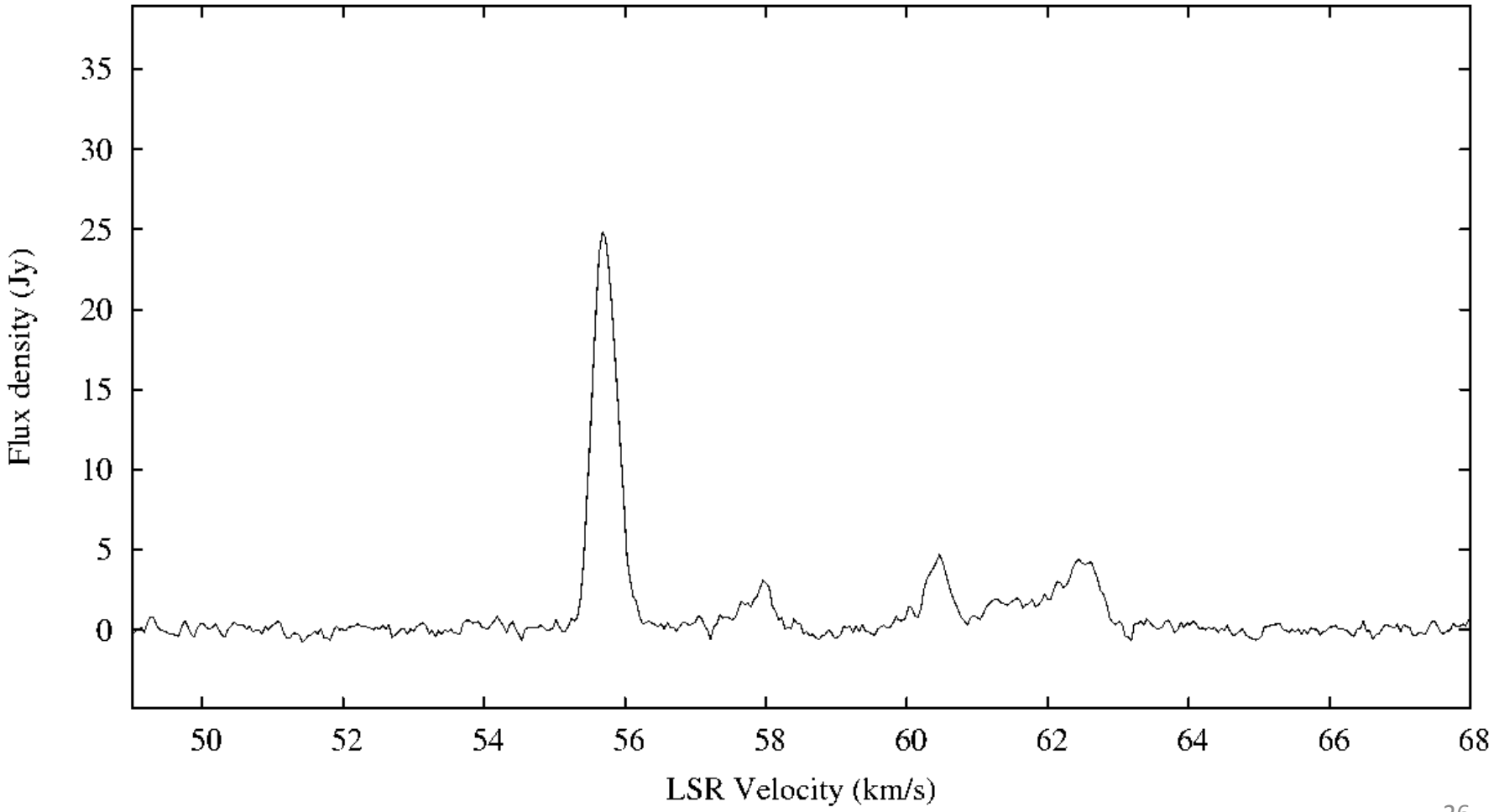
34.39+0.24

DOY= 220

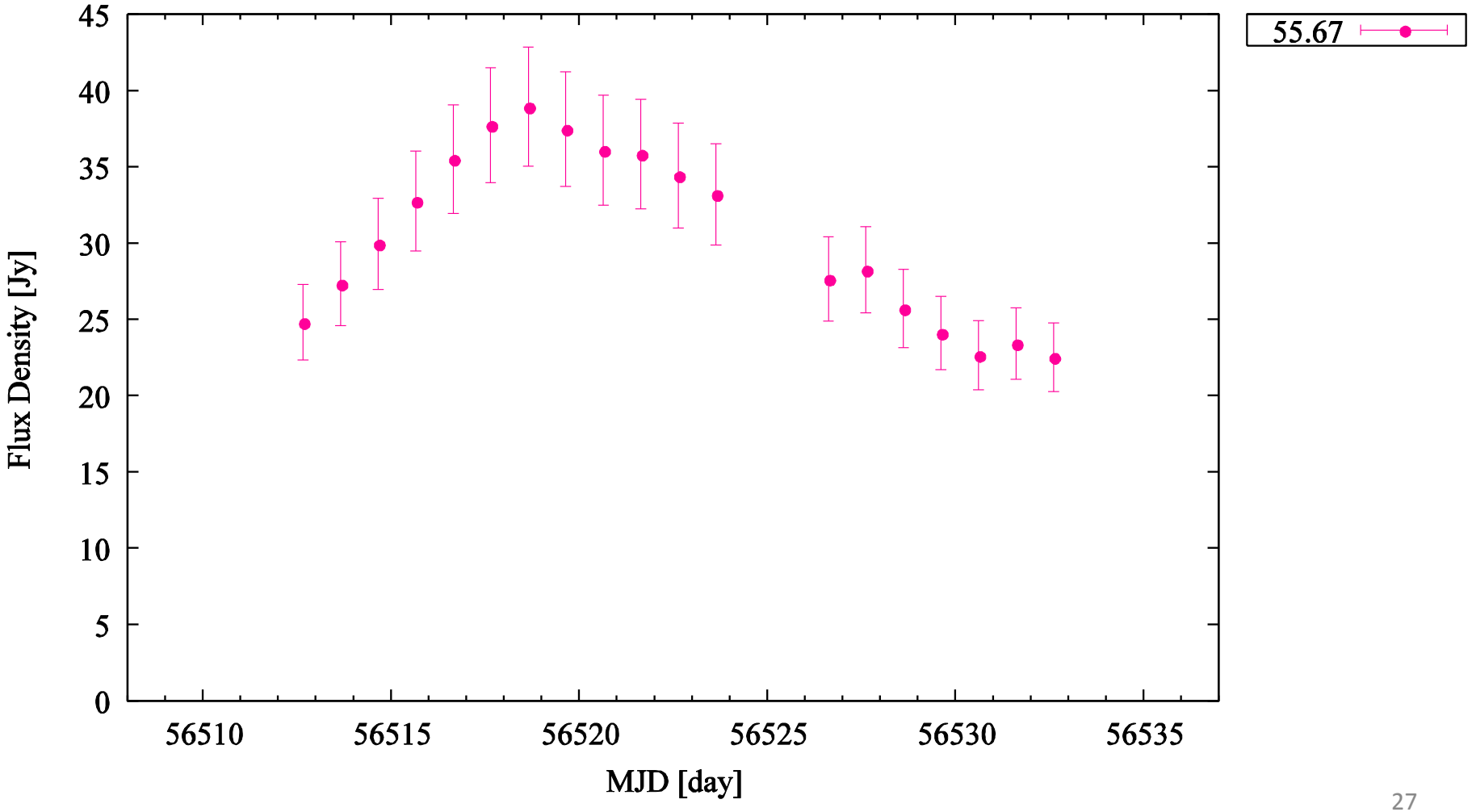


34.39+0.24

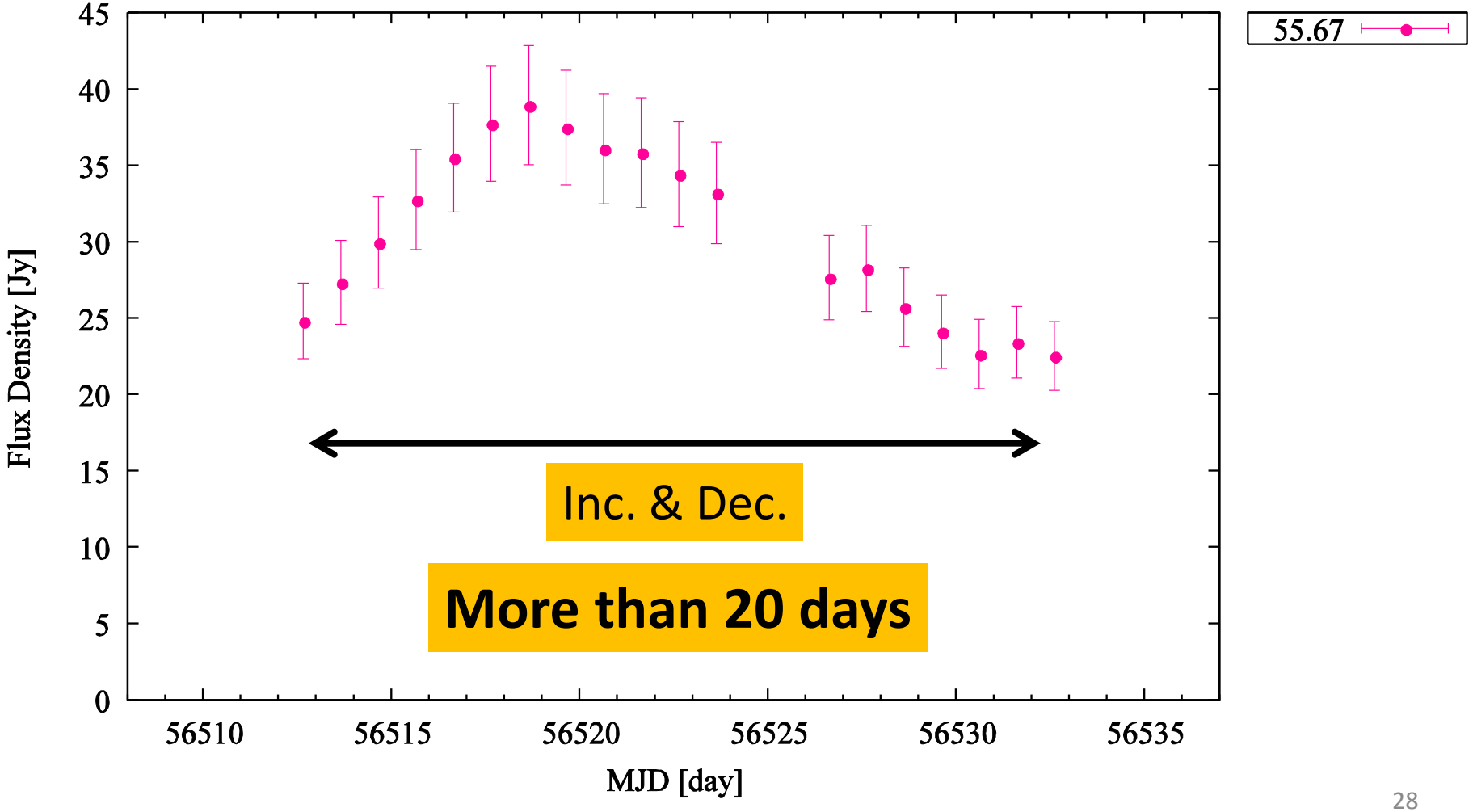
DOY= 220



34.39+0.24

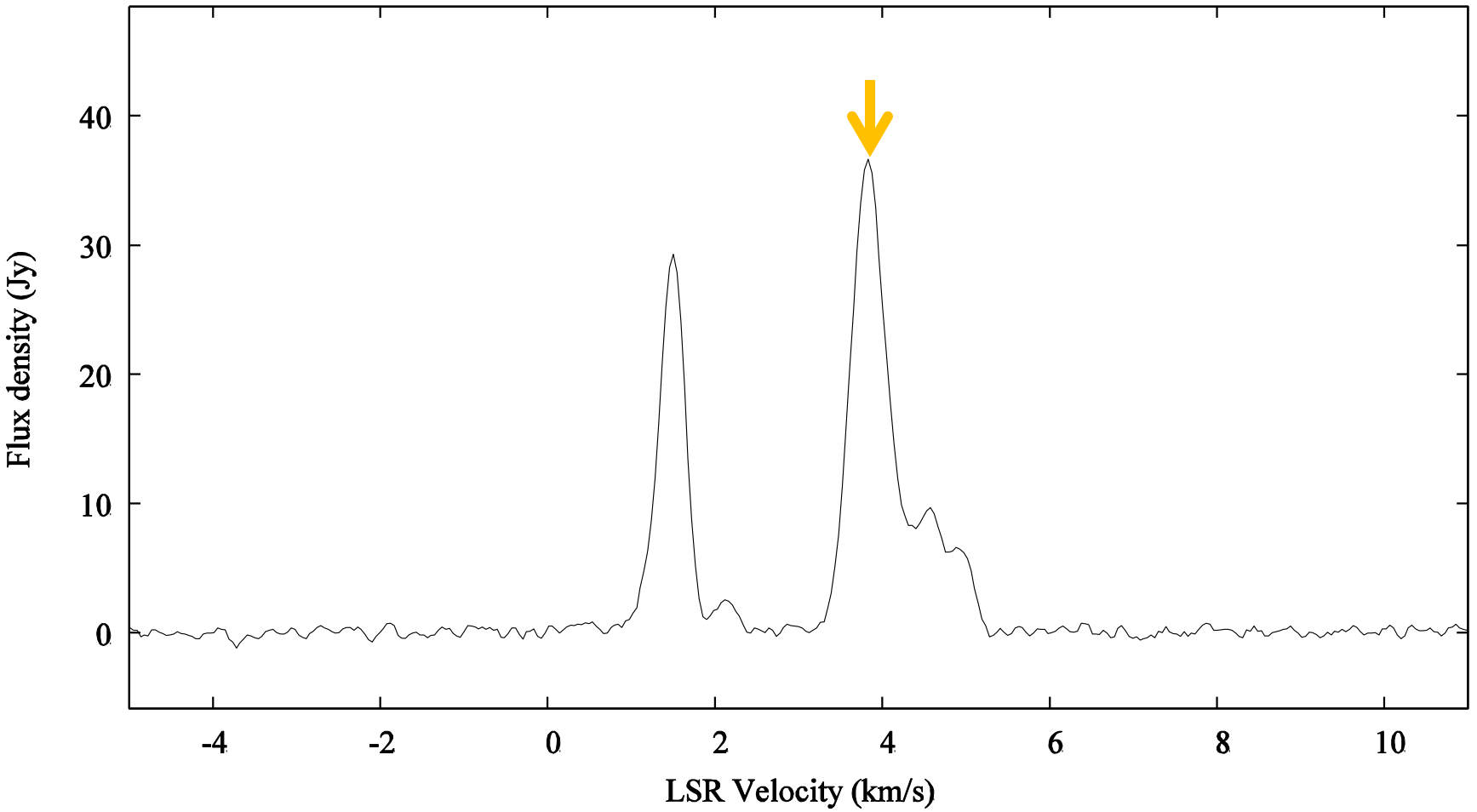

55.67
Flux Density [Jy]
MJD [day]
0
5
10
15
20
25
30
35
40
45
56510
56515
56520
56525
56530
56535

34.39+0.24


55.67
Flux Density [Jy]
MJD [day]
0
5
10
15
20
25
30
35
40
45
56510
56515
56520
56525
56530
56535
Inc. & Dec.
More than 20 days

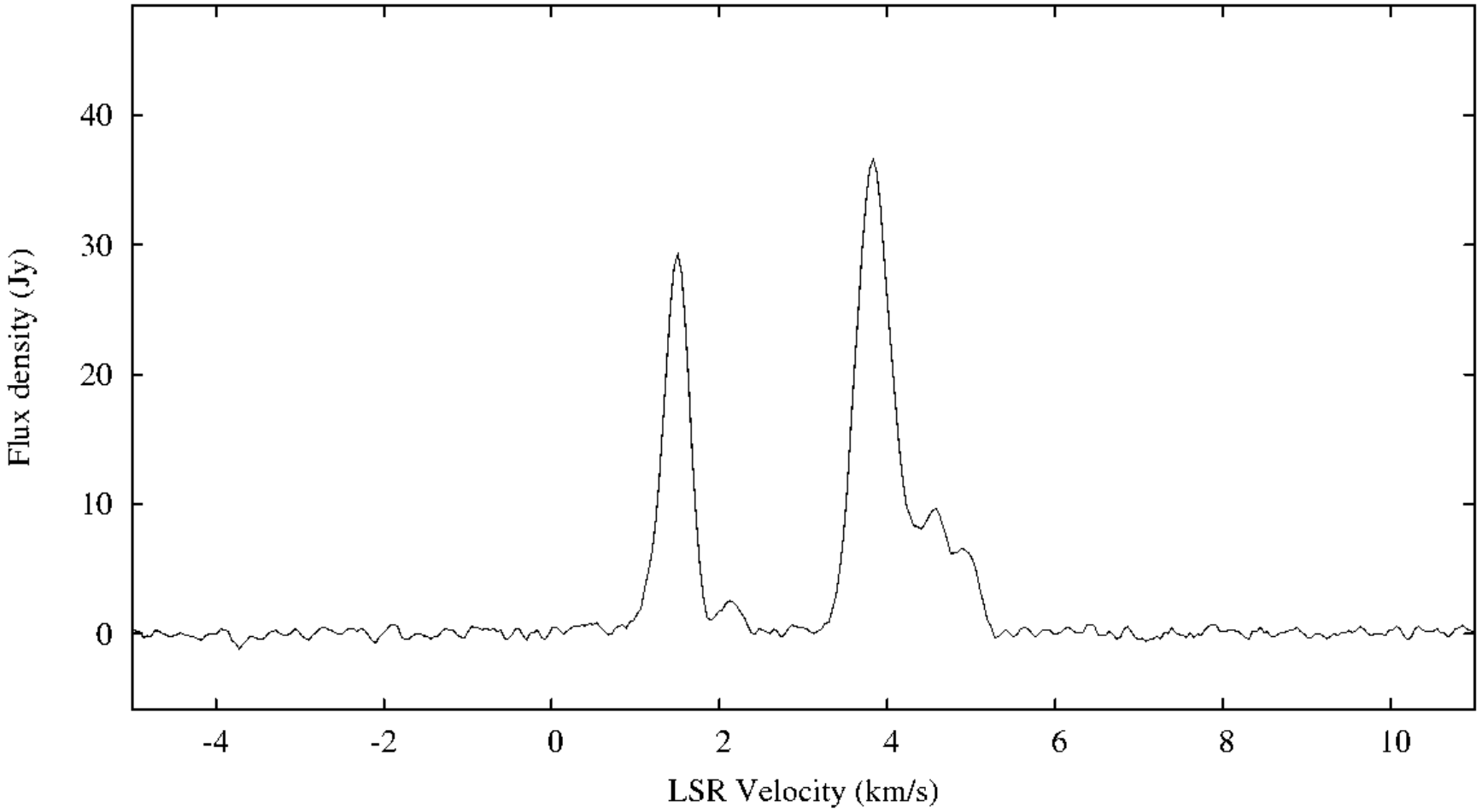
174.19-0.09

DOY= 220

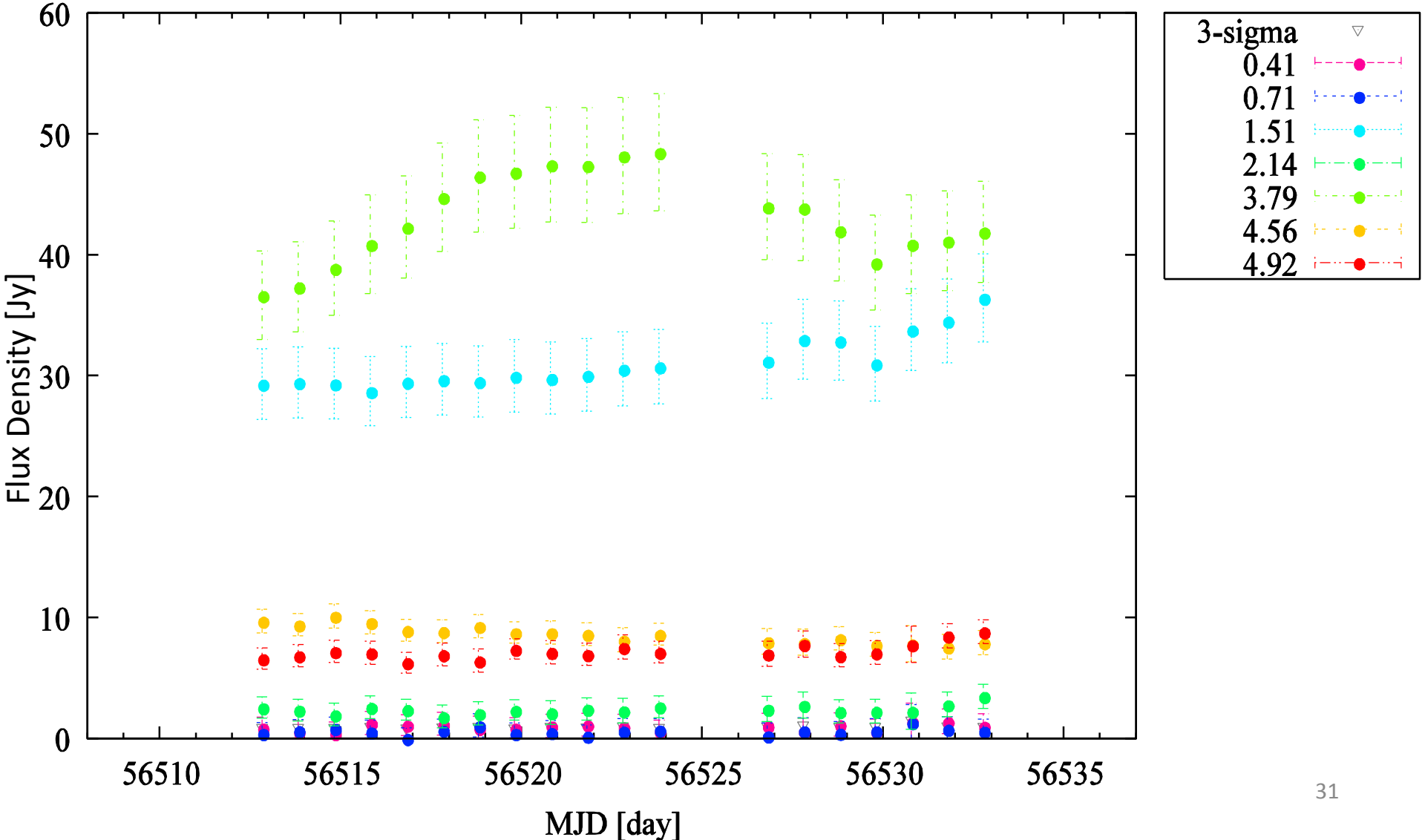


174.19-0.09

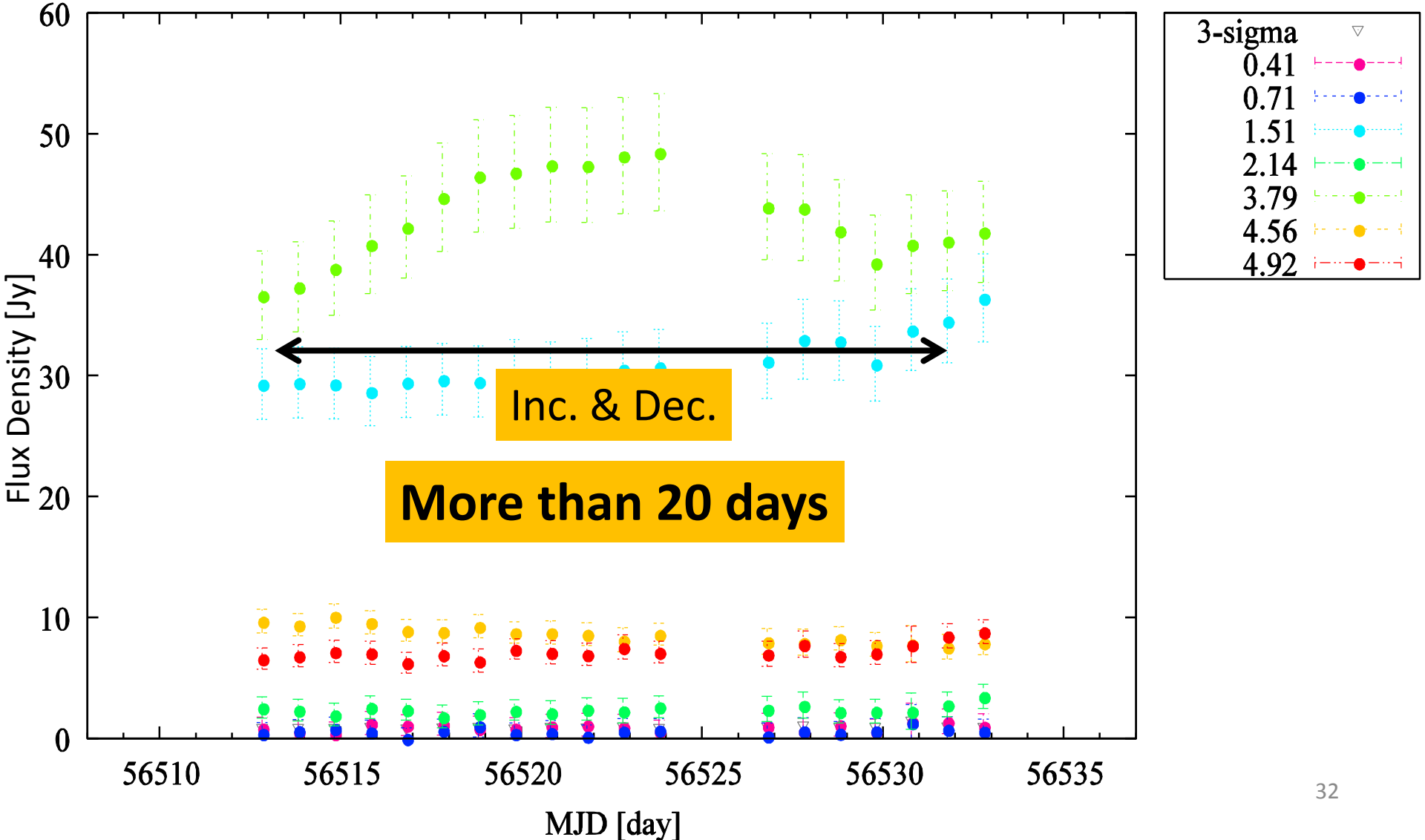
DOY= 220



174.19-0.09

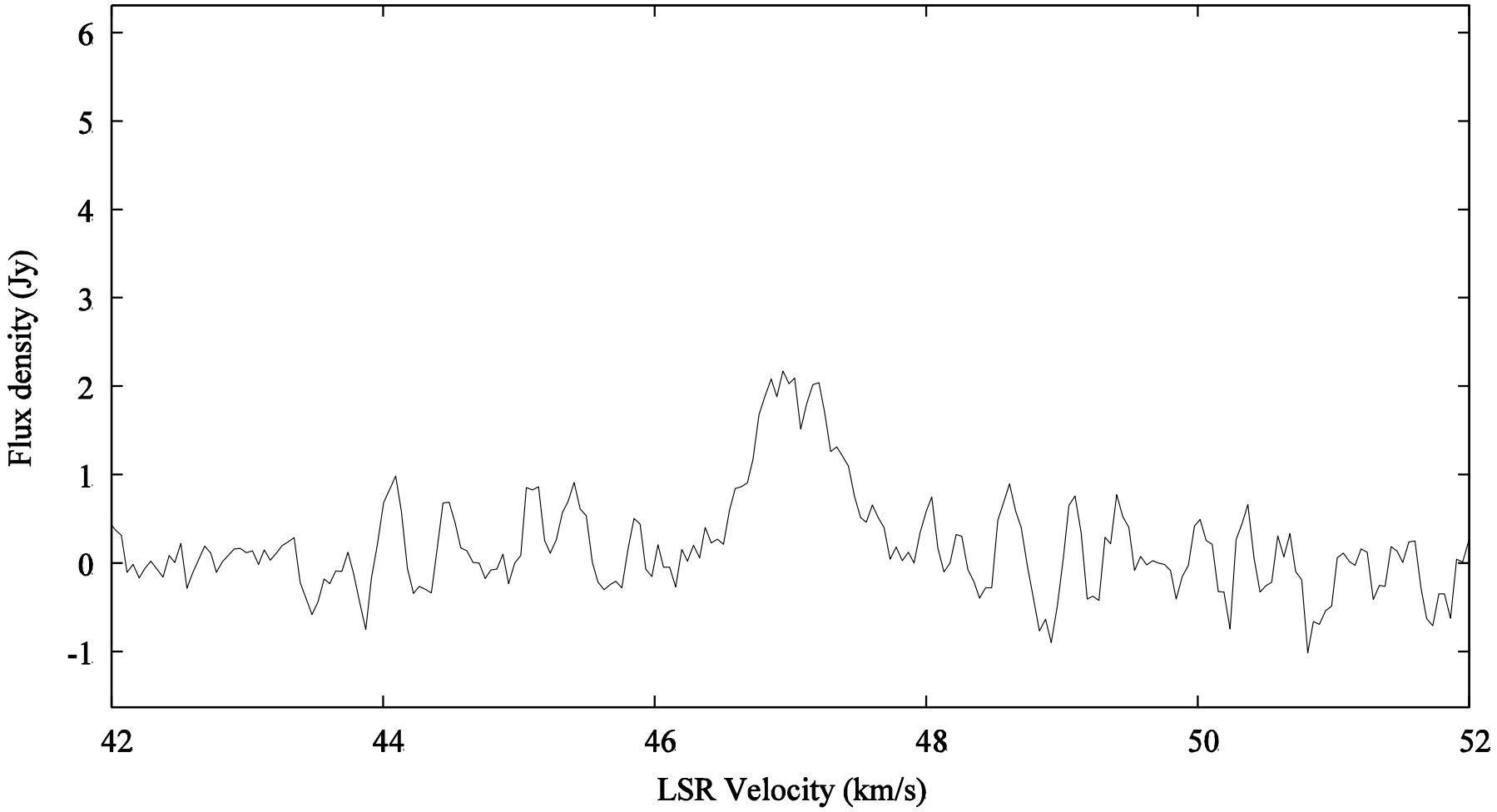

60
50
40
30
20
10
0
Flux Density [Jy]
56510
56515
56520
56525
56530
56535
MJD [day]
3-sigma
0.41
0.71
1.51
2.14
3.79
4.56
4.92

174.19-0.09


60
50
40
30
20
10
0
Flux Density [Jy]
56510
56515
56520
56525
56530
56535
MJD [day]
3-sigma
0.41
0.71
1.51
2.14
3.79
4.56
4.92
Inc. & Dec.
More than 20 days

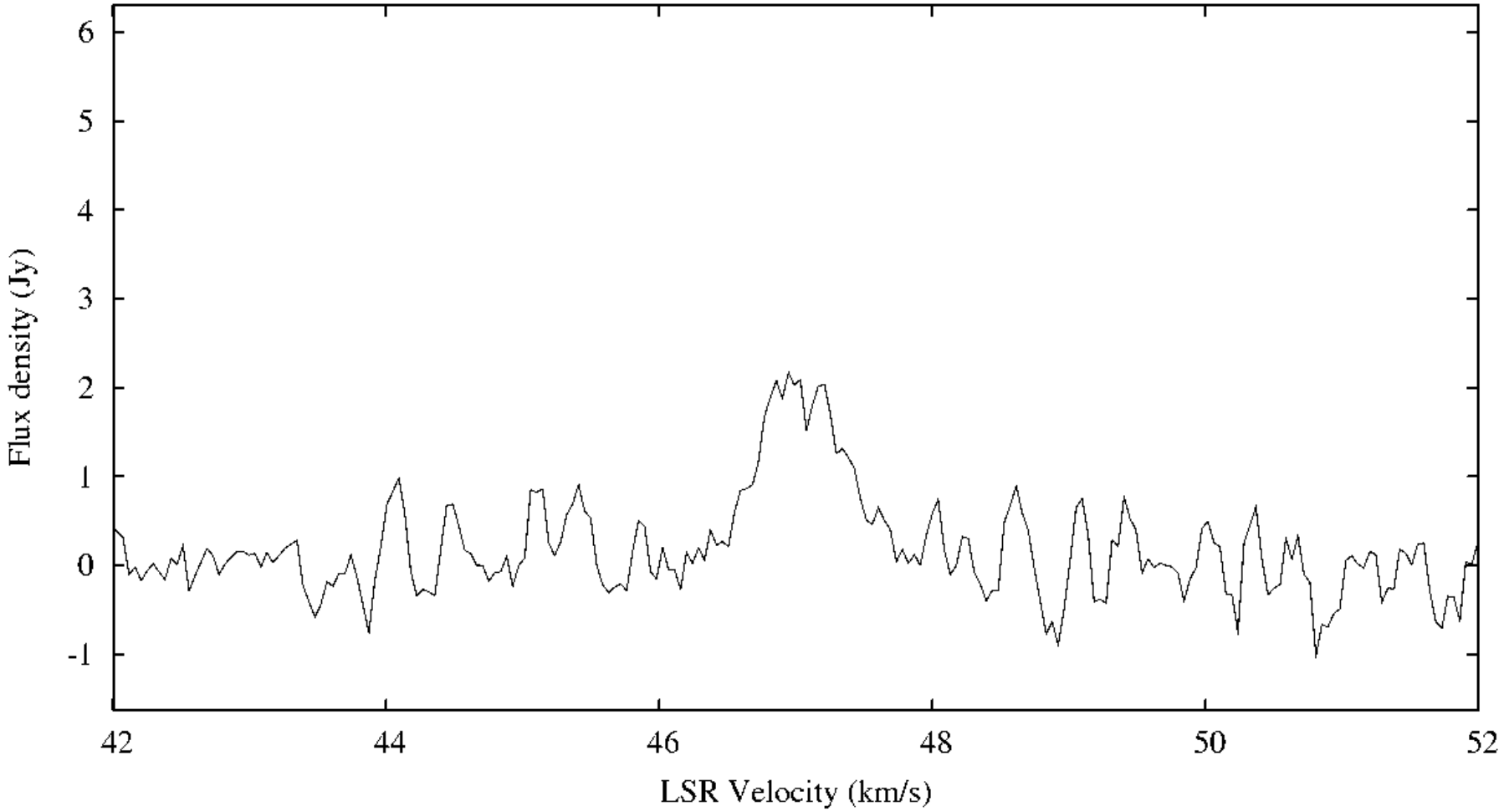
19.884-0.534

DOY= 220

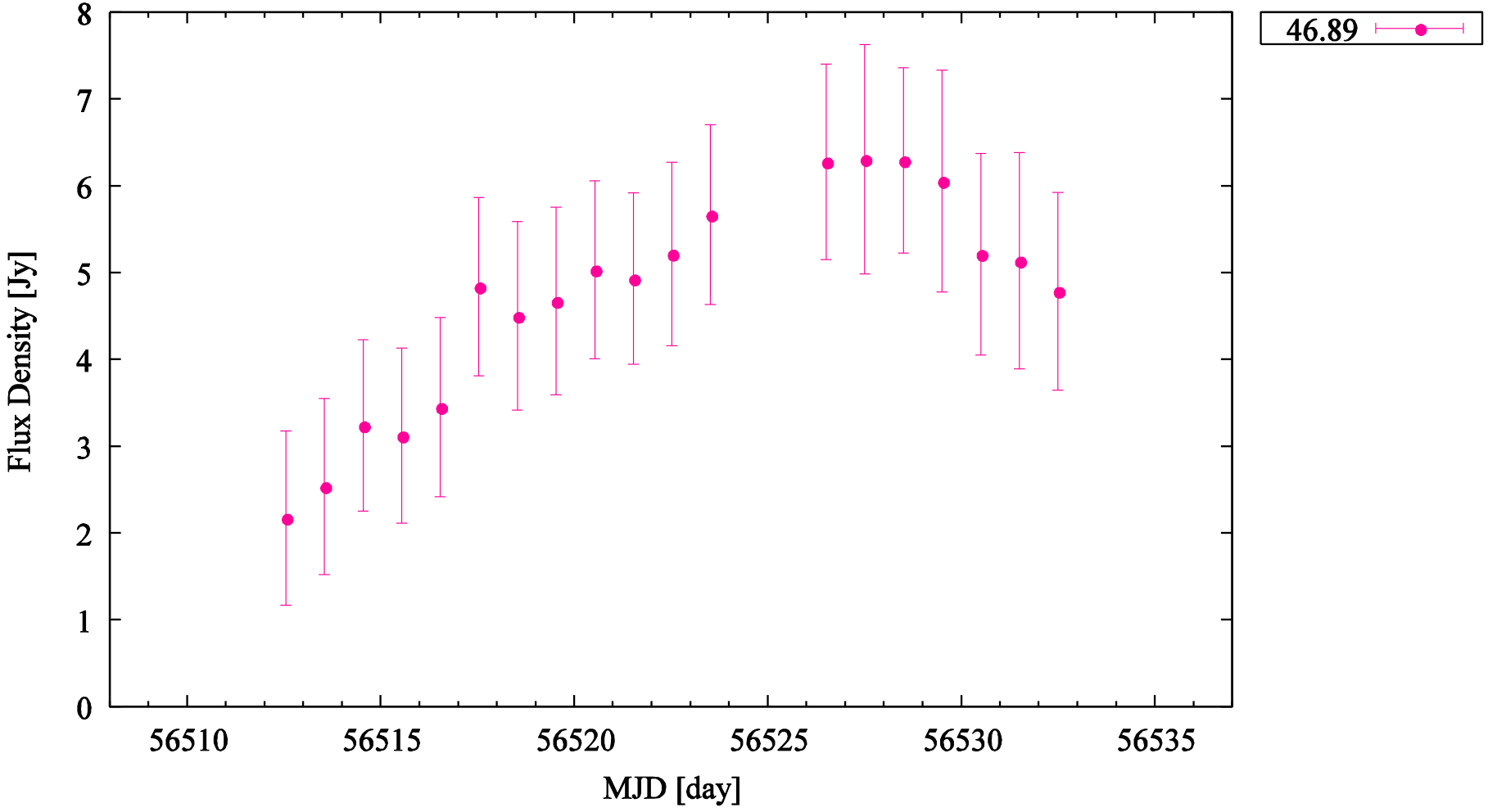


19.884-0.534

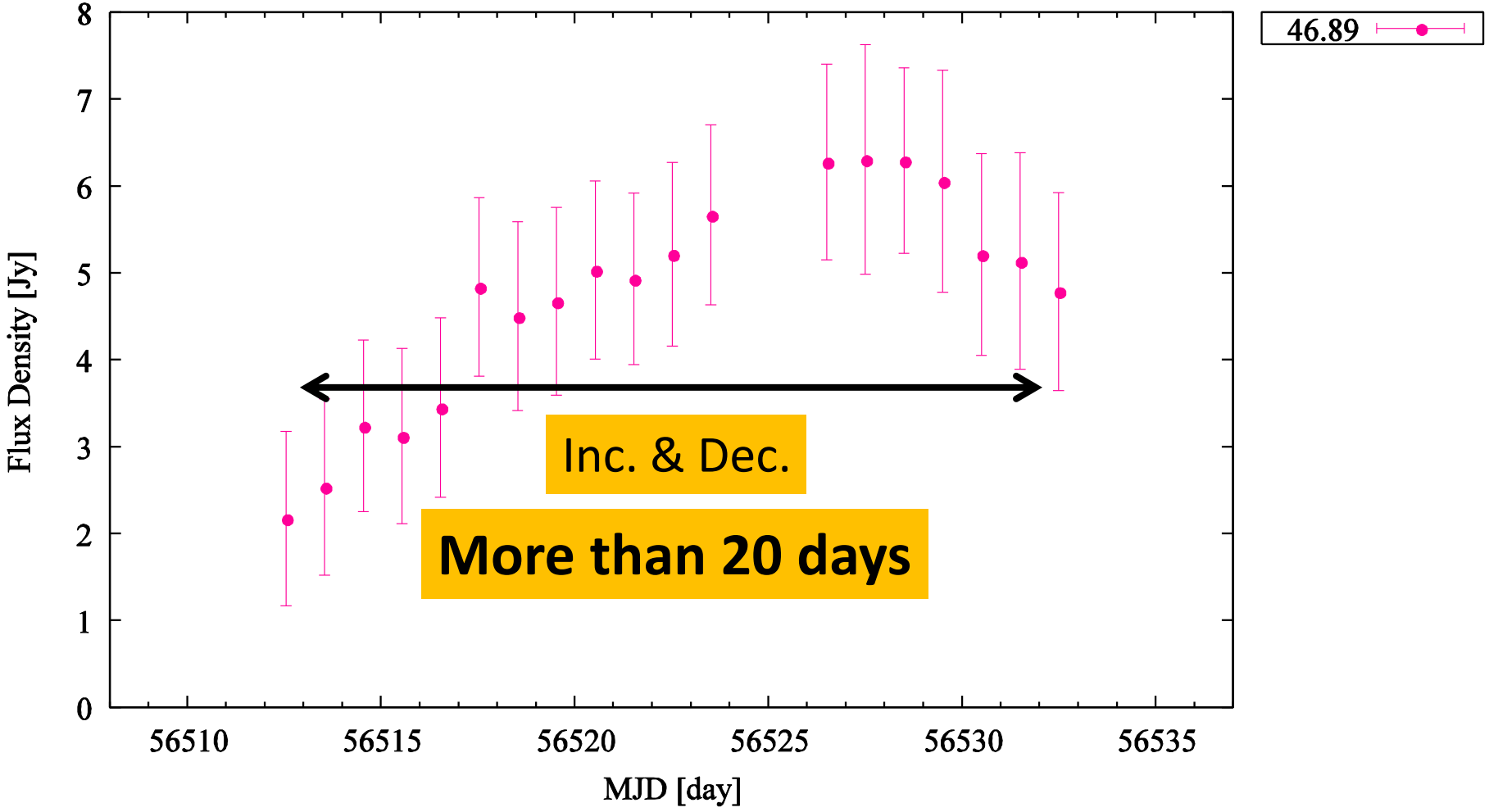
DOY= 220



19.884-0.534


46.89
Flux Density [Jy]
MJD [day]
0
1
2
3
4
5
6
7
8
56510
56515
56520
56525
56530
56535

19.884-0.534


46.89
Flux Density [Jy]
MJD [day]
0
1
2
3
4
5
6
7
8
56510
56515
56520
56525
56530
56535
Inc. & Dec.
More than 20 days

Observation summary

- Observations at the Takahagi Ant.
  - ➢ To detect short-period variable samples.
  - ➢ We observed 51 maser sources.
  - ➢ For 21 days everyday.
- Sources with Increase & decrease variation were selected as a possible variable source.
- Selected 5 sources.

Source name	Peak vel. (km/s)	Inc. & Dec. Time scale (day)
0.167-0.446	13.71	≃10
78.10+3.64	-6.67, -6.93, -5.60	≃20
34.39+0.24	55.67	≳20
174.19-0.09	3.79	≳20
19.884-0.534	46.89	≳20

Future works

1. Additional monitoring observations
   - Daily monitoring more than 2 months.
   - From Dec. 2014 onward at the Takahagi Ant.

Selected Source name	Inc. & Dec. Time scale (day)	Hoped period (day)
0.167-0.446	$\simeq$10	$\simeq$10
78.10+3.64	$\simeq$20	$\simeq$20
34.39+0.24	$\gtrsim$20	$\simeq$20
174.19-0.09	$\gtrsim$20	$\simeq$20
19.884-0.534	$\gtrsim$20	$\simeq$ 36

Future works

2. Estimation of periodic variability
   - Variable Index

$$VI = \sqrt{\frac{\sum_{i=1}^{N}(m_i - \bar{m})^2 - \sum_{i=1}^{N}(n_i - \bar{n})^2}{N-1}} / \bar{m}$$

N : total number of observations

m_i : observed flux density at each i epoch

n_i : 1-sigma at each i epoch

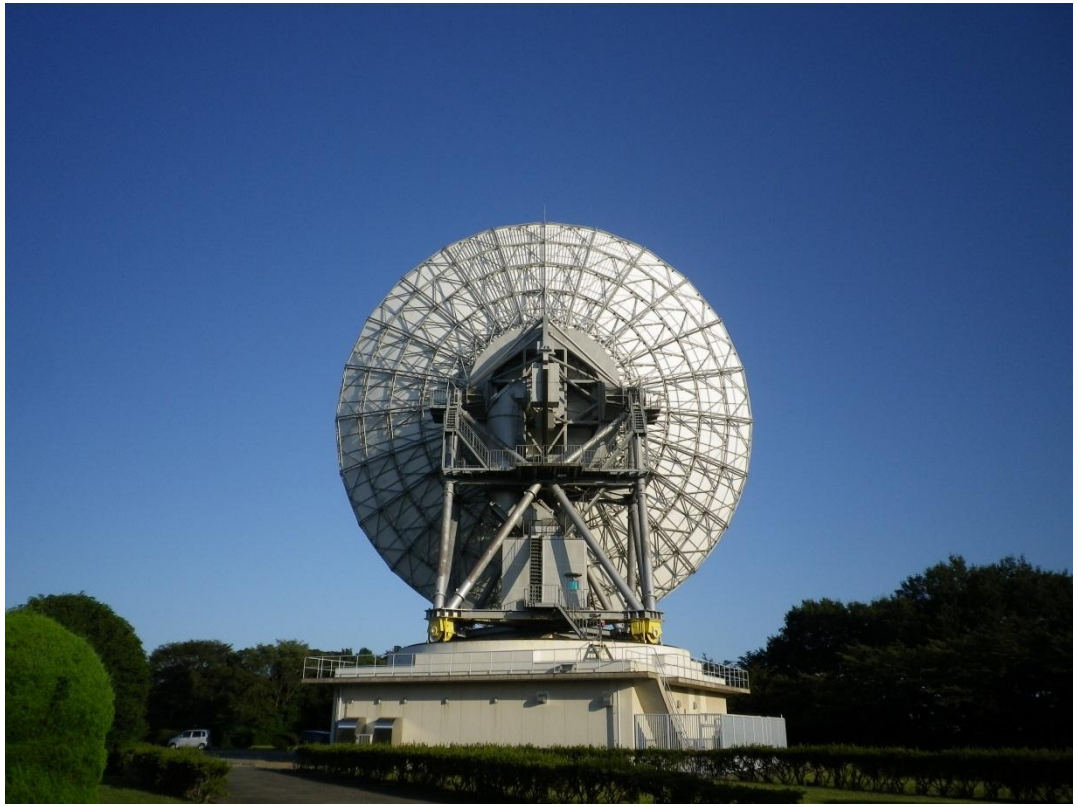
$\bar{m}, \bar{n}$: average flux density

Estimation by Variable Index

Source name	Peak Vel. (km/s)	VI	Smax/N
0.167-0.446	13.71	0.314	14.1
78.10+3.64	-6.67	0.164	123.4
	-6.93	0.139	59.8
	-5.60	0.165	10.5
34.39+0.24	55.67	0.187	104.8
174.19-0.09	3.79	0.086	161.1
19.884-0.534	46.89	0.268	14.3
		$\gtrsim 0.1$	> 10

- Variability = VI ≥ 0.1 and Smax/N ≥ 10 ?
- How do we distinguish possibility of periodicity (increase and decrease variation) ?

Thank you very much.



Summary

- Observations at the Takahagi Ant.
  - ➢ We observed 51 maser sources
  - ➢ For 21 days everyday
  - ➢ To detect short-period variable samples.
- Sources with Increase & decrease variation were selected as a possible variable source.
- Selected 5 sources.

Source name	Peak vel. (km/s)	Inc. & Dec. Time scale (day)
0.167-0.446	13.71	≃10
78.10+3.64	-6.67, -6.93, -5.60	≃20
34.39+0.24	55.67	≳20
174.19-0.09	3.79	≳20
19.884-0.534	46.89	≳20