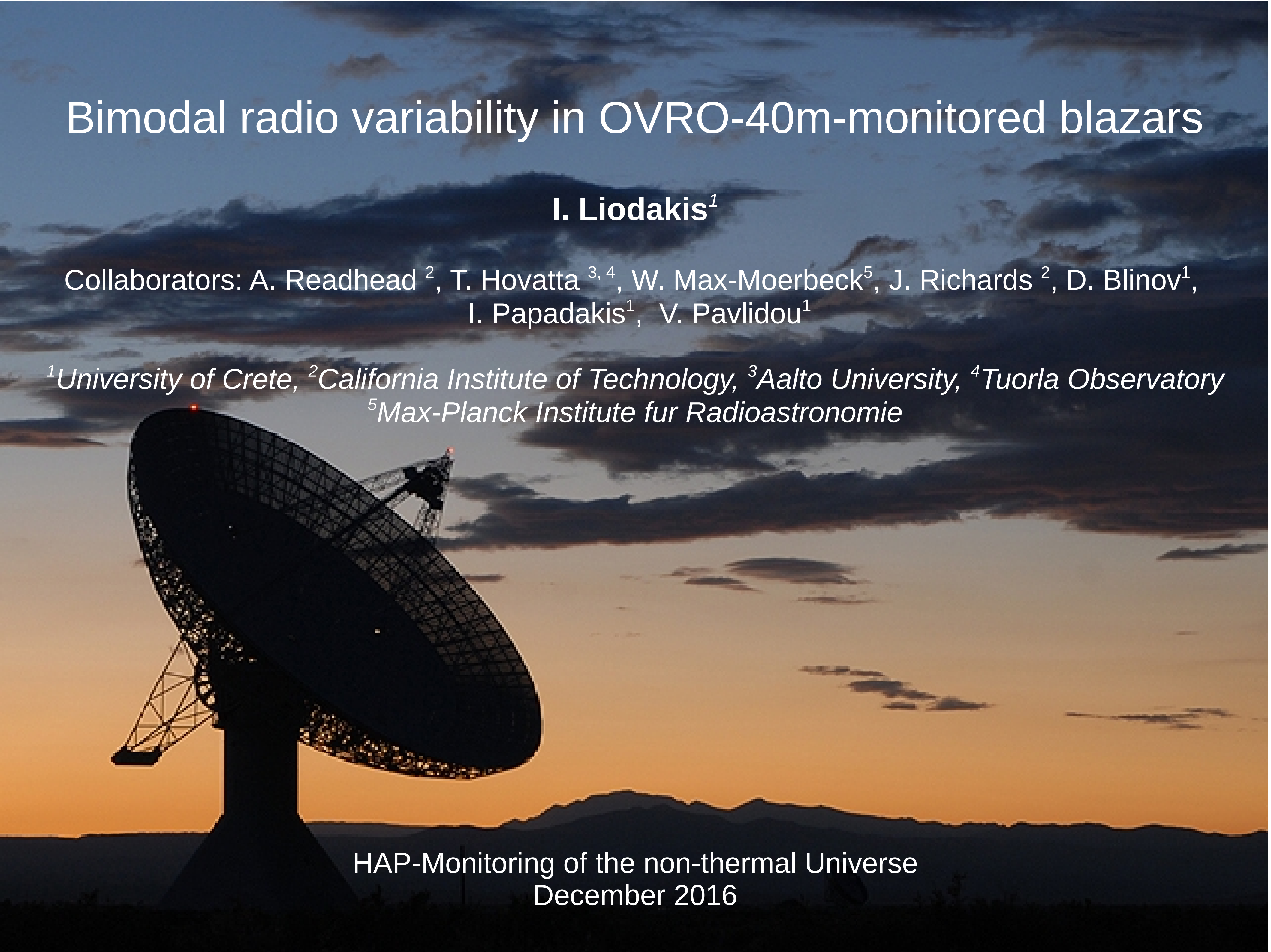

Bimodal radio variability in OVRO-40m-monitored blazars

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HAP-Monitoring of the non-thermal Universe
December 2016

OVRO monitored blazars...

– Monitoring blazars **since 2008** in support of Fermi gamma-ray space telescope:

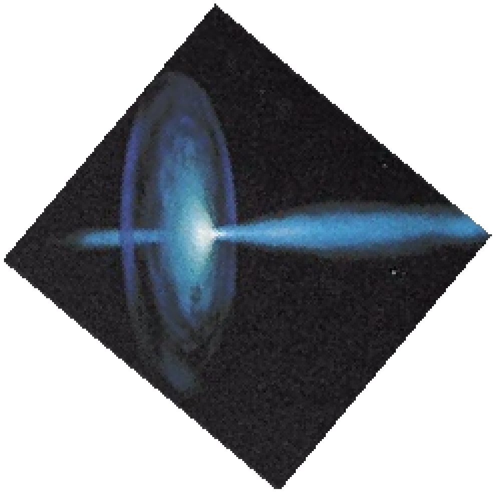
– At **15 GHz**

– 1158 sources from the Candidate Gamma-Ray Blazar Survey (CGRaBS, a complete sample)

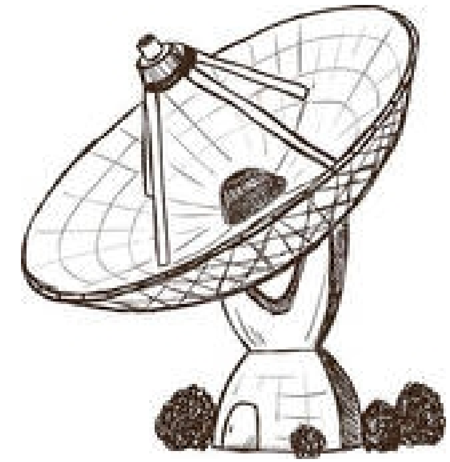
– additional gamma-ray loud sources resulting in sample of **>1800** sources

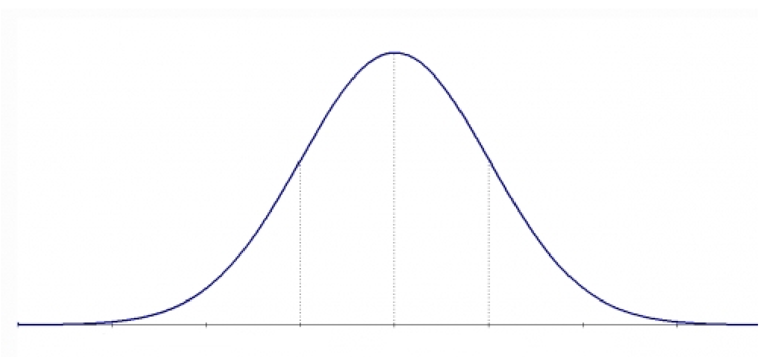
– cadence of **twice per week**

First maximum likelihood approach...

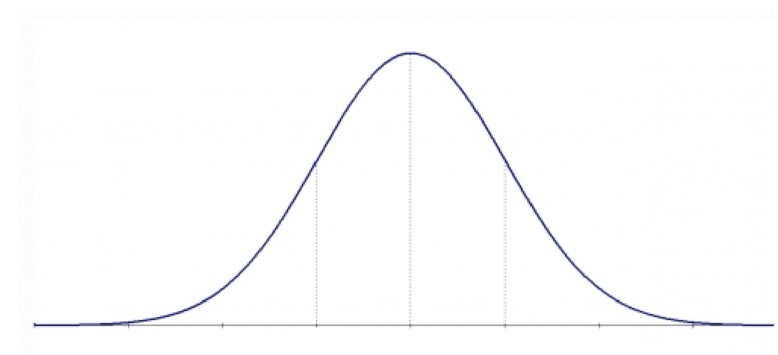


$$S_{true}$$





$$P(S_{true}|S_o,\sigma_o)$$

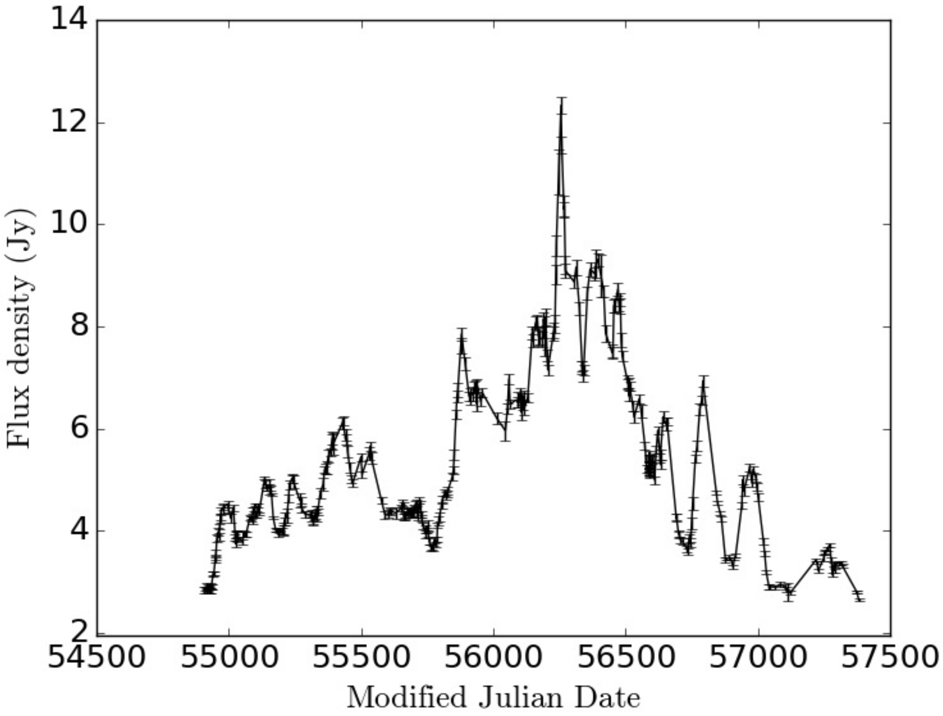


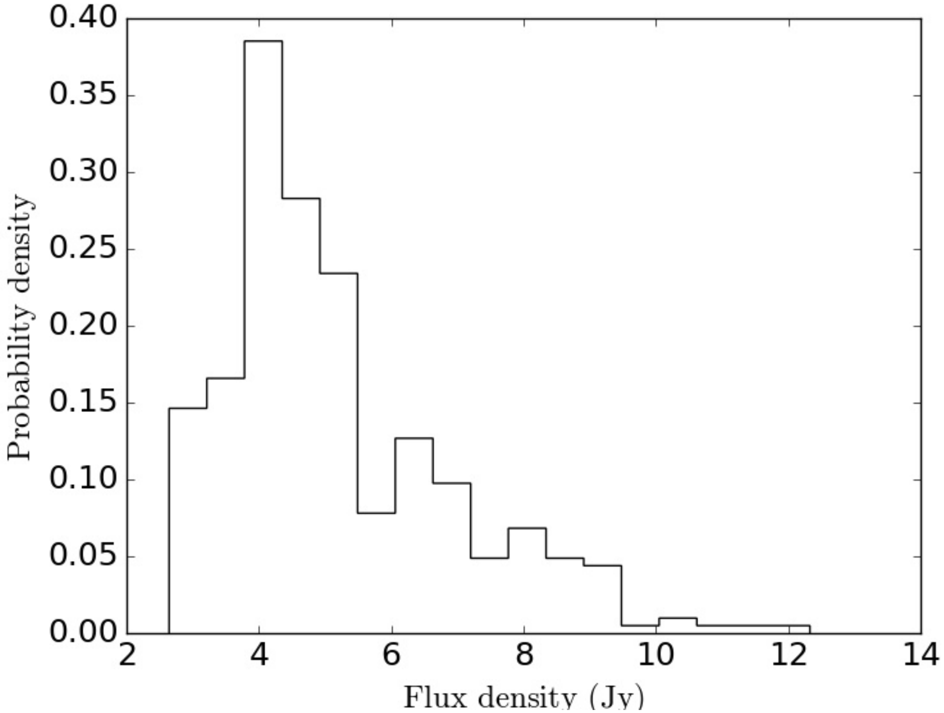
$$P(S_{obs},\sigma_{obs}|S_{true})$$

$$l_{obs}=\frac{1}{\sqrt{2\pi(\sigma_{obs}^2+\sigma_o^2)}}\ \exp\left[\frac{-(S_{obs}-S_o)^2}{2(\sigma_{obs}^2+\sigma_o^2)}\right]$$

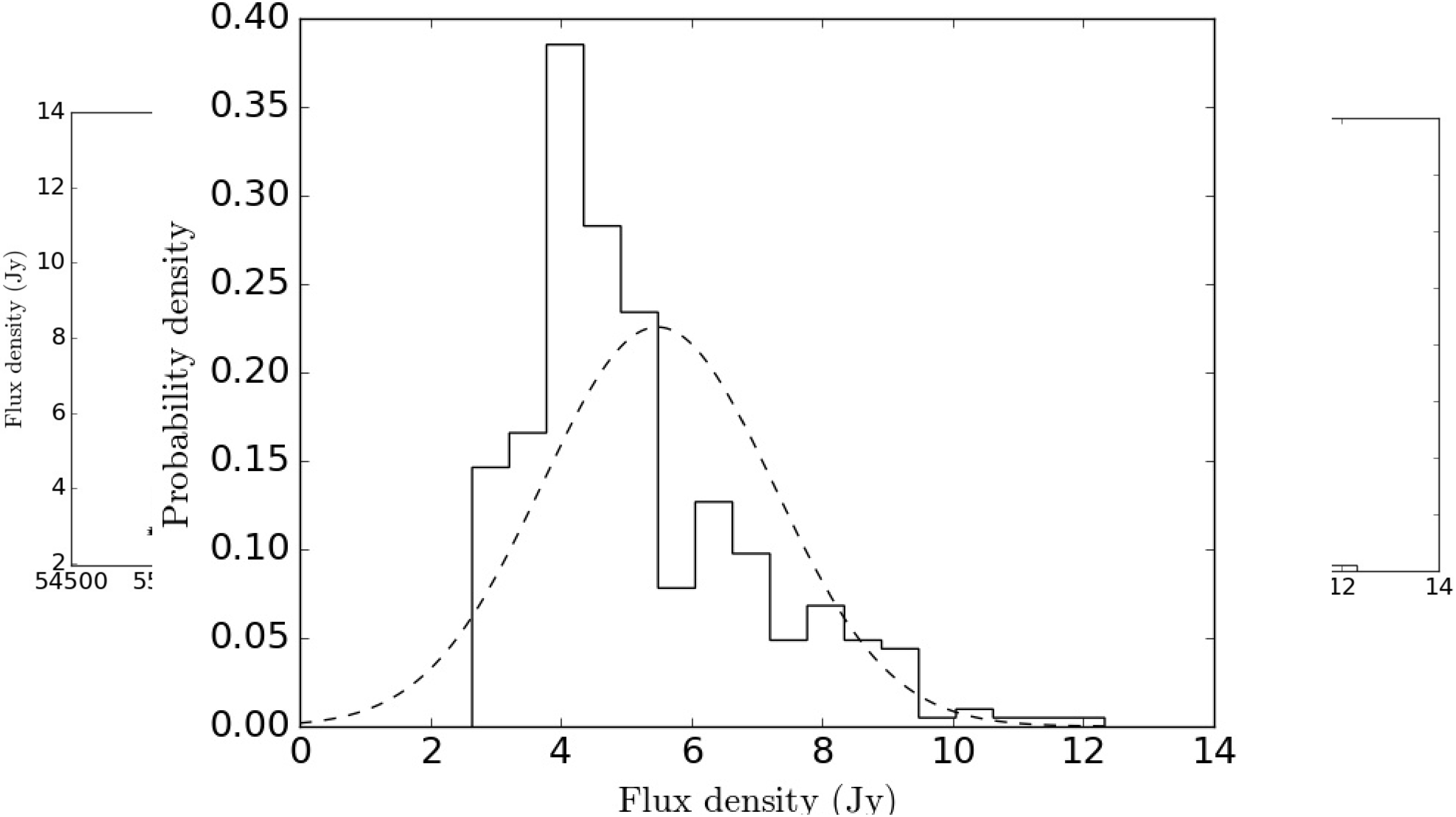
(Richards et al. 2011)

15 GHz BL Lacertae

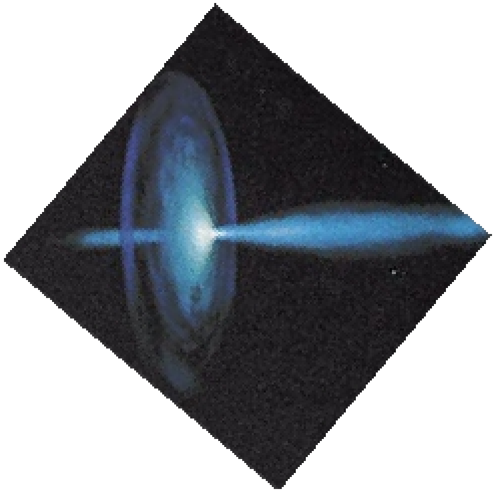




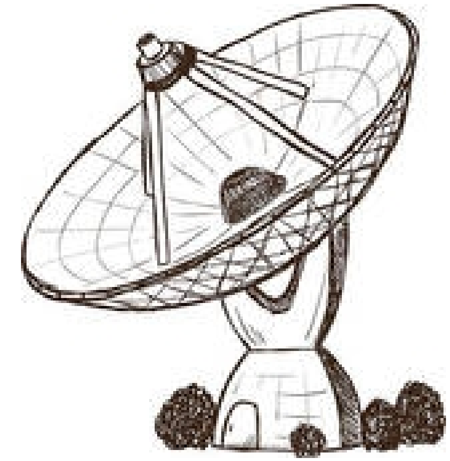
15 GHz BL Lacertae

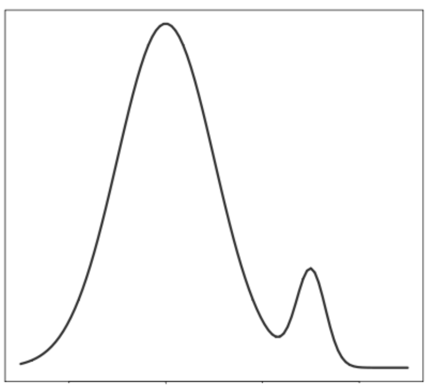


Bimodal model...

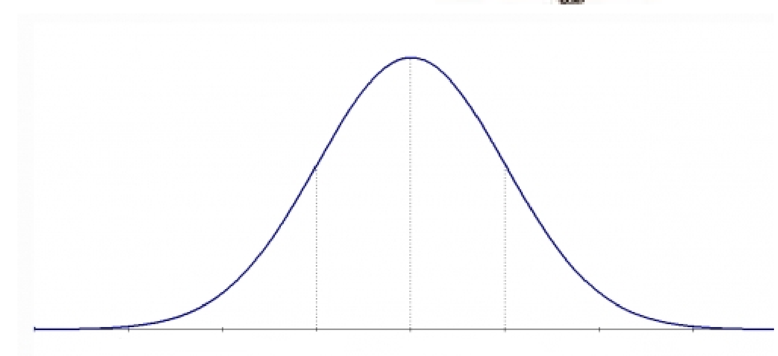


$$S_{true}$$





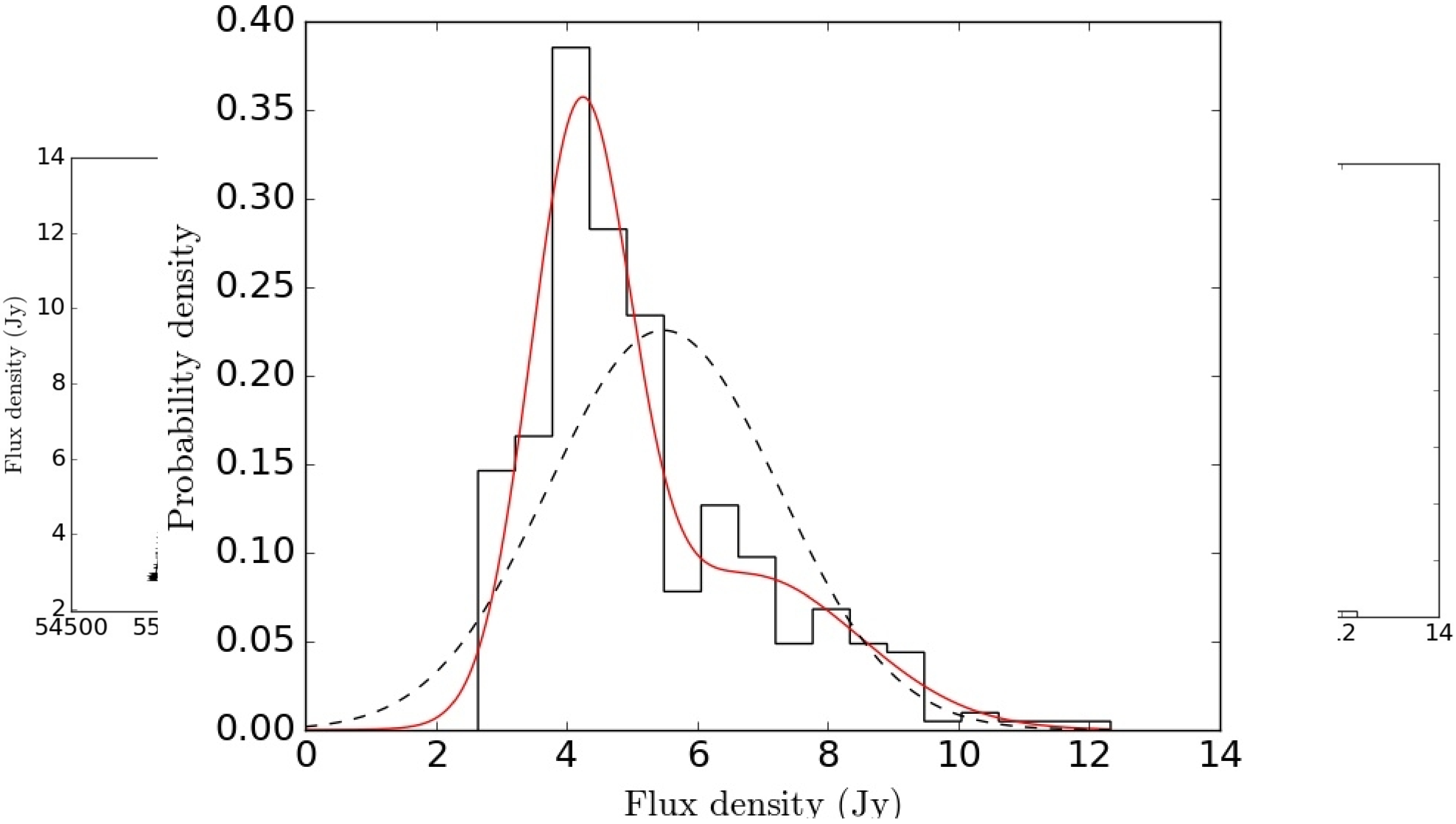
$$P(S_{true}|f_t, S_{off}, \sigma_{off}, S_{on}, \sigma_{on})$$



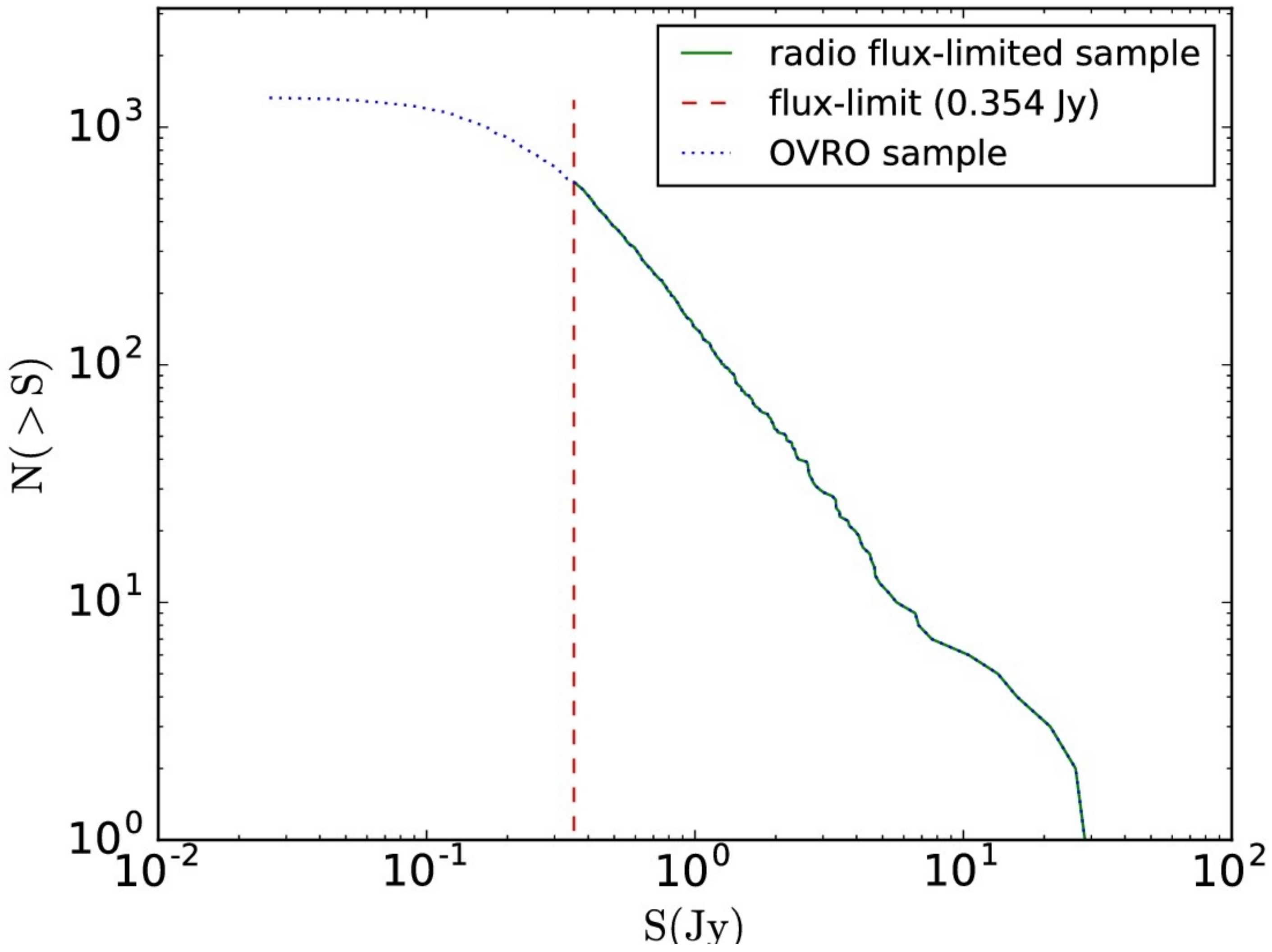
$$P(S_{obs}, \sigma_{obs}|S_{true})$$

$$l_{obs} = \frac{(1-f_t)}{\sqrt{2\pi(\sigma_{obs}^2+\sigma_{off}^2)}} \exp\left[\frac{-(S_{obs}-S_{off})^2}{2(\sigma_{obs}^2+\sigma_{off}^2)}\right] + \frac{f_t}{\sqrt{2\pi(\sigma_{obs}^2+\sigma_{on}^2)}} \exp\left[\frac{-(S_{obs}-S_{on})^2}{2(\sigma_{obs}^2+\sigma_{on}^2)}\right]$$

15 GHz BL Lacertae



Sample...



435 FSRQs

81 BL Lacs

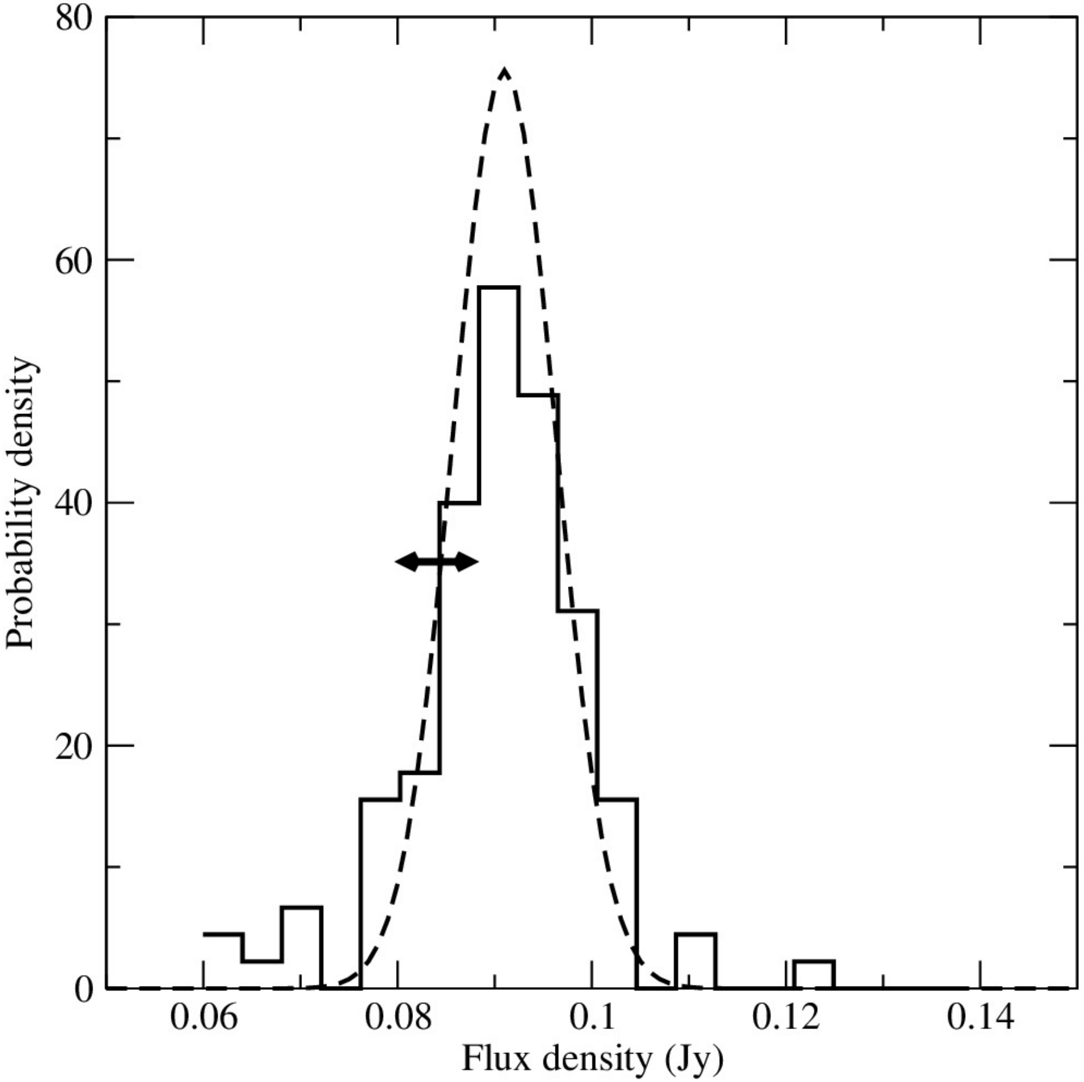
68 Radio Galaxies or unidentified sources

Total: 584 sources

of which: 293 γ-ray loud

(Richards et al. 2011)

Sanity check...



1) Are all sources bimodal?

~8.9% *(52)* sources can be considered consistent with a single-Gaussian

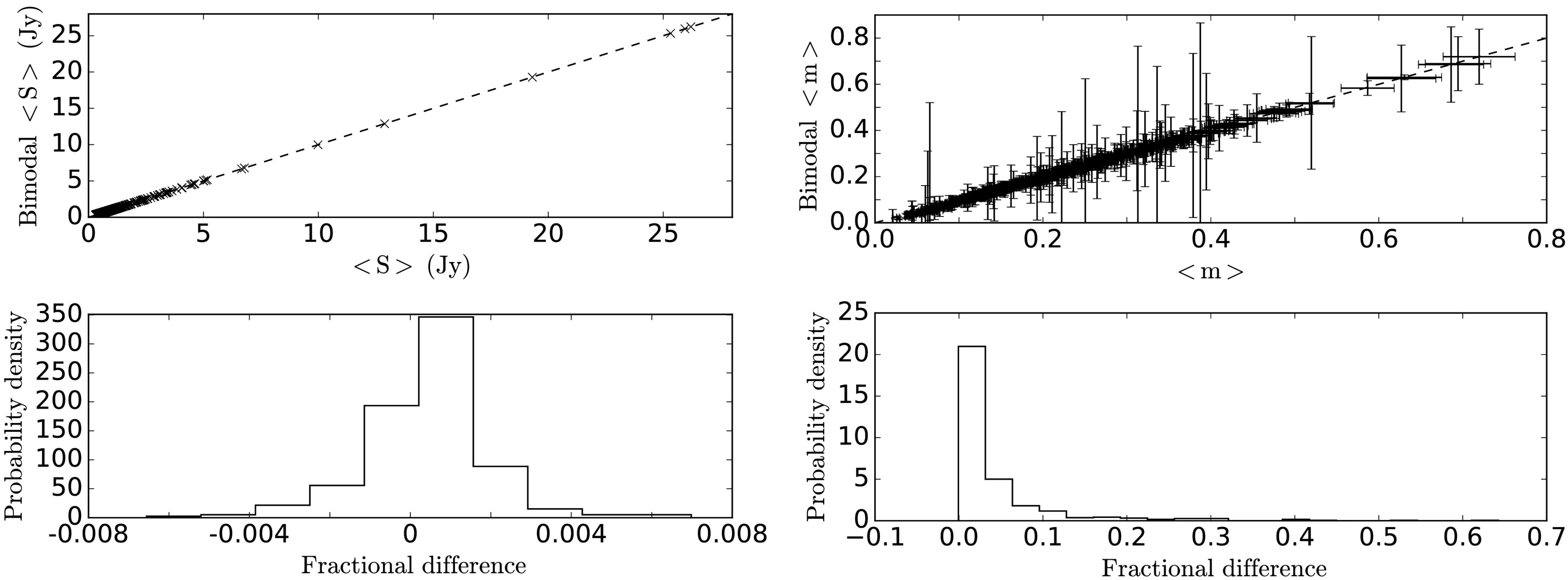
2) How does bimodal fare against and non-likelihood?

$$\langle S \rangle = (1 - f_t) S_{off} + f_t S_{on}$$

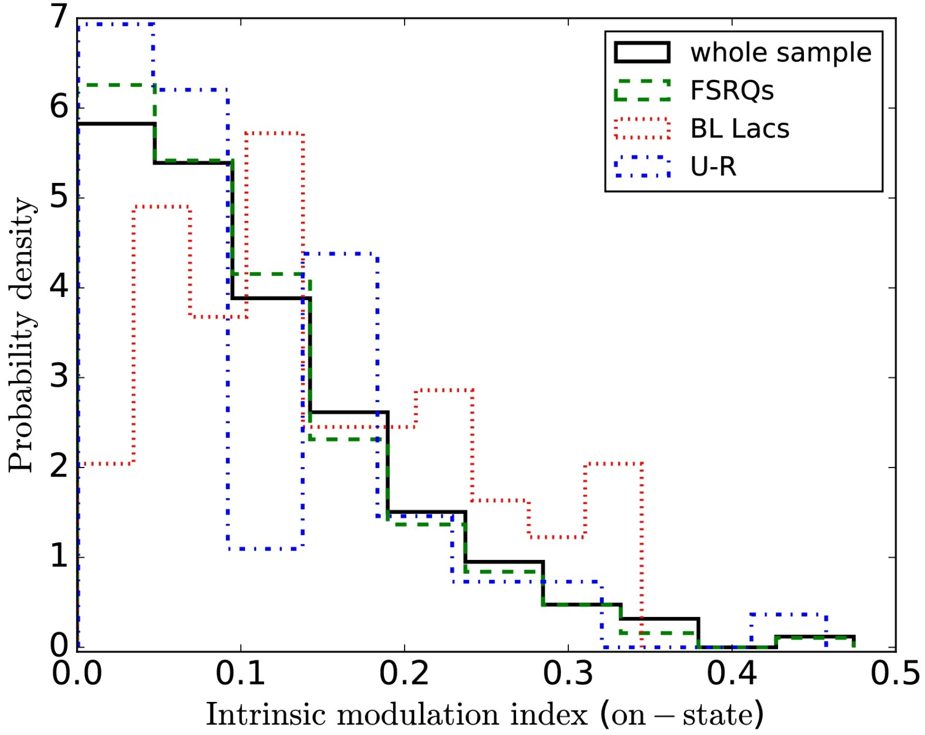
$$\langle m \rangle = \sqrt{\langle Var \rangle} / \langle S \rangle$$

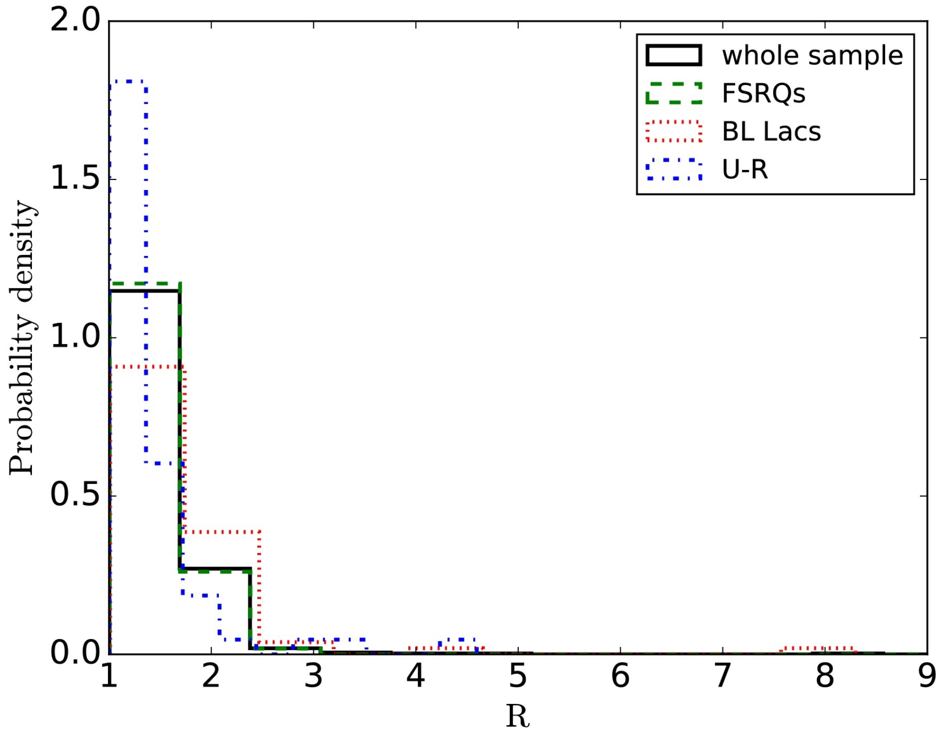
$$\langle Var \rangle = (1 - f_t)(\sigma_{off}^2 + S_{off}^2) + f_t(\sigma_{on}^2 + S_{on}^2) - \langle S \rangle^2$$

Bimodal vs Not-likelihood



Results...





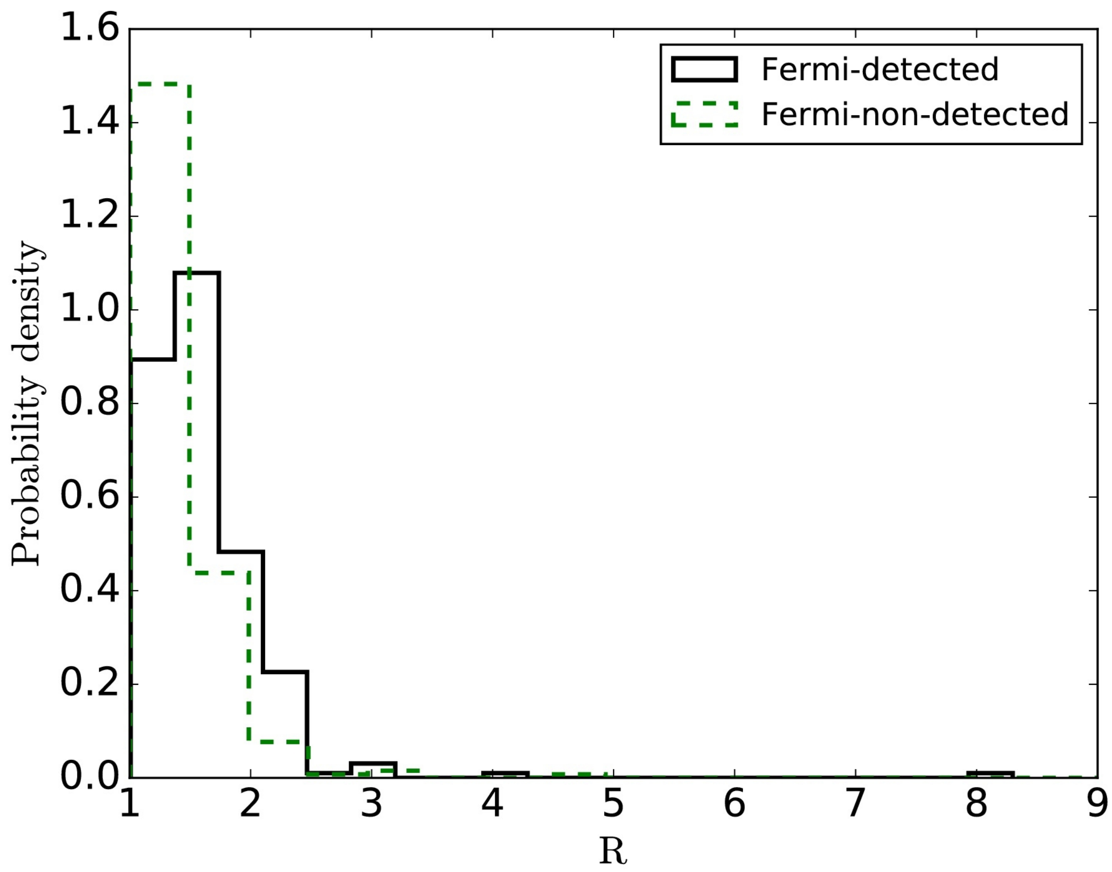
Exponential distribution with mean:

$$\langle m_{on} \rangle = 0.089 \pm 0.004$$

Exponential distribution with mean:

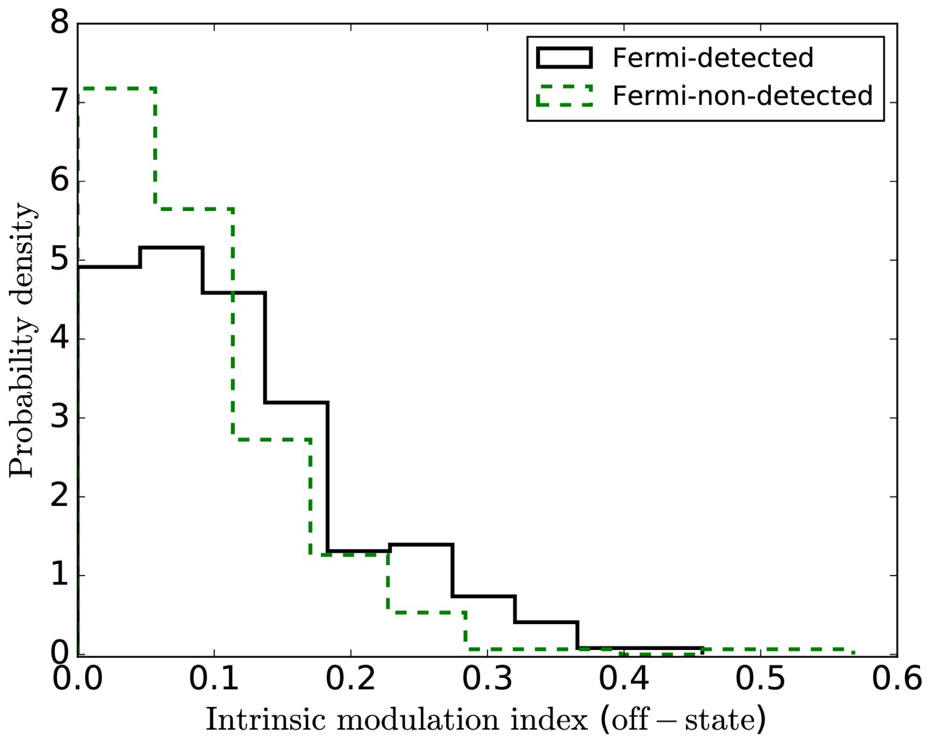
$$\langle R = S_{on} / S_{off} \rangle = 1.485 \pm 0.006$$

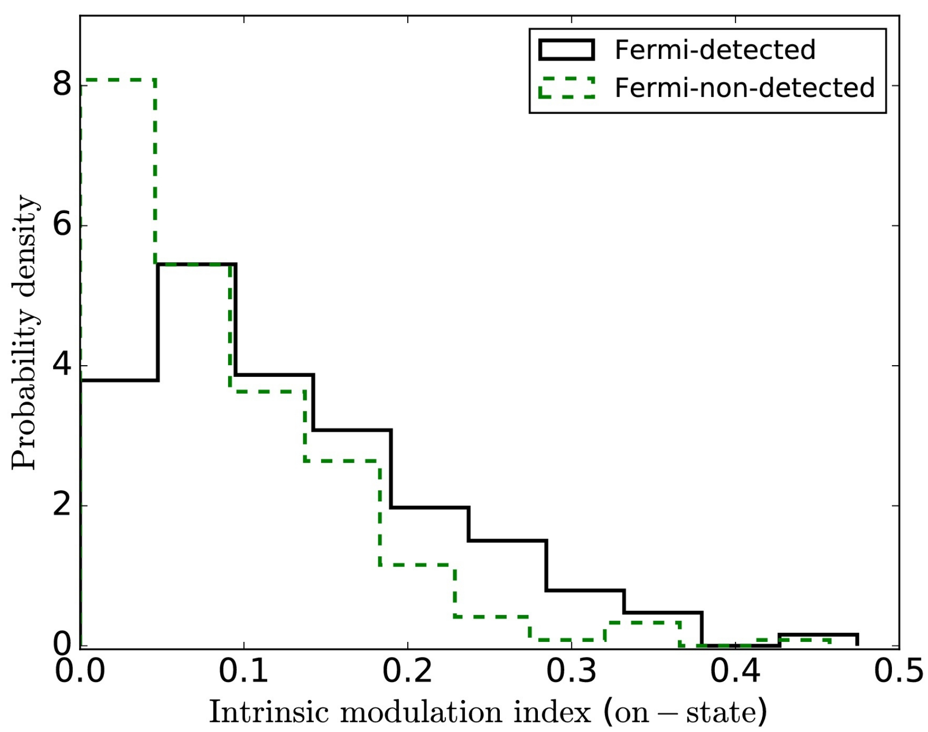
Gamma-ray loud vs Gamma-ray quiet



Kolmogorov-Smirnov : **10^{-8}%**
Wilcoxon rank sum: **10^{-10}%**

Gamma-ray loud vs Gamma-ray quiet





Kolmogorov-Smirnov : **0.26%**
Wilcoxon rank sum: **0.009%**

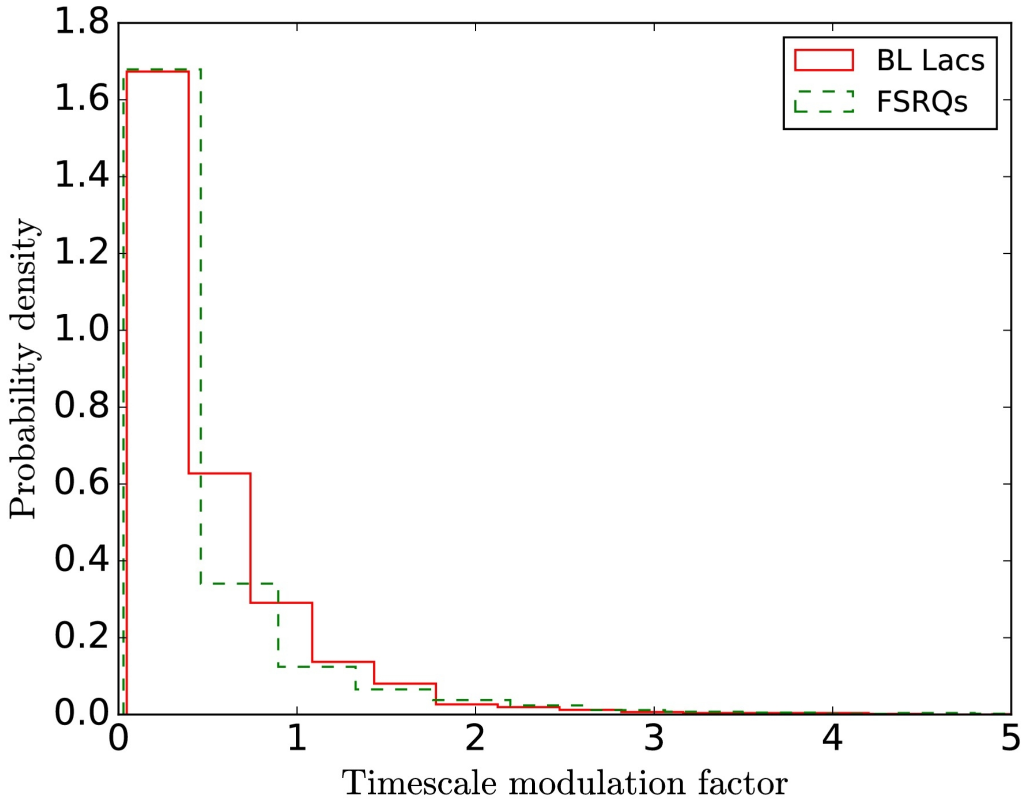
Kolmogorov-Smirnov : **0.001%**
Wilcoxon rank sum: **10^{-7}%**

Intrinsic distribution of timescales

The timescale modulation factor (m) follows an exponential distribution!

(Liodakis & Pavlidou 2015a; Liodakis, Pavlidou & Angelakis 2016a)

$$m_t = \frac{\Delta t'}{\Delta t} = \frac{1+z}{\delta}$$



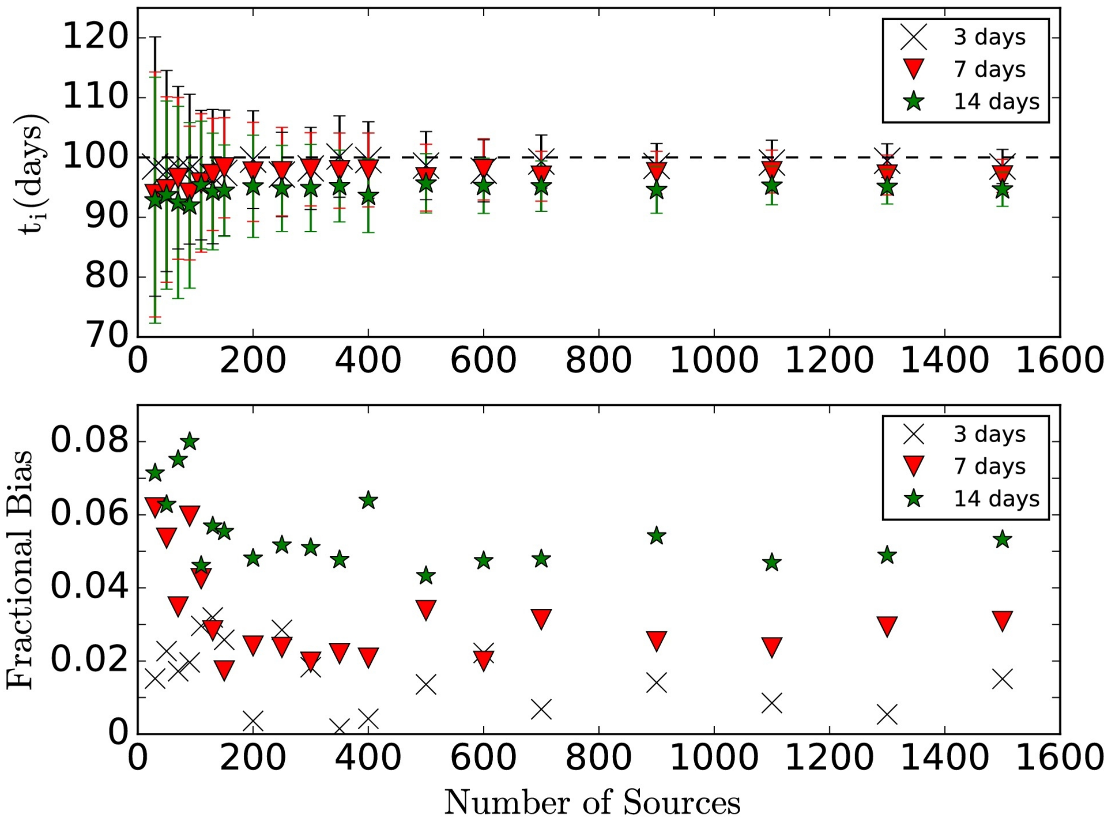
Intrinsic distribution of timescales

Intrinsic probability density function

$$P(t_o) = \int_{m_{t,min}}^{m_{t,max}} P(t_i) P(m_t) \frac{1}{m_t} dm_t$$

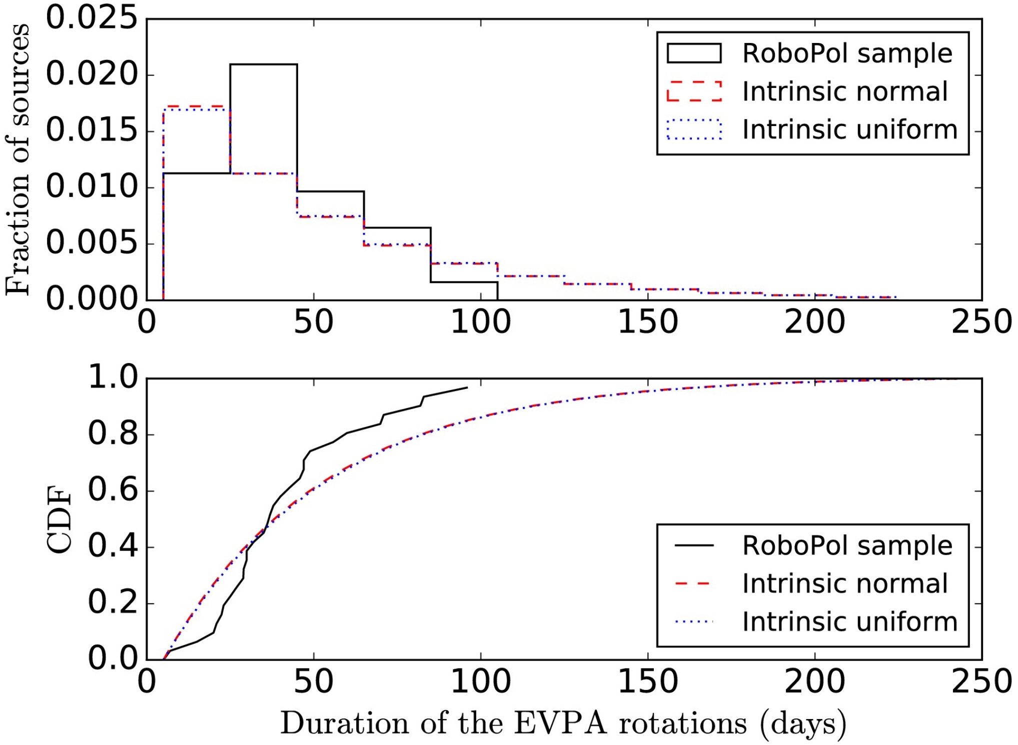
Observed probability density function

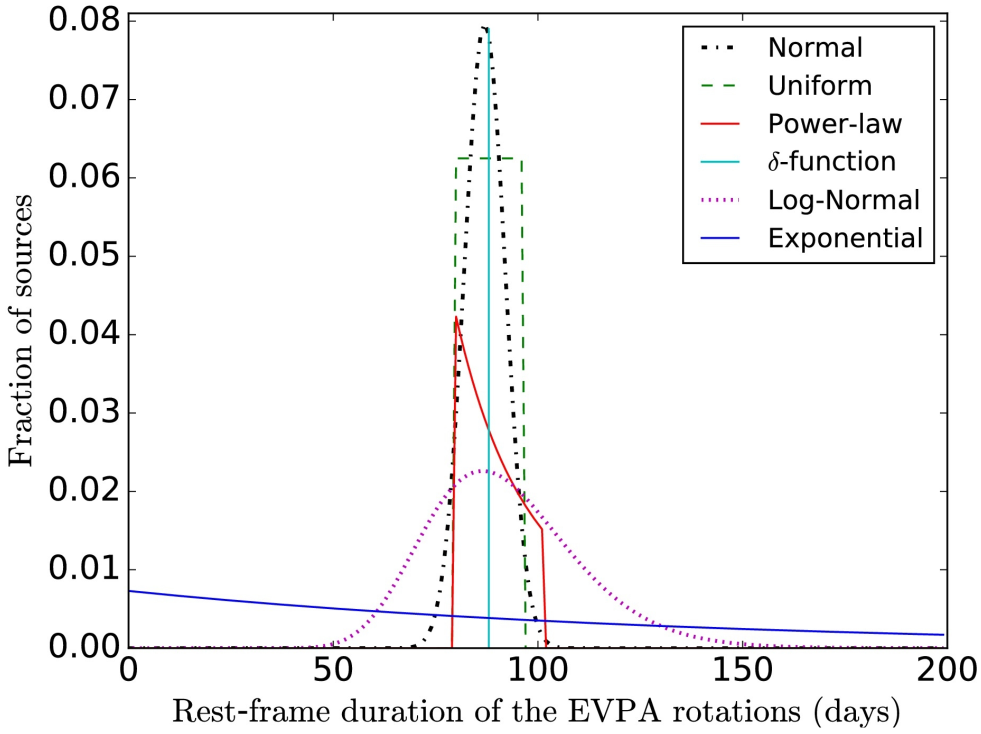
Exponential distribution



(Liodakis et al., 2016b)

Application to EVPA rotations observed by RoboPol!





K-S test – Normal: **31.5%**

K-S test – Uniform: **31%**

$$Normal: \mu = 87\ days, \sigma = 5\ days$$

$$Uniform: t_{min} = 80\ days, t_{max} = 96\ days$$

(Liodakis et al., 2016b)

Summary & Conclusions...

We have created a 5-d maximum likelihood formalism to capture the bimodal behavior of OVRO monitored blazars

The flaring ratio and off-state and on-state modulation indices follow **exponential distributions**.

BL Lacs are **more variable in their on-state** with larger outbursts than the FSRQs

Blazars are **more variable** with larger outbursts than the U-Rs **in either state**.

Gamma-ray loud sources are **systematically more variable with larger outbursts** than the Gamma-ray quiet sources.

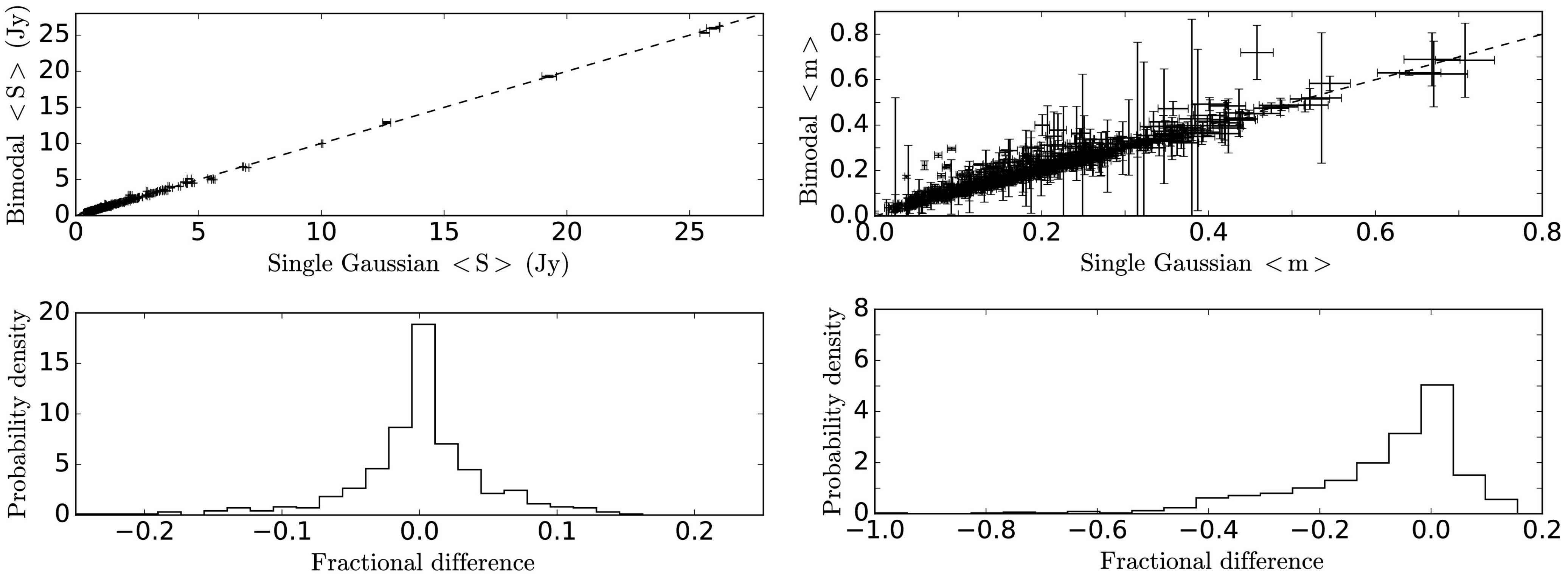
We have created a novel mathematical formalism to **uncover the intrinsic distribution of timescales** in blazars

The fractional bias of our method is below **8% regardless of sample size** for time intervals between observations <14 days

The intrinsic distribution of EVPA durations seen by RoboPol is **narrow** (most probable either normal or uniform)

ADDITIONAL SLIDES

Bimodal vs single-Gaussian



Bimodal vs Not-likelihood (Below flux-limit)