In the Name of God

Simulation of a strategy for the Pixel Lensing of M87 by HST

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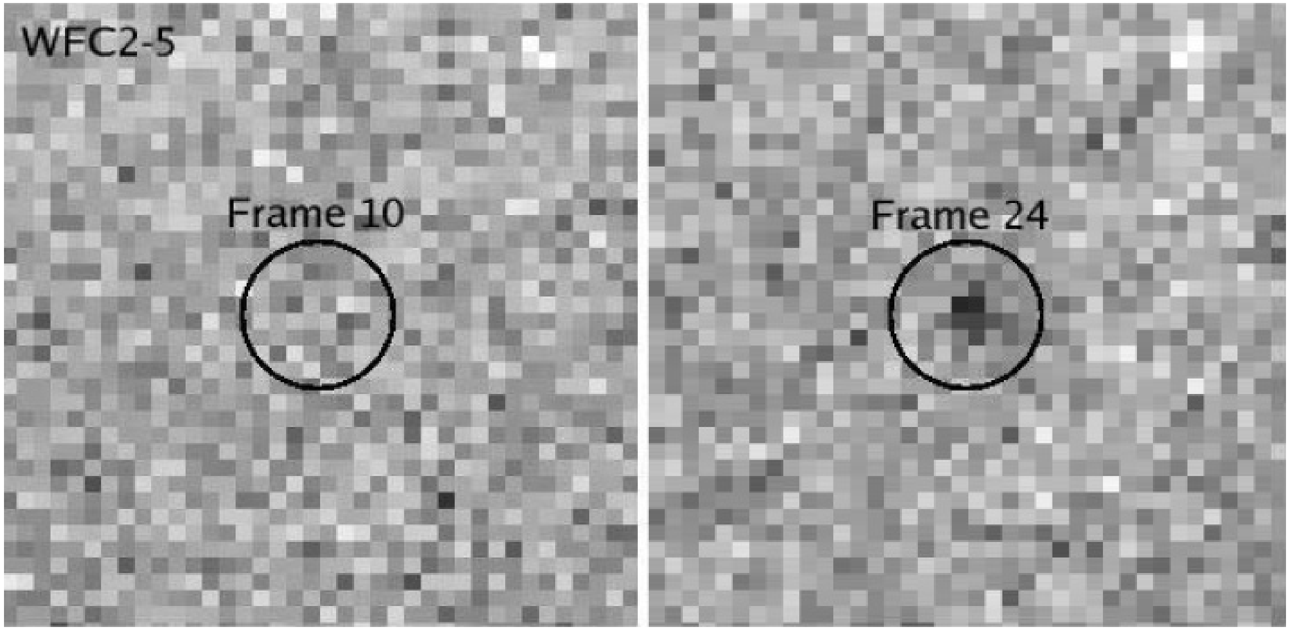
- Pixel lensing
- M87: The brightest elliptical galaxy in Virgo
- History
- High magnification events towards M87
- Estimation of rate of events
- Monte-Carlo simulation
- Possibility of observing micro-halos
- Conclusion

Pixel lensing:

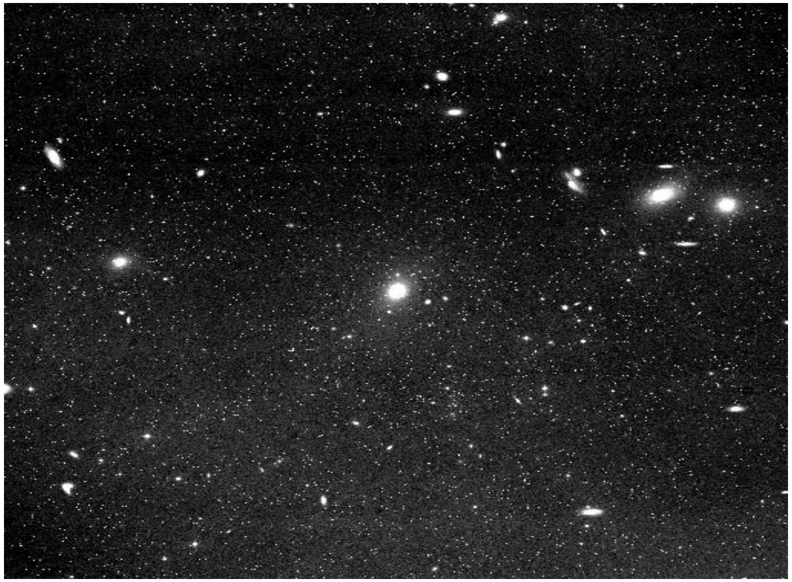
- Measuring the time variation of the light in each PSF.
- The smaller PSF of the telescope, the more efficient pixel lensing.



Baltz et al. 2004

M87: the brightest elliptical galaxy in Virgo

- ***Virgo cluster:***
  - Containing 1300 galaxies
  - Angular size : 8°
  - Distance : 16.5 Mpc
  - Coordinate: RA≈12 hr and DE≈12°
  - Radius of Virgo halo: 2.2 Mpc



- ***M87 galaxy:***
  - The brightest elliptical galaxy in Virgo cluster
  - Radius of M87: 40 kpc
  - Radius of M87 halo: 150 kpc

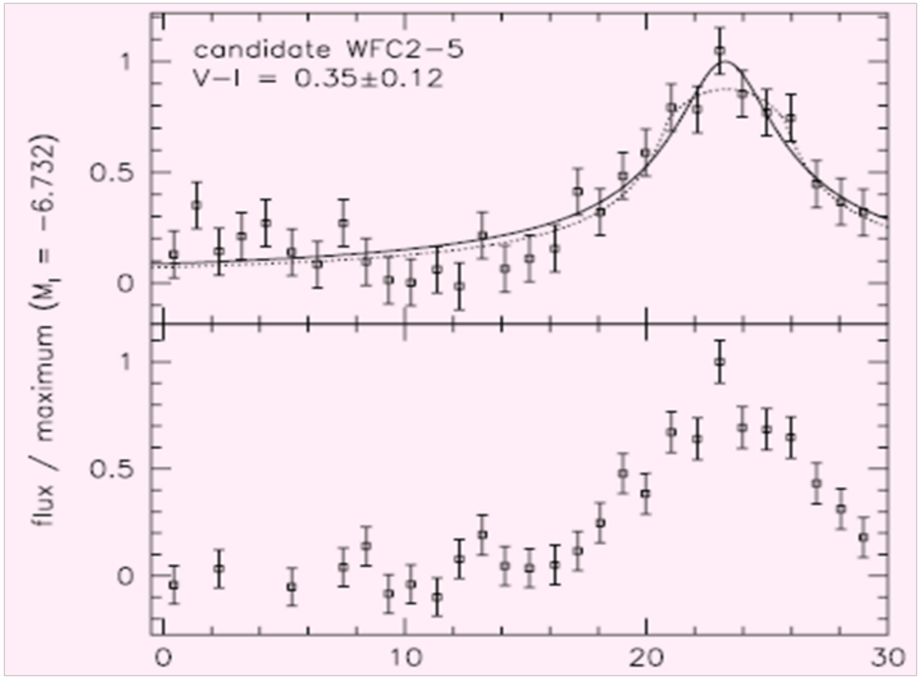
Mei et al. 2007, Fouque et al. 2001

History:

- **Gould 1995:** proposed observation of M87 with HST during one month with daily sampling.

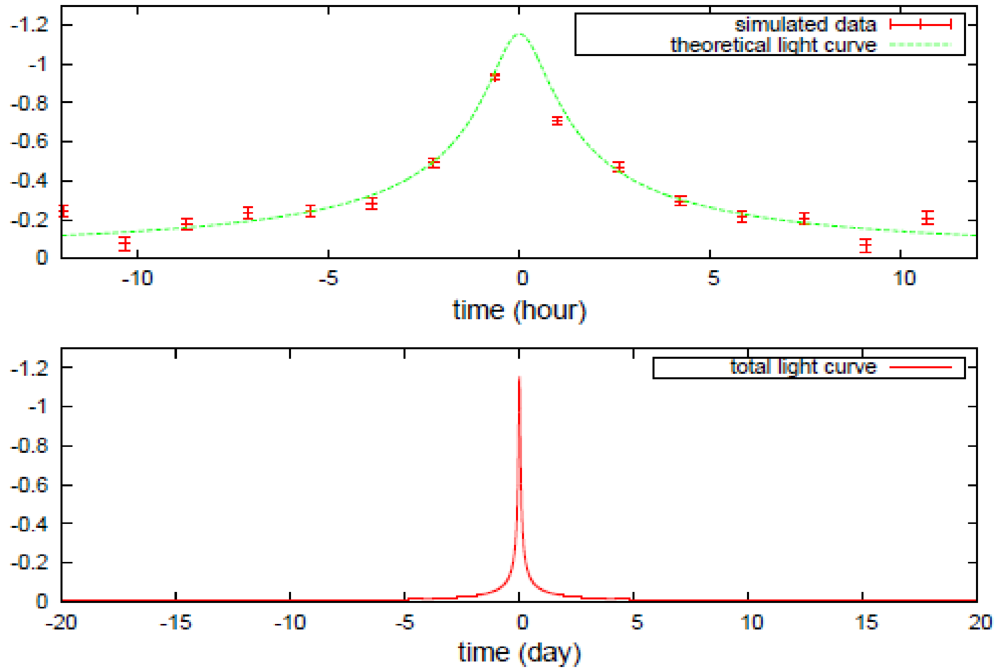
$$\Gamma \approx 18\, f\ day^{-1}$$

- **Baltz et al. 2004:** monitored M87 with Gould strategy and found only one microlensing events during one Month observation.



High magnification events towards M87:

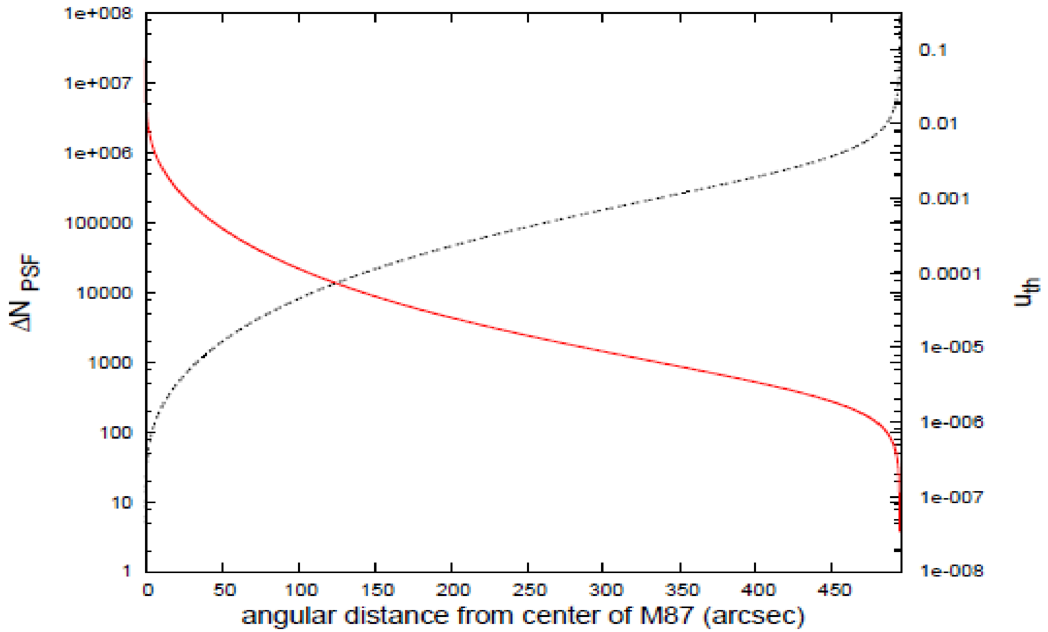
- Number of stars inside the PSF of HST ~ 1000
- High magnification microlensng events with A> 1000
- Time scale in the order of few hours. $t_{1/2} \approx t_E u_0$
- **Proposing an intensive observation of M87 with short cadence in the order of one hour by HST in each HST orbit.**



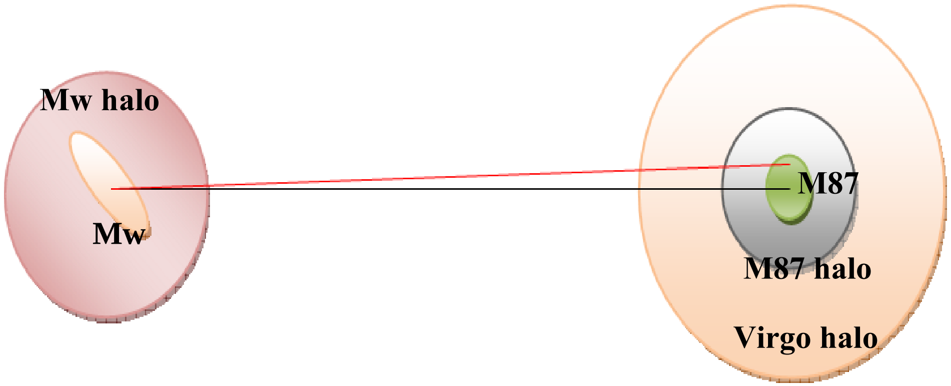
Estimation of rate of events:

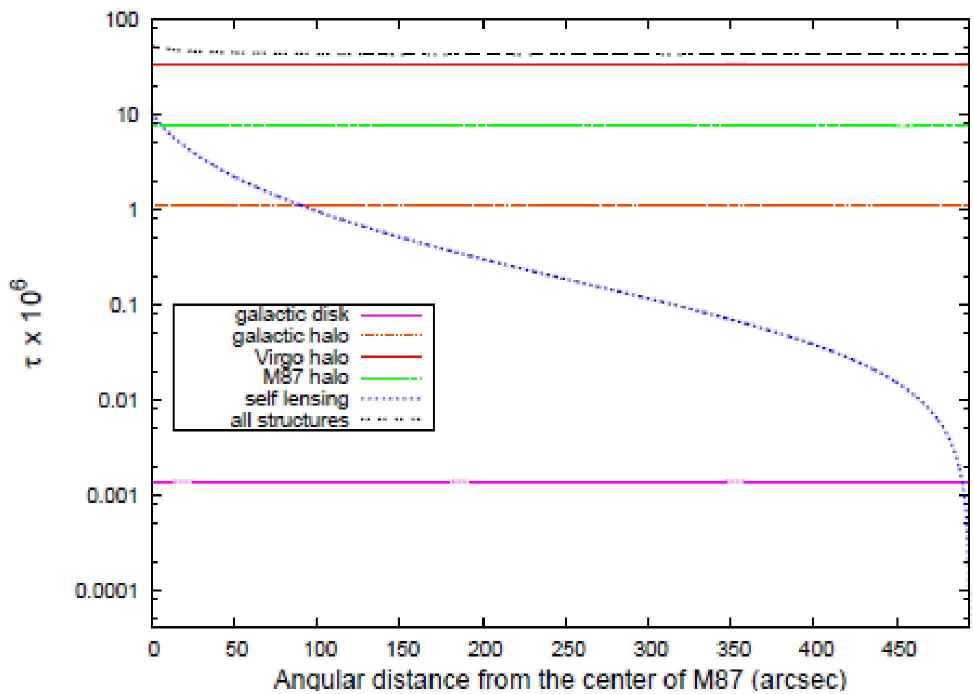
- **Step1:**

- Column density of stars in M87: $\Sigma(r) = \int n(r,z)dz$
- Number of stars inside PSF: $\Delta N_{PSF} = D_s^2\,\Sigma(r)\,\Omega_{PSF}$
- Threshold of magnification: $A_{th} > \Delta N_{PSF}$
- Threshold of impact parameter: $u_{th} < (\Delta N_{PSF})^{-1}$

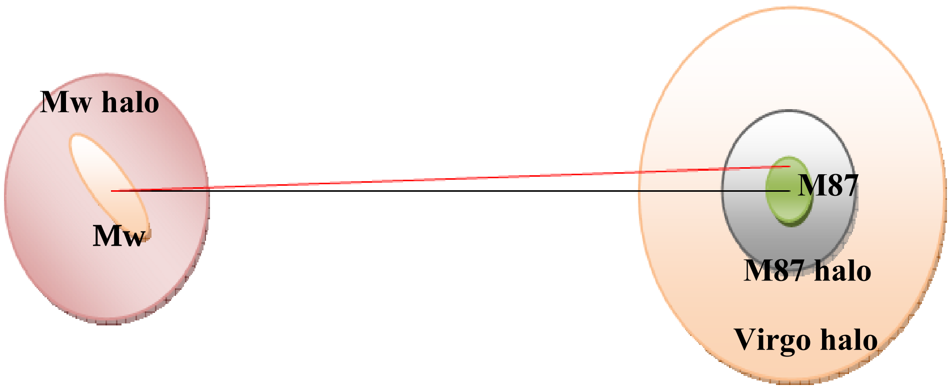


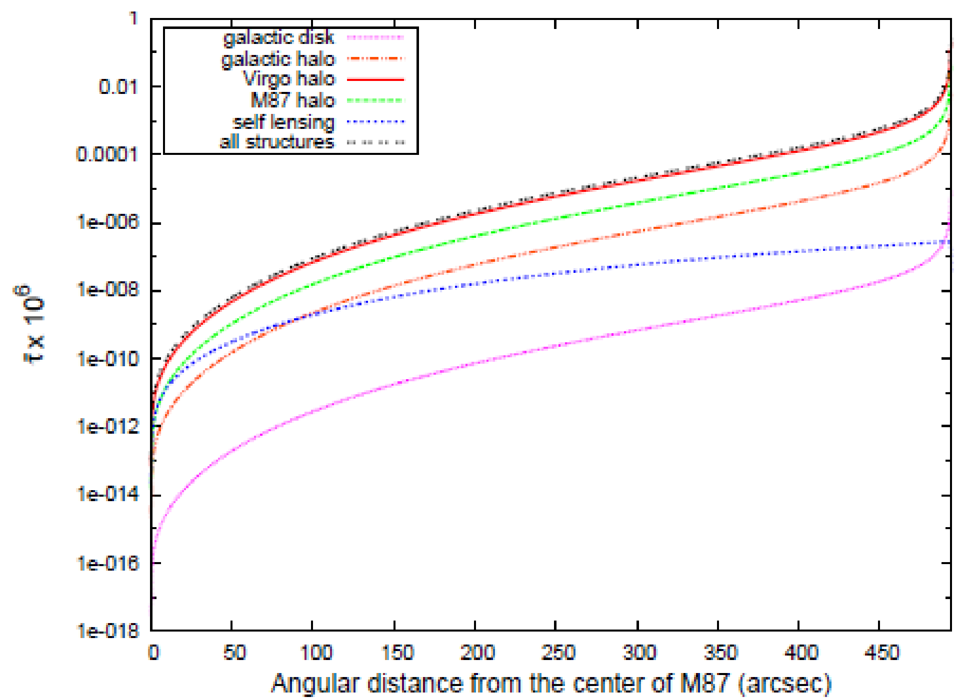
○ **Step2:** Optical depth:





	Structure	Density
a	Galactic disk	Binney & Tremaine 1987
b	Galactic halo	**NFW** Battaglia et al.2005
c	Virgohalo	**NFW** MacLaughlin 1999
d	M87 halo	**NFW** Doherty et al. 2009
e	Self lensing	MacLaughlin 1999





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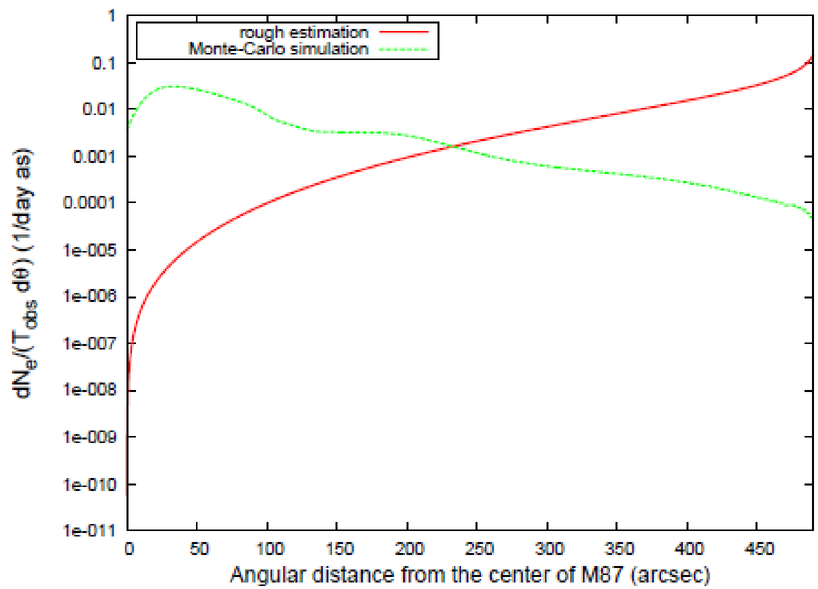
Reduced optical depth: $\tilde{\tau}(\hat{n}) = u_{th}^2(\hat{n})\tau(\hat{n})$

- Mean optical depth: $$\langle \tau \rangle = \frac{\sum_i \tau_i I_{M87}(r_i) r_i}{\sum_i I_{M87}(r_i) r_i}$$

	a	b	c	d	e	overall
$\bar{\tau} \times 10^{11}$	0.00074	0.118	3.622	0.819	0.0028	4.563
$\bar{t}_{1/2}(hr)$	6.11	5.39	17.32	9.02	32.26	15.85
$N_e(1/day)$	0.0023	0.432	4.127	1.79	0.0091	6.36

Total number of events in one day observation is about ~ 6

- Number of events:



Monte-Carlo simulation:

- **Step 1: Synthesizing Stellar distribution in M87**

➤ Using Padova Isochrones:

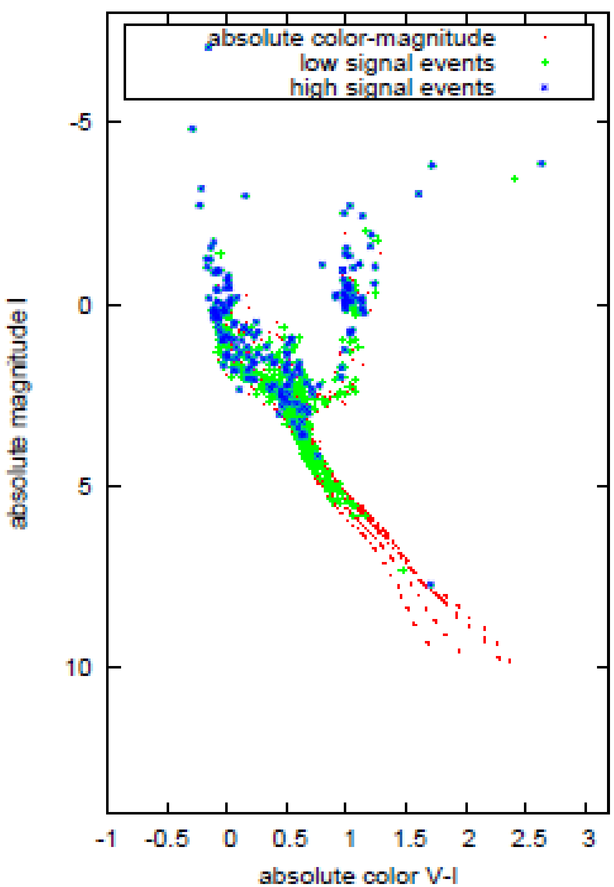
$$\log\left(\frac{t}{yr}\right) = [6.6, 10]$$

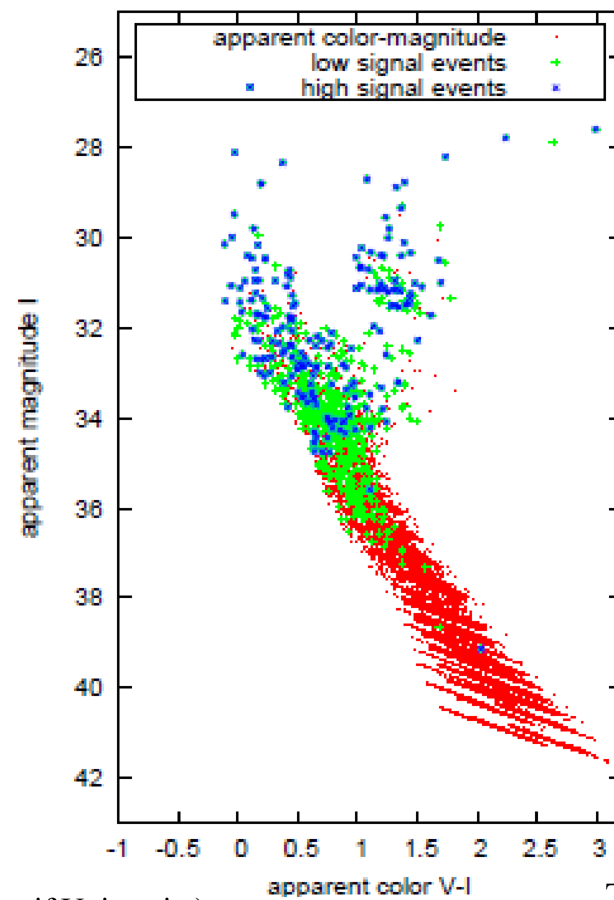
$$Z = [0.0004, 0.03]$$

➤ Extinction and reddening:

Electron number density in M87:

$$n_e(r) = n_0 \frac{(r/a_1)^{-\alpha}}{1 + (r/a_1)}$$





Karami M.Sc. Thesis 2010 (Sharif University)

Tsai 1994

Step 2: Parameters of lenses:

	Galactic disk	Galactic halo	Virgo halo	M87 halo	M87 stars
Mass	Salpeter [1-3] $M_{\odot}$	Salpeter $[1M_J, 1M_{\odot}]$	Salpeter $[1M_J, 1M_{\odot}]$	Salpeter $[1M_J, 1M_{\odot}]$	Sapltere [1-3] $M_{\odot}$
velosity	Rahal et. al. 2009	Boltzman distribution $\sigma = 156\ km/s$	Boltzman distribution $\sigma = 1000\ km/s$	Boltzman distribution $\sigma = 360\ km/s$	Boltzman distribution $\sigma = 360\ km/s$

Step3: Position of lenses:

$$d\Gamma/dx \propto \rho(x)\sqrt{x(1-x)}$$

Step4: Position of sources:

- Choosing position in sky plane from the surface brightness distribution of M87
- Indicating position on the line of sight direction using mass density distribution.

- **Step 5: finite size effect**

  - Mean sequence stars: $R_\star = M_\star^{0.8}$
  - Red giants: $M_{RG}^{1/2} R_{RG}^{3/2} = const.$

Hayashi et al. 1962

- **Step 6:** Hot pixels occur with the probability about 1.5 % for 1000 s exposure time.

Sirianni et al. 2005

  - Variable stars and novas can be ignored in short duration of observation.

Madrid et al. 2007

- **Step 7:**

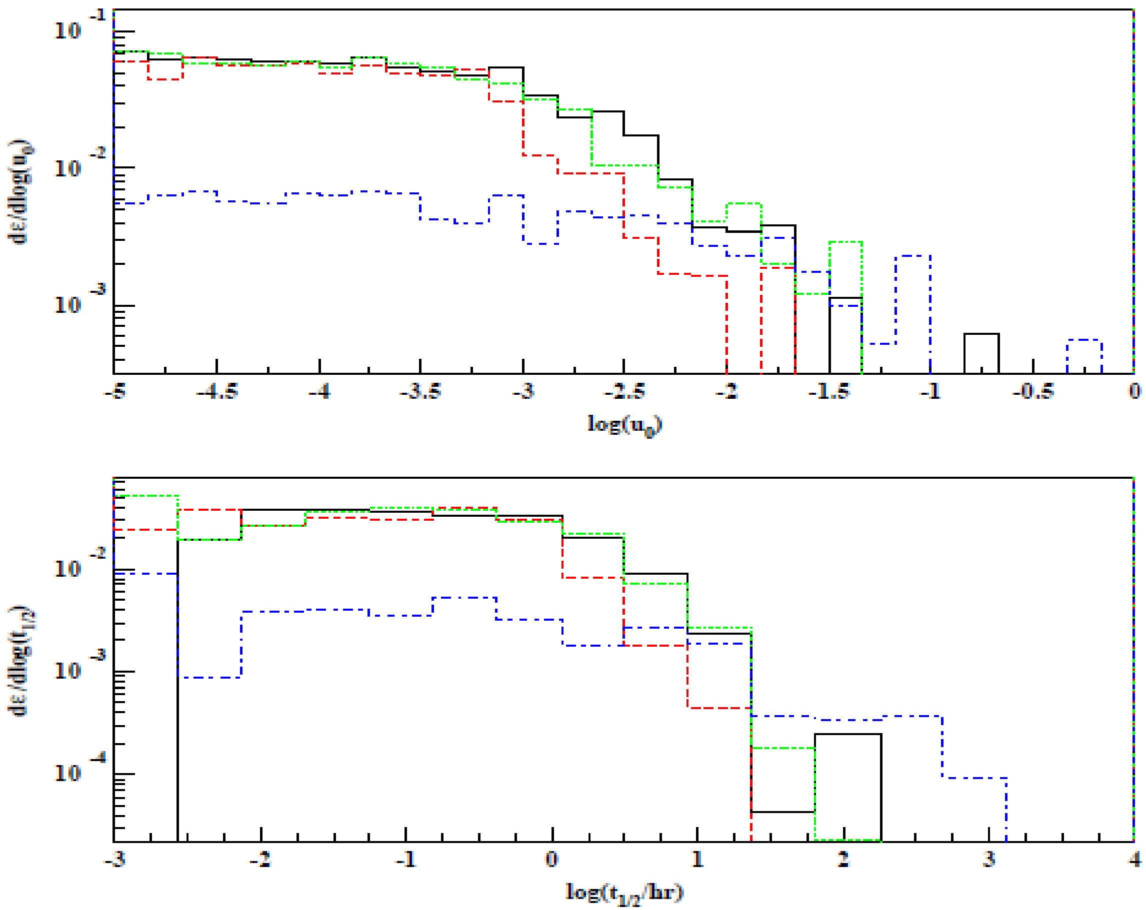
We assume HST monitors M87 with one observation per one orbit

for duration one to few days observation.

- **Step 8: signal to noise ratio:**
  - Signal: $\delta N = (A-1) \times t_{exp} \times 10^{-0.4(m_I - m_I^{zp})}$
  - Noise: $\sqrt{N} = 10^{0.2 m_I^{zp}} \sqrt{\Omega_{PSF}(10^{-0.4\mu_I} + 10^{-0.4\mu_{sky}}) t_{exp}}$
  - Exposure time : 6×260 s
  - F814W(I-band): $\Omega_{PSF} = 0.0129\, as^2 , m_I^{ZP} = 25.10\, mag$

- **Step 9: criterions for accepting events:**
  - $Q = \sqrt{\sum_i (\delta N_i / \sqrt{N})^2} > Q_{crit}$
  - Q_{crit} =5 for loose signal and 30 for high signal

❑ Detection efficiency:



One day observation with 15 data points

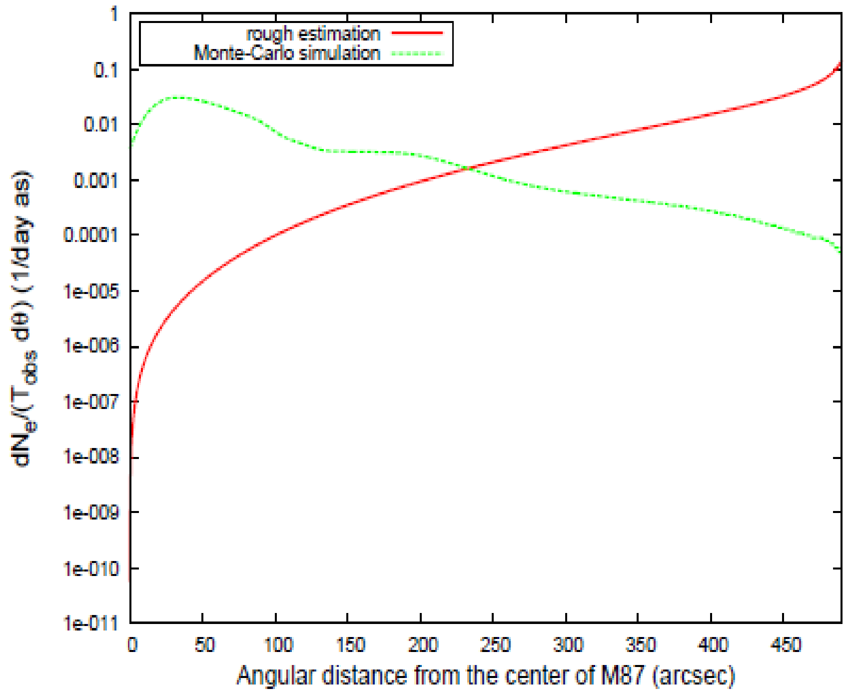
Two days observation with 30 data points

Three days observations with 45 data points

One month observation with 30 data points

- Number of observed events:

$T_{obs}\ (day)$	1	2	3	30
N_{obs}	4.60	7.74	11.56	1.64
$\bar{t}_{1/2}(hr)$	15.54	19.36	21.41	173.38
$t_E(day)$	16.58	17.58	18.18	15.41



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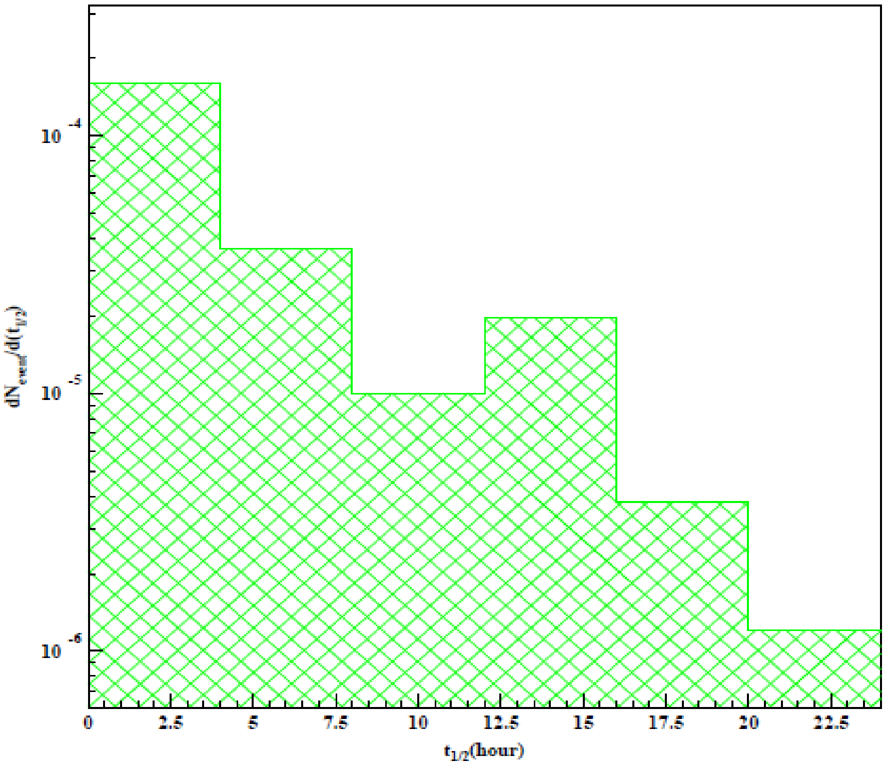
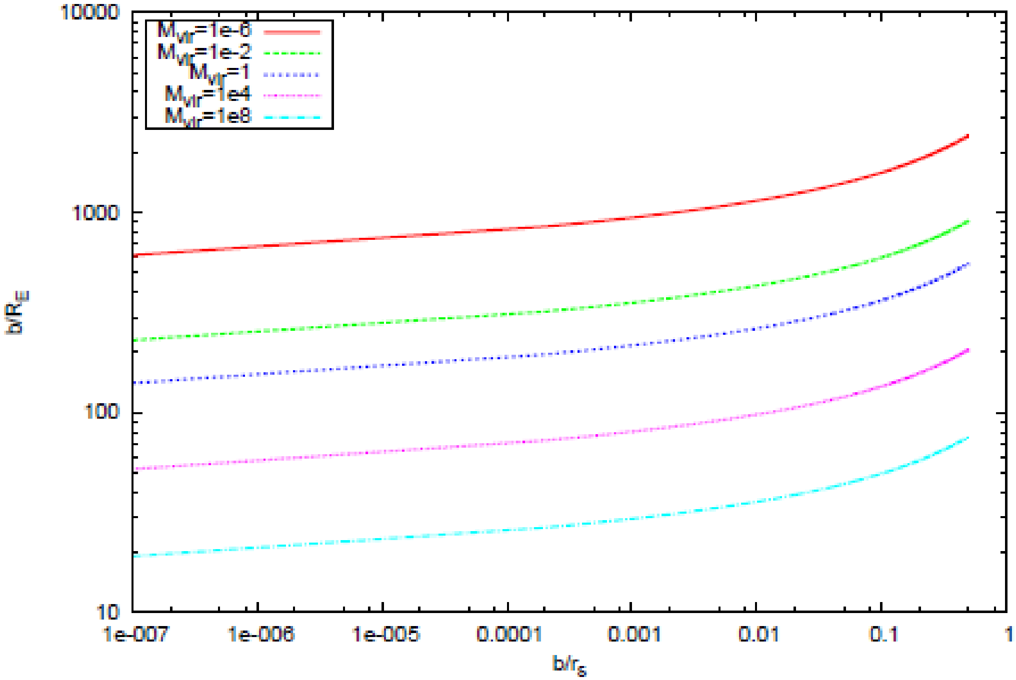


Distribution of time scale:

Micro-halos as lenses:

- NFW profile as mass distribution for micro-halo:



- **For the micro-halos the normalized impact parameter is always greater than one!**

 Ignoring their possible distribution in the pixel lensing.

Conclusion:

- **HST observation of M87 during 1 Month with daily sampling (Gould strategy), One microlensing event was detected in 2004.**

- **With new strategy, intensive observation of M87 during 2 days with one data point per orbit, we can observe short duration high magnification events: 7.7 events will be detected (Monte-Carlo).**

- **This observation can put limit on the fraction of intracluster MACHOs in halo.**

- **Micro-dark matter halos can not be observed by this method.**

Thanks for your attention