Microlensing, MEGA

and M31

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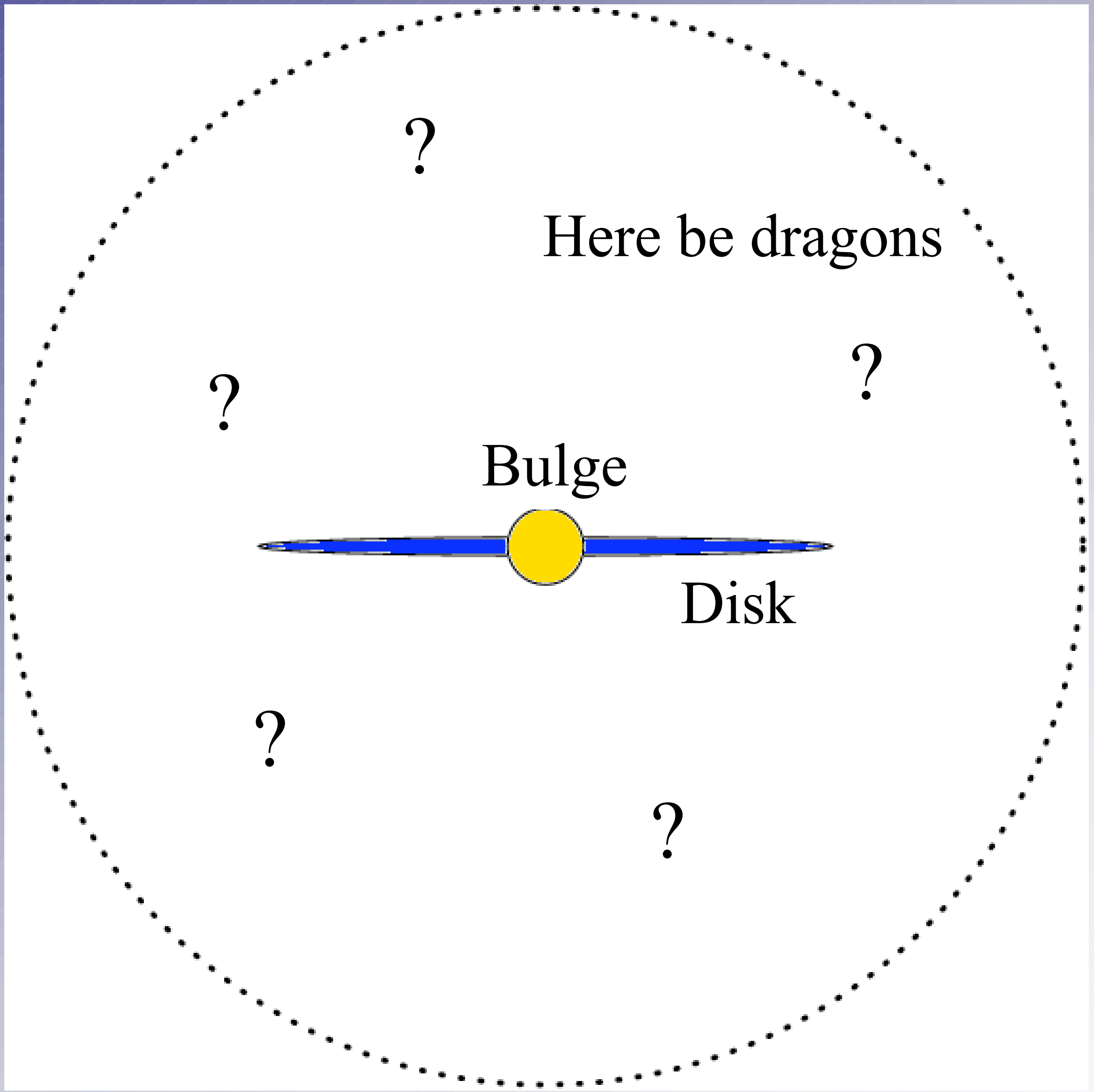
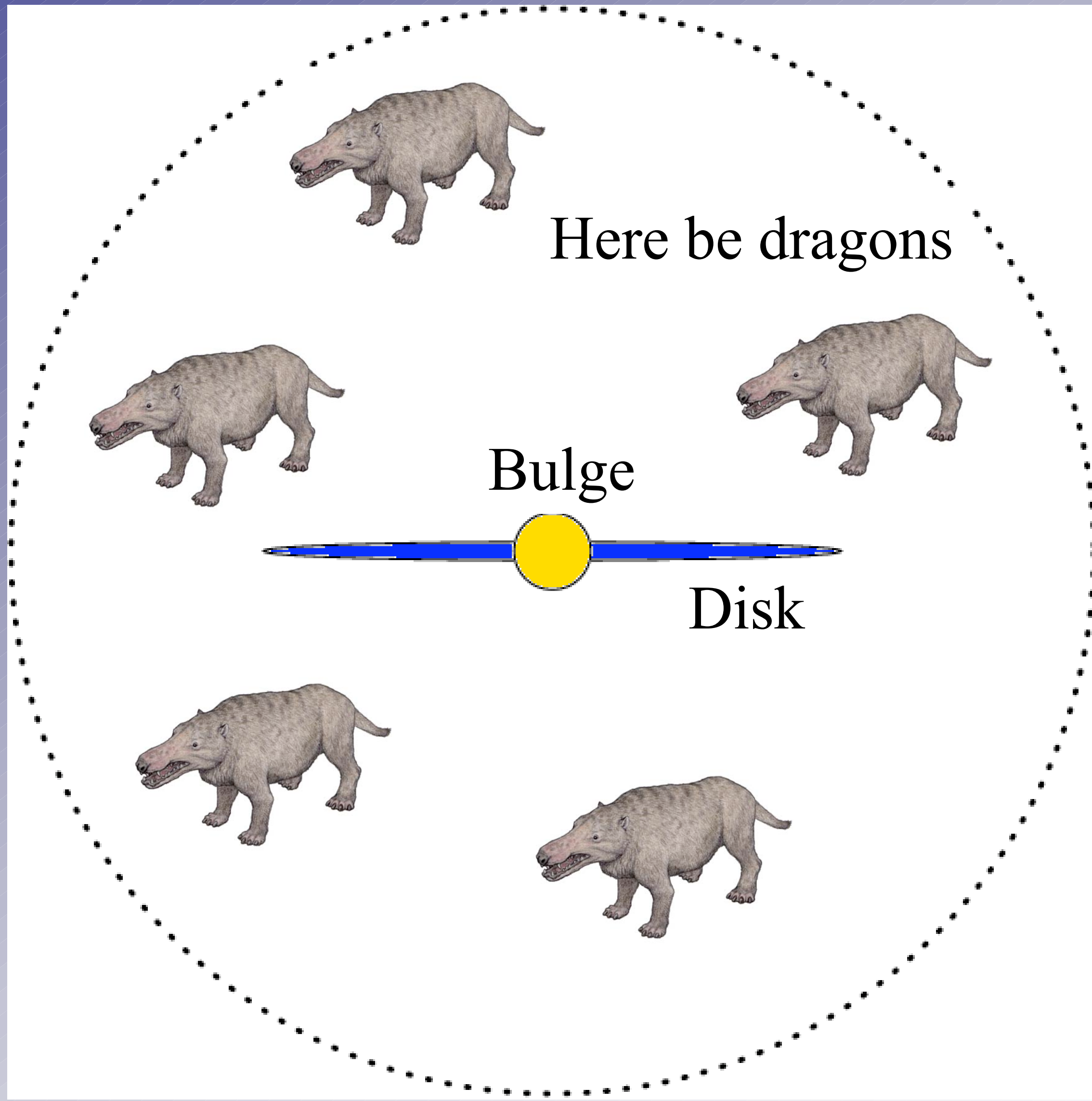
Adler Planetarium, U. Chicago
7/12/2005

The content of halos is not well constrained...



The content of halos is not well constrained...



What is in the Halo?

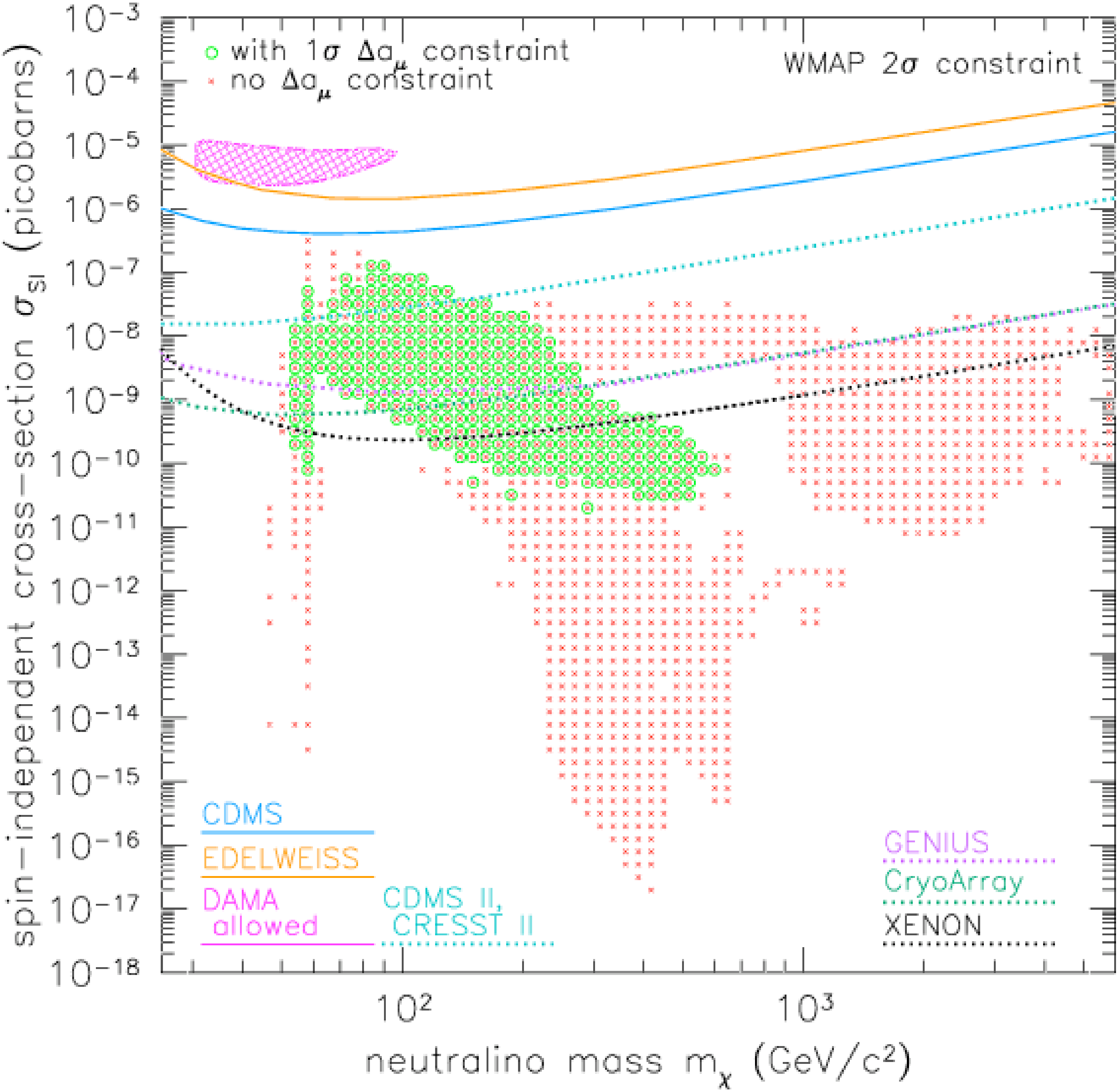
- Dark Halo
  - Dark!
  - Collisionless

Compact???

- Phase transition relics
- PBH
- Dark matter solitons

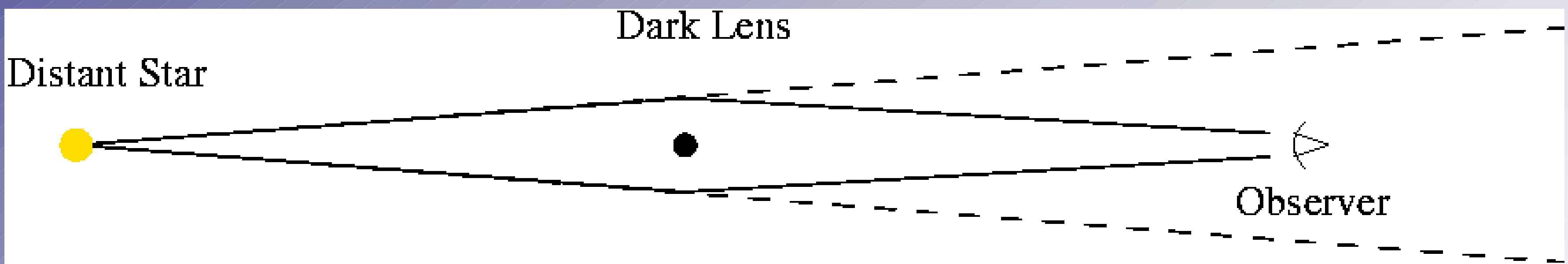
- Other stuff
  - Relics of galactic evolution
    - Faint Red Dwarfs?
    - Brown Dwarfs?
    - Stellar Remnants?

Compact {

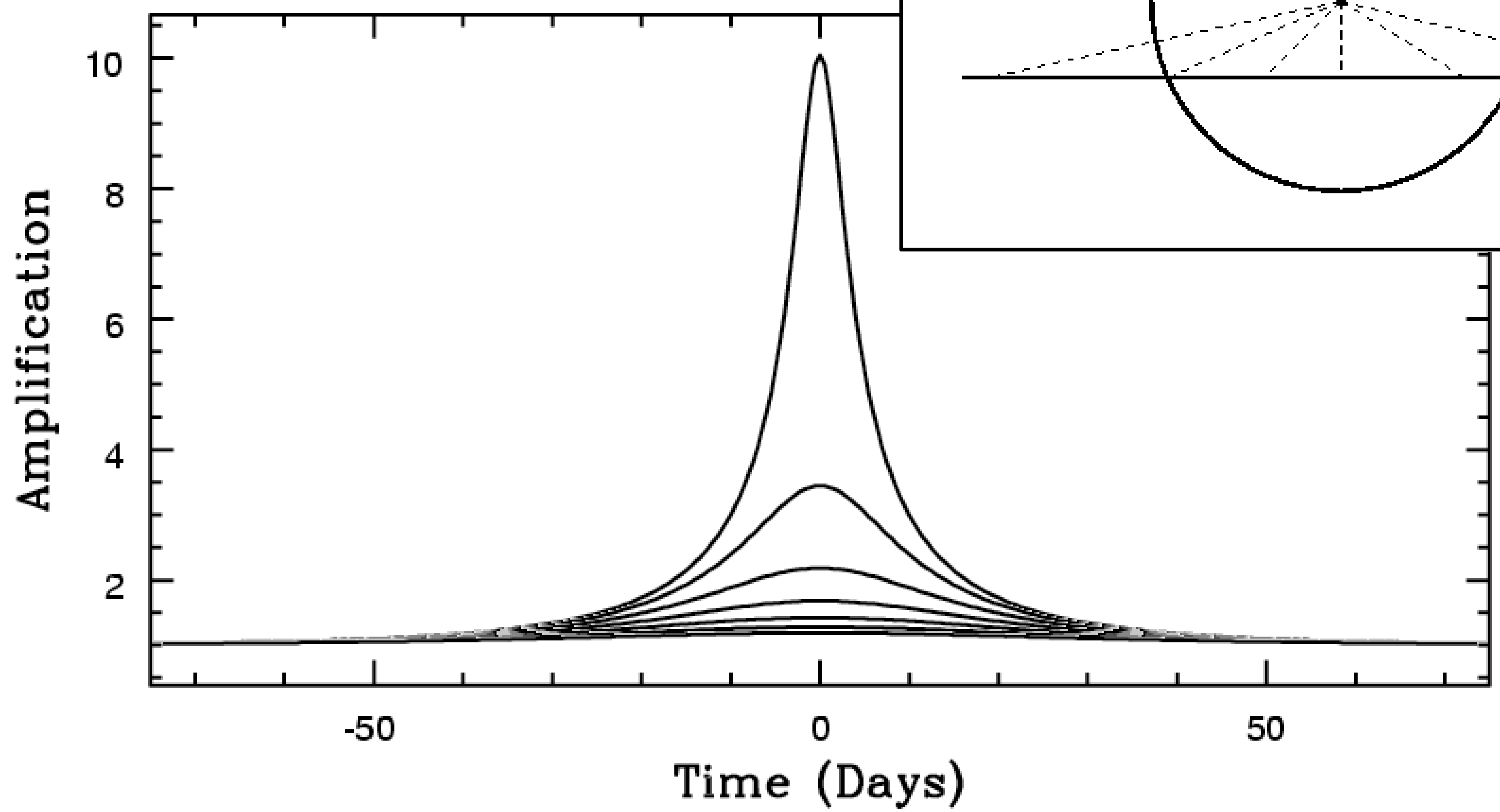


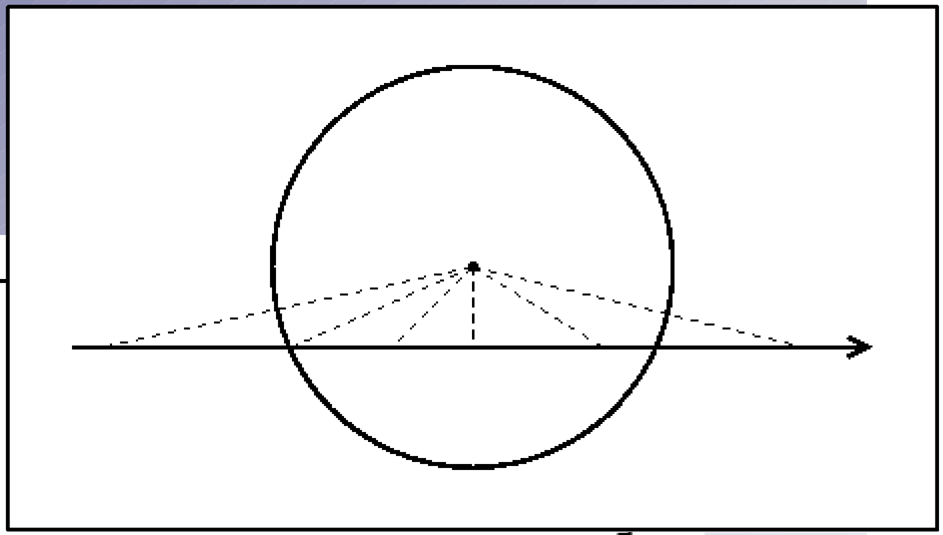
with 1σ Δa_μ constraint
no Δa_μ constraint
WMAP 2σ constraint
spin−independent cross−section σ_SI (picobarns)
neutralino mass m_χ (GeV/c²)
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
10^-16
10^-17
10^-18
10^2
10^3
CDMS
EDELWEISS
DAMA allowed
CDMS II, CRESST II
GENIUS
CryoArray
XENON

Microlensing

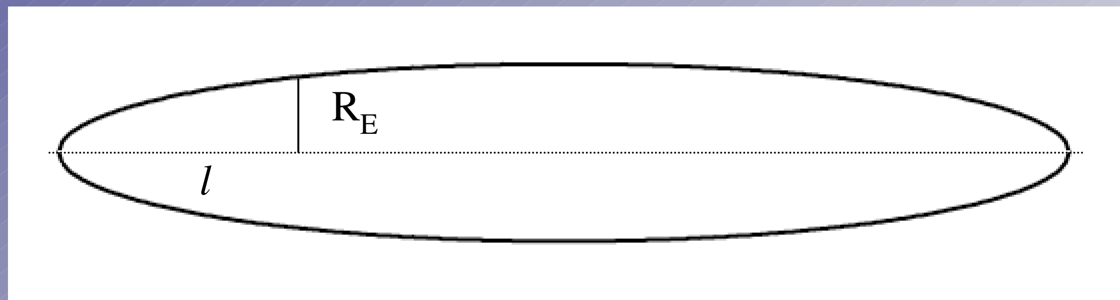


Microlensing lightcurve





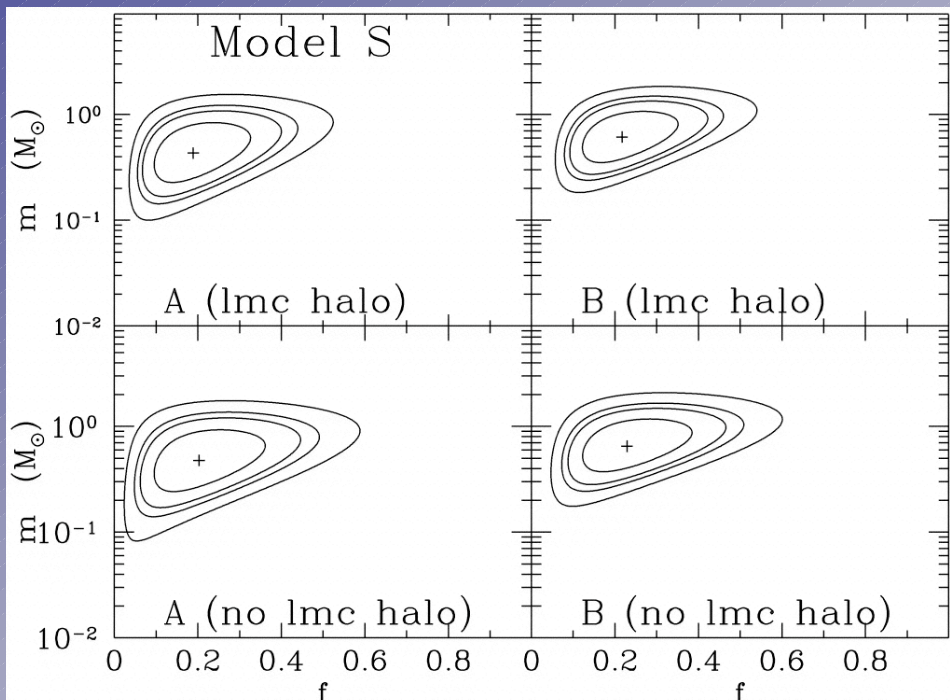
Microlensing Tube



$$R_E(l) = \sqrt{\frac{4Gm}{c^2}\frac{l(D_s - l)}{D_s}},$$

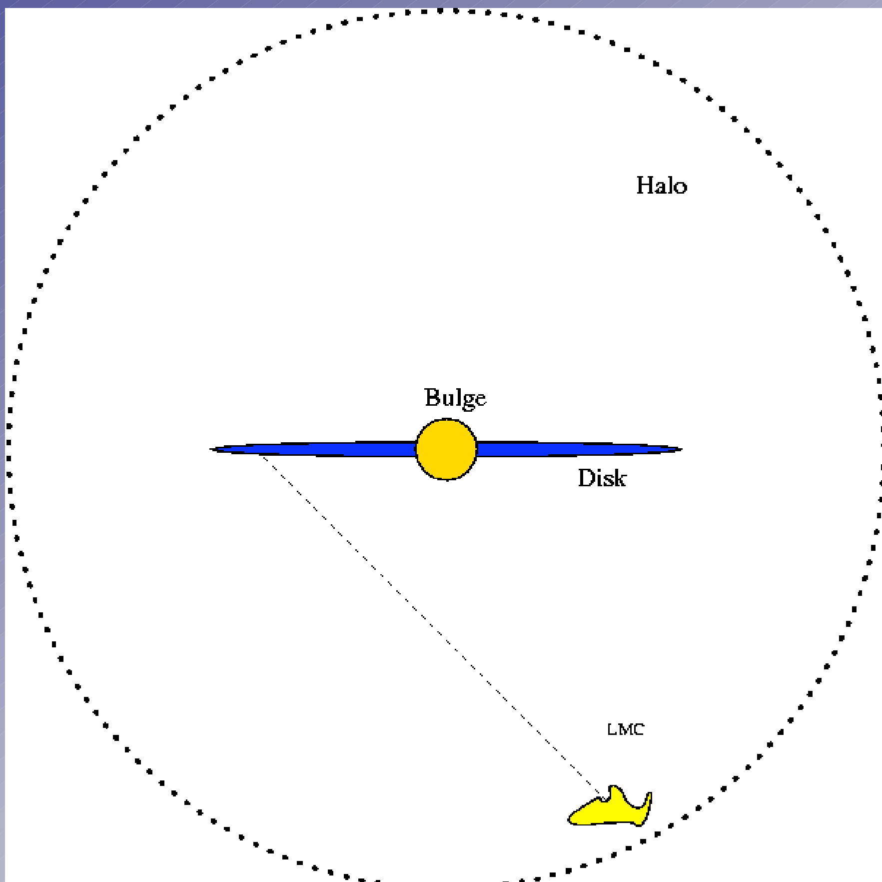
$$\tau = \frac{4\pi G}{c^2 D_s}\int_0^{D_s} x(D_s - x)\rho(x)dx$$

Microlensing in Our Halo



- Line of sight to LMC
- Microlensing detected
- Typical masses ~0.5 M_
- Substellar objects ruled out
- Consistent with ~20% of halo in compact objects

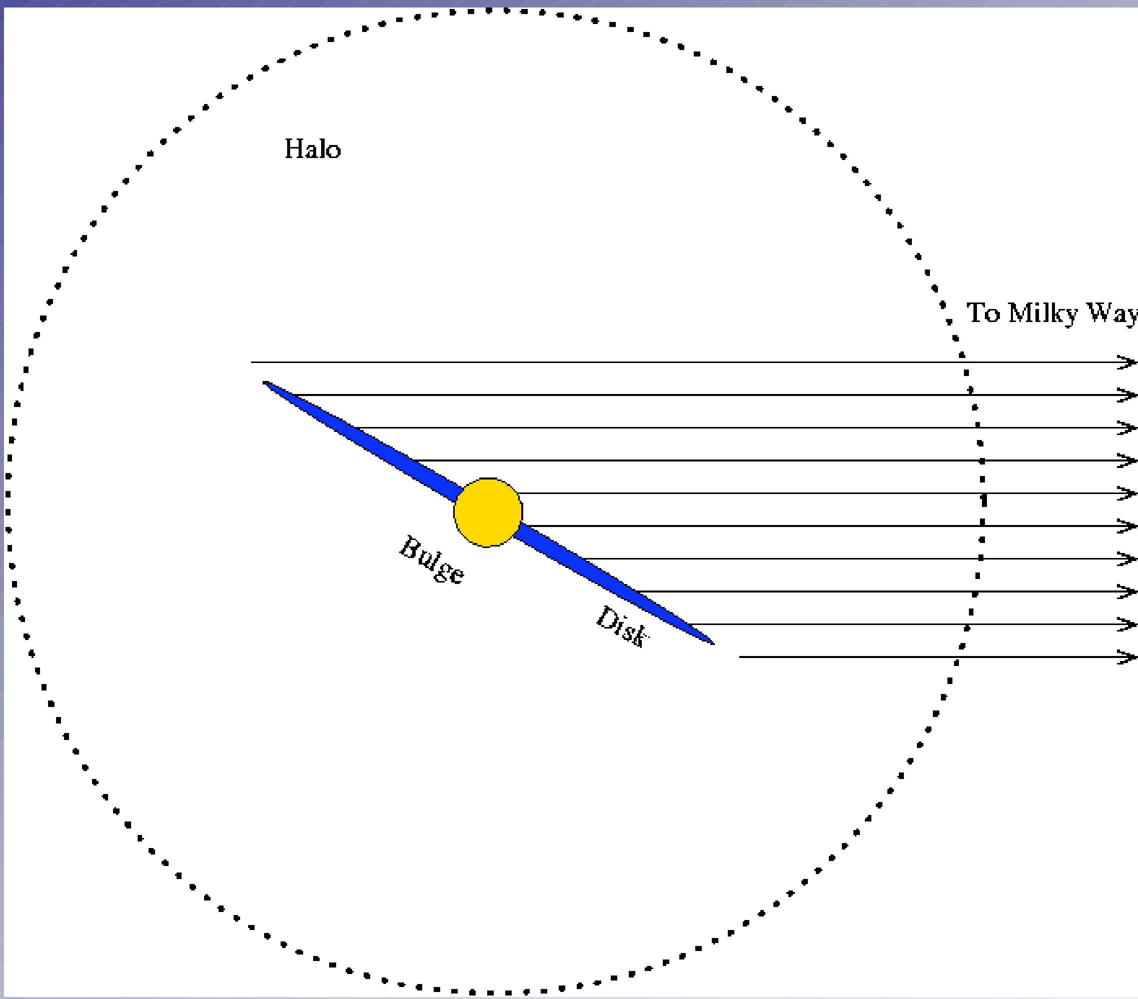
Microlensing in Our Halo



_ Unclear Interpretation
  – model dependent
  – self-lensing by LMC?
_ Limited
  – low event rates
  – few and "awkward" lines of sight

Why stay at home?

Benefits

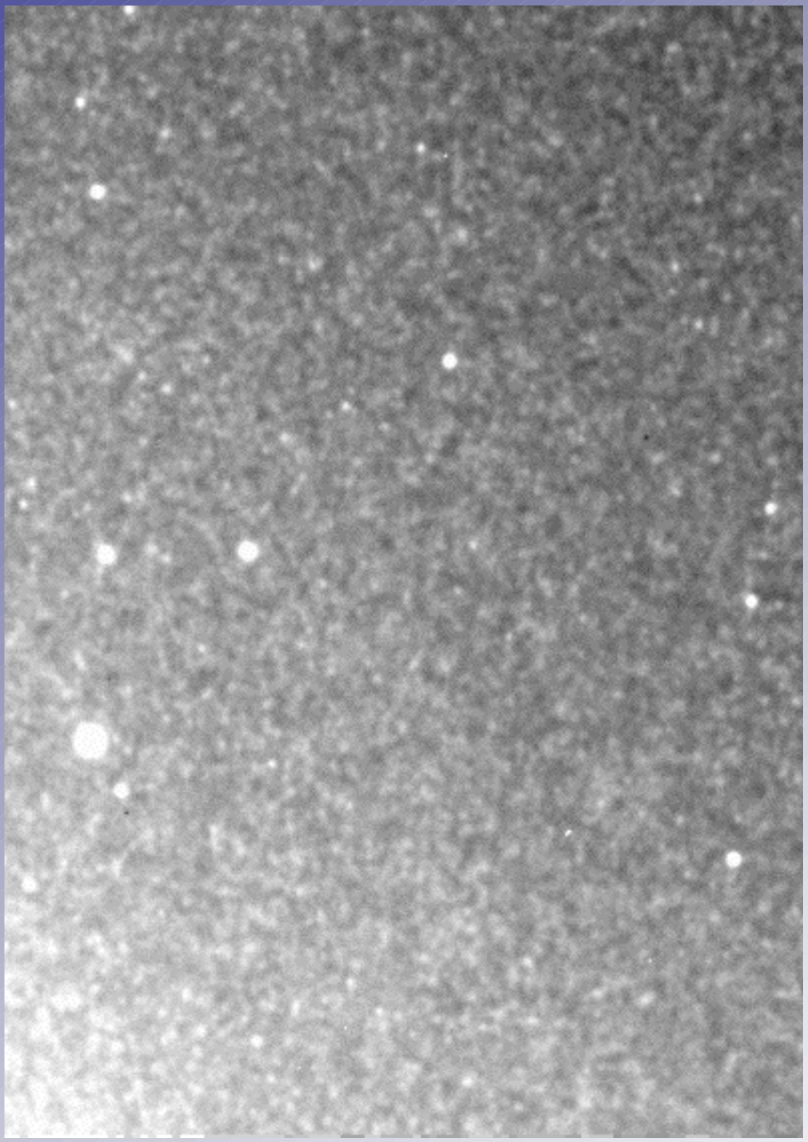


- Multiple lines of sight
- High event rates
- Built-in control
- Uniqueness

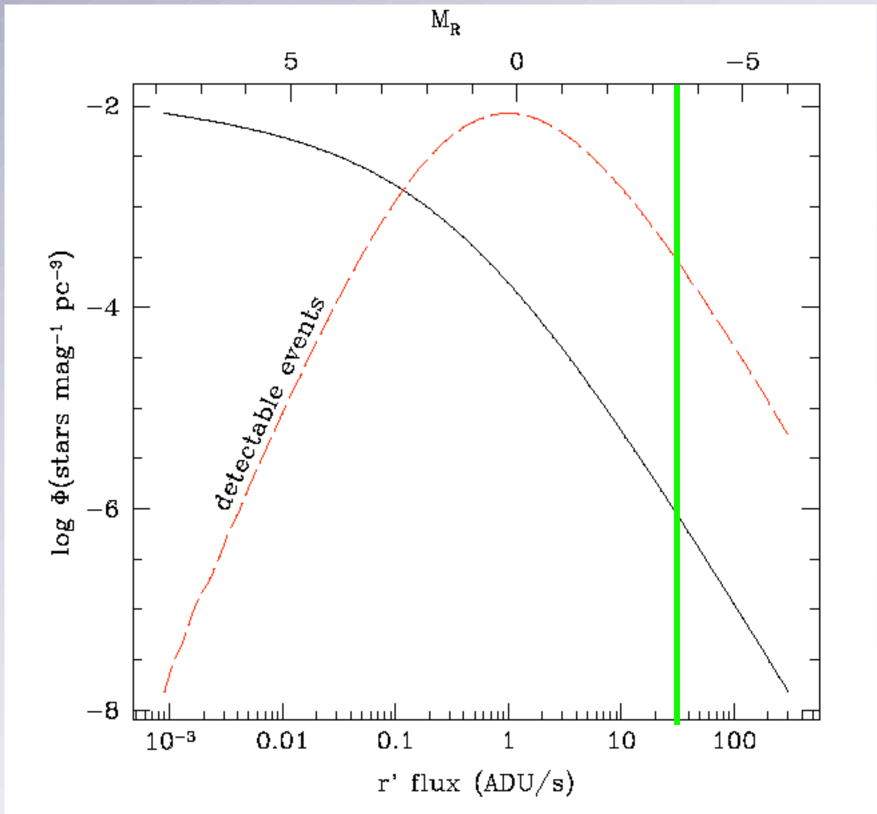
Stellar targets

- Potentially billions of targets

Stellar targets



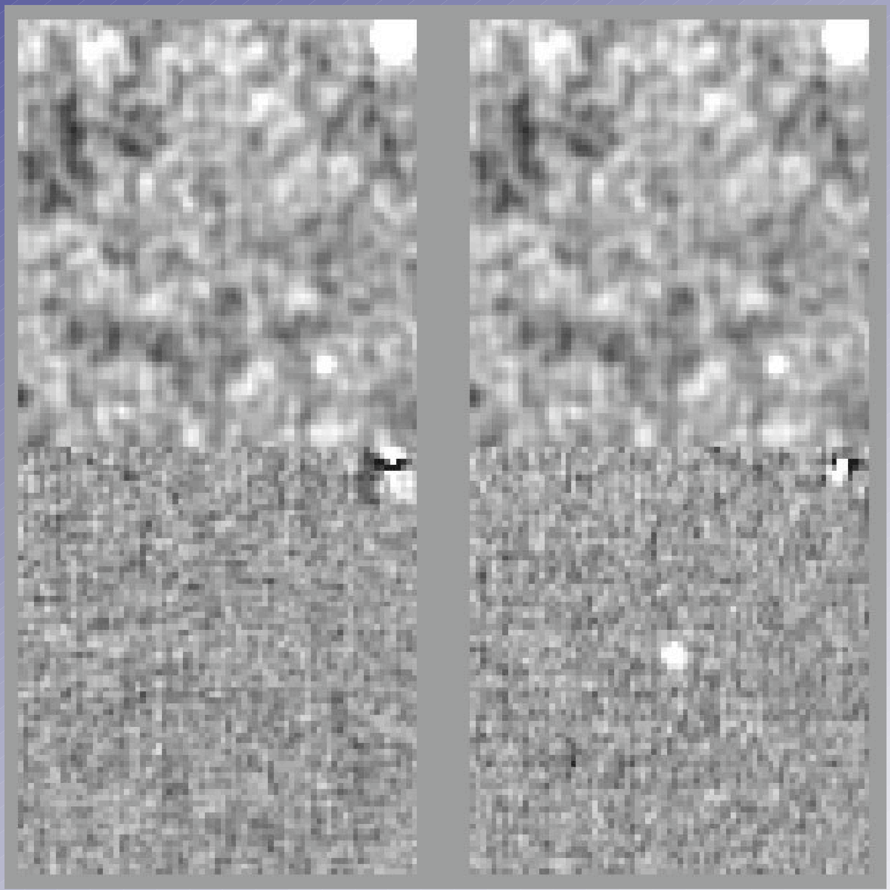
- Potentially billions of targets



Stellar targets

- Potentially billions of targets
- Few bright stars: most far below surface fluctuations
- Superpixels
- Difference Imaging

Difference Imaging



- Image registered to a reference image
- Convolution kernel transforms image PSF to reference PSF
- Consecutive residuals threaded to form light curve
- Can probe far below the surface fluctuations
- Very good error controls (within 2x photon noise!)

Microlensing Exploration of the Galaxy in Andromeda

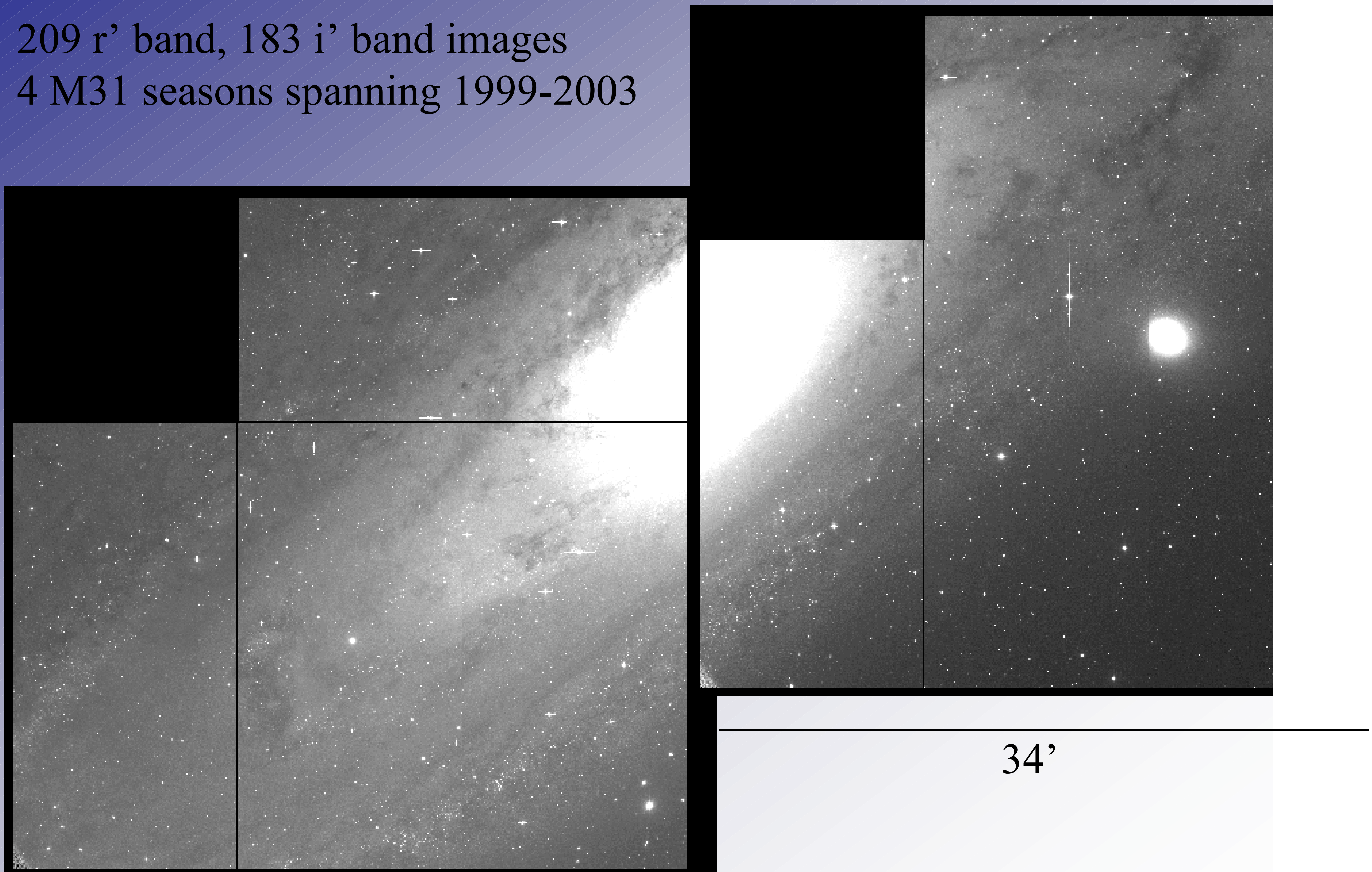
- Multiyear project (since 1998)
- Large database (terabytes)
- Multinational (U.S., Canada, England, Holland, Australia)

- Columbia University
  - Arlin Crotts
  - Robert Uglesich
  - David Alves
  - Alexander Bergier
- Adler Planetarium
  - Geza Gyuk
- Stanford
  - Ted Baltz
- Queens University
  - Larry Widrow
- Kapteyn
  - Conrad Kuijken
  - Jelte deJong
- Mt. Stromlo
  - Penny Sackett
- Cambridge
  - Will Sutherland

- KPNO Mayall 4-m
- INT 2.5-m
- MDM 2.4-m and 1.3-m
- Subbaru 8-m

INT data:

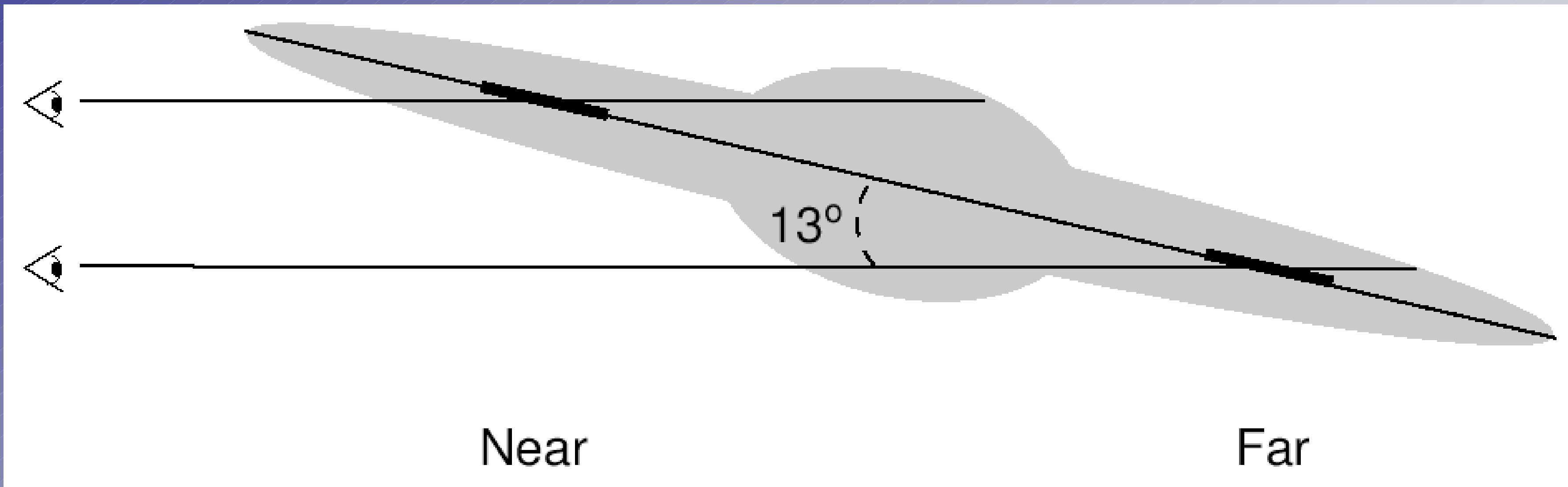
209 r’ band, 183 i’ band images
4 M31 seasons spanning 1999-2003



INT 4 year light curves

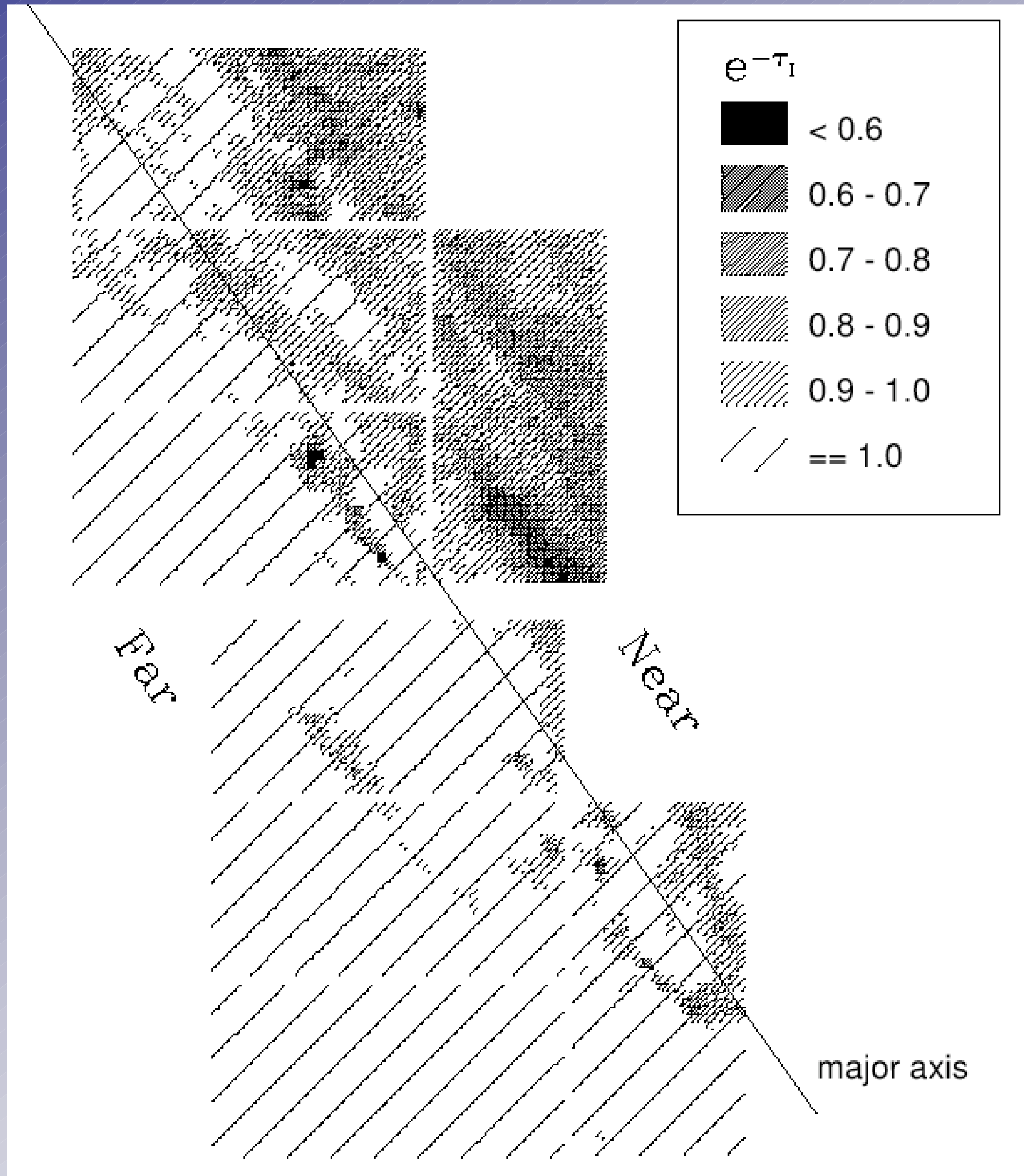
- ~105,000 variable sources
  - Variable stars
  - Novae
  - Background events
- Not symmetric
  - Even variable stars
    - Dust extinction

Extinction



$$I_{obs} = x\, I_{intr} + (1\text{-}x) I_{intr}\, e^{-\tau}$$

w/ x derived from galaxy models



$e^{-\tau_I}$
< 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1.0
== 1.0
Far
Near
major axis

Microlensing Event Selection

- Well sampled light curve (>100 points)
- Well sampled peak (4+ points 3σ above baseline)
- Peak within well sampled region

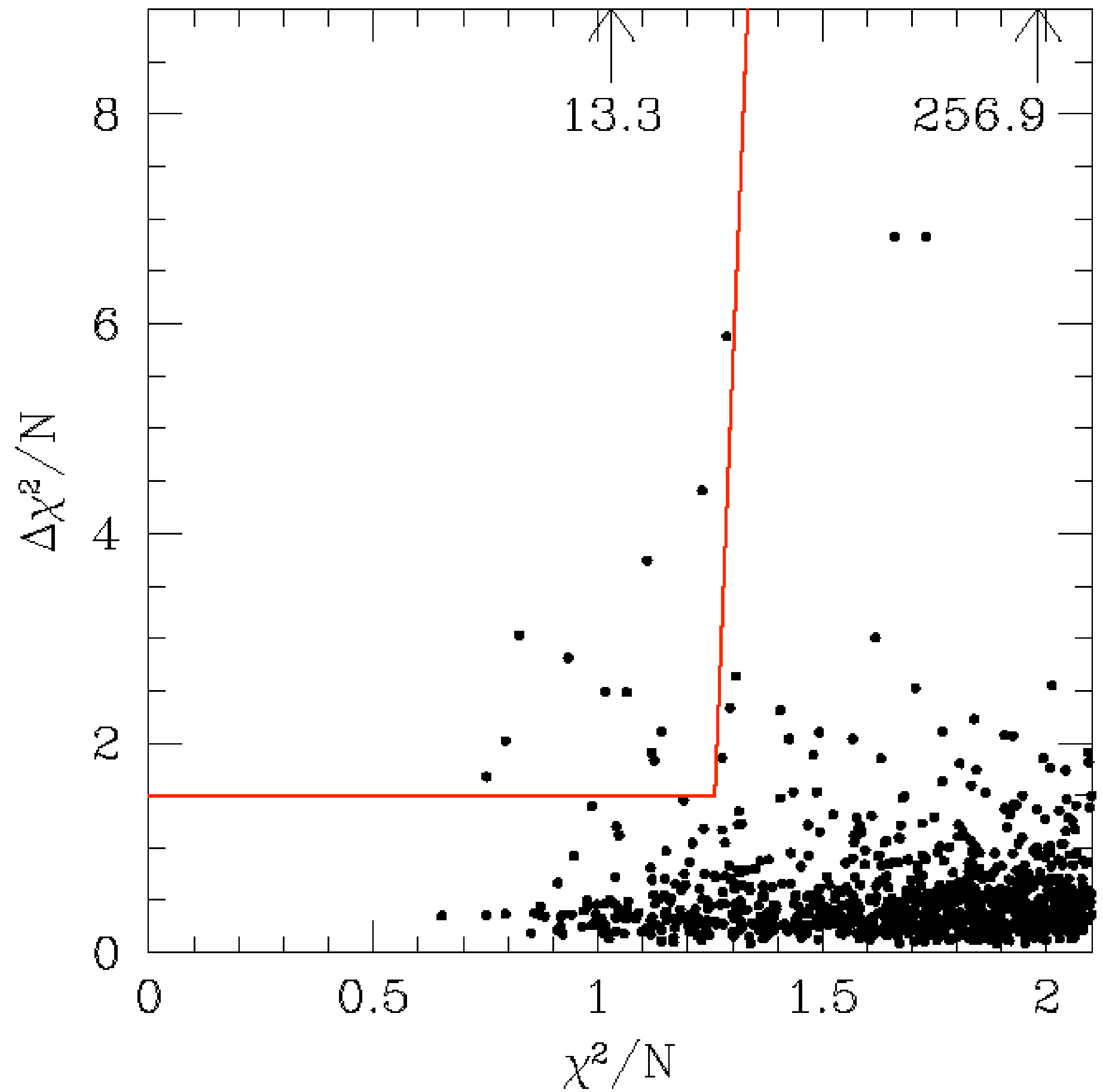
==> 29,000 lightcurves

- Simultaneous (r' and i') fits of light curves

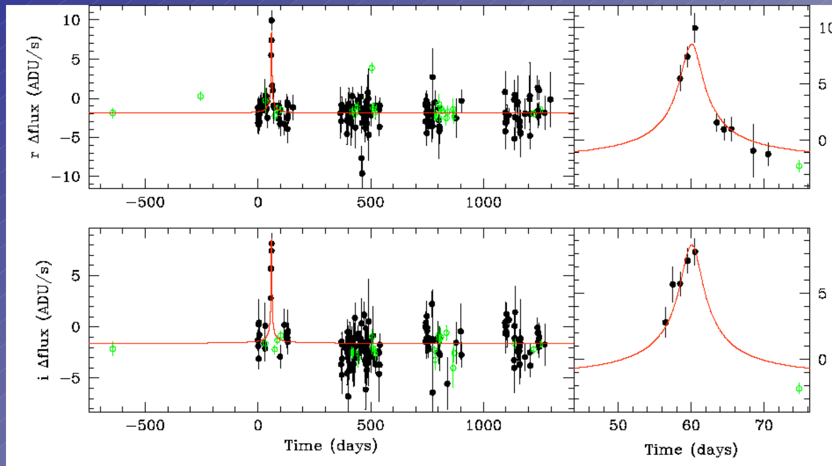
$\Delta\chi^2 > 1.5\ N$

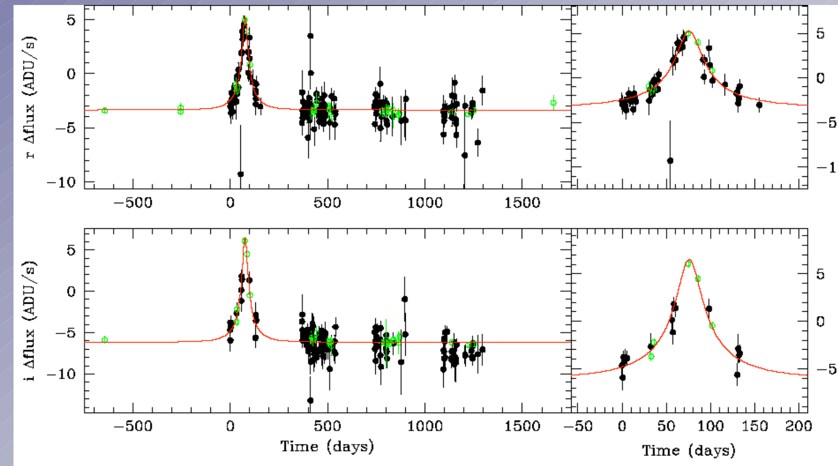
$\chi^2 < (N\text{-}7)\ (\Delta\chi^2/100+1) + 3\ (2\ (N\text{-}7))^{1/2}$

==> 14 light curves



13.3
256.9
8
6
4
2
0
0
0.5
1
1.5
2
$\Delta\chi^2/N$
χ^2/N


r Δflux (ADU/s)
i Δflux (ADU/s)
Time (days)
Time (days)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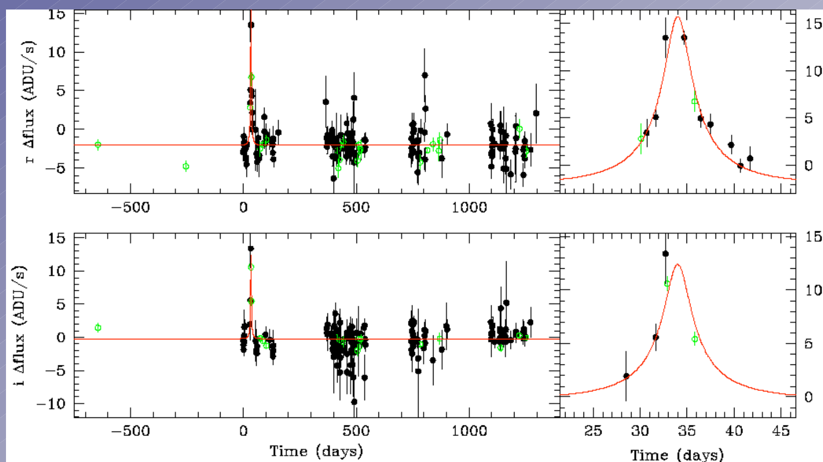
i Δflux (ADU/s)
Time (days)
Time (days)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i Δflux (ADU/s)
Time (days)
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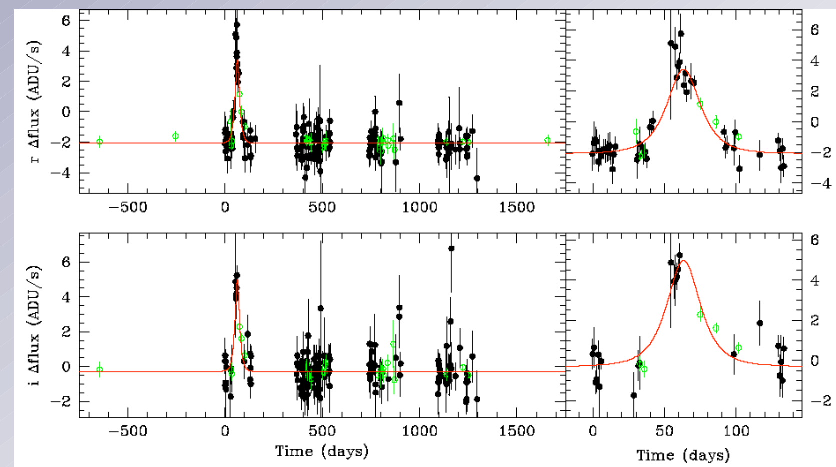
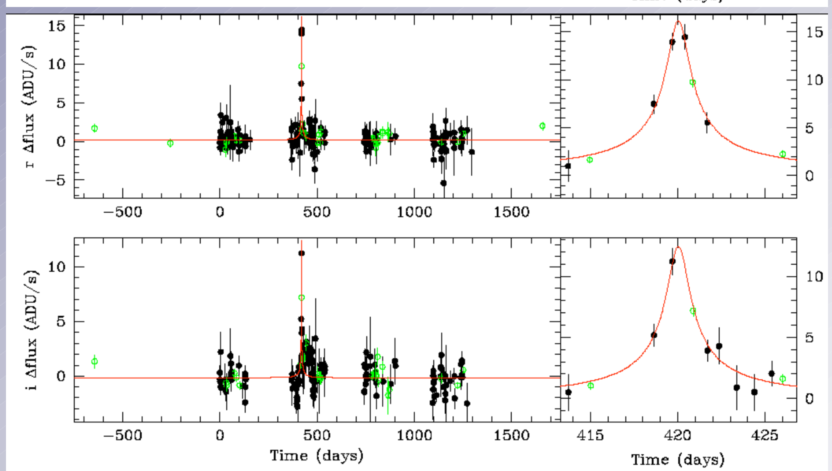
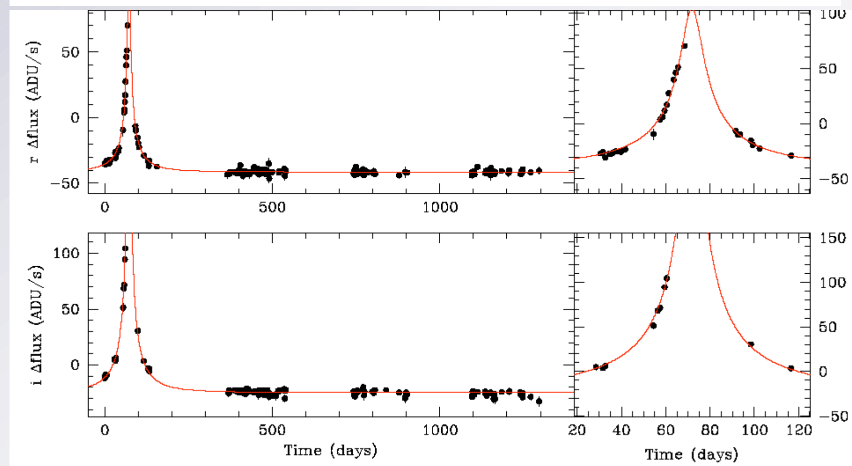
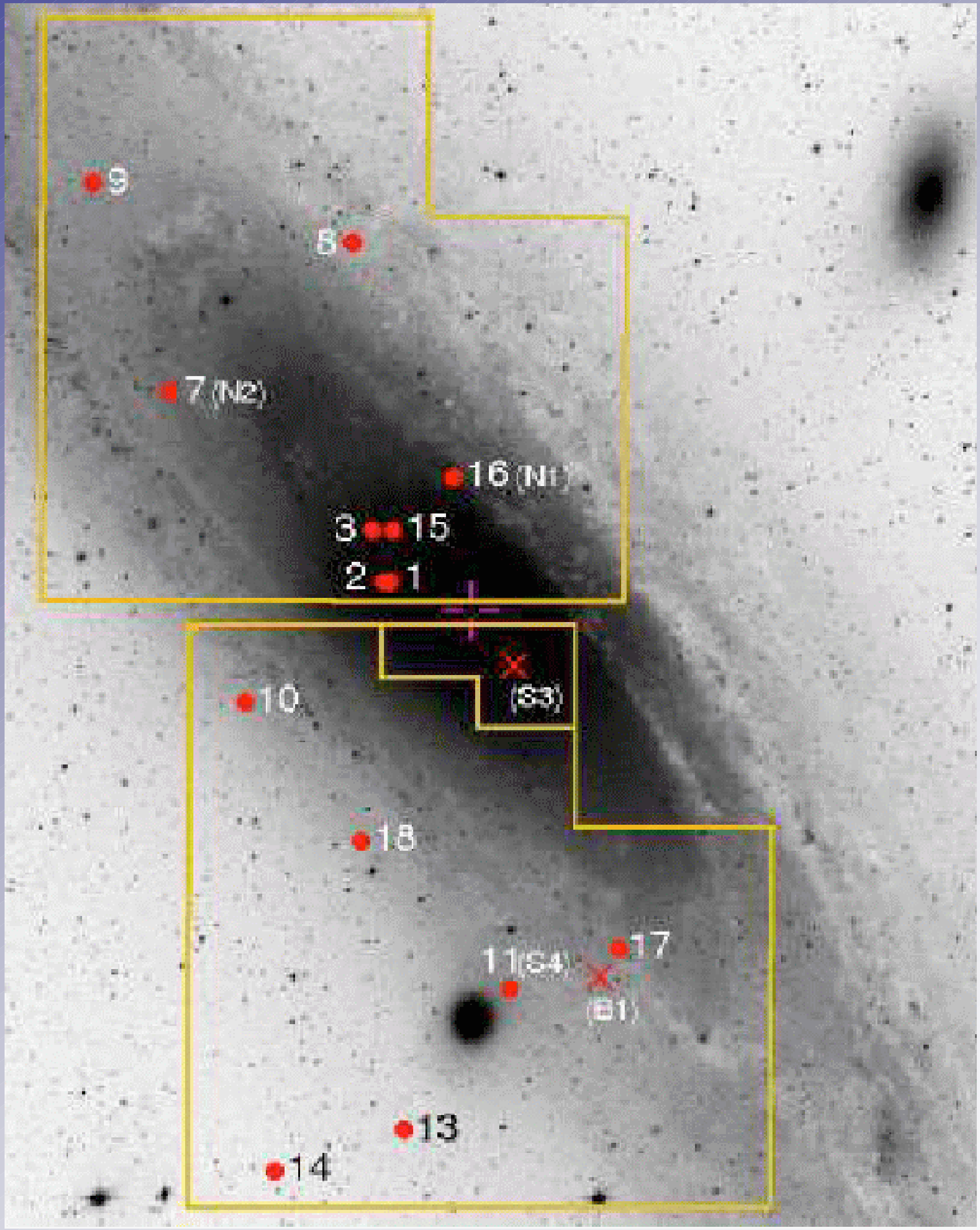

r Δflux (ADU/s)
i Δflux (ADU/s)
Time (days)
Time (days)


r Δflux (ADU/s)
i Δflux (ADU/s)
Time (days)
Time (days)


r Δflux (ADU/s)
i Δflux (ADU/s)
Time (days)
Time (days)

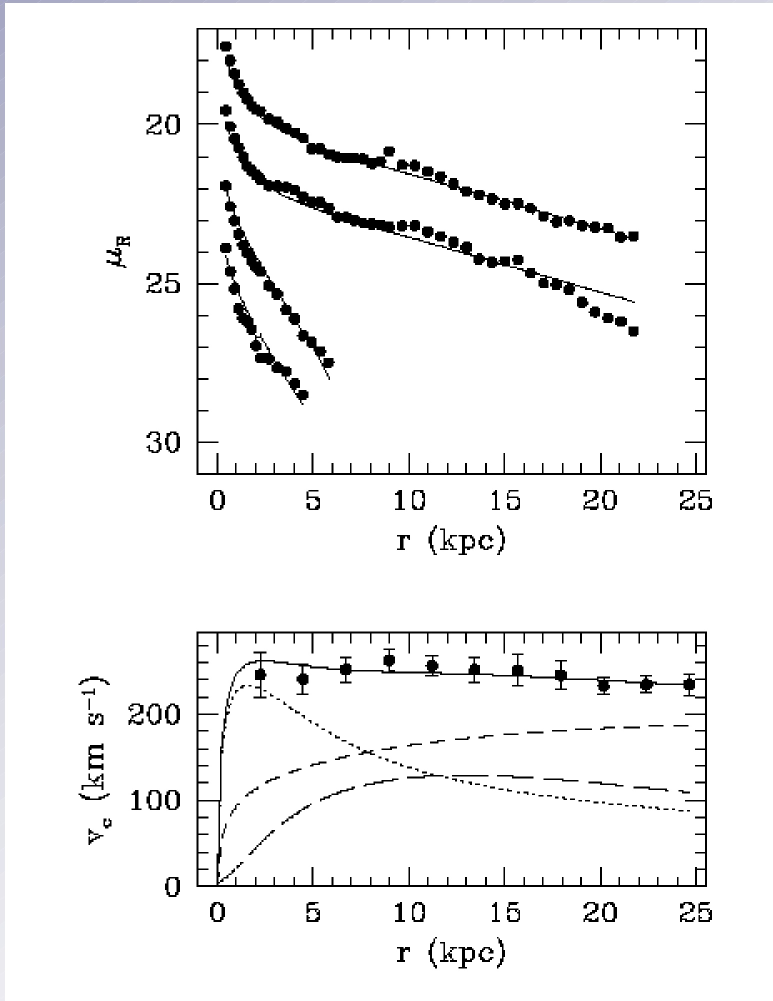

9
8
7 (N2)
16 (N1)
3
15
2
1
(S3)
10
18
11 (S4)
17
(B1)
13
14

What does it mean?

- Detection efficiencies
  - Artificial event catalogs
- Self consistent M31 mass and luminosity models
  - exp-sech2 disk
  - Hernquist bulge
  - NFW halo

M31 Modelling

- Self consistent 3 component models
- M/L ratio
- Rotation curve
- Luminosity map
- Comparison to edge-on galaxies



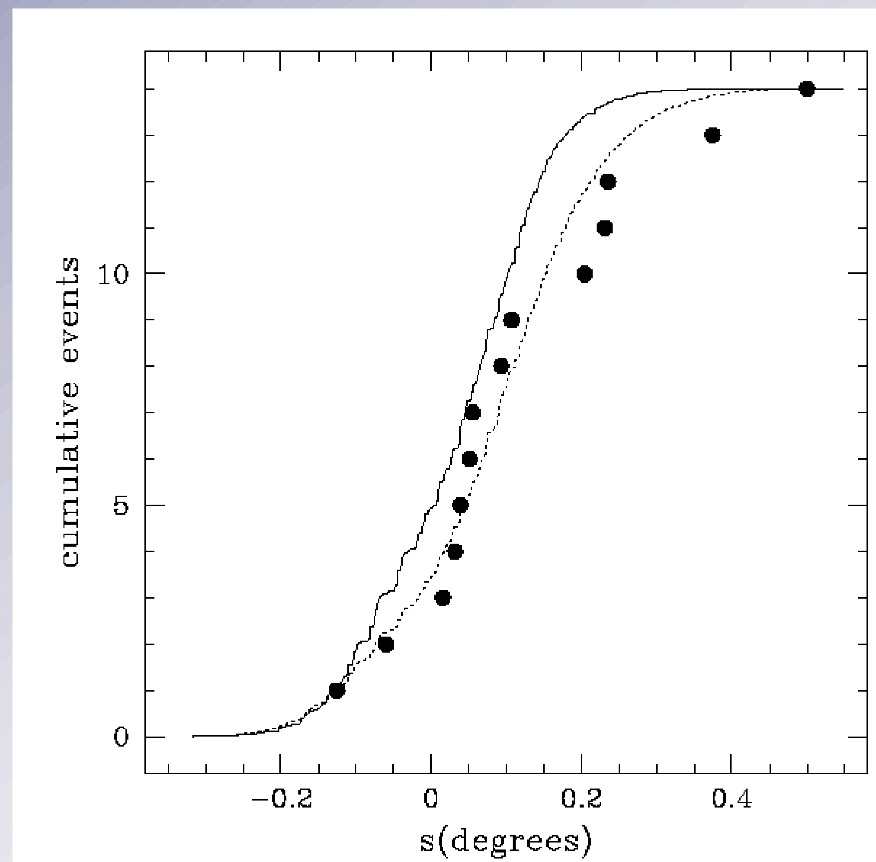
Event Rates

- Broadly consistent with self-lensing
- Expect 10-16 events from known components, have 14

$$\Gamma = 2\int_0^{D_s} R_E(l)\frac{\rho(l)}{m} < |v_\perp| > dl.$$

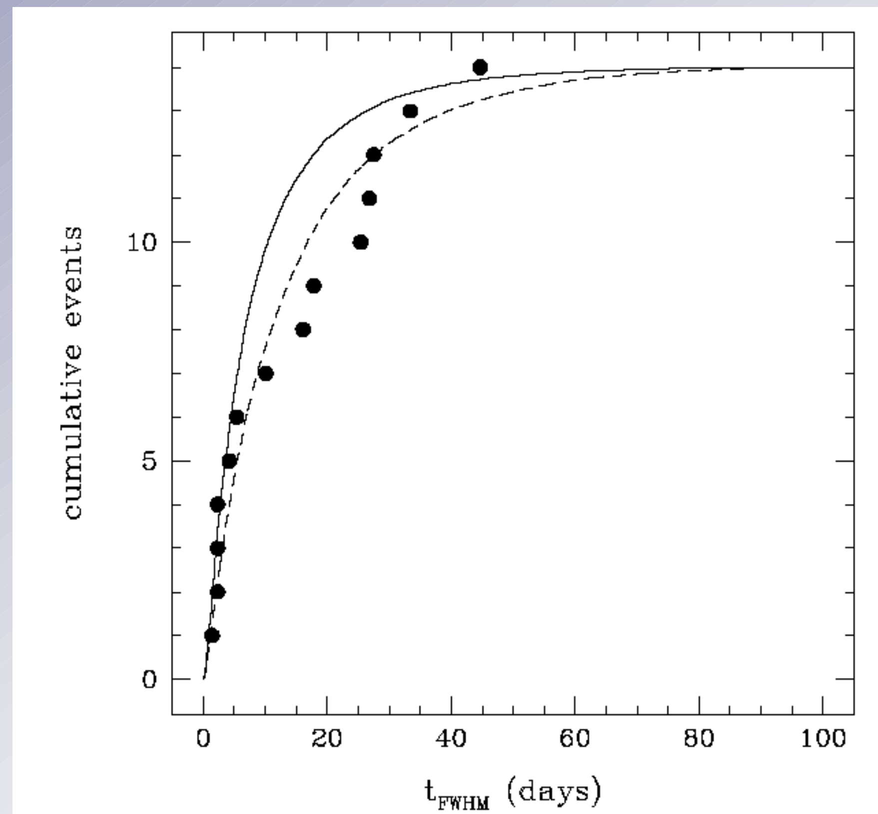
Spatial Distribution

- Events strongly asymmetric
- Favors halo models
- Asymmetry large even for halo

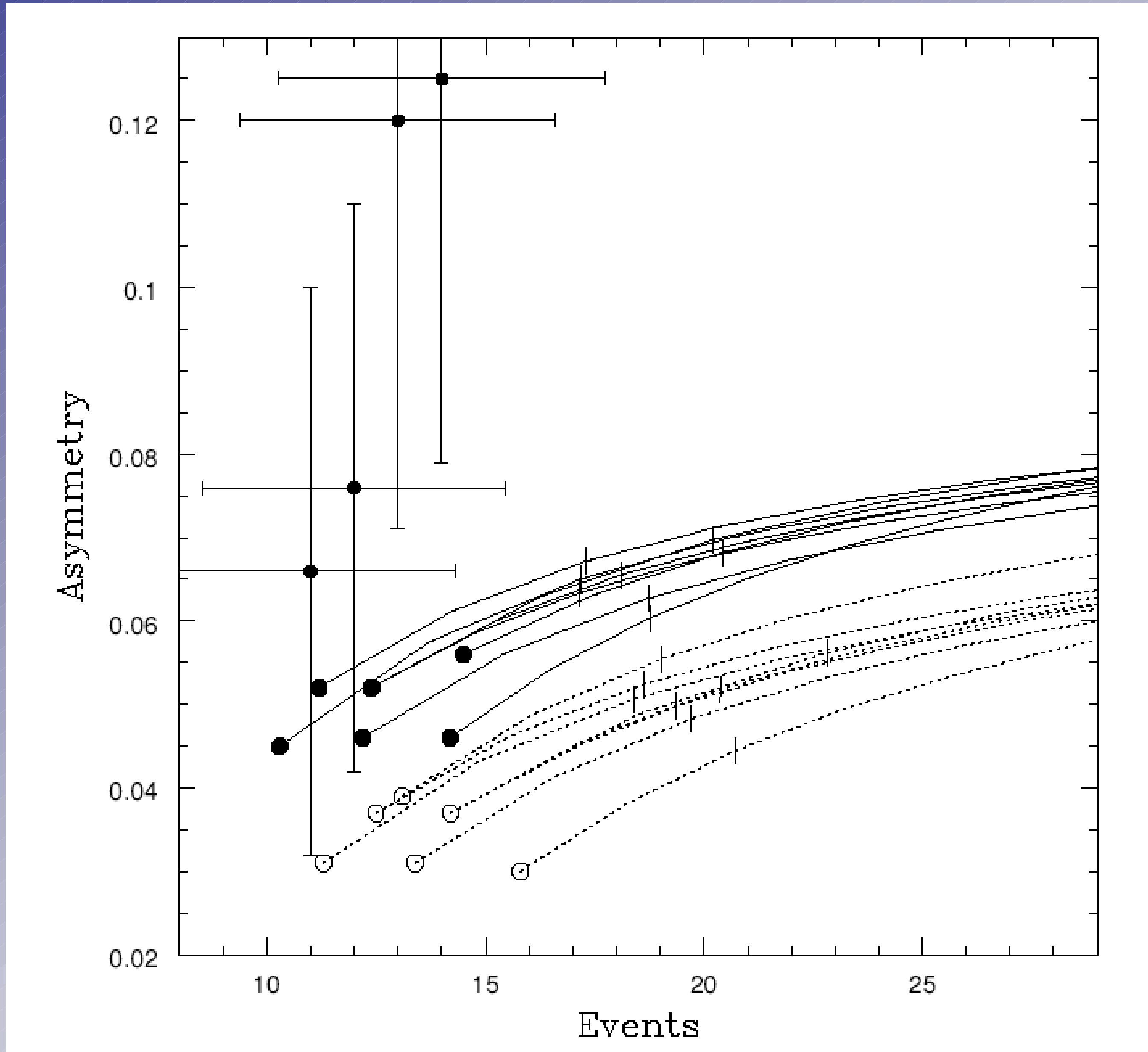


Timescale Distribution

- Timescales consistent with stellar mass objects
- Timescales favor halo models



$A = \Sigma s_i / N$



Conclusions

- M31 microlensing detected (~14 events)
- Results intriguing!
  - Distribution (asymmetry) appears to be halo-like
  - Event rates appear to be self-lensing-like
  - Halo fraction as large as 0.25 not excluded
- M31 not as ideal a test as thought
  - Dust
  - Tidal streams and satellites

Future steps

- Better understanding of dust
- Baselines continue to be monitored
- More HST followup
- Major effort to analyze joint INT, KPNO, MDM data underway.

- SNAP, LSST near ideal

The End

The Case for Baryons

- Primordial nucleosynthesis
  - light element abundances consistent with 5% baryons
- Cluster baryon fraction
  - cluster hot gas more massive than stars
- Visible stars < 1% of mass

$\Rightarrow$ In local group, most baryons are invisible!

Faint Stars?

_ Above hydrogen burning limit

_ Should have been seen in various deep Hubble fields

_ Limit of <<1% of halo in faint stars

White Dwarfs in the Halo?

- Advantages
  - well understood
  - about right mass
  - plausible amount of baryons
- Disadvantages
  - metal pollution
  - light pollution
  - radically different galaxy history

What to do?

- Want to probe more of halo!
- Need targets with low self lensing

- Wait as LMC/SMC orbit.....
- Other targets?
  - globular clusters?
  - dwarf spheroidals?
  - tidal tails?
  - stellar disk?