Halo Microlensing in M31

Arlin Crotts

KITP, 21 August 2002

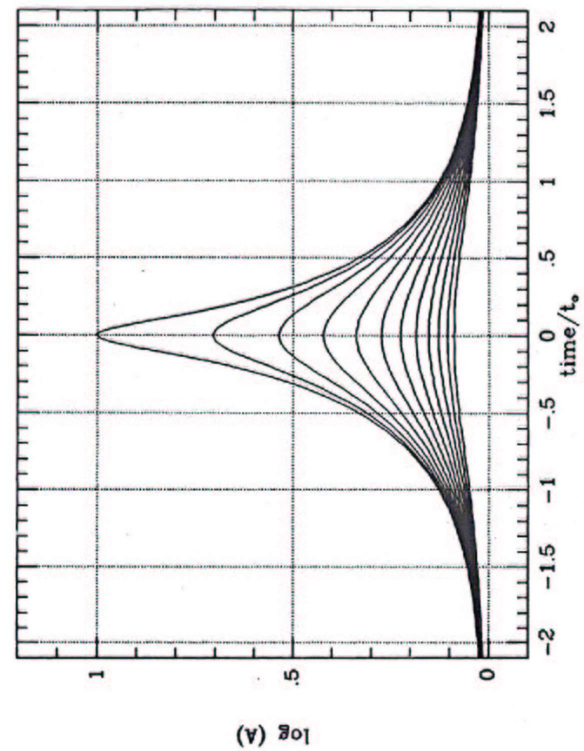


FIG. 2.—Time variation of the amplification due to gravitational microlensing for events with the impact parameter d/R_0 equal 0.1, 0.2, ..., 1.1, 1.2. The largest amplitude corresponds to the smallest impact parameter. The unit of time is given as $t_0 = R_0/v$, where R_0 is the radius of ringlike image formed when the source, the lensing mass, and the observer are perfectly aligned (see eq. [2] and [16]) and v is the relative tangential velocity of the lensing object.

$u \equiv d/R_0$

$A = \frac{u^2+2}{u(u^2+4)^{1/2}}$

(Paczynski 1986)

Halo Microlensing in M31:

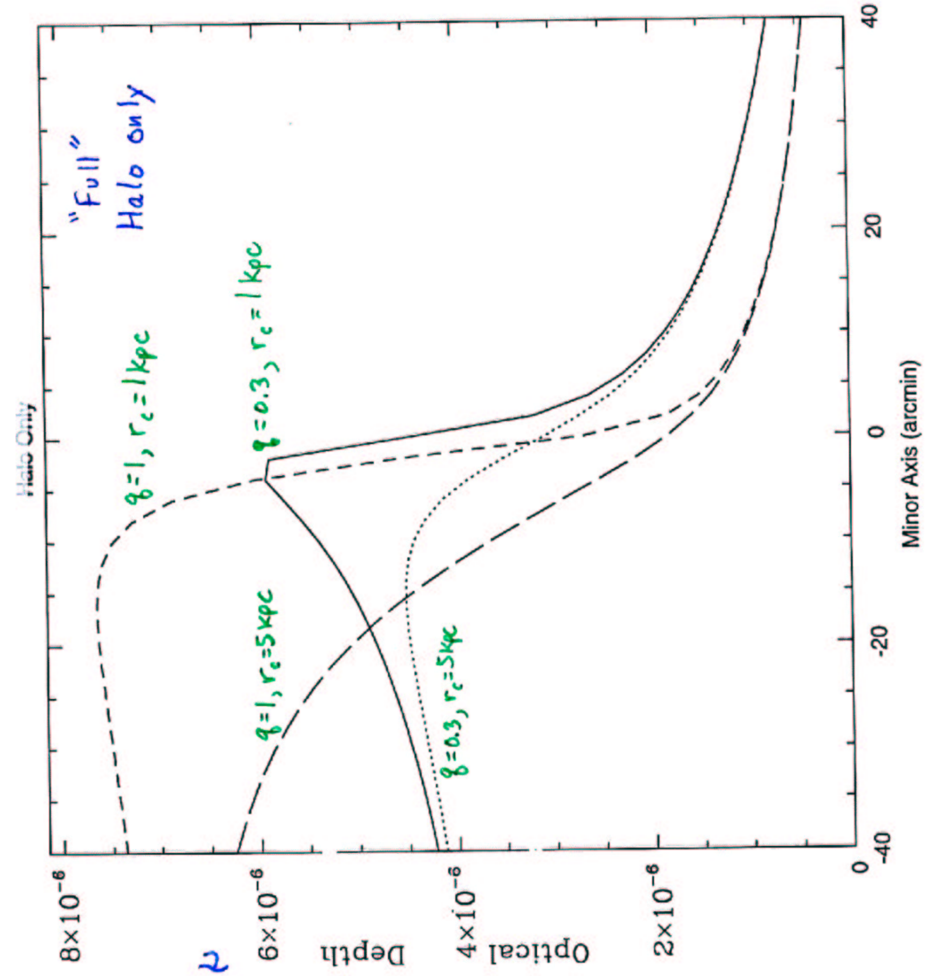
Assume the number density distribution $\eta(r)$ of halo masses produces a flat rotation curve v_{rot}, hence $\eta = v_{rot}^2/(4\pi G m r^2)$. The probability of an M31 disk star being amplified by at least 34% is

$$\tau = \int_{l_{max}}^{0} \sigma\, \eta\, dl \approx \int_{l_{max}}^{0} v_{rot}^2 \frac{l\, dl}{c^2 R^2}$$

$$= \left(\frac{v_{rot}}{c}\right)^2 \left[(\pi - i - s/r_{max}) \cot i + \ln\left(\frac{r_{max} \sin i}{s}\right)\right]$$

where l is line-of-sight distance, i the (complement of the) inclination angle, and s the impact parameter of the line of sight.

Note: $\tau \propto$ total halo mass, regardless of m.



R. Uglesich + A. Crotts

40

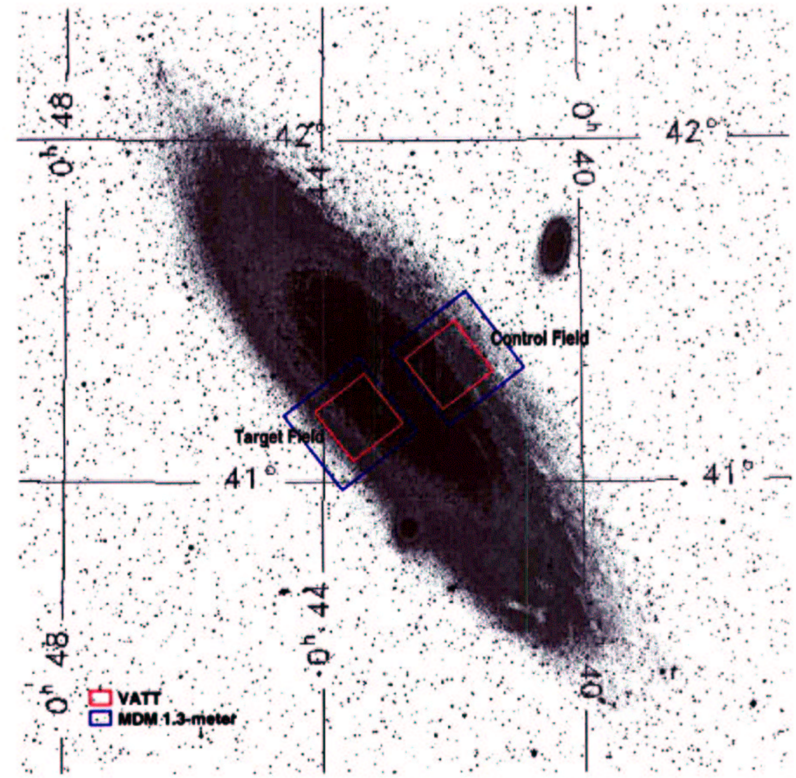


Figure 2.2: Ground-based optical image of M31 taken from the Digitized Sky Survey (DSS). Image size is approximately 2° × 2°. The locations of our various survey fields are indicated.

Columbia/VATT Survey of microlensing in M31

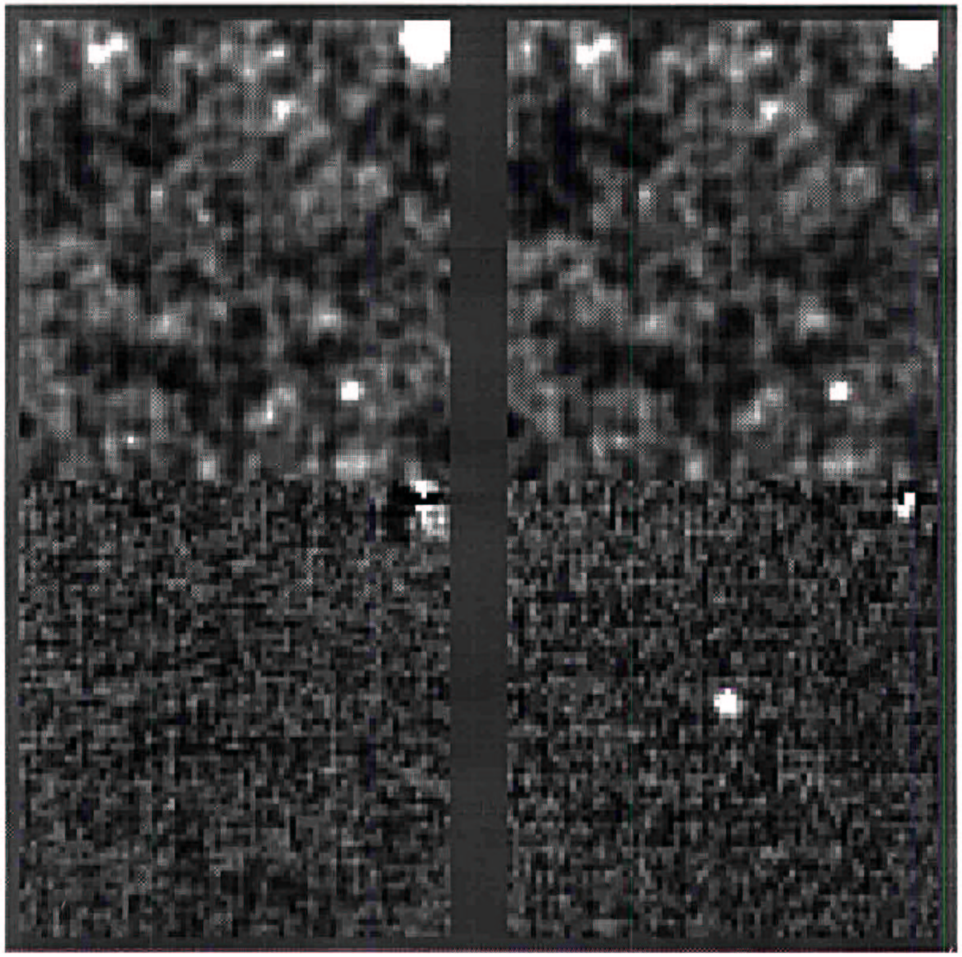
Robert Uglesich, Arlin Crotts, Ted Baltz, Austin Tomaney (Columbia U.)

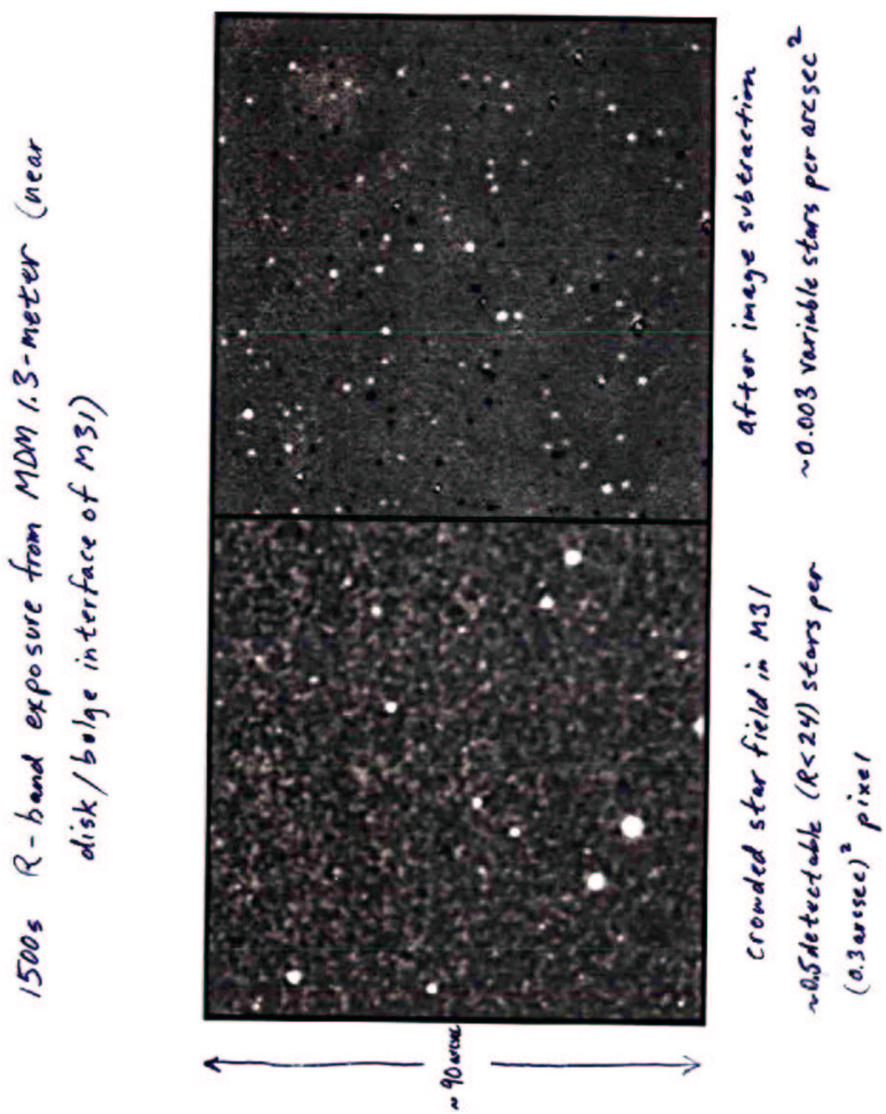
Jelte deJong (Kapteyn)

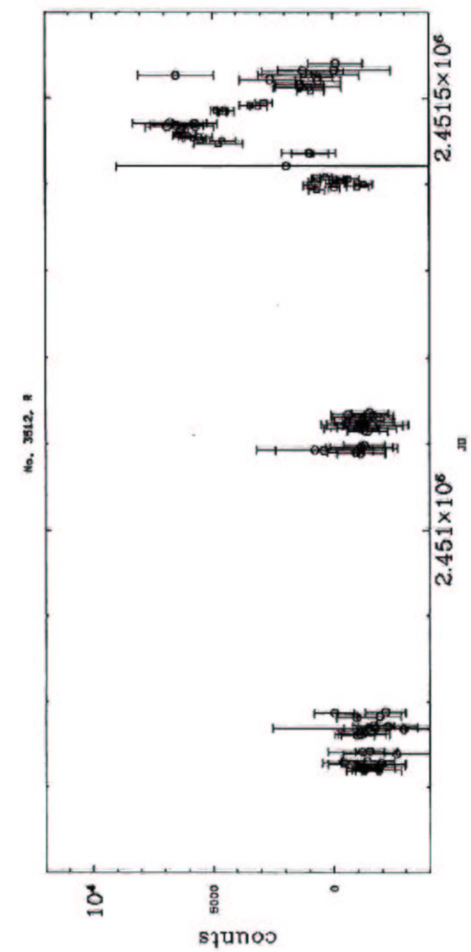
Rich Boyle, Chris Corbally (Vatican Obs.)

Andy Gould (Ohio State)

Monitored 240 arcmin^2 (390 arcmin^2) area on VATT 1.8m (MDMO 1.3m) intensively from 1997-1999, about 40-60 epochs per season, plus less intensive monitoring 1995-present.




1500s R-band exposure from MDM 1.3-meter (near disk/bulge interface of M31)
after image subtraction
~0.003 variable stars per arcsec²
Crowded star field in M31
~0.5 detectable (R<24) stars per (0.3 arcsec)² pixel
~90 arcsec


No. 3512, R
counts
10⁴
5000
0
2.451×10⁶
2.4515×10⁶

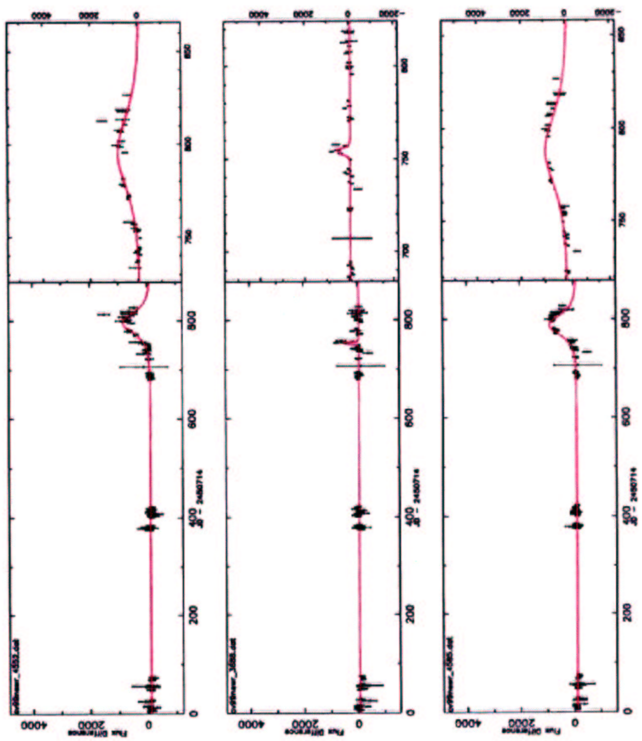


Figure 3.12: Columbia/VATT microlensing events located in the farside field. Left-hand panel shows full range of data while right-hand panel shows data from the season in which the event occurred. Fit is Paczynski microlensing curve of the form, $F(t) = F_0[A(t) - 1] + C$. Some data for JD-2450714 > 600 were obtained at the INT during the MEGA survey.

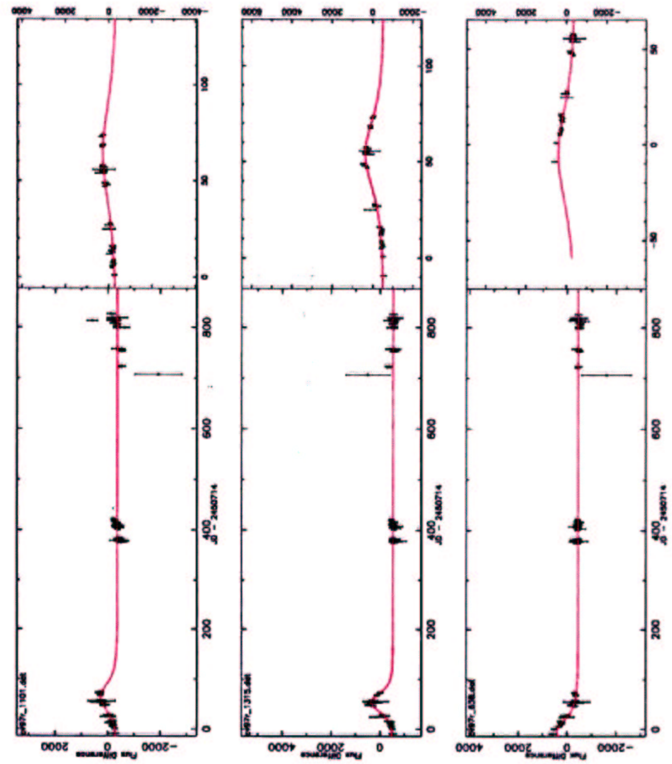
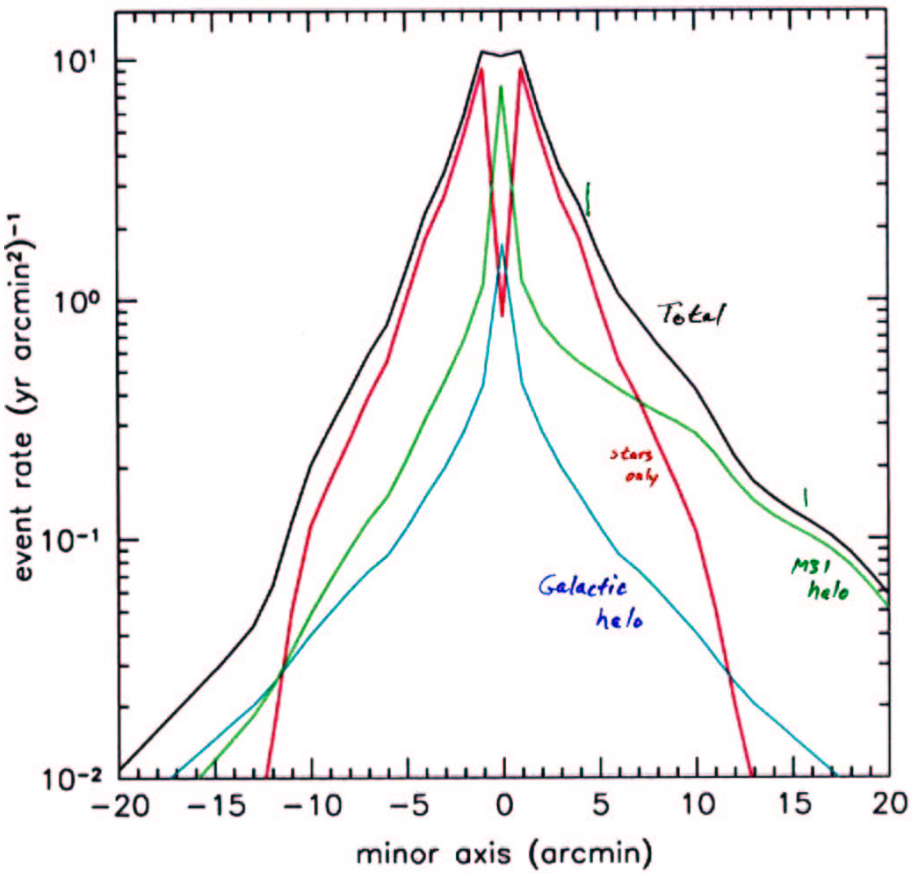
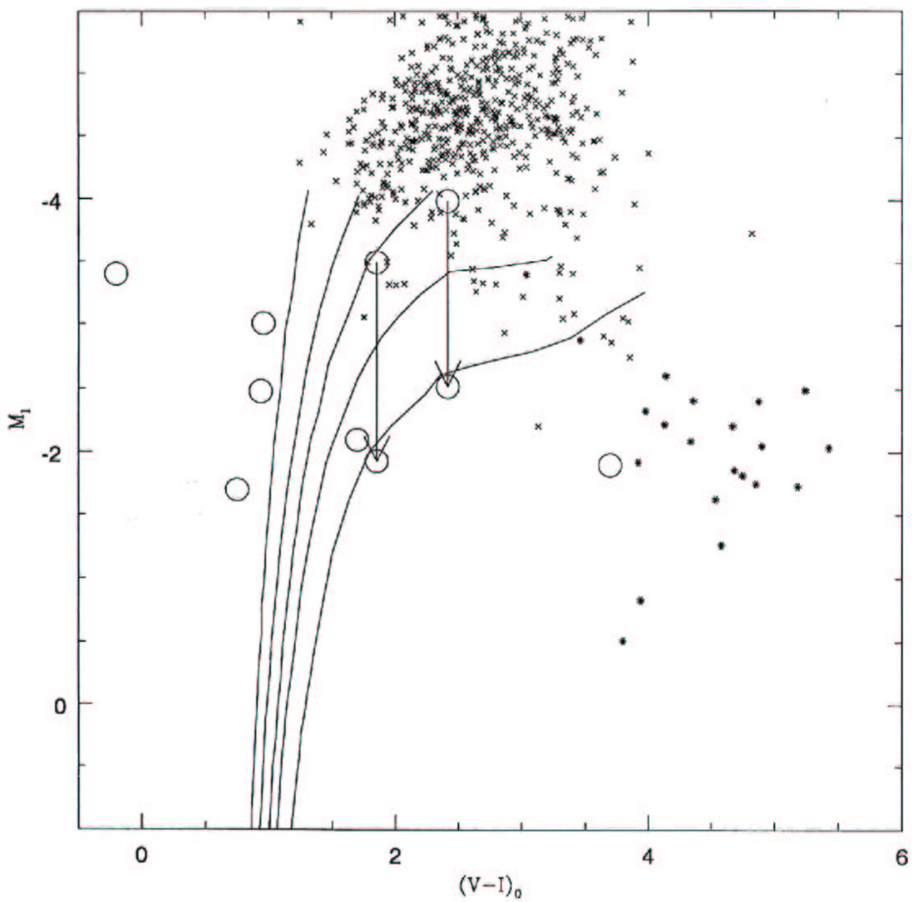
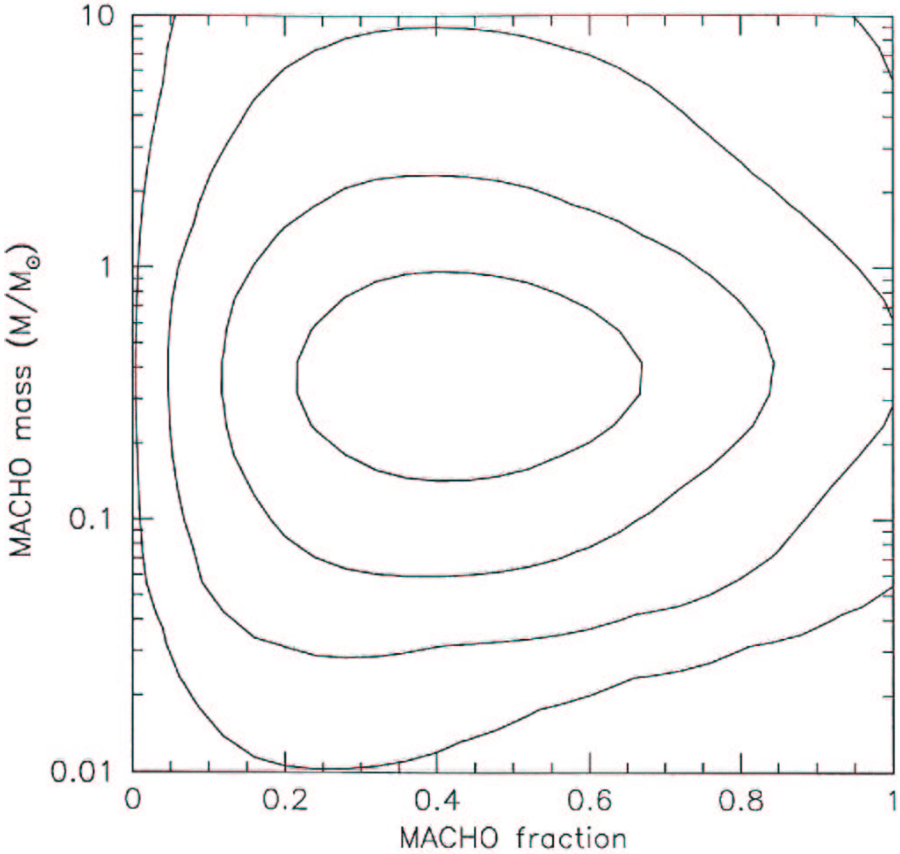


Figure 3.5: Columbia/VATT microlensing events located in the farside field. Left-hand panel shows full range of data while right-hand panel shows data from the season in which the event occurred. Fit is Paczynski microlensing curve of the form, $F(t) = F_0[A(t) - 1] + C$.


event rate (yr arcmin²)⁻¹
minor axis (arcmin)
Total
stars only
Galactic halo
M31 halo


M_I
(V−I)₀



Results from Columbia/VATT Survey

Based on 25 candidates (6+ ~14 real?):

Halo macho fraction: 0.42 ± 0.20

Macho component mass: $0.37^{+0.58}_{-0.22}\ M_\odot$

(assuming spherically symmetric, $r_c = 2$ kpc halo)

MEGA (Microlensing Exploration of the Galaxy & Andromeda)

Arlin Crotts, David Alves, Patrick Cseresnjes, Robert Uglesich,
Ted Baltz, Alex Bergier (Columbia U.)

Jelte deJong, Penny Sackett, Konrad Kuijken (Kapteyn)

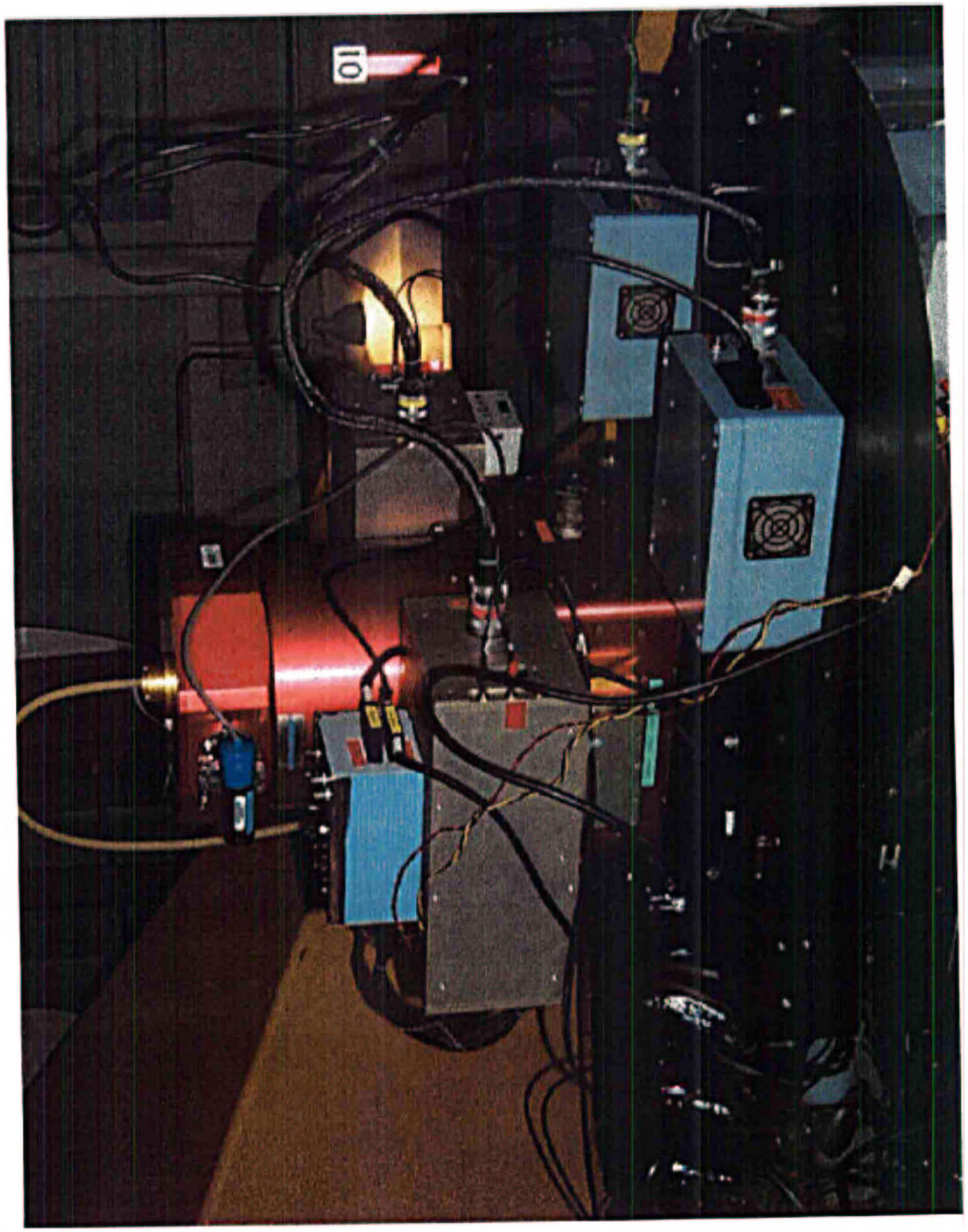
Geza Gyuk (Adler, U. Chicago)

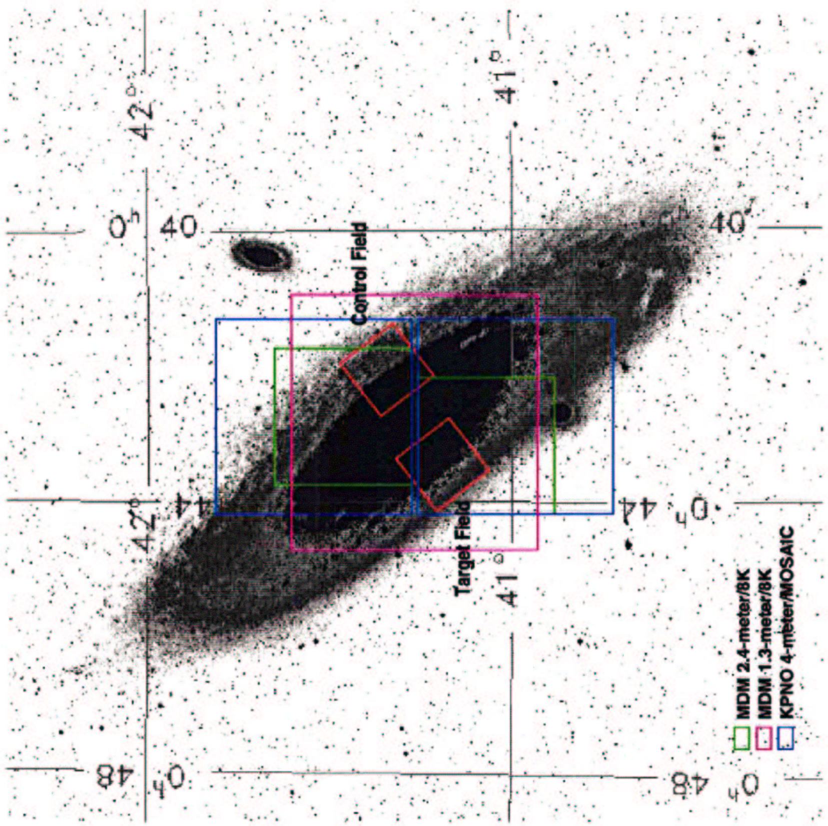
Larry Widrow (Queens U.)

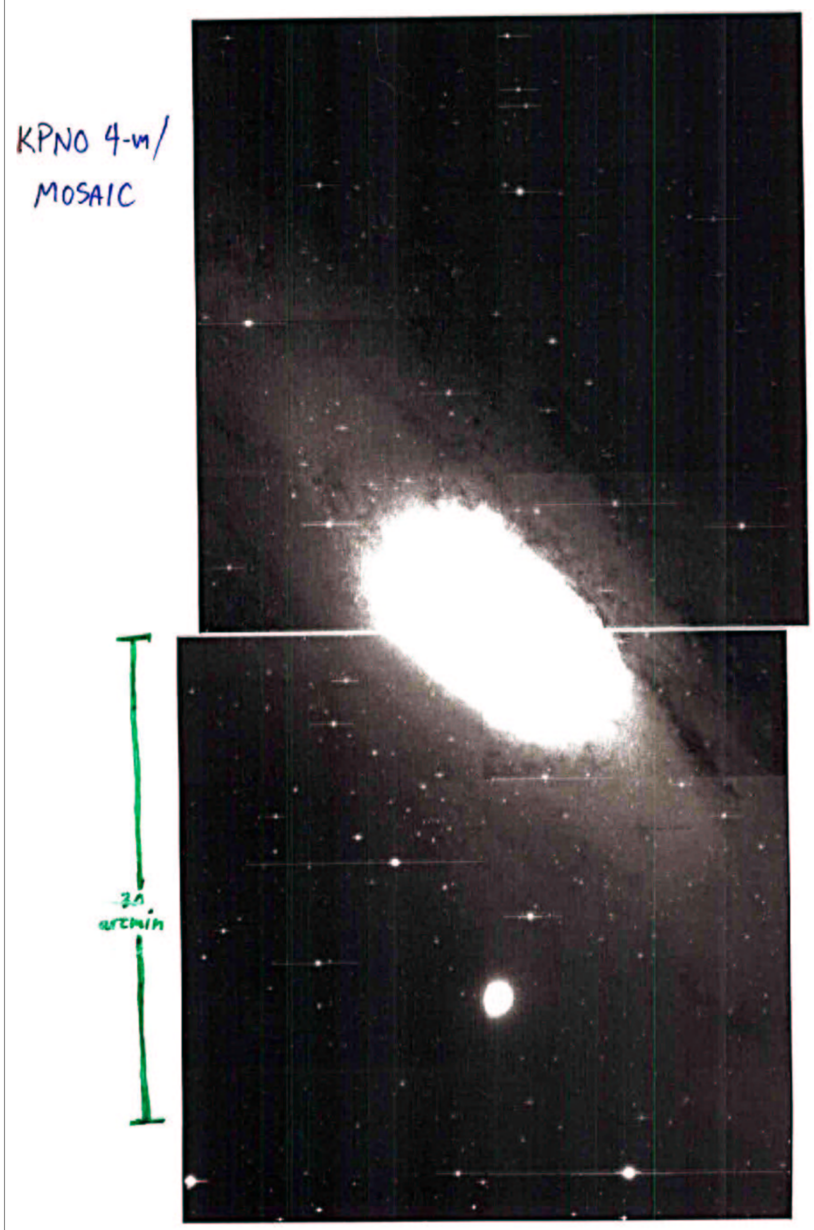
Andy Gould (Ohio State)

Wll Sutherland (Oxford)

Monitoring ≥1200 arcmin^2 area on MDMO 2.4m & 1.3m, KPNO 4m, INT 2.4m, CFHT 3.6m, Subaru 8.3m. intensively from 1999-2002, about 80-100 epochs per season, plus less intensive monitoring 1997-2004.




Control Field
Target Field
MDM 2.4-meter/8K
MDM 1.3-meter/8K
KPNO 4-meter/MOSAIC


KPNO 4-m/
MOSAIC

Lensing Optical Depth Towards M31:

Crotts 1992, ApJ, 399, 43: $\tau \approx 10^{-5}$ for all of M31 mass, in farside fields

—

Jetzer 1994, A&A, 286, 426: $\tau \approx 10^{-6}$ in central field, for large core radius, dark matter only

—

Han & Gould 1996, ApJ, 473, 230: $\tau \approx 7 \times 10^{-6}$ in center, due mostly to bulge, drops to about 3×10^{-6} at $s \approx 2$ kpc, mostly DM halo

PLUS

Gould 1994, ApJ, 435, 573: $\tau \approx 4 \times 10^{-7}$ due to M31 disk star lensing

PLUS

Paczynski 1986: $\tau \approx 10^{-6}$ due to Galactic halo

Gyuk & Crotts 2000, ApJ

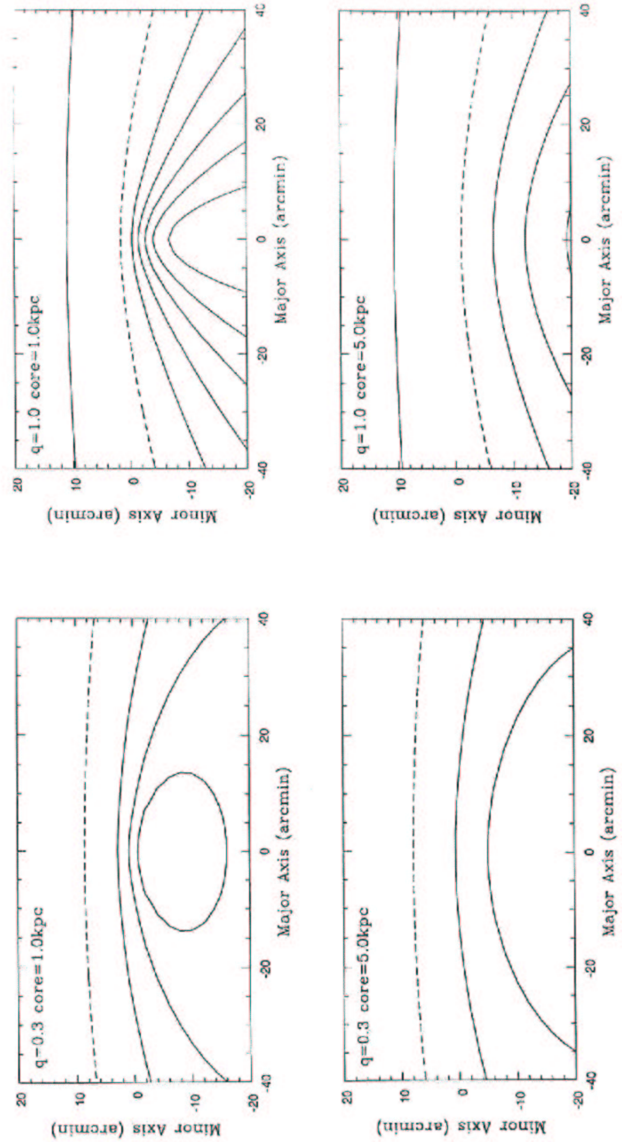
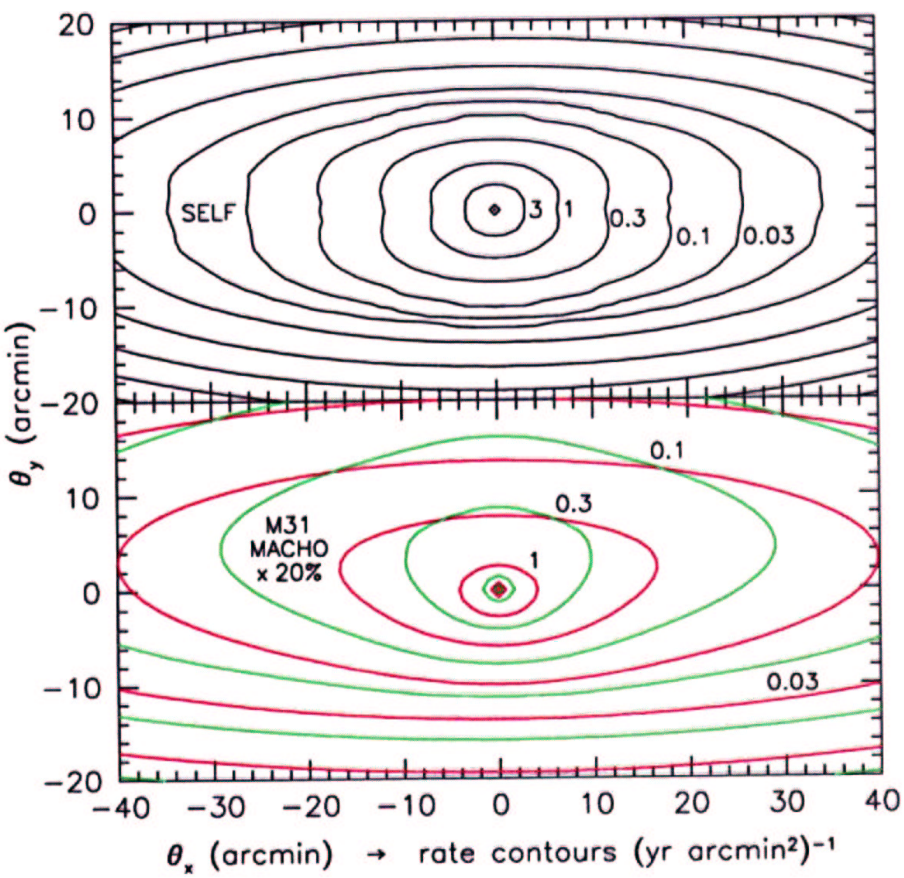


Figure 3. Contours of optical depth for halo models a) q=0.3 core=1.0, b) q=0.3 core=5.0, c) q=1.0 core=1.0 halo and d) q=1.0 core=5.0. Contours are from top to bottom: a) 2,3,4 and 5 $\times 10^{-6}$, b) 2,3 and 4 $\times 10^{-6}$, c) 1,2,3,4,5,6 and 7 $\times 10^{-6}$ and d) 1,2,3,4 and 5 $\times 10^{-6}$. For all models the dashed contour is 2.0×10^{-6}.



Predicted MEGA Results (from 1999-2002 data)

Halo macho fraction	$\Delta f \approx 0.04$
Component mass	$\Delta m \approx 0.1 M_\odot$
Halo flattening	$\Delta q \approx 0.1$
Halo core radius	$\Delta r/r \approx 0.3$