26th International Microlensing Conference: 30th anniversary of the first microlensing results by EROS – MACHO - OGLE The beginning of EROS: EROS 1

Michel Spiro

President International Union of Pure and Applied Physics (IUPAP)

Outline

- The birth of EROS: a tribute to Bodhan Paczynski and to Charles Alcock
- The beginning of EROS: EROS1 Schmidt plates for long duration events, plus small telescope (40 cm diameter) with wide field camera for small duration events
- EROS1 the first candidate events
- EROS1: from discoveries to **limits on the dark galactic halo MACHO content**: we established the most stringent limits, all along these past 30 years (statement still valid today, although OGLE is taking over).
- A word on AGAPE M31 pixel microlensing survey
- Marc Moniez will cover EROS 2 and the combination with MACHO

Trigger for EROS 1

- B. Paczynski, 1986, Ap. J. 304, 1 we must confess that we did not notice this seminal paper, with the initial idea
- Halloween 1989: Jim Rich from Saclay, was in Berkeley, hesitating between attending his children Halloween parade and attending Charles Alcock seminar on MACHOs and the MACHO project (although the acronym MACHO was invented by K. Griest a bit later). Jim made the right choice (personal view)
- Both Jim Rich (Saclay) and Yannick Giraud-Héraud (Collège de France) attended Charles'seminar and were enthusiastic. This gave birth to the French EROS (Expérience de Recherche d'Objets Sombres) and AGAPE (Andromeda Galaxy and Amplified Pixel Experiments) projects/collaborations. Both focused on detecting MACHOs in galactic halos
- For both collaborations, it was the first time, particle physicists move to optical observational cosmology, with the culture of massive data treatment

EROS 1 The collaboration at the time of the "discovery" date (1993)

Evidence for gravitational microlensing by dark objects in the Galactic halo

E. Aubourg*, P. Bareyre*, S. Bréhin*, M. Gros*, M. Lachièze-Rey*, B. Laurent*, E. Lesquoy*, C. Magneville*, A. Milsztajn*, L. Moscoso*, F. Queinnec*, J. Rich*, M. Spiro*, L. Vigroux*, S. Zylberajch*, R. Ansari†, F. Cavalier†, M. Moniez†, J.-P. Beaulieu‡, R. Ferlet‡, Ph. Grison‡, A. Vidal-Madjar‡, J. Guibert§, O. Moreau§, F. Tajahmady§, E. Maurice‖, L. Prévôt‖ & C. Gry¶

* DAPNIA, Centre d'Études de Saclay, 91191 Gif-sur-Yvette, France
† Laboratoire de l'Accélérateur Linéaire, Centre d'Orsay, 91405 Orsay, France
‡ Institut d'Astrophysique de Paris, 98bis Boulevard Arago, 75014 Paris, France
§ Centre d'Analyse des Images de l'Institut National des Sciences de l'Univers, Observatoire de Paris, 61 avenue de l'Observatoire, 75014 Paris, France
‖ Observatoire de Marseille, 2 place Le Verrier, 13248 Marseille 04, France
¶ Laboratoire d'Astronomie Spatiale de Marseille, Traverse du Siphon, Les Trois Lucs, 13120 Marseille, France

EROS 1 The collaboration at the end of EROS 1 1997

Observational Limits on Machos in the Galactic Halo. ⋆

C. Renault[1], C. Afonso[1], É. Aubourg[1], P. Bareyre[1], F. Bauer[1], S. Brehin[1], C. Coutures[1], C. Gaucherel[1], J.F. Glicenstein[1], B. Goldman[1], M. Gros[1], D. Hardin[1], J. de Kat[1], M. Lachièze-Rey[1], B. Laurent[1], É. Lesquoy[1], C. Magneville[1], A. Milsztajn[1], L. Moscoso[1], N. Palanque-Delabrouille[1], F. Queinnec[1], J. Rich[1], M. Spiro[1], L. Vigroux[1], S. Zylberajch[1], R. Ansari[2], F. Cavalier[2], F. Couchot[2], B. Mansoux[2], M. Moniez[2], O. Perdereau[2], J.-Ph. Beaulieu[3], R. Ferlet[3], Ph. Grison[3], A. Vidal-Madjar[3], J. Guibert[4], O. Moreau[4], É. Maurice[5], L. Prévôt[5], C. Gry[6], S. Char[7], J. Fernandez[7]

The EROS collaboration

[1] CEA, DSM, DAPNIA, Centre d'Études de Saclay, F-91191 Gif-sur-Yvette Cedex
[2] Laboratoire de l'Accélérateur Linéaire, IN2P3 CNRS, Université Paris-Sud, F-91405 Orsay Cedex
[3] Institut d'Astrophysique de Paris, CNRS, 98 bis Boulevard Arago, F-75014 Paris
[4] Centre d'Analyse des Images de l'INSU, Observatoire de Paris, 61 avenue de l'Observatoire, F-75014 Paris
[5] Observatoire de Marseille, 2 place Le Verrier, F-13248 Marseille Cedex 04
[6] Laboratoire d'Astronomie Spatiale de Marseille, Traverse du Siphon, Les Trois Lucs, F-13120 Marseille
[7] Universidad de la Serena, Faculdad de Ciencias, Departemento de Fisica, Casilla 554, La Serena, Chile

We lost and deeply regret

- Cécile Renault PhD student: she did her thesis

on EROS and pursued in observational cosmology

1970 - 2021

- Alain Milsztajn, one of the key player in the analysis

and in the deep understanding behind microlensing

- Pierre Bareyre, one of the initiator and key player in the hardware of EROS

- Luciano Moscoso who joined in the middle of EROS 1 and became a major player in the analysis
- Jean Guibert, the master of the MAMA, Schmidt Plates digitizing machine at Observatoire de Paris
- Éric Maurice, Astronomer at Observatoire de Marseille who helped us a lot
- Sergio Char, La Serena, Chile

EROS 1 ESO La Silla 1m f/3 Schmidt plates for long duration microlensing events

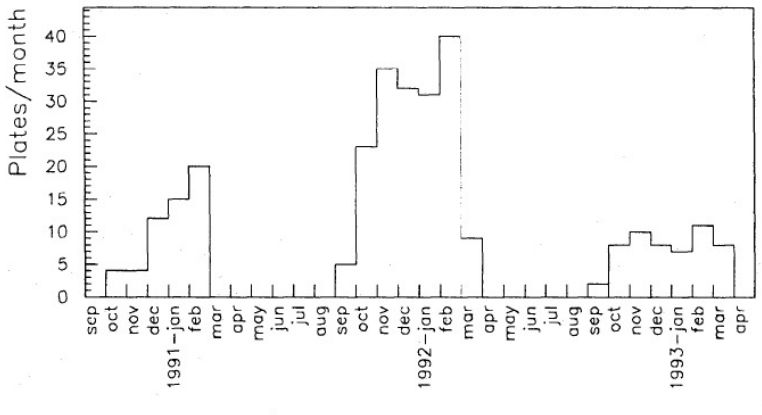
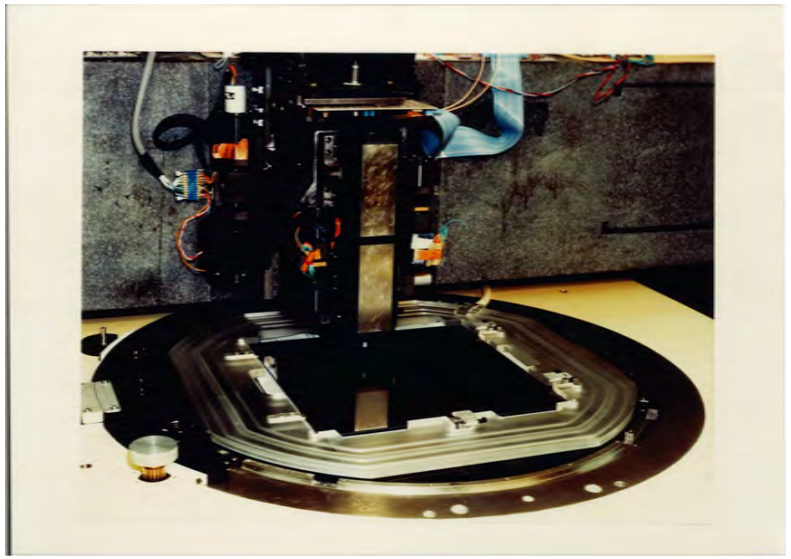


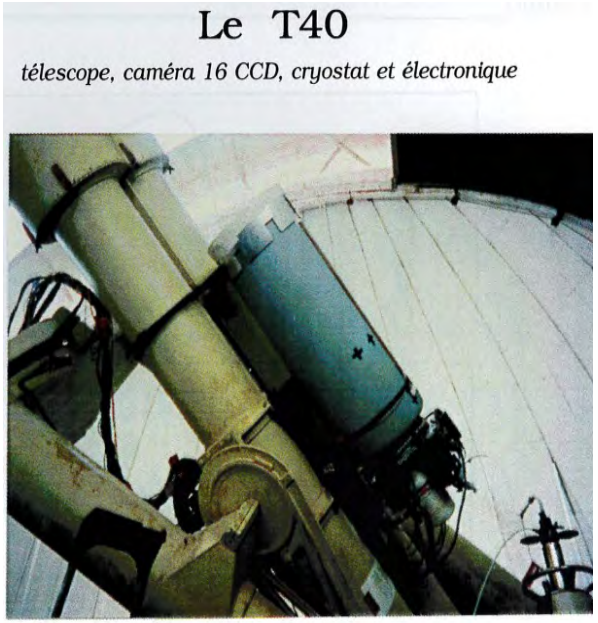
Fig. 1. Time distribution of the photographic plates taken for EROS (from 1990 to 1993).

From 1 day to 3 days sampling

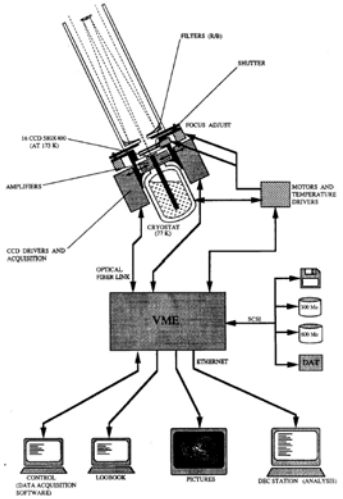


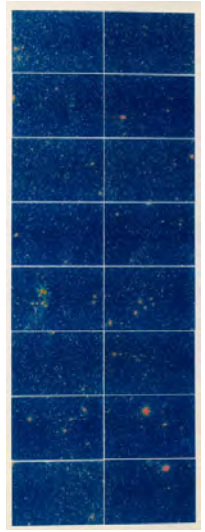
290 29x29 cm^2 usable plates, carefully selected,
digitized by “la MAMA” microdensitometer, 10 microns px

EROS 1: 40 cm ⌀ GPO telescope with 16 CCD 579x400 px, field 0.4°x1.1° for short duration



- La Silla
- Sensitivity from 15 minutes to few days' duration, one field only (first three years one field in the bar of LMC, last year one field in SMC)
- Largest CCD camera in the world. Then came MACHO, then EROS2 and then Megacam





EROS 1 The Nature paper 1993

- The two first Microlensing evidence, towards LMC stars, were published in the same issue of Nature
- MACHO paper

given star. (While this paper was in preparation, we were informed by J. Rich (personal communication) of the candidate events reported by the EROS collaboration. Note that the two

- EROS Paper

of variable star. During the preparation of this paper we learned that a similar microlensing event has been observed by the 'MACHO' collaboration (C. Alcock, personal communication).

The Dim Stars We Can't See May Be a Heart of Darkness

NEW YORK (NYT)—Two scientific teams reported they had independently observed what could be evidence that some of the invisible, or dark, matter making up much of the mass of the universe exists in the form of stillborn or extremely dim stars at the edges of galaxies.

Such objects, known as Massive Compact Halo Objects, or MACHOs, have been hypothesized for years as likely candidates for dark matter. The acronym was chosen to contrast with theories involving exotic subatomic particles as yet undiscovered bearing the name WIMPs, for Weakly Interacting Massive Particles.

If the new findings of MACHOs on the fringes of the Milky Way galaxy are confirmed by further sightings, astrophysicists said, this would be the first observational breakthrough in astronomy's concerted search for the mysterious dark matter.

It would be the first identification of the unseen matter that causes galaxies to weigh 10 times as much as they appear to in visible light or other detectable radiations. The existence of these greater masses has been inferred by their gravitational effects on the shape and motion of the galaxies, but its form has eluded detection.

The discoveries were announced in cautiously worded statements at two scientific conferences in Italy. American and Australian scientists said they turned to report their results when they learned that a French team planned to make public the results of their own similar but independent observations.

The American-Australian team, led by Dr. Charles Alcock of Lawrence Livermore Laboratory in California, reported that in monitoring 3.3 million stars for a year, they had detected one remarkable event that could reveal the existence of dark matter in the form of MACHOs.

The two EROS candidates came from Schmidt plates analysis

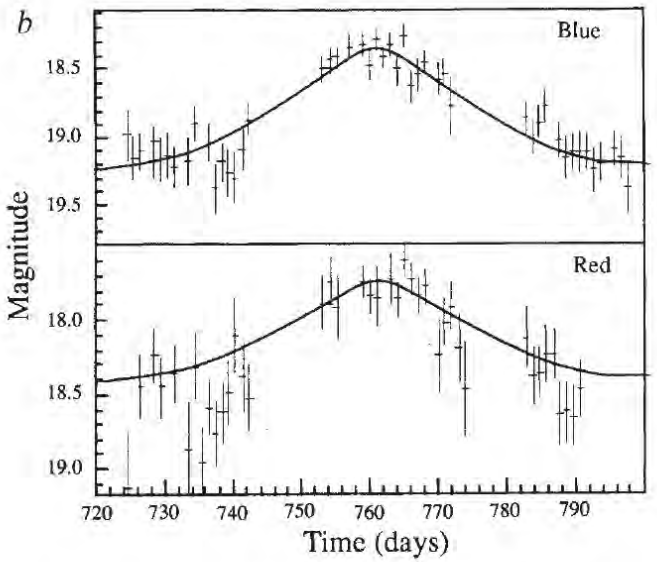


FIG. 1 *a*, The measured magnitudes for candidate 1 as a function of time. The time is counted from 1 January 1990. The error bars correspond to the estimated 1σ errors. *b*, The light-curve of candidate 1 on an expanded scale. The curve shows the best fit for the microlensing hypothesis. The parameters of the best fit are shown in Table 1.

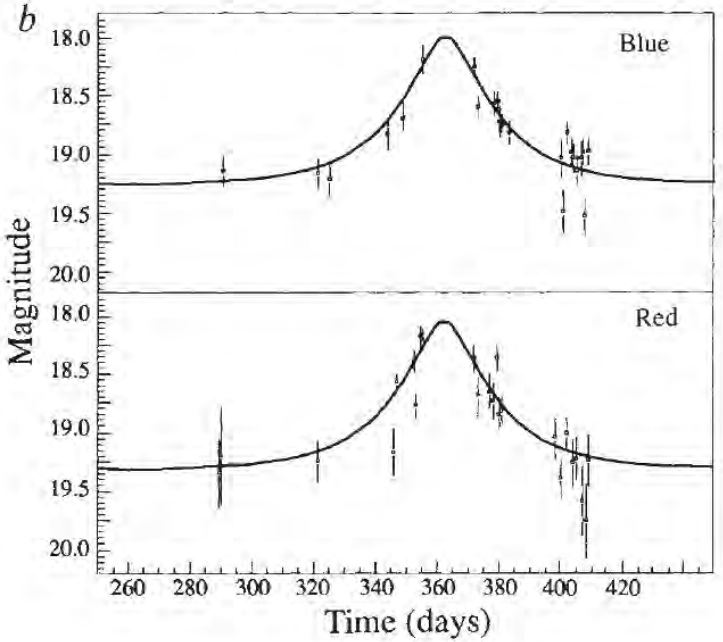


FIG. 2 As Fig. 1, for candidate 2.

From EROS 1 evidence to limits on the galactic dark halo MACHO content

- Schmidt plates: Candidate 1 (duration of 23 days) was found to be a BE star and candidate 2 (duration of 29 days) an eclipsing binary (2.8 days) A0 star. NB. both events were on stars that showed subsequent similar variations in the macho and eros data, eliminating them as microlensing candidates
- No candidates were found with the short duration CCD 40 cm diameter telescope campaigns

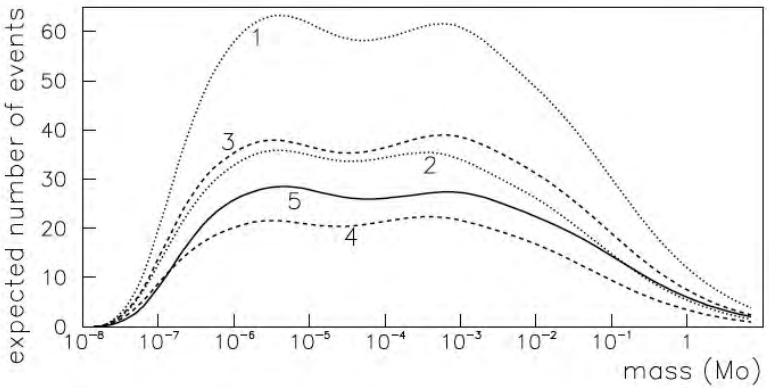


Fig. 1. Expected number of microlensing events in the EROS programs (CCD -LMC and SMC sources- and Schmidt plates) assuming that all Galactic dark matter is in the form of machos of the same mass. The five curves refer to the Galaxy models of table 1. The full curve corresponds to the reference model, dashed curves to flattened models and dotted curves to the spherical models.

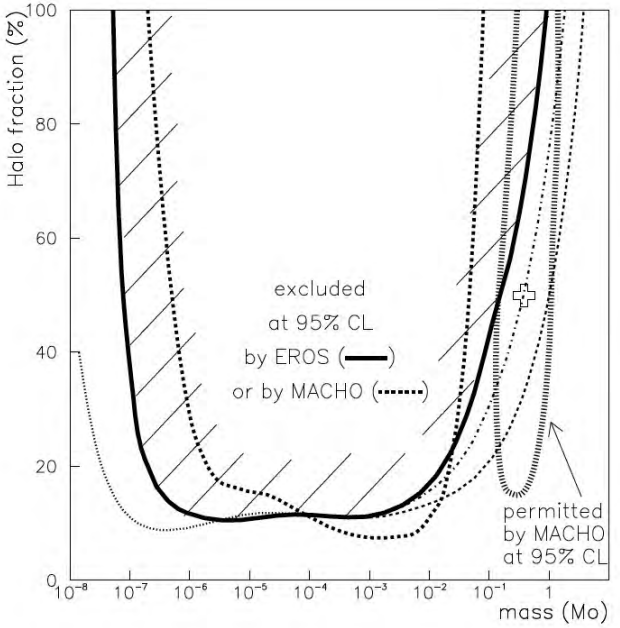


Fig. 2. Exclusion diagram at 95 % CL for the reference model with all EROS data, assuming all deflectors to have the same mass. For the CCD program, we show the influence of blending and finite size effects (the dotted line on the left is the limit without those effects). Limits are shown for 0 (dashed line), 1 (mixed line) or 2 (full line) candidates assumed to be actual microlensing. The cross is centered on the area allowed at 95 % CL by the MACHO program (Alcock *et al*, 1996b) assuming 6 microlensing events and a standard spherical model (model S, very similar to our reference model). We also indicate the MACHO exclusion contour obtained by combining all their results with $\tau \leq 20$ days (Alcock *et al*, 1996a).

A word on AGAPE M31 pixel microlensing survey

They did quite well but this would be another story
They first used a 2m telescope at Pic du Midi France,
and then a 2.5 m INT Telescope at La Palma
Few candidate events were observed

LOOKING FOR MICROLENSING OF STARS OF THE ANDROMEDA GALAXY M31 BY MONITORING PIXELS

P. Baillon[1] A. Bouquet[2] C. Ghesquière[3] Y. Giraud-Héraud[3]
P. Gondolo[2] J. Kaplan[2] A.L. Melchior[2]
[1] CERN Genève, [2] LPTHE Universités Paris 6 et 7,
[3] LPC Collège de France Paris

January 1994

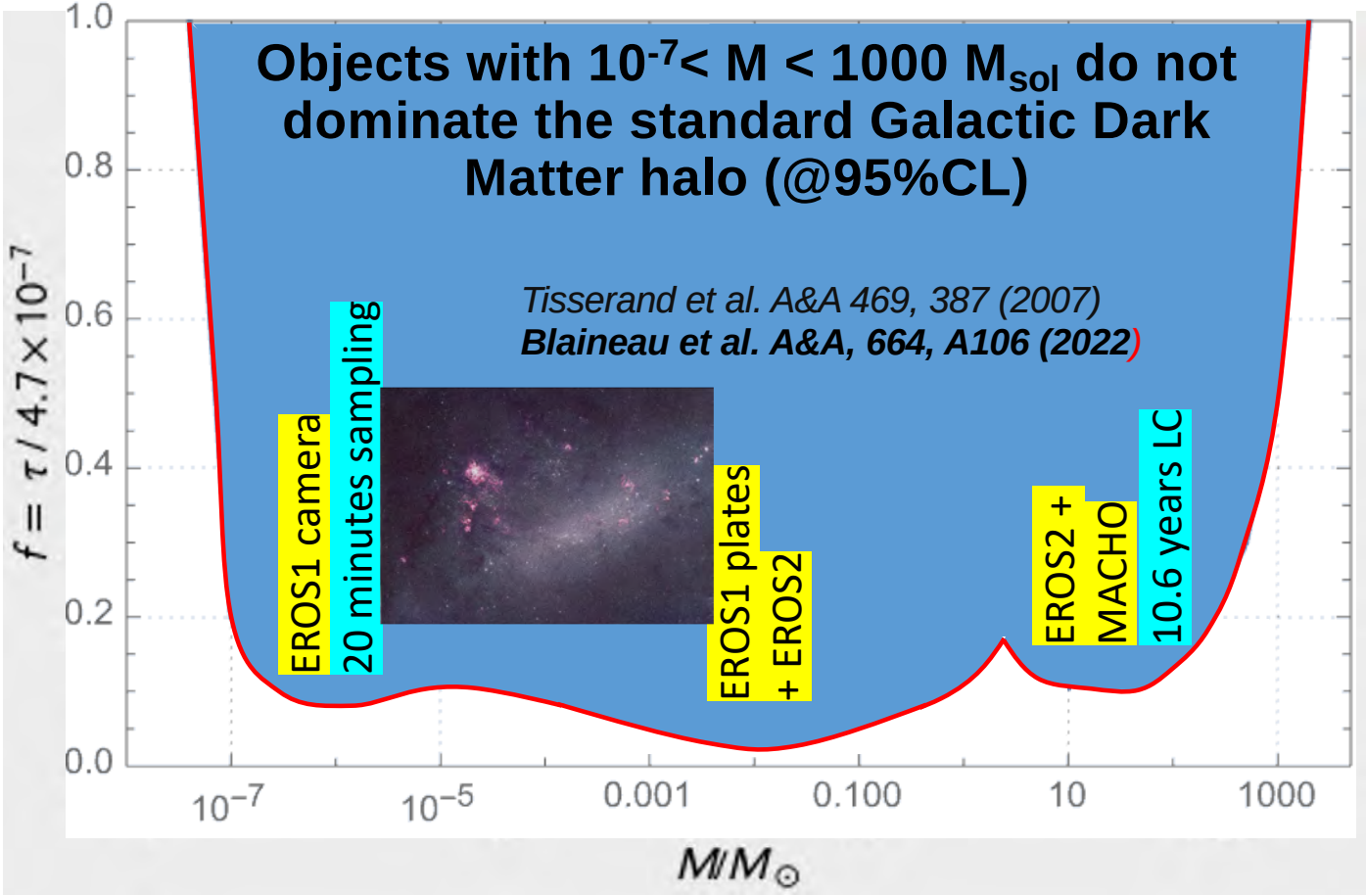
Abstract

The galaxy M31 is a very good potential target for microlensing searches. However, only few stars are resolved, and a different method is therefore needed : monitor pixels and not stars. This method and the present status of the study of its feasibility are presented here.

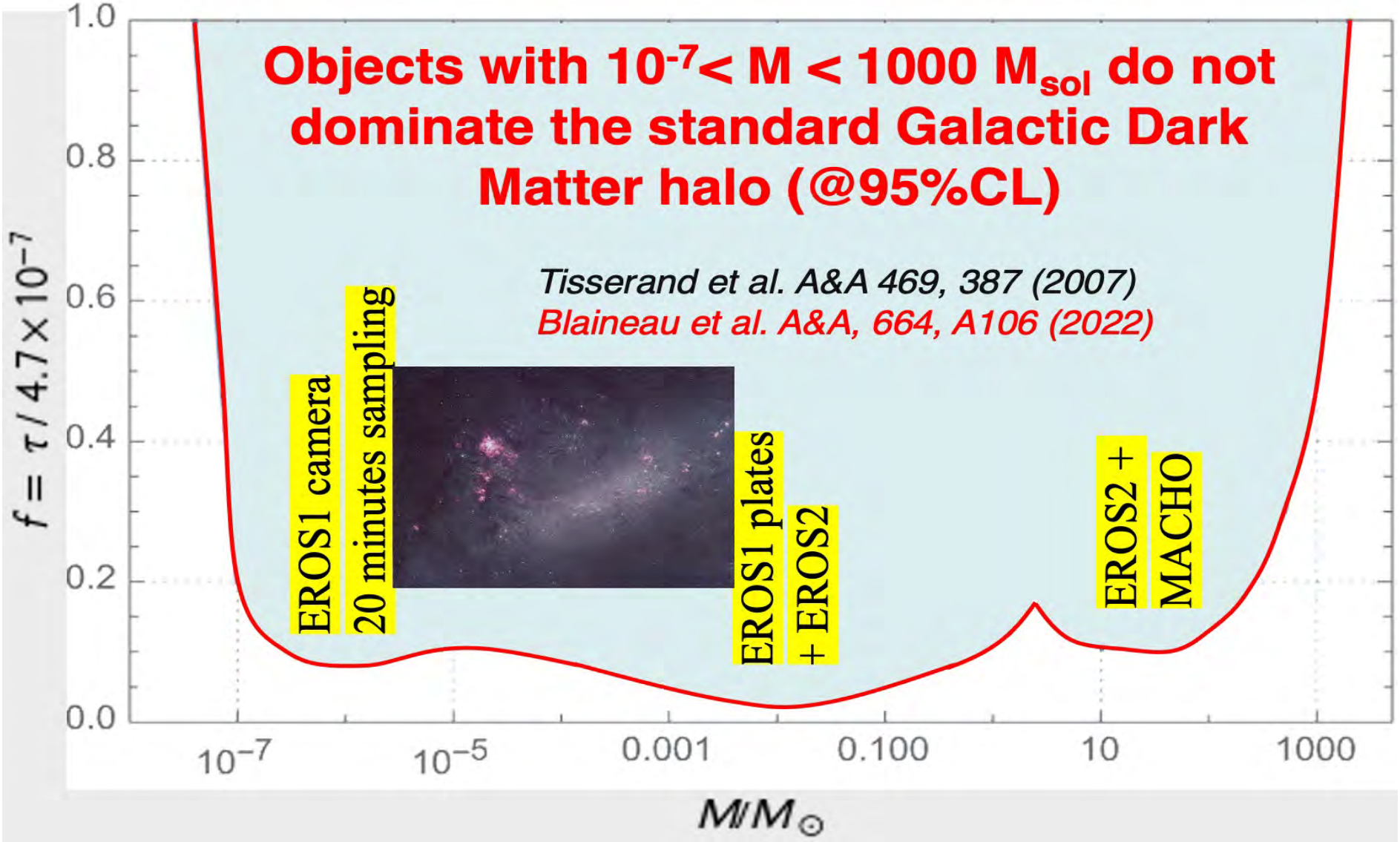
EROS results as of today, on microlensing

You will here more from Marc Moniez

Galactic halo: all EROS data + combine EROS+MACHO



You will know more from Marc Moniez



That illustrated, I hope, part of the story of the MACHO – EROS "coopetition", and the start of a new field thanks to OGLE, MACHO and EROS

- Thanks for organizing this celebration
- And thanks for inviting us!!!