

The epic of EROS

Expérience de Recherche d'Objets Sombres

30 years of research on microlensing and variable stars



this talk is dedicated to those of EROS who have passed away

Johannes Andersen
Pierre Bareyre
Florian Bauer
Sergio Char
Jean Guibert
Éric Maurice
Alain Milsztajn
Luciano Moscoso
Cécile Renault

Last minute: At the start of EROS, I heard almost the same remark as J-P Beaulieu (see his talk), but from another distinguished professor: « *You will never discover microlensing events...* »

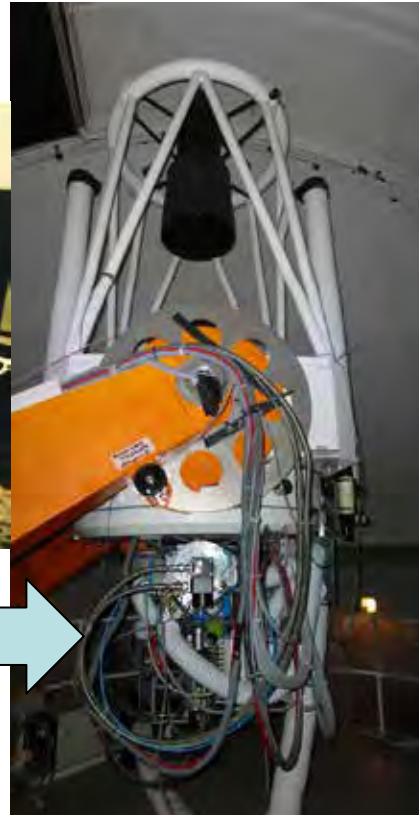
M. Moniez (IJCLab-CNRS)

Instruments, detectors



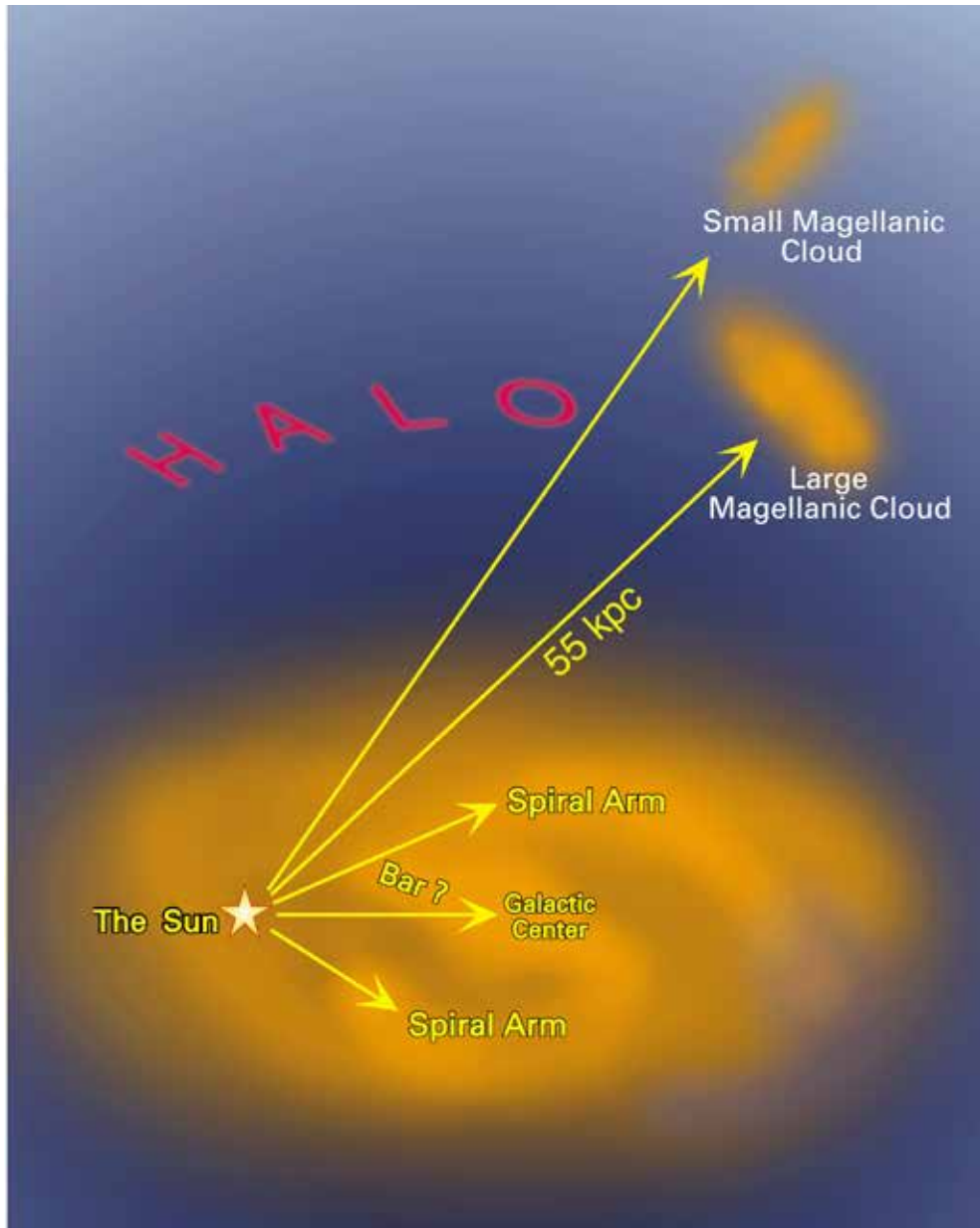
EROS-1: 1990-1994

- **290 photographic plates** taken at the 1m Schmidt (ESO), **digitized** with the MAMA (1Gpixels/plate). $5 \cdot 10^6$ stars.
- (first) 16 butttable **CCD-camera** (4M-pixels!) on a 40cm telescope. **19,000 images of the LMC bar**. $2.5 \cdot 10^5$ stars



EROS-2: 1996-2003

2 cameras with 32 Mpixels each, on a 1m telescope



Main targets

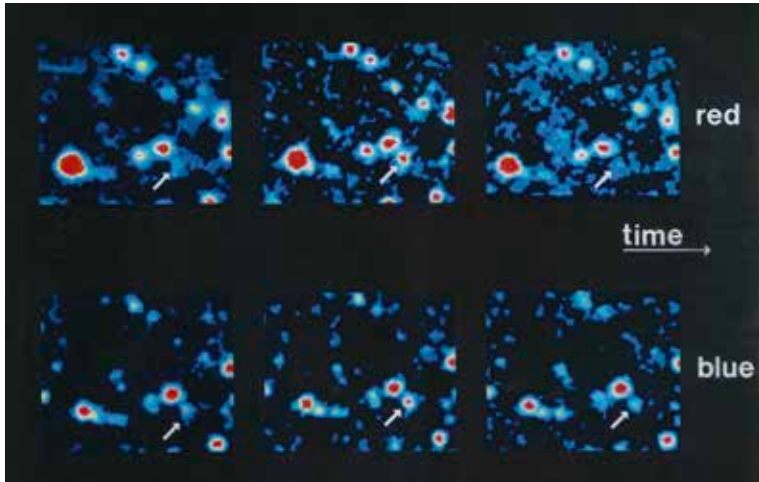
monitored by EROS2 in 1996-2003 (~ 40 participants)

- **Magellanic Clouds** => probe hidden matter in **halo** ($t \sim 5 \cdot 10^{-7}$)
- **Galactic center** => probe ordinary stars as lenses in **disk/bulge** ($t \sim 2 \cdot 10^{-6}$)
- **Spiral arms**
=> probe ordinary stars in **disk, bar + hidden matter in thick disc** ($t \sim 5 \cdot 10^{-7}$)

50 Terabytes of data

850,000 images processed
~ 77×10^6 stars measured 300 to 500 times

The first discoveries: 1993 => *signal ≤ 2 events*



Aubourg et al, Nature, 365, 623 (1993)

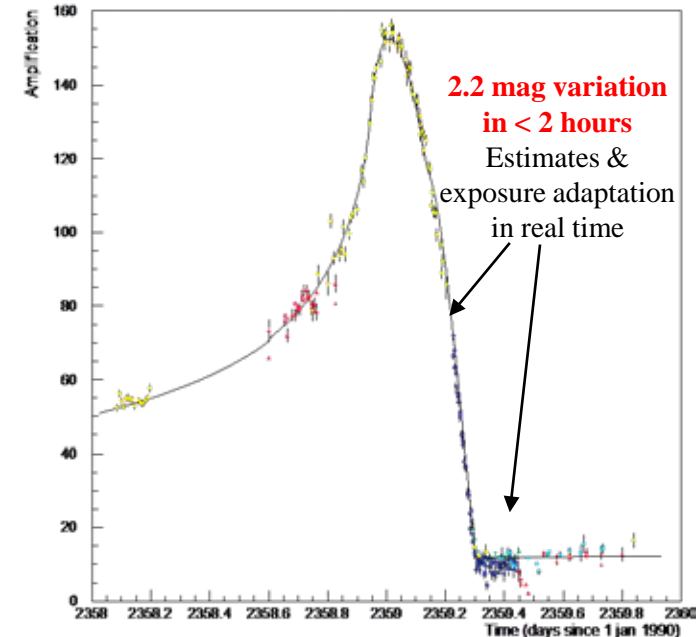
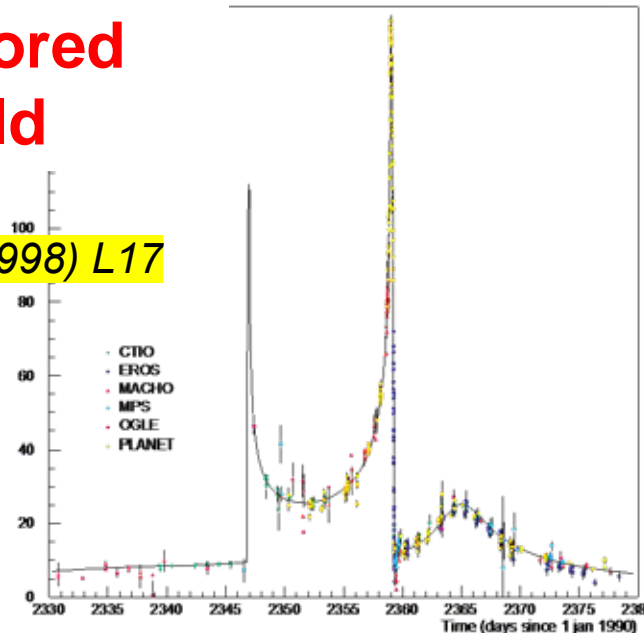


cautious conclusion
upper limit on dark matter

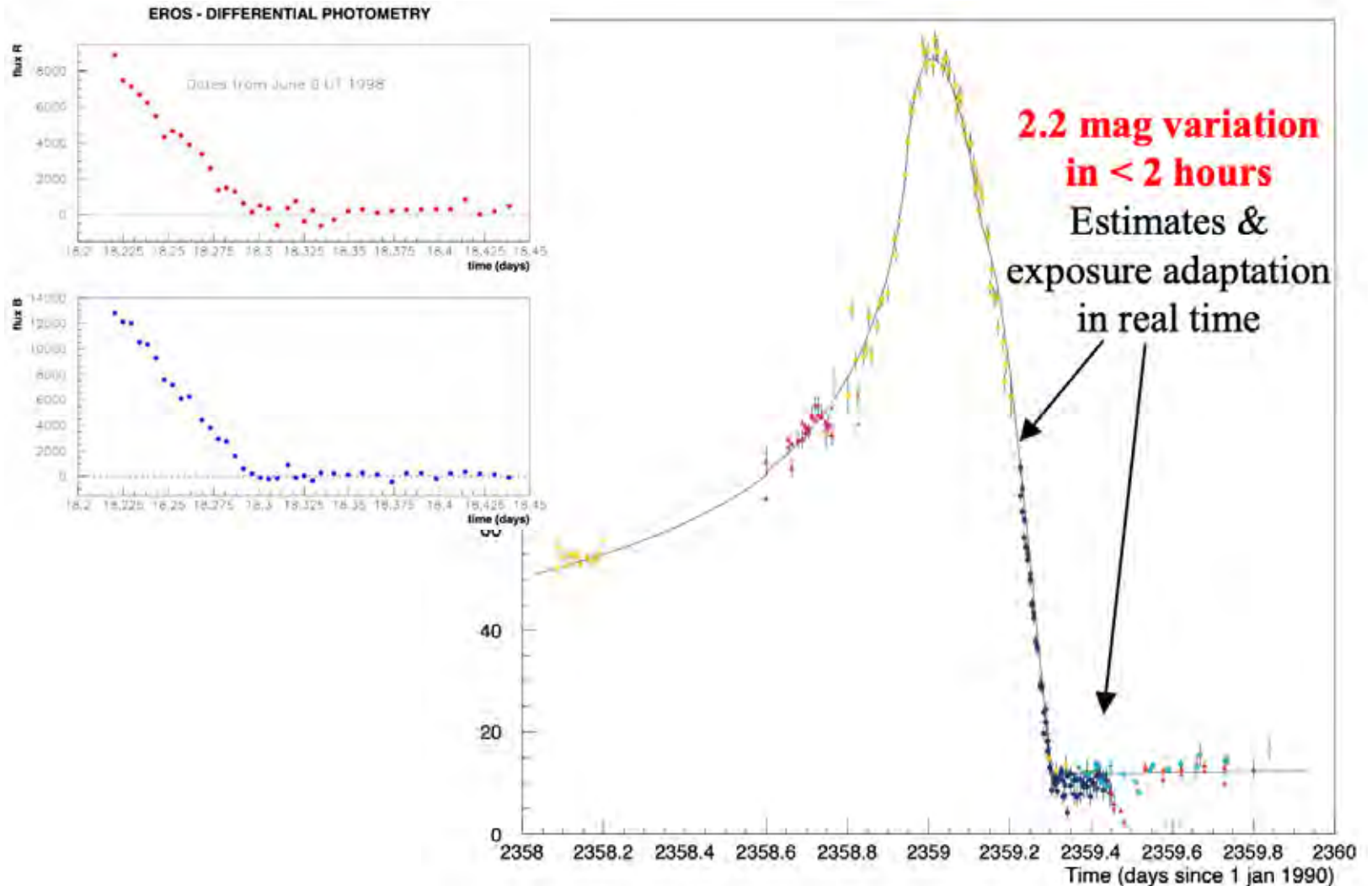
EVENT 98-SMC-1

1998: The first caustic crossing monitored around the world

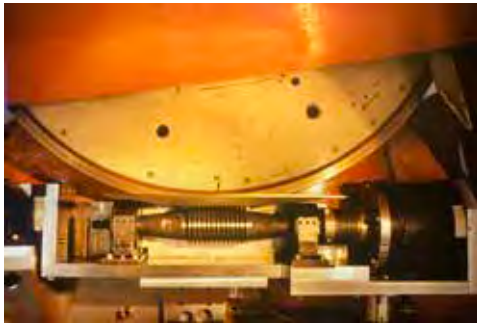
EROS contribution in Afonso et al. A&A 337 (1998) L17



1998: The first caustic crossing monitored around the world



My personal memories of this episode



Big Brother 1996 1997 1998 1999 2000 2001 2002 2003 construction

Mercredi 17 Juin 1998

- I had **just arrived at La Silla** with a team of mechanical engineers (C. Bourgeois & R. Cizeron) for a major intervention on the telescope
- **Weather**, which had been rainy the previous day, **suddenly improved** just before SMC became visible (1h30 am)
- I **forced all the protection limits** to point the telescope as soon as possible
-> SMC elevation was **26°52'**
- For 5 hours, extraction of **photometry in real time** enabled to properly **adjust exposure times**.

In those days, we still used landline telephones to communicate with South Africa and Australia, so as to be kept precisely informed of the progress of the event and observations.

```
20h18: Shift J.H. Ch.C + Marc et al. arrives cet apres midi.
20h19:
20h19: Tres mauvais temps toute la journee: nuages et vent.
20h20: Sur la fin, humidite jusqu'a 82%.
Pas de flats.
20h21: Nous sommes prêts pour la "nuit caustique", avec le Marly,
20h22: le Danois, et une T.O. pour un spectre NTT.
20h22: Le ciel aura peut etre pitie de nous: quelques etoiles sont
20h23: visibles dans un ciel encore perturbe. Mais l'humidite
20h23: se maintient autour de 80%

22h46: Ca se degage ! Foyer ....
```

```
01h38: Lancement de smc207 a 18h24 ST.
01h39: L'observation de la caustique est en cours.
_Image_[01h38]: smc207_8f1744.fits
01h41: L'elevation pour la premiere photo du smc007 etait
01h41: de 26degrees52" et le decalage avec le meridien voisin
01h42: de 6h20.
_Image_[01h41]: smc207_8f1745.fits
T... 1746.fits
... 747.fits
... 748.fits
... 749.fits
... 750.fits
... 8f1751.fits
... 8f1752.fits
Image_[01h41]: smc207_8f1753.fits
```

Salut Fred,
ici il y a de l'ambiance. On suit la descente de la caustique depuis
1h30 du mat. C'est impressionnant. L'Afrique du sud a vu passer
le maximum et on suit la descente (vertigineuse), l'Australie
(ou il fait beau) suit juste derriere.

My personal experience of this episode

Jim Rich 1996 1997 1998 1999 2000 2001 2002 2003 construction

JR Jim Rich
EROS caustic crossing data
A: gould@payne.mps.ohio-state.edu

20h18: Shift J.H, Ch.C + Marc et al. arrives cet apres midi.
20h19: Tres mauvais temps toute la journee: nuages et vent.

Dear Microlensers

- I have placed at our web site (www.lal.in2p3.fr/EROS/) the EROS light curve of the SMC binary lens on the night of June 17/18. The curve shows a linear decline in flux with a kink at UT= 7h23 +/- 6 minutes (June 18.31). The flux is relatively constant after the kink.
 - We monitored the star every 6-10 minutes for 5 hours tonight with our telescope and also with the Danish 1.5 meter.
 - All data will be available to the community after reduction is finished.
 - Thanks to the many members of the microlensing community who helped us in the planning of these observations and, of course, to MACHO for providing the alert.
- best regards
EROS
can be kept precise and observations.

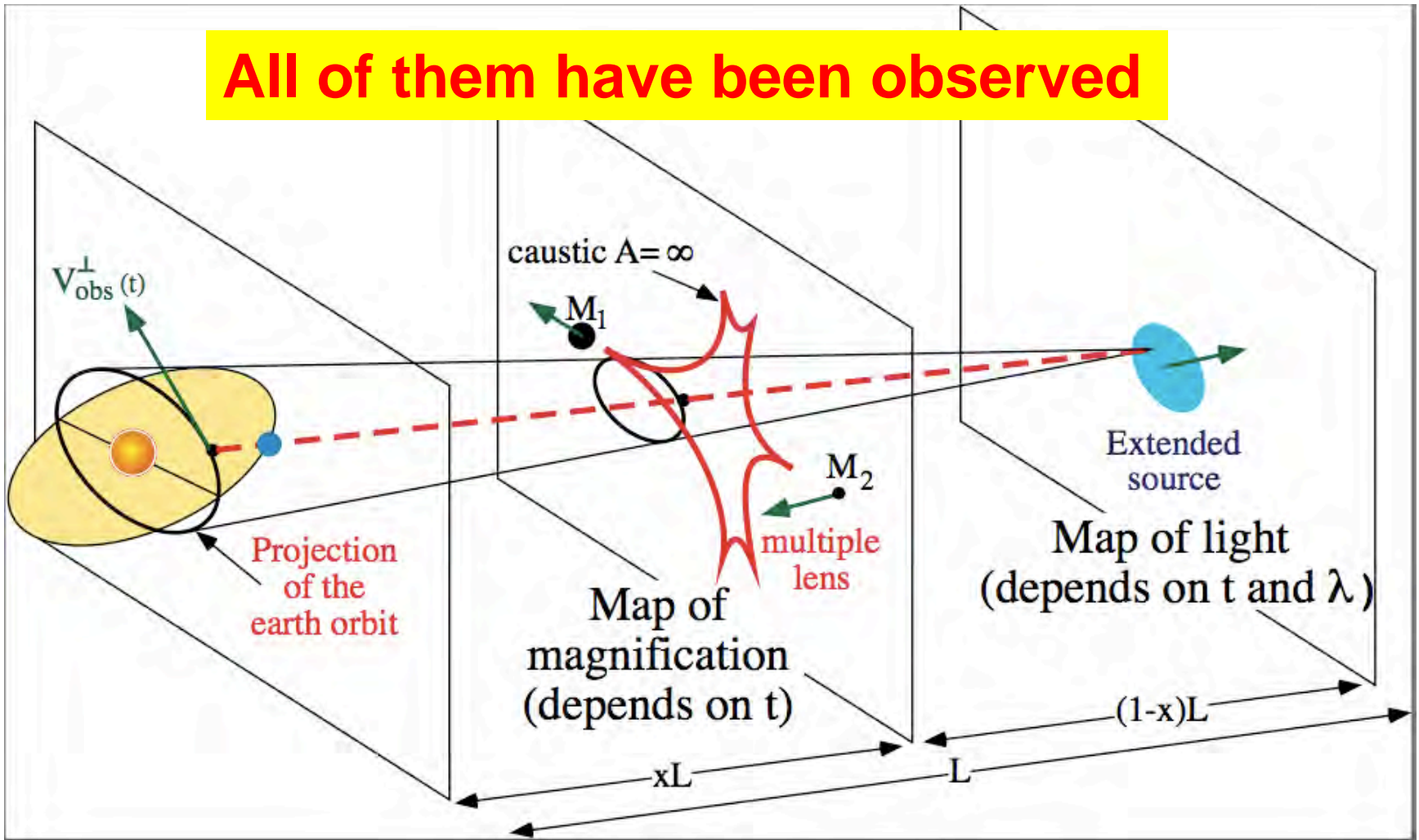
alcock@beowulf.llnl.gov
"nuit caustique", avec le Marly, Centre NTT. quelques etoiles sont
MVArchive et 10 de plus
10 Jun 1998 12:52

Défaills

Salut Fred,
ici il y a de l'ambiance. A 1h30 du mat. C'est impressionnant le maximum et on suit la descente (ou il fait beau) suit juste derriere.

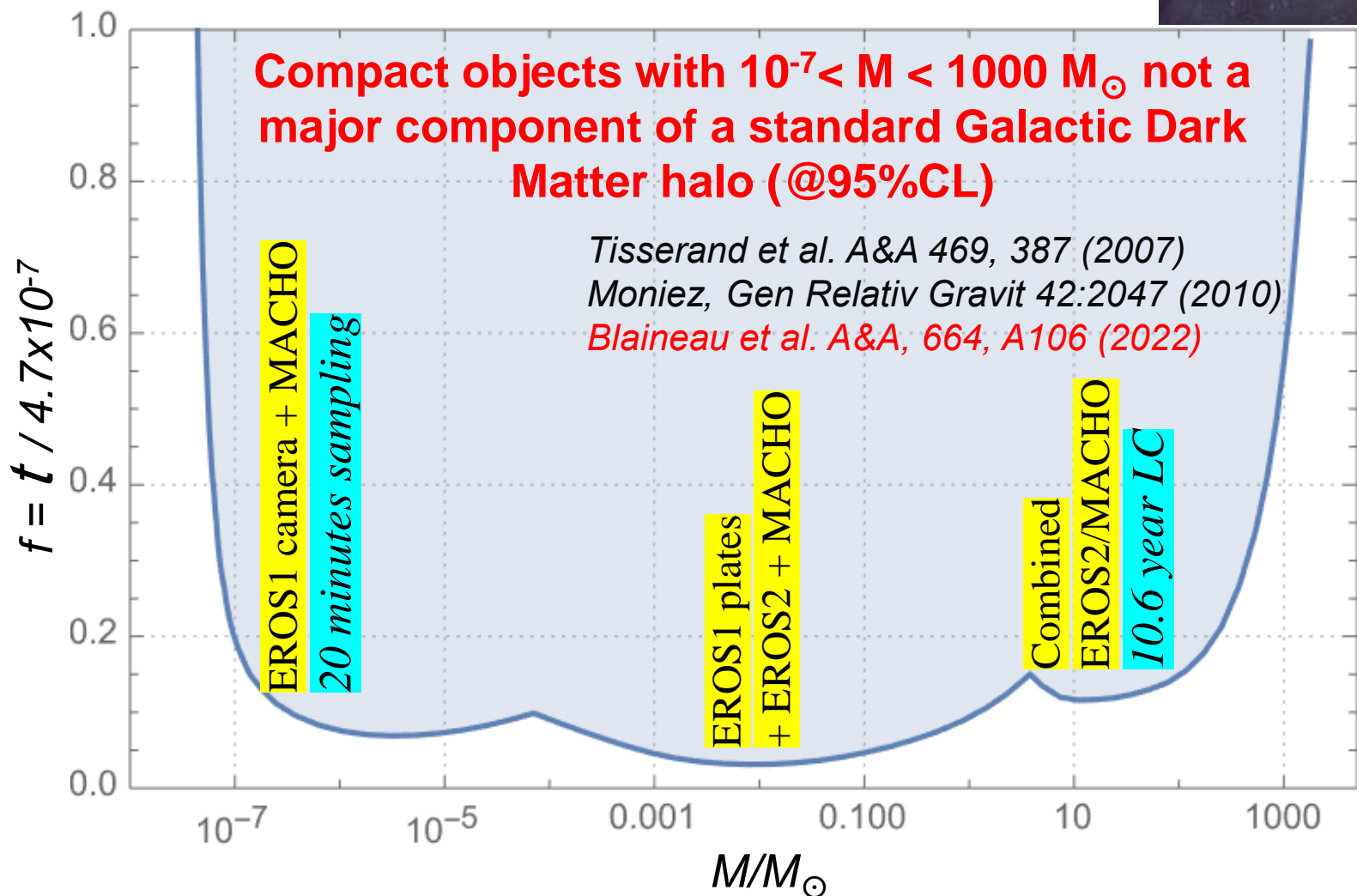
Many complications to Point-source-Point-lens rectilinear events

All of them have been observed



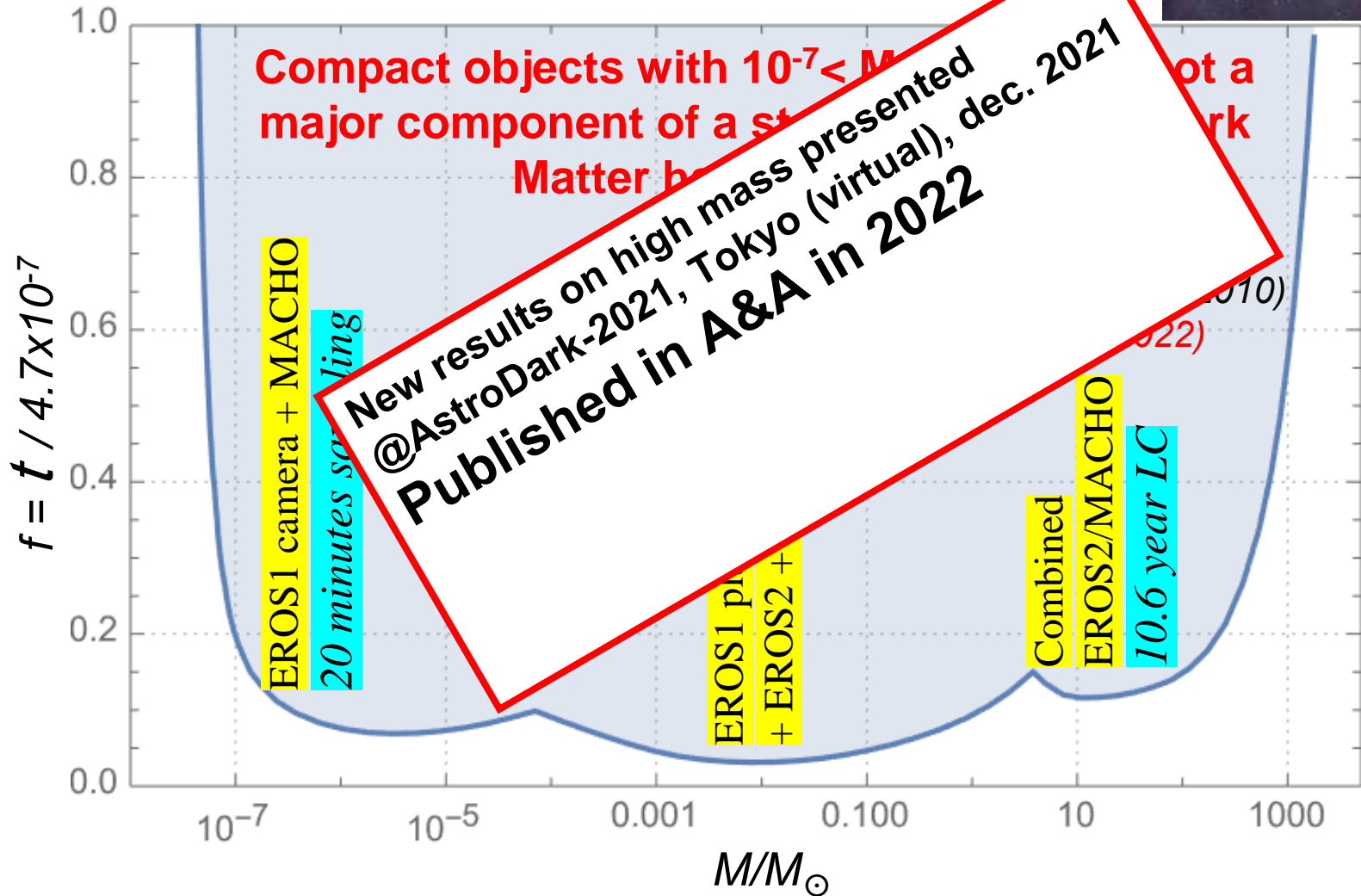
EROS combined results in dark matter

(1) Galactic halo: all data + combine EROS+MACHO toward LMC



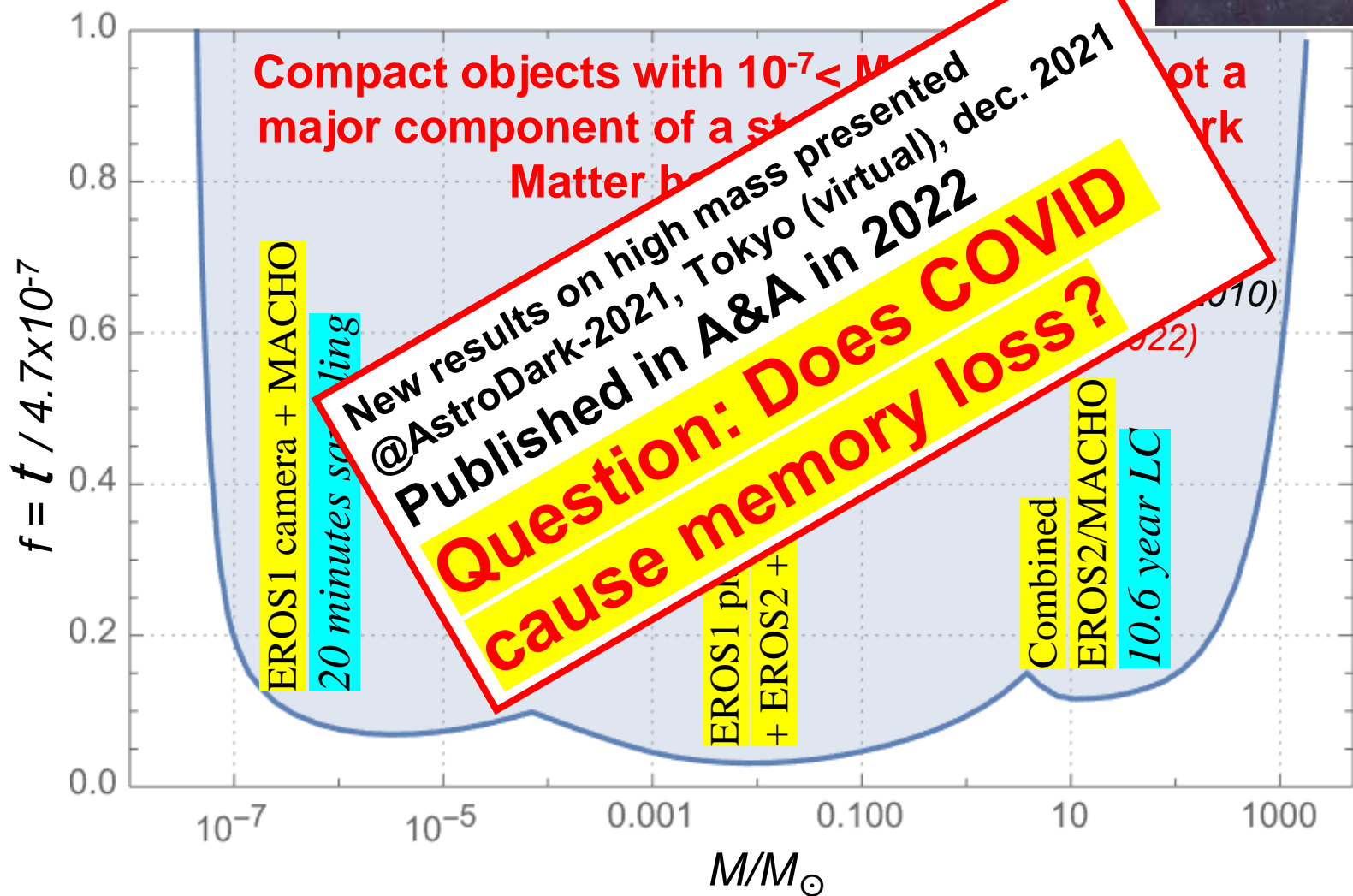
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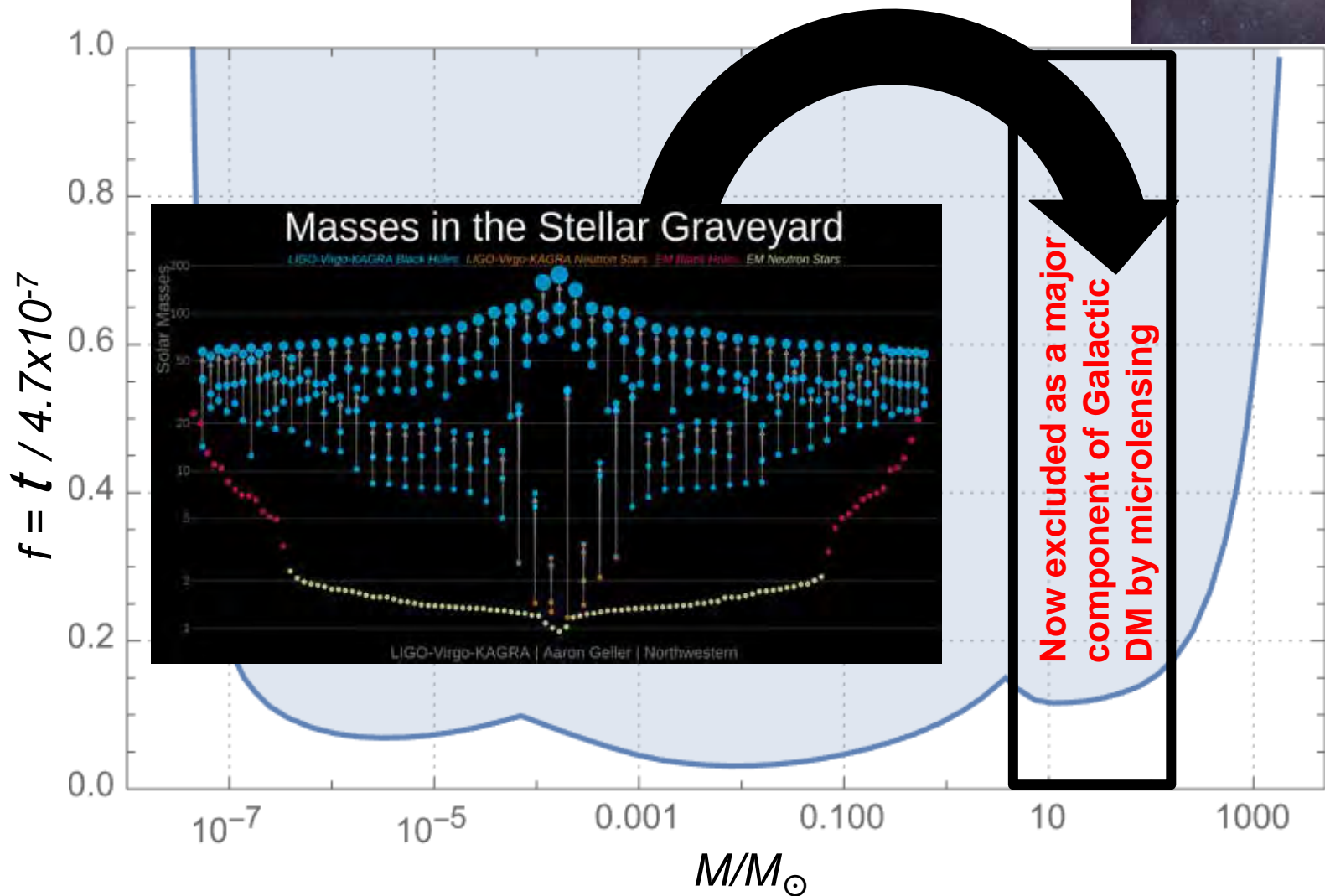
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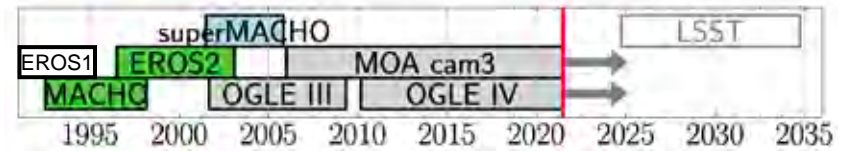


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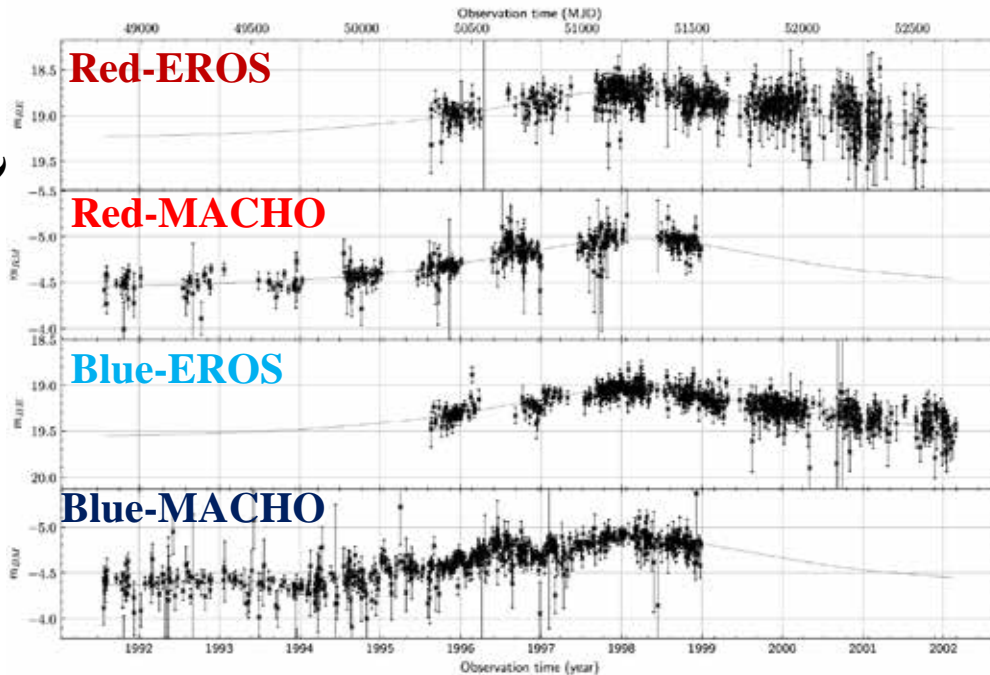
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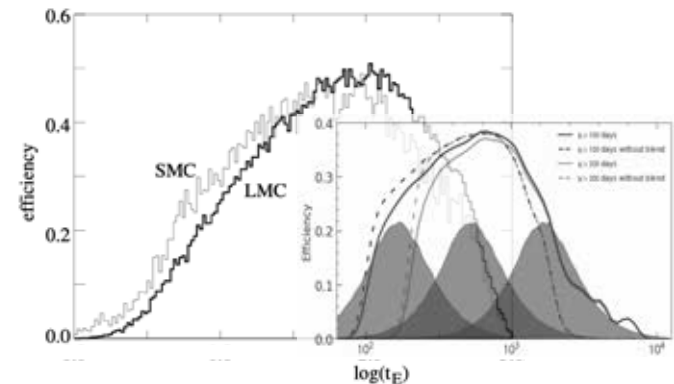
Combining light-curves to search for $t_E > 100$ days events



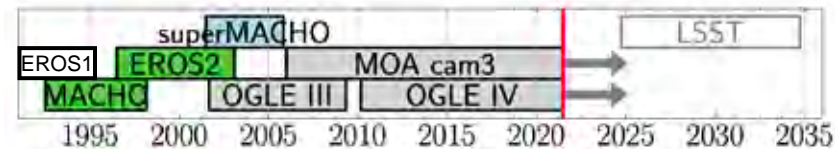
This is a QSO



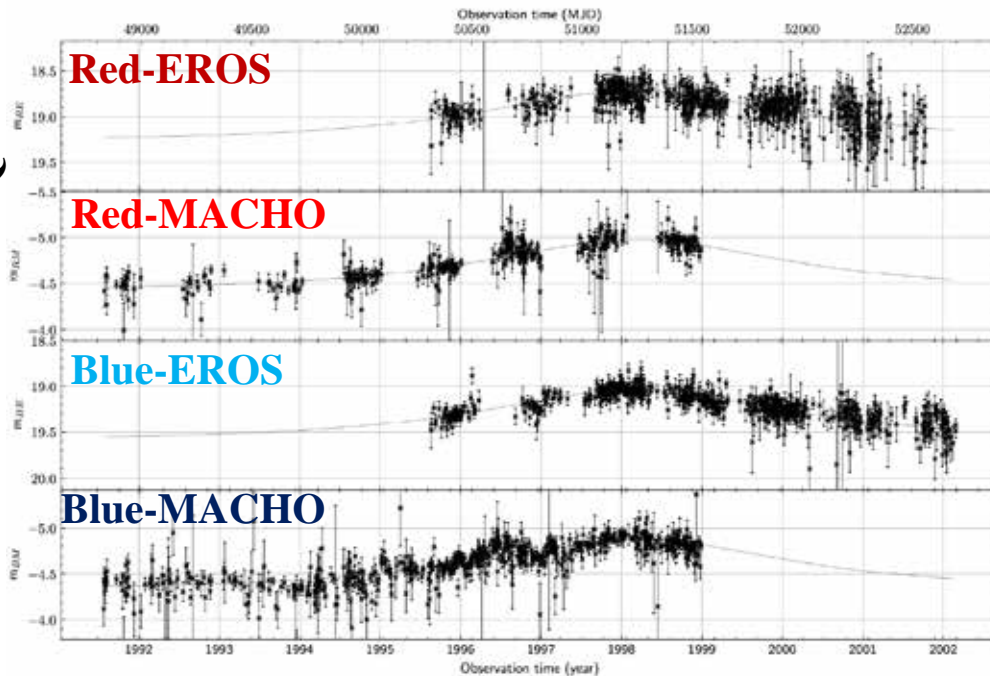
detection efficiency for events > 100 days greatly improved by combining light curves



Combining light-curves to search for $t_E > 100$ days events

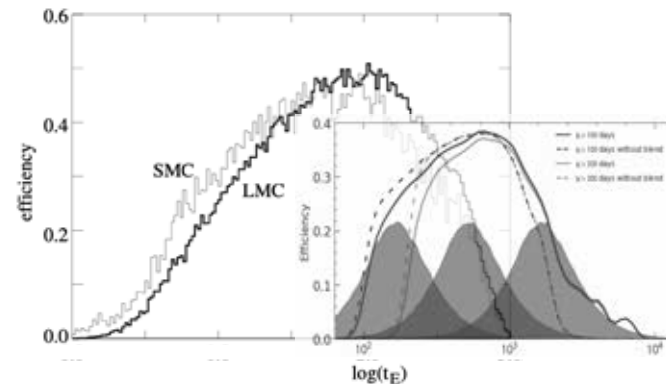


This is a QSO



Note: C. Stubbs offered to use superMACHO data too, but the superpowers of a Harvard professor weren't enough to overcome bureaucracy

detection efficiency for events > 100 days greatly improved by combining light curves



EROS results in microlensing

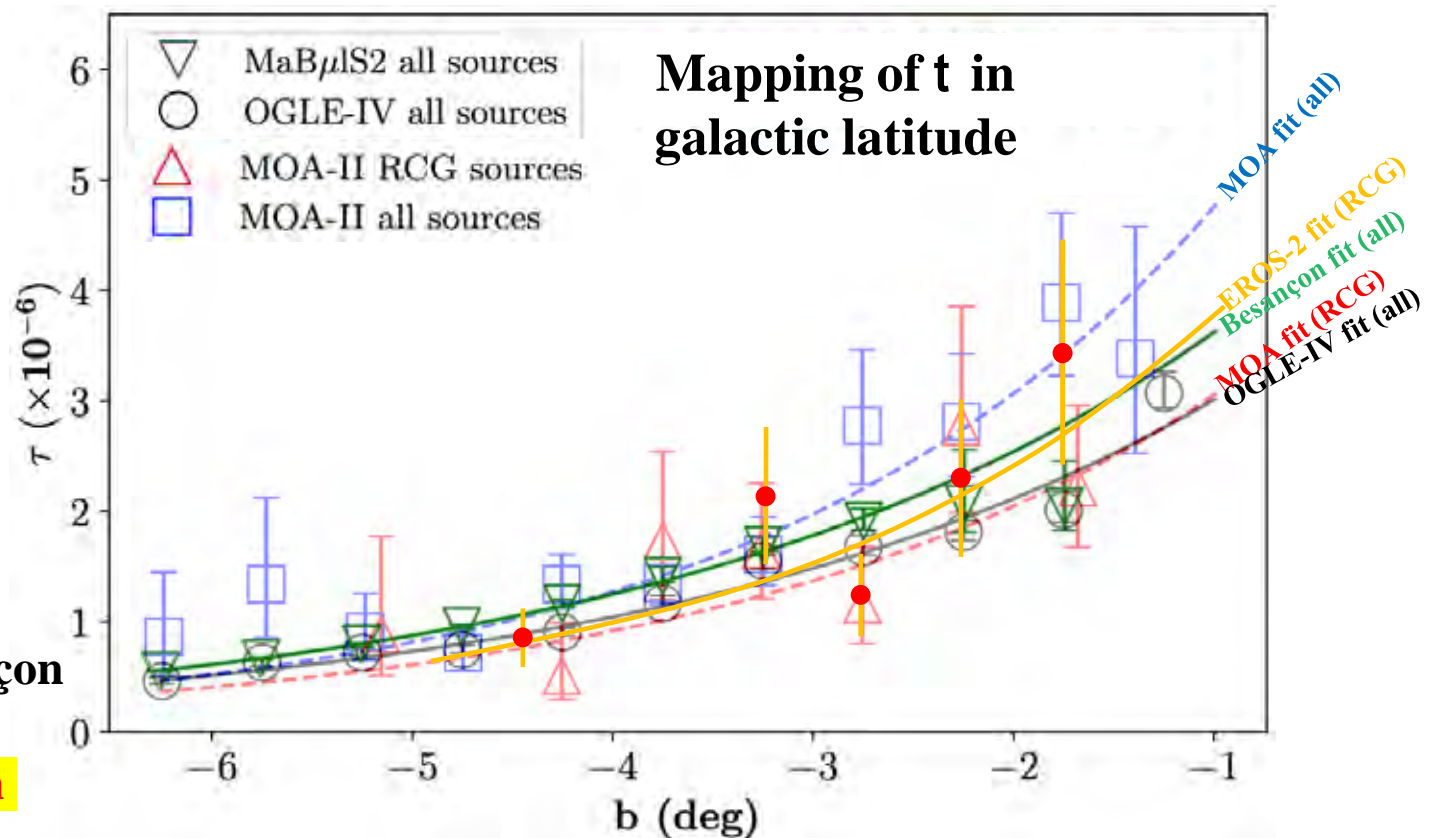
(2) Galactic plane: **Galactic center**

The optical depth τ

- probability for a source to be behind an Einstein disk at a given time (Amplification > 1.34)

EROS contribution in Hamadache et al. A&A 454, 185 (2006)

[Adapted from Specht et al. (2020)]



2nd generation of
Manchester-Besançon
model ~ OK

**No need for hidden
compact objects**

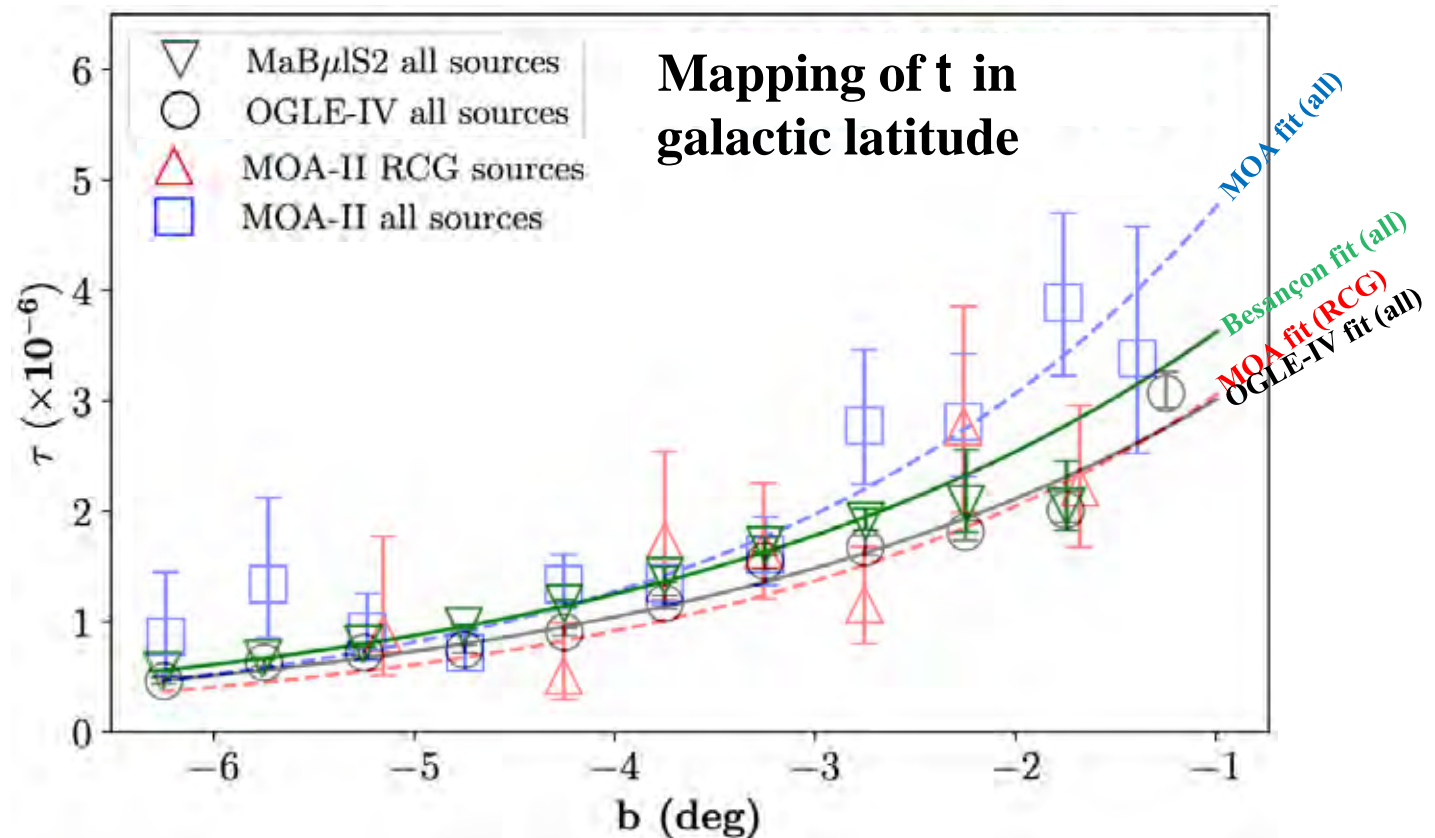
EROS results in microlensing

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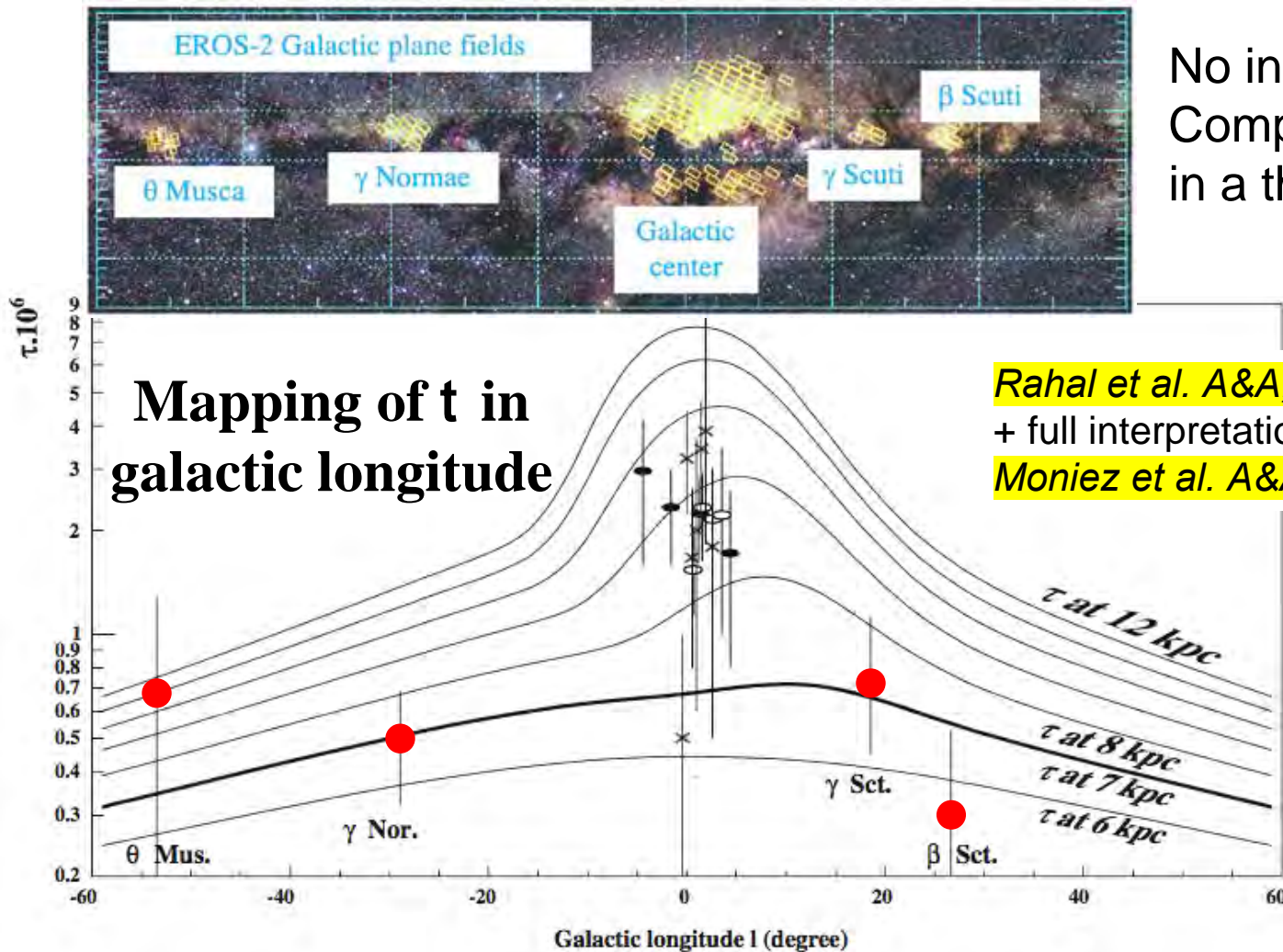
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EROS results in microlensing

(3) Galactic plane : **Galactic spiral arms** (only EROS before 2020)



No indication of Compact Objects in a thick disk

Rahal et al. A&A, 500, 1027 (2009)
+ full interpretation (with CMDs) in
Moniez et al. A&A 604, A124 (2017)

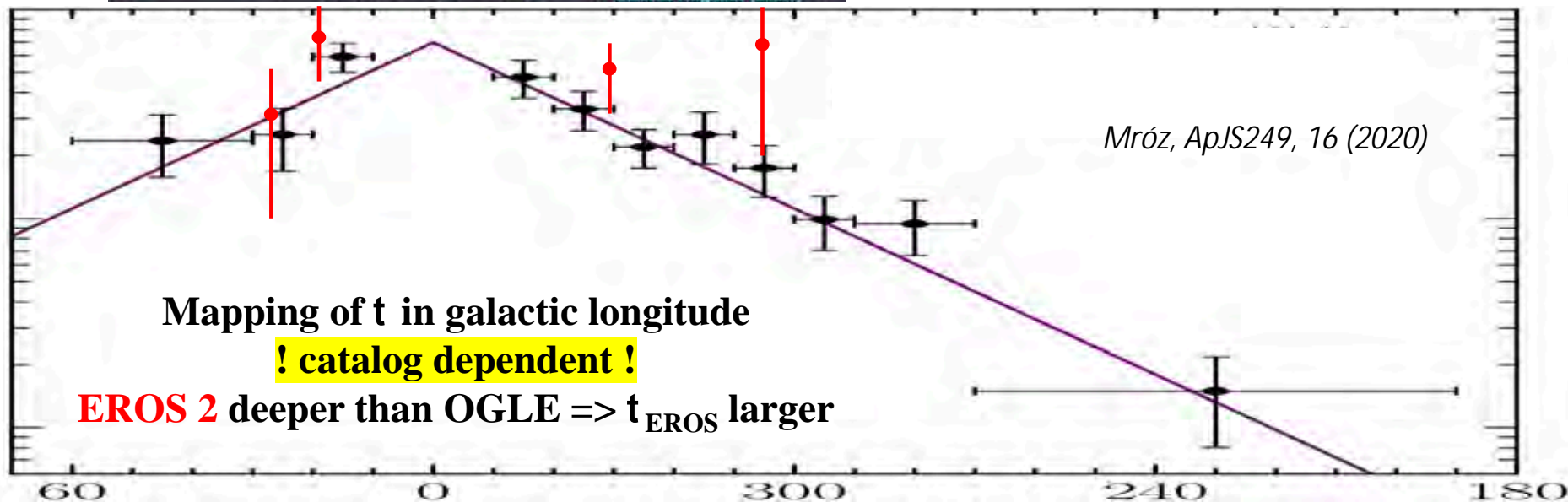
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Other science

- **Systematic search for SNIa** (1999 and 2000) measurement of explosion rate @ $z = 0.13$ within the current uncertainties ($2 \pm 0.6 \cdot 10^{-5}/\text{yr}/\text{cMpc}^3$), based on 16 confirmed SNIa: **Blanc et al. A&A 423, 881 (2004)**

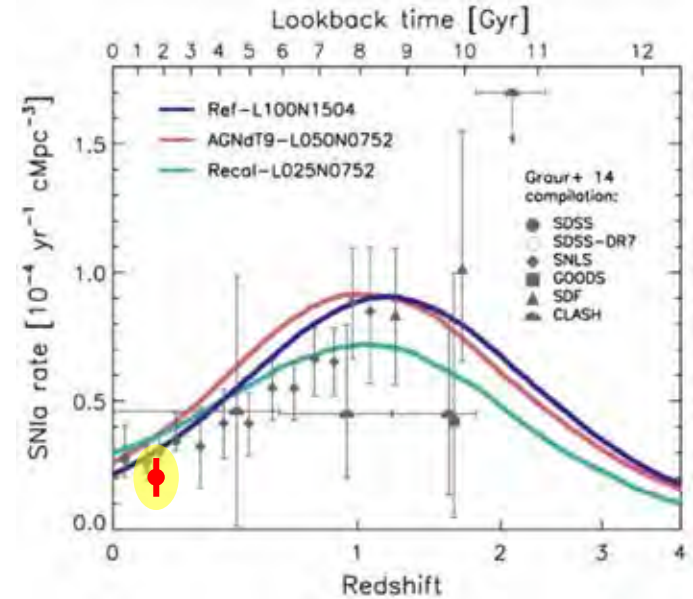
- **Periodic variable stars**

d-Sct, cepheids, RR-Lyrae, eclipsing binaries...
within LMC: *Dae-Won et al. A&A, 566 (2014)*

- **Rarities (non-periodic):** R-coronae borealis, caustic crossings (microlensing again)

- **SN1987a echoes:** found as a source of fake microlensing when superimposed with cataloged stars

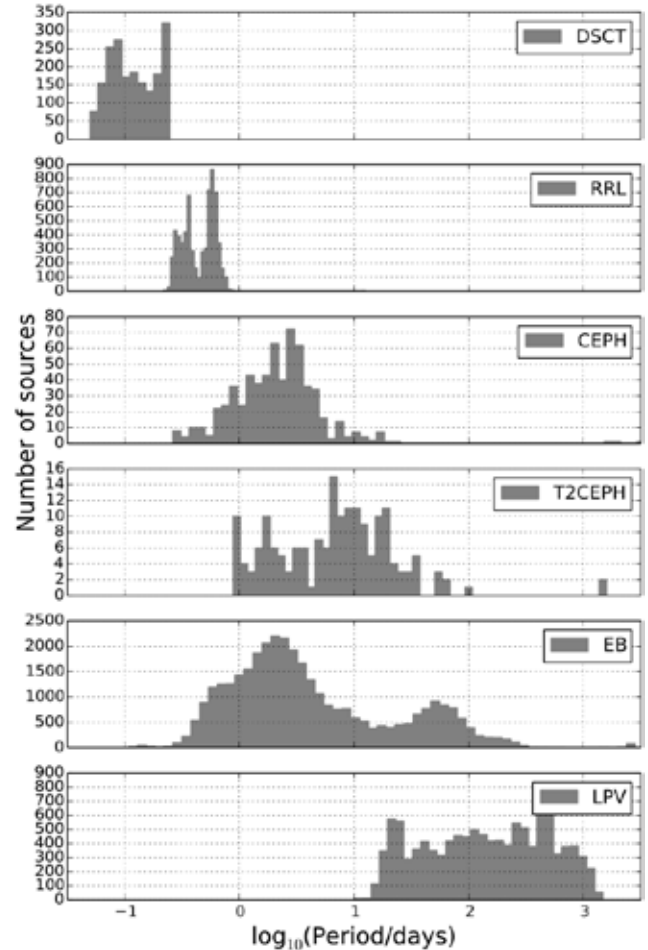
- **Potential** for asteroids, EROS LAC deep-field...



Schaye et al. MNRAS 446, 521–554 (2015)

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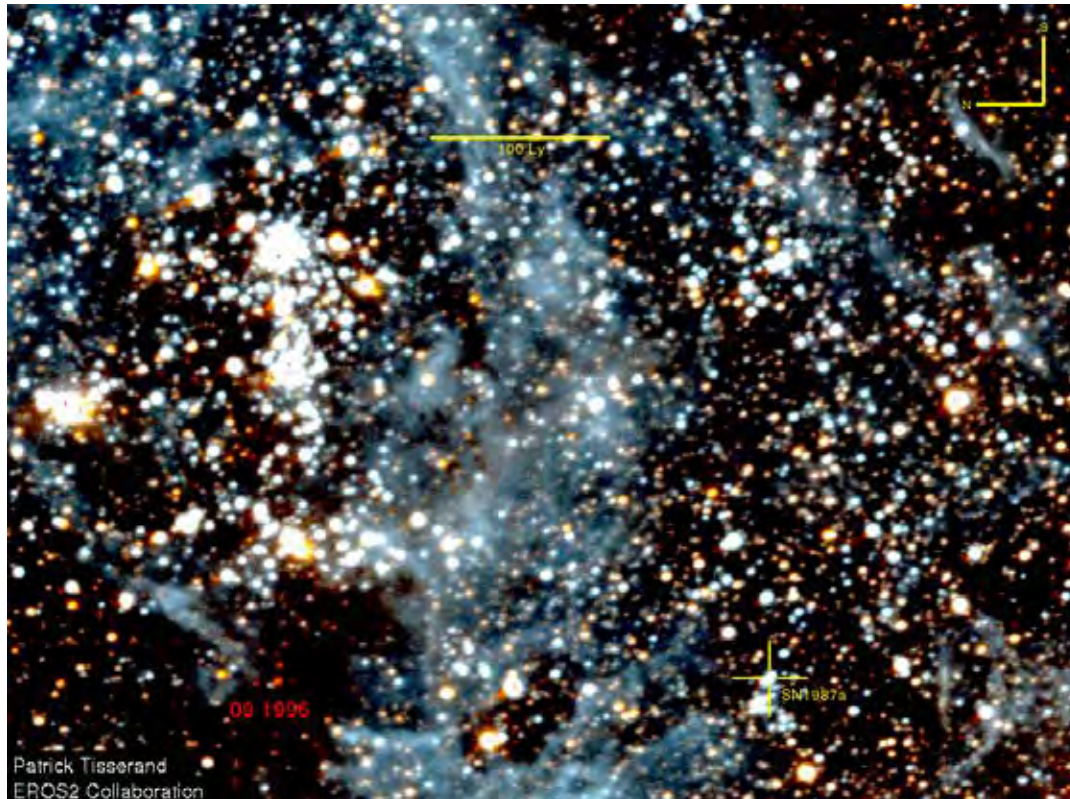
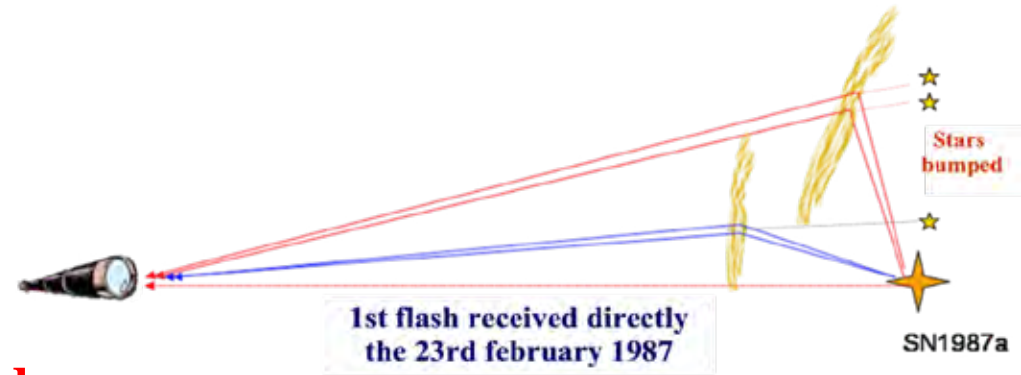


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Serendipitous discovery

Residual microlensing background

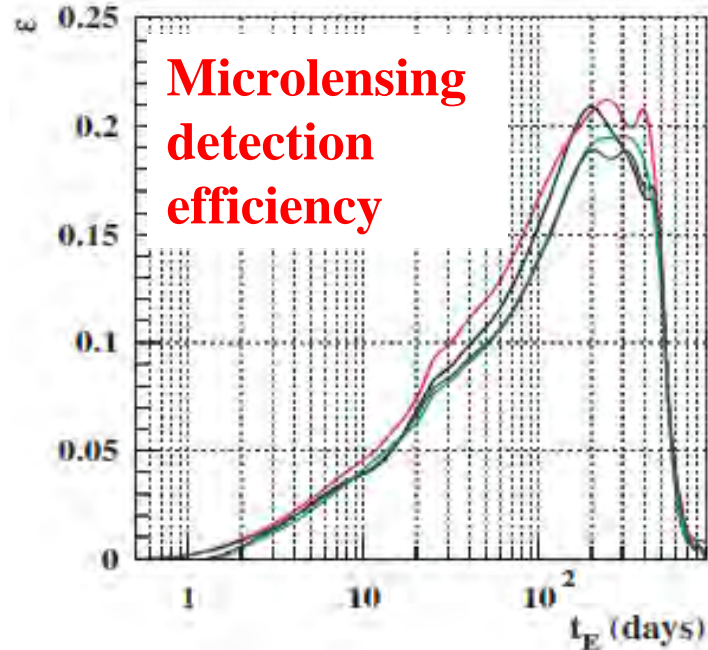
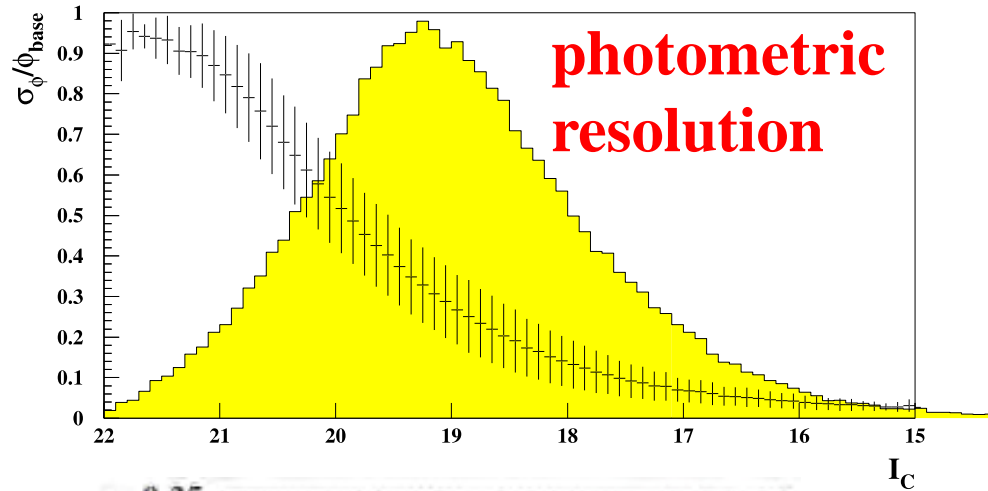
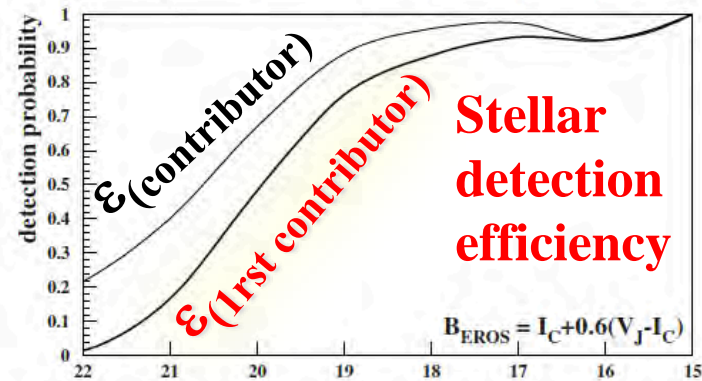
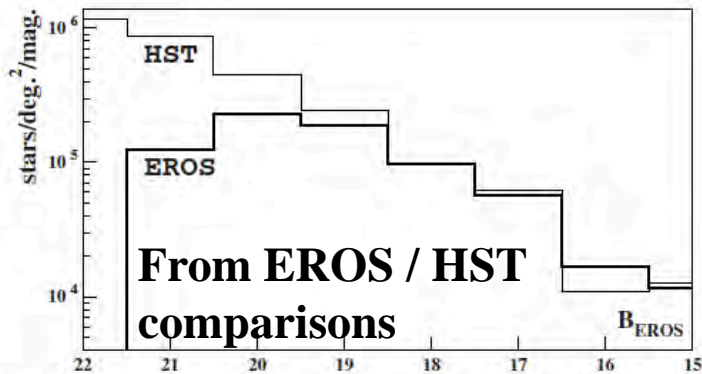
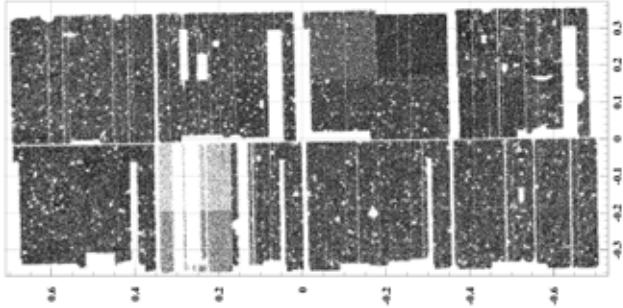


SN1987A echoes

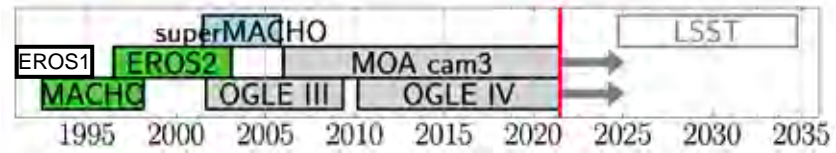
- Diffusion of the light emitted by the SN on interstellar gas
- If superimposed on a monitored star
 - > brightness seems to vary
- Unexpected microlensing background...

**Reliable results come from a deep understanding of the detector
=> Not frequently shown because fiducial is not good com.**

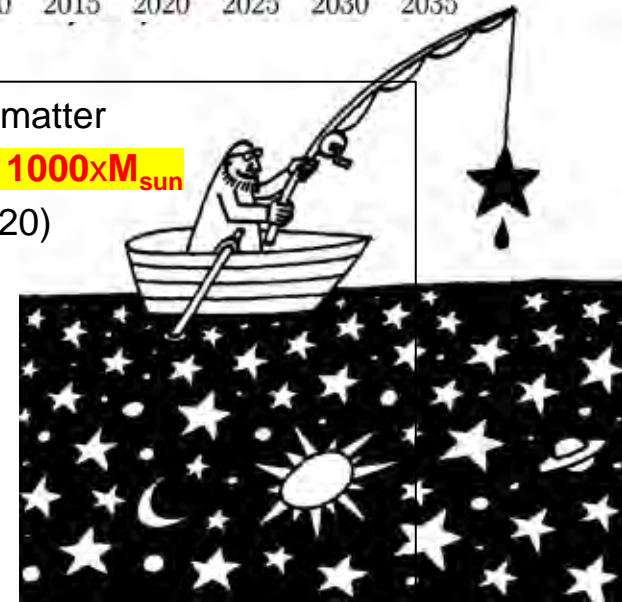
Effective field of view



EROS: 10 years of data 30 years of analysis



- **Initially designed for microlensing searches** to constrain halo dark matter
 - Dark matter results exceed expectations: **exclusion from 10^{-7} to $1000 \times M_{\text{sun}}$**
 - Galactic Center, Galactic Spiral Arms (EROS exclusivity until 2020)
 - Extras: Caustic-crossings / microlensing exotics
- **Other results + searches** : all types of variability
 - In 1998, **EROS was the main discoverer for SN's @ $z \sim 0.1$**
- **Rarities**
 - R-coronae Borealis, DY Per stars
 - SN1987a echoes



EROS legacy, a brilliant future: EROS is finalizing a database for public use

- Will be used by brokers (like Fink), to help categorization of the Rubin-LSST alerts.
- For **combined analysis** with data from current and future surveys (OGLE, Gaia, ZTF, Rubin-LSST, ROMAN...) for very long timescale variabilities

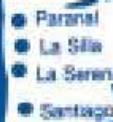
Few key numbers

- $O(10^8)$ stellar sources monitored for 10 years with 300-500 photometric measurements
- $O(10^5)$ stellar sources monitored for almost **20,000 times** in 4 years (sampling 20 min.)
- $O(10^4)$ cepheids and RR-Lyrae + variables of undetermined type (like LPV > years)

Final final... in 50000 years...

THE MESSENGER

Archeological remains from EROS ?



A time capsule whose contents are described in Dr. Richard West's article was then deposited by President Frei with the works being blessed by the Archbishop of Antofagasta, Monsignor Patricio Infante.

The Time Capsule

During the December 4, 1996 event at Paranal, President Frei placed a Time Capsule with selected materials in the wall of the UT1 building. This capsule, an aluminium cylinder of 15 cm diameter and 45 cm long, was filled with nitrogen gas and sealed hermetically. A commemorative plaque was fixed in front of the cavity. In addition to the various papers listed below, the capsule also contains a list of contents etched on a metal plate which will survive virtually indefinitely in this environment, while it cannot be excluded that the papers may deteriorate with time.

Contents of the Time Capsule:

1. Document signed by President Frei on the occasion;
2. Copy of the Acuerdo between ESO and Chile;
3. One outstanding scientific paper from each of ESO's member countries (a list of the titles is available at the ESO Web-site)
4. Copy of December 4 issues of the Chilean newspapers *El Mercurio* and *La Epoca*;
5. Copies of the written version of the speeches delivered on the occasion;
6. Viewgraph and description of VLT, as presented at the exhibition;
7. List of VLT Team members;
8. Photos of Paranal before and after construction;
9. Photo of the VLT model at exhibition.

R.M. West

Final final... in 50000 years...

THE MESSENGER

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● Paranal
● La Silla
● La Serena
● Santiago

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hoping to see you for the 50th anniversary (before the 50000th). I'm saving a few other anecdotes for this occasion

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