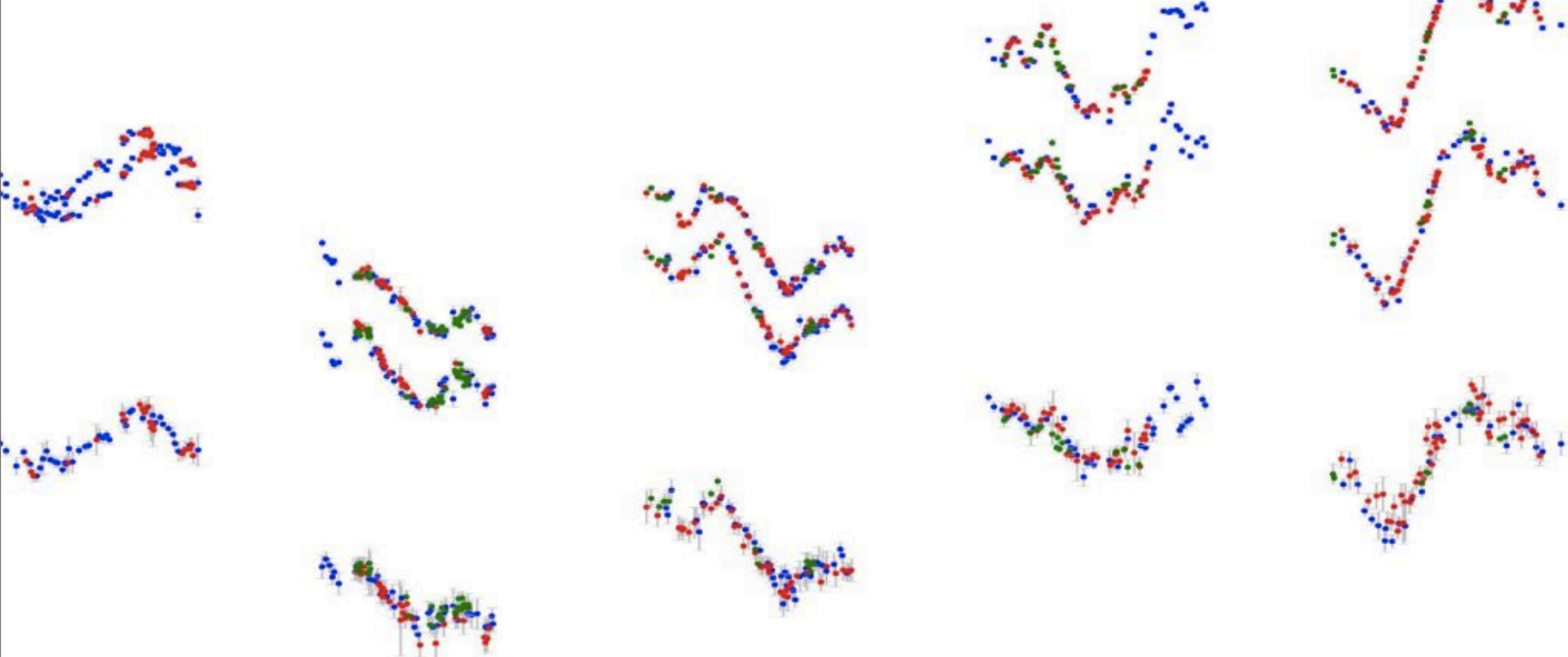
COSMOGRAIL: present and future

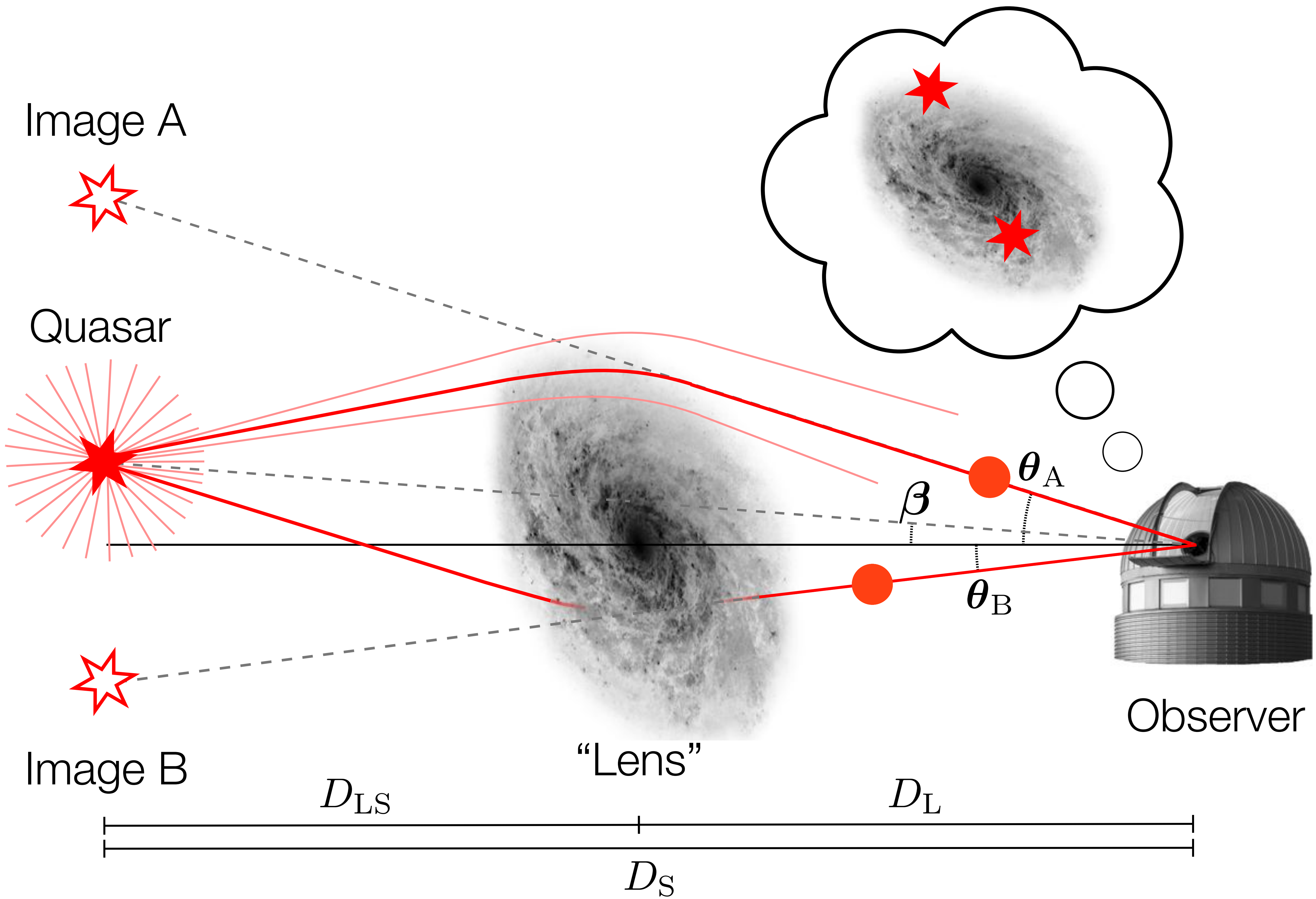
F. Courbin, G. Meylan, V. Bonvin, M Tewes, D. Sluse, D. Paraficz ...
For the COSMOGRAIL collaboration



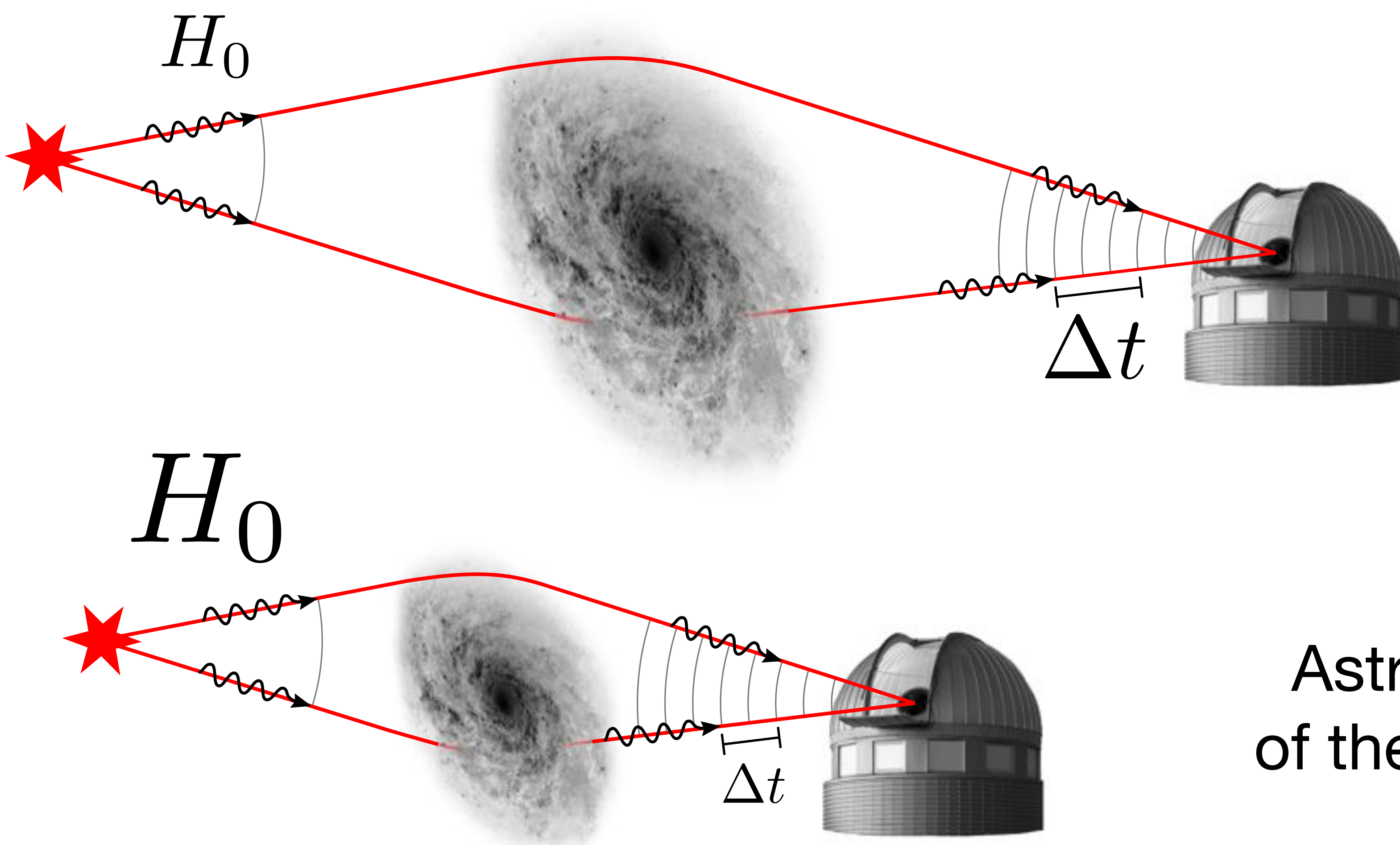
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
Laboratoire d'astrophysique http://lastro.epfl.ch
Ecole Polytechnique Fédérale de Lausanne (EPFL)

Strong Lensing Meeting
Tokyo (IPMU) November 2014

Strong gravitational lensing of quasars : multiple images



Time delays probe the Hubble Constant H_0



Lens potential at the images

Source position (unconstrained)

Astrometry of the images

$$\Delta t = \frac{1+z_{\rm L}}{c} \underbrace{\frac{D_{\rm L} D_{\rm S}}{D_{\rm LS}}}_{\propto 1/H_0} \cdot \Delta\left(\frac{1}{2}|\vec{\theta} - \vec{\beta}|^2 - \psi(\vec{\theta})\right)$$

- Measured time delays provide *direct* and *independent* constraints on H_0.
- A percent-level determination of H_0 is highly complementary to other probes, and critical to constrain and test the ingredients of cosmological models.

Advantages

- Does not rely on any knowledge of a standard candle
- No need of secondary distance estimators
- Insensitive to local motions
- Insensitive to dust
- Independent of any other cosmological probe
- Can be combined with other probes
- Does not need a 20-m telescope in space

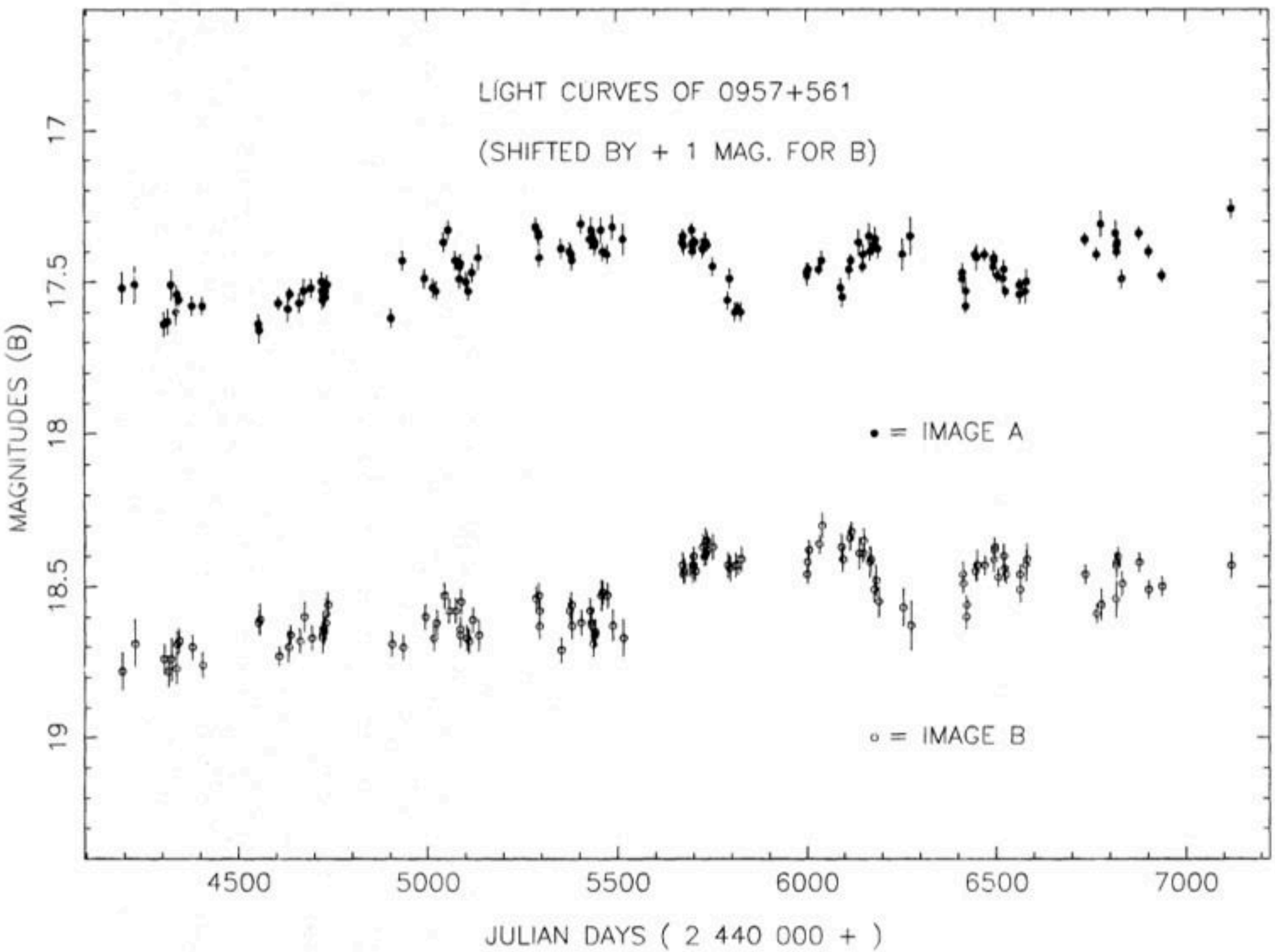
Ingredients

- **Time delays** are hard (but possible) to measure with high accuracy
- Historically, the field has suffered from the Q0957+561 time delay «controversy»
- Need a **mass model** for the lensing galaxy (mass-slope degeneracy)
- Need some knowledge of the **environment of the lens** (mass-sheet degeneracy)

First measurements of time delays (1989-1997)

- First photometric monitoring of **Q0957+561** by three groups
- **Vanderriest et al. 1989, A&A, 215, 1**: optical monitoring: Δt = 415 ± 20 days
- **Schild 1990, AJ, 100, 1771**: optical monitoring: Δt = 404 - 406 days
- **Lehar et al. 1992, ApJ, 384, 453**: radio monitoring at the VLA leading to a delay of Δt = 513 ± 40 days

First measurements of time delays (1989-1997)



(Vanderriest et al. 1989, A&A, 215, 1)

Time delay controversy solved in 1997

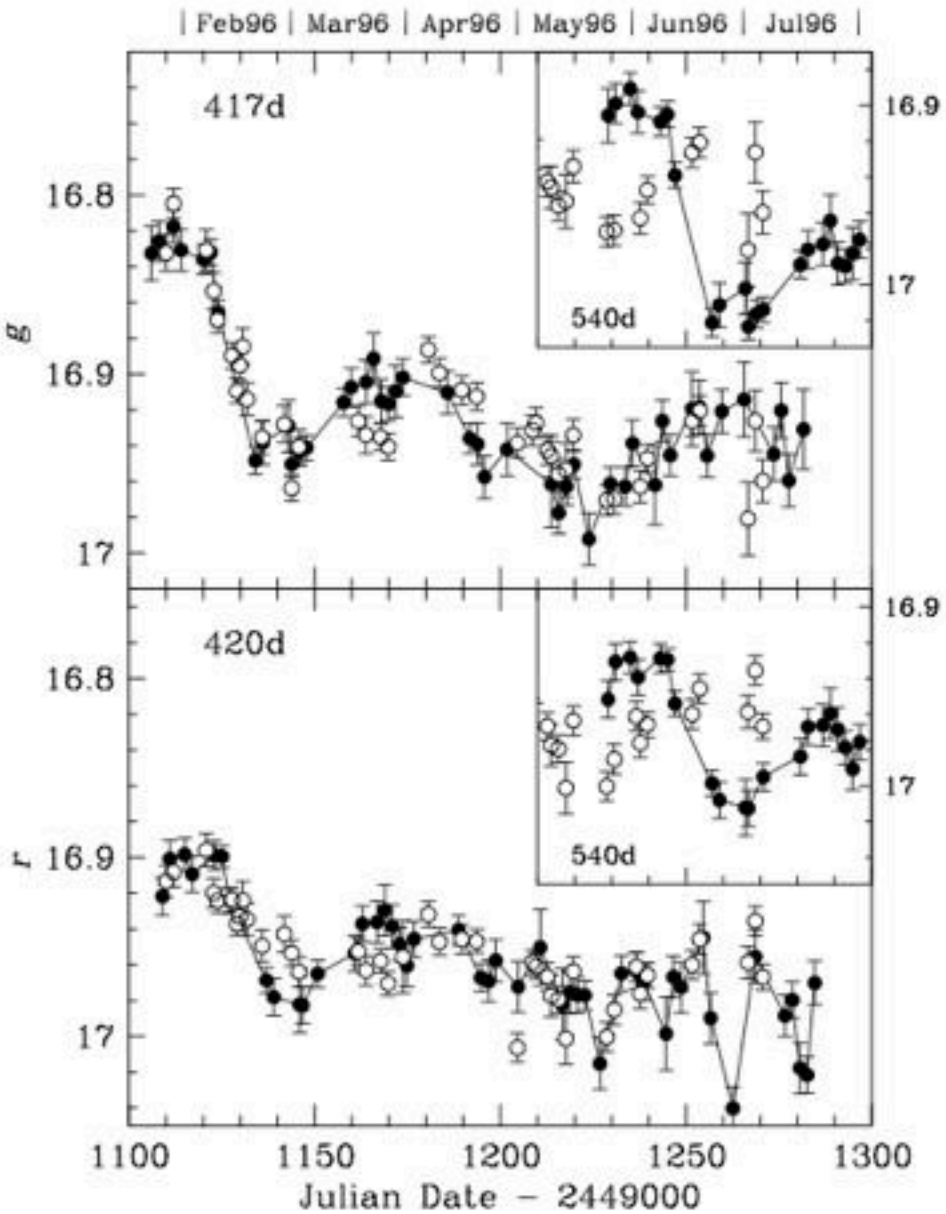


FIG. 3.—The 1995 A light curves (*filled circles*) shifted by the optimal values of the time delay Δt and the magnitude offset Δm, superimposed on the 1996 image B data (*open circles*). The fits are based on the linear method analysis, but the parameters given by other fitting methods are nearly identical. See text for details. Insets show the overlapping regions of A and B light curves assuming the long delay of 540 days (and fitting for the magnitude offset). This delay is clearly excluded by the data.

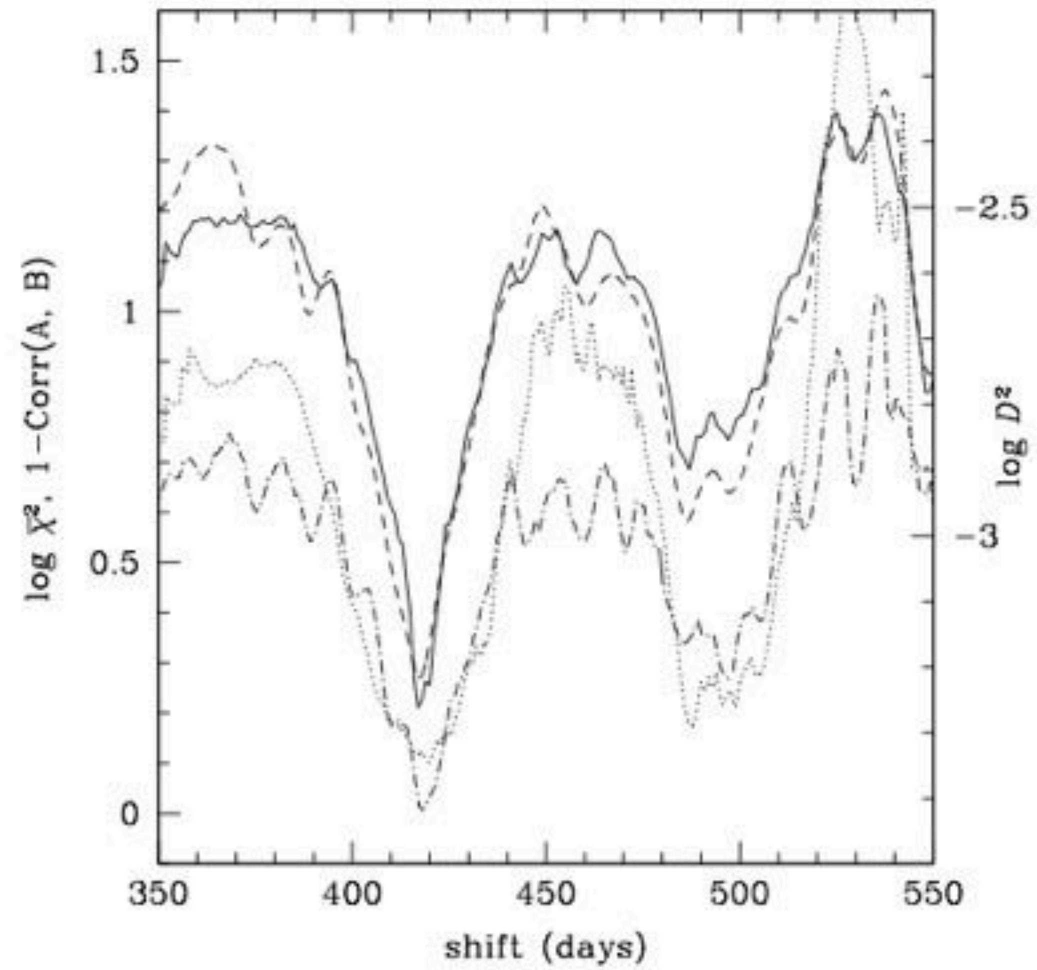
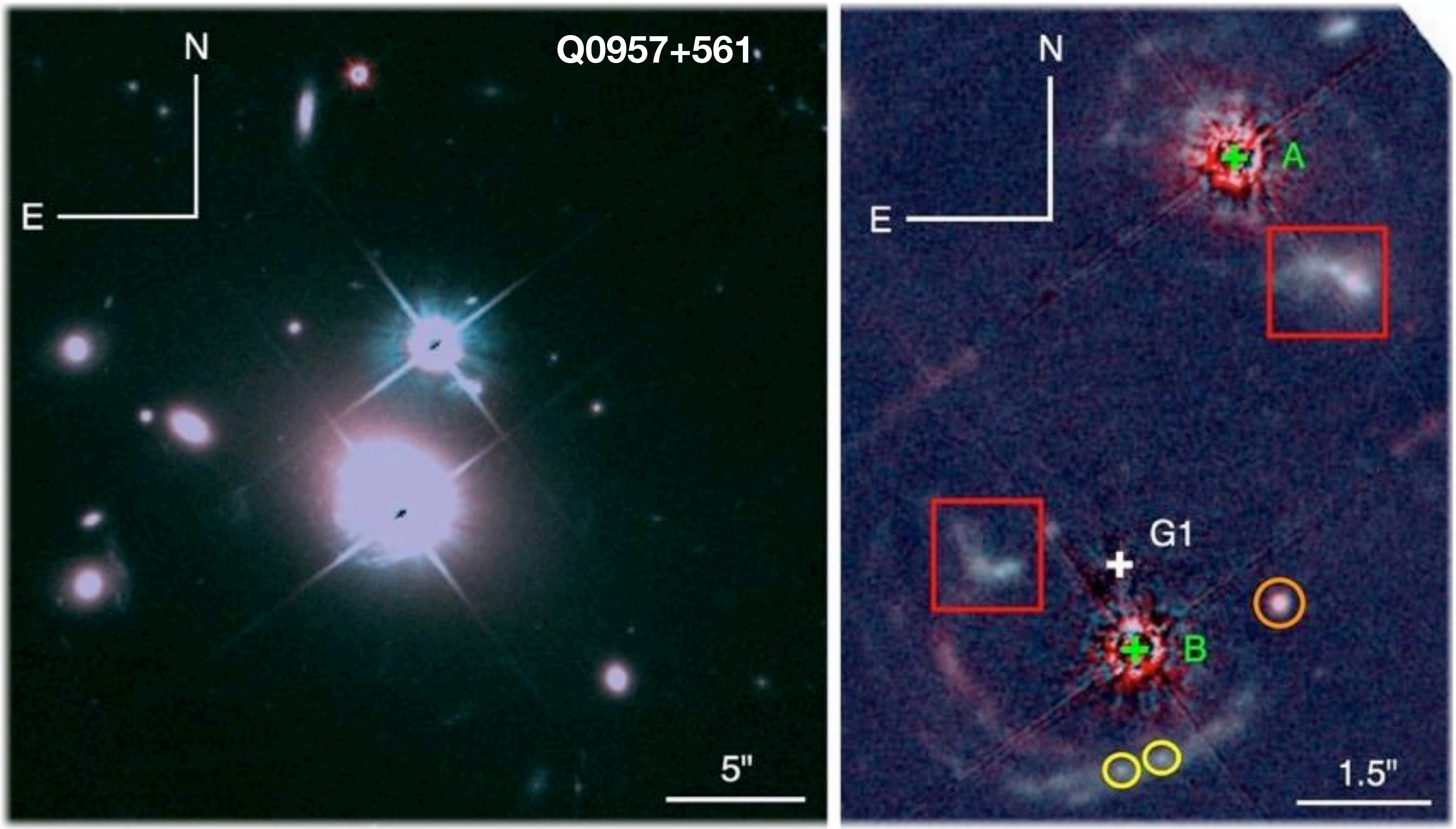


FIG. 2.—Figure of merit for various statistical methods as a function of time delay Δt based on *g*-band light curves. Curves are arranged so that their minima correspond to the best-fit delays. The second fitted parameter, magnitude offset Δm, was minimized at each value of Δt. The values of $\bar{\chi}^2$ for the linear and PRH methods are represented with solid and dot-dashed lines, respectively; the dispersion measure D^2 of the PHKRS method is shown with a dashed line, and the complement of the cross-correlation coefficient with a dotted line. Note that three different vertical coordinates are represented, depending on the statistical technique. All methods give minima at ∼417–420 days and strongly reject a delay of ∼540 days.

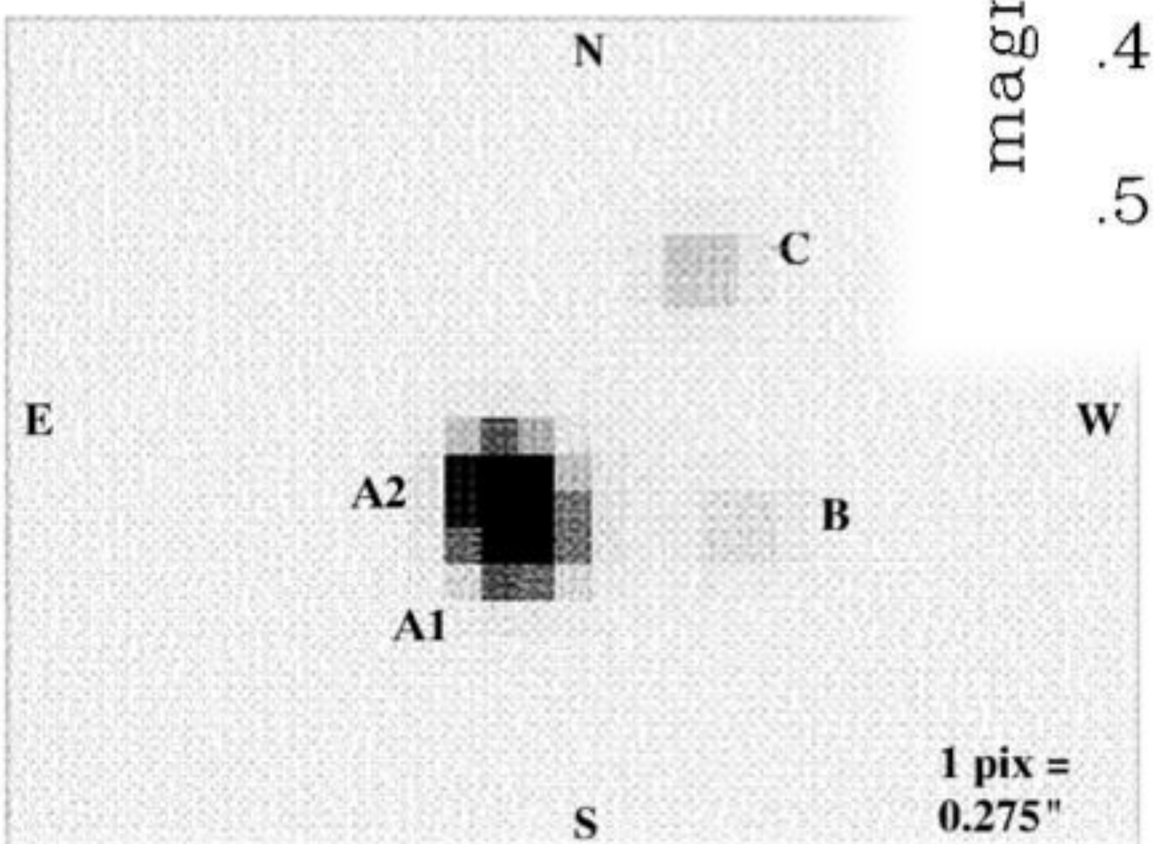
(Kundic et al. 1997, ApJ, 482, 75)

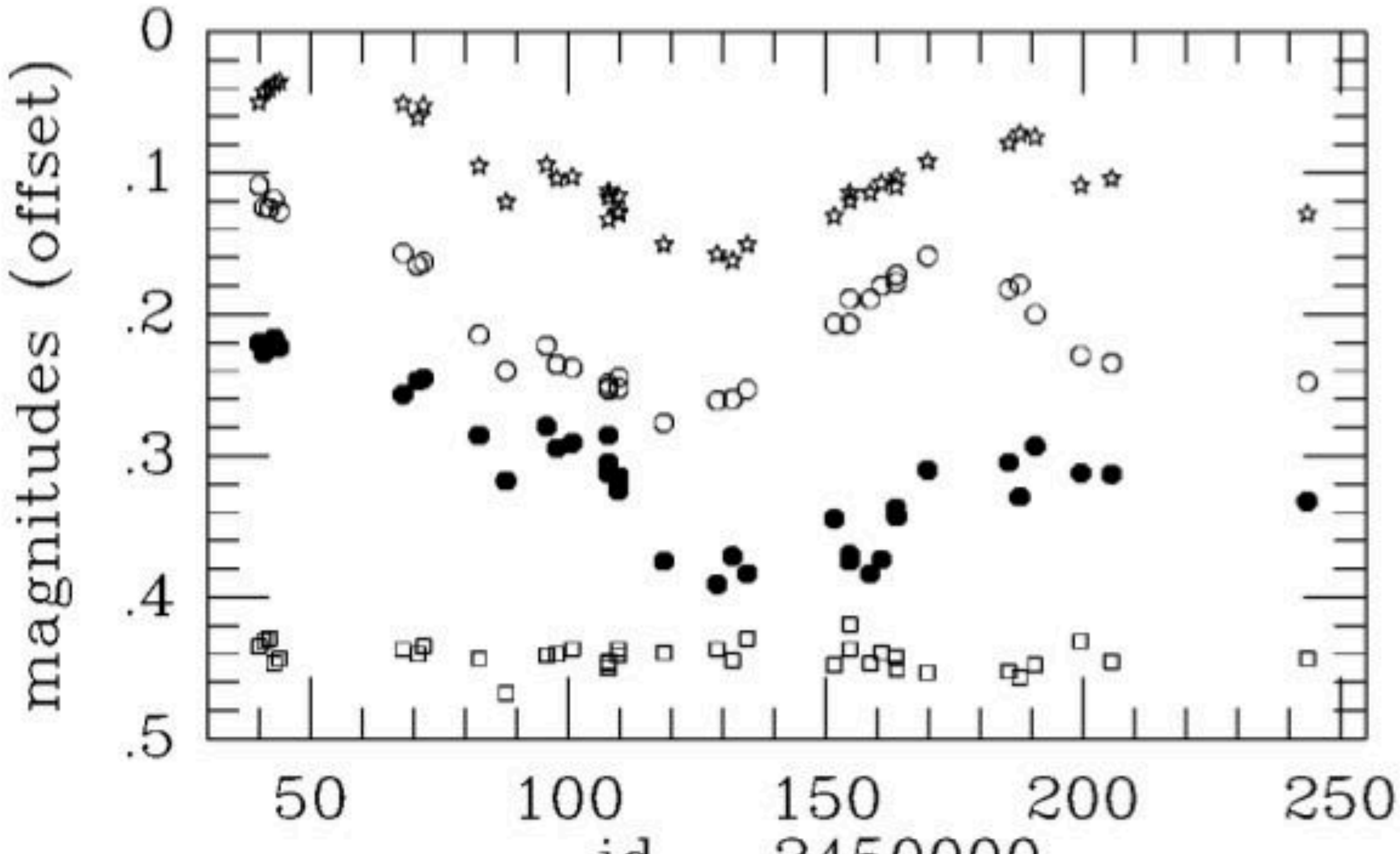
First measurements of time delays (1989-1997)



(Fadely et al. 2010, ApJ, 711, 242)

PG 1115+080





(Schechter et al. 1997, ApJ, 475, L85; see also Barakana 1997, ApJ, 489, 21)

PG 1115+080

- PG1115+080: first long, well sampled light curve of a lensed quasar in the optical (Schechter et al. 1997, ApJ, 475, L85)

- B1608+656: **VLA** radio monitoring with no contamination by microlensing (Fassnacht et al. 2002, ApJ, 581, 823)

- Series of optical time delays by Burud et al. (2002, A&A, 391, 481; 2002, A&A 383, 71), Hjorth et al. (2002, ApJ, 572, L11) using optical data from the **Nordic Optical Telescope and from ESO.**

- Time delays from optical light curves with small telescopes become available around 2000-2005 (i.e., **feasibility is demonstrated**), but

    - The accuracy of the delays remains low (10% or worse)

    - Lens models are underconstrained (including line-of-sight contribution)

COSMOGrail

Cosmological **Mo**nitoring of **Gravi**tational **L**enses

... to measure "time delays", to constrain H_0, to learn about DE

EPFL: **G. Meylan, F. Courbin**, V. Bonvin, D. Paraficz

IIA Bangalore: T. Prabhu, C.S. Stalin, R. Kumar

Univ. Bonn: M. Tewes

Univ. Liège: P. Magain, D. Sluse

UzAS Tashkent: I. Asfandiyarov

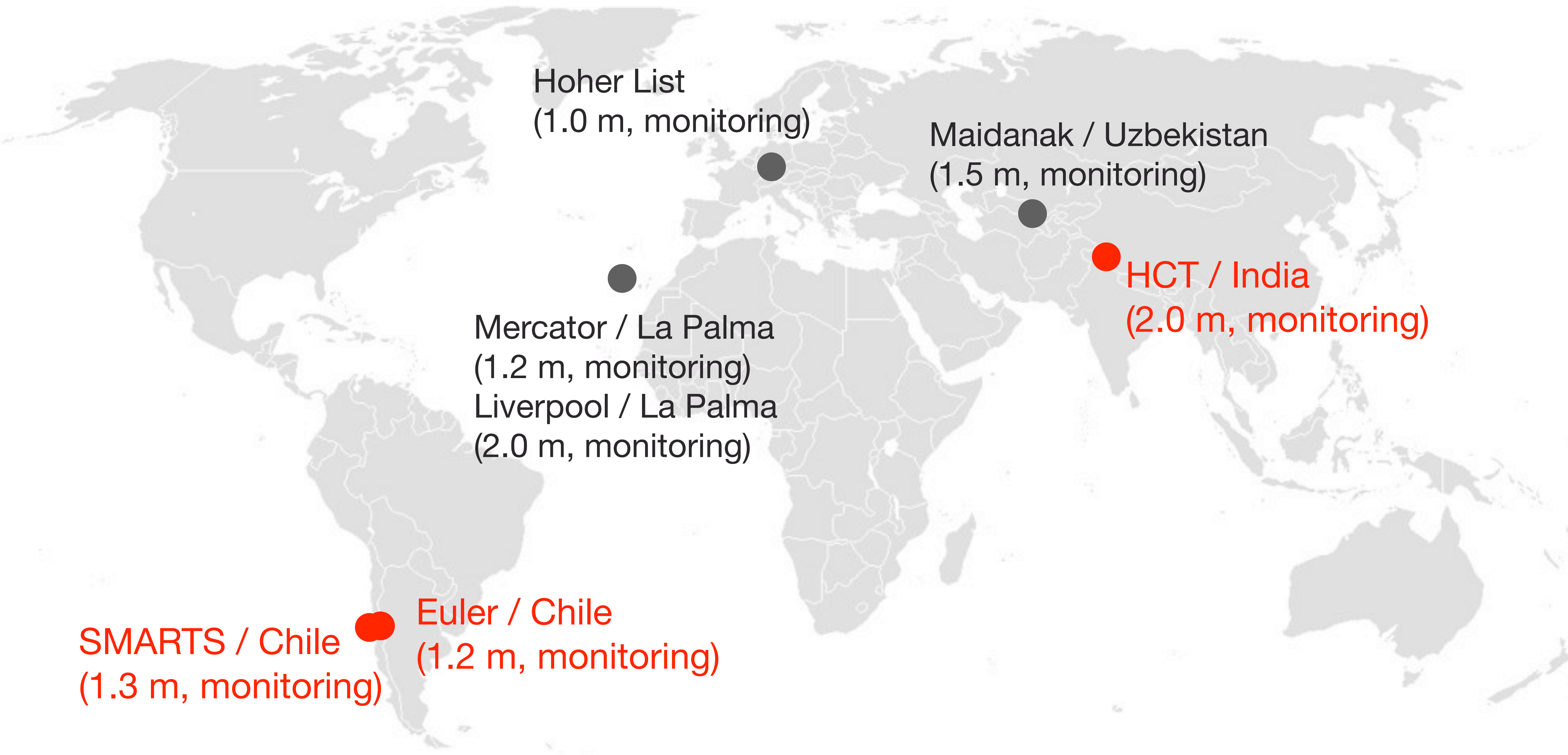
Univ. Zürich: P. Saha, J. Coles

Univ. Nottingham: S. Dye

Now also in close collaboration (monitoring, microlensing) with:
C. Kochanek, A. Mosquera (Ohio),
C. Morgan, C. MacLeod, L. Hainline (USNA)

And the lens modeling & cosmography experts :
S. Suyu (ASIAA), T. Treu, M. Auger, P. Marshall, S. Hilbert, C. Fassnacht, R. Blandford, T. Collett

COSMOGRAIL monitoring telescopes



Main teams doing lens monitoring joined forces in 2010 :

1) EPFL-led COSMOGRAIL team (started in 2004) : Lead time delay work
2) Group of C. S. Kochanek (Ohio), using SMARTS 1.3-m : Lead microlensing work

Measurements of time delays (2005+)

Euler Telescope, La Silla, Chile (1.2m)

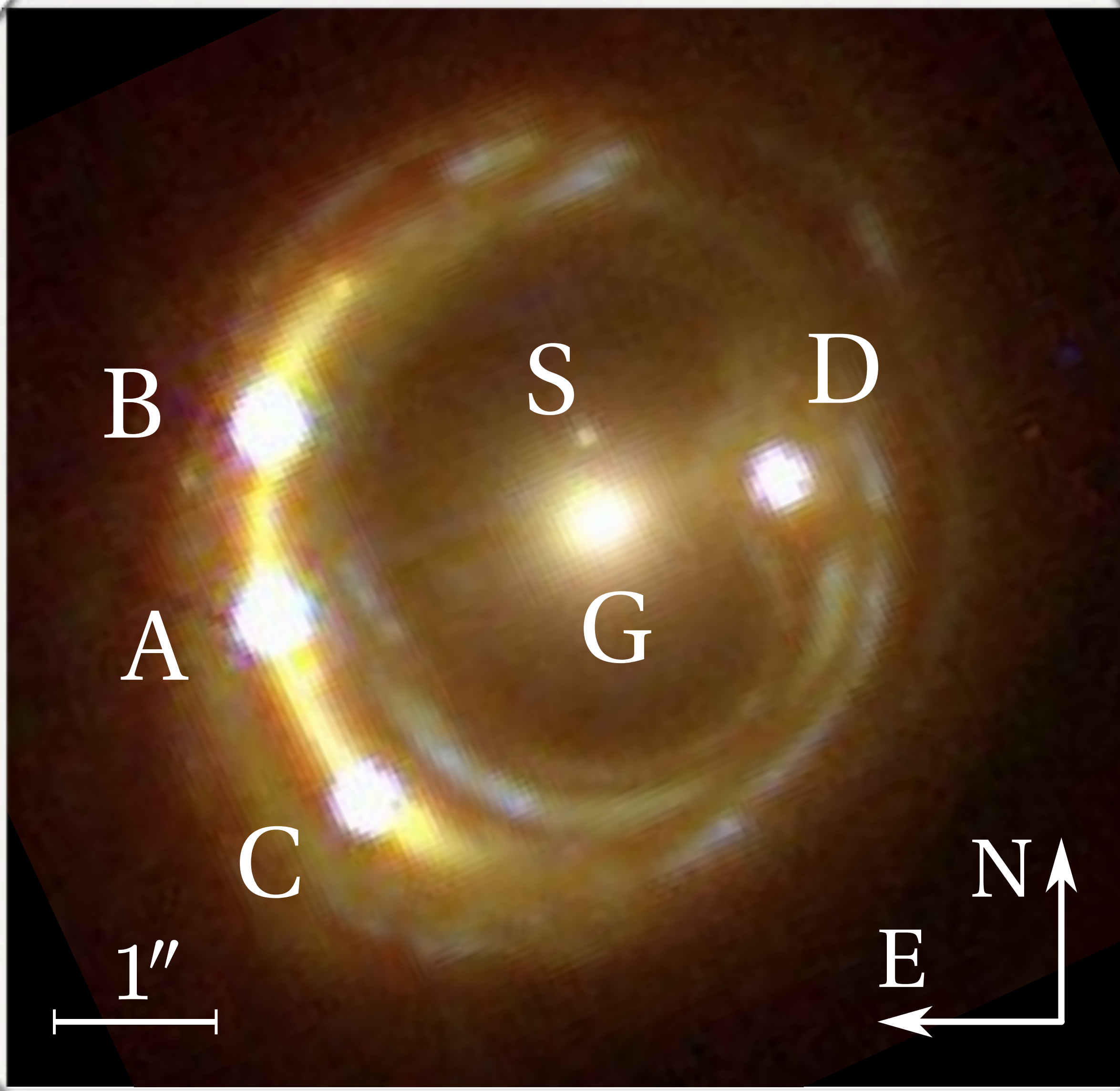
- Dedicated (optical) monitoring program to measure many lensed quasars over a decade or more
- Small telescopes are used, but with high temporal sampling
- Deconvolution technique to sharpen the images

Himalayan Chandra Telescope, India (2m)

Mercator Telescope, La Palma, Spain (1.2m)

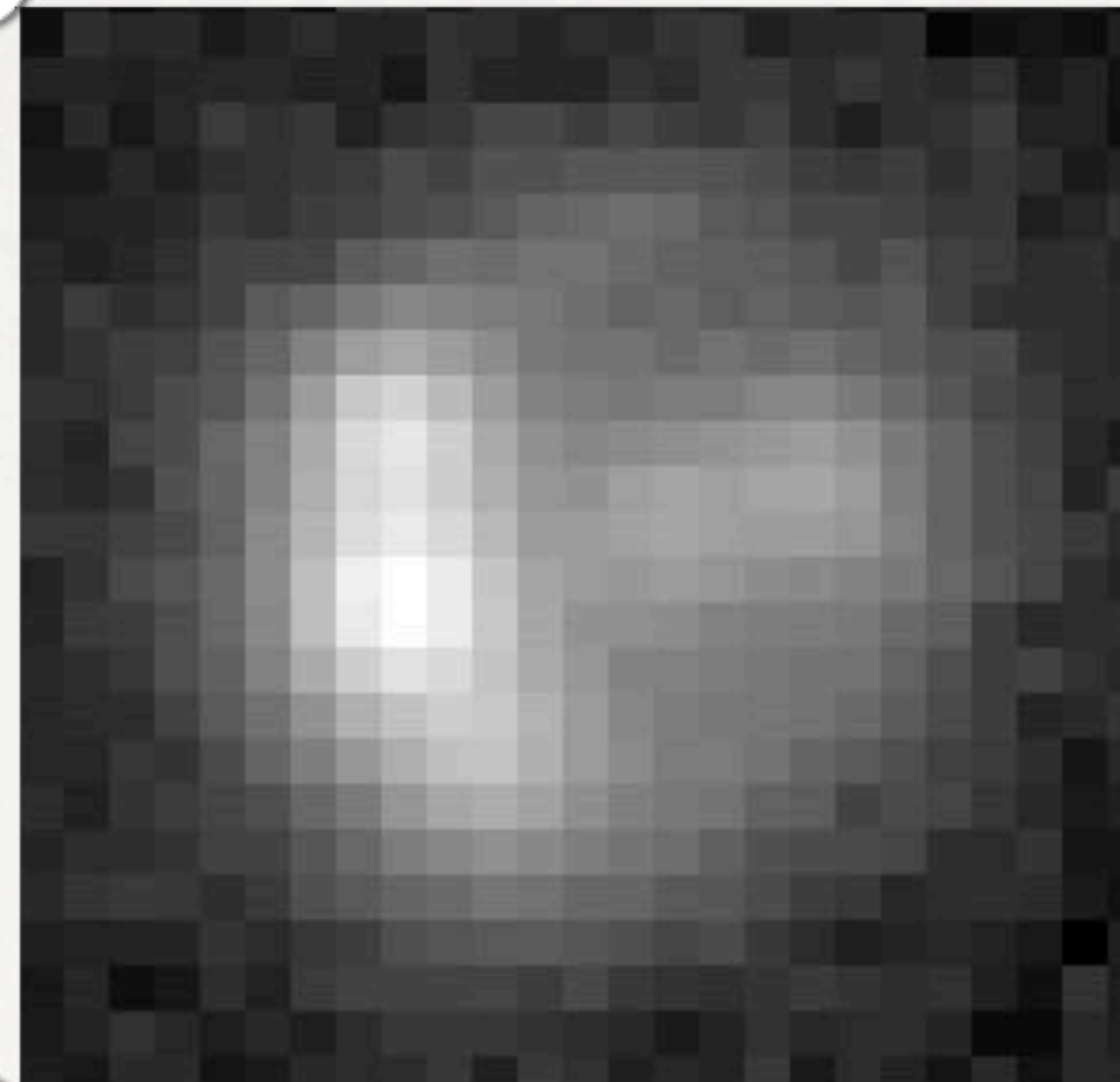
Maidanak observatory, Uzbekistan (1.5m)

RX J1131-1231, seen from space and ground



Hubble Space Telescope

Data from CASTLES, PI C. S. Kochanek
ACS + NICMOS2



Euler

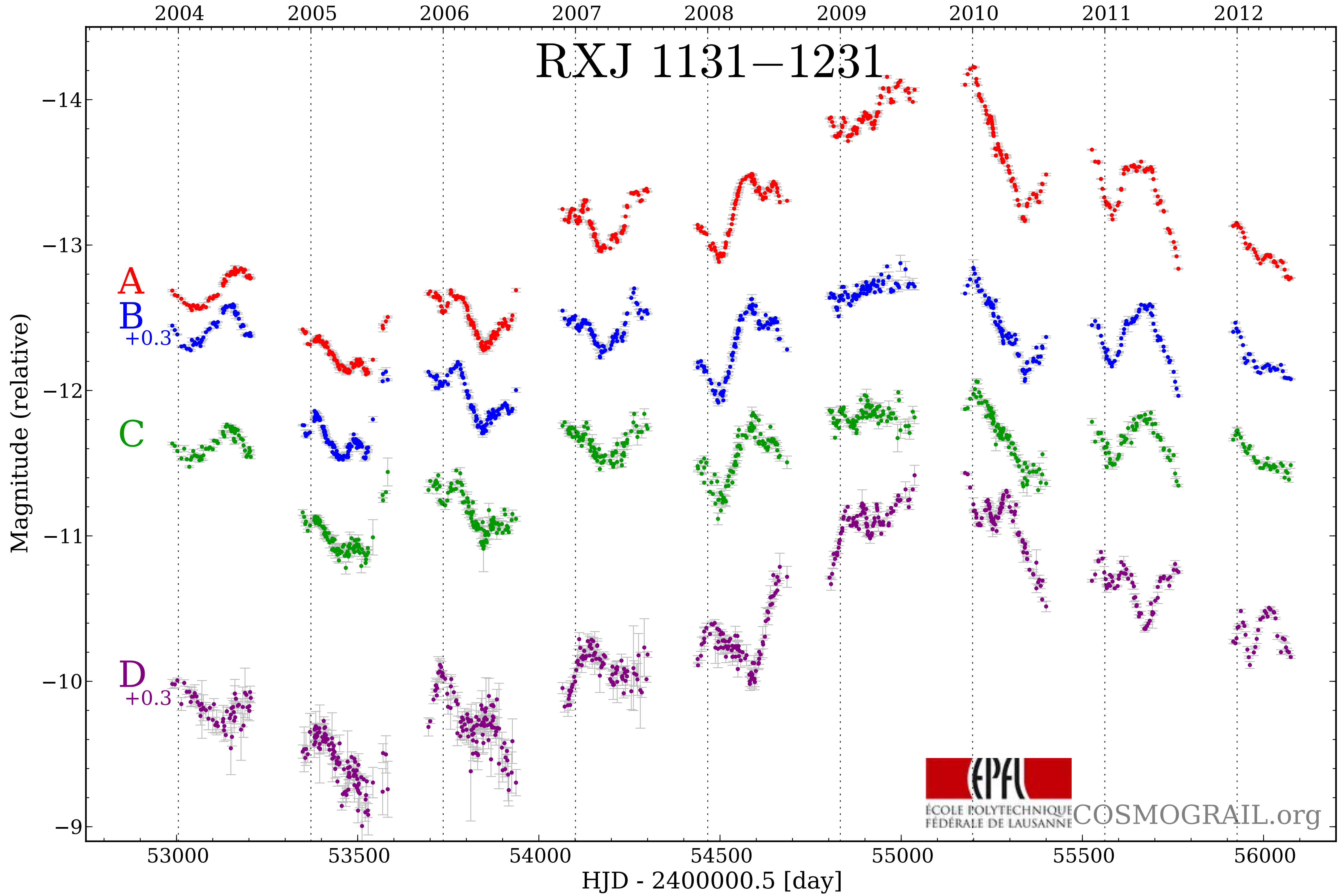
1.2 m Swiss Euler Telescope T_{exp} = 360 s
Camera C2, FWHM 1.0 arcsec R filter

COSMOGRAIL Deconvolution Photometry Pipeline

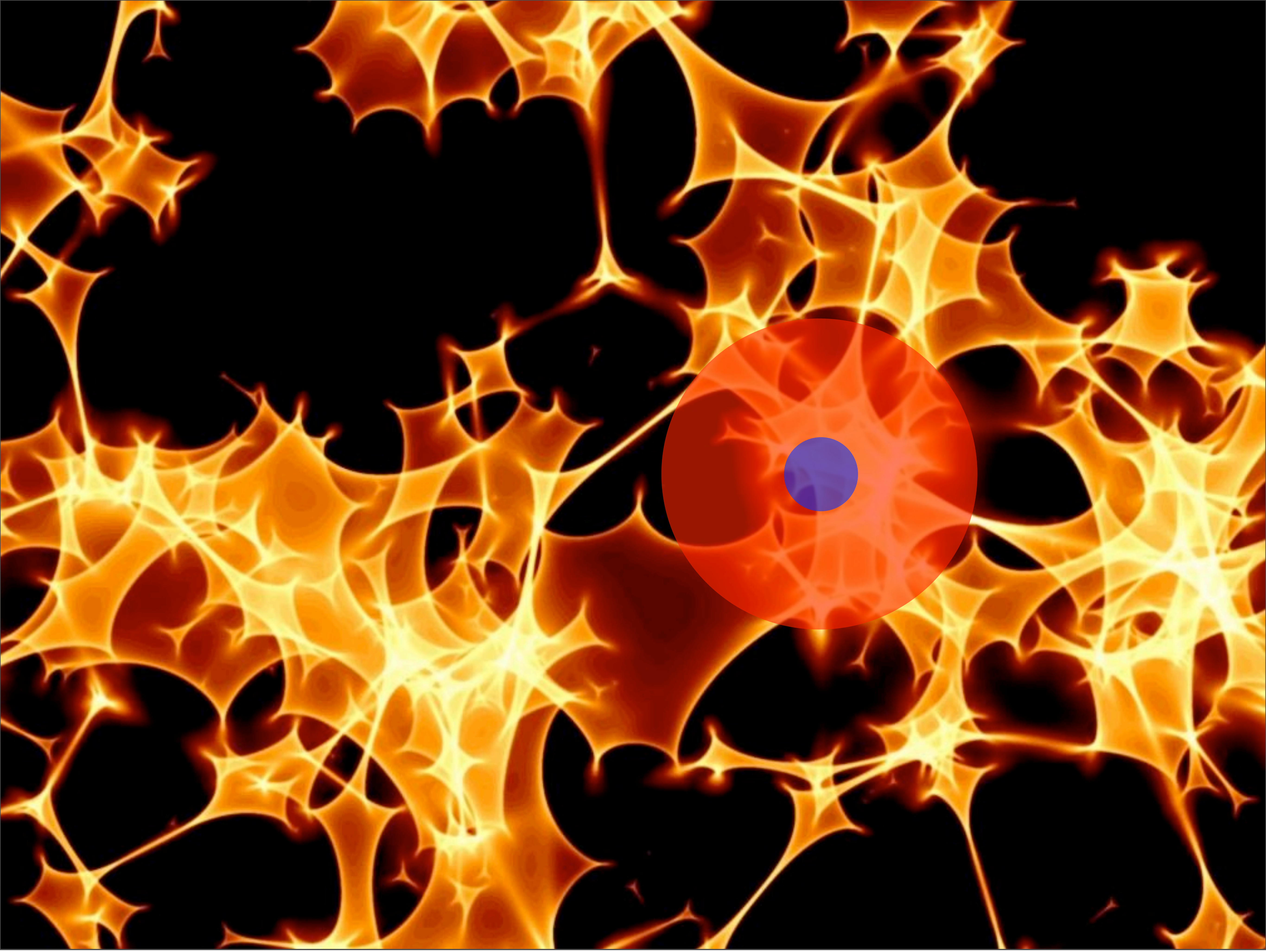
Step 1 : characterize the point spread function (PSF) of each exposure

Step 2 : simultaneously fit one single model to all exposures

(+ CCD calibrations, photometric normalizations... Tewes et al. 2012)



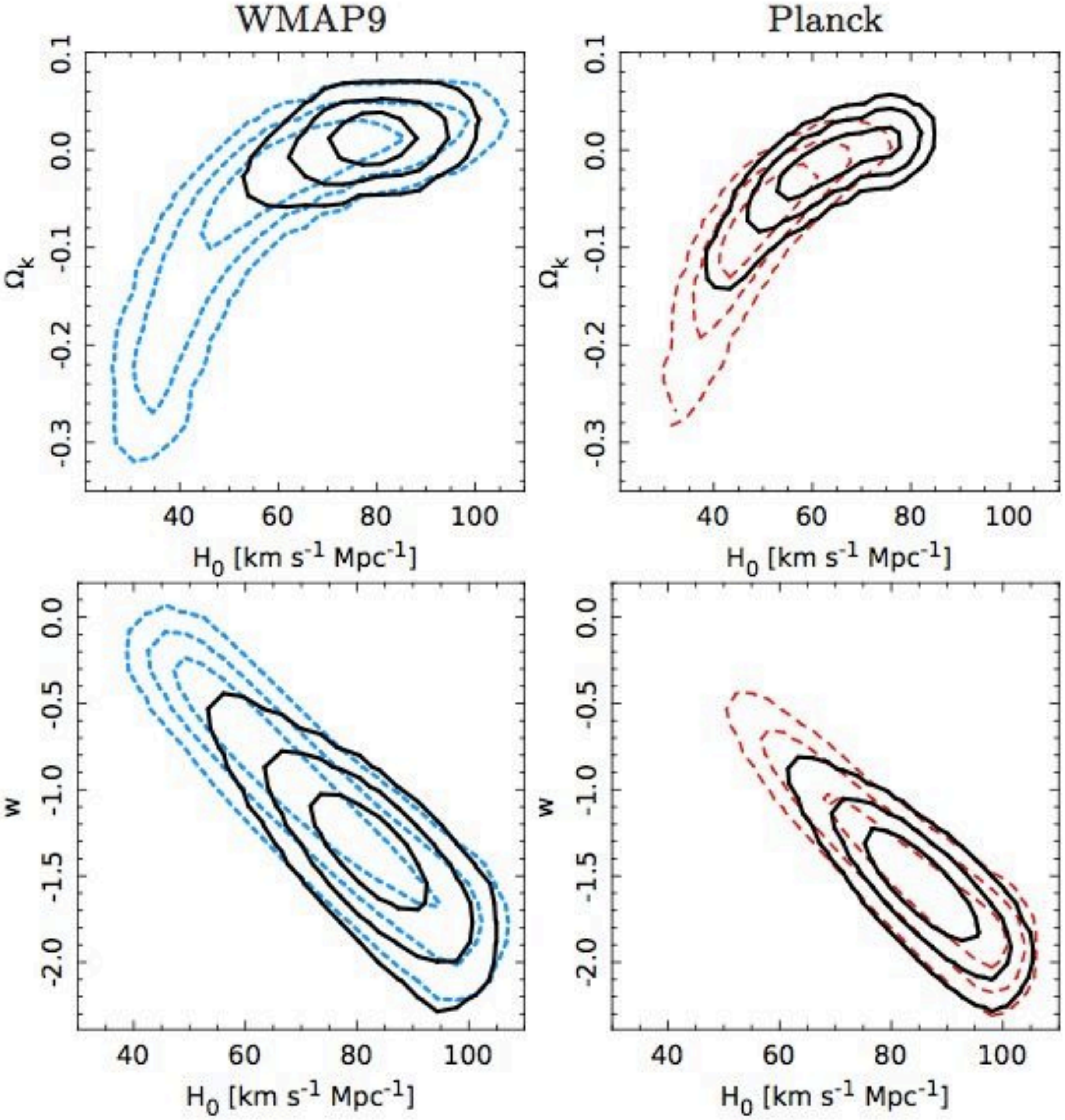
From M. Tewes PhD



Update using Planck results

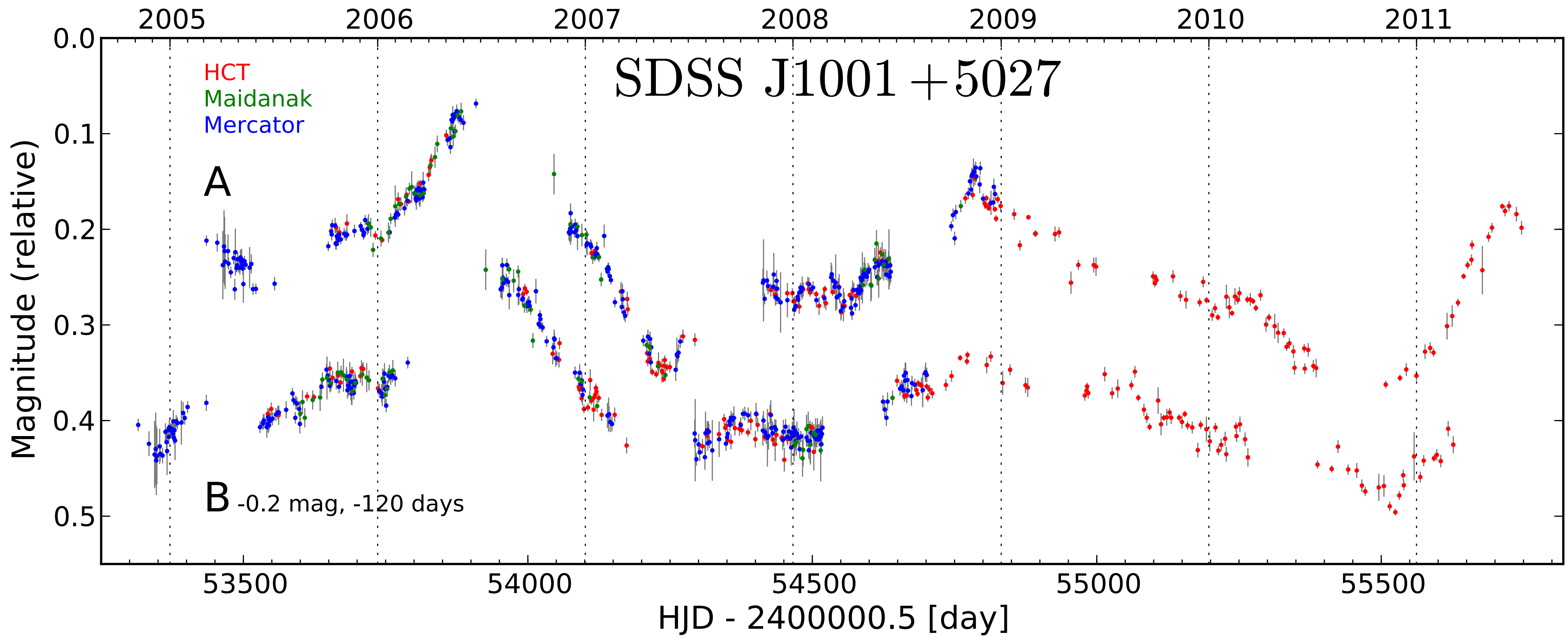
Open ΛCDM

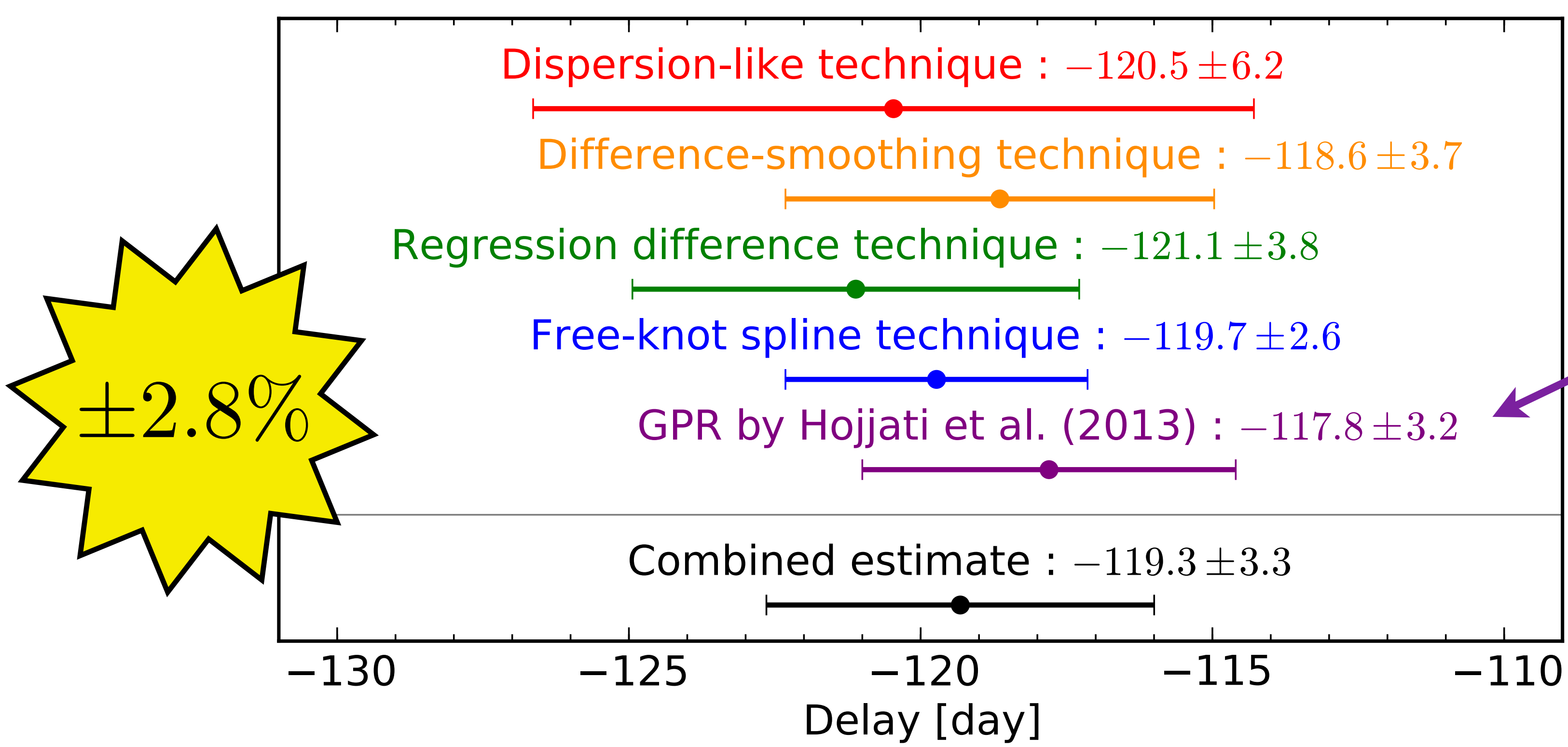
Flat wCDM



Suyu et al. (2014, ApJ, 788, L35)

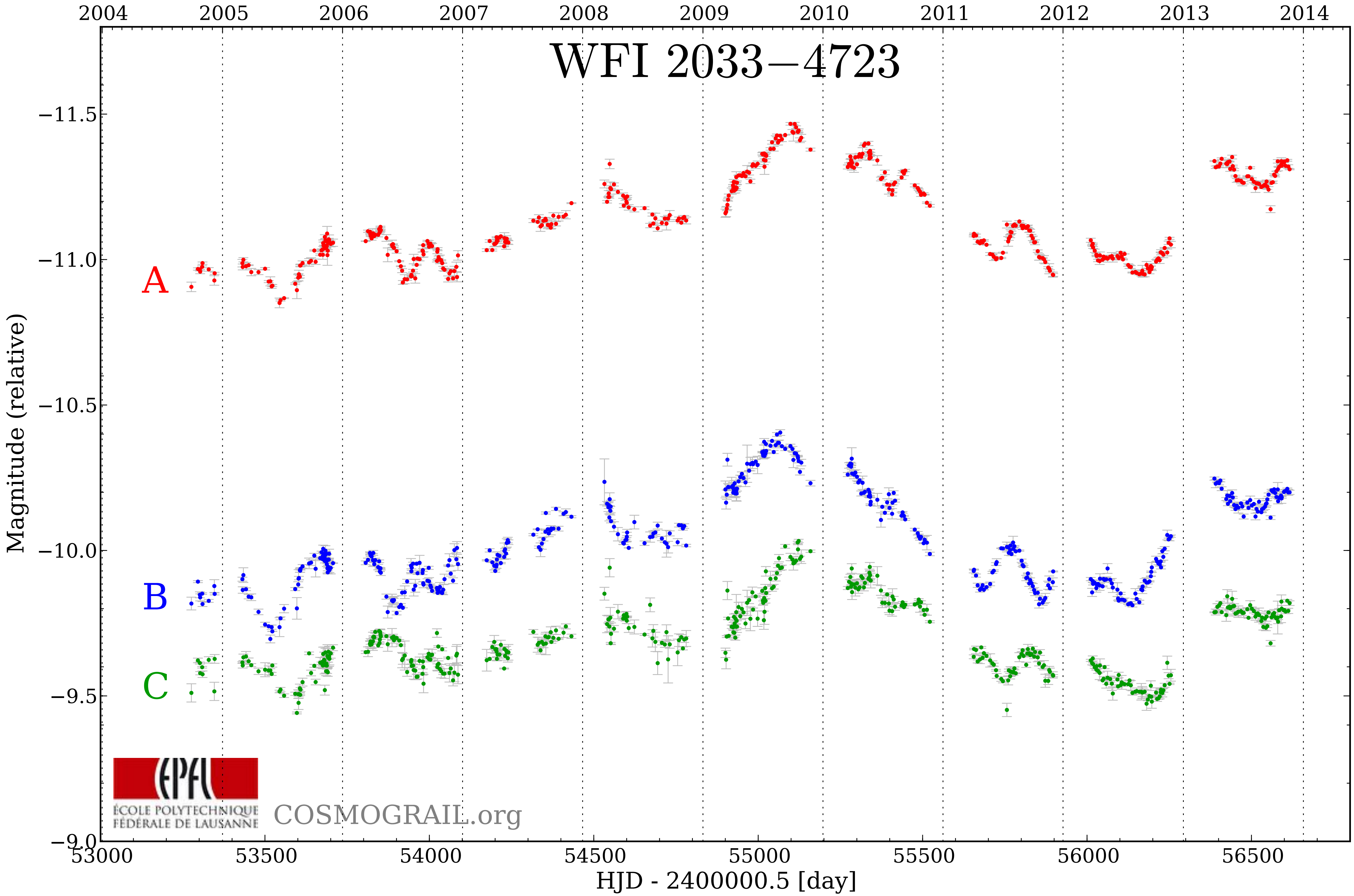
Blind comparison with a newly developed technique





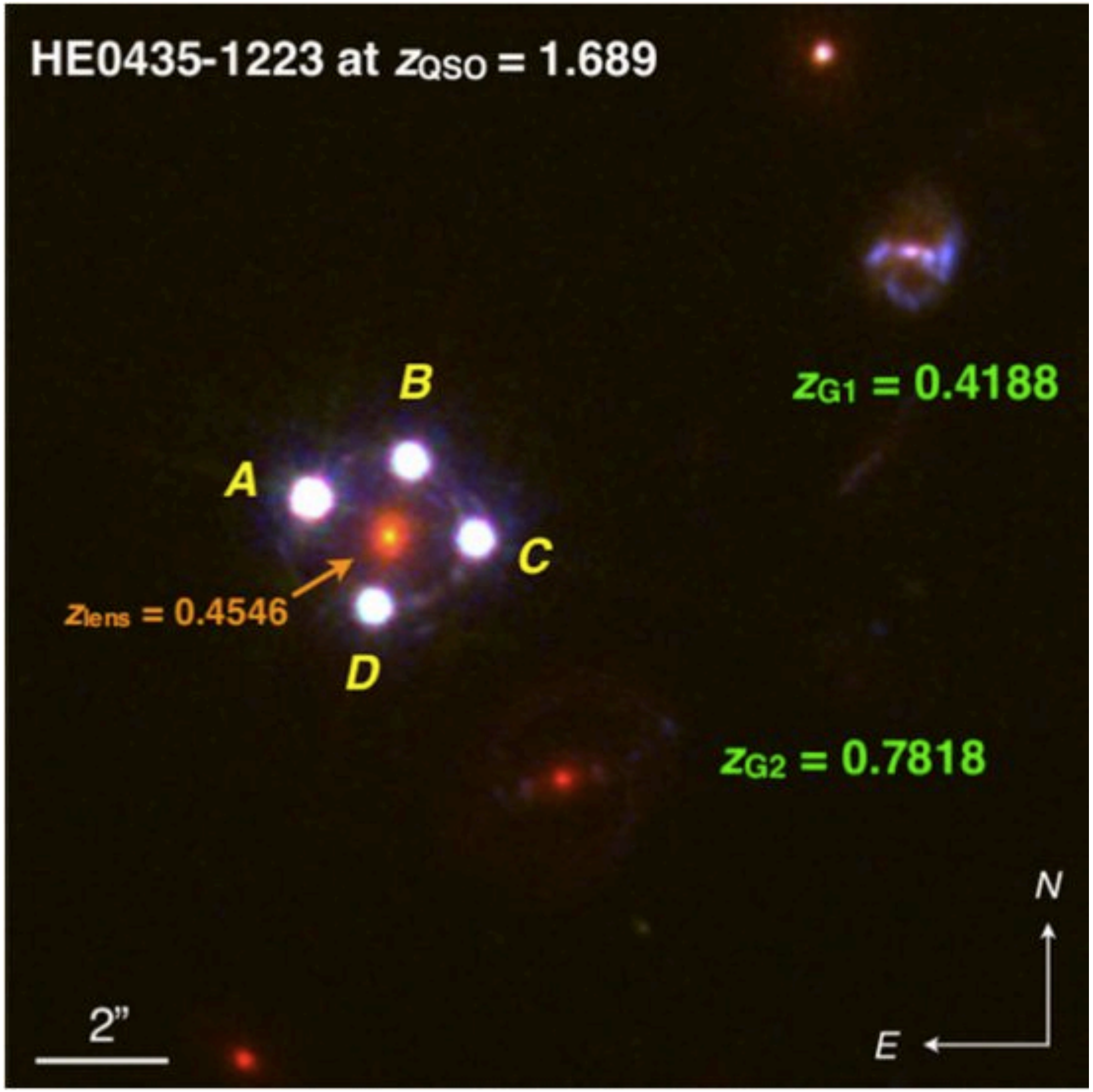
Blind test by Hojjati, Kim, Linder (2013, Phys. Rev. D 87 V12)

Rathna Kumar, Tewes et al. (2013, A&A, 557, A44)



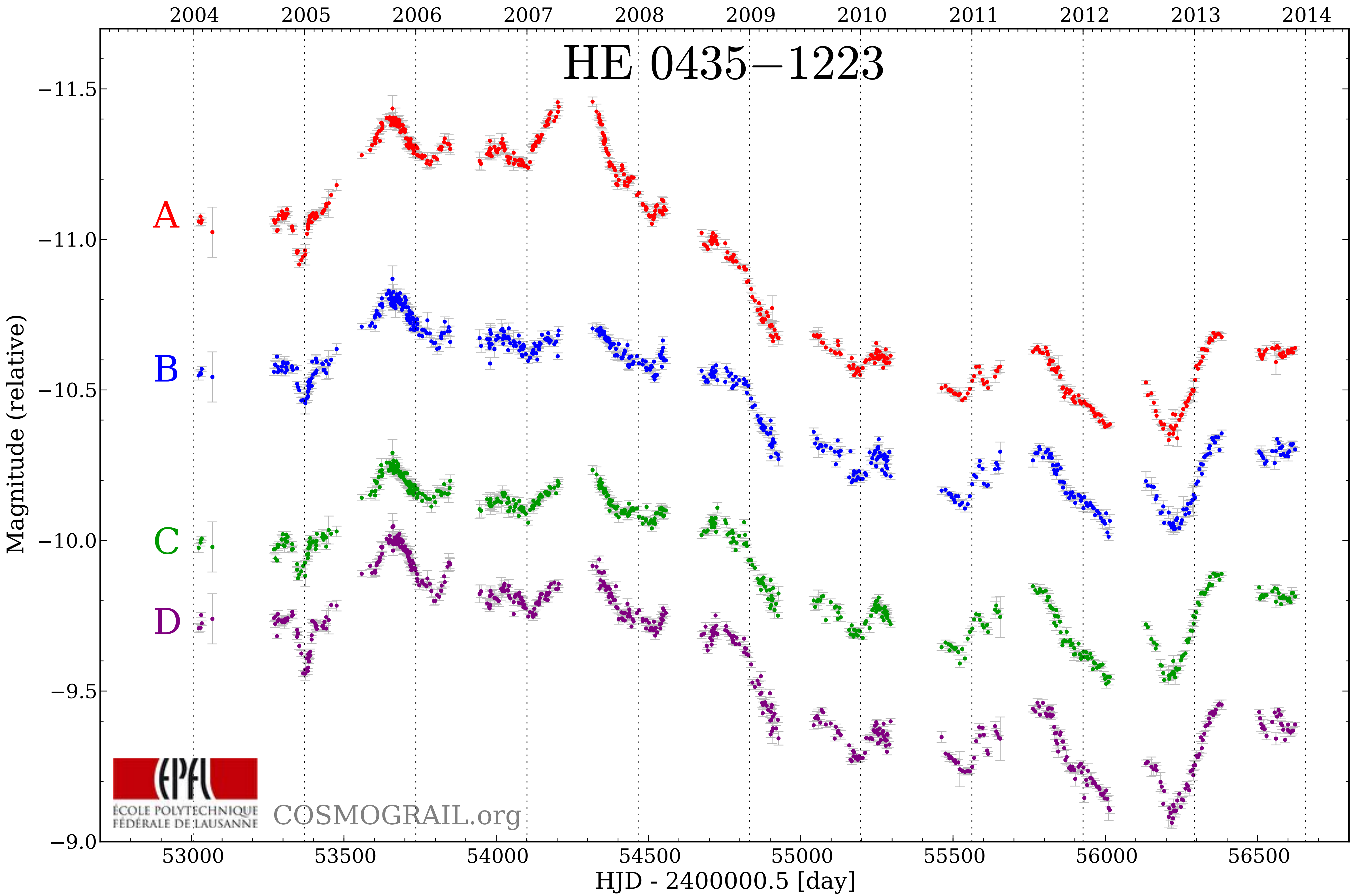
WFI 2033−4723
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Magnitude (relative)
−11.5
−11.0
−10.5
−10.0
−9.5
−9.0
A
B
C
53000
53500
54000
54500
55000
55500
56000
56500
HJD - 2400000.5 [day]
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
COSMOGRAIL.org

HE 0435-1223: next COSMOGRAIL high-quality target



From Hsiao-Wen et al. (2013, MNRAS, 438, 1435)

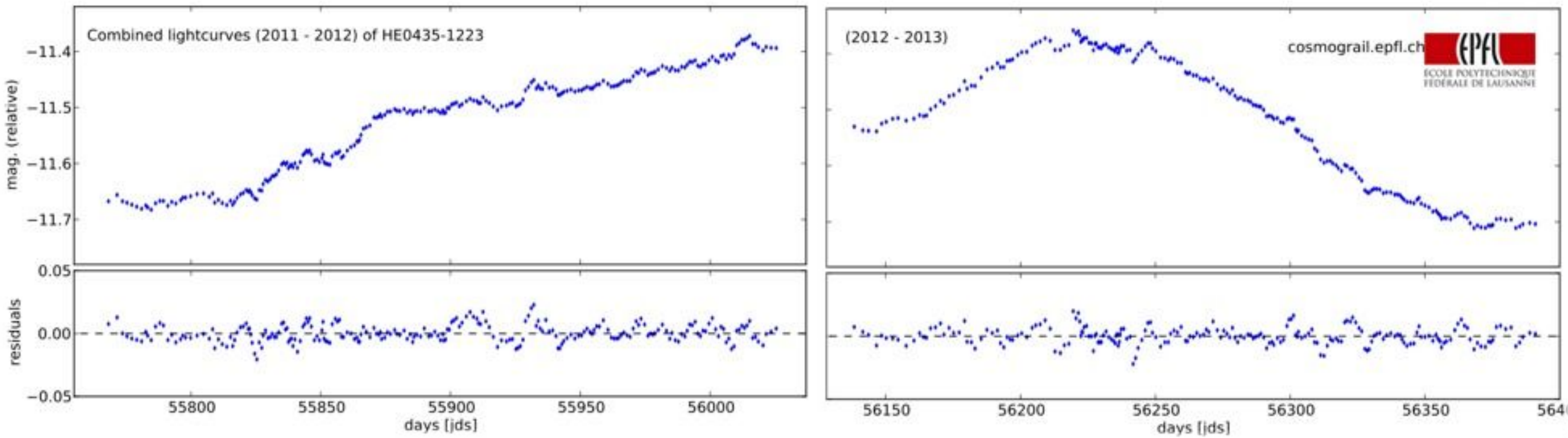
HE 0435-1223: next COSMOGRAIL high-quality target



Bonvin et al. 2015

Future: high cadence monitoring at high SNR (>1000)

«Stacked» COSMOGRAIL data for HE 0435-1223



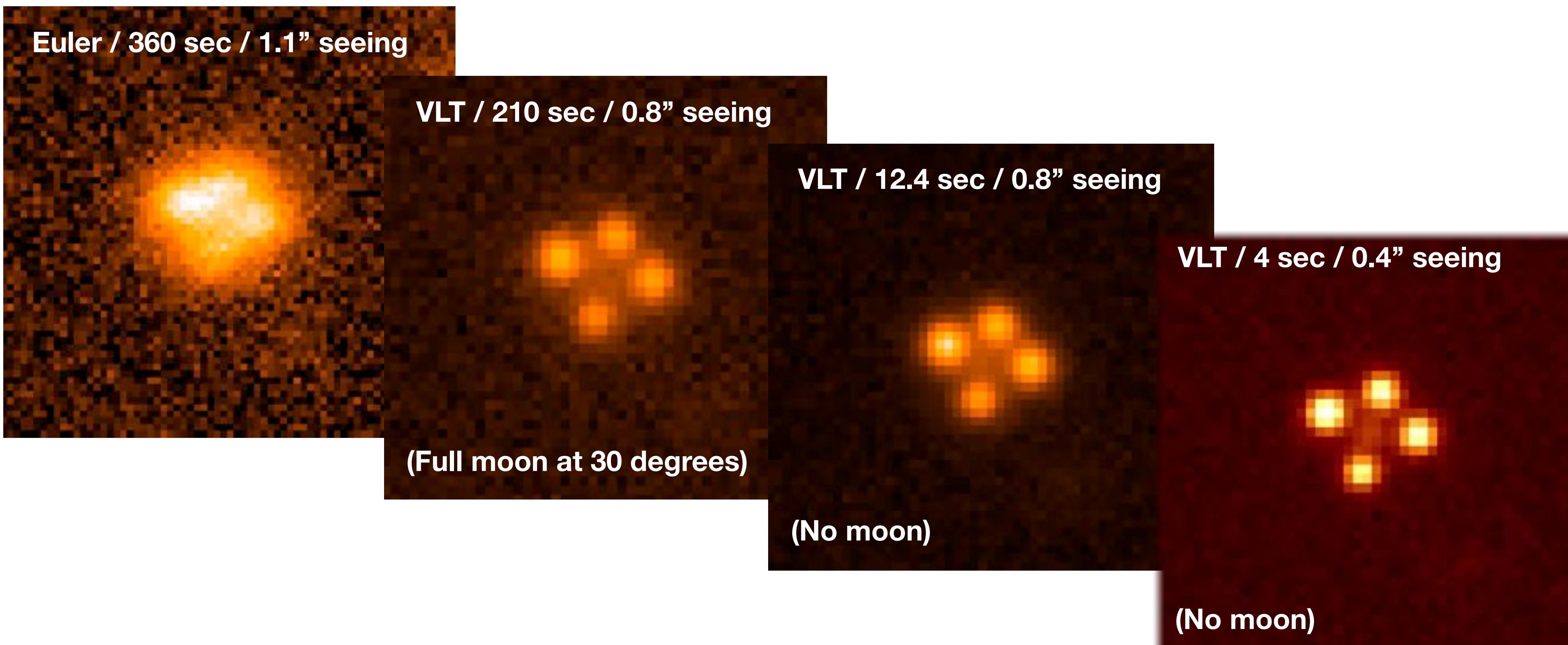
Use small (mmag) variations, shorter than microlensing

Go to larger telescopes WITH flexible scheduling capability.

Goal: time delays to 1% or below within a few months of observations

VLT monitoring of HE 0435-1223

- 1 point per day (210 sec exposure) from Oct 2014 to April 2014 (maybe a bit more)
- Simultaneous monitoring with Euler with improved cadence (1 day^{-1}) in Nov-Dec 2014
- + SMARTS (Kochanek) and LCOGT (Moustakas, Keeton)



Using the ESO 3.5m NTT at La Silla ?

- Call for ideas to use the NTT between 2015 and 2019
- We answered the call in March 2014
- **Confirming DES lenses + spectroscopy of line of sight + daily lens monitoring during 4 periods of 3 months + 10% of the time for «fillers»**
- Pre-selected in August 2014
- Submitted formal proposal to ESO OPC on Oct 1, 2014
- **Draft agreement between ESO and us being prepared**
- News from ESO STC and OPC by the end of November 2014
- **April 2015: earliest possible start of observations**

Using the ESO 3.5m NTT at La Silla ?

AGREEMENT

CONCERNING THE GRANTING OF OBSERVING TIME

at the

NEW TECHNOLOGY TELESCOPE (NTT)

at the La Silla Site of the La Silla Paranal Observatory in Chile

between the

European Organisation for Astronomical Research in the Southern Hemisphere
Karl-Schwarzschild-Strasse 2
D-85748 Garching bei München, Germany
hereinafter referred to as ***ESO***

on the one hand,

and the

École polytechnique fédérale de Lausanne
Route Cantonale, 1015
Lausanne, Switzerland
hereinafter referred to as ***EPFL***

on the other hand.

ANNEX A

Standard cost rates for EPFL

1.	**Contribution to the Operations**	
	Per executed observing night at the NTT (2015)	€ 4150
	The above nightly rates are subject to revision due to yearly cost variation indexing as approved on an annual basis by ESO internal bodies.	
2.	**Travel, Board and Lodging Costs in Chile (Rates as of January 1, 2013)**	
	Lodging in ESO Guesthouse Santiago (breakfast included)	€ 60.00
	Main meal in ESO Guesthouse Santiago	€ 15.00
	Round trip air transfer to/from La Serena	€ 130.00
	24 hrs stay at La Silla	€ 60.00
	One – way surface transport between La Serena and La Silla	€ 25.00
	Transfer (one-way) within Santiago	€ 25.00
	The above prices for board, travel and lodging are subject to revision and are updated on a regular basis and can be found at "http://www.eso.org/sci/observing/travel/visas-instruc.html". The board, travel and lodging prices published on the ESO website shall prevail.	

Total cost: 1.5 Meuro for 1 full year of NTT (split over 4 years)

Summary

- COSMOGRAIL has demonstrated that time delays can be accurately measured
- H0LiCOW: H_0 Lenses in COSMOGRAIL Wellspring
  --> turn time delays into cosmology (see talk by Sherry & Ken)
- DES, KIDS, LSST, Euclid will discover hundreds of new targets
- Long and well-sampled light curves are needed to handle microlensing properly
- The mass-slope degeneracy can be broken at least when an Einstein ring is seen
- The mass-sheet (line of sight) degeneracy can be minimized for individual systems. It averages out when considering many systems
- **Need 1% time delays quickly -> medium-size dedicated telescopes**