Direct optical measurements with IACTs

Synergies between GTC and IACTs: systems of ultra-fast optical detectors

Tarek Hassan
DESY-Zeuthen

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

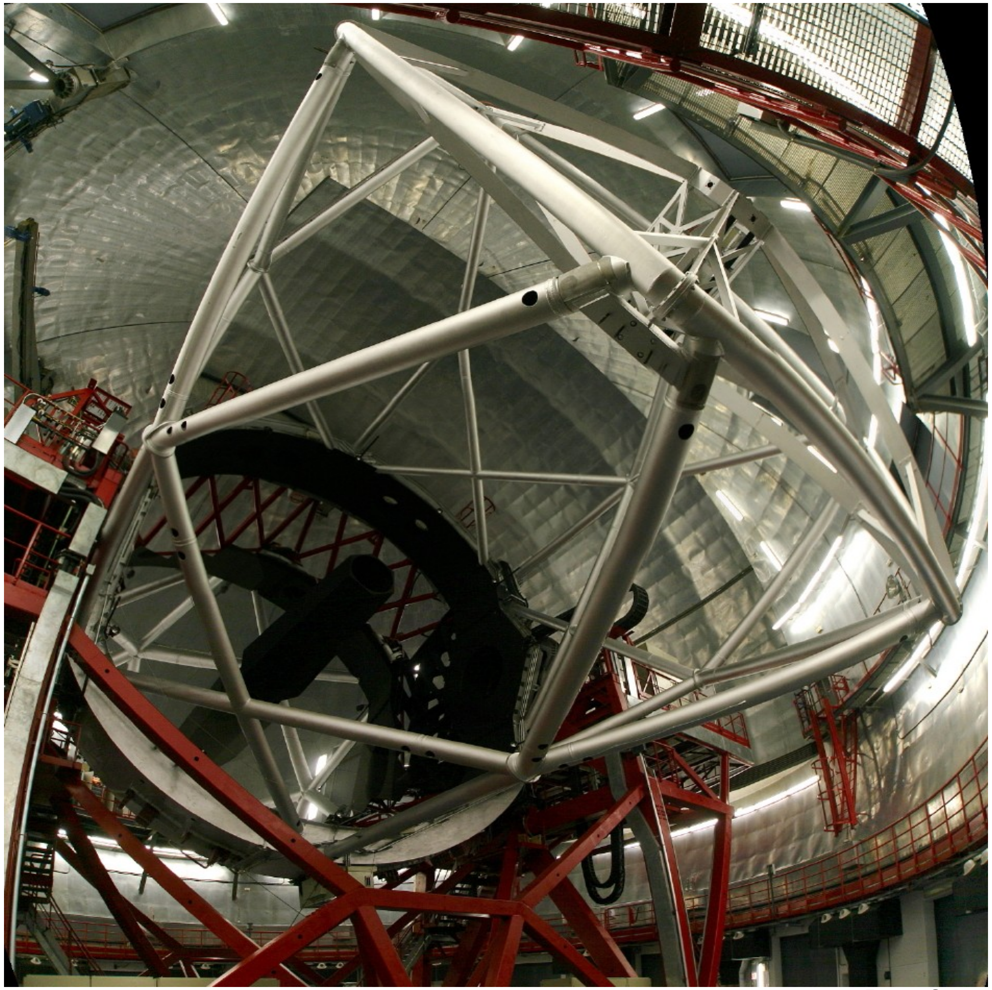
VERITAS

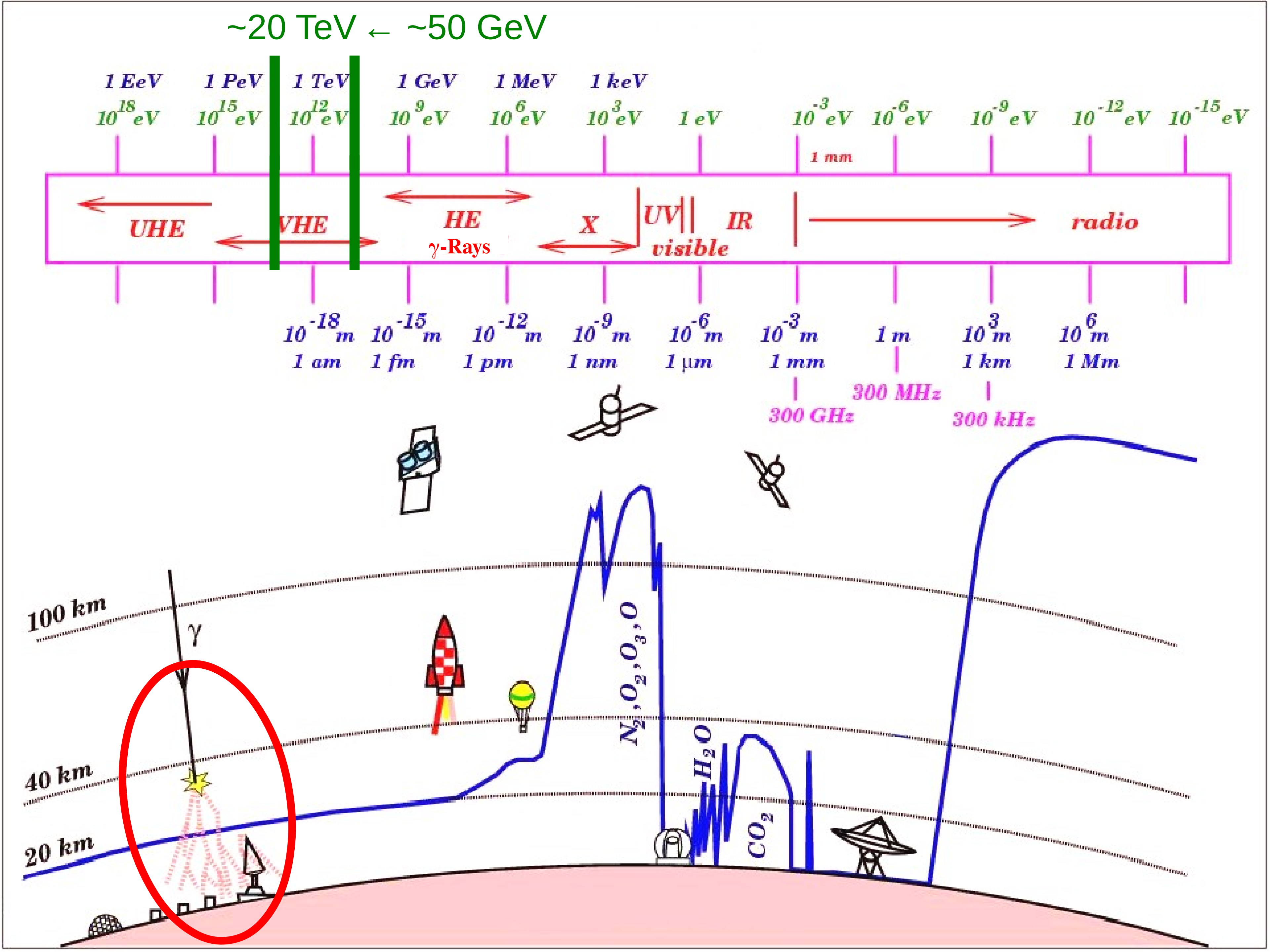
cta cherenkov telescope array

DESY

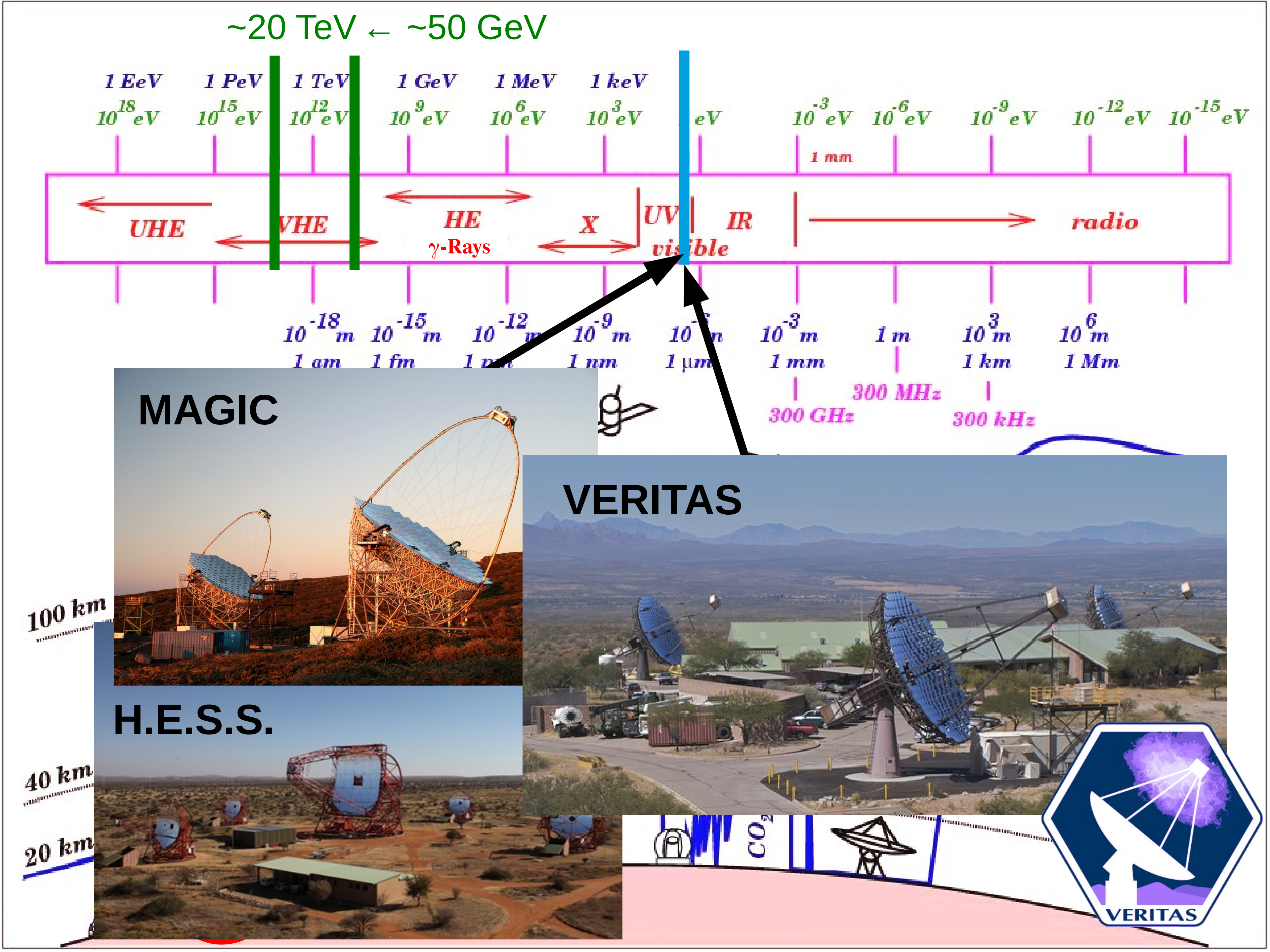
IACT technique – Overview

- Imaging Atmospheric Cherenkov Telescopes (IACTs) are relatively similar to “normal” optical telescopes





~20 TeV ← ~50 GeV
1 EeV
1 PeV
1 TeV
1 GeV
1 MeV
1 keV
10^{18} eV
10^{15} eV
10^{12} eV
10^{9} eV
10^{6} eV
10^{3} eV
1 eV
10^{-3} eV
10^{-6} eV
10^{-9} eV
10^{-12} eV
10^{-15} eV
1 mm
UHE
VHE
HE
γ-Rays
X
UV
visible
IR
radio
10^{-18} m
1 am
10^{-15} m
1 fm
10^{-12} m
1 pm
10^{-9} m
1 nm
10^{-6} m
1 μm
10^{-3} m
1 mm
1 m
10^{3} m
1 km
10^{6} m
1 Mm
300 GHz
300 MHz
300 kHz
100 km
40 km
20 km
γ
N_2, O_2, O_3, O
H_2O
CO_2


~20 TeV ← ~50 GeV
1 EeV
1 PeV
1 TeV
1 GeV
1 MeV
1 keV
10^18 eV
10^15 eV
10^12 eV
10^9 eV
10^6 eV
10^3 eV
eV
10^-3 eV
10^-6 eV
10^-9 eV
10^-12 eV
10^-15 eV
1 mm
UHE
VHE
HE
γ-Rays
X
UV
visible
IR
radio
10^-18 m
10^-15 m
10^-12 m
10^-9 m
10^-6 m
10^-3 m
1 m
10^3 m
10^6 m
1 am
1 fm
1 pm
1 nm
1 μm
1 mm
1 km
1 Mm
300 MHz
300 GHz
300 kHz
MAGIC
VERITAS
H.E.S.S.
100 km
40 km
20 km
CO2
VERITAS

IACT technique – Overview

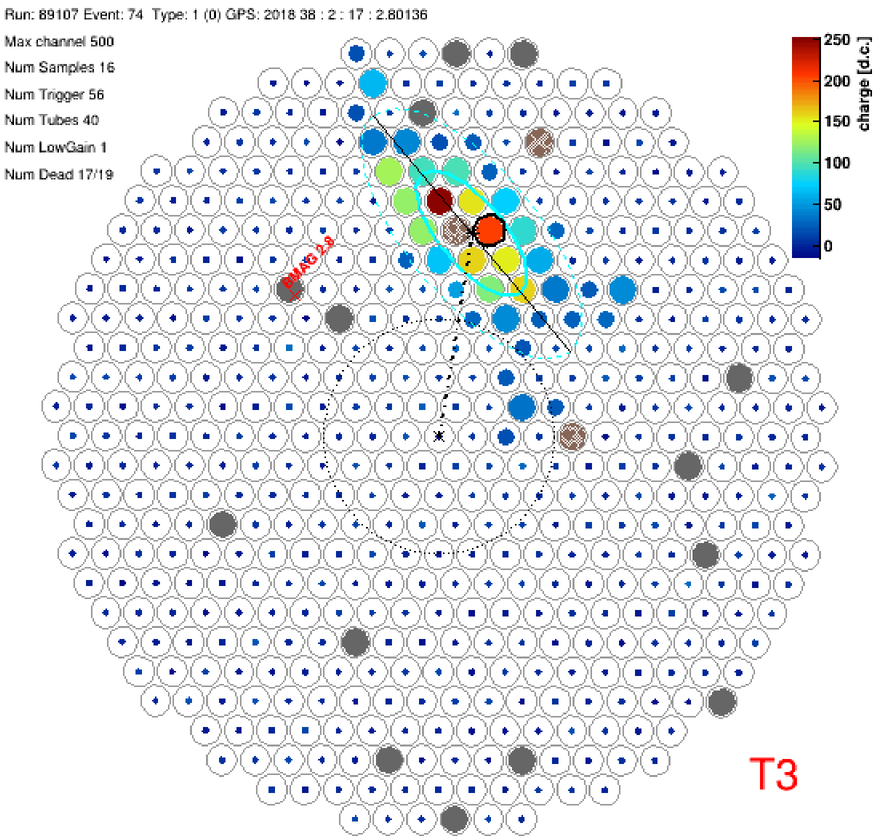
- Imaging Atmospheric Cherenkov Telescopes (IACTs) are very similar to normal optical telescopes

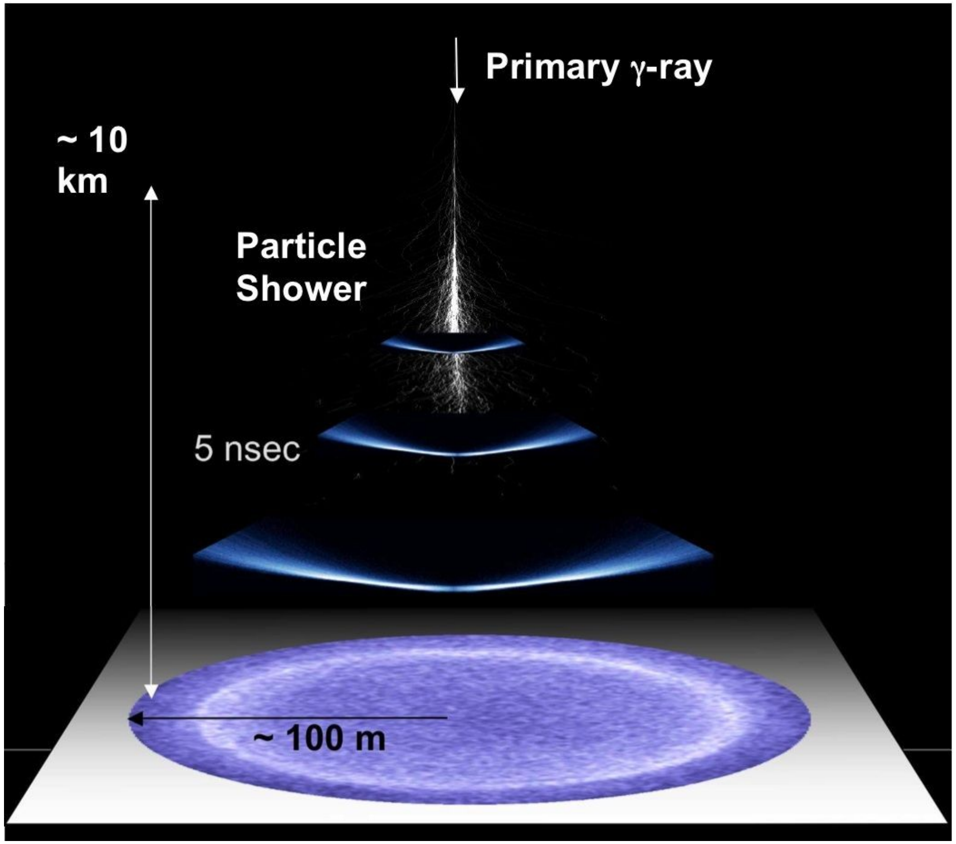
- The "only" difference is that optical telescopes **directly** detect photons from the emitting source (stars, galaxies…) while IACTs detect **indirectly** the incoming gamma-rays

- IACTs detect the very-brief **blue** Cherenkov optical flashes produced within extended air showers
  - So Cherenkov telescopes **are** "optical telescopes"
  - Optimized to measure ultra-fast signals (~ ns)

IACTs vs optical telescopes

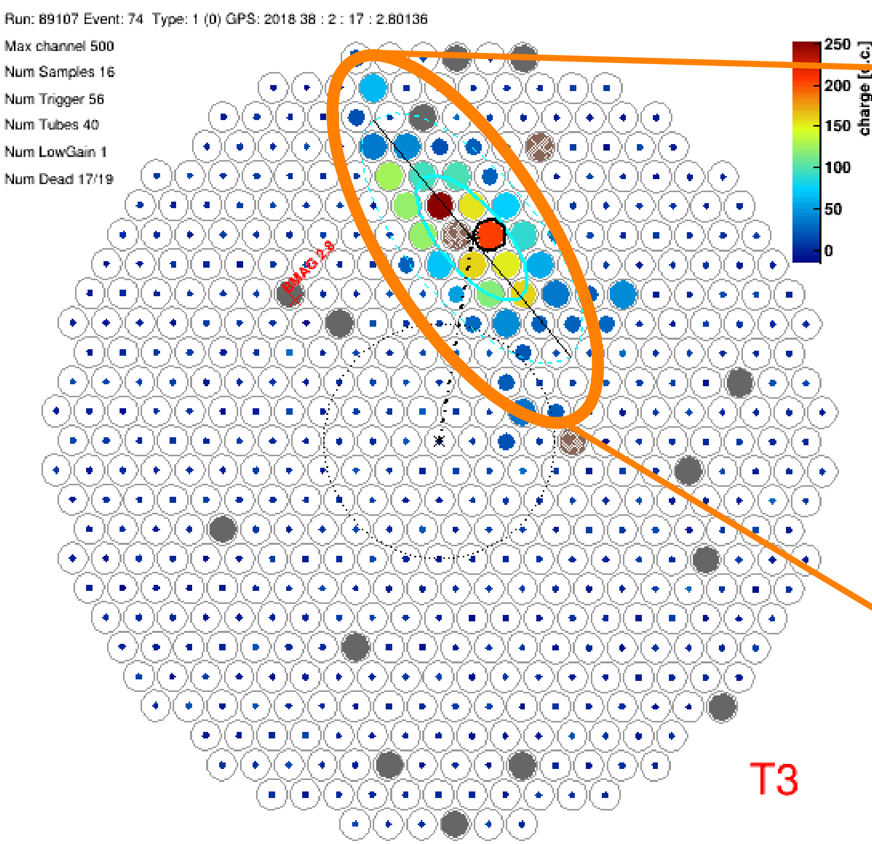
- These are the kind of images IACTs take:



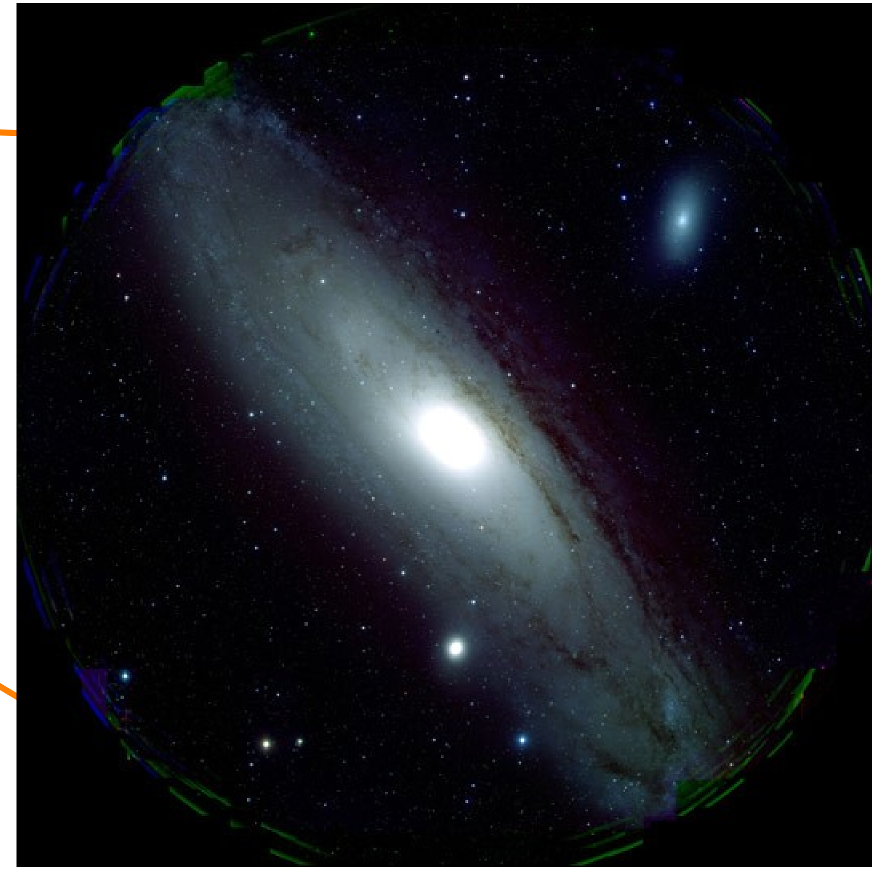


IACTs vs optical telescopes

- These are the kind of images IACTs take:



Similar angular size as M31



HSC's M31 (80 Mpix)
1.5 deg FoV

IACTs as optical telescopes

- IACTs are optical telescopes with very **large reflecting surfaces** equipped with fast (ns) photo-detectors

- For long exposure times (~ sec/min), classical telescopes (great optical PSF) equipped with CCD cameras are more effective: very good **QE** and **S/N**

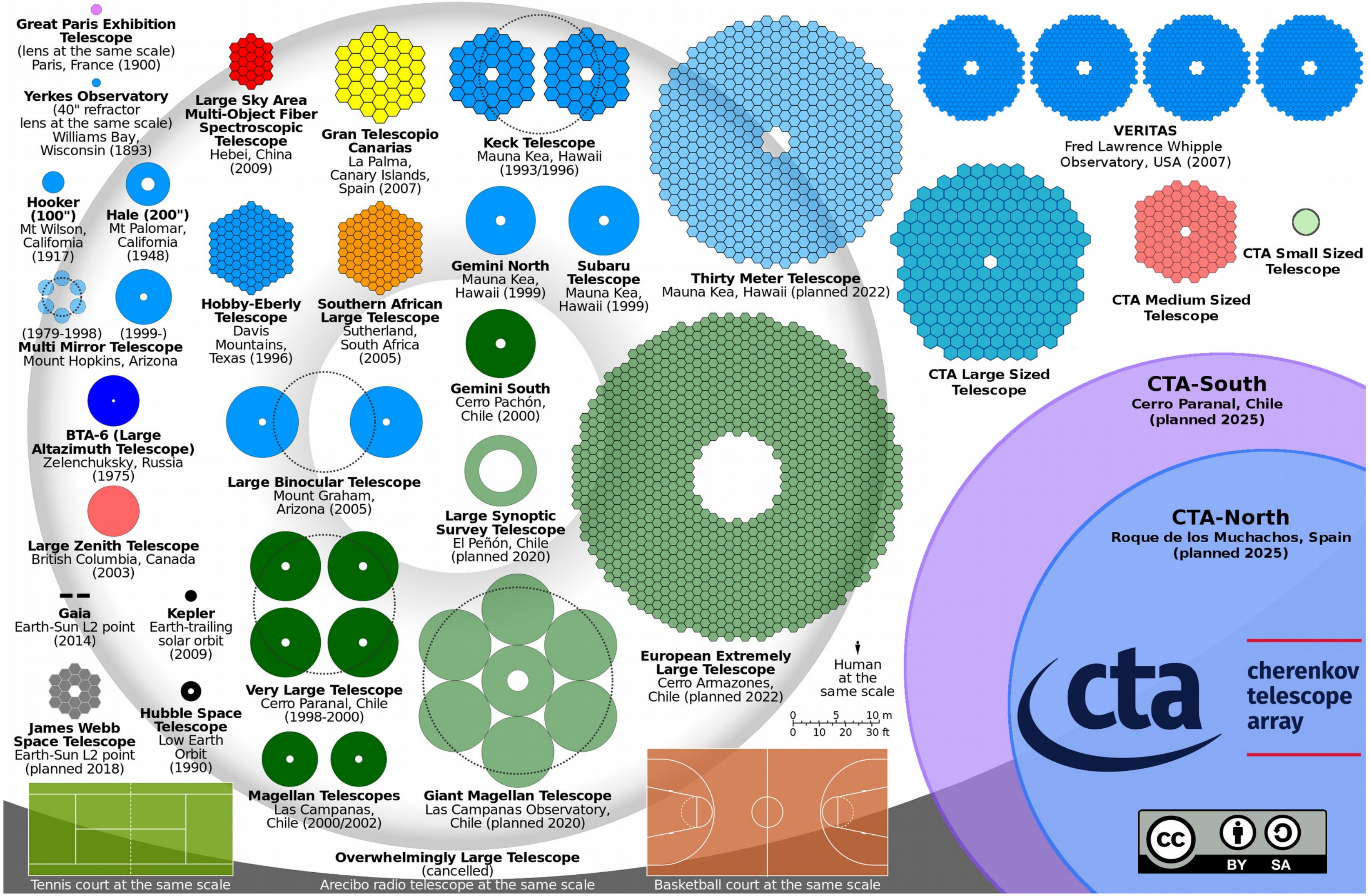
- For short exposure times (t < ~ms), CCD cameras are less suitable while **scintillation** noise limits the sensitivity of small—medium telescopes

    - Larger telescopes mitigate the effect of atmospheric turbulence

    - IACTs are **huge**, therefore their main limitation is the very large FoV they integrate over a single pixel (~ 0.15 deg)

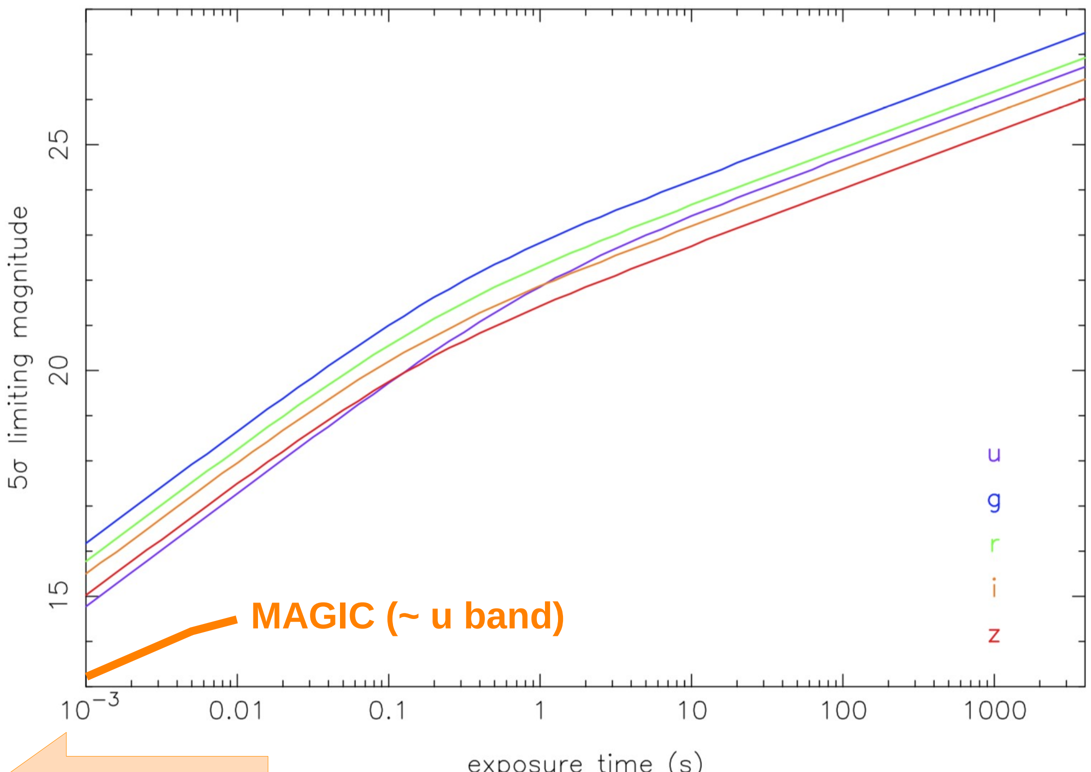
IACTs as optical telescopes

- Mirror area of world-wide optical telescopes



IACTs vs GTC's HiPERCAM

- The GTC (10.2 m) equipped with **HiPERCAM**:



[V. Dhillon et al 2016]()

- GTC + HiPERCAM → world's best fast optical detector
- Reach up to 1 kHz, sampling 5 bands simultaneously
- IACT sensitivity is not **that** far away, and are able to sample **way faster**
- IACTs cannot compete with HiPERCAM regarding sensitivity, but provide similar S/N on **bright sources**

IACTs as optical detectors

- IACTs were already used as direct optical telescopes for several studies:
  - Searching for optical bursts associated with **FRBs**
  - Search for extraterrestrial intelligent life (**OSETI**)
  - Detecting planetary transits and **asteroid occultations**
  - High angular resolution astronomy via **Intensity Interferometry**

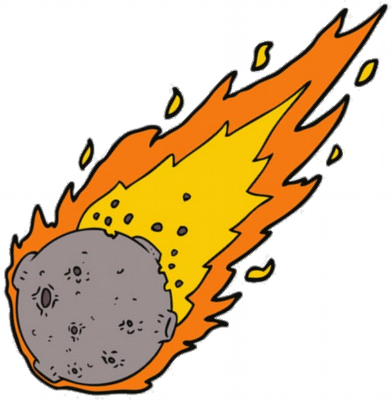
Asteroid occultations with VERITAS

New method to perform sub-milliarcsecond resolution observations

What is an asteroid occultation?

(not to scale)

What is an asteroid occultation?

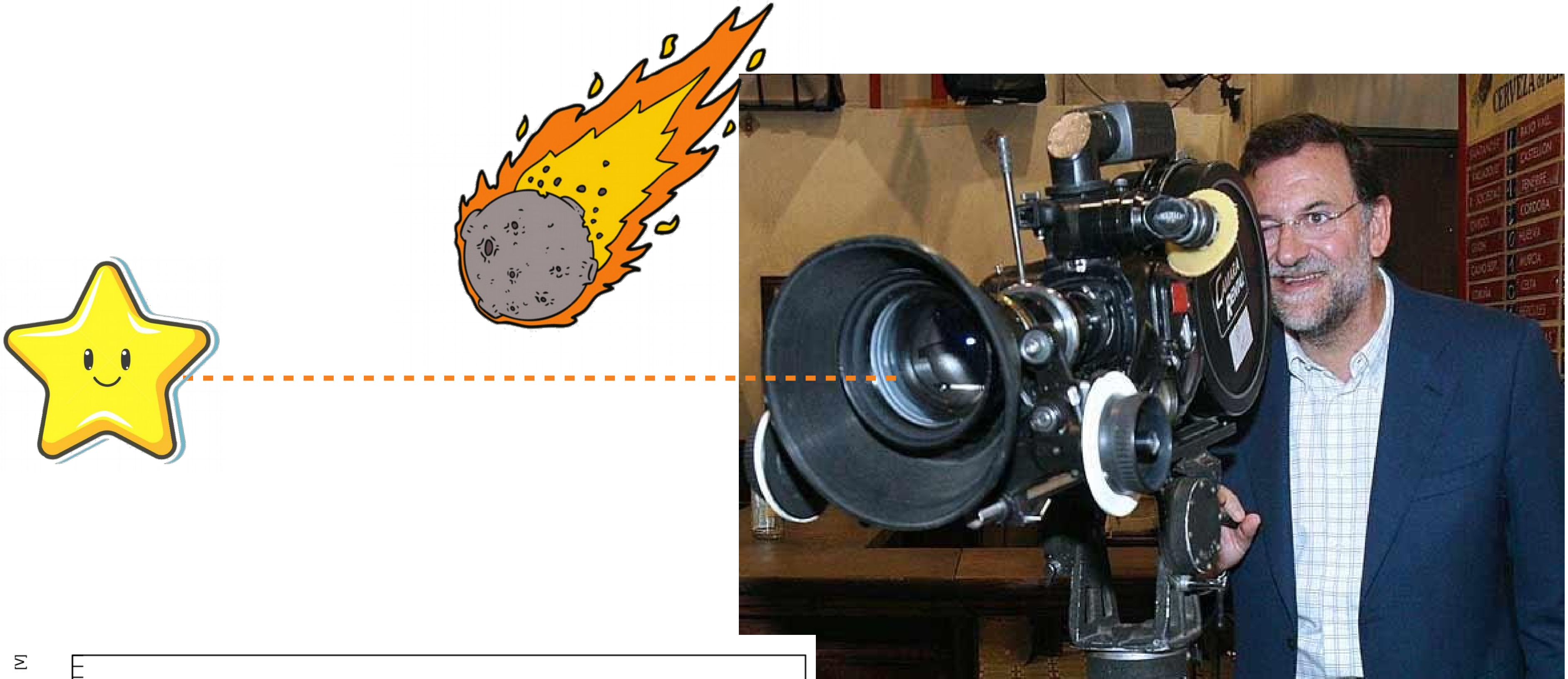


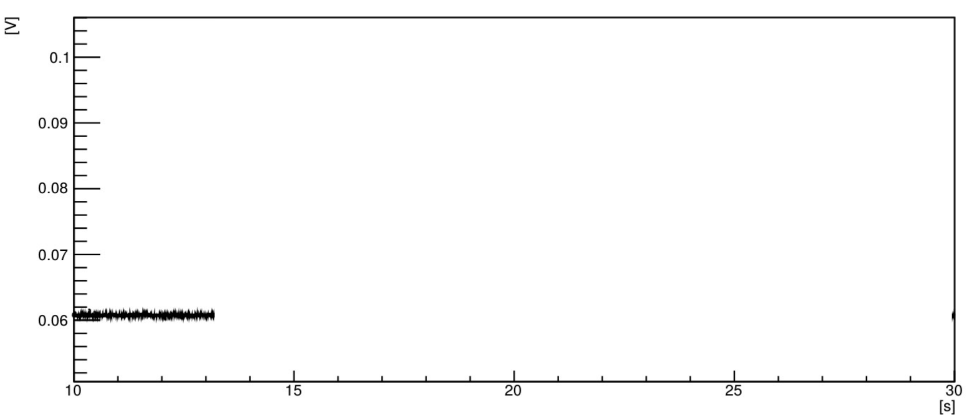
(not to scale)

What is an asteroid occultation?

(not to scale)

What is an asteroid occultation?

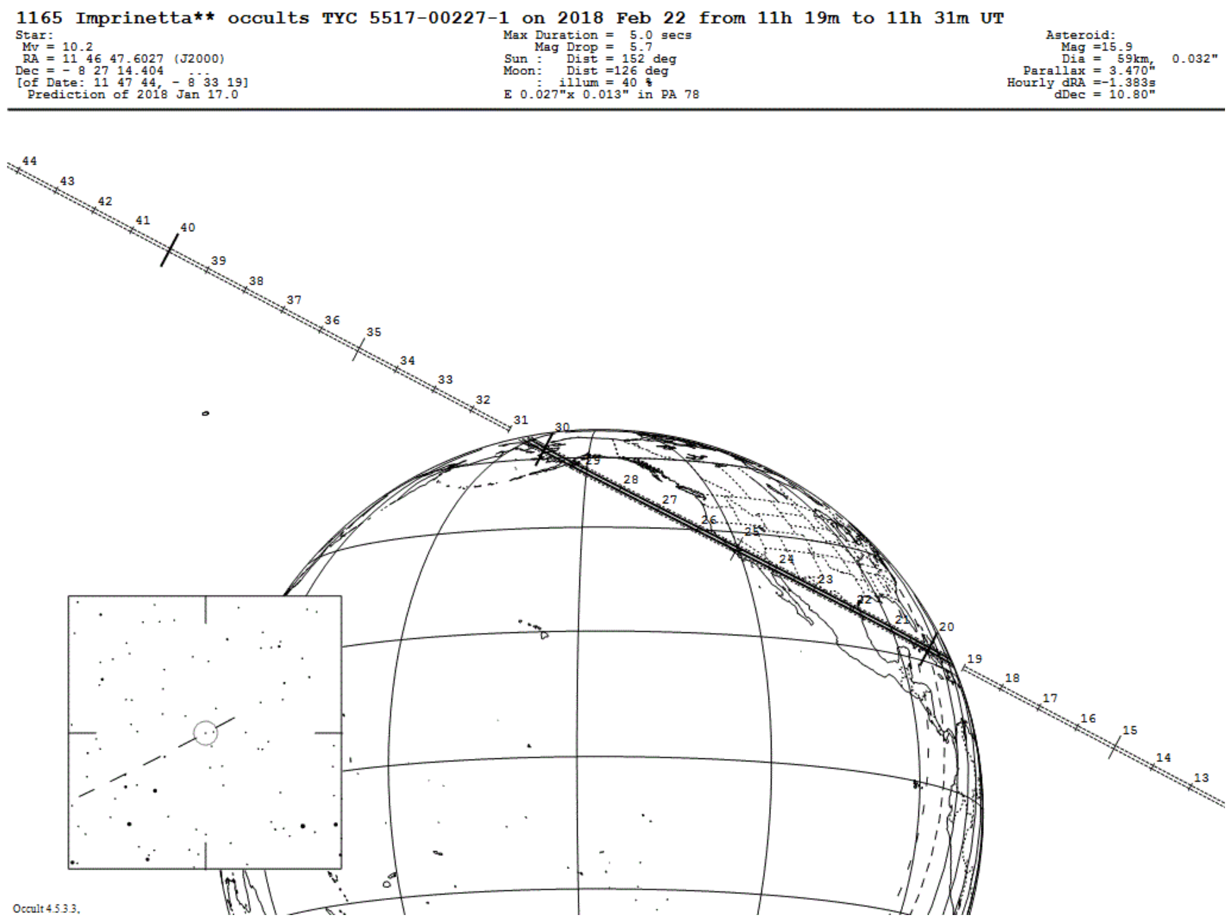




(not to scale)

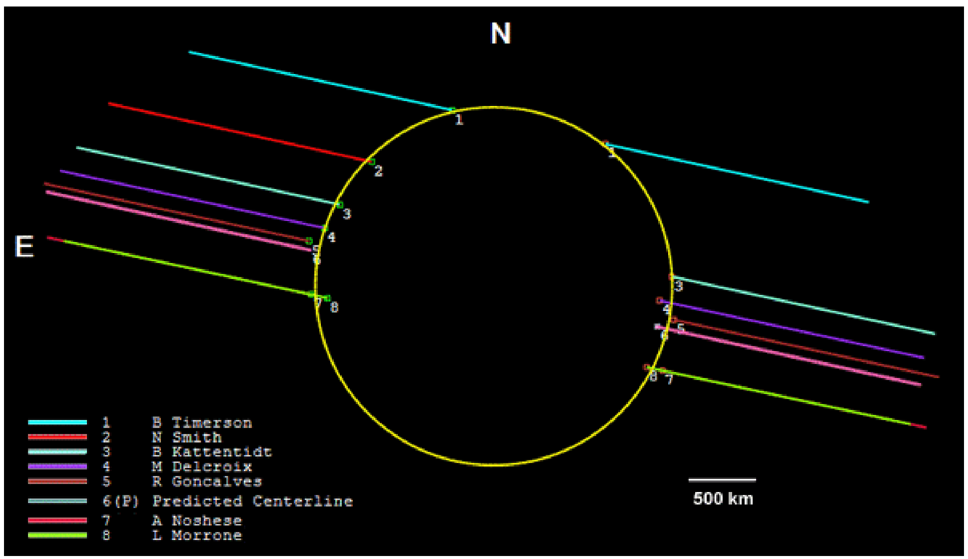
Asteroid occultations – The basics

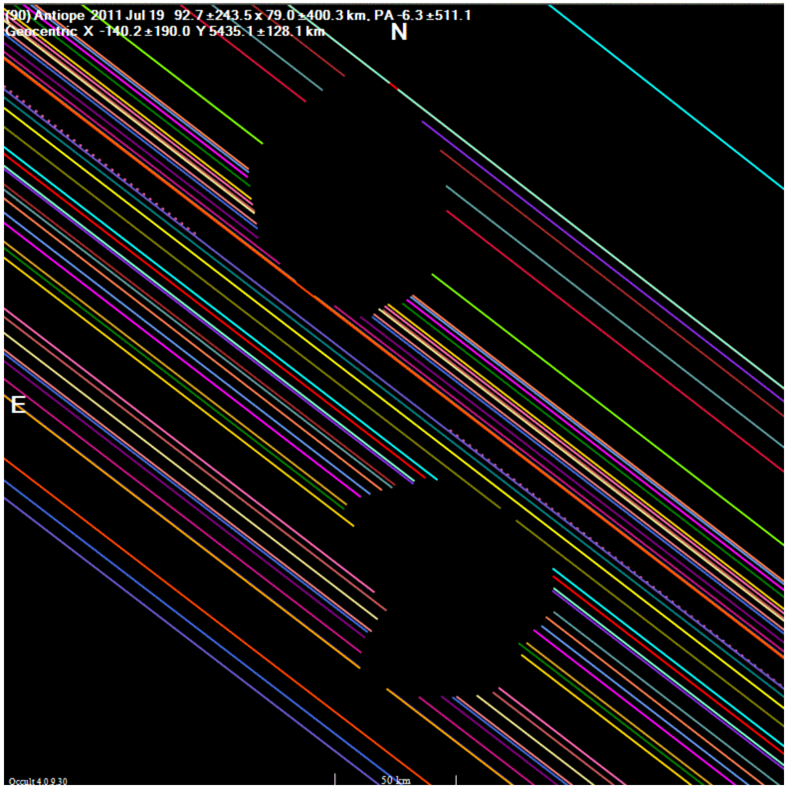
- These events occur when an asteroid passes between a star and the Earth, projecting its shadow through the planet (see **http://www.asteroidoccultation.com/** for public predictions)



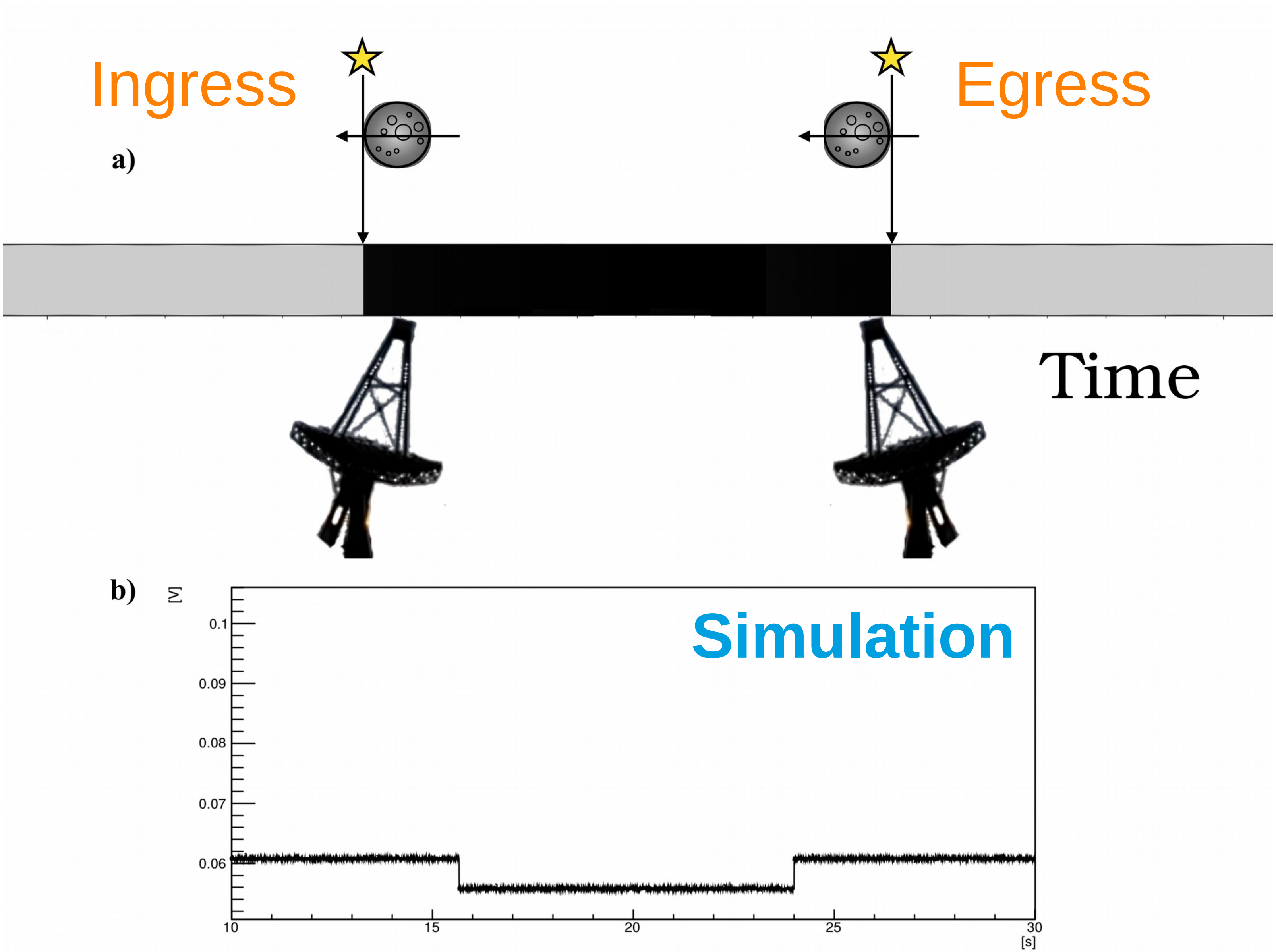
Asteroid occultations – The basics

- If several observers follow these events (predicted ~days/month in advance), you can reconstruct the shape of the asteroid

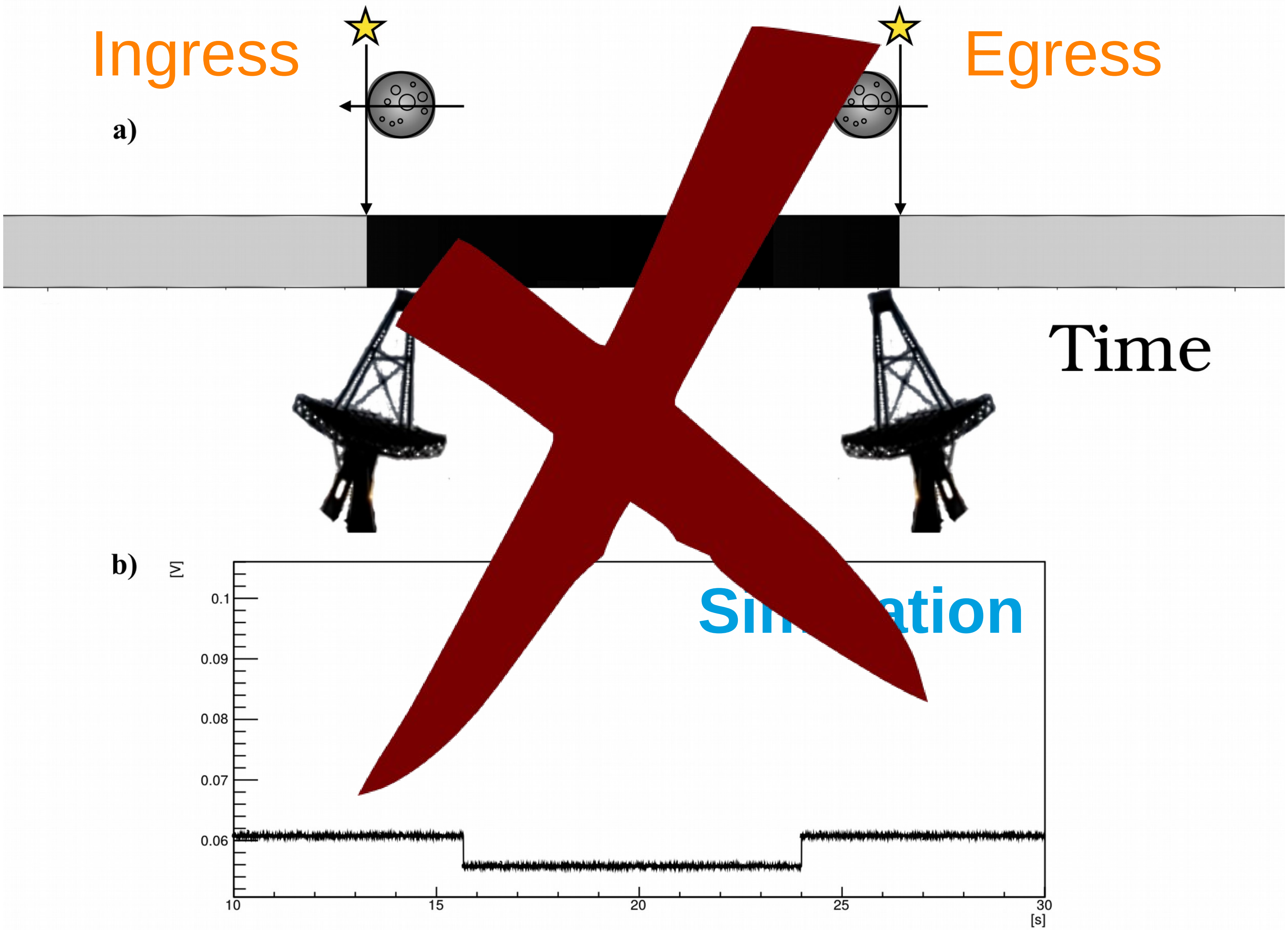




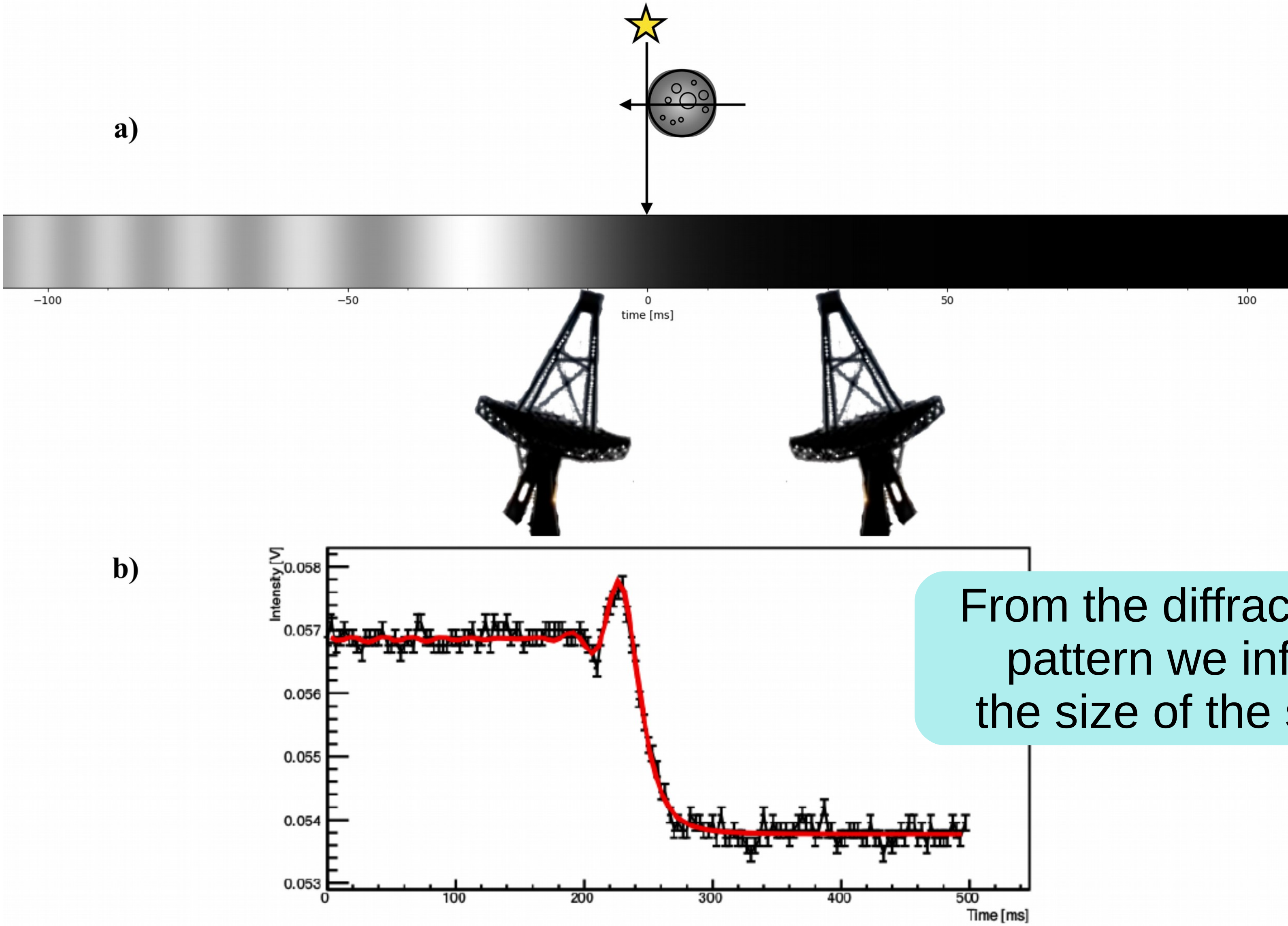
Asteroid occultations with VERITAS



Asteroid occultations with VERITAS



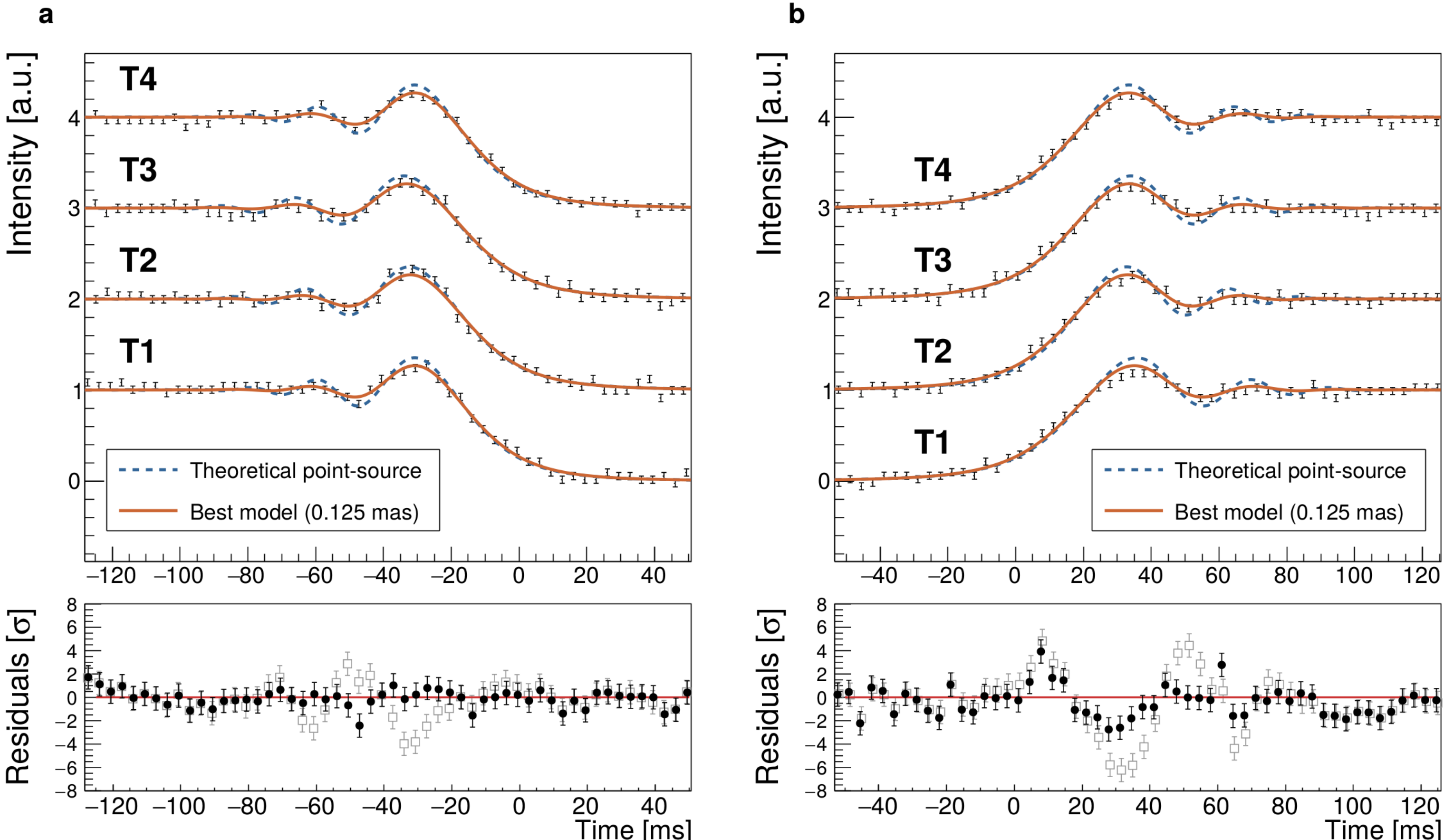
Asteroid occultations – Diffraction pattern



From the diffraction pattern we infer the size of the star

Occultations analysis – Results

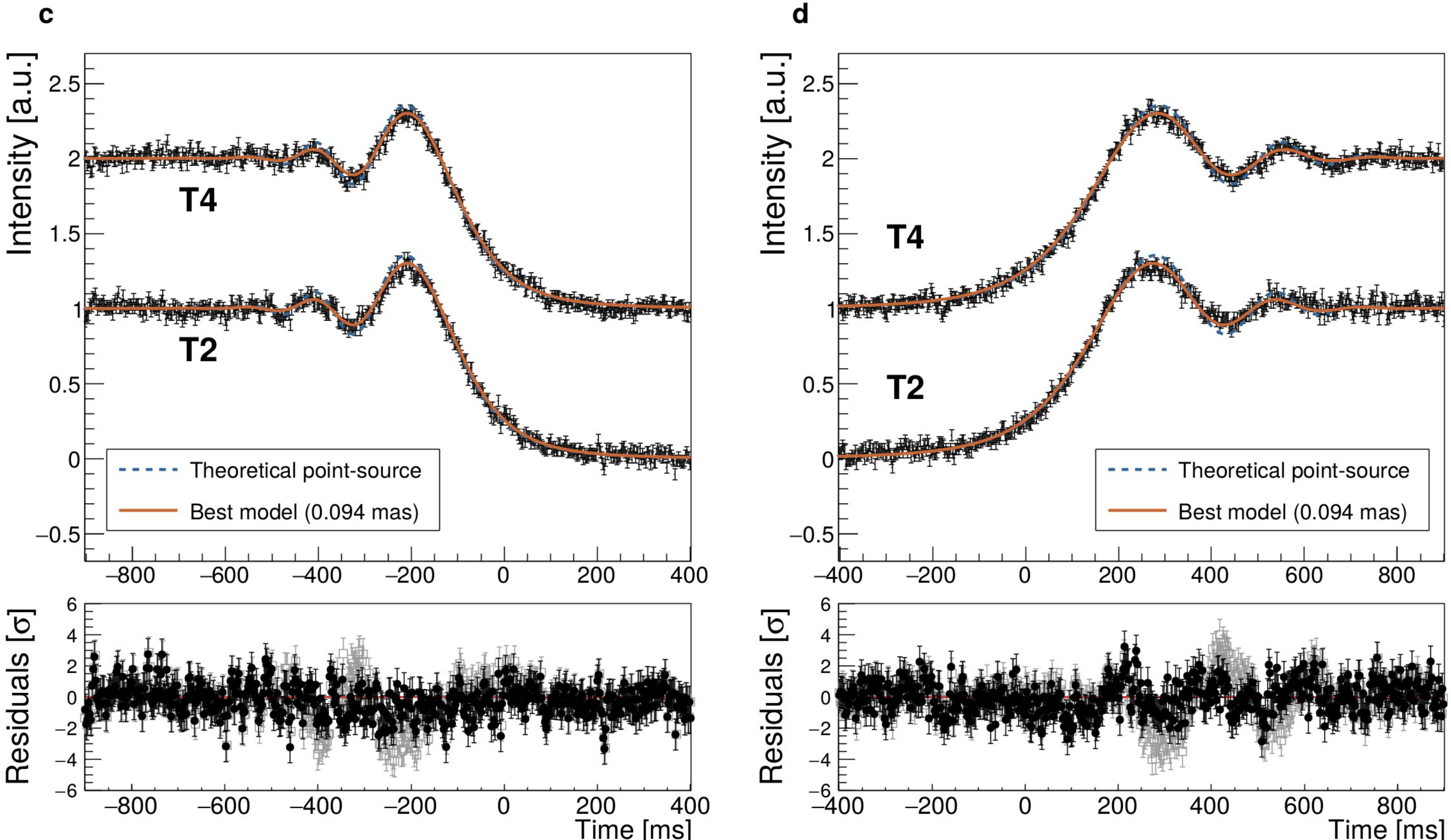
- Which star size fits best TYC 5517-00227-1 (Imprinetta)?



W. Benbow et al, 2019

Occultations analysis – Results

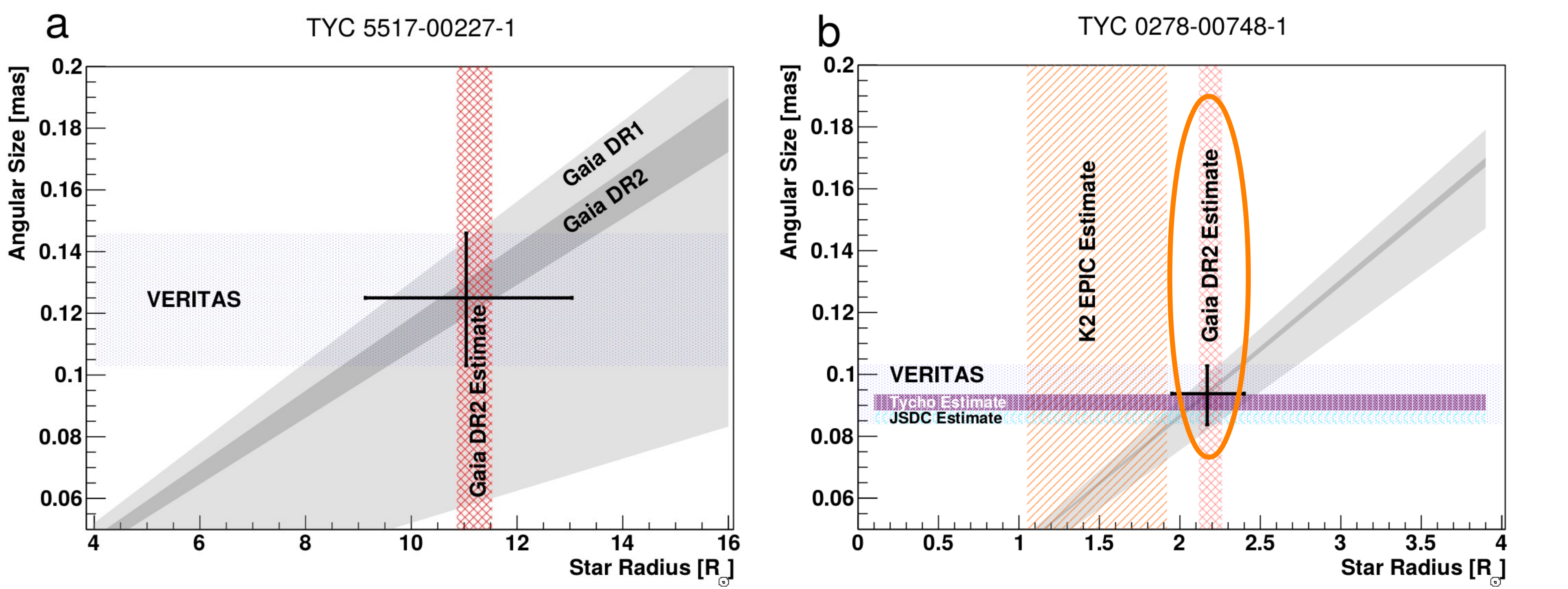
- Which star size fits best TYC 278-748-1 (Penelope)?



W. Benbow et al, 2019

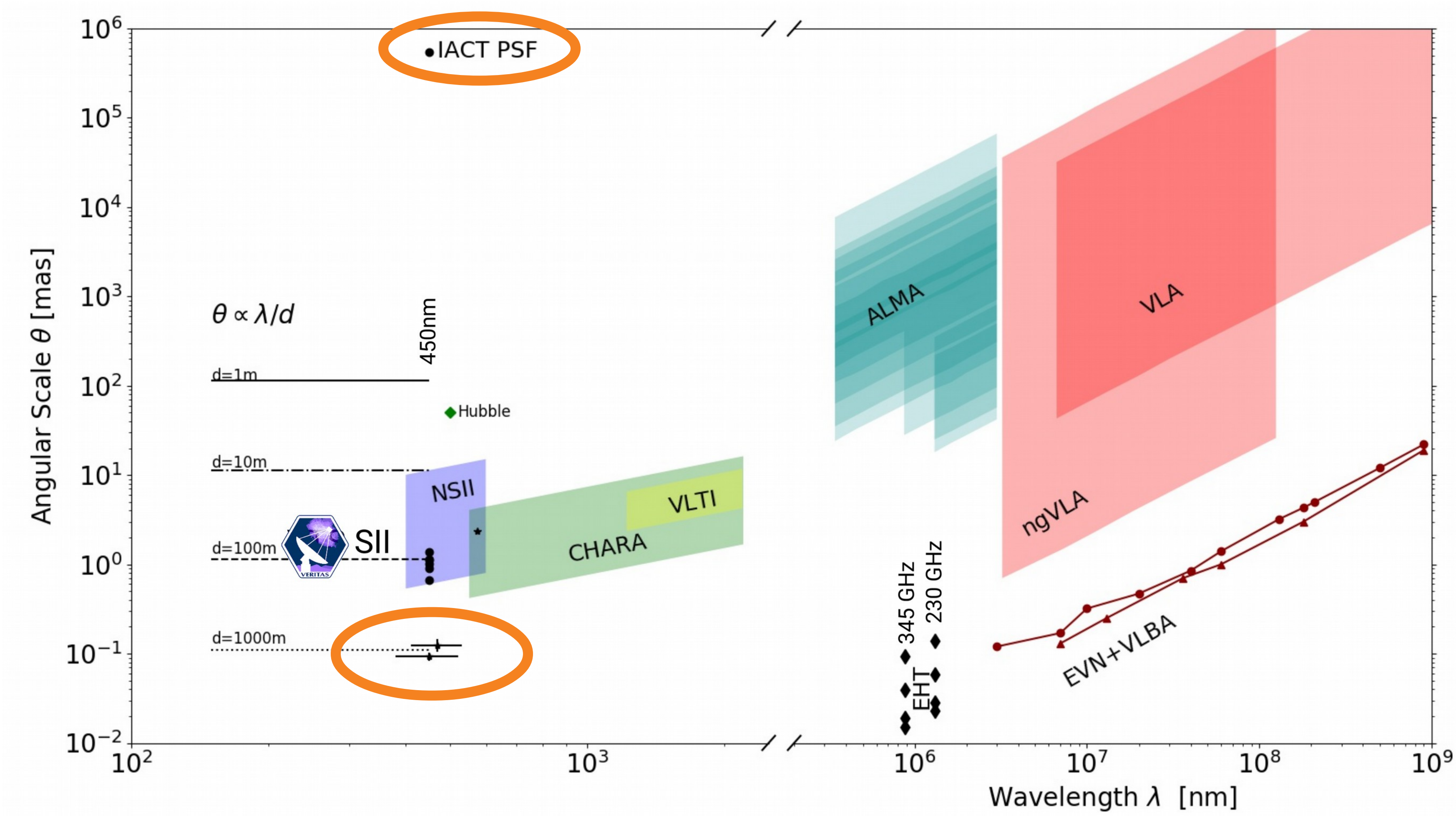
Occultations analysis – Results

- Using Gaia DR2 parallax measurement:

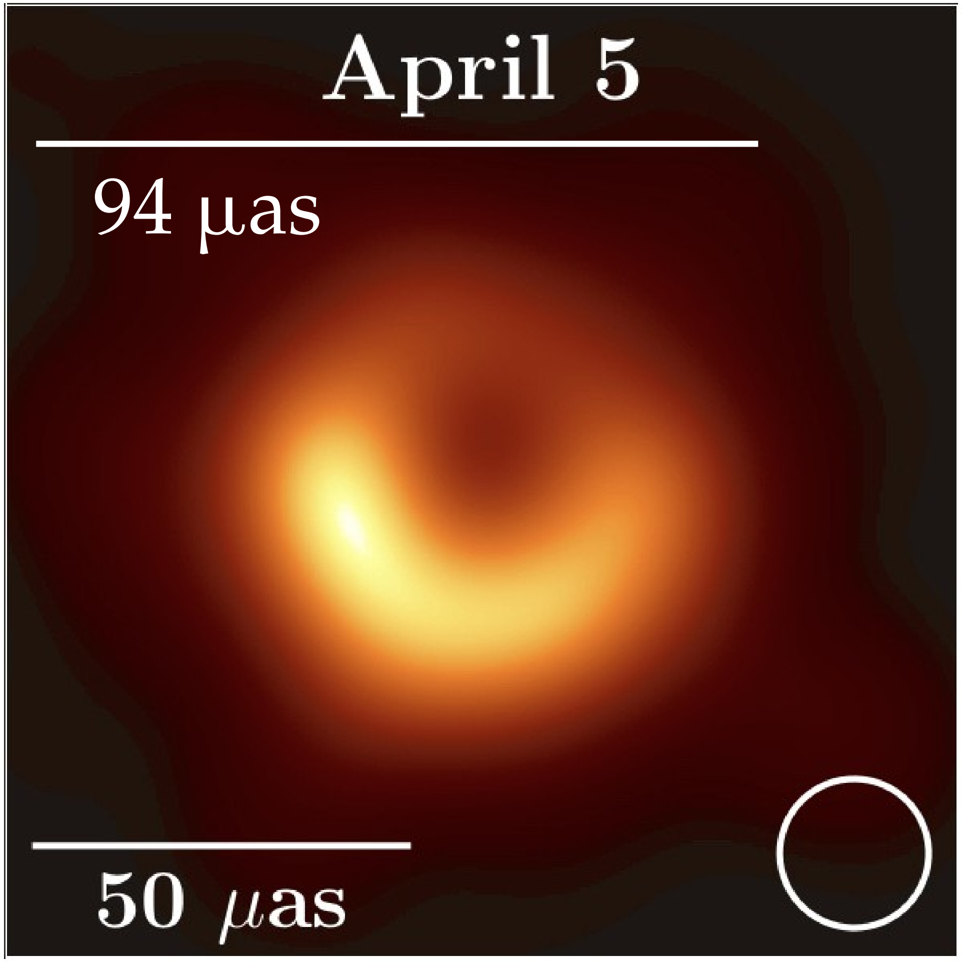


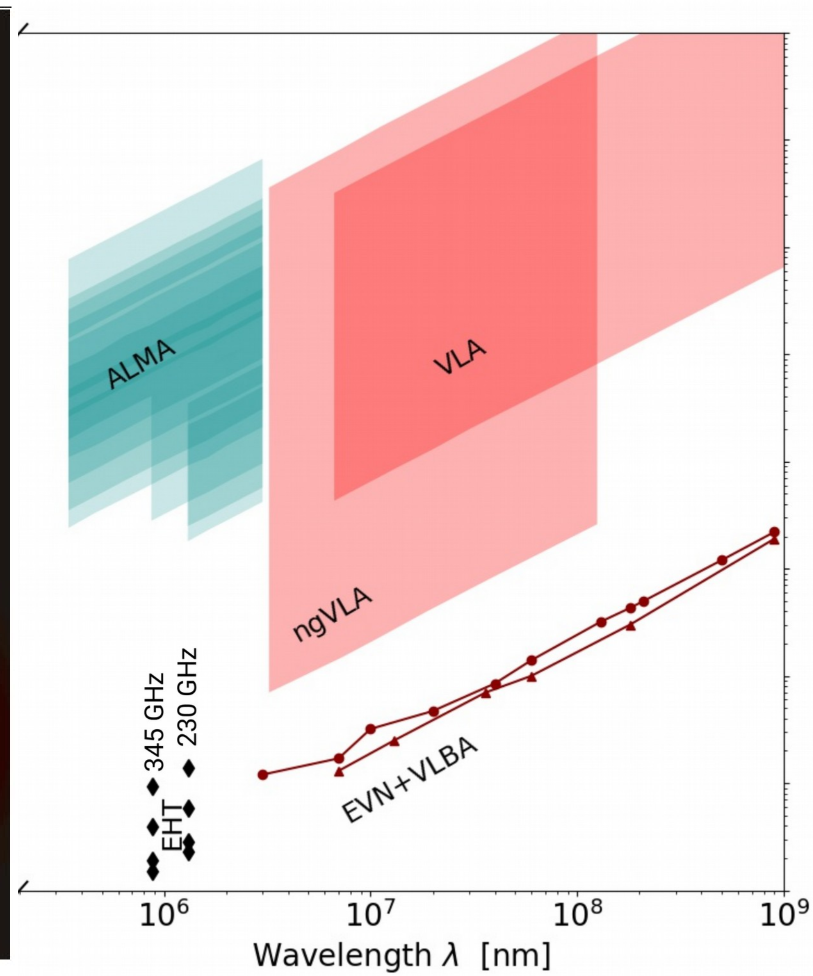
- These measurement allow to classify TYC 5517-00227-1 as a K0III giant star of $11^{+1.9}_{-2.0}\,R_\odot$, and TYC 0278-00748-1 as a $2.17^{+0.22}_{-0.23}\,R_\odot$ sub-giant (IV)

Star size direct measurement



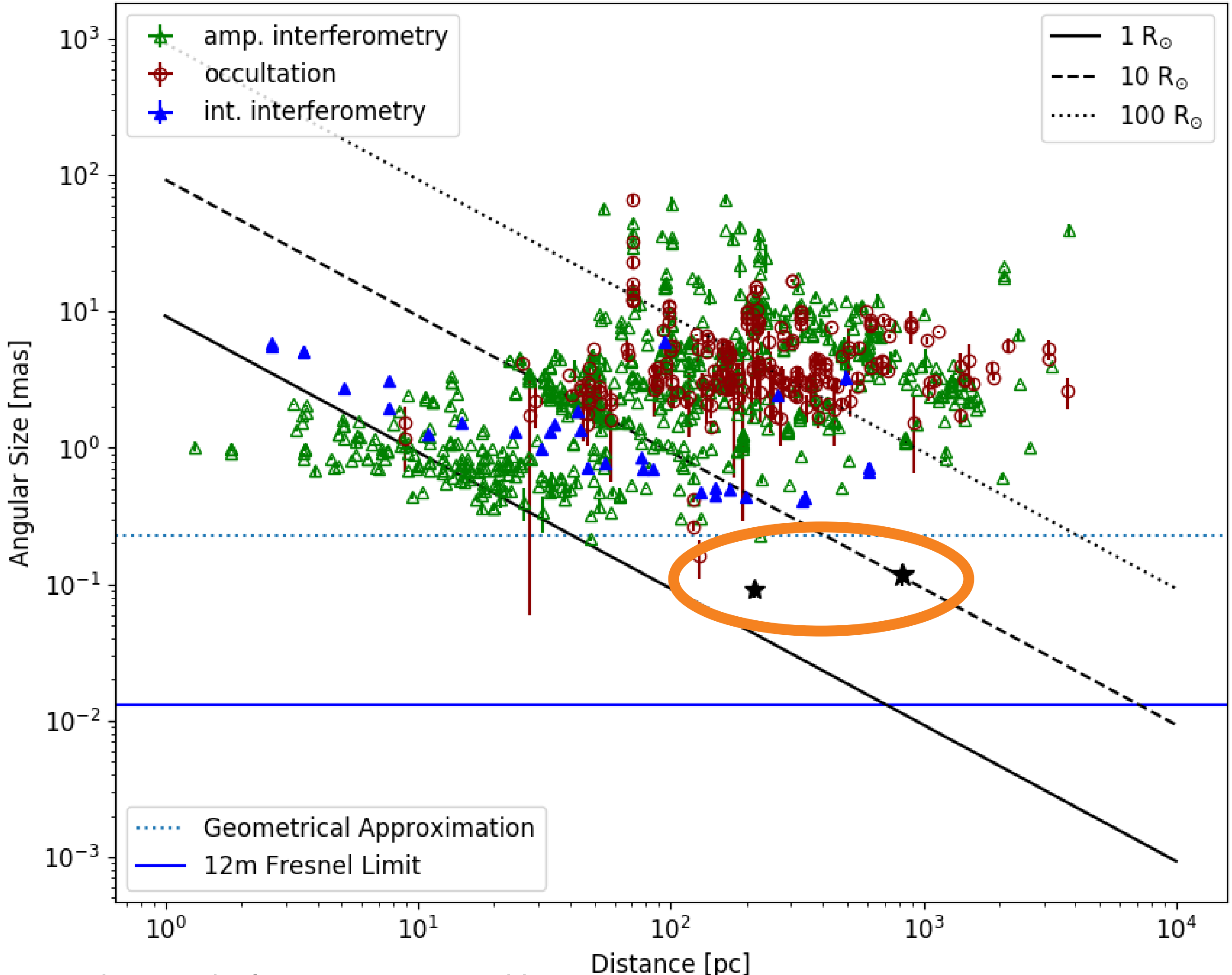
Star size direct measurement





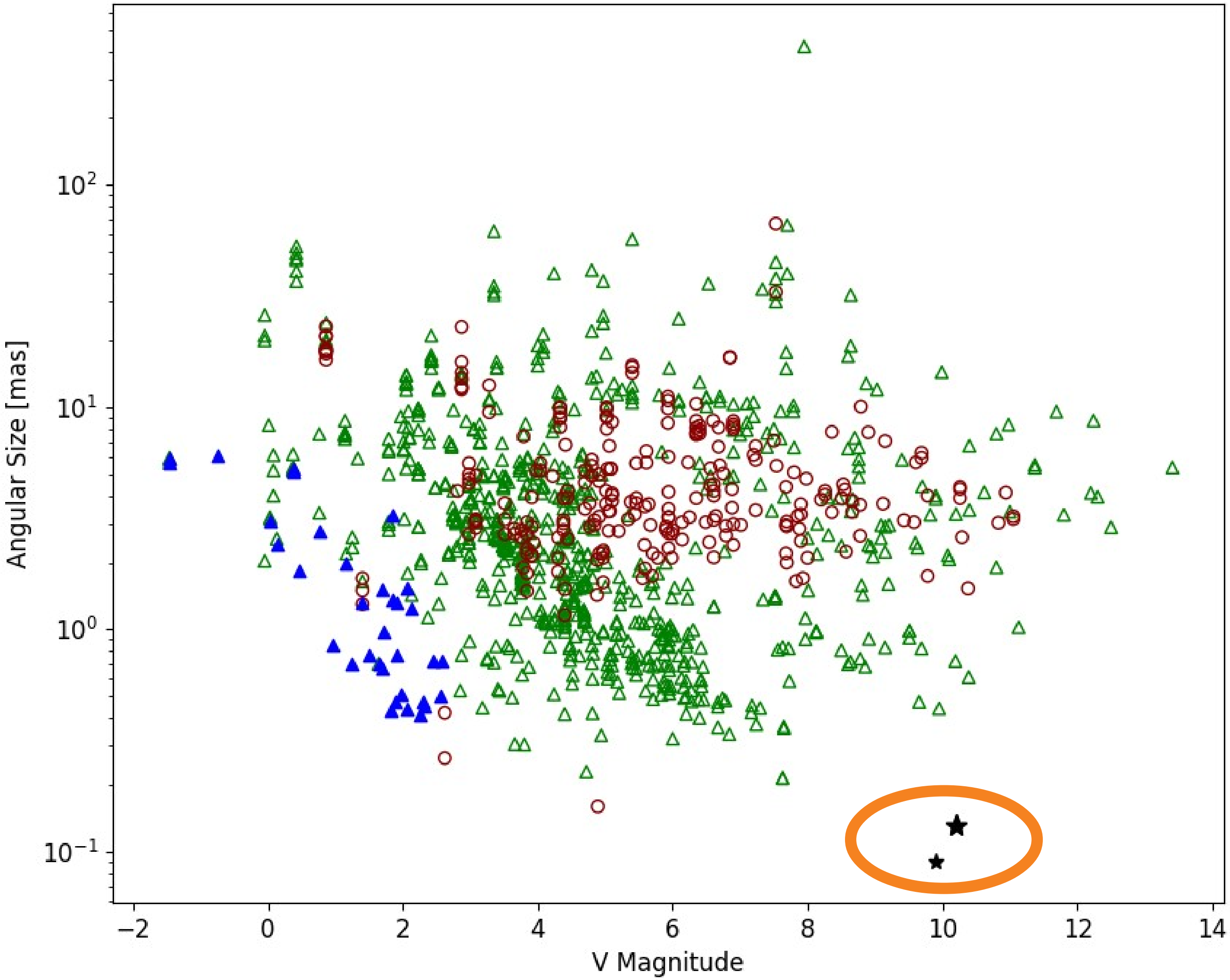
Occultations analysis – Results

- A new star-diameter detection technique is born



Occultations analysis – Results

- A new star-diameter detection technique is born

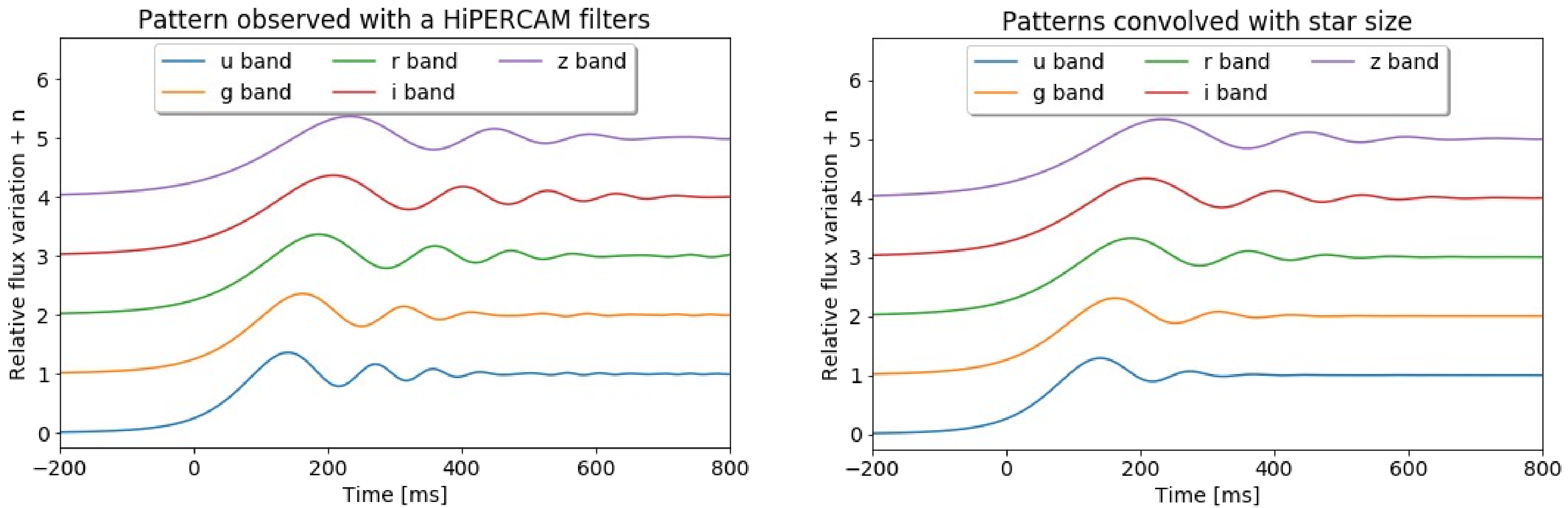


Occultations analysis – HiPERCAM

- IACTs are able to provide excellent S/N for measuring bright targets

- GTC measuring an asteroid occultation would provide 5 simultaneous bands measuring diffraction fringes:

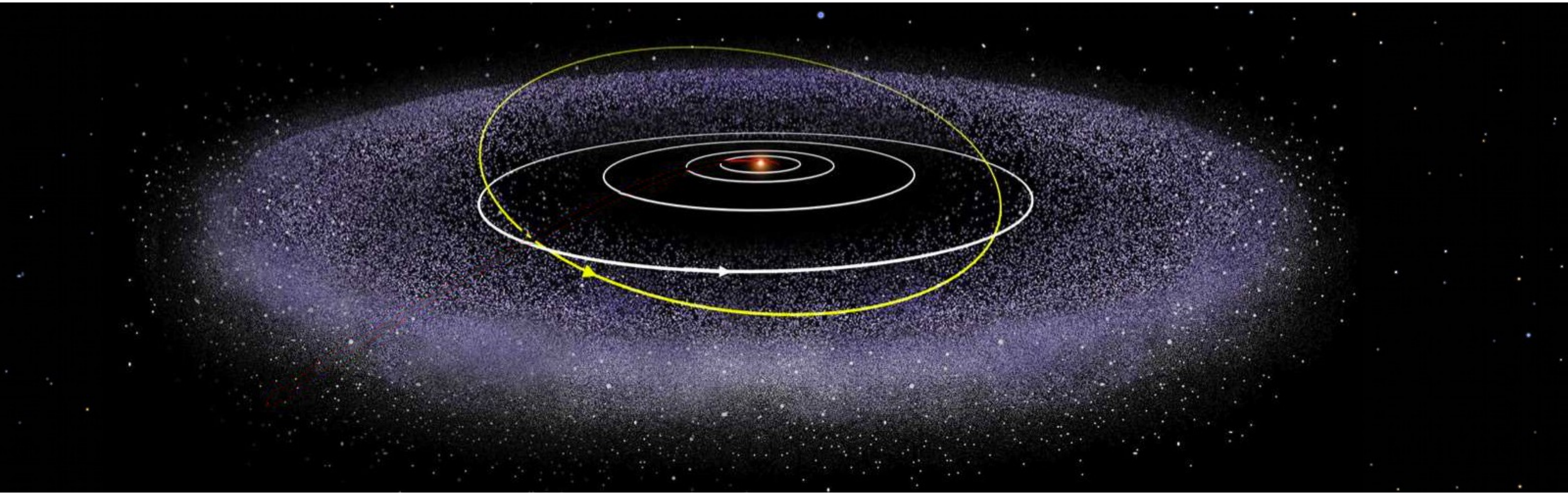
  - The 5 additional bands (with excellent S/N) would improve relative errors (well below the 3% level)



Kuiper Belt Objects – HiPERCAM

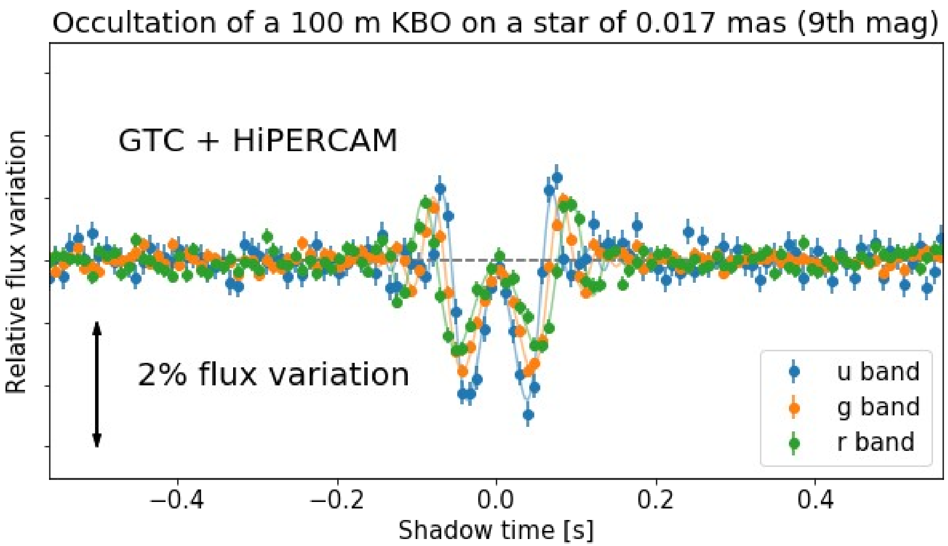
- An even more interesting topic is constraining the population of sub-km Kuiper Belt Objects (KBOs)

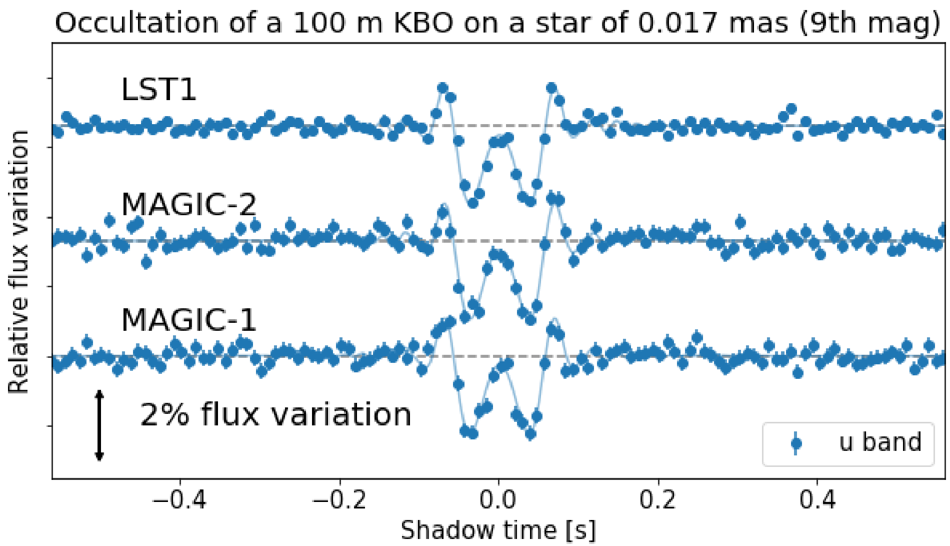
- Constraining the frequency of very small KBOs would help to constrain the collisional history of the Solar System



Kuiper Belt Objects – HiPERCAM

- LSTs + GTC-HiPERCAM would be the ideal instruments for such a search:
  - A simultaneous detection from several telescopes would unambiguously detect the smallest KBOs to date
  - GTC colors would measure the distance to the KBO (independently measuring its size)

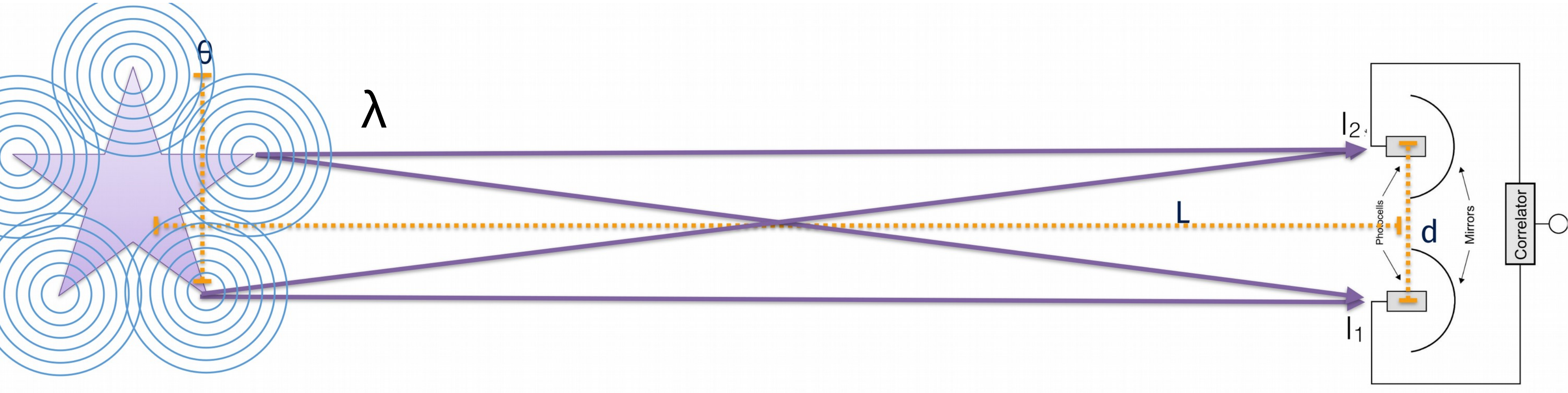




Gentle introduction to optical intensity interferometry

Introduction to Intensity Interferometry

- The basic theory:



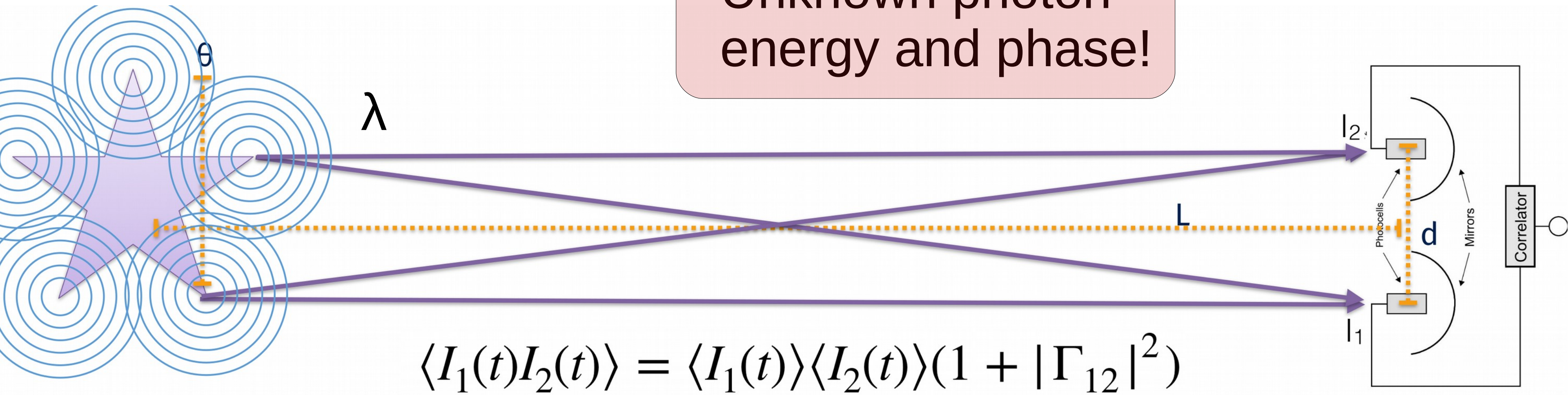
- A bright body of angular size θ is made of many incoherent emitting regions, producing a pattern of size λ/θ

- If the distance between observer 1 and 2 is << λ/θ, they observe **the same fluctuations**

Introduction to Intensity Interferometry

- The basic theory:

Unknown photon energy and phase!



$$\langle I_1(t)I_2(t)\rangle = \langle I_1(t)\rangle\langle I_2(t)\rangle(1 + |\Gamma_{12}|^2)$$

Average intensity at 1

Average intensity at 2

Coherence

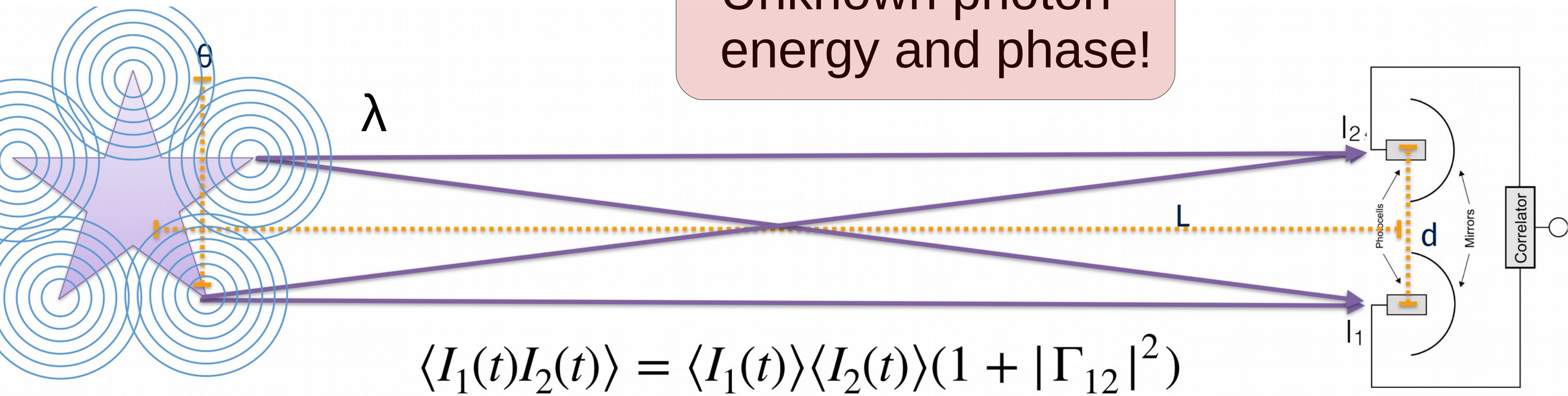
In case there is coherence between 1 and 2 signal is **enhanced a ~ 0.01%**

Large photon statistics needed to see it above noise level (large mirrors!)

Introduction to Intensity Interferometry

- The basic theory:

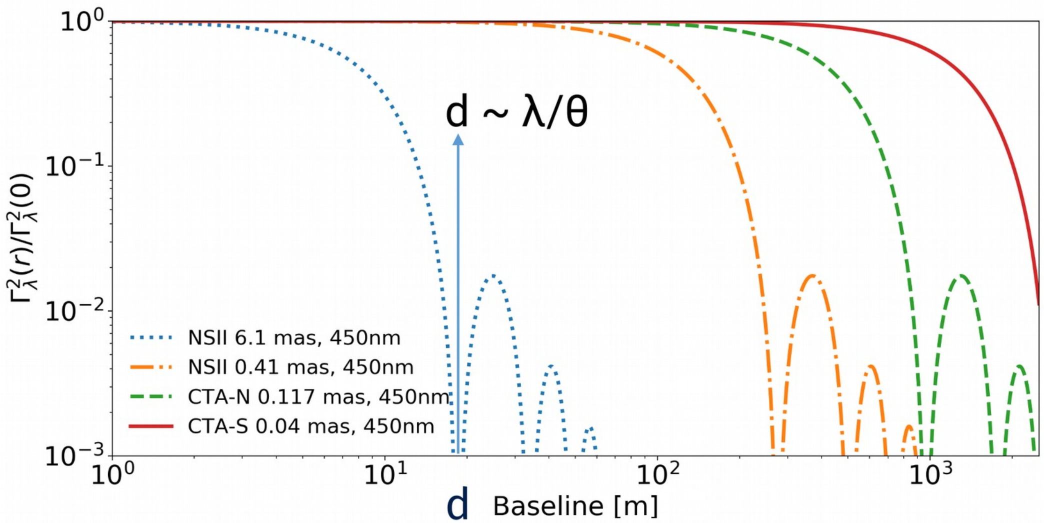
Unknown photon energy and phase!



$$\langle I_1(t) I_2(t)\rangle = \langle I_1(t)\rangle\langle I_2(t)\rangle(1 + |\Gamma_{12}|^2)$$

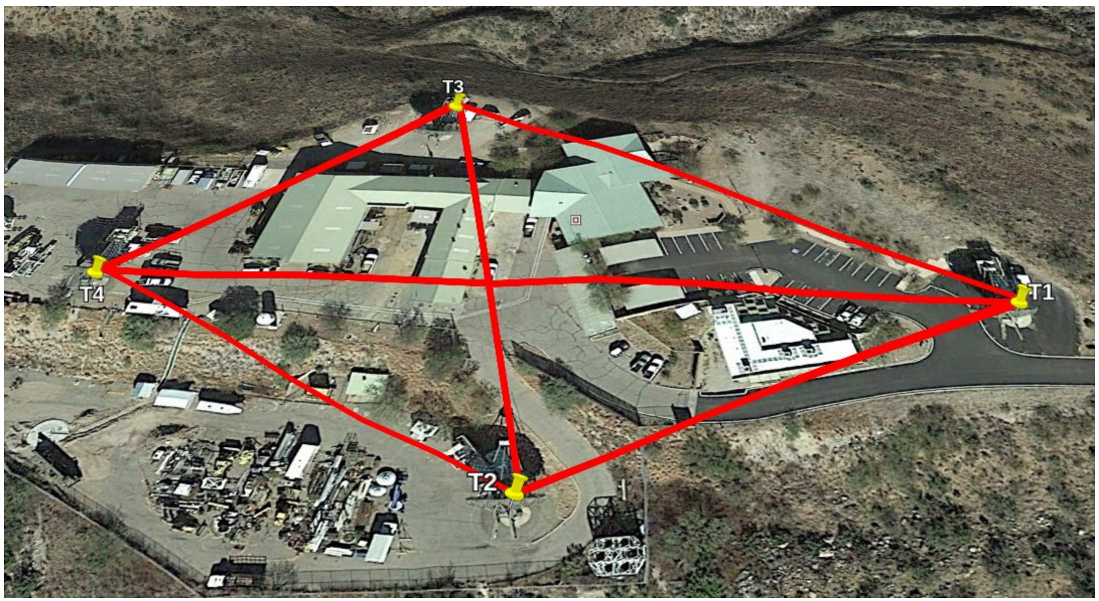
In a simple case (1D):

Studying the **varying** coherence vs baseline (different telescope distances) allows to perform sub-mas resolution measurements



Introduction to SII

- Example: VERITAS SII measurement of 2 stars

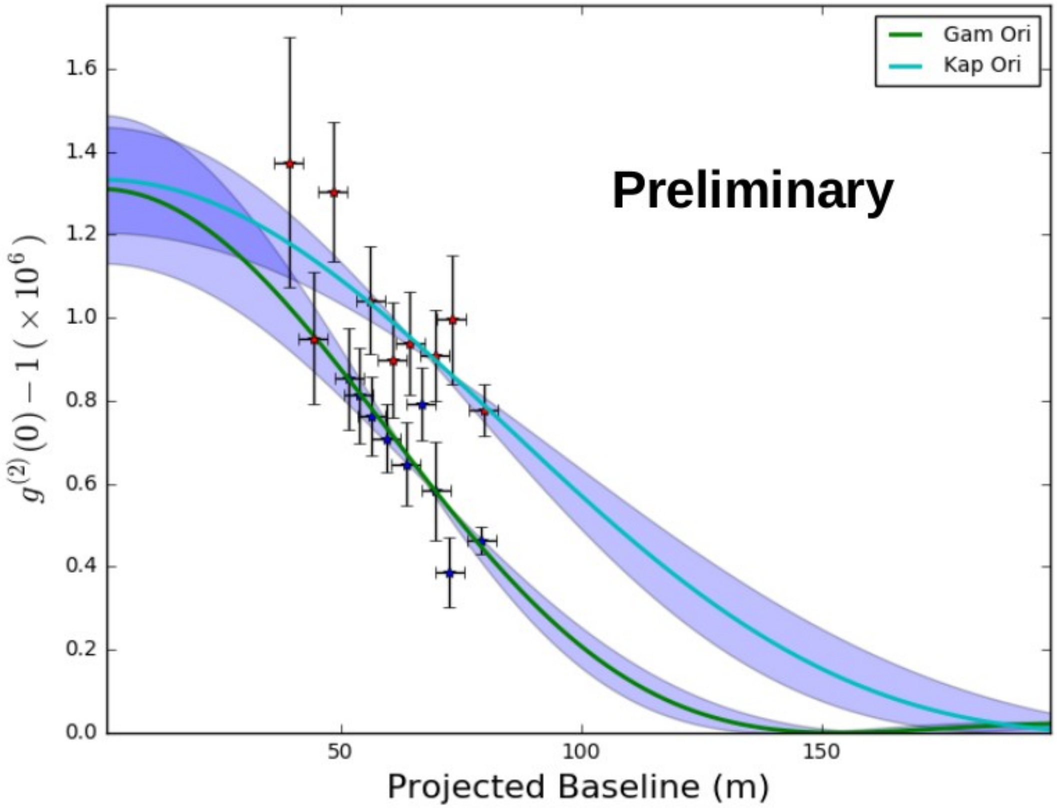


With 2 telescopes, VERITAS was able to measure the size of **Gamma** and **Kappa Orion**

2T baseline is constant, but the **Earth rotates**, modifying the projected telescope distance (~50 → 170 m)

Introduction to SII

- Example: VERITAS SII measurement of 2 stars



With 2 telescopes, VERITAS was able to measure the size of **Gamma** and **Kappa Orion**

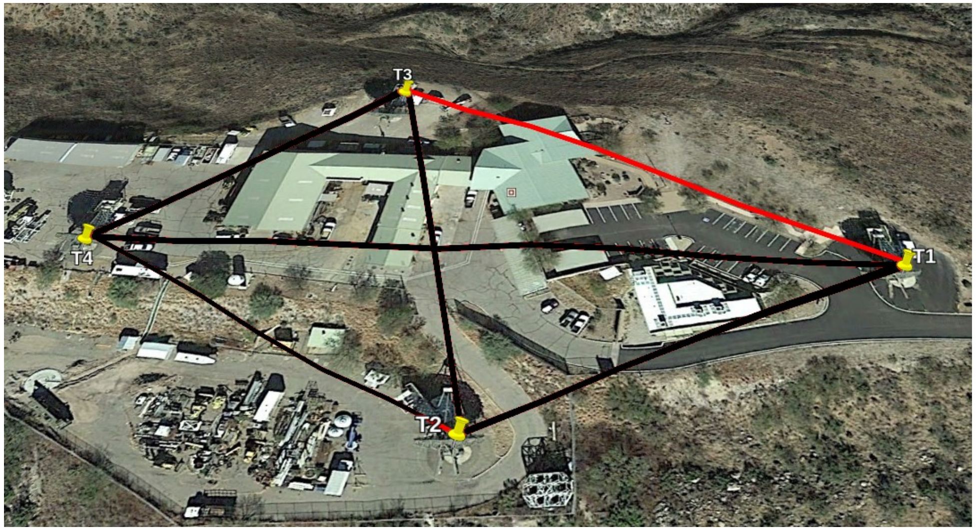
2T baseline is constant, but the **Earth rotates**, modifying the projected telescope distance (~50 → 170 m)

4T system ready: Simultaneously gathering **N(N-1)/2** baselines (resolution ~ 0.6→2 mas)

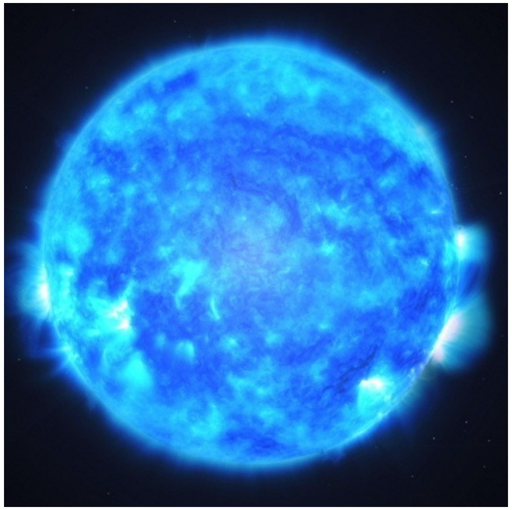
N. Matthews APS April Meeting 2019

MAGIC: V. A. Acciari et al. 2019

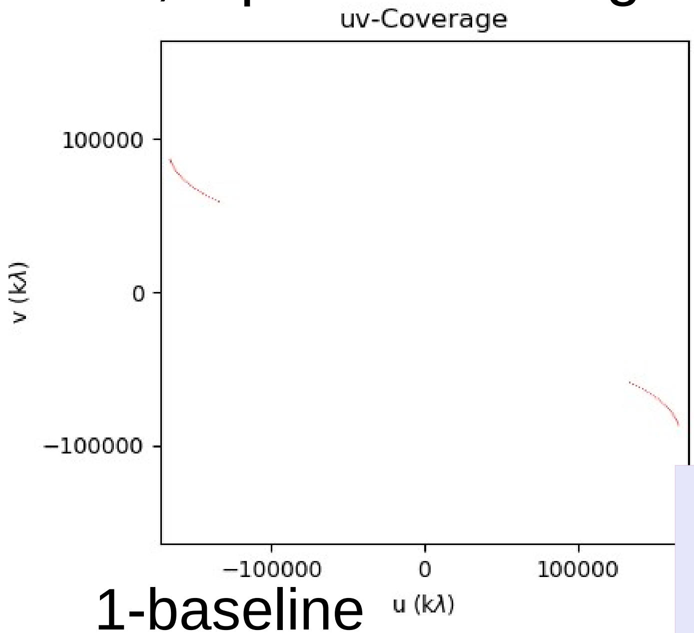
Introduction to SII Imaging



1-mas star model



u, v plane coverage

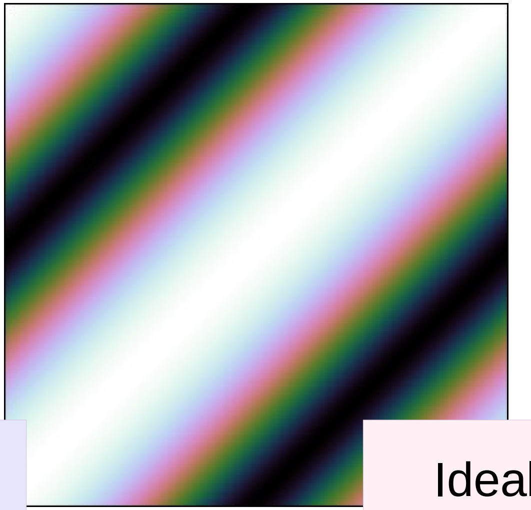


1-baseline

VERITAS
2T system

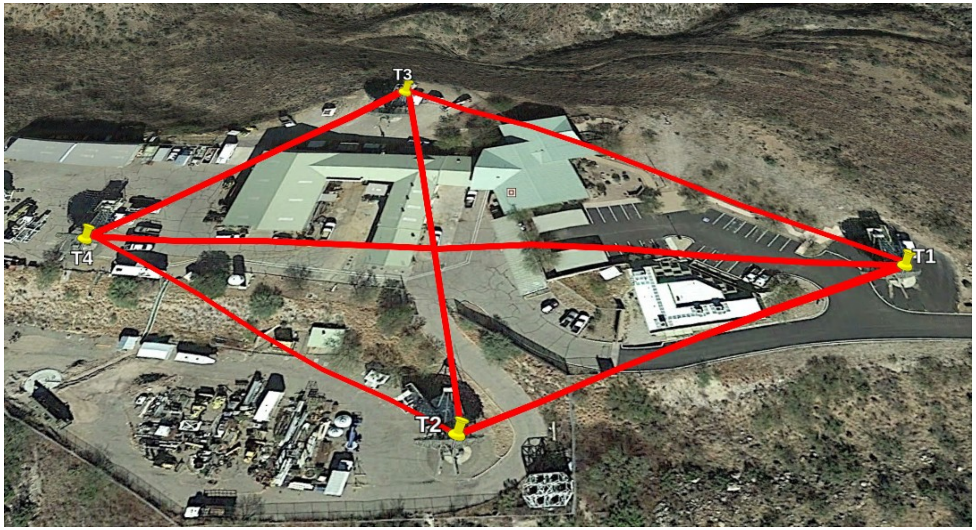
Strong assumptions required

Reconstructed image

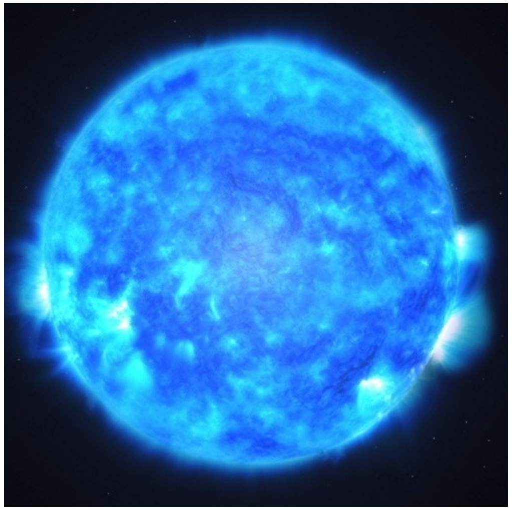


Idealized!
(ignoring S/N)

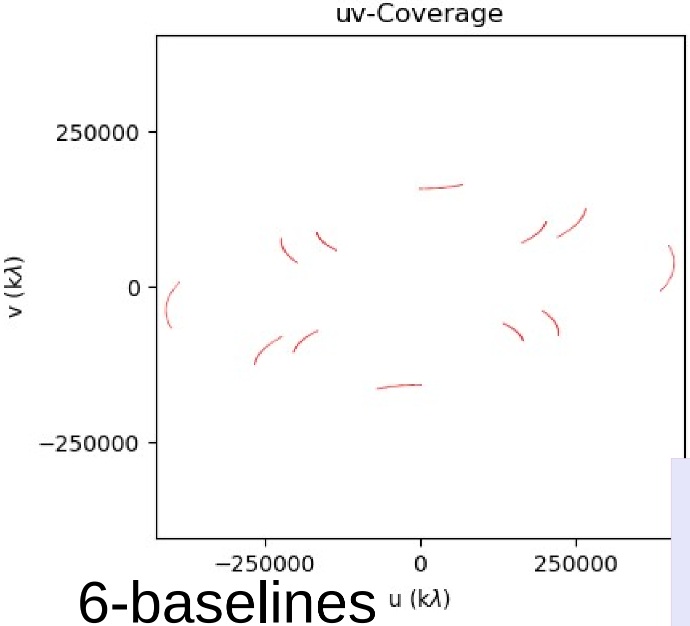
Introduction to SII Imaging



1-mas star model



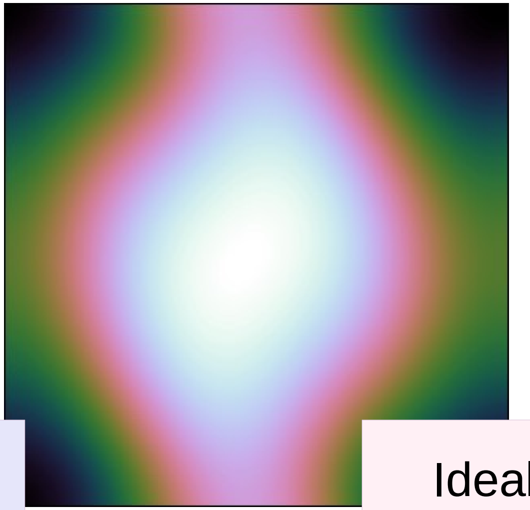
u, v plane coverage



6-baselines

VERITAS
4T system

Reconstructed image

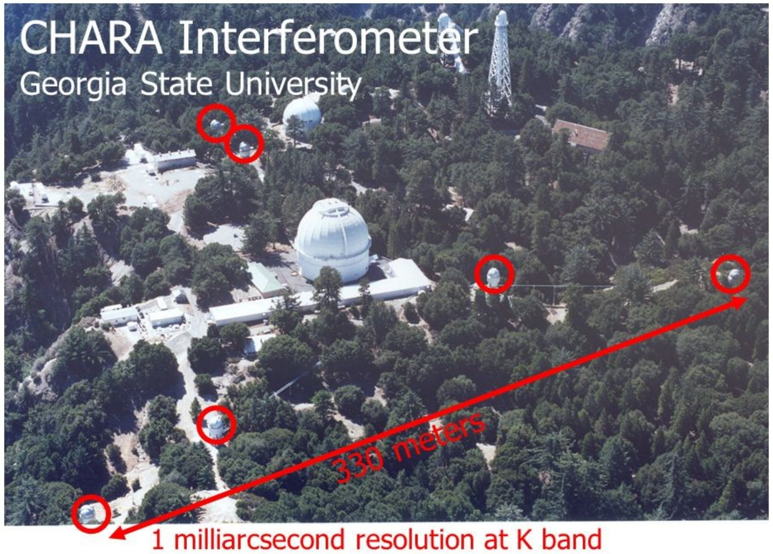


"Some" assumptions required

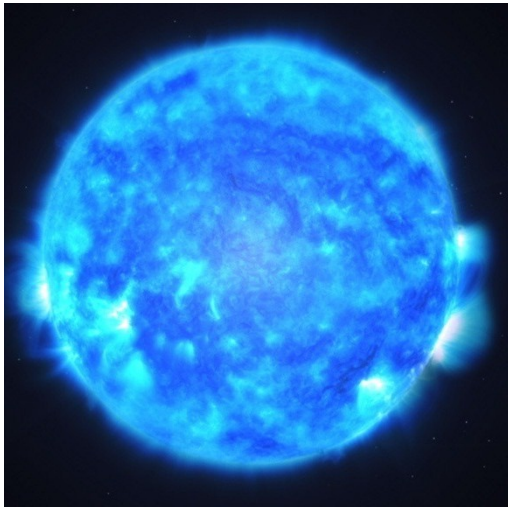
Idealized!
(ignoring S/N)

Introduction to SII Imaging

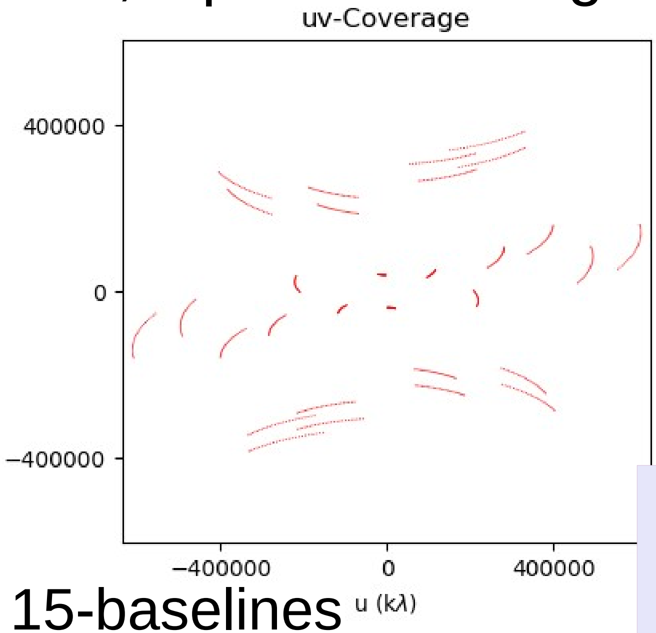
1-mas star model



1-mas stars are too small for CHARA imaging



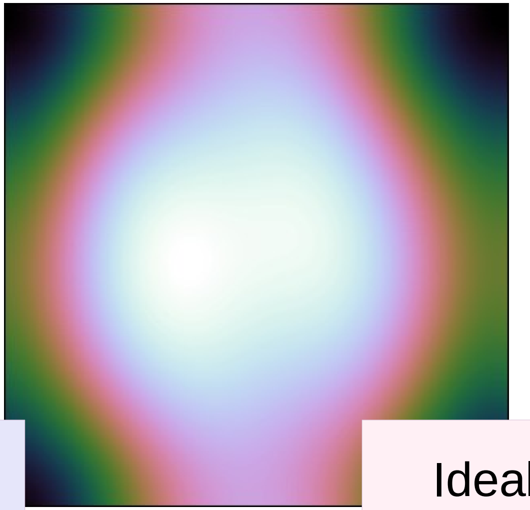
u, v plane coverage



15-baselines

CHARA 6T system

Reconstructed image

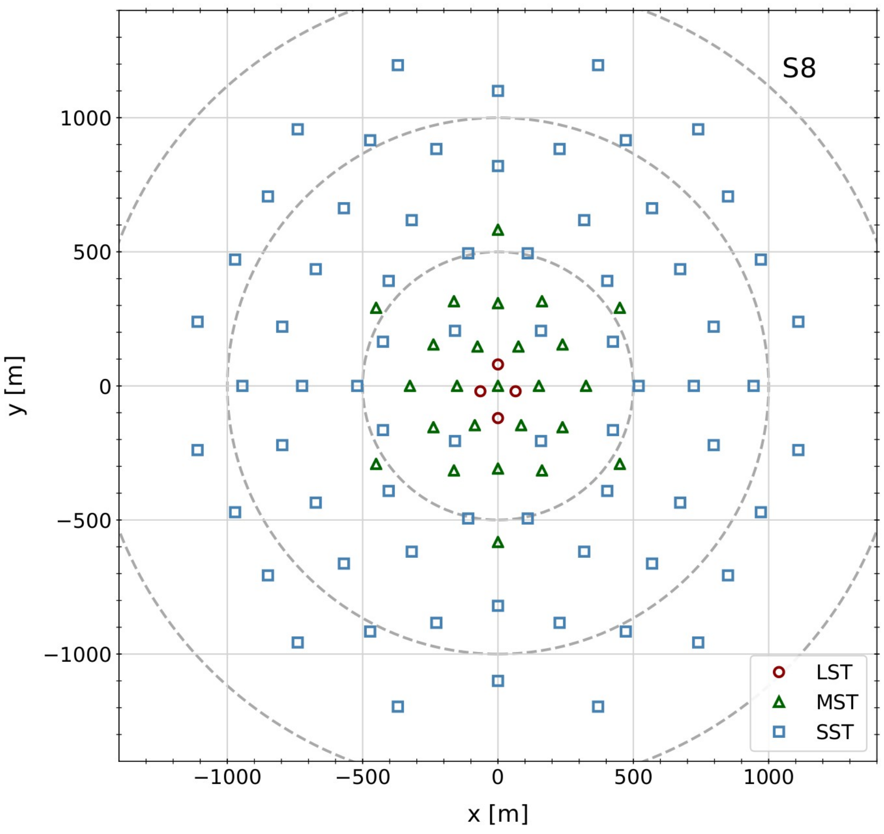


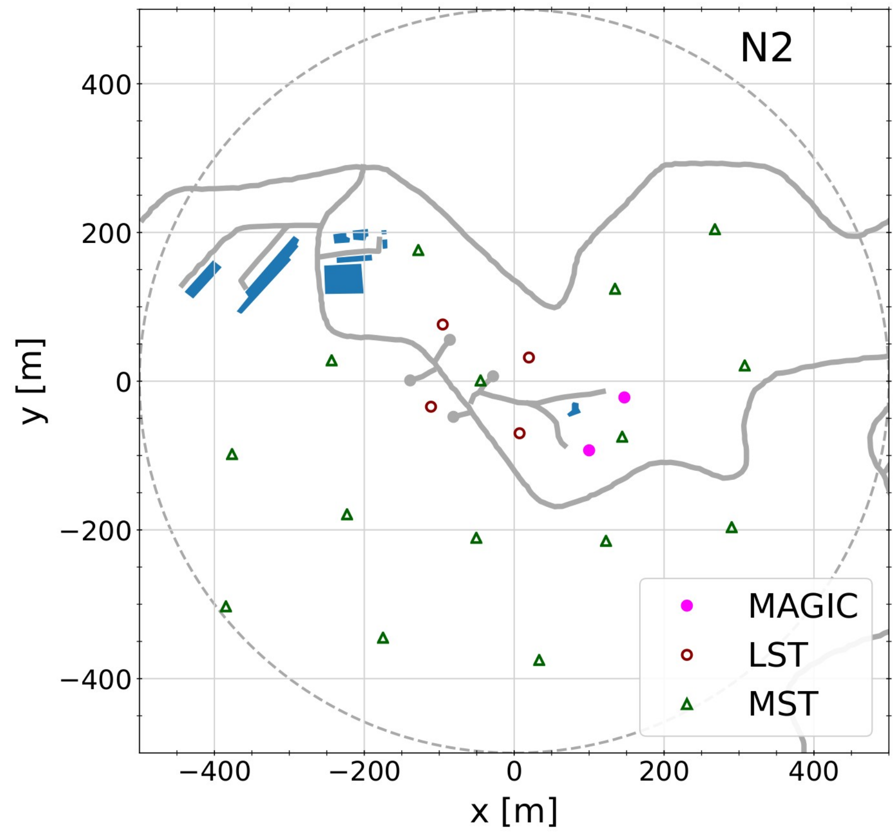
“Some” assumptions required

Idealized! (ignoring S/N)

Intensity Interferometry with CTA

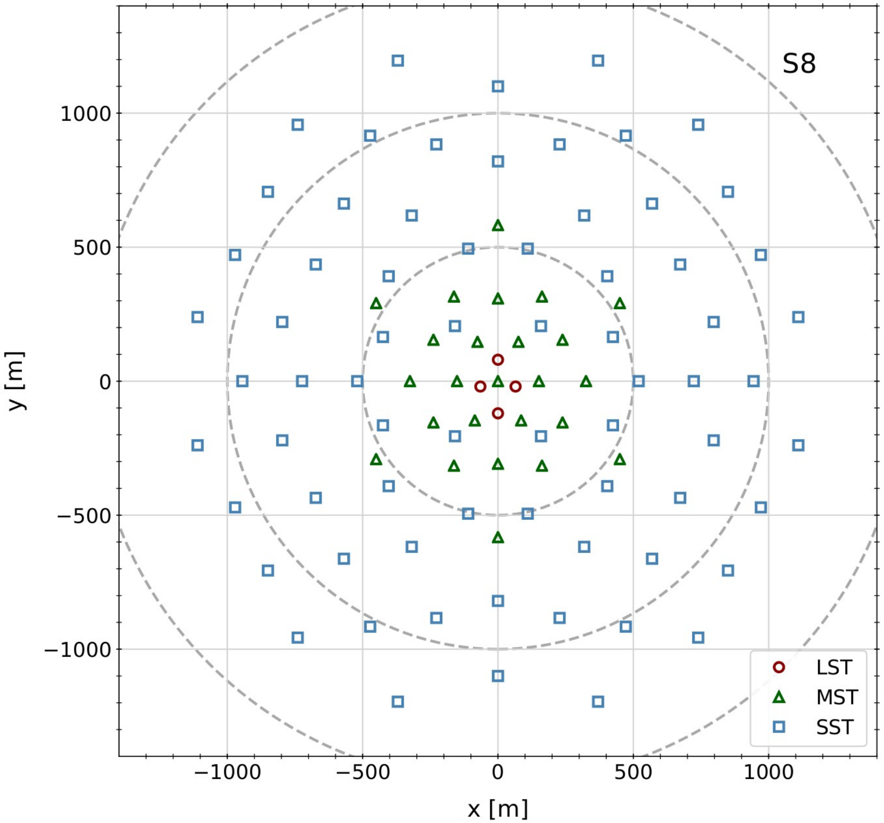
- SII with CTA-South baseline array:

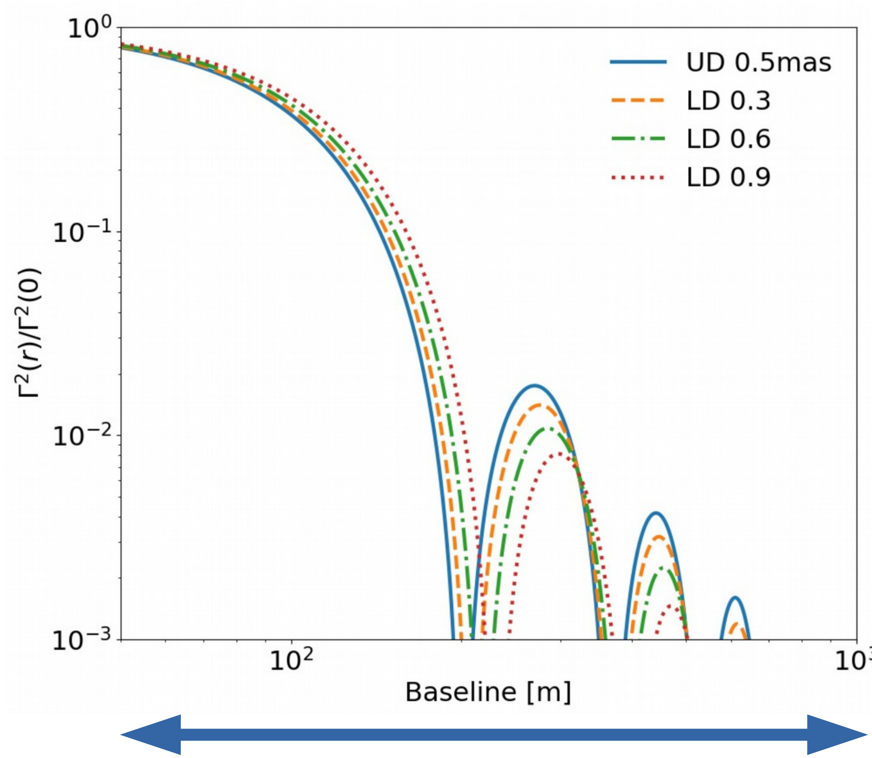




Intensity Interferometry with CTA

- SII with CTA-South baseline array:





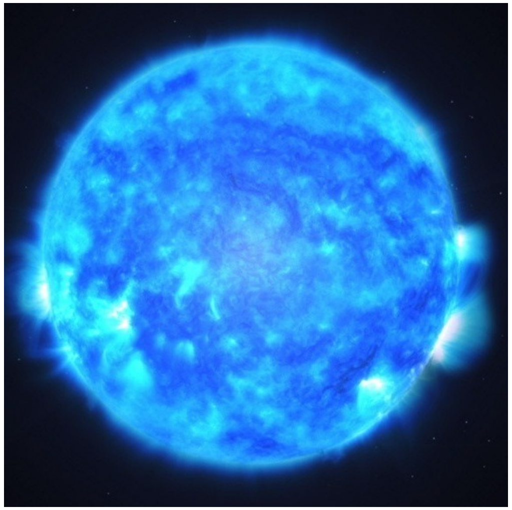
A single observation could simultaneously sample all baselines from ~50 m to ~ 2 km

Introduction to SII – Imaging

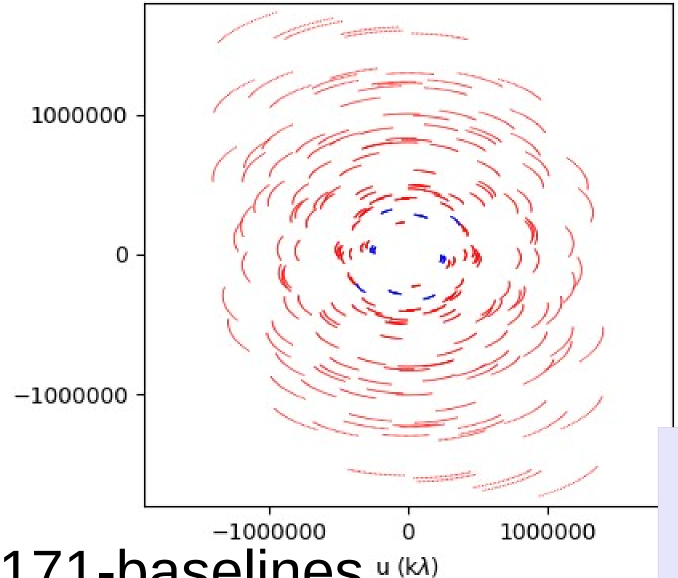
- If we have enough coverage of the u,v plane, we can perform “model independent” imaging:

$$g^{(1)}(u, v, 0) = \int\int I(l, m)\mathrm{e}^{-2\pi(lu+mv)}\mathrm{d}l\mathrm{d}m$$

1-mas star model



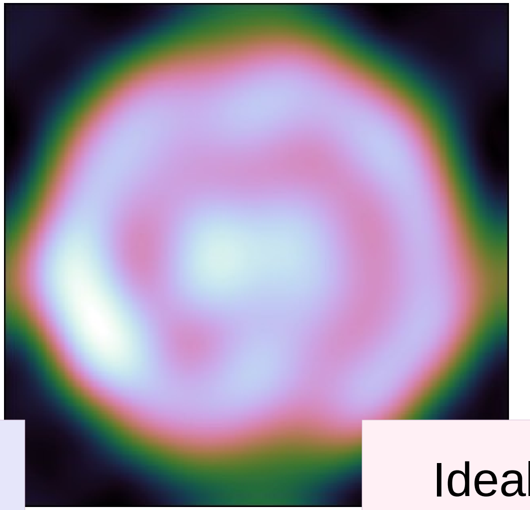
u, v plane coverage



171-baselines

CTA-N
19T system

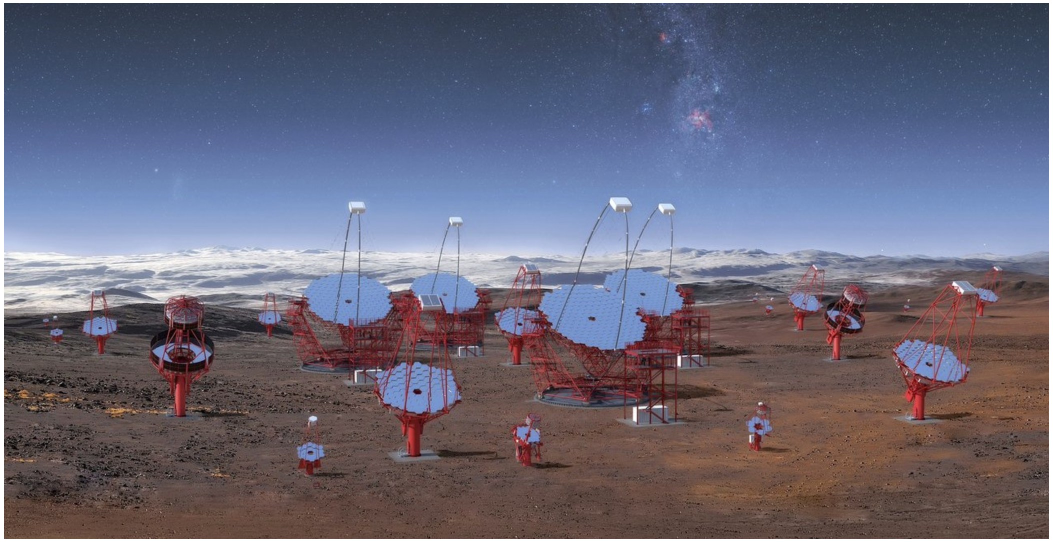
Reconstructed image



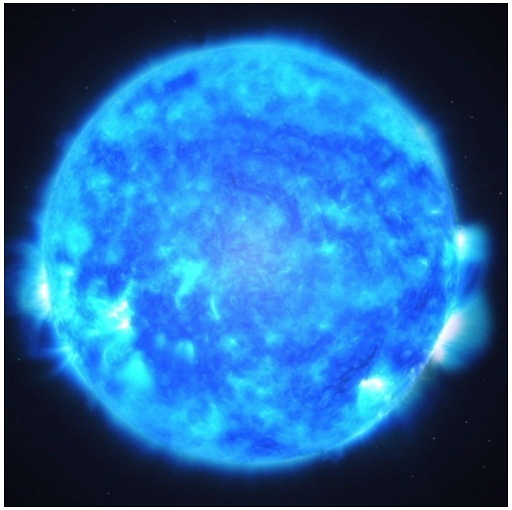
Approaching model independent imaging

Idealized!
(ignoring S/N)

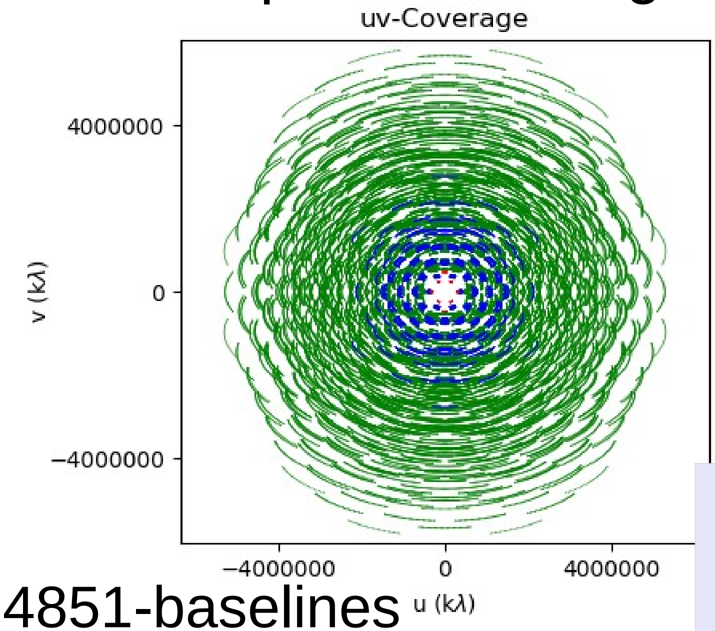
Introduction to SII Imaging



1-mas star model



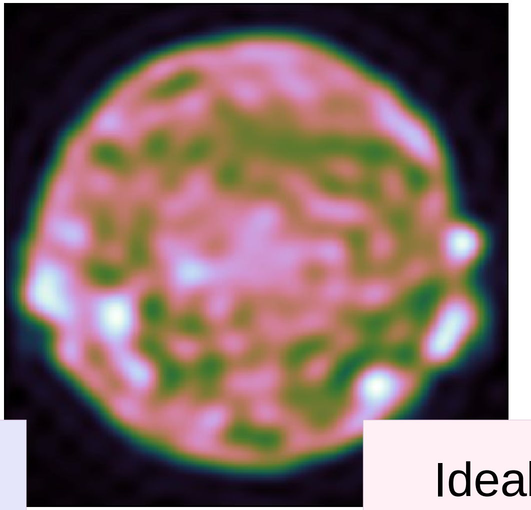
u, v plane coverage



4851-baselines

CTA-S
99T system

Reconstructed image

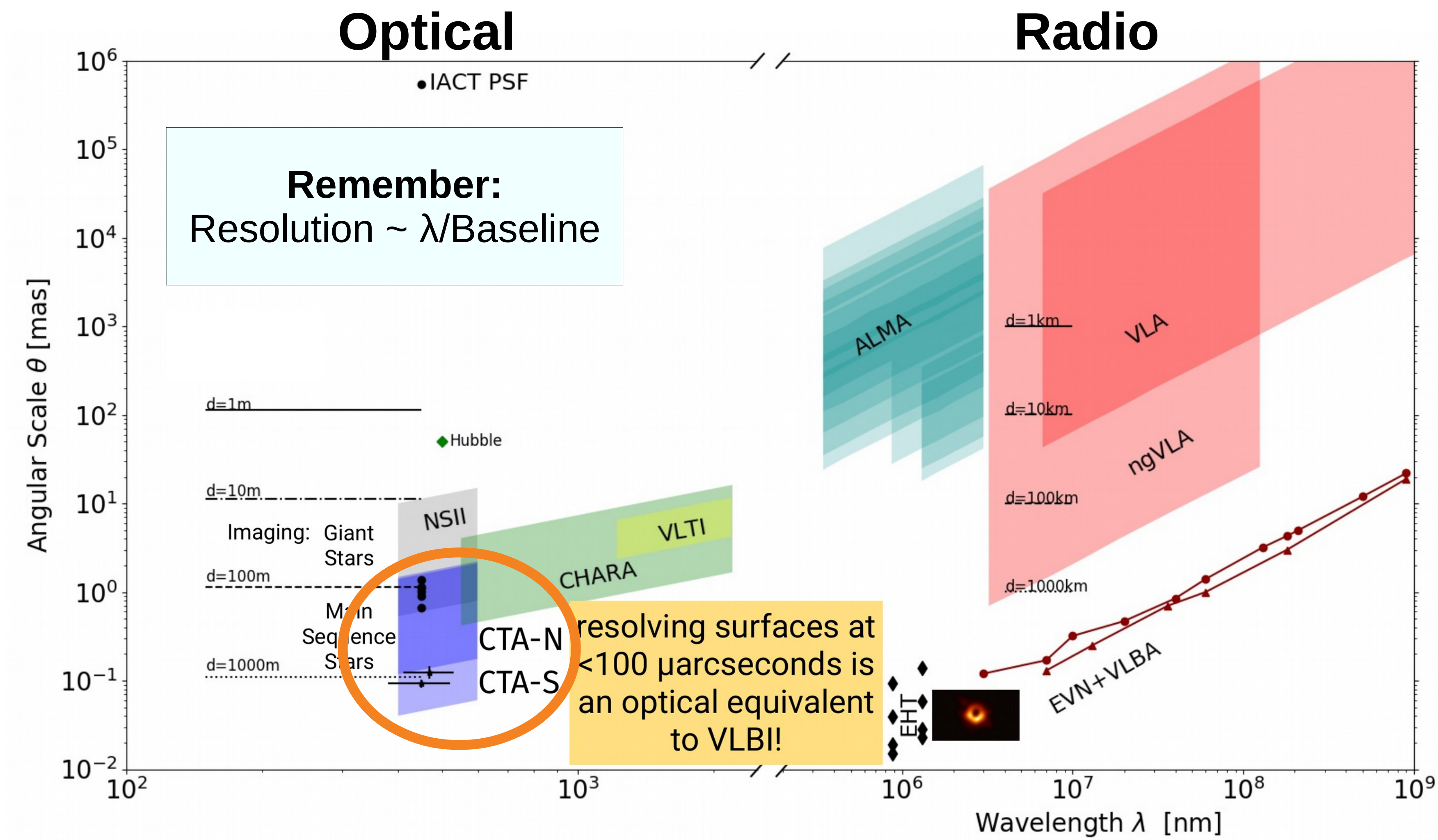


Full model
independent imaging

Idealized!
(ignoring S/N)

Interferometry: Highest angular resolution

- CTA will improve current optical resolution by a factor 10:



Conclusions

- IACTs are world-class telescopes to study (very) fast optical astronomy (s → **ms** → **ns**)

- The high NSB they sum over a pixel, limits the magnitude they are able to observe (+ enormous source confusion), but when studying bright sources they are extremely competitive

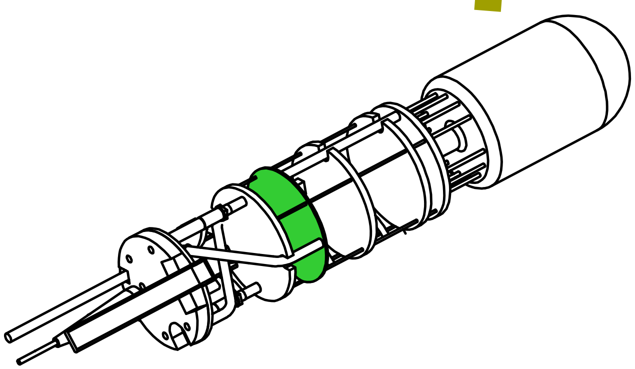
- Asteroid occultations allow ~100 µas scale measurements (highest resolution ever reached in the optical)

- Intensity interferometry is the only known technique (realistically) scalable to baselines > km, and IACT arrays are the ideal instruments to carry out these measurements

Thank you!


BACKUP

IACTs as optical detectors – MAGIC



MAGIC

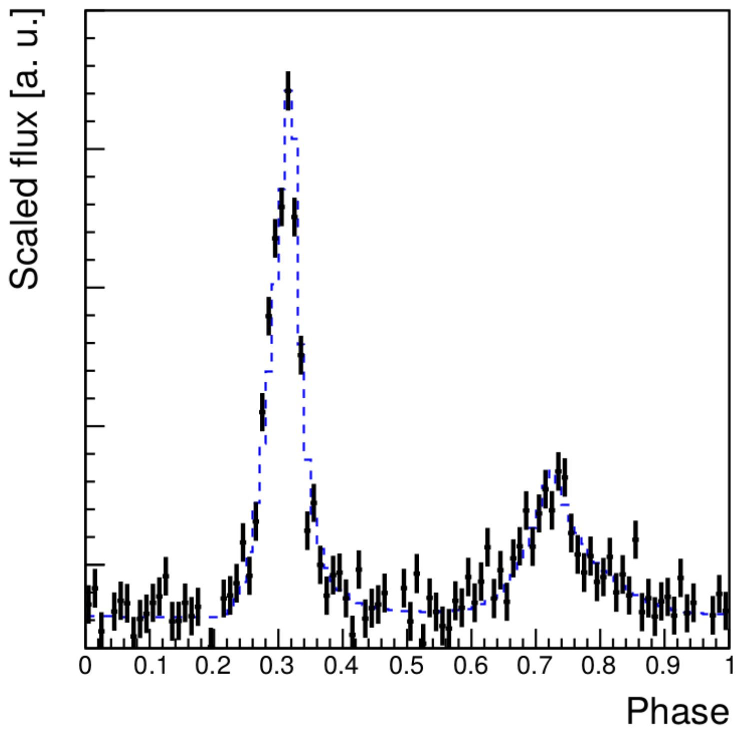
- 2 IACTs – 17 m diameter
- FoV = ~3.5º
- VHE gammas E > ~50 GeV

(Optical) MAGIC

- 17 m diameter
- FoV ~ 0.1º
- Sensitive to optical photons (U band)
- Frecuencies 1 → 10^4 Hz

IACTs as optical detectors

- IACTs showing excellent optical performance:

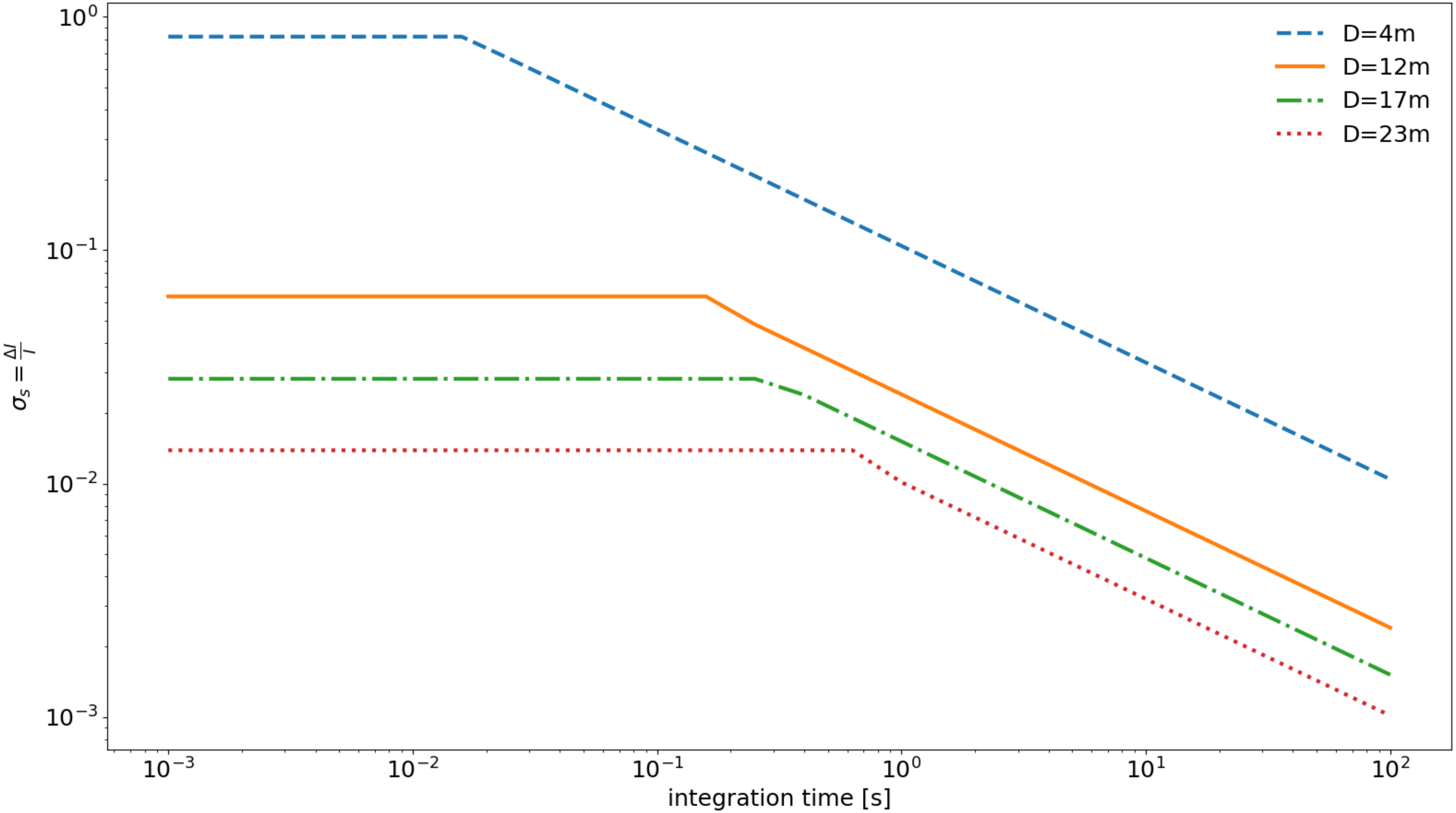


F. Lucarelli et al 2008,
T. Hassan et al 2017,
J. Hoang et al (in prep)

- MAGIC is able to detect the Crab pulsar profile in less than 10 seconds
- MAGIC is able to detect optical ms flashes of about **13th magnitude**
- VERITAS sensitivity is slightly worse (smaller reflecting surface + bigger pixels)
- VERITAS is **DC coupled**

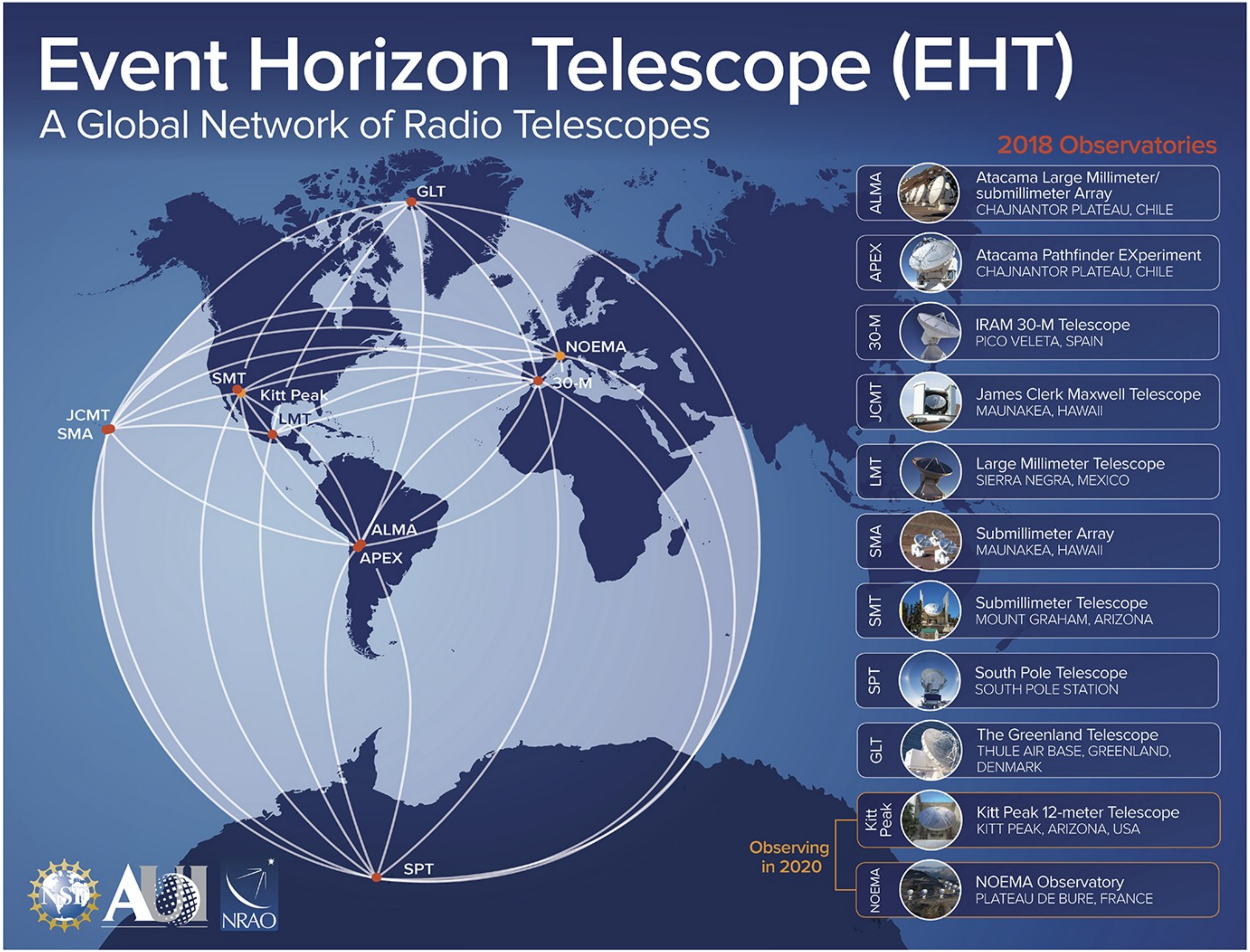
IACTs as optical detectors

- Scintillation vs telescope aperture:

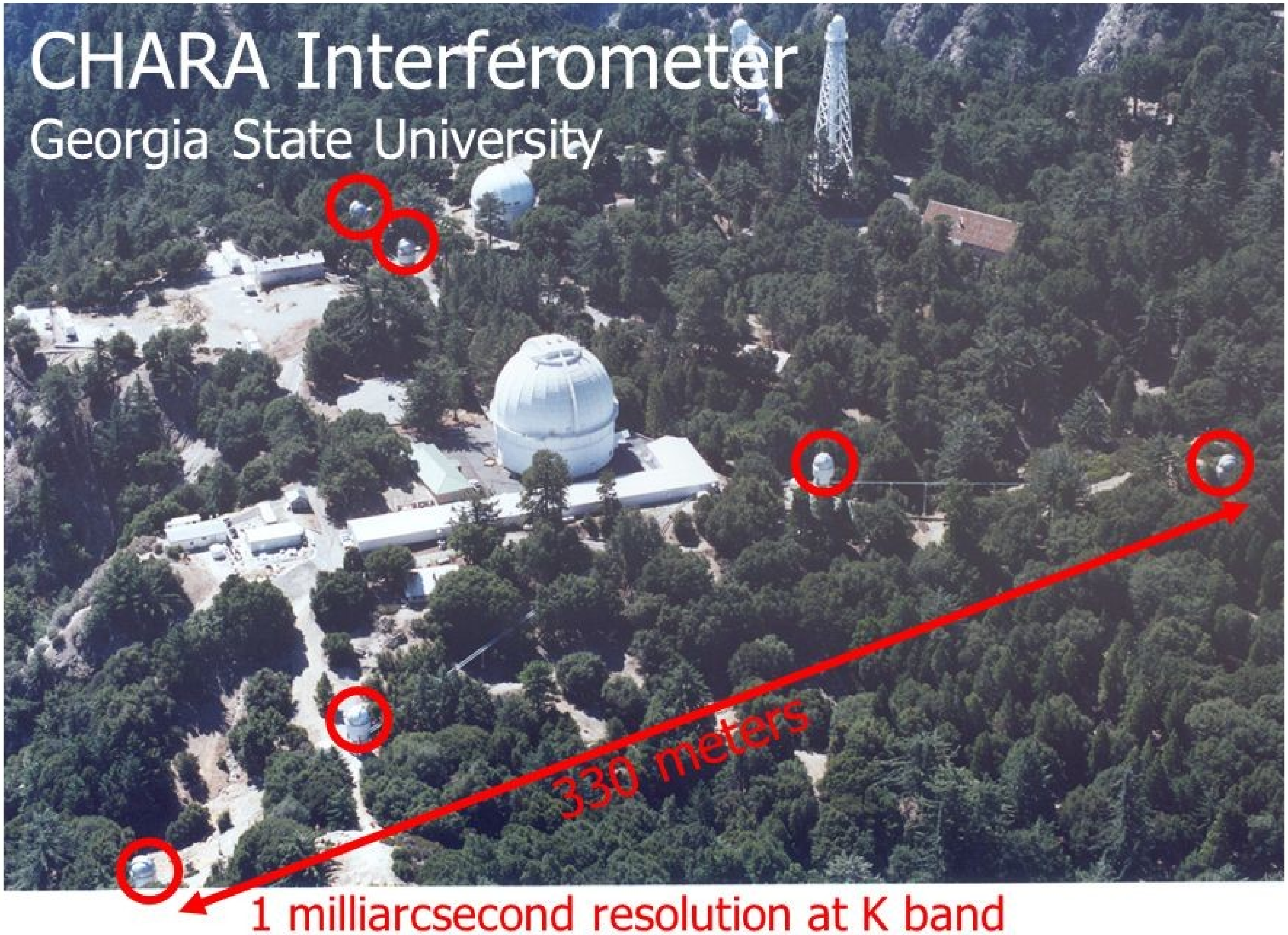


Current generation of interferometers


The Global VLBI - Array
Brewster
North Liberty
Hancock
Green Bank
Jodrell Lovell
Jodrell Mk2
Cambridge
Onsala 25m and 20m
Metsähovi
Los Alamos
Owens Valley
Pie Town
Mauna Kea
Kitt Peak
Urumqi
Shanghai
Westerbork
Medicina
Noto
EVN
VLBA
European VLBI Network (EVN)
Very Long Baseline Array (VLBA)
High Sensitivity Array (HSA)
Ft. Davis
St. Croix
V L A
Arecibo
Effelsberg
Yebes
Wettzell
Torun
Hartebeesthoek

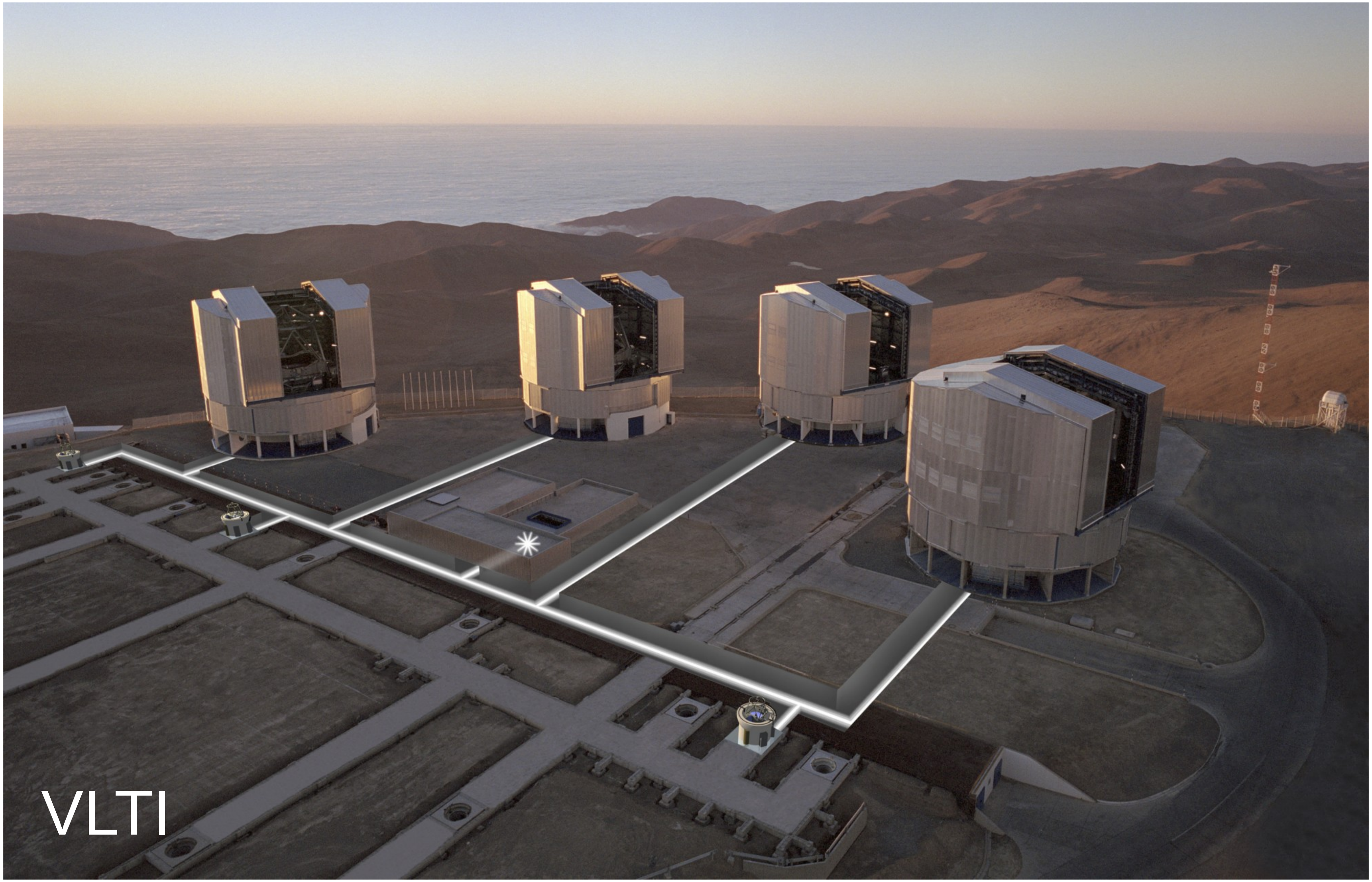

Event Horizon Telescope (EHT)
A Global Network of Radio Telescopes
2018 Observatories
GLT
NOEMA
SMT
Kitt Peak
30-M
JCMT
SMA
LMT
ALMA
APEX
SPT
ALMA
Atacama Large Millimeter/ submillimeter Array
CHAJNANTOR PLATEAU, CHILE
APEX
Atacama Pathfinder EXperiment
CHAJNANTOR PLATEAU, CHILE
30-M
IRAM 30-M Telescope
PICO VELETA, SPAIN
JCMT
James Clerk Maxwell Telescope
MAUNAKEA, HAWAII
LMT
Large Millimeter Telescope
SIERRA NEGRA, MEXICO
SMA
Submillimeter Array
MAUNAKEA, HAWAII
SMT
Submillimeter Telescope
MOUNT GRAHAM, ARIZONA
SPT
South Pole Telescope
SOUTH POLE STATION
GLT
The Greenland Telescope
THULE AIR BASE, GREENLAND, DENMARK
Observing in 2020
Kitt Peak
Kitt Peak 12-meter Telescope
KITT PEAK, ARIZONA, USA
NOEMA
NOEMA Observatory
PLATEAU DE BURE, FRANCE
NRAO

Optical Phase Interferometry



(K ≡ infrared at 2.2 μm)

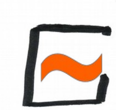
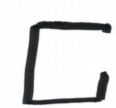
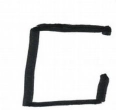
Optical Phase Interferometry



Optical Phase Interferometry

Occultation analysis – The basics

$$I(x) = I_0\left(\left|\int_{-\infty}^{x}\cos\left(\frac{\pi u^2}{L\lambda}\right)du\right|^2 + \left|\int_{-\infty}^{x}\sin\left(\frac{\pi u^2}{L\lambda}\right)du\right|^2\right)$$

- Apart from the **star size**, the following variables are the main parameters affecting the diffraction patter:
  - Distance asteroid – Earth 
  - Speed of the shadow (shadow distance → time) 
  - Wavelength of the detected photons 
  - Time of occultation 
  - Occultation angle 

Asteroid Ccultations – Orbital parameters

- Asteroid motions are very well known, and their uncertainties are very small → They will be used as **fixed parameters**
  - Uncertainties on orbital parameters in the 1E-4%

Orbital Elements at Epoch 2458200.5 (2018-Mar-23.0) TDB
Reference: JPL 37 (heliocentric ecliptic J2000)

Element	Value	Uncertainty (1-sigma)	Units
e	.2128203579254091	3.4125e-08	
a	3.12487363561751	1.4959e-08	au
q	2.459836910013717	1.0512e-07	au
i	12.8113558497366	4.5784e-06	deg
node	203.7920967664546	1.7117e-05	deg
peri	96.87526582127354	2.0142e-05	deg
M	257.711987043056	1.2596e-05	deg
t_p	2458773.783388887074 (2019-Oct-17.28338889)	7.2932e-05	JED
period	2017.655969973909 5.52	1.4488e-05 3.967e-08	d yr
n	.1784248679444867	1.2812e-09	deg/d
Q	3.789910361221303	1.8142e-08	au

Orbit Determination Parameters

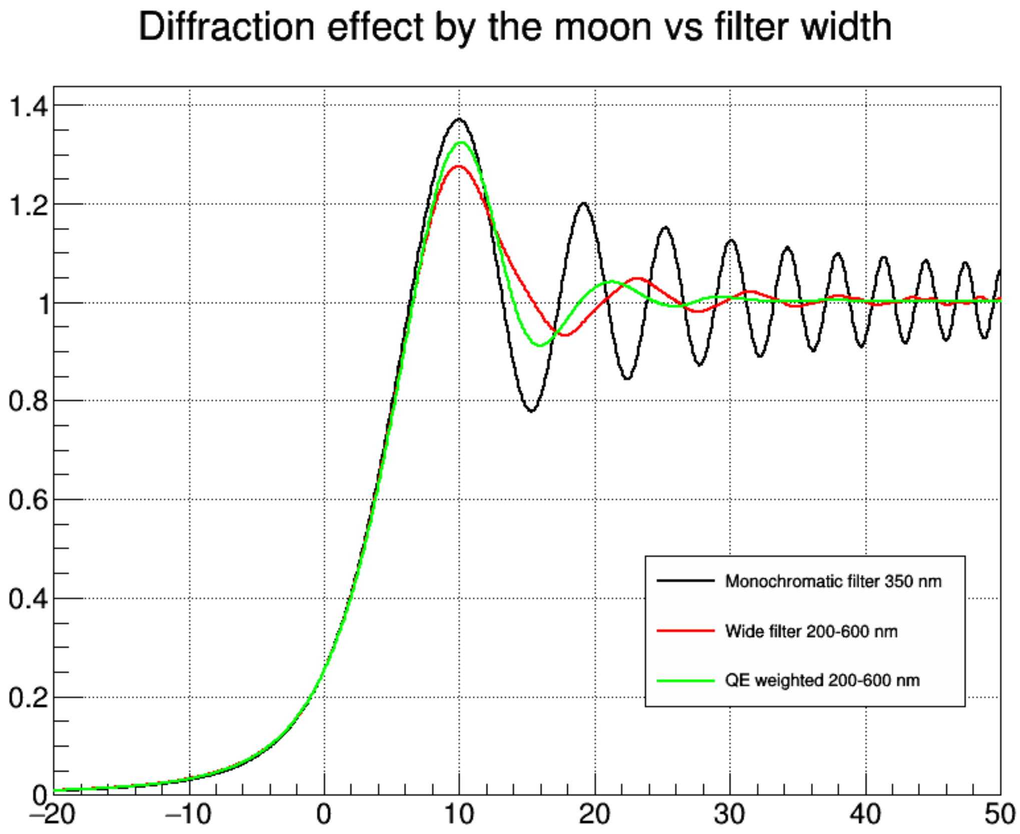
# obs. used (total)	2164
data-arc span	39642 days (108.53 yr)
first obs. used	1909-10-10
last obs. used	2018-04-23
planetary ephem.	DE431
SB-pert. ephem.	SB431-N16
condition code	0
fit RMS	.5132
data source	ORB
producer	Otto Matic
solution date	2018-May-07 02:29:54

Additional Information

Earth MOID = 1.48566 au
Jupiter MOID = 1.70775 au
T_jup = 3.142

VERITAS pixels – Optical photon wavelength

- The optical photon wavelength dilutes the diffraction pattern:



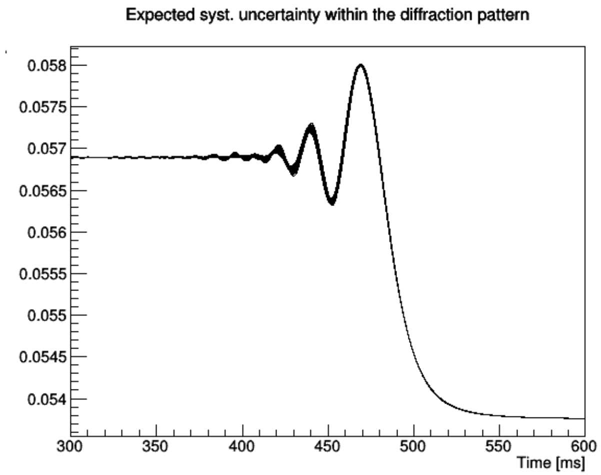
Note that this effect may be very similar to the effect produced by a ”non point-like” star

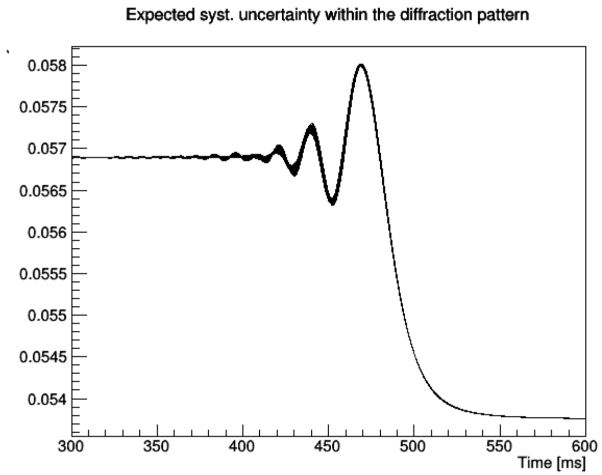
Main source of systematic uncertainty

Needs to be studied in detail!

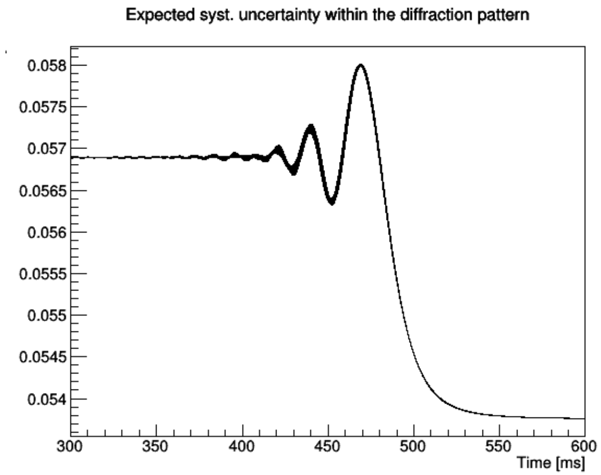
VERITAS pixels – Optical photon wavelength

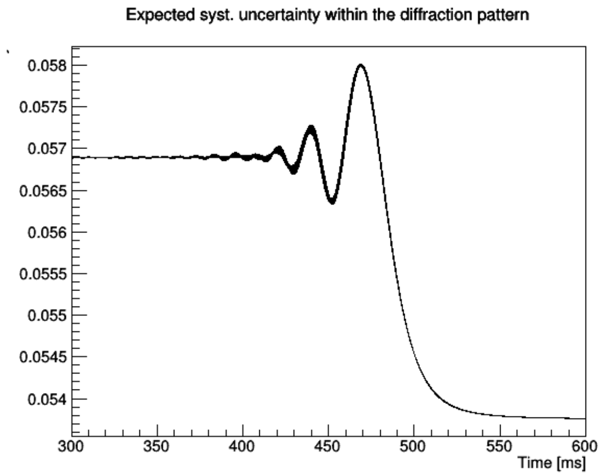
- Even if these curves are quite diverse, the effect over the diffraction pattern is not that significant:





There could be effects we are not taking into account that may increase this uncertainty





The good news are that the different shapes of these distributions dominate over the relatively small differences

Occultation analysis – The basics

- The analysis of the diffraction pattern by asteroid occultations is mainly a fitting problem

- Given the large distance to the main belt asteroids (~4E11 m) and their small size (2-10E3 m) the difference between a straight edge and disc diffraction pattern is negligible
  (See e.g. http://iopscience.iop.org/article/10.1086/301122/meta)

We will be using:

$$I(x) = I_0\left(\left|\int_{-\infty}^{x} \cos\left(\frac{\pi u^2}{L\lambda}\right)du\right|^2 + \left|\int_{-\infty}^{x} \sin\left(\frac{\pi u^2}{L\lambda}\right)du\right|^2\right)$$

L: Distance to asteroid
λ: Photons wavelength

To convert distance to time:
v: Asteroid speed

Occultations analysis – Implementation

- From many tests on the fitting process we concluded that:
  - The most conservative (and risk free) approach to treat the occultation time and angle is as nuisance parameters, **individually** to each lightcurve

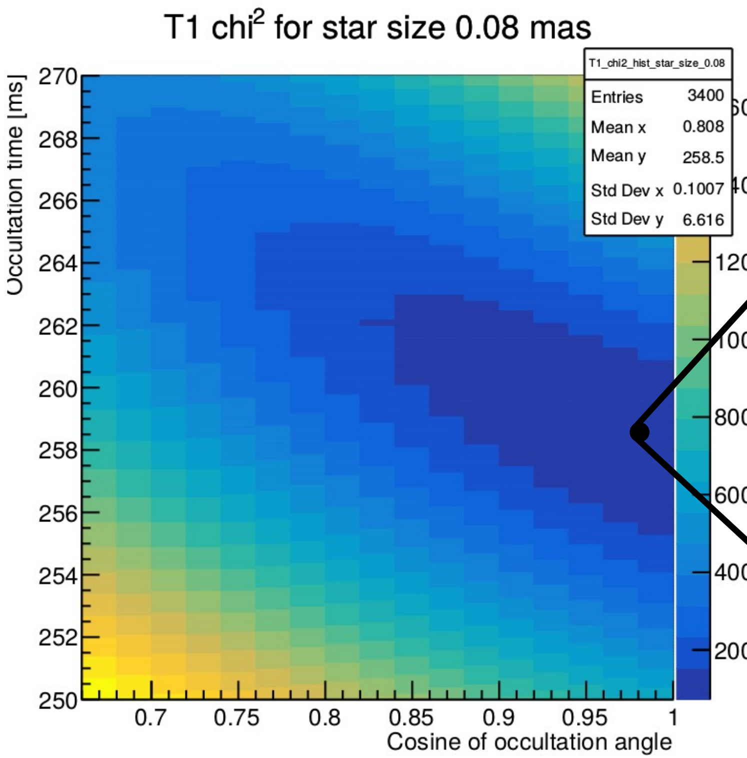
    → No assumptions on the asteroid shape and roughness

  - We should not rely on minuit (terrible error evaluation, black-box feeling frequently falling into local minima)

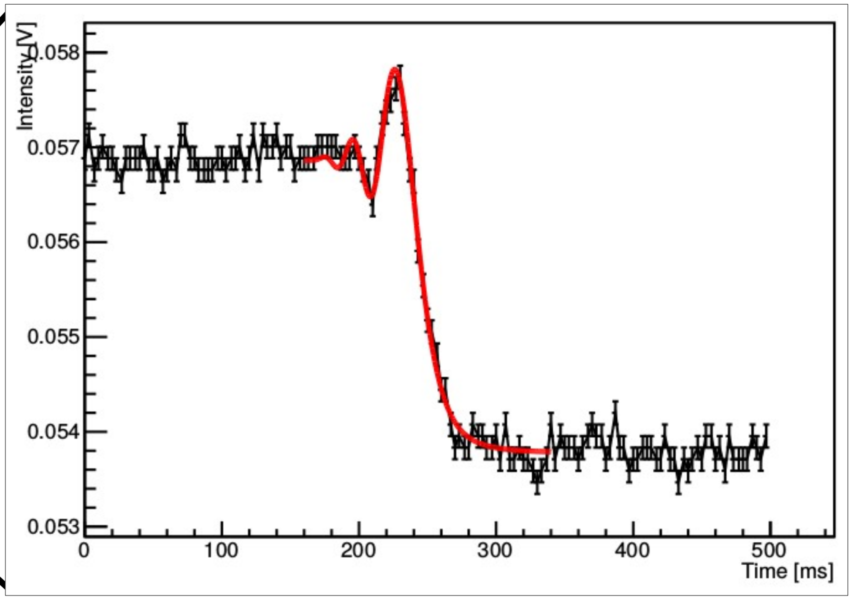
    → Full parameter profiling would be preferred (trivial calculation of contours, correlations, chi2...)

Occultations analysis – Implementation

- Current analysis results:
  - Individual Chi2 minimization for each star size value with 2 free parameters on each diffraction patter (4 x 2)

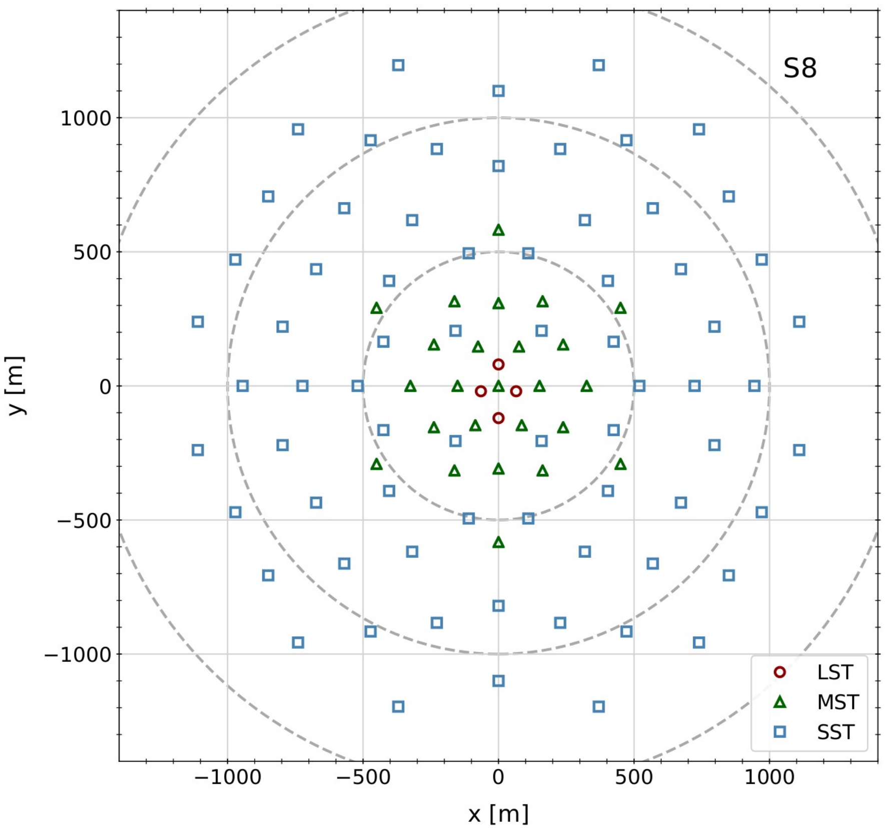


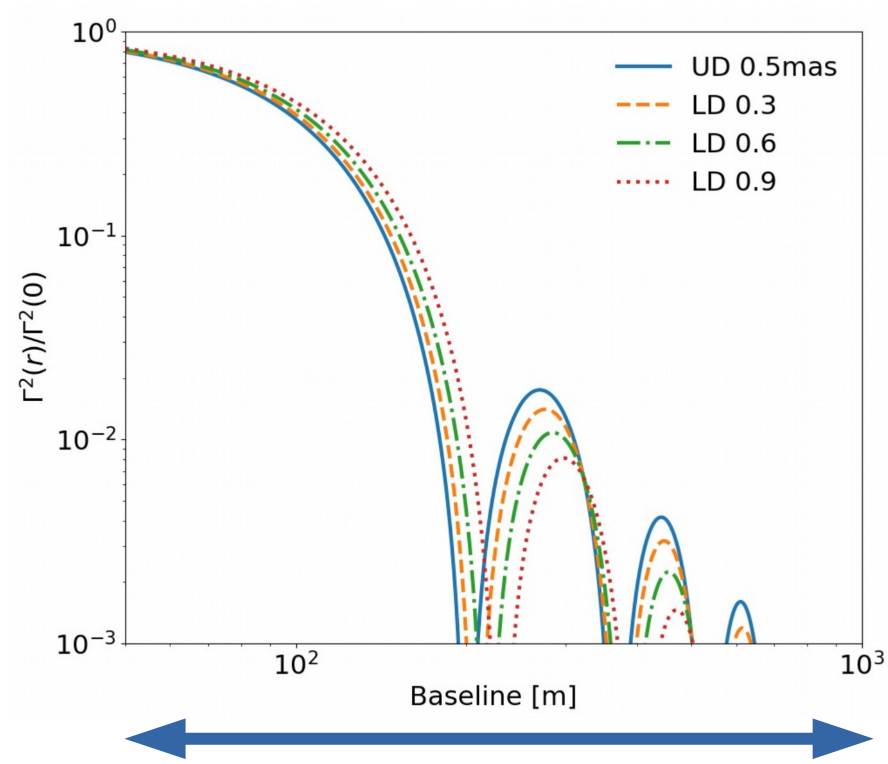
Each min chi2 model



Intensity Interferometry with CTA

- SII with CTA-South baseline array:





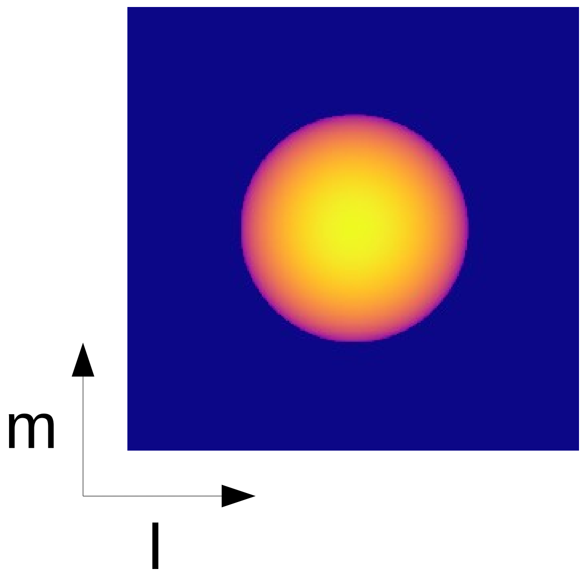
A single observation could simultaneously sample all baselines from ~50 m to ~ 2 km

Introduction to Intensity Interferometry

- Van Cittert-Zernike Theorem:

$$g^{(1)}(u, v, 0) = \iint I(l, m)\mathrm{e}^{-2\pi(lu+mv)}\mathrm{d}l\mathrm{d}m$$

Sky coordinates



Spatial frequencies

u and v are the spacial frequencies:

$u = B_u / \lambda$ $\quad$ $v = B_v / \lambda$

B ≡ telescope pair(s) baseline

Introduction to Intensity Interferometry

- Van Cittert-Zernike Theorem:

$$g^{(1)}(u,v,0) = \int\int I(l,m) \mathrm{e}^{-2\pi(lu+mv)} \mathrm{d}l \mathrm{d}m$$

Allows you to calculate the expected correlation vs u and v for a given source model I(l, m)

SII **measures** the **squared absolute value**:

$$\frac{< I_1 I_2 >}{< I_1 > < I_2 >} = g^{(2)}(u,v,t) = 1 + |g^{(1)}(u,v,t)|^2$$

Phase information is lost, but can be recovered:

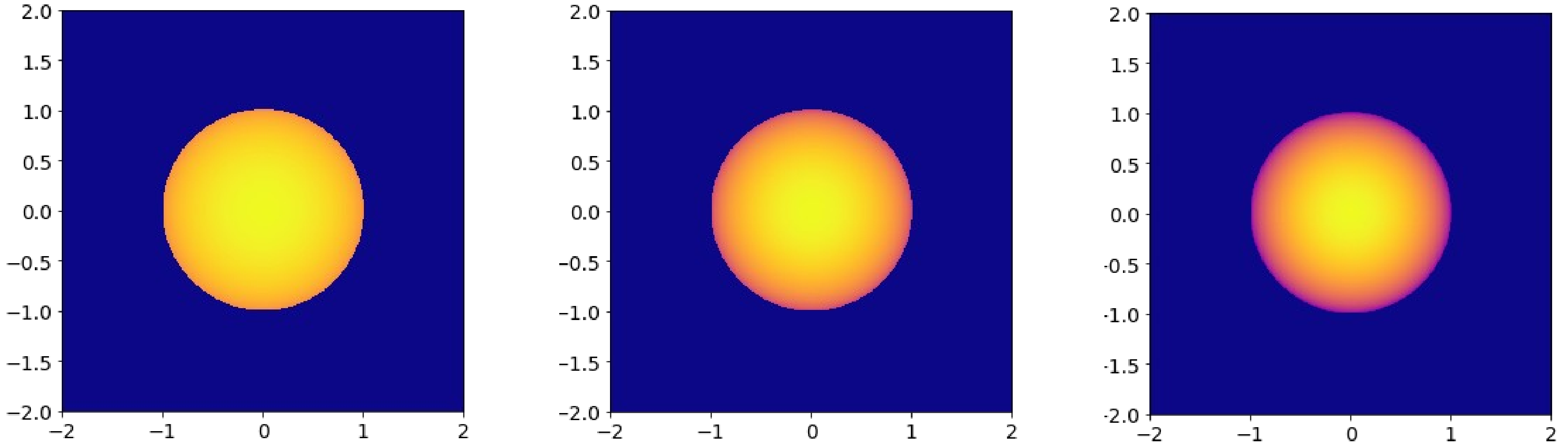
P. D. Nuñez et al, 2012, MNRAS, 424, 1006,
P. D. Nuñez & A. D. de Souza, 2015, MNRAS, 453, 1999

Introduction to Intensity Interferometry

- Van Cittert-Zernike Theorem:

$$g^{(1)}(u, v, 0) = \iint I(l, m) e^{-2\pi(lu+mv)} \mathrm{d}l\mathrm{d}m$$

Allows you to calculate the expected correlation vs u and v for a given source model I(l, m)



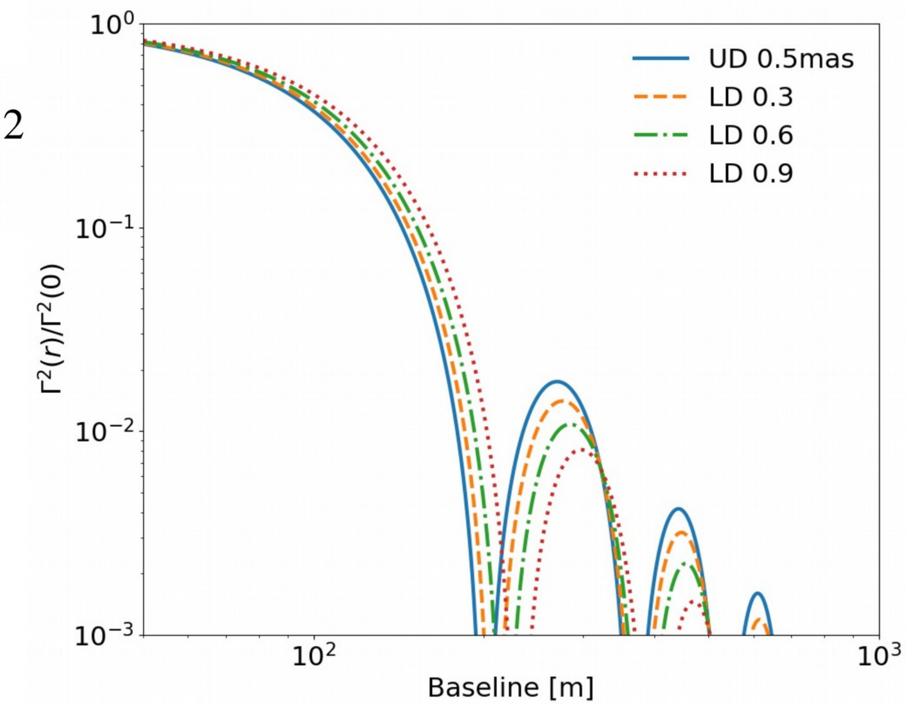
Introduction to Intensity Interferometry

- Van Cittert-Zernike Theorem:

$$g^{(1)}(u, v, 0) = \iint I(l, m) e^{-2\pi(lu+mv)} \mathrm{d}l \mathrm{d}m$$

Allows you to calculate the expected correlation vs u and v for a given source model I(l, m)

$$g^{(2)}(u, v, t) = 1 + |g^{(1)}(u, v, t)|^2$$

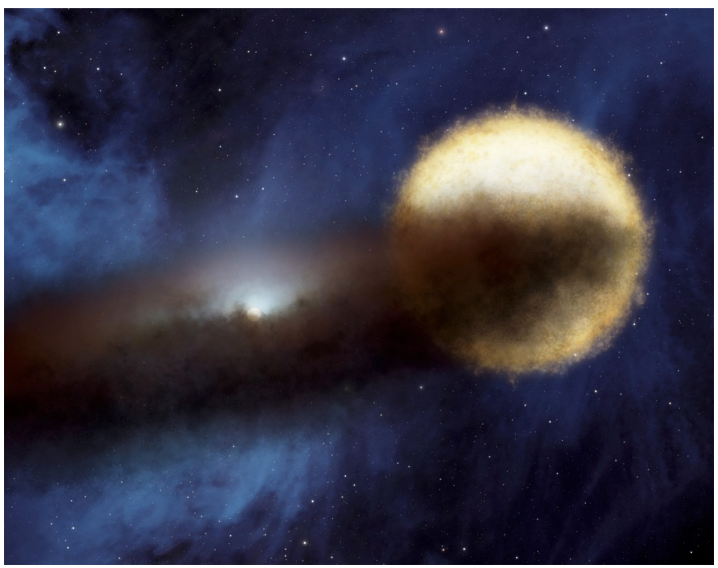


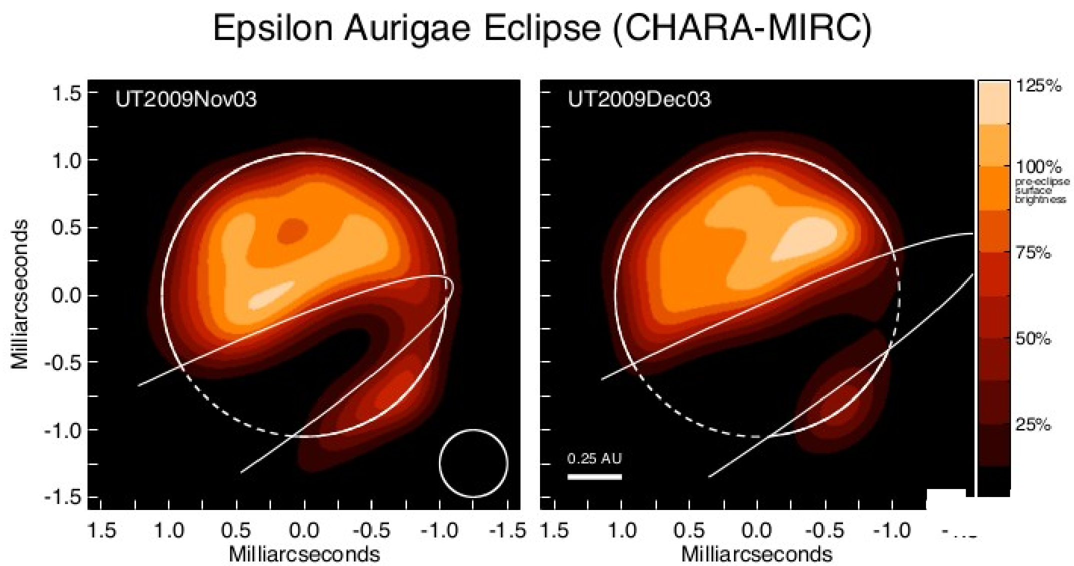
(Just in 1D, for the moment)

Science with SII – The sub-mas optical regime

- CTA will provide unprecedented resolution: ~ 1 to 0.04 mas

- This does not only mean that we will be able to measure **more** stars (farther away), it means we will study them with **unprecedented resolution**

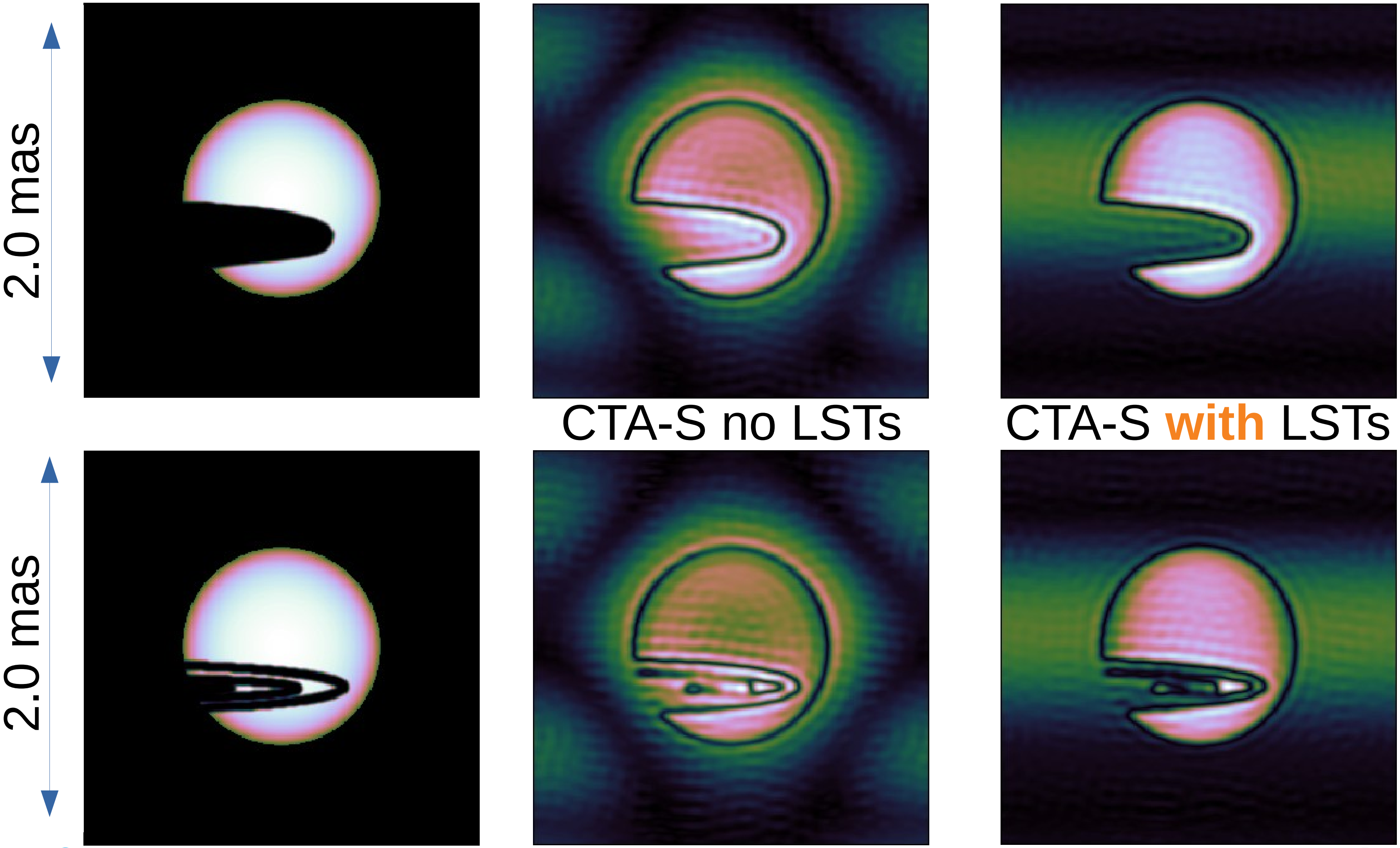




B. Kloppenborg et al, 2010 Nature, 464, 870

Science with SII – Epsilon Aurigae-like

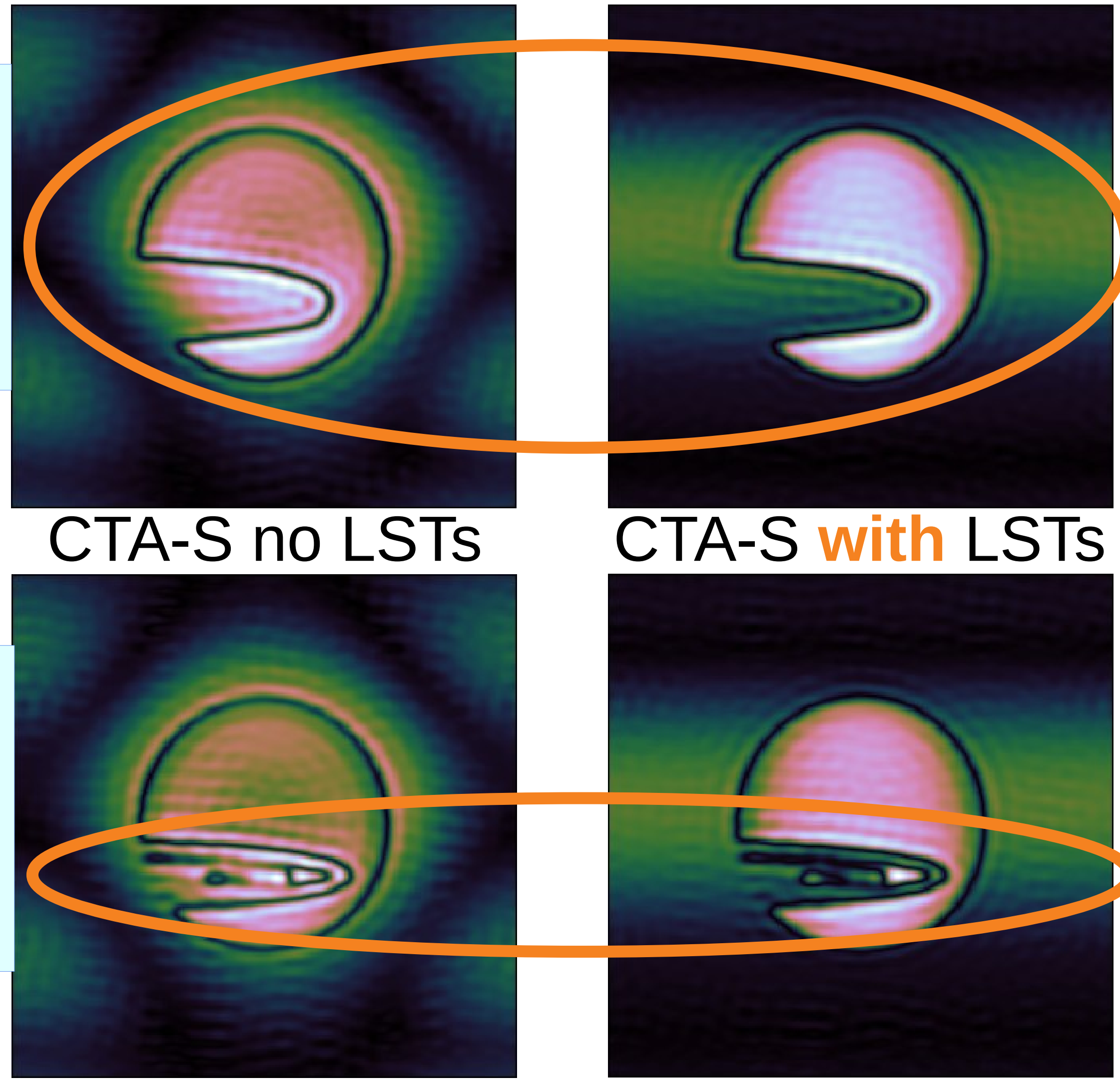
- CTA would be able to detect sub-structure within the occulting disc



Science with SII – Epsilon Aurigae-like

- CTA would be able to detect sub-structure within the occulting disc

Short baselines allow to properly constrain the shape of the star



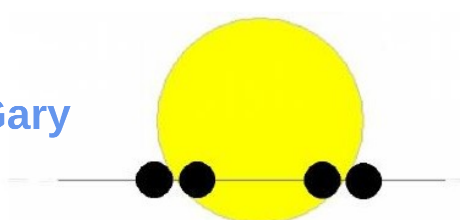
Long baselines allow to detect (for the first time) finer structures

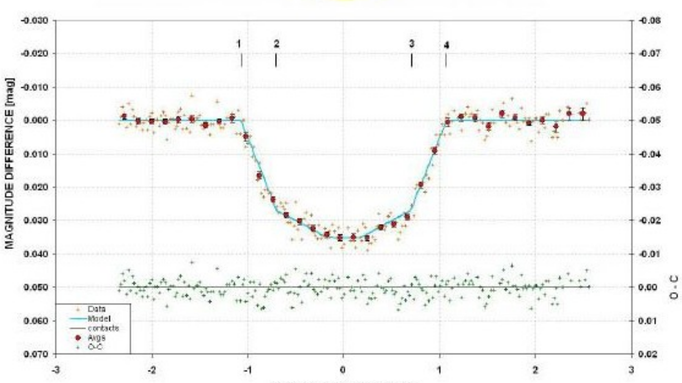
Science with SII – Stellar size and limb profile

• Measuring the **stellar size** of stars **with enough precision** is key for understanding exoplanets: their physical and orbital properties, atmosphere, habitability…

[A. Crida 2018, APJ, 860, 112](), [T. Boyajian 2015, MNRAS, 447, 846](), [K. von Braun 2012, APJ, 753, 171]()

B. L. Gary





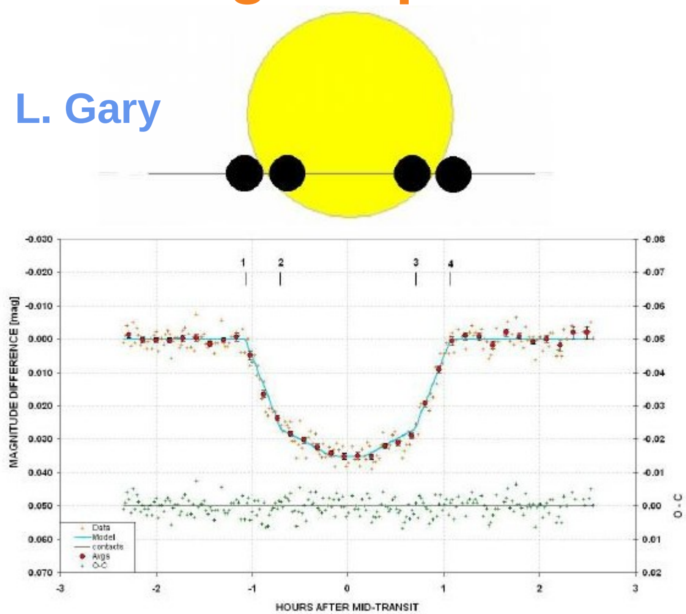
Science with SII – Stellar size and limb profile

- Measuring the **stellar size** of stars **with enough precision** is key for understanding exoplanets: their physical and orbital properties, atmosphere, habitability…

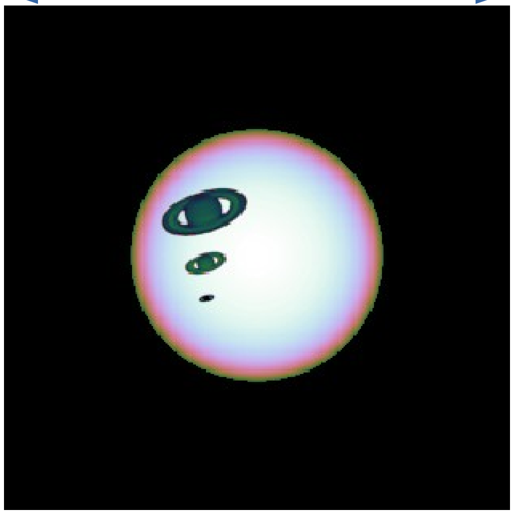
[A. Crida 2018, APJ, 860, 112](), [T. Boyajian 2015, MNRAS, 447, 846](), [K. von Braun 2012, APJ, 753, 171]()

- CTA will not only be able to constrain/fit limb darkening profiles of target stars, it could potentially be able to **image transiting exoplanets**

B. L. Gary

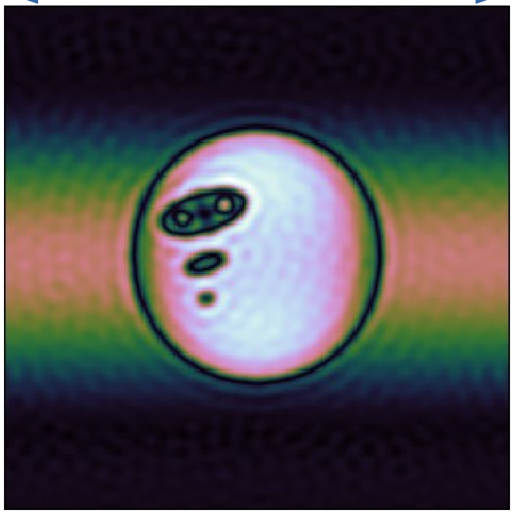


2.0 mas



Model

2.0 mas



Simulated CTA-S

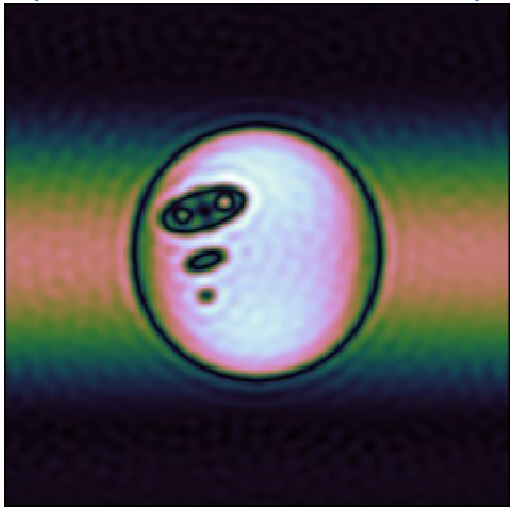
Science with SII – Stellar size and limb profile

- Measuring the **stellar size** of stars **with enough precision** is key for understanding exoplanets: their physical and orbital properties, atmosphere, habitability…

A. Crida 2018, APJ, 860, 112, T. Boyajian 2015, MNRAS, 447, 846, K. von Braun 2012, APJ, 753, 171

- CTA will not only be able to constrain/fit limb darkening profiles of target stars, it could potentially be able to **image transiting exoplanets**

2.0 mas



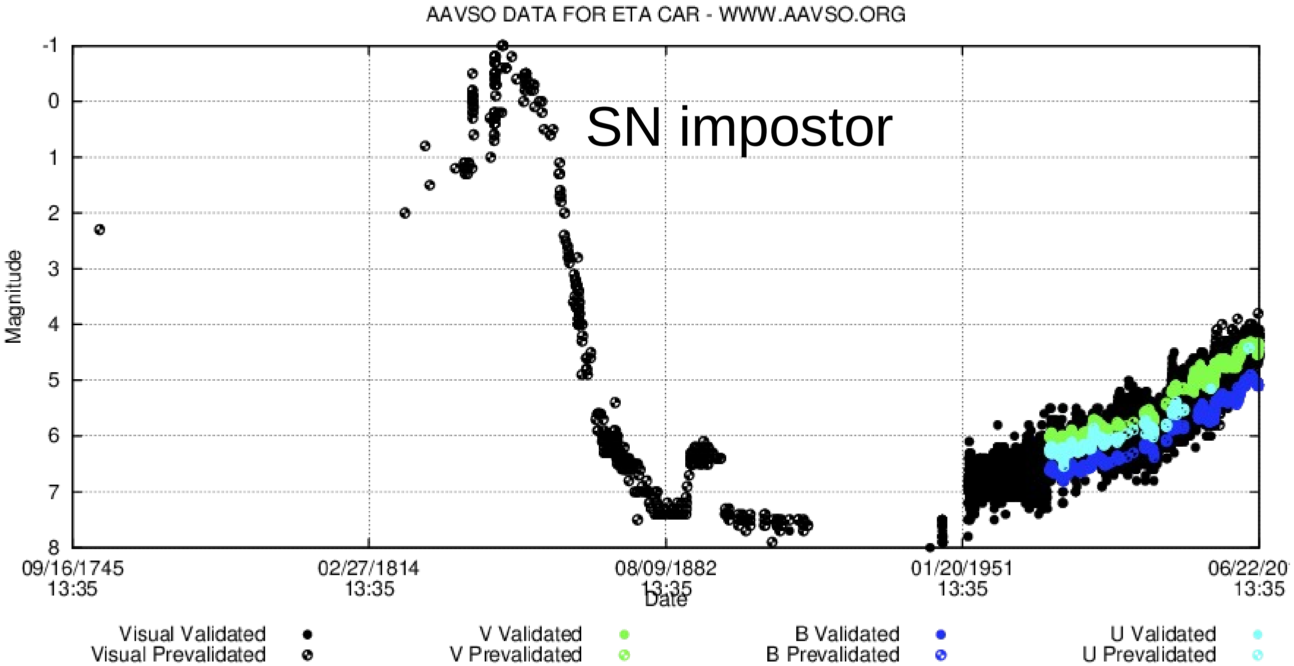
Simulated CTA-S

Transiting exoplanets will be very small (high-res) moving targets (need high stats)

If an optical instrument can image them, that is CTA by combining LSTs + SSTs

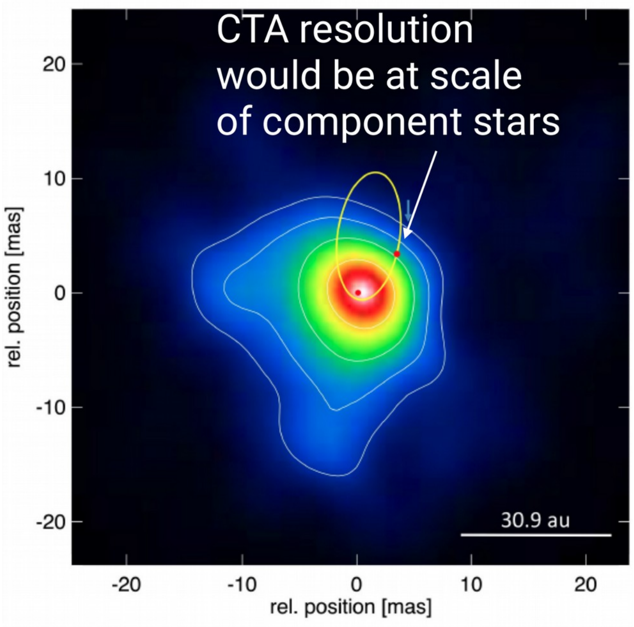
Science with SII – Stellar activity

- Studying blue supergiants such as **η Carinae**:
    - The most luminous known star in the galaxy, with an extremely turbulent history (and TeV emission!)



Science with SII – Stellar activity

- Studying blue supergiants such as **η Carinae**:
  - The most luminous known star in the galaxy, with an extremely turbulent history (and TeV emission!)
  - Resolving **η Car A** is within CTA reach, and could help to constrain the extremely complex system



G. Weigelt at al, 2016

Science with SII – Stellar activity

- Hot stars (O, B, A) are not expected to have spots (lack of convective layer). Kepler data seem to suggest flaring activity in A type stars
  - Cool surface features of hot stars could prove, for the first time, such activity

    L. A. Balona, Starspots on A stars. MNRAS, 2017.

  - Additional evidence in Kepler data for the existence of exoplanets in orbit around rapidly rotating (spotted) A stars

    L. A. Balona, Possible planets around A stars. MNRAS, 2014.