TRANSFORMER IN SPACE

Lessons from the MOST microsat for remote robotic observatories on Earth

Jaymie Matthews

Dept. of Physics & Astronomy
University of British Columbia
Vancouver, Canada

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Rewriting the textbooks

Asteroseismology and exoplanets

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Rewriting my conference talk

An overwhelming time of the year

1342

Rulebook for the MOST microsatellite mission

- ✓ only one egg in the basket
- ✓ R & R resilience & redundancy
- ✓ autonomous operations even if conditions change
- ✓ high performance
- ✓ low cost, power, mass, volume, bandwidth, …

1342

Rulebook for most robotic observatories

the MOST microsatellite mission

- ✓ only one egg in the basket
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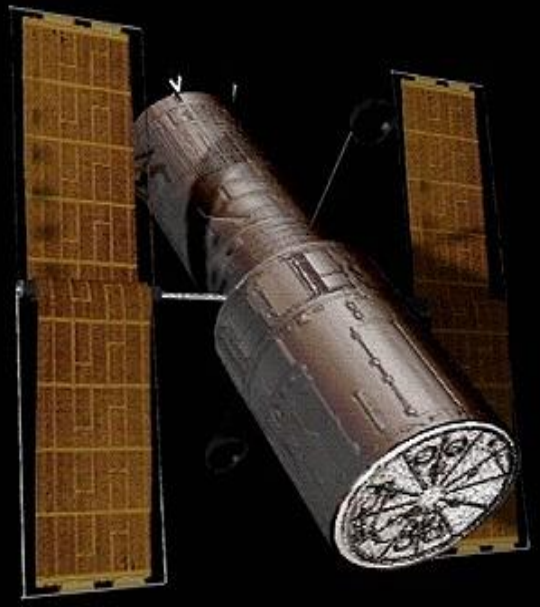
America's space telescope

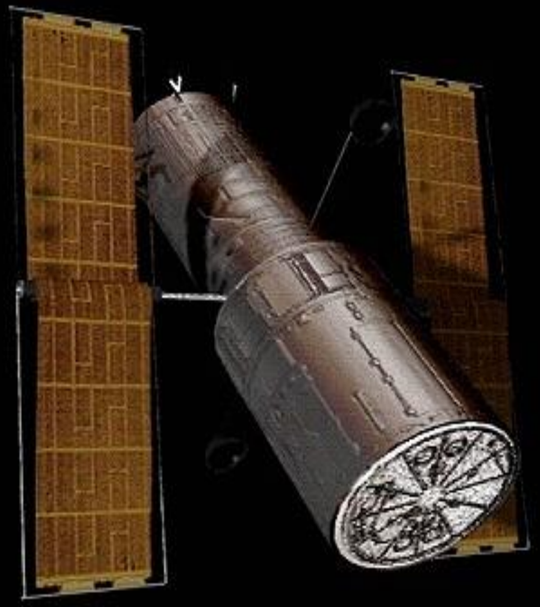


Hubble Space Telescope

Canada's space telescope

shown to scale

MOST

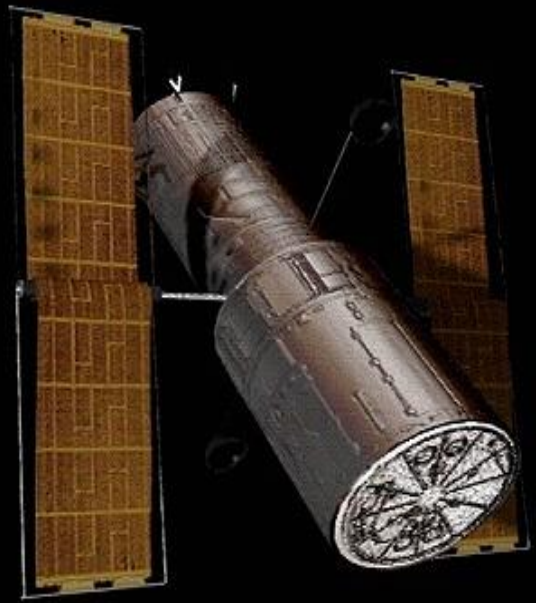


Hubble Space Telescope

Canada’s space telescope

Microvariability & Oscillations of STars
Microvariabilité et Oscillations STellaire

MOST

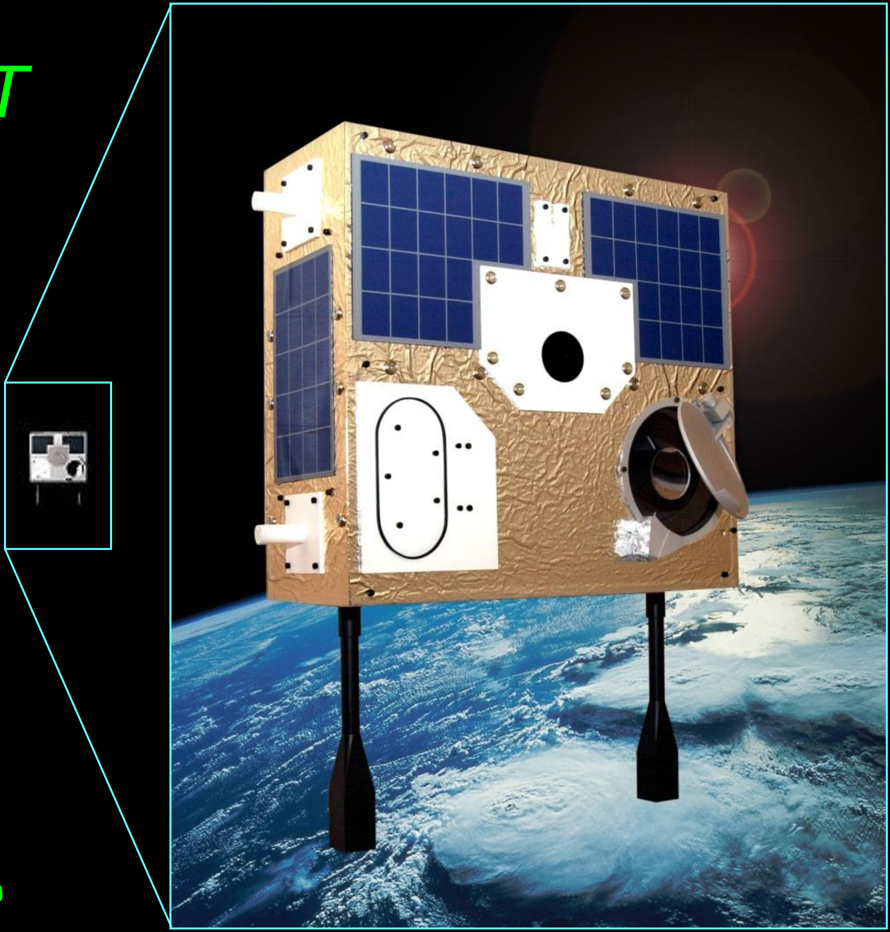


Hubble Space Telescope

Canada's space telescope

The "Humble" Space Telescope

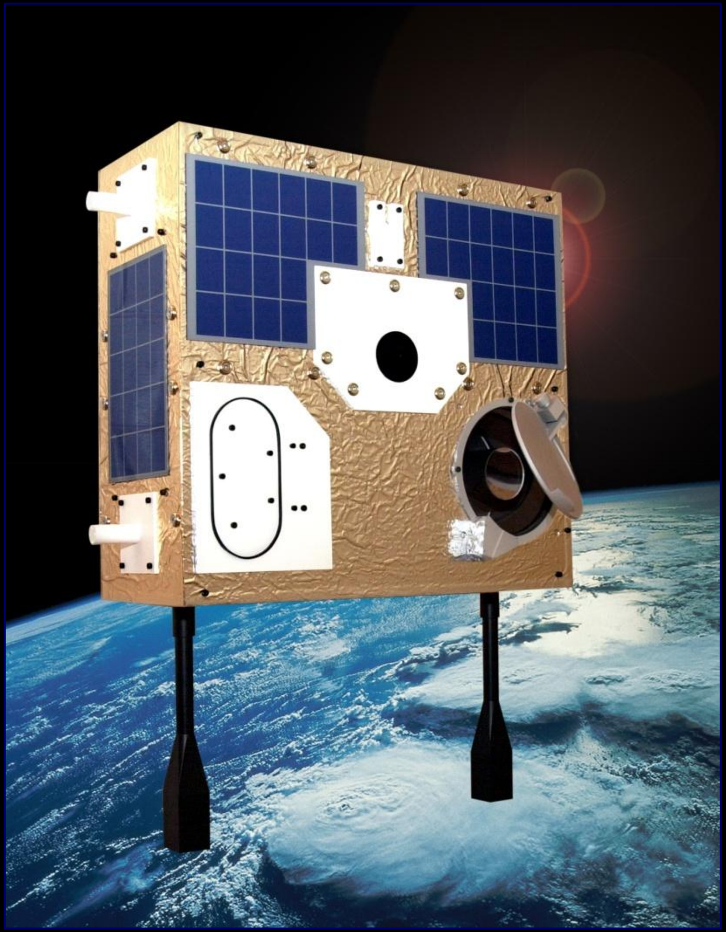
MOST



Hubble Space Telescope

Canada's space telescope

The "Humble" Space Telescope Squarepants



An ultraprecise photometer in space

which can see
oscillations in starlight
as small as
1 part per million
(0.0001%)

University of British Columbia
CRESTech, Spectral Applied Research
Ceravolo Optical Systems

How sensitive is MOST?

To see a drop in brightness of only
1 part per million …

How *sensitive* is MOST?

To see a drop in brightness of only

1 part per million

Imagine looking at the Empire State Building at night with all the lights on and office blinds open

How <u>sensitive</u> is MOST?

To see a drop in brightness of only
<u>1 part per million</u>

Imagine looking at the Empire State Building at night with all the lights on and office blinds open

and having one person pull down one blind

How <u>sensitive</u> is MOST?

To see a drop in brightness of only

<u>1 part per million</u>

Imagine looking at the Empire State Building at night with all the lights on and office blinds open

and having one person pull down one blind

<u>3 centimetres</u>

MOST at a glance

Satellite

- ✓ 54 kg, 60×60×30 cm
- ✓ Power: solar panels
  peak ~ 38 W
- ✓ Attitude Control System:
  reaction wheels
  pointing accuracy ~ 1″
- ✓ Communication: S-band
  frequency ~ 2 GHz
- ✓ Lifetime: 9 – 12 years +?

CONTRACTORS: Dynacon Inc.
U of T Institute for Aerospace Studies

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U of T Institute for Aerospace Studies

Imagine trying to observe a star with a *telescope* from a dinghy on a choppy sea

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CONTRACTORS: Dynacon Inc.
U of T Institute for Aerospace Studies

Imagine trying to observe a star with a *telescope* from a dinghy on a choppy sea

Now imagine trying with *handheld binoculars*

That's what it's like to point a microsat

MOST at a glance

Satellite

- ✓ 54 kg, 60×60×30 cm
- ✓ Power: solar panels
  - peak ~ 38 W
- ✓ Attitude Control System:
  - reaction wheels
  - pointing accuracy ~ 1″
- ✓ Communication: S-band
  - frequency ~ 2 GHz
- ✓ Lifetime: 8 – 12 years +?

CONTRACTORS: Dynacon Inc.
U of T Institute for Aerospace Studies

Me at a glance

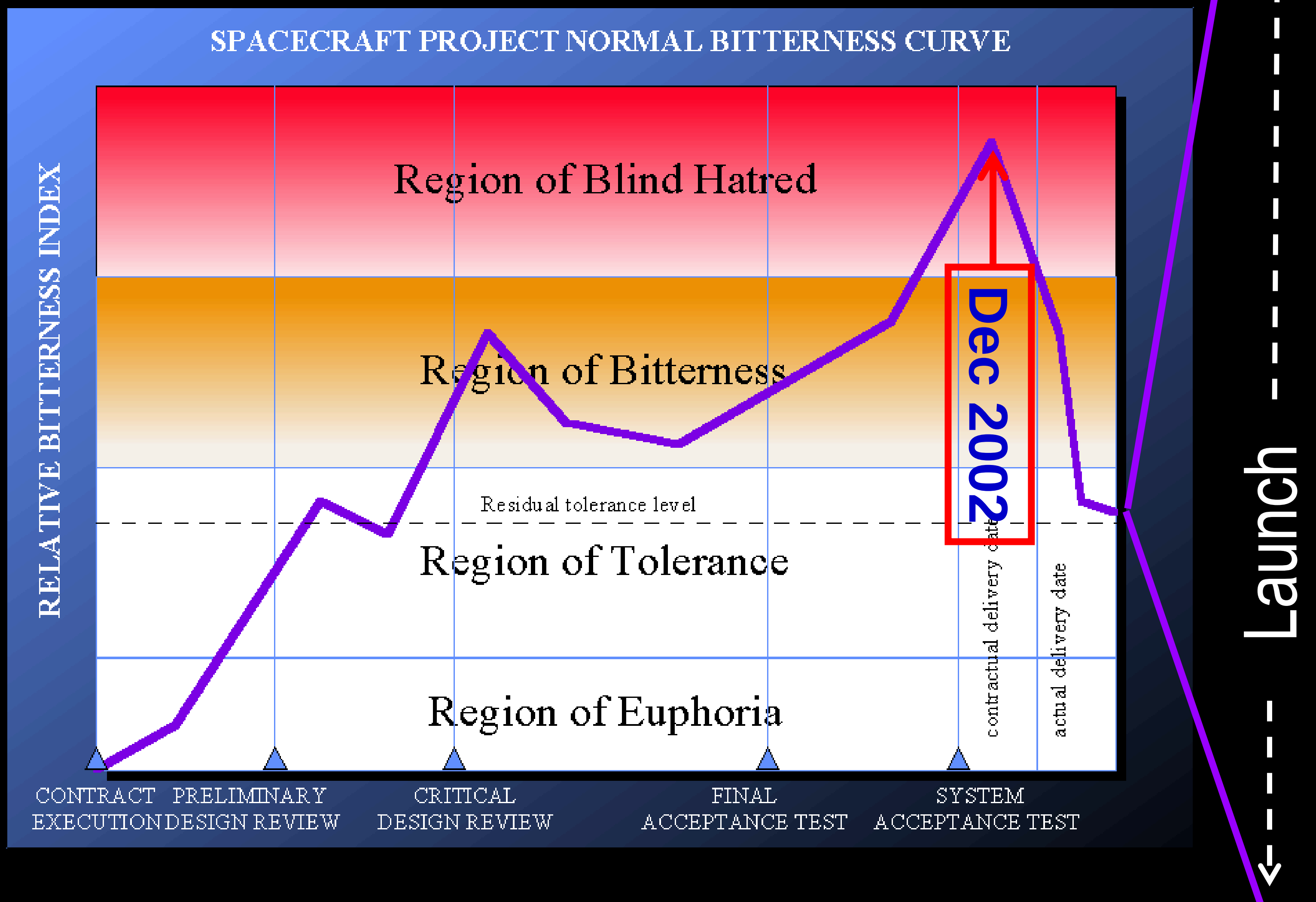
Mission Scientist

- ✓ > 54 kg, 182 cm high
- ✓ Power: hydrocarbons
  - peak ~12 MW at disco/pub
- ✓ Attitude uncontrolled
  - reactions slow
  - doesn't always have a point
- ✓ Communication: loud
  - high-frequency
- ✓ Lifetime: fun while it lasts

CONTRACTORS: my parents
Mr. & Mrs. Matthews

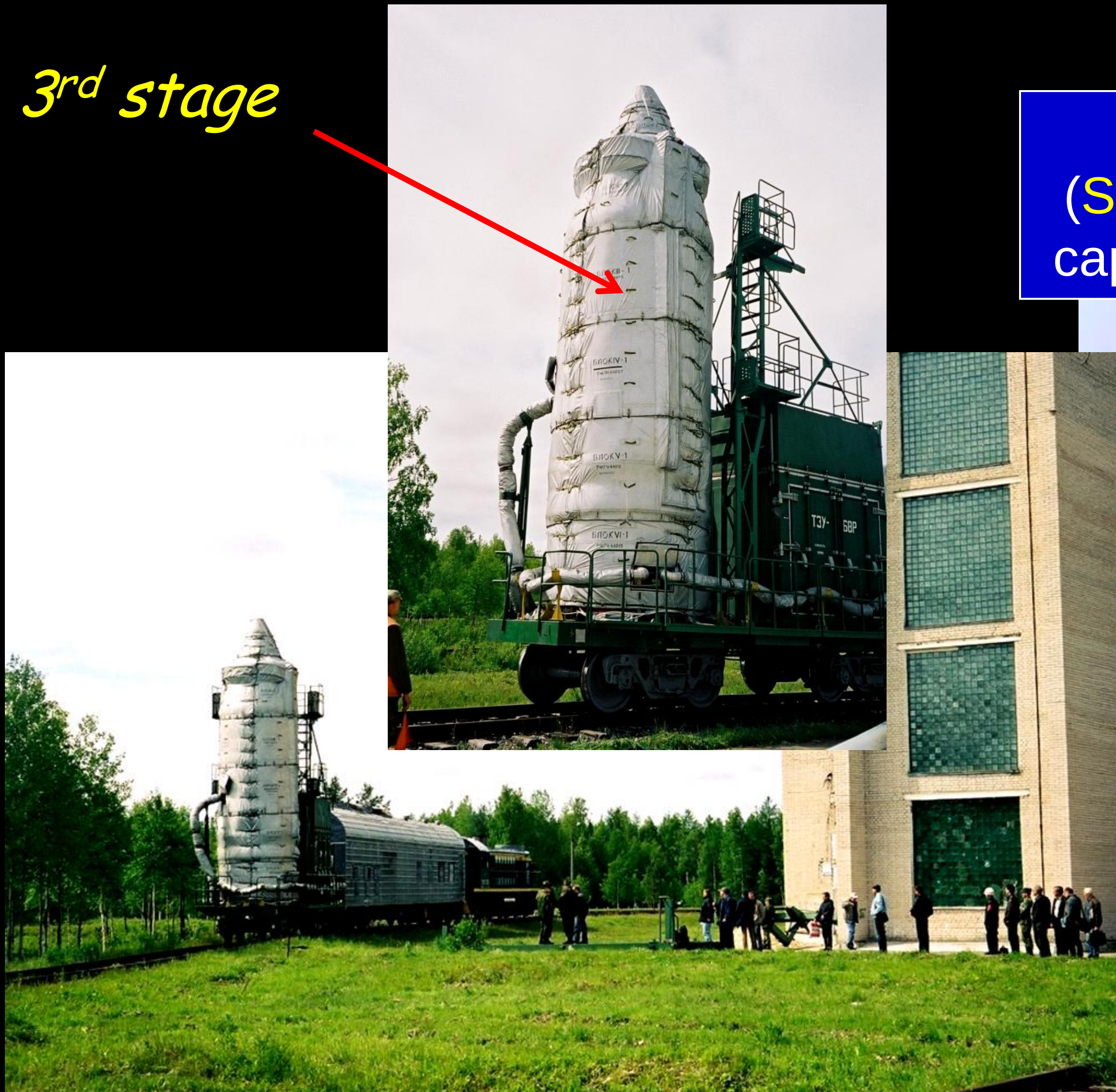
MOST's short route to space

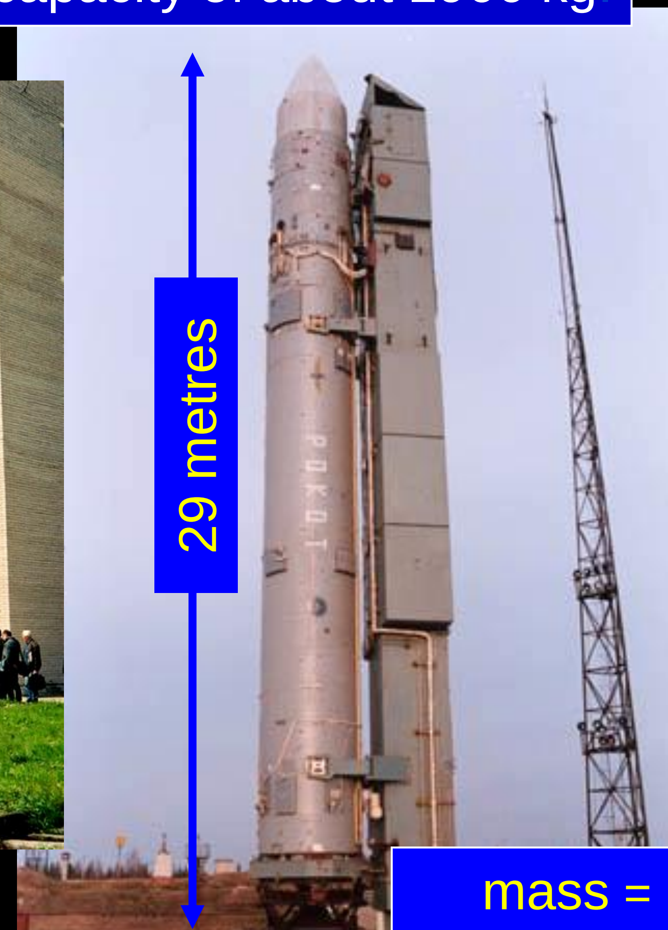
proposed in 1997 → launched in 2003



ROCKOT

3-stage former ICBM (SS –19) with low-orbit lift capacity of about 1900 kg

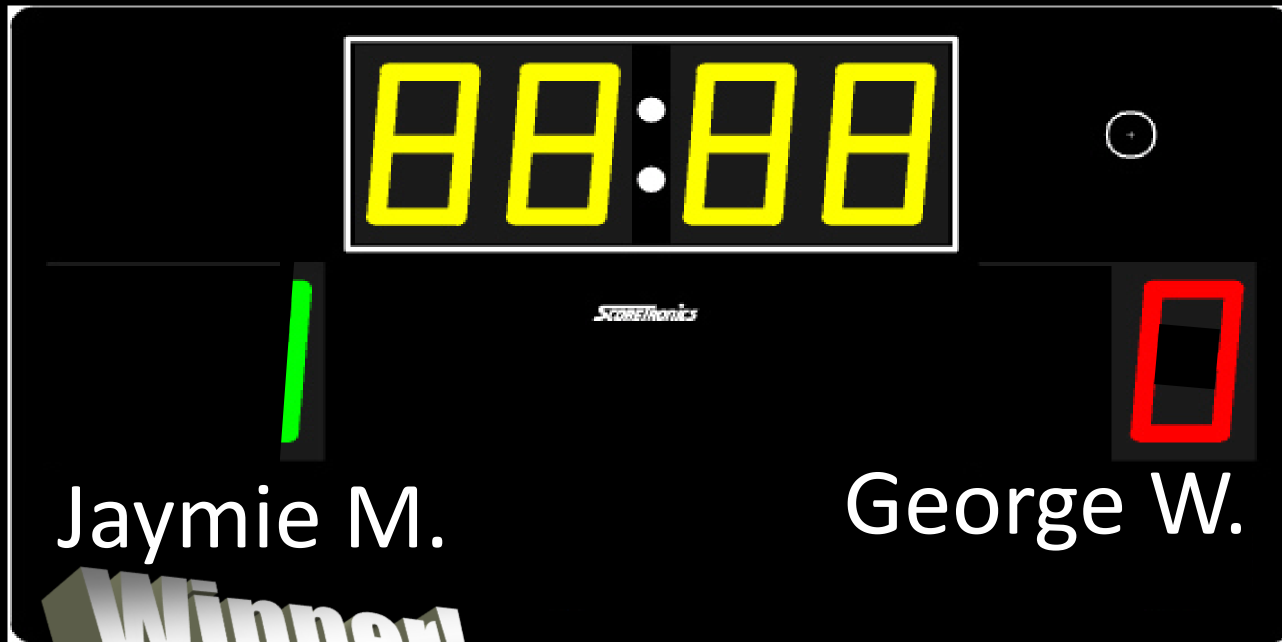




Eurockot = Astrium + Khrunichev Space Research Centre

Jaymie M.


1
0
Jaymie M.
George W.



as of 20 Jan 2009

Launch: 30 June 2003 – 16:15:00.323 UTC

Plesetsk Cosmodrome

Launch + 7 hr

Launch + 7 hr + 1 ns

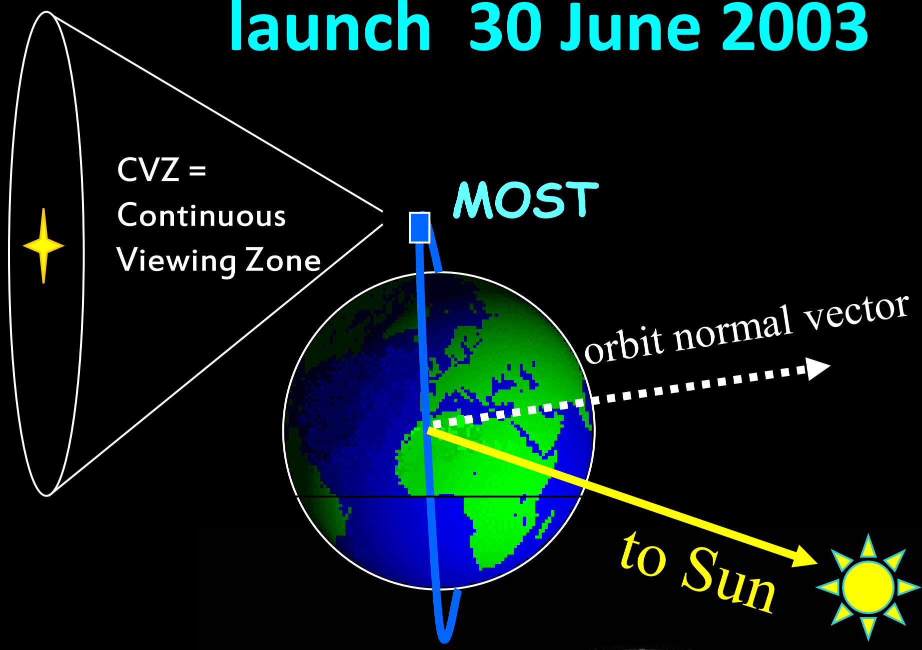
Launch + 12 hr

MOST at a glance

Orbit

launch 30 June 2003

- ✓ circular polar orbit
  - altitude *h = 820 km*
  - period *P = 101 min*
  - inclination *i = 98.6º*
- ✓ Sun-synchronous
  - *stays over terminator*
- ✓ Continuous Viewing Zone
  - CVZ ~ 54° wide
  - -18º < δ < +36º
  - *stars visible for up to 8 weeks without interruption*



Sun-synchronous, dawn-dusk orbit

Rewriting the textbooks

Asteroseismology and exoplanets

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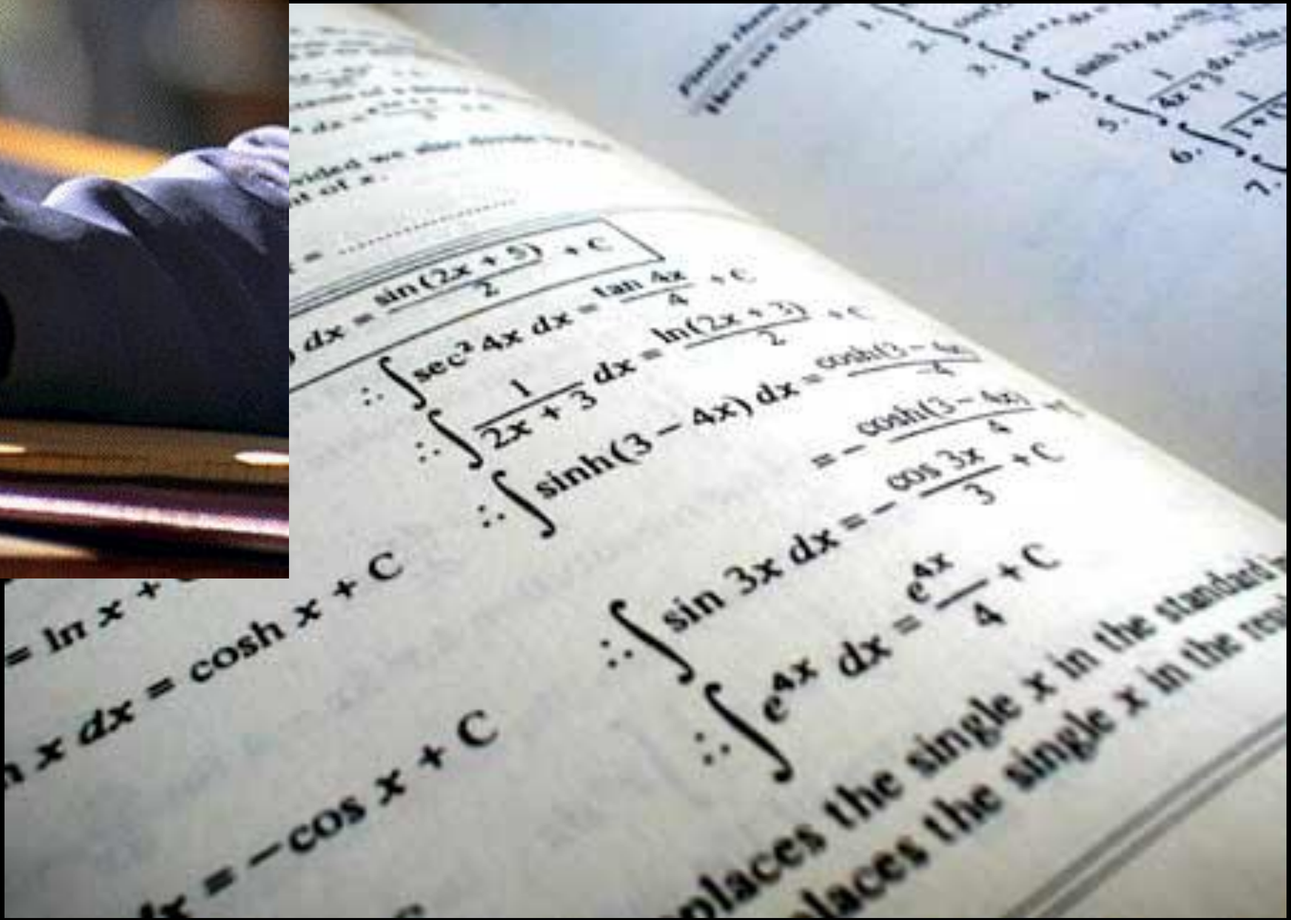
A pen to rewrite the textbooks

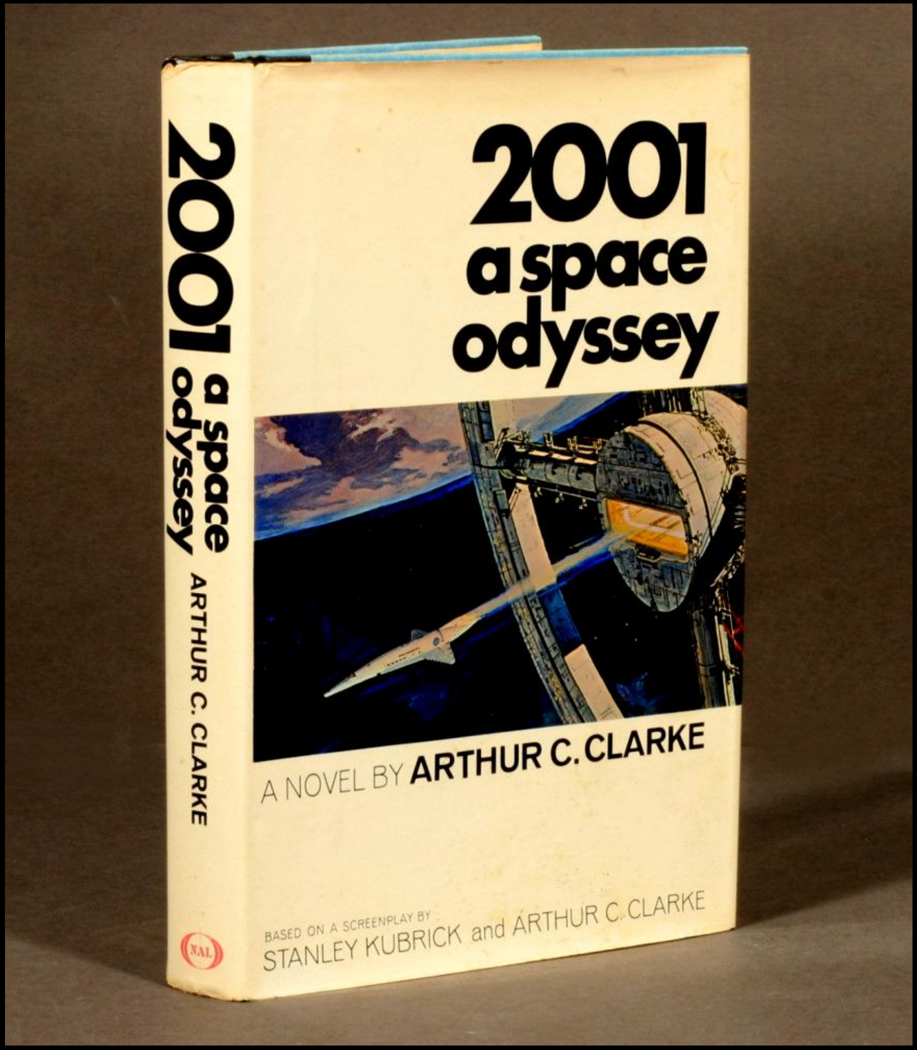


A pen to rewrite the textbooks

for people exploring space

A pen to rewrite the textbooks

for people exploring space
back in 2001



A pen to rewrite the textbooks

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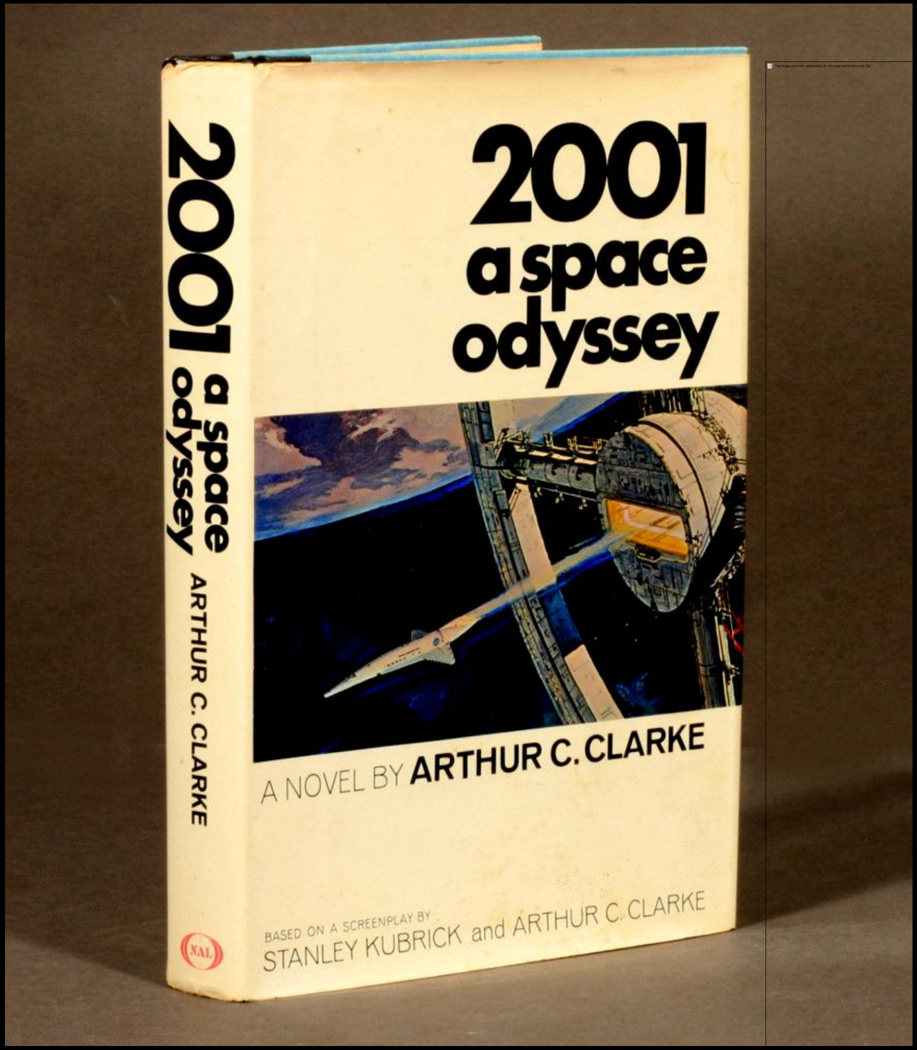


A pen to rewrite the textbooks

for people exploring space
back in 2001

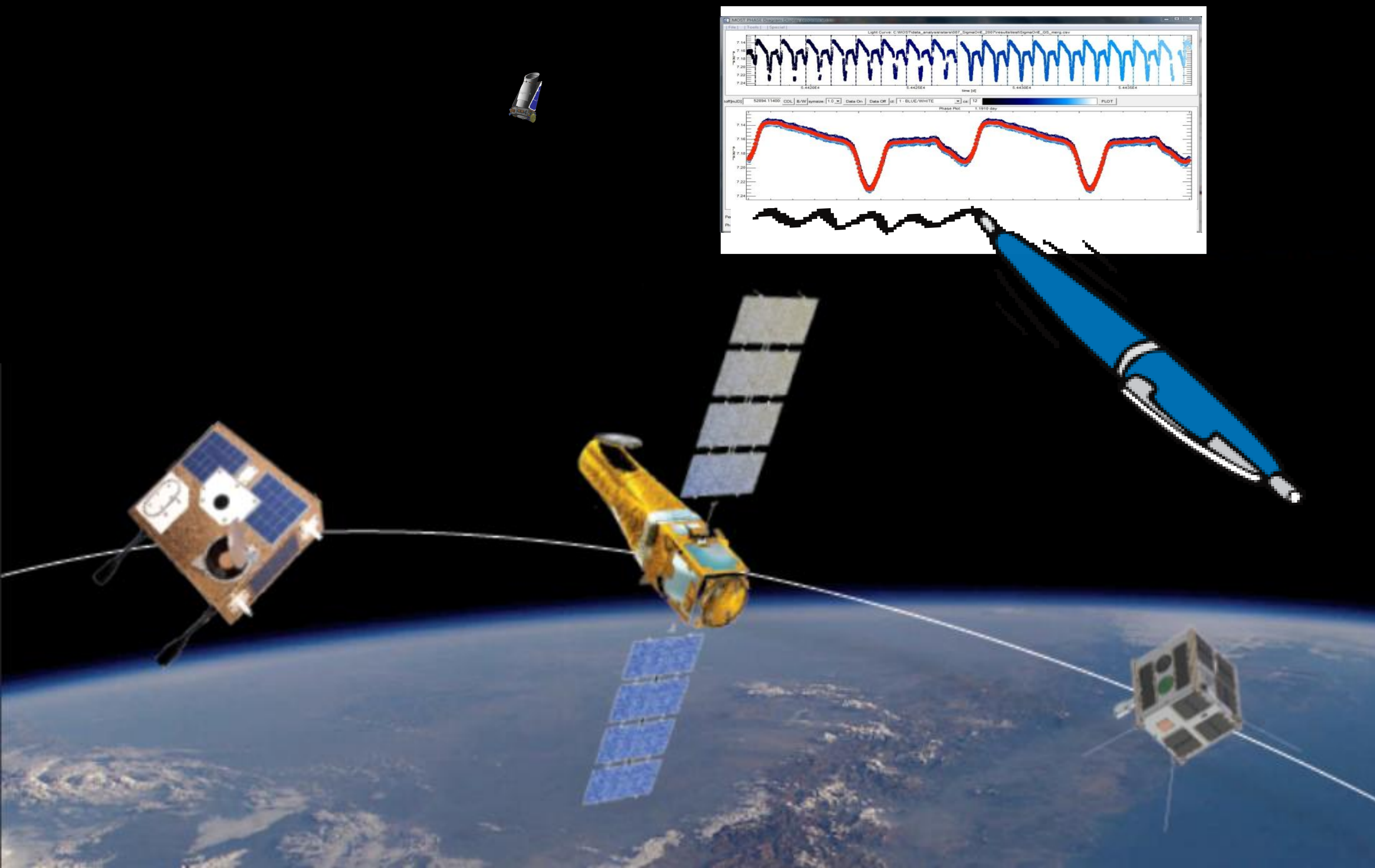
A pen to rewrite the textbooks

for people exploring space
back in 2001

What about today?

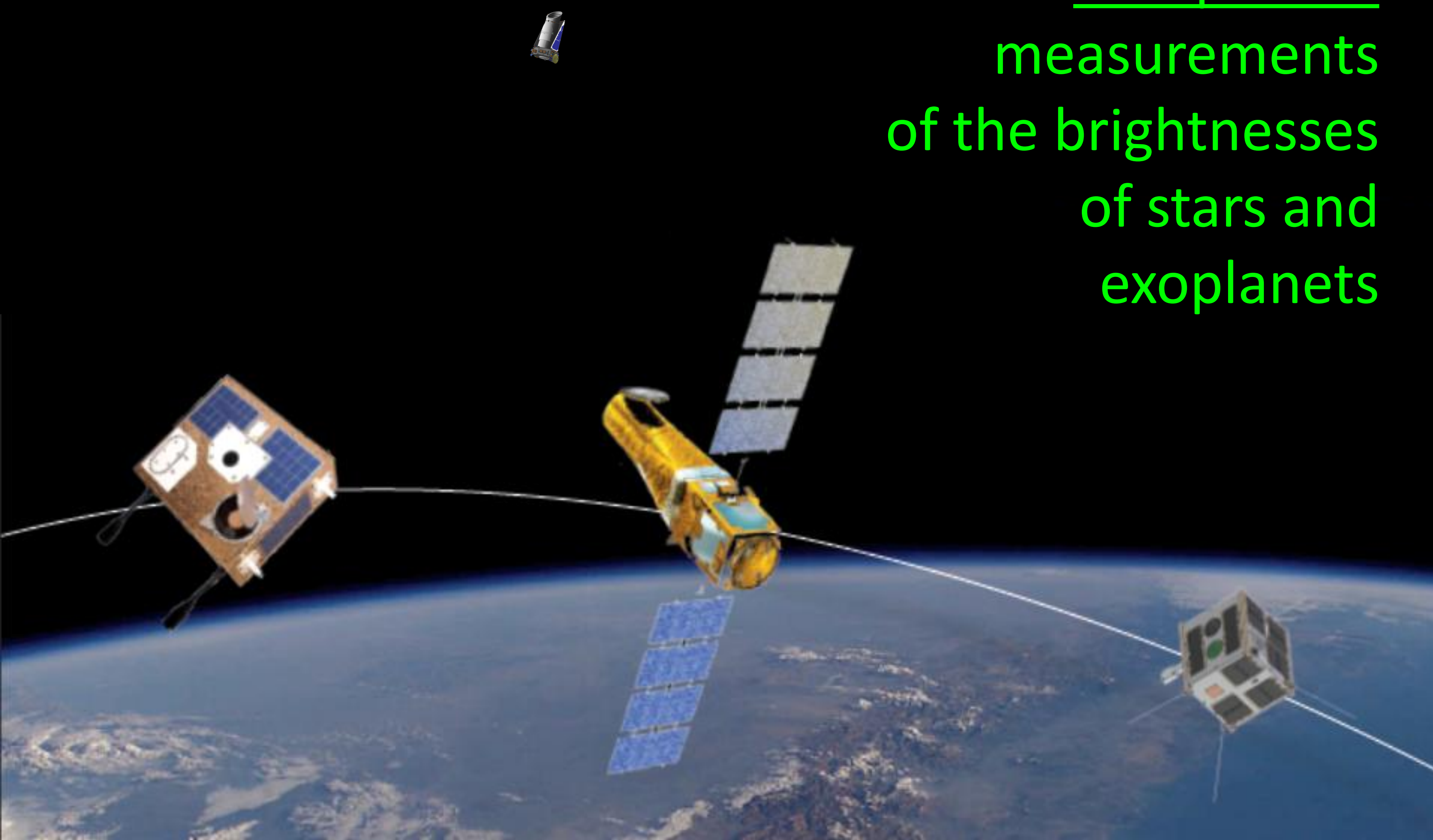
My pens to rewrite the textbooks

Pens that draw light curves



Pens that draw light curves

<u>ultraprecise</u>
measurements
of the brightnesses
of stars and
exoplanets



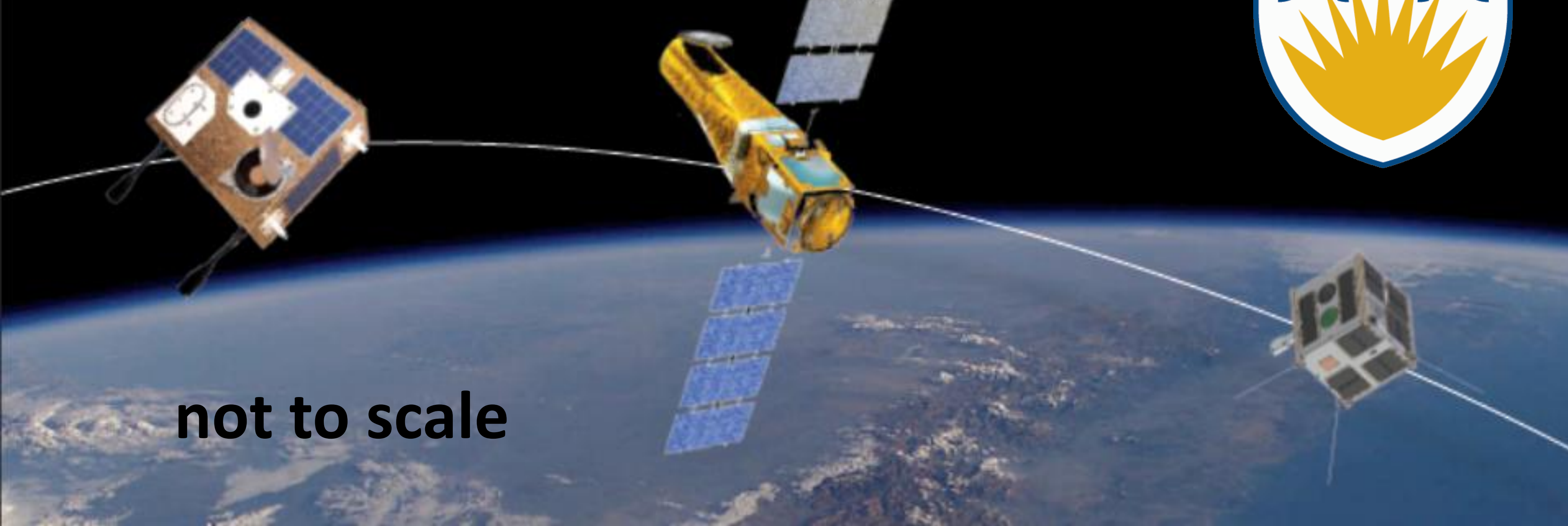
Canada's space telescope

designed, built
and operated
at UBC

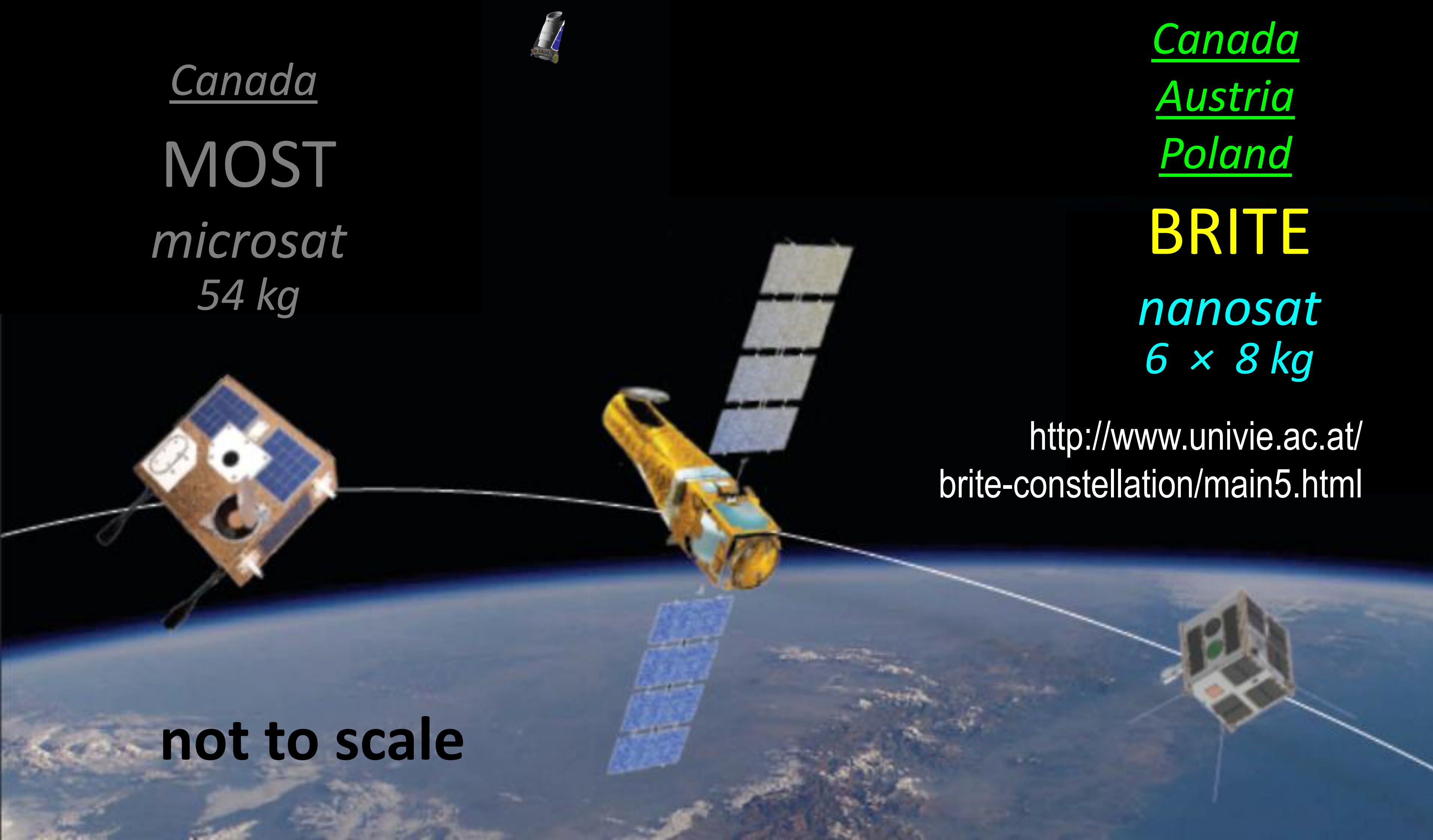
Canada

MOST

microsat
54 kg



Our telescope's having babies!



Joining us in orbit 3½ years later

Canada

MOST

microsat
54 kg

France

CoRoT

smallsat
630 kg

Canada
Austria
Poland

BRITE

nanosat
6 × 8 kg

http://www.univie.ac.at/brite-constellation/main5.html

not to scale

And nearly 7 years later …

Canada

MOST

microsat
54 kg

France

CoRoT

smallsat
630 kg

Canada
Austria
Poland

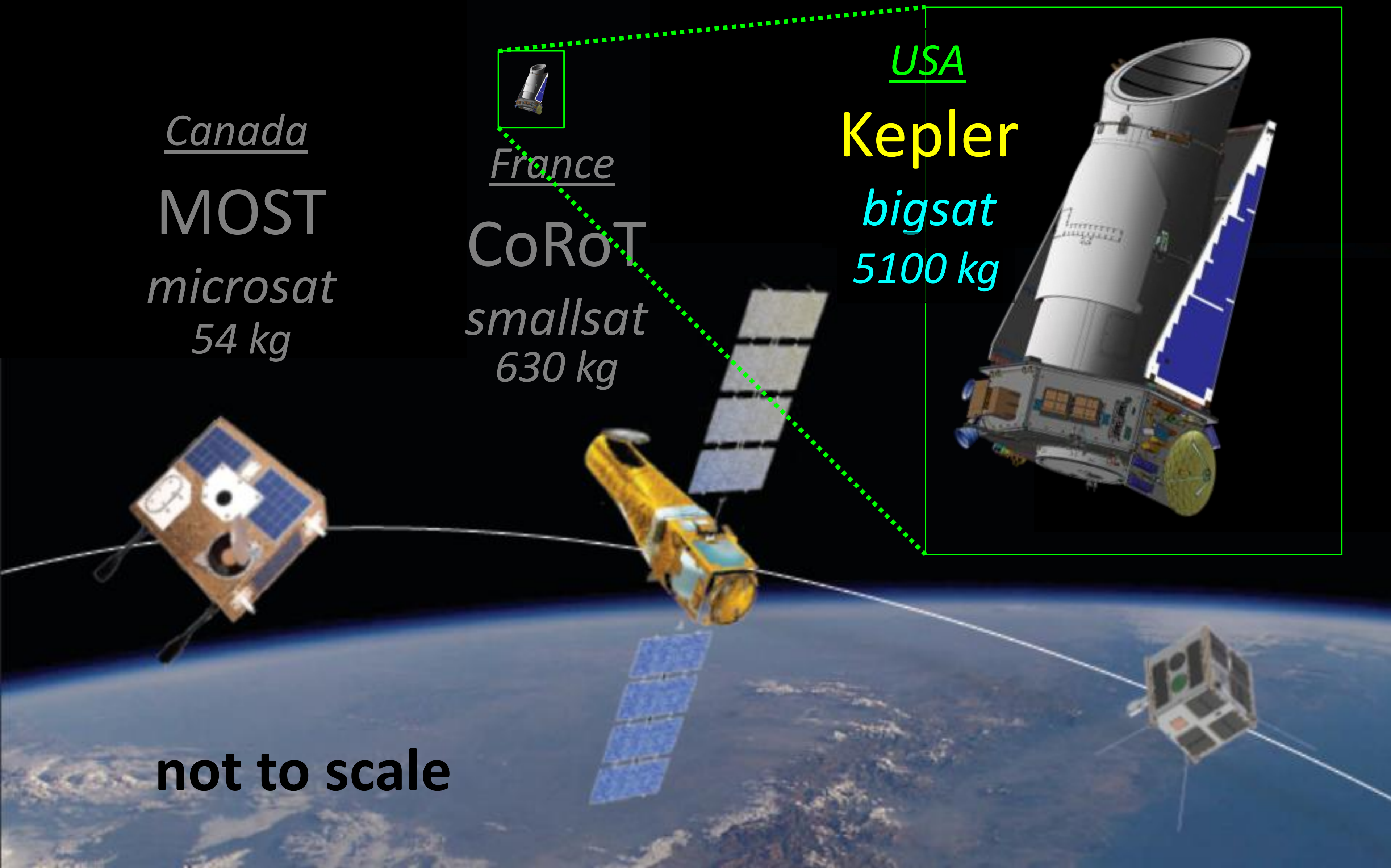
BRITE

nanosat
6 × 8 kg

http://www.univie.ac.at/brite-constellation/main5.html

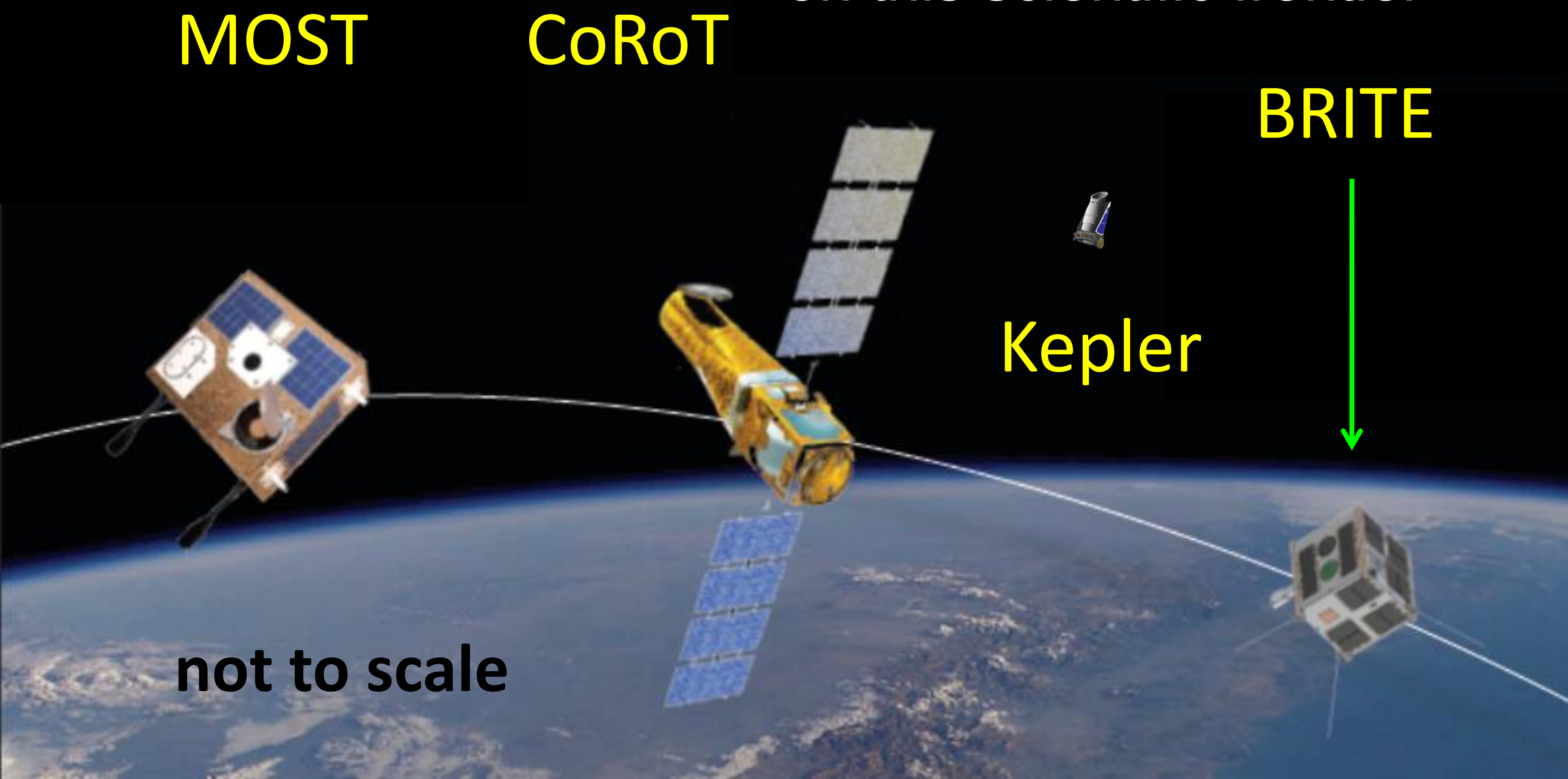
not to scale

NASA's exo-Earth hunter



Ultraprecise space photometry

MOST has been joined by *CoRoT* and *Kepler* and will be joined soon by *BRITE Constellation* on this scientific frontier



9¼, going on 10

9¼, going on 10

“Middle age in 2012 MOST years”

operations
currently
planned
until 2016

9¼, going on 10

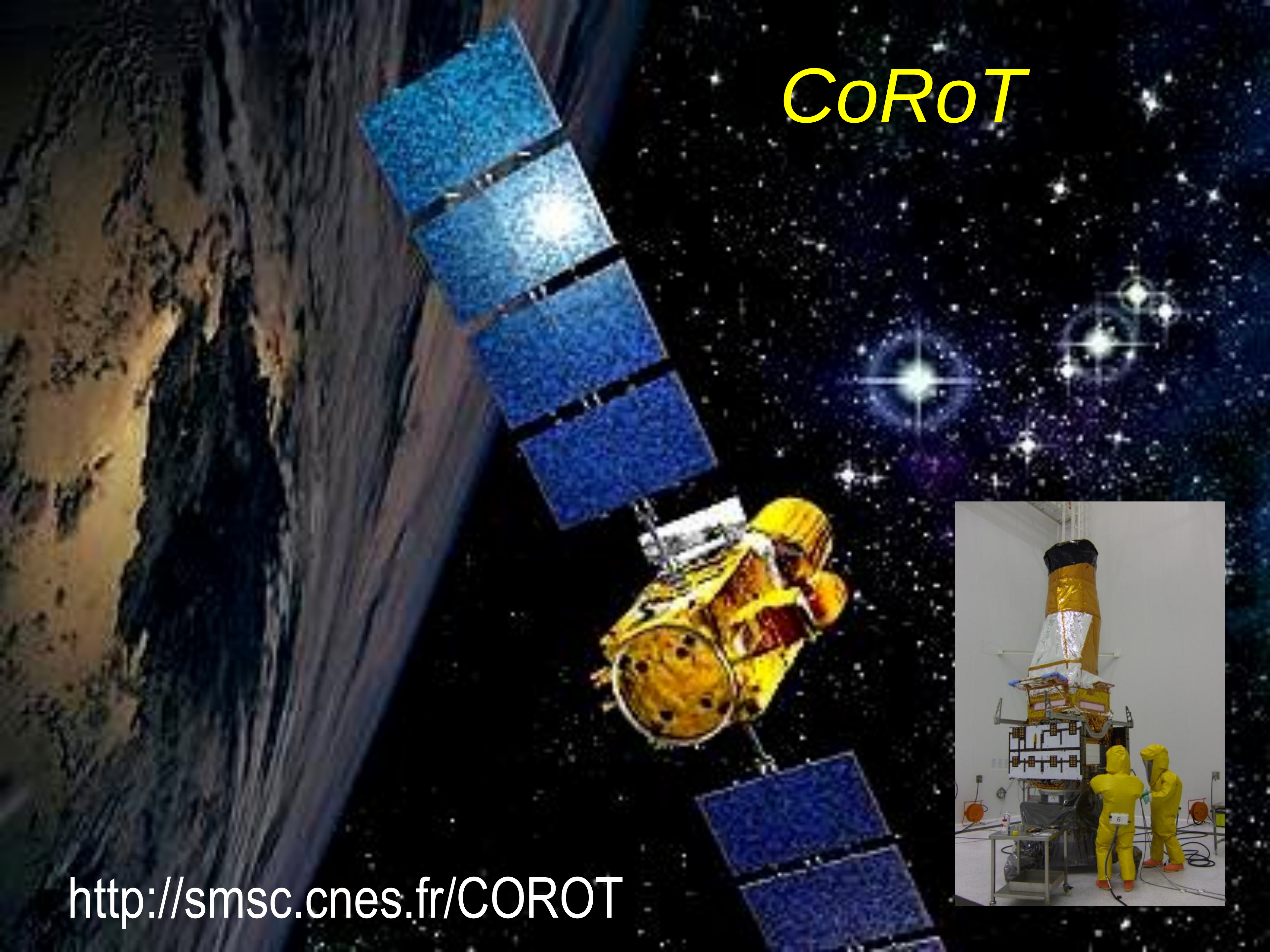
over 65 in microsat years

"Advanced old age in 2003 MOST years"

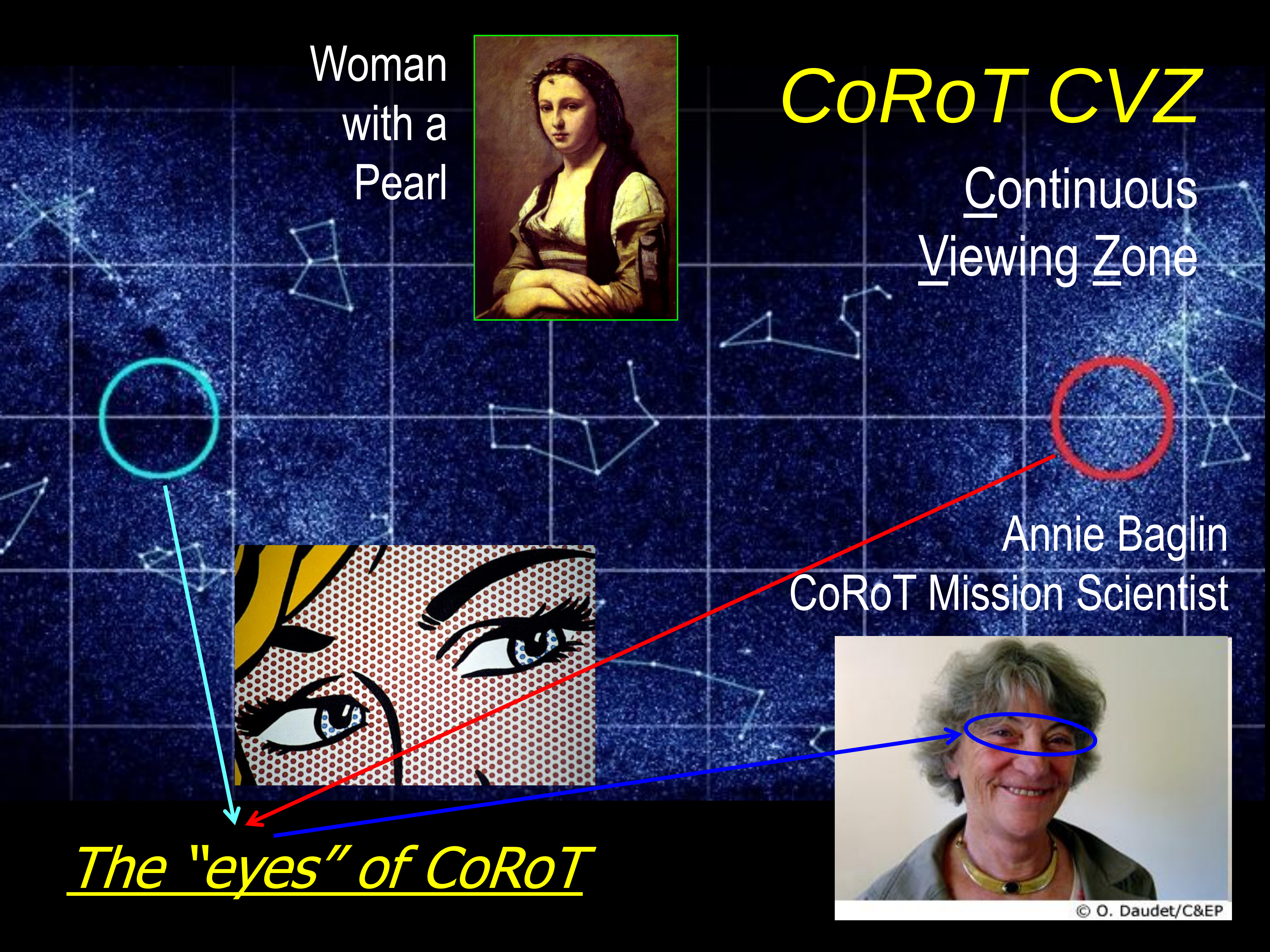
9¼, going on 10

“Over the hill?” in CoRoT and Kepler years

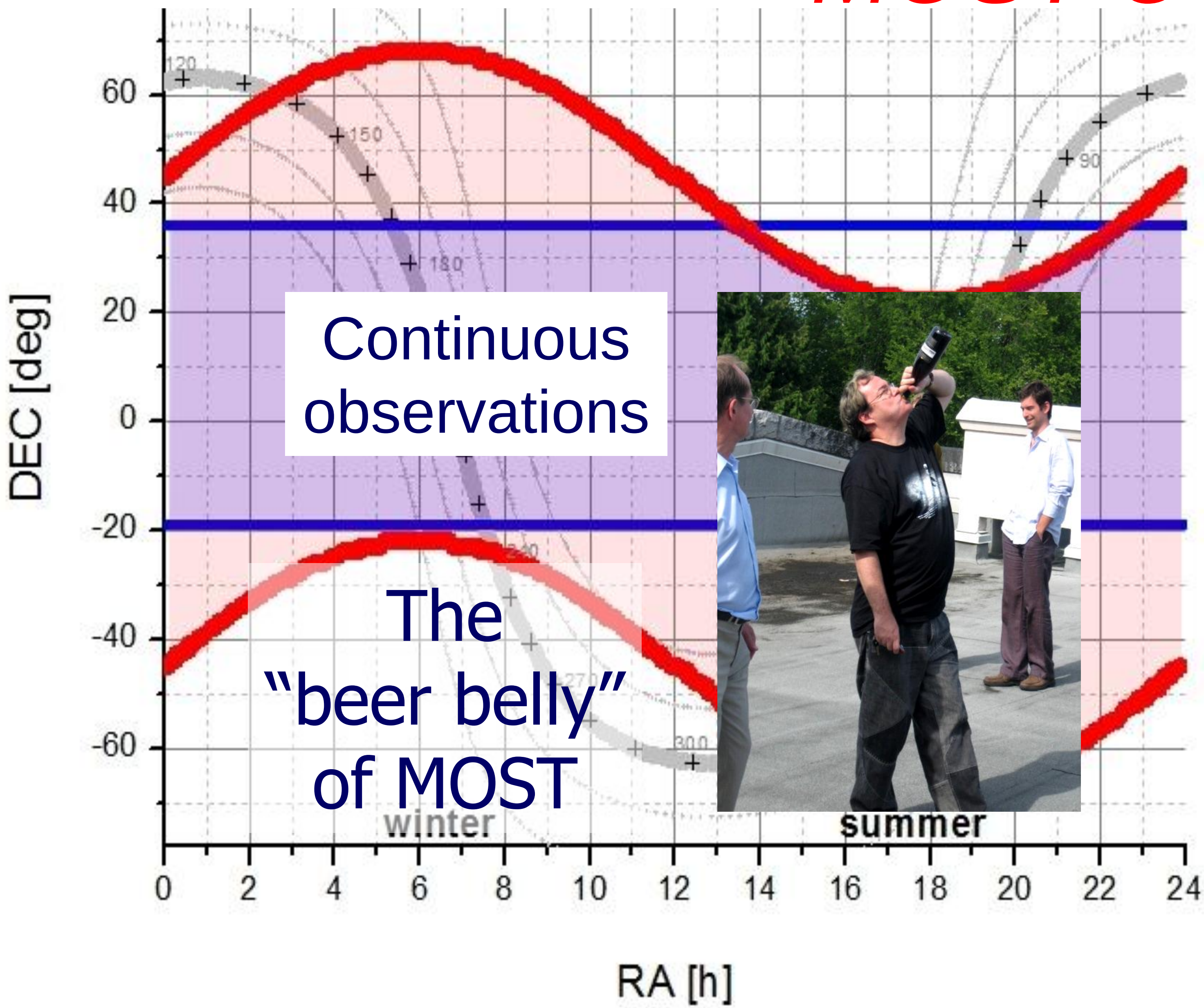
CoRoT

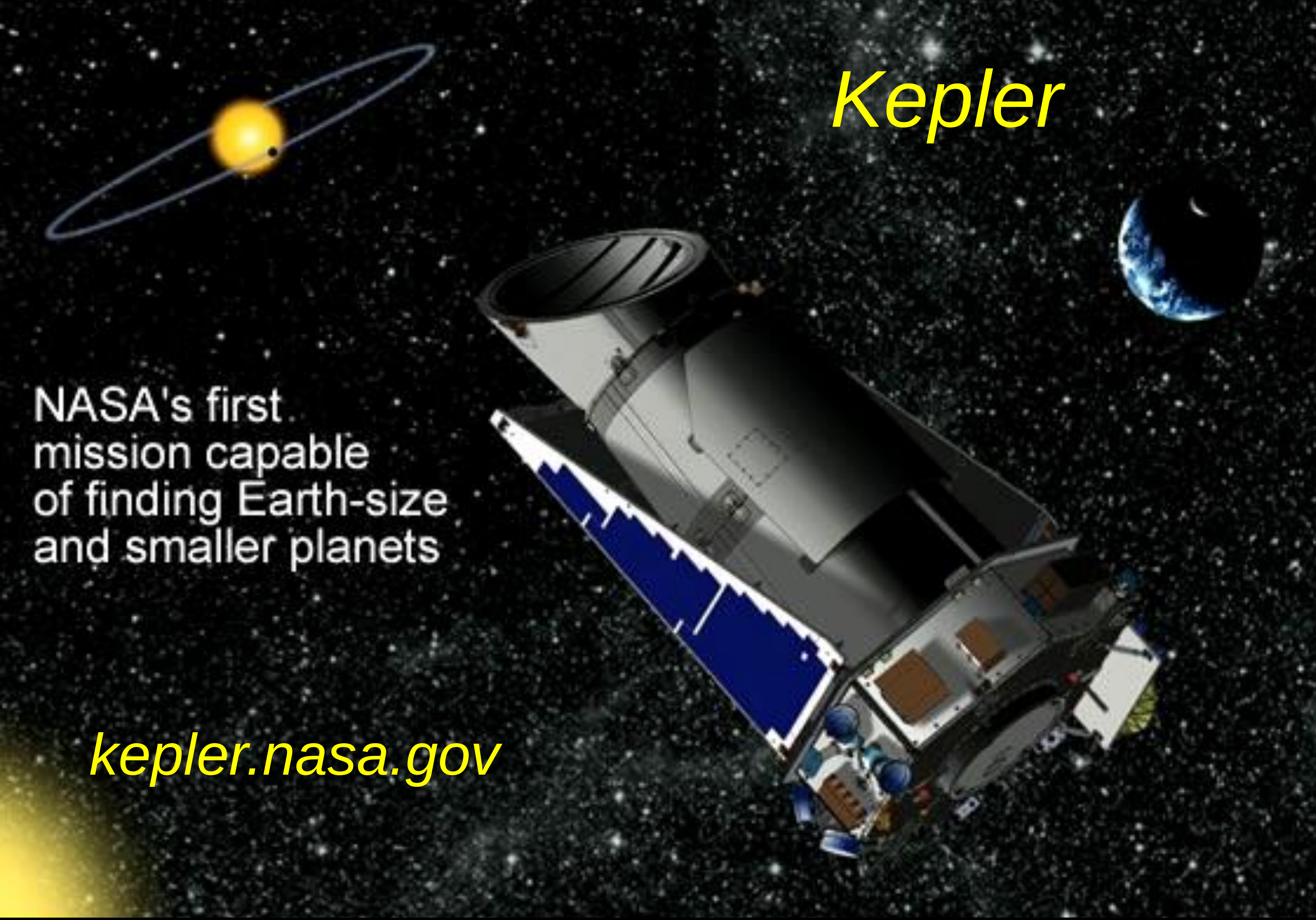


http://smsc.cnes.fr/COROT

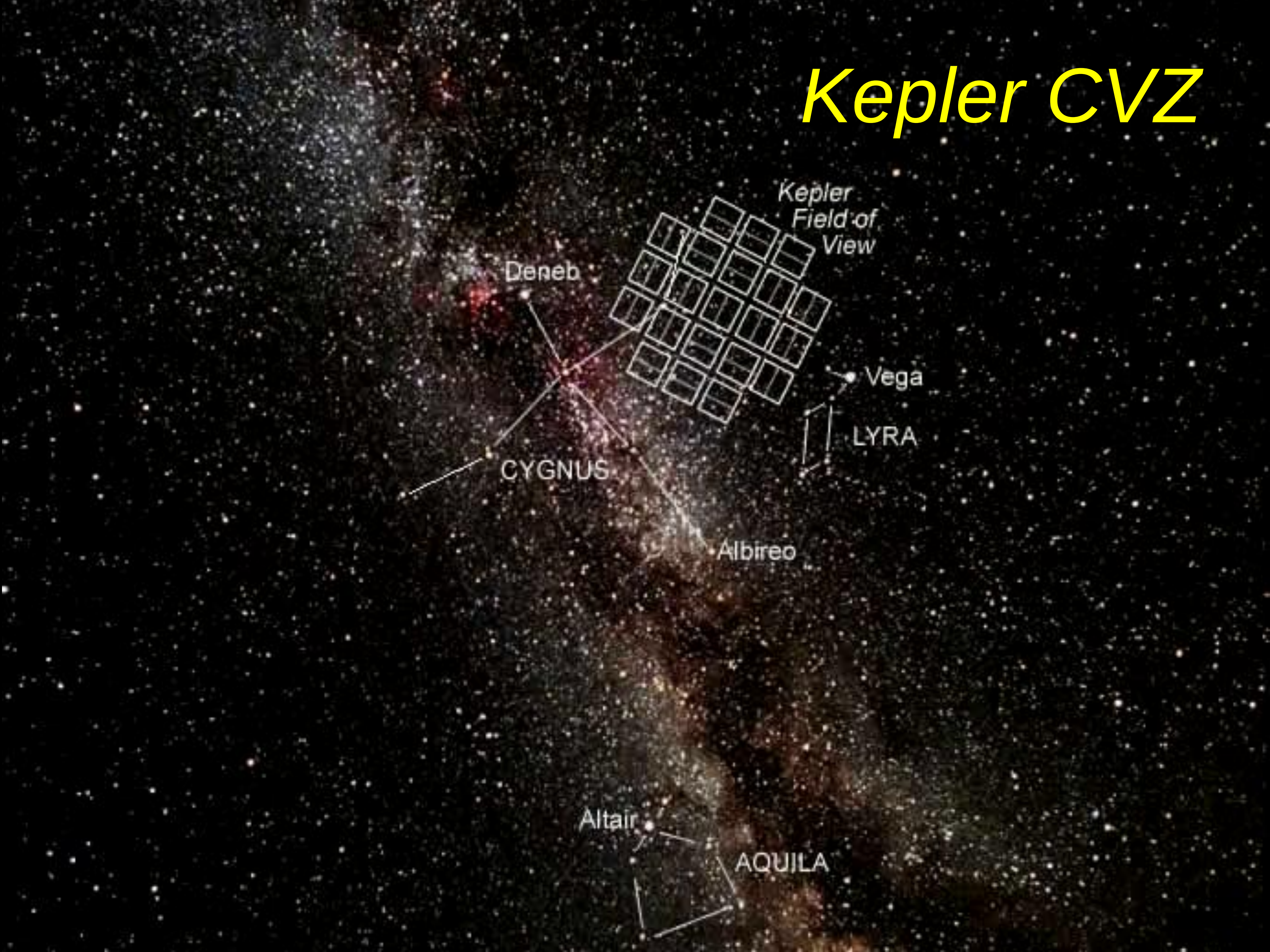

CoRoT CVZ
Continuous
Viewing Zone
Woman
with a
Pearl
Annie Baglin
CoRoT Mission Scientist
© O. Daudet/C&EP
The "eyes" of CoRoT

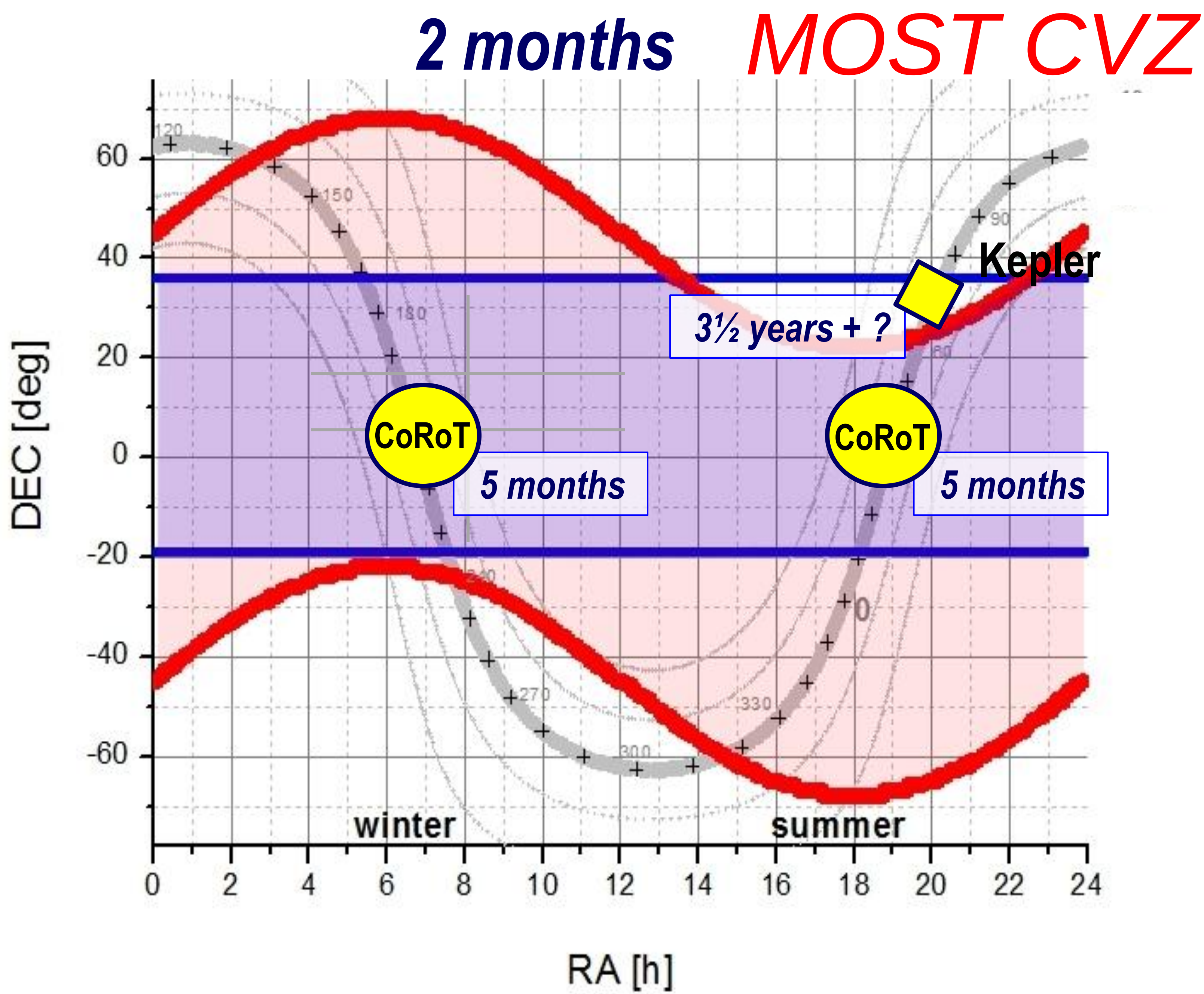
MOST CVZ

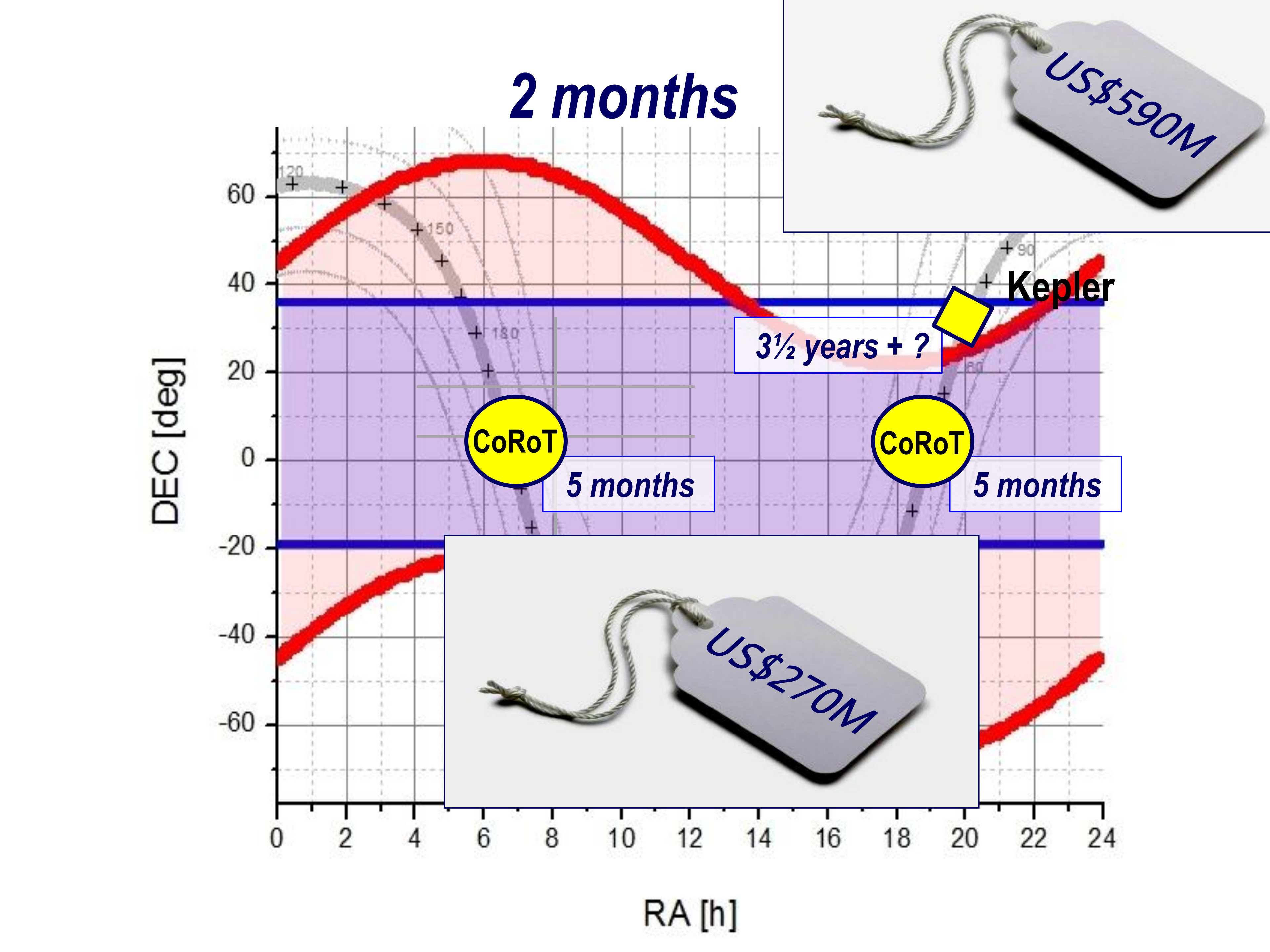

Continuous observations
The "beer belly" of MOST
DEC [deg]
RA [h]
60
40
20
0
-20
-40
-60
0
2
4
6
8
10
12
14
16
18
20
22
24
120
150
180
90
300
winter
summer


Kepler
NASA's first mission capable of finding Earth-size and smaller planets
kepler.nasa.gov

Kepler CVZ


Kepler
Field of
View
Deneb
Vega
LYRA
CYGNUS
Albireo
Altair
AQUILA

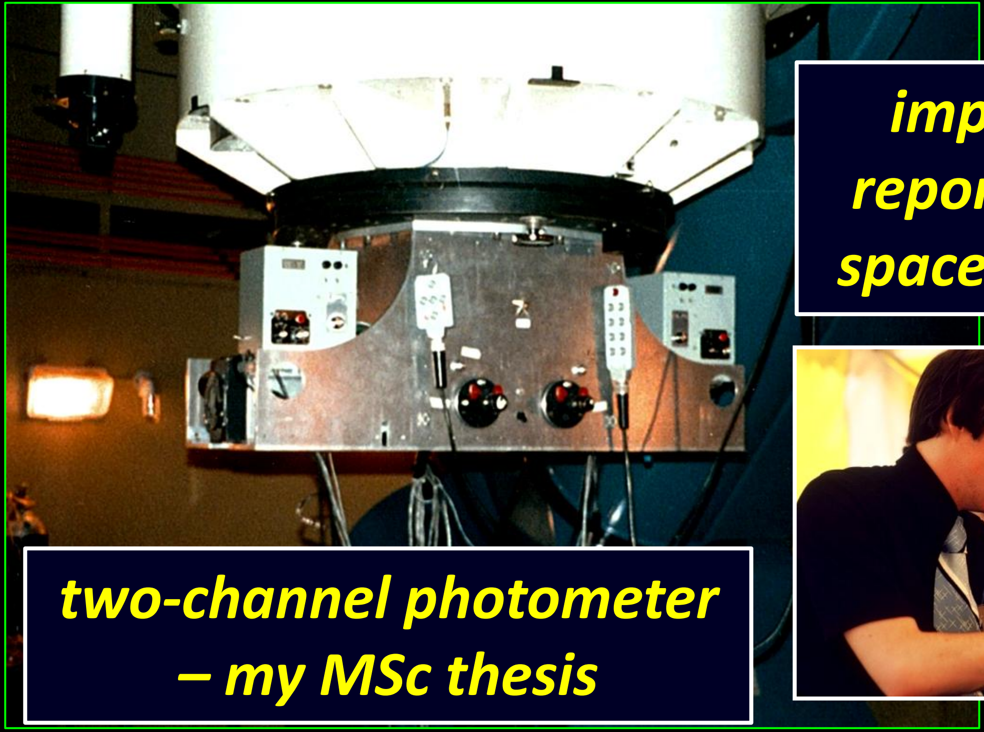

2 months
MOST CVZ
Kepler
3½ years + ?
CoRoT
5 months
CoRoT
5 months
winter
summer
DEC [deg]
RA [h]
60
40
20
0
-20
-40
-60
0
2
4
6
8
10
12
14
16
18
20
22
24
120
150
180
240
270
300
330
90
60



2 months
US$590M
Kepler
3½ years + ?
CoRoT
5 months
CoRoT
5 months
US$270M
DEC [deg]
RA [h]
60
40
20
0
-20
-40
-60
0
2
4
6
8
10
12
14
16
18
20
22
24

Science fiction *30 years ago*

As a grad student, starting to explore stellar pulsation, I couldn't have imagined there would some day be *four* space missions dedicated to optical photometry of stars



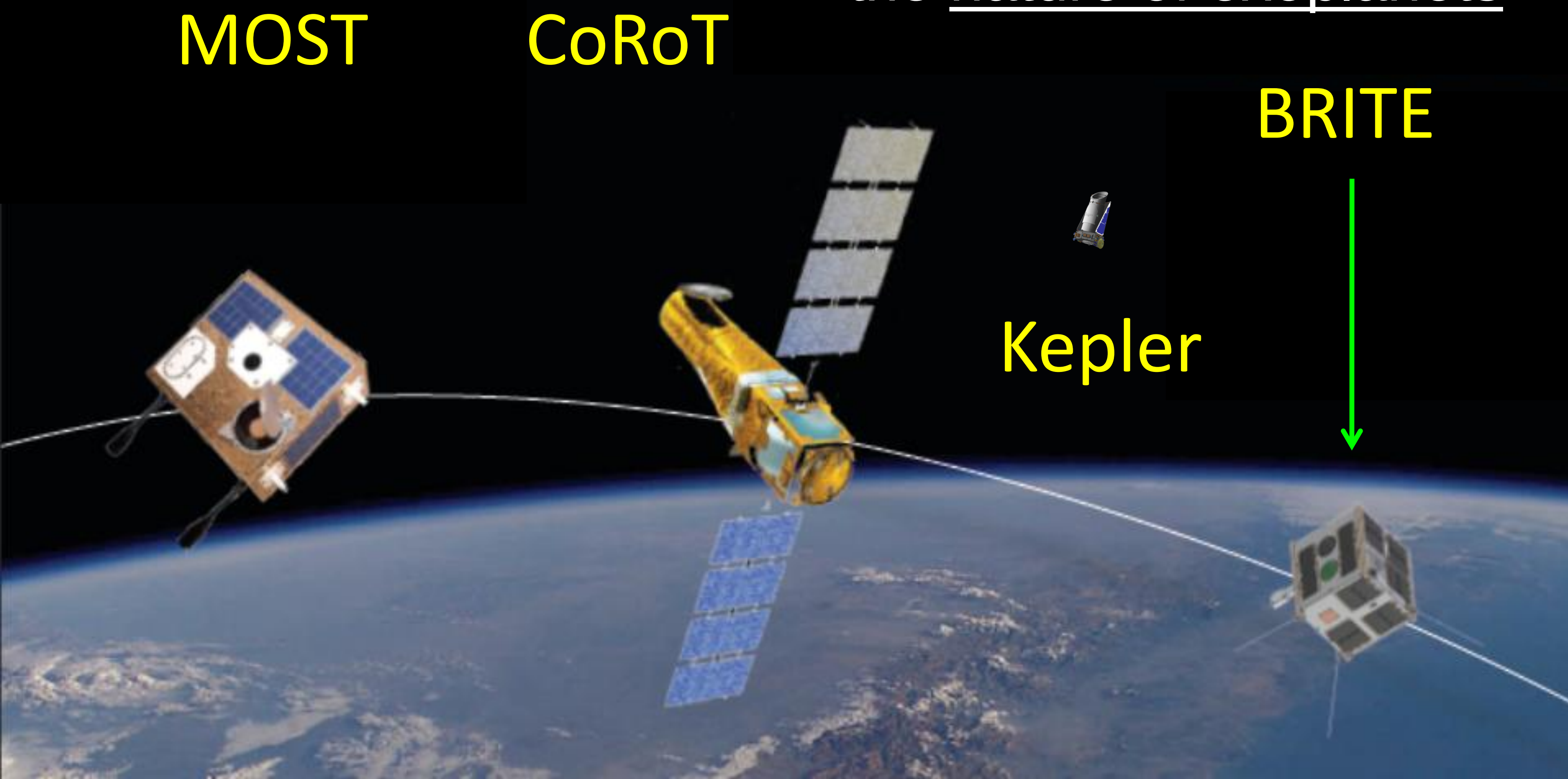
two-channel photometer – my MSc thesis

impersonating a reporter at the first space shuttle launch

my going-away party

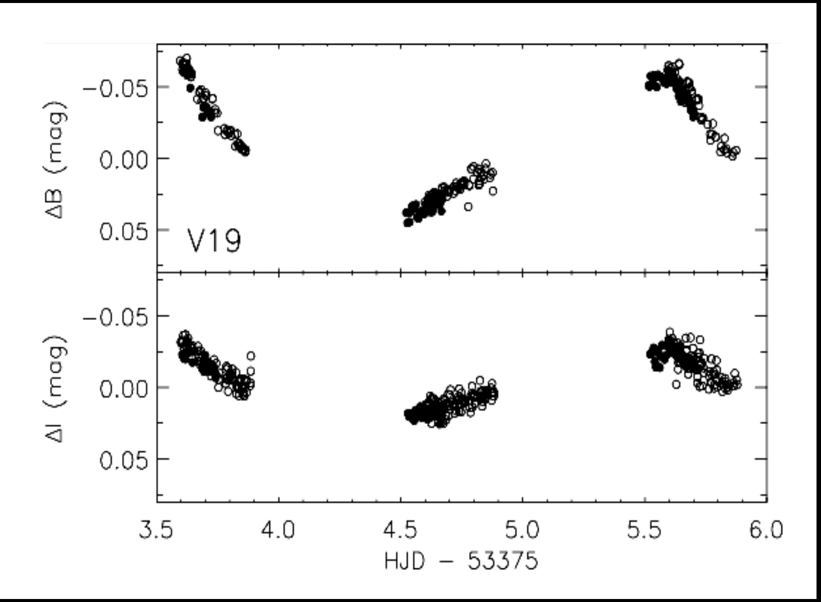
Science fact *today*

We are in an unprecedented era of probing the <u>internal structures of stars</u> and understanding the <u>nature of exoplanets</u>



Why go to space?

3 nights of photometry
of a variable star from
a single site on the ground

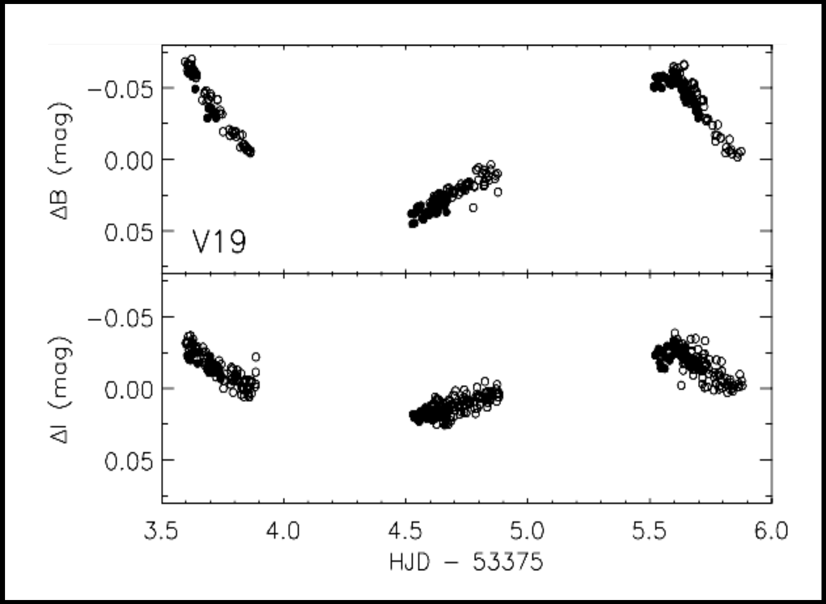


Arentoft et al. 2007, A&A, 465,965

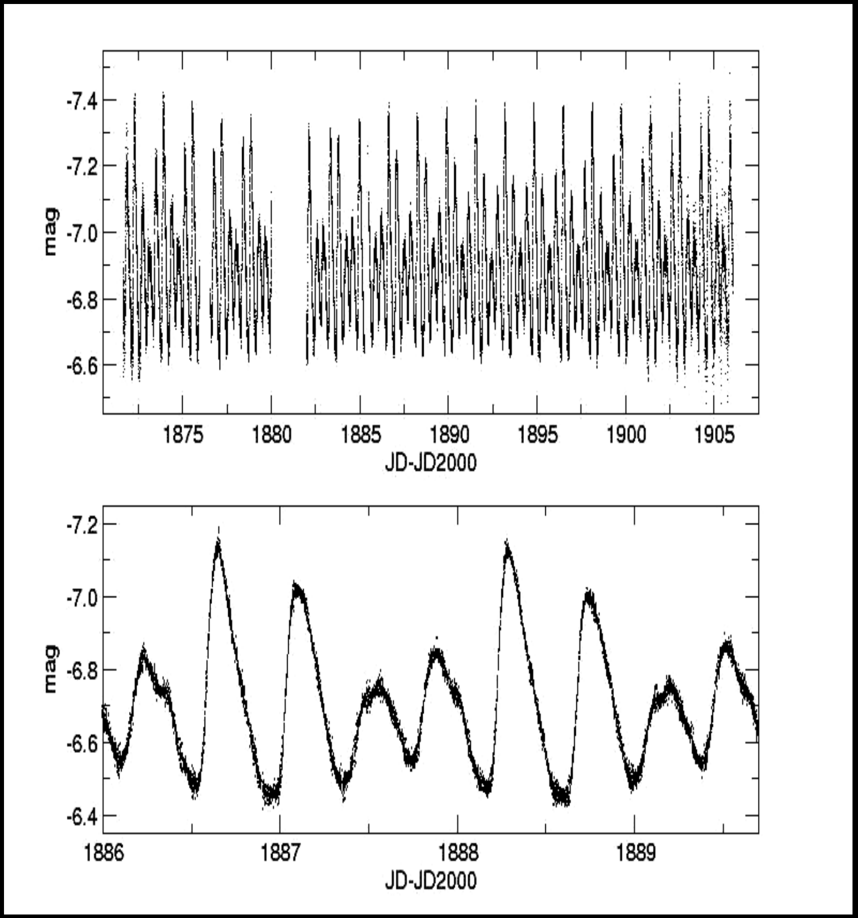
Why go to space?

3 nights of photometry of a variable star from a single site on the ground

34 days of photometry of the double-mode RR Lyrae star AQ Leo from MOST in orbit



Arentoft et al. 2007, A&A, 465,965

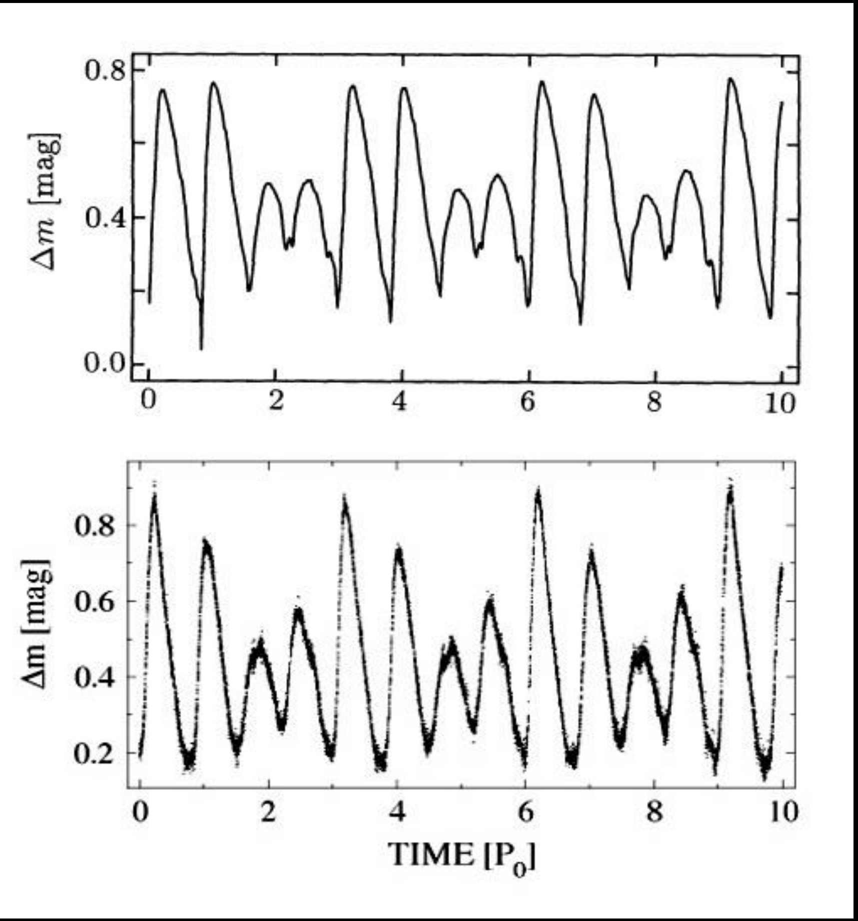


Gruberbauer et al. 2007, MNRAS

Why go to space?

Kovacs & Buchler modeled the pulsations of AQ Leo a decade before MOST observed it

a subset of 10 days of photometry of the double-mode RR Lyrae star AQ Leo from MOST in orbit



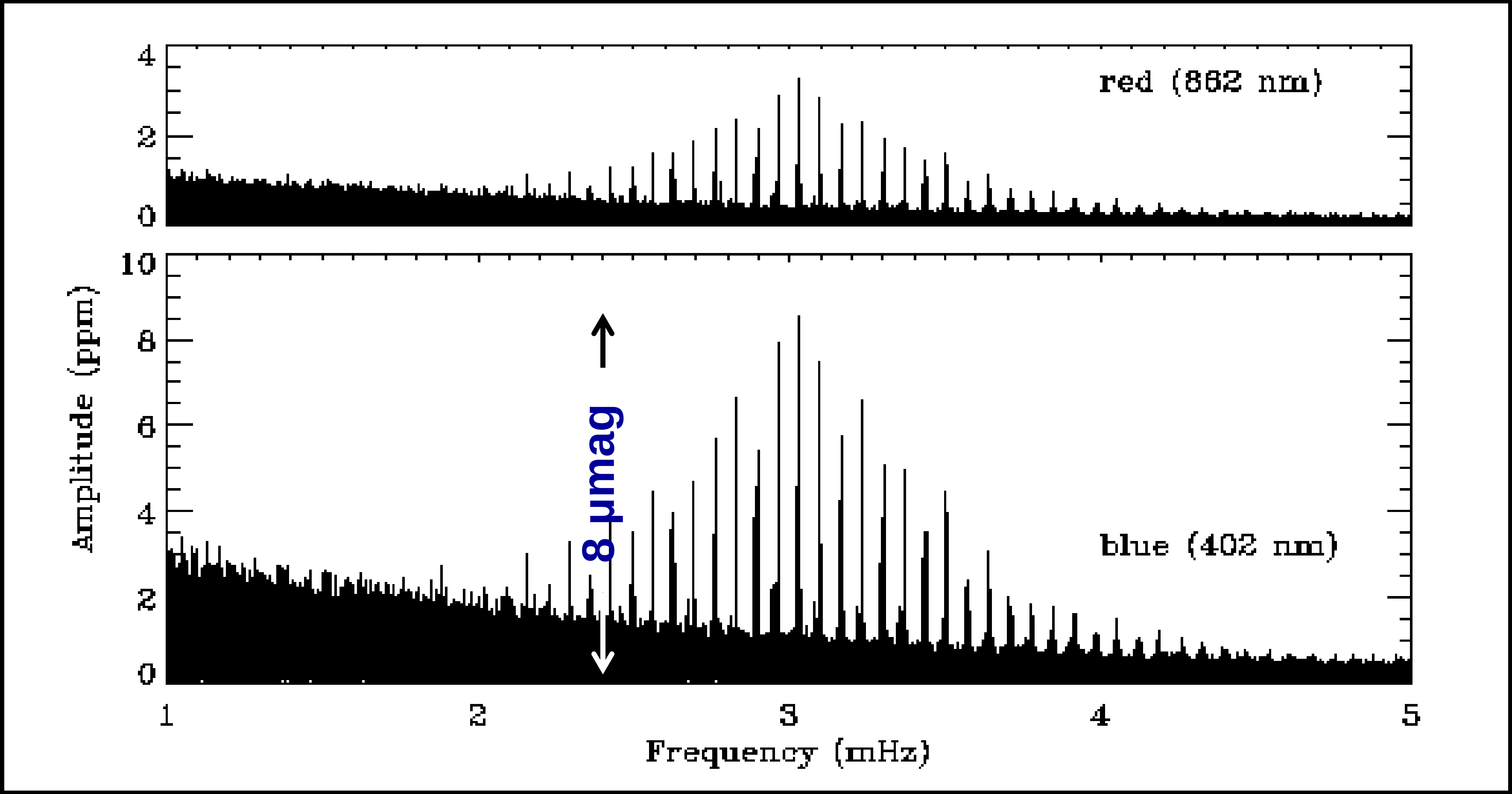
SPOT THE SUPERCOMPUTER SIMULATION !

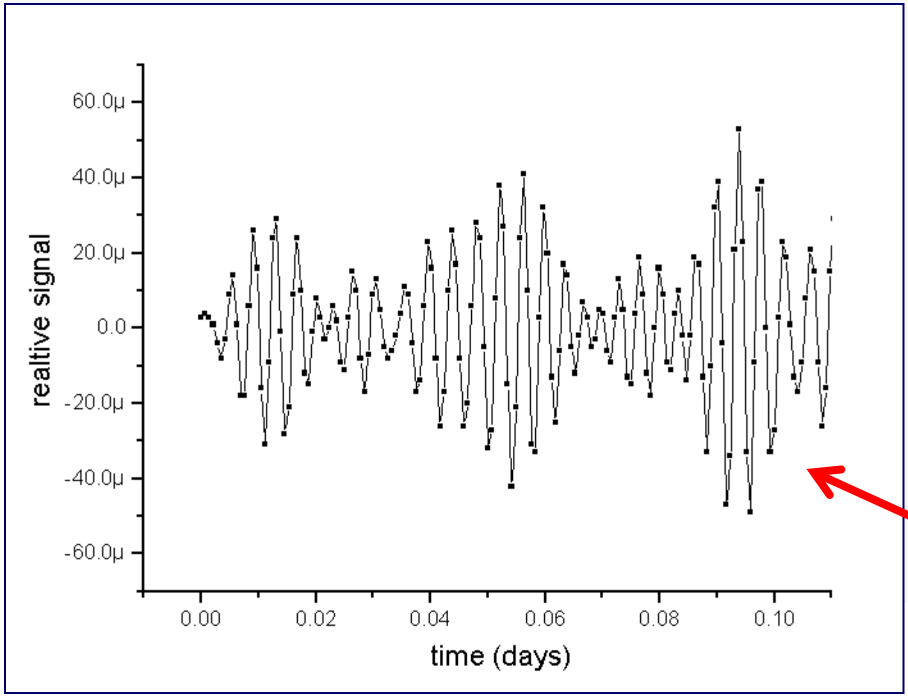
Gruberbauer et al. 2007, MNRAS

The µmag & µHz challenge !

Fourier amplitude spectrum of the Sun's 5-minute oscillations seen in integrated sunlight; i.e., the Sun as an unresolved star

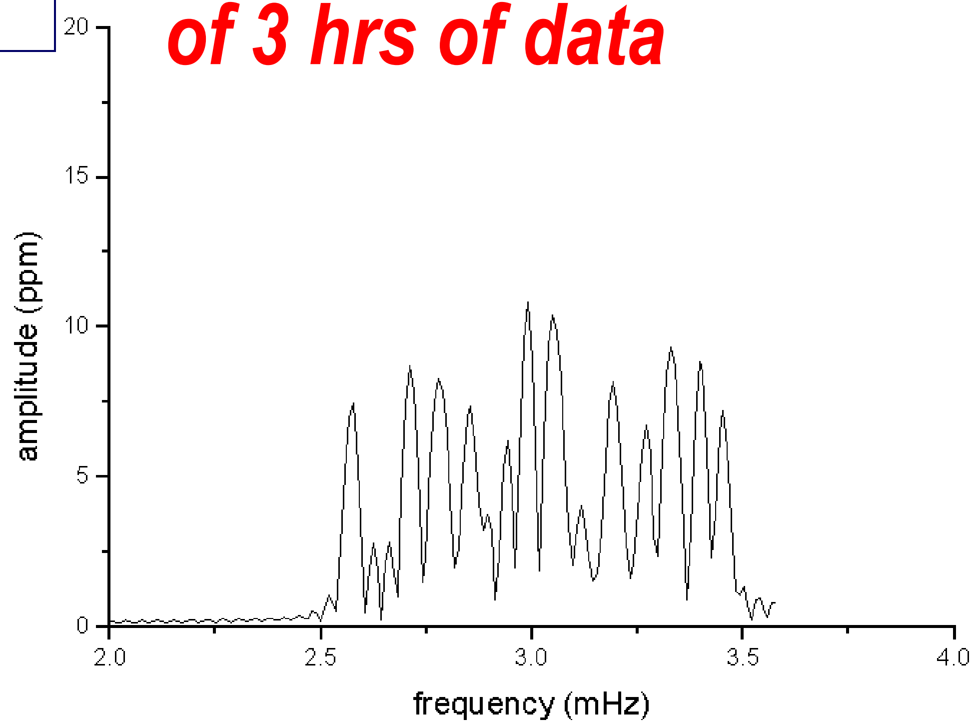
VIRGO photometry



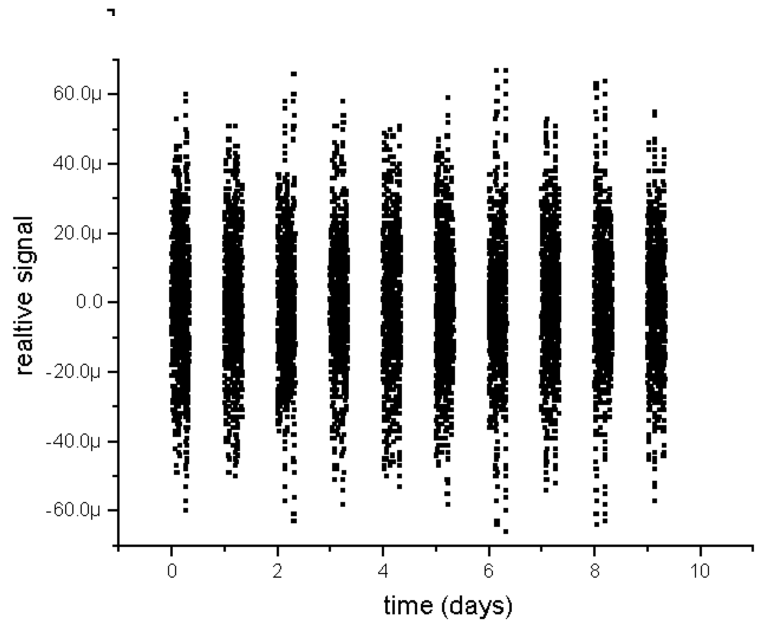


- 8 hrs of data
- no noise

expanded view of 3 hrs of data

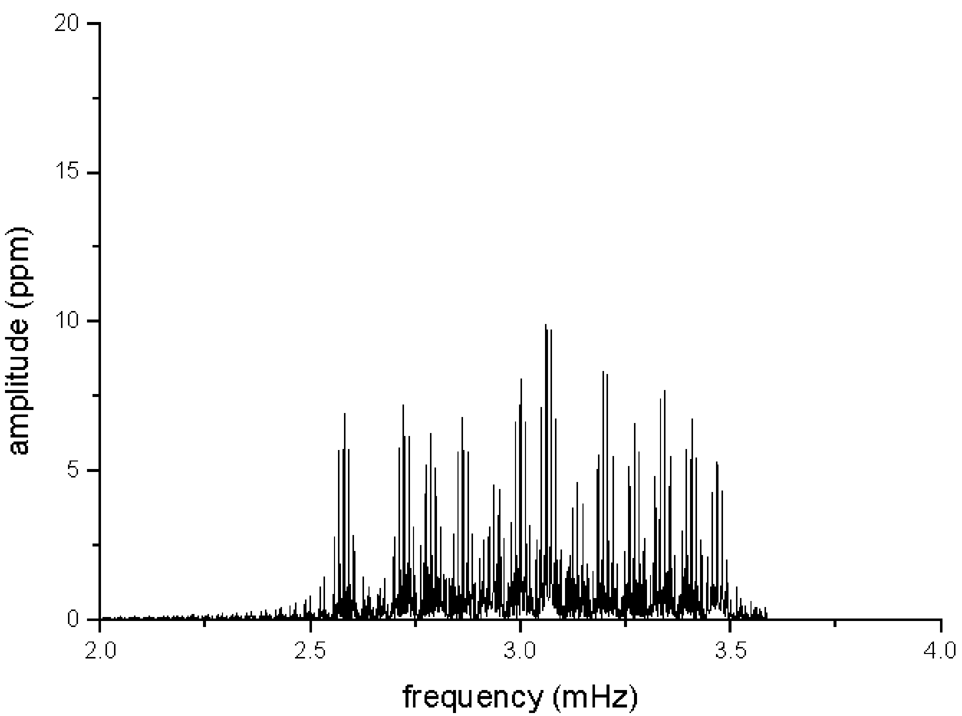


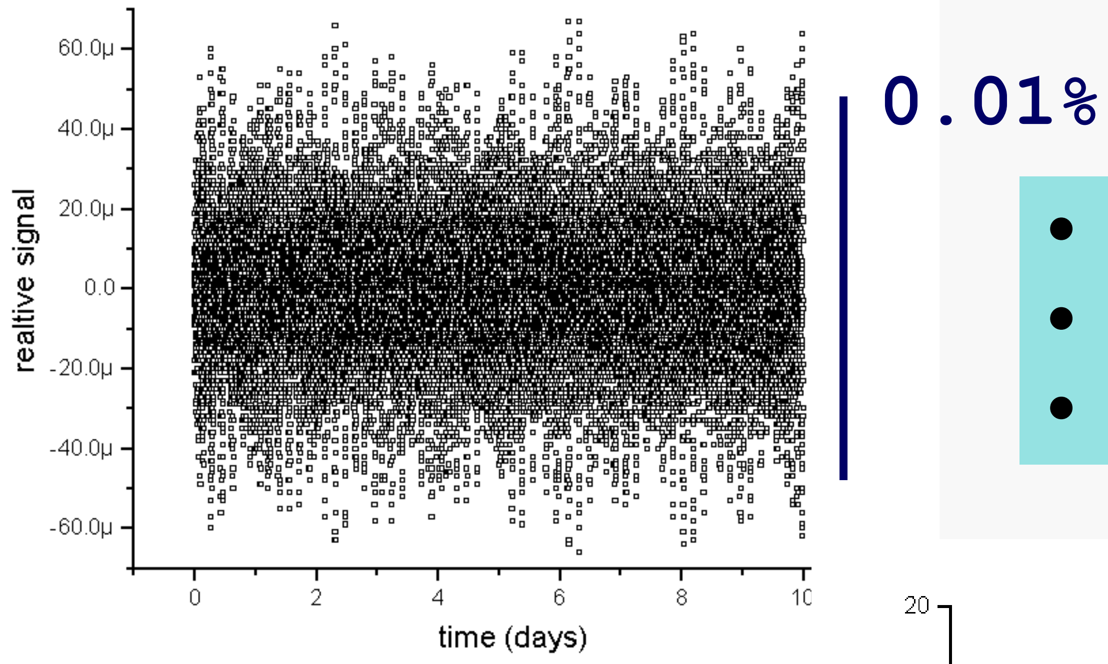
poor frequency resolution



- 10 d of data
- no noise
- daily gaps

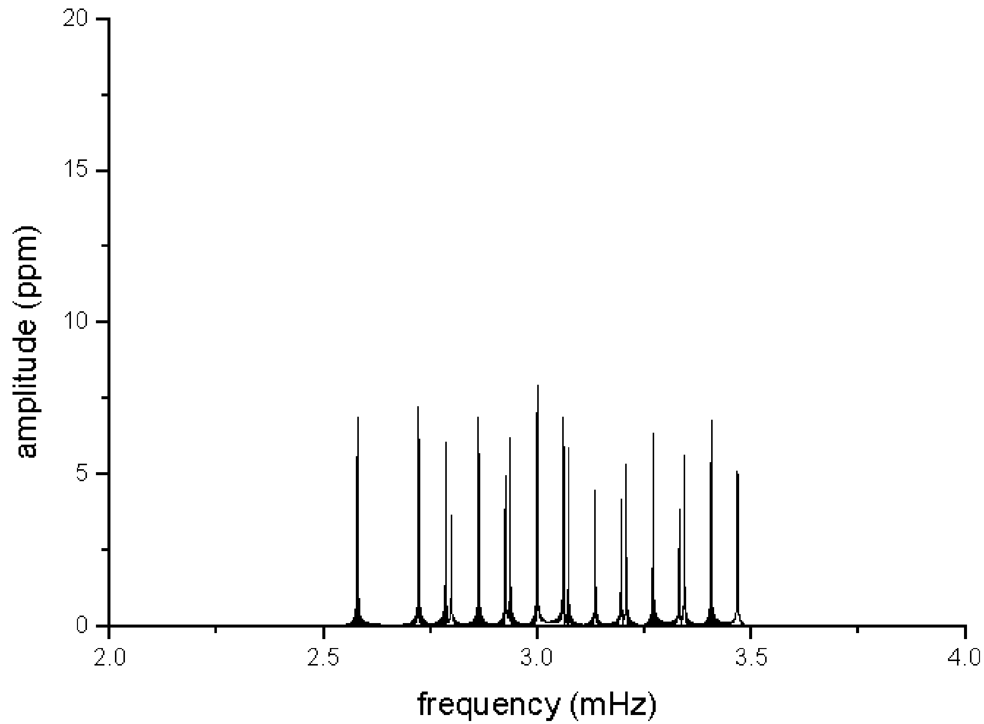
good frequency resolution but aliasing

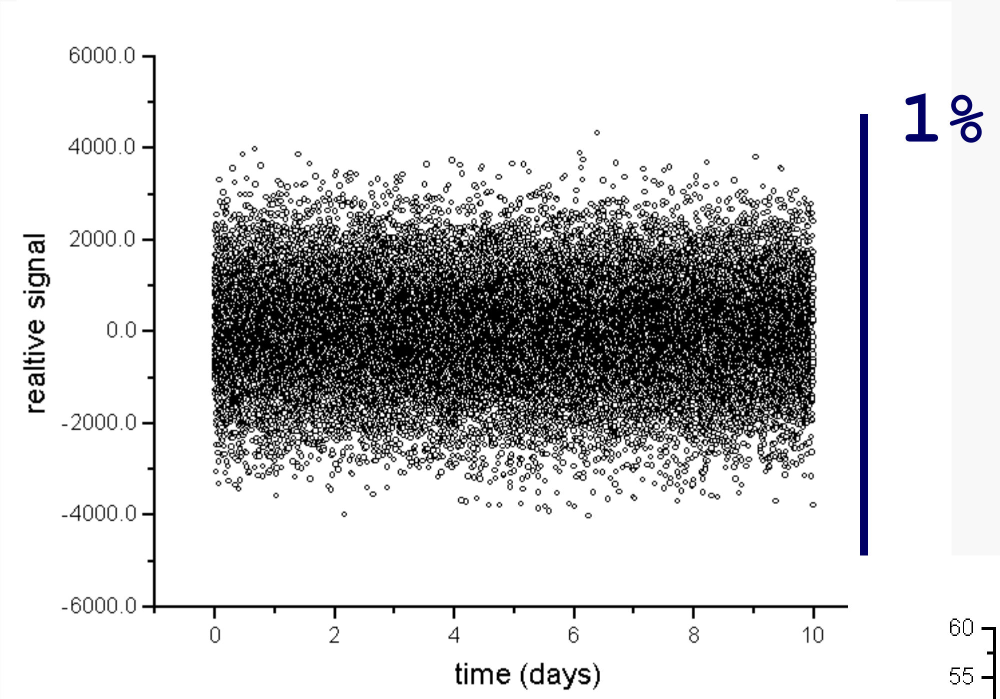




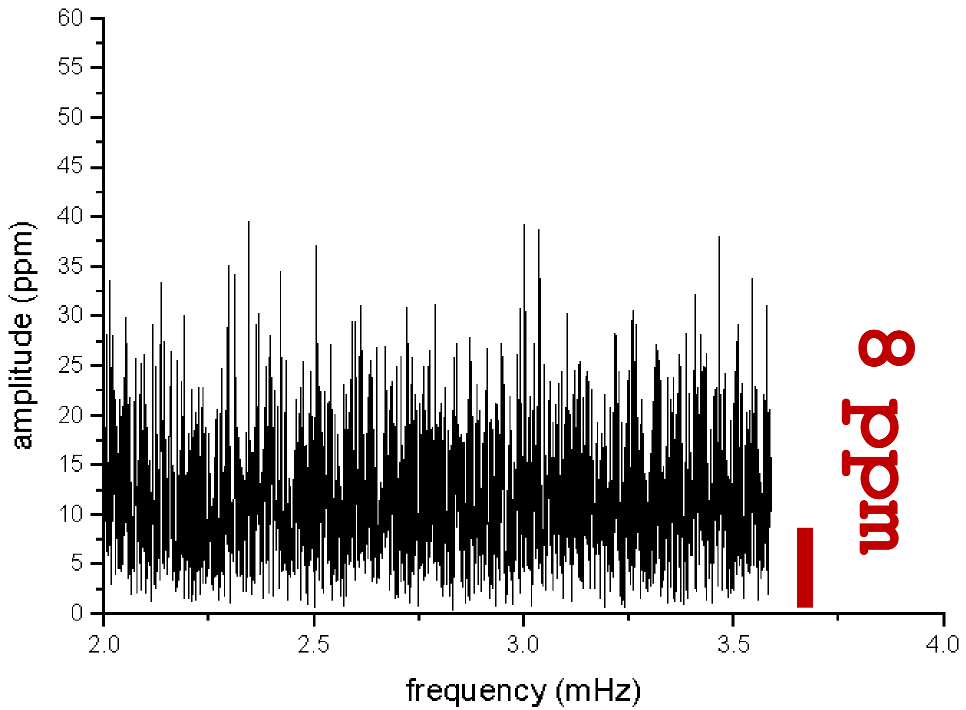
- 10 d of data
- photon noise
- no gaps

good frequency resolution & no aliasing





- 10 d of data
- atmospheric scintillation

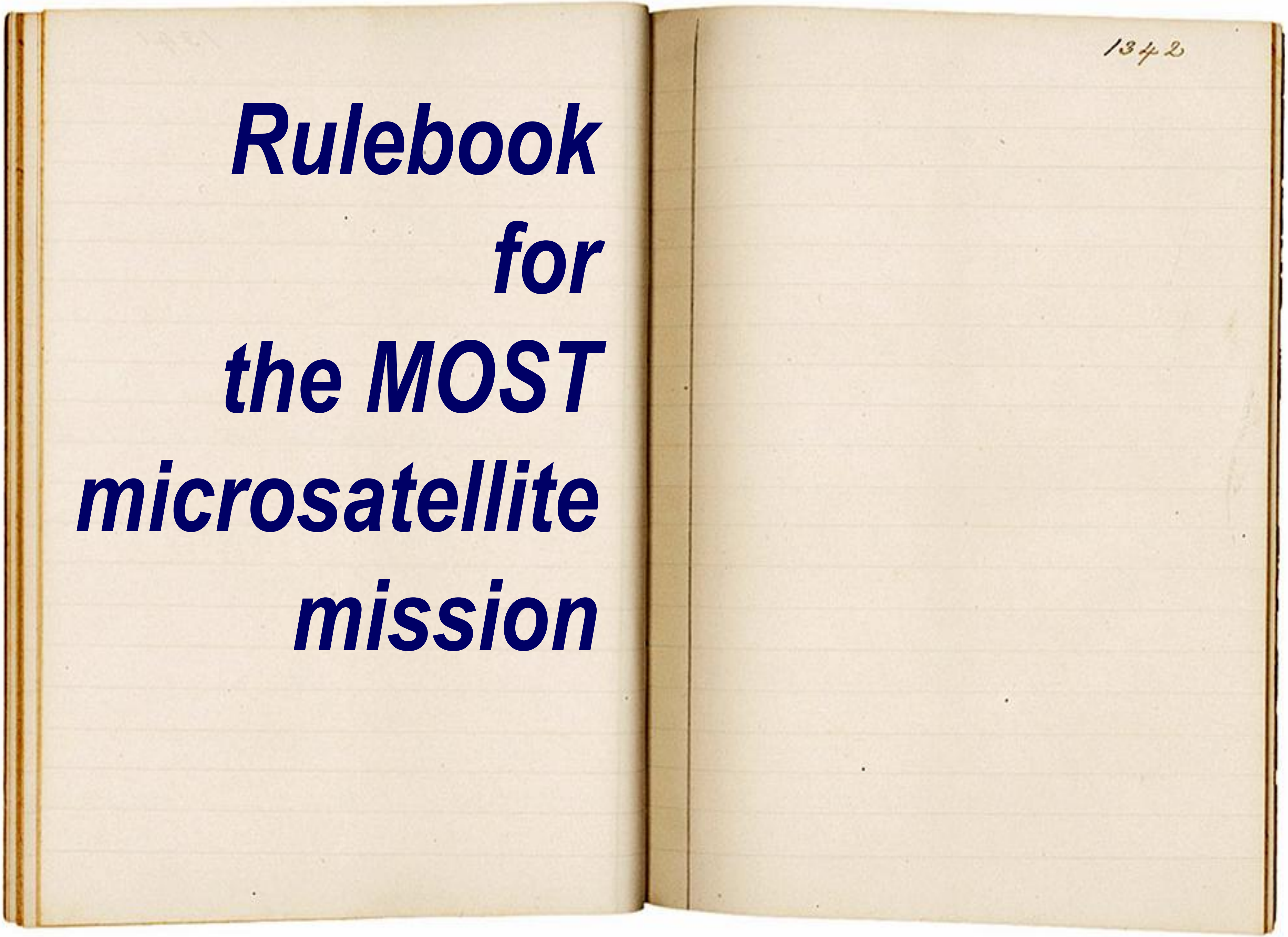


NO DETECTION!

Why I went into space

in a virtual sense

Rulebook for the MOST microsatellite mission



Rulebook for the MOST microsatellite mission

- ✓ only <u>one egg</u> in the basket

Rulebook for the MOST microsatellite mission

1342

✓ only one egg in the basket

1 instrument
1 type of data
1 unique capability

Rulebook for the MOST microsatellite mission

- ✓ only <u>one egg</u> in the basket

1 instrument
1 type of data
1 unique capability

- ✓ <u>high performance</u>

Set detailed science requirements and stick to them!

Rulebook for the MOST microsatellite mission

But have optimistic goals to aim beyond

1342

- ✓ only one egg in the basket

  1 instrument
  1 type of data
  1 unique capability

- ✓ high performance

  Set detailed science requirements and stick to them!

Rulebook for the MOST microsatellite mission

But have optimistic goals to aim beyond

✓ only <u>one egg</u> in the basket

EXCITING science objectives which everyone on the team understands

1 instrument
1 type of data
1 unique capability

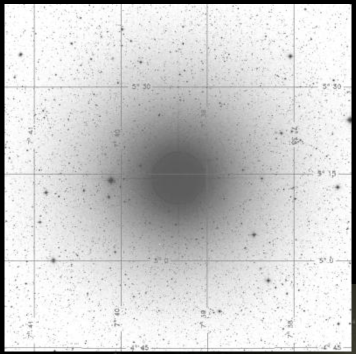
✓ <u>high performance</u>

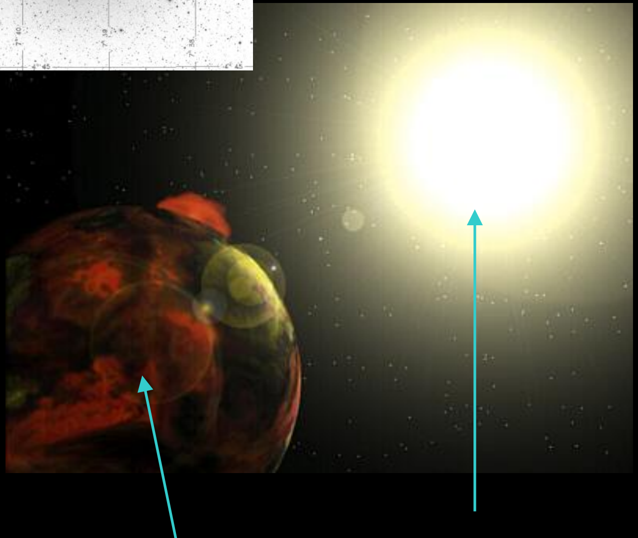
Set detailed science requirements and stick to them!

MOST science

- ✓ Sun-like stars
  - ✓ asteroseismology
  - ✓ surface spots, activity
- ✓ ancient halo intruders
- ✓ magnetic (Ap) stars
- ✓ massive evolved stars
  - ✓ wind turbulence
  - ✓ pulsations
- ✓ exoplanet systems
- ✓ pulsating protostars
- ✓ red giants *… and more!*

Procyon





51 Peg b *51 Peg a*

Undergraduate superstars



Reka Moldovan UBC


Dan Milisavljevic McMaster
now at Dartmouth

Heather King-Kamps UBC

Undergraduate superstars



Reka Moldovan UBC


13 refereed papers based on MOST research have undergrads as first authors

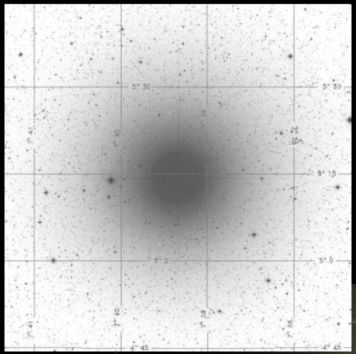
Dan Milisavljevic McMaster
now at Dartmouth

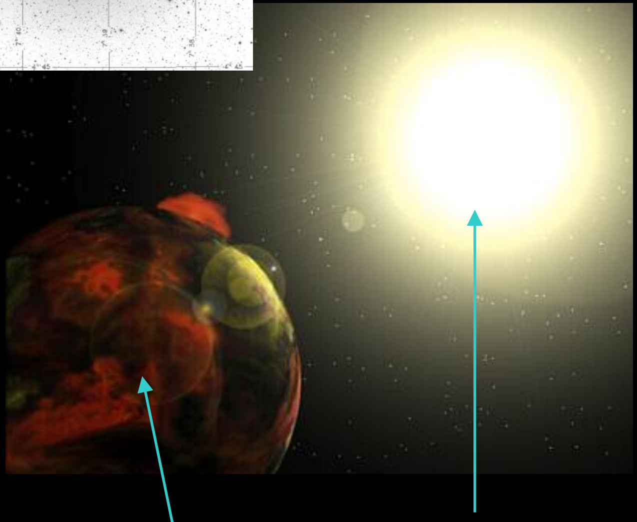
Heather King-Kamps UBC

MOST science

- ✓ Sun-like stars
  - ✓ asteroseismology
  - ✓ surface spots, activity
- ✓ ancient halo intruders
- ✓ magnetic (Ap) stars
- ✓ massive evolved stars
  - ✓ wind turbulence
  - ✓ pulsations
- ✓ exoplanet systems
- ✓ pulsating protostars
- ✓ red giants *… and more!*

Procyon





51 Peg b *51 Peg a*

ASTRONOMY

Tiny space telescope reveals 'super-Earth'

BY MARGARET MUNRO

Canada's tiny space telescope has unmasked a "super-Earth" that has an international team of astronomers, including University of B.C.'s Jaymie Matthews, buzzing.

The planet, named 55 Cancri e, is the densest solid planet known and whips around its star in just 18 hours, according to the team that released its findings Thursday.

"You could set dates on this world by your wrist watch," said Matthews.

Not that there is much chance of life on the planet, he said, noting that the surface temperature is believed to be close to 2,700 C. Despite the inferno, the astronomers say the planet may retain an atmosphere because of its strong gravity.

"It's so exotic, it's like the poster child for rocky super-Earths," Matthews added.

It is also so close to Earth — its home star is visible to the naked eye — that the scientists say 55 Cancri e is a "unique laboratory to investigate the story of how planets form and evolve."

The team used Canada's bargain-basement space telescope

University of B.C. astronomer Jaymie Matthews is part of the team studying 55 Cancri e.

to "stake out" the exoplanet and determine its orbit, mass and size. The suitcase-sized telescope, called MOST for Microvariability and Oscillations of Stars, was launched by the Canadian Space Agency in 2003 to study 10 stars. The mission was expected to last a year.

Almost eight years later, MOST is still going strong and has observed more than 2,000 stars, says Matthews, mission scientist for MOST.

"We've had a big bang for the buck," said Matthews, who has taken to calling the $10-million MOST "the Zellers of space telescopes."

Planet hunters have now spotted more than 500 exoplanets but Matthews and his colleagues said 55 Cancri e stands out because it is so dense and so close to Earth.

55 Cancri e is part of a planetary system that includes four planets that have been studied by U.S. scientists since 1997 using a technique that measures "wobbles" in stars caused by the gravitational pull of its unseen planets.

Last year Rebekah Dawson, a PhD student at Harvard University, and Daniel Fabrycky, at University of California at Santa Cruz, proposed that the orbit of 55 Cancri e could be measured, not in days as had been assumed, but in hours.

They teamed up with astronomers at MIT, Harvard and UBC to take a closer look and put the planet's home star under surveillance using MOST, which monitored it continuously for two weeks in February.

The space telescope detected subtle dips in the star's brightness, as the planet passed in front of it during each orbit.

"These 'transits' occur like clockwork every 17 hours and 41 minutes," the team reports.

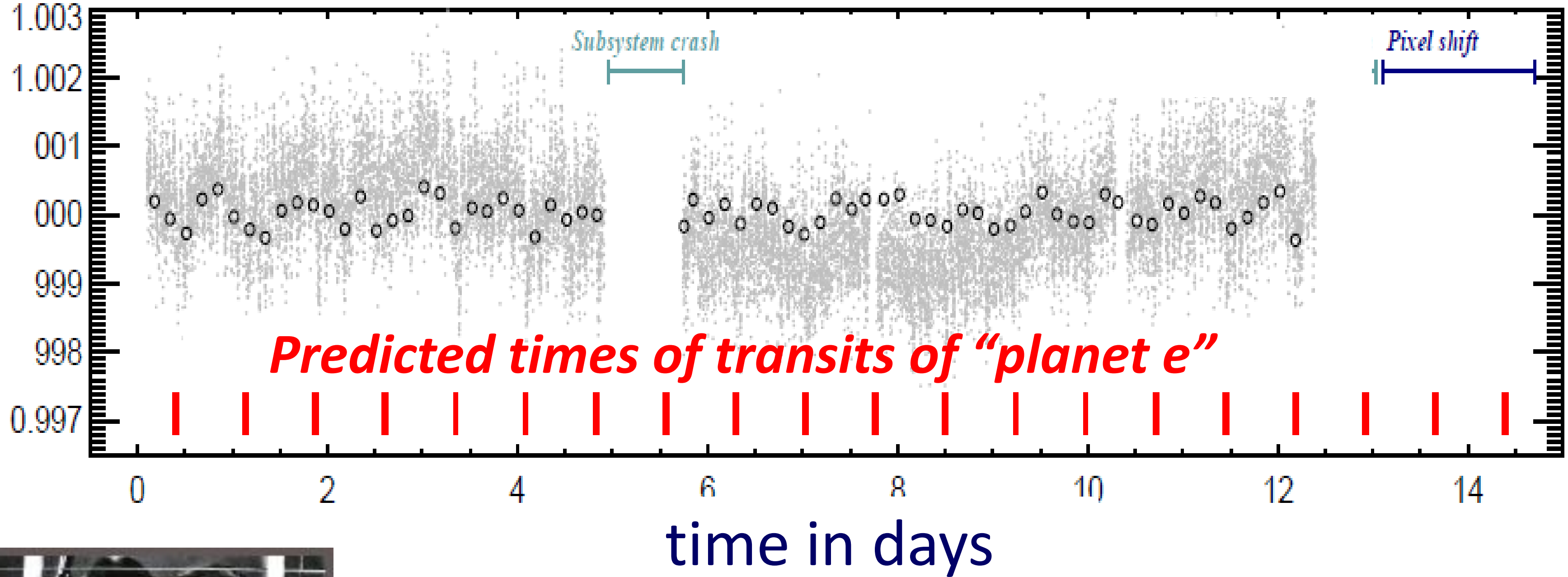
The data collected by MOST indicates the planet's diameter is only 60-per-cent larger than Earth's, but eight times more massive.

"In fact, 55 Cancri e is the densest solid planet known, anywhere," says the teams.

The team says the planet is too small to be visible, even through a telescope, but its host star, 55 Cancri A, can be observed with the naked eye for the next two months on clear nights.

Postmedia News

Vancouver Sun
Friday, 29 April 2011

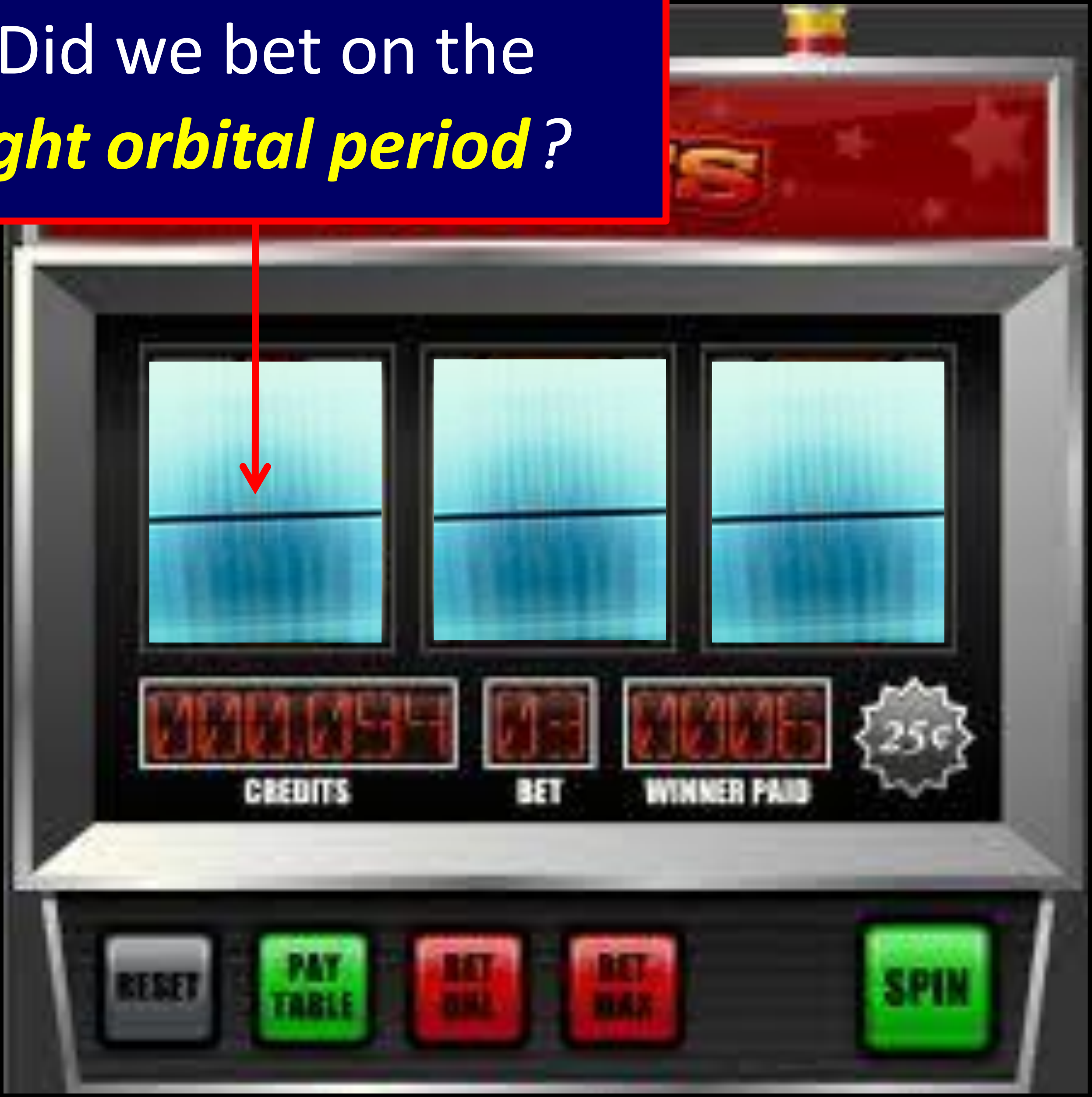


The MOST team put the star
55 Cancri A under an astronomical
“stake-out” for two weeks
in February 2011
looking for tell-tale signs
of an elusive exoplanet

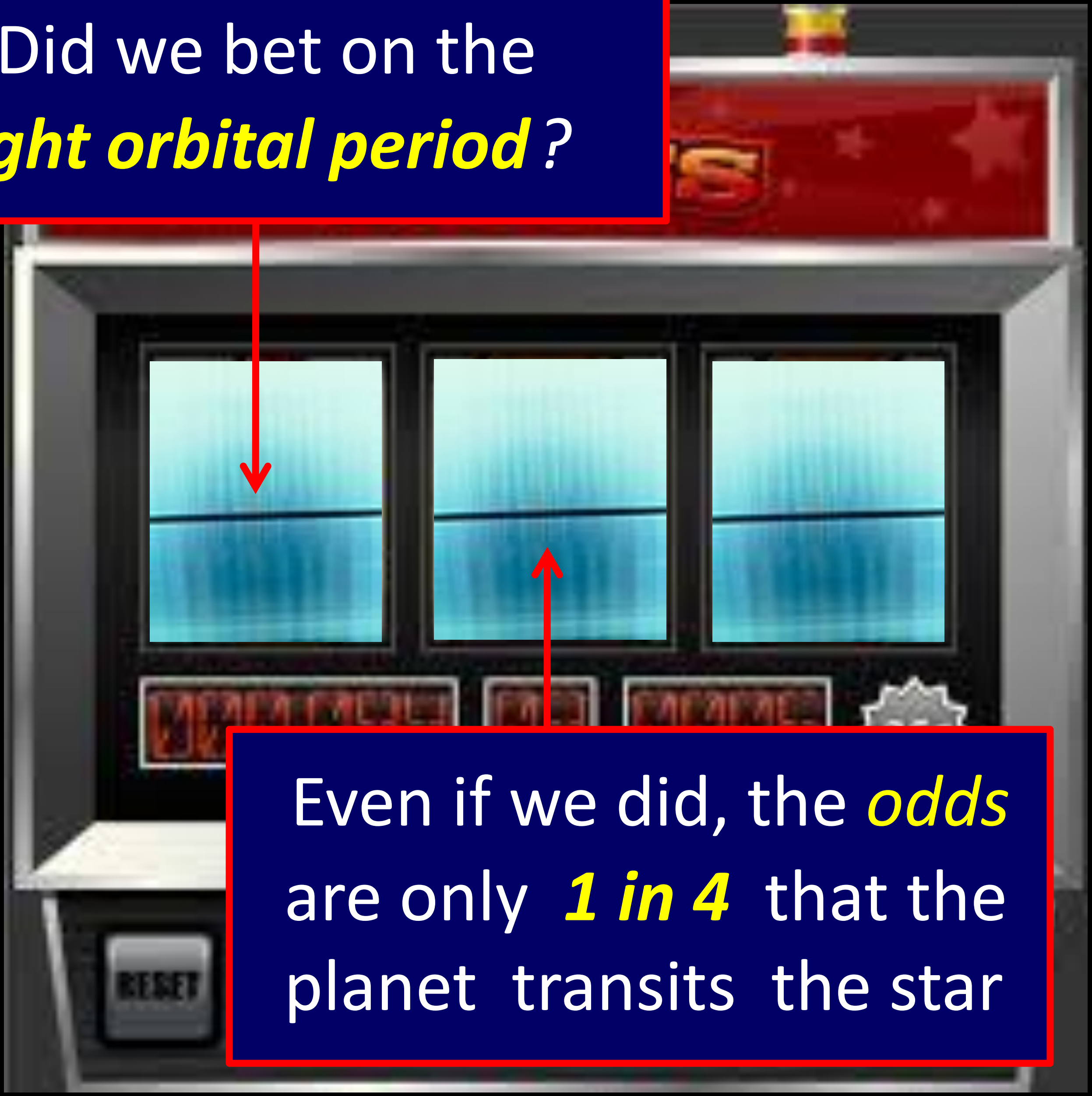

WELCOME
TO Fabulous
LAS VEGAS
NEVADA
BALLYS
NOW AT
BALLYS
TIFFANY & CO.
© USATourist.com


super
SLOTS
BAR
CREDITS
BET
WINNER PAID
25¢
RESET
PAY TABLE
SPIN

Did we bet on the ***right orbital period*** ?



Did we bet on the ***right orbital period*** ?

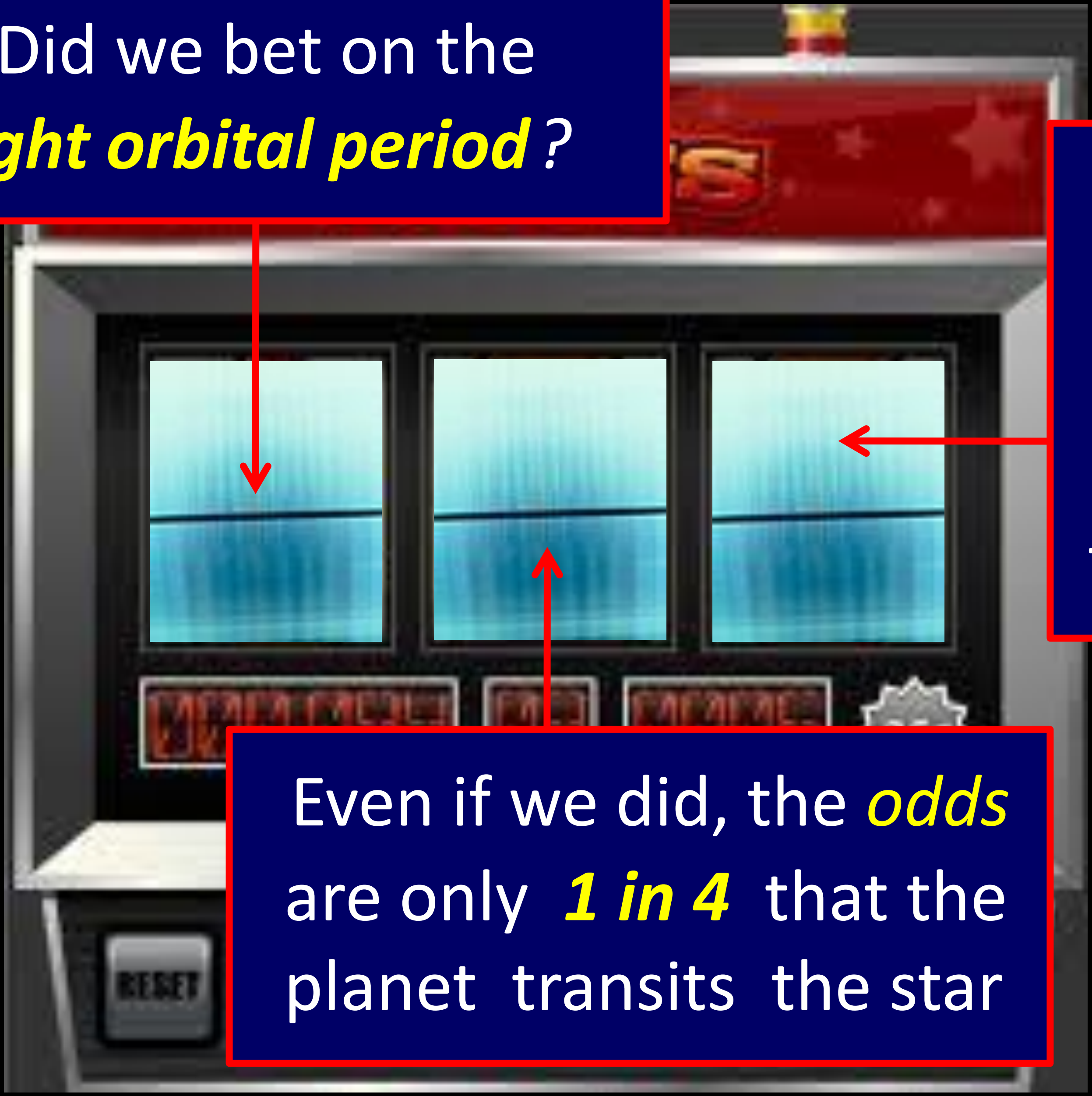


Even if we did, the *odds* are only ***1 in 4*** that the planet transits the star

Did we bet on the ***right orbital period*** ?

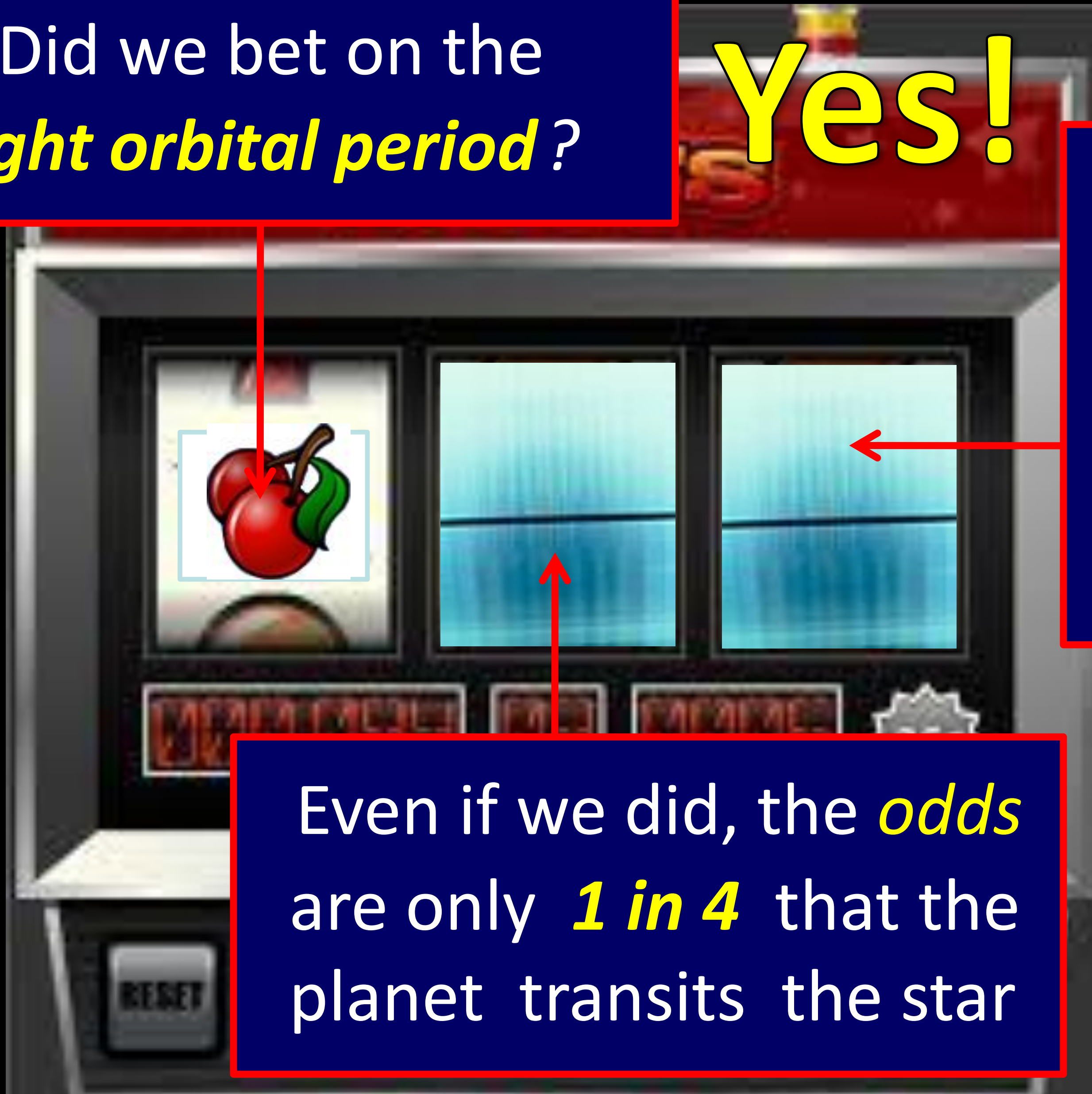
Is the planet ***large enough*** to detect?

Even if we did, the *odds* are only ***1 in 4*** that the planet transits the star



Did we bet on the ***right orbital period*** ?

Yes!

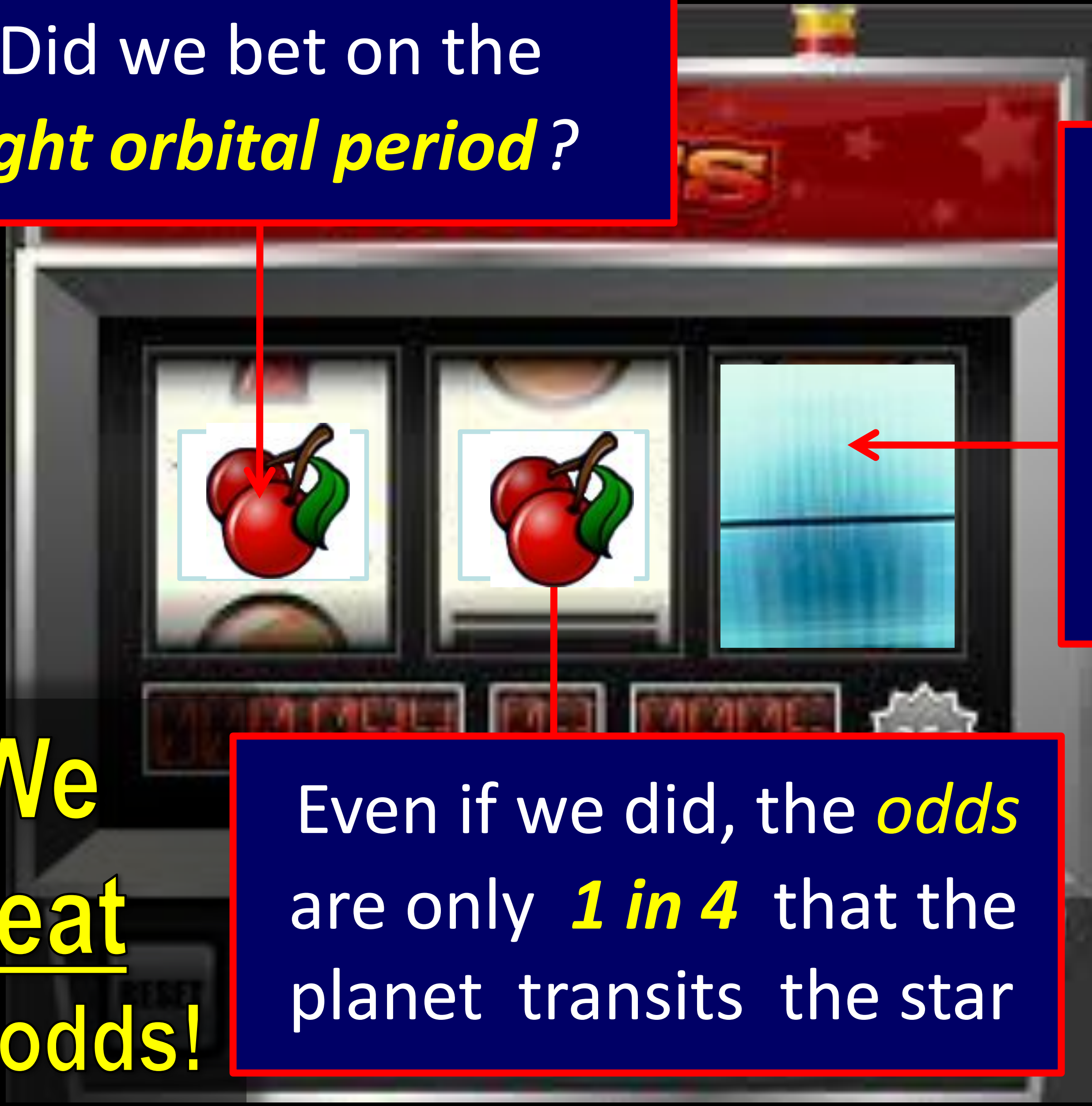


Is the planet ***large enough*** to detect?

Even if we did, the *odds* are only ***1 in 4*** that the planet transits the star

Did we bet on the *right orbital period* ?

Is the planet ***large enough*** to detect?

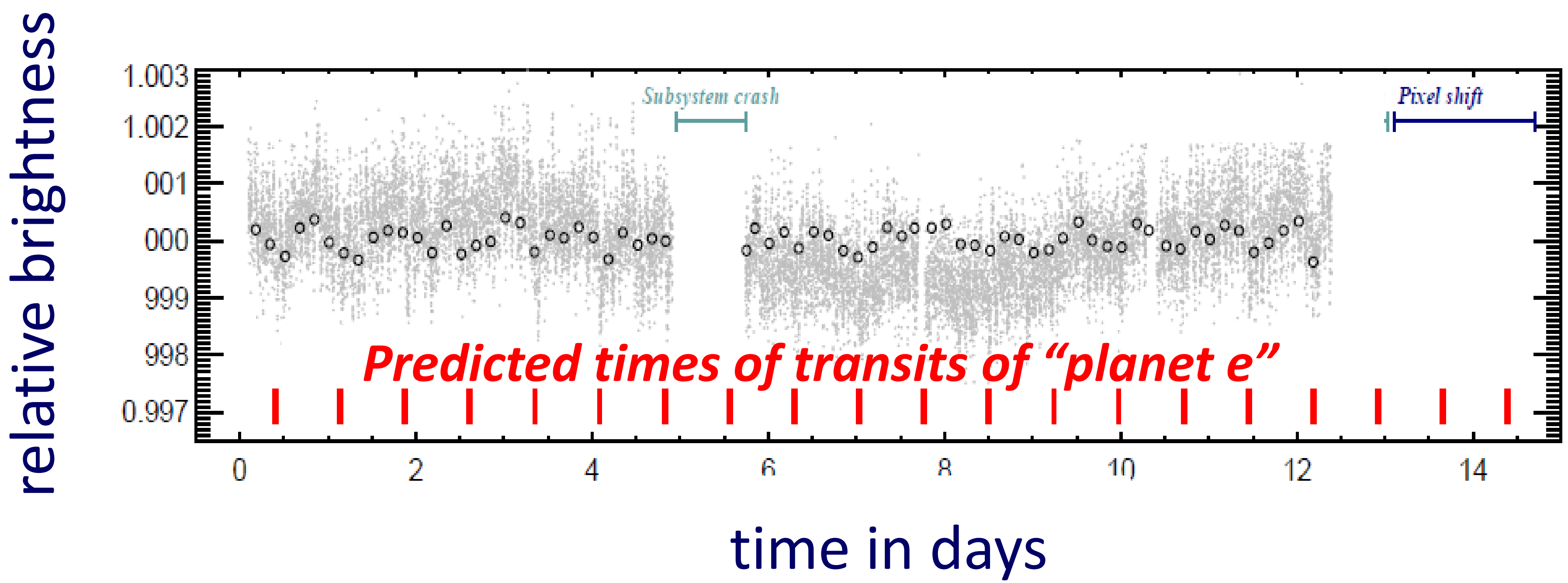


Even if we did, the *odds* are only ***1 in 4*** that the planet transits the star

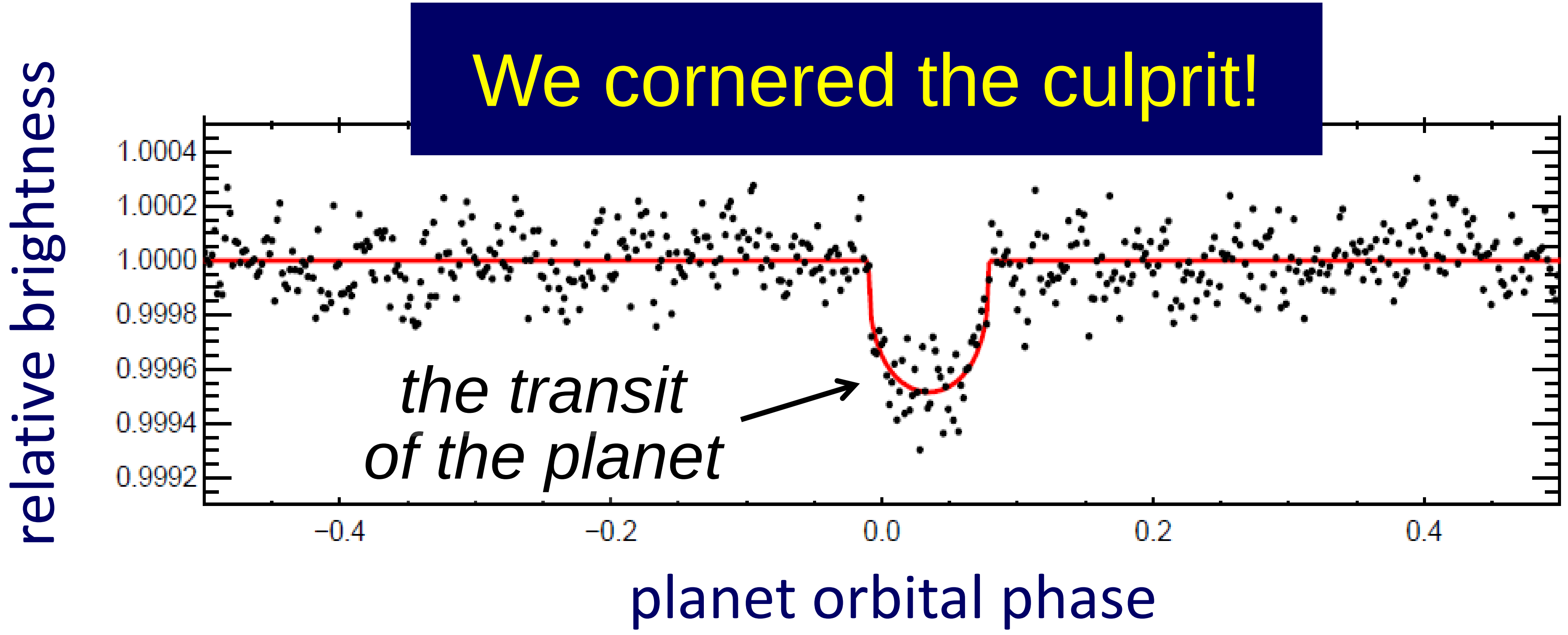
We <u>beat</u> the odds!


Jackpot!
Jackpot!
25¢
RESET
PAY TABLE
SPIN

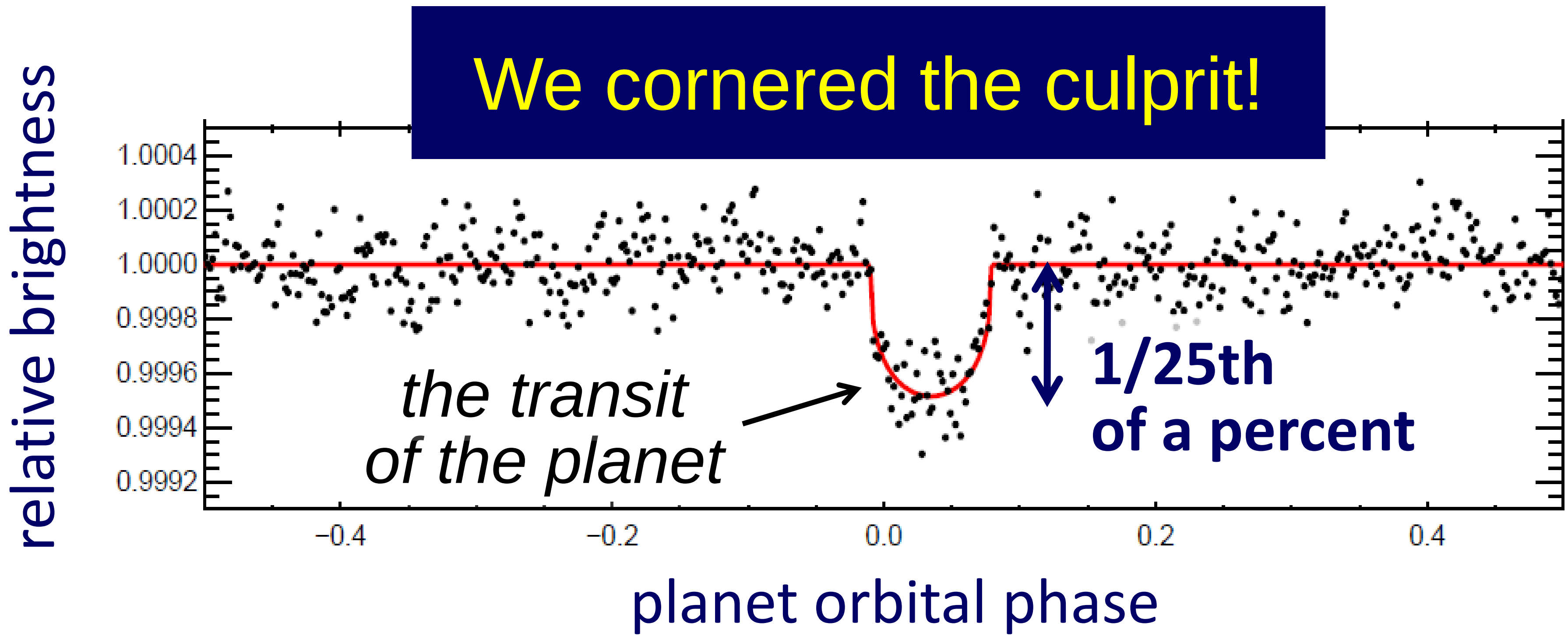
By ‘folding’ the “light curve” at the suspected orbital period of the planet



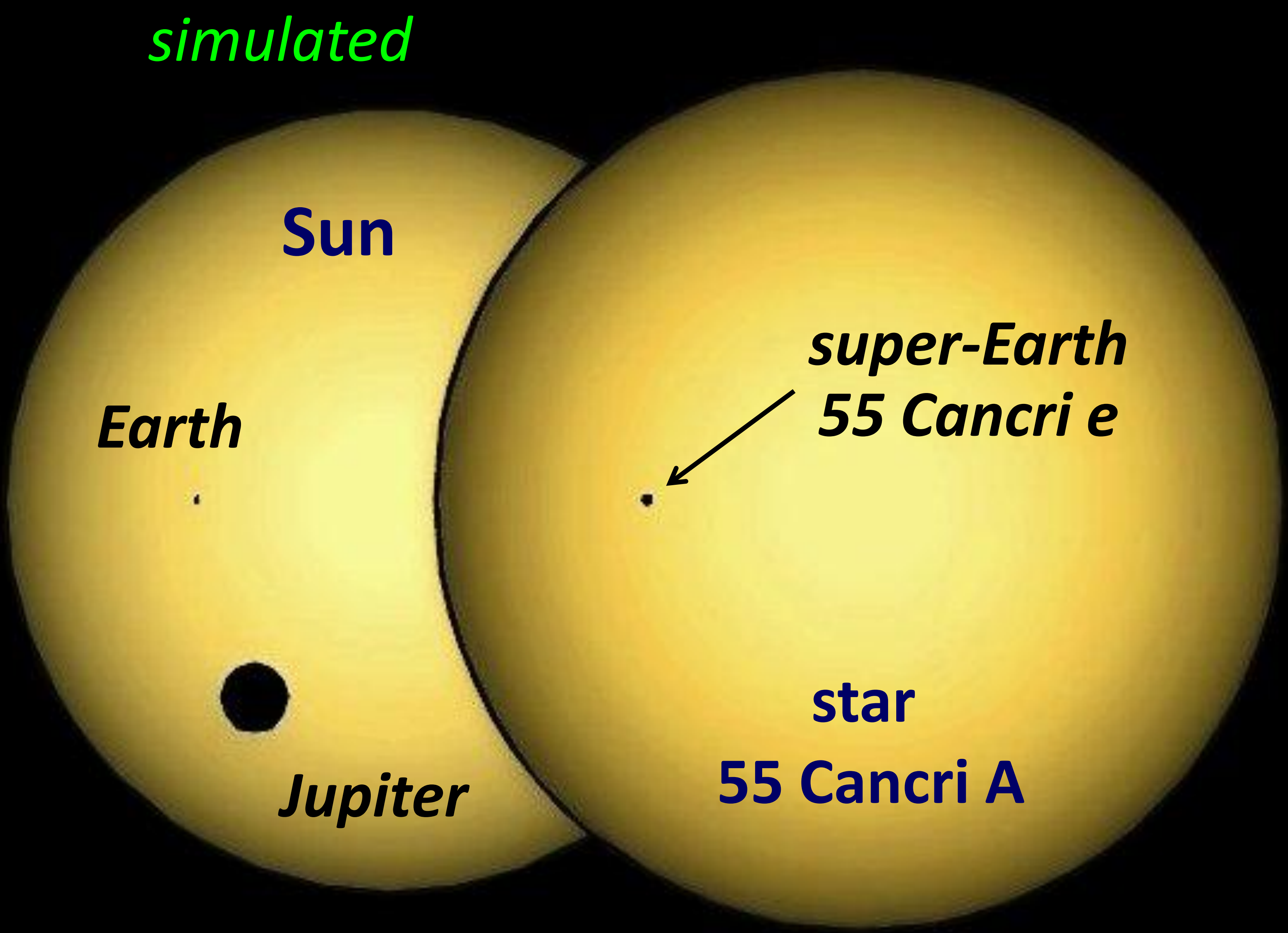
By ‘folding’ the “light curve” at the suspected orbital period of the planet, the subtle dip in the star’s brightness during each passage of the planet in front of the star becomes evident



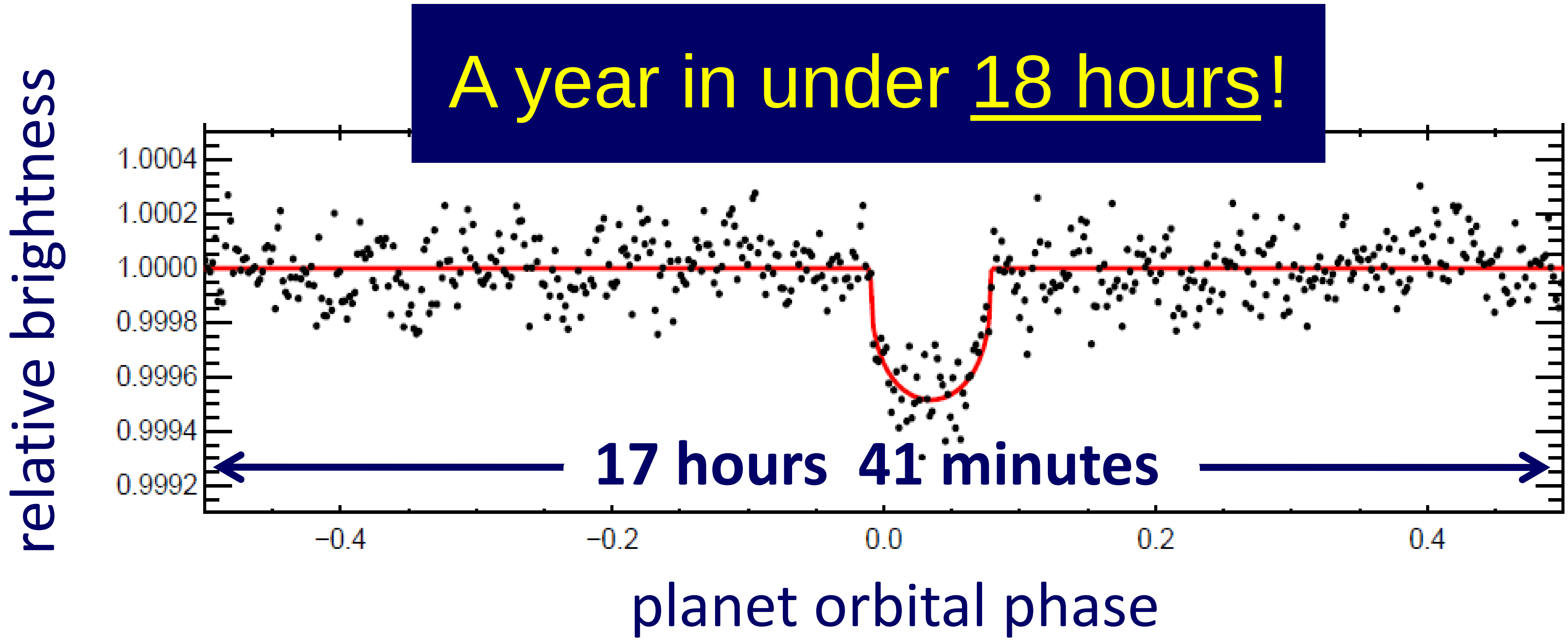
By ‘folding’ the “light curve” at the suspected orbital period of the planet, the subtle dip in the star’s brightness during each passage of the planet in front of the star becomes evident



Family portrait of two neighbours

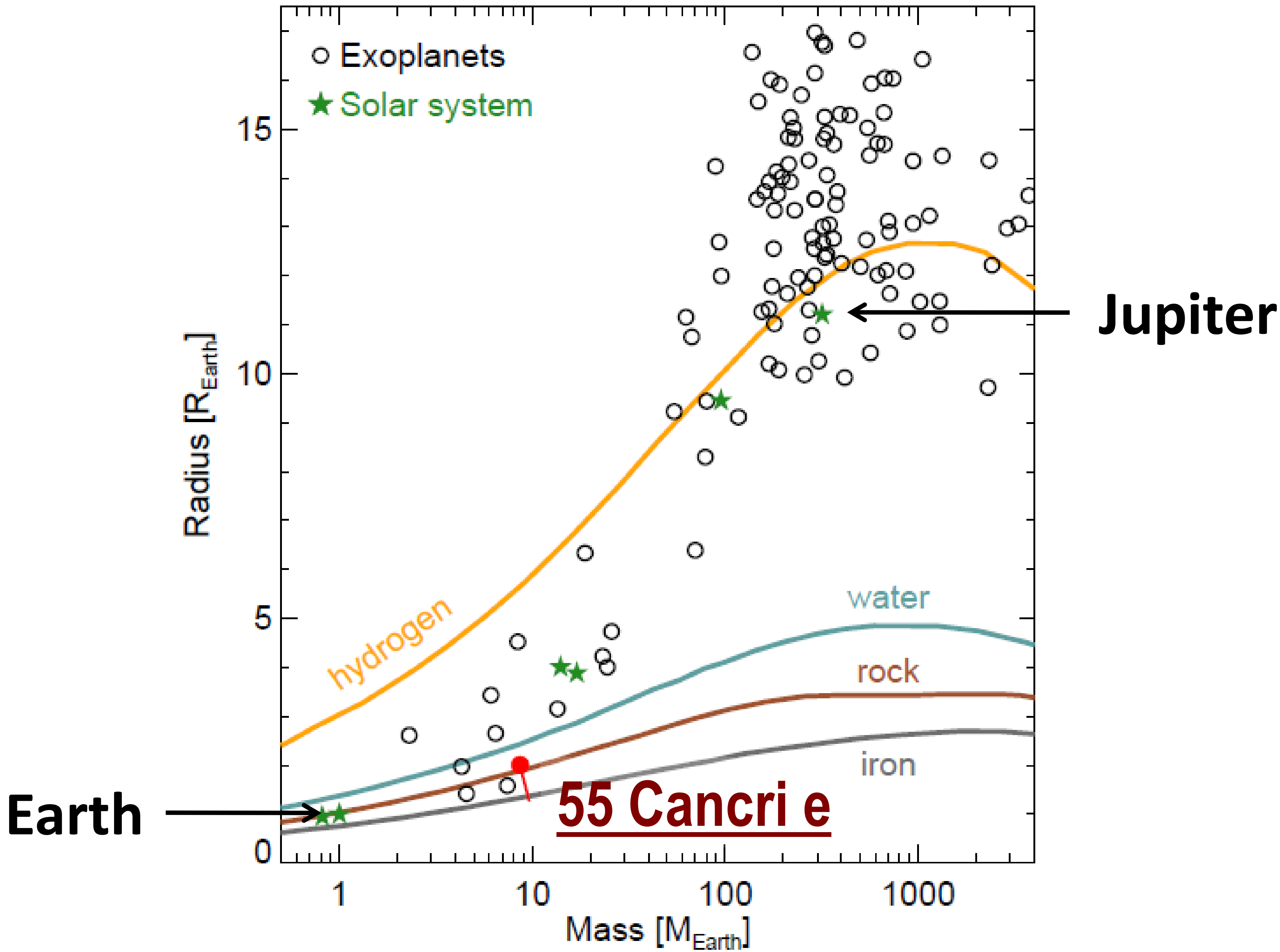


By ‘folding’ the “light curve” at the suspected <u>orbital period of the planet</u>, the subtle dip in the star’s brightness during each passage of the planet in front of the star becomes evident

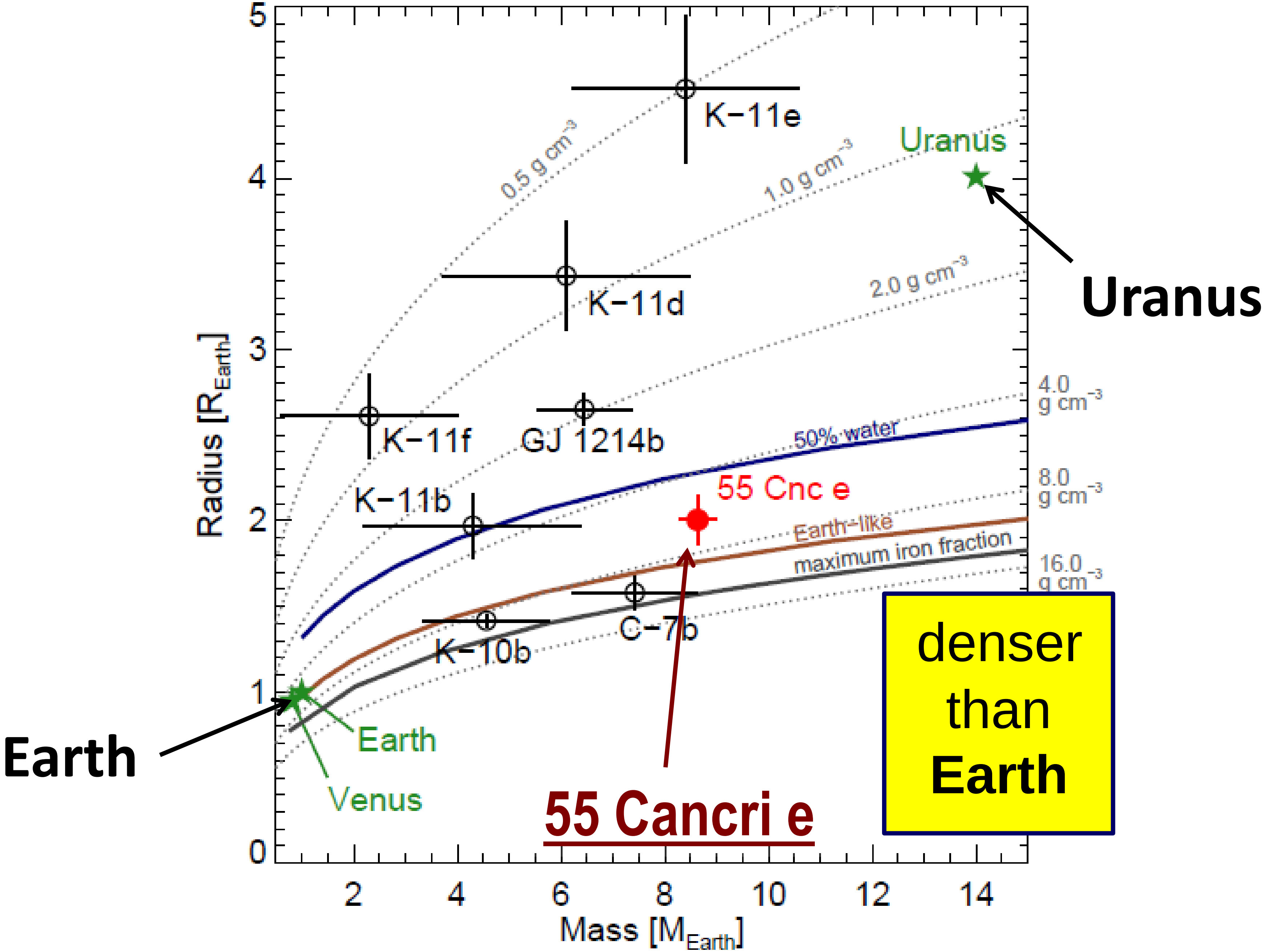


Romance on Earth

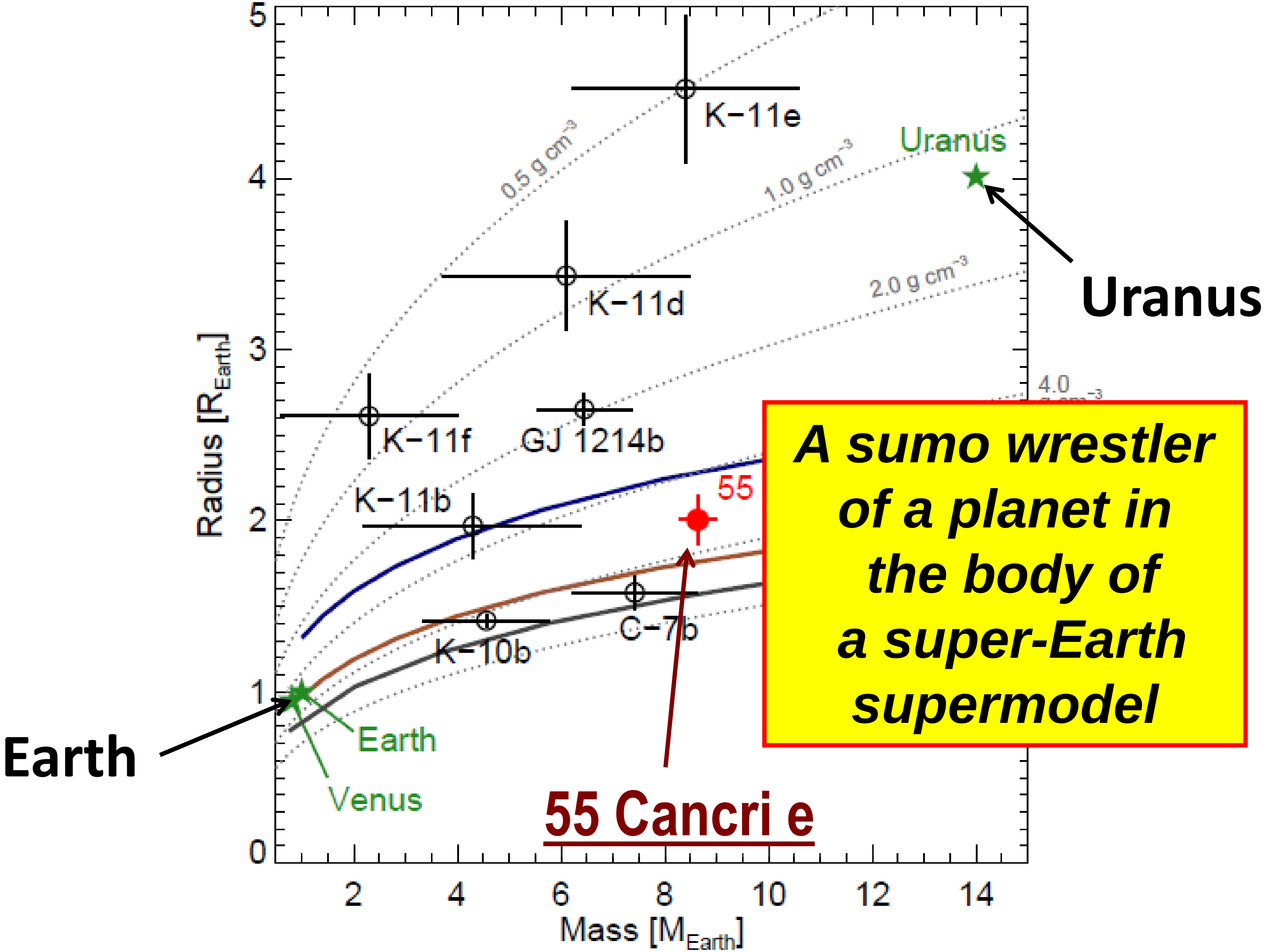
Romance on 55 Cnc e



Exoplanets
Solar system
hydrogen
water
rock
iron
Jupiter
Earth
55 Cancri e
Radius [R_Earth]
Mass [M_Earth]
15
10
5
0
1
10
100
1000



Radius [R_{Earth}]
Mass [M_{Earth}]
0.5 g cm^{-3}
1.0 g cm^{-3}
2.0 g cm^{-3}
4.0 g cm^{-3}
8.0 g cm^{-3}
16.0 g cm^{-3}
50% water
Earth-like
maximum iron fraction
K−11e
K−11d
K−11f
GJ 1214b
K−11b
55 Cnc e
K−10b
C−7b
Uranus
Earth
Venus
Uranus
Earth
55 Cancri e
denser than Earth

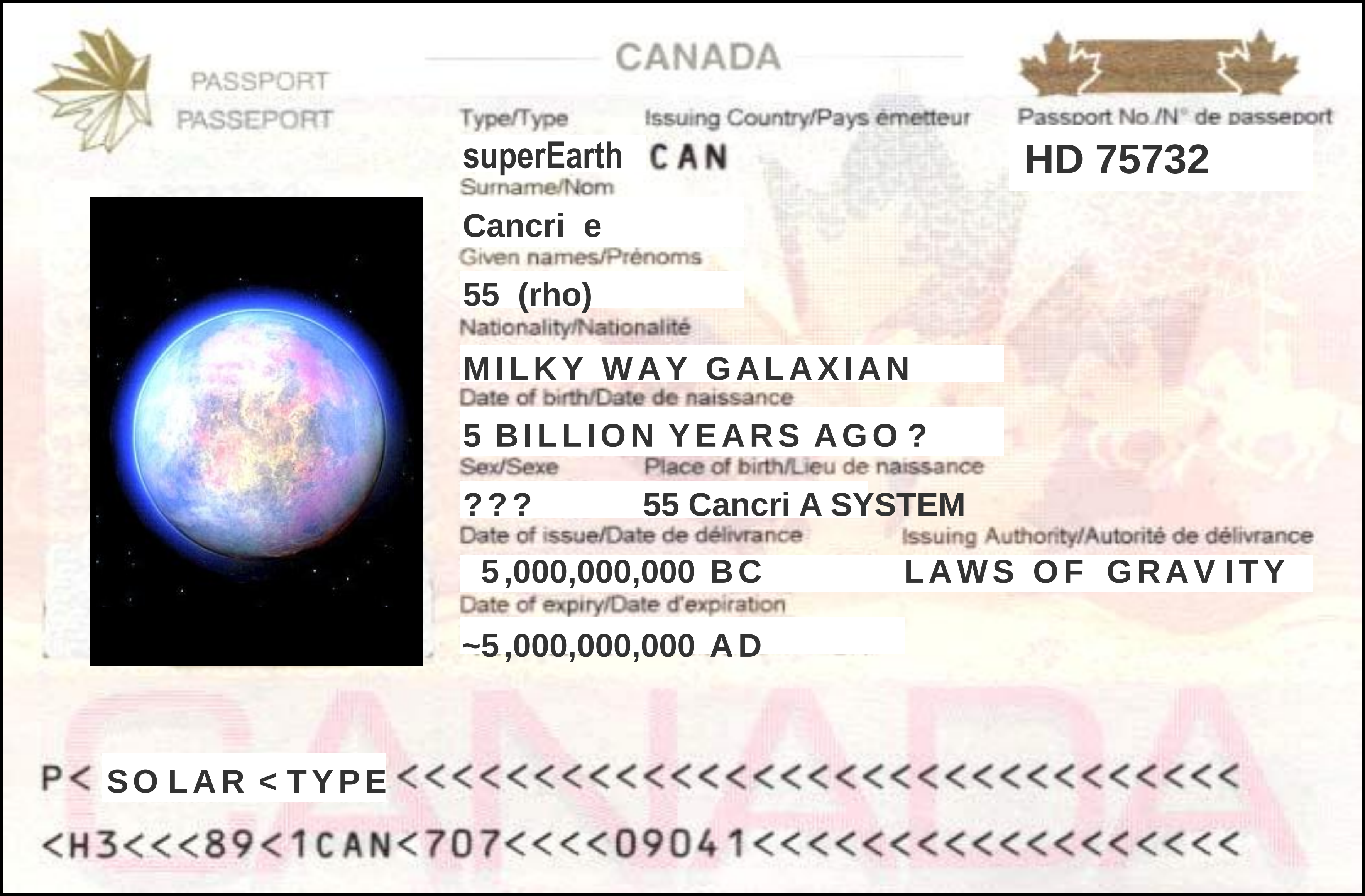


A sumo wrestler of a planet in the body of a super-Earth supermodel
Uranus
Earth
55 Cancri e
K−11e
K−11d
K−11f
GJ 1214b
K−11b
K−10b
C−7b
55
Uranus
Earth
Venus
0.5 g cm−3
1.0 g cm−3
2.0 g cm−3
4.0
Radius [R_Earth]
Mass [M_Earth]

Parameter	Value
Orbital period, P [d]	0.736540 ± 0.000003
Midtransit time [HJD]	$2,455,607.05562 \pm 0.00087$
Transit depth [ppm]	380 ± 52
Transit duration, first to fourth contact [d]	0.0658 ± 0.0013
Transit ingress or egress duration [d]	0.00134 ± 0.00011
Planet-to-star radius ratio, $R_p/R_\star$	0.0195 ± 0.0013
Transit impact parameter	0.00 ± 0.24
Orbital inclination, i [deg]	90.0 ± 3.8
Fractional stellar radius, $R_\star/a$	0.2769 ± 0.0042
Fractional planetary radius, R_p/a	0.00539 ± 0.00038
Orbital distance, a [AU]	0.01583 ± 0.00020
Amplitude of orbital phase modulation, $\epsilon_{\rm pha}$	168 ± 70
Occultation depth, $\epsilon_{\rm occ}$	48 ± 52
Planetary mass [$M_\oplus$]	8.63 ± 0.35
Planetary radius [$R_\oplus$]	2.00 ± 0.14
Planetary mean density [g cm^{-3}]	$5.9^{+1.5}_{-1.1}$
Planetary surface gravity [m s^{-2}]	$21.1^{+3.5}_{-2.7}$

Josh Winn (*MIT*), Jaymie Matthews (*UBC*), Bekki Dawson (*Harvard*)
Dan Fabrycky (*UC Santa Cruz*), Matt Holman (*Harvard-Smithsonian*)
Thomas Kallinger (*UBC, U. Vienna*) *and the rest of the MOST Team*

Clearing extraterrestial customs



CANADA

PASSPORT
PASSEPORT

Type/Type: superEarth
Issuing Country/Pays émetteur: CAN
Passport No./N° de passeport: HD 75732

Surname/Nom: Cancri e

Given names/Prénoms: 55 (rho)

Nationality/Nationalité: MILKY WAY GALAXIAN

Date of birth/Date de naissance: 5 BILLION YEARS AGO ?

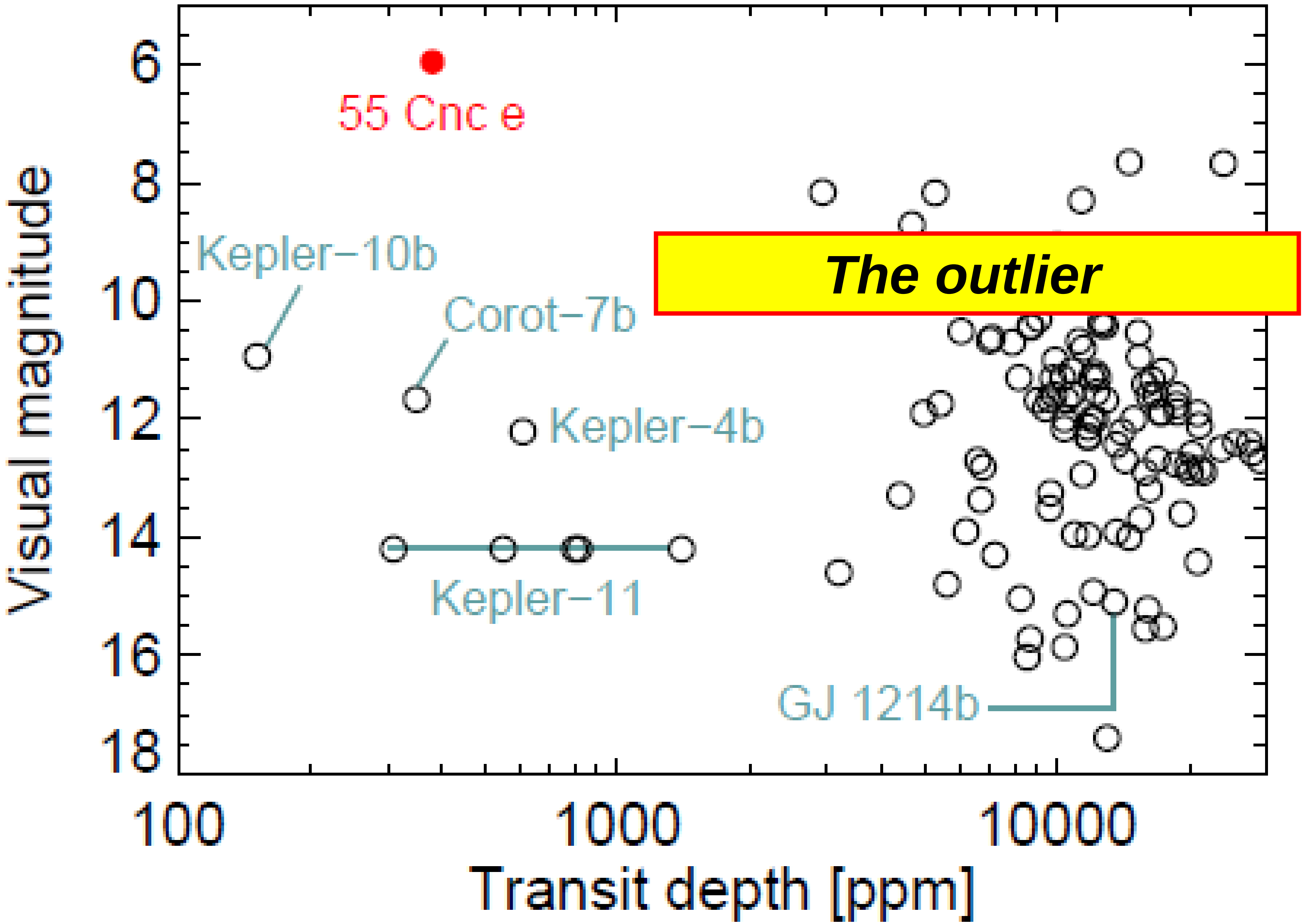
Sex/Sexe: ? ? ?
Place of birth/Lieu de naissance: 55 Cancri A SYSTEM

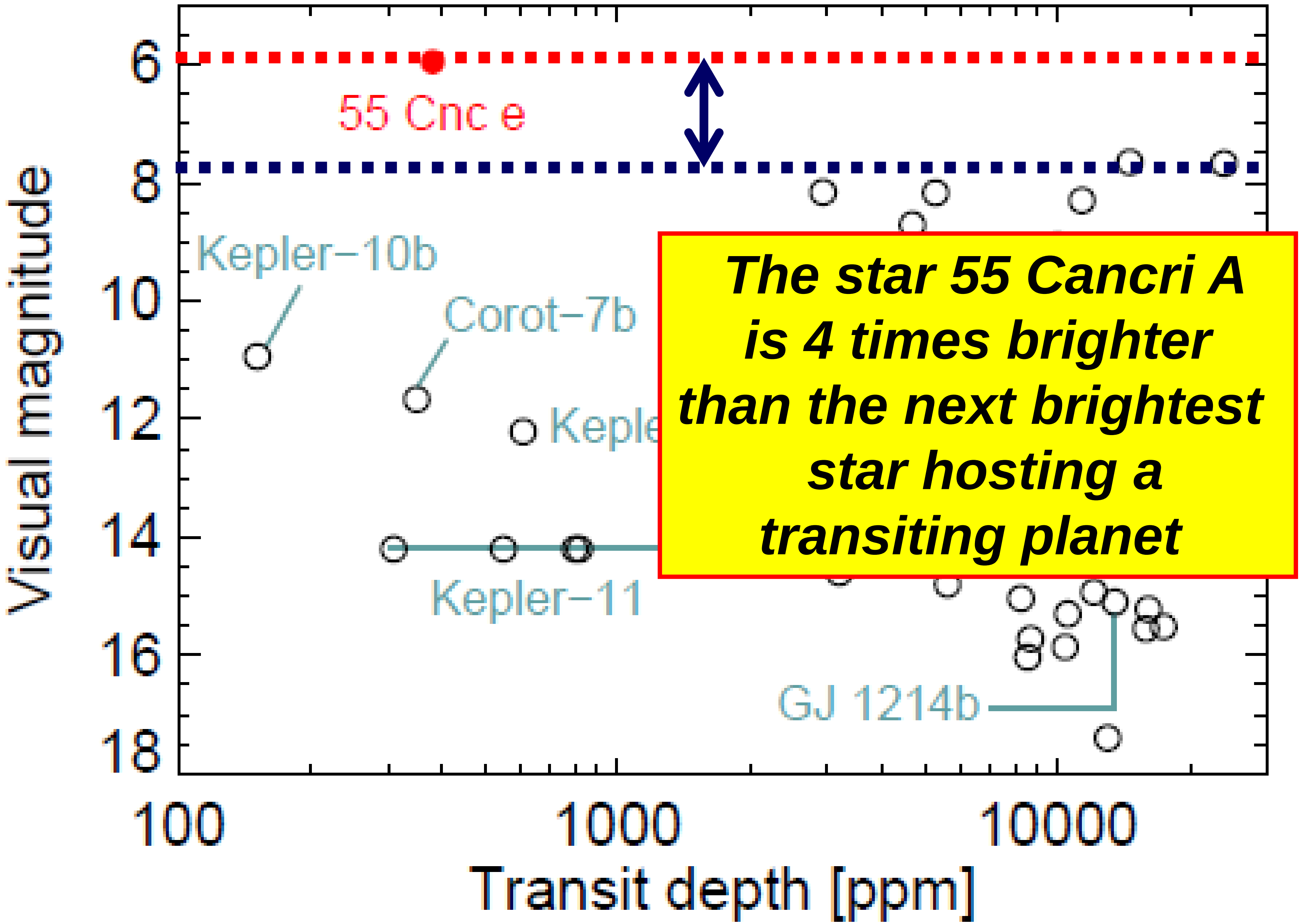
Date of issue/Date de délivrance: 5,000,000,000 BC
Issuing Authority/Autorité de délivrance: LAWS OF GRAVITY

Date of expiry/Date d'expiration: ~5,000,000,000 AD

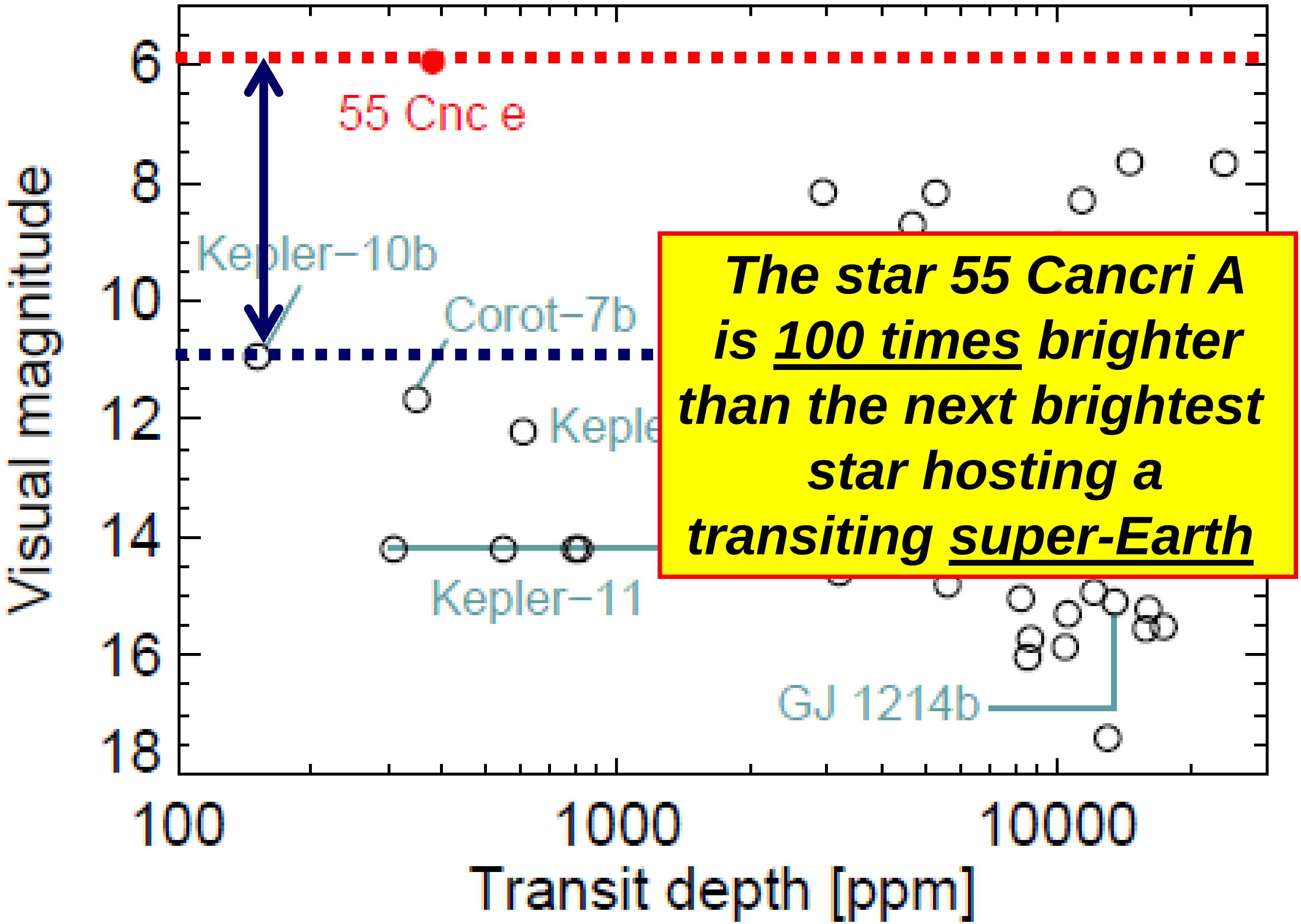
P< SOLAR <TYPE<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<

<H3<<<89<1CAN<707<<<<09041<<<<<<<<<<<<<<<<<<<<

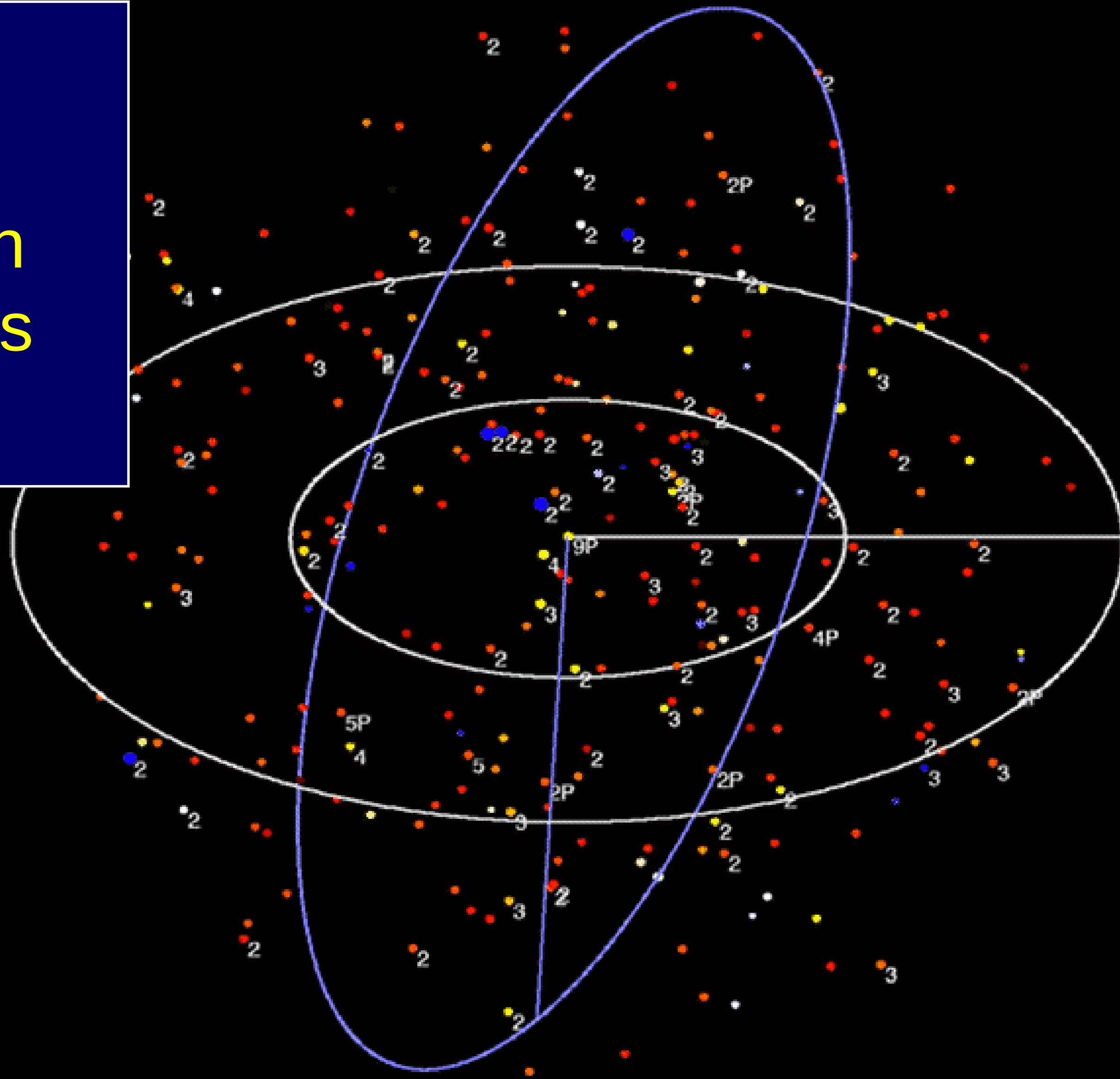

55 Cnc e
Kepler−10b
Corot−7b
Kepler−4b
Kepler−11
GJ 1214b
The outlier
Visual magnitude
Transit depth [ppm]
6
8
10
12
14
16
18
100
1000
10000



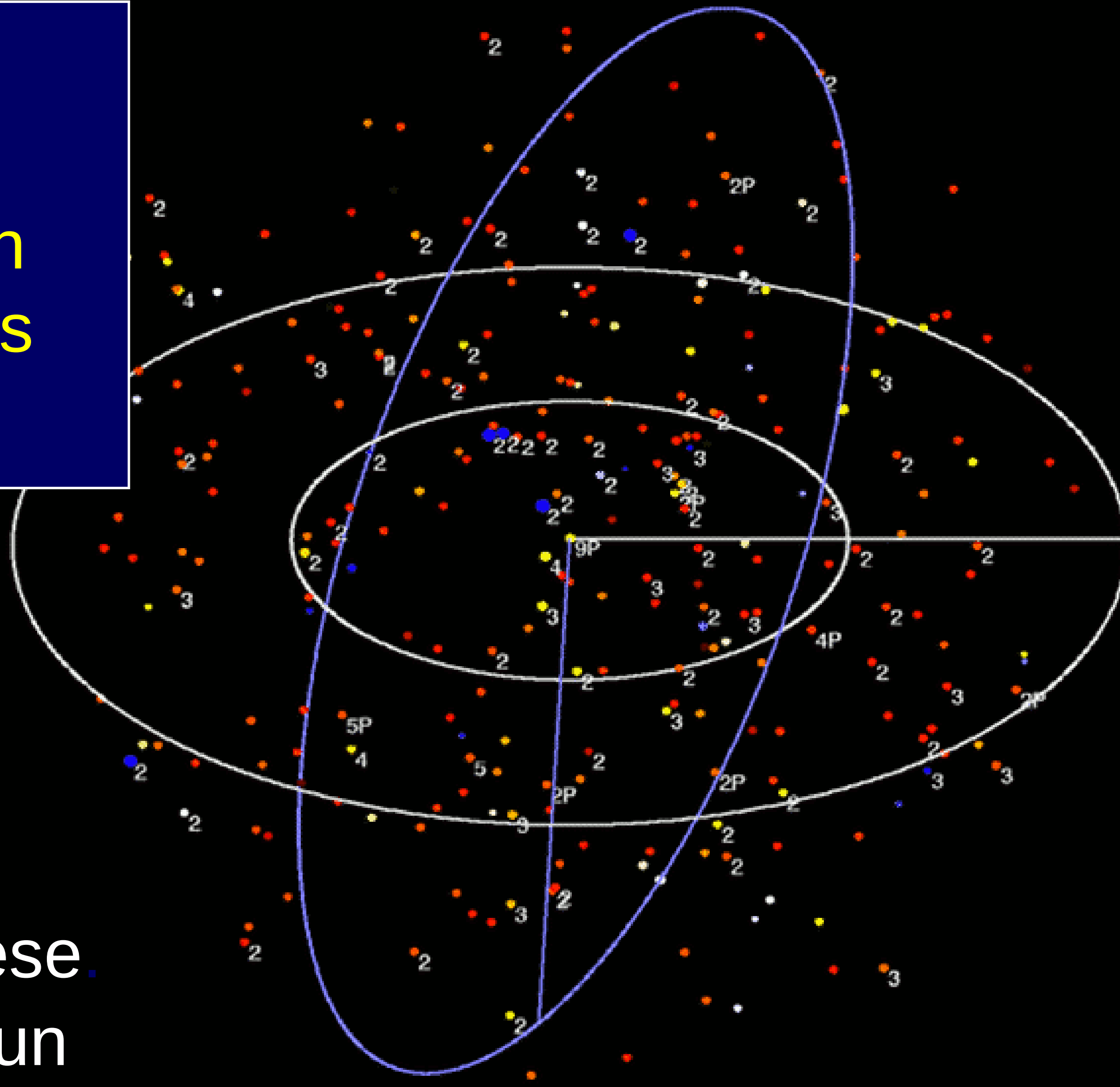
55 Cnc e
Kepler−10b
Corot−7b
Keple
Kepler−11
GJ 1214b
The star 55 Cancri A is 4 times brighter than the next brightest star hosting a transiting planet
Visual magnitude
6
8
10
12
14
16
18
100
1000
10000
Transit depth [ppm]


55 Cnc e
Kepler-10b
Corot-7b
Keple
Kepler-11
GJ 1214b
Visual magnitude
Transit depth [ppm]
6
8
10
12
14
16
18
100
1000
10000
The star 55 Cancri A is 100 times brighter than the next brightest star hosting a transiting super-Earth

There are
~ 271 stars
known within
33 light years
of Earth

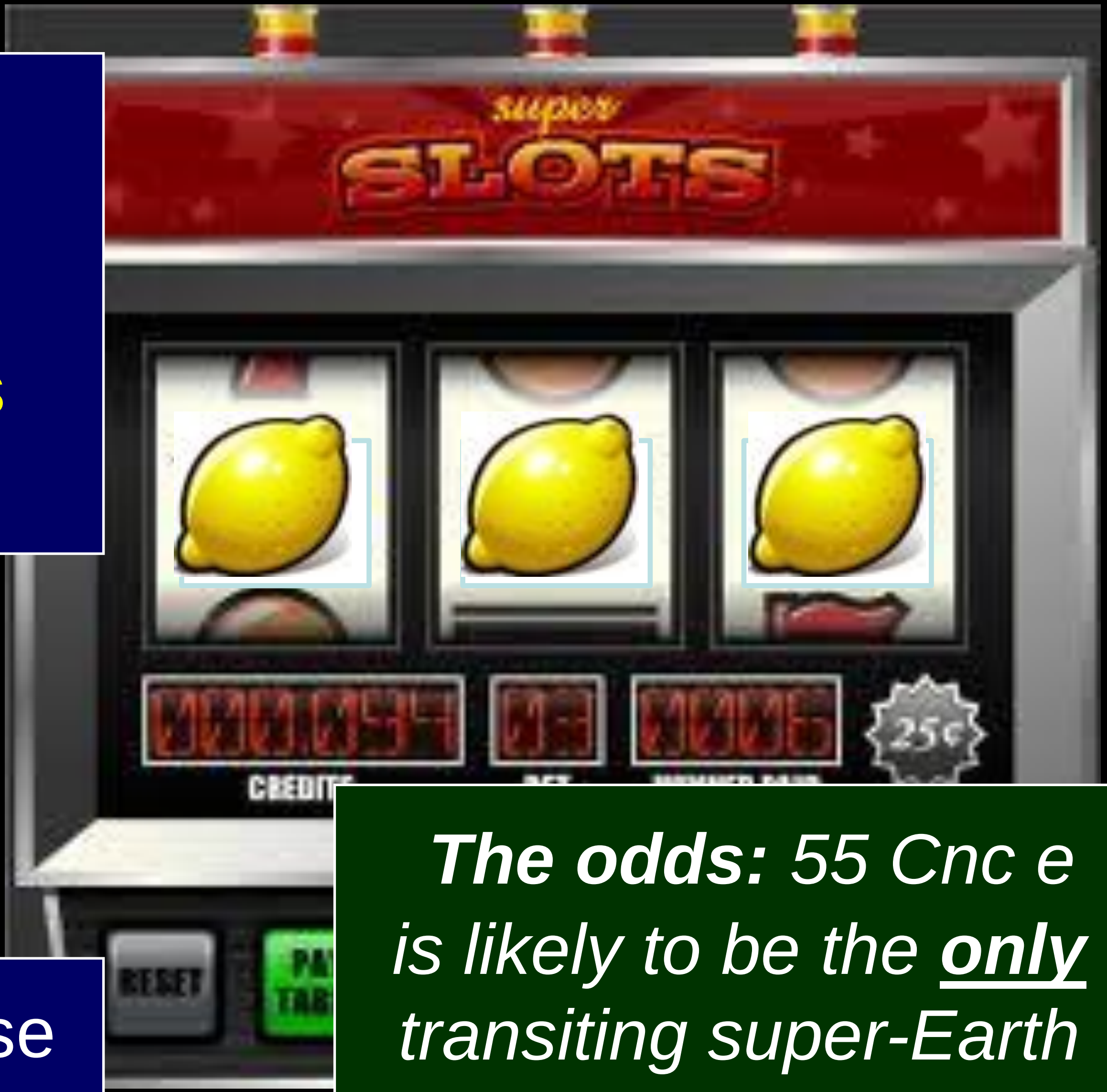


There are
~ 271 stars
known within
33 light years
of Earth



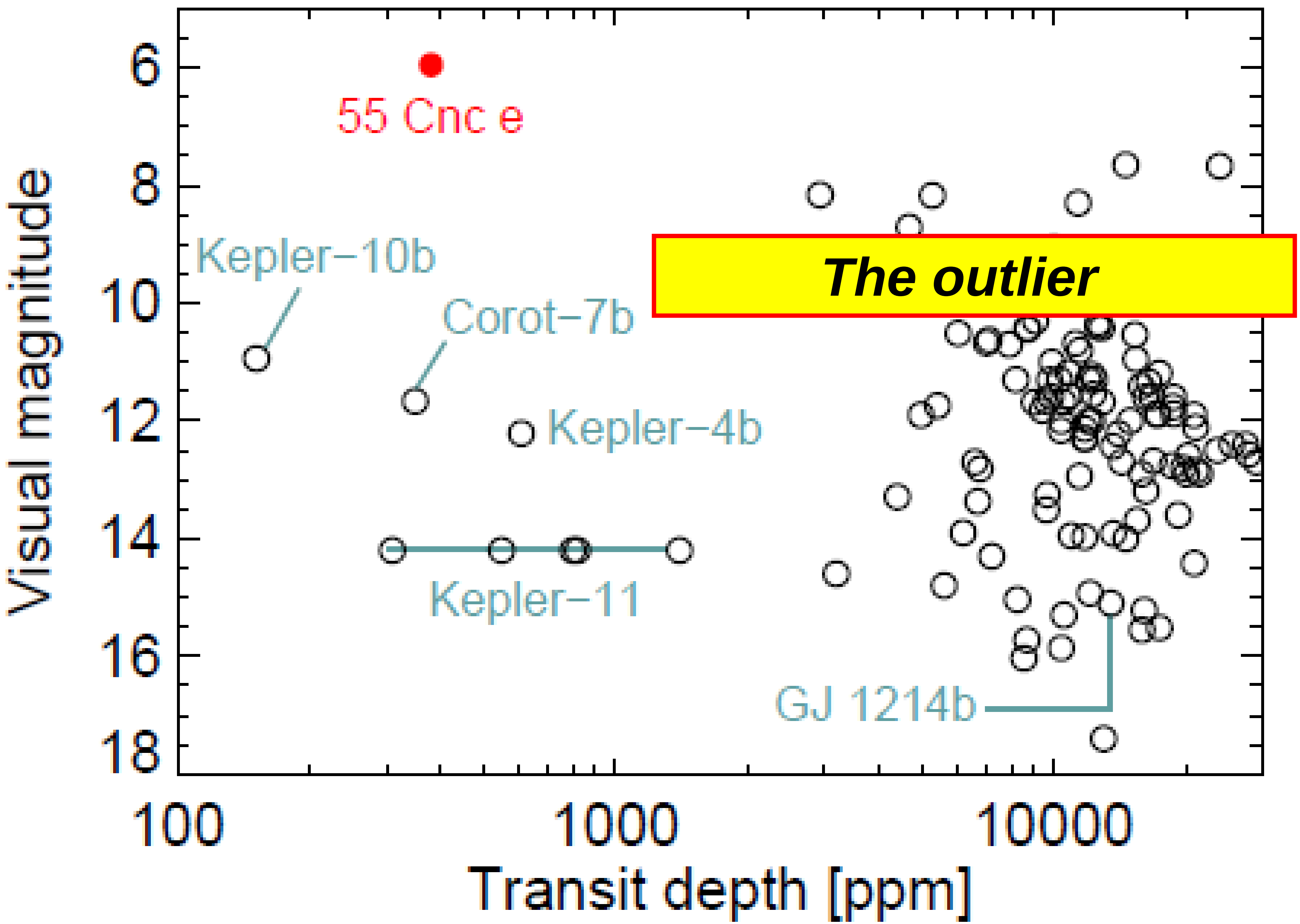
Only 20 of these
are like the Sun

There are
~ 271 stars
known within
33 light years
of Earth

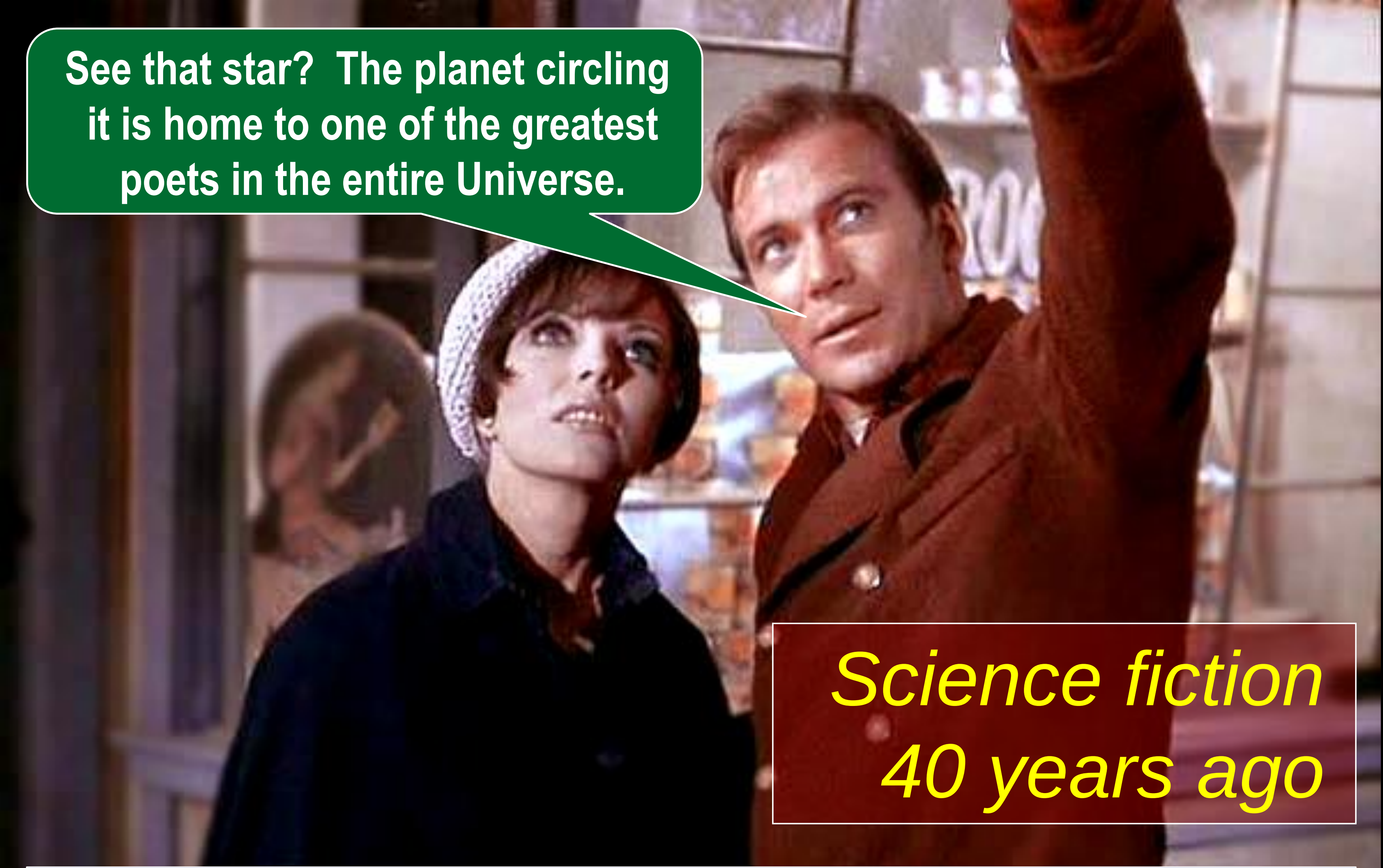


Only 20 of these
are like the Sun

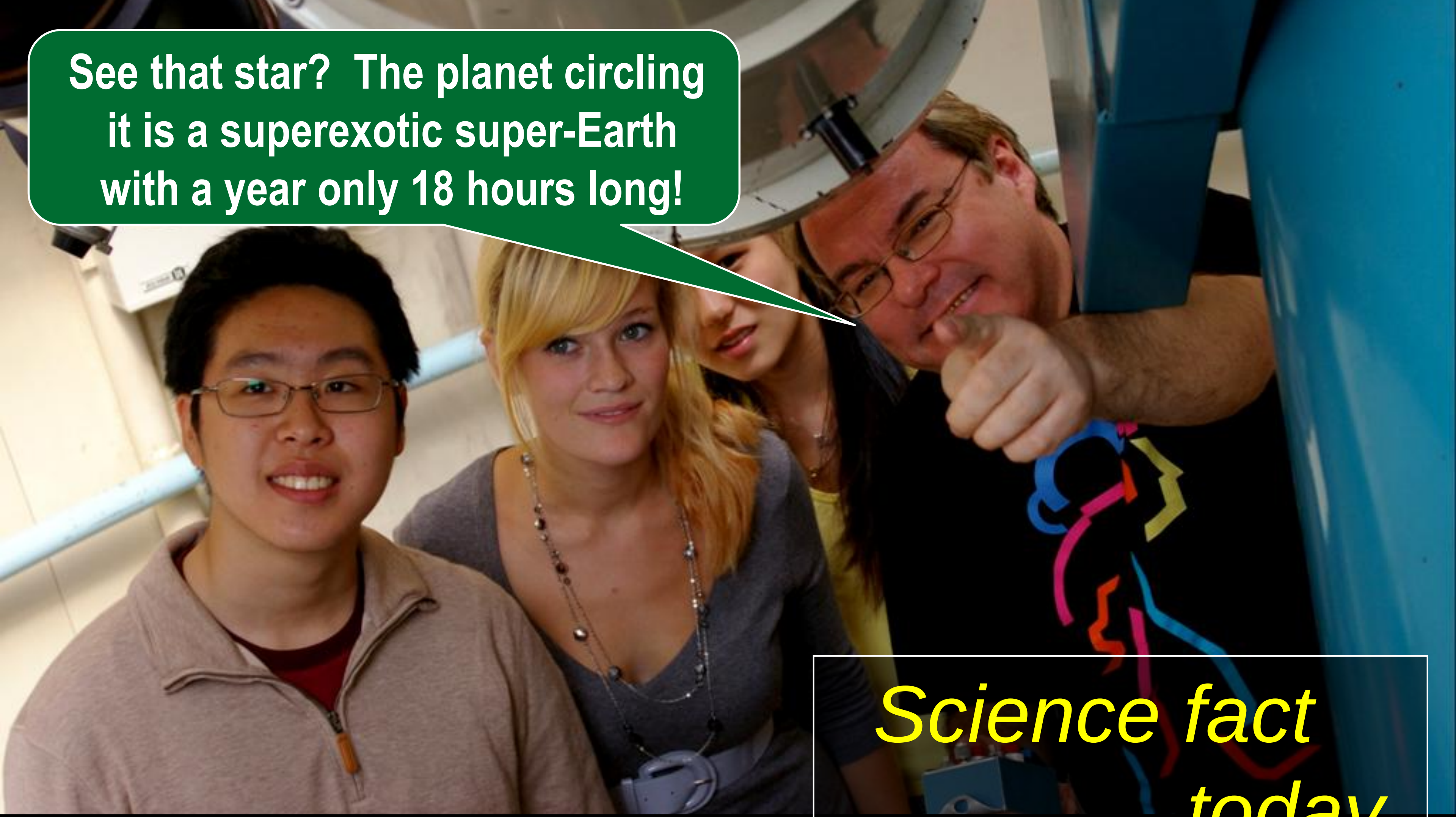
The odds: *55 Cnc e
is likely to be the **<u>only</u>**
transiting super-Earth
within 40 light years*


55 Cnc e
Kepler−10b
Corot−7b
Kepler−4b
Kepler−11
GJ 1214b
The outlier
Visual magnitude
Transit depth [ppm]
6
8
10
12
14
16
18
100
1000
10000

You can see this star *by eye*

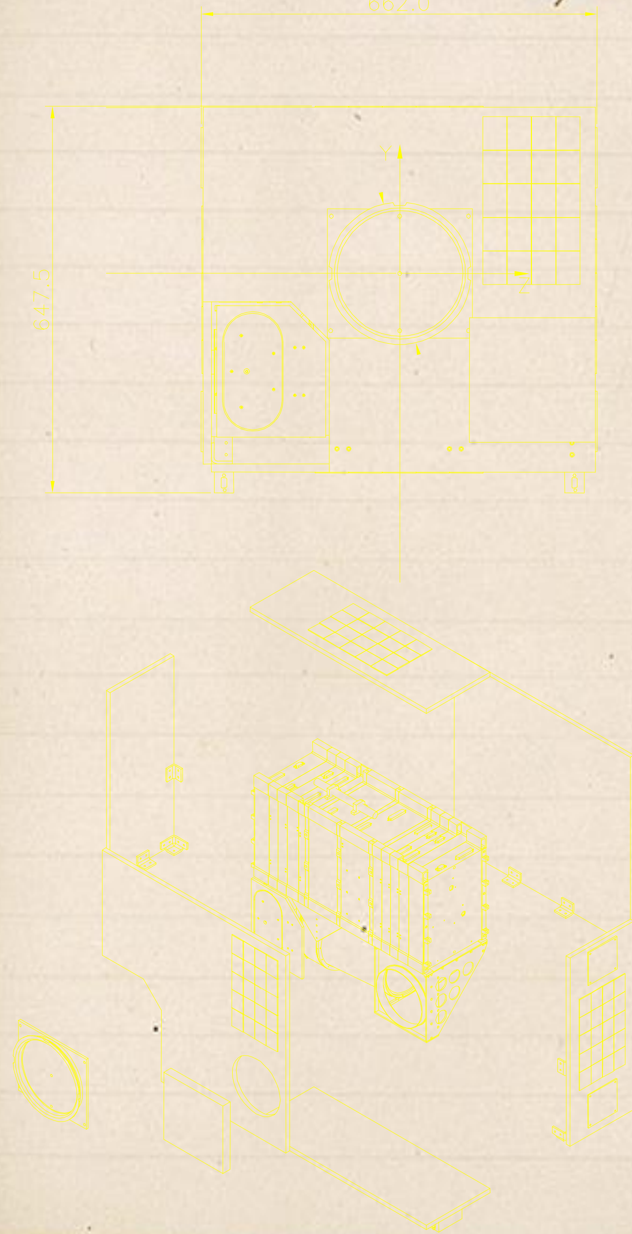


Scene from the Star Trek episode *The City of the Edge of Forever* where Captain Kirk woos Edith Keeler on Earth in the 1930’s

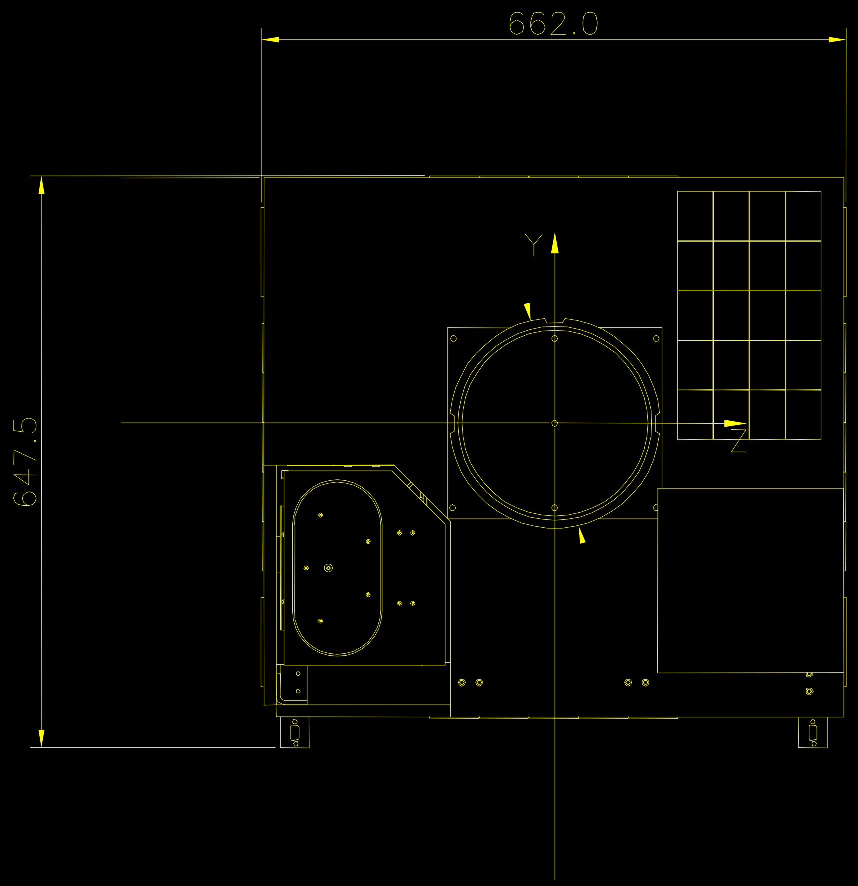


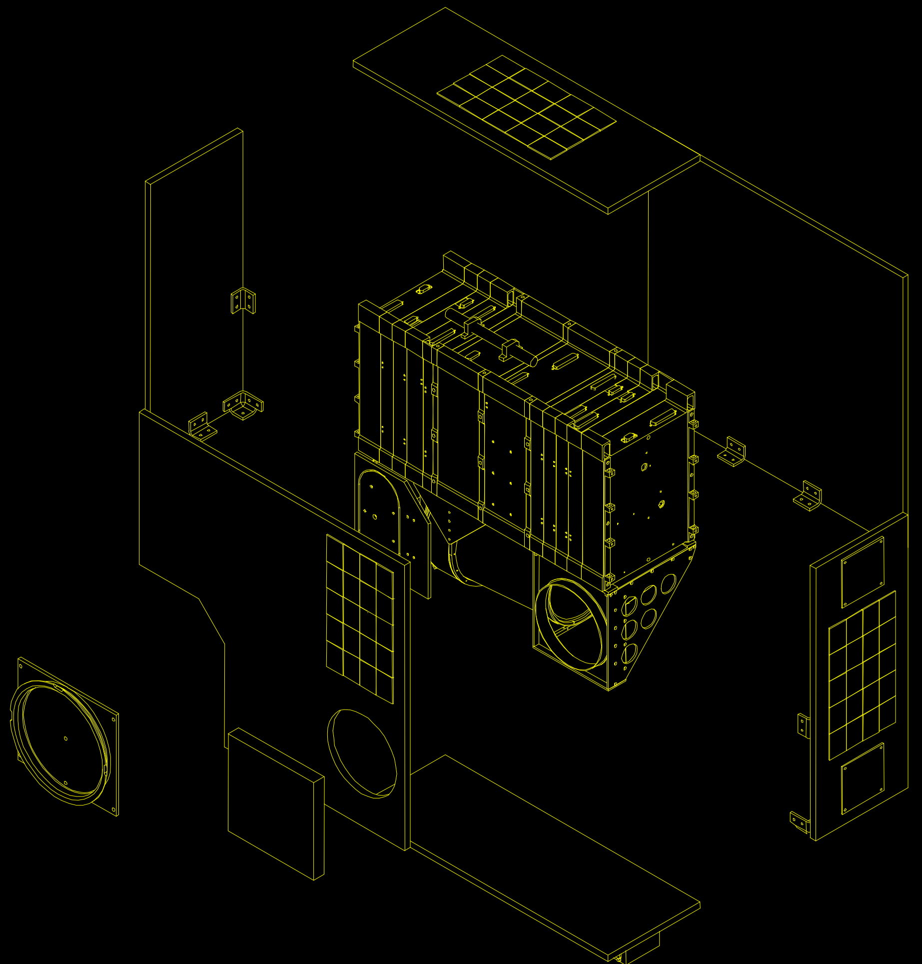
Scene from the *UBC Department of Physics & Astronomy* where Captain Jaymie introduces students to the cosmos

Blueprints for the MOST microsatellite mission

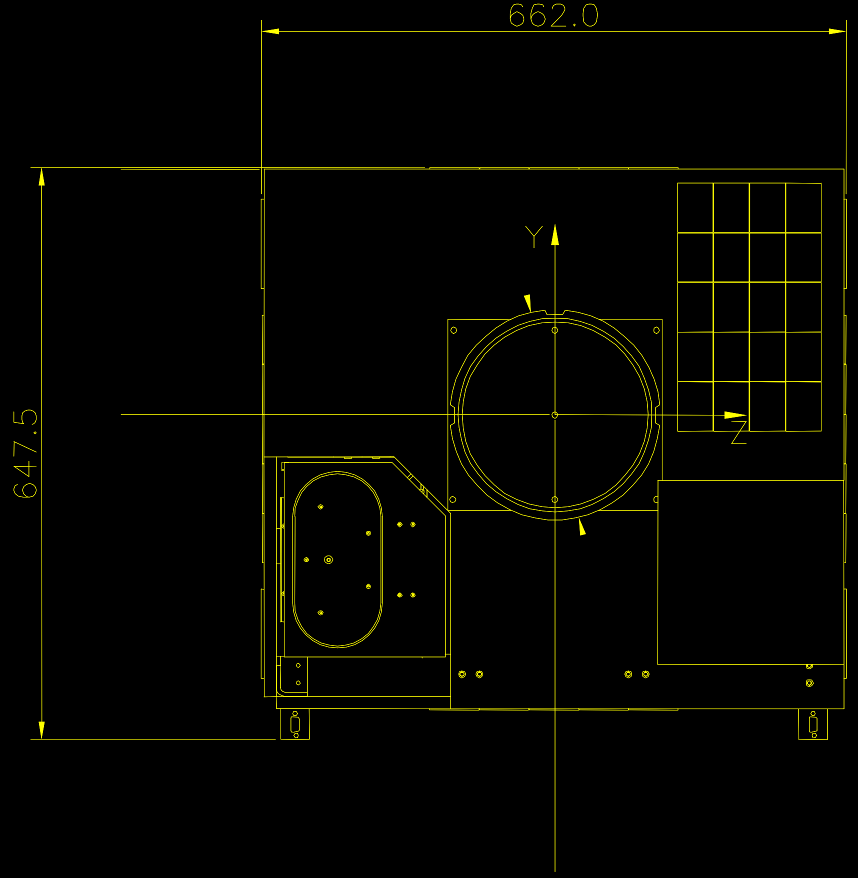


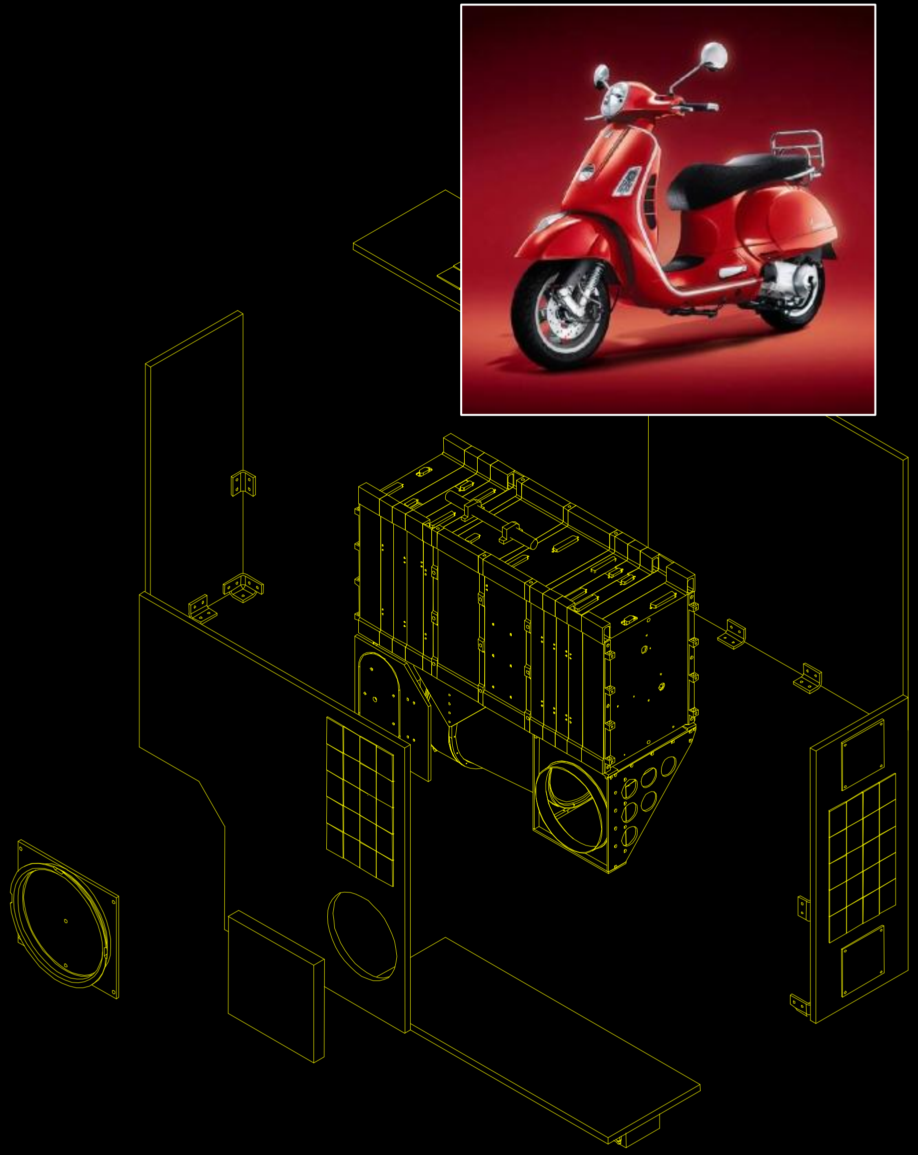
Layout of the MOST bus

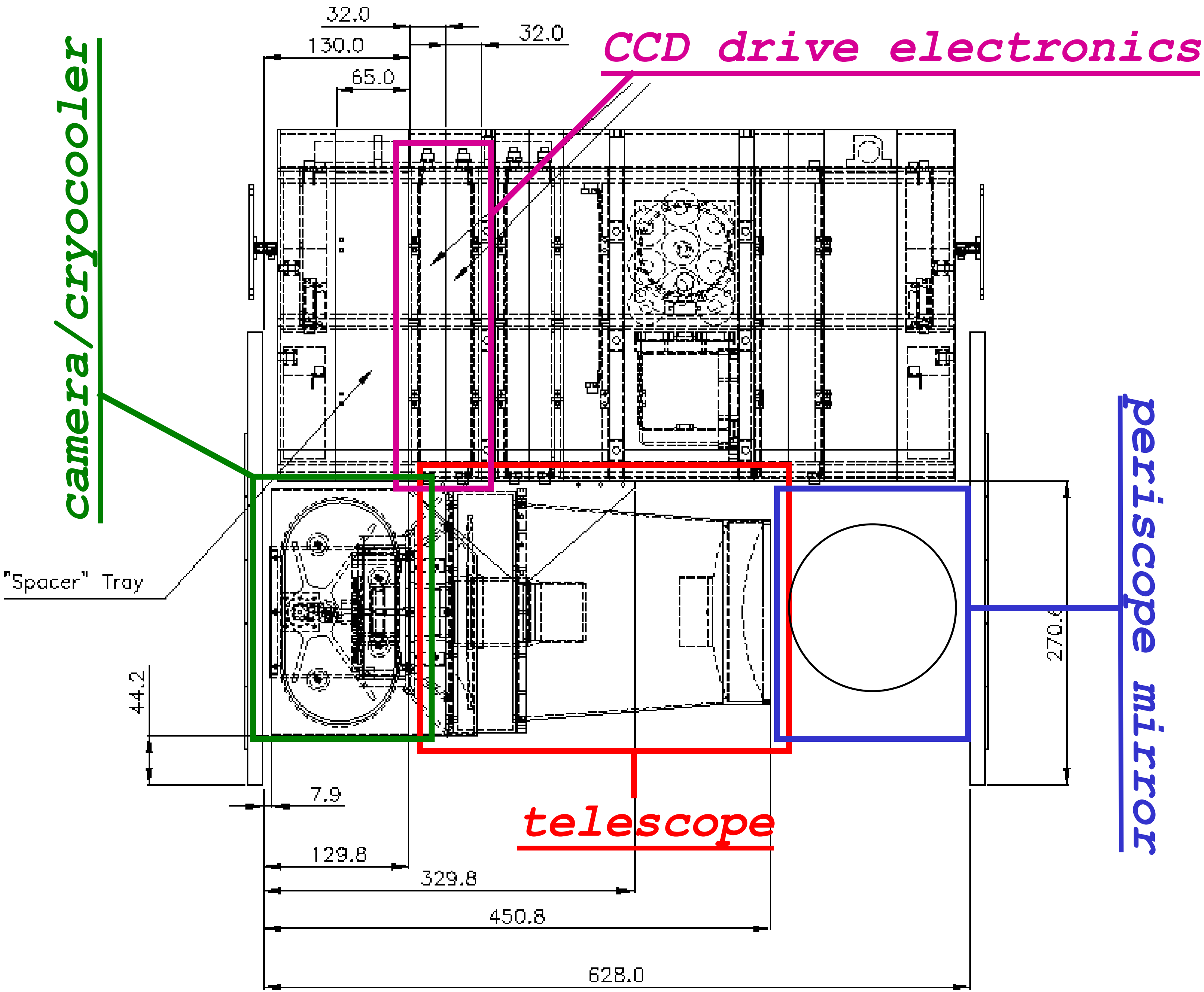




Layout of the MOST bus Vespa







CCD drive electronics
camera/cryocooler
periscope mirror
telescope
"Spacer" Tray
32.0
130.0
65.0
32.0
44.2
7.9
129.8
329.8
450.8
628.0
270.0

Rulebook for the MOST microsatellite mission

- ✓ only <u>one egg</u> in the basket
- ✓ <u>R & R</u> resilience & redundancy
- ✓ <u>autonomous</u> operations even if conditions change
- ✓ <u>high performance</u>
- ✓ low cost, power, mass, volume, bandwidth, …

Rulebook for most robotic observatories

- ✓ only one egg in the basket
- ✓ R & R resilience & redundancy
- ✓ autonomous operations even if conditions change
- ✓ high performance
- ✓ low cost, power, mass, volume, bandwidth, …

Rulebook for the MOST microsatellite mission

- ✓ only one egg in the basket
- ✓ R & R resilience & redundancy
- ✓ autonomous operations even if conditions change
- ✓ high performance
- ✓ low cost, power, mass, volume, bandwidth, …

mass and power budgets

instrument only

mass

instrument = 12.5 kg

electronics = 0.5 kg

13.0 kg

power

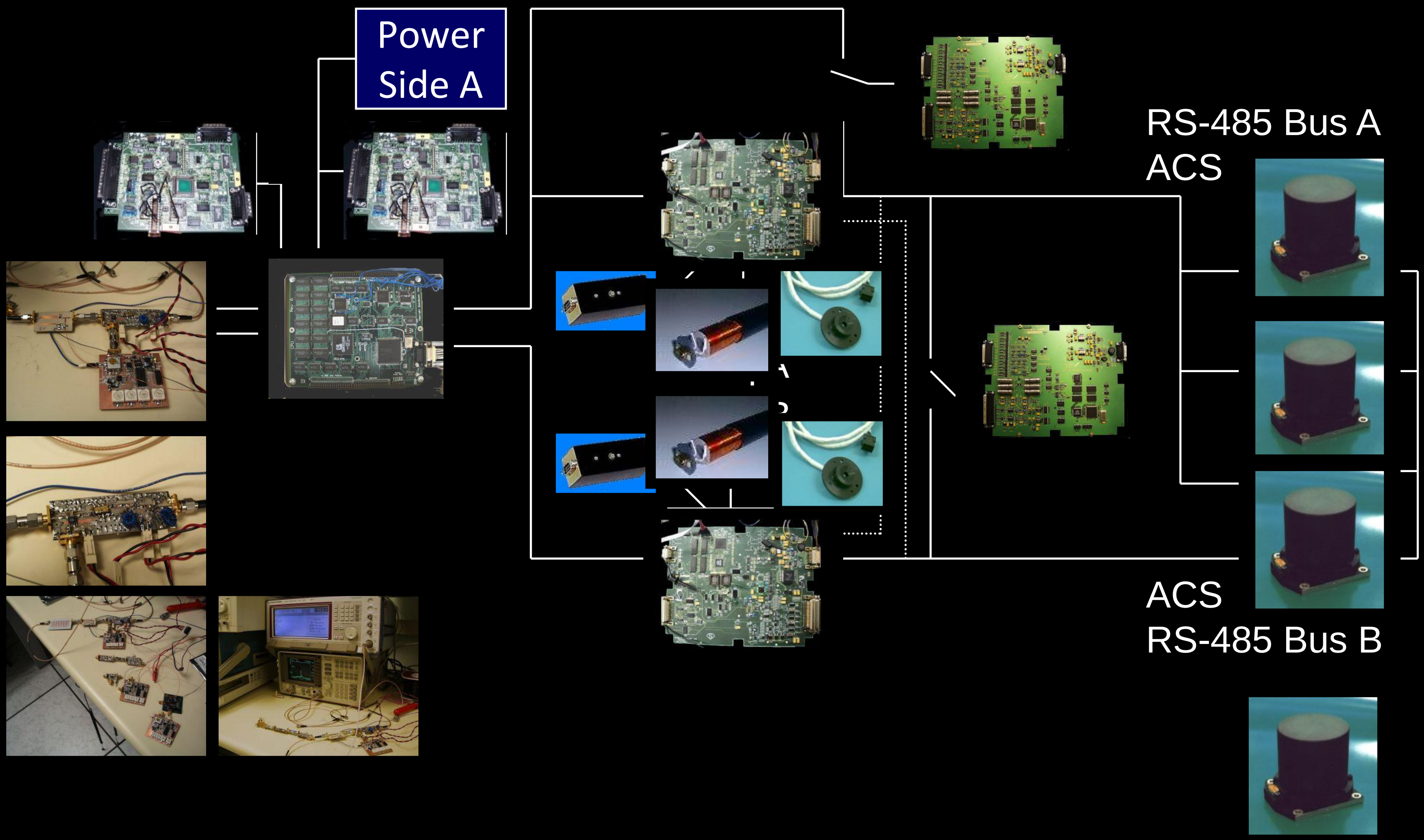
CCD & TCS ~ 7 W

peak power consumption

Rulebook for the MOST microsatellite mission

- ✓ only one egg in the basket
- ✓ R & R resilience & redundancy
- ✓ autonomous operations even if conditions change
- ✓ high performance
- ✓ low cost, power, mass, volume, bandwidth, …

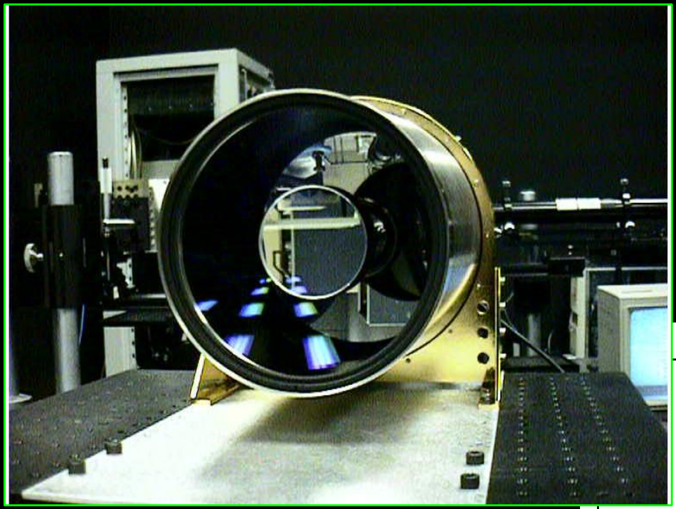
Spacecraft block diagram



Rulebook for the MOST microsatellite mission

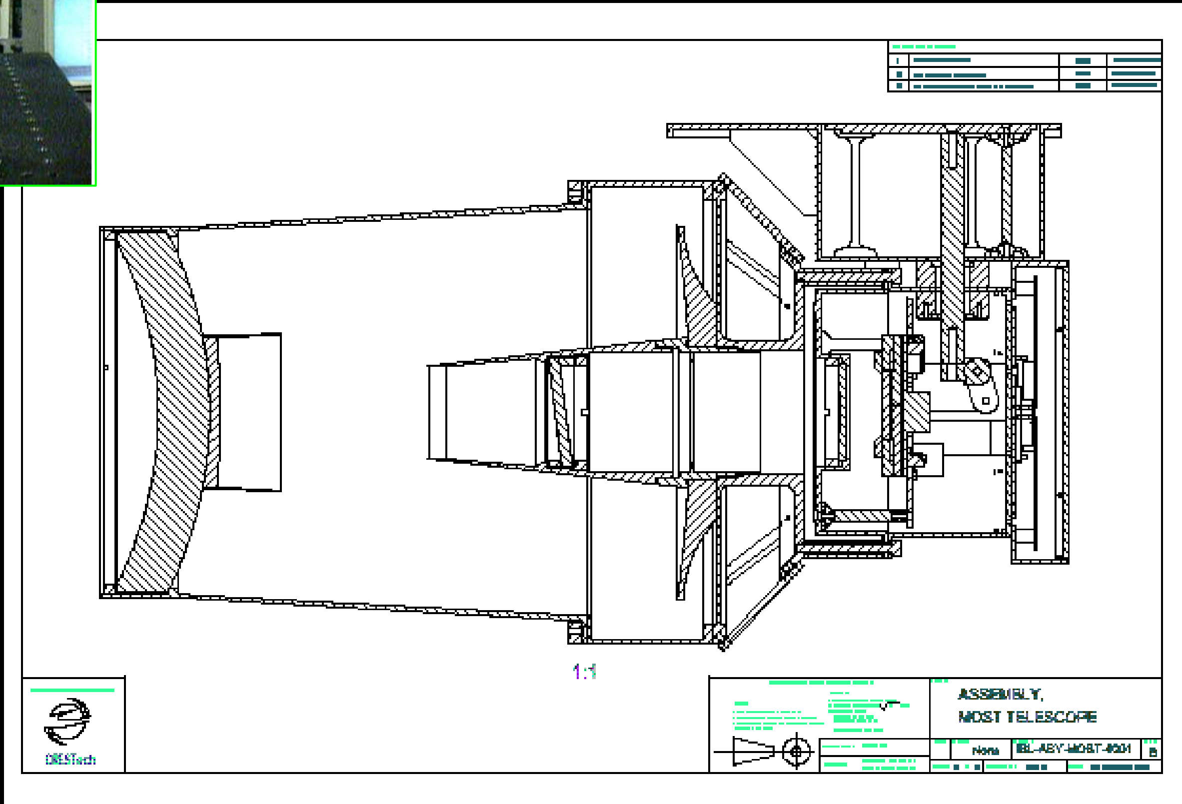
- ✓ only one egg in the basket
- ✓ R & R resilience & redundancy
- ✓ autonomous operations even if conditions change
- ✓ high performance
- ✓ low cost, power, mass, volume, bandwidth, …

MOST instrument

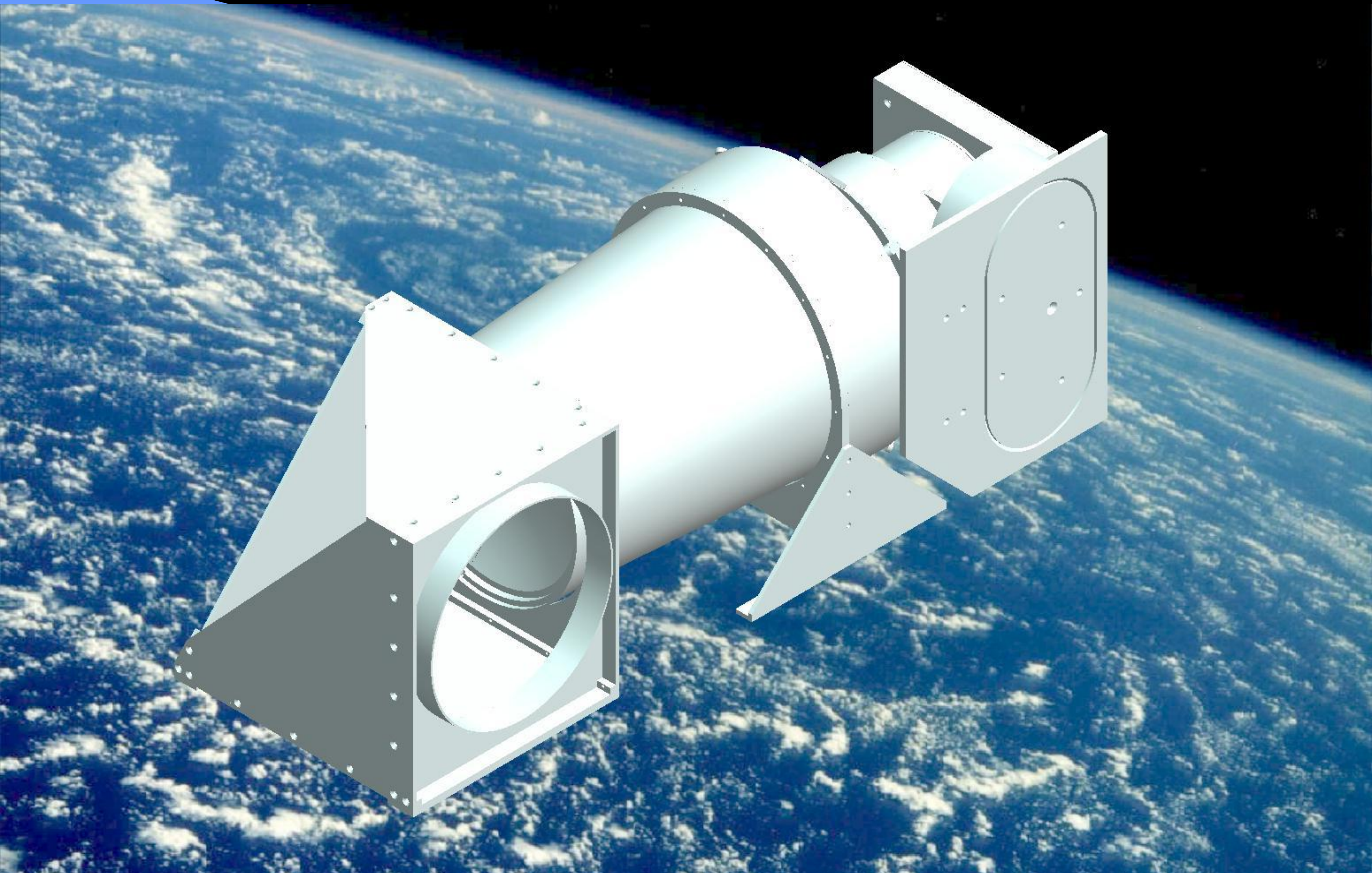


Maksutov telescope

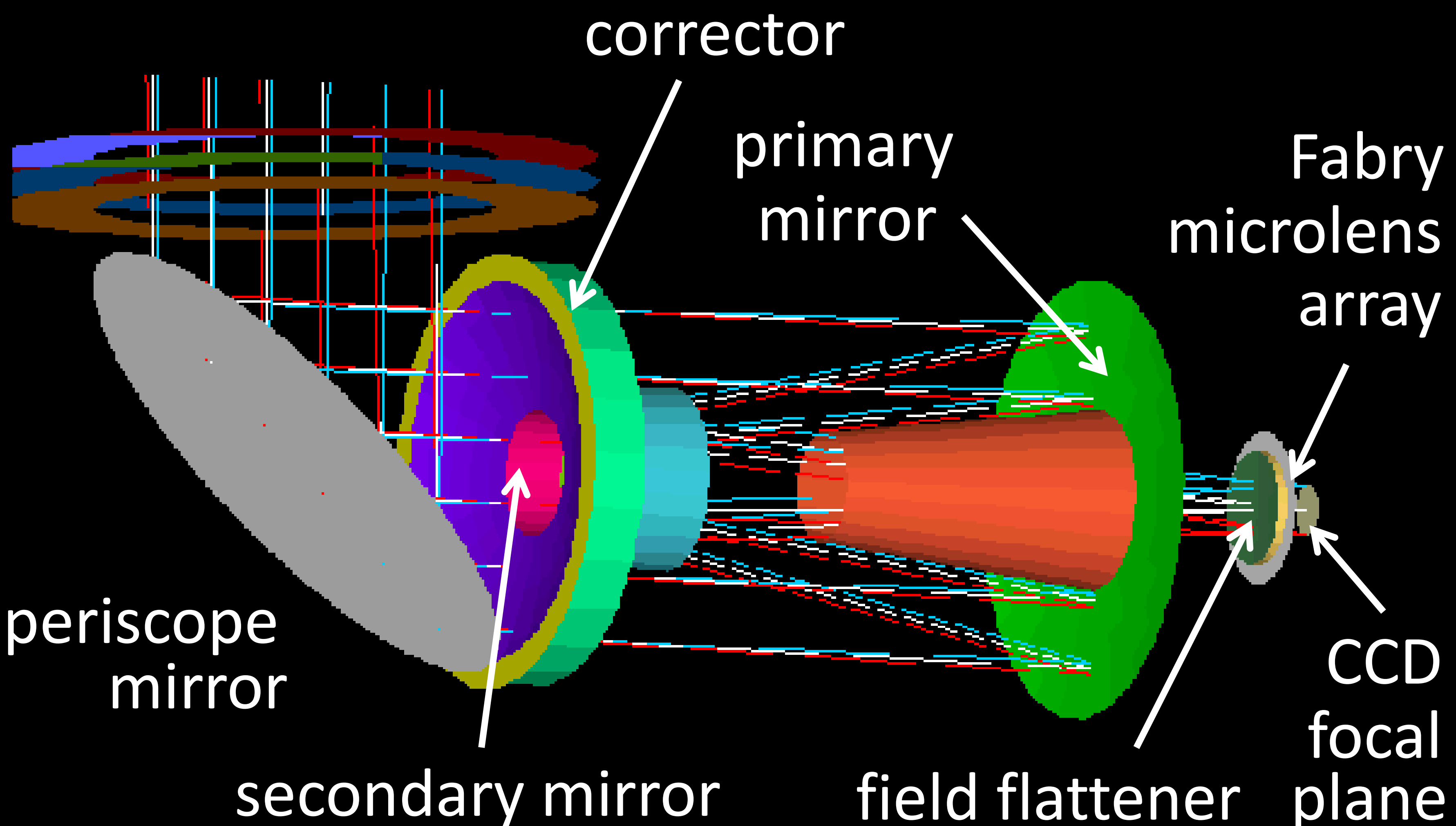
- ✓ aperture = 15 cm
- ✓ field of view = 2° diameter



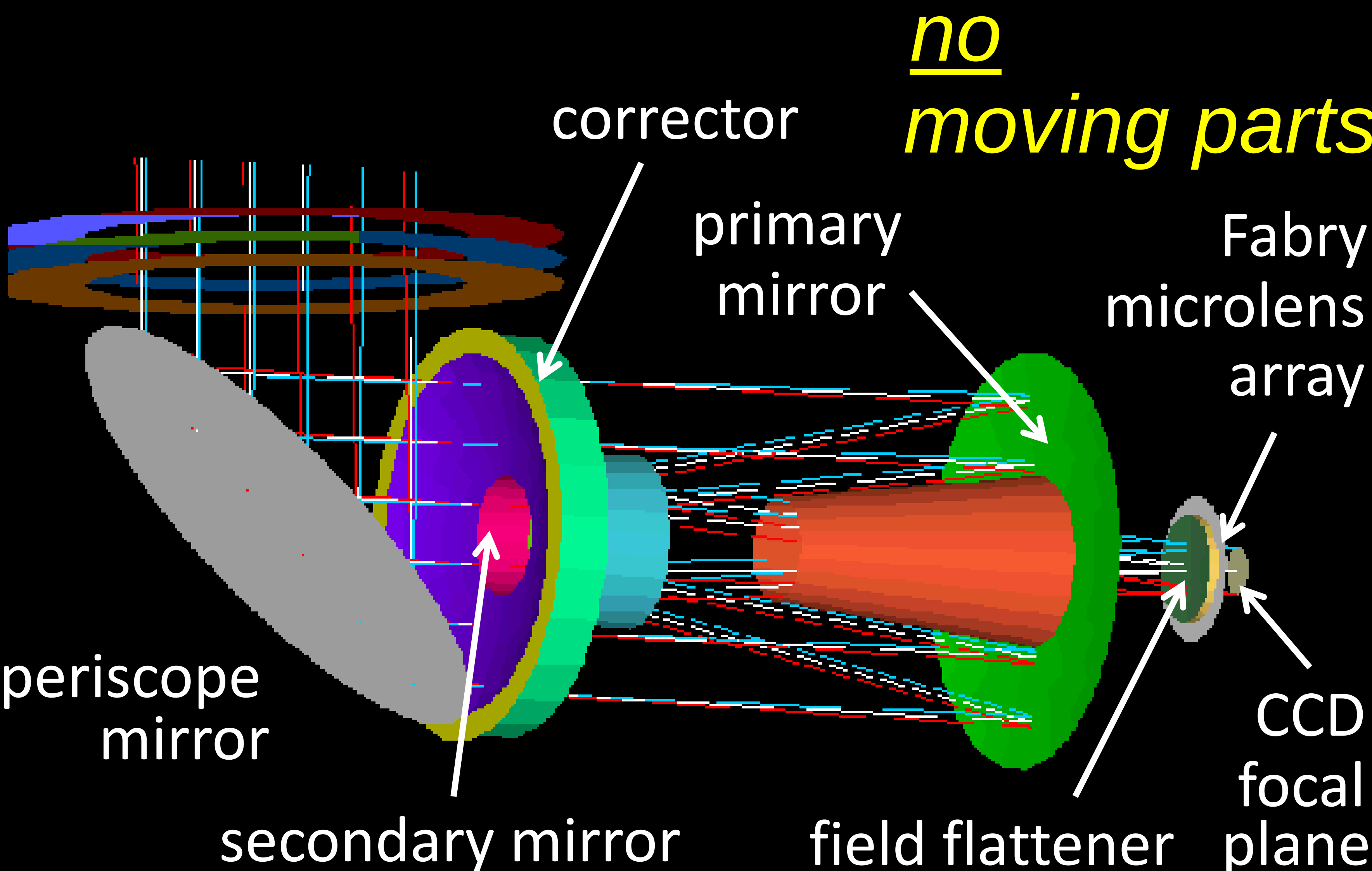
fed by
entrance baffle
and
periscope
mirror



MOST optical design



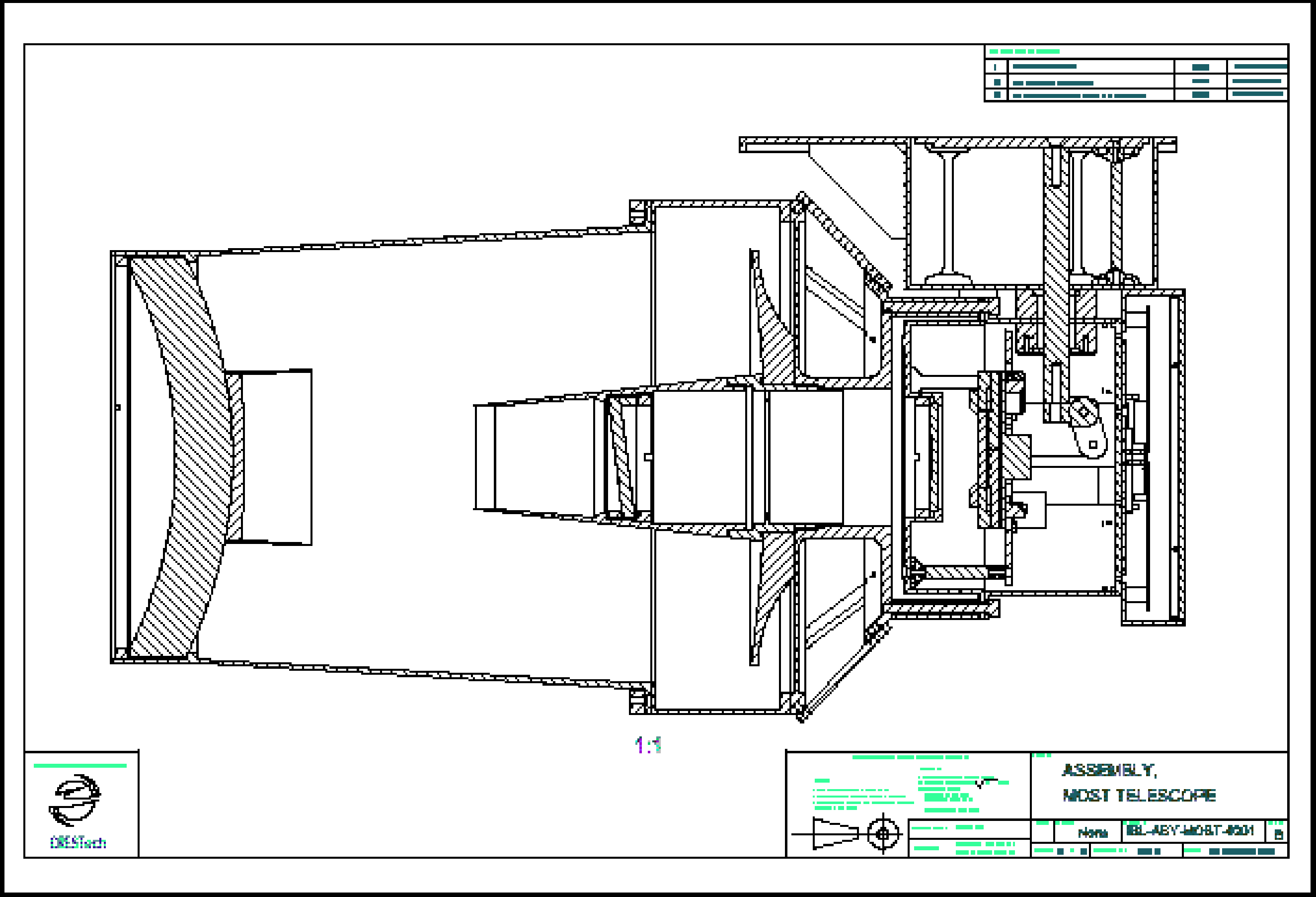
MOST optical design



MOST optical design

athermal structure maintains focus across a wide range of T

<u>no</u> moving parts

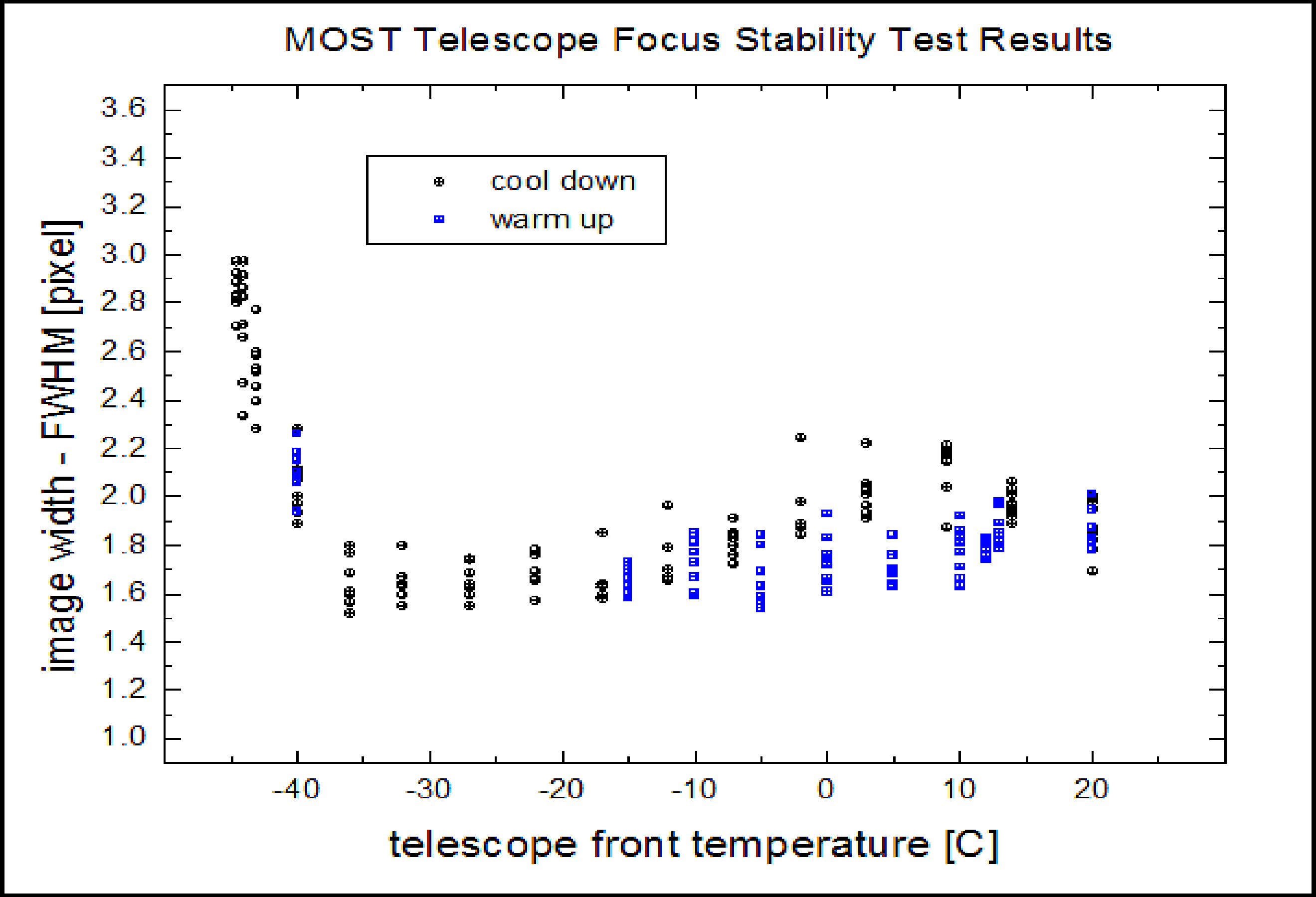


MOST optical design

athermal structure maintains focus across a wide range of T

–20° < T < +40°

no moving parts



Rulebook for the MOST microsatellite mission

- ✓ only <u>one egg</u> in the basket
- ✓ <u>R & R</u> resilience & redundancy
- ✓ <u>autonomous</u> operations even if conditions change
- ✓ <u>high performance</u>
- ✓ <u>low cost</u>, power, mass, volume, bandwidth, …

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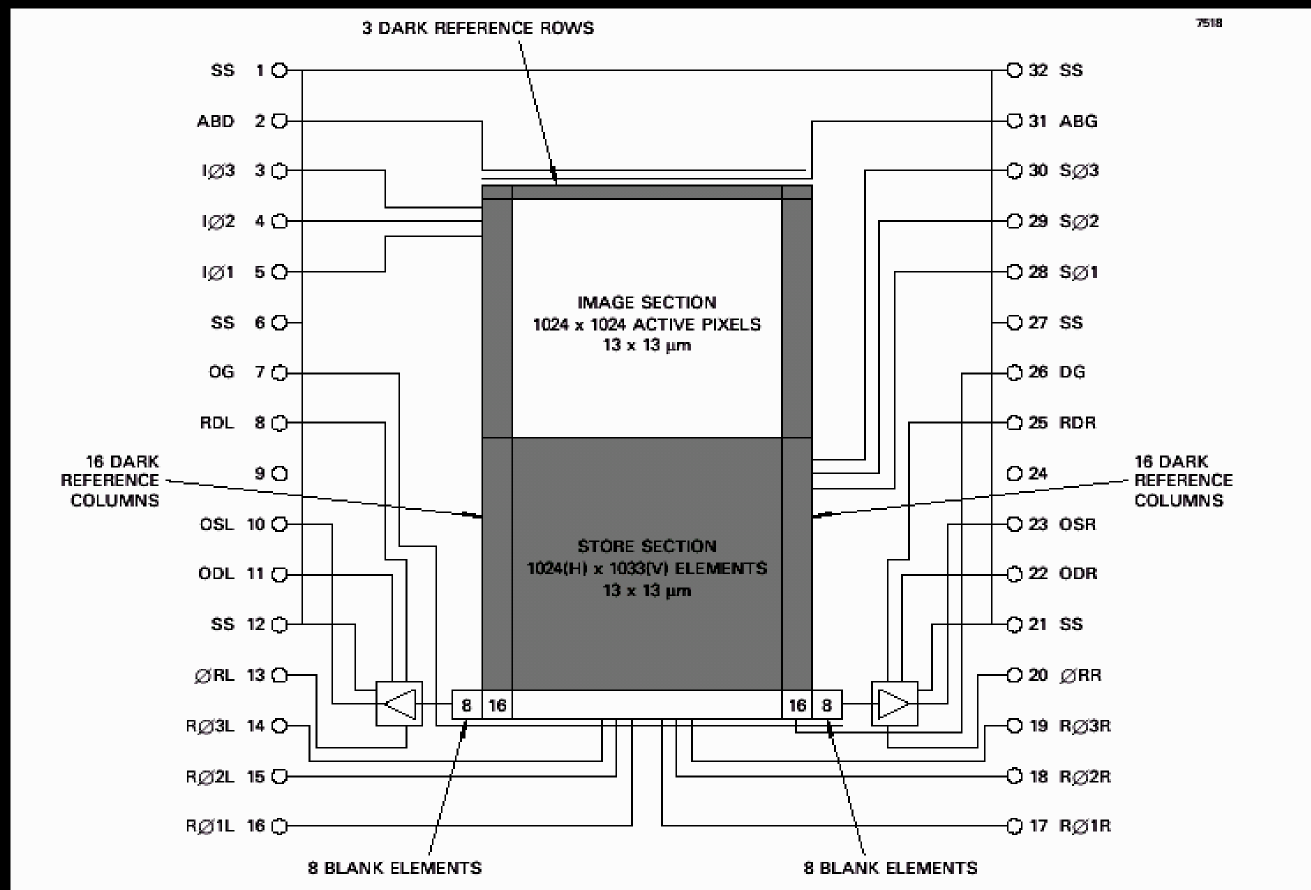
MOST structural design

no shutter

exposures ended by rapid frame transfer

no moving parts



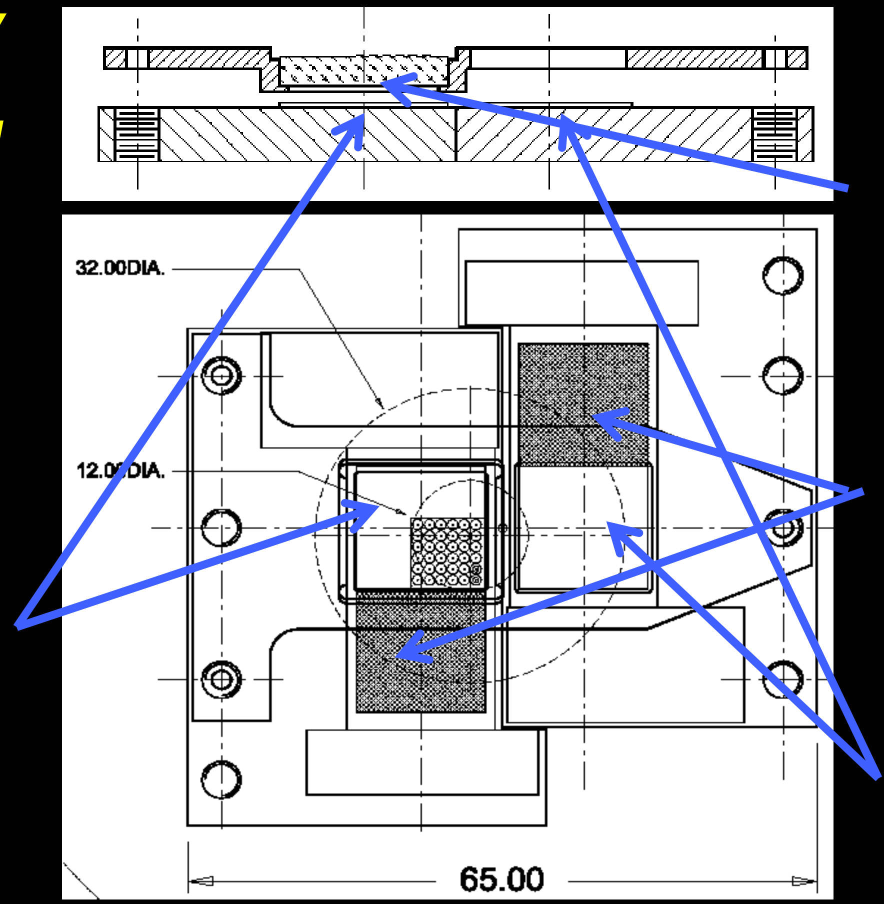
E2V 47-20 1k x 1k

MOST structural design

no separate startracker telescope

guiding in the field of a single scope

by second twin CCD



MOST structural design

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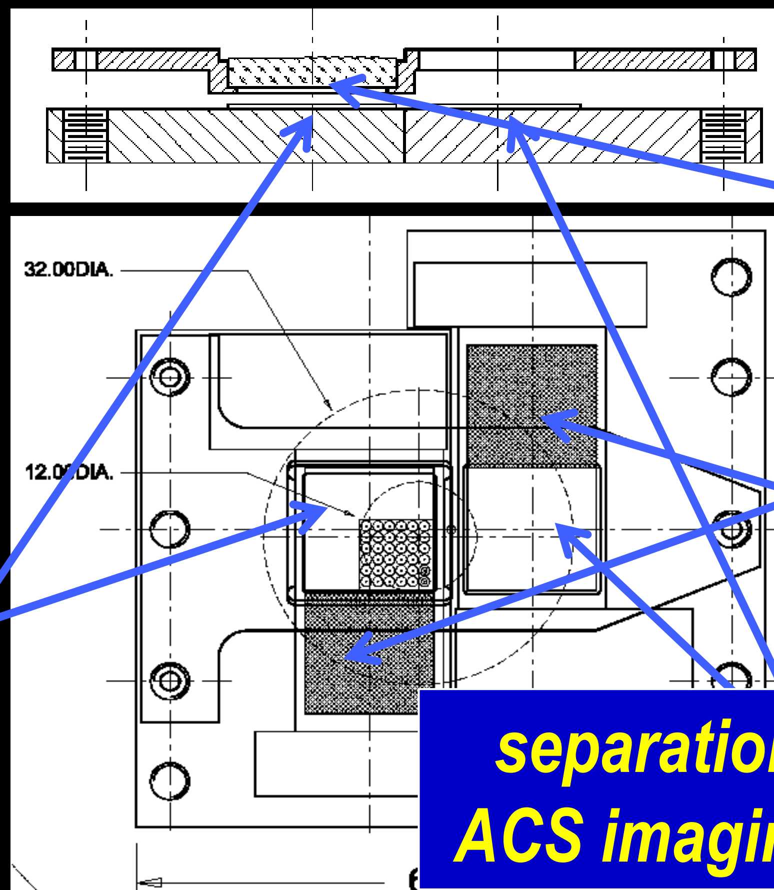
SIDE



microlens array

frame transfer buffers

Science CCD

TOP

separation of Science and ACS imaging areas = 3.5 mm

Rulebook for the MOST microsatellite mission

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MOST CCD electronics

- derived from design of Magellan guide star camera

Greg Burley

- power consumption = 3 W for drive electronics
  + CCD pre-amplifiers + power supply
- low noise: ~2 electrons per readout
- DSP radiation-tested to 12.5 krad
  - *equivalent to 10 years in orbit*

1342

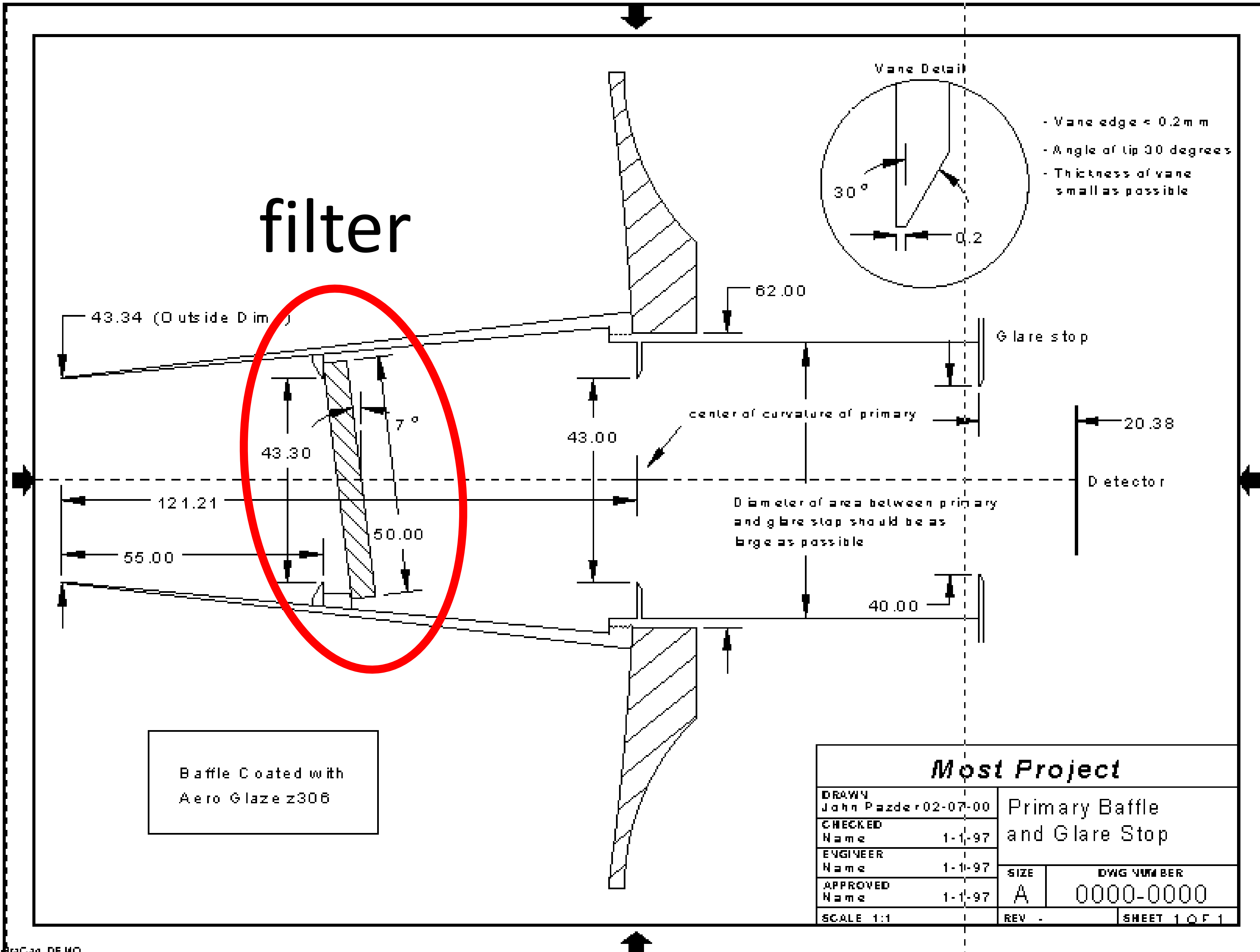
Rulebook for the MOST microsatellite mission

✓ only one egg in the basket

1 instrument
1 type of data
1 unique capability

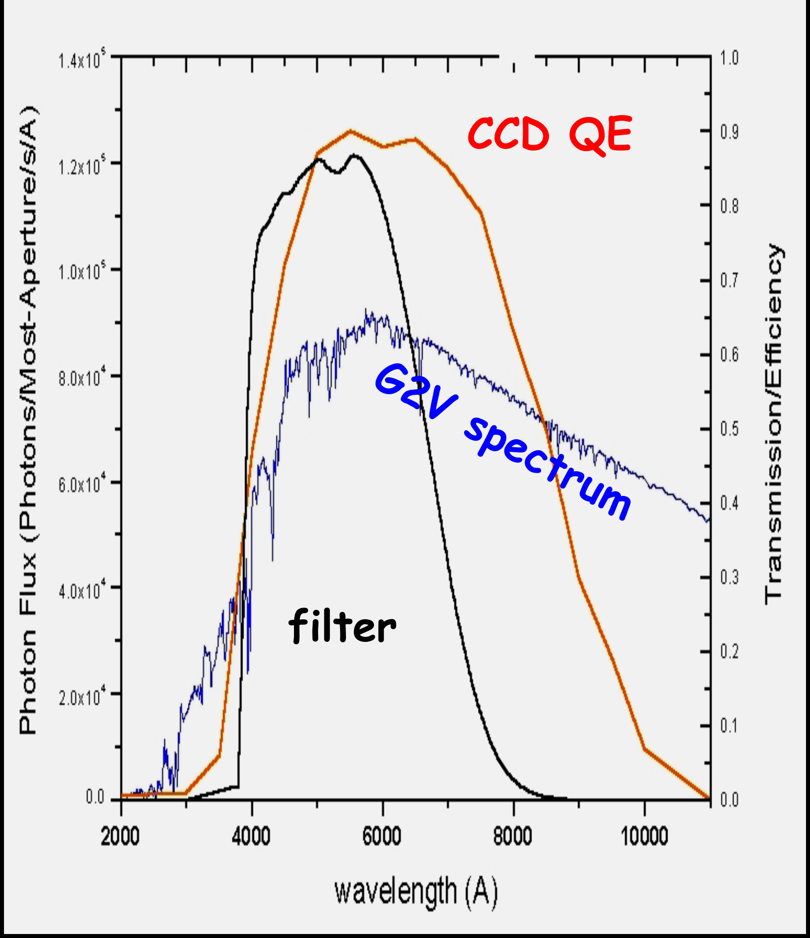
✓ high performance

Set detailed science requirements and stick to them!


filter
Vane Detail
30°
0.2
- Vane edge < 0.2 mm
- Angle of tip 30 degrees
- Thickness of vane small as possible
62.00
43.34 (Outside Dim.)
Glare stop
7°
43.30
43.00
center of curvature of primary
20.38
Detector
121.21
Diameter of area between primary and glare stop should be as large as possible
50.00
55.00
40.00
Baffle Coated with Aero Glaze z306
Most Project
DRAWN John Pazder 02-07-00
CHECKED Name 1-1-97
ENGINEER Name 1-1-97
APPROVED Name 1-1-97
Primary Baffle and Glare Stop
SIZE A
DWG NUMBER 0000-0000
SCALE 1:1
REV -
SHEET 1 OF 1
DesignCAD DEMO

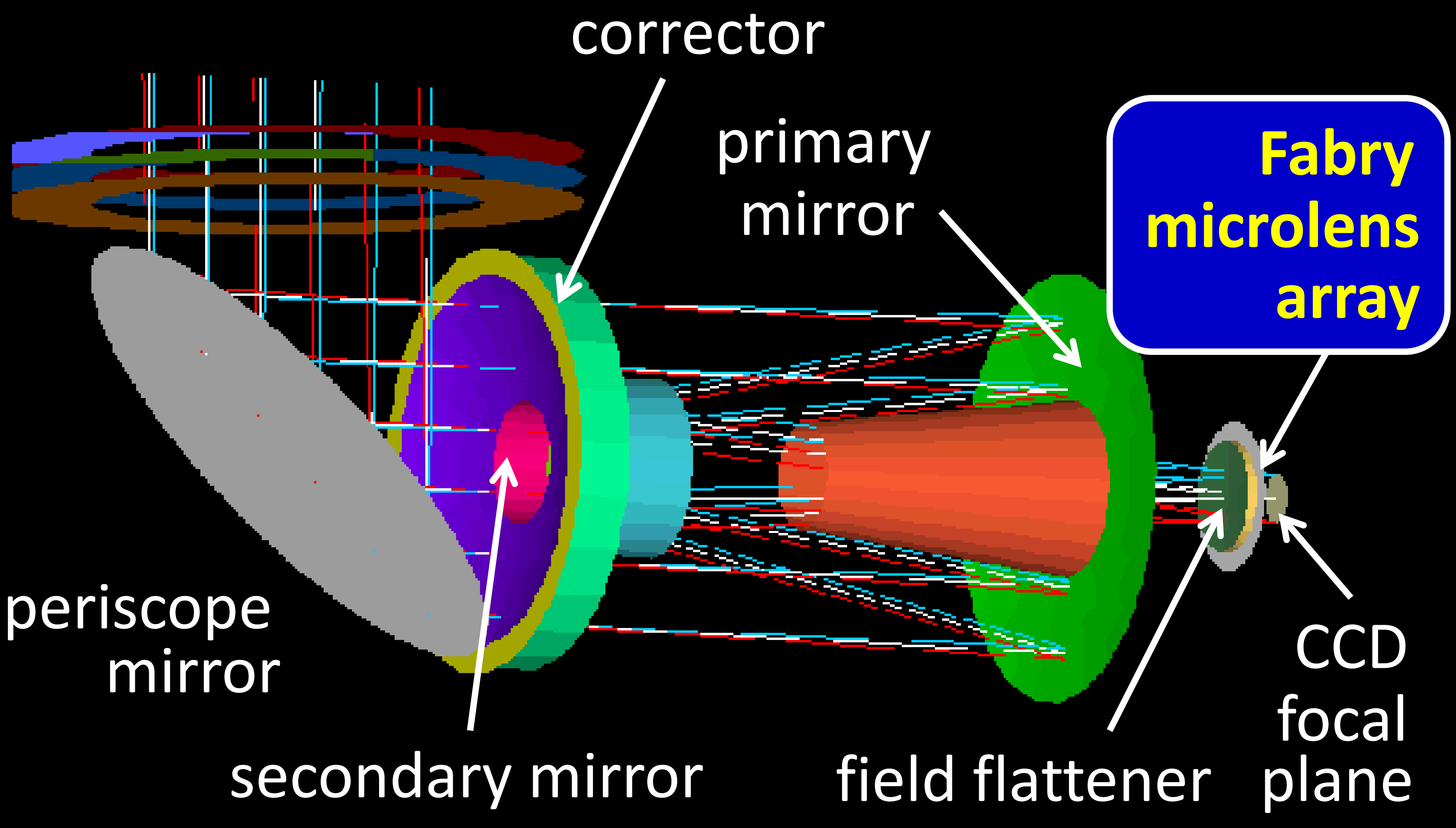
MOST filter bandpass

- ✓ 380 – 700 nm
- ✓ wide bandpass takes advantage of CCD QE
- ✓ 2.5 × throughput of Johnson V filter
- ✓ long λ cutoff near 700 nm reduces fringing
- ✓ solar oscillation amplitude large in this λ range
- ✓ space-qualified design



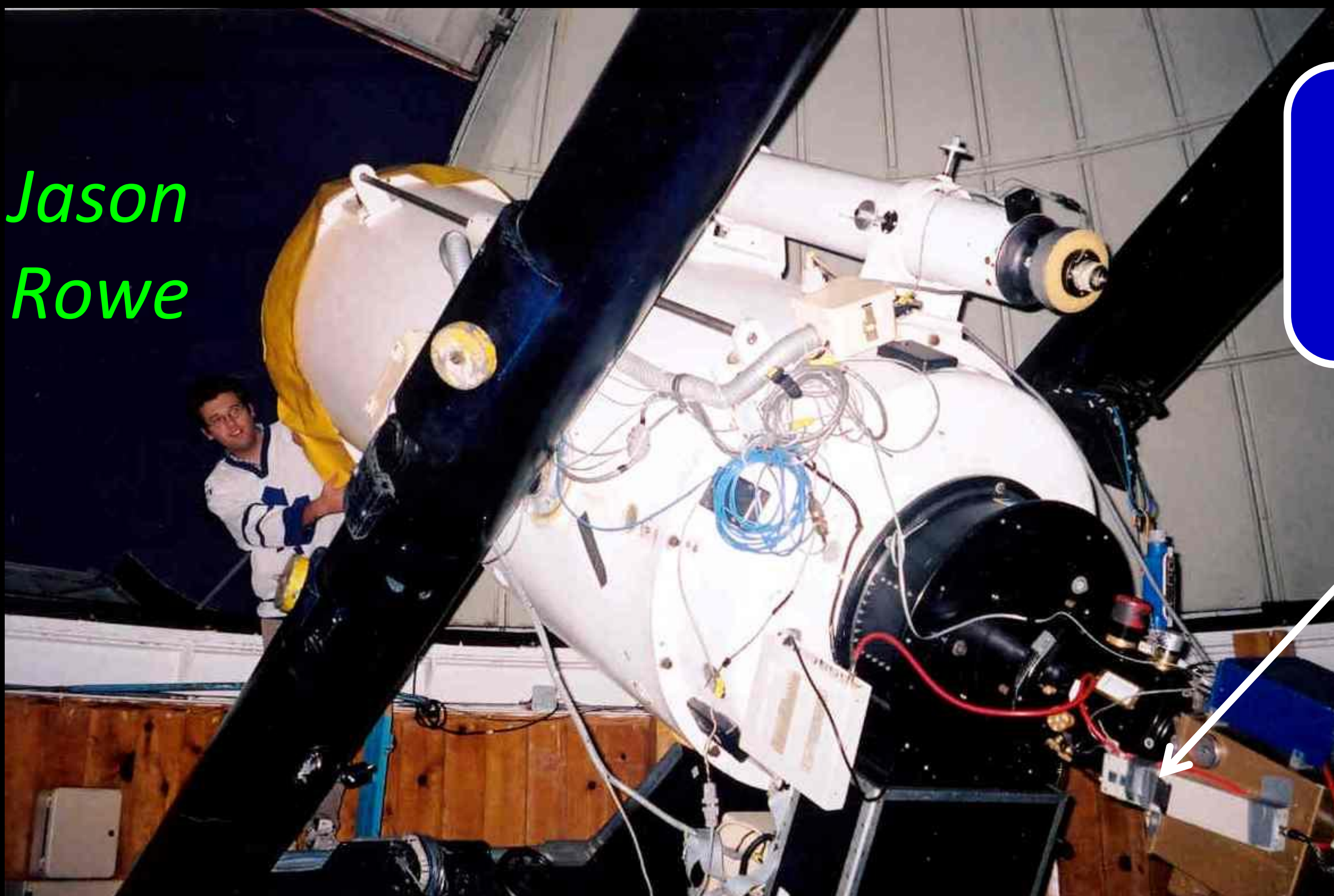
Custom Scientific
Phoenix, Arizona, USA

MOST optical design



MOST optical design

inspired by photoelectric photometry



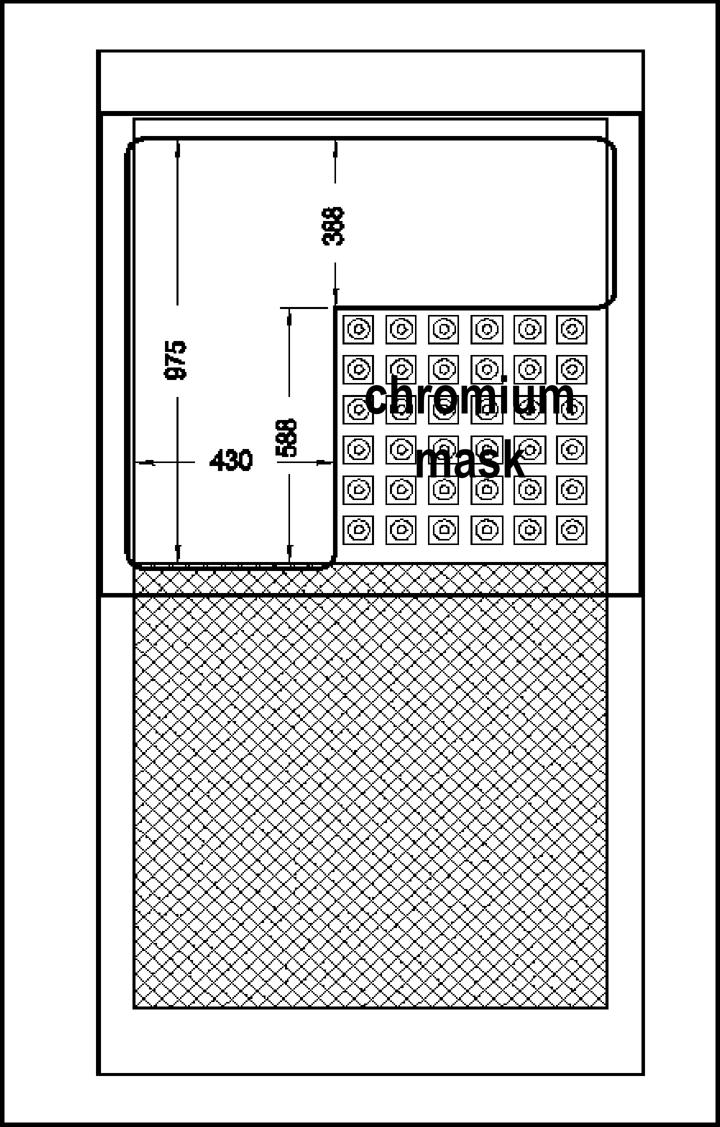
MOST optical design

open area

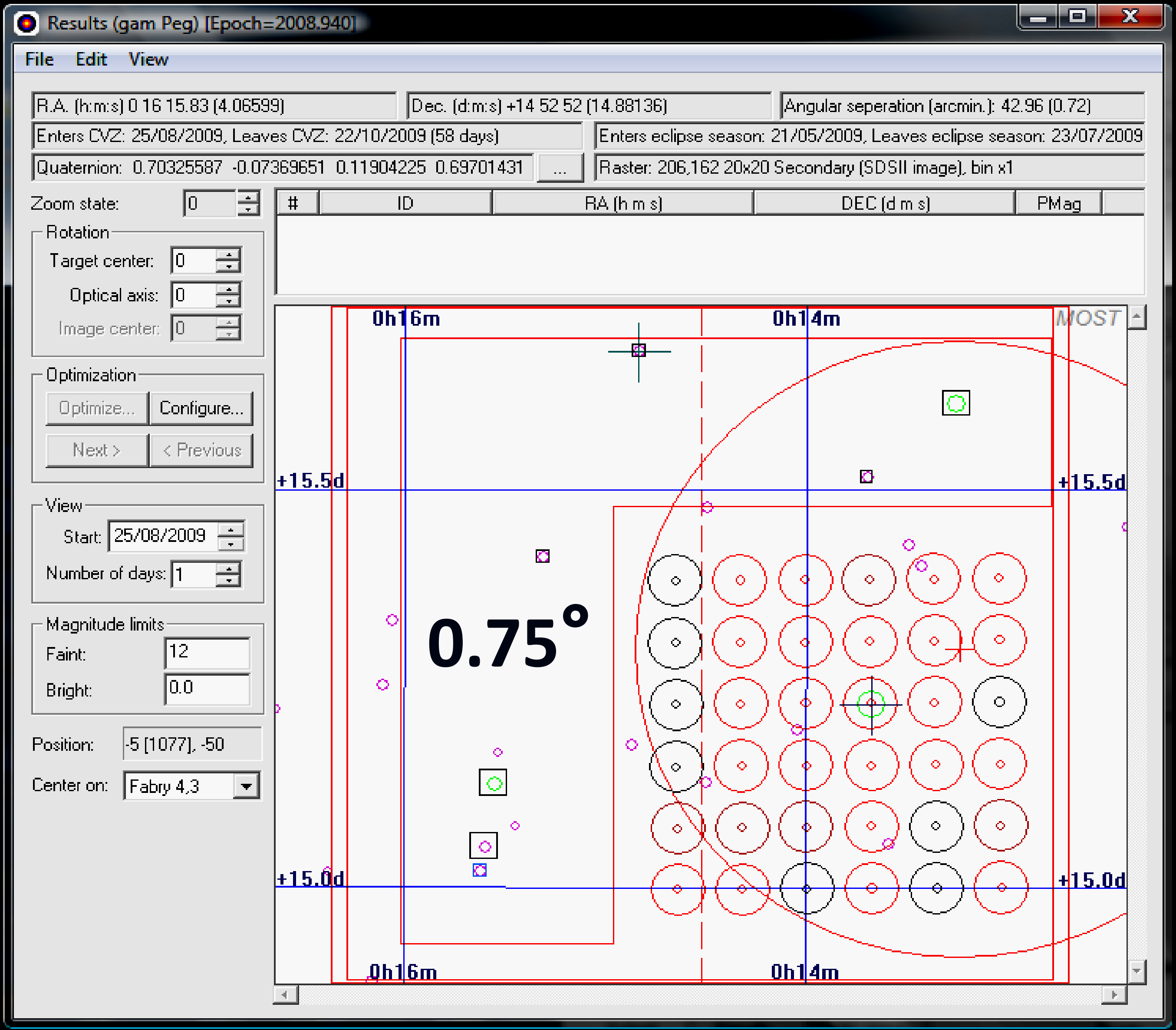
6 x 6 Fabry array

Advanced Microoptic Systems
Saarbrücken, Germany

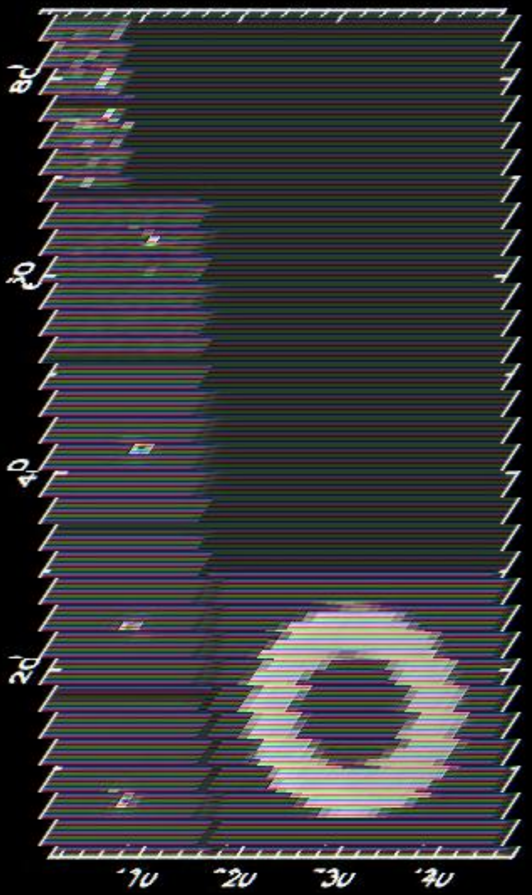
frame transfer area

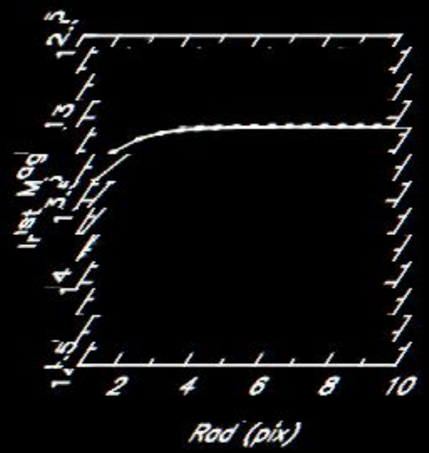


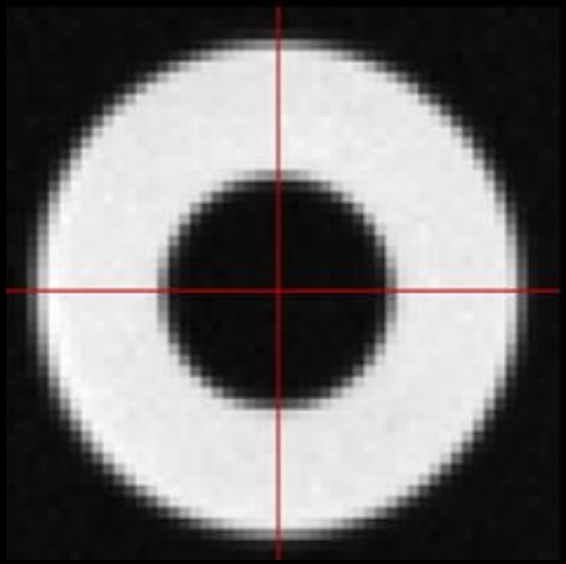
MOST optical design

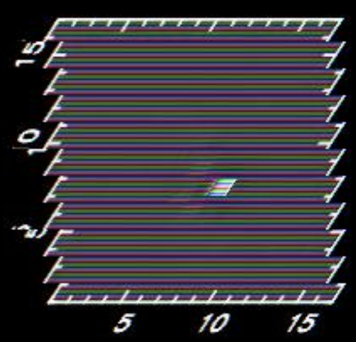


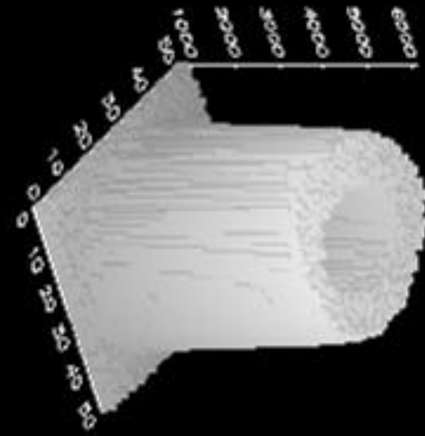
MOST optical design

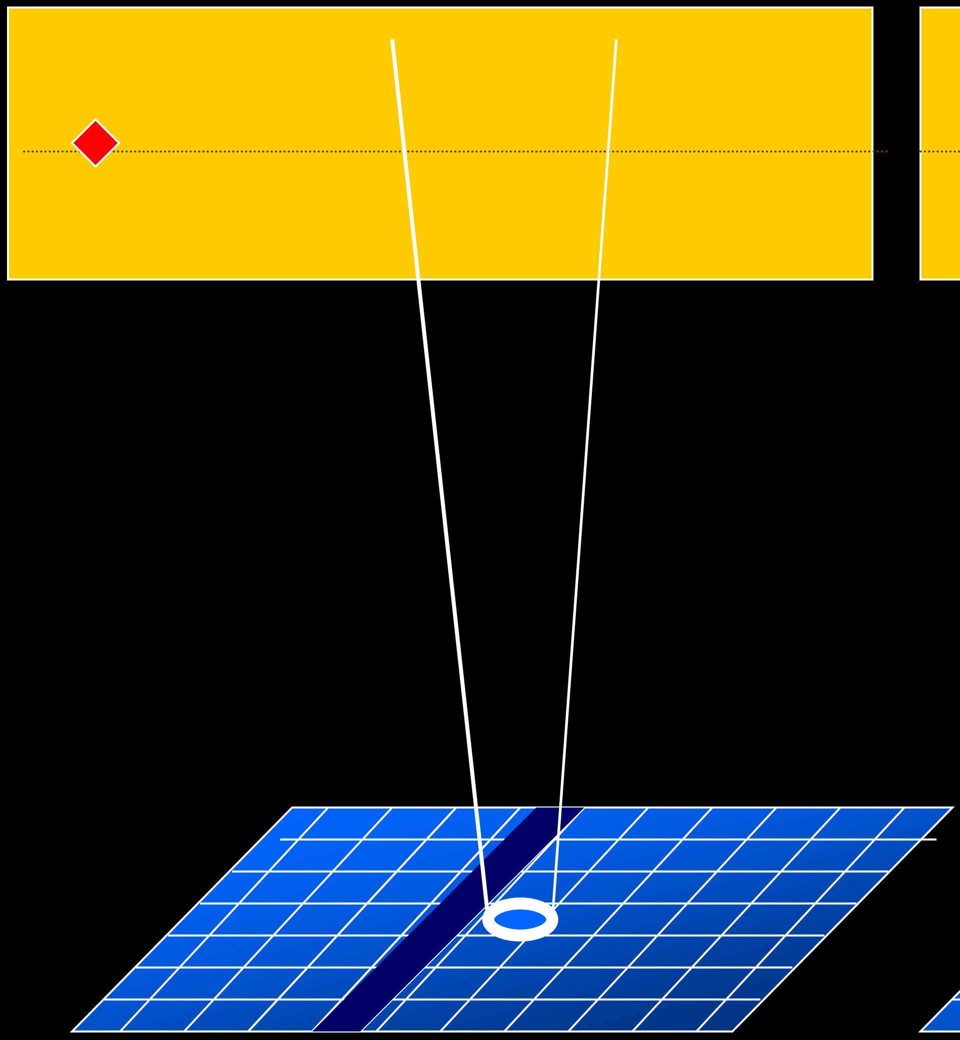




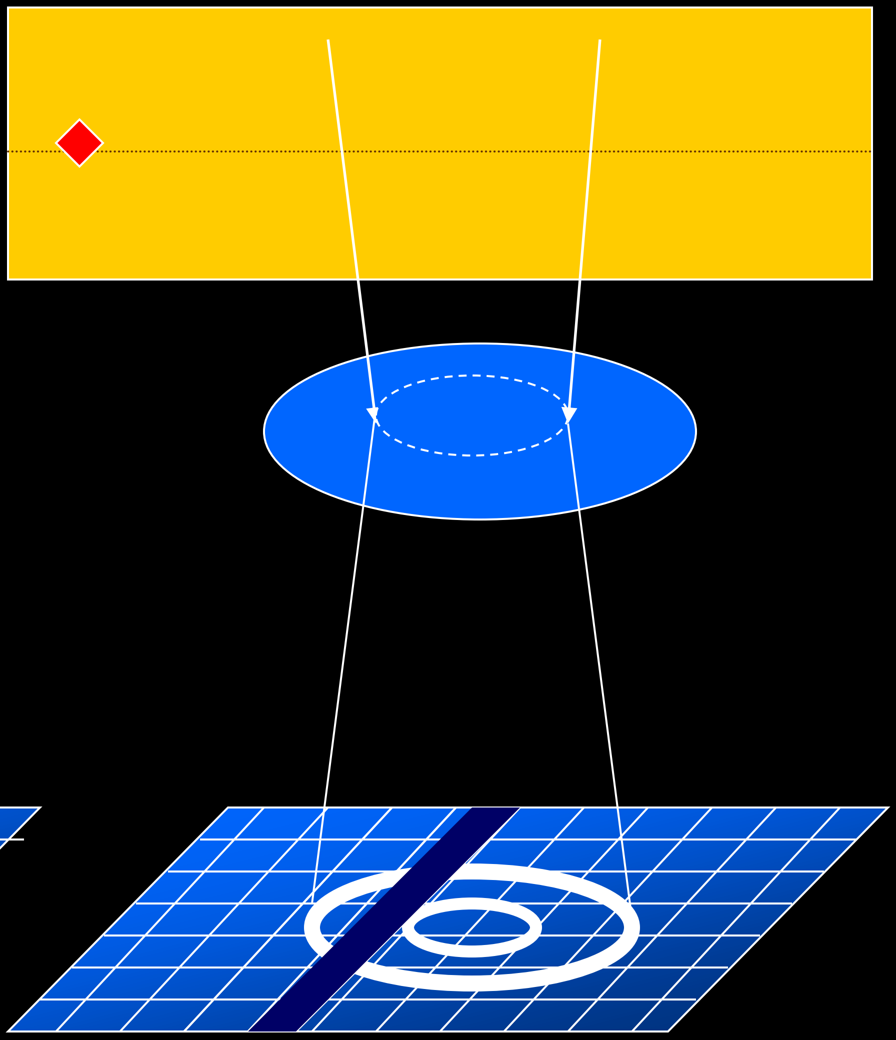




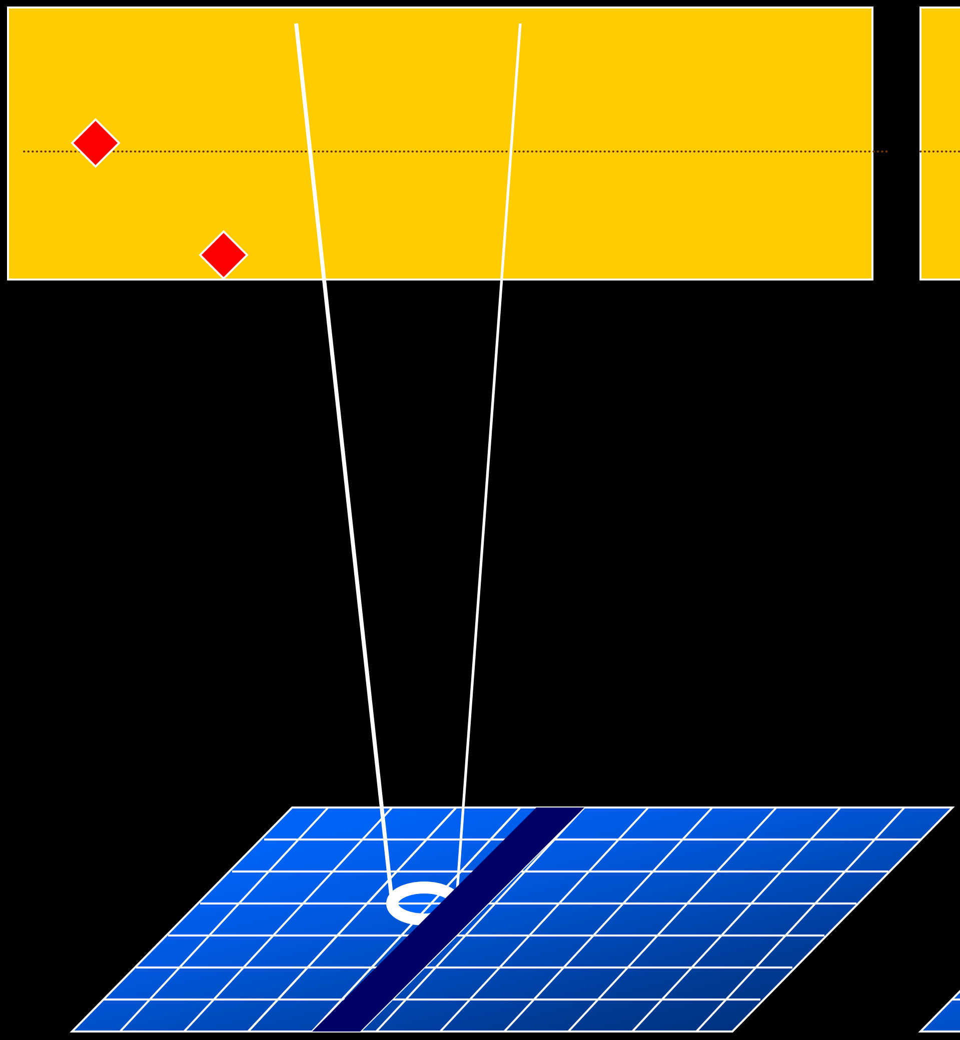




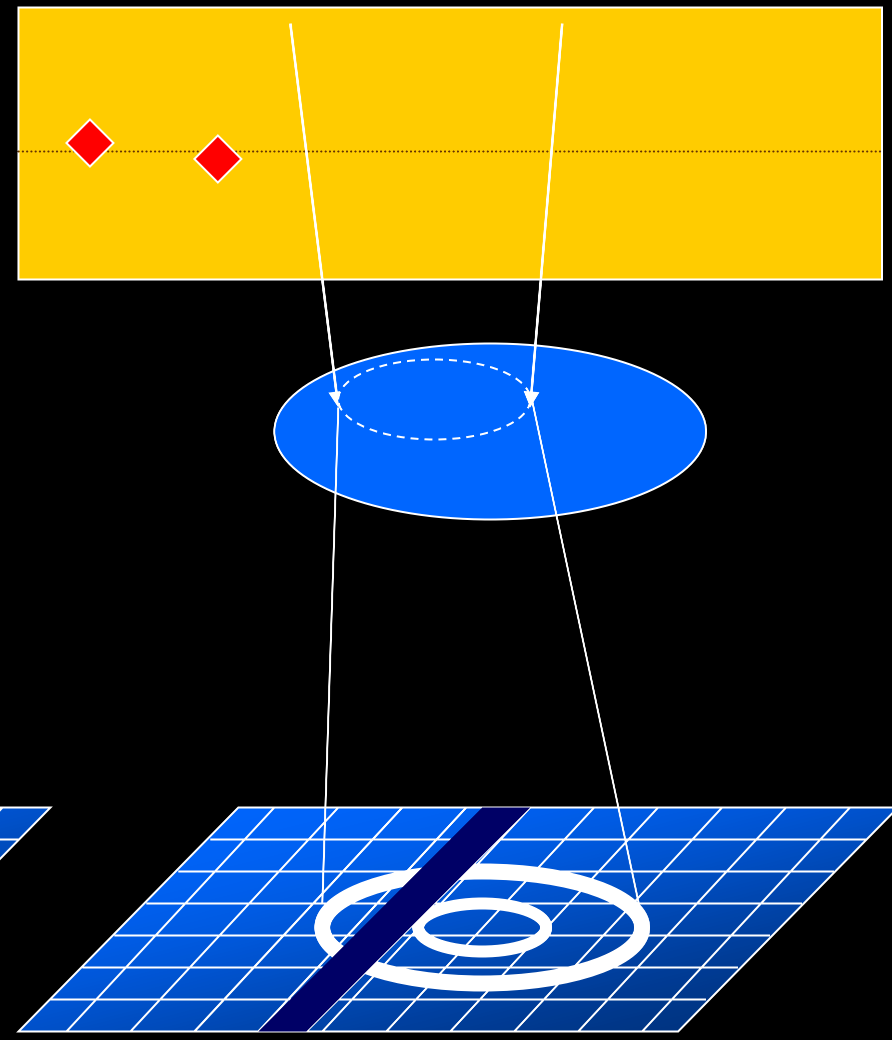
in focus



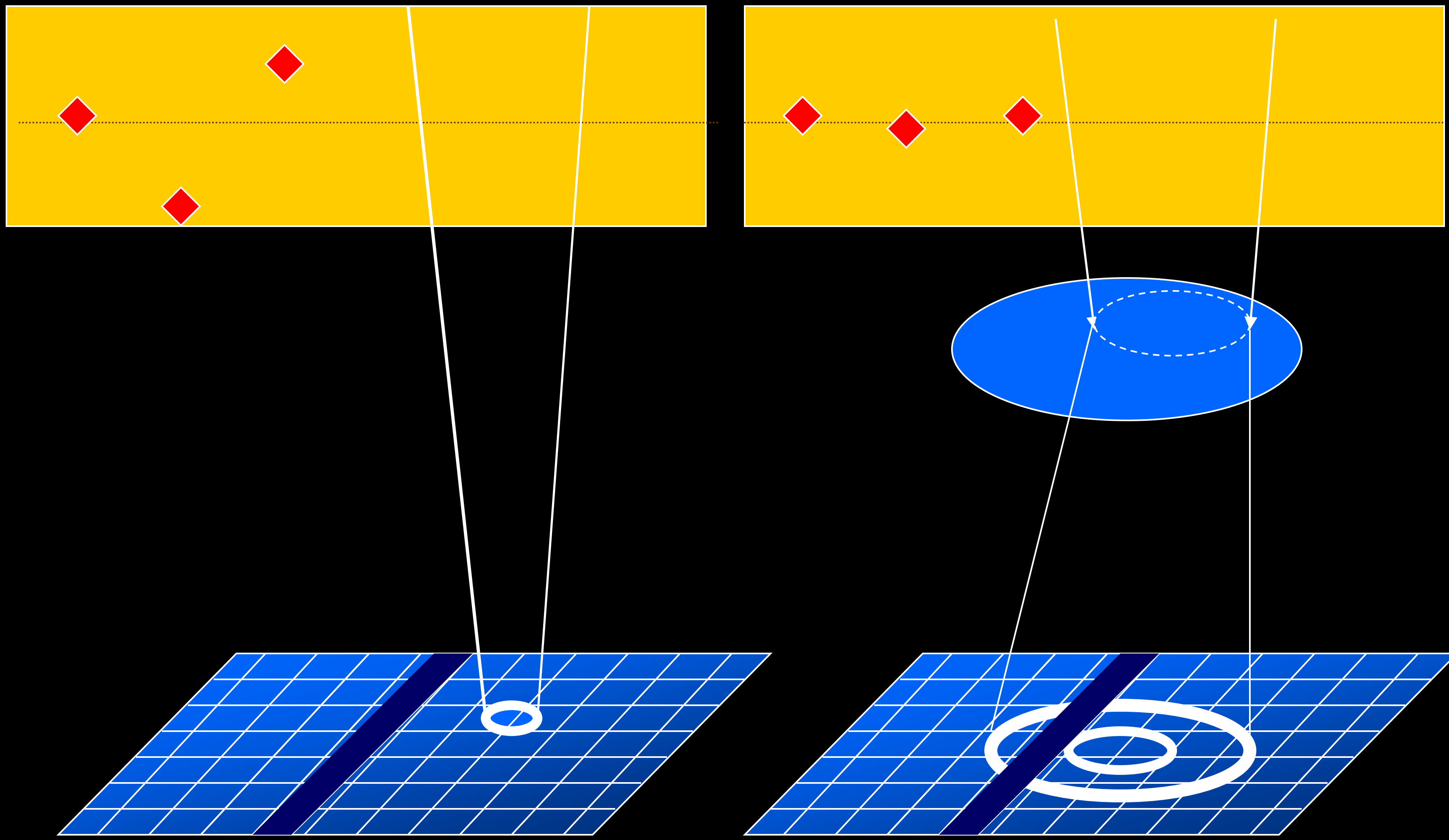
Fabry image



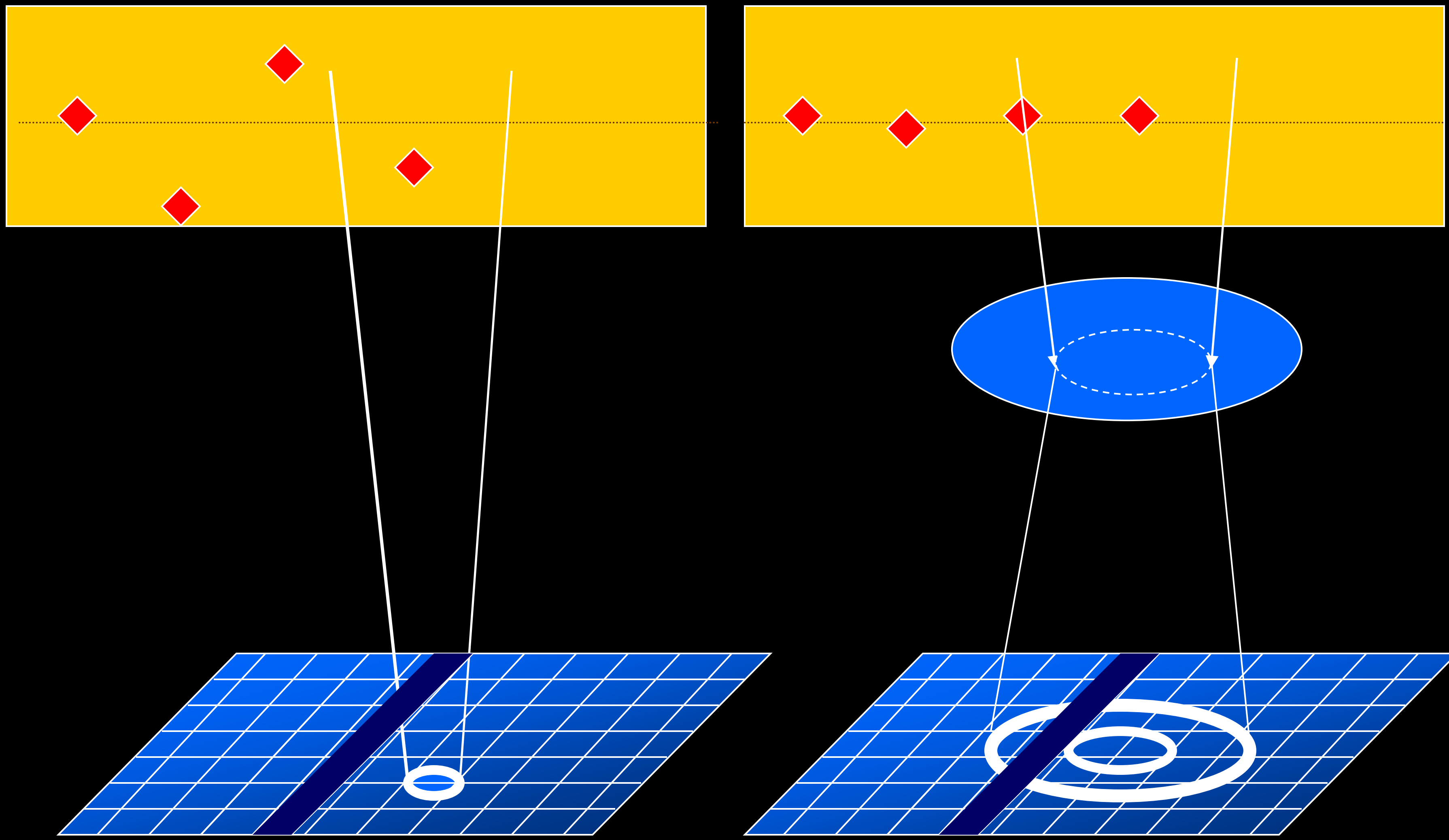
in focus



Fabry image

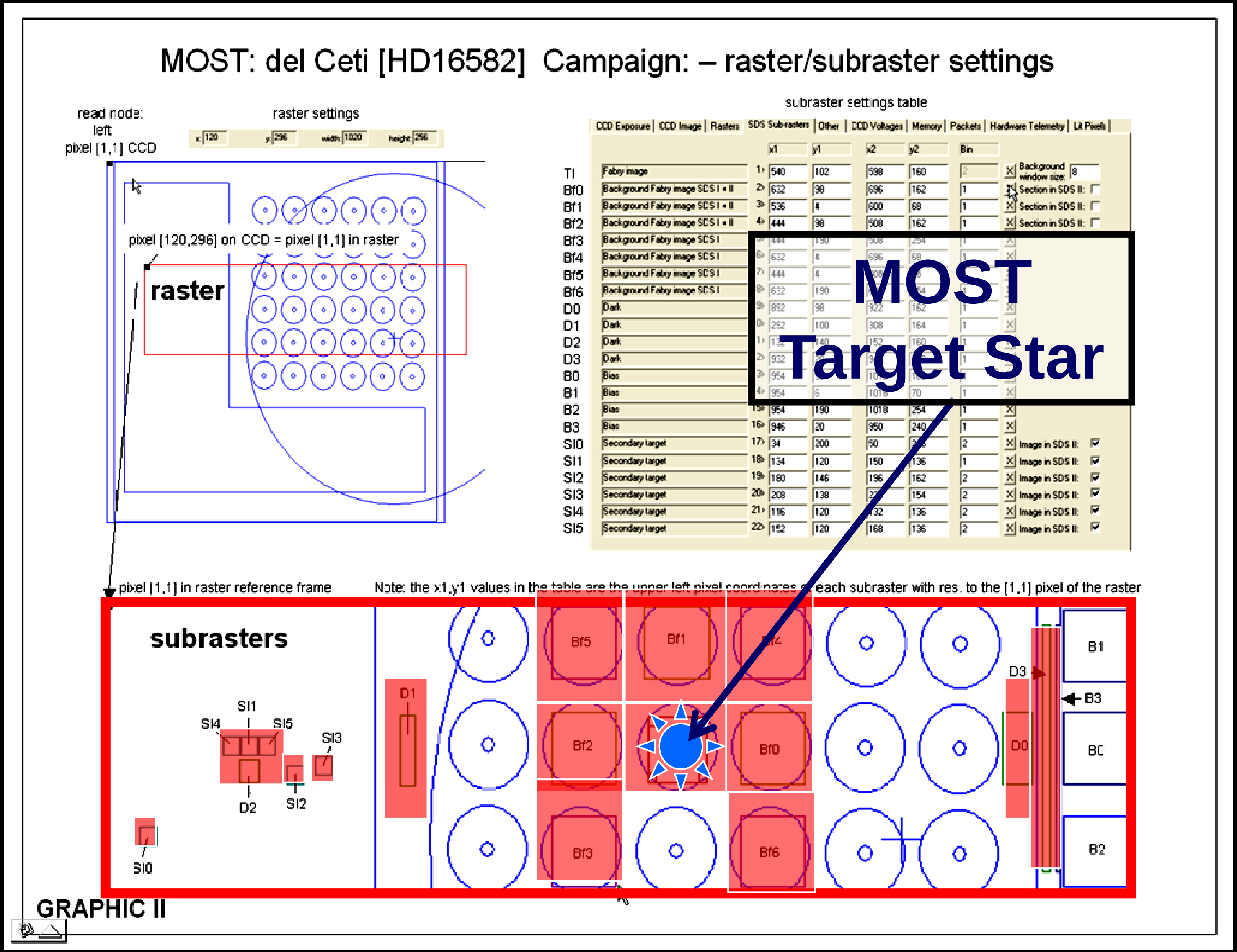


in focus *Fabry image*



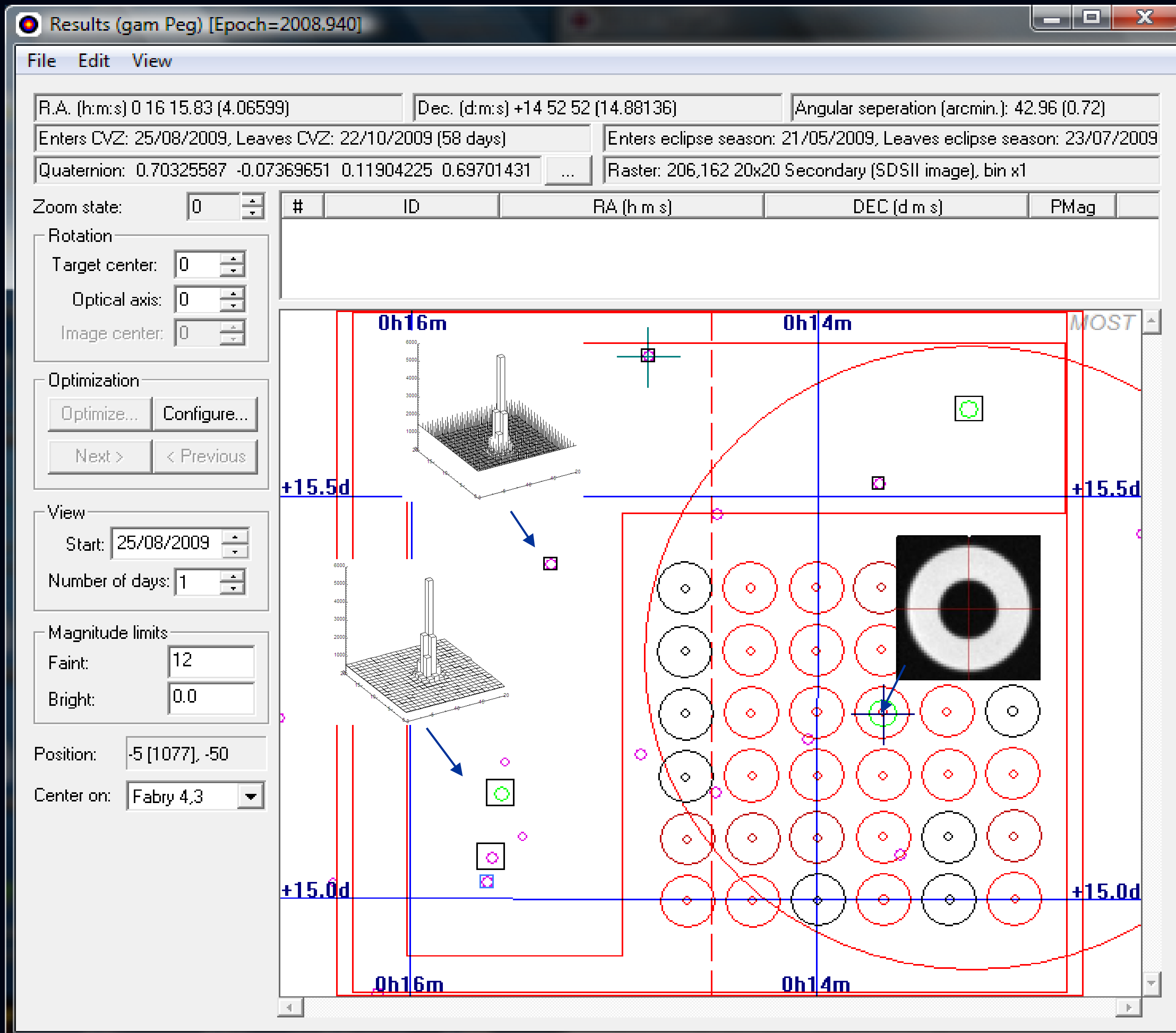
in focus *Fabry image*

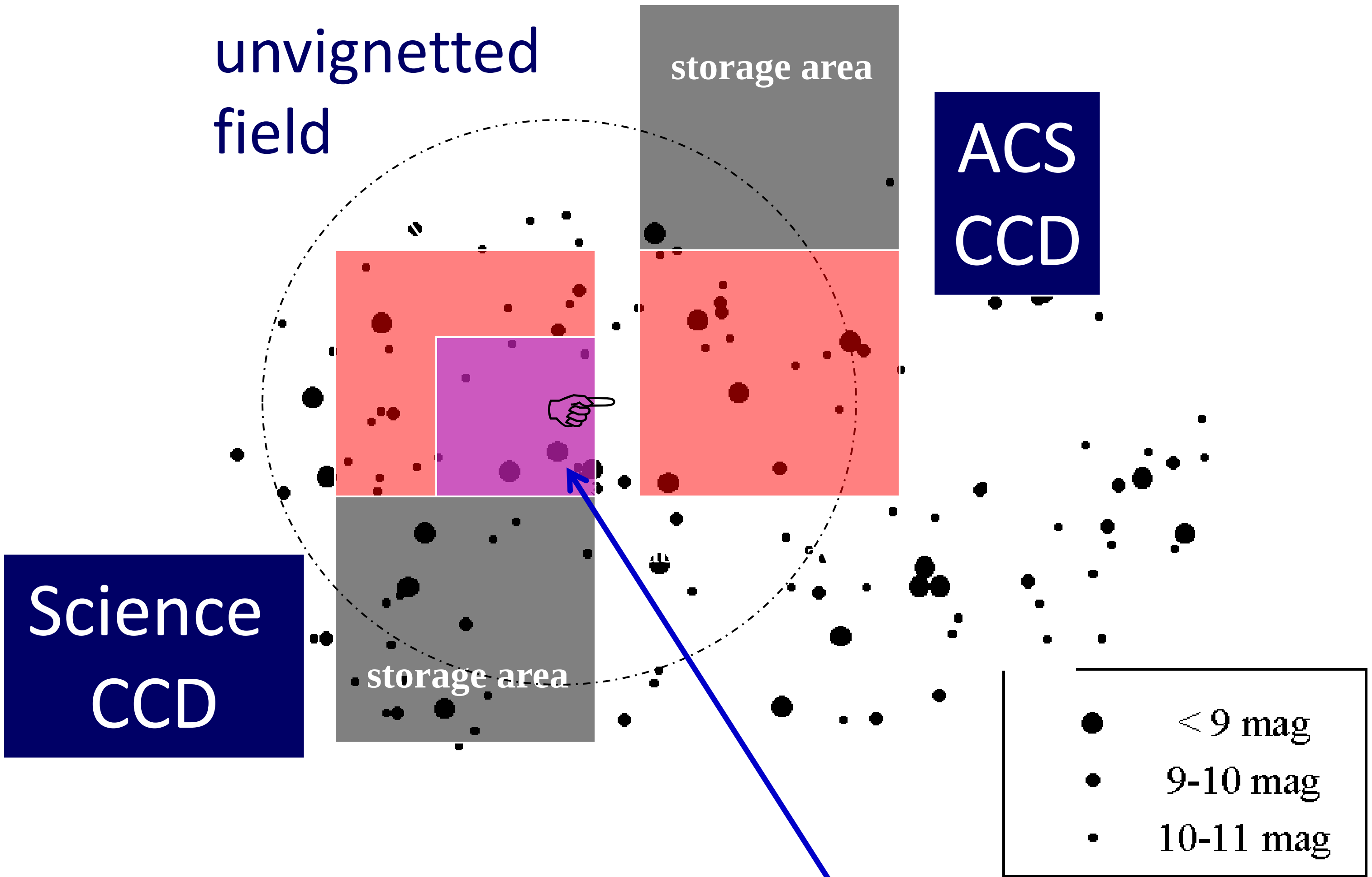
MOST optical design



= region of CCD read out

= subraster

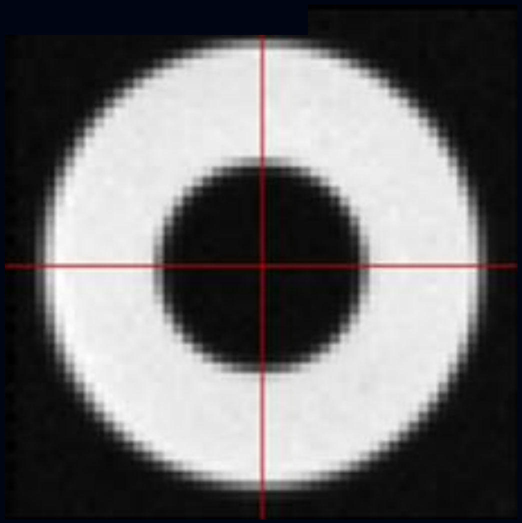

Results (gam Peg) [Epoch=2008.940]
File
Edit
View
R.A. (h:m:s) 0 16 15.83 (4.06599)
Dec. (d:m:s) +14 52 52 (14.88136)
Angular seperation (arcmin.): 42.96 (0.72)
Enters CVZ: 25/08/2009, Leaves CVZ: 22/10/2009 (58 days)
Enters eclipse season: 21/05/2009, Leaves eclipse season: 23/07/2009
Quaternion: 0.70325587 -0.07369651 0.11904225 0.69701431
Raster: 206,162 20x20 Secondary (SDSII image), bin x1
Zoom state: 0
Rotation
Target center: 0
Optical axis: 0
Image center: 0
Optimization
Optimize...
Configure...
Next >
< Previous
View
Start: 25/08/2009
Number of days: 1
Magnitude limits
Faint: 12
Bright: 0.0
Position: -5 [1077], -50
Center on: Fabry 4,3
#
ID
RA (h m s)
DEC (d m s)
PMag
0h16m
0h14m
MOST
+15.5d
+15.0d

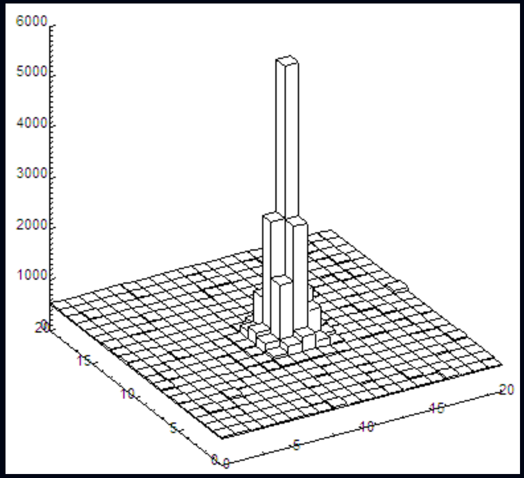


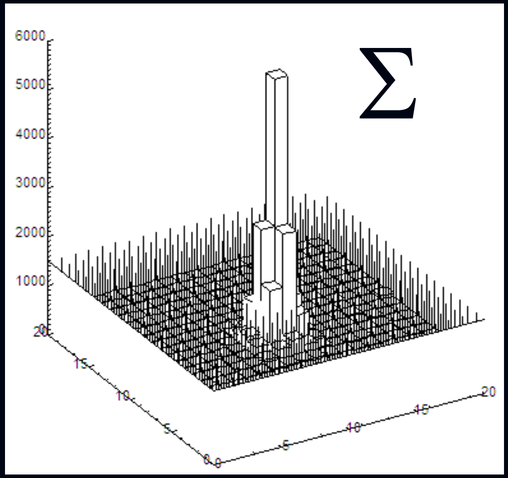
acquisition of solar-type target Procyon

MOST photometry

Fabry Imaging	Direct Imaging	Guide Star



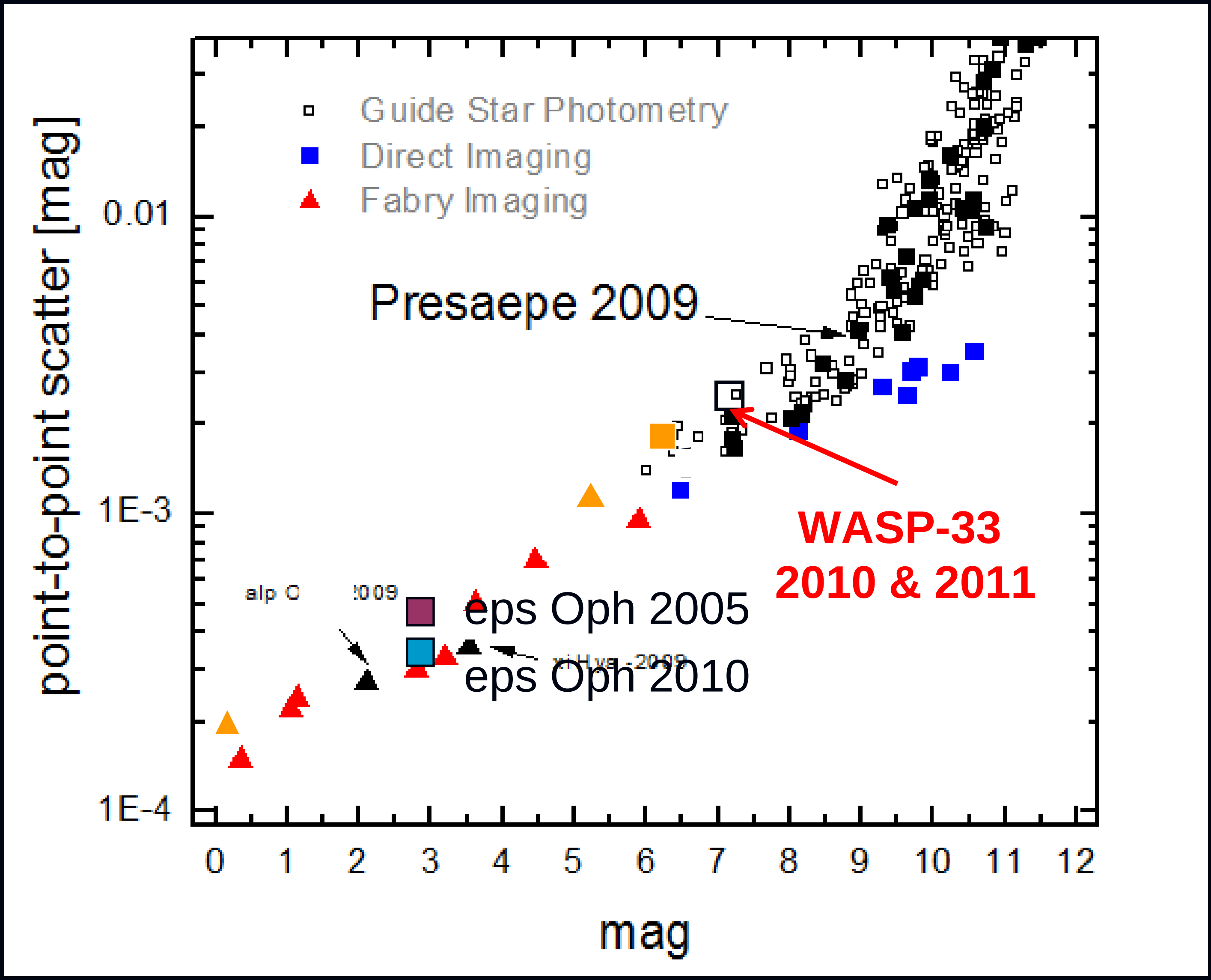




V ~ 0 – 4 V ~ 4 – 12 V ~ 6 – 14

exposure times limited to a range of 0.1 – 3.0 sec

MOST photometric performance



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Rulebook for the most robotic observatories

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The next best places to space?

The next best places to space?

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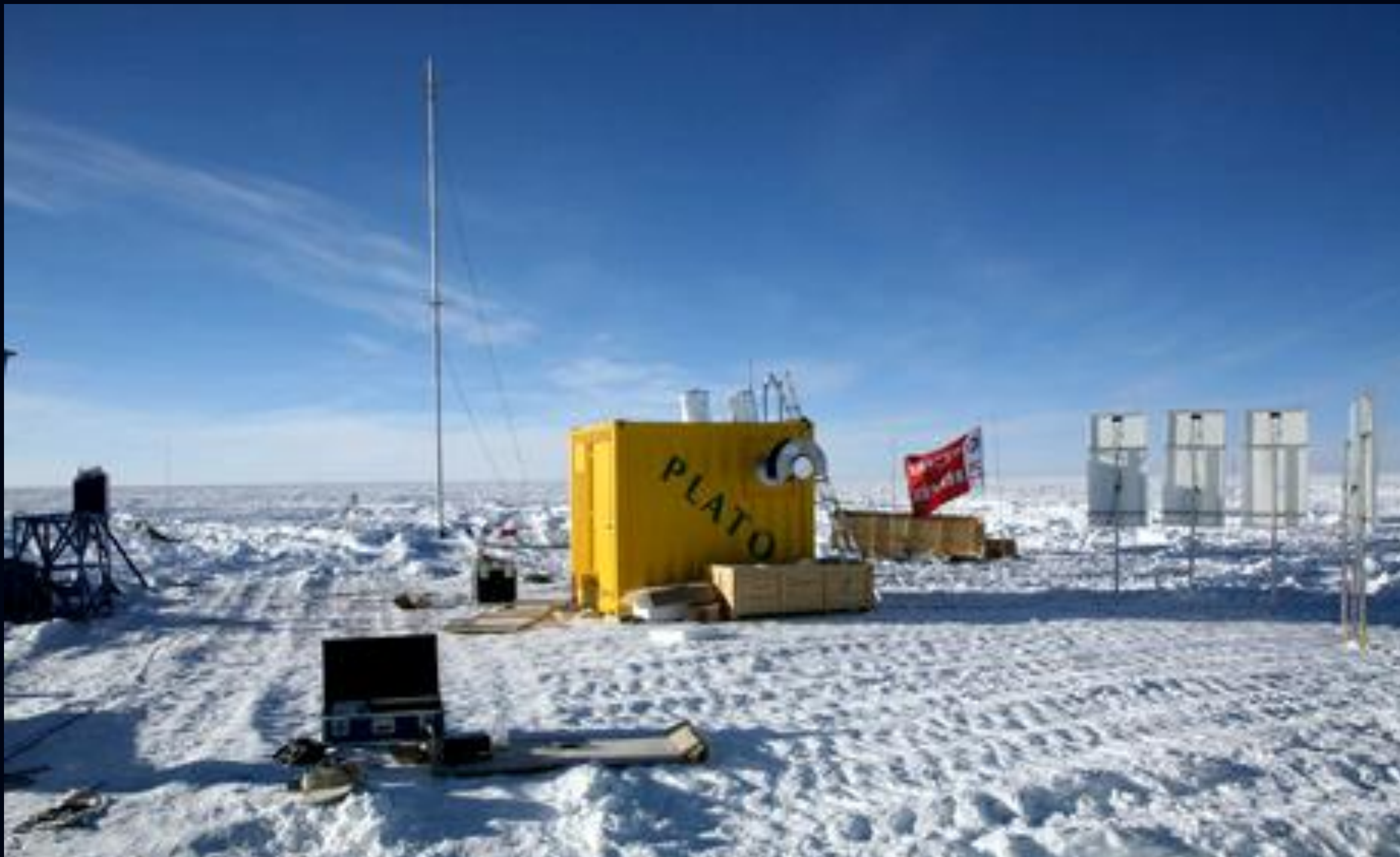


Did I leave time for questions?

matthews@astro.ubc.ca

UBC Department of Physics & Astronomy

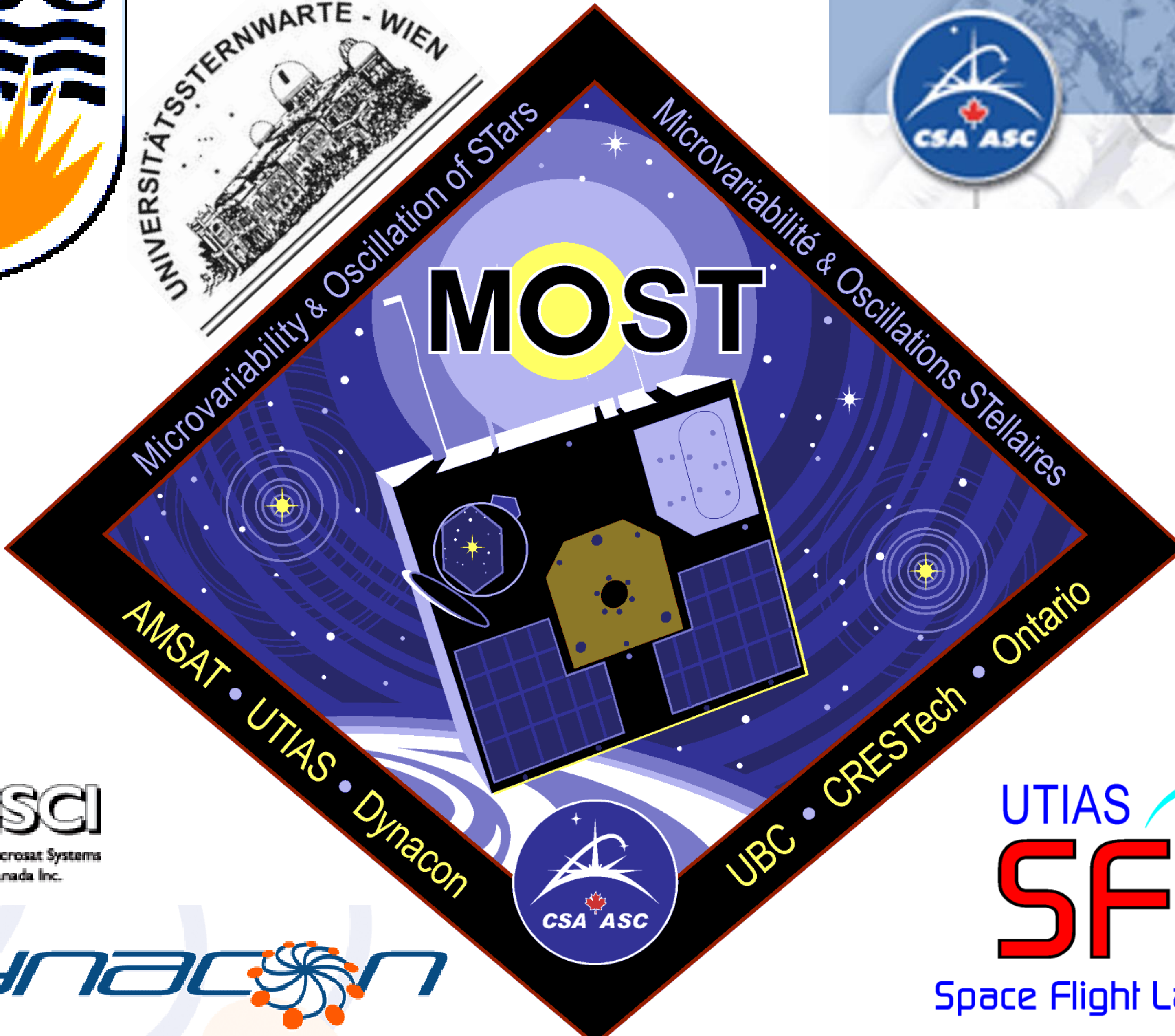
UBC

UNIVERSITÄTSSTERNWARTE - WIEN

Agence spatiale canadienne

Canadian Space Agency

CSA ASC



MSCI
Microsat Systems Canada Inc.

dynacon

UTIAS
SFL
Space Flight Laboratory