

ROBAST

Development of a Non-Sequential Ray-Tracing Simulation Library
and its Applications in the Cherenkov Telescope Array

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for the CTA Consortium

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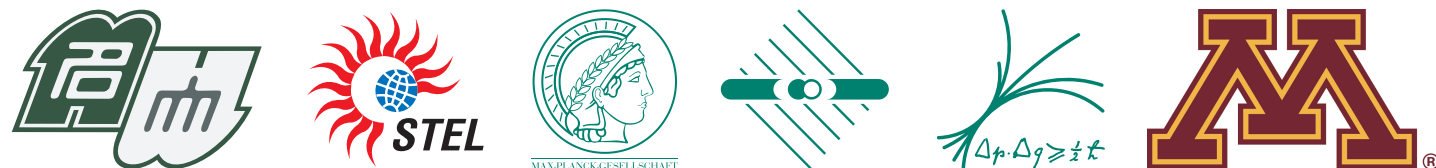
^bMax-Planck-Institut für Kernphysik

^cMax-Planck-Institut für Physik

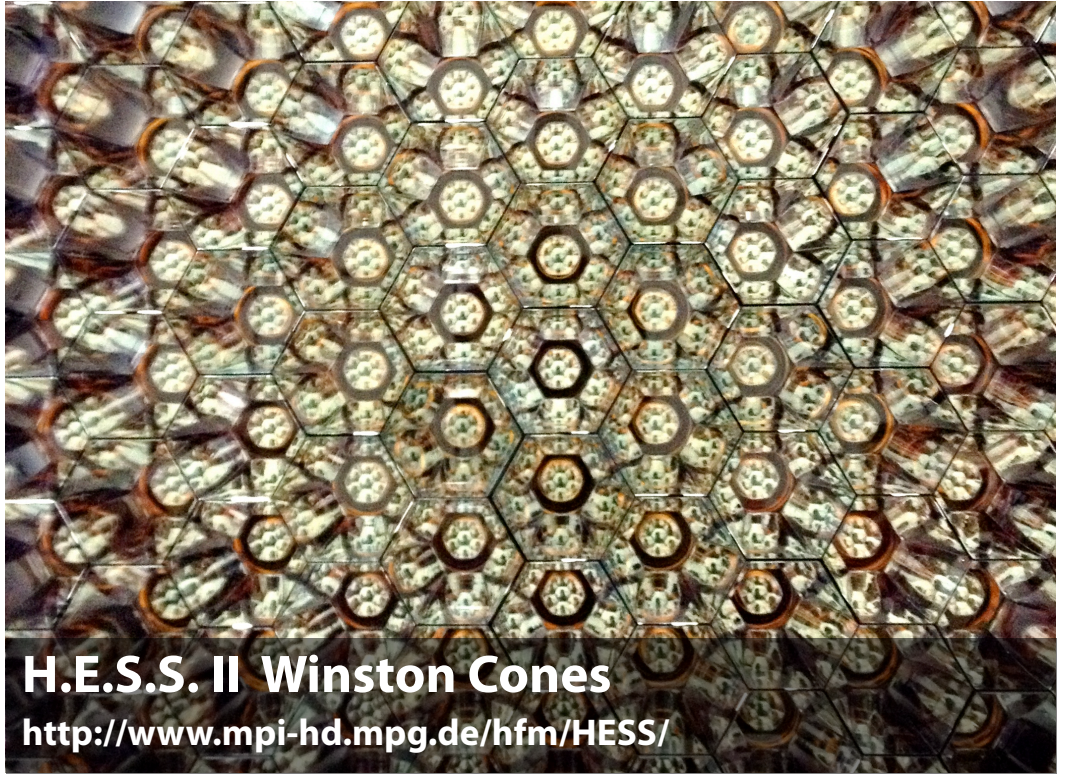
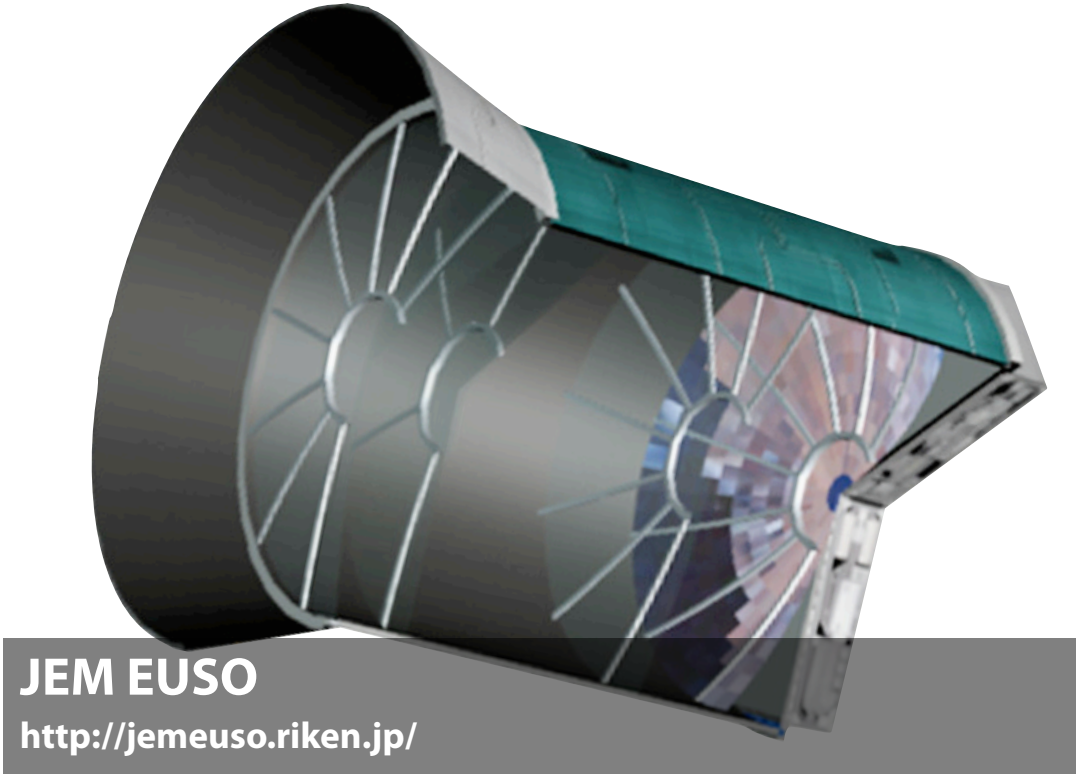
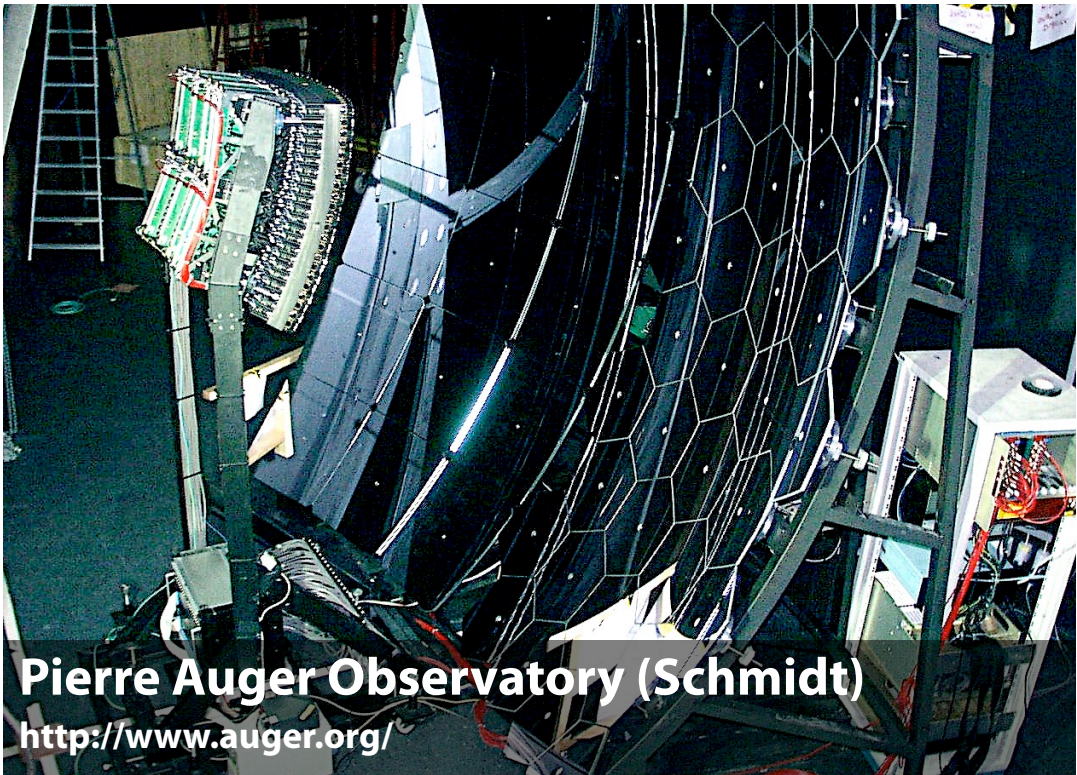
^dDepartment of Physics and Astronomy, University of Minnesota

ICRC 2015 in the Hague
Aug 3, 2015

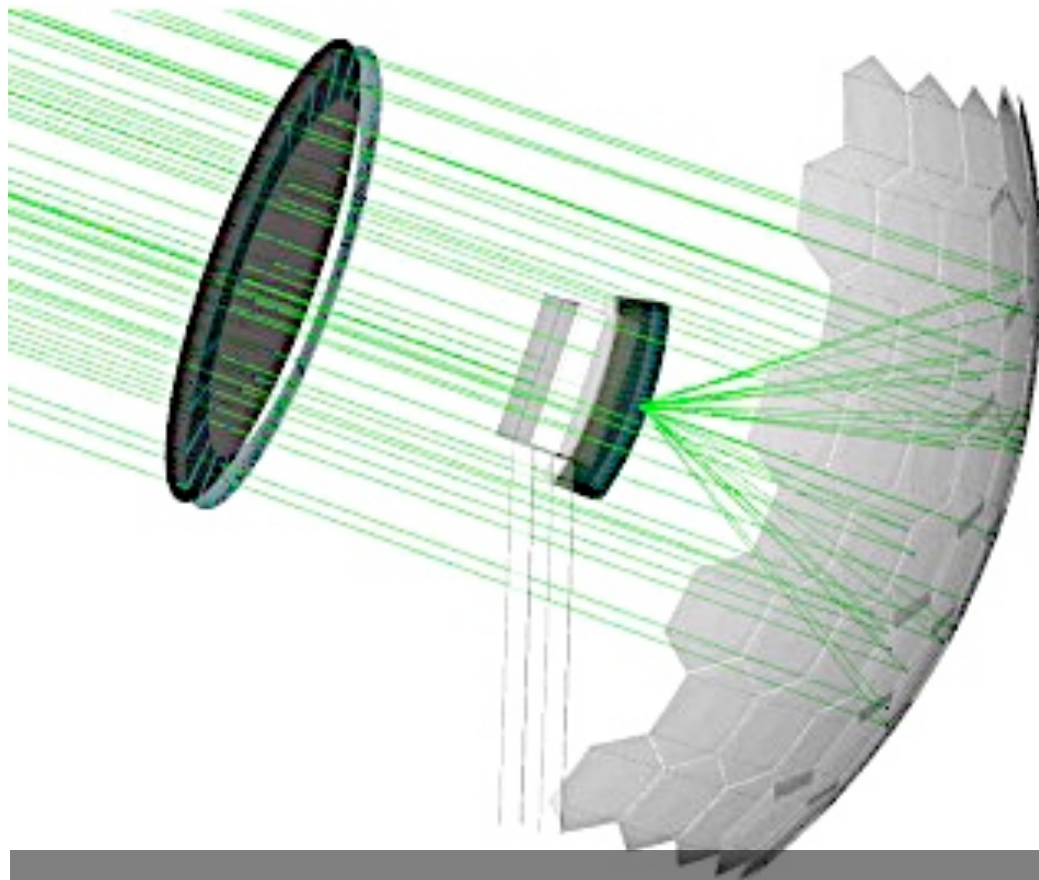
Okumura, Noda, and Rulten (2015)
Submitted to *Astroparticle Physics*



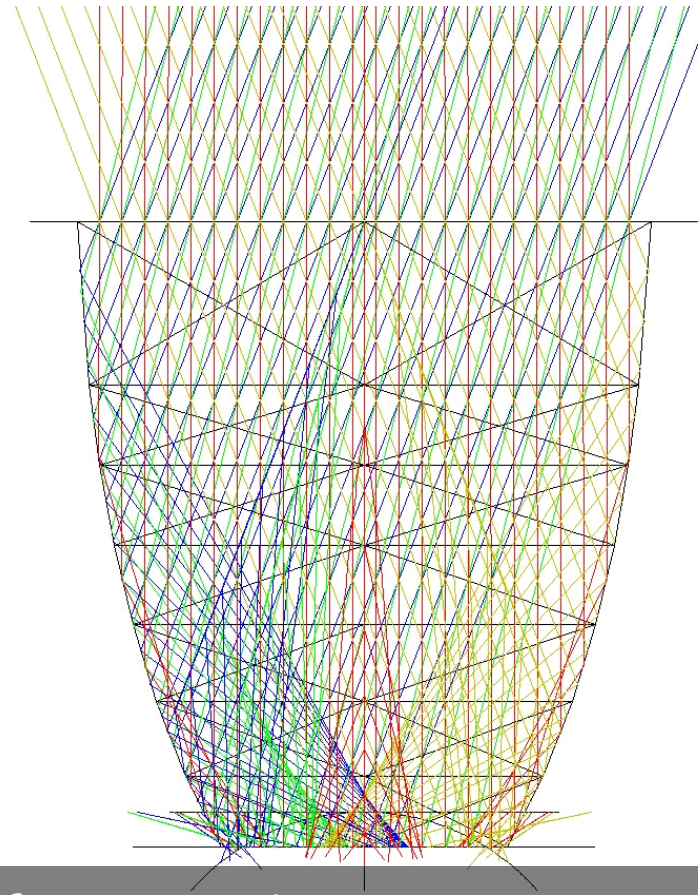
Optics in Gamma-Ray and Cosmic-Ray Telescopes



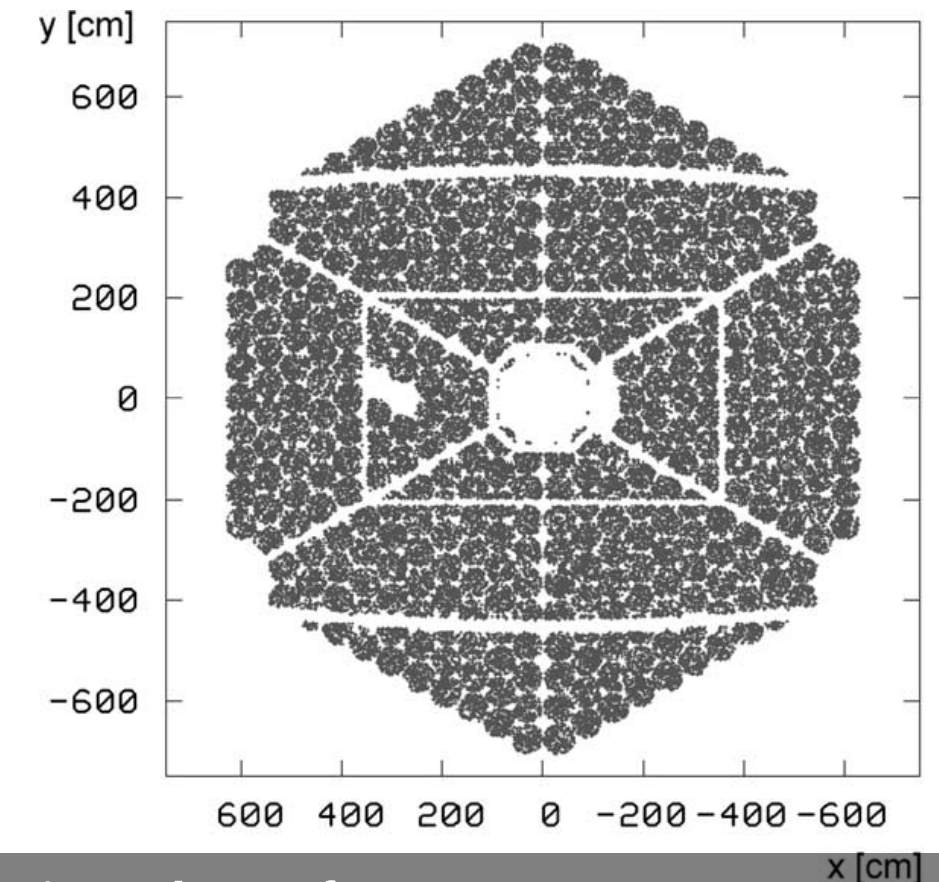
Ray-Tracing Simulations



Geant4 Optical Process for Auger
Abraham *et al.* (2010)



Zemax for a CTA Winston cone
Hénault *et al.* (2013)



sim_telarray for H.E.S.S. I
Bernlöhr *et al.* (2010)

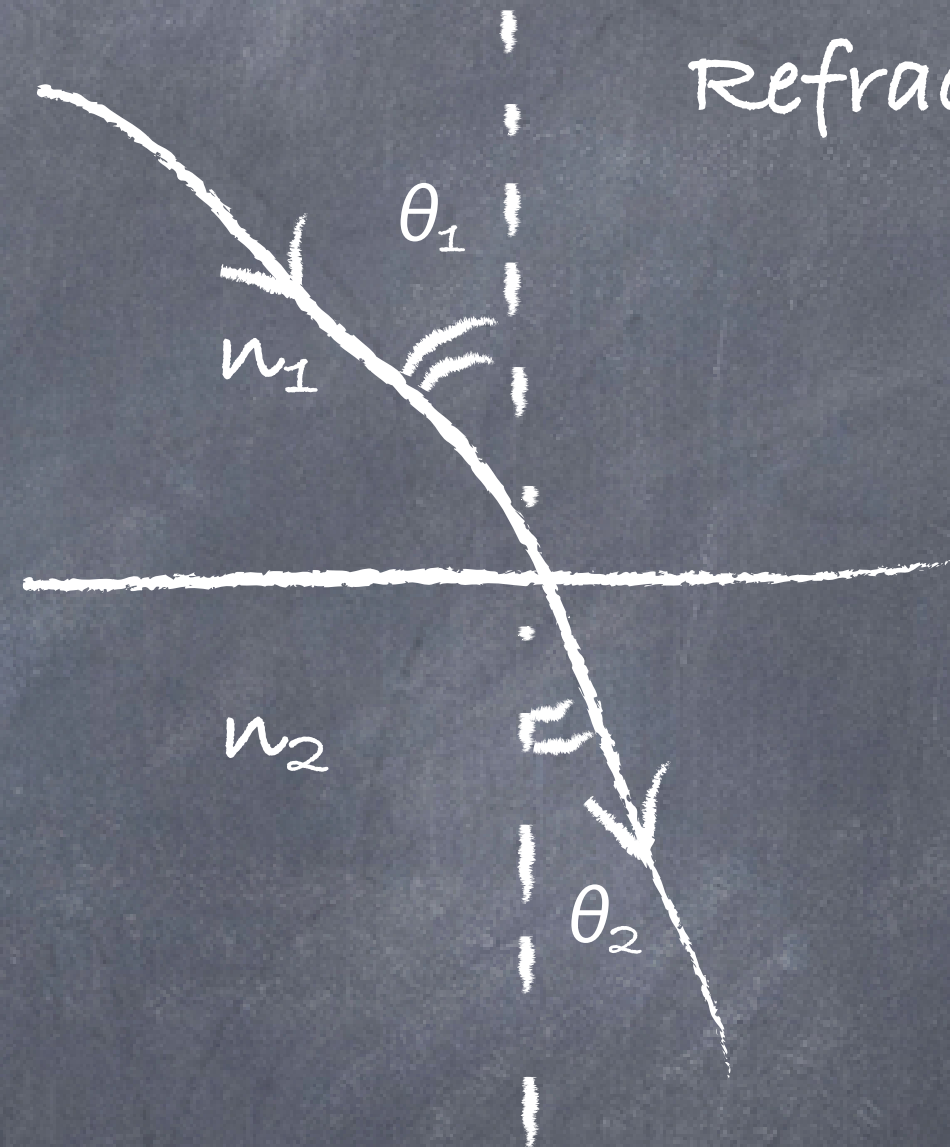
- ❑ Many ray-tracing programs already exist
 - ▶ *Geant4 Optical Process* ... a bit complicated for C++ beginners, limited geometry
 - ▶ *Zemax* ... wide range of functionality, but a commercial license and Windows only
 - ▶ *sim_telarray* ... excellent for full MC of Cherenkov telescopes (also used in CTA), but less flexible than others
- ❑ In addition, many PhD students developed their own “home-brew” software

Geometrical optics

Reflection



Refraction

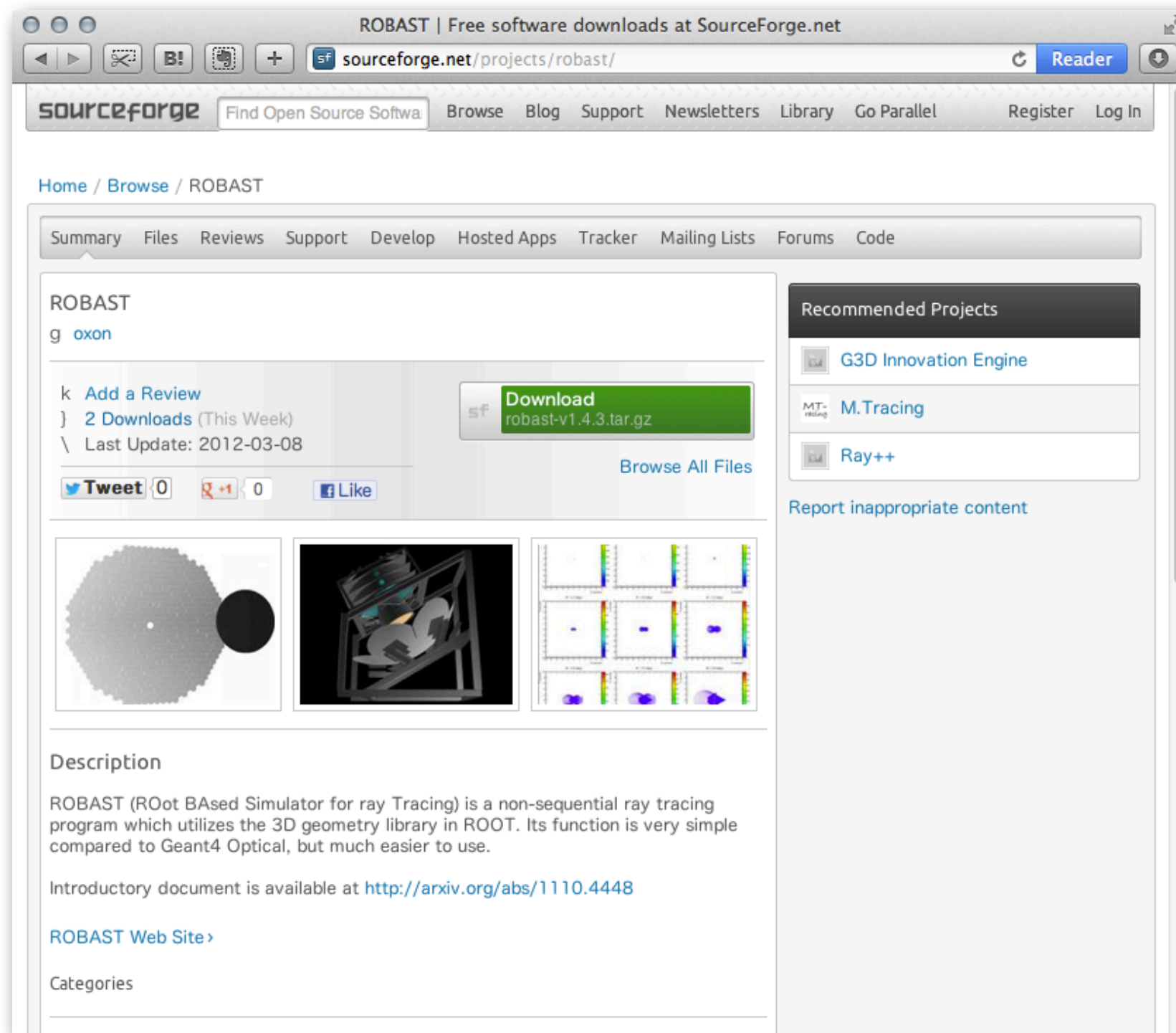


Quite easy mathematics for your students!

However, developing reliable and useful software is a tough work...

Please do **NOT** ask them to write a new simulator from scratch!

ROot-BAsed Simulator for ray Tracing (ROBAST)



<http://sourceforge.net/projects/robast/>

- ❖ I wrote yet another home-brew library, ROBAST, myself
- ❖ Utilizes the ROOT geometry library for photon tracking and geometry construction
- ❖ Useful geometry types for CR telescopes
 - ▶ Aspherical lens/mirror
 - ▶ Winston cone
- ❖ Non-sequential ray-tracing technique
- ❖ Open-source C++ project
- ❖ C++/ROOT/Python
- ❖ OpenGL view
- ❖ Direct analysis in ROOT
- ❖ ~20 users in CTA, and several in other experiments

ROot-BAsed Simulator for ray Tracing (ROBAST)

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ROBAST ROot BAsed Simulator for ray Tracing (ROBAST) is a ...

robast

robast.r-forge.r-project.org/

Welcome to RobAST - Robust Asymptotic Statistics project! The project RobAST aims for the implementation of R packages for the computation of optimally robust ...

R-Forge: RobAST - Robust Asymptotic Statistics: Project Home

r-forge.r-project.org/projects/robast/

Jan 15, 2008 - The project RobAST aims for the implementation of R packages for the computation of optimally robust estimators and tests as well as the ...


Robast B.V.

https://plus.google.com/.../about?gl=nl&hl=en - Translate this page

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Ignore!!! Always annoying.

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Robast B.V.

Beleggingsinstellingen met beperkte toetreding

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Reviews

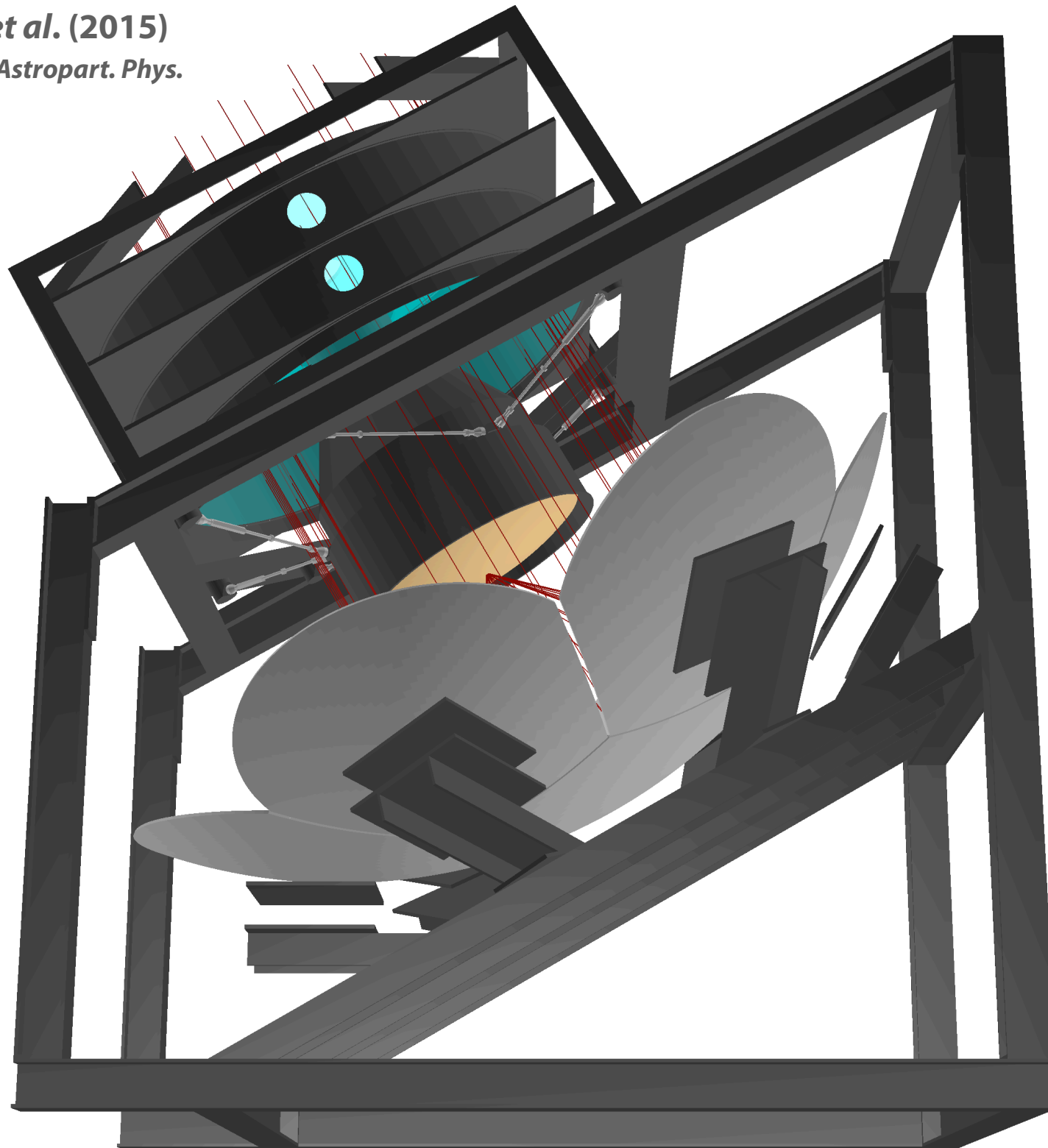
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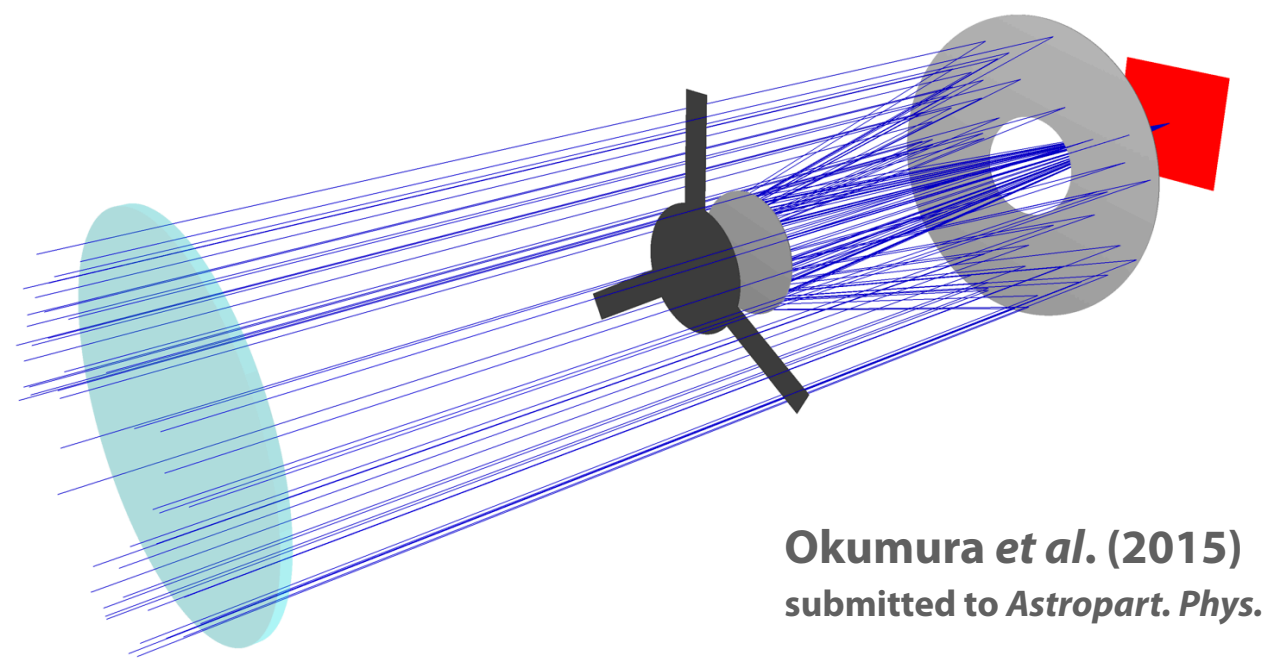
The First Complex ROBAST Application

Okumura *et al.* (2015)
submitted to *Astropart. Phys.*

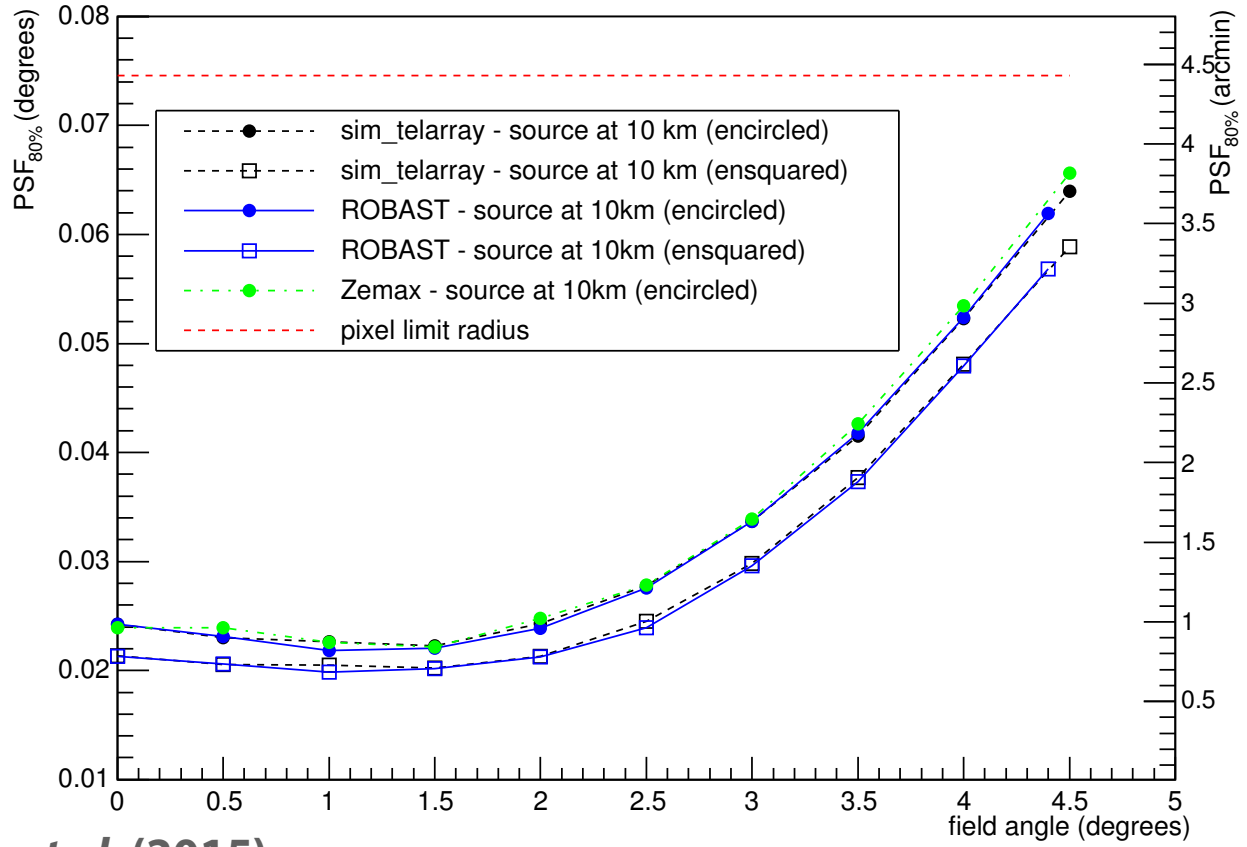


- ❑ ROBAST was initially developed by A.O. for the Ashra project in 2007
- ❑ Released as an open-source project for CTA simulations in 2010
- ❑ Can build complex telescope geometry with ROOT and ROBAST classes
 - ▶ Segmented mirrors
 - ▶ Aspherical lenses
 - ▶ Telescope frames
- ❑ Four optics types
 - ▶ Mirror
 - ▶ Lens
 - ▶ Focal surface
 - ▶ Obscuration

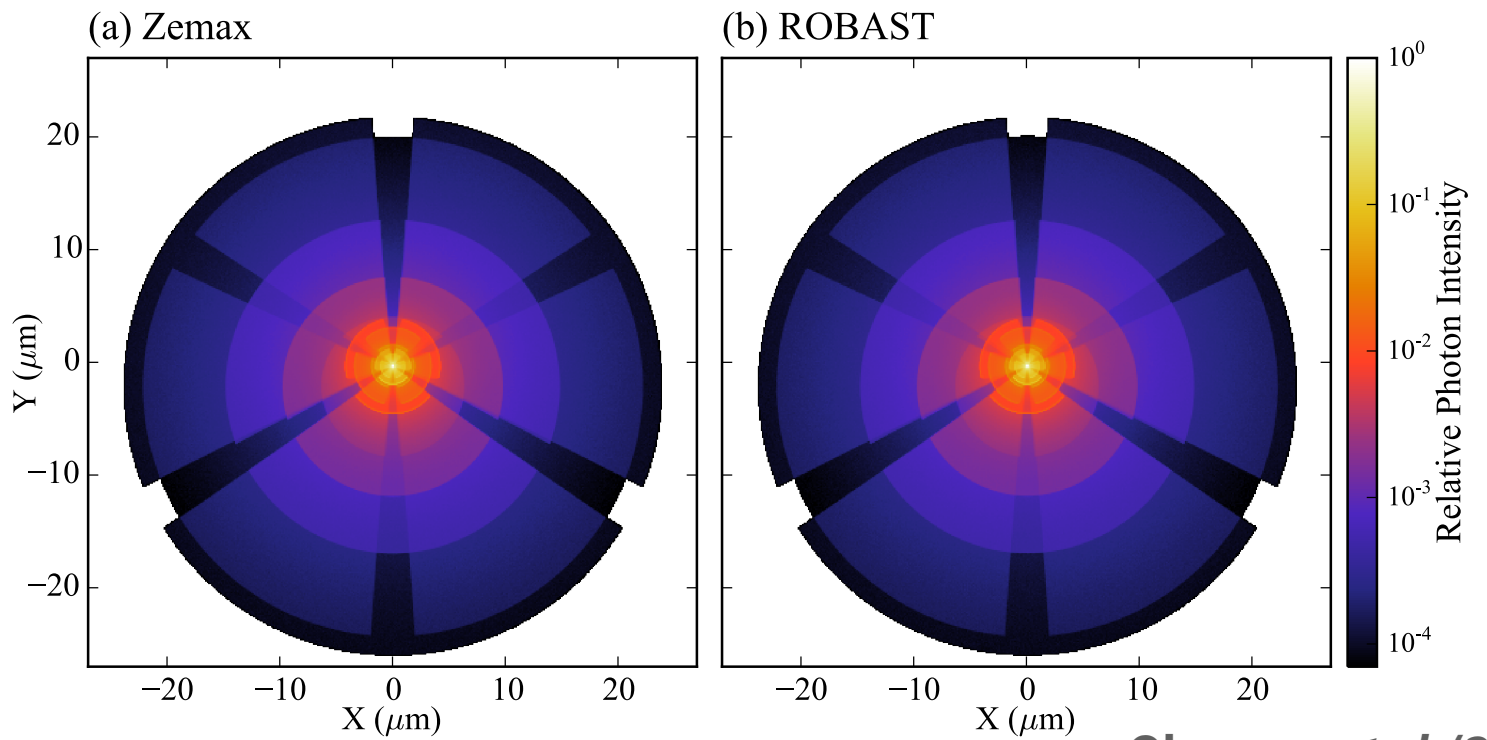
Cross-Check with Zemax and sim_telarray



Okumura *et al.* (2015)
submitted to *Astropart. Phys.*



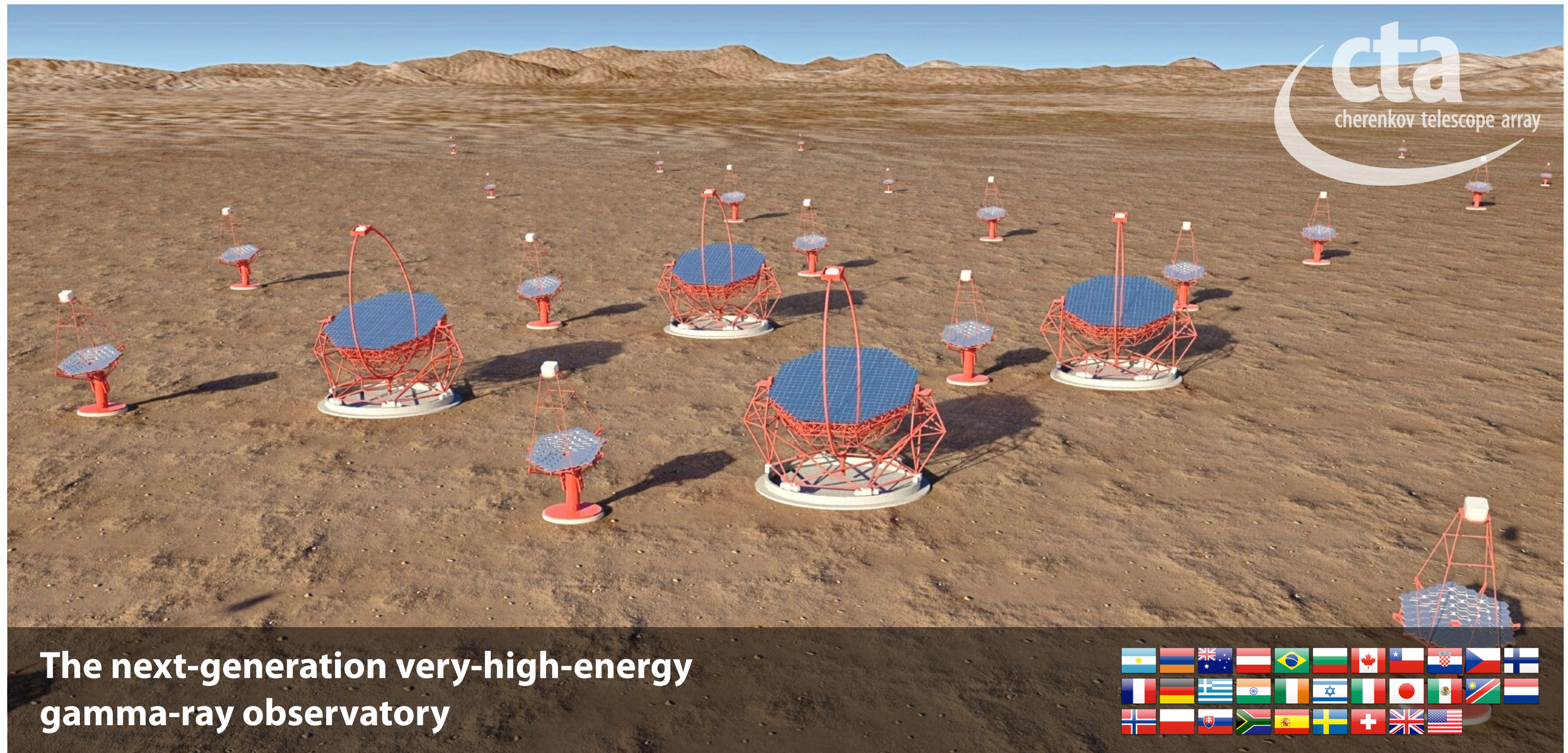
Rulten *et al.* (2015)
to be submitted to *Astropart. Phys.*



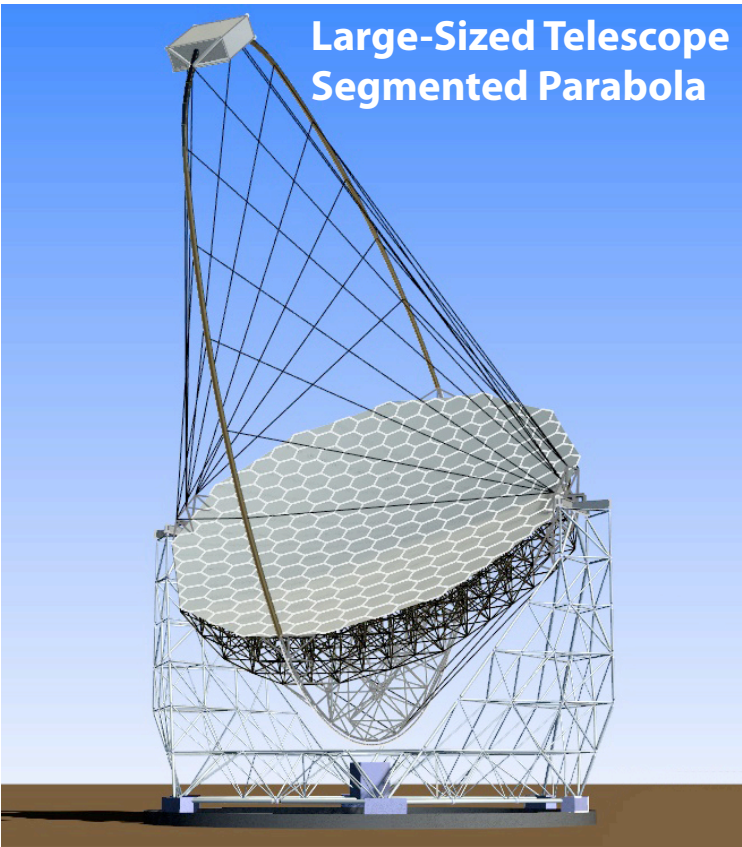
Okumura *et al.* (2015)
submitted to *Astropart. Phys.*

- Performed cross-check simulations with other programs (Zemax, sim_telarray, and some others) for several optical systems
- Consistent results have verified the ROBAST calculation

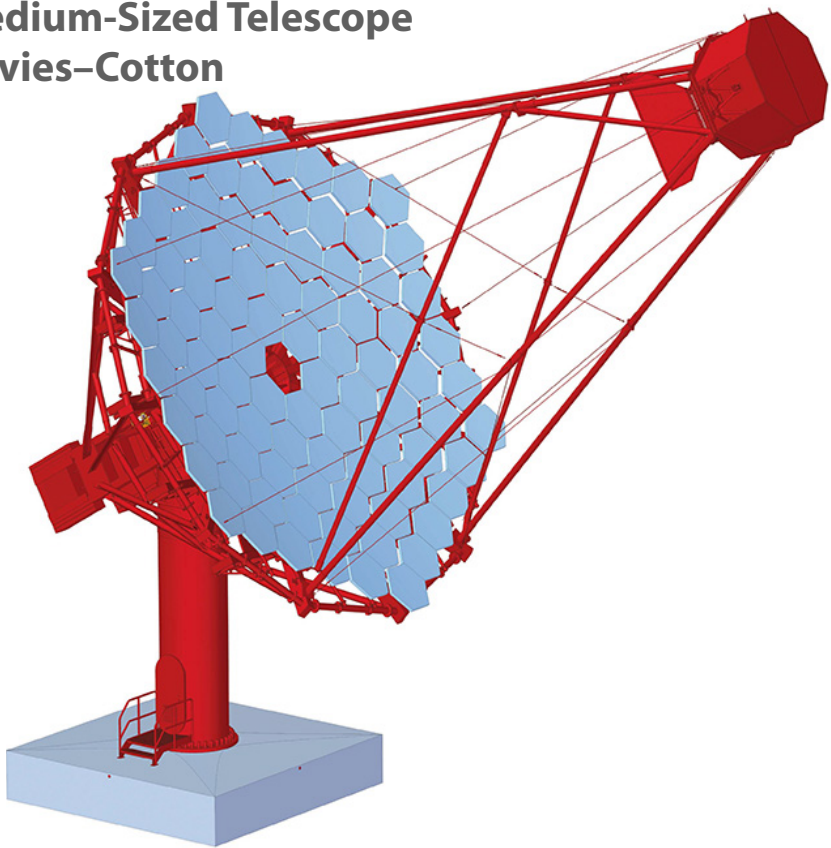
The Cherenkov Telescope Array (CTA)



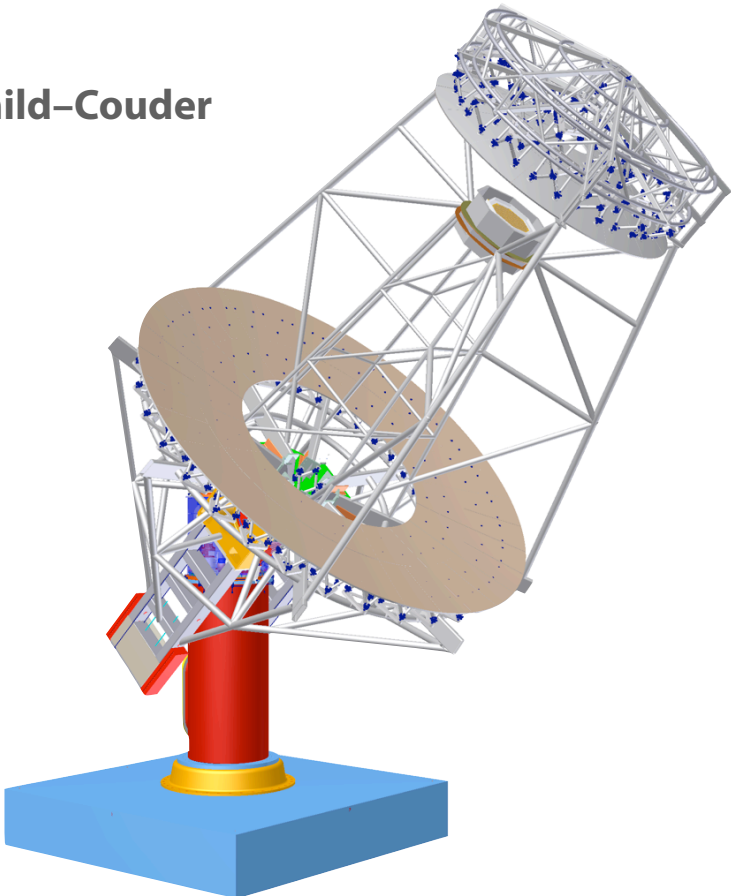
Diverse Optics Designs in CTA



Large-Sized Telescope
Segmented Parabola

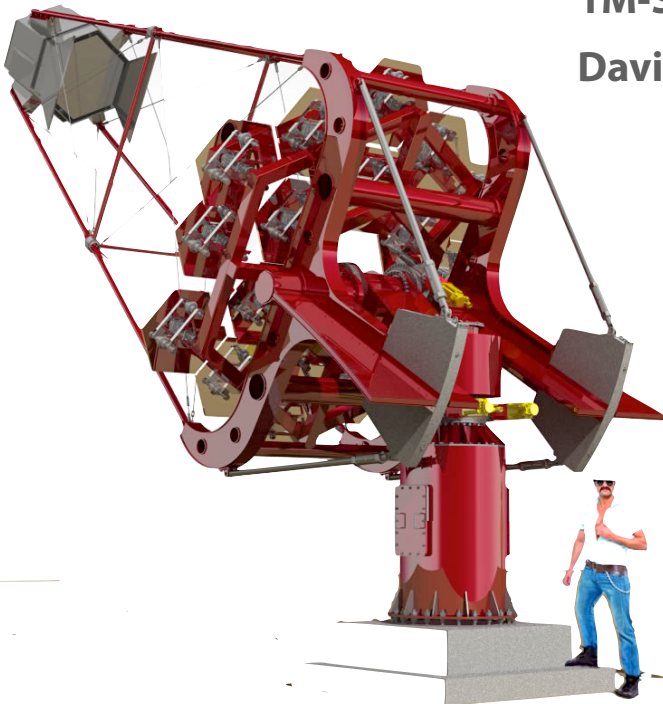
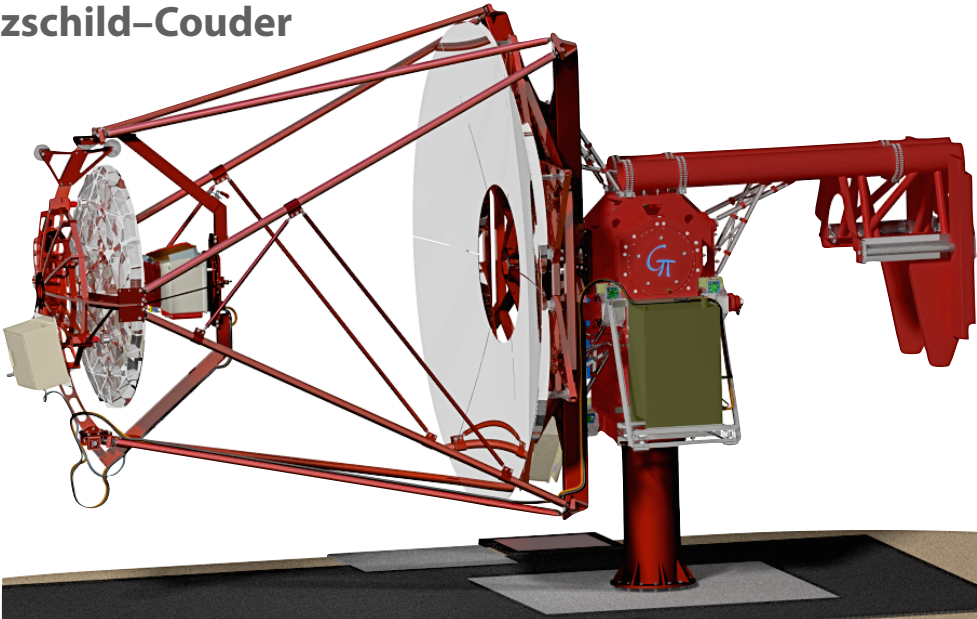


Medium-Sized Telescope
Davies-Cotton



SC-MST
Schwarzschild-Couder

Gamma-ray Cherenkov Telescope (2M-SST)
Schwarzschild-Couder

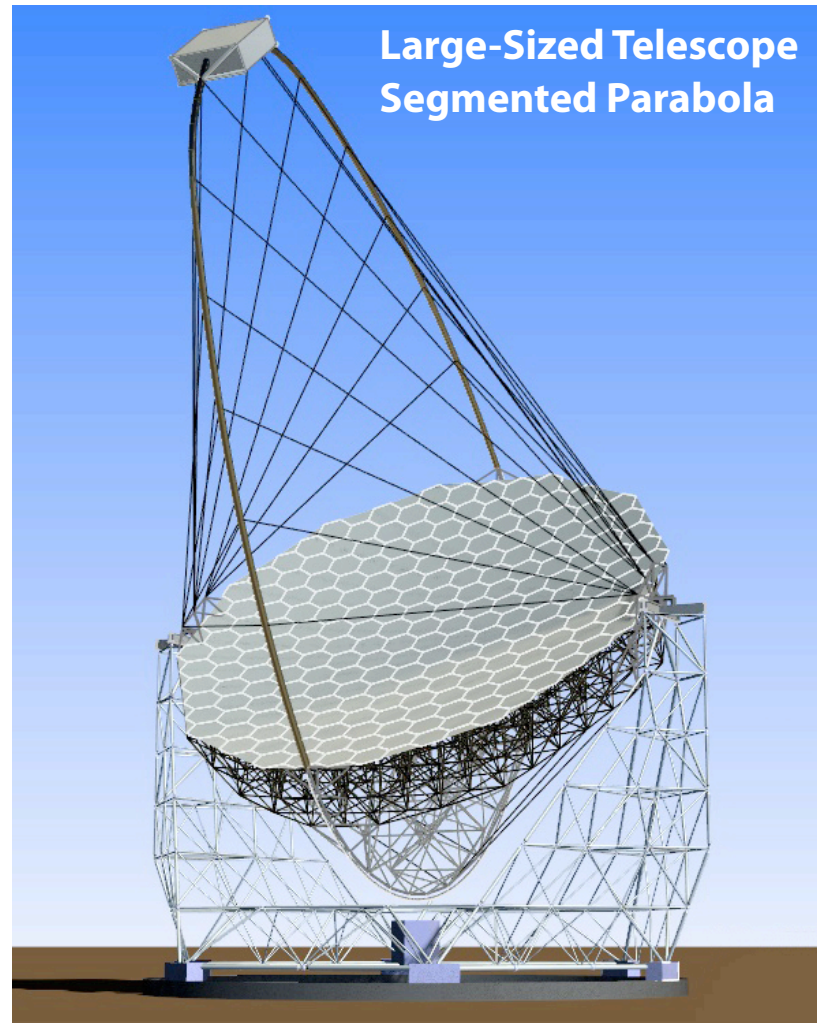


1M-SST
Davies-Cotton

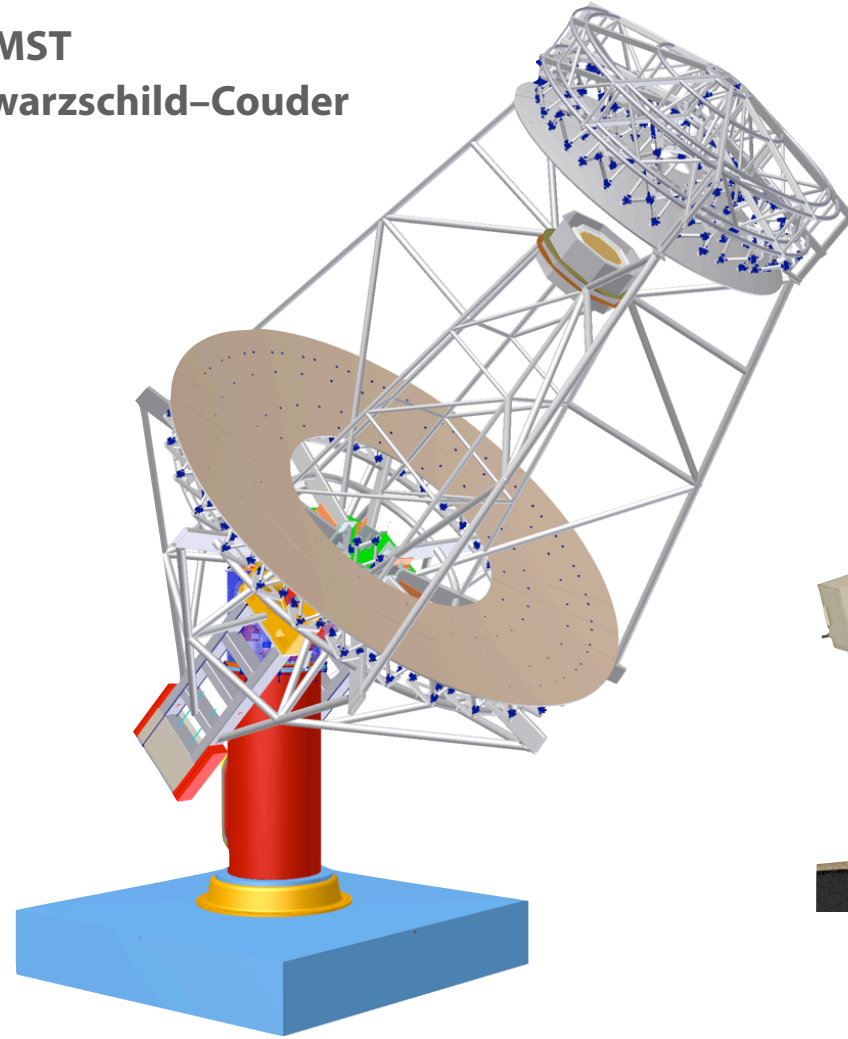


ASTRI (2M-SST)
Schwarzschild-Couder

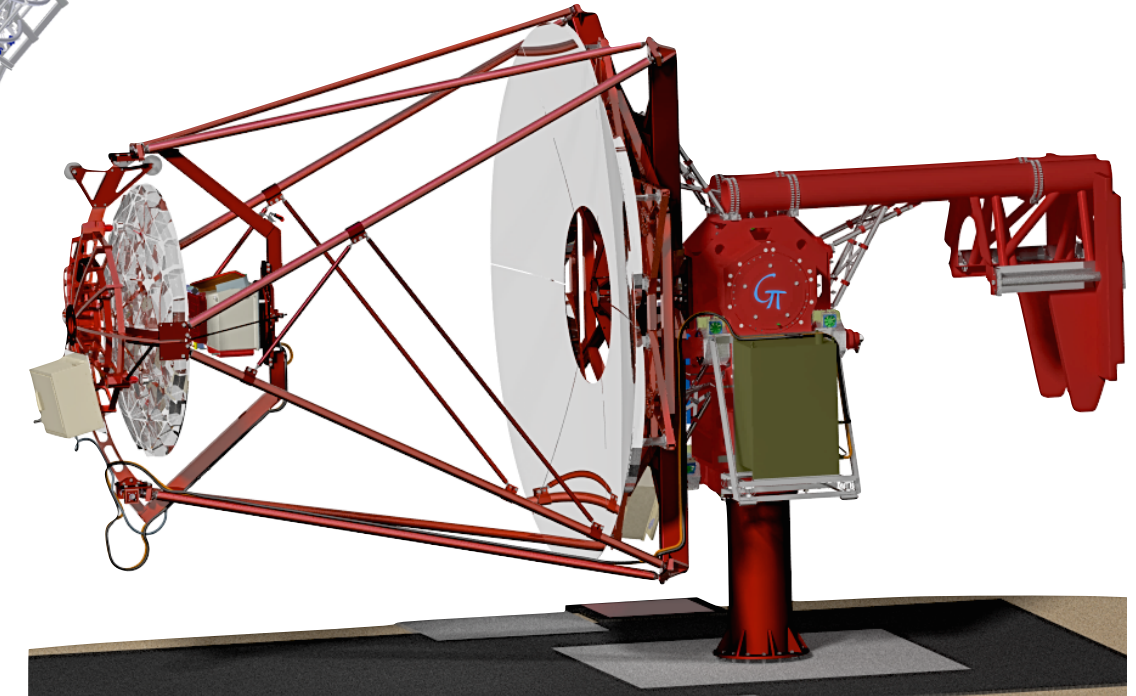
ROBAST Applications in CTA



SC-MST
Schwarzschild-Couder

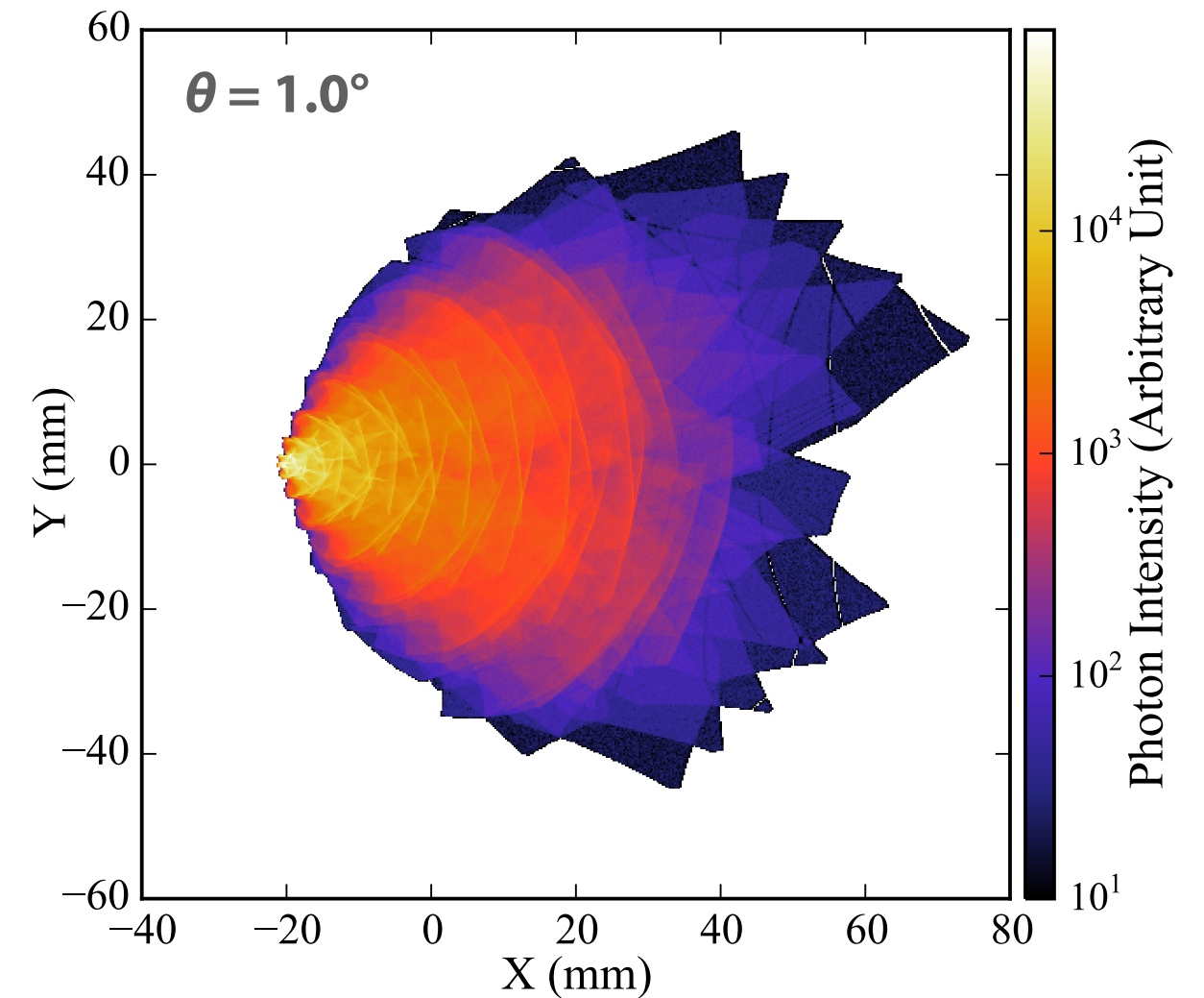
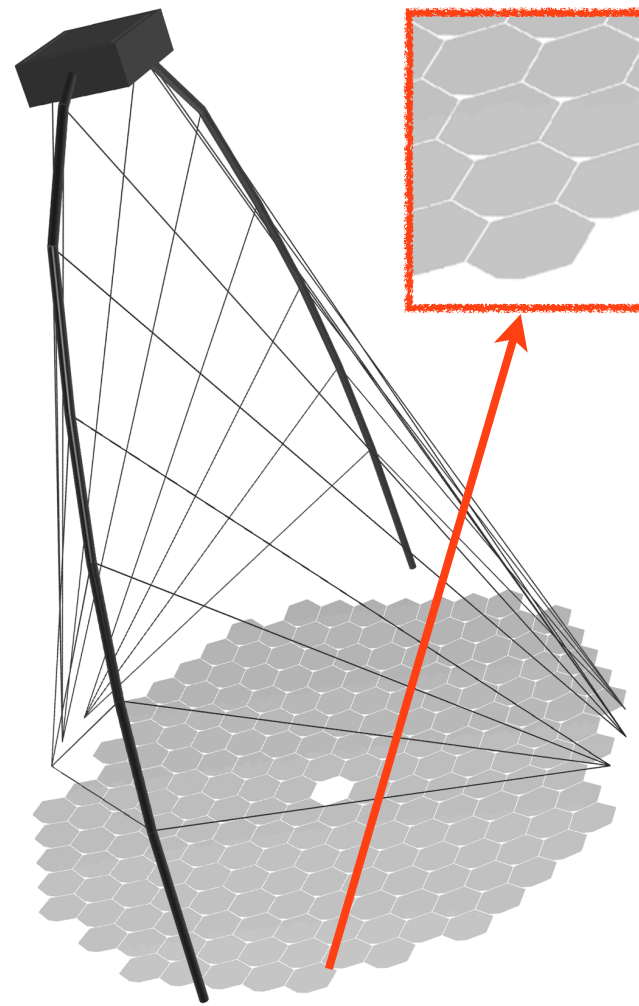
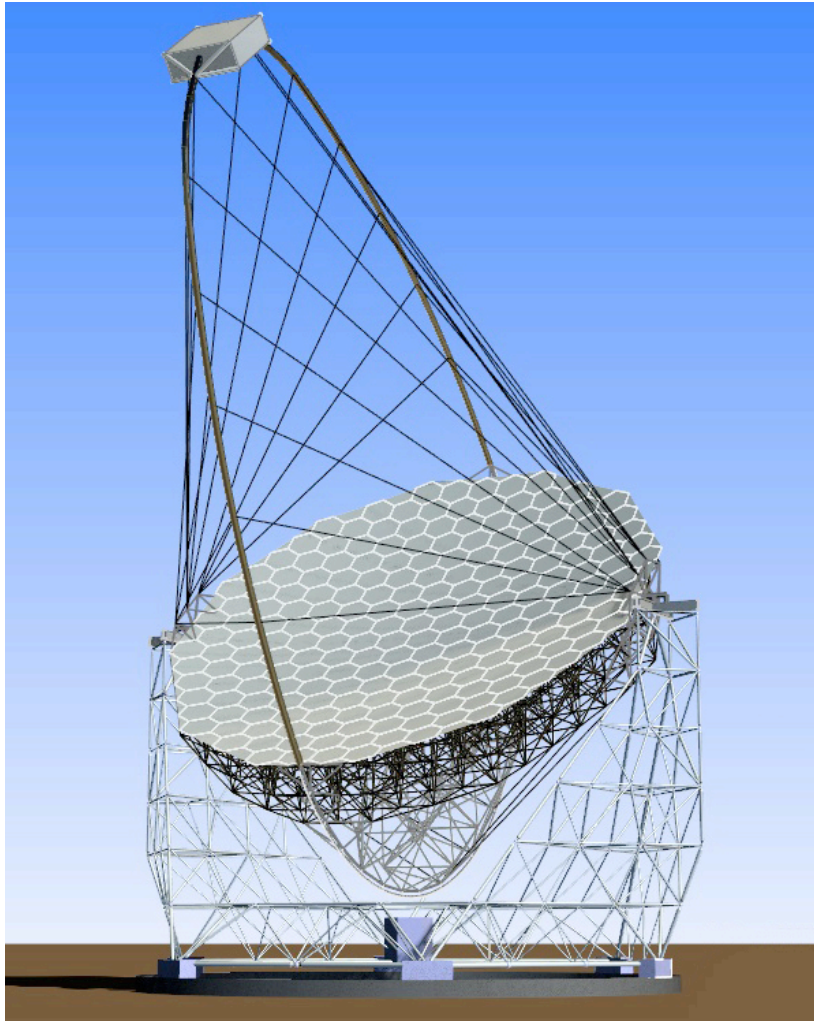


Gamma-ray Cherenkov Telescope (2M-SST)
Schwarzschild-Couder



- ❖ ROBAST is currently used in three of the six telescope designs for PSF simulations, tolerance analysis, shadowing evaluation
- ❖ Exchanged simulation code and experience among the sub projects, enabling us to save time and human power as well as to improve the simulation quality

Large-Sized Telescope (LST)

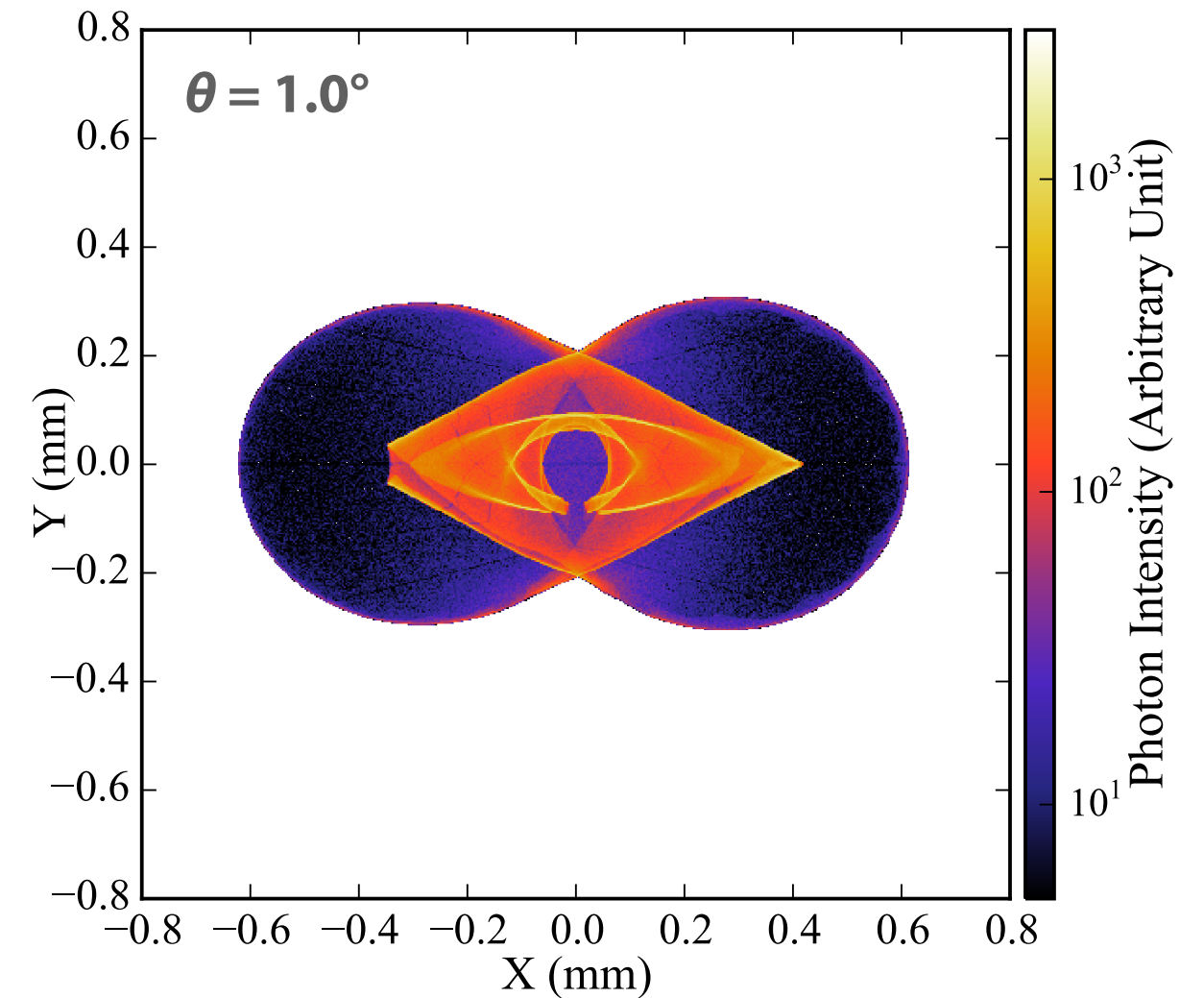
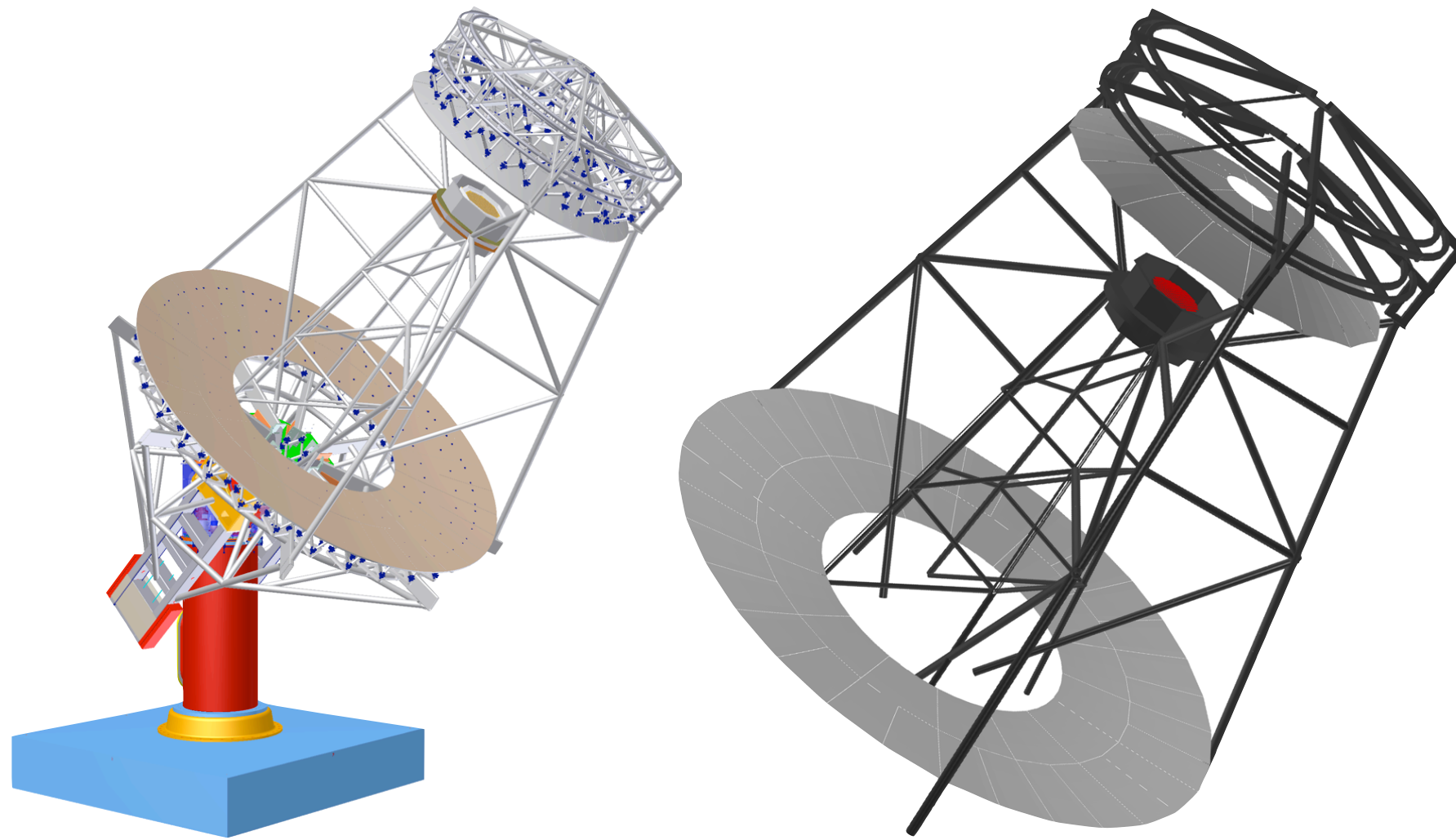


NB: Misalignment of the segmented mirrors or any deviation in the mirror shapes have not been taken into account.

- ❖ Consists of 198 spherical segmented mirrors to form a large parabola (23-m diameter, 28-m focal length)
- ❖ In addition to the comatic aberration, small structure made by segmented mirrors can be seen
- ❖ Similar simulations for Davies–Cotton telescopes can be easily performed as well

Simulation by K. Noda (MPI Physics)

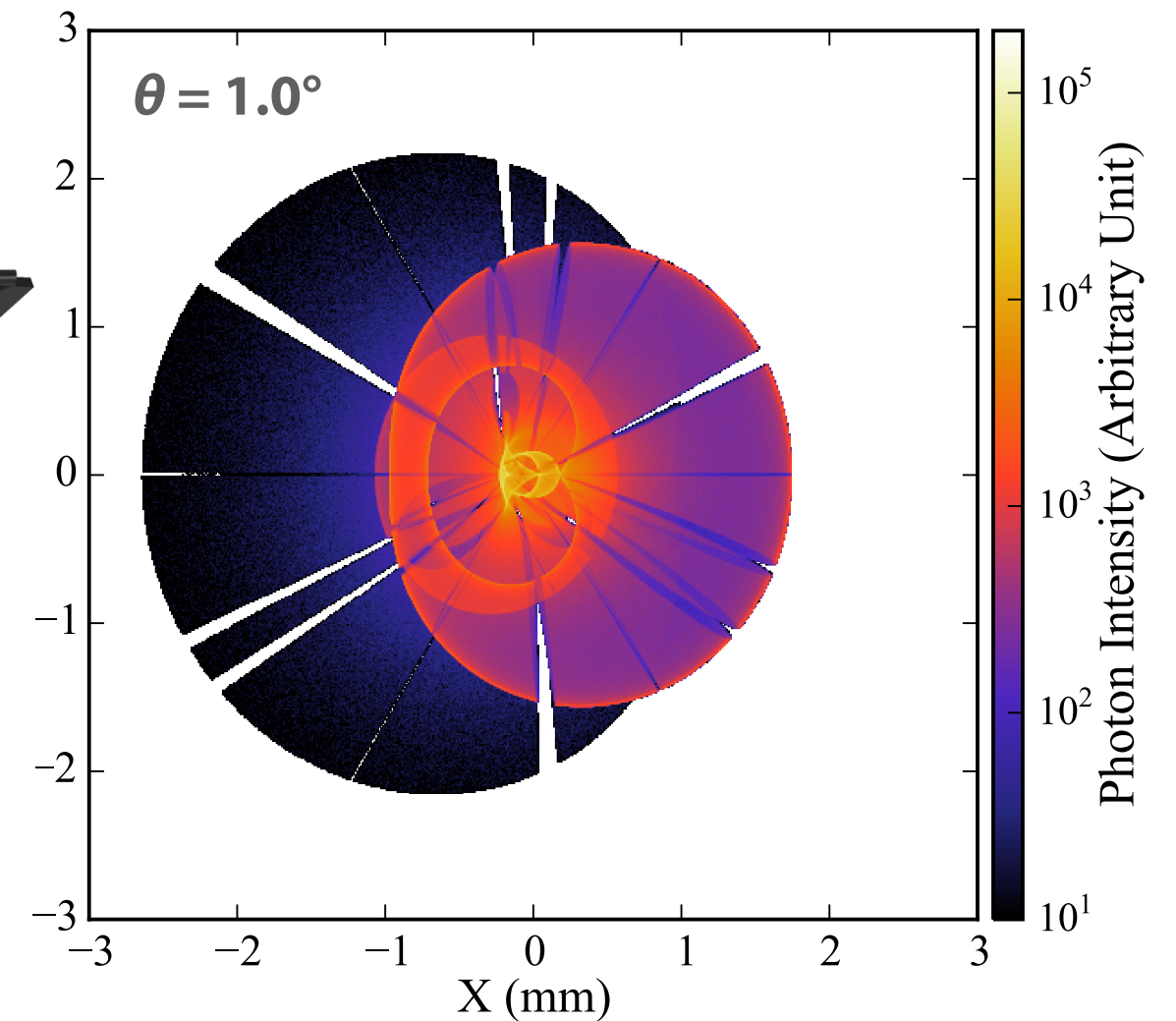
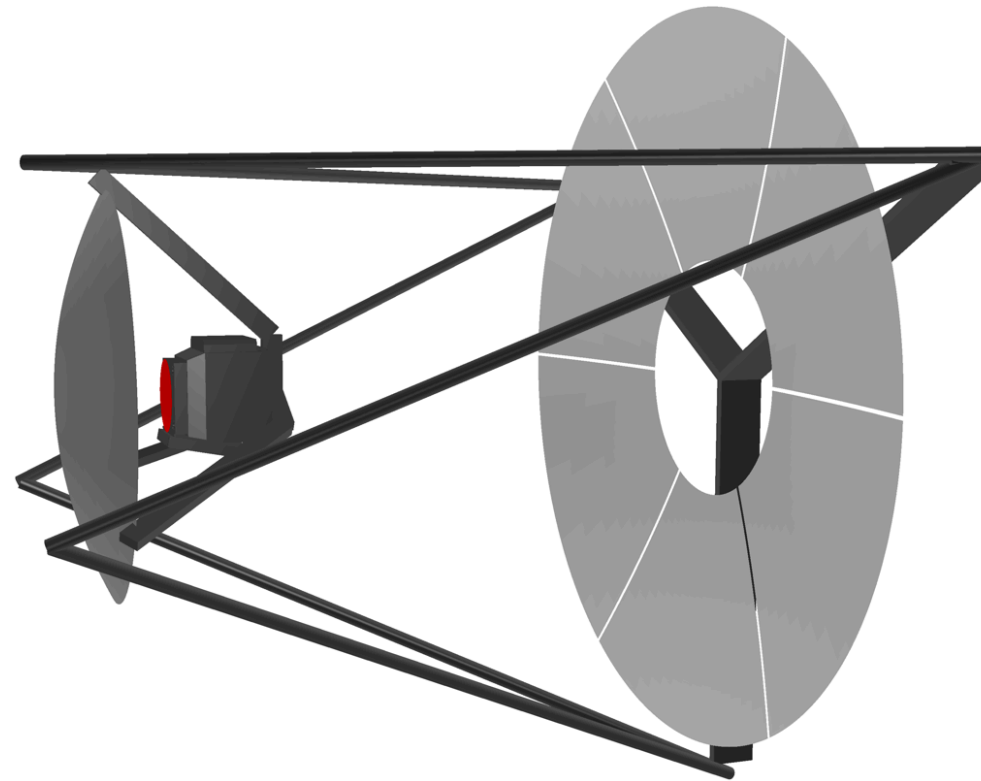
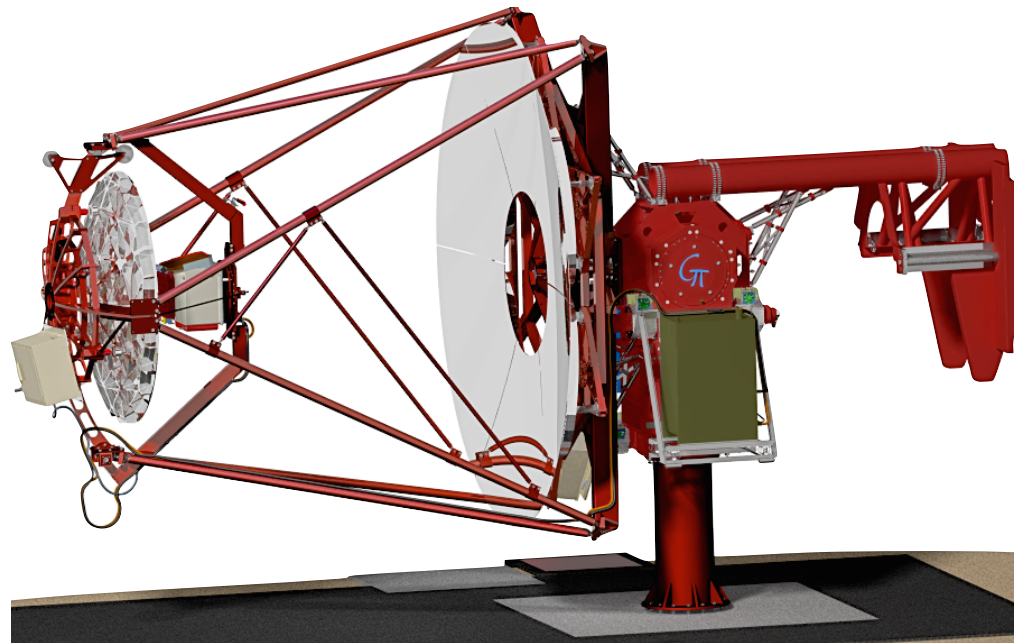
Schwarzschild–Couder Medium-Sized Telescope (SC-MST)



NB: Misalignment of the segmented mirrors or any deviation in the mirror shapes have not been taken into account.

- ❑ Proposed as an extension of Davies–Cotton MST array
- ❑ Aspherical primary (9.7 m) and secondary (5.4 m) mirrors with 72 facets
- ❑ Non-sequential ray tracing is indispensable to simulate shadowing and vignetting by the telescope masts and trusses

Gamma Cherenkov Telescope (One of Small-Sized Telescope Designs)

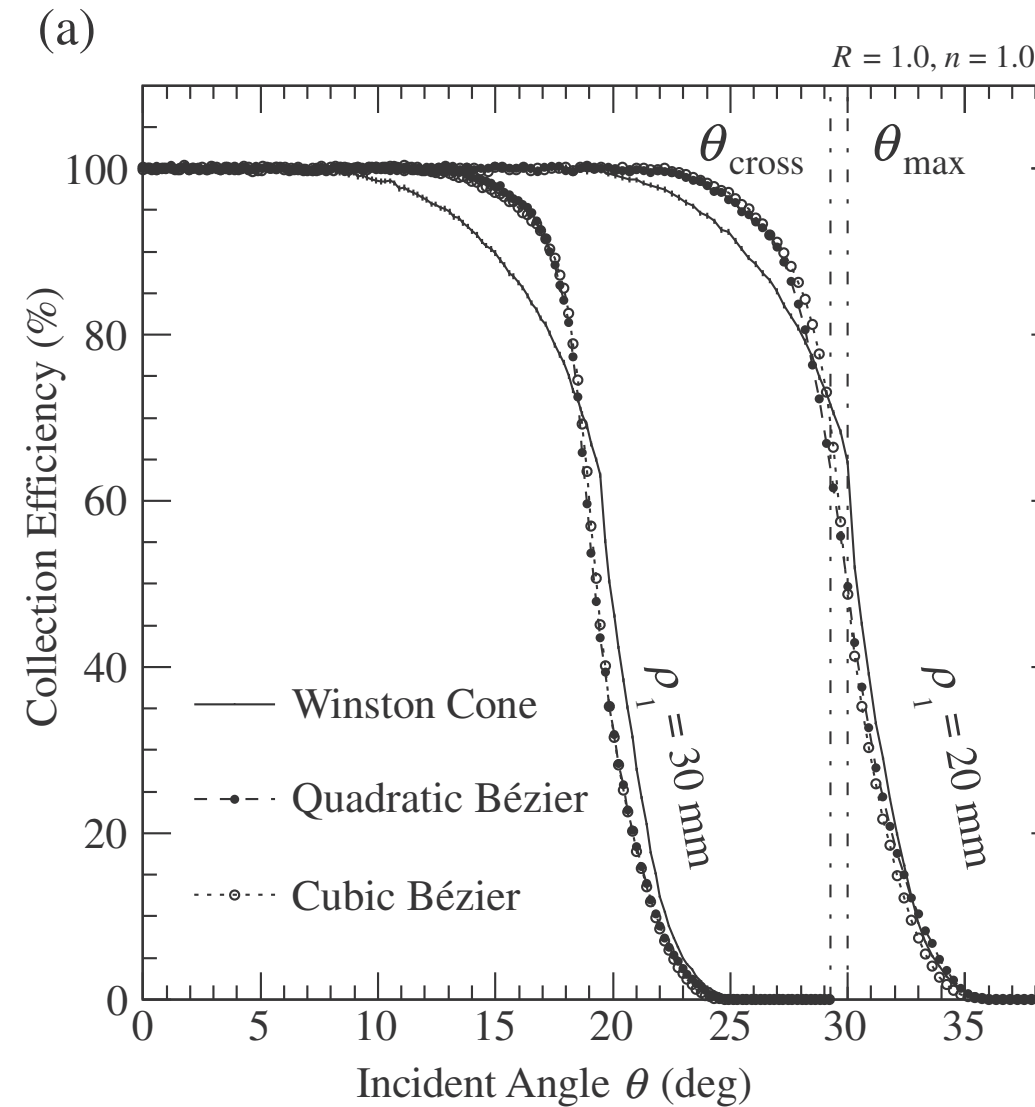
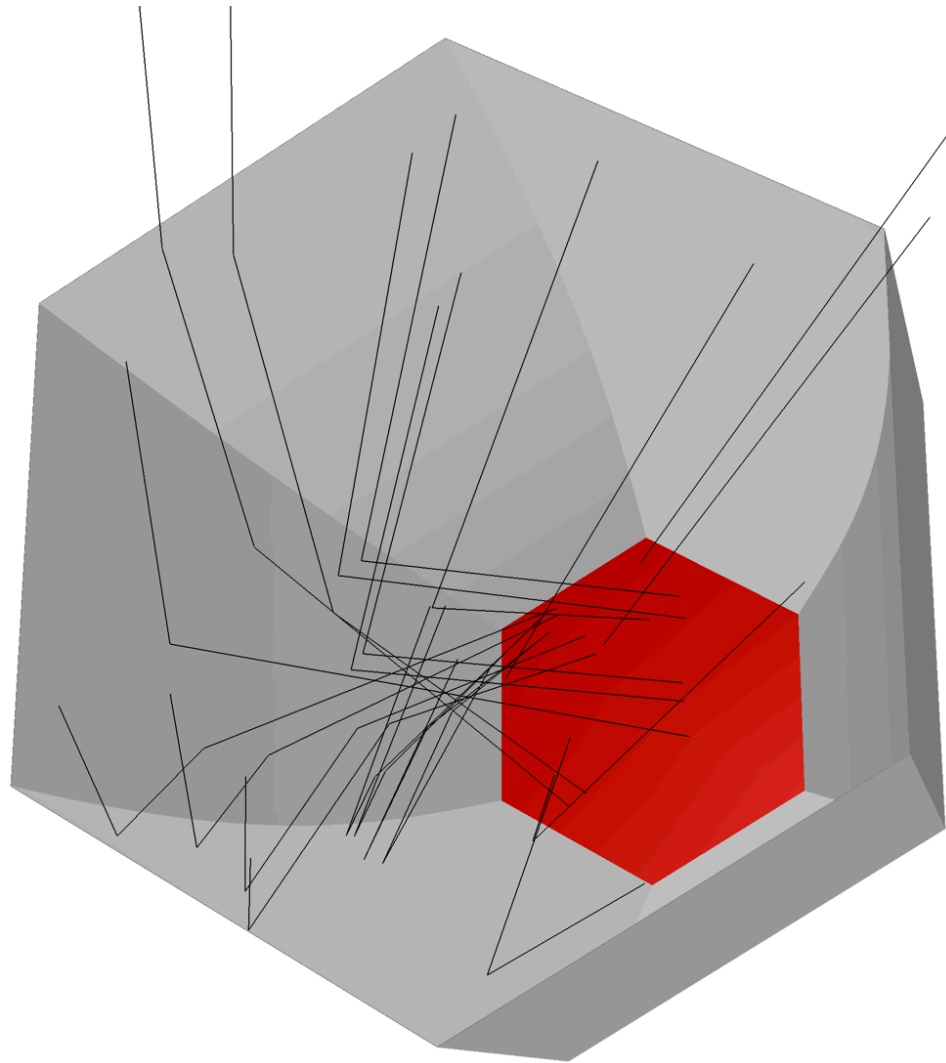


NB: Misalignment of the segmented mirrors or any deviation in the mirror shapes have not been taken into account.

- ❖ Aspherical primary (4 m) and secondary (2 m) mirrors with less numbers of segmented mirrors and telescope masts and trusses
- ❖ Small structures and shadows made by segmented mirrors and telescope masts are visible
- ❖ Verifying that the complex telescope geometries were successfully built and simulated by ROBAST

Simulation by C. Rulten (Minnesota)

Simulation of a Hexagonal Light Concentrator



Okumura (2012) *Astropart. Phys.*

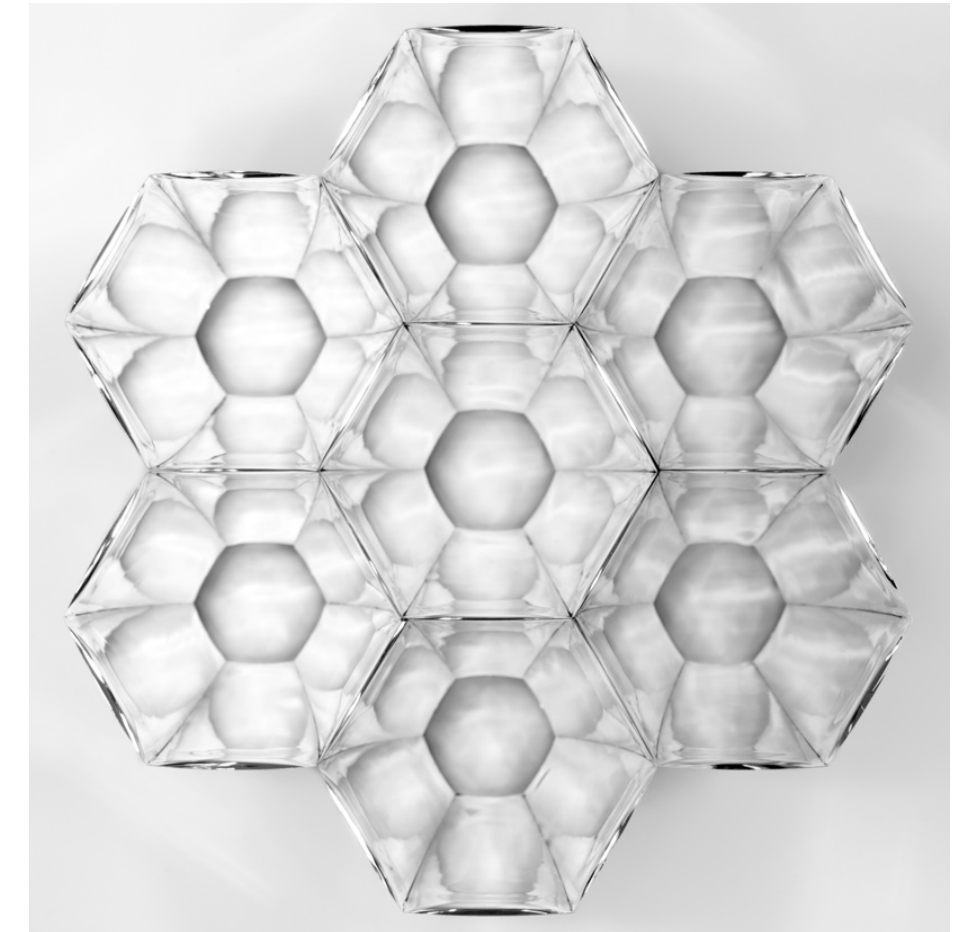


Photo by S. Ono (Ibaraki Univ.)

- ❖ ROBAST is currently used for the development of the LST light concentrators
- ❖ Non-sequential ray-tracing functionality and dedicated geometry classes for Winston cones and Bézier-curve cones make the simulation very easy
- ❖ Please also see my poster (Poster 3 GA, Tue & Wed)

- ❖ We have developed a C++ library, **ROBAST**, for ray-tracing simulations of CR telescopes
- ❖ Equipped with most functionalities required for CR telescopes
- ❖ Verified by comparisons with other programs
- ❖ Actively used in the Cherenkov Telescope Array for simulations of optical systems and light concentrators
- ❖ New users and CR projects are very welcome!