MACHETE
A transit Imaging Atmospheric Cherenkov Telescope to survey half of the VHE γ-ray sky

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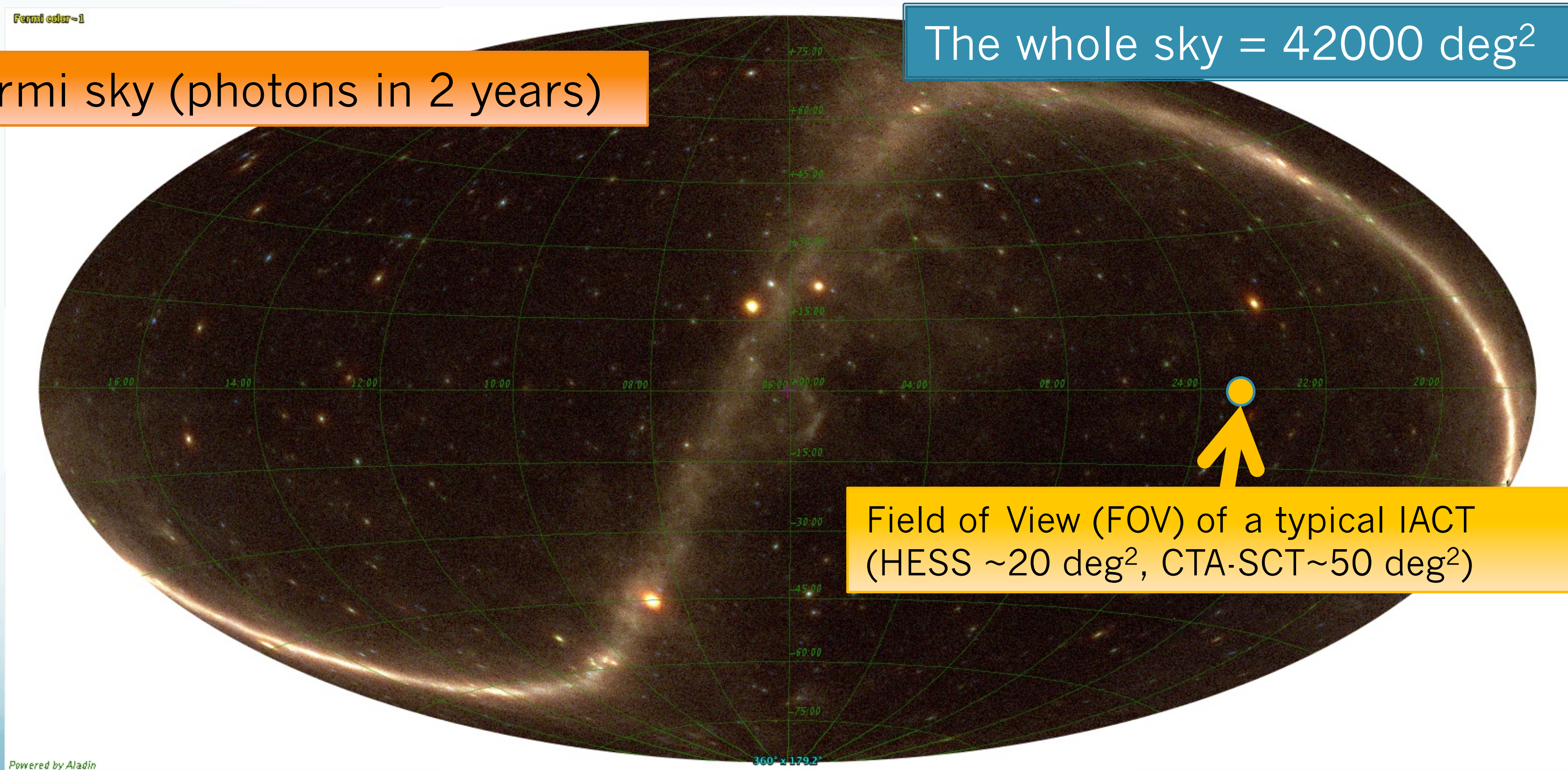
Astrop. Physics, in print

IACTs are pointing instruments

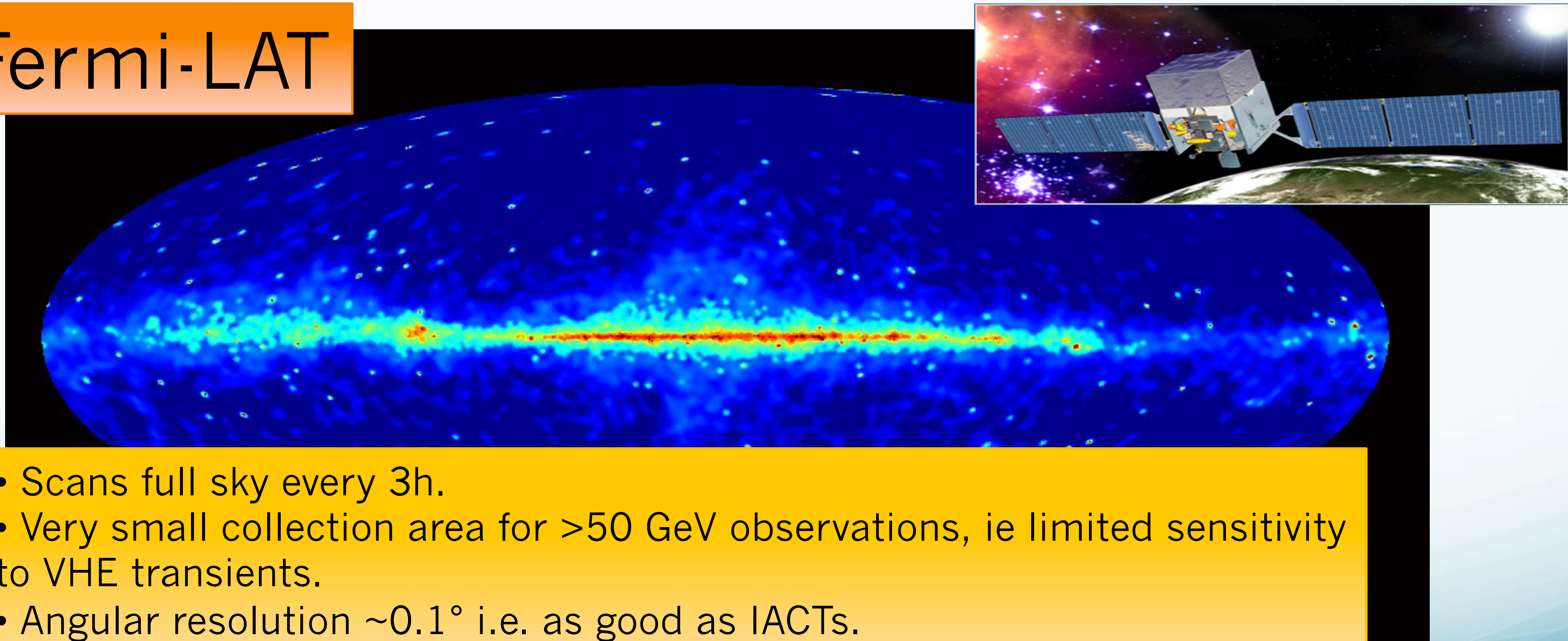


Surveys with IACTs

- Say we need 10h to achieve enough sensitivity. We would need 10000 hours to scan the whole sky: telescopes need ~10 years to collect them.
- It is achievable but there are many other ideas to exploit an IACT for 10 years.
- As a result only a survey of the galactic plane has been performed (HESS, about 1000 deg^2). Adding all pointing observations, we may have explored ~5% of the sky.
- What is in the other 95% of the sky? Active galaxies, off-plane galactic sources, dark matter clumps? Important to make a **Full sky survey in VHE**.
- What it's more, the VHE sky is changing all the time, so we would need to repeat the survey for a few years and we'd very much like to **monitor it every night**.

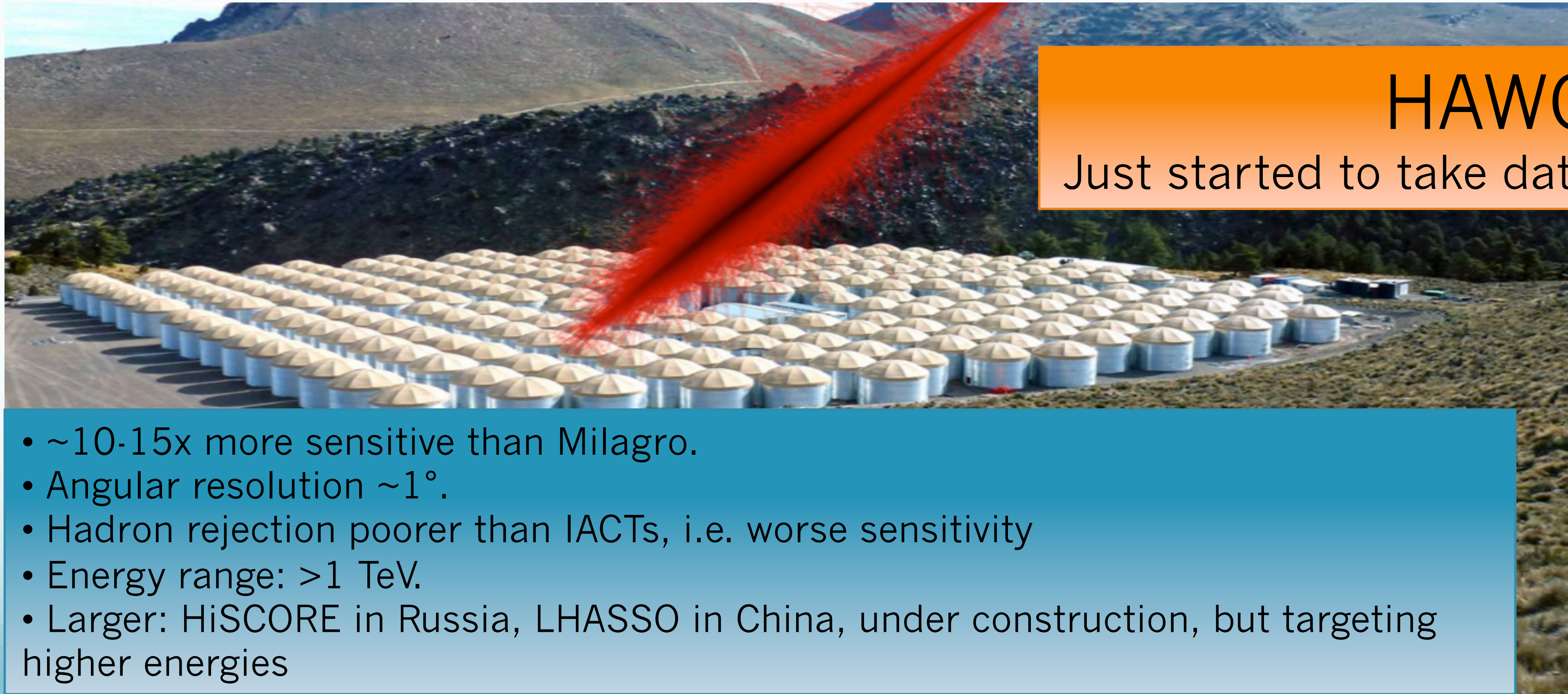
E_γ<10-100 GeV: space based surveys

Fermi-LAT



- Scans full sky every 3h.
- Very small collection area for >50 GeV observations, ie limited sensitivity to VHE transients.
- Angular resolution ~0.1° i.e. as good as IACTs.
- No obvious replacement for Fermi-LAT in the future (>2020?)

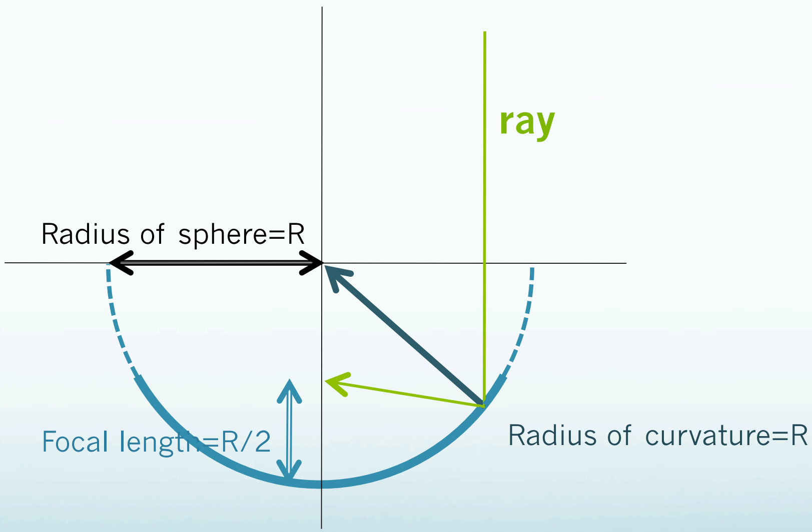
E_γ>1 TeV: surveys with non-IACTs



- ~10-15x more sensitive than Milagro.
- Angular resolution ~1°.
- Hadron rejection poorer than IACTs, i.e. worse sensitivity
- Energy range: >1 TeV.
- Larger: HiSCORE in Russia, LHASSO in China, under construction, but targeting higher energies

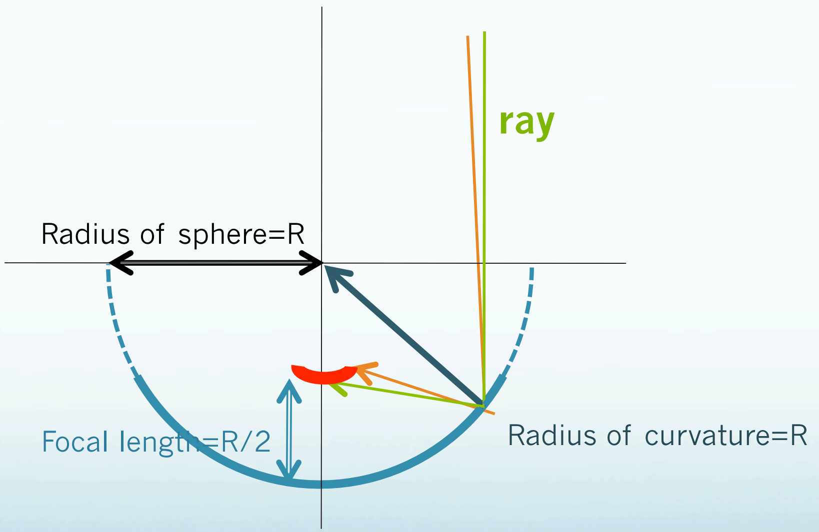
The archetypal wide FOV telescope: the Schmidt telescope

How to build a Schmidt:
STEP 1. Start with a **spherical mirror**. It has aberrations but only spherical aberrations.



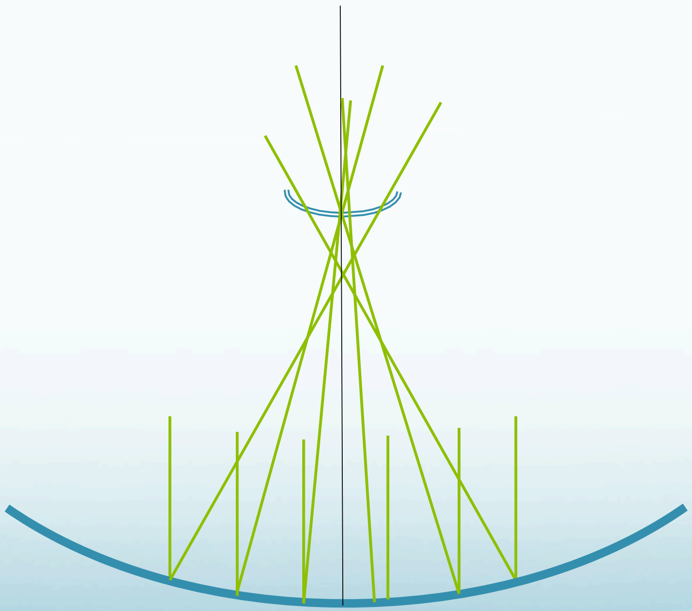
The archetypal wide FOV telescope: the Schmidt telescope

STEP 2. Make the **focal plane spherical**, with center at center of mirror. All incident directions become equivalent.



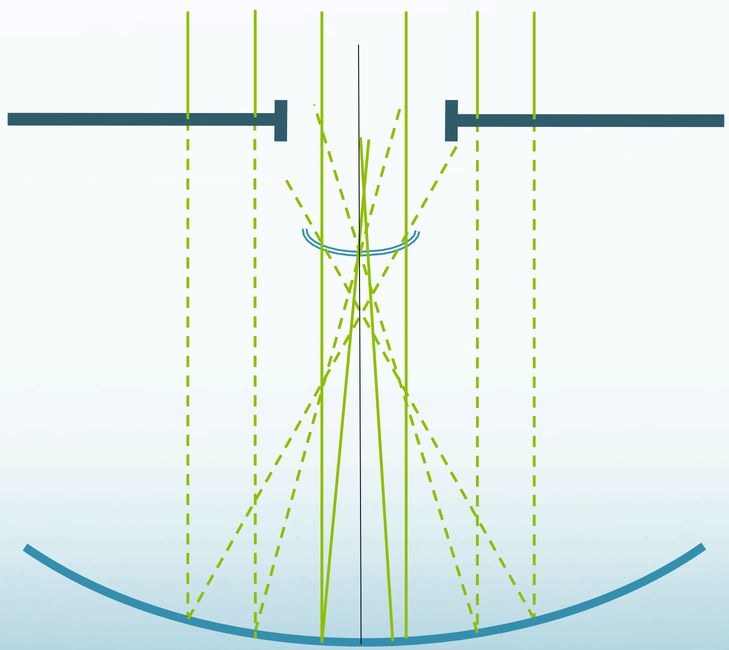
The archetypal wide FOV telescope: the Schmidt telescope

STEP 3. For a spherical mirror as rays hit further and further away from optical axis they get more a more defocused.



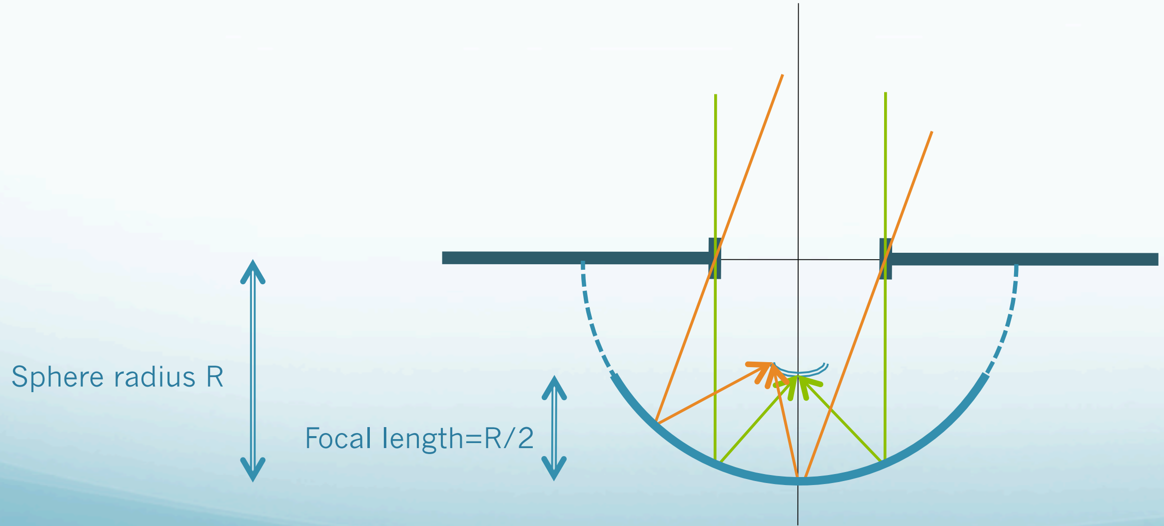
The archetypal wide FOV telescope: the Schmidt telescope

STEP 3. ... adding a “stop” reduces the aberration.



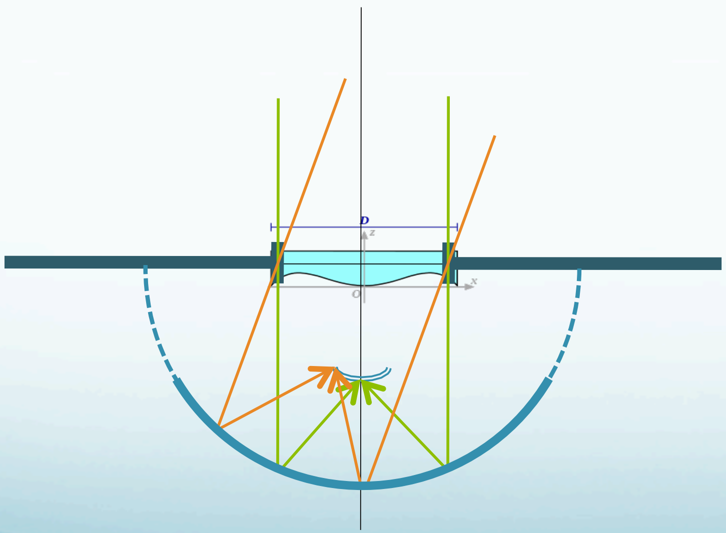
The archetypal wide FOV telescope: the Schmidt telescope

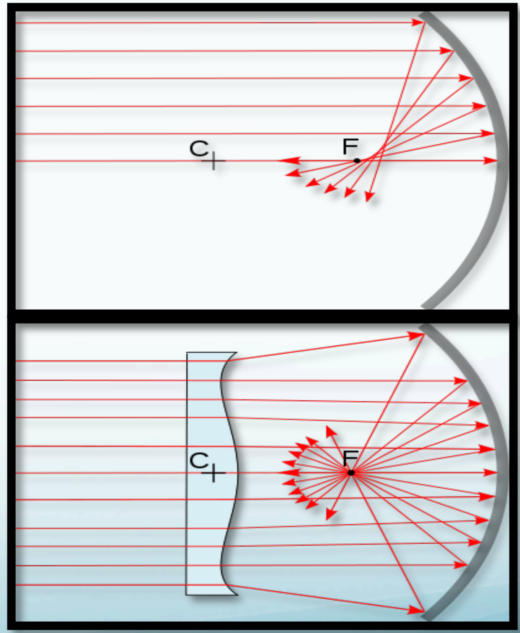
STEP 3. Considering all incident directions: where shall we place **the "stop"**?
At the mirror's center of curvature, so that all directions remain equivalent.



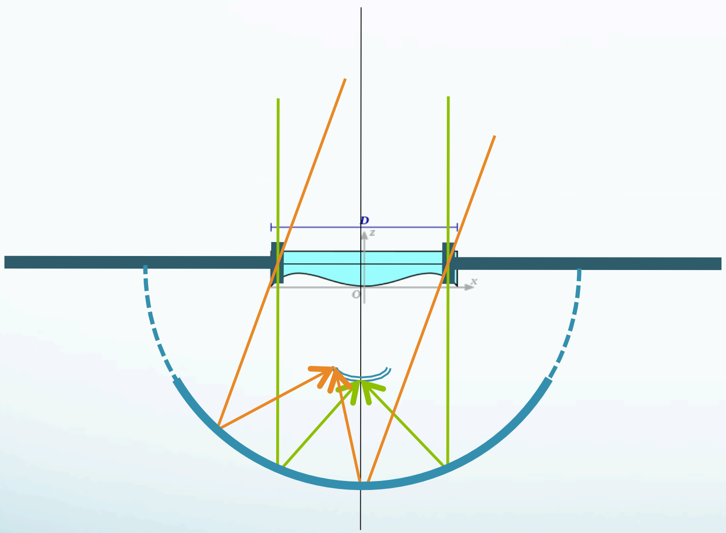
The archetypal wide FOV telescope: the Schmidt telescope

STEP 4. Add the “world-famous” Schmidt **corrector plane** at the stop. That eliminates spherical aberrations.





The archetypal wide FOV telescope: the Schmidt telescope



Well, let's build a "Schmidt IACT"!
This has been proposed: Mirzoyan & Andersen, APP **31** (2009) 1, with D=7m mirror, FOV ø=15°, **f/D=0.8**, PSF RMS=1 arcmin.

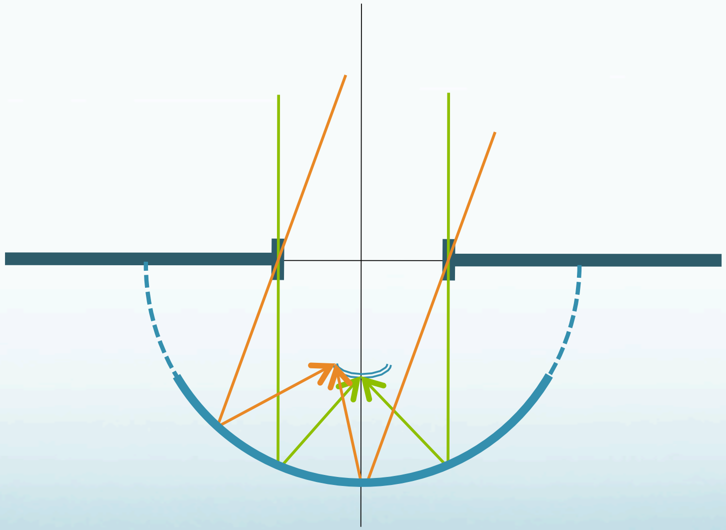
Unfortunately:

- It has chromatic aberration (lens!)
- For the corrector plate they propose a 7m ø PMMA Fresnel lense of 17mm max thickness: challenging!

De-construct a Schmidt

~~4. Add the "world-famous" Schmidt corrector plane at the stop. That eliminates (first order) spherical aberrations.~~

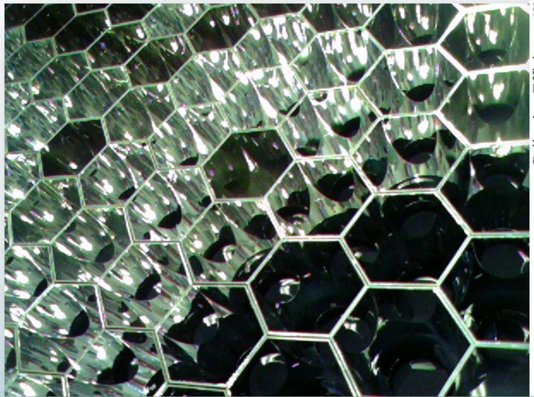
We live with the aberration: after all IACTs need no excellent optics

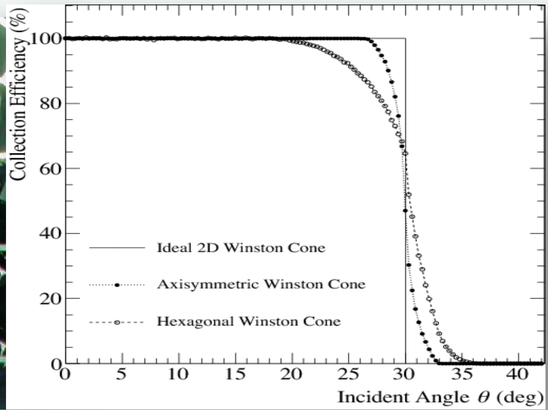


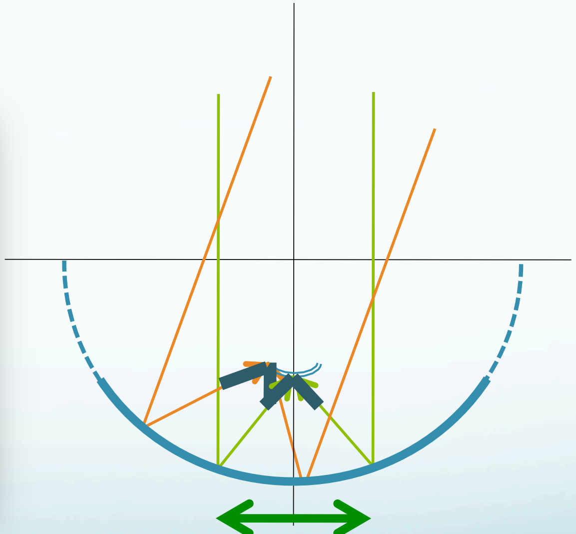
De-construct a Schmidt

~~STEP 3. As rays hit further and further away from optical axis, they get more a more defocused. Add a "stop".~~

Implement it placing a "light concentrator" on each of the pixels



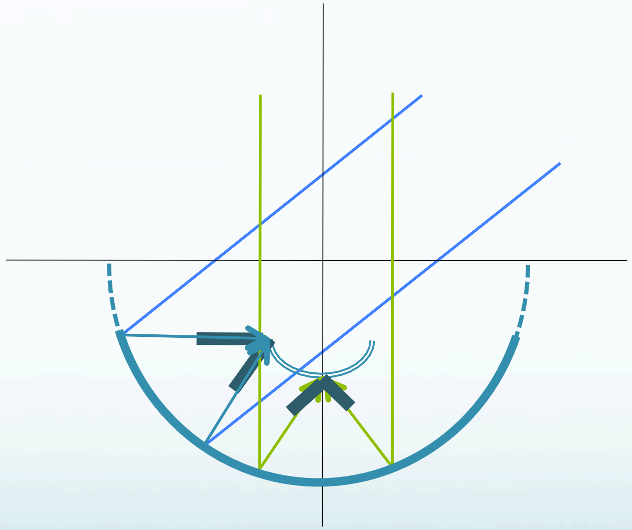




This effectively defines D

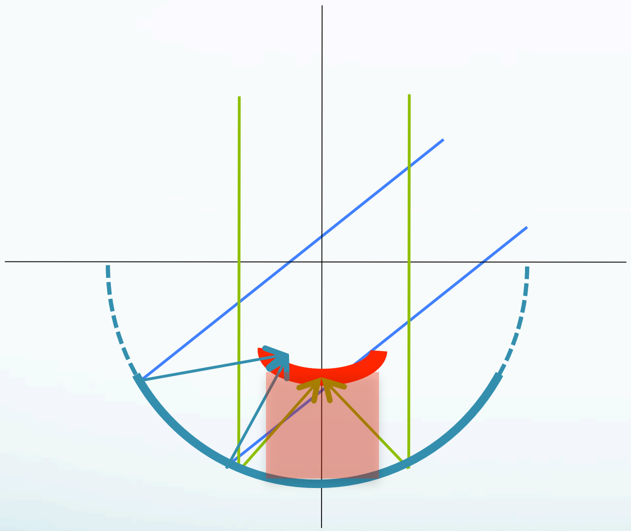
No limit to field of view!?!

Since there is no physical stop the aperture does not decrease as we go further and further off-axis. So we can go to any off-axis angle!



Yes, there's a limit

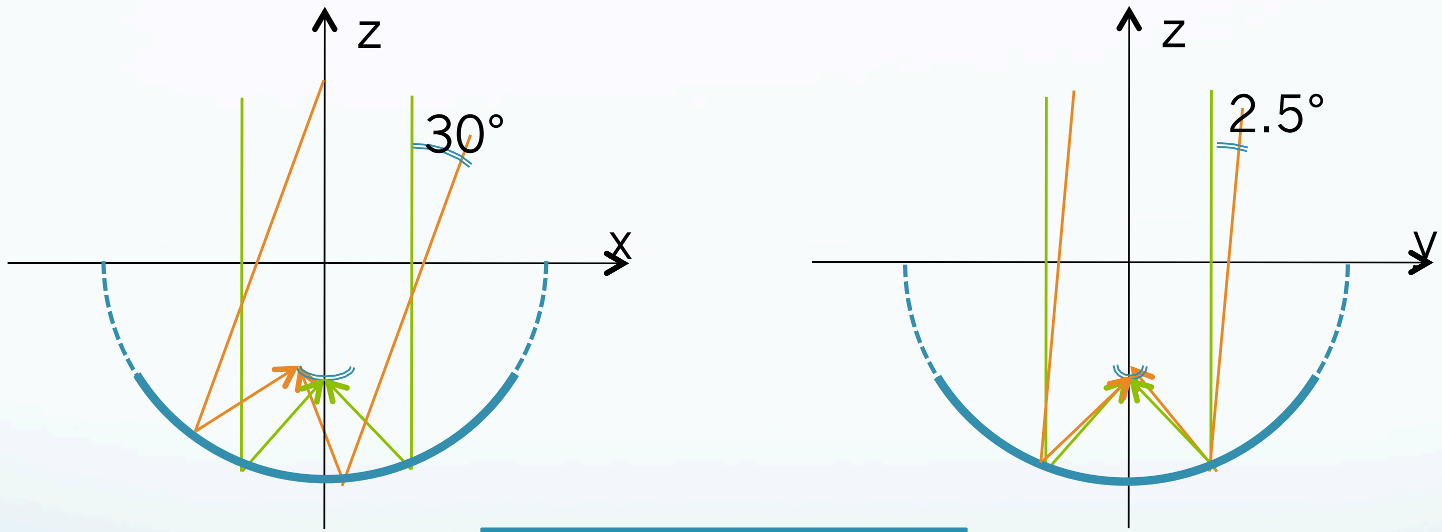
A limit is set by the **shadowing of the camera** on the mirror.



Here is an example: D=12 m, f=17 m (f/D=1.42), circular camera

FOV ø (°)	S_{cam} (m^2)	On-axis shadowing
5	1.77	1.6%
10	7.1	6.3%
15	16.0	14%
20	28.4	25%
25	44.4	40%

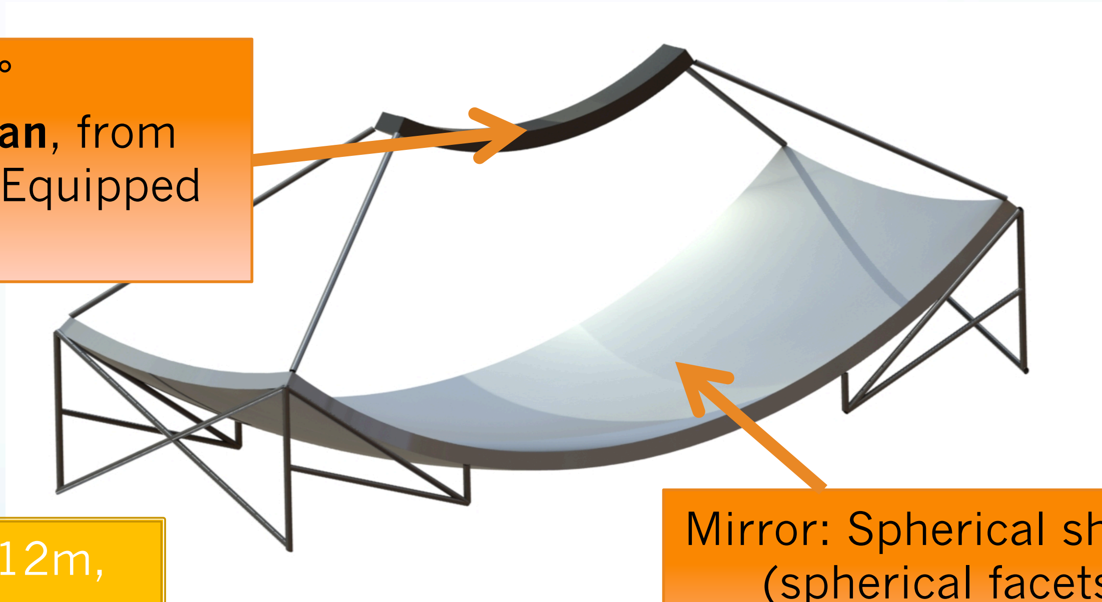
Solution: a non-circular camera



Shadowing = 15%

MACHETE= Meridian Atmospheric CHErenkov Telescope

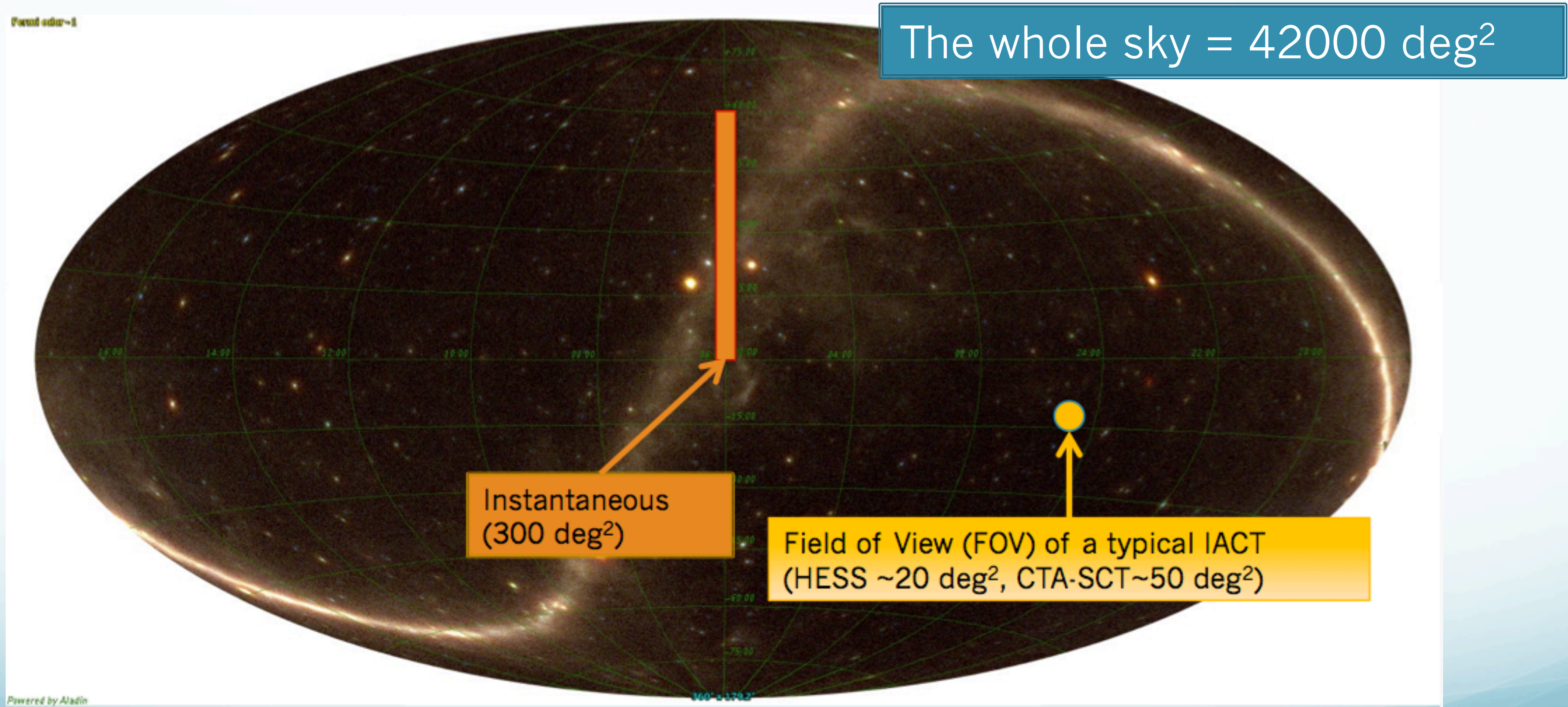
Camera: rectangle of 60° (following the **meridian**, from south to north) x 5°. Equipped with ~15000 pixels.



Effective D=12m, f=17m (f/D=1.42)

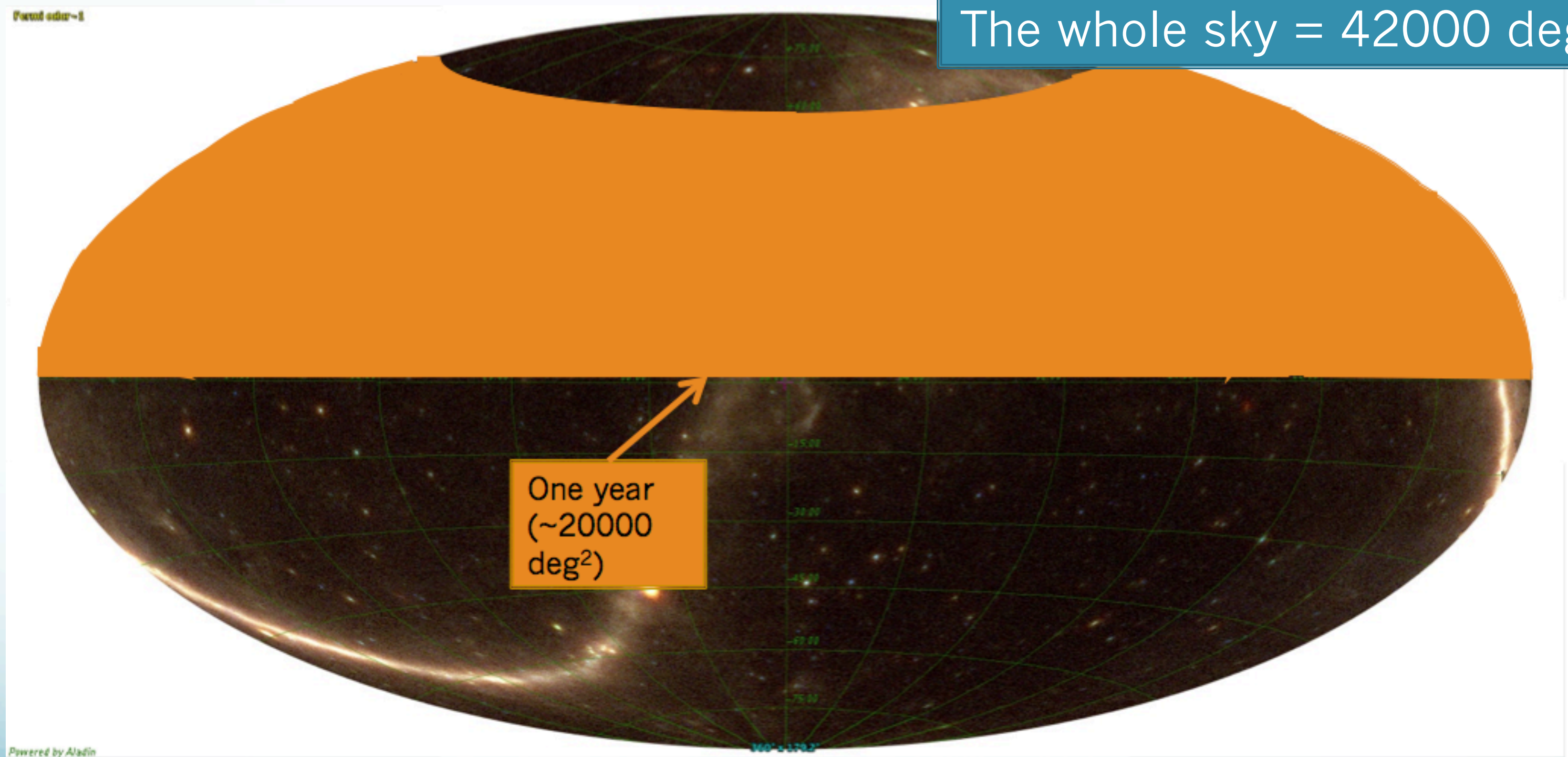
Mirror: Spherical shape (spherical facets following general spherical shape). PSF $r_{80\%}$=0.06°

Field of view

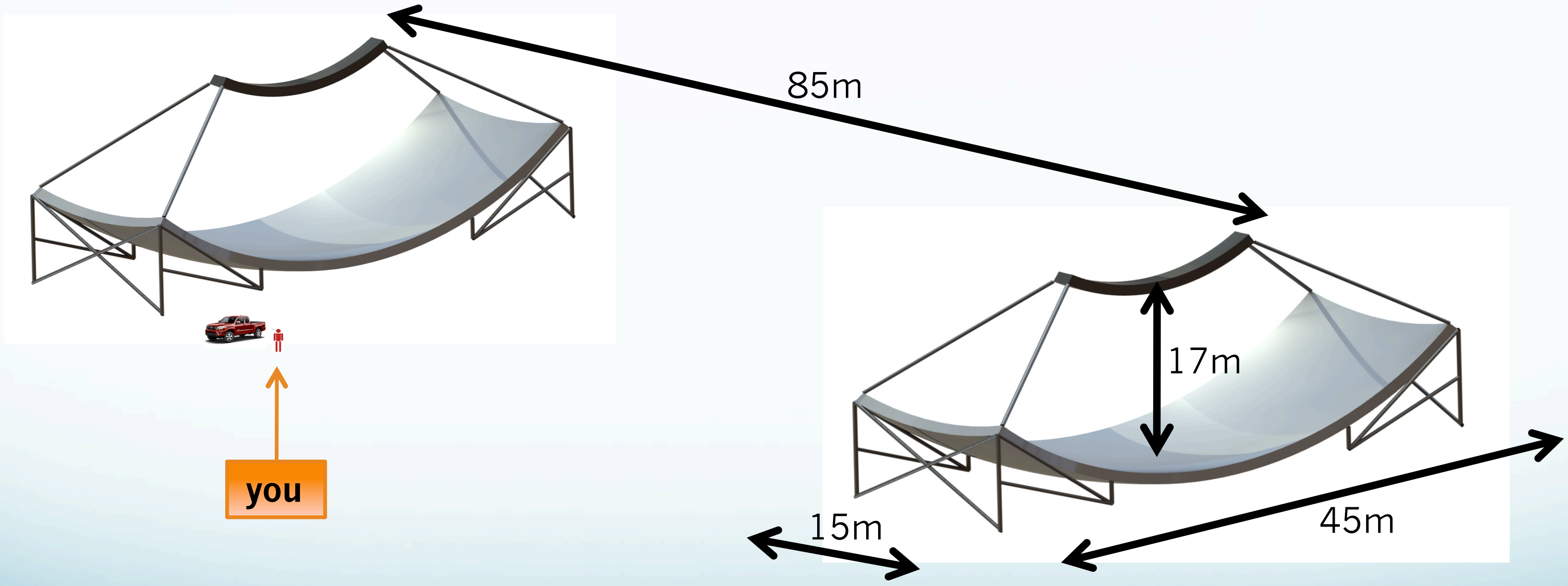


Don’t move telescope! Let the sky move!

The whole sky = 42000 deg^2



MACHETE stereo array



Monte Carlo simulation

- We made a full MC simulation of the instrument using the MAGIC MC and analysis software (thanks, MAGIC!!).
- We simulated a 4x4 deg^2 section of the camera and a section of the spherical mirror with estimated PSF ($r_{80\%}$=0.08° -considering facet misalignment).
- We assumed basically the same performance of MAGIC for all optical (PSF…) and electronic elements (noise, sampling…), except for PMT QE, which we increased by 50% (consistent with available PMTs).

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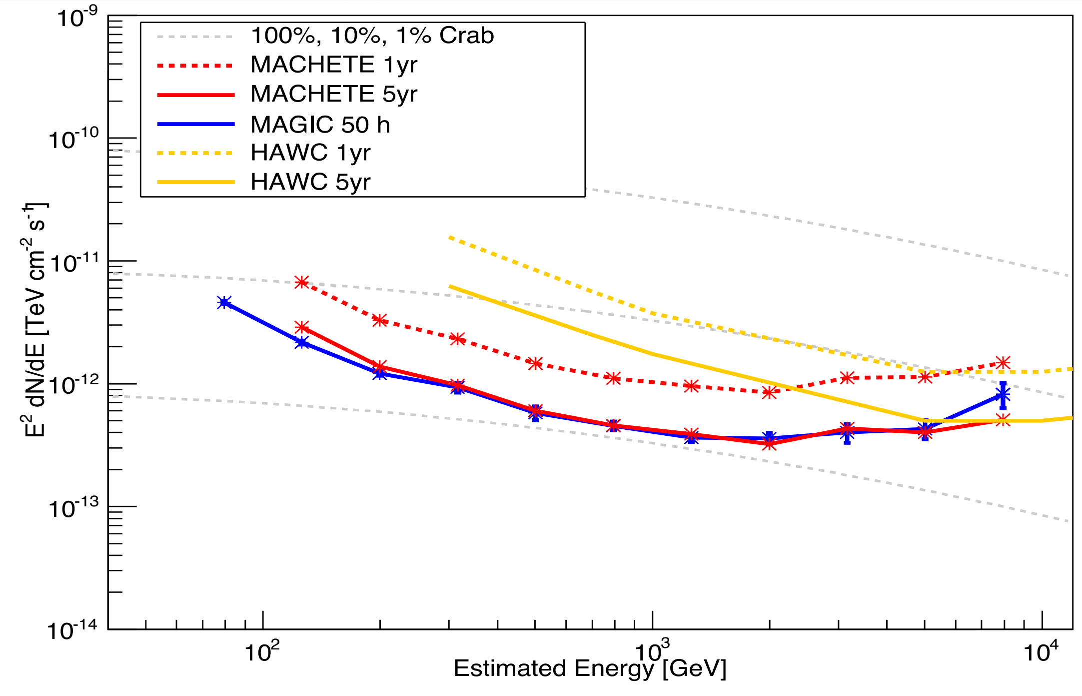
Performance



Sensitivity:

- Reaches 0.77% crab after 5 year survey. ➔ Similar to planned CTA 1000h survey.
- 1yr survey better than HAWC 5yr survey.
- 1 night sensitivity: 12% crab.

Angular resolution: 0.1° and spectral resolution: 20-15% (standard IACT, much better than HAWC)

Physics with MACHETE

- A survey of half of the sky:
  - New Active Galactic Nuclei.
  - New galactic sources, especially if built in the south.
- … and the unknown:
  - "Dark sources" = sources emitting only in VHE.
    - Hadronic AGNs
    - Dark matter clumps?
  - New types of transients.
- Monitor bright VHE sources:
  - Unbiased light curves of AGN and galactic sources.
  - Establish unknown duty cycles (e.g. IC-310).
  - Trigger CTA and other telescopes.

Discussion/conclusions

- We have found a simple optical solution to build a very wide FOV IACT (300 deg^2 with PSF $r_{80\%}$=0.06° for D=12m and f/D=1.42).
- Implemented as a drift telescope, it reaches 0.77% CU sensitivity for ~half of the sky in 5 years / 12% CU in a night.
- The cost is driven by the 15000 photosensors/telescope, but significant potential for cost-reduction: no steering, no strict limit in camera or mirror weight, need to read out only a small fraction of the camera, simple operation…
- Main physics goals: discovery through survey (serendipity!), trigger of transient VHE sources.

Thanks!