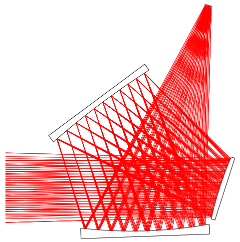

Tools for visualizing the solution space for freeform three-mirror anastigmats

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NASA Mirror-tech Days – 10-12 November 2015

Outline

1. Introduction to TMA design

2. General solution for single-conic axial TMA

3. Creating a useful program for visualizing TMA space

4. Surveying TMA solution space

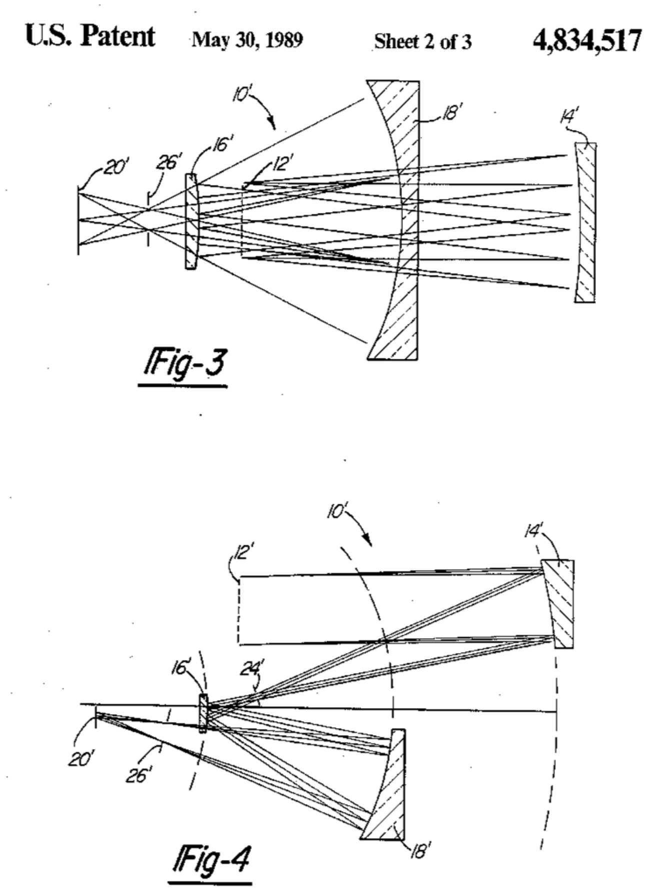
5. Conclusion

What is a conventional TMA?

TMA = **T**hree **M**irror **A**nastigmat
A co-axial three mirror system corrected for the primary 3rd order (4th order in wavefront) aberrations (spherical, coma, and astigmatism).

$$W_{040} = 0, W_{131} = 0, W_{222} = 0$$

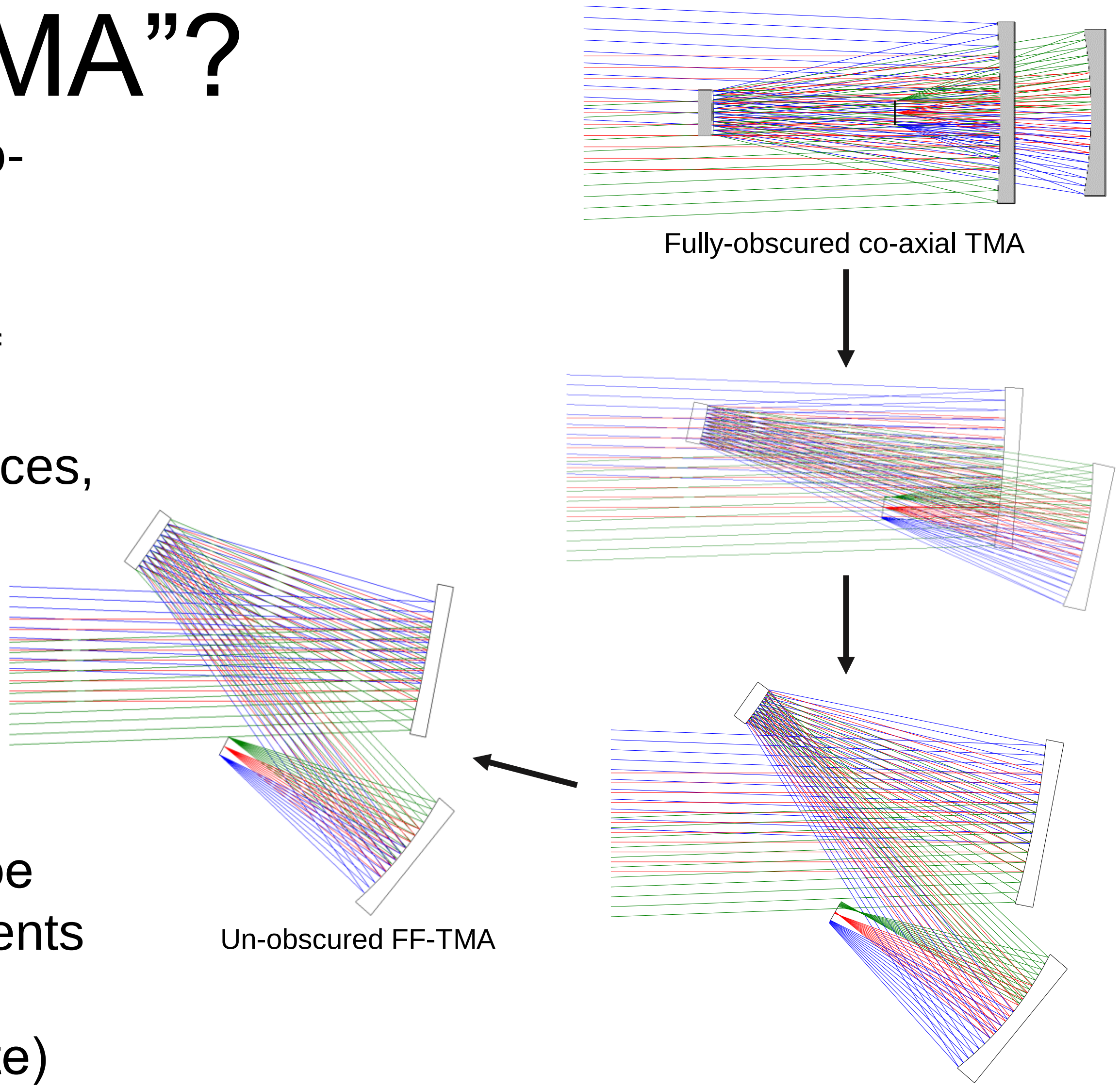
- A system with 2 spherical mirrors and 1 conic mirror can achieve this correction.
- As Rakich shows [1, 2], a subset of these systems also has a flat field (no Petzval curvature)
- Many of these solutions have significant obscurations
  - To reduce obscurations, use field and aperture bias to select off-axis sections of co-axial mirrors
- Such surfaces may become sensitive to tilts and decenters



Cook [5]

What is a freeform “TMA”?

- A freeform TMA typically begins from an obscured co-axial TMA design, and then the surfaces are tilted to avoid obscurations
  - Tilting surfaces introduces, primarily, large amounts of astigmatism and coma
- To correct the aberrations induced by tilting the surfaces, we need more degrees of freedom
  - Zernike surfaces
  - NURBS
  - 2D Chebyshev polynomials
  - 2D Forbes polynomials
  - Radial basis functions
- The resulting system is no longer a proper “TMA” type design, as the 4th order wavefront aberration coefficients are no longer zero, but instead are used to balance higher order terms (“reflective triplet” is more accurate)



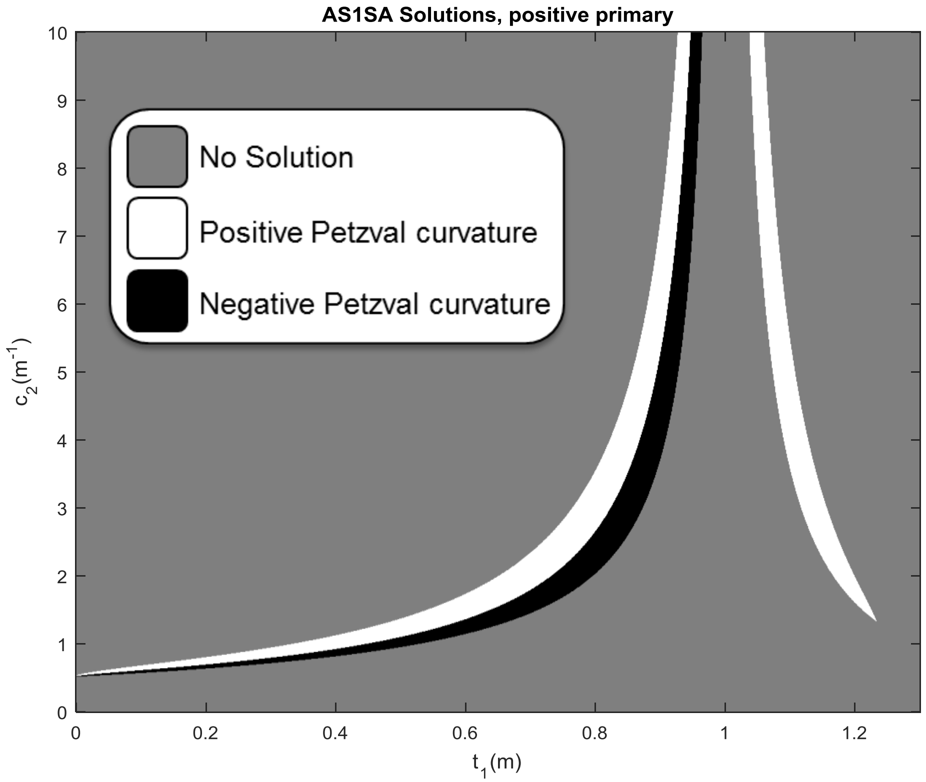
TMA solution space maps

The Three Mirror Anastigmat design space for 2 spheres and 1 conic has been mapped out by Rakich [1, 2]

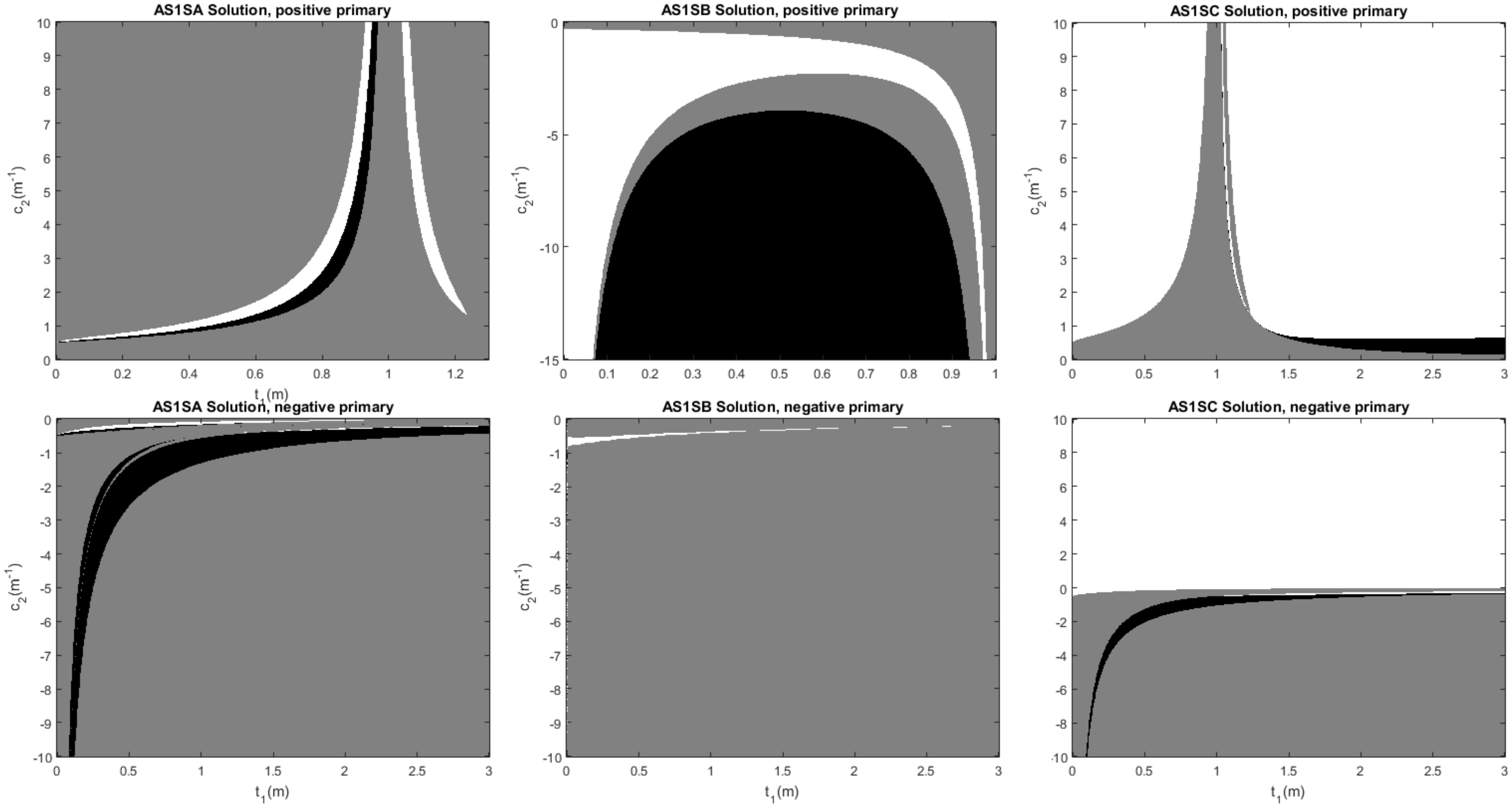
- Solution is based on the “plate diagram” by Burch [3]
- 2 spherical and 1 conic mirror creates a total of 4 “plates”
- Solve for system parameters by substituting them into the plate equations, which are then solved
- By fixing the radius of the primary, and given t_1 (primary-to-secondary distance) and c_2 (secondary curvature), the equations to correct spherical, coma, and astigmatism result in a cubic equation for c_3 (tertiary curvature)
- The solution space is then mapped out on a t_1-c_2 plane (figure to the right)
- Due to the cubic equation, there are 3 solutions for each of 4 geometries, for a total of 12 solution maps.

Burch Plate Equations

$$W_1 + W_2 + W_3 + W_4 = 0$$
$$W_1\, x_1 + W_2\, x_2 + W_3\, x_3 + W_4\, x_4 = 0$$
$$W_1\, {x_1}^2 + W_2\, {x_2}^2 + W_3\, {x_3}^2 + W_4\, {x_4}^2 = 0$$



TMA solutions – conic on primary (AS1)

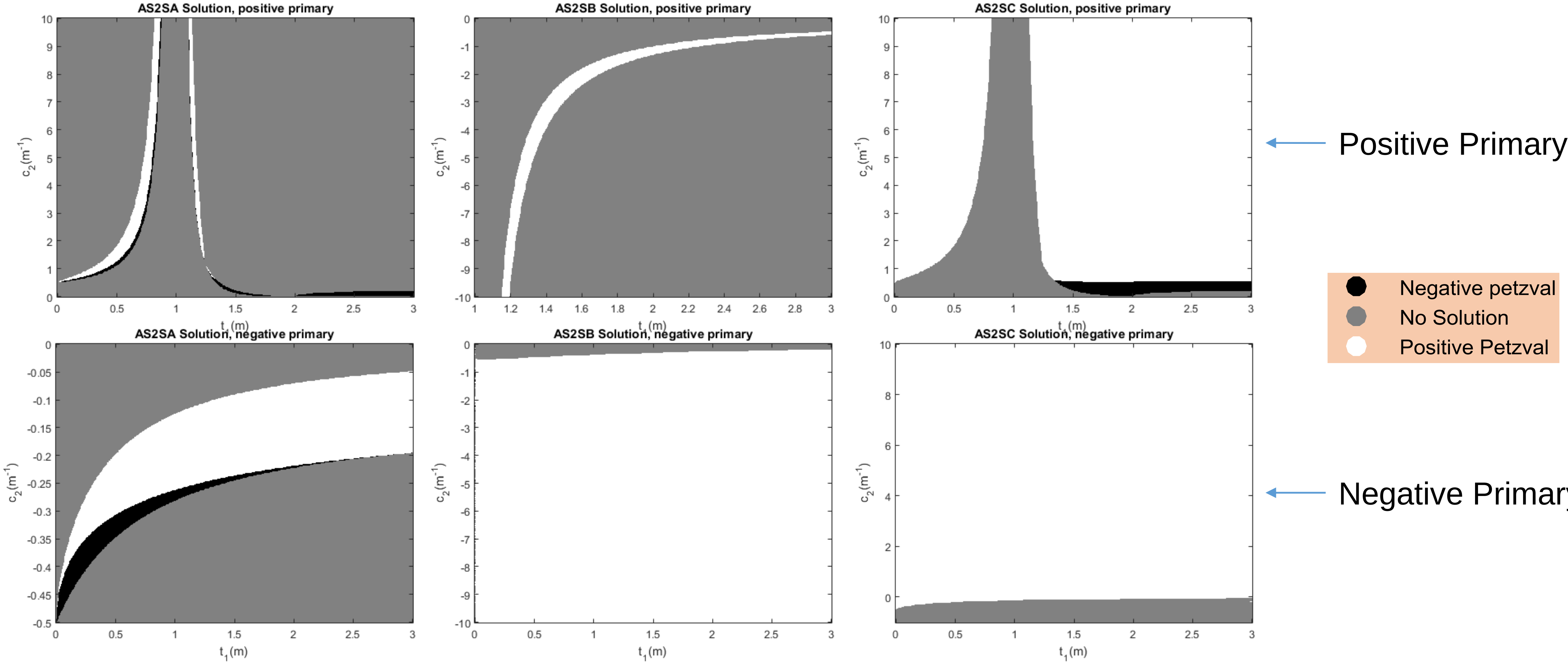


Positive Primary

Negative Primary

- Negative petzval
- No Solution
- Positive Petzval

TMA solutions – Conic on secondary (AS2)



Purpose of this study

Purpose:

To enable the design of large aperture, wide field-of-view, unobscured telescope designs:

4° circular full FOV

300 mm aperture

Broad spectral coverage (UV, Vis., NIR, FIR)

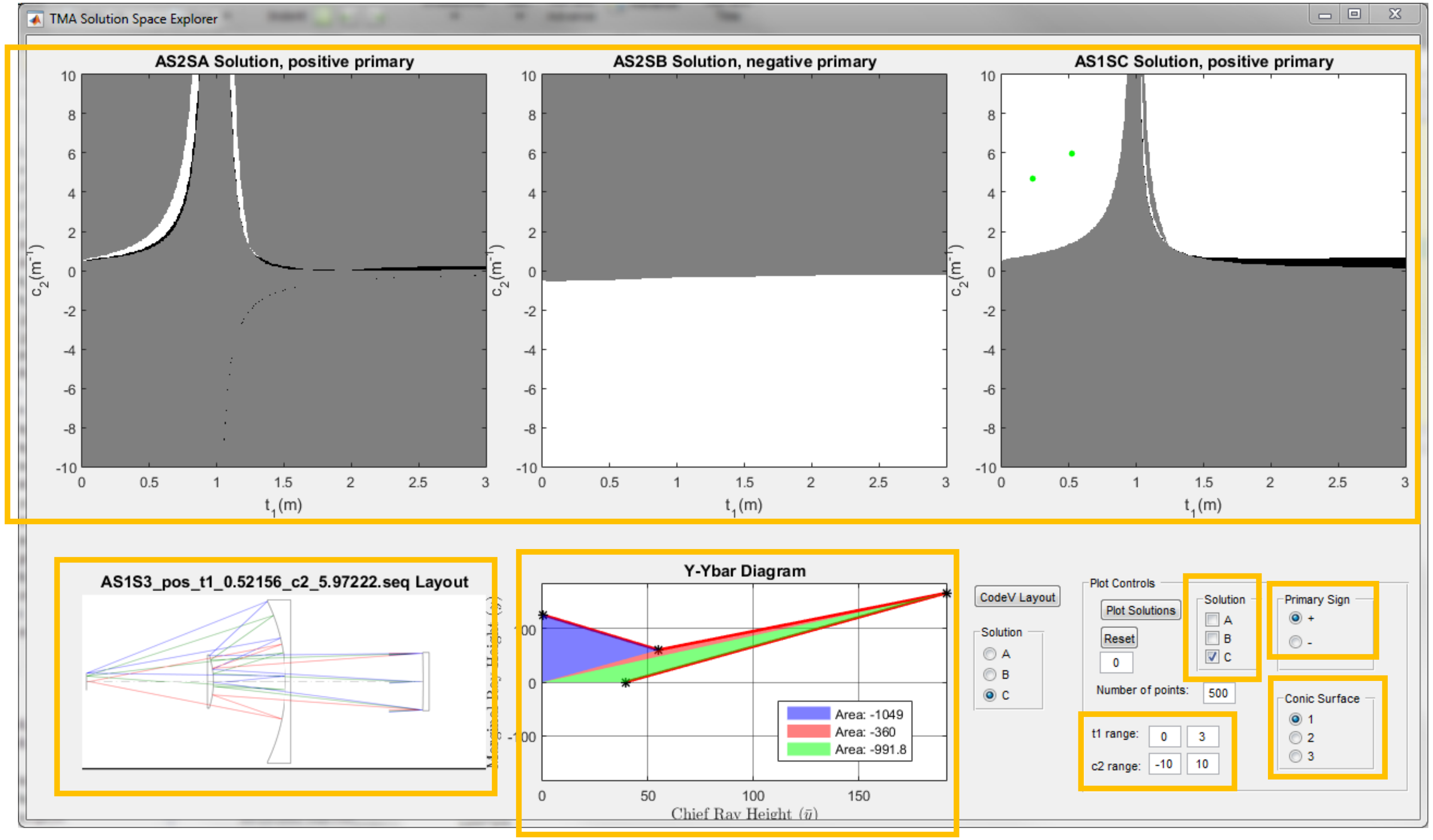
Compact footprint

Method:

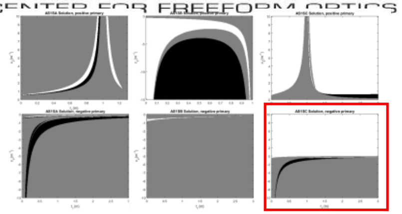
Survey solutions to select candidate starting points for further freeform study, including solutions with negative primaries not considered in Rakich’s study

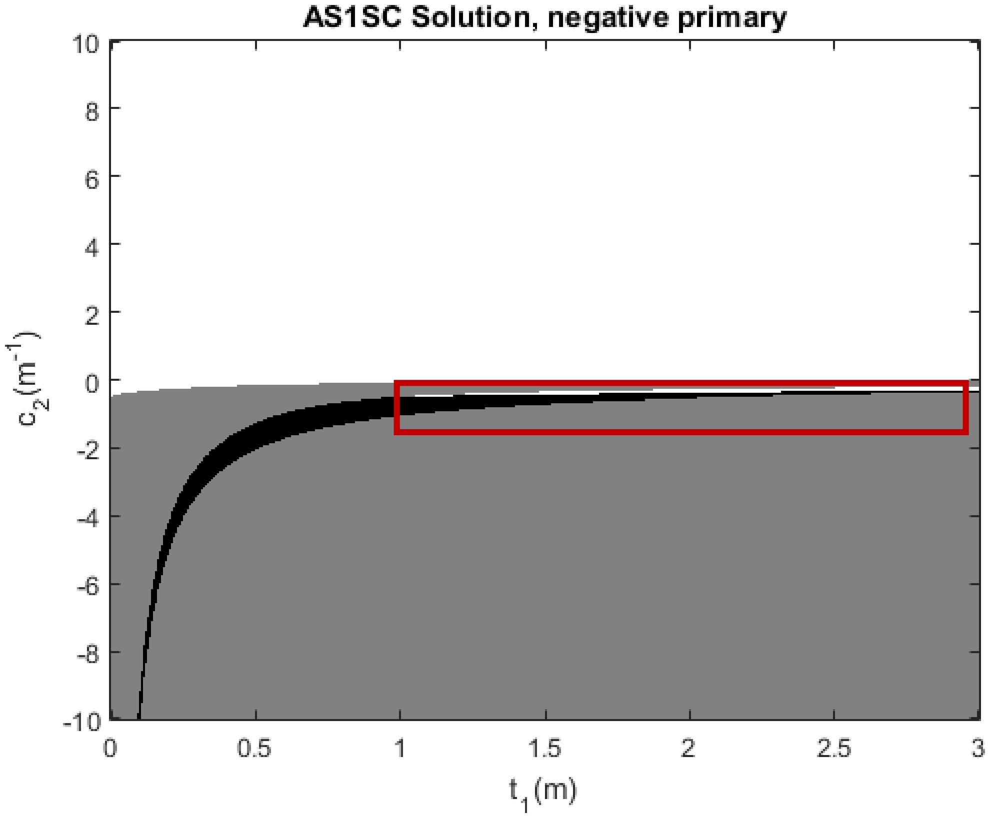
Creating a useful GUI for visualizing Rakich TMA solutions

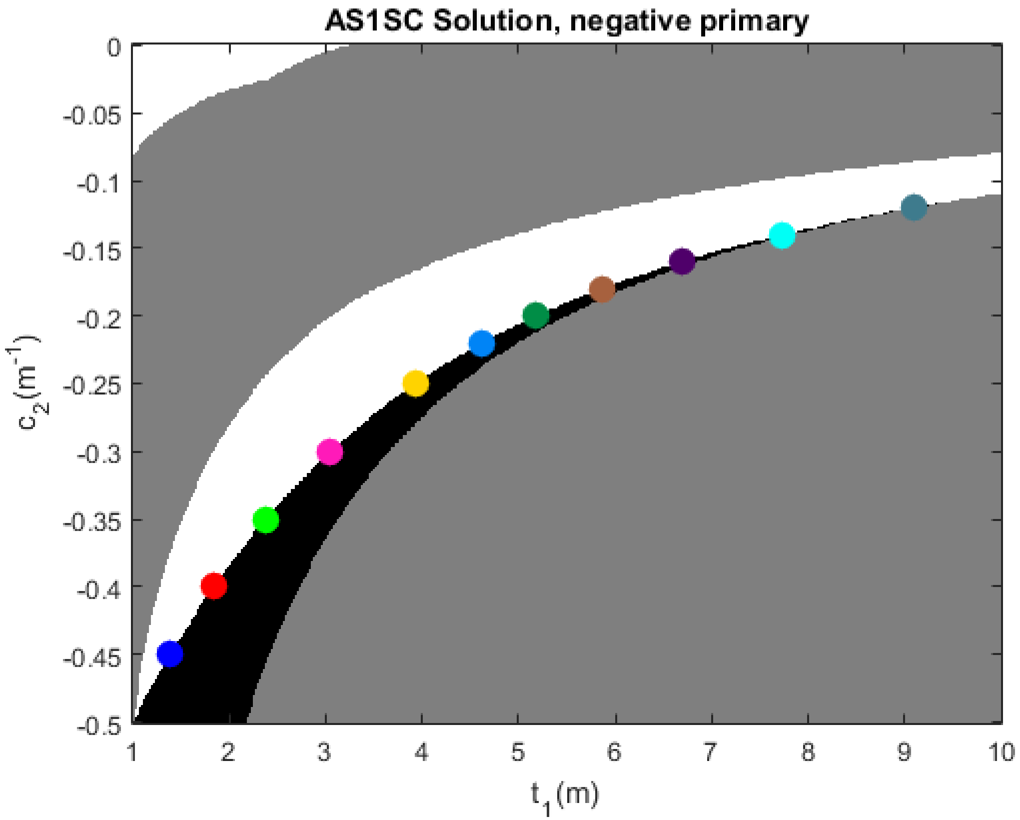
- Programmed in MATLAB
- 3 solution maps to cubic Rakich equations are plotted on top
- Select which solution(s) to plot/update
  - Select which surface is aspherized
  - Select the sign of the primary mirror
  - Select which cubic solution (A, B, C)
- Interactively change the plot regions and plot resolution by typing the range directly or selecting the region of interest with the mouse
- Select a point on the plots to display the layout (using CODE V ® via COM interface)
- Display the Y-Ybar plot of the selected point, with bounding box lines



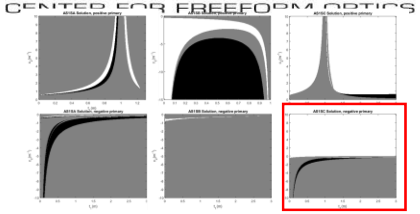
AS1SC-N – flat field region

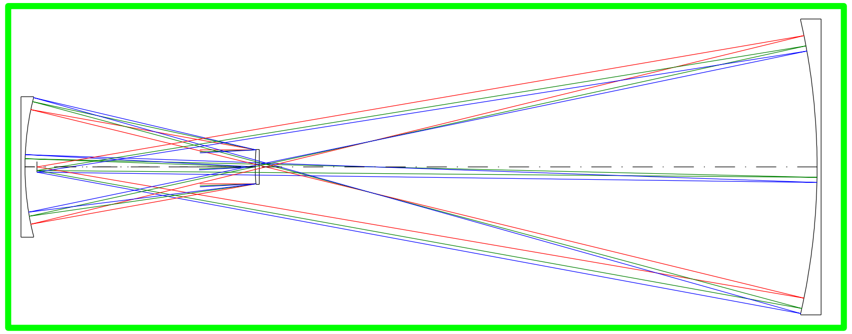


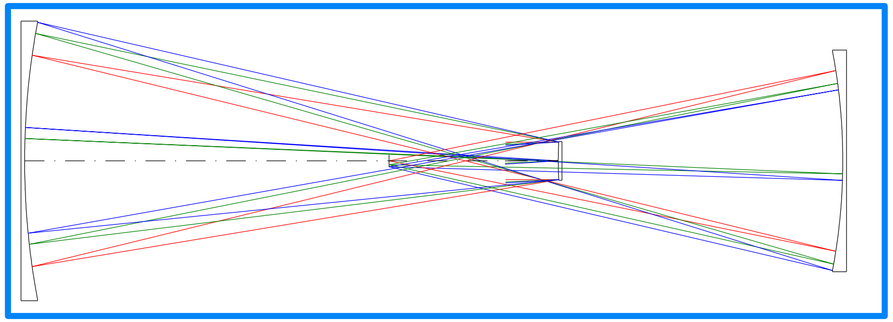


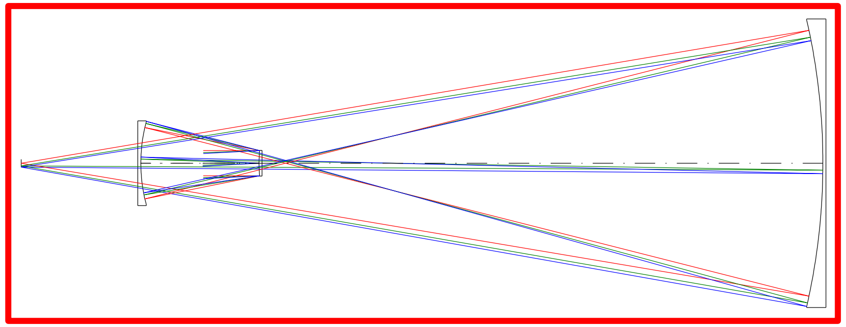


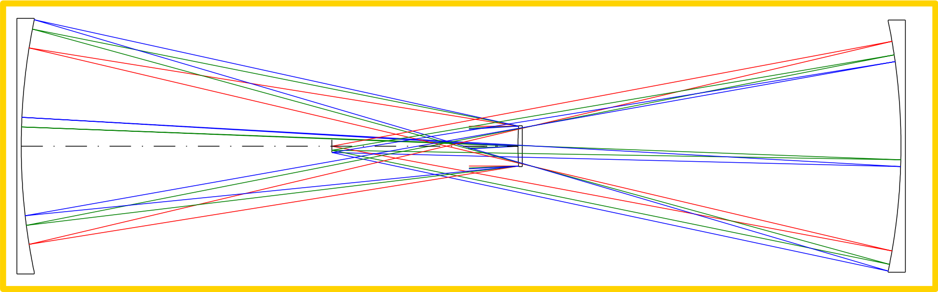
AS1SC-N – Region 2 – Flat Field

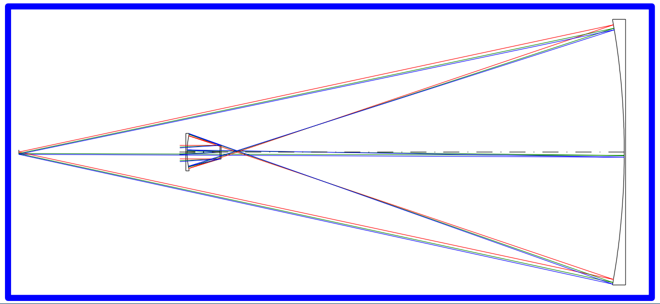


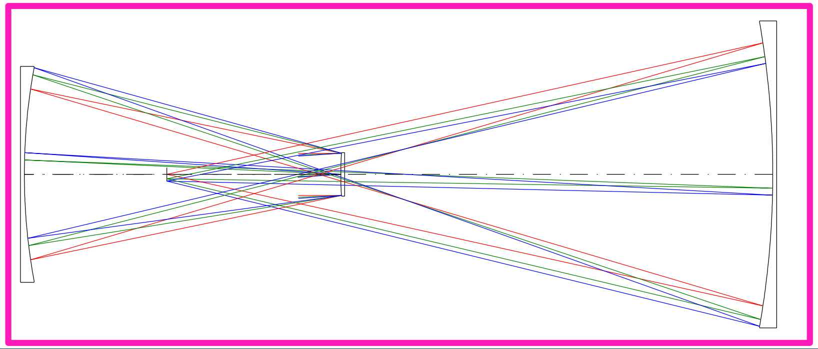


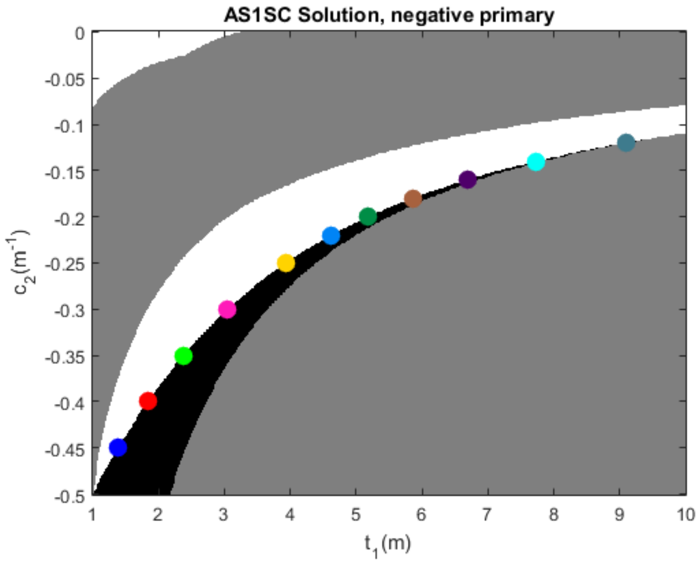




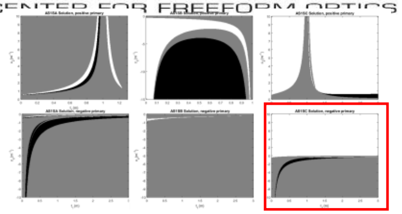


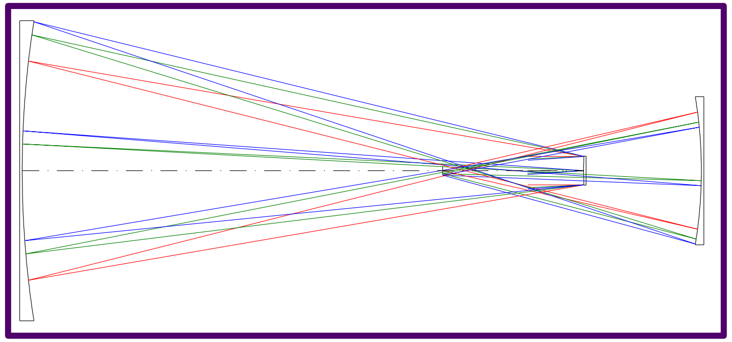


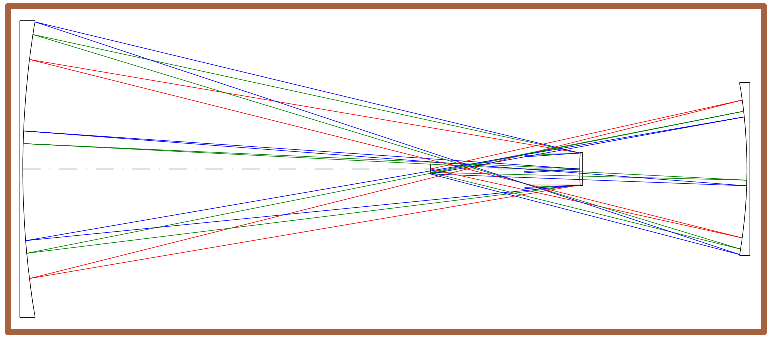


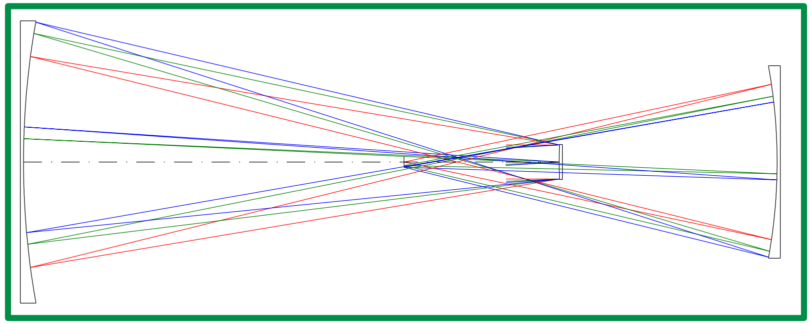


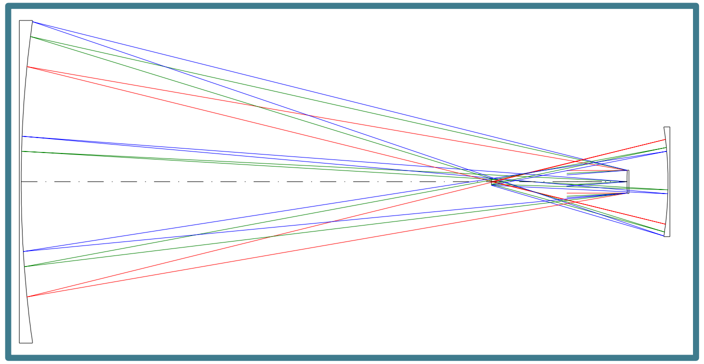
AS1SC-N – Region 2 – Flat Field

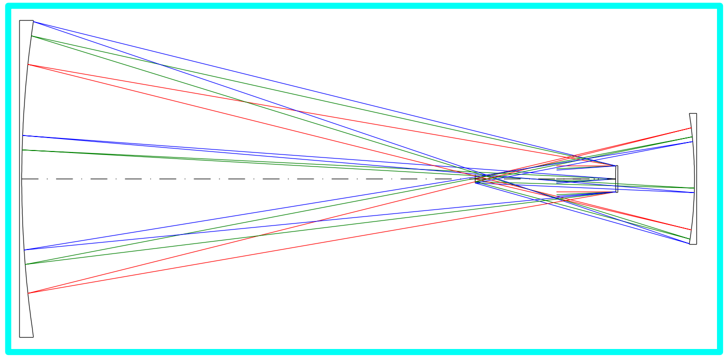


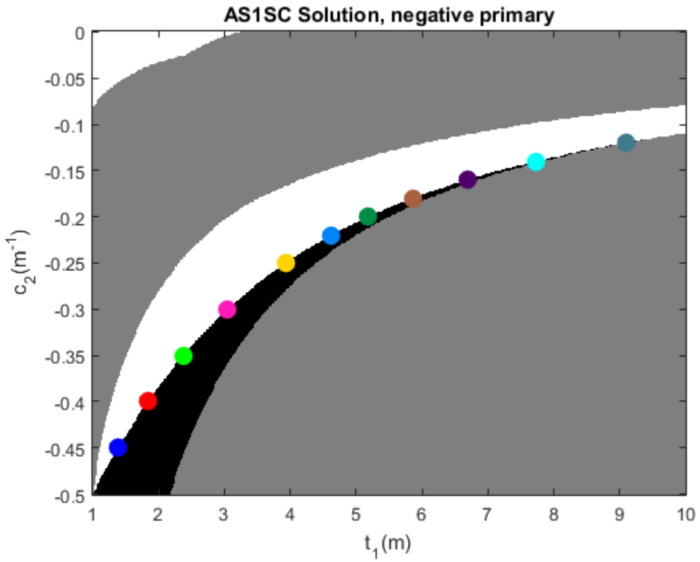










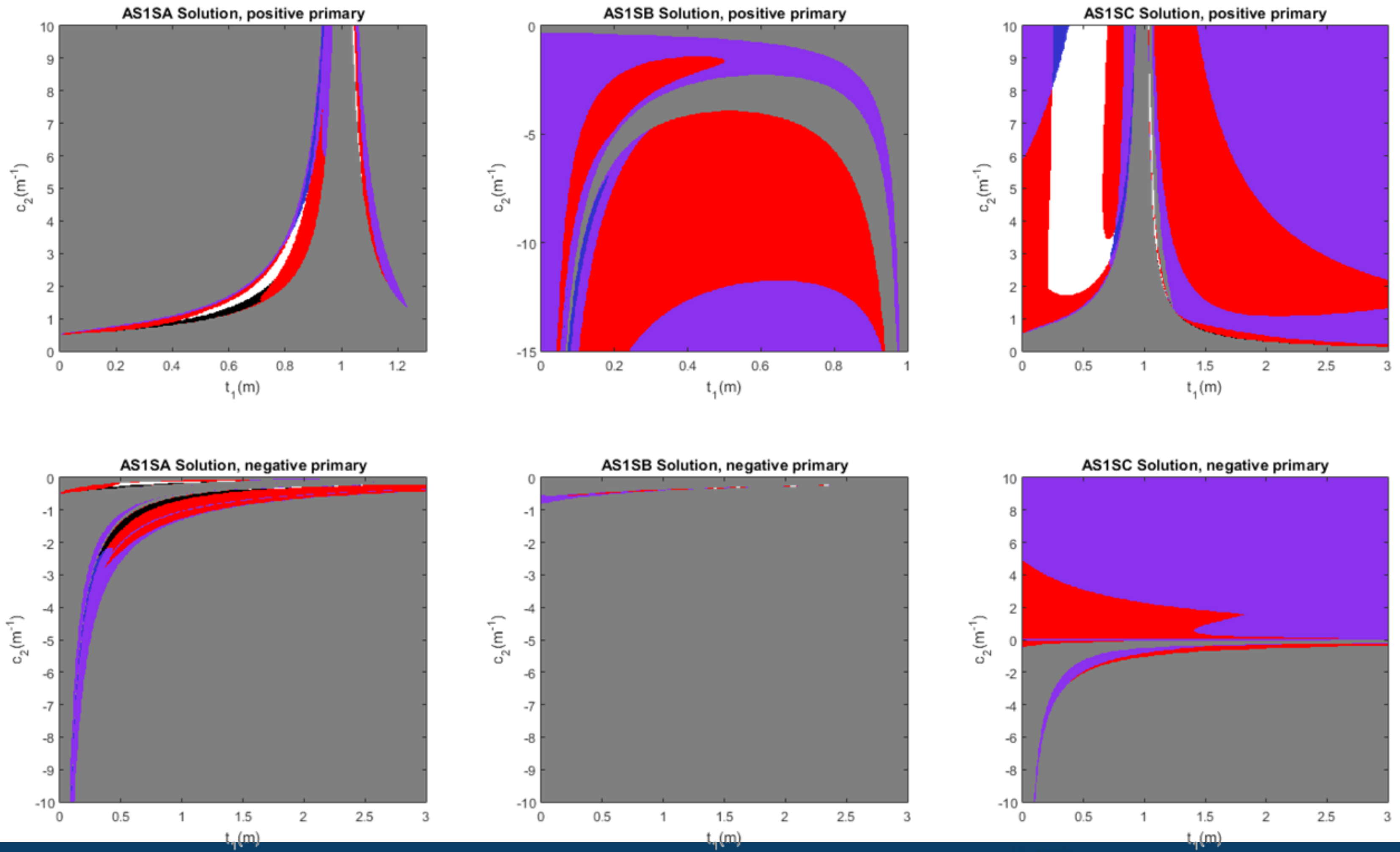


Survey results

- This survey showed that most of these solutions are outside of the range of feasibility (as Rakich also found)
  - Extreme distances between mirrors
  - High curvatures
  - Large apertures
- We can apply filters to show the regions which have reasonable solutions

- Rakich did not consider solutions with negative primary mirrors because of their obscurations, but as we know from Pathfinder 1 [4], freeform solutions with negative primaries are possible.
  - There are multiple candidate solutions for further freeform study with negative primaries

AS1 Filtered

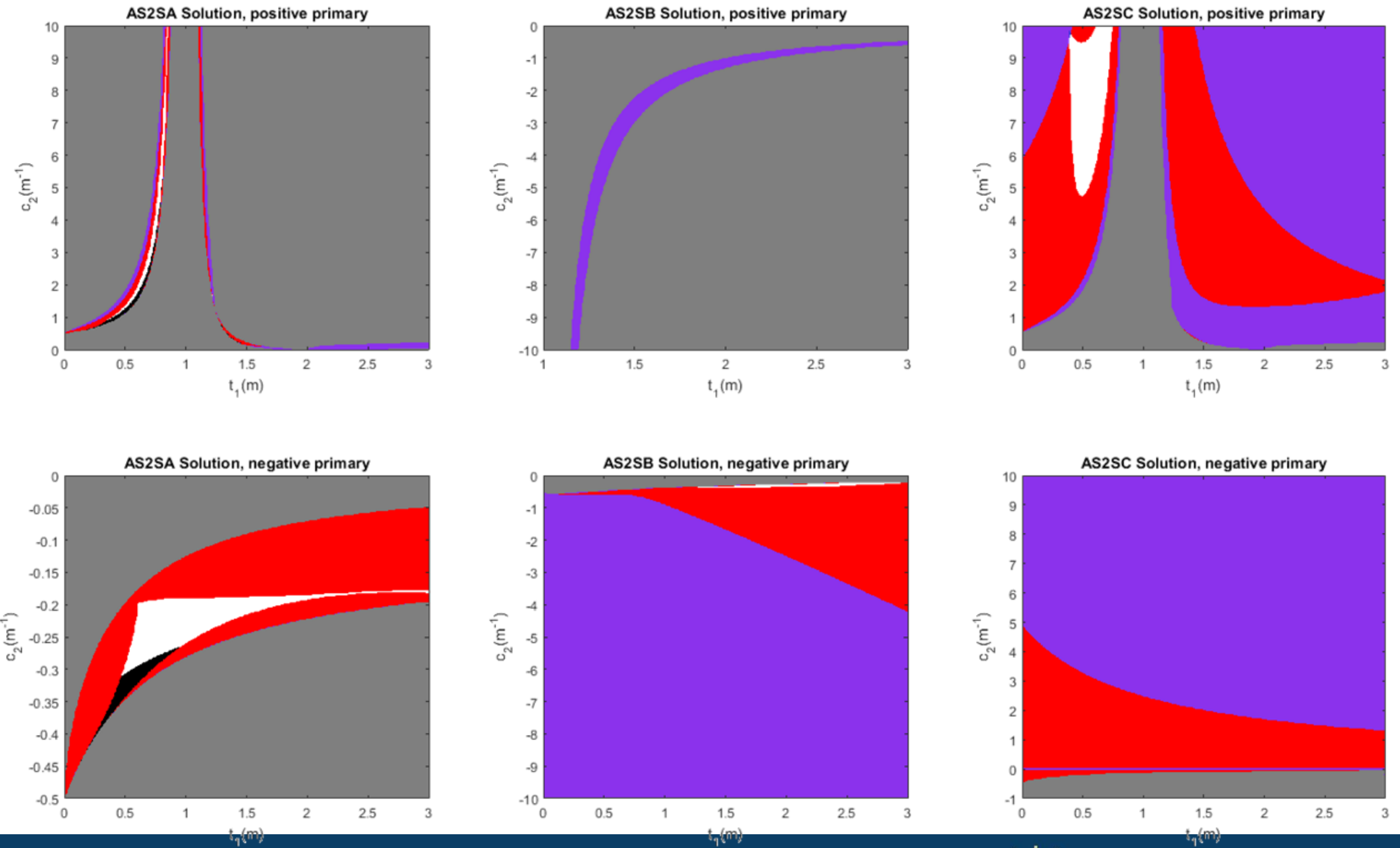


Positive Primary

- Negative Petzval
- No Solution
- Positive Petzval
- t_1, t_2, t_3 filter
- c_1, c_2, c_3 filter
- Both filters

Negative Primary

AS2 Filtered



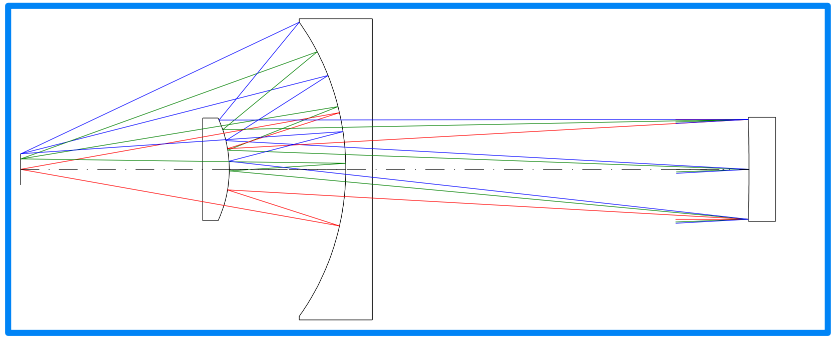
Positive Primary

- Negative Petzval
- No Solution
- Positive Petzval
- t_1, t_2, t_3 filter
- c_1, c_2, c_3 filter
- Both filters

Negative Primary

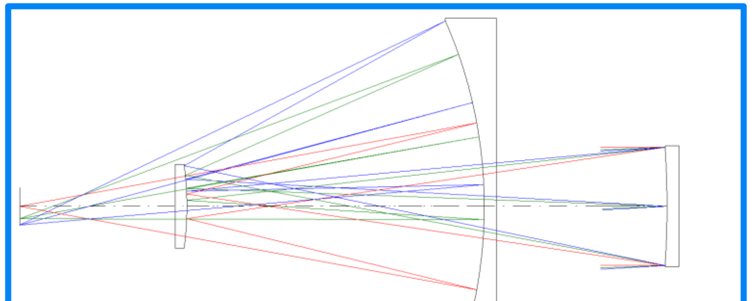
Interesting solutions from this study

AS1SC-P – Region 1



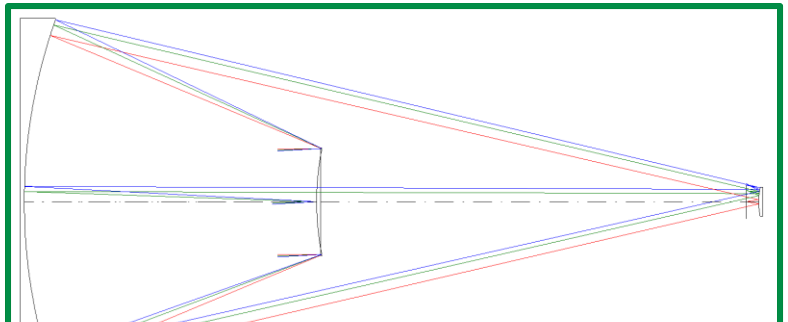
Resembles a Schwarzschild with a Schmidt plate

AS1SC-P – Region 2 – Flat Field



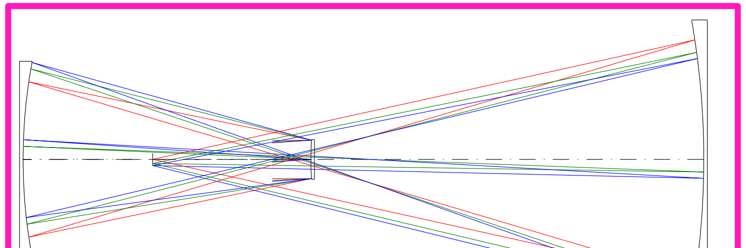
Internal image

AS1SB-N



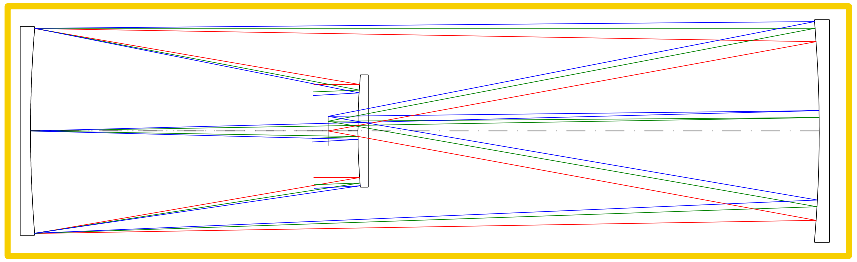
Schwarzschild-like

AS1SC-N – Region 2 – Flat Field



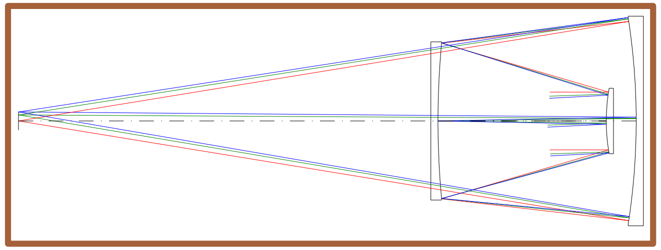
Internal image

AS2SA-N – Region 1 – Flat field



Similar to Fuerschbach type

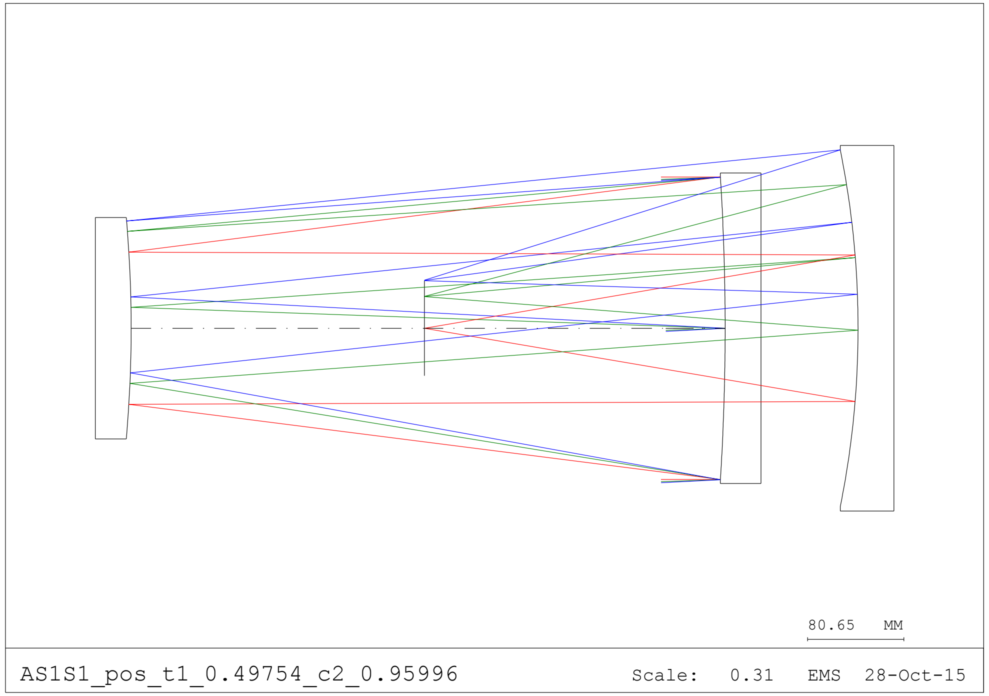
AS2SA-N – Region 1



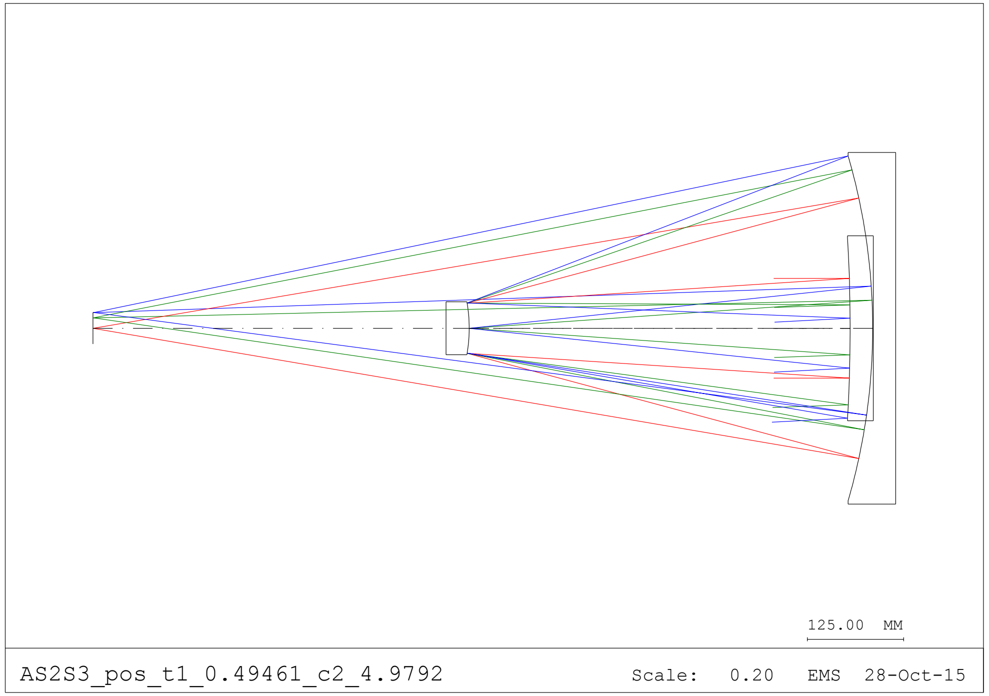
Variation on Fuerschbach

Interesting solutions from filters

AS1SA-P



AS2SC-P



Conclusion

- Using Rakich's equations for 2 spheres, 1 conic type TMAs, we have created a program and GUI to survey these solutions (extending to negative primaries)
- Using this tool, we have surveyed the design space for co-axial TMAs while applying filters applicable for transforming those solutions into freeform TMAs
- From these results, we selected interesting forms for further freeform study, including both positive and negative primary solutions
- Comparison of results from the freeform study is in progress

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[4] Fuerschbach, Kyle, et al. "Assembly of a freeform off-axis optical system employing three φ-polynomial Zernike mirrors." *Opt. Lett* 39.10 (2014): 2896-2899.

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