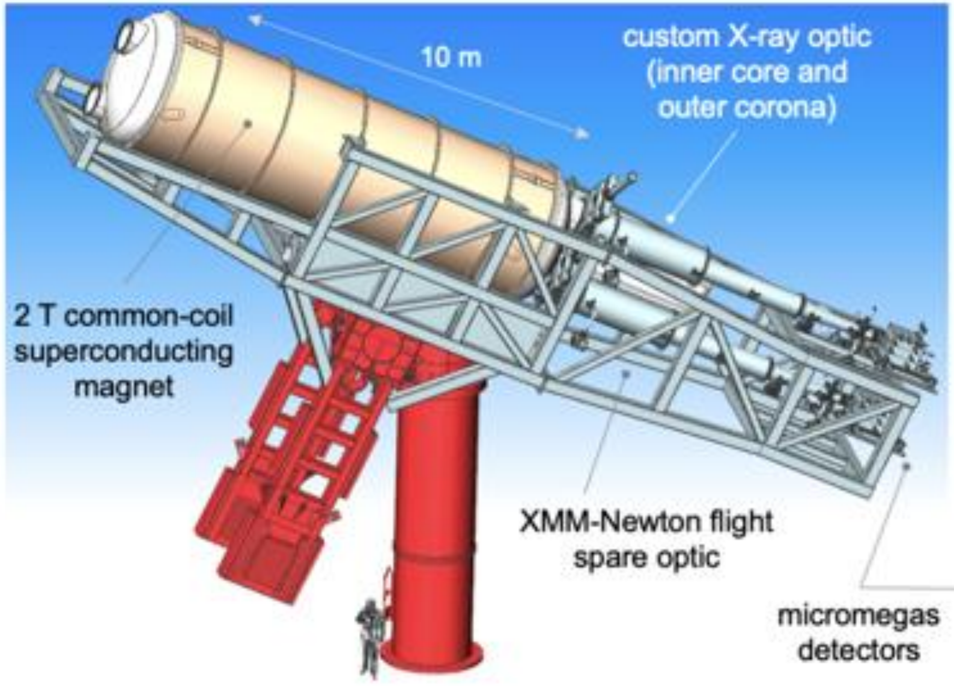
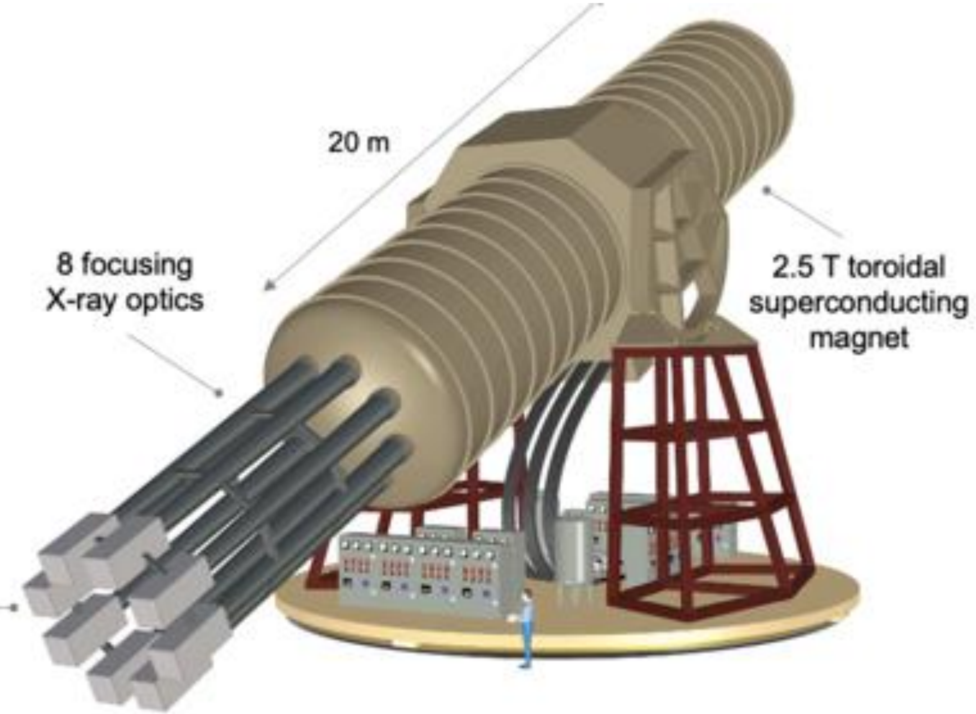




Creating X-Ray Optics for the Baby International Axion Observatory

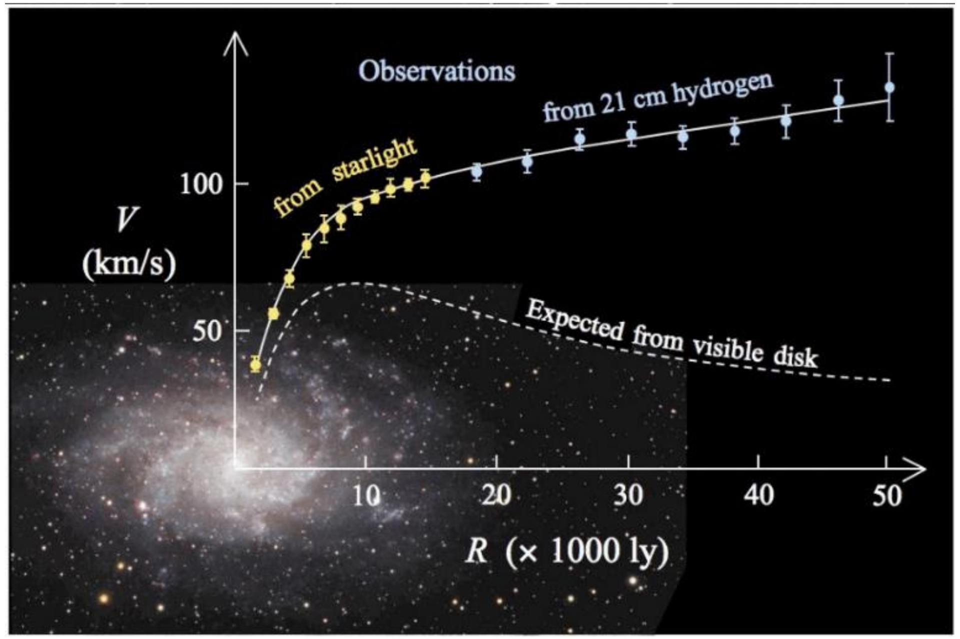
BY: JOSEPH SCHOPEN

Motivation

Dark Matter is a hypothesis to solve the missing matter problem

Dark Matter is speculated to make up 25% of the universe

IAXO is planning on looking for the Axion, which is a candidate for dark matter



Gravitational Curves of Galaxies

Axions could solve strong CP Problem and are a dark matter candidate

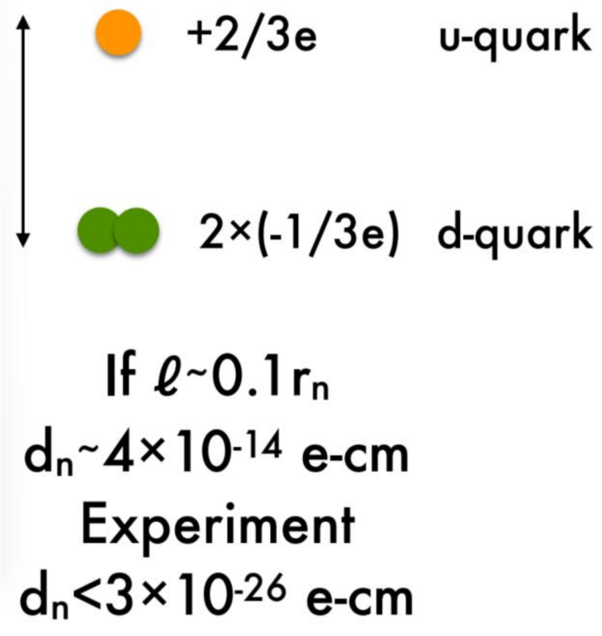
Axions are small (under 1 eV) particles that doesn’t interact well with light, making them great dark matter candidates

Strong CP symmetry in a neutron: if the coordinates and the charge of the quarks in a neutron were flipped, the physics of the neutron would stay in the same

Current observations show that strong CP symmetry is preserved in

nature, however, the SM tells us that strong CP symmetry can be violated

Axions force strong CP symmetry to be preserved, thus solving the CP Problem

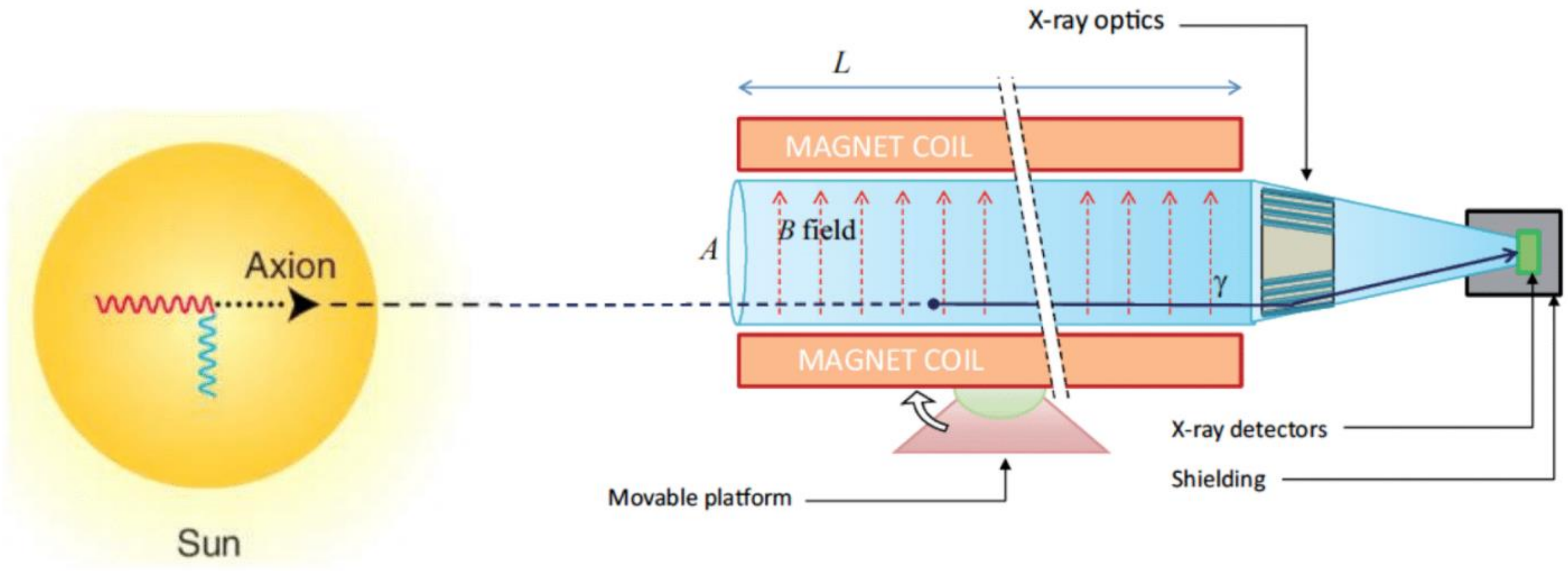


L. Winslow (2020)

IAXO looks to the sun for axions

The sun, which has extreme electromagnetic conditions, turns x-rays into axions, which will then come to Earth.

IAXO utilizes a strong magnet to turn axions bombarding Earth back into visible x-ray Photons



$$g_{a\gamma}^4 \propto \underbrace{(BL)^{-2}A^{-1}}_{\text{magnet}} \times \underbrace{t^{-1/2}}_{\text{exposure}} \times \underbrace{s^{1/2}\varepsilon_0^{-1}}_{\text{optics}} \times \underbrace{b^{1/2}\varepsilon^{-1}}_{\text{detectors}}$$

B = magnetic field
L = magnet length
A = cross-sectional area

t = time

s = spot size
ε_0= efficiency

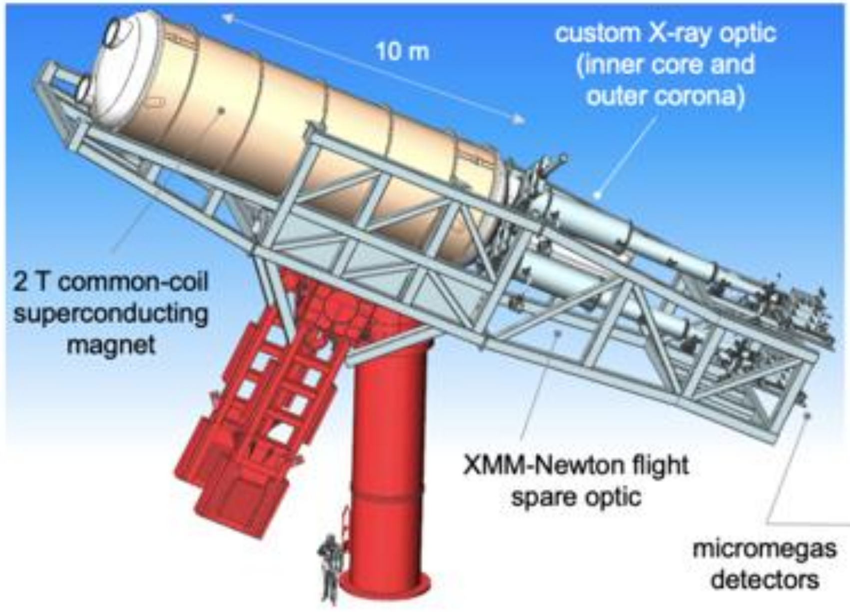
b = background
ε = efficiency

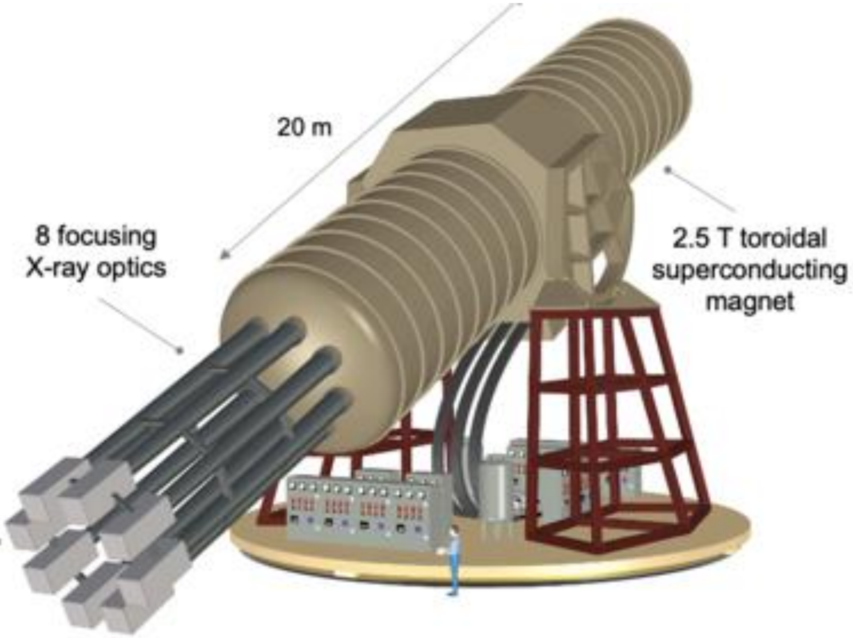
K. Perez (2023)

IAXO Design

IAXO and BabyIAXO utilizes superconducting magnets

BabyIAXO will house two X-Ray optics; IAXO will house eight





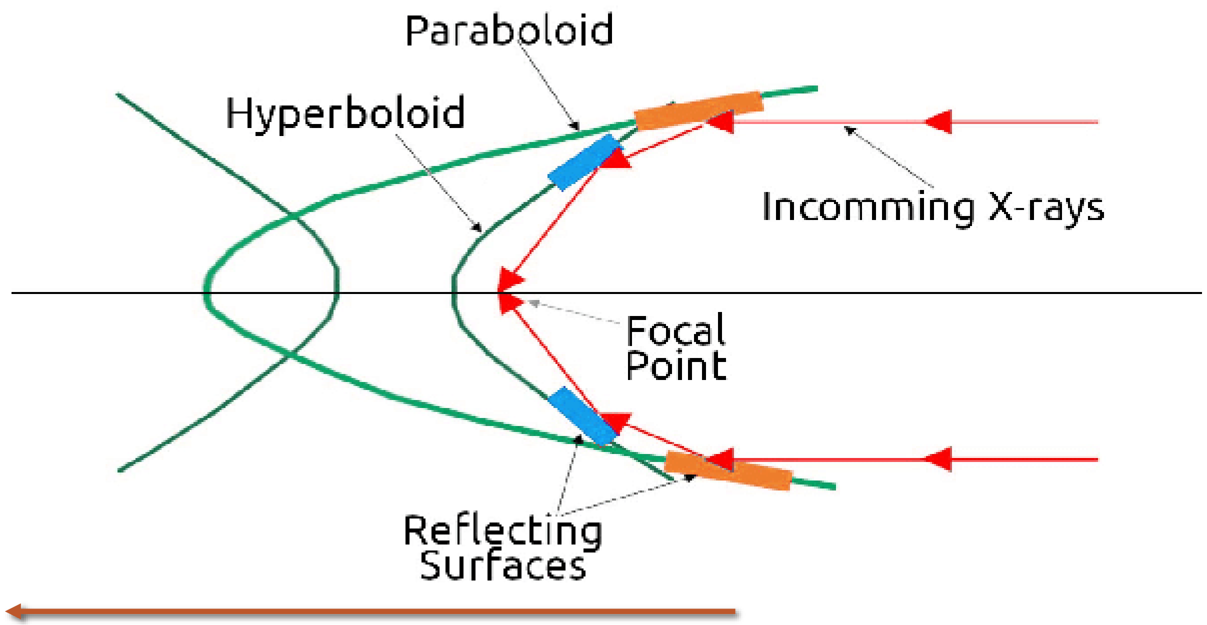
IAXO Collaboration, JHEP 05 (2021) 137

IAXO Collaboration, JCAP 1906 (2019) 047

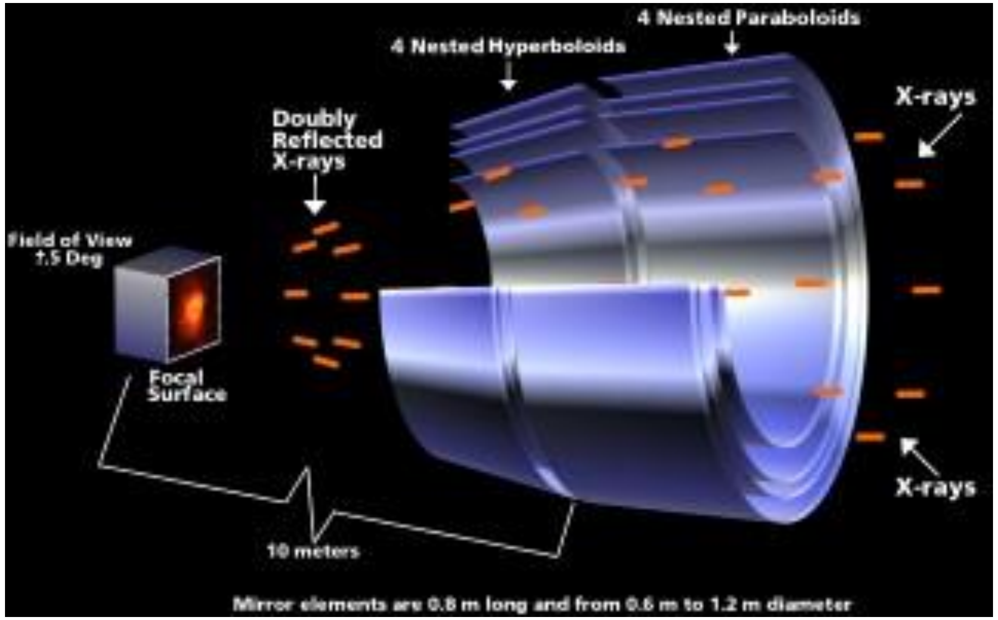
Proven Xray Optics for IAXO

IAXO utilizes the Wolter I X Ray Telescope Design to focus Xray signal

X Rays only bounce off shallow angles, so the parabolic and hyperbolic mirrors are only tilted a couple degrees

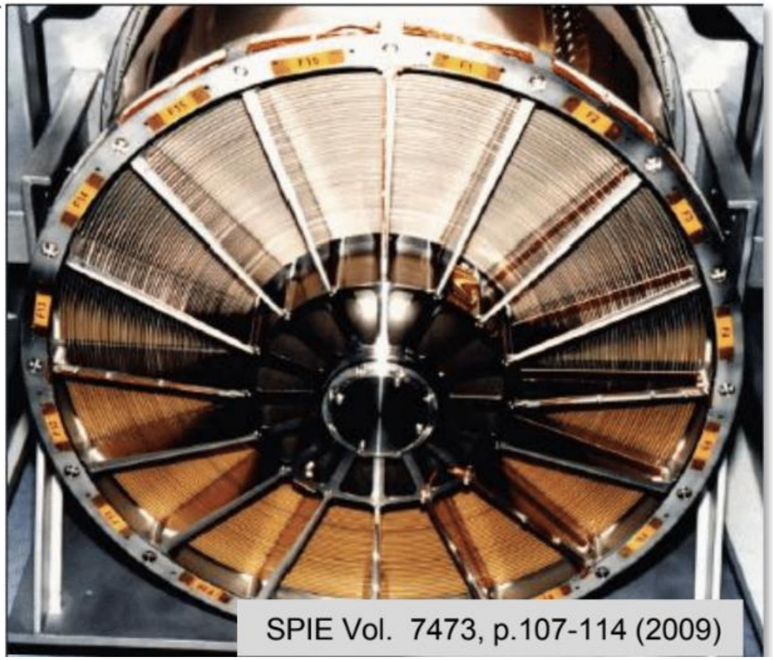


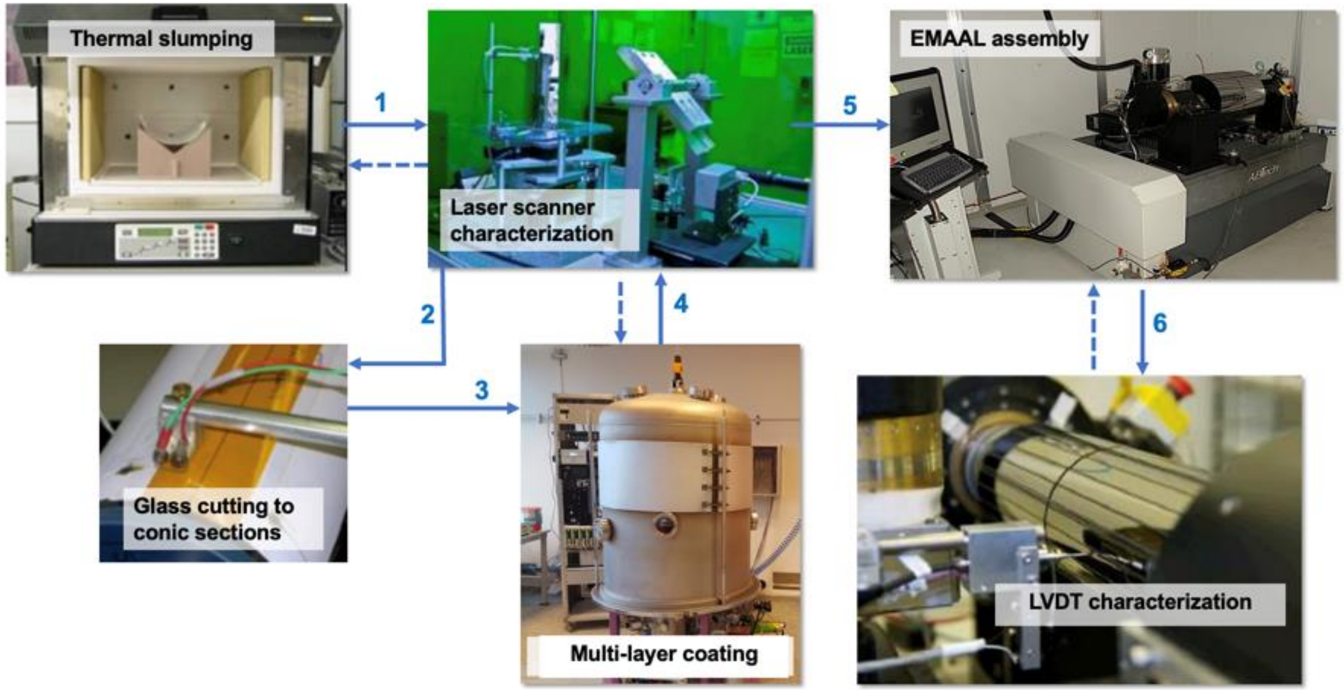
Mehdi Abbasian Motlagh (2020)



NASA/Chandra/ Smithsonian Astrophysical Observatory

Optical Assembly





Slumping Glass Overview

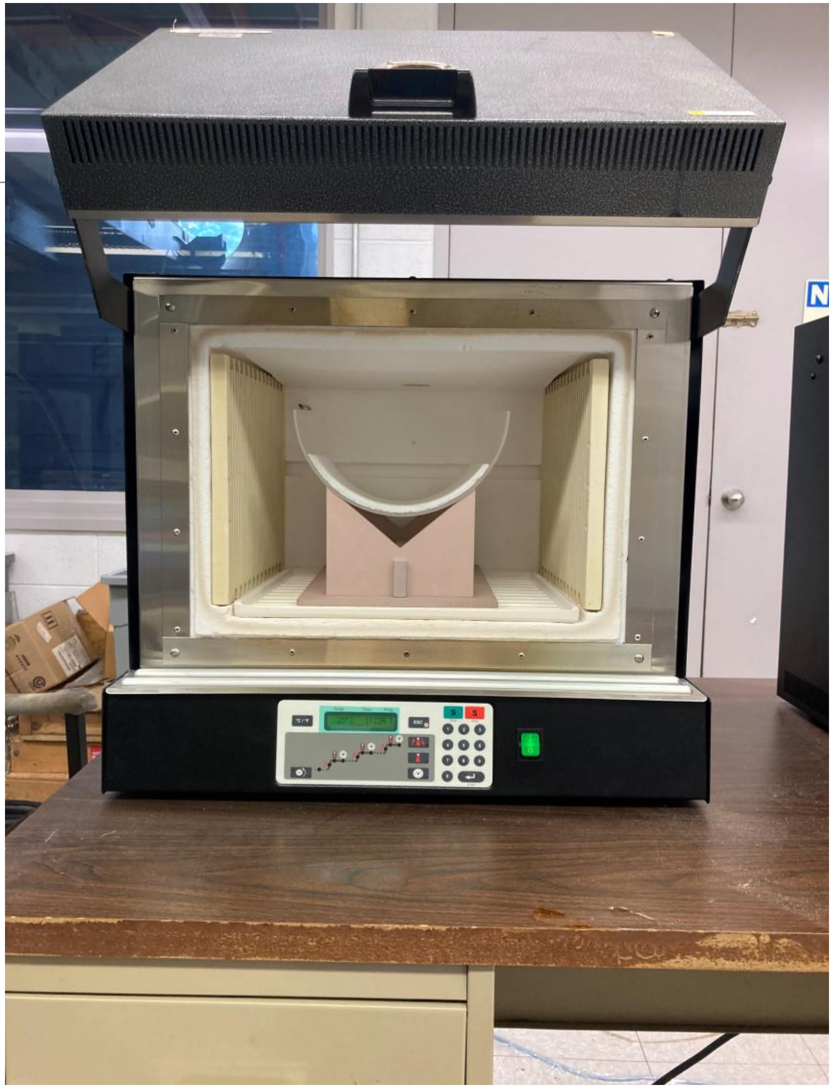
Glass is cut to sit on top of mandrel

Slumping happens in 3 stages

Adjustable Parameters: Temperature Rise (C/min), Temperature of Stage, Length of Stage, Length of Glass,

Settings are experimentally determined to produce the highest quality of glass

	Stage 1	Stage 2 (Thermalization)	Stage 3 (Soak)
Temperature Rise (C/min)	15	9	5
Temperature (C)	310	529	620
Length(min)	0	3	3

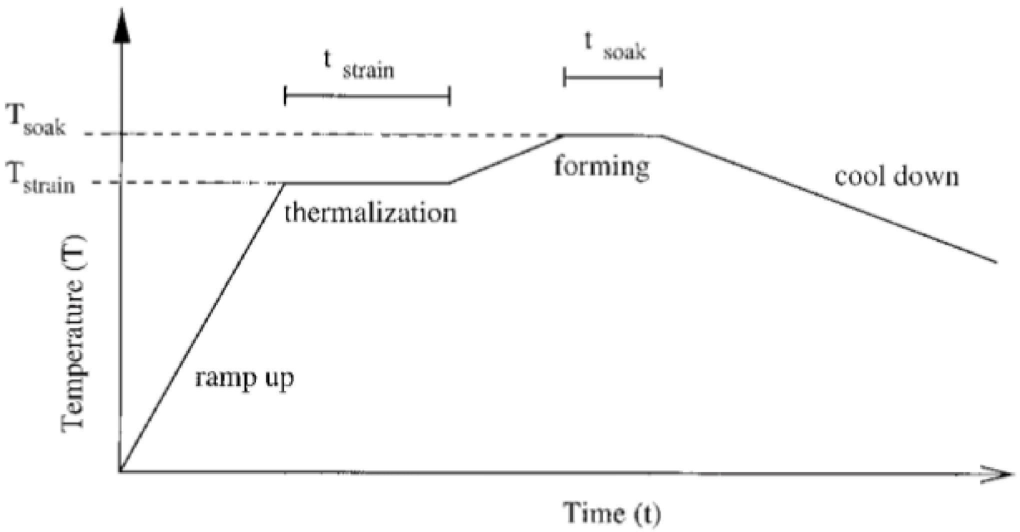


Optimizing Parameters

Thermalization: Keeping the glass at a certain temperature for a certain time to reduce a thermal gradient in the oven.

Soak Temperature: Higher soak temperature means faster slumping

Soak Time: A higher soak time means the glass substrate becomes more slumped



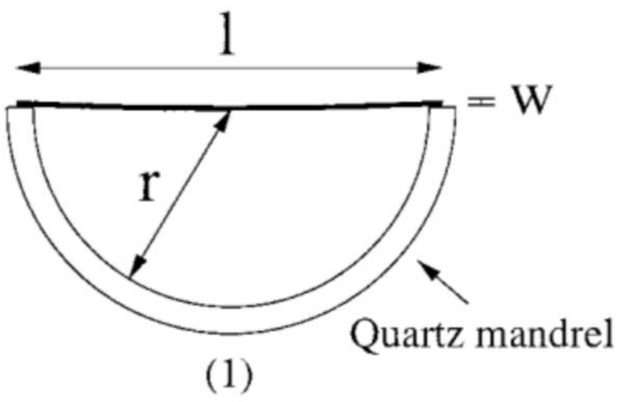
Jimenez,Garate (2003)

Optimizing Parameters Continued

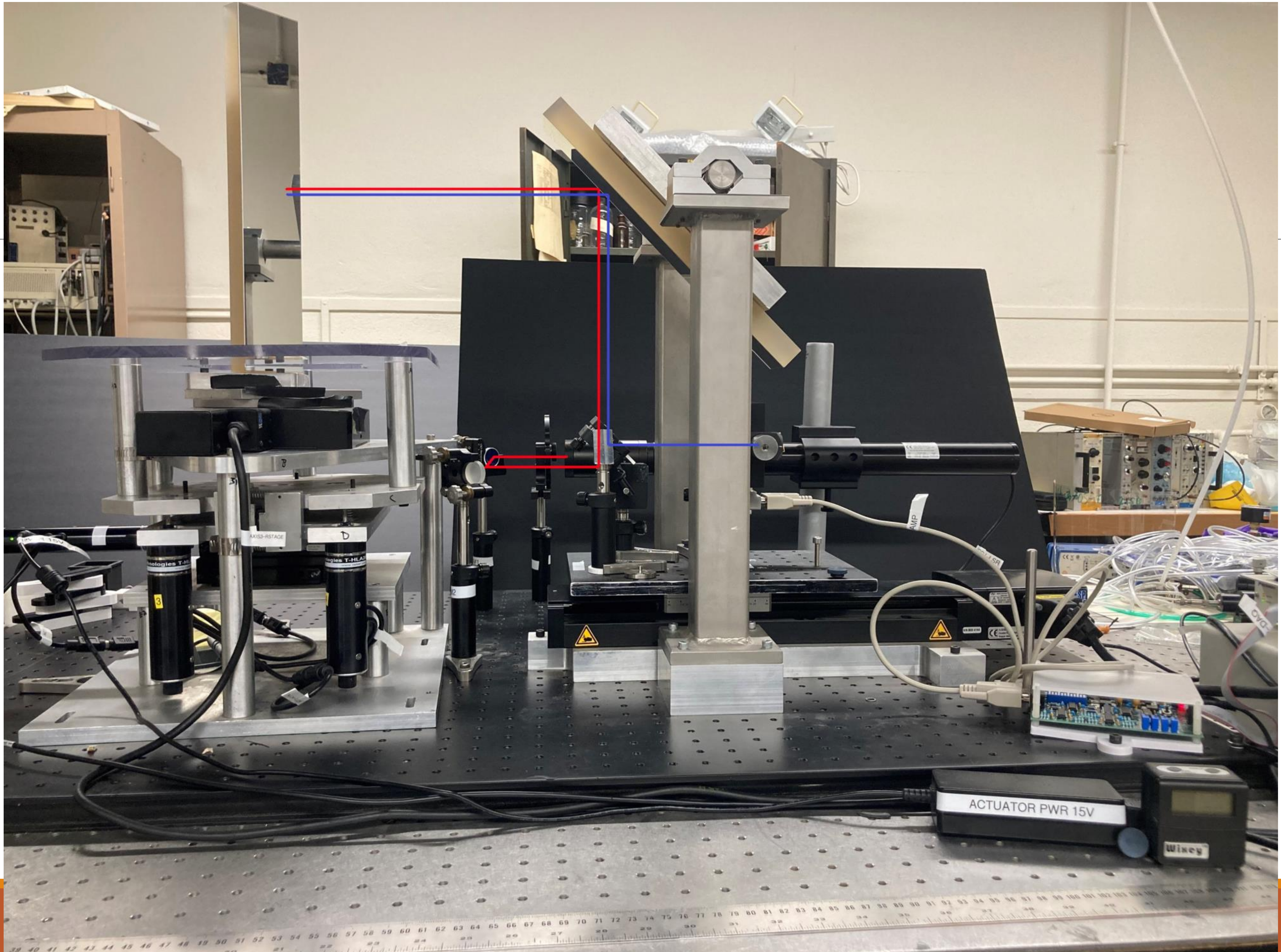
Mandrel Radii: The larger the mandrel, the earlier it slumps.

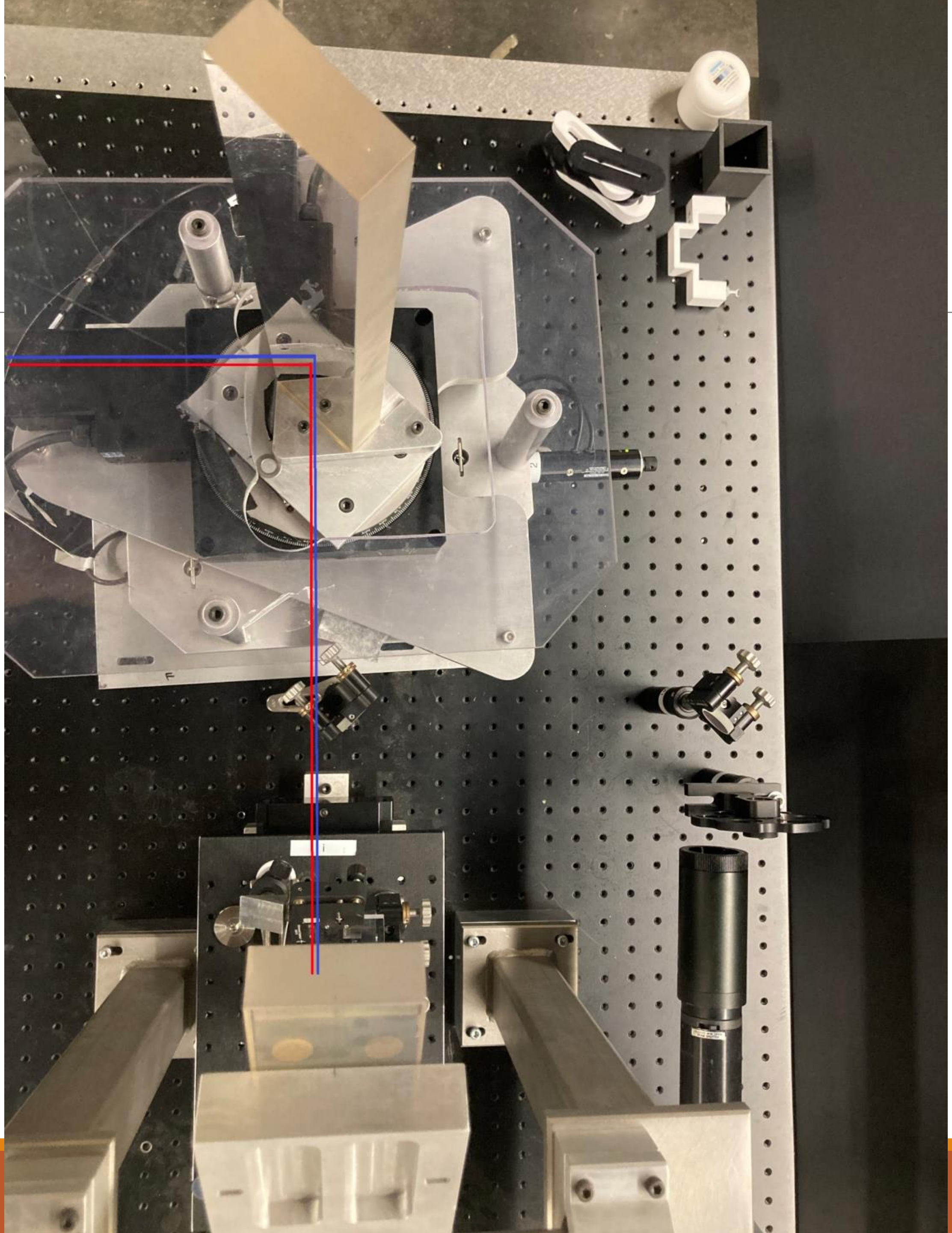
Glass Length:

- Originally cut to the outer Diameter (See Figure)
- Corners of the glass kept “catching” one of the ledges
- Glass cut down to in between the inner diameter and the outer diameter
- Result: More consistent slumping and less skewing



Jimenez,Garate (2003)


ACTUATOR PWR 15V
AXIS3-RSTAGE
Wixey

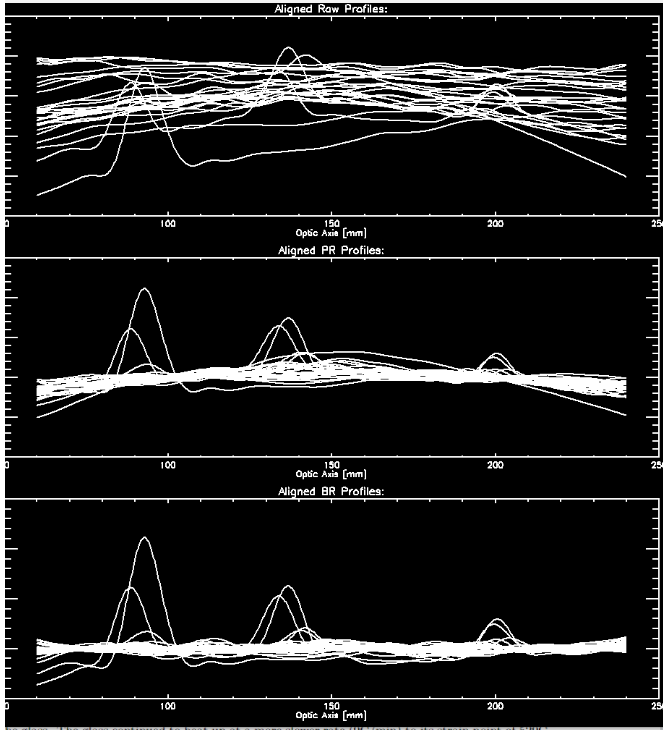


Laser Scanner shows HPD of slumped glass

Laser scan performs 31 scans of each piece of glass, each at a different azimuthal position

This scan checks the Bow Height of the glass, as well as checks for any irregularities (divots) on the glass surface

Code (in IDL) determines the HPD of the whole Xray optic if that optic was only made from that piece of glass



Previous NuSTAR Data (Courtesy Doug Thornhill)

Results

Soak Temperature decreases with increasing radii

Larger radii pieces are heavier, therefore making it easier to slump

Ideal larger radii pieces had a soak temperature of 570 C, with around a soak time of 11 minutes.

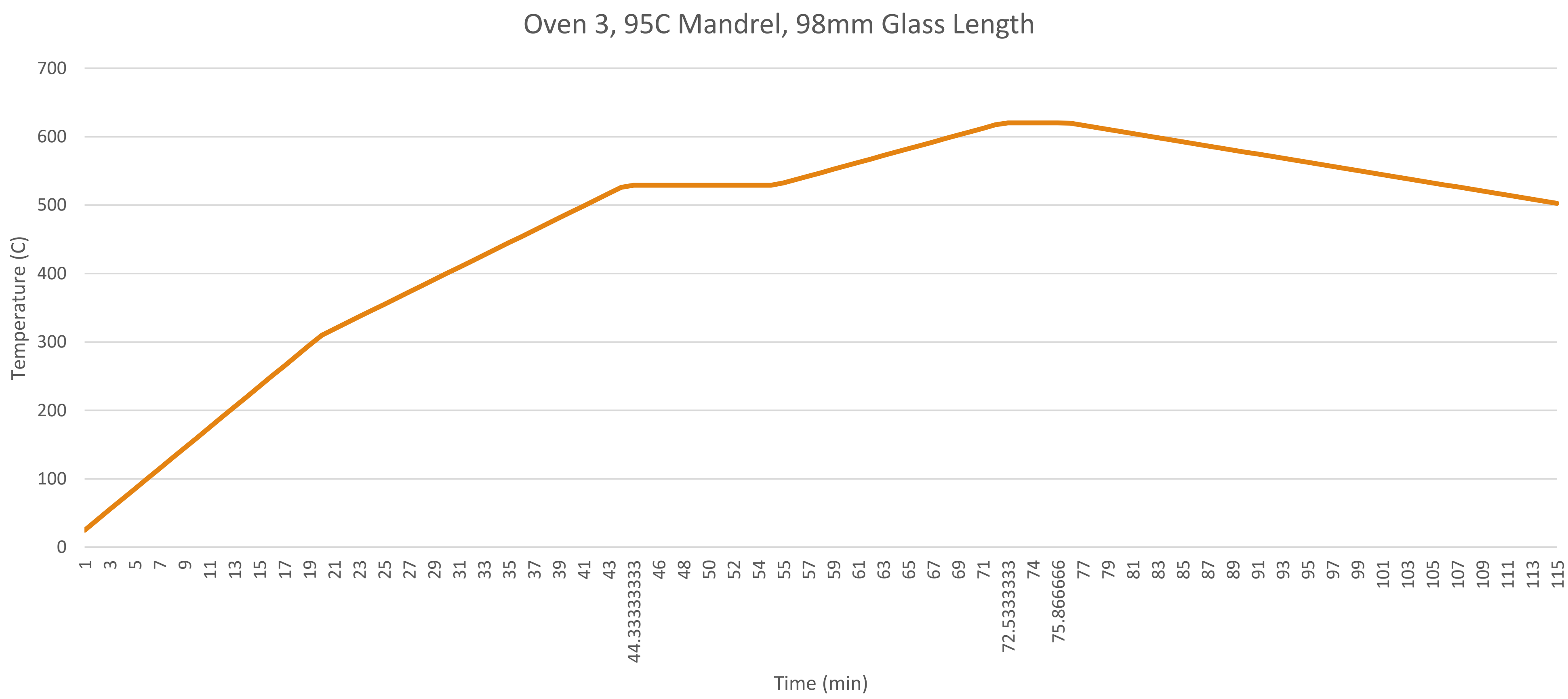
A higher soak temperature worked better (like 620C) than a lower soak temperature for lower radii mandrels

This is due to the glass slumping faster, which decreases the chance of it “catching” one of the corners of the mandrel, which decreases the chance of skewing

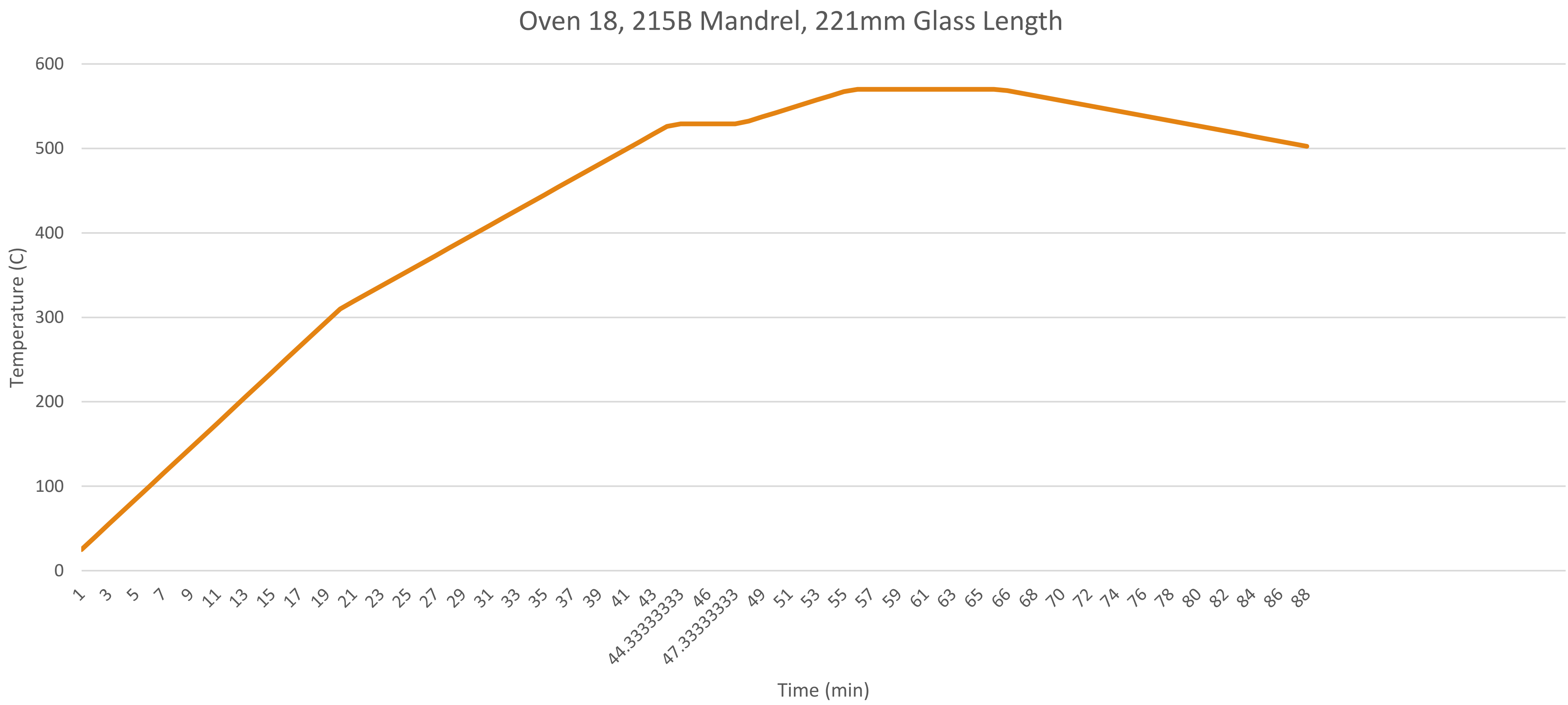
Ideal Glass Lengths for each mandrel:

- 91A: 94mm
- 95C: 98mm
- 215B: 221mm

General Recipe Found



General Recipe Continued



Summary/Looking Forward

Baby IAXO and IAXO will look towards the sun for axions

Baby IAXO is anticipated to be constructed in 2027, with full operation beginning in 2029

IAXO's construction is anticipated to be constructed within the next decade

General formula found for slumping substrates of glass for IAXO

More testing on different soak times should be done

More investigation on larger Radii substrates using laser scanner

Acknowledgements

Dr. Kerstin Perez

Mike Law

Marcela Stern

Doug Thornhill

National Science Foundation (Grant number PHY/1950431)

Nevis REU Program

Backup: Strong CP Problem solved by the existence of axions

Without QCD Axions:

$$\mathcal{L}_{\Theta} = -\bar{\Theta}\,(\alpha_s/8\pi)\,G^{\mu\nu a}\tilde{G}^{a}_{\mu\nu}$$

Gluon field strength tensor

With QCD Axions:

Axion Field

$$\mathcal{L} = \left(\frac{\phi_A}{f_A} - \bar{\Theta}\right)\frac{\alpha_s}{8\pi}\,G^{\mu\nu a}\tilde{G}^{a}_{\mu\nu}$$

Symmetry breaking scale

Backup: Formula for Glass Slumping

Oven 16, 91A mandrel	Stage 1	Stage 2	Stage 3
Temperature Rise (C/min)	15	9	5
Peak Temperature (C)	310	529	620
Time at Peak Temperature (min:sec)	0:00	3:00	3:00

Backup: More Formula for Slumping

Oven 16, 95C mandrel	Stage 1	Stage 2	Stage 3
Temperature Rise (C/min)	15	9	5
Peak Temperature (C)	310	529	620
Time at Peak Temperature (min:sec)	0:00	3:00	4:00

Oven 18, 215B mandrel	Stage 1	Stage 2	Stage 3
Temperature Rise (C/min)	15	9	5
Peak Temperature (C)	310	529	570
Time at Peak Temperature (min:sec)	0:00	3:00	11:00

Backup: Inner workings of Laser Scanner