# Miniature Lightweight X-ray Optics (MiXO) for Solar System Exploration

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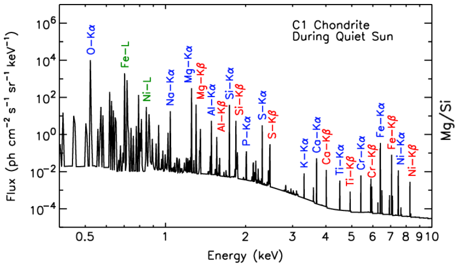
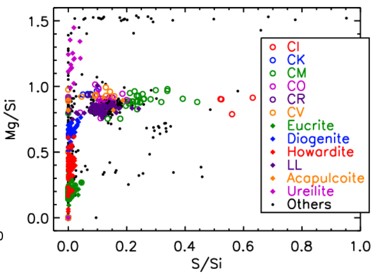
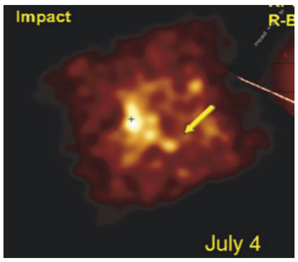
## I. Scientific Motivation

X-ray observations of solar system objects provide a unique window on fundamental processes associated with the formation and evolution of the emitting bodies and the Solar System as a whole. A primary science objective of planetary X-ray observation is to determine the elemental composition of diverse airless planetary bodies. The energy of X-ray fluorescence (XRF), intrinsic to atomic energy levels, carries an unambiguous signature of the surface elemental composition (>10 μm depth) of the emitting bodies.




(*Left*) Simulated X-ray fluorescence spectrum of an asteroid of C1 chondrite composition at 1 AU during the quiet sun state illustrating diverse elemental composition. (*Right*) Abundance ratios (Mg/Si vs. S/Si) as an identifier of a wide range of meteorite specimen types (Nittler et al. 2004).




X-ray *imaging* spectroscopy enables the measurement of spatial variation of both the absolute and relative elemental abundances without being constrained by the morphology and will be essential for understanding the dynamic activities of asteroids from crater-induced subsurface grain exposure to volatile depletion. For example, near-target X-ray imaging spectroscopy of a comet will isolate the elemental composition of the comet nucleus, as the coma, optically thin in X-rays, can be spatially separated from the nucleus.

*Chandra* images of 9P/Tempel 1 showing the impact ejecta (Lisse et al. 2007)

## II. X-ray Optics History & Future

We introduce Miniature X-ray Optics (MiXO) that can bring highly successful Wolter-I X-ray optics to planetary science within affordable mass, power, and cost constraints. The proposed concept takes the technology that is being developed for lightweight optics for X-ray astronomy and adapt it for planetary missions.

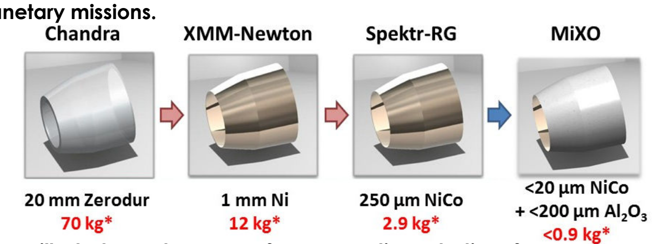
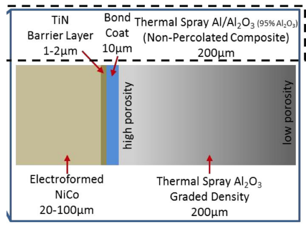
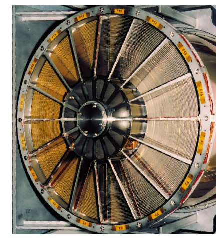



Figure illustrates advances of X-ray optics, starting from a ground and polished glass substrate used in *Chandra X-ray Observatory* and electroformed Ni shell in *XMM-Newton* to thin electroformed NiCo shell employed in *Spektr-RG*. Our new approach (*Right*) combines the plasma thermal spray technology with the electroformed Nickel replication process to largely replace thick high density NiCo shell (1 mm, 8.9 g/cm$^3$) with thin, light ceramic compound (<200 μm, 2.3–2.9 g/cm$^3$). The weights (*) are for a 70 cm dia. 60 cm long mirror shell. For small mirrors (~5 cm dia.) suitable for planetary science, a single shell would weigh ~50 g or less.

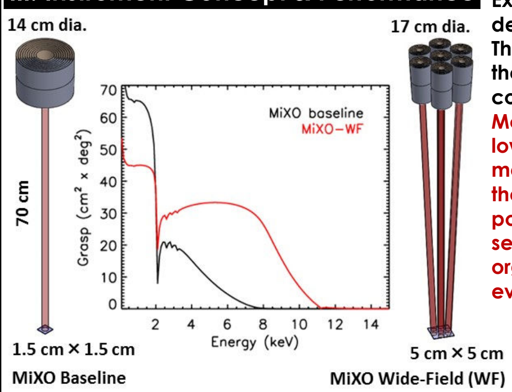



Proposed layer micro-structure consisting of NiCo, TiN barrier, bond, and a porosity graded alumina.

Electroformed mirror modules and the "spider" support structures of *XMM-Newton*.



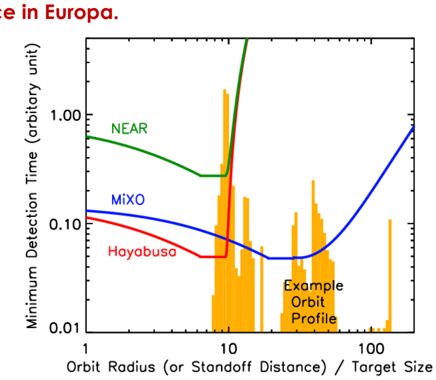
## III. Instrument Concept & Performance




| Example MiXO Telescopes | | |
|---|---|---|
| Parameters | MiXO | MiXO-WF |
| Focal Length (f) | 70 cm | 70 cm |
| Shells | 50 | 25 × 7 |
| Size (Diameter) | 4 – 14 cm | 2–5.6 cm<br>17 cm overall |
| Mass (g) | 920 | 210 × 7 |
| Detector | 1.5×1.5 cm$^2$ | 5 ×5 cm$^2$ |
| FoV (Ω) | 1 deg$^2$ | 7 deg$^2$ |
| Angular Res. | 30″ | 30″ |
| Effective Area* ($A_E$, cm$^2$) | 65 @ 1 keV<br>15 @ 4 keV | 6.4 @ 1 keV<br>4.6 @ 4 keV |
| Graz. Ang. | 0.41°– 1.43° | 0.20°– 0.51° |

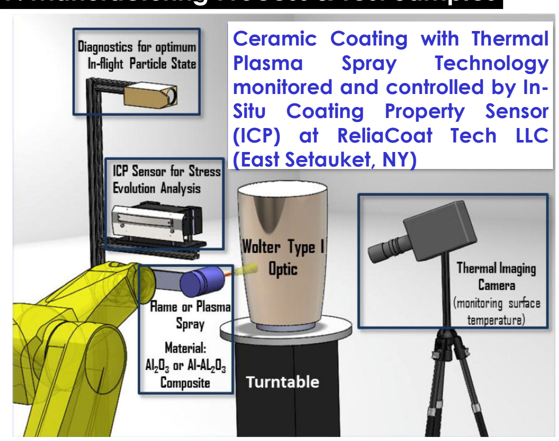
*Assume 10% reduction for align. fixture

Example MiXO telescopes: (*Left*) the baseline design and (*Right*) a wide-field option (MiXO-WF). The top plot shows grasp (effective area x FoV) for the baseline MiXO vs. MiXO-WF telescope with Ir coating (no surface or multilayer optimization). Modular design of MiXO can be easily scaled from low-cost Explorer-class to small Discovery or medium class New Frontiers. For Flagship missions, the proposed technology will open a door for powerful, cost-effective X-ray optics, a kind that is sensitive enough to distinguish between different organic species and thus detect astrobiological evidence in Europa.




Minimum detection time (non-imaging) of XRF as a function of distance to the target (normalized to the target radius) with an orbital profile (scaled from the planned profile of *OSIRIS-REx*).

## IV. Manufacturing Process & Test Samples




Ceramic Coating with Thermal Plasma Spray Technology monitored and controlled by In-Situ Coating Property Sensor (ICP) at ReliaCoat Tech LLC (East Setauket, NY)


(*Left*) Polished 2-inch diameter flat mandrel with several replicas used for adhesion and thickness tests. (*Right*) Test single bounce conical shells and mandrel.