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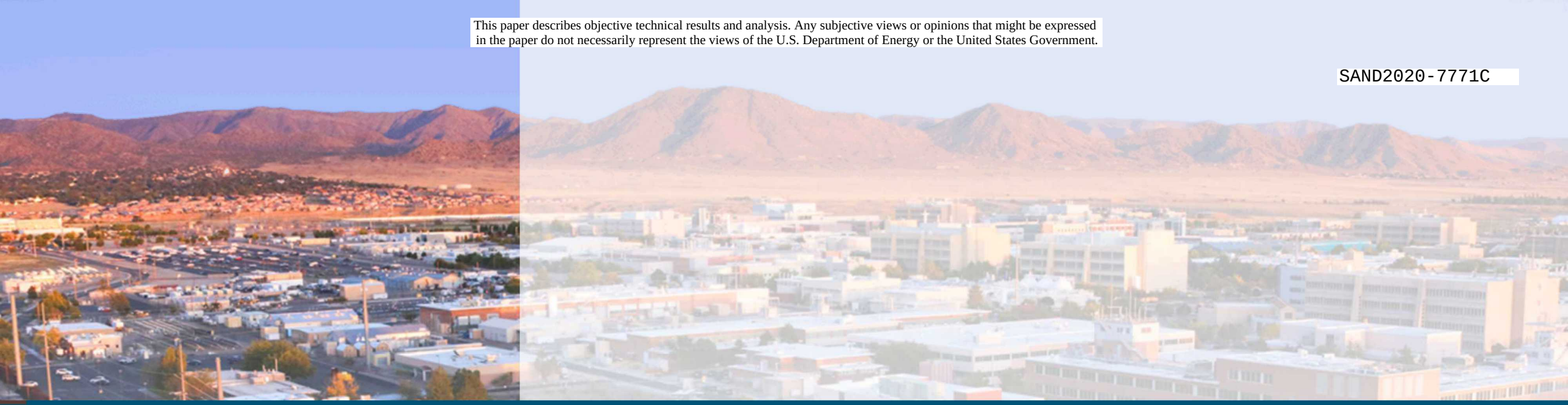

Shock Compression Response of Rutile TiO_2

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SAND2020-XXXX

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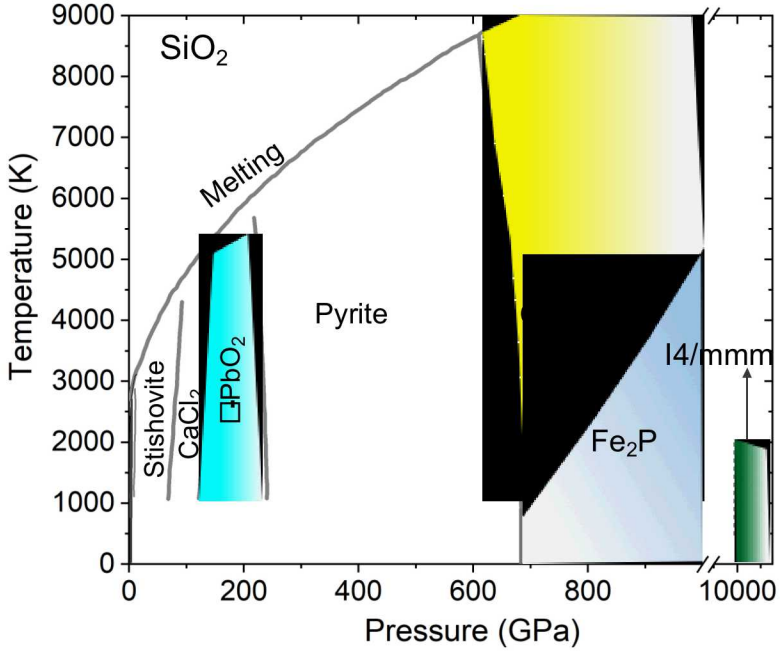
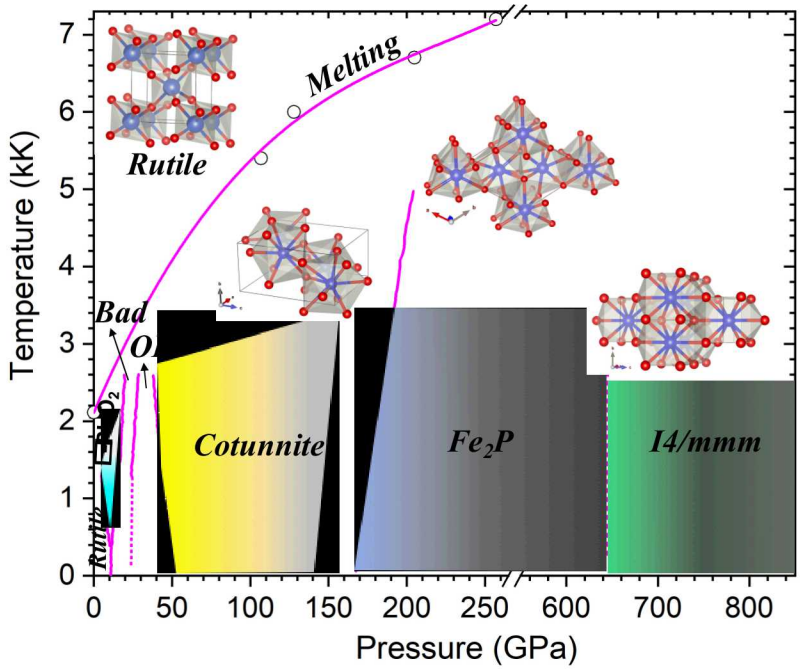
TiO_2: Applications/Motivation

Various Industrial applications of TiO_2

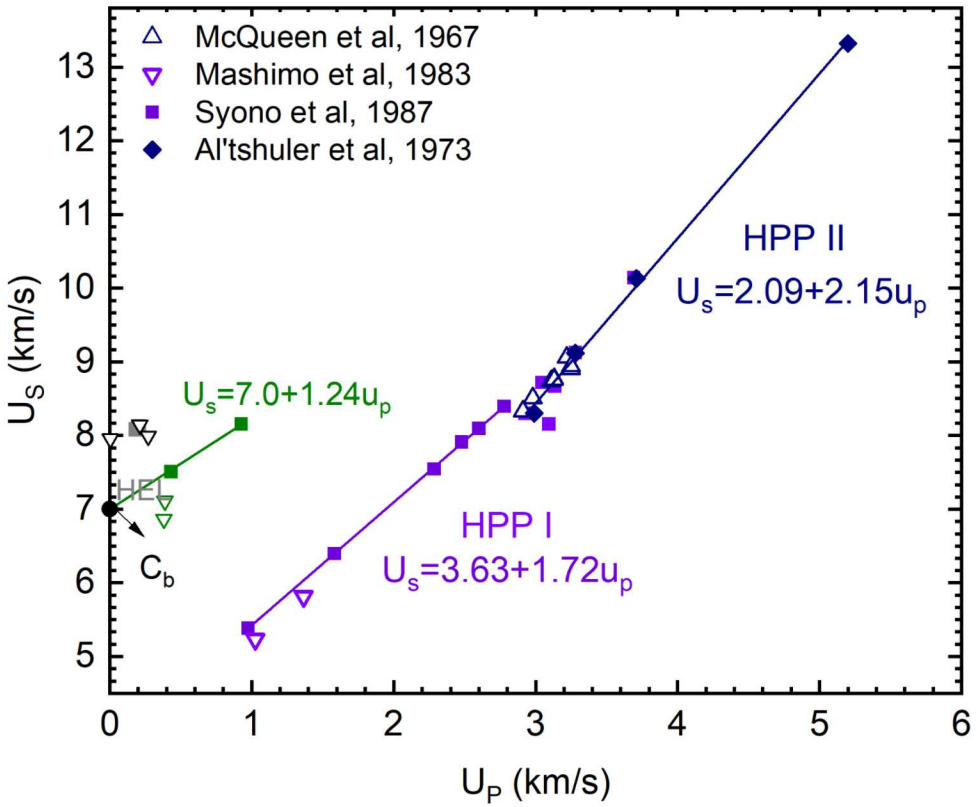


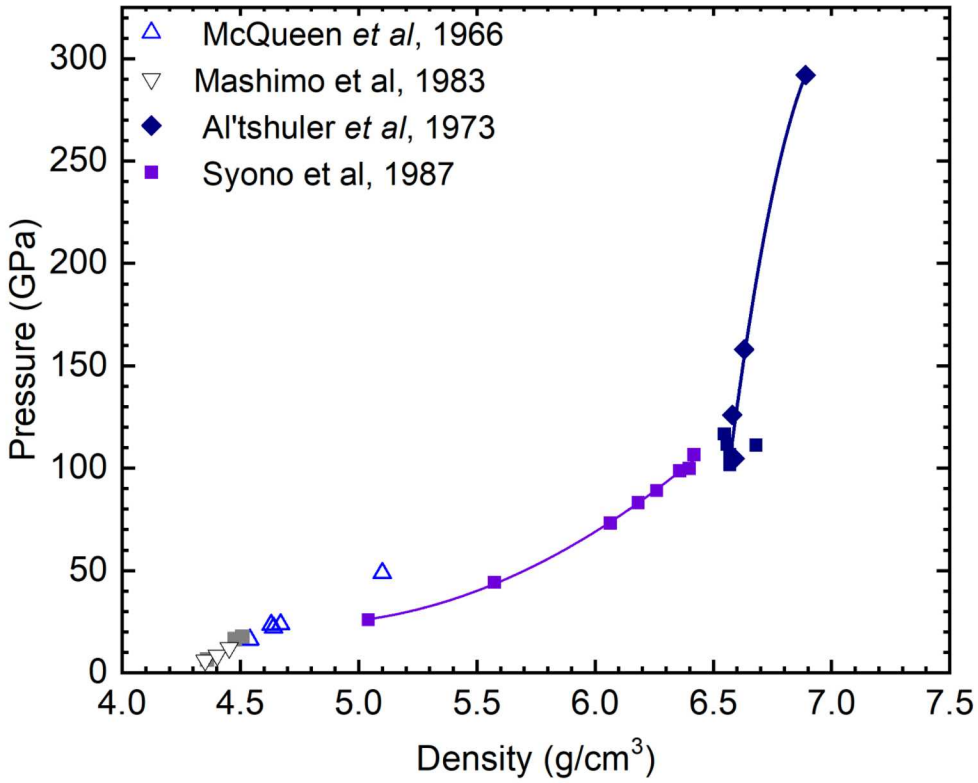


- Structural analogs to the AX_2 systems, such as TiO_2
- Pressure-induced phase transitions are quenchable to ambient pressure
- Predicted phase transitions in SiO_2 at 10 TPa could happen at pressures as low at 640 GPa

Obtain a complete equation of state for TiO_2

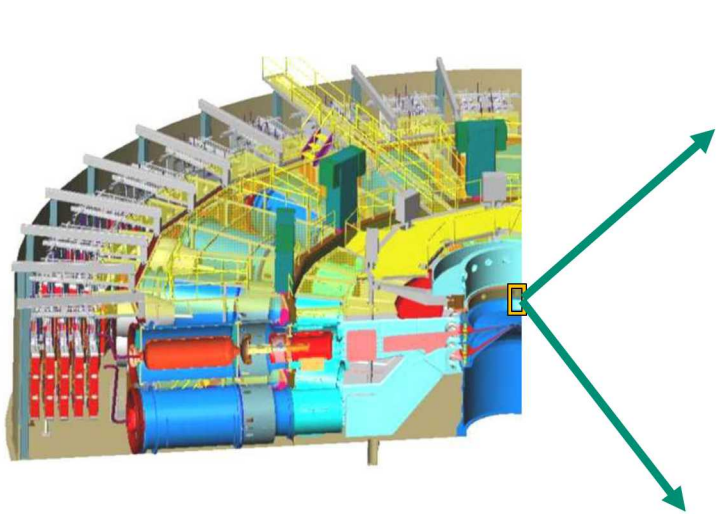
Prior Shock Work

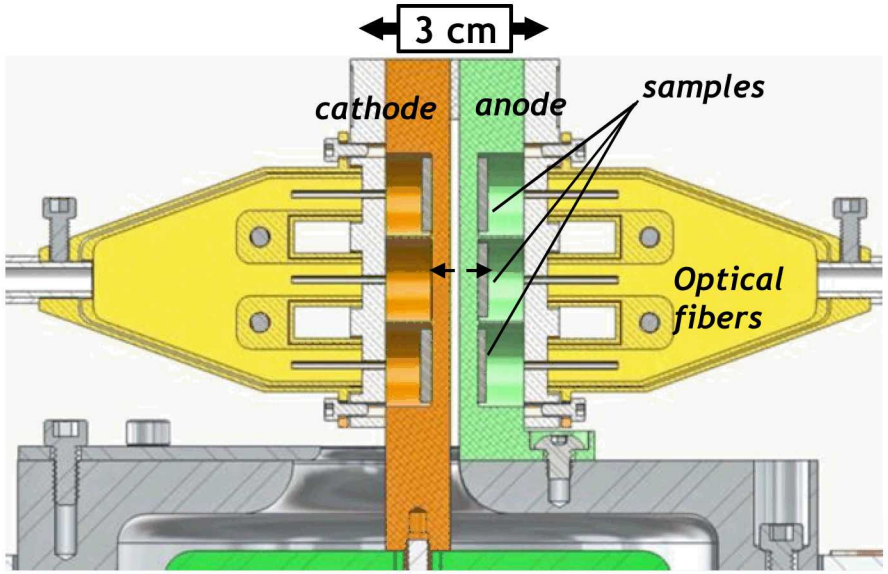




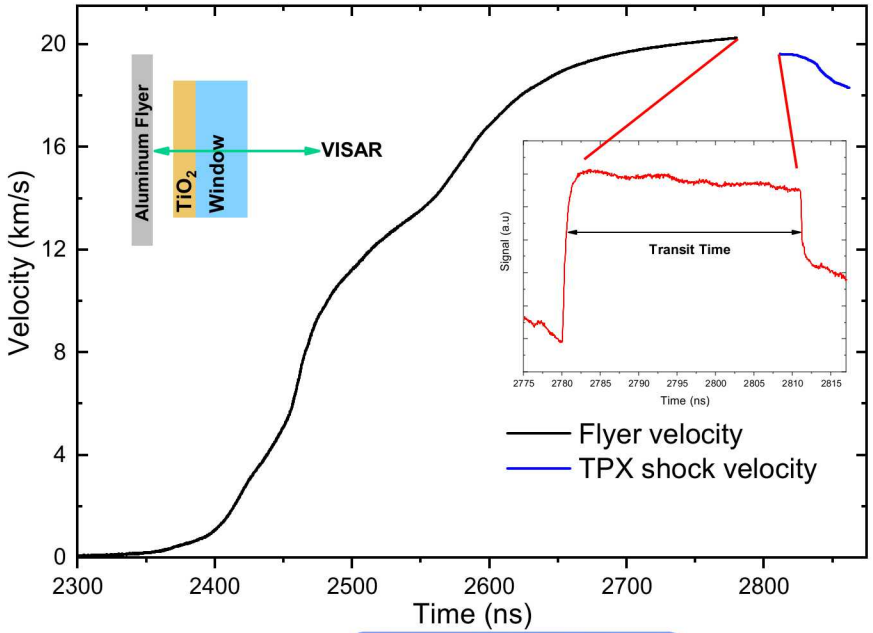
- Hugoniot data of TiO_2 limited to ~300 GPa
- TiO_2 concluded to have 'virtually incompressible' Hugoniot by Al'tshuler et al

Z Experiments





Target assembly for Z-experiment



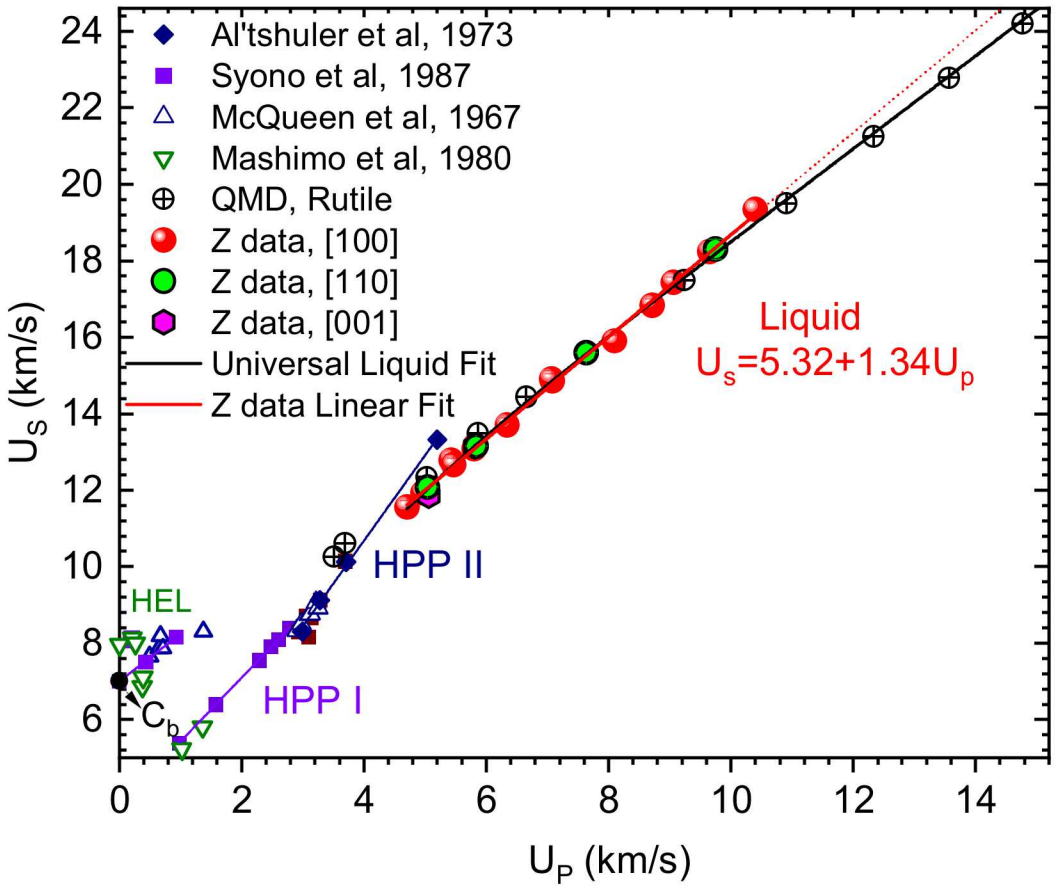
Z-VISAR trace

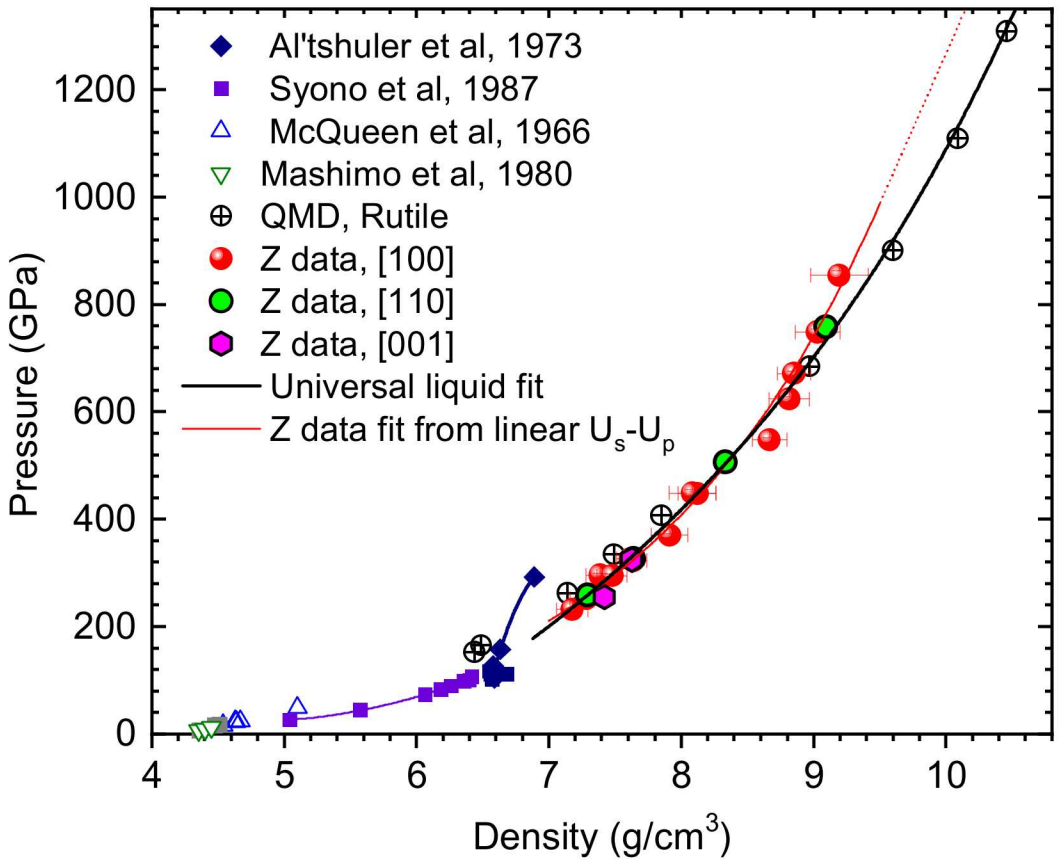
- Single crystal [110], [111], [001] TiO_2 investigated
- TiO_2 backed by TPX/Quartz window for release measurements
- Z machine shocklessly accelerate Aluminum flyers
- Flyer Velocities: 12 to 22.5 km/s
- Generating steady shocks in TiO_2
- At impact velocities < 20 km/s the shock front is not reflective
- VISAR measures impact velocity, shock velocities and transit times

Twenty Z shots at different flyer velocities

Shot	Orientation	Window	V_F (km/s)	U_P (km/s)	U_S (km/s)	ρ (g/cm^3)	P (GPa)
Z3297S6[c]	[100]	TPX	22.49 ± 0.09	9.66 ± 0.07	18.24 ± 0.20	9.03 ± 0.11	748.8 ± 6.3
Z3297N6[c]	[100]	TPX	21.10 ± 0.06	9.06 ± 0.05	17.43 ± 0.15	8.85 ± 0.13	671.3 ± 4.4
Z3267S5[c]	[100]	TPX	20.24 ± 0.06	8.72 ± 0.06	16.83 ± 0.18	8.82 ± 0.15	623.5 ± 4.7
Z3267N5[c]	[100]	TPX	18.77 ± 0.06	8.10 ± 0.05	15.90 ± 0.15	8.67 ± 0.13	547.7 ± 3.9
Z3343N6	[100]	TPX	16.52 ± 0.09	7.08 ± 0.06	14.86 ± 0.18	8.12 ± 0.14	447.3 ± 4.5
Z3274S5	[100]	TPX	14.74 ± 0.06	6.34 ± 0.05	13.71 ± 0.18	7.91 ± 0.14	369.8 ± 3.5
Z3274N5	[100]	TPX	13.59 ± 0.06	6.35 ± 0.05	13.18 ± 0.14	7.62 ± 0.10	326.3 ± 2.8
Z3325N1[a]	[100]	TPX	12.83 ± 0.09	5.44 ± 0.03	12.79 ± 0.15	7.39 ± 0.11	295.2 ± 3.4
Z3427N5	[100]	TPX	10.94 ± 0.05	4.71 ± 0.05	11.55 ± 0.18	7.18 ± 0.12	231.2 ± 2.5
Z3441S7	[100]	Quartz	24.27 ± 0.09	10.40 ± 0.08	19.34 ± 0.26	9.19 ± 0.22	854.9 ± 8.0
Z3343N7	[100]	Quartz	16.52 ± 0.14	7.07 ± 0.09	14.91 ± 0.26	8.08 ± 0.18	448.2 ± 6.2
Z3391S2	[100]	Quartz	13.51 ± 0.06	5.80 ± 0.05	13.08 ± 0.14	7.64 ± 0.10	322.5 ± 2.8
Z3325N5[b]	[100]	Quartz	12.77 ± 0.07	5.47 ± 0.05	12.67 ± 0.06	7.48 ± 0.10	294.5 ± 3.0
Z3396S3	[100]	Quartz	11.56 ± 0.05	4.97 ± 0.05	11.93 ± 0.19	7.29 ± 0.13	252.0 ± 2.7
Z3441N7	[110]	TPX	22.68 ± 0.07	9.75 ± 0.07	18.30 ± 0.25	9.09 ± 0.21	758.2 ± 6.9
Z3343S3	[110]	TPX	17.81 ± 0.09	7.64 ± 0.06	15.59 ± 0.14	8.33 ± 0.12	506.1 ± 4.3
Z3391N5	[110]	TPX	13.15 ± 0.15	5.84 ± 0.05	13.15 ± 0.15	7.64 ± 0.11	326.2 ± 2.9
Z3396N5	[110]	TPX	11.74 ± 0.08	5.04 ± 0.05	12.08 ± 0.15	7.29 ± 0.11	258.7 ± 3.0
Z3391N2	[001]	TPX	13.56 ± 0.08	5.82 ± 0.06	13.14 ± 0.19	7.63 ± 0.14	325.0 ± 3.7
Z3396N2	[001]	TPX	11.70 ± 0.07	5.06 ± 0.05	11.85 ± 0.15	7.42 ± 0.11	254.9 ± 2.8

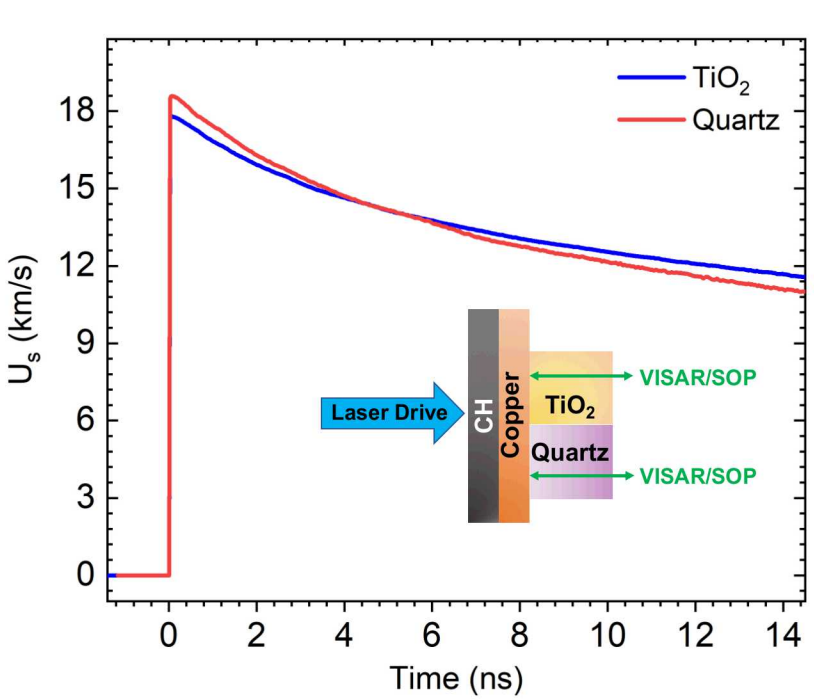
Z experimental Results

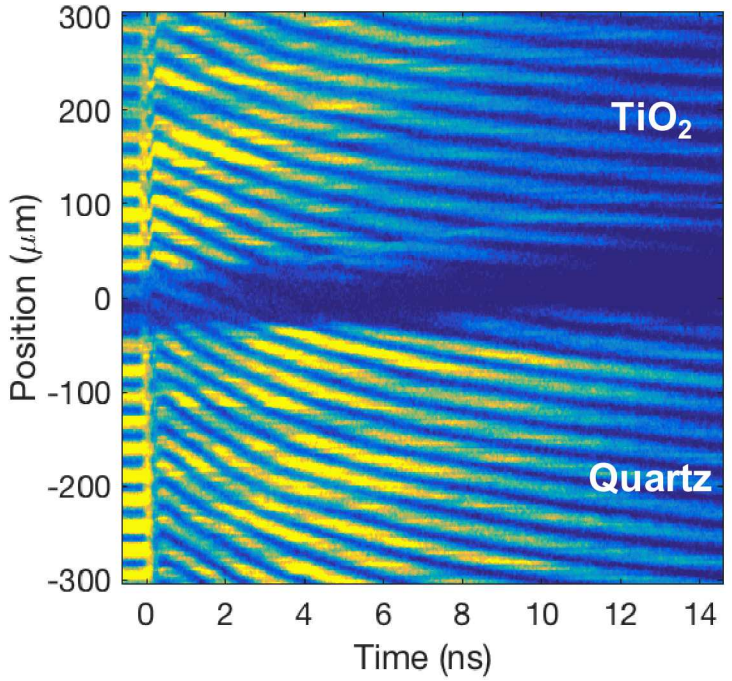


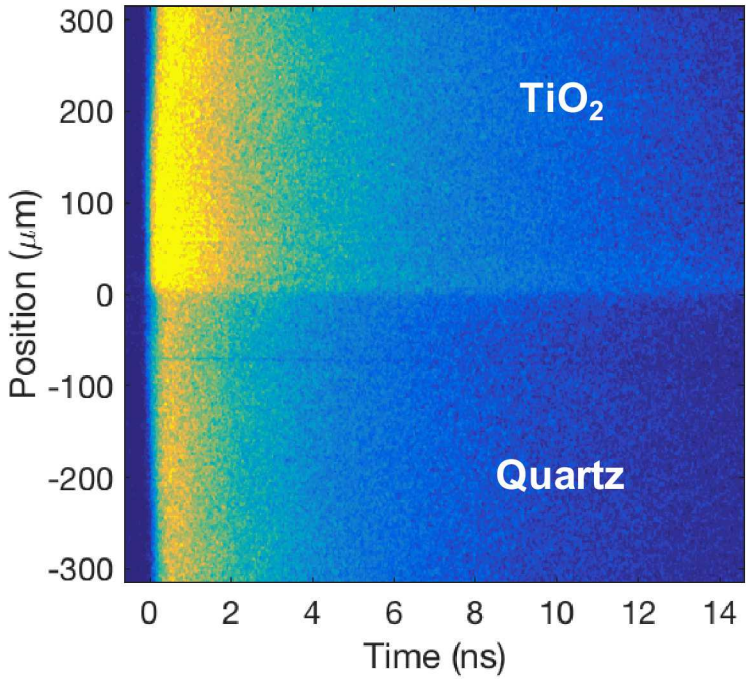


- High precision Hugoniot data obtained from Z → strikingly different than what Al'tshuler reported
- Z-data are in excellent agreement with the QMD data
- No-orientation dependence observed indicating possible transformation to a liquid phase

Omega experiments to measure temperature

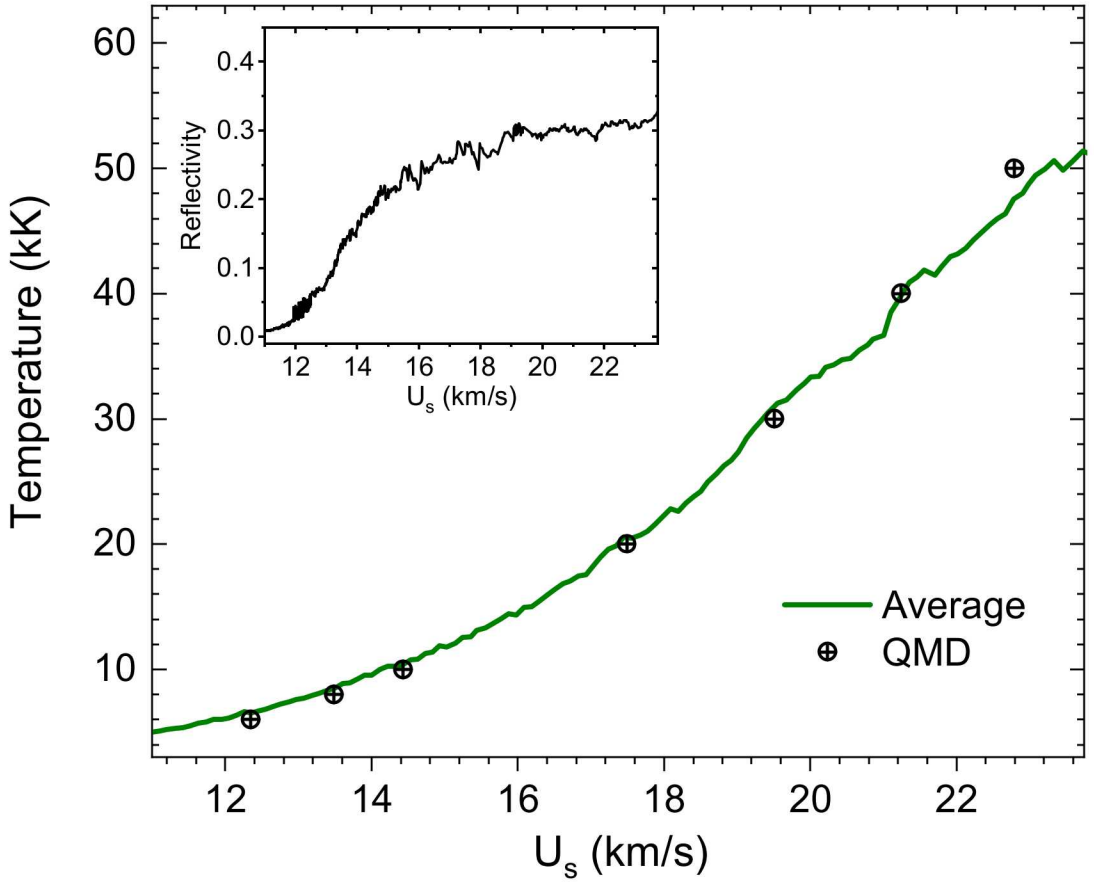


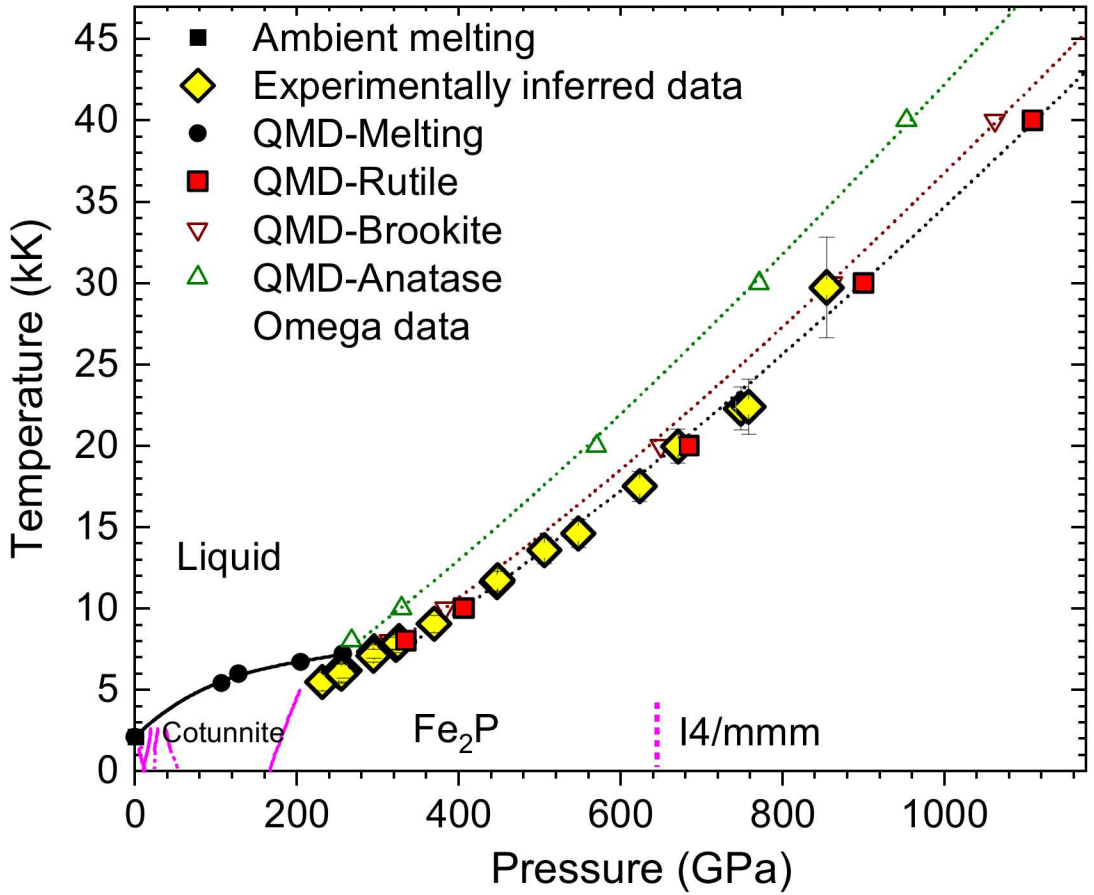




- Laser driven shock decay experiments to measure shock velocity as a function of temperature
- Kapton file backed by copper, which is backed by TiO_2 and Quartz
- SOP fielded to measure emission → Reflectivity → Temperature

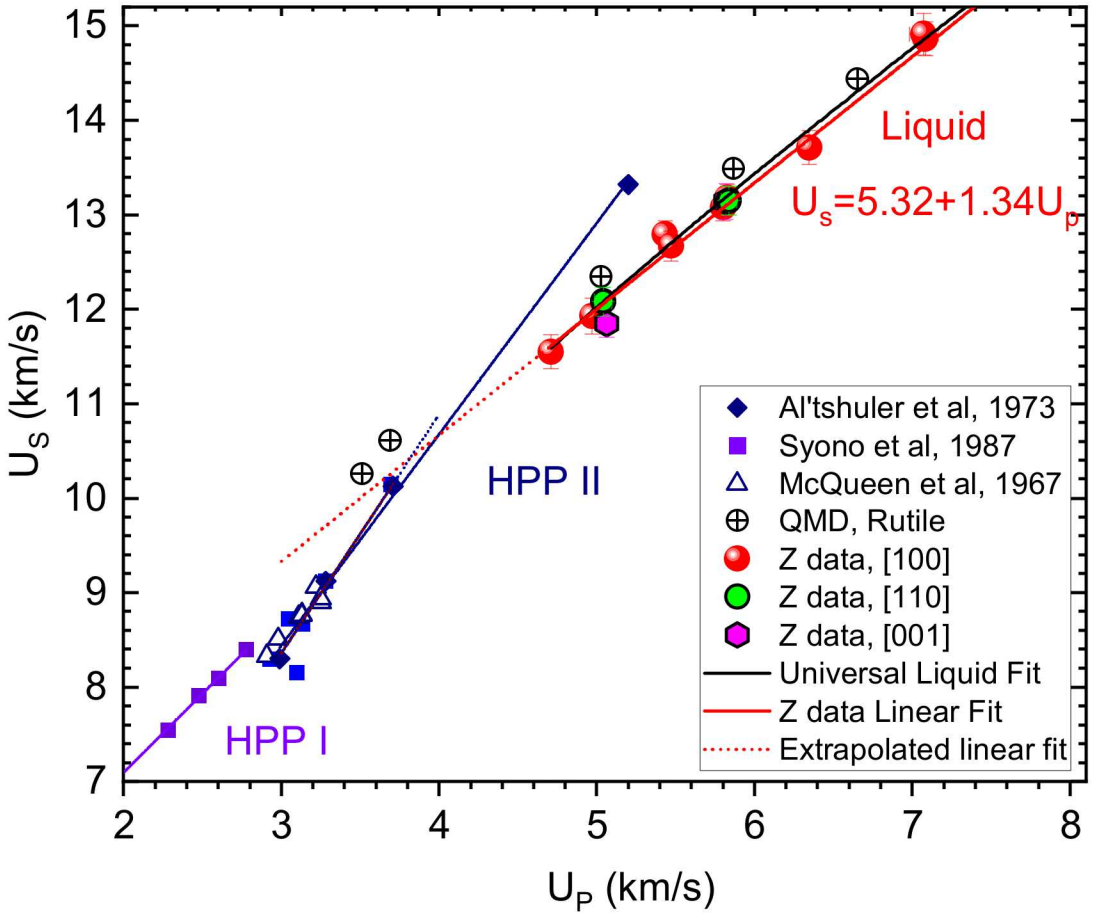
Omega data suggest liquid TiO_2 above 240 GPa

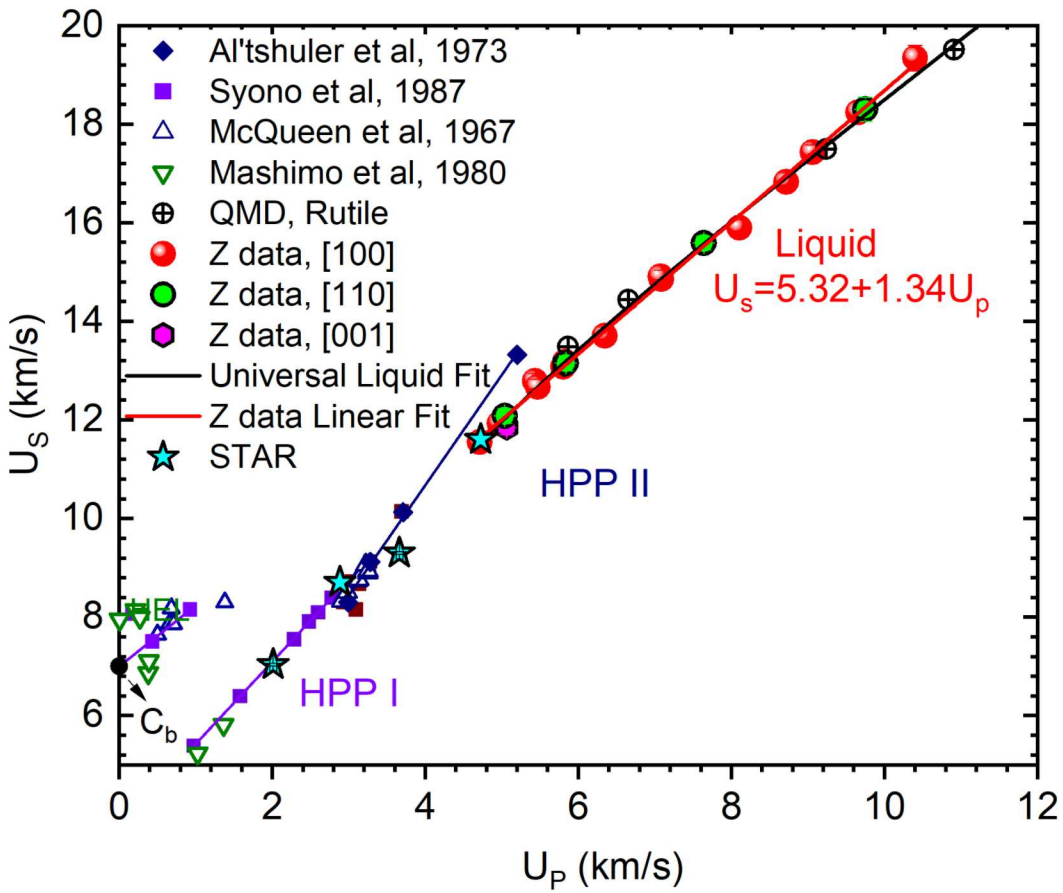




- Temperature measurements from four different shots.
- Measured data consistent with QMD calculations
- Measured reflectivity suggests liquid phase

Transition from HPPII to liquid





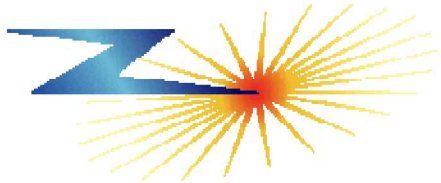
- Two-stage gas gun shots to fill in the missing data
- More data to pin down the phase boundary from HPPII to liquid

Summary

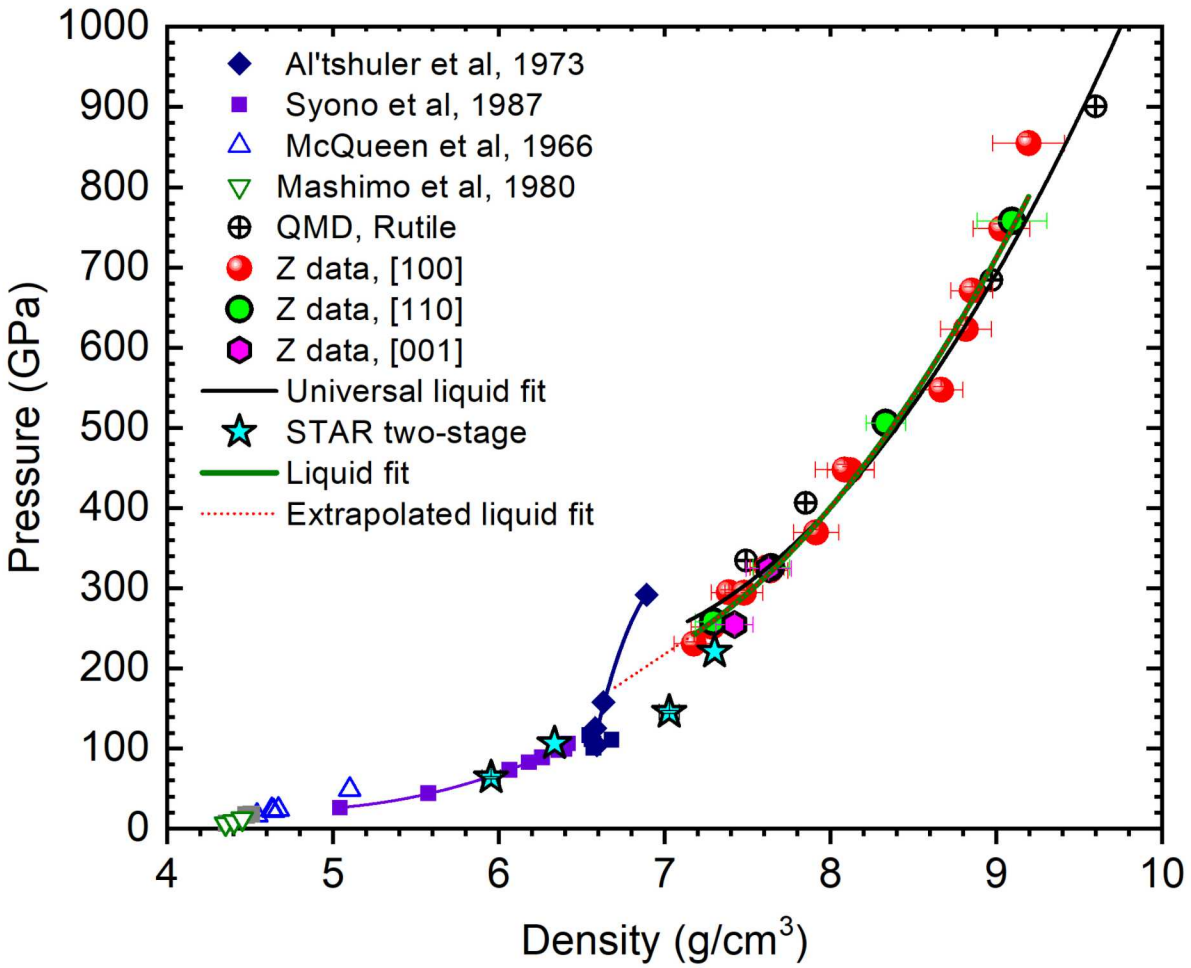
- A complete Hugoniot in P-ρ-T space for TiO_2 has been measured.
- TiO_2 is in liquid phase above 240 GPa.
- Current data drastically different from Al'tshuler's 'virtually incompressible' Hugoniot data.
- More study at lower pressure ongoing to pin point the melt boundary.

Acknowledgements

- Chad McCoy, Seth Root, Philippe Weck, Patricia Kalita, Tommy Ao, Heath Hanshaw, Kyle Cochrane
- STAR: Bill Reinhart, Scott Alexander, John Martinez, Bernardo Farfan, Robert Palomino, Rafael Sanchez
- Z: Leo Molina, Roger Harmon and all of the Z technologists
- DICE: Lena Pacheco
- Jim Williams, Caroline Blada
- Diagnostic Support Staff



Transition from HPPII to liquid



Thank you!