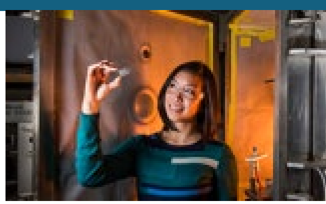
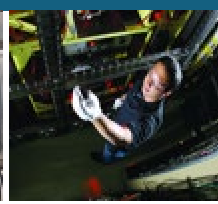
Sandia National Laboratories

The Life Cycle of Helium-3 in Erbium Tritide


PRESENTED BY

Clark S. Snow, Sandia National Labs

Properties of the Er:T system

Erbium = HCP

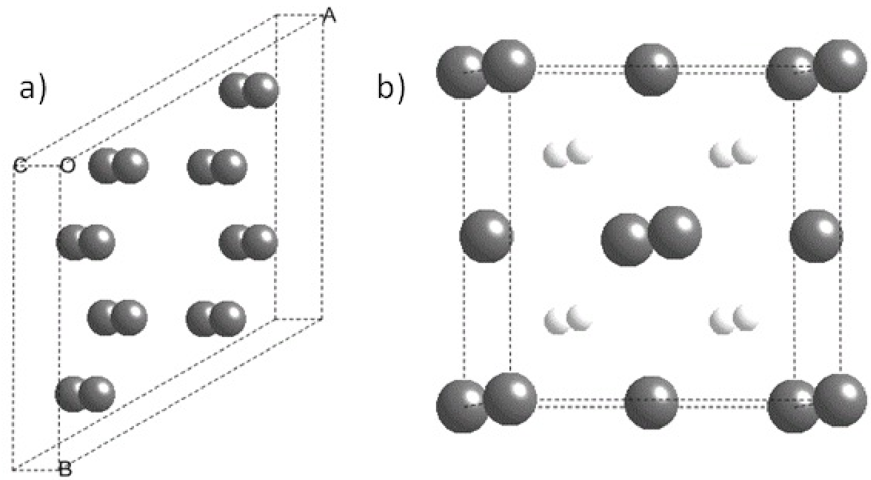
ErT_2 β-phase = FCC

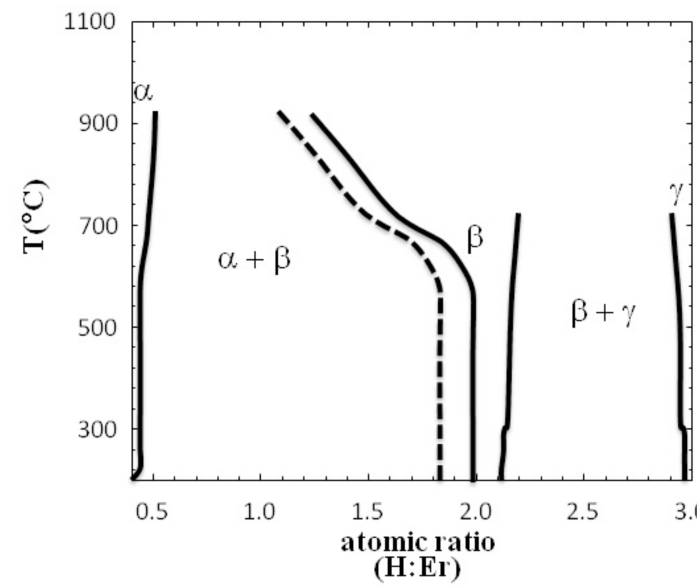
β-phase extends from 2.0 - ~2.2.

Sub-stoichiometric β-phase due to stoichiometric deficiency δ.

$ErT_{2-\delta+x}$

- x is excess Tritium in octahedral sites
- δ is stoichiometry deficiency such that Erbium sites can not bind Tritium causing an over-counting
- We often observe 1-2% oxygen as large Er_2O_3 chunks and as nano-clusters.
- Other impurities like other RE's





Overview of this Study

500 nm thick Erbium film deposited via e-beam PVD on Silicon Molybdenum interaction barrier.

Expect 10-15% swelling upon conversion to ErT_2.

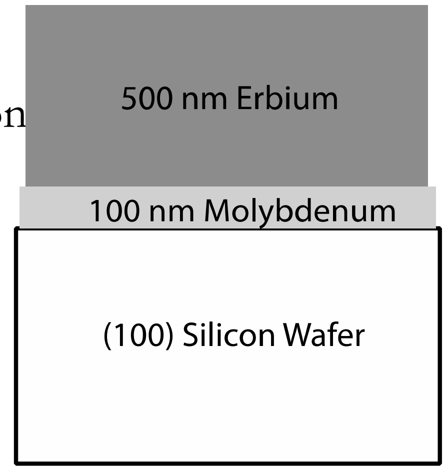
Average stoichiometric deficiency of $\delta \sim 0.1$.

TEM to image bubbles

XRD for lattice changes

Nano-Indentation for mechanical property changes

IBA/ERD for helium retention



Load Run	T:Er
1	1.844
1	1.927
2	1.842
2	1.987
3	1.851
3	1.909
Average	1.893
Std. Dev.	0.058

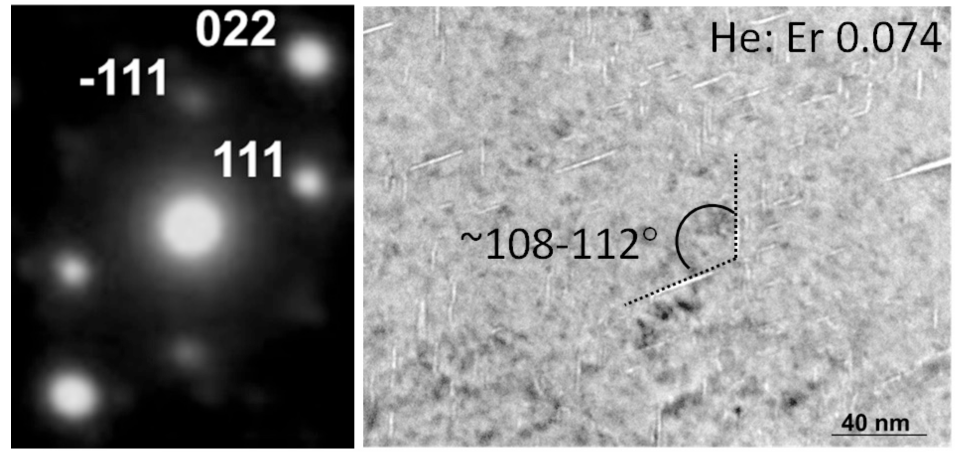
Helium Bubble Shape

Helium stored in platelets oriented along (111) planes.

4 (111) planes in FCC, only observe 2 at a time in TEM.

Width ~ 1-2 nm.

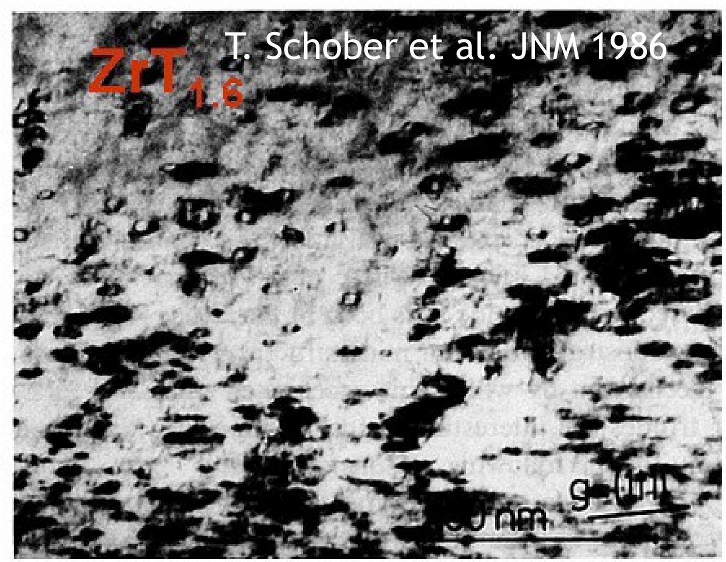
Platelets v. Spheres



Ratio of $\frac{Surface\ Energy}{Strain\ Energy} = \frac{2\gamma}{\mu b}$

> 0.1 Sphere
< 0.1 Platelet

ErT_2 ~ 0.06
ZrT_2 ~ 0.26



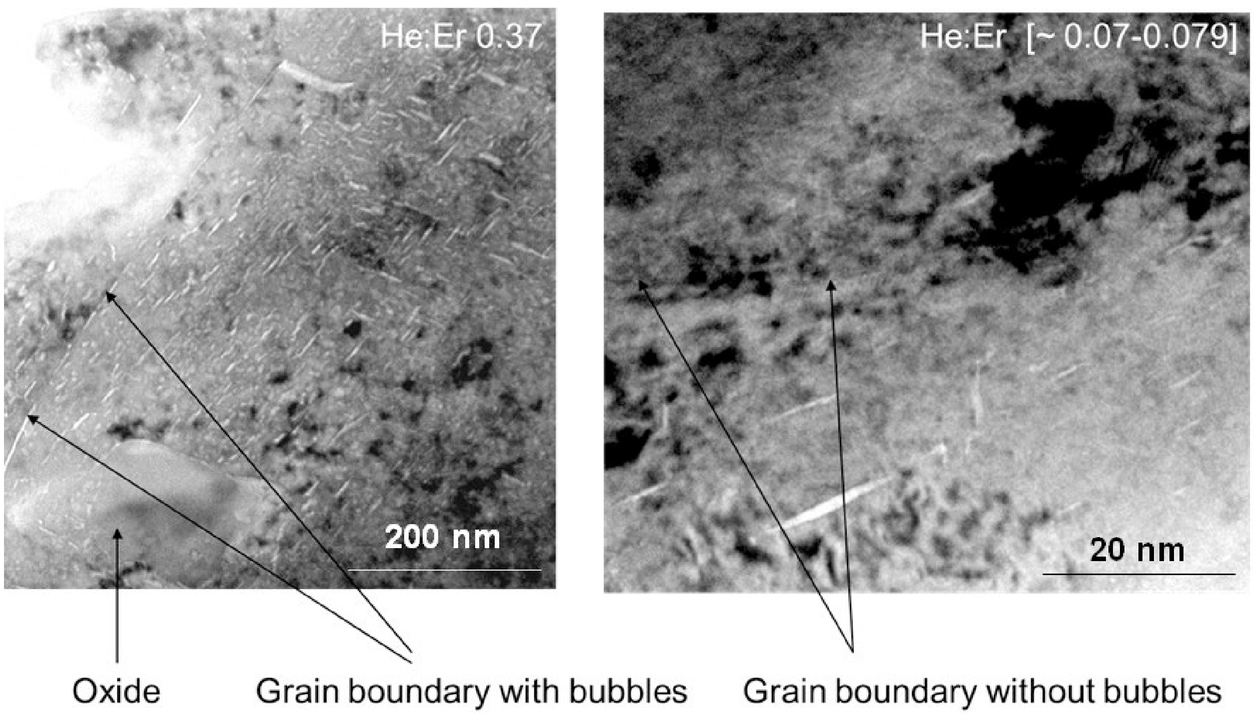
Theory work of Don Cowgill

Helium Bubble Spatial Distribution

Bubbles observed evenly distributed throughout film.

Grain Boundary decoration only when GB aligns along (111) plane

Bubbles observed around Er_2O_3 pieces.



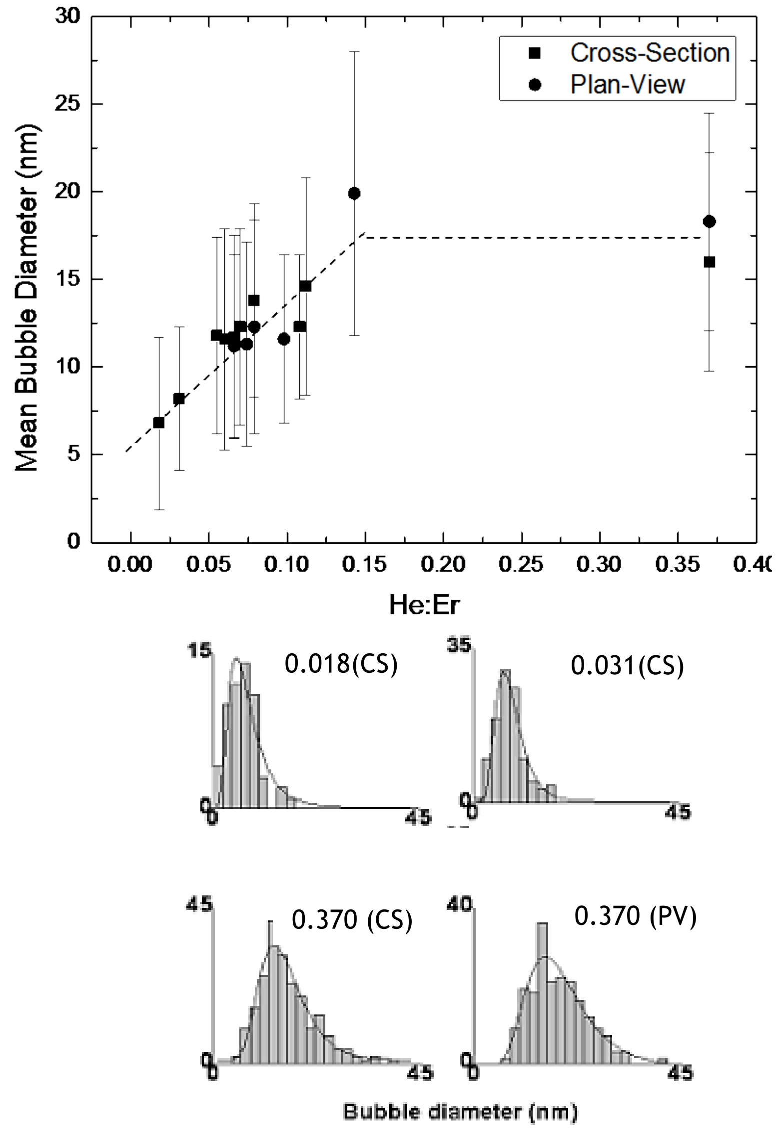
Helium Bubble Growth and Interactions I

Length increases with time up to He:Er ~ 0.15.

Width doesn't change until He:Er ~0.15.

Size distribution log-normal throughout life.

- Tight distribution early
- Larger distribution later



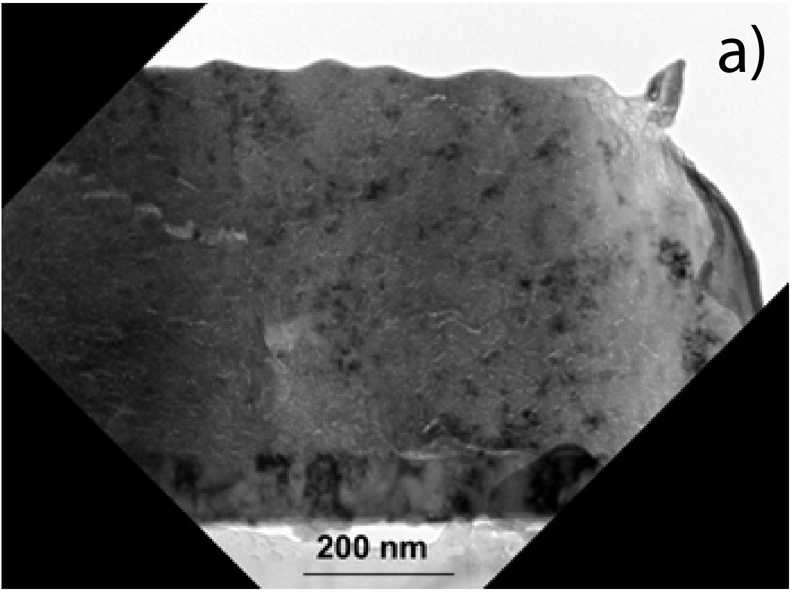
Bond et al., J. Appl. Phys. 107, 083514 (2010)

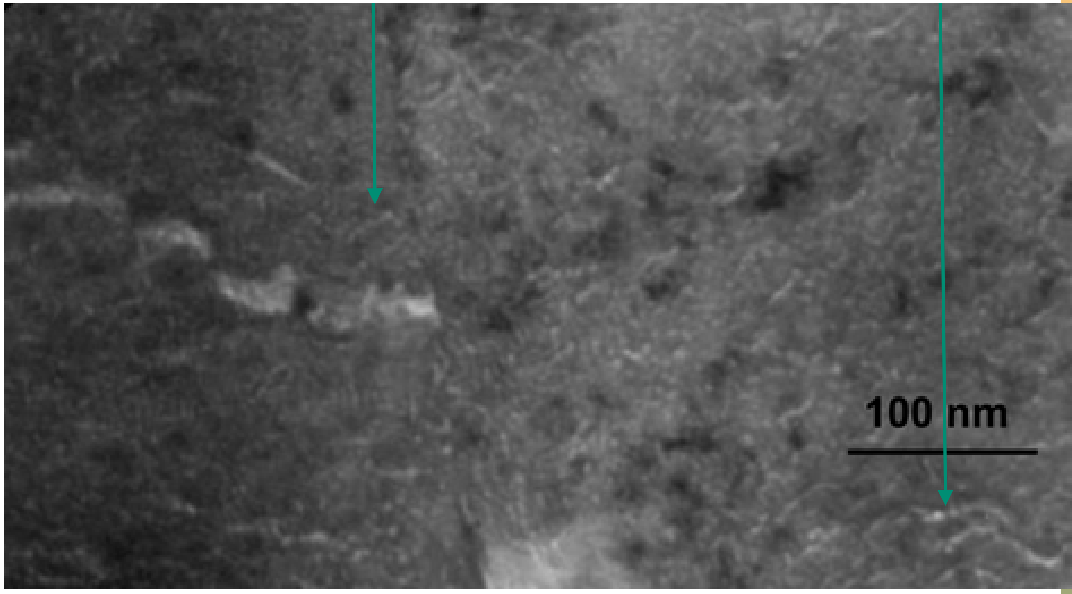
Helium Bubble Growth and Interactions II

Bubbles begin to link later in life.

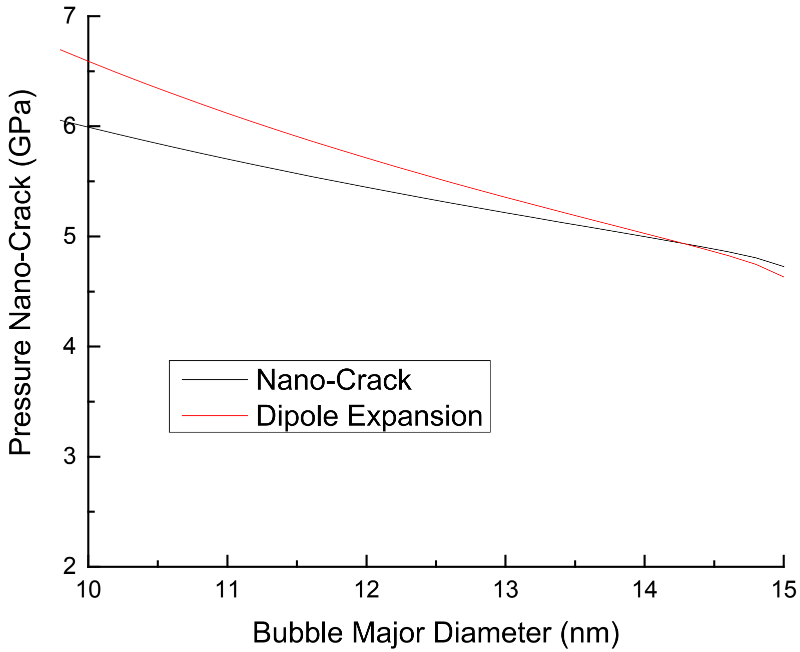
Length stops growing, width begins to increase.

Becomes very difficult to even define what is a bubble.





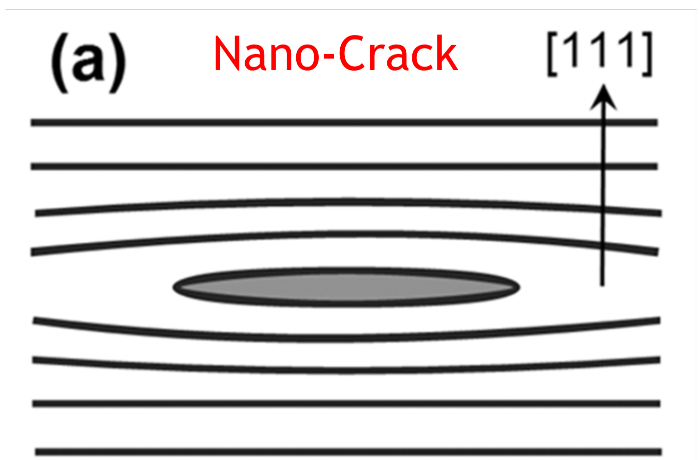
Helium Bubble Transition Point

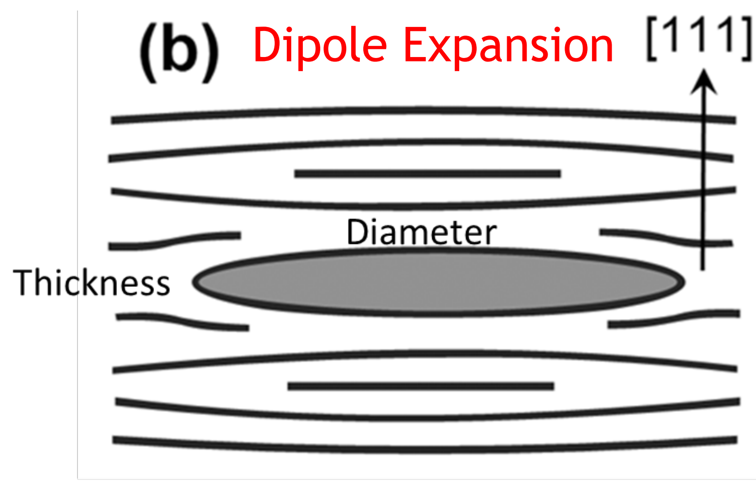


$$P_{Nano\_Crack} = \frac{\pi G m}{2(1-\nu)} \frac{s}{d}$$

$$P_{dipole} = \frac{2\gamma}{s} \frac{(d+b+s)}{(d+b)} + \frac{G_m d_{111}}{(d+b)}$$

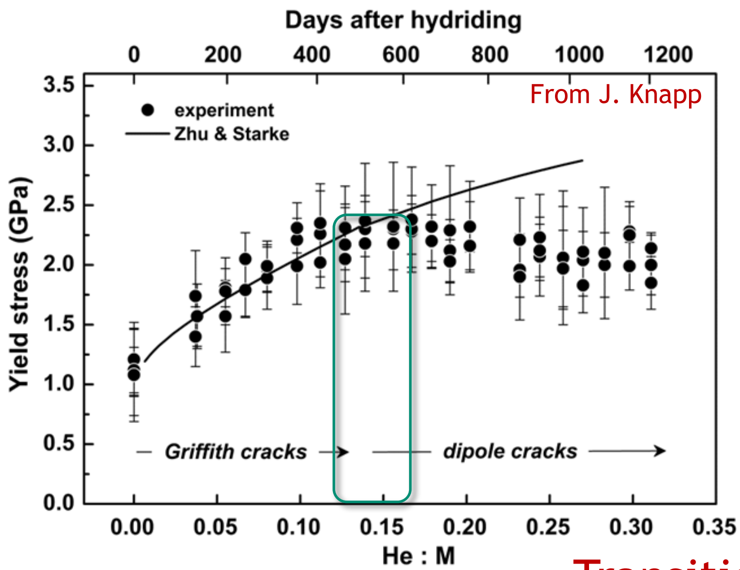
γ = Surface Energy
ν = Poisson's ratio
d = platelet diameter
s = platelet thickness
b = Burger's vector
d_{111} = 111 plane spacing
G_m = effective Shear modulus

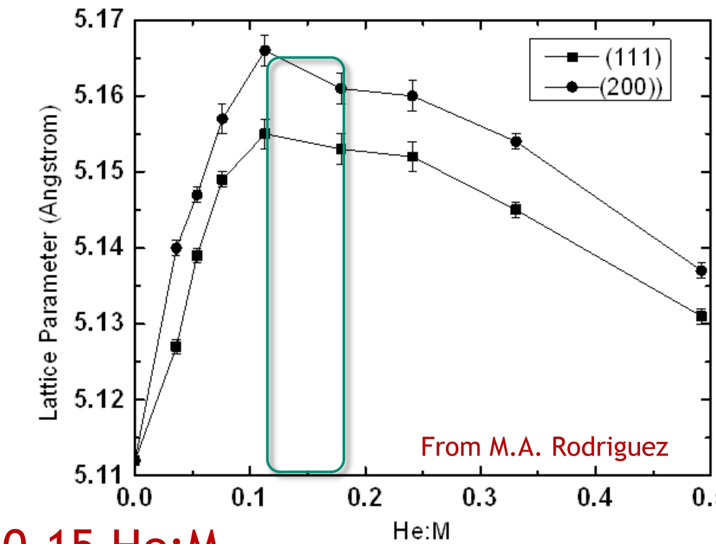




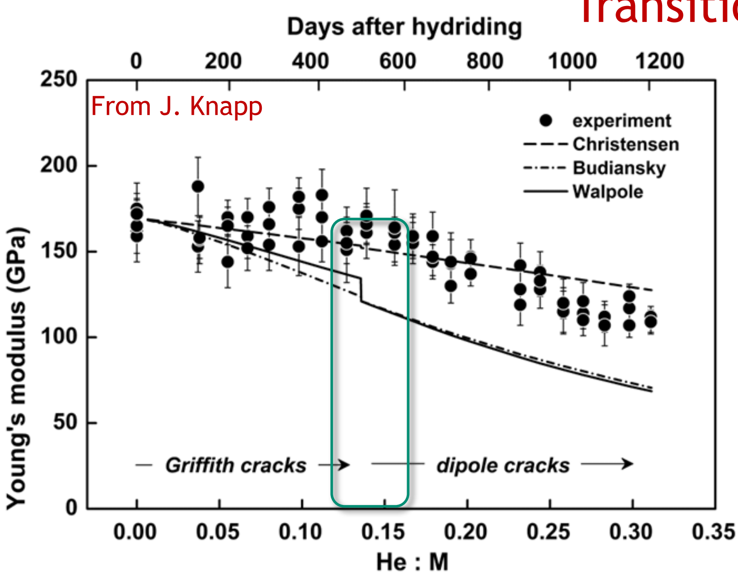
From D. Cowgill

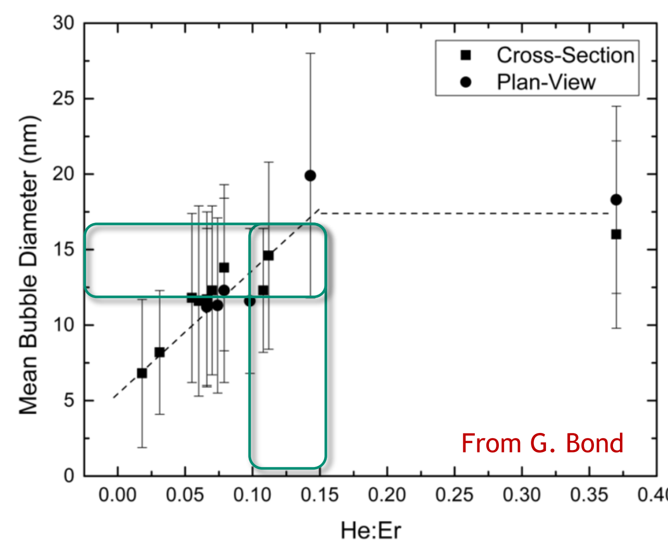
Evidence for Bubble Growth Model





Transition ~ 0.12-0.15 He:M





Helium Bubble Pressure

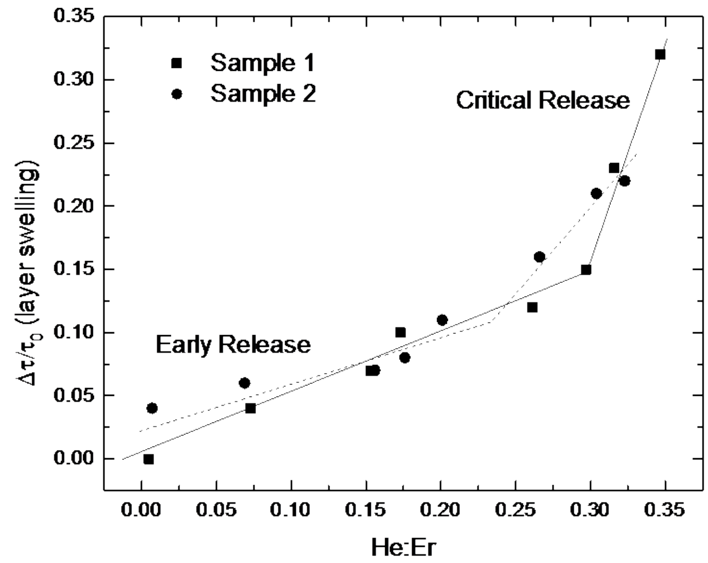
Pressure in bubble

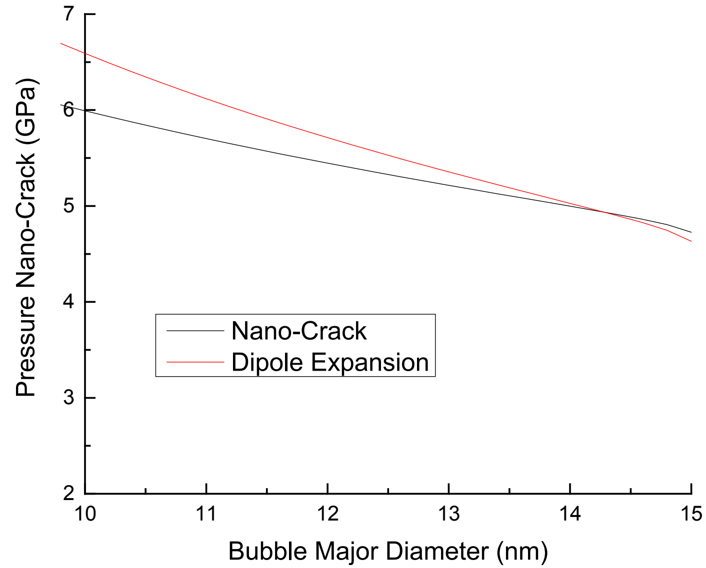
$$\frac{\Delta V}{V} = \frac{c_{T0} t\lambda\Delta vTHe}{\Omega}$$

- $\sim cT_0\, \lambda\, t\left[\left(\frac{v_{He}}{\Omega}\right) * \left(\frac{\Delta vI}{\Omega}\right) - \left(\frac{\Delta vT}{\Omega}\right)\right]$
- Ω = atomic volume (volume of the tritide per metal atom)
- v_{He} =volume required by 3-He in the high pressure bubbles
- $\Omega = \Omega_0[1 + cT({}^{\Delta v}/_{\Omega_0})_T]$
- Using EOS for 3-He can extract bubble pressure

Using Neutron Reflectivity to measure swelling P ~1-3 GPa

Models predict 5 GPa

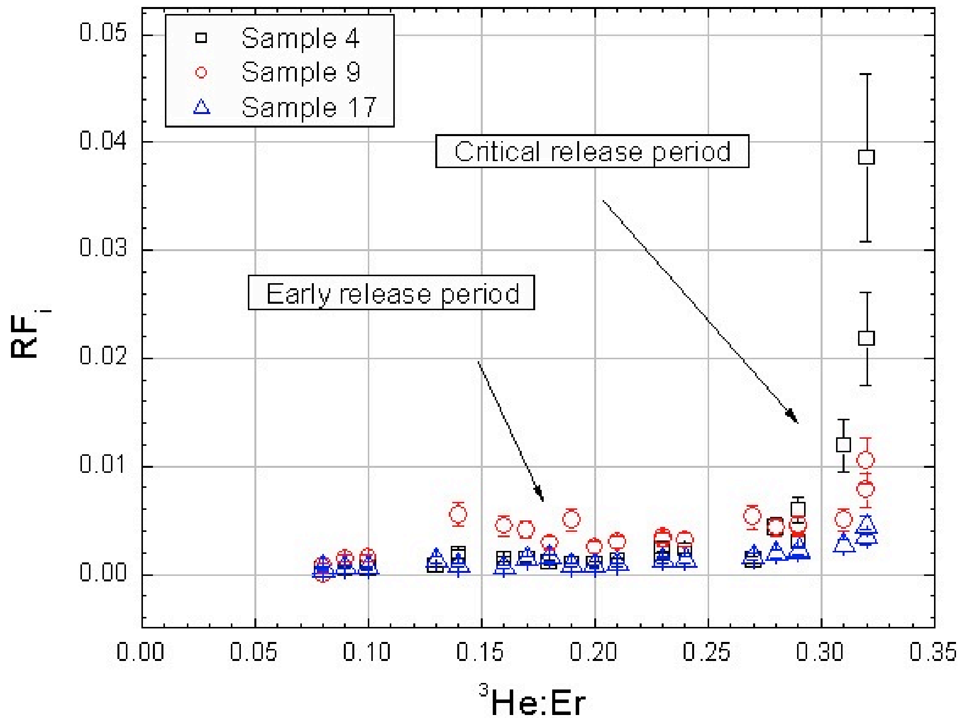


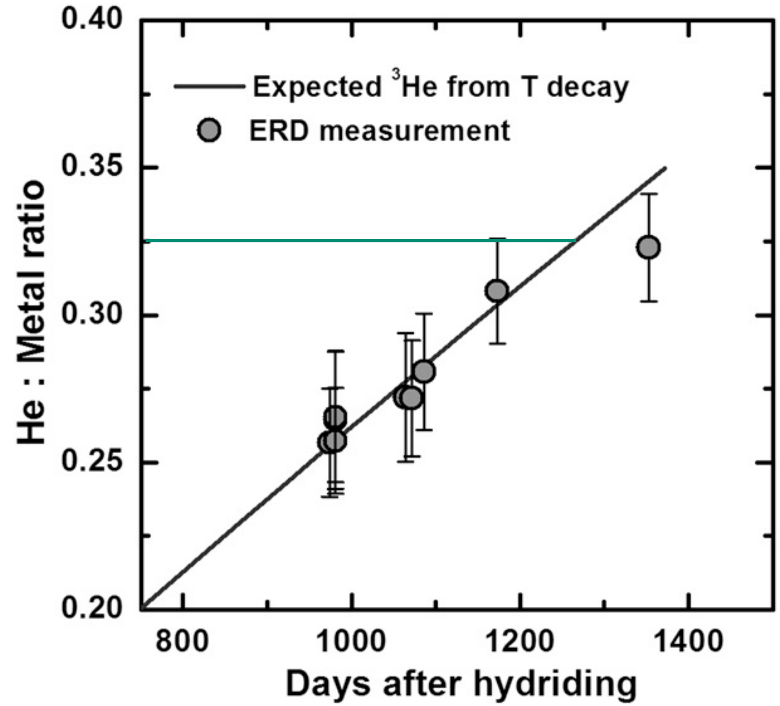


Helium Release

Early life helium storage ~100%.

Critical release occurs at He:M ~0.33



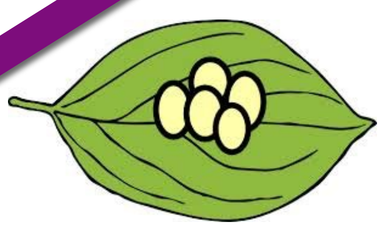


Conclusions and Further Questions

At ~0.33 He:M
“critical release”
then it dies

Nano-cracks

At 0.14 He:M growth mode transitions from nano-crack to dipole-expansion



Don’t know how the eggs get there.

Question: Is the self-trapping mechanism appropriate for stoichiometric metal tritides?