Flüssigmetalle als Wärmeträgermedium für CSP - Ein neuer Anlauf

Thomas Wetzel, Luca Maroco, Julio Pacio und KALLA-Team

Institut für Thermische Verfahrenstechnik, Institut für Kern- und Energietechnik

Requirements for a heat transport fluid (HTF)

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- **Extended temperature range**
  - **Low** melting point (to avoid or reduce auxiliary heating)
  - **High** upper limit in view of chemical stability
- **High thermal conductivity:** large heat transfer as single-phase liquid
- **Large heat capacity** would allow direct thermal storage in the HTF

- Low/moderate vapor pressure
- Low/moderate viscosity for pressure drop
- Compatible with structural materials (e.g. steel) at high temperatures
- No safety risk
- Operational experience
- Low/moderate costs

- No existing HTF fits all the requirements
- **Liquid metals are promising in some aspects, particularly upper T-limit and heat transfer capability**

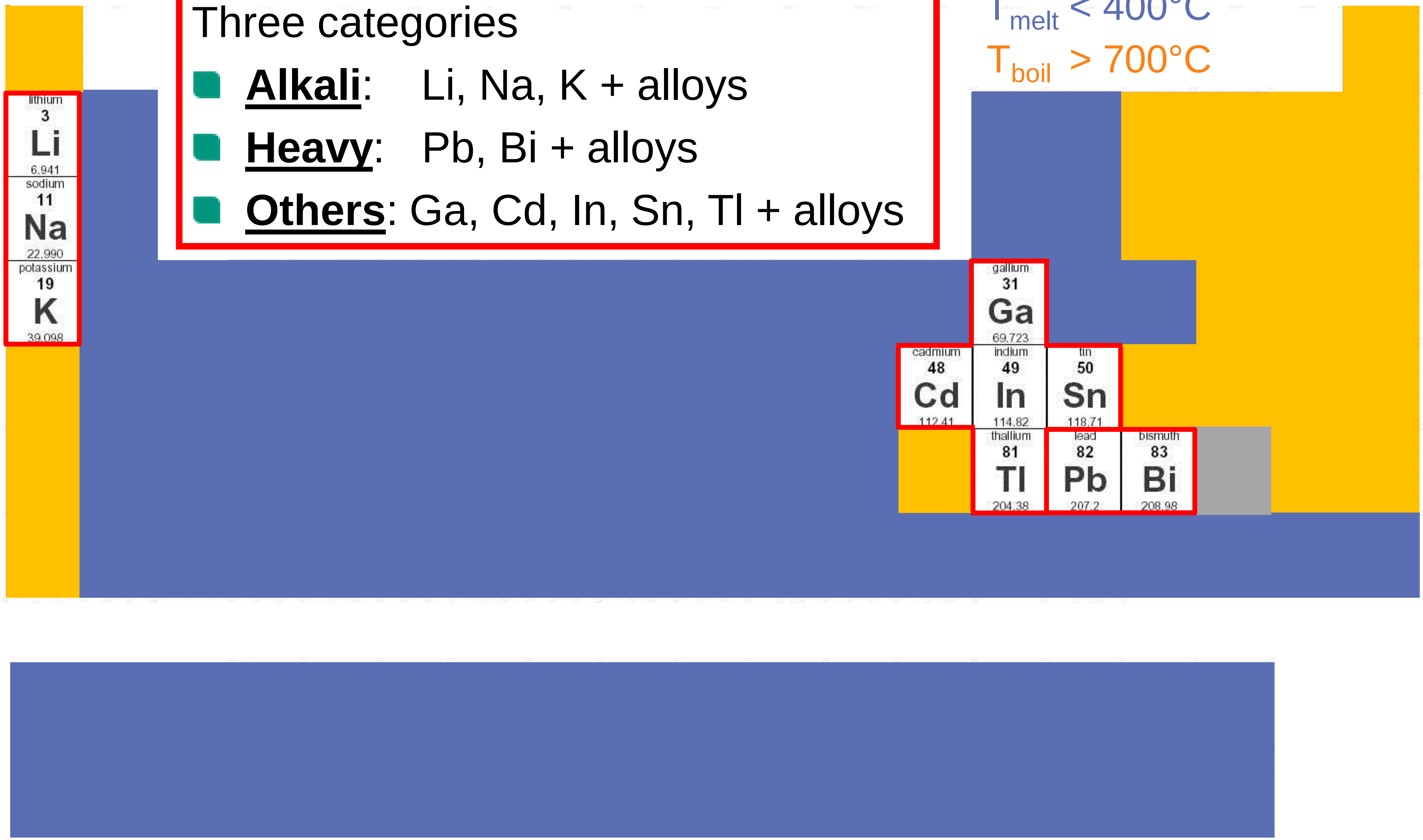
Which LMs? Screening of candidate materials

Three categories

- **Alkali**: Li, Na, K + alloys
- **Heavy**: Pb, Bi + alloys
- **Others**: Ga, Cd, In, Sn, Tl + alloys

T_{melt} < 400°C

T_{boil} > 700°C



Forseeable advantages and limitations of LMs

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- Physical properties evaluated at 1 bar, 550°C

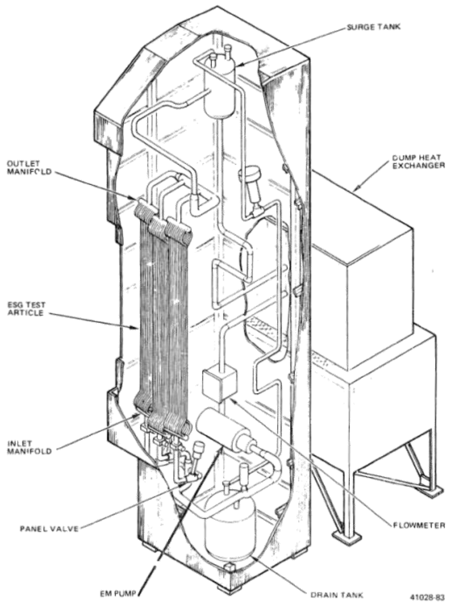
Fluid	Air	He	S. Salt	Na	LBE	Sn
Tmin, °C	<r.t.	<r.t.	220	98	125	232
Tmax, °C	n.a.	n.a.	565	883	1553	2687
λ, W m^{-1} K^{-1}	0.06	0.32	0.55	64.9	14.9	32.7
$\rho * c_p$, kJ m^{-3} K^{-1}	0.2	3.0	2675	1042	1415	1815

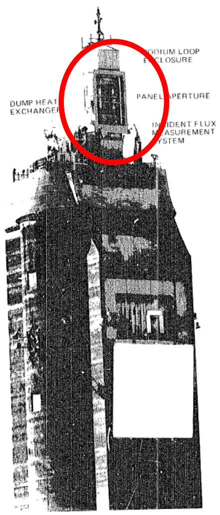
- Heat transfer coefficients at 750°C, 1 bar, u=5 m s^{-1}, D = 15 mm

Fluid	Air	He	S. Salt	Na	LBE	Sn
α, W m^{-2} K^{-1}	20	105	-	47724	24676	38572

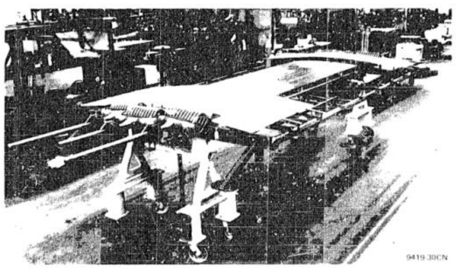
LMs (Na) were tested in CSP in the 1980s

USA: Sandia CRTF

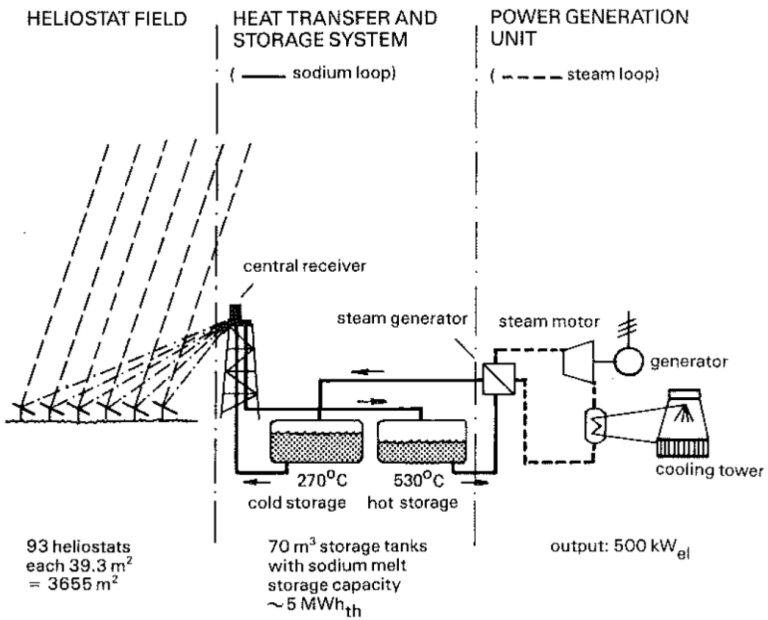




- Only receiver
- 750 liters
- 70 hours



Europe: PSA (E, D)



- Complete plant
- 70 000 liters
- 5 years

Very good thermalhydraulic results

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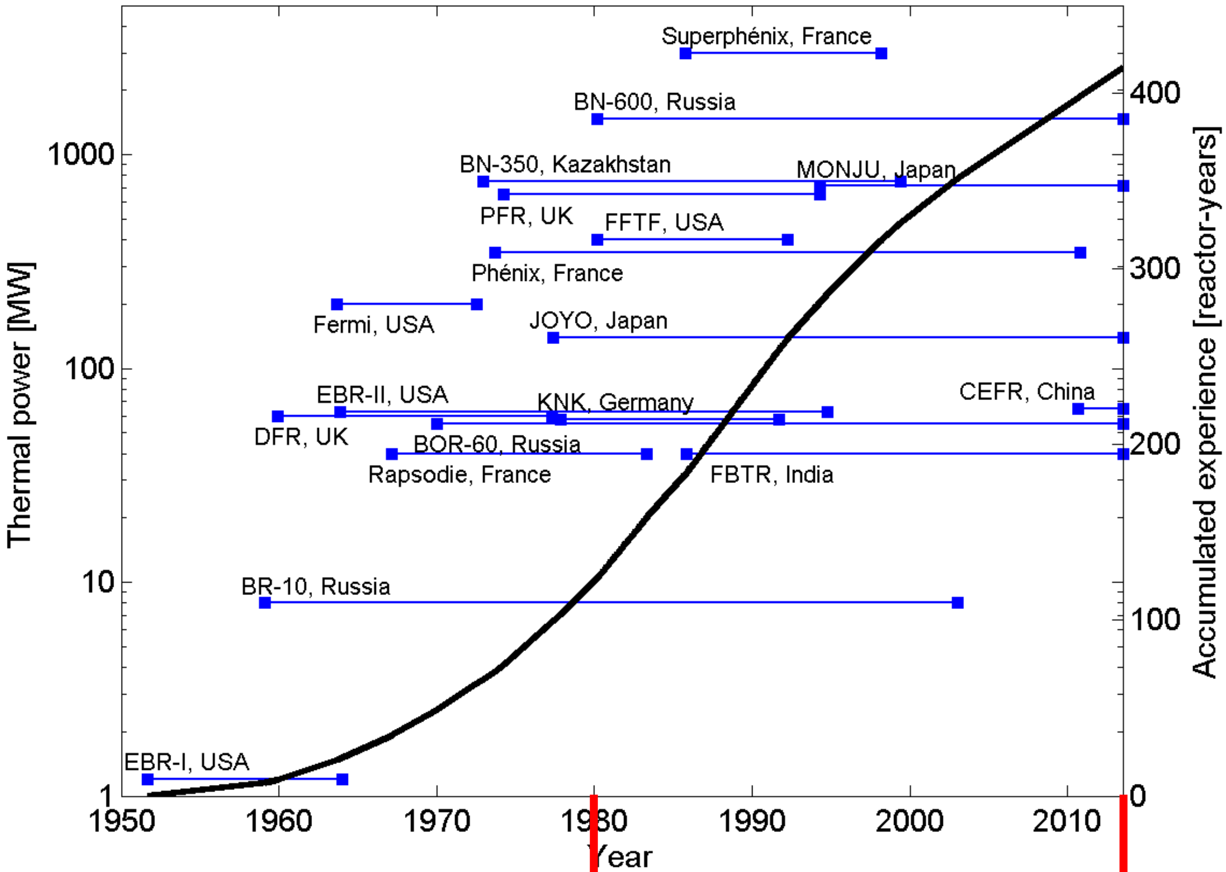
Test facility	CRTF (US)	PSA (E)	PSA (E)
Type	External	Cavity	External
Developer	Rockwell Intl. (US)	Interatom (D)	Samprogetti (I)
Manufacturer	Rockwell Intl. (US)	Sulzer (CH)	Tosi Industriale (I)
Test period	Oct1981 – Mar1982	1981-Apr 1983	1983-1986
Power, MW	2.5	2.5	up to 3.5
Peak heat flux, MW m^{-2}	1.53	1.4	2.5
Measured efficiency	90-96%	88%	92%
T inlet/outlet, °C	288 / 593	270 / 530	270 / 530
Aperture area, m^2	-	9.7	
Absorber area, m^2	[illegible].6	17	8.32
Thermal losses, kW	?	5[illegible]	230
Tube diameter, mm	21.4	?	14
Tube wall thickness, mm	1.2	?	1.0
Tube material	316 SS	316 SS	316 SS

And still: Development stopped!
For 28 years now!
Stopped completely?

LMs since the 1980‘s: much more experience



- **1980**: 122 RYs
- **2013**: 411 RYs

- Na - nuclear reactors
  - Experimental
  - Prototypical
  - Commercial
  - 6 in operation
  - 2 u. construction
- Operating licenses
- LM is not only Na!
  - Pb – PbBi
  - Sn
- Extensive R&D on LM **coolant technology**

LM science, experience and know-how at KIT

- Lead, Lead-Bismuth, Indium-Gallium-Tin, Sodium, Sodium-Potassium, Tin
- *Experiments and Simulation*
- *Material issues (corrosion protection)*
- *Experience on liquid metal technology: pumps, heat exchangers, instrumentation, operation and control safety*
- > 30 years experience, leading partner in European LM research

EURATOM THINS SEARCH HELMHOLTZ | ASSOCIATION

MAXSIMA MARISA LIMTECH Alliance

From laboratory scale…

COSTA: COrrosion test stand for STagnant liquid lead Alloys

- Operative since 1997
- Pb, Pb-Bi, Sn
- Equipped with O_2-control
- Influence of protection layers and coatings on corrosion

CRISLA: Creep-to-Rupture In Stagnant Lead Alloys

- Operative since 2007
- Pb or PbBi at max. 650°C
- Equipped with O_2-control
- Impact of liquid-metal environment on creep performance

… to prototype dimensions

KALLA: KArlsruhe Liquid Metal LAboratory

- Operative since 2002
- PbBi loops **THESYS** and **THEADES** (No. 1 in Europe), Na loop **ALINA**, InGaSn loop GALINKA, corrosion loop **CORRIDA**, etc.
- Research on liquid metal (low Pr-Number) thermal hydraulics, for both bounded and free surface flows

KASOLA: KArlsruhe SOdium LAboratory

- Operative in 2014
- Two versatile test sections
- Supporting facilities (HEMCP)
  - ATeFa: AMTEC Test Facility
  - SOLTEC: SOdium Loop for liquid metal TEChnology

Example: THEADES LBE loop at KALLA

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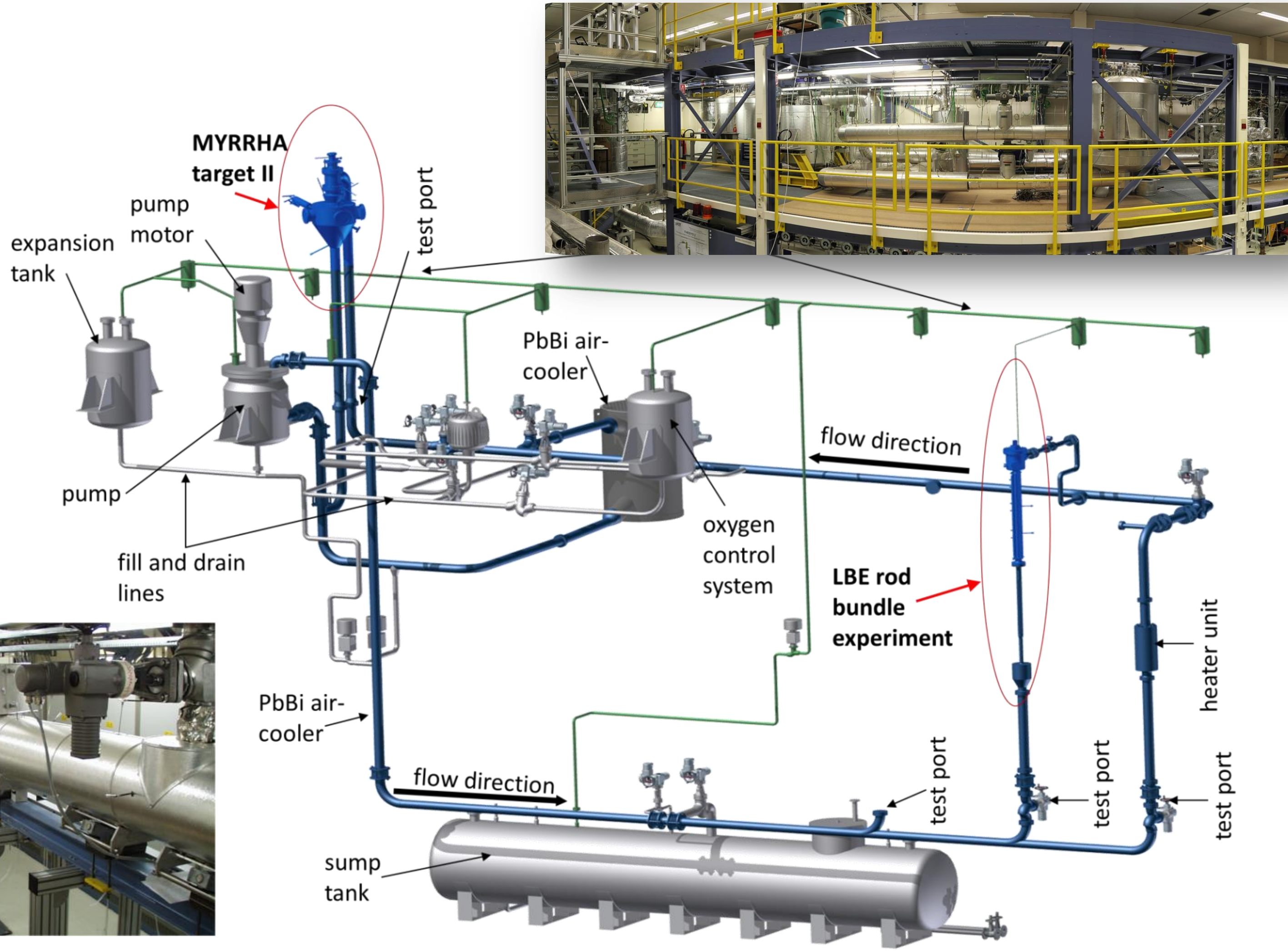
190°C - 450°C

42 m³/h

10 bar

4 m³ / 44 t

1 MW_{th}



Liquid Metals (LM) for CSP: Research topics

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- LM compatible CSP system **components**:
  - Receivers, pumps, heat exchangers, instrumentation, …
  - SOMMER@KALLA under construction
- **Material** compatibility at high temperatures
  - Pb/PbBi > 550 °C: corrosion prevention …
  - Na > 700 °C: Filtering and cleaning
  - Sn: Graphite, Molybdenum, …?

TELEMAT 750 °C corrosion facility just completed

- Alkali Metal Thermal Electric Conversion **AMTEC** as topping system?
- Thermal **storage** for 24/7 operation
  - Direct storage unlikely due to high price and low heat capacity
  - Indirect storage with exchangers etc. are needed

Ongoing R&D activities in Germany

DLR

KIT Karlsruhe Institute of Technology

HELMHOLTZ | ASSOCIATION

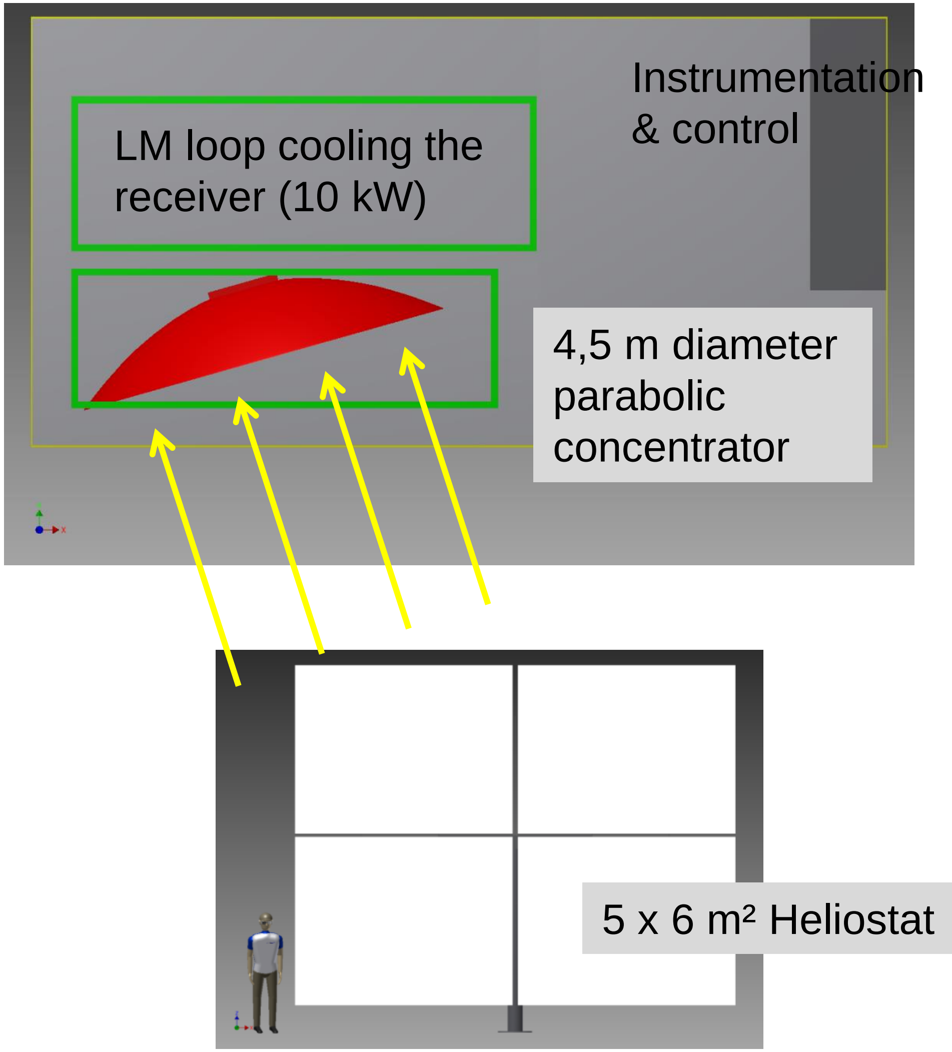
LIMTECH Alliance

- **HELMHOLTZ Alliance LIMTECH** 2012 - 2017
- **HELMHOLTZ Research Program** 2015 - 2019

- DLR and KIT combining their specific expertise
  - KIT: Coolant technology, for LBE, tin and sodium
  - DLR (German Aerospace Center): solar-specific know-how

- Main objectives
  - **Evaluation** of utility-scale LM-CSP plants, up to LCOE
  - **Materials and technology** (re)development
  - Receiver and system **tests at small scale** (~10 kW) until 2016
  - Receiver **tests at pilot scale** (~ 100 kW) until 2019

SOMMER @ KALLA



SOlar furnace with **M**olten **ME**tal cooled **R**eceiver

Vielen Dank für Ihre Aufmerksamkeit!