A few lessons learned from the Lycnean CLS

Rod Loewen

Oct 10, 2023

Lyncean Technologies, Inc. (dissolved mid-2022)

Lyncean (Lin-see-uhn), a. keen-sighted,
The Lynx was once believed to have incredible powers of vision. The word's origin likely comes from the mythological Lynceus, the helmsman of Jason's Argo, who was renowned for his sharpness of sight and could even see things that were underground.

SLAC

Prof. Ron Ruth

Dr. Rod Loewen

Founded in 2002 by Prof. Ron Ruth, Dr. Rod Loewen and Jeff Rifkin to develop and commercialize the Compact Light Source

2002
LTI
Founded

2005
First
Stored
Electron
Beam

2006
First X-rays
Observed

CLS development was funded through $29M of NIH grants (+ 1 DOE award)

2009
First X-ray
Application
Publication

LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN LMU

2012
First
Purchase
Contract

TUM TECHNISCHE UNIVERSITÄT MÜNCHEN

2015
First
Installation
@ TUM

Munich CLS has been in continuous operation with only 1 unscheduled maintenance visit since April 2015

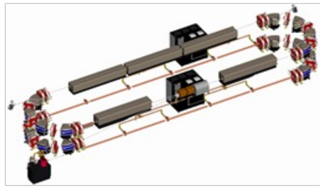
xradia™ ZEISS

Dr. Michael Feser

Jack Kasahara

2016
Dr. Michael
Feser
Hired as
CEO

2017
EUV Source
Patent
Filed



Chris Juan

2018
$21M Series B
Financing

intel

Jay Chen

2019
€49M
contract to
build gamma-ray source

eli nuclear physics

lyncean TECHNOLOGIES, INC.

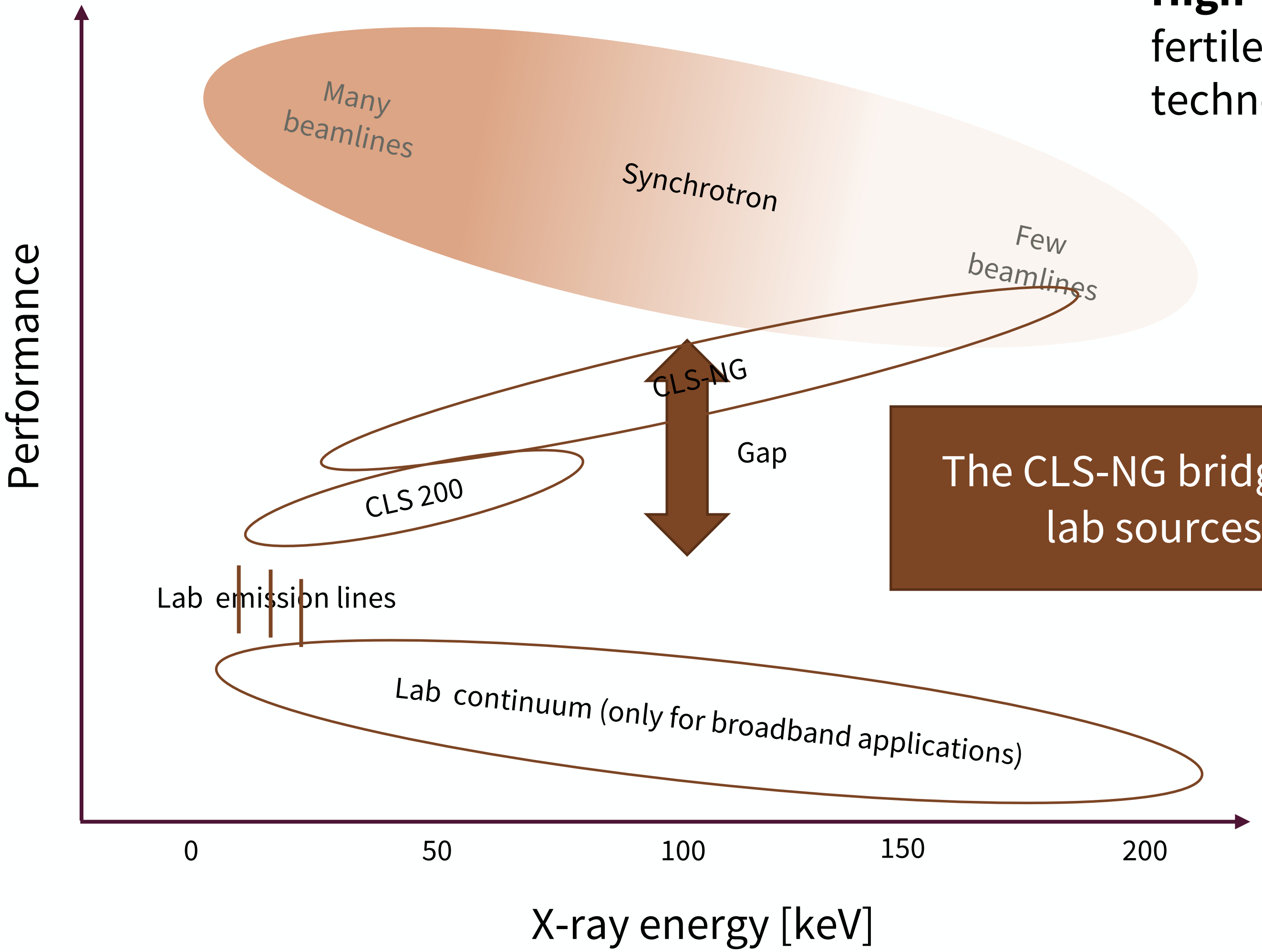
'Best' design for CW ICS source

- Storage ring and optical cavity work at tens of MHz rep rate. Good idea.
  - MuCLS source (still alive!) shows that a "first generation" storage ring source is productive
- Design a storage ring with low emittance to improve performance
  - Go to high enough energy to get radiation damping ~ **>50MeV**
  - Use top-up injection to increase and control stored beam current
  - Use 'long' bunches to reduce intrabeam scattering for high charge (benefit of backscatter)
- Design optical cavity to handle average power (~1 MW should be OK)
  - High finesse cavities demonstrated with >10,000 gain
  - Use frequency stabilized laser sources in MOPA configurations to get to ~100W
  - Laser development at other wavelengths, such as holmium/thulium at 2 μm will lower x-ray energy accessibility while maintaining good electron beam energy
- Even if engineering all of this technology well, synchrotron storage rings will always outperform ICS sources on the scale of ~10 keV photons.

What a Next Generation (NG) CLS might look like

- The technology exists to develop a next-generation CLS with significantly different performance capabilities aimed for hard X-rays
    - Technology improvements originated from the CGS (gamma-ray) development from Lyncean’s (now defunct) contract with ELI-NP
    - “Low risk” technology implementation is misleading. It’s still an engineering exercise that requires niche expertise in accelerator and laser science.
- Assessing the value of this new concept – is it worth the cost and effort?
    - Does it open up new application spaces?
    - Can a science case be developed?
        - Widens the gap between lab source and CLS
    - Can a business case be developed?
        - Without something to drive the technology, it will be a difficult road to realize

The X-ray source landscape

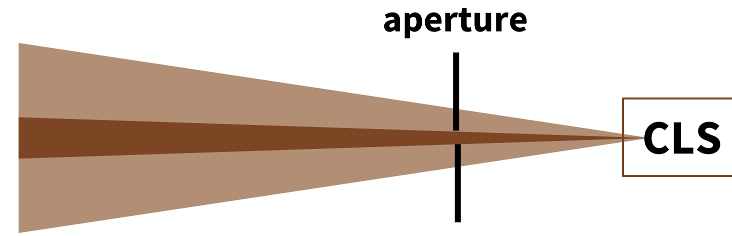


High-energy X-rays may be a fertile ground to differentiate ICS technology development

The CLS-NG bridges the gap between traditional lab sources and synchrotron facilities

A concept for the Next Generation CLS

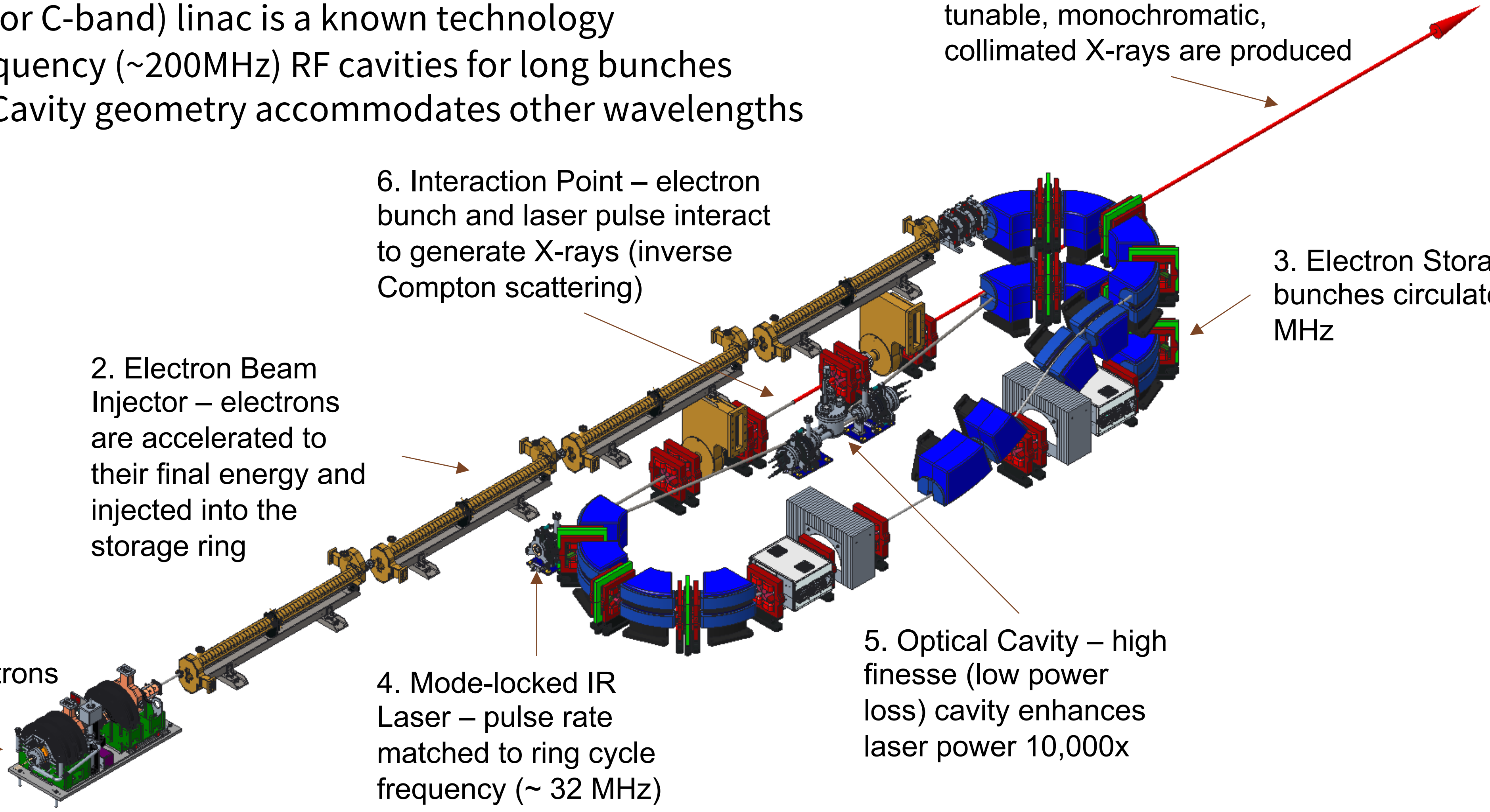
- The concept for the next generation CLS has been developed
  - Higher energy electron beam allows lower emittance and higher storage ring current
  - Lower emittance and more parallel beams provide lower divergence and narrow bandwidth X-rays
- Features of the next generation CLS are
  - **X-ray energy is significantly higher** → up to 180 keV
  - **Significant brightness increase benefits a wide range of applications**:
    - Use the central beam with narrow bandwidth for high energy focused beam applications
    - Use the full divergence beam for imaging applications with large FOV



	MuCLS	~~CLS-200~~	Next Gen CLS Concept			
Stored electron energy (max)	45 MeV	~~45 MeV~~	~100 MeV			
Optical cavity wavelength	1 µm	~~1 µm~~	2 µm		1 µm	
X-ray energy range (keV)	15 – 35	~~8 – 42~~	~30 – 90		~60 – 180	
Brightness (1/s mrad^2 mm^2 0.1%BW)	~1 x 10^{10} @ 35 keV	~~~1 x 10^{11} @ 35 keV~~	~1 x 10^{13} @ 90 keV		~1 x 10^{13} @ 180 keV	
Bandwidth (FWHM)	3 - 5%	~~3 - 8%~~	1.5 - 2.5%	6 - 15%	1.5 -2.5%	6 - 15%
Divergence (mrad)	4	~~6~~	1	4	1	4
Flux @ max energy (ph/s)	~3 x 10^{10}	~~~3 x 10^{11}~~	~1 x 10^{12}	~1 x 10^{13}	~1 x 10^{12}	~1 x 10^{13}

A Next Generation Compact Light Source

- S-band (or C-band) linac is a known technology
- Low Frequency (~200MHz) RF cavities for long bunches
- Optical Cavity geometry accommodates other wavelengths



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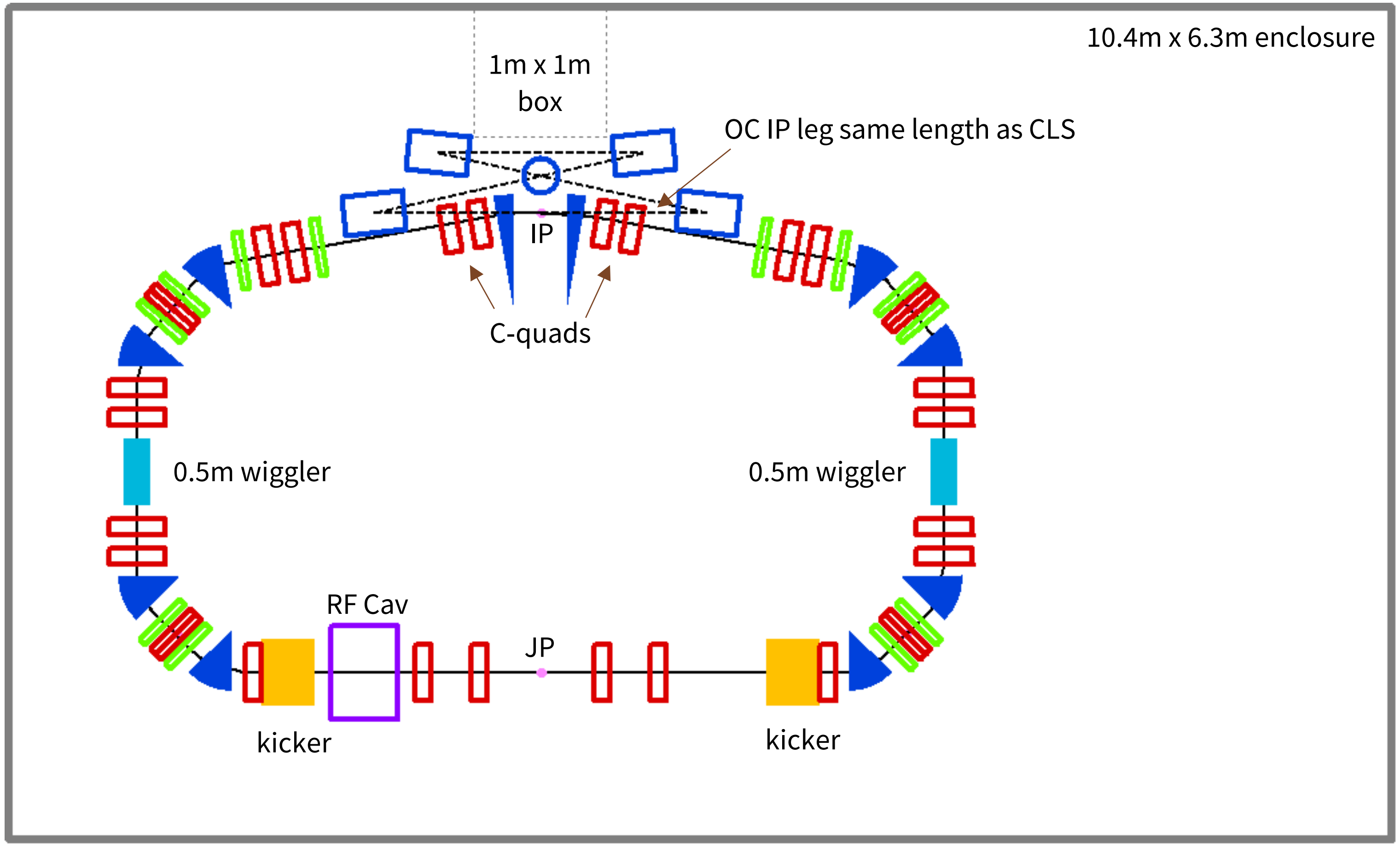
Another geometry to allow damping wigglers



A Next Generation CLS opens up a new application space

- High brightness, monochromatic, tunable high energy
  - Provides capabilities that can only be found at a handful of synchrotron beamlines
  - High flux density at high energy is ideal for micro-CT of materials science samples
  - Supports the growing demand for high energy, high resolution diffraction
  - Tunable energy enables elemental contrast imaging techniques for higher-Z (atomic number) samples
  - Facilitates spectroscopy experiments on actinides, lanthanides and heavier transition metals
  - Enables millisecond time scale dynamic measurements
  - Establishes a platform for novel radiotherapy research
    - Can be designed to fit in a conventional radiotherapy vault to transition to a clinical environment

A cautionary tale, but try to find a win-win partnership

- ICS sources sound good, but there is a lot of know-how in <u>making</u> the source
- There are few (maybe no) viable businesses in this market
  - One reason is that the technology is expensive, slow to develop, and there has been no industrial <u>needs</u> that can justify the cost
  - Another reason is the significant investment in the infrastructure and personnel to maintain and support the machine by the users
  - And last but not least, large national labs subsidize the development and use of synchrotrons to a worldwide community. This is a barrier for 'boutique' ICS light sources.
- The <u>advantage</u> of an ICS source as a stepping stone to AfLS source
  - Educational opportunity to learn technologies associated with synchrotrons
  - Ability to <u>partner</u> with a university or laboratory program to share development successes and costs. Be a "learning partner" !