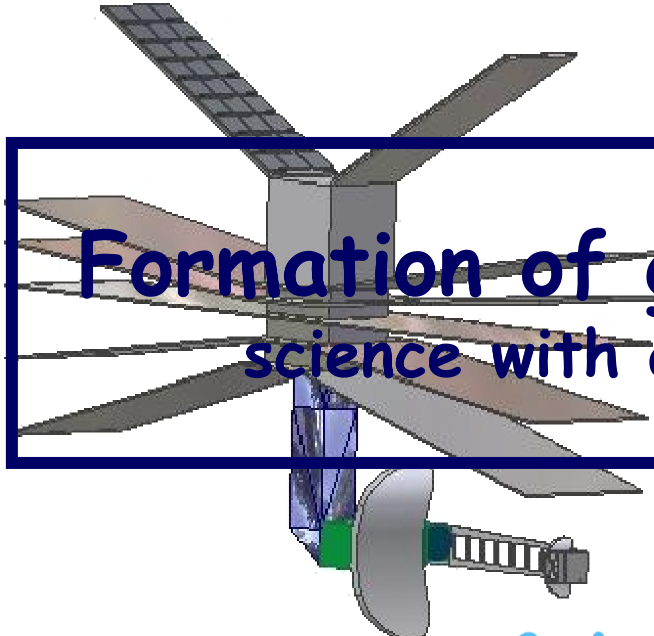

Formation of galaxies, stars and planets:

science with a future far-IR mission (FIRM)

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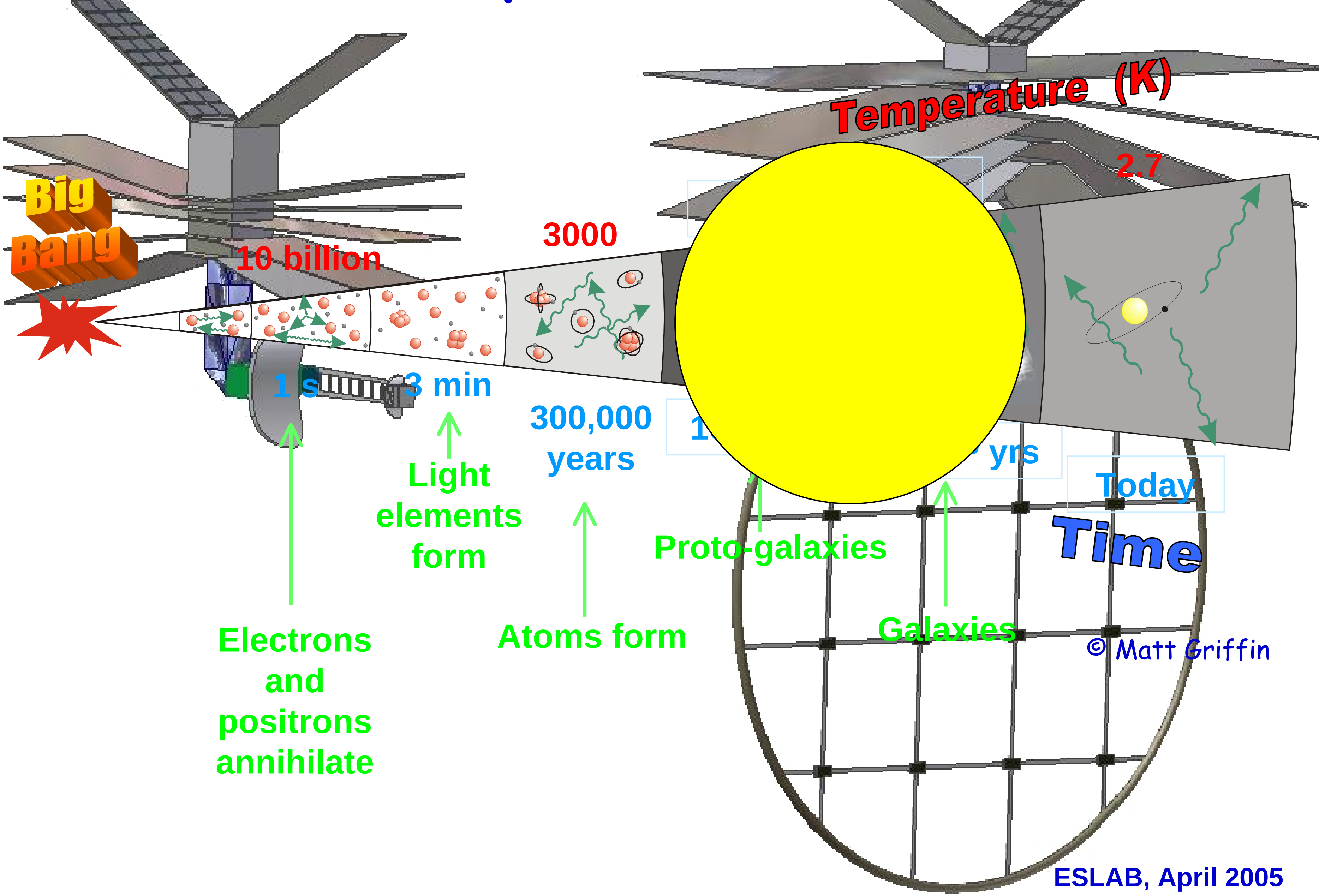
UK Astronomy Technology Centre

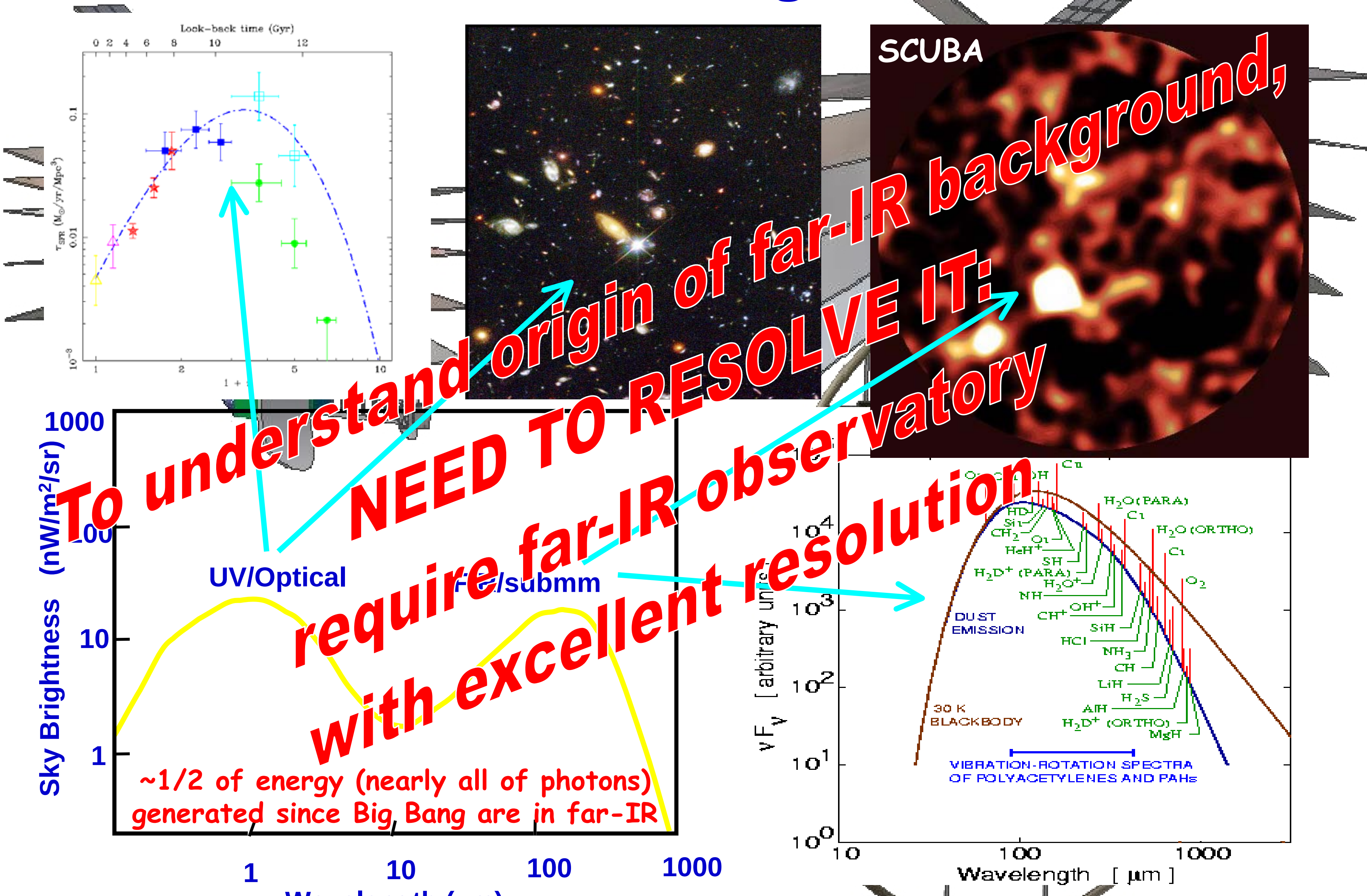
Institute *for* Astronomy

ESLAB, April 2005

History of the Universe

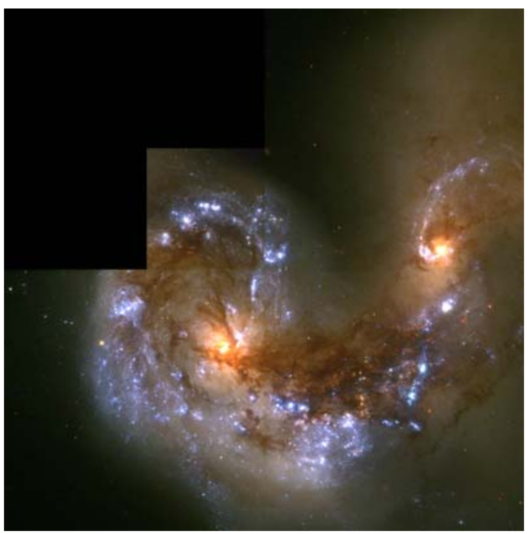


Cosmic Backgrounds



Key questions about galaxy formation

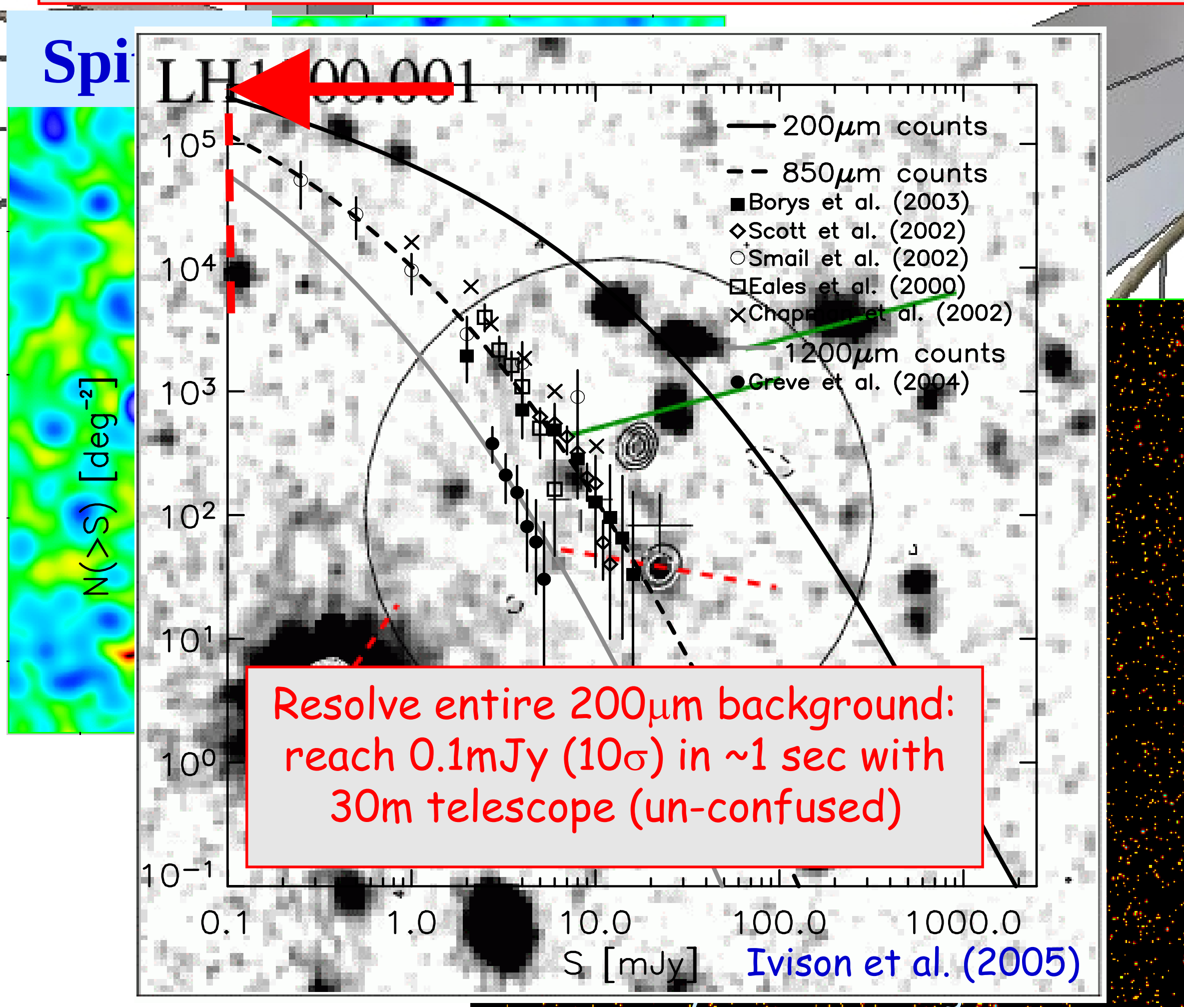
1. When and how were galaxies like our own assembled?
2. What were the first luminous objects?
3. What role do AGN play in galaxy evolution?
4. Chemical history: when/how did heavy-element production occur? (when might life have become feasible in a galaxy such as ours?)
5. How did structure evolve from the big bang to the present day?



Key observational goals in galaxy formation

I. Resolve far-IR background at its peak (200μm)

Detailed, unbiased study of entire zoo of galaxies



Resolve entire 200μm background: reach 0.1mJy (10σ) in ~1 sec with 30m telescope (un-confused)

Current submm surveys resolve *some* of background into discrete galaxies.

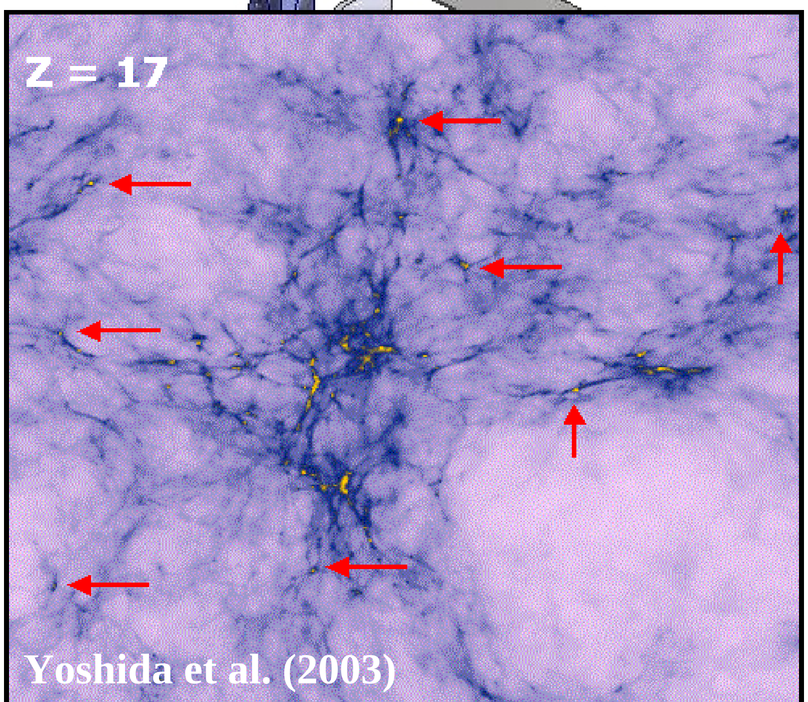
Progenitors of all but the most massive galaxies are below current confusion limit.

Redshifts, luminosities, knowledge of physical and chemical nature -> **high spatial and spectral resolution!**

Key observational goals in galaxy formation

II. First Light

Detect the very first stars as they formed

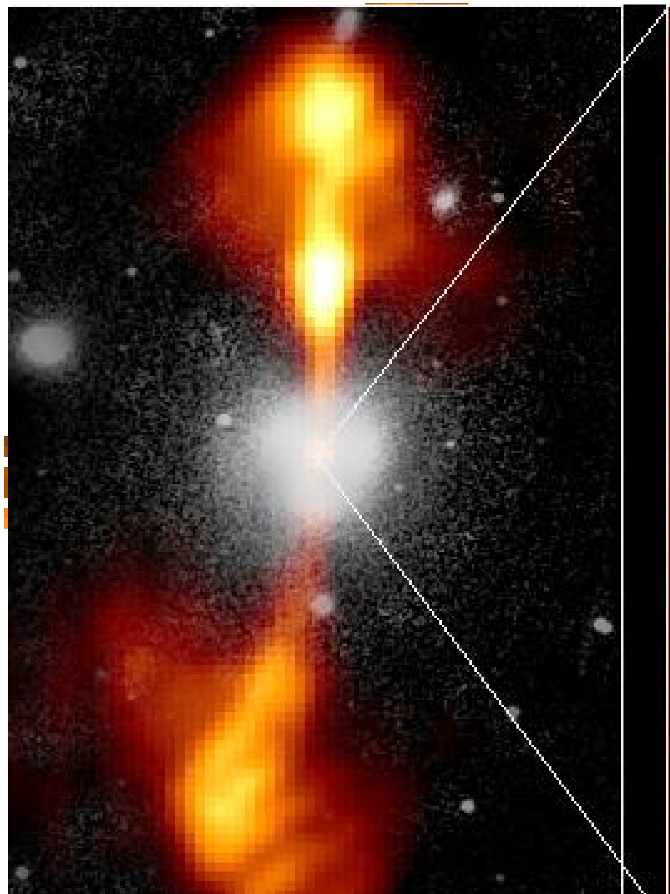


- First objects formed from clouds of primordial gas (H, He)
- Condensing gas cooled by rotational H_2 transitions (6.9, 8.1, 9.6, 12, 17, 28μm)
  - **H_2 lines shifted to far-IR for z ~ 10-20**
  - **unique signature of first collapsing objects**
- First stars enrich proto-galactic gas with first heavy elements
  - profound influence on future galaxy/star/planet formation

Key observational goals in galaxy formation

III. Determine role of black holes in galaxy evolution

SDSS0756

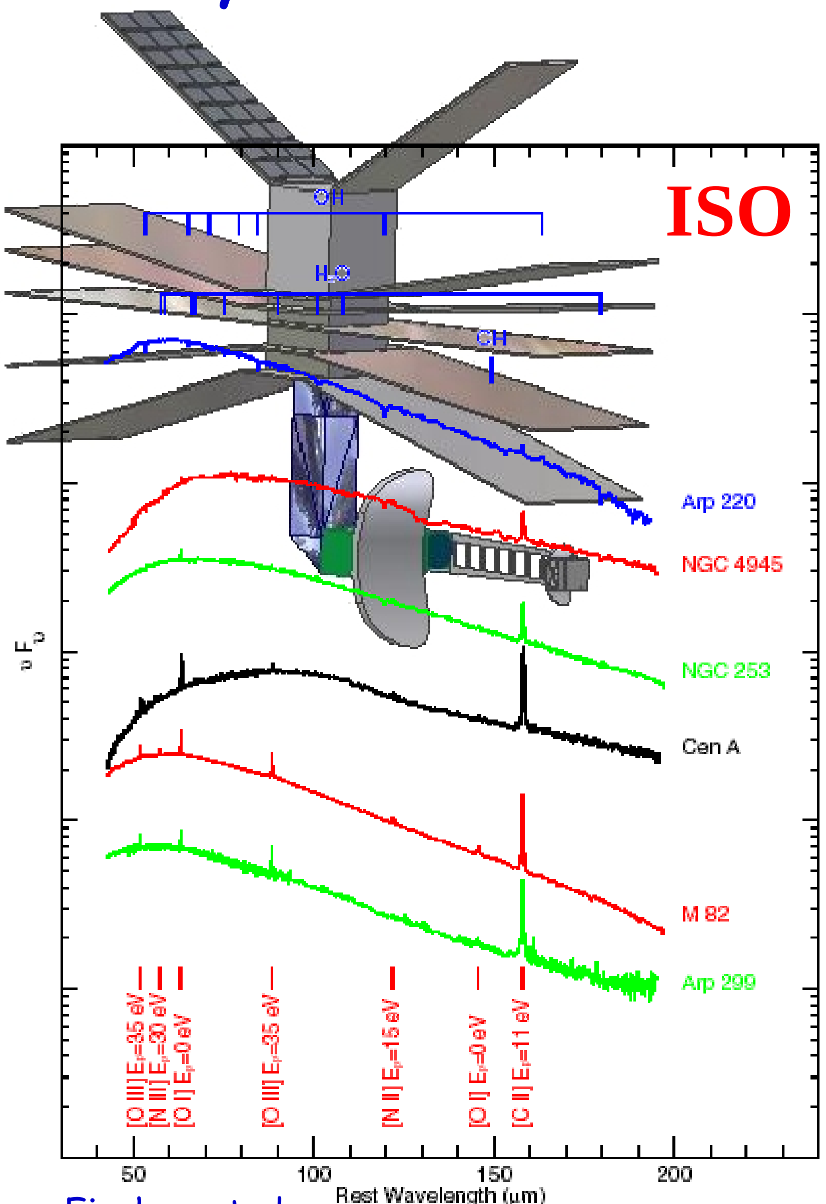


- Accretion hidden by Compton-thick gas, and by dust
- Complementarity with Xeus
- Only detectable in far-IR (and hard X-rays)

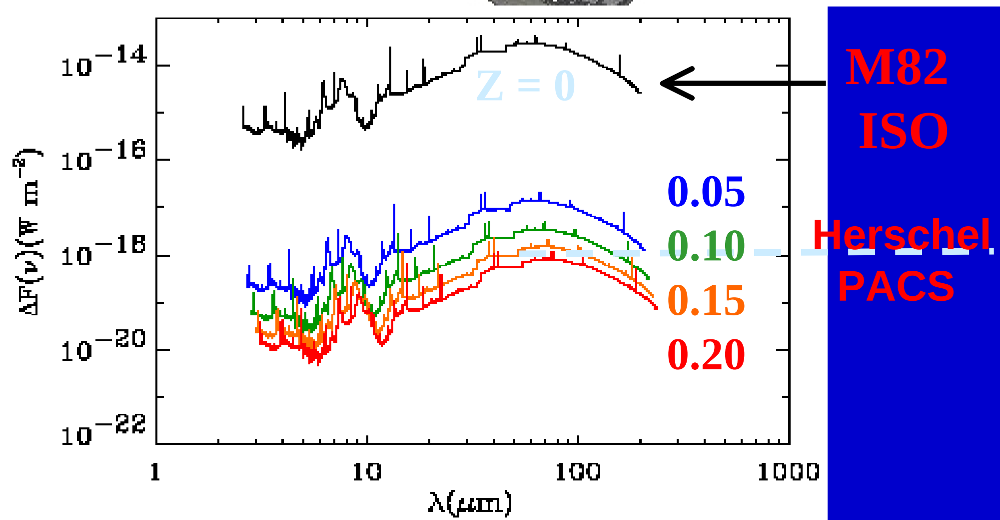
Test unified model for AGN with ~1" resolution: spectra of H_2, CO etc. at 10-300μm, to reveal dense torus

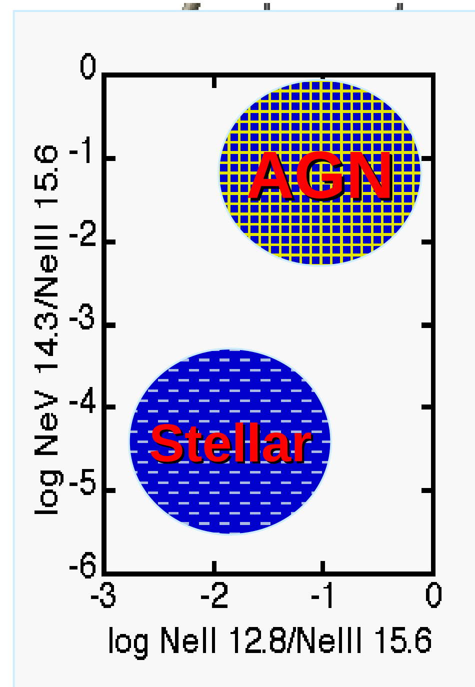
SCUBA

Key observational goals in galaxy formation



Fischer et al.





Power source:

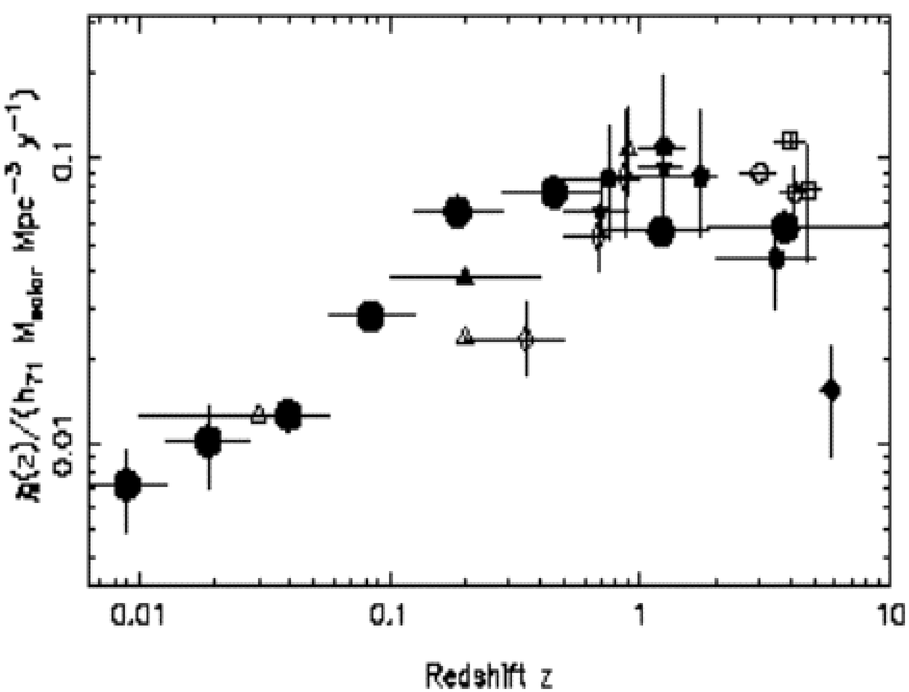
Fine-structure line ratios tell us whether *star formation* or *accretion onto black hole*

Key observational goals in galaxy formation

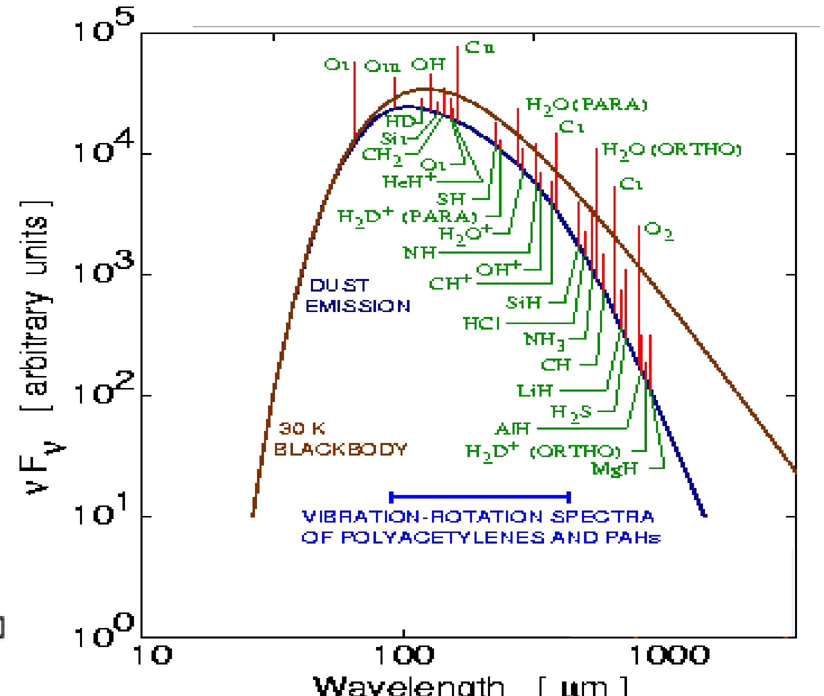
IV. Unbiased chemical history

Measure history of star formation and track the build-up of heavy elements in unbiased way

Star-formation history



Chemical history

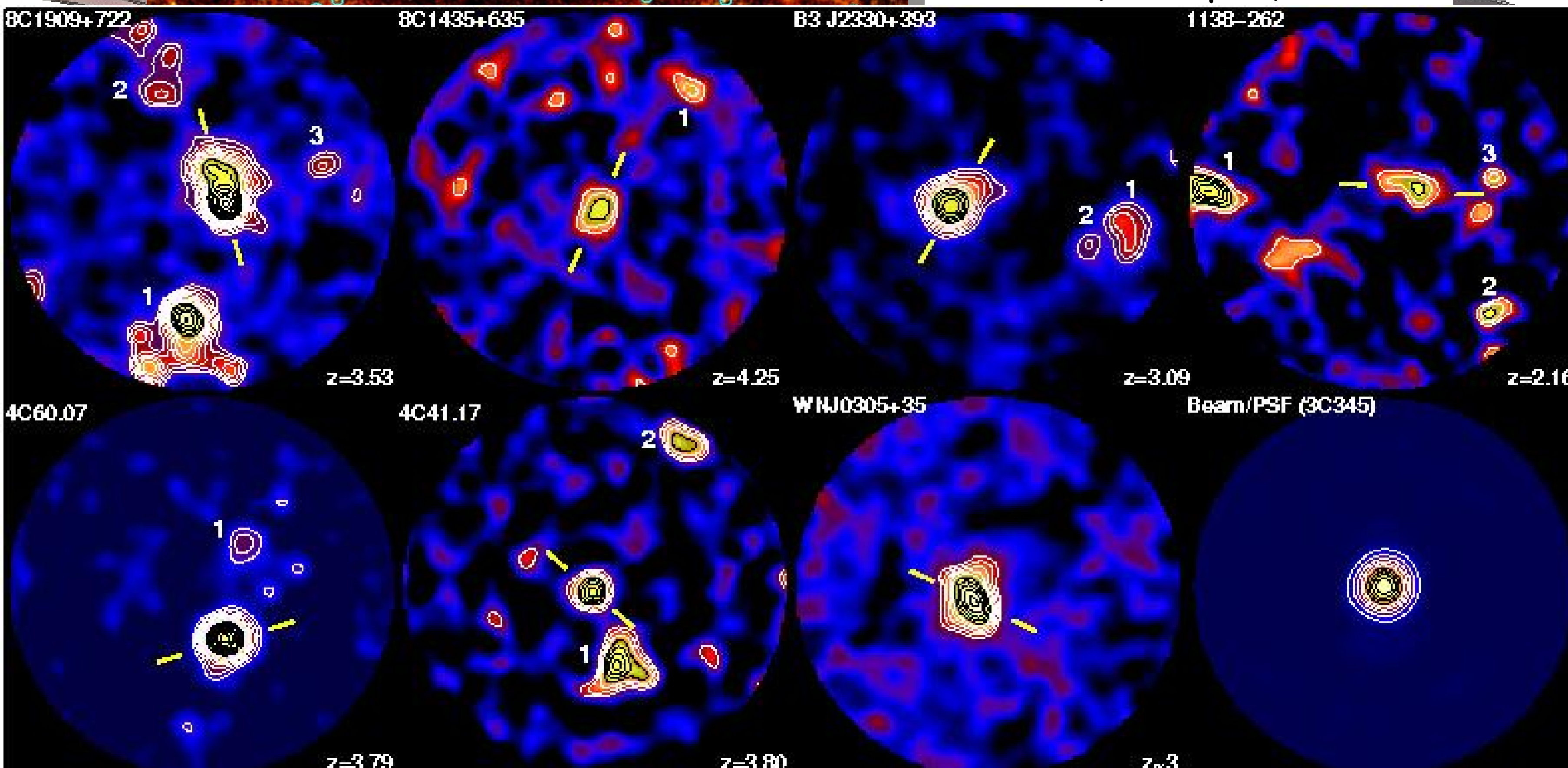


Key observational goals in galaxy formation

V. Unbiased view of structure formation

Bright submm galaxies around high-redshift radio galaxies:

30m, 200μm, 1.4"

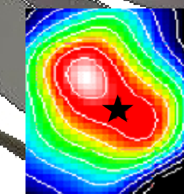


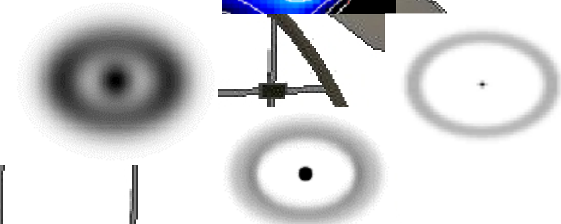
(Ivison et al. 2000; Stevens et al. 2003)

How do stars and planetary systems form?

Star formation:

- Formation controlled by turbulence, or magnetic field?
- What is the true IMF?
  - High-res molecular line spectroscopy (chemical and dynamical evolution: H_2O, HD, OH, H_3O^+, CH^+, ...)
  - Polarimetry with high spatial resolution (-> mag field)
  - Sensitive continuum surveys (sub-stellar objects)





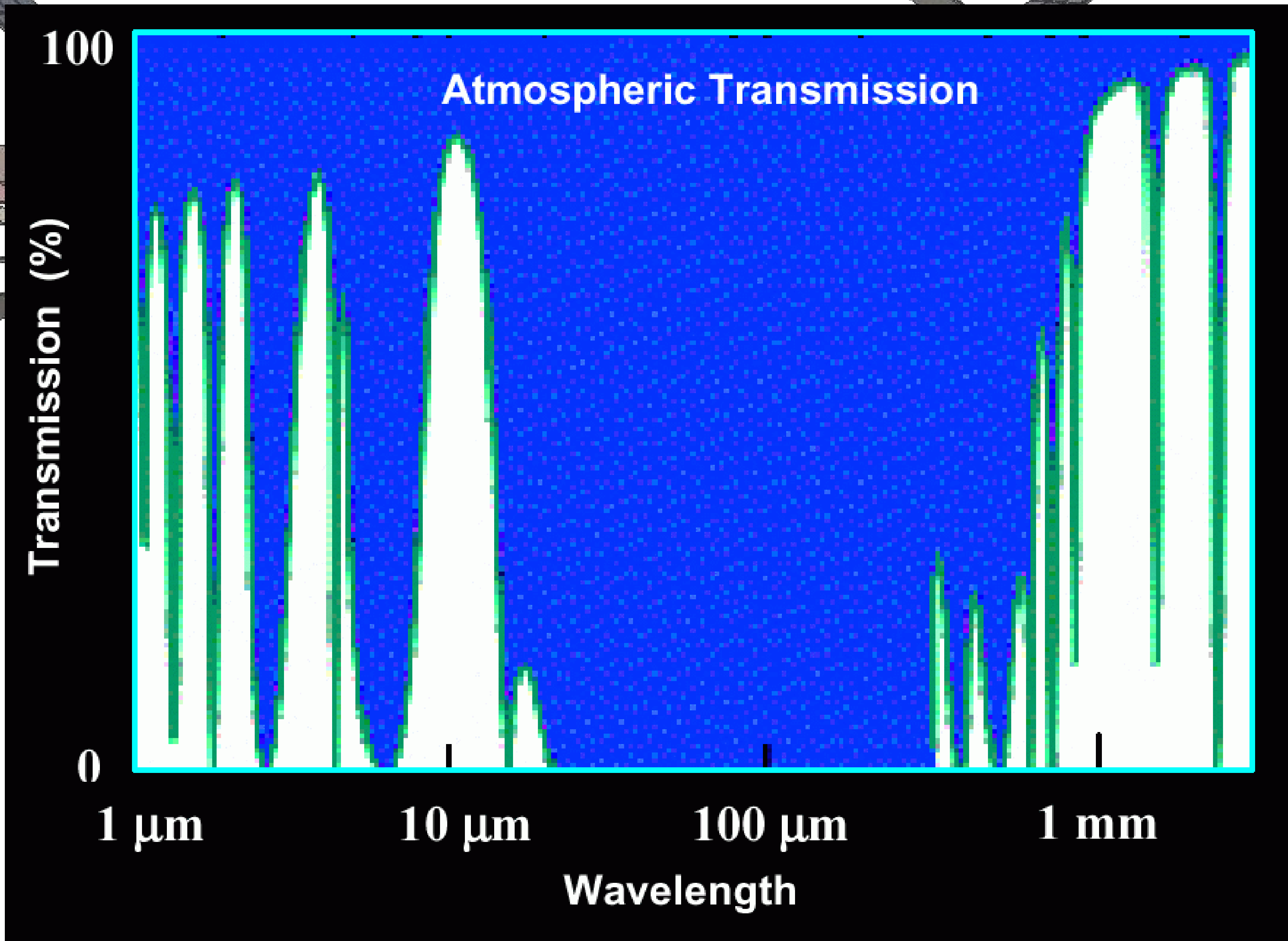
Planet formation:

- Core accretion? Gravitational instability?
- What are the architectures of planet systems?
- Evidence for life? Origin of water?
- Evidence of large organic molecules, e.g. Glycine?

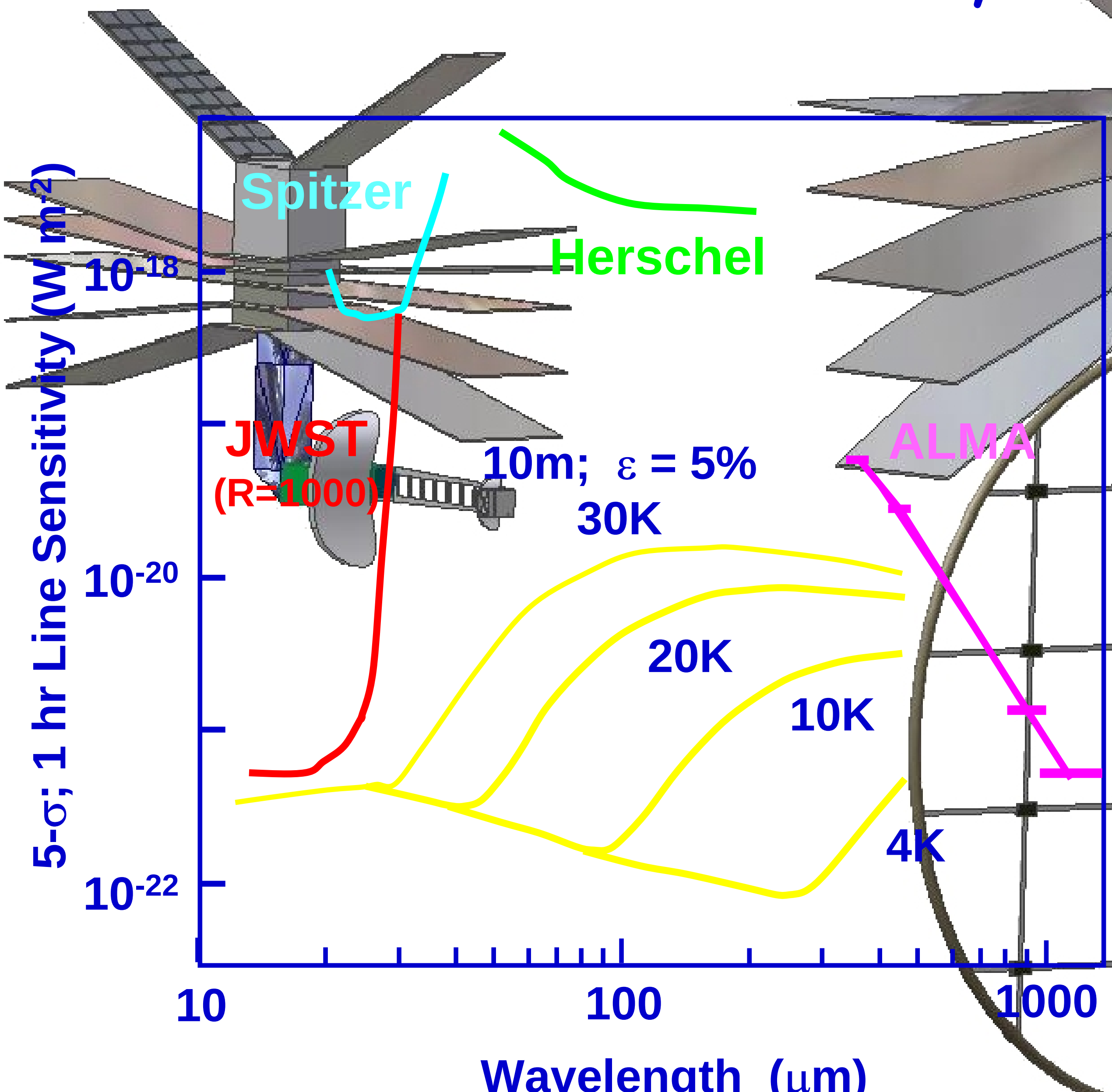
Requirements:

- Need to probe scales of 1-1000 AU at typical distance ~100 pc
- Hi-res imaging/spectroscopy in far-IR (min resolution ~1", prefer ~0.01")
  - ~30m dish or long-baseline interferometer (~1km)
- Hi-res spectroscopy ($R\sim10^5$) -> heterodyne receivers

The need for space



Sensitivity

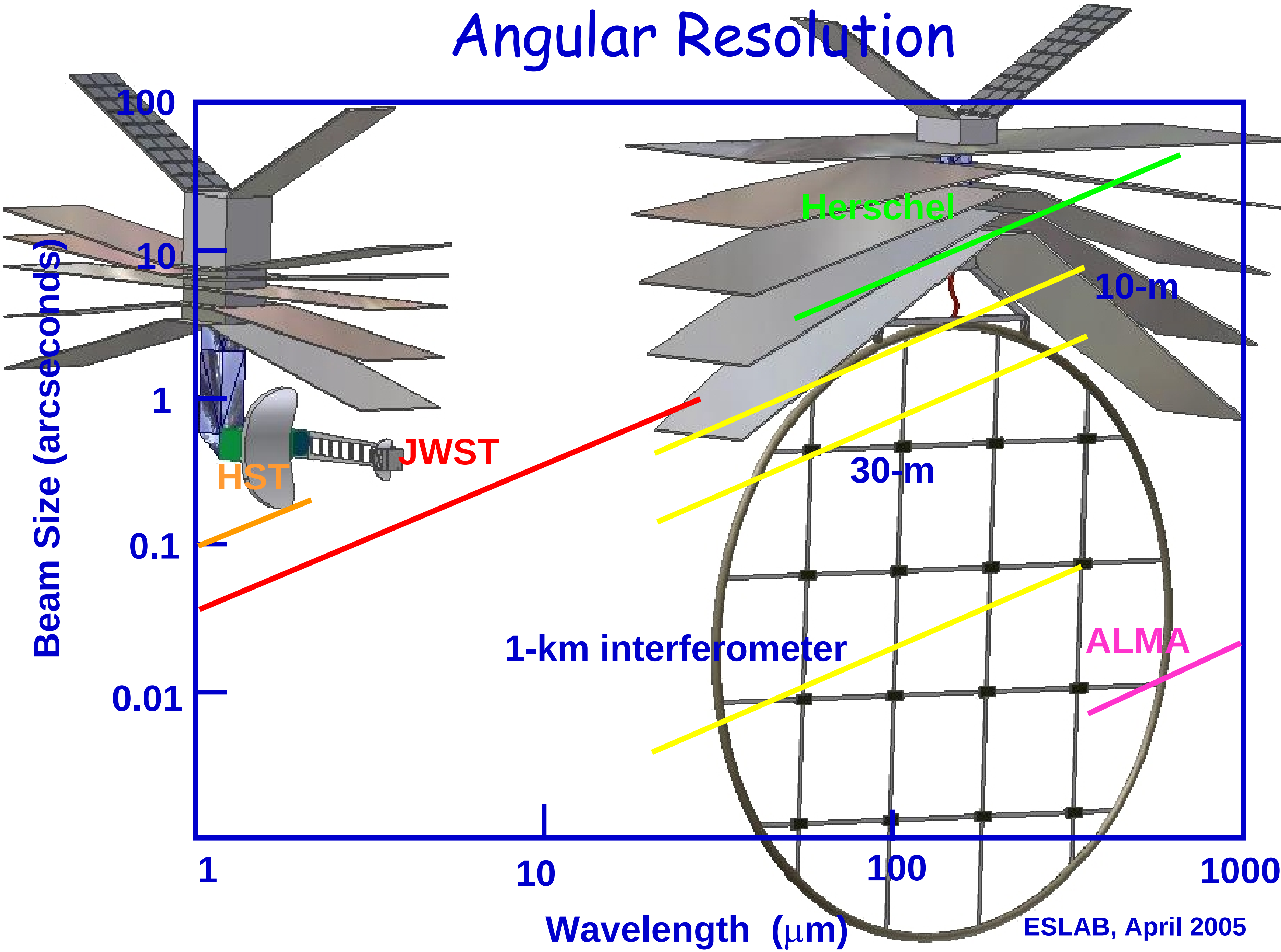


4-K telescope is background-limited:

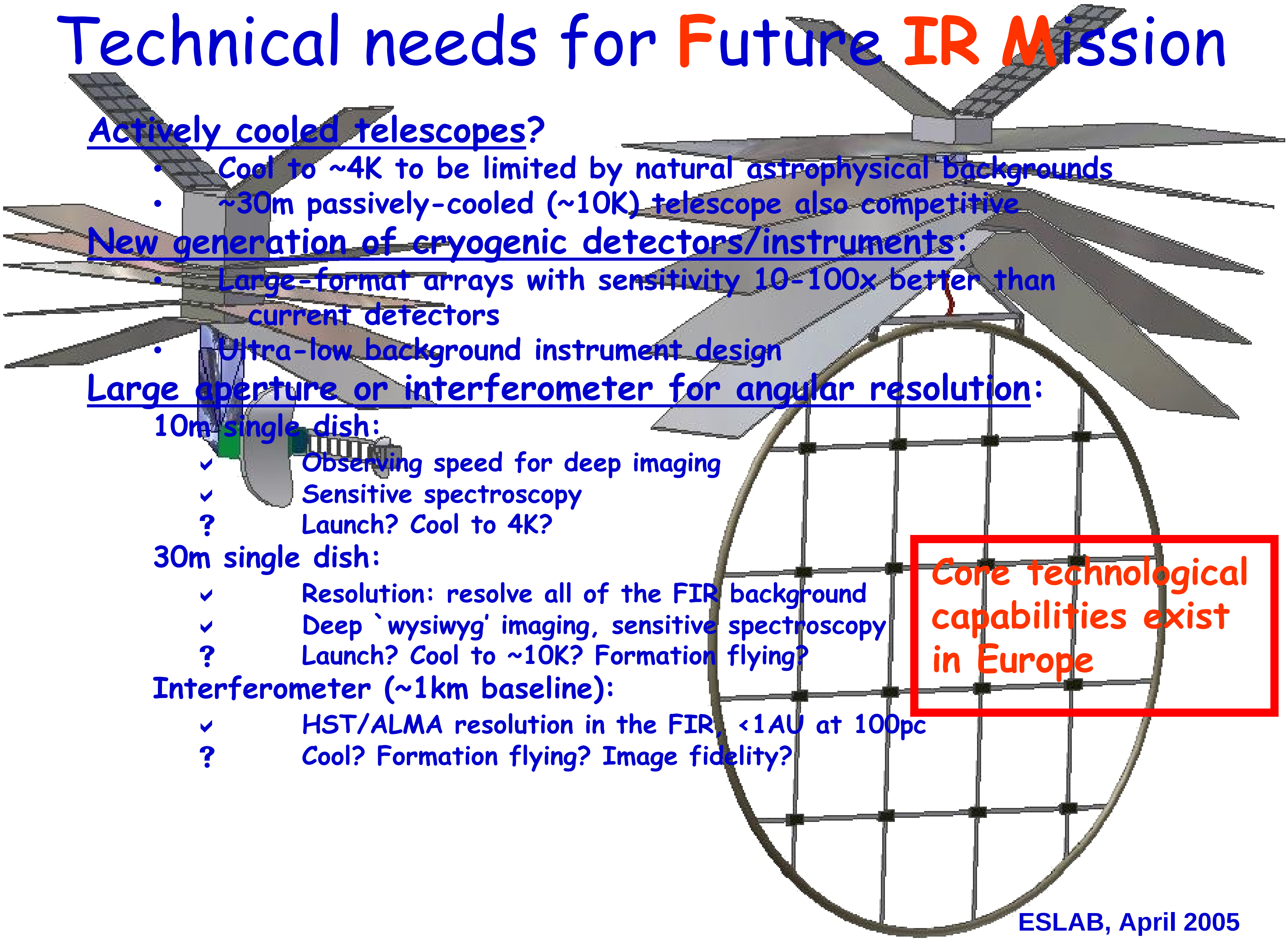
- Zodiacal light below 200μm
- Background (confusion) above 200μm

ESLAB, April 2005

Angular Resolution



Technical needs for Future IR Mission



Actively cooled telescopes?

- Cool to ~4K to be limited by natural astrophysical backgrounds
- ~30m passively-cooled (~10K) telescope also competitive

New generation of cryogenic detectors/instruments:

- Large-format arrays with sensitivity 10-100x better than current detectors
- Ultra-low background instrument design

Large aperture or interferometer for angular resolution:

10m single dish:

- ✓ Observing speed for deep imaging
- ✓ Sensitive spectroscopy
- ? Launch? Cool to 4K?

30m single dish:

- ✓ Resolution: resolve all of the FIR background
- ✓ Deep `wysiwyg' imaging, sensitive spectroscopy
- ? Launch? Cool to ~10K? Formation flying?

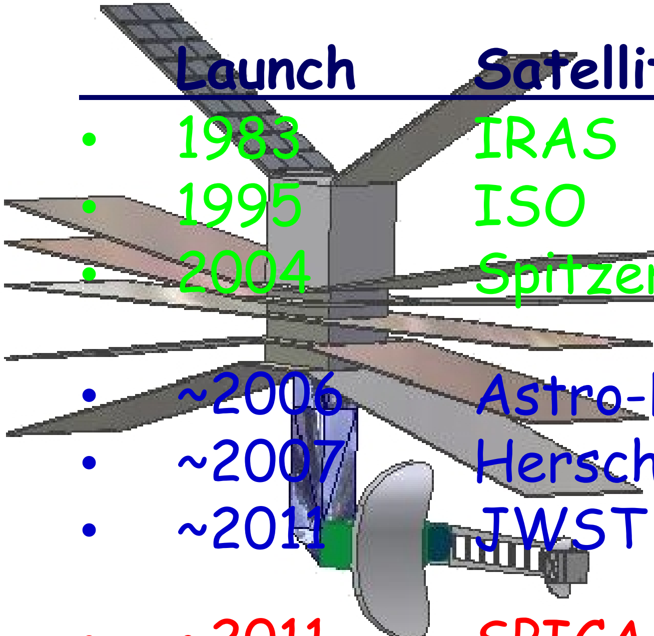
Interferometer (~1km baseline):

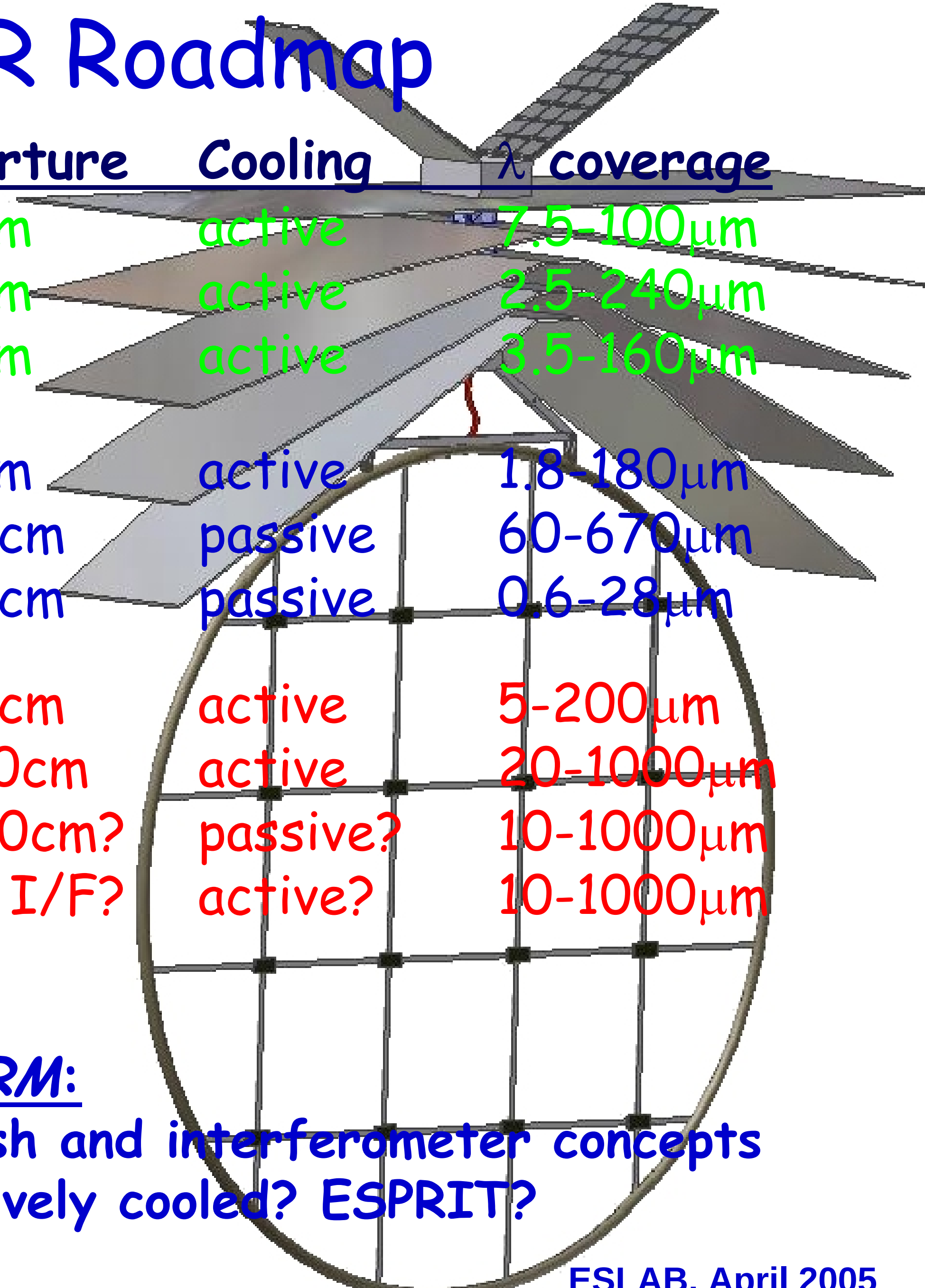
- ✓ HST/ALMA resolution in the FIR, <1AU at 100pc
- ? Cool? Formation flying? Image fidelity?

Core technological capabilities exist in Europe

Far-IR Roadmap

Launch	Satellite	Aperture	Cooling	λ coverage
• 1983	IRAS	58cm	active	7.5-100μm
• 1995	ISO	60cm	active	2.5-240μm
• 2004	Spitzer	85cm	active	3.5-160μm
• ~2006	Astro-F	67cm	active	1.8-180μm
• ~2007	Herschel	350cm	passive	60-670μm
• ~2011	JWST	650cm	passive	0.6-28μm
• ~2011	SPICA	350cm	active	5-200μm
• ~2015?	SAFIR	1000cm	active	20-1000μm
• ~2020	**FIRM**	3000cm?	passive?	10-1000μm
		1km I/F?	active?	10-1000μm

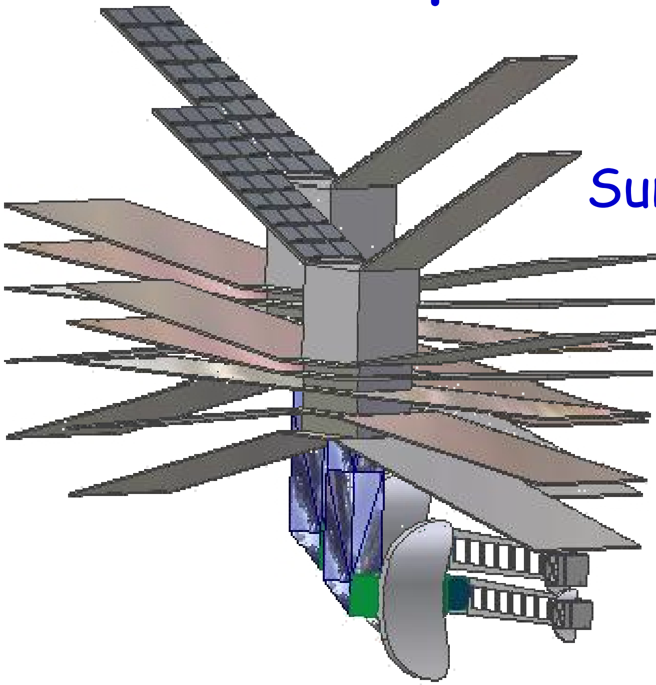




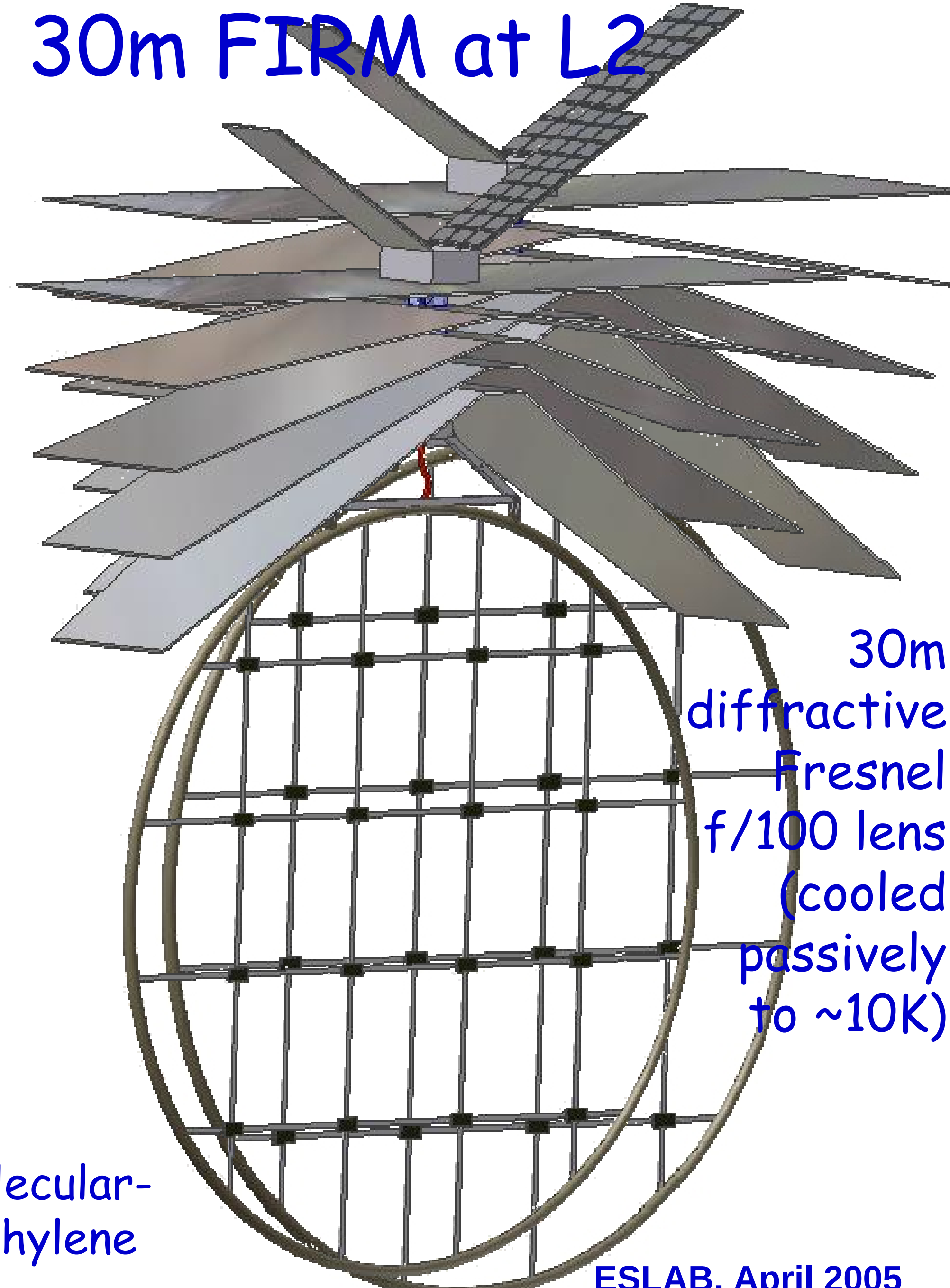
ESA technology study for *FIRM*:

Ongoing comparison of large dish and interferometer concepts
10m actively cooled? 30m passively cooled? ESPRIT?

Impression of 30m FIRM at L2



Sunshades

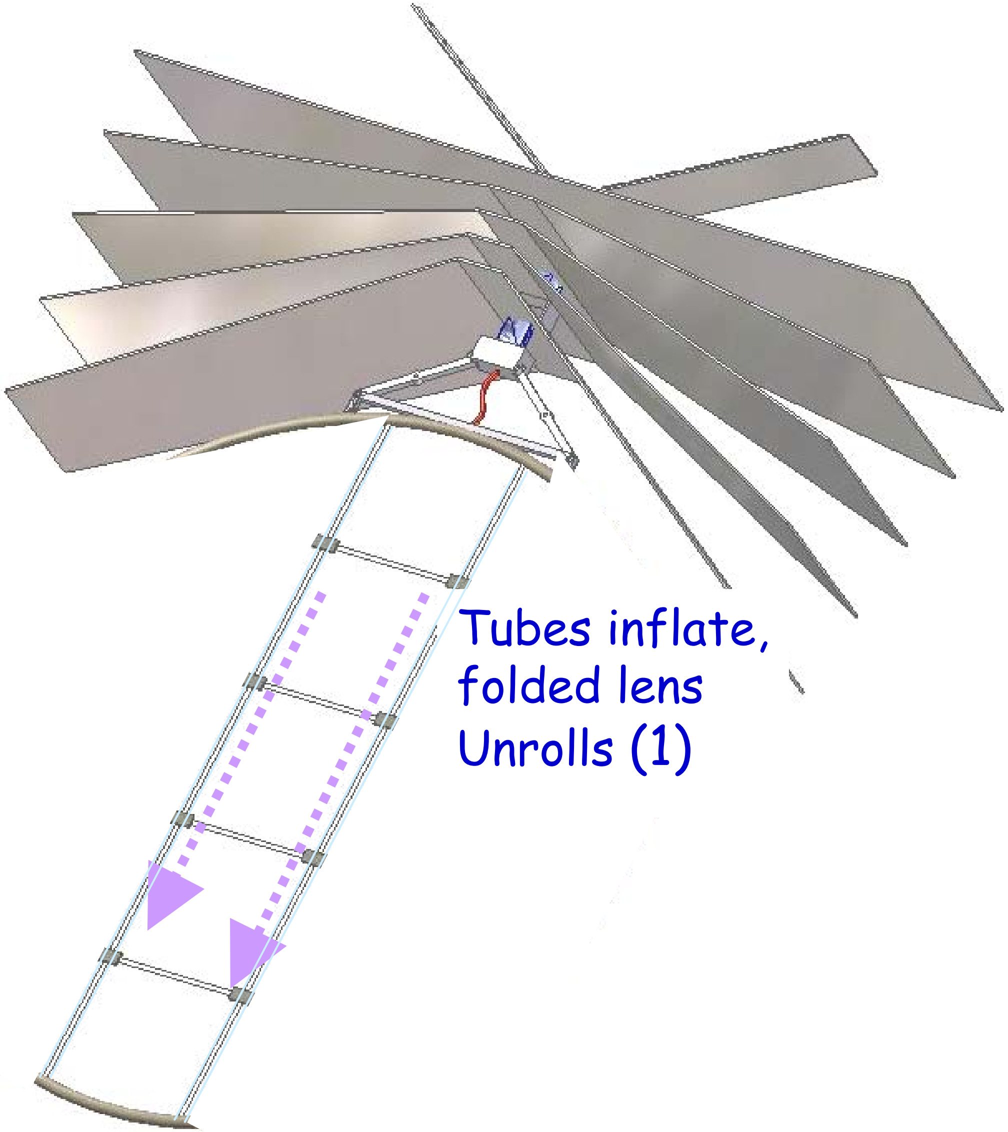


Field/corrector optics & instruments
- cooled actively to 4K
- ~3km from primary lens

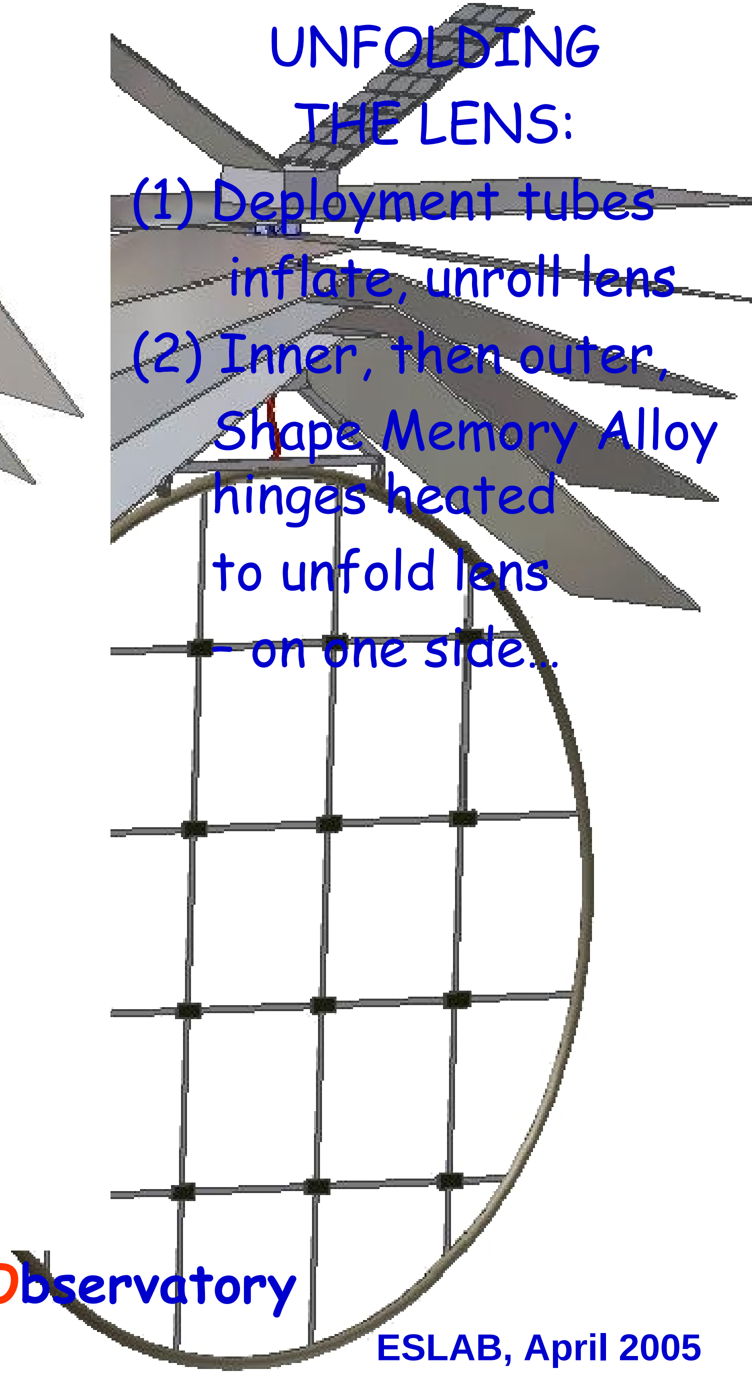
30m diffractive Fresnel f/100 lens (cooled passively to ~10K)

Ultra-High Molecular-Weight Polyethylene

GISMO



Tubes inflate,
folded lens
Unrolls (1)



UNFOLDING
THE LENS:

(1) Deployment tubes
inflate, unroll lens

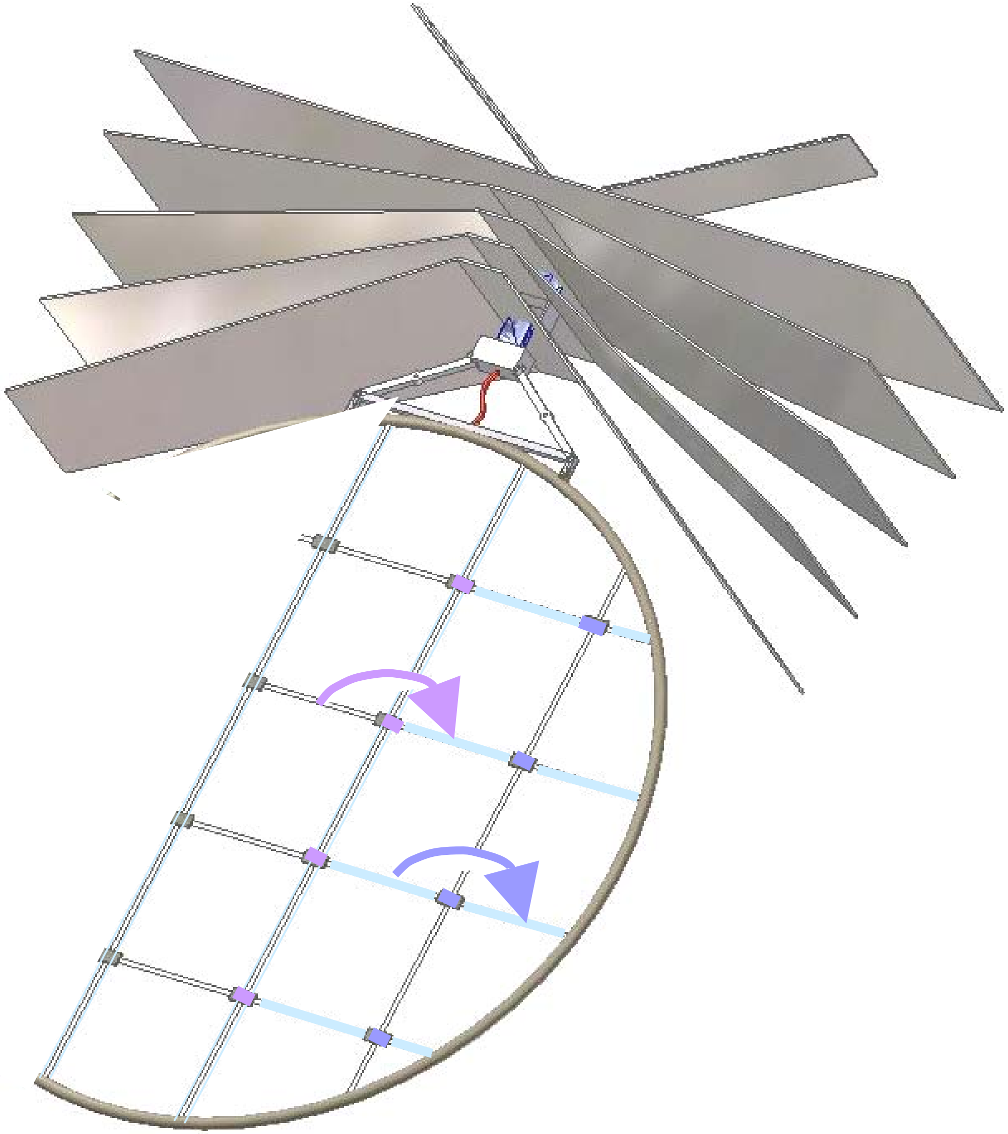
(2) Inner, then outer,
Shape Memory Alloy
hinges heated
to unfold lens
– on one side...

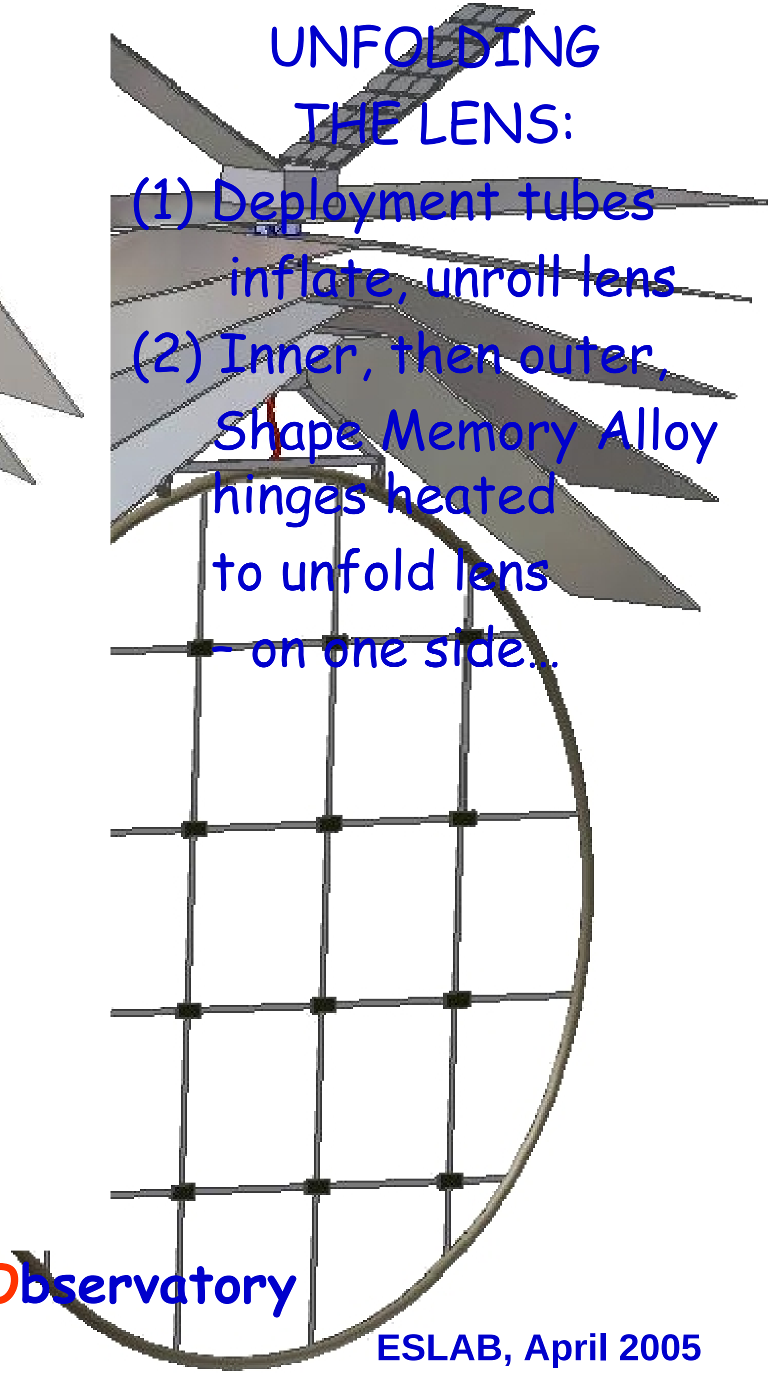
Giant IR SubMm Space Observatory

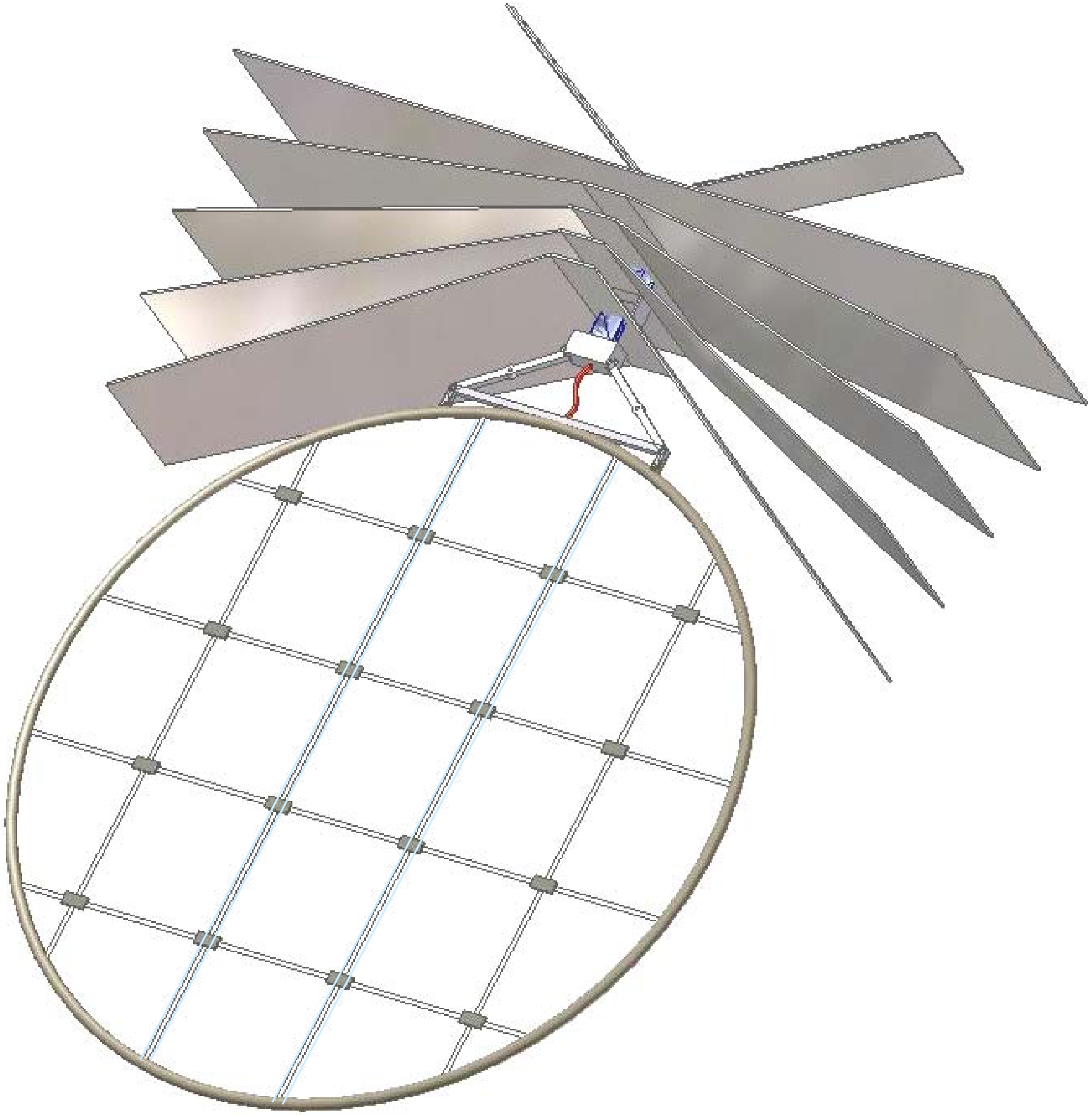
UNFOLDING THE LENS:

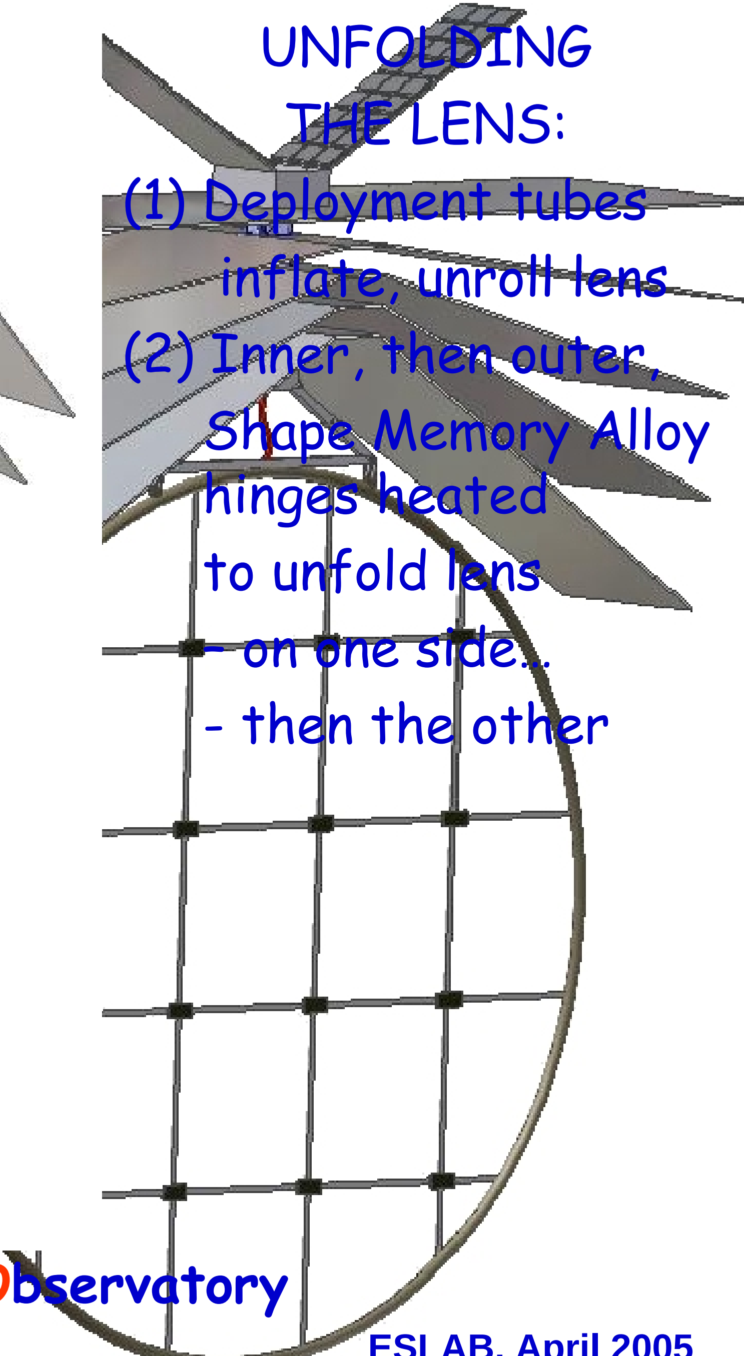
(1) Deployment tubes inflate, unroll lens

(2) Inner, then outer, Shape Memory Alloy hinges heated to unfold lens – on one side…





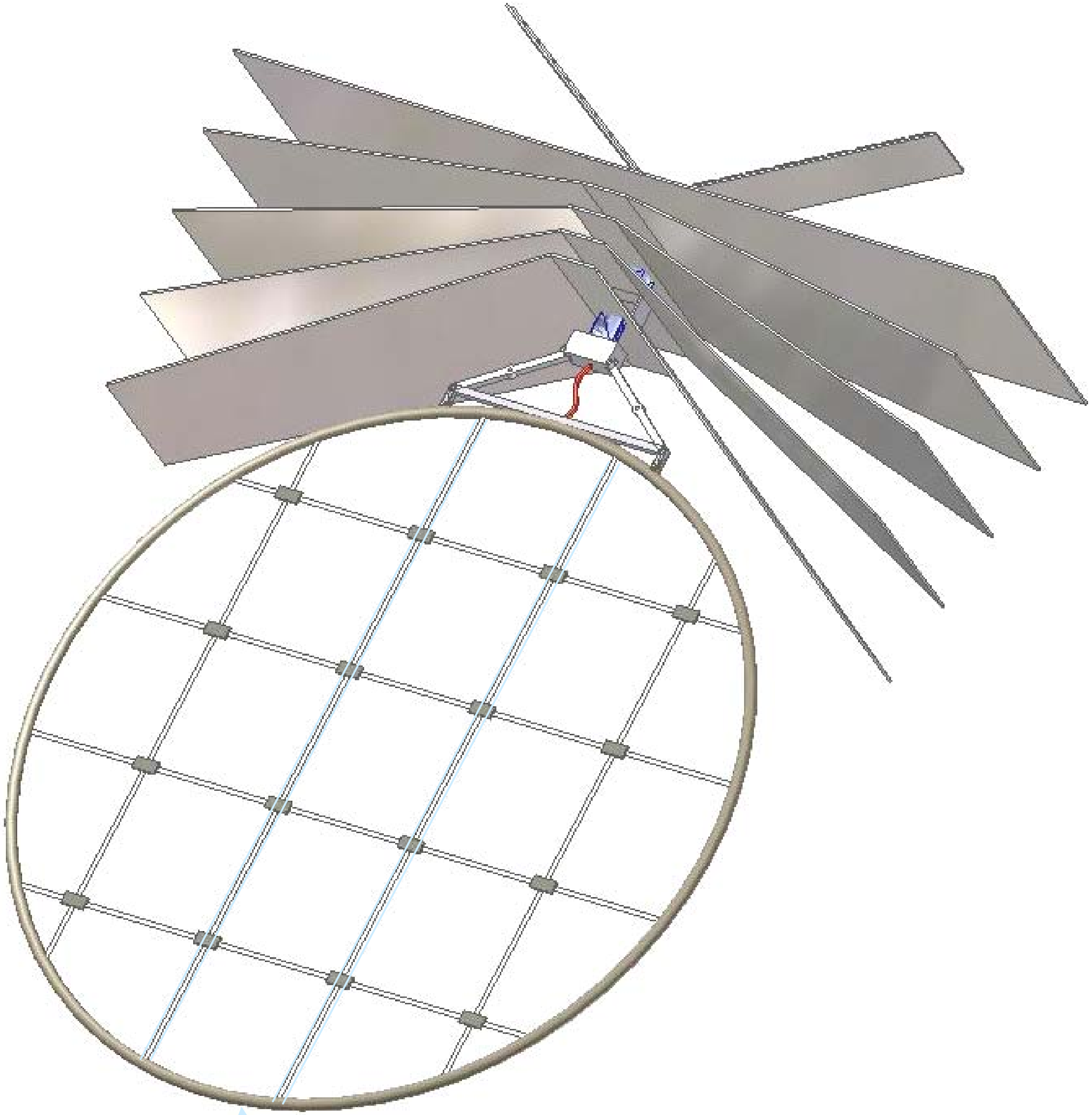




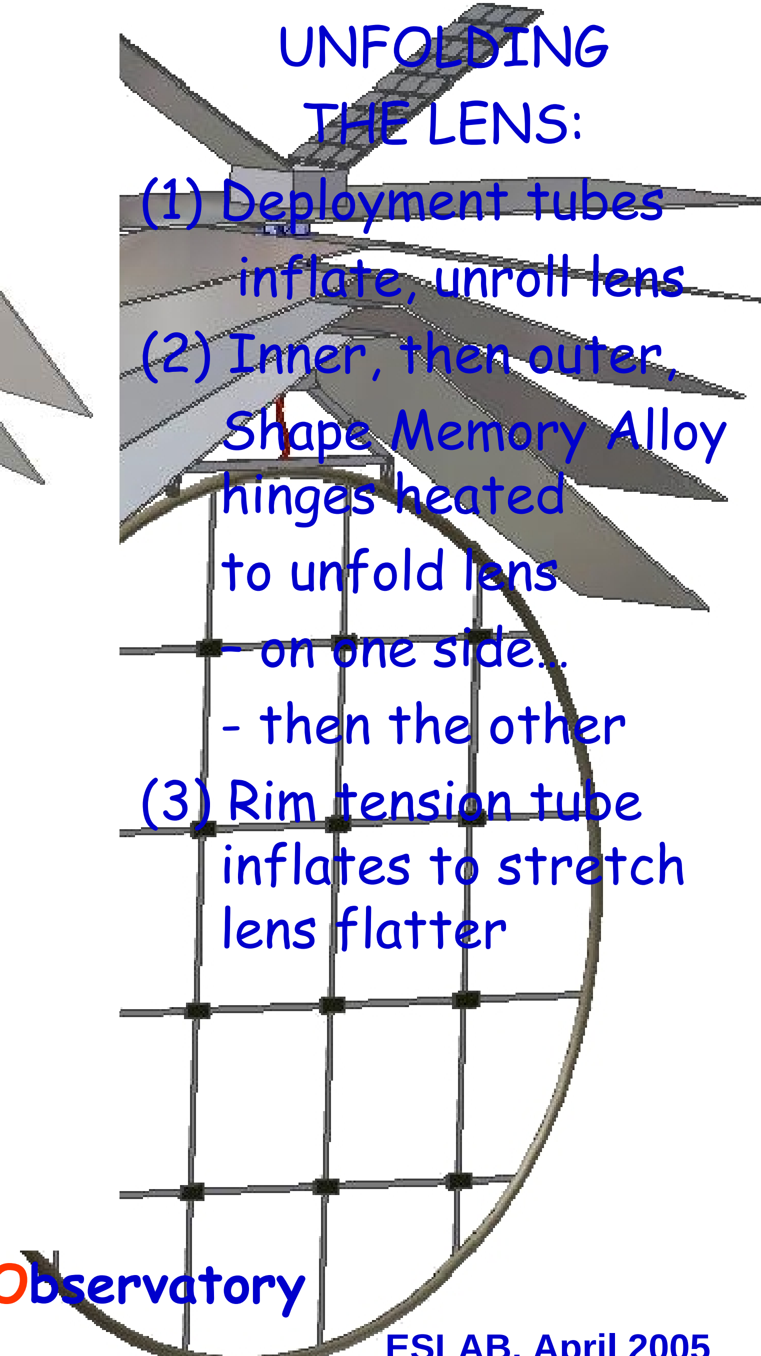
UNFOLDING THE LENS:

(1) Deployment tubes inflate, unroll lens

(2) Inner, then outer, Shape Memory Alloy hinges heated to unfold lens
- on one side...
- then the other



Rim tension tube inflates (3)



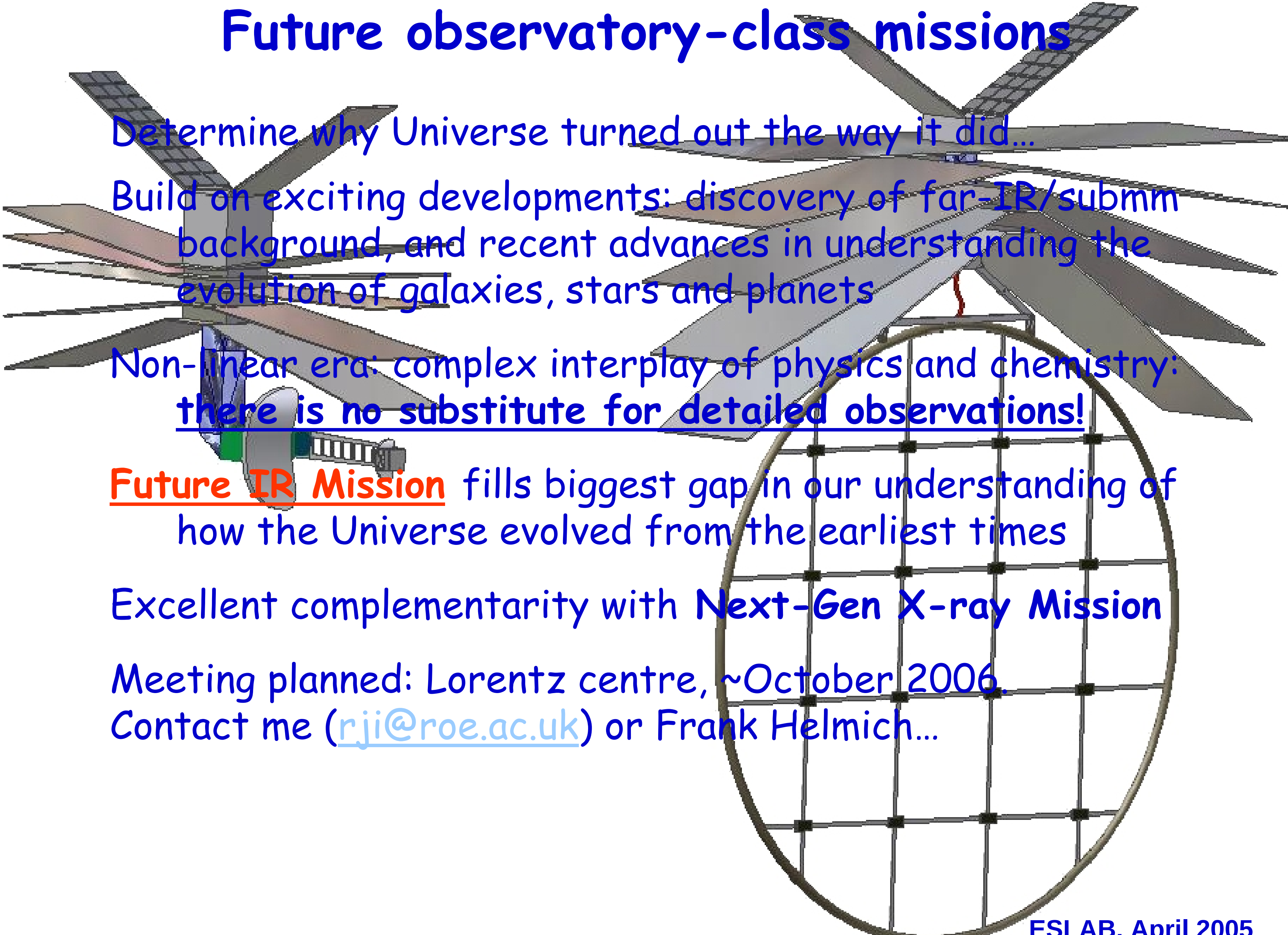
UNFOLDING
THE LENS:

(1) Deployment tubes inflate, unroll lens

(2) Inner, then outer, Shape Memory Alloy hinges heated to unfold lens
- on one side...
- then the other

(3) Rim tension tube inflates to stretch lens flatter

Future observatory-class missions



Determine why Universe turned out the way it did…

Build on exciting developments: discovery of far-IR/submm background, and recent advances in understanding the evolution of galaxies, stars and planets

Non-linear era: complex interplay of physics and chemistry: **there is no substitute for detailed observations!**

Future IR Mission fills biggest gap in our understanding of how the Universe evolved from the earliest times

Excellent complementarity with **Next-Gen X-ray Mission**

Meeting planned: Lorentz centre, ~October 2006.
Contact me (rji@roe.ac.uk) or Frank Helmich…