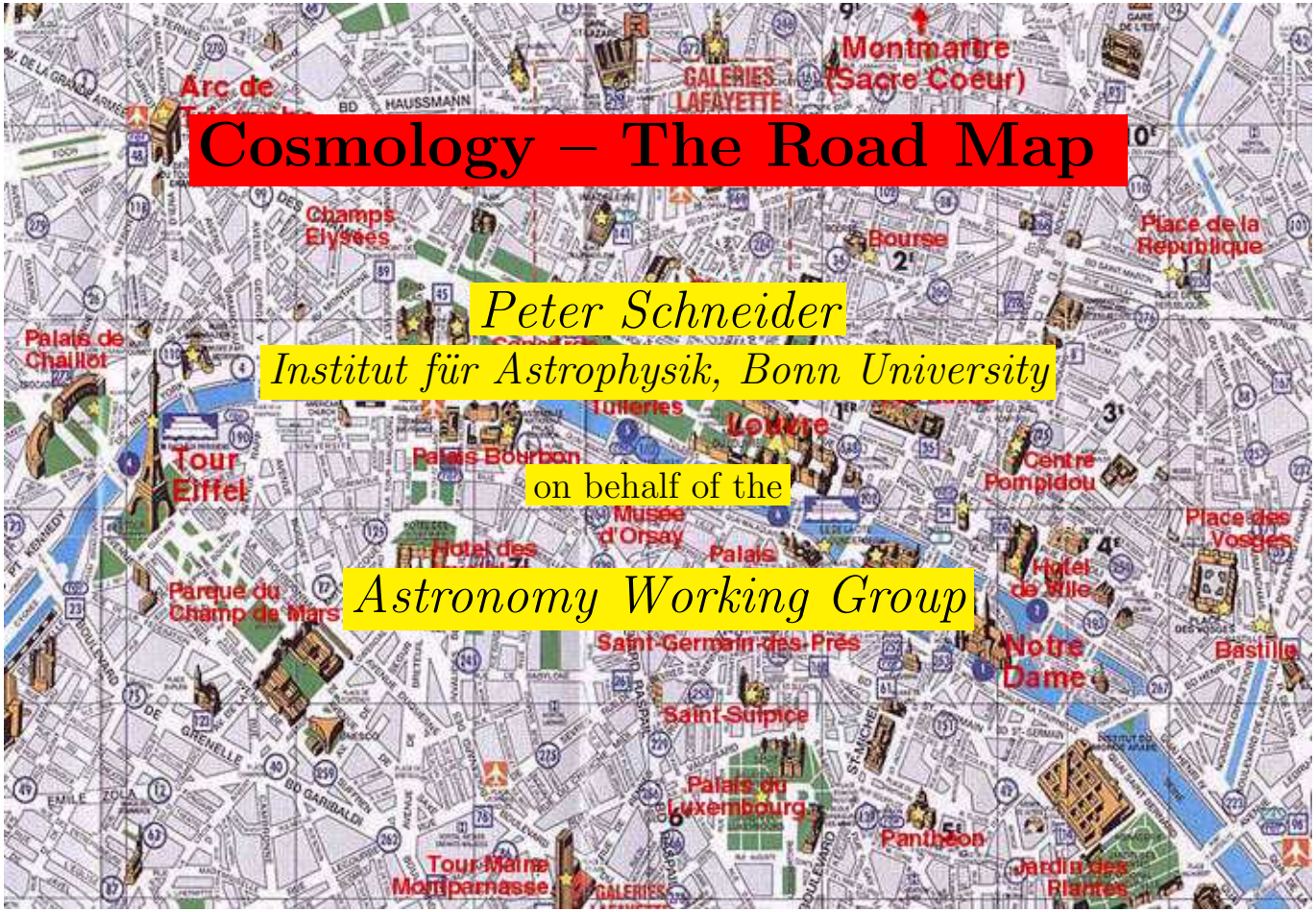
Cosmology – The Road Map
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on behalf of the
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Cosmology's Themes

- Fundamental Cosmology
  - Probing inflation
  - Investigating Dark Energy
- Astrophysical Cosmology
  - The observable Universe taking shape

Probing inflation

Inflation lies at the base of cosmology!
Absolutely needed for a complete cosmological picture, the 'origin' of our standard Friedmann cosmology + seeds of structure formation.

- **Power spectrum of primordial fluctuations ($\Rightarrow$ WMAP, Planck + ground-based observations)**
- **Power spectrum of gravitational waves:**
  - **Direct detection through GW antennae ('SuperLISA')**
  - **B-modes in CMB polarization ($\rightarrow$ J.-L. Puget)**

Nature of Dark Energy

Existence of Dark Energy came as BIG surprise

DE is THE challenge for fundamental physics

... and astrophysics

Empirical link to quantum gravity

Can only be probed on cosmic scales!

DE dominates cosmic expansion after z$\sim$ 0.7

$\Rightarrow$ needs to combine precision observations at high (CMB) and low redshift, to study evolution:

Equation of state of DE!

Is DE the cosmological constant??

Probing Dark Energy

- DE affects geometry and cosmic expansion
  $\Rightarrow$ luminosity–redshift relation
  - needs standard candles – SN Ia
- DE affects structure growth
  $\Rightarrow$ measure power spectrum P(k,z)
  - needs unbiased method for measuring the (Dark) matter distribution – the LSS

  $\Rightarrow$ weak gravitational lensing: Cosmic shear

Cosmic shear and SN Ia lightcurves:
similar observational requirements.

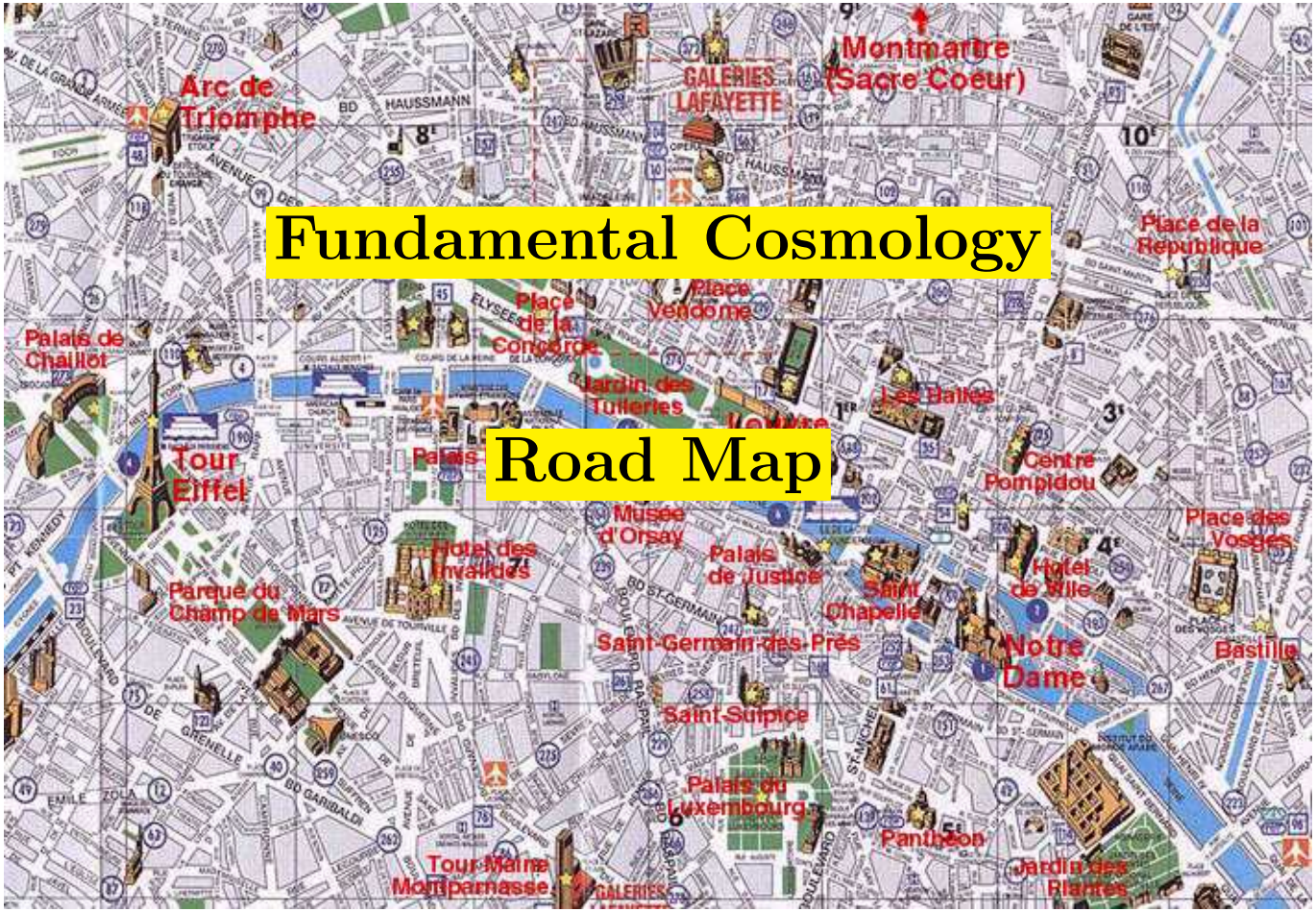
Probing Dark Energy

E.g., cosmic shear measurements require:

- Wide-field optical imaging
- multi-band optical and near-IR photometry for photometric redshifts
- very well-controlled PSF

e.g. to constrain EOS parameter w to within $\sim 3\%$ requires $\sim$ 3000 sq.deg.

Also yields exquisite measurement of P(k,z)!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COBE → WMAP → Planck →

- **All-sky CMB polarization mapper**

Space needed due to sensitivity!

Ground-based WFI + HST small-field obs. →

- **Optical/Near-IR Wide-Field imager**
  - **as ESA project, and/or**
  - **ESA participation in JDEM**

Space needed for PSF control and near-IR!

Perspective: GW antennae (after LISA's proof of concept)

Astrophysical Cosmology

Goal: Understanding the evolution of structure and objects in the Universe

$\Rightarrow$ Looking into the past
$\Leftrightarrow$ Looking in the distance.

Requires a multi-wavelength approach!

Observatory-type missions.

When do the stars form?

- Formation of very first stars:
  The end of the Dark Ages.
  molecular hydrogen-cooling, 17 & 28 microns
  rotational levels, redshifted into FIR
- very first massive star explosions,
  as GRBs? X-rays
- star-formation history:
  - rest-frame optical (JWST)
  - dust obscured star-formation FIR
- star formation on large scales: galaxy evolution

Where are the baryons today?

From e.g. nuclear physics 1 min. after Big Bang, we know the cosmic baryon density.
Only 10% of them are seen today (in stars, ISM).

Where is the rest? –
Not even that component of the Universe which we understand physically is well studied!

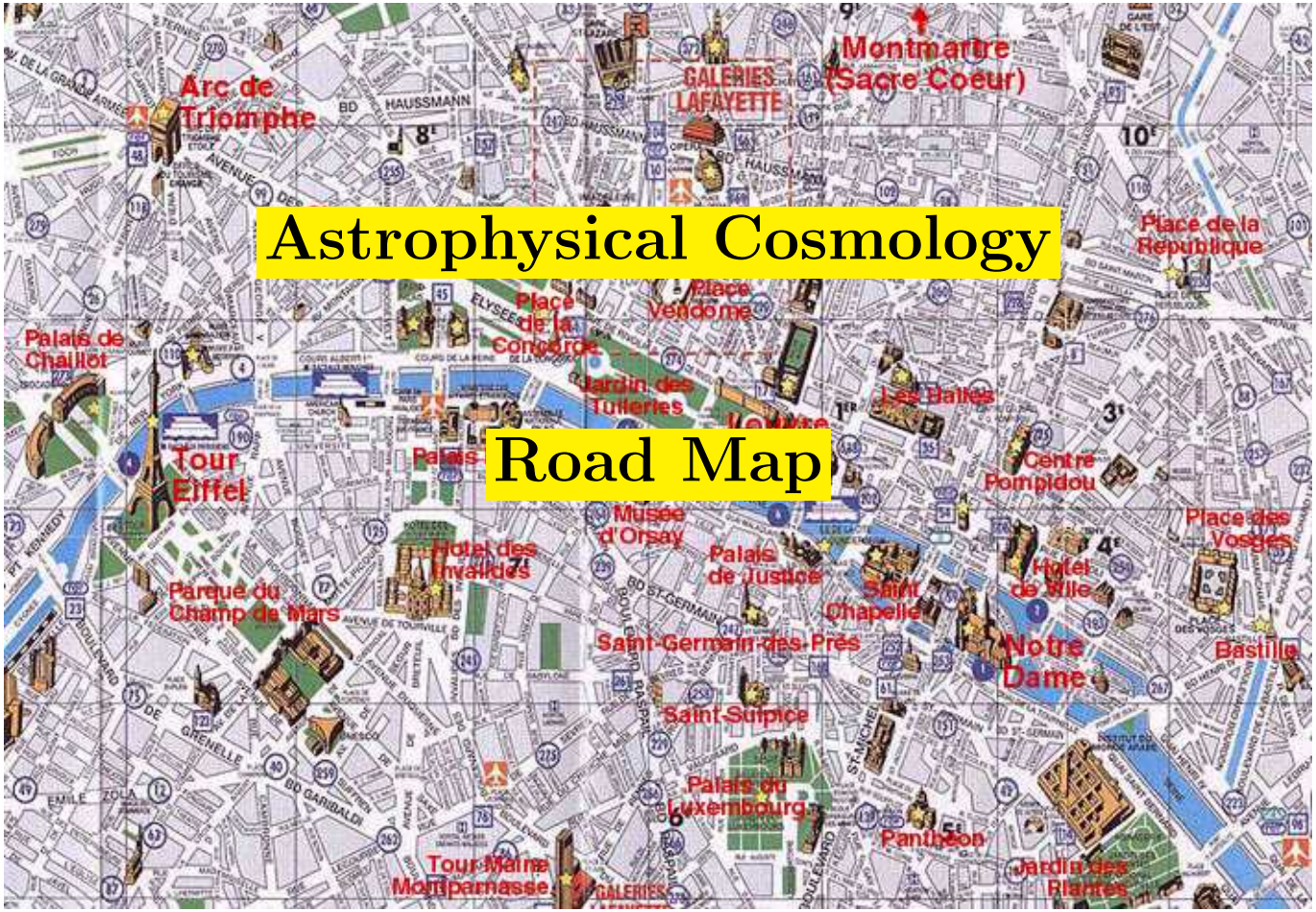
At high redshift, we 'see them all' in intergalactic absorption.

Most likely place to hide: Warm-hot IGM, requires UV spectroscopy and X-ray spectroscopy ('heavy-element forest')

Galaxies and clusters

- joint galaxy – SMBH evolution:
  Quasars are SMBHs in formation.
  - AGN demographics; often hidden from optical view (Type II) X-ray and FIR
- Census of high-redshift clusters
  - Provides handle of structure evolution and thus DE;
  - maps out the LSS at high-z

requires X-ray telescope with high spectral resolution and large throughput.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Three highest priority observatory missions
(ordered by wavelength!)
Space needed due to atmospheric transparency!

ISO → Herschel → JWST →

- large aperture FIR observatory
  (→ M. Griffin)

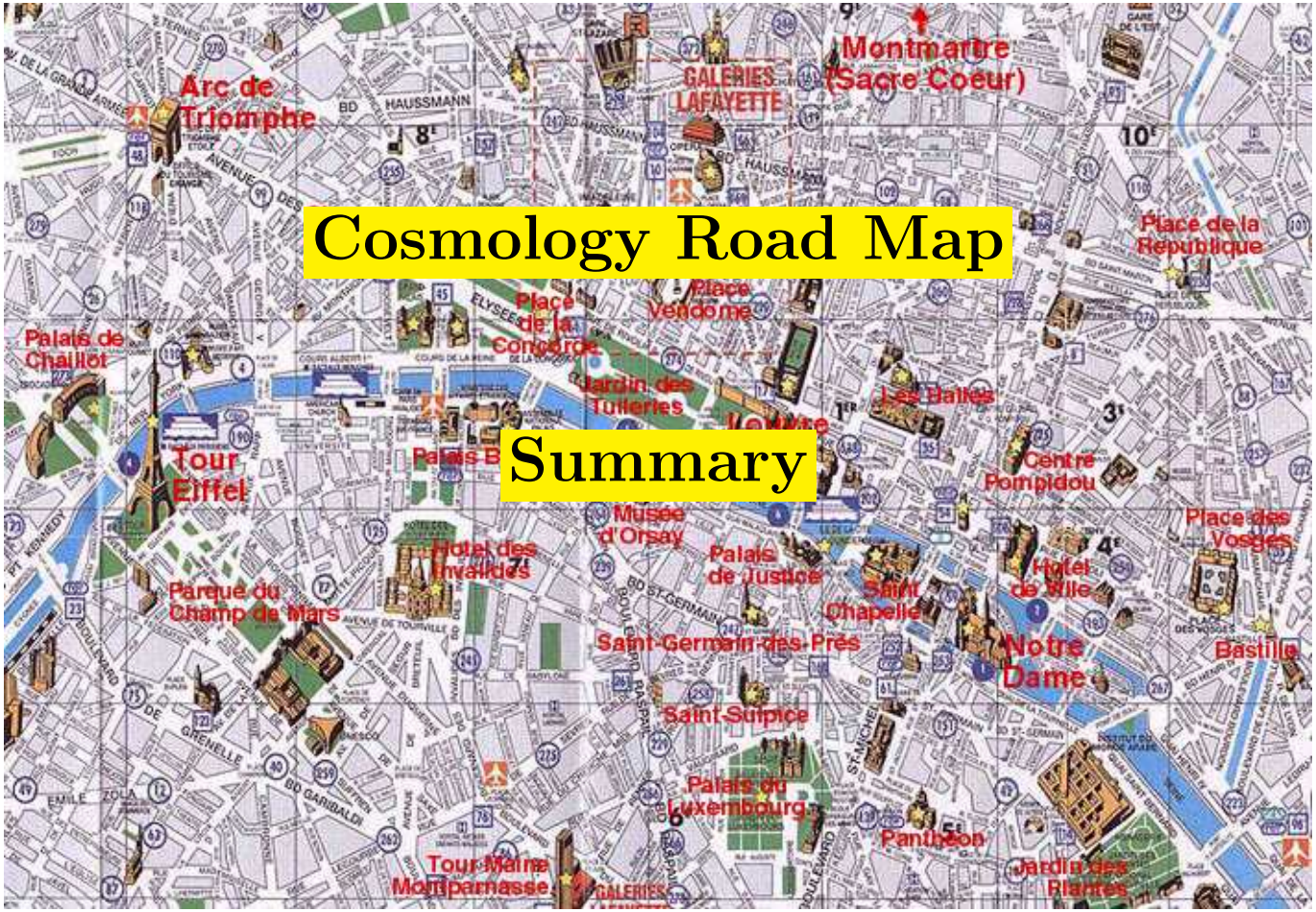
IUE → HST →

- UV observatory with high-res. spectroscopy:
  - warm-hot IGM spectroscopy
  - UV lightcurves of SN Ia as low-z templates for high-z sources

ROSAT → XMM-Newton + Chandra →

- **large-aperture X-ray observatory:**
  - **SMBH, growth and evolution**
  - **galaxy clusters at all redshifts**
  - **hot IGM spectroscopy (→ G. Hasinger)**

All these observatories serve other communities as well!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Future instrumental opportunities will allow us to appoach three of the most fundamental physical questions:

- **Inflation,**
  or what is the origin of our Universe?
- **Dark Energy,**
  or what is the origin (and future) of accelerated cosmic expansion?
- **Structure evolution,**
  or what is the origin of our present-day world?

Fundamental Cosmology

- All-sky CMB polarization mapper
- Optical/Near-IR Wide-Field imager

Astrophysical Cosmology

- large aperture FIR observatory
- UV observatory with high-resolution spectroscopy
- large-aperture X-ray observatory