Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

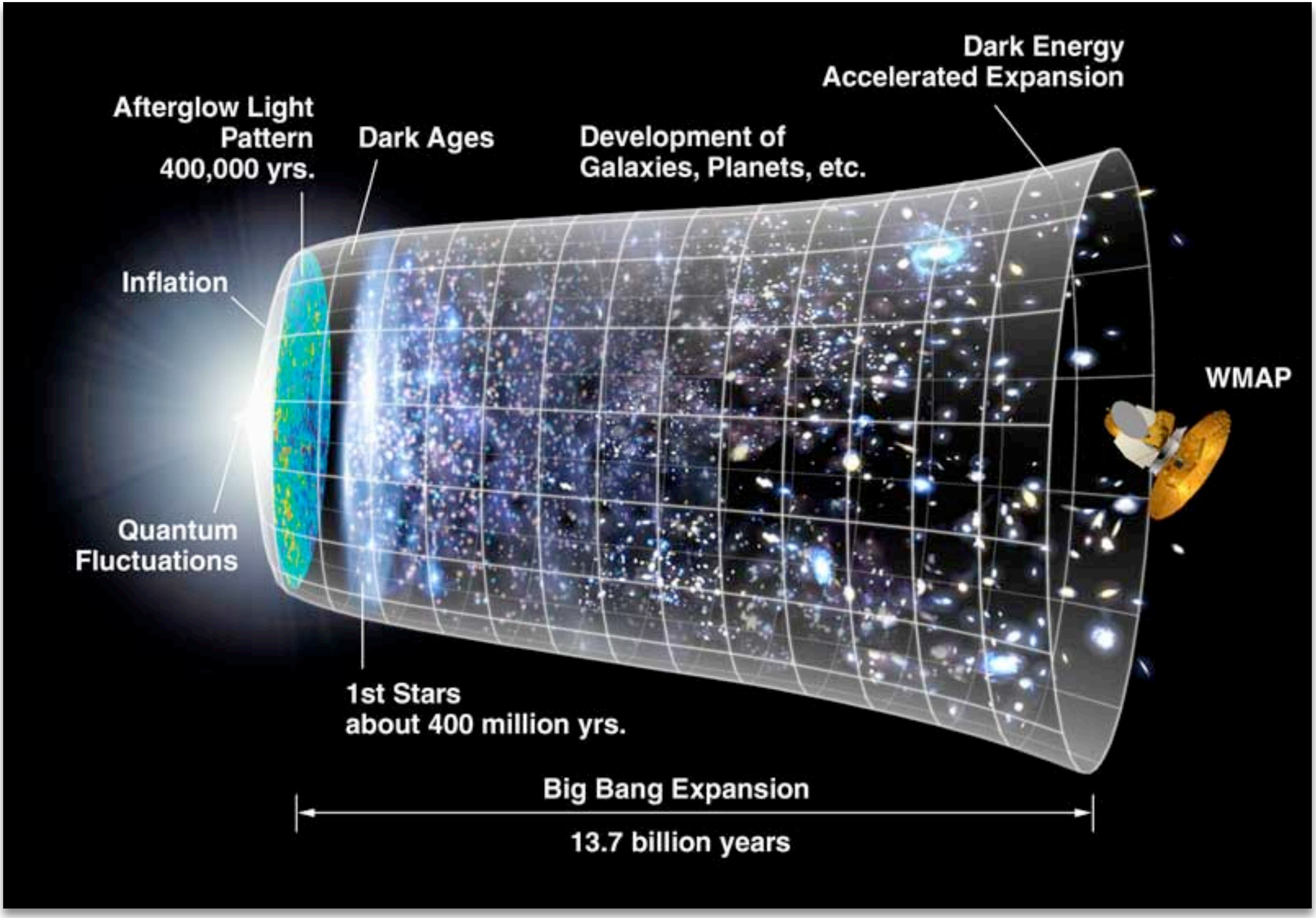
Tackling The Dark Universe With Euclid

Adam Amara
ETH, Institute for Astronomy

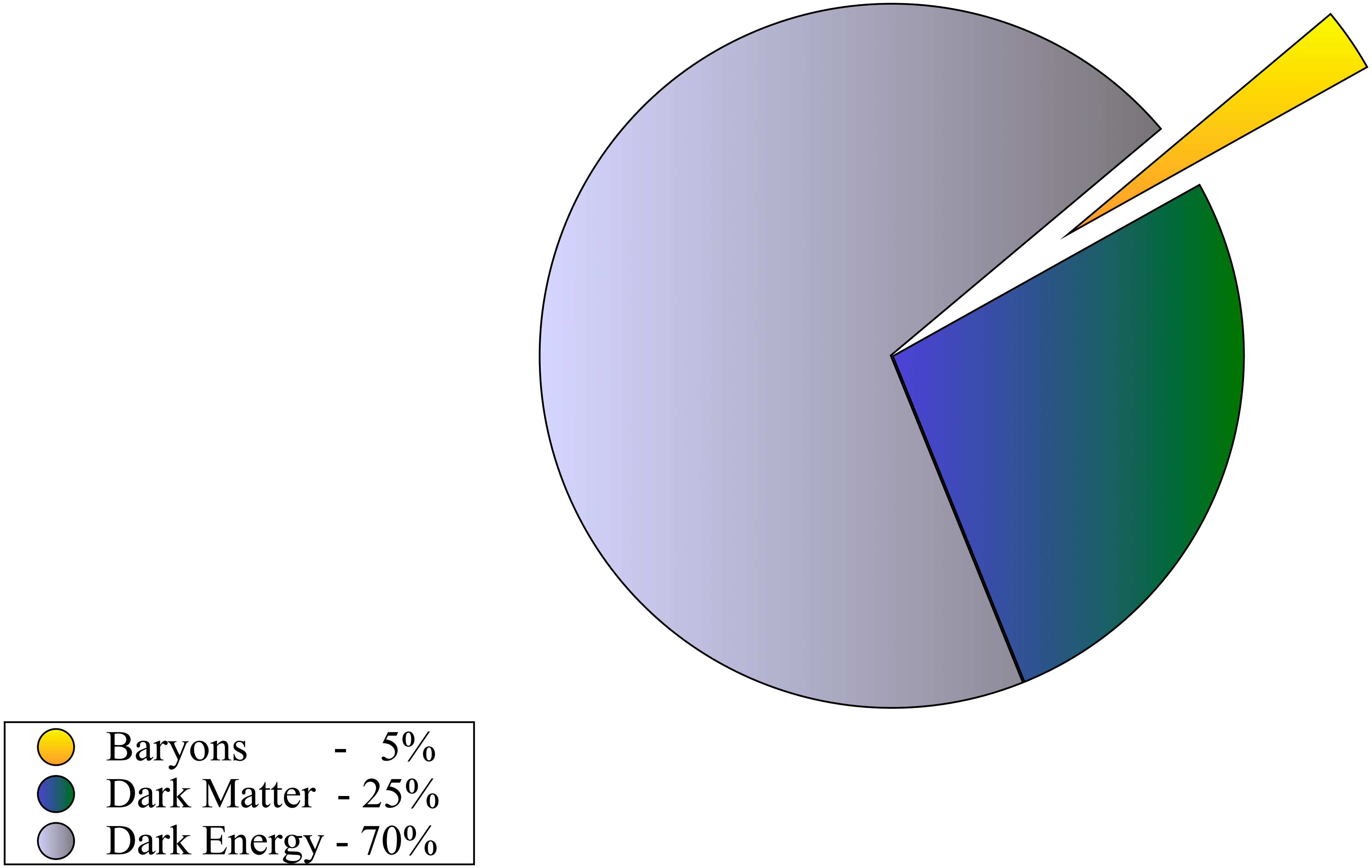
Talk Outline

- What we know about the Dark Universe:
  - Dark Matter
  - Dark Energy
- iCosmo
  - Online calculations
  - wiki pages - teaching resource
  - public source coe
- Outline of the Euclid mission
  - History (DUNE and SPACE)
  - Main Science Objectives
  - Current mission
- Challenges and GREAT08
  - Lensing potential and challenges
  - The GREAT08 pascal challenge

The Cosmological Model

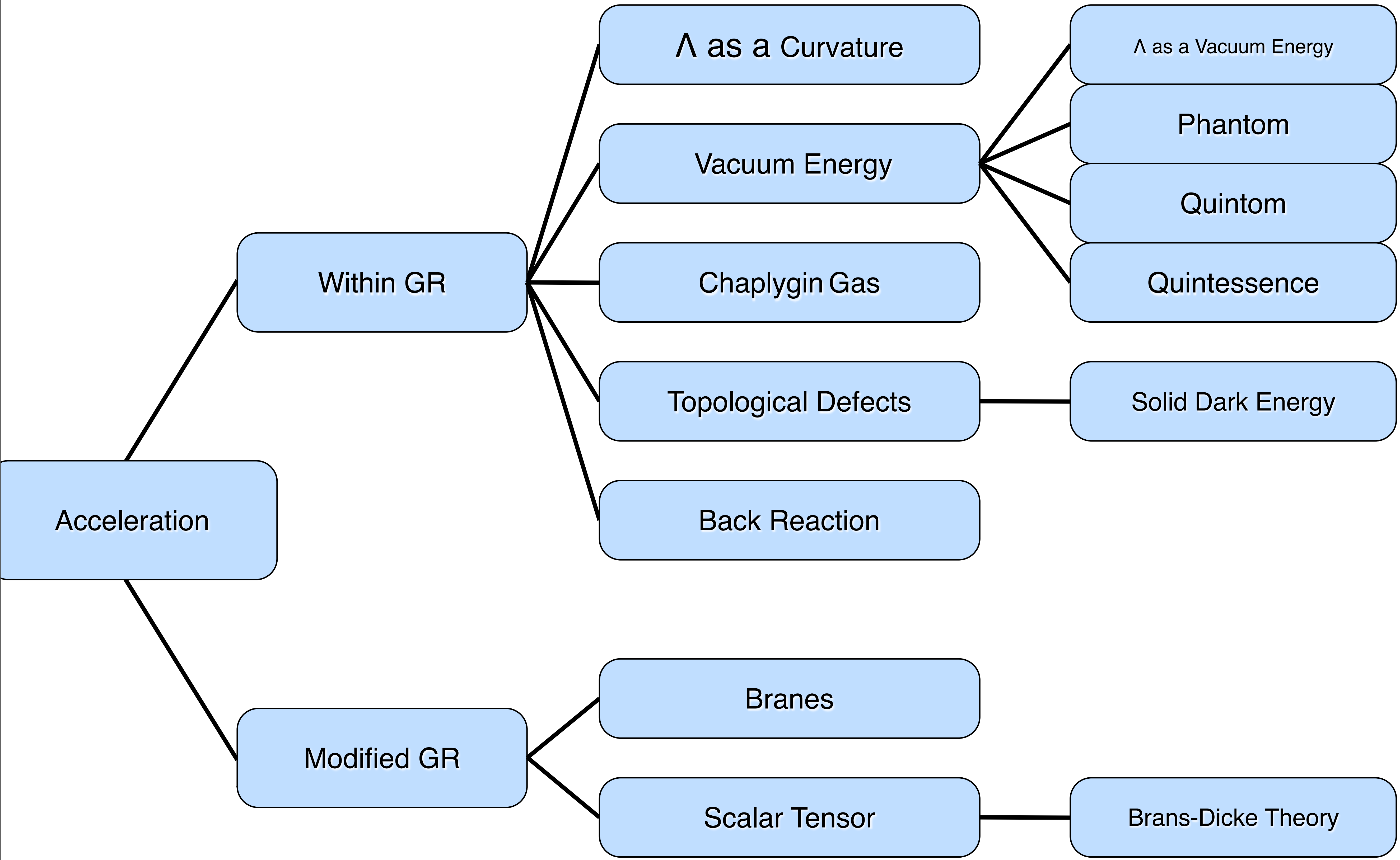


The Cosmological Model

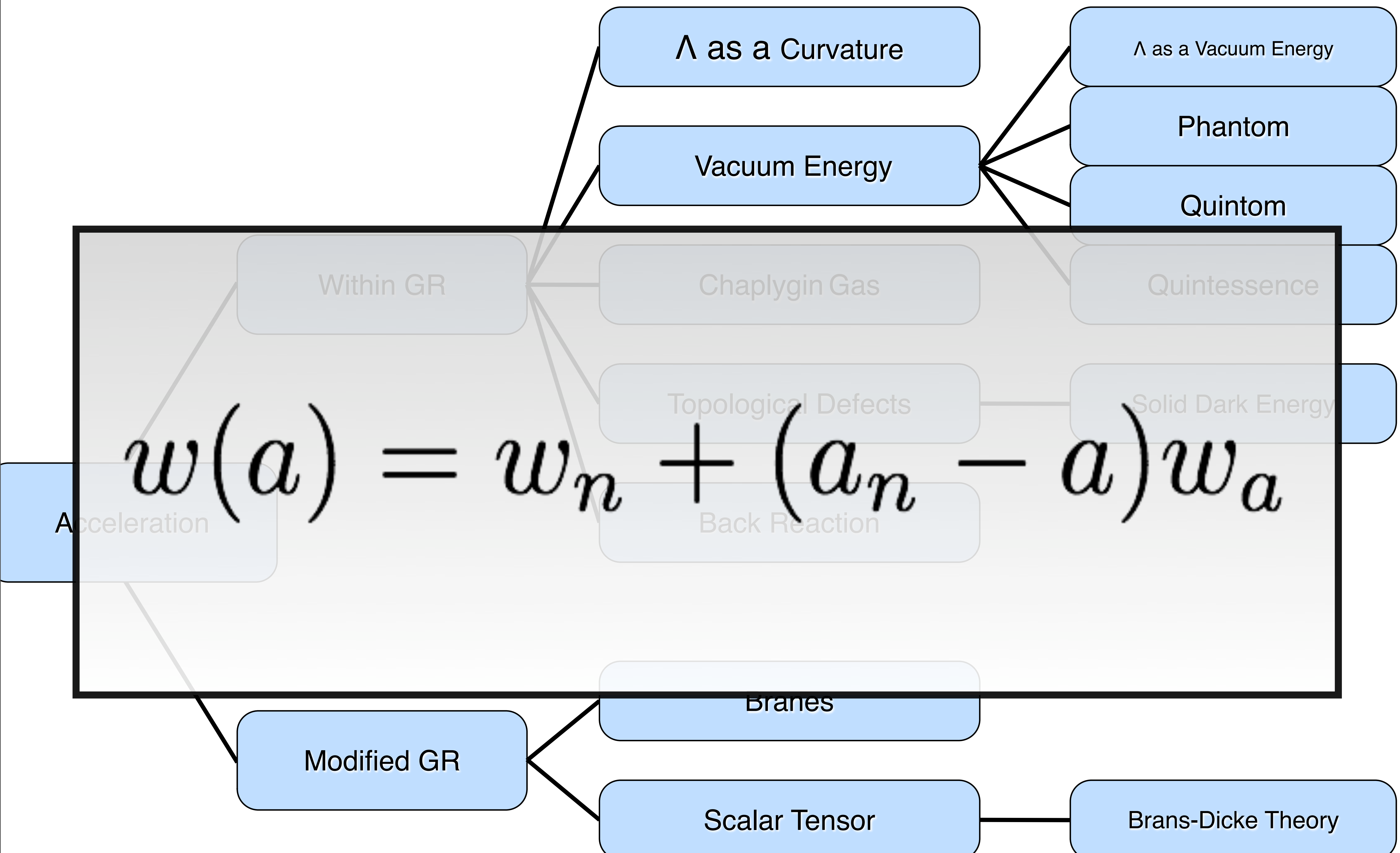


ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

The Dark Energy Zoo



The Dark Energy Zoo



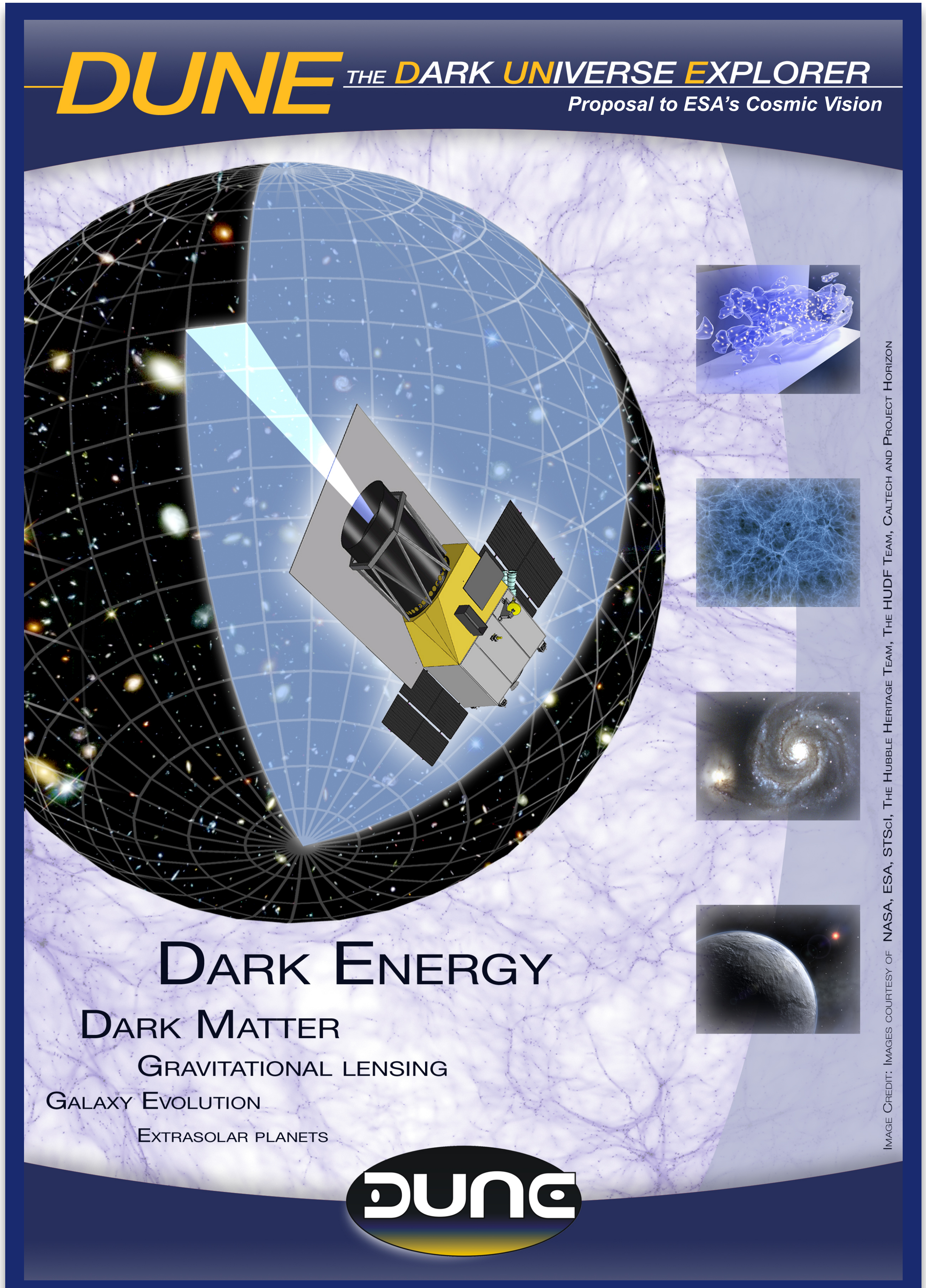
$$w(a) = w_n + (a_n - a)w_a$$

iCosmo:
cosmology for every level

- Repository of web-based resources for cosmology:
  - www.icosmo.org
- Background material on several topics in cosmology
  - (wikipages so still growing)
- Web based cosmology calculations
  - (very easy to use)
- Publically available source code
  - (transparent box - i.e. opposite of black box)

ESA Cosmic Vision

- Calls for both M and L Class missions
- The M class launch in 2017
- Two of the entries in the astronomy category proposed measuring dark energy and dark matter (DUNE and SPACE)
- These were ranked top of the proposals by AWG
  - DUNE - Centered on weak lensing
  - SPACE - Centered on galaxy correlations
- Two missions merged to form Euclid
- Down selection to two M class missions next year


DUNE
THE DARK UNIVERSE EXPLORER
Proposal to ESA's Cosmic Vision
DARK ENERGY
DARK MATTER
GRAVITATIONAL LENSING
GALAXY EVOLUTION
EXTRASOLAR PLANETS
DUNE
IMAGE CREDIT: IMAGES COURTESY OF NASA, ESA, STScI, THE HUBBLE HERITAGE TEAM, THE HUDF TEAM, CALTECH AND PROJECT HORIZON

DUNE (The Dark Universe Explorer) - Space based

- **Consortium for ESA proposal:**
  - France: **Refregier**, Bedered, Boulade, Amara, Mellier, Pain, Aghanim, Puget, Casoli, Astier, Milliard, etc
  - Italy: Scaramella, Maoli, Amendola,etc
  - UK: Peacock, Lahav, Frenck, Silk, Bridle, etc
  - Germany: Schneider, Bender, Walter-Rix, Bartelmann, etc
  - Switzerland: Meylan, Lilly, Seljack, etc
  - US (JPL): Rhodes, Moustakas, Hong, etc, + others ← NIR module
-
- **Steering Committee:**

  Refregier (Chair, France), Peacock (UK), Bridle (UK), Walter-Rix (Germany), Schneider (Germany), Astier (France), Milliard (France), Scaramella (Italy), Moscardini (Italy), Lilly (Switzerland), Meylan (Switzerland), Rhodes (US), Hong (US)

- **Working Groups (coordinators):**
  - Weak lensing: Amara (France), Taylor (UK)
  - Theory: Amendola (Italy), Seljak (Switzerland)
  - Supernovae: Della Valle (Italy), Hook (UK)
  - BAO: Baugh (UK), Castender (Spain)
  - Galaxy evolution: Sommerville (Germany), Carollo (Switzerland)
  - Clusters/CMB: Aghanim (France), Weller (UK)
  - Strong lensing: Bartelmann (Germany), Moustakas (US)
  - Galactic studies: Grebel (Switzerland), Zinnecker (Germany)
  - Photo-z's: Lahav (UK), Fontana (Italy)
  - Image simulations: Rhodes (US), Moscardini (Italy)
- **Instrumental group.**

SPACE - the SPectroscopic All-sky Cosmic Explorer

- Spectroscopic red-shifts of galaxies in extra-galactic sky
- Measure dark energy using galaxy correlation function
- Galaxy spectra allow large number of other science goals
- P.I. A. Cimatti

Euclid

- High quality imaging for weak lensing
- Near Infra-red photometry
- Near Infra-red spectroscopy

- Imagining:
  - CCD focal plane for visible imaging
  - NIR focal plane for Photometry

- Spectrometry
  - DMD for slits
  - spectral resolution R400
  - NIR detectors

Primary Science Goals

Issue	Target
What is Dark Energy	Measure the DE equation of state parameters w_0 and w_a to a precision of 2% and 10%, respectively, using both expansion history and structure growth.
Test of General Relativity	Distinguish General Relativity from the simplest modified-gravity theories, by measuring the growth factor exponent γ with a precision of 2%.
The nature of dark matter	Test the Cold Dark Matter paradigm for structure formation, and measure the sum of the neutrino masses to a precision better than 0.04eV when combined with Planck.
The seeds of cosmic structures	Improve by a factor of 20 the determination of the initial condition parameters compared to Planck alone.

Current Status of Euclid

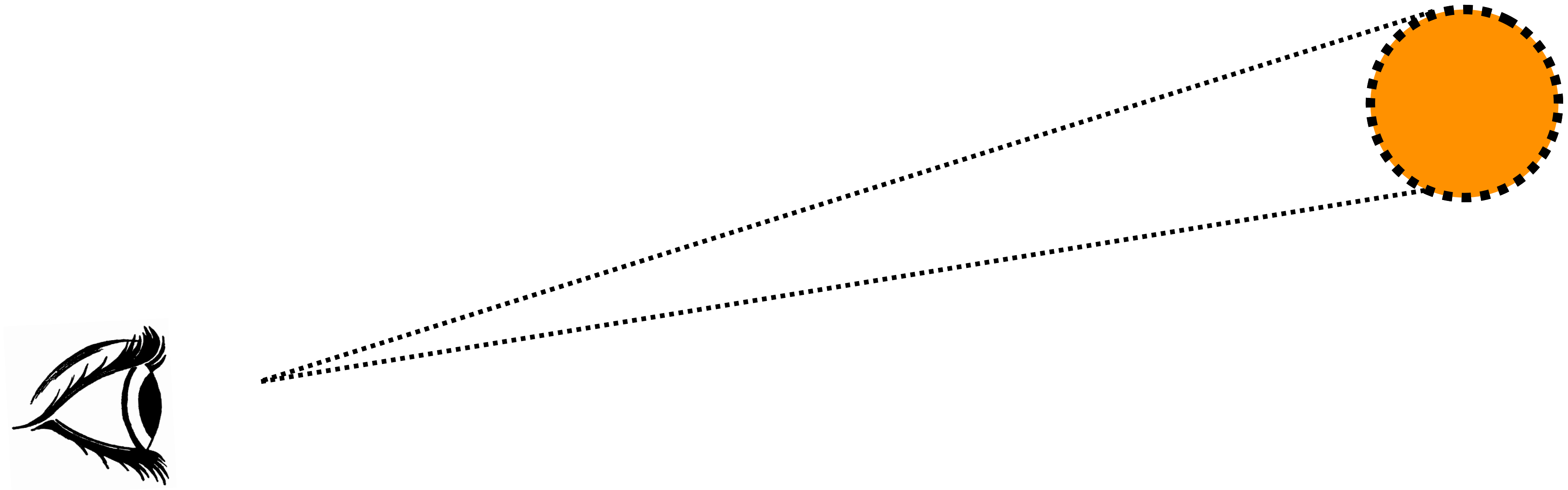
- Entered industrial study phase:
  - Two industry contractors are studying the entire mission
  - Imaging consortium (VIP and NIP) - former DUNE team
  - Spectroscopic consortium (NIS) - former SPACE team
- Teams studying both the science and engineering
- My main focus is weak lensing and the weal lensing requirements.

- Aside: NASA has also placed a dark energy mission as there top priority (JDEM)

Current and Planned Lensing Surveys

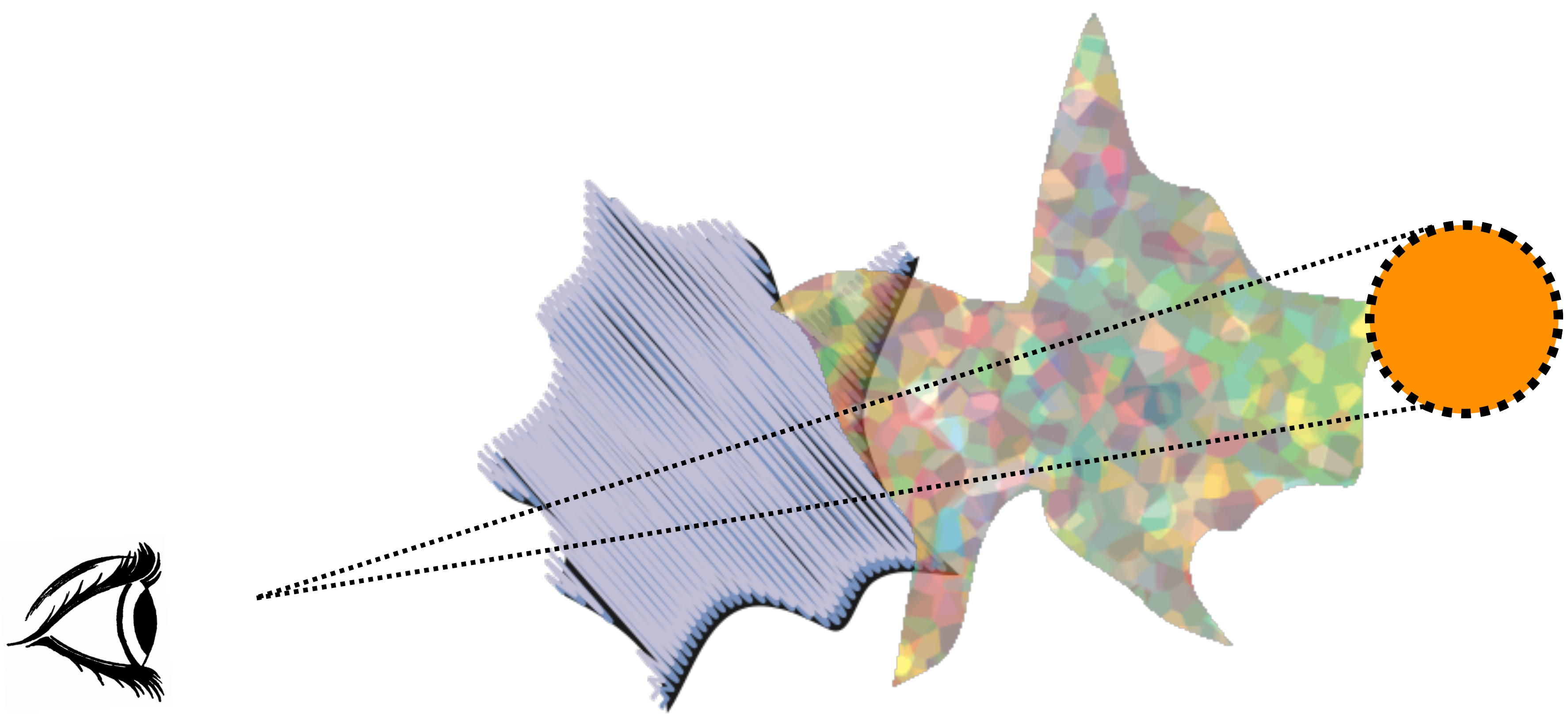
Survey	Diameter (m)	FOV (deg2)	Lensing Area (deg2)	Start (out of date)
DLS	2 x 4	2 x 0.3	28	1999
CFHTLS	3.6	1	172	2003
VST	2.6	1	100	2006
VISTA/Darkcam	4	2	10,000	2008?
DES	4	2.2	5,000	2008
Pan-STARRS	4 x 1.8	4 x 4	20,000	2008
LSST	8.4	7	20,000	2012
DUNE	1.2 → 1.5	0.5	20,000	2015
JDEM	2.0 → 1.8	0.7	1,000 ?	2013-2018

Basics of Gravitational Lensing



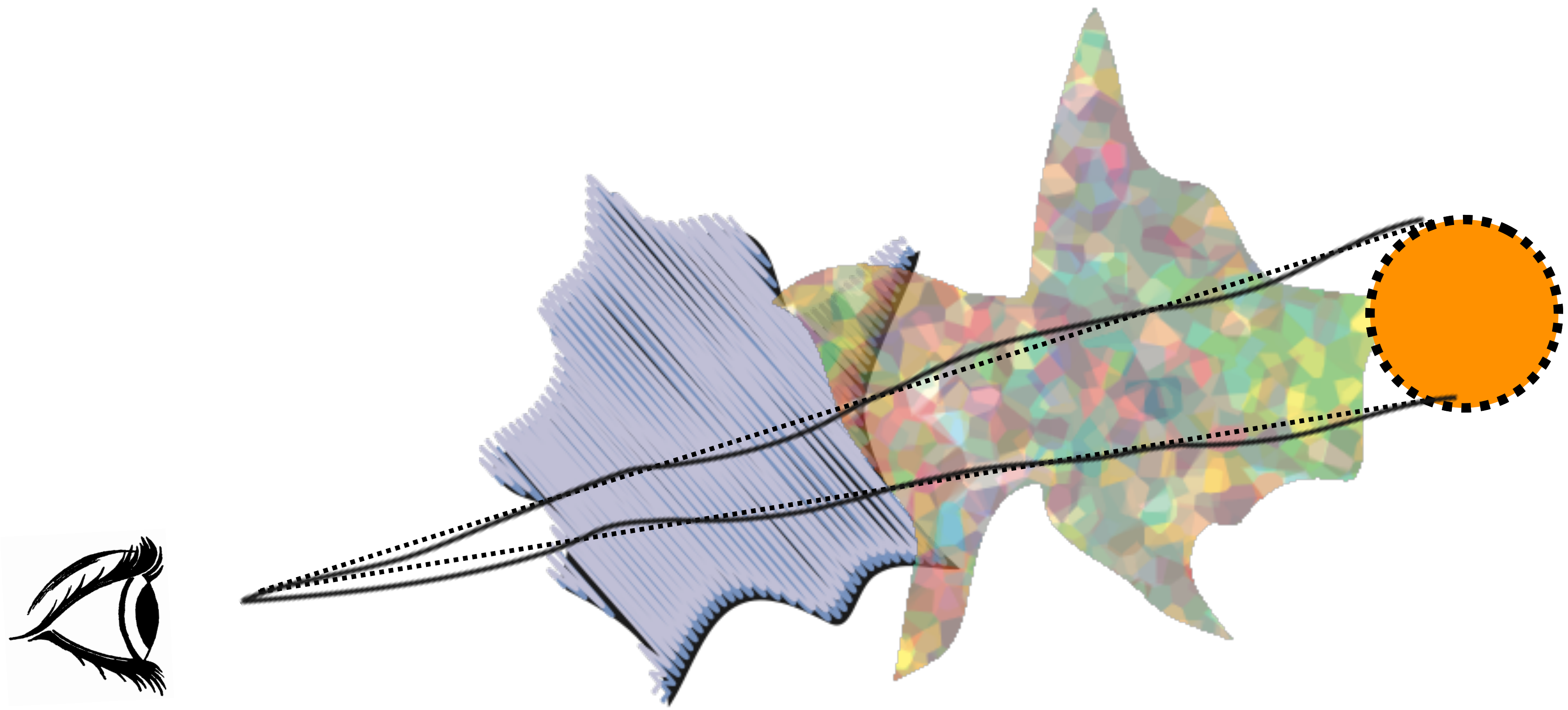
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Basics of Gravitational Lensing



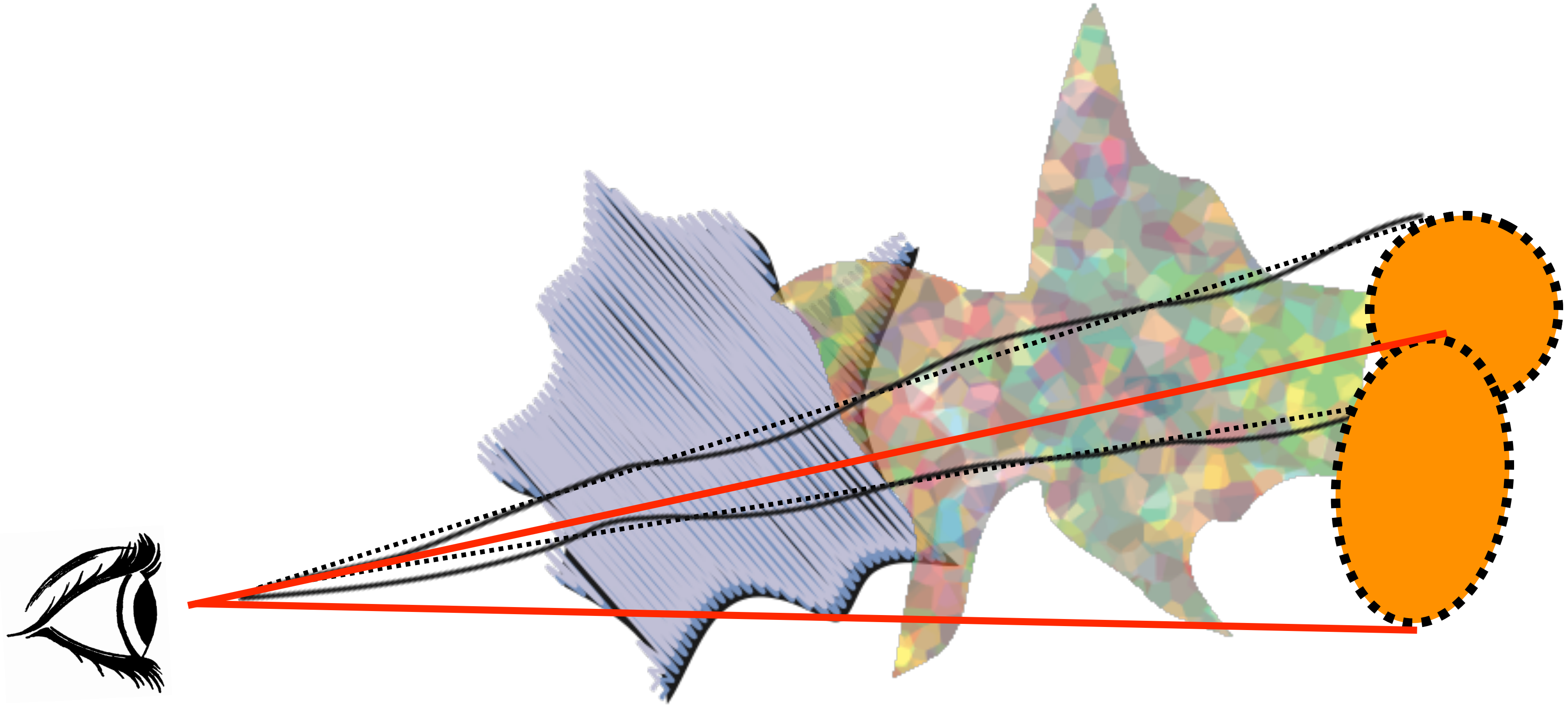
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Basics of Gravitational Lensing



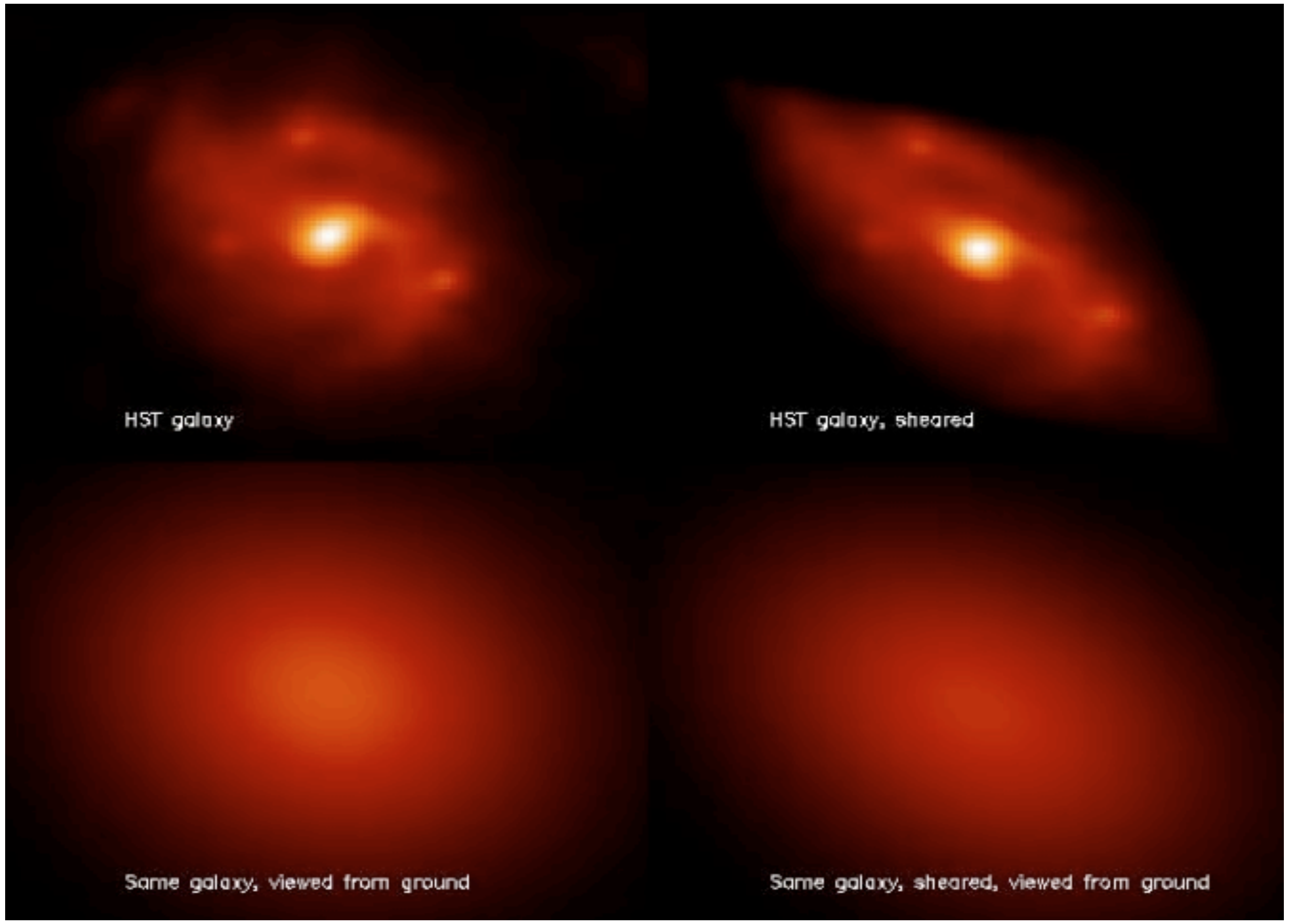
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

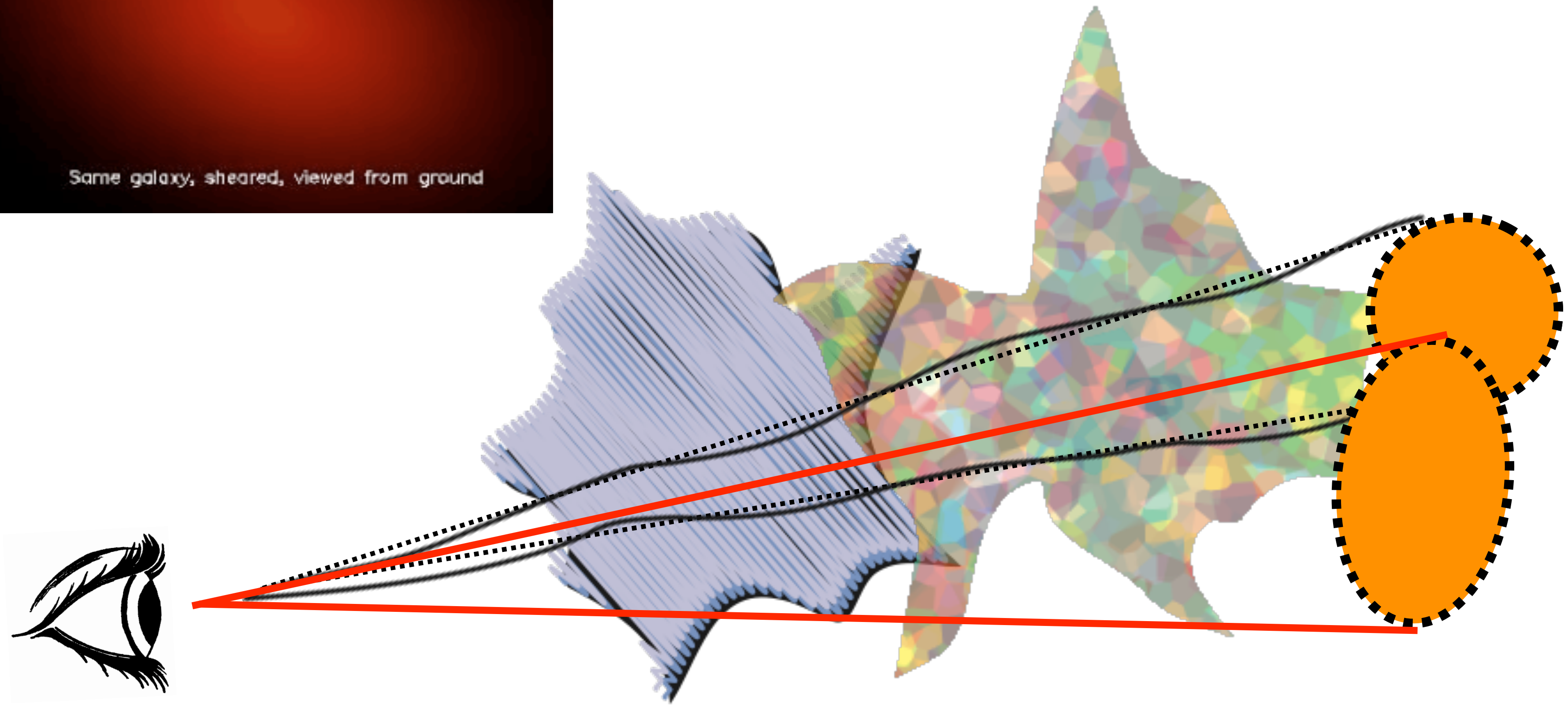
Basics of Gravitational Lensing



ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

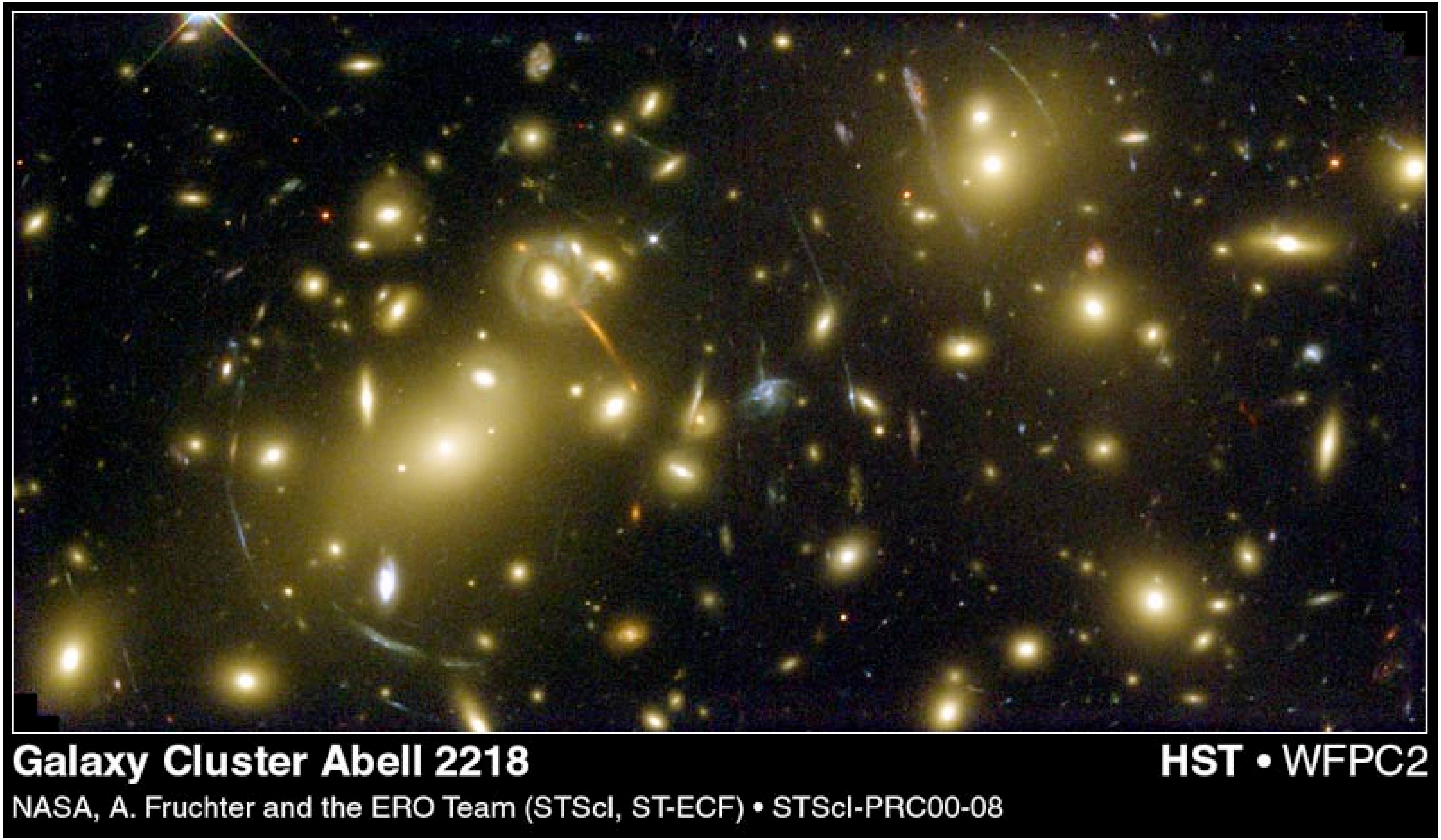
Basics of Gravitational Lensing



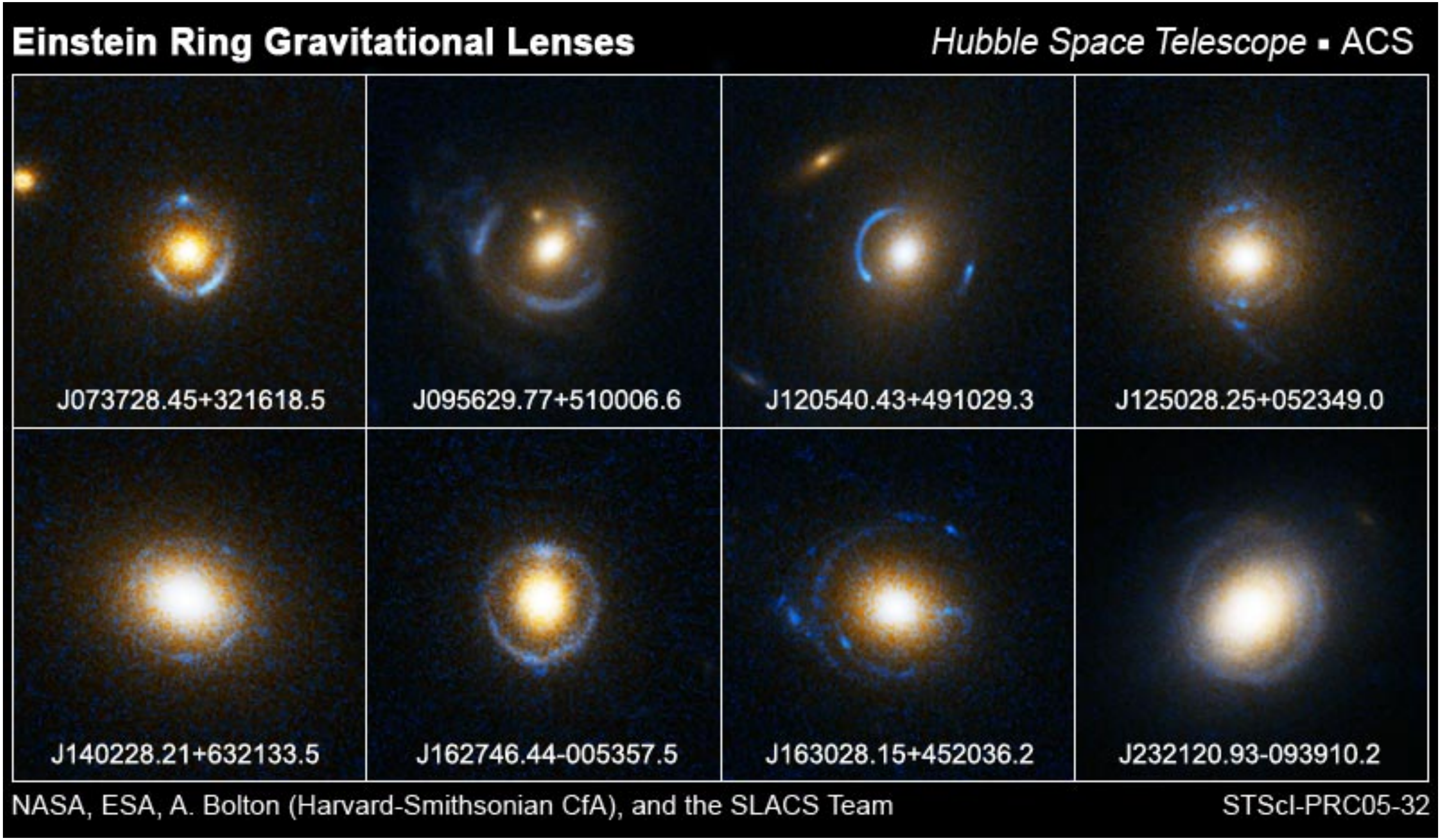


ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Lensing examples: Giant Arcs



Lensing examples: Einstein Rings



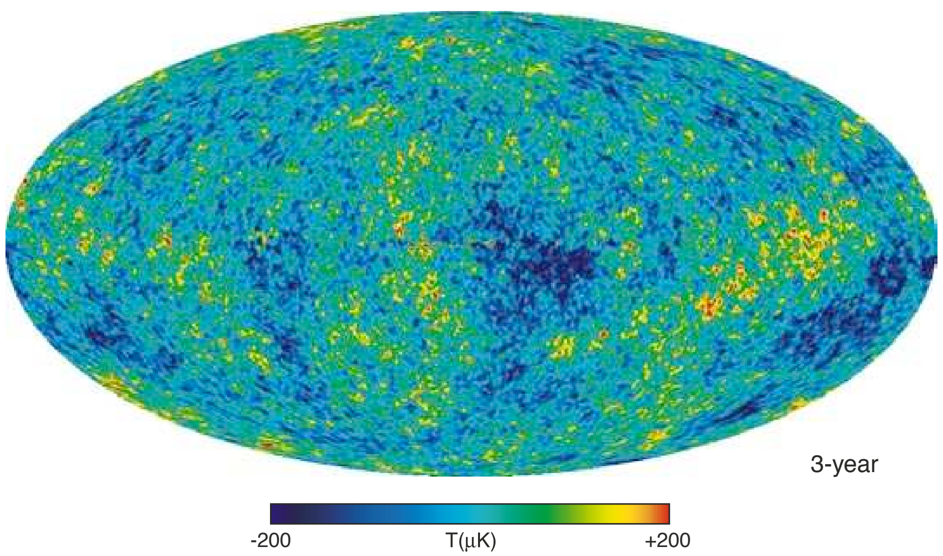
Lensing examples: Cosmic Lensing/Weak Shear

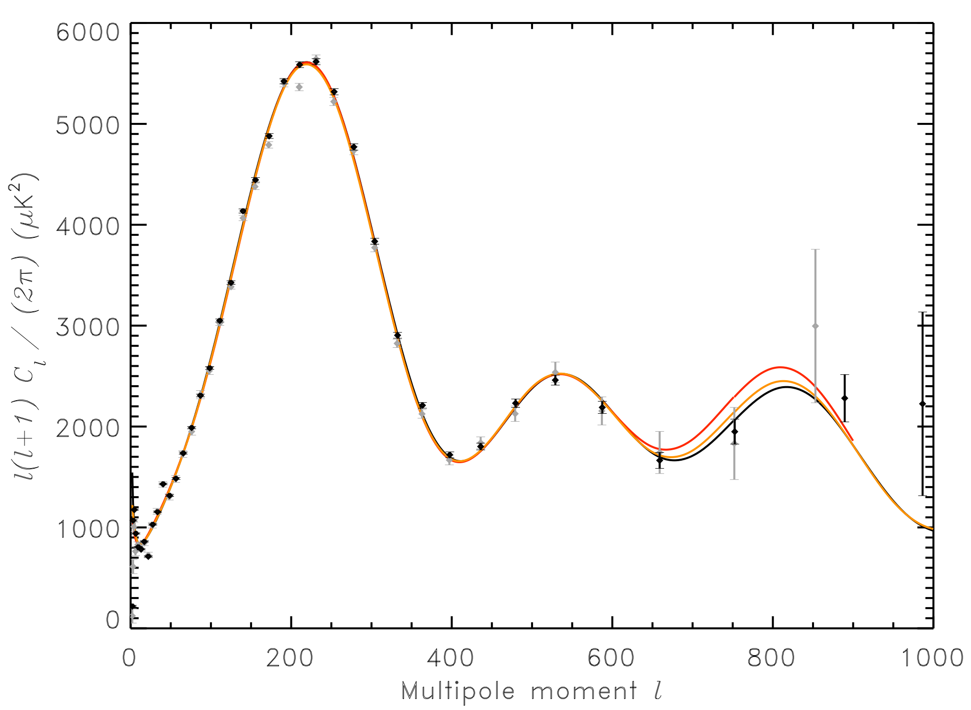
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Temperature map

WMAP 3 year data

CMB

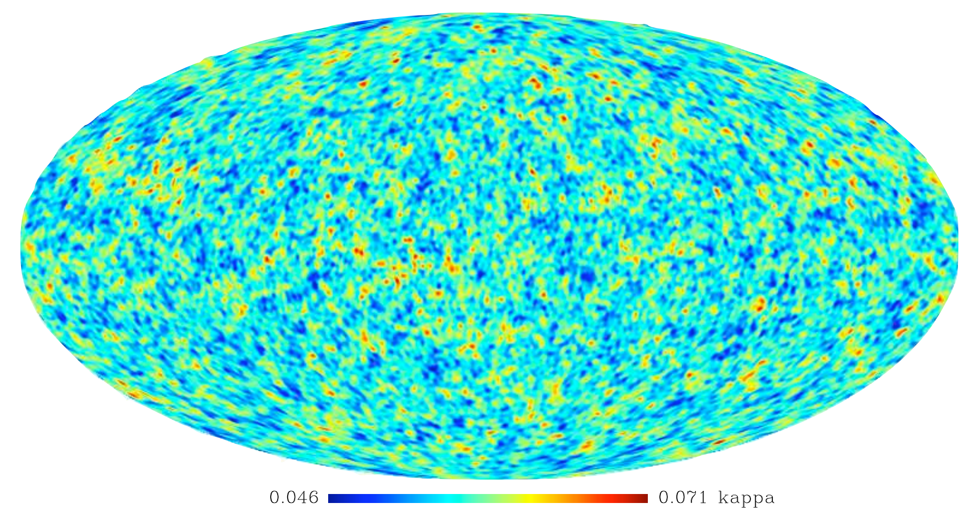


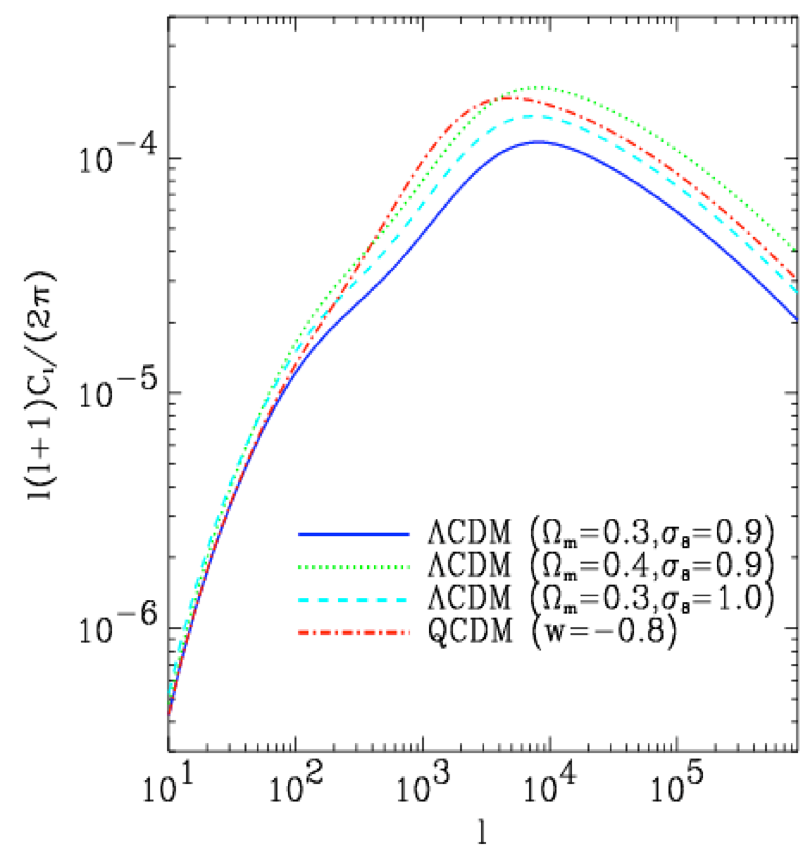


Mass map

Simulated DUNE data
(simulations by Tessyier et al)

Cosmic Shear

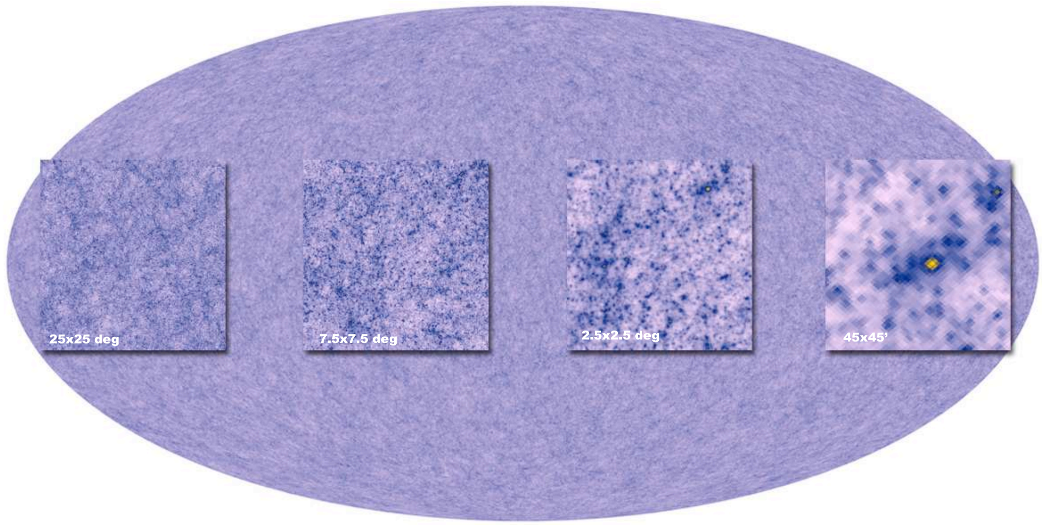




ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

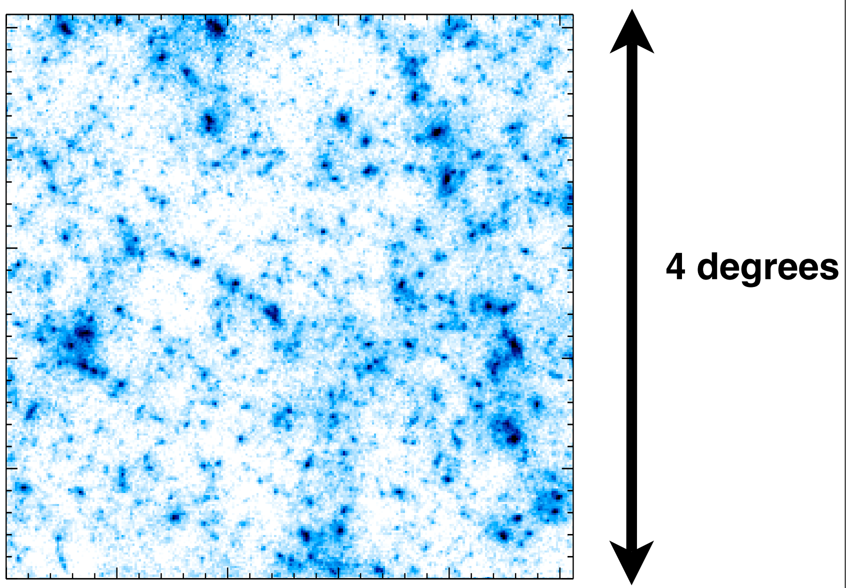
Summary: Lensing on All Scales

- **All Sky** Kappa Map
- 1 Ultra-large simulation
- Born approximation



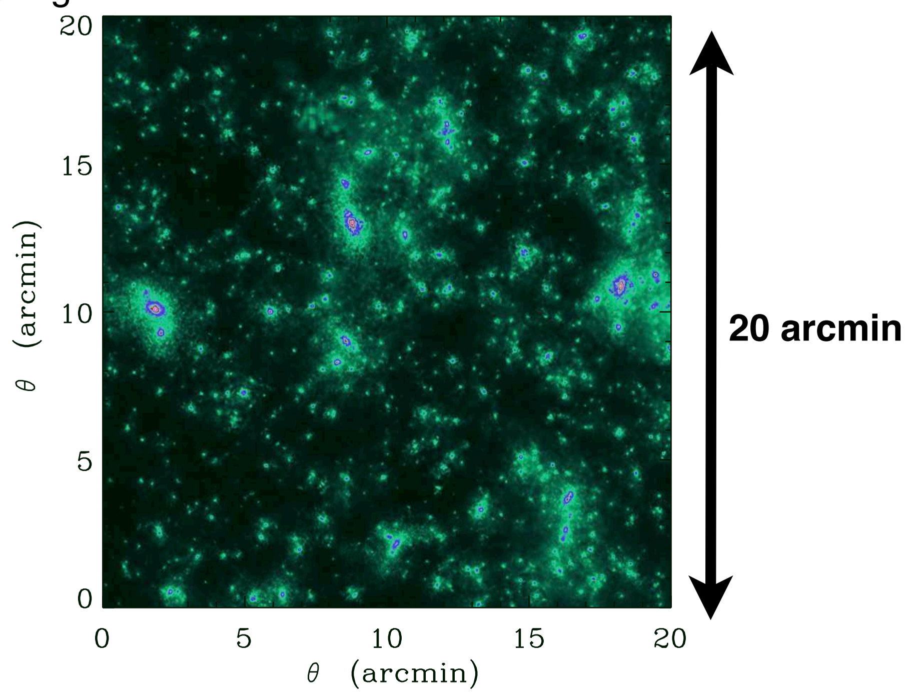
Teyssier et al

- Intermediate scale
- Set of simulations (few hundred)
- Born approximation

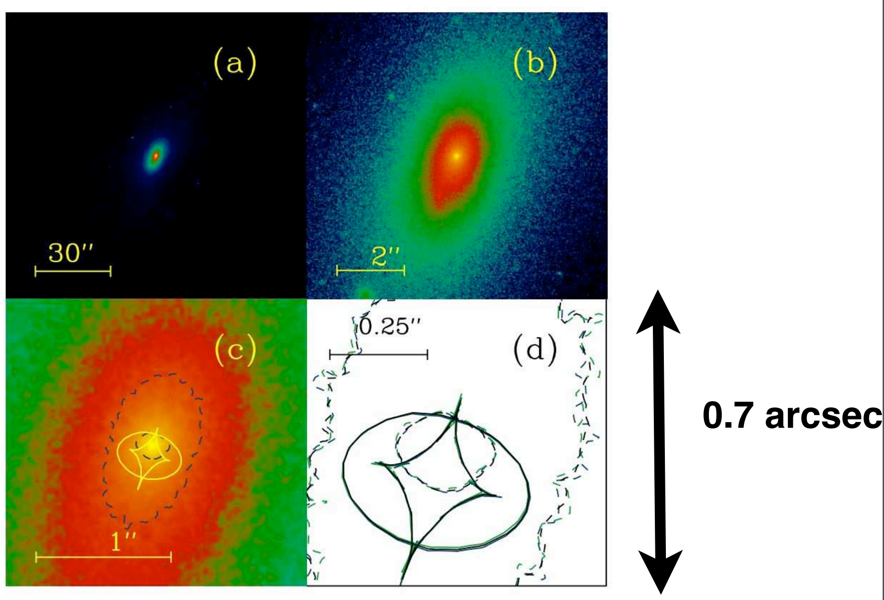


Pires et al

- Small scale weak lensing
- Multiple sheet ray shooting
- Baryons important



- Very Small Scale - Strong lensing
- Ray shooting
- Image finding
- Baryons crucial

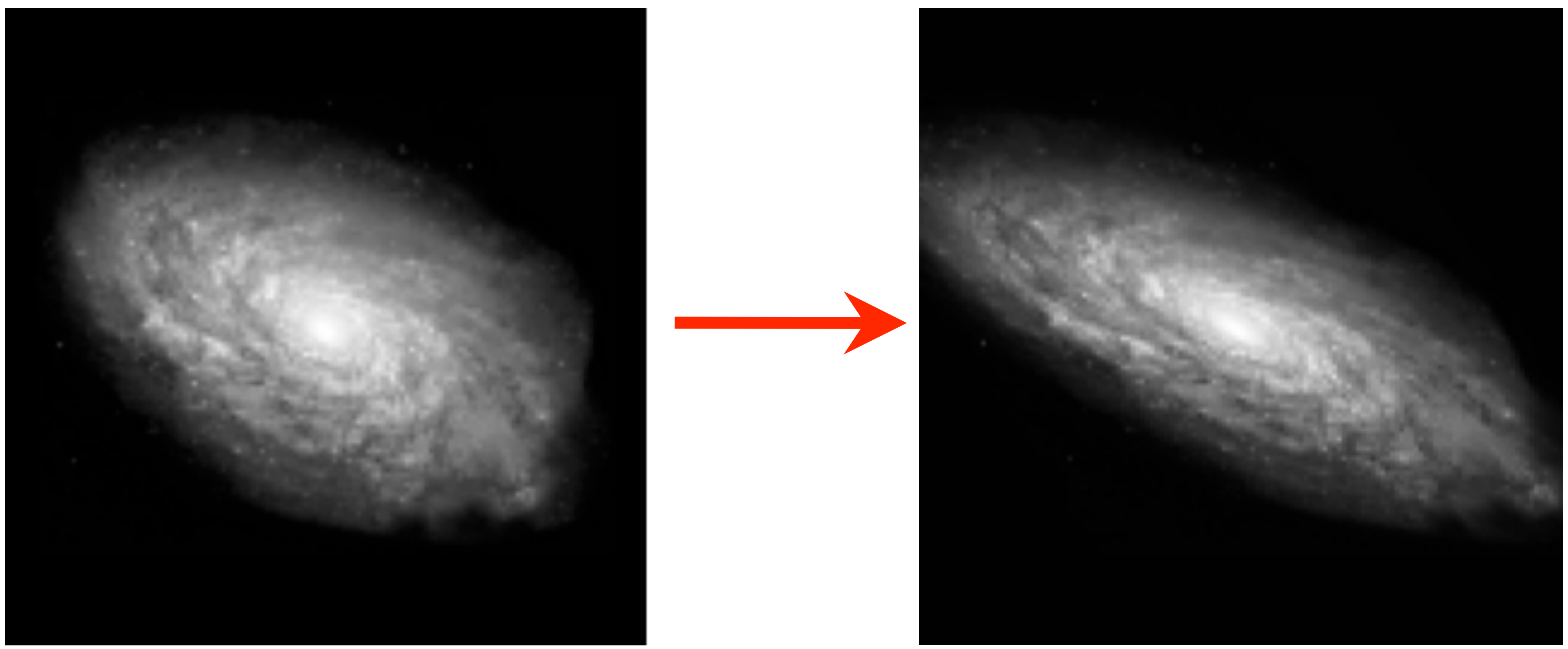


Following slides from Sarah Bridle

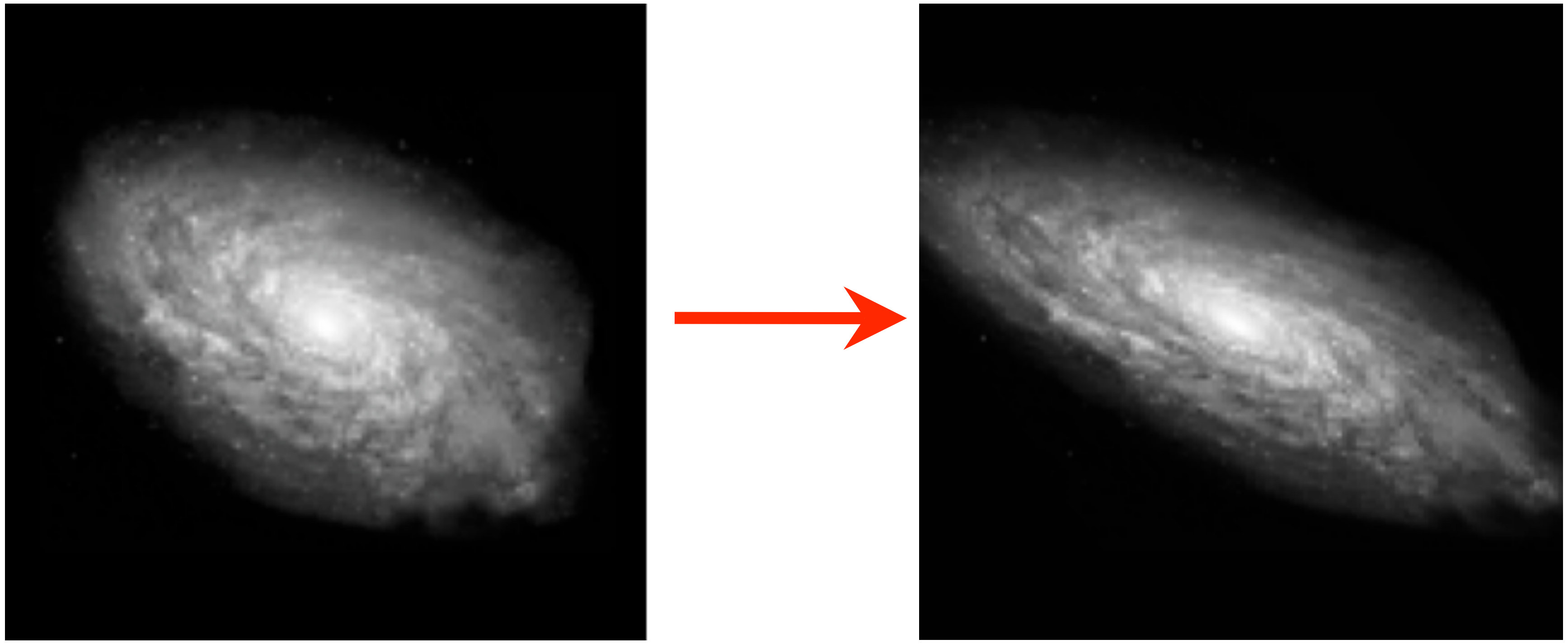
By Sarah Bridle[1], John Shawe-Taylor[1], Adam Amara[2], Douglas Applegate[3], Sreekumar T. Balan[1], Joel Berge[4,5,6], Gary Bernstein[7], Hakon Dahle[8], Thomas Erben[9], Mandeep Gill[10], Alan Heavens[11], Catherine Heymans[12,19], Will High[13], Henk Hoekstra[14], Mike Jarvis[7], Donnacha Kirk[1], Thomas Kitching[15], Jean-Paul Kneib[8], Konrad Kuijken[16], David Lagatutta[17], Rachel Mandelbaum[18], Richard Massey[5], Yannick Mellier[19], Baback Moghaddam[4,5], Yassir Moudden[6], Reiko Nakajima[7], Stephane Paulin-Henriksson[6], Sandrine Pires[6], Anais Rassat[6], Alexandre Refregier[6], Jason Rhodes[4,5], Tim Schrabback[16], Elisabetta Semboloni[9], Marina Shmakova[3], Ludovic van Waerbeke[12], Dugan Witherick[1], Lisa Voigt[1], and David Wittman[17].

[1]*University College London*, [2]*University of Hong Kong*, [3]*Stanford Linear Accelerator Center*, [4]*Jet Propulsion Laboratory*, [5]*California Institute of Technology*, [6]*Commissariat a l'Energie Atomique, Saclay*, [7]*University of Pennsylvania*, [8]*Laboratoire dAstrophysique de Marseille*, [9]*University of Bonn*, [10]*Ohio State University*, [11]*Royal Observatory, University of Edinburgh*, [12]*University of British Columbia*, [13]*Harvard University*, [14]*University of Victoria*, [15]*University of Oxford*, [16]*University of Leiden*, [17]*University of California, Davis*, [18]*Institute for Advanced Study, Princeton* and [19]*Institut d'Astrophysique de Paris*

Cosmic Lensing

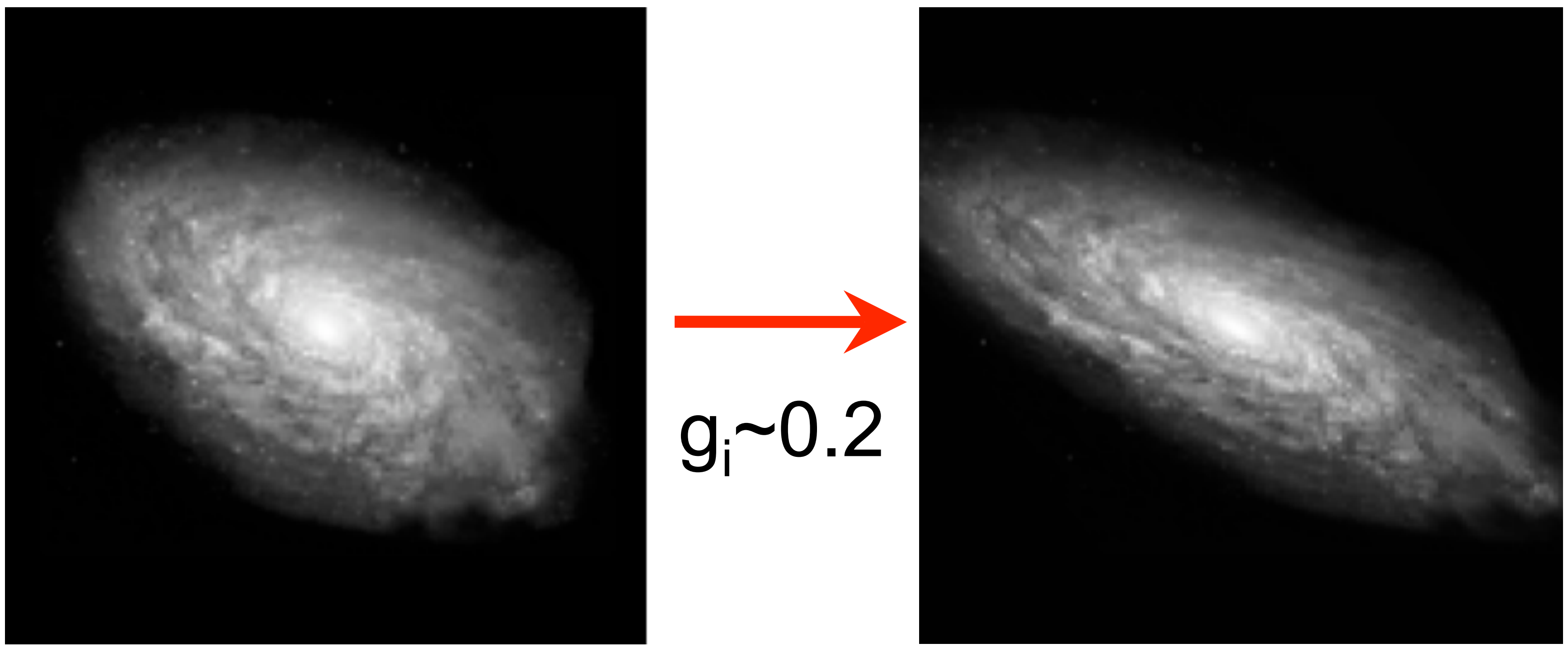


Cosmic Lensing



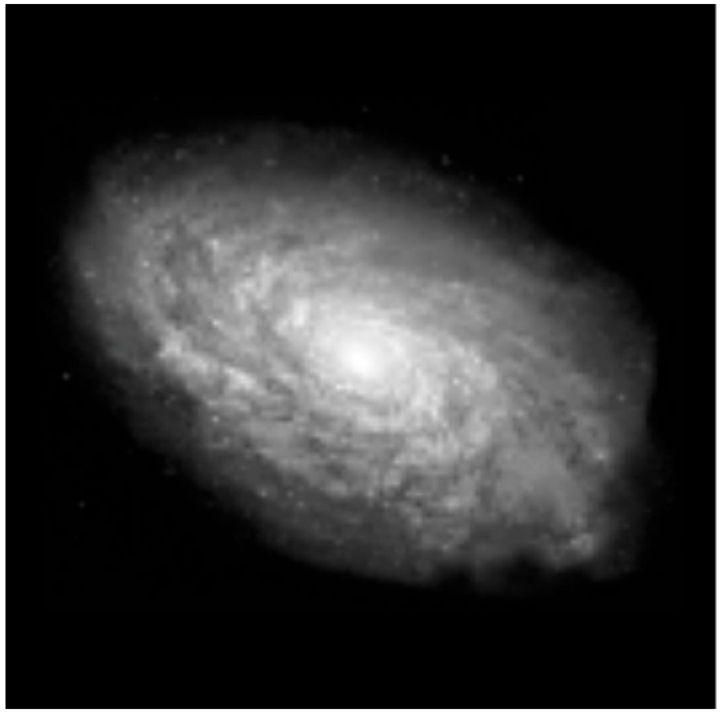
$$\begin{pmatrix} x_u \\ y_u \end{pmatrix} = \begin{pmatrix} 1-g_1 & -g_2 \\ -g_2 & 1+g_1 \end{pmatrix} \begin{pmatrix} x_l \\ y_l \end{pmatrix}$$

Cosmic Lensing

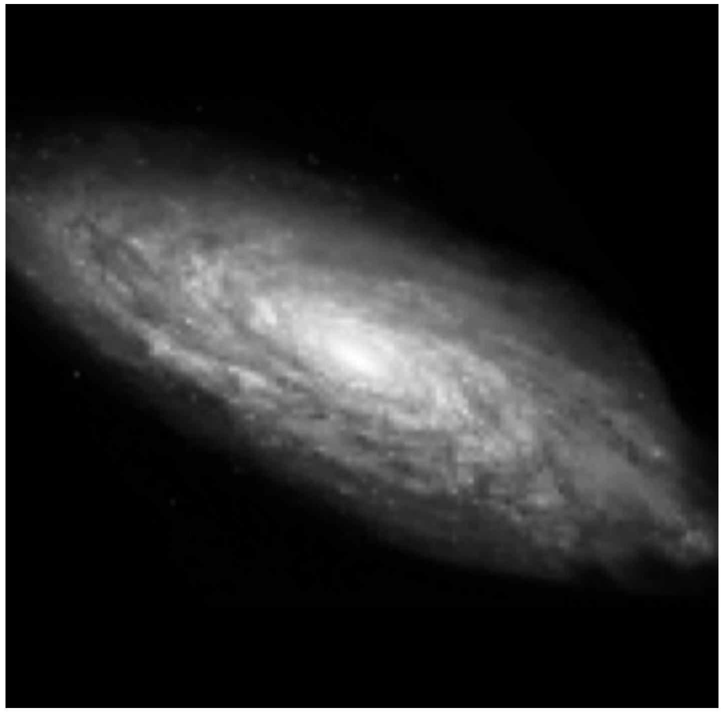


$$\begin{pmatrix} x_u \\ y_u \end{pmatrix} = \begin{pmatrix} 1-g_1 & -g_2 \\ -g_2 & 1+g_1 \end{pmatrix} \begin{pmatrix} x_l \\ y_l \end{pmatrix}$$

Cosmic Lensing



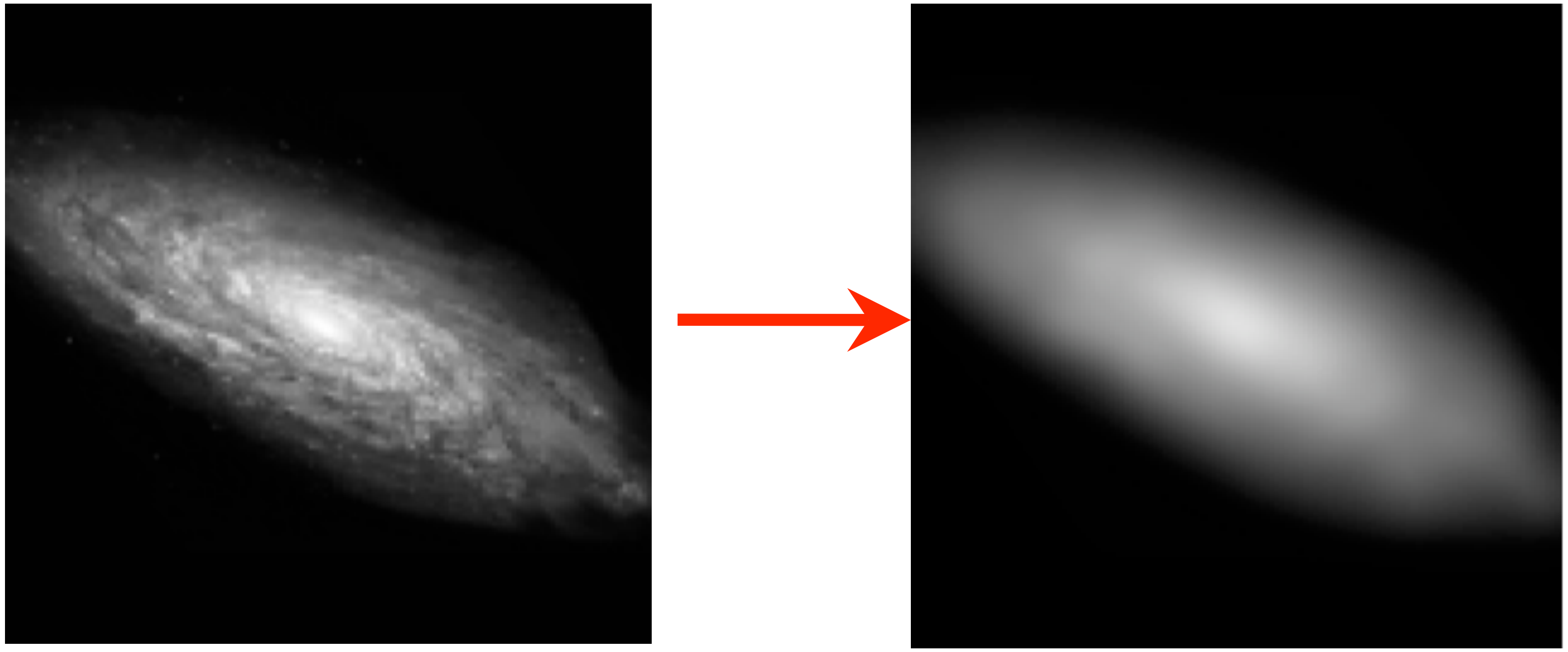
g_i~0.2



$$\begin{pmatrix} x_u \\ y_u \end{pmatrix} = \begin{pmatrix} 1-g_1 & -g_2 \\ -g_2 & 1+g_1 \end{pmatrix} \begin{pmatrix} x_l \\ y_l \end{pmatrix}$$

Real data:
g_i~0.03

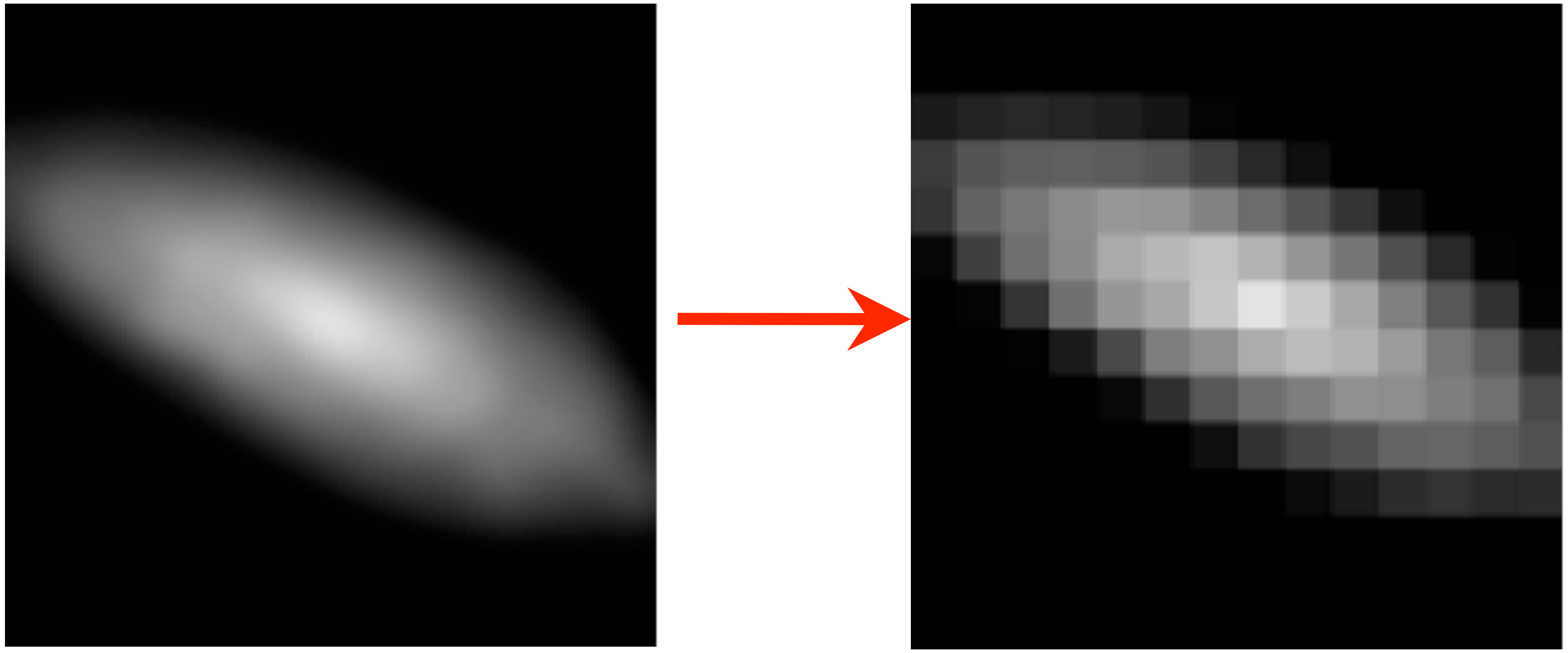
Atmosphere and Telescope



Convolution with kernel

Real data: Kernel size ~ Galaxy size

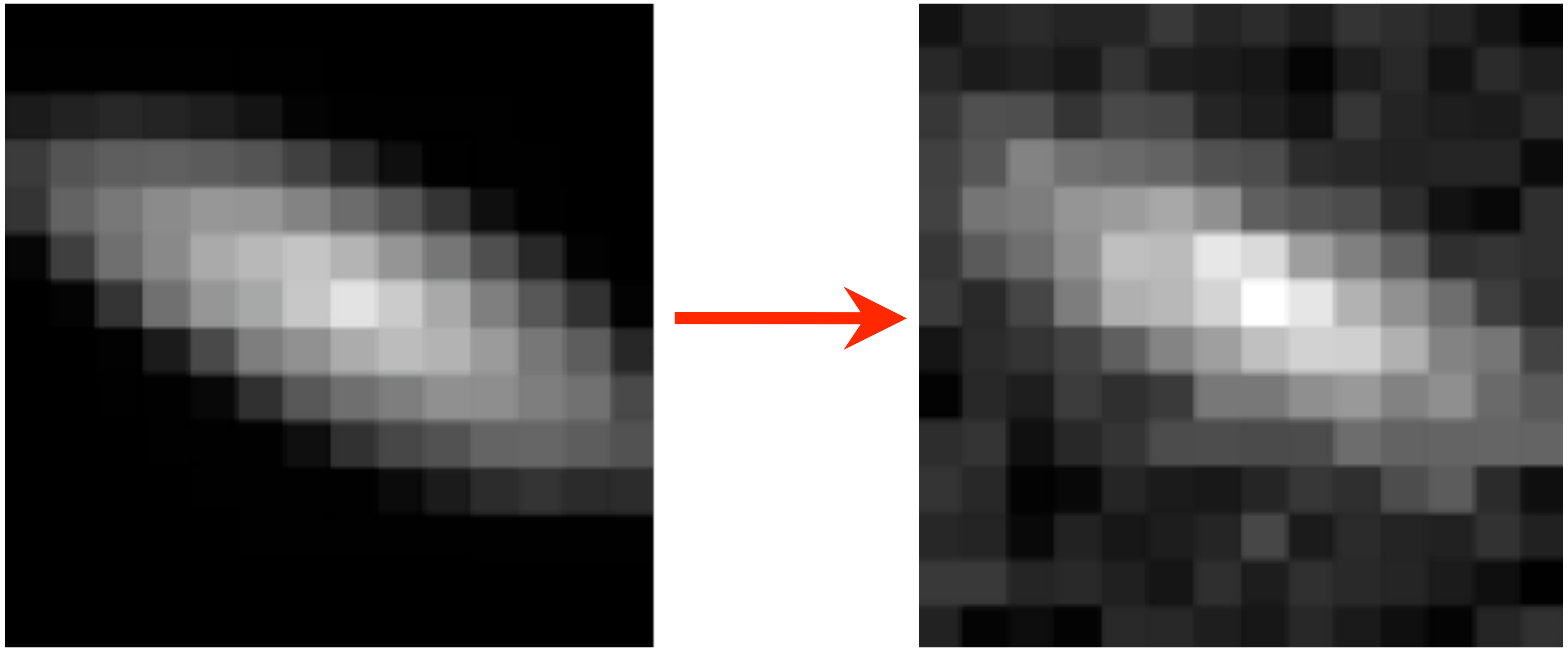
Pixelisation



Sum light in each square

Real data: Pixel size ~ Kernel size /2

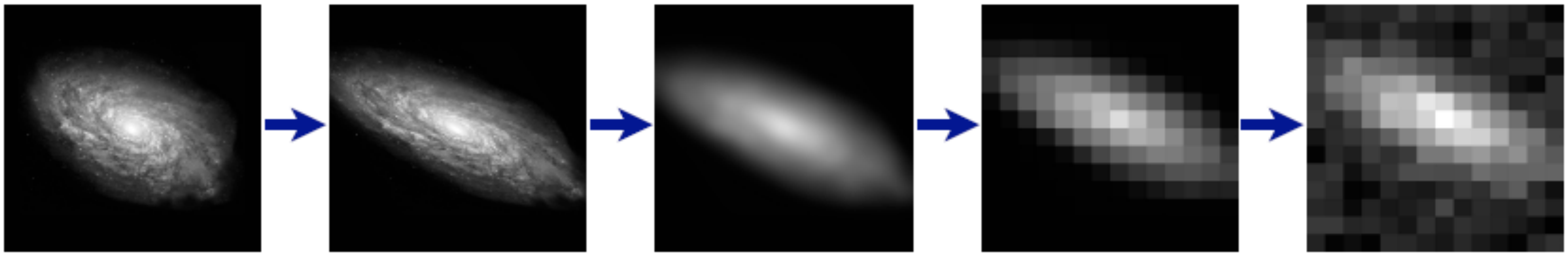
Noise



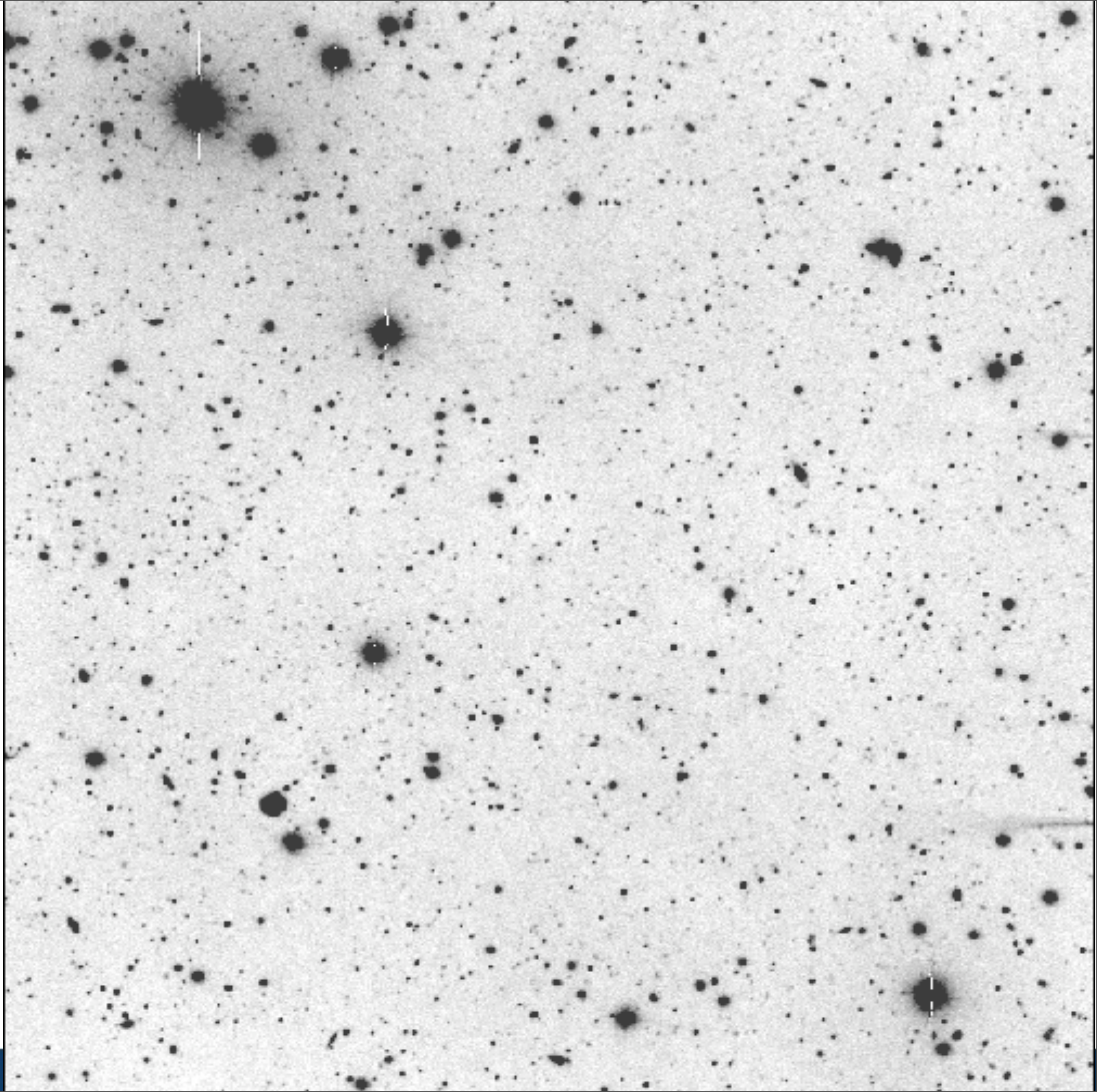
Mostly Poisson. Some Gaussian and bad pixels.
Uncertainty on total light ~ 5 per cent

The Forward Process.

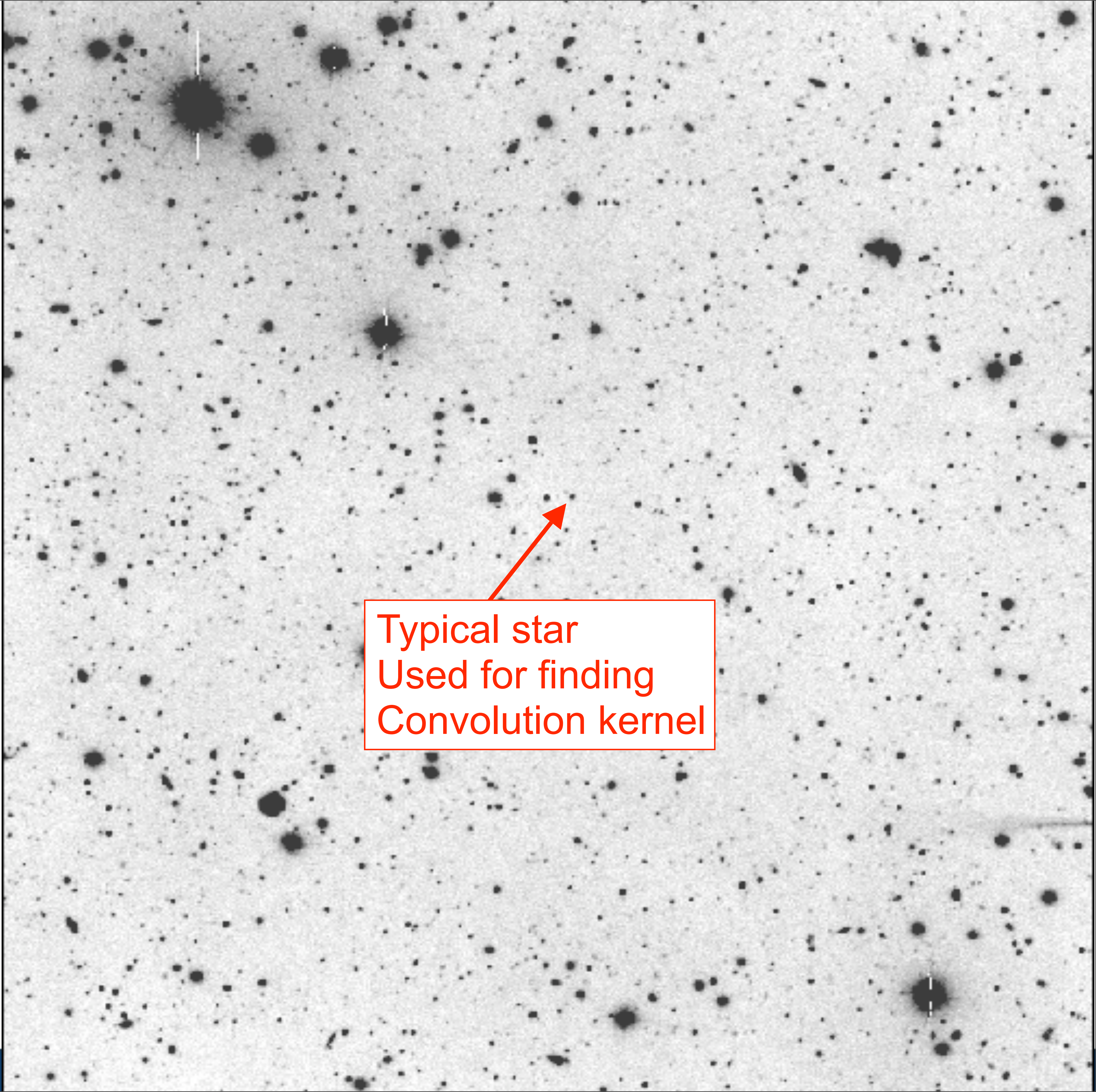
Galaxies: Intrinsic galaxy shapes to measured image:

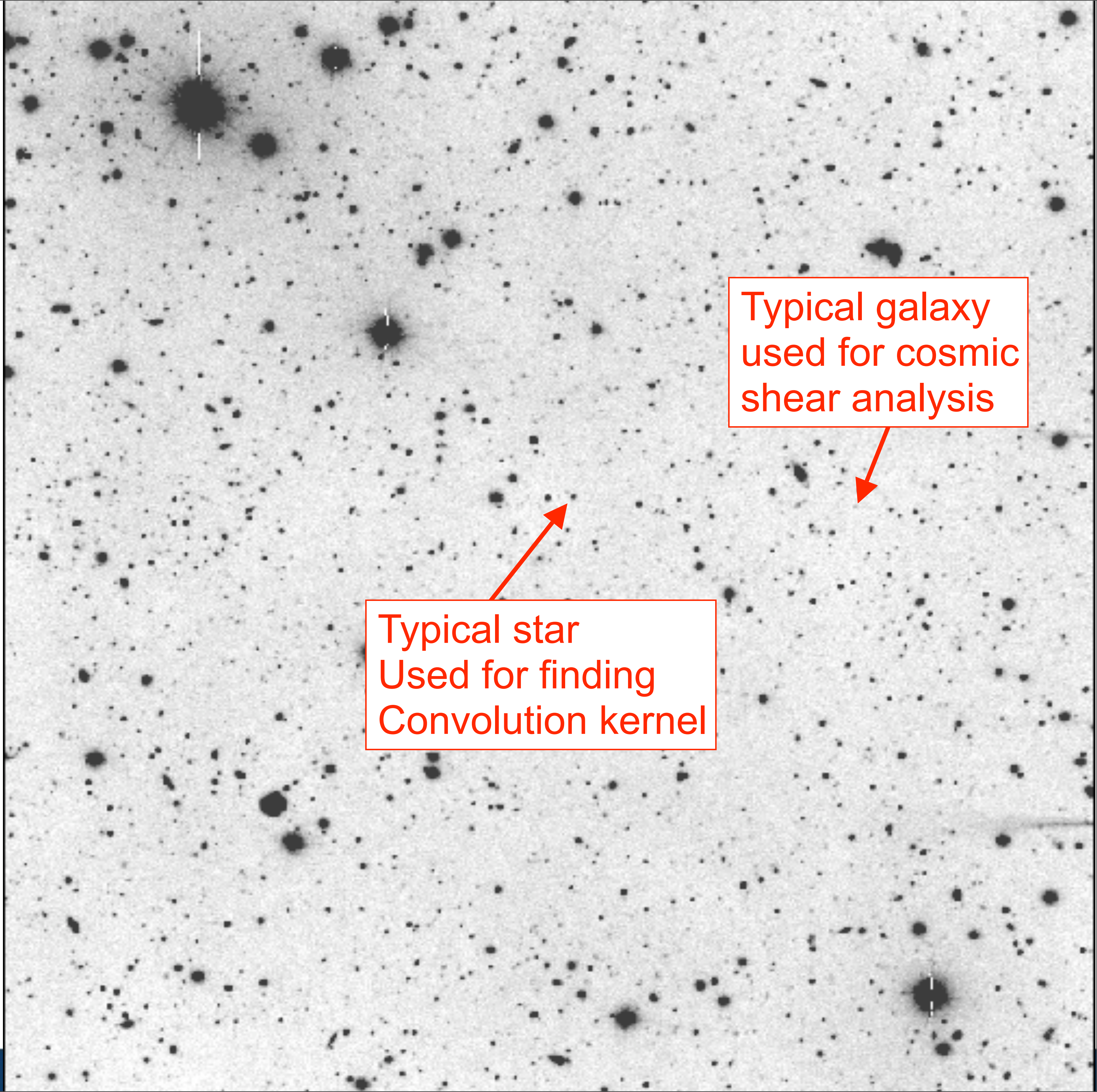


Intrinsic galaxy (shape unknown) → Gravitational lensing causes a ***shear (g)*** → Atmosphere and telescope cause a convolution → Detectors measure a pixelated image → Image also contains noise



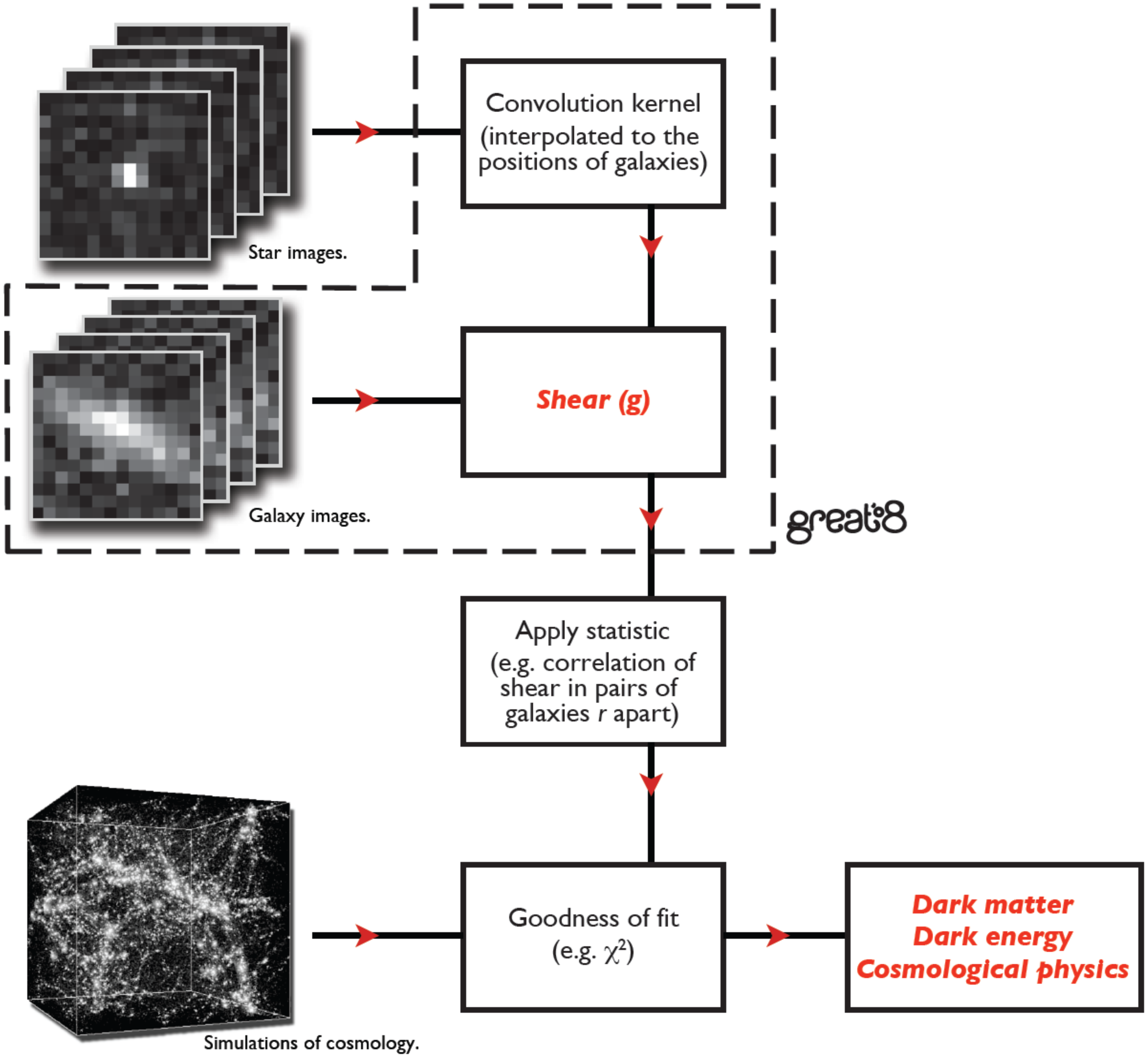
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich




Typical galaxy
used for cosmic
shear analysis
Typical star
Used for finding
Convolution kernel

A full weak lensing pipeline:

The broader context typical for cosmological measurements



GREAT08 Data

	True shears provided	Blind competition
Low noise	GREAT08 LowNoise-Known	GREAT08 LowNoise-Blind
Realistic noise	GREAT08 RealNoise-Known	GREAT08 RealNoise-Blind

One galaxy per image
Kernel is given
One shear per set
Noise is Poisson

GREAT08 Data

	True shears provided	Blind competition
Low noise	GREAT08 LowNoise-Known	GREAT08 LowNoise-Blind
Realistic noise	GREAT08 RealNoise-Known	GREAT08 RealNoise-Blind

150 000 galaxies

One galaxy per image
Kernel is given
One shear per set
Noise is Poisson

GREAT08 Data

	True shears provided	Blind competition
Low noise	GREAT08 LowNoise-Known	GREAT08 LowNoise-Blind
Realistic noise	GREAT08 RealNoise-Known	GREAT08 RealNoise-Blind

150 000 galaxies

3 000 000 galaxies

One galaxy per image
Kernel is given
One shear per set
Noise is Poisson

GREAT08 Data

	True shears provided	Blind competition
Low noise	GREAT08 LowNoise-Known	GREAT08 LowNoise-Blind
Realistic noise	GREAT08 RealNoise-Known	GREAT08 RealNoise-Blind

150 000 galaxies

3 000 000 galaxies

150 000 galaxies

One galaxy per image
Kernel is given
One shear per set
Noise is Poisson

GREAT08 Data

	True shears provided	Blind competition
Low noise	GREAT08 LowNoise-Known	GREAT08 LowNoise-Blind
Realistic noise	GREAT08 RealNoise-Known	GREAT08 RealNoise-Blind

150 000 galaxies

3 000 000 galaxies

150 000 galaxies

27 000 000 galaxies

One galaxy per image
Kernel is given
One shear per set
Noise is Poisson

GREAT08 Data

	True shears provided	Blind competition
Low noise	GREAT08 LowNoise-Known	GREAT08 LowNoise-Blind
Realistic noise	GREAT08 RealNoise-Known	GREAT08 RealNoise-Blind

150 000 galaxies

3 000 000 galaxies

150 000 galaxies

27 000 000 galaxies

One galaxy per image
Kernel is given
One shear per set
Noise is Poisson

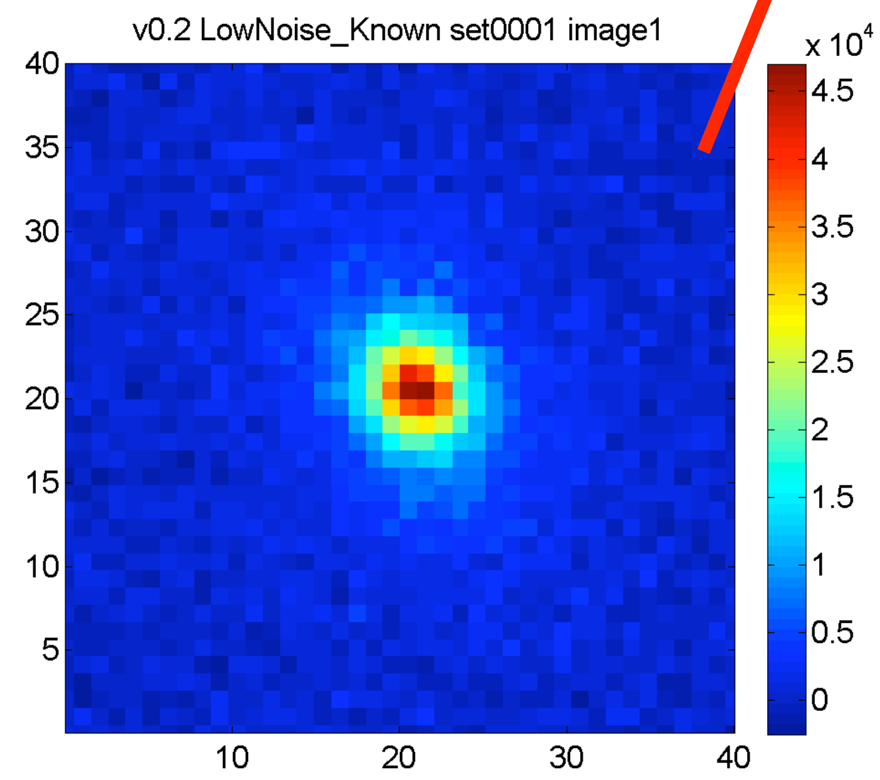
All divided into sets containing 10 000 galaxies each

GREAT08 Data

	True shears provided	Blind competition
Low noise	GREAT08 LowNoise-Known	GREAT08 LowNoise-Blind
Realistic noise	GREAT08 RealNoise-Known	GREAT08 RealNoise-Blind

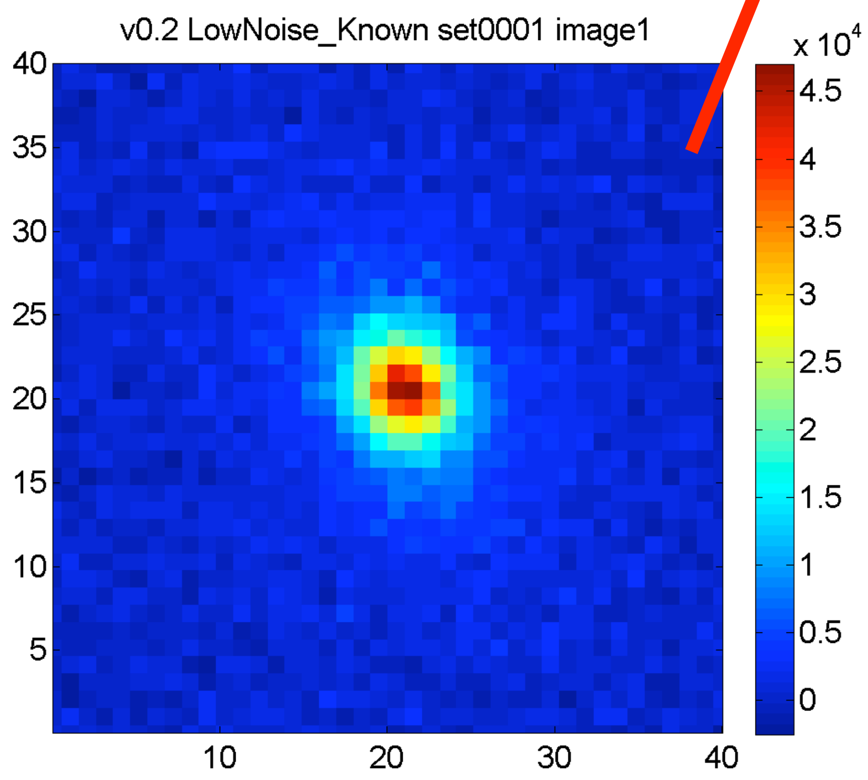
GREAT08 Data

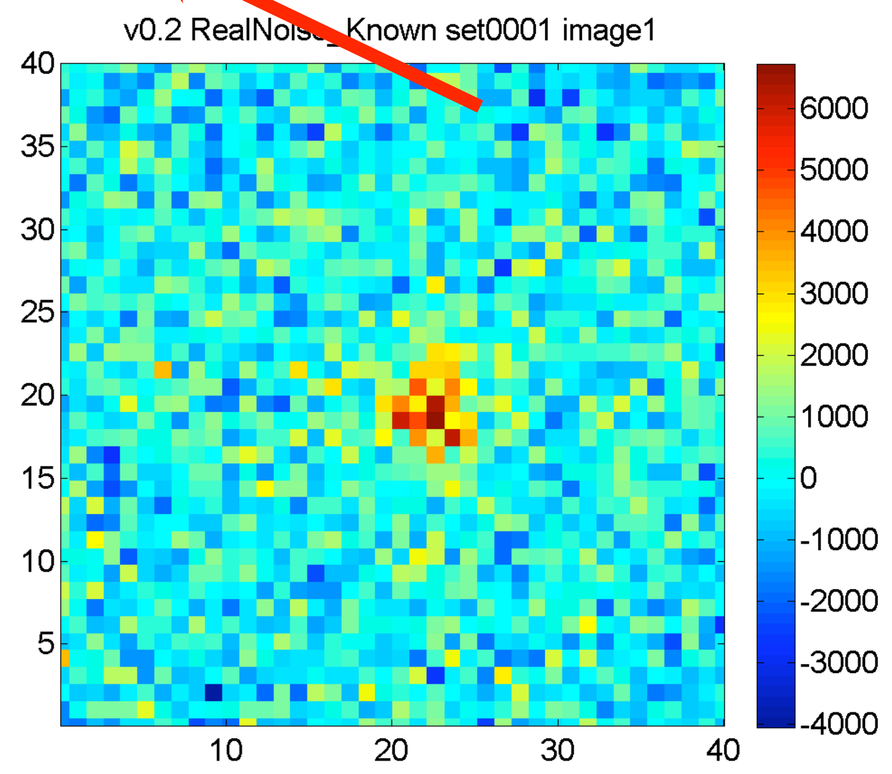
	True shears provided	Blind competition
Low noise	GREAT08 LowNoise-Known	GREAT08 LowNoise-Blind
Realistic noise	GREAT08 RealNoise-Known	GREAT08 RealNoise-Blind



GREAT08 Data

	True shears provided	Blind competition
Low noise	GREAT08 LowNoise-Known	GREAT08 LowNoise-Blind
Realistic noise	GREAT08 RealNoise-Known	GREAT08 RealNoise-Blind





GREAT08 Results

Name	Method	Q	Error Flag	Number of Submissions	Date of Last Submission
A. Einstein	BestLets	1001	-	15	25 Dec 2008
Team Bloggs	Joe1	582	Warning	2	2 Nov 2008
Dr. Socrates	ArcheoShapes	116	Warning	212	23 Sept 2008
W. Lenser*	KSB+++	99	-	12	10 Aug 2008
A. Monkey	Guess Again	1.2	Warning	5	30 Nov 2008

GREAT08 Results

Name	Method	Q	Error Flag	Number of Submissions	Date of Last Submission
A. Einstein	BestLets	1001	-	15	25 Dec 2008
Team Bloggs	Joe1	582	Warning	2	2 Nov 2008
Dr. Socrates	ArcheoShapes	116	Warning	212	23 Sept 2008
W. Lenser*	KSB+++	99	-	12	10 Aug 2008
A. Monkey	Guess Again	1.2	Warning	5	30 Nov 2008

You submit g_1, g_2 for each set of images

GREAT08 Results

Name	Method	Q	Error Flag	Number of Submissions	Date of Last Submission
A. Einstein	BestLets	1001	-	15	25 Dec 2008
Team Bloggs	Joe1	582	Warning	2	2 Nov 2008
Dr. Socrates	ArcheoShapes	116	Warning	212	23 Sept 2008
W. Lenser*	KSB+++	99	-	12	10 Aug 2008
A. Monkey	Guess Again	1.2	Warning	5	30 Nov 2008

You submit g_1, g_2 for each set of images

$$Q = \frac{10^{-4}}{\langle (\langle g_{ij}^{m} - g_{ij}^{t} \rangle_{j \in k})^2 \rangle_{ik}}$$

GREAT08 Results

Name	Method	Q	Error Flag	Number of Submissions	Date of Last Submission
A. Einstein	BestLets	1001	-	15	25 Dec 2008
Team Bloggs	Joe1	582	Warning	2	2 Nov 2008
Dr. Socrates	ArcheoShapes	116	Warning	212	23 Sept 2008
W. Lenser*	KSB+++	99	-	12	10 Aug 2008
A. Monkey	Guess Again	1.2	Warning	5	30 Nov 2008

You submit g_1, g_2 for each set of images

$$Q = \frac{10^{-4}}{\langle(\langle g_{ij}^{m} - g_{ij}^{t}\rangle_{j\in k})^2\rangle_{ik}}$$

GREAT08 Results

Name	Method	Q	Error Flag	Number of Submissions	Date of Last Submission
A. Einstein	BestLets	1001	-	15	25 Dec 2008
Team Bloggs	Joe1	582	Warning	2	2 Nov 2008
Dr. Socrates	ArcheoShapes	116	Warning	212	23 Sept 2008
W. Lenser*	KSB+++	99	-	12	10 Aug 2008
A. Monkey	Guess Again	1.2	Warning	5	30 Nov 2008

You submit g_1, g_2 for each set of images

$$Q = \frac{10^{-4}}{\langle (\langle g^m_{ij} - g^t_{ij} \rangle_{j \in k})^2 \rangle_{ik}}$$

GREAT08 Timeline

- Feb 2008 GREAT08 Handbook public
- Jun 2008 Internal release of simulations
- Aug 2008 First simulations public
- 27 Oct 2008 Launch of public challenge
- Leaderboard starts containing internal results
- 5 Jan 2009 – mid-term workshop at UCL
- 30 Apr 2009 Competition deadline
- ~June 2008 Workshop; Release final report
- Input shears public

Summary

- Dark Matter/Dark Energy
- iCosmo
- Euclid
- GREAT08