Keck Institute for Space Studies mini-program

Shedding Light on the Nature of Dark Matter

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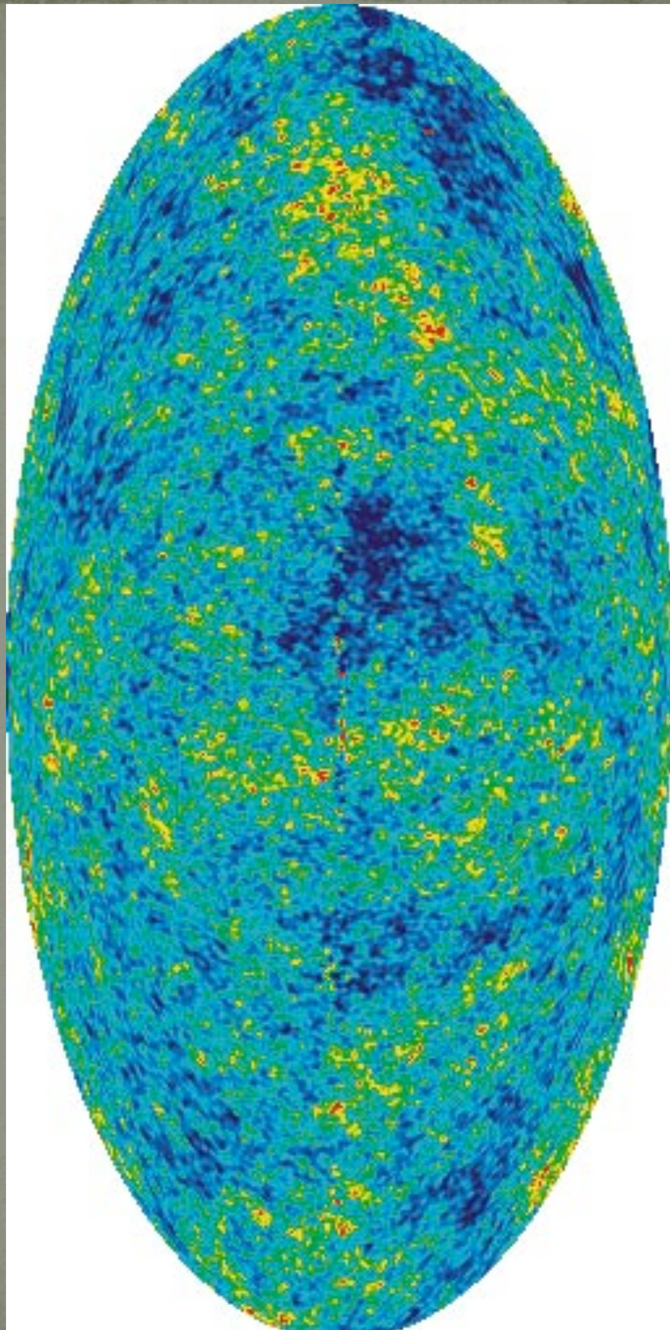
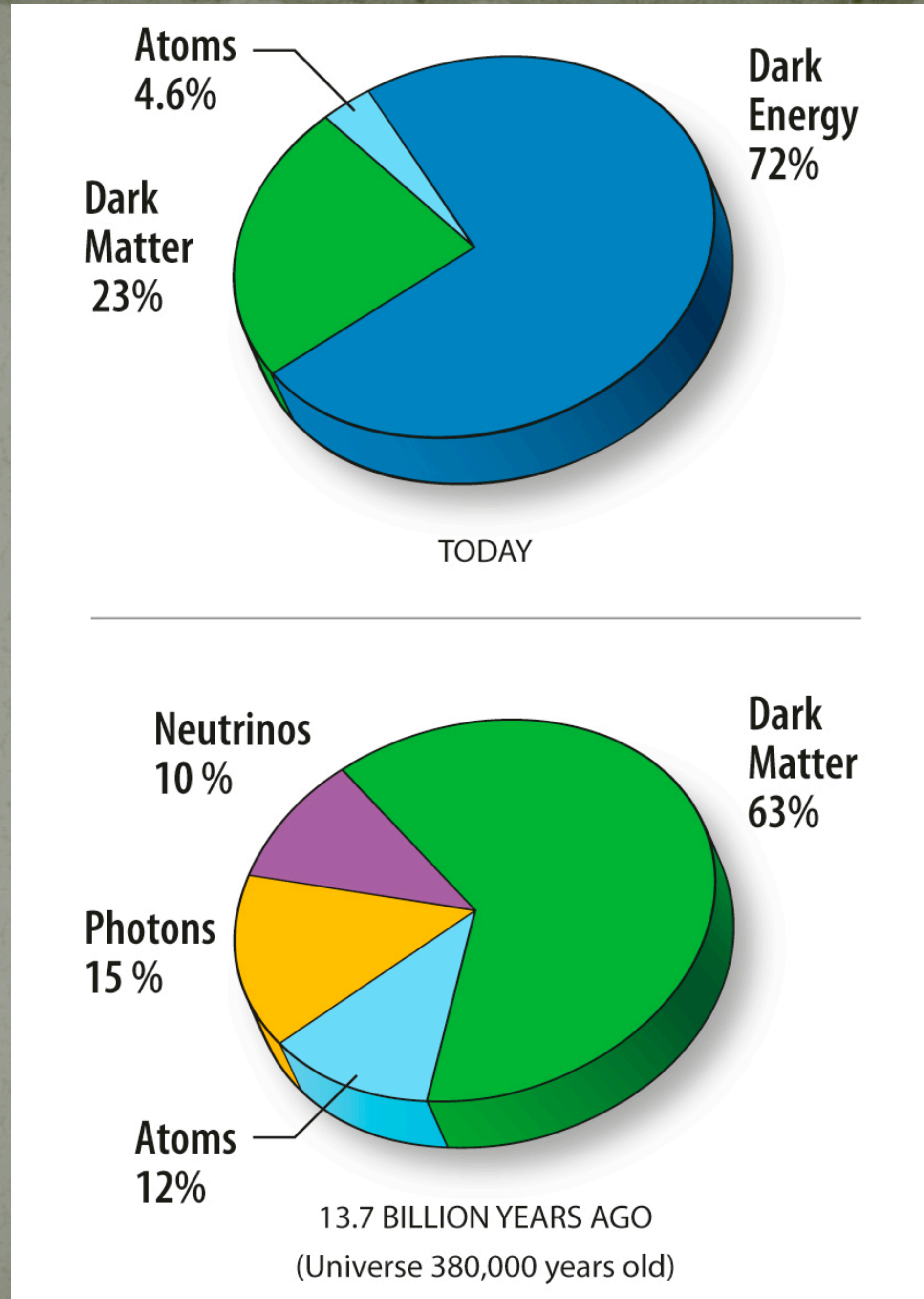
Electronic++ Communication…

- Wiki for expositions and figure sharing
  - Need an account if you don't have one yet (see AB)
  - Open to at-large community to contribute (email AB)
- Talk PDFs will be posted
  - Please provide PDFs of talks and discussion intros
- Daily highlights on our blog for record + comments
  - LAM by default but open to all participants!
- Twitter updates @kissdarkmatter – pass it on!
  - Dima Tseliakhovich & Sam Lee
- CVS Repository for workshop report write-up
- Perspective snapshot filming, Shane Rymer, Director
  - http://ultrafinemedia.com

Name	Organization	Keck Institute Dark matter workshop - July 2009									
		Week 1					Week 2				
Name	Organization	13	14	15	16	17	20	21	22	23	24
Leonidas Moustakas	JPL/Caltech										
Andrew Benson	Caltech										
Kevork Abazajian	Univ Maryland										
Marusa Bradac	UC Davis										
James Bullock	UC Irvine										
Dan Coe	JPL/Caltech										
Art Congdon	JPL										
Jonathan Feng	UC Irvine										
Marla Geha	Yale										
Rudy Gilmore	UC Santa Cruz										
Sunil Golwala	Caltech										
Tesla Jeltema	UCO/Lick Observatories										
Marc Kamionkowski	Caltech										
Manoj Kaplinghat	UC Irvine										
Charles Keeton	Rutgers Univ										
Savvas Koushiappas	Brown Univ										
Mike Kuhlen	IAS, Princeton										
Ricardo Munoz	Yale										
Priya Natarajan	Yale										
Annika Peter	Caltech										
Joel Primack	UC Santa Cruz										
Stefano Profumo	UC Santa Cruz										
Jason Rhodes	JPL/Caltech										
Kris Sigurdson	U Brit Columbia										
Josh Simon	Carnegie										
Daniel Stern	JPL/Caltech										
Louie Strigari	Stanford										
James Taylor	Univ Waterloo										
Risa Wechsler	KIPAC/Stanford										
Ross Fadely	Rutgers Univ										
Richard Massey	ROE										

setting the stage…




Atoms
4.6%
Dark
Energy
72%
Dark
Matter
23%
TODAY
Neutrinos
10 %
Dark
Matter
63%
Photons
15 %
Atoms
12%
13.7 BILLION YEARS AGO
(Universe 380,000 years old)

The canonical baseline model

- Joel's talk in a few moments will give us the background and context for the "canonical" framework we can start from. In a nutshell, we take this to include:
  - A power spectrum P(k) set in place from inflation;
  - A structure growth function governed by a gravitational and collisionless dark matter; and
  - A dark matter particle with properties that reproduce the observed cosmic abundance.

A little more detail on dark matter…

- What dark matter must be…
  - It must be non-relativistic enough to have allowed structure to form as observed.
  - It must be long lived to be have survived to the present.
  - It is not baryonic, since Omega_matter is >> than Omega_baryons.
- What dark matter may be…
  - Dark matter could be thermal or non-thermal.
  - While the chemical de-coupling is fixed by the cosmic abundance, the kinematic and acoustic de-coupling is fair game.
  - There is a lot of room between what direct detection experiments might measure, and what astrophysical measurements might constrain…
  - Also, there could be many kinds of dark matter, that may even be beyond the capability of direct or indirect experiments!

"Extensions" to the canonical view

- DM-DM elastic scattering cross sections
- DM-baryon scattering cross-sections
  - elastic
  - inelastic
  - spin-dependent
- Late-decaying dark matter (NLSP->LSP with a $\Delta m/m$)
- Broken scale invariance in the power spectrum
- The phase space density
- Cold + hot (massless) dark matter component
- Dark U(1)
- Warm dark matter (m_{DM}, mixing angle)

Connecting observations…

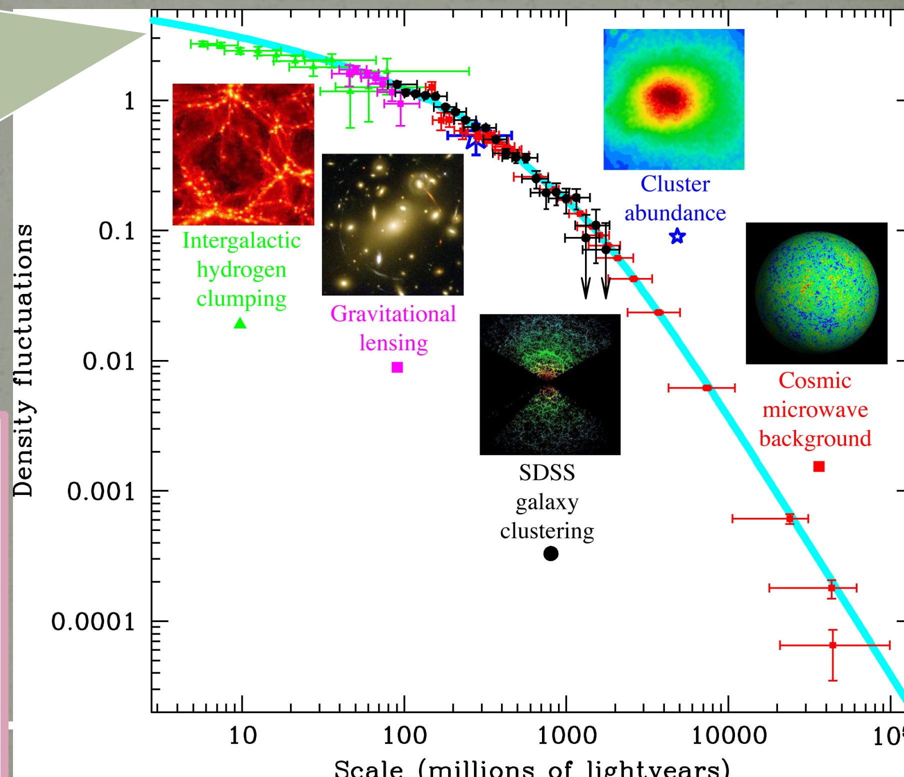
- Each of these descriptive "extensions" captures one or several aspects that are fundamental to the nature of the dark matter particle (or particles).

- For a concrete example, consider the case where the power spectrum has a cutoff scale k_{cutoff}.
  - Several of the 'extensions' can produce cutoffs, with a variety of physical mechanisms

The matter power spectrum

100pc 1kpc 10kpc 100kpc 1Mpc

??

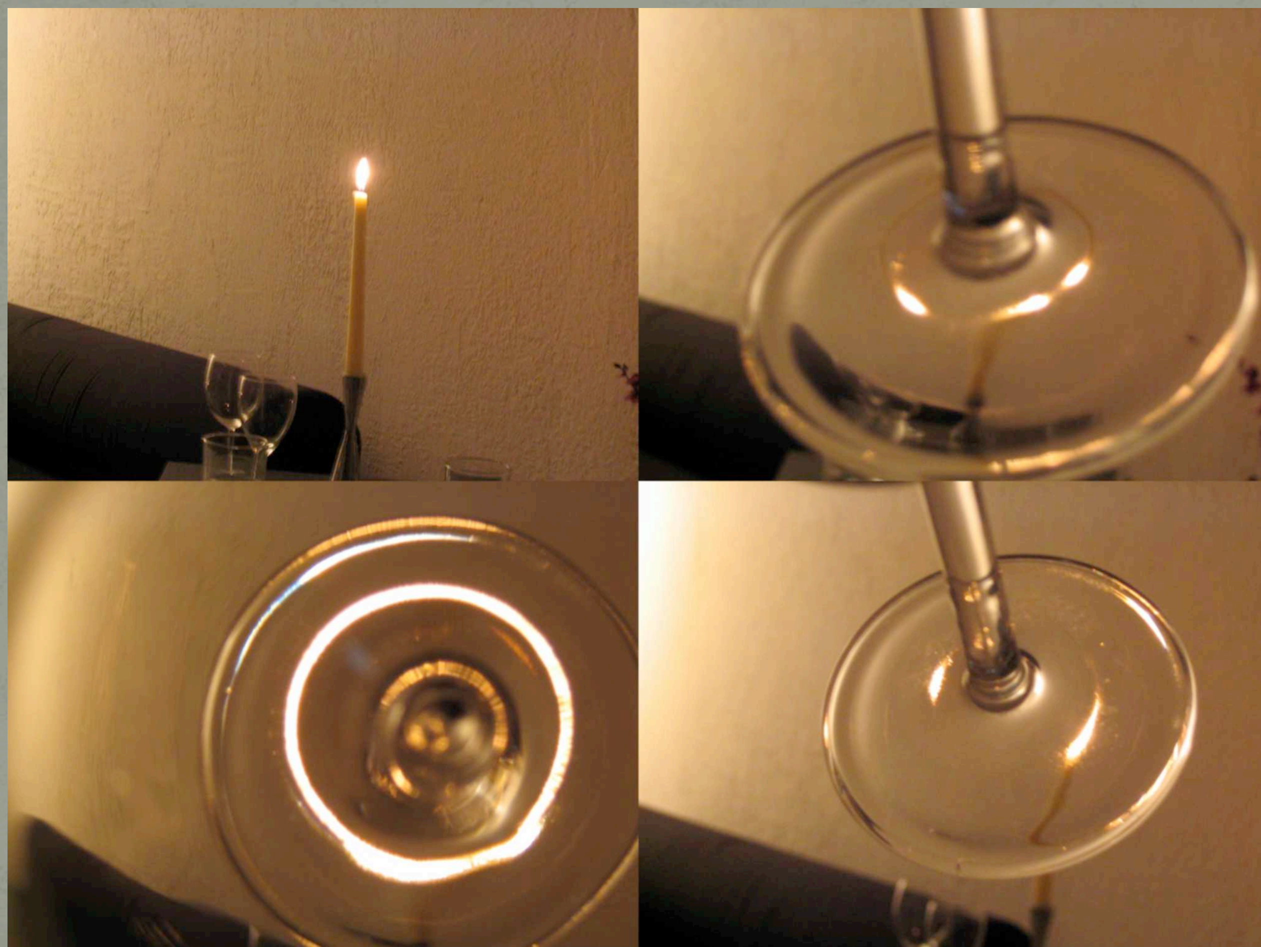


What goes on at small scales is tied to fundamental properties of dark matter!

It is also a regime probed uniquely by strong gravitational lensing, at many distinct cosmic epochs.

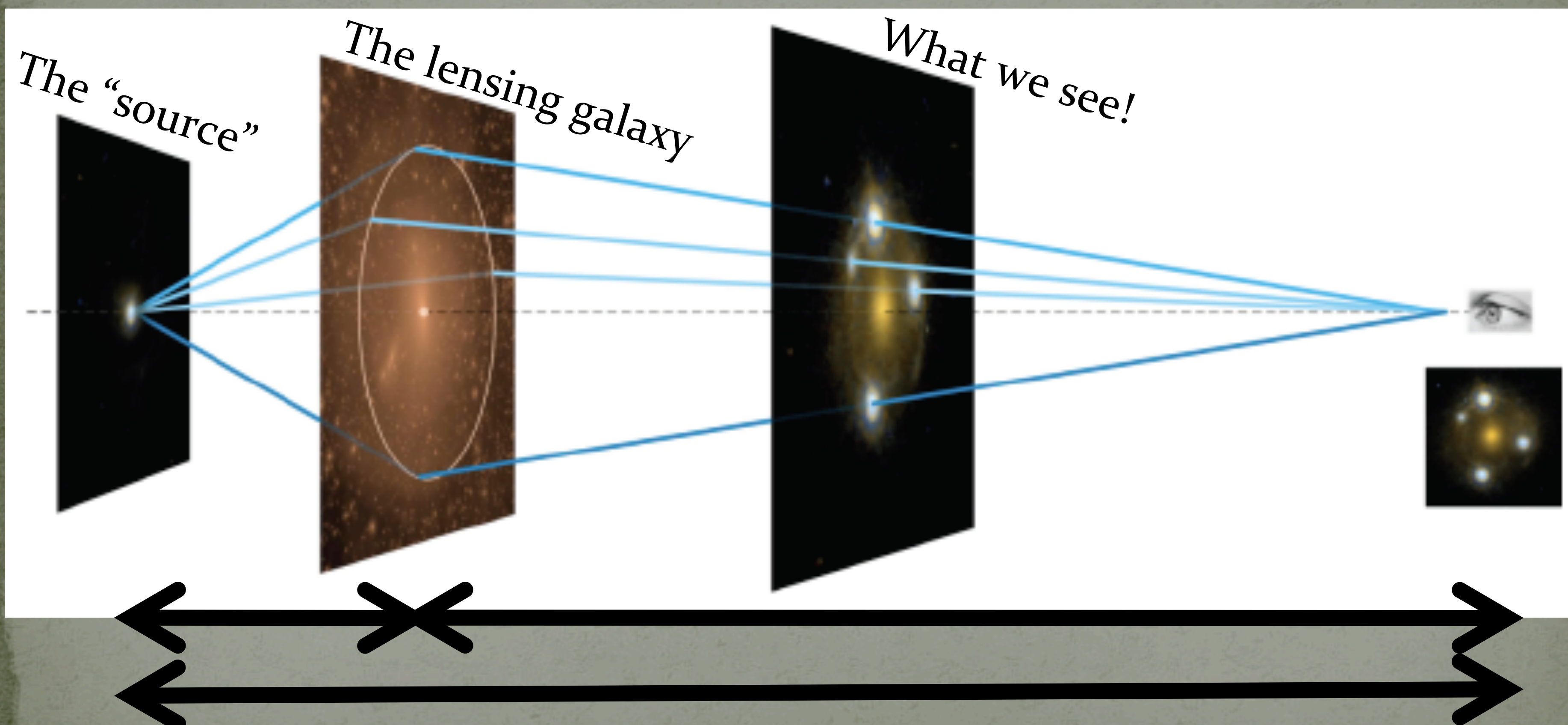
Max Tegmark figure

Lensing with a wineglass

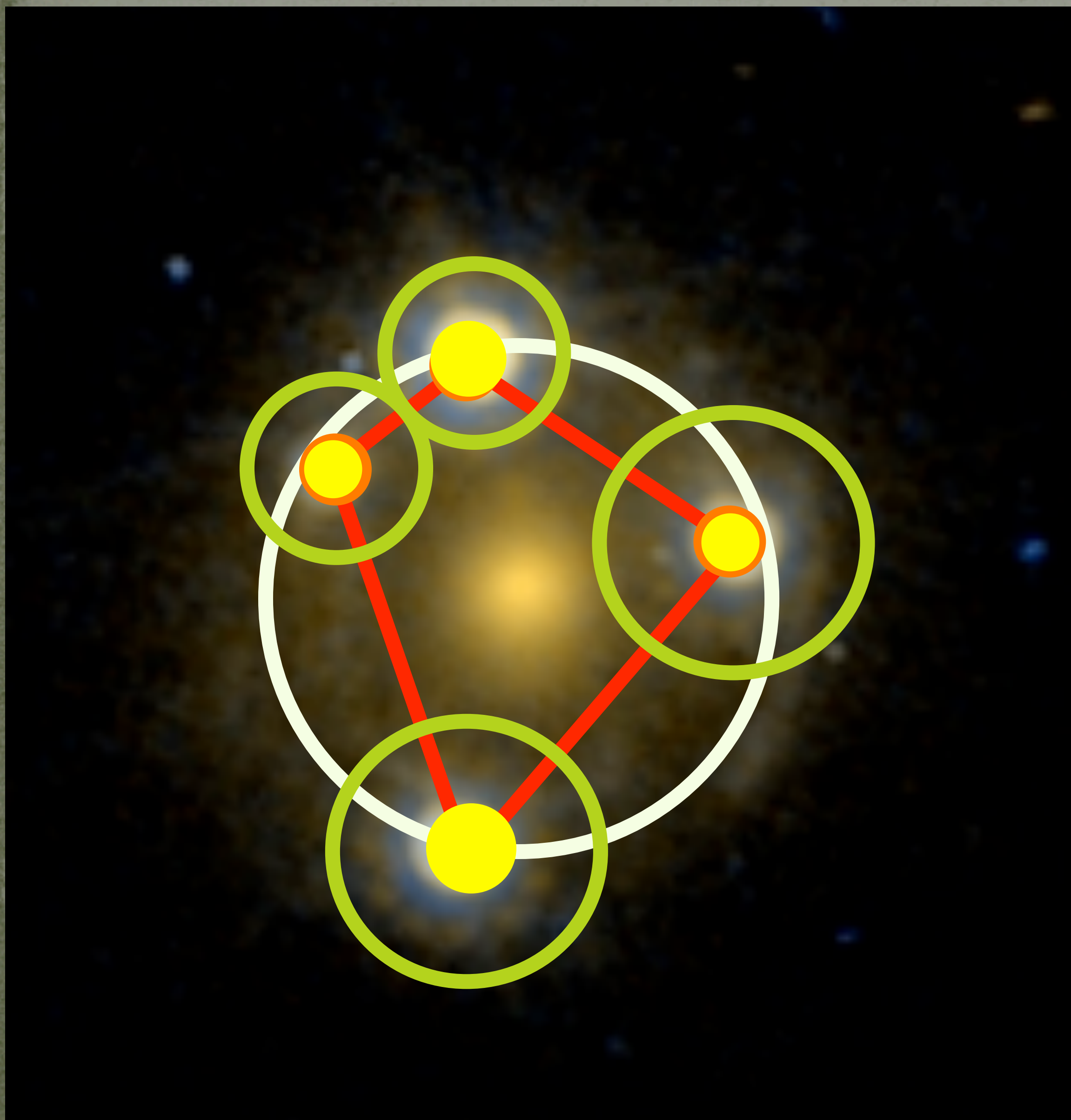


Courtesy Phil Marshall

The basic lensing diagram…



A galaxy-AGN strong lens & dark matter



1. Einstein radius: total mass (dm+stars) enclosed.
2. Microlensing at each image: dark matter to stellar fraction.
3. Magnification perturbations: (m) moment of dm mf.
4. Position perturbations: ($m^{3/2}$)th moment of dm mass function.
5. Time delay perturbations: (m^2) moment of dm mass function.

Strong lensing & small scale P(k)

- There are some measurements of the abundance of small scale dark matter structure in lens galaxies already.
- The potential behind using strong lensing as a high fidelity and very precise measurement of the actual mass function *shape* over many decades of scale, at many different cosmic epochs, is great!
- The challenge is not only in synthesizing these, but to make useful connections with dark matter properties.

connections

- There are, naturally, many different observables that are possible to make today, or in the future. A small list:
  - The cosmic abundance of dark matter
  - Lyman alpha forest / P(k)
  - Strong lensing dark matter substructure / P(k)
  - 21cm / P(k)
  - Phase space density Q
  - Dwarf galaxy abundances
  - Dark matter cusps
  - Diffuse x-ray emission
  - Gamma ray annihilation
  - Tidal tails
  - Galaxy cluster weak lensing
  - Direct detection experiments with different parameters
- We wish to develop a quantitative framework for connecting the "extensions" to the ensemble of observables.

connections – side by side

Theoretical extensions, each with a "M_i" factor

- DM-DM elastic scattering cross sections
- DM-baryon scattering cross-sections
  - elastic
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- Late-decaying dark matter (NLSP->LSP with a $\Delta m/m$)
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- The phase space density
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Observational parameters, each w/ "O_j"

- The cosmic abundance of dark matter
- Lyman alpha forest / P(k)
- Strong lensing dark matter substructure / P(k)
- 21cm / P(k)
- Phase space density Q
- Dwarf galaxy abundances
- Dark matter cusps
- Diffuse x-ray emission
- Gamma ray annihilation
- Tidal tails
- Galaxy cluster weak lensing
- Direct detection experiments with different parameters

Model parameters that describe broad and generic dark matter particle features

M_i

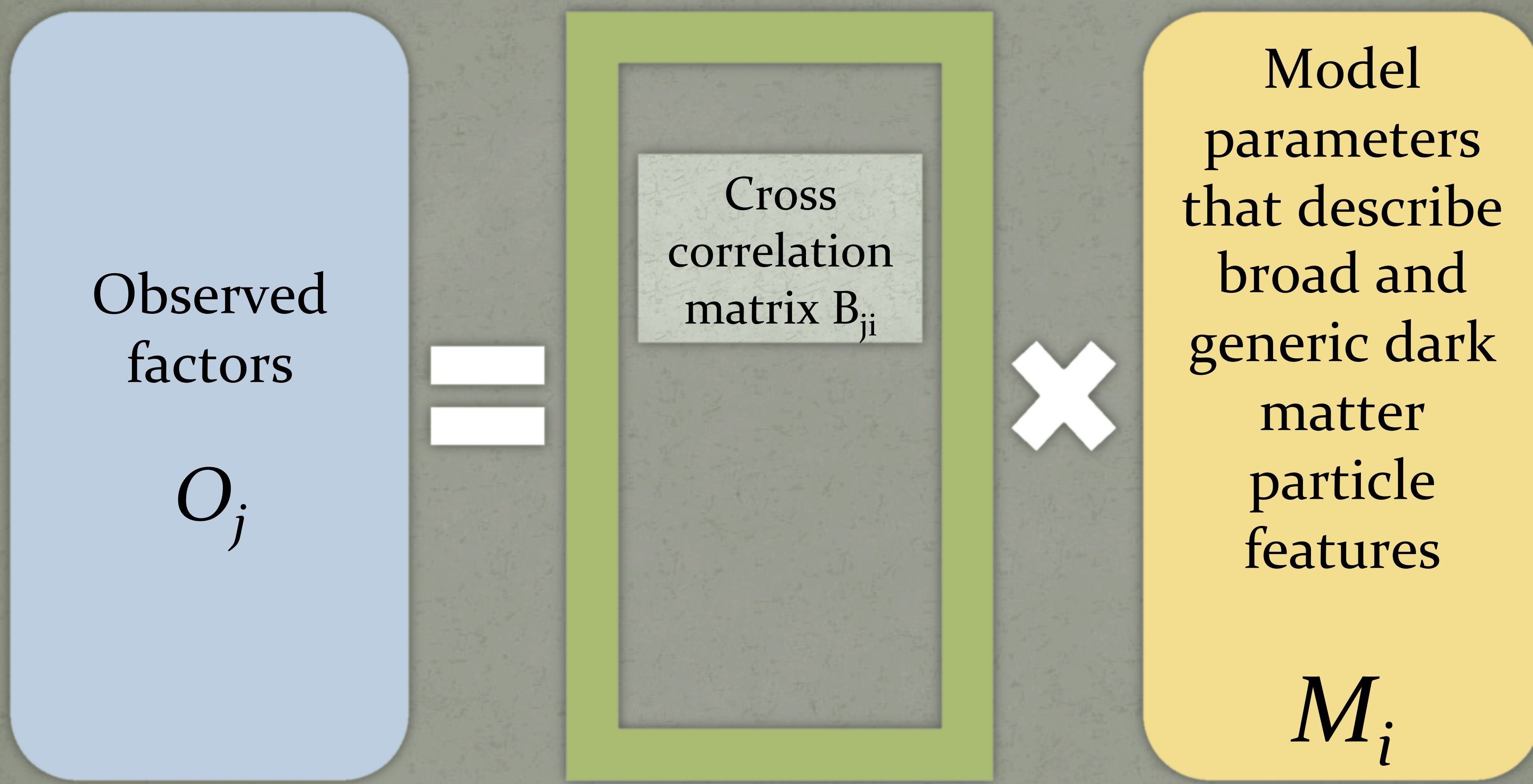
=

Cross correlation matrix A_{ij}

×

Observed factors

O_j


Observed factors
O_j
=
Cross correlation matrix B_{ji}
×
Model parameters that describe broad and generic dark matter particle features
M_i

Levels or Stages of the analysis

- there are different “levels” or “stages” to do this:

- A: try to set up the extensions array in a super general way, so that generic particle properties are captured, that post facto can be compared against different candidates
- B: set up the M=AO or O=BM equations *for each flavor of particle candidate*, since the physics of each candidate may dictate how different extension properties inter-relate

- I. ‘yes’ or ‘no’ in correlation matrix for each Mi
- II. Relative importance values in correlation matrix for each Mi
- III. Full Fisher matrix for each Mi against all observables or vice versa……

what is the right way to do this?

- Why do we want to do this?
  - to fold in as much information as possible
  - to be able to quantitatively evaluate different dm candidates – and possibly figure out how to rule some out now or in the future
  - to help direct what experiments, observations, or missions need to be pursued, and to be able to build community-wide support
- Most of all: we wish to develop a straightforward enough framework that is extendable and flexible, that can be an important tool in the future as well as today
- Dan Coe will lead a discussion on precisely this in the afternoon

Goals summary

- Mathematical framework for connecting diverse observations with extensions
  - Develop the (linear?) parameters that describe each of these on both sides – for many / most of them if possible
  - Work out the best way to draw these connections
- Discuss whether it is possible to currently set best future goals / experiments, based on what we know today
- What is the best way to *rule candidates out*?
- Have fun & germinate new ideas!

How is this going to work?

- Mornings: In Cahill
  - A talk (20-50 minutes), whether ppt or whiteboard
  - Moderated discussion on prepared topic(s)
- Afternoons: At home-base, Downs/Lauritsen
  - Moderated discussion on prepared topic(s)
- Some social events – see calendar!
- For discussion "note taking", use the wikipage!!
- We are already working on the workshop report, which everyone will pitch in with.