Resonant Magnetic Fields from Inflation

In collaboration with C Byrnes, L Hollenstein and R K Jain

Your next 15 minutes

- Cosmological Magnetism in bits
- Inflating Magnetism, and backfiring
- Resonating Magnetism, and some results

- Cosmological magnetic fields are ubiquitous and omnipresent

  __Galaxies: ~ 10 μG, ordered on 10 kpc scales
  __Clusters: ~ 1 μG, coherent on scales up to 100 kpc
  __Filaments: ~ 0.1 μG, aligned on scales around 1 Mpc
  __IGM: $\gtrsim 10^{-15}$ G, correlated over few Mpc

- Models rely on

  Astrophysics → Struggle to achieve large correlations

  Cosmological Phase Transitions → Same as before

  Inflation → Troubled by backreactions, gives little strength

- Electromagnetism in curved space is conformally invariant, and our FLRW Universe is conformally flat → Conformal triviality
  → I need to modify the action if I want curved space to have any effect on my EM dynamics

- I have several possibilities: $I^2 F_{\mu\nu} F^{\mu\nu}$ $\quad f F_{\mu\nu} \tilde{F}^{\mu\nu}$ $\quad \cancel{M^2 A_\mu A^\mu}$

- Why magnetic fields from inflation?
  __Large field variation
  __Vacuum conditions, no conductivity / resistivity
  __Large scales dynamics

- The data point at fields with strength around 0.1 to 10 μG in all large structures, and much smaller (but nonzero) in the IGM

- Q: Does this work?
- A: Not quite → Backreactions can be important!
  __The inflaton potential needs to be flat or inflation does not last
  __The interaction term makes for an effective potential term
  ⇒ As we produce *B*, we impact the inflaton dynamics

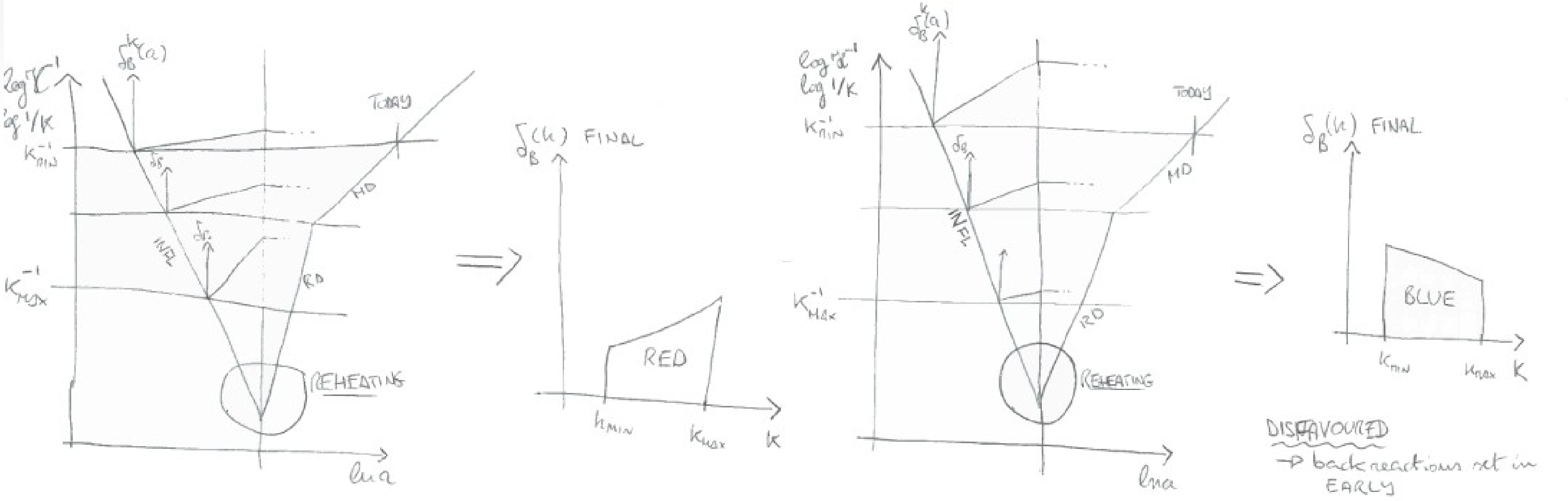
- Simple examples:

$$A_h'' + (k^2 + hkf')A_h = 0 \quad \text{for } F\tilde{F}$$
$$A_h'' + (k^2 - I''/I)A_h = 0 \quad \text{for } F^2$$

- Inside the horizon the coupling term is irrelevant → free waves

- The coupling term becomes relevant at horizon crossing:
  __axial coupling is only efficient for a small time
  __time-dependent α continues to work all the way to the end

- A few more remarks
  __Normally all modes are amplified democratically
  __Small coupling is required for both perturbativity and consistent IC
  __Blue spectra tend to be favoured over red or even flat



- The possible way out: take advantages of resonances!

- Two reasons to believe it may work:
  __Small coupling does not imperil large (resonant) effects
  __Resonances are efficient only for small resonance bands

- A Toy Model: the Mathieu equation

$$A_h''+\left(k^2+2h\gamma\omega k\cos 2\omega\eta\right)A=0$$

- The form of f depends on the dynamics of the inflaton; focussing on the simplest quadratic, chaotic potential, $V(\varphi)=\frac{1}{2}m^2\varphi^2$ we find:

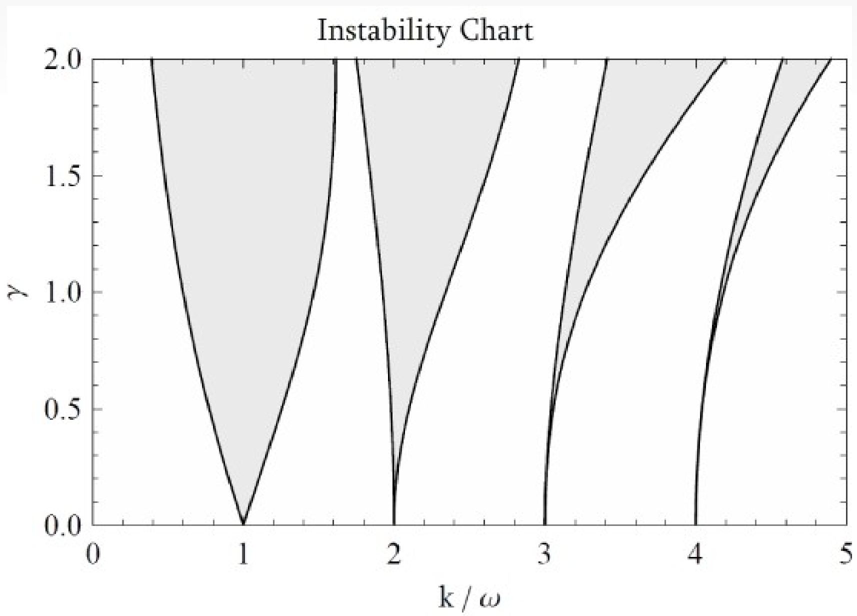
$$\eta\propto\exp\left(\frac{\varphi^2}{4M_4^2}\right)$$ hence: $$f(\varphi)=\gamma\sin\left[2\hat{\omega}\exp\left(\varphi^2/4M_4^2\right)\right]$$

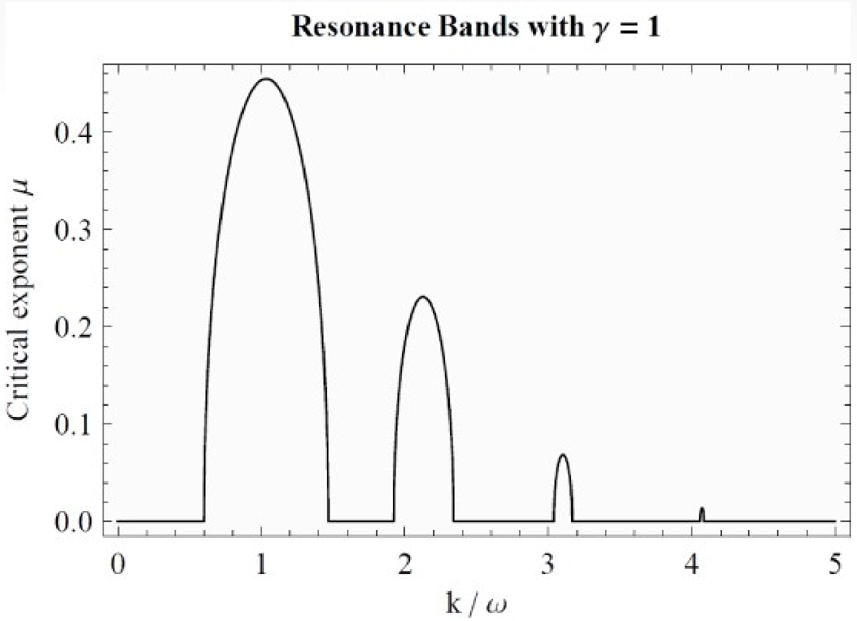
- For a given γ, around $k = n\omega$ we have the unstable solution

$$A(\eta) \propto \exp(2\mu\omega\Delta\eta)$$

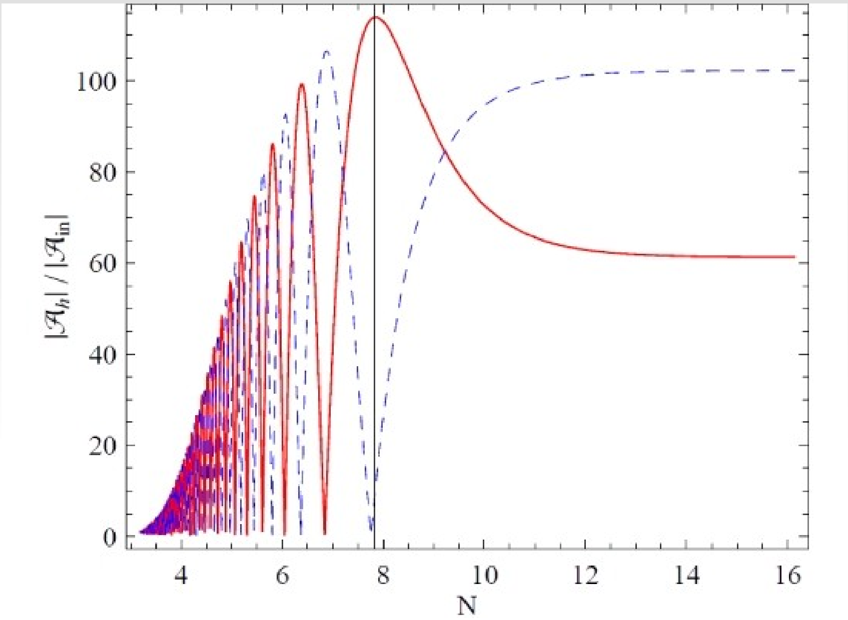
μ = critical exponent

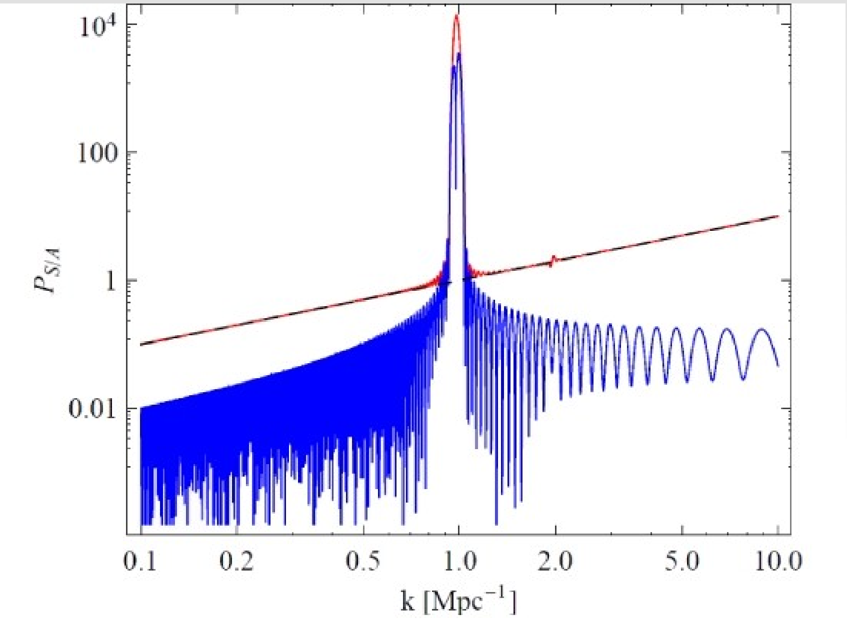
- The resonances bands charts look like





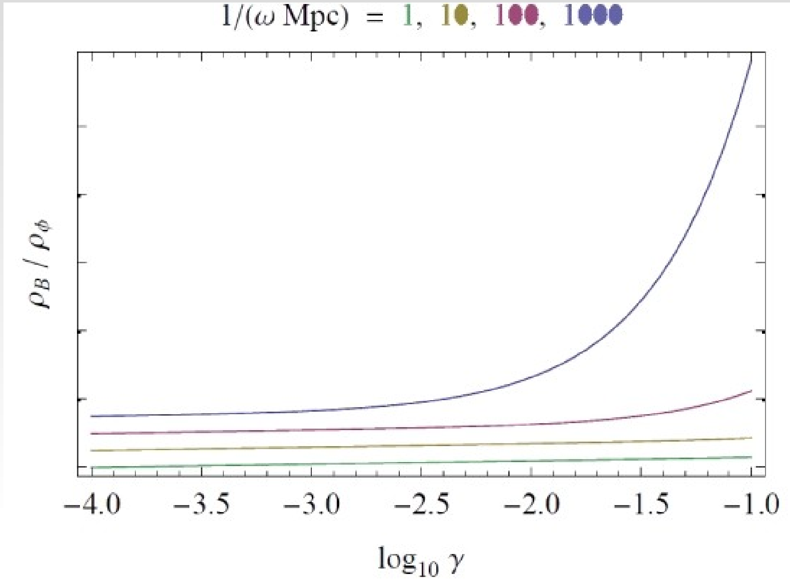
- Let's look at some results





- I find exponential amplification for a narrow band $k = \omega$
- The spectrum is “monochromatic”
- I can control both the peak and the magnification quite independently on inflationary dynamics

- I can keep track of the relative energy density to the inflaton



__I see once again that longer wavelengths are more pestiferous
__I am doubly exponentially sensitive to N (e-folds)

- This is simply a Toy, useful as we know the mathematics
$\rightarrow$ We need to look at more realistic models, such as
__Time varying parameters $\Leftrightarrow$ resonances only temporary
__Different (less sharp in N) interaction terms

- The two obvious extensions we consider are
- Time-dependent amplitude γ
  __I can easily implement switch-on and switch-off
  __I have both sine and cosine oscillations
- Time-dependent frequency ω
  __The resonance moves across different frequencies
  __I can effectively turn on/off the coupling at the EOM level
- These two are degenerate at early times, much before horizon exit
- ...results underway...

- Conclusions

__B fields are observed in most objects in the sky
__More puzzingly, even where there is barely any gas (IGM)
__Their origin is very much mysterious

__Inflation is a plausible locus for the dawn of magnetism...
__but one that is plagued by backreaction problems

__Resonant production could circumvent this issue!

- References:

C Byrnes, L Hollenstein, R K Jain, FU in preparation
Demozzi, Mukhanov, Rubinstein 09
Kanno, Soda, Watanabe 09